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Editors: Jacco van Loon, Ambra Nanni and Albert Zijlstra

Editorial

Dear Colleagues,

It is our pleasure to present you the 216$^{\rm th}$ issue of the AGB Newsletter. There are some interesting new results based on radio observations, and results related to stellar explosions, as well as dust production and lots more. To get an update on planetary nebula research why not read the review at the end of the newsletter?

After a good special meeting on AGB stars at the European Week of Astronomy and Space Science (attended by over 1100 people – ok, not all attending the AGB sessions) in Tenerife last week, we are looking forward to the "STEPS" meeting on stellar end products, in Garching next week.

The next issue is planned to be distributed around the 1$^{\rm st}$ of August, just before the IAU general Assembly.

Editorially Yours,
Jacco van Loon, Ambra Nanni and Albert Zijlstra

Food for Thought

This month's thought-provoking statement is:

What has asteroseismology taught us about AGB stars?

Reactions to this statement or suggestions for next month's statement can be e-mailed to astro.agbnews@keele.ac.uk (please state whether you wish to remain anonymous)

Refereed Journal Papers

The composition of a disrupted extrasolar planetesimal at SDSS J0845+2257 (Ton 345)

David J. Wilson[1], *Boris T. Gänsicke*[1], *Detlev Koester*[2], *Odette Toloza*[1], *Anna F. Pala*[1], *Elmé Breedt*[1] *and Steven G. Parsons*[3]

[1]Department of Physics, University of Warwick, Coventry CV4 7AL, UK

[2]Institut für Theoretische Physik und Astrophysik, University of Kiel, 24098 Kiel, Germany

[3]Departamento de Física y Astronomía, Universidad de Valparaíso, Avenida Gran Bretaña 1111, Valparaíso 2360102, Chile

We present a detailed study of the metal-polluted DB white dwarf SDSS J0845+2257 (Ton 345). Using high-resolution HST/COS and VLT spectroscopy, we have detected hydrogen and eleven metals in the atmosphere of the white dwarf. The origin of these metals is almost certainly the circumstellar disc of dusty and gaseous debris from a tidally-disrupted planetesimal, accreting at a rate of 1.6×10^{10} g s^{-1}. Studying the chemical abundances of the accreted material demonstrates that the planetesimal had a composition similar to the Earth, dominated by rocky silicates and metallic iron, with a low water content. The mass of metals within the convection zone of the white dwarf corresponds to an asteroid of at least $\sim$ 130–170 km in diameter, although the presence of ongoing accretion from the debris disc implies that the planetesimal was probably larger than this. While a previous abundance study of the accreted material has shown an anomalously high mass fraction of carbon (15 per cent) compared to the bulk Earth, our independent analysis results in a carbon abundance of just 2.5 per cent. Enhanced abundances of core material (Fe, Ni) suggest that the accreted object may have lost a portion of its mantle, possibly due to stellar wind stripping in the asymptotic giant branch. Time-series spectroscopy reveals variable emission from the orbiting gaseous disc, demonstrating that the evolved planetary system at SDSS J0845+2257 is dynamically active.

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An updated Wing TiO sensitive index for classification of M-type stars

Fatemeh Azizi[1] *and Mohammad Taghi Mirtorabi*[1]

[1]Department of Physics, Alzahra University, 1993891176, Tehran, Iran

By careful searching of synthetic and observed spectra in a sample of cool giant and supergiant stars, we have updated the continuum band-passes of near-infrared Wing three filter system. This photometric system measures the strength of Titanium Oxide (TiO) absorption in Near-Infrared (NIR) at 719 nm. We show that new reference continuum band-passes are essentially free from molecular absorptions and the updated TiO-index defines the temperature variation in a sample of cool giants with less scatter. A TiO-index vs. effective temperature calibration is derived based on new continuum band-passes.

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Available from arXiv:1505.04332
and from http://adsabs.harvard.edu/abs/2015Ap&SS.357...96A

Initial–final mass relation for 3 to 4 $M_\odot$ progenitors of white dwarfs from the single cluster NGC 2099

Jeffrey D. Cummings[1], *Jason S. Kalirai*[2,1], *P.-E. Tremblay*[2] *and Enrico Ramirez-Ruiz*[3]

[1]Center for Astrophysical Sciences, Johns Hopkins University, USA

[2]Space Telescope Science Institute, USA

[3]Department of Astronomy and Astrophysics, University of California, USA

We have expanded the sample of observed white dwarfs in the rich open cluster NGC 2099 (M 37) with the Keck Low-Resolution Imaging Spectrometer. Of 20 white dwarf candidates, the spectroscopy shows 19 to be true white dwarfs with 14 of these having high S/N. We find 11 of these 14 to be consistent with singly evolved cluster members. They span a mass range of $\sim$ 0.7 to 0.95 $M_\odot$, excluding a low-mass outlier, corresponding to progenitor masses of $\sim$ 3 to 4 $M_\odot$. This region of the initial–final mass relation (IFMR) has large scatter and a slope that remains to be precisely determined. With this large sample of white dwarfs that belong to a single age and metallicity population, we find an initial–final mass relation of $M_{\rm final} = (0.171 \pm 0.057) M_{\rm initial} + 0.219 \pm 0.187$ $M_\odot$, significantly steeper than the linear relation adopted over the full observed white dwarf mass range in many previous studies. Comparison of this new relation from the solar metallicity NGC 2099 to 18 white dwarfs in the metal-rich Hyades and Præsepe shows that their IFMR also has a consistently steep slope. This strong consistency also suggests that there is no significant metallicity dependence of the IFMR at this mass and metallicity range. As a result, the IFMR can be more reliably determined with this broad sample of 29 total white dwarfs giving $M_{\rm final} = (0.163 \pm 0.022) M_{\rm initial} + 0.238 \pm 0.071$ $M_\odot$ from $M_{\rm initial}$ of 3 to 4 $M_\odot$. A steep IFMR in this mass range indicates that the full IFMR is nonlinear.

