Planet-induced spirals in circumbinary disk of GG Tau A

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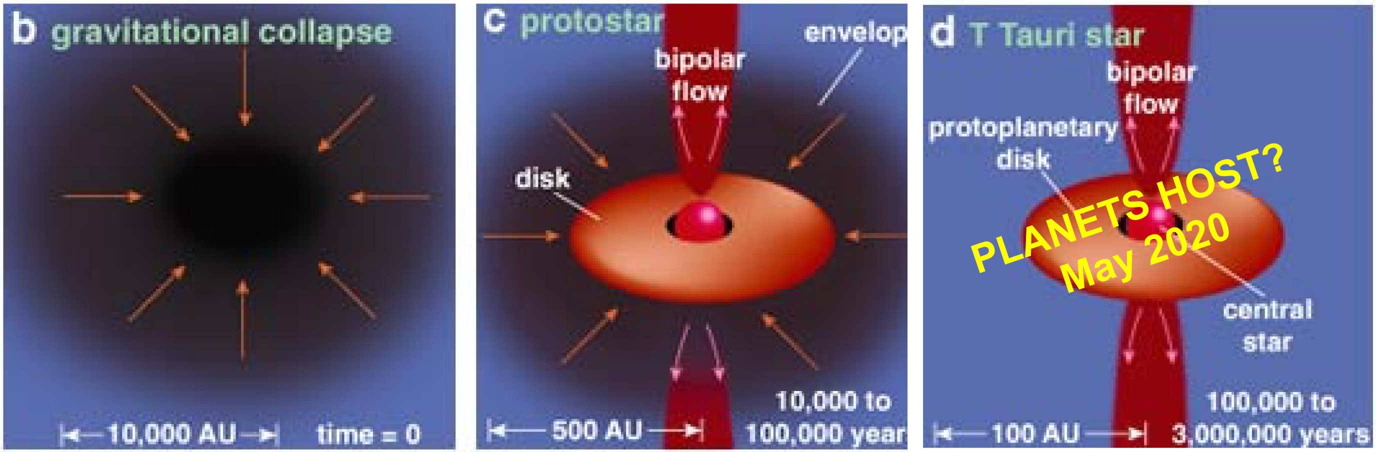
Quy Nhon, August 11, 2023

Outline

1. **Protoplanetary disk and GG Tau A**
2. **ALMA observations of CO sprials in circum-triple disk of GG Tau A**
3. **Summary**

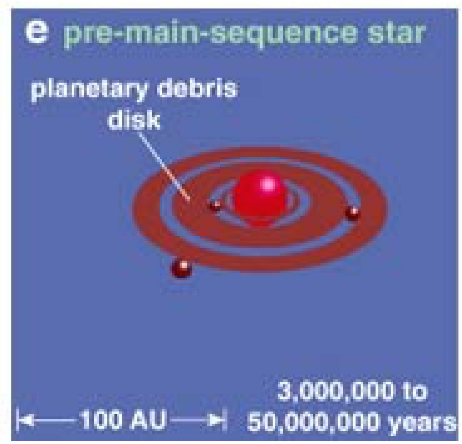
Protoplanetary disks

- Star forms from small fractions (dense cores) of the dust and gas contained in relatively dense and cool molecular clouds.



- Disk form around protostar as a consequence of angular momentum conservation.

- A small quantity of material remains in the disk for few million years, allowing planets to form (hence the name "**protoplanetary" disks – PPD**).

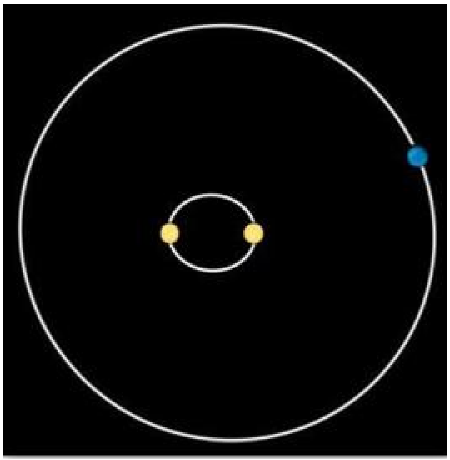


Greene (2001)

