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Abstracts of recently accepted papers

Semiregular variables of types SRa and SRb. New JHKL′M-photometry for 200 stars.

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This paper presents new JHKL′M observations of 200 Semiregular variables (SRVs) of types SRa and SRb. The sample was defined in Kerschbaum & Hron (1992, Paper I) by means of a certain limit in bolometrical magnitude. From the sample of 350 objects, 260 now have near infrared (NIR) photometry – for 60 of these stars data from the literature are used. In total 290 datasets are available because of some multiple observations.

We briefly compare the photometry obtained at different observatories. Small but significant differences are found.

A first analysis of the photometry supports one of the main findings of Paper I. The, in many aspects inhomogenous, O-rich semiregular variables of types SRa and SRb can be successfully split in two subgroups called the 'blue' and 'red'/'Mira' SRVs. A separation of the 'red' SRVs from intrinsic Miras additionally requires variability information.

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Detection of Radio Continuum Emission from Circumstellar Dust Around CRL 2688 and IRC+10216

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We report the detection by the VLA of continuum emission at 8.4 GHz (3.6 cm) from the evolved carbon stars CRL 2688 and IRC+10216. The emission from CRL 2688 extends at least 15″ (2×10^{17} cm at 1 kpc distance) from the star. Comparison with the infrared and submillimeter flux shows that the likeliest mechanism is emission from warm circumstellar dust; if so, the dust emissivity is high at wavelengths well into the radio

régime; the best-fit long-wavelength power-law exponent is $\beta \sim 0.8$. This high emissivity shows that the dust has amorphous or layered structure, and also offers the possibility of mapping the distribution of matter in circumstellar envelopes at high angular resolution at wavelengths where the emission is optically thin.

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A revised model for circumstellar molecular emission

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A model is presented to calculate the line profiles of thermal emission of molecules in an expanding spherically symmetric circumstellar envelope. Special attention is given to the heating and cooling mechanisms which determine the kinetic temperature of the gas. The constraints that the presence of dust put on the molecular emission model are discussed. The following processes are found to have an effect of more than 10% on the integrated intensities (relative to a standard model): cooling by ^{13}CO and HCN in carbon stars, cooling by H_2O in oxygen-rich stars, and the location of the inner boundary of the molecular shell. The model including all physical features considered predicts CO(6-5) intensities which are 25% larger and CO(1-0) intensities which are 10% smaller than those of the standard model. Photoelectric heating can be the dominant source of heating in the outer layers, thereby determining the CO(1-0) intensity, depending on the beam size of the telescope and the efficiency of the shielding of UV radiation by dust.

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The mass loss rates of OH/IR 32.8–0.3 and OH/IR 44.8–2.3

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In a previous paper a model was presented to calculate the thermal emission of molecules around a central star. The model includes a self-consistent determination of the gas kinetic temperature, photoelectric heating, cooling by water molecules and the constraint that the presence of dust puts on the molecular excitation.

The model is applied to the CO(1-0) and CO(2-1) observations of the OH/IR stars OH32.8–0.3 and OH44.8–2.3 (abbreviated to OH32.8 and OH44.8). Both come from the sample observed by Heske et al. (1990) who noted that in the less extreme OH/IR stars (like OH44.8) the mass loss rate derived from infrared properties agrees reasonably well with that estimated from the CO emission but that in extreme OH/IR stars (like OH32.8) the mass loss rate derived from the infrared is an order of magnitude larger than that derived from CO emission.

For a dust opacity at 60 μm of 228 $cm^2 gr^{-1}$ the best model for OH44.8 has the following parameters: $\dot{M} = 9.0\ 10^{-6}\ M_\odot/yr$, dust-to-gas ratio $\Psi = 0.0035$ and mean dust grain size $a = 0.14\ \mu m$. The derived mass loss rate is insensitive to the adopted opacity. The results are relatively insensitive to any model assumptions.

