JWST Imaging of Edge-on Protoplanetary Disks: The Case of Tau042021

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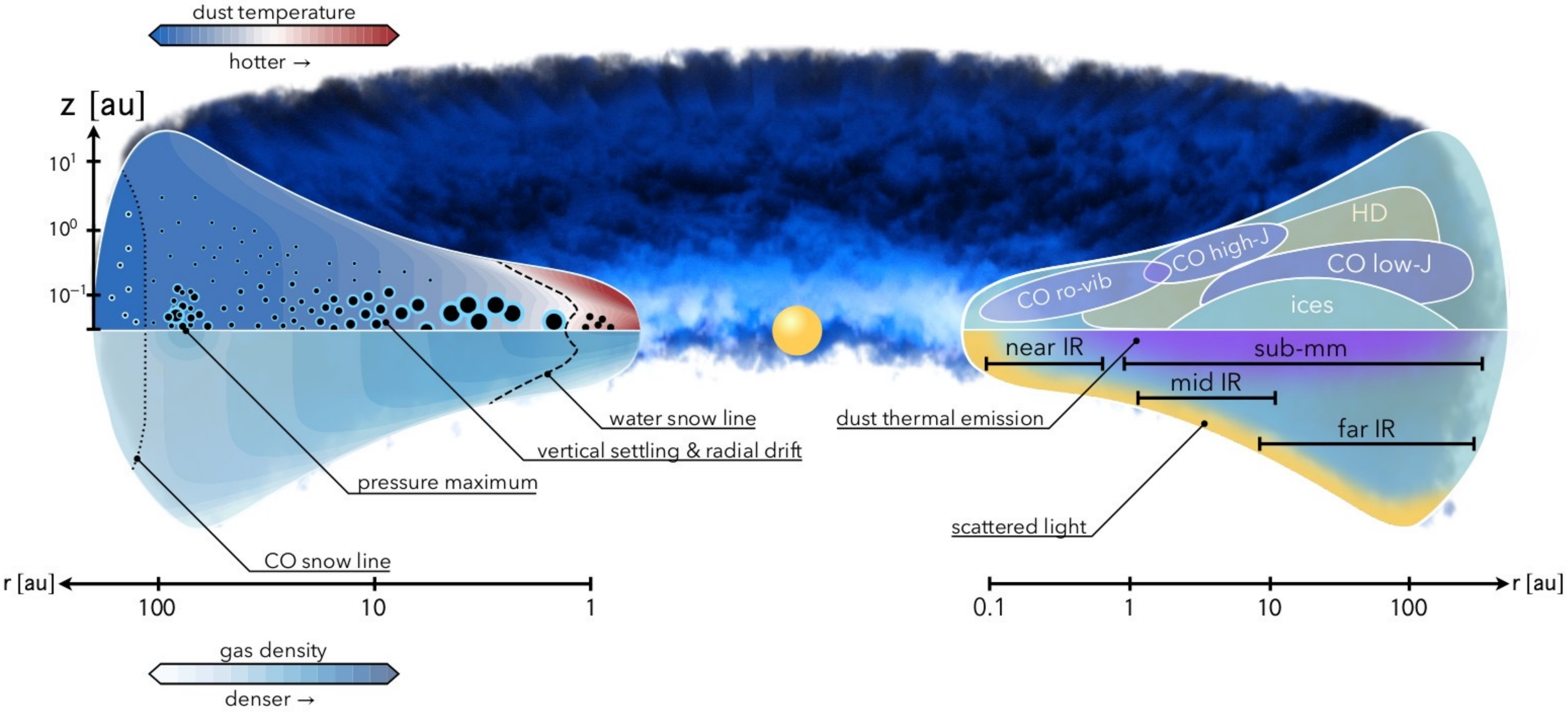
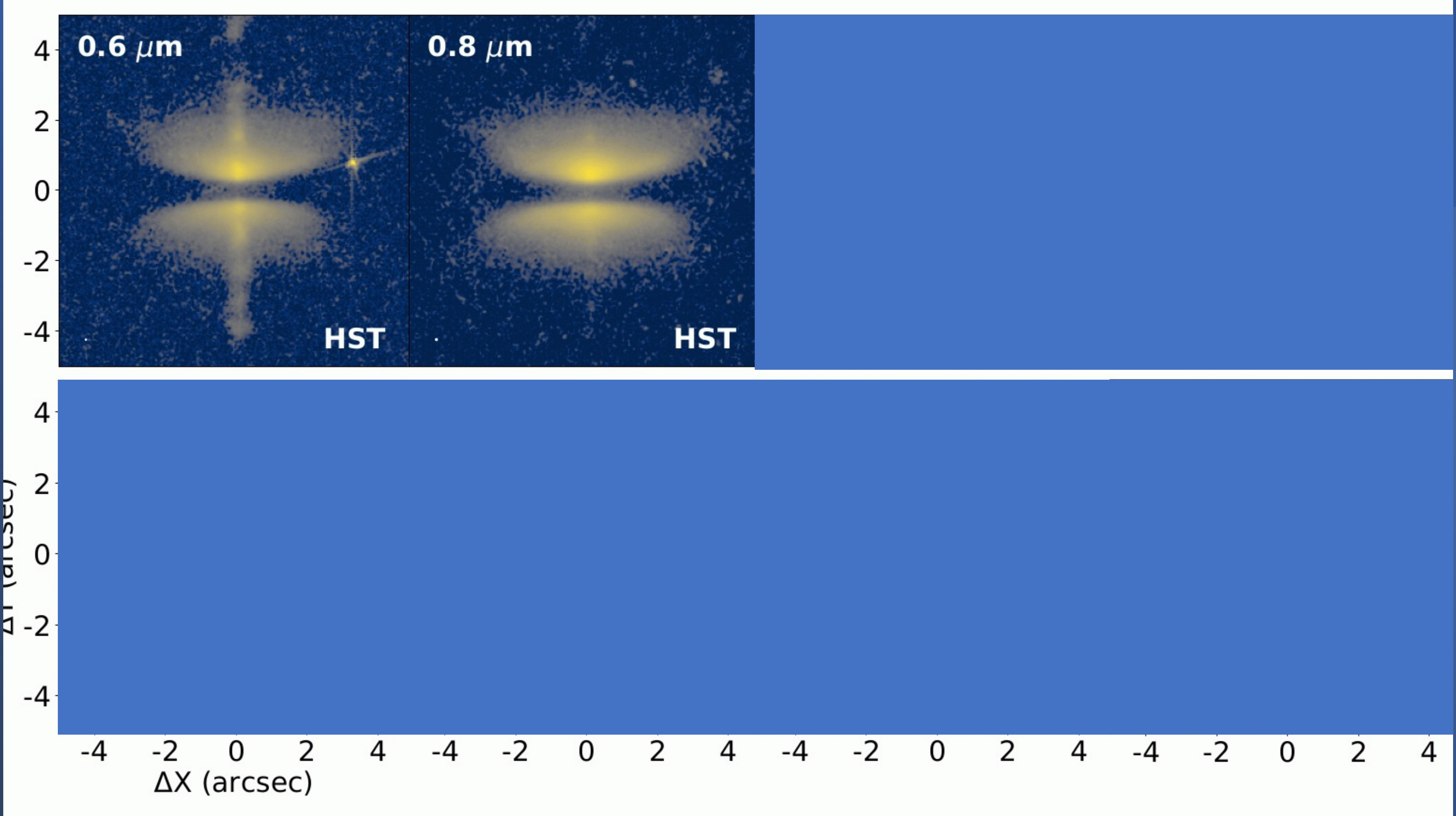
Theoretical picture of a protoplanetary disk

