The Census of Planetary Nebulae in the Local Group

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Planetary nebulae (PNe), the fate of the vast majority of stars with a mass similar to the Sun or a few times higher, represent a short but well characterised stage of stellar evolution. It is the time at which stars experiment their last thermonuclear burning on the surface of a core that has been left naked by strong mass loss during the previous red giant phase. The combination of a hot luminous star (up to 500,000 K and more than 10,000 solar luminosities) and a low density expanding wind, allows the formation of an extremely luminous nebula that reprocesses the energetic continuum radiation from the stellar nucleus into specific emission-line spectra from atomic ionised gas. This makes PNe easily observable in our own galaxy (being among the preferred targets for amateur telescopes), but equally well detectable in external galaxies even with relatively small telescopes.

The technique used for searching PNe in external galaxies is almost invariably that of obtaining a narrow-band, continuum-subtracted image in a filter isolating the forbidden emission at 5007 Å from double-ionised atomic oxygen [OIII]. A large fraction of the total luminosity of the star is in fact concentrated in this line, and this is the unique property that makes individual stars in the planetary nebula phase visible to very large distances: up to several hundred solar luminosities can be emitted in a single and very narrow spectral line! Observation of the hydrogen Hα line, also very bright, is sometimes added to discriminate against the detection of highly redshifted galaxies (e.g. [OII] emitting galaxies at redshift z=0.34, which shifts the O+ emission to the rest wavelength of [OIII]λ5007, or Lyman-α emitters at redshift 3.1), or to estimate the ionisation class and discuss possible contamination by compact HII regions. Another basic criterium to select candidate extragalactic PNe is that they are not spatially resolved by ground based imaging, their sizes being usually a fraction of a parsec which translates into a couple of hundredth of an arcsec at a distance of 1 Mpc, approximately the outer edge of the Local Group.

PNe in external galaxies provide a tool to investigate some important astrophysical problems. First of all, their number reflects the total mass of the underlying stellar population from which they derive. In fact, one of the most robust predictions of stellar evolution theories allows us to relate the number of objects n_j in any post main-sequence evolutionary phase to the lifetime of that specific phase, in the hypothesis of a population of coeval, chemically homogeneous stars (Renzini & Buzzoni, 1986). The relation is as simple as this:

$$n_j = \dot{\xi} \cdot L_T \cdot t_j \quad ,$$

where $\dot{\xi}$ is the so-called specific evolutionary flux (number of stars per unit luminosity leaving the main sequence each year), L_T is the total luminosity of the galaxy, and t_j the duration of the evolutionary phase j (≤10,000 yrs for the PN phase). Note that $\dot{\xi}$ is only slightly dependent on the age of the stellar population, its initial mass function and metallicity. Thus counting PNe implies measuring the total mass of the parent stellar population. Once the masses of the progenitors of the PNe are estimated, it also allows us to discuss the star formation history of the host galaxy for the range of ages covered by the PN progenitors, roughly 1 to 10 Gyr (it is still not clear which is the lower mass limit for forming a planetary nebula). In particular, PNe have proven to be excellent tracers of stellar populations in large volumes with a relatively low density of stars, whose integrated stellar light is low and hardly detectable, like the intergalactic and intracluster space and in the haloes of elliptical galaxies (Arnaboldi et al., 2002).

Extragalactic PNe also provide important information on the chemical evolution of the host galaxies, as the nebular abundances of elements like oxygen, neon, sulphur, or argon, do not vary significantly during the evolution of low-mass stars (i.e. they are not significantly produced or destroyed). Therefore the abundances of these elements probe the initial metallicity of their environment at the time when their progenitors were born. This covers a range in ages that can be hardly covered using other classes of stars.

Moreover, nowadays PNe are used as reliable extragalactic distance indicators, through the invariance of their luminosity function with galaxian type and metallicity (Jacoby, 1989). Finally, as they are also detected in stellar systems of low surface brightness, they are extremely valuable test particles to map the dynamics of stars in galaxies up to very large galactocentric distances (the Planetary Nebula Spectrograph at the WHT is an instrument especially built for this purpose, see e.g. Merrifield et al. (2001).

For the reasons above, we have been intensively searching for PNe in nearby galaxies as one of the main objectives of the Local Group Census (LGC). The LGC is a narrow-band survey of the galaxies of the Local Group observable from La Palma, that was awarded observing time during period two of the ING Wide Field Imaging Survey programme (`http://www.ing.iac.es//WFS/`). Observations are being obtained with the Wide Field Camera at the 2.5m Isaac Newton telescope, covering a field of view of 34′×34′. The aim of the survey is to find, catalogue and study old and young emission-line populations (e.g. HII regions, PNe, SN remnants, Luminous Blue Variables, WR stars, symbiotic binaries, etc.) to unprecedented levels. The value of narrow band [OIII], Hα, [SII], and HeII images is enhanced with complementary broad band data (g, r, i). This enables, in principle, the linkages between stellar populations to be probed.

