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Mid-infrared Photometry of Carbon Stars and Perspectives for Surveys in the Magellanic Clouds from Dome-C

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Abstract. A preliminary analysis of the data from the MSX space infrared satellite, seems to confirm that the [8.8]-[12.5] micron color index is well correlated with the mass-loss rates in carbon stars of our Galaxy. The extension of this mid-infrared observation criterion to the Magellanic Clouds, with a small-size telescope like IRAIT, able to perform a continuous survey from Dome-C on the Antarctic Plateau, could be crucial to trace the local AGB population and evolution.

Key words. techniques: mid-infrared photometry – infrared: stars – stars: carbon – Magellanic Clouds

1. Introduction

The Midcourse Space Experiment[1] (MSX satellite; Mill et al. 1994) was launched in April 1996, as an USA ballistic missile defense project. The first ten months of the mission were devoted to mid-infrared observations with a solid hydrogen cooled telescope (SPIRIT III: Spatial Infrared Imaging Telescope III). This instrument had focal plane infrared arrays operated at 11 to 12 °K by employing a solid hydrogen cryostat, that spanned the spectral region from 4.2 to 26 microns, with a beam-size 35 times smaller than IRAS, resulting in images with excellent spatial resolution. The sensitivity in the MSX A band (8.28 μm) was about four times then IRAS. The cryogen phase of the mission ended on February 1997. A full set of experiments mapped the entire Galactic Plane between +5° and -5° of latitude, the ∼4% of the sky unobserved by IRAS, the zodiacal background, confused regions away from the Plane, deep surveys of selected fields at high galactic latitudes, large galaxies, asteroids and comets. The data from Galactic Plane and IRAS gaps surveys as well as observations of the LMC have been processed by the Air

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[1] http://www.ipac.caltech.edu/ipac/msx/

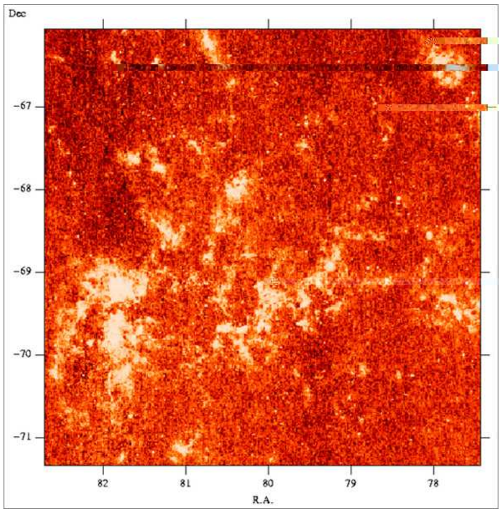

Fig. 1. MSX Spirit III infrared mosaic image of the Large Magellanic Cloud in its broad A band (centered at 8.276μm with a bandwidth between 6.8μm and 10.8μm).

Force Research Laboratory (AFRL) and an atlas of images and a catalog of point sources have been produced. Over 200 Gb of data on Celestial Backgrounds were obtained during the ten month cryogen phase of the mission (archive data at IRSA[2]). The MSX Infrared Point Source Catalog version 1.2 (Egan et al. 2001) is accompanied by an Explanatory Guide describing the instruments, data processing, calibration, the catalogs and the photometric/positional accuracy (Egan et al. 1999). The validation method for the absolute calibration of the SPIRIT III infrared radiometry is described in (Cohen, Hammersley, & Egan 2000).

The other data used in this work are taken from the last two observing winter campaigns of the mid-infrared camera TIRCAM II (the upgraded version of the Tirgo mid-InfraRed CAMera, see Persi et al. 2001, 1994) at the Tirgo Observatory[3] (Gornergrat Infrared Telescope, Mannucci 2003). The instrument is endowed of a Rockwell high flux 128x128 Si:As blocked-impurity-band (BIB) focal plane array, suited for the high background condition typical of the ground based applications. In perspective of the adaptation to IRAIT (Italian/International Robotic Antarctic Infrared Telescope) Tosti et al. 2003a; Tosti et al. 2003b; Busso et al. 2002), the control system has been revised both on hardware and software components (Corcione et al. 2003).

