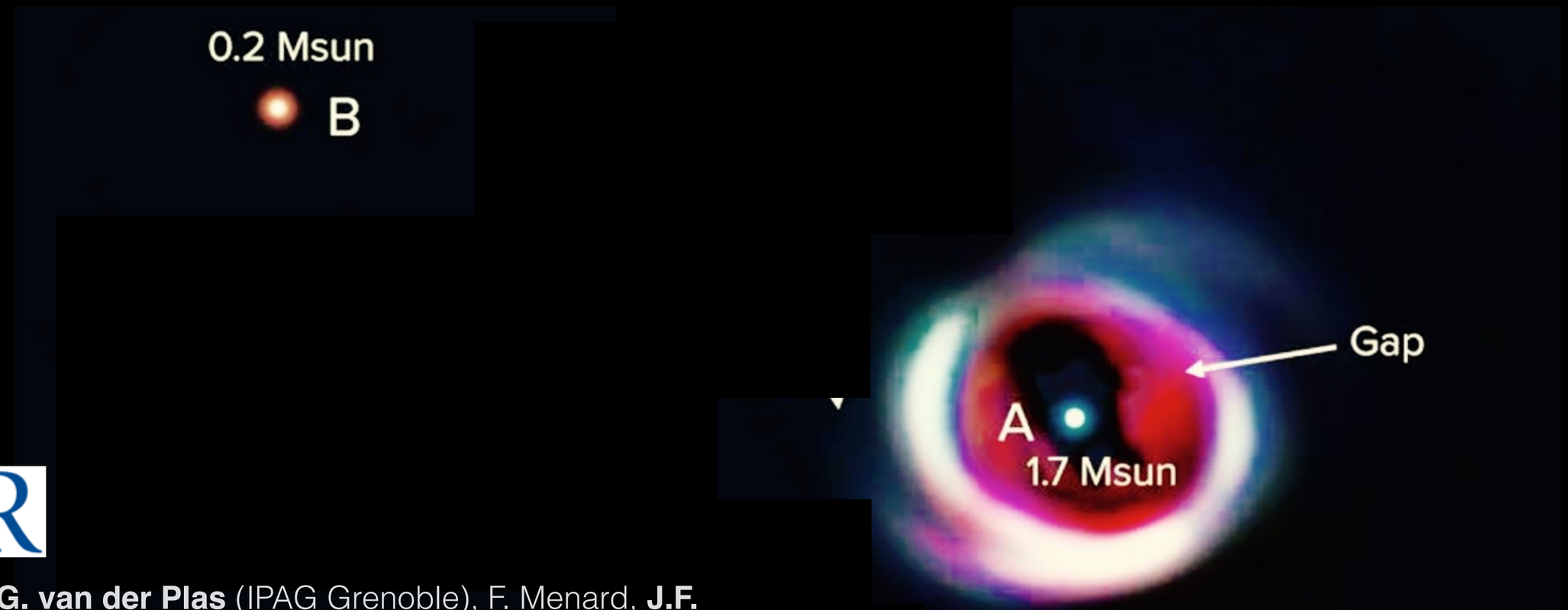
Testing spiral arm formation in the HD 100453 AB system



Adapted from Wagner et al. (2018)

G. van der Plas (IPAG Grenoble), F. Menard, **J.F. Gonzalez, C. Pinte, S. Perez**, L. Rodet, **S. Casassus, L. Cieza**, **M. Benisty**, **G. Duchene**

HD 100453

E N

(Chen+ 2006, Colins+ 2009)

0.2 Msun

B

(Wagner+ 2015)

Spirals

Connected?

(Benisty+ 2015)

Shadows

Disk cavity

(Wagner+ 2015)