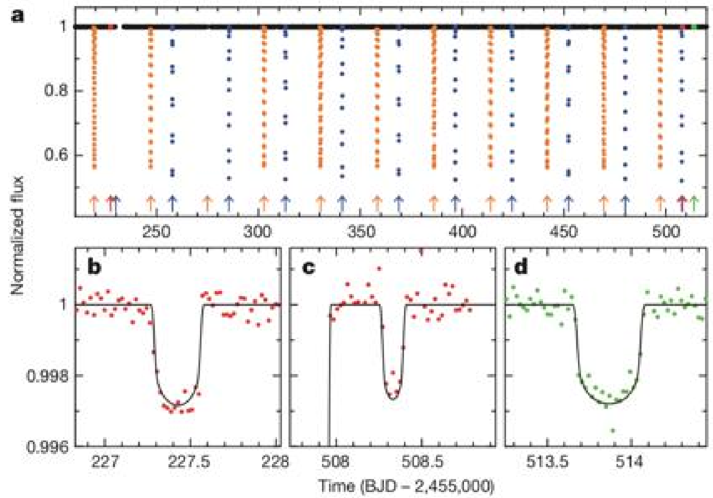
Planets formation in binary systems

- 50% of stars are in binary/multiple systems (possible reservoir of planets ?)
- Planets can form either in circumbinary (CB) or circumstellar (CS) disks

Kepler 34: one of the first CB planets



Credit: Rahul Sharma



- primary eclipses
- secondary eclipses
- primary transits
- secondary transits

Welsh et al. (2012)

- Studying the gas and dust properties in these environments is a necessary step to understand the formation of planets in binary/multiple systems and unveil the variety of planetary systems.

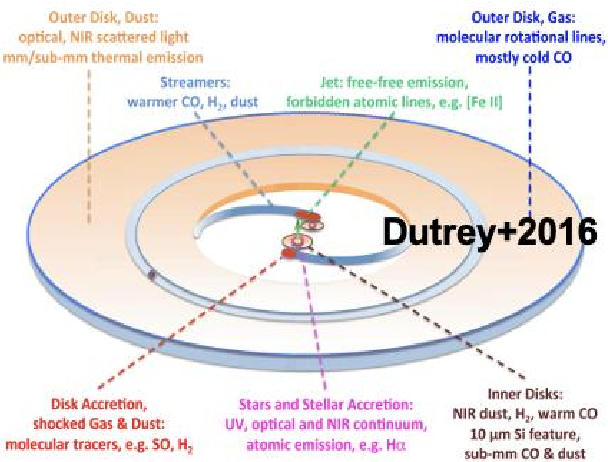
GG Tau A – the best case study of a triple young low-mass system

What can be observed in a binary TTauri system?

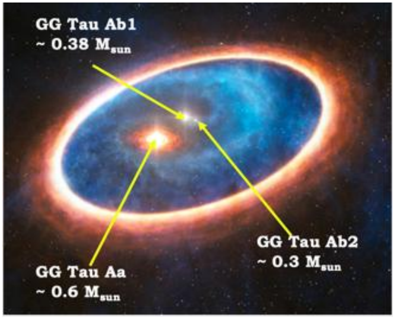
i) the circumstellar disks

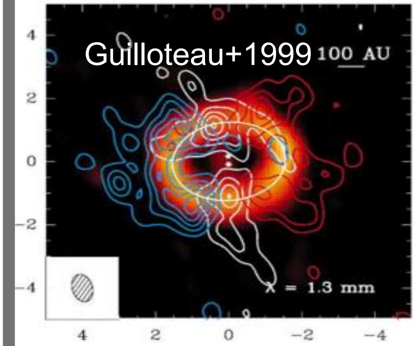
ii) the cavity and the “streamers”

iii) the circumbinary ring or disk



1.3 M_{Sun}, 150 pc,
in Taurus-Auriga
$d_{Aa \rightarrow Ab}$: 35 au
$d_{Ab1 \rightarrow Ab2}$: 4.5 au



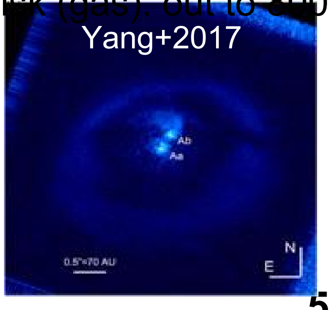


Cavity <= 180 au

Circum-triple disk (0.15 M_0)

