RevMexAA (Serie de Conferencias), **38**, 74–76 (2010)

OBSERVATIONS OF THE B[E] STAR MWC 349 WITH MID-INFRARED INTERFEROMETRY

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RESUMEN

MWC 349 A es probablemente una estrella masiva joven rodeada por un disco y un fuerte viento ionizado desde la superficie del disco. Las características más espectaculares del disco de MWC 349 A son líneas máser y láser de recombinación del hidrógeno en longitudes de onda milimétrica, sub-milimétrica y de IR-medio. Hemos conducido observaciones de MWC 349 A con el instrumento MIDI del VLTI a 10 μm. Las visibilidades en el continuo muestran la firma característica esperada en un disco de polvo. Además, las firmas de por lo menos una docena de líneas de emisión han sido identificadas en los datos interferométricos.

ABSTRACT

MWC 349 A is likely a young massive star surrounded by a disk and a strong ionized wind from the disk surface. The most spectacular features of the MWC 349 A disk are hydrogen recombination line masers and lasers at mm, sub-mm and mid-IR wavelengths. We have conducted observations of MWC 349 A with the MIDI 10 μm instrument of the VLTI. The continuum visibilities show the expected characteristic signature of a dust disk. In addition, the signatures of at least a dozen emission lines have been identified in the interferometric data.

Key Words: instrumentation: interferometers — stars: emission-line, Be — stars: individual (MWC 349A)

1. INTRODUCTION

MWC 349 A is bright throughout the infrared, and it is one of the brightest radio stars known. Its bolometric luminosity is at least $2 \cdot 10^4\ L_\odot$ if corrected for foreground extinction, but probably much higher if much of the absorbing material is in a disk allowing most of the stellar radiation to escape. A luminosity as high as $5 \cdot 10^5\ L_\odot$ appears plausible if a bolometric correction corresponding to a hot main sequence star is applied. A host of fine structure lines from ions with ionization potentials up to 41 eV are detected in the ISO spectrum of MWC 349 A, confirming that the effective temperature of the star is at least 35,000 K (Quirrenbach et al. 2001).

Evidence for a circumstellar disk was obtained from high-resolution VLA images (White & Becker 1985). Near-infrared emission-line spectra have been successfully interpreted by a photo-evaporating disk model (Hamann & Simon 1986). The most spectacular features of the MWC 349 A disk are the strong hydrogen recombination line masers at mm and sub-mm wavelengths (H21α to H35α), which are located in the disk at $\sim$ 40 AU. MWC 349 A was observed with the SWS and LWS grating spectrometers on the ISO satellite (Thum et al. 1998a; Quirrenbach et al. 2001). Among the $\sim$ 100 detected hydrogen recombination lines are all 12 α-transitions within the wavelength range accessible to ISO, from Brα at 4.05 μm to H 15α at 169.4 μm. The α-lines with $n \leq 6$ are optically thick; the lines with higher n are amplified, and thus constitute *infrared lasers*. Combining the ISO results with millimeter and sub-millimeter data gives the first global view on the recombination line laser/maser phenomenon in this star: the maximum line-integrated amplification –by a factor of $\sim$ 30– occurs in the region near $n = 19$ at $\sim 300\,\mu$m.

Complementary information on the MWC 349 A disk comes from recent high-resolution observations in the near-infrared (aperture masking at the Keck I Telescope, Danchi et al. 2001; speckle interferometry at the SAO 6 m Telescope, Hofmann et al. 2002). These data sets reveal a disk seen almost edge-on at a position angle of $100° \pm 3°$ on the sky, consistent with the position angle of a dark lane observed previously in the VLA continuum maps. It appears that the uniqueness of MWC 349 A (the only known hydrogen recombination line maser source known) is a consequence of its being in a short-lived evolutionary stage, combined with an almost edge-on orientation.

