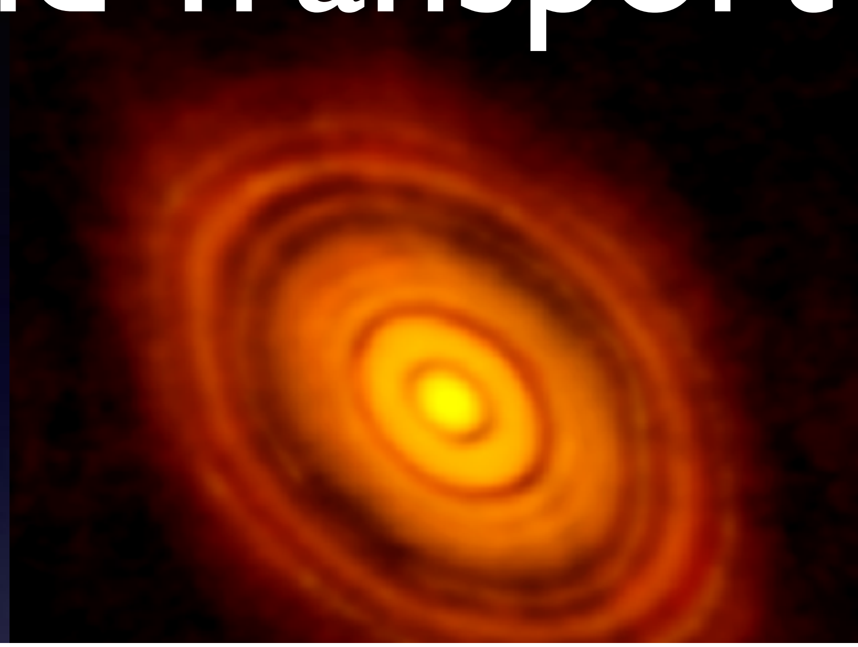
Magnetically Induced Disk Winds and Transport in the HL Tau Disk