(Miotello et al. Protostars & Planets VII)

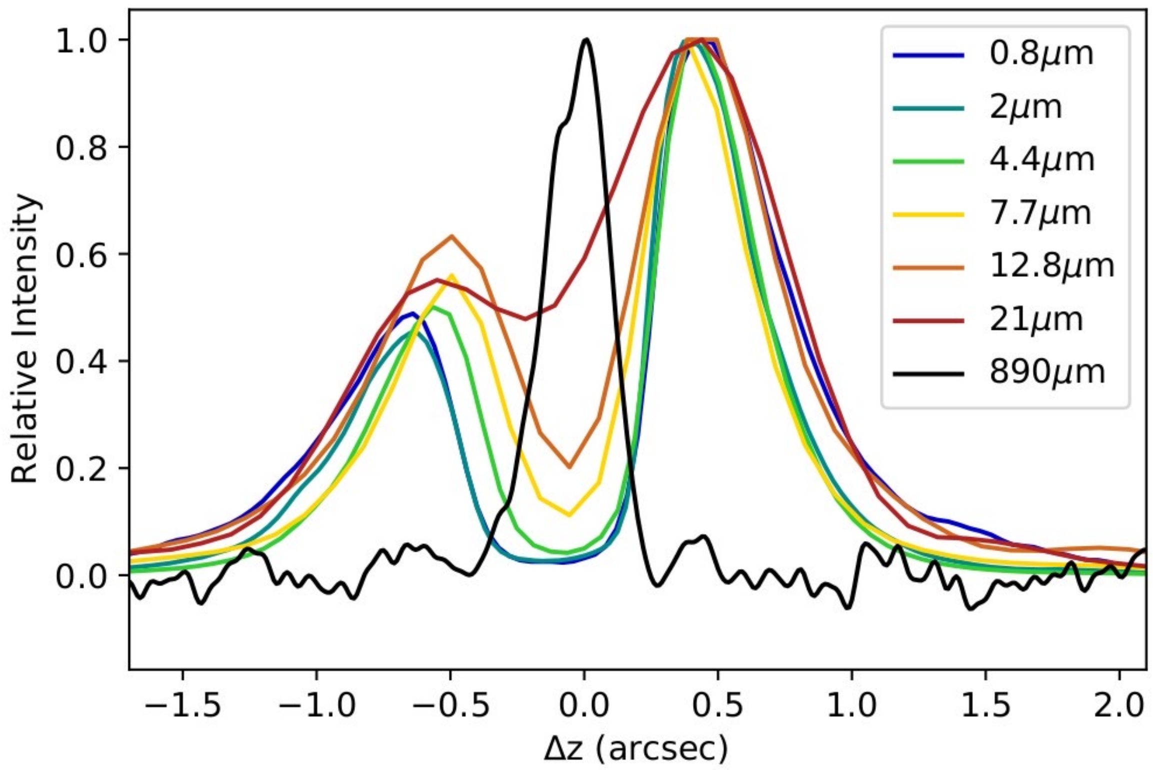


Three whys: Edge-on disks, JWST, Tau042021

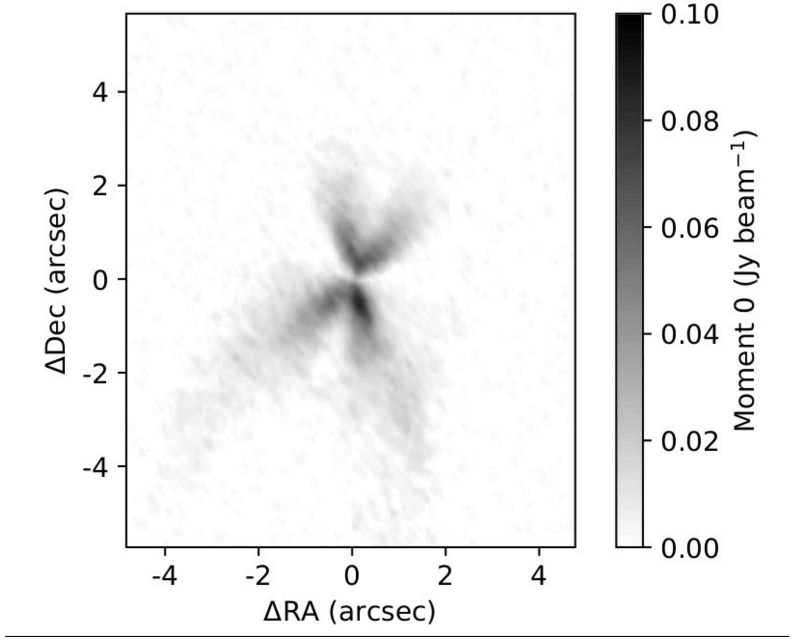
- Protoplanetary disks are opaque at wavelengths < 100 µm. So when seen edge-on they block the star, thus no coronagraph is needed to see the disk
- When edge-on, the disk vertical structure is presented to view. Using scattered light models, can study topics such as dust settling to the midplane, an early stage of planet formation
- Since 1994, our group has been finding these objects in nearby star-forming regions and imaging them with HST, in the millimeter, etc.
- JWST provides the first opportunity for useful imaging of these objects in the mid-infrared
- Our Cycle 1 GO program targeted four of the larger edge-on disks in nearby star-forming regions d ≤ 160 pc, at different evolutionary stages
- Tau042021 is the largest EOD in Taurus, has bipolar jets but little envelope. M1 spectral type
    - HST results from Duchene et al. 2014
    - ALMA results from Villenave et al. 2020 but presented more fully here
    - JWST data from 2023 January


