Disk theory meets observations: Planet formation in the era of ALMA

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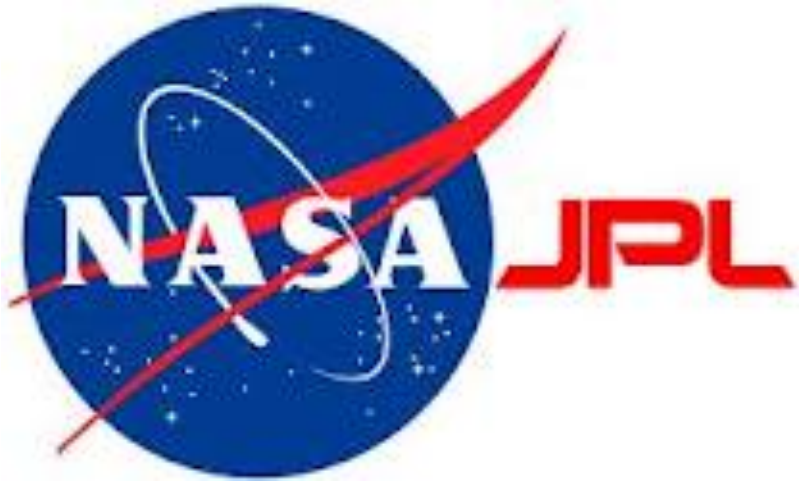
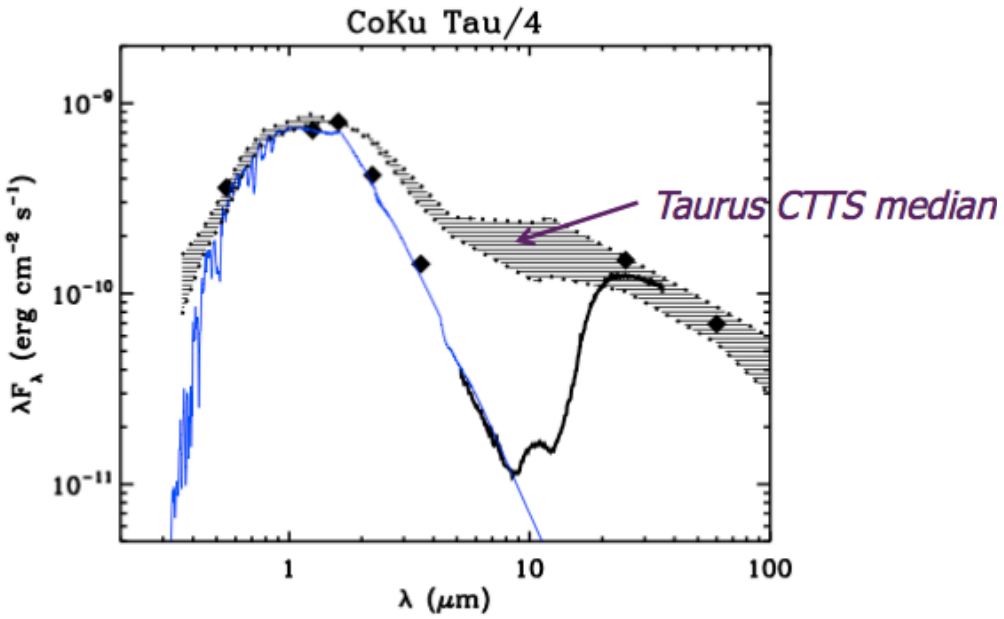
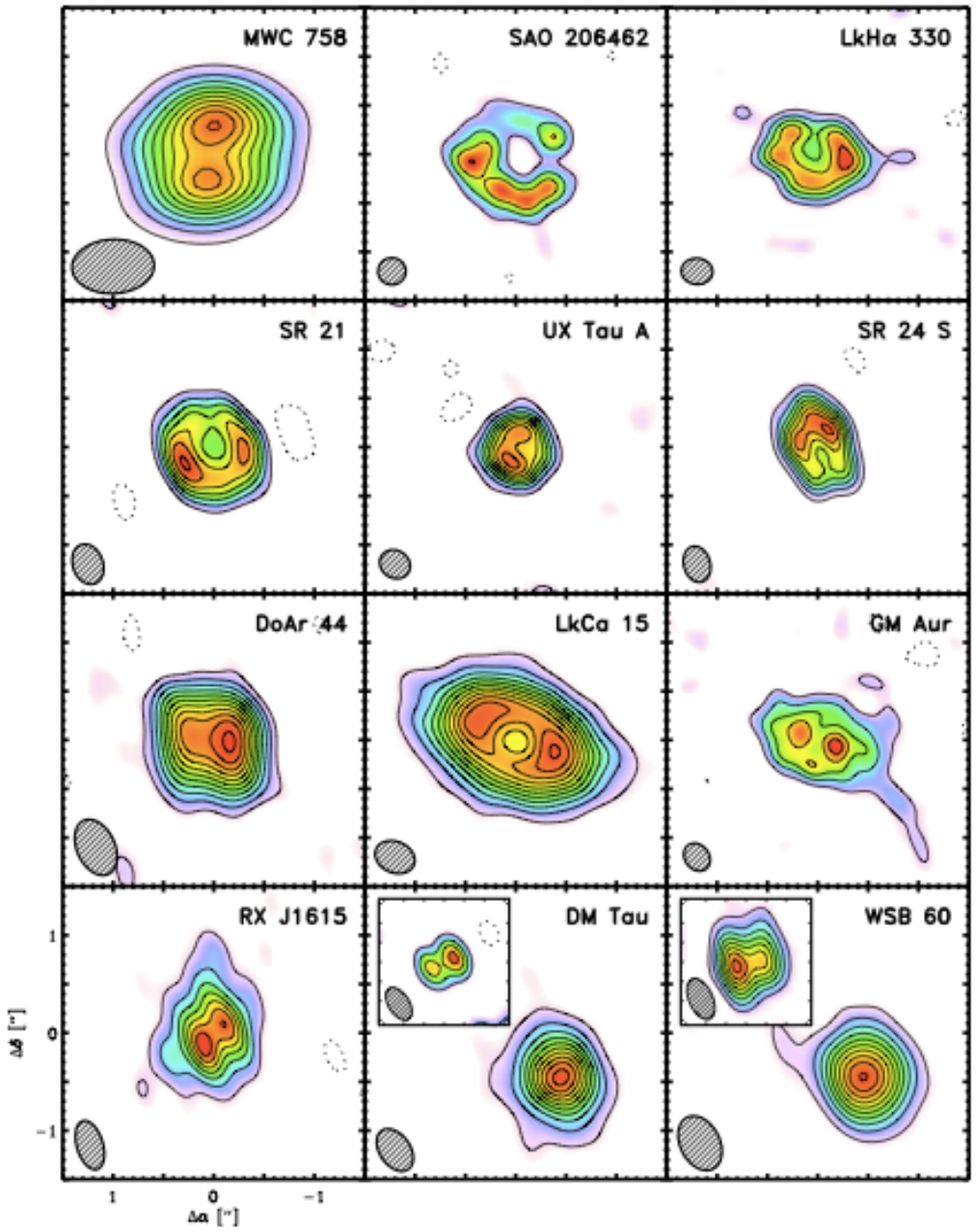


