On the diversity of asymmetries in gapped protoplanetary disks

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Introduction

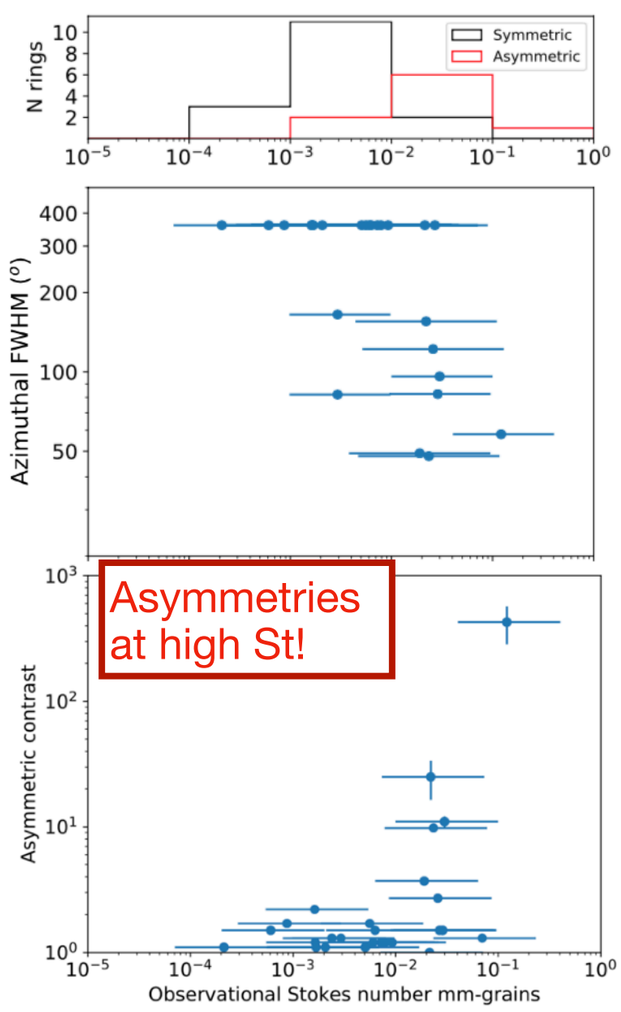
- Many protoplanetary disks show dust rings and dust asymmetries, thought be caused by dust trapping at the edge of a planet gap (Pinilla et al. 2012, van der Marel et al. 2013, 2016)
- Asymmetries are seen in about 20% of the transition disks (Francis & van der Marel 2020), and thought to be caused by vortices or horseshoe (Barge & Sommeria 1995, Ragusa et al. 2017)
- The origin of the low occurrence rate is unknown, and has been suggested to be linked to the destruction lifetime of vortices (e.g. Miranda et al. 2017, Hammer et al. 2017)

