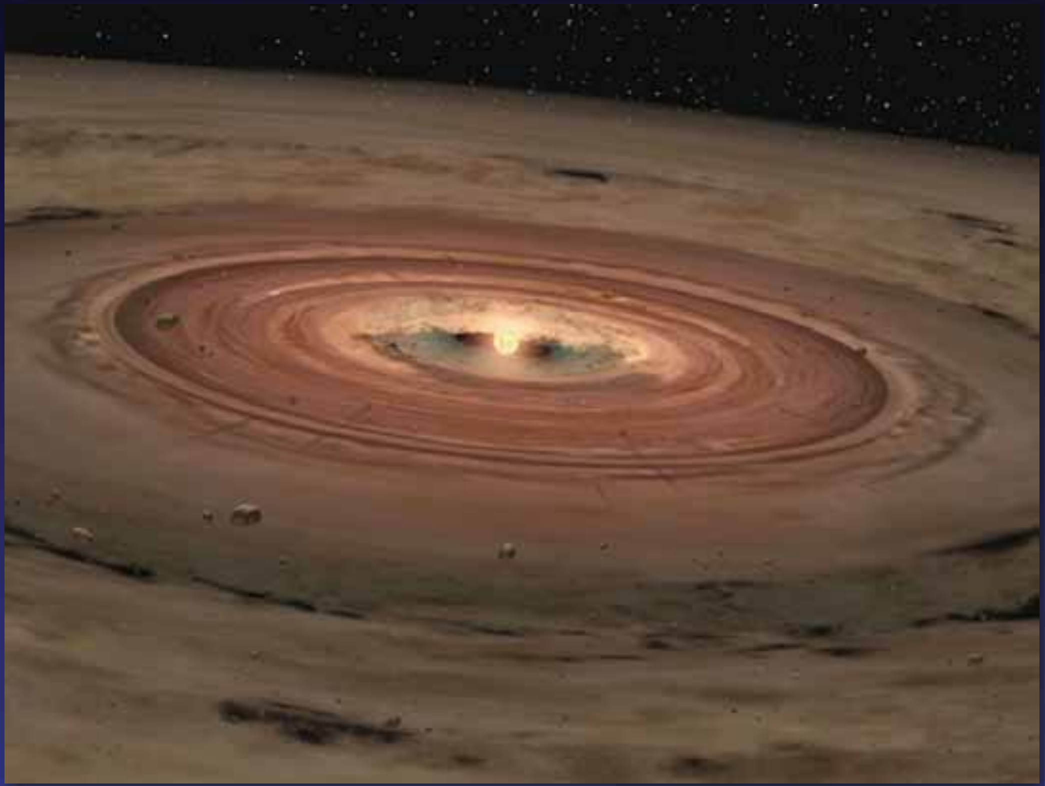
What Drives Accretion in Protoplanetary Disks?



NASA

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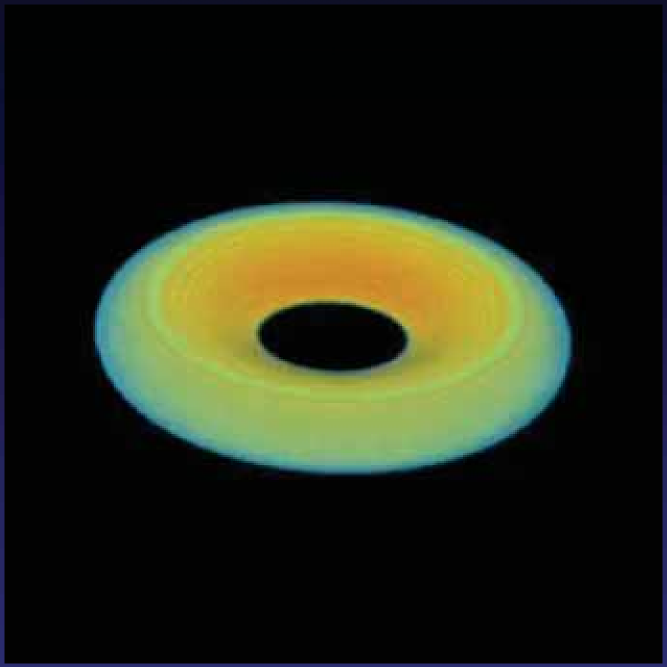
Astrophysical Frontiers:

Exoplanets, the Solar System and the Origins of Disks, Planets and Life

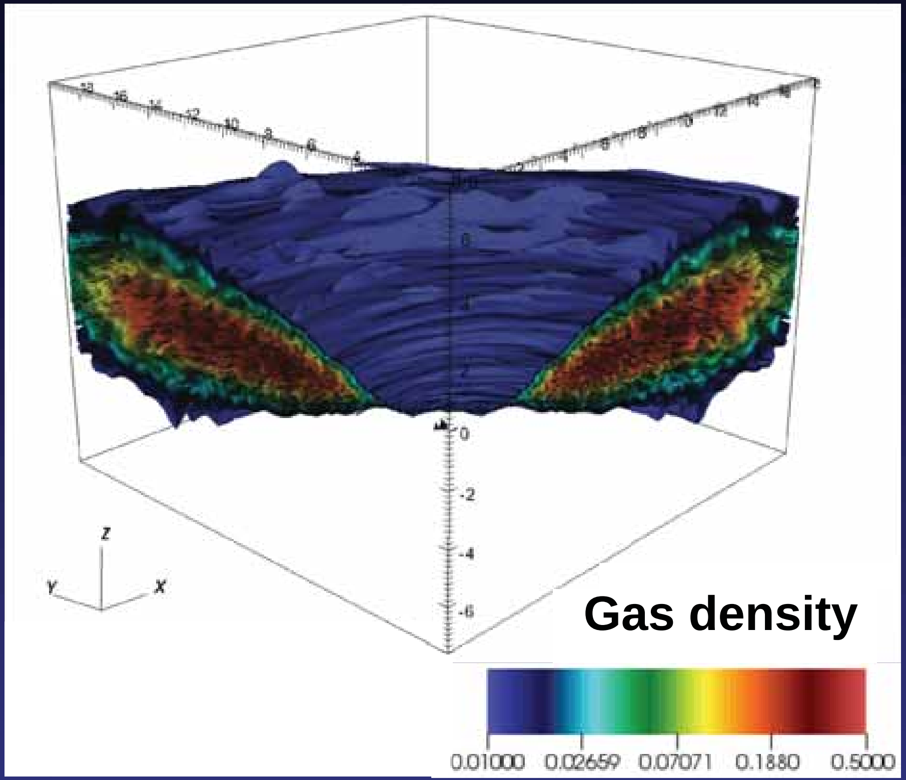
Portland, Oregon

Collaborators: Kevin Flaherty, Meredith Hughes, Xuening Bai

The long standing problem of disk accretion was solved with the discovery of the MRI