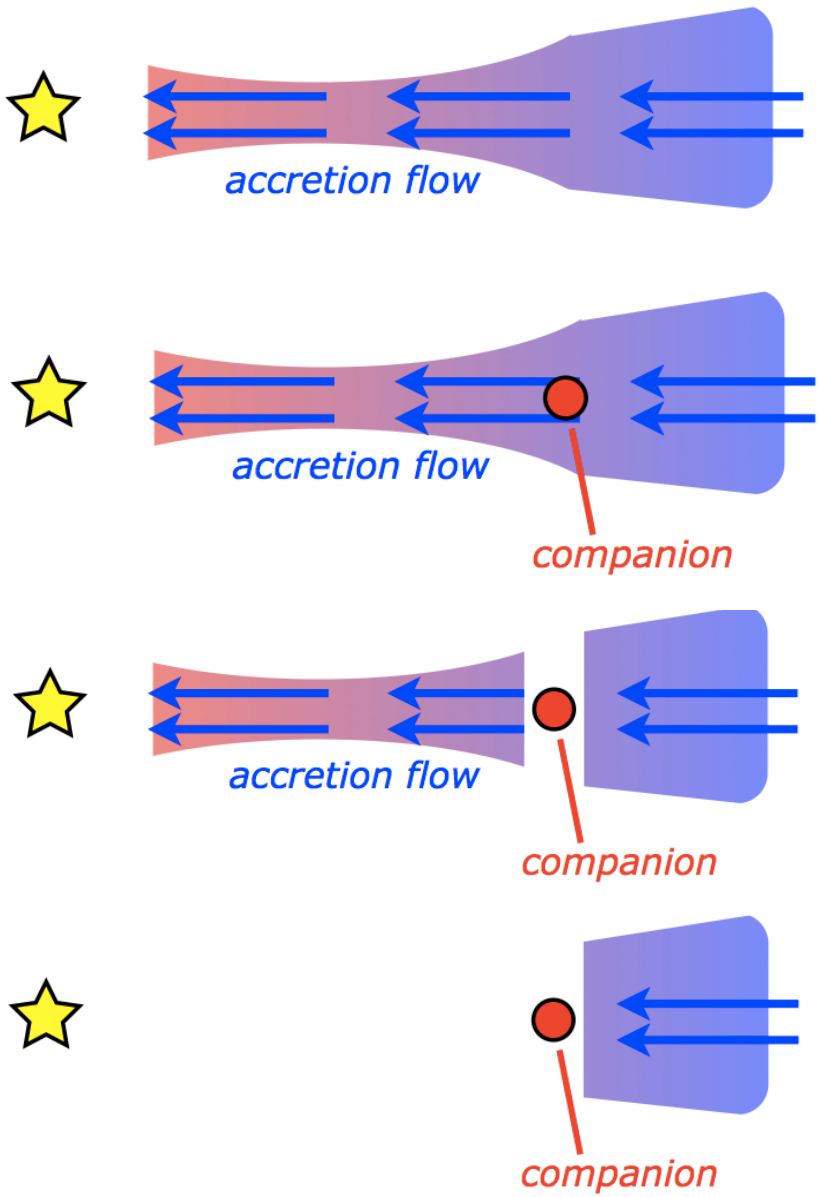
ExSoCal15
Sep 24th, 2015

Transition Disks: Disks with missing hot dust.

