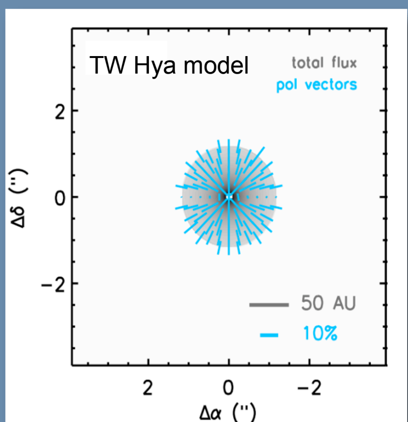
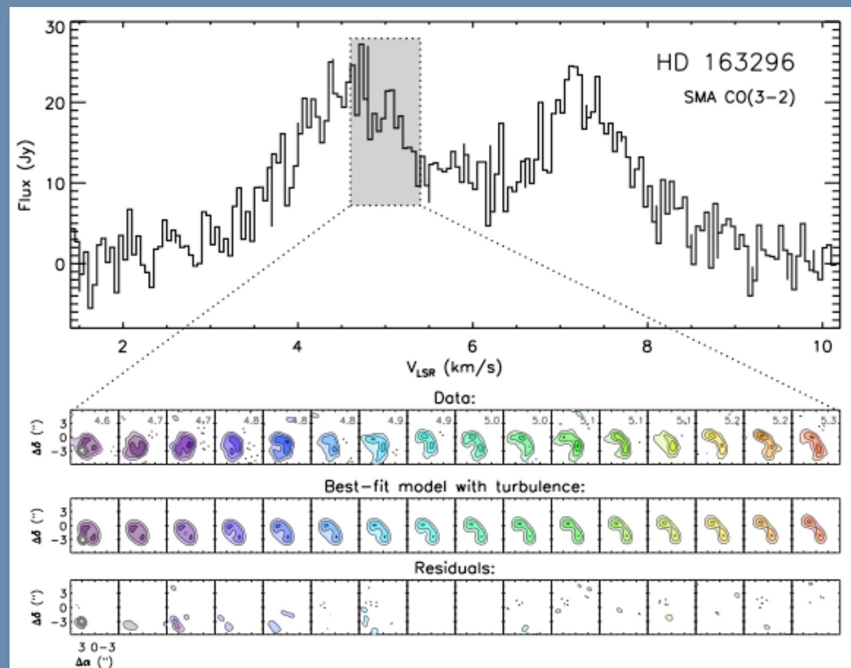
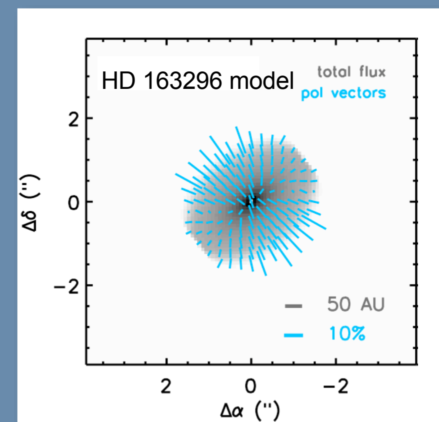
Millimeter-Wavelength Signatures of Viscous Transport in Circumstellar Disks







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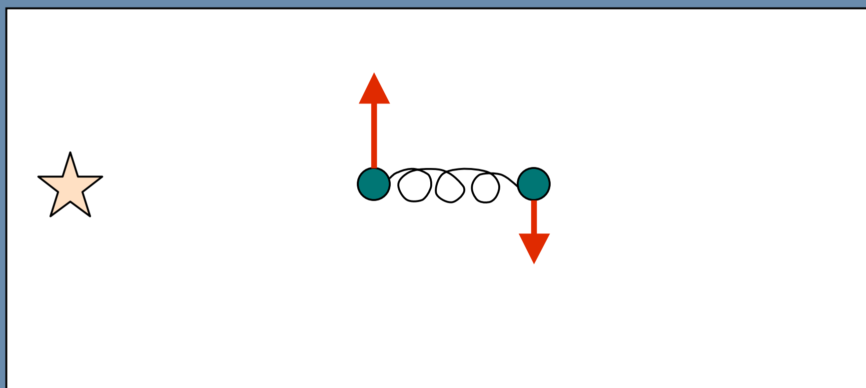
Circumstellar disks as accretion disks

Important: the mass distribution in a disk changes over time as material is transported by viscosity of unspecified origin.



