Planetary shocks and spirals in transition disks

Wladimir Lyra

California State University, Northridge

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Blake Hord (Dobbs Ferry High School, Stanford University),

Alex Richert (Penn State University)

Mario Flock (JPL),

Neal Turner (JPL),

Aaron Boley (University of British Columbia)

Mordecai-Mark Mac Low (AMNH)

Satoshi Okuzumi (Tokyo Tech)

NUMPDI, Nov 23rd, 2017

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Faculty Position in Astrophysics

Submission Information

Publish Date: Saturday, November 11, 2017
Archive Date: Saturday, December 9, 2017
To event remaining 15 days

Job Summary

Job Category: Faculty Positions (tenure and tenure-track)
Institution Classification/Type: Large Academic
Institution/Company: California State University Northridge
Department Name: Physics & Astronomy
Street Line 1: 18111 Nordhoff Street
City: Northridge
State/Province: California
Zip/Postal: 91330
Country: United States of America

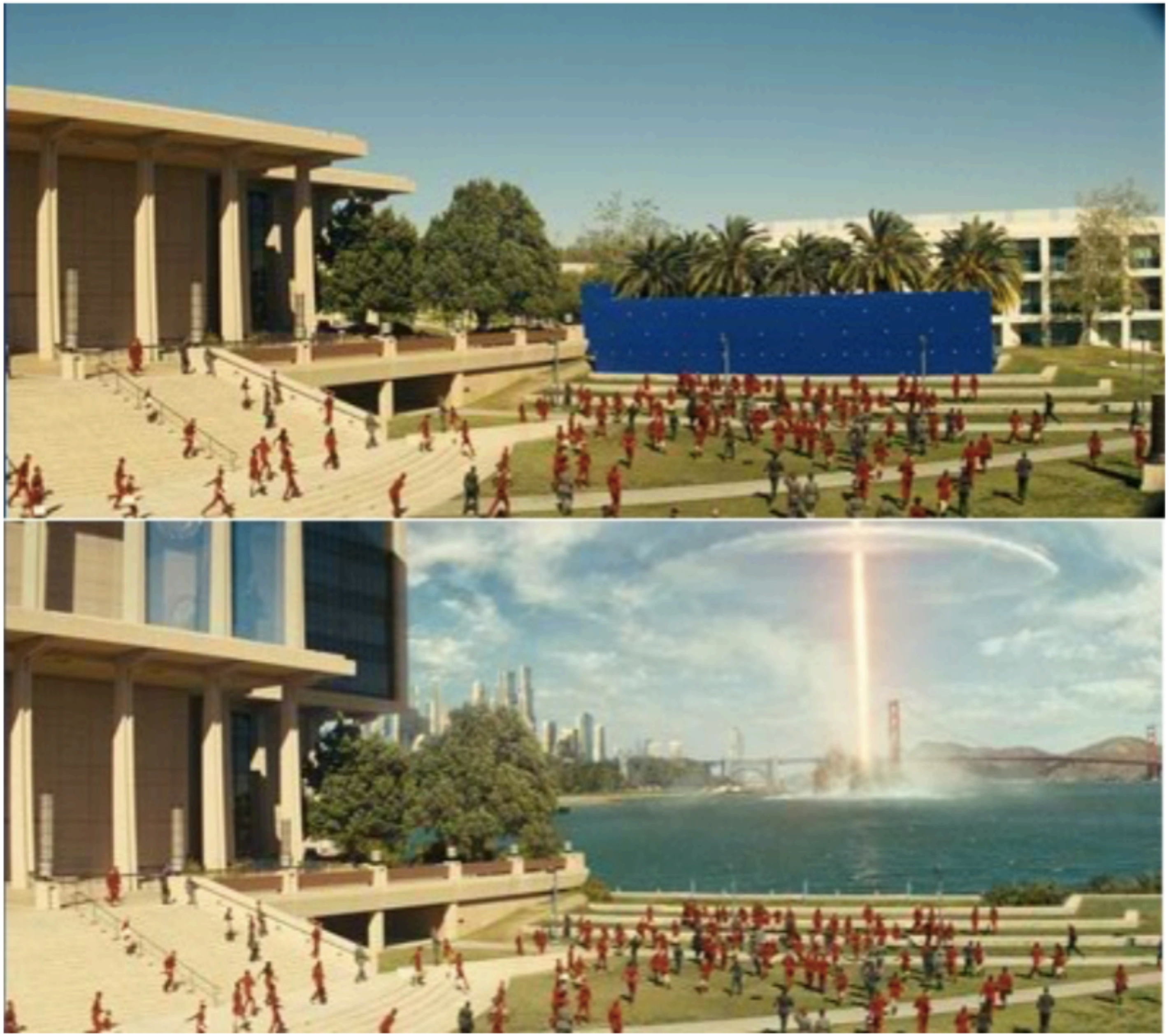
Announcement

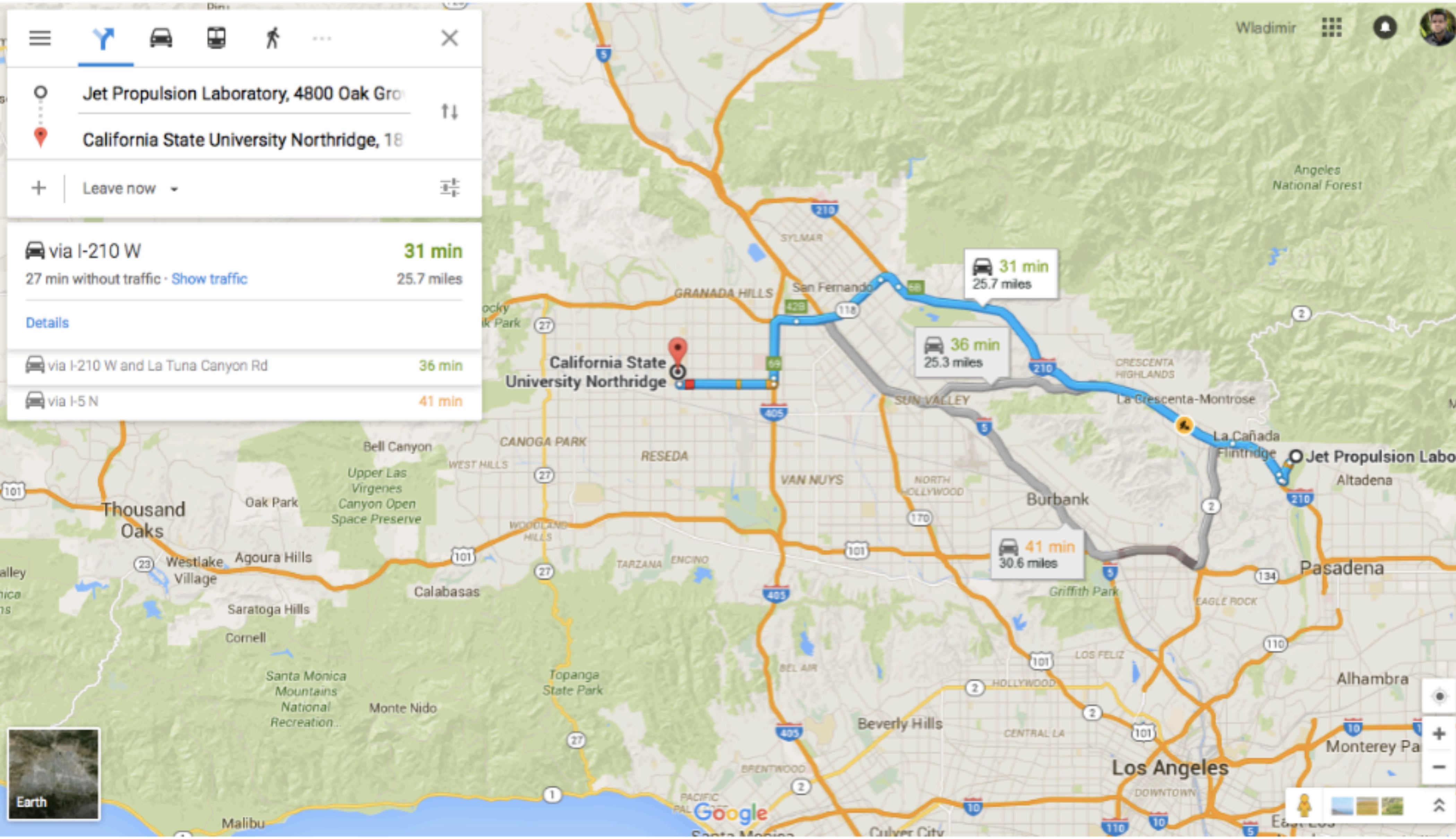
Job Announcement Text:

Faculty Position in Astrophysics

The Department of Physics and Astronomy at California State University, Northridge, invites applications for a tenure-track position to begin in Fall 2018 at the Assistant Professor level in observational astrophysics. Applicants should have a Ph.D. degree, preferably with postdoctoral experience in the research areas of exoplanets and in complementing research areas of

CSUN
aka Starfleet Academy





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Monte Nido
Topanga State Park
Malibu
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NUMPDI, Oct 23th, 2017

The Astrophysical Journal, 804:95 (11pp), 2015 May 10 doi:10.1088/0004-637X/804/2/95

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

Alexander J. W. Richert[1,2,3,4], Wladimir Lyra[3,4,7], Aaron Boley[5], Mordecai-Mark Mac Low[6], and Neal Turner[3]
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[3] Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA; wlyra@jpl.nasa.gov, neal.j.turner@jpl.nasa.gov
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Received 2014 March 31; accepted 2015 March 31; published 2015 May 6

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

Richert et al. (2015)

The Astrophysical Journal, 817:102 (9pp), 2016 February 1 doi:10.3847/0004-637X/817/2/102

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

Wladimir Lyra[1,2,3], Alexander J. W. Richert[4], Aaron Boley[5], Neal Turner[2], Mordecai-Mark Mac Low[6,7], Satoshi Okuzumi[2,8], and Mario Flock[2]
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[8] Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8551, Japan; okuzumi@geo.titech.ac.jp
Received 2015 September 24; accepted 2015 November 12; published 2016 January 26

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 p
tempting to suspect that planetary perturbers are resp
not free of problems. The observed spirals have large p
effectively unpolarized, implying thermal emission of

Lyra et al. (2016)

The Astrophysical Journal, 849:164 (15pp), 2017 November 10 https://doi.org/10.3847/1538-4357/aa8fcf

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], and Mordecai-Mark Mac Low[4]
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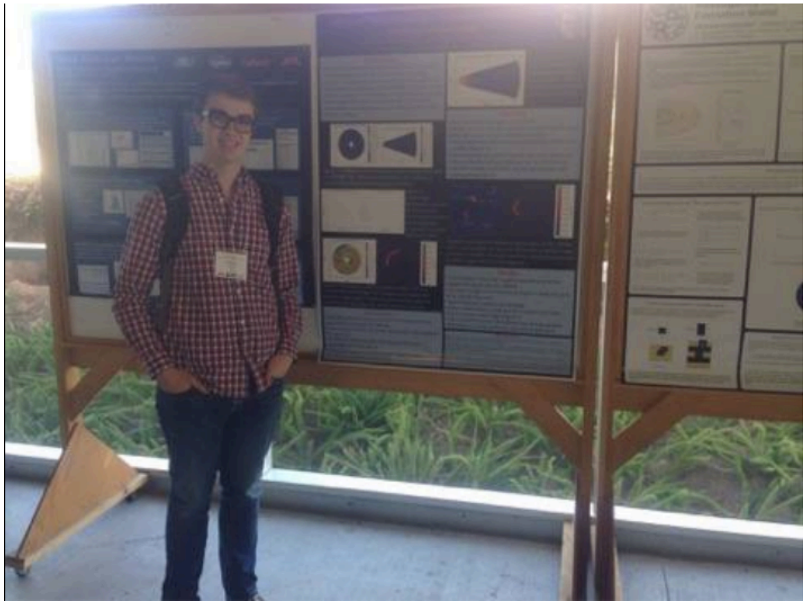
Abstract

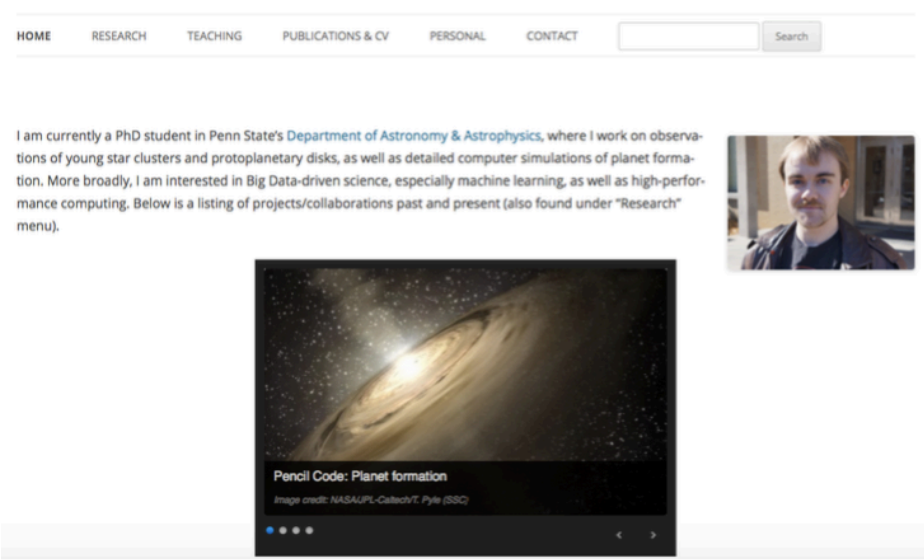
Recent observations of the protoplanetary disk around the Herbig Be star HD 100546 show two bright features in infrared (H and L' bands) at about 50 au,with one so far unexplained. We explore the observational signatures of a high-mass planet causing shock heating in order to determine if it could be the source of the unexplained infrared feature 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, including volumetric heating. A stronger shock heating rate by a factor of 20 would be necessary to qualitatively reproduce the morphology of the second infrared source. Instead, we find that the outer edge of the gap carved by the planet heats up by about 50% relative to the initial reference temperature, which leads to an increase in the scale height. The bulge is illuminated by the central star, producing a lopsided feature in scattered light,

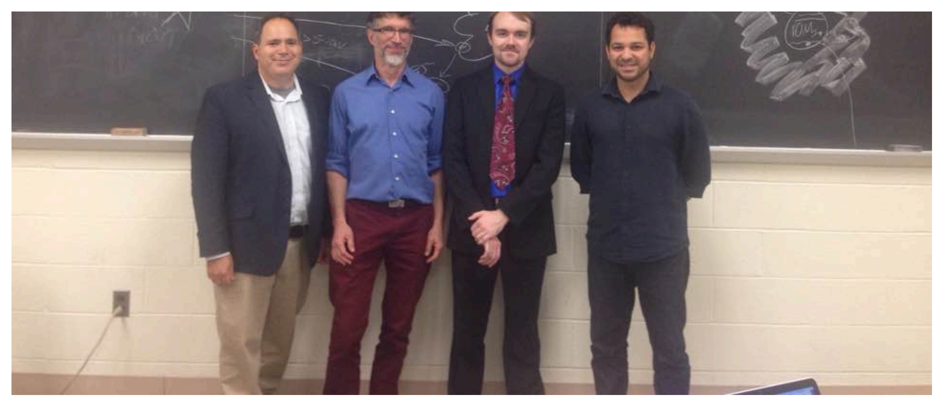
Hord et al. (2017)

Blake Hord

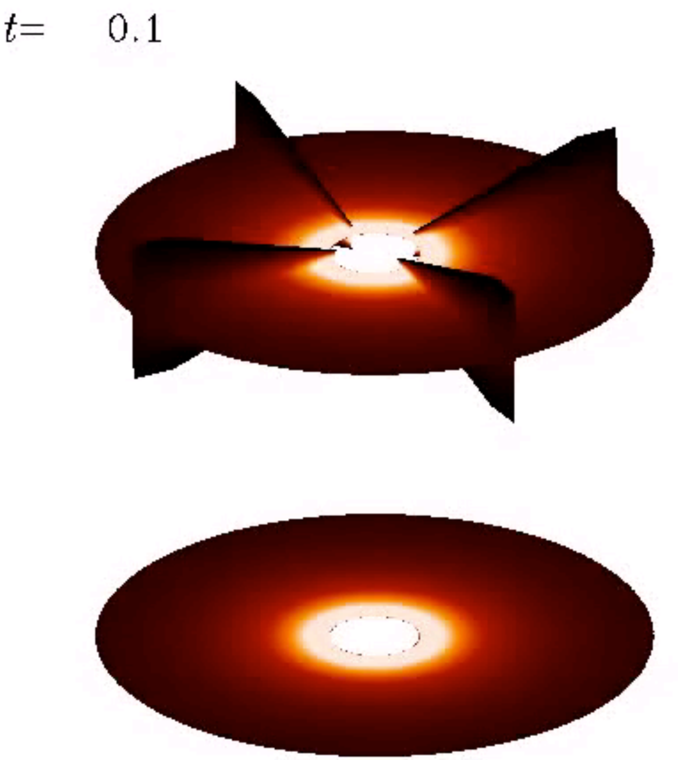


Alex Richert





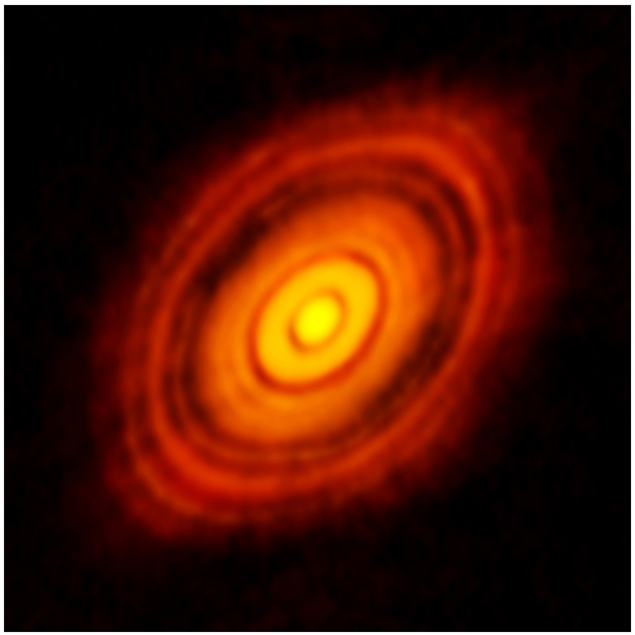
Planet-disk interaction model predictions: gaps, spirals, and vortices.



