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MAD
Millenium Nucleus For Disk Research with Alma

Spiral arms in the transition disk of HD 142527

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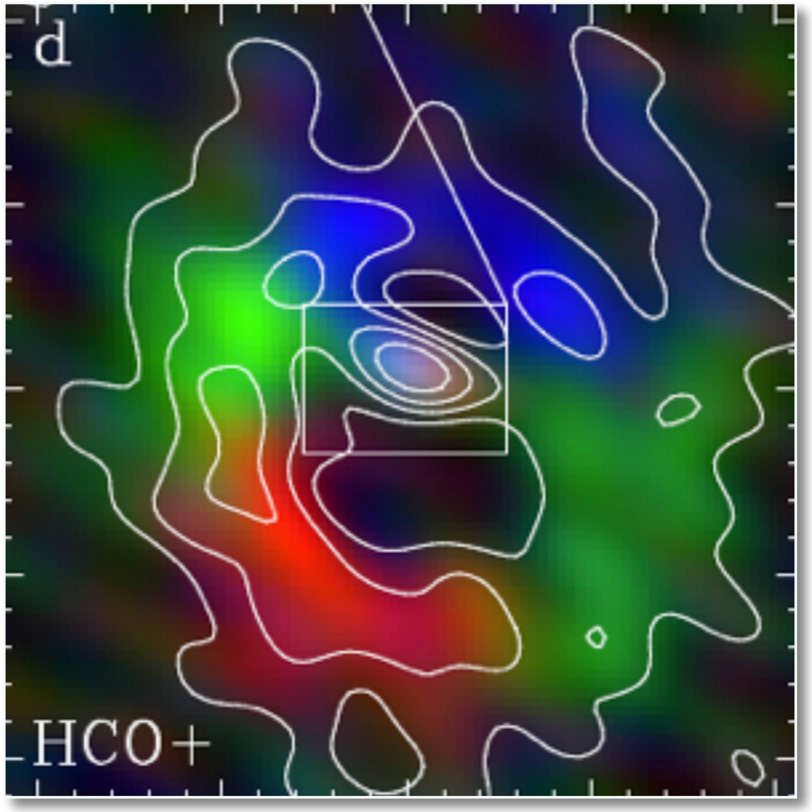
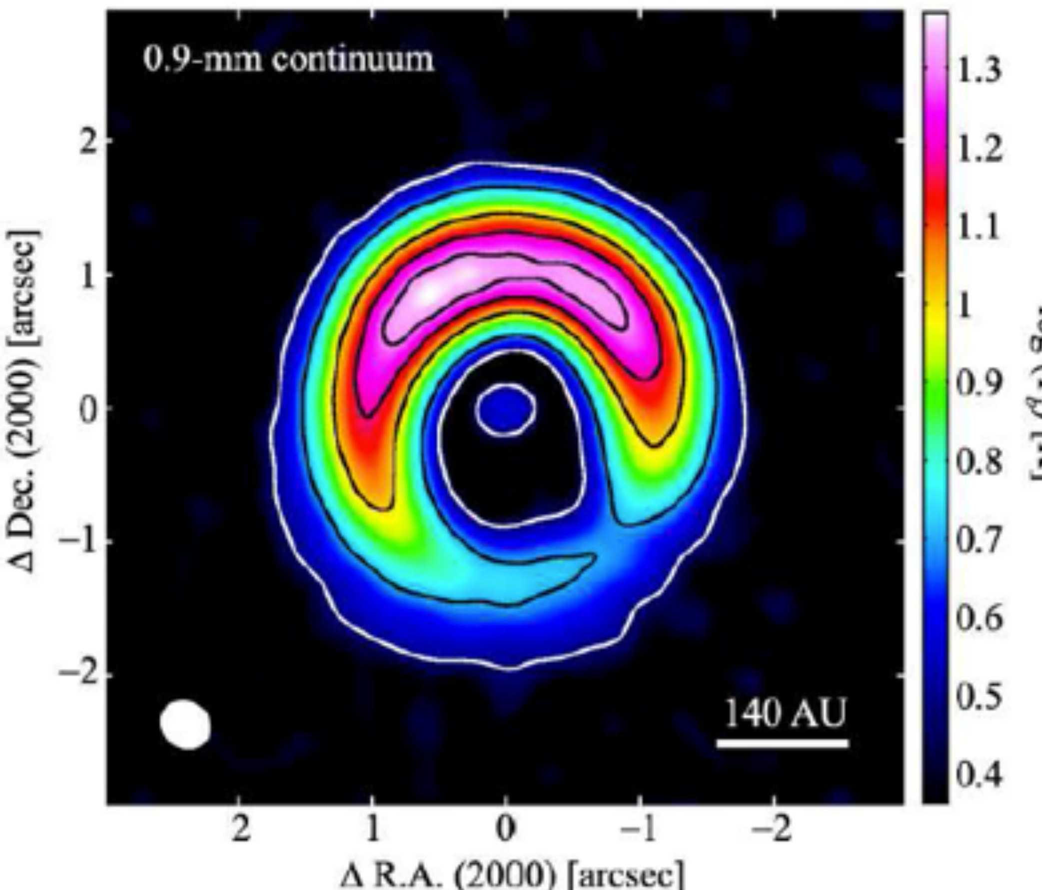
Revolution in astronomy with ALMA - Tokyo - 10/12/2014

HD 142527

- Herbig Ae star: 2-5 Myrs old, 2 $M_\odot$
- Distance ~ 140 pc
- HD 142527 B at ~ 12 au
- Transition disk almost face-on (*i* ~ 28°)
  - Inner disk ~10 au (Verhoeff+11)
  - Gap 10-130 au:
    - Dust-depleted, but with residual gas
    - Gap crossing flows (Casassus+13)
  - Outer disk >130 au:
    - Horseshoe continuum (Ohashi+08, Casassus+13)
    - Near-IR spiral structures (Casassus+12, Canovas+13)
    - Large-scale spiral structures: this work