Theories of disk evolution generally invoke MRI-driven turbulence as source of anomalous viscosity.

Balbus & Hawley (1991), Stone et al. (2000)

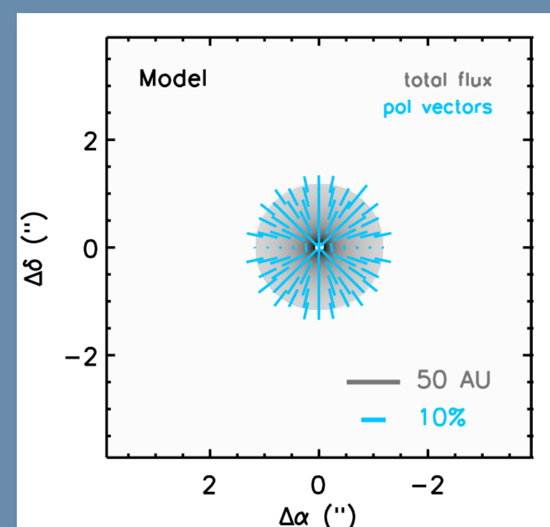
What is observable?

- B-field needed to drive MRI

Aligned dust grains should generate polarized emission

- Turbulence that generates viscosity

Nonthermal widths of molecular lines



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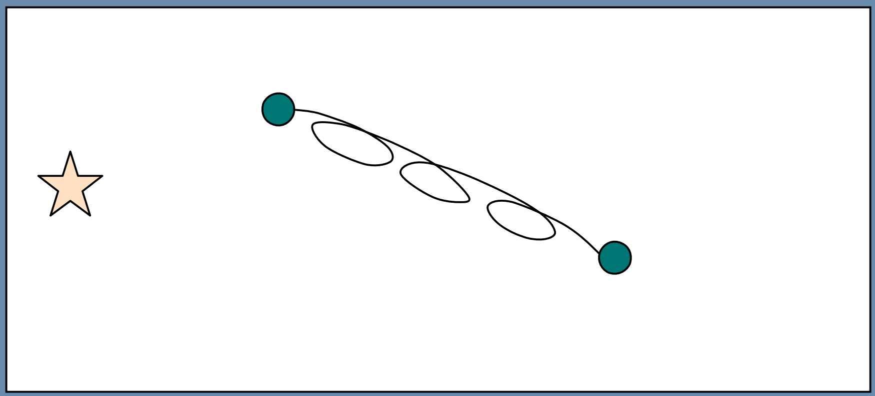

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Why should you care?

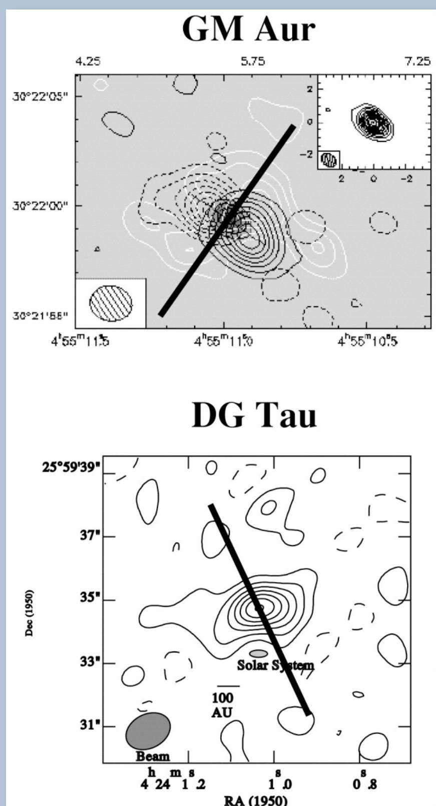
Turbulence solves (and creates?) problems in planet formation