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ALMA observations of TiO_2 around VY Canis Majoris

Elvire De Beck[1], *W. Vlemmings*[1], *S. Muller*[1], *J.H. Black*[1], *E. O'Gorman*[1], *A.M.S. Richards*[2], *A. Baudry*[3,4], *M. Mærcker*[1], *L. Decin*[5,6] *and E.M. Humphreys*[7]

[1]Department of Earth and Space Sciences, Chalmers University of Technology, Onsala Space Observatory, 43992 Onsala, Sweden

[2]Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK

[3]Université de Bordeaux, LAB, UMR 5804, F-33270 Floirac, France

[4]CNRS, LAB, UMR 5804, F-33270 Floirac, France

[5]Instituut voor Sterrenkunde, Katholieke Universiteit Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium

[6]Sterrenkundig Instituut Anton Pannekoek, University of Amsterdam, Science Park 904, 1098 Amsterdam, The Netherlands

[7]European Southern Observatory, Karl-Schwarzschild-Straße 2, 85748 Garching bei München, Germany

Context: Titanium dioxide, TiO_2, is a refractory species that could play a crucial role in the dust-condensation sequence around oxygen-rich evolved stars. To date, gas phase TiO_2 has been detected only in the complex environment of the red supergiant VY CMa.
Aims: We aim to constrain the distribution and excitation of TiO_2 around VY CMa in order to clarify its role in dust formation.
Methods: We analyse spectra and channel maps for TiO_2 extracted from ALMA science verification data.
Results: We detect 15 transitions of TiO_2, and spatially resolve the emission for the first time. The maps demonstrate a highly clumpy, anisotropic outflow in which the TiO_2 emission likely traces gas exposed to the stellar radiation field. A roughly east–west oriented, accelerating bipolar-like structure is found, of which the blue component runs into and breaks up around a solid continuum component. A distinct tail to the south-west is seen for some transitions, consistent with features seen in the optical and near-infrared.
Conclusions: We find that a significant fraction of TiO_2 remains in the gas phase outside the dust-formation zone and suggest that this species might play only a minor role in the dust-condensation process around extreme oxygen-rich evolved stars like VY CMa.

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Radial abundance gradients from planetary nebulæ at different distances from the Galactic plane

W.J. Maciel[1], *R.D.D. Costa*[1] *and O. Cavichia*[2]

[1]University of São Paulo, Brazil

[2]Unifei, Brazil

We investigate the variations of the radial O/H abundance gradients from planetary nebulæ (PN) located at different distances from the Galactic plane. In particular, we determine the abundance gradients at different heights from the plane in order to investigate a possible gradient inversion for the objects at larger distances from the plane. We consider a large sample of PN with known distances, so that the height relative to the Galactic plane can be derived, and accurate abundances, so that the gradients can be determined.

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The post-common envelope central stars of the planetary nebulae Henize 2-155 and Henize 2-161

David Jones[1,2], *Henri M.J. Boffin*[3], *Pablo Rodríguez-Gil*[1,2], *Roger Wesson*[3], *Romano L.M. Corradi*[1,2], *Brent Miszalski*[4,5] *and Shazrene Mohamed*[4]

[1]IAC, Spain

[2]ULL, Spain

[3]ESO, Chile

[4]SAAO, South Africa

[5]SALT, South Africa

We present a study of Hen 2-155 and Hen 2-161, two planetary nebulæ which bear striking morphological similarities to other planetary nebulæ known to host close-binary central stars. Both central stars are revealed to be photometric variables while spectroscopic observations confirm that Hen 2-155 is host to a double-eclipsing, post-common-envelope system with an orbital period of $3^{\rm h}33^{\rm m}$ making it one of the shortest period binary central stars known. The observations of Hen 2-161 are found to be consistent with a post-common-envelope binary of period ~ 1 day.

A detailed model of central star of Hen 2-155, is produced, showing the nebular progenitor to be a hot, post-AGB remnant of approximately 0.62 $M_{\odot}$, consistent with the age of the nebula, and the secondary star to be an M dwarf whose radius is almost twice the expected ZAMS radius for its mass. In spite of the small numbers, all main-sequence companions, of planetary nebulæ central stars, to have had their masses and radii constrained by both photometric and spectroscopic observations have also been found to display this "inflation". The cause of the "inflation" is uncertain but is probably related to rapid accretion, immediately before the recent common-envelope phase, to which the star has not yet thermally adjusted.

The chemical composition of both nebulæ is also analysed, showing both to display elevated abundance discrepancy factors. This strengthens the link between elevated abundance discrepancy factors and close binarity in the nebular progenitor.