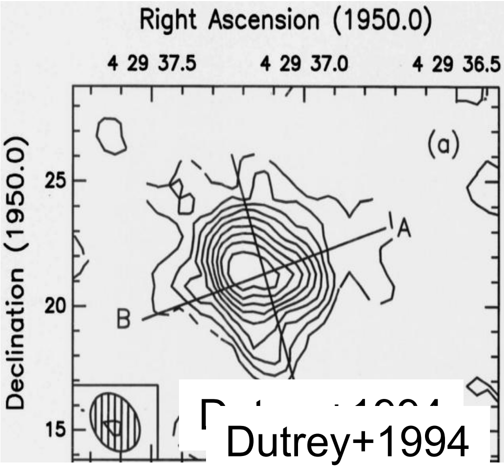
+ring(gas+dust):180–260 au

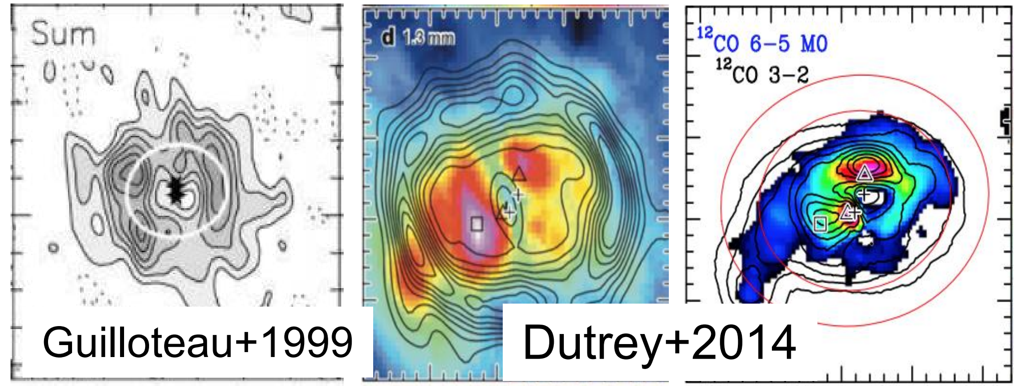
+disk (gas): out to 800 au

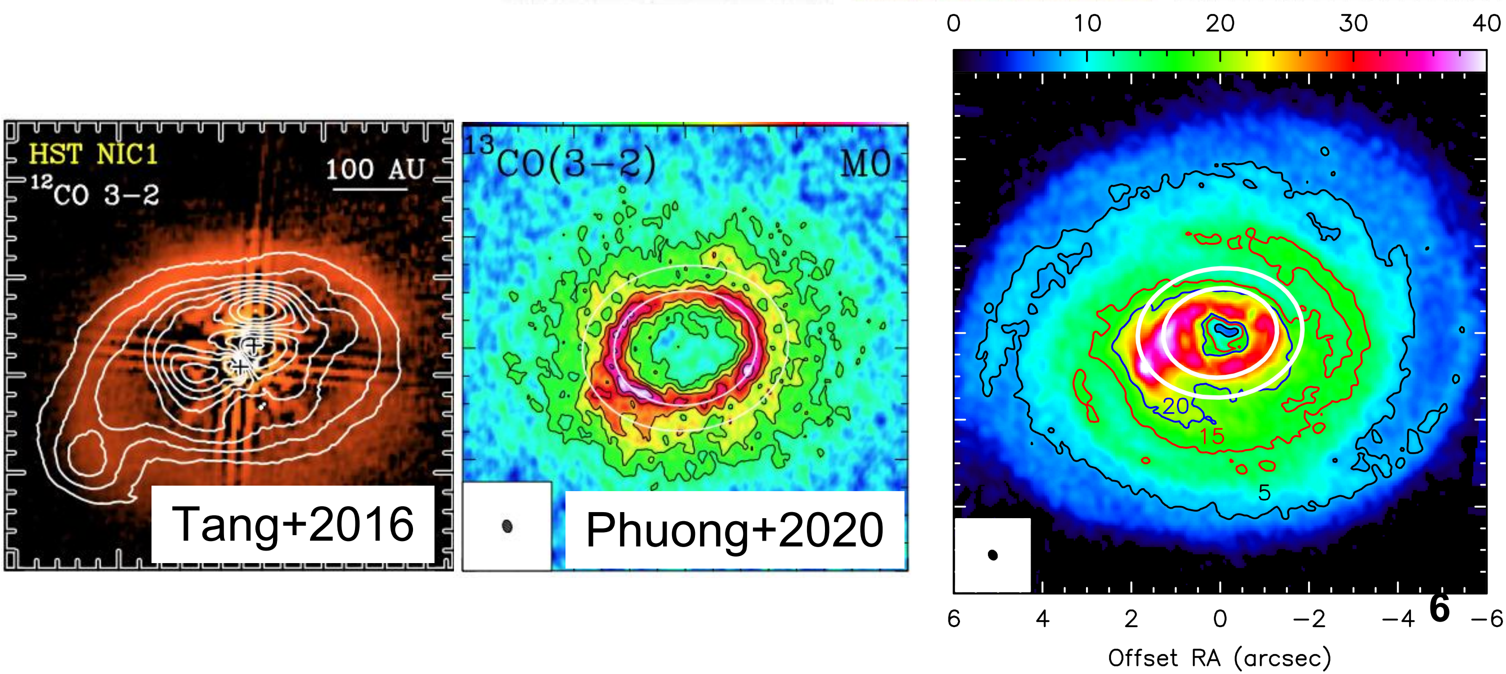


Circumstllar disks:
Aa: (sub)mm+IR
Ab1/Ab2: IR

NOEMA & ALMA observations of GG Tau A







We fit the observed spiral to a spiral wave produced by a companion in disk as performed by Rafikov (2002) and Muto et al. (2012)

