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Abstract of recently accepted papers

Binarity of Central Stars of Planetary Nebulae

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I list the 16 planetary nebulae (PNe) known to contain close-binary nuclei, and show that the nebulae generally have axisymmetric structures, including elliptical, bipolar, or ring morphologies. The orbital periods range from 2.7 hr to 16 days, and close binaries constitute $\approx 10\%$ of all central stars. Since the known binaries were found mainly from photometric variability, which depends on heating effects at very small stellar separations, radial-velocity surveys will be necessary to find the large predicted population of binary nuclei with periods of about 10-100 days. Other PN phenomena that may arise from binary-star interactions include jets and point-symmetry, the periodically spaced arcs revealed by *HST* in the faint halos around several PNe and proto-PNe, and the existence of PNe in globular clusters. There is thus considerable circumstantial evidence that binary-star processes play a major role in the formation and shaping of many or even most PNe.

Invited review, to appear in Asymmetrical Planetary Nebulae II: from Origins to Microstructures, ASP Conference Series, J.H. Kastner, N. Soker, & S.A. Rappaport, eds.
Preprints can be obtained contacting bond@stsci.edu
via WWW on http://xxx.lanl.gov/abs/astro-ph/9909516

The Triple-Shell Structure and Collimated Outflows of the Planetary Nebula NGC 6891

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Narrow-band Hα and [N II] images and high-dispersion spatially-resolved echelle spectroscopy of the planetary nebula NGC 6891 are presented. These observations show a great wealth of structures. The bright central nebula is surrounded by an attached shell and a detached outer halo. Both the inner and intermediate shells can be described as ellipsoids with similar major to minor axial ratios, but different spatial orientations. The kinematical ages of the intermediate shell and halo are 4800 and 28000 years, respectively. The inter-shell time lapse is in good agreement with the evolutionary inter-pulse time lapse. A highly collimated outflow is observed to protrude from the tips of the major axis of the inner nebula and impact on the outer edge of the

intermediate shell. Kinematics and excitation of this outflow provide conclusive evidence that it is deflected during the interaction with the outer edge of the intermediate shell. At the same time, both the kinematics and the morphology of the intermediate shell appear to be affected by this interaction.

To appear in MNRAS
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H_2 and Brγ narrow-band imaging of bipolar planetary nebulae

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We present near-IR narrow-band continuum-subtracted images in the H_2 2.122μm, and Brγ 2.166μm emission lines for a sample of 15 bipolar planetary nebulae. H_2 emission was definitely detected for most of the objects in this sample (13 out of 15). The very high H_2 detection rate supports the idea that bipolar planetary nebulae have important reservoirs of molecular material and offer suitable physical conditions for the excitation of H_2. The strength of the H_2 emission and the H_2/Brγ flux ratio are found to correlate with the morphology of the bipolar nebulae observed. Bipolar PNe with broad and bright rings exhibit stronger H_2 emission than bipolar PNe with narrow twists. High-quality (sub-arcsec) [N II] and Hα optical images have been used to compare the distribution of the ionized and molecular material. The H_2 emission lies just outside the optical [N II] emission zone.

To appear in ApJS
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High resolution spectroscopy and broad-band imaging of the young planetary nebula K 3-35

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We present high-resolution echelle and long-slit spectra and broad–band (R, I) images of the very young planetary nebula K 3-35. Several emission lines have been identified, including the He II 4686 line and strong [N II]6548,6583 and [O III]4959,5007 emissions (I([NII])/I(Hα) $\simeq$ 5.5, I([O III])/I(Hβ) $\simeq$ 30). A systemic velocity $V_{LSR} \simeq 10 \pm 2$ km s^{-1} for K 3-35 is obtained from the optical emission lines. Two different kinematic components are identified in the nebula. One of them is probably related to the elliptical envelope previously observed. The second component exhibits systematic changes of the radial velocity with position and a relatively small velocity width. This component may be attributed to the precessing jet-like outflows previously identified. The R and I images and the deduced $R-I$ color map strongly support the existence of a dense, partially neutral disk-like region in the equatorial plane of the nebula, which probably represents an equatorial density enhancement in a

previously ejected slow wind. Diagnostic diagrams for line intensity ratios in K 3-35 and collimated components of other planetary nebulae suggest that the emission spectrum of this kind of structures is a combination of radiative and shock excitation, in agreement with recent models of shocks in a strongly photoionized medium.