- Time evolution of disk structure
- Dust grain transport
- Meteoritic mixing
- Dust settling
- Chemistry
- Planetesimal Migration

Polarization

Feasibility: single-dish observations, models

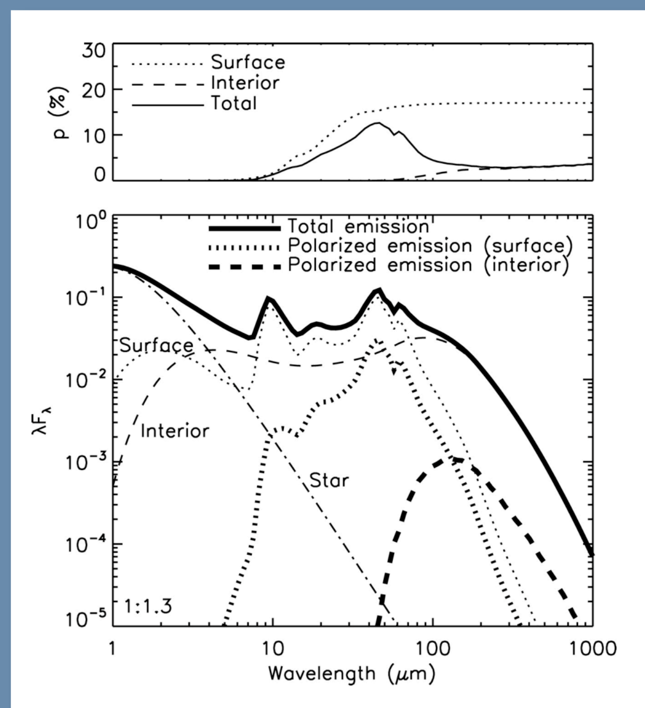
Tentative (3σ) 3% polarization detection in two disks with JCMT

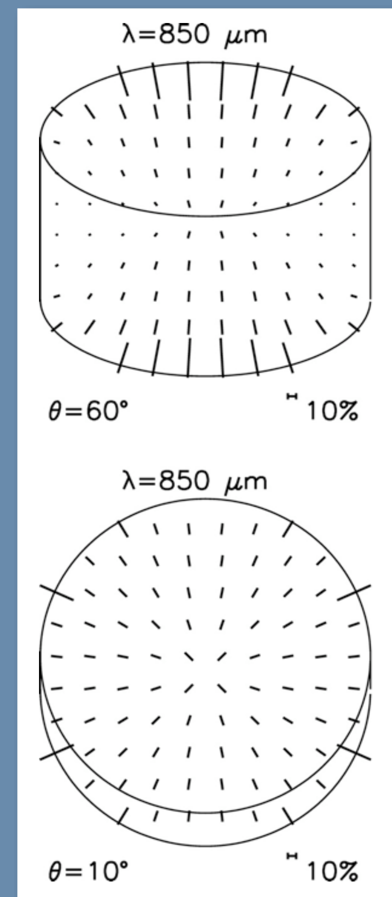


Tamura et al. (1999)

First realistic models of polarized emission from disks predict 2-3% polarization at mm wavelengths

