Planet Formation Lab

The Dynamics of Protoplanetary Disks

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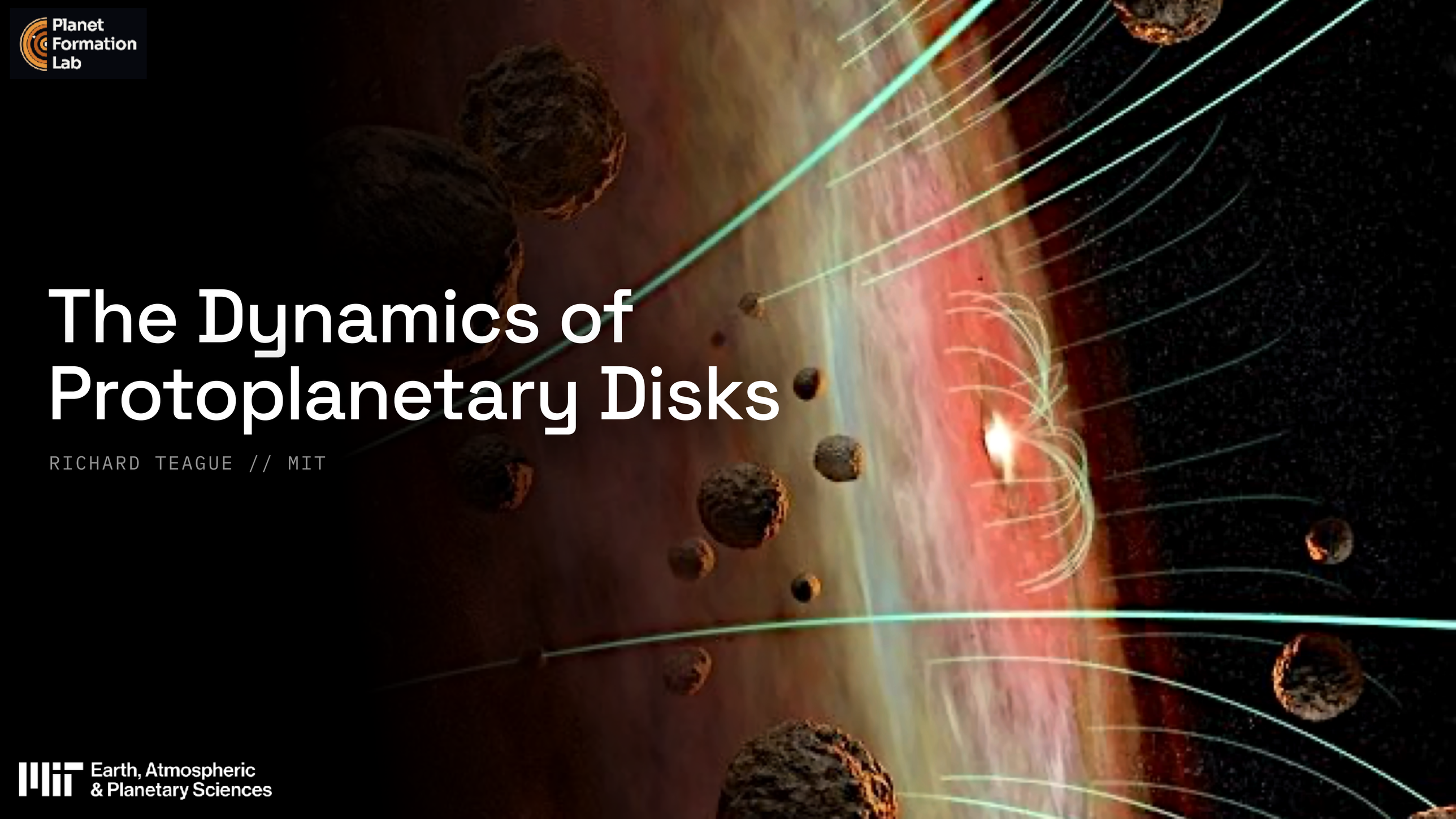


Earth, Atmospheric & Planetary Sciences

Many possible scenarios for the evolution of the disk

Active MHD

Viscously transported angular momentum via the magneto-rotational instability.

Magnetized Winds

Broadly laminar disks with angular momentum extracted from the surface of the disk.

