

A SIX DIMENSIONAL VIEW OF STELLAR AND PLANETARY SYSTEMS WITH HIGH PRECISION ASTROMETRY

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RESUMEN

Astrometría de alta precisión proporciona información sobre la posición y velocidad de miembros individuales en sistemas estelares. En esta contribución, presento nuestro trabajo sobre el uso de la radio astrometría, complementada con *Gaia*, para estudiar la estructura 3D de regiones de formación estelar y la cinemática interna de cúmulos estelares jóvenes. También presento trabajos recientes sobre búsquedas astrométricas de exoplanetas en estrellas aisladas y binarias, así como la caracterización 3D de sus órbitas.

ABSTRACT

High-precision astrometry provides the six-dimensional information (position and velocity) of individual members in stellar systems. In this contribution, I present our work on using radio astrometry, complemented with *Gaia*, to study the 3D structure of star-forming regions and the internal kinematics of young stellar clusters. I also present recent work on astrometric searches for exoplanets in single and binary stars and the characterization of their 3D orbits.

Key Words: astrometry — stars: protostars — stars: distances — stars: fundamental parameters — ISM: clouds — planetary systems

1. INTRODUCTION

Significant progress in astrometric accuracy was achieved in the last decade with the launch of the *Gaia* mission and the development of Radio Interferometry. In the field of star and planet formation, the unprecedented astrometric precision provided by these instruments opened new lines of research that were previously inaccessible. *Gaia* is collecting the parallax and proper motions of > 1000 million stars, which represents $\sim 1\%$ of the stars in the Galaxy. In the current Data Release 3 (DR3), uncertainties in parallax and proper motions are $10\text{--}20\ \mu\text{as}$ and $10\text{--}20\ \mu\text{as yr}^{-1}$, respectively, both for a magnitude below $G = 15$ (Gaia Collaboration et al. 2023). For astrometric studies in star-forming regions, however, it is necessary to complement *Gaia* measurements with the astrometry provided by radio interferometers. This is because star formation occurs in molecular clouds, within dense cores rich in dust. Radio observations, on the other hand, can overcome the high dust extinction, allowing astrometric measurements of the youngest and most embedded objects.

2. 6D STRUCTURE OF MOLECULAR CLOUDS AND YOUNG STELLAR SYSTEMS

We conducted the Gould’s Belt Distances Survey (GOBELINS), a radio astrometric survey of (em-

bedded) young stellar objects located in the most prominent and nearby star-forming regions (Taurus, Perseus, Serpens, Ophiuchus and Orion). GOBELINS used the Very Long Baseline Array (VLBA) to observe the non-thermal radio continuum emission from ~ 270 targets, delivering high precision astrometric parameters of about 100 stars. Published catalogs contain parallaxes and distances with an accuracy of 0.3% to a few percent, and proper motions accuracies better than $0.2\ \text{mas yr}^{-1}$. We also obtained the spatial velocities of a subset of the stars, as well as stellar masses from monitoring of binary systems.

Combining *Gaia* DR1 and radio astrometry, we found that distances and velocities of individual clouds in the Taurus complex change significantly across the cloud (Galli et al. 2018). The measurements revealed the depth of the cloud along the line of sight to be 36 pc. Later, we extended the sample of young stars with six-dimensional information by using *Gaia* DR2 astrometry and radial velocities from the literature (Galli et al. 2019). We found relative distances among the various clouds of 25 pc on average and relative space motions of a few km s^{-1} .

In Orion, the work by Kounkel et al. (2017) was one of the first studies that revealed the 3D structure of the cloud. Using VLBA data alone from GOBELINS, we found a distance gradient of about 40 pc between the ONC and L1641 and a similar

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value between NGC 2068 and NGC 2024. A prominent distance gradient of 30 pc from east to west was also found in the Perseus complex (Ortiz-León et al. 2018a) and a small distance gradient of 6 pc in Ophiuchus (Ortiz-León et al. 2018b). We also investigated the kinematical properties of the IC 348 and NGC 1333 clusters in Perseus (Ortiz-León et al. 2018a), finding that their internal motions are dominated by random motions, rather than by ordered motions due to expansion, contraction or rotation.

Finally, we derived the astrometry of water masers associated to a protostar in the very young ($\sim 2 \pm 1 \times 10^5$ yr) Serpens South cluster (Ortiz-León et al. 2023). No optical sources with good astrometric solutions were available in *Gaia* DR3. Thus, a direct distance determination was only possible thanks to the observations performed at radio wavelengths.

3. ASTROMETRIC CHARACTERIZATION OF EXOPLANETARY SYSTEMS

Astrometric accuracy of tens of micro-arcseconds (μas) has the potential to reveal the presence of hidden companions, which would induce a reflex motion on the star about the system's barycenter. Very Long Baseline Interferometry observations of the radio emission from nearby ($\lesssim 10$ pc) low mass stars (M-dwarfs, ultracool dwarfs and brown dwarfs) have allowed us to search for companions with planetary masses. Using the VLBA, we discovered a Saturn-mass exoplanet associated to the ultracool dwarf TVLM 513–46546 (Curiel et al. 2020). This planet has a period of 221 ± 5 days and induces an astrometric signature (semi-major axis of the star's orbit) of $145 \pm 20 \mu\text{as}$.

We also performed VLBA observations of the M3.5+M4.5 binary GJ 896AB, detecting both components (Curiel et al. 2022). Fitting the positions of the primary star, including acceleration terms to take the perturbation of the secondary star into account, revealed significant residuals that suggest the presence of a new close companion orbiting the primary star. The absolute positions of the primary and secondary star, as well as the relative positions of the binary (from radio and optical data) were fitted simultaneously with a combined model that includes the new companion. We found a period of 284 ± 2 days and a mass of $2.3 \pm 0.6 M_{\text{Jup}}$ for the planetary companion. The astrometric signature induced by the planet on the host star is $510 \pm 150 \mu\text{as}$. The true 3D orientation of the binary and planetary orbits is shown in Fig. 1. Using the angles obtained from the astrometric fittings we estimated a mutual inclination angle between the orbits of 148° .

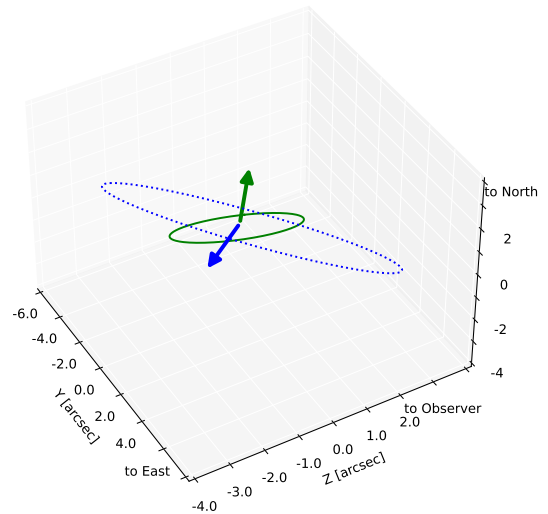


Fig. 1. 3D representation of the binary (blue) and planetary (green) orbits in GJ 896. The arrows indicate the orbital angular momentum vectors. The planetary orbit has been scaled by a factor of 20.

4. FINAL REMARKS

Radio astrometry and *Gaia* have been fundamental for the characterization of molecular cloud 6D structure and the stellar systems that live within them. In the field of exoplanet exploration, high-precision astrometry is now making important contributions. The 3D shapes and the true inclination between planetary and binary orbits can be investigated. With more discoveries that next-generation instruments can bring, astrometry could help to better understand planet formation in single and binary stars and their dynamical evolution.

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STAR MEMBERSHIP IN THREE NEARBY OPEN CLUSTERS

J. Alfonso¹ and A. García-Varela¹

We carry out a star membership study in three nearby open clusters: Pleiades, Praesepe and Blanco 1, employing a Bayesian astrometric model with proper motions and an unsupervised clustering machine learning algorithm DBSCAN using positions, proper motions and parallaxes, all data from the Gaia Data Release 3 catalogue. The final membership lists are the crossmatch between results from both methods.

The Bayesian model uses two bivariate probability density functions: a circular for the open cluster $\psi_c(\mu_{\alpha*,i}, \mu_{\delta,i})$ and an elliptical for the field stars $\psi_f(\mu_{\alpha*,i}, \mu_{\delta,i})$ (Vasilevskis et al. 1958). These two densities can be collected in the joint probability function given by Eq. (1), which depends on nine parameters that were estimated via the maximum likelihood estimation and Markov chain Monte Carlo. We maximize the likelihood function given by Eq. (2), then, membership probabilities were computed using the Eq. (3).

$$\psi(\mu_{\alpha*,i}, \mu_{\delta,i}) = n_c \psi_c(\mu_{\alpha*,i}, \mu_{\delta,i}) + (1 - n_c) \psi_f(\mu_{\alpha*,i}, \mu_{\delta,i}). \quad (1)$$

$$\ln \mathcal{L}(\vec{\theta}) = \sum_{i=1}^n \ln \psi(\mu_{\alpha*,i}, \mu_{\delta,i} | \vec{\theta}). \quad (2)$$

$$P_i(\text{cluster} | \mu_{\alpha*,i}, \mu_{\delta,i}) = \frac{n_c \psi_c(\mu_{\alpha*,i}, \mu_{\delta,i})}{n_c \psi_c(\mu_{\alpha*,i}, \mu_{\delta,i}) + (1 - n_c) \psi_f(\mu_{\alpha*,i}, \mu_{\delta,i})}. \quad (3)$$

The DBSCAN algorithm (Ester et al. 1996) was applied in a five-dimensional astrometric space (α , δ , $\mu_{\alpha*}$, μ_{δ} , ϖ) computing distances using the Euclidean metric. We standardised data and in order to obtain the ϵ and minPts with the best efficiency, first, we compute the k -th nearest-neighbour distance (k-NND) histogram of data and store the median value as ϵ_{kNN} . Second, generate random samples for data from a Gaussian kernel, compute the k-NND histogram and store the median as ϵ_{rand*} . An average of 30 repetitions was performed and ϵ_{rand} is the average of ϵ_{rand*} . Finally, the ϵ was determined as $\epsilon = (\epsilon_{kNN} + \epsilon_{rand})/2$ (see Fig. 1). We chose $\text{minPts} = 8$ for each cluster.

From the selected members, we fit the King model (King 1962) to the radial density profiles in order to

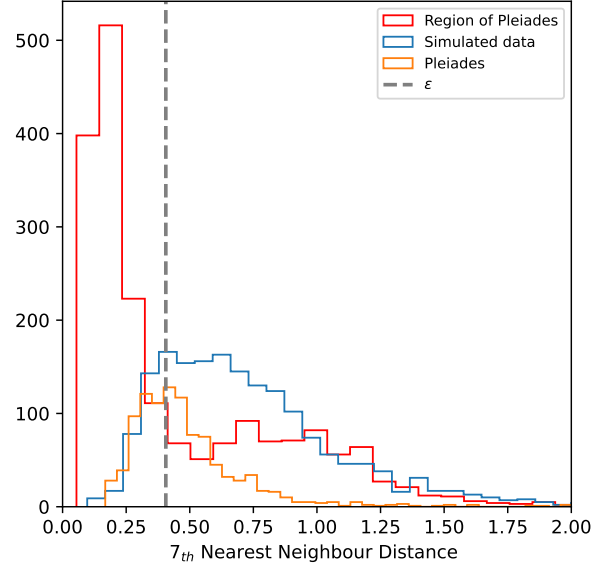


Fig. 1. Histogram of the 7th-NND for the region of Pleiades (red), simulated data (blue), and the Pleiades members selected from the PM model (orange). The grey dashed vertical line is the selected ϵ .

compute core and tidal radius (Alfonso & García-Varela, 2023). We also estimate age and metallicity from *Gaia* photometry using BASE-9 (von Hippel et al. 2006) and the PARSEC models (Bressan et al. 2012). These results were close to previous works, however, there are some differences for the tidal radius that may be a product of stretching in the spatial distributions because of coordinate transformations.

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THE BENEFITS OF EXTENDING THE FRIPON-CHILE NETWORK TO SURROUNDING COUNTRIES

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FRIPON (<https://www.fripon.org>) is an acronym for *Fireball Recovery and Inter-Planetary Observation Network*. It is an efficient ground-based network of more than a hundred all-sky cameras mainly installed in France and dedicated to the observation of fireballs to characterize the extra-terrestrial matter falling on Earth, and determining the impact area for facilitating the recovery of freshly fallen meteorites. This network started in France in 2016 and has been

extended first to Europe and Canada and more recently to Chile (<https://www.fcla.cl/fripon-chile>) for filling in the gap in the detection of these events in the southern skies and thereby obtaining an exhaustive view of fireball activity. In this talk, we will first introduce the FRIPON network with a special focus on its recent extension in Chile as well as a short report of the first detections we obtained from the southern hemisphere. Then we will emphasize the necessity of extending the network to the surrounding countries of Chile for increasing the probability of meteorite recovery after meteor detection by the network.

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SECULAR AND RESONANT EFFECTS GENERATED BY THE HYPOTHETICAL PLANET 9.

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The hypothesis of the existence of a planet with high eccentricity and inclination, not yet discovered, beyond the orbit of Neptune (called Planet 9), was developed by the authors Batygin y Brown (2016), to explain a series of anomalous dynamic behaviors in trans-Neptunian objects (TNO), such as the existence of objects grouped in their perihelion longitude ϖ , the distance of their perihelions from the Neptune region, or the existence of objects with a high inclination.

Viera 2023 (MSC Thesis) analyzes the validity and potential of using semi-analytical models for the study of secular and resonant dynamics generated by a disturber with high eccentricity and inclination, and its application to the Planet 9 hypothesis. We present here some of the relevant results.

Using a semi-analytic model the secular dynamics without limitations in (a, e, i) are studied, demonstrating that a disturber with high eccentricity and inclination is capable of reproducing the clusters in ϖ reported by Batygin y Brown (2016), for TNO with $a \geq 250$ ua. The parameters used for Planet 9 were: $m_9 = 10m_\oplus$, $e_9 = 0.6$ and $i_9 = 10^\circ$.

By using a semi-analytical model for resonant dynamics, developed by Gallardo (2020), the characteristics of the resonances generated by Planet 9 are studied, the areas where they interact with the resonances of Neptune, and the generation of chaotic zones. The results are verified using dynamic maps (see Fig. 1).

We find that the resonances generated by an eccentric perturber are broad and depend weakly on the eccentricity of the particle (see Fig. 1).

Using numerical integrations, the secular dynamics within resonances for a period similar to the age of the Solar System are studied. It is verified that the resonant dynamics is capable of generating groupings in ϖ for the same values as the secular dynamics. It is shown that secular dynamics within resonances is capable of generating particles with high inclination for $a > 250$ au. The best observation conditions for these objects, that means

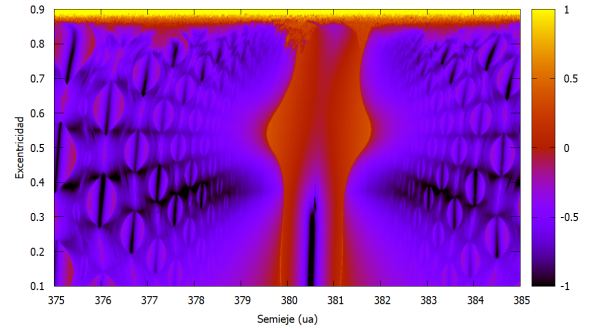


Fig. 1. Dynamic map for test particles with $375 \text{ au} < a < 385 \text{ au}$ and $0.1 < e < 0.9$ generated, including Neptune and P9. The main structure is the resonance 5:2 with Planet 9. The color indicates the variation of the semimajor axis on a logarithmic scale.

lower q , occur for $\Delta\varpi \sim 90^\circ$ y 270° and $i \sim 90^\circ$.

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ABSTRACT ONLY**THE ASYMMETRIC SUNRISE EFFECT ON
THALES’ ALLEGED MEASUREMENT OF THE
SUN ANGULAR SIZE**J. Cuadra^{1,2}

Reports from the 2nd and 3rd Century AD attribute the first measurement of the angular size of the Sun to Thales of Miletus, in the 6th Century BC. Cleomedes, also in the 2nd Century AD, described a method to perform the measurement, based on timing the duration of the sunrise. Several modern authors have suggested Thales used Cleomedes’ method, but others are skeptical of the connection. I present an objection that has not been discussed in the literature, namely, that the proportionality between the size of the Sun and the duration of sunrise is not constant, but changes with latitude and time of the year, due to what I call the “asymmetric sunrise effect”. I show that this effect is large enough to have prevented Thales from obtaining the roughly accurate recorded value.

Please find a copy of the poster at https://jrcuadra.github.io/plaga/larim_thales/ or read the full-length paper at <https://doi.org/10.1093/pasj/psad026>.

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ABSTRACT ONLY

UNSUPERVISED DECONTAMINATION OF
 FIELD STARS IN COLOR-MAGNITUDE
 DIAGRAMS OF STAR CLUSTERS
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Knowledge of the fundamental parameters of star clusters is key to understanding the structure and evolution of galaxies. This is because star clusters are excellent tracers of the different galactic sub-systems. In this work, we present an unsupervised method for decontaminating stars from the field in color-magnitude diagrams (CMD) of star clusters, developed in Python, which allows assigning statistical probabilities of membership to each star observed in the field of a star cluster.

The membership probability of a star to a star cluster is evaluated from the comparison of the properties observed in color-magnitude diagrams of the regions surrounding the cluster of interest and that of the cluster.

The method of cleaning the star clusters’ CMDs consists in the implementation of a Python code that compares the CMDs of areas adjacent to the star cluster with the observed CMD of the cluster of interest. The stars removed from the observed cluster CMD are those closest to the field CMD stars. We perform this process with a thousand different adjacent fields and then estimate the membership probability of each star in the cluster based on survival in the elimination process.

This statistical method was applied to more than 30 star clusters in the Small Magellanic Cloud. This is the first step in order to determine their astrophysical parameters (e.g., age, metallicity and heliocentric distances), with the aim of analyzing their kinematics in the galaxy.

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THE LLAMA RADIOTELESCOPE: PRESENT STATUS, AVAILABLE INSTRUMENTATION, AND SCIENTIFIC PERSPECTIVES

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The LLAMA Observatory, in the Argentinian Andes at 4800m altitude, in the Salta province, is a project of Argentina and Brazil, which started in 2014 with an agreement between FAPESP (research foundation of Sao Paulo State), University of São Paulo, and MinCyt (Ministry of Science and technology of Argentina). The expenses will be equally shared. The 12m diameter antenna was constructed by VERTEX Antennentechnik GmbH (Duisburg, Germany). The surface precision of the dish will reach 15 microns r.m.s. deviations from an ideal parabola, after a period of fine adjustments. The antenna will perform observations at mm and sub-mm radio waves, like the international ALMA interferometer. The LLAMA antenna will be equipped with two lateral Nasmyth cabins, similarly to the APEX antenna. Initially, we will work with receivers for band 5, band 6 and band 9 (band names of the ALMA observatory), constructed at NOVA Labs (University of Groningen, Holland). Brazil contributed to the acquisition of part of the receivers and construction of sub-systems, like the optomechanical system to be installed inside the Nasmyth and Cassegrain cabins, the cryogenics, and cryostat, where the receivers will be installed, and a system for holography.

The mounting of the antenna, which was slow in last years is going quite rapidly now, after Mincyt

attributed to INVAP, a strong engineering and technological company, the task of mounting. It is predicted that the mounting will be concluded in March 2024, and the first light will happen 2 years later.

The main scientific uses will be in the following areas: Galaxy Formation in the Early Universe, Astrochemistry, molecular evolution of interstellar clouds and identification of unknown lines, extra-solar planets and proto-planetary disks, polarimetry of radio sources and of the Interstellar Medium, Solar Physics (few antennas at this frequency can be pointed towards the Sun, like LLAMA).



Fig. 1. The dish of the LLAMA Radio Telescope being mounted.

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BOCOSUR: AN ALL SKY NETWORK FOR FIREBALL DETECTION IN URUGUAY

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We present the BOCOSUR network, a set of 20 stations widely spread across the entire territory of Uruguay, for automatic detection of fireballs.

Meteorites constitute relics of the early formation of the Solar System. A rapid recovery of fallen material is essential in retrieving a fresh and unweathered sample, which, together with the determination of the meteoroid’s pre-atmospheric orbit, can significantly constrain the conditions on its origin. The most cost-effective way of rapidly retrieving such material is through the deployment of automated networks for the detection of fireballs.

The BOCOSUR network is an initiative driven by the Department of Astronomy of the Faculty of Sciences of the University of the Republic of Uruguay (UdelaR), and comprises 20 stations of all sky systems for automatic detection of fireballs, focused on very bright fireballs of asteroidal origin that may give rise to meteorites. Most of the stations are located in secondary schools. The reason for this is that the project is intended to have a strong citizen science profile, involving teachers and students in the operation of each station.

The acquisition system is based on a ZWO ASI 178MM (Mono) camera, which has a 1/1.8” CMOS sensor (IMX178) and a 14-bit ADC. The sensor’s peak quantum efficiency (QE) is 81%, and the highest available video resolution is 2080x3096 pixels.

All of the applications and scripts for camera control, calibration, data acquisition, data transfer and post-processing have been locally developed in MATLAB (applications) and Python (scripts). The application for camera control, calibration and data acquisition runs locally on each PC, and enables to set the most relevant camera properties. Additionally, an application for post-processing detected events allows to perform both astrometric and photometric calibrations, and apply them to a fixed (e.g. Moon, planets, stars) or moving (meteor) body on the video stream.

We carried out a comparison between the astrometric and photometric performances of the ZWO ASI cam-

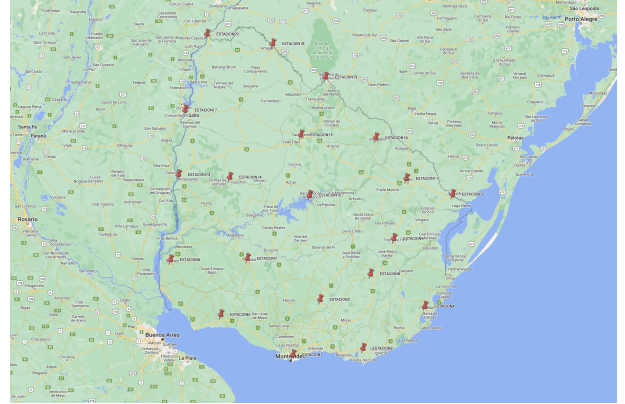


Fig. 1. Location of the 20 stations that comprise the BOCOSUR network.

era versus a widely used, low resolution camera (Watec 902 H2). The reason is that the latter is still widely used in different meteor networks. The mean absolute error (MAE) of astrometric calibrations were 15’ and 5’, for Watec and ASI, respectively. As for the photometric results, a 30s integration of Watec data yields a limiting magnitude ($\text{SNR} \geq 5$) of +2.79, while a 10s integration of ASI data gives a limiting magnitude of +3.18.

The data processing pipeline was applied to a very bright event detected by five of the southeaster most cameras of the network, yielding a peak absolute magnitude of -9.0 mag. The computed geocentric radiant was coincident with that of the Northern Taurids, associated with the comet 2P/Encke.

In summary, we have successfully deployed a nationwide network for automatic detection of fireballs, which contributes to unbiased the geographical distribution of similar networks around the world. The data processing pipeline which has been developed enables to reconstruct the meteoroids pre-atmospheric orbit, and lays the ground for further developments which will enable to model the dark flight, essential to limit the search area of meteoric material.

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SEMI-SUPERVISED DOMAIN ADAPTATION FOR MULTI-BAND SUPERNOVAE CLASSIFICATION

J. Saavedra-Bastidas¹, D. Moreno-Cartagena², M. Pérez-Carrasco³, G. Cabrera-Vives²

We introduce a novel approach that extends the Minimax Entropy (MME) algorithm for the multiband photometric light curve classification of supernovae. We assess the performance of our classifier based on the number of objects provided during training, the number of observations during prediction, and the multiband capabilities of the top candidates. Our results demonstrate the effectiveness of our method in the early classification of Zwicky Transient Facility (ZTF) transients.

In this work, we utilize two datasets: transients obtained through the ALerCE broker with forced photometry from ZTF and synthetic light curves (SLC). Both datasets include fluxes for type Ia, II, Ibc, and super-luminous supernovae in the g band (~ 464 nm) and r band (~ 658 nm), along with temporal information regarding the first alert per object.

We defined two sets of experiments: a *fine-tuning* strategy that involves taking a deep learning model previously trained with SLC data and further training it using a smaller labeled set from the ZTF sample, and a *domain adaptation* experiment through Minimax Entropy (MME, Saito et al. 2019). This experiment utilized the full simulated dataset, a small number of labeled items from the ZTF sample, and an unlabeled dataset comprising the remaining ZTF objects. We optimized the model parameters via a two-term loss function:

$$\mathcal{L} = H(y_s, \hat{y}_s) + \lambda H(\hat{y}_u) \quad (1)$$

Here, the first term represents the cross-entropy loss between the true and predicted values, and the second term denotes the entropy of the predicted labels for the unlabeled dataset.

The results for various sequential models (RNN: Muthukrishna et al. 2019; TCN: Bai et al. 2018;

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TABLE 1
METRIC SCORE, 15TH DAY AFTER THE FIRST ALERT.

Shots	Train	F1-Score(%)		
		RNN	TCN	TLC
1	FT	49±8	52±2	39±7
	MME	49±7	54±7	27±4
5	FT	50±5	51±4	44±5
	MME	49±7	55±3	41±5
10	FT	49±6	55±3	46±4
	MME	54±6	55±5	36±7
15	FT	52±5	53±3	44±7
	MME	55±2	51±7	37±5
20	FT	44±4	51±7	40±2
	MME	50±7	50±6	38±2

TLC: Astorga et al. 2023) on the 15th day after the trigger, sorted by ZTF objects delivered during training, are presented in Table 1. The Temporal Convolutional Network (TCN) proves to be the most suitable for classification, outperforming the Recursive Neural Network (RNN) and the Transformer (TLC). The MME algorithm is the most effective, requiring only five ZTF objects per class during training, surpassing fine-tuning (FT), which needs a minimum of ten objects. When evaluating the top TCN classifiers on the SLC dataset on the 15th day after the trigger, MME achieves 52±3%, outperforming FT (51±3%) and remaining competitive with the fully-trained TCN on SLC data (55±1%).

Acknowledgments: We extend our gratitude to Dr. Daniel Muthukrishna and the ALerCE team for providing access to the data used in this study. We also acknowledge the support of the ANID BASAL project FB21003.

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WHAT IS THIS? WIT OBJECTS AND OTHER SERENDIPITY DISCOVERIES IN THE VVV/VVX SURVEY

Dante Minniti^{1,2,3}, Roberto K. Saito³ and Philip W. Lucas⁴

The WIT objects (short for What Is This?) are sources that defy classification found in the near-IR database of the VISTA Variables in the Vía Láctea (VVV) survey and its extension the VVX survey. Here we summarize some specific cases of these previously unclassified variable sources.

We have been monitoring the Galactic bulge and southern disk in the near-IR using the VISTA telescope at ESO Paranal Observatory since year 2010. Massive searches for variable stars have been carried out in this vast database, resulting in the discovery of $> 10^6$ variables, including eclipsing binaries, RR Lyrae, Miras/LPVs, δ Scuti stars, classical Cepheids, type II Cepheids, novae, microlensing events, etc. These catalogs of variable stars have wide applications for studies of stellar populations, stellar formation and evolution, star clusters, and Galactic structure (e.g., Ferreira Lopes et al. 2020, Navarro et al. 2020, Herpich et al. 2021, Molnar et al. 2022).

Interestingly, within our database we have also found some objects that defy classification, and therefore we labeled them as WIT objects. Upon closer inspection, in the end some of the candidate WITs turn out to be observational glitches. Some of them appear fit into the previously known kinds of objects, but that are observed through extreme conditions like very high extinction. However, a few of them appear to be manifestations of new astrophysical phenomena, with light curves that exhibit unique peculiarities. These WIT objects represent a wide variety of extreme or rare sources, including for example:

- VVV-WIT01, a very reddened novae or supernova or a protostellar collision (Lucas et al. 2019).
- VVV-WIT04, an extragalactic radio source violently variable in the near-IR (Saito, et al. 2019a).
- VVV-WIT06, an extreme infrared transient as a probable dusty nova (Minniti et al. 2018).

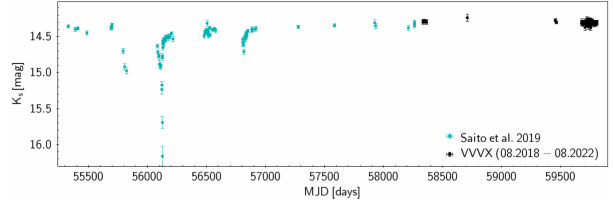


Fig. 1. Ks-band light curve for VVV-WIT07 covering a 12-year baseline, including VVV and VVX data.

- VVV-WIT07 (Figure 1), that is likely another Tabby star or Mamajek object (Saito et al. 2019b).
- VVV-WIT08, a disappearing source, nicknamed ‘the giant that blinked’ (Smith et al. 2021).
- VVV-WIT12, an unusual long period source that induces variability in its surrounding nebula, probably a light echo (Saito et al. 2023).

New classes of variable stars emerge, as illustrated by the discovery of the dipping giants (Lucas et al. 2024). They constitute a population of aperiodic late-type giant stars with extreme variability, that suggests the presence of deep extinction events. They are strongly clustered in the nuclear disc of the Milky Way, suggesting that they are very metal-rich giants undergoing high mass loss.

In most cases spectroscopic follow-up observations are needed to properly characterize the rare sources. These WIT objects, some of which were initially serendipitous discoveries, are now subject to a more systematic search in the rich VVX database. Our work also underscores the need to take into account serendipity in future large surveys. To placate some critics, we note that these are not mere fishing expeditions, because new science is emerging. . .

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RADIO TELESCOPES FOR MEXICO AND LATIN AMERICA

S. E. Kurtz¹ and D. M. Gale²

Inspired by efforts in Asia, Australia and Africa, we have undertaken the conversion of a retired telecommunications antenna into a radio telescope. The Tulancingo-1 antenna is a 32-meter parabolic dish, located at the Tulancingo Earth Station in the Mexican state of Hidalgo. When fully operational, we anticipate a useful frequency range from 1 to 15 GHz, and possibly as high as 23 GHz. Here, we describe the current state of the conversion project, mention several of the many potential science applications, and extrapolate our experience to what might be achieved by a Latin American network of radio telescopes, based on similarly converted antennas.

