Warps in transition disks

Simon Casassus et al.
Universidad de Chile

http://www.das.uchile.cl/~simon

Hydro/obs postdoc position available!

Monash 2019

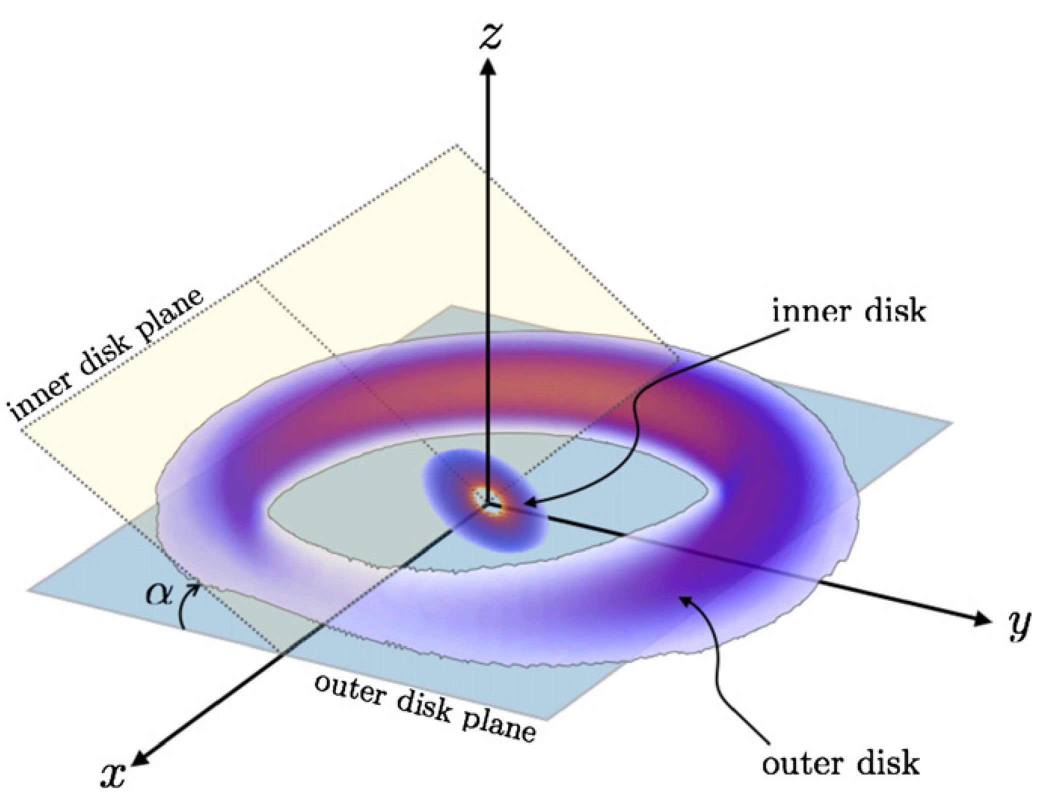
Outline

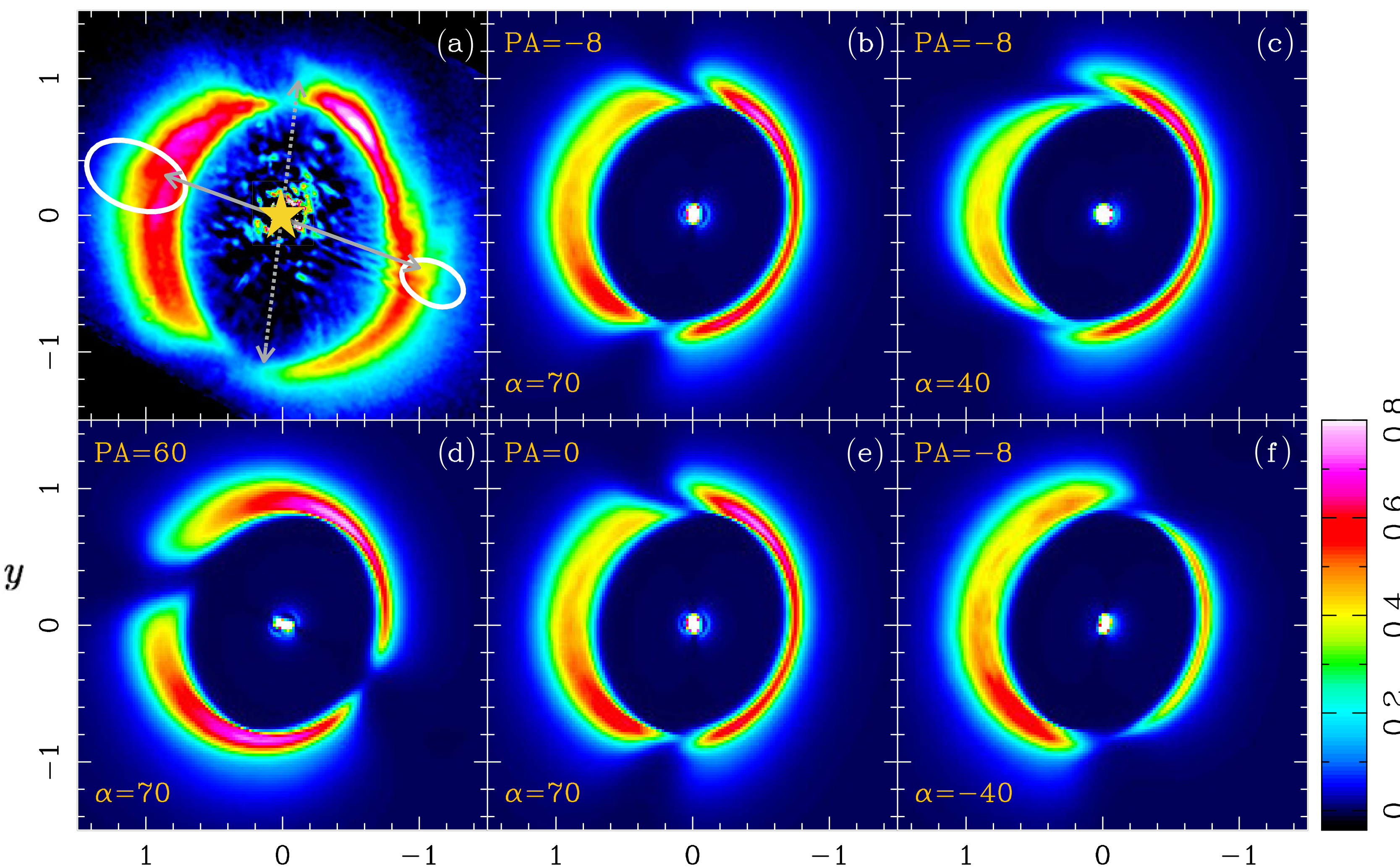
1. The sharp warp in HD142527
2. A few more warps
3. What can we learn from warps?
4. Summary

Outline

1. **The sharp warp in HD142527**
2. A few more warps
3. What can we learn from warps?
4. Summary

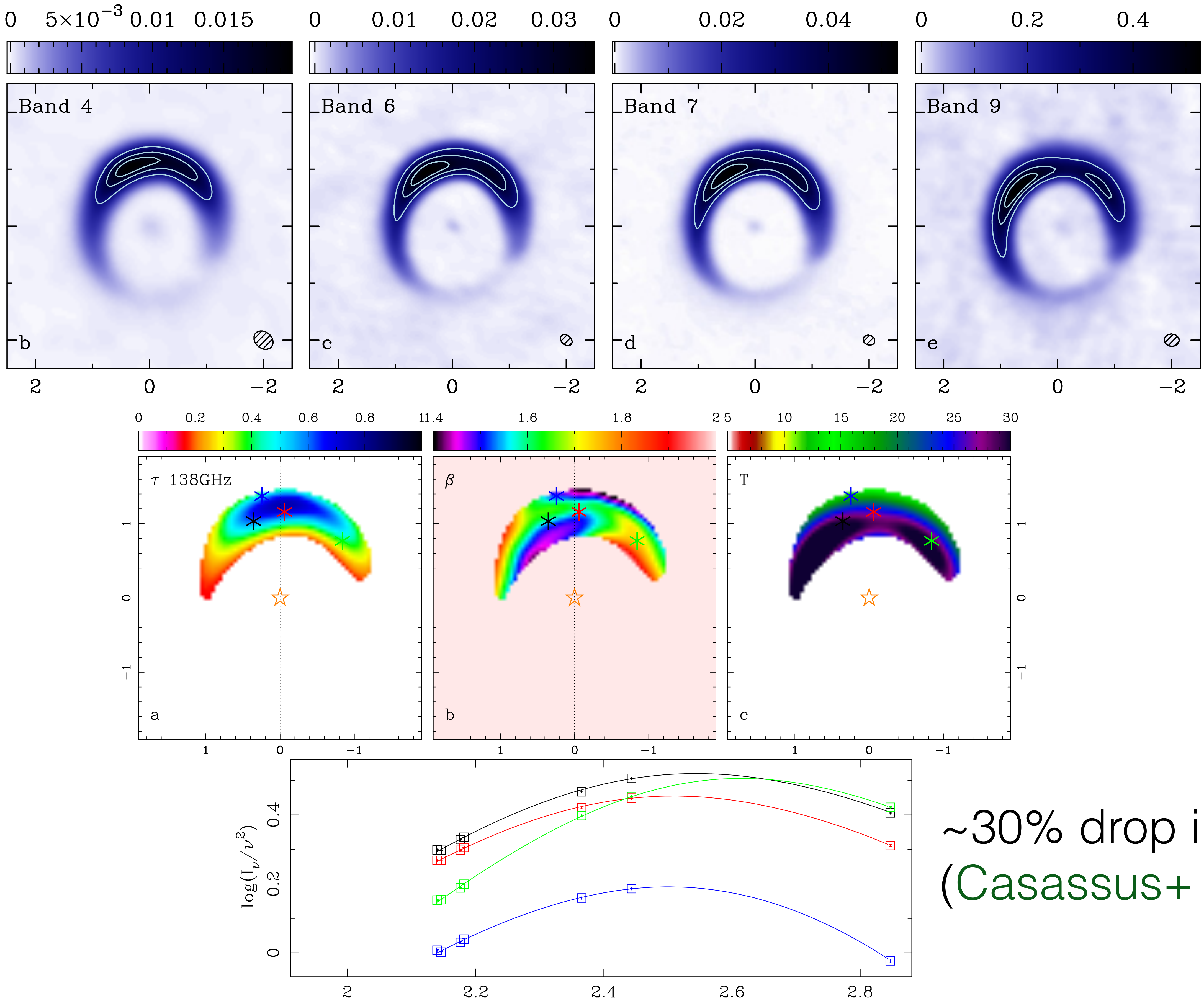
HD 142527: clear case for a 70deg warp





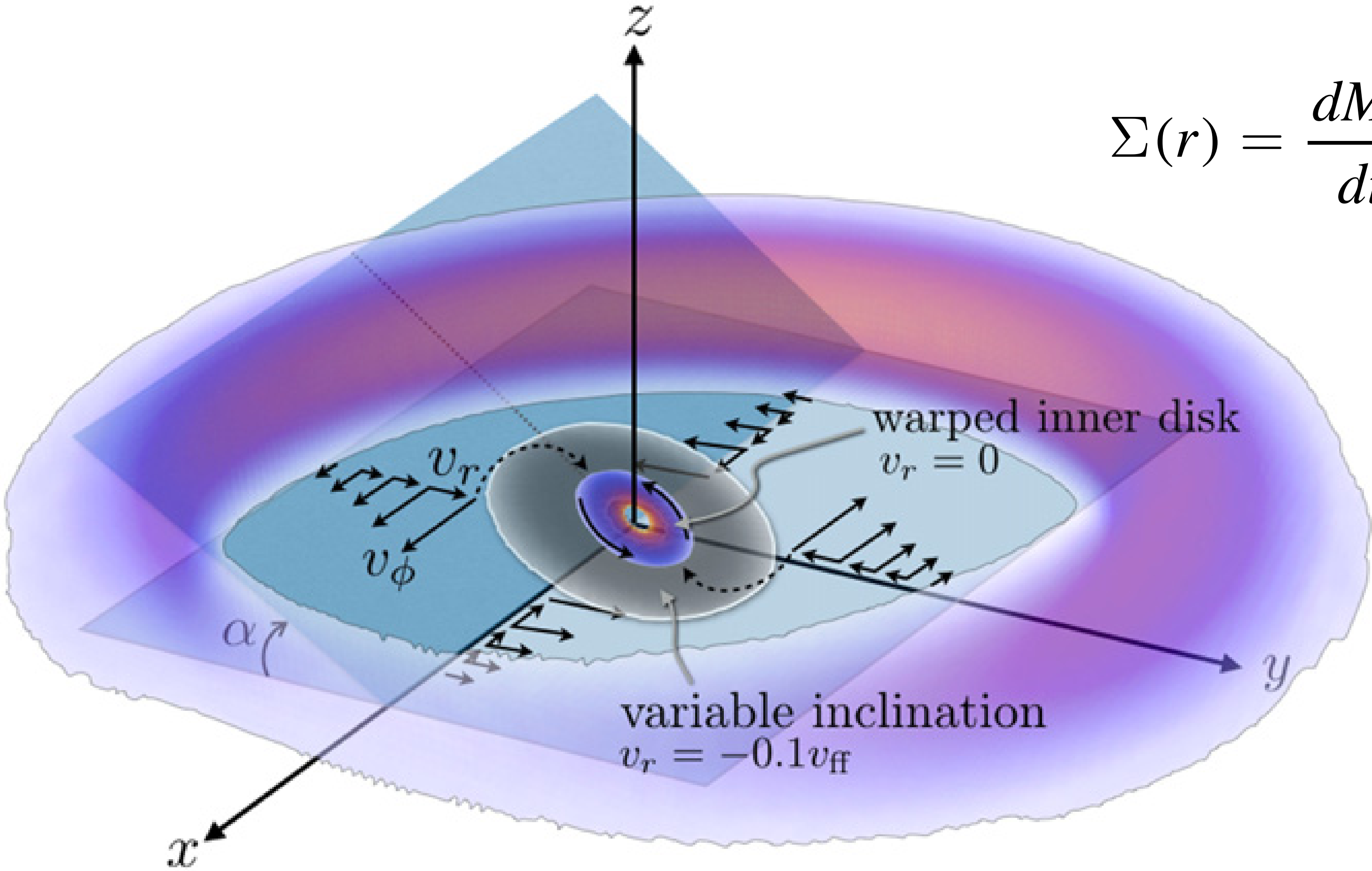
- Shape of the shadows unambiguously confirms a dramatic warp, with a 70deg inclination change(Marino+ 2015). Note clean shadow → regular, long lived inner disk.

HD 142527: temperature drop under the shadows

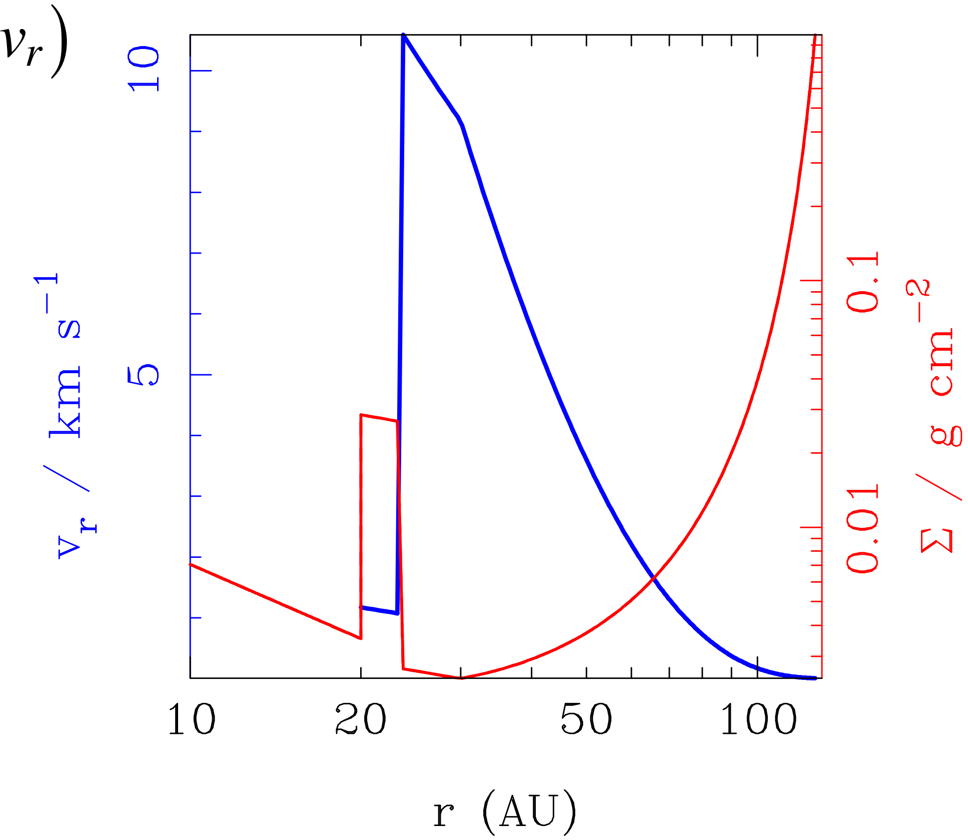


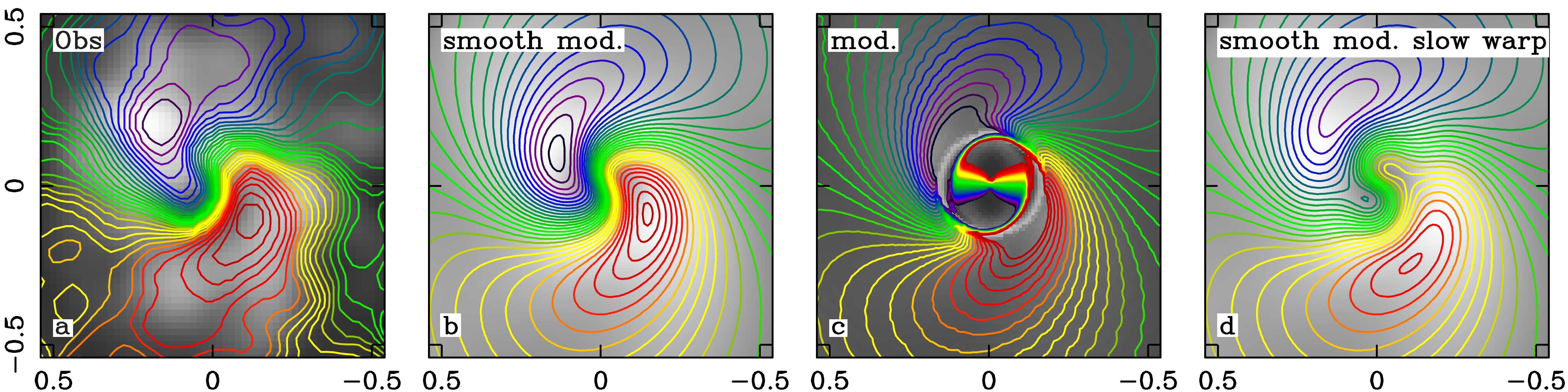
~30% drop in T (Casassus+ 2015a).