The first part of the analysis of our survey data has been focused on the search for PNe in dwarf irregular galaxies of the Local Group. We are especially interested in these objects as dwarf galaxies are the most numerous galaxies in the nearby Universe. According to the hierarchical scenarios of galaxies formation, dwarf galaxies are the first structures to form and from their merging, larger galaxies are built. The Local Group, which appears to the rest of the Universe as an ordinary collection of dwarf galaxies (90% of its 40 known members) dominated by two main spiral galaxies, is an ideal laboratory as the low-luminosity dwarf galaxies can be studied in detail.

Before our census, only a small number of PNe were known in the dwarf irregular galaxies of the Local Group (3 in Sagittarius, Walsh et al., 1997; Dudziak et al., 2000; one in Fornax, Danziger et al., 1978; one in Leo A and another one in Sextans A, Jacoby & Lesser, 1981; one in NGC 6822, Killen & Dufour, 1982). With our survey, so far 16 PNe in IC 10, 5 in Sextans B and 3 in IC 1613 were newly discovered, while the existence of one candidate planetary nebula in Leo A, one in Sextans A, and about 25 in NGC 6822 were confirmed (Magrini et al., 2002, 2003; Leisy et al., 2003). No PNe are instead found in GR8, as expected because of the small luminosity of this galaxy. The data are illustrated in the colour figures in the next page; in each image, green is the [OIII] emission, red the Hα one, while blue corresponds to the broad band Sloan-g images, mainly dominated by continuum stellar emission. In these images, planetary nebulae stand out as green or yellow dots (a striking example is the green luminous object on the upper-left side of the image of Leo A).

The LGC detections provide a more complete view of the population of PNe in the Local Group. These new data appear to be consistent with the predictions of the stellar evolution theories mentioned above, as the number of observed PNe in each galaxy scales reasonably well with the luminosity of the galaxy (Magrini et al., 2003). In spite of this agreement, there are also some interesting peculiarities. For instance, Sextans A and Sextans B have very similar V-band luminosities and mass, but while five PNe were discovered in Sextans B, only one candidate is detected in Sextans A. Statistically, this difference is only marginally significant, but may suggest some differences in their star formation history, as evidenced by the stronger main-sequence population of Sextans A compared to Sextans B.

We have also investigated the behaviour of the numbers of planetary nebulae with galaxy metallicity, and found a possible lack of PN 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. This might in turn be related 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.

Another result of our survey is the discovery of candidate planetary nebulae at large galactocentric distances, like in the case of IC 10 where they cover an area of 3.6×2.7 kpc, much more extended than the 25 mag·arcsec^{-2} diameter (1.1×1.3 kpc). Are these PNe related to the enormous neutral hydrogen envelope surrounding IC 10 (Huchtmeier, 1979)?

The new detections of the LGC are clearly a starting point for future spectroscopical studies of individual objects, aimed at confirming their nature as PNe and, more importantly, at determining their physical and chemical properties and of their host galaxies. This will be our next objective, together with the analysis of the other galaxies observed by the LGC.

Updated information on the status of the project, including the list of all the astronomers and institutions involved, can be found at: http://www.ing.iac.es/~rcorradi/LGC/. ¤

