THE AGB NEWSLETTER

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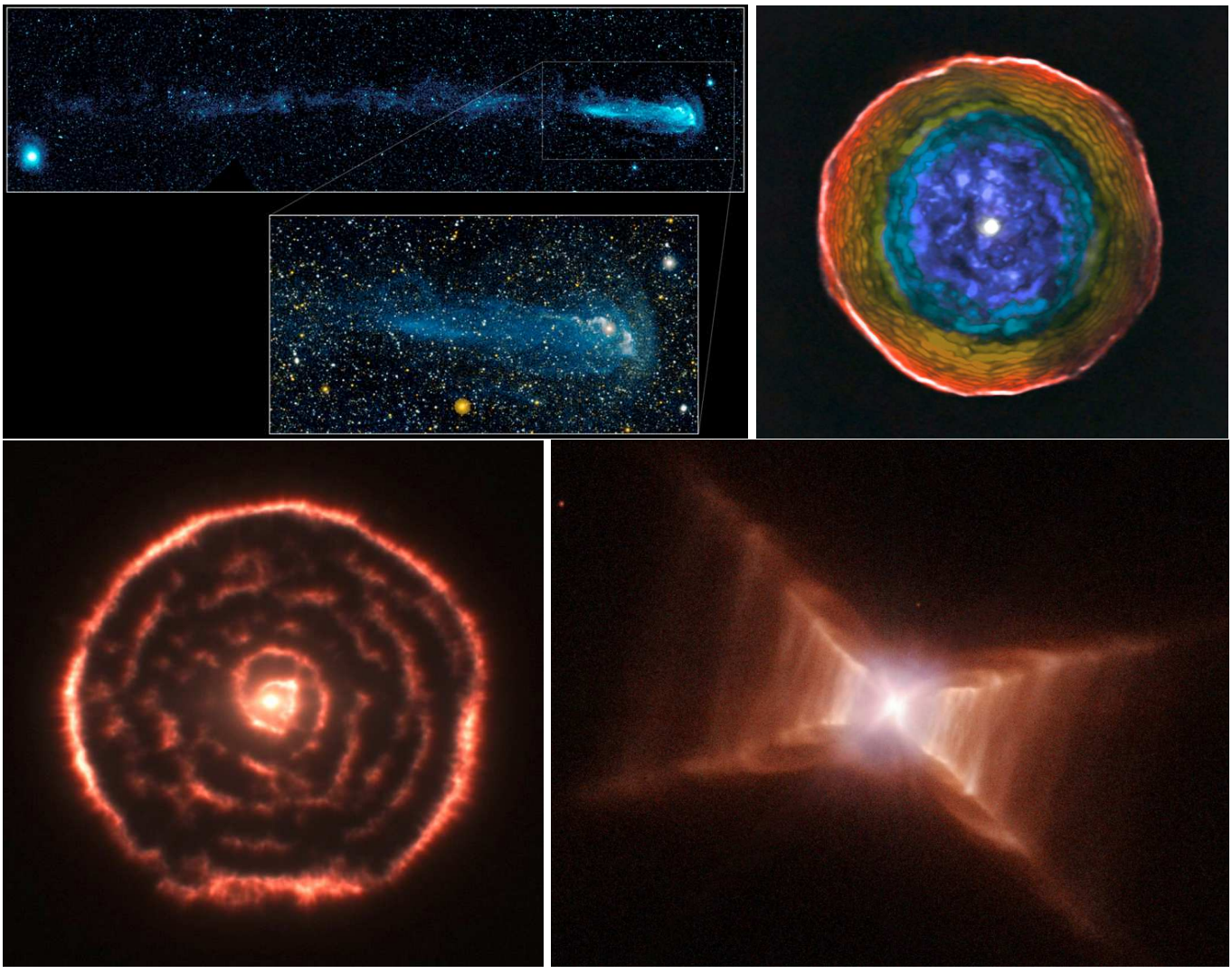


Figure 1: Voted by you as the most iconic AGB-related pictures: **Mira** (upper left) – NASA/JPL-Caltech/C. Martin (Caltech)/M. Seibert (OCIW); **U Ant** (upper right) – ALMA (ESO/NAOJ/NRAO), F. Kerschbaum; **R Scl** (bottom left) – ALMA (ESO/NAOJ/NRAO)/M. Maercker et al.; **Red Rectangle** (bottom rigt) – H. Van Winckel (K.U. Leuven), M. Cohen (U.C. Berkeley), H. Bond (STScI), T. Gull (GSFC)/ESA/NASA.

Editorial

Dear Colleagues,

It is a pleasure to present you the 250$^{\text{th}}$ issue of the AGB Newsletter. It features the most iconic relevant picture on the front cover – as voted by you. Because each of the four nominations got an equal number of votes (5), they *all* feature on the front cover! A very satisfying outcome indeed.

Unfortunately, the sad news reached us of the passing of Stuart Pottasch. Please read the obituary in memory of his life and works.

The next issue is planned to be distributed around the 1$^{\text{st}}$ of June.