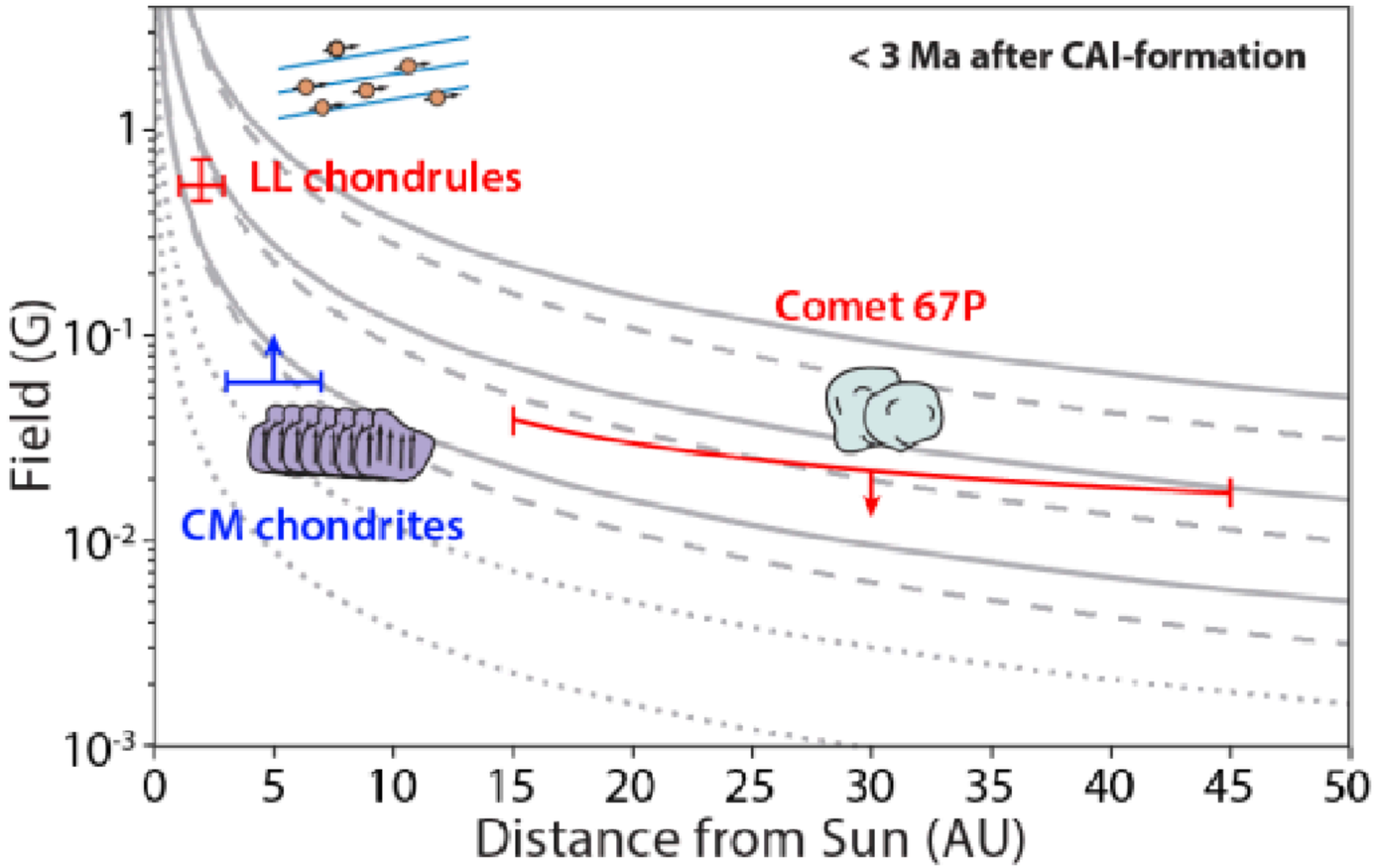
Active HD

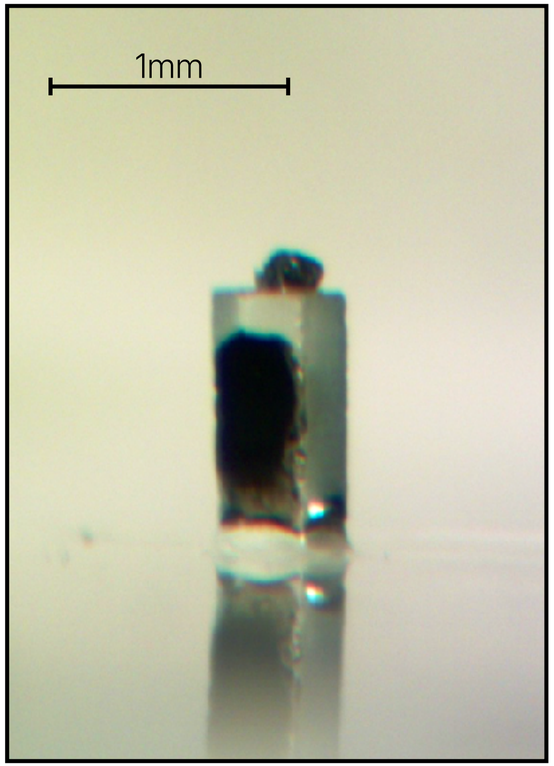
Pure hydrodynamical instabilities dominate the angular momentum transport through the disk.

Quiescence

No obvious mechanism to efficiently remove or transport angular momentum from the disk.

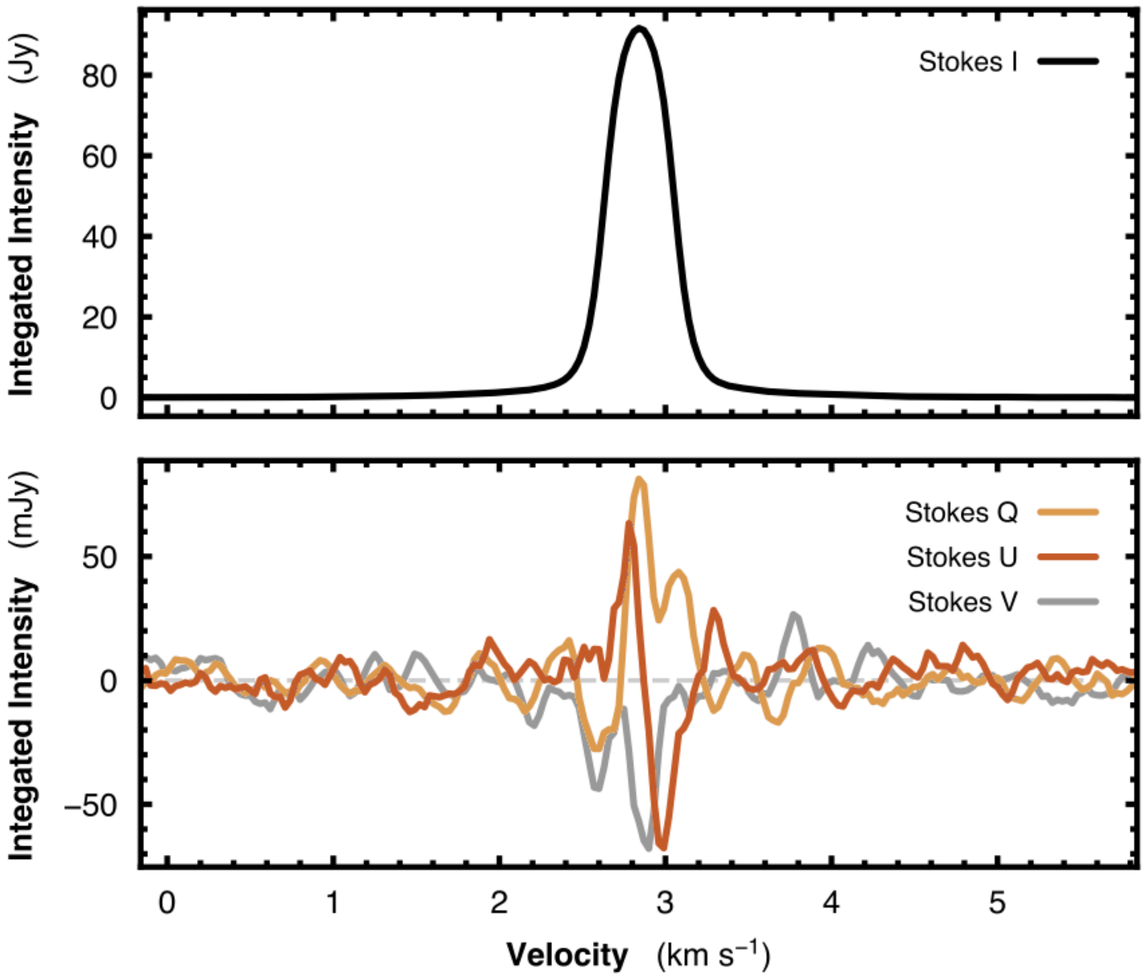
The most stringent limits come from paleomagnetic measurements





WEISS ET AL. (2021), LARSON ET AL. (IN PREP)

