Modelling Protostellar Disks

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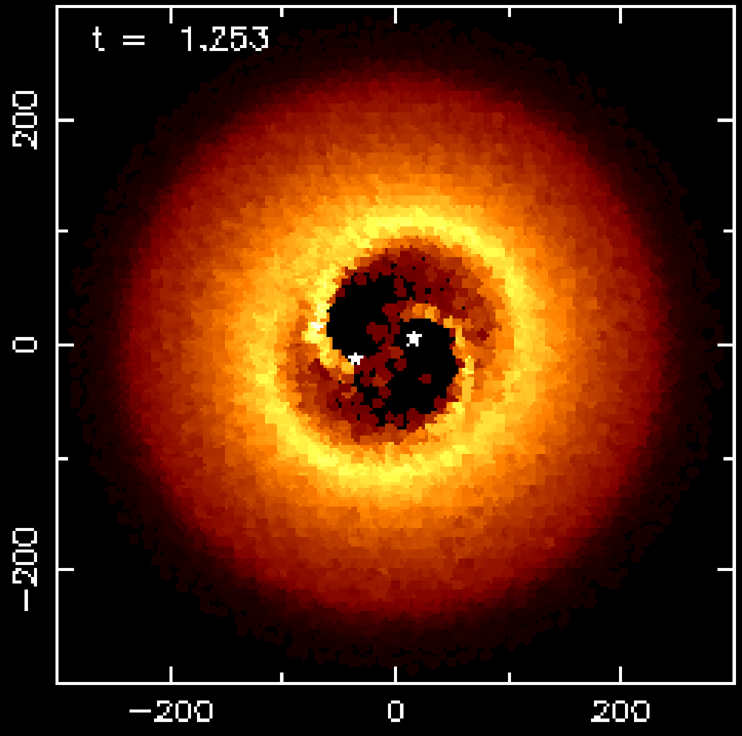
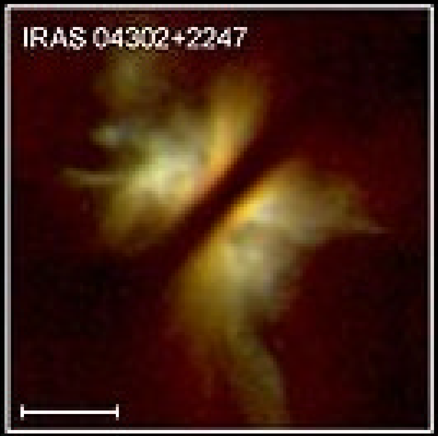
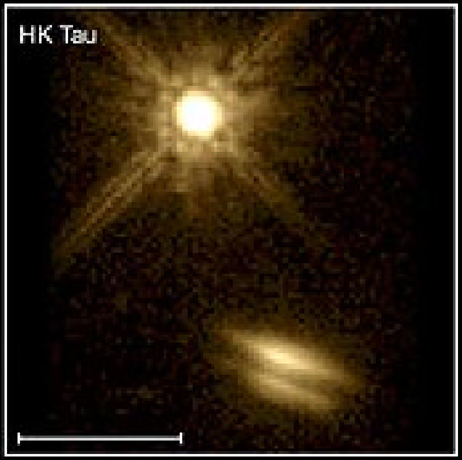




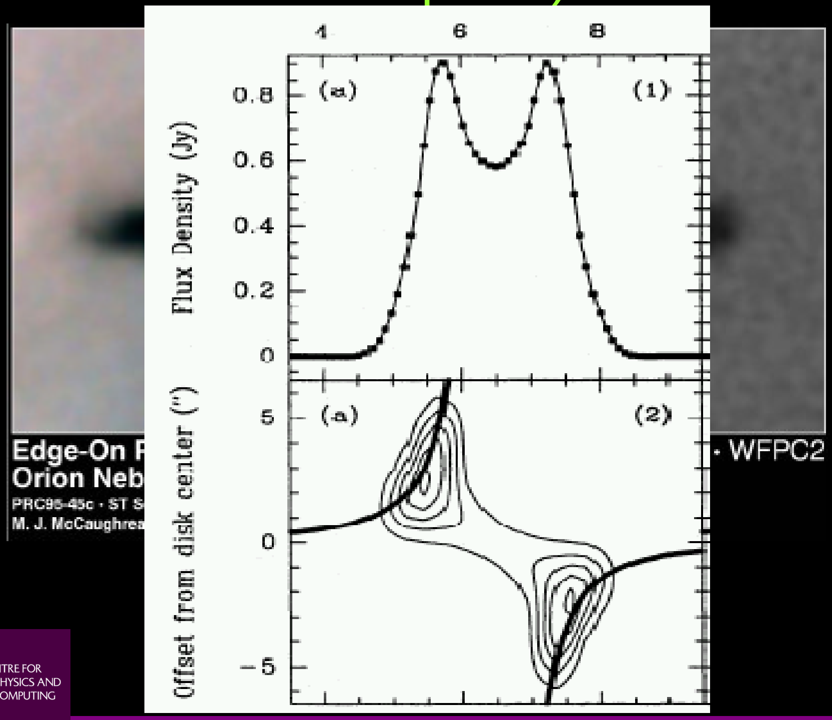
Overview



- Types of circumstellar disks:
  - protostellar disks
  - circumbinary disks
  - protoplanetary disks
- Modelling disk - important parameters:
  - M_{disk}, R_{disk}, $H(r)$, i, $T(r,z)$, $\rho(r,z)$...
  - grain properties

