

Forming localized dust concentrations in a dust ring

DM Tau case study

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ABSTRACT

Context. Previous high-angular-resolution 225 GHz (~ 1.3 mm) continuum observations of the transitional disk DM Tau have resolved an outer ring at 20–120 au radii that is weakly azimuthally asymmetric.

Aims. We aim to examine dust growth and filtration in the outer ring of DM Tau.

Methods. We performed $\sim 0''.06$ (~ 8.7 au) resolution Karl G. Jansky Very Large Array (JVLA) 40–48 GHz (~ 7 mm; Q band) continuum observations, along with complementary observations at lower frequencies. In addition, we analyzed the archival JVLA observations undertaken since 2010.

Results. Intriguingly, the Q band image resolved the azimuthally highly asymmetric, knotty dust emission sources close to the inner edge of the outer ring. Fitting the 8–700 GHz spectral energy distribution (SED) with two dust components indicates that the maximum grain size (a_{max}) in these knotty dust emission sources is likely $\gtrsim 300 \mu\text{m}$, whereas it is $\lesssim 50 \mu\text{m}$ in the rest of the ring. These results may be explained by a trapping of inwardly migrating “grown” dust close to the ring inner edge. The exact mechanism for developing the azimuthal asymmetry has not yet been identified, which may be due to planet-disk interaction that might also be responsible for the creation of the dust cavity and pressure bump. Otherwise, it may be due to the fluid instabilities and vortex formation as a result of shear motions. Finally, we remark that the asymmetries in DM Tau are difficult to diagnose from the $\gtrsim 225$ GHz observations, owing to a high optical depth at the ring. In other words, the apparent symmetric or asymmetric morphology of the transitional disks may be related to the optical depths of those disks at the observing frequency.

Key words. Protoplanetary disks – Planets and satellites: formation – (ISM:) dust, extinction – Radio continuum: ISM

1. Introduction

2. Data and reduction

2.1. Data

We carried out the JVLA observations towards DM Tau at Q (40–48 GHz), Ku (12–18 GHz), and X (8–12 GHz) bands in 2019.

We performed a $\sim 3''$ angular resolution SMA 200–400 GHz survey towards 47 Class II objects in the Taurus-Auriga region in 2021 that included DM Tau as one of the target sources.

We retrieved the archival ALMA Band 3 (~ 95 – 111 GHz), Band 4 (~ 144 – 159 GHz), and Band 9 (~ 659 – 676 GHz) observations that the maximum recoverable angular scales (MAS) are larger than $3''$ for the purpose of deriving the (sub)millimeter SEDs.

Finally, to reference the locations of spatially resolved features in the JVLA observations, we utilized the high-angular-resolution ALMA 216–233 GHz images towards DM Tau, which were detailed in Kudo et al. (2018) (c.f. Hashimoto et al. 2021).

2.2. JVLA data processing

We manually calibrated the JVLA data following the standard strategy (see details below) using the CASA software package.

For the Q band (40–48 GHz) observations taken in 2019 (Table ??), we additionally used the observations on 3C138 to

calibrate the cross-hand delay and absolute polarization position angle and we used the observations on J0319+4130 (3C84) to calibrate the polarization leakage (i.e., D-terms).

We performed multi-frequency synthesis (nterms=2) imaging (Rau & Cornwell 2011) using the CASA tclean task. For individual epochs of observations, the achieved synthesized beams and root-mean-square (RMS) noise in the Briggs Robust=2.0 weighted images are summarized in Table ??.

We jointly imaged all C band (4–8 GHz) observations taken in 2011, which yielded a $5.3 \mu\text{Jy beam}^{-1}$ RMS noise.

3. Results

4. Discussion

4.1. Spectral index distribution and model

4.2. Physical implications

4.2.1. Asymmetry in protoplanetary disks

4.2.2. Dust growth in an initially smooth background disk

5. Conclusion

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