Accretion Variability and Multiplicity in Sun-like Young Stars

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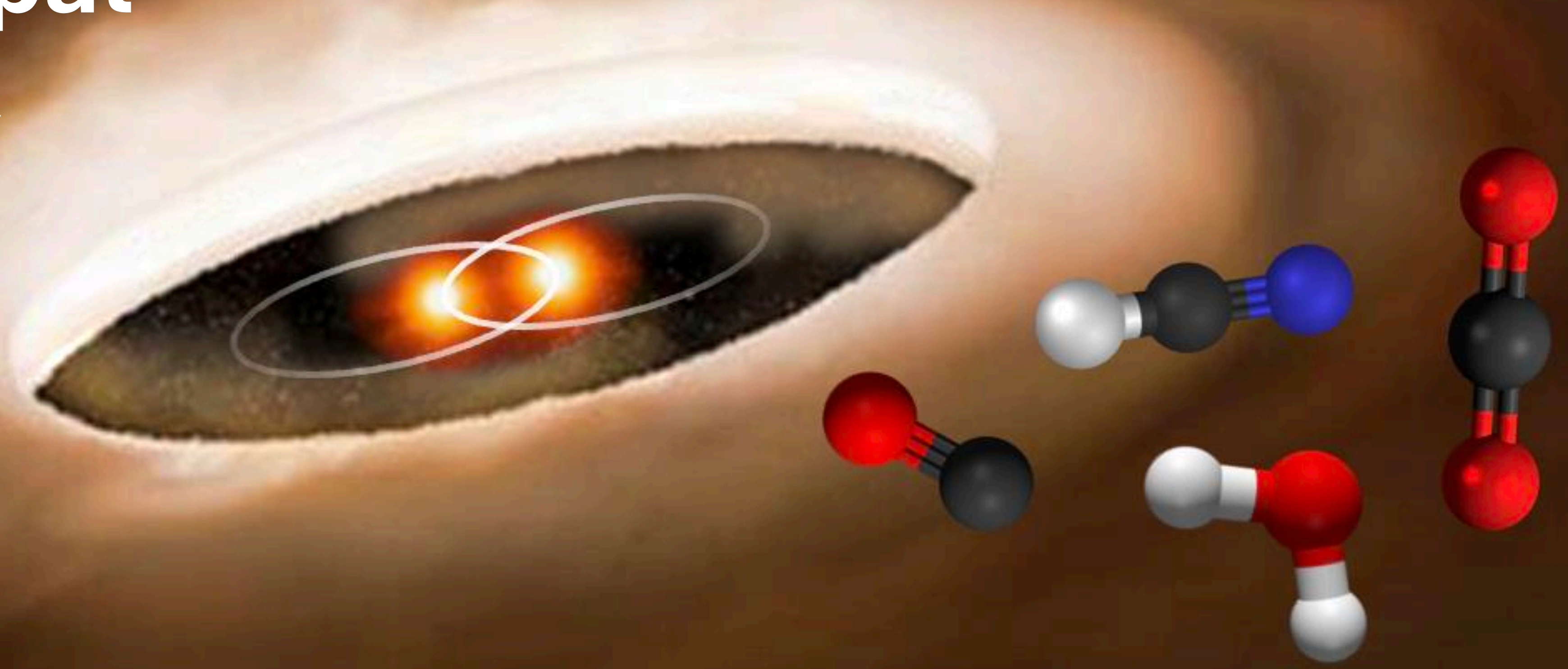
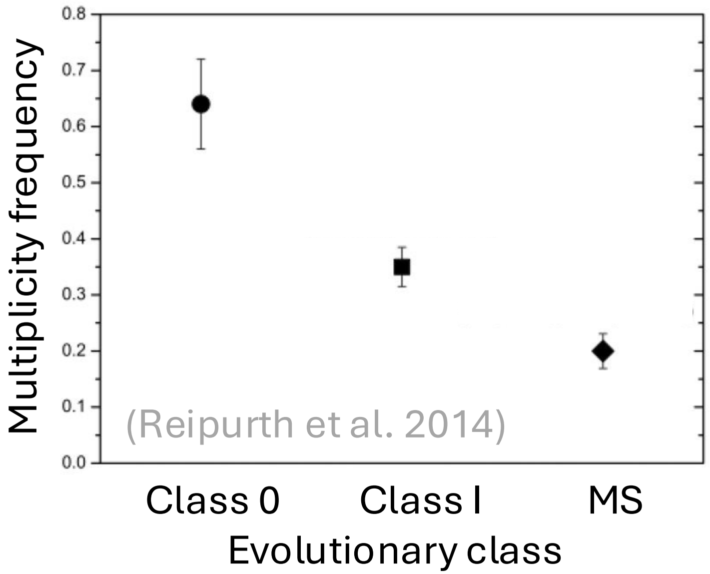
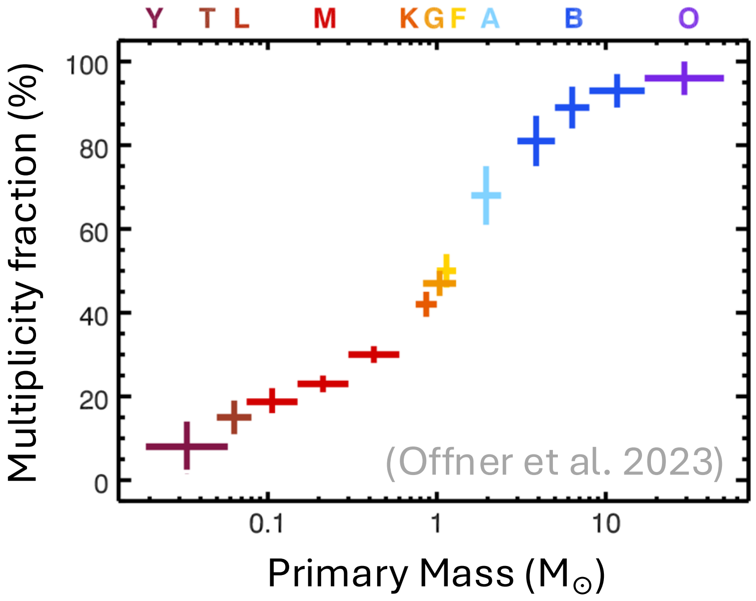


Perspectives of Planet and Star Formation, MPIA, Heidelberg, June 23, 2026

Motivation

- **Why study accretion in young stars?**
  - Accretion disks build stars
  - Accretion disks start forming planets
  - Fundamental process in star formation, disk evolution, and planet formation
- **Why study multiplicity?**
  - Most stars form in multiple systems
  - Later they break up due to dynamical interactions
  - Multiplicity is a common outcome of star formation (~50% for solar-type stars)
  - There are planets in multiple stellar systems





Accretion in young stars

- Single-star accretion from a disk: **magnetospheric accretion**
- Accretion is funnelled by the stellar magnetic field, which disrupts the disk at a few R_*; matter falling at ~free-fall velocities hits the stellar surface → kinetic energy is dissipated
- **Observational tracers**: UV excess; optical, near-infrared, mid-infrared HI lines, continuum veiling, photometry

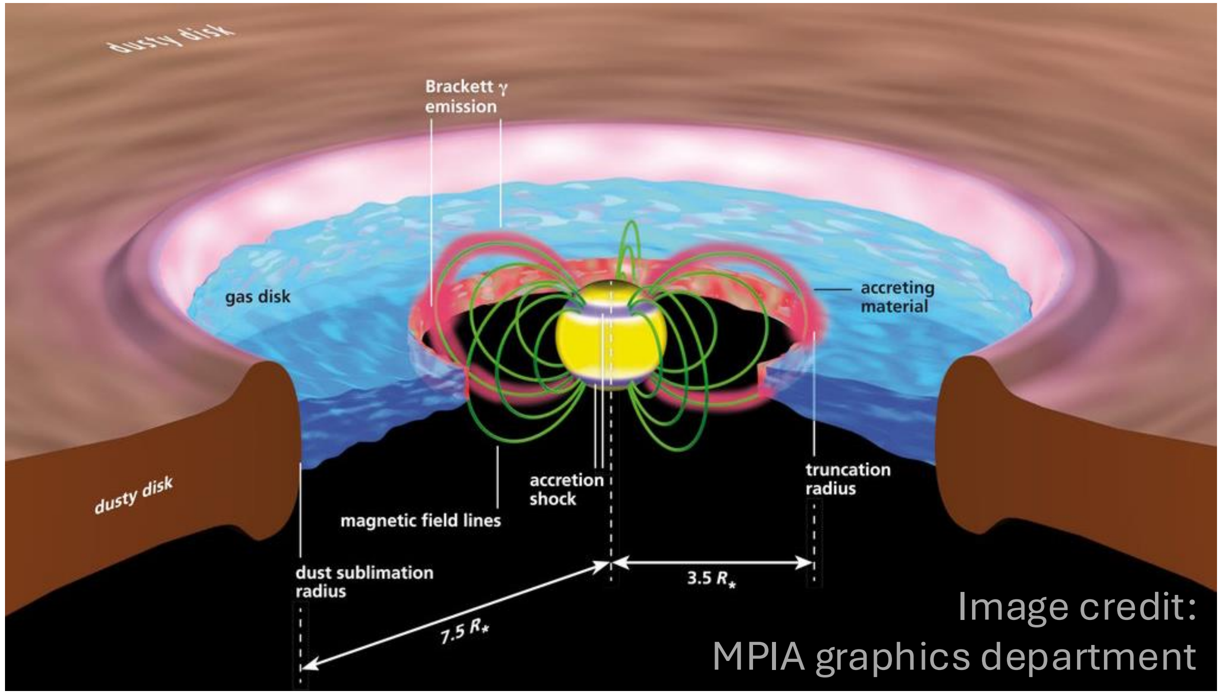
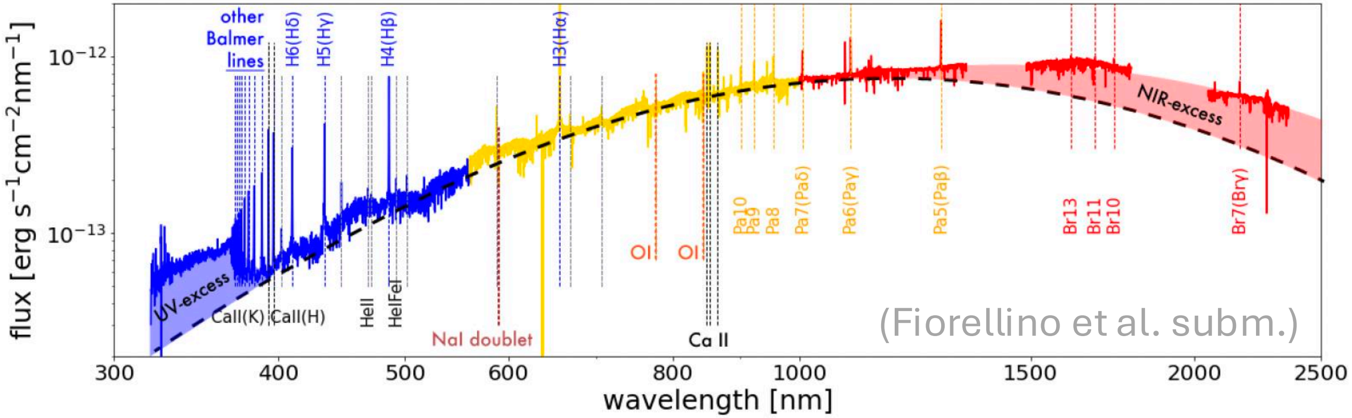