Accretion kinematics in the HD142527 warp



$$\Sigma(r) = \frac{dM_\star}{dt} \Big/ (2\pi r v_r)$$



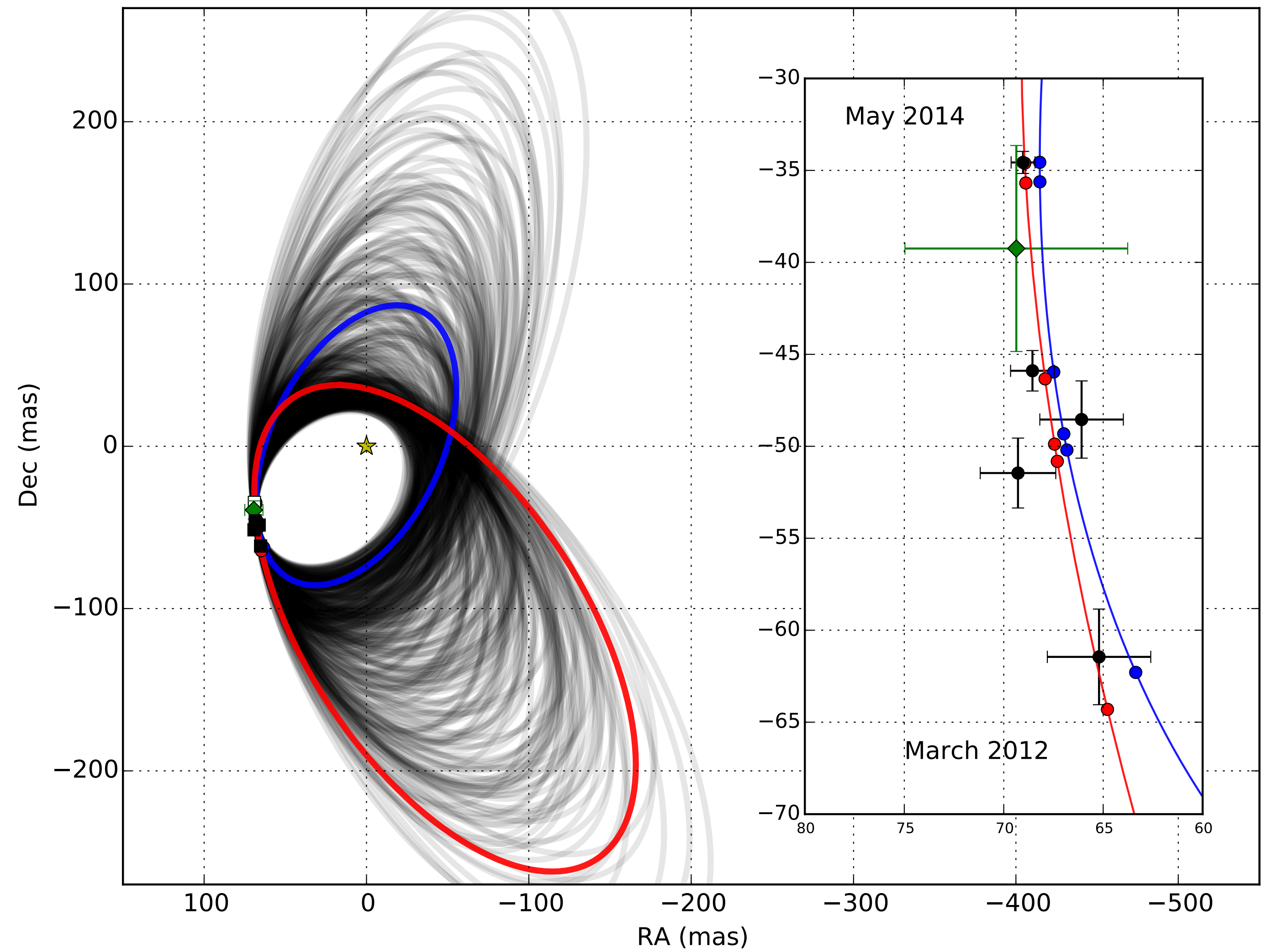


- Resolved gas-rich cavities ➪ interesting kinematics (Casassus+ 2015b).

Disk breaking in HD142527?

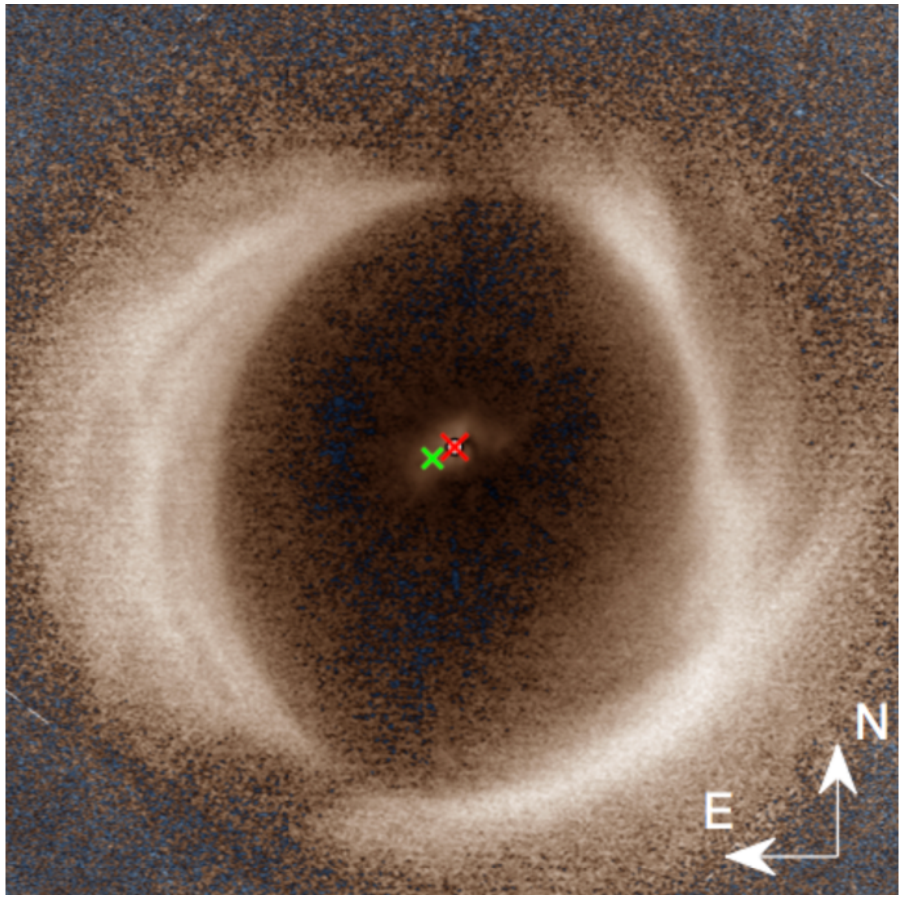
- Only 1 case of resolved cavity kinematics: HD142527 ➪ clear case for fast accretion (at free-fall) through an abrupt warp.
- Disk breaking by a tilted companion?

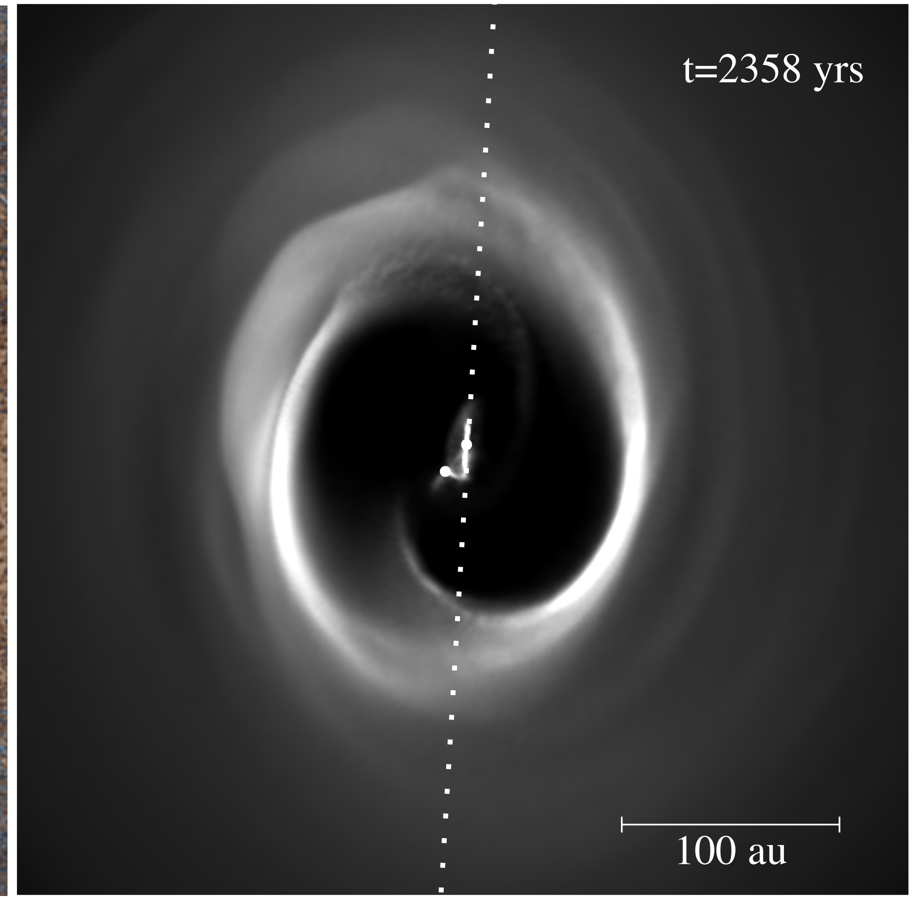
HD142527B orbit
Lacour+ 2016



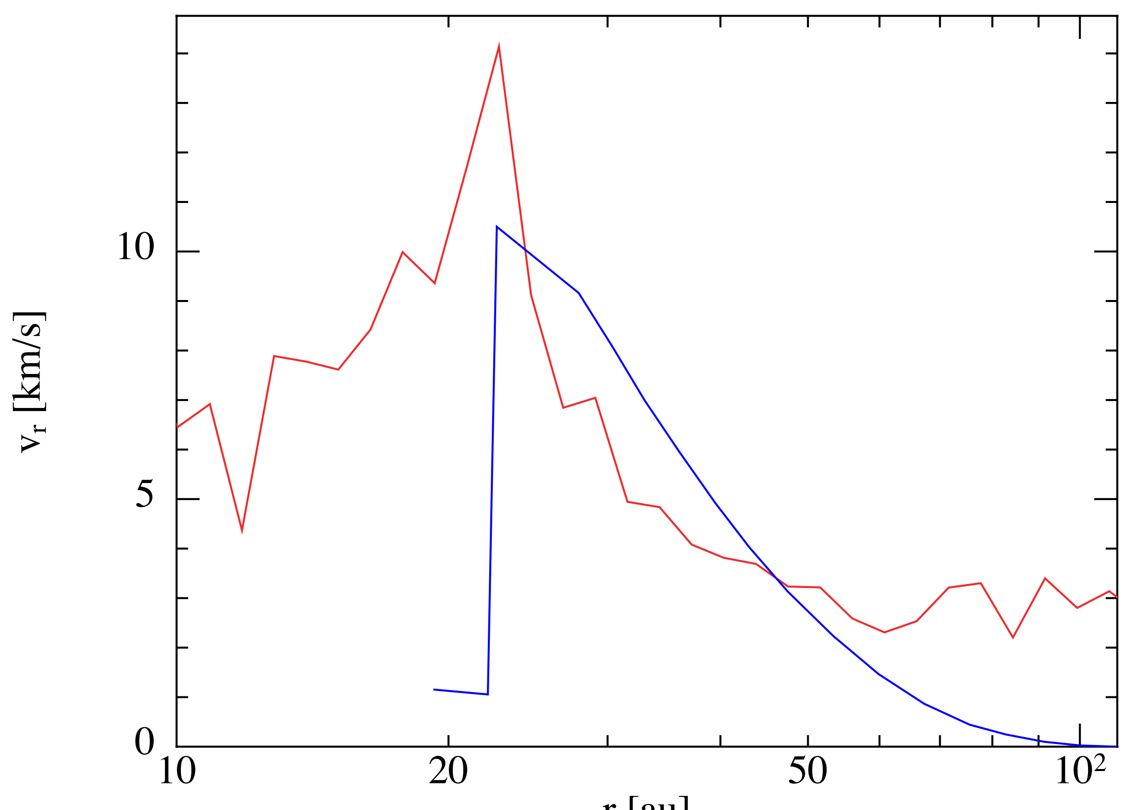
- HD142527B: mass ratio ~0.1 (Close+ 2014, Christiaens+ 2018)

Disk breaking in HD142527?





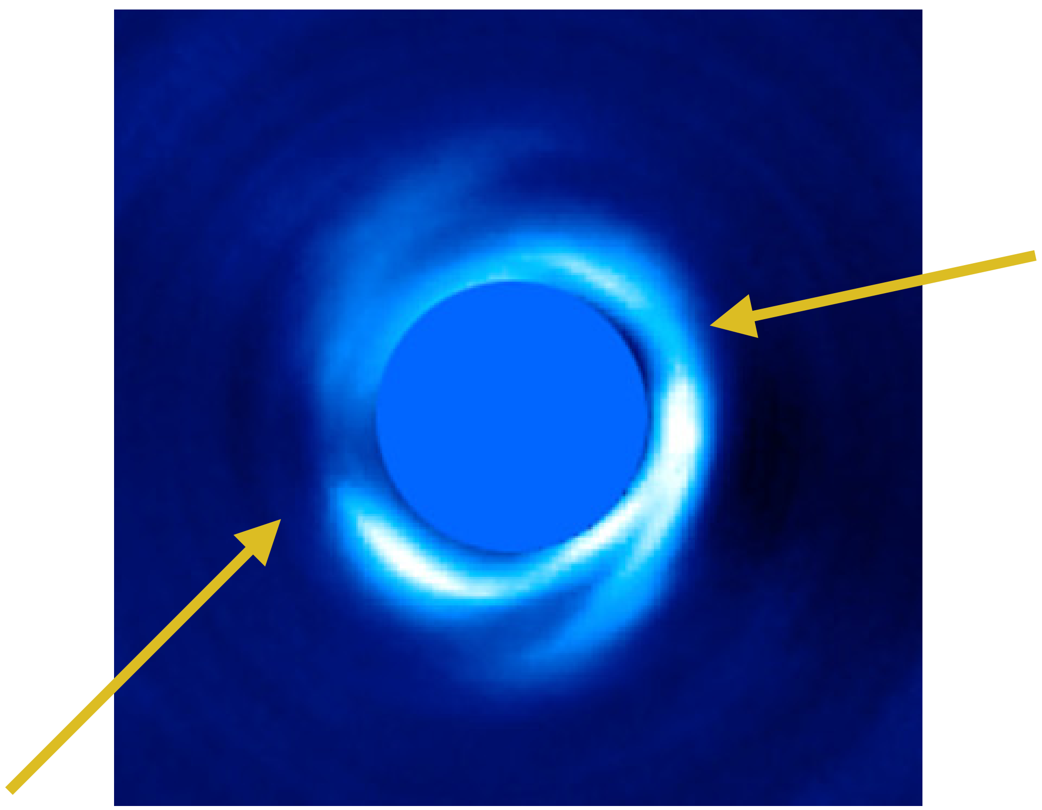
PHANTOM simulation
(Price+ 2018)



