Revista Mexicana de Astronomía y Astrofísica, **48**, 3–7 (2012)

THE SAN PEDRO MÁRTIR KINEMATIC CATALOGUE OF GALACTIC PLANETARY NEBULAE

J. A. López,[1] M. G. Richer,[1] M. T. García-Díaz[1] D. M. Clark,[1]
J. Meaburn,[2] H. Riesgo,[1] W. Steffen,[1] and M. Lloyd[2]

Received 2011 August 25; accepted 2011 September 8

RESUMEN

El catálogo cinemático de nebulosas planetarias galácticas de San Pedro Mártir provee espectros Echelle de rendija larga, resueltos espacialmente, para casi 600 nebulosas planetarias. Los datos se presentan calibrados en longitud de onda y corregidos por movimiento heliocéntrico. Para la mayoría de los objetos se han obtenido múltiples espectros y para cada objeto se presentan imágenes donde las posiciones de las rendijas han sido indicadas con precisión. Esta es la fuente individual más grande y homogénea de datos relacionada con la cinemática interna del material nebular ionizado en nebulosas planetarias. Los datos se pueden obtener para objetos individuales o seleccionar grupos de objetos que comparten alguna característica, como es la clase morfológica, la población galáctica, núcleos binarios, presencia de flujos de alta velocidad, etc. El catálogo está disponible en la dirección `http://kincatpn.astrosen.unam.mx`.

ABSTRACT

The San Pedro Mártir kinematic catalogue of galactic planetary nebulae provides spatially resolved, long-slit, Echelle spectra for about 600 planetary nebulae. The data presented are wavelength calibrated and corrected for heliocentric motion. For most objects multiple spectra have been acquired and images with accurate slit positions on the nebula are also presented for each object. This is the most extensive and homogeneous single source of data concerning the internal kinematics of the ionized nebular material in planetary nebulae. Data can be retrieved for individual objects or selected by groups that share some common characteristic, such as morphological classes, galactic population, binary cores, presence of fast outflows, etc. The catalogue is available through the world wide web at `http://kincatpn.astrosen.unam.mx`.

Key Words: catalogs — ISM: jets and outflows — ISM: kinematics and dynamics — planetary nebulae: general — stars: AGB and post-AGB

1. INTRODUCTION

The kinematics of the ionized nebular shell of planetary nebulae (PNe) provides key information on the physics that drives their expansion, which is necessary to understand their formation and evolution, as well as their role as galactic chemical contaminants of processed material through stellar mass-loss from the TP-AGB to the white dwarf stages. PNe are excellent tracers of galactic structure in our own and other galaxies and have been used as extragalactic standard candles by means of the distribution of their [O III] luminosity function, which depends to a certain degree on the evolution of the ionized nebular shell. The complex morphological structures of PNe revealed in recent times by the *HST* and ground-based telescopes that achieve subarcsec image quality demand the knowledge of detailed expansion patterns to disentangle real outflows from projection, scattering and light-cone effects, particularly in the early stages of the forming ionized nebular shells.

There have been a number of compilations on the systemic heliocentric velocity of PNe. For example, Schneider et al. (1983) published heliocentric

[1]Instituto de Astronomía, Universidad Nacional Autónoma de México, Ensenada, B. C., Mexico.
[2]Jodrell Bank Center for Astrohysics, University of Manchester, UK.

radial velocities for 524 PNe, and Durand, Acker, & Zijlstra (1998) increased the data set to 867 PNe. These works have been useful for statistical studies and to derive the galactic rotation curve from the PNe population. However, the research on the internal motions in PNe started with the pioneering works of Campbell & Moore (1918), Wilson (1989) and Osterbrock, Miller, & Weedman (1966). During the 1980's the field regained an intense activity (e.g., Robinson, Reay, & Atherton 1982; Chu et al. 1984). Sabbadin (1984) compiled expansion velocities for 165 PNe and Weinberger (1989) expanded this compilation from diverse sources to 288 PNe. Those works, together with many others on relatively small groups or individual objects (e.g., Miranda & Solf 1990; López, Meaburn, & Palmer 1993; López et al. 1998; Guerrero, Vázquez, & López 1999; Gesicki & Zijlstra 2000; Gonçalves, Corradi, & Mampaso 2001; Hajian et al. 2007; Meaburn et al. 2008; Dobrinčić et al. 2008) have allowed to identify differences in expansion patterns among different morphological classes and to isolate components from different mass-loss episodes and age of the nebular shell. Furthermore, the growing high-quality data of the last decade has made clear the relevance of embedded collimated outflows, poly-polarity and other complex symmetries in their structural development (e.g., Sahai, Morris, & Villar 2010; Kwok 2010). Unfortunately, detailed, spatially resolved kinematic information on the expansion patterns of the various components of the PNe shells can only be found scattered in the literature for a relatively small number of objects. Therefore, to understand the dynamics of PNe from an in-depth perspective a systematic and homogeneous set of high quality, spatially resolved, kinematic information of high spectral resolution, spanning most of the evolutionary stages, morphologies, progenitor masses and galactic populations is required. That is what the SPM kinematic catalogue on galactic planetary nebulae aims to provide.