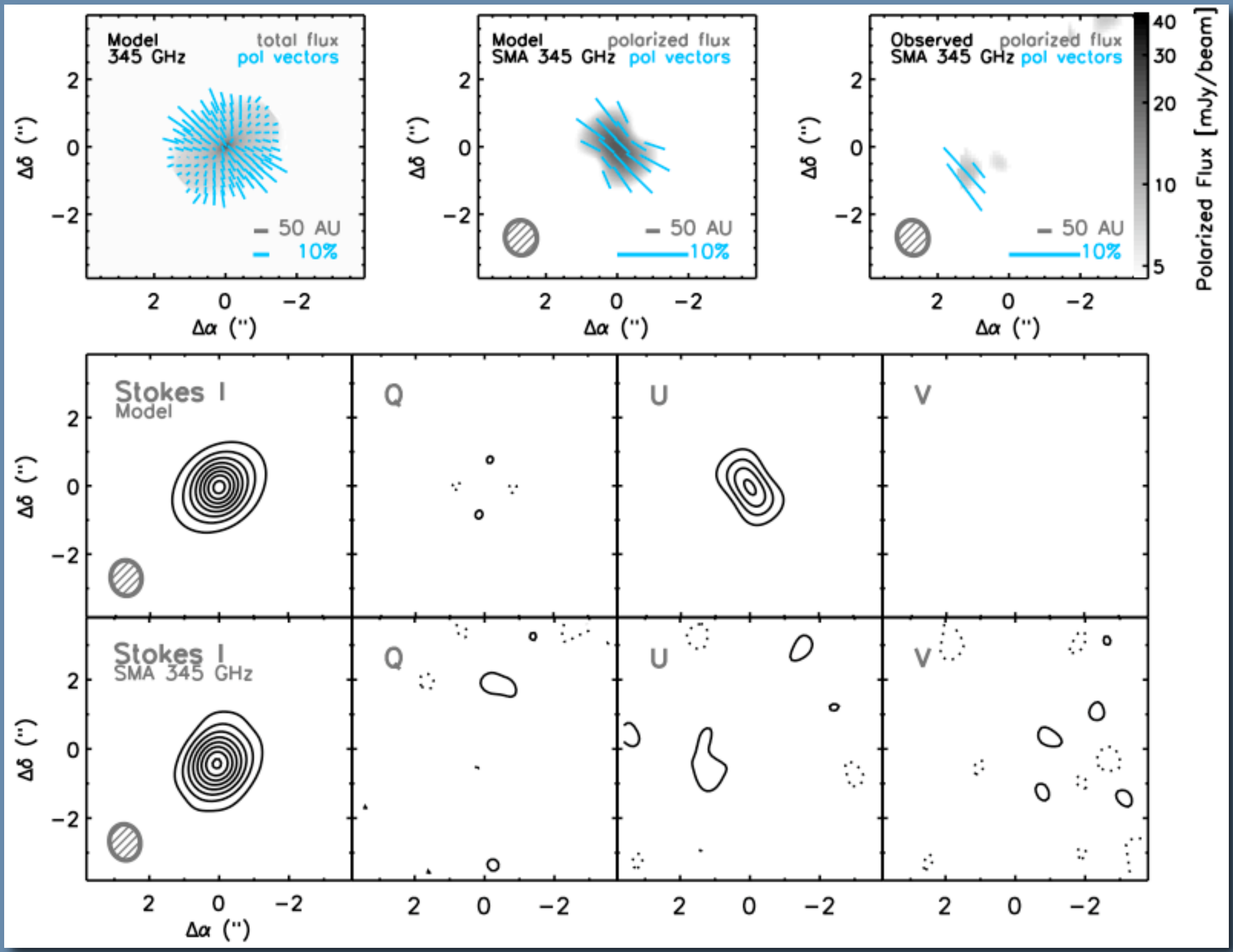
- Grains aligned by radiative torque
- Chiang & Goldreich disk model
- Toroidal B-field
- Vary grain shape, size dist.