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We present high-resolution echelle and long-slit spectra and broad–band (R, I) images of the very young planetary nebula K 3-35. Several emission lines have been identified, including the He II 4686 line and strong [N II]6548,6583 and [O III]4959,5007 emissions (I([NII])/I(Hα) $\simeq 5.5$, I([O III])/I(Hβ) $\simeq 30$). A systemic velocity $V_{LSR} \simeq 10 \pm 2$ km s^{-1} for K 3-35 is obtained from the optical emission lines. Two different kinematic components are identified in the nebula. One of them is probably related to the elliptical envelope previously observed. The second component exhibits systematic changes of the radial velocity with position and a relatively small velocity width. This component may be attributed to the precessing jet-like outflows previously identified. The R and I images and the deduced $R-I$ color map strongly support the existence of a dense, partially neutral disk-like region in the equatorial plane of the nebula, which probably represents an equatorial density enhancement in a previously ejected slow wind. Diagnostic diagrams for line intensity ratios in K 3-35 and collimated components of other planetary nebulae suggest that the emission spectrum of this kind of structures is a combination of radiative and shock excitation, in agreement with recent models of shocks in a strongly photoionized medium.

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Properties of Dust Grains in Planetary Nebulae I. The Ionized Region of NGC 6445

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One of the factors influencing the spectral evolution of a planetary nebula is the fate of the dust grains that are emitting the infrared continuum. Several processes have been proposed that either destroy the grains or remove them from the ionized region. To test whether these processes are effective, we study new infrared spectra of the evolved nebula NGC 6445. These data show that the thermal emission from the grains is very cool and has a

low flux compared to Hβ. A model of the ionized region is constructed, using the photo-ionization code CLOUDY 90.05. Based on this model, we show from depletions in the gas phase elements that little grain destruction can have occurred in the ionized region of NGC 6445. We also argue that dust-gas separation in the nebula is not plausible. The most likely conclusion is that grains are residing inside the ionized region of NGC 6445 and that the low temperature and flux of the grain emission are caused by the low luminosity of the central star and the low optical depth of the grains. This implies that the bulk of the silicon-bearing grains in this nebula were able to survive exposure to hard UV photons for at least several thousands of years, contradicting previously published results.

A comparison between optical and infrared diagnostic line ratios gives a marginal indication for the presence of a t^2-effect in the nebula. However, the evidence is not convincing and the differences could also be explained by uncertainties in the absolute flux calibration of the spectra, the aperture corrections that have been applied or the collisional cross sections. The photo-ionization model allowed an accurate determination of the central star temperature based on model atmospheres. The resulting value of 184 kK is in good agreement with the average of all published Zanstra temperatures based on a blackbody approximation.

The off-source spectrum taken with LWS clearly shows the presence of a warm cirrus component with a temperature of 24 K as well as a very cold component with a temperature of 7 K. Since our observation encompasses only a small region of the sky, it is not clear how extended the 7 K component is and whether it contributed significantly to the FIRAS spectrum taken by *COBE*. Because our line of sight is in the galactic plane, the very cold component could be a starless core.

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or via WWW on http://www.pa.uky.edu/~peter/refereed.html
or via anonnymous ftp on ftp://ftp.cita.utoronto.ca/pub/vanhoof/publ/n6445.ps.gz

On the origin of the 13 μm feature. A study of ISO-SWS spectra of oxygen-rich AGB stars

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We have derived a mean profile of the 13 μm emission feature from 11 ISO spectra of oxygen-rich AGB stars and present an overview of the mineral species that could account for it. Our results can be summarized as follows: i) Spherical particles of α-Al_2O_3 (corundum) have a sharp emissivity maximum peaking at 12.7 μm. The difference of 0.3 μm in the peak position compared to the mean observed band profile is a serious obstacle to assigning the 13 μm dust feature to this dust species. ii) From a continuous distribution of ellipsoidal α-Al_2O_3-particles, a broad emissivity profile peaking at 13 – 14 μm emerges. It is difficult to reconcile the large width of this profile with the width of the observed 13 μm band. iii) The most prominent emissivity maximum of TiO_2 (rutile) is located at 13.5 μm; its width is larger and its strength three times smaller than the emissivity maximum of corundum. iv) Core-mantle-grains composed of rutile and corundum or of corundum and amorphous olivine can both produce, in a certain domain of core volume fractions, a spectral signature very similar to the observed 13 μm feature. However, the necessity to assume rather artificial distribution functions of the core volume fractions makes this scenario improbable. v) We consider $MgAl_2O_4$ (spinel) to be the most promising candidate for the carrier of the 13 μm feature since its emissivity peaks are located at 12.95 μm and at 16.8 μm for spherical particles and since at *both* positions features are present in most of the spectra of our sample. In view of the relevance of this substance for circumstellar shells, laboratory spectra of spinel particles embedded in KBr are also presented.