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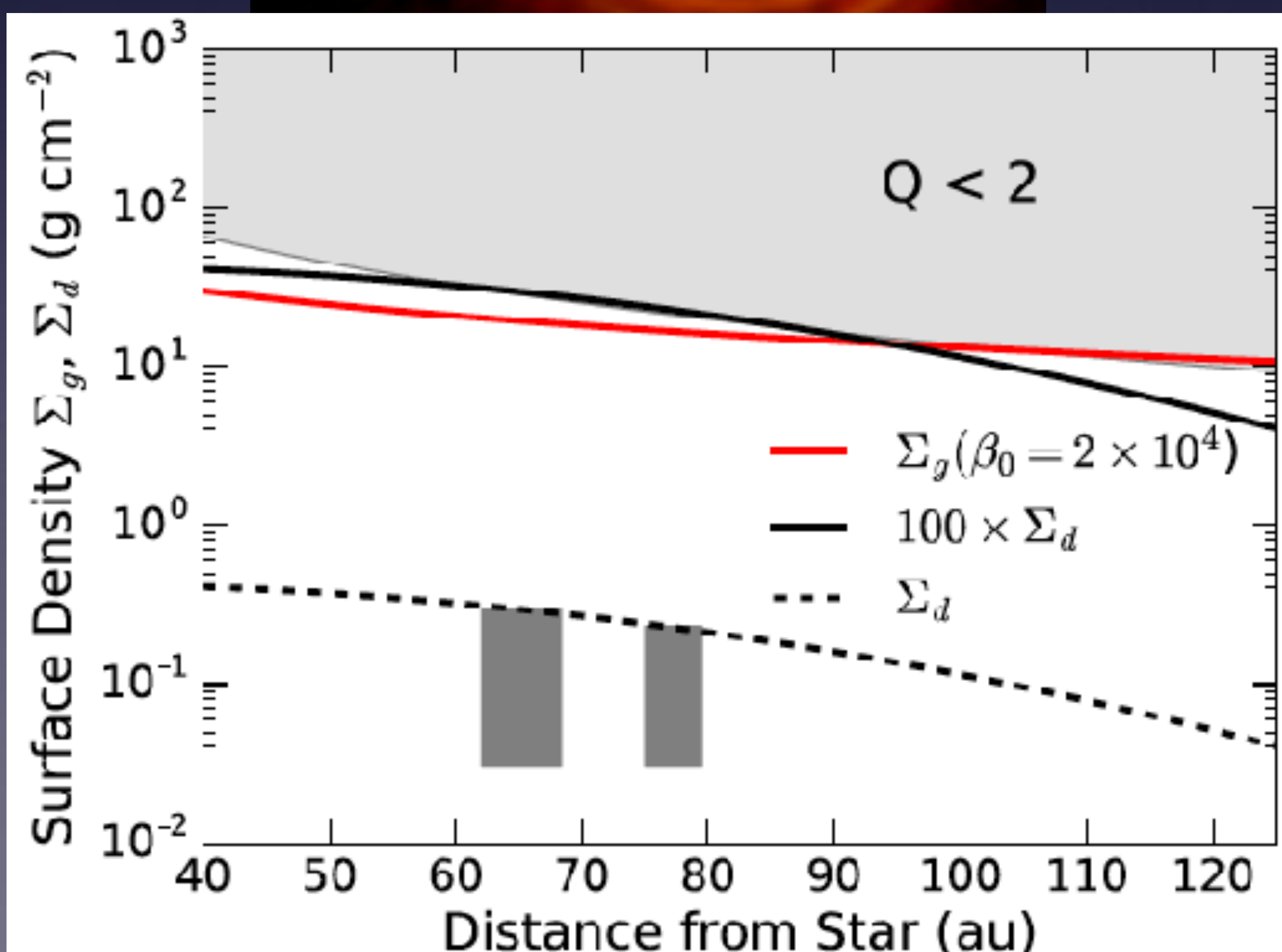
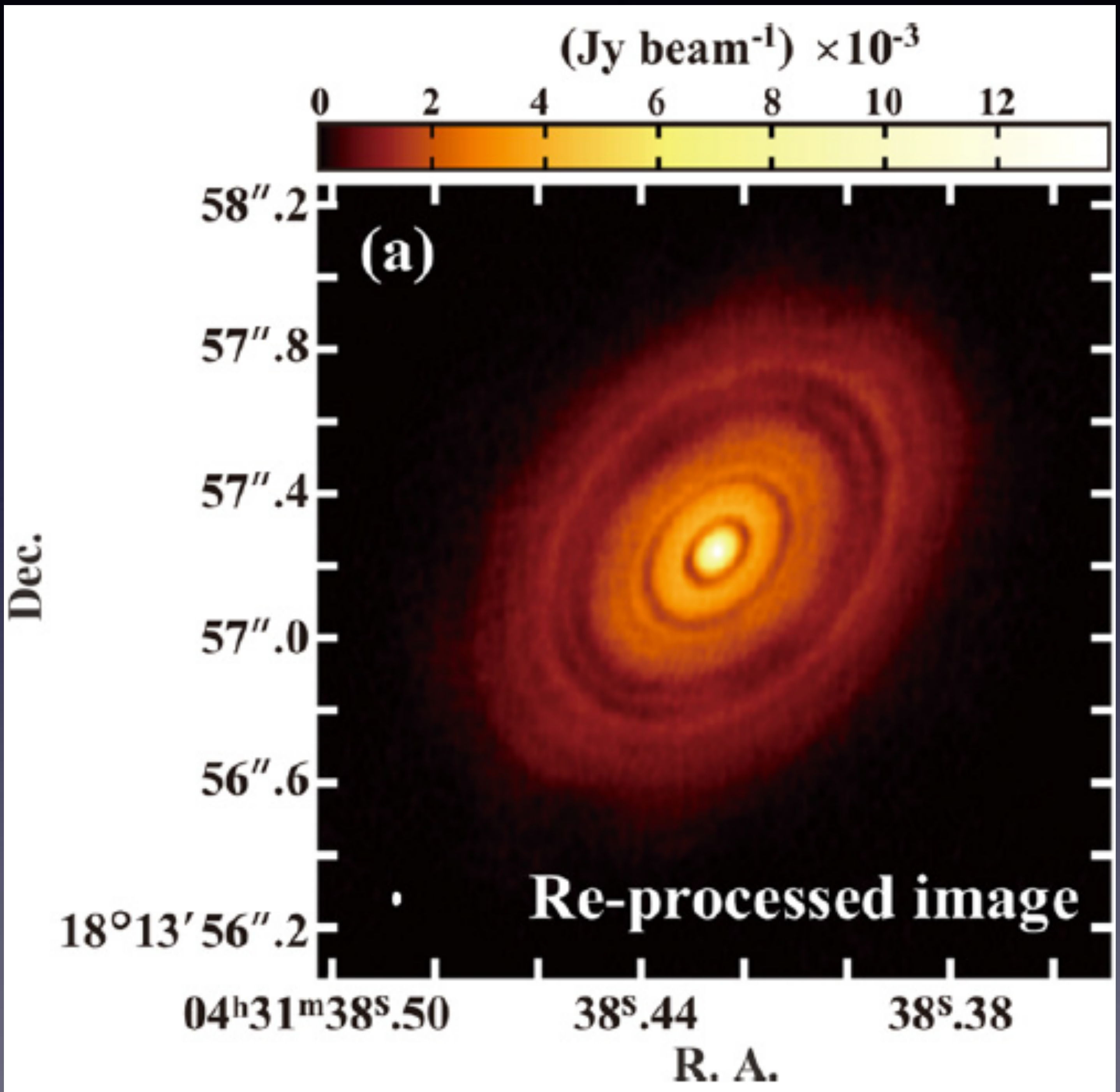


in collaboration with
Satoshi Okuzumi (TokyoTech)
Mario Flock (JPL/Caltech)
Neal Turner (JPL/Caltech)

Astonishing ALMA Images of HL Tau

ALMA Partnership et al 2015



HL Tau : a Class I/II YSO
: ~140 pc (< 1 Myrs)

Nearly concentric multiple gaps in the dust thermal emission

Potential signature of planet formation

The origin of observed gaps is not identified yet!!

