MWC 297: a young high-mass star rotating at critical velocity

Bram Acke (KULeuven, Belgium)

Tijl Verhoelst, Mario van den Ancker, Pieter Deroo, Christoffel Waelkens, Olivier Chesneau,
Eric Tatulli, Myriam Benisty, Elena Puga, Rens Waters, Arjan Verhoeff and Alex de Koter

Introduction

Located at a distance of 250 pc (association with the Aquila Rift) and with a mass of approximately 10 solar masses (Drew et al. 1997, MNRAS 286, 538), **MWC 297** is one of the closest **young high-mass stars**. The source has been the subject of many investigations, covering the entire spectral range from X-rays to centimeter wavelengths. Despite the wealth of observational data, its nature is far from well understood. One of the most remarkable assets of MWC 297 is the **high projected rotational velocity** of the central star (350±50 km/s).

The Spectral Energy Distribution of MWC 297 is characterized by a significant infrared excess. The central star is attenuated with 8 magnitudes in the optical. Its broad environment is rich in dust and gas, as evidenced by e.g. the cold dust emission in the *Spitzer* IRAC images (see Fig. 1) and sub-millimeter CO emission on scales of several arc-minutes (~0.1 pc at 250 pc).

Extinction towards the system

The infrared ISO-SWS spectrum of MWC 297 is characterized by a shallow silicate absorption band at 10 micron. The shape of the absorption band is indicative for the presence of small, ISM-like silicate grains. Moreover, at shorter wavelengths, CO_2 and H_2O-ice absorption bands are detected. A priori, it is unclear whether the extinction towards the central star and its surroundings is due to circumstellar matter, directly associated to the star, or interstellar matter in the line of sight. However, the presence of the ices and the large scale dust and CO emission is most naturally explained by the presence of an **interstellar cloud** complex in between us and MWC 297. The cold dust is also the reason for most of the excess emission observed beyond 25 micron (ISO-LWS, IRAS 25, 60, 100 µm). This is witnessed by a measurement by di Francesco et al. (1994), who spatially resolved the 50 and 100 µm-emission region. A comparison with the *Spitzer* IRAC images shows that it is the same cold material radiating. We argue that the dust and gas observed around MWC 297 is **remnant material of the natal cloud** from which the system has formed.

In Fig. 2, the SED of MWC 297 is shown. It is dereddened assuming a standard interstellar extinction law (Savage & Mathis 1979, ARA&A 17, 73; Steenman & Thé 1989, Ap&SS 159, 189 and 1991, Ap&SS 184, 9). It can be seen that the silicate absorption band becomes a moderate emission feature in the dereddened spectrum.

New observations

We have observed MWC 297 with ESO's **Very Large Telescopes Interferometer** (VLTI, Paranal, Chile) in the near- (AMBER) and mid-infrared (MIDI). These instruments sample the spatial brightness distribution of the target on milli-arcsecond scales at 1.6-2.5 and 8-13 micron. All measured closure and differential phases are within the error bars equal to zero, indicating a point-symmetric brightness distribution at all sampled wavelengths. The visibilities in the near-IR probe the hot dust and gas that is present in the circumstellar environment, while the mid-IR data sample the hot material, as well as warm dust further away from the star.

A reconstruction of the **image of the MWC 297 circumstellar environment** could be achieved with an intensity model consisting of three Gaussian curves. The extent (FWHM) of these curves was fixed to be equal at all wavelengths. Two Gaussians represent the hot and warm matter, which radiates in both the near-IR and mid-IR and accounts for the IR continuum. The last one represents the silicate dust, which produces the 10 micron emission feature. By definition, the latter only contributes in the mid-IR. In combination with the SED data, brightness temperatures can be connected to the three components in our reconstructed image. The best-fit results are summarized in the Table. The flux contributions of the individual components to the total SED is overplotted in Fig. 2. The model image of the circumstellar matter in MWC 297 at different wavelengths is shown in Fig. 3.

Table – Results of the best fit to the interferometry and SED.

component	FWHM [mas]	(AU)	$T_{brightness}$ [K]
A	4.2 ± 0.3	(1)	1700 ± 200
B	12 ± 1	(3)	930 ± 80
C	40.8 ± 0.7	(10)	520 ± 20

