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Abstracts of recently accepted papers

The 218 day period of the peculiar late B-type star HD 101584

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We have searched for periodicity in the photometric and spectroscopic variations of the enigmatic star HD 101584 and found a long-term variability on a typical time scale of 1700 days (4.7 years) and a highly significant period of 218 ± 0.7 day. This period is most prominently present in the photometric indices which are a measure for the Balmer jump (Geneva d and Strömgren c_1^0). The Doppler velocities of the high-excitation photospheric absorption lines (He I and C II) seem to be variable with the photometric period. Our data favor the 218 day period for the Doppler velocities with a small probability that the true period is 436 days. We argue that HD 101584 is a close (highly) eccentric 218 day binary system with a low-mass unseen secondary. The photometric and Doppler variations are attributed to changes in the velocity law and mass-loss rate of the stellar wind which lead to asymmetric line profiles and a phase dependent Balmer discontinuity. Binary interaction is responsible for the changes in velocity law and mass-loss rate leading to the observed phenomena.

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CO in planetary nebuale and proto-planetary nebulae

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The evolution between the asymptotic giant branch (AGB) and the planetary nebulae (PN) phases has long been a "missing link" in our understanding of stellar evolution. Through the study of cool IRAS sources, an increasing number of transition objects, or "proto- planetary nebulae", has now been identified. The CO molecule has been found to be a useful tracer of the evolution from the AGB to PN. The detection of CO emission in PN represents one of the key piece of evidence that PN are created from the circumstellar envelopes of AGB stars through the interacting winds process.

Invited review, IAU Symp 170, CO: 25 years of millimetre wave spectroscopy, Tucson, 1995

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Spectral analyses of late–type WC central stars of planetary nebulae

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The optical spectra of the seven late–type Wolf–Rayet central stars NGC 40 ([WC8]), BD+30°3639 ([WC9]), He 2–99 ([WC9]), CPD−56°8032, He 2–113, M 4–18 and K 2–16 (all [WC11]) are analyzed by means of spherically expanding model atmospheres. The NLTE simulations account for the elements helium, carbon and oxygen. As main results effective temperature T_*, element abundances and final velocity of the wind v_∞ are determined for each star. Assuming distances or luminosities for the objects, also the stellar radii and the mass–loss rates can be fixed. The values of T_* and v_∞ are found to be correlated with the spectral subtype ([WC8]: 78 kK, 1000 km s^{-1}; [WC9]: 47 – 49 kK, 700 – 900 km s^{-1}; [WC11]: 30 – 32 kK, 200 – 350 km s^{-1}). The obtained carbon–to–helium ratios are about unity (by mass), and the oxygen abundances are between 4 and 10 % (mass fractions). Stellar hydrogen abundances are below the limit of save detection in all cases (typically ≤ 2 % by mass); however in one star (He 2–113) we find a weak indication for the presence of hydrogen. Furthermore the occurrence of nitrogen lines in two of the stars (He 2–113, K 2–16) is discussed qualitatively. The results of these analyses put empirical constraints for the evolutionary status of WC–type central stars as post–AGB objects and provide input for modeling their planetary nebulae.

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/pub/leuenhagen/preprints/Leuenhagen_Hamann_Jeffery_95.ps.gz

H_2 Emission from Planetary Nebulae: Signpost of Bipolar Structure

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We report the results of an imaging survey of 2.122 μm H_2 emission from $\sim$ 60 planetary nebulae (PNe). We detected 23 PNe, including 11 first time detections. Adding from the literature 48 PNe previously searched for H_2, we find that $\sim$ 40% of the combined sample displays H_2 emission. The detections are dominated by objects that possess bipolar morphology (i.e., those that display well defined polar lobes and/or equatorial regions in optical images). All 7 H_2-emitting PNe that are not considered bipolar (based on Hα images) are rings or disks, strongly suggesting that these objects are in fact bipolar PNe viewed at large inclinations. This interpretation also follows from the fact that the brightest H_2 emission is typically located along the equatorial plane (waist) of a bipolar nebula, and that several nebulae that are bipolar in optical emission lines appear ring-like in H_2. We therefore confirm the validity of Gatley's rule: the detection of H_2 emission from a PNe confirms the bipolar structure of that PNe. The H_2-bright waist (or torus, in the case of a Ring-like PN) is presumably the remnant of a molecule-rich circumstellar disk that predates the production of a PN. We confirm and strengthen the claim that PNe detected in H_2 are confined to lower galactic latitudes, and therefore had larger progenitor masses, than PNe without detectable emission. These results therefore reinforce the connection between PN progenitor mass, PN morphology, and the presence or absence of 2.122 μm H_2 emission.