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A high-resolution study of episodic mass loss from the carbon star TT Cygni

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CO radio line observations with the IRAM Plateau de Bure interferometer show that the carbon star TT Cyg is surrounded by a large (radius $\sim$35″ or 2.7×10^{17} cm), geometrically thin (average width $\sim$2.5″ or 1.9×10^{16} cm) shell of gas, which has a remarkable overall spherical symmetry (e.g., its radius varies by less than $\pm$3%). It expands with a velocity of $\sim$12.6 km s^{-1}. The emitting gas is very evenly distributed in the shell when averaged over a solid angle of about 0.2 steradians. We estimate a molecular hydrogen density of $\sim$250 cm^{-3}, a gas kinetic temperature of $\sim$100 K, and a mass of $\sim$0.007 M$_\odot$ for the shell if the medium is homogeneous. There is no evidence for matter immediately inside or outside the shell, nor is there any evidence for structure in the radial direction of the shell brightness distribution (it is essentialy perfectly fitted with Gaussians). The shell centre is displaced $\sim$1.7″ (position angle $\sim$–20°) with respect to the star. We favour an interpretation of this displacement in terms of TT Cyg being a member of a binary system. We put forward several arguments for a shell medium that consists almost entirely of a large number of small ($\leq$1″) clumps (in which case the density required to fit the observational data is much higher, $\sim10^4$ cm^{-3}, and the kinetic temperature is considerably lower, $\leq$20 K). TT Cyg is presently losing mass at a modest rate, $\sim3\times10^{-8}$ M$_\odot$ yr^{-1}, and with a low expansion velocity, $\sim$3.8 km s^{-1}. This is inferred from CO line emission from a region centred on the present position of the star. The systemic velocity is estimated, from both the centre and the shell emission, to be –27.3$\pm$0.1 km s^{-1} in the LSR system. All quantitative results are obtained assuming the Hipparcos distance of 510 pc.

These data strongly support that TT Cyg has recently ($\sim7\times10^3$ yr ago) gone through a period of drastically varying mass loss properties. We discuss briefly two scenarios: a short period (a few hundred years) of very intense mass loss (a rate in excess of 10^{-5} M$_\odot$ yr^{-1}), and a related scenario with a more modest mass ejection and where most of the shell gas is swept-up from a previous, slower stellar wind. It is presently not possible to favour any of these two scenarios, but we suggest that in either case it is a coordinated mass ejection that caused the shell formation. The He-shell flash phenomenon in AGB-stars can provide this coordination, and it also fits the time scales involved.

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The dust content of planetary nebulae: a reappraisal

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We have performed a statistical analysis using broad band IRAS data on about 500 planetary nebulae with the aim of characterizing their dust content. Our approach is different from previous studies in that it uses an extensive grid of photoionization models to test the methods for deriving the dust temperature, the dust-to-gas mass ratio and the average grain size. In addition, we use only distance independent diagrams.

With our models, we show the effect of contamination by atomic lines in the broad band IRAS fluxes during planetary nebula evolution. We find that planetary nebulae with very different dust-to-gas mass ratios exist, so that the dust content is a primordial parameter for the interpretation of far infrared data of planetary nebulae. In contrast with previous studies, we find no evidence for a decrease in the dust-to-gas mass ratio as

the planetary nebulae evolve. We also show that the decrease in grain size advocated by Natta & Panagia (1981, ApJ 248,189) and Lenzuni et al. (1989, ApJ 345, 306) is an artefact of their method of analysis. Our results suggest that the timescale for destruction of dust grains in planetary nebulae is larger than their lifetime.

