Dust trapping in protoplanetary disk vortices

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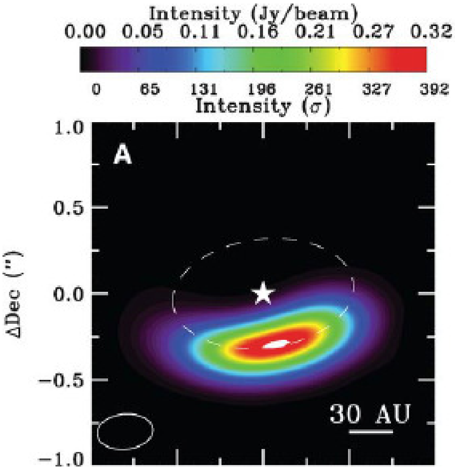
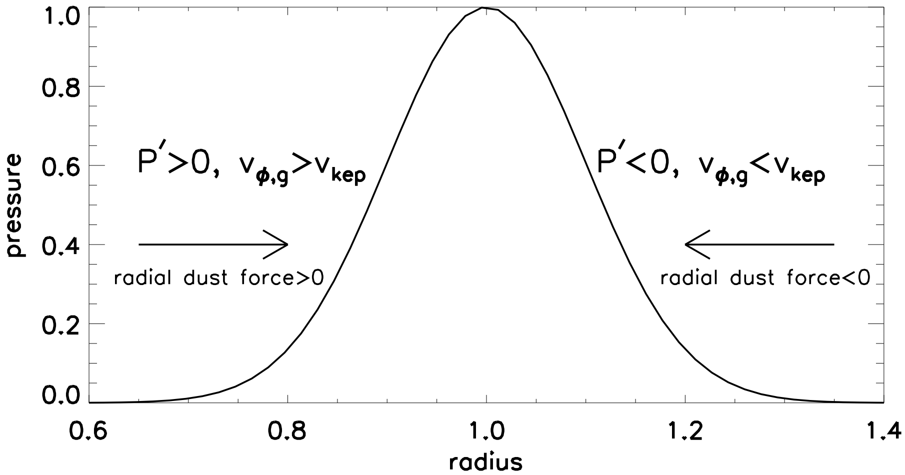
Large scale asymmetries in transition disks



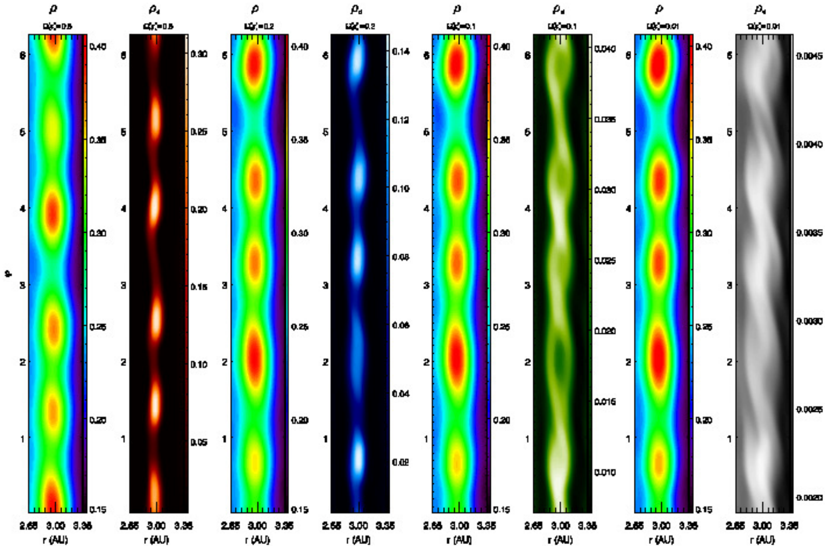
(Oph IRS 48, van der Marel et al., 2013)

Dust trapping at pressure maxima

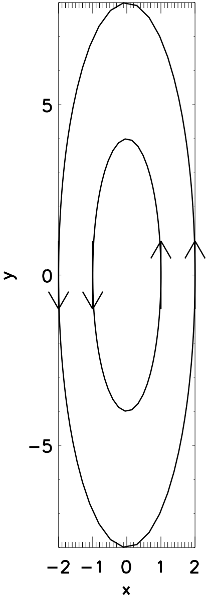


Asymmetric trapping by vortices

Meheut et al. (2012): add dust to disk with vortices



Models of elliptic vortices



Each ellipse with aspect-ratio χ:

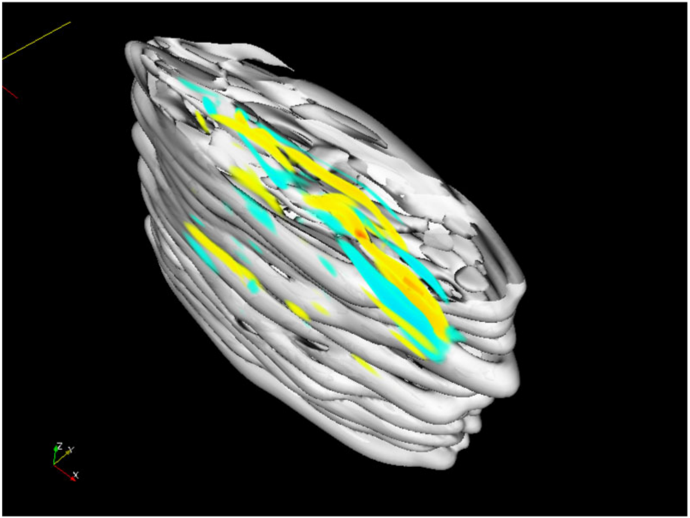
$$x = a\cos\phi,$$
$$y = a\chi\sin\phi.$$

Velocity field:

$$u_x = \Omega_v y/\chi,$$
$$u_y = -\Omega_v x\chi$$

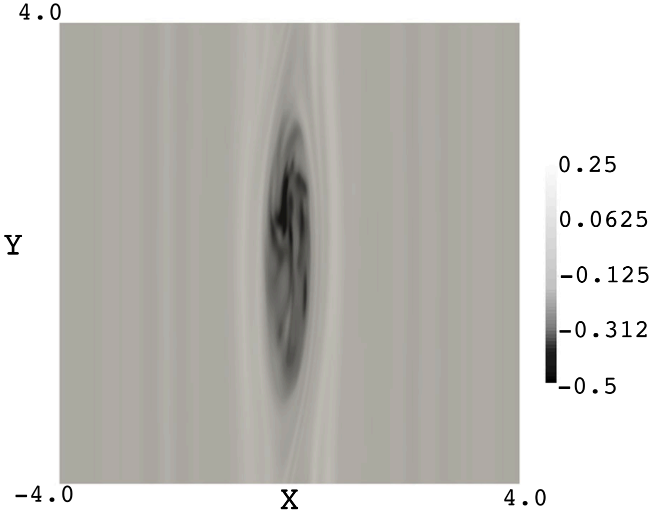
(Kida, 1981; Goodman et al., 1987)

Vortice are generally unstable



(Lesur & Papaloizou, 2009)

Vortex formation vs. destruction



(Lesur & Papaloizou, 2010)

Dust trapping vs. diffusion

Particle concentration vs. turbulent diffusion (Lyra & Lin, 2013)

$$\frac{\partial \rho_d}{\partial t} + \nabla \cdot (\rho_d \mathbf{v}_d) = D\nabla^2 \rho_d$$

- D: from instability of vortex core
- $\mathbf{v}_d = \mathbf{v}_g + \tau c_s^2 \nabla \ln \rho_g$, isothermal gas
- $\mathbf{v}_g$ from model of an elliptic vortex (e.g. Kida vortex)
- τ friction time

Parameters:

$\delta = D/H^2\Omega$: dimensionless turbulence strength

$\mathrm{St} = \tau\Omega$: dimensionless friction (Stokes number)

Steady state equation

Steady-state dust distribution in elliptic vortices (Lyra & Lin, 2013)

$$\left[\nabla^2 - \left(Ay\chi^{-1} - B_1 x\right)\partial_x + \left(Ax\chi + B_2 y\right)\partial_y + B\right]\rho_d = 0.$$

Decomposition in ϕ:

$$\rho_d(a,\phi) = \mathrm{Re}\left[\sum_{m=0}^{\infty} \rho_m(a)\exp\left(\mathrm{i}m\phi\right)\right].$$