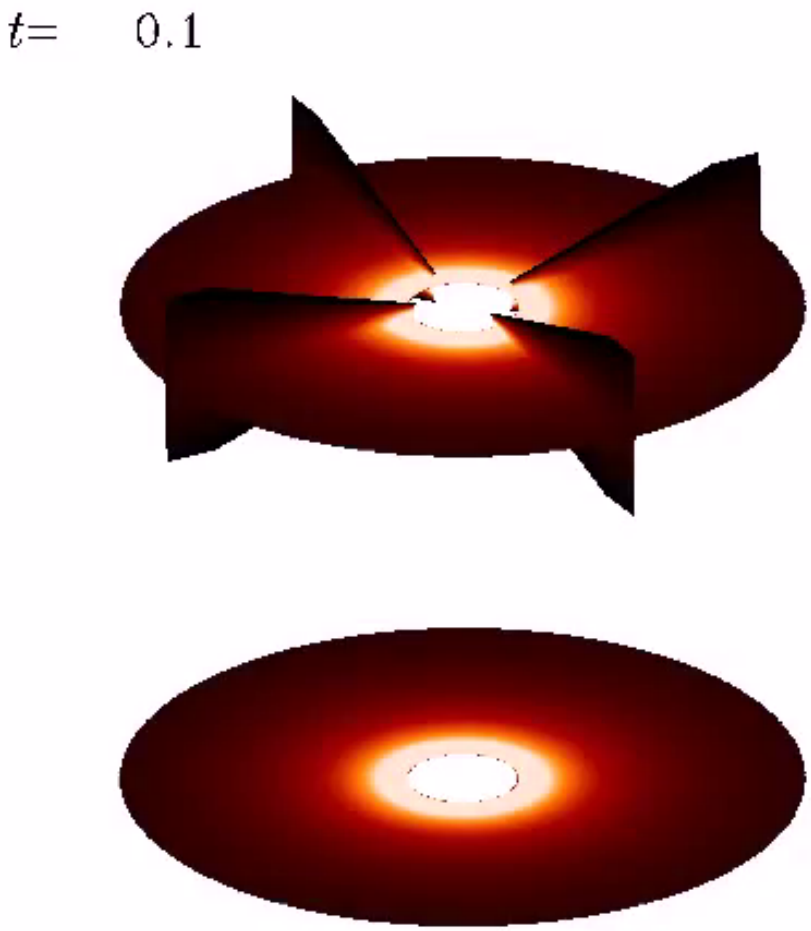




Planetary companion



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

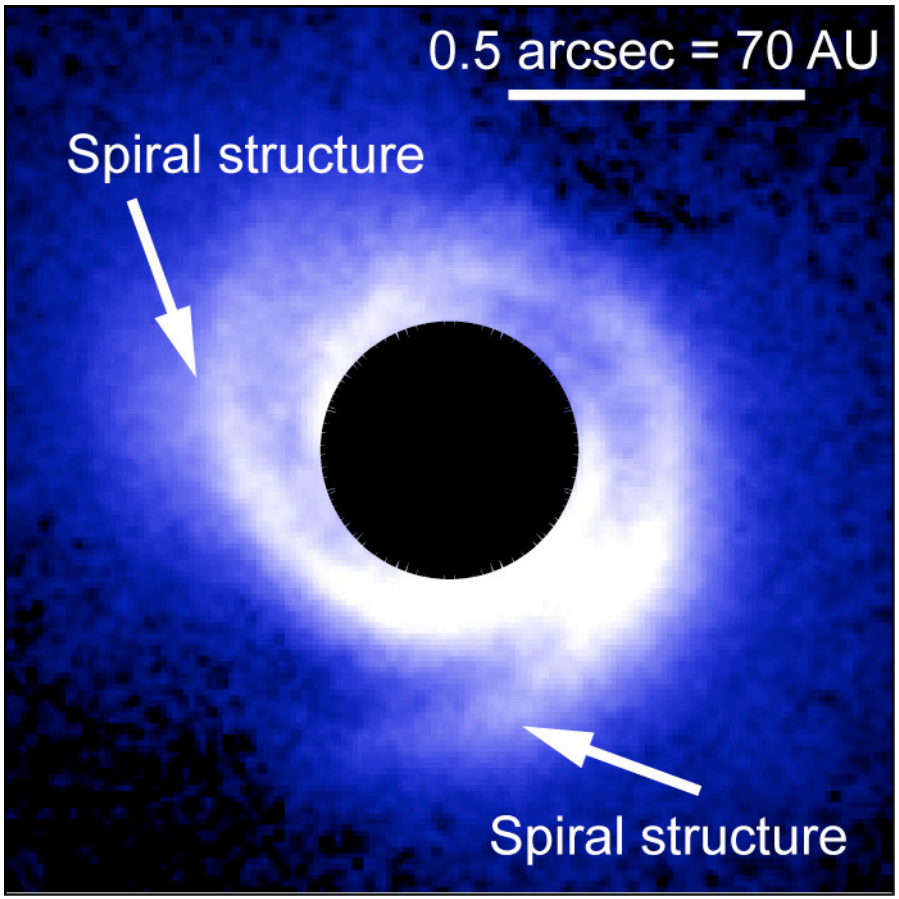


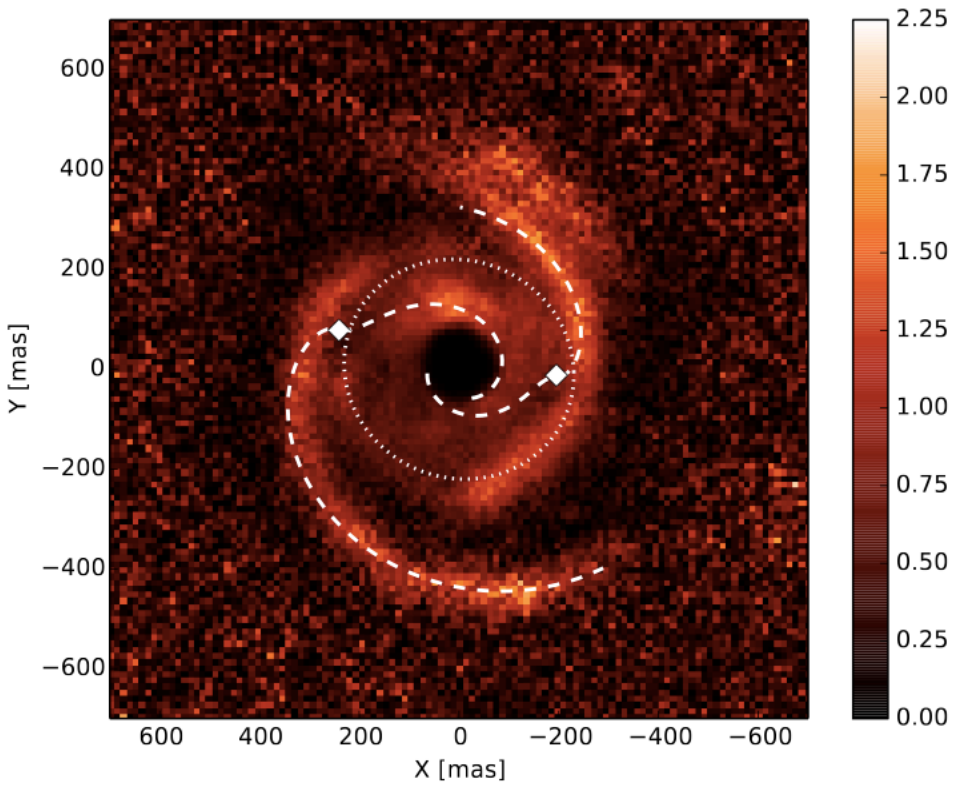
Lyra (2009)

Planet tides carve gap

Gap walls are unstable to Kelvin-Helmholtz instability

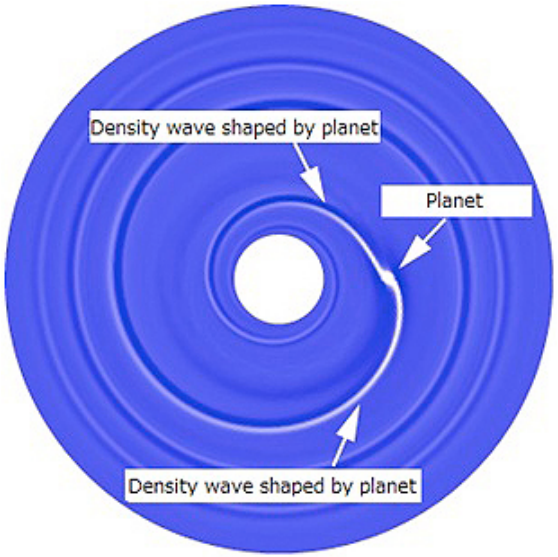
Observational evidence: Spirals





Spiral arm fitting leads to problems

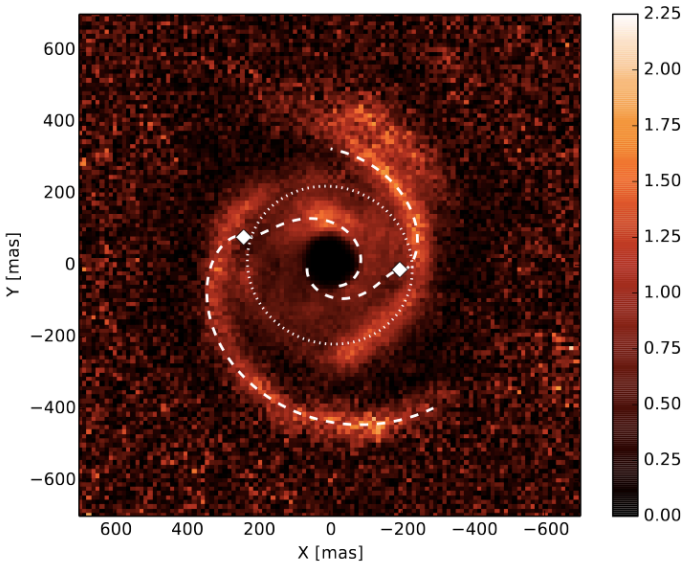
Analytical spiral fit



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

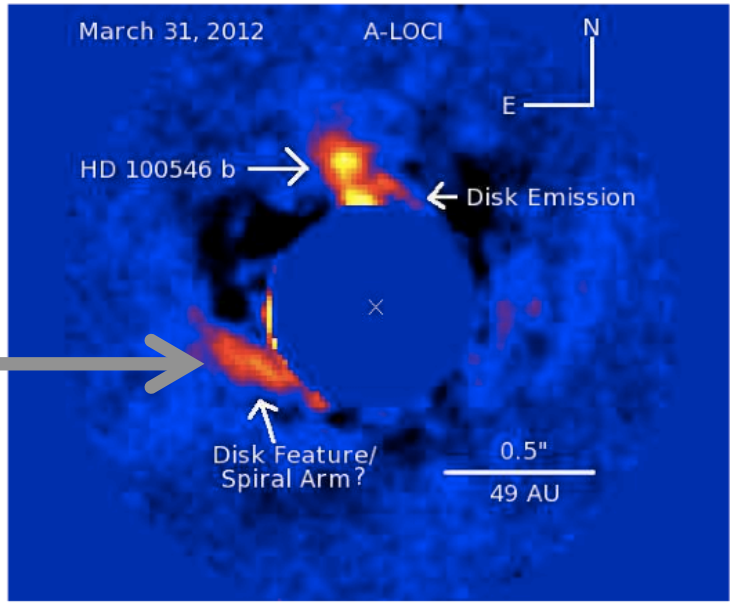
Rafikov (2002)
Muto et al. (2012)

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



Benisty et al. (2015)

Spiral has little polarization. Must be thermal emission at 1000K.

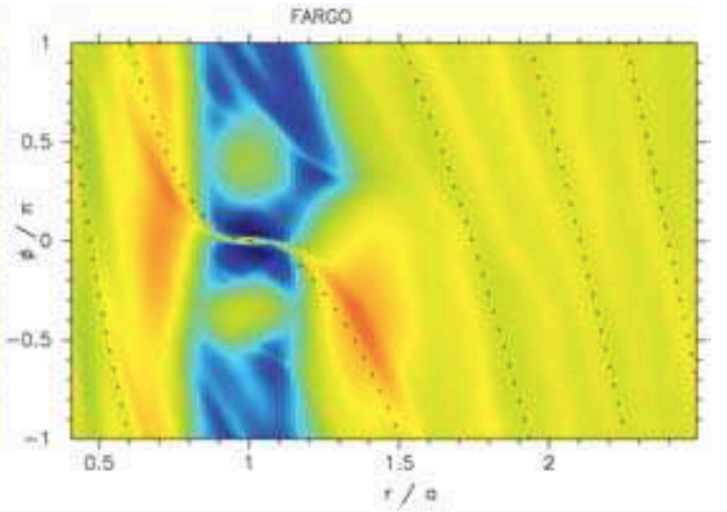


Currie et al. (2014)

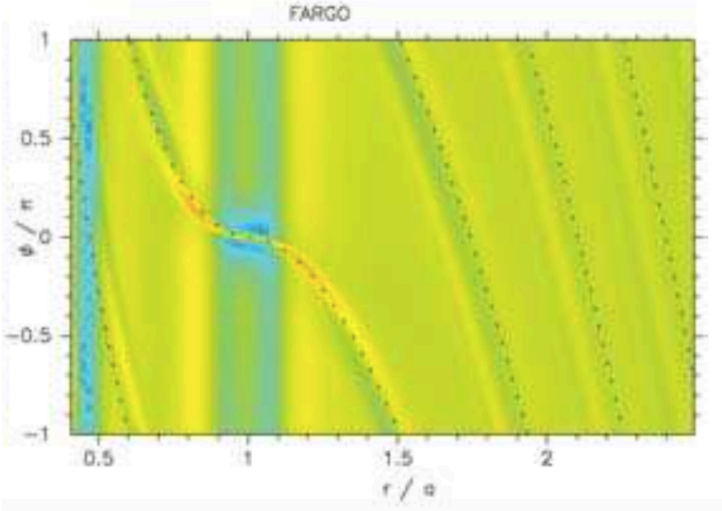
The “hot spiral problem” has never been a problem