(Lyra et al. 2009b)

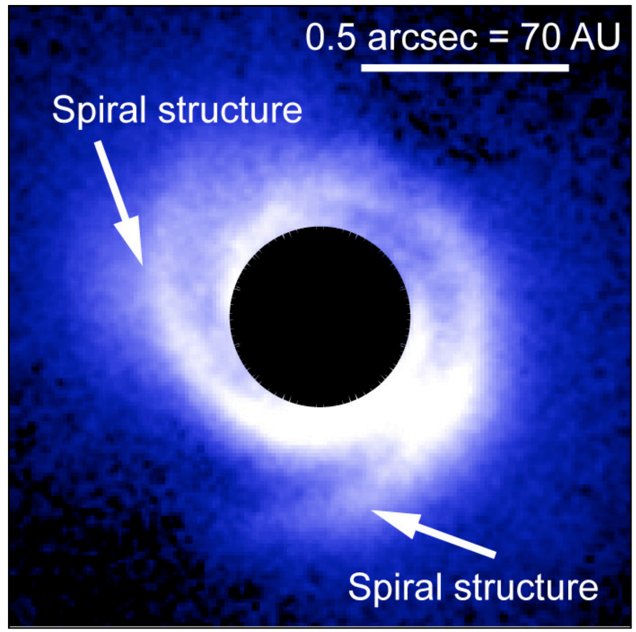
Observational evidence: gaps, spirals, and vortices

HL Tau



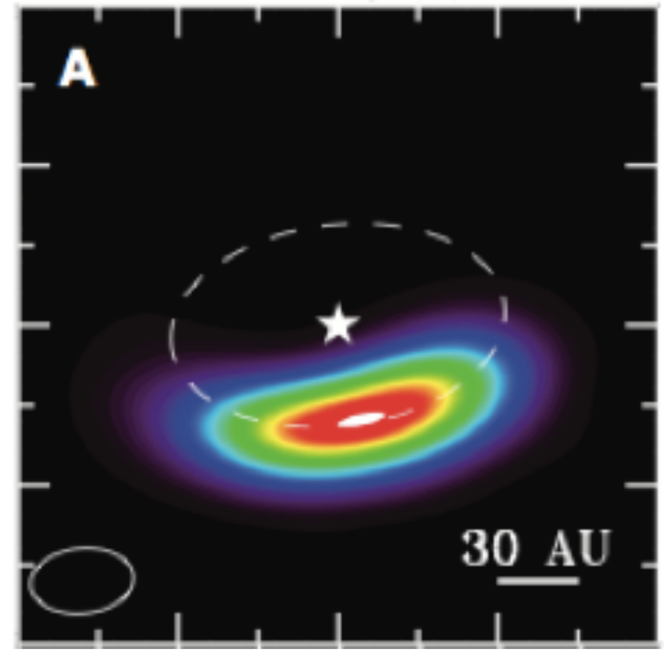
The ALMA Partnership et al. (2015)

SAO 206462



Muto et al. (2012)

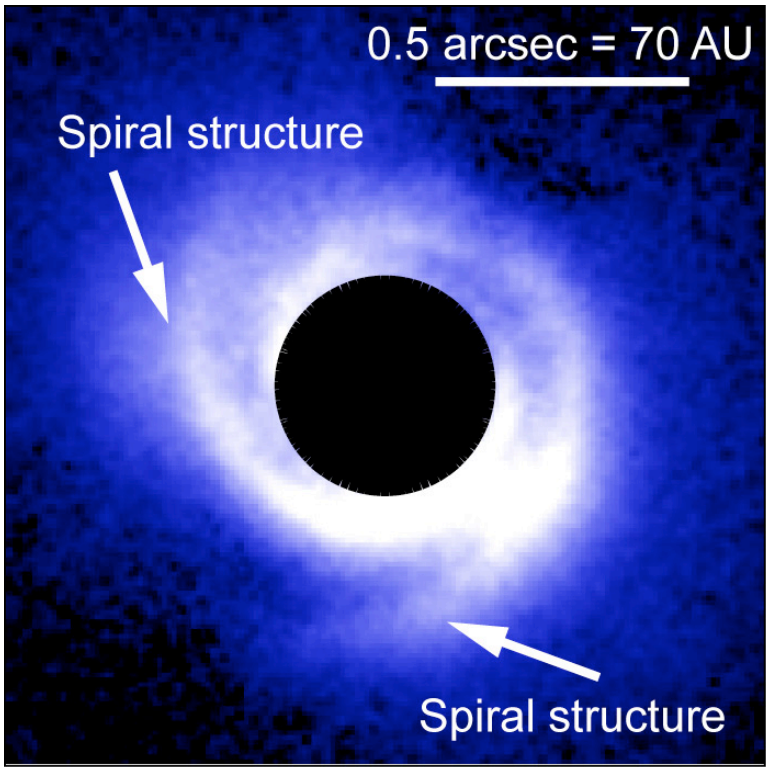
Oph IRS 48



van der Marel et al. (2013)

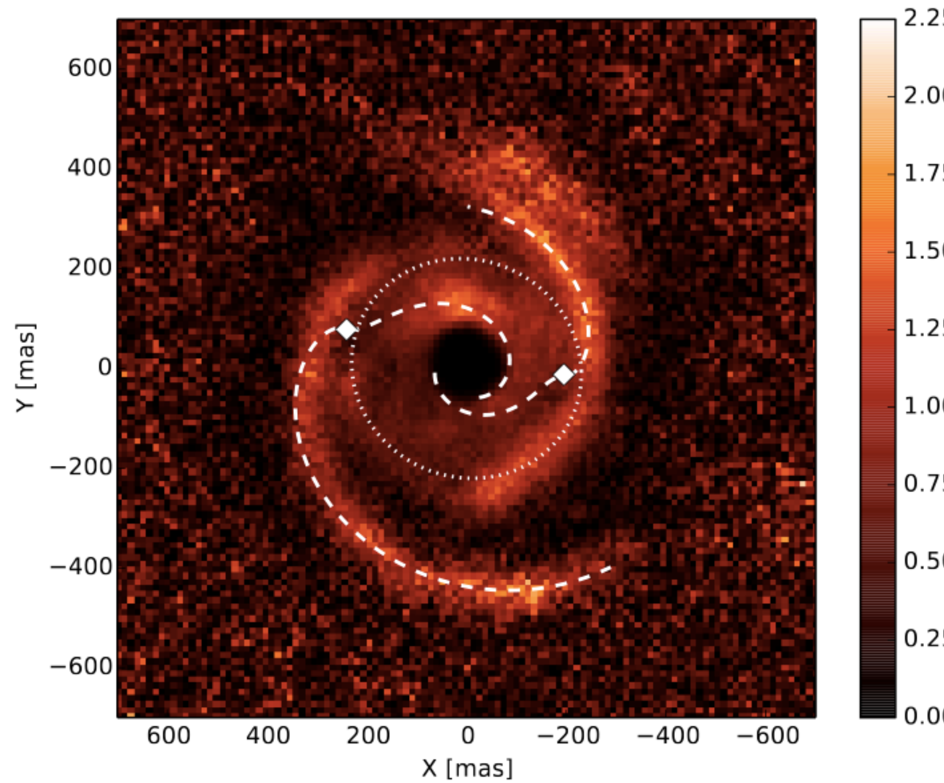
Observational Evidence: Spirals

SAO 206462



Muto et al. (2012)

MWC 748



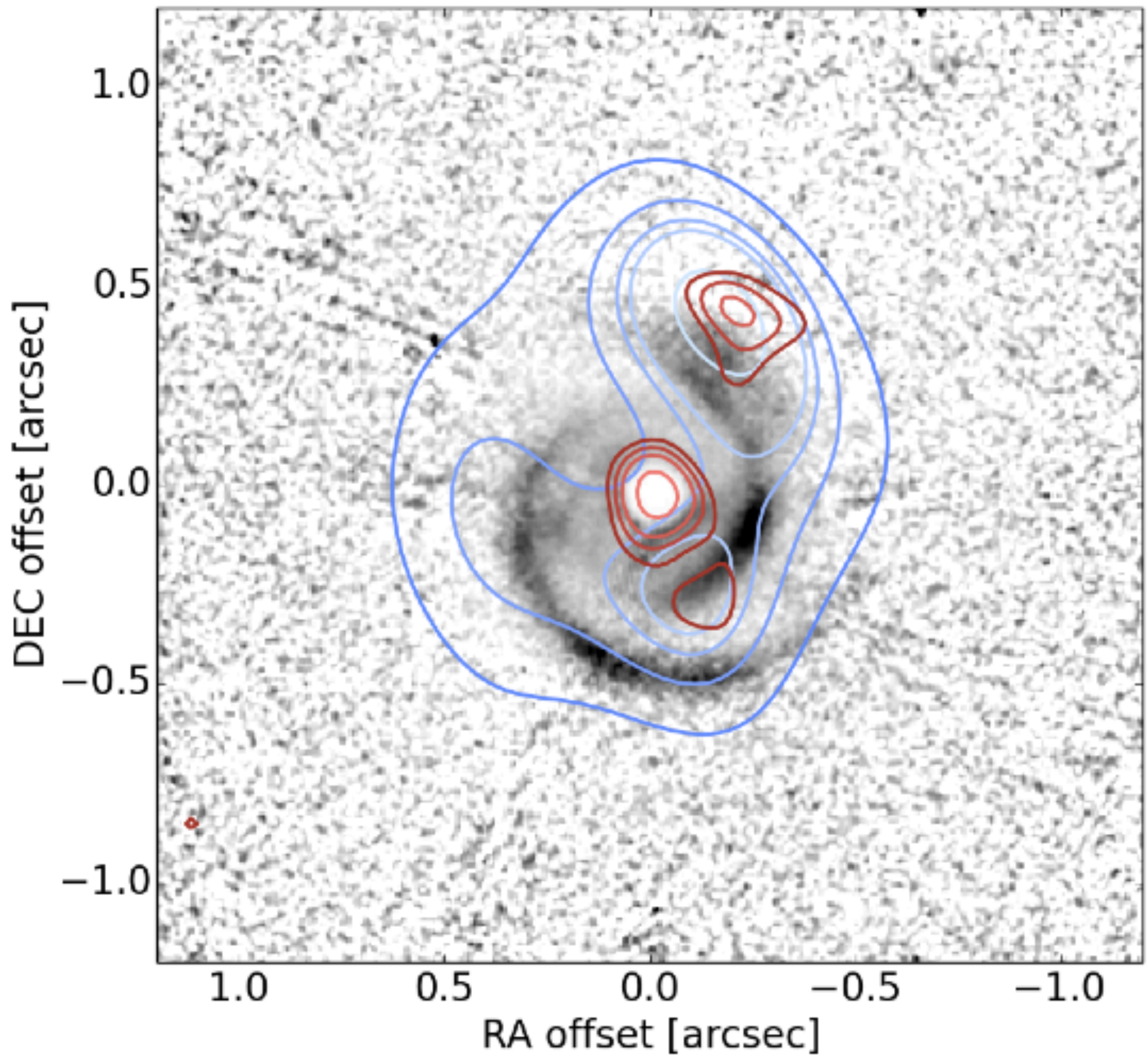
Benisty et al. (2015)

SPHERE-ALMA-VLA overlay of MWC 758

SPHERE (μm)

ALMA (~ mm)

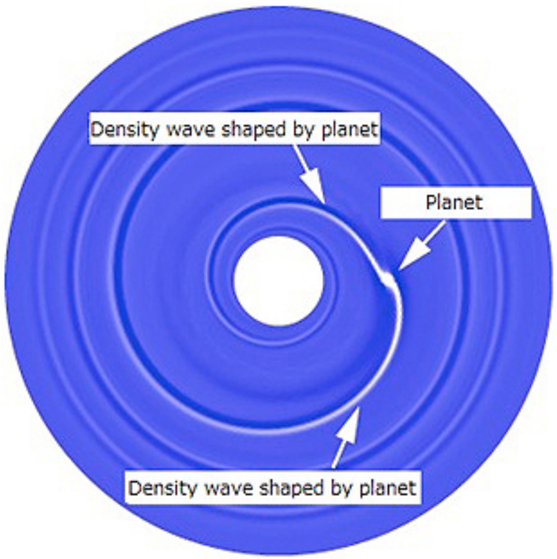
VLA (cm-m)



Marino et al. (2015)

Spiral arm fitting leads to problems

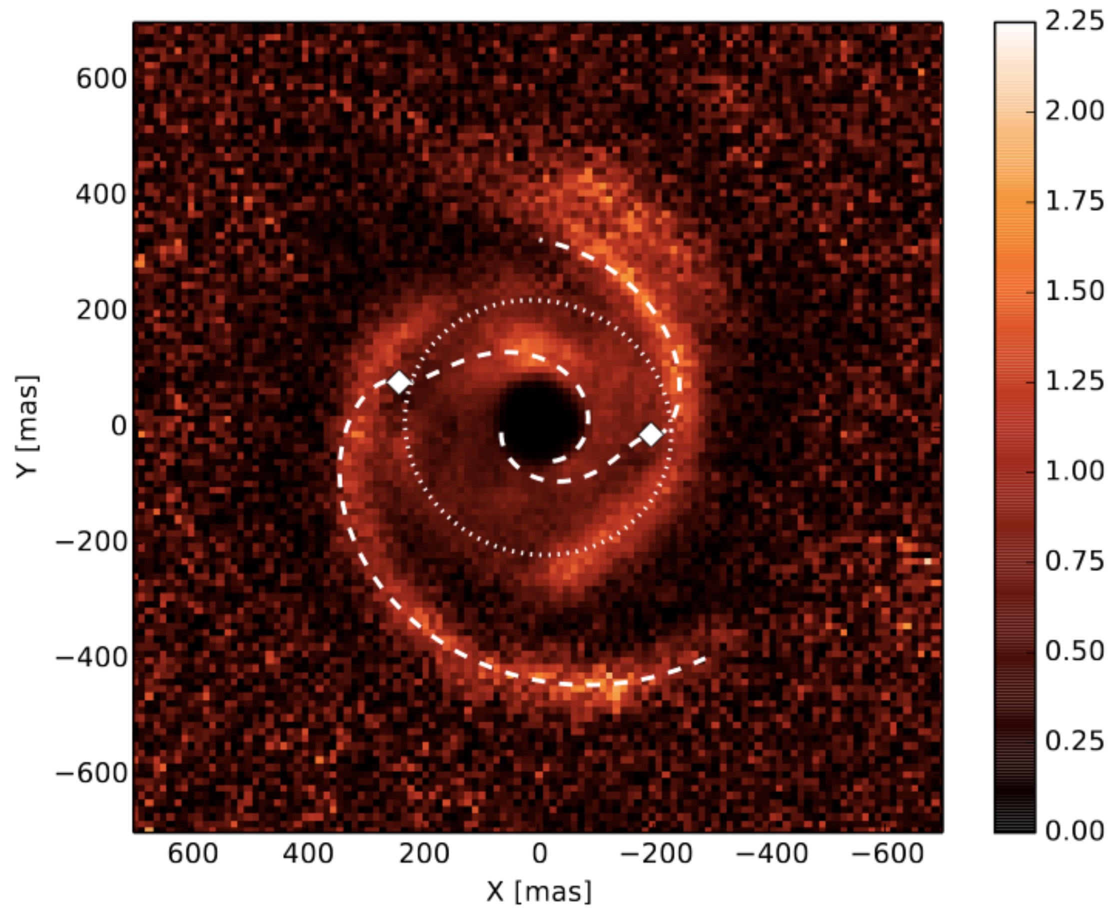
Analytical spiral fit



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

Rafikov (2002)
Muto et al. (2012)

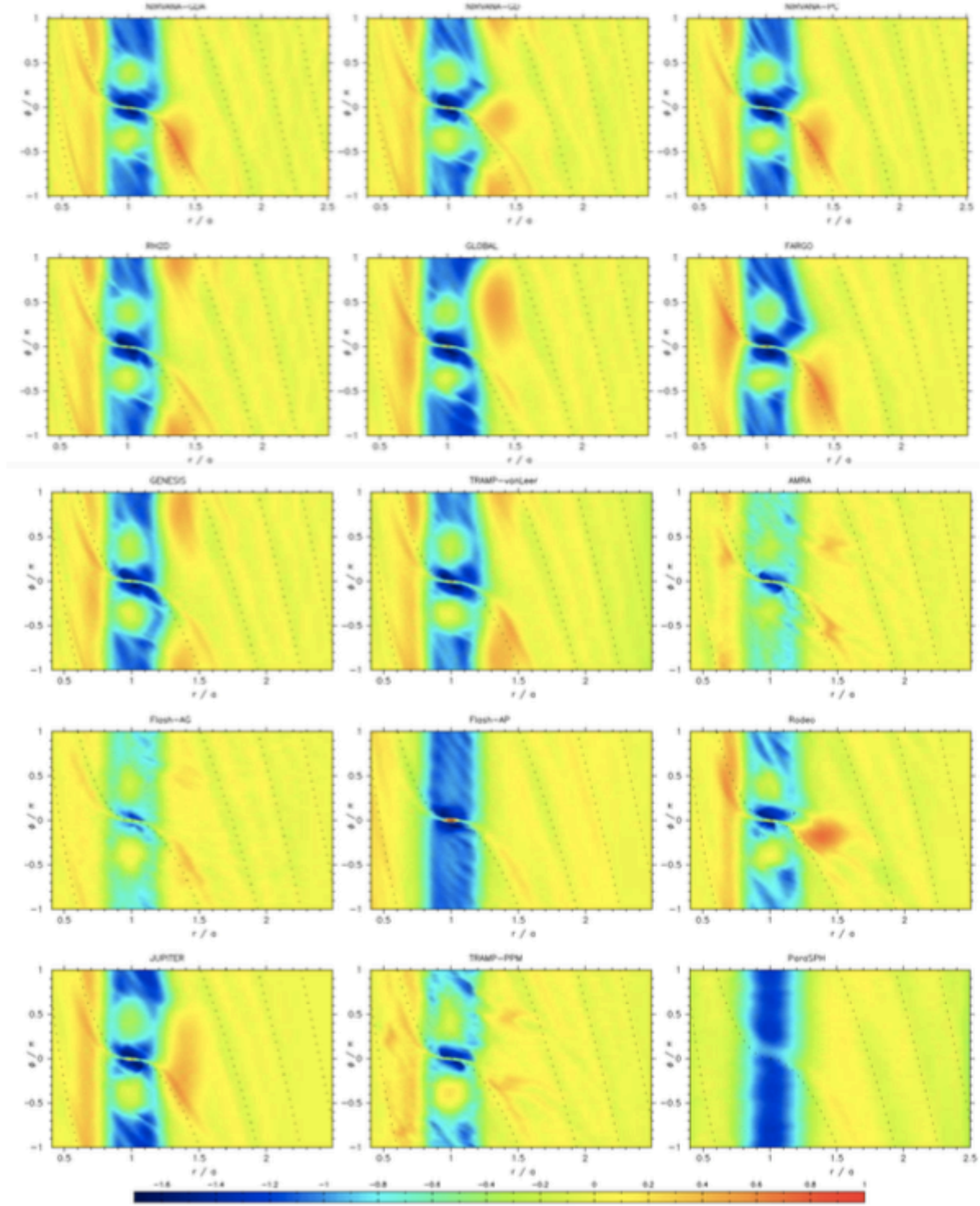
Spirals are **too wide**,
hotter (300K) than ambient gas (50K).



Benisty et al. (2015)

The code comparison project of 2006 (de Val-Borro et al. 2006)

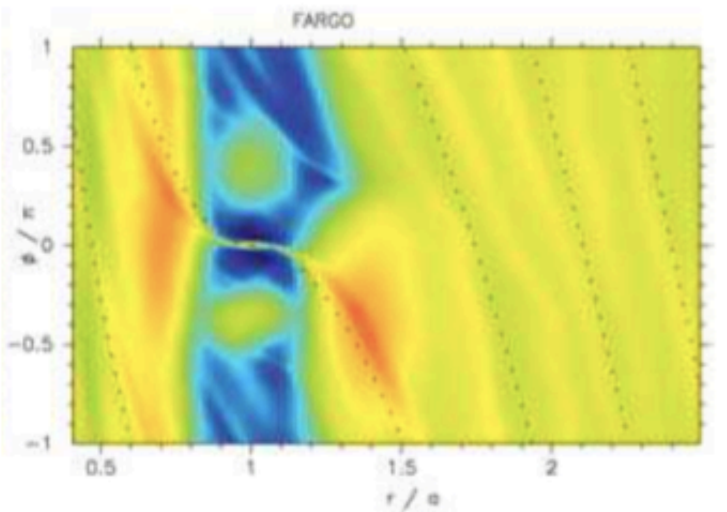
Problem of choice:
2D 'vanilla' planet-disk interaction.



