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Abstracts of recently accepted papers

Circumstellar dust envelopes of oxygen-rich AGB stars

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Using IRAS observational data, the best-fitting models are searched for oxygen-rich AGB stars in various evolutionary stages from optically visible red giant stars to OH/IR stars with heavy mass loss. The model infrared spectral energy distributions of the red giant stars with circumstellar dust envelopes are calculated with the use of a radiative transfer code.

It is found that the oxygen-rich IRAS AGB stars surrounded by circumstellar dust envelopes are divided into three groups, which can be clearly distinguished by their mass loss rate and the grain temperature at the inner boundary of the circumstellar dust envelopes. One group corresponds to Mira type objects with a moderate mass loss rate and a grain formation temperature of about 500 K, the second to OH/IR star type objects with a large mass loss rate and a high grain formation temperature, and the third to M stars with a very cold grain temperature at the inner boundary, indicating that the moderate mass loss stopped a considerable time ago in these objects. The higher grain formation temperature of the OH/IR star type objects indicates a grain formation point closer to the stellar surface, suggesting an effective acceleration of dust grains by radiation pressure. Such an effective acceleration can play an important role in the mass loss phenomena of OH/IR stars with large mass loss rates.

From the model fitting results, it is suggested that an AGB star undergoes several dozen phases of moderate mass loss of $\dot{M} \sim 10^{-7} - 10^{-6} M_{\odot}\mathrm{yr}^{-1}$ for a period of $10^3 - 10^4$ years with interruptions of $10^3 - 10^4$ years during the ordinary Mira variable phase before becoming an OH/IR star with a mass loss rate exceeding $10^{-5} M_{\odot}\mathrm{yr}^{-1}$ and a lifetime of about $10^3 - 10^4$ years.

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Dust shells around infrared carbon stars

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The spectral energy distributions (SEDs) and LRS spectra of 21 infrared carbon stars are fitted using a dust radiative transfer model. The parameters derived are the temperature of the dust at the inner radius (T_{inn}), the mass loss rate and the ratio of silicon carbide (SiC) to amorphous carbon (AMC) dust. Mass loss rates between a few 10^{-6} and 1.3 10^{-4} $M_\odot$ yr^{-1} are found. The SiC/AMC ratio and $T_{\rm inn}$ are found to decrease with increasing S_{25}/S_{12} ratio. The former correlation may be due to an increasing C/O ratio. The latter correlation may be due to the fact that dust growth continues until the density is too low. For increasing mass loss rates (i.e. larger S_{25}/S_{12} ratios) this leads to larger effective dust radii and hence to a decrease of $T_{\rm inn}$.

The standard model with a constant mass loss rate and amorphous carbon dust (with $Q_\lambda \sim \lambda^{-\beta}$; $\beta \approx 1$ for $\lambda >$ 30 μm) predicts too much flux at 60 and 100 μm compared to the observations. The discrepancy increases with the S_{25}/S_{12} ratio. This indicates that either $\beta > 1$ and/or that the mass loss rate has been lower in the past. Mass loss histories as proposed by Bedijn (1987) and related to thermal pulses are considered. An increase in the mass loss rate by a factor of 3-30 over the past 10^4 yrs or β's in the range 1.2-1.9 both fit the observed IRAS 60 and 100 μm flux-densities. Theoretically one expects that β decreases or remains constant as the dust continuum temperature decreases, contrary to the β's needed to fit the observed IRAS 60 and 100 μm flux-densities. This points to the mass loss histories rather than a steeper slope of the absorption coefficient to explain the observed 60 and 100 μm flux-densities, at least for the reddest stars in the sample. Both mass loss histories predict sub-mm fluxes in better agreement with observations than a large value for β. From the SEDs the precise form of the mass loss rate history can not be reconstructed. It is suggested that with mapping the circumstellar shell with 2" resolution in the far-infrared and sub-mm region this may become possible.

An excess emission above the dust emission and photospheric component is found at sub-mm wavelengths for all seven stars where sub-mm data is available. This is possibly due to free-free emission.

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The evolution of Galactic carbon stars

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Based on a comparison of observations with new synthetic AGB evolution calculations we propose a revised evolutionary scenario for carbon stars in the solar neighbourhood. From observations we derive that the lowest initial mass from which carbon stars form is about 1.5 $M_\odot$. This constraint combined with four other constraints (the observed initial-final mass relation, the birth rate of carbon stars, the observed abundance ratios in planetary nebulae (PNe) and the number ratios C/M and S/C of AGB stars) are used to derive the following parameters for the synthetic AGB evolution model. Third dredge-up occurs for core masses above 0.58 $M_\odot$ and the dredge-up efficiency is $\lambda = 0.75$. We consider a Reimers mass loss law (with a scaling factor $\eta_{\rm AGB}$) and the mass loss rate law recently proposed by Blöcker & Schönberner (1993; with a scaling factor $\eta_{\rm BS}$). We find $\eta_{\rm AGB} = 4$ and $\eta_{\rm BS} = 0.08$. Both models fit the observations equally well.