A

1.7 Msun

Small inner disk

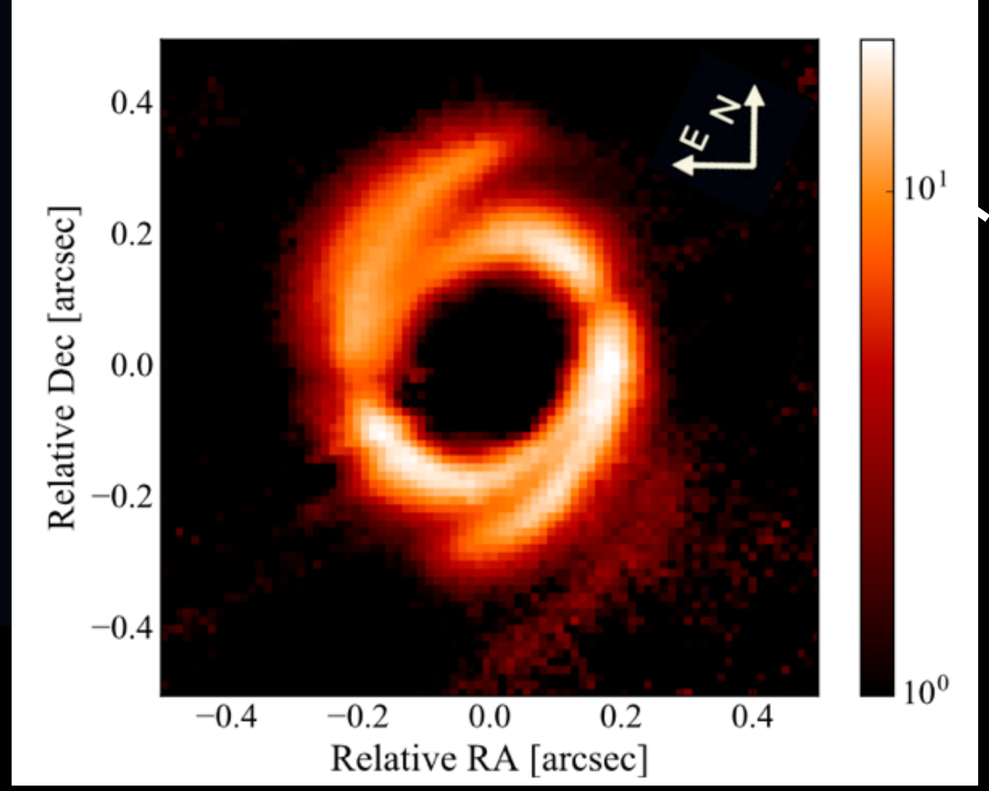
(Lazareff+ 2017)