Introduction to PS Disks

- Disks are a natural by-product of star formation process
- Indirect evidence for disks:
  - IR excess in SED (disk thermal emission)
  - blue shifted forbidden lines (receding ionized outflow obscured)
  - polarimetry (light scattered above & below disk plane)
- Direct evidence:
  - direct observations….
  - kinematic signature of Keplerian rotation



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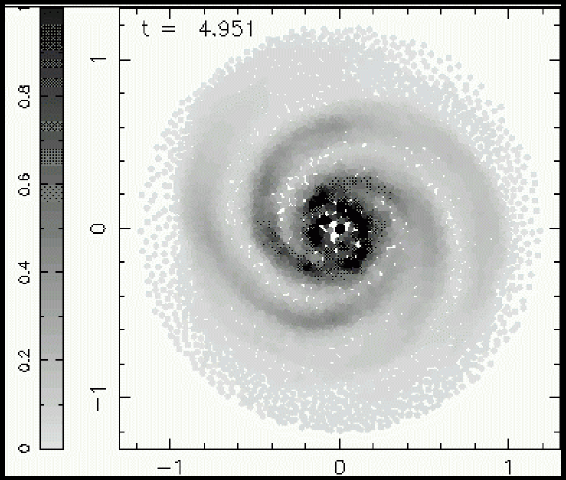
Accretion in PS Disks

- Evolution of PS disks largely driven by accretion, whereby AM and energy move outwards and matter flows inwards.
- But what drives the accretion? Transport mechanism depends on disk mass:
  - low disk mass:
    accretion driven by turbulent viscosity (thermal convection or MHD instabilities)
  - high disk mass:
    gravitational toques induce AM transfer

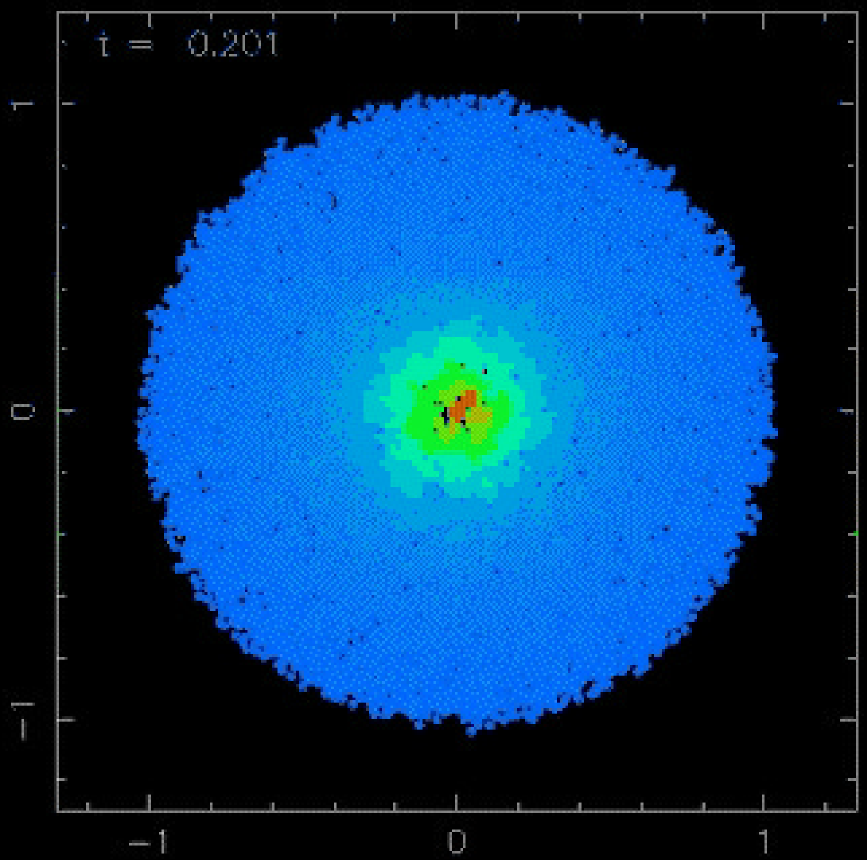
Evolution of Massive PS Disks

- When disks form, they're probably quite massive (continue to accrete infalling material from parent cloud)

- Thus gravitational instabilities can dominate evolution by driving mass and AM transfer
  - leads to transient spiral instabilities
  - or even disk fragmentation is extreme cases
  - and then even the seeds of a companion??