The model predicts that stars in the range 1.5 $M_\odot \lesssim M \lesssim 1.6$ $M_\odot$ become carbon stars at their last thermal pulse (TP) on the AGB and live only a few 10^4 yrs as carbon stars. More massive stars experience additional TPs as carbon stars (up to about 25 for a 3 $M_\odot$ star) and live up to 10^6 yrs. For $M \gtrsim 4$ $M_\odot$ hot-bottom burning prevents the formation of carbon stars. For $M \lesssim 2$ $M_\odot$, M-stars skip the S-star phase when they become carbon stars. The average lifetime of the carbon star phase is $\sim$3 10^5 yrs.

The carbon stars for which C/O ratios have been derived in the literature (with values $\lesssim 1.5$) are predominantly optical carbon stars with a 60 μm excess. Yet, disk PNe are known with C/O ratios up to about 4. We predict that carbon stars with C/O ratios $\gtrsim 1.5$ are to be found among the infrared carbon stars. The model predicts that the probability that a carbon star has C/O $\gtrsim 1.5$ is about 30%, in reasonable agreement with the observed ratio of the surface density in the galactic plane of infrared carbon stars to all carbon stars. The infrared carbon stars are predicted to be (on average) more massive than the optical carbon stars.

The fact that carbon stars with C/O $\gtrsim 1.5$ apparently never reach the optical carbon star phase (with a detached shell) is probably due to differences in evolution. If indeed infrared carbon stars are on average more massive (i.e. have larger core masses) than optical carbon stars, the interpulse period is shorter, and the increase in

luminosity during the TP is smaller (due to the larger envelope mass). Both effects will decrease the likelihood of a detached shell to occur. We predict that two-thirds of all detached shells around optical carbon stars are oxygen-rich.

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The Distribution of HCN, $H^{13}CN$ and CN in IRC+10216

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We present aperture synthesis images of mm-wavelength molecular emission lines of HCN (J=1–0 at 88.6 GHz), $H^{13}CN$ (J=1–0 at 86.3 GHz) and CN (N=1–0, J=3/2–1/2 at 113.5 GHz) toward the carbon star IRC+10216. The HCN and $H^{13}CN$ images were made with the BIMA interferometer, while the CN images were from a combination of interferometer and single-dish data. The HCN and $H^{13}CN$ images have an angular resolution of 8 arcsec and a velocity resolution of ~ 1.3 km s^{-1}; the CN images have an angular resolution of 11 arcsec and a velocity resolution of ~ 0.9 km s^{-1}. The images show that HCN and $H^{13}CN$ are found concentrated towards the center of the envelope, while CN is found in a shell surrounding the central star. The data for HCN and $H^{13}CN$ are compared with the output of a statistical equilibrium code, which takes into account the excitation by IR photons and collisions with H_2, and calculates the radial brightness profiles and spectra. The models are used to determine the abundance distribution of $H^{13}CN$. HCN is too optically thick for accurate modelling; we infer the HCN abundance by scaling $H^{13}CN$ up by a factor of 40. For CN, a simple LTE calculation is used to derive the abundance of the molecule as a function of distance from the star. The distributions of HCN and CN are qualitatively consistent with chemical models for AGB star envelopes. Our best estimate of the peak CN/HCN abundance ratio is about 0.12, and the radius of the peak CN abundance is 19 arcsec from the star. Both of these values are significantly less than recent photochemical model predictions. We suggest that CN photodissociates or reacts with other radicals or ions more rapidly than these models assume.

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A Survey of Lithium in the Red Giants of the Magellanic Clouds

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A spectroscopic search for the Li I λ6707 resonance line has been carried out in 112 red giants from both the Small and Large Magellanic Clouds. The spectra are a mixture of high – ($R = \frac{\lambda}{\Delta\lambda} = 18,000$) and low-resolution ($R = 4,000$) data and the stars surveyed consist of spectral types M, S, and C. Most of these stars have absolute bolometric magnitude, $M_{\rm bol}$, determinations available from various published investigations. The Li I line is detected in 35 of these red giants (29 S stars and 6 C stars). All stars with a measurable Li I feature are asymptotic giant branch (AGB) stars with the majority (26) being luminous S-stars within the narrow luminosity range of $-7.2 \lesssim M_{\rm bol} \lesssim 6.0$ ($\bar{M}_{\rm bol} = -6.52 \pm 0.38$ in this subset of the stars.) Abundance estimates of lithium in these stars fall in the range of $\log \epsilon$(Li)$\sim 1.0 - 4.0$. The presence of Li in these highly-evolved AGB stars is ascribed to hot-bottom convective envelope (HBCE) burning and a comparison of the Li abundances derived here with published models of HBCE shows reasonably good agreement.