Far side of disk

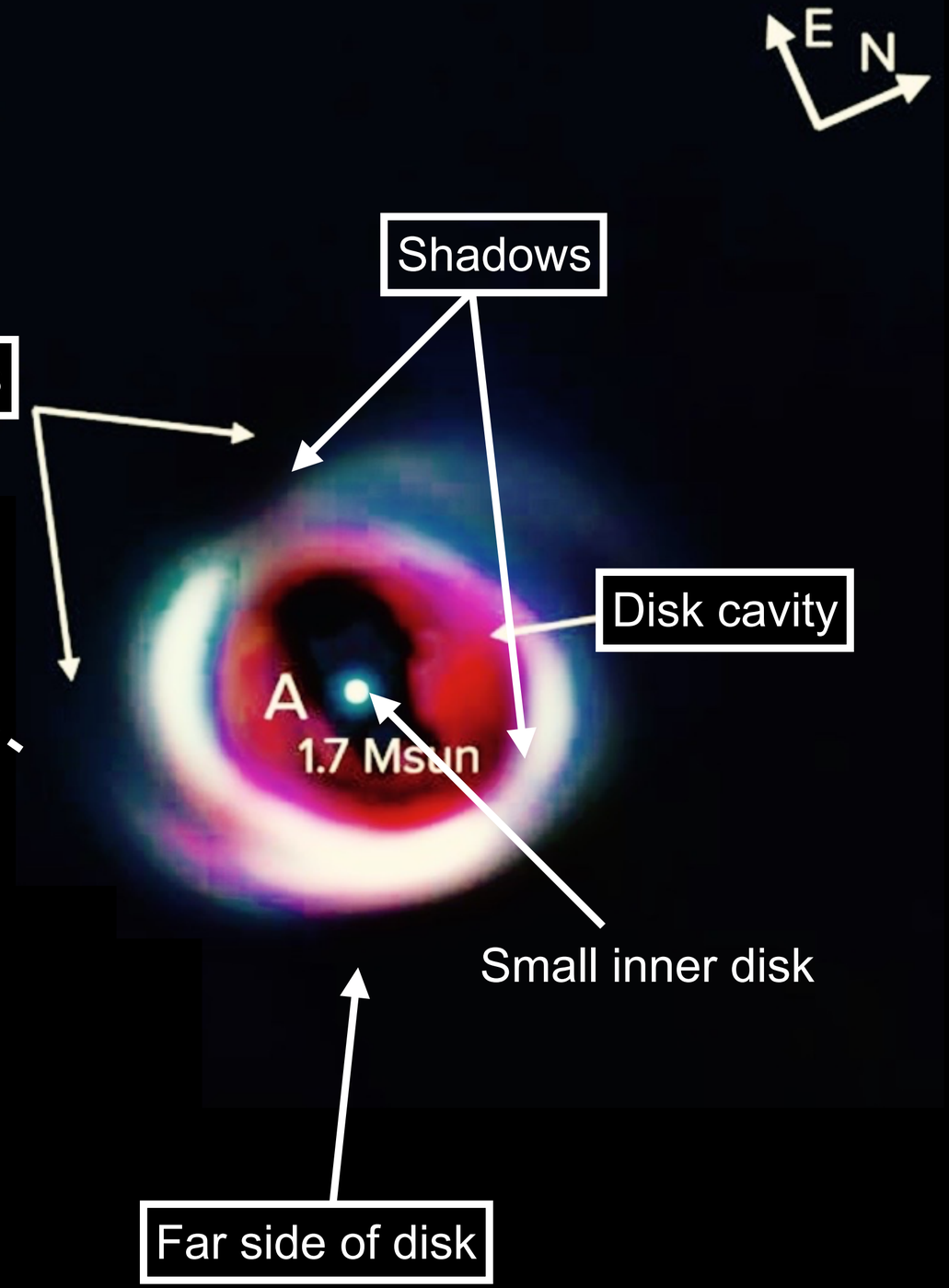
(Benisty+ 2015)