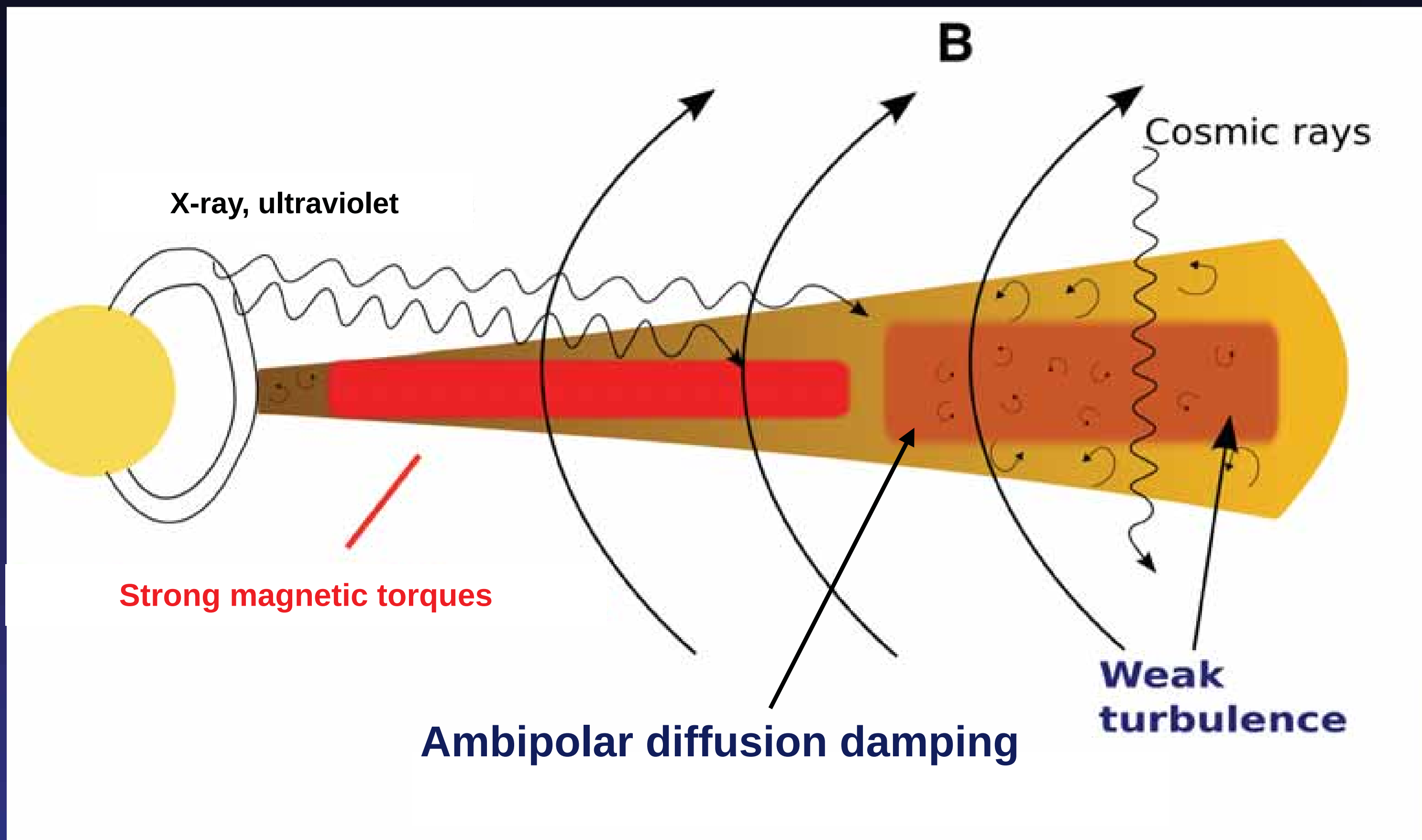
Hawley (2000)



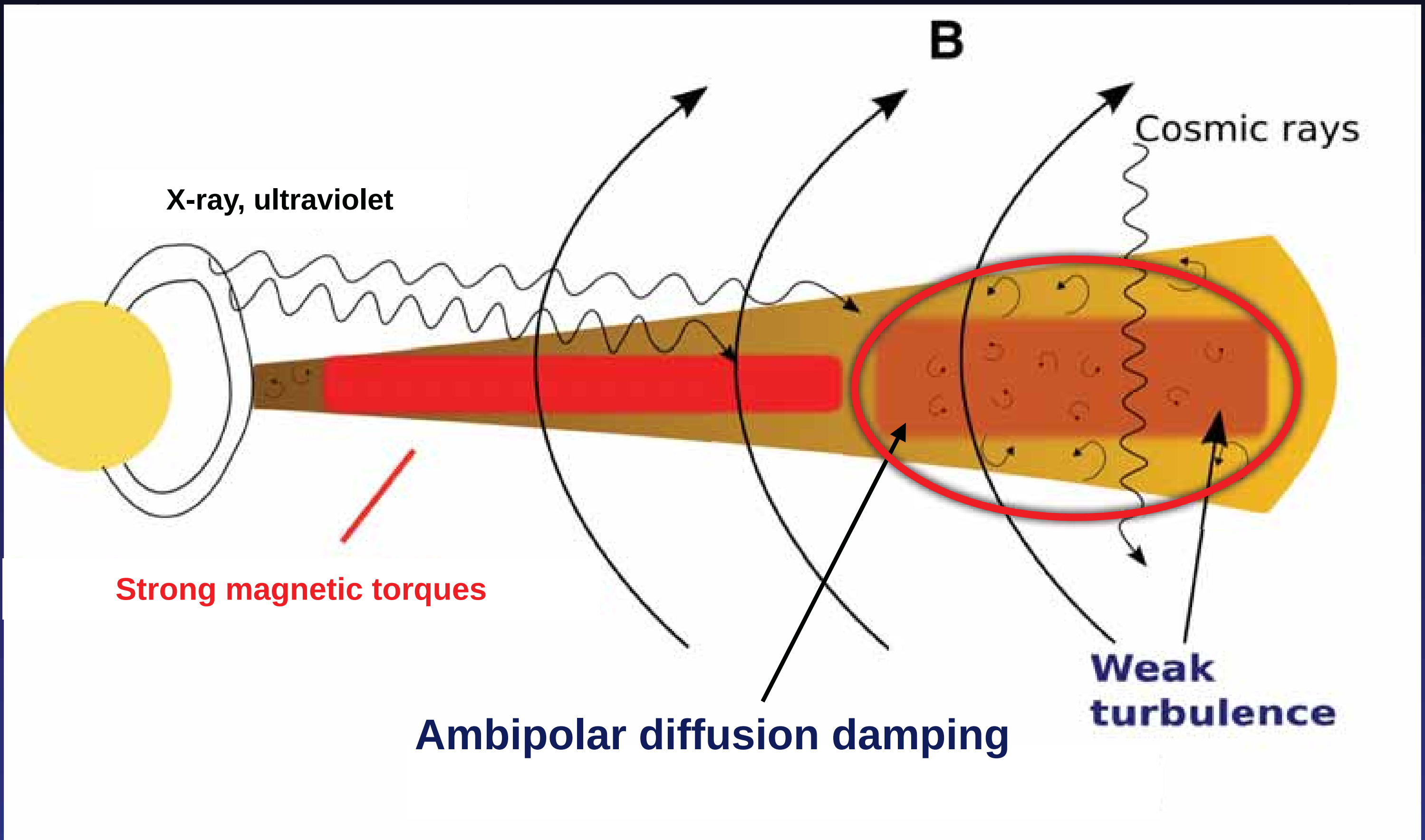
Beckwith, Armitage, Simon (2011)

At least for fully ionized disks…

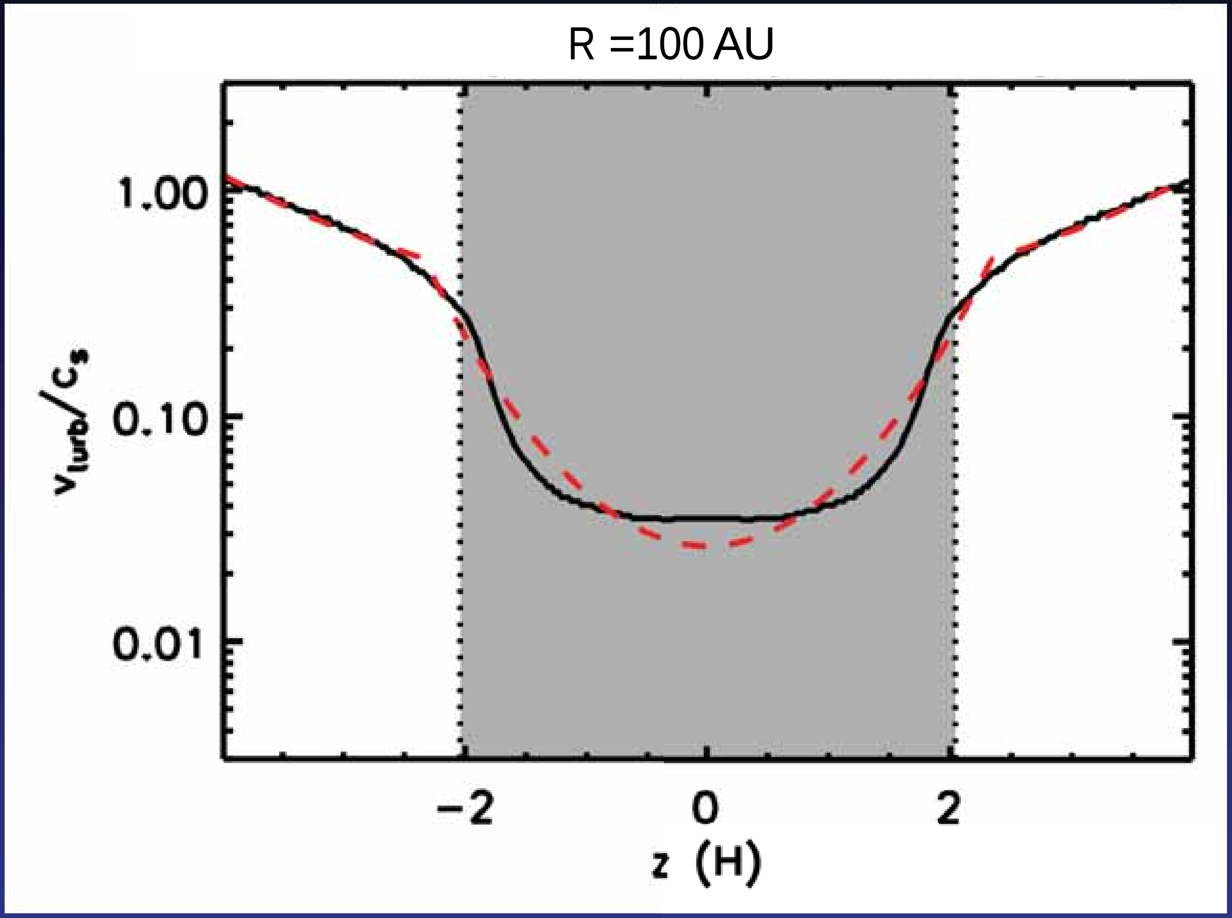
Protoplanetary disks are colder and thus more weakly ionized