2. THE OBSERVATIONS AND THE DATA

The data for this first release of the SPM catalogue have been obtained over 55 observing runs. Fifty two observing runs were obtained at the 2.1 m, f/7.5 telescope in San Pedro Mártir National Observatory, Mexico, with the Manchester Echelle Spectrometer (Meaburn et al. 2003) and three additional runs were obtained in the southern hemisphere at the 3.9 m, f/8, Anglo-Australian Telescope, two of them using a twin MES and a third one with the UCLES spectrometer (Diego et al. 1990), used in single order format.

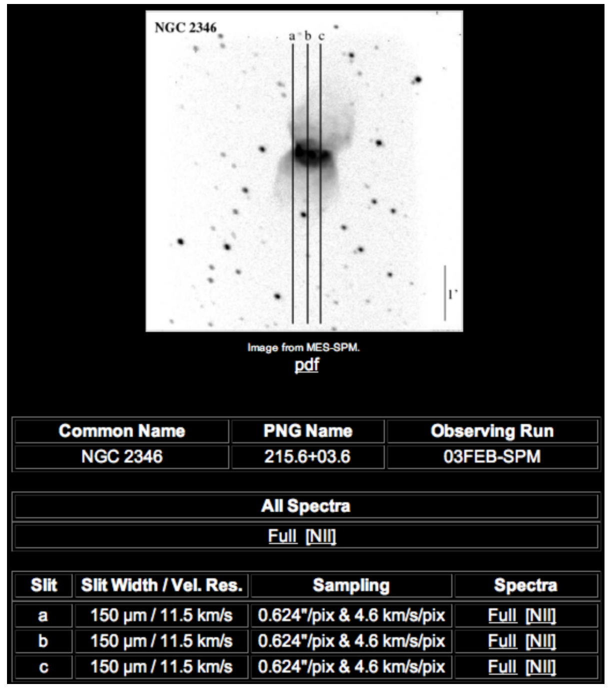

Fig. 1. Example of the presentation of a PN in the catalogue.

MES is an Echelle, long-slit spectrometer optimized for nebular work. MES does not have a cross disperser; it isolates single orders using interference filters (Meaburn et al. 2003). For example, the 87th order covers the Hα, He IIλ6560 Å, C IIλ6578 Å, and the [N II]$\lambda\lambda$6548,6583 Å emission lines, and the 114th order contains the [O III]λ 5007 Å line. The order containing the [S II]$\lambda\lambda$6717,6731 Å emission lines has also been observed for some objects.

All of the spectra are contained in a database accessible via the world wide web at `http://kincat.astrosen.unam.mx/`. After selecting an individual PN an image of the nebula with accurate slit positions overlaid on it is presented and all the available data for that PN are displayed in a table below the image (see Figure 1). The table provides at the top the common name and PNG identifier and the run(s) identifier denoting when it was observed. The data consists of "Full" meaning the full spectral range (see Figure 2), calibrated in wavelength or individual bi-dimensional line spectra labeled by the corresponding line identifier such as [N II] that refers to the λ6583 Å emission line or [O III] referring to the λ5007 Å emission line (see Figure 3). In the latter case this is the only line of interest in the order; therefore this is never labeled as "Full" since it is always presented as an individual line spectrum.