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Better alternative to "astronomical silicate": Laboratory-based optical functions of chondritic/solar abundance glass with application to HD 161796

Angela K. Speck[1], *Karly M. Pitman*[2] *and Anne M. Hofmeister*[3]

[1]University of Missouri, USA

[2]Space Science Institute, USA

[3]Washington University St. Louis, USA

"Astronomical" or "circumstellar" silicate optical functions (real and imaginary indices of refraction n and k have been previously derived from compositionally and structurally disparate samples; past values were compiled from different sources in the literature, and are essentially kluges of observational, laboratory, and extrapolated or interpolated values. These synthetic optical functions were created because astronomers lack the quantitative data on amorphous silicates at all wavelengths needed for radiative transfer modeling. This paper provides optical functions that (1) are created with a consistent methodology, (2) use the same sample across all wavelengths, and (3) minimize interpolation and extrapolation wherever possible. We present electronic data tables of optical functions derived from mid-ultraviolet to far-infrared laboratory transmission spectra for two materials: iron-free glass with chondritic/solar atmospheric abundances, and metallic iron. We compare these optical functions to other popular n, k data used to model amorphous silicates (e.g., "astronomical" or "circumstellar" silicate), both directly and in application to a simple system: the dust shell of the post-AGB star HD 161796. Using the new optical functions, we find that the far-IR profile of model SEDs are significantly affected by the ratio of glass to iron. Our case study on HD 161796 shows that modeling with our new optical functions, the mineralogy is markedly different from that derived using synthetic optical functions and suggests a new scenario of crystalline silicate formation.

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The Local Group galaxy IC 1613 and its asymptotic giant branch variables

J.W. Menzies[1], *P.A. Whitelock*[1,2] *and M.W. Feast*[2,1]

[1]South African Astronomical Observatory, South Africa

[2]University of Cape Town, South Africa

$JHK_{\rm s}$ photometry is presented from a three-year survey of the central regions of the Local Group dwarf irregular galaxy IC 1613. The morphologies of the colour-magnitude and colour–colour diagrams are discussed with particular reference to the supergiants and M- and C-type asymptotic giant branch (AGB) stars. Mean $JHK_{\rm s}$ magnitudes, amplitudes and periods are given for five O-rich and nine C-rich Mira variables for which bolometric magnitudes are also estimated. A distance of 750 kpc ($(m - M)_0 = 24.37 \pm 0.08$ mag) is derived for IC 1613 by fitting a period–luminosity relation to the C-rich Miras. This is in agreement with values from the literature. The AGB stars exhibit a range of ages. A comparison with theoretical isochrones suggests that four luminous O-rich Miras are as young as 2×10^8 yr. One of these has a lithium absorption line in its spectrum, demonstrating that it is undergoing hot bottom burning (HBB). This supports the idea that HBB is the cause of the high luminosity of these AGB stars, which puts them above the fundamental period–luminosity (PL) relation. Further studies of similar stars, selected from their positions in the PL diagram, could provide insight into HBB. A much fainter, presumed O-rich, Mira is similar to those found in Galactic globular clusters. The C Miras are of intermediate age. The O-rich variables are not all recognized as O-rich, or even as AGB stars, on the basis of their J–$K_{\rm s}$ colour. It is important to appreciate this when using near-infrared surveys to classify AGB stars in more distant galaxies.

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Si-bearing molecules towards IRC +10°216: ALMA unveils the molecular envelope of CW Leo

L. Velilla Prieto[1,2], J. Cernicharo[1], G. Quintana-Lacaci[1], M. Agúndez[1], A. Castro-Carrizo[3], J.P. Fonfría[4], N. Marcelino[5], J. Zúñiga[6], A. Requena[6], A. Bastida[6], F. Lique[7] and M. Guélin[3,8]

[1]Group of Molecular Astrophysics, ICMM, CSIC, C/Sor Juana Inés de la Cruz 3, 28049 Cantoblanco, Madrid, Spain

[2]Centro de Astrobiología, INTA–CSIC, E-28691 Villanueva de la Cañada, Madrid, Spain

[3]Institut de Radioastronomie Millimétrique. 300 rue de la la Piscine, F-38406, Saint Martin d'Hères, France

[4]Departamento de Estrellas y Medio Interestelar, Instituto de Astronomía, Universidad Nacional Autónoma de México (UNAM). Ciudad Universitaria, 04510, México City, México

[5]INAF, Istituto di Radiastronomia, via P. Gobetti 101, 40129 Bologna, Italy

[6]Departamento de Química Física, Facultad de Química, Universidad de Murcia. Campus Espinardo, 30100 Murcia, Spain

[7]LOMC–UMR 6294, CNRS–Université du Havre, 25 rue Philippe Lebon, BP. 1123, 76063 Le Havre cedex, France

[8]LERMA, Observatoire de Paris, PSL Research University, CNRS, UMR 8112, F-75014, Paris, France

We report the detection during the ALMA Cycle 0 of SiS rotational lines in high-vibrational states as well as SiO and SiC_2 lines in their ground vibrational state, towards IRC +10°216. The spatial distribution of these molecules shows compact emission for SiS and a more extended emission for SiO and SiC_2 , and also proves the existence of an increase in the SiC_2 emission at the outer shells of the circumstellar envelope. We analyze the excitation conditions of the vibrationally excited SiS using the population diagram technique and we used a large velocity gradient model to compare with the observations. We found moderate discrepancies between the observations and the models that could be explained if SiS lines detected are optically thick. Additionally, the line profiles of the detected rotational lines in the high energy vibrational states show a decreasing linewidth with increasing energy levels. This may evidence that these lines could be excited only in the inner shells, i.e. the densest and hottest, of the circumstellar envelope of IRC +10°216.