Cho & Lazarian (2007)

Observations



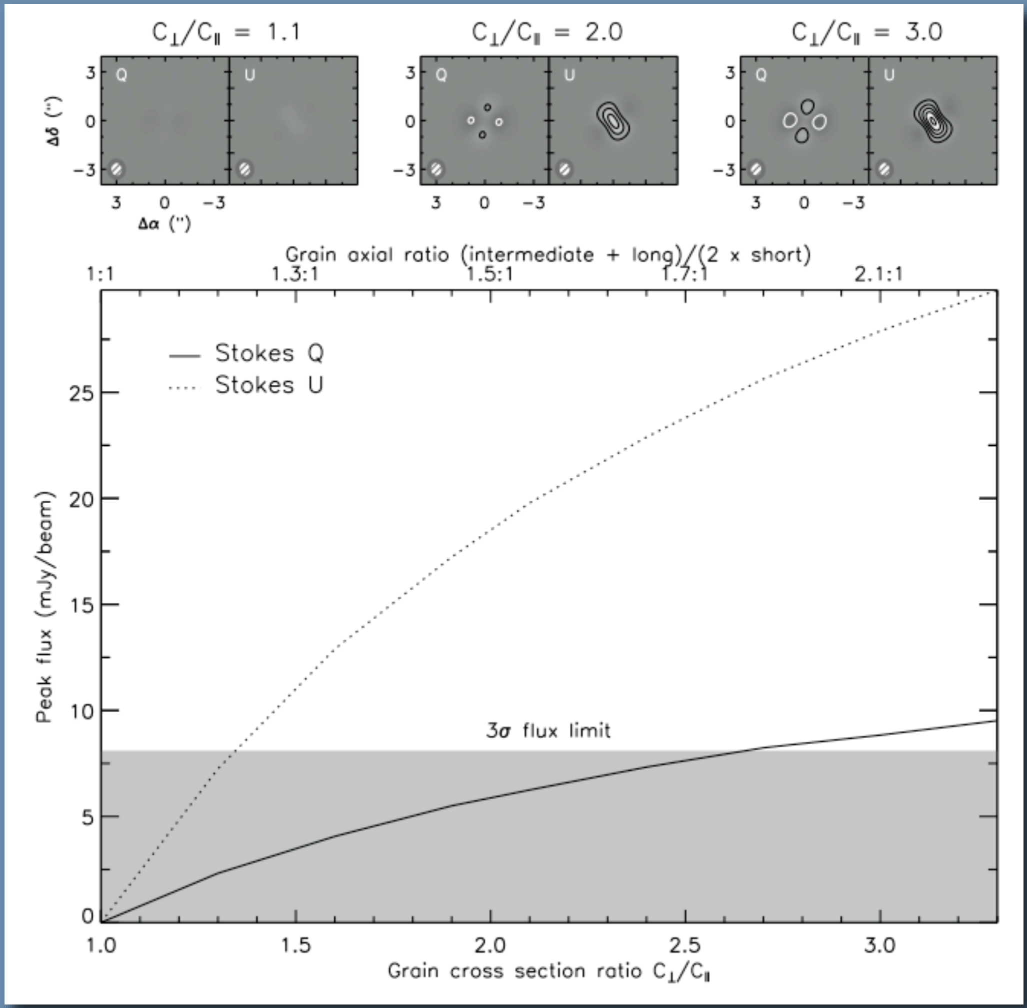
Hughes et al. (2009)

Model Comparison

Observations do not match predictions: what does this tell us?