In the outer disk, this leads to significantly reduced turbulence at the cold mid-plane



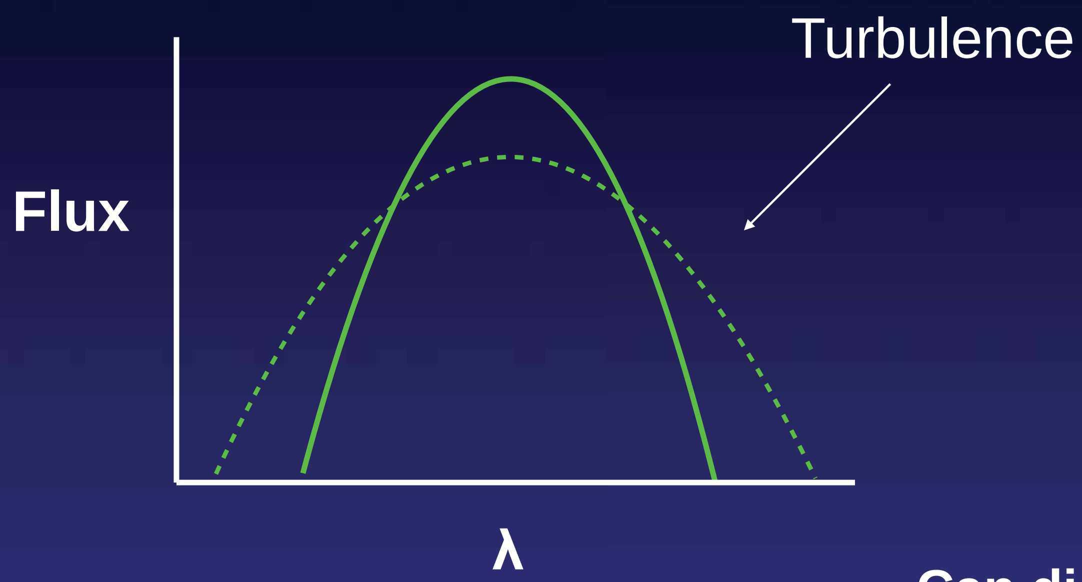
Strong gradient in turbulent velocity towards disk mid-plane



Simon et al. (2015a), ApJ

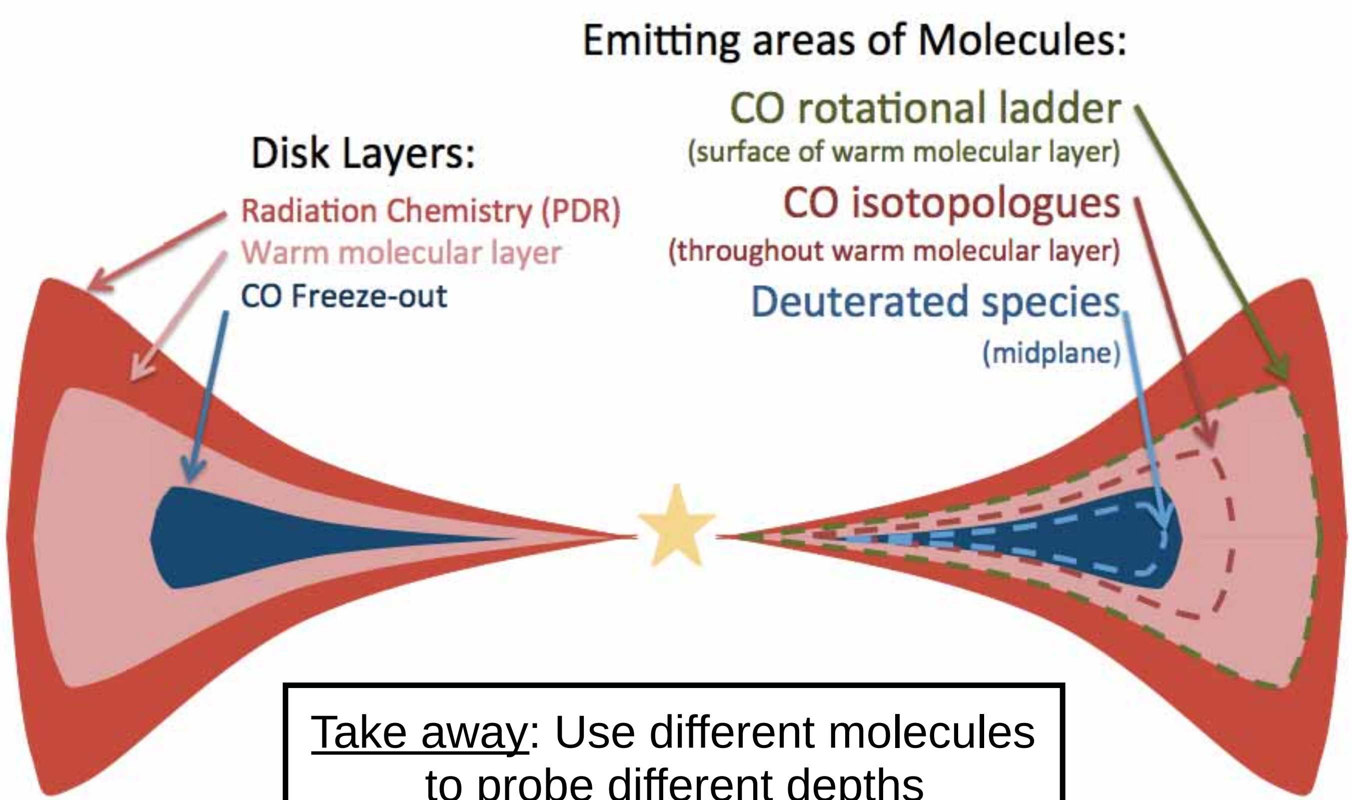
We use the broadening of molecular lines to quantify turbulence

Emission line broadening



Can disentangle from thermal broadening!