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Infrared two-color diagrams for AGB stars, post-AGB stars, and planetary nebulæ

Kyung-Won Suh[1]

[1]Department of Astronomy and Space Science, Chungbuk National University, 362-763, South Korea

We present various infrared two-color diagrams (2CDs) for AGB stars, post-AGB stars, and Planetary Nebulæ (PNe) and investigate possible evolutionary tracks. We use catalogs from the available literature for the sample of 4903 AGB stars (3373 O-rich; 1168 C-rich; 362 S-type), 660 post-AGB stars (326 post-AGB; 334 pre-PNe), and 1510 PNe in our Galaxy. For each object in the catalog, we cross-identify the IRAS, AKARI, MSX, and 2MASS counterparts. The IR 2CDs can provide useful information about the structure and evolution of the dust envelopes as well as the central stars. To find possible evolutionary tracks from AGB stars to PNe on the 2CDs, we investigate spectral evolution of post-AGB stars by making simple but reasonable assumptions on the evolution of the central star and dust shell. We perform radiative transfer model calculations for the detached dust shells around evolving central stars in the post-AGB phase. We find that the theoretical dust shell model tracks using dust opacity functions of amorphous silicate and amorphous carbon roughly coincide with the densely populated observed points of AGB stars, post-AGB stars, and PNe on various IR 2CDs. Even though some discrepancies are inevitable, the end points of the theoretical post-AGB model tracks are generally converged to the region of the observed points of PNe on most 2CDs.

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Kepler's Supernova: An overluminous Type Ia event interacting with a massive circumstellar medium at a very late phase

Satoru Katsuda[1], *Koji Mori*[2], *Keiichi Maeda*[3,4], *Masaomi Tanaka*[5], *Katsuji Koyama*[6,7], *Hiroshi Tsunemi*[6], *Hiroshi Nakajima*[6], *Yoshitomo Maeda*[1], *Masanobu Ozaki*[1] *and Robert Petre*[8]

[1]Institute of Space and Astronautical Science (ISAS), Japan Aerospace Exploration Agency (JAXA), Japan

[2]University of Miyazaki, Japan

[3]Department of Astronomy, Kyoto University, Japan

[4]Kavli Institute for the Physics and Mathematics of the Universe (WPI), University of Tokyo, Japan

[5]National Astronomical Observatory of Japan, Japan

[6]Osaka University, Japan

[7]Department of Physics, Kyoto University, Japan

[8]NASA Goddard Space Flight Center, USA

We have analyzed XMM–*Newton*, *Chandra*, and *Suzaku* observations of Kepler's supernova remnant (SNR) to investigate the properties of both the SN ejecta and the circumstellar medium (CSM). For comparison, we have also analyzed two similarly-aged, ejecta-dominated SNRs: Tycho's SNR, thought to be the remnant of a typical Type Ia SN, and SNR 0509−67.5 in the Large Magellanic Cloud, thought to be the remnant of an overluminous (SN1991T-like) Type Ia SN. By simply comparing the X-ray spectra, we find that line intensity ratios of iron-group elements (IGE) to intermediate-mass elements (IME) for Kepler's SNR and SNR 0509−67.5 are much higher than those for Tycho's SNR. We therefore argue that Kepler is the product of an overlumious Type Ia SN. This inference is supported by our spectral modeling, which reveals the IGE and IME masses respectively to be $0.95^{+0.34}_{-0.37}$ $M_\odot$ and $0.12^{+0.19}_{-0.05}$ $M_\odot$ (Kepler's SNR), $0.75^{+0.51}_{-0.15}$ $M_\odot$ and $0.34^{+0.08}_{-0.25}$ $M_\odot$ (SNR 0509−67.5), and $0.35^{+0.55}_{-0.15}$ $M_\odot$ and $0.70^{+0.12}_{-0.28}$ $M_\odot$ (Tycho's SNR). We find that the CSM component in Kepler's SNR consists of tenuous diffuse gas (~ 0.3 $M_\odot$) present throughout the entire remnant, plus dense knots (~ 0.035 $M_\odot$). Both of these components have an elevated N abundance (N/H ~ 4 times the solar value), suggesting that they originate from CNO-processed material from the progenitor system. The mass of the diffuse CSM allows us to infer the pre-SN mass-loss rate of the system to be $\sim 1.5 \times 10^{-5} (v_{\rm w}/10\,{\rm km\,s^{-1}})$ $M_\odot$ yr^{-1}, in general agreement with results from recent hydrodynamical simulations. The dense knots have slow optical proper motions as well as relatively small X-ray-measured ionization timescales, which indicates that they were located a few pc away from the progenitor system and were only recently heated by forward shocks. Therefore, we argue that Kepler's SN was an overluminous (91T-like) event that started to interact with massive CSM a few hundred years after the explosion. This supports the possible link between 91T-like SNe and the so-called "Ia-CSM" SNe – a rare class of SNe Ia associated with massive CSM. The link implies that $\sim 10\%$ of SNe Ia are associated with massive CSM which most likely originates from a companion star in a single degenerate progenitor system.