Massive PS Disks



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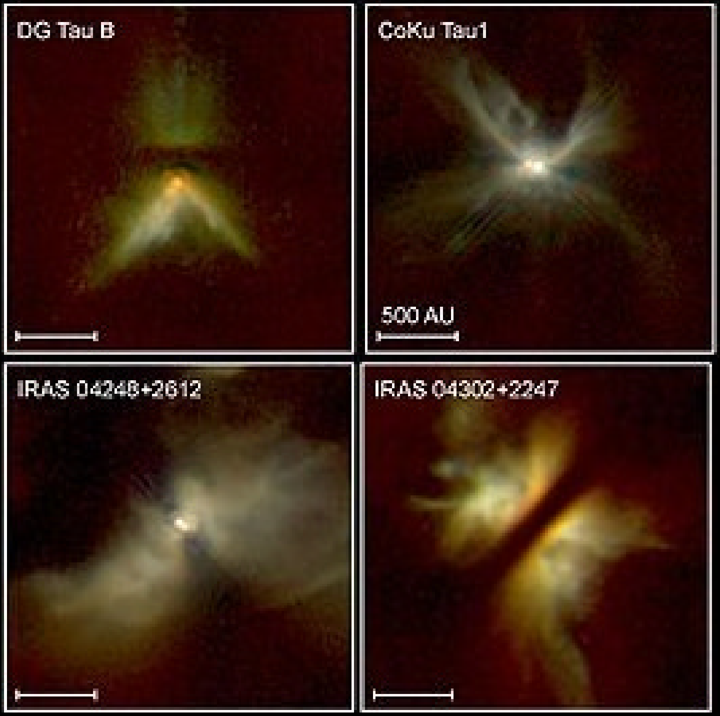
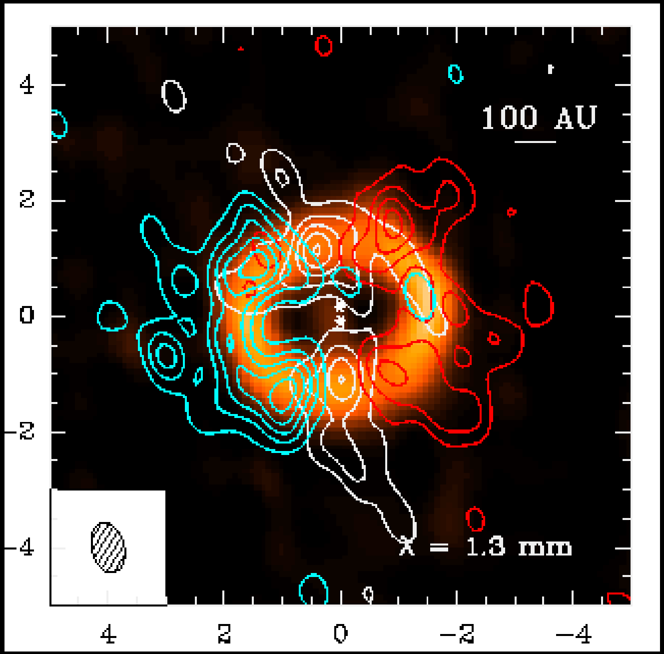
Circumbinary Disks

Most stars, unlike the Sun, are in binary or multiple systems. So most binaries are probably surround by circumbinary disk.



NICMOS Orion disks
(Padgett et al. 1999)

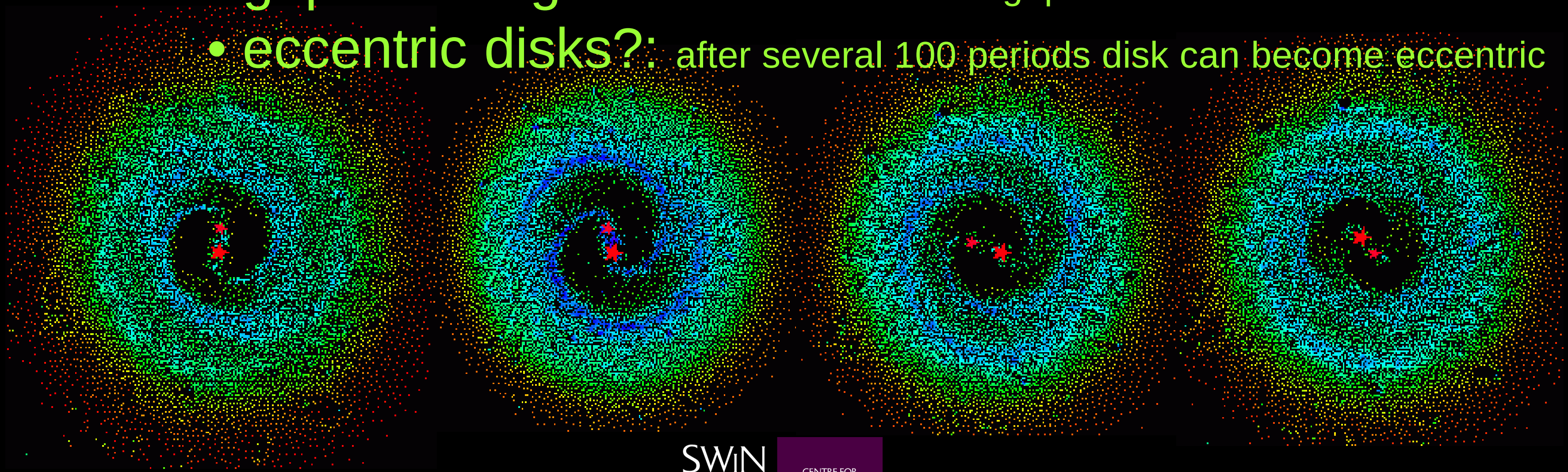
GG Tau is the first CB disk observed at mm and IR wavelengths - clear signature of rotation in mm and annulus seen in IR.