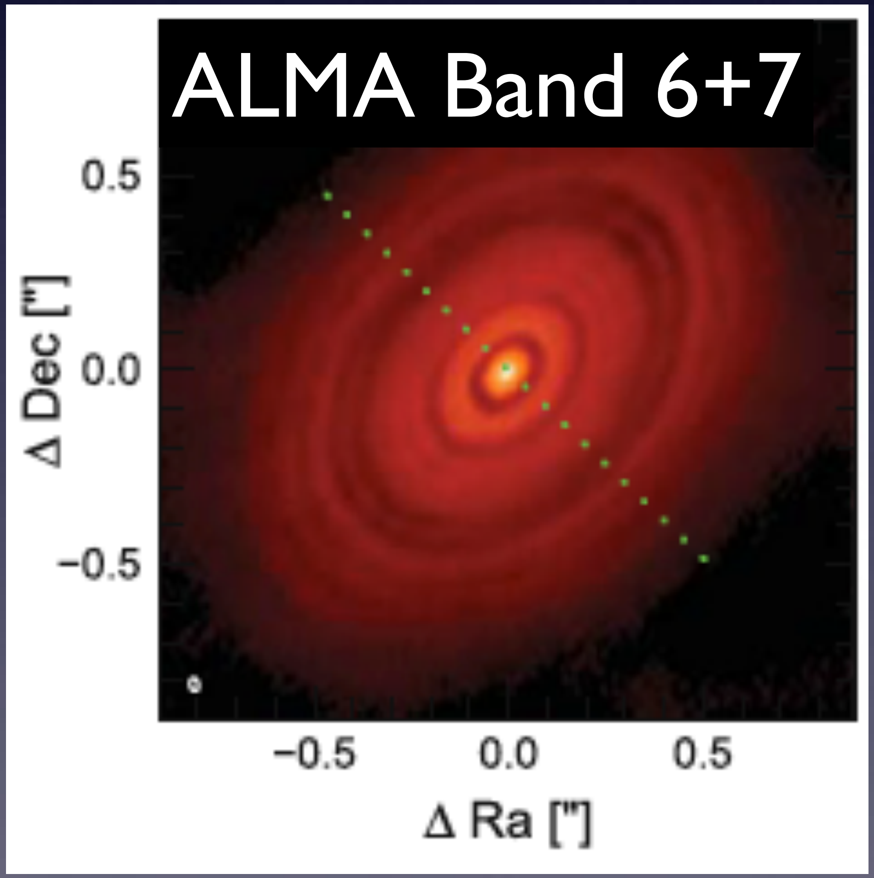
Global Properties of the HL Tau Disk

Disk accretion rate $\simeq 10^{-7} - 10^{-6}\ \mathrm{M}_\odot\ \mathrm{yr}^{-1}$

Hayashi et al 1993, Beck et al 2010

Global diffusion coefficient : $\alpha_{\rm GL} \simeq 10^{-2} - 10^{-1}$

=> can be explained by MRI and MHD turbulence



ALMA Partnership et al 2015

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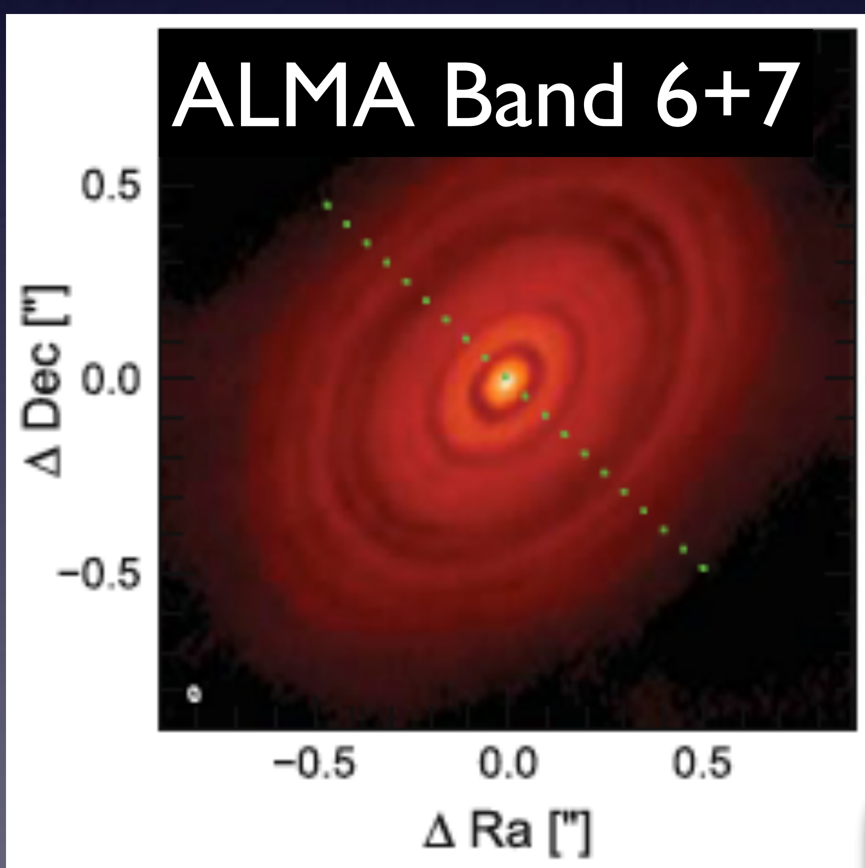


