Planet signatures in transition disks

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State College, Sep 8th, 2017

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Richert et al. (2015)

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ON SHOCKS DRIVEN BY HIGH-MASS PLANETS IN RADIATIVELY INEFFICIENT DISKS. I. TWO-DIMENSIONAL GLOBAL DISK SIMULATIONS

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ABSTRACT

Recent observations of gaps and non-axisymmetric features in the dust distributions of transition disks have been interpreted as evidence of embedded massive protoplanets. However, comparing the predictions of planet–disk interaction models to the observed features has shown far from perfect agreement. This may be due to the strong approximations used for the predictions. For example, spiral arm fi...
mass planets in an isothermal gas. In this work, we describe two-d...
of disks with embedded protoplanets, with and without the assump...
to-star mass ratios 1–10 M_J for a 1 $M_\odot$ star. We use the Pencil Co...
that the inner and outer spiral wakes of massive protoplanets (M...
can trigger buoyant instabilities. These drive sustained turbulen...

Lyra et al. (2016)

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ON SHOCKS DRIVEN BY HIGH-MASS PLANETS IN RADIATIVELY INEFFICIENT DISKS. II. THREE-DIMENSIONAL GLOBAL DISK SIMULATIONS

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ABSTRACT

Recent high-resolution, near-infrared images of protoplanetary disks have shown that these disks often present spiral features. Spiral arms are among the structures predicted by models of disk–planet interaction and thus it is tempting to suspect that planetary perturbers are responsi...
not free of problems. The observed spirals have large pitc...
effectively unpolarized, implying thermal emission of the...

Hord et al. (2017)

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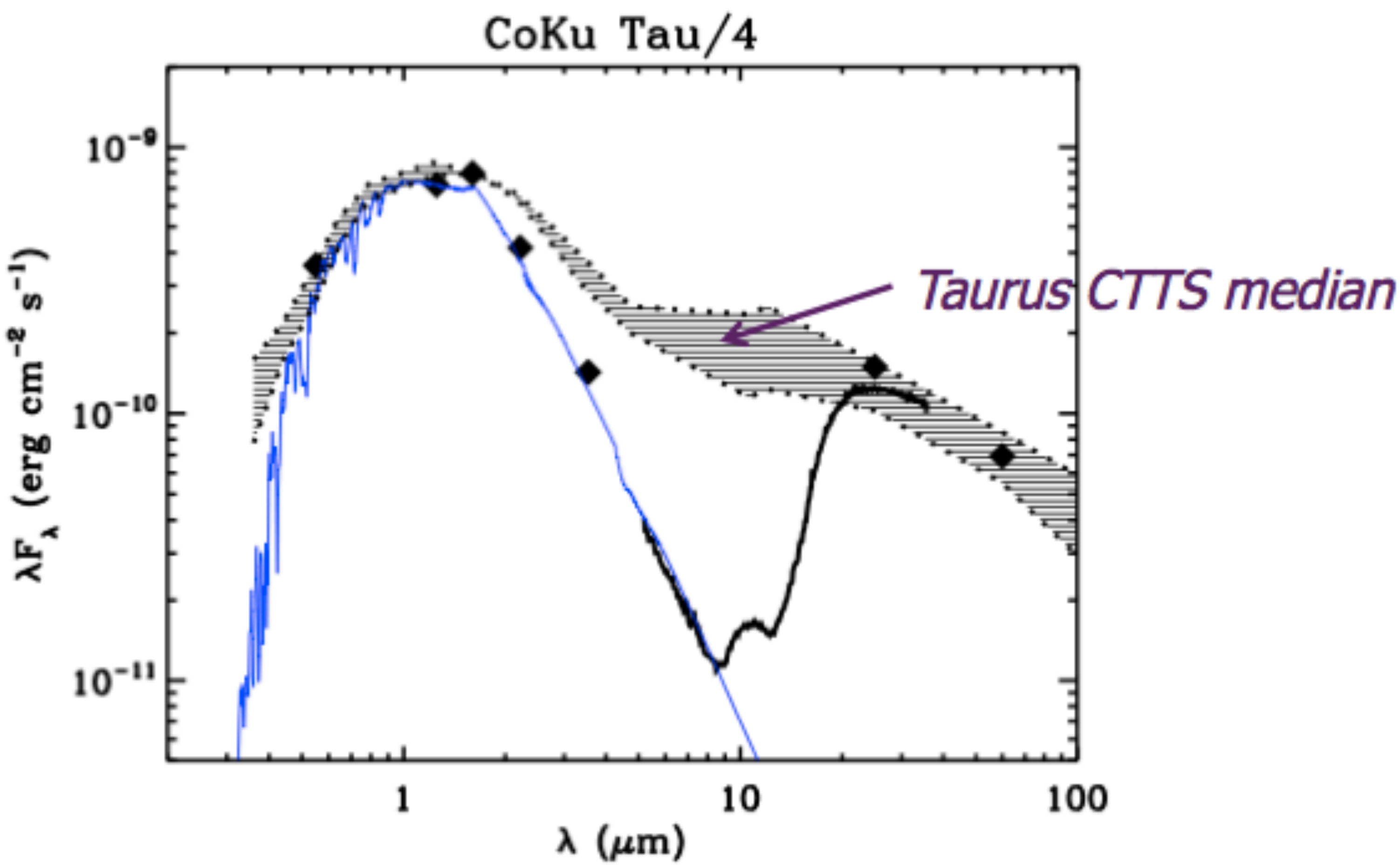
ON SHOCKS DRIVEN BY HIGH-MASS PLANETS IN RADIATIVELY INEFFICIENT DISKS. III. OBSERVATIONAL SIGNATURES IN THERMAL EMISSION AND SCATTERED LIGHT.

Blake Hord[1,2,3], Wladimir Lyra[2,3],
Mario Flock[3], Neal J. Turner[3]
(Dated: Received ; Accepted)
Draft version

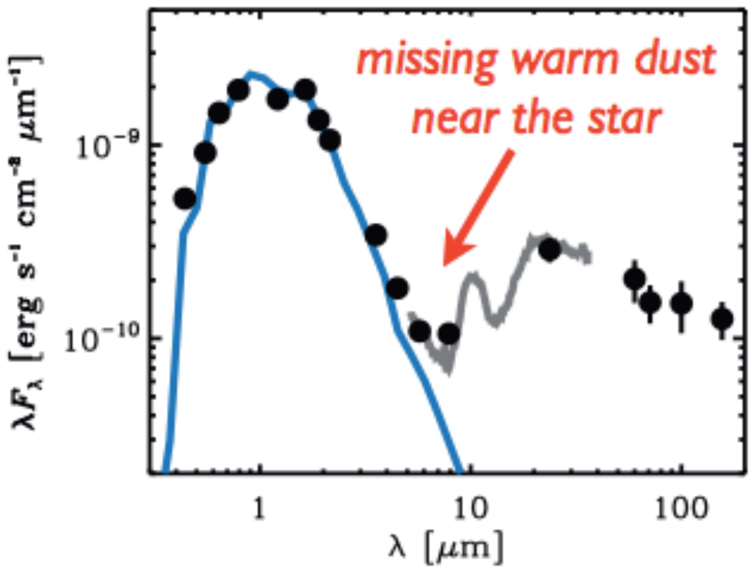
ABSTRACT

Recent observations of the protoplanetary disk around the Herbig Be star HD 100546 show two bright features in infrared (bands H and L') at about 50 AU. While one appears at the location of a confirmed exoplanet, the other has not been explained. A recent hydrodynamic model of the effects of shocks induced by a high mass planet shows that these shocks heat regions around the planet to relatively high temperatures (≈500 K). These shocks could be the source of the excess infrared emission in the disk around HD 100546. We explore the observational signatures of a high mass planet causing shock heating throughout its disk in order to determine if it could be the source of the infrared arm in HD 100546. More fundamentally, we identify and characterize planetary shocks as an extra, hitherto ignored, source of luminosity in transition disks. The RADMC-3D code is used to perform dust radiative transfer calculations on the hydrodynamical disk models. This uses a more

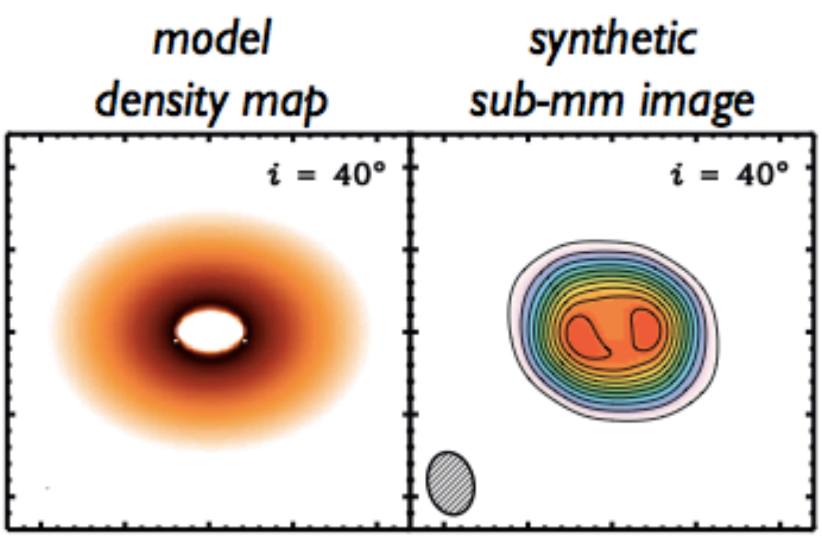
Transition Disks: Disks with missing hot dust.



Transition Disks: Disks with missing hot dust.

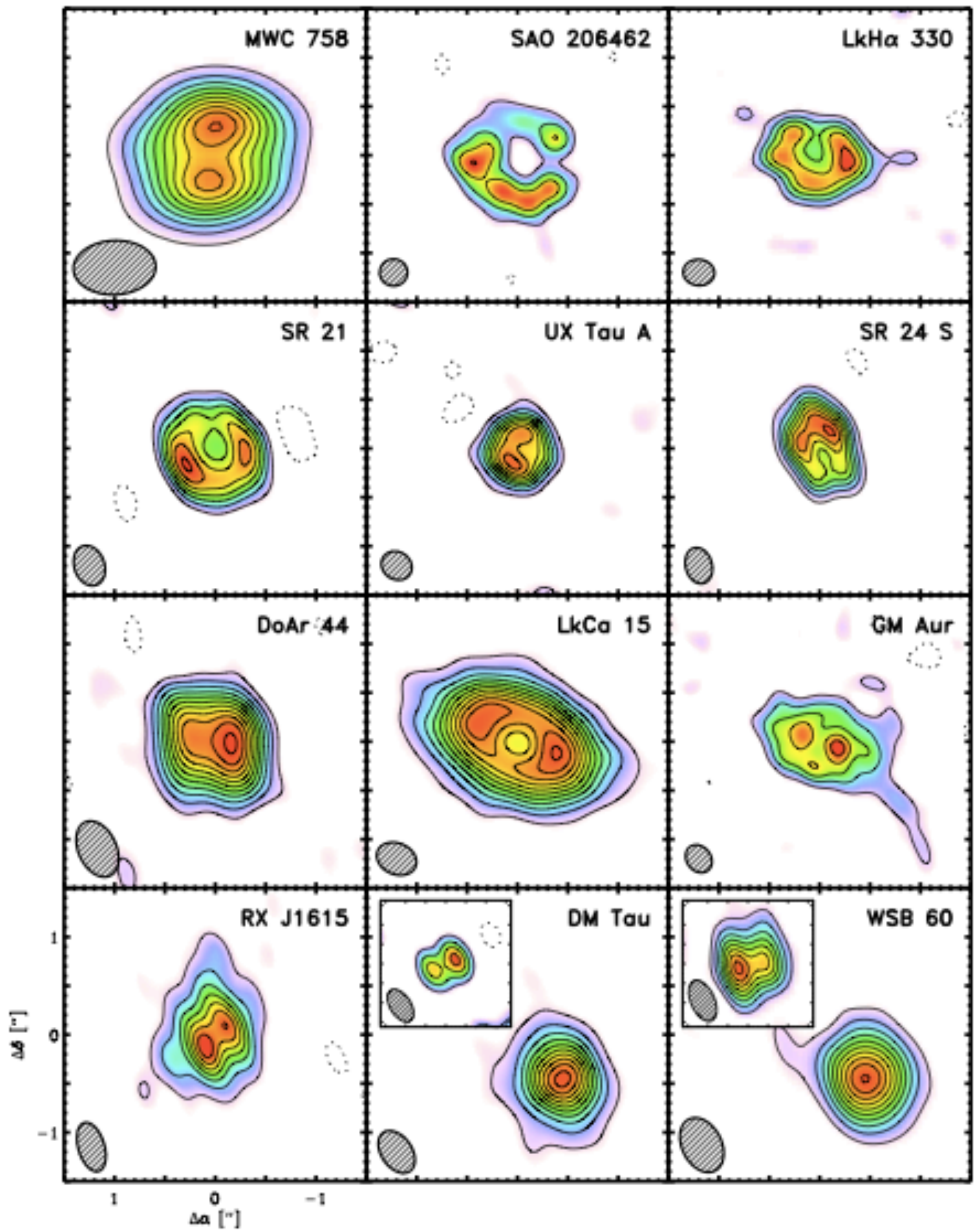


[e.g., Furlan et al. 2009]



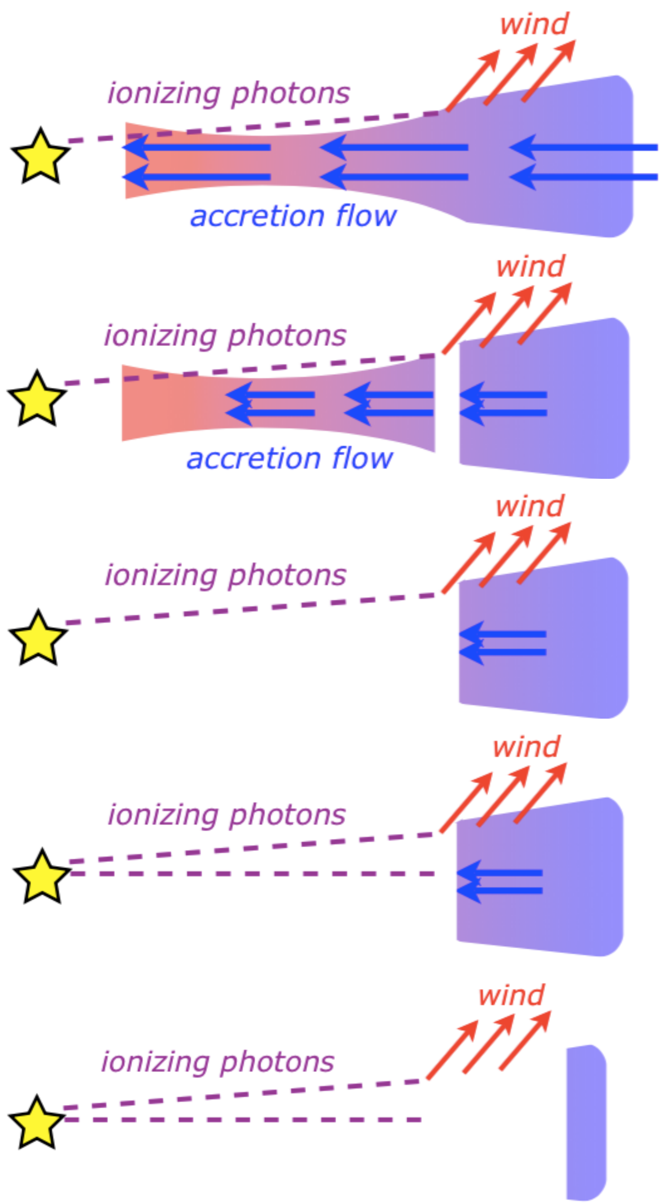
a disk with a large reduction
in optical depth near the star
(i.e., a "cavity" or "hole")