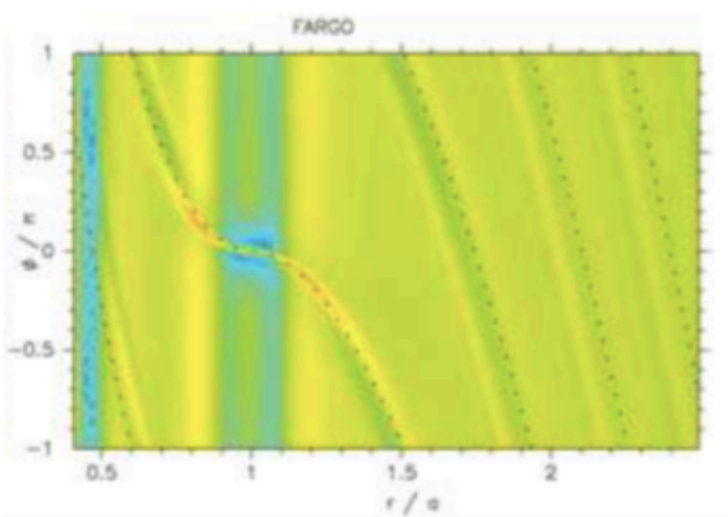
The “hot spiral problem” has never been a problem

Wakes of high-mass planets are not sonic, but *supersonic*.

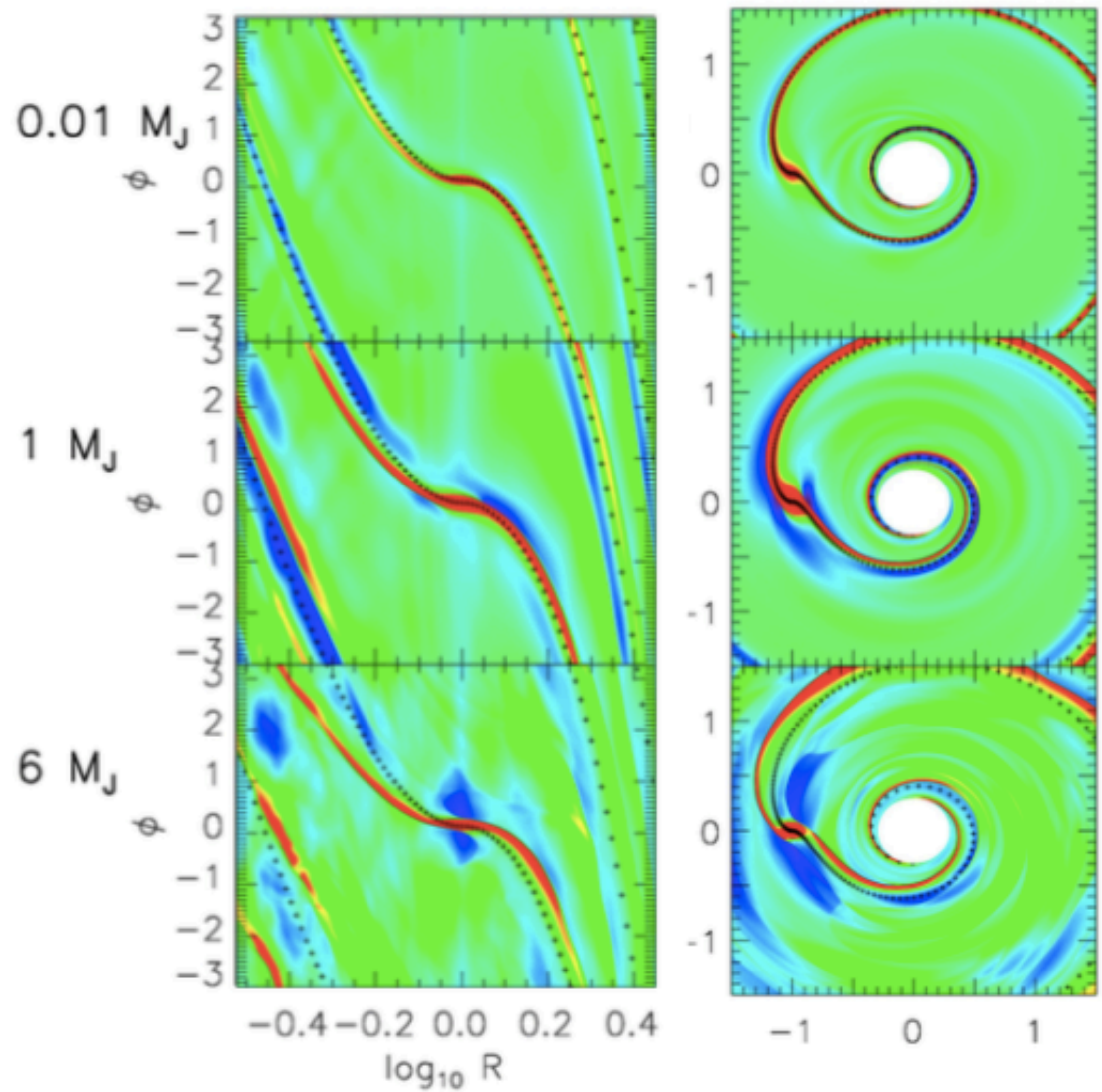
Jupiter-mass (non-linear)



Neptune-mass (linear)



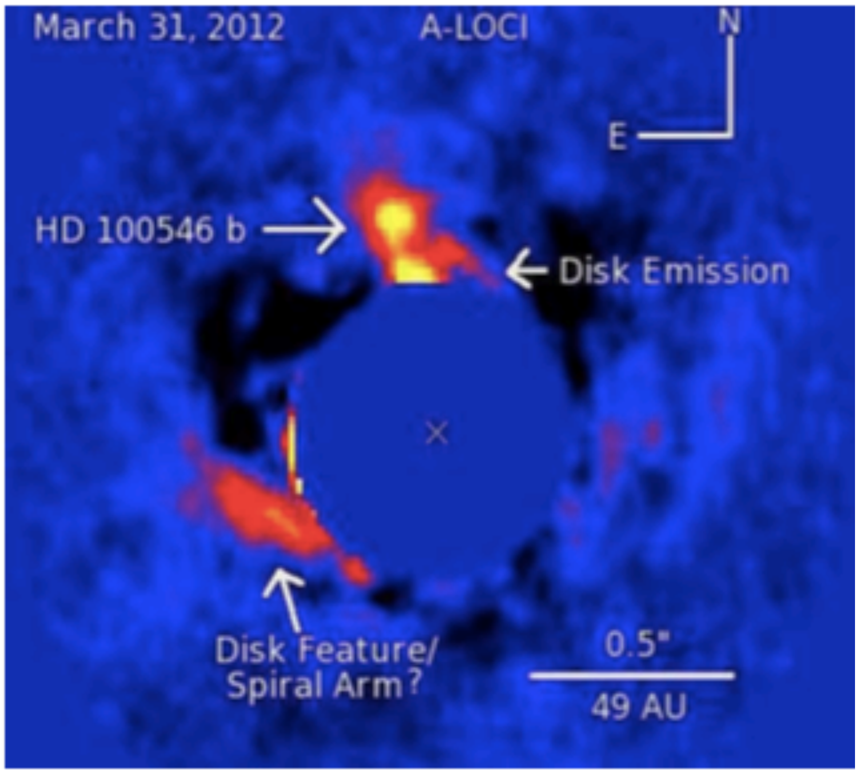
de Val-Borro al. (2006)



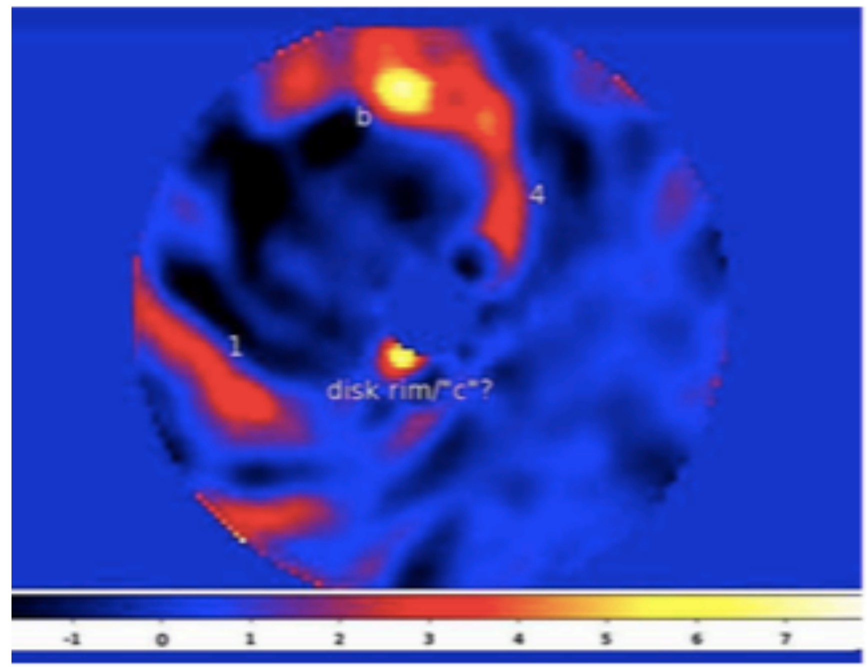
Zhu et al. (2015)

The strange case of thermal emission in HD 100546

L band (~3.5 μm)

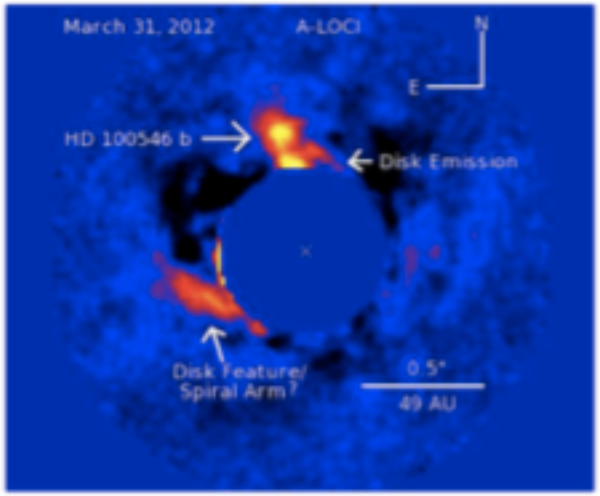


H band (~1.6 μm)

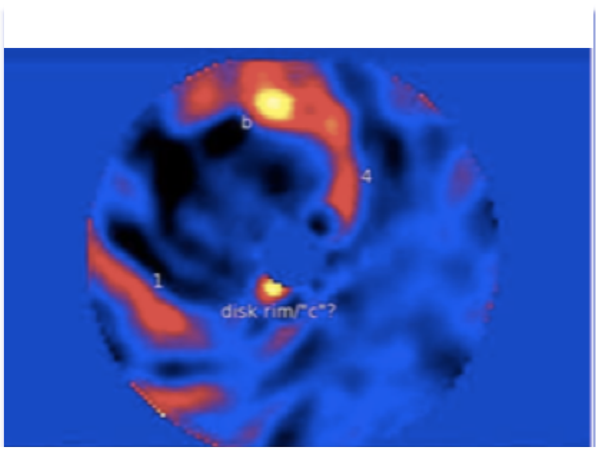


Currie et al. (2014), Currie et al. (2015)

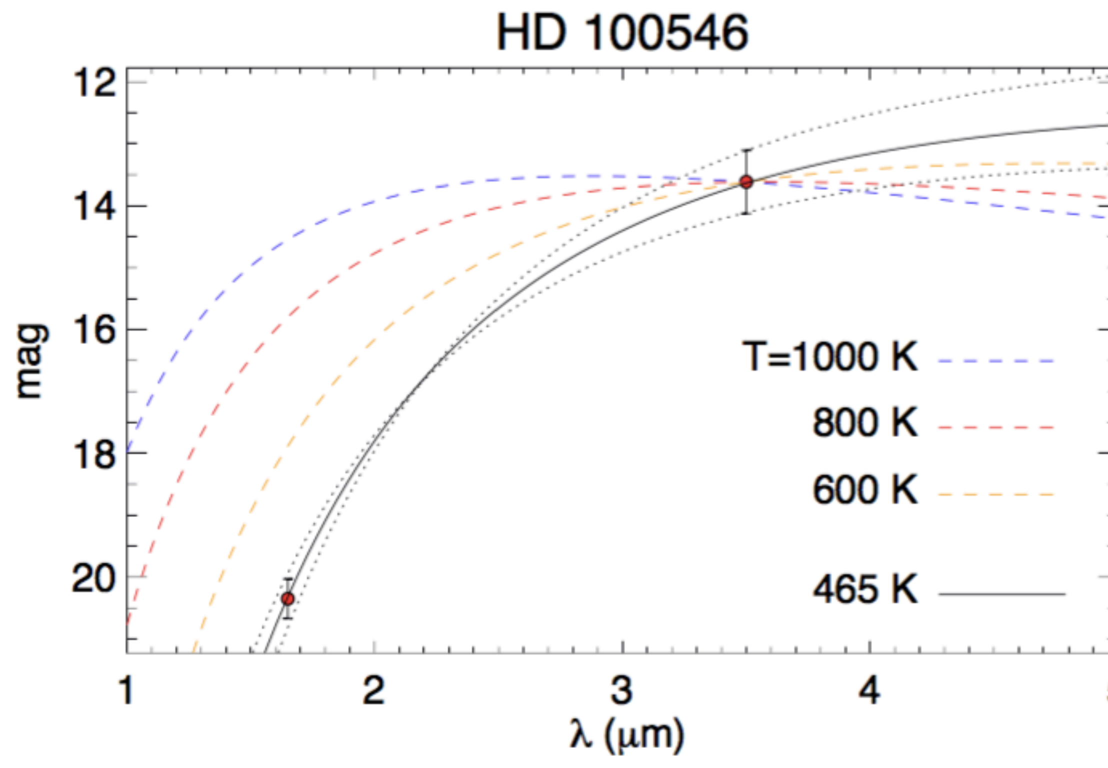
Pinning down the temperature



L band

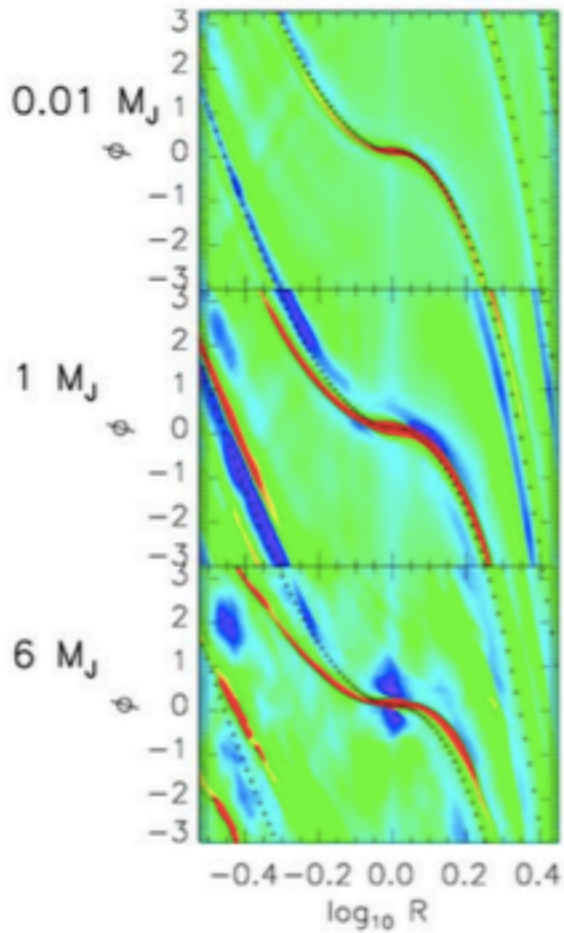


H band



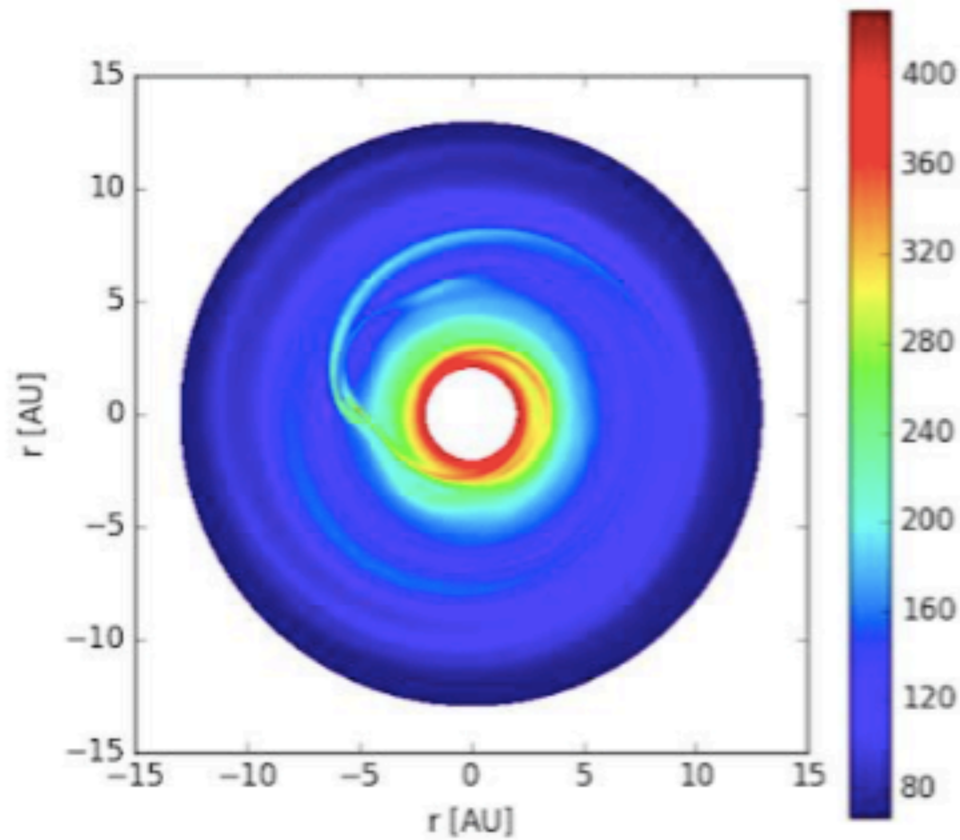
Lyra et al. (2016)