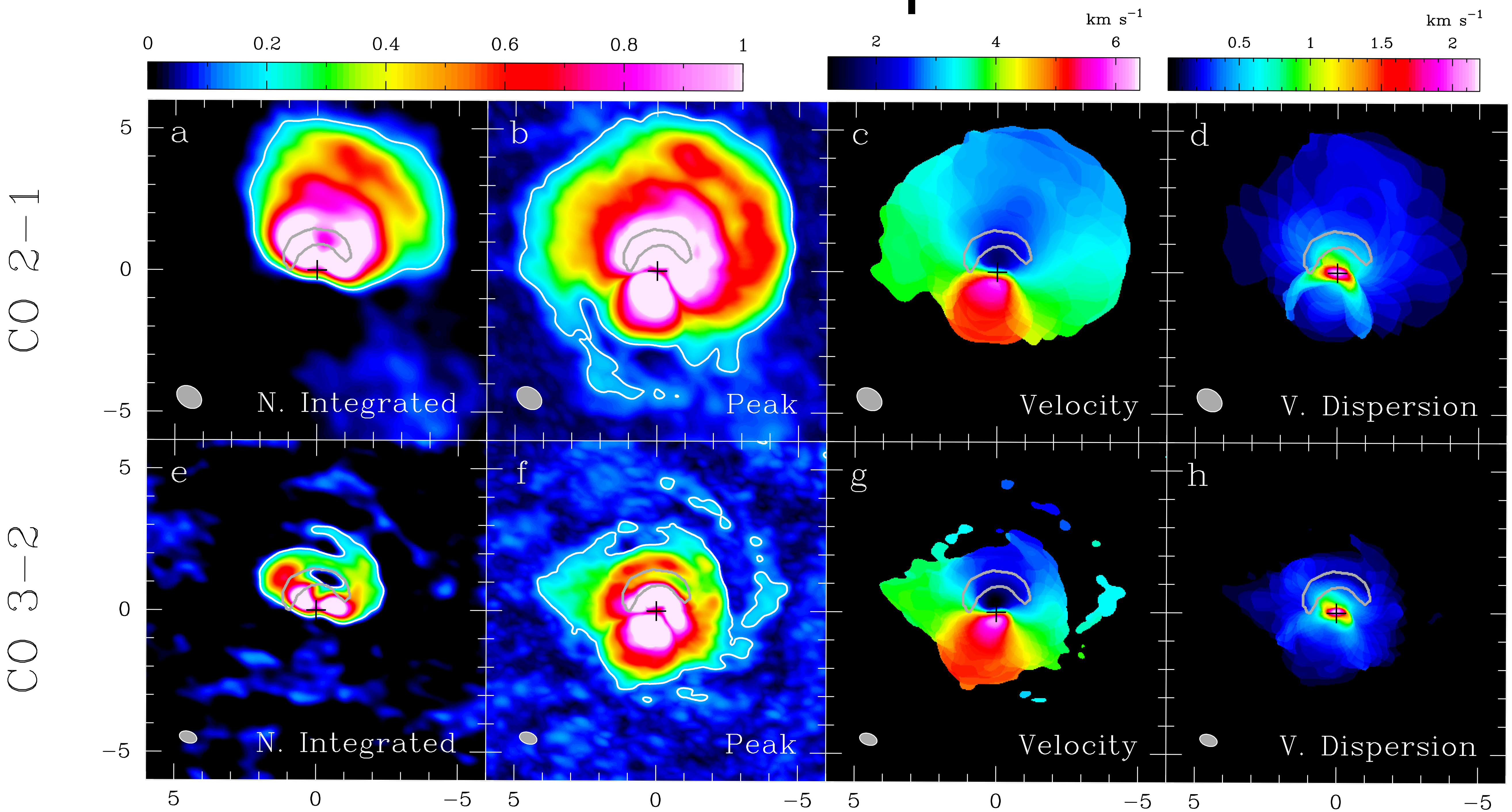


(Casassus+13)

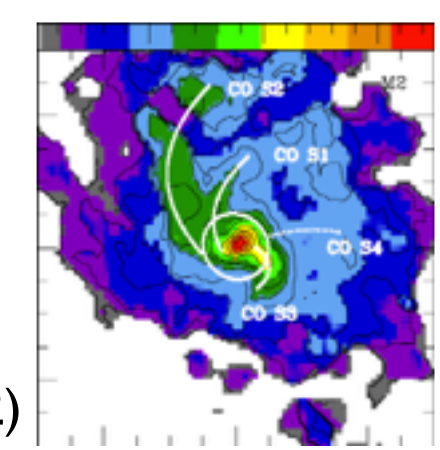


(Fukagawa+13)

Moment maps

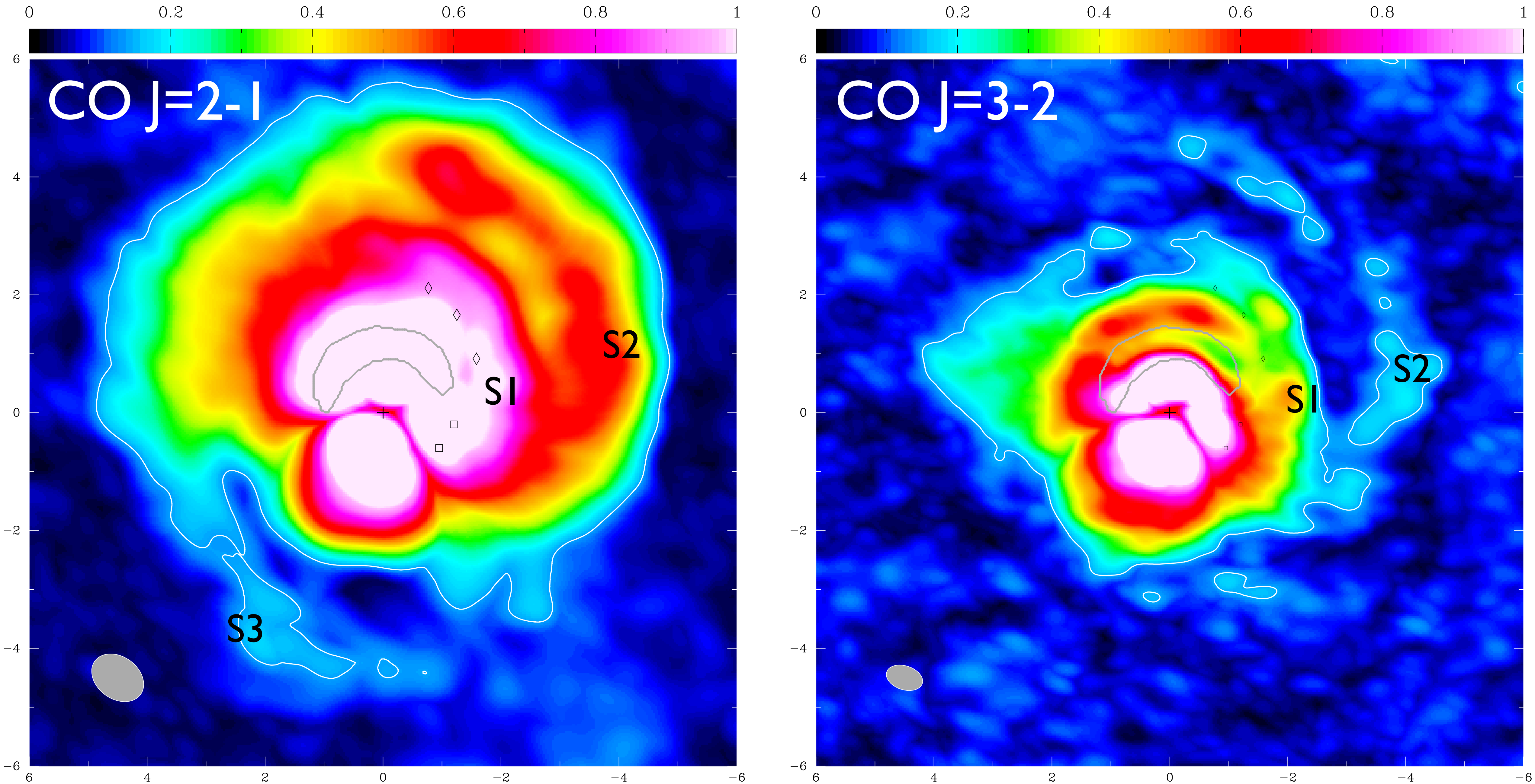


> Intervening cloud absorbs signal from the South of the disk (Casassus+13)
> I_{Peak} maps in CO 2-1 and CO 3-2 reveal spirals hinted in I_{Int} maps
> No significant departure from Keplerian velocity under the spirals $\neq$