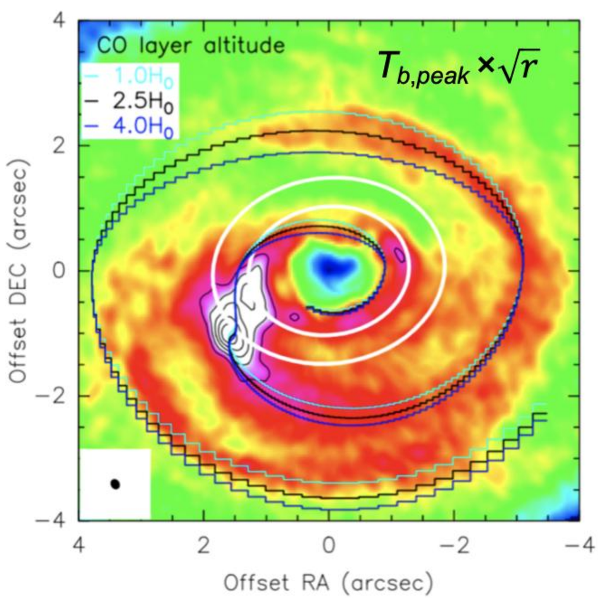
companion's position

exponent of sound speed radial profile

$$\Phi(r) = \Phi_c + \frac{sgn\,(r-r_c)}{h_c}\left(\frac{r}{r_c}\right)^{1+b}\left(\frac{1}{1+b} - \frac{1}{1-a+b}\left(\frac{r}{r_c}\right)^{-a}\right) - \frac{sgn(r-r_c)}{h_c}\left(\frac{1}{1+b} - \frac{1}{1-a+b}\right)$$

disk aspect ratio

exponent of disk rotation radial profile



Fixed parameters (Dutrey+14, Phuong+20a)

