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Hunting post-AGB/RSG objects using Virtual Observatories and other internet-based technology.

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Abstract. After the Asymptotic Giant Branch or Red Supergiant stage of evolution, stars evolve rapidly from cool M-type to F-type and hotter before their final fates. We describe the use of the European Virtual Observatory to derive a set of properties based on published data which identify post-AGB transition objects. We then apply these selection criteria to find new candidate transition objects and investigate their images and spectra in more detail. Heterogenous data collections from all over the world can be tracked down, manipulated and compared using the internet. The internet is itself part of the telescope in a separate development, real-time correlation of E-VLBI observations of hydroxyl masers from the post-RSG star IRC+10420.

Key words. Masers – Methods: miscellaneous – Techniques: interferometric – Astronomical data bases: miscellaneous – Stars: AGB and post-AGB – Stars: evolution

1. Introduction

In the space of a few decades, a star can go from being totally optically obscured, perhaps revealed as a Mira variable by an IR survey, harboring an almost-spherical dusty maser shell, to a hot 'early-type' star with a bipolar outflow. Within the timescale of human celestial observations, such a star will progress through being optically naked to the appearance of a planetary nebula (or a supernova, if it has a massive progenitor). There is much speculation as to how the nature of the progenitor affects the asymmetry of the nebula (binarity? magnetic collimation?) and on the mix of elements which are returned to the ISM, yet we do not have anything like a statistically complete observational picture of the evolutionary path, nor any real idea whether the few well-studied high-mass objects are typical.

Recently-developed VO tools give access to images and spectra at all wavelengths, in heterogenous formats at a variety of reso-

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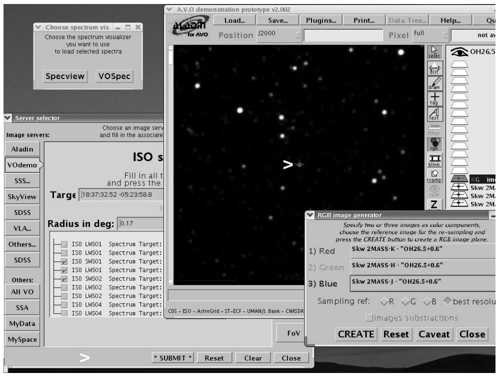

Fig. 1. The AVO tool has been used to make a 3-colour composite image of the region around OH26.5+0.6 using 2MASS data (it is only detected in K-band) and to search for spectra, offering a choice of display tool.

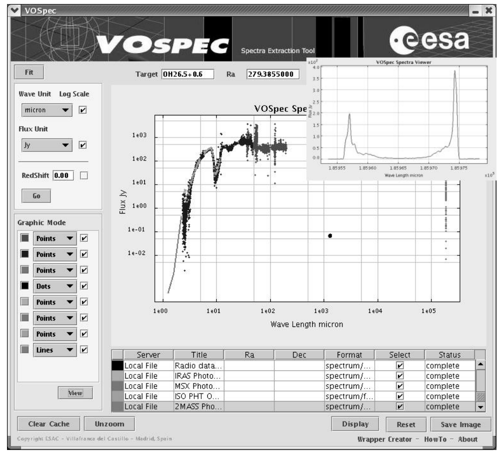

Fig. 2. VOSpec display of IRAS, 2MASS, MSX, ISO, radio photometry and (enlarged in inset) OH maser data for OH26.5+0.6.

lutions, through a single interface. Rapidly-evolving objects are identified from their IR colours; data from several different satellite missions are needed to exclude contaminants. We can even incorporate our own data or fit simple off-the-shelf models. UV, optical and radio data yield more details of the evolutionary state of individual objects.

Finally we show a recent break-through in almost instant radio interferometry, using real-time European VLBI correlation over the internet, to image the OH masers around IRC+10420, which has gone from M- to F-type since the 1970s.

