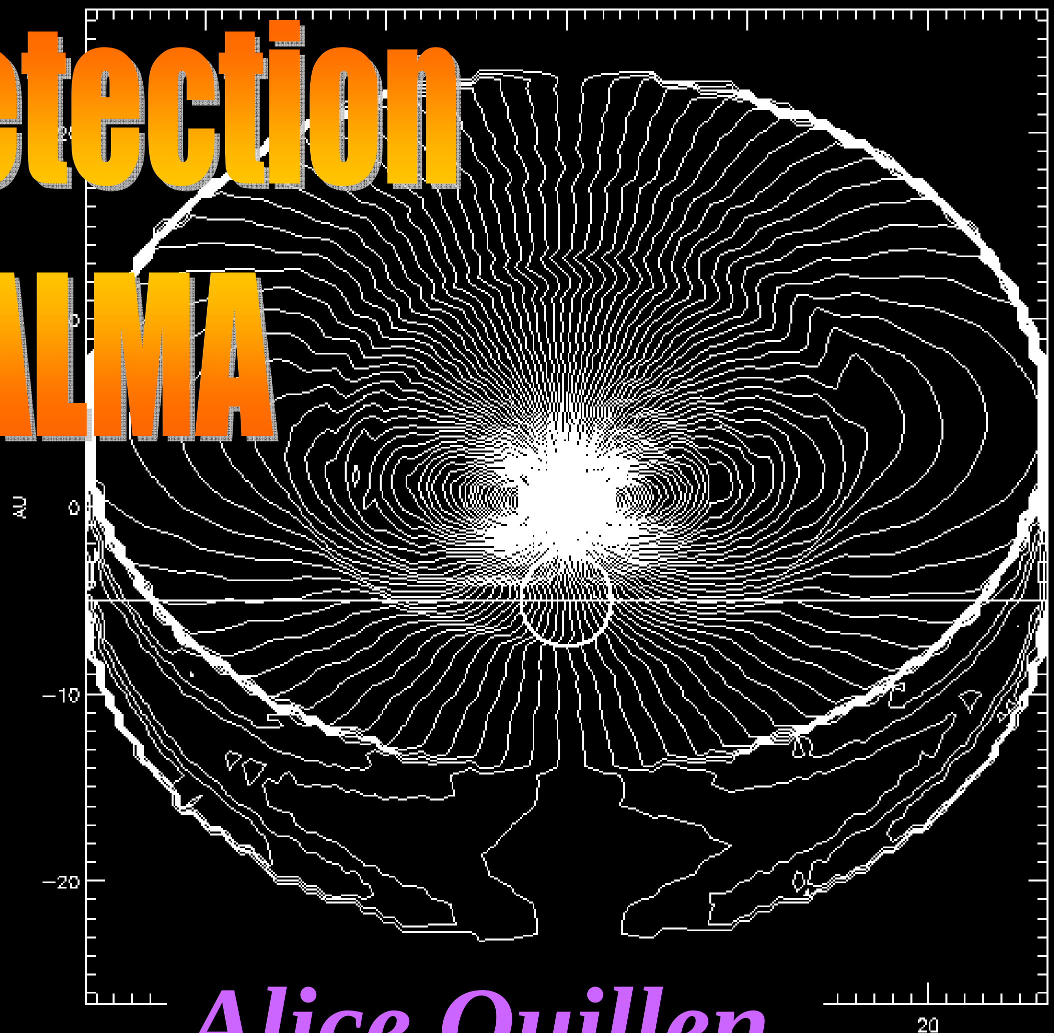
Planet Detection with ALMA



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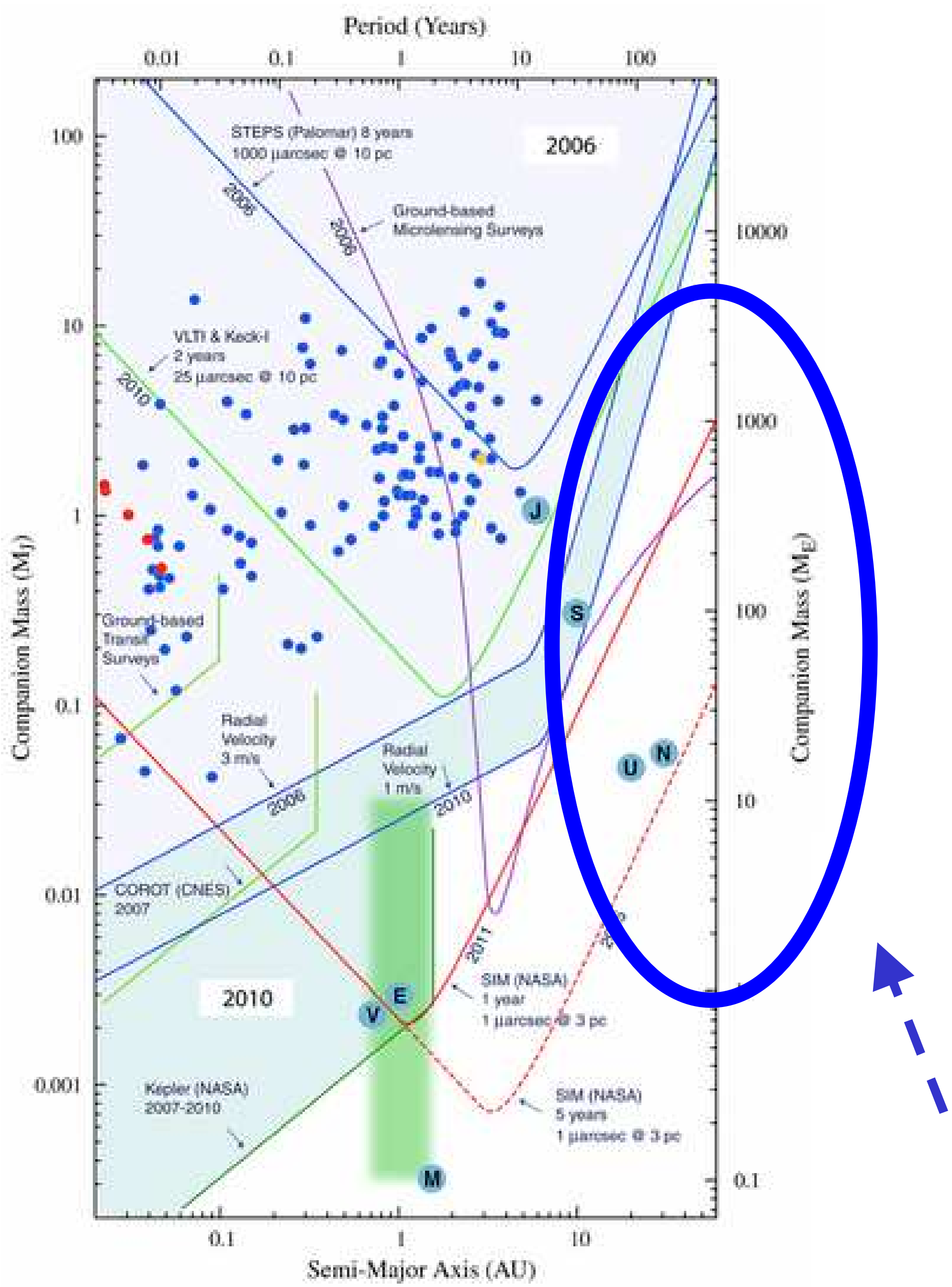
Discovery Space for ALMA