mm image of GG Tau
(Guilloteau et al. 1998)

Evolution of CB Disks

- The binary potential effects the system's evolution
  - effect of disk on binary
    - changes in e, a and $q = M_2 / M_1$
  - effect of binary on disk
    - transient spiral arms
    - gap clearing: inner region clears due to resonant torques
    - gap crossing: accretion streams cross gap in warmer thicker disk
    - eccentric disks?: after several 100 periods disk can become eccentric



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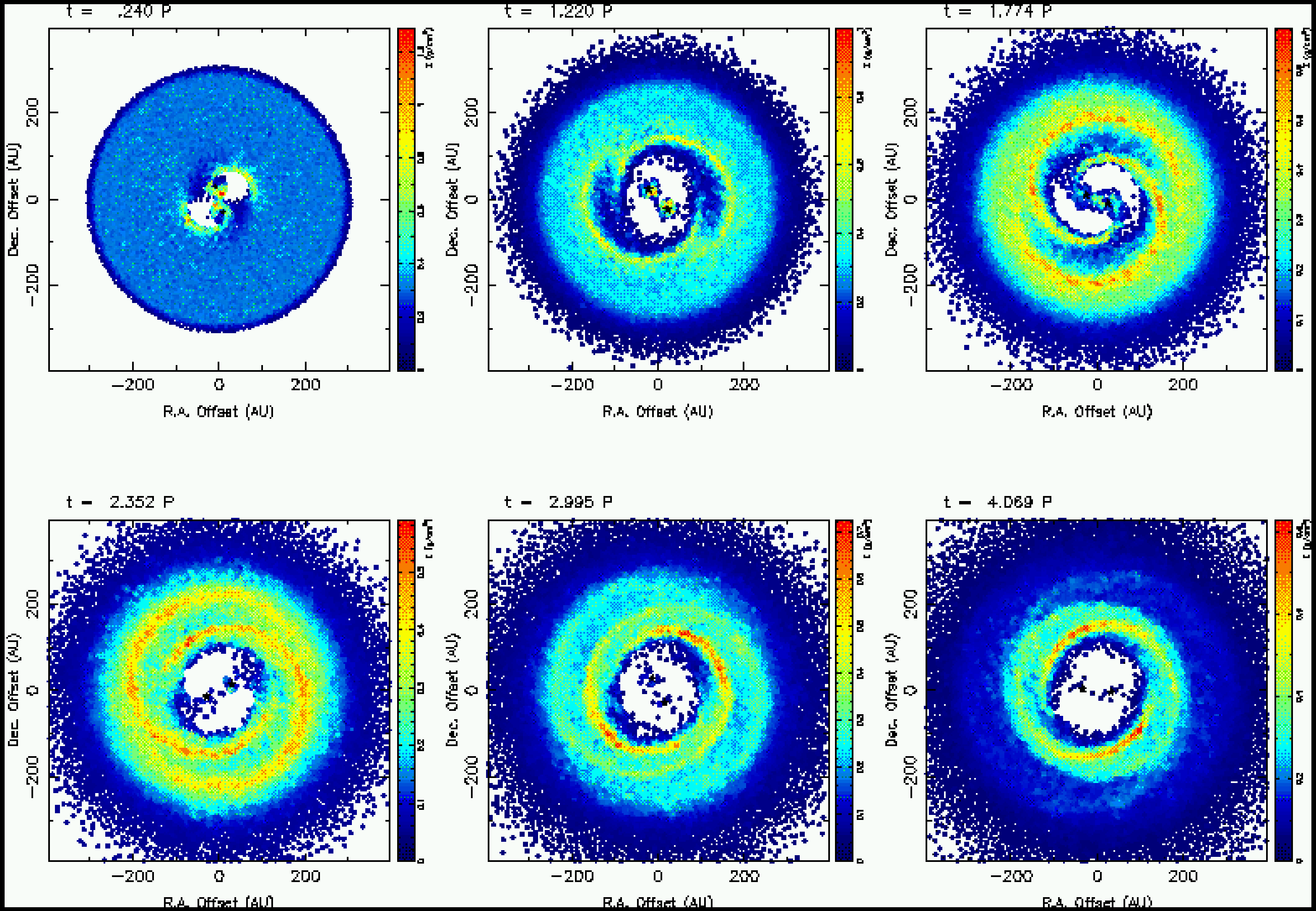
SPH simulation of initial CB disk clearing