2. Spectral properties of AGB-PNe transition objects

Bayo et al. (in prep.) used the AVO tool (2005), an enhanced version of Aladin (2005), to search for images and catalogues containing data on typical transition objects. The VOSpec (2005) plugin (developed at ESAC) uses the internationally agreed Simple Spectral Access (SSA 2005) protocol to display both photometry points and high-resolution spectra. Data can be supplied locally or found via Vizier (2003) or by direct discovery of archives which publish SSA-compliant data. Data need to be in FITS or VOTable (2004) format; other formats e.g. ascii can be converted to VOTable (ConVot 2004; TopCat 2005). Any S.I. units and linear combinations (e.g. Jy, c.g.s.) are allowed and common magnitude systems can be converted to physical units. Special treatment may be needed to achieve errors of a fraction of a percent (such as applying aperture- or colour-corrections) but the accuracy of VO tools allows a sample of hundreds of thousands to be whittled down to a few hundred.

2.1. Late AGB: OH26.5+0.6

The AVO tool (Fig. 1) was used to find data for this very obscured OH/IR star. VOSpec (Fig. 2) shows that the source becomes undetectable at $\lambda < 1\mu$m, has a very absorbed silicate feature near 10μm, faint radio continuum (Vollmer et al. 2005) and twin-peaked OH maser emission (Etoka & Le Squeren 2004). OH26.5+0.6 still has a cool, probably ~spherical, dusty molecular shell but the radio continuum suggests the beginning of a hot wind.

2.2. Post-AGB HD161796

In the optical and UV, HD161796 looks like an F5 giant, but VOSpec black-body fitting (Fig. 3) shows two components, one at $\approx$ 5000 K and the other at $\approx$ 130 K, the second

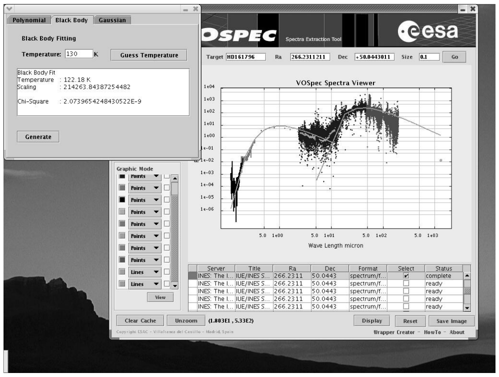

Fig. 3. The spectral energy distribution of HD161796 showing IUE, 2MASS, IRAS, ISO and radio continuum data, overlaid with a black-body fit.

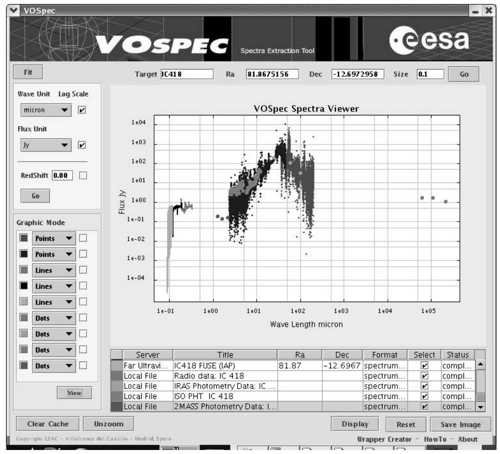

Fig. 4. The spectral energy distribution of IC 418 showing hot stellar UV (FUSE and IUE), IR from the warm dust shell (IRAS, ISO and 2MASS) and nebular radio continuum.

showing the presence of a fossil shell of cool dust which the star is not yet hot enough to ionise.

2.3. Young PNe IC 418

Fig. 4 shows various nebular emission lines overlaid on the UV stellar continuum from IC 418, confirming the presence of the expanding hot wind (also producing radio continuum emission). An absorption bump in the UV and PAH emission in the IR at 11μm reveal the presence of warm dust. The IUE spectra of IC 418 and HD161796 are compared in Fig. 5 which shows the lines from the former in more detail including a C IV P Cygni profile at just over 0.1μm; the shapes of the spectra show that it is much hotter than HD161796.