"hot spot" → $\mathbf{\Phi_c}$= 125o, $\boldsymbol{r_c}$ = 290au

Disk is in Keplerian rotation → **a** = 3/2

Temperature ~ r −1 → **b**=0.45

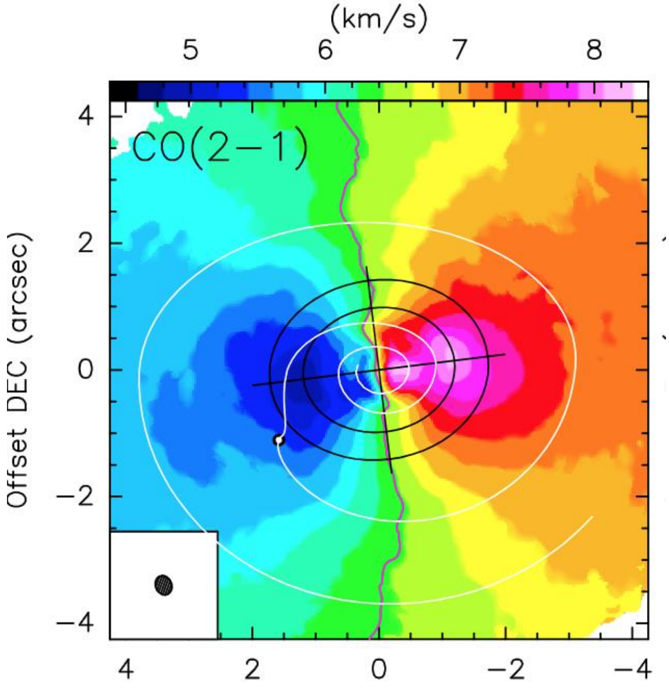
Scale height $H(r)=17\times(r/200\text{au})^{+1}$

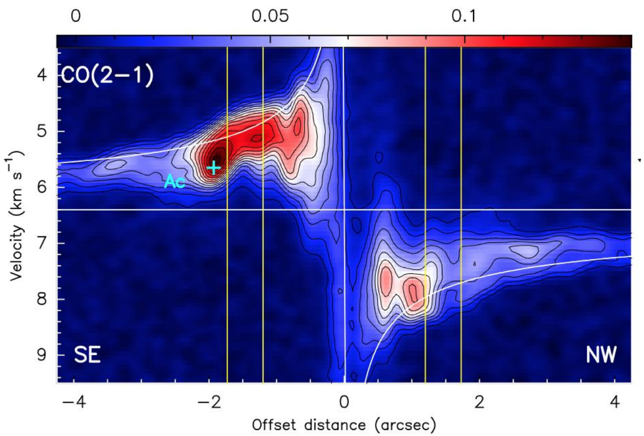
→ constant disk aspect ratio $\boldsymbol{h_c}$ = 0.085

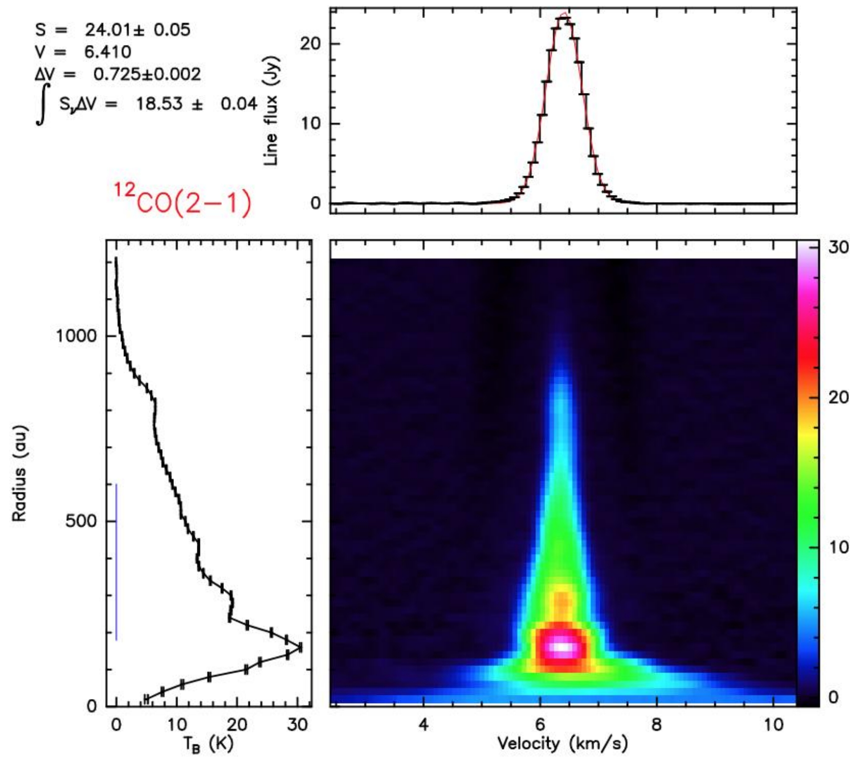
Final fit: The height of the τ= 1 layer in CO in scale height units along the spiral.