Adapted from Wagner et al. (2018)

HD 100453



(Benisty et al. 2017, see also Min et al. 2017)



Adapted from Wagner et al. (2018)

HD 100453

E N

0.2 Msun

B

Spirals

Shadows

Connected?

Disk cavity

A

1.7 Msun

Small inner disk

Far side of disk

(Dong+ 2016)

Adapted from Wagner et al. (2018)

4 recipes for m=2 spiral arms:

1. By **tidal interaction** with multiple planetary mass companions or 1 stellar companion (either inside disk (e.g. Ogilvie & Lubow 2002) or external to disk (e.g. Dong+ 2016).

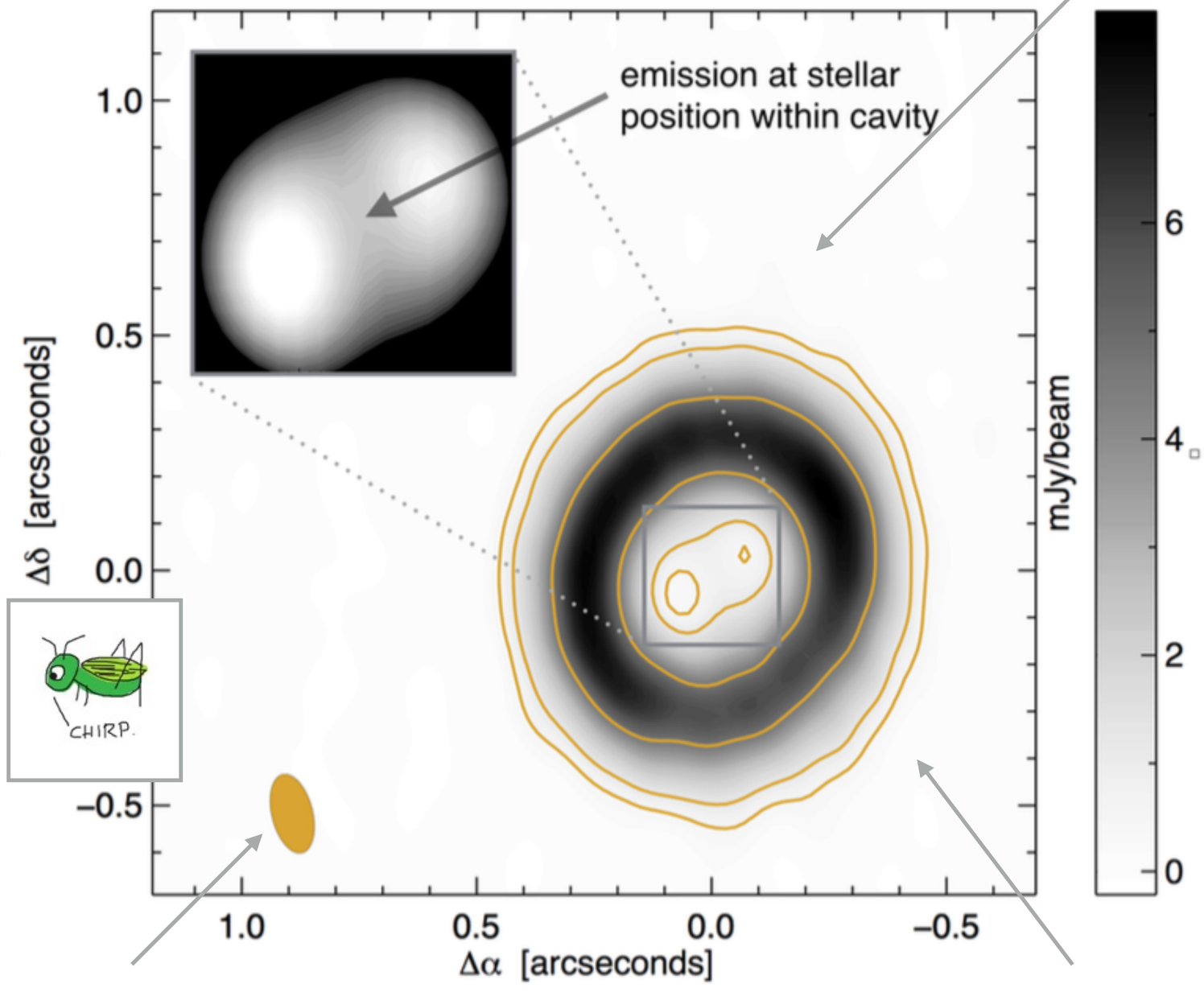
2. By **(sub)stellar Fly-by** (e.g.Larwood+ 2001, Augereau+ 2004)