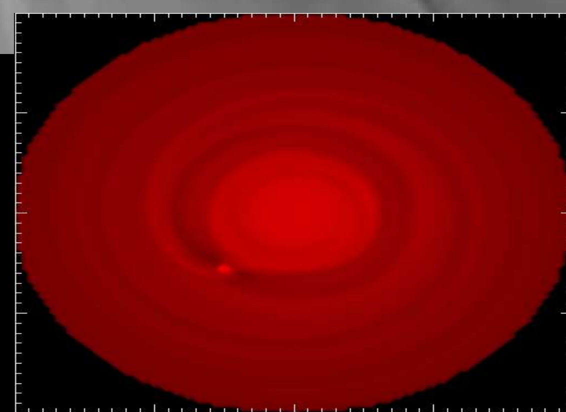
Extrasolar planets discovered by radial velocity (blue dots), transit (red) and microlensing (yellow) to 2004.

Also detection limits of forthcoming space- and ground-based instruments.

Planet detections based on disk/planet interactions

What tells us there is a planet?

- Gaps and clearings (sharp edges)
- Illuminated disk edges
- Proto-Jovian outflows and circumplanetary accretion disks
- Spiral density waves driven by embedded planets and embryos
- Clumps? Eccentricity? Warps?

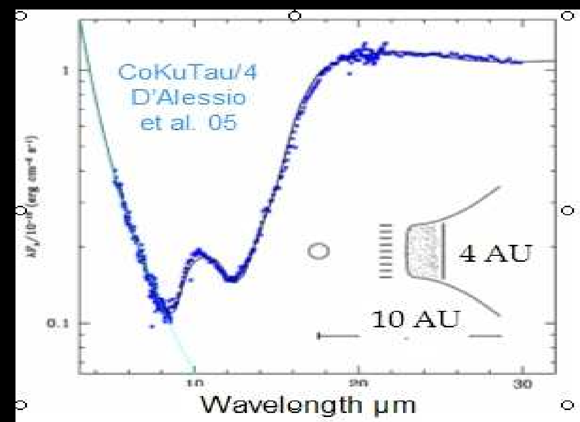


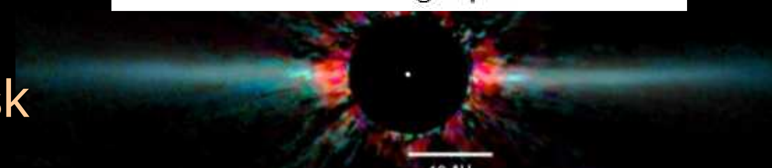
What allows us to **measure planet** properties and differentiate between planet and other models?

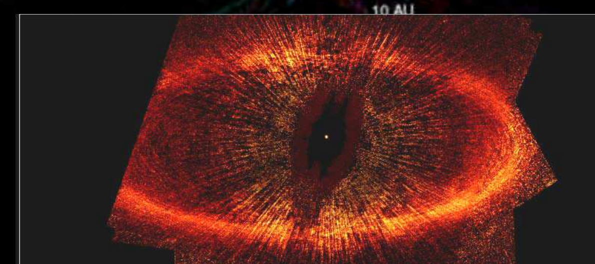
Existing Constraints on planet masses and key observations