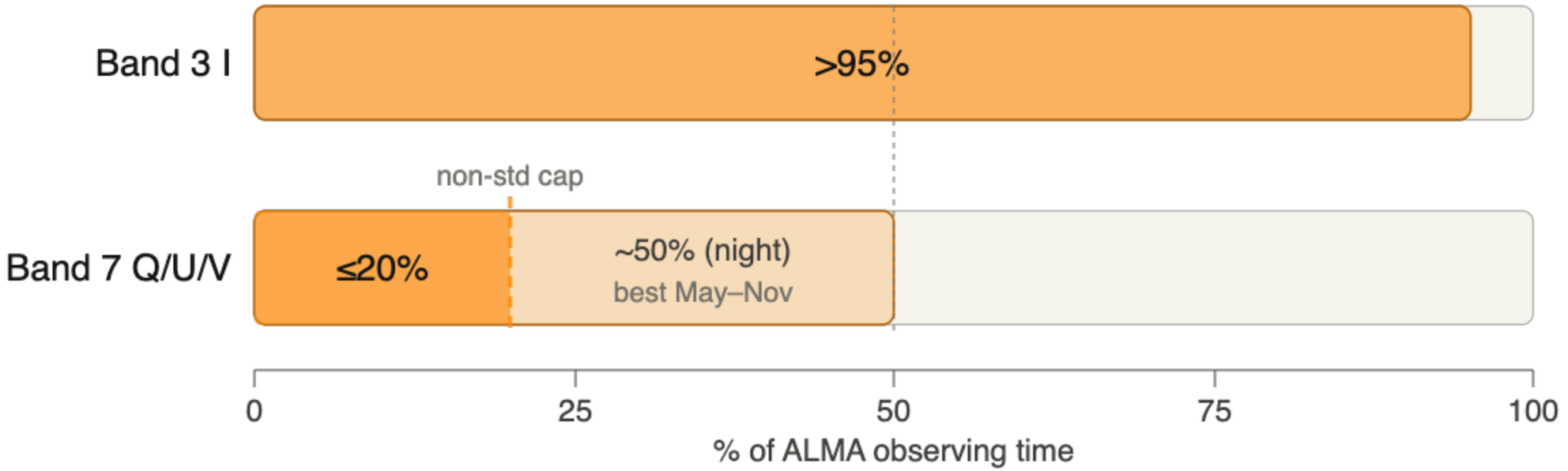
Molecular polarization is a robust probe of magnetic fields



We detected linearly polarized CO emission from TW Hya, arising from the Goldreich-Kylafis effect.

TEAGUE ET AL. (2021)

Zeeman splitting can be detected in total intensity observations

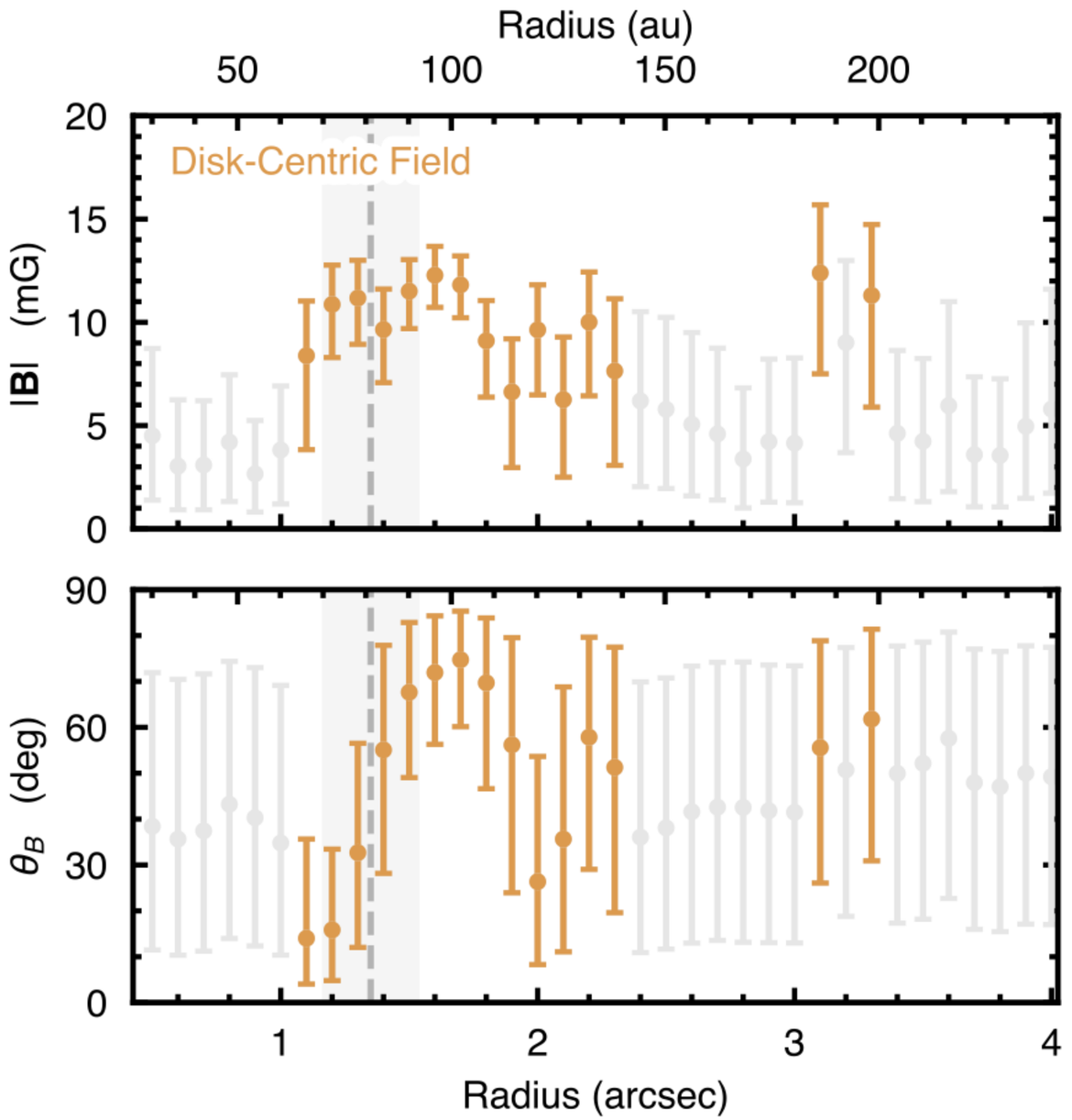


Not only is this far easier to schedule, this approach still allows us to infer something about the field morphology.