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

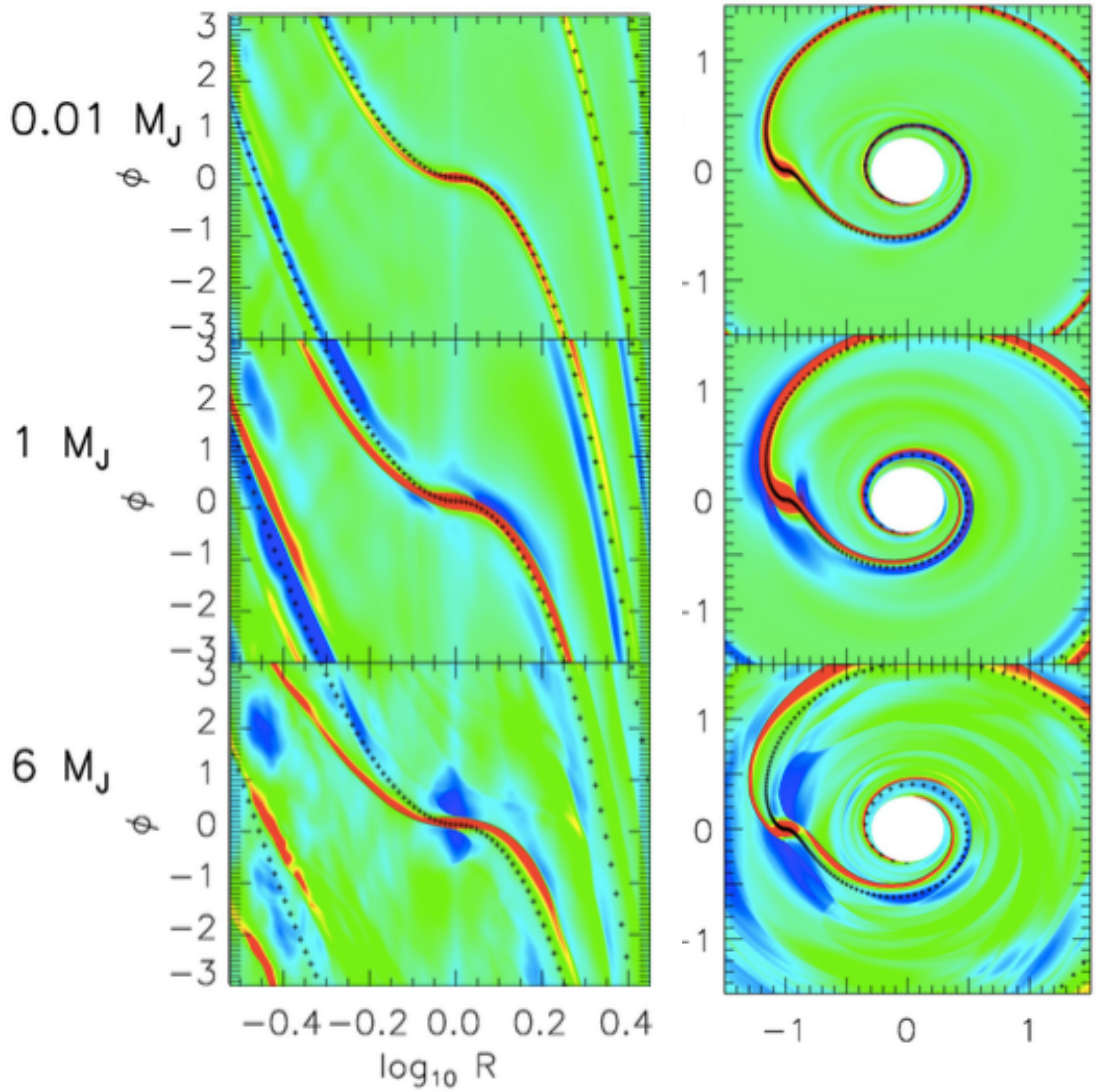
Jupiter-mass (non-linear)



Neptune-mass (linear)

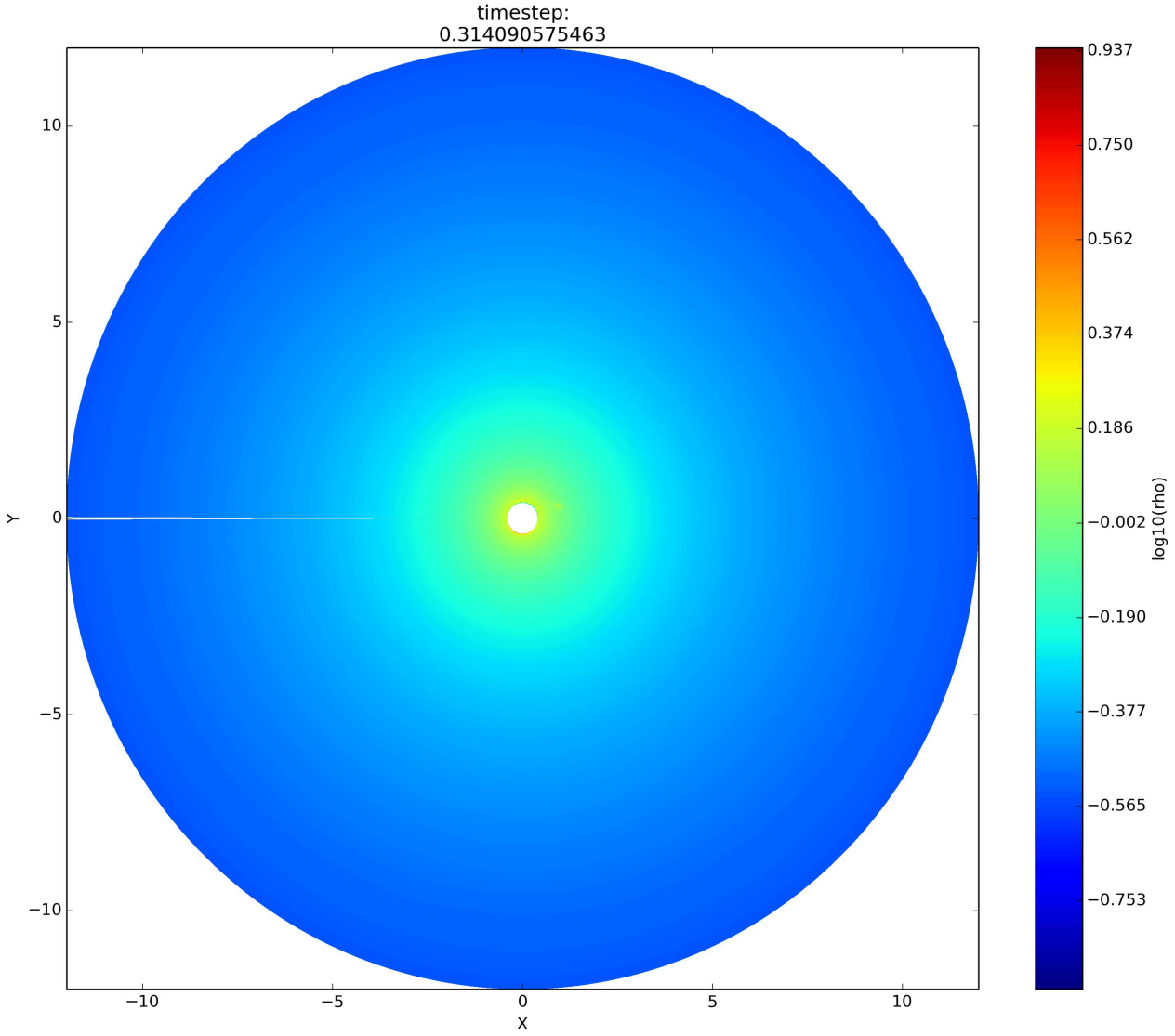


de Val-Borro al. (2006)