Outline

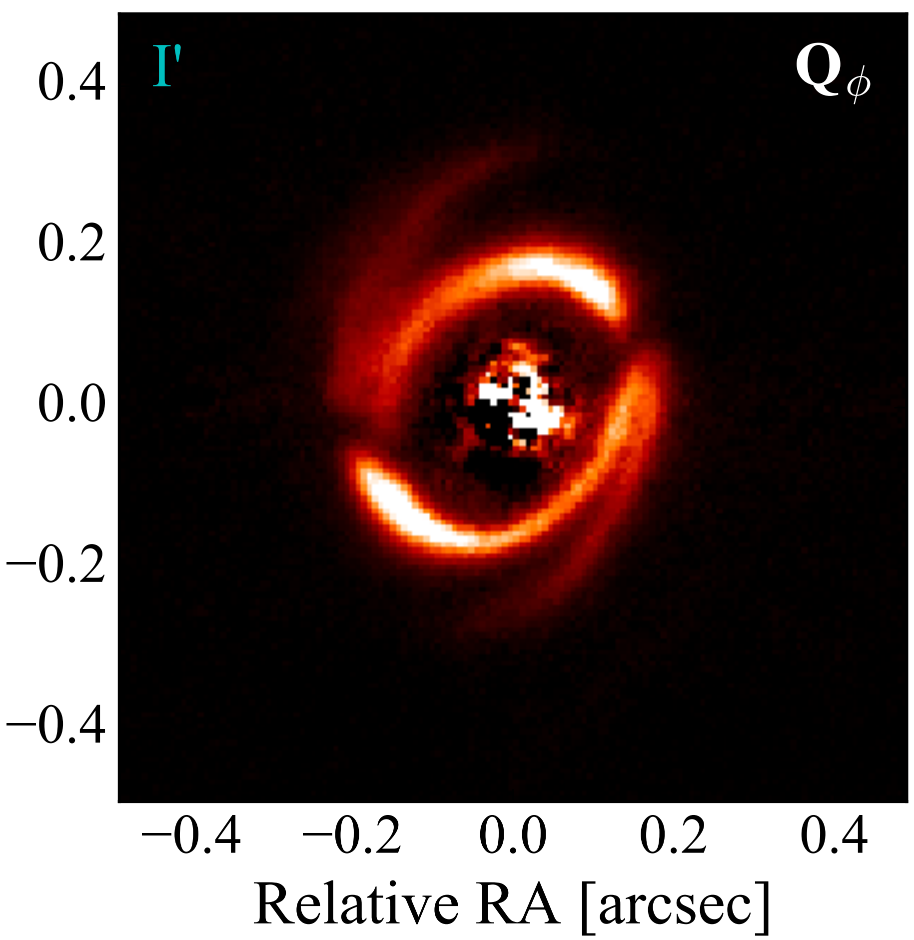
1. The sharp warp in HD142527
2. **A few more warps**
3. What can we learn from warps?
4. Summary

Another 70deg warp: HD 100453

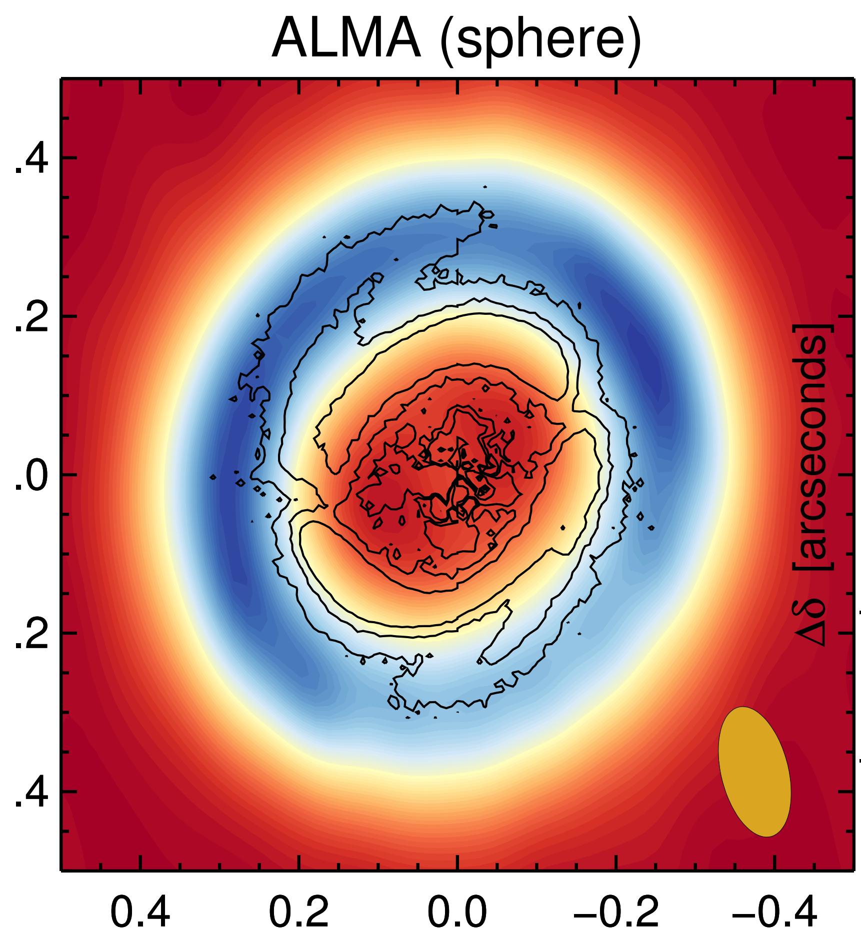


- Illumination effects in HD100453 (SPHERE 1.04um, Wagner+ 2015, Casassus 2016)

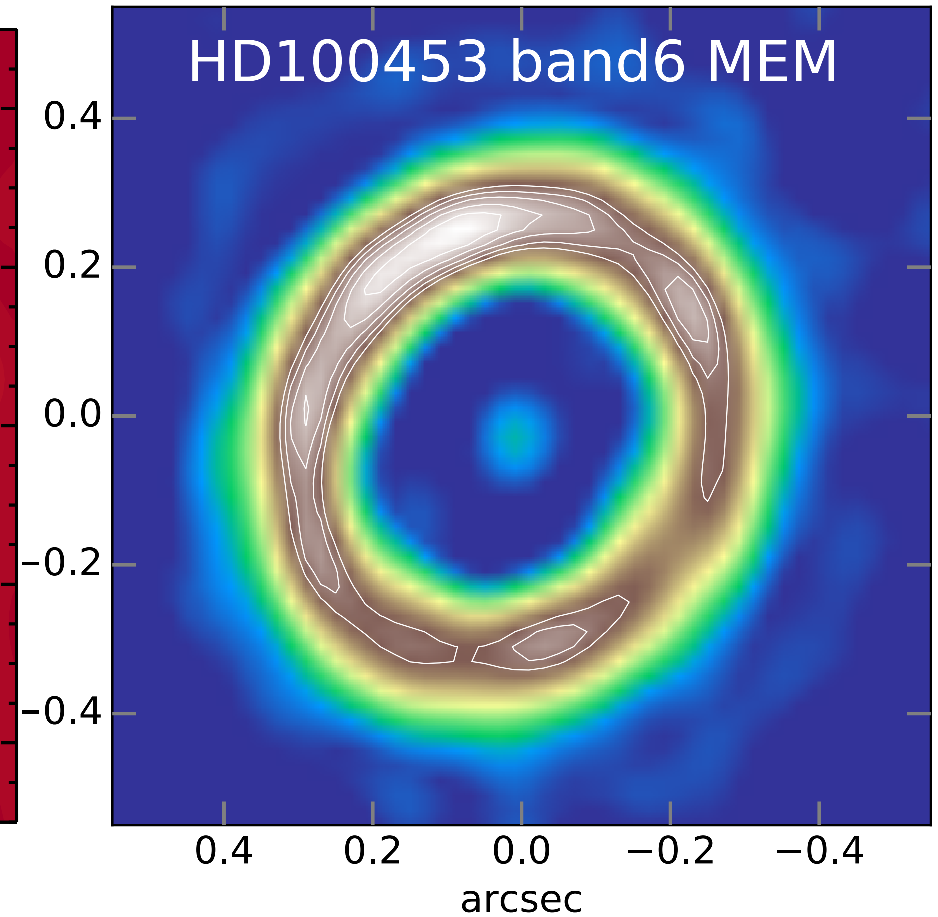
Another 70deg warp: HD 100453



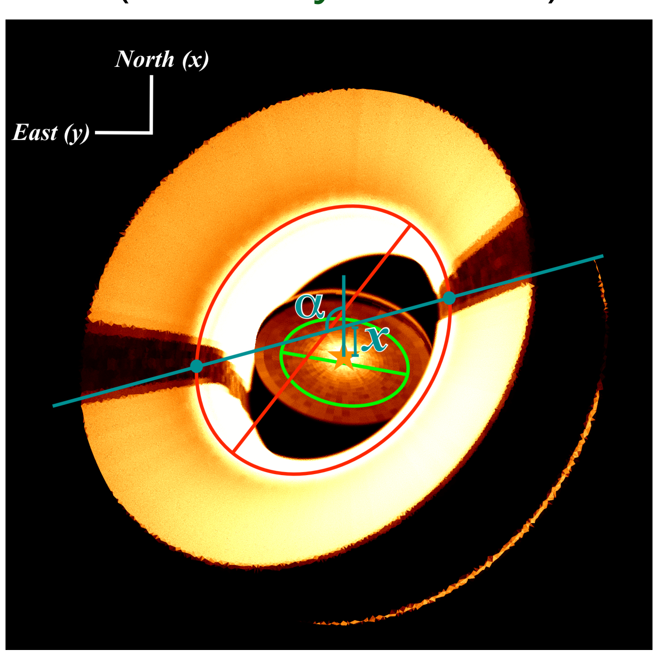
VLT+SPHERE PDI
(Benisty+ 2017)



ALMA CLEAN
(van der Plas 2019+)

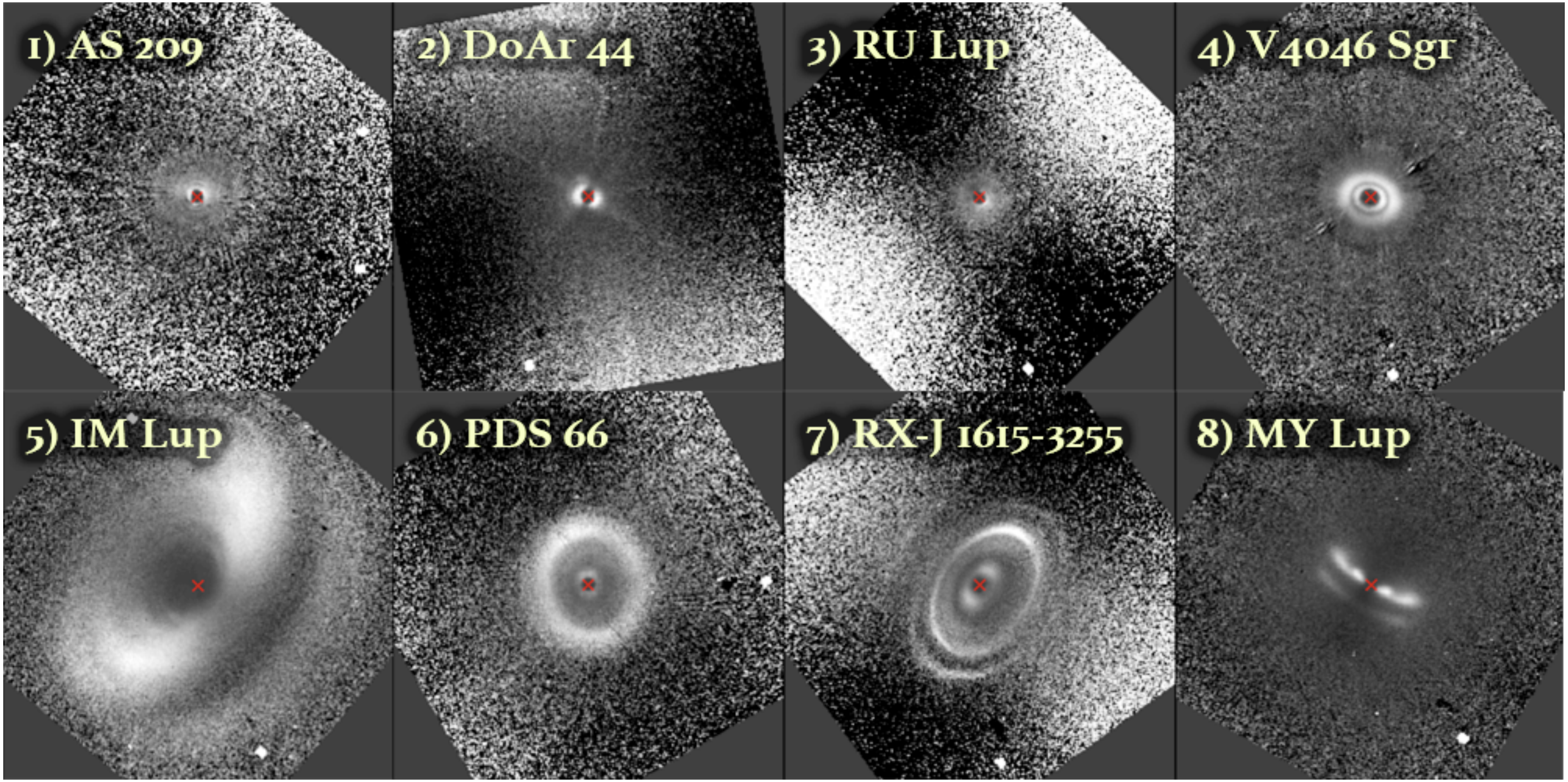


ALMA GPU UVMEM
Cárcamo+



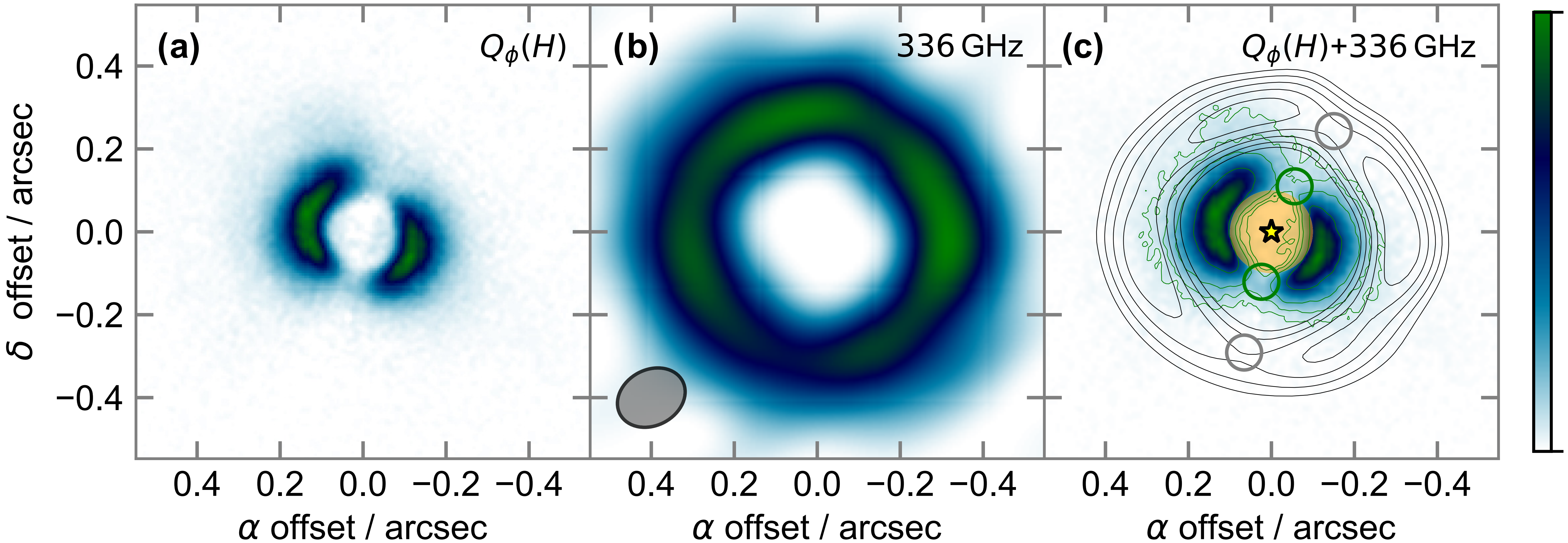
Min+ 2017

Searching for illumination effects in TTauri stars with Differential Polarized Imaging



- PDI + next generation cameras (Avenhaus+ 2018)