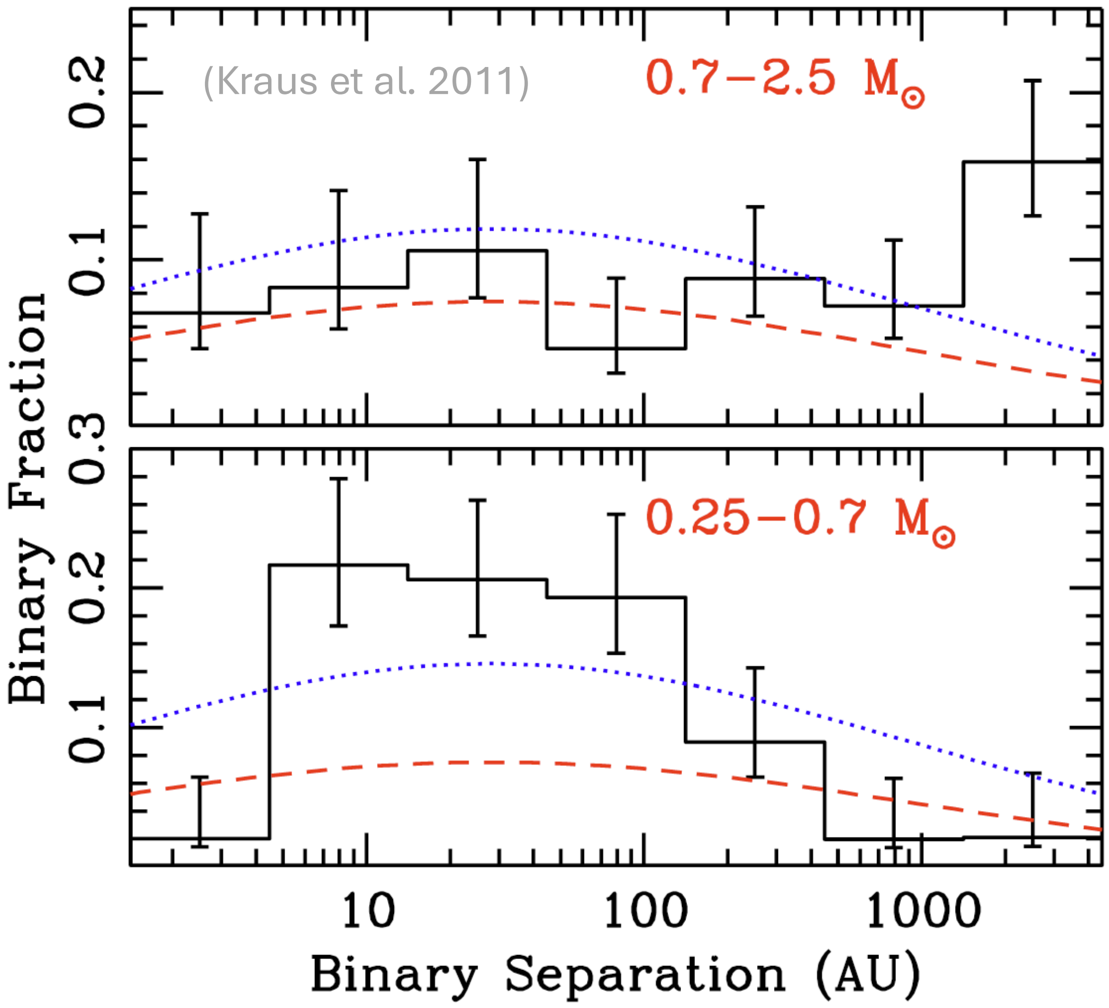
Image credit: MPIA graphics department



(Fiorellino et al. subm.)

Multiplicity in young stars

- **Binary fraction** vs. mass:
  - 62% for 0.7 – 2.5 $M_\odot$
  - 77% for 0.25 – 0.7 $M_\odot$
- **Separation distribution** (close binaries, wide pairs)
- Role of binarity in **shaping circumstellar architecture** (→ accretion)
- **Key parameters**: separation, mass ratio, eccentricity

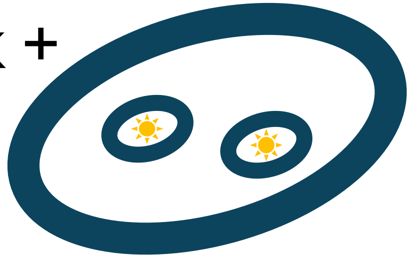


Circumstellar environment configurations

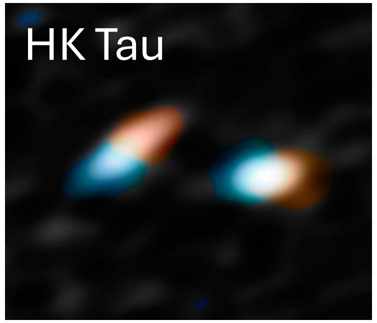
- **Wide binaries** → largely independent disks

- **Intermediate separations** → truncated circumstellar disks

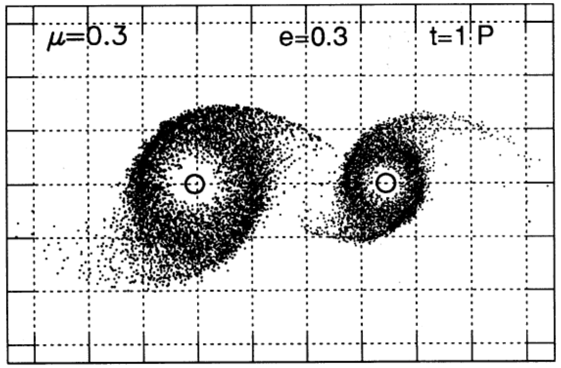
- **Close binaries** → circumbinary disk + circumstellar mini-disks



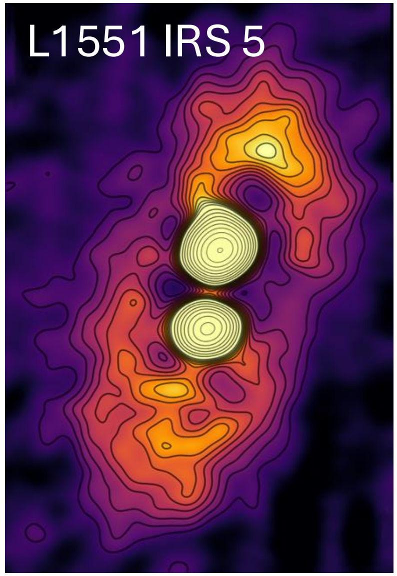
- **Even closer binaries** → circumbinary disk



Jensen & Akeson (2014)
Separation: 386 au



Artymowicz & Lubow (1994)

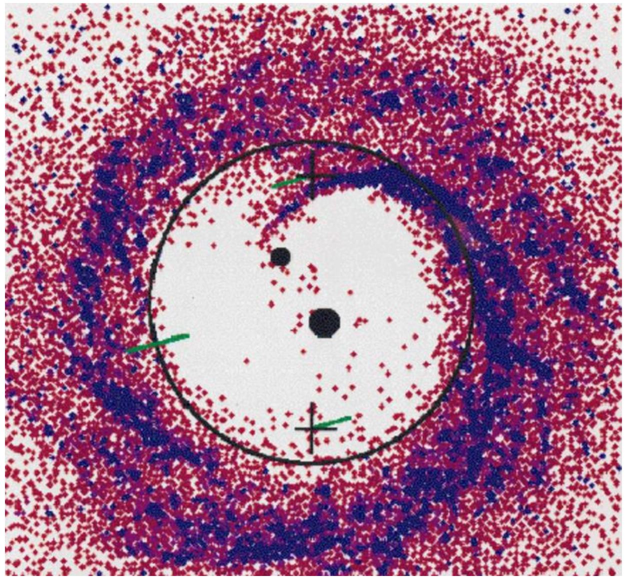


Cruz-Sáenz de Miera (2019)
Separation: 51 au

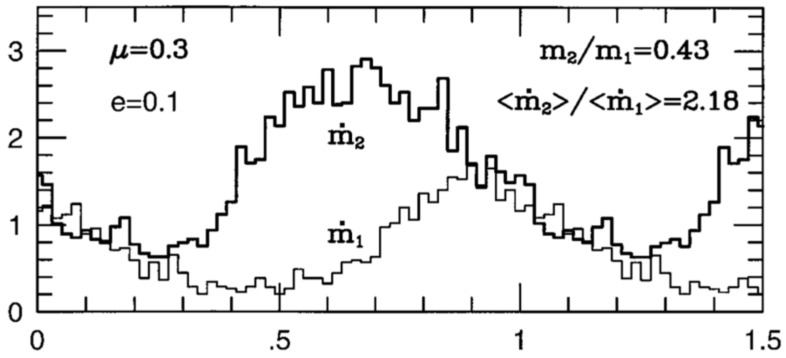
Hernández Garnica et al. (2024)
Orbital period: 296 yr

