Herschel PACS and SPIRE imaging of CW Leo

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1. Introduction :

Ever since the discovery paper by Becklin et al. (1969), the object IRC +10 216 (CW Leo) has spurred much interest. We now know that it is a carbon star in an advanced stage of stellar evolution on the asymptotic giant branch (AGB), pulsating and surrounded by an optically thick dust shell and large molecular circumstellar envelope. The deep optical images taken by Mauron & Huggins (1999, 2000), Mauron et al. (2003), and Leão et al. (2006) show that the dusty envelope is not smooth but consists of a series of arcs or incomplete shells. The average angular separation between the dust arcs suggests a timescale for the change in mass-loss rate of the order of 200-800 yr. The lack of kinematic information on the dust arcs precludes any firm conclusion about the true three-dimensional structure of the arcs or shells. From large-scale mapping at a relatively low angular resolution of the CO J=1-0 emission, Fong et al. (2003) discovered a series of large molecular arcs or shells at radii of ~100" in the outer envelope. They attribute these multiple shells as "being the reverberations of a single Thermal Pulse erupting over 6000 yr ago". The timescale inferred from the spacing between these arcs is about 200-1000 yr.

In the following, we discuss our new results on the outer shell of CW Leo from observations with the *Herschel Space Observatory* (Pilbratt et al. 2010) and their connection to the results from *GALaxy Evolution Explorer Space Observatory* (GALEX) by Sahai & Chronopoulos (2010).

2. Observations and data analysis :

Using Herschel instruments a 30'x30' maps of CW Leo were taken :

- PACS images at 70 µm and 160 µm.
- SPIRE images at 250 µm, 350 µm and 500 µm.

Near-UV (NUV, 2271Å) and far-UV (FUV, 1528Å) GALEX data from the archives were added to the analysis.

λ (µm)	Flux (Jy)	λ (µm)	Flux (Jy)	λ (µm)	Flux (Jy)
0.15	(20±5)x10^{-4}	70	3.51±0.54	250	4.31±0.66
0.23	(2±0.5)x10^{-4}	160	7.70±1.17	350	1.70±0.27
				500	0.73±0.14

Table 1. Derived fluxes for the extended emission.

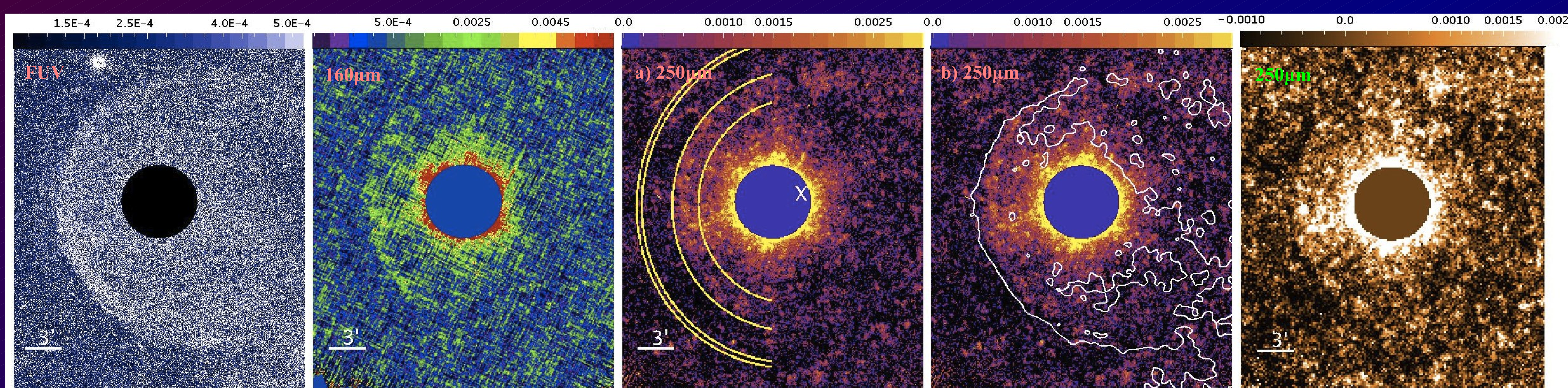

Fig. 1. Surface brightness maps in Jy/pixel. Overplotted on the 250 µm map (a) the annuli segments between which we integrated the flux for the extended emission (inner annulus) and the sky (outer annulus). The white cross represents the center of the ellipse. Overplotted on the 250 µm map (b) the contour from the FUV map at 4.4x10^{-5} mJy/arcsec^{-2} limit. FOV for all images is 23'x27'.North is up and east is to the left.

3. Bow shock, thermal pulse or both ?

A bow shock in the form of an arc is seen at 160 µm, 250 µm, and 350 µm with a spatial scale as large as 22' . This extended emission matches the position and the shape of the FUV extended emission (Sahai & Chronopoulos, 2010) (see Fig. 1).