Identify model inputs that most strongly affect pol %, given Stokes I

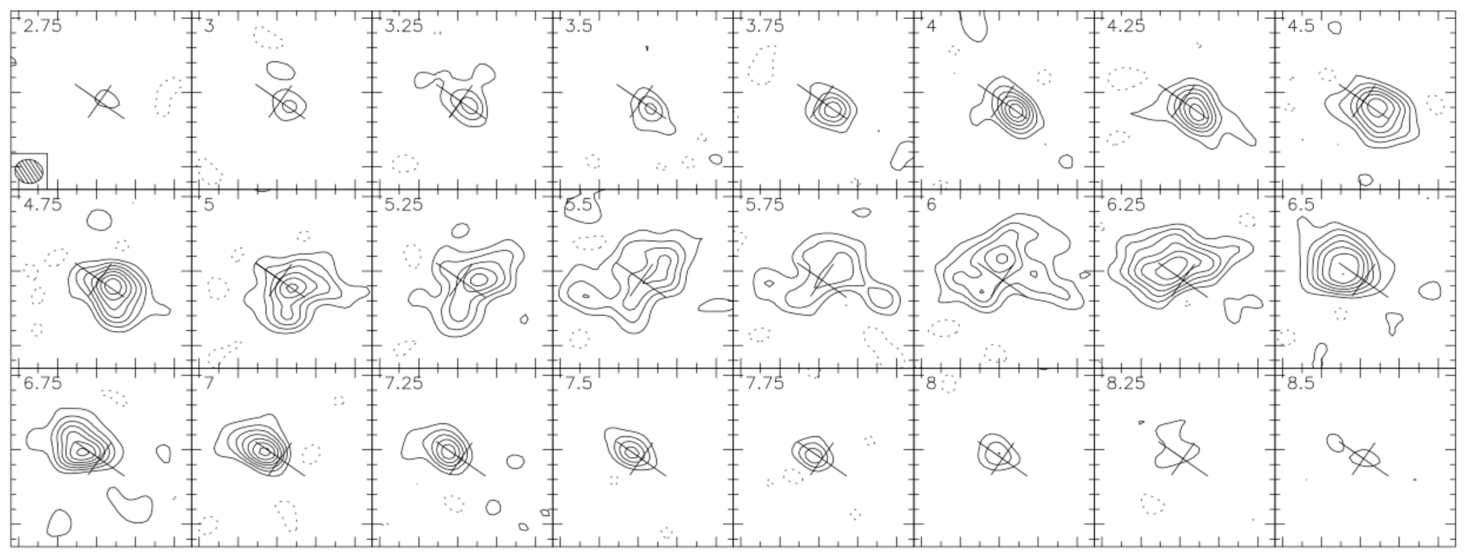
1) Grain elongation
2) Alignment efficiency
3) ~~Grain size distribution~~
4) ~~B-field strength~~
5) B-field regularity
6) ~~Scattering...~~



Hughes et al. (2009)

Turbulence

Feasibility: low-res spectra indicate detectable Δv_{turb}



Modeling GM Aur, Dutrey et al. (1998):

We also found that a moderate turbulent velocity is required to best model the CO data.

Modeling DM Tau, LkCa15, and MWC 480, Pietu et al. (2007):