Methods

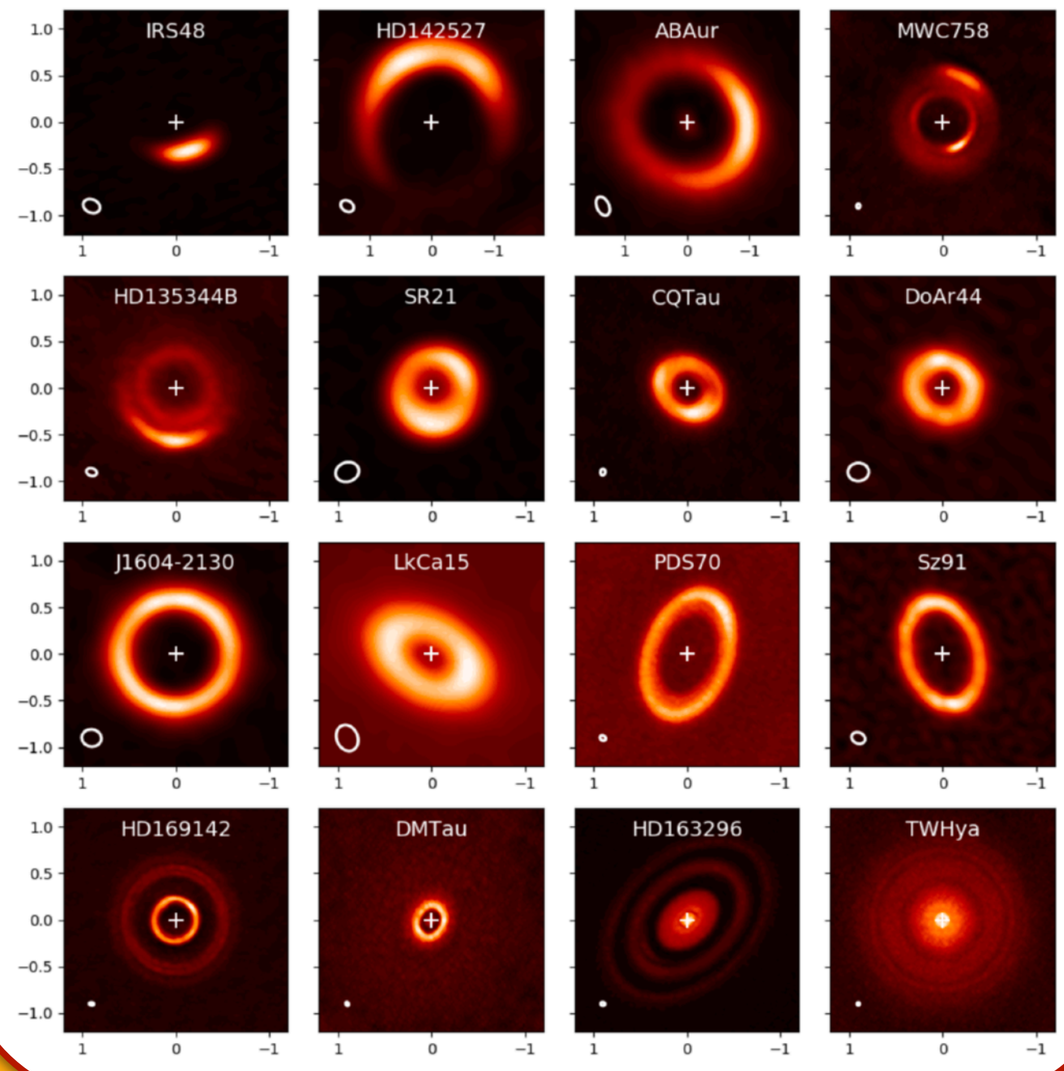
- We select a sample of 16 gapped disks with constraints on the gas surface density from CO isotopologue data.
- For each disk, the asymmetric nature is quantified with both azimuthal contrast and azimuthal FWHM in each dust ring using Galario.
- This parameter is compared with the observational Stokes number at the dust ring location:

$$St = \frac{a_{\rm grain}\rho_s\pi}{2\Sigma_{\rm gas}(R_{\rm dust})} \quad a_{\rm grain} = \lambda_{obs}/(2\pi) \quad = \frac{\lambda_{\rm obs}\rho_s}{4\Sigma_{\rm gas}(R_{\rm dust})}$$