After extensive work by the metrology team of the INAOE and technicians from the San Pedro Mártir Observatory operated by the UNAM, the Tulancingo-1 antenna is now ready for commissioning, which we expect to last for most of the 2024 calendar year. The development of a pointing model and overall testing of the telescope will be carried out with an L-band receiver covering 1400 to 1800 MHz. After this initial commissioning, we plan to install a cryogenic C-band receiver, and also to make test observations with a warm K-band receiver. Early science applications will include maser and AGN monitoring observations.

Through the *Iniciativa VLBI Ibero Americana* (IVIA) we have contacted researchers throughout Latin America and identified a number of retired telecommunications antennas that might be suitable for conversion. As these radio telescopes come on-line, our long-term goal is to equip them for VLBI observations and thus involve Latin America in global centimeter-wave VLBI projects.

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Fig. 1. Front view of the 32-m Tulancingo-1 antenna. The electro-mechanical work for the conversion to a radio telescope is largely complete; commissioning will commence in 2024 using an L-band receiver.

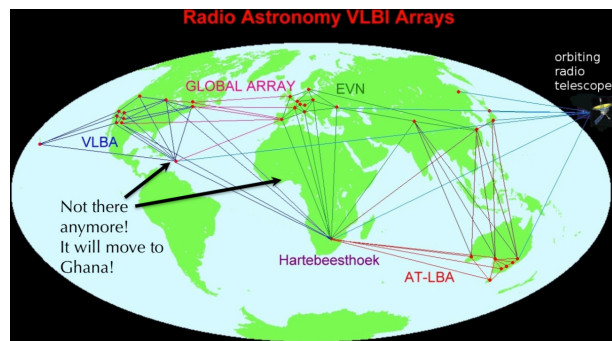


Fig. 2. The map shows existing centimeter-wave VLBI networks. With the collapse of the Arecibo telescope (and the coming-online of the Ghana telescope) existing baselines will shift further eastward. Central and South America is the most notable region without cm-VLBI coverage. The IVIA effort seeks to bring Latin America into the global cm-VLBI fold.

ABSTRACT ONLY

PROLIFERATION OF NIGHTTIME
ARTIFICIAL LIGHTING AND LIGHT
POLLUTION IN MAJOR URBAN AREAS OF
LATIN AMERICA

Kennet J. Rueda Espinosa¹, Andrés F. Guerrero
Guio² and Santiago Vargas Domínguez²

Light pollution is a form of environmental degradation that is increasing worldwide and affecting the natural environment, flora, fauna, and various aspects of human life. Despite growing concern about this issue, its study is still limited in Latin America. In this research work, we conducted a comprehensive analysis of the expansion of artificial night light in major Latin American urban centers between 2012 and 2022. The study focused on the cities of Ciudad de Mexico, São Paulo, Bogota, Lima, Santiago, Buenos Aires, Rio de Janeiro, Caracas, San Jose, Havana, Quito, Asuncion, Montevideo, and La Paz. The data reveals a wide range of radiance growth rates across the surveyed cities. While Asuncion and Lima experience significant annual radiance increases (4.55 and 6.84, respectively), Caracas shows a notable decline (-2.28). This disparity suggests diverse trajectories in urban lighting practices. Cities like Santiago de Chile and Buenos Aires show substantial increases in the illuminated area (847 km² and 547 km², respectively). Conversely, cities like Caracas and La Habana demonstrate a reduction in illuminated areas. These findings provide valuable information on the growing threat of light pollution in Latin America and supports the need for action to help control associated environmental degradation. It is essential to raise awareness of the negative impacts of light pollution on the ecosystem, human health, and astronomical observations. Implementing lighting regulations, promoting energy-efficient lighting technologies, and incorporating light pollution considerations into urban planning are essential steps to mitigate the effects of light pollution and protect the natural environment in major Latin American urban centers.

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ABSTRACT ONLY

TOWARDS A FIRST
SPECTRO-PHOTOMETRIC
CHARACTERIZATION OF THE CHILEAN
NIGHT SKY

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Arancibia^{3,2}

Light pollution is widely recognized as a global issue that, like other forms of anthropogenic pollution, has significant impacts on ecosystems and adverse effects on living organisms. In recent years, it has emerged as a fertile field for interdisciplinary scientific research, socioeconomic studies, and wide-ranging cultural debates. Chile is widely known for its rich and distinctive ecosystems, and the superb quality of its northern skies has transformed it into one of the most important astronomical nodes in the world. Nevertheless, a coordinated scientific approach to characterize, quantify and monitor the effects of ALAN on the Chilean sky has only recently started. Our interdisciplinary research group on ALAN was born five years ago with the explicit purpose of filling this need, and aims at providing the international community with the first spectrophotometric characterization of one of the most pristine skies of planet Earth. Since 2019 we have been regularly monitoring more than twenty distinctive sites across the Coquimbo Region (also known as “Región Estrella”), including professional astronomical observatories, astrotourism centers, natural parks, and metropolitan areas. In this poster contribution we will introduce our research group by describing its *raison d’être*; stating its short, medium and long-term goals; and presenting the first results of our surveying campaigns. We further describe how our scientific projects and outreach initiatives, through a constant synergy with public and private institutions, contribute to heighten public awareness about the subtle but devastating effects of light pollution. Finally, we offer an example where our scientific conclusions have supported different public committees in taking more enlightened decisions to preserve the darkness of the Chilean sky, a natural and cultural heritage that is our scientific, moral and social obligation to protect and defend for all future generations.

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ABSTRACT ONLY

RESEARCH AND DEVELOPMENT OF
SONIFICATION TOOLS FOR ASTRONOMICAL
AND ASTROPHYSIC DATA: THE CASE OF
SONOUNO

J. Casado^{1,2} and B. García^{1,3}

Data analysis in space sciences has been done exclusively visually for many years, even when there is evidence that more than one sensory style is possible (as is with sonification). Maintaining the data analysis exclusively visual not only limits the study of the unknown to the current resolution of the screens but also excludes a group of people who present different degrees of visual impairment. Considering those above and the fact that people with functional diversity experience a large number of barriers to achieving higher education and stable jobs, within the framework of my doctoral thesis, a new modality to access scientific data from the space sciences was investigated⁴. SonoUno is a product of this research that makes possible a multisensory display (use of more than one sense) of data files with two or more columns, taking into account the accessibility and inclusion of people with functional diversity from the beginning⁵. Based on the fact that multisensory perception can be a good complement to visual exploration for the understanding of complex scientific data and the exchange and feedback received from users over the past six years, sonoUno presents a framework focused on the user and is an application that can be used independently on the computer or through a web page. Additionally, the package presents different scripts for specific sonifications and use in bash. The work presented here maintains the next fundamental pillars: providing solutions and removing barriers (in education and scientific work, up to now); the use of free programming languages; and the design of infrastructure to improve inclusion.

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⁴<https://arxiv.org/abs/2305.05635>

⁵<https://reinforce.sonouno.org.ar/>

ABSTRACT ONLY**MASSIVE PHOTOMETRIC CATALOGS FOR
S-PLUS: OBJECT CLASSIFICATION AND
QUASAR PHOTOMETRIC REDSHIFTS**

L. Nakazono^{1,2}, R. Valença¹, G. Jacob Perin³, R. Izbicki⁴, N. S. T. Hirata², Ž. Ivezić², C. Mendes de Oliveira¹

The Southern Photometric Local Universe Survey (S-PLUS; Mendes de Oliveira et al. 2019) will cover 9300deg² of the Southern Sky with an 80-cm telescope (T80S) located at Cerro Tololo Inter-American Observatory in Chile. The S-PLUS optical filter system includes five broad bands: u , g , r , i , z (similar to the SDSS filter system, except for the u band) and seven narrow-band filters: J0378, J0395, J0410, J0430, J0515, J0660 and J0861, centred on [OII], Ca H+K, H γ , G-band, Mgb triplet, H α and Ca triplet features, respectively. The latest public data release (DR4) covers 3000 squared degrees.

In this work we detailed the construction of two value-added catalogues for S-PLUS DR4: the star/quasar/galaxy classification and quasar photometric redshifts. The former was obtained by a Random Forest algorithm that classifies any S-PLUS observation in quasar, star or galaxy. A complete description of all tested feature spaces, metrics, cross-validation, and performances on S-PLUS DR2 can be found in Nakazono et al. (2021). For the quasar photometric redshifts we use data from S-PLUS DR4 in three machine learning methods: Random Forest, FlexCoDE, and Bayesian Mixture Density Network. FlexCoDE had the best performance with a precision of 0.042 and conditional density estimation loss of -2.84. Using the information from these two value-added catalogues, we then provide a catalogue of quasar candidates (Nakazono & Valença, submitted) containing 626 418, 220 177, and 131 376 quasar candidates with probabilities higher than 80%, 90%, and 95%, respectively.

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ABSTRACT ONLY

EVALUATION OF THE IMPACT OF ARTIFICIAL LIGHT ON THE NOCTURNAL LANDSCAPE AND SOUNDSCAPE OF LAS BRUJAS (CANELONES, URUGUAY)

F. Reichmann¹, L. Lagaxio², A. Sosa³, M. Arim¹ &
A. Canavero¹

Increasing the emission of artificial light at night has well-documented negative effects on the quality of natural dark skies and changes the natural light/dark cycles, on which many species depend. Dark skies are relevant as natural values and for their cultural and heritage significance. This issue is just beginning to be perceived as a problem by decision makers and the civil society. The present work is a response to the concern of residents of Las Brujas (Canelones, Uruguay) regarding public lighting installation in July 2022. This research analyzes the nocturnal landscape before and after the placement of public lighting and its impact over the natural soundscape. Soundscapes are defined as the set of sounds generated by the elements that compose an environment. Through soundscape analysis, it is possible to estimate the response of organisms to anthropogenic pressures and to account for the structure and dynamics of the environment. For analyzing the nocturnal landscape, the sky brightness was measured at impact and control sites using an SQM photometer. From measurements obtained at 17 sampling points, sky brightness maps before and after the impact were made. For the analysis of the soundscapes, a Before- After, Control-Impact sampling design was implemented. A passive acoustic monitoring (PAM) was carried out, in which the soundscapes of 5 sites (1 impacted and 4 control sites) were recorded before and after the implementation of the new public lighting. By performing an analysis of variance, significant differences were found in the sky brightness before and after the public lighting was operational. However, the analyzed acoustic data shows that there are no significant variations in the acoustic landscape despite the alteration of the nocturnal landscape. Hypotheses that can explain this phenomenon are discussed and recommendations for the management of the socio-environmental problem are proposed.

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LA SERENA SCHOOL FOR DATA SCIENCE: APPLIED TOOLS FOR DATA-DRIVEN SCIENCES

V. Mesa,^{1,2,3} G. Damke,⁴ A. Bayo,⁵ M.J. Graham,⁶ D. Norman,⁷ M. Cerda,⁸ Francisco Förster,⁹ and Ibarlucea, C. ⁴

The volume and complexity of astronomical data continues to grow as the current generation of surveys come online (PanSTARRS, Gaia, Dark Energy Survey, VISTA). Astronomers will need to work with giga, tera and even petabytes of data in real time (LSST). This poses the challenges of developing and using new tools for data discovery, access, and analysis. At the same time, there are new opportunities for interdisciplinary research in applied mathematics, statistics, machine learning, crowd-sourcing, etc. Astronomy provides a sand-box where scientists can come together from diverse fields to address common challenges within the “Big Data” paradigm.

In response, since 2013 the AURA-O/NOIRLab together with other Chilean organizations such as the ULS and Universidad de Chile, have implemented the “La Serena School for Data Science: Tools for Data-Driven Sciences”. In this contribution we present our initiative, which is developed annually at the AURA campus in La Serena, Chile. Between July and August, the school receives 32

students and 10 expert professors for 10 days, following an intensive program of introductory classes with an important component of hands-on learning. This is materialized mainly by the development of group projects, where students solve complex problems in groups, applying what they have learned and guided by the teachers. Participants come from various countries such as the US (NSF-funded), Chile, and other Latin American countries such as Ecuador, Brazil, Mexico or Colombia. Students from different disciplines are encouraged to participate, including (but not limited to) astronomy, physics, computer science, statistics, mathematics, biology medical informatics.

Since LSSDS began 10 years ago, we have trained more than 230 students in data science. As seen in the statistics, efforts have been made to promote diversity in all possible areas. Also, the alumni of the school has been particularly active not only “returning” as Teaching Assistants, but also replicating parts of their schools at their home institutes.

The interest of the scientific community is increasing, with a record of applicants in the last year, mainly from Latin American countries.

We are very pleased to announce that the NSF has just approved the budget to fund LSSDS through 2024. ¹⁰ We invite all Latin American institutions to support this initiative!

Acknowledgements

Thanks to our funding from NSF (Award Number (FAIN): 1637359) and ANID (Gemini/ANID program, Chile N° ASTRO21-0067), along with other international partners, applications from students in US, Chilean, Ecuadorian (members of CEDIA) and Latin American (members of Red-CLARA) institutions are eligible for full scholarships that cover all school expenses. We also thank NSF’s NOIRLab, AURA Observatory in Chile, Universidad de Chile, Universidad de La Serena, NIC Chile, REUNA, Millennium Institute of Astrophysics (MAS). V.M. also acknowledges support from project DIDULS Regular N° PR2353857.

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¹⁰Additional information and applications: http://www.aura-o.aura-astronomy.org/winter_school/

BRIDGES BETWEEN CULTURES: THE ASTRONOMY AS UNIVERSAL LANGUAGE

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To commemorate the UNESCO International Day of Light (IDL), NASE proposes to carry out experiences of great educational interest and big impact. Although the IDL is May 16th, the activities can be perform between March and September equinoxes.

Throughout history, Astronomy marked the lives of human beings in diverse ways. The approach to the starry sky was important from the ritual and daily ceremonial point of view and occupied a good part of the activity of all people on Earth. Although we have fragments of knowledge of the peoples of the past, we know that astronomy allowed us to establish patterns that became part of universal culture: compass, clock, calendar, intangible heritage of humanity, according to the UNESCO declaration of 2007. Bridges between cultures, is the annual proposal of the Astronomy Education Network in the School (NASE) associated with the UNESCO call for May 16th, the International Day of Light. This activity aims, hand in hand with universal astronomical themes, ancestral knowledge, discoveries of the modern era and great challenges of science dedicated to the study of the “light” that arrives from the Cosmos, to reestablish the links that identify us as a species. The idea started in 2018 and the invitation to people all over the Globe is to perform a simple activity which connect them with the nature, using astronomical instruments.

The topics along the years were: detecting the invisible, measuring the power of the Sun, working with the parallel Earth, determining the Latitud (Ros & Garcia 2022) (Figure 1) and looking for micrometeorites (Ros & Garcia 2023) (Figure 2).

Every year, more than a hundred teachers participate, several hundred reports are sent from more than 200 students (5-18 and college), who come from more than 25 countries around the world.

The indicators that allow evaluating the impact of the activities proposals and the testimonies of participants who constitute diverse audiences that come, many times for the first time, to the discipline



Fig. 1. Determining the latitud, Iran, 2022



Fig. 2. Looking for micrometeorites, China, 2023

that, without a doubt, confirm that astronomy is a universal language, which even allows us to write our stories in and thanks to the stars.

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FRONTIER ASTRONOMY. ACTIVITIES FROM THE PERIMETER INSTITUTE AND THE ICTP-SAIFR FOR THE SECONDARY CLASSROOM.

Martín Monteiro ¹

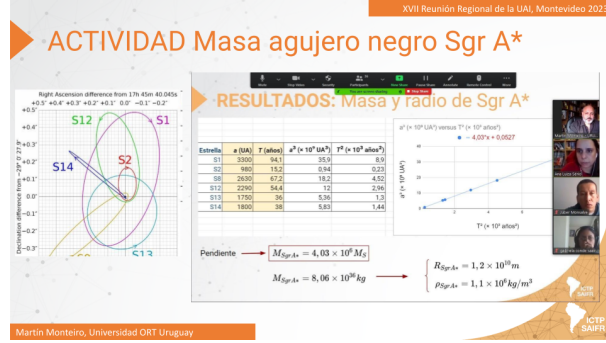


Fig. 1. Screenshot of one of the virtual activities on black holes, in which the mass of Sgr A* is determined from the orbits of some of its satellite stars.

“Frontier Astronomy” and “Frontier Physics” are a series of activities for the highschool classroom that aim to share teaching techniques and strategies for the inclusion of modern and contemporary astronomy topics in the classroom, both in face-to-face classes and online. The activities are designed to be easily attached to regular physics or astronomy courses, without the need to change the curriculum, including motivating topics for students, addressing current issues such as dark matter, exoplanets, the expansion of the universe, cosmology, black holes, gravitational waves, among others.

The almost 100 activities, included in 18 books, were developed by the renowned Perimeter Institute for Theoretical Physics of Canada, and translated and adapted into Portuguese and Spanish by the ICTP-SAIFR (South American Institute for Fundamental Research), a physics center associated with Abdus Salam ICTP (Trieste, Italy) and associated with the Institute of Theoretical Physics of the University of São Paulo, Brazil (IFT-UNESP).

Each activity includes: a sequence of practices and related questions for discussion of activities in small groups; and an evaluation to consolidate learning.

The activities translated into Spanish began to be

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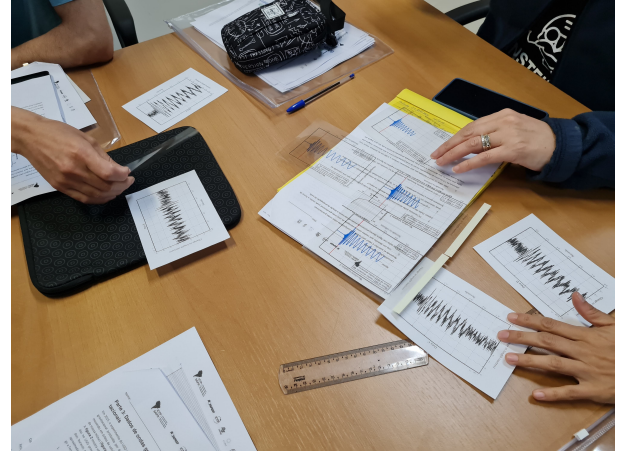


Fig. 2. An in-person activity on gravitational waves. Students use transparent templates with different waveforms to compare them with theoretical models.

disseminated in March 2021 to physics teachers from Latin America through virtual workshops (Figure 1), organized by the ICTP-SAIFR and coordinated by Ana Luiza Serio. Since then, 47 virtual meetings lasting more than 2 hours have been held, reaching a total of 1339 participant entries from 20 countries.

Although the activities were adapted to virtuality, they were originally designed and are ideal to be carried out in face-to-face activities. Figure 2 shows an example of an activity on gravitational waves carried out in Montevideo for physics and astronomy teachers.

Finally, we encourage teachers to join the workshops and adapt the activities to the needs of their own classes.

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A DIGITAL GAME TO TEACH STELLAR NUCLEOSYNTHESIS: DESIGN AND STUDENT FEEDBACK

C. C. Siqueira¹, N. Figueiredo¹, A. F. Oliveira¹, M. R. A. Silva¹, & M. A. F. Faria²

The use of digital technologies combined with an interdisciplinary approach that connects the periodic table to astronomy can provide students with a better understanding of the stellar nucleosynthesis of chemical elements, and thus motivate them to study these subjects. This work presents an educational digital game entitled “The Periodic Table According to Cosmochemistry”, developed to playfully approach the synthesis of chemical elements in the context of astronomy.

At the beginning of the first phase, the player should capture a proton and throw it towards another one to produce a deuteron, a positron and a neutrino. Next task is to capture a deuteron and throw it towards a proton to synthesize a helium-3 nucleus. Each time a new chemical element is synthesized, the player sees a drawing with a brief description of that element, which is then placed on a periodic table. This phase ends when the player synthesizes the other elements of the proton-proton chain: lithium, beryllium and boron. In the second phase, the player goes through the triple-alpha process, the CNO cycle and the carbon-burning process. Finally, the last phase corresponds to a supernova explosion, in which heavier elements are synthesized.

Written in Python, the game is currently available in English and Portuguese (Siqueira 2023) and can be freely downloaded from <https://sites.google.com/site/credianafaria/>. In order to evaluate the effectiveness of the game, we conducted teaching sessions at different school levels to investigate students’ learning and perception about the game. These sessions involved 52 students, which were enrolled at an elementary school (12 students), a high school (8 students) and a university (32 students). In each session, students answered a questionnaire containing open and multiple-choice questions, played the game and answered the questionnaire again. The answers were then analyzed qualitatively and quantitatively, so that we could compare the answers before and after playing the game.

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TABLE 1

UNDERGRADUATE STUDENTS’ FEEDBACK.

Component	N	N_i
Motivation	11	2
User experience	17	9
Learning	3	2

The undergraduates also answered a questionnaire adapted from an educational game evaluation model developed by Savi et al. (2011), which consists of 3 subcomponents (motivation, user experience and learning), comprising 15 dimensions, 29 standard items and 3 customized items. The learning subcomponent includes customized items, which address the first three levels of Bloom’s revised taxonomy: remember, understand and apply (Anderson & Krathwohl 2001). The feedback pointed out the strengths and weaknesses of the current version of the game and provided suggestions for future improvement. A summary of the results can be found in Table 1, which shows each subcomponent, the total number of items N and the number of items that need to be improved N_i .

The qualitative and quantitative results provided evidence that this game is an effective educational resource, capable of motivating students, promoting learning, and providing a positive gaming experience. The use of educational digital games, such as this one, can be a promising approach to improve the teaching of stellar nucleosynthesis and the origin of the chemical elements. By integrating astronomy, chemistry, nuclear physics, and digital technologies, educators have the opportunity to spark students’ interest and encourage their pursuit of knowledge in a meaningful way.

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ANALOG SIMULATION TO EXPLORE AND TEACH EXOPLANETOLOGY CONCEPTS

J. N. Molina Córdoba^{1,2}, J. Murcia Rocha², C. A. Ospina Castillo², M. A. Patiño Ochoa²

In this work we present a proposal of analog simulation that allows to generate light curves for simple simulated exoplanetary systems, in transit with the purpose to use this resource to explain how to know from the analysis of the light curve, the semi-major axis, orbital period and reason of exoplanet/star sizes from an exoplanetary system. The assembly is set up for two exoplanetary systems, referred to: System A System B, obtaining a margin of error in their sizes estimation of 1.5% for system A and 4.25% for system B. The frequency spectrum of the time series for both systems leads to a reliable estimation about the traslation period for both of the systems arranged in the assembly. The high sampling rate of the light sensor incorporated in an average cell phone (100 ms), allows to make a test scaling 1 second = 1 day, in order to bring the framework of the test proposal in line with the scientific data in the study of exoplanet light curves. Due to the uncertainty of the fluxes measured for each light curve obtained ($\approx 1e-7$ lx), the setup is efficient and could be used to develop more rigorous investigations taking into account better analysis criteria (a ratio of star sizes/exoplanet more concordant with known exoplanetary systems), and better controlled laboratory conditions, in addition to being a low-cost proposal.

This proposal seeks to replicate, within a controlled indoor environment, the light curve readings of uncomplicated exoplanetary systems. Specifically, we aim to simulate Keplerian systems characterized by zero eccentricity and orbital inclination, utilizing the light sensors typically found in mobile devices, through the mobile application Arduino Science Journal (ASJ).

The assembly provides calibration details for an

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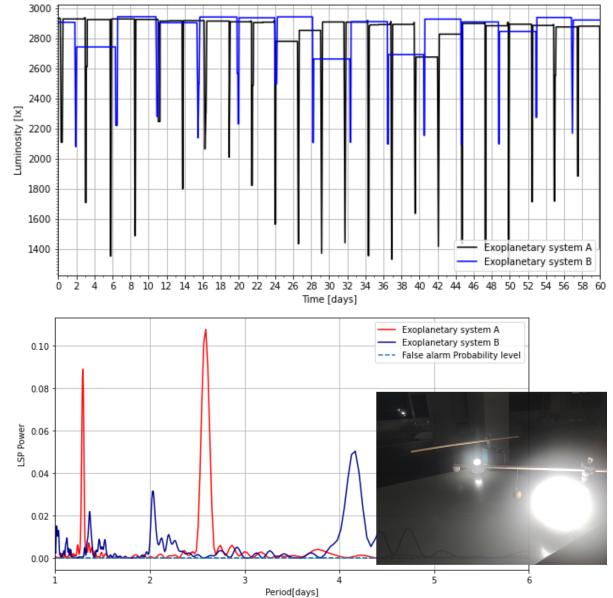


Fig. 1. Up: Light curves of systems organized in the montage under the parameters: same star, different orbital speeds of translation, and 2 exoplanets of different sizes. Down. Frequency spectra obtained for each exoplanetary system. Bottom right: Final assembly photography.

astronomy teaching proposal, aligning with scientific processes for determining measurable properties of real exoplanets via the planetary transit method. By modifying assembly parameters, real exoplanetary systems can be modeled, using more sensitive sensors with a minimum sampling time interval of 1 ms. The setup’s efficiency, reflected in low error percentages (1.5% and 4.25%) for determining exoplanet sizes, allows for analogous simulations of exoplanetary systems.

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TEACHING ASTRONOMY WITH ASTROLAB AT PUCP

Myriam Pajuelo¹, Aldo Panfichi S.¹, Michele Gerbaldi², Nicole van der Blik³

We present our experiences teaching an introductory-level astronomy course at the Pontifical Catholic University of Peru (PUCP). Students attended theory sessions alongside practical experiences observing remotely using the Las Cumbres Observatory 40 cm telescopes <https://lco.global/>. This was done using the ASTROLAB (Starlight in the university lab) tutorial, a project of the Office of Astronomy for Development (OAD) of the IAU <https://www.astro4dev.org/astrolab-starlight-in-the-university-lab/>. With this effort, we try to make up for the few opportunities that undergraduate Peruvian students have to do observational astronomy, due to the limited number of astronomical facilities that exist in the country.

Students taking the course are introduced to methods of scientific research as they go through the same steps astronomers do when preparing and performing an observing program. They learn how to plan observations, submit proposals, process their data and analyze their results using astronomy software and Virtual Observatory (VO) tools on images obtained from the remote telescopes at Las Cumbres Observatory. This experience teaches students to develop teamwork abilities, understand the complexity and ambiguity of empirical work, develop practical skills, learn to perform error analysis, defend their results both in written and oral form, and most importantly: develop critical thinking.

This course was taught in three separate semesters between 2021 and 2023. Individual and group-based observation and analysis projects focused on a series of different observable astronomical objects and phenomena. Observations took the form of photometric (B, V, rp) images, due to the instruments we had access to from the Las Cumbres Observatory network. The analysis performed was primarily aperture photometry, although the mechanism to perform the analysis changed between semesters as the course developed, from pre-written Python algorithms the students had to manipulate to use of

the IRIS software. Projects ranged from creating lightcurves of eclipsing binary stars, making color-magnitude diagrams of open clusters, identifying asteroids, and even obtaining a lightcurve of the recent supernova in M101, SN2023ixf; in each case students had to not only understand the nature of the scientific analysis to be performed, but also understand observational constraints and perform target selection.

By being exposed to a variety of kinds of objects, which behave very differently from an observational standpoint and thus require different modes of analysis, the students were able to be exposed to a wide panorama of the kinds of research done in astronomy, even while restricted purely to optical photometry. Individual and group reports of each project were submitted to the instructor for grading and feedback purposes.

This work makes use of observations from the Las Cumbres Observatory global telescope network (program LCOEPO2018A-001).

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FIRST ANDEAN NETWORK OF ENTREPRENEURS IN ASTROTOURISM

G. Pinzón¹, N. Vásquez² and Beatriz García³

It is inspiring to see how astronomy is being used to foster development and improve local conditions in various regions, including those with challenging weather conditions such as the Andean Region in Latin America. In this contribution we describe the main goals of the first andean network of entrepreneurs in astrotourism and possible roles that professional and amateur astronomers could play in it.

Despite being one of the most cloudy regions around world and thus not very suitable for conducting optical astronomical observations, in countries as Ecuador, Colombia, Perú, Venezuela and Bolivia the interest on Astronomy has been growing during last two decades. This interest is not only to a professional level of formation but also it is related to some rural communities searching for improvement of their own local conditions through sustainable projects that make use of astronomy. Pioneer OAD projects such as “Astronomy for Himalayan Livelihood Creation” have shown how digital education, energy access to remote unelectrified communities and in general, an improvement of local conditions can be reached through astronomy⁴.

With the aim to promote responsible and innovative tourism of stars in the Andean region, especially in rural areas in which it could become a real driving force for local economies, the OAD and EPN (Ecuador) organised the IV Workshop Astronomía en los Andes : “Engaged communities in development through Astrotourism” held in Quito in October 2023. Almost seventy entrepreneurs from 4 andean countries were sharing experiences with experts. An important outcome of this meeting was the creation of the **First Andean Network of Entrepreneurs in Astrotourism**, a platform



Fig. 1. First Andean Regional meeting on astrotourism in Quito during October 2023

for dialogue between entrepreneurs and experts aimed to avoid misconceptions in astronomy and to reaches communities with a clear explanation about how science and particularly astronomy works.

One important task of the first andean network is to enrich the experiences and practices through meetings with astronomy students, amateur and professional astronomers. As well as collaborations, the network requires support from initiatives such as the Network for Astronomy School Education - NASE⁵. It's truly fascinating how astronomy can be used as a tool for development, education, and economic growth. These initiatives are demonstrations of the power of science in transforming communities and improving livelihoods.

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⁴<https://www.astro4dev.org/category/astronomy-for-himalayan-livelihood-creation/>

⁵<https://www.naseprogram.org/es/>

ABSTRACT ONLY**PROTOPLANET EXPRESS, A VIDEO GAME
BASED ON HYDRODYNAMICAL
SIMULATIONS**J. Cuadra^{1,2}, M. Vergara³, B. Escárate¹,
J. Sandoval³, B. Cordero¹

High-resolution observations obtained during the last decade show that protoplanetary discs can be very complex objects. Rather than uniform discs, we see that they have large cavities, spiral arms, rings, gaps, and asymmetries. To understand these features, astrophysicists many times have to develop numerical simulations, in which planets or unseen stellar companions are added to reproduce the observed morphologies. While the spectacular observed images are popular in mainstream media, the simulation side is rarely known by the general public.