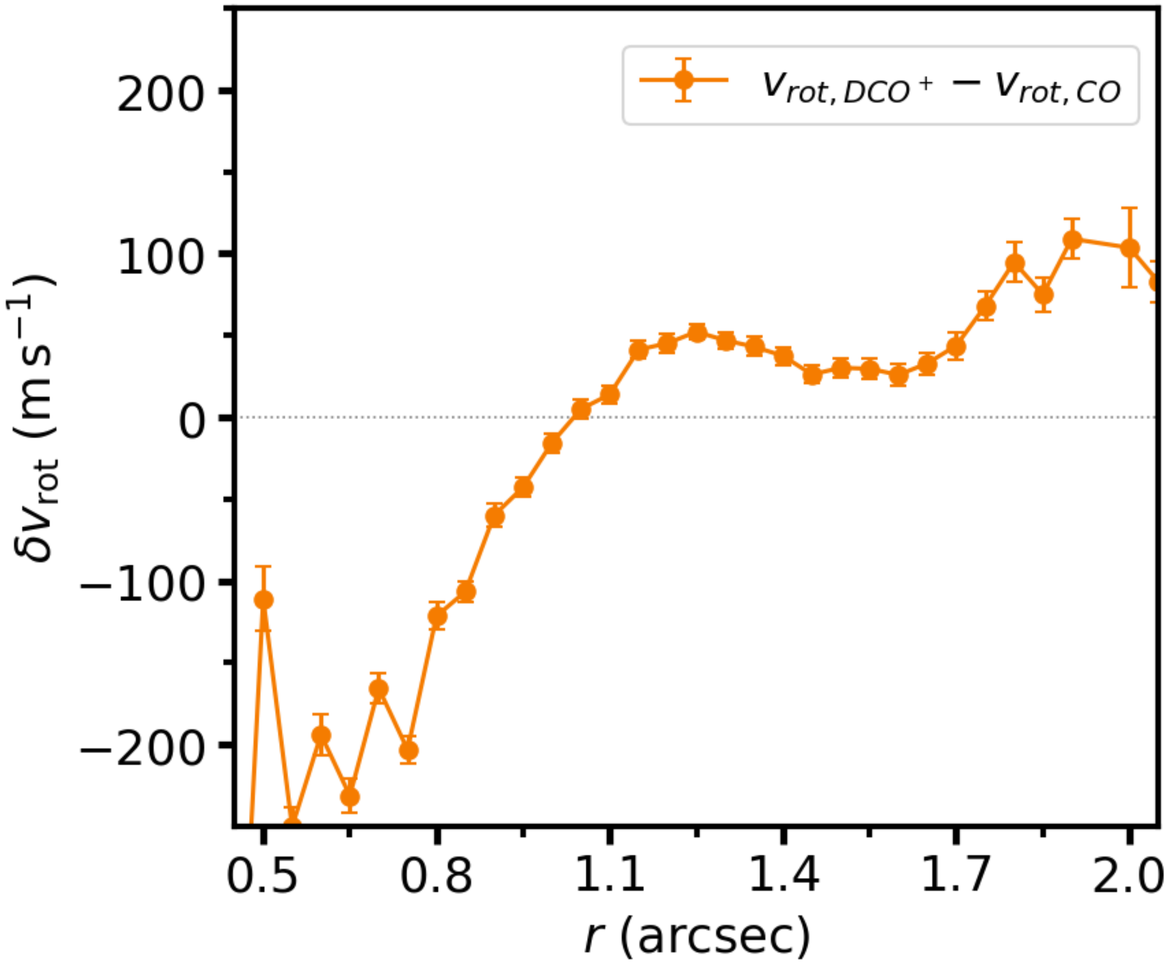
LANKHAAR & TEAGUE (2023)

TW Hya is threaded by 10mG field

There is an apparent transition from a poloidal (vertical) field to a toroidal field at 80au in the disk.



Tentative evidence of Ion-Neutral drift in TW Hya



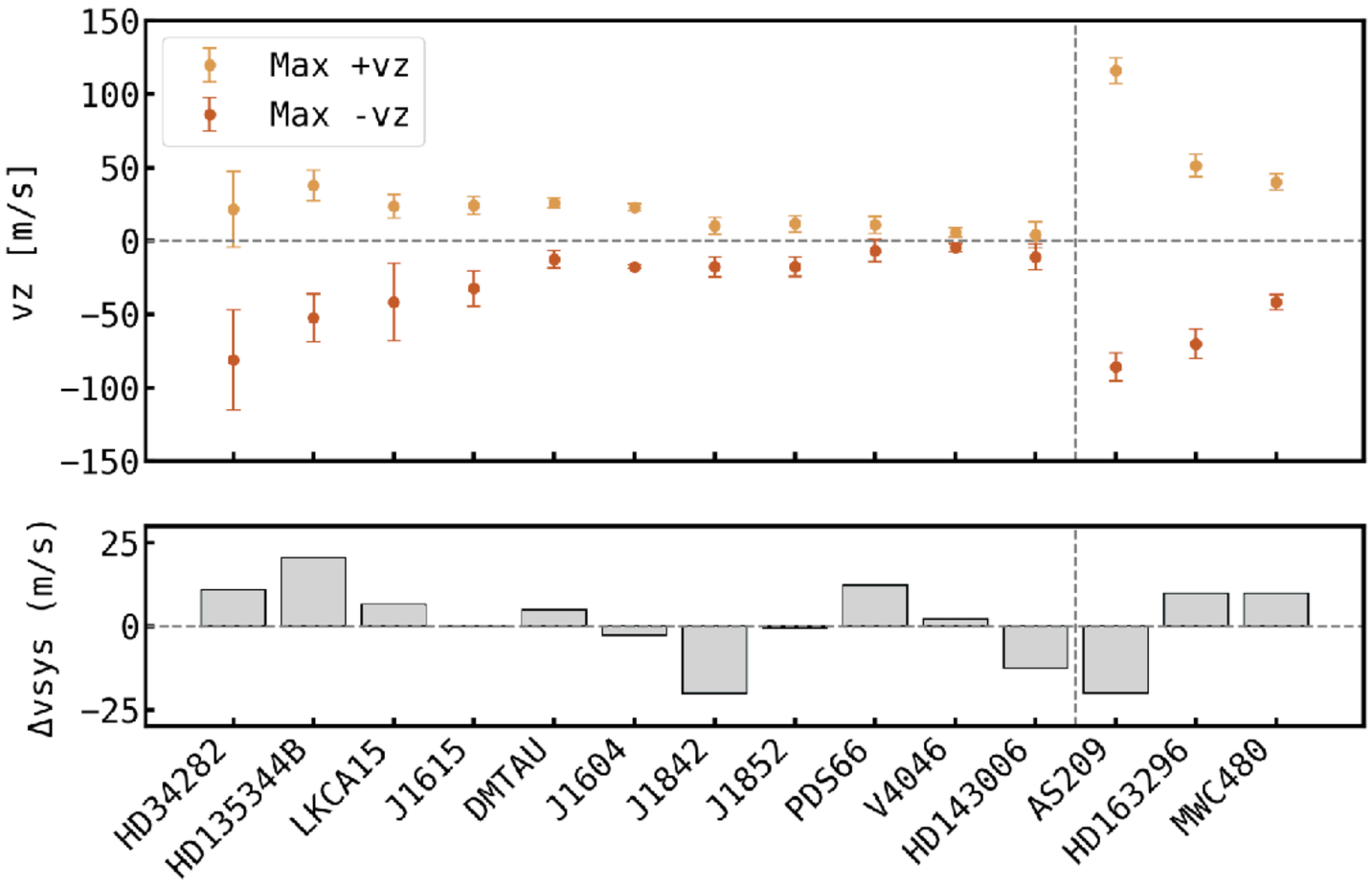
Subtle variations found between the rotation speeds of ions and neutrals suggestive of non-ideal effects.

