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THE COLD CIRCUMSTELLAR ENVIRONMENT OF THE STAR VEGA: AN LMT PERSPECTIVE

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RESUMEN

Se presentan las observaciones y el análisis preliminar de la estrella Vega (HD 172167, α Lyrae) llevadas a cabo con el Gran Telescopio Milimétrico Alfonso Serrano (GTM) con su apertura inicial de 32m. Se utilizó la cámara AzTEC, sensible en 1.1mm, bajo condiciones de opacidad atmosféricas de excelentes a buenas, que permitieron alcanzar una profundidad de 0.30 mJy después de integrar en la fuente durante 8.8 horas. El mapa de Vega (detectada a 10σ) y su entorno muestra con claridad la naturaleza extendida del polvo circunestelar frío (T$\sim$40 K), perceptible hasta aproximadamente 180 au de la estrella. Considerando las incertidumbres en el flujo detectado, no se identifican inhomogeneidades en la emisión del disco frio que puedan ser atribuidos a la presencia de un planeta. Un mapa significativamente más profundo será obtenido con la cámara sucesora de AzTEC, el instrumento multibanda (1.1, 1.4 y 2 mm) TolTEC, que previsiblemente permitirá establecer si existen subestructuras en el sistema.

ABSTRACT

We present the observations and preliminary analysis of the star Vega (HD 172167, α Lyrae) conducted with the Large Millimeter Telescope Alfonso Serrano (LMT), with its initial aperture of 32m diameter. We used the AzTEC continuum camera at 1.1mm under benign atmospheric conditions that allowed to reach a depth of 0.30 mJy after 8.8 hours of integration on source. The reduced map of Vega (detected at 10σ) and its environment clearly shows the extended nature of the cold circumstellar dust (T$\sim$40 K), which extends up to approximately 180 au from the star. To within the observational uncertainties, we cannot identify inhomogeneities on the cold ring that could plausibly be ascribed to the presence of a planet. A significantly deeper map will be obtained with the AzTEC camera successor, the multi band (1.1, 1.4 y 2 mm) continuum instrument TolTEC, that foreseeably will be able to identify if substructures are present in the system.

Key Words: stars: circumstellar matter — stars: individual: Vega

1. INTRODUCTION

The gas- and dust-rich circumstellar disks around young stars are the formation site of planetesimals, which are the building blocks of planets. These planetesimal belts are still detectable around old stars by detection of continuum emission at infrared and millimeter wavelengths, from dust produced in collisions between planetesimals, and thus referred to as "debris disks". Vega (RA=18:36:56.33, DEC= +38:47:01.2802), a relatively young (age $\sim$ 400-700 Myr; Monnier et al. 2012) A0 V star at 7.7 pc (van Leeuwen 2007), was the first star to be identified as having a circumstellar debris disk (Aumann et al. 1984). As such, it is the prototypical debris disk system and has been extensively studied at optical, infrared, and (sub-)millimeter wavelengths to characterize the star (Gulliver et al. 1994; Aufdenberg et al. 2006), the disk (Su et al. 2013; Sibthorpe et al. 2010; Hughes 2012; Holland et al. 2017), and to search for planets (Meshkat et al. 2018). Characterisaztion of the Vega debris disk at millimeter wavelengths, essential to trace the dust-producing planetesimal belt(s) within the system, has been conducted with virtually all available infrastructures from space and from the ground.

The global picture emerging from the numerous investigations is that Vega contains two systems of inner warm belts that are surrounded by a cold disk ($T \sim 40$ K), with a mass estimated to be 0.7 times that of the Moon. The cold component extends up to 200 au, in a face-on geometry, and has been extensively analyzed with single dish and interferometric infrastructures (Matrà et al. 2020, and references therein), some of which have provided tentative evidence of the presence of inhomogeneities that could