We have created “Protoplanet express”, a video game in which the user visits different known protoplanetary discs, which are rendered in 3D from actual hydrodynamical simulations. The user will encounter in the models the same features observed with ALMA and other telescopes, and their goal will be to find the reason for each of them. For example, the user completes a level once they find the planet causing an observable gap in the disc.

Please find a copy of the poster at https://jrcuadra.github.io/plaga/larim_ppe/ and a related article at <https://arxiv.org/abs/2303.17654>. The game is available at https://store.steampowered.com/app/2601120/Protoplanet_Express/.

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ABSTRACT ONLY

ASTRONOMY AND NON-FORMAL
EDUCATION AS PROMOTERS OF SCIENTIFIC
LITERACY: THE CASE OF THE RODOLPHO
CANIATO ASTRONOMICAL POLE

Camila Maria Sitko^{1,2}, Oscar Rodrigues dos
Santos² and Michel Corci Batista³

Astronomy is one of the Sciences that most causes fascination and curiosity in the general public, and thus, it can be used as a gateway to motivate the interest and participation of students and the general community in the scientific enterprise, thus enhancing the formation of scientifically literate citizens. , capable of making critical decisions about the world around them. As a way of working towards this cause, the use of Non-Formal Education spaces becomes an interesting alternative. In this sense, as a way of exemplifying how this relationship between Astronomy and the formation of scientifically literate citizens occurs, this work presents an overview of the activities and research in teaching carried out within the scope of the Rodolpho Caniato Astronomical Pole, located at UTFPR Campus Campo Mourão, Brazil, to which scientific literacy indicators are associated and discussed.

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ABSTRACT ONLY

PROPOSAL FOR TEACHING ASTRONOMY IN
BRAZILIAN MIDDLE SCHOOLS BASED ON
GAGNÉ’S LEARNING THEORYT. F. Vieira¹, M. C. Batista², O. R. Santos², M.
Ferreira³ and C. M. Sitko²

Qualified teaching of Physics requires alignment between a learning theory (psychological, descriptive) and grounded methodologies (SILVA FILHO; FERREIRA, 2009). Gagné’s theory, developed in the transition between behaviorists and cognitivists-during the behaviorist AND cognitivist transition (MOREIRA, 2022), frames learning as hierarchical information processing. This structure involves: **a. Discrimination** (distinguishing stimuli), **b. Concepts** (classifying objects), **c. Rules** (applying symbols like math), and **d. Higher order rules** (problem-solving). A Brazilian high school Astronomy course (13 hours, six modules) operationalized this theory through nine instructional events, focusing on gravitation via reflective, theory-guided activities. Students synthesized learning by creating mental maps, analyzed using Novak and Gowin (1984) criteria: concept hierarchy, thematic scope, original ideas, and technique application. Results demonstrated that most students successfully organized concepts and established relational dependencies. The integration of Gagné’s theory with the methodology promoted hierarchical, meaningful learning with critical and interdisciplinary components. Key indicators-autonomy, conceptual relationships, and hierarchy-validated the approaches effectiveness, supported by complementary epistemological and methodological frameworks. This case underscores the value of theory-driven pedagogy in fostering structured, engaged learning.

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ABSTRACT ONLY**ASTRONOMICAL OUTREACH ACTIVITIES AT
THE OBSERVATORIO ASTRONÓMICO LOS
MOLINOS**Andrea Maciel¹

In this poster we present the different outreach activities that take place at the Observatorio Astronómico Los Molinos (from here on, OALM), located at the outskirts of Montevideo, Uruguay. Face-to-face activities, as well as social networks interactions (which have noticeably increased after 2020) are shown, as a way to take Astronomy and related sciences to as many people as possible.

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ABSTRACT ONLY**A DIDACTIC EXPERIENCE IN THE STUDY OF
THE PROPER MOTION OF STARS IN THE
CLASSROOM**Rafael Girola Schneider¹

The proper motion of stars is a very important topic in an Astronomy course. In principle, it allows us to measure the spatial speed of the stars in relation to the Sun and, from this, determine distances and other stellar parameters, allowing us to probe the proximities of the solar neighborhood and the speed of the local stars in the galaxy. That is why a work carried out by the Physics teachers in the subject of Astronomy II of the “Héctor Medici” Institute is presented. The work unifies a historical view of how and what was interpreted in the year 1718 when Edmund Halley found that the stars Sirius, Arcturus and Aldebaran had moved in the sky more than half a degree since the observations made by Hipparchos, along with a didactic sequence. That is where students, through actions, link their knowledge and previous experiences, with some question that comes from reality and with information about an object of knowledge, managing to differentiate the improper movements of the stars, in which the coordinates stars are affected to the same extent by the movement of precession, nutation and aberration of light, deducing that only the proper movement corresponds to the real movement of the stars. One of the examples that has been highlighted in class is the proper motion of Barnard’s Star moving 10.2”/year. One of the tools on which the work is based is the information from the Tycho catalog, as well as measurements made by Hipparchos and Gaia satellites.

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ABSTRACT ONLY

CITIZEN SCIENCE ON THE FIREBALL DETECTION NETWORK: *BÓLIDOS DEL CONO SUR (BOCOSUR)*

L. Velasco¹, V. Abraham¹, M. Hernández¹, L.
Barrios¹, M. Caldas¹, G. Tancredi¹ and A.
Guaimare¹

We have successfully established a national fireball detection network, comprising 20 stations strategically positioned to cover the entire Uruguayan territory. The primary challenge we encounter is managing the substantial volume of generated data, leading us to initiate a crucial Citizen Science project. To widely disseminate the BOCOSUR Project, we crafted a website featuring comprehensive information and a fireball report form. Concurrently, we installed stations in high schools nationwide and conducted over 30 talks, engaging with a diverse audience of over 1000 students. Additionally, we conducted 4 virtual training workshops tailored for high-school teachers and students eager to contribute to video analysis within the network. Each workshop comprised 3 sessions. The initial meetings focused on presenting the project and delving into essential theoretical concepts, showing station operations, and imparting manual video classification skills. The third session aimed at applying acquired knowledge to video classification. Across these editions, we had 141 participants, including 105 students and 36 teachers from 40 different institutions. Around 70 participants successfully completed all activities. In the latest edition, over 1400 videos were analyzed, uncovering 170 meteors. Recently, we concluded the first phase of developing a web app for swift video classification. This was tested in a workshop with 30 teachers from diverse institutions, resulting in the classification of 70 as meteors, from a pool of almost 400 videos. Building a comprehensive database, not limited to fireballs, is crucial for training the machine learning classification algorithm developed by the AutoBol group as an Electrical Engineering final project (Ballestrino et al. 2022).

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ABSTRACT ONLY**ASTROMICRO: ASTRONOMY ARRIVES IN
MICRO TO TELEVISION**S. Ramírez Alegría¹, K. Peña Ramírez¹ and J.
Carballo-Bello²

In the summer of 2023, the educational channel of the Chilean television channel TVN broadcasted the first six episodes of the show “AstroMicro”. The event was a significant milestone for this interdisciplinary scientific communication project, bringing astronomers, animators, filmmakers, producers, writers, and project managers together. “AstroMicro”, jointly funded by the TV channel, the Chilean Astronomy Society, and the Chilean Agency for Research and Development (Agencia Chilena de Investigación y Desarrollo), occurs on a “micro” where all the astronomical concepts are revisited with simple but accurate jargon relating the different experiences of the diverse passengers to everyday experiences in a bus. This approach avoids hierarchical communication within the team from the very early stages of the project, fostering communication and avoiding outsourcing the creative components of the product. In this talk, we will share details of the story behind the production, from the original idea to the screening of the first episodes.

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ABSTRACTS

RECA: PROMOTING CAREER DEVELOPMENT OPPORTUNITIES IN ASTRONOMY TO STUDENTS OF COLOMBIAN INSTITUTIONS

N. Oliveros-Gomez¹, J. P. Uchima-Tamayo², S.
Rojas³, K. Peña-Ramirez⁴ and RECA
Collaboration

The Network of Colombian Astronomy Students (RECA) is a student-led association formed in 2014. It seeks to support the astronomy student community with the aim of 1) Connecting the astronomical community with the main goal of supporting early career astronomers in Colombia, and 2) overcoming systematic barriers in academia and research. Early career and senior Colombian astronomers conform to this collaborative community. We will highlight the work from 3 nodes. The RECA education program works with schools from all regions of Colombia, providing tools and interaction with Colombian professional astronomers, using virtual chats, connection to remote observations in large telescopes, or personal counseling. The RECA mentoring program connects undergraduate students with astronomers in advanced career stages. They have personalized tutoring one-on-one, for career advice and guidance for applying to graduate programs in astronomy. Furthermore, the RECA summer internship program provides the opportunity for Colombian undergraduates to participate in astronomy research projects led by professional astronomers around the globe. All the programs are running their third version, and their successes have been seen with the positive impact of synergies within the Colombian student population of all academic levels. Funding for some programs has been obtained from national and international entities. The work of the RECA nodes highlights the importance of a student-led community both in connecting the astronomical community, and supporting beginning astronomers.

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ABSTRACT ONLYTHE 0TH MERIDIAN OF BUENOS AIRESD. D. Carpintero^{1,2} and R. B. Orellana^{1,2}

The Buenos Aires meridian was used at the end of the 19th century as a reference origin to establish limits between the provinces and the then national territories. However, the exact position that materialized this meridian could never be established, with the consequent uncertainty in the limits that depended on it. In this work, we determine for the first time the exact position of the meridian of the city of Buenos Aires.

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ABSTRACT ONLY**HANDS-ON ACTIVITIES FOR STUDYING
LIGHT POLLUTION: PHOTOMETRIC
MEASURING OF ZENITH NIGHT SKY
BRIGHTNESS**L. M. R. Volpe¹ and J. Gregorio-Hetem¹

Night sky brightness (SB) is an important quantity to investigate light pollution contamination at a given site. It can be measured by different methods and apparatus, resulting in different forms of analysis and comprehension of the artificial light regime. The objective of this work is to present some of these measuring methods in order to elaborate hands-on scholar activities material. Two main methods were tested during the year of 2022 at the Observatório Abrahão de Moraes (Valinhos, SP, Brasil): by telescope with coupled CCD camera (the Argus telescope) and by IOS Dark Sky Meter (DSM) app.

Values for SB were found for the photometric Johnson B ($16,82 \pm 0,30$ mag/arcsec²) and V filters ($16,49 \pm 0,48$ mag/arcsec²), indicating that the sky at the observatory is highly light polluted, similar to big cities. The DSM app was consistent in its own scale to evaluate night sky brightness variations. However, it is roughly compatible with V or B bands from the UBV Johnson system, showing fainter magnitudes with 2,5 mag offset. The results were used to elaborate a script to conduct similar activities, both locally at a given observatory or remotely through the “Telescópios na Escola” project, allowing students to measure SB with the same Argus telescope used during the work. We also addressed experiments with the DSM app for light pollution teaching and outreach, in order to promote awareness and discussions about its impacts where the usage of astrometric apparatus is neither viable nor recommended.

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ABSTRACT ONLY**THE SCIENTIFIC CONTRIBUTIONS OF THE
FIRST MODERN COLOMBIAN ASTRONOMER**

Freddy Moreno Cárdenas¹, Santiago Vargas
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Astronomical interest within the current Colombian territory has its roots in the Botanical Expedition of the New Kingdom of Granada, which stimulated the creation of an astronomical observatory in 1803, the first one established in the New World to pursue systematic observations and meteorological studies. After the death in 1816 of its first director, Francisco José de Caldas, during the convulsive independence period, no major astronomical observations were made for decades, with few exceptions. In this work we delve into the contributions of the astronomer José María González Benito (JMGB), main reactivator of the National Astronomical Observatory of Colombia (OAN) in the second half of the 19th century, pointing out his pioneering efforts that put worldwide attention to it, and to his own private observatory. We have collected evidence supporting the fact that JMGB was one of the most important figures in the history of Colombian astronomy, not only due to the advances and discoveries that he achieved as a result of innumerable investigations and projects but also because of his unique sense of patriotism. As director of the OAN and of his private observatory (Flammarion Observatory), JMGB made numerous observations on different astronomical topics, being reports on comets among the most extended ones. In 1893 he observed the comet Rordame-Quénisset, nine days before the observations made from the US and France that were the ones designated as the official discovery. JMGB also observed meteor showers: the Leonids, on 14 Nov. 1867 and 13 Nov. 1899, and an unidentified one he reported on 24 Nov. 1872 in Andromeda. JMGB was a well-known astronomer in Europe and kept continuous communication with his colleague and friend Flammarion. Indeed, JMGB made observations from the Flammarion Observatory that had been completely unknown by the Colombian academic community until found by this research.

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ABSTRACT ONLY**TEACHING ASTRONOMY BASIC CONCEPTS
USING SMARTPHONE SENSORS.**Martín Monteiro ¹ Arturo Martí²

Smartphones are computers that, in addition to fitting in the palm of the hand, have the additional advantage of including several sensors that, with the appropriate knowledge, allow these devices to be transformed into very useful and economy portable laboratories for doing and teaching science.

In recent years, dozens of experiments have been proposed to teach science and to engage students by allowing them to do science on their own (Monteiro 2022), and in particular as valuable tools to teach astronomy (Monteiro 2020). Some activities can be carried out in basic courses of astronomy at high school and university. Using the smartphone’s camera students can perform parallax stellar distance measurements on a scaled system to obtain the distance and the parallactic ellipse (Fitzgerald 2011). By using the light sensor of a smartphone, students are able to measure the light curve of a 3D printed scale asteroid to determine the period and shape factors (Ziffer 2019). Another useful activity with the same sensor aids to learn how to discover exoplanets by planetary transits in a scaled star system (Barrera-Garrido 2015).

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ABSTRACT ONLY**THE MANUEL FOSTER OBSERVATORY -
HISTORY, SCIENCE AND NEW LIFE OF THE
FIRST PROFESSIONAL OBSERVATORY IN
CHILE**Thomas H. Puzia¹ & Simón Ángel¹

The history of the Manuel Foster Astronomical Observatory, affiliated with the Pontificia Universidad Católica de Chile and situated in the heart of Santiago’s Metropolitan Park on top of San Cristóbal Hill, presents a prime opportunity to promote astronomy and natural sciences to the general public. Established in 1903, the observatory stands as one of the oldest in the Southern hemisphere. At the forefront of cutting-edge research in the early 20th century, it was designated a Historical Monument in 2010, and since then, it has garnered increasing attention from the public. Given the few million visitors and tourists who annually visit San Cristóbal Hill in Santiago, the Foster Observatory has undoubtedly become an essential stop on their journey. We highlight the scientific achievements, infrastructure and the recent transformation and repurposing of the Foster Observatory into an astronomical museum and outreach center. Our goal is to preserve and educate using its unique and original historical assets. We offer weekly diurnal and nocturnal observations that pave the way for a regular visitor program, primarily targeting students from educational institutions across the region, country and the continent.

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ABSTRACT ONLY**QUBIC OBSERVATORY: EDUCATION,
OUTREACH AND CULTURE CONNECTED
WITH THE ORIGIN OF THE UNIVERSE**B. García^{1,2} on behalf of QUBIC Collaboration

The link of the human being with the cosmos is ancient. However, the approach to knowing what the universe is like has changed remarkably over time. New projects, with avant-garde instrumentation, are installed in astronomically exceptional regions, where the ancestral culture of native peoples has existed for centuries. Such is the case of QUBIC (Q-U Bolometric Interferometer for Cosmology), an instrument that aims to detect evidence of the time of universal inflation, installed in November 2022 in the Puna of Salta, land of the Kolla, Kolla del Desierto, Atacamas peoples, among others. At this crossroads between ancestral knowledge and modern science, QUBIC has developed, even before its realization, a link with the local inhabitants and seeks to establish a bridge between both cultures where, in addition, art has its space. In this presentation we seek to show a possible way to address the issues of education and dissemination of astronomy and astrophysics, living with them and transmitting their ideas to the world, maintaining the complex balance between these two cultures, to ensure that local communities take ownership of scientific developments that, without a doubt, contribute to the progress of not only of science, but also of the sites that host them and the local populations

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² QUBIC Collaboration.

ABSTRACT ONLY

EDUCATION AND ASTRONOMICAL DIFFUSION ACTIVITIES IN BOLIVIA

Paola Ochoa¹

The activities of education and dissemination of astronomy in Bolivia, intend to reflect the work done with students, teachers, amateur astronomers, and the general public in the different regions of Bolivia, both in rural and urban areas. sharing the objectives of the IAU, with a public that for the most part is still unaware of this important institution. work that motivates us to continue growing.

¹ NOC NAEC BOLIVIA International Astronomical Union.

ABSTRACT ONLY

A JOURNEY TO THE MOON: EXPLORING
MULTISENSORY RESOURCES IN THE
TEACHING AND LEARNING OF ASTRONOMY

M.F. Gomes¹, A.C. Silva ², P.A. Marques ² and S.
Lorenz-Martins ¹

Astronomy can be a gateway to STEAM engagement, but achieving this in educational environments requires equal access to information. As science teaching usually relies on visual resources, blind and visually impaired (BVI) individuals may face barriers to accessing adapted materials to their needs. The Universo Acessível project, based at the Valongo Observatory (UFRJ) in partnership with the Instituto Benjamin Constant, develops didactic resources to improve Astronomy learning for BVI students. The Brazilian Basic Education curriculum related to Universe encourages reflection on the role of the human species in the cosmos, beyond purely understanding concepts. This work presents the multisensory resources developed by the working group addressing a key component in the curriculum, the Moon: tactile model, booklet, and a talking book. The initiative responds to challenges identified through research on Brazilian teachers’ relates and their difficulties in understanding and teaching astronomical concepts. Each resource has its specificity, engaging students through minds-on, hands-on, and hearts-on experiences. The integration of multisensory resources fosters autonomy and inclusion. This approach has the potential to contextualize content and encourages critical thinking, aiming to achieve a meaningful learning. We seek to promote interdisciplinary exploration and the sharing of personal perceptions. Extending beyond people with disabilities, these resources reach a diverse audience, ensuring usability and specificity for each one. Active user participation is crucial to understand needs, overcome barriers, and find new ways to make Astronomy accessible—improving existing materials and creating new ones. These actions help make the Universe, everyone’s home, truly accessible.

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ABSTRACT ONLY**BRIDGING ASTRONOMICAL HERITAGE AND
SOCIETY IN A SCIENCE MUSEUM:
HISTORICAL SCIENTIFIC INSTRUMENTS AS
A TOOL TO PRESERVE OUR HISTORY**M. F. Gomes¹, J. V. Fonseca¹, and D. F. Silva¹

Building bridges between society and historic scientific instruments (HSIs) in a museum collection is a challenging task, due to the different historical and sociocultural backgrounds involved in the construction of Brazilian society. Creating an environment that encourages dialogues about heritage and learning the history of national Astronomy through these artifacts requires the use of methodologies that foster the connection between the public and the objects. In this work, we aim to share some of the educational practices developed and applied using the astronomical artifacts from the collection of the Museum of Astronomy and Related Sciences (MAST), exploring not only their role in history or pedagogical dimensions but also their role in the process of constructing society, promoting dialogues and critical reflections on scientific culture. Through activities such as mediated guided visits, the project follows four main pillars: (1) models and modeling, (2) three-way interactivity (hands-on, minds-on, hearts-on), (3) museum education, and (4) horizontal teaching and learning. These aspects promoted the exploration of the HSIs from the collection that played an essential role in the development of Brazilian Astronomy, giving them a new meaning that transcends the walls of an exhibition. Using them as a powerful tool to bridge Astronomical heritage and society, it is possible to expand the socio-pedagogical dimension of the collection, promoting the process of identifying the public, since our memories, culture, and history as a society are also intangible heritage to be preserved.

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ABSTRACT ONLY**ASTRONOMY AND SUSTAINABLE CULTURAL
TOURISM. A PROPOSAL FOR THE
CONSTRUCTION OF THE FIRST CULTURAL
PLANETARIUM IN SOACHA-COLOMBIA**M. A. Patiño Ochoa¹, J. N. Molina Córdoba² & J.
Murcia Rocha³

Commune VI of Soacha, Cundinamarca, faces challenges impacting its population. In areas like Altos de la Florida, existing tourist attractions could alleviate difficulties for residents, mainly families displaced by violence. The main community issues include limited formal education access, social stigmatization, and informal employment. Despite significant tourist potential in the municipality’s hills, issues persist. There is a drive to promote a positive image through astronomical tourism, developing Soacha’s first planetarium. This initiative aims to foster respect for nature and stars, promoting education and enhancing quality through astronomy programs. The planetarium, as the municipality’s first, enriches infrastructure and provides community astronomy training. The primary goal is to educate the community, leveraging a nonprofit group’s scientific outreach expertise. The planetarium complements this effort, promoting science in areas with rich indigenous traditions. Ultimately, this social integration for scientific knowledge appropriation could serve as an example for Latin American regions facing similar issues and undiscovered cultural richness.

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ABSTRACT ONLY**ASTEROID DISTRICT: EXTENDING CITIZEN
SCIENCE FROM BOGOTÁ-COLOMBIA**E. Suárez¹, C. Ayala², D. A. Valderrama³

Asteroid District is a citizen science program started by the District University for the promotion and appropriation of knowledge and scientific dissemination, focus its attention on the study of Near-Earth Asteroids (NEA). It's important to show the academic community the results of the training and projections carried out as a didactic strategy that develops complex thinking and the systemic vision of science, allowing conceptual approaches, it makes that the search for asteroids activity is constituted as a socio-scientific issue.

The Astronomical Observatory "LatitUD" of the Faculty of Engineering of District University has organized since 2021 Asteroid District, asteroid search campaigns framed in "The International Astronomical Search Collaboration (IASC)"; It has allowed more than 1200 people to participate to do researching and making discoveries from main belt asteroids and trans-Neptunian objects.

This research shows the activities carried out by project, their potential of these campaigns in the social appropriation of knowledge and scientific procedures, results, tensions and prospects, seeking to develop citizen science from astronomy, as an axis of construction of critical thinking, for making informed decisions, the development of scientific vocations and learning of the sciences. In this way, the importance of learning from non-formal educational settings and the inter-institutional collaboration becomes evident.

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ABSTRACT ONLY**ETHNOASTRONOMY OF THE CURRIPACO,
PIAPOCO, PUINAVE, SIKUANI AND CUBEO
ETHNIC GROUPS**G. M. Peña Idrobo¹, A. M. Navarro Torres ¹

In this collaborative research with students from a school in Colombia, we have explored and documented the rich tradition of indigenous astronomy from five ethnic groups: Curripaco, Piapoco, Puinave, Sikuani, and Cubeo. Our main objective was to rescue and preserve the unique astronomical knowledge of these communities, which has been transmitted through oral tradition and is at risk of being lost in the modern era. Throughout the process, we worked closely with respected members of each ethnic group, who shared with us their ancestral stories related to constellations and cosmos. Through extensive interviews and intercultural dialogues, identified the significant constellations for each ethnic group and documented the stories that accompany them. These stories not only hold astronomical value but are also intricately woven with beliefs, traditions, and ways of life of each community. Furthermore, we have created a unique star map that depicts the constellations of these ethnic groups, labeling individual stars with their scientific names and their corresponding names in indigenous languages. This map acts as a bridge between ancestral knowledge and contemporary science, enabling a deeper understanding the connections between both perspectives. One of the most striking findings of our research is how constellations are intricately linked with everyday practices, such as food agriculture. Each ethnic group has developed its own worldview that reflects its natural environment and its relationship with the land and the sky. Ultimately, our research not only highlights the importance of preserving these valuable traditions but also underscores the richness and diversity of human knowledge about the universe. By sharing these stories and insights with the global astronomy community at this international event, we hope to foster a greater appreciation for the connection between science culture, as well as inspire ongoing efforts to safeguard the voices and perspectives of indigenous communities in modern world.

ON THE FORMATION OF NS-NS AND NS-BH BINARIES FROM BINARY-DRIVEN HYPERNOVAE

L. M. Becerra^{1,2} and J. A. Rueda²

The binary-driven hypernova (BdHN) model proposes an explanation for long gamma-ray bursts (GRBs) associated with type Ic supernovae (SNe). In this model, a binary system comprising a carbon-oxygen (CO) star and a neutron star (NS) companion undergoes various physical episodes, triggered by the core collapse of the CO star. This collapse leads to a SN explosion, forms a newborn NS (ν NS) at its center and produces an accretion process on the ν NS and the NS companion at super-Eddington rates. Using hydrodynamics simulations, we determine the maximum orbital period of the initial CO-NS binary that can stay bound after a BdHN event, resulting in NS-NS or NS-BH binaries. This provides insights into the outcomes of such cataclysmic events in binary systems.

We used the SN-SPH code (Fryer et al. 2006) to follow the evolution of the binary stars (the ν NS and the NS companion) as the SN material expands. The simulations start when the SN shock front reaches the CO’s outer radius. The ν NS and NS, treated as point masses, interact gravitationally with SN ejecta particles and each other, while they can accrete additional particles from the SN ejecta (see Becerra et al. (2019) for more details of the simulations).

We perform simulations with a CO star coming from a progenitor with $M_{\text{zams}} = 25M_{\odot}$ and a $2M_{\odot}$ and a $1.4M_{\odot}$ NS companion. At collapse, the CO star leaves a $1.85M_{\odot}$ ν NS and ejects about $4.99M_{\odot}$ through the SN explosion. The code tracks the position and velocity evolution of all the SN ejecta particles as well as the point-mass particles. In order to determine whether the system remains gravitationally bounded, we compute the total energy of the ν NS-NS system as:

$$E = \frac{1}{2} \frac{M_{\nu\text{NS}} M_{\text{NS}}}{M_{\nu\text{NS}} + M_{\text{NS}}} |\vec{v}_{\nu\text{NS}} - \vec{v}_{\text{NS}}|^2 - \frac{GM_{\nu\text{NS}} M_{\text{NS}}}{|\vec{r}_{\nu\text{NS}} - \vec{r}_{\text{NS}}|}, \quad (1)$$

where $(M_{\nu\text{NS}}, \vec{r}_{\nu\text{NS}}, \vec{v}_{\nu\text{NS}})$ and $(M_{\text{NS}}, \vec{r}_{\text{NS}}, \vec{v}_{\text{NS}})$ are the

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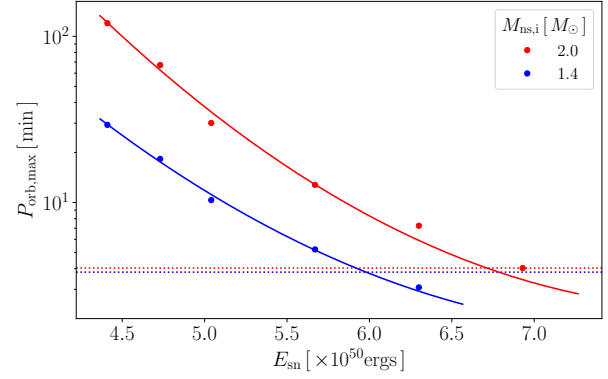


Fig. 1. Longest initial binary period for which the outcome binary after a BdHne event remains bounded in function of the SN energy. The horizontal dotted lines represent the minimum period for the system, defined as the minimum binary separation at which there is no Roche-Lobe overflow before the SN explosion.

mass, vector position and velocity of the ν NS and the NS companion, respectively. If the total binary energy becomes negative, $E < 0$, the remnant systems of a BdHNe event remain gravitationally bounded. Then, the CO-NS initial systems with the longest initial binary period, $P_{\text{orb,max}}$, is the one that makes $E = 0.0$. Figure 1 shows the relation between $P_{\text{orb,max}}$ and the SN energy, E_{sn} . There is a maximum SN energy that will lead to bounded systems, otherwise, all binary systems will remain unbounded regardless of the initial binary period. The minimum SN energy is about 5.97×10^{50} ergs and 6.64×10^{50} ergs for the $1.4M_{\odot}$ and $2M_{\odot}$ NS companion, respectively.

The final bounded systems will be compact binary systems (NS-NS or NS-BH), which will eventually merge through the emission of gravitational in 10^4 to 10^9 yrs. BdHNe I produces a series of rapidly merging NS-BH binaries that give rise to ultrashort gamma-ray flashes (U-GRFs) (Fryer et al. 2015).

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BINARY SYNTHESIS OF MERGING COMPACT OBJECT POPULATIONS FROM EVOLVING INITIAL CONDITIONS

L. M. de Sá¹; A. Bernardo¹; R. R. A. Bachega¹; L. S. Rocha^{1,2}; J. E. Horvath¹

In this work, we implement models for a metallicity- and SFR-dependent IMF and correlated initial mass ratio, orbital period and eccentricity in performing binary population synthesis with the code COMPAS for binaries born at redshifts up to 10. We are able to obtain the time-evolution of all three classes of compact binary mergers, which we find found to peak between redshift 1 and 4 depending on the model; additionally, we found a robust trend of merging black holes to be more massive at higher redshift.

We have studied two variations of initial condition models in performing binary population synthesis (BPS) with the code COMPAS. In the “Canonical” model, when sampling our newborn binaries for evolution, we implement the invariant Kroupa (2001) IMF, for sampling masses, and the traditional independent distributions for orbital parameters: uniform for the mass ratio (q), log-uniform for the orbital period (P), and set $e = 0$. In the “IGIMF” model, we implement the varying IMF by Jeřábková et al. (2018), based on empirical fits that make it top-heavy at low metallicities and high SFRs, alongside the correlated orbital parameters by Moe & Di Stefano (2017)

Based on the work of Chruślińska et al. (2020) (and references therein), we sample metallicity-SFR (or redshift) pairs based on the cosmic star formation history in order to build a composite binary population with binaries born between redshift 0 and 10. For each of our two initial models, we sample and evolve $\sim 10^8$ binaries over 120 different metallicity-SFR/redshift pairs.

