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# BETIS: Bidimensional Exploration of the warm-Temperature Ionized gas

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Understanding the relationship between stellar formation processes and the interstellar medium (ISM) is a key step in discerning the complexity of the evolutionary history of galaxies. A problem in this regard has been understanding the nature and importance of feedback processes in which massive stars deposit energy into the interstellar medium through photoionization, stellar winds, and supernovas. This feedback mechanism affects the physical and dynamic state of the ISM and, therefore, influences the rate and distribution of stellar formation in galaxies. In this context, the existence of a warm and ionized component of the ISM that is distributed ubiquitously in galaxy disks has been known for decades, both in our Galaxy and in extragalactic sources. This component is called Diffuse Ionized Gas (DIG).

In this work, we define a sample of 265 galaxies observed with the MUSE IFS instrument on the VLT-8.1m telescope to conduct a spectral study and spatial analysis of the DIG. We explore the distributions of low-ionization species [OIII], [OI], [NII], and [SII] in DIG regimes along the galactic planes and discern the different ionization mechanisms resulting in this gas. We create a methodology based on the generation of emission line maps from MUSE data cubes after synthesizing stellar populations for each spaxel. Additionally, we develop an adaptive binning method to increase the signal-to-noise ratio of weaker lines, such as [OIII], [OI], and [SII]. We test this methodology using a subset of the BETIS sample consisting of 7 different galaxies.

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# Is the oldest planetary nebula really a member of the open cluster M37?

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We have found very strong evidence that an extended bipolar planetary nebula (PN), lying in the line-of-sight of the Galactic open cluster M37, is actually its physical member-only the third such instance confirmed in the Galaxy. The rarity of such an association underlies the importance of its detailed study. This analysis, combined with our previous data of open cluster PNe, provides valuable independent data to the fundamental initial-to-final-mass relation that is vital for stellar evolution studies and for understanding the enrichment of both carbon and nitrogen in the Galaxy. We estimated the properties of the PN and its progenitor from Gaia DR3 cluster color-magnitude diagrams and Padova theoretical isochrone fitting. Among our remarkable results, we emphasize the following: we found the mass of the progenitor star to be around 2.8 $M_{\odot}$. The nebula is huge (having a major axis of 445 arcsec), which implies a kinematical age of around $80x10^3$ yrs- the oldest PN ever recorded- suggesting that PNe in clusters do not dissipate as fast as those in the field.

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## Investigating the potential of methanol as a shock tracer in the AGN-starburst galaxy NGC 1068 with UCLCHEM

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The behavior of methanol ($CH_3OH$) in the composite galaxy NGC 1068 was analyzed to investigate its effectiveness as an extragalactic shock tracer and to study the effect of shock velocity ($v_s$) and formation routes (gas and solid state mechanisms) on the predicted interstellar abundance of methanol. With a parameterized C-shock physical model, C-shock chemistry was investigated with `UCLCHEM` to study the chemical abundance of $CH_3OH$ as a function of time in different locations of the Circumnuclear Disc (CND) near the active galactic nuclei (AGN) and the starburst (SB) ring of NGC 1068. It is concluded that the gas-phase methanol can trace C-type shocks as its abundance increases significantly due to grain sputtering or sublimation during shock propagation. This increase in the abundance is consistent for both low ($\sim$ 10 km/s) and high ($\sim$ 45 km/s) velocity shocks. It is also shown that the main reaction leading to the formation of methanol in the grain is the radical-molecule H-atom abstraction route, which is in good agreement with Simons et al. (2020) and Santos et al. (2022). These modeling results will be contrasted with observed methanol abundance from Atacama Large Millimeter/submillimeter Array (ALMA) from Huang et al. (2023, submitted) and discussed with different parameters explored, such as gas temperature ($T_k$), density ($n_{H_2}$), and cosmic-ray ionization rate ($\zeta$) and their dependence on methanol formation under the studied conditions.

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## Chemical properties of the SMC Main Body traced by star clusters

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We derived radial velocities and Ca II Triplet (CaT) metallicity of more than 150 red giant stars in six SMC star clusters and their surrounding fields, with the instrument GMOS on GEMINI South. The mean cluster radial velocity and metallicity were obtained with mean errors of 2.2 km/s and 0.03 dex, respectively. We add this information to that available for another 51 clusters and 30 fields with CaT metallicities on the same scale. Using this expanded sample we analyze the chemical properties of the SMC Main Body. We found a high probability that the metallicity distribution of the Main Body clusters is bimodal with a metal-rich and a metal-poor cluster group. Metal-rich clusters present a clear age-metallicity relation, while metal-poor clusters present no chemical enrichment throughout the life of the galaxy. We present observational evidence that the chemical enrichment is complex in the SMC Main Body.