Results

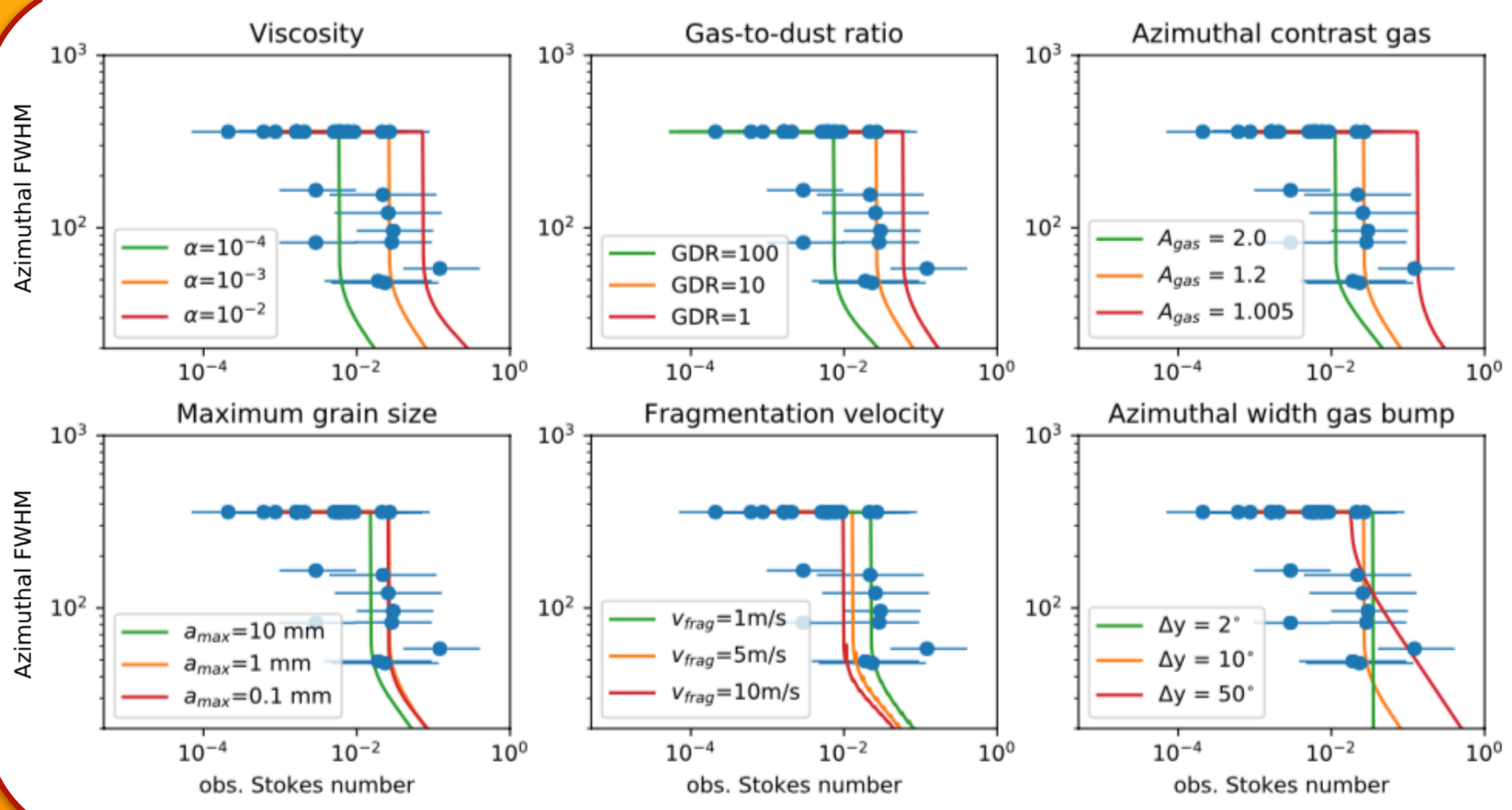


Sample (ALMA archival data)



Consequences

- Dust asymmetries are always located in low gas surface density regions.
- Dust asymmetries are always found in the outer dust ring in multi-ring disk.
- Lifetime constraints are not necessary to explain the occurrence of asymmetries.
- Gas asymmetries (vortices, horseshoes, spiral arms) may be present throughout every disk, just not visible in mm dust observations.
- Dust asymmetries may be found at cm wavelengths with e.g. ATCA/JVLA, even in axisymmetric disks (Norfolk et al., in rev.).



Dust evolution model

- The data are compared with a model from Birnstiel et al. 2013 that analytically solves for the equilibrium of azimuthal drift and azimuthal mixing of dust particles.
- The model reproduces the observed trend. We explore a number of parameters describing the gas asymmetric feature and disk properties and show the parameter degeneracy.
- Multi-wavelength observations can further constrain the model parameters.