Resolved transition disks with the Sub-millimeter Array (SMA)

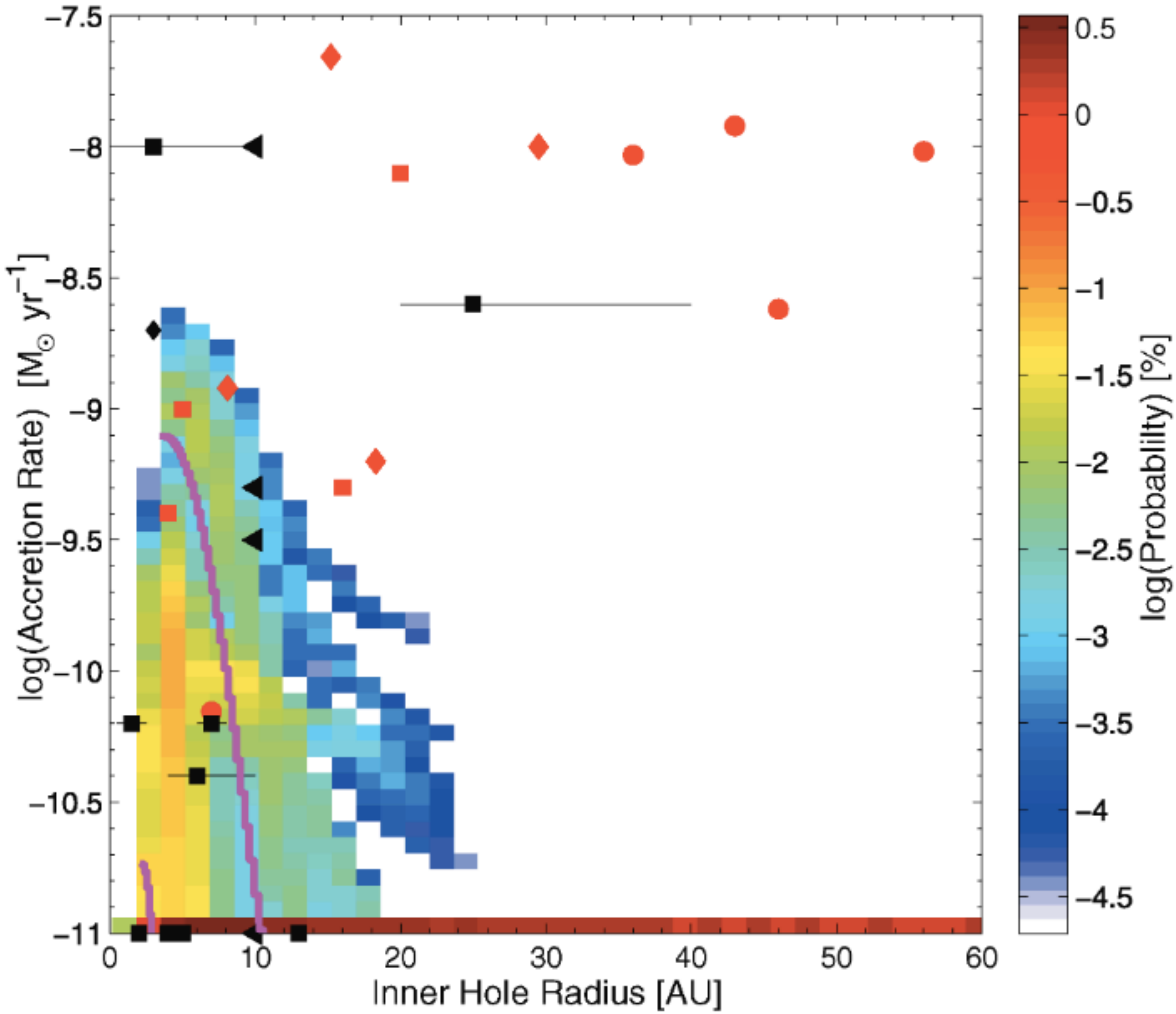


0.85mm
0.3” ~ 20 AU resolution

Photoevaporation



Bimodal distribution of transition disks

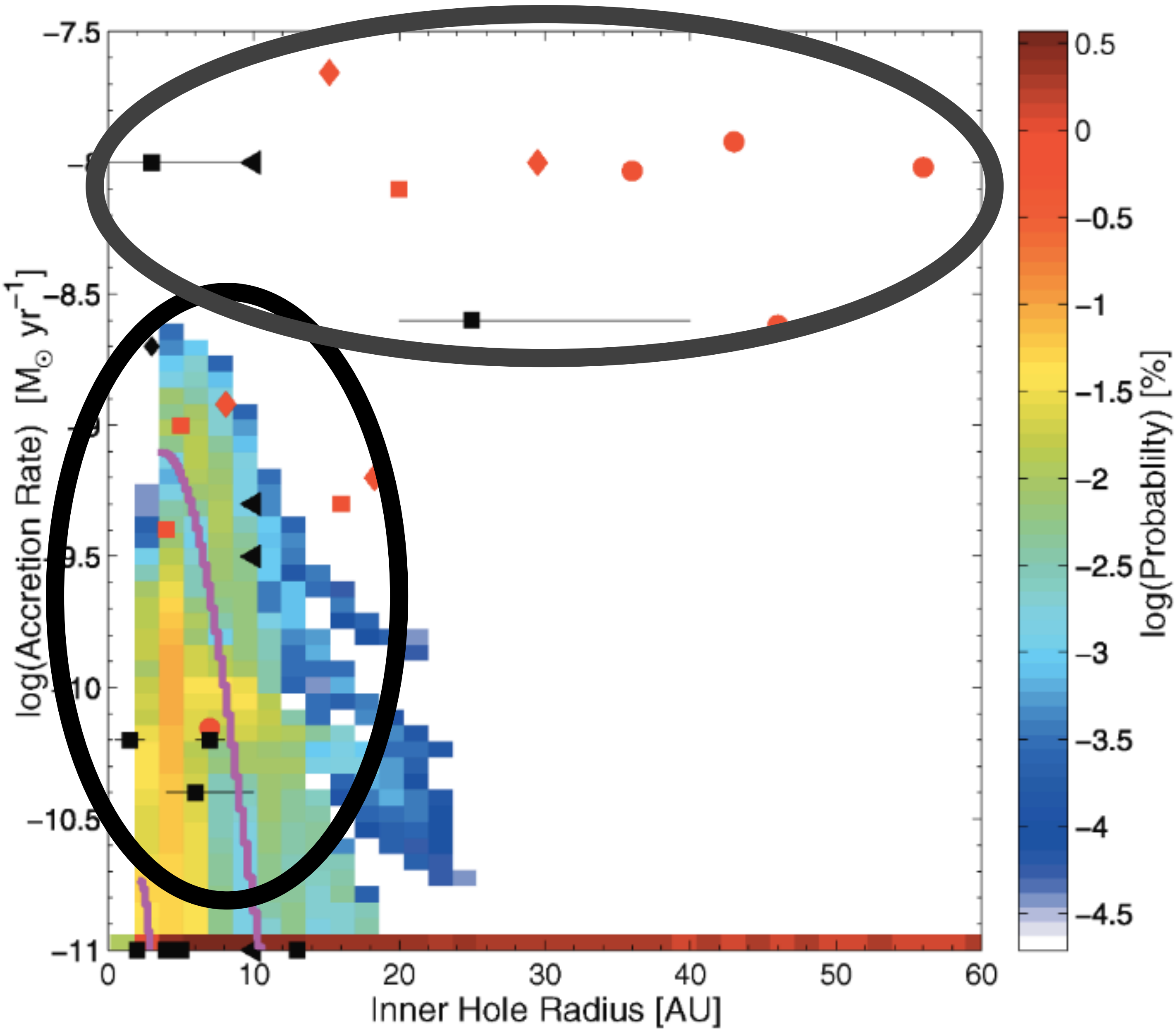


(Owen et al. 2011)

Bimodal distribution of transition disks

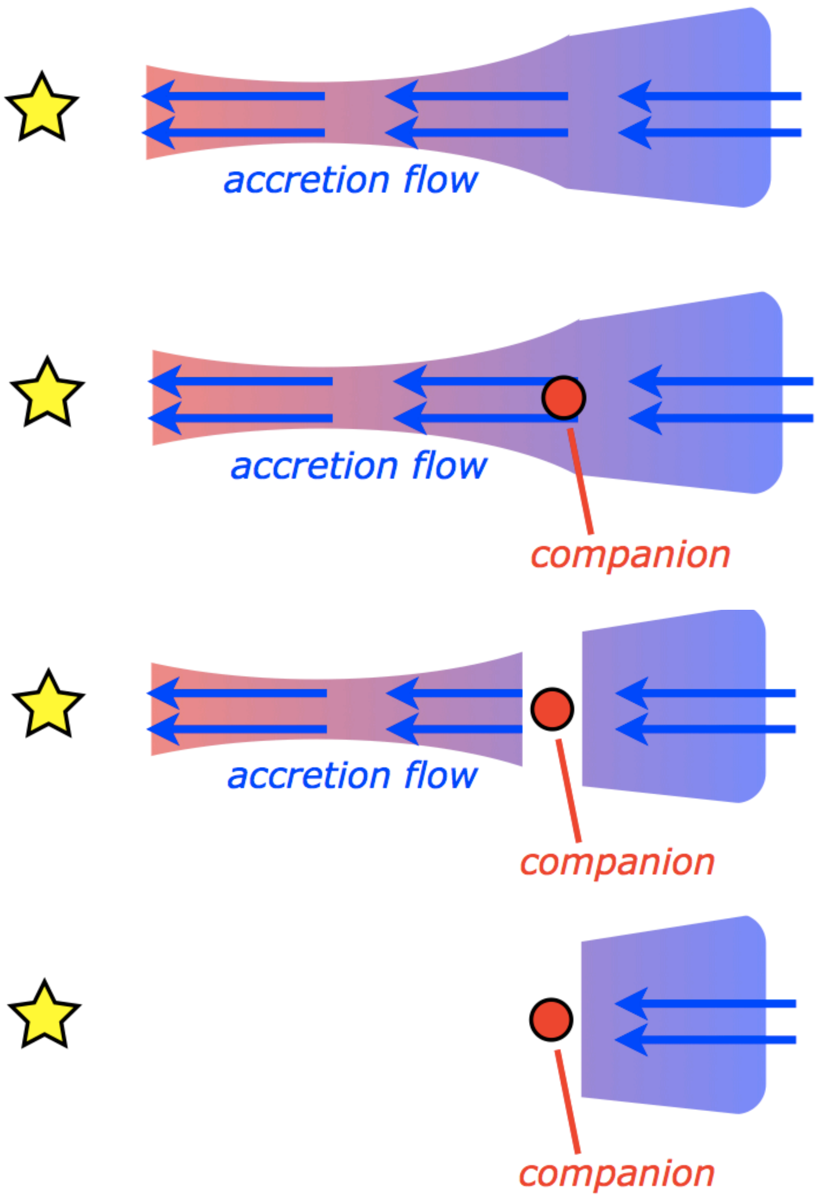
Not explained by photo-evaporation

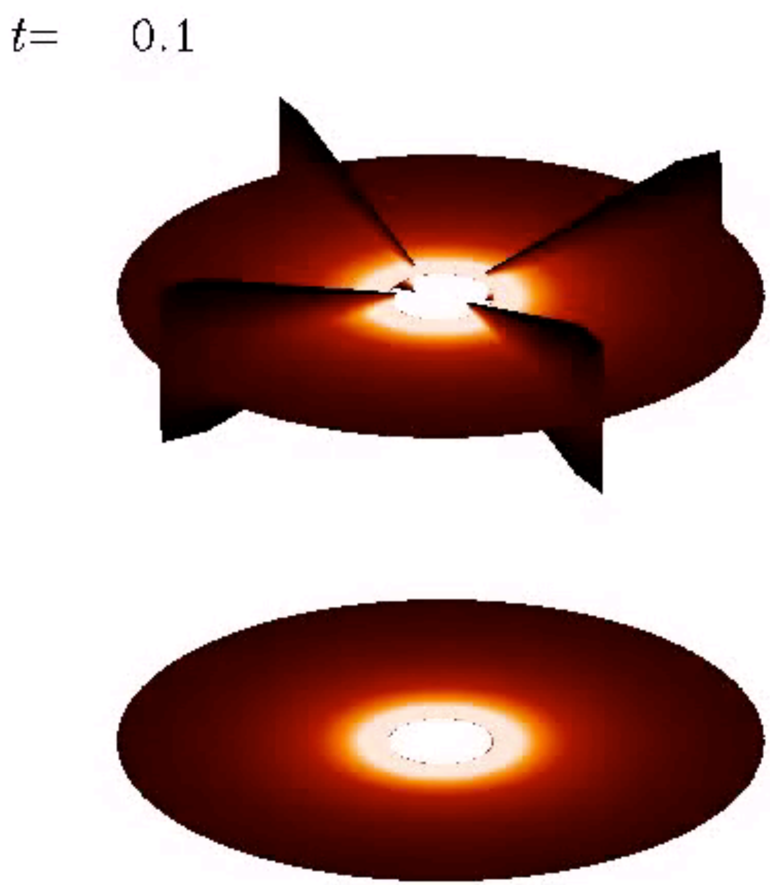
Explained by Photo-evaporation



(Owen et al. 2011)

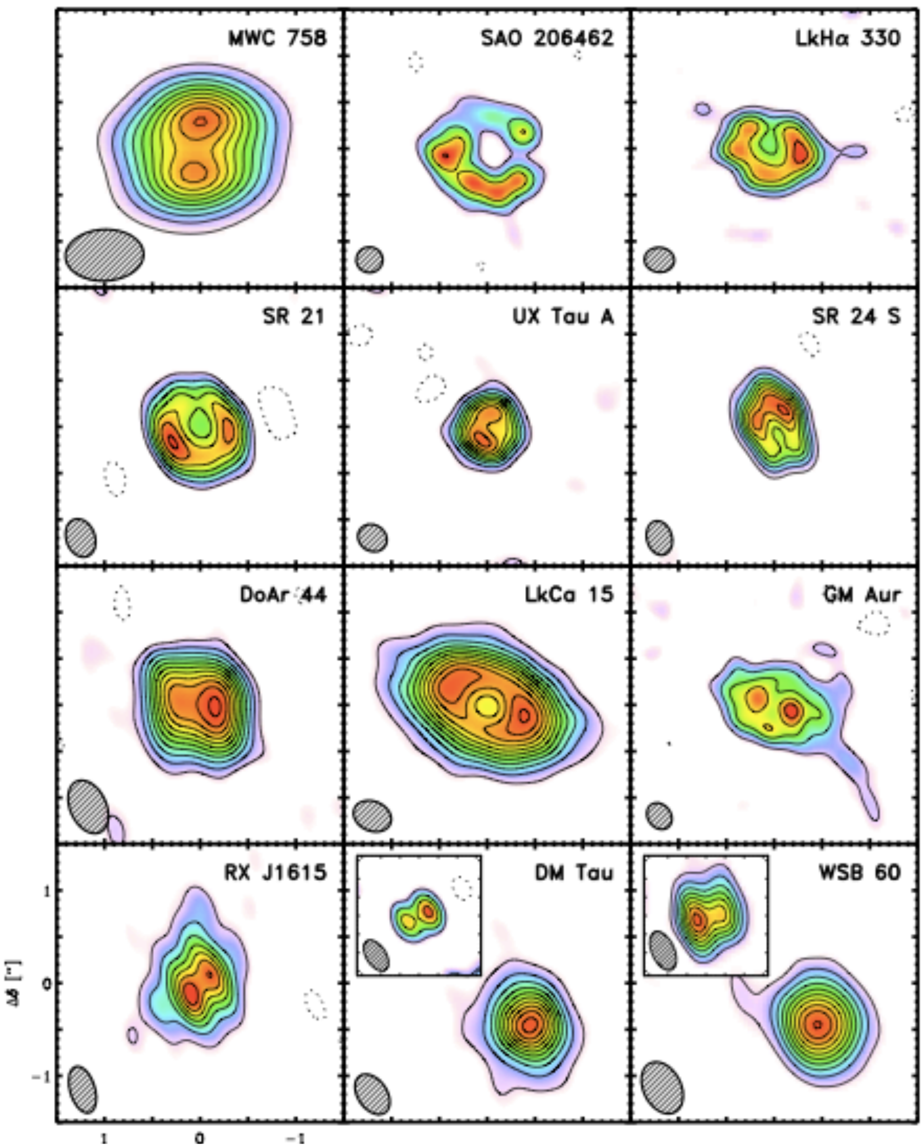
Planetary companion





(Lyra 2009)