For OH32.8 no model is found that fits the observed line profiles for a constant mass loss rate throughout the envelope. For a grain size of $a = 0.125\ \mu m$, an opacity of 228 $cm^2 gr^{-1}$ (following the result for OH44.8) and a mass loss history in which the mass loss rate drops by a factor of 10 for radial distances larger than a critical distance R_c, the following model reproduces the observed intensities: (present-day) $\dot{M} = 2.0\ 10^{-5}\ M_\odot/yr$, $\Psi = 0.015$ with $R_c \approx 1.3\ 10^{17}$ cm (corresponding to a timescale of about 2800 years). Models with $\dot{M} \gtrsim 4.0\ 10^{-5}\ M_\odot/yr$ can not be made to fit the observations, models with $\dot{M} < 2.0\ 10^{-5}\ M_\odot/yr$ probably can, but result in higher dust-to-gas ratios ($\Psi \sim \dot{M}^{-1}$).

The distinction made by Heske et al. (1990) between moderate OH/IR stars (like OH44.8) and extreme OH/IR stars (like OH32.8) can be understood as follows: the CO shell in the extreme OH/IR stars is so large that the outer part samples a previous phase of lower mass loss, several 10^3 yrs ago.

Finally, I comment on the possibility that in extreme mass losing stars the temperature in the outer parts of the circumstellar shells drops below the cosmic background radiation temperature. Based on the models for the two OH/IR stars I derive that this occurs if $\dot{M}_{-5} \gtrsim 4.8\ Q_{0.01}\ L_4^{4/3}\ v_{10}^{1/3}$, where $Q_{0.01}$ is the effective absorption coefficient in units of 0.01, $\dot{M}_{-5}$ is the mass loss rate in 10^{-5} $M_\odot$/yr, L_4 the stellar luminosity in 10^4 $L_\odot$ and v_{10} the expansion velocity of the shell in 10 km/s. This relation is expected to be valid for oxygen-rich stars and standard values for the dust opacity and the photoelectric heating rate.

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Evidence for the Early Onset of Aspherical Structure in the Planetary Nebula Formation Process: Spectropolarimetry of Post-AGB Stars

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We present optical spectropolarimetry of 31 post-asymptotic giant branch (post-AGB) stars, objects that are believed to represent the first phases of the transition from the AGB to the planetary nebula stage. Twenty-four of these objects are found to be intrinsically polarized. We group these objects into four classes based on their observed polarization properties, P(λ) and $\theta(\lambda)$, and discuss possible explanations for the observed behaviors. Type 1 objects display high levels of polarization and large position angle rotations. Type 2 objects lack large position angle rotations, but have polarizations too large to be attributed to foreground interstellar material. Type 3 objects show position angle rotations and polarization changes across TiO absorption features; and finally, Type 4 are objects in which the observed polarization can be entirely attributed to interstellar effects. The currently popular paradigm of planetary nebula morphology of a dense torus plus bipolar lobes can explain the P and θ behavior of the Type 1 and Type 2 objects. However, a large number of the objects exhibit time-variable P and θ. This implies that their morphologies may not be stable, but rather evolving or transient structures. Regardless of any specific model for the morphology, our main result is that aspherical structure appears very early in the transition from the AGB to the planetary nebula stage.

We compare the polarization properties of the post-AGB stars to the morphological characteristics of evolved planetary nebulae. Our results indicate that the nebular morphology may originate at an early evolutionary stage. We do not observe any correlation between chemistry (O-rich versus C-rich) and polarization class in the AGB stars. We examine the formation of aspherical planetary nebulae in the context of binary star evolution. If bipolar geometry is a consequence of binary star evolution, the number of highly polarized post-AGB stars in our sample requires a high binary star frequency.