0.6 μm
HST
0.8 μm
HST
ΔX (arcsec)
ΔY (arcsec)

Vertical cuts across the dust lane : the disk thickness hardly changes from 4-21 microns

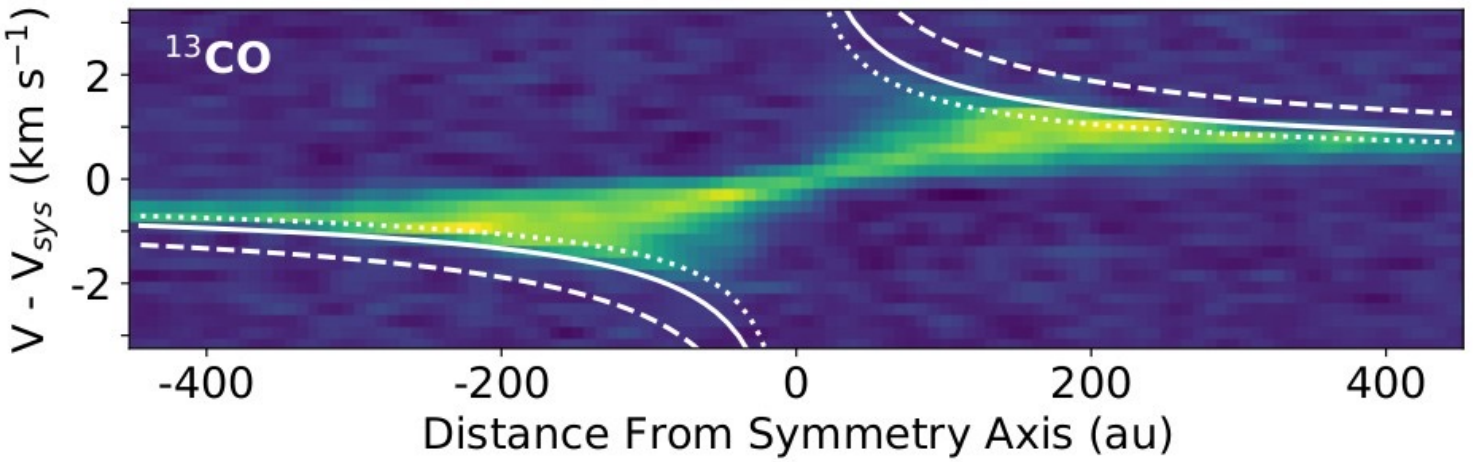


Instrument	Filter	λ (μm)	d_{neb} ($''$)	Flux Ratio
HST/ACS†	F606W	0.6	1.14	0.41
HST/ACS	F814W	0.8	1.17	0.44
JWST/NIRCam	F200W	2.0	1.11	0.44
JWST/NIRCam	F444W	4.4	1.04	0.49
JWST/MIRI$^{\#}$	F770W	7.7	0.89	0.56
JWST/MIRI$^{\dagger\#}$	F1280W	12.8	0.91	0.61
JWST/MIRI	F2100W	21	0.96	0.55