Supersonic Wakes of High Mass Planets



Density

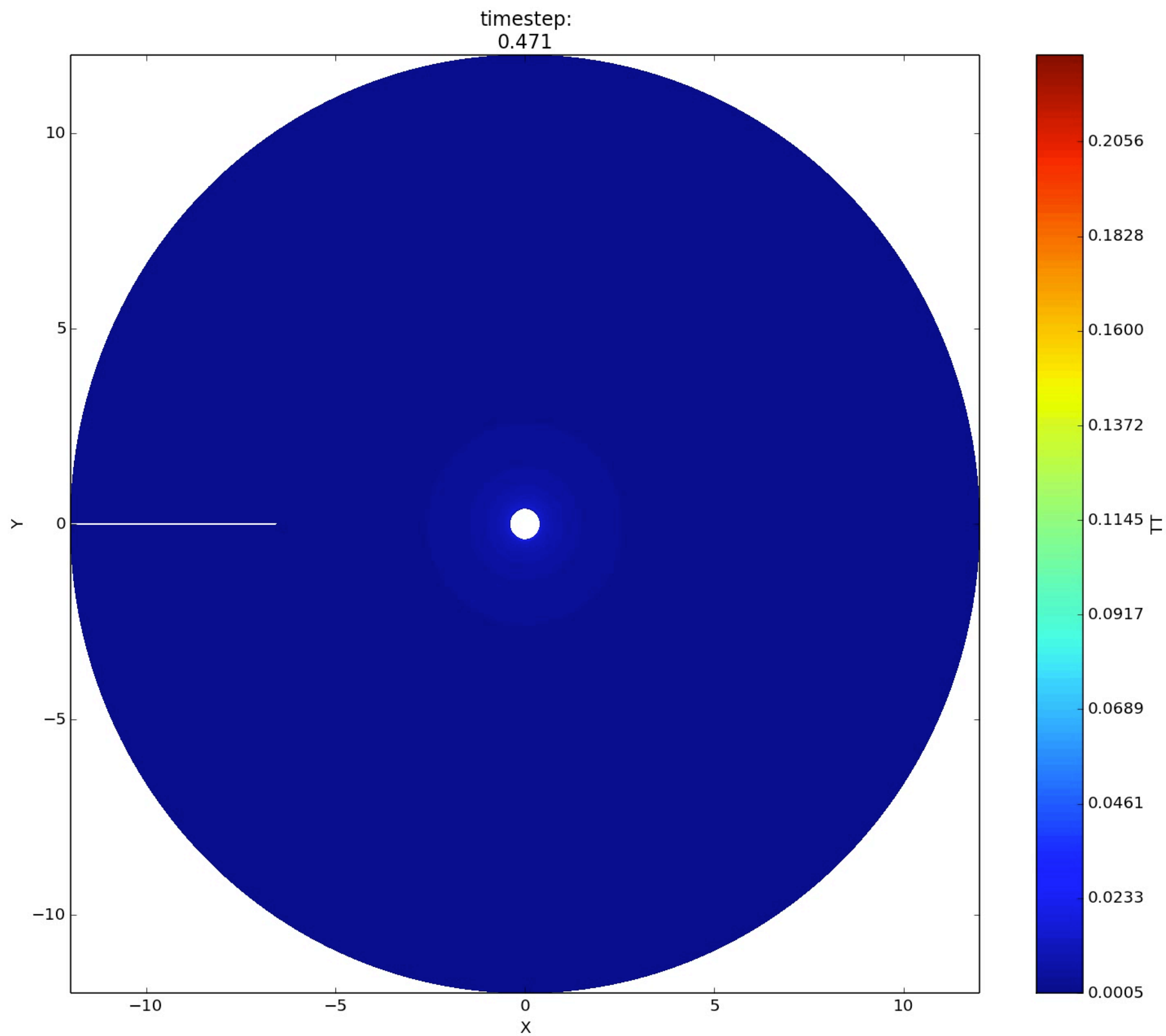
Zhu et al. (2015)



Temperature - **5M$_J$**

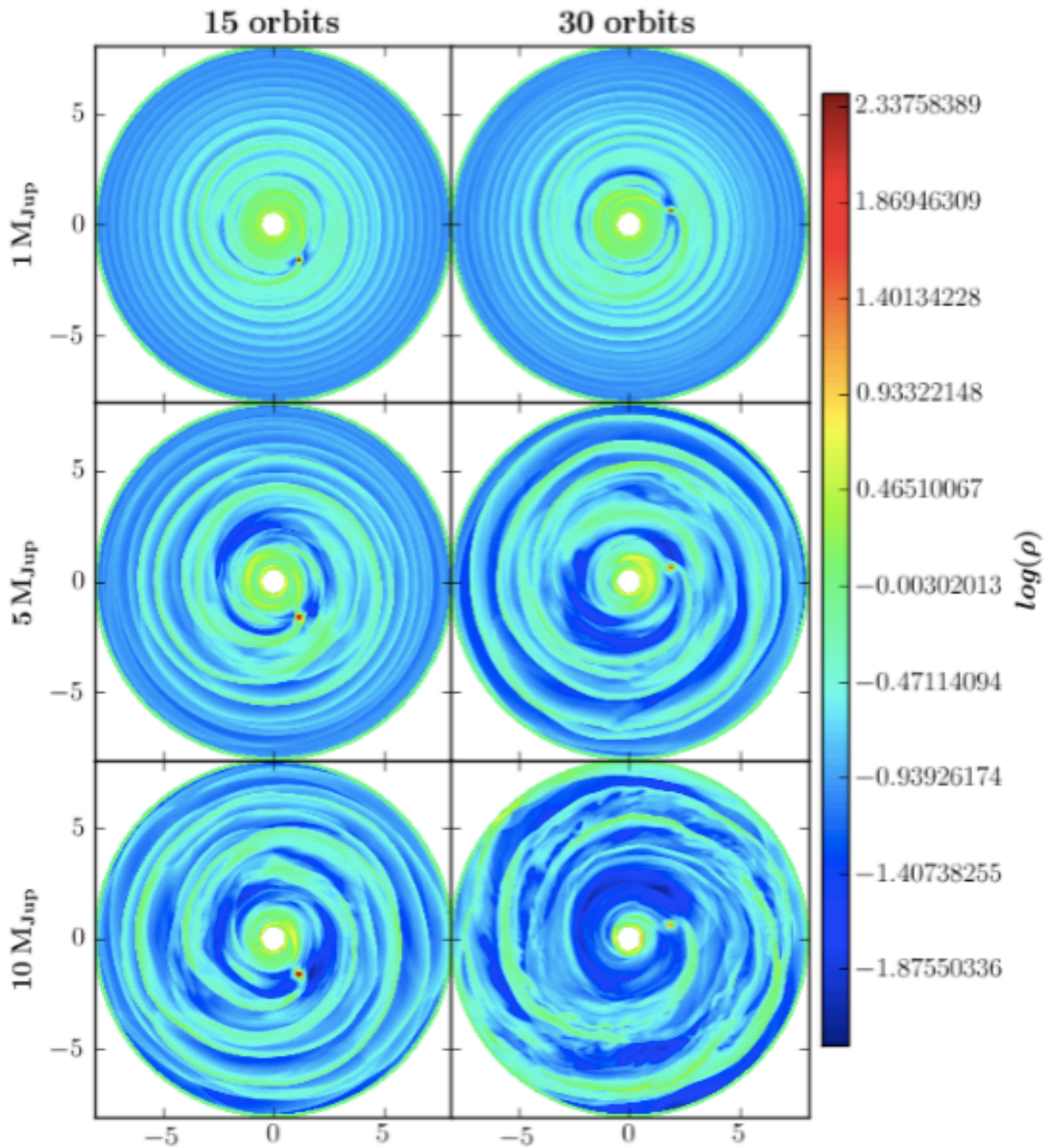
Lyra et al. (2016)

Planet-driven turbulence

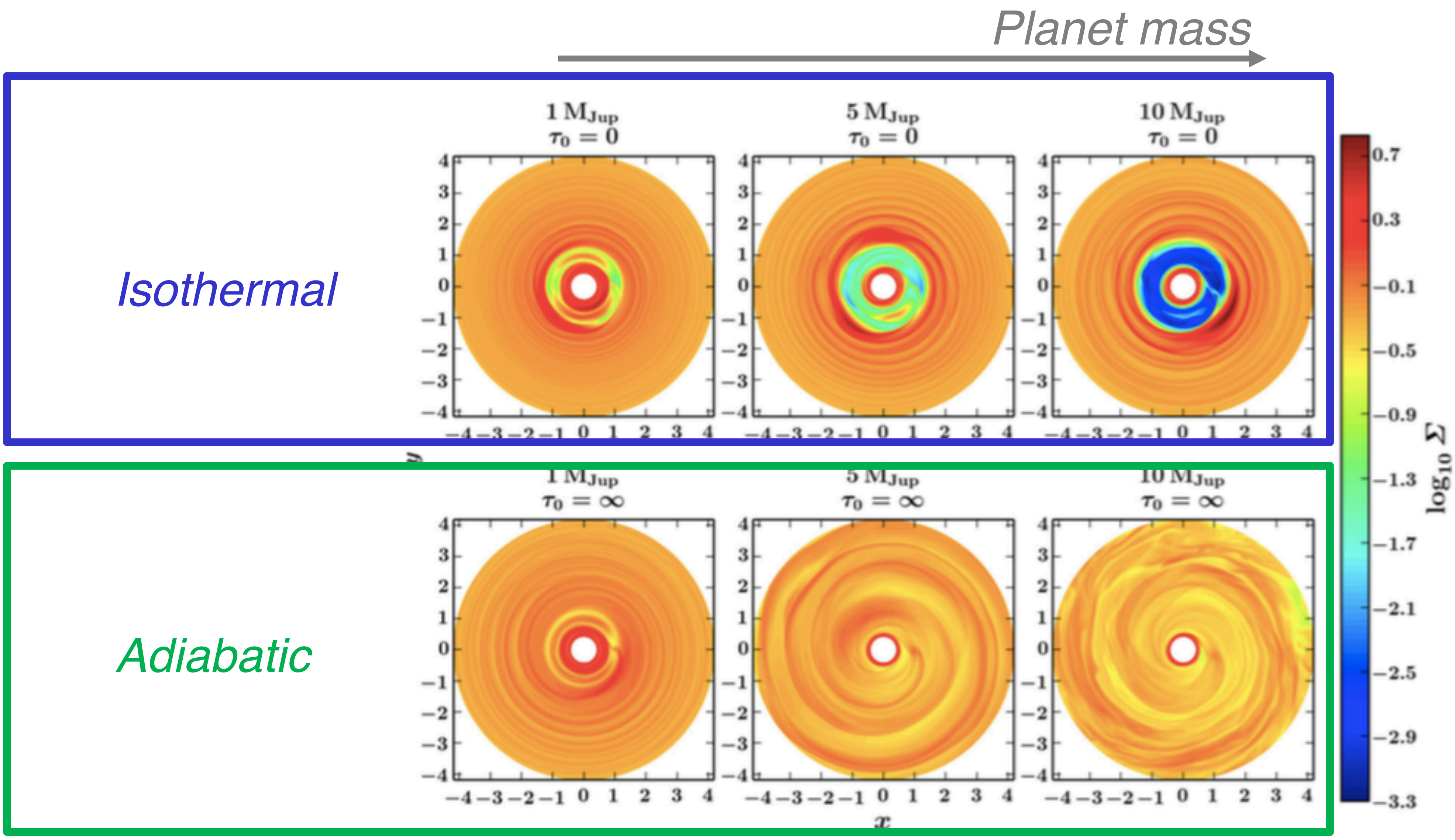


Richert et al. (2015)

Some crazy turbulence showing up at high planet mass….

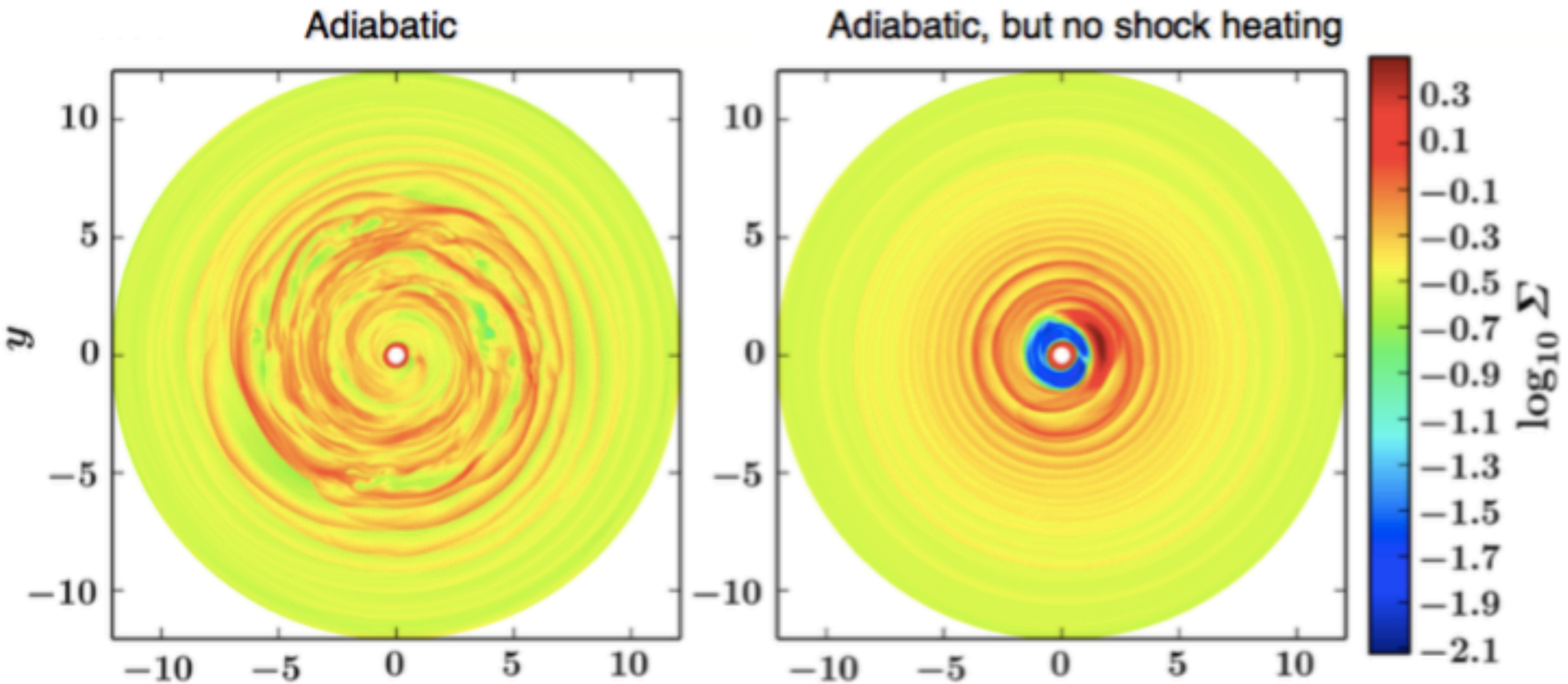


Turbulence in high-mass planets in adiabatic disks



Richert et al. (2015)

The energy source: shock heating!



Richert et al. (2015)

Radiative transfer approximation

$$T\frac{\mathrm{D}s}{\mathrm{D}t} = -c_V\frac{(T - T_{\mathrm{ref}})}{t_{\mathrm{cool}}} + \Gamma_{\mathrm{sh}},$$

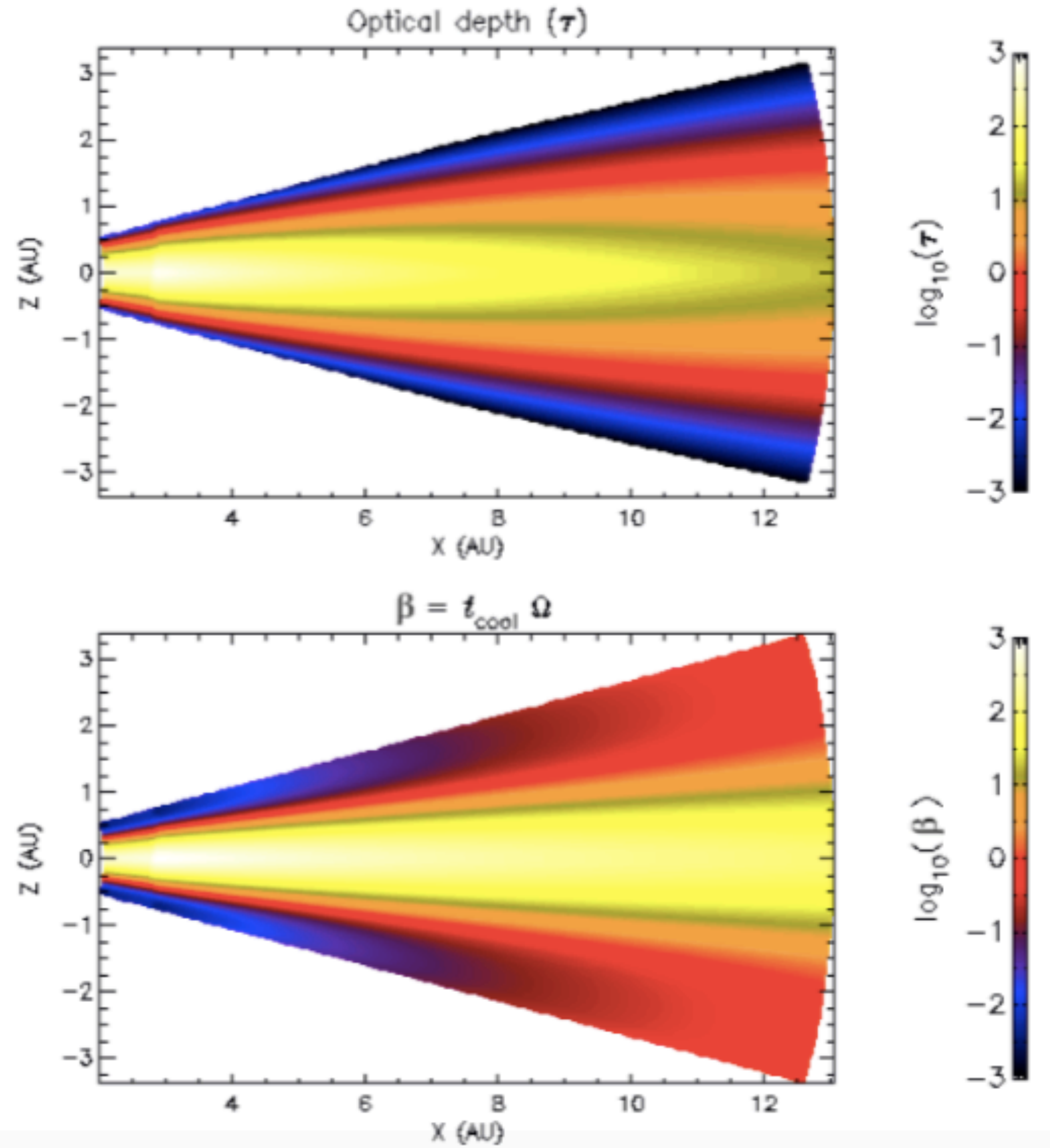
$$t_{\mathrm{rad}} = E/\dot{E}$$

$$\dot{E} = \boldsymbol{\nabla}\cdot\boldsymbol{F}$$

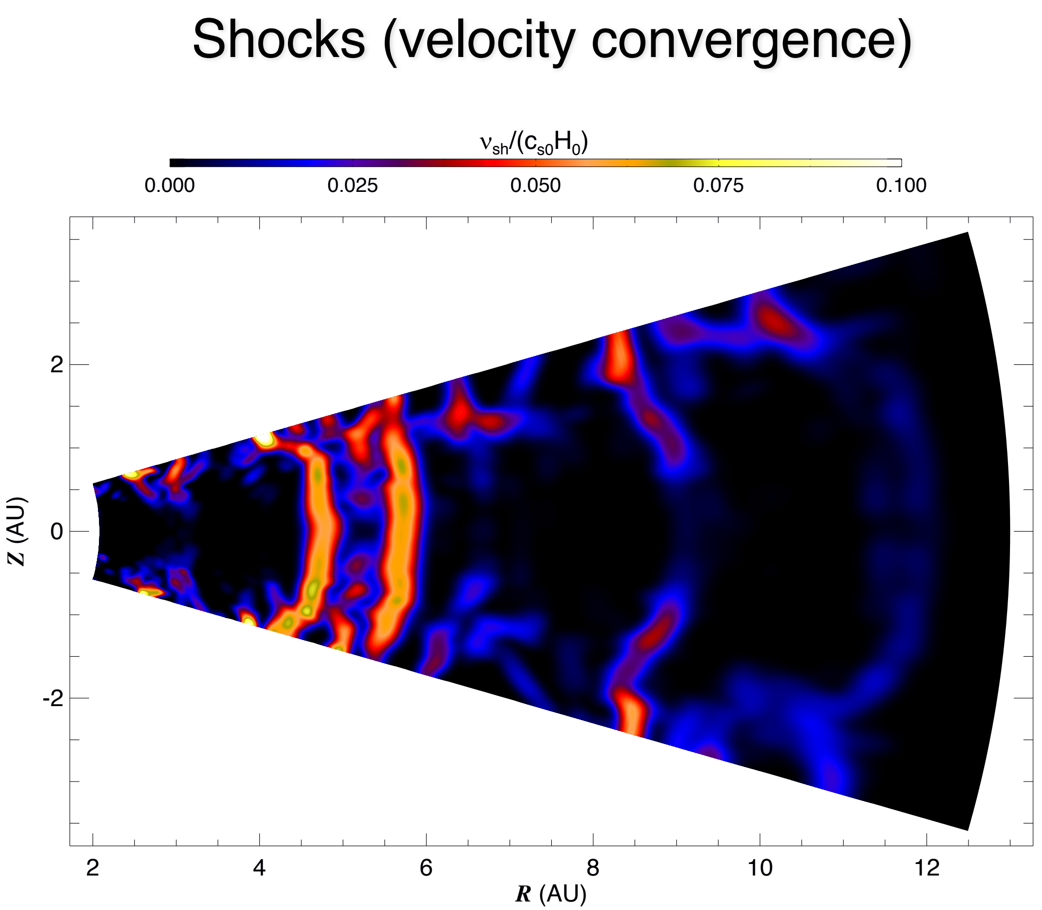
$$t_{\mathrm{cool}} \equiv \frac{\int E dV}{\int F\hat{\boldsymbol{n}}\cdot d\boldsymbol{A}}.$$