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Optical and near-infrared spectrophotometric properties of Long Period Variables and other luminous red stars

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Based on a new and large sample of optical and near-infrared spectra obtained at the Mount Stromlo and Siding Spring Observatories (Lançon & Wood 1998; Lançon & Wood, in preparation), spectrophotometric properties of cool oxygen- and carbon-rich Long Period Variables and supergiants are presented. Temperatures of oxygen-rich stars are assigned by comparison with synthetic spectra computed from up-to-date oxygen-rich model atmosphere grids. The existence of reliable optical and near-infrared temperature indicators is investigated. A narrow relation between the bolometric correction BC_I and the broad-band colour I−J is obtained for oxygen-rich cool stars. The ability of specific near-infrared indices to separate luminosity classes, atmospheric chemistry or variability subtypes is discussed. Some comments are also given on extinction effects, water band strengths in Long Period Variables and the evaluation of $^{12}CO/^{13}CO$ ratio in red giants.

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CO content of bipolar planetary nebulae

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We report high-sensitivity millimeter-wave CO observations of recently discovered bipolar planetary nebulae (PNe). Three objects (BV 5-1, K 3-94 and K 3-24) have been detected, and one of them (BV 5-1) is resolved by the ∼10'' telescope beam. The envelopes of the three newly detected objects display values of the molecular to ionized mass ratio of ∼ 0.2, and sizes of ∼ 0.1 pc. This indicates that these PNe are rather evolved, with K 3-24 being the youngest of the three (∼ 10^3 years) according to its CO line profile and kinematic ages.

In BV 5-1, the molecular gas appears to be distributed in an irregular disk or ring surrounding the central star and perpendicular to the bipolar nebula. This is similar to the situation found in other better studied bipolar PNe (e.g. NGC 2346, M 2-9, KjPn8), and thus seems to be the rule in this class of objects. This suggests a common mechanism for the rings and the bipolar flows that shape the optical nebula.

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Preprints can be obtained by contacting josselin@oan.es

A New Look At Carbon Abundances In Planetary Nebulae. IV. Implications For Stellar Nucleosynthesis

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This paper is the fourth and final report on a project designed to study carbon abundances in a sample of planetary nebulae representing a broad range in progenitor mass and metallicity. We present newly acquired optical spectrophotometric data for three Galactic planetary nebulae IC 418, NGC 2392, and NGC 3242 and combine them with UV data from the IUE Final Archive for identical positions in each nebula to determine accurate abundances of He, C, N, O, and Ne at one or more locations in each object. We then collect abundances of these elements for the entire sample and compare them with theoretical predictions of planetary nebula abundances from a grid of intermediate mass star models. We find some consistency between observations and theory, lending modest support to our current understanding of nucleosynthesis in stars below 8 $M_{\odot}$ in birth mass. Overall, we believe that observed abundances agree with theoretical predictions to well within an order of magnitude but probably not better than within a factor of 2 or 3. But even this level of consistency between observation and theory enhances the validity of published intermediate-mass stellar yields of carbon and nitrogen in the study of the abundance evolution of these elements.

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The hypersonic, bipolar, knotty outflow from the Engraved Hourglass planetary nebula, MyCn18

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The remarkable velocity structure of the different components of the young planetary nebula MyCn18 have been revealed by obtaining imagery and spatially resolved spectrometry of the Hα and N[II] $\lambda\lambda$ 6548 Å & 6584 Å lines with the Manchester echelle spectrometer combined with the 3.9 m Anglo-Australian telescope.

The bright, bipolar, nebular core is shown to be composed of two extended hemispherical cavities whose axis is tilted at 52° to the plane of the sky. Ionized flows, at $\leq$ 90 km s^{-1} and parallel to the walls of these cavities are occurring.

The full extent of the elongated bipolar assembly of high-speed knots which apparently lie along the same axis is now revealed in a continuum subtracted image in the light of the Hα and N[II] $\lambda\lambda$ 6548 Å & 6584 Å nebular emission lines. Complete spatial coverage of line profiles from these knots is also presented for the first time. In their most likely configuration, these knots are shown to have a range of outflowing speeds of $\leq$ 630 km s^{-1} that are proportional to their distance from the central star. There is some degree of point/velocity symmetry, indicating that some pairs of knots have been ejected in opposing directions at the same speed. Curiously, the line profiles from the knots are very narrow i.e. from 15 to 30 km s^{-1}. Among several possible explanations of the origin of these hypersonic knots is a recurrent nova–like ejection from a central binary star.

