Gaps, Rings, and Non-axisymmetric Structures in Protoplanetary Disks

ALMA press release

- Gaps
- Orbit of Neptune = 30 AU
- Orbit of Earth = 1 AU
- Thermal emission of solid particles ≈ 1 cm
ALMA Achievement

- Baseline up to 15 km (SV Data, ALMA Partnership et al. 2015)
- Best spatial resolution: 0.025″ (3.5 AU)
New Paradigm in Disk Observations

H band scattered light image (Subaru/SEEDS – Follette et al. 2015)

Green – 440 \( \mu m \) ALMA contours (van der Marel et al. 2013)

Yellow – 18 \( \mu m \) VLT/VISIR contours (Geers et al. 2007)

**Vortices:** Barge & Sommeria 1995, Klahr & Henning 1997, …

**Turbulent eddies:** Johansen & Klahr 2005, Cuzzi & Hogan 2003, …

**Zonal flows:** Johansen et al. 2009, Johansen, Klahr & Henning 2011, …
Benisty et al. (2015) – MWC 758 (Y band – 1.04 µm (7.5 AU) – 0.027")
3D Global Stratified MHD Simulation

Radius: 1-10 AU

8 pressure scale heights

Blue Gene/P and Pluto code: Flock et al. (2011)
Turbulence and Particle Trapping

PLUTO: Non-ideal global stratified MHD simulation (D/G=10^{-2})

Gaps rings and asymmetries without a planet

- surface density jump at the dead-zone edge
  - strong enough to trap large grains in ring structures
  - triggers RWI, vortex generation and destruction cycle
  - concentration of particles
Turbulence and Particle Trapping – Large Particles

Ruge et al. (2015)
The End ....

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