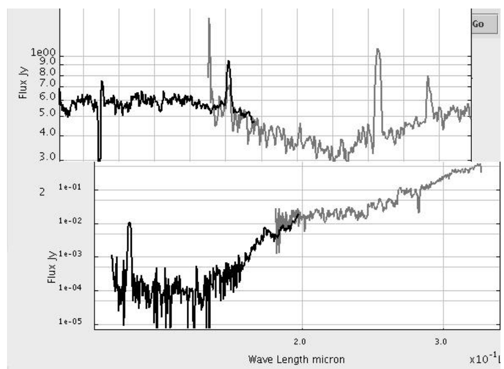

Fig. 5. IUE spectra of IC 418 (upper) and HD161796 (lower)

3. Transition object sample selection

Bayo et al. (in prep.) started by using the AVO tool to select objects from the MSX catalogue with detections $\geq 5\sigma$ (49000 sources) and from the IRAS Point Source Catalogue with good quality data (70000 sources). The Crossmatch plugin was used to match IRAS sources with the closest MSX source within 30″, giving 7000 sources. The tool automatically converts the IRAS B1950 coordinates to J2000. The facility for adding columns was used to create the $8-11\mu$m colour [A-C] and the $14-60\mu$m colour [D-60] (where the A,C and D band measurements are from MSX and the 60μm measurements are from IRAS). Another plugin sends the entire crossmatched list as a query to SIMBAD, performing a cone search within 30″ of each MSX position to find the single closest match. A final combined catalogue contained objects with SIMBAD classifications and [A-C] and [D-60] colours. The filter facility in the Aladin tool allows the selection of objects of known types in the sample; Fig. 6 shows that the distribution of YSOs is concentrated very close to the Galactic plane.

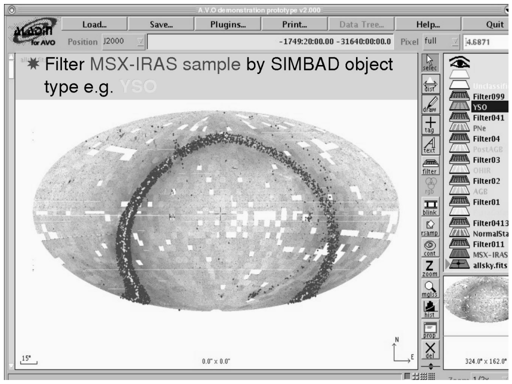

Fig. 6. The all-sky distribution of the MSX-IRAS crossmatched sample (dark) overlaid with objects classified as YSO (pale).

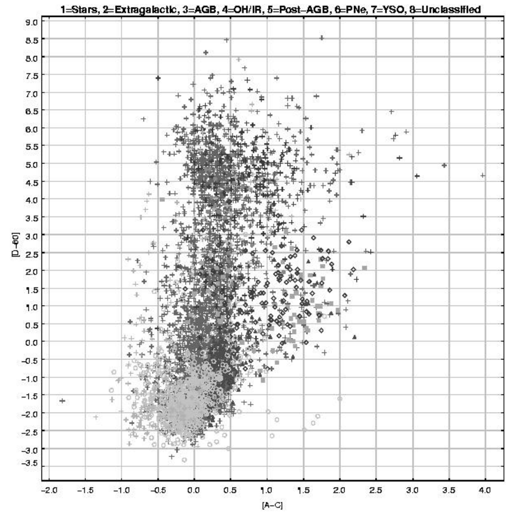

Fig. 7. Colour-colour plot using combined MSX and IRAS data showing the distribution of sources of various types.

VOTables were created containing the data for each of 7 source types: normal stars, extragalactic objects, AGB stars, OH/IR stars, post-AGB stars, PNe and YSO, and an 8th group of unclassified objects. These are plotted using the VOPlot (2005) plugin in Fig. 7 where it can be seen that sources of various types occupy different regions in the colour-colour diagram. A region was selected containing the maximum number of known PNe (50%, mostly shown by follow-up to be young, reddened objects) and post-AGB stars (27.3%), out of 132 classified objects. There were also 10.6% OH/IR stars and 1.5% AGB stars, both very red and potential transition objects and 0.8% each of objects (mis)classified as a normal star and an extragalactic source. The main contaminant was 9.1% YSO, which can be excluded by adopting a cutoff $|b| > 2°$ which was used to find criteria for removing these objects at any b using other data.