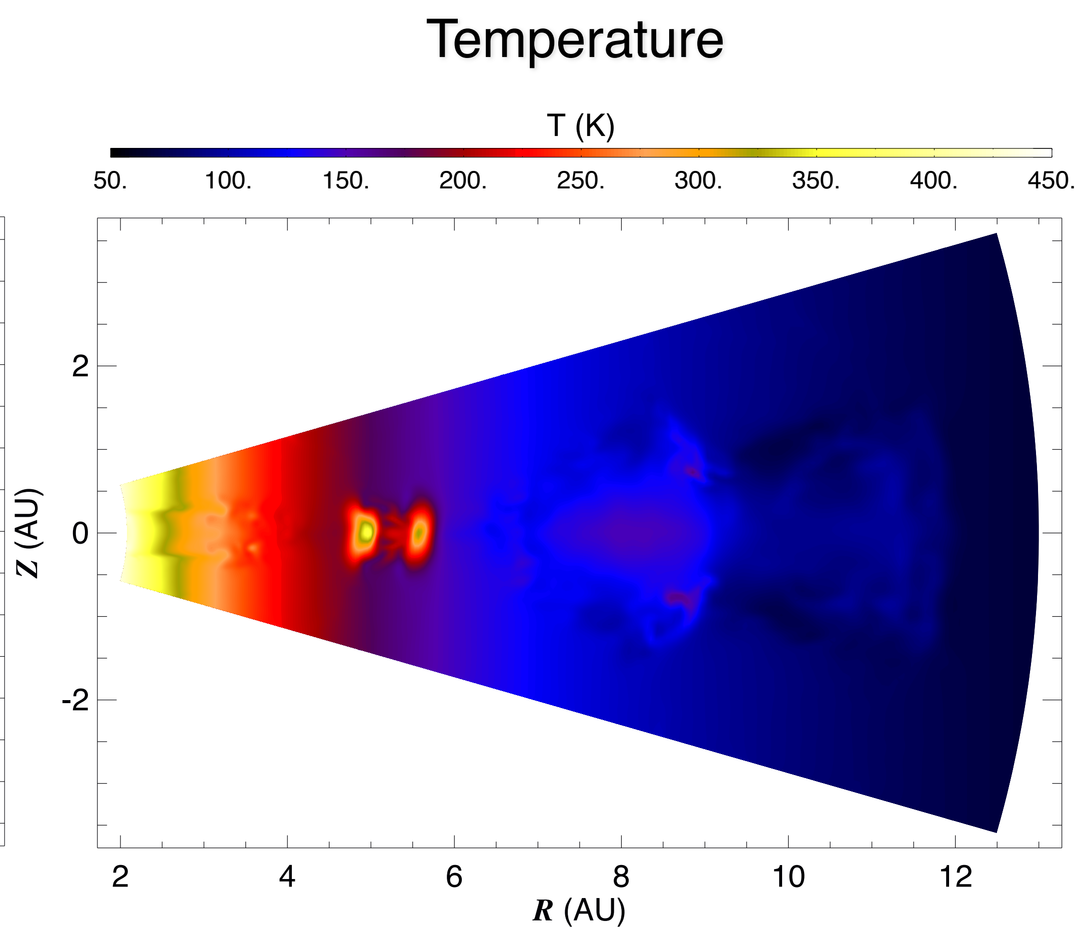
$$t_{\mathrm{cool}} = \frac{c_V\rho H\tau_{\mathrm{eff}}}{3\sigma T^3}.$$

$$\tau_{\mathrm{eff}} = \frac{3\tau}{8} + \frac{\sqrt{3}}{4} + \frac{1}{4\tau}.$$



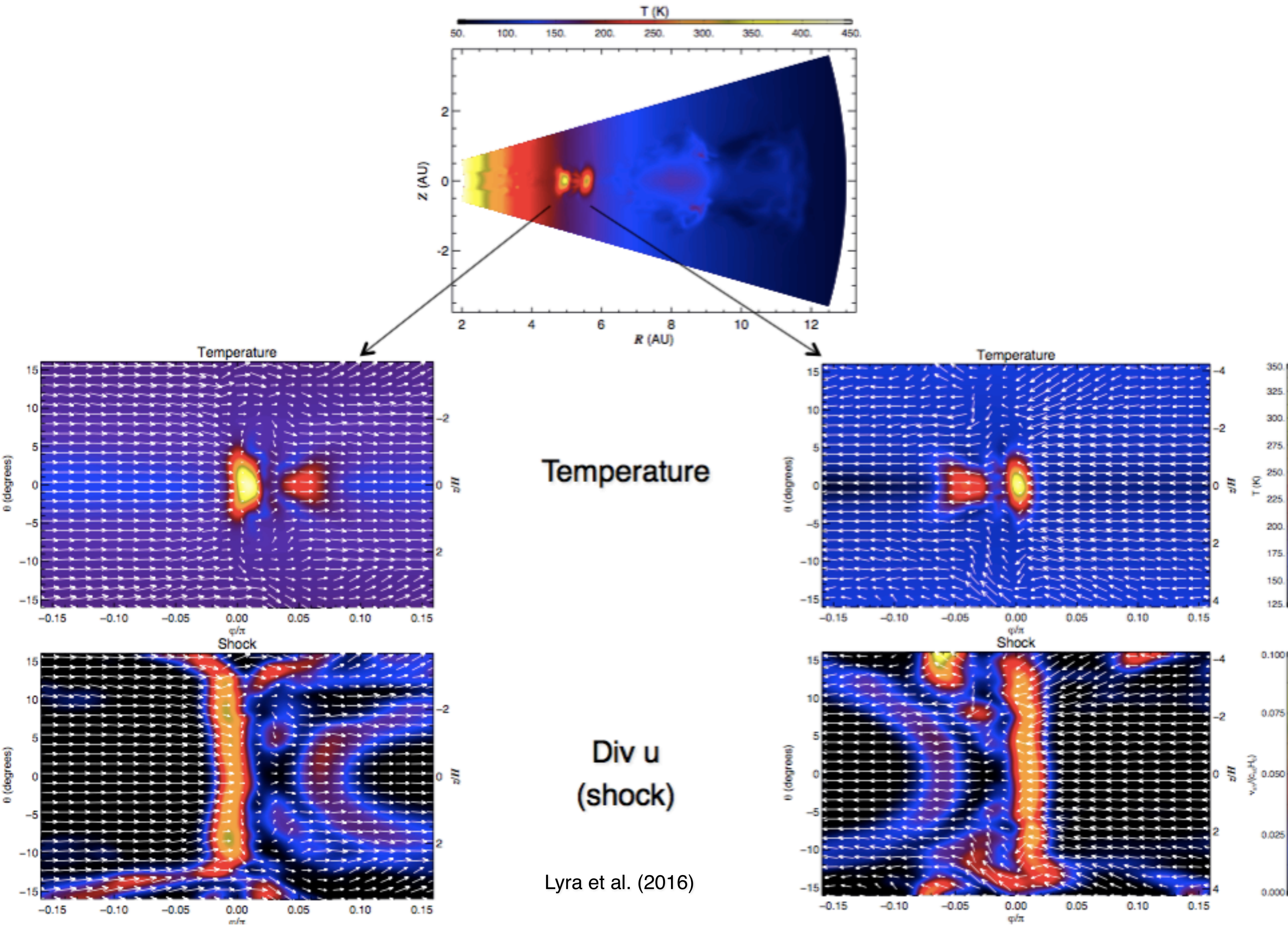
3D: Shock bores





Lyra et al. (2016)

3D shocks: bores and breaking waves

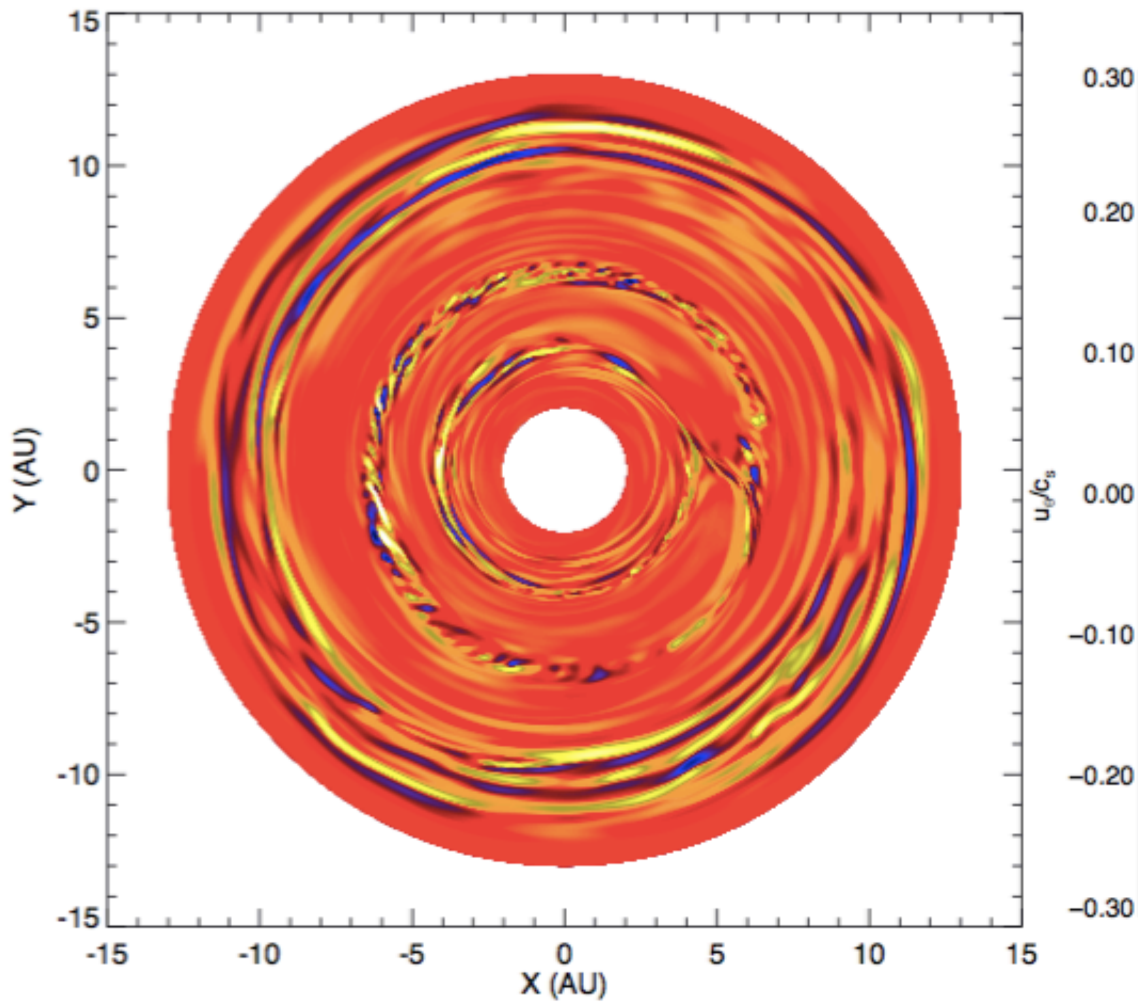


Temperature

Div u
(shock)

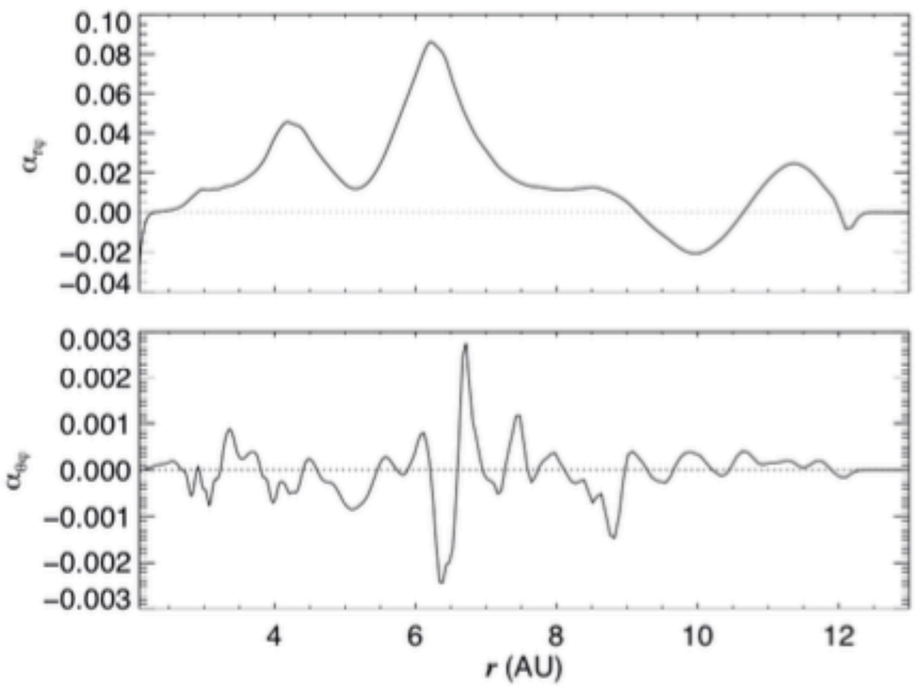
Lyra et al. (2016)

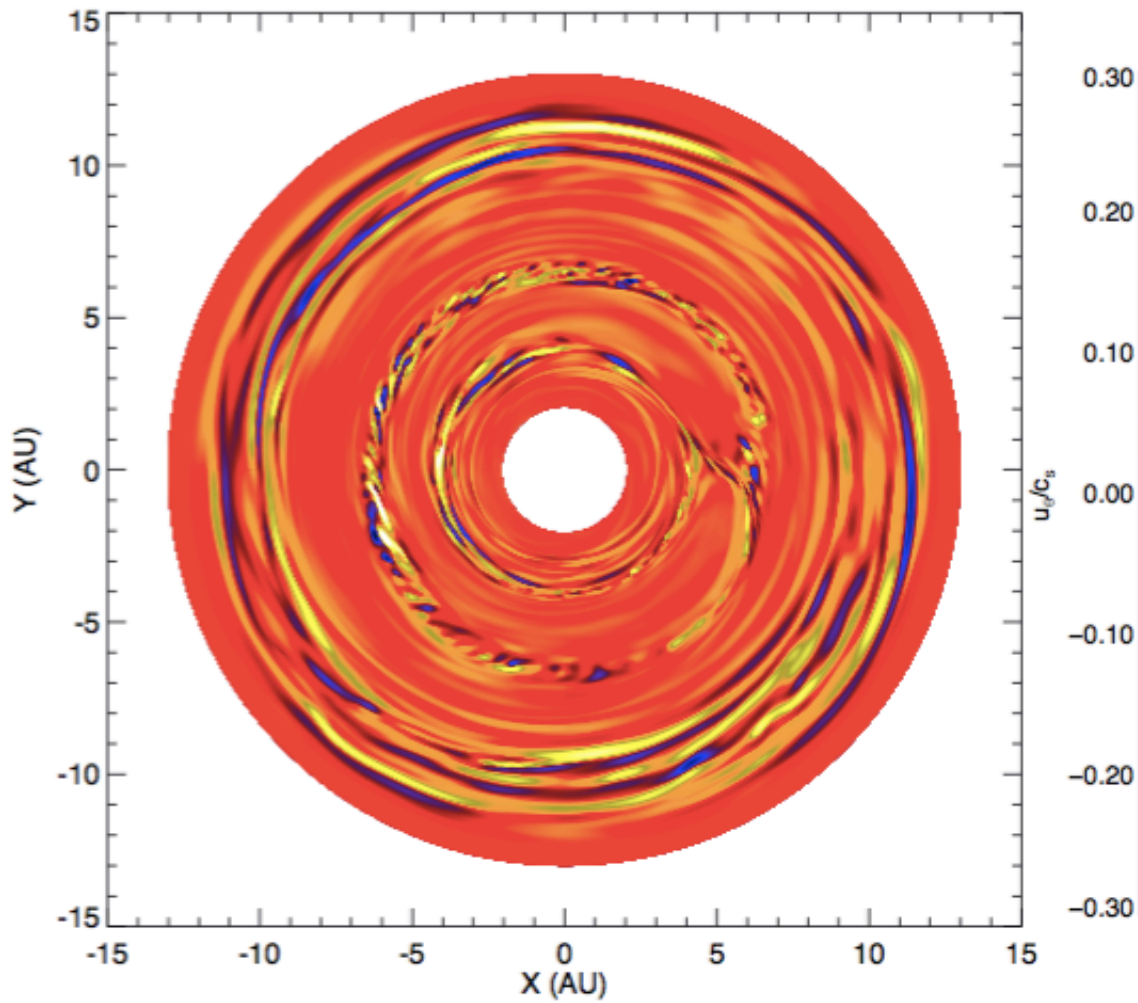
Turbulent surf



Lyra et al. (2016)