Probe layered structure with different molecular lines

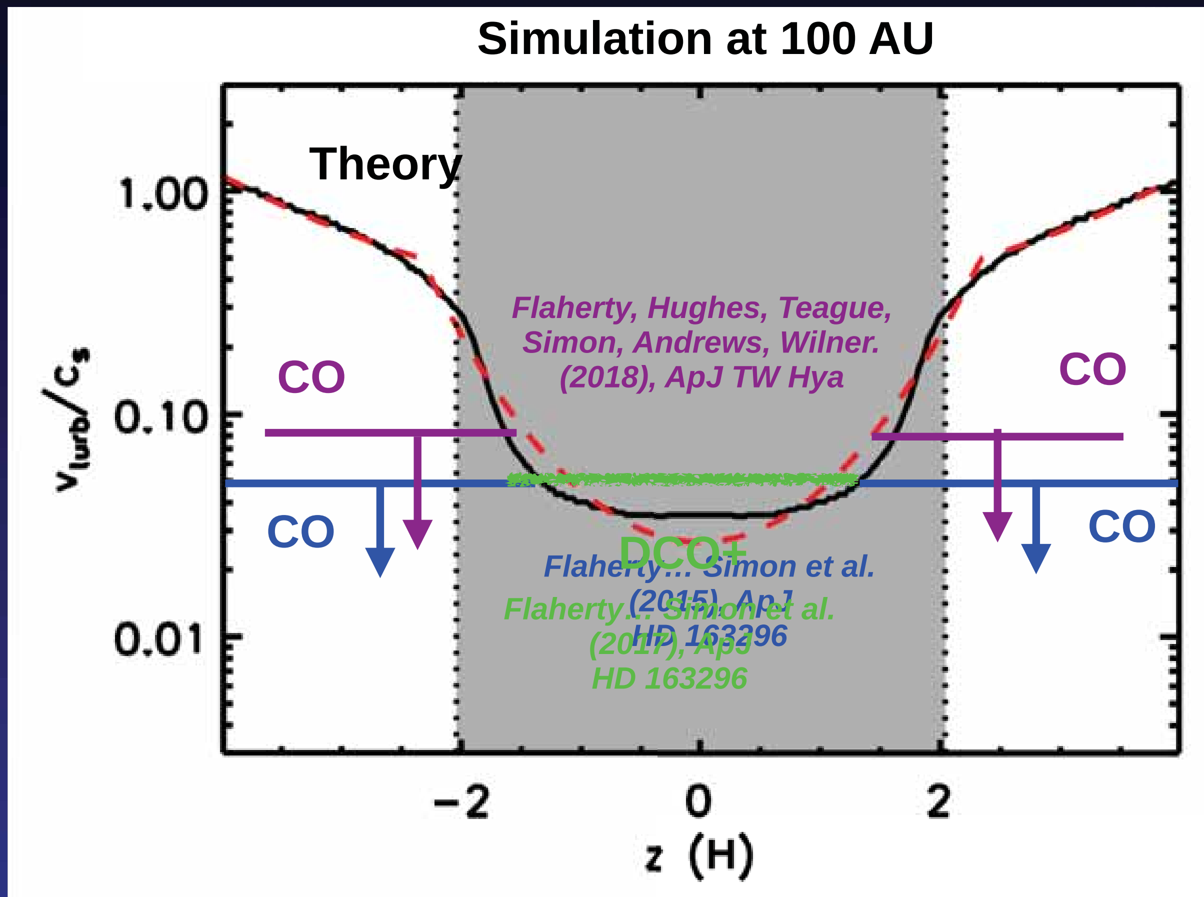


<u>Take away</u>: Use different molecules to probe different depths

Meredith Hughes

So, what do observations tell us?

Prediction of strong turbulence in disk surface layers is inconsistent with observations

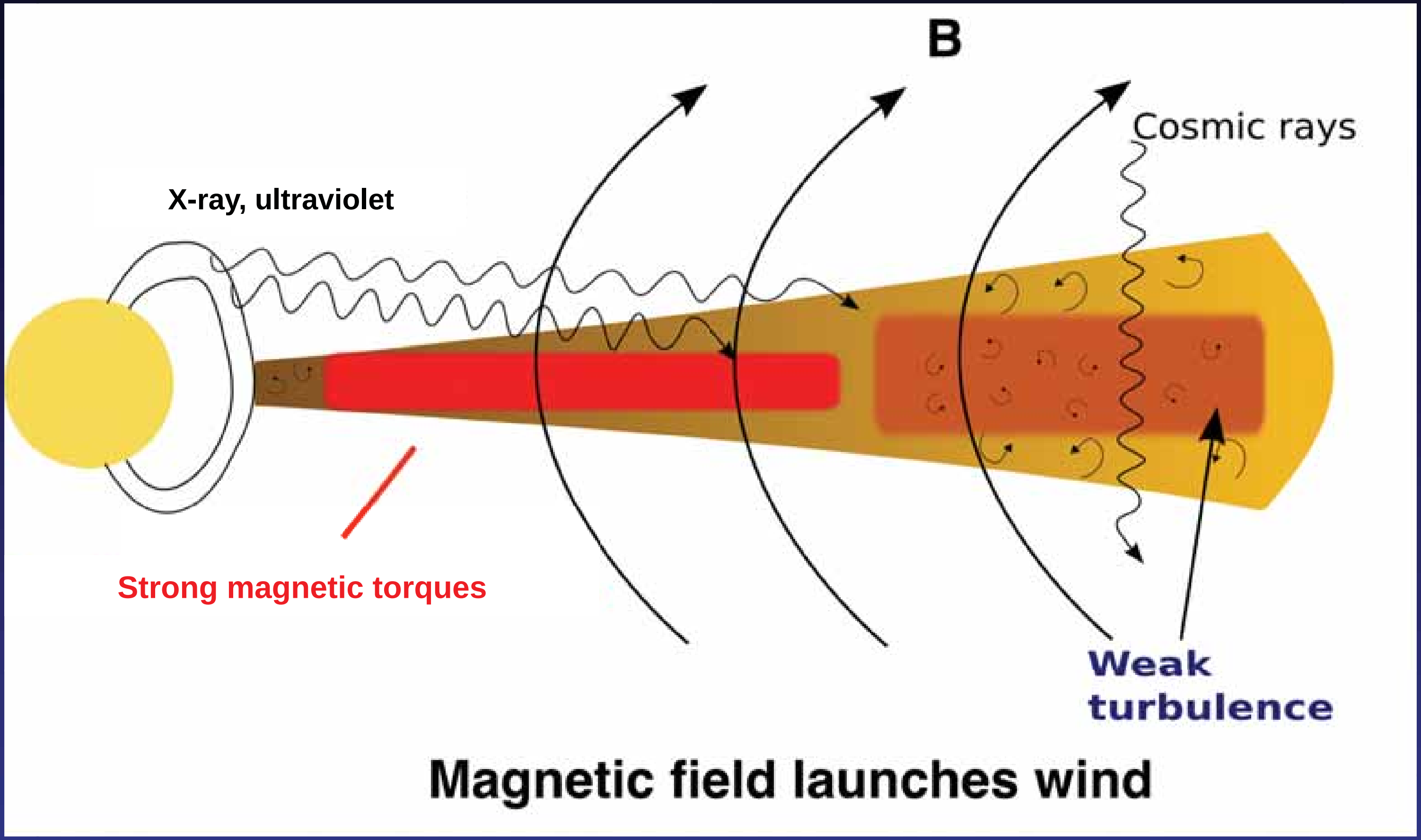


Simon et al. (2015a), ApJ

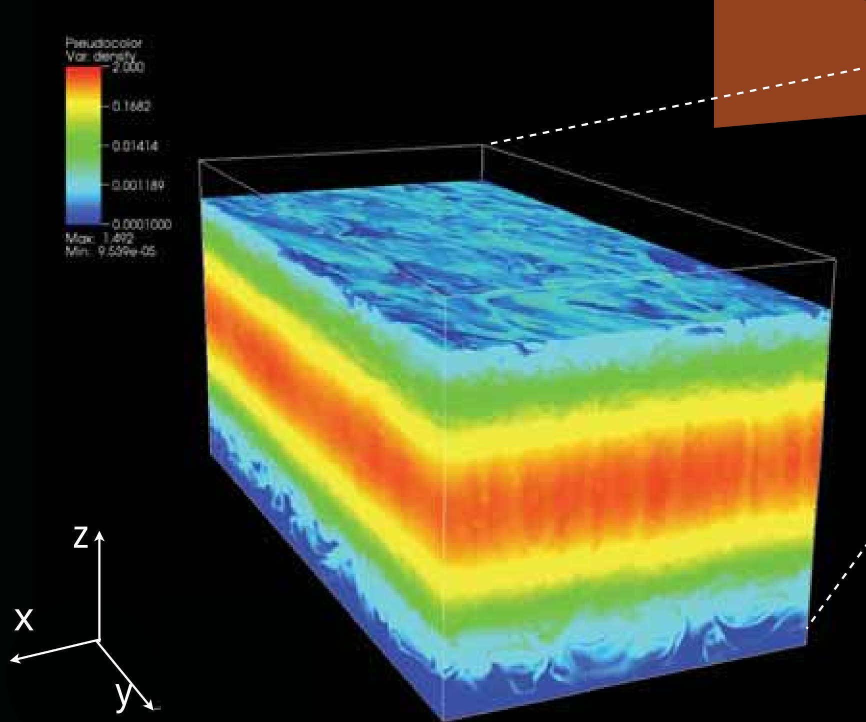
At least for these disks, we find an upper limit of ~5% of the sound speed (at large distances from the star)

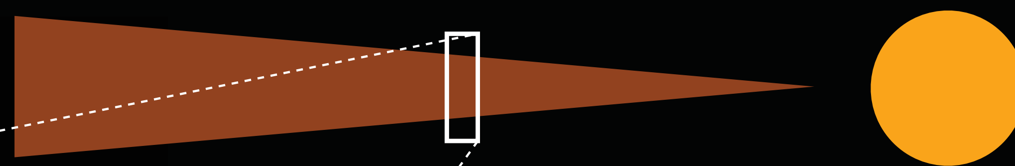
For HD163296, this is inconsistent with the accretion rate onto the star:
$5 \times 10^{-7}\ M_{Sun}/yr$

Could it be that winds are the *only* source of angular momentum transport?