3. By **shadows** from a misaligned inner disk (e.g. Montesinos+ 2016, 2018)

4. By disk **self-gravity** (e.g. Cossins+ 2009,Kratter+2010)

Excess emission at NNW, at same location as Northern scattered light spiral

Nothing at location of HD 100453 B



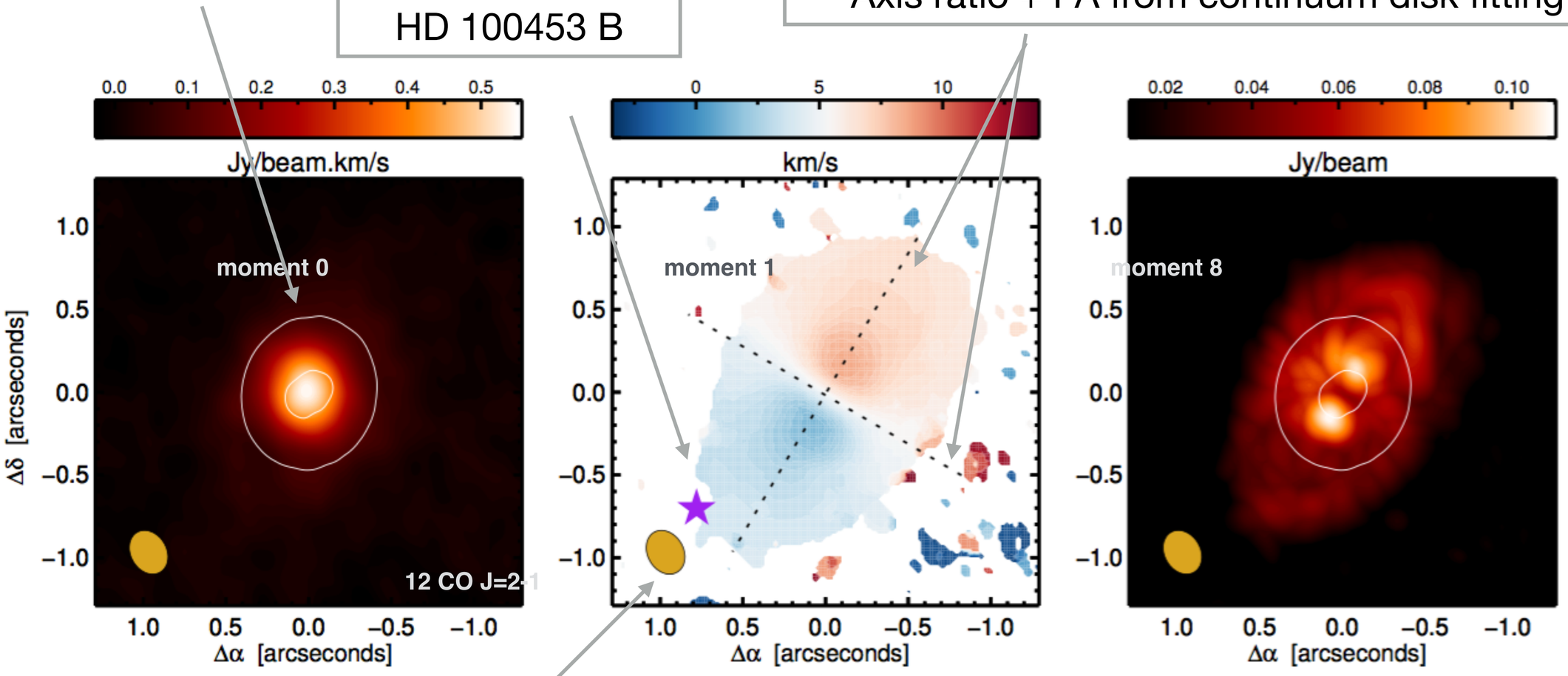
0.08 x 0.17 beam

Ring between 0.22 and 0.40”