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On carbon burning in super asymptotic giant branch stars

R. Farmer[1], *C.E. Fields*[1,2] *and F.X. Timmes*[1,2]

[1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA

[2]Joint Institute for Nuclear Astrophysics

We explore the detailed and broad properties of carbon burning in Super Asymptotic Giant Branch (SAGB) stars with 2755 MESA stellar evolution models. The location of first carbon ignition, quenching location of the carbon burning flames and flashes, angular frequency of the carbon core, and carbon core mass are studied as a function of the ZAMS mass, initial rotation rate, and mixing parameters such as convective overshoot, semiconvection, thermohaline and angular momentum transport. In general terms, we find these properties of carbon burning in SAGB models are not a strong function of the initial rotation profile, but are a sensitive function of the overshoot parameter. We quasi-analytically derive an approximate ignition density, $\rho_{\rm ign} \approx 2.1 \times 10^6$ g cm^{-3}, to predict the location of first carbon ignition in models that ignite carbon off-center. We also find that overshoot moves the ZAMS mass boundaries where off-center carbon ignition occurs at a nearly uniform rate of $\Delta M_{\rm ZAMS} \Delta f_{\rm ov} \approx 1.6$ $M_\odot$. For zero

overshoot, $f_{\rm ov} = 0.0$, our models in the ZAMS mass range $\approx$ 8.9 to 11 $M_\odot$ show off-center carbon ignition. For canonical amounts of overshooting, $f_{\rm ov} = 0.016$, the off-center carbon ignition range shifts to $\approx$ 7.2 to 8.8 $M_\odot$. Only systems with $f_{\rm ov} \geq 0.01$ and ZAMS mass $\approx$ 7.2–8.0 $M_\odot$ show carbon burning is quenched a significant distance from the center. These results suggest a careful assessment of overshoot modeling approximations on claims that carbon burning quenches an appreciable distance from the center of the carbon core.

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New measurements of the radio photosphere of Mira based on data from the JVLA and ALMA

L.D. Matthews[1], *M.J. Reid*[2] *and K.M. Menten*[3]

[1]MIT Haystack Observatory, USA
[2]Harvard–Smithsonian Center for Astrophysics, USA
[3]Max Planck Institut für Radioastronomie, Germany

We present new measurements of the millimeter wavelength continuum emission from the long period variable Mira (*o* Ceti) at frequencies of 46 GHz, 96 GHz, and 229 GHz ($\lambda \approx 7$ mm, 3 mm, and 1 mm) based on observations obtained with the *Jansky* Very Large Array (JVLA) and the Atacama Large Millimeter/submillimeter Array (ALMA). The measured millimeter flux densities are consistent with a radio photosphere model derived from previous observations, where flux density $S_\nu \propto \nu^{1.86}$. The stellar disk is resolved, and the measurements indicate a decrease in the size of the radio photosphere at higher frequencies, as expected if the opacity decreases at shorter wavelengths. The shape of the radio photosphere is found to be slightly elongated, with a flattening of $\sim$ 10–20%. The data also reveal evidence for brightness non-uniformities on the surface of Mira at radio wavelengths. Mira's hot companion, Mira B was detected at all three observed wavelengths, and we measure a radius for its radio-emitting surface of $\approx 2.0 \times 10^{13}$ cm. The data presented here highlight the power of the JVLA and ALMA for the study of the atmospheres of evolved stars.

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High resolution imaging of NGC 2346 with GSAOI/GeMS: disentangling the planetary nebula molecular structure to understand its origin and evolution

Arturo Manchado[1,2,3], *Letizia Stanghellini*[4], *Eva Villaver*[5], *Guillermo García-Segura*[6], *Richard A. Shaw*[4] *and D. Anibal García-Hernández*[1,2]

[1]Instituto de Astrofísica de Canarias, Vía Láctea S/N, E–38205 La Laguna, Tenerife, Spain
[2]Departmento de Astrofísica, Universidad de La Laguna (ULL), E–38206 La Laguna, Tenerife, Spain
[3]Consejo Superior de Investigaciones Científicas, Spain
[4]National Optical Astronomy Observatory, 950 N. Cherry Avenue, Tucson, AZ 85719, USA
[5]Departamento de Física Teórica, Universidad Autónoma de Madrid, Cantoblanco 28049 Madrid, Spain
[6]Instituto de Astronomía–UNAM, Apartado postal 877, Ensenada, 22800 Baja California, México

We present high spatial resolution ($\approx$ 60–90 milliarcseconds) images of the molecular hydrogen emission in the Planetary Nebula (PN) NGC 2346. The data were acquired during the system verification of the Gemini Multi-Conjugate Adaptive Optics System + Gemini South Adaptive Optics Imager. At the distance of NGC 2346, 700 pc, the physical resolution corresponds to $\approx$ 56 au, which is slightly higher than that an [N II] image of NGC 2346 obtained with HST/WFPC2. With this unprecedented resolution we were able to study in detail the structure of the H_2 gas within the nebula for the first time. We found it to be composed of knots and filaments, which at lower resolution had

appeared to be a uniform torus of material. We explain how the formation of the clumps and filaments in this PN is consistent with a mechanism in which a central hot bubble of nebular gas surrounding the central star has been depressurized, and the thermal pressure of the photoionized region drives the fragmentation of the swept-up shell.