Test with local simulations of a small, co-rotating disk patch

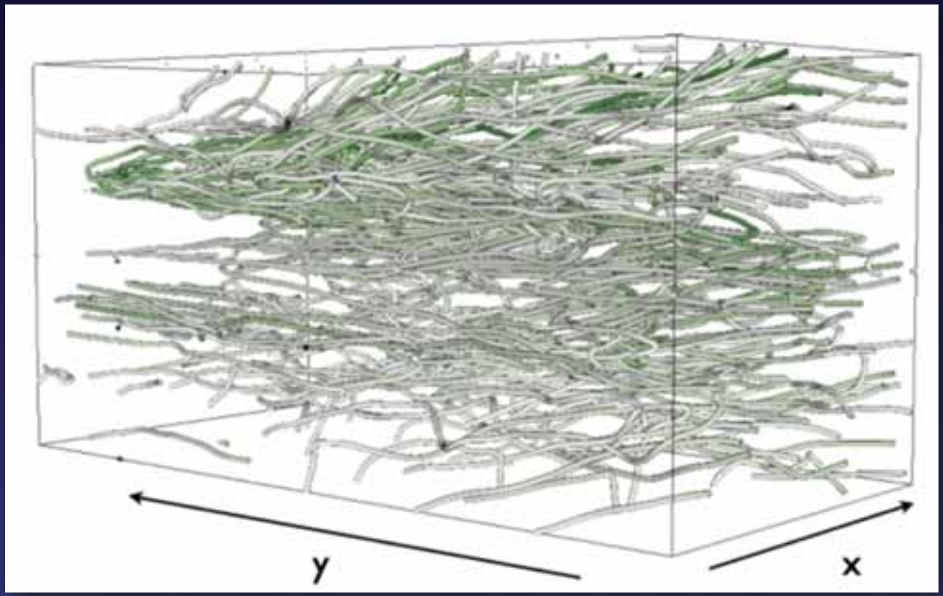




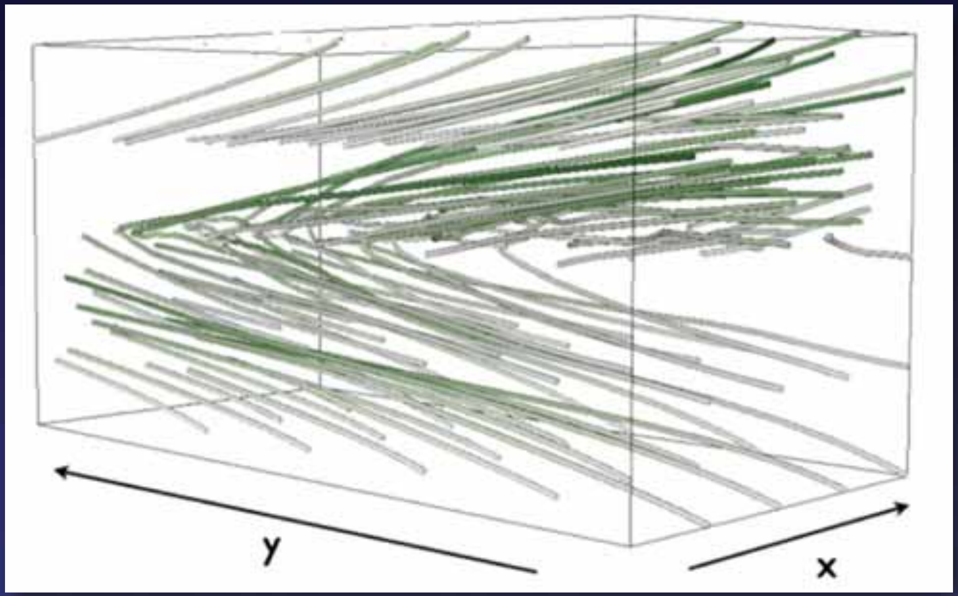
- Assume Cartesian geometry
- Add appropriate source terms
- Solve equations of MHD
- Shearing periodic boundaries
- Valid if H/R << 1
- Assume gas is isothermal

Whether or not wind dominates over turbulence is determined by the strength of the magnetic field

Weak field: turbulent

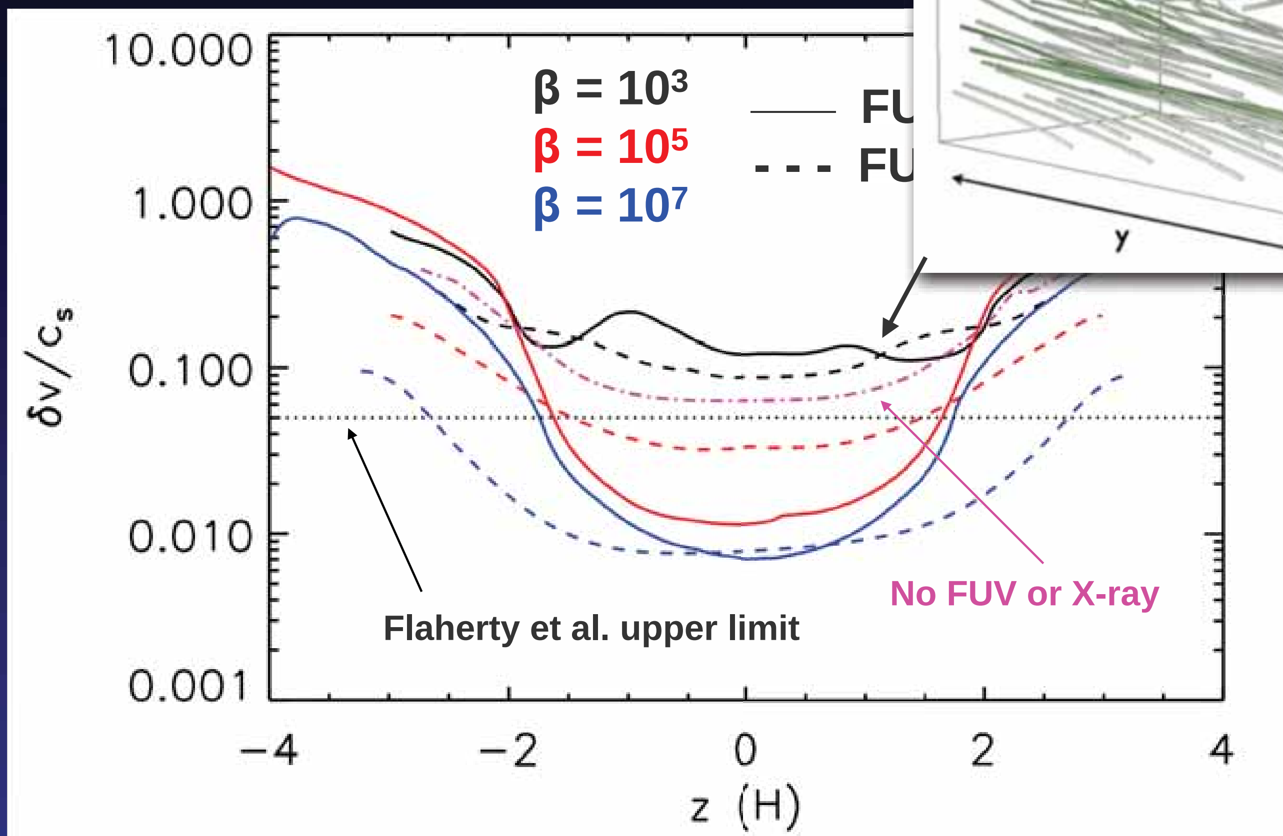


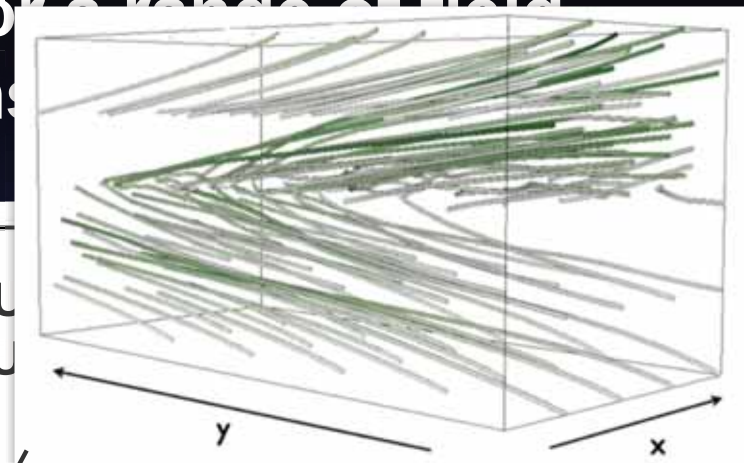
Strong field: laminar



Simon et al. (2013b)

