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THE MASSIVE STAR NEWSLETTER

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Accepted Papers

A Pulsational Mechanism for Producing Keplerian Disks around Be Stars

Steven R. Cranmer[1]

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Classical Be stars are an enigmatic subclass of rapidly rotating hot stars characterized by dense equatorial disks of gas that have been inferred to orbit with Keplerian velocities. Although these disks seem to be ejected from the star and not accreted, there is substantial observational evidence to show that the stars rotate more slowly than required for centrifugally driven mass loss. This paper develops an idea (proposed originally by Hiroyasu Ando and colleagues) that nonradial stellar pulsations inject enough angular momentum into the upper atmosphere to spin up a Keplerian disk. The pulsations themselves are evanescent in the stellar photosphere, but they may be unstable to the generation of resonant oscillations at the acoustic cutoff frequency. A detailed theory of the conversion from pulsations to resonant waves does not yet exist for realistic hot-star atmospheres, so the current models depend on a parameterized approximation for the efficiency of wave excitation. Once resonant waves have been formed, however, they grow in amplitude with increasing height, steepen into shocks, and exert radial and azimuthal Reynolds stresses on the mean fluid. Using reasonable assumptions for the stellar parameters, these processes were found to naturally create the inner boundary conditions

required for dense Keplerian disks, even when the underlying B-star photosphere is rotating as slowly as 60 percent of its critical rotation speed. Because there is evidence for long-term changes in Be-star pulsational properties, this model may also account for the long-term variability of Be stars, including transitions between normal, Be, and shell phases.

Reference: ApJ, 701, in press (August 20, 2009).

On the web at: `http://arxiv.org/abs/0906.2772`

Preprints from: `scranmer@cfa.harvard.edu`

Red Supergiants in the Andromeda Galaxy (M31)

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Red supergiants (RSGs) are a short-lived stage in the evolution of moderately massive stars (10-25$M_\odot$), and as such their location in the H-R diagram provides an exacting test of stellar evolutionary models. Since massive star evolution is strongly affected by the amount of mass-loss a star suffers, and since the mass-loss rates depend upon metallicity, it is highly desirable to study the physical properties of these stars in galaxies of various metallicities. Here we identify a sample of red supergiants in M31, the most metal-rich of the Local Group galaxies. We determine the physical properties of these stars using both moderate resolution spectroscopy and broad-band $V - K$ photometry. We find that on average the RSGs in our sample are variable in V by 0.5 mag, smaller but comparable to the 0.9 mag found for Magellanic Cloud (MC) RSGs. No such variability is seen at K, also in accord with what we know of Galactic and MC RSGs. We find that there is a saturation effect in the model TiO band strengths with metallicities higher than solar. The physical properties we derive for the RSGs from our analysis with stellar atmosphere models agree well with the current evolutionary tracks, a truly remarkable achievement given the complex physics involved in each. We do not confirm an earlier result that the upper luminosities of RSGs depend upon metallicity; instead, the most luminous RSGs have $\log L/L_\odot$ ~5.2-5.3. We find that, on average, the RSGs are considerably more reddened than O and B stars, suggesting that circumstellar dust is adding a significant amount of extra extinction, ~0.5 mag, on average. This is in accord with our earlier findings on Milky Way and Magellanic Cloud stars. Finally, we call attention to a peculiar star whose spectrum appears to be heavily veiled, possibly due to scattering by an expanding dust shell.

Reference: ApJ, in press

On the web at: `http://arxiv.org/abs/0907.3767`

Preprints from: `phil.massey@lowell.edu`

Variability of Be Stars in Southern Open Clusters

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We recently discovered a large number of highly active Be stars in the open cluster NGC 3766, making it an excellent location to study the formation mechanism of Be star disks. To explore whether similar disk appearances and/or disappearances are common among the Be stars in other open clusters, we present here multiple epochs of H-alpha spectroscopy for 296 stars in eight open clusters. We identify 12 new transient Be stars and confirm 17 additional Be stars with relatively stable disks. By comparing the H-alpha equivalent widths to the photometric y–H-alpha colors, we present a method to estimate the strength of the H-alpha emission when spectroscopy is not available. For a subset of 128 stars in four open clusters, we also use blue optical spectroscopy and available Stromgren photometry to measure their projected rotational velocities, effective temperatures, and polar surface gravities. We combine our Be star detections from these four clusters to investigate physical differences between the transient Be stars, stable Be stars, and normal B-type stars with no line emission. Both types of Be stars are faster rotating populations than normal B-type stars, and we find no significant physical differences between the transient and stable Be stars in our sample.

