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Abstract of recently accepted papers

MgS in detached shells around carbon stars. Mining the mass-loss history

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We investigate the dust composition of detached shells around carbon stars, with a focus to understand the origin of the cool magnesium-sulfide (MgS) material around warm carbon stars, which has been detected around several of these objects (Hony et al., 2003). We build a radiative transfer model of a carbon star surrounded by an expanding detached shell of dust. The shell contains amorphous carbon grains and MgS grains. We find that a small fraction of MgS dust (2% of the dust mass) can give a significant contribution to the IRAS 25 μm flux. However, the presence of MgS in the detached shell cannot be inferred from the IRAS broadband photometry alone but requires infrared spectroscopy.

We apply the model to the detached-shell sources R Scl and U Cam, both exhibiting a cool MgS feature in their ISO/SWS spectra. We use the shell parameters derived for the molecular shell, using the CO submillimetre maps (Lindqvist et al., 1999; Schöier & Olofsson, 2001). The models, with MgS grains located in the detached shell, explain the MgS grain temperature, as derived from their ISO spectra, very well. This demonstrates that the MgS grains are located at the distance of the detached shell, which is a direct indication that these shells originate from a time when the stellar photosphere was already carbon-rich. In the case of R Scl, the IRAS photometry is simultaneously explained by the single shell model. In the case of U Cam, the IRAS photometry is under predicted, pointing to a contribution from cooler dust located even further away from the star than the molecular shell.

We present a simple diagnostic to constrain the distance of the shell using the profile of the MgS emission feature. The emission feature shifts to longer wavelength with decreasing grain temperature. One can therefore infer a temperature and a corresponding distance to the star from the observed profile. Such a diagnostic might prove useful for future studies of such systems with SIRTF or SOFIA.

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Preprints can be obtained by contacting shony@rssd.esa.nl

Spectroscopy of the W Vir star V1 (K 307) in the globular cluster M 12

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High resolution CCD-spectra have been obtained for the fisrt time for the W Vir star V1 (K 307) in the globular cluster M 12 and its neighbour K 307b ($m_{pg} = 14^m$, the angular distance from V1 $\delta < 1$ arc sec). The fundamental parameters ($T_{eff} = 5600$ K, $\log g = 1.3$ and $T_{eff} = 4200$ K, $\log g = 1.0$ for the W Vir star and the neighboring star, respectively) and detailed chemical composition were determined. The derived metallicity of the both stars ([Fe/H] $= -1.27$ and -1.22 relative to the solar value) are in good agreement with metallicities of other cluster members. Changed CNO abundances are found in the atmosphere of the W Vir star: a small carbon overabundance, [C/Fe] $= +0.30$ dex, and a large nitrogen overabundance, [N/Fe] $= +1.15$ dex, with oxygen being underabundant, [O/Fe] ≈ -0.2 dex. The C/O ≥ 1. Na and α-process elements Mg, Al, Si, Ca, Ti are various enhanced with to iron. We found an enhanced abundance of s-process metals relative to iron: [X/Fe] $= +0.34$ for Y, Zr, Ba. The overabundance of the heavier s-process metals, La, Ce and Nd, is larger: [X/Fe] $= +0.49$. The largest overabundance was found for the r-process element europium, [Eu/Fe] $= +0.82$. The spectrum of the W Vir star exhibits the Hα, Hβ absorbtion-emission profiles and the He I λ 5876 Å emission line, which are traditionally interpreted as a result of a shock wave propagation in the atmosphere. However, the radial velocities determined from absorbtion and emission details are in conflict with the formation pattern of a strong shock. The high luminosity $\log L/L_{\odot} = 2.98$, the chemical abundances pattern, and spectral peculiarity are consistent with the post-AGB evolution in the instability strip. The chemical abundances pattern [X/Fe] in the atmosphere of the neigbouring star K 307b is solar. Statistically significant differences were found for sodium and α-process elements only: an mean excess of light metals is [X/Fe] $= +0.35$.