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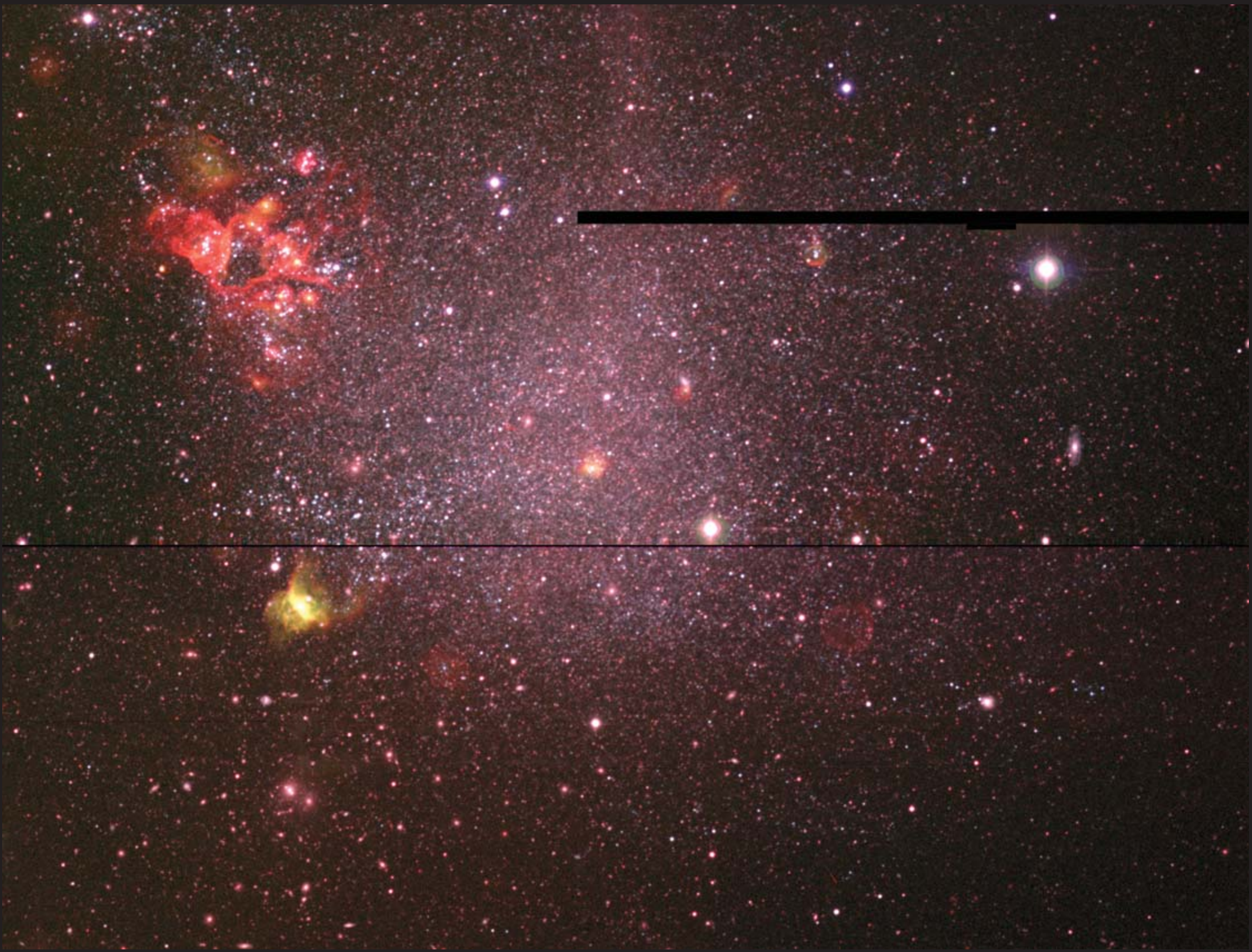
Next page: Three-colour images of NGC6822, IC1613, IC10, Leo A, GR8, Sextans B, Sextans A and WLM galaxies of the Local Group. In each image, green is the [OIII] emission, red the Hα one, while blue corresponds to the broad band Sloan-g images, mainly dominated by continuum stellar emission. In these images, planetary nebulae stand out as green or yellow dots (a striking example is the green luminous object on the upper-left side of the image of Leo A).

NGC 6822



IC 1613

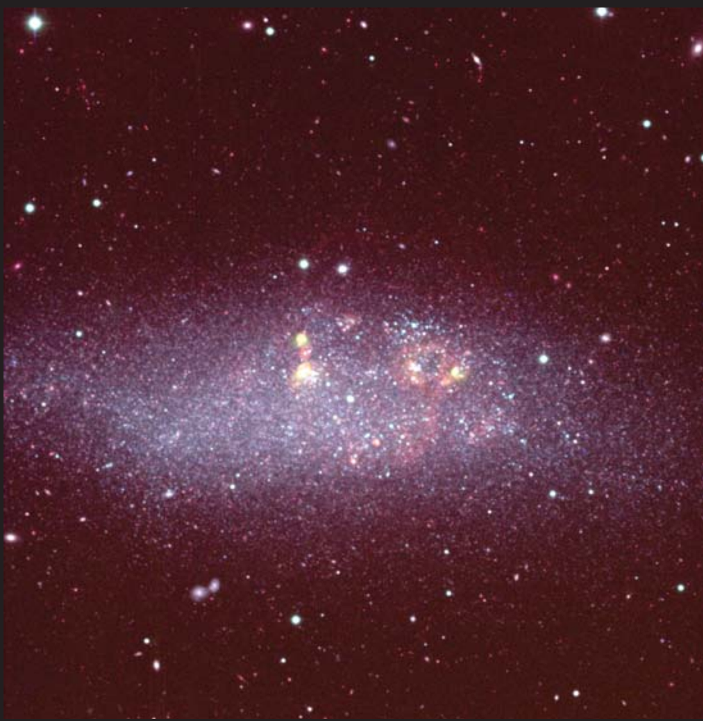
IC 10

Leo A

GR 8

Sextans B

Sextans A



WLM