Expected impact on accretion rates

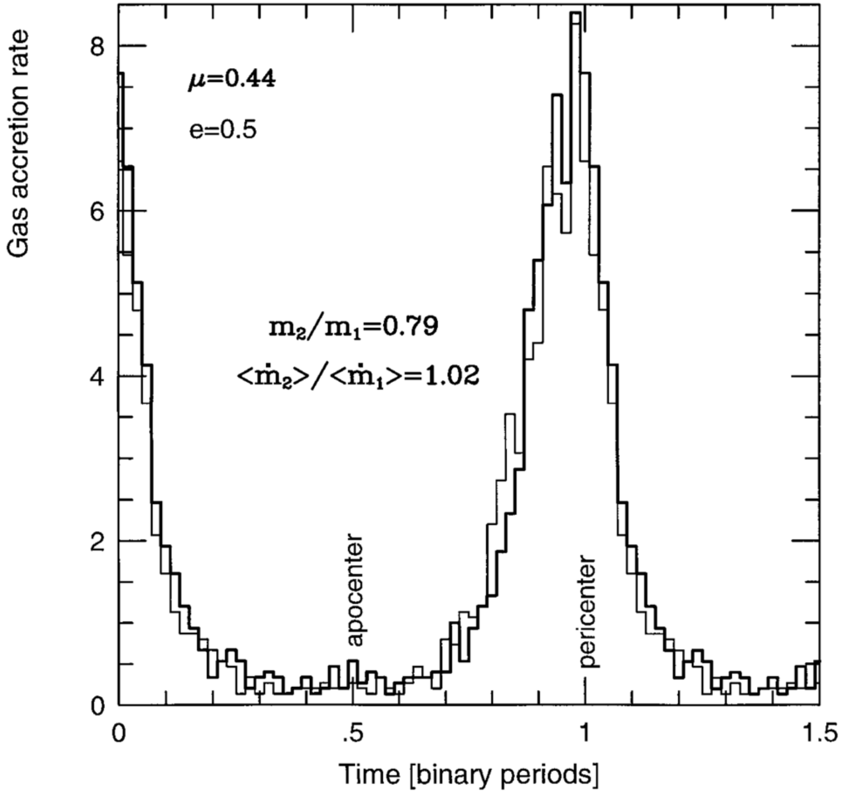
- **Numerical simulations** of circumbinary disk feeding
- Scaling with mass ratio and eccentricity



Low-eccentricity binary with unequal component masses



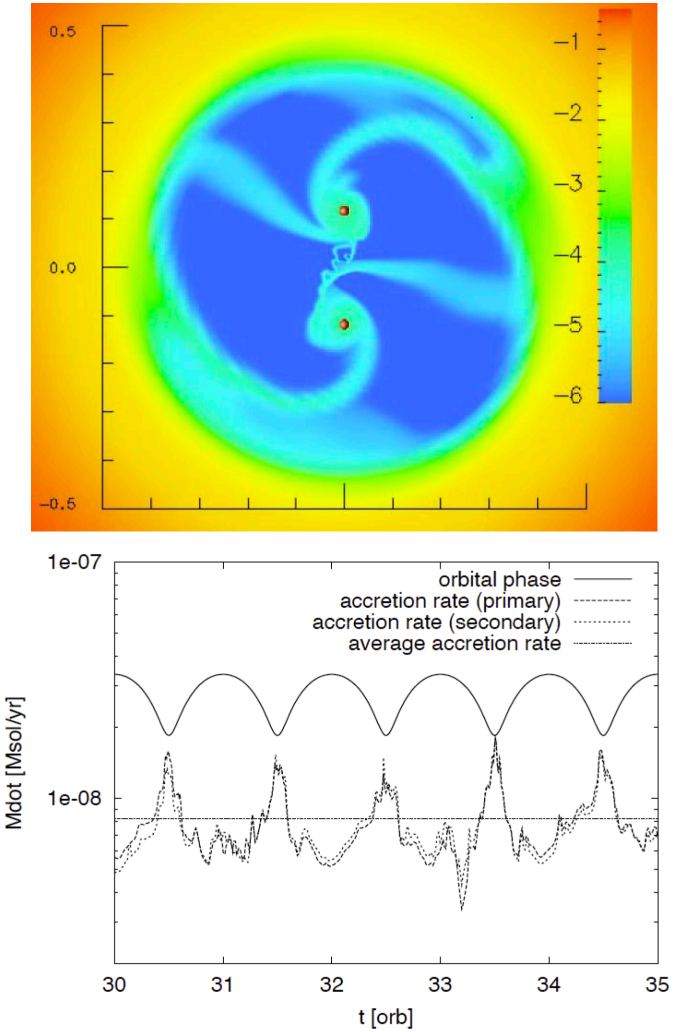
Eccentric binary with similar components



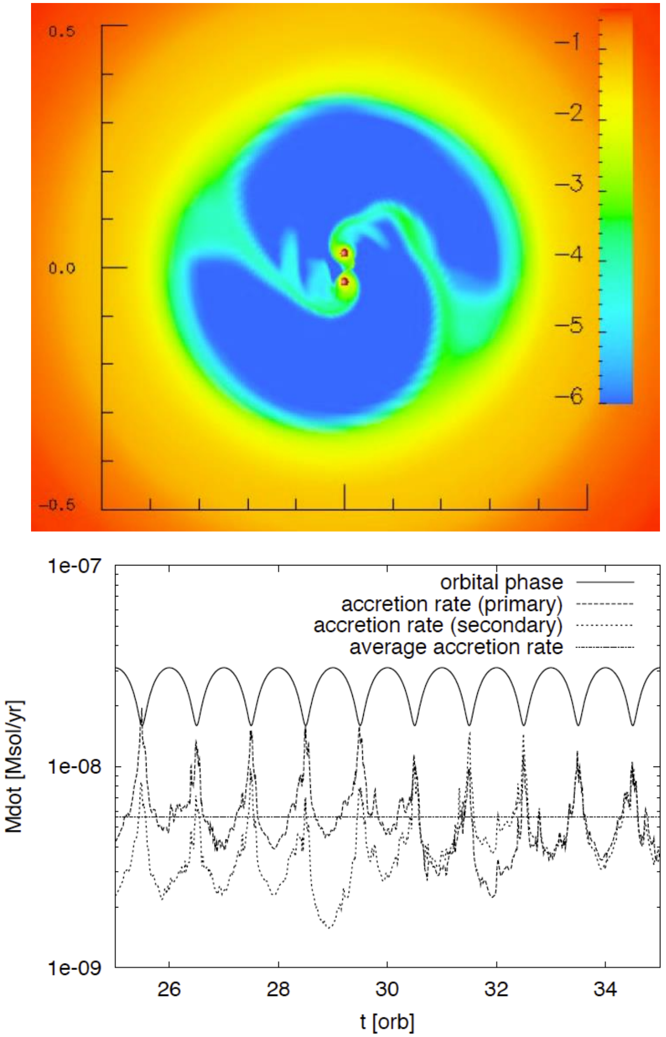
Artymowicz & Lubow (1996)

Expected impact on accretion rates

AK Sco



DQ Tau



- Clear **accretion streams** close to periastron
- Accretion rate is **periodic** with $P = P_{\mathrm{orbital}}$
- Factor of few – order of magnitude **changes** in $\dot{M}_{\mathrm{acc}}$ over the orbit
- Not always the same star is the dominant accretor

Günther & Kley (2002)

Pulsed accretors

- Double-line spectroscopic (SB2) binaries, eccentric orbit
- Light curves showing periodic peaks → accretion bursts at periastron
- Example systems: DQ Tau, UZ Tau E, TWA 3A

Mathieu (1994)

Table A3 Pre-main-sequence single-lined spectroscopic binaries

HBC[a]	Name	P (days)	γ (km s^{-1})	e	$a_1 \sin i$ (AU)	$f(m)$ ($M_\odot$)	Ref.	Spec. Class	L_* ($L_\odot$)	Hα (Å)	12μm Jy	V mag	K mag	Location
	155913-2233 [b]	2.42378	-2.3	0	0.014	0.064	1	K5	0.9	0.7 [c]		11.21	8.08	Sco-Cen
	160905-1859	10.400	-6.4	0.17	0.015	0.0042	1	K1	1.2	-0.27 [c]		11.67	8.08	Sco-Cen
	VSB126	12.924	17.0	0.18	0.017	0.0040	2	K0		-1.9		13.43	11.4 [d]	NGC2264
	Lk Ca 3	12.941	14.9	0.20	0.032	0.027	3	M1 [e]	2.6 [e]	2.5 [e]	<0.05 [e]	12.10 [e]	7.53 [e]	Tau-Aur
	155808-2219 [b]	16.925	-5.0	0.10	0.048	0.051	3	M3 [c]	0.34 [c]	3.32 [c]		13.74 [c]	8.80 [c]	Sco-Cen
459	P1925	32.94	25.9	0.55	0.045	0.011	2	K3				13.38	8.5 [f]	Trapezium
	162819-2423S	89.1	-4.9	0.41	0.10	0.017	1	G8	2.4	wk em [c]	2.54	10.57	6.70	ρ Oph
	160814-1857	144.7	-6.6	0.26	0.19	0.048	1	K2	1.3	0.71 [c]		11.94	7.68	Sco-Cen
	P1771	149.5	25.6	0.57	0.16	0.024	2	K4				13.47	9.5 [f]	Trapezium
85	GW Ori	241.9	28.1	0.04±0.06	0.10	0.0026	4	G5	66	27.6	7.87	9.80	6.19	B30
644	Haro 1-14c	591	-8.7	0.62	0.36	0.018	5	K3			< 0.04	12.29		ρ Oph
	VSB111	879	26.3	0.80	0.6	0.04	2	G8		-0.3		12.37	10.2 [d]	NGC2264
	045251+3016	2530.	14.9	0.48	1.6	0.09	1,3	K7	1.4	0.7 [c]	0.11: [e]	11.60	8.27	Tau-Aur