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Hard X-ray Emission Associated with White Dwarfs II

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We have previously conducted a search for X-ray sources coincident with white dwarfs using the white dwarf catalog compiled by McCook & Sion (1999) and the ROSAT sources in the WGACAT (Paper I). To include the white dwarfs discovered since 1999 and to include the X-ray sources detected in ROSAT Position Sensitive Proportional Counter (PSPC) observations made with a boron filter, we have carried out another search using an updated list of white dwarfs and the final catalogs of the ROSAT PSPC observations with and without a boron filter. Forty-seven new X-ray sources convincingly coincident with white dwarfs are found and reported in this paper. Among these, only 5 show hard X-ray emission: three possess confirmed or suggested late-type companions, one is apparently single, and the other is likely a misclassified BL Lac object. The apparently single white dwarf with hard X-ray emission, KPD 0005+5106, was discussed extensively in Paper I. Photospheric origin for the hard X-ray emission from hot DO and DQZO white dwarfs remains a tantalizing possibility, but high-quality near IR spectroscopic observations and monitoring of the Hα emission line are needed to rule out the existence of a faint dMe companion.

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Hot Gas in Planetary Nebulae

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Diffuse X-ray emission has been detected in a small number of planetary nebulae (PNe), indicating the existence of shocked fast stellar winds and providing support for the interacting-stellar-winds formation scenario of PNe. However, the observed X-ray luminosities are much lower than expected, similar to the situation seen in bubbles or superbubbles blown by massive stars. Ad hoc assumptions have been made to reconcile the discrepancy between observations and theoretical expectations. We have initiated FUSE programs to observe OVI absorption and emission from PNe, and our preliminary results indicate that OVI emission provides an effective diagnostic for hot gas in PN interiors.

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X-ray Observations of Planetary Nebulae

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Planetary nebulae (PNe) are an exciting addition to the zoo of X-ray sources. Recent Chandra and XMM-Newton observations have detected diffuse X-ray emission from shocked fast winds in PN interiors as well as bow-shocks of fast collimated outflows impinging on the nebular envelope. Point X-ray sources associated with PN central stars are also detected, with the soft X-ray (¡0.5 keV) emission originating from the photospheres of stars hotter than 100,000 K, and the hard X-ray (¿¿0.5 keV) emission from instability shocks in the fast stellar wind itself or from a low-mass companion's coronal activity. X-ray observations of PNe offer a unique opportunity to directly examine the dynamic effects of fast stellar winds and collimated outflows, and help us understand the formation and evolution of PNe.

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Three-component modeling of C-rich AGB star winds. III. Micro-physics of drift-dependent dust formation

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A proper treatment of the non-equilibrium dust formation process is crucial in models of AGB star winds. In this paper the micro-physics of this process is treated in detail, with an emphasis on the effects of drift (drift models). We summarize the description of the dust formation process and make a few additions to previous work. A detailed study shows that different growth species dominate the grain growth rates at different drift velocities. The new models show that the net effect of drift is to significantly increase the amounts of dust, seemingly without affecting the mean wind properties, such as e.g., the mass loss rate. In some cases there is several times more dust in drift models, compared to the values in the corresponding non-drift models. We study the formation of a dust shell in the inner parts of the wind and find that drift plays an active role in accumulating dust to certain narrow regions. In view of the results presented here it is questionable if drift – under the current assumptions – can be ignored in the grain growth rates.

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Evolution of rotating AGB stars and the s-process nucleosynthesis

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We present new results on the evolution and nucleosynthesis in rotating AGB stars. We analyze the role of the gradient of mean molecular weight in the mixing process and show that neglecting this component induces a potentially strong third dredge-up. We also quantify the impact of rotation on the structure and conclude that the effects of rotation (1) mainly concern the inner, fast rotating regions of the stars and (2) are relatively weak as long as rotational mixing does not induce a deep third dredge-up. We also focus our investigations on the s-process nucleosynthesis and show that rotational mixing tends to inhibit the production of s-elements. This results from the contamination of the ^{13}C-rich layers responsible for the neutron production by the poisonous ^{14}N. Our calculations also indicate that the distribution of s-process elements depends sensitively on the magnitude of the diffusion coefficient. These results suggest that rotational mixing is not the main mechanism responsible for the production of s-elements in AGB stars, but that it can influence and in particular reduce, the final enrichment in s-elements.

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Nucleosynthesis of s-elements in rotating AGB stars

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We analyze the s-process nucleosynthesis in models of rotating AGB stars, using a complete nuclear network covering nuclei up to Polonium. During the stage of thermal pulses, the extreme shear field that develops at the base of the convective envelope leads to the injection of protons into the adjacent ^{12}C-rich core. Subsequent proton captures lead to overlapping ^{14}N-rich and ^{13}C-rich layers. While the ^{13}C nuclei release neutrons due to α-captures during the interpulse phase, the persistence of mixing due to differential rotation produces a contamination of the whole ^{13}C-rich layer with ^{14}N. The result is a quenching of the s-process efficiency. Our study emphasizes the sensitivity of the s-process nucleosynthesis on the strength and duration of the shear mixing phase. Uncertainties in the rate of ^{13}C(α,n) turn out to have small effects on the resultant distribution of s-elements. Finally, we show that in this framework, a deeper third dredge-up tends to further inhibit the production of s-elements.