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

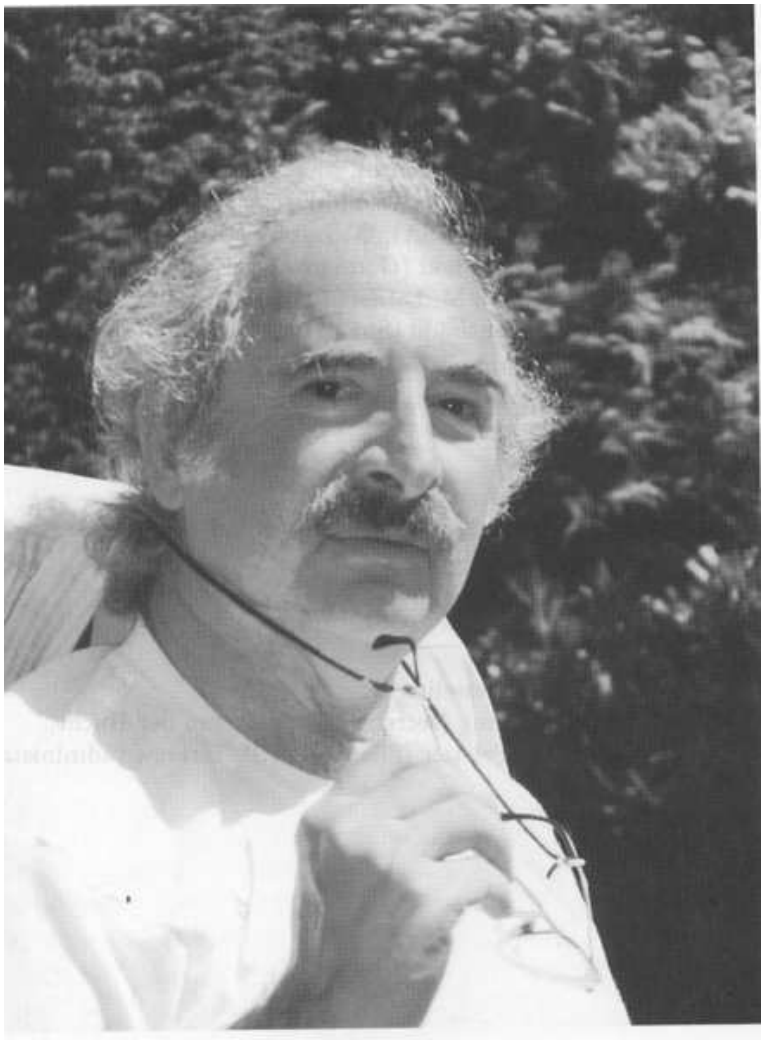
Food for Thought

This month's thought-provoking statement is:

Models are never wrong

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)

Stuart Pottasch 1932–2018



During April the news came that Stuart Pottasch has died, after an extended illness. Many of you will have known him personally, or know his research which spanned more than 6 decades. Stuart's first paper was in 1956, on the topic of diffuse nebulæ. Afterwards, he worked on novæ, the solar corona, the interstellar medium and H II regions, with a sideline on line radiative transfer. The papers reveal his versatility and ability to move between topics – or languages: one of his paper was in French. His first paper involving planetary nebulæ was in 1962, when he showed that the He I triplet lines have significant optical dept. PNe became his main topic of research from 1977 onward, starting with a study of extinction and quickly moving to central stars, ionized masses and distances. His last paper, Pagomenos et al. (2018), is currently in press in the journal he founded, A&A.

Stuart supervised many research students over the years. HIs very first student (masters) was Yervant Terzian who himself went on to a remarkable career. I was one of those many students. Stuart was both inspiring and exasperating as supervisor. He expected complete independence. But he also had a knack of always asking the right questions, and he would come to my desk almost every day with a new idea or problem he wanted to discuss. It now seems that most of my career has been trying to find answers to the many questions he asked. A notable aspect of Stuart was that he did not require his students to agree with him. He was even happy to be on papers that he disagreed with. Stuart once told me that interpretations and conclusions would change over time, but data was in the literature forever. As long as the data was correct, the paper would remain useful.

Stuart's obituary from the University of Groningen is reprinted below. The original can be found on
https://www.rug.nl/research/kapteyn/news/2018/obituarypottasch.pdf

To me, Stuart will always be the person who taught me to really look at planetary nebulæ, their diversity and their complexity of physics. His inspiration became my fascination. In 1965, Stuart wrote that the study of planetary nebulæ was much more advanced than that of diffuse nebulæ. In hindsight, at the time this may have been overstated. Much of our current understanding of planetary nebulæ and their evolution has come from the many questions Stuart would raise. A star has died.

Albert Zijlstra

OBITUARY STUART POTTASCH
16 January 1932 – 4 April 2018

Following a long illness, Prof. Stuart Pottasch died in Groningen on 4 April 2018. Stuart was Professor Emeritus at the Kapteyn Institute of the Rijksuniversiteit Groningen, where he had been a professor since 1963. Stuart served as chairman of the Department of Astronomy in Groningen from 1969 until 1982, and with the coming of the space research group (SRON) he oversaw a major expansion of the research effort in astronomy during his tenure as chairman. Among his other achievements, Stuart was editor-in-chief of the Bulletin of the Astronomical Institutes of the Netherlands (1963–1969), an editor of the European journal of Astronomy and Astrophysics from its founding (1969–1976), editor of the Letters edition of that journal (1976–1998) and an editor of Astronomy and Astrophysics Reviews (1990–1999). In these functions he played a major role in the integration of the joint European astronomical research community. Over his career, Stuart published roughly 400 papers that received more than ten thousand citations and wrote a highly regarded major textbook on the subject of planetary nebulæ, his primary research interest. He supervised the successful dissertation work of 22 PhD students.

Stuart was born in New York City on 16 January 1932 to Jewish immigrants. He received his bachelors degree in Engineering Physics from Cornell University in 1954 and his masters from Harvard in 1957 after spending a year in Leiden in 1955. He was awarded his PhD from the University of Colorado in 1958 for his dissertation entitled "The Novæ Outburst" carried out under the supervision of R.N. Thomas. As was typical for young astrophysicists then (and now), he spent several peripatetic years at various institutes: the National Bureau of Standards (U.S.), the Observatoire de Meudon, Princeton University and the Institute for Advanced Study, and Indiana University. During these years he formed a number of lasting contacts, one of the most notable examples being with Jean-Louis Steinberg in Meudon. In 1963 Adriaan Blaauw, who was revamping the old Kapteyn Institute in Groningen, offered Stuart the position of professor of astrophysics, and here he remained. Stuart was a traditional astrophysicist in the style of Henry Norris Russell and Lyman Spitzer. He dealt with known problems of atomic physics and radiative processes in astronomical environments – the interstellar medium and diffuse nebulæ. Stuart was interested in real problems that he felt he could solve and less in the more speculative aspects of modern theoretical astrophysics.

His many students have included Harm Habing, Klaas de Boer, Jacqueline van Gorkom, Roel Gathier, Peter Roelfsema, Albert Zijlstra, Rob Assendorp, René Laureijs, Griet van der Steene and René Oudmaijer. Stuart's style of supervision was relaxed; he did not closely monitor or direct the research of students but encouraged a great deal of independence. This style agreed with some and not with others, but this was Stuart. To those meeting him for the first time, he often seemed somewhat introverted and remote, but, in fact, being underestimated was his management tactic, as a number of colleagues later discovered. In connection with his work, Stuart traveled extensively, in particular to India and China where he established numerous collaborations leading to a multi-cultural flow of students to Groningen. Stuart was not only a very busy and successful astrophysicist, he also had several consuming hobbies. He had one of the largest collections of cacti in the Netherlands; tourists came from afar to visit his greenhouses. He collected not only exotic plants but also exotic tropical birds. He kept and bred parrots of numerous and various species – amazons, grays, macaws, cockatoos, and love birds to name a few. He must have had a very deep and abiding interest in these creatures which, as anyone knows who has had just one, are not the easiest pets. Stuart met his first wife, Anna Maria, during his first visit to Leiden. They had a daughter and two sons. After Anna Marie's death in 1989, Stuart remarried Greet. Together they began a new life in a different village, Tolbert, and a different home, a farm house intentionally chosen for its isolation to accommodate his lively birds. Greet was with him as he passed away on the evening of 4 April 2018.