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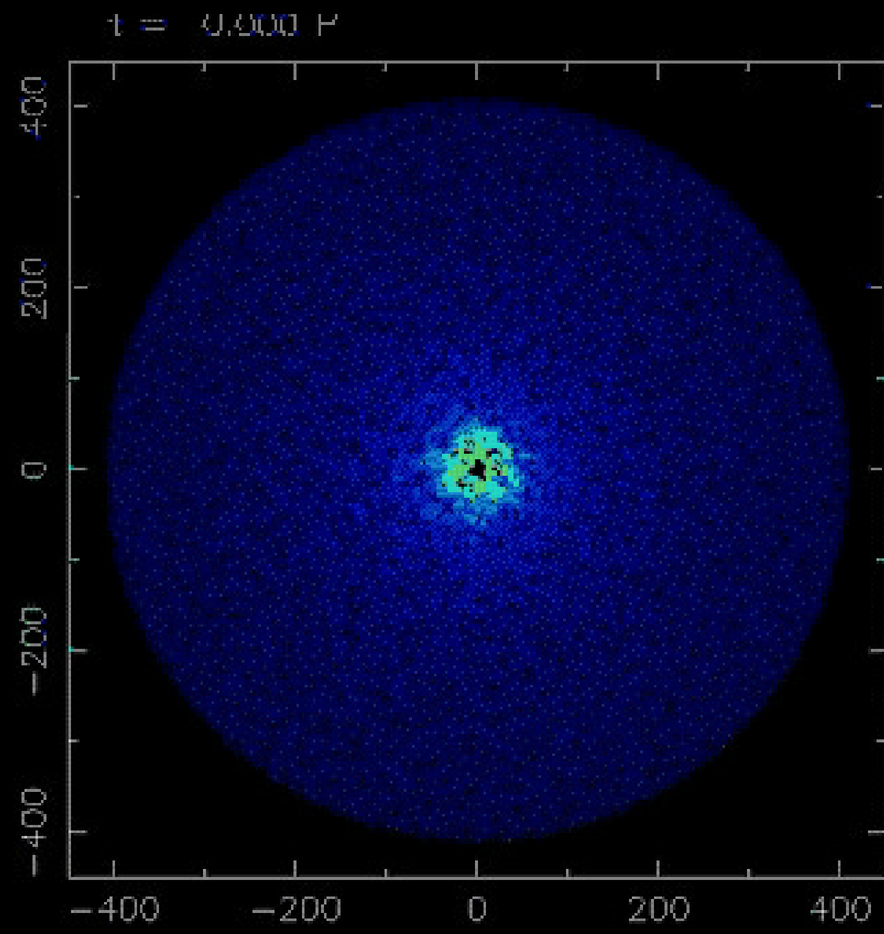
CB disk clearing simulation



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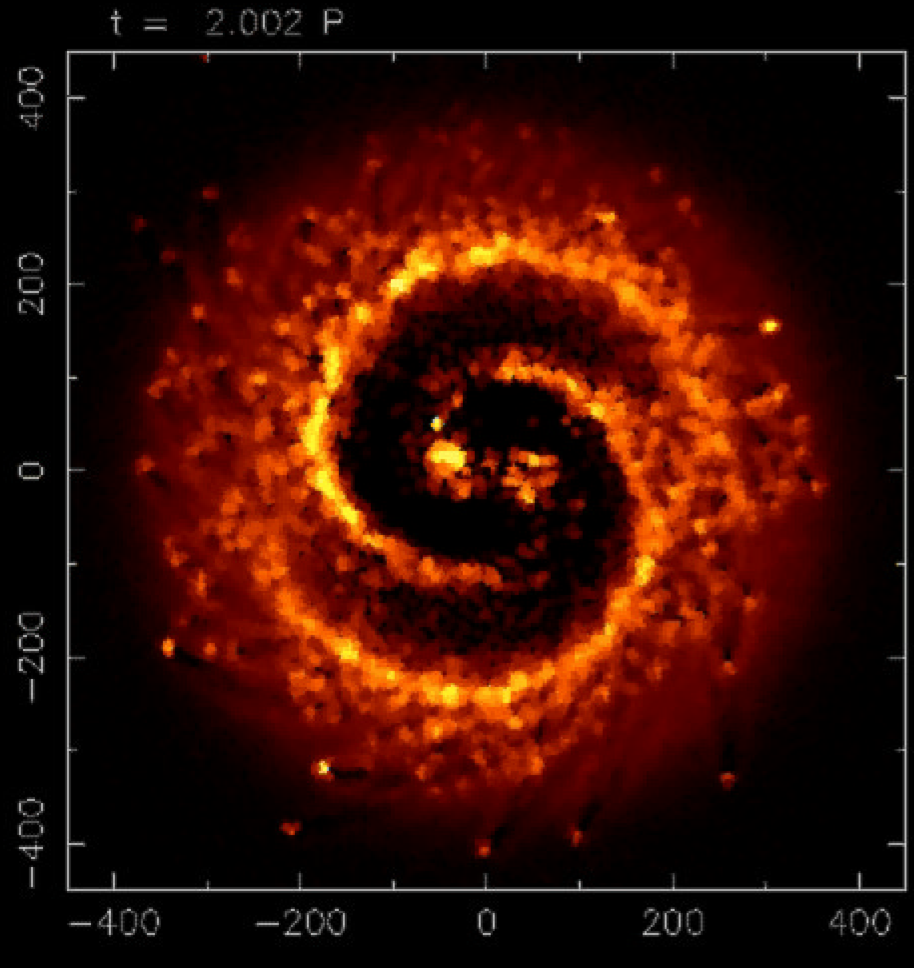
Continued CB disk evolution



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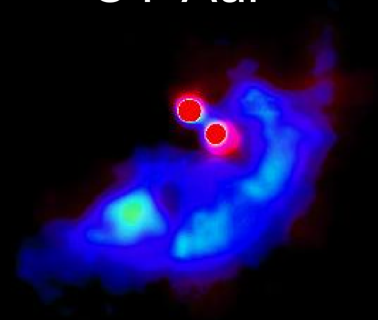
Modelling CB Disks