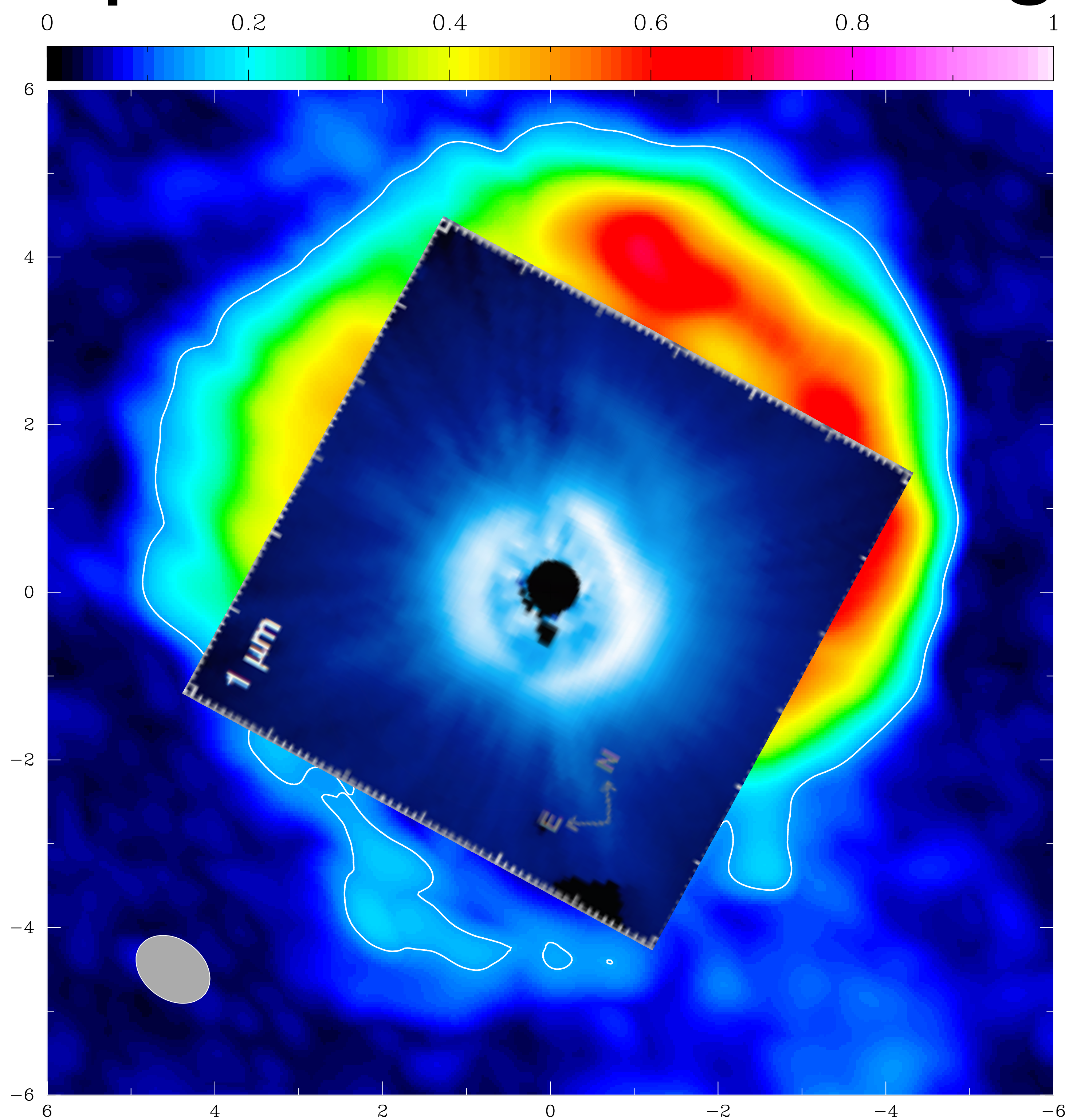
(Tang+ 12)

CO 2-1 and CO 3-2 I_{Peak} maps



> Radial extent of S1: 290-380 au; S2 & S3: 520-670 au
> S3 has the same v_{rad} as foreground cloud (Casassus+13b) => self-absorption
> T_b(S2) ~ T_{ex}(S2) ~ 13-15K < 18-20K => CO should freeze-out (e.g. Qi+13)
=> either CO is efficiently desorbed (e.g. Hersant+09), or dust is depleted or settled under S2

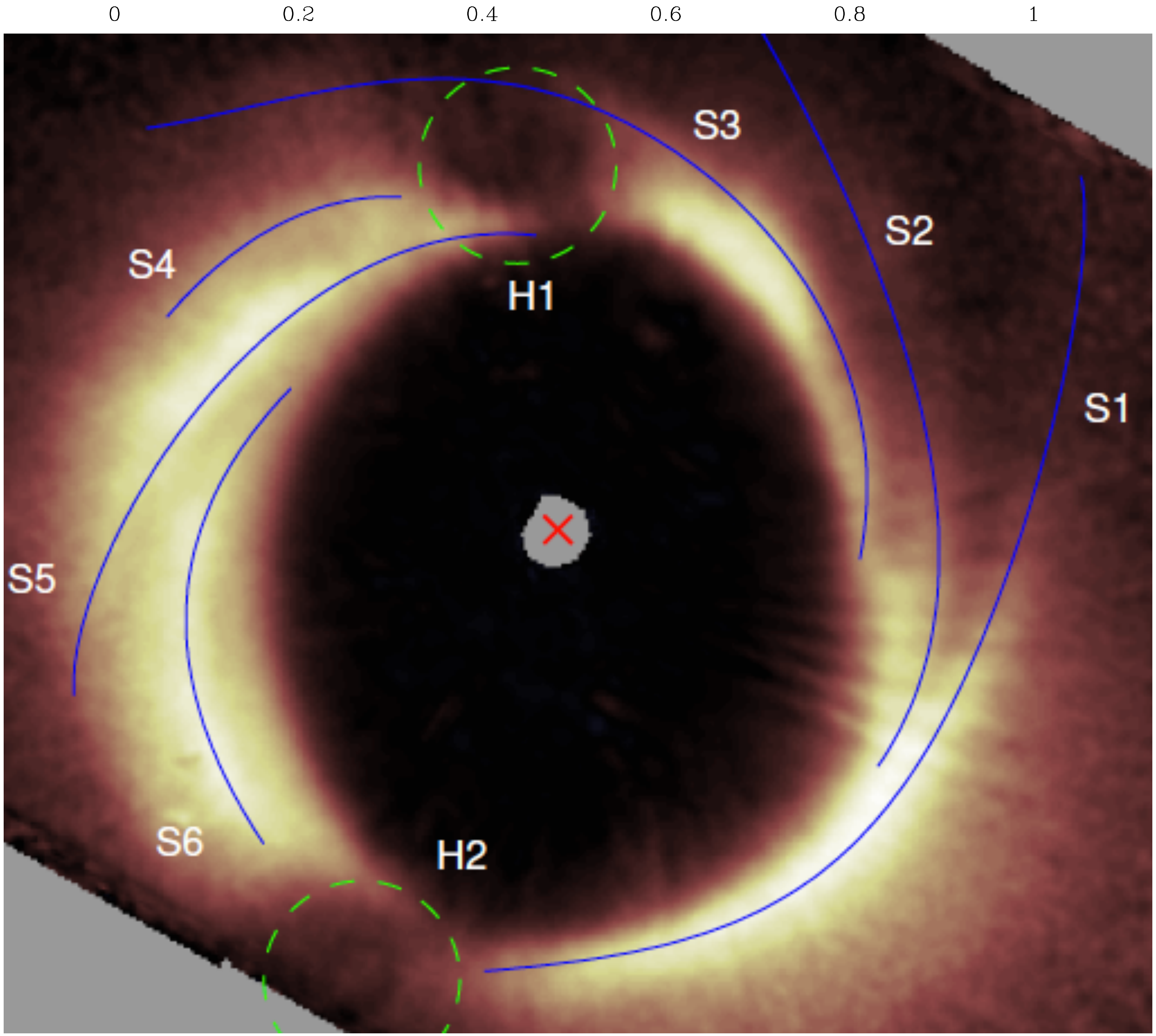
Comparison with HST image



HST, obs. in 98

> asymmetric arcs at gap edge and conspicuous spiral
> slight radial shift between HST and ALMA spiral => scattering surface vs bulk emission?