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Metallicity distribution of bulge planetary nebulae and the [O/Fe] × [Fe/H] relation

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The O/H metallicity distribution of different samples of planetary nebulae in the bulge of the Milky Way and M31 are compared. O/H abundances are converted into [Fe/H] metallicity by the use of theoretical [O/Fe] × [Fe/H] relationships both for the bulge and the solar neighbourhood. It is found that these relationships imply an offset of [Fe/H] abundances by a factor up to 0.5 dex for bulge nebulae. Systematic errors in the O/H abundances as suggested by some recent recombination line work, ON cycling and statistical uncertainties are unable to explain the observed offset, suggesting that the adopted relationship for the bulge probably overestimates the oxygen enhancement relative to iron.

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The circumstellar CO emission of RV Bootis.
Evidence for a Keplerian disk?

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We report on high-resolution CO J=1–0 and J=2–1 interferometric observations of the oxygen-rich semiregular variable RV Boo supplemented by single-dish multi-transition data of CO(J=1–0, 2–1, 3–2, 4–3). Detections of the thermal SiO(v=0, J=2–1, 3–2) transitions as well as the vibrationally excited SiO(v=1, J=2–1) line are also reported. The interferometric CO J=2–1 observations, with a spatial resolution of about 1.7″, reveal a disk-like structure of size 4.2″ × 3.3″ around RV Boo. Furthermore, the position-velocity information along a line through the center of the source at a position angle of about 150° can be interpreted as a sign of Keplerian rotation. Six symmetrically placed features, possibly corresponding to three rings, around a central feature are seen. These observations may therefore, to our knowledge, present the first indications of a rotating disk around an AGB star. However, it cannot be fully excluded that the observed kinematical structure is caused by a bipolar outflow. From the single-dish CO observations we estimate the molecular mass of the source to be $3 \times 10^{-5}\,M_{\odot}$.

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Identification of SH $\Delta v = 1$ ro-vibrational lines in R And

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We report the identification of SH $\Delta v = 1$ ro-vibrational lines in the published high-resolution infrared spectrum of the S-type star, R And. This is the first astronomical detection of this molecule. The lines show inverse P-Cygni profiles, indicating infall motion of the molecular layer due to stellar pulsation. A simple spherical

shell model with a constant infall velocity is adopted to determine the condition of the layer. It is found that a single excitation temperature of 2200 K reproduces the observed line intensities satisfactory. SH is located in a layer from 1.0 to $\sim$ 1.1 stellar radii, which is moving inward with a velocity of 9 km s^{-1}. These results are consistent with the previous measurements of CO $\Delta v = 3$ transitions. The estimated molecular abundance SH/H is 1×10^{-7}, consistent with a thermal equilibrium calculation.

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On the Puzzle of the Anomalous Oxygen Recombination Lines in Planetary Nebulae

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We discuss the conundrum of the O II recombination lines in planetary nebulae (PNe). The strengths of these lines in a few previously observed PNe indicated implausibly high O/H abundances. In a survey of ten PNe, we find several for which the O/H values from O II recombination lines agree with those derived from collisionally excited [O III] lines, and others in which the recombination lines yield abundances that are higher by up to factors of 4–5. Certain transitions tend to yield higher abundances than other lines. We interpret this as a line enhancement effect due to an unidentified physical mechanism which is more significant for some lines and nebulae than others. We speculate that elevated dielectronic recombination rates, perhaps in hot gas, or time-dependent effects such as ionization or recombination fronts, may be responsible.

To appear in "Asymmetrical Planetary Nebulae II: from Origins to Microstructures," ASP Conference Series, J.H. Kastner, N. Soker, & S.A. Rappaport, eds.
Preprints can be obtained by contacting harriet@astro.as.utexas.edu

Extinction Mapping of the Bipolar Outflow NGC 2346

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We have acquired narrow band imaging of NGC 2346 in the transitions HI λ6563 Å + λ4861 Å and [OIII] λ5007 Å. As a result, we are able to evaluate the variation of both excitation and extinction over the projected central parts of the nebular shell.

Extinction appears to be surprisingly uniform, and there is (in particular) little evidence for the reddening asymmetries proposed in previous analyses. Cusp-like enhancements in A_v at the periphery of the source are attributed to a layer of extincting material at the limits of the HII region, implying a value of major axis reddening $\Delta A_v < 0.5$ mags. Similar extinctions are also deduced from an analysis of infrared and millimetric observations. It is unclear what proportion of this reddening may be attributed to the molecular belt, although it seems likely that this feature contributes ~ 0.3 mags of extinction in the northern lobe, and explains the N-S asymmetries noted in optical images.