DoAr 44: a TTauri warp at 30deg

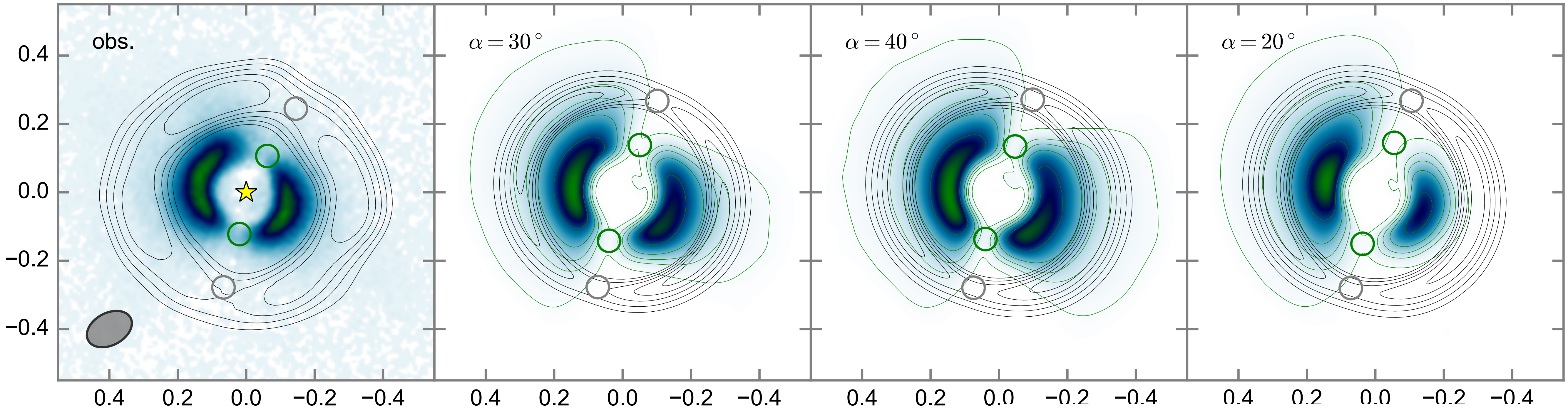


Casassus+ 2018

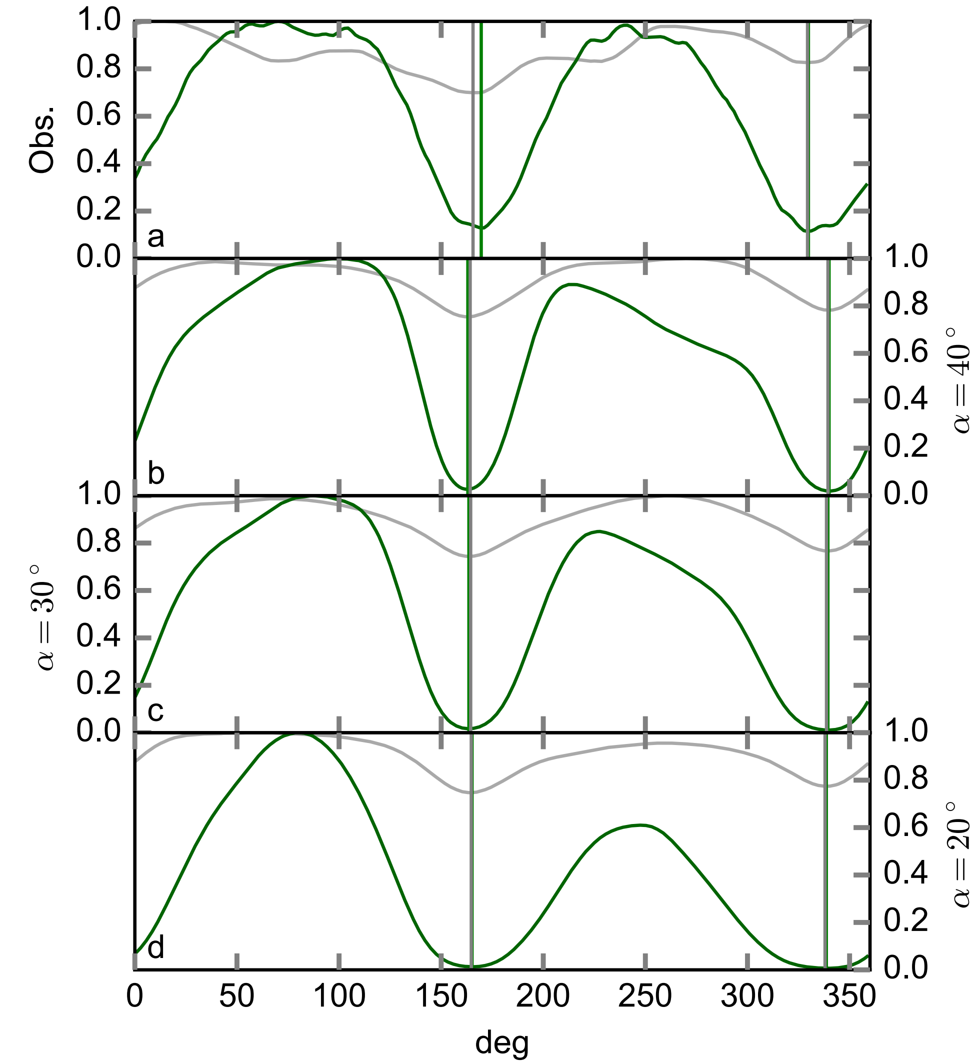
- mm-continuum: face-on cavity ~33au radius
- SPHERE DPI: smaller ring with two-sided decrements

DoAr 44: a TTauri warp at 30deg

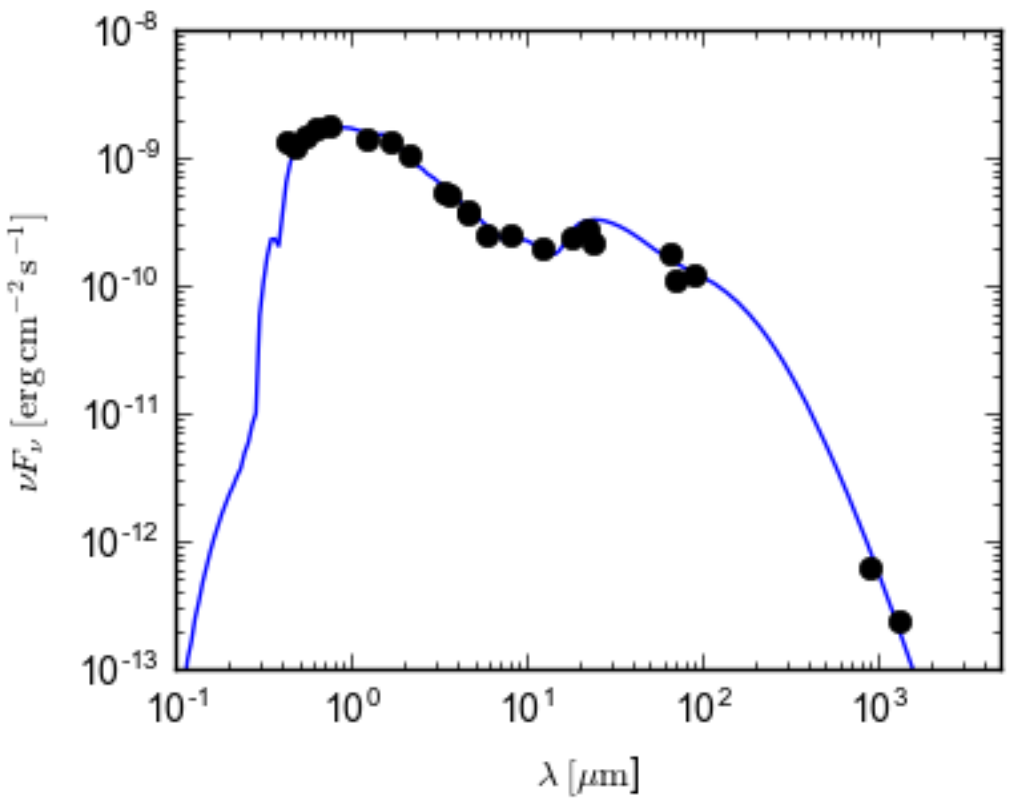
Casassus+ 2018

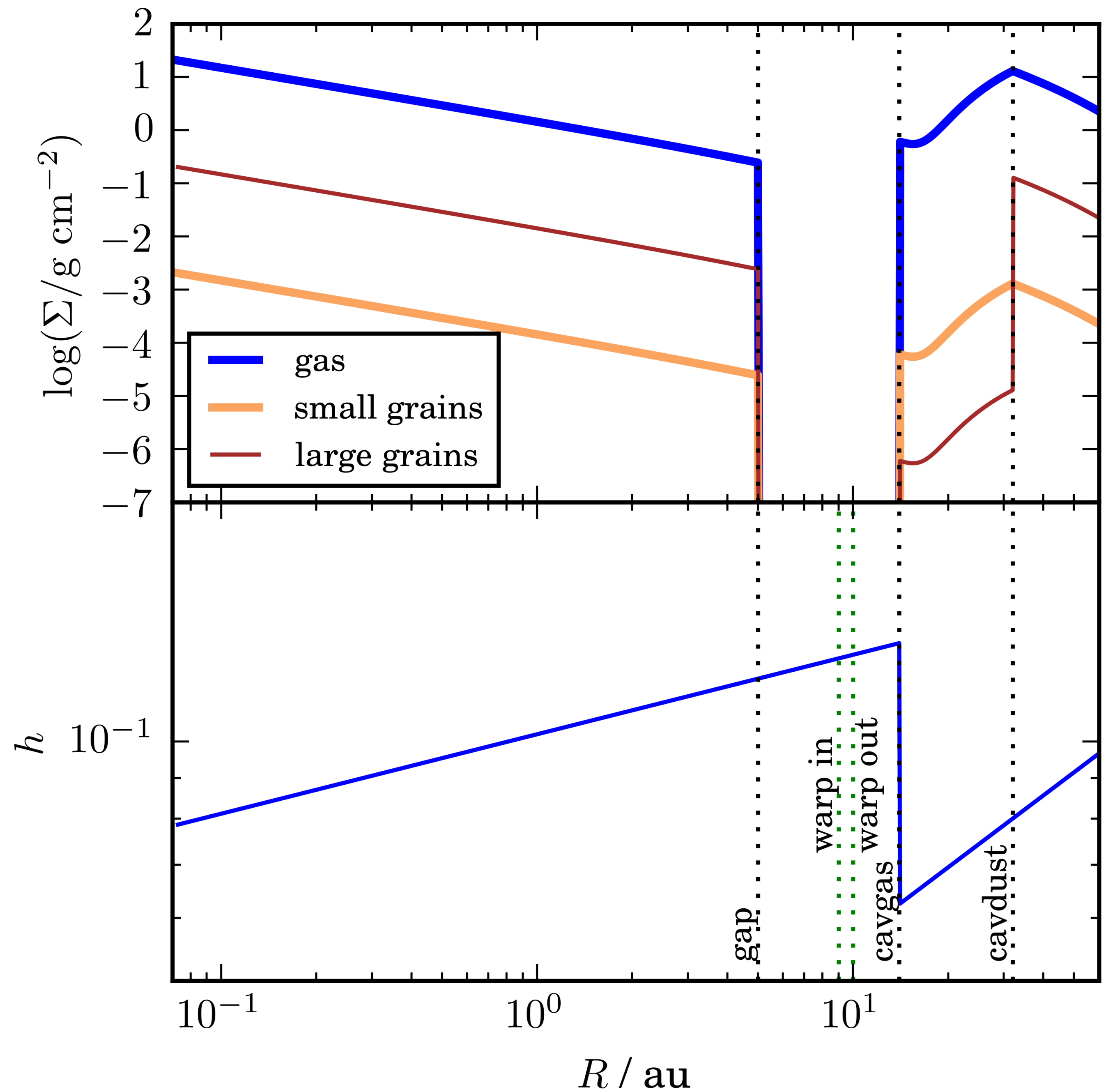


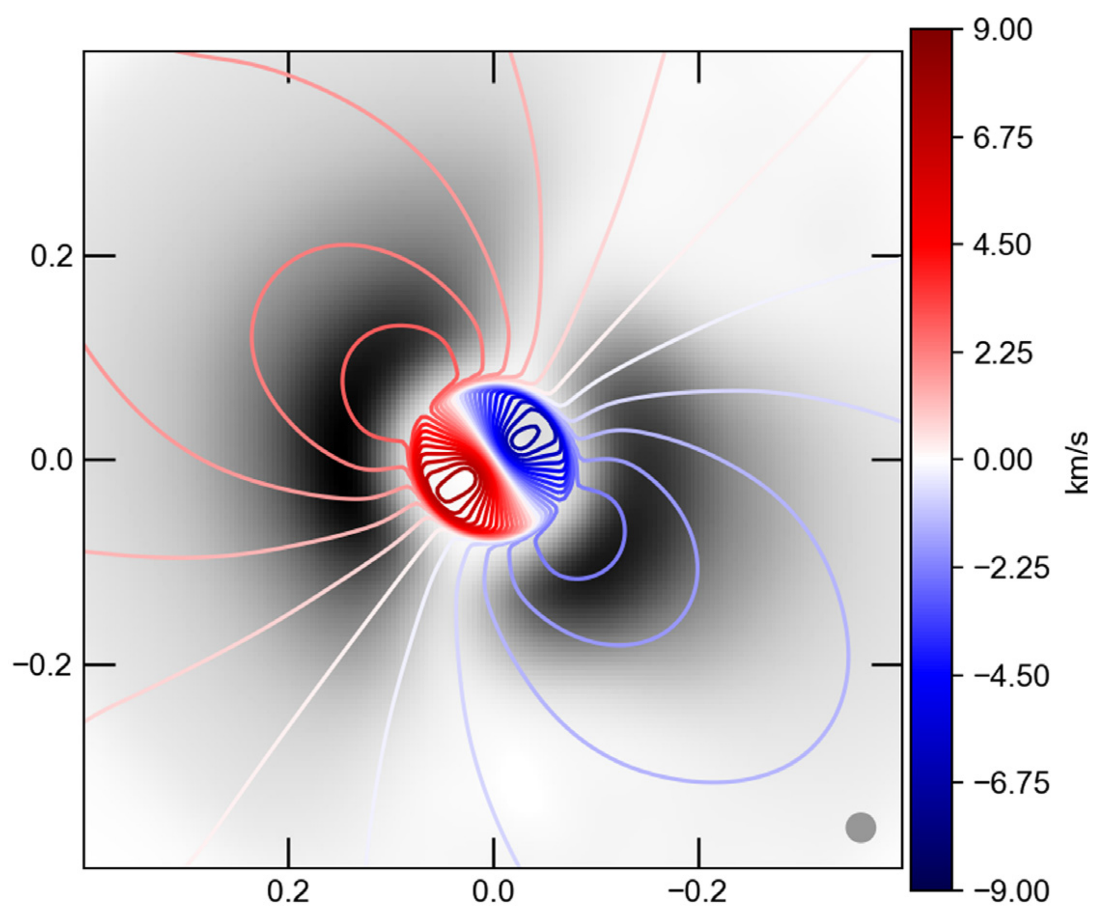
- DPI shadows correspond to mm-continuum dips ⇨temperature decrements, as in HD142527.
- Shadow PA + stellar offset + angle between shadows gives inner disk orientation ⇨ relative inclination 35±5deg.



DoAr 44: how do the planes connect?



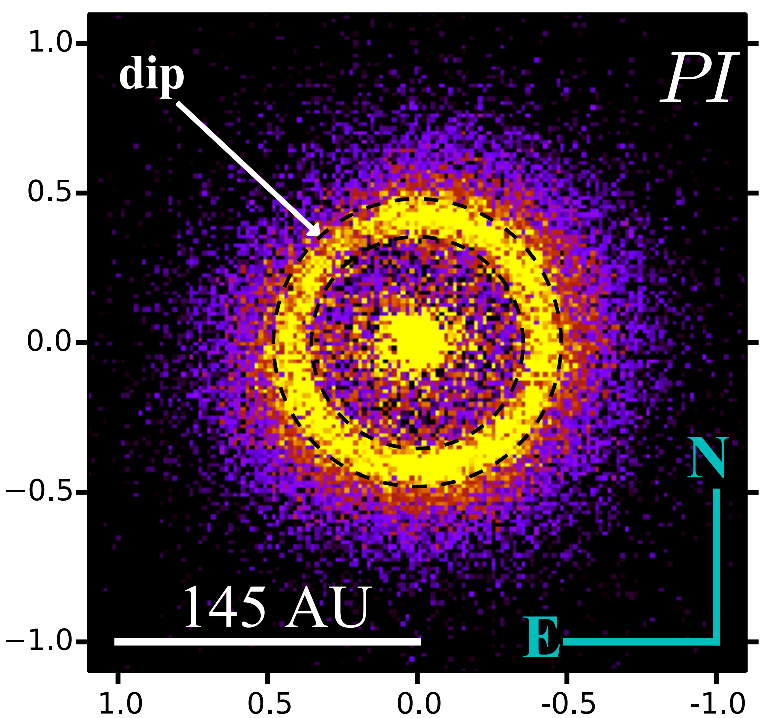




- CO observations can test the warp hypotheses

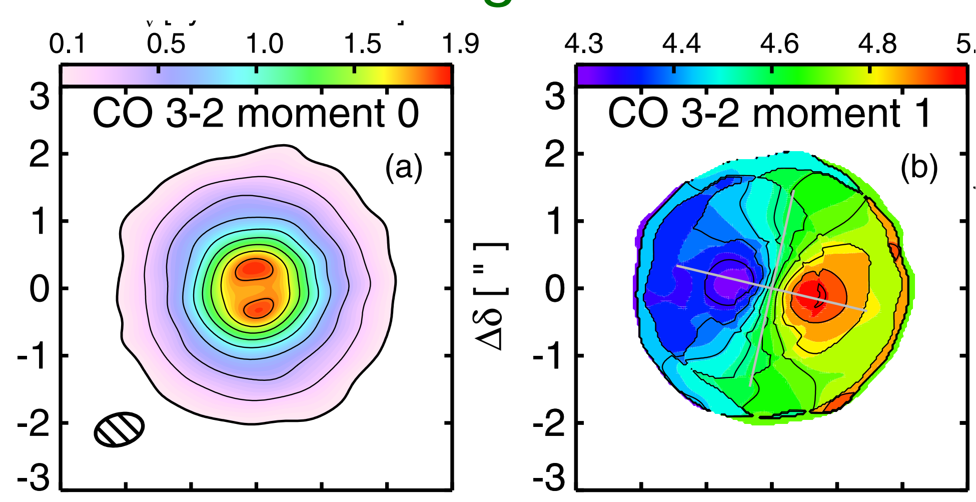
Illumination effects in dipper star J1604-2130