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# Astrochemical analysis of the nuclear environments of galaxies in the local universe

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Building upon previous research on the emission of polycyclic aromatic hydrocarbons (PAHs) in the mid-infrared (mid-IR), the present work studies a sample of 28 local galaxies (D $\leq$ 30Mpc) from the Spitzer Survey of Near-infrared Galaxies (SINGS). All objects show optical signatures of an active galaxy nucleus (AGN), and PAHs are also detected. The sample covers 28 nuclear regions, one for each galaxy. Molecules in each region were identified by fitting them with the NASA Ames PAH IR Spectroscopic Database (PAHdb). The molecules present were categorized into families based on their composition: PAH, amorphous (molecules that contain only carbon in their formula), nitrogen-bearing polycyclic aromatic hydrocarbons (N-PAHs), and Polycyclic Aromatic Hydrocarbons with heteroatom (any atom other than hydrogen, carbon, or nitrogen). With this categorization, it is easy to notice, in general, that PAHs and amorphous ones, such as C24, have the highest flux contribution in the studied regions. The C24 molecule has a remarkable contribution to the flux of some galaxies. When categorizing the molecules it is possible to notice that the percentage of PAH is predominant in most of the galaxies, while the amorphous ones predominate in the others. The percentages of N-PAH and heteroatom change little or nothing between the galaxies. The next goal is to determine what conditions are causing the different flux contributions of each family of molecules depending on the environment. In addition, laboratory studies using the C24 molecule and PAHs with 24 carbon atoms will be carried out using the techniques of time-of-flight mass spectrometry (TOF-MS) and infrared spectroscopy (FTIR), to verify the stability and the pathways of break-down of these species under radiation field.

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# Kinematics, Metallicities, and Ages of the Inner 2 Degrees of the Bulge of the Milky Way

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Ages and kinematics play a crucial role in Milky Way's Bulge studies, as they contain valuable information about its formation history. Photometric studies have concluded that most bulge stars are around 10 Gyrs old. On the other hand, high-resolution spectroscopy of microlensed bulge stars suggests that 2/3 of super-solar metallicity stars are younger than ~6 Gyrs. We will use deep observations from HST and VLT/MUSE, in the low extinction SWEEPS window, to measure, for the first time, spectroscopic metallicities for turnoff stars. This will allow us to obtain a clean turnoff for each of the two main metallicity components (sub-solar and super-solar) and derive their relative age. Note that we will decontaminate from disk foreground stars as the proper motions from HST are available. Shallower VLT/MUSE data in the inner bulge (b<2°) will be used to derive the radial velocity distribution, and then the 3D velocities, by cross-match with the proper motion from VVV available to our group. This will allow us to fully characterize the velocity dispersion peak reported by a few authors in the bulge innermost region. The analysis of the 3D velocity will allow us to establish whether the detected radial velocity peak is due to anisotropies, or to a genuine larger velocity dispersion, thus related to a larger concentration of mass. Our results will provide crucial data to constrain dynamical models of the Milky Way central region.

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# VISCACHA Survey: the SMC Southern Bridge in 8D

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The Magellanic Bridge is a stream of gas and stars connecting the Magellanic Clouds, formed by tidal forces as a consequence of a close encounter between the SMC and LMC $\sim$ 200 Myr ago. We performed a 6D phase−space vector, plus age and metallicity, analysis of star clusters in the Southern Bridge. We derived distances, ages, metallicities and velocities from the VISCACHA Survey photometric data and its Gemini/GMOS spectroscopic follow-up, also adopting proper motions from the GAIA Survey. We found that Southern Bridge clusters are moving towards the LMC and share the kinematics of the Northern Bridge. Also, we reinforced the idea that the two Bridge branches have not experienced the same chemical evolution.

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# Revealing dense gas kinematics in the G012.80 protocluster

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We study the dense $N_2H^+$ (1-0) gas in the nearby (2.4 kpc) and massive ($4.6 \times 10^3\ M_\odot$) protocluster G012.80 observed as part of the ALMA-IMF large program. We combined our analysis with additional ALMA-IMF tracers such as H41$\alpha$, SiO, $C^{18}O$ and dense core catalogs. We modeled the full $N_2H^+$ emission and constructed intensity-weighted position-velocity (PV) diagrams in the full region. Here, we find that $\sim 30\%$ of the spectra have 2 velocity components (peaks separated by 2.1 km s$^{-1}$), and the remainder are well-fit by a single component. In PV diagrams, we observe zig-zag and twisting velocity structures pervasively in the dense gas traced by our $N_2H^+$ observations. We do not detect $N_2H^+$ emission in the center of G012, where the H41$\alpha$ and continuum emission are concentrated, likely due to radiative feedback effects arising from massive star formation. We calculated velocity gradients in two subregions in G012 (R1 & R2) that present different features in PV diagrams. R1 is associated with a potential filament rotation signature and is dominated by the first velocity component. In contrast, R2 is associated with core accretion features in PV diagrams and is dominated for both velocity components (first and second). We obtained corresponding timescales for R1 & R2 of 0.07 Myr (equivalent velocity gradient 15.3 km s$^{-1}$ pc$^{-1}$) and 0.11 Myr (8.8 km s$^{-1}$ pc$^{-1}$) respectively. The next steps involve analysis of column density by optical depth estimations and mass profiles in both sub-regions, especially in R2 where the current N($H_2$) data is well detected.

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# IGRINS Chemical Tagging of Stars in Streams to Progenitors: Fimbulthul

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We propose near-infrared (near-IR) high-resolution spectroscopic follow-up of selected stellar streams to perform a detailed elemental abundance analysis. The stream candidates were identified over the whole sky, and a few selected stars have previously been observed during observations from IGRINS/Gemini. Using near-IR spectra we aim to perform the first Chemical Tagging of potential stream stars, linking them to their progenitor streams. The new spectral data will allow us to confirm or discard the possible association of these streams with known globular clusters, and provide additional information for a set of chemical species (C, N, O, Mg, Al, Si, Ti, Ni, Cu, Co, Ce, Nd, Yb, among others) accessible from the H-band. We will also examine the presence or absence of the multiple-population phenomenon in the selected streams, and its relation with globular clusters, and strongly constrain the dynamical history for both stars observed with IGRINS and their progenitors.

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