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The particle size distribution in the dust ejected from IRC+10216

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We propose that in the outer envelope (> 15" from the star) around IRC+10216 the grains are amorphous carbon spheres of radius a with a size distribution of the form $n(a) \sim a^{-3.5} exp(-a/a_0)$ and $a_0 \approx 0.10$ μm. Small grains ($a << a_0$) are required to explain the shielding of circumstellar molecules against destruction by interstellar ultraviolet radiation. Larger grains ($a >> a_0$) are required to explain the observed circumstellar polarization at K-band. In this model ~0.1% of the mass in the ejected dust is contained in particles that are larger than 1 micron in diameter. If the size distribution of the ejected SiC particles is similar to the size distribution that we derive for the amorphous carbon grains, then at least some of the micron-sized SiC inclusions in meteorites thought to originate from mass-losing carbon stars may have been produced in the outflows from stars such as IRC+10216. **Accepted by Astrophysical Journal** *For preprints, contact* jura@bonnie.astro.ucla.edu

Circumstellar CO around bright oxygen-rich semi-regulars

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We report high signal to noise millimeter wave observations of 11 nearby Semi-Regular variables, most with periods between 89 and 160 days, in the transitions ^{12}CO ($J = 2 - 1$) and ($J = 1 - 0$) and ^{13}CO ($J = 2 - 1$). The line profiles have been fitted by a model including molecular excitation and radiative transfer and the derived envelope properties (expansion velocity, mass loss rate, outer radius, kinetic temperature distribution) are compared to the predictions of theoretical models. The mass loss properties of this sample of Semi-Regulars appear to be very similar with those of longer period ($300 \leq$ P < 400 days) Miras, observed with the same telescope. This result is consistent with the view that the Semi-Regulars are overtone pulsators while the Miras are in the fundamental pulsational mode. The pulsational mode does not strongly affect the mass loss from the star.

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Direct optical observations of the secondary component of UU Sagittae

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CCD photometry and spectroscopy are presented for the eclipsing binary central star of the planetary nebula Abell 63, obtained during several primary minima. High signal-to-noise and high time resolution photometry show that the eclipse is total and the duration of the flat-bottomed portion of the minimum is ~ 14 min. At this point in the light curve, the observed flux must originate from the averted hemisphere of the cool secondary star without contamination from the hot, luminous primary component. The observed $(V-I)_{\rm c}$ colour index at phase 0.0 is 0.96 ± 0.09. If this star can be thought of as a main-sequence star then $(V-I)_{\circ} = 0.34 \pm 0.25$ implying $T_{\rm eff} = 7\,200^{+1\,500}_{-1\,300}$ K. When the dereddened flux distribution of the cool star is compared with that predicted from model atmospheres, good agreement can be obtained with a model generated using $T_{\rm eff} = 6\,250 \pm 250$ K and $\log g = 4.5$. The astrophysical data derived using this temperature show little variation from those found by Pollacco & Bell. Consistency with post-AGB evolution tracks appropriate to the mass of the primary component can only be obtained if a limb-brightened model for the cool star is invoked. Using the distance of 2.4 ± 0.4 kpc derived from our analysis, the ionized mass of Abell 63 is found to be at least an order of magnitude less than that expected for typical old, low density planetary nebulae and is more closely related to the amount of material expelled during a large nova outburst.

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A radiation-gasdynamical method for numerical simulations of ionized nebulae: The Radiation-Gasdynamics of Planetary Nebulae I

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We present a numerical method to combine radiation processes for diffuse gaseous nebulae with numerical gasdynamic methods. The method encompasses detailed calculations of the ionization, heating, and cooling processes. We have constructed two codes based on different gasdynamic numerical methods: FCT/LCD and a Roe Solver. We apply the two new radiation-gasdynamics codes to the interacting winds model for the formation of planetary nebulae and compare the new results to the non-radiative results.

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From the Owl to the Eskimo: The Radiation-Gasdynamics of Planetary Nebulae IV

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We present the results of two-dimensional radiation-gasdynamic simulations of aspherical Planetary Nebulae (PNe) evolution. These simulations were constructed using the Generalized Interacting Stellar Winds (GISW) scenario of Balick (1987) where a fast, tenuous wind from the central star expands into a toroidal, slow, dense wind. We demonstrate that the GISW model can produce a wide range of aspherical flow patterns. The dependence of the shock morphology on the initial parameters conforms to the expectations of analytical models (Icke 1988). We find that radiative cooling slows the evolution of the forward shock by removing energy from the hot bubble and that radiation heating and cooling changes the temperature structure of the shocked slow wind material.

