

Spitzer Detection of Cepheid Circumstellar Emission

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ABSTRACT

Our *Spitzer* Space Telescope survey of nearby Cepheids has revealed for the first time the presence of circumstellar emission at IRAC and MIPS infrared wavelengths. The observed sample includes both long and short period Cepheids, first overtone and fundamental mode pulsators and Cepheids in clusters and in isolation. IRAC and MIPS colors provide an excellent Period-Luminosity relation, and show evidence of a small infrared excess for about 1/4 of the observed targets. This excess may be associated to warm dust (~ 500 K) in proximity to the star. A few targets, including δ Cep, SZ Tau and RS Pup, show extended emission on spatial scales as large as 10^4 AU, whose nature is currently undetermined. This detection of circumstellar material supports the hypothesis of active mass loss during the Cepheids phase.

Subject headings: Cepheids — infrared: stars — stars: mass loss

1. Introduction

Exactly 100 years after the Cepheids Period Luminosity relation was discovered by Henrietta Leavitt (1908), these stars still maintain a crucial importance in astronomy. Classical Cepheids are fundamental calibrators of the extragalactic distance scale, and play an important role in testing stellar evolution models of intermediate mass stars. Even distances derived with different calibrators are still affected by the Classical Cepheids calibration:

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Riess et al. (2005) found that when only high quality SN Ia data and HST Cepheids are used, the value of H_0 may change by as much as 15%.

Despite their importance, there are still unresolved issues in the theoretical understanding of Cepheids, in particular the ‘‘Cepheids mass discrepancy’’. Comparison of *evolutionary mass estimates* obtained with stellar evolution models, with the *pulsation mass* based on the mass-dependent Period-Luminosity-Color relation, or with the *dynamical mass* (when available, as in the case of the nearest Cepheid, Polaris; see e.g. Evans et al. 2008) show unresolved inconsistencies. Even though the uncertainties in these predictions are still comparable to the difference between pulsations and evolutionary mass, once a large enough sample is considered (31 Cepheids in Caputo et al. 2005) these differences becomes systematic and significant. Despite improvements in evolutionary models spurred on by this issue, recent investigations suggest that the discrepancy may still be up to 10–15% (see e.g. Bono et al. 2002; Keller & Wood 2006). A number of solutions have been proposed to solve this discrepancy, including *extra-mixing*, *rotation*, better *radiative opacities* and most importantly *mass loss*.

Mass loss betrays itself by the presence of dust shells, detectable as infrared excess or optical reflection nebulae, or by stellar winds which produce blue-shifted absorption dips in the ultraviolet. Empirical estimates of mass loss rates based on infrared (IRAS) and ultraviolet (IUE spectra) observations for a large sample of Galactic Cepheids suggest mass loss rates ranging from 10^{-10} to $10^{-7} M_{\odot} \text{ yr}^{-1}$ (Deasy 1988), but are hardly conclusive. The unprecedented sensitivity of the *Spitzer* Space Telescope (Werner et al. 2006), and its angular resolution two orders of magnitudes better than IRAS, offer a unique opportunity to understand whether mass loss is strong enough to play a significant role in Cepheids evolution by searching for circumstellar emission at infrared wavelengths.

With this goal in mind, we have obtained *Spitzer* images of a sample of nearby Cepheids with both the InfraRed Array Camera (IRAC, Fazio et al. 2004) and the Multi-band Infrared Photometer (MIPS, Rieke et al. 2004). This program has been recently completed, and we present here the preliminary results of these observations.

2. Observations

Our sample consists of 29 nearby Cepheids in clusters and in isolation, observed with IRAC and MIPS during the *Spitzer* Cycle-3. The sample was selected to cover a range in several characteristics which might influence mass loss, or enable us to understand it better (luminosity, pulsation mode, amplitude, binarity, cluster/field membership).

The observations have been executed between July 19, 2006 and October 28, 2007, as part of the program PID 30666. Each star has been observed with either subarray or stellar mode (according to their brightness) in the 3.6, 4.5, 5.8 and 8.0 μm IRAC bands, and with the 24 and 70 μm bands with MIPS. Starting with the Basically Calibrated Data (BCD) provided by the *Spitzer* Space Center (SSC) pipeline version S16, we have produced mosaics in each band for both instruments using the SSC mosaiker MOPEX and our custom software IRACproc (Schuster, Marengo & Patten 2006).