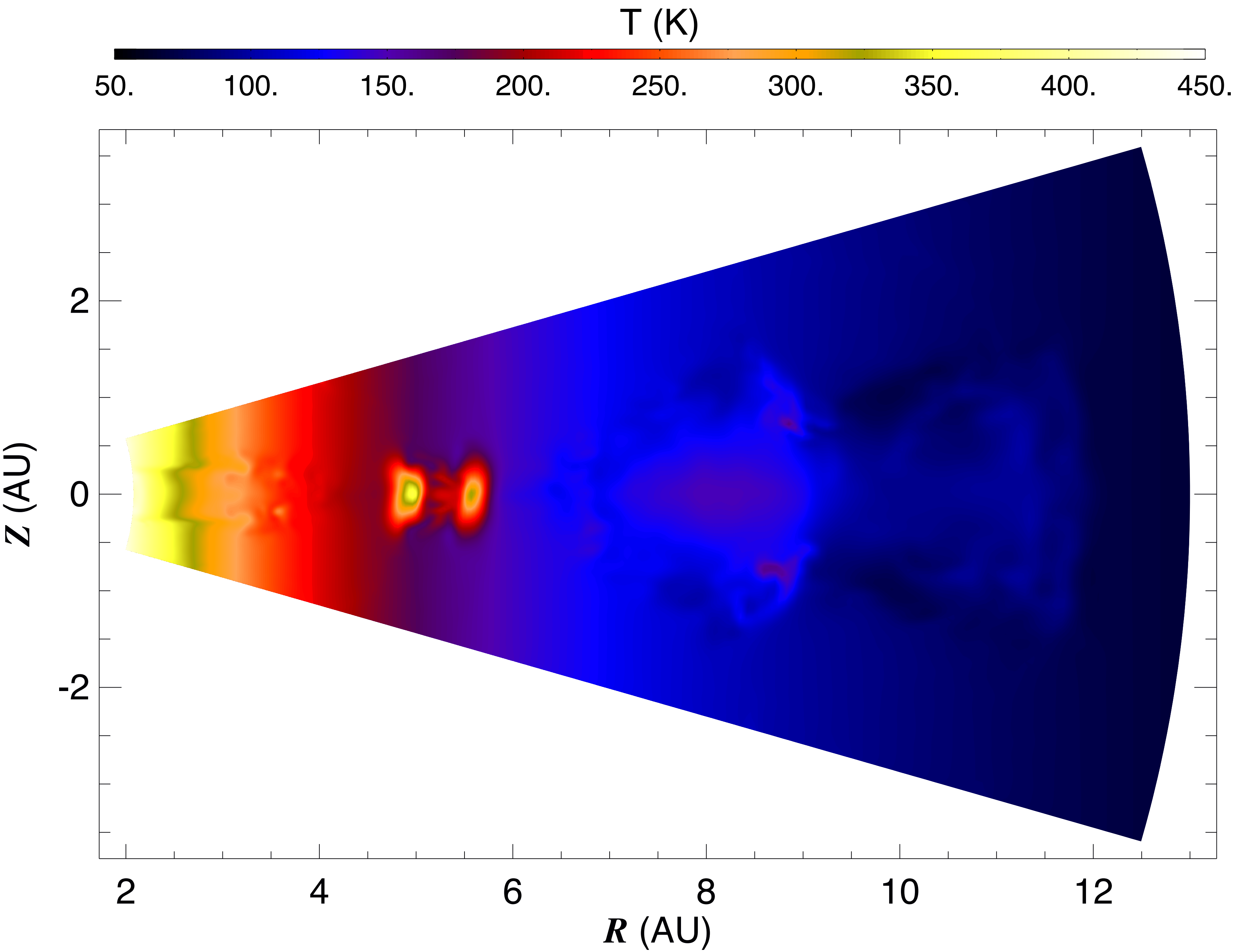
Turbulent surf





Lyra et al. (2016)

Your model doesn't look like my observation. Why should I care?



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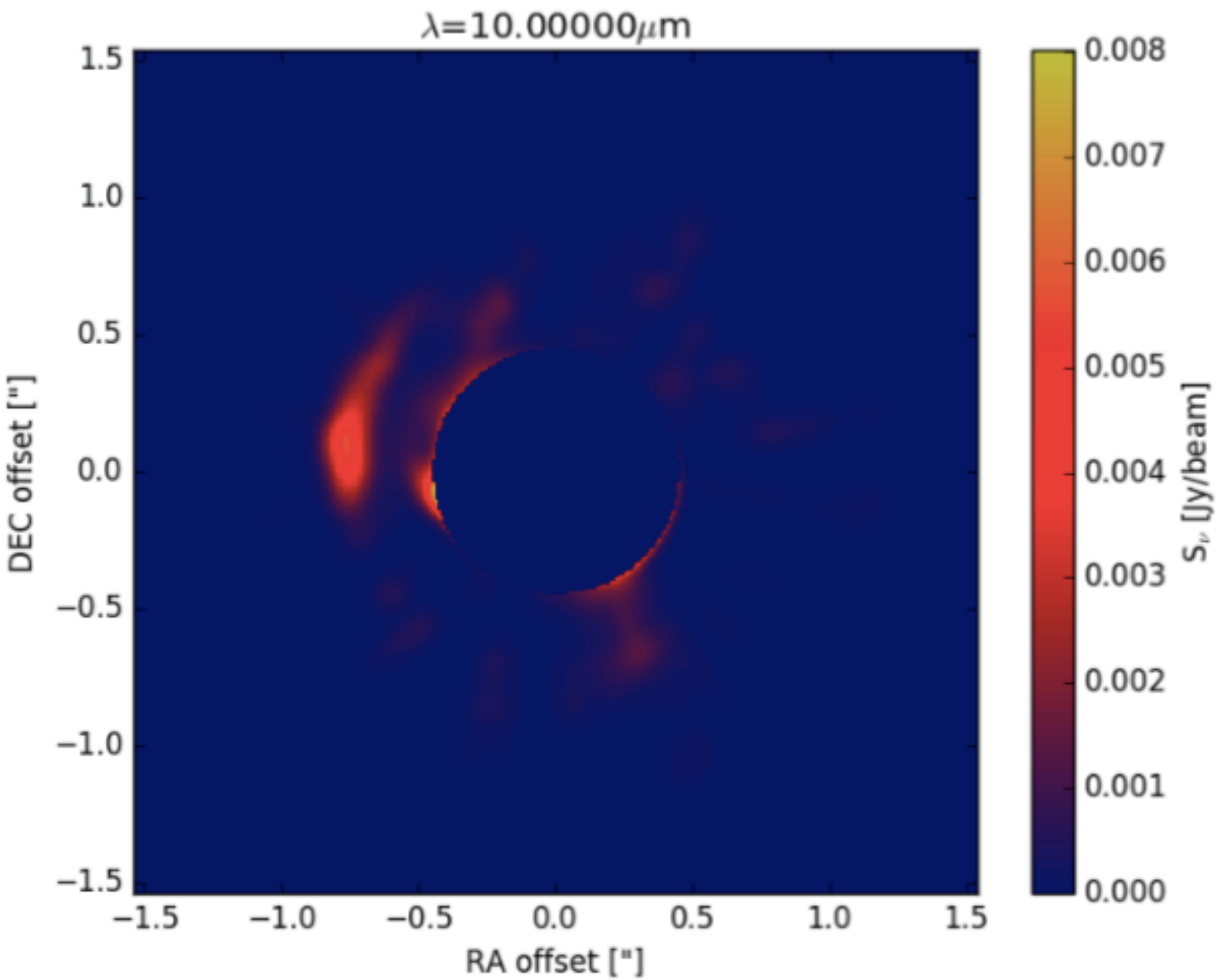
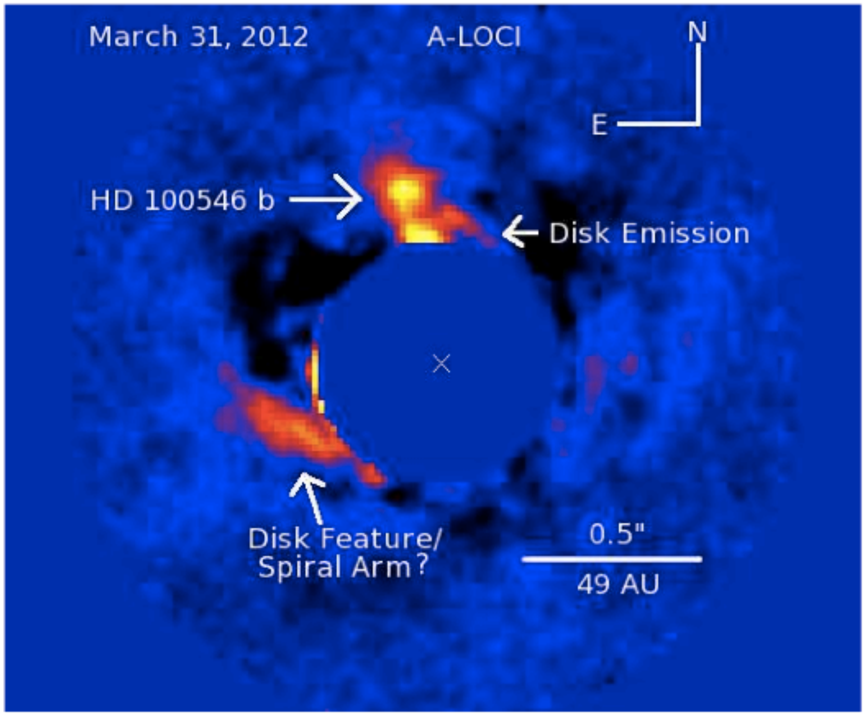
R (AU)

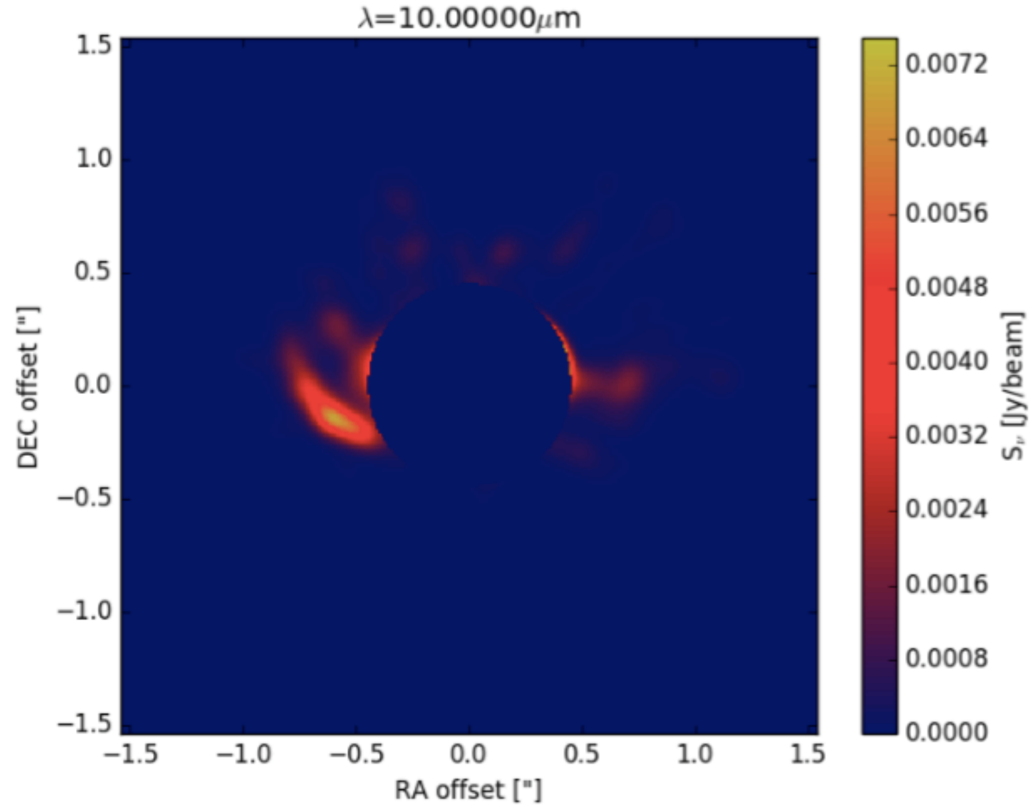
Synthetic image



Hord et al. (2017)

Observation vs Synthetic Image

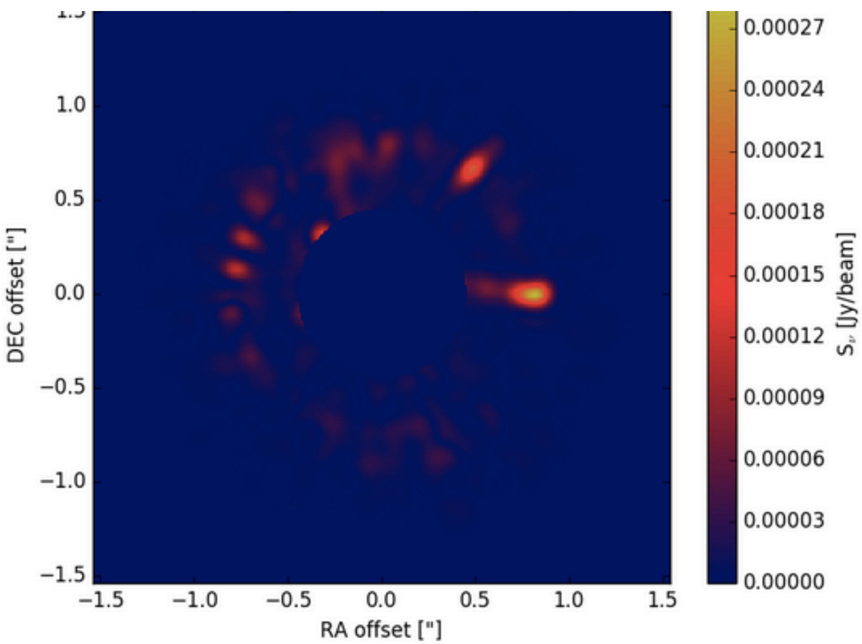




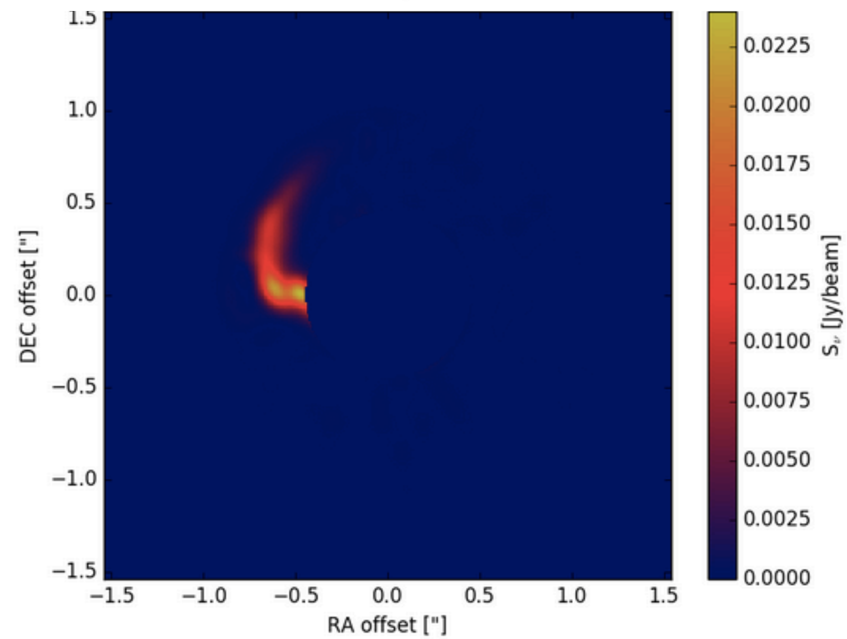
Hord et al. (2017)

Effect of shocks alone

1 μm

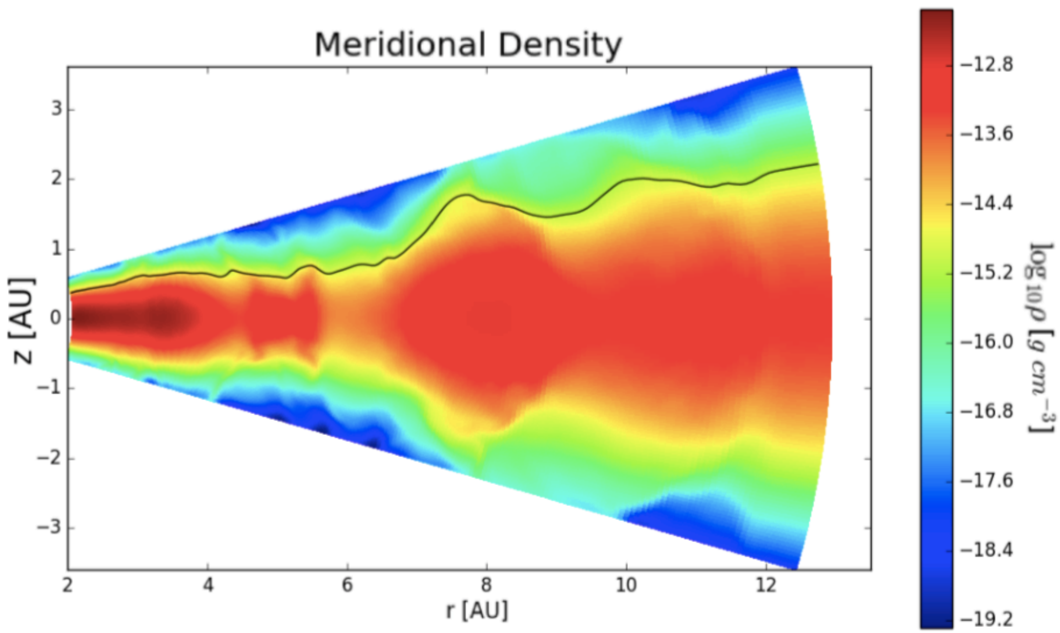


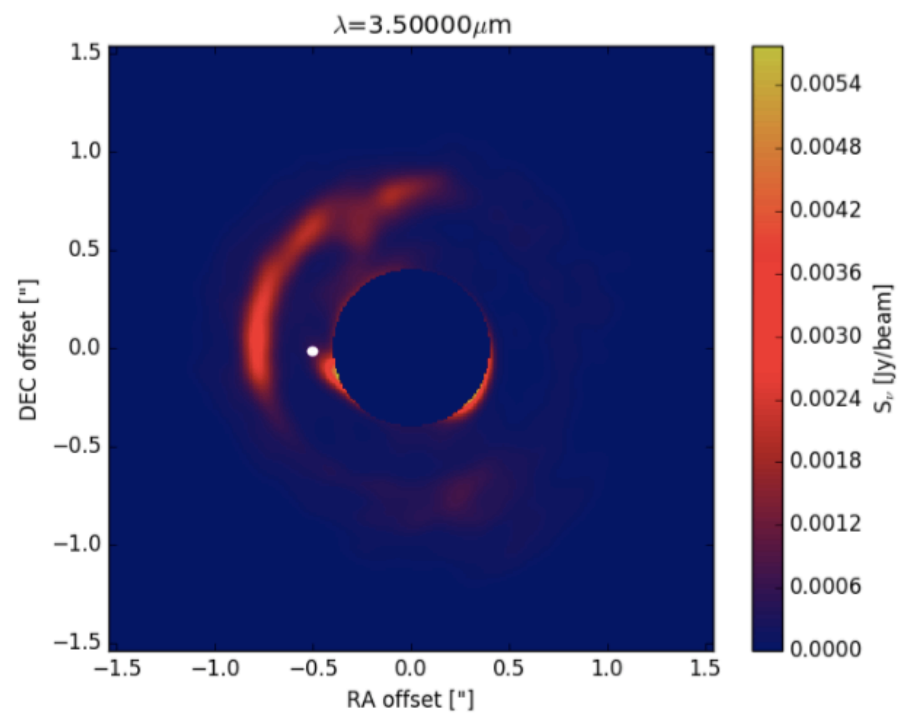
10 μm



Hord et al. (2017)