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A new nonlocal thermodynamical equilibrium radiative transfer method for cool stars

Julien Lambert[1], *Eric Josselin*[2], *Nils Ryde*[1] *and Alexandre Faure*[3]

[1]Lund Observatory, Sweden

[2]Laboratoire Univers et Particules de Montpellier (LUPM), CNRS/Université Montpellier 2, France

[3]Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), Université Joseph Fourier/CNRS/OSUG, France

Context: The solution of the nonlocal thermodynamical equilibrium (non-LTE) radiative transfer equation usually relies on stationary iterative methods, which may falsely converge in some cases. Furthermore, these methods are often unable to handle large-scale systems, such as molecular spectra emerging from, for example, cool stellar atmospheres.
Aims: Our objective is to develop a new method, which aims to circumvent these problems, using nonstationary numerical techniques and taking advantage of parallel computers.
Methods: The technique we develop may be seen as a generalization of the coupled escape probability method. It solves the statistical equilibrium equations in all layers of a discretized model simultaneously. The numerical scheme adopted is based on the generalized minimum residual method.
Results: The code has already been applied to the special case of the water spectrum in a red supergiant stellar atmosphere. This demonstrates the fast convergence of this method, and opens the way to a wide variety of astrophysical problems.

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Pre-supernova neutrino emissions from ONe cores in the progenitors of core-collapse supernovæ: are they distinguishable from those of Fe cores?

Chinami Kato[1], *Milad Delfan Azari*[1], *Shoichi Yamada*[1,2], *Koh Takahashi*[3], *Hideyuki Umeda*[3], *Takashi Yoshida*[4] *and Koji Ishidoshiro*[5]

[1]School of Advanced Science and Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan

[2]Advanced Research Institute for Science and Engineering, Waseda University, 3-4-1, Okubo, Shinjuku, Tokyo 169-8555, Japan

[3]Department of Astronomy, The University of Tokyo, Tokyo 113-0033, Japan

[4]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

[5]Research Center for Neutrino Science, Tohoku University, Sendai 980-8578, Japan

Aiming to distinguish two types of progenitors of core collapse supernovae, i.e. one with a core composed mainly of oxygen and neon (abbreviated as ONe core) and the other with an iron core (or Fe core), we calculated the luminosities and spectra of neutrinos emitted from these cores prior to gravitational collapse, taking neutrino oscillation into account. We found that the total energies emitted as $\bar{\nu}_e$ from the ONe core are $\lesssim 10^{46}$ erg, which is much smaller than $\sim 10^{47}$ erg for Fe cores. The average energy, on the other hand, is twice as large for the ONe core as those for the Fe cores. The neutrinos produced by the plasmon decays in the ONe core are more numerous than those from the electron-positron annihilation in both cores but they have much lower average energies $\lesssim 1$ MeV. Although it is difficult to detect the pre-supernova neutrinos from the ONe core even if it is located within 200 pc from the earth,

we expect $\sim$ 9–43 and $\sim$ 7–61 events for Fe cores at KamLAND and Super-Kamiokande, respectively, depending on the progenitor mass and neutrino-mass hierarchy. These numbers might be increased by an order of magnitude if we envisage next-generation detectors such as JUNO. We will hence be able to distinguish the two types of progenitors by the detection or non-detection of the pre-supernova neutrinos if they are close enough ($\lesssim$1 kpc).

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Exploring masses and CNO surface abundances of red giant stars

Ghina M. Halabi[1] *and Mounib El Eid*[1]

[1]American University of Beirut, Lebanon

A grid of evolutionary sequences of stars in the mass range 1.2–7 $M_\odot$, with solar-like initial composition is presented. We focus on this mass range in order to estimate the masses and calculate the CNO surface abundances of a sample of observed red giants. The stellar models are calculated from the zero-age main sequence till the early asymptotic giant branch (AGB) phase. Stars of $M \leq 2.2$ $M_\odot$ are evolved through the core helium flash. In this work, an approach is adopted that improves the mass determination of an observed sample of 21 RGB and early AGB stars. This approach is based on comparing the observationally derived effective temperatures and absolute magnitudes with the calculated values based on our evolutionary tracks in the Hertzsprung–Russell diagram. A more reliable determination of the stellar masses is achieved by using evolutionary tracks extended to the range of observation. In addition, the predicted CNO surface abundances are compared to the observationally inferred values in order to show how far standard evolutionary calculation can be used to interpret available observations and to illustrate the role of convective mixing. We find that extra mixing beyond the convective boundary determined by the Schwarzschild criterion is needed to explain the observational oxygen isotopic ratios in low-mass stars. The effect of recent determinations of proton capture reactions and their uncertainties on the $^{16}O/^{17}O$ and $^{14}N/^{15}N$ ratios is also shown. It is found that the $^{14}N(p, \gamma)^{15}O$ reaction is important for predicting the $^{14}N/^{15}N$ ratio in red giants.