Low (15 to 45) g:d ratio

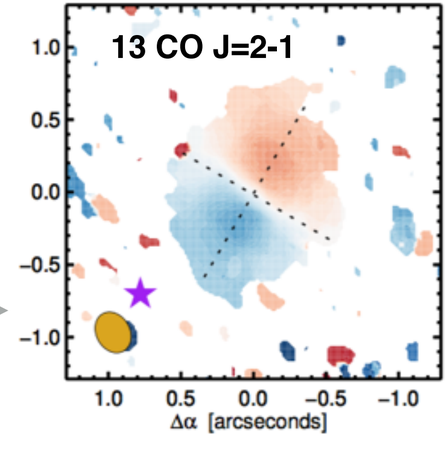
HD 100453 B

Axis ratio + PA from continuum disk fitting

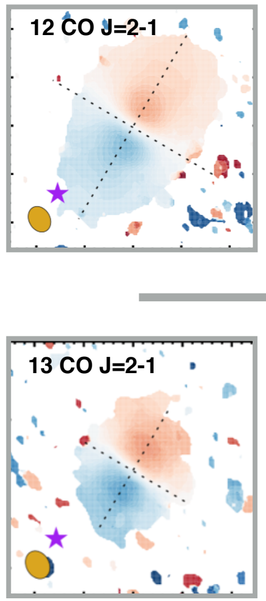


0.29 x 0.23 beam

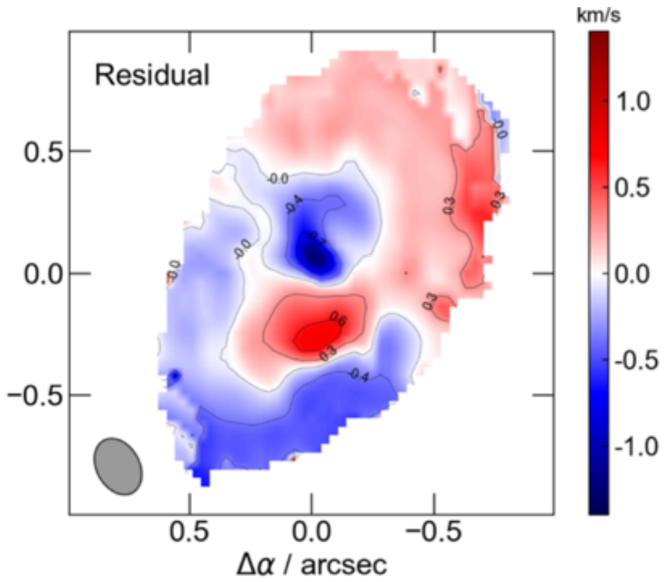
Compare shape 12CO and 13CO map



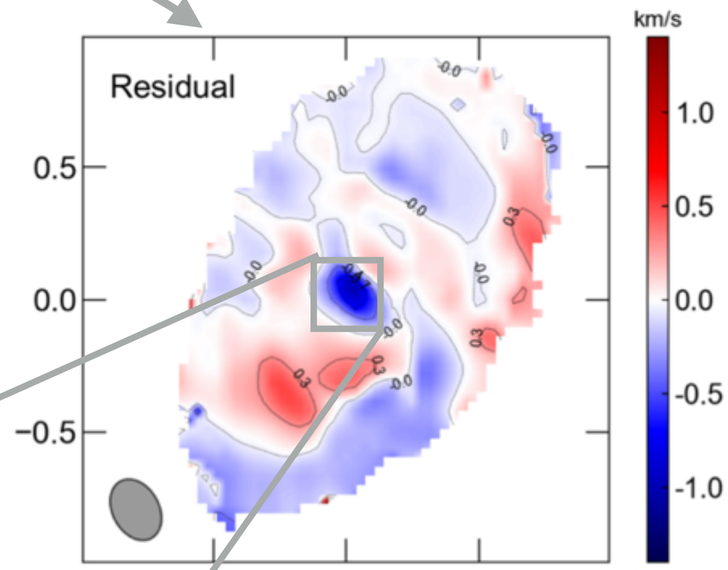
What's going on in the cavity?



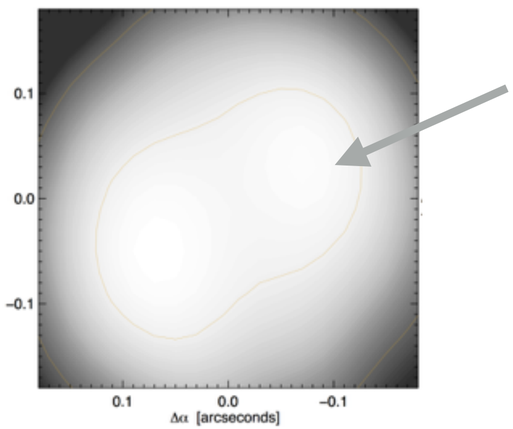
Subtract Keplerian disk

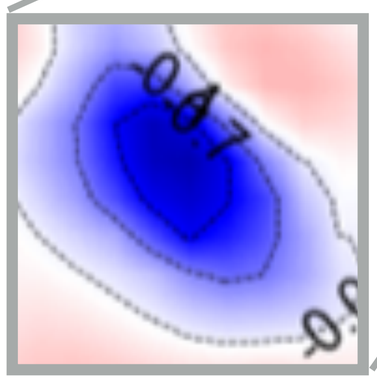


Disk warp at 27 au with twist of ~5 degrees in i and PA



Inner disk still unresolved at few au scale

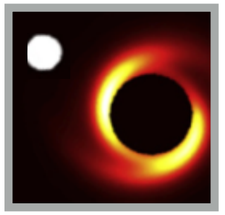




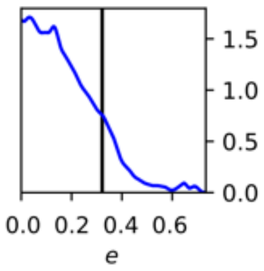
Spiral wake of planet?

Work by: Sebastian Perez (U. de Chile)

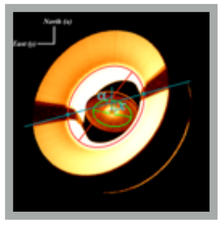
~~4~~2 recipes for m=2 spiral arms:



Tidal interactions?



~~(sub)stellar Fly-by?~~ (Wagner+ 2018, van der Plas+ 2019)



Shadows from a misaligned inner disk?

