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Abstracts of recently accepted papers

Atomic Carbon in the Circumstellar Envelopes of Evolved Stars

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We report JCMT observations of the 609 μm ground-state fine-structure line of neutral atomic carbon in the circumstellar envelopes of a sample of evolved late-type stars. C I emission is detected in the envelopes of α Ori and IRC+10216 with line intensities of 10.9 K km s^{-1} and 3.9 K km s^{-1}, respectively, but is not detected in other envelopes (including Mira) down to much lower levels of 0.4–1.9 K km s^{-1}. The detections are in good agreement with previous C I observations indicating that C I is not present in the inner envelope of IRC+10216 (with a C I/CO abundance ratio of $\lesssim$0.01) but is present in a shell structure of radius 14″, whereas in α Ori C I is the main carrier of carbon in the inner envelope, with C I/CO $\approx$ 5. The absence of C I emission from the other stars places upper limits on C I/CO in the bulk of their envelopes of $\lesssim$1 in most cases, implying that CO is a good indicator of their mass-loss rates. The extreme case of α Ori can be ascribed to its supergiant status and the presence of a chromosphere.

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Axisymmetrical Structures of Planetary Nebulae and SN 1987A

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I summarize some recent models and ideas for the formation of axisymmetrical structures of planetary nebulae and the three rings of SN 1987A, as follows. (a) I review the general role of binary companions, including brown dwarfs and planets. (b) I propose a mechanism for axisymmetrical mass loss on the AGB that may account for the axially symmetric structures of elliptical planetary nebulae and that operates for slowly rotating AGB stars, $10^{-4}\Omega_{\rm Kep}\lesssim\Omega\lesssim10^{-2}\Omega_{\rm Kep}$, where $\Omega_{\rm Kep}$ is the equatorial Keplerian angular velocity. (c) I propose a model for the formation of the two outer rings of SN 1987A, which is based on the numerical simulation of Soker (1989), and discuss a mechanism for their displacement from the exploding star.

In the proceedings of the conference Physical Processes in Astrophysical Fluids (January 1998). Will be published as a special volume of Physics Reports.

Preprints can be obtained by contacting soker@physics.technion.ac.il

The circumstellar shell of the post-AGB star HD 56126: the $^{12}C^{12}C/^{12}C^{13}C$ isotope ratio and $^{12}C^{16}O$ column density

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We have made the first detection of circumstellar absorption lines of the $^{12}C^{13}C$ $A^1\Pi_u - X^1\Sigma_g^+$ (Phillips) system 1-0 band and the $^{12}C^{16}O$ $X^1\Sigma^+$ first-overtone 2-0 band in the spectrum of the post-AGB star HD 56126 (IRAS 07134+1005). All current detections of circumstellar molecular absorption lines towards HD 56126 ($^{12}C_2$, $^{12}C^{13}C$, $^{12}C^{14}N$, $^{13}C^{14}N$, and $^{12}C^{16}O$) yield the same heliocentric velocity of $v_{\rm CSE} = 77.6 \pm 0.4$ km s^{-1}. ¿From a curve of growth analysis of the $^{12}C_2$ Phillips band lines ($v'' = 0$, $v' = 1, 2, 3, 4$) we infer a Doppler broadening parameter of $b = 0.49 \pm 0.05$ km s^{-1}. The $^{12}C_2$, $^{12}C^{13}C$, and $^{12}C^{16}O$ lines give rotational temperatures and integrated column densities of $T_{\rm rot} = 328 \pm 37$ K, $\log N_{\rm int} = 15.34 \pm 0.10$ cm^{-2}, $T_{\rm rot} = 256 \pm 30$ K, $\log N_{\rm int} = 13.79 \pm 0.12$ cm^{-2}, and $T_{\rm rot} = 51 \pm 37$ K, $\log N_{\rm int} = 18.12 \pm 0.13$ cm^{-2} respectively. The rotational temperatures are lower for molecules with a higher permanent dipole moment. Derived relative column densities ratios are $^{12}C_2/^{12}C^{13}C = 36 \pm 13$, and $^{12}C^{16}O/(^{12}C_2 + ^{12}C^{13}C) = 606 \pm 230$. Combined with data from Paper III we find relative column densities of $^{12}C^{16}O/(^{12}C^{14}N + ^{13}C^{14}N) = 475 \pm 175$ and $^{12}C^{14}N/^{13}C^{14}N = 38 \pm 2$.