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Post-outburst spectra of a stellar-merger remnant of V1309 Scorpii: from a twin of V838 Monocerotis to a clone of V4332 Sagittarii

T. Kamiński[1,2]*, E. Mason*[3]*, R. Tylenda*[4] *and M.R. Schmidt*[4]

[1]ESO Santiago, Chile
[2]Max-Planck-Institut für Radioastronomie, Bonn, Germany
[3]INAF, Trieste, Italy
[4]CAMK, Toruń, Poland

We present optical and infrared spectroscopy of V1309 Sco, an object that erupted in 2008 in a stellar-merger event. During the outburst, V1309 Sco displayed characteristics typical of red transients, a class of objects similar to V838 Mon. Our observations were obtained in 2009 and 2012, i.e. months and years after the eruption of V1309 Sco, and illustrate severe changes in the remnant, mainly in its circumstellar surroundings. In addition to atomic gas observed in earlier epochs, we identified molecular bands of TiO, VO, H_2O, ScO, AlO, and CrO. The infrared bands of CrO we analyse are the first astronomical identification of the features. Over the whole period covered by our data, the remnant was associated with a cool ($\lesssim$1000 K) outflow with a terminal velocity of about 200 km s^{-1}. Signatures of warmer atomic gas, likely to be still dissipating the energy of the 2008 outburst, dramatically decreased their brightness between 2009 and 2012. In addition, the source of optical continuum disappeared sometime before 2012, likely owing to the formation of new dust. The final stage of V1309 Sco's evolution captured by our

spectra is an object remarkably similar to an older red transient, V4332 Sgr. In addition to providing a detailed view on the settling of the eruptive object, the observations presented here reinforce the conclusion that all the Galactic red transients are a manifestation of the same phenomenon, i.e. a stellar merger. The late spectra of V1309 Sco also suggest peculiarities in the chemical composition of the remnant, which still need to be explored.

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Methanol observation of IRAS 19312+1950: A possible new type of Class I methanol masers

Jun-ichi Nakashima[1,2], Andrej M. Sobolev[3], Svetlana V. Salii[1], Yong Zhang[2,4], Bosco H.K. Yung[2] and Shuji Deguchi[5]

[1]Department of Astronomy and Geodesy, Institute of Natural Sciences, Ural Federal University, Lenin Avenue 51, 620000, Ekaterinburg, Russia

[2]Department of Physics, University of Hong Kong, Pokfulam Road, Hong Kong, China

[3]Astronomical Observatory, Institute of Natural Sciences, Ural Federal University, Lenin Avenue 51, 620000, Ekaterinburg, Russia

[4]Space Astronomy Laboratory, Faculty of Science, The University of Hong Kong, Pokfulam Road, Hong Kong, China

[5]Nobeyama Radio Observatory, National Astronomical Observatory of Japan, Minamimaki, Minamisaku, Nagano 384-1305, Japan

We report the result of a systematic methanol observation toward IRAS 19312+1950. The properties of the SiO, H_2O and OH masers of this object are consistent with those of mass-losing evolved stars, but some other properties are difficult to explain in the standard scheme of stellar evolution in its late stage. Interestingly, a tentative detection of radio methanol lines was suggested toward this object by a previous observation. To date, there are no confirmed detections of methanol emission towards evolved stars, so investigation of this possible detection is important to better understand the circumstellar physical/chemical environment of IRAS 19312+1950. In this study, we systematically observed multiple methanol lines of IRAS 19312+1950 in the λ = 3-mm, 7-mm, and 13-mm bands, and detected 6 lines including 4 thermal lines and 2 class I maser lines. We derived basic physical parameters including kinetic temperature and relative abundances by fitting a radiative transfer model. According to the derived excitation temperature and line profiles, a spherically expanding outflow lying at the center of the nebulosity is excluded from the possibilities for methanol emission regions. The detection of class I methanol maser emission suggests that a shock region is involved in the system of IRAS 19312+1950. If the central star of IRAS 19312+1950 is an evolved star as suggested in the past, the class I maser detected in the present observation is the first case detected in an interaction region between an evolved star outflow and ambient molecular gas.

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IR photometry and models for the dust shells of two oxygen Mira variables

M.B. Bogdanov[1], Olga G. Taranova[2] and V.I. Shenavrin[2]

[1]Chernyshevskii State University, ul. Astrakhanskaya 83, Saratov, 410012 Russia

[2]Lomonosov Moscow State University, Sternberg Astronomical Institute, Universitetskii pr. 13, Moscow, 119992 Russia

Long-term JHKLM photometric measurements of the oxygen Mira variables RU Her and RS Vir are presented. Variations of the brightnesses and colors of these stars over the observation period are analyzed, and master light curves and color indices of these stars are derived. A linear trend was present in the mean infrared brightness of RS Vir on a

time scale of ~ 6000 days, possibly related to changes in the dust shell of the Mira. The results of model calculations of spherically symmetric dust shells of stars based on mean-flux data supplemented by observations from the IRAS and AKARI satellites in the intermediate- and far-IR are presented. The visual optical depth of the dust shell of RU Her, which has a temperature at its inner boundary $T_1 = 590$ K, is quite low: $\tau_V = 0.33$. The dust shell of RS Vir is much cooler ($T_1 = 410$ K), and has $\tau_V = 0.77$. The estimated mass-loss rate of RU Her is 6.2×10^{-7} $M_\odot$ yr^{-1}, while the mass-loss rate of RS Vir is 7.1×10^{-7} $M_\odot$ yr^{-1}.

Published in Astronomy Reports

Three fundamental periods in a 87 years light curve of the symbiotic star MWC 560

Elia M. Leibowitz[1] *and Liliana Formiggini*[1]

[1]The Wise Observatory and The School of Physics and Astronomy, Tel Aviv University, Israel

We have constructed a visual light curve of the symbiotic star MWC 560 covering the last 87 years of its history. The data were assembled from the literature and from the AAVSO data bank. Most of the periodic components of the system brightness variation can be accounted for by the operation of 3 basic clocks of the periods $P_1 = 19000$ d, $P_2 = 1943$ d and $P_3 = 722$ d. These periods can plausibly, and consistently with the observations, be attributed to 3 physical mechanisms in the system. They are, respectively, the working of a solar-like magnetic dynamo cycle in the outer layers of the giant star of the system, the binary orbit cycle and the sidereal rotation cycle of the giant star. MWC 560 is the 7$^{\rm th}$ symbiotic star with historical light curves that reveal similar basic characteristics of the systems. The light curves of all these stars are well interpreted on the basis of current understanding of the physical processes that are the major sources of the optical luminosity of these symbiotic systems.