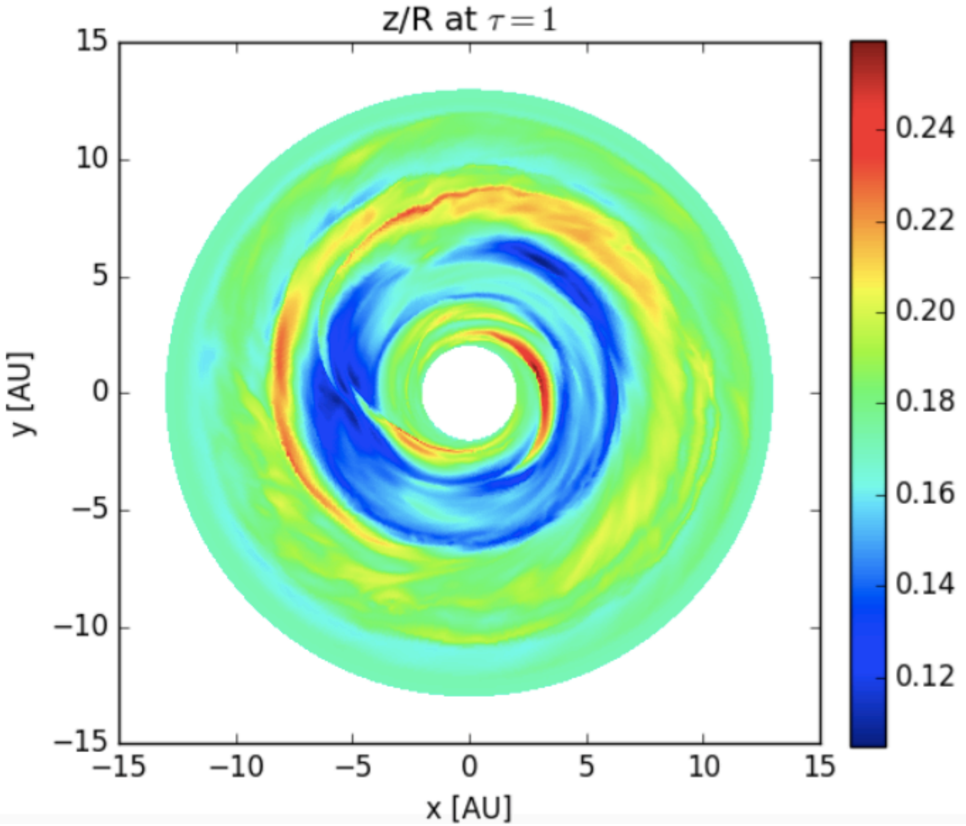
Scattering – A puffed up outer gap

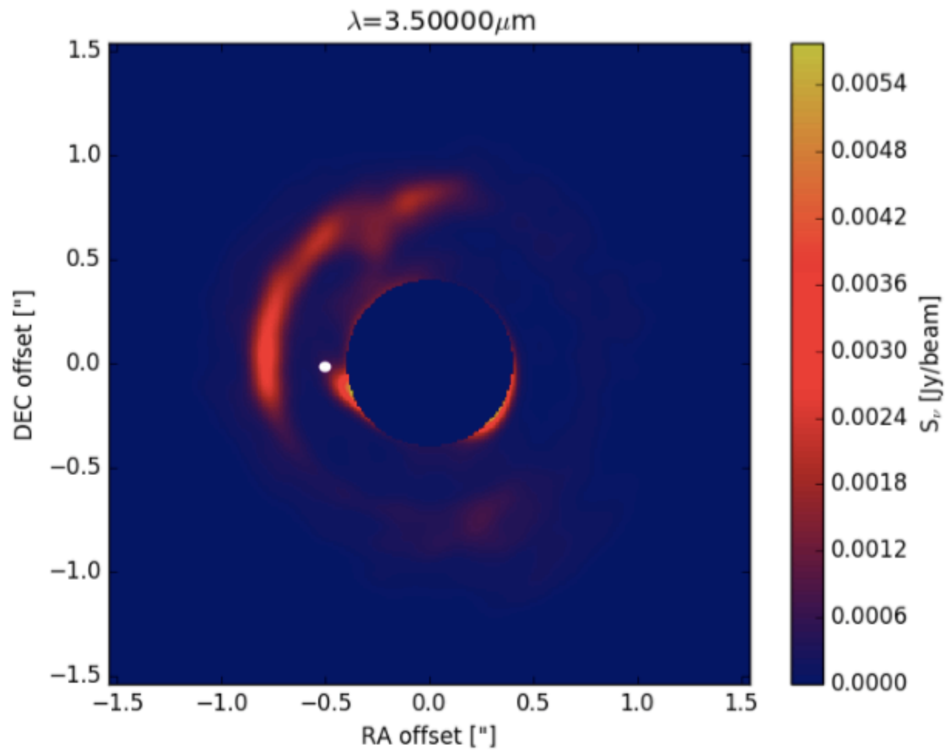




Hord et al. (2017)

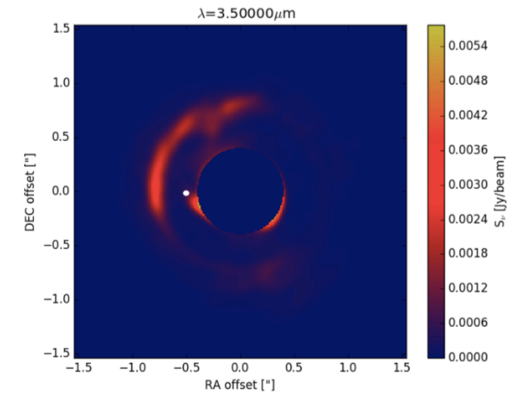
Scattering

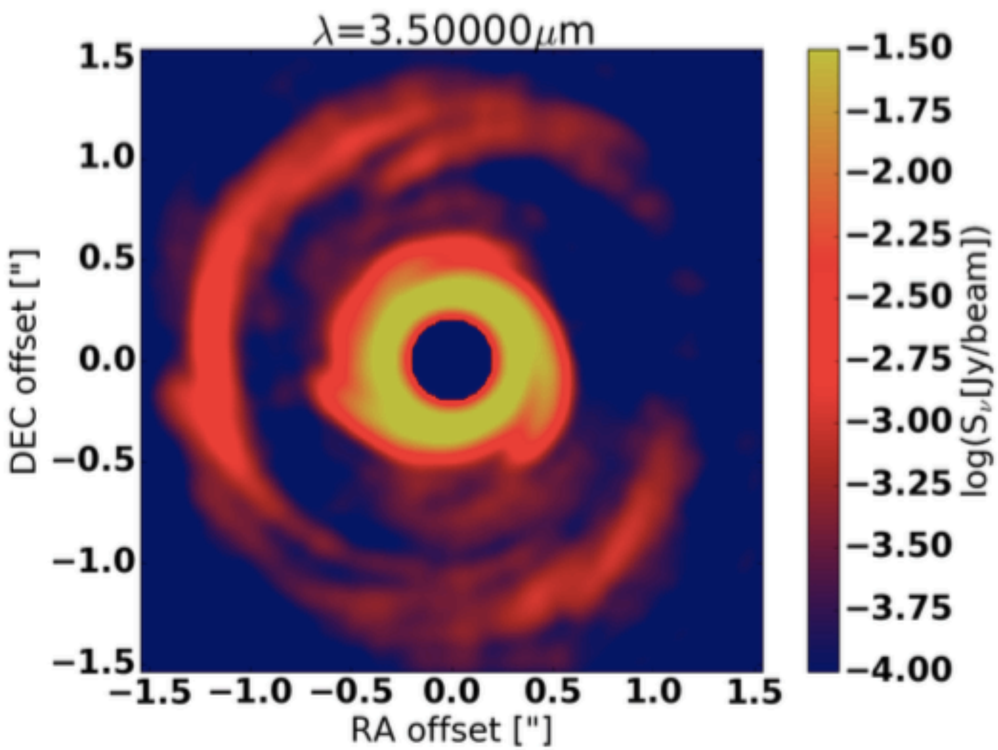


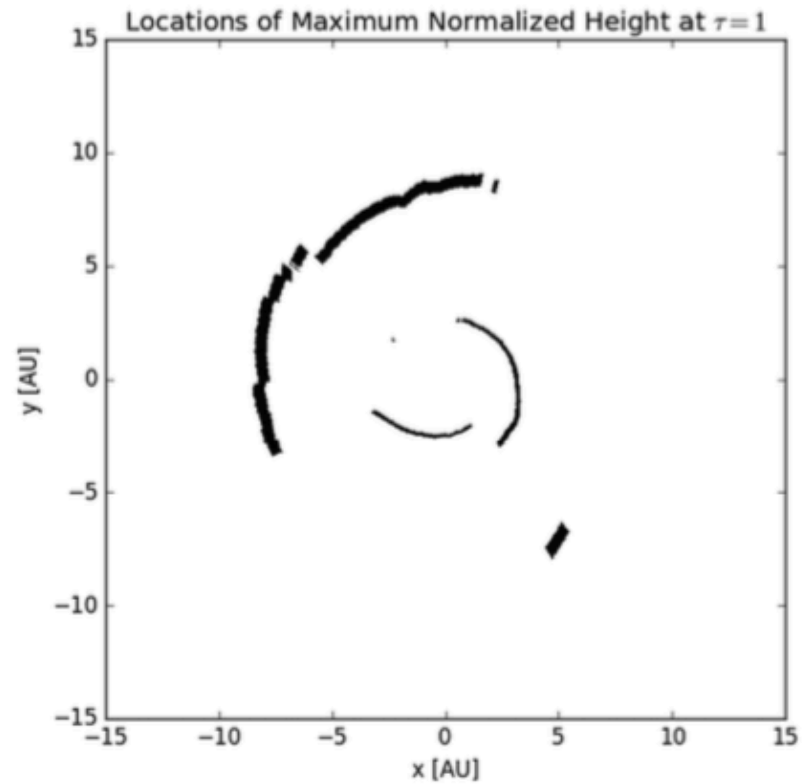


Hord et al. (2017)

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





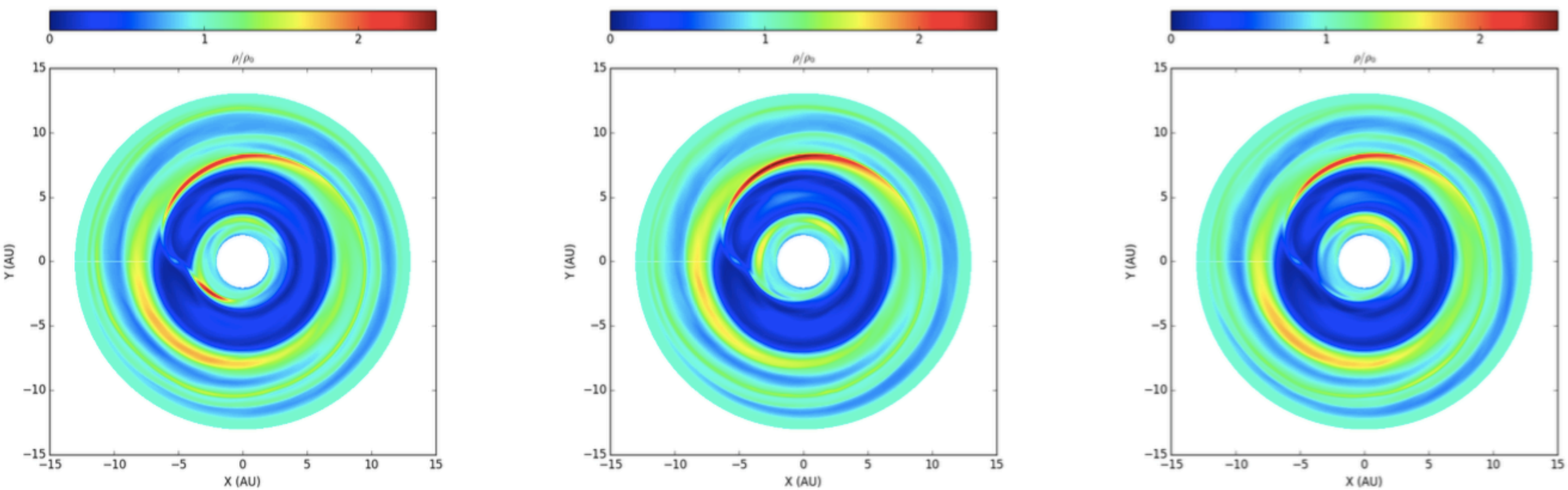


Hord et al. (2017)

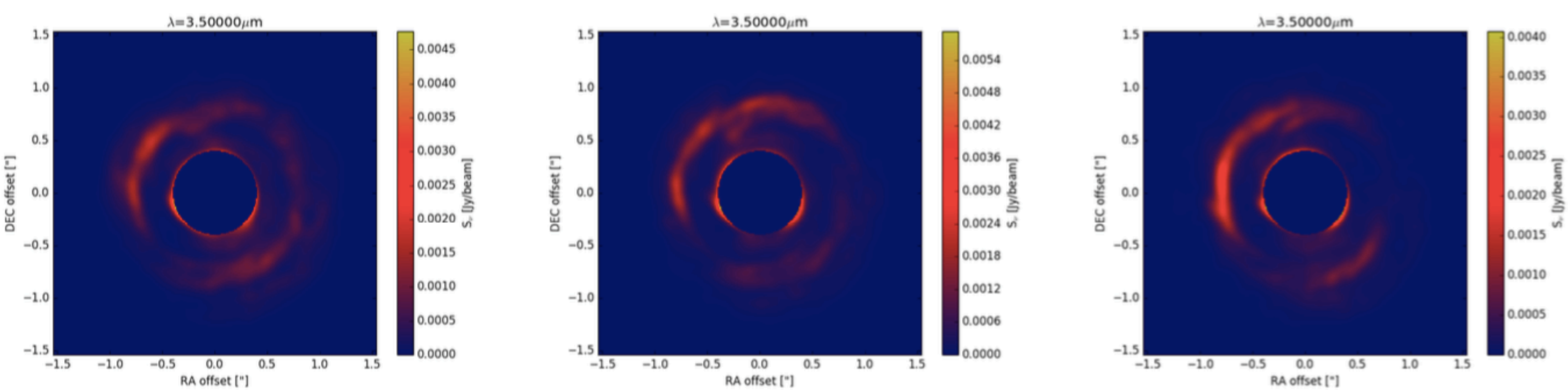
The pattern is stationary

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

Density

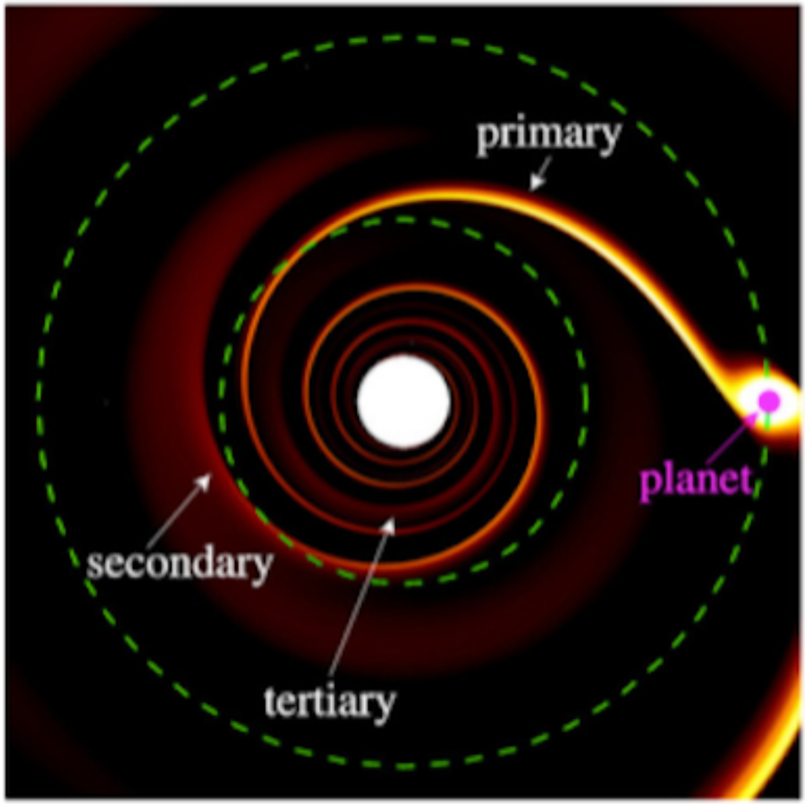


Intensity

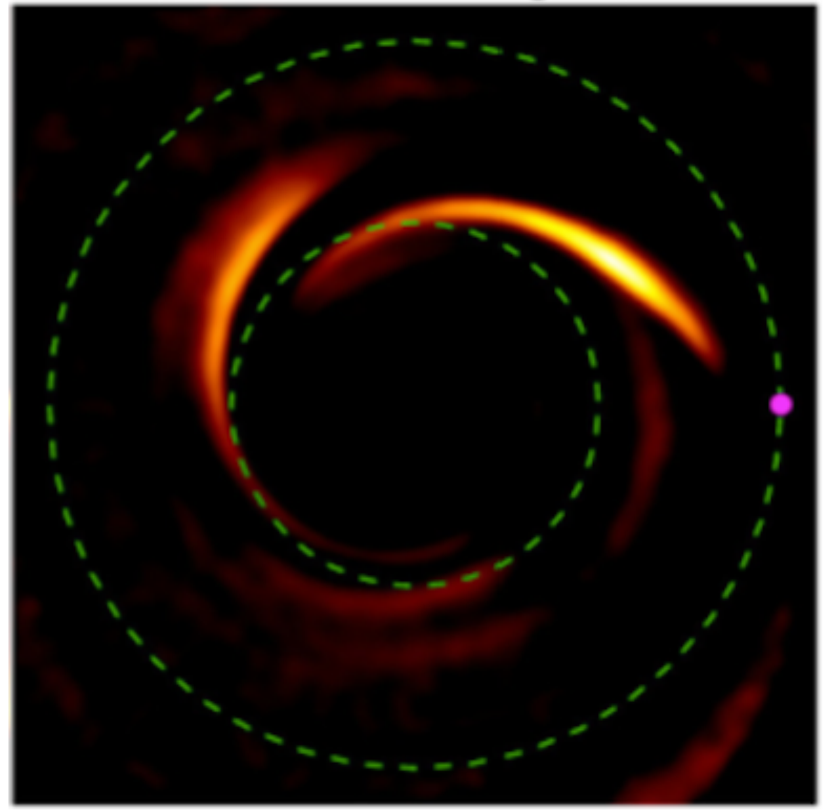


Hord et al. (2017)