Reference: McSwain et al. 2009, ApJ, 700, 1216

On the web at: `http://arxiv.org/abs/0905.0640`

Preprints from: `mcswain@lehigh.edu`

The Correlation between X-Ray Line Ionization and Optical Spectral Types of the OB Stars

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Marked correlations are reported between the ionization of the X-ray line spectra of normal OB stars, as observed by the Chandra X-Ray Observatory, and their optical spectral types. These correlations include the progressive weakening of the higher ionization relative to the lower ionization X-ray lines with advancing spectral type, and the similarly decreasing intensity ratios of the H-like to He-like lines of the alpha ions. These relationships were not predicted by models, nor have they been clearly evident in astrophysical studies of a few objects; rather, they have emerged from morphological analysis of an adequate (albeit still small) sample, from which known peculiar objects such as magnetic stars and very rapid rotators have been isolated to reveal the normal trends. This process is analogous to that which first demonstrated the strong relationships between the UV wind profiles and the optical spectral types of normal OB stars, which likely bear a physical as well as a historical connection to the present X-ray results. Since the optical spectral types are calibrated in terms of fundamental stellar parameters, it follows that the winds and X-ray spectra are determined by the latter. These observations provide strong guidance for further astrophysical modeling of these phenomena.

Reference: ApJ, in press

On the web at: `http://arxiv.org/abs/0907.4738`

Preprints from: `walborn@stsci.edu`

Spitzer SAGE Infrared Photometry of Massive Stars in the Large Magellanic Cloud

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We present a catalog of 1750 massive stars in the Large Magellanic Cloud, with accurate spectral types compiled from the literature, and a photometric catalog for a subset of 1268 of these stars, with the goal of exploring their infrared properties. The photometric catalog consists of stars with infrared counterparts in the Spitzer SAGE survey database, for which we present uniform photometry from 0.3-24 microns in the UBVIJHKs+IRAC+MIPS24 bands. The resulting infrared color-magnitude diagrams illustrate that the supergiant B[e], red supergiant and luminous blue variable (LBV) stars are among the brightest infrared point sources in the Large Magellanic Cloud, due to their instrinsic brightness, and at longer wavelengths, due to dust. We detect infrared excesses due to free-free emission among ∼900 OB stars, which correlate with luminosity class. We confirm the presence of dust around 10 supergiant B[e] stars, finding the shape of their spectral energy distributions (SEDs) to be very similar, in contrast to the variety of SED shapes among the spectrally variable LBVs. The similar luminosities of B[e] supergiants ($\log L/L_{\odot} \geq 4$) and the rare, dusty progenitors of the new class of optical transients (e.g. SN 2008S and NGC 300 OT), plus the fact that dust is present in both types of objects, suggests a common origin for them. We find the infrared colors for Wolf-Rayet stars to be independent of spectral type and their SEDs to be flatter than what models predict. The results of this study provide the first comprehensive roadmap for interpreting luminous, massive, resolved stellar populations in nearby galaxies at infrared wavelengths.