5.6. Turbulence in outer disks

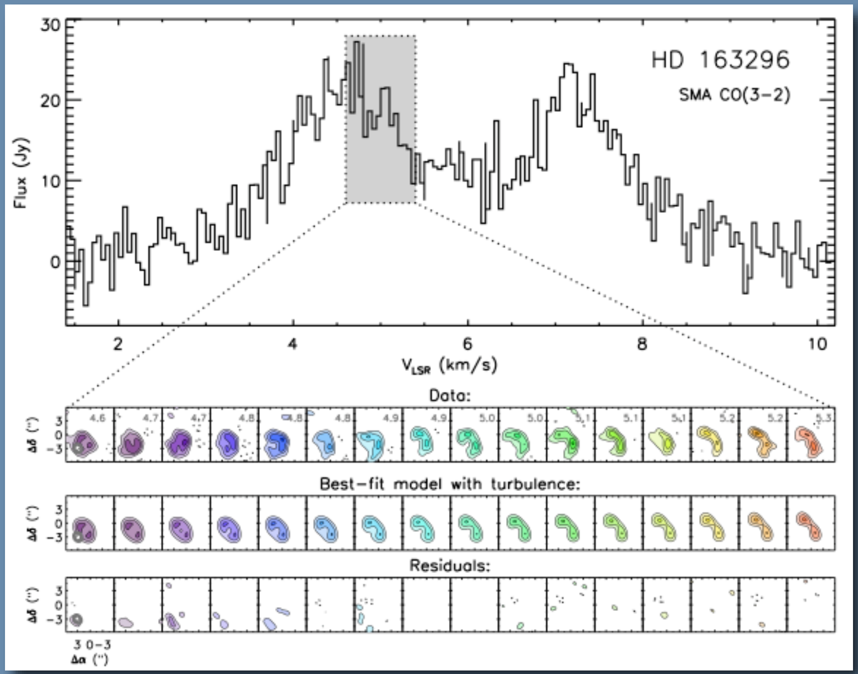
We derive intrinsic (local) line widths ranging between 0.12 and 0.29 $\mathrm{km\,s^{-1}}$. When taking into account the thermal component (0.08 to 0.15 $\mathrm{km\,s^{-1}}$), from Eqs. (6) and (7) we derive turbulent widths below 0.15 $\mathrm{km\,s^{-1}}$. These values should be used as upper limits, since the spectral resolution used for the analysis (0.2 $\mathrm{km\,s^{-1}}$) is comparable to the derived line widths. They are nevertheless significantly smaller than the sound speed, $C_s = 0.3$ to 0.5 $\mathrm{km\,s^{-1}}$ in the relevant temperature and radius range. The turbulence is thus largely subsonic. A more precise analysis, using the full spectral resolution and accurate knowledge of the kinetic temperature distribution, is required for a better determination.

Need better spectral resolution!

Observations

The HiRes correlator mode on the SMA can achieve a spectral resolution of 20-40 m/s, less than the inferred turbulent linewidth of these disks.

HD 163296



Preliminary modeling: turbulent linewidth of ~200 m/s, or ~30% of the sound speed

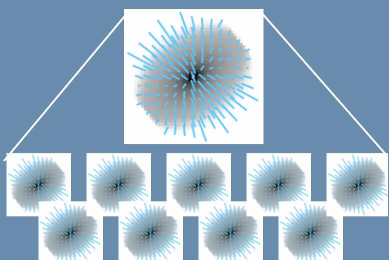
Challenge: disentangle sources of broadening (turbulent, thermal, rotation, τ, ...)

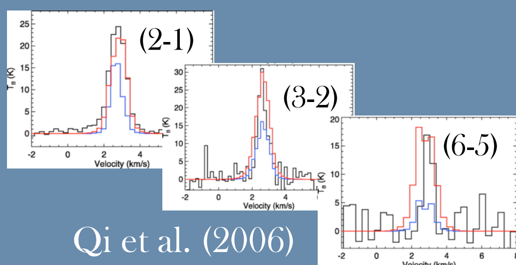
Summary & Future Work

- We have placed the most stringent limits to date on polarized mm-λ emission from two circumstellar disks

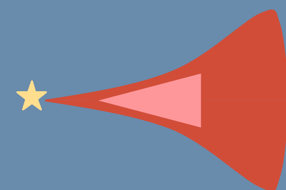
Sensitivity → Numbers:
Is pol fraction uniformly low?

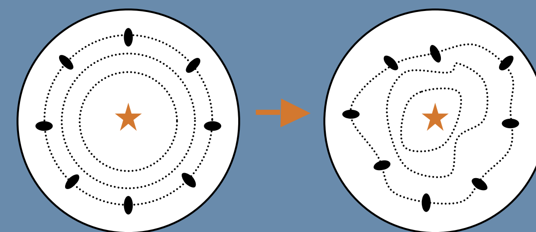
Resolution:
(JCMT:SMA :: SMA:ALMA)
Importance of small structure?





Qi et al. (2006)





- High spectral resolution observations can constrain the turbulent linewidth; so far, appears consistent with theoretical expectations

Sensitivity → Lines:
What is vertical distribution of temp/turbulence?

Resolution:
Info about scale height sizes
Dead zone vs. outer disk?