Comparison with VLT/NACO image

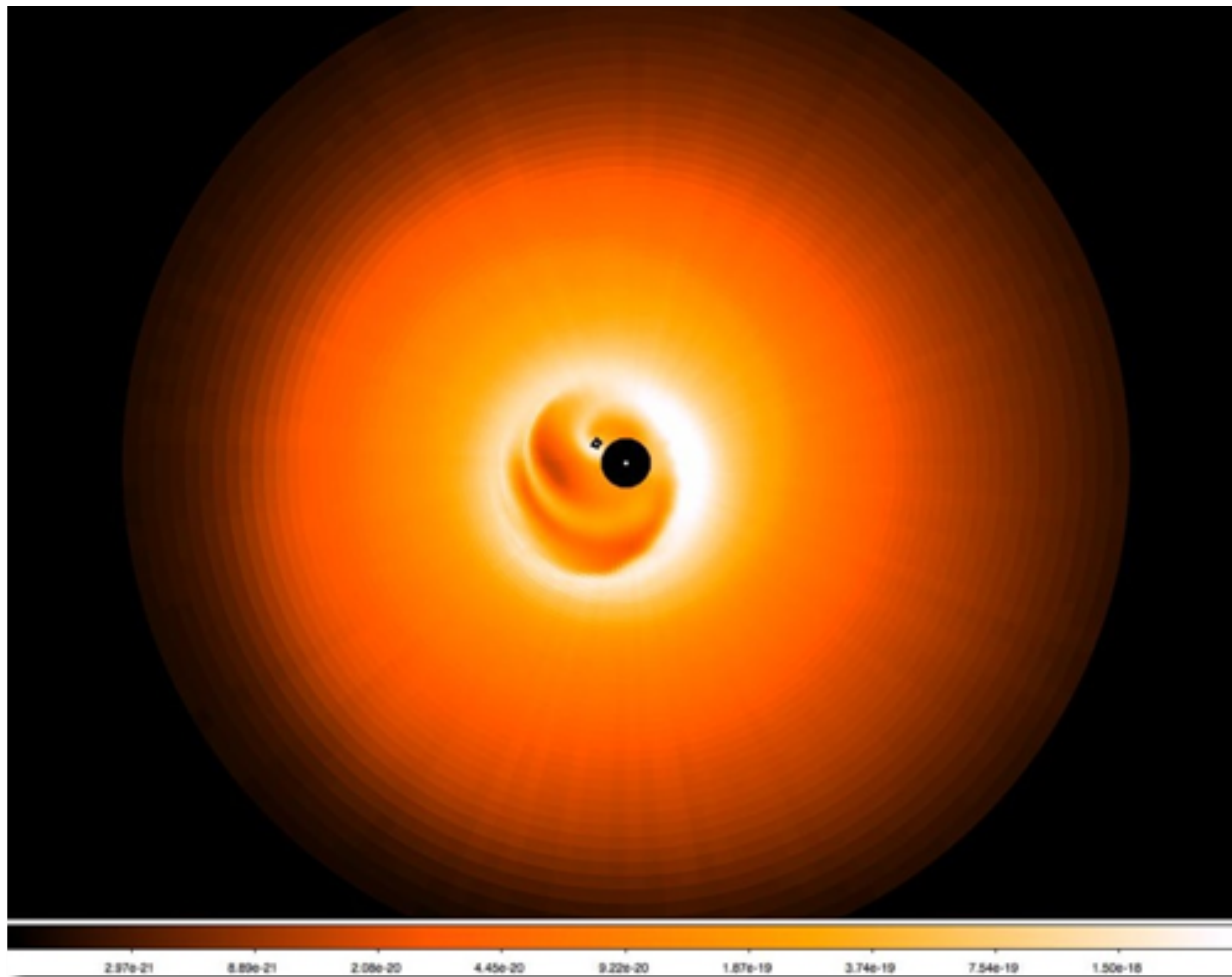


Avenhaus+14

> Pattern of NIR spirals stemming from the edge of the ~1" annular gap
> Near-IR "S1" at the root of ALMA S1
> Possibly two types of spirals: 1) gap edge spirals; 2) large scale outer spirals

Origin of the spiral pattern at gap edge

- HD 142527 B?



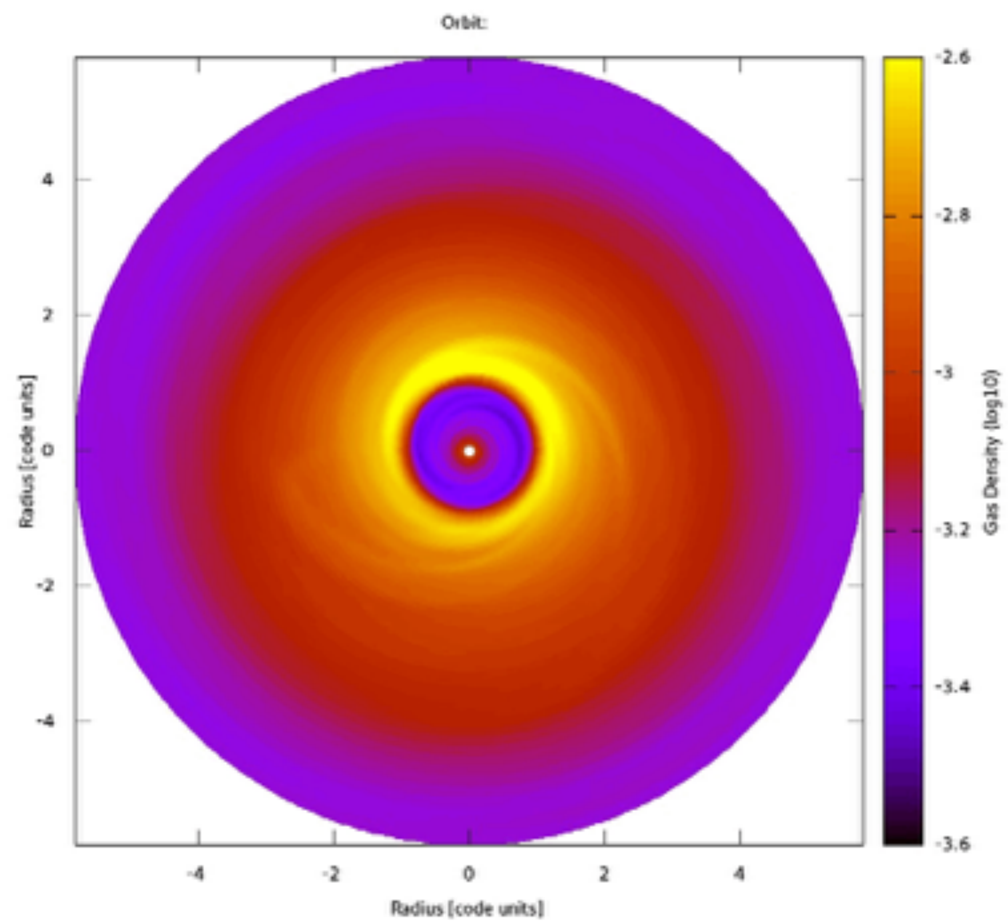
A. Dunhill+

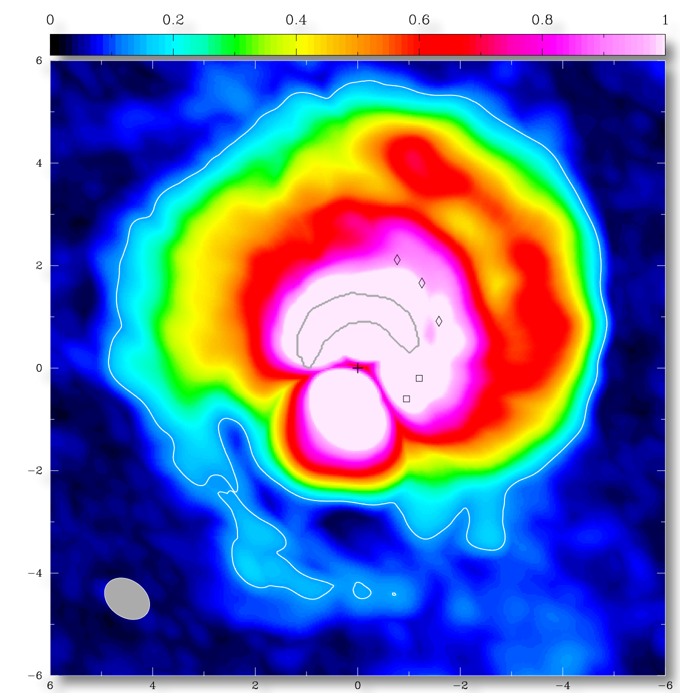
> SPH simulation for another system (different mass ratio, eccentricity & location wrt edge)
> Qualitatively explains the spiral pattern seen at the gap edge (and gap crossing flows)
> Does not explain large scale spirals

Origin of gap edge spirals and S1?

- Unseen planetary companion(s)?