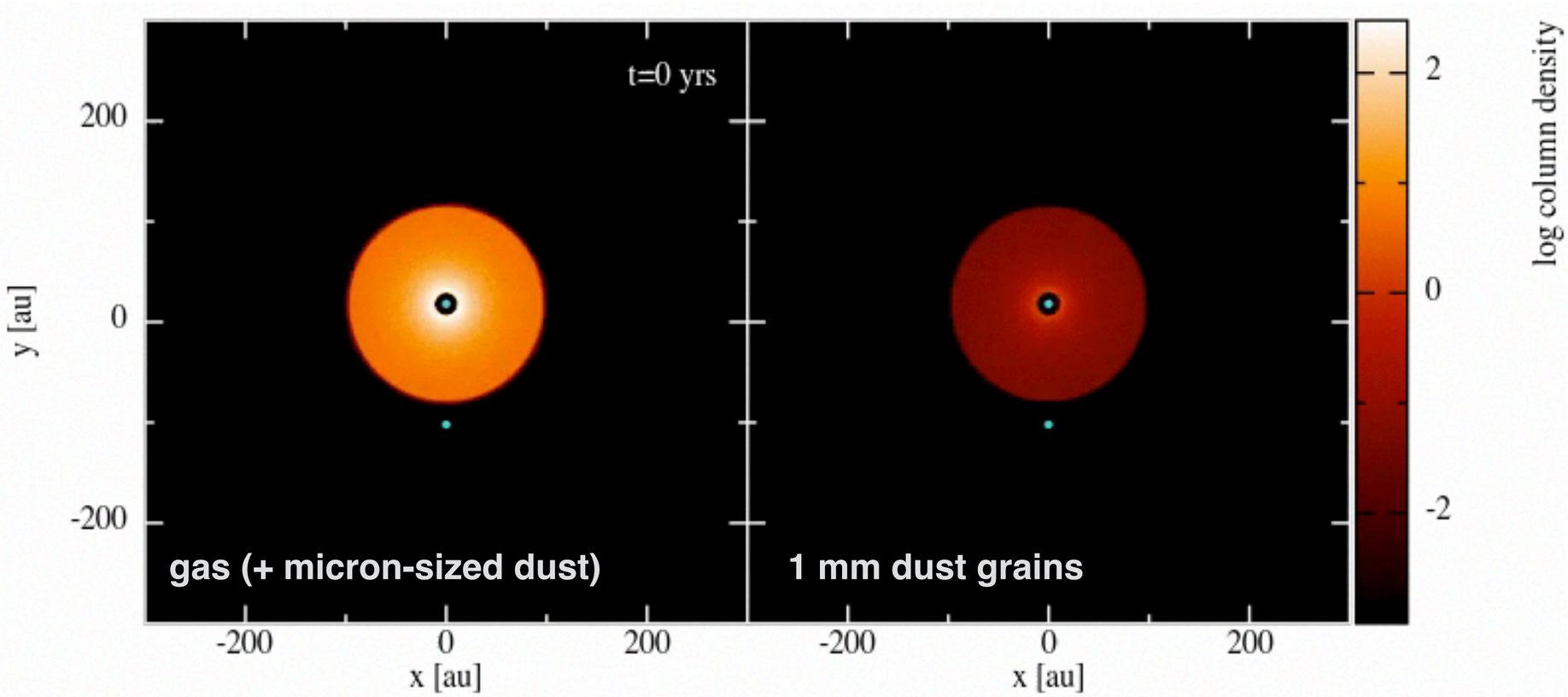
~~Self-gravity?~~ (van der Plas+ 2019)

How strong is the tidal truncation for a co-planar orbit?

PHANTOM: 3D SPH gas+dust code:

- Aerodynamic drag with back-reaction of dust on gas
- Self-consistent, **grain-size dependent dynamics**

Lodato+Price 2010; Price+Federrath 2010; Laibe+Price 2012a,b,2014; Price+Laibe 2015; Price+ 2018



Work by: Jean-Francois Gonzalez (U. Lyon)

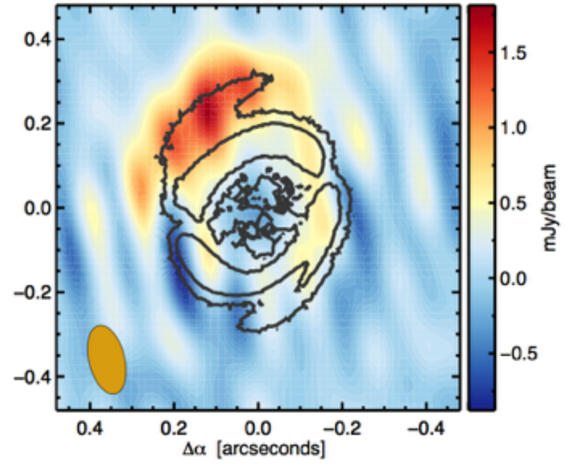
Tidal interactions?