Robert Sanders

Refereed Journal Papers

Revised coordinates of variable stars in Cassiopeia

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The identification of the 35 red variable stars published on IBVS #3573 has ben revised on the basis of the original (unpublished) finding charts. Discrepancies from half arcmin to tens of arcmin have been found in the coordinates. Cross check with the 2MASS catalog has been made to get much more accurate coordinates and to confirm their nature from their J–H,H–K colors. The 8 Mira stars of the sample, given their known periods, could be used with the astrometric parallaxes of the forthcoming Gaia catalog to improve the Period–Luminosity relation.

Published in IBVS
Available from http://www.konkoly.hu/cgi-bin/IBVS?6236

A model of the Mira-type star T UMi

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Stellar evolution calculations were carried out from the main sequence to the final stage of the asymptotic giant branch for stars with initial masses from 1 to 2 $M_\odot$ and metallicity $Z = 0.01$. Selected models of evolutionary sequences were used as initial conditions for solution of the equations of radiation hydrodynamics and time-dependent convection describing radial stellar pulsations. The study was aimed to construct the hydrodynamic models of Mira-type stars that show the secular decrease in the pulsation period Π commenced in 1970s at $\Pi = 315$ day. We show that such a condition for the period change is satisfied with evolutionary sequences $1\ M_\odot \leq M_{\rm ZAMS} \leq 1.2\ M_\odot$ and the best agreement with observations is obtained for $M_{\rm ZAMS} = 1.2\ M_\odot$. The pulsation period reduction is due to both the stellar radius decrease during the thermal pulse of the helium burning shell and mode switch from the fundamental mode to the first overtone. Theoretical estimates of the fundamental parameters of the star at the onset of pulsation period reduction are as follows: the mass is $M = 0.93\ M_\odot$, the luminosity is $L = 4080\ L_\odot$, and the radius is $R = 220\ R_\odot$. The mode switch occurs 35 years after the onset of period reduction.

Accepted for publication in Astronomy Letters
Available from https://arxiv.org/abs/1803.11387

Evolution of the magnetic field of Betelgeuse from 2009–2017

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Betelgeuse is an M-type supergiant that presents a circularly polarized (Stokes V) signal in its line profiles, interpreted in terms of a surface magnetic field.
The weak circular polarization signal has been monitored over 7.5 years in order to follow its evolution on different timescales, and eventually to determine its physical origin. Linear polarization measurements have also been obtained regularly in the last few years.
We used both the ESPaDOnS and Narval spectropolarimeters to obtain high signal-to-noise ratio (S/N) spectra, which were processed by means of the least-squares deconvolution (LSD) method. In order to ensure the reality of the very weak circular polarization, special care has been taken to limit instrumental effects. In addition, several tests were performed on the Stokes V signal to establish its stellar and Zeeman origin.
We confirm the magnetic nature of the circular polarization, pointing to a surface magnetic field of the order of 1 G. The Stokes V profiles present variations over different timescales, the most prominent one being close to the long secondary period (LSP; around 2000 d for Betelgeuse) often invoked in red evolved stars. This long period is also dominant for all the other Stokes parameters. The circular polarization is tentatively modeled by means of magnetic field concentrations mimicking spots, showing in particular that the velocity associated with each "spot" also follows the long timescale, and that this signal is nearly always slightly redshifted.
From the coupled variations of both linear and circular polarization signatures in amplitude, velocity and timescale, we favour giant convection cells as the main engine at the origin of polarization signatures and variations in all the Stokes parameters. This strengthens support for the hypothesis that large convective cells are at the origin of the LSP.

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Available from https://arxiv.org/abs/1804.01831

The limited role of recombination energy in common envelope removal

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We calculate the outward energy transport time by convection and photon diffusion in an inflated common envelope and find this time to be shorter than the envelope expansion time. We conclude therefore that most of the hydrogen recombination energy ends in radiation rather than in kinetic energy of the outflowing envelope. We use the stellar evolution code MESA and inject energy inside the envelope of an asymptotic giant branch star to mimic energy deposition by a spiraling-in stellar companion. During 1.7 years the envelope expands by a factor of more than 2. Along the entire evolution the convection can carry the energy very efficiently outwards, to the radius where radiative transfer becomes more efficient. The total energy transport time stays within several months, shorter than

the dynamical time of the envelope. Had we included rapid mass loss, as is expected in the common envelope evolution, the energy transport time would have been even shorter. It seems that calculations that assume that most of the recombination energy ends in the outflowing gas are inaccurate.

Submitted to MMRAS
Available from https://arxiv.org/abs/1803.05864

Submillimeter-wave emission of three Galactic red novæ: cool molecular outflows produced by stellar mergers

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Red novæ are optical transients erupting at luminosities typically higher than those of classical novæ. Their outbursts are believed to be caused by stellar mergers. We present millimeter/submillimeter-wave observations with ALMA and SMA of the three best known Galactic red novæ, V4332 Sgr, V1309 Sco, and V838 Mon. The observations were taken 22, 8, and 14 yr after their respective eruptions and reveal the presence of molecular gas at excitation temperatures of 35–200 K. The gas displays molecular emission in rotational transitions with very broad lines (full width $\sim$ 400 km s^{-1}). We found emission of CO, SiO, SO, SO_2 (in all three red novæ), H_2S (covered only in V838 Mon) and AlO (present in V4332 Sgr and V1309 Sco). No anomalies were found in the isotopic composition of the molecular material and the chemical (molecular) compositions of the three red novæ appear similar to those of oxygen-rich envelopes of classical evolved stars (RSGs, AGBs, post-AGBs). The minimum masses of the molecular material that most likely was dispersed in the red-nova eruptions are 0.1, 0.01, and 10^{-4} $M_\odot$ for V838 Mon, V4332 Sgr, and V1309 Sco, respectively. The molecular outflows in V4332 Sgr and V1309 Sco are spatially resolved and appear bipolar. The kinematic distances to V1309 Sco and V4332 Sgr are 2.1 and 4.2 kpc, respectively. The kinetic energy stored in the ejecta of the two older red-nova remnants of V838 Mon and V4332 Sgr is of order 10^{46} erg, similar to values found for some post-AGB (pre-PN) objects whose bipolar ejecta were also formed in a short-duration eruption. Our observations strengthen the link between these post-AGB objects and red novæ and support the hypothesis that some of the post-AGB objects were formed in a common-envelope ejection event or its most catastrophic outcome, a merger.