Reference: The Astronomical Journal

On the web at: `http://arxiv.org/abs/0905.1328v2`

Preprints from: `bonanos@stsci.edu`

Yellow Supergiants in the Andromeda Galaxy (M31)

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The yellow supergiant content of nearby galaxies can provide a critical test of stellar evolution theory, bridging the gap between the hot, massive stars and the cool red supergiants. But, this region of the color-magnitude diagram is dominated by foreground contamination, requiring membership to

somehow be determined. Fortunately, the large negative systemic velocity of M31, coupled to its high rotation rate, provides the means for separating the contaminating foreground dwarfs from the it bona fide yellow supergiants within M31. We obtained radial velocities of about 2900 individual targets within the correct color magnitude range corresponding to masses of 12Mo and higher. A comparison of these velocities to thoseexpected from M31's rotation curve reveals 54 rank 1 (near certain) and 66 rank 2 (probable) yellow supergiant members, indicating a foreground contamination $\geq 96\%$. We expect some modest contamination from Milky Way halo giants among the remainder, particularly for the rank 2 candidates, and indeed follow-up spectroscopy of a small sample eliminates 4 rank 2's while confirming 5 others. We find excellent agreement between the location of yellow supergiants in the H-R diagram and that predicted by the latest Geneva evolutionary tracks which include rotation. However, the relative number of yellow supergiants seen as a function of mass varies from that predicted by the models by a factor of > 10, in the sense that more high mass yellow supergiants are predicted than are actually observed. Comparing the total number (16) of $>$ 20Mo yellow supergiants with the estimated number (24,800) of unevolved O stars indicates that the duration of the yellow supergiant phase is about 3000 years. This is consistent with what the 12Mo and 15Mo evolutionary tracks predict, but disagrees with the 20,000-80,000 year time scales predicted by the models for higher masses.

Reference: ApJ, in press

On the web at: `http://arxiv.org/abs/0907.5471`

Preprints from: `phil.massey@lowell.edu`

Hot stars observed by XMM-Newton I. The catalog and the properties of OB stars

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Aims : Following the advent of increasingly sensitive X-ray observatories, deep observations of early-type stars became possible. However, the results for only a few objects or clusters have until now been reported and there has been no large survey comparable to that based upon the ROSAT All-Sky Survey (RASS). Methods : A limited survey of X-ray sources, consisting of all public XMM observations (2XMMi) and slew survey data (XMMSL1), is now available. The X-ray counterparts to hot, massive stars have been searched for in these catalogs. Results : About 300 OB stars were detected with XMM. Half of them were bright enough for a spectral analysis to be possible, and we make available the detailed spectral properties that were derived. The X-ray spectra of O stars are represented well by low (<1keV) temperature components and seem to indicate that an absorption column is present in addition to the interstellar contribution. The X-ray fluxes are well correlated with the bolometric fluxes, with a scatter comparable to that of the RASS studies and thus larger than found previously with XMM for some individual clusters. These results contrast with those of B stars that exhibit a large scatter in the $L_X - L_{\rm BOL}$ relation, no additional absorption being found, and the fits indicate a plasma at higher temperatures. Variability (either within one exposure or between multiple exposures) was also investigated whenever possible: short-term variations are far more rare than long-term ones (the former affects a few percent of the sample, while the latter concerns between one third and two thirds of the sources). Conclusions : This paper presents the results of the first high-sensitivity investigation of the overall high-energy properties of a sizable sample of hot stars.

Reference: accepted by A&A

On the web at: `http://arxiv.org/abs/0908.1461`

Preprints from: `naze@astro.ulg.ac.be`

3D models of radiatively driven colliding winds in massive O+O star binaries - II. Thermal radio to sub-mm emission

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In this work the thermal emission over cm to sub-mm wavelengths from the winds in short-period O+O-star binaries is investigated (potential non-thermal emission is presently ignored). The calculations are based on three-dimensional hydrodynamical models which incorporate gravity, the driving of the winds, orbital motion of the stars, and radiative cooling of the shocked plasma. The thermal emission arises from the stellar winds and the region where they collide. We investigate the flux and spectrum from a variety of models as a function of orbital phase and orientation of the observer, and compare to the single star case. The emission from the wind-wind collision region (WCR) is strongly dependent on its density and temperature, being optically thick in radiative systems, and optically thin in adiabatic systems. The flux from systems where the WCR is highly radiative, as investigated for the first time in this work, can be over an order of magnitude greater than the combined flux from identically typed single stars. This excess occurs over a broad range of wavelengths from cm to sub-mm. In contrast, when the WCR is largely adiabatic, a significant excess in the thermal flux occurs only below 100 GHz. Eccentric systems may show order of magnitude or greater flux variability, especially if the plasma in the WCR transitions from an adiabatic to a radiative state and vice-versa - in such cases the flux can display significant hysteresis with stellar separation. We further demonstrate that clumping can affect the variability of radio lightcurves. We investigate the spectral index of the emission, and often find indices steeper than +0.6. Our predictions are of interest to future observations with the next generation of radio and sub-mm telescopes (abridged).