= 1 at scale height of 2.5 H_0

Velocity disturbances



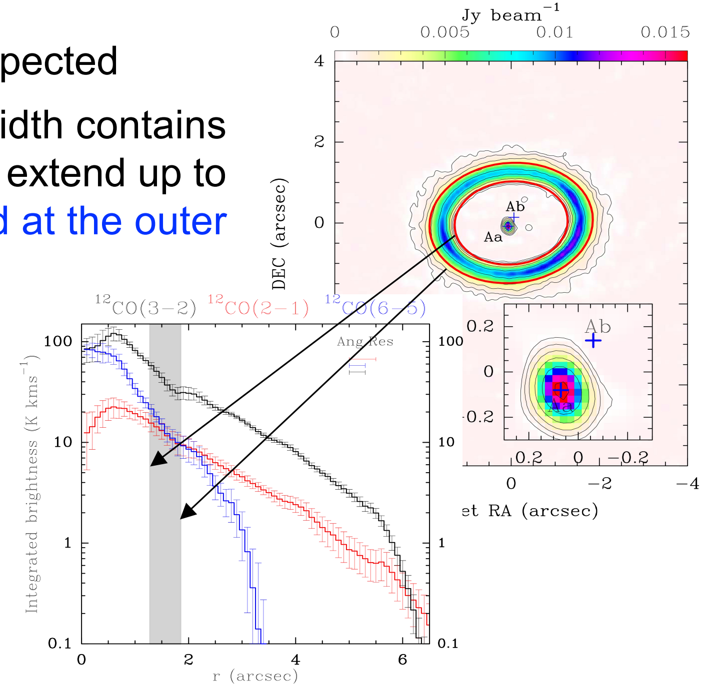


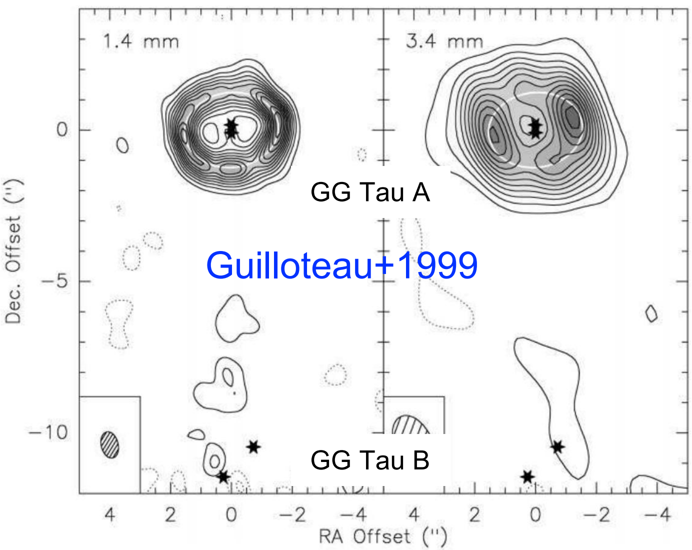


Major questions remain unexplained in GG Tau A

1) Wide cavity: 2 times wider than theoritical expected

2) Narrow and massive ring: a ring of 80 au width contains 80% mass ($0.12M_{Sun}$) of the disk ($0.15M_{Sun}$) that extend up to 800 au: confinement by a (proto-) planet located at the outer edge of the ring.





