Time-resolved protoplanetary disk physics in DQ Tau with JWST

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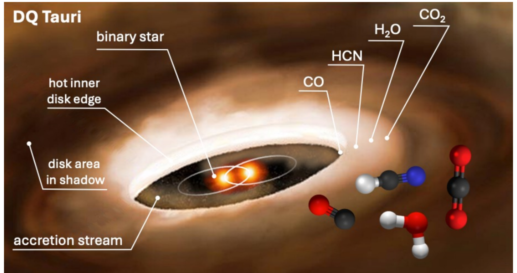


Artist's impression of the ever-changing disk around the twin stars in the DQ Tauri system. Source: modification of a figure from NOIRLab/NSF/AURA/P. Marenfeld.

Abstract

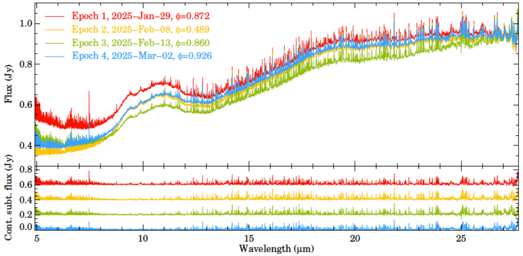
Accretion variability is ubiquitous in young stellar objects. While large outbursts may strongly affect the disk structure, the effects of moderate bursts are less understood. In this project, we characterized the physical response of the disk around the eccentric binary system DQ Tau to its periodic accretion changes that revealed variability in the disk temperature, inner rim location, and outer disk shadowing.

Our target: DQ Tau

- Eccentric (e = 0.56), extremely close binary (orbital period P = 15.80 d) of two nearly equal mass M0-type stars ($M_\star \sim 0.75\ M_\odot$). The components' distance at periastron/apastron is 0.06/0.22 au
- Around periastron, the system's X-ray, UV, optical, IR, and sub-mm continuum flux increases. The X-ray/radio flares are due to interactions between the young stars' magnetospheres. The UV/optical brightenings are due to pulsed accretion. The IR brightening is due to heating of the inner dusty disk rim during the pulsed accretion events at periastron

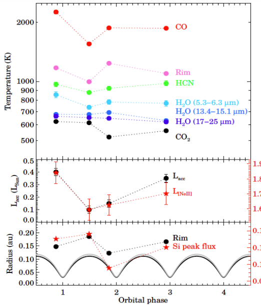
Observations

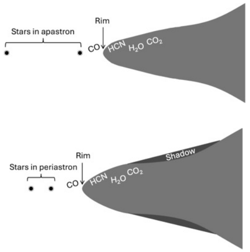
- We conducted a four-epoch mid-infrared spectroscopic monitoring of DQ Tau with JWST/MIRI
- We targeted three consecutive periastrons (high accretion state) and one apastron (quiescence)
- Complementary observations:
  - IRTF/SpeX optical/near-IR spectra
  - Chandra X-ray spectra
  - UV, optical, and near-IR photometric monitoring



Results 1 (Kóspál et al. 2025)

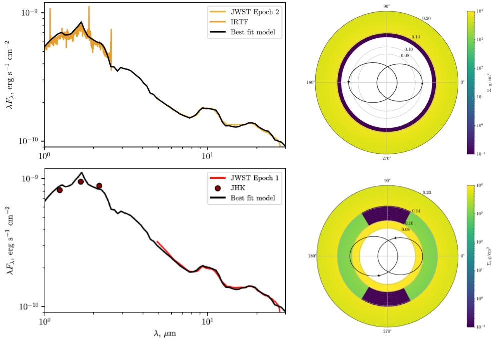
- **Simple slab models for the gas lines, blackbody fit to the inner disk rim**
- The temperature, luminosity, and location of the inner dust rim vary in response to the movement of stars and the L_{acc} variations (0.10–0.40 $L_\odot$)
- This causes variable shadowing of the outer disk → anti-correlation between rim temperature and strength of the 10 μm silicate feature
- The excitation of CO, HCN, and hot H_2O molecules, as well as the luminosity of the [NeII] line correlate L_{acc} changes
- The warm and cold H_2O components are mostly constant





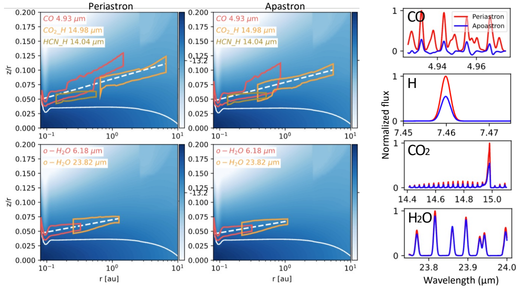
Results 2 (Zwicky et al. in prep.)

- **Dust radiative transfer modeling using RADMC-3D**
- First step: fit the apastron epoch with an azimuthally symmetric model
- Next step: use the obtained global structure to then fit the other epochs by making physically motivated modifications to that structure
- Modeling confirms the radial and vertical structural changes and reveals azimuthal asymmetries at periastron as well



Results 3 (Portilla-Revelo et al. in prep.)

- **Thermochemical modeling using ProDiMo**
- Model flux of H, CO, CO_2, HCN, and H_2O near 6 μm are stronger at periastron than at apastron due to 4x higher L_{acc}
- Water lines at 24 μm exhibit the opposite trend: stronger at apastron
- Variations in the integrated fluxes lie within a 2x between epochs, in reasonable agreement with the observations
- Snowline shifted outwards by ~20% at periastron relative to its apastron position



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