Given that levels of local extinction are quite modest, it seems likely that the larger part of the observed reddening ($A_v \approx 2$ mags) arises from intervening IS material; a conclusion which is again at variance with

previous analyses. Such a presumption would explain the relative uniformity in extinction over the face of the nebula, and similarity between distances estimated from extinction, and those determined through alternative analyses. If this is accepted, however, then it follows that prior estimates of central star extinction must be greatly in error.

One possible origin for this error is noted from Hubble imagery in [NII] λ6584 Å, where it is clear that a secondary star is located close to the presumed A-type central star; a component which was not allowed for in previous analyses. It is unclear whether this star is physically associated with the core binary system.

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The young detached CO shell around U Camelopardalis

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We report IRAM Plateau de Bure interferometer observations of the carbon star U Cam in the CO(J=1−0) and CO(J=2−1) lines. The remarkable images show that U Cam is surrounded by a geometrically thin, $\sim 10^{16}$ cm, shell of gas at a distance of $\sim 6\times10^{16}$ cm from the star, that expands with a velocity of $\sim$23 km s^{-1}. The estimated mass of the shell is low, $\sim 10^{-3}$ M$_\odot$. In addition, we detect emission that peaks at the stellar position. From this we estimate a present mass loss rate and gas expansion velocity of $\sim 2.5\times10^{-7}$ M$_\odot$ yr^{-1} and 12 km s^{-1}, respectively. One possible explanation to the structure of the circumstellar medium is that the shell was produced during a very short period, $\sim$150 yr, of high mass loss rate, $\sim 10^{-5}$ M$_\odot$ yr^{-1}, about 800 yr ago. U Cam may fit into the scenario where a helium-shell flash modulates the mass loss rate on short times scales.

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2.4 – 197 μm spectroscopy of OH/IR stars: The IR characteristics of circumstellar dust in O-rich environments

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Infrared spectra of a number of evolved O-rich stars have been obtained with the Short- and Long- Wavelength spectrometers on board the Infrared Space Observatory. The very broad wavelength coverage (2.4–197μm) obtained by combining observations made with the two spectrometers includes practically all of the flux emitted by the sources, and allows us to determine the emission and absorption features of the dense circumstellar dust

shells. Agreement between the fluxes obtained by the two instruments is generally very good; the largest discrepancies are probably due to source variability. Our sample of oxygen-rich AGB stars exhibits a wealth of spectral features due to crystalline silicates and crystalline water ice in emission and absorption. In this study a qualitative overview of all features due to crystalline silicates and water ice in these high mass loss rate objects is presented. It seems that there is a certain onset value for the mass loss rate above which these features appear in the spectrum. Moreover, crystalline silicate emission features have been detected for the first time at wavelengths where the amorphous silicates are still in absorption, implying different spatial distributions for the two materials. A spherically symmetric and an axi-symmetric geometry are proposed.

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or via anonnymous ftp on ftp://ceres.astro.uva.nl/pub/ciska/H1687.ps

Planetary nebulae: abundances and abundance gradients

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In this work, a review is given of some recent results and problems involved in the determination of chemical abundances of galactic planetary nebulae, particularly regarding disk and bulge objects.

Invited review, Workshop Chemical evolution of the Milky Way: stars versus clusters, F. Giovannelli, F. Matteucci (eds.), Kluwer, in press
Preprints can be obtained by contacting maciel@iagusp.usp.br
or via WWW on http://www.iagusp.usp.br/~maciel/index.html

Announcements

DUSTY: A New Version

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A new release of the radiative transfer code DUSTY, which models emission from sources in dusty environments, is available at *http://www.pa.uky.edu/~moshe/dusty/*. The new version can handle both spherical and planar geometries, runs much faster and has an improved user interface. Furthermore, DUSTY now allows user control of its wavelength grid, which can be modified to accommodate spectral features of interest.

DUSTY has been tested on a variety of existing platforms. The solution, including dust scattering, absorption and emission, is exact to within the specified numerical accuracy. The code has built in optical properties for the most common types of astronomical dust and is supplied with a library for many others. It supports various analytical forms for input, and can perform a full dynamical calculation for radiatively driven winds around AGB stars. Arbitrary dust optical properties, density distributions and external radiation can be entered in user supplied files. A single DUSTY run can process an unlimited number of models, with each input set producing a run of optical depths, as specified. The user controls the detail level of the output, which can include spectral, imaging and radial properties as well as other quantities of interest.

We welcome user feedback for improving both the program and its manual, and would greatly appreciate comments and suggestions sent to:

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