Beust +2006 found that a few possible orbital configurations exist for the two binaries (GG Tau A/B) that peal out the outer part of the large CB disk orbiting GG Tau A

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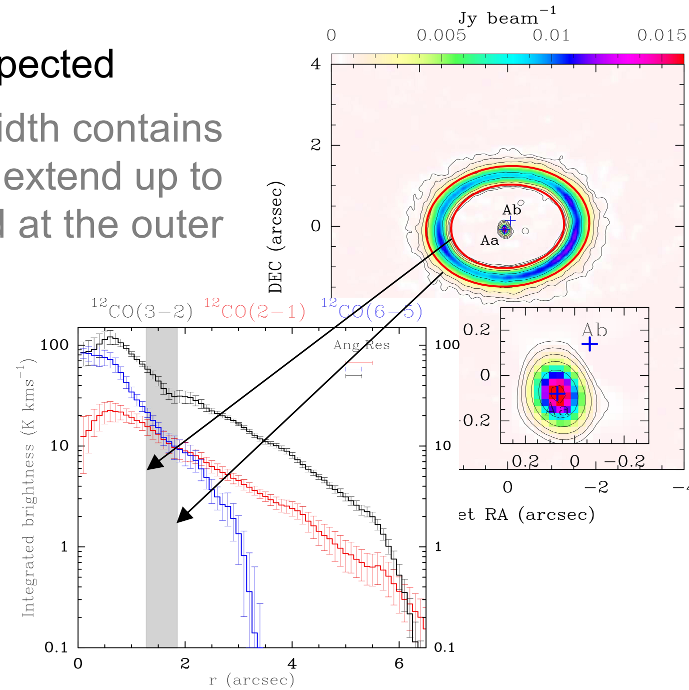