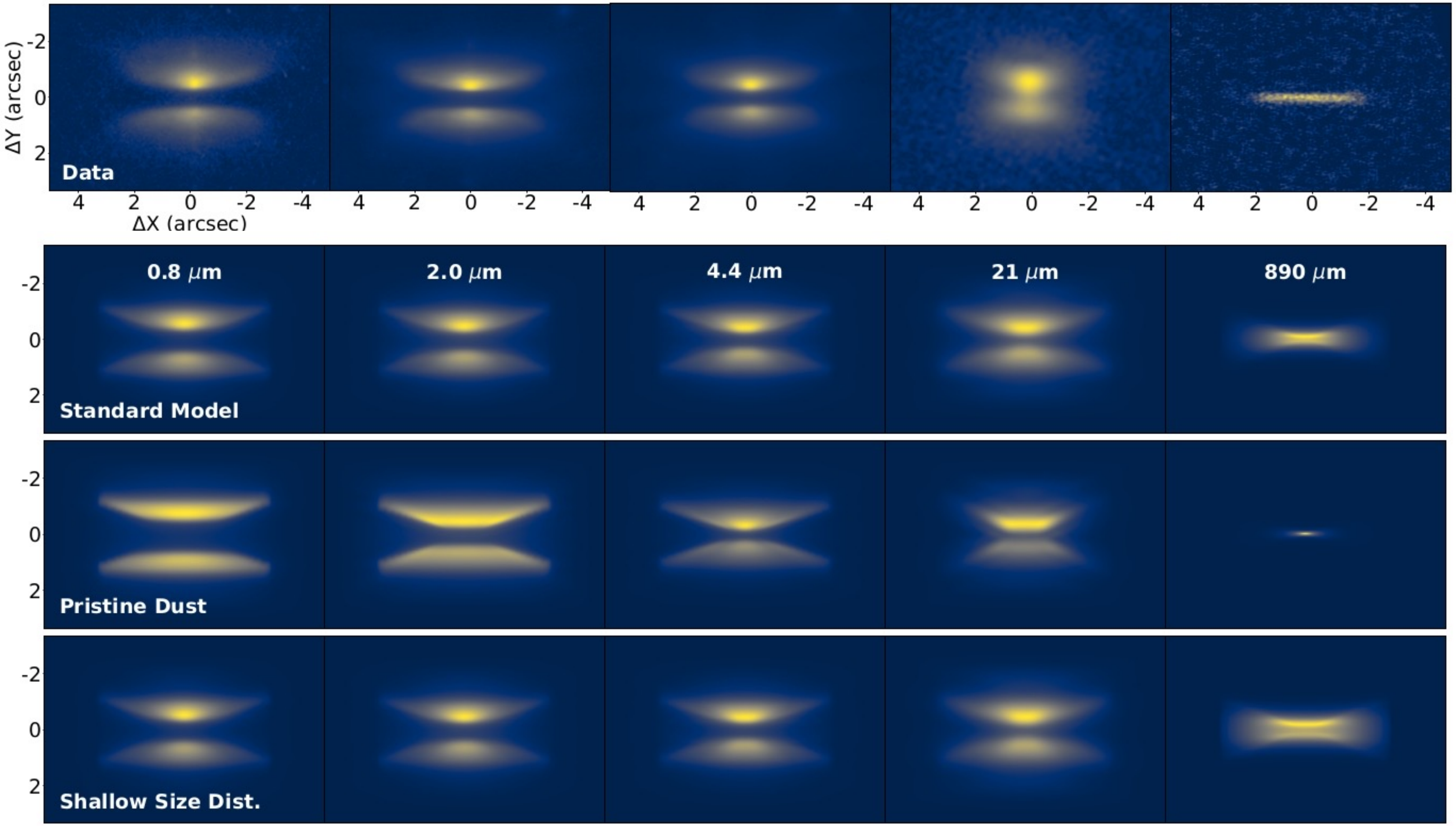
ALMA band 6
12CO moment maps

In some channel maps, emission extends to radii of 7" (1000 au) - nearly double the disk size in scattered light



ALMA band 6
13CO PV diagram
0.25, **0.4,** 0.8 Msun trial fits for the dynamical mass of the central star

Scattered light model exploration 1.