We have constructed self-consistent synthetic observations of the models from forbidden line emissivities used in the energy loss term. We present integrated intensity and long-slit spectrum, (Position-Velocity) maps of the models projected at different angles on the sky. These synthetic observations are compared with real intensity and Position-Velocity maps of PNe. We find that there is a very good match between the synthetic and real observations in terms of morphologies, kinematics, and physical conditions.

From the results of these simulations we conclude that the GISW scenario can account for most, if not all, PNe morphologies, thus confirming Balick's (1987) conjecture.

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Broken Symmetry: The Structure of the Dust Envelope of IRC +10216

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We present polarimetric, coronagraphic near-infrared images of the reflection nebula surrounding the carbon star IRC +10216. These images demonstrate convincingly that the dust envelope is not spherically symmetric. In unocculted images at J (1.25 μm) and in occulted images at H (1.65 μm) and K (2.2 μm), the nebula appears elongated, with major axis lying at position angle $\sim 20^o$. The position angle of elongation is the same as that previously determined from near-infrared speckle interferometry for the inner $\sim 1''$ of the envelope. The elliptical symmetry of the J polarimetric map offers additional evidence of the axial symmetry of the envelope, and indicates that the equatorial plane of IRC +10216 lies perpendicular to the major axis of the nebula. The polarization map also indicates that the source of illumination — presumably the stellar photosphere or hot dust located very near the photosphere — is directly detected at wavelengths as short as ~ 1 μm. We find that

the density distribution of grains in the polar regions is roughly $n \propto r^{-2}$, and estimate that the scattering dust mass within $12''$ in radius of the central star is $\sim 5 \times 10^{-6} M_{\odot}$.

These results support a model in which the envelope of IRC +10216 is weakly bipolar and is viewed at an intermediate inclination angle such that we have a direct line of sight to the central star. The axisymmetric near-infrared intensity and polarization morphologies are best understood in terms of enhanced mass loss in the equatorial plane. An examination of previous near-infrared and millimeter-wave mapping observations supports this hypothesis. These observations make clear that axisymmetric structure can be well established before an intermediate-mass star leaves the asymptotic giant branch. It is possible that the dust envelope of IRC +10216 presents an early manifestation of the more profound bipolar structure that characterizes highly evolved pre-planetary nebulae.

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Two-fluid models for stationary dust driven winds
I. Momentum and energy balance

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Self-consistent two-fluid models of stationary dust driven winds around cool C-stars have been calculated. The dust and the gas component are coupled by the condensation of dust from the gas phase and grain-gas collisions and are described by separate sets of equations.

It was found that in the regime of substantial mass loss where purely dust driven winds are possible the dust grains move with their equilibrium drift velocity relative to the gas. Compared to one-fluid models the dust component is dynamically diluted, leading to a decreased radiative acceleration of the wind in the outer region.

We have included detailed energy exchange rates between gas and radiation field by vibrational transitions of CO and pure rotational transitions of dipolar molecules (CO, HCN, C_2H, C_3H, CS, SiS). Our models show that frictional heating by drifting dust grains raises the gas temperature considerably above its radiative equilibrium value. This leads to significant extension of the dust condensation zone.

A sequence of models with increasing luminosities shows that the drift velocity of the dust decreases for higher luminosities. Consequently the drift related effects are more pronounced at lower luminosities.

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SN 1987A's Circumstellar Envelope, I: The Shape of the Double-Lobed Nebula and Its Ring, and the Distance to the LMC

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We have used light echoes from the inner few arcseconds of the region around SN 1987A to define the three-dimensional geometry of its circumstellar nebula. SN 1987A appears to be surrounded by a double-lobed nebula, the waist of which is nearly coincident with the prominent elliptical ring, $1.7''$ in major axis length, readily seen in atomic recombination lines. The symmetry axis of this double-lobed structure corresponds closely to the axis that would also imply that the ring is actually circular, and just seen as an ellipse in projection. (We caution that the southern lobe may appear slightly off the symmetry axis defined by the northern lobe and ring.) By confining the range of ring geometries, this supports previously described techniques using the light travel time across the ring compared to its angular size to produce an estimate the distance to SN 1987A. With corrections for the distance between the SN and the LMC disk at that end of the galaxy, as well as the correction to the center of the LMC caused by the tilt of the galaxy, one can infer a distance to the LMC of 51.9 ± 3.1 kpc (or 52.9 ± 2.6 kpc if one simply assumes that the ring is circular).