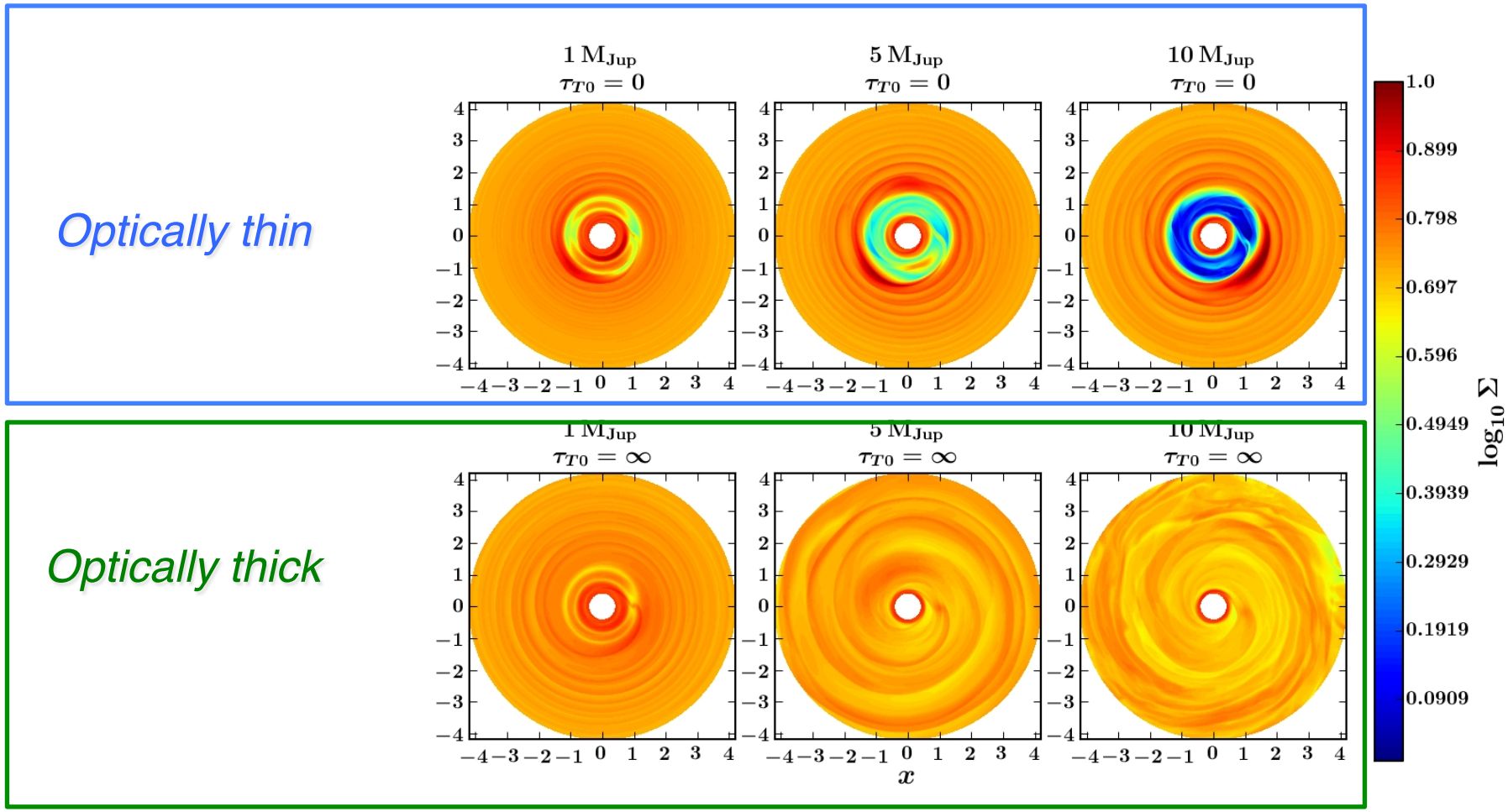
Zhu et al. (2015)

Spiral ake of high-mass planets in non-isothermal disks



Richert et al. (2015)

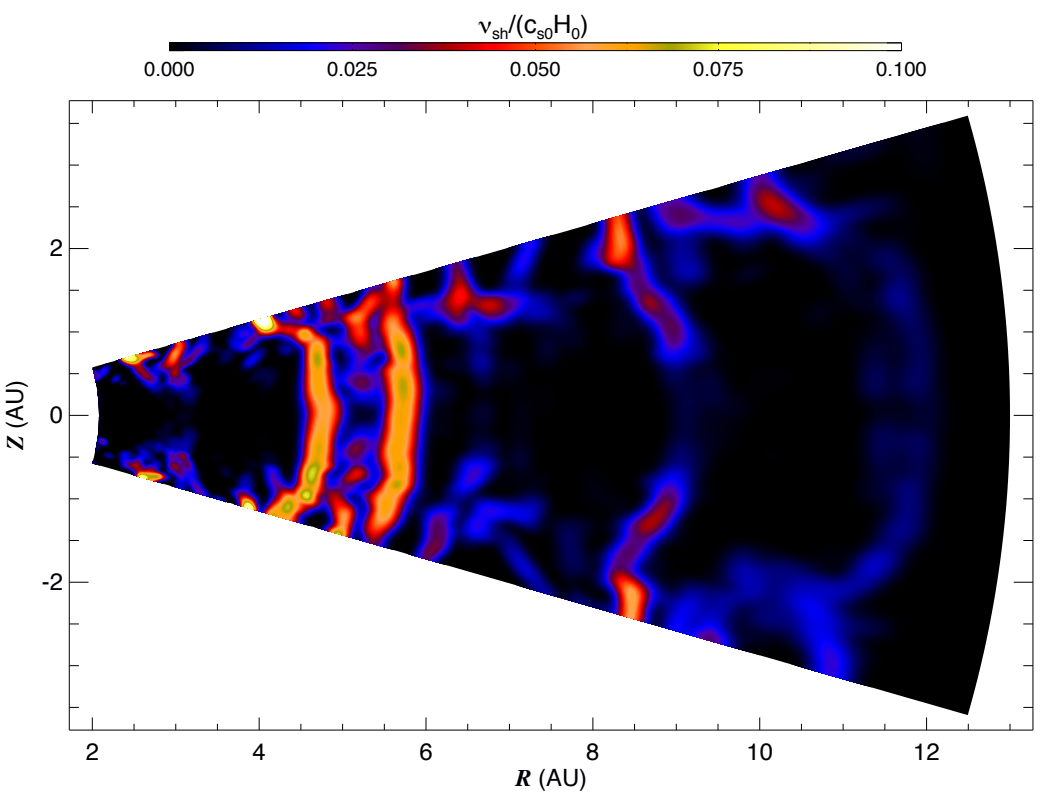
Shows up for high-mass planets in optically thick disks