These cavities may be the telltale signature of forming planets



(Lyra et al. 2009b)

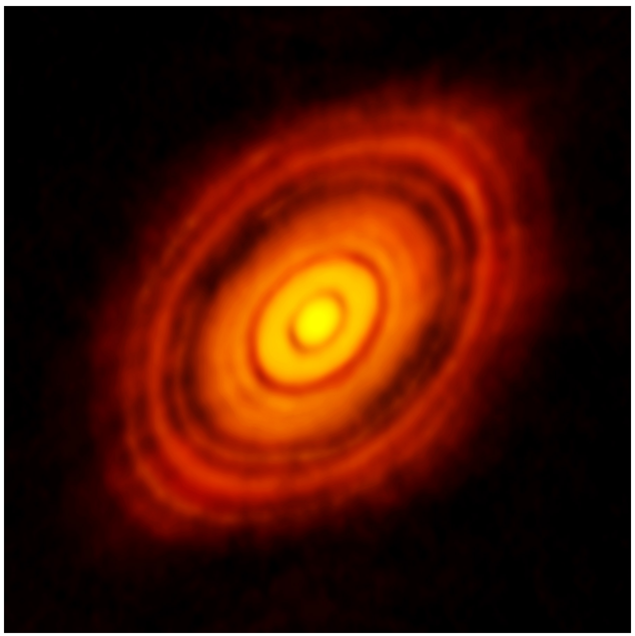
A way to directly study planet-disk interaction

Planet-disk interaction: gaps, spirals, and vortices.

(Lyra et al. 2009b)

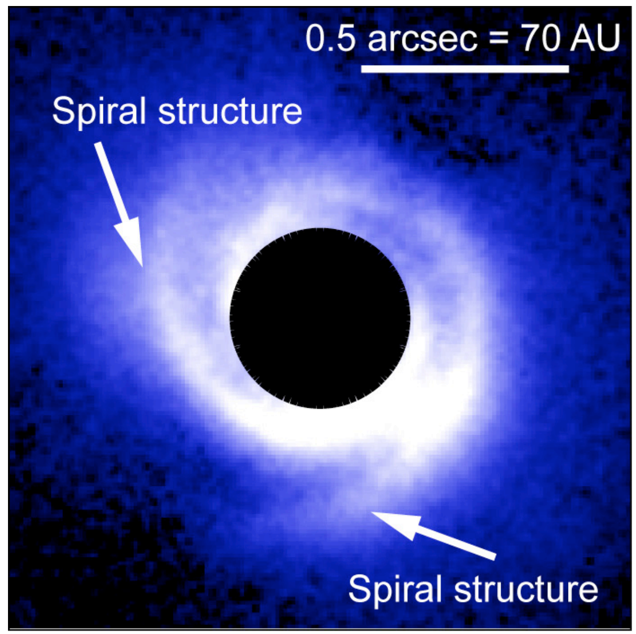
Observational evidence: gaps, spirals, and vortices

HL Tau



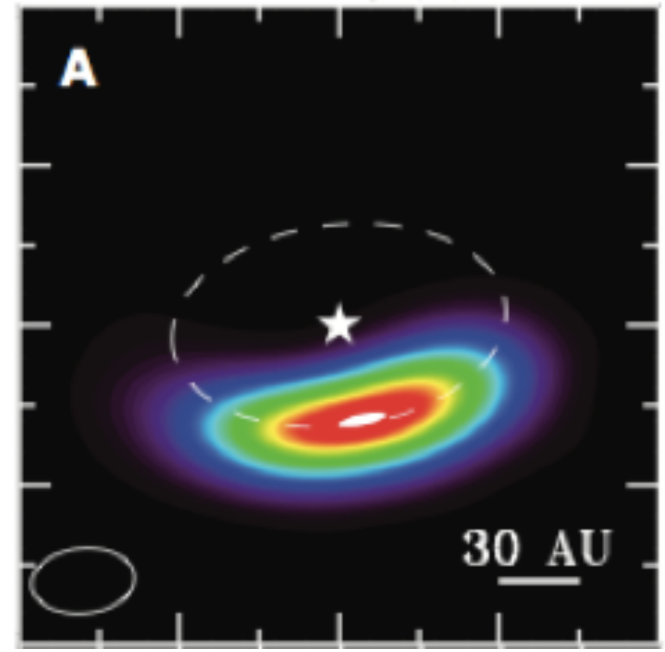
The ALMA Partnership et al. (2015)

SAO 206462



Muto et al. (2012)

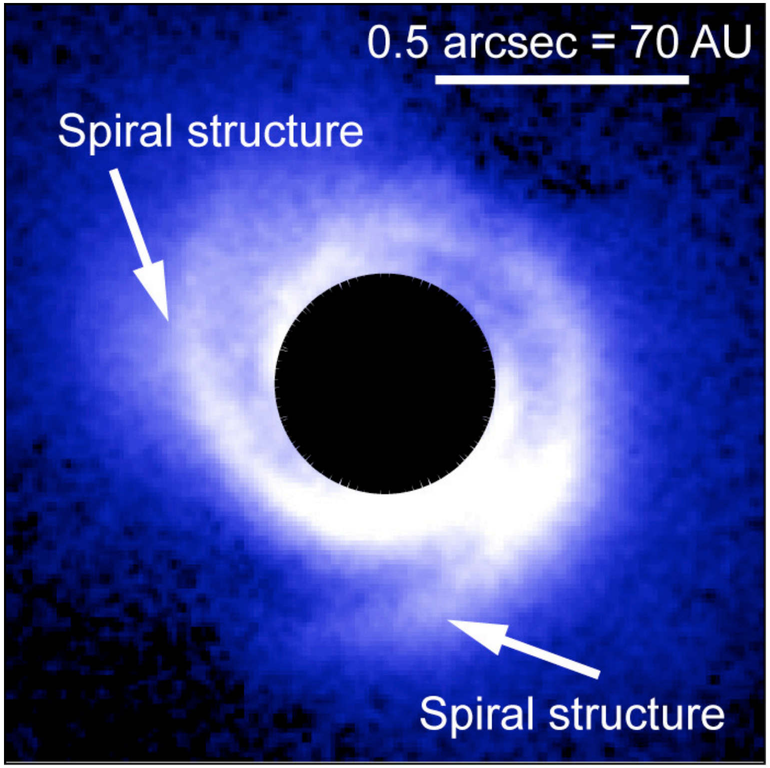
Oph IRS 48



van der Marel et al. (2013)

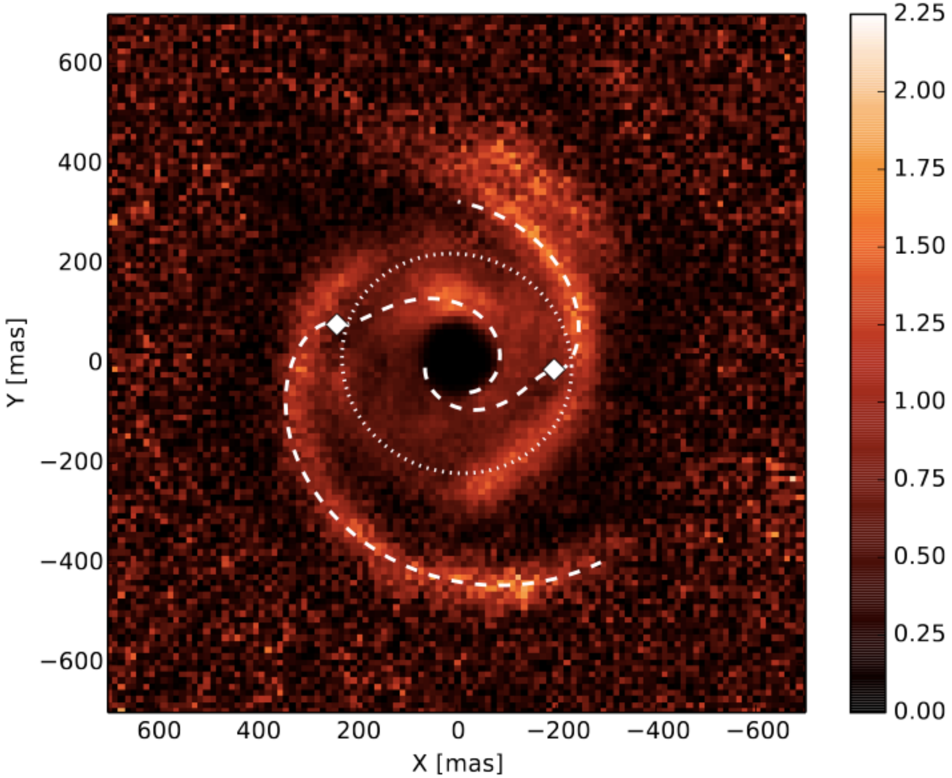
Observational Evidence: Spirals

SAO 206462



Muto et al. (2012)

MWC 748



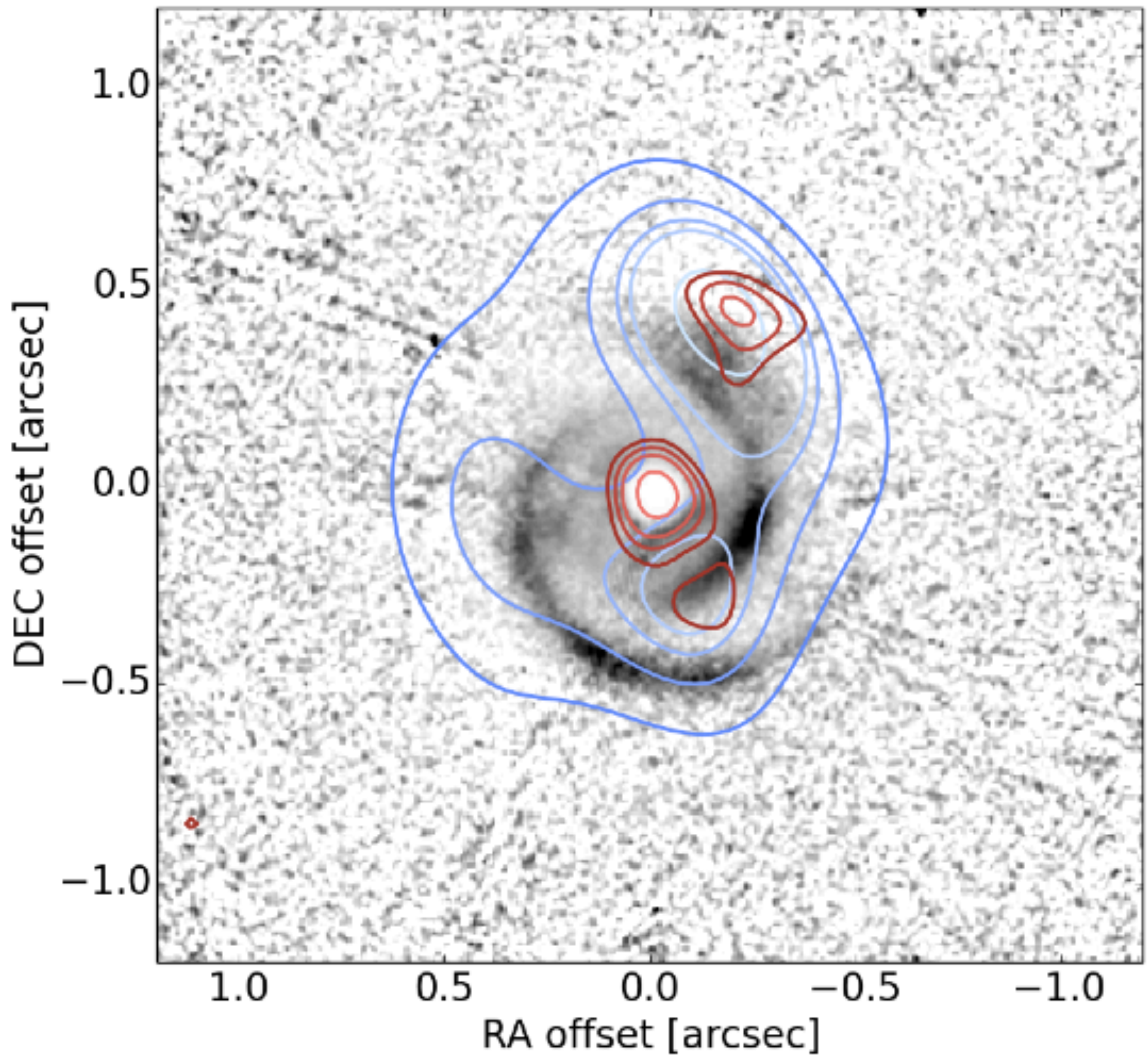
Benisty et al. (2015)

SPHERE-ALMA-VLA overlay of MWC 758

SPHERE (μm)

ALMA (~ mm)

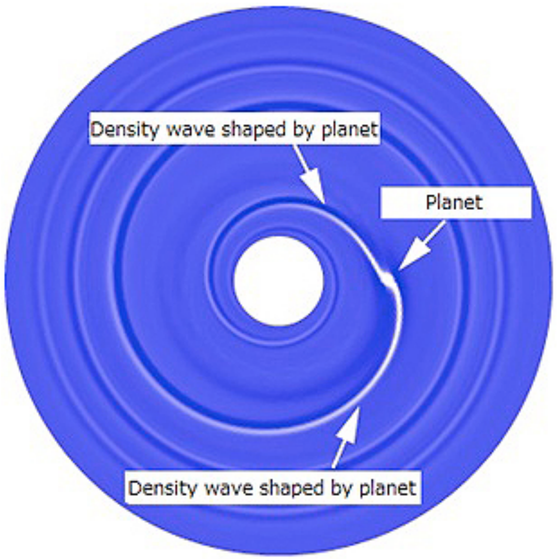
VLA (cm-m)



Marino et al. (2015)