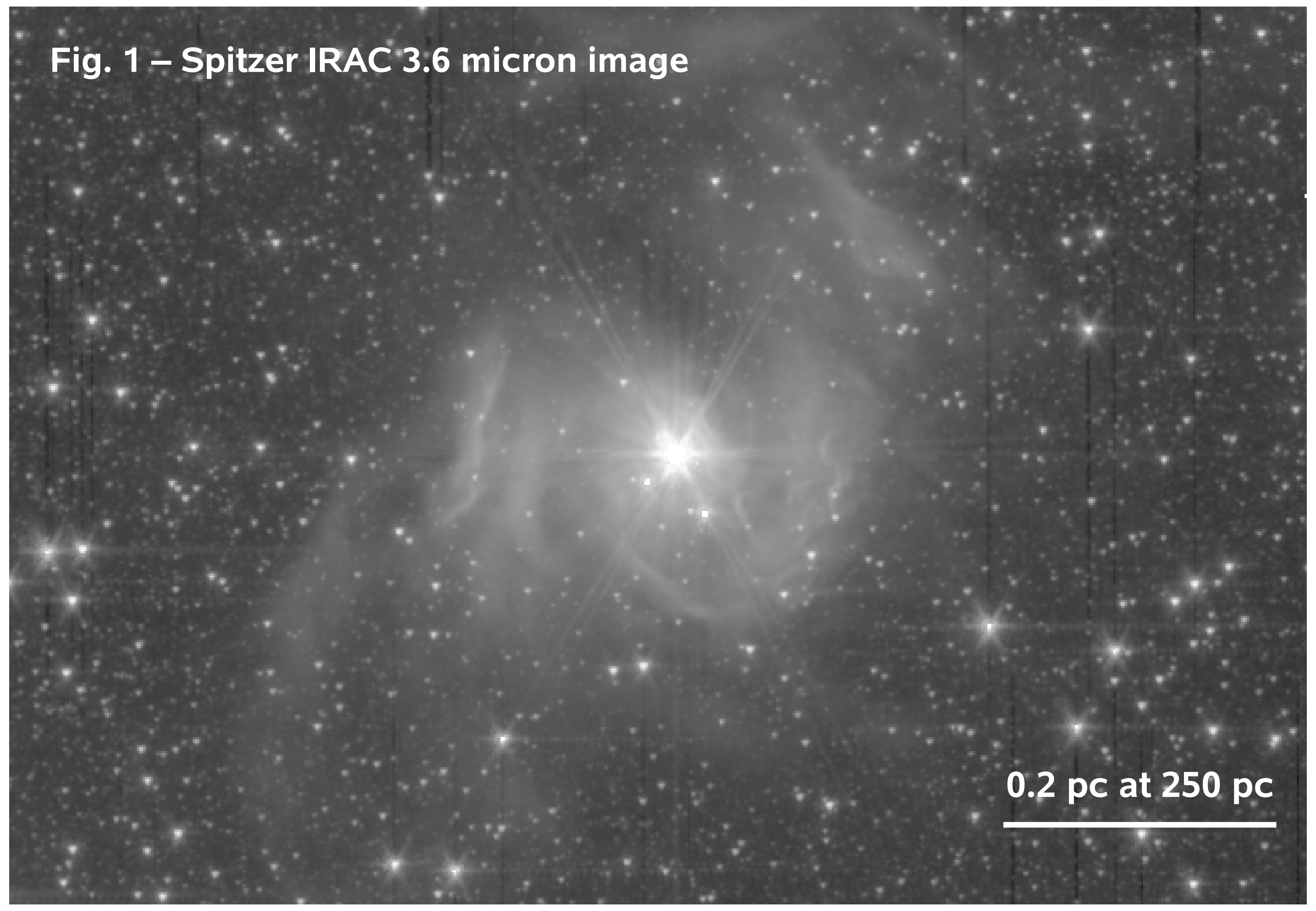

Fig. 1 – Spitzer IRAC 3.6 micron image

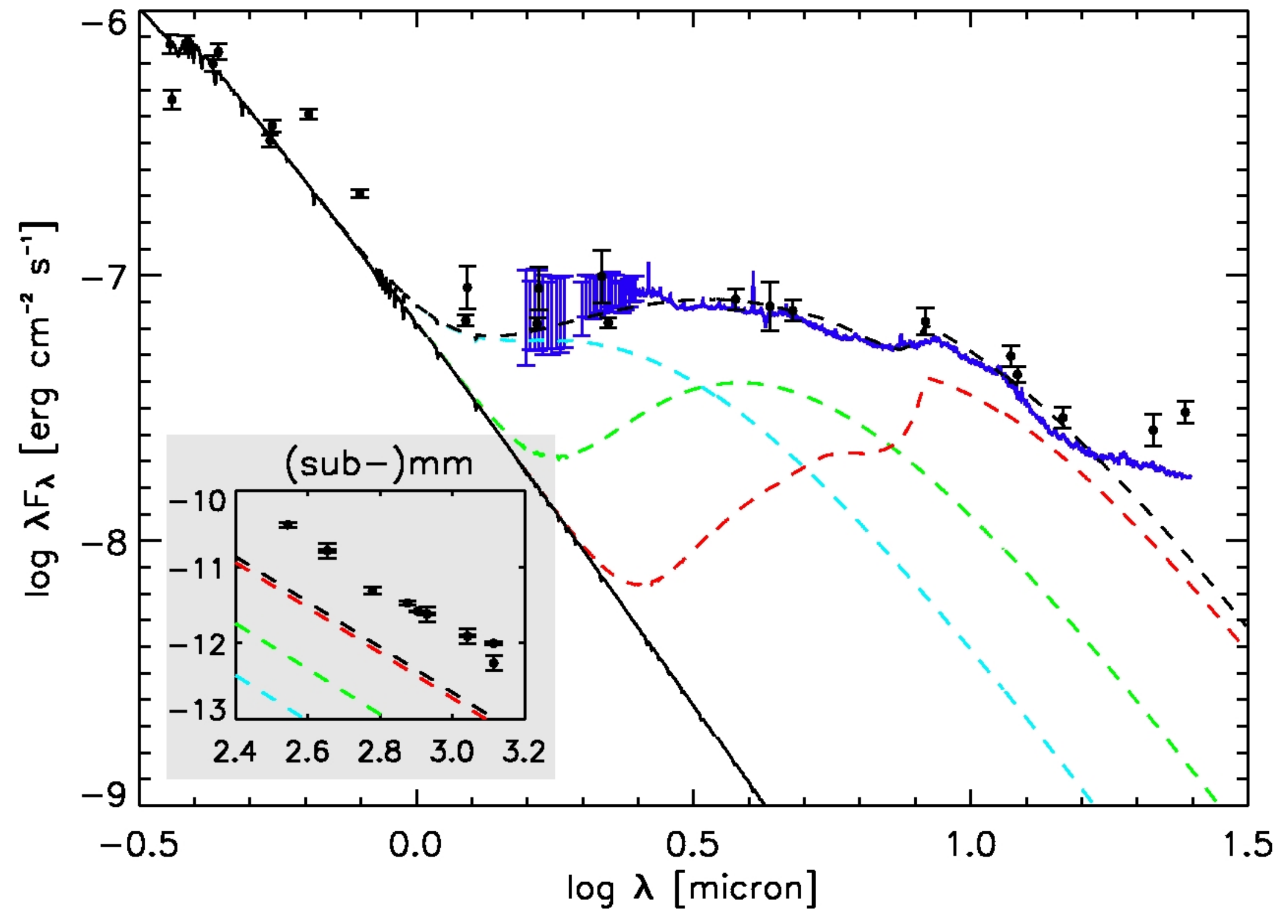

Fig. 2 – Dereddened SED.

black line: Kurucz model; **blue error bars:** AMBER spectrum; **blue line:** ISO-SWS spectrum; **blue**, **green**, **red** and **black** dashed lines: flux contributions of the three components and total flux of the best-fit model to the interferometry.