2. MIDI OBSERVATIONS

Our interferometric observations of MWC 349 A in the N band have been designed to develop a de-

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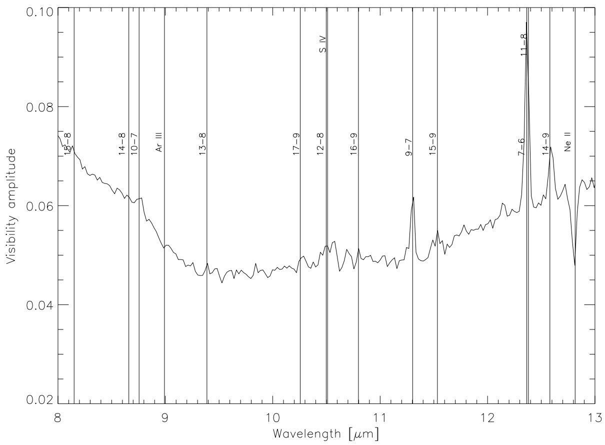

Fig. 1. Instrumental visibility from one observation on the UT1-UT3 baseline. For details see the text.

tailed model of the mass, geometry, density, and temperature distribution of the disk (see also Albrecht et al. 2006; Quirrenbach et al. 2006). We observed MWC 349 A with the MIDI instrument of the VLTI, which provides spectrally resolved data from $\approx 8\,\mu$m to $\approx 13\,\mu$m (Leinert et al. 2003). We obtained a total of 13 *uv* data points with the 8 m Unit Telescopes of the VLTI using the grism mode ($R \approx 230$), and 7 additional data points with the 1.8 m Auxiliary Telescopes using the prism ($R \approx 30$).

3. RESULTS AND MODELING

For each observation with one specific baseline length and orientation, the continuum visibility as a function of wavelength has a characteristic shape (see Figure 1): it is rather high at short wavelengths (around $8\,\mu$m), drops to a minimum in the range $10\,\mu$m – $11\,\mu$m, and increases again towards the long-wavelength end of the spectrometer range (near $13\,\mu$m). Visibilities with this type of wavelength dependence are characteristic for disks, in which a warmer smaller component dominates the shorter wavelengths within the N band, and a cooler larger component the longer wavelengths. Mineralogy of the dust which constitutes the disk might also play a role. The mass absorption by amorphous silicates, which are thought to be abundant in proto-planetary disks, rises from the short wavelength side of the band-pass of MIDI, peaks at $9.7\,\mu$m, and decreases again towards longer wavelengths. That means one actually probes colder layers closer to the mid-plane of the circumstellar disk at the long and short wavelength regimes of the spectrum, while at wavelengths around $9.7\,\mu$m one probes hotter layers higher above the mid-plane.

Simple geometric models that include dust with a temperature distribution between ~ 300 K and ~ 1700 K can simultaneously fit the continuum visibilities and the total spectral energy distribution as observed by the ISO satellite. Due to the rather high declination of MWC 349 A ($+40°$) and the limited number of VLTI baselines available, the *uv* coverage of our observations is not sufficient to obtain synthesis images of the disk. It is clear, however, that the sky brightness distribution is strongly non-circular, as expected for a disk seen nearly edge-on. The position angle of the disk derived from our MIDI data is fully consistent with the orientation given by Danchi et al. (2001).

The observed visibilities show a rich structure as a function of wavelength, due to strong emission lines. This opens the possibility of assessing the sizes and geometries of the disk, the region in the wind emitting the forbidden atomic fine structure lines, and the hydrogen recombination line region. Our data provide separate information on no fewer than a dozen emission lines. In this context it should be pointed out that it is the overall consistency (e.g., *all* hydrogen lines with quantum numbers up to H17-9 in the MIDI band produce peaks of the visibility) that makes us confident that all lines marked in Figure 1 are indeed true detections.

A pronounced drop of the visibility at the wavelength of [NeII] λ12.81 and a likely drop at [ArIII] λ8.99 indicate that the forbidden line region is larger than the dust disk, as expected in models in which these lines are formed in a wind that originates from the disk. (A similar drop would be expected at the position of [SIV] λ10.51, but this line is blended with a strong hydrogen recombination line.)

A broad spectral emission feature centered at $8.6\,\mu$m has been seen in the ISO spectrum of MWC 349 A and tentatively attributed to the C-H in-plane bending mode of PAHs (Thum et al. 1998b). This feature is not immediately apparent in the visibility spectra, but more detailed modeling of the continuum emission will be needed to reach a firm conclusion on the contribution of PAH emission to the correlated flux.

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