Reference: Accepted for publication in MNRAS

On the web at: `http://arxiv.org/abs/0908.1003`

Preprints from: `jmp@ast.leeds.ac.uk`

New magnetic field measurements of β Cephei stars and Slowly Pulsating B stars

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We present the results of the continuation of our magnetic survey with FORS1 at the VLT of a sample of B-type stars consisting of confirmed or candidate β Cephei stars and Slowly Pulsating B (hereafter

SPB) stars, along with a small number of normal B-type stars. A weak mean longitudinal magnetic field of the order of a few hundred Gauss was detected in three β Cephei stars and two stars suspected to be β Cephei stars, in five SPB stars and eight stars suspected to be SPB stars. Additionally, a longitudinal magnetic field at a level larger than 3σ has been diagnosed in two normal B-type stars, the nitrogen-rich early B-type star HD52089 and in the B5 IV star HD153716. Roughly one third of β Cephei stars have detected magnetic fields: Out of 13 β Cephei stars studied to date with FORS1, four stars possess weak magnetic fields, and out of the sample of six suspected β Cephei stars two show a weak magnetic field. The fraction of magnetic SPBs and candidate SPBs is found to be higher: roughly half of the 34 SPB stars have been found to be magnetic and among the 16 candidate SPBs eight stars possess magnetic fields. In an attempt to understand why only a fraction of pulsating stars exhibit magnetic fields, we studied the position of magnetic and non-magnetic pulsating stars in the H-R diagram. We find that their domains in the H-R diagram largely overlap, and no clear picture emerges as to the possible evolution of the magnetic field across the main sequence. It is possible that stronger fields tend to be found in stars with lower pulsating frequencies and smaller pulsating amplitudes. A somewhat similar trend is found if we consider a correlation between the field strength and the vsini-values, i.e. stronger magnetic fields tend to be found in more slowly rotating stars.

Reference: Astronomische Nachrichten 330, 317-329

On the web at: `http://arxiv.org/abs/0902.1314`

Preprints from: `mschoell@eso.org`

Magnetic survey of emission line B-type stars with FORS1 at the VLT

S. Hubrig[1], M. Schöller[2], I. Savanov[3], R.V. Yudin[4], M.A. Pogodin[4], St. v Stefl[5], Th. Rivinius[5], and M. Curé[6]

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We report the results of our search for magnetic fields in a sample of 16 field Be stars, the binary emission-line B-type star υ Sgr, and in a sample of fourteen members of the open young cluster NGC3766 in the Carina spiral arm. The sample of cluster members includes Be stars, normal B-type stars and He-strong/He-weak stars. Nine Be stars have been studied with magnetic field time series obtained over ∼1 hour to get an insight into the temporal behaviour and the correlation of magnetic field properties with dynamical phenomena taking place in Be star atmospheres. The spectropolarimetric data were obtained at the European Southern Observatory with the multi-mode instrument FORS1 installed at the 8 m Kueyen telescope. We detect weak photospheric magnetic fields in four field Be stars, HD62367, μ Cen, o Aqr, and ϵ Tuc. The strongest longitudinal magnetic field, $< B_z >= 117 \pm 38G$, was detected in the Be star HD62367. Among the Be stars studied with time series, one Be star, λ Eri, displays cyclic variability of the magnetic field with a period of 21.12min. The binary star υ Sgr, in the initial rapid phase of mass exchange between the two components with strong emission

lines in the visible spectrum, is a magnetic variable star, probably on a timescale of a few months. The maximum longitudinal magnetic field $< B_z >= -102 \pm 10G$ at MJD 54333.018 was measured using hydrogen lines. The cluster NGC3766 seems to be extremely interesting, where we find evidence for the presence of a magnetic field in seven early B-type stars out of the observed fourteen cluster members.