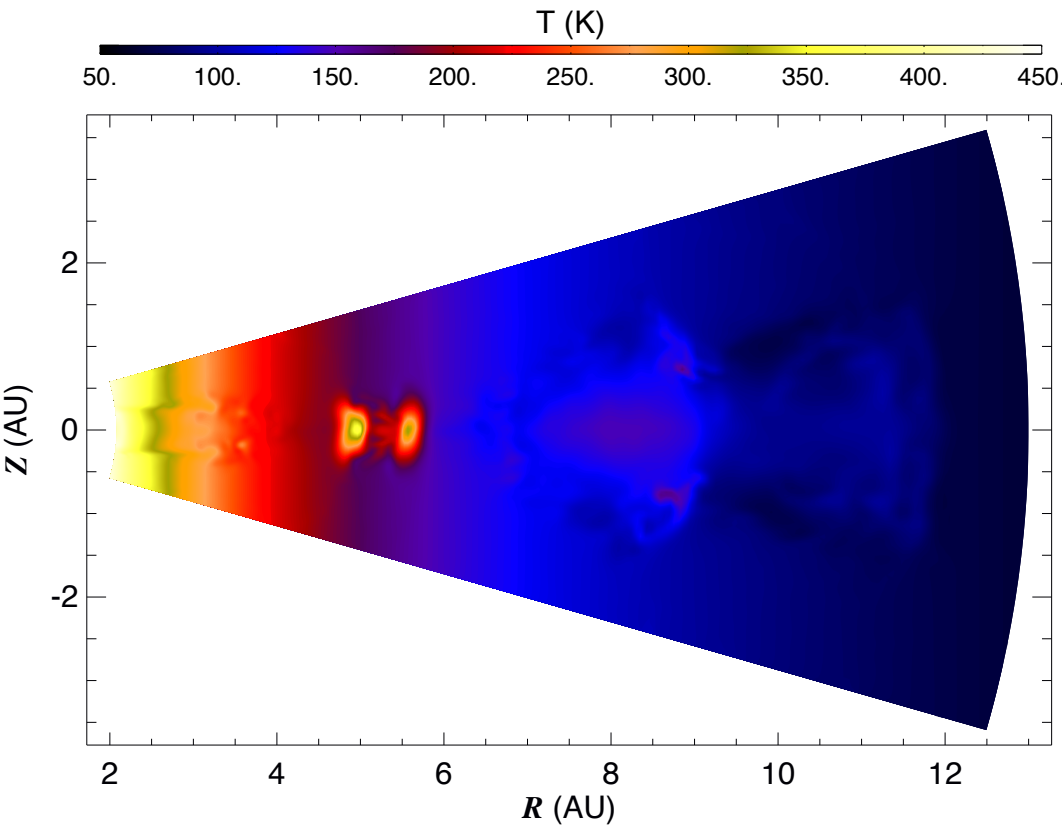
Richert et al. (2015)

Shock bores

Velocity convergence

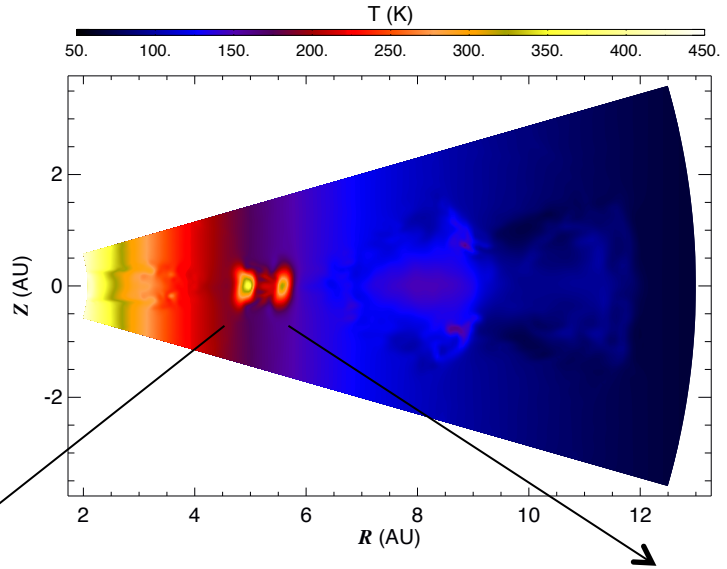


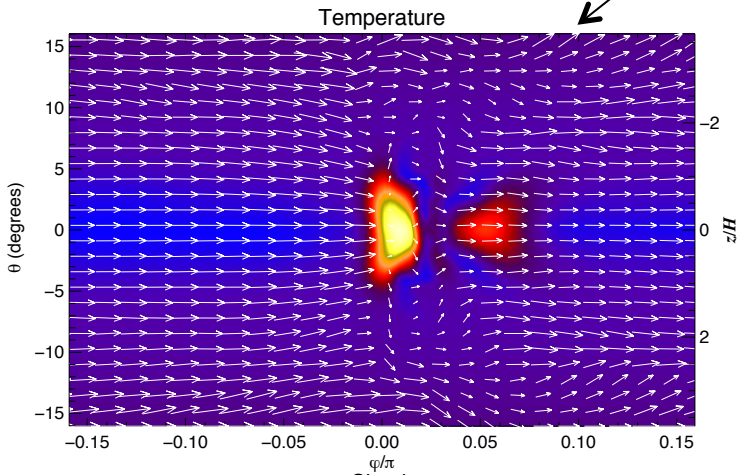
Temperature

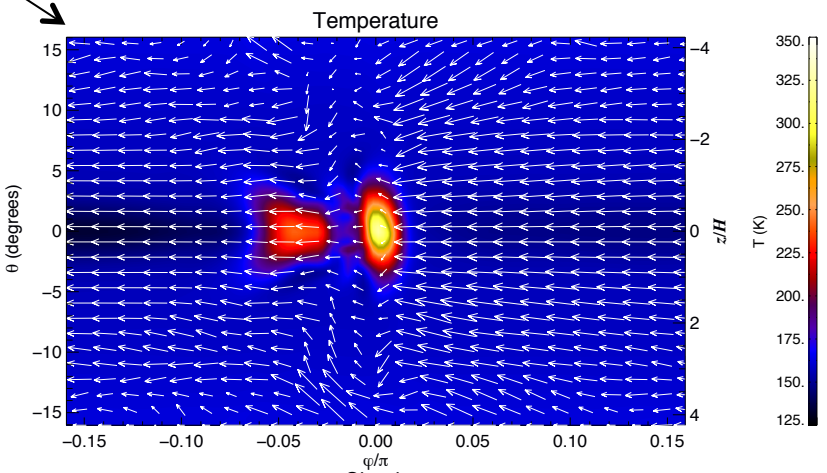


Lyra et al. (2015b, submitted)