Pinte et al 2016

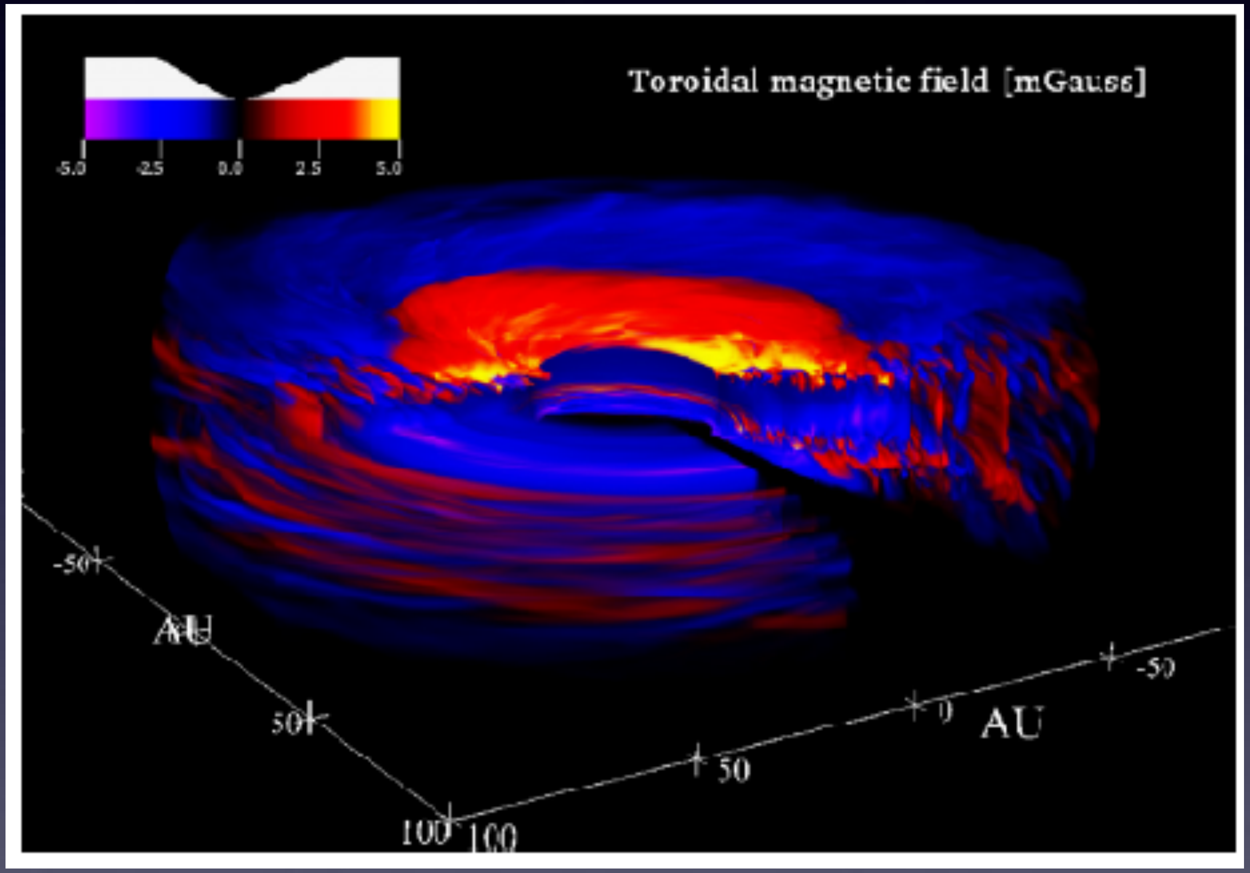
Vertical dust height ~1au at r =100 au

Local diffusion coefficient : $\sim 10^{-4}$

Magnetically Driven Disk Accretion

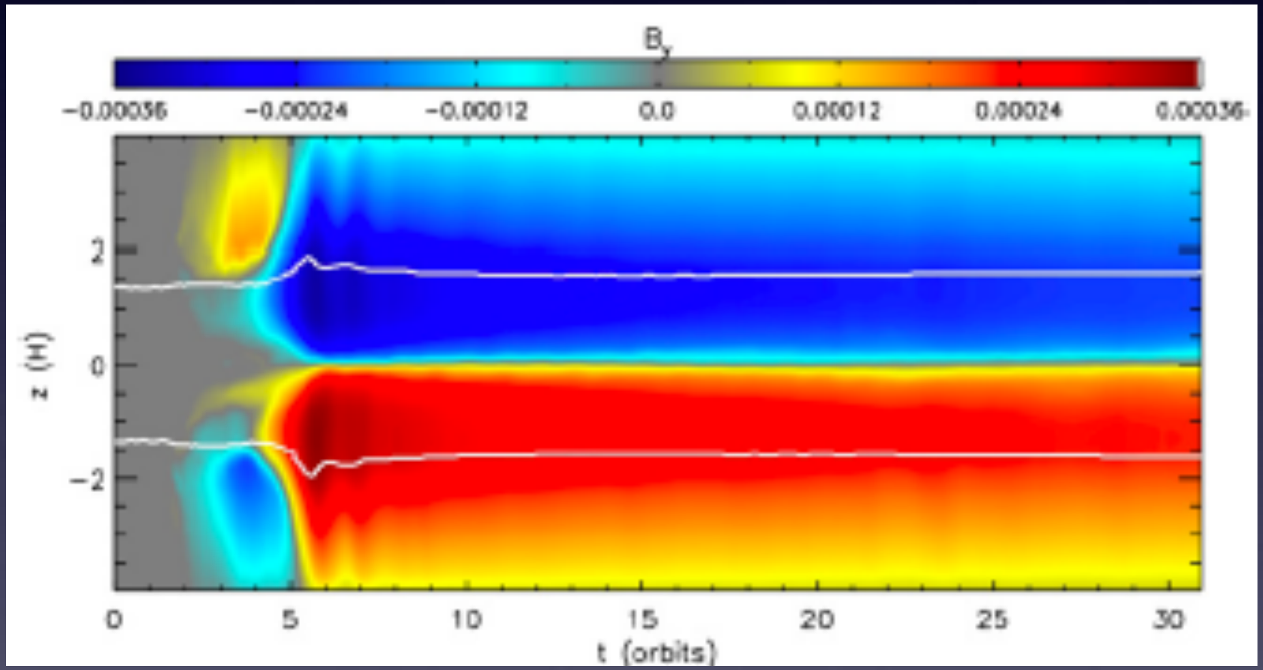
e.g., Armitage et al 2011, Bai & Stone 2013, Turner et al 2014, Suzuki et al 2016