Spiral arm fitting leads to problems

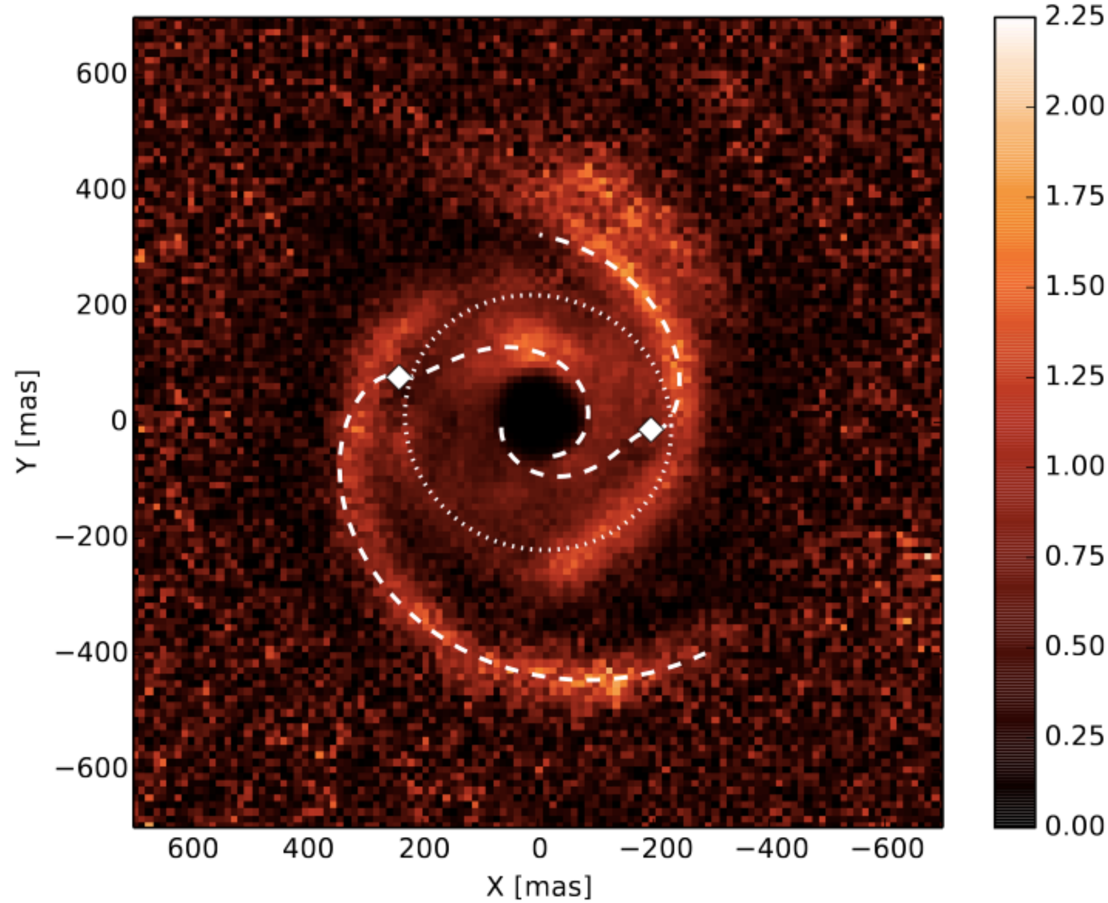
Analytical spiral fit



$$\theta(r) = \theta_c + \frac{\mathrm{sgn}(r - r_c)}{h_c} \times \left\{ \left(\frac{r}{r_c}\right)^{1+\beta} \left[\frac{1}{1+\beta} - \frac{1}{1-\alpha+\beta} \left(\frac{r}{r_c}\right)^{-\alpha} \right] - \left(\frac{1}{1+\beta} - \frac{1}{1-\alpha+\beta} \right) \right\},$$

Rafikov (2002)
Muto et al. (2012)

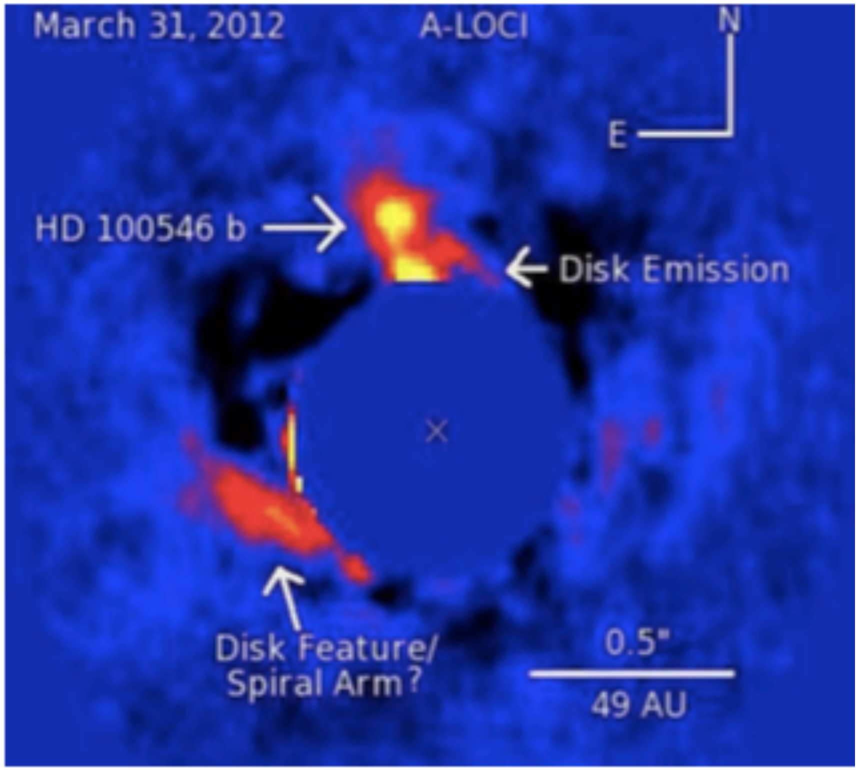
Spirals are **too wide**,
hotter (300K) than ambient gas (50K).



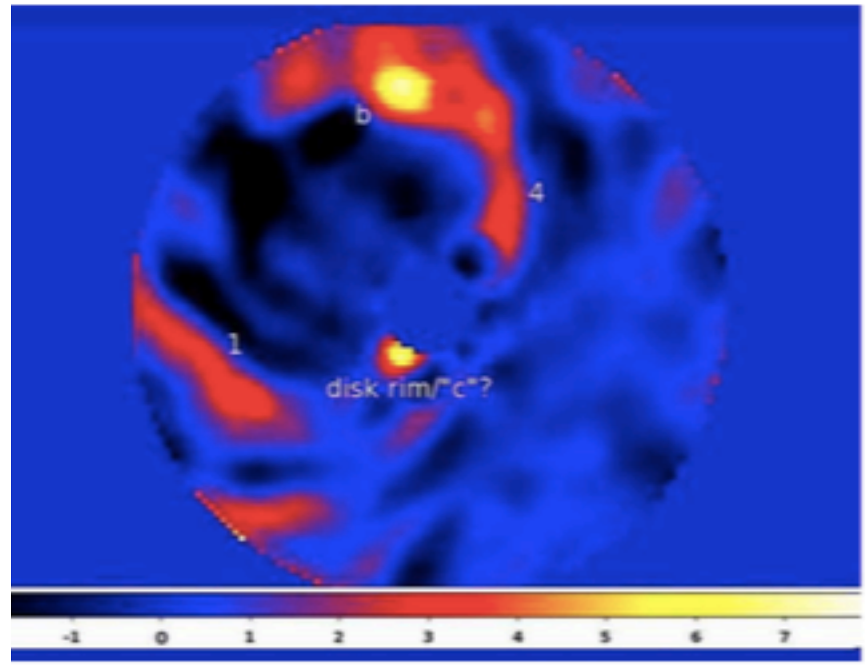
Benisty et al. (2015)

The strange case of thermal emission in HD 100546

L band (~3.5 μm)

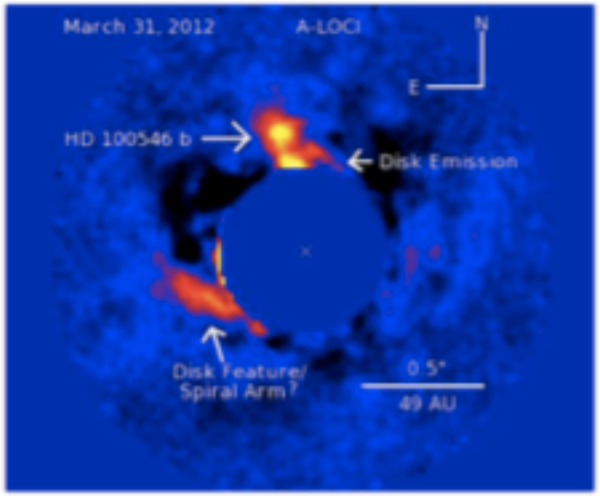


H band (~1.6 μm)

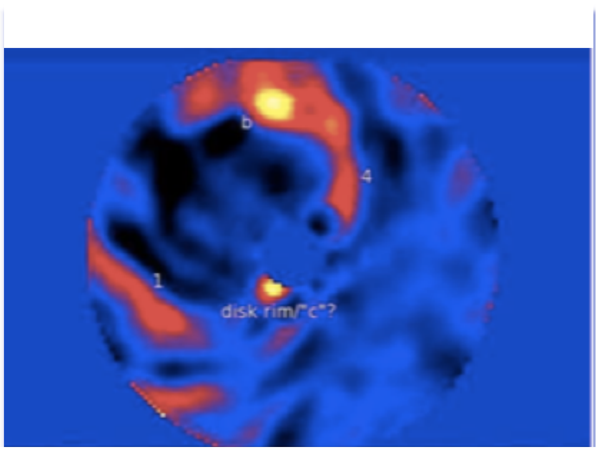


Currie et al. (2014), Currie et al. (2015)