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The Local Group Census:planetary nebulae in IC10, Leo A and Sextans A

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In the framework of our narrow-band survey of the Local Group galaxies, we present the results of the search for planetary nebulae (PNe) in the dwarf irregular galaxies IC10, Leo A and Sextans A. Using the standard on-band/off-band technique, sixteen new candidate PNe have been discovered in the closest starburst galaxy, IC10. The optical size of this galaxy is estimated to be much larger than previously thought, considering the location of the new PNe in an area of 3.6 kpc$\times$2.7 kpc. We also confirm the results of previous studies for the other two dwarf irregular galaxies, with the detection of one candidate PN in Leo A and another one in Sextans A. We review the number of planetary nebulae discovered in the Local Group to date and their behaviour with metallicity. We suggest a possible fall in the observed number of PNe when [Fe/H]<<-1.0, which might indicate that below this point the formation rate of PNe is much lower than for stellar populations of near Solar abundances. We also find non-negligible metallicity effects on the [OIII] luminosity of the brightest PN of a galaxy.

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Preprints can be obtained by contacting laura@arcetri.astro.it

Multiple Point-Symmetric Ejections in IC 4634

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We present a spatio-kinematical study of the planetary nebula (PN) IC 4634 which has experienced several episodes of point-symmetric ejections oriented at different directions. The nebula displays two S-shaped low-ionization arcs that are probably related to two relatively recent point-symmetric ejections, the outer S-shaped arc representing a beautiful example of a bow-shock resolved in a PN. We report here the discovery of an arc-like string of knots at larger distances from IC 4634 central star that represents a much earlier point-symmetric ejection.

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Imaging and Spectroscopy of the Planetary Nebula NGC 6778

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We present narrow-band images and long-slit echelle spectra of the planetary nebula (PN) NGC 6778. The data show this PN as bipolar, with a very prominent low-excitation equatorial toroid, high-excitation lobes and two pairs of collimated outflows. Morphologically, the pairs of outflows are different from each other; one is linear and oriented along the bipolar axis, the other presents an S-shape with changing orientations. Besides the different morphology, both pairs of collimated outflows present radial velocities increasing with distance from the central star and share a common origin in bright knots at the tips of the shell.

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Title of the paper

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PN G135.9+55.9 is a compact, high excitation nebula that has been identified recently as the most oxygen-poor halo planetary nebula. Given its very peculiar characteristics and potential implications in the realms of stellar and Galactic evolution, additional data are needed to firmly establish its true nature and evolutionary history. Here we present the first long-slit, high spectral resolution observations of this object in the lines of Hα and He IIλ4686. The position-velocity data are shown to be compatible with the interpretation of PN G135.9+55.9 being a halo planetary nebula. In both emission lines, we find the same two velocity components that characterize the kinematics as that of an expanding elliptical envelope. The kinematics is consistent with a prolate ellipsoidal model with axis ratio about 2:1, a radially decreasing emissivity distribution, a velocity distribution that is radial, and an expansion velocity of 30 km/s for the bulk of the material. To fit the observed line profiles, this model requires an asymmetric matter distribution, with the blue-shifted emission considerably stronger than the red-shifted emission. We find that the widths of the two velocity components are substantially wider than those expected due to thermal motions, but kinematic structure in the projected area covered by the slit appears to be sufficient to explain the line widths. The present data also rule out the possible presence of an accretion disk in the system that could have been responsible for a fraction of the Hα flux, further supporting the planetary nebula nature of PN G135.9+55.9.

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Processing of presolar grains around post-AGB stars: silicon carbide as the carrier of the "21" μm feature

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Some proto-planetary nebulae (PPNs) exhibit an enigmatic feature in their infrared (IR) spectra at $\sim$21μm. This feature is not seen in the spectra of either the precursors to PPNs, the AGB stars, or the successors of PPNs, "normal" planetary nebulae (PNs). However the "21"μm feature has been seen in the spectra of PNs with Wolf-Rayet central stars. Therefore the carrier of this feature is unlikely to be a transient species that only exists in the PPNs phase. This feature has been attributed to various molecular and solid state species, none of which satisfy all constraints, although titanium carbide (TiC) and polycyclic aromatic hydrocarbons (PAHs) have seemed the most viable.