> Near-IR upper mass limits: 4-5 M_{Jup} at r > 0.3" (Casassus+13)
> Hydrodynamical simulations with Fargo (S. Perez):





~200 eccentric orbits with a 0.3 M_{Jup}

> A planet with either a circular or eccentric orbit can create gap edge or S1-like spirals
> A planet on an eccentric orbit or multiple planets can create branching spiral arms (as observed for S1 with SPHERE)
> Does not explain large scale spirals

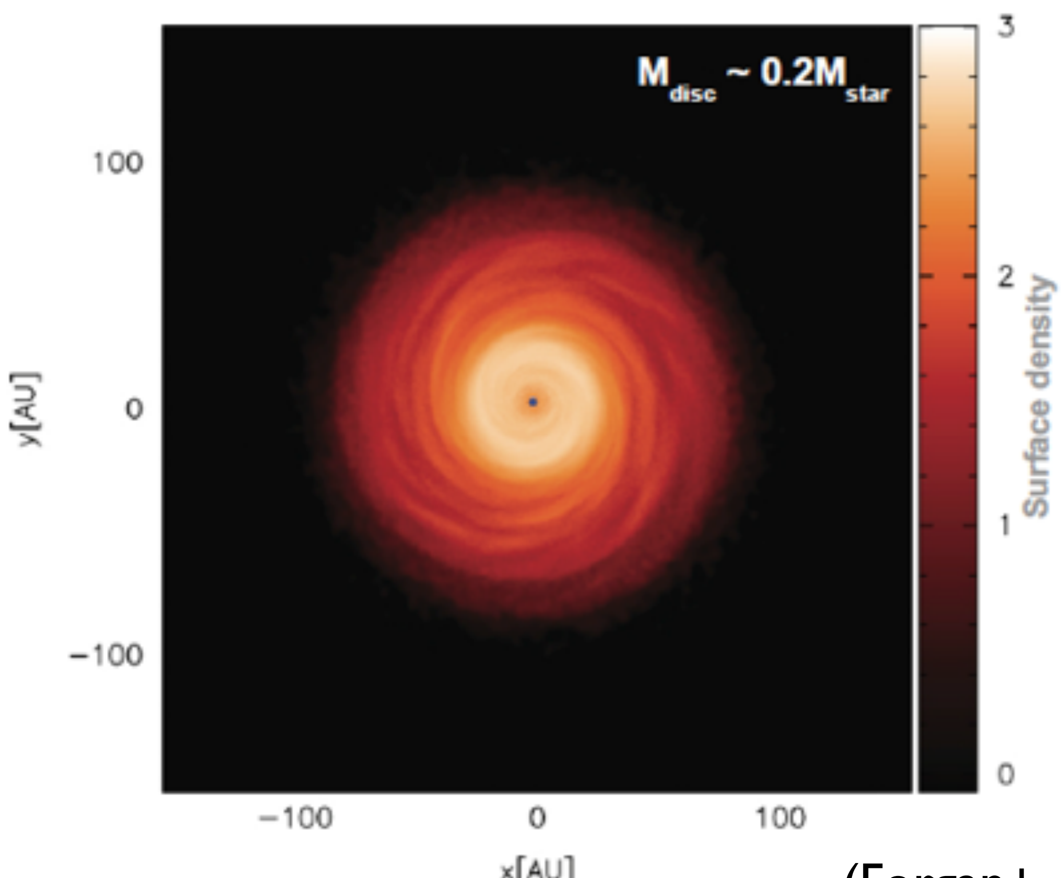
Origin of S1, S2 & S3?

- Disk self-gravity?

> Global estimate: $Q = \frac{c_s \Omega}{\pi G \Sigma} \approx \frac{M_\star}{M_d} h \sim 2.0$ ⟶ marginally stable (but large uncertainty on M_d)

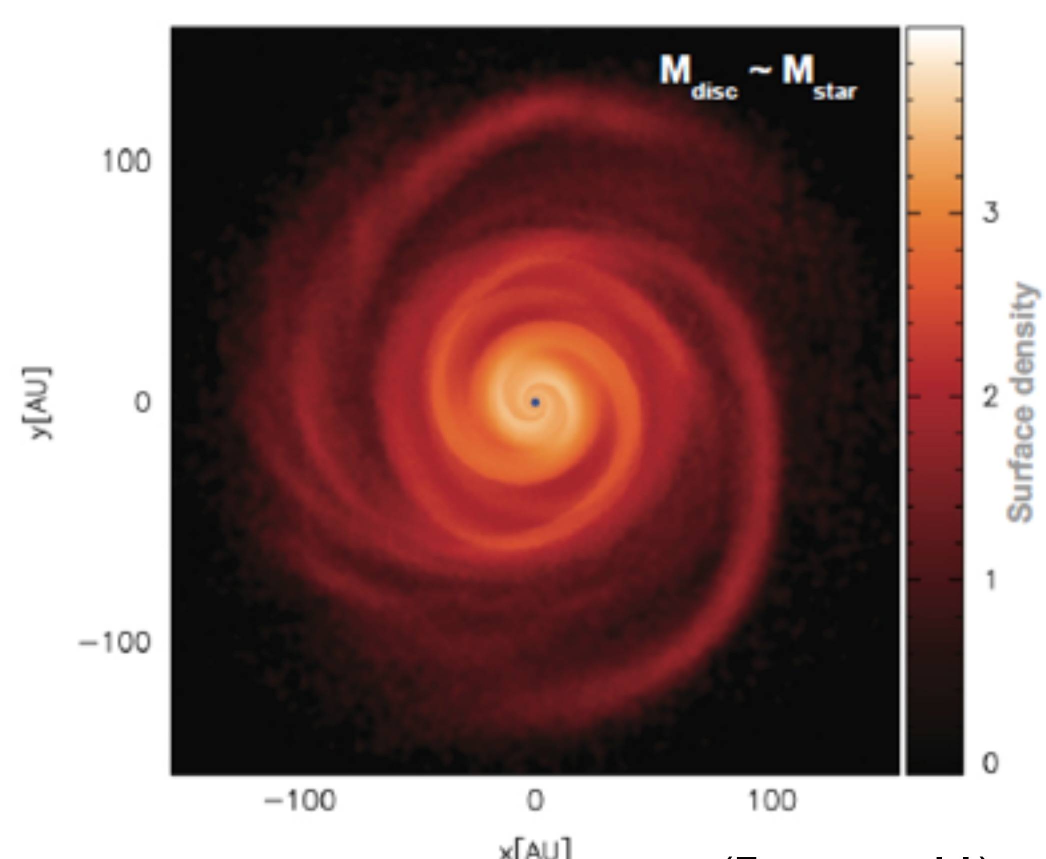
> Local estimate under S2 (from ^{13}CO J=2-1 non-detection): Q > 50
⟶ stable, but also large uncertainty (e.g. ratio of CO frozen on grains at T~13-15K?)

> If $\tau_{cool}\Omega > 3-5$, no fragmentation, and depending on disk mass and elapsed time:



(Forgan+ 11)

or



(Forgan+ 11)

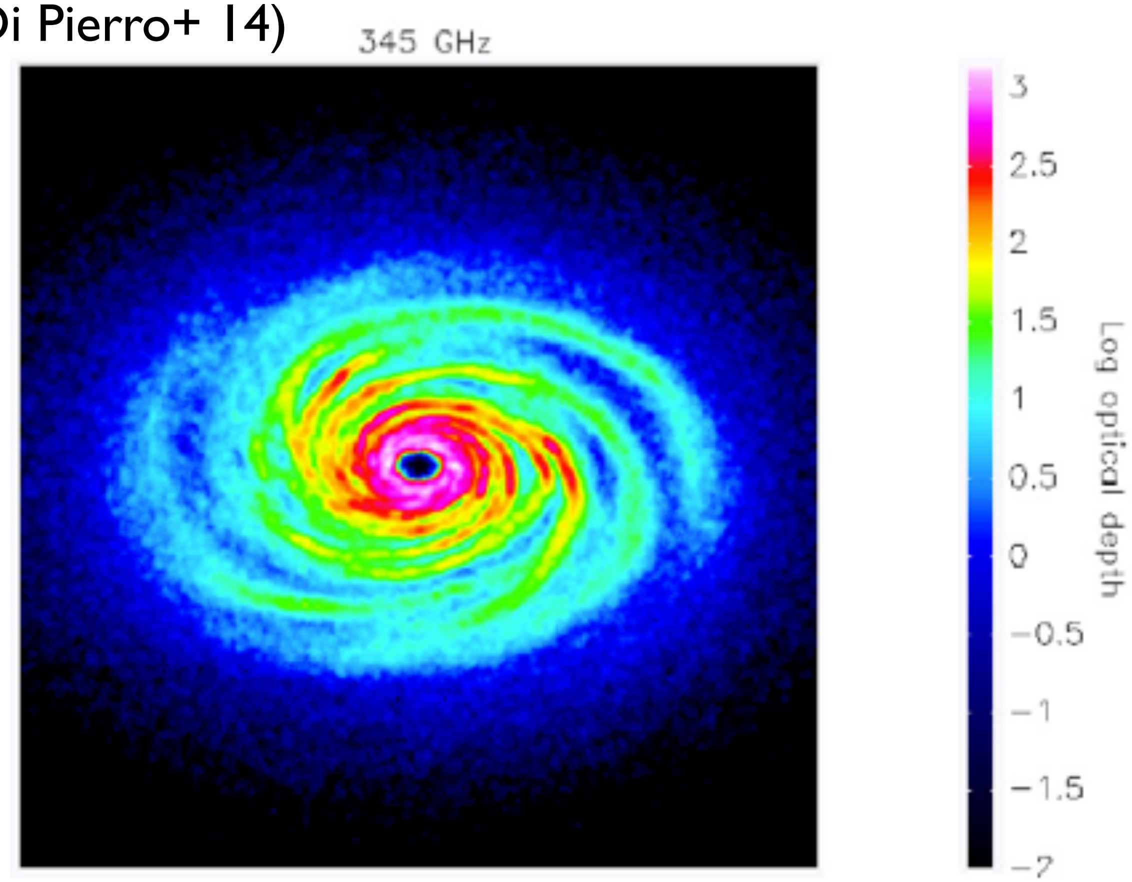
Origin of S1, S2 & S3?