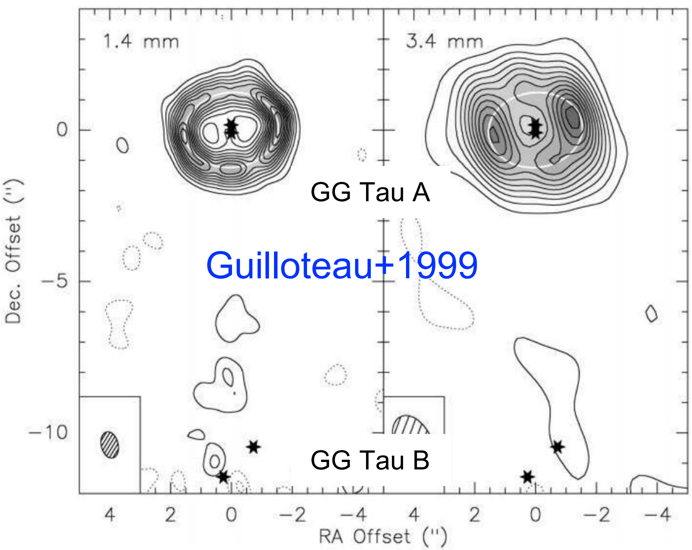

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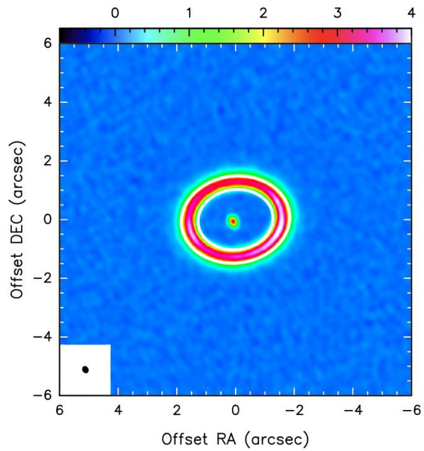
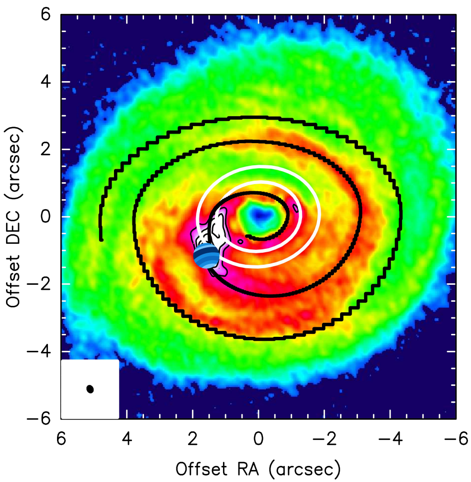
(Pierens & Nelson 2008)
→ inward migration halted due to the formation of a narrow ring located in between the edge of the central cavity and the planet orbit: the migration rate > viscous drift rate: require the planet not to open a deep gap.



Gap opening depends on **planet mass, disk aspect ratio, and viscosity**



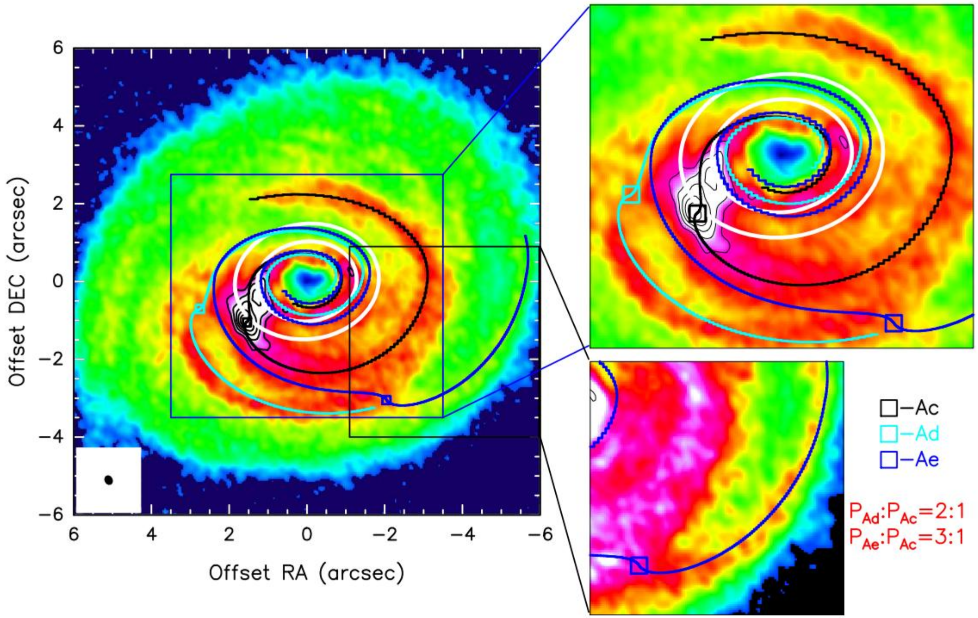
a planet of the mass of Neptune or lower

- open a partial gap similar to what is observed in CO images (CO J=6-5 by Dutrey+14, CO J=3-2 by Tang+16 and the CO J=2-1 in this study)
- dynamical evolution is stable: the planet orbiting near the edge of the cavity formed by the binary

The planet confinement mechanism helps to explain the narrow massive ring

Multiple circum-triple planets system

Other spirals pattern can be explained by other 2 putative planets located nearly 3:2:1 mean-motion resonance with the “hot-spot” planet



The 2:1 resonance configuration is already observed in the case of PDS 70 (Haffert+19, Bae+19).

The 3:2:1 resonance is by far the most frequent resonant configuration observed among Kepler multiple exoplanet systems (Fabrycky+14).

SUMMARY

The indirect evidence of Neptune planet(s) in formation in circum-triple disk GG Tau A has been observed in CO gas emission.

The (proto-)planet GG Tau Ac appears to externally confine the ring in a stable configuration, explaining its high mass.

In the GG Tau A case, orbital resonances appear to play an important role in shaping this multiple circum-triple planet system.

Thank you for your attention!