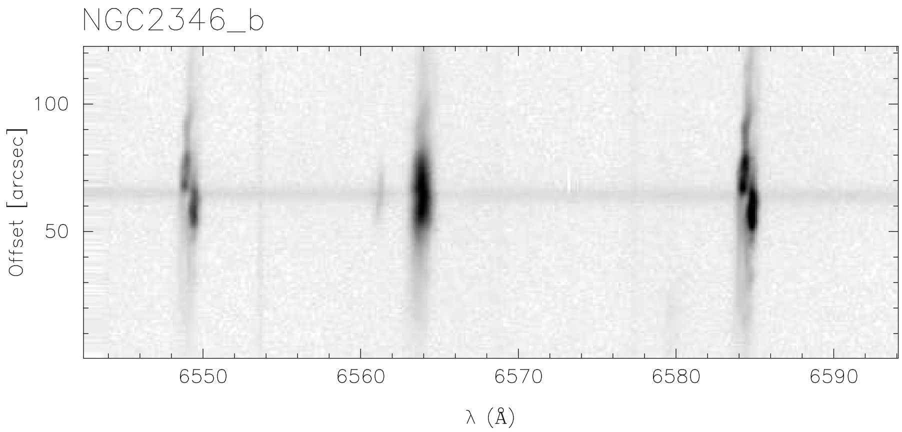

Fig. 2. Full spectral range for the Hα order corresponding to the central slit, *b*, in NGC 2346, see Figure 1.

All individual line spectra are presented calibrated to heliocentric velocity.

Next in the table and below the label "All Spectra" there are underlined keywords such as Full, Hα+[N II], [O III] or [N II], in case the object has multiple observations. Clicking on any of these keywords all available data for the corresponding keyword for that object will be displayed at the right of the table. Below each image or spectrum there is a link for downloading a pdf file of it. Wavelength calibrated FITS files for individual objects can also be requested through the contact email address that appears in the front page of the web-based catalogue.

The full slit length in MES is in most cases 5.′2. This length is dependent on the CCD size format so it varies slightly in some cases depending on the CCD we used at the time. For the CCDs we used throughout these runs the slit varies from 5.′2 to ∼7.′0. Only in the case of the spectra obtained at the AAT with UCLES the slit length is less than one arcmin, specifically 57″. In many cases it is not necessary to depict the full length of the slit on an image, only the portion that produces relevant data. All the images that accompany each object and show the location of the slits on them are oriented with north up and east left and show an angular scale bar. Likewise, all the position-velocity or bi-dimensional line profiles for each object are presented with an angular scale along the slit axis. Given the relatively large slit length most of the images are drawn either from the Digital Sky Survey or have been obtained with MES in its imaging mode. For only a few cases they are drawn from other sources. A legend at the bottom of the image with the slits shows the image origin.

The slit width has been for most objects 150 μm $\equiv$ 11.5 km s^{-1} in velocity resolution; for some bright objects we have used the 70 μm $\equiv$ 6 km s^{-1} and for some faint targets in some cases we have used a 300 μm $\equiv$ 22 km s^{-1}. Since on some occasions we observed a target in more than one run, possibly with a different CCD or with different slit widths, or different on-chip binning, for each object we list in the associated table all its associated slit positions, the slit width, its equivalent velocity resolution and associated spectral and spatial sampling information. Clicking on the keywords of the last column of the table, the individual "Full" or line spectra are displayed.

3. THE DATABASE

To connect to the database the user must provide her or his email address. After logging in the search page, the database provides the option to search for an individual PN by its common name or PNG name, following the IAU format. For the common name the prefix PN used by SIMBAD is omitted and for the PNG name the prefix PN G used by SIMBAD is also omitted.

In addition to searching for an individual object the entire database can be browsed with the option Full List. The list can be ordered by common or PN G name. Objects can be searched and grouped by galactic coordinates or within a range of them. Additional, extended search methods are listed below that exploit the small wavelength range covered by the Echelle orders. For example, there is an option to search nebulae that show the presence or absence of the He IIλ6560 Å emission line. This serves as a method to search for high (evolved) or low (relatively younger) excitation objects. Likewise, there are options to search for objects in the database that lack the [N II]λλ6548,6583 Å emission lines in their