- Disk self-gravity?

> Higher-modes spirals might be filtered out due to a combination of:

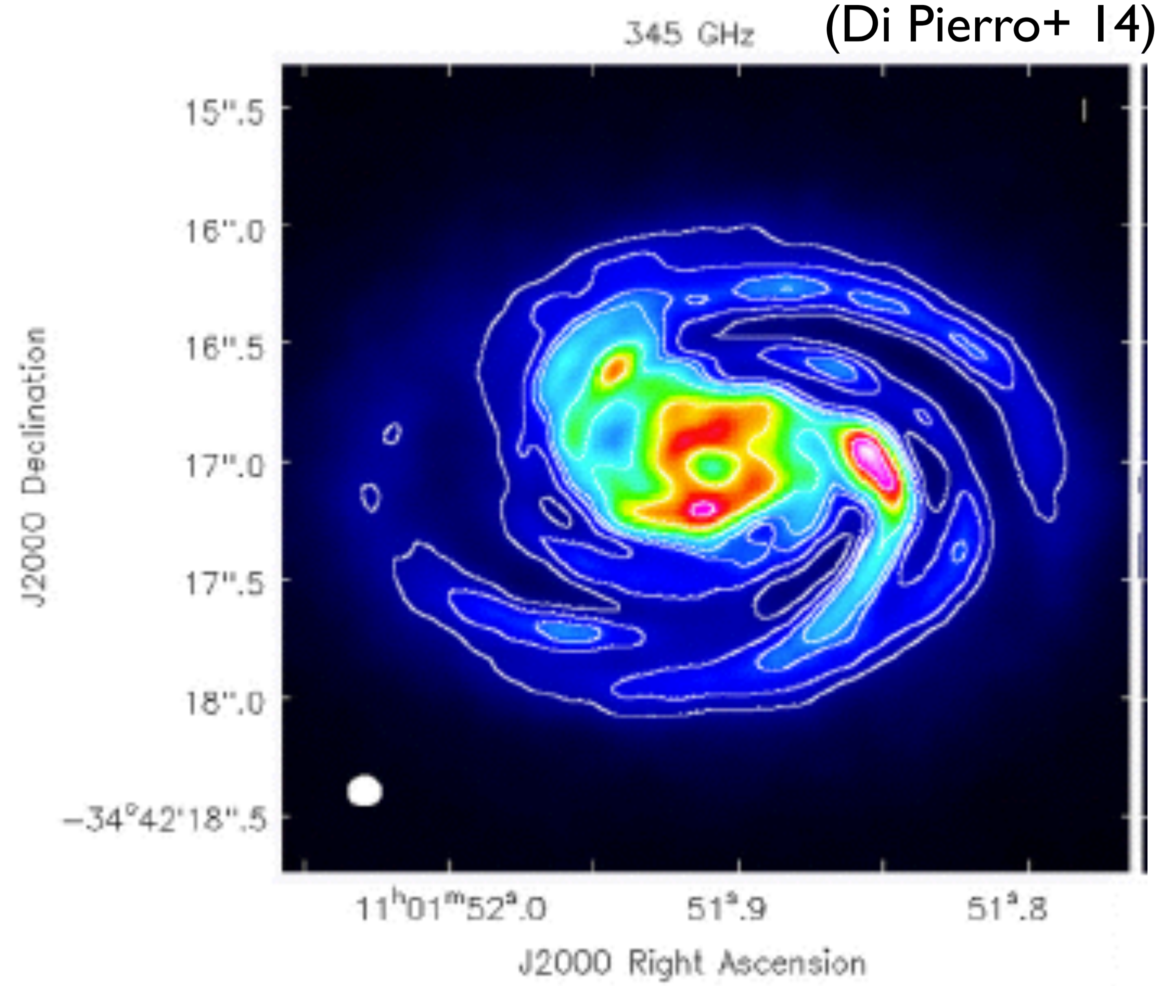
- finite resolution
- inclination
- transient spiral merging (↗brightness)

(Di Pierro+ 14)



seen as:

(Di Pierro+ 14)