AGE and regime

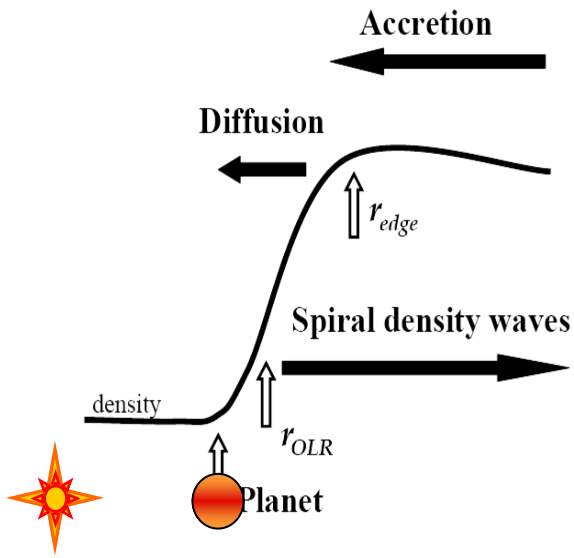
- **CoKuTau/4** (young disk with clearing) critical gap opening planet mass estimate depends on !accretion disk properties. Edge thickness and dust content interior to edge – remain unexploited clues.
- **AU Mic** (young debris disk lacking gaps): disk thickness and normal disk opacity
- **Fomalhaut** (older system with eccentric ring): edge slope, disk thickness, normal disk opacity