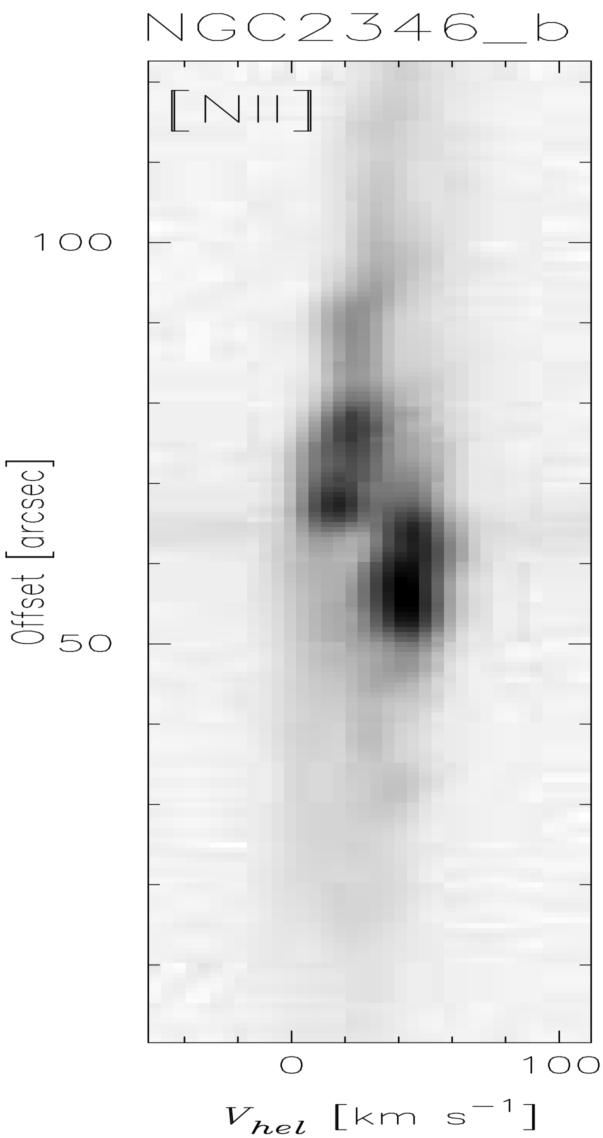

Fig. 3. Individual [N II]λ6583Å line profile corresponding to the central slit, *b*, in NGC 2346, see Figure 1.

spectra. These PNe are usually high-excitation objects located near the end of the constant luminosity track and about to start the turn-down in luminosity. There is also an option to direct the search to select objects that show the presence of the only carbon recombination line, C IIλ6578 Å, located within the wavelength range covered by the Hα order.

During the course of putting together the catalogue we realized that there are a number of PNe that exhibit very wide Hα wings; some are likely produced by Raman scattering of Lyβ photons into neighboring Hα frequencies from high density nebulae, some symbiotic nebulae seem to be involved in this sample, others show P-Cygni profiles and others show extended wings in Hα and the [N II]$\lambda\lambda$6548,6583 Å emission lines, indicating true high-speed, low-emissivity, bipolar outflows.

The database allows also to retrieve those PNe that have been identified in different sources as containing a W-R or WELS type CS spectrum. Likewise, the catalogue also links PNe that are known to host binary and close binary central stars. PNe that exhibit high velocity outflows have also been provided with a link. Here the definition of high-velocity is usually applied, somewhat arbitrarily, for objects with outflows that show projected expansion velocities $\geq$70 km s^{-1} and for objects where de-projected velocities are known to fulfill this criterion.

A coarse morphological classification has been applied to the nebula in the catalogue, providing just primary, main morphologies and descriptors. In some cases where the morphology was not clear from available images but was clear enough from the basic geometry indicated by the line profiles and the radial velocity information, as described in Steffen & López (2006), the classification was done based on the latter. If the spectra could not provide a main morphological class then the nebulae were classified simply as compact. In this way, PNe can be retrieved based on primary morphological class.

As it was to be expected, we have come accross some nebulae that are known to be, or probably are mimics. We are providing a link in this case to identify them; comments from the community that may help distinguish more of these cases from true PN are welcome. Additionally, it is also possible to select PNe based on their membership to a specific galactic population. As in the case with morphology, the classification is done based only on primary descriptors, such as galactic location, systemic radial velocity and abundances in some instances. Therefore, revisions in some particular cases may be necessary.

Every time a group of PNe is selected and listed, the opportunity is also presented to the user to plot the group by galactic coordinates and to display the thumbnail images with their slit locations for all the members in that group.

Since the literature on the objects contained in the catalogue is so vast, we do not cite specific references for any of them. Instead, the catalogue provides a link at the top of the page for each PN to query SIMBAD automatically on that particular object if the user wishes to do so. Finally, at the end of the search page we have collected a number of related, useful www links. We welcome suggestions to include additional links in this section, for the benefit of the user.