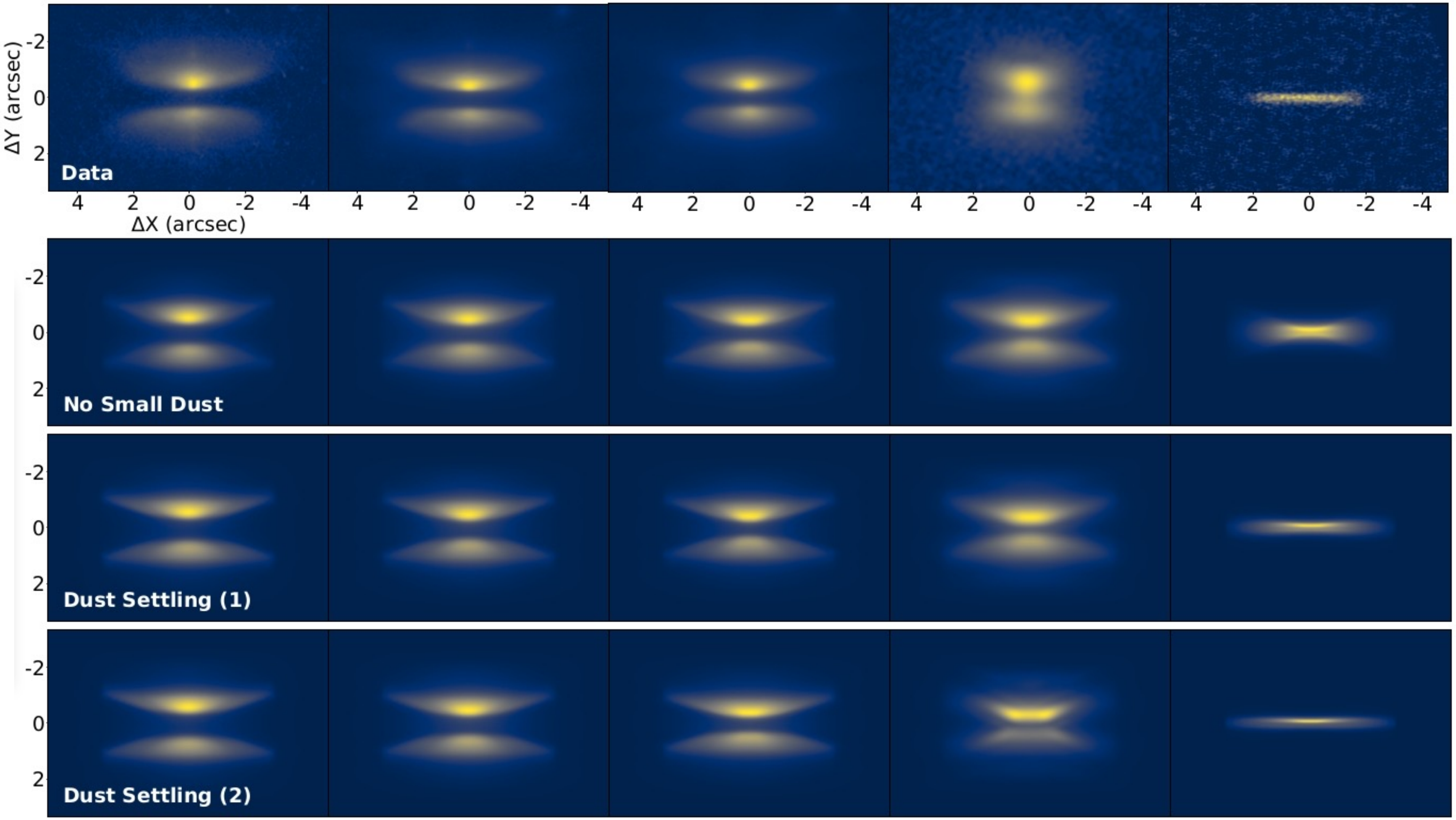


Too thick at 890 μm

Dust lane narrows too quickly

Too thick at 890 μm

Scattered light model exploration 2.