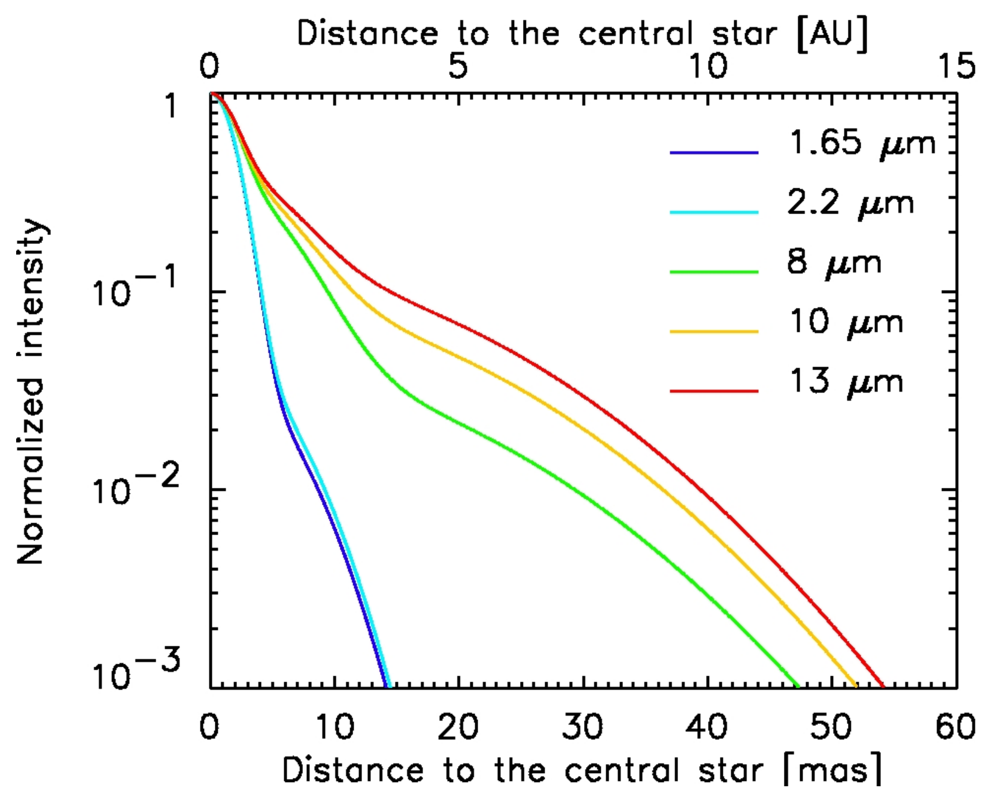

Fig. 3 – Reconstructed image of MWC 297.

Image deduced from the near-IR and mid-IR interferometry and the dereddened SED. Different colors refer to different wavelengths. Note the ***extremely compact nature*** of the circumstellar matter (image FWHM < 1.5 AU at *all* λ) and the presence of dust emission well within the dust sublimation radius of 15 AU for small olivine grains.

The nature of the disk

We have tested spherically symmetric geometries (halo, outflow), but no model could simultaneously explain the extremely compact nature of the object, the spectral energy distribution and the extinction towards the central star: a compact halo with enough mass to produce the observed IR excess invokes an extremely high optical extinction. Therefore, the circumstellar matter around MWC 297 resides in a disk-like structure. The presence of dust within the sublimation radius proves that this disk must contain extremely dense gas close to the star, which effectively shields the dust from direct stellar radiation. A **dense gas+dust disk** is also consistent with a large number of observations at all wavelengths, including extremely strong hydrogen emission (optical-IR), thermal forbidden oxygen emission (optical), the shallow spectral index of the SED at sub-mm wavelengths, and diamond emission (near-IR).

Rotating at critical velocity

All interferometric data available to date are inconsistent with an elongated brightness distribution on the sky. This indicates that the disk can only be moderately inclined. We derive an **upper limit to the inclination of 40º**. If the rotational axis of the disk and star are –as expected– aligned, the low inclination makes that the high observed projected rotational velocity of the star corresponds to a velocity equal to, or **exceeding 450±70 km/s**, the critical velocity at which the gravitational and centrifugal force are in balance. MWC 297 is the first pre-main-sequence star discovered to be a **critical rotator**.

MWC 297: future and past

Stellar rotation is a fundamental property that can determine the evolution and ultimate fate of high-mass stars. Some 20% of all B-type main sequence stars exhibit the so-called ***classical Be* phenomenon**: they are fast rotators and surrounded by gaseous disks producing H, He and metallic emission lines in the optical spectrum. It has been claimed that the phenomenon occurs when a fast –but initially sub-critically– rotating B star slowly expands on the main sequence until its gravitational field at the equator becomes too weak to keep the surface layers from escaping. Stellar magnetic fields and pulsations likely also play a role. Here we have shown that, alternatively, stars can be *born* as critical rotators. MWC 297 is a classical Be star to be.

It is interesting to understand why MWC 297 has become a critical rotator so early in its evolution. For lower-mass T Tauri stars, Shu et al. (1994, ApJ 429, 781) suggested that the eventual rotational velocity of the star is determined by the interaction of the star and its accretion disk. Magnetic fields lock the stellar surface rotation to the orbital rate close to the inner edge of the disk. A higher accretion rate, as well as a weaker magnetic field, shifts this *co-rotation radius* inwards, implying a higher stellar rotation rate. Theory hence predicts –for low-mass stars– than the **inner radius of the disk is small if the stellar rotation rate is high**.

The extremely compact and dense disk, with no detected inner gap, in combination with the extraordinary rotational velocity of the star in MWC 297 may therefore provide information on their mutual origin. If the above theory also applies for high-mass stars, this would indicate that MWC 297 has been subjected to extremely high accretion rates and/or that its magnetic field is insignificant.

In general, the low detection rate of magnetic fields in high-mass stars is consistent with, and may provide an explanation for, the higher-than-average rotational speeds in this group of stars.

The full analysis and details can be found in
Acke et al., 2008, A&A 485, 209

Requests, questions and remarks:
contact me here at the conference or email me at
bram@ster.kuleuven.be