Jensen et al. (2007)

CTTS Spectroscopic Binaries

Binary System	Period (days)	e	M_2/M_1	Spectral Type	L ($L_\odot$)	Disk Mass[a] ($M_\odot$)	Photometric Periodicity?	Balmer Line Periodicity?	References
V4046 Sgr..................	2.421	≤0.01	0.94	K5	0.82	0.0085	Yes ($\Delta B \approx 0.1$)	Yes	1, 2, 3
GW Ori	241.9	0.04	SB1	G0	26	0.3	? ($\Delta V \approx 0.7$)	?	4, 5
UZ Tau E	19.131	0.33	0.30	M1	0.91	0.063	Yes ($\Delta I \approx 0.8$)	Maybe	6, 7, 8
ROXs 43B..................	89.1	0.41	SB1	G0	0.4	<0.00037	? ($\Delta V = 0.1$)	?	1, 9, 10, 11
AK Sco	13.609	0.47	0.99	F5	8.40	0.002	No ($\Delta y \approx 1.5$)	Yes	1, 12, 13
ROXs 42	35.95	0.48	0.92	K4	0.4	<0.00025	? ($\Delta V = 0.4$)	?	1, 10, 11, 14, 15
DQ Tau	15.804	0.56	0.97	K7–M1	0.95	0.020	Yes ($\Delta V \approx 0.5$)	Yes	16, 17
KH 15D......................	48.38	0.57–0.65	0.83[b]	K7[c]	0.4[c]	. . .	Eclipse ($\Delta I \approx 3.5$)	?	18, 19, 20

Pulsed accretors

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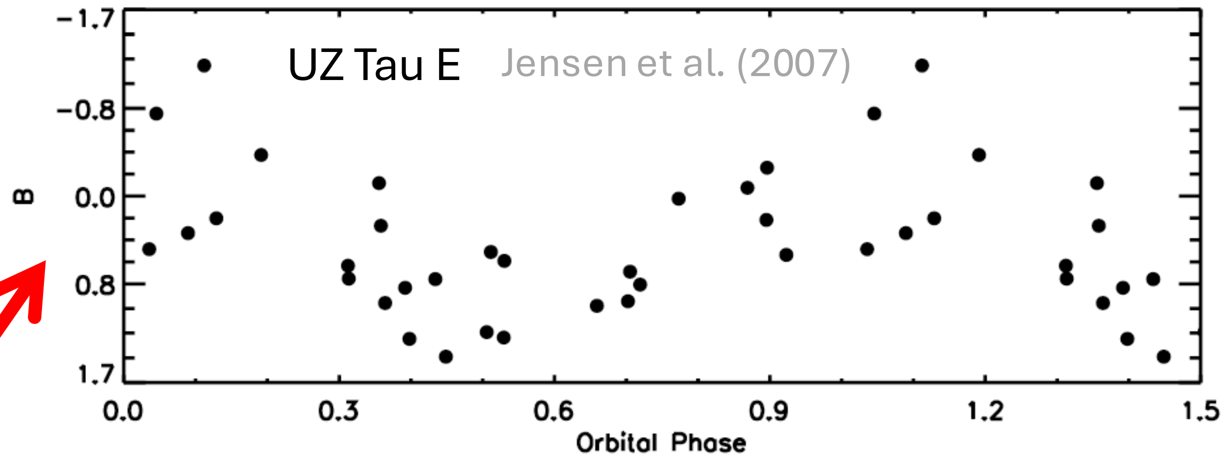
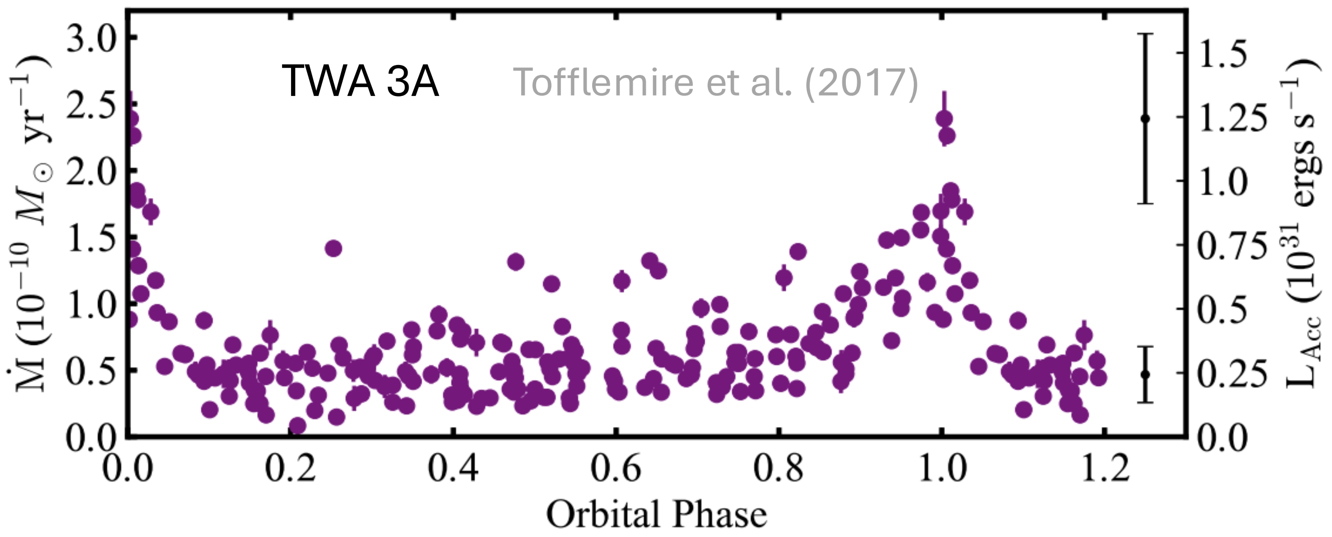
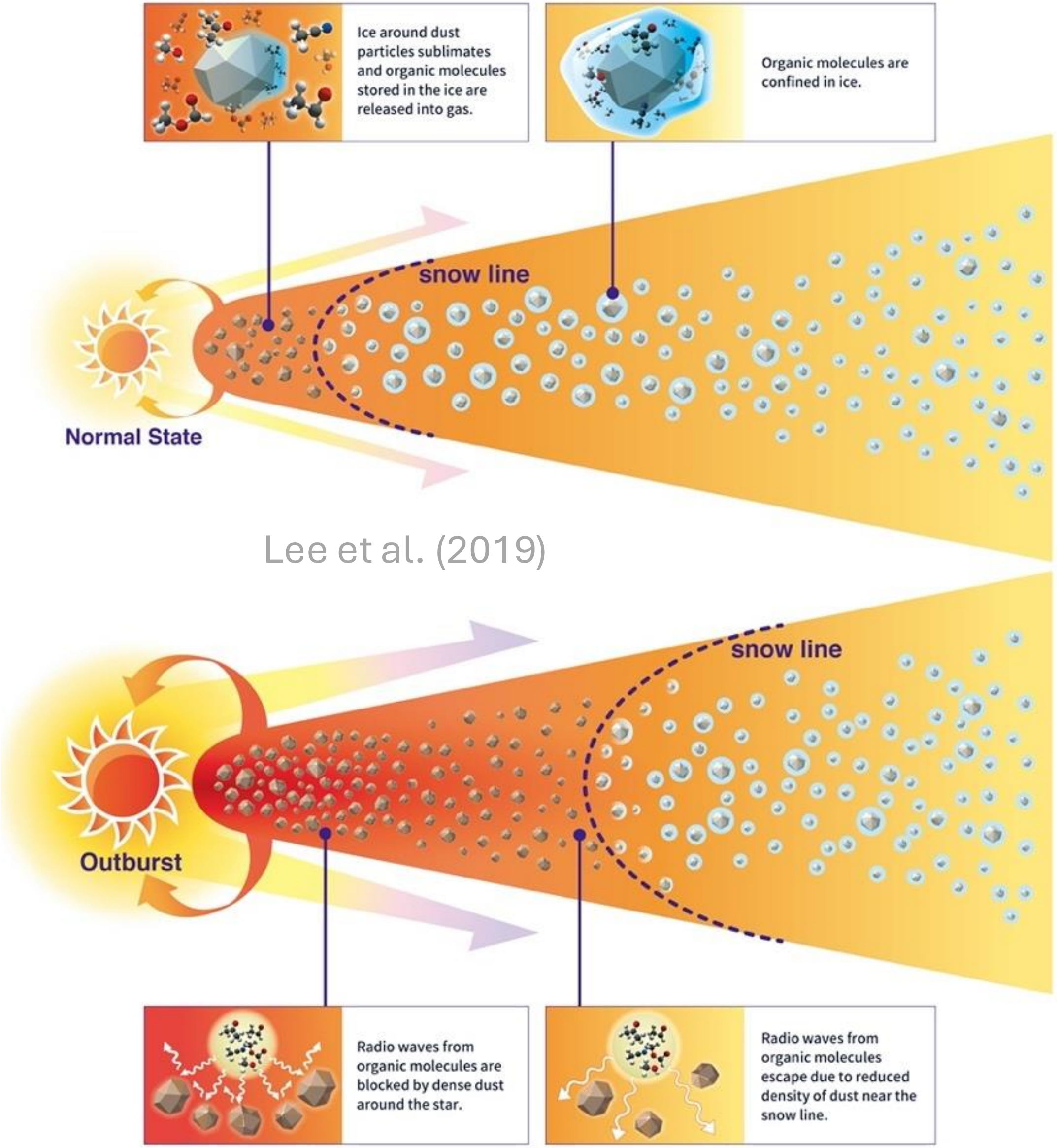




Implications for disk properties

- **Variable accretion → variable disk heating**
- Accretion outburst moves the **snowline**
- Molecules are **sublimated**
- Various **chemical reactions** may happen
- May influence **dust growth and planetesimal formation**
- Depending on timescales, it may have **a long-lasting, cumulative effect**



Lee et al. (2019)