EXOALMA

An ALMA Large Program characterizing disk dynamics

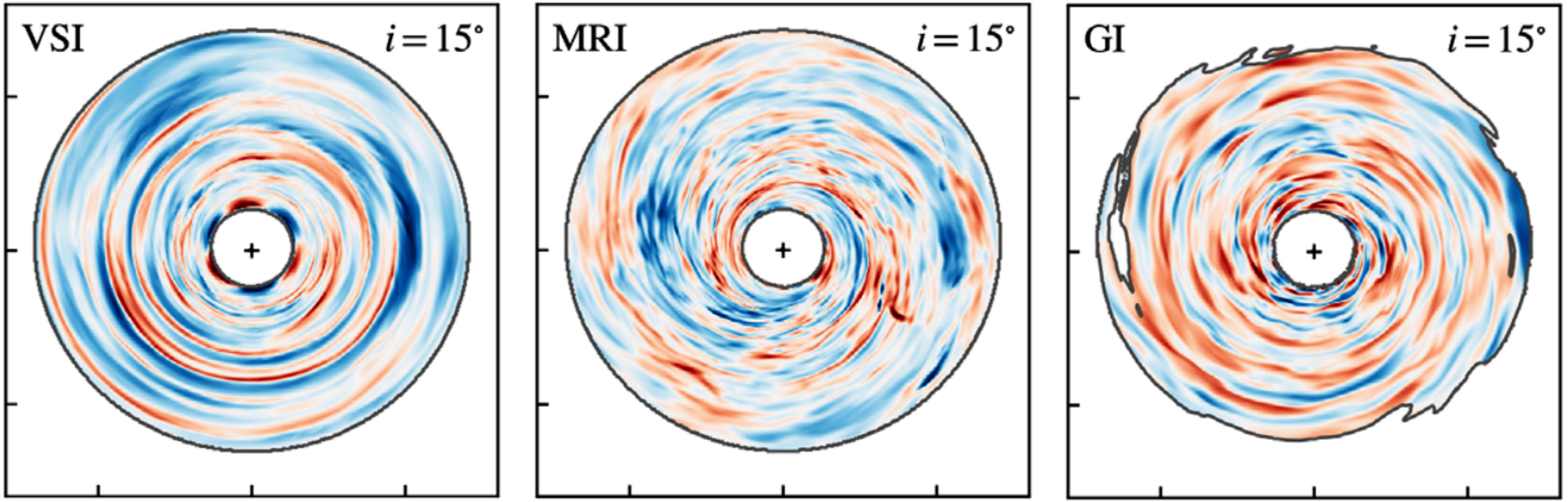
Observed 15 sources with high angular and spectral resolution in order to map the gas dynamics in unparalleled detail.

exoALMA did not find convincing evidence for disk winds



Variations clearly seen in all disks, but no evidence for systematic flows indicative of winds.

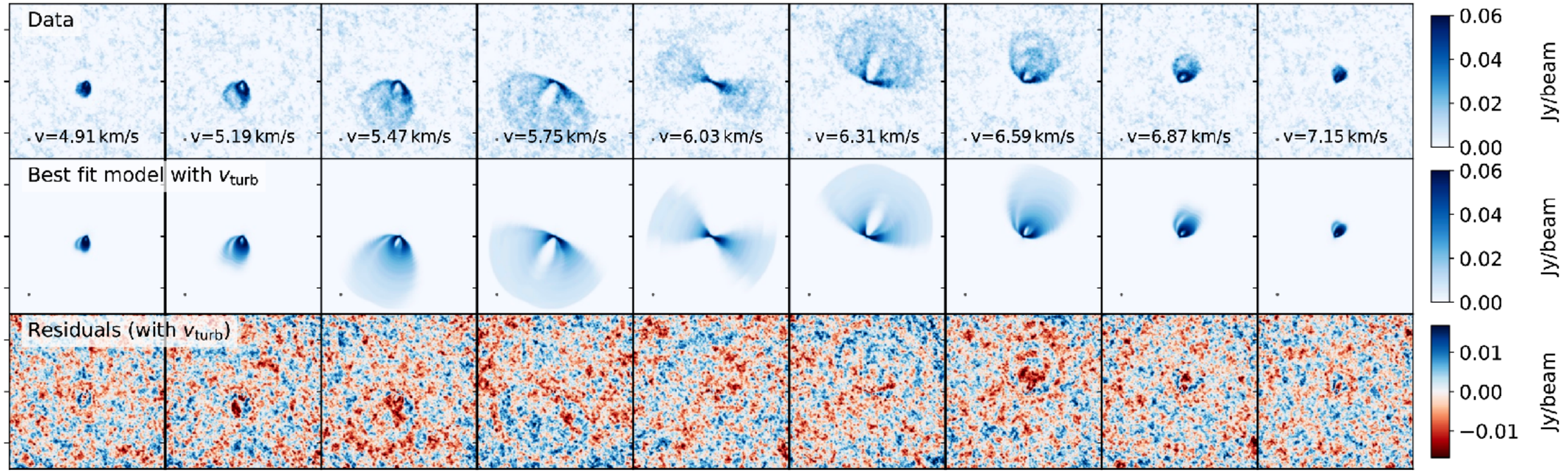
exoALMA did not find convincing evidence for large-scale instabilities



No obvious signatures of well-known instabilities were found.