Coupled ODEs:

$$\mathcal{B}_m\rho_{m-2} + \mathcal{A}_m\rho_m + \mathcal{C}_m\rho_{m+2} = 0.$$

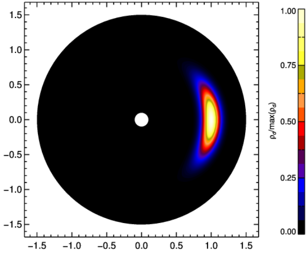
A simple solution

$$\rho_d(a) \propto \exp\left(-\frac{a^2}{2H_v^2}\right),$$

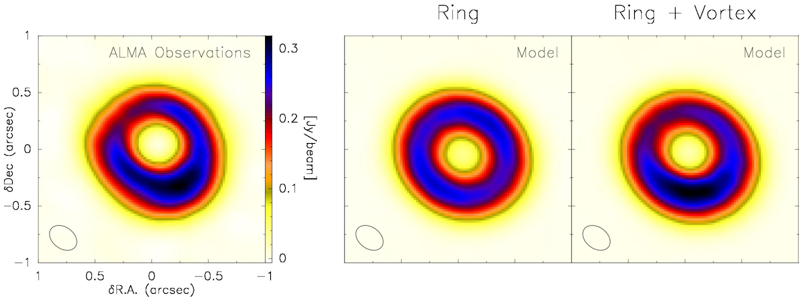
with

$$H_v(\chi, \delta, \mathrm{St}) = \frac{H_g}{f(\chi)}\sqrt{\frac{\delta}{\delta + \mathrm{St}}}.$$

Technically: dust density averaged over an ellipse
EXACT solution for certain vortex models
(e.g. Kida vortex with $\chi = 7 \rightarrow$ no pressure gradient along ellipses)

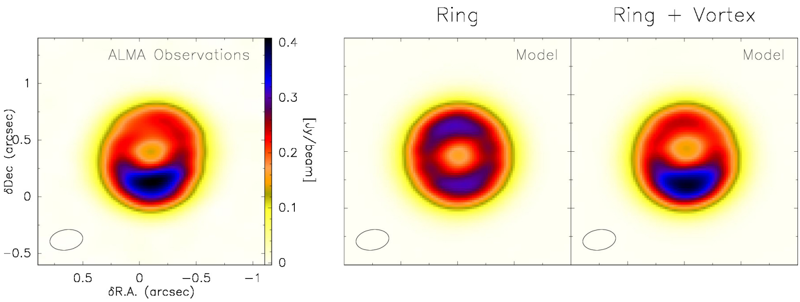


Application to observations



(SAO 206462, Pérez et al., 2014)
$\chi_{\rm obs} \sim 7$, model+ data $\rightarrow v_{\rm turb} \sim 0.22 c_s$.

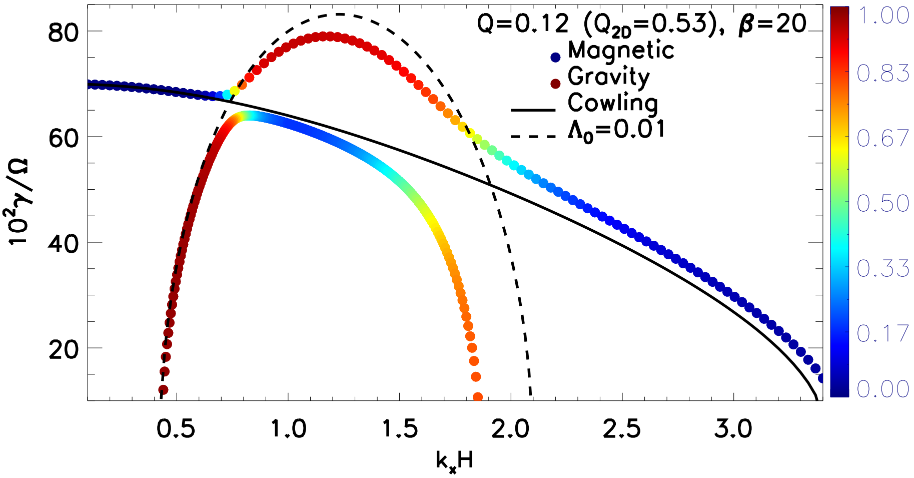
Application to observations



(SR 21, Pérez et al., 2014)

$\chi_{\rm obs} \sim 3$, model+ data $\rightarrow v_{\rm turb} \sim 0.16 c_s$.

Magnetized self-gravitating disks



CITA fluid discussion: Thursday 11am @ 1318

The end

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