After 10 orbits in a co-planar configuration:

- There is are vanishingly small amounts of gas in the extended CP disk, while some material get accreted onto in the CS disk and CB disks
- The 12CO vs 13CO and C18O morphology is reproduced (tenuous gas reservoir outside CPD)
- The primary spiral arms holds most mass
- The double spiral arm is reproduced in micron and mm dust

A (significantly) misaligned orbit for HD 100453B:

- Has less impact on the extent of the CPD gas
- Transfers less material to the CBD + CSD
- Is supported by the orbital fit.



And the Northern mm arm holding most mass?

- Is not so much of a problem if the spiral pitch angle depends on temperature (see Lee & Gu (2015) and Juhasz & Rosotti (2018)), with higher temperatures facilitating larger pitch angles (more open spirals).

And what about Shadows?

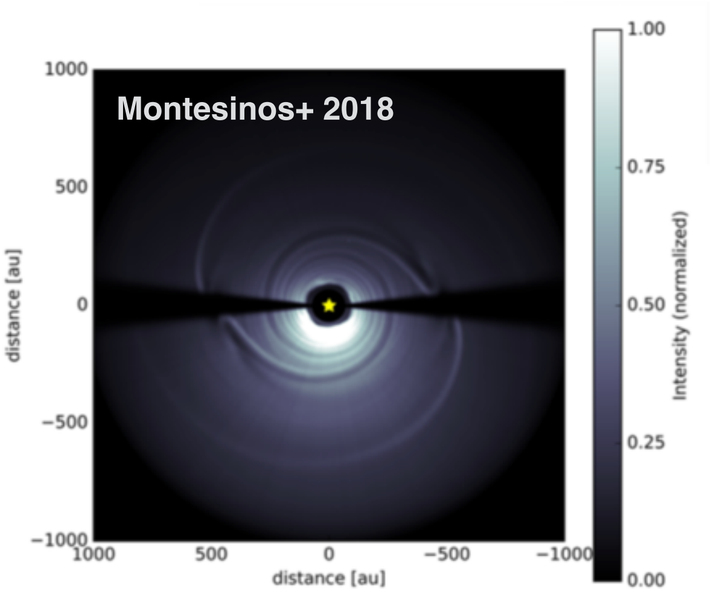
- How? slowly precessing inner disk launches spiral at co-rotation radius in outer disk

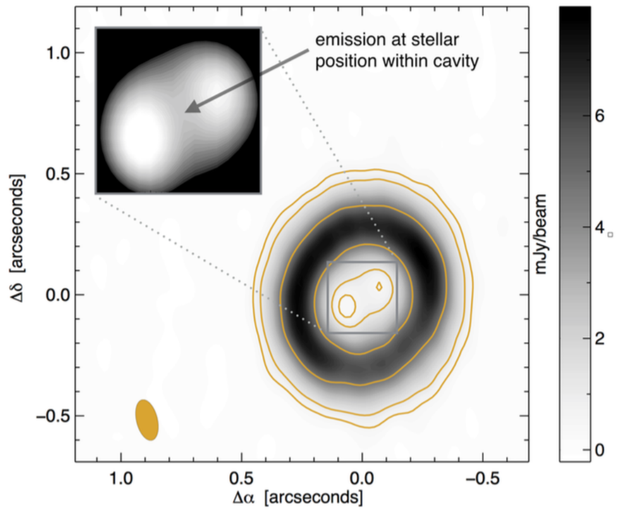
- Launching point spirals coincides with inner-disk shadows. A disk cavity and misaligned inner disk are detected.

- Montesinos+ 2016, 2018: static and prograde shadows can trigger spiral arms much similar to those expected from perturbation by planets

- Asymmetric spirals can be explained by inner disk geometry

- **However**: this mechanism does not produce detectable sub-mm spirals (Cuello+ 2019)…





Take-home message:

- We find:

  1. Strong indications that the cavity is carved by yet another body (HD 100453 C?)

  2. A mm counterpart to the northern spiral arm

  3. A continuous CO disk in counterclockwise and Keplerian rotation that extends ~up to the projected separation of the companion.

- #2 and #3 (above) appear to be in conflict with the thesis that the 2 spiral arms in the HD 100453 disk are driven by a companion on a circular and co-planar orbit. **However**, a misaligned orbit and a thermally stratified disk relieve those tensions and HD 100453 B is (still) the best candidate for triggering the spiral arms.

- Another (less likely) candidate formation mechanism for the spiral arms are co-moving shadows from a precessing, misaligned, inner disk.

See van der Plas+ (2019) for more details