BARRAZA-ALFARO ET AL. (2025)
IZQUIERDO ET AL. (2025), FUKAGAWA ET AL. (2026)

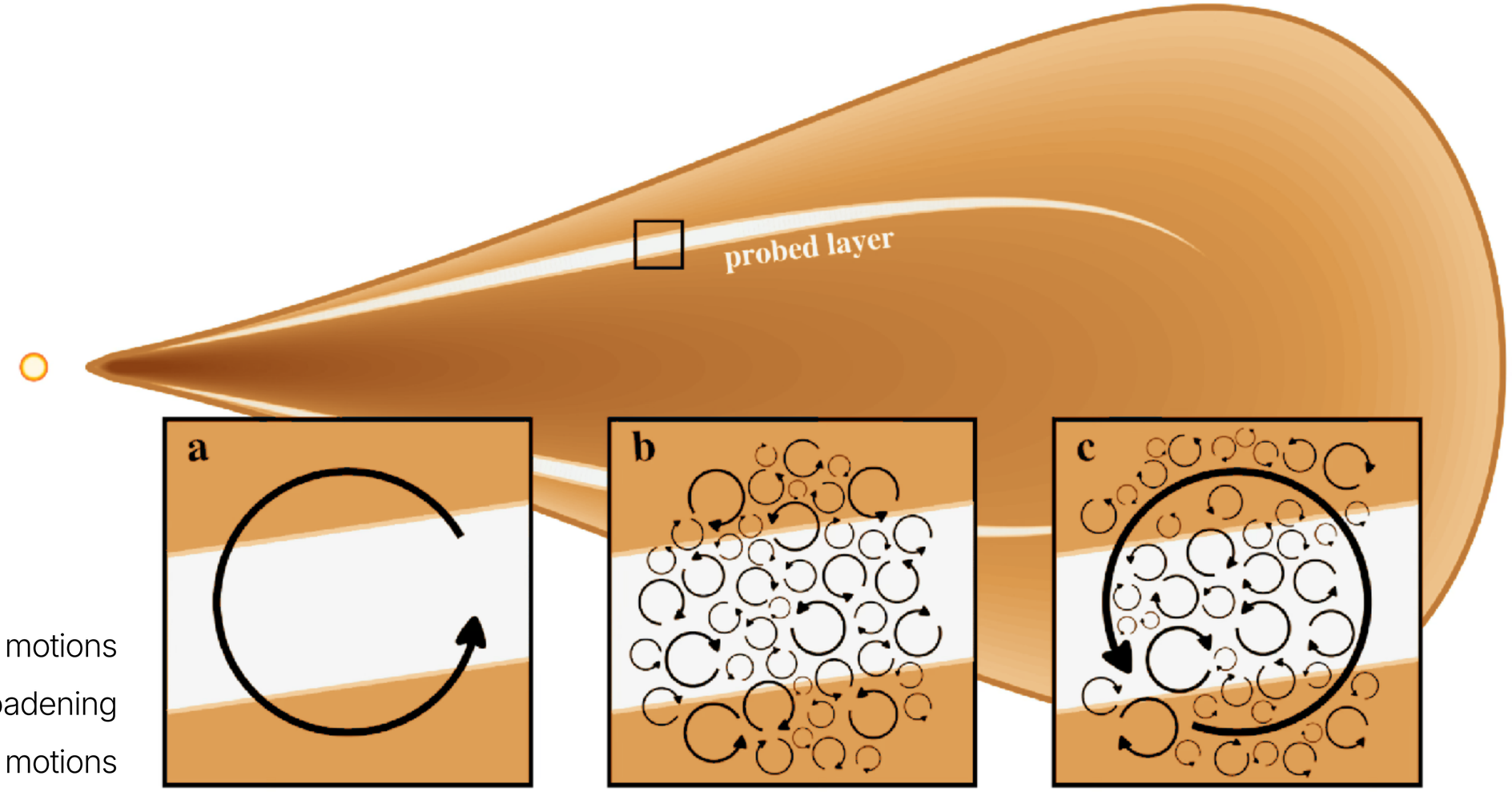
exoALMA did find evidence for non-thermal broadening



With higher spatial resolution and deep observations, the need for a non-thermal broadening component in DM Tau persisted.

HARDIMAN ET AL, (2026)
SEE ALSO GUILLOTEAU ET AL. (2012), FLAHERTY ET AL. (2020)

Are we simply probing the wrong spatial scales?