For each source we have derived aperture photometry in all IRAC and MIPS bands. In the case of the IRAC observations executed in stellar mode, the source was saturated in all images. For these sources we have derived PSF fitting photometry by matching the unsaturated diffraction spikes and “tails” of the source images with our High Dynamic Range PSF derived from the observation of bright stars (see description in Marengo et al. 2006). The typical photometric accuracy is of 0.05 mags or better in all IRAC bands and at MIPS 24 μm , and ~ 0.1 mags at MIPS 70 μm .

3. Spitzer Period-Luminosity Relation and Infrared Excess

Spitzer Period-Luminosity relations have been obtained for Cepheids in the Large Magellanic Cloud by Freedman et al. 2008 and Ngeow & Kambur 2008. Figure 1 and Figure 2 show the IRAC and MIPS Period-Luminosity relation for our sample of galactic Cepheids. Absolute magnitudes at 8.0 and 24 μm have been derived from the measured photometry using available distances (astrometric or interferometric) for each source. The figures show a tight relation in both bands (similar plots can be obtained at 3.6, 4.5 and 5.8 μm) indicating that if an infrared excess is present due to circumstellar dust, it does not affect the linearity of the relation between the absolute magnitude and the pulsation period. Given the small effect of interstellar extinction in the infrared, these plots show how IRAC and MIPS photometry can be used to derive higher quality Period-Luminosity distances than in the optical bands.

Preliminary analysis of the relation between period and infrared colors, however, suggest the presence of a small excess ($\lesssim 0.1$ mag) in IRAC colors for a subset of the observed targets (about 1/4 of the total sample). The sources showing excess include Cepheids with long and short period, and pulsating either in the fundamental or in the first overtone. This excess can be explained by the presence of warm dust (~ 500 K) in proximity to these stars, which may be an indication of recent dusty mass loss. Some of the sources with infrared excess were found to have evidences of circumstellar shells by interferometric observations (Mérand et al. 2006, 2007; Kervella et al. 2006).

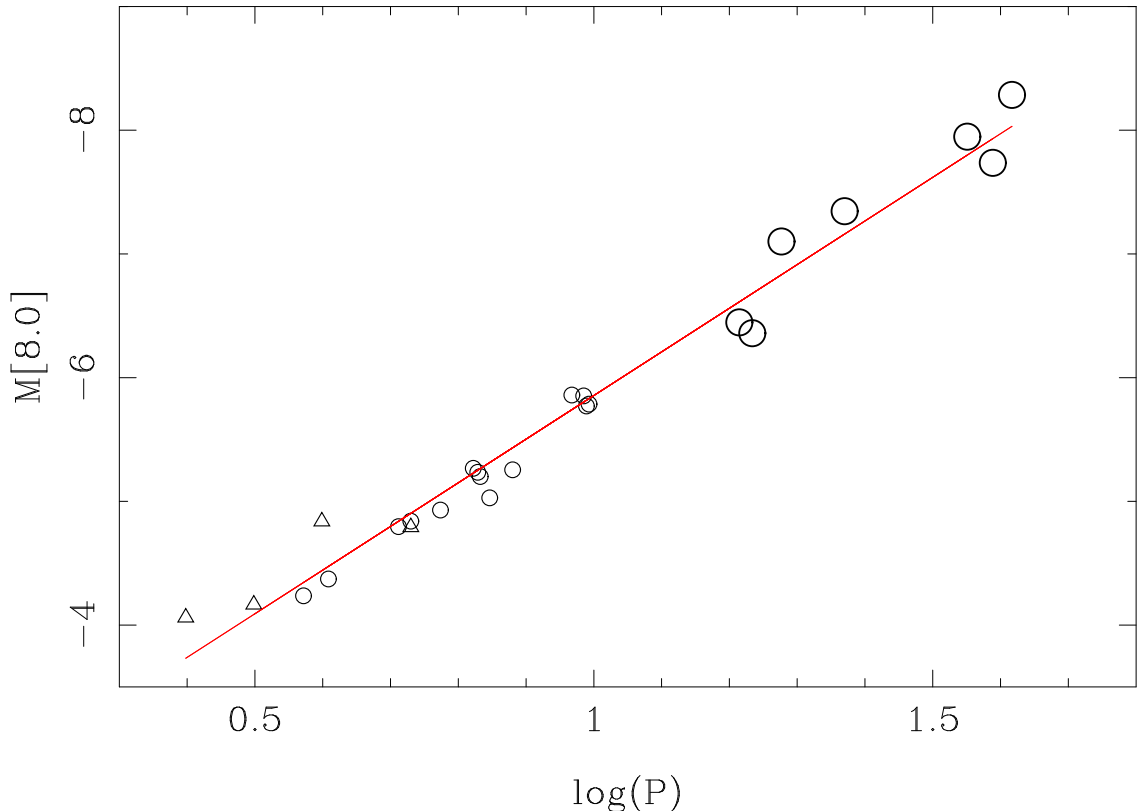


Fig. 1.— Period vs. IRAC 8.0 μm absolute magnitude for the sample stars. Triangles are first overtone and circle are fundamental mode Cepheids. Large circles are Cepheids with period longer than 100 days.