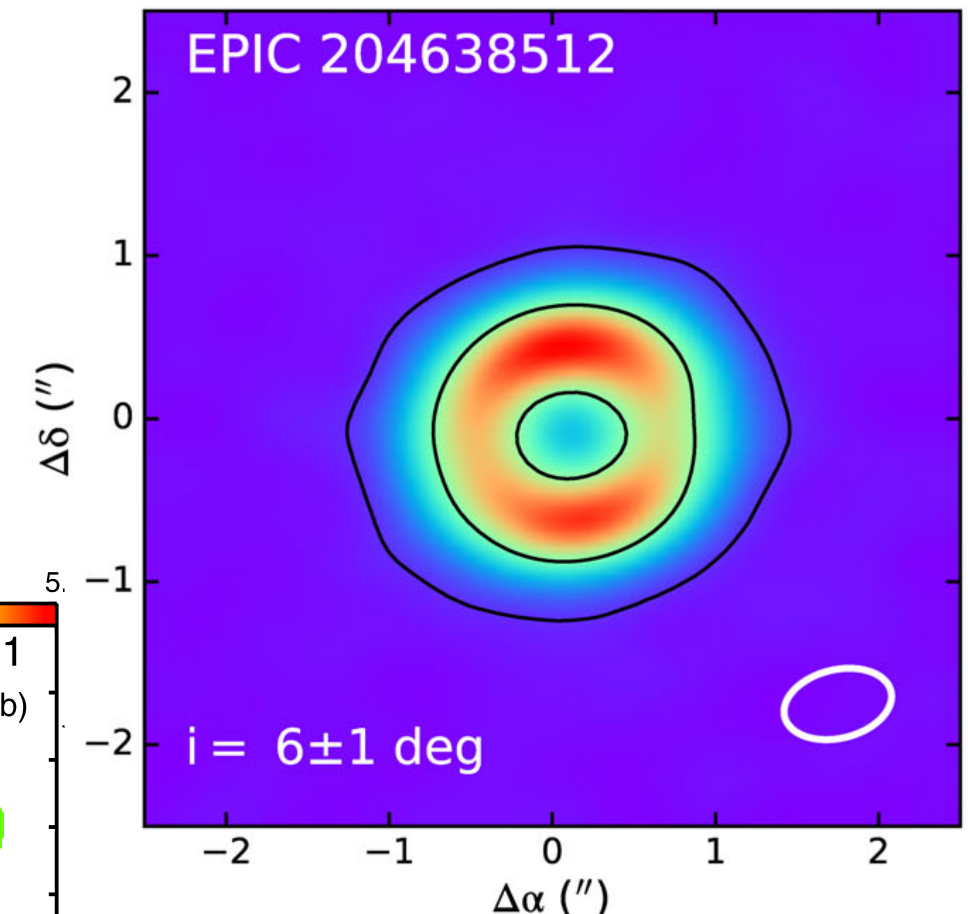
- Another less when known dipper: J1604-2130 (Ansdell+ 2017)



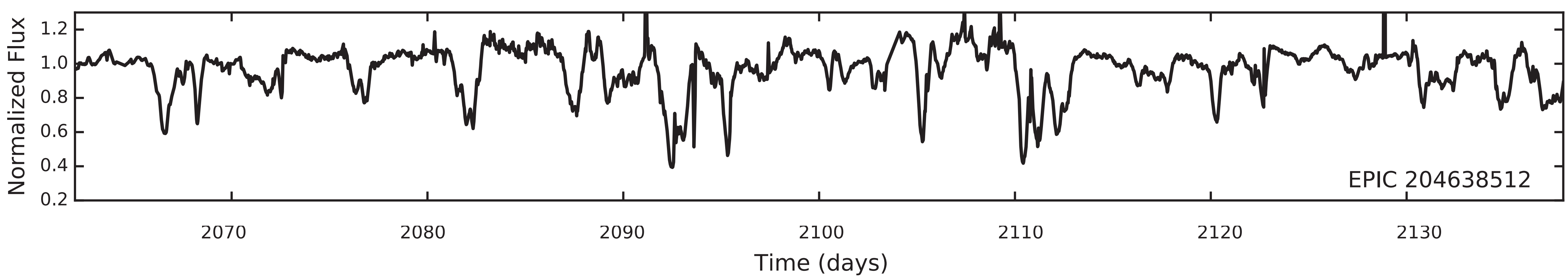
Pinilla+ 2015

Zhang+ 2014



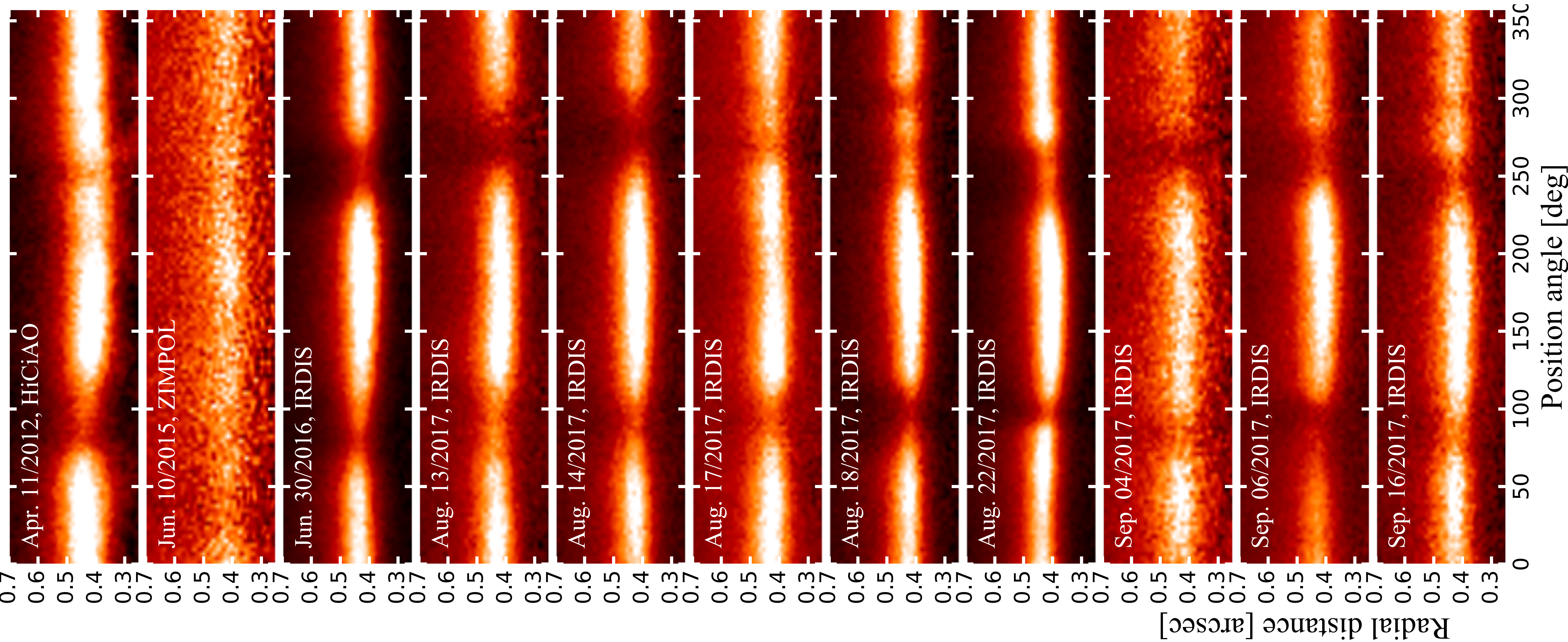


Ansdell+ 2017



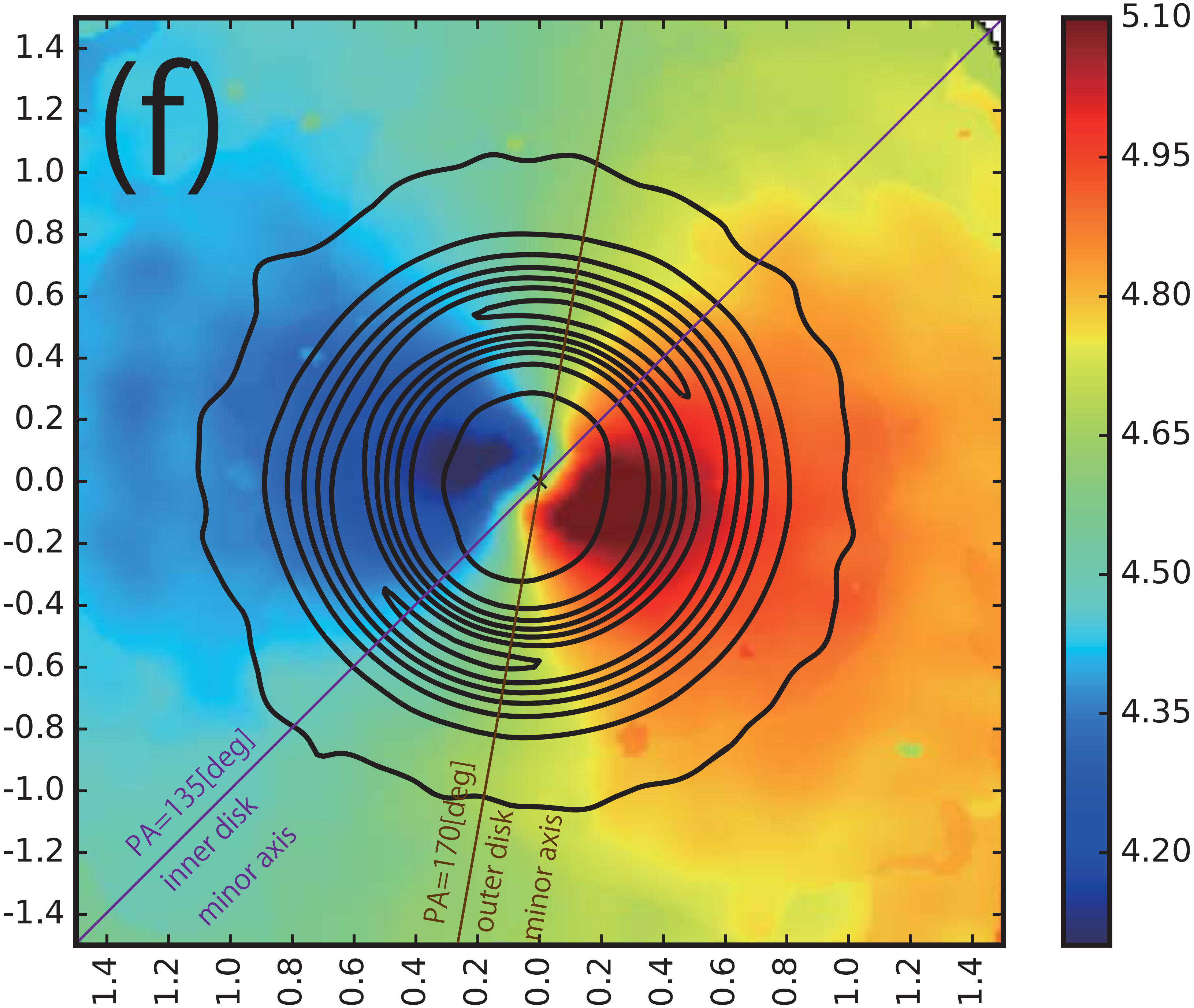
Illumination effects in dipper star J1604-2130

- The DPI shadows are variable but roughly 2-sided (Pinilla+ 2018)

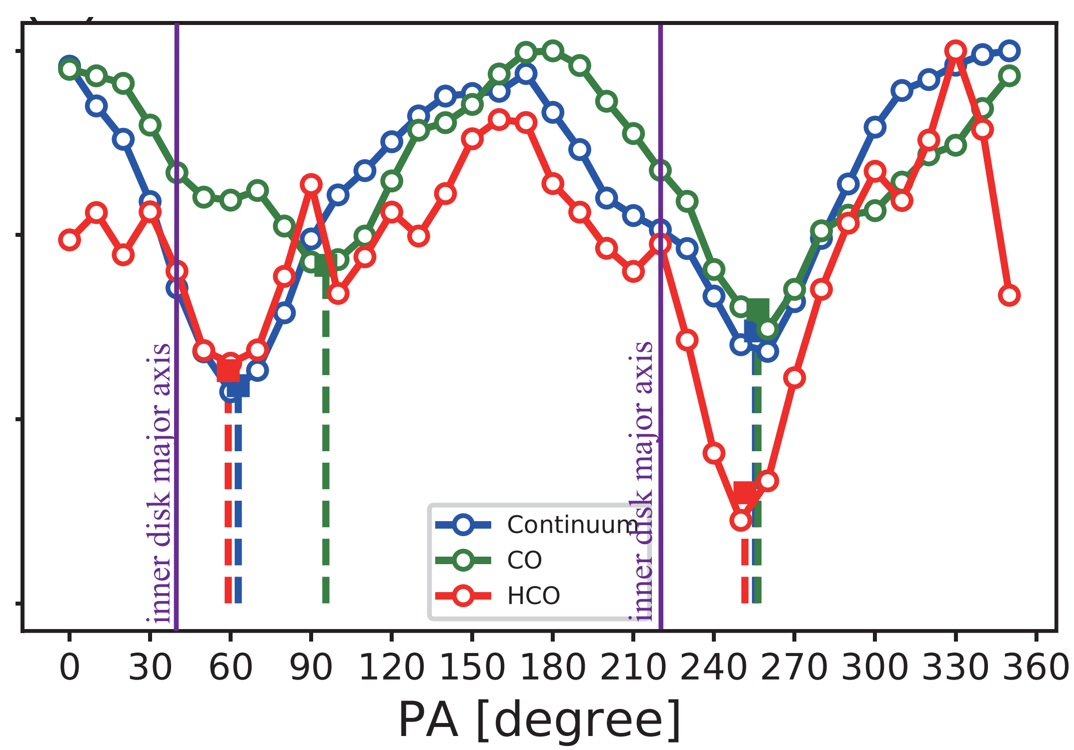


Illumination effects in dipper star J1604-2130

- Molecular line data show warped kinematics (Mayama+ 2018)

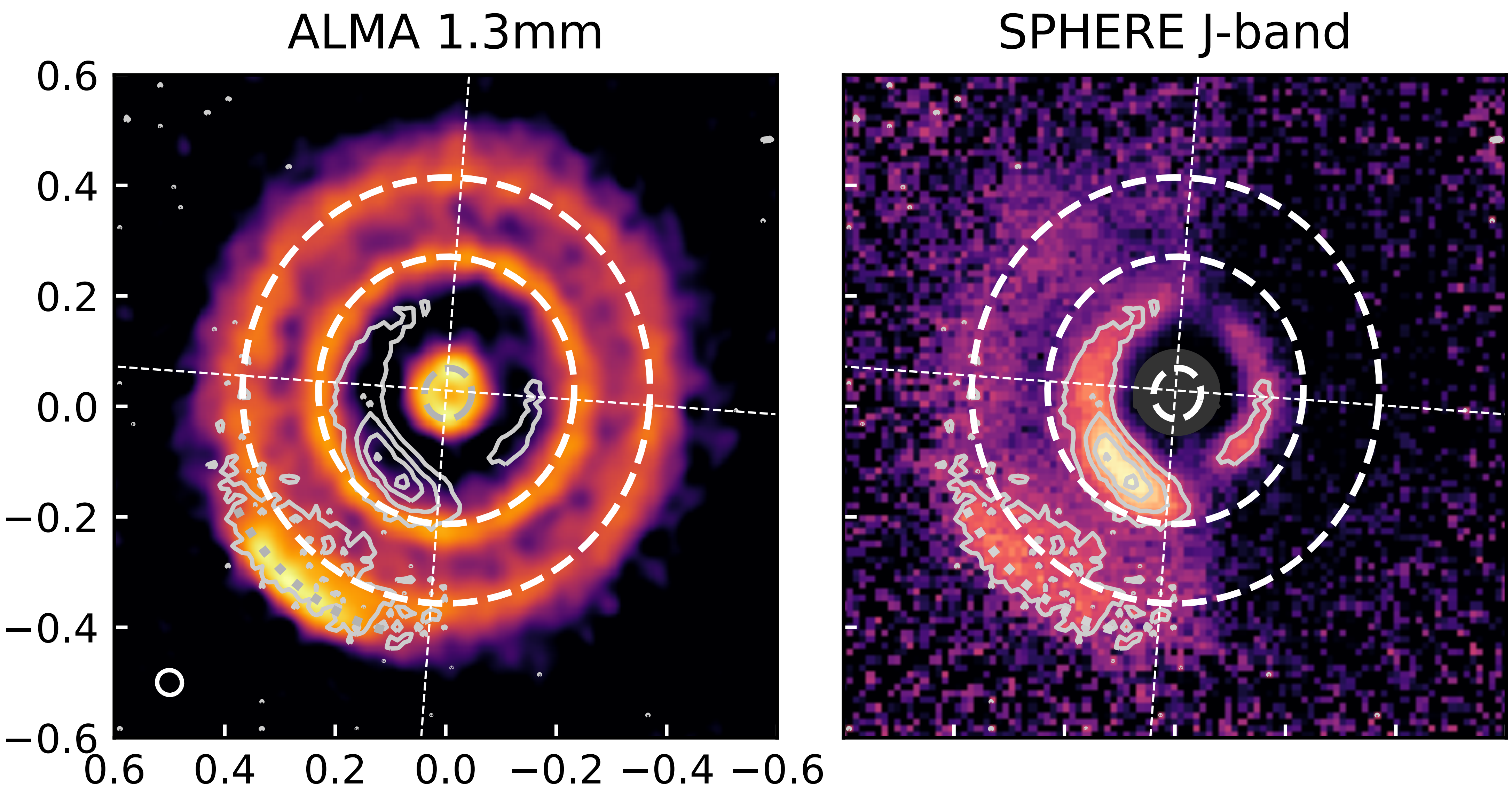


- DPI shadows may also be seen in continuum, despite coarse elongated beam (Mayama+ 2018)