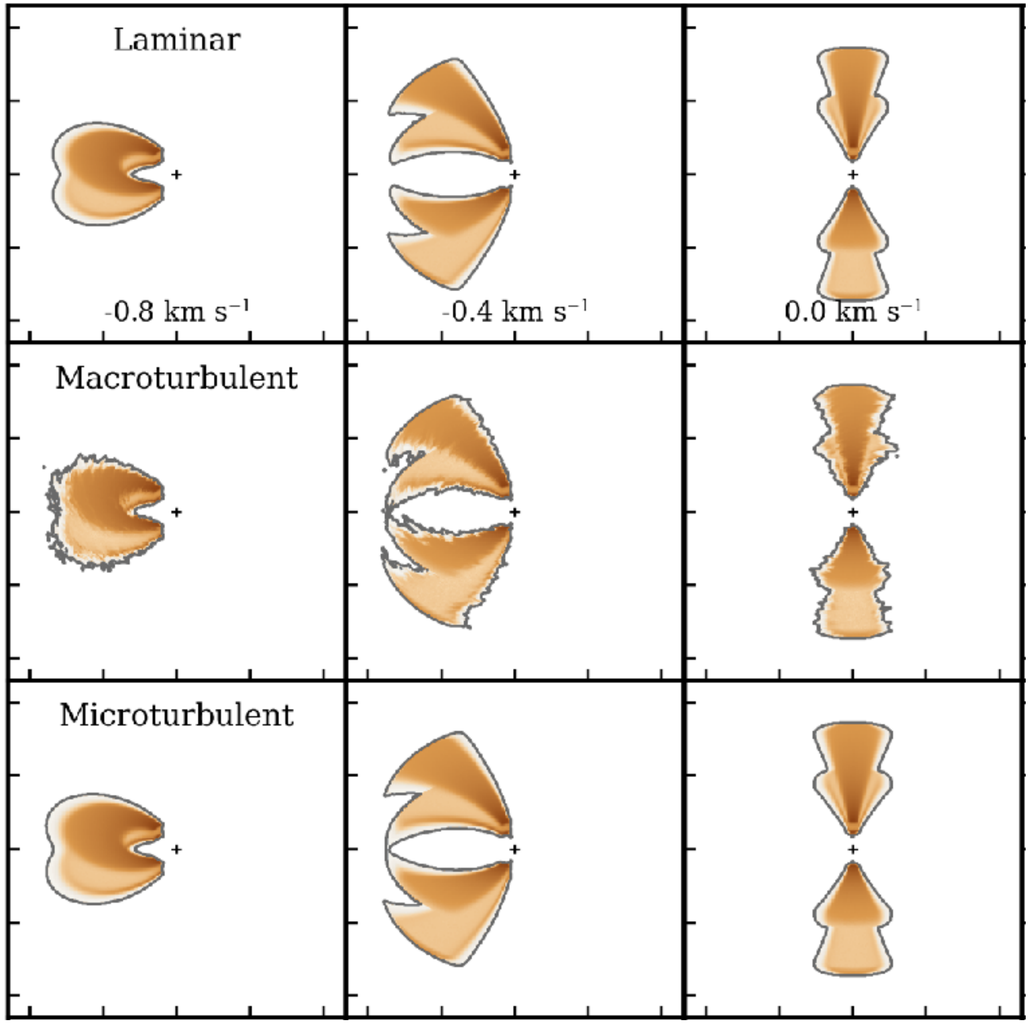


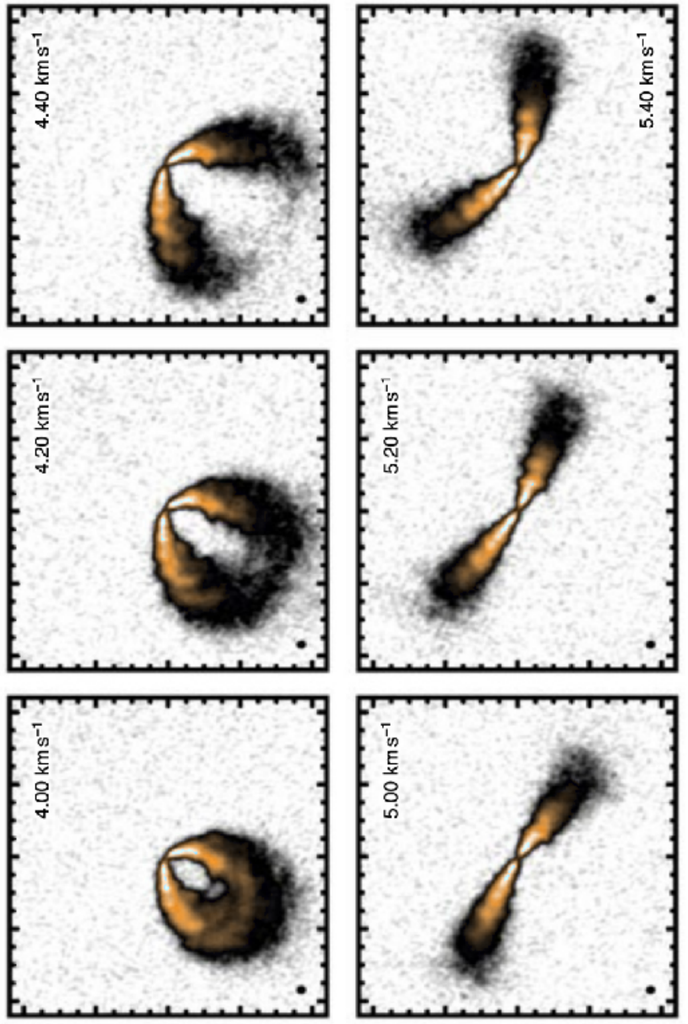
a - Large scale motions

b - non-thermal broadening

c - semi-resolved motions

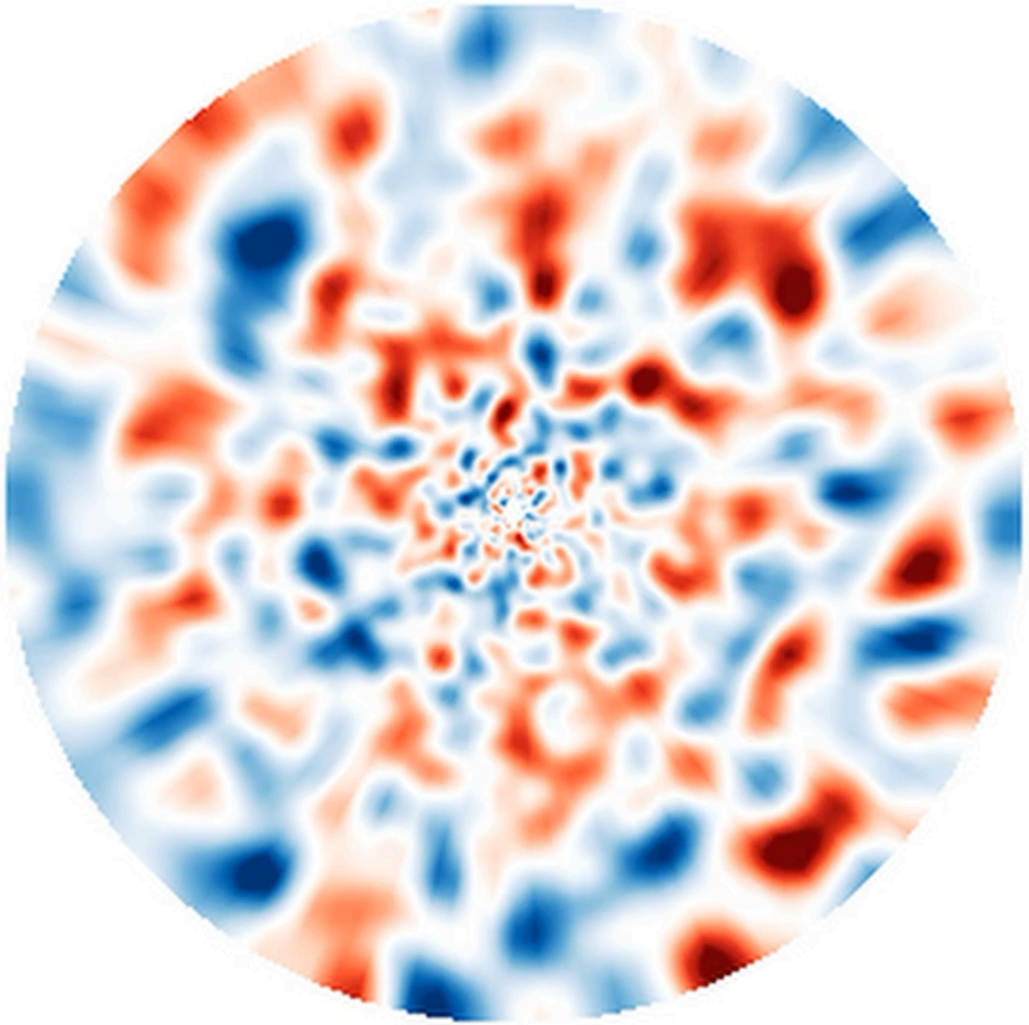
Meso-scale fluctuations look more like noise than signal