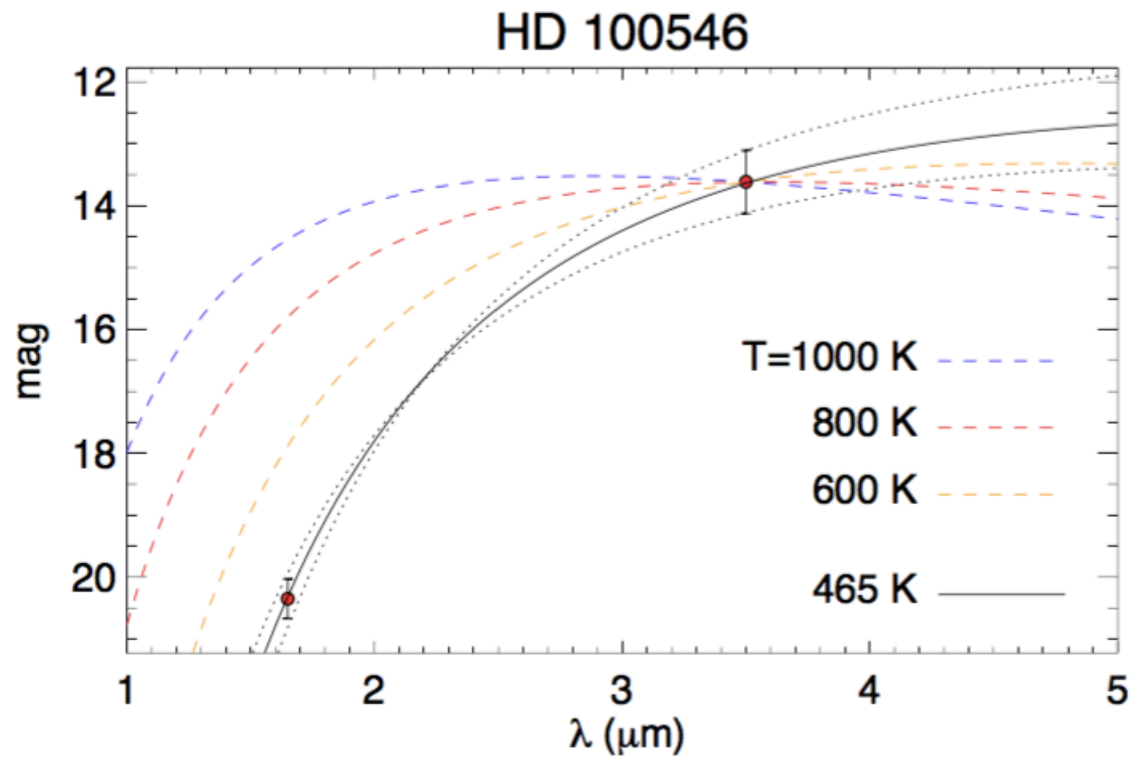
Pinning down the temperature



L band

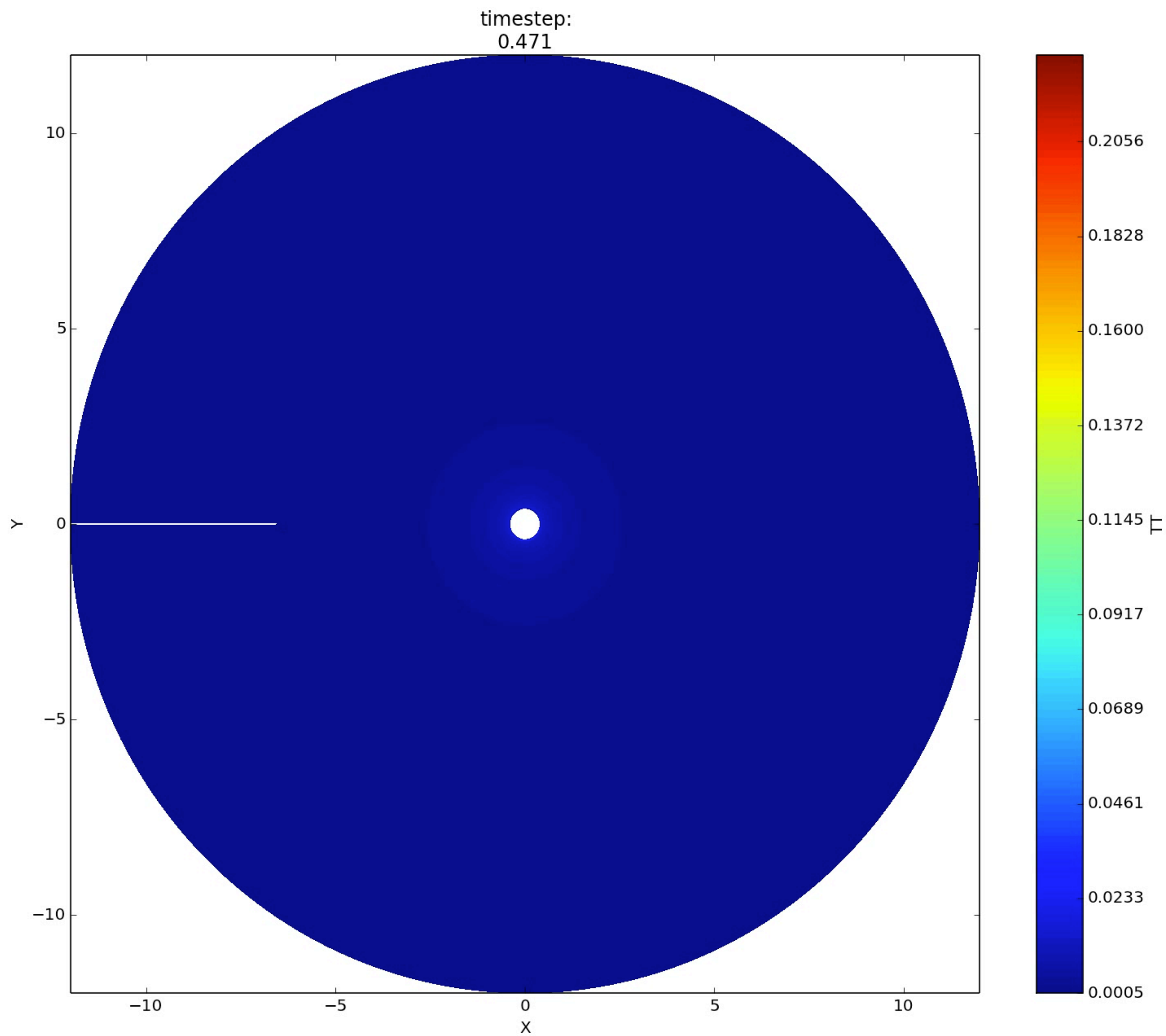


H band



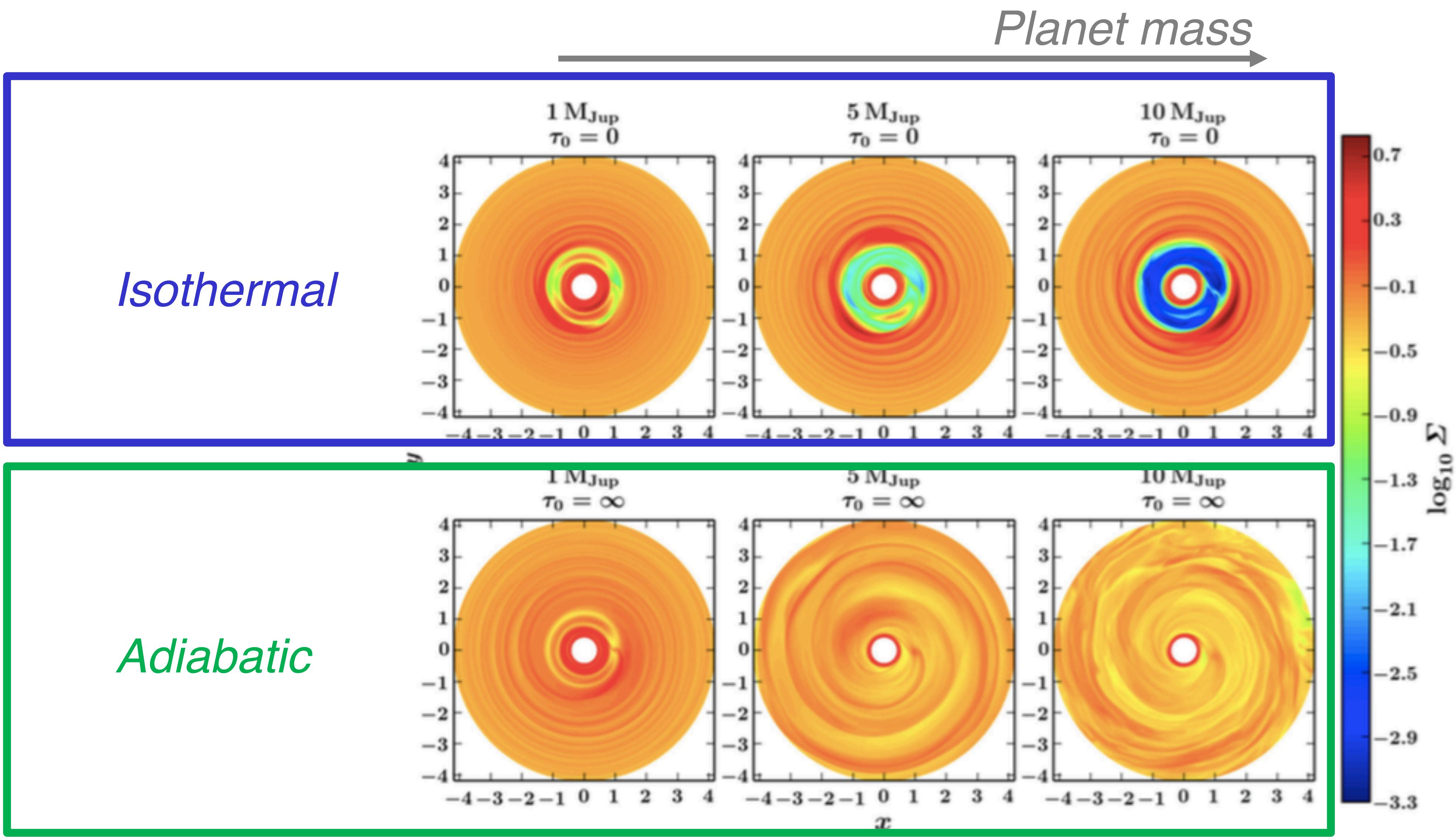
Lyra et al. (2016)

Planet-driven turbulence



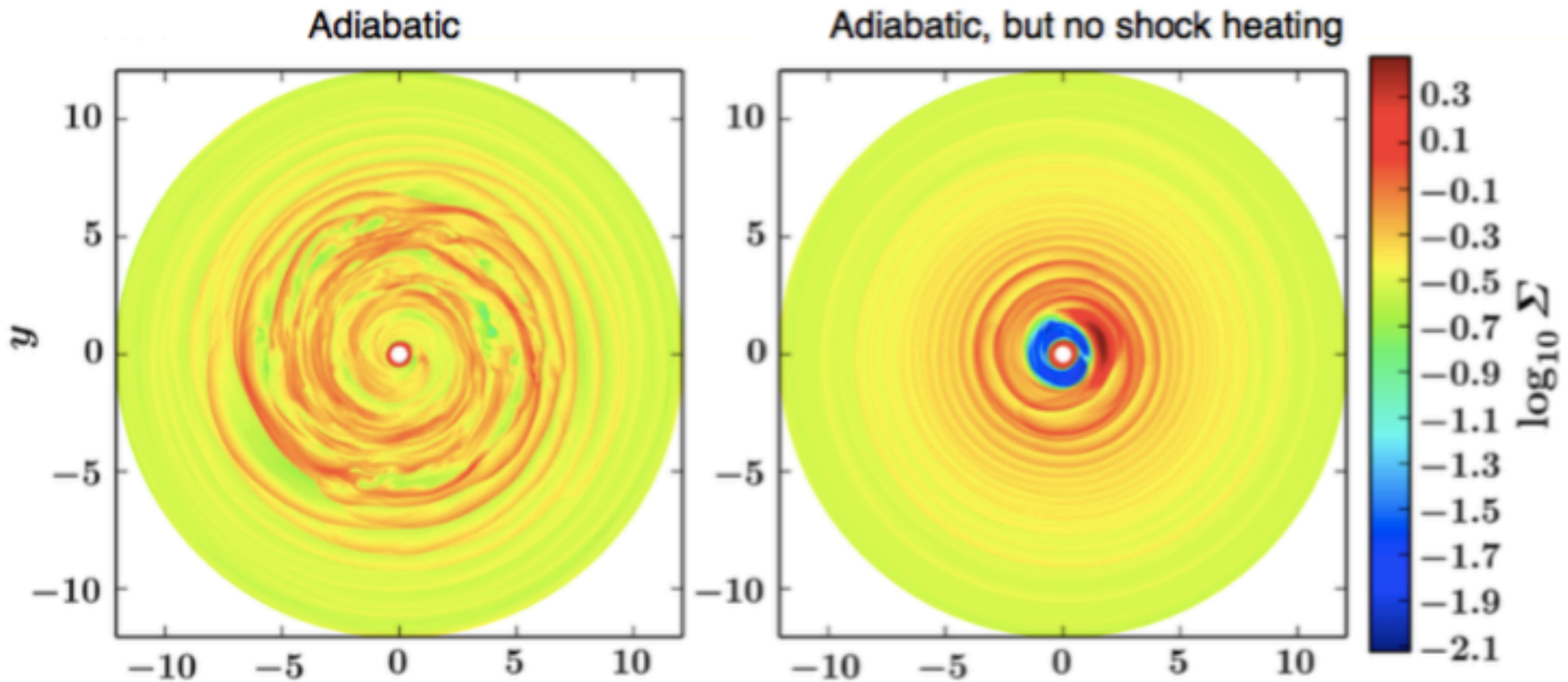
Richert et al. (2015)

Turbulence in high-mass planets in adiabatic disks



Richert et al. (2015)

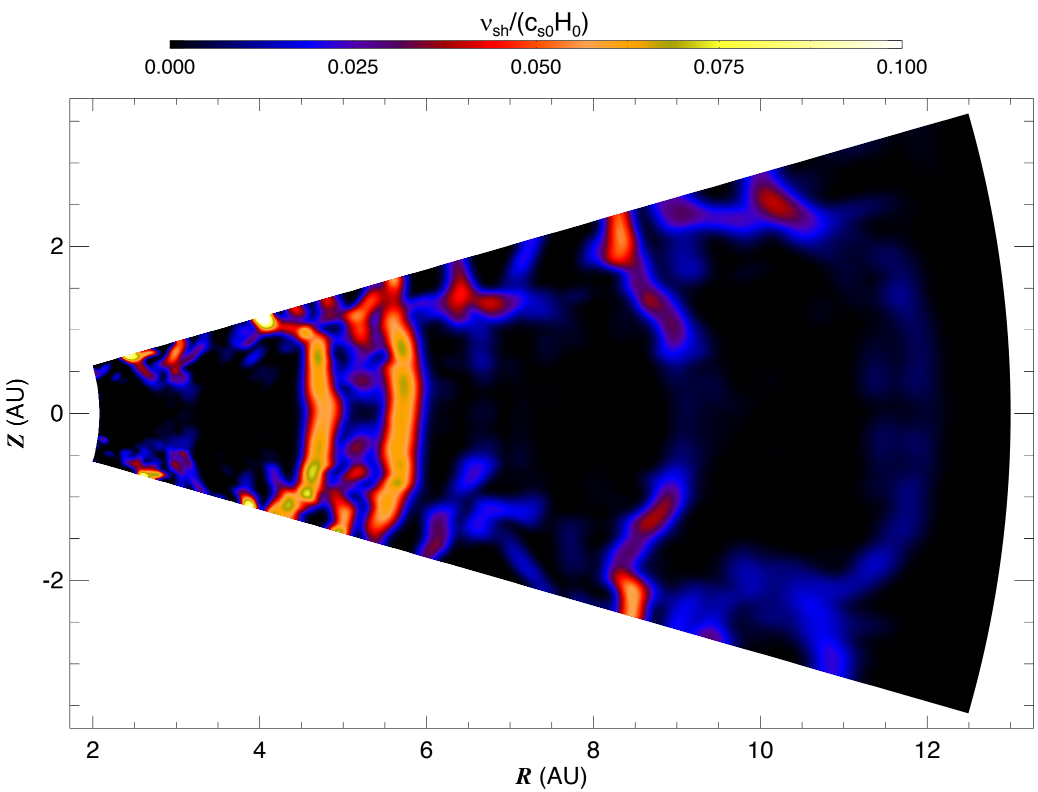
The energy source: shock heating!



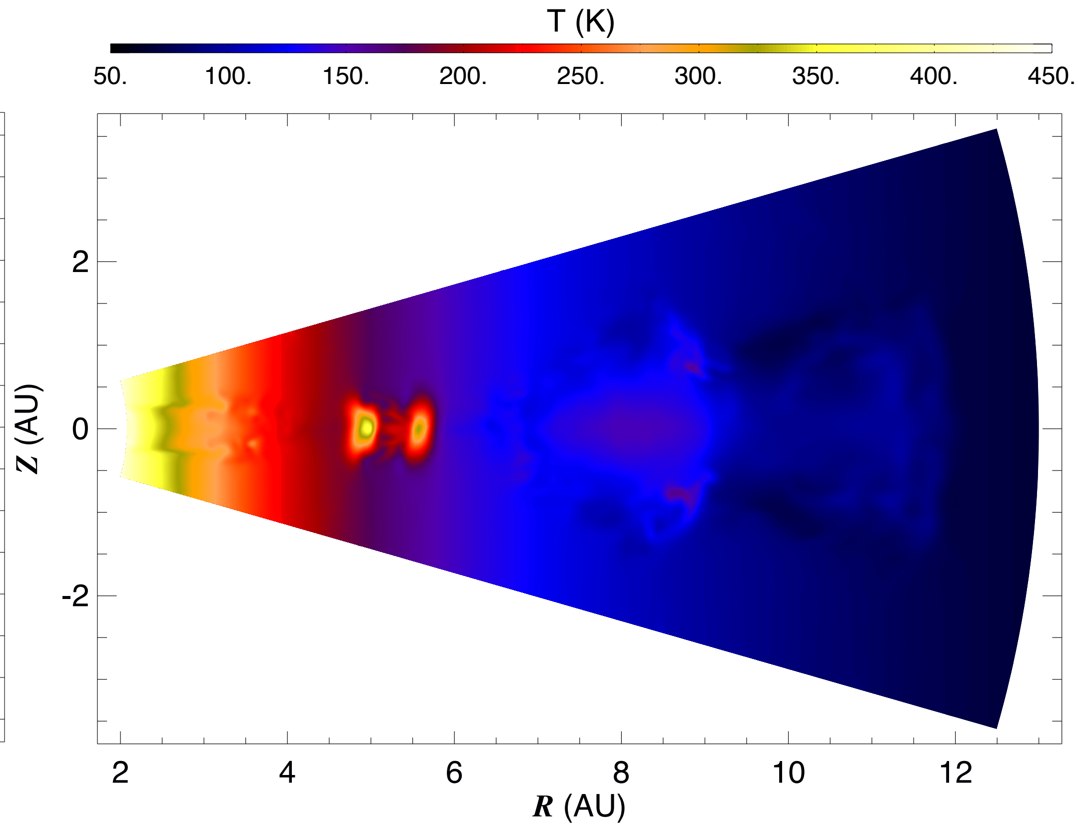
Richert et al. (2015)

3D: Shock bores

Shocks (velocity convergence)