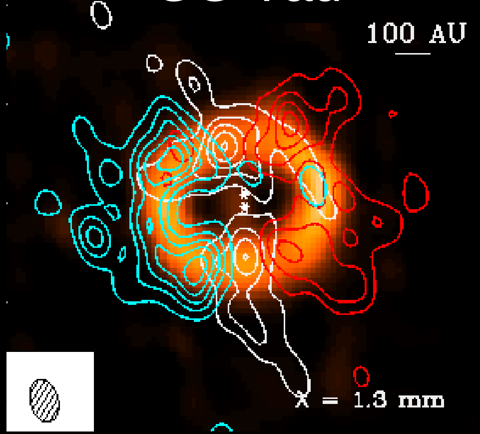
- firstly, can you see a CB disk?
  - then, can you see a cleared gap?
    - or, can you see accretion streams?

UY Aur

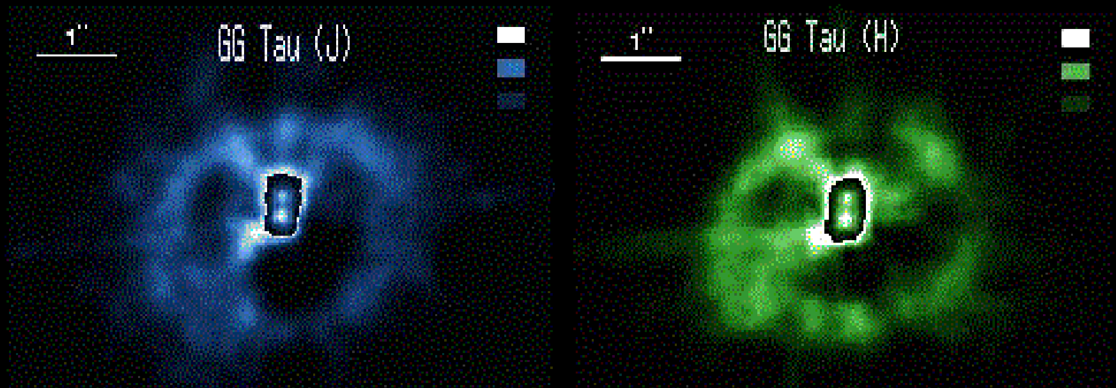


Close et al. (1999)

GG Tau



(Guilloteau et al. 1998)



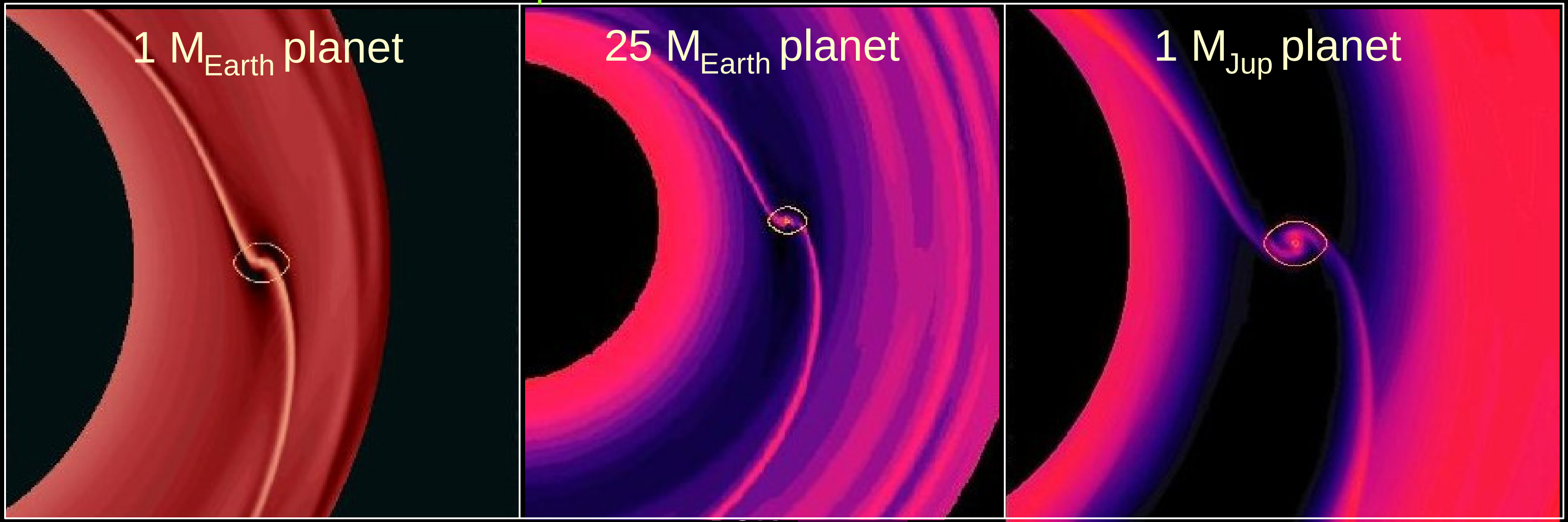
(Roddier et al. 1999)

Protoplanetary Disks

Model PS disks with a planetary perturber in it – and see what happens.