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Bipolar flow in a slowly expanding circumstellar envelope around X Her

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We report high signal to noise millimeter wave CO observations of the circumstellar envelope around the nearby oxygen-rich Semi-Regular variable X Her. This envelope is partially resolved by the IRAM 30m telescope at 1mm and the line shapes appear narrower and more complex than most of the profiles observed towards AGB envelopes. We interpret the CO (1−0) and (2−1) profiles as resulting from three components in the wind : a very slowly expanding spherical component ($v_{exp} = 2.5$ km s^{-1}) and two higher-velocity components ($v_{exp} \geq 10$ km s^{-1}). These "high-velocity" components are symmetrically displaced compared to the slow component and are likely to be the red and blue shifted cones of a weakly collimated bipolar flow, probably seen with a small viewing angle ($\sim 15°$).

The bipolar flow contains between one fifth and one third of the total detected circumstellar gas mass of about 3×10^{-4} M$_\odot$. The mass loss rate in the bipolar flow of about 1×10^{-7} M$_\odot$ yr^{-1} is comparable to the rate in the slowly expanding spherical envelope.

The mechanism responsible for non-spherical mass loss is still unclear, but there is strong evidence for asymmetries in or very near the stellar photosphere. The asymmetric flow may be especially conspicuous since the spherical portion of the mass loss has such a low velocity.

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Dust Emission from IRC+10216

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Infrared emission from the dust shell around IRC+10216 is analyzed in detail, employing a self-consistent model for radiatively driven winds around AGB stars that couples the equations of motion and radiative transfer in the dust. The resulting model provides agreement with the wealth of available data, including the spectral energy distribution in the range 0.5–1000 μm, and visibility and array observations. Previous conclusions about two dust shells, derived from modeling the data with a few single-temperature components of different radii, are not supported by our results. The extended, continuous temperature and density distributions derived from our model obviate the need for such discrete shells. The IR properties vary with the stellar phase, reflecting changes in both the dust condensation radius r_1 and overall optical depth τ — as the luminosity increases from minimum to maximum, r_1 increases while τ decreases. We find that the angular size of the dust condensation zone varies from $0\farcs3$ at minimum light to $0\farcs5$ at maximum. The shortage of flux at short wavelengths encountered in previous studies is resolved by employing a grain size distribution that includes grains larger than ~ 0.1 μm, required also for the visibility fits. This distribution is in agreement with the one recently proposed by Jura (1994) in a study that probed the outer regions of the envelope. Since our constraints on the size distribution mostly reflect the envelope's inner regions, the agreement of these independent studies is evidence against significant changes in grain sizes through effects like sputtering or grain growth after the initial formation at the dust condensation zone.

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Infrared Imaging of Late-Type Stars

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Infrared imaging properties of dusty winds around late-type stars are investigated in detail, employing a self-consistent model that couples the equations of motion and radiative transfer. Because of general scaling properties, the angular profiles of surface brightness are self-similar. In any given star, the profile shape is determined essentially by overall optical depth at each wavelength and it is self-similarly scaled by the size of the dust condensation zone. We find that mid-IR is the best wavelength range to directly measure the angular size of this zone, and from IRAS data we identify the 15 best candidates for such future observations. We also show that the visibility function at short wavelengths ($< 2\mu m$) directly determines the scattering optical depth, and produce theoretical visibility curves for various characteristic wavelengths and the entire parameter range relevant to late-type stars. The infrared emission should display time variability because of cyclical changes in overall optical depth, reflecting luminosity-induced movement of the dust condensation point. Calculations of the wavelength dependence of photometric amplitudes and time variability of envelope sizes are in agreement with observations; envelopes are bigger and bluer at maximum light.

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Exact Analytic Solutions for Stellar Wind Bow Shocks

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Stellar wind bow shocks have been seen in association with a wide variety of stellar objects from pulsars to young stars. A new solution method is presented for bow shocks in the thin-shell limit, stressing the importance of the conserved momentum within the shell. This method leads to exact analytic solutions to the classical problem of Baranov, Krasnobaev & Kulikovskii (1971). Simple formulae are given for the shell shape, mass column density and velocity of shocked gas at all points in the shell. These solutions will facilitate detailed comparison between observed sources and bow shock models.

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The Sensitivity of Circumstellar Masers to Dust Type

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The incidence of masers in oxygen-rich circumstellar shells is correlated with their IRAS low resolution spectral type (LRS). Thus 67% of shells with silicate emission features and 27% of those without have mainline OH masers when they have a known water or SiO maser. This result does not depend on IR color. The generality of a dependence in the incidence of masers on dust-type is tested here by compiling statistics from extant OH, water and SiO observations. These show that these masers each have a similar dependence on dust type that is independent of the IR colors in thin shells. The detection rate for water and for OH masers from LRS 21-25 type shells is intermediate between that of "featureless" (1n) shells and that of shells with a stronger 9.7 μm line. When the joint occurrence of water and mainline masers is considered, there is a factor of 5 difference between detection rates from the most disparate LRS types, that is not reduced much by treating all OH masers together.