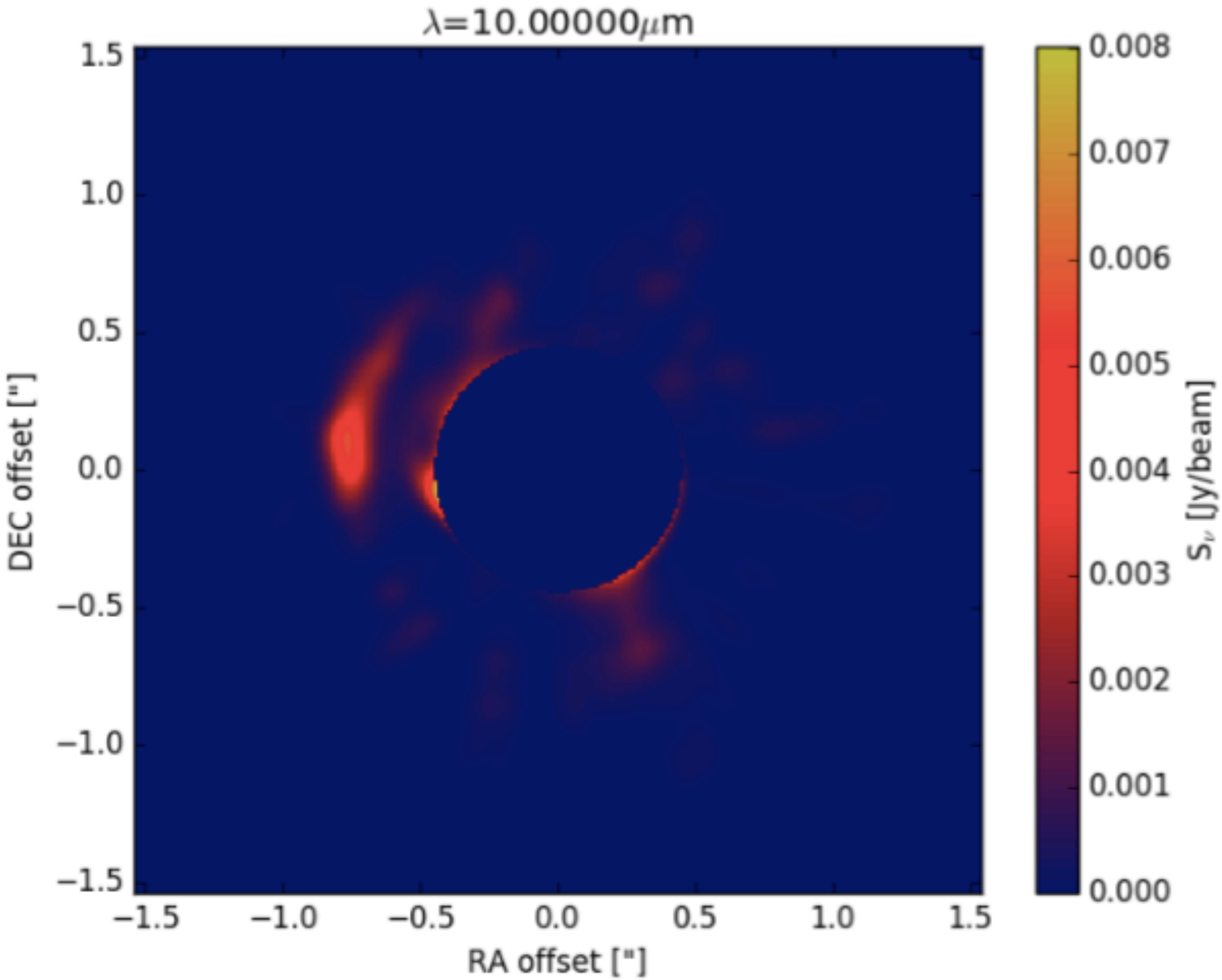


Temperature



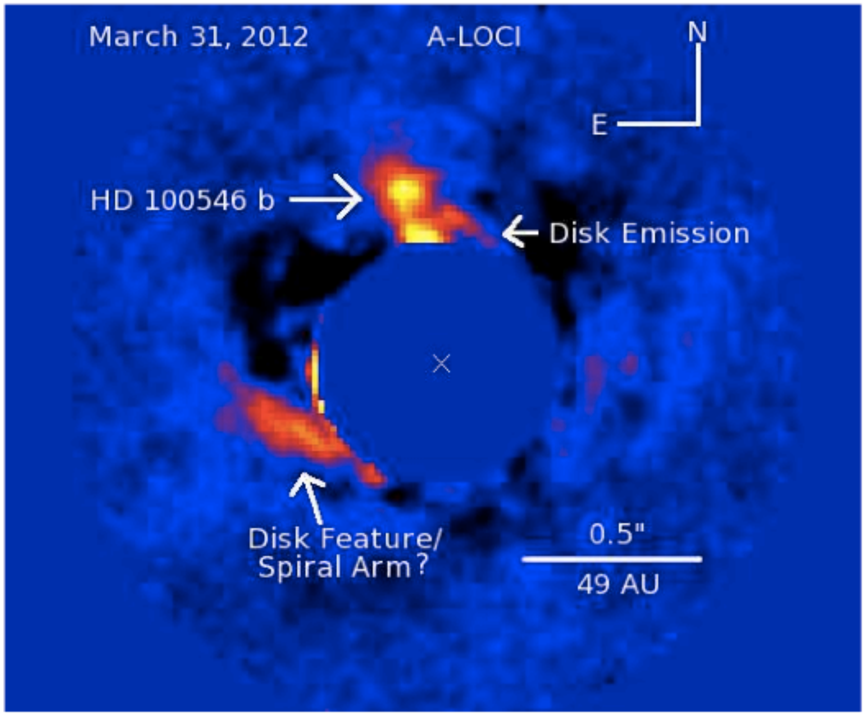
Lyra et al. (2016)

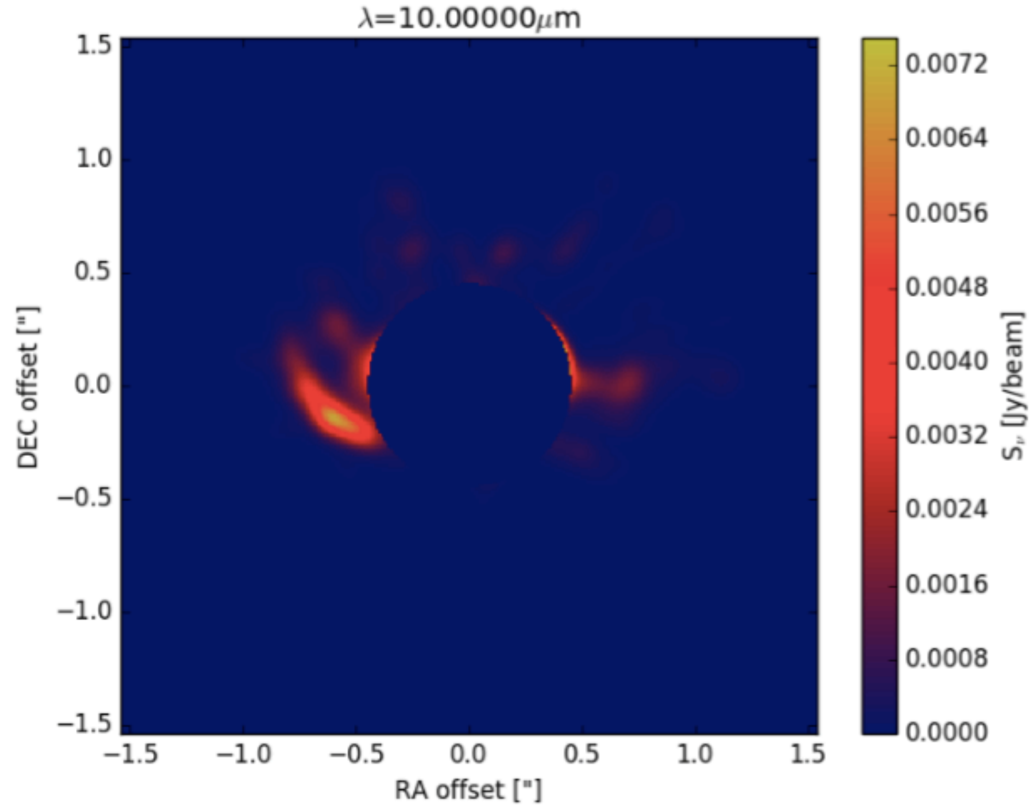
Synthetic image



Hord et al. (2017)

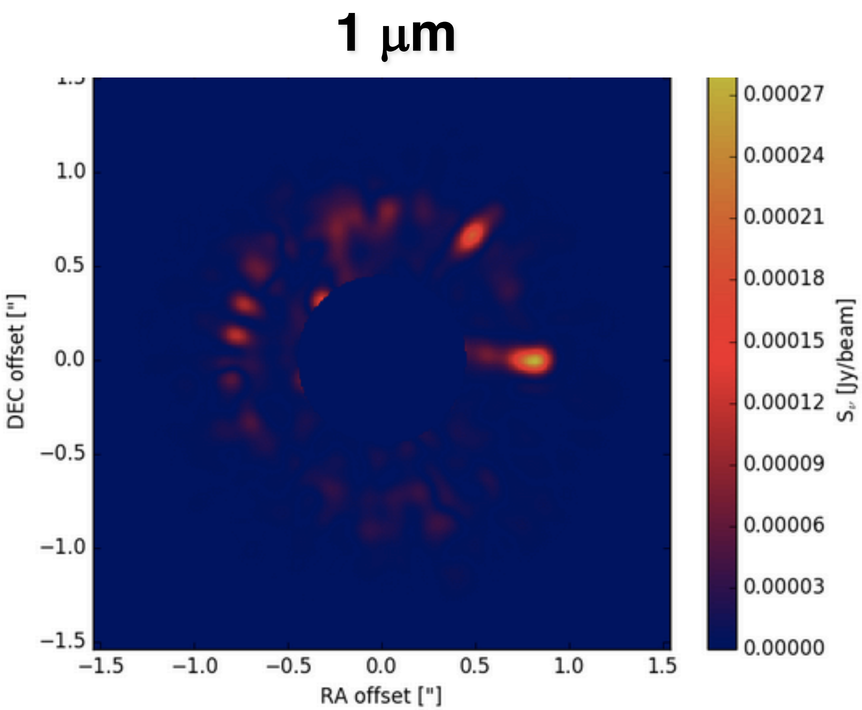
Observation vs Synthetic Image

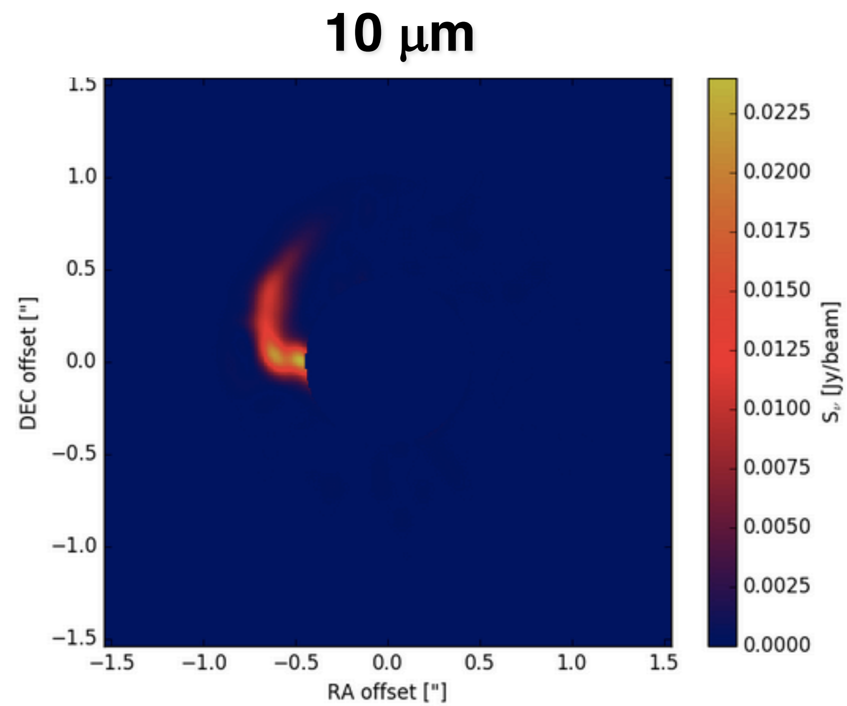




Hord et al. (2017)

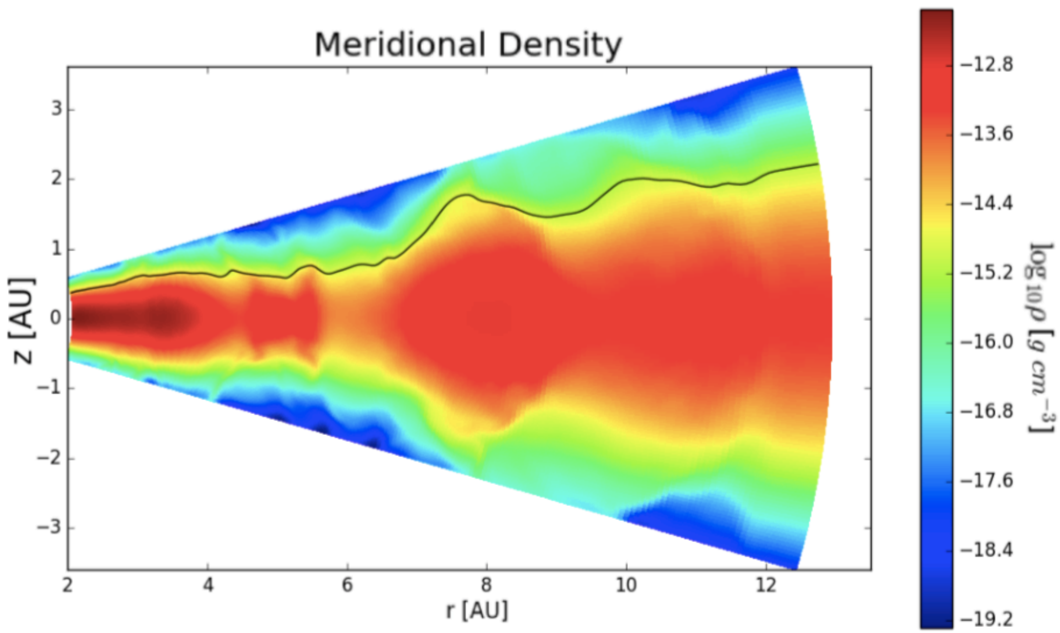
Effect of shocks alone

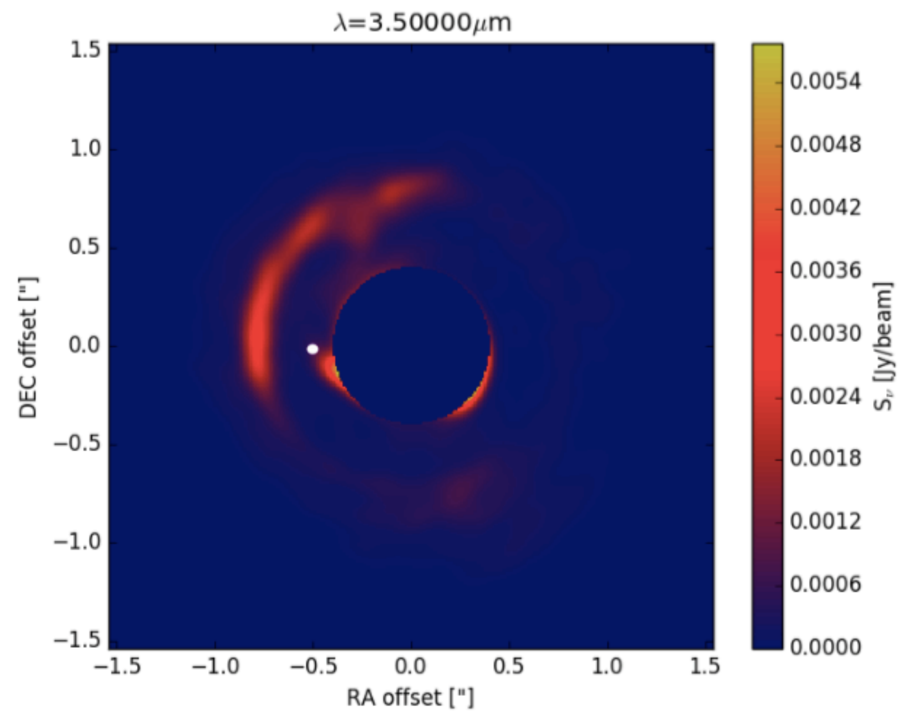




Hord et al. (2017)