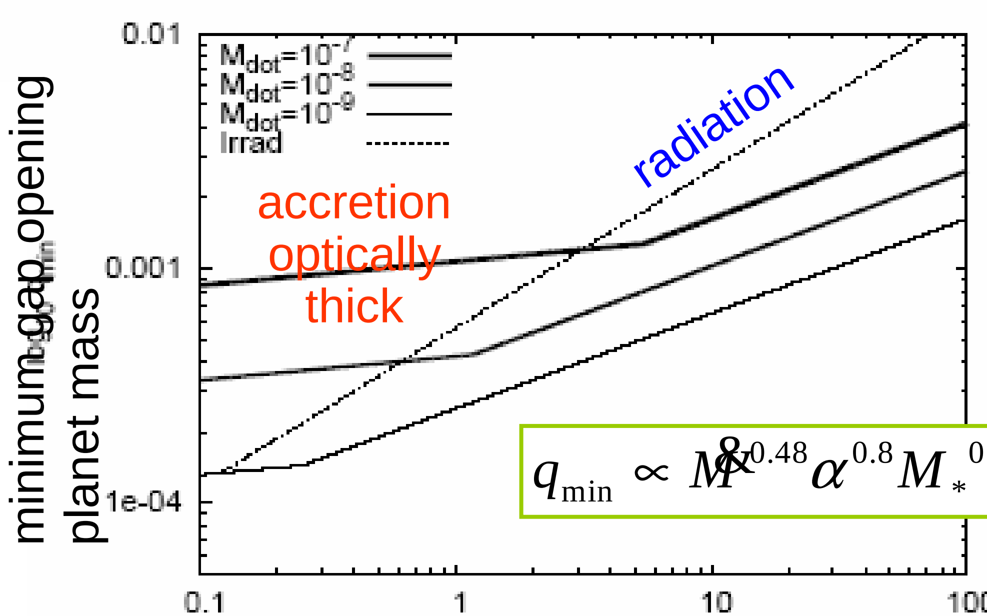






Accretion disk regime
Torque + Spiral density waves



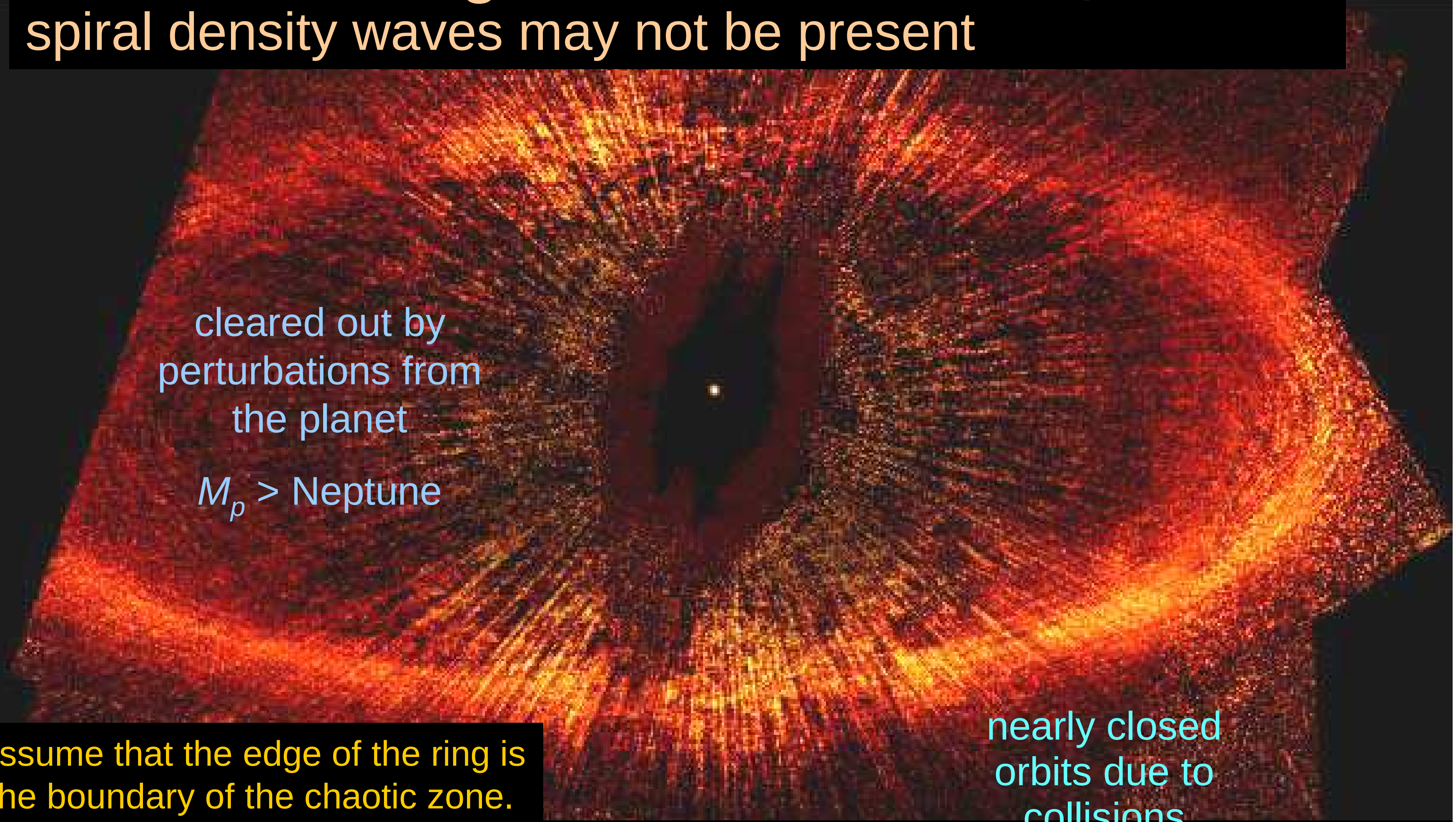


Gapless disks lack planets

$$q_{\min} \propto \dot{M}^{0.48} \alpha^{0.8} M_*^{0.42} L_*^{-0.08}$$

Edgar et al. 07

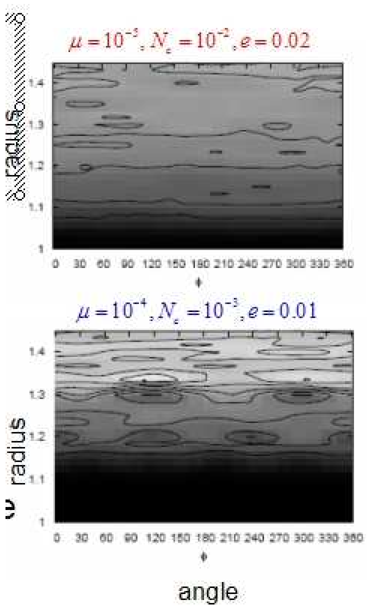
Debris disk regime -- collisions are important, spiral density waves may not be present



Assume that the edge of the ring is the boundary of the chaotic zone. Planet can't be too massive otherwise the edge of the ring would thicken → M_p < Saturn

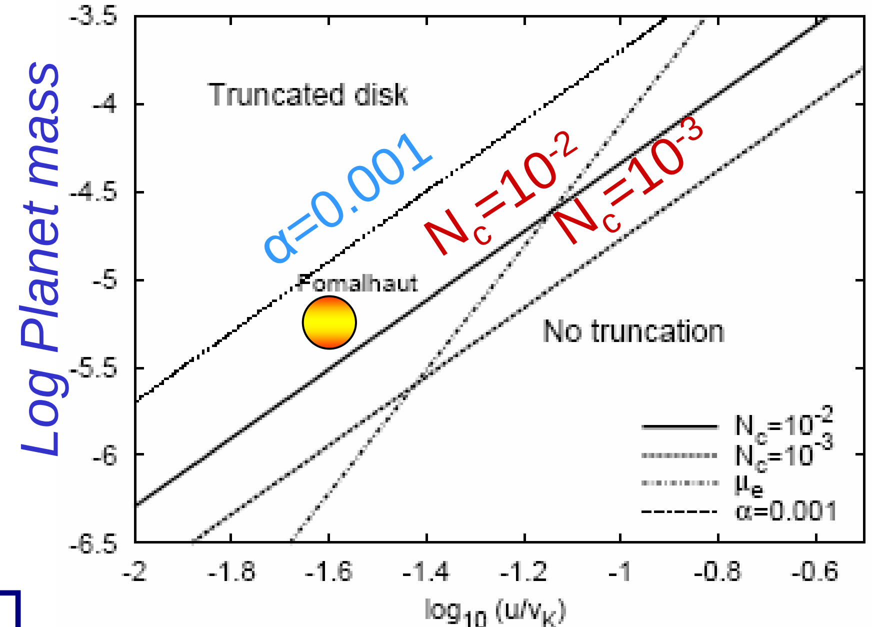
eccentricity of ring equal to that of the planet

Collisional disk morphology + opacity and dispersion



te a disk a planet must have mass above

$$\log_{10}\mu > -6 + 0.43\log_{10}\left(\frac{\tau_n}{5\times10^{-3}}\right) + 1.95\left(\frac{u/v_K}{0.07}\right)$$



Log Velocity dispersion

Observables can lead to planet mass estimates, motivation for better imaging leading to better estimates for the disk opacity and thickness