This LRS-type dependence of masers is caused by a change in the UV extinction of dust with type, which is expected when the size of dust grains about most objects *without* silicate features is $\geq$0.02 μm, so the scattering of UV becomes important. More of the UV photons are then available to degrade molecules, which reduces their ability to support masers. These changes in the incidence of masers are postulated to result from an increase in the number of large, absorptive rather than scattering, grains as the silicate feature strengthens: there is also some evidence for a UV wavelength dependence to the dust-grain extinction. The previously noted blue IR color sensitivity of both the water and OH mainline detection rates is, however, an artifact of a changing proportion of the various LRS types with color.

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Jets in Planetary Nebulae

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The occurrence of highly collimated outflow phenomena in Planetary Nebulae is reviewed. The observations are diverse. Sometimes fast knots are seen (so called FLIERs), sometimes more jet-like phenomena are observed. These structures are normally not only anomalous in their outflow velocity, but also in their (N) abundance. The presence of a hot star further complicates their structure. Several models for the formation of these structures have been proposed but none go into much detail. These models are reviewed as well.

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A spectral line survey observation of IRC+10216 between 28 and 50 GHz

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This paper report on a spectral-line survey of the circumstellar envelope of IRC+10216 between 28 and 50 GHz using the Nobeyama 45-m telescope with a sensitivity $<$ 10 mK. A total of 188 spectral lines were observed, 150 of which have been assigned to 22 molecules and their isotopic variants. We derived the column densities and excitation temperatures of the observed species by using a local thermodynamic equilibrium approximation. The observed frequency range is characterized by many long carbon chain molecules, up to HC_9N, as well as by 38 unidentified lines.

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Discovery of the first extra-galactic SiO maser

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We report on the detection of SiO J=2–1 v=1 (86 GHz) maser emission from the red supergiant IRAS04553–6825 in the LMC. It has thereby become the first known source of SiO maser emission outside the Milky Way. We used the Swedish-ESO Submm Telescope at the European Southern Observatory at La Silla. With the help of good atmospheric conditions, the excellent performance of the brand new 3 mm SIS receiver, and 26 hours total observing time we reduced the noise level to only 63 mJy rms. This allowed us to detect the 0.28 Jy maser peak. Integrating the flux of the maser profile resulted in a 6.9 σ detection. The SiO maser peak was situated 16 km s^{-1} redward of the center of the already known, double peaked OH maser emission. We argue that the SiO maser peak velocity coincides with the stellar velocity, which is supported by a spectrum of Hα that we took four months later. This would mean that the outflow velocity of the circumstellar matter around IRAS04553–6825 is $v_{exp} \sim 26$ km s^{-1}, which is typical for galactic red supergiants, instead of the abnormally low 11 km s^{-1} inferred from the OH data alone. The peak intensity of the SiO maser emission is not incompatible with ranges found in galactic RSGs, but the total integrated photon flux is lower than expected for this extremely red and luminous supergiant.

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A Moderate-Resolution Spectral Atlas of Carbon Stars: R, J, N, CH, and Barium Stars

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We have compiled a moderate-resolution spectral atlas to aid in the classification of carbon stars on the Revised MK System (Keenan 1993) as refined and extended by the present work. The main purpose of this atlas is to permit rapid and reasonably accurate comparison of the properties of carbon stars in the Solar neighborhood with those in the Galactic bulge, the Magellanic Clouds, and in other nearby external systems. The classification scheme employed makes no assumptions about evolutionary status of the stars but is based entirely on observable criteria. Spectra of 39 stars are presented in detail, along with a catalog of 119 carbon stars classified according to the Revised MK System.

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Are a-spherical AGB shells due to a-spherical central stars ?

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Drake et al. (1991) observed the carbon star IRC +10 216 with the VLA at 2 cm and determined the FWHM size of the emission region to be 80 x 59 mas with a position angle of 41°. In principle the emission is due to stellar, dust and free-free emission. Based on a detailed dust model that fits the spectral energy distribution and various other constraints it is shown that dust emission at 2 cm is negligible. From a radiative transfer calculation follows that free-free emission is optically thin ($\tau_{2cm} = 0.03$), and that the FWHM of the brightness distribution should equal the diameter of the central star. The observed size and shape of the 2 cm emission region are therefore interpreted as due to an a-spherical central star. The position angle is in reasonable agreement with that characterizing the circumstellar shell. It is suggested that the a-spherical circumstellar shell observed in IRC +10 216 is due to an a-spherical central star.

Three stars have previously been identified as being a-spherical (o Cet, R Cas en χ Cyg). I discuss the available observations in the literature and conclude that in all three cases there is evidence that the circumstellar shells of these stars are a-spherical as well. These three stars all have binary companions (while none is known for IRC +10 216).

I conclude that non-radial pulsations (NRP), or a (as yet unidentified) binary component which has spun up the central star, are the most likely explanations for the a-sphericity of IRC +10 216. Monitoring the a-sphericity in time should constrain the possible effect of NRP.

Finally, the 0.5-2 cm region is an ideal wavelength region to study the shapes and sizes of (nearby) stars. Even for stars with high mass loss rates, dust emission is relatively small in synthesized apertures $\lesssim$1 arcsec, while free-free emission is also relatively unimportant.

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