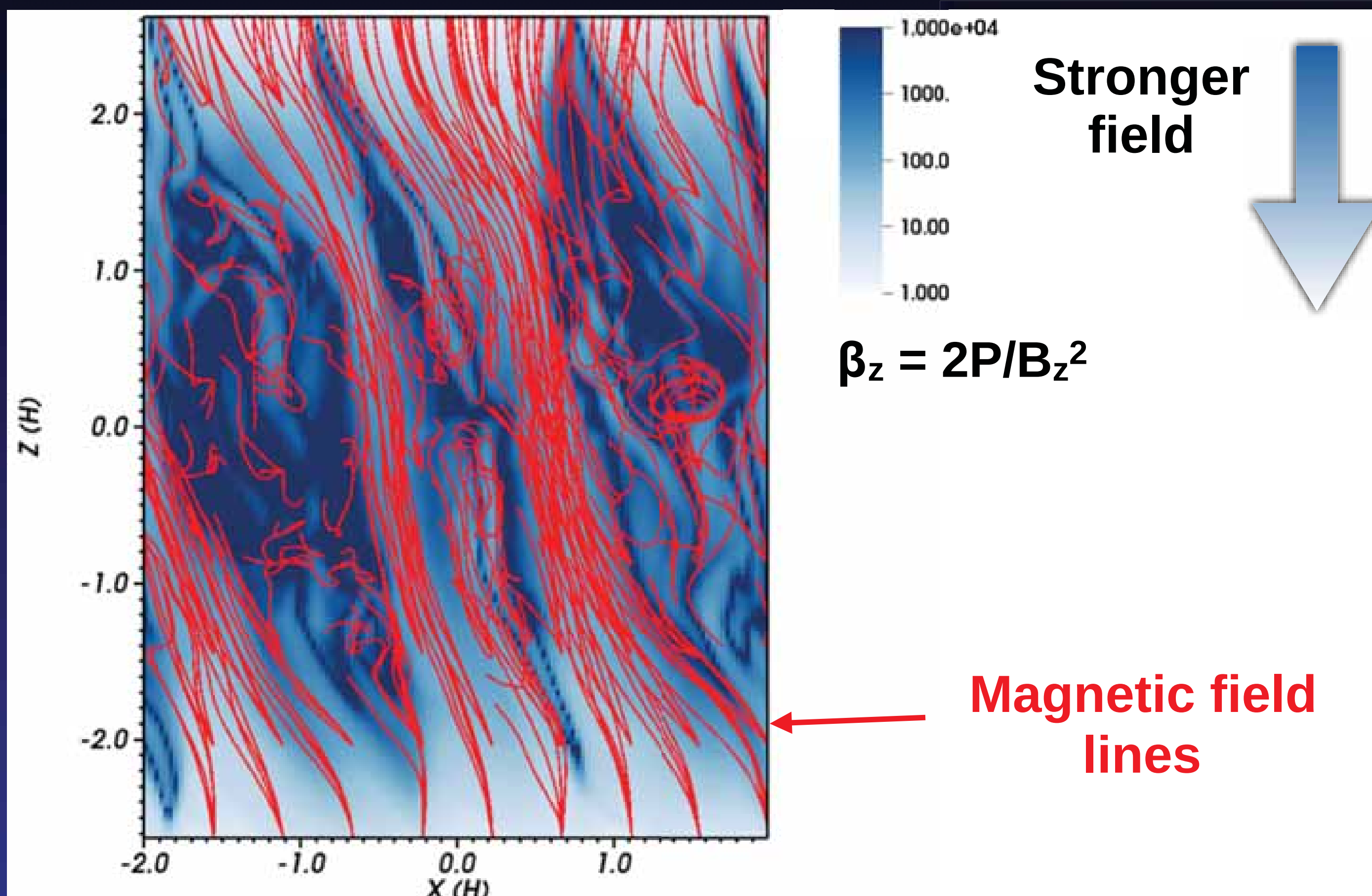
Strong turbulent velocities for a range of field configurations