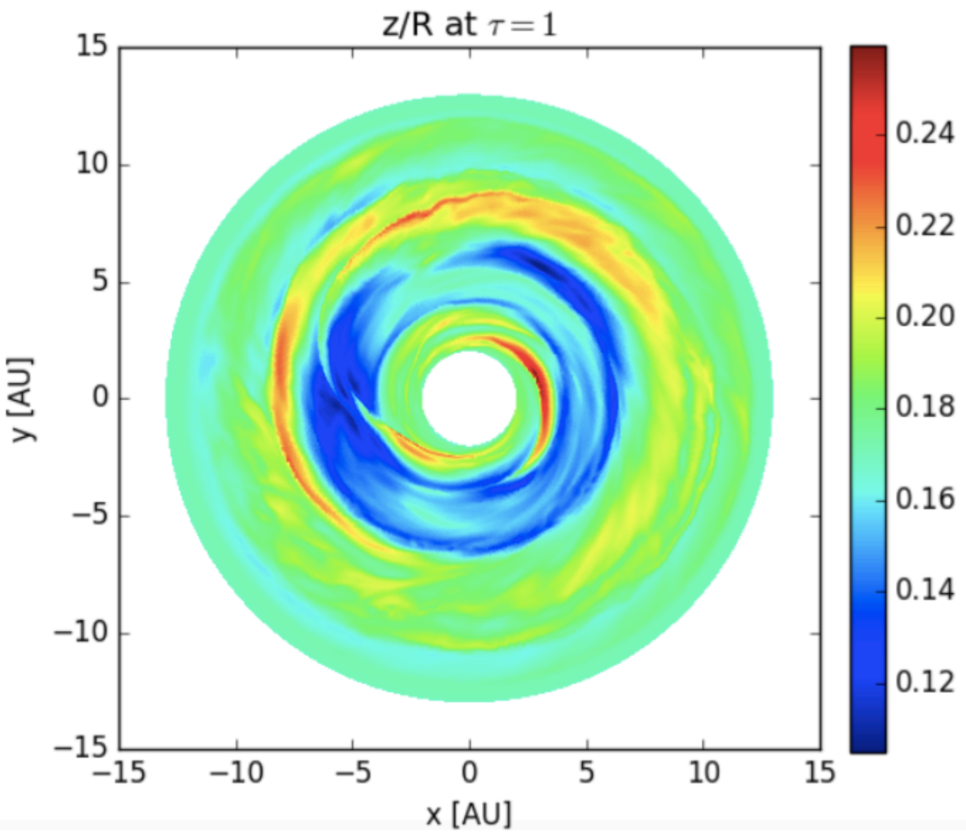
Scattering – A puffed up outer gap

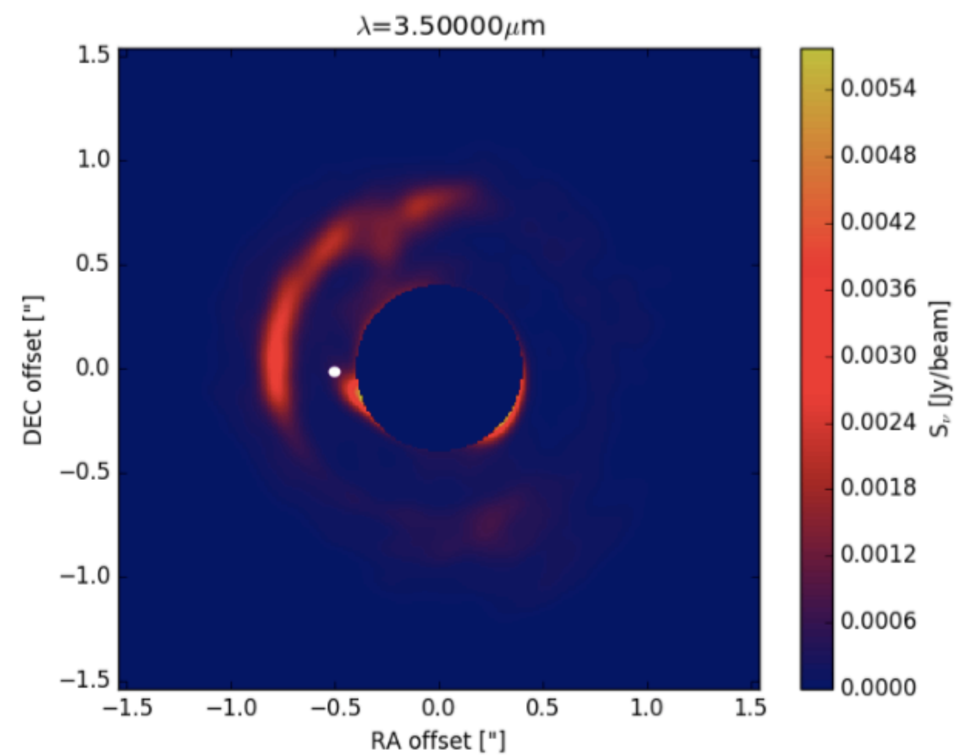




Hord et al. (2017)

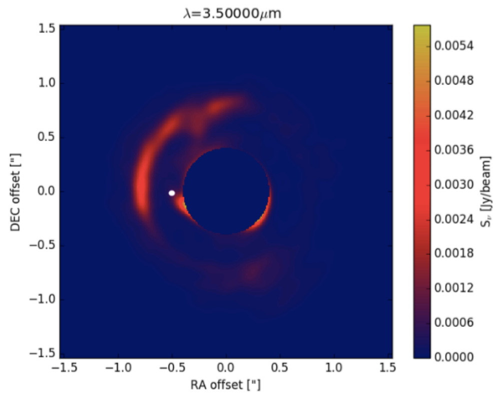
Scattering

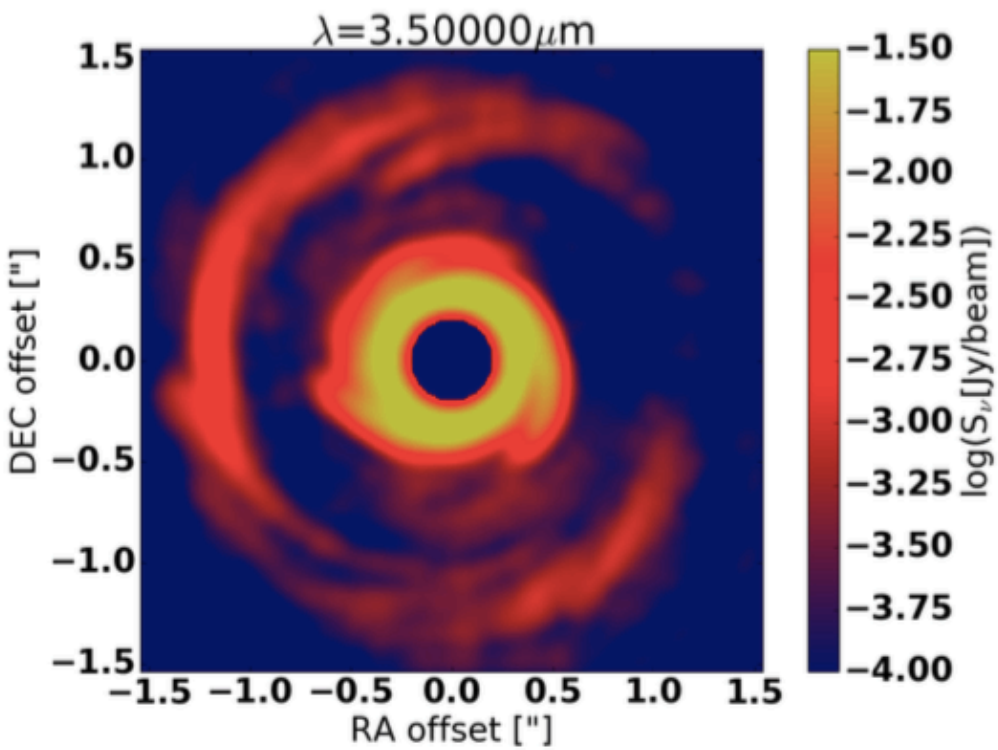


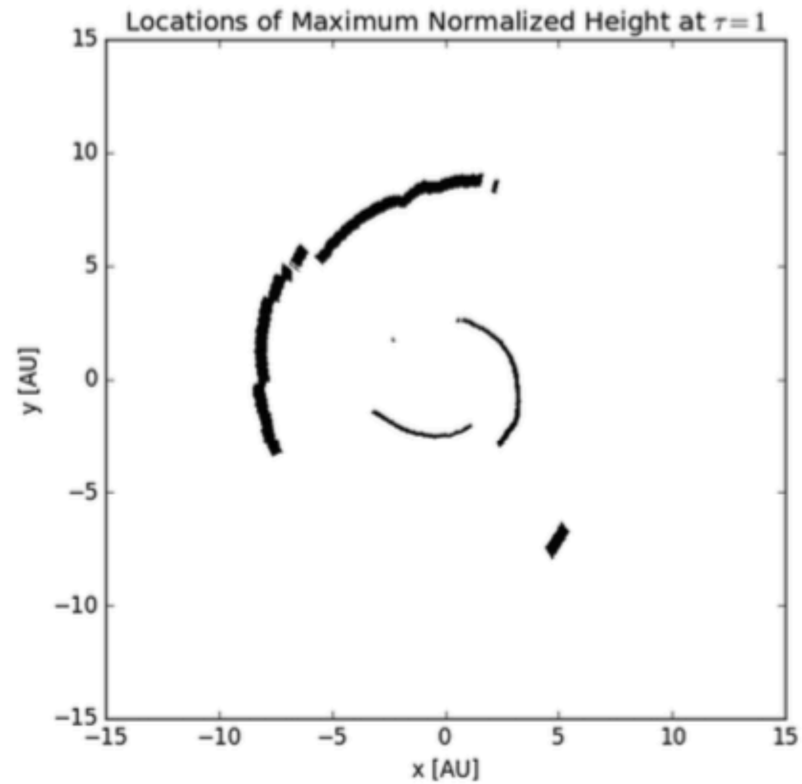


Hord et al. (2017)

We see what is not in the shadow of the inner disk spirals





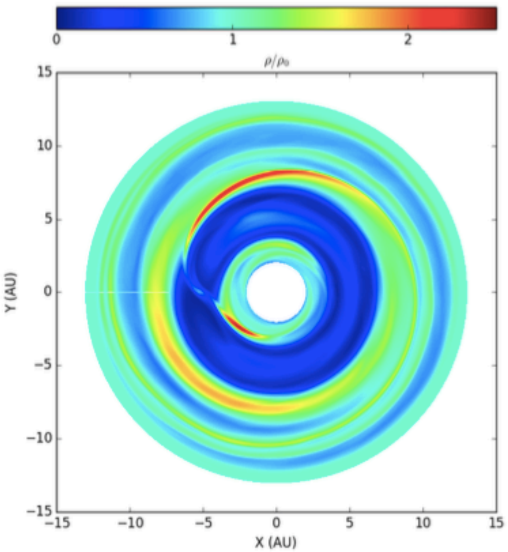


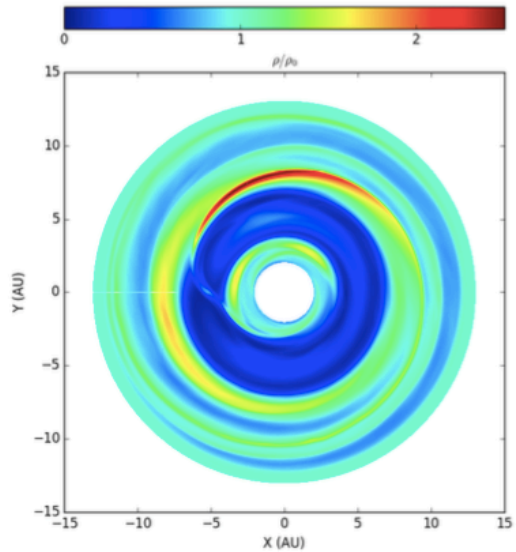
Hord et al. (2017)