Case study: the DQ Tau system

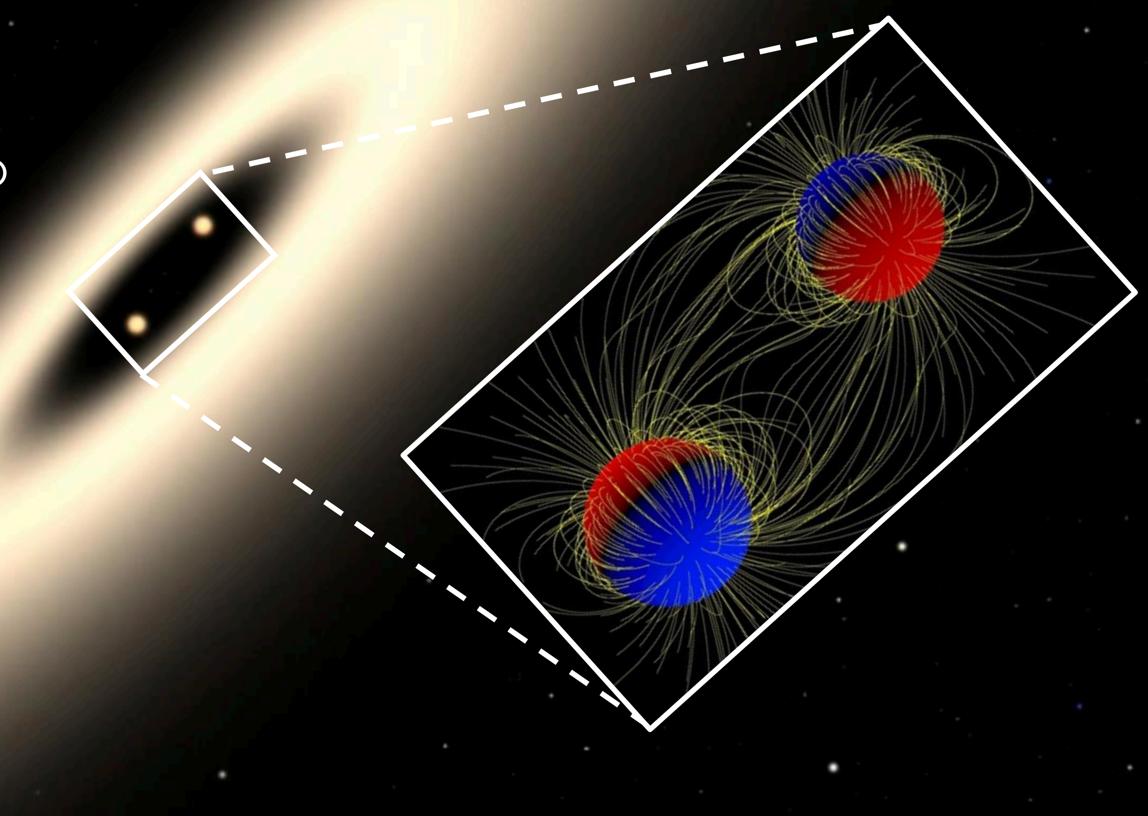
Two almost identical 0.6 $M_\odot$ stars (M_1/M_2=0.94)

Orbital period: P = 15.80158 days

Closest approach: 0.06 au / 8 $R_\star$ / 12.5 $R_\odot$

Eccentric orbit: e = 0.568

(Czekala et al. 2016)



During periastron:

– radio, millimeter, X-ray flares

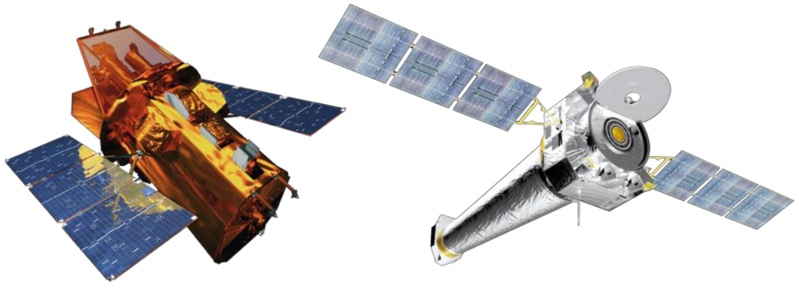
– UV, optical, and infrared brightenings

Image credit: David A. Aguilar / CfA, Volkmar Holzwarth / KIS Freiburg

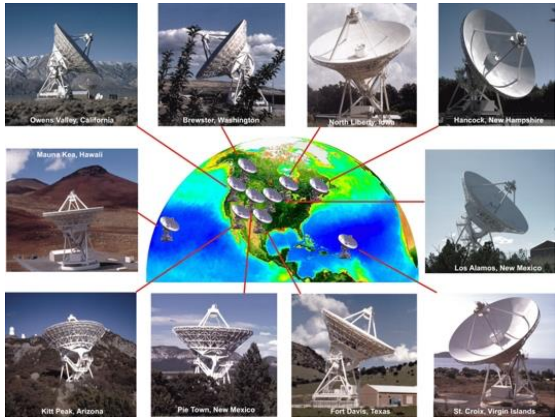
Time-resolved disk physics in DQ Tau with JWST

- **Spectroscopic monitoring:**
  - **JWST/MIRI**
  - IRTF/SpeX
  - MPG 2.2m/FEROS
- **Optical / NIR photometric monitoring:**
  - ASAS−SN *g*
  - RC80 *B g V r I*
  - Suhora *B V* R_C I_C
  - REM *g r i z J H K*
  - Atlas *c o*
  - AAVSO *B V* R_C I_C

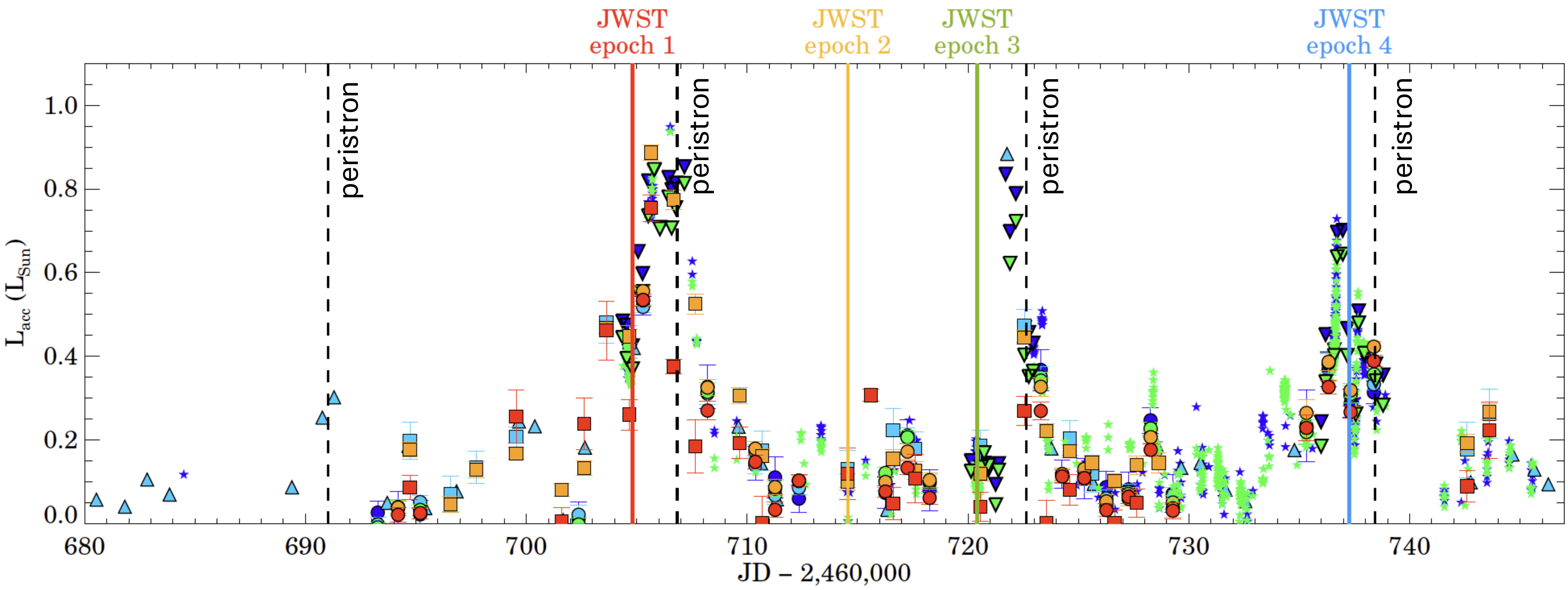
- **X-ray / UV monitoring:**
  - Swift/UVOT *B V*
  - Swift/XRT
  - Chandra/ACIS-I3