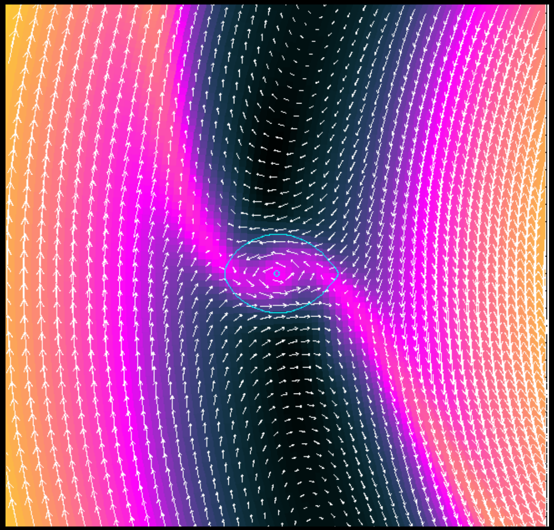
- Gravitational interactions b/w the planet and disk will result in spiral density waves
- Protoplanet continues to grow and a gap form around the protoplanet, separating it from the surrounding disk
- To clear a gap, the planet needs to be sufficiently large, generally $M > M_{Jup}$

Simulations by Pawel Artymowicz

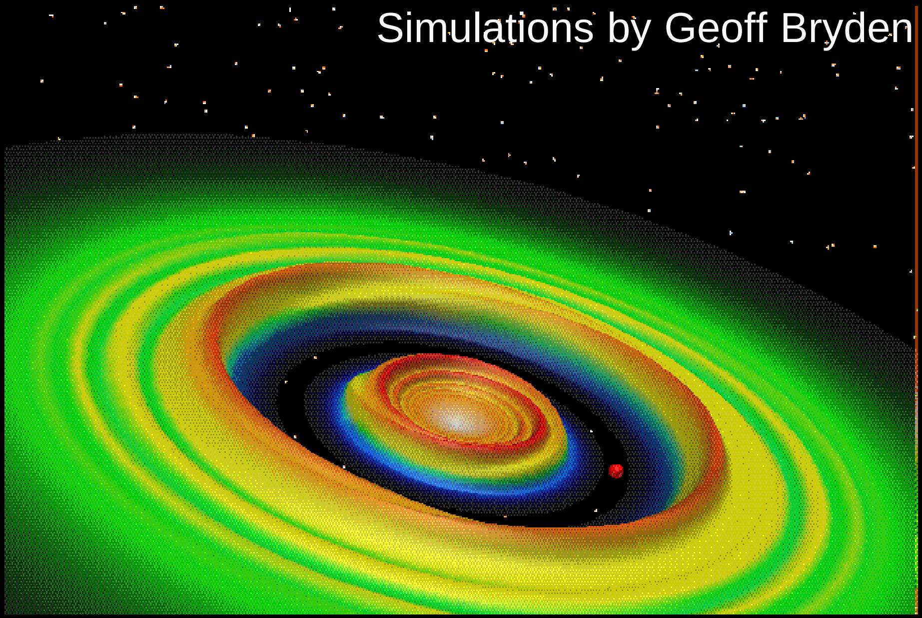


Depending on conditions in the disk (T and H) and the protoplanet's mass, the gap can separate the planet from the disk and effectively stops the accretion process, thereby determining the planet's final mass.

Simulations by Geoff Bryden



accretion streams?



M_{Jup} planet clearing a gap

Or disk conditions may be such that accretion streams continue to feed the growing planet.