Magnetized Turbulence



Flock et al 2015

Magnetically Induced Disk Winds



Simon et al 2013

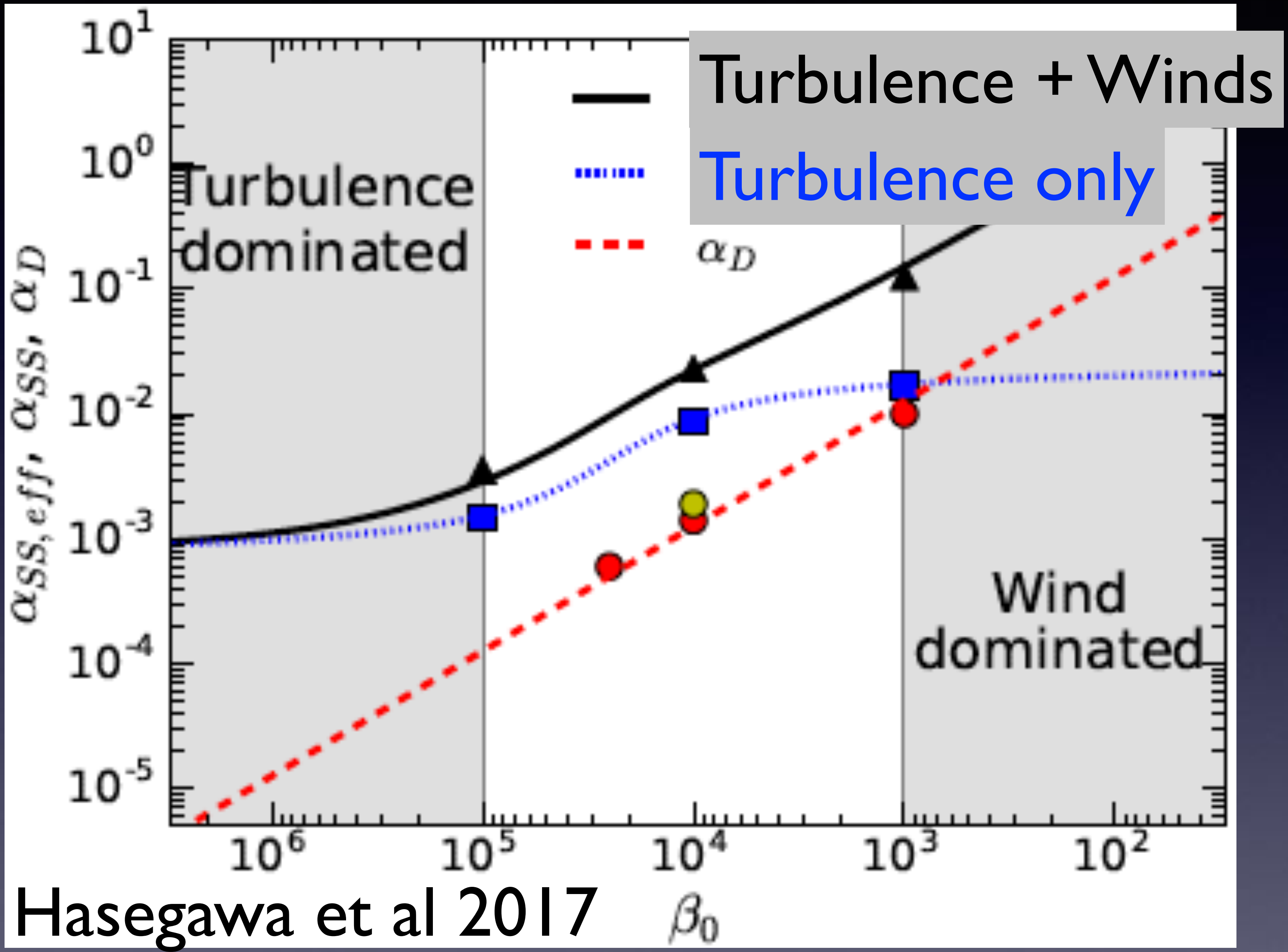
Weak

Strong

B-fields

Magnetically Driven Disk Accretion

e.g., Armitage et al 2011, Bai & Stone 2013, Turner et al 2014, Suzuki et al 2016