Submitted to A&A
Available from https://arxiv.org/abs/1804.01610

An unusual face-on spiral in the wind of the M-type AGB star EP Aquarii

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High-resolution interferometric observations of the circumstellar environments of AGB stars show a variety of morphologies. Guided by the unusual carbon monoxide line profile of the AGB star EP Aquarii, we have observed its circumstellar environment with ALMA band 6 in cycle 4. We describe the morphological complexity of the CO, SiO and SO_2 molecular emission. The CO emission exhibits the characteristics of a bi-conical wind with a bright nearly

face-on spiral feature around the systemic velocity. This is the first convincing detection of a spiral morphology in an O-rich wind. Based on the offsets of the centers of the two bi-conical wind hemispheres, we deduce the position angle of the inclination axis to be $\sim 150^\circ$ measured counterclockwise from north. Based on the velocity width of the spiral signature we estimate the inclination angle of the system to be between 4° and 18°. The central emission zone exhibits a morphology that resembles simulations modelling the spiral-inducing wind-Roche-lobe-overflow mechanism. Though the spiral may be a (companion-induced) density enhancement in the stellar outflow, the extremely narrow width of the spiral signature in velocity space suggests that it may be a hydrodynamical perturbation in a face-on differentially rotating disk. The SiO emission does not show the spiral, but exhibits a local emission void $\approx 0\farcs5$ west of the continuum brightness peak. We hypothesise that this may be a local environment caused by the presence of a (stellar) companion with a mass of at most 0.1 $M_\odot$, based on its non-detection in the continuum. Finally, the SO_2 emission remains confined to a $0\farcs5$ radius, and does not show any obvious substructure, but it exhibits a clear rotation signature. Combined, the properties of the molecular emission favour the face-on rotating disk scenario. We observe unexpectedly large red and blue shifted wings in the spectral line of SiO, which could be explained by the potential NLTE nature of driven, mixed, partly granular fluids.

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Available from https://arxiv.org/abs/1804.05684

Discovery of a new classical nova shell around a nova-like cataclysmic variable

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The morphology and optical spectrum of IPHASX J210204.7+471015, a nebula classified as a possible planetary nebula are, however, strikingly similar to those of AT Cnc, a classical nova shell around a dwarf nova. To investigate its true nature, we have obtained high-resolution narrowband [O III] and [N II] images and deep optical spectra. The nebula shows an arc of [N II]-bright knots notably enriched in nitrogen, while an [O III]-bright bow shock is progressing throughout the ISM. Diagnostic line ratios indicate that shocks are associated with the arc and bow shock. The central star of this nebula has been identified by its photometric variability. Time-resolved photometric and spectroscopic data of this source reveal a period of 4.26 hr, which is attributed to a binary system. The optical spectrum is notably similar to that of RW Sex, a cataclysmic variable star (CV) of the UX Uma novalike (NL) type. Based on these results, we propose that IPHASX J210204.7+471015 is a classical nova shell observed around a CV-NL system in quiescence.

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and from http://iopscience.iop.org/article/10.3847/1538-4357/aab669

Rotation of the asymptotic giant branch star R Doradus

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High-resolution observations of the extended atmospheres of asymptotic giant branch (AGB) stars can now directly be compared to the theories that describe stellar mass loss. Using Atacama Large Millimeter/submillimeter Array (ALMA) high angular resolution (30×42 mas^2) observations, we have for the first time resolved stellar rotation of an AGB star, R Dor. We measure an angular rotation velocity of $\omega_R \sin i = (3.5 \pm 0.3) \times 10^{-9}$ rad s^{-1}, which indicates a rotational velocity of $|v_{\rm rot} \sin i| = 1.0 \pm 0.1$ km s^{-1} at the stellar surface ($R_\star = 31.2$ mas at 214 GHz). The rotation axis projected on the plane of the sky has a position angle $\Phi = 7 \pm 6^\circ$. We find that the rotation of R Dor is two orders of magnitude faster than expected for a solitary AGB star that will have lost most of its angular momentum. Its rotational velocity is consistent with angular momentum transfer from a close companion. As a companion has not been directly detected, we suggest R Dor has a low-mass, close-in companion. The rotational velocity approaches the critical velocity, set by the local sound speed in the extended envelope, and is thus expected to affect the mass-loss characteristics of R Dor.

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Available from https://arxiv.org/abs/1804.04709

The parallax of the red hypergiant VX Sgr with accurate tropospheric delay calibration

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We report astrometric results of VLBI phase-referencing observations of 22 GHz H_2O masers emission toward the red hypergiant VX Sgr, one of most massive and luminous red hypergiant stars in our Galaxy, using the Very Long Baseline Array. A background source, J1820−2528, projected 4.°4 from the target VX Sgr, was used as the phase reference. For the low declinations of these sources, such a large separation normally would seriously degrade the relative astrometry. We use a two-step method of tropospheric delay calibration, which combines the VLBI geodetic-block (or GPS) calibration with an image-optimization calibration, to obtain a trigonometric parallax of 0.64±0.04 mas, corresponding to a distance of $1.56^{+0.11}_{-0.10}$ kpc. The measured proper motion of VX Sgr is 0.36±0.76 and −2.92±0.78 mas yr^{-1} in the eastward and northward directions. The parallax and proper motion confirms that VX Sgr belongs to the Sgr OB1 association. Rescaling bolometric luminosities in the literature to our parallax distance, we find the luminosity of VX Sgr is $(1.95 \pm 0.62) \times 10^5$ L$_\odot$, where the uncertainty is dominated by differing photometry measurements.

