Characterizing the dust content of disk substructures in TW Hya

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Motivation

Characterizing the dust content of protoplanetary disks is key to understand planet formation:
- What is the dust mass available to form planetesimals?
- Are mm/cm sized pebbles, necessary to trigger the streaming instability, present in disks?
- What is the origin and role of disk substructures? Do substructures harbor the necessary conditions to form new generations of planetesimals?

The closest protoplanetary disk to Earth: TW Hydrae

We obtained new ALMA long baseline 3 mm observations. We have combined these new data with archival high resolution ALMA observations at 0.87 mm, 1.3 mm, and 2 mm.

Fig. 1: Images of the protoplanetary disk around TW Hya at 0.87 mm, 1.3 mm, 2.1 mm (archival ALMA data), and at 3.1 mm.

Multi-wavelength radial profiles

Fig. 2 Azimuthally averaged radial intensity profiles at 0.87 mm, 1.3 mm, 2.1 mm, and 3.1 mm. The vertical lines indicate the positions of the bright (dashed) and dark (dotted, aka gaps) rings.

Our approach

Using multi-wavelength (sub-)mm observations we can estimate the radial variations in dust density, temperature, and particle size distribution taking into account the effects of optical depth and self-scattering (Macias+ 2019; Carrasco-González+ 2019).

\[ I_\nu = f(T_d, \tau_\nu, \omega_\nu) = f(T_d, \Sigma_d, a_{max}, p) \]

Dust characterization

Fig. 4 Radial profile of normalized marginalized posteriors of dust temperature, dust surface density, maximum grain size, and slope of particle size distribution in TW Hya. The red line shows the expected value of each parameter at each radius. The vertical lines indicate the positions of bright (dashed) and dark (dotted) rings. The white dashed curve on the top-right panel indicates the expected temperature profile for a passively irradiated flared disk (D’Alessio et al. 1998). The white dashed and dotted curves in the top-right plot show the dust surface density profile for which the Toomre Q parameter equals 1, assuming a gas to dust ratio of 100 or 1, respectively.

Conclusions

- Inner 20 au are completely optically thick -> cannot characterize dust content at r<20 au. **Longer wavelengths (VLA) are needed.**
- Maximum grain size \( a_{max} > 1 \text{ mm} \) at \( r > 20 \text{ au} \).
- When varying the slope of particle size distribution, \( a_{max} \) cannot be fully constrained.
- **Large particles are accumulating at the rings** (higher dust densities paired with lower values of \( T_d \)) -> ideal locations to trigger streaming instability.
- Total dust mass of the disk is between 250 and 330 \( M_{\text{Earth}} \), which represents a global gas-to-dust mass ratio between 50 and 70.
- Our mass measurement is a factor of 4.3 - 5.7 higher than the mass that one would estimate using the typical assumptions of large demographic surveys.

References

Macías, E., et al. 2020, ApJ, 893, 114
Espaillat, C., et al. 2020, ApJ, 893, 155
D’Alessio, P., et al. 1998, ApJ, 503, 811
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Final results to appear soon in Macías et al. (2020, submitted)

Questions? Contact me through Slack or at enrique.macias@alma.cl