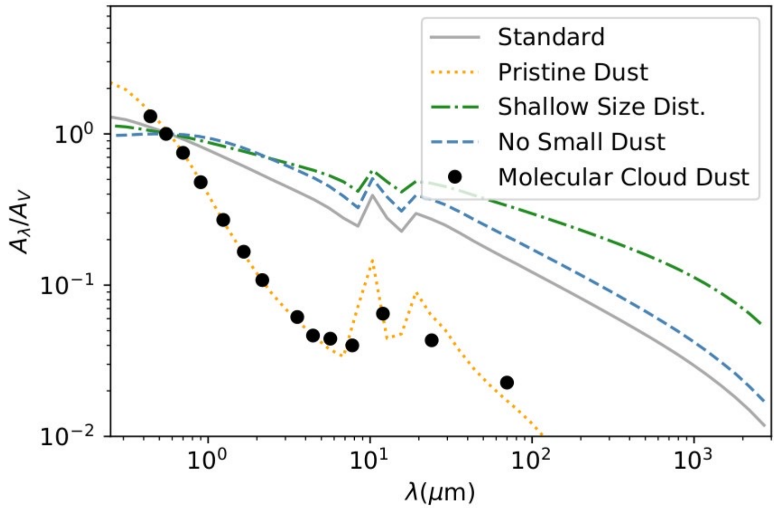
Too thick at 890 μm

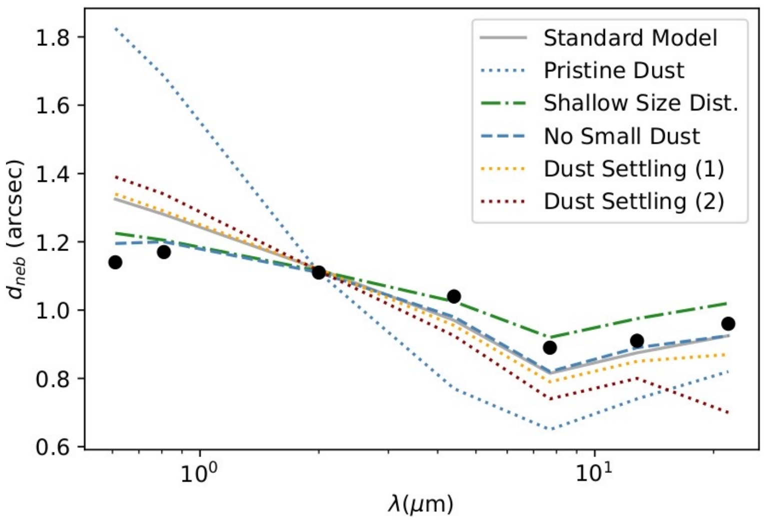
Sort-of OK, better than the rest

Dust lane narrows too quickly

Table 3. Summary of Model Exploration

Model	Grain Size Distribution p	$a_{\min}$ (μm)	Settling $\alpha_{\rm settl}$	$a_{\rm mix}$ (μm)	Total Dust Mass ($10^{-4}\ M_\odot$)	Dark Lane Thickness	890 μm Map	SED
Standard	3.5	0.03	None		4.9	(✓)	×	(✓)
Pristine Dust	see Section 4.1		None		1.05	×	×	×
Shallow Size Distribution	3.25	0.03	None		13	✓	×	(✓)
No Small Dust	3.5	0.3	None		5.1	✓	×	×
Dust Settling (1)	3.5	0.03	0.5	10	4.9	(✓)	(✓)	(✓)
Dust Settling (2)	3.5	0.03	0.5	1	7.0	×	(✓)	×