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Available from https://arxiv.org/abs/1804.00894

Vibrational satellites of C_2S, C_3S, and C_4S: microwave spectral taxonomy as a stepping stone to the millimeter-wave band

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We present a microwave spectral taxonomy study of several hydrocarbon/CS_2 discharge mixtures in which more than 60 distinct chemical species, their more abundant isotopic species, and/or their vibrationally excited states were detected using chirped-pulse and cavity Fourier-transform microwave spectroscopies. Taken together, in excess of 85 unique variants were detected, including several new isotopic species and more than 25 new vibrationally excited states of C_2S, C_3S, and C_4S, which have been assigned on the basis of published vibration–rotation interaction constants for C_3S, or newly calculated ones for C_2S and C_4S. On the basis of these precise, low-frequency measurements, several vibrationally exited states of C_2S and C_3S were subsequently identified in archival millimeter-wave data in the 253–280 GHz frequency range, ultimately providing highly accurate catalogs for astronomical searches. As part of this work, formation pathways of the two smaller carbon–sulfur chains were investigated using ^{13}C isotopic spectroscopy, as was their vibrational excitation. The present study illustrates the utility of microwave spectral taxonomy as a tool for complex mixture analysis, and as a powerful and convenient "stepping stone" to higher frequency measurements in the millimeter and submillimeter bands.

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Available from https://arxiv.org/abs/1804.04126

The red-giant branch bump revisited: constraints on envelope overshooting in a wide range of masses and metallicities

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The red-giant branch bump provides valuable information for the investigation of the internal structure of low-mass stars. Because current models are unable to accurately predict the occurrence and efficiency of mixing processes beyond convective boundaries, one can use the luminosity of the bump – a diagnostic of the maximum extension of the convective envelope during the first-dredge up – as a calibrator for such processes. By combining asteroseismic and spectroscopic constraints, we expand the analysis of the bump to masses and metallicities beyond those previously accessible using globular clusters. Our dataset comprises nearly 3000 red-giant stars observed by *Kepler* and with APOGEE spectra. Using statistical mixture models, we are able to detect the bump in the average seismic parameters $\nu_{\rm max}$ and $\langle\Delta\nu\rangle$, and show that its observed position reveals general trends with mass and metallicity in line with expectations from models. Moreover, our analysis indicates that standard stellar models underestimate the depth of efficiently mixed envelopes. The inclusion of significant overshooting from the base of the convective envelope, with an efficiency that increases with decreasing metallicity, allows to reproduce the observed location of the bump. Interestingly, this trend was also reported in previous studies of globular clusters.

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The *Hubble* Space Telescope UV legacy survey of Galactic globular clusters – XIV. Multiple stellar populations within M 15 and their radial distribution

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In the context of the *Hubble* Space Telescope UV survey of Galactic globular clusters (GCs), we derived high-precision, multi-band photometry to investigate the multiple stellar populations in the massive and metal-poor GC M 15. By creating for red-giant branch (RGB) stars of the cluster a 'chromosome map', which is a pseudo two-colour diagram made with appropriate combination of F275W, F336W, F438W, and F814W magnitudes, we revealed colour spreads around two of the three already known stellar populations. These spreads cannot be produced by photometric errors alone and could hide the existence of (two) additional populations. This discovery increases the complexity of the multiple-population phenomenon in M 15.

Our analysis shows that M 15 exhibits a faint sub-giant branch (SGB), which is also detected in colour–magnitude diagrams (CMDs) made with optical magnitudes only. This poorly-populated SGB includes about 5% of the total number of SGB stars and evolves into a red RGB in the $m_{\rm F336W}$ vs. $m_{\rm F336W}$–$m_{\rm F814W}$ CMD, suggesting that M 15 belongs to the class of Type II GCs.

We measured the relative number of stars in each population at various radial distances from the cluster centre, showing that all of these populations share the same radial distribution within statistic uncertainties. These new findings are discussed in the context of the formation and evolution scenarios of the multiple populations.

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Multicolor photometry and spectroscopy of the yellow supergiant with dust envelope HD 179821 = V1427 Aquilæ

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We present the results of multicolor ($UBVJHKLM$) photometry (2009–2017) and low-resolution spectroscopy (2016–2017) of the semi-regular variable V1427 Aql = HD 179821, a yellow supergiant with gas–dust envelope. The star displays low-amplitude ($\Delta V < 0\overset{\rm m}{.}2$) semi-periodic brightness variation superimposed on a long-term trend. The light curve shape and timescale change from cycle to cycle. There are temperature variations characteristic for pulsations, and brightness oscillations with no significant change of color are also observed. The UBV data for the 2009–2011 interval are well reproduced by a superposition of two periodic components with $P = 170^{\rm d}$ and $P = 141^{\rm d}$ (or $P = 217^{\rm d}$ – the one year alias of $P = 141^{\rm d}$). The variation became less regular after 2011, the timescale increased and exceeded $250^{\rm d}$. An usual photometric behavior was seen in 2015 when the star brightness increased by $0\overset{\rm m}{.}25$ in the V filter in 130 days and reached the maximum value ever observed in the course of our monitoring since 1990. In 2009–2016 the annual average brightness monotonically increased in V, J, K, whereas it decreased in U and B. The annual average $(U-B)$, $(B-V)$, and $(J-K)$ colors grew, the star was getting redder. The cooling and expanding of the star photosphere along with the increasing of luminosity may explain the long-term trend in brightness and colors. Based on our photometric data we suppose that the photosphere temperature decreased by ~ 400 K in the 2008–2016 interval, the radius increased by $\sim 24\%$, and the luminosity grew by $\sim 19\%$. We review the change of annual average photometric data for almost 30 years of observations. Low-resolution spectra in the λ4000–9000 Å wavelength range obtained in 2016–2017 indicate significant changes in the spectrum of V1427 Aql as compared with the 1994–2008

interval, i.e. the Ba II and near-infrared Ca II triplet absorptions have turned stronger while the O I λ7771–4 triplet blend has weakened that points out the decrease of temperature in the region where the absorptions are formed. The evolutionary stage of the star is discussed. We also compare V1427 Aql with post-AGB stars and yellow hypergiants.

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Seeing red in NGC 1978, NGC 55, and NGC 3109

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Spectra of the intermediate age star cluster NGC 1978 and the dwarf irregular galaxies NGC 55 and NGC 3109 that span the 0.7–1.1 μm wavelength interval are discussed. The NGC 1978 spectra are used to examine stochastic effects on the integrated red light from an intermediate age cluster. The removal of either the brightest M giant or the brightest C star from the co-added NGC 1978 spectrum has minor affects on the equivalent widths of the Ca triplet. The most robust signature of C stars in the integrated cluster spectrum at these wavelengths is the CN band head near 0.79 μm. The equivalent widths of Ca triplet lines in the NGC 1978 spectrum and in the spectra of individual cluster stars are larger than expected for a scaled-solar abundance system, and it is suggested that these stars have been subject to extra mixing processes. Ca lines weaken with increasing distance from the disk plane in the NGC 55 spectra. Comparisons with models suggest that the red light from NGC 55 is dominated by stars with ages 1–2 Gyr, in agreement with star-forming histories (SFHs) obtained from the analysis of CMDs. The NGC 3109 observations sample three different parts of that galaxy but have a low signal-to-noise ratio. Comparisons with models suggest that the light from the NGC 3109 disk at red wavelengths is dominated by RSGs with ages of at most a few tens of Myr, in qualitative agreement with SFHs that are based on photometric measurements.