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Temporal evolution of the size and temperature of Betelgeuse's extended atmosphere

E. O'Gorman[1]*, G.M. Harper*[2]*, A. Brown*[2]*, E.F. Guinan*[3]*, A.M.S. Richards*[4]*, W. Vlemmings*[1] *and R. Wasatonic*[3]

[1]Department of Earth and Space Sciences, Chalmers University of Technology, Onsala Space Observatory, 439 92 Onsala, Sweden

[2]Center for Astrophysics and Space Astronomy, University of Colorado, 389 UCB, Boulder, CO 80309, USA

[3]Department of Astrophysics and Planetary Science, Villanova University, Villanova, PA 19085, USA

[4]Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, UK

Spatially resolved multi-wavelength centimeter continuum observations of cool evolved stars can not only constrain the morphology of the radio emitting regions, but can also directly probe the mean gas temperature at various depths of the star's extended atmosphere. Here, we use the Very Large Array (VLA) in the A configuration with the Pie Town (PT) Very Long Baseline Array (VLBA) antenna to spatially resolve the extended atmosphere of Betelgeuse over multiple epochs at 0.7, 1.3, 2.0, 3.5, and 6.1 cm. The extended atmosphere deviates from circular symmetry at all wavelengths while at some epochs we find possible evidence for small pockets of gas significantly cooler than the mean global temperature. We find no evidence for the recently reported e-MERLIN radio hotspots in any of our multi-epoch VLA/PT data, despite having sufficient spatial resolution and sensitivity at short wavelengths, and conclude that these radio hotspots are most likely interferometric artefacts. The mean gas temperature of the extended atmosphere has a typical value of 3000 K at 2 $R_\star$ and decreases to 1800 K at 6 $R_\star$, in broad agreement with the findings of the single epoch study from Lim et al. (1998). The overall temperature profile of the extended atmosphere between $2R_\star \lesssim r \lesssim 6R_\star$

can be described by a power law of the form $T_{\rm gas}(r) \propto r^{-0.6}$, with temporal variability of a few 100 K evident at some epochs. Finally, we present over 12 years of V band photometry, part of which overlaps our multi-epoch radio data. We find a correlation between the fractional flux density variability at V band with most radio wavelengths. This correlation is likely due to shock waves induced by stellar pulsations, which heat the inner atmosphere and ionize the more extended atmosphere through radiative means. Stellar pulsations may play an important role in exciting Betelgeuse's extended atmosphere.

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Conference Papers

How important are metal-poor AGB stars as cosmic dust producers?

Lars Mattsson[1]*, Bernhard Aringer*[2] *and Anja C. Andersen*[3]

[1]Nordita, KTH Royal Institute of Technology & Stockholm University, Sweden
[2]Department of Astronomy, University of Vienna, Austria
[3]Dark Cosmology Centre, NBI, University of Copenhagen, Denmark

The efficiency of dust formation in oxygen-rich AGB stars should (in theory) be metallicity dependent since they are not producing their own raw material for dust production. Metal-poor carbon stars may not be very efficient dust producers either, because of more radiative heating of the grains forming in their atmospheres. We have just confirmed that inefficient dust and wind formation in simulations of metal-poor carbon stars is a real physical effect, albeit within the limitations of our simulations. Taken at face value, this implies that the amount of dust supplied by low-metallicity AGB stars to the build up of the cosmic dust component is clearly limited. Consequently, one may also ask how large a contribution AGB stars can make in general, when compared to recent observations of cosmic dust, which are suggesting major contributions from other sources?

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Runaway growth of fractal dust grains

Lars Mattsson[1] *and Joakim D. Munkhammar*[2]

[1]Nordita, KTH Royal Institute of Technology & Stockholm University, Sweden
[2]Department of Engineering Sciences, Uppsala University, Sweden

Fractal grains have large surface area, which leads to more efficient condensation. The special limit case where the volume-area ratio is constant (corresponding to, e.g., a very rough grain surface or non-compacts aggregates) is particularly interesting, as well as convenient, from a mathematical point of view. If dust grains from AGB stars have "rough surfaces", it may have important implications for our understanding of dust and wind formation in AGB stars.

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Review Paper

Planetary Nebulæ in 2014: A review of research

Albert Zijlstra[1]

[1]Jodrell Bank Centre for Astrophysics, School of Physics and Astronomy, The University of Manchester, UK

Planetary nebulæ had a double anniversary in 2014, 250 years since their discovery and 150 years since the correct spectroscopic identification. This paper gives an overview of planetary nebula research published in 2014. Topics include surveys, central stars, abundances, morphologies, magnetic fields, stellar population and galactic dynamics. An important continuing controversy is the discrepancy between recombination-line and forbidden-line abundances. A new controversy is the relation between symbiotic stars and [WC]stars. PN of the year is undoubtedly CRL 618, with papers on its binary symbiotic/[WC] nucleus, rapid stellar evolution, expanding jets and magnetic fields.

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