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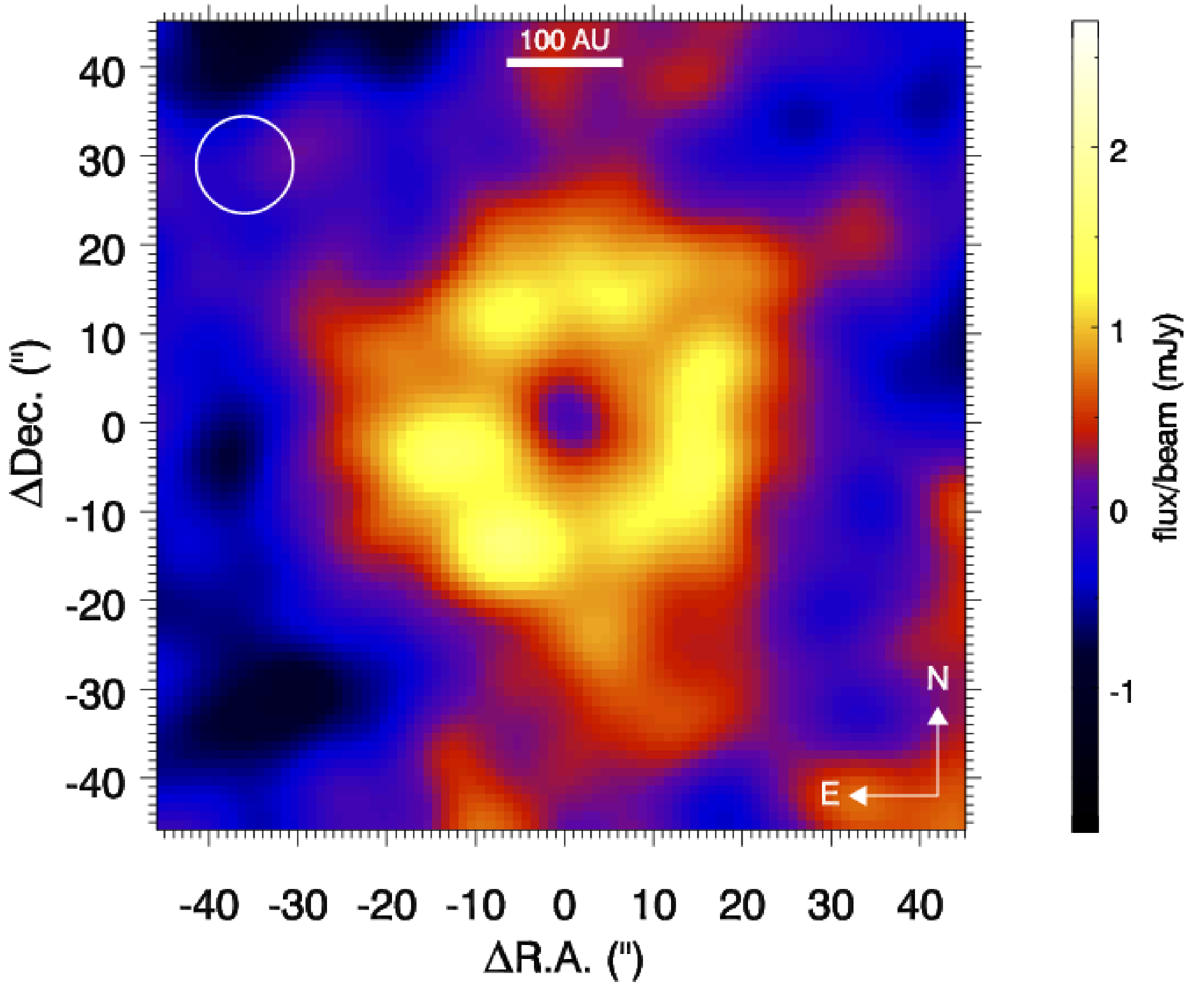

Fig. 1. The LMT/AzTEC map of the Vega system at 1.1 mm, with a Gaussian PSF subtracted at the star's location, with peak of 2.56 mJy/beam. The instrument beam size of 10.9 arcsec FWHM is given by the white circle in the top left.

plausibly arise from the interaction between a planet and the observed cold dust.

The Vega system of cold dust has, nevertheless, posed a difficult challenge for the identification of clumpy substructures due to it being face-on, smooth, and with a large angular extent (diameter $> 20''$). The low angular resolution of many single dish facilities, such as the James Clerk Maxwell Telescope (Holland et al. 2017), blends the star and disk, whilst interferometric facilities, such as the Submillimeter Array (SMA) or the Atacama Large Millimeter Array (ALMA, Hughes 2012), have little sensitivity, due to the large angular scale of the disk. Some evidence for clumps in the disk has been presented at low significance (Holland et al. 1998; Marsh et al. 2006), but a clear identification of substructure within the disc remains elusive (Hughes 2012).