Under chemical equilibrium conditions, $^{12}C^{13}C$ is formed twice as easily as $^{12}C_2$. The isotopic exchange reaction for $^{12}C_2$ is too slow to significantly alter the $^{12}C_2/^{12}C^{13}C$ ratio and the $^{12}C_2$ to $^{12}C^{13}C$ ratio a good measure of half the carbon isotope ratio: $^{12}C/^{13}C = 2 \times ^{12}C_2/^{12}C^{13}C = 72 \pm 26$. This is in agreeement with our prediction in Paper III that the isotopic exchange reaction for $^{12}C^{14}N$ is efficient.

A fit of the C_2 excitation model of van Dishoeck & Black (1982) to the relative population distribution of C_2 yields $n_c\sigma/I = 3 \pm 1 \times 10^{-14}$. At $r \simeq 10^{16}$ cm this translates in $n_c = 2 \times 10^5$ cm^{-3} and $\dot{M} \simeq 1 \times 10^{-5}$ M$_\odot$ yr^{-1}.

Submitted to ApJ. *Preprints can be obtained by contacting* e.j.bakker@fel.tno.nl
or via WWW on http://viking.as.utexas.edu:8080/articles.html

Full polarization structure of the OH mainline maser envelopes of W Hydrae

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Simultaneous MERLIN observations of the OH 1665- and 1667-MHz maser lines in the circumstellar envelope of the semi-regular star W Hya have been taken in all Stokes parameters. The 1665-MHz emission comes from two elongated clusters located 80 au from the star. The 1667-MHz emission arises in an incomplete shell of radius 130 au, with the blue-shifted features located in the northern part of the envelope and the red-shifted components clustered south of the centre. The circularly polarized maser components exhibit spatial separation along the north-south direction. The linearly polarized components were found from the near side of the envelope. Their polarization position angles indicate that the projected axis of the magnetic field at PA$\simeq -20^\circ$ is consistent with spatial segregation of circular polarization. The intensity of the magnetic field, estimated from a tentative

measurement of Zeeman splitting, is about 0.6 mG at the location of the 1667-MHz emission, with the field pointing away from the observer. A small change of position angles of linear polarization observed in both maser lines is interpreted as a weak Faraday effect in the maser regions with the electron density of about 2 cm^{-3}. The overall polarization structure of the envelope suggests an ellipsoidal or weak bipolar geometry. In such a configuration, the circumstellar magnetic field may exert a non-negligible influence on mass loss. The velocity field in the circumstellar envelope recovered from observations of SiO, H_2O, OH and CO lines at five radial distances reveals a logarithmic velocity gradient of 0.25 and 0.21 in the 1665- and 1667-MHz maser regions respectively. The acceleration within tens of stellar radii cannot be explained by the classical model of radiation pressure on dust.

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or via WWW on http://asterix.astro.uni.torun.pl/ msz/msz_pub.html

Hydrodynamical models and synthetic spectra of circumstellar dust shells around AGB stars: II. Time-dependent simulations

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We have employed time-dependent two-component hydrodynamics / radiative transfer calculations to investigate the structure, dynamics and emergent spectral energy distribution of dusty circumstellar shells around carbon and oxygen stars in the final stages of their AGB evolution. These internally consistent, physical models describe a stellar wind driven by radiation pressure on dust grains and subsequent momentum transfer to the gas component via collisions. Detailed stellar evolution calculations, with a prescribed mass loss rate that is a function of the fundamental stellar parameters, have been used as a time-dependent inner boundary condition for the numerical solution of the coupled equations of hydrodynamics and frequency-dependent radiative transfer governing the structure and temporal evolution of the circumstellar dust/gas shell.