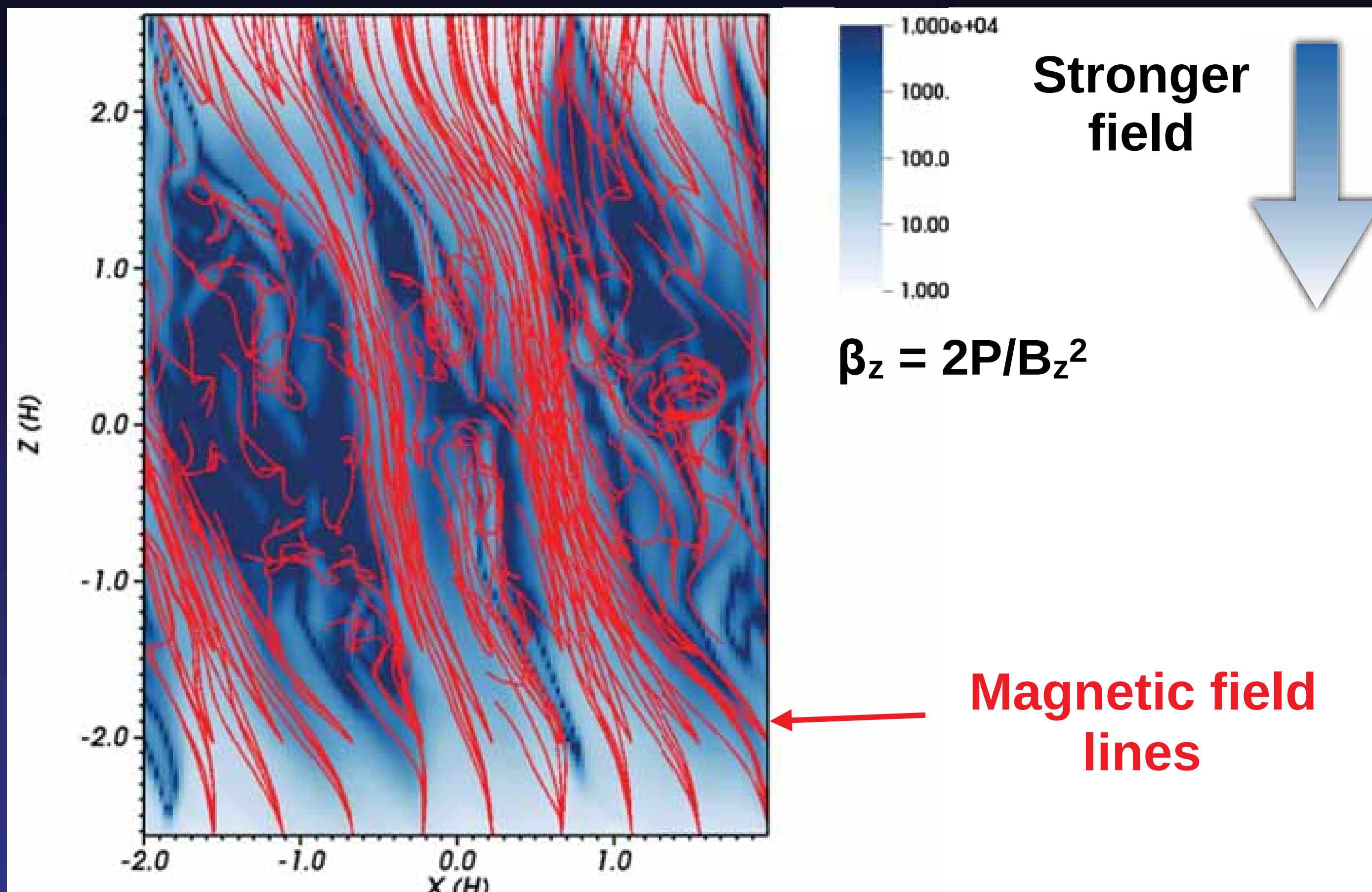
$$\beta = \frac{2P}{B^2}$$

Examine a simulation with a "wind-like" magnetic field



Simon et al. (2018)
arXiv:1711.04770

Regions of weak field (unstable to the MRI) develop and generate turbulence



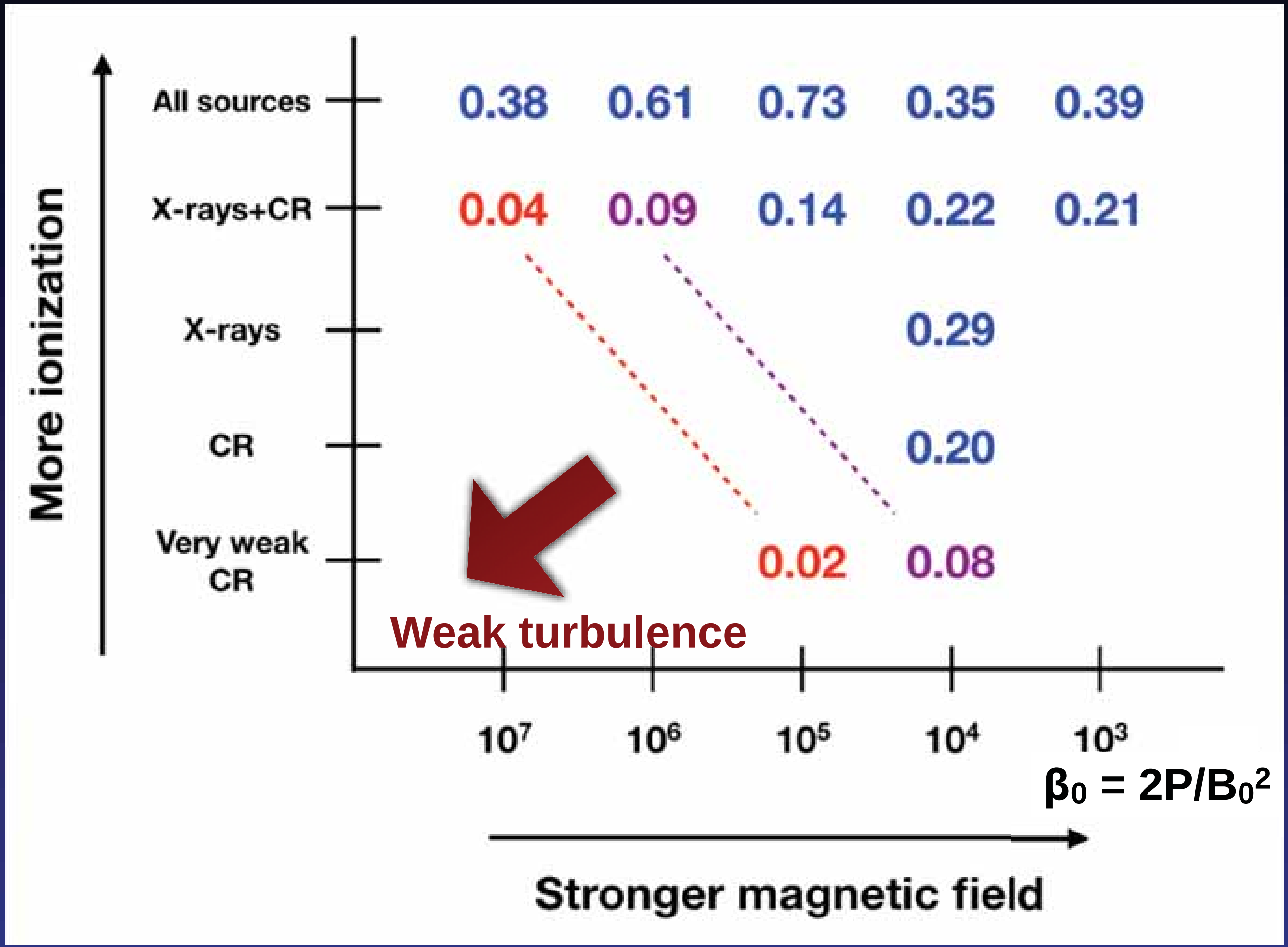
$\beta_z = 2P/B_z^2$

Simon et al. (2018)

arXiv:1711.04770

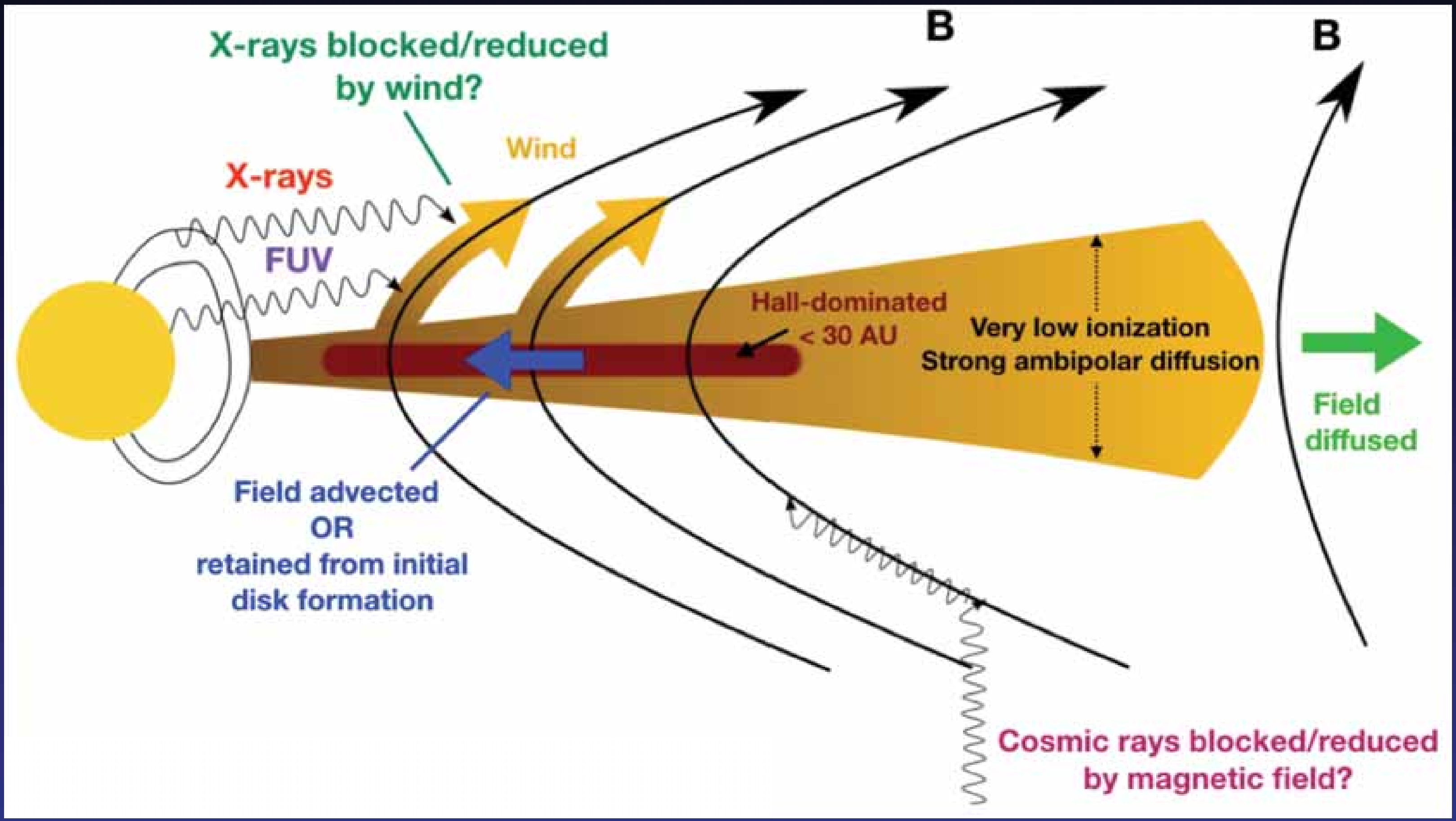
If winds are present, so should be the MRI and turbulence!