Morphology and embryos

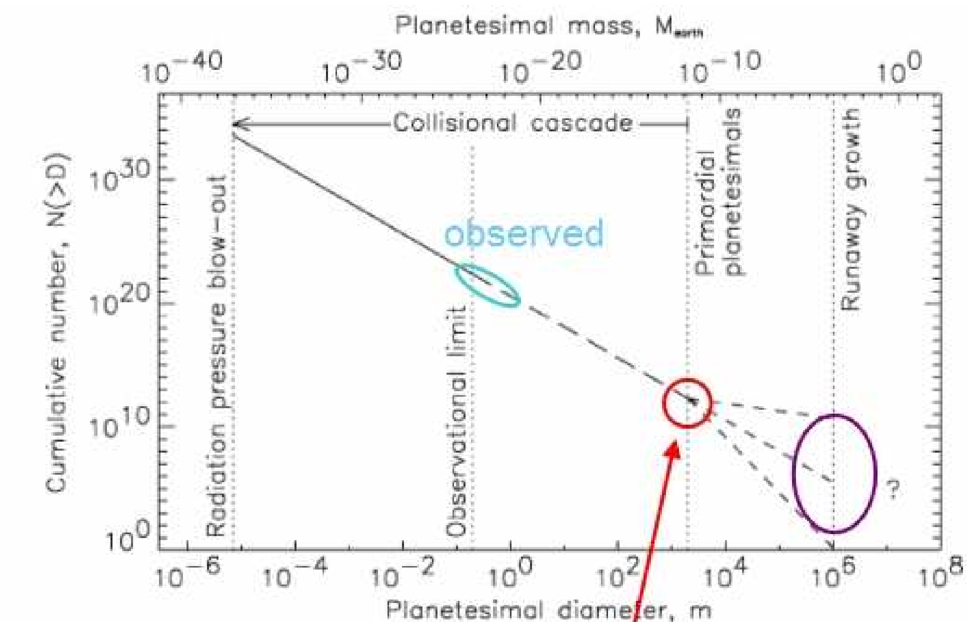
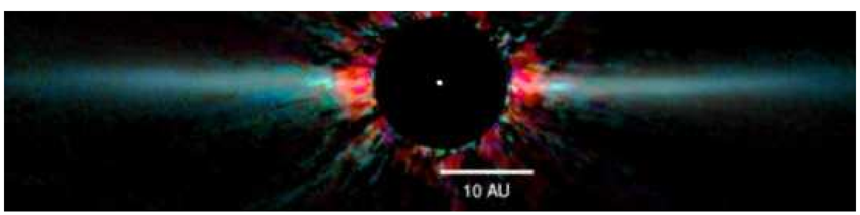
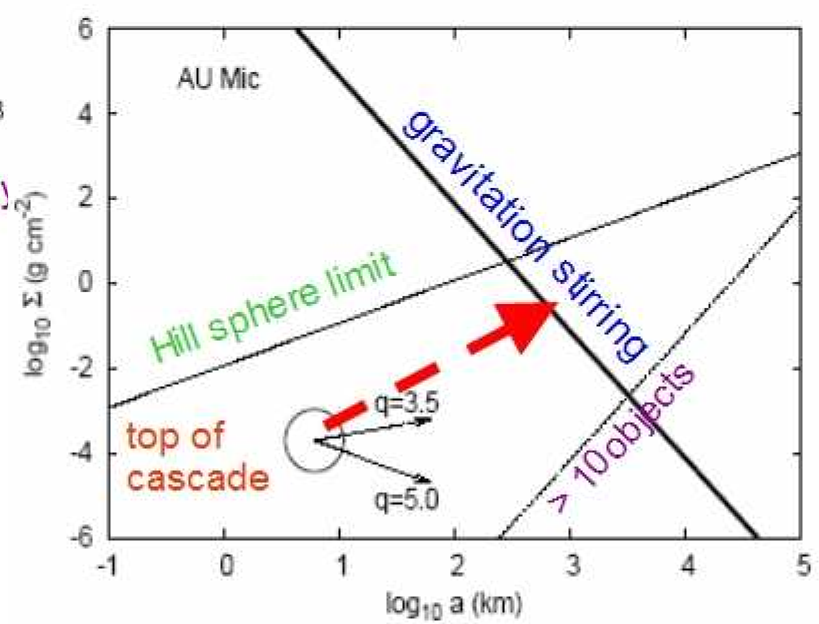