There are 103 unclassified sources in the candidate sample region of the [A-C] v. [D-60] plot, 80% of which are likely to be AGB-PNe transition objects. These are now being followed up by more detailed investigation in Bayo et al. (2005, in prep.) which will contain a fuller description of the distributions in Fig. 7. Note that all the steps in the workflow described here take a few minutes or less on a 1- or 2-GHz processor computer, with the exception of sending a query containing 7000 sources to SIMBAD, which takes 30 min.

4. First spectral line science results from the e-EVN

Until recently VLBI (Very Long Baseline Interferometry) involved tape-recording data from individual antennas for deferred correlation; it could be many months between observation and imaging. The move towards disc-based recording as the norm allows data to be transferred to the correlator over the internet. In Europe this uses the GÉANT research network and routine tests have been carried out since 2002, achieving data rates of 1 Gb s^{-1} from 6 antennas. In 2004 the first transatlantic real-time fringes were followed by a 3-station e-EVN continuum observation and, in October, by observations of the 1612-MHz masers around IRC+10420. This used the Torun, Onsala, Westerbork and Cambridge antennas with a maximum baseline of 1250 km, giving a resolution of 25 mas and a spectral resolution of 0.18 km s^{-1}, in dual polarization. The data were correlated and pipelined at JIVE so that the PI could retrieve partially processed

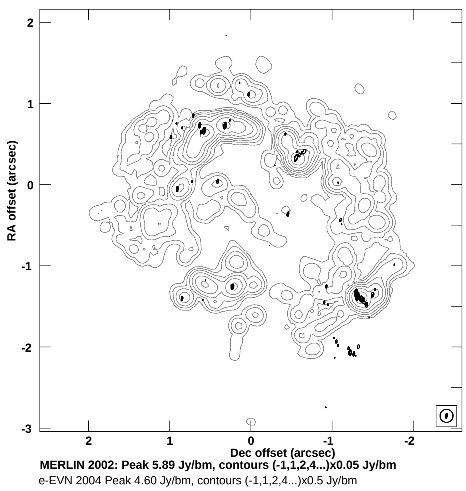

Fig. 8. The central 1/3 of the velocity range of OH 1612-MHz masers from IRC+10420. MERLIN data are shown in grey and E-EVN data in black.

data within 2 days of observation (again using the internet).

Masers were detected over a total velocity range of nearly 80 km s^{-1} with a twin-peaked profile. Fig. 8 shows a near-circular cross-section of the circumstellar envelope, in which the EVN detects the hotspots. IRC+10420 is a 10 $M_\odot$ supergiant which was recorded as G0-F8 in the 1970's but is now an 8500 K A5 star (Klochkova et al. 2002). For a distance of 5 kpc, the maser shell has a radius $\approx$ 7500 AU. At an expansion velocity of 40 km s^{-1} this contains 900 years of history which must date back to when the star was cool enough to produce a molecular wind containing enough dust to shield the masers for nearly a millenium.

5. Conclusions and future work

The AVO tool (2005) has been used to identify $\approx$ 80 candidate AGB-PNe transition objects using the MSX and IRAS catalogues. These are being followed up using multi-wavelength data mined and analysed with VO tools. The AstroGrid (2005) portal will provide a means of building a workflow so that a complicated set of queries and manipulations can be automated and repeated with small changes. The methods described can be applied to other objects, for example distinguishing between O- and C-rich Miras or investigating the evolved-star populations of nearby galaxies in *Spitzer* SINGS data. They form part of the Euro-VO Science Reference Mission (Padovani 2005).

We have also shown that radio interferometry data can be transferred reliably over 800 km and correlated in near-real time using E-EVN. The data can also be retrieved by a one-stop ftp ready for processing with standard software. RadioNet (2005) is coordinating further advances in access to radio astronomy data in Europe including publishing archives to VOs.

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