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Chemical composition of giant stars in the open cluster IC 4756

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Context: Homogeneous investigations of red giant stars in open clusters contribute to studies of internal evolutionary mixing processes inside stars, which are reflected in abundances of mixing-sensitive chemical elements like carbon, nitrogen, and sodium, while α- and neutron-capture element abundances are useful in tracing the Galactic chemical evolution.
Aims: The main aim of this study is a comprehensive chemical analysis of red giant stars in the open cluster IC 4756, including determinations of $^{12}C/^{13}C$ and C/N abundance ratios, and comparisons of the results with theoretical models of stellar and Galactic chemical evolution.
it Methods: We used a classical differential model atmosphere method to analyse high-resolution spectra obtained with the FEROS spectrograph on the 2.2-m MPG/ESO Telescope. The carbon, nitrogen, and oxygen abundances, $^{12}C/^{13}C$ ratios, and neutron-capture element abundances were determined using synthetic spectra, and the main atmospheric parameters and abundances of other chemical elements were determined from equivalent widths of spectral lines.
Results: We have determined abundances of 23 chemical elements for 13 evolved stars and $^{12}C/^{13}C$ ratios for six stars of IC 4756. The mean metallicity of this cluster, as determined from nine definite member stars, is very close to solar – [Fe/H] $= -0.02 \pm 0.01$. Abundances of carbon, nitrogen, and sodium exhibit alterations caused by extra-mixing: the mean $^{12}C/^{13}C$ ratio is lowered to 19 ± 1.4, the C/N ratio is lowered to 0.79 ± 0.05, and the mean [Na/Fe] value,

corrected for deviations from the local thermodynamical equilibrium encountered, is enhanced by 0.14 ± 0.05 dex. We compared our results to those by other authors and theoretical models.
Conclusions: Comparison of the α-element results with the theoretical models shows that they follow the thin disc α-element trends. Being relatively young ($\sim$ 800 Myr), the open cluster IC 4756 displays a moderate enrichment of s-process-dominated chemical elements compared to the Galactic thin disc model and confirms the enrichment of s-process-dominated elements in young open clusters compared to the older ones. The r-process-dominated element europium abundance agrees with the thin disc abundance. From the comparison of our results for mixing-sensitive chemical elements and the theoretical models, we can see that the mean values of $^{12}C/^{13}C$, C/N, and [Na/Fe] ratios lie between the model with only the thermohaline extra-mixing included and the model which also includes the rotation-induced mixing. The rotation was most probably smaller in the investigated IC 4756 stars than 30% of the critical rotation velocity when they were on the main sequence.

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Tracers of stellar mass-loss – II. Mid-IR colors and surface brightness fluctuations

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I present integrated colors and surface brightness fluctuation magnitudes in the mid-IR, derived from stellar population synthesis models that include the effects of the dusty envelopes around thermally pulsing asymptotic giant branch (TP-AGB) stars. The models are based on the Bruzual & Charlot CB* isochrones; they are single-burst, range in age from a few Myr to 14 Gyr, and comprise metallicities between $Z = 0.0001$ and $Z = 0.04$. I compare these models to mid-IR data of AGB stars and star clusters in the Magellanic Clouds, and study the effects of varying self-consistently the mass-loss rate, the stellar parameters, and the output spectra of the stars plus their dusty envelopes. I find that models with a higher than fiducial mass-loss rate are needed to fit the mid-IR colors of "extreme" single AGB stars in the Large Magellanic Cloud. Surface brightness fluctuation magnitudes are quite sensitive to metallicity for 4.5 μm and longer wavelengths at all stellar population ages, and powerful diagnostics of mass-loss rate in the TP-AGB for intermediate-age populations, between 100 Myr and 2–3 Gyr.

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Age-resolved chemistry of re giants in the solar neighborhood

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In the age of high-resolution spectroscopic stellar surveys of the Milky Way, the number of stars with detailed abundances of multiple elements is rapidly increasing. These elemental abundances are directly influenced by the evolutionary history of the Galaxy, but this can be difficult to interpret without an absolute timeline of the abundance

enrichment. We present age-abundance trends for [M/H], [α/M], and 17 individual elements using a sample of 721 solar neighbourhood *Hipparcos* red giant stars observed by APOGEE. These age trends are determined through a Bayesian hierarchical modelling method presented by Feuillet et al. (2016). We confirm that the [α/M]–age relation in the solar neighbourhood is steep and relatively narrow (0.20 dex age dispersion), as are the [O/M]– and [Mg/M]–age relations. The age trend of [C/N] is steep and smooth, consistent with stellar evolution. The [M/H]–age relation has a mean age dispersion of 0.28 dex and a complex overall structure. The oldest stars in our sample are those with the lowest and highest metallicities, while the youngest stars are those with solar metallicity. These results provide strong constraints on theoretical models of Galactic chemical evolution (GCE). We compare them to the predictions of one-zone GCE models and multi-zone mixtures, both analytic and numerical. These comparisons support the hypothesis that the solar neighbourhood is composed of stars born at a range of Galactocentric radii, and that the most metal-rich stars likely migrated from a region with earlier and more rapid star formation such as the inner Galaxy.

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Opening PANDORA's box: APEX observations of CO in PNe

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Context: Observations of molecular gas have played a key role in developing the current understanding of the late stages of stellar evolution.
Aims: The survey Planetary nebulæ AND their cO Reservoir with APEX (PANDORA) was designed to study the circumstellar shells of evolved stars with the aim to estimate their physical parameters.
Methods: Millimetre carbon monoxide (CO) emission is the most useful probe of the warm molecular component ejected by low- to intermediate-mass stars. CO is the second-most abundant molecule in the Universe, and the millimetre transitions are easily excited, thus making it particularly useful to study the mass, structure, and kinematics of the molecular gas. We present a large survey of the CO (J =3–2) line using the Atacama Pathfinder EXperiment (APEX) telescope in a sample of 93 proto-planetary nebulæ and planetary nebulæ.
Results: CO (J = 3–2) was detected in 21 of the 93 objects. Only two objects (IRC+10°216 and PN M 2-9) had previous CO (J = 3–2) detections, therefore we present the first detection of CO (J = 3–2) in the following 19 objects: Frosty Leo, HD 101584, IRAS 19475+3119, PN M 1-11, V852 Cen, IC 4406, Hen 2-113, Hen 2-133, PN Fg 3, PN Cn 3-1, PN M 2-43, PN M 1-63, PN M 1-65, BD +30°3639, Hen 2-447, Hen 2-459, PN M 3-35, NGC 3132, and NGC 6326.
Conclusions: CO (J = 3–2) was detected in all 4 observed pPNe (100%), 15 of the 75 PNe (20%), one of the 4 wide binaries (25%), and in 1 of the 10 close binaries (10%). Using the CO (J = 3–2) line, we estimated the column density and mass of each source. The H_2 column density ranges from 1.7×10^{18} to 4.2×10^{21} cm^{-2} and the molecular mass ranges from 2.7×10^{-4} to 1.7×10^{-1} M$_\odot$.