- **Radio monitoring**
  - VLBA



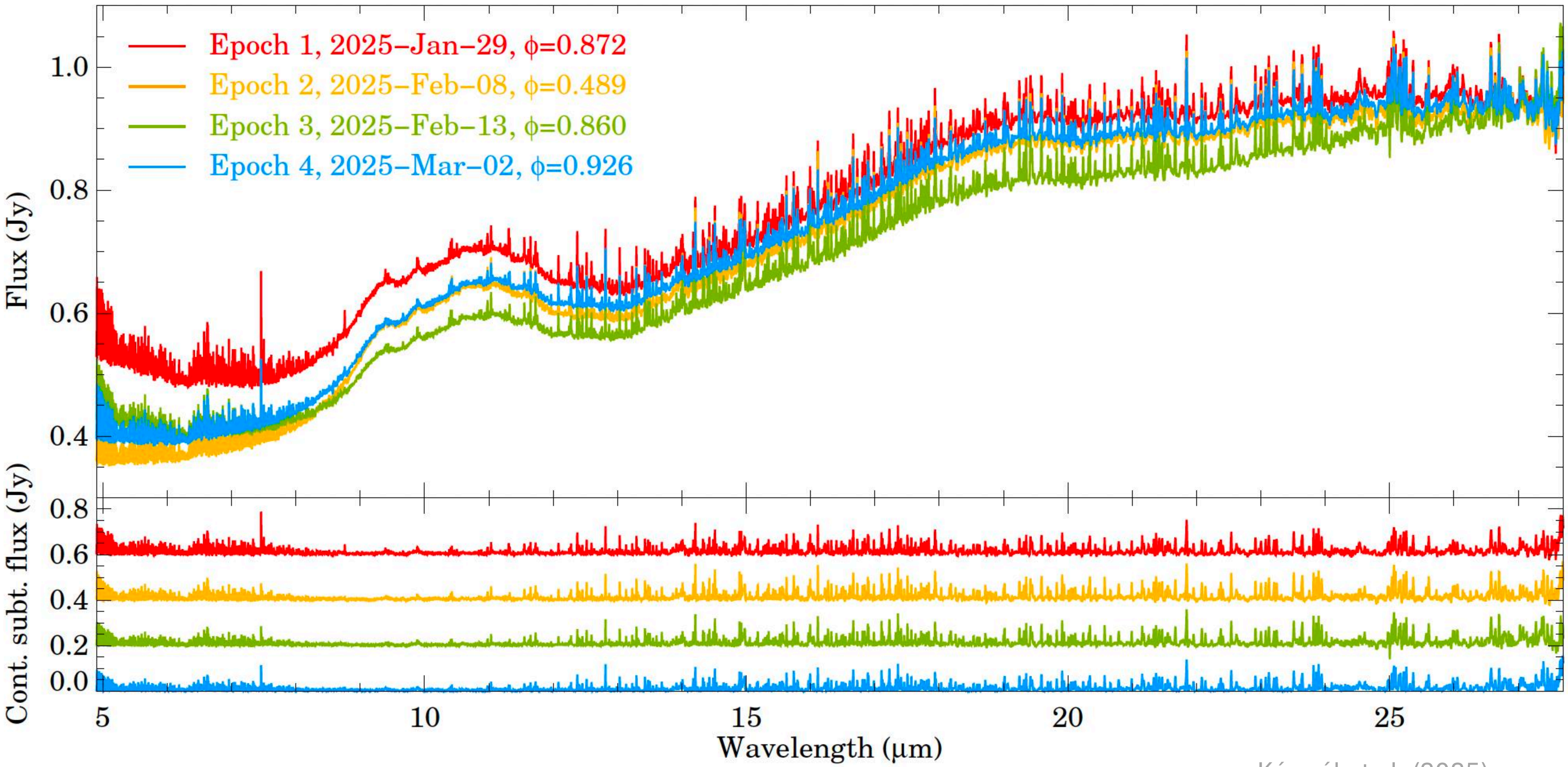
Time-resolved disk physics in DQ Tau with JWST



Kóspál et al. (2025)

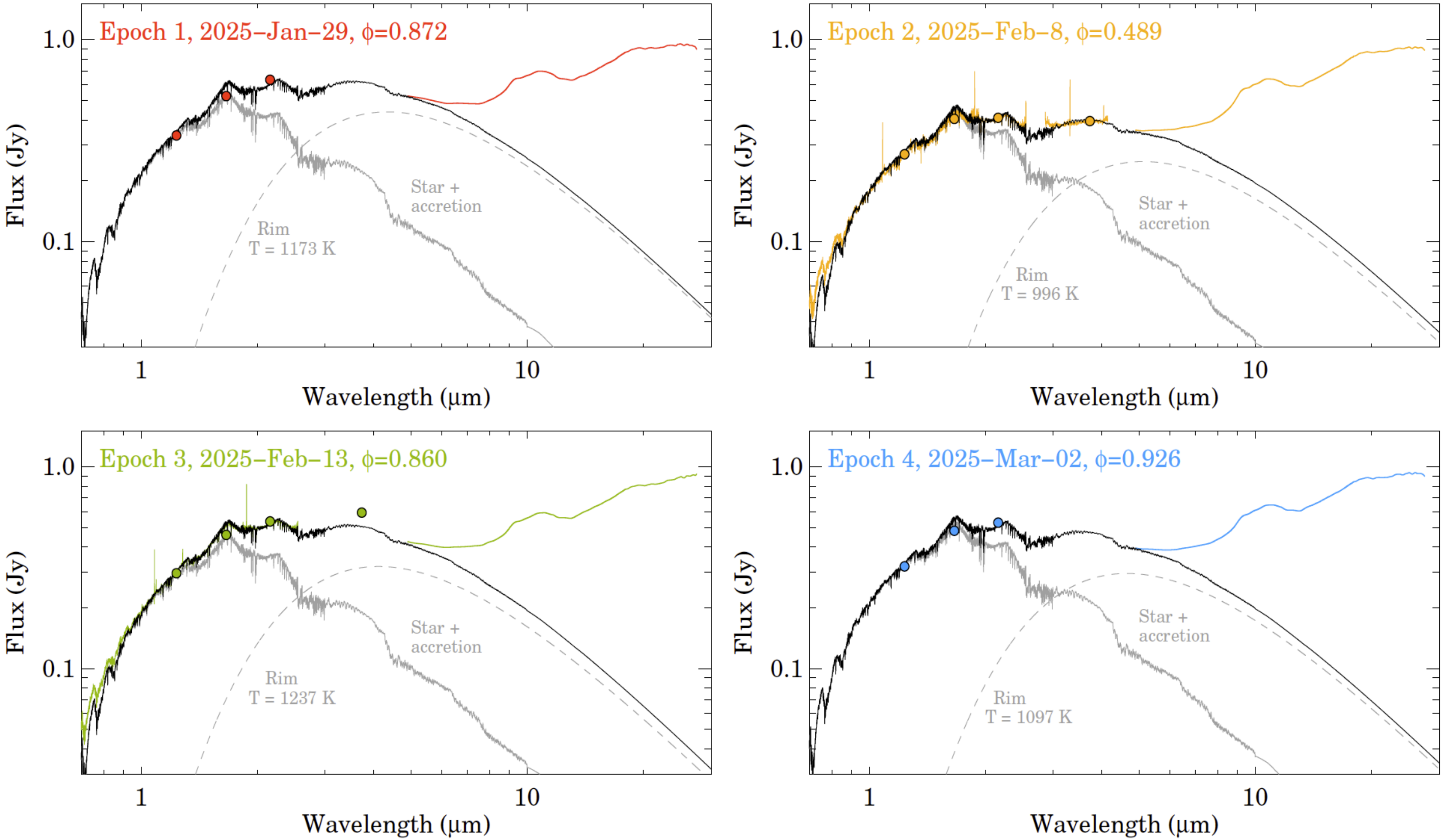
$L_{acc,1} = 0.40\ L_{\odot}$ $L_{acc,2} = 0.10\ L_{\odot}$ $L_{acc,3} = 0.15\ L_{\odot}$ $L_{acc,4} = 0.35\ L_{\odot}$

JWST/MIRI monitoring of DQ Tau



Kóspál et al. (2025)

SED changes in DQ Tau

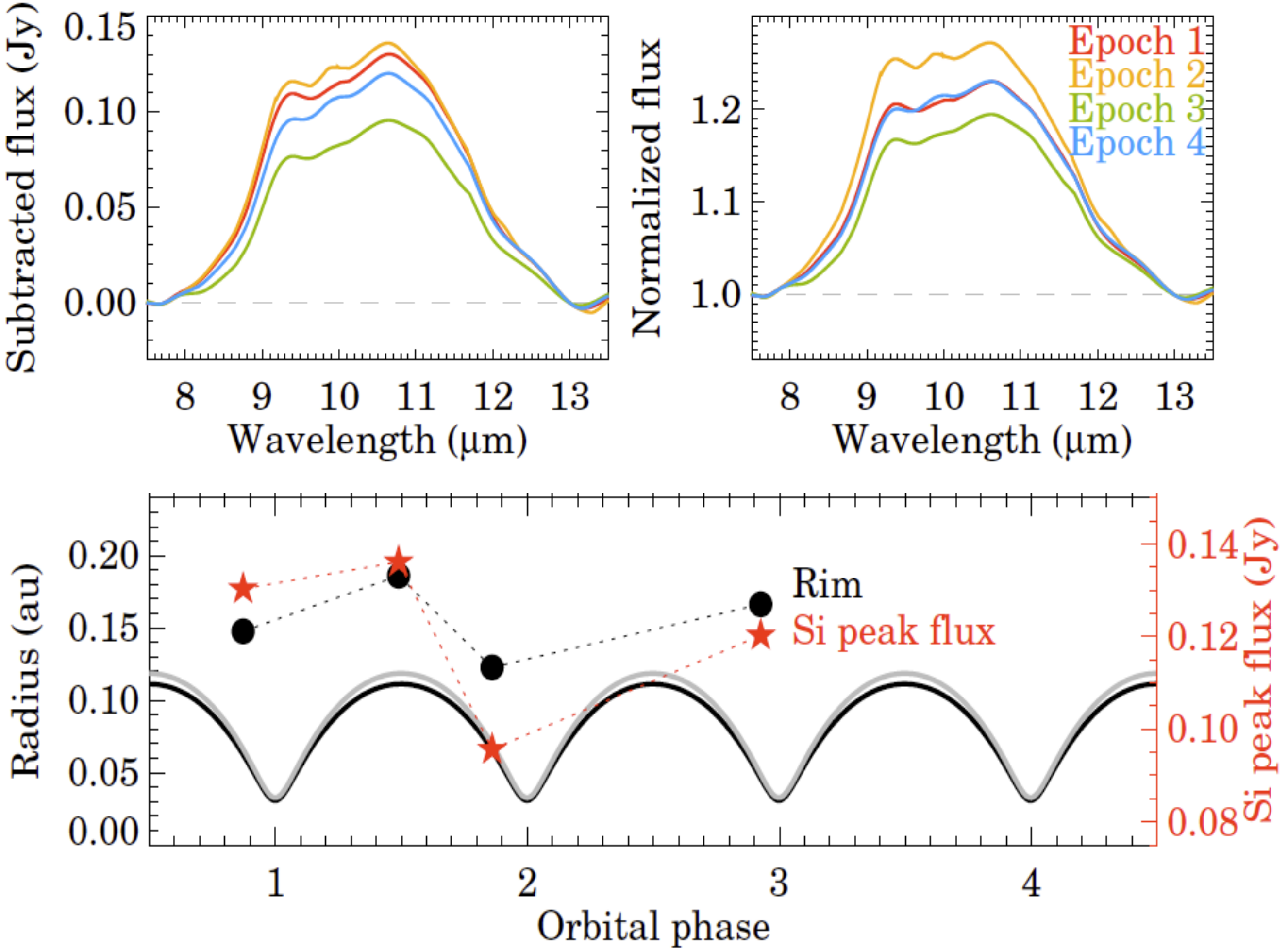


- Scaled stellar photosphere for star + accretion
- BB fit to the rim: 996 – 1223 K
- **The *T*, *L*, and location of the inner dust rim vary** in response to the movement of stars and the L_{acc} variations