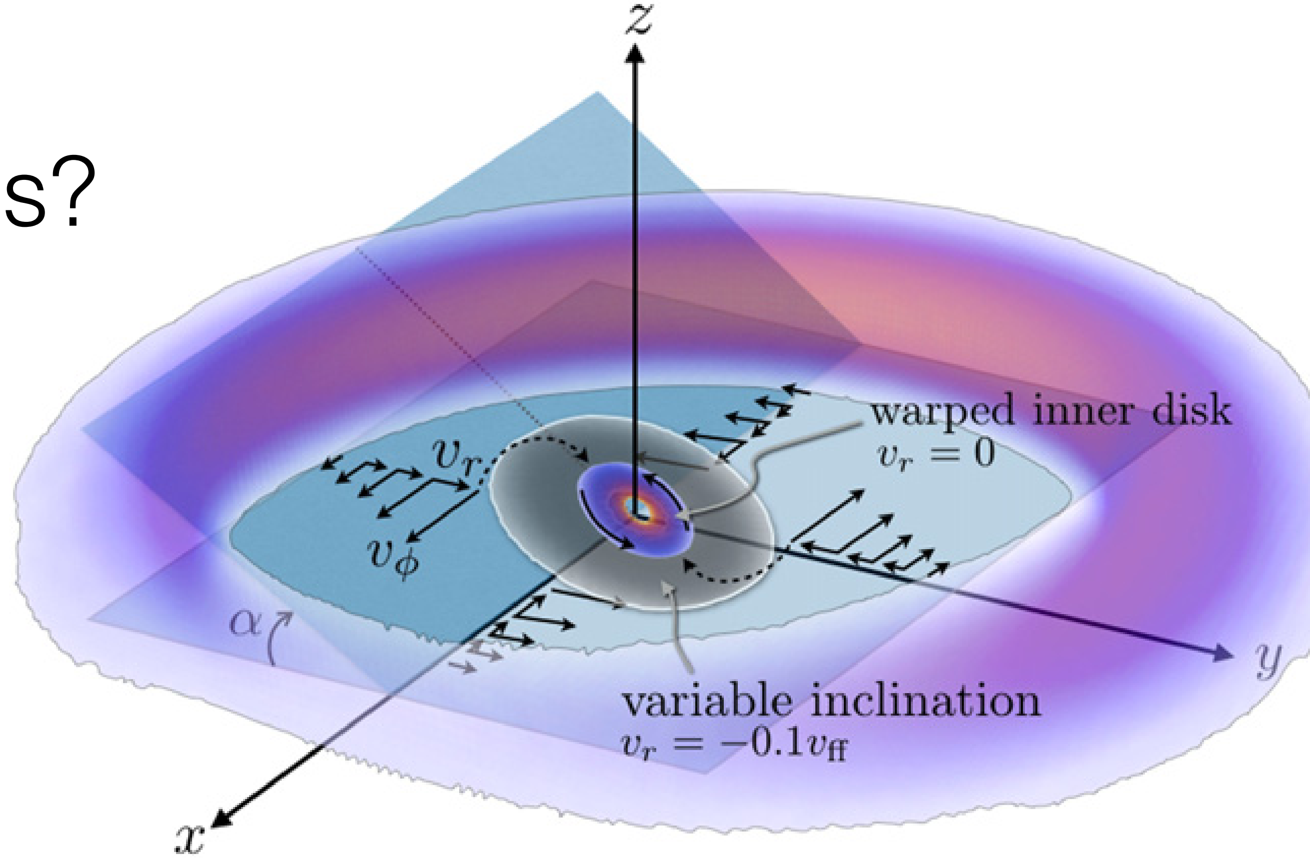
Most recent reported warp: HD 143006

- TTauri star HD143006 also appears to show 2-sided shadows, roughly consistent with a mild ~3deg warp (Benisty+ 2018)
- Not matched by decrements in ALMA continuum, but CO(2-1) kinematics do show signs of a warp (Pérez, L.+ 2018)



Summary: observations

- Sharp misaligned inner disks with 30deg to 70deg tilts fairly common in gapped disks: 5 systems so far.
- The 2-sided Optical/IR shadows correspond to dust temperature decrements in HD142527, DoAr44 and J1604, but not in HD100453 and HD143006.
- When available, ^{12}CO data match expected warped kinematics (HD142527, HD143006, J1604).
- Origin of warp?
  Are these all circumbinary disks?



Outline

1. The sharp warp in HD142527
2. A few more warps
3. **What can we learn from warps?**
4. Summary

What can we learn from warps?

- Disk response to forcing by out-of-plane companion depends on the **disk viscosity** α_T and **disk mass.**
- Perhaps comparing resolved kinematics with hydro predictions could constrain α_T and the mass?
- Need case-studies where companions have been characterized.
- Only HD142527 for now (Price + 2018), pending new data…

What can we learn from warps?

- Why is there such a variety in the radio counterparts to the optical/IR shadows?
- In 3 examples dust cools fast enough for detectable temperature drops ⇒finite cooling times and rotation should result in shift ahead of shadows.
- Can we measure the **cooling timescale** and the **disk mass** by observing the OIR/radio shift?

Simple model for the temperature in the gaseous flow under fixed shadows

$$F_c \approx -2(1-\exp(-\tau_P))\sigma T^4$$ ← Vertical cooling through surface layers

$$F_h \approx 2(1-\exp(-\tau_P))\sigma T_h^4$$ ← Vertical heating through surface layers

$$F_\phi^D \approx \frac{\partial}{R\partial\phi} 2\pi H^2 \Lambda \frac{16\sigma T^3}{3\kappa_R \Sigma} \frac{\partial T}{R\partial\phi}$$ ← Azimuthal radiative diffusion

$$F_a = -\frac{v}{R}\frac{\partial U}{\partial\phi}$$ ← Advection of internal energy

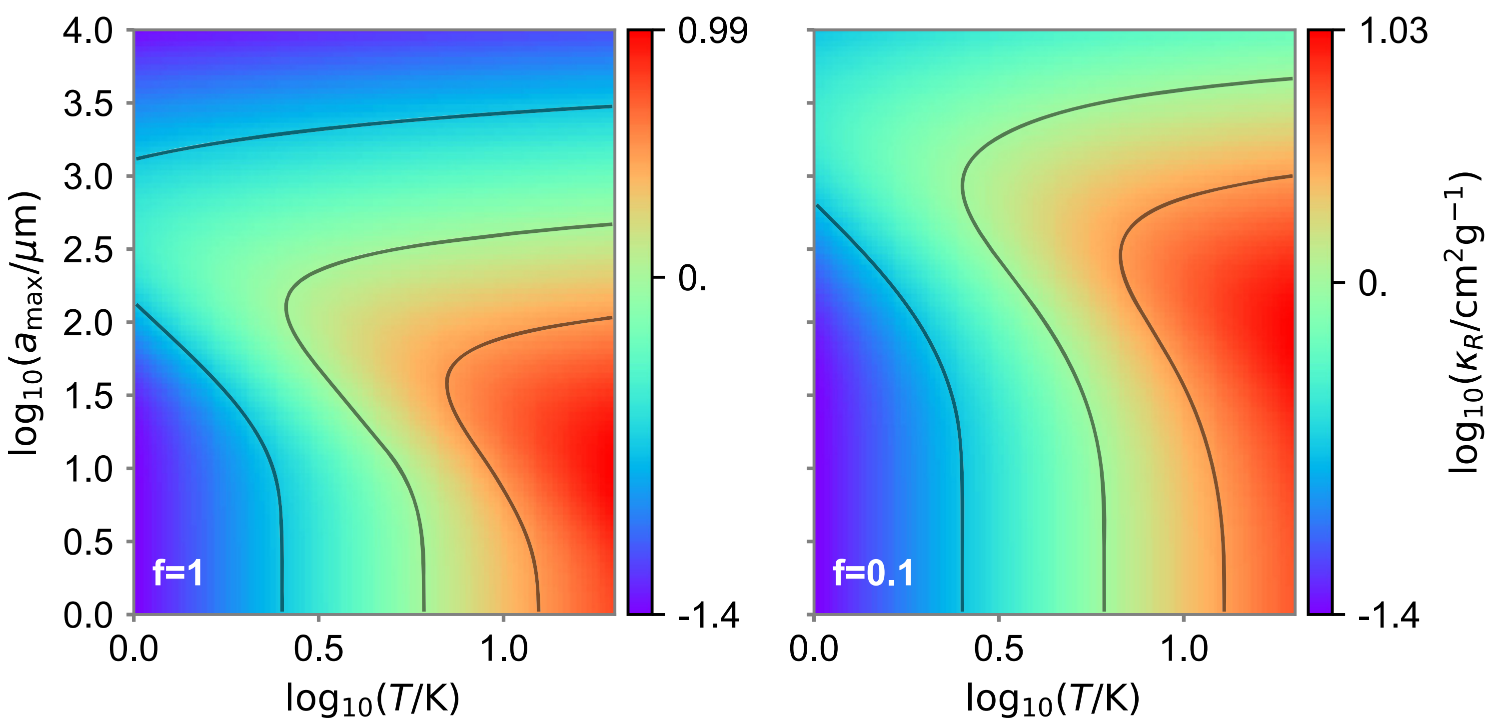
- In steady state, energy balance requires:

$$F_a + F_\phi^D + F_c + F_h = 0$$

Casassus+ 2019

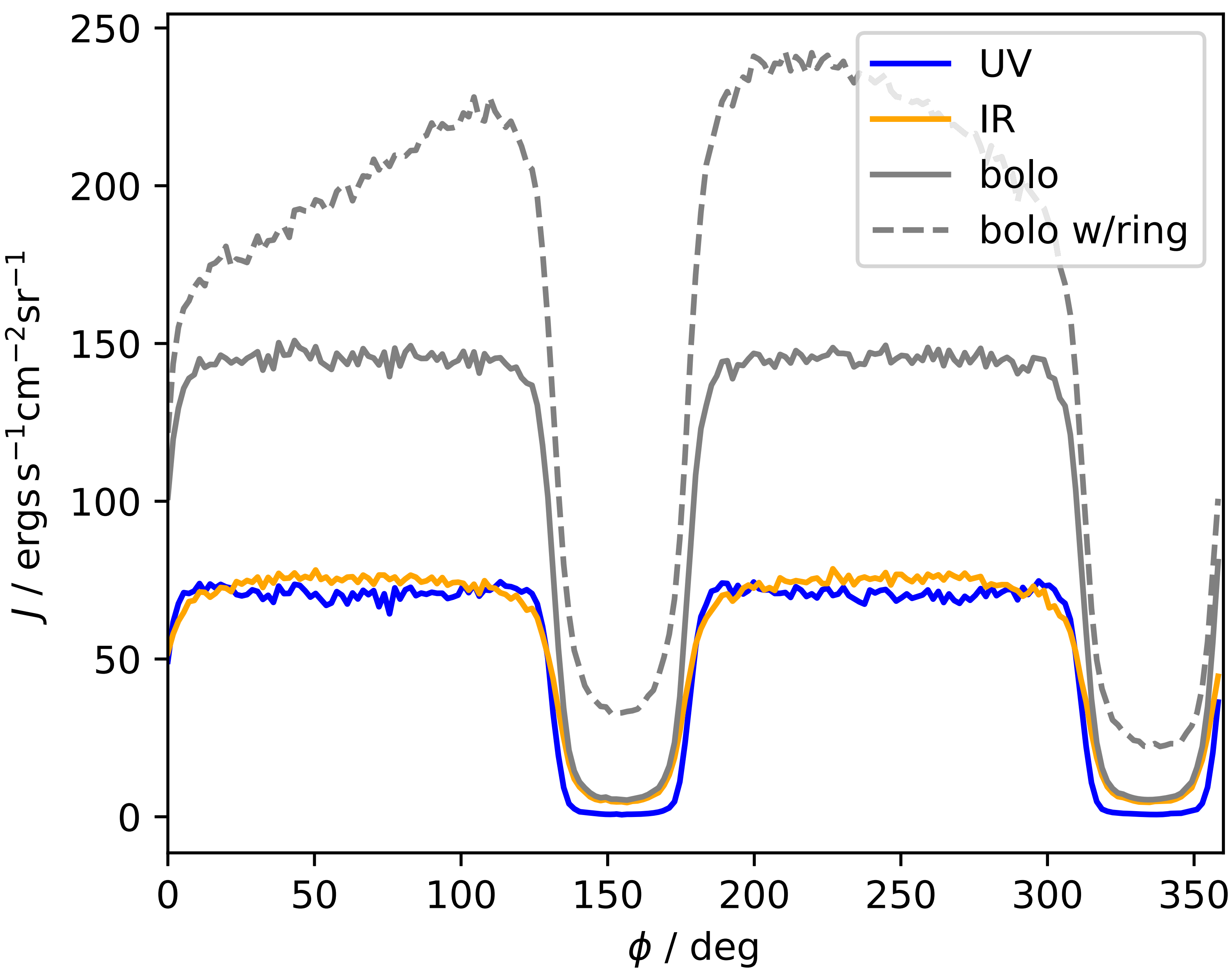
Simple model for the temperature in the gaseous flow under fixed shadows

- Simple ODE for the temperature profile $T(\phi)$
- Disk geometry and heat source $T_h(\phi)$ fixed either by observations or RT modeling.
- Key free parameters are: gas surface density Σ, gas-to-dust mass ratio $f_{\rm gd}$, dust filling factor f and maximum grain size $a_{\rm max}$.



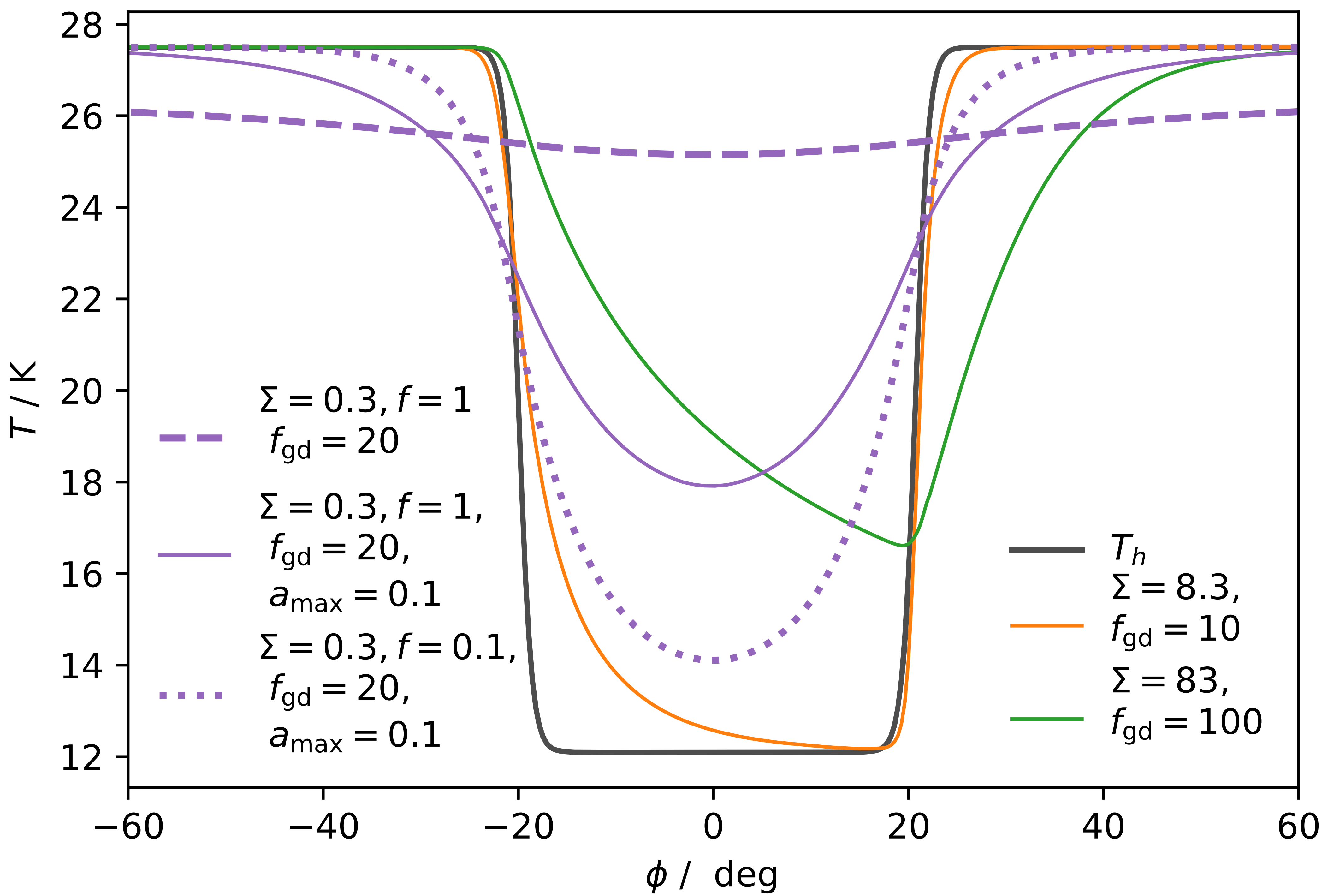
Choice of the heat source for HD142527

- Large grains in the mid plane heated by IR photons so heat source $T_h(\phi)$ follows bolometric mean intensity.



Solutions for HD142527

- HD142527 disk very lopsided, only Northern shadow is clearly matched by a radio decrement.