4. Imaging the Extended Emission

The deeper 5.8 and 8.0 μm exposures obtained for the subset of the target Cepheids observed in stellar mode (total integration time of 2 sec on source in each band), and the larger field of view of the IRAC full frames allowed a search for spatially resolved extended emission around these sources. A similar investigation was possible for all targets in the MIPS 24 and 70 μm maps.

Figure 3 shows the results for three stars: the Cepheid class prototype (short period, fundamental mode) δ Cep, the short period, first overtone SZ Tau and the long period fundamental mode RS Pup. δ Cep, after PSF subtraction to remove the light from the bright central point source, shows asymmetric extended emission at 8.0 μm (and at 5.8 μm , not shown in the figure), extending as far as $\sim 30,000$ AU, centered on the star. Circumstellar emission is also detected at 70 μm , in the form of a bright arc enclosing the filaments imaged at shorter wavelengths. In the case of SZ Tau the emission extends $\sim 10,000$ AU, and is

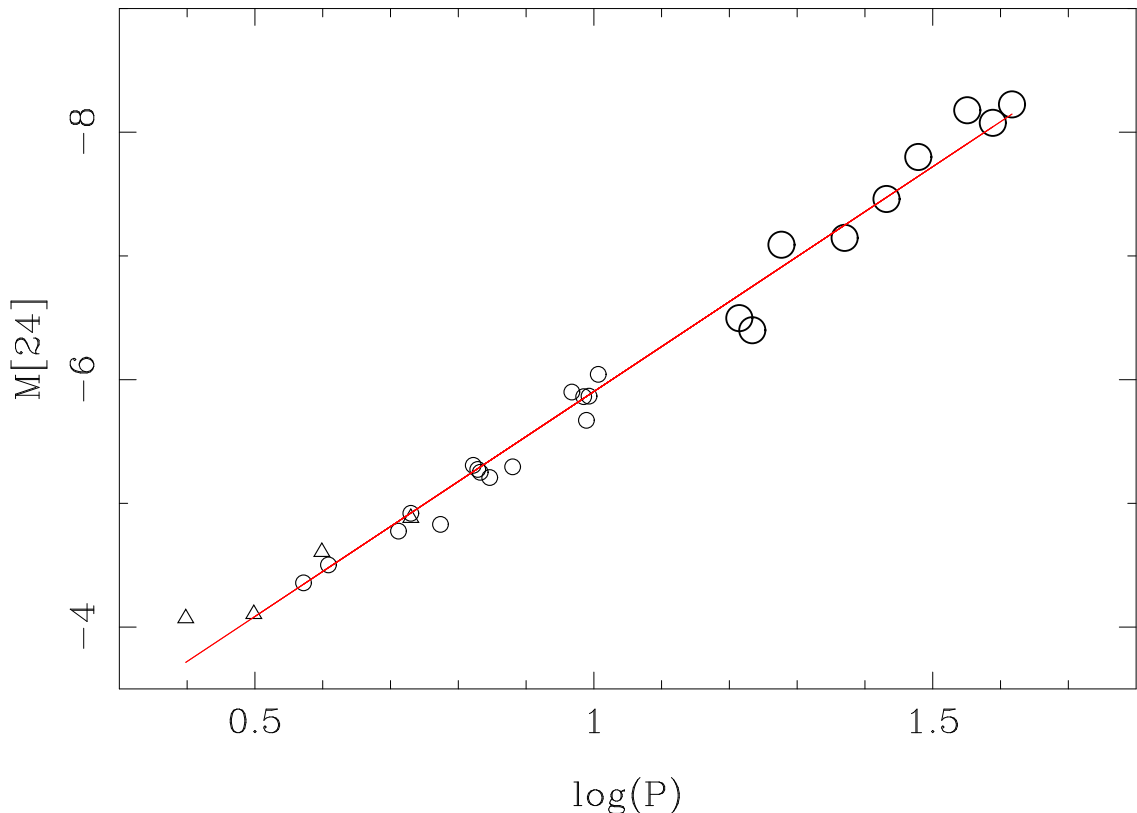


Fig. 2.— Period vs. MIPS 24 μm absolute magnitudes for the sample stars. The symbols are the same as in Figure 1.

