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THROES: A caTalogue of HeRschel Observations of Evolved Stars.

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Abstract

We are building a catalogue of interactively reprocessed observations of all evolved stars observed with Herschel. The catalogue will offer not only the reduced PACS spectroscopic data for each observation, but also complementary information from other infrared observatories. As a first step, we are concentrating our efforts on two main activities: 1) the reprocessing and data-reduction of more than 120 individual sources, observed by Herschel/PACS in the 55-210 micron range, available in the Herschel Science Archive (HSA). 2) the creation of a catalogue, accesible via a web-based interface and through the Virtual Observatory (VO). Our ultimate goal is to carry out a comprehensive and systematic study of the far infrared properties of low-and intermediate-mass evolved stars using these data. These objects cover the whole range of possible evolutionary stages in this short-lived phase of stellar evolution, from AGB phase to the PN stage, displaying a wide variety of chemical and physical properties.

1 Introduction

Towards the end of their lives, low-to-intermediate mass stars (1 $M_\odot \leq$ M $\leq 8\ M_\odot$) have burnt up their central hydrogen and helium, leaving a quiescent C/O core with H and He fusion reactions taking place in thin shells surrounding the core. These objects are ascending the asymptotic giant branch (AGB). This phase, during which the atmosphere expands and cools down, is characterized by an intense mass loss (from 10^{-7} to 10^{-4} $M_\odot$ yr^{-1}) that originates the circumstellar envelope (CSE) around the star. The chemistry found in this envelope shows the products created by the stars along their previous evolution.

As the star ends its AGB phase, the mass-loss rate decreases and the temperature of the central object becomes high enough to start the ionization of the surrounding circumstellar envelope. If the temperature increases on a timescale shorter than the dispersion time of the matter previously ejected by the star, a Planetary Nebula (PN) will appear.

The intermediate stage between the AGB and PN phases is called the post-AGB phase. This phase is also known as pre-PN phase. However, some authors [6], [7] prefer not to use this term, as there are objects that evolve directly to white dwarfs without ever becoming a PN. During the post-AGB phase, the shell, formed in the AGB phase, detaches from the central star [3].

The physical and chemical properties found in AGBs, post-AGBs and PNe are very different. Particularly, the infrared and sub-millimeter regions of the spectrum are of great scientific interest because of the rich variety of diagnostic atomic, ionic, molecular and solid-state spectral features that are present.

For that reason, *Herschel* [4], launched in May 2009, thanks to the capabilities of the three instruments on board: HIFI [1], SPIRE [2] and PACS [5], that cover the wavelength range (60-670 μm), is uniquely placed to study the stars that are in the late stages of their lives.

2 PACS Spectroscopy data reprocessing

PACS spectrometer covers the wavelength range from 51 to 210 microns in two channels that operate simultaneously in the blue (51-105 microns) and red (102-220 microns) bands. The Field of View (FoV) of the spectrometer covers a 47"$\times$ 47" region in the sky using a 5$\times$5 spatial pixels ("spaxels") footprint, each spaxel is a 9.4"$\times$9.4" square and, each of them, has 16 pixels along the spectral dimension. This configuration generates data in 3D cube format (wavelength vs flux density vs spatial position). PACS provides a resolving power between 940 and 5500 (i.e. a spectral resolution of 75-300 km/s) depending on the wavelength range. As shown in *PACS Observer's Manual* the PSF of the PACS spectrometer ranges from 6"x9" in blue band to 11"x13" in red band.

The data available in the HSA, was generated using the Standard Product Generator (SPG), an automated pipeline that takes data from level 0 (raw data) to level 2, a complete explanation about the steps applied in this reduction process is found in the *PACS Data Reduction Guide: Spectroscopy*

However, there are some data reduction tasks, available in HIPE (Herschel Interactive Processing Environment) [1], that were not applied in the SPG because they require a direct interaction of the user. Taking this into account, the 570 spectra associated to the 124 low-to-int mass stars, available in the HSA, have been reprocessed in THROES project, introducing those tasks that were not applied in the Standard Reduction pipeline. These tasks are:

- FlatField correction: It fits an n-grade polynomium to the PACS spectra to obtain a better SNR and a better shape of the continuum.
- Telescope Background Correction: This correction uses the telescope background emission to flux calibrate the spectra instead of using the Relative Spectral Response Function (RSRF) applied in the SPG.

[1] http://herschel.esac.esa.int/hipe/

- Point Source Correction (PSC): Once the level 2 cubes are generated, this task can be applied to correct for the fraction of the PSF that falls out of the (central) spaxel. The output is a 1D spectrum.
- Correction for slight mispointing and semi extended sources (1-to-9 correction): This correction is, again, applied to the level 2 cubes. Basically, it scales the flux of the spectrum extracted from the central spaxel to the flux level of the spectrum extracted from the 3x3 central spaxels.