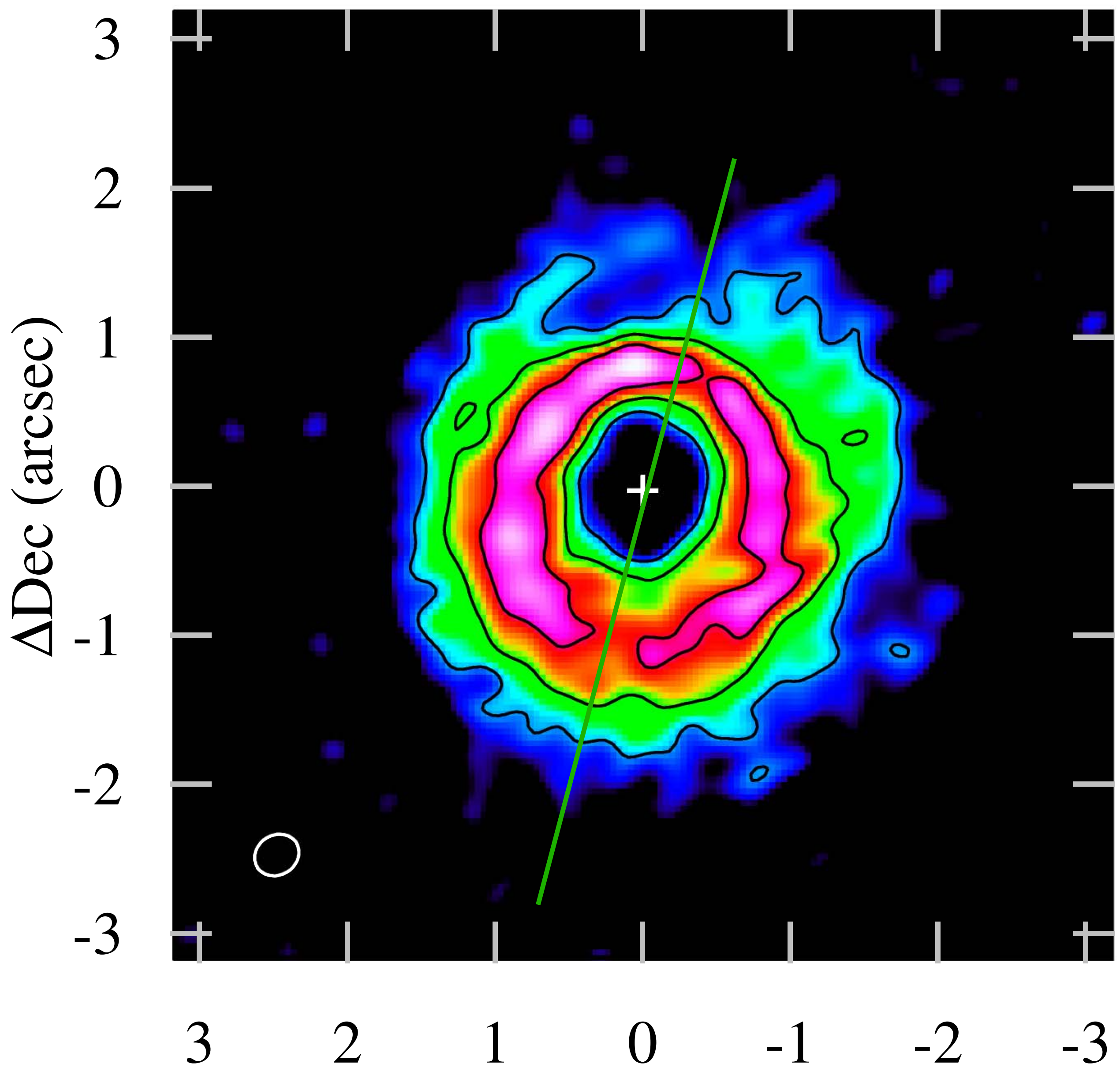
Solutions for HD142527

- HD142527 disk very lopsided, only Northern shadow is clearly matched by a radio decrement.

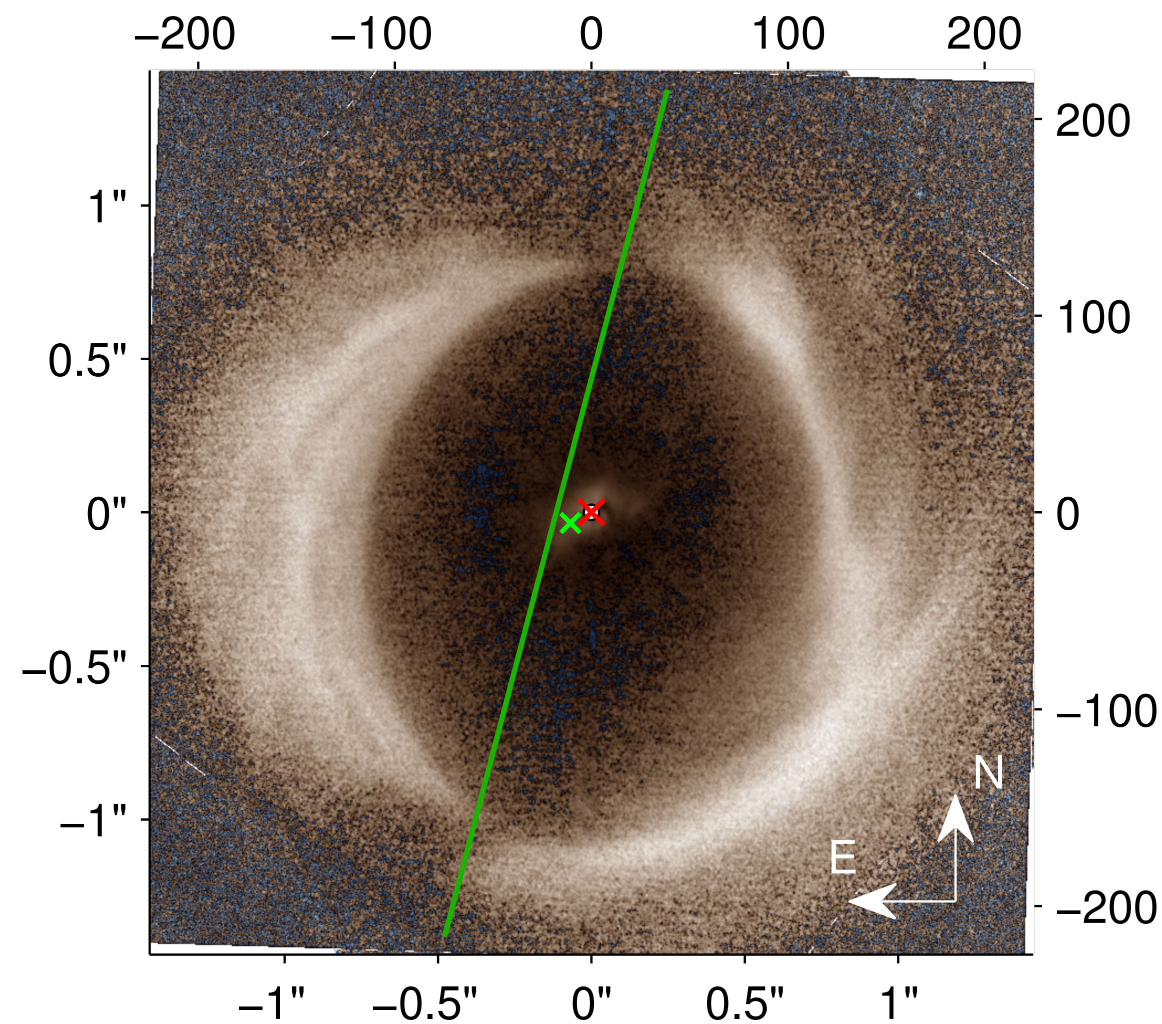
- Simple 1D model predicts >10deg shift for massive gaseous disk, with peak $\Sigma > 8.3\,\mathrm{g\,cm^{-2}}$

- At low Σ such that $\tau_R = \kappa_R \Sigma \ll 1$, radiation will smooth out the temperature decrements.

Radio/IR shift in HD142527 ?



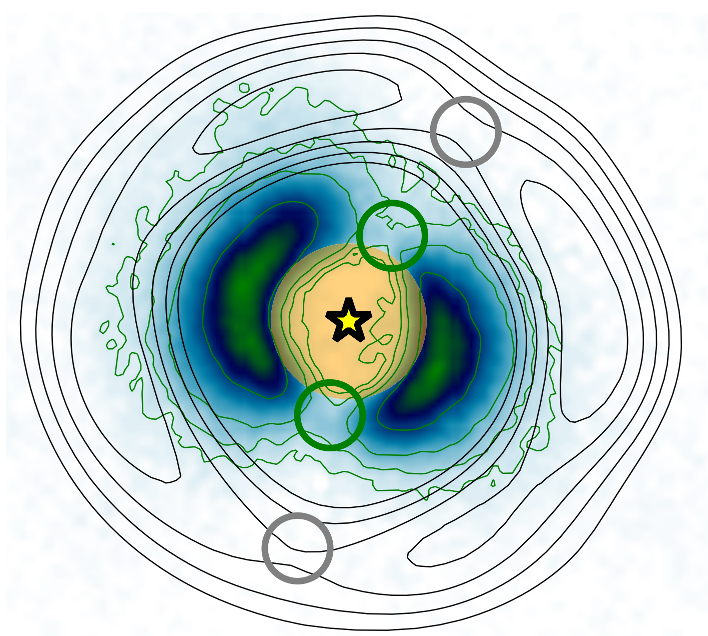
C18O(3-2) integrated intensity from Boehler+ 2017

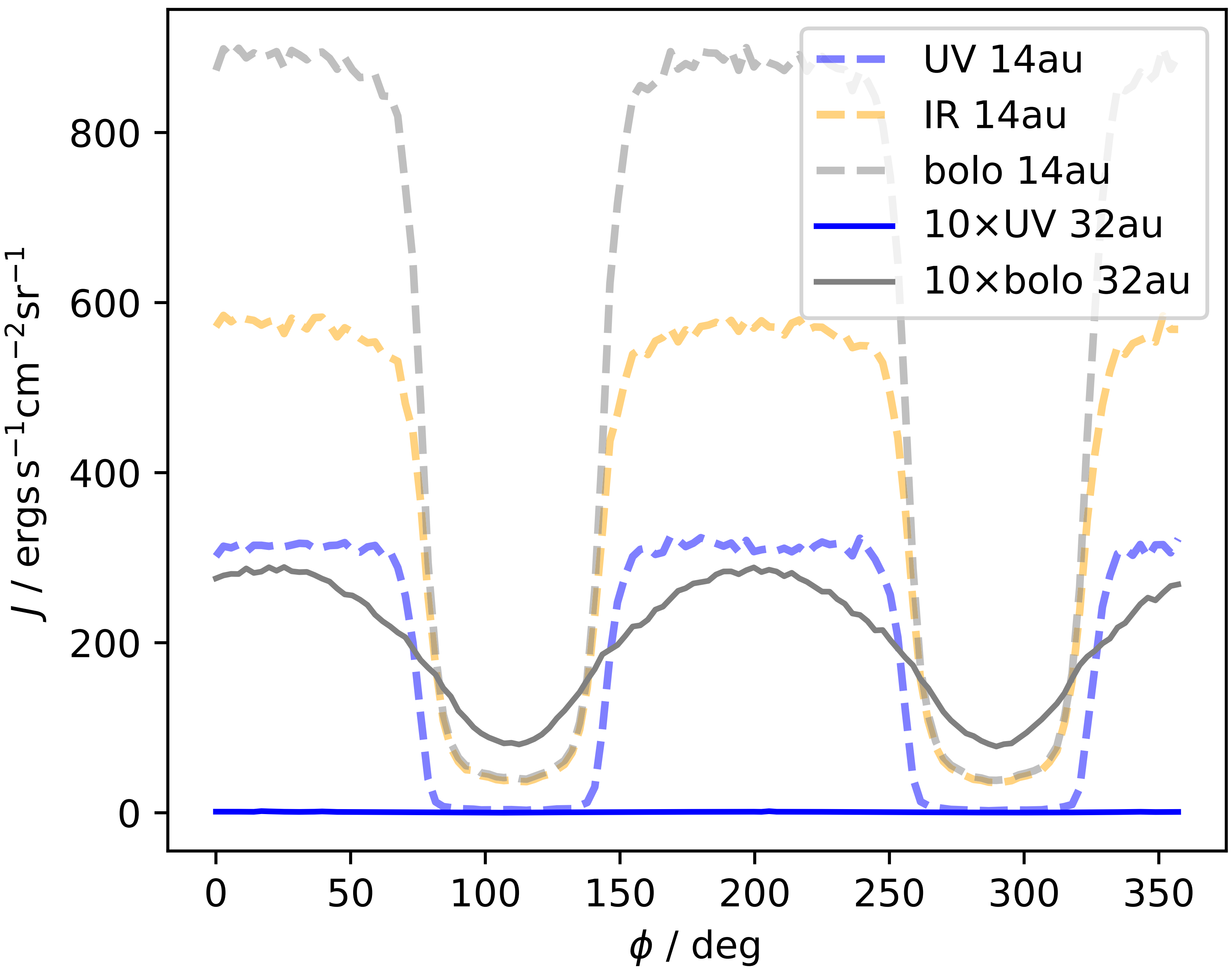


PDI image from Avenhaus+ 2017

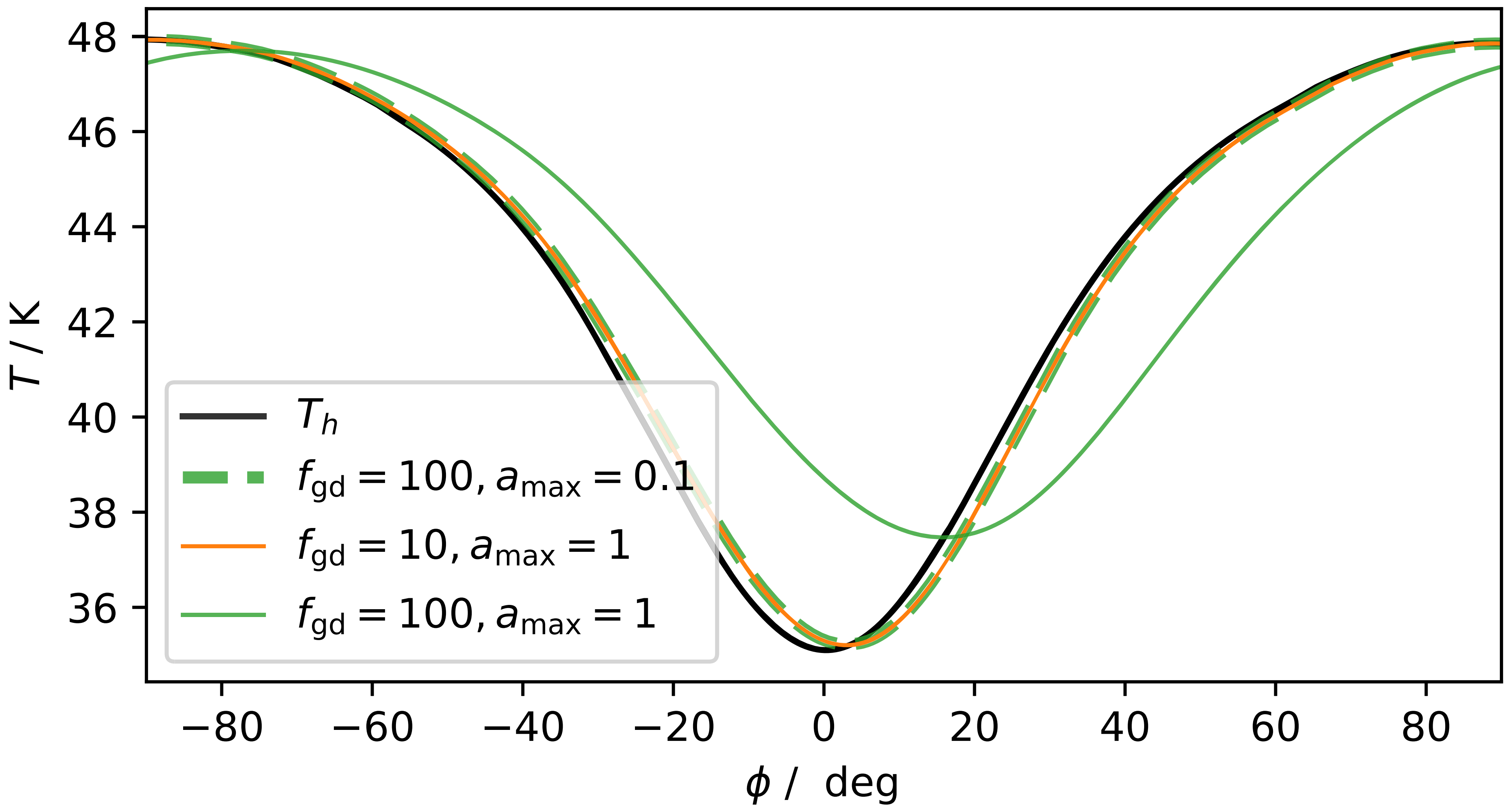
Choice of the heat source for DoAr44

- In DoAr44 the mm-ring is at ~32au, while the IR ring is at 14au, so heat source $T_h(\phi)$ must be transferred through cavity gas and small dust.





Solutions for DoAr44



- Available observations rule out a massive disk with $\Sigma > 13\,\mathrm{g\,cm^{-2}}$ at 5σ given a standard dust population

Prospects for more realistic models of temperature drops?