Reference: Astronomische Nachrichten 330, 708-716

On the web at: http://arxiv.org/abs/0907.0882

Preprints from: mschoell@eso.org

The evolution of massive and very massive stars in clusters

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The present paper reviews massive star (initial mass $\leq$ 120 Mo) and very massive star (initial mass $>$ 120 Mo) evolution. I will focus on evolutionary facts and questions that may critically affect predictions of population and spectral synthesis of starburst regions. We discuss

a. the effects of ever-lasting factor 2 or more uncertainty in the stellar wind mass loss rates;

b. the effects of rotation;

c. the effects of binaries;

d. the effects of stellar dynamics in dense cluster cores on the formation and evolution of very massive stars.

Reference: New Astronomy Reviews 53 (2009), 27

Preprints from: dvbevere@vub.ac.be

The interactions of winds from massive young stellar objects: X-ray emission, dynamics, and cavity evolution

Parkin, E. R.[1]; Pittard, J. M.[1]; Hoare, M. G.[1]; Wright, N. J.[2]; Drake, J. J.[2]

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2D axis-symmetric hydrodynamical simulations are presented which explore the interaction of stellar and disk winds with surrounding infalling cloud material. The star, and its accompanying disk, blow winds inside a cavity cleared out by an earlier jet. The collision of the winds with their surroundings generates shock heated plasma which reaches temperatures up to $\sim 10^8$ K. Attenuated X-ray spectra are calculated from solving the equation of radiative transfer along lines-of-sight. This process is repeated at various epochs throughout the simulations to examine the evolution of the intrinsic and attenuated flux. We find that the dynamic nature of the wind-cavity interaction fuels intrinsic variability in the observed emission on timescales of several hundred years. This is principally due to variations in the position of the reverse shock which is influenced by changes in the shape of the cavity wall. The collision of the winds with the cavity wall can cause clumps of cloud material to be stripped away. Mixing of these clumps into the winds mass-loads the flow and enhances the X-ray emission measure. The position and shape of the reverse shock plays a key role in determining the strength and hardness of the X-ray emission. In some models the reverse shock is oblique to much of the stellar and disk outflows, whereas in others it is closely normal over a wide range of polar angles. For reasonable stellar and disk wind parameters the integrated count rate and spatial extent of the intensity peak for X-ray emission agree with *Chandra* observations of the deeply embedded MYSOs S106 IRS4, Mon R2 IRS3 A, and AFGL 2591.(abridged)

Reference: Accepted for publication in MNRAS
Comments: 19 pages, 14 figures

On the web at: `http://adsabs.harvard.edu/abs/2009arXiv0908.0468P`

Preprints from: `phy1erp@leeds.ac.uk`

Spectral synthesis including massive binaries

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1-University of Cambridge, UK; 2-University of Bristol, UK.

We have constructed a new code to produce synthetic spectra of stellar populations that includes massive binaries. We have tested this code against the broadband colours of unresolved young massive stellar clusters in nearby galaxies, the equivalent widths of the Red and Blue Wolf-Rayet bumps in star-forming SDSS galaxies and the UV and optical spectra of the star forming regions Tol-A and B in NGC5398. In each case we find a good agreement between our models and observations. We find that in general binary populations are bluer and have fewer red supergiants, and thus significantly less flux in the I-band and at longer wavelengths, than single star populations. Also we find that Wolf-Rayet stars occur over a wider range of ages up to 10 Myrs in a stellar population including binaries, increasing the UV flux and Wolf-Rayet spectral features at later times. In addition we find that nebula emission contributes significantly to these observed properties and must be considered when comparing stellar models with observations of unresolved stellar populations. We conclude that incorporation of massive stellar binaries can improve the agreement between observations and synthetic spectral synthesis codes, particularly for systems with young stellar populations.