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Hβ luminosities of planetary nebula central stars

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The determination of the luminosities of planetary nebula central stars from Hβ nebular fluxes is investigated. A correlation is obtained with the luminosities derived from independent stellar parameters. An average scaling factor is determined for Hβ luminosities of optically thick nebulae, as well as correlations of this parameter with the Zanstra HeII and HI temperatures.

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Full Synthesis Maps of Circumstellar SiC_2 in IRC+10216

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The molecule SiC_2 in the circumstellar shell around the evolved star IRC+10216 has been mapped using the BIMA millimeter-wave interferometer. In this paper we present results of a full synthesis mapping of the 4_{22}-3_{21} transition of SiC_2. This is an improvement over earlier interferometry of SiC_2 because we have used single-element observations to fill in the central "hole" in the Fourier transform plane; data taken with the NRAO 12-meter telescope were combined with the interferometry to fully sample the *u-v* plane. A comparison of the full synthesis maps in the present work is made with previous interferometry of SiC_2. Full synthesis maps show a clear shell-like structure with a bipolar symmetry. Our results indicate that SiC_2 is distributed in a shell with inner and outer radii $\sim 2 \times 10^{16}$ cm and $\sim 6 \times 10^{16}$ cm, respectively. We estimate a fractional abundance, $[SiC_2]/[H_2]$, of 1.4×10^{-6}. The fractional abundance of SiC_2 in the inner envelope ($\lesssim 5 \times 10^{-8}$) is at least an order of magnitude less than the calculations of thermal equilibrium chemistry will allow. The most likely reason for the discrepancy is that silicon is rapidly incorporated into grains in the inner envelope; grain formation is not considered in the thermal equilibrium models. Implications for the chemistry and evolution of the circumstellar envelope are discussed.

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Morphological populations of planetary nebulae: which progenitors? I. Comparative properties of bipolar nebulae

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We have investigated morphological *vs.* physical properties of planetary nebulae (PNe). The sample consists of about 400 objects with high quality optical images. An extensive list of 43 bipolar (*butterfly*) nebulae has been built by adding to our data several objects found in the literature.

Particular emphasis has been given to the comparison between the elliptical and bipolar nebulae. We find that the latter class has:
a) a scale height on the Galactic plane of 130 pc compared to the value of 320 pc for the elliptical objects and of 260 pc for the global sample of Galactic disk PNe;
b) smaller deviations than the other morphological types from pure circular Galactic rotation;

c) the hottest central stars among PNe;
d) chemical overabundaces of helium, nitrogen and *neon*;
e) outflow velocities up to one order of magnitude larger than the typical expansion velocities of PNe;
f) giant dimensions.

We also suggest empirical evolutionary tracks for PNe in the two–colour IRAS diagram.

The above properties indicate that *bipolar PNe are produced by more massive progenitors than the other morphological classes.* We conservatively adopt a lower limit of 1.5 $M_{\odot}$ for the progenitors of bipolar PNe and solar values ($M \lesssim 1.1$ $M_{\odot}$) for the ellipticals.

The present results can be used to constrain the discussion of the AGB mass loss geometry and the formation of the different morphological classes of PNe. Models considering *single* or *interacting binary* stars are reviewed.

The peculiar nature of M 2–9 is discussed separately.

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Dissertation Abstracts

Radiative effects in extended stellar atmospheres: Application to the formation of emission lines in long-period variables.

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The long-period variables of Mira type are pulsating stars of the asymptotic giant branch. Strong emission lines, especially the Balmer transitions of hydrogen around the maximum of luminosity, are observed in their spectrum together with the typical spectral features of cold stars. This thesis is devoted to the formation of these strong emission lines.

We investigate the non-LTE radiative effects that could be present in the hydrogen recombination zone of the miras. We study this region by solving the equations of radiative transfer together with the equations of statistical equilibrium in a layer illuminated from one side. We show that strong emission lines created by fluorescence mechanisms emerge from this zone, which is found quite deep in the Mira atmosphere. We also propose that the cold spectral features are formed higher, mainly by pure absorption mechanisms.

We suggest to mimic the cycle of variations of the miras as resulting from the shift of the hydrogen recombination zone in the star. This region would be found deeper at the minimum of luminosity. The emerging spectrum would then be cool without any lines. At the maximum of luminosity the H II/H I zone would be formed higher and the strong Balmer lines would emerge in emission.