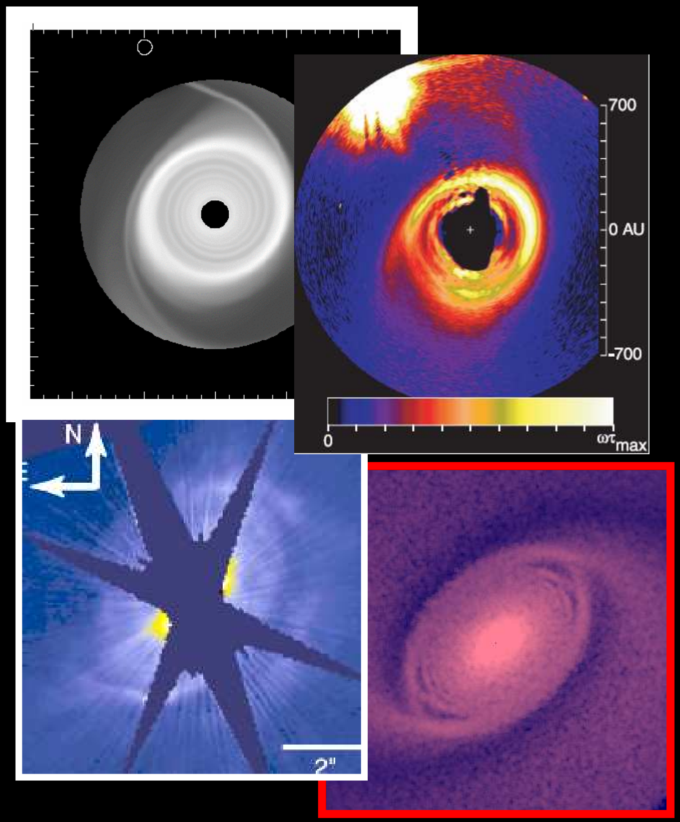
Figure from Wyatt & Dent 2002

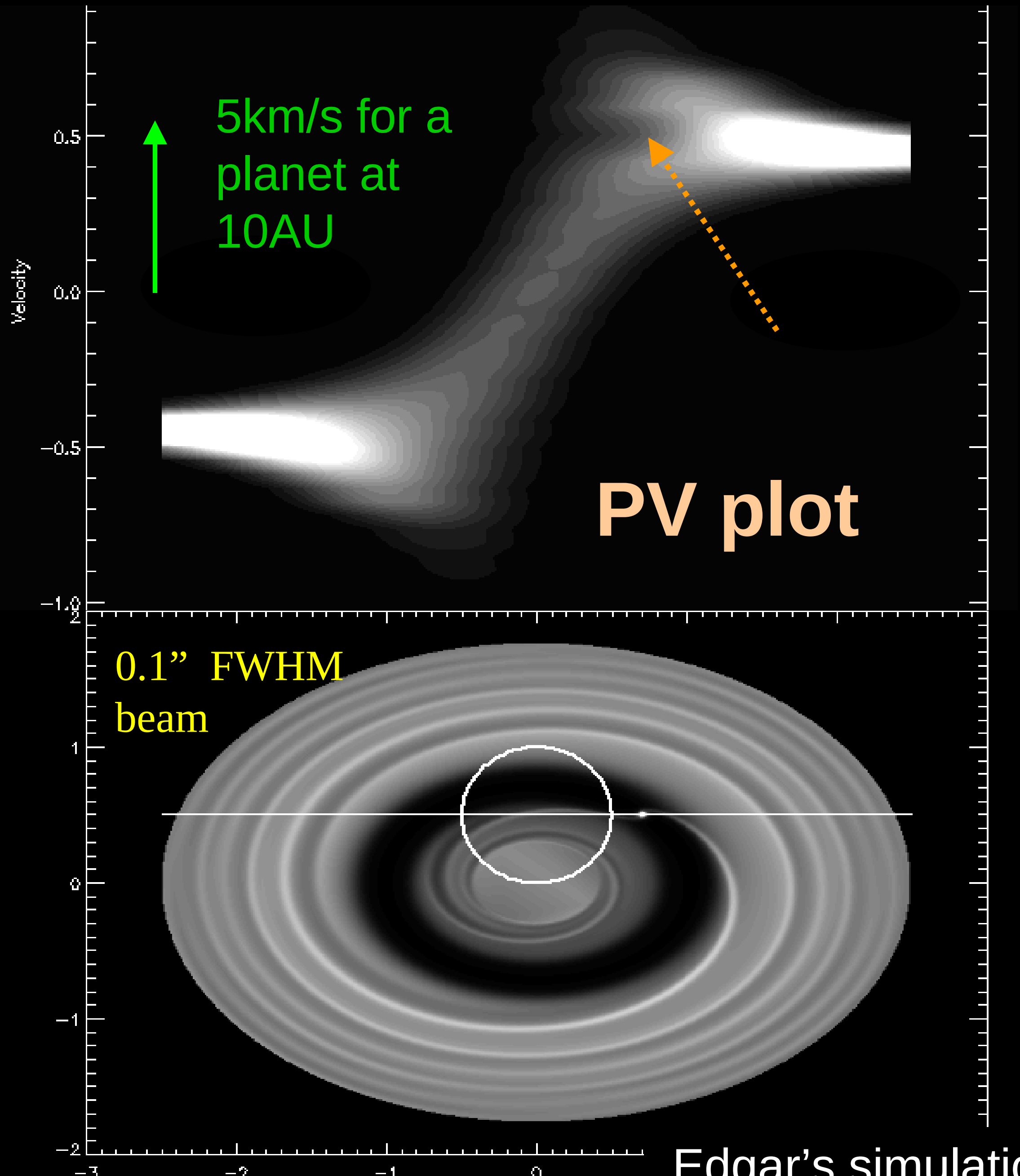




Phenomena that might be caused by interesting things other than planets

- Coagulation, fragmentation, vortices, gravitational and other instabilities (Mach 1+, not localized, open arms)
- Disk turbulence (< Mach 1, not localized)
- Envelope dynamics
- Variations in disk illumination and chemistry
- Accretion holes, ionization fronts
- Perturbations by nearby stars