From the 1D intensity profile, an offset of ~20" is found between FUV and the far-IR intensity peaks which suggests a different origin of the two emissions.

The total flux (see Table 1) in the bow shock was calculated within the segment of an elliptical annulus matching the spatial scale of the extended emission (see Fig. 1). A dust temperature of 25±3 K is derived by fitting a modified black body to the photometry.

With the estimated interpulse period of 6 000-33 000 years (using Wagenhuber & Groenewegen, 1998 relation) and with a flow timescale in the unshocked and shocked winds of 19 900 and 56 000 years at least one thermal pulse is expected to have occurred but no obvious density enhancement is seen in the unshocked wind.

4. Space motion of the star and the ISM flow velocity

Using a distance of d= 135 pc and a mass-loss rate $\dot{M}$= 2.2x10^{-5} $M_\odot$ (Groenewegen et al. 1998), a gas expansion velocity of V_{exp} = 15.4 km/s, a radial velocity V_{LSR}= -25.5 km/s (Groenewegen et al. 2002), corresponding to V_{helio}= -18.6 km/s, and a proper motion $\mu_\alpha \cos\delta$= +26 ± 6, μ_δ =+4 ± 6 mas/yr (Menten et al. 2006), we derived the main parameters of the bow shock and the star's space motion.

- The heliocentric space velocity of the star is estimated to be about 25.1 km/s at a heliocentric inclination angle of the space motion vector of 47.8 degrees (measured from the plane of the sky away from us) and a PA of 81.3° for the proper-motion vector in the plane of the sky.
- The stand-off distance is of (8.0± 0.3)x10^{17}cm with the apex of the shock oriented at 61.9°±0.3° (it could be pointing away from us or towards us) with respect to the plane of the sky into the PA of 88°.

From the ram pressure balance equation, the relative velocity of the star with respect to the ISM is V_{star} = 106.6±8.7/$n_{ISM}^{0.5}$ km/s, where n_{ISM} is the number density of the ISM local to CW Leo in cm^{-3}.

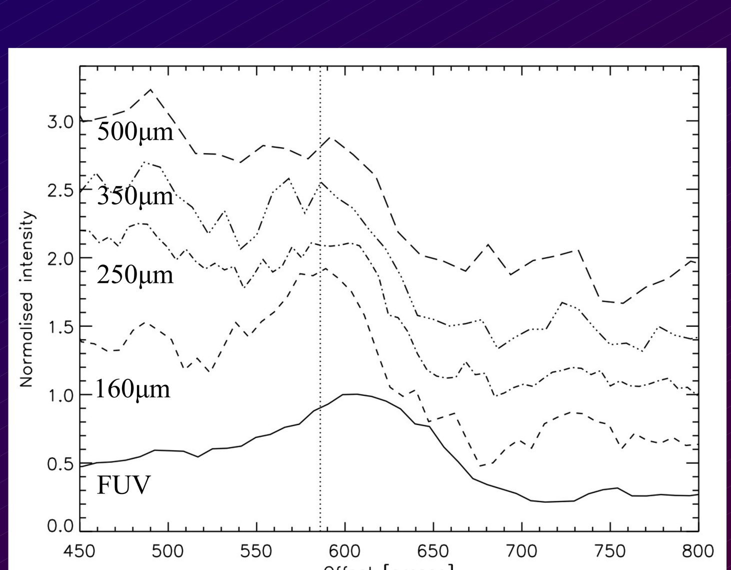

Fig. 2. Intensity profyles as a function of the offset along the minor axis of the ellipse increasing from west to east. Each wavelength was normalised to the intensity at 558" and shifted up for clarity. The normalisation factor in mJy/arcsec2 the vertical shift: (0.065, 0.0), (0.063, 0.8), (0.023, 1.1), (0.008,1.4) (0.004, 1.8). The vertical dotted line indicates the position of the dust emission peak from the center of ellipse.

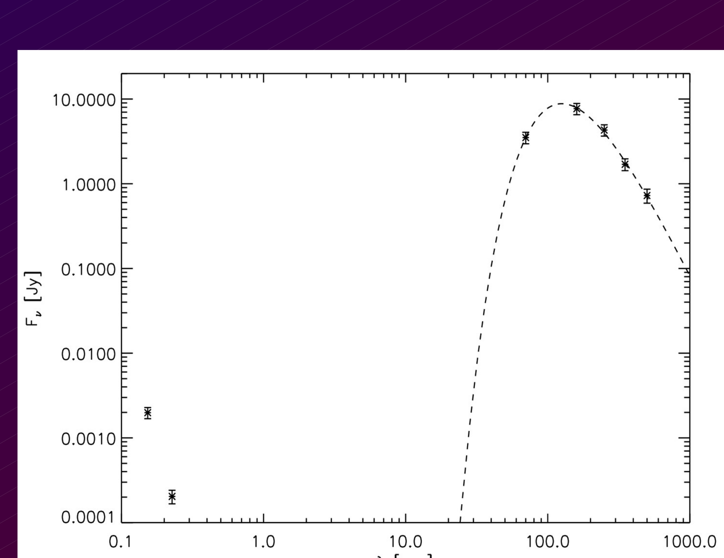

Fig. 3. Modified black body (T = 25±3 K and β = 1.6±0.4) fit (dashed curve) to the derived fluxes (symboles) for the extended emission.