Our main results are the time-evolution of the merger rates up to redshift 10 for black hole-black hole (BHBH), black hole-neutron star (BHNS) and neutron star-neutron star (NSNS) mergers. Two differences between the results for the IGIMF model and for the Canonical model stand out: the later positions for the merger rate peaks; and rates one order

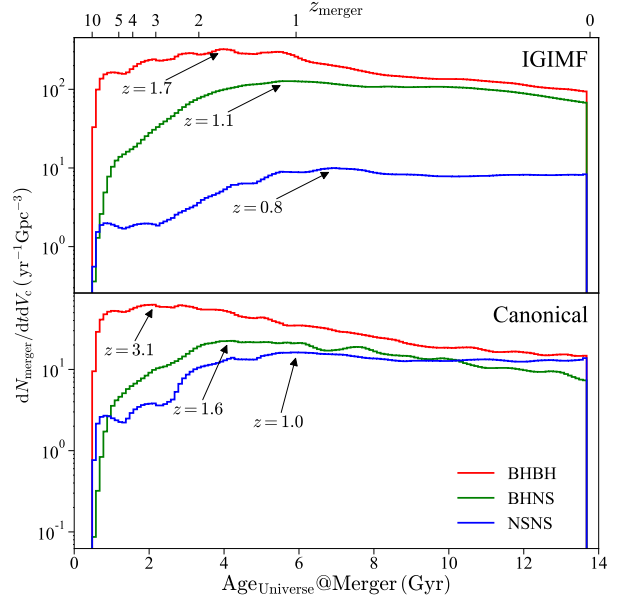


Fig. 1. Merger rate time-evolution for BHBH, BHNS and NSNS mergers in both IGIMF and Canonical models.

of magnitude greater for BHBH and BHNS mergers. Both are a consequence of implementing a IMF that becomes top-heavy for high SFRs. Because the SFR peaks around $z = 2$, the rate peaks come at later redshift; and because a top-heavy IMF increases the production of black hole merges more strongly than that of neutron star mergers, the BHBH and BHNS rates are more affected. We also find a trend of black hole masses to increase with redshift, particularly strong in the IGIMF model.

A complete exposition and discussion of results for rates and masses of all three merger classes, in both IGIMF and Canonical models, will be published in the near future as de Sá et al. (submitted).

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MACHINE LEARNING EXPLORATIONS IN GRB STUDIES: FROM CLASSIFICATION TO EXTENDED EMISSION IDENTIFICATION

K. Garcia-Cifuentes¹, R. L. Becerra¹, and F. De Colle¹

Gamma-ray bursts (GRBs) have traditionally been classified based on their duration. Nevertheless, extended emission (EE) GRBs, characterised by a duration larger than two seconds and properties similar to short GRBs, challenges the conventional classification methods. By using a non-supervised machine-learning technique (t-distributed stochastic neighbor embedding, t-SNE), we performed a better photometric classification and the identification of extended emission in Swift/BAT GRBs. Furthermore, we introduce an innovative tool, ClassiPyGRB, designed for astronomers whose research centers on GRBs from Swift/BAT telescope.

Gamma-ray bursts (GRBs) have been classified mainly considering their duration (Kouveliotou et al. 1993). Short GRBs (SGRBs) typically last less than two seconds, exhibit harder spectral properties, and are associated with the merging of compact objects, such as neutron stars or a neutron star and a black hole (i.e., Berger 2014). On the other hand, long GRBs (LGRBs) have a duration larger than two seconds, a softer emission, and are associated with the collapse of massive stars (i.e., Bromberg et al. 2012).

EEGRBs challenge this classification scheme by having a total duration larger than 2 seconds but sharing characteristics of both SGRBs and LGRBs (i.e., Gehrels et al. 2006). Finally, duration classification also has instrumental selection effects, as demonstrated by Qin et al. (2013). This evidence remarks the need for a more comprehensive understanding of GRBs and motivates further exploration into alternative classification criteria.

Jespersen et al. (2020) proposed a new classification scheme based on similarity analysis via t-SNE, a popular machine learning (ML) algorithm. Although its classification discerns two subgroups of GRBs, they do not consider the impact of noise in their classification, and their dataset is currently outdated.

In Garcia-Cifuentes et al. (2023), we use a dataset

consisting of BAT GRBs observed until July 2022 by the Swift/Burst Alert Telescope instrument in all its energy bands. We reduced noise on the light curves using the Bayesian approach FABADA (Sánchez-Alarcón & Ascasibar 2023). Subsequently, we preprocessed the noise-reduced light curves using the same procedure as Jespersen et al. (2020), and we applied t-SNE implemented on `scikit-learn` in *Python3*.

One of the most relevant results obtained in our research is that it is possible to discern two subgroups of GRBs in the t-SNE maps, and their properties are similar to those related to SGRBs and LGRBs. Moreover, our research highlights the relevance of handling noise in ML-based classifications, and we show that the dependence on duration remains invariant despite reducing noise.

On the other hand, it is possible to discern small clusters of EEGRBs in the reduced-noise classification. The most significant outcome of our research is that, by examining the nearest neighbors of previously identified EEGRBs, we can effectively classify new instances of EEGRBs. This approach not only streamlines the analytical effort but also introduces a novel method for classifying such events.

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ABSTRACT ONLY

FIRST RESULTS OF THE GLITCHING
PULSARS MONITORING PROGRAM AT THE
ARGENTINE INSTITUTE OF
RADIOASTRONOMY

E. Zubieta^{1,2} & PuMA Collaboration^{2,3}

Although pulsars exhibit a particularly stable rotation, this stability can be affected by glitches. This phenomenon consists of a sudden increase in the rotation frequency of pulsars. Its cause is not well understood, but it is likely related to the behavior of matter inside neutron stars. Therefore, glitches can provide constraints on the equation of state of neutron stars. With the aim of thoroughly characterizing these glitches, since 2019 we have been conducting a high-cadence monitoring campaign of glitching pulsars from the Argentine Institute of Radio astronomy (IAR). Up to date, we have detected and characterized two giant glitches in the Vela pulsar, one in PSR J0742–2822, one in PSR J1740–3015, and two mini glitches in PSR J1048–5832. We fully describe them in this poster presentation.

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ABSTRACT ONLY

STELLAR WINDS IN THE GALACTIC
CENTRE: VARIABLE ACCRETION AND
FORMATION OF A DISC

D. Calderón¹, J. Cuadra² and C. Russell³

Sgr A*, located only 8 kpc away, allows us to study in detail the accretion process on to a supermassive black hole. Only in our Galactic centre we can directly observe the source of the material feeding the accretion, which in this case corresponds to around 25 young, massive stars, with powerful stellar winds. We describe our hydrodynamical models of the gas surrounding Sgr A*, originating from the observed stars, with known orbits and stellar wind properties. Our simulations show that these winds and their collisions can naturally account for the properties of the hot plasma detected in X-ray observations. Moreover, the complex interaction of the winds with the medium produces cold clumps and streams, and perhaps even a disc around the black hole, as inferred from ALMA observations. Finally, the stellar orbits and the infall of streams make the accretion vary on time-scales of decades to millennia, potentially explaining the observed X-ray echoes related to past activity from Sgr A*.

For more details please see <https://doi.org/10.3847/2041-8213/ab5e81>.

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ABSTRACT ONLY

THE LENGTH OF THE SLOW STABLE
HYBRID STAR BRANCH AND ITS LINKAGE
WITH NEUTRON STAR OBSERVATIONS

M. Mariani^{1, 2}, M. G. Orsaria^{1, 2}, L. A. Divano¹, I.
F. Ranea-Sandoval^{1, 2}

The internal composition of neutron stars, one of the densest astronomical objects in the universe, is still unknown. Although in the last decade, with the onset of multi-messenger gravitational wave astronomy, several astrophysical observations placed strong constraints on these compact objects, there is still a lack of understanding of the dense matter equation of state. In this work, we model neutron stars as hybrid stars -composed of an inner core of quark matter and a mantle of hadronic matter-, considering an abrupt and slow first-order hadron-quark phase transition in their core. We model the hadronic phase with a piecewise polytropic fit, and the inner quark core through a Color Flavor Locked superconducting equation of state, with corrections due to the strong coupling constant, within the framework of the MIT Bag model. In the framework of this abrupt and slow scenario, it is possible to obtain an extended branch of stable stellar configurations. It has been shown that the appearance of such branches could resolve the existing tension between current astrophysical observations. We analyze the behavior of this extended stability branch by quantifying and systematically studying, for the first time, its length, relating this quantity to fundamental properties of the hybrid equation of state. This study allows not only a deeper understanding of the extended stability scenario with slow hadron-quark conversions but could help reveal the mystery of the composition of neutron stars and, consequently, clarify the uncertainty about the equation of state of dense matter.

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ABSTRACT ONLY**WI ASTEROSEISMOLOGY REVISITED:
UNIVERSAL RELATIONSHIPS THAT INCLUDE
SLOW STABLE HYBRID STARS**Ignacio F. Ranea-Sandoval^{1,2}, Mauro Mariani^{1,2},
Octavio M. Guilera^{1,3} and Germán Lugones⁴

We show that, within the slow hadron-quark conversion regime where extended branches of hybrid stars (SSHS) appear, all universal relationships for wI-modes available in the literature do not hold (for details, see Ranea-Sandoval et al. 2022). Then, we show newly discovered universal relationships that include SSHS, and present potential astronomical applications of such relationships, showing that, if the frequency and damping time of the fundamental mode are measured, its mass, radius, and dimensionless tidal deformability can be inferred (for details, see Ranea-Sandoval et al. 2023). The errors of such estimates are smaller than a few per cent for the mass and the radius. For the dimensionless tidal deformability, the errors for compact objects with masses above 1.4 solar masses are typically less than 100%.

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ABSTRACT ONLY**IMPACT OF THE MATCHING FORMALISM IN
NEUTRON STARS AND THEIR OSCILLATION
MODES**

Martin O. Canullan-Pascual^{1,2}, Mauro Mariani^{1,2},
Ignacio F. Ranea Sandoval^{1,2} and Milva G.
Orsaria^{1,2}

The interior of neutron stars (NS) contains matter with densities several times higher than nuclear atomic density. Obtaining an accurate equation of state (EoS) to describe NS is crucial for enhancing our understanding of matter in such extreme environments. To achieve this, we built ten EoS by considering three different crusts which are added to the core of these compact objects using a new thermodynamically consistent formalism. Essentially, for an isolated and cold NS, we assume a linear relationship for pressure and energy density in a small region between the core and the crust. This establishes an interpolation function in the pressure/baryonic-chemical-potential plane. We compared this new way of “gluing” EoS with the classical method that neglects causal and thermodynamic consistency. Then, we solved the TOV equations, which describe a non-rotating, spherically symmetric and static object, to obtain the mass-radius relationship and compared it with the existing observational constraints of NS. In addition, we explored changes that the new matching formalism can cause in the oscillation modes. With alternative matching formalisms, even for two or three interpolations of the same crust, the p_1 mode exhibited differences in oscillation frequencies and damping times for low-mass NS. In contrast, no visible effects can be appreciated for the f mode, neither in the three models of the crust nor in the interpolations considered. We conclude that independently of the model used for the EoS, the method of construction will impact in NS observables such as the radius, frequencies and damping times of non-radial oscillations.

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ABSTRACT

A REVIEW OF THE CURRENT STATE OF
RESEARCH ON EXTRAGALACTIC SOURCES
THAT EMIT GAMMA RAYS IN THE TEV
RANGE, USING THE CHERENKOV

TECHNIQUE.

C. C. Valdez^{1,2}

Gamma rays are a form of high-energy electromagnetic radiation that is unaffected by galactic magnetic fields. Although the study and detection of gamma-ray emissions, both from satellites and terrestrial sources, have experienced significant advances throughout history, starting with the installation of the MIT gamma-ray instrument in the 1960s, we will focus on the sensitivity of the Cherenkov atmospheric technique. Extensive air showers result from collisions between photons and protons. The total cross-section of these collisions has measured center-of-mass energies up to 200 GeV. The predominant interactions are electromagnetic, with cross-sections for the production of hadron and muon pairs much smaller than those for electron pairs. In this electromagnetic cascade, photons generate electron-positron pairs, and electrons and positrons generate photons through bremsstrahlung, exponentially increasing as it propagates through the atmosphere, dividing the primary energy among more and more particles. However, as the energy decreases, the ionization energy loss mechanism becomes more important than bremsstrahlung.

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ABSTRACT ONLY**PARTICLE ACCELERATION IN THE
HELIOSPHERE AND IN SUPERNOVA
REMNANTS**L. R. Magalhães¹, C. N. Koshikumo¹, M. V. del
Valle¹ and R. Santos-Lima¹

Cosmic rays are charged particles that permeate astrophysical environments with energies much higher than the ambient thermal particles. The bulk of the galactic cosmic-ray protons and heavier nucleus, with energies up to PeV, are most probably energized in shocks resulting from supernova remnants (SNR) expansion in the interstellar medium, although the process is not yet fully understood. In the interplanetary medium, directly detected ions with energies in the tens of MeV range are correlated with shock fronts. This research aims to develop a one-dimensional model to study the confinement and injection of energized protons in the heliosphere, using magnetohydrodynamic (MHD) simulations, that can be compared with direct particle observations and also with previous models. Furthermore, this modified model, including a kinetic representation of the relativistic particles (Particle-In-Cell-MHD), was applied in SNR scenarios. Our models were able to reproduce the evolution of shock events observed in the heliosphere, in accordance with previous MHD models in the literature, with the advantage of providing the energy distribution of the energetic particles, which can be used to better constrain the acceleration and diffusion processes. In the SNR case, our simulations produced the instabilities believed to regulate the self-confinement of the particles which affect the acceleration efficiency. In the future, we intend to apply it to construct non-thermal emission models of SNR that can be compared to observations. This approach will contribute to the understanding of the cosmic ray acceleration process, as certain open questions, such as the development of instabilities near the shock, can be tested in the interplanetary medium, where direct observations are available.

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ABSTRACT ONLY

BREAKING OF QUADRUPOLEAR F -MODES
UNIVERSAL RELATIONSHIPS UNDER THE
SLOW HADRON-QUARK CONVERSION
REGIME.

Ignacio F. Ranea-Sandoval^{1,2}, Mauro Mariani^{1,2},
Marcos O. Celi^{1,2}, M. Camila Rodríguez^{1,2}, and
Lucas Tonetto^{3,4}

In the past fifteen years, our understanding of compact stars has significantly advanced through key observations, such as the pulsars PSR J0348+0432 and PSR J0740+6620, whose radius has recently been estimated using NICER and XMM-Newton data, along with the analysis of gravitational waves (GW) events, as GW170817.

In this work, we consider polar perturbations, and we calculate the frequency and damping time of the quadrupolar fundamental f -mode of compact objects, constructed using a wide range of model independent hybrid equations of state that include quark matter. We give special attention to the impact of the hadron-quark conversion speed that, in the slow case, gives rise to a branch of slow stable hybrid stars. Moreover, we study the validity of universal relationships proposed in the literature and find out that none of them remains valid when slow stable hybrid stars are taken into account, as has also been shown for the wI -modes and f -modes in Ranea-Sandoval et al. (2022, 2023) respectively. This fact could constrain the applicability of asteroseismology methods with fundamental modes designed to estimate the properties of pulsating compact objects. We hope that this result could be tested with the start up of the third generation gravitational wave observatories, which might shed some light on the f -mode emission from compact objects.

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Ranea-Sandoval, I. F., Mariani, M., Celi, M. O., Rodríguez, M. C., & Tonetto, L. 2023, Phys. Rev. D, 107, 123028

ABSTRACT ONLY**THE DARK SECTOR WINDOW WITH
EXTREME LASER PULSES**Pablo Pais^{1,2} and Sergei V. Bulanov^{3,4}

Parameter bounds for the dark matter candidates can be obtained not only from astrophysical sources or large particle colliders but also from laser experiments. One of these experiments consists of shining a wall with a laser and trying to convert the photon into a dark matter candidate particle through an external magnetic field coupling, named light shining through the wall (LSW). On the other side of the wall, another magnetic field region would reconvert the weak interacting particle into a photon before passing through a detector. We explore the possibility of implementing LSW to detect dark matter candidates, taking advantage of the power laser pulses achieved at the Extreme Light Infrastructure and the Shanghai Superintense Ultrafast Laser Facility shortly.

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ABSTRACTS ONLY**A REVIEW ON THE POST-MERGER
GRAVITATIONAL WAVES EMITTED IN
BINARY NEUTRON STAR MERGERS**G. Conde-Saavedra¹, Odylio D. Aguiar¹, Henrique
de Oliveira², Maximiliano Ujevic³

Gravitational waves detected from the inspiral stage of a binary neutron star merger give information about the nature of the initial components such as their masses, spins, radii and tidal deformabilities. Similarly, observations of the post-merger stage would give hints on the characteristics and the evolution of the remnant of these coalescences. Since post-merger observations by earth-based detectors are not available yet, only numerical simulations are used to study this stage. Therefore, we will review the main characteristics of this kind of mergers, as well as the results given by the numerical simulations in order to better understand the different outcomes that are produced in these systems and how the final fate is related to the initial components.

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THE ROLE OF MODELING AND OBSERVATIONS FOR A COMPLETE EXPLANATION OF CORONAL HEATING

M. López Fuentes¹

RESUMEN

El problema de cómo la corona solar se encuentra cientos de veces más caliente que la fotosfera subyacente continúa siendo objeto de intenso estudio e interés para la comunidad de física solar. Uno de los desafíos que aún persisten es que los procesos fundamentales ocurren en escalas espaciales que están más allá del poder de resolución de los instrumentos actuales. Por lo tanto, una fuerte interacción entre modelos y observaciones es necesaria. Por parte de los modelos, la diversidad de escalas espaciales, desde el radio de giro de las partículas individuales (de cm a decenas de m) a la estructura de los arcos magnéticos coronales (decenas a centenas de Mm), hace imposible incluir todas ellas en un mismo escenario numérico, demandando en su lugar diferentes aproximaciones y formalismos físicos para regímenes en distintas escalas. Respecto de las observaciones, es necesario poner bajo un mismo marco fenomenológico diversos conjuntos de datos obtenidos en longitudes de onda desde radio hasta rayos X. Aquí repasaremos los aspectos principales del problema, su estado presente y algunos de los avances recientes en la comprensión de los procesos fundamentales.

ABSTRACT

The problem of how the solar corona is hundreds of times hotter than the underlying photosphere continues to be a subject of intense study and interest for the solar physics community. One of the main persisting challenges is that fundamental processes occur on spatial scales that are beyond the resolution power of instruments presently available. Therefore, a strong interaction between models and observations is necessary. From the side of modeling, the highly diverse spatial scales, from single particle gyroradii (cm to tens of m) to the structure of coronal magnetic loops (tens to hundreds of Mm), make it impossible to include all of them in single numerical simulations, demanding instead the use of different approaches and physical formalisms for different spatial scale regimes. Regarding observations, it is necessary to put under the same phenomenological frame diverse sets of data obtained in wavelengths spanning from radio to X-rays. Here, we review the main aspects of the problem, its present state and some of the recent advances in understanding the underlying processes.

Key Words: sun: atmosphere — sun: corona — sun: magnetic fields — sun: activity

1. INTRODUCTION

In the second half of the nineteenth century, when astronomers began to use spectrographs to observe the solar corona during total solar eclipses, they found spectral emission lines associated to known elements such as H and Ca, but they also found previously unidentified lines that they associated to unknown elements, such as He, found on Earth in the first decade of the twentieth century, and a suspected new element called “Coronium”. It wasn’t until the 1940s that it was found that the “Coronium” line corresponded in fact to Fe in a high state of ionization (FeXIV, Edlén 1943), indicating that the solar corona must be at a temperature of more than 1 MK.

Thanks to radiative transfer modeling and observations, nowadays we count with a reconstruction of the coronal thermal structure consisting of a photosphere (the main radiant surface of the Sun, whose spectrum is mostly in the visible range) at 5800 K, a chromosphere extending up to 5 Mm with temperatures ranging from 4500 to 20000 K, and a narrow transition region (TR) of a few hundred km width where temperatures vary from a few tens of thousands of K to more than 1 MK in the solar corona (Foukal 2004). The density suffers similarly dramatic changes from 10^{17} cm^{-3} in the photosphere to 10^{12} cm^{-3} in the chromosphere to 10^9 cm^{-3} in the corona. It was shown that the energy fluxes needed to keep the corona at those temperatures are of the order of $10^7 \text{ erg cm}^{-2} \text{ s}^{-1}$ on active regions and $3 \times 10^5 \text{ erg cm}^{-2} \text{ s}^{-1}$ in the quiet-Sun (Withbroe & Noyes 1977). It has been demonstrated that the only

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way to store and release those amounts of energy in the solar corona is by means of the magnetic field. The Poynting flux injected by convective motions, acting on magnetic field lines rooted on the photosphere, provides the required energy budget (Priest 2014).

The solar atmosphere is strongly dominated and structured by the magnetic field. Due to the low magnetic resistivity, leading to the “frozen-in” condition of the plasma and the magnetic field, and the force free condition due to the low plasma β (the ratio between the gas and magnetic pressures) in the low corona, both heat conduction and plasma motions are confined along magnetic field lines (Reale 2014). For this reason, the coronal plasma, particularly in active regions, is observed to be structured in the form of magnetic flux tubes or loops. These can be considered the building blocks of the coronal structure. Any model proposed to explain coronal heating must be consistent with the observed characteristics and evolution of these loops (Klimchuk 2015).

The physical mechanism by which free magnetic energy accumulated in the field is released in the form of plasma heating, is still the subject of intense study and discussion. The proposed processes can be broadly divided in three main families: 1) the release of magnetic stress by reconnection (see, e.g., Parker 1988; Priest 2011; López Fuentes & Klimchuk 2010) or Ohmic dissipation (Gudiksen & Nordlund 2005), 2) magnetohydrodynamic waves dissipation by resonant absorption (O’Neill & Li 2005) or phase mixing (Heyvaerts & Priest 1983), and 3) turbulent regimes (Dmitruk & Gómez 1997). As we thoroughly describe in the following sections, in this report we focus on results obtained with the first type of models, in particular, the so called nanoflare heating model, originally proposed by Parker (1988).

2. LOOP MODELING AND OBSERVATIONS

In order to test the predictions of the models described in Section 1, it is necessary to convert the heating rates provided by them in emission outputs susceptible to be compared with observations. To do this, it is first necessary to compute the response of the plasma to the heating, in terms of the evolution of its temperature, density and velocity. As we described in Section 1, the coronal plasma, particularly in active regions and in the low corona in general, is structured in the direction of the magnetic field, forming coronal loops. It is therefore possible to model the evolution of the plasma in the loops using a one-dimensional hydrodynamic approach. This

consists in solving the equations of mass, moment and energy conservation, plus an equation of state (see e. g., Reale 2014), to obtain the temporal evolution of the spatial distribution of temperature, density and velocity of the plasma along the loops. The hydrodynamic modeling output can be further modeled to simulate synthetic observations to be eventually compared with actual observations. Alternatively, diagnostic techniques can be applied directly to observations to infer temperatures, densities and velocities that can be compared with hydrodynamic modeling outputs.

Among the usual procedures to obtain temperatures and densities from observations, one of the simplest is the so-called filter ratio technique. Considering the emission in two different instrumental bands, in the isothermal case it can be shown that the ratio of the intensities is a function only of temperature. The temperature can then be obtained from the instrumental response in both bands, $I_a/I_b = S_a(T)/S_b(T) = R(T)$, and the density is obtained from the emission measure in any of those bands (see, e. g., López Fuentes et al. 2007). A more sophisticated procedure, useful to characterize multithermal plasmas, is to obtain the differential emission measure distribution, *DEM*. Expressing the emitted intensity as an integral in temperature (instead of as a spatial integral), $I = \int DEM(T) S(T) dT$, the method consists in testing different parametrizations of the *DEM*, choosing the one that better fits simultaneous observations in different bands or spectral lines (see e. g., Schmelz & Pathak 2012; Warren et al. 2012; Nuevo et al. 2020).

3. HEATING REGIMES

According to the wavelength in which they are observed, coronal loops can be classified in two broad classes: 1) hot loops, mostly observed in soft X-rays in active region cores, with temperatures above 2 MK and densities of the order of 10^8 cm^{-3} , and 2) “warm” loops, observed in the Extreme Ultraviolet (EUV) in the periphery of active regions, with temperatures of around 1.5 MK and densities of more than 10^9 cm^{-3} . One of the first studies dedicated to characterize the thermal state of loops was done by Rosner et al. (1978). They assumed that loops were in a state of equilibrium, or evolving in quasi-static equilibrium, such that a slowly varying heating source was instantaneously balanced by thermal conductive and radiative losses. Later research showed that although hot loops observed with the Soft X-ray Telescope (SXT, Tsuneta et al. 1991) on board Hinode, were consistent with this kind of

scenario (Porter & Klimchuk 1995), warm loops observed with the Transition Region and Coronal Explorer (TRACE, Handy et al. 1999) had densities and scale heights that were too high to be consistent with equilibrium solutions (Aschwanden et al. 2001; Winebarger et al. 2003). Instead, it was demonstrated that the high densities and broad temperature distributions observed in warm loops could only be explained by impulsive heating (see, e. g., Warren et al. 2002).

In a recent paper, Nuevo et al. (2020) studied 13 loops of the warm class observed with Atmospheric Imaging Assembly (AIA, Lemen et al. 2012) on board the Solar Dynamics Observatory. They modeled the analyzed loops using two alternative scenarios: 1) constant heating assuming loops in equilibrium, and 2) heating by impulsive events or nanoflares. Their results showed that the loops were overdense with respect to loops in quasi-static equilibrium and that impulsive heating correctly reproduced the observed densities and temperatures. They also found that the width of the temperature distribution was consistent with loops formed by multiple strands.

4. NANOFLARE MODEL

Proposed by Parker (1988), the nanoflare model is based on the idea that loops are made of elementary subresolution magnetic strands that are shuffled and tangled by photospheric convective motions. This, in turn, produces field discontinuities and current sheets leading to reconnection heating events called nanoflares. The evolution of observed loops would be, then, due the summed contribution of a number of these strands evolving independently. López Fuentes & Klimchuk (2015) developed a model based on the interaction and reconnection between strands using a cellular automata scheme. The evolution of the plasma on each individual strand was modeled using the Enthalpy Based Thermal Evolution of Loops (EBTEL, Cargill et al. 2012) code. In a later work (López Fuentes & Klimchuk 2016) they showed that synthetic lightcurves constructed by adding the contribution of the evolution of a number of strands from the model, using typical solar parameters, reproduced the main statistical properties, such as the mean, standard deviation and skewness, of real observed lightcurves. They also showed that the model reproduced DEM distributions consistent with other authors observations (Schmelz & Pathak 2012; Warren et al. 2012). Analyzing cross correlation factors between the emission in different SDO/AIA bands, Viall & Klimchuk (2012) found

time lags that are consistent with the presence of impulsive heating and cooling processes, confirming the plausibility of the nanoflare model.

5. PLASMA FLOWS

An important prediction of the nanoflare model is the ubiquitous presence of plasma flows. Doppler shifts and non-thermal broadenings of spectral emission lines associated with upflows and downflows are frequently observed in coronal observations (Tripathi et al. 2012; Winebarger et al. 2013). The density changes associated with the nanoflare model are accompanied by flows from and into the chromosphere and corona. López Fuentes & Klimchuk (2022) analyzed the effect of plasma flows from the nanoflare model on EUV synthetic spectral lines. The lines were obtained integrating the contribution of model strands along typical observation times. They considered a set of 11 lines of ions with temperature formations ranging from 0.5 to 7.8 MK. Lines were integrated along 30 s samplings, as it is customary for spectrometers like the EUV Imaging Spectrometer (EIS) on board Hinode, taken from the modeled strand evolutions. The obtained synthetic lines were then analyzed with usual diagnostic techniques based in the computation of the moments of the line profiles, that provide Doppler shifts and non-thermal widths. The results are generally consistent with observations for the temperature range below 3 MK (Brooks & Warren 2016; Testa et al. 2016). For the hotter temperature range (above 5 MK) there are still very few observational reports to compare with. This is the kind of observations expected from a new generation of instruments dedicated to explore that temperature range in the near future (see, e. g., De Pontieu et al. 2022).

6. QUIET-SUN LOOPS

In the quiet-Sun corona, loops are usually not directly observable as they are in active regions, mainly because the contrast with their environment is very low. Using the DEM tomographic technique described by Vázquez (2016), Mac Cormack et al. (2017) reconstructed the mean coronal plasma properties along a solar rotation. The technique provides the 3D distribution of the mean temperature and density in a spherical grid between 1.025 and 1.25 $R_{\odot}$. Combining the obtained distributions with potential models of the coronal magnetic field (PFSS) they reconstructed and characterized physical parameters along integrated loops. Mac Cormack et al. (2023, in preparation) used the tomographic reconstruction of Carrington rotation 2082

(April 2009) to statistically analyze mean thermal properties of reconstructed loops. Using a superposed epoch analysis procedure they compared these reconstructions with loops modeled with a 1D hydrodynamic code (HYDRAD, Bradshaw & Cargill 2013) for constant and impulsive heating. Their results showed a good consistence with impulsive heating localized near the base of the loops.

7. CONCLUSIONS

We analyzed some of the problems and methods associated with the study of coronal heating. We saw that due to the fact that most fundamental mechanisms lie beyond present instrumental capabilities, the interaction between models and observations is crucial for a complete explanation of the problem. We introduced the nanoflare model and we showed that it is able to explain much of the sometimes confusing observational evidence, making it one of the main candidates to explain coronal heating (at least in active regions and the lower corona). The investigations reported here suggest that the statistical characteristics of quiet-Sun loops may be also consistent with impulsive heating. Among things that still need to be confirmed is the presence of high velocity upflows at temperatures above 5 MK. It is expected that new space and ground observatories (Parker Solar Probe, Solar Orbiter, MUSE, Solar-C, DKIST) and novel methods of analysis would soon provide long awaited answers and newer questions for future study.

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CME DEFLECTIONS: A BRIEF REVIEW AND NEW INSIGHTS

M. Cécere¹

RESUMEN

Investigaciones recientes han demostrado el importante papel que desempeñan las estructuras magnéticas que circundan los eventos de eyecciones coronales de masa (ECM) en su desarrollo inicial y progresión. Los agujeros coronales y los *pseudostreamers* son componentes clave de la corona que contribuyen a la desviación de las trayectorias de las ECM de su trayectoria radial. Por lo tanto, estudios observacionales exhaustivos, junto con interpretaciones teóricas y simulaciones numéricas, son vitales para comprender la evolución temprana de las ECM y determinar con precisión su trayectoria tridimensional en el medio interplanetario. Este enfoque es crucial para reducir errores en la estimación del tiempo de llegada de eventos geoeeficaces. En esta concisa revisión, se recopila las investigaciones teóricas, numéricas y observacionales que han proporcionado información sobre los factores que influyen en la deflexión de las ECM fuera de su típica trayectoria radial.