α_D : vertical mixing of dust

Weak

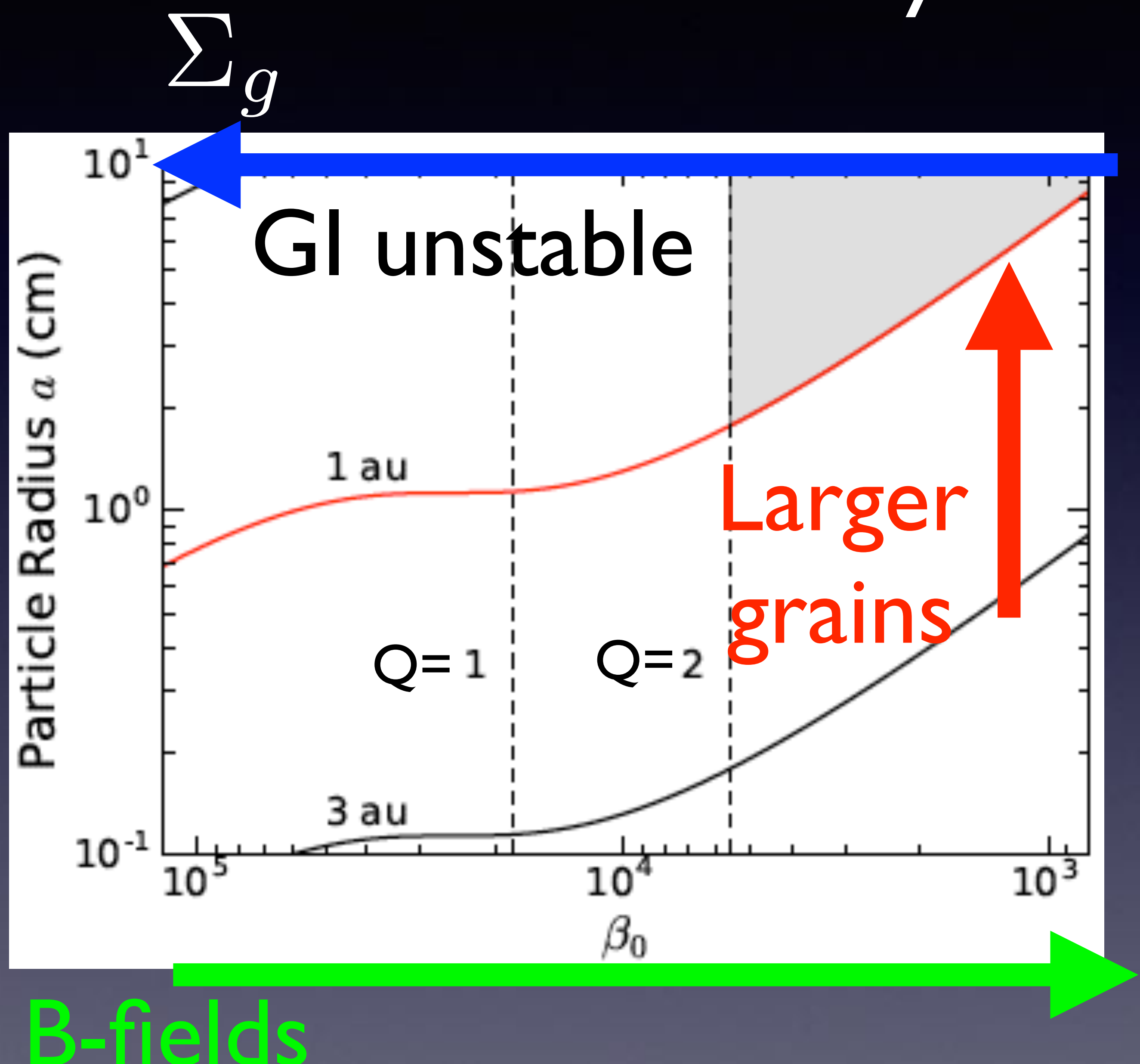
Strong

B-fields

Simulation results from Simon et al 2013, Zhu et al 2015 are used

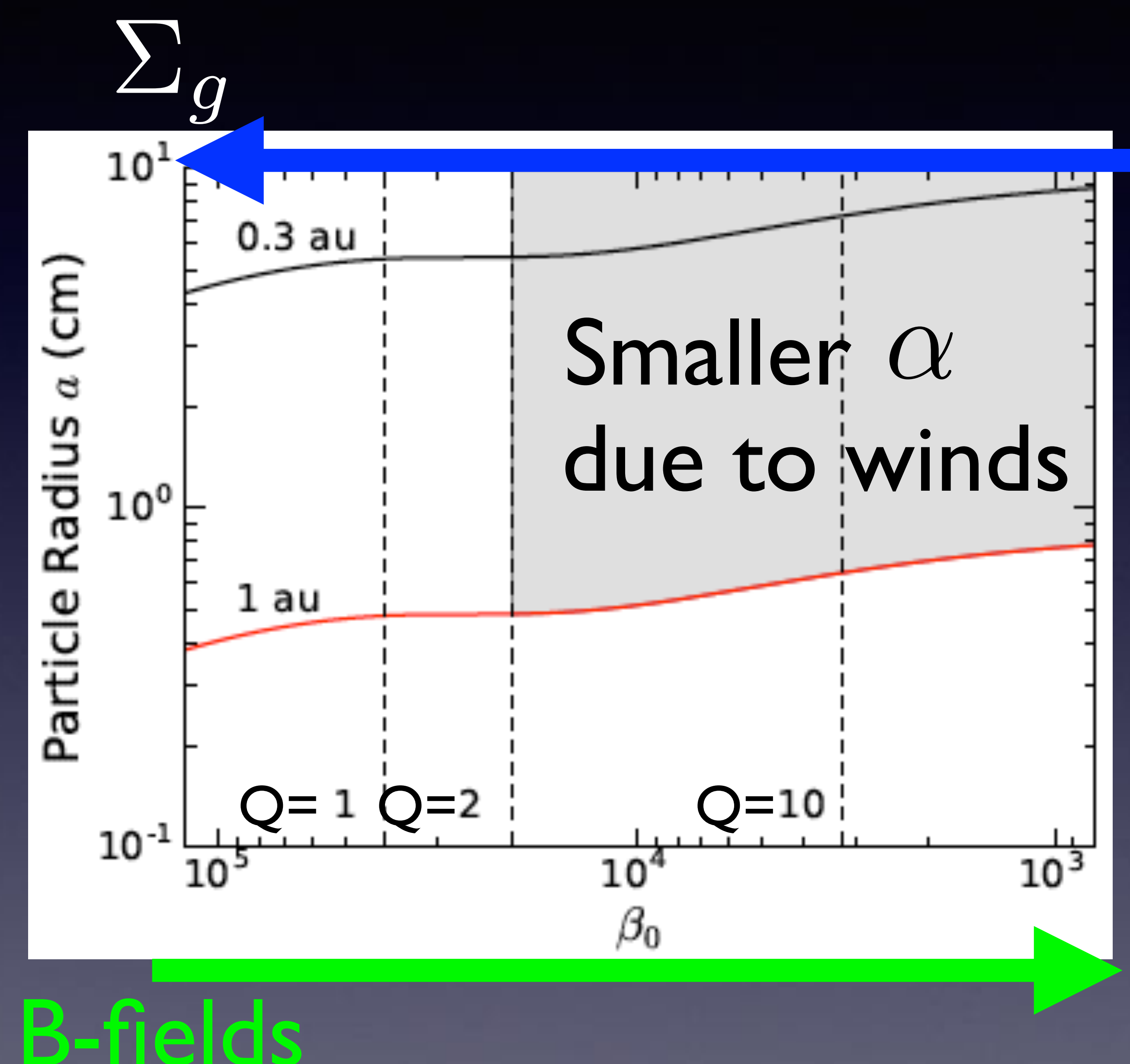
Minimum Size of Dust Particles at r = 100 au