The calculations are based on one particular evolutionary track for an initial stellar mass $M_{\rm i} = 3.0\ M_\odot$ and a final mass $M_{\rm f} = 0.605\ M_\odot$, but for different assumptions concerning the composition of the dust grains: amorphous carbon or "astronomical" silicates. Using our hydrodynamics code to simulate the dynamical response of the circumstellar wind shell to the evolutionary changes of the stellar parameters, we find that the large temporal variations of stellar luminosity and mass loss rate associated with the final thermal pulses near the end of the AGB evolution lead to characteristic, time-dependent signatures in the density structure and emergent energy distribution of the circumstellar dust shell. We present the resulting "loops" in the IRAS two-color-diagram, which we find to extend to regions quite remote from the simple color-color relation defined by steady state models.

These time-dependent hydrodynamical models explain the existence of carbon and oxygen stars with excess emission near $\lambda 60$ and $100\,\mu$m as a natural consequence of the sharp decrease of the mass loss rate following a thermal pulse, leading to the development of a *detached dust shell*. As an illustration, we present a series of synthetic spectra and corresponding $100\,\mu$m surface brightness distributions showing the time-evolution of the circumstellar dust emission during a thermal pulse cycle, both for a carbon–rich and an oxygen–rich dust shell.

We demonstrate that it is unrealistic to assume a fixed velocity profile which is independent of mass loss rate: to a first approximation, the gas velocity is a bimodal function of the mass loss rate. A short event of high mass loss does *not* simply translate into a correspondingly narrow, high-density shell moving through the circumstellar envelope. Rather, the signature of a short mass loss peak broadens due to velocity gradients as it moves towards the outer regions of the wind. Hence, this is hardly a viable scenario to explain the existence of very thin molecular shells that have recently been detected around some carbon stars. Our simulations suggest a more promising mechanism producing thin shells of enhanced gas density in the outer regions of carbon–rich AGB shells: interaction of winds of different speed and density.

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Preprints can be obtained by contacting MSteffen@aip.de

76 mas speckle–masking interferometry of IRC +10 216 with the SAO 6 m telescope: Evidence for a clumpy shell structure

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We present the first K′-band image of the carbon star IRC +10 216 with 76 mas resolution. The diffraction-limited image was reconstructed from 6 m telescope speckle data using the speckle masking bispectrum method. The image shows that the dust shell of IRC +10 216 is extremely clumpy. Five individual clouds within a 0.21 as radius of the central star have been resolved for the first time. On the basis of consistent theoretical models we argue that these structures are produced by circumstellar dust formation. The fragmentation of the shell structure gives most likely direct evidence for an inhomogeneous mass-loss process which may be interpreted in terms of large-scale surface convection-cells (Schwarzschild 1975) being a common phenomenon for red giants.

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Preprints can be obtained by contacting weigelt@mpifr-bonn.mpg.de
or via WWW on http://www.speckle.mpifr-bonn.mpg.de/publications.html
or via anonymous ftp on 134.104.20.101 *in* /pub/papers/Weigelt_etal_AuA_333_L51_1998/WBBFOW98.ps.gz

Infrared monitoring of OH/IR stars near the Galactic Center

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We have monitored 102 fields of size $1\prime \times 1\prime$ within ∼0.7deg of the Galactic Center for 1200 days in the K band. Each field was centered on one of the OH/IR stars found by Lindqvist et al. (1992). Infrared colours $J-K$, $H-K$ and $K-L$ were also obtained. Periods have been determined for 80 known OH/IR stars, including 5 from Sjouwerman (1997), and a further 29 previously unknown long-period variables (LPVs) of large (> 0.5 mag.) K amplitude. The overall period distribution of the variables extends from ∼200 days to ∼1100 days and it is dominated by LPVs with $P < 600$ days. The existence of LPVs with $P < 300$ days indicates the presence of sub-solar metallicity, old, low mass stars near the Galactic Center. These old LPVs have luminosities equal to those of similar LPVs elsewhere in the Galaxy. However, the LPVs with $P > 300$ days near the Galactic Center have lower luminosities and higher wind expansion velocities $v_{\rm exp}$ at a given period than similar stars in the Galactic bulge or solar vicinity, indicating that the metal abundance of Galactic Center stars is ∼2-4 times solar. Another consequence of the observed low luminosities of the Galactic Center LPVs is that the $(M_{\rm bol}, \log P)$ and $(K, \log P)$ relations must be metallicity dependent, at least for metallicities of solar or above. The maximum periods and luminosities of Galactic Center LPVs exceed those of bulge LPVs suggesting that there are AGB stars near the Galactic Center which are more massive than any stars in the bulge. AGB masses up to ∼4 $M_\odot$ are relatively common, with a few AGB stars having masses up to ∼7 $M_\odot$. There should be ∼1000 main-sequence precursors in the same volume for each of these massive AGB stars. The high expansion velocity ($v_{\rm exp} > 18$ km s^{-1}) OH/IR stars are separated from the lower expansion velocity OH/IR stars in the $(M_{\rm bol}, \log P)$ diagram: this separation suggests that the stars with higher $v_{\rm exp}$ have higher metallicity, as well

