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THE 3-D VIEW OF PLANETARY NEBULAE

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RESUMEN

Considerando las nebulosas planetarias (PNe) de manera tridimensional (3-D), demonstramos que se pueden reducir las grandes incertidumbres asociadas con los métodos clásicos de modelar y observar PNe para obtener sus estructuras 3-D y distancias. Usando espectrofotometría de ranura larga o empleando un Integral Field Unit para restringir los modelos de fotoionización 3-D de PNe y así eliminar dicha incertidumbre de la densidad y de la fracción del volumen que emite radiación (filling factor), determinamos las detalladas estructuras 3-D, los parámetros de las estrellas centrales y las distancias con una precisión de 10-20%. Los métodos clásicos típicamente daban estos parámetros con una incertidumbre de un factor 3 o más.

ABSTRACT

By taking a 3-D view of Planetary Nebulae (PNe) we show that the large uncertainties associated with classical methods of modeling and observing PNe to obtain their 3-D structures, distances and physical parameters are significantly reduced. Using long slit or Integral Field Unit spectrophotometry to constrain modern 3-D photoionization models for PNe, we determine detailed 3-D structures, central star parameters, and distances accurate to 10-20% by eliminating the uncertainties in the density and filling factor. Traditional 1-D methods gave distances to typically a factor of 3 or more with the associated very large uncertainties on the physical parameters of the objects.

Key Words: **PLANETARY NEBULAE**

1. PLANETARY NEBULAE STRUCTURE AND DISTANCES

Planetary Nebulae (PNe) are the visible ionized results of the final evolutionary stage of most low- to intermediate mass stars, during which between 0.2 and more than 1 $M_\odot$ is lost to form a low density envelope around the hot, dense stellar core of around 0.6 $M_\odot$ which is left to contract at constant luminosity —but increasing it's temperature to the point that the matter surrounding the star is ionized and therefore made visible— and then to cool along WD tracks in the left lower part of the HR diagram to eventually die as cold, invisible embers of past glory.

PNe have been used as Galactic low density plasma laboratories, to trace stellar populations in the Galaxy, and in and between other galaxies, and as standard candles to determine extragalactic distances. Good, general discussions of all aspects of PNe research have been published by Pottasch(1984) and Gurzadyan(1997).

Major problems in PNe research have traditionally been the determination of their distances and three-dimensional structures. Observations, no matter how sophisticated they may be, only ever provide a 2-D projection onto the plane of the sky of the 3-D PNe. Distances to individual objects depend on measuring the flux of one or more emission lines, the angular extent of the object, and the so-called filling factor, ϵ, the fraction of the nebula that emits radiation. Our work has tackled these two problems by applying 3-D photoionization models to PNe. The model is simultaneously constrained by fluxes in several emission lines, the angular size of the emission line maps in these lines, and the density map of the nebula from the [SII] doublet. By guesstimating a structure for the nebula based on the appearance of the line and density maps and using an iterative procedure to refine the structure and fit to all lines simultaneously, we arrive at a model nebula that typically is in agreement with the observations to within 5-10% for strong and better than 40% for the weak lines. Input is also a central star luminosity and temperature. This way the 3-D structure and distance are determined with much higher precision than has so far been possible. See Gruenwald, Viegas & Broguière(1997), Monteiro, Morisset, Gruenwald & Viegas(2000), Ercolano et al.(2003), and

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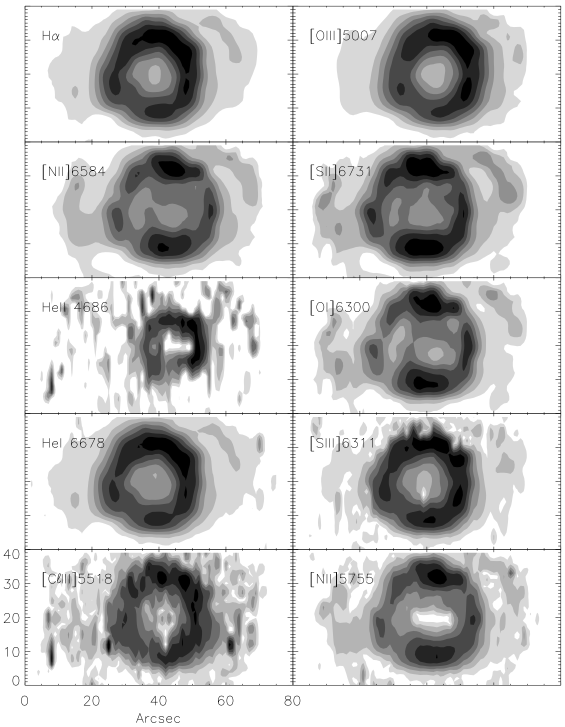

Fig. 1. Line maps generated from several long slit spectra taken across NGC 6369 taken from Monteiro et al. (2004). The maps have been corrected for reddening using the Hα / $H\beta$ extinction map.

Monteiro, Schwarz, Gruenwald, Guenthner & Heathcote(2005) for more details on our method and 3-D photoionization codes.

In Figure 1 we show constructed line maps, Figure 2 shows a 3-D structure, and in Figure 3 the final results for the central stars we have observed to date with our method are shown in the HR diagram.

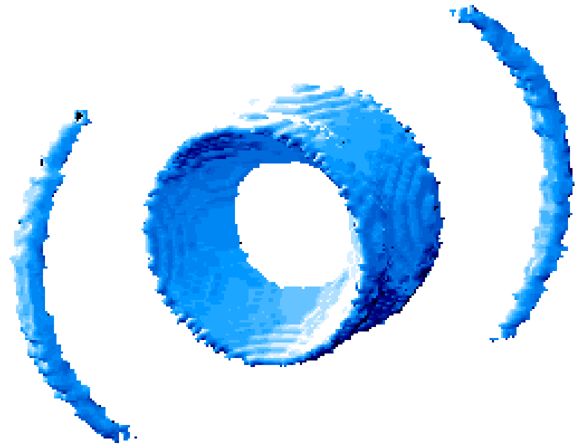

Fig. 2. Thre dimensional structure for NGC 6369 taken from Monteiro, Schwarz, Gruenwald & Heathcote(2004). Random density variations have been added to mimick those observed in this PN.

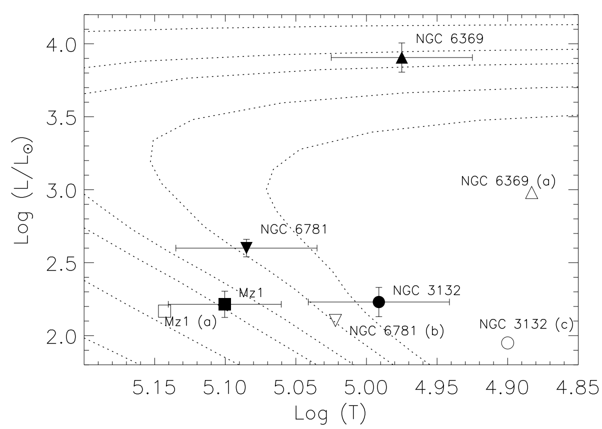

Fig. 3. HR diagram for NGC 6781, NGC 3132 (Monteiro et al. 2000), NGC 6369 (Monteiro et al. 2004), MZ 1 (Monteiro et al. 2005), all PNe that had their central star properties determined by our method. Also plotted are the literature values for comparison. a) Stanghellini et al. (1993); b) Stanghellini et al. (2002); c) Gathier & Pottasch (1989). The evolutionary tracks are from Vassiliadis & Wood (1994).

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