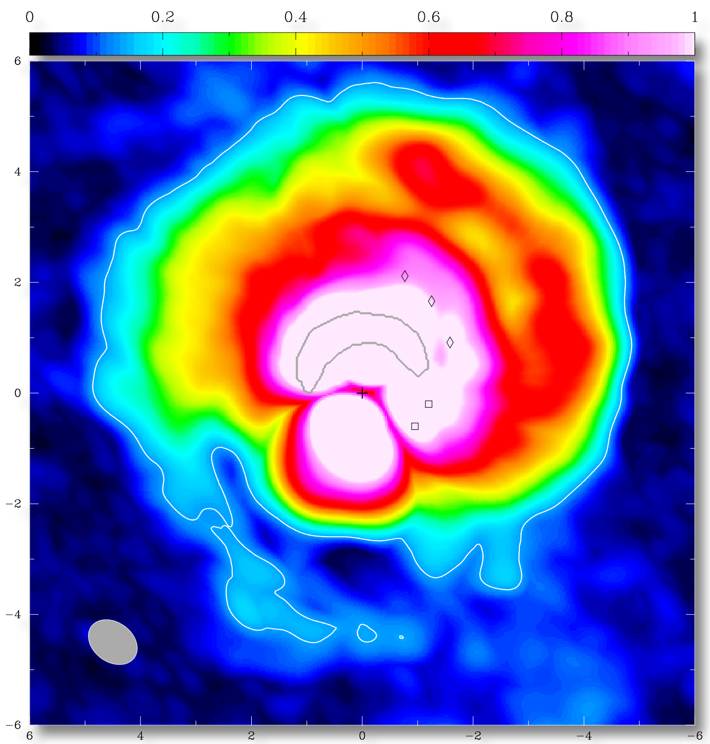


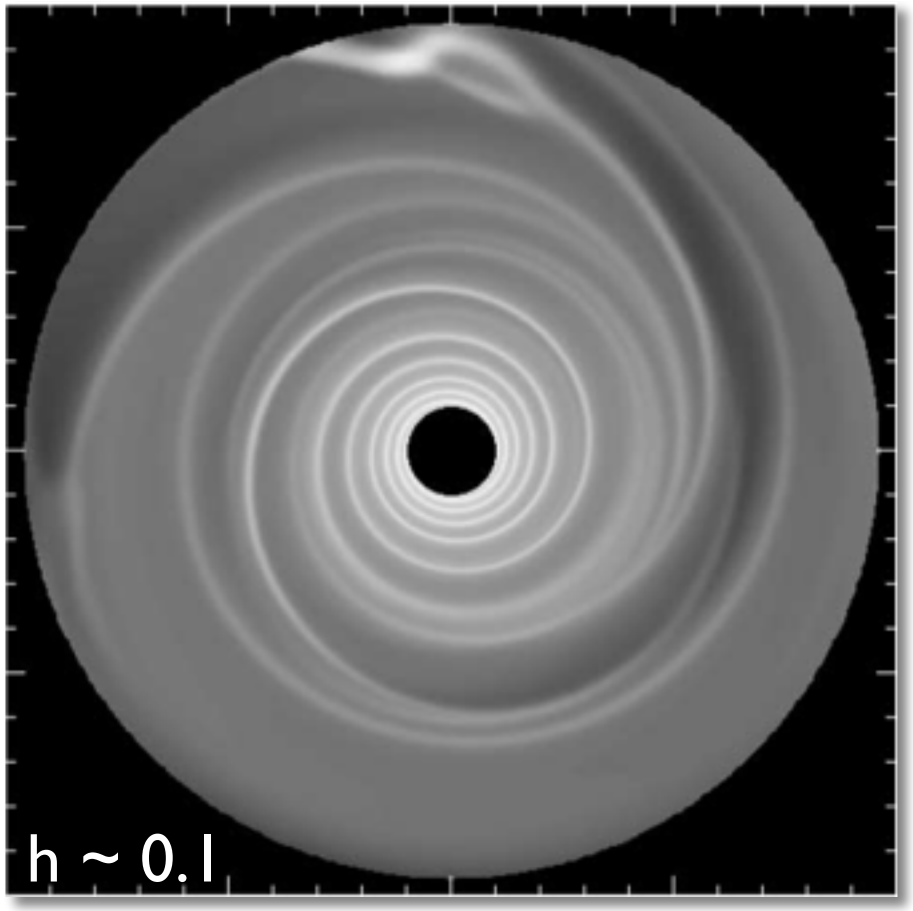
Origin of S2 & S3?

- Tidal interaction by a past stellar encounter?

(e.g. Larwood+ 01, Augereau+ 04, Quillen+ 05)

> Transient spirals (a few dynamical timescales ~ 10^3 years)





Quillen+ 05

> Recent encounter => perturbing star is still in the neighbourhood
> Necessity to follow objects up to a few arcmin away
> Answer soon with proper motions measured thanks to Gaia

Summary

- ☆ Three CO spiral arms in the disk of HD 142527 (+ gap edge spirals):
  - ALMA S1 is radially shifted outward with respect to a near-IR spiral
  - S2 and S3 are new and at larger scale (> 500au)
- ☆ Possible origins:
  - HD 142527 B ⟶ gap edge spirals + S1?
  - Planetary companions ⟶ gap edge spirals + S1?
  - Self-gravity ⟶ all (gap edge + large scale) spirals?
  - Stellar encounter ⟶ large scale m=2 spirals?
- ☆ More details in Christiaens et al. 2014, ApJL, 785, 12

Perspectives

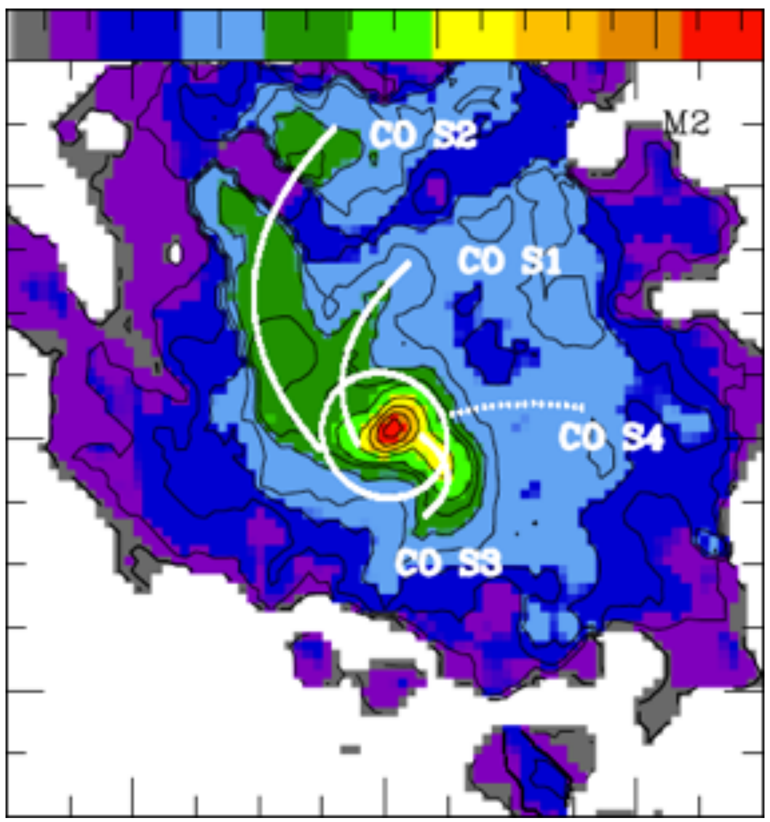
- Cycle 2 ALMA data with both same and different gas tracers
  ⟶ test self-gravity, with better disk/spirals mass estimates
- Analysis of deeper near-IR images in the gap (SPHERE-IRDIS)
  ⟶ test the multiple planets scenario
- On-going SPH simulation ⟶ test spirals due to HD 142527 B
- Gaia's astrometry of neighbouring stars
  ⟶ test the stellar encounter possibility

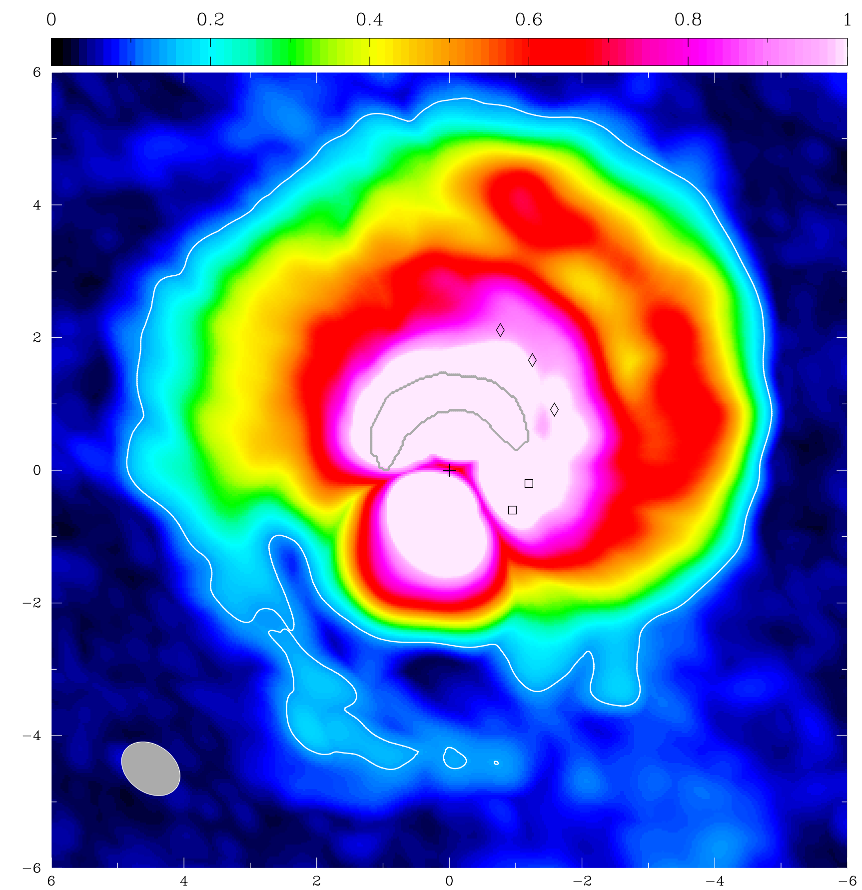
Appendix: Comparison with AB Aur

Late envelope infall? No! (Tang+ 12)

- AB Aur: Herbig star, large gap, only TD with known sub-mm spirals

(Tang+ 12)