- 1st order approximation for 3D model: post-process temperature field. Solve for T in:

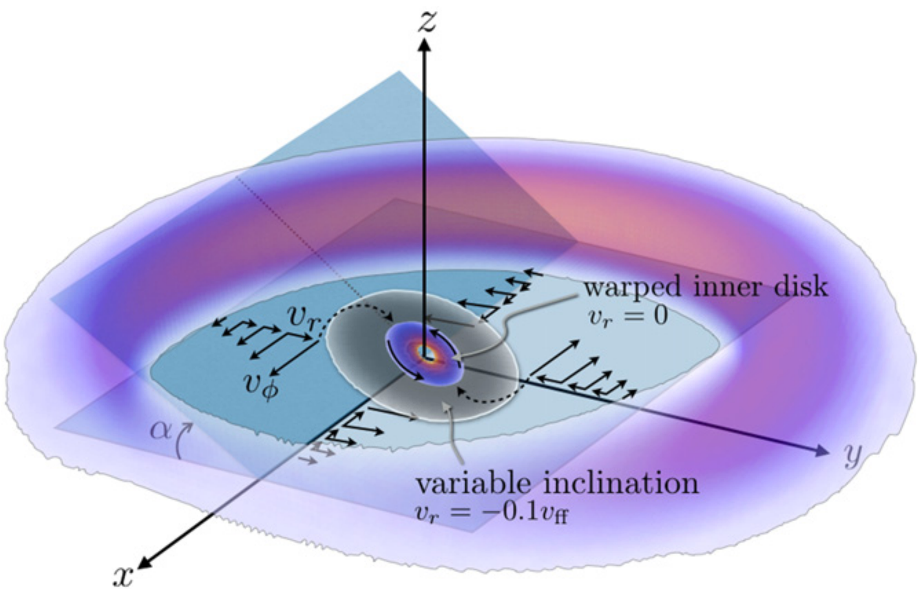
$$\vec{u} \cdot \vec{\nabla}(aT^4) = -\kappa_P \rho c a T^4 + \rho \int d\nu \kappa_\nu^a J_\nu$$

- Perhaps full-blown hydro + RT possible with PHANTOM?

Outline

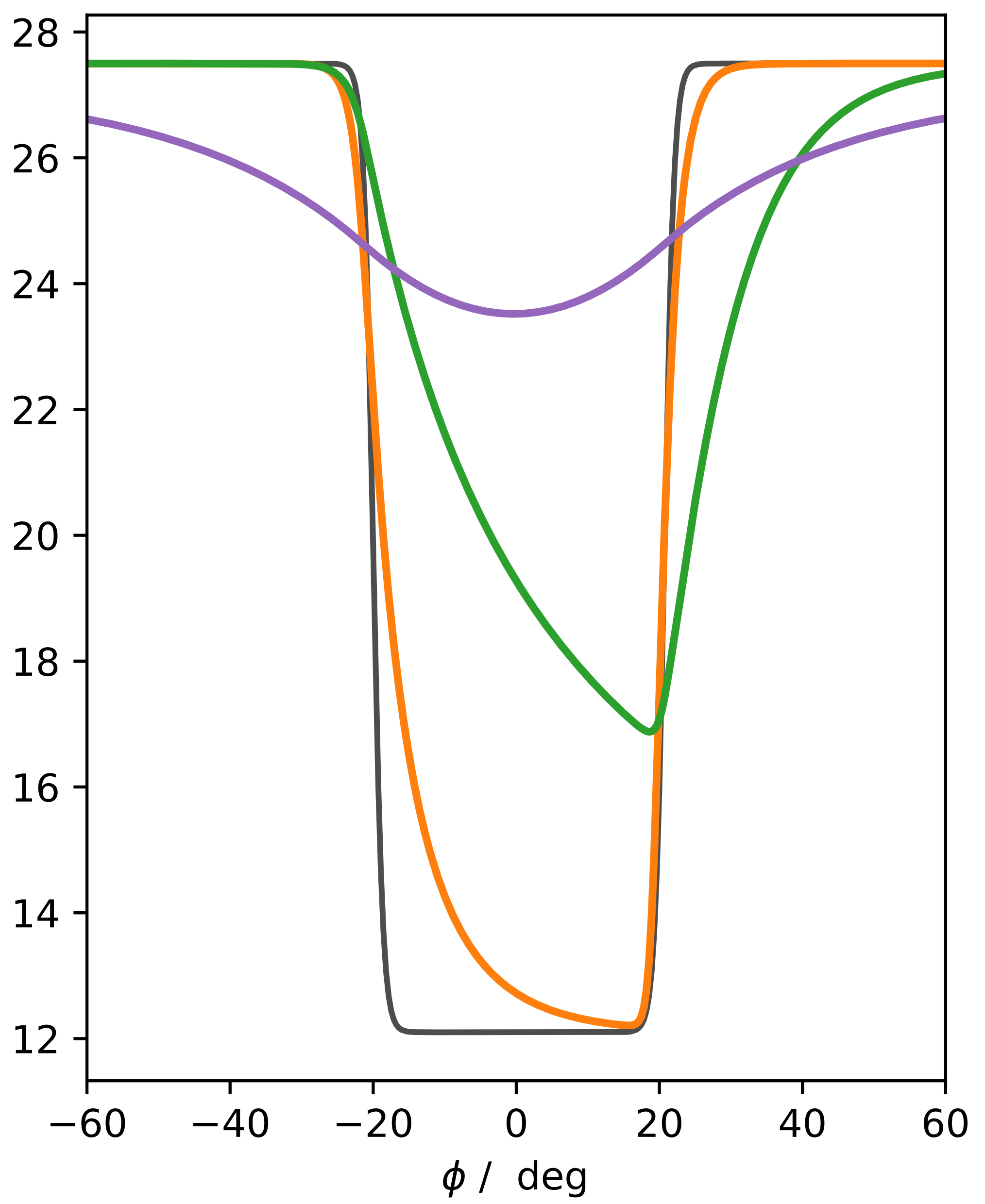
1. The sharp warp in HD142527
2. A few more warps
3. What can we learn from warps?
4. **Summary**

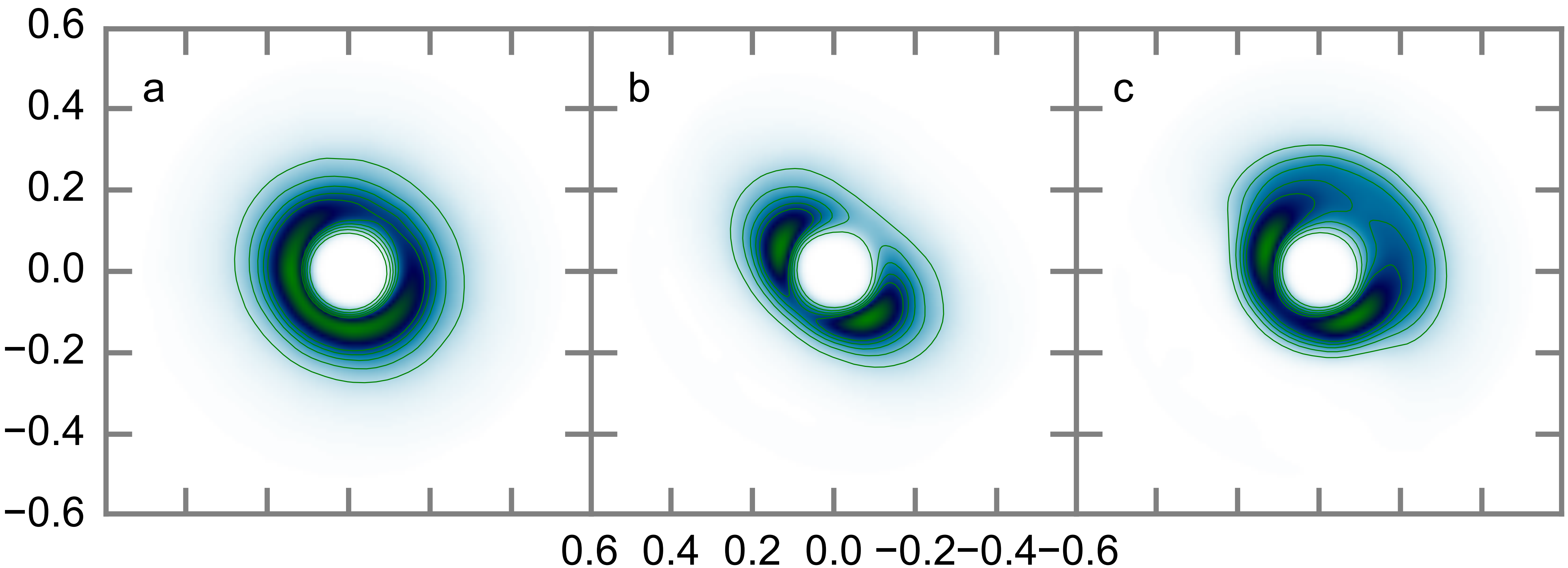
Summary

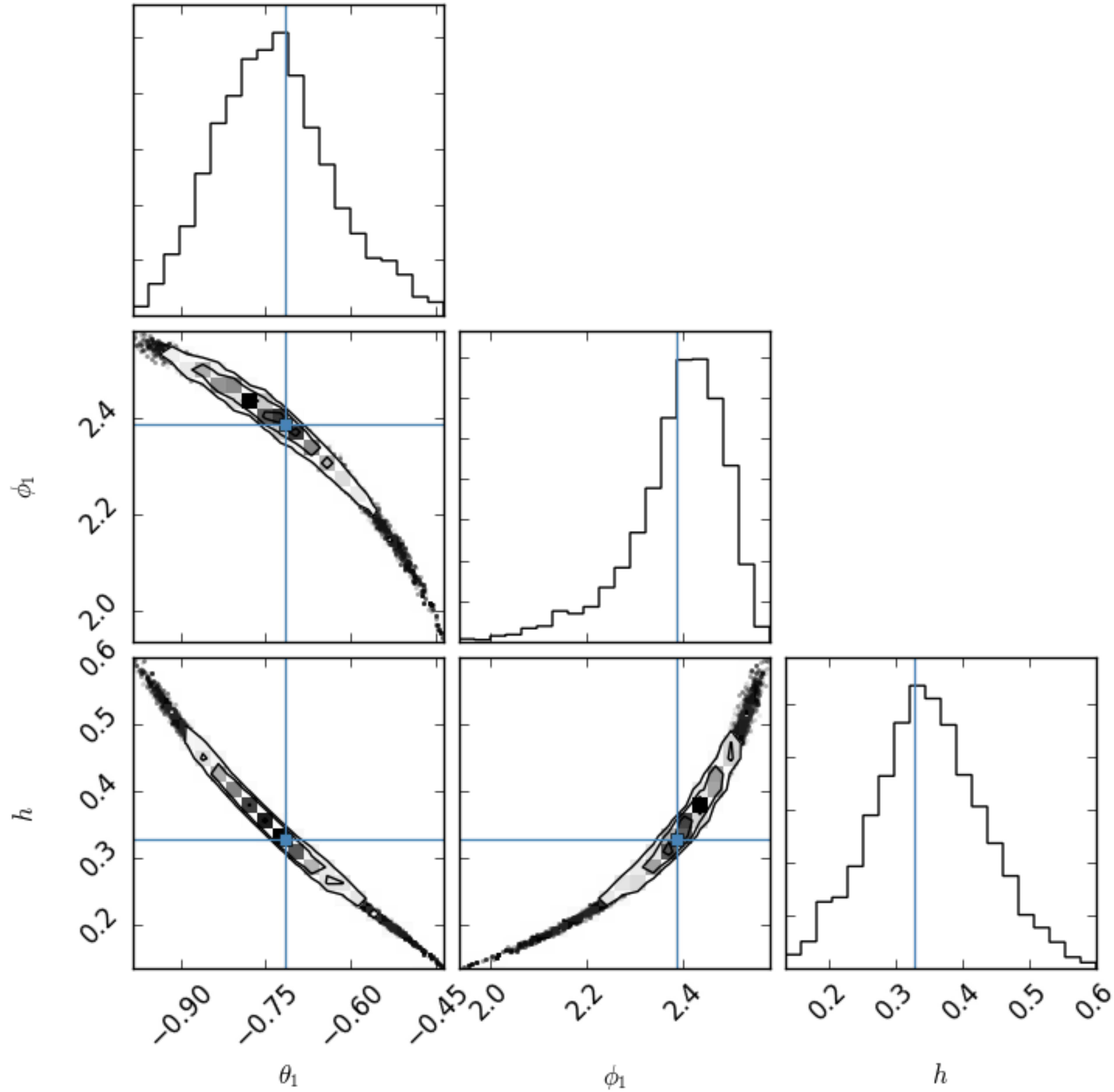


- **Transition disks** allow identification of **warp geometries**, especially sharp inner disk tilts.
- Data on warp kinematics only in HD142527, gas **flows through the warp in freefall**.

- In HD142527, DoAr44, J1604, **dust cools** enough under the shadows for detectable continuum decrements, but not in HD100453, HD143006.
- **Lack of temperature decrements** due to smoothing by radiation **in low surface densities** and/or short crossing times.
- Shape of temperature profiles can constrain **surface density**, **gas to dust ratio**, **a_{max}** and **grain filling factor**.

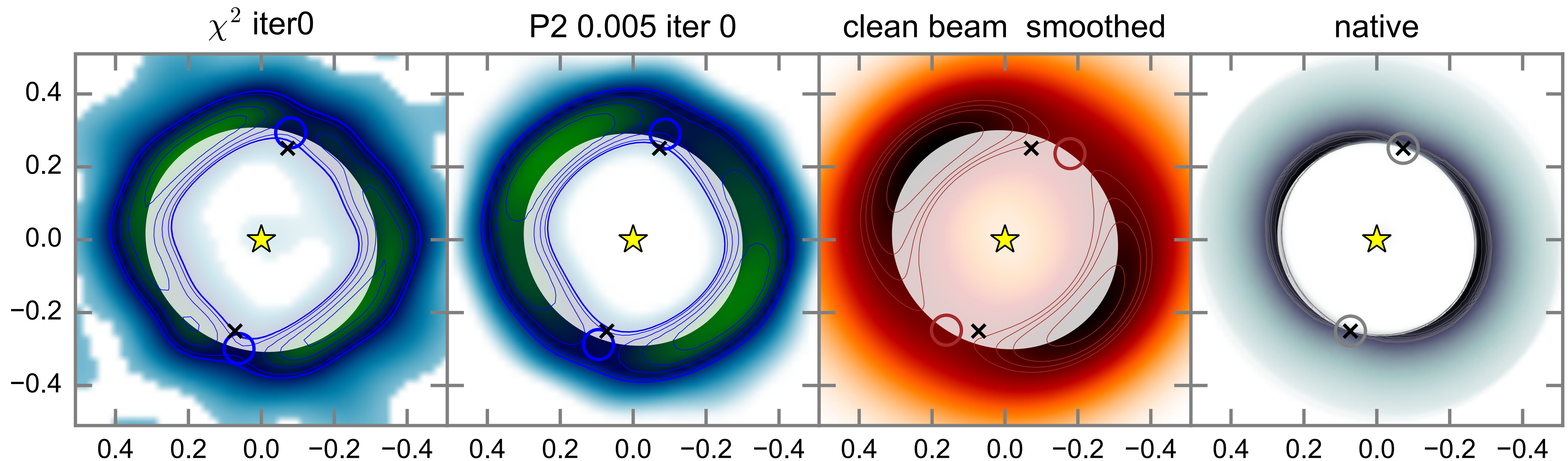


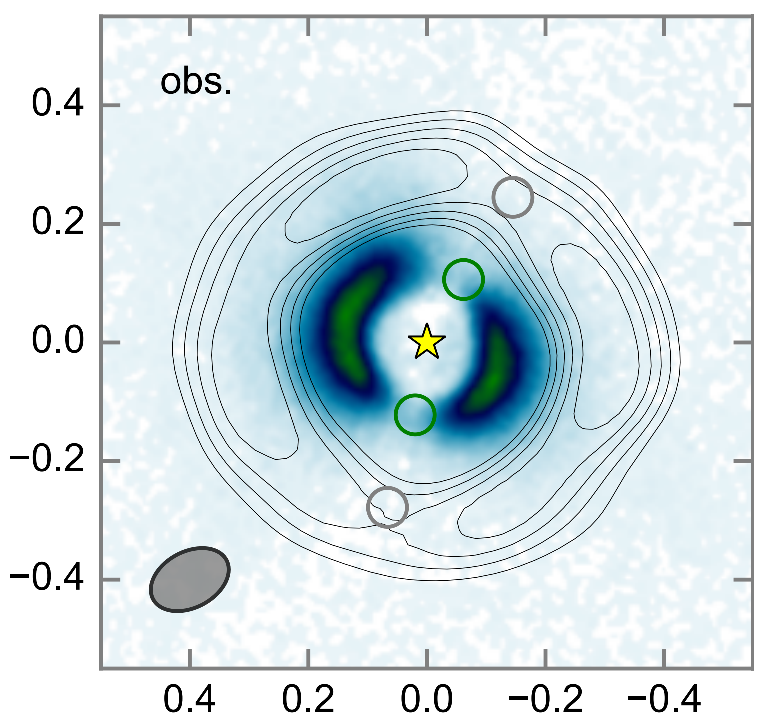

a
b
c
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0.6 0.4 0.2 0.0 −0.2 −0.4 −0.6



2.4
2.2
2.0
ϕ_1
0.6
0.5
0.4
0.3
0.2
h
−0.90
−0.75
−0.60
−0.45
2.0
2.2
2.4
0.2
0.3
0.4
0.5
0.6
θ_1
ϕ_1
h

Radio/IR shift requires very fine and circular beams in DoAr44.





- Simulations: strong bias with elliptical beam is alleviated by non-parametric image synthesis, (with regularization).