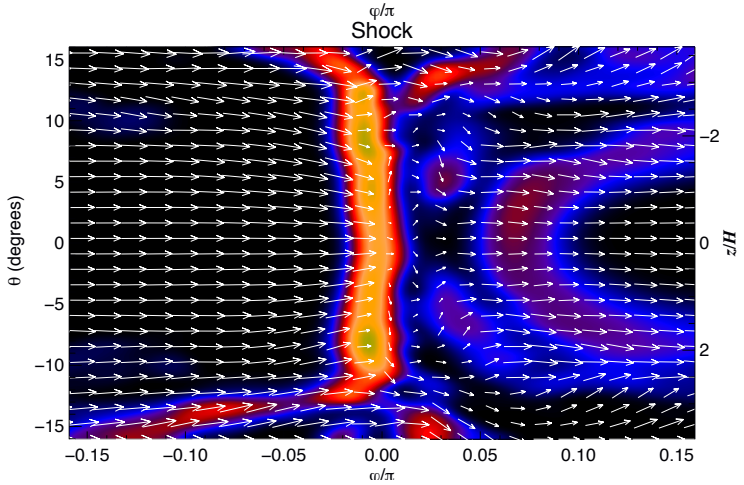
3D shocks: bores and breaking waves

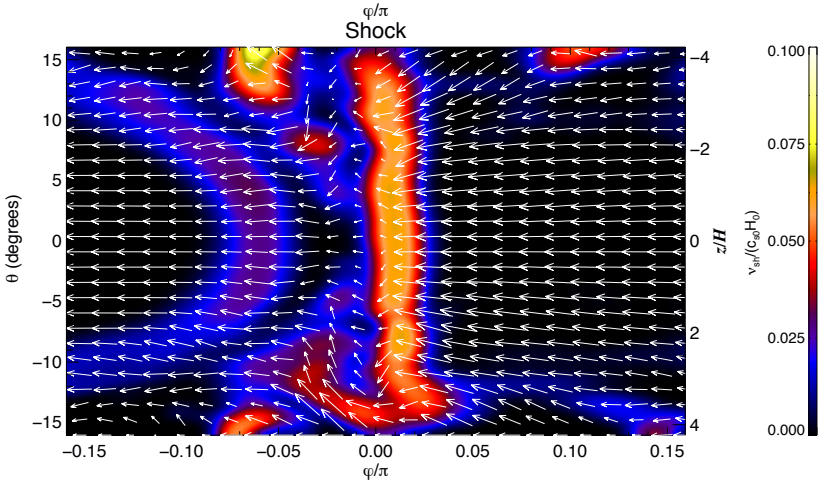






Temperature

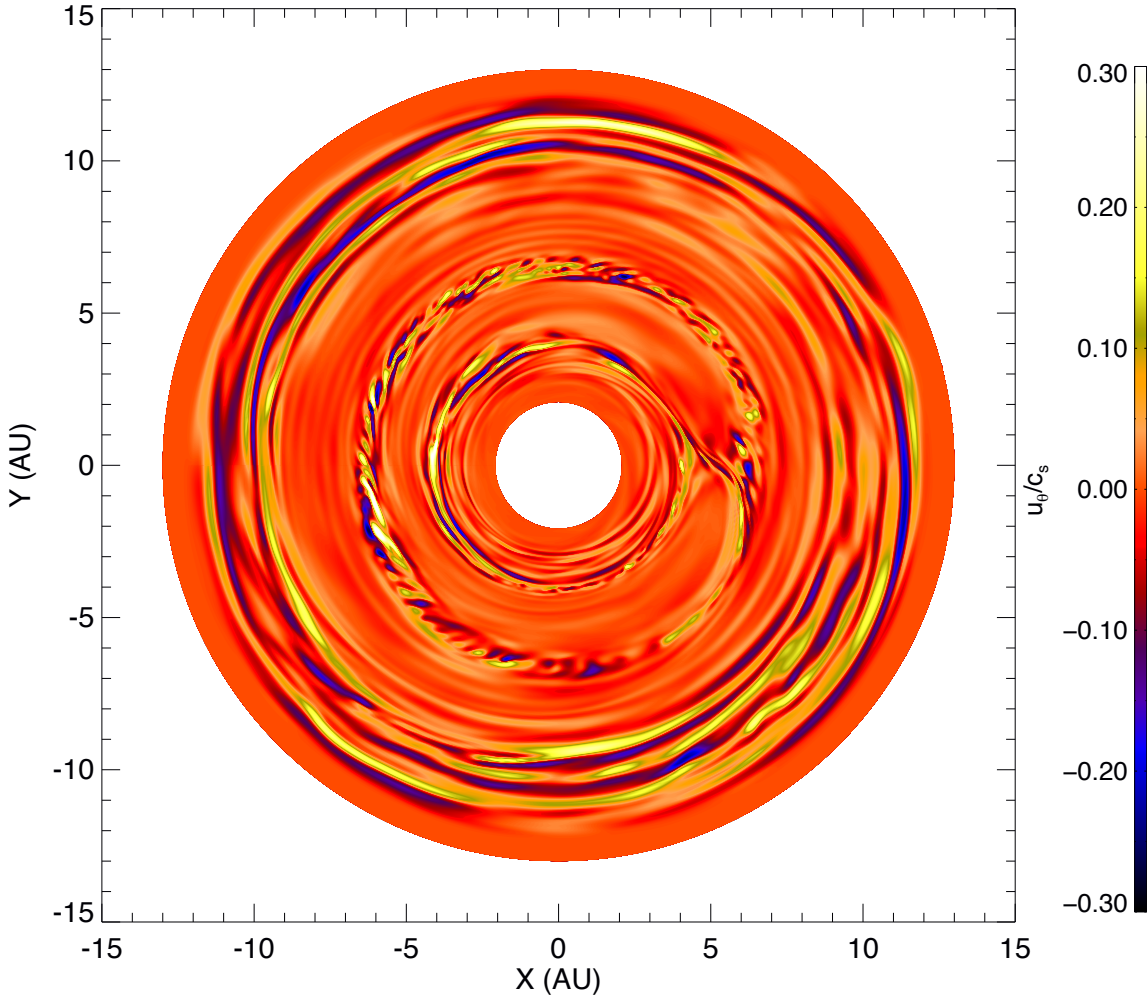




Div u
(shock)

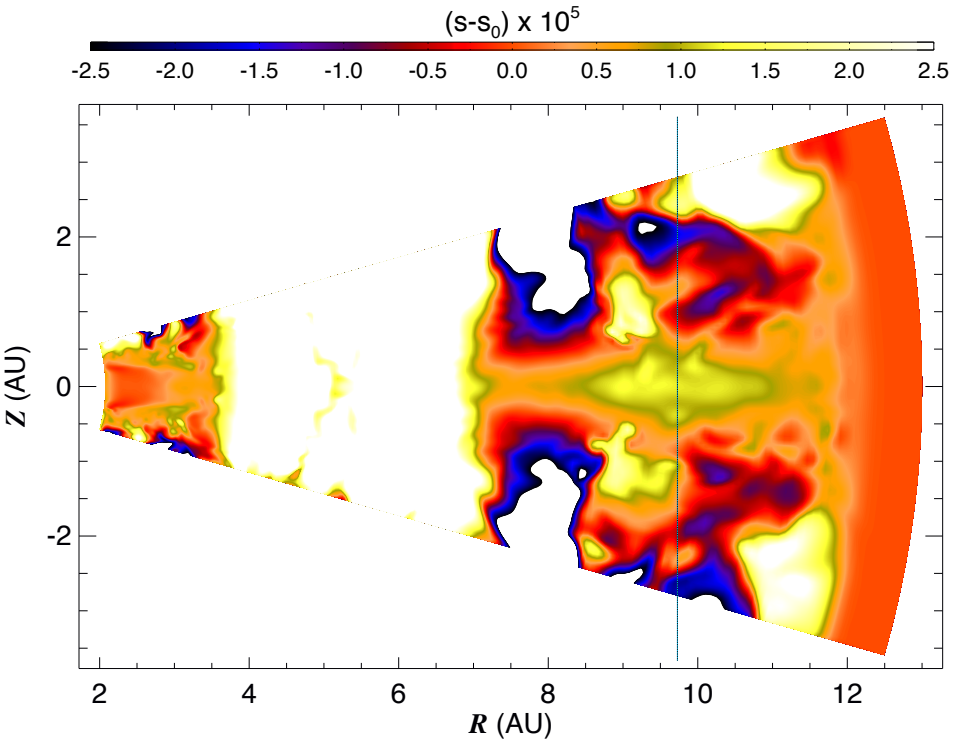
Lyra et al. (2015b, submitted)

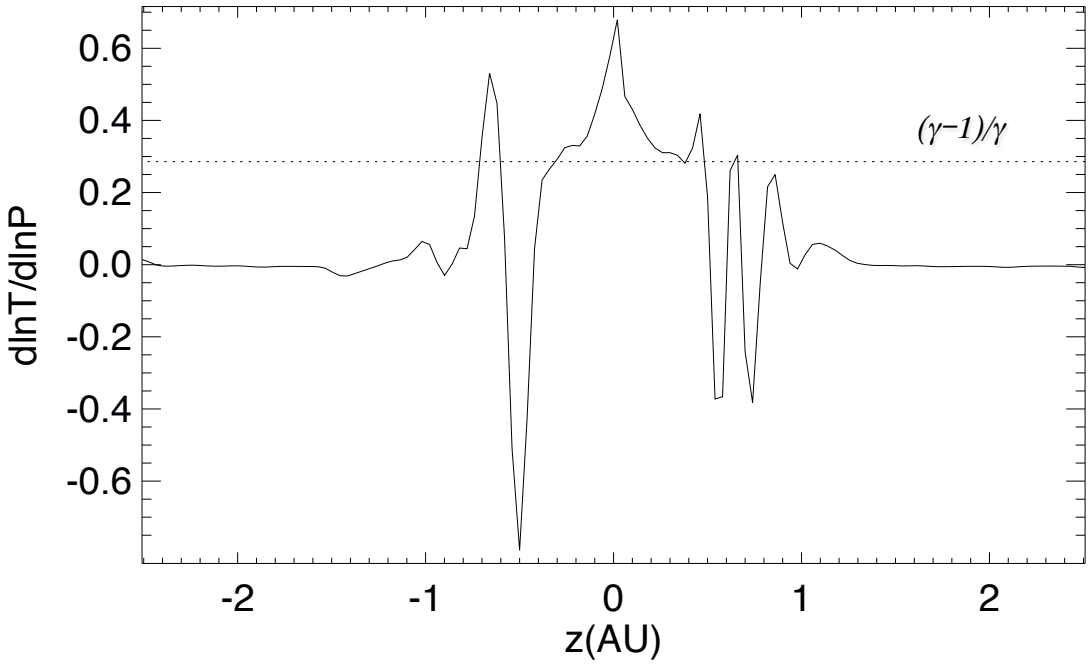
Turbulent surf



Lyra et al. (2015b, submitted)