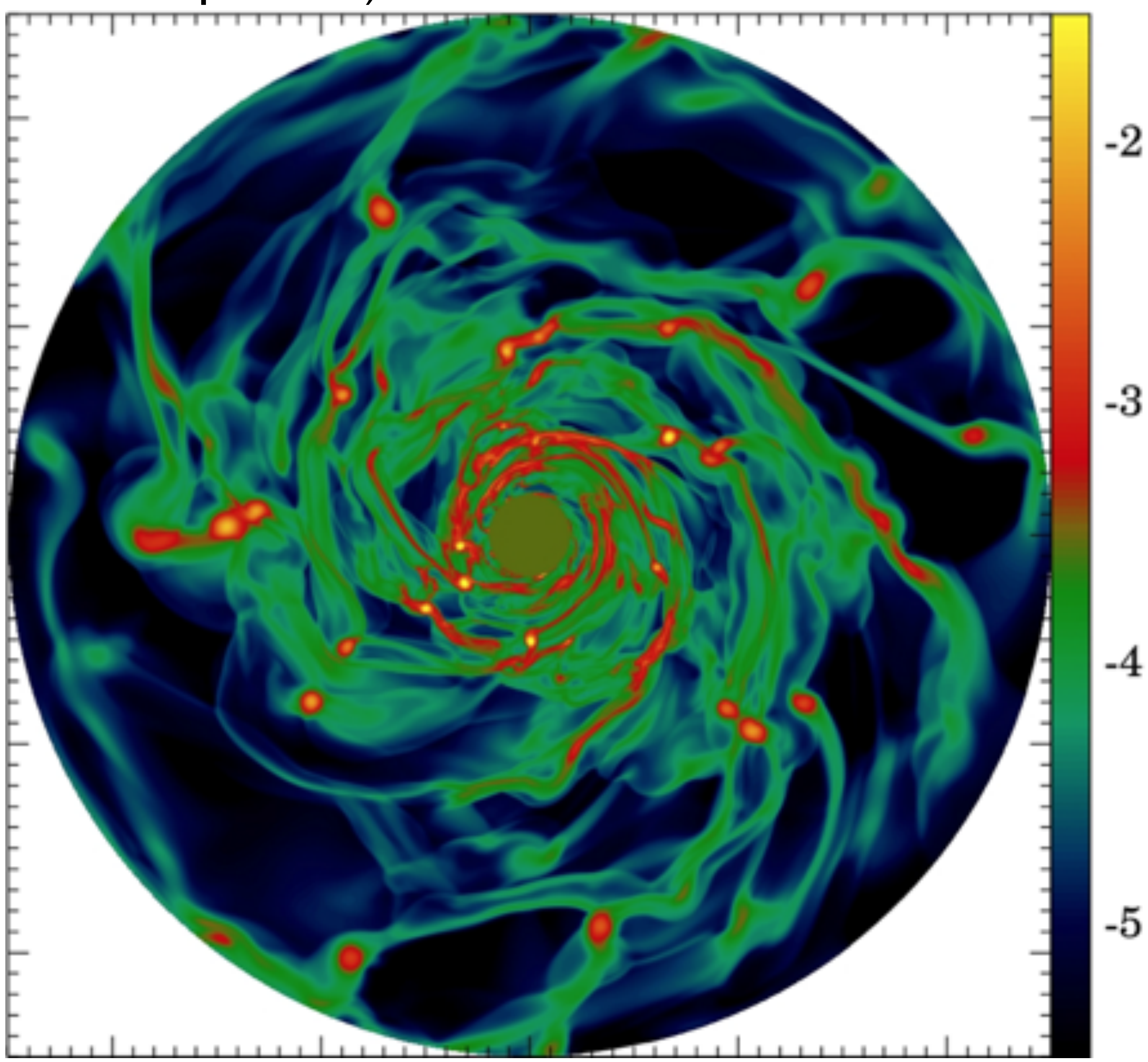




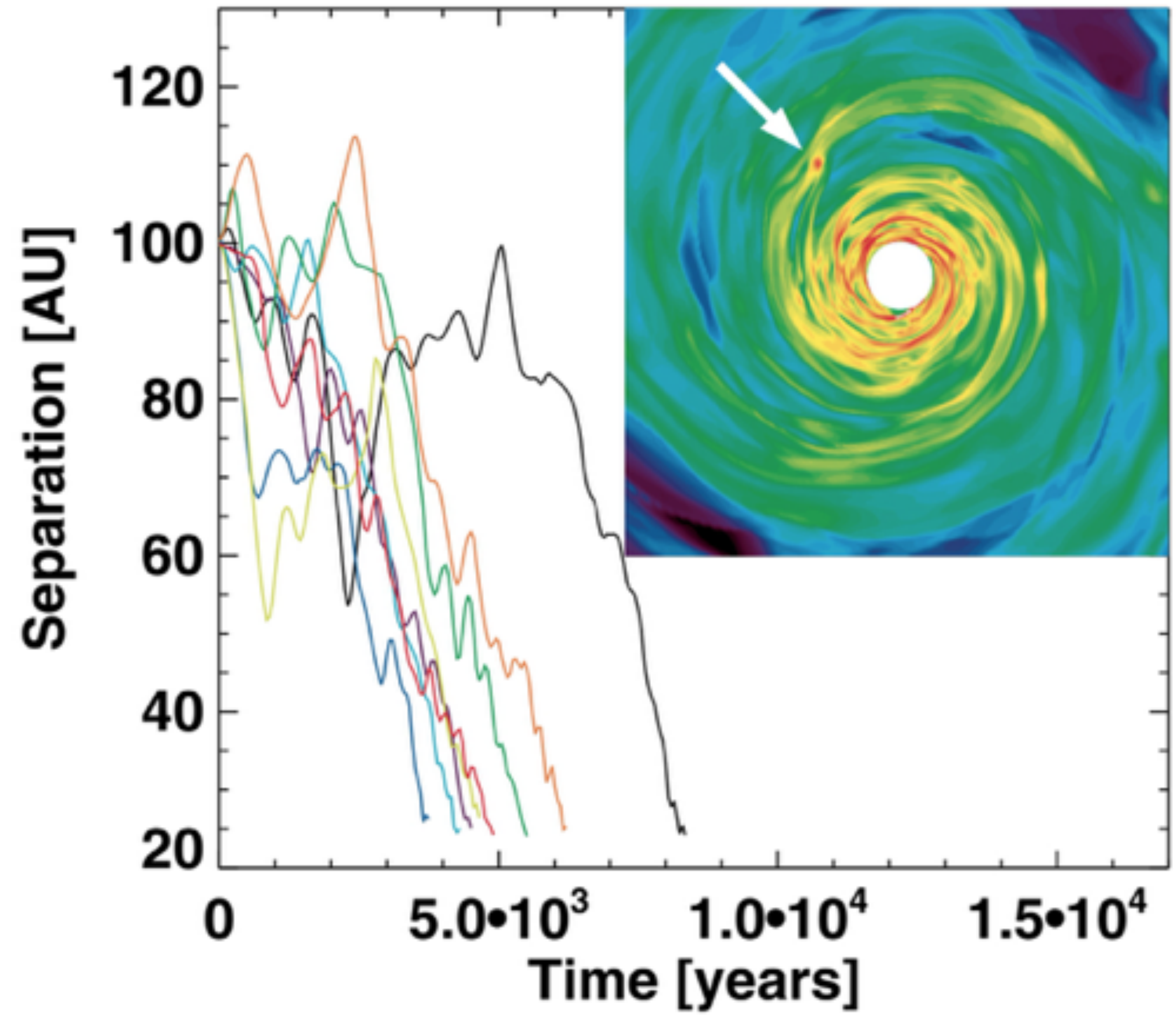
• AB Aur spiral arms have a larger pitch angle.
• AB Aur spiral arms seem to counter-rotate with the disk (vel. disp.).
=> Late envelope infall above or below the mid-plane of the disk.

Appendix: GI fragmentation

(Paardekooper+ 11)



(Baruteau+ 14)



If $\tau_{\rm cool}\Omega \leq 3-5$, fragmentation in clumps => followed by rapid inward migration

(Mayer+ 02, Baruteau+ 11, Zhu+ 12)