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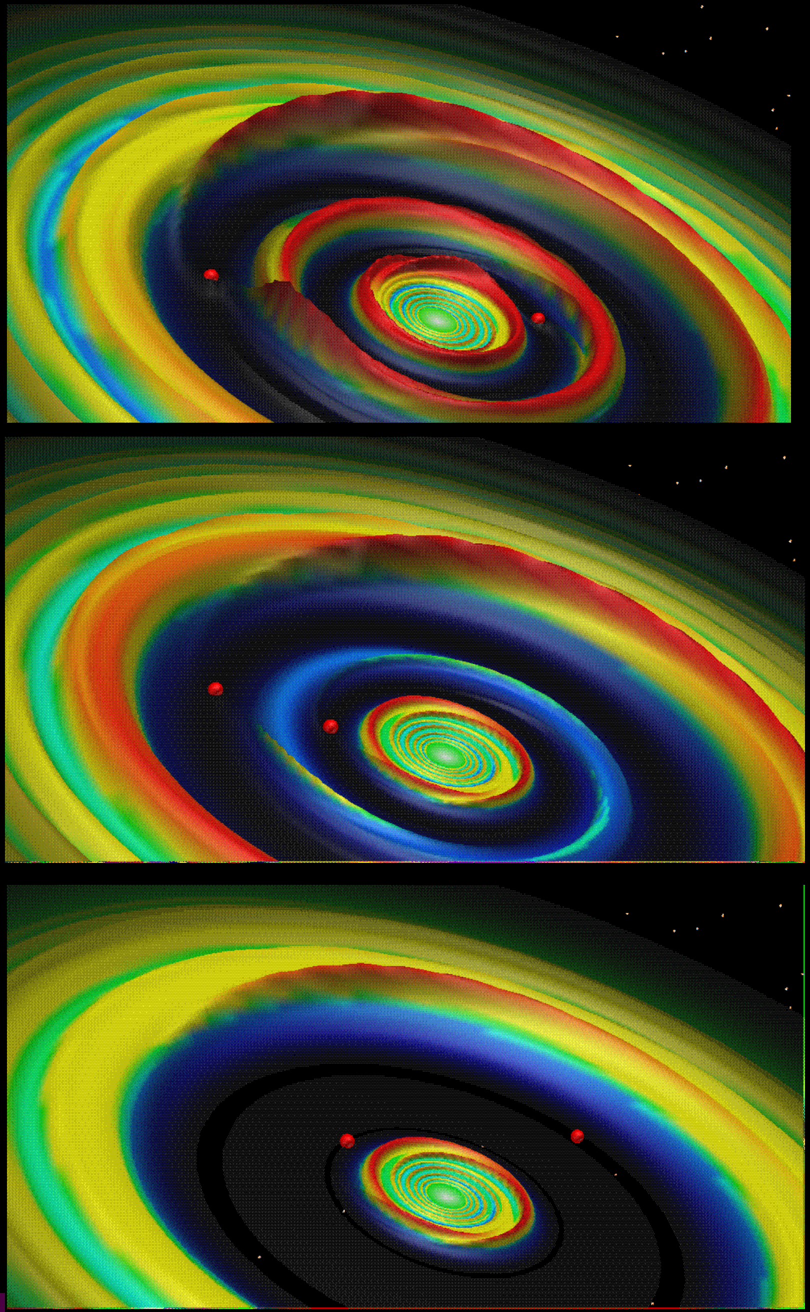
- Add a few planetary perturbers and see what happens:
  - – protoplanetary interactions (migration in or out?)
  - – coupled to disk or separated from disk?
  - – ejection from system?
- Can simulations explains new observations? (e.g. hot Jupiters, eccentirc super-Jupiters…)



Simulations by Geoff Bryden

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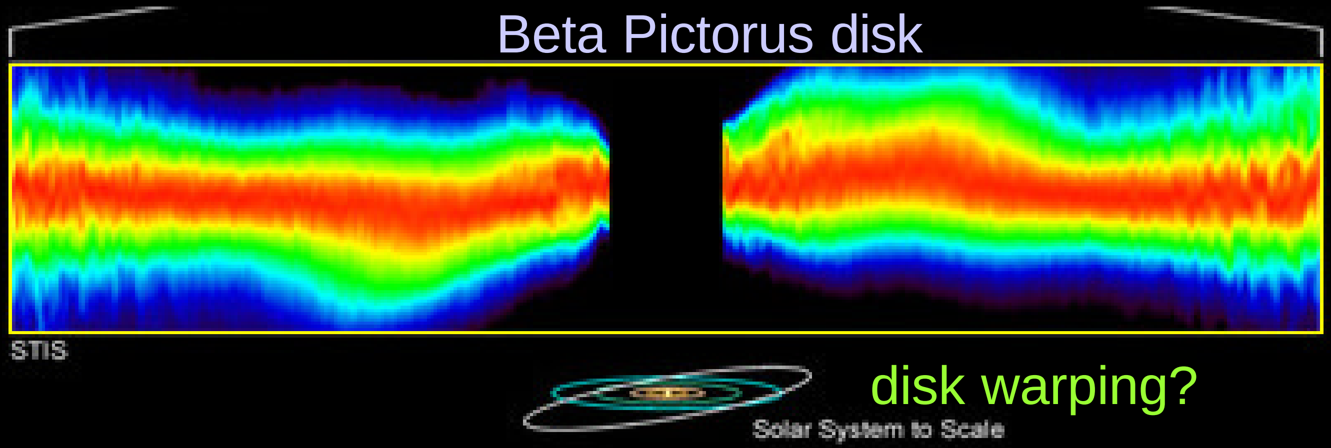
And What About….

- the boundary layer?
- the disk-jet connection?
- outburst? (Fuor and Xor outburst)
- convection in accretion disks? (AM flow in or out?)
- warps in disks?
- dispersion of the disk?

Beta Pictorus disk



disk warping?

Modelling PS Disks

What do mm observations tell you about your disk, and what parameters do you need to know for your modelling?

- what mm gives you:
  - *observe* mm flux density
  - *derive* radial extent and inclinations (assuming distance)
  - *model fits* to disk mass etc...

- important modelling parameters:
  - disk mass and inclination
  - density and temperature profiles
  - radial extent, disk thickness and disk flaring
  - grain properties
  - any z information available (e.g. $T(r,z)$, $\rho(r,z)$…)

Summary

Lots of work going on in the world of dynamic modelling of disks around young stars:

- accretion disks and physics of accretion processes
- gravitational instabilities in massive disks
- convection within the disk
- circumbinary disks: effects of binary potential on disk evolution and visa versa; gap clearing and accretion streams to determine final stellar masses; ...
- protoplanetary disks: effects of planets on disk evolution and visa versa; gap clearing and accretion streams to determine final planetary masses; planetary migration through disks; ...

Observations need to tell of disk mass, thickness & flaring, temperature and density, grain properties...