Primary and Secondary spiral arms

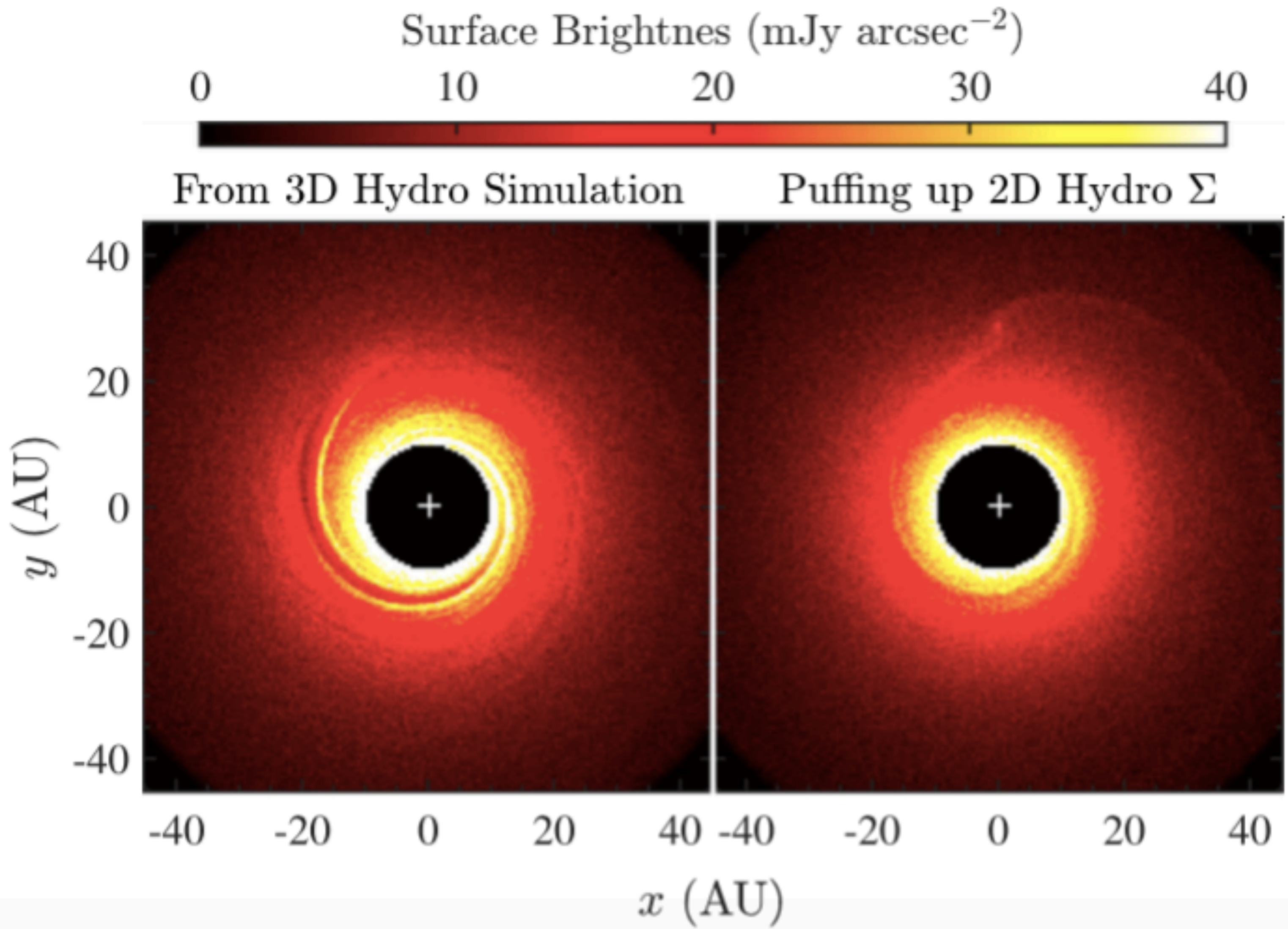


Scattered Light



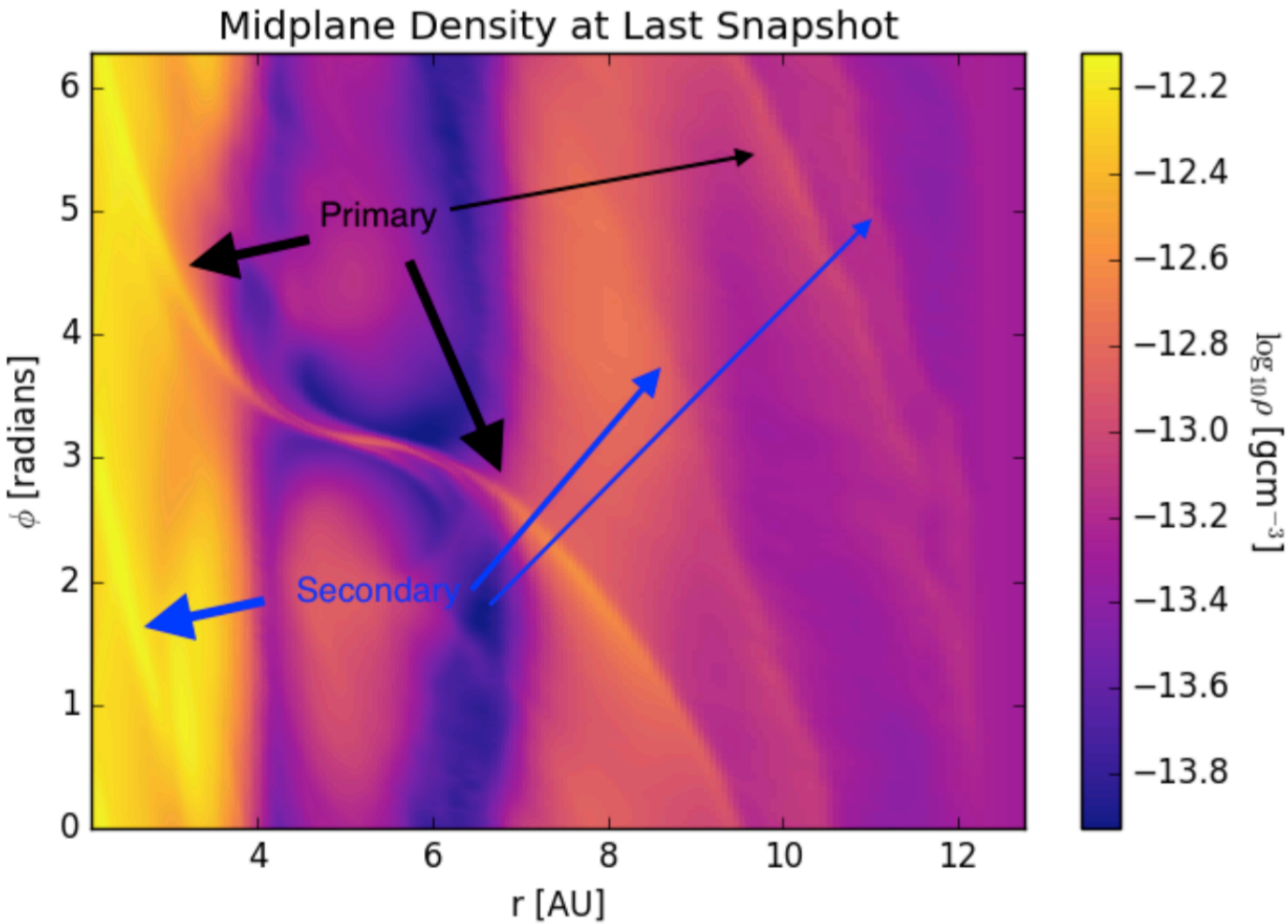
Dong et al. (2015)

3D is needed



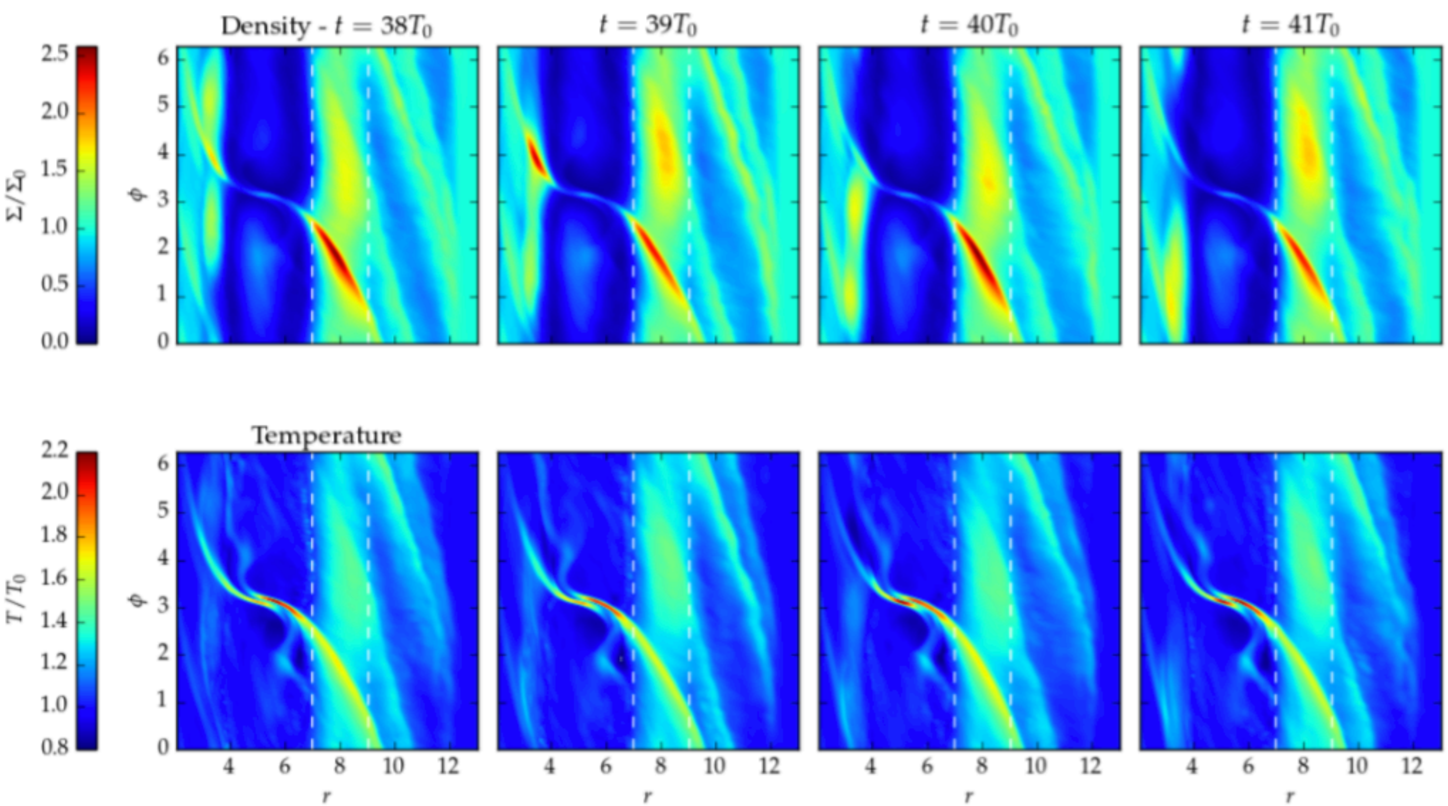
Dong & Fung (2017)

Primary and Secondary spiral arms

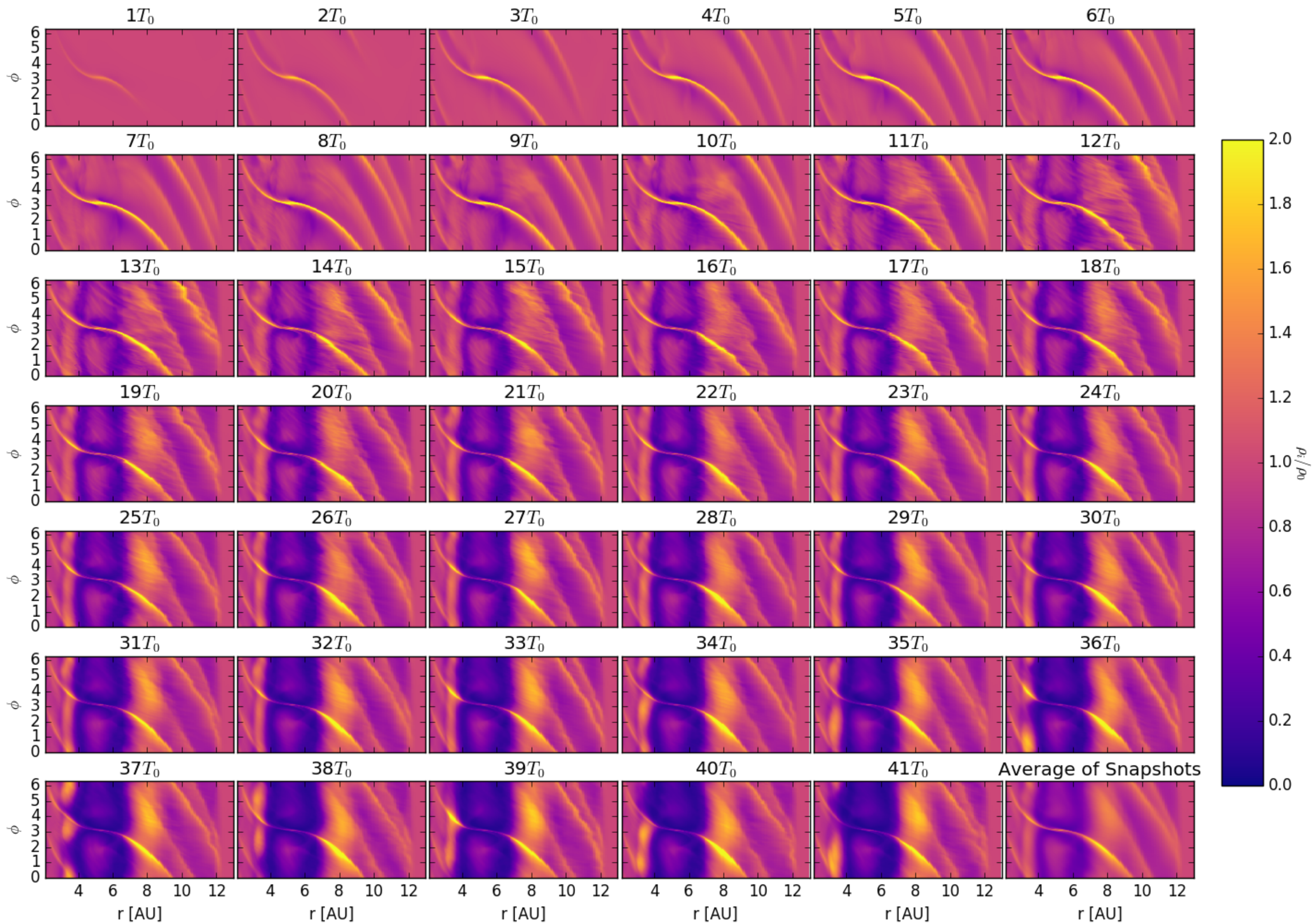


Hord et al. (2017)

Is the stationary pattern a secondary spiral arm?



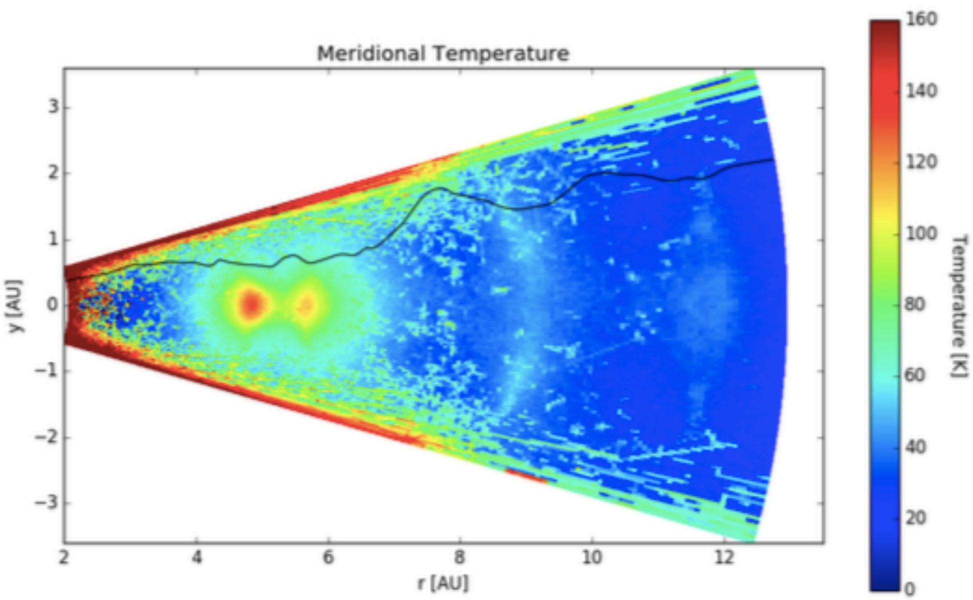
The raised feature has its origins in a secondary spiral arm

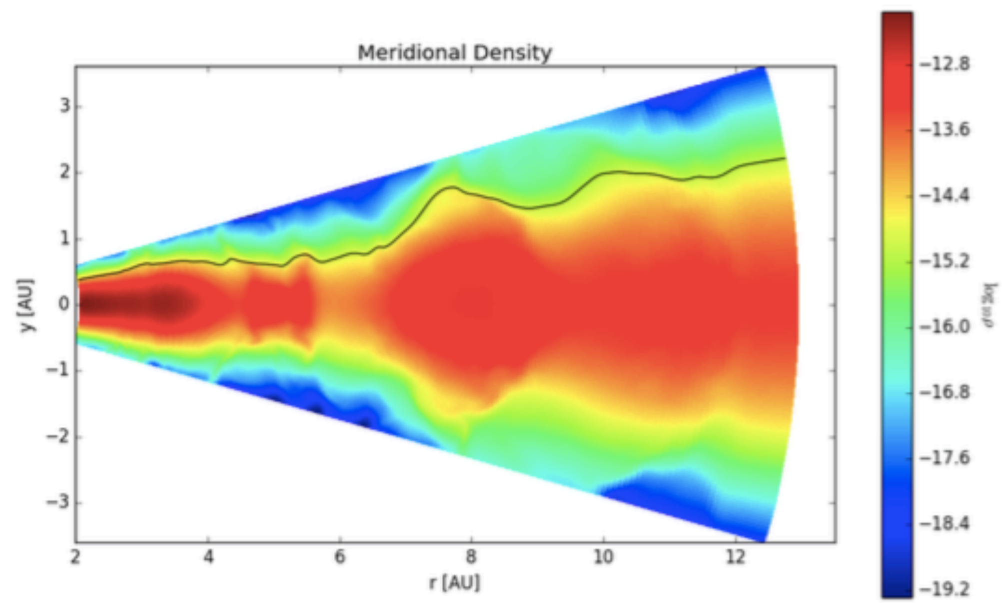


Hord et al. (2017)

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





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