Kóspál et al. (2025)

Variability of the dust feature

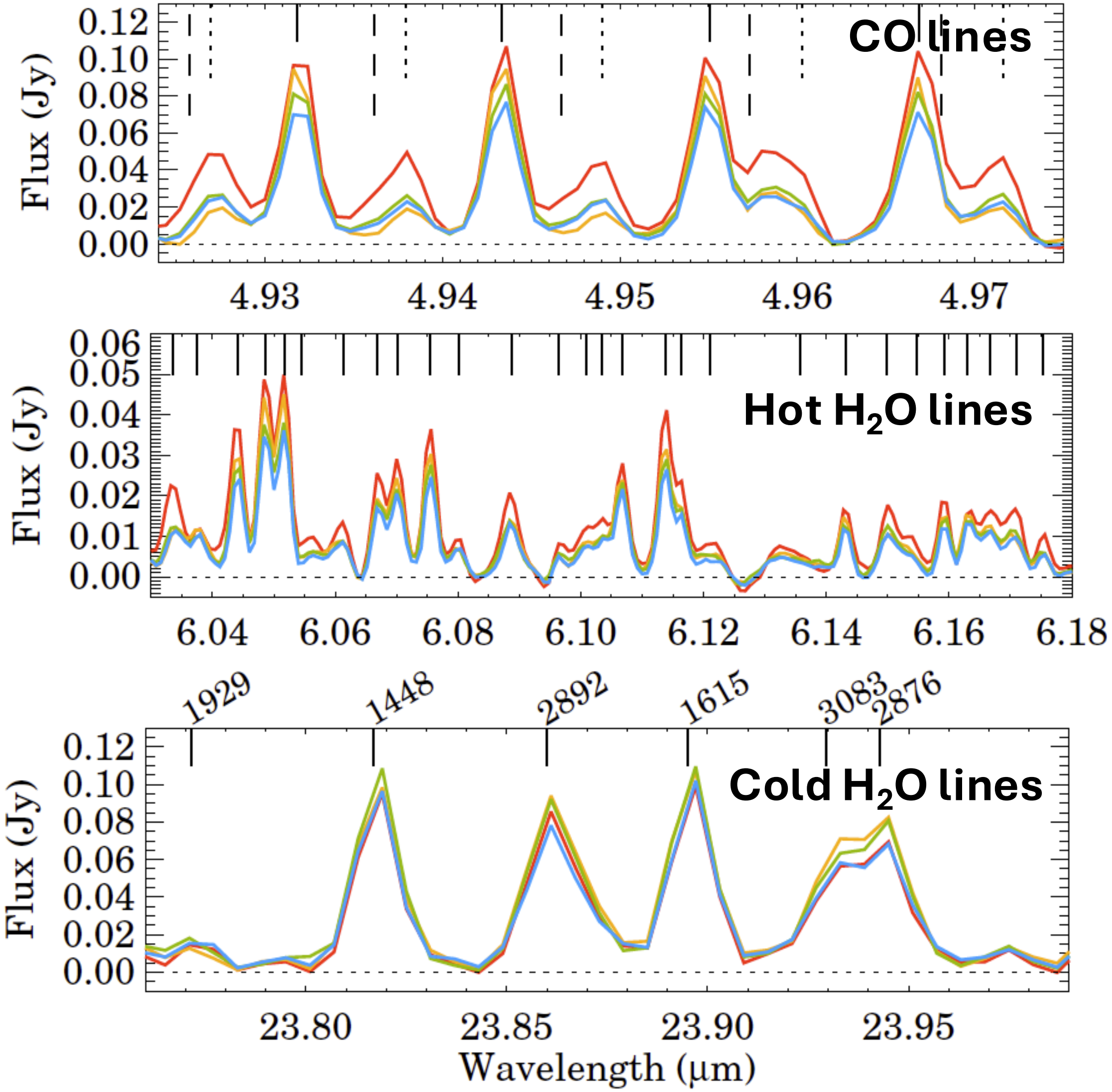
10 μm silicate feature

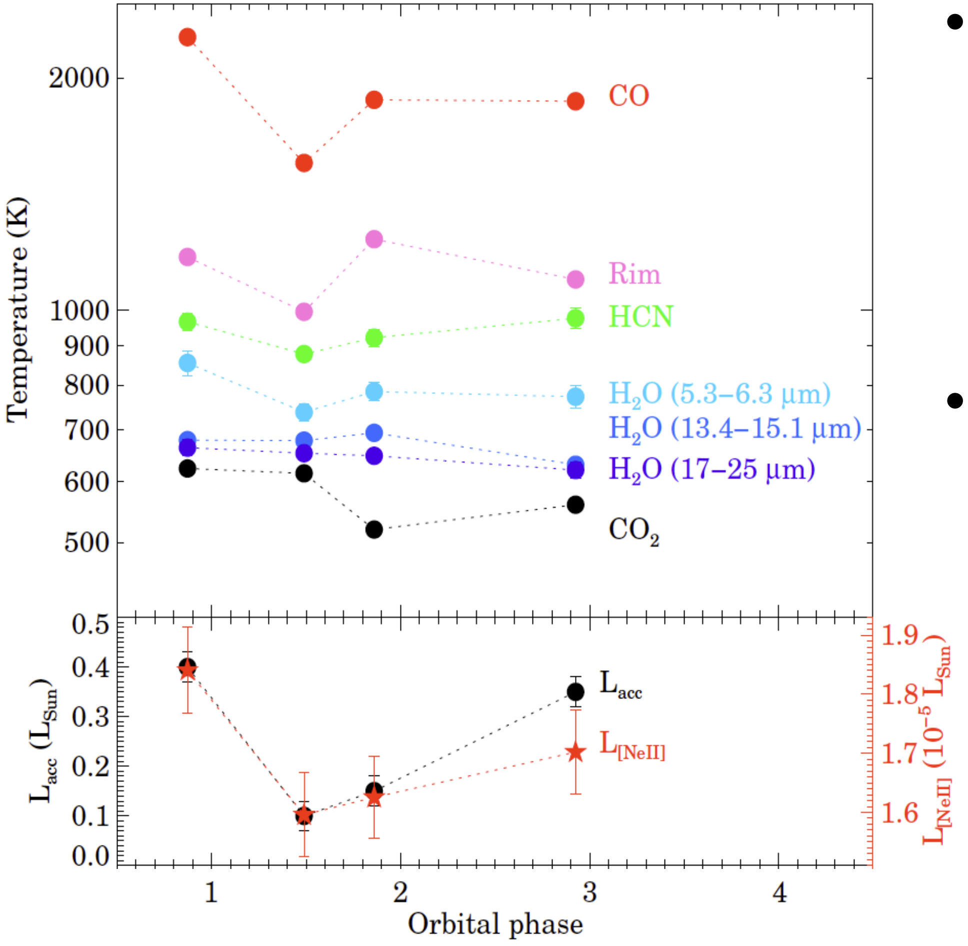


Kóspál et al. (2025)

- Mineralogical **composition is constant with time** (mostly large, 2– 5 μm amorphous olivies and pyroxenes with some contribution from 5 μm-sized crystalline enstatite)
- Feature **strength changes** in correlation with the location of the inner dust rim
- **Variable shadowing**