The heliocentric space velocity components of the star can be converted to the heliocentric Galactic space velocity components [U, V, W] of [21.6±3.9, 12.6±3.5, -1.8±3.3] km/s , and also to the LSR Galactic space velocity components of [30.6±3.9, 24.6±3.5, 5.2±3.3] km/s. The heliocentric ISM flow velocity is 117.6 km/s if the bow cone is facing us (i.e. the apex pointing toward) or 82.6 km/s if the bow cone is facing away from us.

The comparison between the shape of CW Leo's bow shock and Wareing et al. (2007) 3D hydrodynamical models for AGB stars (Fig. 4) suggests that the density of the local ISM to CW Leo is probably higher than 2 cm^{-3} implying an upper limit of 75 km/s to Vstar.

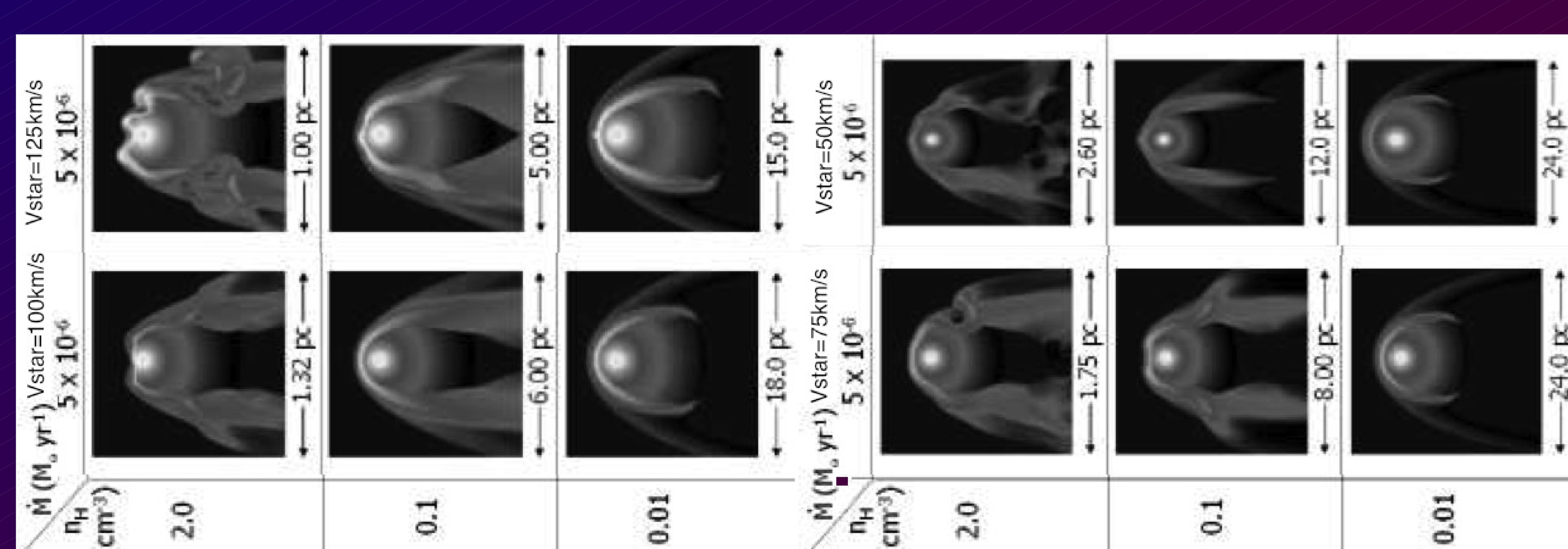

Fig. 4. 3D hydrodynamical models for AGB stars by Wareing (2007). Each panel is for a different mass-loss rate, number density of the ISM and velocity of the star relative to the ISM.

4. Conclusion :

For the first time, we resolved the infrared emission of the wind-ISM intereaction of CW Leo and we derived the basic parameters of the bow shock. The temperature of the dust is estimated to be of 25±3 K.

The stellat velocity relative to the ISM is V_{star} = 106.6±8.7/$n_{ISM}^{0.5}$ km/s, where n_{ISM} is the number density of the ISM local to CW Leo in cm^{-3}.

By comparing the the bow shock to the 3D hydrodynamical models of Wareing et al. (2007) we could infer that the density of the ISM is probably higher than 2 cm^{-3} with an upper limit for the stellar velocity relative to the ISM of 75 km/s.

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