Turbulence only



20 mm-sized dust is needed to reproduce ALMA image

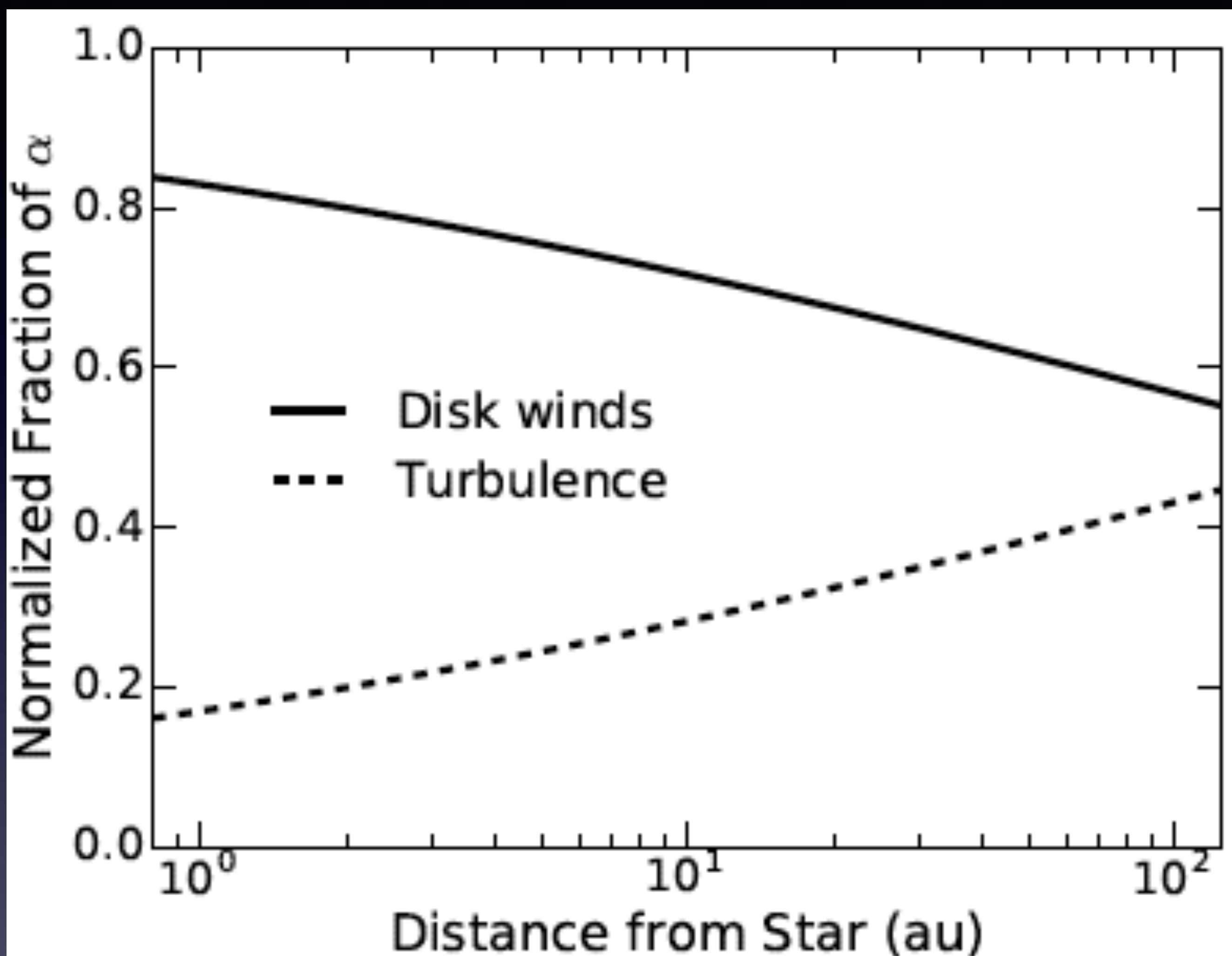
Turbulence + Winds

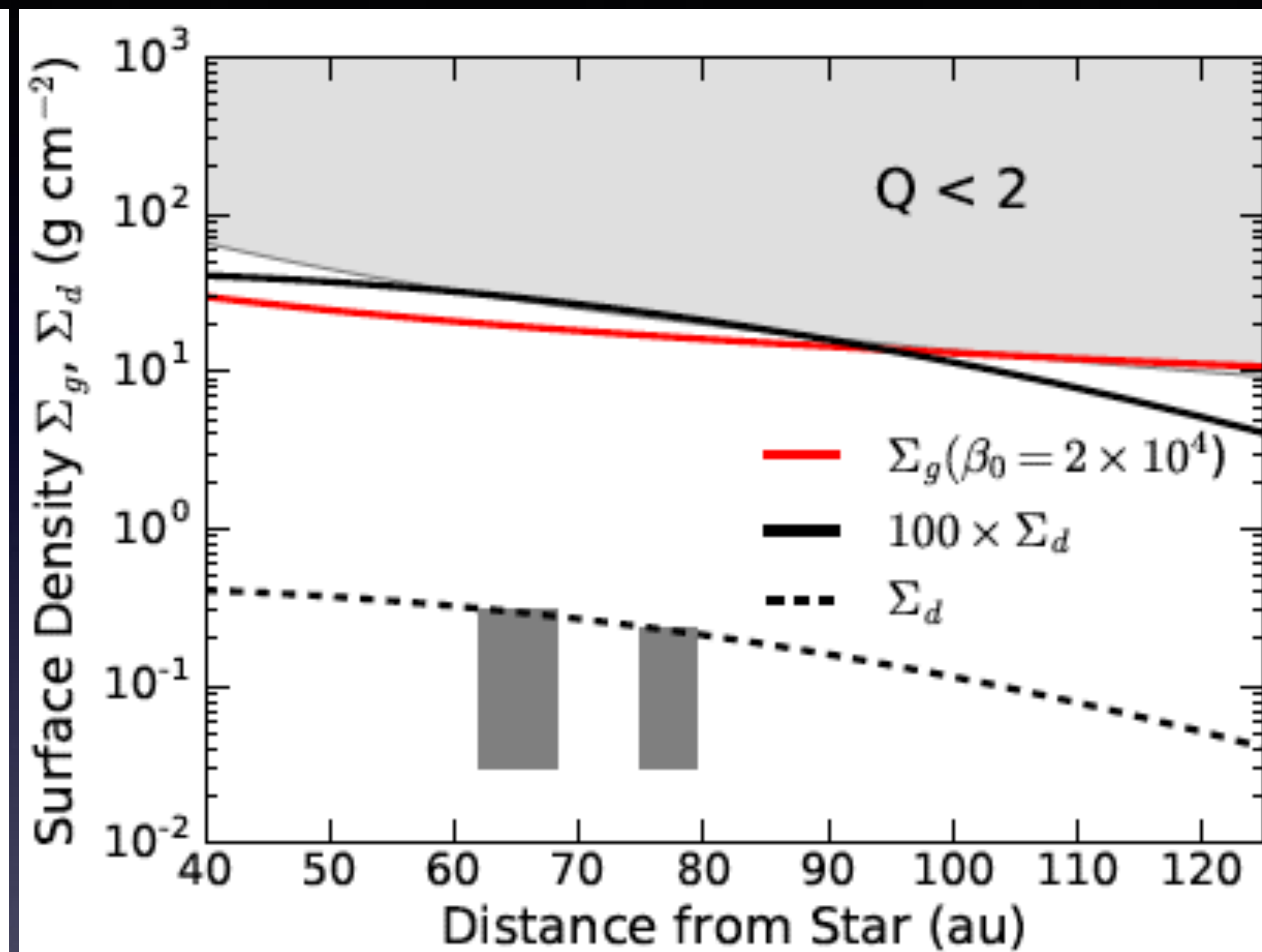


4 mm-sized dust is needed to reproduce ALMA image

Results are obtained for given values of disk accretion rate, disk temperature