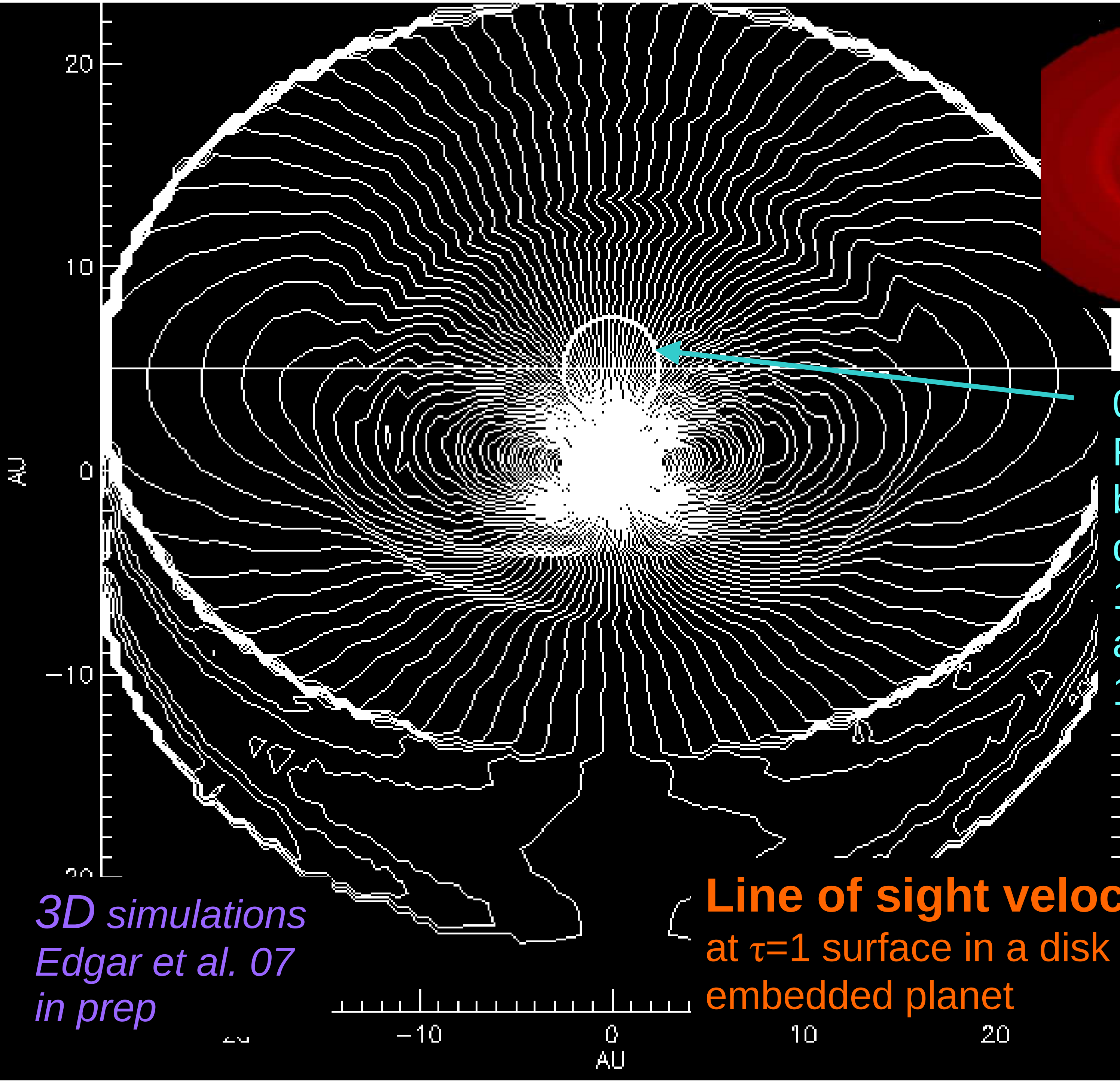


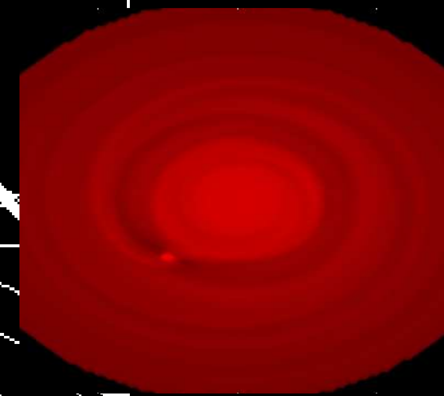


Previous work focused on continuum morphology
Here we look at line emission.

Velocity field of 2D disks:
Gaps are clearly detected even when not resolved.