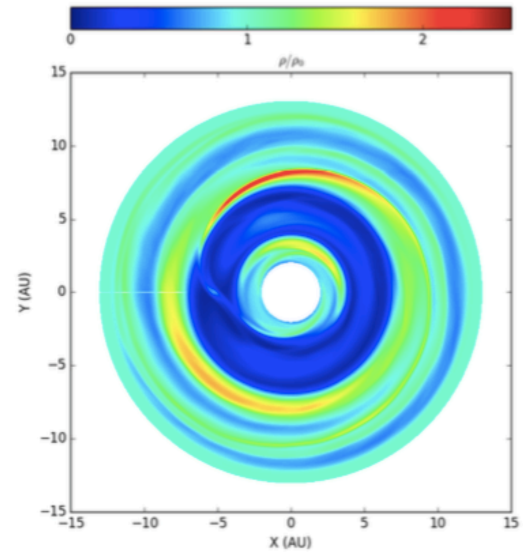
The pattern is stationary

T = 39 orbits | T = 40 orbits | T = 41 orbits

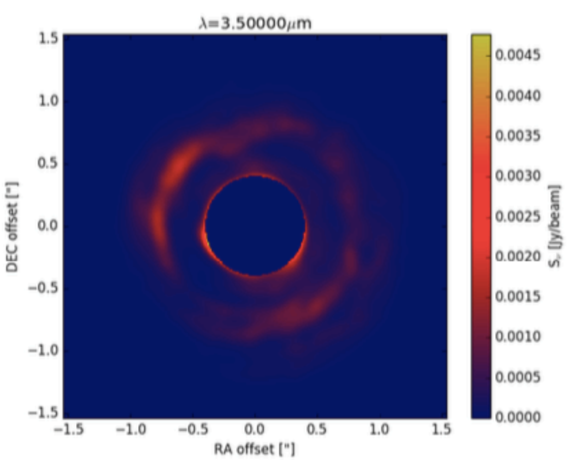
Density

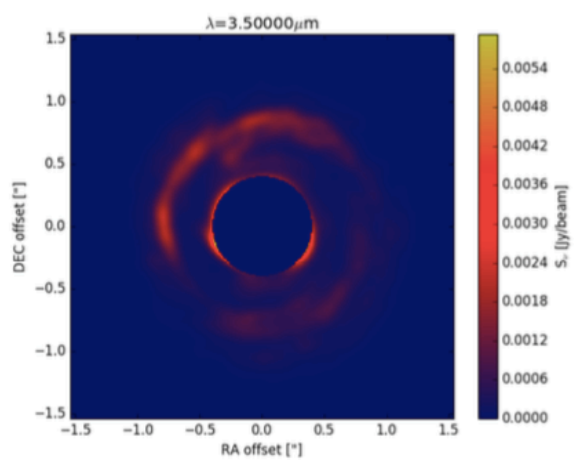


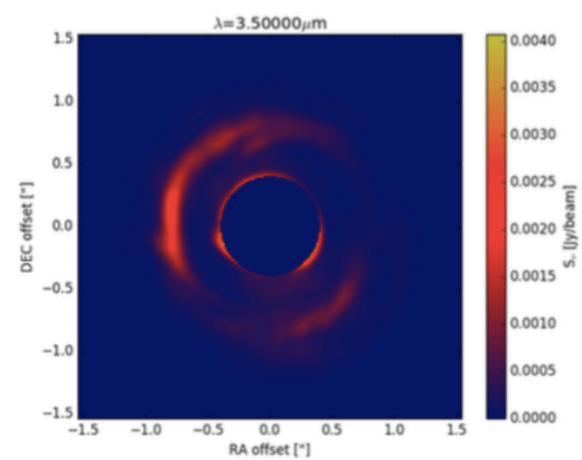




Intensity

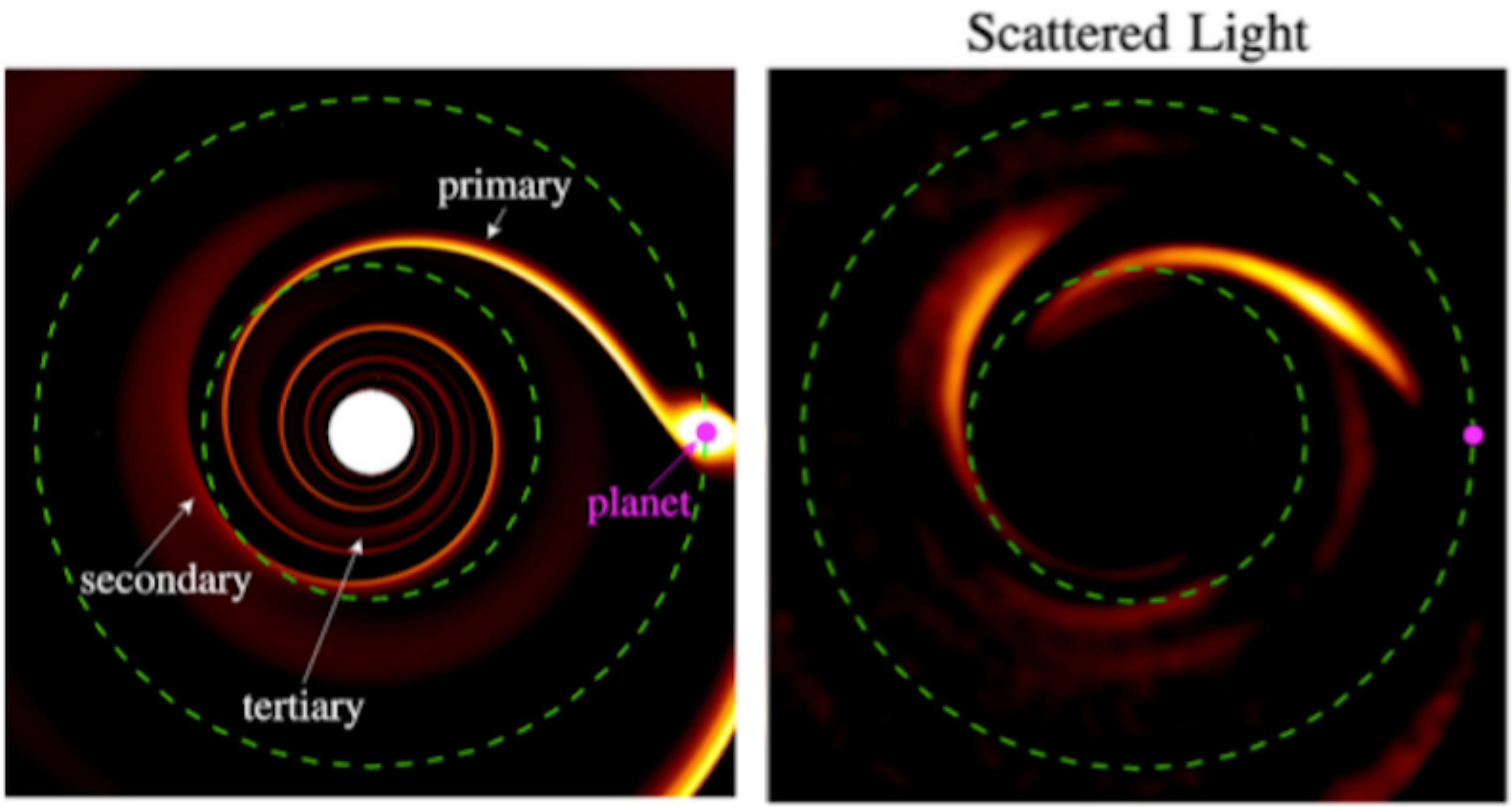






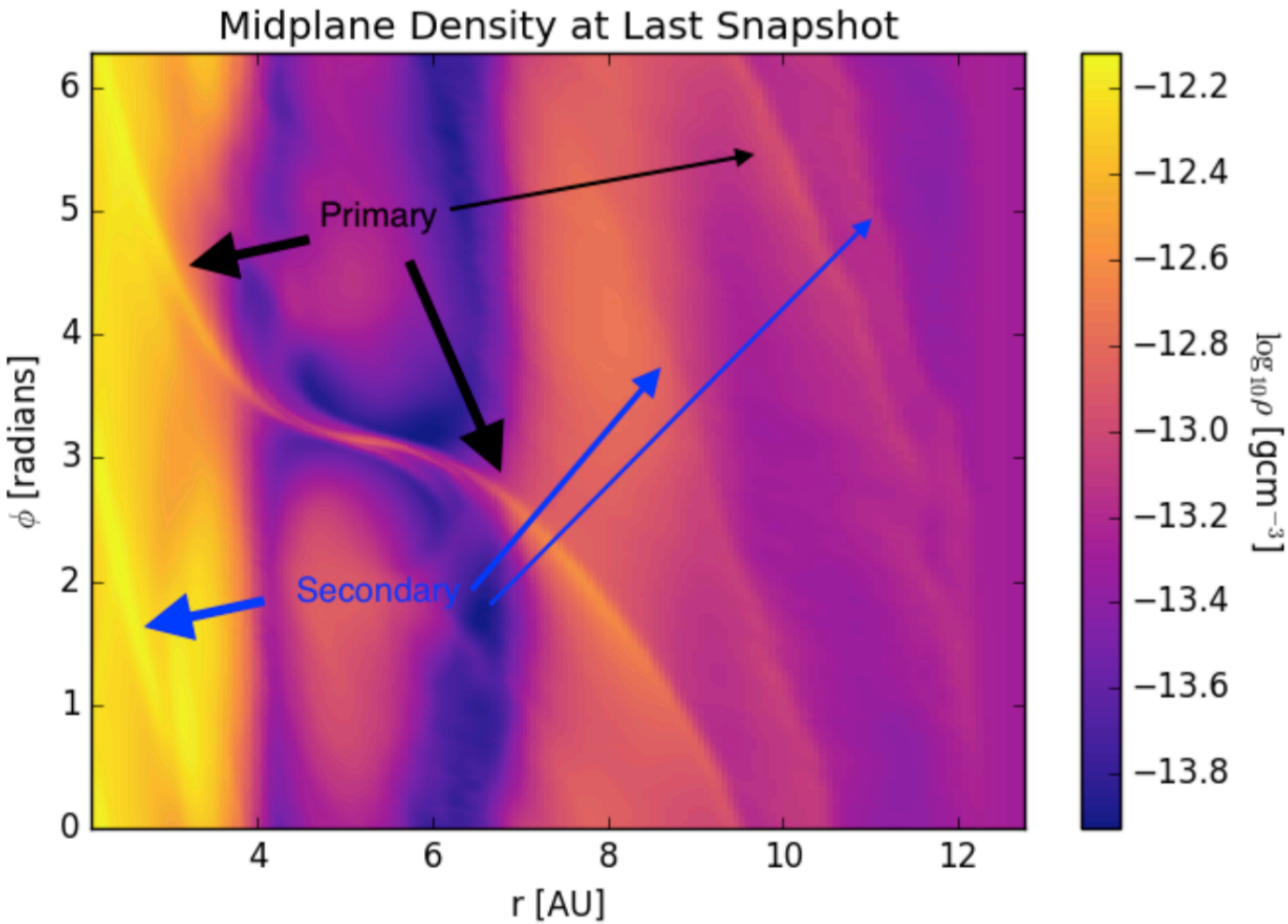
Hord et al. (2017)

Primary and Secondary spiral arms



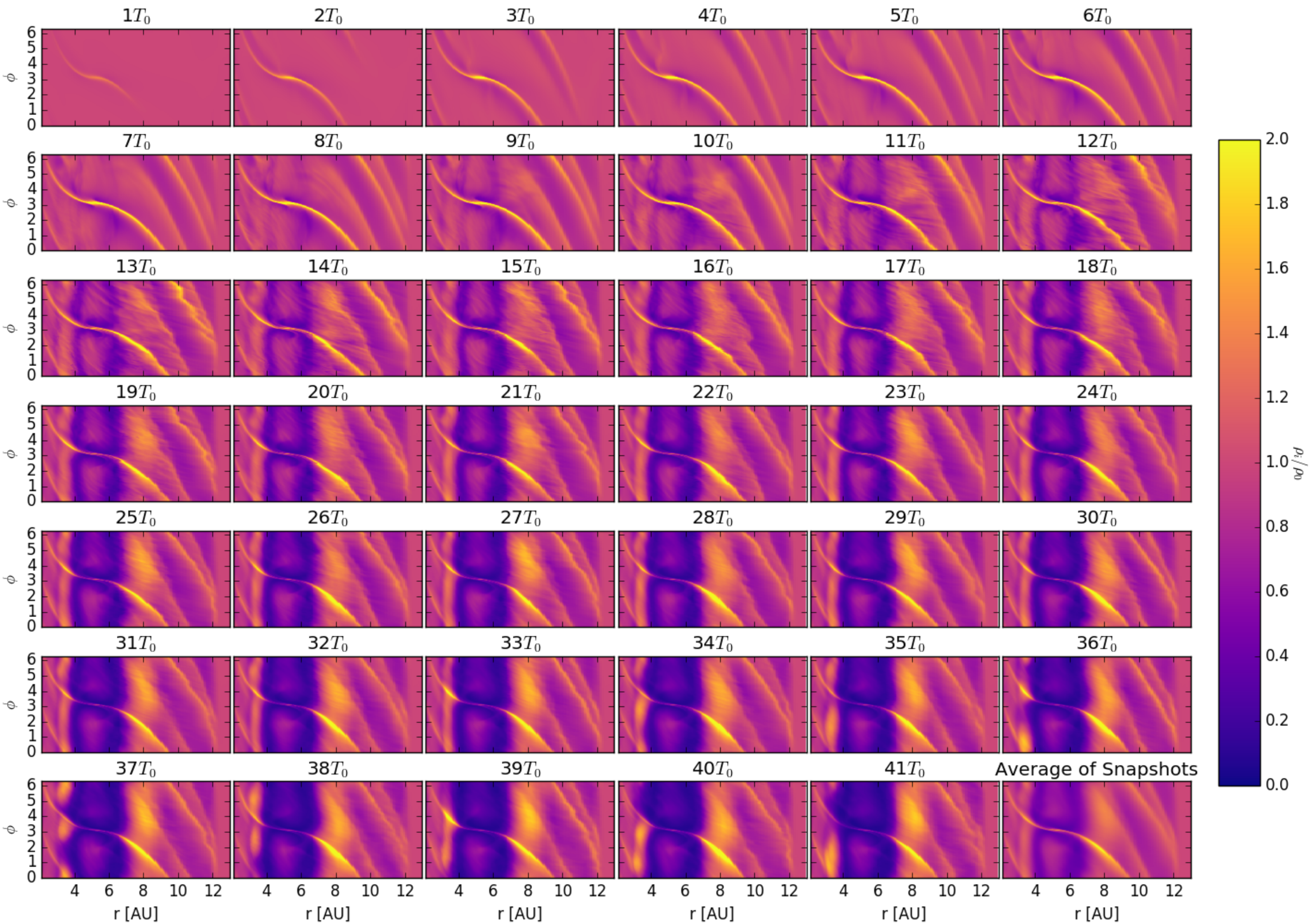
Dong et al. (2015)

Primary and Secondary spiral arms



Hord et al. (2017)

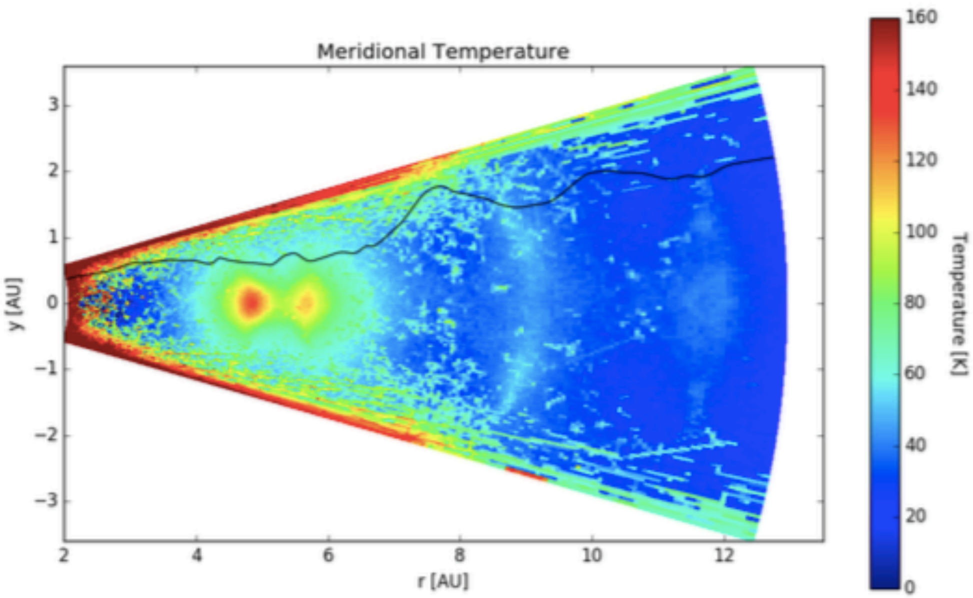
The raised feature has its origins in a secondary spiral arm

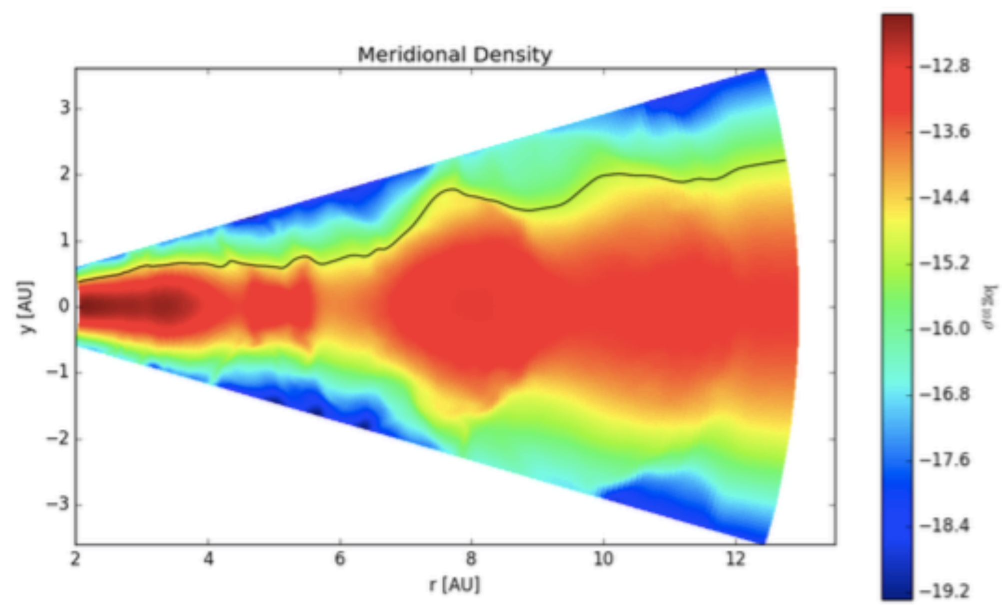


Hord et al. (2017)

Conclusions

- 3D radiation-hydro models give results widely different than 2D isothermal
- Planet-induced shocks modify disk structure
- Hot lobes near high-mass planets in high resolution
- Planets puff up their outer gaps – visible in scattered light





Conclusions

- 3D radiation-hydro models give results widely different than 2D isothermal
- Planet-induced shocks modify disk structure
- Hot lobes near high-mass planets in high resolution
- Planets puff up their outer gaps – visible in scattered light