We present new laboratory data for silicon carbide (SiC) and show that it has a spectral feature which is a good candidate for the carrier of the 21μm feature. The SiC spectral feature appears at approximately the same wavelength (depending on polytype/grain size) and has the same asymmetric profile as the observed astronomical feature. We suggest that processing and cooling of the SiC grains known to exist around carbon-rich AGB stars are responsible for the emergence of the enigmatic 21μm feature. The emergence of this feature in the spectra of post-AGB stars demonstrates the processing of dust due to the changing physical environments around evolving stars.

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Optical and Near-IR Spectra of O-rich Mira Variables : a Comparison between Models and Observations

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Pulsation models are crucial for the interpretation of spectrophotometric and interferometric observations of Mira variables. Comparing predicted and observed spectra is one way of establishing the validity of such models. In this paper, we focus on the models published between 1996 and 1998 by Bessell, Hofmann, Scholz and Wood. A few new model spectra are added, to improve available phase coverage. We compare the synthetic spectra with observed low resolution spectra of optically selected oxygen-rich Miras, over a range of optical and near-IR wavelengths that encompasses most of the stellar energy output. We investigate the overall energy distributions, and specific spectral features in the near-IR wavelength range. The agreement between the observed and the model-predicted properties is found to be reasonably good. However, there are discrepancies seen especially in various molecular bands.

We find that different combinations of stellar parameters and pulsation phases often result in very similar model spectra. Therefore the problem of deriving parameters of a Mira variable from its spectrum has no unique solution. More advanced models than presently available, providing even better fits to the data and covering a wider range of parameters, would be needed to achieve better discrimination.

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Preprints can be obtained by contacting lancon@astro.u-strasbg.fr *or via the WEB* : astro-ph/0309689

Australia Telescope Compact Array imaging of circumstellar HCN line emission from R Scl

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We present radio-interferometric observations of HCN $J = 1 \rightarrow 0$ line emission from the carbon star R Scl, obtained with the interim 3-mm receivers of the Australia Telescope Compact Array. The emission is resolved into a central source with a Gaussian $FWHM$ of $\sim$1″, which we identify as the present mass loss envelope. Using a simple photodissociation model and constraints from single-dish HCN spectra, we argue that the present mass-loss rate is low, $\sim 2 \times 10^{-7}$ $M_{\odot}$ yr^{-1}, supporting the idea that R Scl had to experience a brief episode of intense mass loss in order to produce the detached CO shell at $\sim$10″ radius inferred from single-dish observations. Detailed radiative transfer modelling yields an abundance of HCN relative to H_2, $f_{\rm HCN}$, of $\sim 10^{-5}$ in the present-day wind. There appears to be a discrepancy between model results obtained with higher transition single-dish data included and those from the $J = 1 \rightarrow 0$ interferometer data alone, in that the interferometer data suggest a smaller envelope size and larger HCN abundance than the single-dish data. The lack of HCN in the detached shell, $f_{\rm HCN} < 2 \times 10^{-7}$, is consistent with the rapid photodissociation of HCN into CN as it expands away from the star.

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Absorption and reflection infrared spectra of MgO and other diatomic compounds

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Oxide and sulphide minerals are expected to occur in diverse astronomical environments. However, optical constants for such minerals are either lacking or poorly characterized. Minimizing errors in laboratory data, while extrapolating over wide frequency ranges, is the focus of this report. We present reflection and absorption spectra of single-crystal MgO from about $\sim$100 to 18,000 cm^{-1} ($\sim$100 to 0.5μm), and derive emissivity, dielectric and optical functions (n and k) using classical dispersion analysis and supplementary data to ensure that the reflectivity values are correct at the low- and high-frequency limits. Absorbance spectra of thin films of oxides (MgO, CaO, FeO and ZnO) and sulphides (MgS, CaS and FeS) are in good agreement with available reflectivity measurements, and provide information on the various effects of chemical composition, structure and optical depth. The greatest mismatch occurs for MgO, connected with this compound having the broadest peak in reflectance. The ferrous compounds (FeO and FeS) have relatively weak infrared features and may be difficult to detect in astronomical environments. Previous optical data based on transmission spectra of dispersions have underestimated the strength of the main infrared features because this approach includes spectral artefacts that arise from the presence of opaque particulates, or from non-uniform optical depth. We show that areal coverage, not grain size, is the key factor in altering absorption spectra from the intrinsic values, and discuss how to account for 'light leakage' in interpreting astronomical data. Previous reflectivity data on polycrystals differ from intrinsic values because of the presence of additional, internal reflections, creating errors in the derived optical functions. We use classical dispersion analysis and supplemental data from optical microscopy to provide correct n- and k-values for FeO from the far-infrared to the visible, which can then be used in radiative transfer