ABSTRACT

Recent research has demonstrated the significant role played by magnetic structures surrounding coronal mass ejection (CME) events in their initial development and progression. Coronal holes and pseudostreamers are key components of the corona that contribute to the deviation of CME trajectories from their radial path. Therefore, comprehensive observational studies, coupled with theoretical interpretations and numerical simulations, are vital in understanding the early evolution of CMEs and accurately determining their three-dimensional trajectory in the interplanetary medium. This approach is crucial for reducing errors in estimating the arrival time of geoeffective events. In this concise review, it is compiled from the theoretical, numerical, and observational investigations that have provided insights into the factors influencing CME deflection away from their typical radial trajectory.

Key Words: Sun — coronal mass ejections — magnetic fields

1. GENERAL

The understanding of coronal mass ejections (CMEs) propagation is critical for space weather forecasting, with factors such as deflection of CME playing significant roles.

Observational research has revealed interesting patterns regarding CME deflection. During periods of minimal solar activity, CMEs consistently deflect toward lower latitudes, where the heliospheric current sheet -a region of minimal magnetic energy- is located (Cremades & Bothmer 2004). However, in high-activity periods, this trend is lost.

Considering other structures with regions of low magnetic energy -as pseudostreamers (PSs)- suggests that the magnetic environment surrounding the eruption region can influence the deflection of CMEs within the first few solar radii (Liewer et al. 2015). Analyzing the magnetic forces generated by the background corona, Shen et al. (2011) show the magnetic pressure play pivotal rol.

On the other hand, certain magnetic structures, like coronal holes (CHs) and active regions (ARs), possess the ability to repel CMEs. This deviation occurs due to the strong magnetic field topology of the AR and the open flow area of an adjacent CH (Möstl et al. 2015).

However, there are observational studies that show that it is difficult to predict the trajectory of a CME when there are multiple magnetic structures surrounding the source of the CME (Jiang et al. 2007; Sieyra et al. 2020).

Therefore, in order to characterize general behaviors, it is essential to comprehend the root causes of deviations. Given the intricacies of the phenomena, it is necessary to consider various factors and mechanisms that contribute to these deflections.

2. REPULSORS AND ATTRACTORS

Observational studies have examined how CHs deflect CMEs from their radial trajectory. Cremades et al. (2006), analyzing a large number of events, showed that CMEs systematically move away from CHs. From their analysis, they demonstrated the existence of a force that causes this divergence, which

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is linearly dependent on the area of the CH and inversely proportional to the distance between the CME source and the hole. Three years later, Gopalswamy et al. (2009), additionally showed that this force is linearly dependent on the magnetic field of the CH. In this way, CHs are considered as magnetic walls, acting as repulsors that push CMEs away.

On the other hand, pseudostreamers act as attractors of CMEs. Yang et al. (2015) show in observational studies that the CME approaches the region of low magnetic energy, and an imbalance in magnetic pressure occurs due to magnetic reconnection, deflecting the CME.

3. MODEL AND NUMERICAL STUDIES

Observations in white light reveal that CMEs are composed of a leading edge, a dark cavity, and a bright core. This structure corresponds to a flux rope (FR) model, where a helical magnetic field can support and expel material from the corona into the interplanetary medium through coronal mass ejection. Using the catastrophe model proposed by Forbes (1990), the dynamics of this FR can be resolved by solving the MHD equations through numerical simulations.

In this way, in Sahade et al. (2020, 2021), the deflection of a FR in the presence of a CH was analyzed in isolation. We found that the combination of both magnetic structures creates a region of minimum magnetic energy where the CME is deflected, and then the deflection is channeled by the magnetic field lines of the CH. We numerically demonstrated that the deflection increases when the magnetic field of the CH is stronger, when the distance between the CH and FR is smaller, and when the area of the CH is larger, consistent with the aforementioned observational studies. We also showed that the CH can act as an attractor. If the polarity of the FR is anti-aligned with respect to the CH, an approach to the CH occurs first, and then, the guidance of the CH magnetic field lines leads to the motion away from the CH.

On the other hand, in Sahade et al. (2022), we analyzed how a PS influences the deflection of a FR. In this case, since the PS intrinsically possesses a region of minimum magnetic energy at its cusp -null point (NP)-, the presence of the FR creates another NP where the rope initially moves toward. However, we demonstrated that depending on the intensity of the magnetic field of the PS, the FR can move toward the NP of the PS, it can move away from this NP, or it may not eject.

Using this knowledge, in Sahade et al. (2023) we explain the anomalous trajectory of the famous

Cartwheel Event, the CME suffers a double deflection due to the combination of a neighboring PS and CH.

4. FINAL COMMENTS

These investigations highlight that the crucial factor for the initial deflection is the presence of regions of low magnetic energy. Subsequent alterations in the trajectory of the CME are attributed to the channeling of the ambient magnetic field. The anomalies observed in specific cases are further elucidated by considering the relative magnetic polarity between the CME source and the adjacent magnetic structure.

Nevertheless, observational studies show that within a dynamic and magnetically intricate coronal environment, there are additional factors to take into account. These include magnetic reconnections that modify the magnetic topology, the inertia or the twisting within the CME, and various other dynamical effects. Understanding these complexities is essential for unraveling the intricate dynamics of CME trajectories.

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APPLICATION OF DEEP LEARNING TECHNIQUES IN SOLAR PHOTOSPHERE MODELING

N. Morales¹, J. E. Agudelo¹, S. Vargas Domínguez¹, S. Shelyag²

This proceedings paper summarizes the research on the application of deep learning techniques in modeling the solar photosphere. The study explores the challenges of precisely modeling the complex and variable photosphere and introduces generative adversarial networks as an innovative approach to capture physical structures without direct reliance on MHD equations.

Recent leaps in observational technology, catalyzed by milestones like cutting-edge space telescopes, have propelled our understanding of the universe. Confronted with atmospheric constraints, modern astronomical instrumentation and projects have tackled the challenge, despite significant expenses and intricate construction. In pursuit of nimble alternatives, current investigations delve into the fusion of artificial intelligence (AI), specifically leveraging deep learning techniques. Neural networks have demonstrated potency in diverse domains, from medical diagnostics and smart marketing to autonomous driving and secure data encryption.

Our work provides a comprehensive overview of research focused on applying deep learning techniques to model the solar photosphere, emphasizing the use of generative adversarial networks (GANs). We delve into the challenges associated with accurately representing the intricate and dynamic nature of the Sun’s surface, introducing GANs as an innovative solution that doesn’t rely directly on MHD equations. In particular, we are interested in exploring the use of deep learning techniques for generating solar photospheric structures based on numerical simulations from the MURaM code. With a specific use of Convolutional Neural Networks (CNNs) and GANs, the study aims to efficiently produce realistic images of complex solar phenomena. The primary objective is to develop GANs tailored for solar photosphere modeling. The methodology encompasses data collection from various solar instruments, with a detailed exploration of the proposed

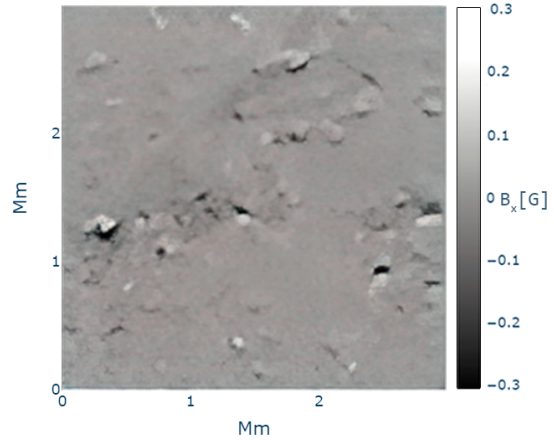


Fig. 1. Magnetogram of a magnetic field cube generated by the DCGAN, the activation functions of the network generate normalized magnetic field magnitudes ranging from -1 to 1 Gauss (rescaled to -0.3 to 0.3 Gauss in the figure).

DCGAN (Deep Convolutional Generative Adversarial Network). This includes the 3D structure, training process, and physical implications, such as incorporating magnetic field divergence into the loss function. Multiple experimental runs are conducted to validate the proposed configurations and explore various physical conditions, resulting in visually appealing and physically accurate outcomes (Fig.1). The obtained results showcase remarkable performance, surpassing traditional methods and underscoring the potential of GANs in capturing intricate patterns within the solar photosphere. Quantitative validation metrics, visual representations, and comparisons with traditional methods further substantiate the robustness and superiority of the deep learning approach. The results highlight the computational efficiency of the models, suggesting practical implications for real-time solar observation and modeling.

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ABSTRACT ONLYSYNTHESIS AND INVERSION OF STOKES
PARAMETERS IN THE SOLAR CONTEXT
APPLYING DEEP LEARNING TECHNIQUESJuan Esteban Agudelo Ortiz ¹ ; Germain Nicolás
Morales Suarez ¹ ; Santiago Vargas Domínguez ¹ ;
Sergiy Shelyag²

The solar photosphere is the optical limit for which we can observe the sun at a greater depth. It is here where the structures generated by plasma convection to the solar interior are evident. The study of the photosphere allows us to analyze the emergency zones of magnetic fields, whose evolution can generate highly energetic phenomena such as flares, and turbulent movements that can be one of the causes of nanoflare generation. Although observations of the Sun are limited by the resolution of telescopes, during the last two decades an increasing number of realistic simulations of the configuration of the solar interior and atmosphere have been developed, which employ the equations of the magnetohydrodynamics and various other conditions, depending on the particular characteristics and activity in each zone of the sun, whereby the physical properties and details of the structure of various solar zones can be studied. In this work, the MURaM code is used to generate simulated physical parameters such as plasma density, temperature and velocity, including also the magnetic field, at different optical depths in the convective zone and the solar photosphere. The main objective, based on the simulations, is to train a 1D convolutional neural network, which takes the values of density, temperature, magnetic field and speed, the latter two in the line of sight, along a column. The trained network is capable of generating the corresponding Stokes parameters. Based on this model, another version is created which has an inverse functionality such that now having the Stokes parameters as inputs, the corresponding physical parameters of the plasma and the magnetic field in the same domain can be recovered.

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ABSTRACT ONLY

THE EFFECT OF CROSS-SECTION
EXPANSION ON THE EVOLUTION OF
CORONAL LOOPS

M. López Fuentes¹ and J. A. Klimchuk²

Solar coronal dynamics is strongly dominated by the magnetic field. The presence of loop structures, observed in Extreme Ultraviolet and X-ray images of active regions, are the most conspicuous manifestations of this. The “frozen-in” condition of the coronal plasma obliges it to flow along magnetic field lines making magnetic strands and loops the basic blocks of the coronal structure. This led, in recent decades, to a growing interest in studying the geometric and dynamic properties of these loops, in particular, in relation to the problem of coronal heating. In this work, we use a one-dimensional hydrodynamic code to analyze how the loop geometry, determined by the expansion factor of its cross-section, affects the evolution of the plasma contained in them. For that, we apply different geometries and heating regimes to modeled loops for later comparison with actual observations. Our preliminary results show that the evolution of the plasma parameters, mainly the density, are remarkably affected by different schemes of cross-section variation along the loops. This, in turn, produces clearly identifiable differences in the observational signatures of the parameters, as can be deduced from the analysis of synthetic spectral lines obtained from the models.

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ABSTRACT ONLY**INTERMITTENT FEATURES IN THE SOLAR
WIND: A CASE STUDY**M. S. Nakwacki¹ and J. Peralta-Ramos

The solar wind (SW) is a natural scenario to study intermittency in magnetohydrodynamic (MHD) turbulence for systems with low dissipation rates. These intermittent structures can be characterized by computing the degree of phase correlation of the magnetic field. In this work, we study in situ observations of magnetic field intensity, velocity, and proton density from the Advanced Composition Explorer spacecraft ACE, which is located near one astronomical unit from the Sun, in the SW near Earth. We obtained spectral indices and flatness scaling exponents of the studied fields characterizing their intermittent features.

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ABSTRACTS OF CONTRIBUTED PAPERS

ASSESSING THE PREDICTABILITY OF SOLAR ACTIVE REGIONS USING HELIOSEISMIC HOLOGRAPHY: AN EXPLORATORY DATA ANALYSIS

Daniel Alberto Rodríguez Torres¹, Benjamín Calvo-Mozo¹, and Juan Camilo Buitrago-Casas²

For solar astrophysics and space weather, deepening our understanding of the relationship between solar Active Regions (ARs) and solar flares is essential to predict and mitigate their effects on our planet. This study focuses on assessing the possible connection between ARs on the far side of the Sun, identified through holographic helioseismology techniques, and the ARs that rotate onto the visible side of our star, the near side. Using Doppler observations from the Solar Dynamic Observatory (SDO), the Northwest Research Associates (NWRA), in collaboration with Stanford University, regularly generates acoustic maps of the far side of the Sun (one map every 12 hours), allowing us to analyze non-visible ARs from Earth. This poster will present exploratory data analysis of ARs in the identifiable regions on both the far and near sides of the Sun, covering the period from April 25, 2010, to July 31, 2023. The list and characteristics of active regions on the visible solar disk are taken from standard catalogs compiled by the National Oceanic and Atmospheric Administration (NOAA) for this purpose. The analysis aims to assess the existence (or lack thereof) of a relationship between active regions on the far side of the Sun and those that become visible due to the rotation of our star. We analyze key parameters such as acoustic intensity and morphological evolution of active regions, to then visualize them and carried out descriptive statistical techniques to evaluate potential statistical correlations among them. This exploratory data analysis is the first step of a broader project that seeks to use the acoustic characteristics of the Sun’s far side as predictors of subsequent solar flares on the visible side of our star.

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ABSTRACT ONLY**TERRESTRIAL INFLUENCE OF SOLAR
ACTIVITY: THE SEPTEMBER 1941 SOLAR
STORM AND ITS RELATIONSHIP WITH
UNEXPLAINED TERRESTRIAL EVENTS**Freddy Moreno Cárdenas¹, Santiago Vargas
Domínguez², Juan Camilo Buitrago Casas³

Solar activity refers to the various phenomena that occur on the Sun, including sunspots, solar flares, and coronal mass ejections (CMEs), mainly driven by the highly dynamic and complex Sun’s magnetic field. The influence of the Sun on our planet is a fascinating and relevant topic, as solar activity can have significant effects on our environment and many technologies of our contemporary society. In this research work, we explore the relationship between solar activity and various events that occurred on Earth, focusing on the solar storm that took place in 1941. This research focus on preliminary findings and discuss the implications and prospects for future investigations in this field. Our research delves into the intriguing possibility that the intense solar storm of September 1941 may have played a pivotal role in triggering unexplained terrestrial events, including some mysterious explosions. By exploring this hypothesis, we aim to uncover new insights into the complex interplay between solar activity and its terrestrial impacts, particularly in the context of historical events that have remained enigmatic for decades. Central to our hypothesis is the concept of Faraday induction, whereby changes in the local magnetic flux during the geomagnetic storm could have induced currents in the wires connected to dynamite blasting caps. The exact magnitudes of magnetic flux changes capable of potentially triggering the detonation of the explosives during the geomagnetic storm are not definitively established. While our preliminary investigations suggest a potential connection between the solar storm and the unexplained terrestrial events, further in-depth research is needed to solidify the precise link.

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ABSTRACT ONLY**STUDY OF MAGNETIC FIELD VARIATIONS IN
HIGH-CADENCE VECTOR MAGNETOGRAMS
DURING SOLAR FLARES**Santiago Vargas Domínguez¹, Willinton Caicedo
Tez¹, Juan Camilo Buitrago Casas³

During a flaring event, the magnetic field topology changes rapidly, abruptly, and significantly. Some of these eruptive events inject enough energy into the photosphere and sub-photosphere to generate acoustic responses observed as sunquakes. The precise physical mechanism causing the acoustic source of a sunquake is still a topic of debate. A number of authors agree that magnetic field restructuring must play a fundamental role in causing such acoustic drivers. Previous studies have mainly probed the line-of-sight component of the magnetic field in such scenarios. In this work, we investigate the temporal and spatial evolution of the permanent changes in the magnetic field during 4 flares from high-cadence vector magnetograms (135 to 720 s) of the imaging system (dopplergrams and magnetograms) of the SDO/HMI instrument, which are suitable for investigate the phenomenon. These highly energetic events occurred during the current solar cycle 24, in a range of high and low energy, according to the GOES classification. Changes of tens of degrees in the magnetic field inclination are present in the studied flaring events displaying sunquakes. The acoustic wave is produced in the lower atmosphere by the ponderomotive force in the Alfvénic front associated with the magnetic variation. The analysis carried out represents a crucial input for the investigation of sunquake’s origin and dynamics. We conclude that permanent changes in the magnetic field with values greater than 10 degrees in a kernel, are likely to induce sunquake signatures. Injection of particles seems not to take place when the field lines do not display the correct direction (downwards). Our results are in agreement with previous theoretical approaches. Sunquakes offer an opportunity for studying the interaction of acoustic waves with magnetic fields and flows in flaring active regions.

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DUST FILTRATION IN REVENANT PROTOPLANETARY DISKS

María Paula Ronco,^{1,2}

RESUMEN

Estrellas más masivas que el Sol, con masas entre 1.5 y $3M_{\odot}$, experimentan transformaciones notables en su estructura interna y temperatura efectiva durante los primeros millones de años de su existencia. Estos cambios afectan considerablemente a los discos protoplanetarios que se forman a su alrededor, impactando en los procesos de formación planetaria. Aquí investigamos los efectos de la evolución estelar en la evolución simultánea de gas y sólidos en un disco renacido que orbita una estrella de $2.5M_{\odot}$. Este escenario ha sido descrito recientemente por Ronco et al. (2023), representando la reconexión de los discos interno y externo generada después de la apertura de una brecha debido a la fotoevaporación por la estrella central. Nuestras simulaciones muestran que, como era esperable, esta brecha también divide el disco sólido en dos, inhibiendo la migración radial de polvo/gravas desde las regiones externas, lo que podría limitar la formación de núcleos masivos cerca de la estrella. Sin embargo, una vez reconstruido el disco, el flujo de polvo/gravas se reactiva permitiendo que nuevo material alcance las regiones internas que podría contribuir a una formación tardía de Súper-Tierras.

ABSTRACT

Stars more massive than the Sun, ranging between 1.5 and $3M_{\odot}$, undergo notable transformations in their internal structure and effective temperature within the first million years of their existence. These changes significantly affect the protoplanetary disks that form around them, impacting the processes of planetary formation. We here investigate the effects of stellar evolution on the simultaneous evolution of gas and solids in a revenant disk orbiting a $2.5M_{\odot}$ star. This scenario has been recently described by Ronco et al. (2023), portraying the reconnection of the inner and outer disks generated after a gap is opened by photoevaporation from the central star. Our simulations show that, as expected, this gap also divides the solid disk into two, inhibiting the radial drift of dust/pebbles from the outer regions, which may constrain the formation of massive cores near the star. However, once the disk is reconstructed, the dust/pebble flux is reactivated, enabling fresh material to reach the inner regions that could contribute to a late formation of Super-Earths.

Key Words: protoplanetary discs — stars: evolution — planets and satellites: formation

1. INTRODUCTION

Stellar evolution has been found to be a key ingredient in the evolution of protoplanetary disks around intermediate-mass stars. The dissipation timescales decrease as the mass of the central star increases, but the disk pathways show the typical inside-out disk evolution for all stellar masses Kunitomo et al. (2021). Ronco et al. (2023) expanded Kunitomo et al. (2021)’s work considering the effects of stellar evolution and adopting a finer grid of disk parameters, such as different disk masses and viscosities. These authors found that the evolutionary pathways of the gas disk in fact depend on the stellar mass, changing from the typical inside-out, to an homogeneous and to an outside-in evolution as the mass of the star increases. A particular pathway named “revenant disk

evolution”, has been found between the last two. In this scenario, and as a consequence of the changes of the X-ray and FUV photoevaporation rates due to stellar evolution, the gas disk is reconstructed after the first gap opening by X-ray photoevaporation. We here explore how this particular case affect the evolution of the solid component of the disk and thus, on planet formation.

2. THE MODEL

The evolution of the gas component of the protoplanetary disk is computed as in Ronco et al. (2023). Because the dust/pebbles are strongly coupled to the dynamics of the gas, the time evolution of the dust/pebbles surface density is computed by solving a diffusion-advection equation,

$$\frac{\partial \Sigma_p}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r} (r v \Sigma_p) - \frac{1}{r} \frac{\partial}{\partial r} \left[r D^* \Sigma_g \frac{\partial}{\partial r} \left(\frac{\Sigma_p}{\Sigma_g} \right) \right] = \dot{\Sigma}_p, \quad (1)$$

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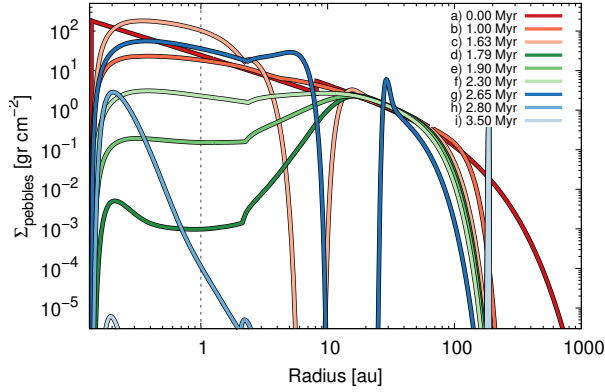


Fig. 1. Time evolution of the solid surface density profiles for the disk case S33 (Ronco et al. 2023) for 1 mm pebbles. Each profile has a correspondence with the gas disk profiles of the revenant disk stages I, II and III, respectively, described in Sec. 3.4 of Ronco et al. (2023).

where Σ_g and Σ_p are the gas and the dust/pebbles surface density, respectively, v the drift radial velocity, D^* the dust diffusivity and $\dot{\Sigma}_p$ the sink term due to dust/pebble sublimation (see details of the model in Venturini et al. 2020; Guilera et al. 2020). To keep this study as simple as possible, we do not compute the dust/pebble growth. Solids are always characterized by a single size along the disk and at every timestep. We run simulations only for the revenant disk case S33 (see sec. 3.4 in Ronco et al. 2023) and considering dust of $1\ \mu\text{m}$ or pebbles of 1 mm, 2.5 mm and 1 cm. The initial dust/pebbles surface density takes into account the water-ice sublimation at the iceline, and the dust-to-gas ratio is taken as 1%.

3. RESULTS

Figure 1 shows the time evolution of the solid surface density profiles for the disk case S33 formed by 1 mm pebbles. The first gap opened in the gas disk due to X-ray photoevaporation (see fig. 5 in Ronco et al. 2023) also opens a gap in the pebble surface density at 1.63 Myr (profile c). This gap limits the pebble flux from the outer region of the disk towards the inner ones as long as the gap exists. However, once the disk is reconstructed due to the combination of a strong decay in the X-ray photoevaporation rate and viscous evolution (profile d), pebbles drift inwards reaching the inner regions later on.

Figure 2 shows the time evolution of the pebble flux computed at 1 au for different solid particle sizes. For pebbles of 1 mm, the pebble flux abruptly decays just after the first gap opening (first dashed vertical gray line) but is reactivated once the disk is rebuilt, which may contribute to the late formation of Super-Earths at ~ 1 au. However, the reac-

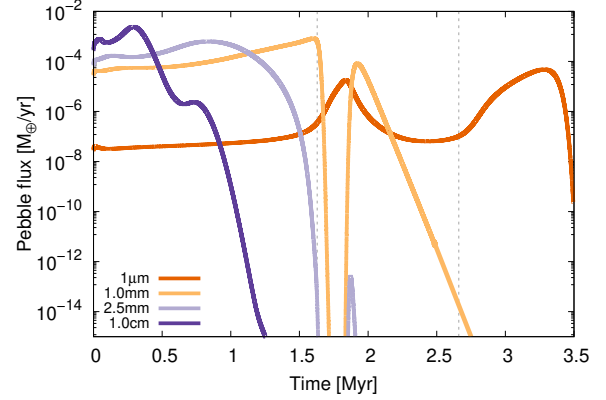


Fig. 2. Time evolution of the dust/pebble flux of the revenant disk case S33 (sec. 3.4 in Ronco et al. (2023)) for different dust/pebble sizes, computed at 1 au. The gray dashed vertical lines represent the times at which the gap opens in the disk due to X-ray and FUV photoevaporation, respectively.

tivation of the pebble flux depends on the particle sizes since this parameter is directly related to the radial drift velocity (see the recent review by Birnstiel 2023). Particles smaller than 1 mm have drift velocities low enough not to empty the outer zones of the disk of solid material before the time of the first gap opening. For this reason, once the disk is reconstructed, there is still solid material that can flow towards the central star. On the other hand, particles with sizes greater than 1 mm have higher drift velocities. This causes the disks to lose most of its solid material rapidly before the time of gap opening. Subsequently, there is no longer material available in the outer regions to supply the inner ones after the disk reconstruction.

4. CONCLUSIONS

For particles with sizes lower than ~ 1 mm we find pebble filtration in revenant disks. This pebble filtration towards the inner regions could promote the late formation of Super-Earths.

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ORBITAL RESONANCES IN PLANETARY SYSTEMS

T. Gallardo¹

RESUMEN

Las resonancias orbitales son mecanismos dinámicos caracterizados por una fuerza capaz de superar otras perturbaciones, logrando mantener los sistemas planetarios capturados en la configuración resonante. Se ubican en ciertos valores específicos de los semiejes mayores pero ocupan una región no despreciable de ese espacio. La existencia de un determinado ancho resonante sumado a que existen mecanismos que conducen a resonancias (a través de migración orbital por ejemplo) hace que los sistemas resonantes sean frecuentes. Mostramos aquí algunas aplicaciones del modelo semianalítico de Gallardo et al. (2021) que es especialmente bueno para sistemas excéntricos e inclinados.

ABSTRACT

Orbital resonances are dynamic mechanisms characterized by a strength capable of overcoming other perturbations, managing to maintain the planetary systems captured in the resonant configuration. They are located at some specific values of the semimajor axes but they occupy a non-negligible region of that space. The existence of a certain resonant width added to the fact that there are mechanisms that lead to resonances (through orbital migration for example) makes resonant systems frequent. We show here some applications of the semi-analytical model of Gallardo et al. (2021) which is especially good for eccentric and inclined systems.

Key Words: orbital resonances — exoplanets

1. MEAN MOTION RESONANCES

A stable planetary system has a certain number of fundamental frequencies which are constant and related to the orbital evolution of the planets. High frequencies are given by the orbital periods and low frequencies are defined by the secular evolution of the orbits. Orbital resonances in planetary systems occurs in two flavors: secular resonances and mean motion resonances (MMRs). Secular resonances occur when there are commensurabilities involving the low frequencies. MMRs between planets 1 and 2 occur when there is a commensurability between the planetary orbital periods or mean motions, n . So, we have $k_1 n_1 - k_2 n_2 \simeq 0$, (e.g. $2n_1 - 3n_2 \simeq 0$) where the k_i are integers. A more sensible indicator of the resonant state is the critical angle $\sigma = k_1 \lambda_1 - k_2 \lambda_2 + \gamma$ which involves positions (λ) instead of angular velocities (n). When two planets are trapped in MMR their mutual perturbations make their orbits to oscillate (librations) with periods of the order of $\sim 10^2$ orbital periods. Their semimajor axes a_i oscillate and σ also does. MMRs are not an instantaneous effect but a cumulative effect of synchronized planetary perturbations that makes the orbits librate due to a kind of forced mode providing stability against other perturbations. MMRs are very common among planetary

systems because planets migrate due to cosmogonic reasons or physical reasons and eventually they fall in resonance. We know the extreme cases of resonant chains with several planets in resonance like TRAPPIST-1 or HD 110067. Several planetary systems exhibit some offset (Charalambous et al. 2022) being the Solar System one of them because the giant planets are close but outside mutual MMRs. Michtchenko & Ferraz-Mello (2001) showed that the Jupiter-Saturn configuration in the exact resonance makes the planetary system chaotic, so the transition to a resonant configuration from one non resonant cannot be done for free. We have also examples of the contrary situation: Gallardo et al. (2021) showed that the HD 31527 system only can be stable if the two external planets are inside the 16:3 resonance.

There exist MMR models for coplanar and low eccentricities orbits but not models for arbitrary planetary orbits. In order to massively explore the properties of the planetary resonances we proposed a simple model (Gallardo et al. 2021) that works very well for all resonances, arbitrary (e, i) , can easily calculate hundreds of resonances and its codes are for non-experts. For example, the model predicts that the libration amplitudes of the planets verify

$$\frac{\Delta a_1}{\Delta a_2} \sim \frac{m_2}{m_1} \left(\frac{k_1}{k_2} \right)^{4/3}$$

that means less massive planets have larger libra-

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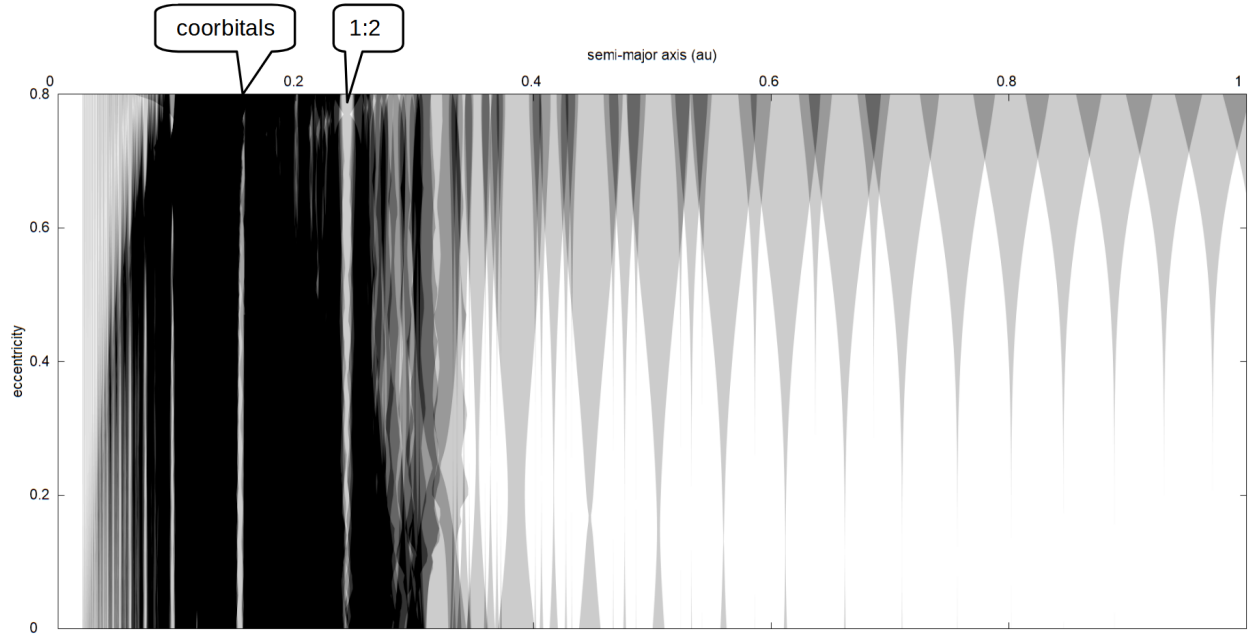


Fig. 1. Resonance domain in the space (a, e) of a $1 m_{\oplus}$ planet coplanar with the very eccentric planet TOI-3362b. Each resonance domain is painted in grey. Dark regions correspond to resonance overlap. Resonances 1:1 and 1:2 are labeled. The structures dominating the right region correspond to resonances 1:N exterior to TOI-3362b. ~ 300 resonances are showed in this plot.

tion amplitude. A recent example of the application of the model to the planetary resonance $1n_1 - 2n_2$ can be found in Giuppone et al. (2023). Codes and materials can be found at <https://sites.google.com/view/mmresonances>.