In this contribution, we present preliminary qualitative results of the observations of VEGA with the Large Millimeter Telescope Alfonso Serrano (LMT), using the AzTEC continuum camera sensitive at 1.1mm, with the goal of verifying the presence (or lack) of dust emission enhancements along the cold disk. The detailed results will soon be presented in Marshall et al. (in preparation).

2. OBSERVATIONS AND DATA REDUCTION

The star Vega was observed with the LMT, in its 32m configuration, in February and March 2016. A total of 8.8 hours on source were devoted to the

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observations with the AzTEC continuum camera[4], under excellent atmospheric conditions, with opacities at 225 GHz that ranged from 0.03 to 0.11. The reduction scheme implemented for the acquired set of 1.1mm maps is that developed by Wilson et al. (2008), and described in some detail in Chavez-Dagostino et al. (2016). We additionally treated the map with the code FRUIT, developed by one of us (DSA), aimed at removing the large scale noise (see also Marshall et al. in preparation, for more details).

3. ANALYSIS AND RESULTS

The final 1.1mm map, with a depth of 0.30 mJy, is presented in Figure 1, where we have extracted the contribution of the star (see figure caption) for the disk to stand out with better clarity. In the image, the north is up and east is left. The beam size is represented by the white circle in the upper left corner of the figure.

We note that, at the working resolution of 10.9" (which also accounts for a Gaussian filtering to increase the signal-to-noise ratio), it is not possible to identify the inner edge of the cold component from the outer edge of the warm dust. We, however, can see that significant emission is detected out to 23" ($\sim$ 180 au) from the star and some apparently clumpy structures seem to be present in the N, E and SE directions. There also seems to be an extension of emission (at low significance though) in the south. The disk is detected, at least, at a 4.1σ level all along the azimuthal angle.

The radial profile of the flux is depicted in Figure 2. The point colors are indicated in the color bar on the right, where we also label the octants for easier reference. The line in black shows the average flux. Whilst the regions with the less prominent flux in the NE ($\sim$0.8 mJy) appear to significantly differ from, for instance, the highest SE emission peak ($\sim$1.7 mJy), the observational uncertainties, of the order of $\pm$0.3 mJy, prevent to conclude that the disk is not smooth.

Higher signal-to-noise ratio observations are required to unambiguously assess on the presence of inhomogeneities in Vega's cold debris disk. We foresee that such a task can be achieved by the multi-band TolTEC camera (Wilson et al. 2020), sensitive in the bands 1.1, 1.4 and 2 mm. TolTEC will soon be commissioned at the LMT, now working with its

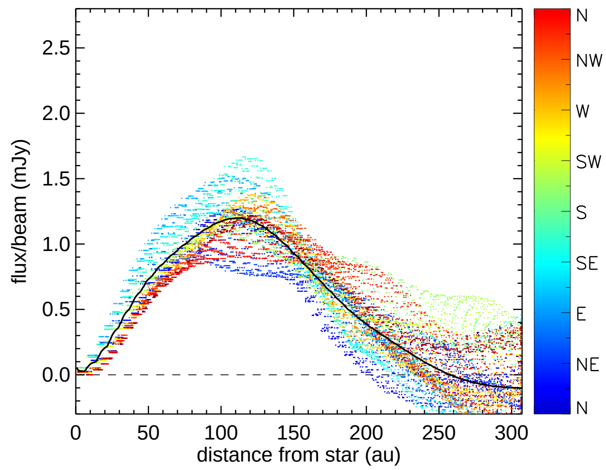

Fig. 2. Radial flux profile of the Vega system. The black continuous line indicates the average value, while the color dots show the profile at the azimuthal angle according to the color bar code.

full aperture of 50 m diameter. Considering the expected sensitivities of TolTEC, with merely 30 min of integration on source we would be able to reach a depth of 0.1 mJy with the smallest feasible (Lissajous) mapping mode, at a spatial resolution of 6", thus providing a better assessment of Vega's debris disk properties.

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[4]The camera AzTEC was decommissioned in 2018 and will soon be replaced by the camera TolTEC (see text).