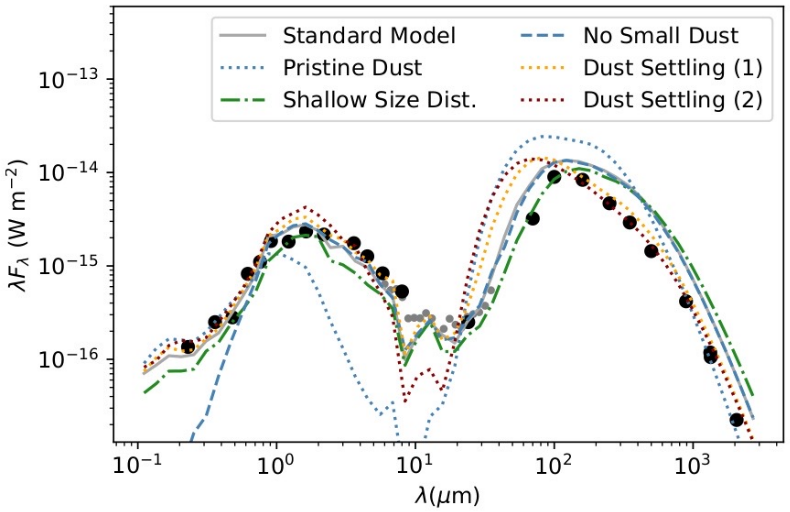
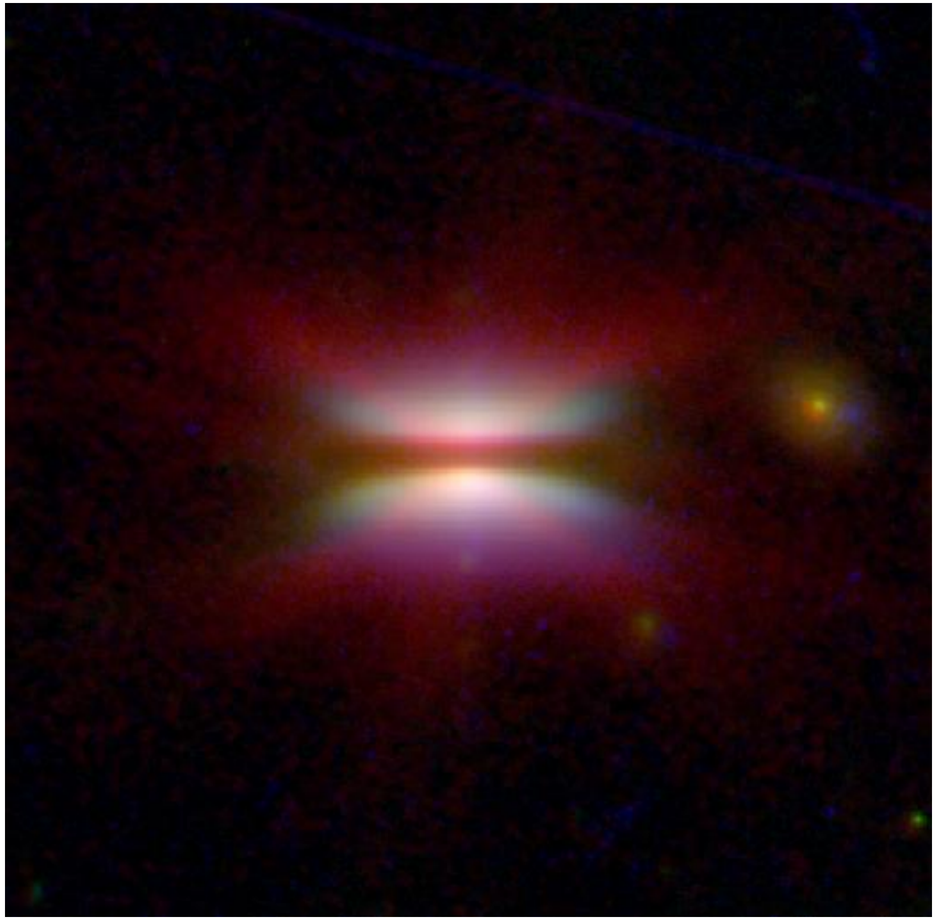


Figure 12. Extinction law of dust models used in this study. The black symbols represent the extinction law observed in molecular clouds (Flaherty et al. 2007; Lim et al. 2015).

Summary

- The Tau042021 edge-on disk is seen purely as a scattered light nebula out to at least to 21 µm, JWST's sensitivity enabled this detection
- ALMA data implies this is a ~1000 au radius disk around a ~0.4 Msun star
- The dust lane thickness changes little between 4-21 µm, implying that ~10 µm grains remain vertically mixed up to the disk surface layers, at least in the outer disk. A constraint on grain shape and/or vertical turbulence.
  - Settling of larger grains is required to reproduce the ALMA observations
  - Our approved ALMA band 9 (450 µm) observations in Cycle 10 (PI Villenave) should provide further constraints on grain vertical stratification in our Cycle 1 targets
  - Follow-up modeling work is focusing on how the observed degree of forward scattering as a function of wavelength can provide additional info on the dust size distribution
- Upcoming AAS talk will present results for our 3 other Cycle 1 edge-on disk targets.
- Our approved JWST Cycle 2 program is providing similar data on another 13 edge-on protoplanetary disks in nearby star-forming regions, aimed at exploring the diversity of disk vertical structure and dust properties

Tau042021 color overlay 0.8, 2.0, and 7.7 µm



"JWST imaging of edge-on protoplanetary disks. I. Fully vertically mixed 10µm grains in the outer regions of a 1000 au disk"

arXiv:2309.07040 (2023) accepted by A.J.

Duchene, G. ; Menard, F. ; Stapelfeldt, K. ; Villenave, M.; Wolff, S. G. ; Perrin, M. D. ; Pinte, C. ; Tazaki, R. ; Padgett, D. L.