[2] `http://irsa.ipac.caltech.edu/applications/MSX/`

2. The mid-IR color to mass-loss diagram

A sample of carbon-rich stars in the Galactic Plane observed by the MSX satellite is preliminary analyzed and showed in Fig. 2, in view of the development of photometric criteria suitable to discriminate between O-rich and C-rich sources. This criteria based on plain mid-infrared colors, should let to derive mass-loss rates and predictions on the evolutionary status of the observed sources, and the consequences for the mass loss history on the Asymptotic Giant Branch (AGB) stars.

In Fig. 2 we show a sample of carbon-rich stars. A well defined relation holds between the mass loss of the gas and the mid-infrared color index [8.8]-[12.5] (μm). In this preliminary diagram we used the mid-infrared observations performed during the last two winter observing campaigns of TIRCAM II, and the data from the MSX database (simply taking the original fluxes in its A and C bands). Mid-infrared ISO fluxes also enclosed in Figure at this two bands, were calculated by the good accuracy data of the Short Wavelength Spectrometer (SWS) of this satellites, (Corti et al. 2003).

Diagram of Fig. 2 was constructed by using mass-loss data

[3] `http://www.arcetri.astro.it/irlab/tirgo/`

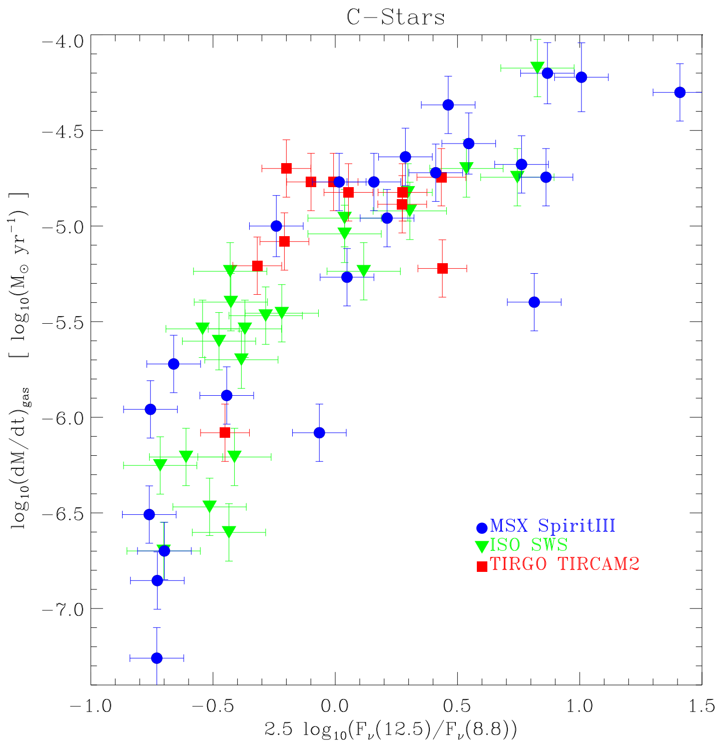

Fig. 2. Color index to mass loss diagrams for our sample of C-rich stars.

compiled by (Knapp et al. 1998; Fuente, Cernicharo, & Omont 1998; Neri et al. 1998; Loup et al. 1993; Kastner et al. 1993). More distinct references were used in the case of singles post-AGB and pre-planetary nebulae (PN) enclosed in the diagram. The analysis with the new mass-loss data appeared in Groenewegen et al. (2002); Olofsson et al. (2002); Le Bertre et al. (2001) and the mid-IR fluxes of MSX on an extended sample of C-rich and S-rich AGB is an ongoing work.

The carbon-rich stars in Fig. 2 are distributed in a well defined branch (except for few cases of peculiar stars, like Y Tau, or V Cyg, where mid-IR variability might have an important role). Our preliminary diagram point out a relation, appearing linear for intermediate values of mass-loss and color, and which seems to continue toward higher wind velocities and higher reddening, in the rather unexplored region of the post-AGB and pre-PNs (top-right part of the plot). The stars in this region, like for example V353 Aur (CRL 618, Westbrook Nebula), CW Leo (Peanut Nebula), OHPN 10, RAFGL 2477, NGC 7027, V354 Lac, IRAS 21282-5050, indeed are all classified as pre-PNs or PNs and the relation looks still valid.