Reference: Accepted for publication in MNRAS
Comments: 12 pages, 8 figures

On the web at: `http://adsabs.harvard.edu/abs/2009arXiv0908.1386E`

Preprints from: `jje@ast.cam.ac.uk`

Proceedings

Radiation Hydrodynamics of Line-Driven Winds

Stan Owocki

Bartol Research Institute Department of Physics & Astronomy University of Delaware

Dimtri Mihalas' textbooks in the 70's and 80's on "Stellar Atmospheres" and "Foundations of Radiation Hydrodynamics" helped lay the early groundwork for understanding the moving atmospheres and winds of massive, luminous stars. Indeed, the central role of the momentum of stellar radiation in driving the mass outflow makes such massive-star winds key prototypes for radiation hydodynamical processes. This paper reviews the dynamics of such radiative driving, building first upon the standard CAK model, and then discussing subtleties associated with the development and saturation of instabilities, and wind initiation near the sonic point base. An overall goal is to illuminate the rich physics of radiative driving and the challenges that lie ahead in developing dynamical models that can explain the broad scalings of mass loss rate and flow speed with stellar properties, as well as the often complex structure and variability observed in massive-star outflows.

Reference: to appear in "Recent Directions in Astrophysical Quantitative Spectroscopy and Radiation Hydrodynamics", proceedings of conference to honor 70th Birthday of D. Mihalas, AIP

Comments: astro-ph > arXiv:0908.1565

On the web at:
`http://www.bartol.udel.edu/∼owocki/preprints/RadWinds-Mihalas70th-Mar09.pdf`

Preprints from: `owocki@bartol.udel.edu`

Jobs

NOVA PhD position on The formation and early evolution of the most massive stars

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The mechanism by which the most massive stars form is poorly understood. Even though they are the most luminous objects in the Galaxy, their formation process and early evolution are obscured from view due to the tens to hundreds of magnitudes of (visual) extinction. Near-infrared imaging and spectroscopic surveys of high-mass star-forming regions reveal an amazingly complex interplay between the star formation process and the environment. K-band spectroscopy has resulted in the identification of young OB-type stars deeply embedded in (ultra-)compact H II regions, some of them still surrounded by a remnant accretion disk.

The key questions are: How are the most massive stars formed? What are the physical properties of the newly formed stars (photospheric parameters, rotational characteristics, radiation-driven wind, remnant accretion disks, binarity)? What is causing the lifetime problem (100x more UCHIIs than predicted by the current star formation rate)? Is the observed large range in spectral/photometric properties due to just a difference in mass (thus timescale), and/or does the environment play an important role?

Our strategy will be to extend the covered wavelength range of the many candidate young massive stars in our large survey down from the near-infrared into the optical (red) domain, thereby directly probing the stellar photosphere and wind. Optical/nIR spectra will be obtained within the VLT/X-shooter GTO program. With VLT/CRIRES the CO bandhead emission will be studied at high spectral resolution, allowing detailed modeling of the remnant accretion disk around the massive YSOs. A study of several star-forming regions has been carried out with VLT/SINFONI and Spitzer, to obtain a full census of their stellar content, ionized material, and outflows. One of the goals of the project is to relate the found results to observations obtained at longer wavelengths (e.g. VLA, ALMA) that likely probe an even earlier phase in the star formation process. Reduction, analysis, and interpretation of the obtained data, including the collection of new data, will form a major part of the project that should lead to a PhD at the University of Amsterdam. The position is offered for a period of 4 years and should be taken up in the Fall of 2009. The salary will be on the standard Dutch university scale.

Interested candidates should have a Master degree in astronomy or physics (or the equivalent). Applications should contain a curriculum vitae, a statement of research experience and interest, and the names of two references.

Attention/Comments: prof.dr. Lex Kaper

Email contact: `L.Kaper@uva.nl`

Closing date: September 7, 2009