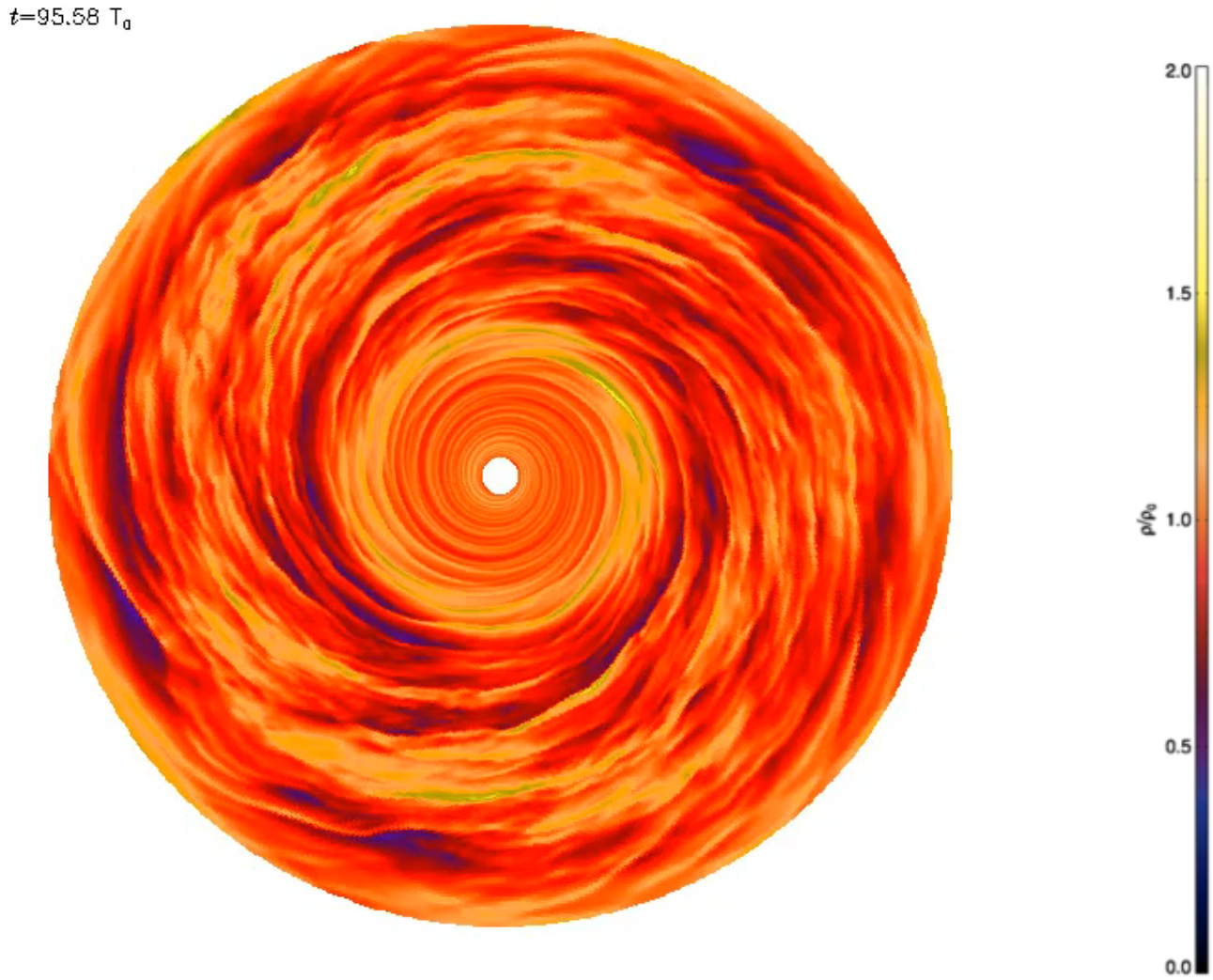
Convection





Lyra et al. (2015b, submitted)

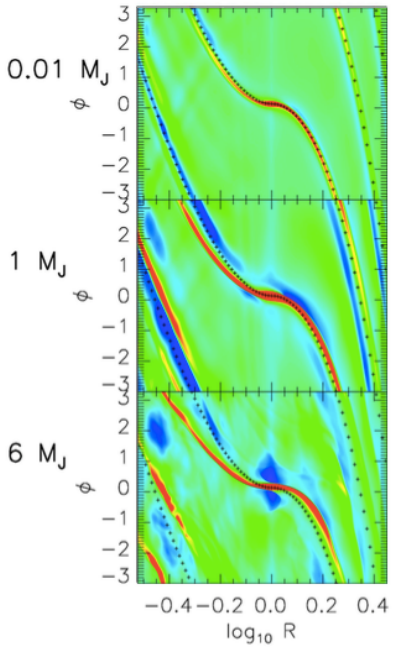
Spirals without planets

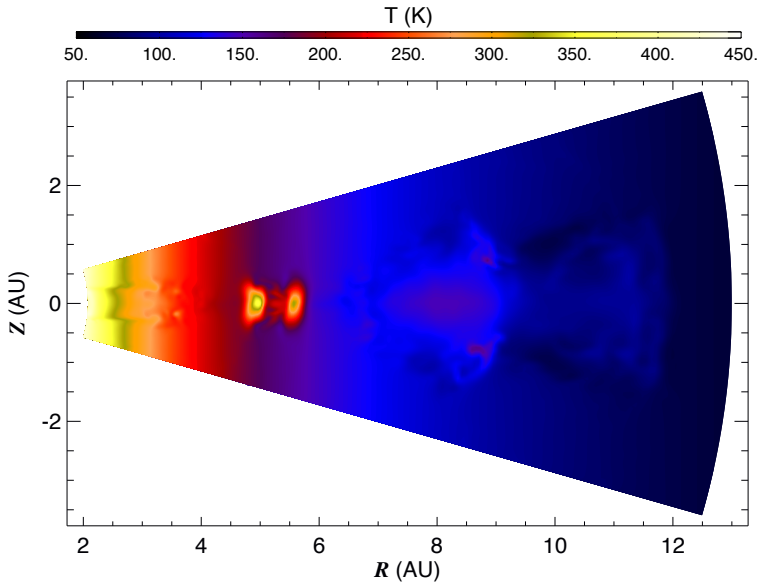


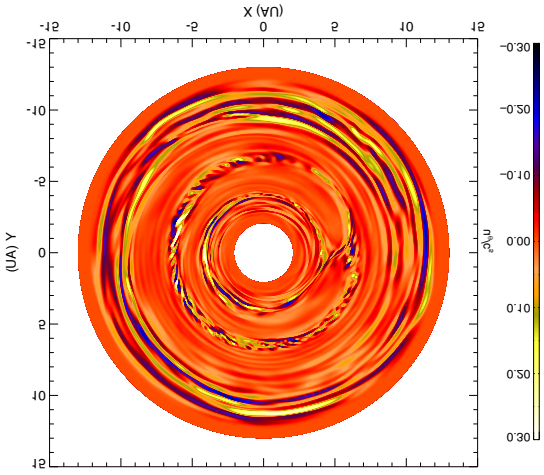
Lyra et al (2015a)

Summary and Conclusions

- Shocks due to high mass planets yield good fits to observed spirals.
- In addition to **supersonic pitch angles**, we predict:
  - **high-temperature lobes** and **turbulent surf** near the planet
  - **convection** far from the planet's orbit
- Waves propagating into non-turbulent regions will be shaped into spirals (***careful before you shout "Planet!"***)







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  - **convection** far from the planet's orbit
- Waves propagating into non-turbulent regions will be shaped into spirals (***careful before you shout "Planet!"***)
- We're in the era of observational testing/confirmation of our model predictions!