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Asymmetric ejecta of cool supergiants and hypergiants in the massive cluster Westerlund 1

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We report new 5.5 GHz radio observations of the massive star cluster Westerlund 1, taken by the Australia Telescope Compact Array, detecting nine of the ten yellow hypergiants (YHGs) and red supergiants (RSGs) within the cluster. Eight of nine sources are spatially resolved. The nebulae associated with the YHGs Wd 1-4a, -12a and -265 demonstrate a cometary morphology – the first time this phenomenon has been observed for such stars. This structure is also echoed in the ejecta of the RSGs Wd 1-20 and -26; in each case the cometary tails are directed away from the cluster core. The nebular emission around the RSG Wd 1-237 is less collimated than these systems but once again appears more prominent in the hemisphere facing the cluster. Considered as a whole, the nebular morphologies provide compelling evidence for sculpting via a physical agent associated with Westerlund 1, such as a cluster wind.

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MESA models of the evolutionary state of the interacting binary ϵ Aurigæ

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Using the MESA code (Modules for Experiments in Stellar Astrophysics, version 9575), an evaluation was made of the evolutionary state of the ϵ Aurigæ binary system (HD 31964, F0 Iap + disk). We sought to satisfy several observational constraints: 1) requiring evolutionary tracks to pass close to the current temperature and luminosity of the primary star; 2) obtaining a period near the observed value of 27.1 years; 3) matching a mass function of 3.0; 4) concurrent Roche lobe overflow and mass transfer; 5) an isotopic ratio $^{12}C/^{13}C = 5$ and, (6) matching the interferometrically determined angular diameter. A MESA model starting with binary masses of 9.85 + 4.5 $M_\odot$, with a 100 day initial period, produces a 1.2 + 10.6 $M_\odot$ result having a 547 day period, and a single digit $^{12}C/^{13}C$ ratio. These values were reached near an age of 20 Myr, when the donor star comes close to the observed luminosity and temperature for ϵ Aurigæ A, as a post-RGB/pre-AGB star. Contemporaneously, the accretor then appears as an upper main sequence, early B-type star. This benchmark model can provide a basis for further exploration of this interacting binary, and other long period binary stars.

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Extended structures of planetary nebulæ detected in H_2 emission

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We present narrow-band near-infrared images of a sample of 11 Galactic planetary nebulæ (PNe) obtained in the molecular hydrogen (H_2) 2.122 μm and Brγ 2.166 μm emission lines and the K_c 2.218 μm continuum. These images were collected with the Wide-field InfraRed Camera (WIRCam) on the 3.6m Canada–France–Hawai'i Telescope (CFHT); their unprecedented depth and wide field of view allow us to find extended nebular structures in H_2 emission in several PNe, some of these being the first detection. The nebular morphologies in H_2 emission are studied in analogy with the optical images, and indication on stellar wind interactions is discussed. In particular, the complete structure of the highly asymmetric halo in NGC 6772 is witnessed in H_2, which strongly suggests interaction with the interstellar medium. Our sample confirms the general correlation between H_2 emission and the bipolarity of PNe. The knotty/filamentary fine structures of the H_2 gas are resolved in the inner regions of several ring-like PNe, also confirming the previous argument that H_2 emission mostly comes from knots/clumps embedded within fully ionized material at the equatorial regions. Moreover, the H_2 image of the butterfly-shaped Sh 1-89, after removal of field stars, clearly reveals a tilted ring structure at the waist. These high-quality CFHT images justify follow-up detailed morpho-kinematic studies that are desired to deduce the true physical structures of a few PNe in the sample.

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Common envelope shaping of planetary nebulæ

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The morphology of planetary nebulæ emerging from the common envelope phase of binary star evolution is investigated. Using initial conditions based on the numerical results of hydrodynamical simulations of the common envelope phase it is found that the shapes and sizes of the resulting nebula are very sensitive to the effective temperature of the remnant core, the mass-loss rate at the onset of the common envelope phase, and the mass ratio of the binary system. These parameters are related to the efficiency of the mass ejection after the spiral-in phase, the stellar evolutionary phase (i.e., RG, AGB or TP-AGB), and the degree of departure from spherical symmetry in the stellar wind mass loss process itself respectively. It is found that the shapes are mostly bipolar in the early phase of evolution, but can quickly transition to elliptical and barrel-type shapes. Solutions for nested lobes are found where the outer lobes are usually bipolar and the inner lobes are elliptical, bipolar or barrel-type, a result due to the flow of the photo-evaporated gas from the equatorial region. It is found that the lobes can be produced without the need for two distinct mass ejection events. In all the computations, the bulk of the mass is concentrated in the orbital or equatorial plane, in the form of a large toroid, which can be either neutral (early phases) or photoionized (late phases), depending of the evolutionary state of the system.

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FastChem: A computer program for efficient complex chemical equilibrium calculations in the neutral/ionized gas phase with applications to stellar and planetary atmospheres

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For the calculation of complex neutral/ionized gas phase chemical equilibria, we present a semi-analytical versatile and efficient computer program, called FastChem. The applied method is based on the solution of a system of coupled nonlinear (and linear) algebraic equations, namely the law of mass action and the element conservation equations including charge balance, in many variables. Specifically, the system of equations is decomposed into a set of coupled nonlinear equations in one variable each, which are solved analytically whenever feasible to reduce computation time. Notably, the electron density is determined by using the method of Nelder & Mead at low temperatures. The program is written in object-oriented C++ which makes it easy to couple the code with other programs, although a stand-alone version is provided. FastChem can be used in parallel or sequentially and is available under the GNU General Public License version 3 at https://github.com/exoclime/FastChem together with several sample applications. The code has been successfully validated against previous studies and its convergence behaviour has been tested even for extreme physical parameter ranges down to 100 K and up to 1000 bar. FastChem converges stably and robustly in even most demanding chemical situations, which posed sometimes extreme challenges for previous algorithms.