as being younger. The overall results suggest that ongoing star formation and metal enrichment have occurred near the Galactic Center.

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Preprints can be obtained by contacting wood@mso.anu.edu.au *or via anonnymous ftp on* ftp://merlin.anu.edu.au/pub/wood/pap

A theoretical model for episodic mass-loss producing detached shells around bright carbon stars

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We present stellar evolution models of the final AGB phase, in which the star undergoes heavy and optically thick mass-loss ("superwind" phase). Our computations are based on consistent, pulsating wind models for carbon-rich stars and include a detailed treatment of dust formation, radiative transfer and wind acceleration (Fleischer et al. 1992). For a specific mass range, around 1.2 $M_\odot$ stellar mass at the foot-AGB and only about 0.2 $M_\odot$ wide, we find particularly pronounced episodic mass-loss which is consistent with all properties of the detached CO shells found by Olofsson et al. (1990, 1993, 1996) around bright carbon stars: kinematic ages of 1 to 2 $\times 10^4$yrs, masses of several 0.01 $M_\odot$, and a mass-loss duration of less than several thousand years.

The physics, micro-physics, and chemistry of our dust-induced superwind is essential for understanding such details of the final stellar mass-loss history. Unlike other superwind models, our mass-loss rate depends very sensitively on the stellar temperature – about $\propto T_{\rm eff}^{-8}$ – and our models require a minimum luminosity to be surmounted. Together, that yields a much pronounced mass-loss variation with the late thermal pulses. In particular, our models suggest the formation of CO shells in the final 2 to 6 $\times 10^4$yrs on the tip-AGB – if the stellar luminosity is close to the critical (Eddington–like) luminosity $\log L_c$ (around 3.5 to 3.7, depending on $T_{\rm eff}$), while the star has only $\lesssim 0.2 M_\odot$ left to lose towards the exposure of its hot core.

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Preprints can be obtained by contacting schroder@weizen.physik.tu-berlin.de

Irregular variables of type Lb. Circumstellar CO emission of an oxygen-rich sample

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We report on the first systematic study of the mass-loss properties of O-rich irregular variables of type Lb. ^{12}CO (J=1–0, 2–1, and 3–2) line observations were carried out using the SEST, the Onsala 20 m telescope, and the JCMT. In total 20 stars were detected among the 31 objects observed (all are new detections; in three cases detections are precluded because of strong interference from interstellar CO emission). Hence, the detection rate is very high for this sample selected on the basis of the 60 μm flux strength. The majority of the detected objects are weak in CO, and the inferred mass-loss rates are low ($\lesssim 10^{-7}$ M$_\odot$/yr). They have, with only a few exceptions, envelopes with small gas expansion velocities (the mean value is $\approx$8 km/s). We find that their mass-loss properties are very similar to those of bright O–rich semiregular (SRa or SRb) and Mira variables, i.e., at least in this mass-loss rate range the stellar mass-loss properties are not strongly influenced by the pulsational behaviour of the star.

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Preprints can be obtained by contacting kerschbaum@astro.univie.ac.at WWW *or via WWW on* http://www.ast.univie.ac.at/ fzi/