In Fig. 1 we show the difference between the THROES final spectra and the spectra found in HSA for a well pointed source and for a mispointed one.

3 Characteristics of the THROES sample

The sample included in THROES contains 124 objects at different evolutionary stages. Attending to the SIMBAD classification and bibliography, the sample can be divided in four main groups: Asimptotic Giant Branch (AGB) stars, OH/IR stars, post-AGB stars and planetary nebulae (PNe).

For the AGBs, post-AGBs and PNe, a chemical classification has been also incorporated when it was available, based on bibliography. The objects can be O-rich or C-rich depending on their C/O ratio.

Our sample presents a number of objects reasonably high for each subgroup. AGB (37%), OH/IR stars (13%), post-AGB (26%) and PNe (24%).

4 Description of the catalogue

All the reprocessed observations have been compiled in a catalogue that will be available via a web interface (See Fig. 2). To create our catalogue we have used the *SVOCat* tool developed by the *Spanish Virtual Observatory*. To organize all the different observations, we have grouped those observations that present the same pointing, in the same entry. So, at the end, we have a unique entry per region in the sky observed. For each entry, there are 12 columns, providing each of them different information.

- **Columns 1 to 4**: The equatorial coordinates (RA and Dec) of the observation are shown in different units: *decimal* in columns 1 and 2 and *hh:mm:ss* and *dd:mm:ss* in columns 3 and 4.
- **Column 5**: The Target Name of the object, as provided by the observers in the proposals.
- **Column 6**: The Astronomy Observing Template. It could be PacsRange or PacsLine. For some objects there are spectra taken in both modes (PacsLine/PacsRange).

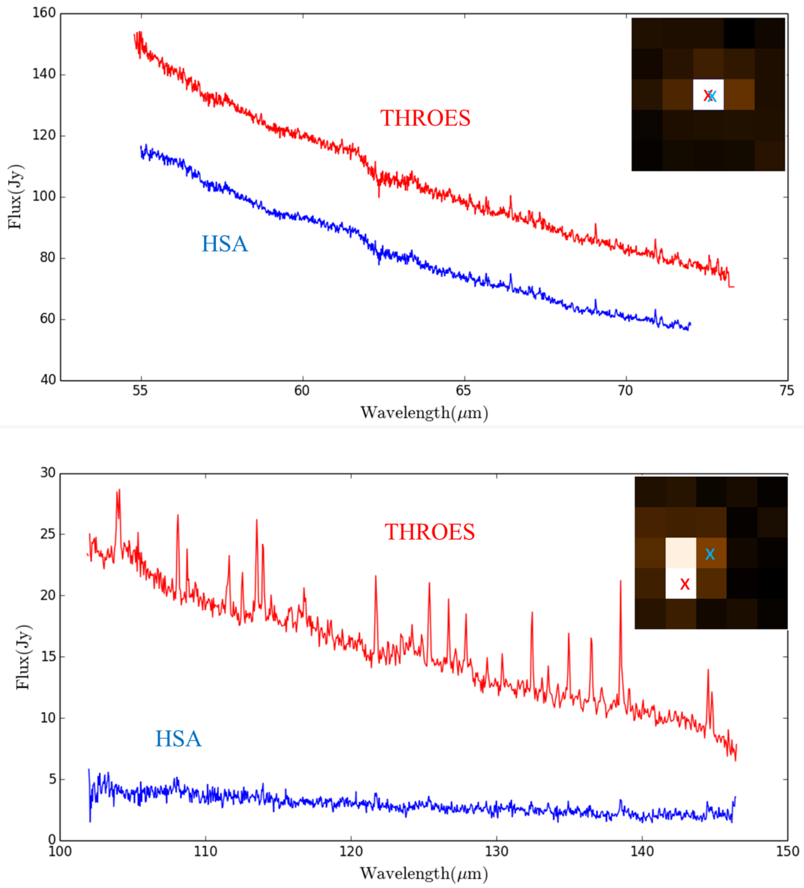

Figure 1: *Top)* One-dimensional spectra of AFGL 3116 obtained with the blue camera of PACS (ObsID: 1342212512) taken from HSA (blue) and our THROES catalogue (red). The THROES spectrum is generated after applying the post-processing tasks, Point Source Correction (PSC) and 1-to-9 correction. Note the significant understimate of the continuum level if these corrections are not applied. At the top right corner of the figure we show a layer of the FinalCube with the 5x5 spaxels of PACS spectrometer. The crosses (red and blue) indicate that both spectra were taken from the central spaxel. *Bottom)* One-dimensional spectra of IRC-10529 obtained with the red camera of PACS (ObsID: 1342208931) taken from the HSA and from THROES catalogue (red). The spectrum offered in HSA is taken from the central spaxel while the spectrum offered in THROES catalogue is taken from the brightest one. Furthermore, THROES spectrum is corrected from PSC but not from 1-to-9 correction. Note the significant loss of flux if the spectrum from the central spaxel is assumed as the correct one. At the top right corner of the figure we show a layer of the FinalCube with the 5x5 spaxels of PACS spectrometer. The crosses (red and blue) indicate the spaxels from wich each spectrum was taken.