The power of the diagnostic tools based on mid-infrared colors was underlined for example in (Busso et al. 1996; Marengo et al. 1999). The different chemical signatures of carbon-rich and oxygen-rich envelopes are put in evidence by mid-IR color-color diagrams, and correlations between the observed colors and mass-loss rates appear clear already in the first data obtained with TIRCAM in the previous years. Moreover plain photometric

Fig. 3. The two main buildings of the Concordia permanent station at Dome C (3280m a.s.l.) on the Antarctica Plateau, as appear at the end of the last summer expedition (Courtesy of M. Candidi).

mid-infrared observations do the possibility to derive direct information on the spatial structure and symmetry of the circumstellar envelopes.

The possibly parabolic relation outlined by the plot, evidences for possible temporal variations in the mass loss rates and an increasing level of the [C/O] abundance going to the upper part of the diagram branch. This might be represented by a semi-analytic and time dependent function. Constraints come from the mass of the final central white dwarfs, because if the circumstellar envelopes are too compact, the mixing in the stellar atmosphere should be not sufficient, obstructing the formation of low mass carbon-stars. The understanding of the nucleosynthesis in low luminosity carbon stars (enriched in s-elements) has recently succeeded using high resolution codes with improved opacities, which account for the third dredge-up. The models point out this stars as the normal outcome of AGB evolution, characterized by production of 12C and neutron-rich nuclei in the He intershell and by mass loss from strong stellar winds (Busso, Gallino, & Wasserburg 1999). An enlargement of the sample with new radio-millimeter estimations of the mass-loss and MSX mid-infrared fluxes will be useful to probe this relation and the diagnostic method.

3. Dome C: perspectives for mid-IR surveys in Magellanic Clouds

The French-Italian base of Dome-C (Candidi & Lori 2003), sited on the Antarctica Plateau at an altitude of 3280m asl will permit the development of interesting astrophysical projects, because the inner Plateau features the best sky conditions for ground-based millimeter and infrared observations (Calisse et al. 2003; Valenziano 2003; Chamberlain et al. 2000; Hidas et al. 2000; Valenziano & Dall'Oglio 1999).

Moderate size telescopes placed in this site, for example could carry out a mid-IR photometric monitoring and survey of the Magellanic Clouds. The 0.8m IRAIT telescope (Italian/International Robotic Antarctic Infrared Telescope, Tosti et al. 2003a; Tosti et al. 2003b; Busso et al. 2002), in the first phase will be operative at Dome C with the update version of TIRCAM II. An analogous diagram might be constructed for the Magellanic Clouds with simple mid-infrared photometric observations by IRAIT (for a preliminary estimation of the IR flux limits and photometric performances see Fiorucci et al. (2003)).

The relation between the mass-loss rates (derivable from millimeter observations if the distance is known) and the [8.8]-[12.5] color index, extended to the Magellanic Clouds of known distance modulus, will allow to derive the directly $\dot{M}$ from a plain mid-IR photometry. The Magellanic Clouds are dwarf irregular galaxies which are in general metal-poor. Nebular abundances are roughly one-third of the solar in the Large Magellanic Cloud (LMC), and one-tenth of the solar in the Small Magellanic Cloud (SMC). Mid-IR samples in this two galaxies from Antarctica, join to the existing and extended Galactic samples (MSX), through the accurate Hipparcos parallaxes, will permit to obtain three source populations of different metallicity very important to study the formations of the planetary nebulae and the return of material in the interstellar medium. The pre-PN phase, between the C-stars of [C/O]$\simeq$1 and the PNs, is a very unexplored field because this stage is completely dominated by infrared emission and invisible in the optical. Over $0.5 M_{\odot}$ are believed loss and about 50-70% of the carbon is transferred to the Galaxy in this phase by the star. This is a very important stage for AGBs and galaxy evolution but almost unexplored, so the expectations for the next mid-IR astronomy from Dome C cannot be anything else than very good.

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