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MULTIGRAIN: a smoothed particle hydrodynamics algorithm for multiple small dust grains and gas

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We present a new algorithm, MULTIGRAIN, for modelling the dynamics of an entire population of small dust grains immersed in gas, typical of conditions that are found in molecular clouds and protoplanetary discs. The MULTIGRAIN method is more accurate than single-phase simulations because the gas experiences a backreaction from each dust phase and communicates this change to the other phases, thereby indirectly coupling the dust phases together. The MULTIGRAIN method is fast, explicit and low storage, requiring only an array of dust fractions and their derivatives defined for each resolution element.

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Detection of C I line emission towards the oxygen-rich AGB star *o* Cet

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We present the detection of neutral atomic carbon C I ($^3P_1$–$^3P_0$) line emission towards *o* Cet. This is the first time that C I is detected in the envelope around an oxygen-rich M-type asymptotic giant branch (AGB) star. We also confirm the previously tentative C I detection around V Hya, a carbon-rich AGB star. As one of the main photodissociation products of parent species in the circumstellar envelope (CSE) around evolved stars, C I can be used to trace sources of ultraviolet (UV) radiation in CSEs. The observed flux density towards omi Cet can be reproduced by a shell with a peak atomic fractional abundance of 2.4×10^{-5} predicted based on a simple chemical model where CO is dissociated by the interstellar radiation field. However, the C I emission is shifted by ~ 4 km s^{-1} from the stellar velocity. Based on this velocity shift, we suggest that the detected C I emission towards *o* Cet potentially arises from a compact region near its hot binary companion. The velocity shift could, therefore, be the result of the orbital velocity of the binary companion around *o* Cet. In this case, the C I column density is estimated to be 1.1×10^{19} cm^{-2}. This would imply that strong UV radiation from the companion and/or accretion of matter between two stars is most likely the origin of the C I enhancement. However, this hypothesis can be confirmed by high-angular resolution observations.

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Registration of H_2O and SiO masers in the Calabash Nebula to confirm the planetary nebula paradigm

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We report on the astrometric registration of very long baseline interferometry images of the SiO and H_2O masers in OH 231.8+4.2, the iconic proto-planetary nebula also known as the Calabash nebula, using the Korean VLBI Network and source frequency phase referencing. This, for the first time, robustly confirms the alignment of the SiO masers, close to the asymptotic giant branch star, driving the bi-lobe structure with the water masers in the outflow. We are able to trace the bulk motions for the H_2O masers over the last few decades to be 19 km s^{-1} and deduce that the age of this expansion stage is 38 ± 2 yr. The combination of this result with the distance allows a full 3D reconstruction and confirms that the H_2O masers lie on and expand along the known large-scale symmetry axis and that the outflow is only a few decades old, so mass loss is almost certainly ongoing. Therefore, we conclude that the SiO emission marks the stellar core of the nebula, the H_2O emission traces the expansion, and there must be multiple epochs of ejection to drive the macro-scale structure.

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Conference Papers

Planets, planetary nebulæ, and Intermediate Luminosity Optical Transients (ILOTs)

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I review some aspects related to the influence of planets on the evolution of stars before and beyond the main sequence. Some processes include the tidal destruction of a planet on to a very young main sequence star, on to a low mass main sequence star, and on to a brown dwarf. This process releases gravitational energy that might be observed as a faint intermediate luminosity optical transient (ILOT) event. I then summarize the view that some elliptical planetary nebulæ are shaped by planets. When the planet interacts with a low mass upper asymptotic giant branch (AGB) star it both enhances the mass loss rate and shapes the wind to form an elliptical planetary nebula, mainly by spinning up the envelope and by exciting waves in the envelope. If no interaction with a companion, stellar or sub-stellar, takes place beyond the main sequence, the star is termed a Jsolated star, and its mass loss rates on the giant branches are likely to be much lower than what is traditionally assumed.

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Bow shocks in water fountain jets

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We briefly introduce the VLBI maser astrometric analysis of IRAS 18043−2116 and IRAS 18113−2503, two remarkable and unusual water fountains with spectacular bipolar bow shocks in their high-speed collimated jet-driven outflows. The 22 GHz H_2O maser structures and velocities clearly show that the jets are formed in very short-lived, episodic outbursts, which may indicate episodic accretion in an underlying binary system.

Oral contribution, published in "IAU Symposium 336: Astrophysical Masers: Unlocking the Mysteries of the Universe", 4–8 September 2017, Cagliari, Italy. IAU Proceedings Series, eds. A. Tarchi, M.J. Reid & P. Castangia
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Large-scale surveys of pulsating stars for studying stellar populations in the inner Galaxy

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Surveys of pulsating stars in the inner Galaxy have been very limited, but recent large-scale surveys are rapidly bringing us new samples of various kinds of variable stars and new insights into stellar populations therein. Because of the severe interstellar extinction along the Galactic disc, the stellar populations in the inner Galaxy are more easily observed in the infrared, but even in the infrared the interstellar extinction may cause a serious problem in revealing their accurate characteristics. Here we review recent discoveries of Cepheids and Miras, two kinds of luminous pulsating stars with period–luminosity relation, in the inner Galaxy.

Oral contribution, published in "IAU Symposium 334", eds. C. Chiappini, I. Minchev, E. Starkenburg & M. Valentini
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AKARI color useful for classifying chemical types of Miras

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The AKARI/IRC color combining the S9W and L18W bands is useful for distinguishing between oxygen-rich and carbon-rich circumstellar dust. Ishihara and collaborators found in 2011 that this color, used together with the near-IR color J–K_s, can be used to classify two groups of dust-enshrouded stars with different chemistry. They investigated the distributions of such dusty AGB stars in the Galaxy and found that those with oxygen-rich dust are more centrally concentrated. While this is consistent with previous studies, the map in Ishihara et al. shows that carbon-rich stars are also present in the Galactic bulge for which almost no carbon-rich stars were reported before. Here we focus on Mira variables whose distances can be well constrained based on the period–luminosity relation. Among some candidates of carbon-rich Miras selected by the AKARI color, we confirmed at least four carbon-rich Miras within the bulge with their optical spectra. This gives a new insight into the complicated nature of stellar populations in the bulge.

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