Variability of the molecular features

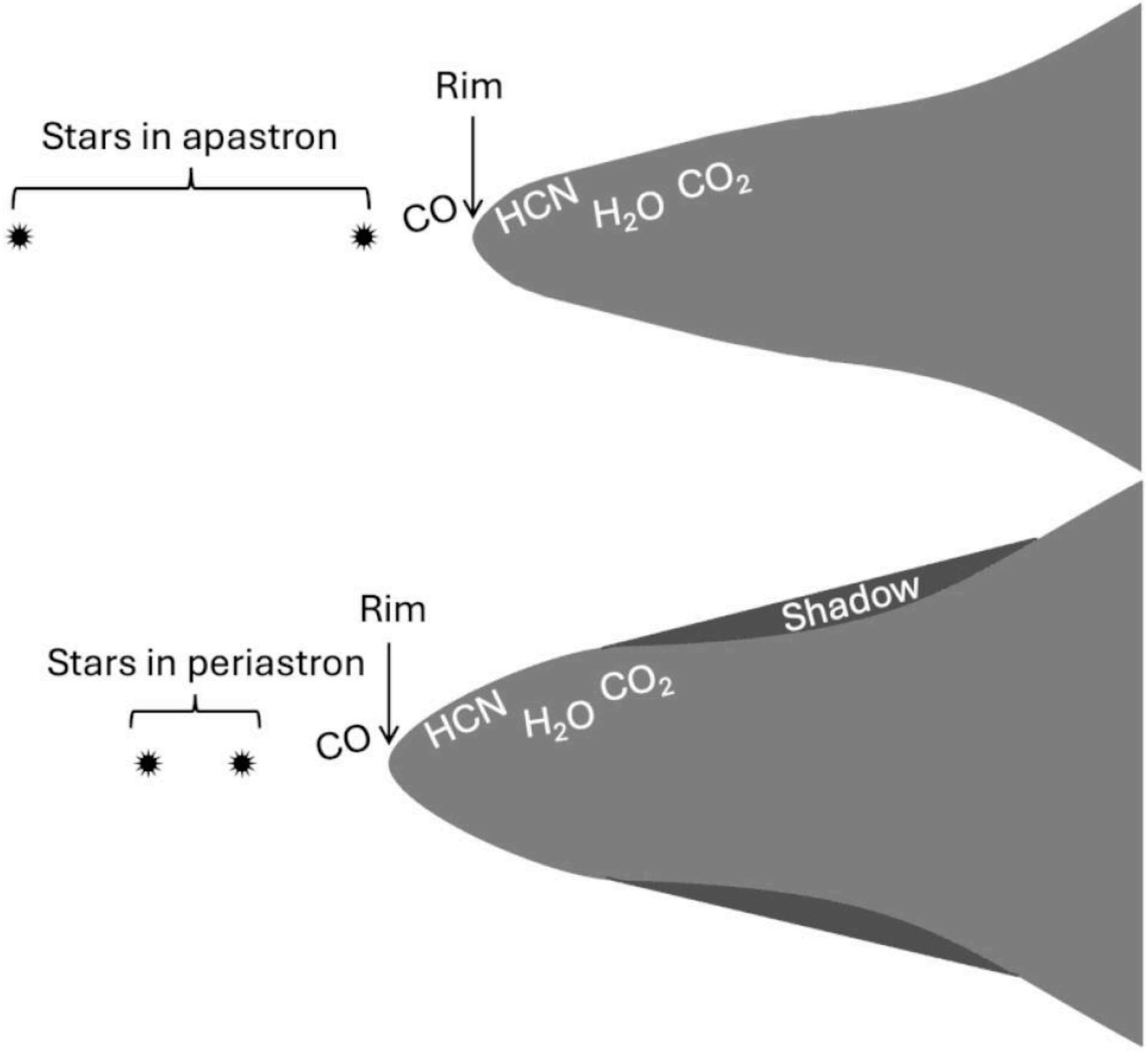




Kóspál et al. (2025)

- CO, HCN, hot H_2O, and [NeII] correlate with L_{acc} changes
- The warm and cold H_2O components are mostly constant

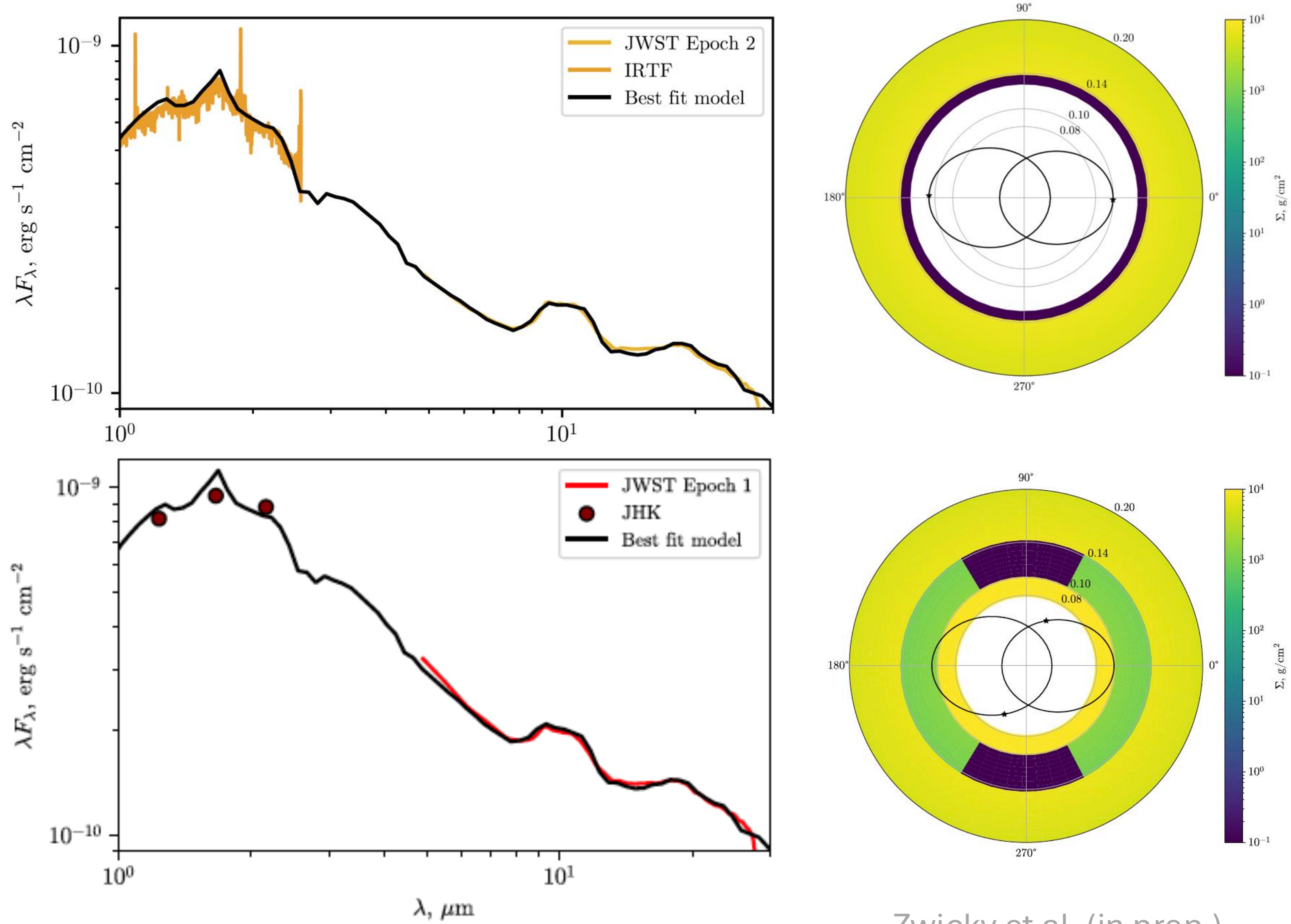
Time-resolved disk physics in DQ Tau with JWST



- 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

Kóspál et al. (2025)

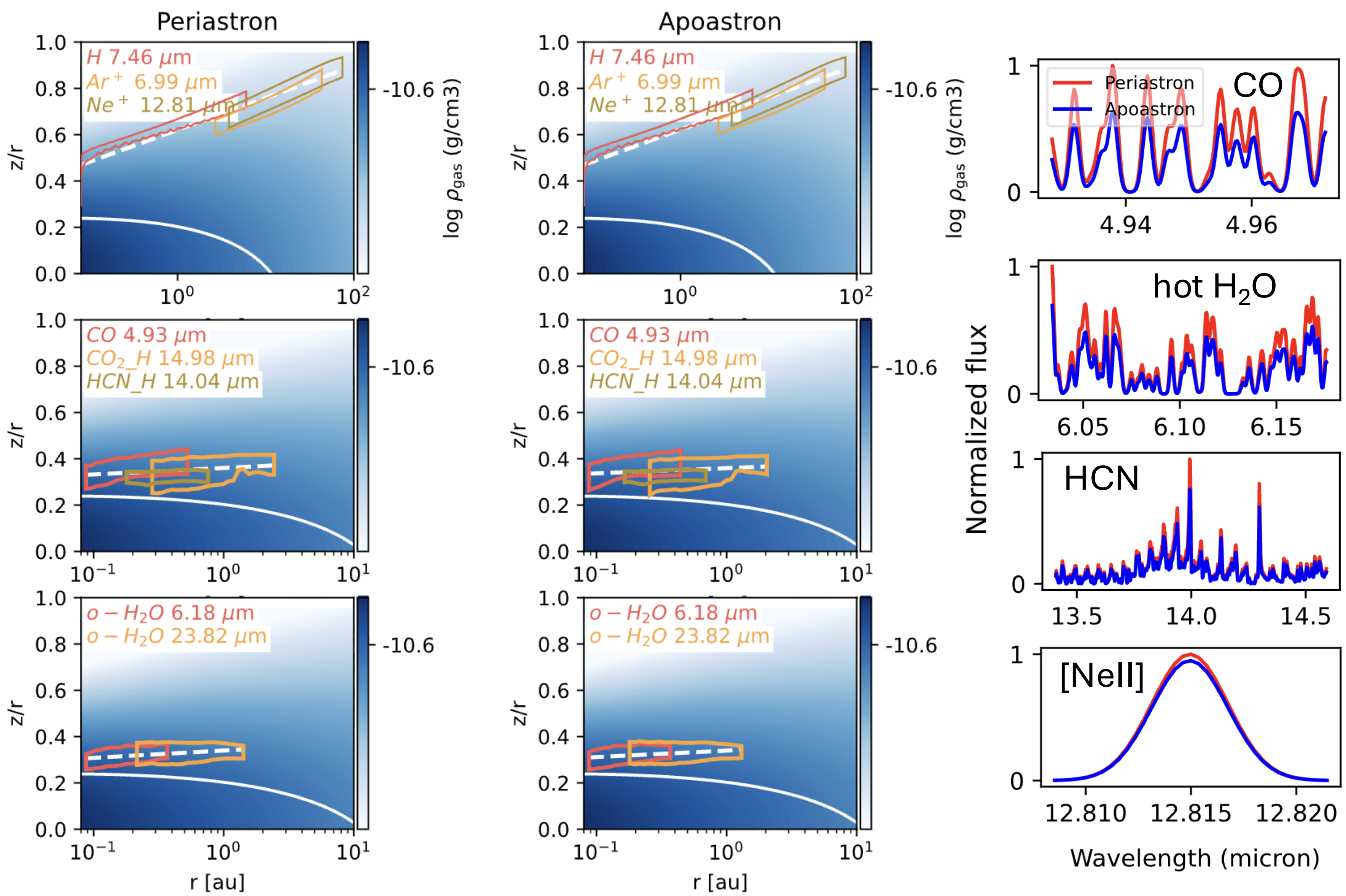
Dust RT modelling of the SED with RADMC3D



Zwicky et al. (in prep.)

- **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

Thermochemical modelling of the lines with ProDiMo



Portilla-Revelo et al. (submitted)

- Model flux of H, CO, CO_2, HCN, and H_2O are **stronger at periastron** than at apastron due to 4x higher L_{acc}
- JWST observations did not coincide with X-ray flares
- **Snowline shifted outwards by ~20% at periastron relative to its apastron position**

Thank you for your attention!

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Background image: modification of a figure from NOIRLab / NSF / AURA / P. Marenfeld.