2. THE CASE OF TOI-3362

According to Dong et al. (2021) this system is composed by a star with $M = 1.445 M_{\odot}$ and a planet with $m = 5 M_{Jup}$, $a = 0.153$ au, $e = 0.815$.

Applying the model we studied the resonances with an hypothetical 1 Earth mass planet. The results are shown in Figure 1. Each resonance domain in (a, e) of the $1 m_{\oplus}$ planet is plotted in grey. We show interior and exterior resonances. Dark regions correspond to resonance overlap which is an indicator of chaos. There is a strong chaotic region close to the giant planet but with apparently at least two non perturbed regions inside: coorbitals and planets in the 1:2 resonance. For this last case we tested the stability with MEGNO indicator (Cincotta & Simo, 2000), dynamical maps and direct numerical integration of the full equation of motions and confirmed that planets remain stable by at least for $\sim 10^4$ orbital periods. In cases of planetary systems like this one with extreme eccentricities we can predict the properties of mutual resonances very well, but the

long term evolution depends crucially on their mutual inclination, which is an undetermined parameter.

3. CONCLUSIONS

The model works very well even for high eccentricity cases and when accompanied by dynamical or chaos maps a good dynamical characterization can be obtained. It seems that systems cannot enter or exit a resonance without a dynamic crisis. Why are some resonant systems stable and others unstable? More studies of MMRs with eccentric planets and more secular resonant evolution studies in the spatial case are needed to answer these questions.

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GAIA’S VIEW OF HYDRATED ASTEROIDS

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We analyze Gaia DR3 asteroid reflected light spectra in an attempt to detect the shallow absorption band around $0.7\ \mu\text{m}$, which is indicative of primitive aqueous alteration.

Gaia DR3 contains reflectance spectra for 60 518 asteroids (Gaia Collaboration et al. 2023). We analysed these spectra in an attempt to detect the feature around $0.7\ \mu\text{m}$ which indicates that in the asteroid’s parent body liquid water was present at some point (e.g. Fornasier et al. 2014). In combination with the asteroid orbital elements, an analysis of this feature can provide insights into where hydration (i.e. water) was present in the primitive solar system.

We used machine learning to identify asteroids with a $0.7\ \mu\text{m}$ band. All Gaia DR3 reflectance spectra were used as input data. The normalized reflectance at the bluest wavelengths was corrected as described in Tiaut-Ruano et al. (2023). Literature classifications were collected for a sample of 1134 asteroids. The classifications were verified by JB and MB on the basis of spectra from the literature. This resulted in 315 C-type asteroids, of which 140 asteroids have the $0.7\ \mu\text{m}$ band and in 139 the band is not present (the remaining C-types being dubious cases). Furthermore there are 569 S/X/Other type asteroids and 233 asteroids of unknown or doubtful taxonomic class. The asteroids with literature classifications were used to train a two-stage machine learning algorithm (scikit-learn’s multilayer perceptron classifier⁵) which first separates C-type asteroids from the rest and then identifies asteroids with a $0.7\ \mu\text{m}$ band from among the C-types. The observational uncertainties were accounted for by running the classification algorithm on multiple random realizations of the data (assuming Gaussian uncertainties). In both classification steps asteroids with mean class probabilities above 0.8 and a scatter in the probabilities of less than 0.1 were retained as C-type and hydrated asteroids, respectively. Some 2200 C-type asteroids were identified of which 230

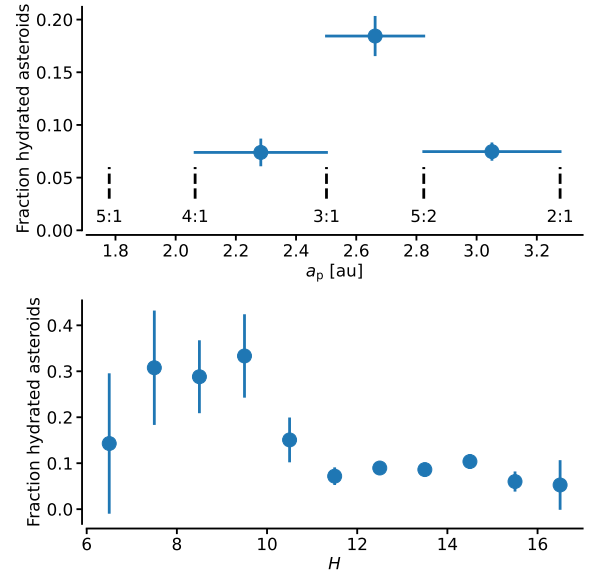


Fig. 1. Hydrated asteroid fraction with respect to all C-types vs. semi-major axis (top) and H -magnitude (bottom). The fractions as a function of semi-major axis are for ranges in a_p in between the indicated mean motion resonances. The error bars refer to Poisson uncertainties.

feature the $0.7\ \mu\text{m}$ band, ~ 400 have no h-band, and the rest could not be confidently classified. Figure 1 shows the fraction of C-type asteroids with the $0.7\ \mu\text{m}$ band as a function of proper semi-major axis and H -magnitude (Asteroid physical properties were obtained from <https://mp3c.oca.eu/>). The fractions are significantly lower than those found by Rivkin (2012), and should be seen as lower limits. No hydrated asteroids were identified for $a_p < 2.1$.

The results are still very preliminary. Future work will focus on improving the identification of asteroids with the $0.7\ \mu\text{m}$ feature in their reflectance spectra and accounting for selection effects.

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⁵<https://scikit-learn.org/stable/>

FEEDBACK-LIMITED VARIABLE ACCRETION ON TO PLANETS

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Accretion on to giant planets triggers a feedback process, which increases its variability. Feedback variability appears as broadband noise, which can be distinguished from eccentricity-induced variability. The heating of the gap may reduce dust concentration.

Protoplanetary discs, and their interaction with forming planets, are typically modelled using hydrodynamical simulations. These models were originally developed with a local isothermal approximation, meaning that the temperature is prescribed as a fixed function of distance from the central star.

Many observed discs show hot spots, which are likely due to giant planets growing within them. The giant planet accretes gas from its surroundings. This results in an accretion luminosity from the planet. The liberated energy heats the surrounding gas and alters its dynamics. In these cases, the locally-isothermal approximation does not hold.

Montesinos et al. (2015) modified the 2D hydrodynamics code FARGO-AD (Baruteau & Masset 2008) implementing a term that accounts for the heating around a growing planet. In that early work the planet luminosity was a free parameter. Using a value of $10^{-4}L_{\odot}$, Montesinos et al. (2015) found that the surroundings get temperatures ~ 300 K, which produces a thermal emission in L' of the order of a millijansky, comparable to observed hot spots.

The planet luminosity however does not need to be a free parameter. Instead, it should be set by the accretion on to the planet, in a *feedback* process. Gárate et al. (2021) implemented this in the code, making the planet luminosity proportional to its accretion rate. The higher temperature close to the planet produces a larger pressure gradient, which reduces the density at that location, and therefore the accretion rate. However, we found that the feedback still allows up to $10^{-3}L_{\odot}$ planet luminosities, without halting accretion. The process also creates vortices, which propagate and make the accretion rate

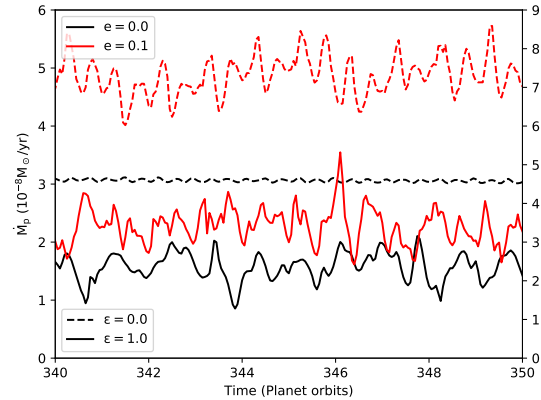


Fig. 1. Accretion rate curves for models with and without feedback implemented ($\epsilon = 1$ and 0), for different orbital eccentricities ($e = 0$ and 0.1) (Gárate et al. 2021).

more variable.

Figure 1 shows that the amplitude of the accretion rate variability is similar to that of a planet in an eccentric orbit. However, the models with feedback seem more stochastic. We quantified this by calculating the accretion power spectra (Arévalo et al. 2012), which confirms that accretion induces a higher broadband noise, compared to the well-defined periodic peaks produced by an eccentric orbit.

Finally, we notice that feedback increases the gas pressure inside the gap carved by the giant planet, decreasing the pressure gradient at its edges. This results in a velocity profile for the gas which is closer to Keplerian. This may have consequences for the dust, which will suffer a slower drift and perhaps reduce its accumulation at the outer edge of the gap. We plan to quantify this process in a follow-up work.

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MID-INFRARED SPECTRA INFORM ON THE COMPLEXITY OF EXTRASOLAR DUST CLOUDS

Genaro Suárez¹, Stanimir Metchev², Johanna M. Vos³, Jacqueline K. Faherty¹, and Kelle Cruz¹

Crucial knowledge about dust clouds in substellar atmospheres comes from Spitzer observations. We summarize here what we have learned about the formation, composition, evolution, and distribution of dust clouds from the analysis of the silicate absorption in Spitzer mid-infrared spectra.

The emergent spectra of the warmest brown dwarfs and exoplanets are shaped by dust clouds in their atmospheres. Therefore, understanding these objects depends on our knowledge of dust clouds. Despite many indirect studies on these clouds, the only *direct* evidence of the existence of dust clouds is a $\sim 9\ \mu\text{m}$ silicate absorption. Prior to JWST, Spitzer was the only telescope able to observe this silicate absorption. We list here the lessons learned about dust clouds from analyses of the silicate absorption.

Dust clouds in substellar atmospheres:

- Comprise a combination of $\lesssim 1\ \mu\text{m}$ -sized amorphous silicate (enstatite, forsterite, quartz, and/or pyroxene) and iron grains (Cushing et al. 2006; Burningham et al. 2021; Luna & Morley 2022; Vos et al. 2023; Suárez & Metchev 2023).
- Are near ubiquitous in L-type atmospheres and form, then thicken, and sediment out of the photosphere in the T_{eff} range $\approx 2000\text{--}1300\ \text{K}$ (Suárez & Metchev 2022).
- Sediment less efficiently in young objects (Suárez & Metchev 2023; Suárez et al. 2023).
- Are preferentially concentrated at the equator compared to the poles (Suárez et al. 2023).
- Are responsible for their color diversity (Cushing et al. 2006, 2008; Burgasser et al. 2008;Looper et al. 2008; Suárez & Metchev 2022; Suárez et al. 2023, see Figure 1) and, potentially, their variability (Suárez & Metchev 2022).

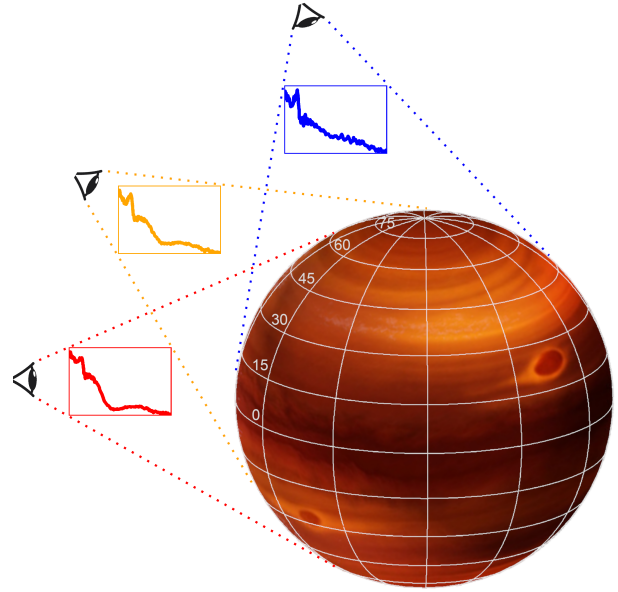


Fig. 1. The appearance of substellar objects is highly influenced by their viewing inclination. Figure adapted from Suárez et al. (2023) to show that lower latitudes exhibit stronger silicate absorption and are redder.

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THREE-DIMENSIONAL MODELING OF SUPERSONIC GAS ACCRETION AND IONIZED ENVELOPE DYNAMICS IN JUPITER-LIKE PLANETS

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We explore gas giant accretion in protoplanetary disks using 3D hydrodynamical simulations of a Jupiter-mass planet. Our model incorporates a non-isothermal energy equation for gas and radiation energy diffusion, enhanced by a novel radiative feedback mechanism from the planet. Key findings demonstrate supersonic gas accretion forming an ionized envelope around the planet, with its extent (0.2-0.4 of the Hill radius) influenced by radiative feedback. This ionization radius serves as a critical boundary for accretion dynamics, impacting the calculation of accretion rates and $H\alpha$ emission luminosities. We show that radiative feedback significantly increases accretion rates, especially inside the ionization radius. Accretion luminosities at this radius are substantially lower than at the Hill radius, providing new perspectives for interpreting current non-detections of $H\alpha$ emissions in planet formation.

We conducted FARGO 3D (Benítez-Llambay & Masset, 2016) numerical simulations to examine the evolution of Jupiter-like planets in a viscous disk, taking into account both gas and radiation energy transport and the radiative feedback of planets (Montesinos et al., 2015). A key discovery is the formation of an ionized envelope around these planets, characterized by an ionization radius that also marks the stopping point of supersonic gas accretion (Figure 1). This radius, fluctuating between 0.2 and 0.4 times the Hill radius, is significantly impacted by the inclusion of radiative feedback.

We observed that the radiative feedback enhances the accretion rate with a subsequent expan-

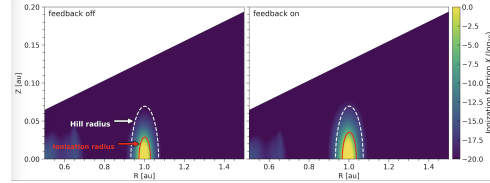


Fig. 1. Representation of the ionization envelope around the planet, in Hill units, at the final stage of the models. This is for scenarios with and without radiative feedback, defined by ionization parameter values $X \geq 0.5$.

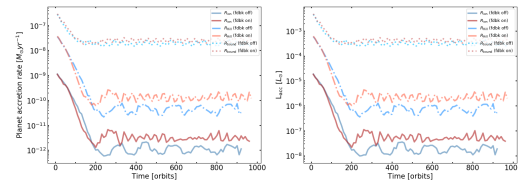


Fig. 2. Planet accretion rate for models with and without feedback computed at different radii: ionization radius R_{ion} , Hill radius R_{Hill} , and bound radius R_{bound} .

sion of the ionization radius when the feedback is active (Figure 2). Comparing the accretion rates at the Hill sphere and the ionization radius, we found that a much smaller fraction of gas passing through the Hill sphere actually contributes to the envelope or reaches the planet’s surface.

This study suggests that computing the accretion rate at the ionization radius, rather than at the Hill radius, is more effective for determining the luminosity associated with $H\alpha$ emissions. Our findings imply that the accretion luminosity, and thus the $H\alpha$ luminosity, computed at the ionization radius is considerably smaller than previously assumed, based on calculations at the Hill radius. This has important implications for interpreting the non-detections of $H\alpha$ emissions in several protoplanetary disks (Zurlo et al., 2020) as indicators of ongoing planet formation.

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RESONANT DYNAMICS OF CLOSE-IN SMALL SATURNIAN SATELLITES AND APPLICATION TO PALLENE (S XXXIII)

D. T. Ceccatto¹ and N. Callegari Jr.¹

In this work we explore the orbital vicinity of the small moon Pallene through numerical integrations and phase space mapping. The results reveal that Pallene’s orbit is currently located close to mixed inclination-eccentricity type associated with the 19:16 Enceladus-Pallene resonance.

Spitale et al. (2006) suggested that Pallene’s orbit is disturbed by a 19:16 resonance with Enceladus with a critical angle given by $\psi_1 = 19\lambda_E - 16\lambda_P - \varpi_P - 2\Omega_P$, where λ represents the mean longitude, ϖ is the pericenter longitude, Ω is the longitude of the node ascending and the subscripts P and E refer to Enceladus and Pallene, respectively.

Muñoz-Gutiérrez et al. (2021) show that ψ_1 and $\psi_2 = 19\lambda_E - 16\lambda_P - \varpi_E - 2\Omega_E$ angles circulate with approximate periods of 3,870 and 9,130 days, respectively, indicating that Pallene’s current orbit is not effectively trapped into the 19:16 resonance.

In this work, we mapped Pallene’s orbital vicinity using spectral analysis. We constructed a dense grid of initial conditions varying the osculating semi-major axis and the osculating eccentricity of tens of thousands of Pallene clones perturbed by Enceladus. The physical parameters and initial conditions for each satellite were obtained from *Horizons* (<https://ssd.jpl.nasa.gov/horizons/>) considering the initial date January 1, 2016.

Figure 1(a) represents the dynamical map for 30,000 Pallene clones considering Enceladus as the main perturber. We can observe two vertical structures limited by darker bands (chaotic regions) which represent the domains for the Ψ_1 and Ψ_3 ($\psi_3 = 19\lambda_E - 16\lambda_P - \varpi_P - \Omega_E - \Omega_P$) multiplets associated with the 19:16 resonance. Our mapping shows that the orbit of Pallene (dark star) is close to the Ψ_2 multiplet associated with a type of corotation inclination resonance and a more detailed view of this region can be seen in Figure 1(b).

Figure 2 shows the temporal variation for geometric angles ψ_1 , ψ_2 , and ψ_3 , for several initial conditions (a_0 , e_0) of Pallene clones indicated in Figure 1(a) and in the plots (see Figure 2(d-f)).

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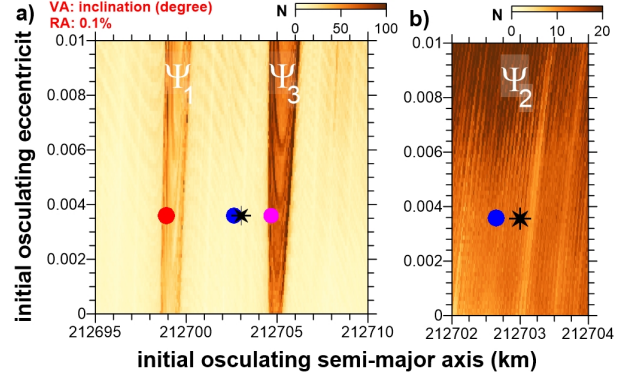


Fig. 1. (a) Dynamical map of the Pallene vicinity revealing the 19:16 resonance multiplets. (b) A zoom into the domain of the multiplet Ψ_2 .

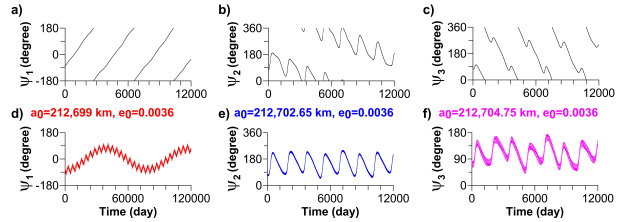


Fig. 2. (a-c) **black star**: *Horizons* in the date 01/01/2016; (d) **red disk**: oscillation of ψ_1 around 0° ; (e) **blue disk**: oscillation of ψ_2 around 135° ; (f) **magenta disk**: oscillation of ψ_3 around 90° .

Conclusions: the current orbit of Pallene is not currently trapped into the 19:16 resonance involving Enceladus, but it is located close to its Ψ_2 multiplet which is located between Ψ_1 and Ψ_3 domains.

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PHYSICAL PROPERTIES, SOURCE REGIONS, AND TOTAL MASS FLUX OF DECIMETRE-SIZED AGGREGATES AROUND 67P/CHURYUMOV-GERASIMENKO

P. Lemos^{1,2}, J. Agarwal^{1,2}, M. Pfeifer^{1,2}, and R. Marschall³

This study focuses on analyzing large solid aggregates (~ 10 cm) around comet 67P/Churyumov-Gerasimenko using data provided by the Rosetta mission. While the smaller particles were analyzed directly with the various on-board dust detectors, the larger particles were observed remotely only, so the information collected is sparse. To address this issue, a novel method is proposed. This method involves statistical comparison of the traces generated by the motion of the aggregates observed in OSIRIS images with those found in synthetic images, generated by modeling the trajectories of the aggregates. This made it possible to extract physical parameters of the aggregates, as well as information on their ejection mechanisms.

The first part of this work consists on the semi-automatic detection of tracks on images obtained by OSIRIS, the main imaging system onboard Rosetta, as described in Lemos et al. (2023). The images were acquired in five different sets between July 2015 ($r_h = 1.32$ au inbound) and February 2016 ($r_h = 2.39$ au outbound), totalling 189 images.

For each one of these real images, their synthetic counterparts were generated. These synthetic images are created by simulating the trajectory of the aggregates under the influence of comet and solar gravity, radiation pressure and gas drag. The gas flow description is the one presented by Marschall et al. (2020). The simulated trajectories depend on three aggregate properties, density ρ , radius r and initial velocity v_{in} , as well as the initial position on the comet surface.

Due to the movement of aggregates in front of the camera, they appear on the images as bright tracks instead of point sources. The last part consists on the comparison of the brightness, length and orien-

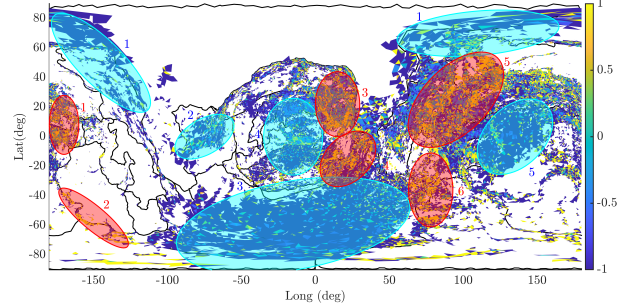


Fig. 1. Map of the ejection efficiency regions on the surface of 67P. The high and low ejection efficiency clusters are shown with red and blue ellipses respectively.

tation of the observed tracks with the same properties of the synthetic ones. By selecting the aggregates that generate track properties distributions resembling the observed ones, we are capable of determining the aggregate properties and their spatial distribution on the surface.

We find that the aggregate properties are consistent among different epochs, with mean values $\rho \simeq 500 \text{ kg m}^{-3}$, $r \simeq 10 \text{ cm}$ and $v_{in} \simeq 1 \text{ m s}^{-1}$, similar to those reported in similar works (Pfeifer et al. 2024). Additionally, we were able to define the *ejection efficiency* as the probability of an aggregate coming from a certain position to generate a resembling track. The spatial distribution of ejection efficiency (Figure 1) is grouped in clusters of high and low ejection, related to heterogeneous and homogeneous terrain types respectively. This result is similar to the one presented by Vincent et al. (2016).

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STELLAR ACTIVITY OR A PLANET? REVISITING DUBIOUS PLANETARY SIGNALS IN GJ581

D. P. González¹, N. Astudillo-Defru² and R. E. Mennickent¹

We reanalyzed the radial velocities and spectroscopic activity indicators of GJ581, an M-dwarf harboring questionable planetary signals. Our analysis challenges the periodic signals previously identified as likely artifacts of stellar activity rather than planetary influence, reinforcing the need for cautious interpretation.

Magnetic activity alters the shape of spectral lines, leading to apparent radial velocity (RV) variations which can be periodic or quasi-periodic and can mimic planetary RV signals. These signals often manifest at the star’s rotational period and its harmonics (Boisse et al. 2011). GJ581, an M-dwarf hosting a multi-planetary system, has a reported stellar rotation period of 132.3 ± 6.3 days (Suárez Mascareño et al. 2015). Notably, it displays two periodic signals attributed to planets d ($P_{\text{orb}} : 66.8$ [d]) and g ($P_{\text{orb}} : 36.5$ [d]), both harmonics of the stellar rotation period. This raises questions about whether these signals originate from planets or are artifacts of stellar activity.

To confirm or refute these signals, we used publicly RV data from HARPS, HIRES and CARMENES instruments, giving a total of 718 RV datapoints. Furthermore, we included activity indicators such as the $S-$ index, $H\alpha$, Na ID.

By modeling $H\alpha$ timeseries using Gaussian Process (GP) regression with a quasi-periodic (QP) kernel, we derived GJ581’s stellar rotation period ($P_{\text{rot}} = 132^{+1.82}_{-1.71}$ days), improving the accuracy compared to the literature value.

We computed the Generalized Lomb-Scargle (GLS) periodogram of the RVs, identifying periodic signals corresponding to planets: b ($P_{\text{orb}} : 5.37$ [d]), c ($P_{\text{orb}} : 12.9$ [d]), d ($P_{\text{orb}} : 66.3$ [d]), and e ($P_{\text{orb}} : 3.14$ [d]). For the other literature planets f and g, the periodogram does not show significant signals attributable to those planets.

We employed Keplerian models to the RVs for the period of planets b, c and e. The best Keplerian fit is

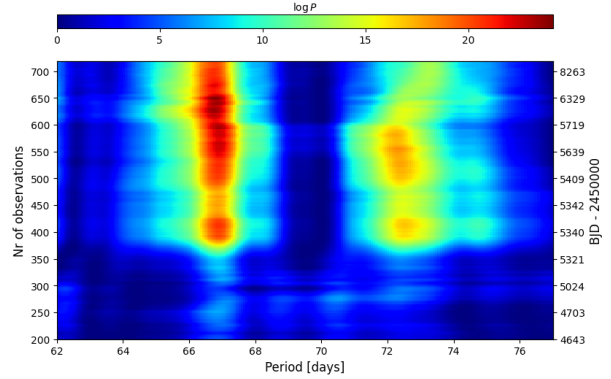


Fig. 1. sBGLS periodogram of the RVs residual from the (3-planet)Keplerian model.

Planet	Period (days)	K (m/s)	$M_p(M_{\oplus})$
b	5.36861 ± 0.00002	12.39 ± 0.07	15.5 ± 0.6
c	12.9180 ± 0.0004	3.49 ± 0.07	5.9 ± 0.2
e	3.14880 ± 0.00004	1.56 ± 0.08	1.6 ± 0.1

Table 1: GJ581 orbital parameters derived from (3-) Keplerian model. K is the semi-amplitude of the signal and M_p is the mass of the planet in Earth masses.

presented in Table 1. Then we analyze the temporal stability of the residual signal from the (3-)Keplerian model using the stacked Bayesian GLS (sBGLS) periodogram (Mortier & Collier Cameron 2017). The level of confidence in detecting a planetary signal should increase with additional data. However, Fig.1 shows that the probability around the 66-day signal attributed to planet d does not steadily rise with an increasing number of observations. Instead, it is alongside another signal around 72 days, with a pattern consistent of a stellar activity-induced signal.

Motivated by this, the next step is performing a simultaneous RV (Keplerian model) and activity indicators (GP+QP kernel) analysis to determine if the 66- day signal can be described by stellar activity.

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IN SEARCH OF THE “MISSING MASS”: MEASURING PROTOPLANETARY DISK DUST MASSES WITH ALMA

L. Zamudio¹, C. Espaillat¹, A. Ribas², and E. Macias³

Protoplanetary disks are an essential component of the planet formation process. The number and size of planets in a system are directly constrained by the amount of dust and gas in the disk. We present disk dust masses (M_{dust}) measured using spectral energy distribution (SED) modeling of 15 disks around T Tauri stars (TTS) in the Serpens star-forming region, using ALMA 1.33mm fluxes from the literature. Calculated M_{dust} are a factor of ~ 1.5 higher than those reported in the literature. Most works assume the disk to be optically thin at all mm wavelengths whereas our modeling finds that disks may be partially optically thick at these ranges. Our results show that disks around Serpens TTS may not have enough material to form planetary systems and do not completely alleviate the “missing” mass problem, known as the reported discrepancy between the available mass in protoplanetary disks and the observable mass in exoplanet systems.

We calculated disk M_{dust} for a sample of 15 TTS located in the Serpens star-forming region using multi-wavelength photometry and Spitzer IRS spectra, and by modeling their SEDs following Ribas (2020). The sample was obtained from an ALMA band 6 survey of Serpens (Anderson 2022). The aim is to compare SED-derived M_{dust} (that account for the effect of optical depth) with mm-flux-derived measurements. The key findings of this work are as follows: [1] SED-derived M_{dust} are ~ 1.5 times higher than literature values (see Figure 1); [2] The sample has a greater median M_{dust} than the populations shared average of 11 star-forming regions (0.5-10 Myr Rillinger 2023); [3] M_{dust} depletion is low, characteristic of younger regions (1-3 Myr) and follows $M_{\text{dust}} \propto t^{-1}$; [4] Serpens’ class II objects do not have enough material in their disks to solve the

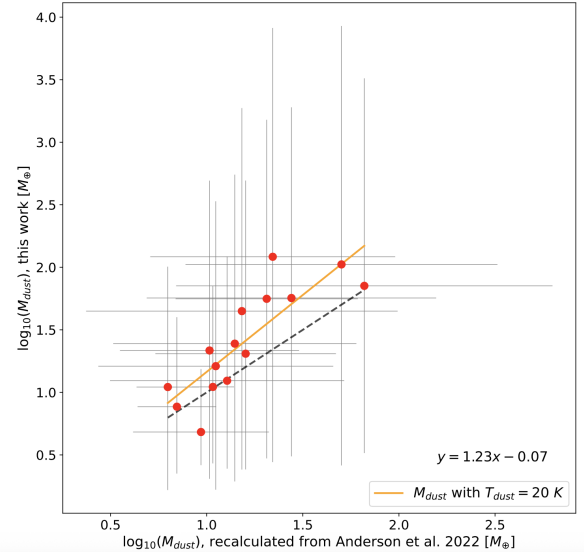


Fig. 1. SED-derived M_{dust} vs literature M_{dust} (Anderson et al. 2022). The panel displays a linear fit (solid orange line) to the comparison to dust masses recalculated assuming a constant dust temperature of 20 K. The black dotted line denotes a 1-to-1 fit. The line equation is displayed for the linear fit.