Edgar’s simulations + Masset’s code

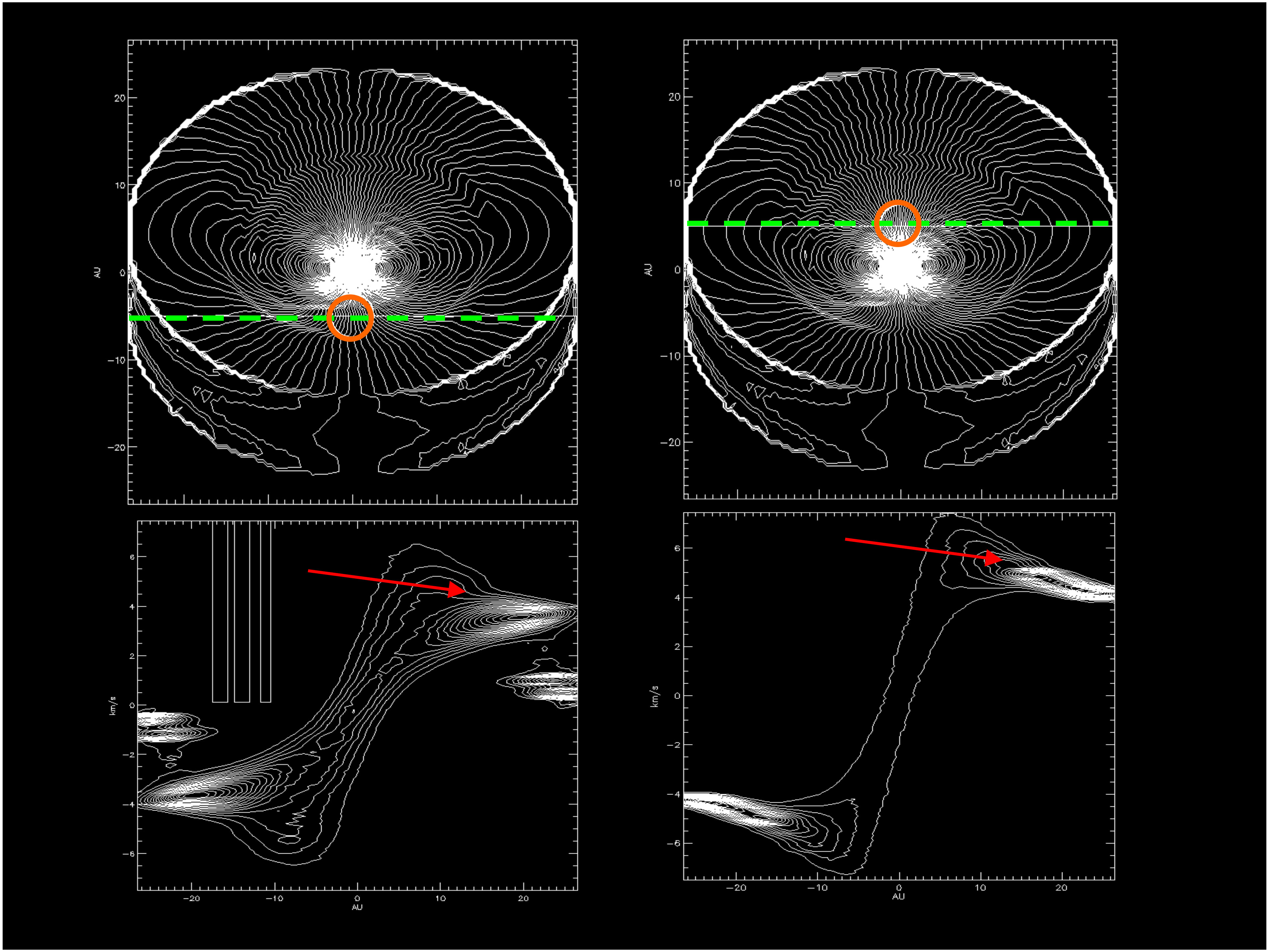


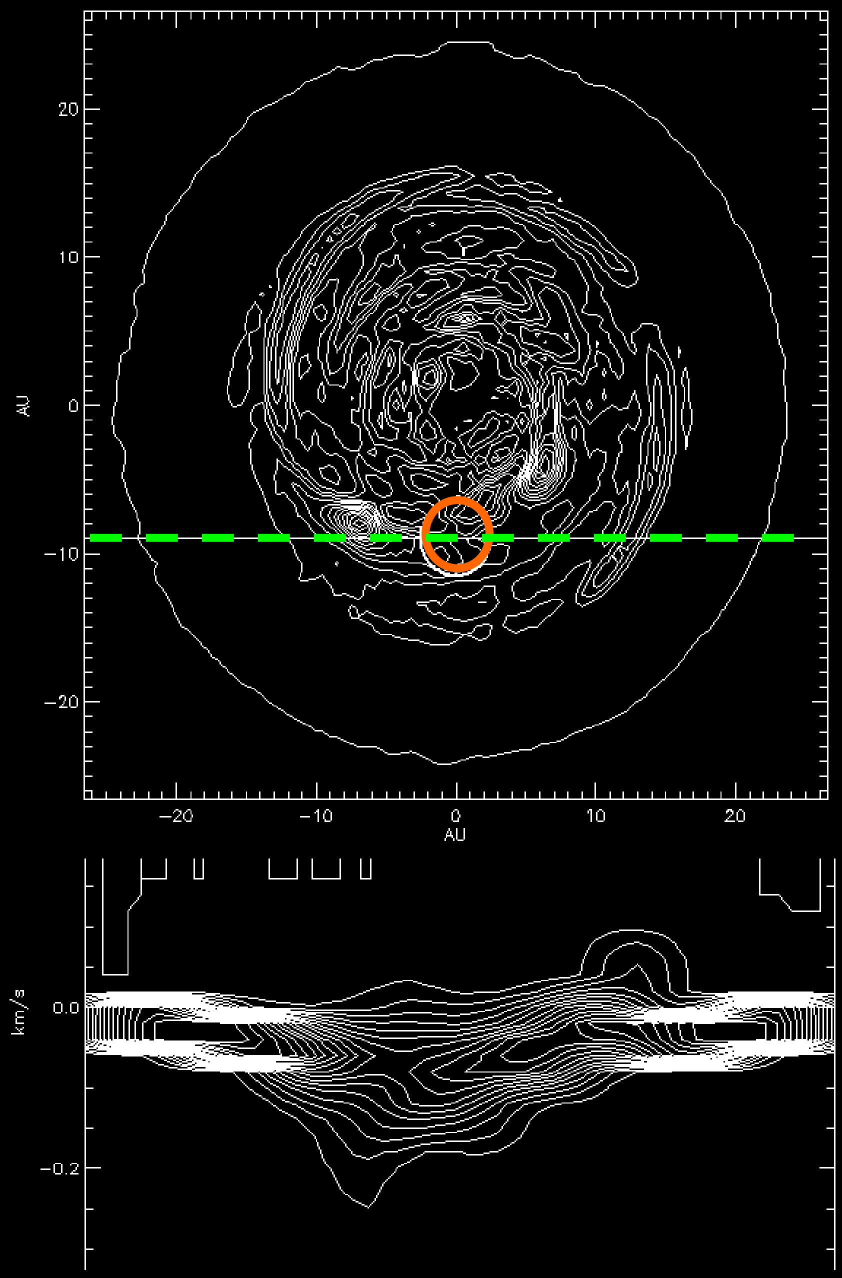


0.05” FWHM beam for a disk at 100pc with a planet at 10 AU

3D simulations
Edgar et al. 07
in prep

Line of sight velocity field
at τ=1 surface in a disk with an embedded planet


AU
AU
km/s
AU
km/s
AU



Face on disk

- Spiral density waves have v_z of order Mach 1 -- detectable when viewed face on
- Turbulence of order $\sqrt{\alpha} c_{sound}$

Results from 3D simulations

- Spiral density waves and un-evacuated gaps from *embedded* planets are likely to be detectable with ALMA from the velocity field in line emission
- Planet location can be estimated via proximity Spiral density waves, $v \sim c_s$
- Vertical opacity and velocity structure important and affects structure in different lines
- Dust, temperature distribution affected by spiral structure – localized velocity perturbations
- Morphology of waves depends on planet mass and time/pattern speed.....

Summary

- Progress in understanding planet/disk interactions in different dynamical regimes.
- Scaling from the current 3-5, the number of planets inferred from disk/planet interactions will rise by 2-3 orders of magnitude due to ALMA observations
- Increasing sophistication of simulations -- 3D disk structure
- To go from phenomena to well constrained planet models + certainty we need
  - Better dust/planetesimal coupled codes
  - 3D hydro+multi physics codes with better radiation coupling, illumination and chemistry