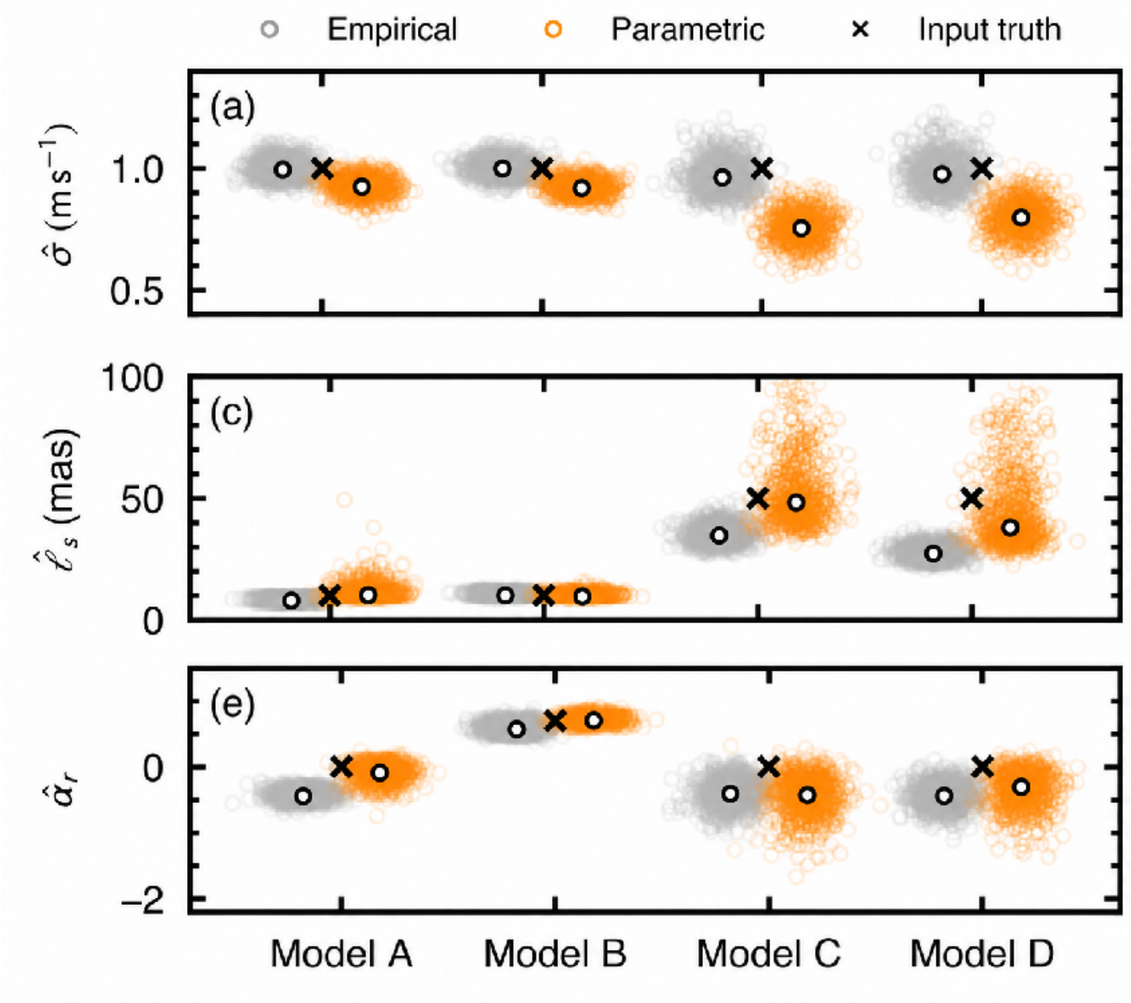
BARRAZA-ALFARO ET AL. (IN PREP), TEAGUE ET AL. (2021)

Revert back to statistical descriptions?



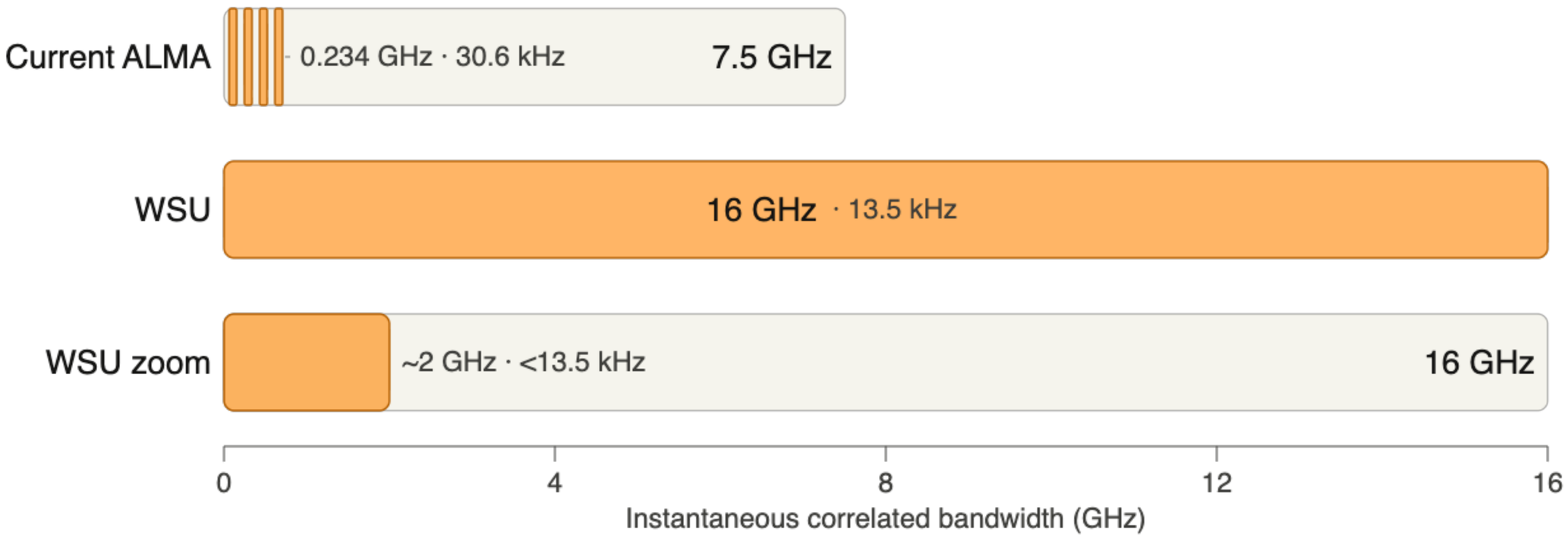
Velocity structures can be mimicked with a correlated Gaussian random field. Empirical heuristics allow us to characterize these sort of structures.

A set of heuristics allow us to characterize the structure in the noise



Spatial variations in the size of the velocity fluctuations may offer an orthogonal constraint on the presence of turbulent motions.

The WSU will transform how we look at protoplanetary disks



The Wideband Sensitivity Upgrade will transform our ability to detect and characterize the magnetic fields which thread disks.

SUMMARY

We are making progress in understanding how disks evolve

- ALMA's spatial and spectral resolution allows for detailed maps of the gas dynamics to be made for many systems.
  We can measure velocities at the 10 ms^{-1} level across 10 au scales.

- We are starting to detect and characterize magnetic fields threading protoplanetary disks.
  Future upgrades will allow us to drastically expand our sample size.

- As a field we are data rich, prediction poor.
  The transformation in data availability has forced us to confront the suitability our models.

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ESO / B TAFRESHI