present only on one side of the star. The same structure is observed at 24 μm (and at 70 μm , not shown in the figure). At 24 μm RS Pup shows the same nebula recently imaged by Kervella et al. (2008) in the optical, and used to derive the distance of the Cepheid from its light echoes. A large field, stellar mode, IRAC image of this target was not obtained as part of our program, preventing the detection of the nebula at IRAC wavelengths.

Due to the large spatial extension of the detected structure, it is clear that the origin of the emission cannot be radiation from warm dust in thermal equilibrium with the stellar flux (at that distance from the stellar photosphere, the dust equilibrium temperature would be too low for 8.0 and 24 μm emission). The observed nebulosity is then most likely associated with a reflection nebula or line nebular emission. Spectral observations are necessary to clarify the exact nature of this emission, and to understand if the circumstellar material that has been detected is the consequence of mass loss originating from the star.

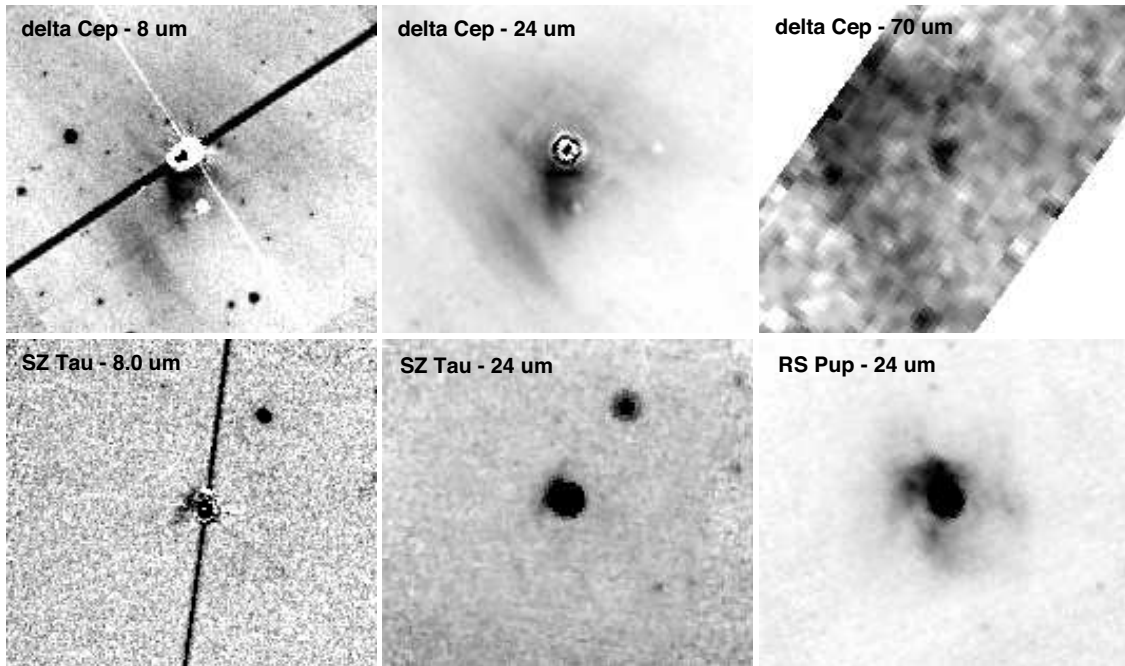


Fig. 3.— IRAC and MIPS PSF-subtracted images of δ Cep, SZ Tau and RS Pup, showing extended emission. The field of view of these images is about 4×5 arcmin

5. Summary

Our *Spitzer* IRAC and MIPS observations of Classical Cepheids have provided evidence for the presence of circumstellar material emitting at infrared wavelength. Infrared excess in the IRAC bands for a fraction ($\sim 1/4$) of our targets suggest the presence of warm dust in proximity to the stars. Extended diffuse emission is also found for some stars, at distances as large as tens of thousands of AU.

While more observations are required to determine the nature of the material responsible for this emission, our data support the possibility of active mass loss during the Cepheid phase. A paper with the complete analysis of our data is in preparation.

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