“missing mass” problem.

Our results show how SED-derived M_{dust} can constrain disk properties. This method allows for a broader study of diverse regions (environment and age). Future ALMA surveys can benefit this endeavor as (sub)mm observations can constrain the disks dimensions and increase the accuracy of the SED-modeling process. Thus providing a detailed view of the disk evolution timeline and a better understanding of the planet formation process that with the explosion in exoplanet detection is of high interest.

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SIMULATION OF POTENTIALLY HABITABLE ENVIRONMENTS ON THE SURFACE OF EXOPLANETS

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In this work, we simulate analogous environments to those expected to be found on the surface of Proxima b, considering atmospheric composition and ultraviolet (UV) radiation. We investigated the survival rates of the yeast *Rhodotorula dairenensis* under these conditions.

Proxima b is an exoplanet with $1.17 M_{\oplus}$ (Mascareño et al. 2020) and is in the habitable zone of an M dwarf. Such stars are interesting for astrobiology studies as they host the majority of terrestrial exoplanets already discovered in habitable zones. However, they are challenging in the biological context due to high levels of stellar activity, presenting frequent and intense flares with high intensity of UV radiation (Mascareño et al. 2020). This radiation is very important for biological systems, but excessive exposure can cause oxidative stress in cells and even damage to nucleic acids (Pourzand & Tyrrell 1999). Thus, this work aims to assess the survival rates of life as we know it in these environments.

To achieve this goal, we conducted experiments with the yeast *Rhodotorula dairenensis*. The sample was collected in Serra dos Cristais in Diamantina, Minas Gerais - Brazil (18.21408°S, 43.58771°W/1398 m), in May 2018. We performed three UV irradiation experiments with desiccated yeast. The first experiment was carried out with a tubular lamp that covers only the UVC region (254 nm). The second experiment was carried out with a continuous spectrum lamp that covers the entire UV range. The third experiment was conducted in the Space and Planetary Simulation Chamber (AstroCam) to simulate hypothetical conditions on the surface of Proxima b. In this chamber, we simulate an extreme atmosphere with 100% CO₂ and one that resembles that of primitive Earth (80% CO₂ and 20% N₂), with a pressure of 1000 mbar and with the continuous spectrum lamp attached to the AstroCam. Our results for this last experiment were inconclu-

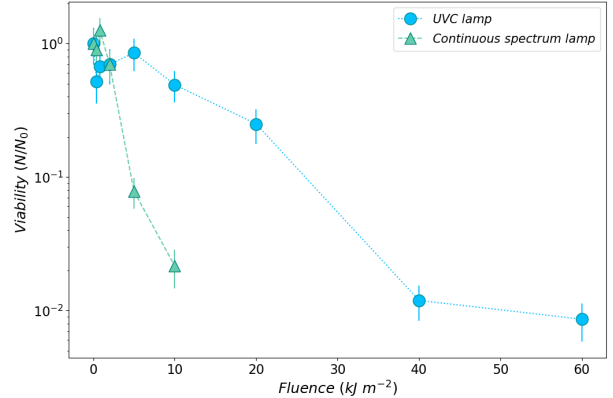


Fig. 1. Survival curves for the experiments with *Rhodotorula dairenensis* desiccated. N_0 is the viable count of non-irradiated microorganisms, N is the viable count after irradiation. Experiments performed in triplicate.

sive due to the large error bars, so we will not discuss it here. Non-irradiated samples were used as control in the three experiments. We compared irradiated and control samples to estimate the survival rate of microorganisms.

The results of the experiments are presented in Figure 1. The results showed that irradiation with the continuous spectrum lamp (green line) was much more lethal than the tubular lamp (blue line). The UVA, UVB and UVC ranges cause different damages to cells and dealing with these stresses simultaneously could make their survival more challenging. Furthermore, we observed that there no viable microorganisms for a fluence of 10 kJ m⁻² to the UV lamp and 60 kJ m⁻² for the UVC lamp. Using the estimated flux of a typical UVC flare for Proxima b’s orbit of 7 W m⁻² (Welsh et al. 2007; Abrevaya et al. 2020), those values would be reached in about 24m at 2.38h, respectively.

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EXPLORING PROTOPLANETARY DISK EVOLUTION VIA MHD WINDS

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We performed population synthesis of protoplanetary disks with MHD winds. We found that, for low viscosities, high torque values and strong disk winds best reproduce the accretion rates observed. We also found outward migration at $\sim 1\text{au}$ for masses $< 1M_\oplus$.

Recent results suggest that low viscosities could be the norm in protoplanetary disks, meaning that viscosity alone may not be the reason for their rapid dispersal. MHD winds act in disks threaded by a magnetic field, extracting mass and angular momentum, inducing accretion and reducing their lifetimes.

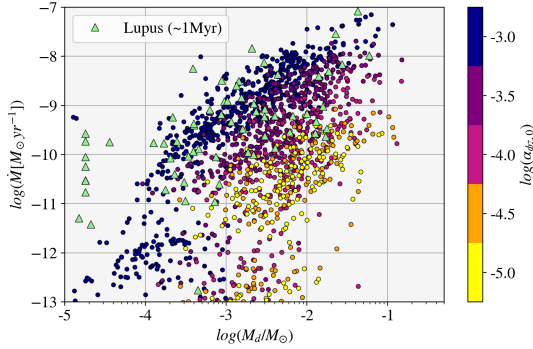


Fig. 1. Accretion rates for the synthesis and Lupus cluster. Values for the DW torque strength are in colors.

Figure 1 shows accretion rates vs disk mass for our population synthesis, in comparison to observational data for the Lupus cluster. The synthesis consists of 5000 disks following empirical initial conditions for the disk and star parameters (Gómez 2023), with $\alpha_{\phi z}$ between 10^{-5} and $10^{-3} M_\star/M_\odot$, in the Strong DW regime (Suzuki et al. 2016). We found that both viscosity and magnetic torque parameters need to be proportional to the stellar mass to account for the observed relation $\dot{M}_{acc} \propto M_\star^2$. We also implemented a star formation rate (Coleman & Haworth 2022) and found it to be fundamental to reproduce the observed high accretion rates, especially in populations of ages $> 2\text{Myr}$. MHD winds can also reproduce the observed dissipation time scales, resulting in characteristic lifetimes of $\sim 7\text{Myr}$.

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MHD winds affect the gas surface density profile, impacting the dynamical evolution of protoplanets. Outward migration is observed for protoplanets of masses $\lesssim 1M_\oplus$, at $r \sim 1\text{au}$ (figure 2). As proposed by Ogiwara et al. (2018), this could explain the in-situ formation of close-in super-earths.

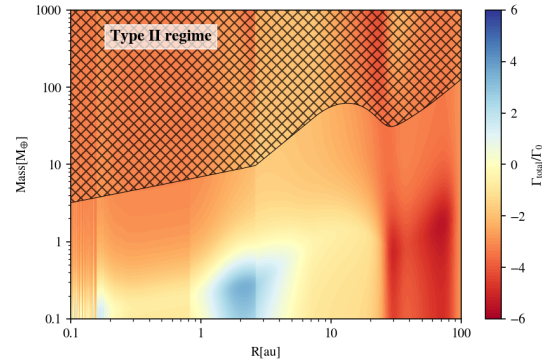


Fig. 2. Migration map at 1Myr for a protoplanetary disk evolving via strong MHD winds with low $\alpha_{\phi z}$. Torque prescriptions are from Jiménez & Masset (2017) and type II regime zones from Crida et al. (2006).

Our results contrast with a recent study by Weder et al. (2023), who concluded that weak DW and strong torques are needed to reproduce the accretion rates, while strong DW cannot due to the rapid dispersal of the disk. The discrepancies could be due to our implementation of a star formation rate, and to the introduction of a proportionality of the magnetic torque parameter with the stellar mass.

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ABSTRACT ONLY

A DENSITY VALLEY ACROSS STELLAR TYPES

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and Marcelo Miller Bertolami²

The radius valley separating super-Earths from mini-Neptunes is a fundamental benchmark for theories of planet formation and evolution. Observations show that the location of the radius valley decreases with decreasing stellar mass and with increasing orbital period. Here, we build on our previous pebble-based formation model. Combined with photoevaporation after disc dispersal, it has allowed us to unveil the radius valley as a separator between rocky and water-worlds. In this study, we expand our model for a range of stellar masses spanning from 0.1 to 1.5 $M_{\odot}$. We find that the location of the radius valley is well described by a power-law in stellar mass as $R_{\text{valley}} = 1.8197 M_{\star}^{0.14(+0.02/-0.01)}$, which is in excellent agreement with observations. Additionally, we note that the radius valley gets filled towards low stellar masses, particularly at 0.1 – 0.4 $M_{\odot}$. This is the result of orbital migration occurring at lower planet mass for less massive stars, which allows for low-mass water-worlds to reach the inner regions of the system, blurring the separation in mass (and size) between rocky and water-worlds. Furthermore, we find that for planetary equilibrium temperatures above 400 K, the water in the volatile layer exists fully in the form of steam, puffing the planet radius up (as compared to the radii of condensed-water worlds). As with Sun-like stars, we find that pebble accretion leaves its imprint on the overall exoplanet population as a depletion of planets with intermediate compositions (i.e. water mass fractions of ~ 0 –20%), carving an planet-depleted diagonal band in the mass-radius diagrams.

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PROBING A LABORATORY ASTEROID
MODEL: MECHANICAL CHARACTERIZATION
UNDER LOADING-UNLOADING CYCLES
C. Sedofeito^{1,2}, T. Gallot¹ and G. Tancredi¹

This study examines the mechanical properties of asteroids on a laboratory scale, focusing on their relevance in space mission design, Earth collision hazard assessment, and understanding collisional processes. Following the NASA-DART mission, the effectiveness of deflection relies on factors like cratering events, momentum distribution in ejecta, and the propagation of impact-induced seismic waves within asteroids.

Our comprehensive laboratory-scale characterization of granular media in dynamic regimes offers a cost-effective alternative to in-situ measurements. Scaling experiments by approximately 300-fold simulates a Dimorphos-sized asteroid, revealing particle sizes of 5 to 50 cm as observed on the mission. Micro-gravity conditions on asteroids yield unique mechanical properties challenging to replicate on Earth. While non-realistic, our experiments aid in understanding seismic wave propagation's role in material expulsion within asteroids, contributing to the comprehension of active asteroids and enhancing our knowledge of asteroid interiors and boulder distribution.

We observe pressure waves with frequencies ranging from 200 to 500 Hz. Independently of the granular media, glass beads (artificial, spherical), sand (natural, irregular), and gravel (natural, irregular), the wavespeed follows a power-law relationship $v \propto p^{1/2}$, and indicates that the speed of seismic body waves is independent of the origin mechanism, suggesting safer wave-generating methods for low-gravity experiments instead of risky impact devices.

The equivalence between wave propagation from impacts and shaker-born perturbations is valuable for non-impacted testing to assess granular material properties in low-gravity conditions. With the upcoming Hera mission to the Didymos-Dimorphos system in 2027, aiming to study internal asteroid structure, our research lays a foundation for a deeper understanding of asteroid interiors and boulder distribution.

ABSTRACT ONLY**THE INFLUENCE OF STELLAR ACTIVITY ON
THE ATMOSPHERIC PROPERTIES OF HOT
JUPITERS**M. Navia¹, L. Ghezzi¹ and P. Cruz²

Hot Jupiters are extremely irradiated gaseous exoplanets with orbital periods less than 10 days. Since they are exoplanets so close to their stars, it is reasonable to assume that there is a stellar influence on the atmosphere of these objects. It was previously shown in the literature that strong magnetic fields and high energy particles from the stellar chromosphere can affect hot Jupiters’ atmospheres by causing mass losses and subsequently orbital decay. We analyze the hypothesis that hot Jupiters without thermal inversion orbit active stars, while hot Jupiters with inversion orbit inactive stars. We use a larger sample and updated data to reproduce two approaches from previous works that try to classify hot Jupiters according to their brightness temperatures in five infrared bands: 3.6 μm , 4.5 μm , 5.8 μm , 8.0 μm (Spitzer), J, H and Ks (2MASS). We also investigated the relationship between the incident radiation and the presence or absence of thermal inversions. We found a good correlation (Pearson r coefficient ≥ 0.6) between 5.8 μm and H brightness temperatures and the chromospheric activity index $\log R'_{\text{HK}}$. However, we did not find a clear separation between exoplanets with and without thermal inversion as a function of stellar activity. We also found that the most irradiated exoplanets have thermal inversion, while the least irradiated ones do not.

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ABSTRACT ONLYSTUDY OF THE DISSIPATION TIMES OF
GASEOUS DISKS IN STELLAR POPULATIONSJ. L. Gomez^{1,2}, O. Guilera²,
M. M. Miller Bertolami² & M. P. Ronco²

Protoplanetary disks are the sites of planet formation. For this reason a correct modelling of protoplanetary disks is key to understanding planetary formation. In this work we present a disk population synthesis study aimed at reproducing the available observable properties of protoplanetary disks. We consider that disks evolve by viscous accretion and internal photoevaporation. The initial conditions, such as the masses and sizes of the discs, follow statistical distributions inferred from observations. We analyze the impact of stellar mass distributions and star formation rates on the time evolution of the fraction of stars with disks, and on the stellar mass accretion rates.

Our models show that, because massive stars dissipate their disks faster, the observed fraction of stars with disks in star-forming regions is dominated by disks around low-mass stars. The lifetime of protoplanetary discs has an uncertain distribution function, to calculate the average lifetime of disc on star formation region we consider that it follows a Log-normal distribution. From our models, we obtain a median disk lifetime of 4.2 My, showing very good agreement with observations.

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ABSTRACT ONLY

VARIABILITY OF WATER VAPOR IN THE
INTERNAL ATMOSPHERE OF MARS
ASSOCIATED WITH THE SOLAR ACTIVITY
CYCLE

J. N. Molina Córdoba¹, S. Vargas Domínguez¹ and
J. I. Zuluaga Callejas²

This work explores the intricate relationship between Mars’ atmospheric variations and dynamic solar activity patterns. We focus on periodic oscillations in H₂O vapor and the Pectinton solar flux index in the $\lambda = 10.7$ cm radio band, around the characteristic 11-year solar cycle. Periodic Mars activity was studied using data from Mars Express’ SPI-CAM instrument spanning 2004-2018. The Lomb-Scargle Periodogram method was applied to analyze the power spectra of both signals around this period, calibrated using peaks associated with the seasonal Martian cycle. This method was validated by analyzing power spectra of chemical species abundances in Earth’s atmosphere, obtained from the NRLM-SISE 00 empirical model provided by the National Oceanic and Atmospheric Administration (NOAA). Model executions reproduced chemical abundance data for various atmospheric species (N₂, O₂, N, H₂, Ar, and He) at two reference heights (upper mesosphere and low ionosphere) over a 1961-2021 time span. Results suggest a connection between variability in H₂O vapor concentration in Mars’ atmosphere and fluctuations in the Pectinton solar flux index. We propose the Lomb-Scargle Periodogram method as a heuristic for studying oscillatory activity in planetary atmospheres with non-uniformly sampled data. While our results provide valuable insights, further analysis, cross-referencing with data from different orbiters, is required to deepen our understanding of these findings in the fields of planetary climatology and atmospheric physics.

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ABSTRACT ONLY

LIKE A WRECKING BALL: UNDERSTANDING GIANT PLANETS AS THE KEY TO FINDING EARTHS

Robert Wittenmyer, Alex Venner, Jonathan
Horner¹

Jupiter-like planets are the key to understanding Earth-like planets. Their presence can disrupt the orbits of inner habitable worlds, or deliver life-sustaining water. While the search for Earth-like planets orbiting nearby stars garners the most attention, it is critically important to understand the presence and properties of giant planets in those systems. In the next decade, three space missions will provide unprecedented new opportunities for understanding the nature of these Jupiter analogs: Gaia, the James Webb Space Telescope, and the Nancy Grace Roman Space Telescope. We aim to take advantage of the multi-messenger synergy of these observatories, in combination with Australia's unique Minerva-Australis telescope array, to obtain a complete picture of the nearest extrasolar planetary systems. Dozens of cold giant planets are known from radial-velocity planet searches. But their true masses remain unknown due to the limitations of the technique. In Data Releases 4 and 5 (2025/26) the Gaia space astrometry mission will deliver the critical measurements of 3-dimensional architecture for these planetary systems. Combined with the minimum masses obtained from radial velocities, we will obtain the true masses of those planets. Our Minerva-Australis observatory is fully dedicated to radial-velocity measurements; it is the only such facility in the Southern hemisphere. We will use these data to better characterise nearby Jupiter analogs for which true masses and orbital inclinations can be derived with forthcoming Gaia data. With detailed knowledge of the properties of those giant planets, we can model the extent to which those planets deliver water to inner Earth analogs via comet impacts. These Jupiter analogs will also be prime targets for direct imaging by JWST and Roman.

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ABSTRACT ONLY**EJECTION EXPERIMENT IN SOFT
GRANULAR MEDIA**V. Abraham¹, T. Gallot¹, G. Tancredi¹ and C.
Sedofeito¹

Asteroids have been shown to be composed of granular media, Tancredi et al. (2012) predicted the creation of dust clouds at low escaping velocities post-impact. Their study proposed that a layer of particles shocked from below could cause particles to ascend from the surface, a phenomenon known as the “cocoa effect”.

Our research focuses on exploring particle velocities ejected from soft granular media, specifically rubber particles sieved into various sizes. The primary objective is to understand the behaviour of the cocoa effect at a laboratory scale, emphasizing the measurement of both height and velocity reached. Rubber serves as our chosen medium due to its notably slower wave velocity compared to harder media, facilitating movement capture through high-speed cameras. The experimental setup entails an acrylic prism filled with rubber, positioned atop a shaker with an attached accelerometer. We varied the shaker’s pulse amplitude. Particle movement is recorded with a high-speed camera and analysed using Particle Image Velocimetry (PIV) and correlation techniques (phase tracking and time correlation).

Initial findings provide insights into the beginning of lofting and velocity variations within the column of material. Notably, the analysis reveals a correlation between the amplitude and slope of the observed phenomena. A larger amplitude corresponds to a steeper slope. To validate our observations, correlation tracking was employed, further substantiating that larger slopes indeed align with more substantial amplitudes. These results contribute to a comprehensive understanding of the dynamics involved in lofting within the soft granular medium, laying the groundwork for further investigation and refinement of our experimental approach.

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ABSTRACT ONLY**WHAT IS THE FREQUENCY OF METEORITE FALLS? IS THERE A PREFERRED DAY?**Acosta, I.¹ and Tancredi, G.¹

Meteoroids are solid natural objects of a size roughly between 30 μm and 1 m moving in interplanetary space, that can reach the Earth upper atmosphere producing a noticeable phenomenon: a meteor. They might survive the meteor phase when passing through the atmosphere, and eventually reach the surface as meteorites. If recovered after observations of their passage they are called falls, whereas, if found by chance they are called finds. As of 20/11/2023 there are 1,218 recorded falls worldwide, with official names in the Meteoritical Bulletin Database. A subgroup among the falls are those that directly affect humans or their belongings (damaging falls). A meteoroid stream is a group of meteoroids with common orbits and origins (e.g., from the fragmentation of an asteroid), and is of great relevance because it might indicate the presence of a larger body, yet to be discovered. The aim of this work is to analyze the temporal distribution of meteorites, calculate how many meteorite falls per year, and how many of them are damaging. We determined if there is any preferred moment of the year with more meteorite falls. The frequency of falls per day over the entire Earth was calculated as a function of the day of the year and solar longitude; and compared with a Poisson process in order to look for dates with higher frequency than expected. From our analysis, an average rate of ~ 7.82 falls and ~ 1.72 damaging falls on urban Earth per year was calculated. Subsequently, $\sim 6,014$ falls per year over the entire Earth's surface, and $\sim 1,777$ falls per year over Earth's landmass were estimated from satellite data. No peaks in the distribution tail were observed, therefore, the presence of a meteoroid stream cannot be asserted. There is no particular day of the year with a higher fall rate, hence, it is likely that there are no highly populated meteoroid streams.

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ABSTRACT ONLY

COORBITAL DYNAMICS: A SEMI-ANALYTICAL APPROACH TO STUDY EQUILIBRIUM POINTS IN RESONANT COORBITAL CONFIGURATIONS UNDER EXTREME INCLINATION AND/OR ECCENTRICITY

Nicolás Pan¹, Tabaré Gallardo¹,

Co-orbital orbital dynamics is really important to understand some aspects of small body populations in our Solar System. The most studied case in the literature are Jupiter Trojans. Not all planets have known coorbitals. For example, Venus, Earth and Mars have confirmed ones but their stability has been a matter of some debate in the literature. There are several co-orbital motion types: tadpoles, horse-shoes and quasi satellites. Remember that in the classic planar circular case we only have two tadpoles which librate around $\pm 60^\circ$, these are called Trojans and are located in usually called L4 and L5 equilibrium points. It is important to notice that when the eccentricity or inclination of the secondary body grows those points change their position. This semi-analytical approach can be used to study any resonance such as 1:1 in this case. It provides a numerically integrated Hamiltonian and equilibrium points, as well as resonance widths and periods of librations. The advantage of using this theory is that we do not have restrictions in eccentricity nor inclination except for almost circular orbits where the hypothesis of the model fails. Our objective is to test the model under extreme conditions. Using it, we have mapped the location of equilibrium points for high eccentric and/or inclination orbits and searched for possible known asteroids in the NASA Horizons catalog that match this type of orbits. Furthermore, some problems can be modeled with this work such as pollution in white dwarf spectra. It has been proposed that post main sequence evolved small body population falling into the star due to resonant perturbations in high eccentric orbits could explain this. Also, we can apply this theory to study systems with two co-orbital planets such as the recent evidence for exoplanet system PDS 70 could indicate.

ABSTRACT ONLY**SEARCH FOR COMETARY ACTIVITY IN
TRANSITIONAL OBJECTS USING ARCHIVAL
IMAGES AND NEW OBSERVATIONS:****PRELIMINARY RESULTS**

S. Martino¹, G. Tancredi¹, M. Banda-Huarca^{2,3}, J.
Bueno Camargo^{2,3}, E. Rondon², D. Lazzaro² and

J. Licandro⁴

We present the monitoring of a set of Asteroids in Cometary Orbits (ACOs) and Activated Asteroids (AAs), which are part of transitional objects: bodies that do not fully fit the traditional categories of asteroids and comets. Using archival images from the Dark Energy Survey (results not revised by the Collaboration yet), ESO’s Very Large Telescope, and Instituto de Astrofísica de Canarias, alongside recent data from Observatório Astronômico do Sertão de Itaparica, we employ two distinct techniques to detect signs of cometary activity: i) the comparison of the surface brightness profile of the objects with those of field stars, ii) the study of the reduced magnitude vs. the heliocentric distance in search of increases in brightness, using data from the Minor Planet Center, and those obtained in the observations. We analyze the profiles of 133 ACOs and seven AAs and the reduced magnitudes of all the ACOs (705). Eleven ACOs presented a deviation in the surface brightness profile and/or in the reduced magnitude. We found a very small percentage of objects with signs of low-level activity, which would rule out a slow transition from active to inert. Four AAs were active in the images, three being coincident with the existing reports, while in the case of P/2015 X₆, we extended the activity period in 19 days. We could observe that the episodes of activity are very restricted in time and do not always occur in the same region of the orbit.

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ABSTRACT ONLY**TIDAL EVOLUTION IN DWARF PLANETS
SYSTEMS AS AN APPLICATION OF THE
CREEP MODEL**K. Gimenez-Coelho¹ and A. Rodríguez¹

To date, there are five confirmed dwarf planets, four of which are located in the trans-Neptunian region, namely: Pluto, Eris, Haumea, and Makemake. All four have natural satellites. It is well known that Pluto-Charon’s rotations are synchronized with the orbital motions. Eris and Dysnomia also have their rotational and orbital periods synchronized, respectively. This synchronous state is a natural consequence of tidal interaction between the dwarf planet and its main satellite. In this work, we propose to investigate the orbital evolution of the tides in Pluto-Charon and Eris-Dysnomia systems using the creep model, where the main parameter is the viscosity attributed to the deformed body. Regarding the action of the tides on both bodies, we integrated the equations for the mean variations of semi-major axis, eccentricity, and rotation velocity over Gyr timescales, to investigate when and how the system could have entered into synchronous motion. In addition, based on the equations of the creep model, we performed a parameter space analysis to obtain the most influential parameter on the orbital evolution of dwarf planets and their satellites.

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ABSTRACT ONLY

REVIEWING COMETARY-LIKE ASTEROIDS IN VIEW OF THE DART EXPERIMENT

G. Tancredi¹

Several objects in asteroidal orbits have presented comae and tails like the ones presented by comets. There are at present (12/2023) 46 objects that have presented, at least for a brief period, this cometary-like appearance. These objects are generally coined “Active Asteroids”, implicitly implying that some kind of on-going endogenous or exogenous active process is the mechanism that produce the long-lasting tails. Nevertheless, what we observe is that those asteroids are temporally dressed as comets. Several hypotheses have been proposed to explain the “activity” of these objects.

Lessons from DART: The NASA-DART experiment gave us an opportunity to review our knowledge of this population. Following the impact of the space probe against asteroid Dimorphos on September 26, 2022, several thousand tons of material were ejected at a wide range of velocities. Tancredi et al. (2023) dubbed the DART experiment as the creation of the first artificial “Active Asteroid”. They proposed that the production of a large amount of low-speed ejected material could be described by the “cocoa effect”: the lofting of small particles from the top of a dust layer by shaking the ground. The seismic shaking, combined with the “cocoa effect,” may lead to the ejection of particles from a significant portion of the affected hemisphere. They predicted a brightness increase due to a slowly moving dust cloud, the obscuration of Dimorphos’ surface by this cloud, and the generation of a long-lasting tail; which were confirmed by the close-by observations of LICI-ACube, as well as long-range tracking from HST and the ground. By July 2023, over 250 days after impact, the tail was still visible.

Based on these results, we reviewed the relevance of the different mechanism proposed to explain the appearance of the population of asteroids temporally dressed as comets.

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ABSTRACT ONLY

QUALITATIVE ANALYSIS OF THE DYNAMICAL EVOLUTION OF PLANETARY SYSTEMS

Eduardo Verrone Sanches¹, Tatiana A.
Michtchenko¹

Discoveries of extrasolar planetary systems have shown that the configuration of our Solar System is an exception to the rule given the number of systems with high relative inclinations, large eccentricities and high mass planets in orbits with periods of hours. Due to these peculiar characteristics, our goal is to understand the processes that led planetary systems to acquire such characteristics, through mutual gravitational interaction and with the proto-planetary disk. To verify the quality of the observational data and the stability of the planetary systems in periods of at least 1 Myr, we use the concepts of Hill Stability (Marchal & Bozis (1982) and Gladman (1993)) that consider the configuration of the systems in terms of total energy and orbital angular momentum; to evaluate their secular movements we work with the construction of Representative Plans that bring with them information of the long-period behavior of the system, based only on the mass ratio of the planets and the ratio of their semi-major axes; To analyze the temporal evolution, we use the theory of semi-analytical perturbation (Michtchenko & Malhotra, 2004) that allows us to explore systems of high eccentricities by not working with series expansions of the Disturbing Function. We work with models that simulate the process of planetary migration (Michtchenko & Rodríguez, 2011), which change the orbital elements in a forced way, seeking to relate the migration trajectories with known processes, interaction of the planet with proto planetary disk, accretion of matter and tidal effects. Using the stability criteria, we selected some planetary systems to start the analysis and, after verifying their secular behavior, we started the simulations of migratory processes to understand through which configurations the system passed until arriving in the current state, considering only the variation of the total energy of the system and the orbital angular momentum.

ABSTRACT ONLY**A LOCAL APPROACH OF PLANETESIMAL
FRAGMENTATION APPLIED TO PLANET
FORMATION**I. L. San Sebastián^{1*}, O. M. Guilera¹, M. M. Miller
Bertolami¹, N. Kaufmann²

One of the challenges in planetary formation models is, including the main physical phenomena in that process, to explain the diverse architectures of planetary systems observed to date. The modelling of collisions and planetesimal fragmentation is key to reproducing planetary formation and evolution correctly. Our previous works show that the inclusion of a detailed model of planetesimal fragmentation, considering different compositions and relative velocities of planetesimals, may inhibit or favour the formation of giant planet cores, drastically changing the final planetary system architectures. However, in global planetary formation models, the detailed modelling of these processes is extremely expensive from a computational point of view. Generally, these models include the planetesimal fragmentation process locally. In this work, we study a local approximation of this process that simplifies the phenomenon numerically, significantly reducing the computing time required for our simulations. We compare these results to our detailed model of planetesimal fragmentation applied to giant planet formation and contrast it with other local approximations in the literature to determine its validity.

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ABSTRACT ONLY

THE AGE-PRO ALMA SURVEY: A GLIMPSE INTO THE GAS EVOLUTION IN PROTOPLANETARY DISK

Carolina Agurto-Gangas¹, Laura M. Pérez¹, Ke
Zhang², Anibal Sierra¹, James Miley^{3,4,5} and
AGE-PRO collaboration

The fundamental question of how the gas and solids in protoplanetary disks evolve with time remains unanswered. However, the ongoing ALMA Large Program AGE-PRO (“ALMA survey of Gas Evolution in PROtoplanetary disks”) was designed to answer this question for the gas component. AGE-PRO will trace the evolution of gas disk mass and size throughout the lifetime of disks, using a well-defined sample of 30 disks between 0.1 and 10 million years old. By studying a large sample of disks at different ages, AGE-PRO will be able to identify the key factors that drive the evolution of gas disks and to better understand how these disks ultimately give rise to planets.