We also note that the red supergiant wind contains a density concentration in the ring plane, as anticipated by hydrodynamic models for the double-lobed nebula. There is evidence, however, that the velocity of this wind might be faster at the poles than along the equator. We put observational limits on the presence of a companion star which might be responsible for these anisotropies.

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Dissertation Abstracts

Internal Structure and Optical Appearance of Circumstellar Dust Shells around Cool Carbon Giants

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Cool late–type giant stars represent important stages in the evolution of low and intermediate mass stars. These objects generally are surrounded by extended circumstellar dust shells accompanied by considerable mass loss.

In this thesis, detailed physical models of the dust forming circumstellar shells around late–type carbon–rich giants are presented. These models include a consistent treatment of hydrodynamics, thermodynamics, chemistry, dust formation and growth and of the radiative transfer problem. The complete atmospheric structure as well as the infrared appearance of the models is a result of the calculations.

This work is divided into two major parts.

In the first part, a selfconsistent solution of the stationary, spherical symmetric dust driven wind problem is presented. The resulting shell structure and the mass loss rate are completely determined by the four fundamental stellar parameters stellar mass $M_\star$, stellar luminosity $L_\star$, stellar temperature $T_\star$ and the element abundances ϵ_i. The results imply, that in a stationary dust driven wind the common assumption of the small particle approximation for calculating the transport coefficients of the dust component is not justified. In particular in the inner shell region, the radiative force acting on the grains is essentially reduced by the presence of large particles. The dependence of the models on the stellar parameters is discussed and the resulting spectra are compared to the observations in the frame of infrared two colour diagrams. Application of these model calculations to the prominent infrared object IRC +10216 yields best agreement with the observed energy distribution and the interferometric data obtained at light maximum for the stellar parameters $M_\star = 0.7 M_\odot$, $L_\star = 2.4 \cdot 10^4 L_\odot$, $T_\star = 2010\text{K}$ and a carbon to oxygen ratio of $\epsilon_\text{C}/\epsilon_\text{O} = 1.40$, which yields a mass loss rate of $\dot{M} = 8 \cdot 10^{-5} M_\odot \text{yr}^{-1}$. From this model a distance to IRC +10216 of $d = 170\text{pc}$ is deduced. The total mass contained in the circumstellar dust shell implies an initial main sequence mass of $M_\text{ZAMS} \geq 1.3 M_\odot$ for IRC +10216.

In the second part, the results of detailed frequency and angle–dependent radiative transfer calculations are presented, which are based on time–dependent models for the pulsating atmospheres around carbon–rich Long–period variable stars (LPVs). These models are specified by the four fundamental stellar parameters and two additional quantities, which describe the interior pulsation of the star. In these calculations, the transport coefficients of the dust component are described in the small particle limit of Mie theory, which is justified in the case of a pulsating atmosphere. Due to the periodic formation of dust layers, an inhomogeneous radial dust distribution is produced, which decisively influences the optical appearance of the models. It is shown that the synthetic lightcurves exhibit intermediate maxima and secondary periods, which similarly occur in the observed lightcurves of real LPVs. The spectra of the dynamic models are compared with observations in the frame of a near infrared two colour diagram. For a physically consistent modelling of the near infrared spectra, it turns out to be necessary to take the effects of the stellar pulsation into account. The discrete shell–like distribution of dust also causes significant structures in the surface brightness profiles and in the synthetic visibility functions, which are in qualitative agreement with the respective observations.

The discrete structure of the circumstellar dust shell for the first time provides an explanation for both, the significant characteristics present in the observed lightcurves of carbon–rich LPVs as well as for the small–scale structures present in the observed spatial spectra and in the brightness profiles.

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