The ultimate objective is that this catalogue be an effective tool to help us to better understand the formation and evolution of planetary nebulae. This work is a companion of the SPM planetary nebulae kinematic catalogue of extragalactic planetary nebulae (Richer et al. 2010) also available on line through one of the links mentioned above, at the end of the search page.

The authors gratefully acknowledge the numerous people that have provided valuable resources and contributed their time and talents to make this project possible. First we recognize the Committee for the Allocation of Telescope Time, CATT, for the San Pedro Mártir National Observatory, for the generous allocation of telescope time throughout the years. We acknowledge the skillful assistance of the telescope operators: Felipe Montalvo, Gabriel García, Gustavo Melgoza and Salvador Monrroy and the whole technical staff of the Observatory that made possible to obtain data along 52 observing runs (about 300 nights) with less than 0.5% down time due to technical failures. During the same runs we were only impeded to observe by bad weather on four nights, so our thanks in this regard go to whom it may concern up there. We thankfully recognize as well the Panel for Allocation of Telescope Time for the Anglo-Australian telescope, where we obtained 3 different observing runs for southern targets. The Manchester Echelle Spectrometer (MES-SPM) resides in San Pedro Mártir thanks to a collaborative agreement between IA-Universidad Nacional Autónoma de México and the University of Manchester. The participating members in this project, including students and postdocs, have benefited throughout the years from the generous financial support of DGAPA-Universidad Nacional Autónoma de México through several PAPIIT projects as well as several Conacyt projects. Lastly, we are grateful to A. J. Clark for insightful discussions concerning the programming of the database.

REFERENCES

Campbell, H. H., & Moore, J. H. 1918, Publ. Lick Obs., 13, 75

Chu, Y.- H., Kwitter, K. B., Kaler, J., & Jacoby, G. H. 1984, PASP, 96, 598

Diego, F., Charalambous, A., Fish, A. C., & Walker, D. 1990, Proc. SPIE, 1235, 562

Dobrinčić, M., Villaver, E., Guerrero, M., & Manchado, A. 2008, AJ, 135, 2199

Durand, S., Acker, A., & Zijlstra, A. A. 1998, A&AS, 132, 13

Gesicki, K., & Zijlstra, A. A. 2000, A&A, 358, 1058

Goncalves, D. R., Corradi, R. L. M., & Mampaso, A. 2001, ApJ, 547, 302

Guerrero, M. A., Vázquez, R., & López, J. A. 1999, AJ, 117, 967

Hajian, A. R., et al. 2007, ApJS, 169, 289

Kwok, S. 2010, PASA, 27, 174

López, J. A., Meaburn, J., Bryce, M., & Holloway, A. J. 1998, ApJ, 493, 803

López, J. A., Meaburn, J., & Palmer, J. W. 1993, ApJ, 415, 135L

Meaburn, J., Lloyd, M., Vaytet, N. M. H., & López, J. A. 2008, MNRAS, 385, 269

Meaburn, J., López, J. A., Gutiérrez, L., Quiróz, F., Murillo, J. M., Valdéz, J., & Pedrayes, M. H. 2003, RevMexAA, 39, 185

Miranda, L. F., & Solf, J. 1990, Ap&SS, 171, 227

Osterbock, D. E., Miller, J. S., & Weedman, W. D. 1966, ApJ, 145, 697

Richer, M. G., et al. 2010, RevMexAA, 46, 191

Robinson, G. J., Reay, N. K., & Atherton, P. D. 1982, MNRAS, 199, 649

Sabbadin, F. 1984, A&AS, 58, 273

Sahai, R., Morris, M. R., & Villar, G. G. 2010, AJ, 141, 134

Schneider, S. E., Terzian, Y., Purgathofer, A., & Perinotto, M. 1983, ApJS, 52, 399

Steffen, W., & López, J. A. 2006, RevMexAA, 42, 99

Weinberger, R. 1989, A&AS, 78, 301

Wilson, O. C. 1989, ApJ, 111, 279

J. A. López, M. G. Richer, M. T. García-Díaz, D. M. Clark, H. Riesgo, and W. Steffen: Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. Postal 877, 22830 Ensenada, B. C., Mexico (jal, richer, tere, dmclark, hriesgo, wsteffen@astrosen.unam.mx).

J. Meaburn and M. Lloyd: Jodrell Bank Center for Astrophysics, University of Manchester, Manchester, M13 9PL, UK (meaburnj@yahoo.co.uk, Myfanwy.Lloyd@manchester.ac.uk).