Here, we present the preliminary analysis on Upper Scorpius and Ophiuchus, the oldest and youngest regions in our sample, respectively. For Upper Scorpius we have imaged gas and continuum emission, and generated disk-integrated line fluxes and radial intensity profiles for all lines and for the continuum, in all 10 disks selected. ¹²CO emission is ubiquitous across the entire sample, with detection in all observed sources. In contrast, transitions of its heavier isotopologues, ¹³CO (2-1), and C¹⁸O (2-1), exhibit lower detection rates of 60% and 40%, respectively.

Additionally, we have analyzed the young Ophiuchus star forming region to examine the nature of the gas rotation with CO isotopologues. We are deriving rotational profiles from the PV diagrams and the size of Keplerian disks for Class I/FS sources.

These results will establish a foundation for understanding the global structure and evolution of protoplanetary disks. This will provide essential context for future in-depth studies of planet formation processes in disks.

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ABSTRACT ONLY**ROTATIONAL PERIOD DETERMINATION OF
FORTUITOUS ASTEROIDS**Johana Murcia-Rocha¹, Camilo Delgado-Correal²
& José Sergio Silva-Cabrera³

In this work we present the results of the photometric analysis of 11 asteroids whose rotation period has not been estimated and which we consider to be fortuitous as they were not the main objective of the photometric observations. They were present in the same field of view as the asteroid of study and showed sufficient brightness for photometric analysis. The images analyzed correspond to 23 nights in 2022, and were obtained from the National Astronomical Observatory of San Pedro Mártir, using the 84 cm telescope. Image processing, aperture photometry, and differential photometry were performed to calculate light curves. Subsequently, a search for the value of the corresponding rotation period was carried out using Fourier series analysis, employing a computational program that performs a rotation curve fitting. The complete data is available in: [here](#).

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ABSTRACT ONLY**EVALUATION OF THE AUTOBOL
ALGORITHM WITHH A SAMPLE OF EVENTS
DETECTED BY THE BOCOSUR NETWORK IN
URUGUAY**

A. Guaimare¹, M. Caldas¹, G. Tancredi¹, J.
Ballestrino², C. Deandraya², C. Uviedo²,
I. Ramírez², V. Abraham¹, L. Velasco¹, L.
Barrios¹, M. Hernández¹

BOCOSUR is a network of 20 stations deployed in Uruguay to detect fireballs (meteors brighter than Venus). Autobol is a machine learning-based algorithm that is capable of processing images and detecting events from a series of videos. The learning process of the algorithm begins with a manual classification of videos as with and without fireballs, this is essential because by choosing good candidates for videos with fireballs the learning is more specific. RANSAC “RANdom SAMple Consensus” is responsible for estimating the parameters of a mathematical model in Autobol.

Since 2019 we have deployed a network of stations with allsky cameras for the detection of bright meteors (fireballs). By October 2021, 6 stations were installed in the south of Uruguay, in what made up the first stage of the Red de Detección de Bóridos del Cono Sur (BOCOSUR). The stations run an application developed by our group (see Caldas et al. in this conference), which detects any change in brightness in consecutive frames. Therefore, a classification should be made between videos with and without fireballs. In 2022, a group of Electrical Engineering students (Ballestrino et al. 2022) developed an algorithm based on machine learning for the automatic classification of the videos, using the classification we had done as a training base. To train the Autobol package, we used the manual classification of ~ 8000 videos, where 363 of them have fireballs. In this poster we present the results of applying these predictive classification models to a database of over 250,000 videos. We present statistics on the performance of the network and the classification algorithm.

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ABSTRACT ONLY

EXPERIMENTAL SIMULATION OF A SOLAR
UV ENVIRONMENT ON MARS AND ITS
EFFECTS ON GERMINATION AND
PHOTOSYNTHETIC PIGMENT CONTENT OF
CHENOPODIUM QUINOAE. P. Puentes-León¹, S. Vargas Domínguez¹, Z. Z.
Ojeda Pérez², A. López-Rodríguez¹, J. H. Bernal
Salinas¹

Mars exploration has become a human goal in recent years, as the possibility of colonizing this planet opens up space for research and innovation in fields such as astronomy, astrophysics, astrobiology, among others. International agencies have directed their efforts to conduct various reconnaissance missions to Mars, with the aim of not only preparing for future human existence on the red planet but also ensuring food sustainability. Considering the above, this work has the main goal of simulating an experimental environment that replicates the environmental conditions of Mars related solely to solar ultraviolet radiation levels and establishing their effect on the germination and photosynthetic pigment content of *Chenopodium quinoa*. We focused on establishing the effect of these conditions on the germination and photosynthetic pigment content of *Chenopodium quinoa*, in order to make a pilot study for future colonization and subsistence on the planet. It was found that UV radiation stimulates the emergence of seeds from different *Chenopodium quinoa* materials, acting as a directed photomorphogenic signal. Specifically, at shorter wavelengths, the germination percentage was higher compared to normal conditions. Something very similar happened with the plants, where treatments with UV resulted in notable increases in the concentration of total chlorophyll at short wavelengths, showing an “automatic” increase in both materials. Further study of these behaviors in more extended experiments and with materials from other plant species would be worthwhile.

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TO USE OR NOT TO USE MODEL STELLAR SPECTRA TO STUDY INTEGRATED STELLAR POPULATIONS?

P. Coelho¹

RESUMEN

Las librerías de espectros estelares son esenciales para los modelos de poblaciones estelares. Estas pueden ser empíricas o teóricas, cada una con sus propias ventajas y desventajas. Aquí discutimos los resultados obtenidos al estudiar el impacto de los espectros estelares modelados en los modelos de poblaciones estelares y hacemos una aplicación a la luz integrada de cúmulos globulares. Concluimos que los modelos de poblaciones estelares contruidos con espectros estelares modelados compiten con, y a menudo superan, a los modelos basados en espectros empíricos.

ABSTRACT

Spectral stellar libraries are essential to stellar population models. They can be empirical or theoretical, each with its own advantages and disadvantages. Here, we discuss the results obtained by studying the impact of model stellar spectra on stellar population models and make an application to integrate light of globular clusters. We conclude that stellar population models built with model stellar spectra rival and often outperform models based on empirical spectra.

Key Words: stellar atmospheres — stellar population models

1. CONTEXT

The field of stellar population studies sits at the frontier between stellar and extragalactic astrophysics. It uses our knowledge of the evolution of stars and gas to predict the light evolution of galaxies (Tinsley 1980). The field was born with Baade (1944), who observed stars in M31 and satellites, noting similarities with Galactic stellar systems. When individual stars cannot be resolved (the vast majority of the universe), we need to use integrated light models to simulate the observables of stellar populations (e.g. Bruzual & Charlot 2003).

The starlight, coming from libraries of stellar spectra, is a central ingredient. While some models eschew isochrones and initial mass function assumptions (e.g. Martins et al. 2019), the selection of a stellar flux library remains unavoidable. These libraries comprise homogeneous compilations of stellar spectra, each tagged with characteristics like effective temperature, surface gravities, and abundances.

The literature features over a hundred such libraries, which are also used for automatic determinations of stellar parameters (e.g. Dias et al. 2015), studies of exoplanets via radial velocities measurements (e.g. Spring et al. 2022), and photometric calibration in surveys (Almeida-Fernandes et al. 2022).

2. A PROBLEM AND AN EXPERIMENT

A spectral stellar library can be empirical (based on observations, e.g. Sánchez-Blázquez et al. 2006) or theoretical (relying on atmosphere models and radiative transfer codes; e.g. Coelho 2014).

Empirical libraries have relatively sparse coverage of the Hertzsprung-Russell (HR) diagram, constrained by the star formation and chemical histories of the observed stars. This limitation prompted the use of stellar population models based solely on theoretical stellar spectra in some cases (e.g. Leitherer et al. 1999; Coelho et al. 2007). Theoretical libraries offer optimal HR diagram coverage but may contain inaccuracies in certain spectral regions or parameter space due to opacities or implemented physics (e.g. Martins & Coelho 2007).

Stellar population models will inherit errors and uncertainties from the chosen library. In the absence of a library with both optimal coverage of stellar parameters and excellent reproduction of spectral line profiles, which should we favour, better parameter coverage (model stellar spectra) or superior spectra on a star-by-star basis (empirical stellar spectra)?

The work by Coelho et al. (2020, hereafter CBC20) attempts to answer that question. The authors modelled Simple Stellar Population (SSP) models with fixed initial mass function and isochrones and three different stellar flux libraries: the empirical MILES (Sánchez-Blázquez et al. 2006),

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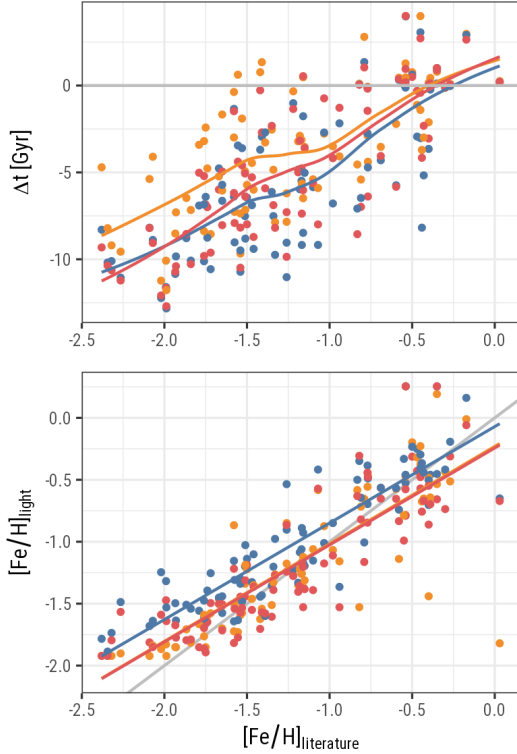


Fig. 1. Results are shown comparing the integrated light properties of galactic globular clusters, inferred from spectral fitting. The top panel shows the difference in age between the integrated light and those derived from isochrones (Δt) as a function of iron abundance $[\text{Fe}/\text{H}]$. The bottom panel depicts integrated light $[\text{Fe}/\text{H}]_{\text{light}}$ versus abundances derived from high-resolution spectral analysis. **Orange symbols** are results obtained from SSP models based on theoretical libraries, **blue symbols** correspond to models based on empirical libraries, and **red symbols** correspond to models based on theoretical libraries with a coverage of the HR equal to that of the empirical library. Lines are fitted to the data for visualization purposes, with a LOESS fit in the top panel and a linear fit in the bottom panel.

the theoretical from Coelho (2014) and a synthetic library with the same (sparser) coverage of the HR as the empirical library. They isolate two effects: the “coverage effect” which pertains to the impact of a sparse HR diagram coverage on SSPs, and the “synthetic effect”, which relates to uncertainties in model stellar spectra.

3. DISCUSSION

CBC20 investigates the impact of different stellar libraries on SSP model predictions and on inferred parameters of a sample of bulges. However, stellar clusters serve as better benchmarks, as we can

compare the integrated light parameters with ages derived from isochrone fitting and high-resolution metallicities obtained for resolved stars

Gonçalves et al. (2020, hereafter, G20) analysed integrated spectra of stellar clusters (Usher et al. 2017) using the spectral fitting code STARLIGHT (Cid Fernandes et al. 2005) and models by Vazdekis et al. (2015). The integrated light parameters reproduced the reference values from the literature reasonably well for high metallicity objects. However, for low-metallicity clusters, ages were significantly underestimated (see their Fig. 11), a phenomenon traditionally attributed to blue horizontal branch stars.

Here we replicate the analysis conducted by G20 using the SSP models provided by CBC20 (figure 1). The top panel, akin to Fig 11 in G20, still exhibits a notable age discrepancy. Yet, the results based on model stellar spectra (orange, with optimal coverage of the HR) are about 2 Gyr closer to the literature values than the ones based on an empirical library (blue, sparser coverage). Concerning metallicities (bottom panel), those obtained from SSPs based on a theoretical library are, on average, closer to the literature values than those obtained from SSPs based on an empirical library ($\Delta[\text{Fe}/\text{H}] = 0.02$ vs. 0.20).

4. CONCLUSIONS

The conventional wisdom has held that SSPs based on model stellar spectra are valuable for systems with chemical patterns differing from the solar neighbourhood and very young systems, while models based on empirical stellar spectra should be favoured otherwise. However, the findings of CBC20 and those presented here paint a different picture: modern theoretical libraries not only compete with but, in some instances, outperform models based on empirical libraries (see as well Martins et al. 2019). Through the study of the integrated light of stellar clusters, we note that the coverage effect can explain up to 25% of the “blue-light excess” of metal-poor star clusters, thus mimicking the presence of blue horizontal branch stars. Additionally, model stars, on average, better reproduce iron abundances from literature. Further work is underway, including stellar clusters from the Magellanic Clouds (Asad, Coelho et al., in preparation).

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THE EARLY STAGES OF STELLAR CLUSTER FORMATION

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RESUMEN

La formación de los cúmulos estelares y los procesos que determinan su riqueza o densidad estelar son preguntas abiertas desde hace mucho tiempo, íntimamente relacionadas con la fragmentación de las nubes moleculares. Se presenta un resumen de las campañas observacionales llevadas a cabo en nuestro grupo con el objetivo de desentrañar qué propiedad, si es que alguna, controla el proceso de fragmentación de las partes más densas de las nubes moleculares, desde escalas de 0.2 pc a escalas de 1000 au. Se presenta una correlación tentativa entre el nivel de fragmentación y el cociente masa-flujo magnético, tal como han predicho numerosos trabajos teóricos y numéricos, además de una correlación fuerte con la densidad. Finalmente, se indican líneas de investigación futuras que involucran las nuevas generaciones de interferómetros como el next-generation Very Large Array.

ABSTRACT

How stellar clusters form and what determines their richness or stellar density are long-standing questions, intimately related to the fragmentation properties of molecular clouds. We present a summary of observational campaigns carried out by our group, aimed at disentangling which properties, if any, finally control the fragmentation process in the dense parts of molecular clouds, from 0.2 pc to 1000 au scales. We show a tentative correlation between the fragmentation level and the mass-to-magnetic flux ratio, as predicted by theoretical and numerical works, along with a strong correlation with density. Finally, we mention future research lines that involve the new generation of interferometers such as the next-generation Very Large Array.

Key Words: ISM: magnetic field — stars: formation — stars: stellar clusters

1. INTRODUCTION

The formation of stellar clusters is an essential and highly evolving topic in Astrophysics. Although this topic has a vital role in Galaxy evolution, the details on how this process takes place are still poorly constrained, in part because it involves a number of physical phenomena. It is widely accepted that stellar clusters form in dense, hierarchically structured and highly dynamic gas clouds (Fig. 1-top), where filamentary structures feed the dense massive cores, usually arranged in a hub-filament system (Fig. 1-bottom-left). As the cloud, and filaments within it, evolve, fragmentation takes place producing the seeds of the future nascent cluster (Fig. 1-bottom-mid), typically located at the hub or the deepest

potential well of the cloud (Fig. 1-bottom-right; e.g., Krause et al. 2020). Thus, the process of fragmentation of a molecular cloud is essential to understanding the formation of stellar clusters. This fragmentation process could be controlled by a number of factors such as the density and temperature structure, turbulence, initial angular momentum, stellar feedback, and magnetic fields (see references in Palau et al. 2021). Disentangling which of these factors, if any, dominates the fragmentation process is a big challenge from an observational point of view.

2. OBSERVATIONS OF THE DIFFERENT FACTORS INFLUENCING THE FRAGMENTATION LEVEL

In order to study the different factors influencing the fragmentation process, several observational campaigns were conducted from 2010 to 2020. The objects under study were selected to be massive dense cores (masses 100–1000 $M_{\odot}$, and sizes of 0.1–0.5 pc) with limited stellar feedback, which are supposed to be the cradles of the future stellar clusters. Two main samples were built for this purpose. To characterize their fragmentation level, we studied these samples using millimeter interferometers at subarcsecond angular resolution (yielding spatial resolutions of about 1000 au at 2 kpc). Regarding the

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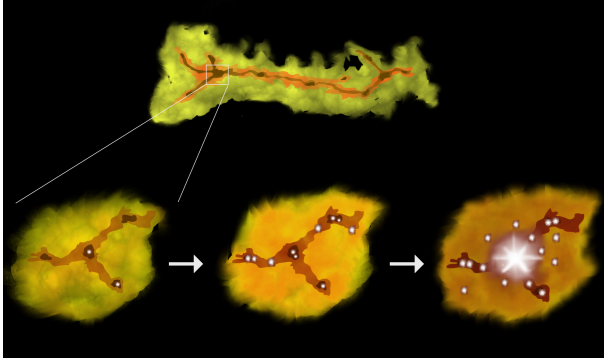


Fig. 1. Sketch describing how stellar clusters form (see main text in Sec. 1).

characterization of the massive dense cores, single-dish observations of millimeter/submillimeter continuum emission and line emission were performed. In addition, Very Large Array (VLA) NH_3 (1,1) observations were gathered for all the regions of the sample. A first sample with all these data is presented in Palau et al. (2013, 2014, 2015). From these works, a study of the fragmentation level, N_{mm} , vs. several parameters was performed. N_{mm} is estimated by counting the number of millimeter compact sources within the same field of view of 0.1 pc for all the regions. The top panels of Fig. 2 show the results for N_{mm} vs. the Mach number and N_{mm} vs. the rotational-to-gravitational energy ratio, β_{rot} . In these two cases, the Spearman's rank correlation coefficient ρ is around 0.4, and the p value is > 0.16 , indicating that there is no correlation.

The second sample was built by requiring that Submillimeter Array (SMA) polarization data were available (mainly from Zhang et al. 2014, and the SMA archive). The data were carefully analyzed in a uniform way and no correlation was found for N_{mm} vs. mass-to-magnetic flux ratio *unless* the velocity field was treated as the magnetic field, i.e., separating the large-scale component from the small-scale component by means of the two-point-correlation function. When doing this, the result of the bottom-left panel of Fig. 2 was found, revealing a tentative correlation ($\rho \sim 0.64$, and $p \sim 0.034$) consistent with numerical and theoretical works: the higher the mass-to-flux ratio, the higher the fragmentation level because the magnetic field is offering less support against gravity. It is important to stress that if the velocity field is not separated into a large-scale and a small-scale component, no correlation is found, consistent with the analysis performed in other works such as Beuther et al. (2023). Finally,

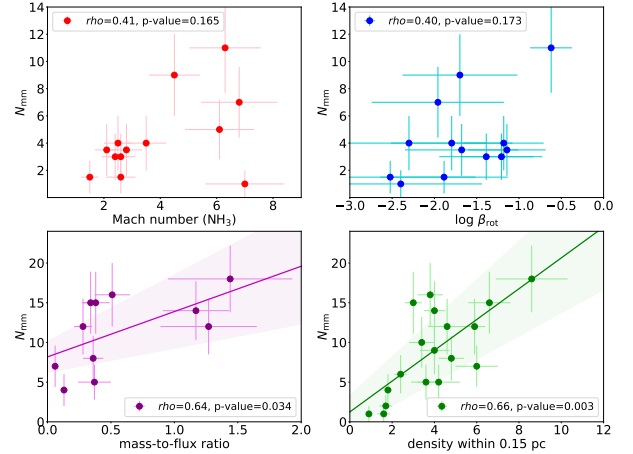


Fig. 2. Summary of correlations between the fragmentation level, N_{mm} , and several parameters of the parental structures (Palau et al. 2014, 2015, 2021).

the bottom-right panel of Fig. 2 shows a strong correlation ($\rho \sim 0.66$, and $p \sim 0.0035$) of N_{mm} with the density averaged within the common field of view of the second sample, of 0.15 pc. Again it is important to note that in order to recover such a strong correlation, the density needs to be calculated within the field of view where fragmentation is assessed, and that there is no strong correlation with the density *structure* or the density power-law index of the parental core as found also by Beuther et al. (2023).

In summary, when the samples are studied carefully in a uniform way, a tentative correlation of N_{mm} with the mass-to-flux ratio and a strong correlation with the density are revealed, suggesting that these factors could potentially be important in the fragmentation process. Future promising research lines focus on the chemical content of the cluster members, such as the detection rate of hot corinos in the nascent cluster and the possible dynamic link between the different cluster members. In this sense, the ngVLA will be of pivotal importance to image the details of the gas linking large-scale structures of the parental core with the compact sources of the cluster, allowing us to further understand this fascinating process of stellar cluster formation.

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TOWARDS A BETTER DETERMINATION OF STELLAR PARAMETERS IN THE PRE-MAIN SEQUENCE PHASE

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RESUMEN

Los sondeos masivos de espectroscopía proveen, por vez primera, muestras robustas de espectros de estrellas jóvenes, que podrían ayudarnos a entender el origen de las poblaciones actuales en el disco Galáctico, así como mejorar la precisión con la cual entendemos la fase de pre-secuencia principal de la evolución estelar.

ABSTRACT

Large scale spectroscopic surveys are providing, for the first time, robust samples of young stars spectra, which may allow us to understand the origin of current Galactic disk populations and to increase the precision with which we study the pre-main sequence stage of stellar evolution

Key Words: stars: pre-main sequence — stars: abundances — techniques: spectroscopic

In the last 10 years, large-scale multi-object fiber spectroscopic surveys (e.g. Gaia-ESO, GALAH, SDSS APOGEE-2), combined with Gaia parameters have allowed us to study the detailed properties of stellar populations. Young stars in our Galaxy allow us to understand the origin population of the galactic disk. Was it similar to what we currently find in nearby star-forming regions? More important: Can these databases help us to characterize the Pre-Main Sequence (PMS) stage of stellar evolution? How robust are the samples we need to allocate the precision to understand parameter variations in terms of complex physical processes like accretion, variability and others?

SDSS APOGEE spectrographs ($R \sim 22500$, $1.5 < \lambda < 1.7 \mu\text{m}$) provide radial velocities near 0.1 km/s precision, can penetrate through dusty regions, and allow to map relatively crowded population using multiple visit schemes. The SDSS Milky Way Mapper (MWM) survey now also includes BOSS $R \sim 3000$ $0.3 < \lambda < 0.9 \mu\text{m}$ optical observations, which improve spectral type classification and provide stronger accretion features. By SDSS DR17-18, a number of important star-forming regions and young cluster regions were explored, yielding a few thousand of YSO spectra Román-Zúñiga et al. (2023). The MWM will increase the sample by one order of magnitude in the next few years.

State of the art software makes use of powerful neural networks (Sprague et al. 2023) to determine the best sets of spectral parameters (T_{eff} , $\log g$, v_{rot} , v_R , $[\text{Fe}/\text{H}]$) using spectral label compilations.

While this approach is powerful, the direct comparison of spectra and synthetic models allows more precision, specially towards the determination of detailed chemical abundances and the characterization of effects like extinction and circumstellar veiling.

Our code TONALLI (Adame et al. 2024) uses the Asexual Genetic Algorithm of Cantó et al. (2009) to locate and interpolate the best possible model from a grid that provides a set of parameters from an APOGEE spectra. Our approach includes a machine learning routine to assign spectro-photometric priors from PMS evolutionary models, which reduces model dependencies, especially for $\log g$.

Our work with TONALLI is currently allowing us to determine chemical abundances in young stars of the solar neighborhood. Our calibration sample is composed of main sequence stars within 100 pc from the Sun (López-Valdivia et al. 2024). Our main goal is to be able to produce a catalog of chemical abundances in nearby (up to 2 kpc from the Sun) star-forming regions and understand how they deviate (or not) from Solar abundances.

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IMPACT OF EVOLUTIONARY STATUS ON COOL GIANT STELLAR ACTIVITY LEVELS

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Since the beginning of the past century, ideas regarding spectral features as indicators of stellar activity began to settle down, spurred by the UV emission taking place in the middle of Ca II H and K absorption lines observed in several stars, which resembles the behavior of magnetically disturbed solar regions (Eberhard & Schwarzschild 1913). Such a feature became standard chromospheric activity proxy after the introduction of the *S-index* in the dedicated long-term monitoring program at Mt. Wilson (Duncan et al. 1991), and its wide usage has made it possible to find activity prevalence all across the HR diagram i.e. in all stages of evolution. Of particular relevance is the central helium burning phase in intermediate-mass stars, as it serves as a relatively stable transitional stage between the Main Sequence and the Asymptotic Giant Branch, and hence as the ideal place to explore the demeanor of activity aiming to explain the decidedly heterogeneous set of observations of both MS and AGB groups.

In this work, the physical parameters of a sample composed of 28 late-type stars (spectral types G and K) were determined using recent parallaxes from Gaia DR3 together with analysis of the medium-resolution spectra (R approximately 21000) obtained in a dedicated observing program managed in the TIGRE, a robotic telescope in central Mexico (Schmitt et al. 2014).

Through comparisons with well-tested evolutionary tracks computed with the Eggleton code in its updated version (Pols et al. 1998), mass values and stages of evolution were also derived, which in turn were put into perspective together with measurements of the *S-index* indicator of chromospheric magnetic activity.

Four of the stars in the sample belong to the open cluster M41, so their coeval nature has made it possible to impose additional constraints to model their evolution, and thanks to this, the permanence of the activity exhibited during the relatively stable central helium-burning stage has been explored in good detail, whereas the non-cluster stars offer an insight into peripheral stages of evolution.

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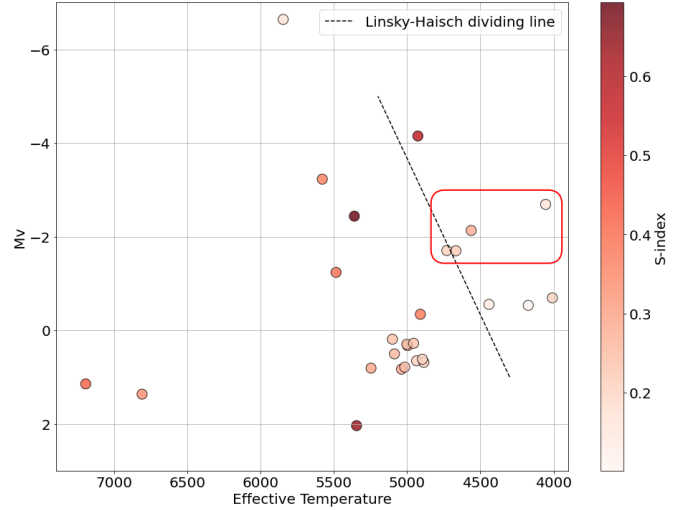


Fig. 1. The Linsky-Haisch Dividing Line location in the HR diagram alongside the stellar sample. M41 giants are framed in red.

Evidence points to a correlation between the state of evolutionary advancement within the horizontal branch and a sustained decline in activity, analogous to what has long been known to occur among cool main-sequence stars, and just as it was discovered to occur in the four Hyades K giants (Schröder et al. 2020). Moreover, the presented measurements mirror the behavior of more energetic activity tracers such as coronal X-ray emission depicted at both sides of the Linsky-Haisch dividing line (Fig. 1), remarking the key role of these particular late stages of evolution in activity development and progression.

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LITHIUM DEPLETION IN SOLAR ANALOGS: AGE, MASS AND PLANET EFFECTS

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The goal of this work is to evaluate the correlation between Li abundance, age, and mass. Our joint analysis of 151 solar-type stars confirms the strong Li abundance-age correlation reported by other works. Mass and convective mass also seem to be connected with Li abundance but with lower significance. We have found a link between the presence of planets and low Li abundances in a sample of 192 stars with a high significance.

Lithium (Li) is an important element for stellar astrophysics because it is destroyed at a temperature of 2.5×10^6 K, which is easily reached in the interior of stars. The base of the convective zone of main-sequence solar-type stars does not reach a temperature above $\sim 2 \times 10^6$ K. Thus, since the standard stellar model does not consider any mixing processes besides convection, the Li abundance of a single solar-type star should not change as the star evolves along the main sequence. However, these stars present a decay of Li abundance with stellar age (Carlos et al. 2019), indicating the existence of non-standard transport mechanisms. Many possible mechanisms were invoked, but there is still no model capable of explaining every characteristic regarding Li abundance.

Our sample consisted of 74 nearby solar twins and analogs (published in Rathsam et al. 2023) plus 79 solar twins from Carlos et al. (2019). The stars have solar metallicity (within ± 0.15 dex) and their mass ranges between 0.85 and 1.10 $M_{\odot}$.

We employed HARPS spectra ($R \simeq 115\,000$; $270 \leq \text{SNR} \leq 1000$) taken from ESO’s public database. To find the atmospheric parameters, we measured Fe lines via the line-by-line differential method and applied the spectroscopic equilibrium with the code q^2 (Ramírez et al. 2014). The masses and ages were found via a probability distribution from q^2 . The Li abundances were determined via spectral synthesis of the 6707.8 Å line with the code MOOG. Convective masses were found via interpolation based on theoretical values from Spada et al. (2017).

Our results show a strong trend of lower A(Li)

with larger age but with a much larger scatter than in the sample of solar twins from Carlos et al. (2019) (Fig. 2 in Rathsam et al. 2023). In particular, low-mass stars appear more Li-depleted. To evaluate the effect of age in A(Li) for solar twins, we selected stars with masses between 0.98 and 1.02 $M_{\odot}$ and performed an orthogonal distance regression. The resulting fit shows a strong correlation, with a significance of $14\text{-}\sigma$.

The stars in our sample show lower A(Li) for lower mass or higher convective mass, which is consistent with what is predicted since low-mass stars present deeper convective envelopes and are expected to burn more Li. To quantify the influence those parameters on A(Li), we fitted the residuals of the relation found for solar twins as a function of mass and (convective mass)/mass for our entire dataset. The results show that while age is still the most important parameter governing A(Li), mass and convective mass also play a role (with a significance of $2\text{-}\sigma$ for mass and $5\text{-}\sigma$ for conv. mass/mass).

Finally, to test whether planet-host stars are more Li-depleted (which could be related to the process of formation of planetary systems, Meléndez et al. 2009), we included in our sample the stars from Martos et al. (2023). Out of 192 stars, 36 had confirmed orbiting planets. We then compared the Li abundance of planet hosts with the average or median abundance of non-hosts “twin” stars and found that planet-hosts appear more Li depleted by ~ 0.2 dex, with a significance above 99% for our results (estimated via a t-test).

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