models. Thin-film absorption data are also affected by internal reflections in the transparent regions: we show how to recognize these features and how to obtain the absorption coefficient, n, and k from thin-film infrared data on CaO, CaS and MgS using the damped harmonic oscillator model.

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Isotopic Compositions of Strontium, Zirconium, Molybdenum, and Barium in Single Presolar SiC Grains and Asymptotic Giant Branch Stars

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The strontium, zirconium, molybdenum, and barium isotopic compositions predicted in the mass-losing envelopes of asymptotic giant branch (AGB) stars of solar metallicity and mass 1.5, 3, and 5 $M_{\odot}$ are discussed and compared with recent measurements in single presolar silicon carbide (SiC) grains from the Murchison meteorite. Heavy-element nucleosynthesis via the s-process occurs in the helium intershell, the region between the helium-burning and hydrogen-burning shells, producing heavy elements beyond iron. After a limited number of thermal runaways of the helium shell (thermal pulses), at the quenching of each instability, the convective envelope penetrates into the top layers of the helium intershell (third dredge-up), mixing newly synthesized ^{12}C and s-process material to the stellar surface. Eventually, the envelope becomes carbon-rich (C¿=O), a necessary condition for SiC grains to condense. In the helium intershell, neutrons are released by (α, n) reactions on ^{13}C and ^{22}Ne during interpulse phases and the thermal pulses, respectively. A ^{13}C pocket is assumed to form in a tiny region in the top layers of the helium intershell by injection of a small amount of protons from the envelope during each third dredge-up episode. This ^{13}C then burns radiately during the interpulse phase. The average neutron density produced is low, but of long duration, so the total neutron exposure is high. We have explored a large range of possible ^{13}C abundances in the pocket. In low-mass AGB stars ($1.5\ M_{\odot} \leq M \leq 4M_{\odot}$), a second small burst of neutrons is released by marginal ^{22}Ne burning in the thermal pulse. The neutron density reaches quite a high peak value but is of short duration, so the neutron exposure is low. In intermediate-mass AGB stars ($4\ M_{\odot} < M \leq 8M_{\odot}$), the ^{22}Ne neutron source is more efficiently activated. The neutron capture process has been followed with a postprocessing code that considers all relevant nuclei from ^{4}He to ^{210}Po. The predicted isotopic compositions of strontium, zirconium, molybdenum, and barium in the envelopes of low-mass AGB stars of solar metallicity are in agreement with the isotopic ratios measured in individual presolar SiC grains, whereas predictions for intermediate-mass stars exclude them as the sources of these grains. A multiplicity of low-mass AGB stars with metallicity around solar, having different masses and experiencing different neutron exposures, are required to account for the measured spread in heavy-element isotopic compositions among single presolar SiC grains. The range of neutron exposures corresponds, on average, to a lower mean neutron exposure than that required to reproduce the s-process main component in the solar system.

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Internal Kinematics of Microstructures and Implications

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High resolution images at different wavelengths show the common presence of structures and microstructures in planetary nebulae (PNe), which are not well incorporated to the existing models for the formation of these objects. We summarize how studies of the internal kinematics, combined with the information provided by high resolution images, may help to establish the nature and possible origin of the observed structures as well as to provide information about the physical processes involved in the formation and evolution of PN.

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PhD Abstract

Extragalactic Planetary Nebulae: tools to understand the nearby universe

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In this Thesis, some aspects of the study of extragalactic Planetary Nebulae have been investigated, using both imaging and spectroscopical observations.
Here I summarize the obtained results:
⋄ We have searched for candidate PNe in several galaxies of the Local Group and of nearby groups using the Wide Field Camera at the 2.5 m Isaac Newton Telescope. With the on-band/off-techniques we discovered: 131 PNe in M 33; 171 in M 81, 117 of which are new; 16 in IC 10; 5 in Sextans B; 3 in IC 1613; 1 in Sextans A and 1 in Leo A. With our observations, most of them carried out within the ING survey called Local Group Census (LGC), we have provided a more complete view of the population of planetary nebulae in the Local Group. With these new data, the PNe population appears to be consistent with the predictions of the stellar evolution theory, as the number of observed planetary nebulae in each galaxy scales with the luminosity of the galaxy.