Even with very weak fields, very low ionization must also be present to be consistent with observations



Simon et al. (2018) arXiv:1711.04770

A preliminary new model for protoplanetary disks



Simon et al. (2018) arXiv:1711.04770

What about other sources?

Are our targets representative of all/most protoplanetary disks?

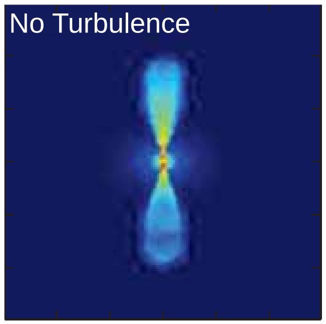
	Turbulence	Stellar Mass ($M_\odot$)	Disk Mass ($M_\odot$)	Age (Myr)	Accretion rate ($M_\odot$/yr)	X-ray Lum ($L_\odot$)	FUV Lum ($L_\odot$)	Cosmic Ray Flux	Magnetic Field
HD 163296	$<0.05c_s$	2.3	0.09	~5	5E-07	1E-04	??	??	??
TW Hya	$<0.08c_s$	0.6	0.05	10-12	2E-10	6.8E-04	7E-03	very low (Cleeves et al. 2015)	??
MWC 480	$<0.05c_s$	1.85	0.05	7-8	5.3E-07	2.6E-06	??	??	??
V4046 Sgr	$<0.05c_s$	0.9,0.9	0.09	12	1.3E-08	3.1E-04	1E-02	??	??
DM Tau	$\sim.28c_s$	0.54	0.04	1	2.9E-09	7.8E-05	3E-03	??	??
Typical	??	many	3e-4 - 0.03 (Andrews et al. 2013)	1-10	5E-11 - 1E-7 (e.g. Manara et al. 2016)	2E-6 - 0.02 (Feigelson et al. 2005)	2E-3 - 0.2 (France et al. 2014)	??	??

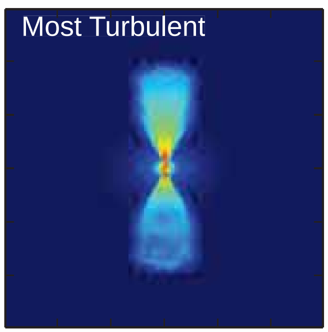
Flaherty… Simon et al., in prep

What are the signatures of turbulence?

Synthetic observations

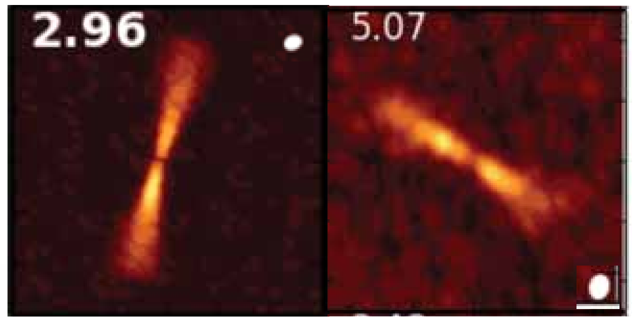
(Simon et al. 2015)





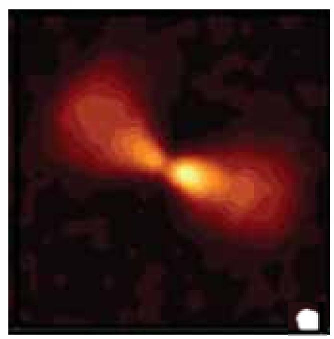
ALMA cycle 4 CO/^{13}CO/C^{18}O(2-1) observations

V4046 Sgr **MWC 480**



$v_{turb} \lesssim 0.05c_s$

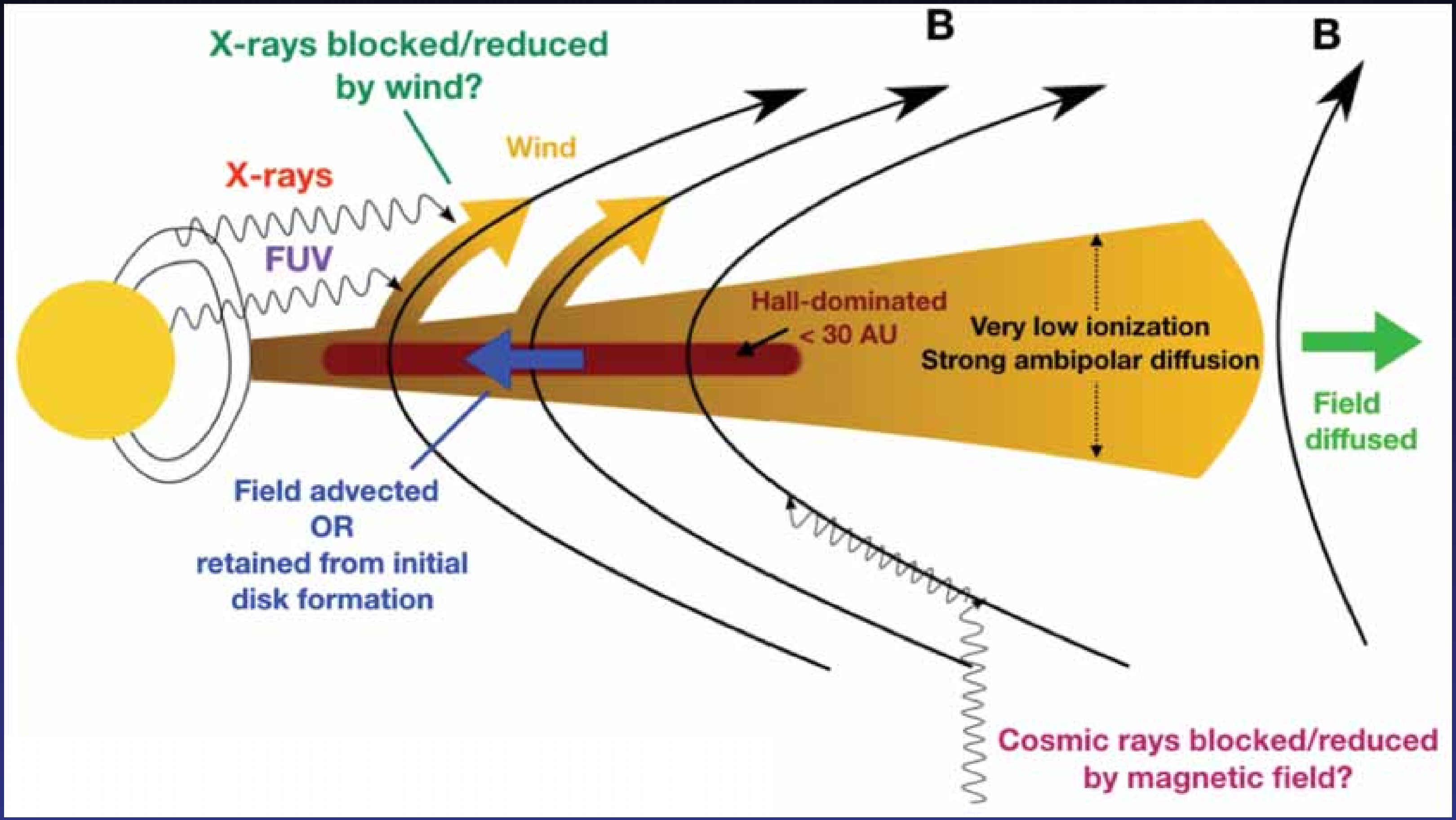
DM Tau



$v_{turb} \sim 0.28c_s$

Flaherty… Simon et al., in prep

A preliminary new model for protoplanetary disks



Simon et al. (2018) arXiv:1711.04770

Take away points

1. Turbulence in outer disk regions is very weak!
2. A magnetically launched wind cannot drive accretion without also inducing turbulence.
3. If the background magnetic field is very weak and the ionization fraction is low (MUST block FUV photons), then we find results consistent with observations.
4. Preliminary model: Strong magnetic fields in the inner disk (R <~ 30 AU) that have been advected from the outer disk launch a wind that blocks ionizing radiation from reaching the outer disk.
5. Several disks show weak turbulence, but one shows significant turbulence. How does the model fit with the known parameters of these disks?