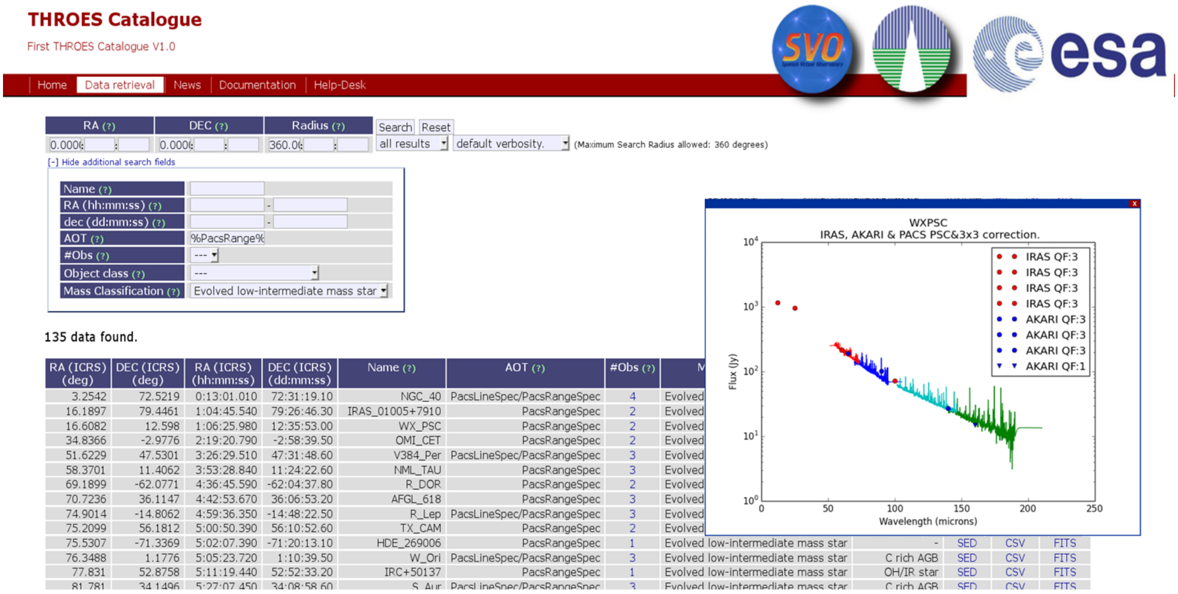

Figure 2: Screenshot of the THROES catalogue webpage. All the columns and search fields described in the section 4 are visible here, as well as, a complete SED with IRAS and AKARI data overplotted.

- **Column 7**: It gives information about the number of observations in that position in the sky. By clicking on the number displaied in this column, a new table is deployed with detailed information for each observation: Target Name, Coordinates (RA and Dec), Proposal, AOT, Obs ID, Observing date and time and AOR Label.

- **Column 8**: Mass classification based on bibliography and SIMBAD `http://simbad.u-strasbg.fr/simbad/`, it can be: Evolved Low-intermediate mass star, Evolved massive star or Unknown.

- **Column 9**: Object classification. Based, again, on bibliography and SIMBAD we incorporate a second classification criterion, attending to the evolutionary stage of the objects and their chemistry when this is known: O-rich AGB, C-rich AGB, OH/IR star, O-rich post-AGB, C-rich post-AGB, O-rich PN or C-rich PN.

- **Column 10**: By blicking on SED, it is plotted using PACS spectroscopy, interactively reduced, data and complementary photometric data from IRAS and AKARI.

- **Column 11**: FITS files are available in a compressed tar file (.tar.gz) to be downloaded including the Final Cubes (level2+FlatField) and the 1D spectra, obtained from these Final Cubes after applying the "post-processing".

- **Column 12**: By clicking on this column a compress folder (.tar.gz) is downloaded with the 1D spectra, post-processed data, in .csv format.

5 Future work

Once all the PACS Spectroscopy observations have been reprocessed, we are starting the scientific exploitation of the data. As mentioned in Section 1, *Herschel* capabilities allow us to study FIR properties in the THROES sample, such us warm CO or H_2O molecular gas that are tracing hotter and closer regions to the central star that are not accesible with submm or radio data. Moreover we are also interested in the study of solid state features, such us forsterite, or ionic lines in PNe.

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