⋄ We used the flux ratio $R = \frac{[OIII]}{H\alpha+[NII]}$ to obtain an indication of the excitation of the candidate PNe. We studied the behaviour of R as a function of the distance from the centre of the galaxy in the case of spiral galaxies (MW, M 33, M 81), finding no significant difference between the excitation of bulge and disk PNe, contrary to previous claims.

⋄ We computed the distance to M 33 and to M 81 using their Planetary Nebulae Luminosity Function (PNLF). Our estimates are in good agreement with previous measurements obtained with different methods. We found no difference between the PNLF built only with bulge PNe, with disk PNe or combining both populations, thus confirming the robustness of this method to measure extragalactic distances.

⋄ We investigated the behaviour of the Local Group PNe population with galaxy metallicity, finding a lack in the formation of PN when [Fe/H]<<-1.0. This might indicate that below this point the formation rate of planetary nebulae is much lower than for stellar populations of near Solar abundances. We suggest this fact to be due to the mass loss mechanism in evolved red-giants, that is governed by radiation pressure on dust grains, and is therefore sensitive to a significant deficiency of heavy elements in the stellar atmosphere.

⋄ We searched for PNe in the intergalactic region between M 81 and M 82 where we discovered two possible candidate intragroup PNe. They allow to estimate the amount of intragroup stars in the 0.32 square degrees area between M 81 and M 82. It is $\sim$1.5% of the total luminosity of the M 81 group, consistently with previous results and with tidal stripping scenarios.

⋄ We obtained spectroscopic observations of 48 emission-line objects of M 33 with the multi-object, wide field, fibre spectrograph AF2/WYFFOS at the 4.2m WHT telescope (La Palma, Spain). We studied their location in the diagnostic diagram (Hα/[SII] vs Hα/[NII]) finding that >70% of the candidates are PNe. We have derived physical parameters and chemical abundances for the three PNe where the 4363Å [OIII] emission line was measurable. No discrepancy in the Helium, Oxygen and Argon abundances has been found in comparison with corresponding abundances of PNe in our Galaxy. Only a lower limit to the sulphur abundance has been obtained since we could not detect any [SIII] line. N/H appears to be lower than the Galactic value, probably because the weakness of the [OII] lines which enter in the calculation of the correction factors needed to determine the total Nitrogen abundance from single ionized ions.

⋄ We studied the ability of the LGC survey to detect symbiotic star candidates in the LG, by deriving detection limits in each of the narrow- and broad-band frames used in the survey. We also estimated the total number of symbiotic stars expected in each LG galaxy. We derived two new diagnostic diagrams, based on the adopted photometric filters, i.e. Hα, [OIII], Stromgren Y, and i', to discriminate between symbiotic stars and other emission-line objects such as planetary nebulae. Our results indicate that we will able to detect a number of symbiotic stars with the Local Group Census observations.

Postdoctoral Research Associate at Lowell Observatory

Applications are invited for a postdoctoral position to work with Dr. Sally Oey at Lowell Observatory. The successful candidate will collaborate on research topics including galactic chemical evolution with respect to stellar populations and/or gas-phase element abundances. There will also be broad opportunity in the area of galactic and cosmic evolution with relation to feedback mechanisms from massive stars, namely: chemical evolution, radiative feedback (HII regions and diffuse, warm ionized medium), mechanical feedback, and/or global star formation processes and history. There will be opportunity to pursue independent research projects, and access to the Lowell Observatory telescope facilities.

The position is available for three years, with a flexible start date to begin during 2004. Applicants should have a Ph.D. and experience in related areas of theoretical and/or observational astronomy. To apply, please submit a curriculum vitae, statement of research interests, and contact information for three references to Dr. Sally Oey at the above address. Applicants must also submit a Lowell Observatory application form available at `http://www.lowell.edu/hr/jobs.html`, or upon request at the above address from Human Resources, Lowell Observatory, phone +1-928-774-3358, fax +1-928-774-6296. Applications received by 30 November 2003 will receive first priority. The full job description is available at the website above; inquiries are welcome to Sally.Oey@Lowell.edu or +1-928-774-3358.

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