Resulting Global Structure of the HL Tau Disk





Disk winds transport the most of angular momentum (50-80 %) across the entire region of the disk

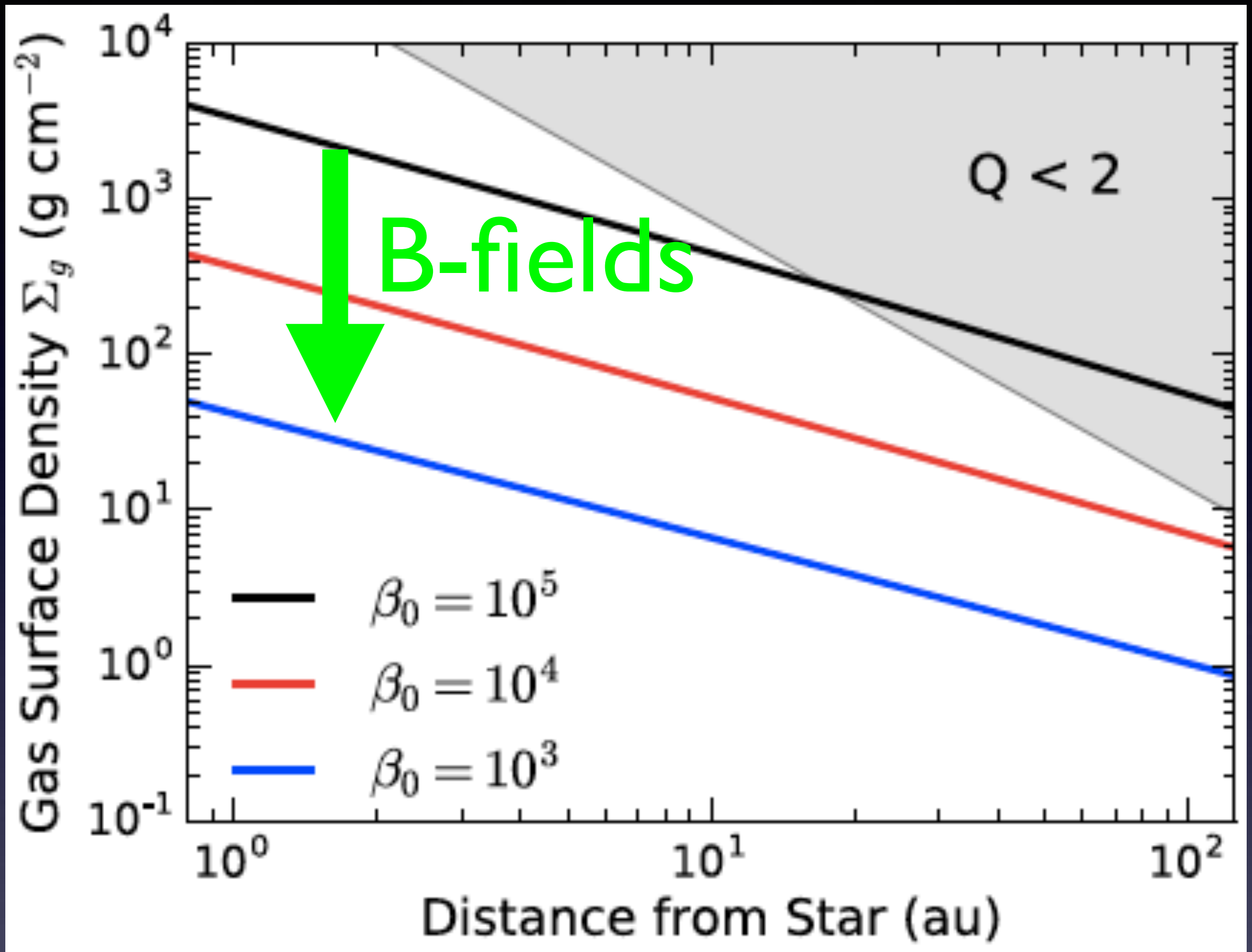
The gas-to-dust rate varies along the distance from the star (lower in the inner region & higher in the outer region)

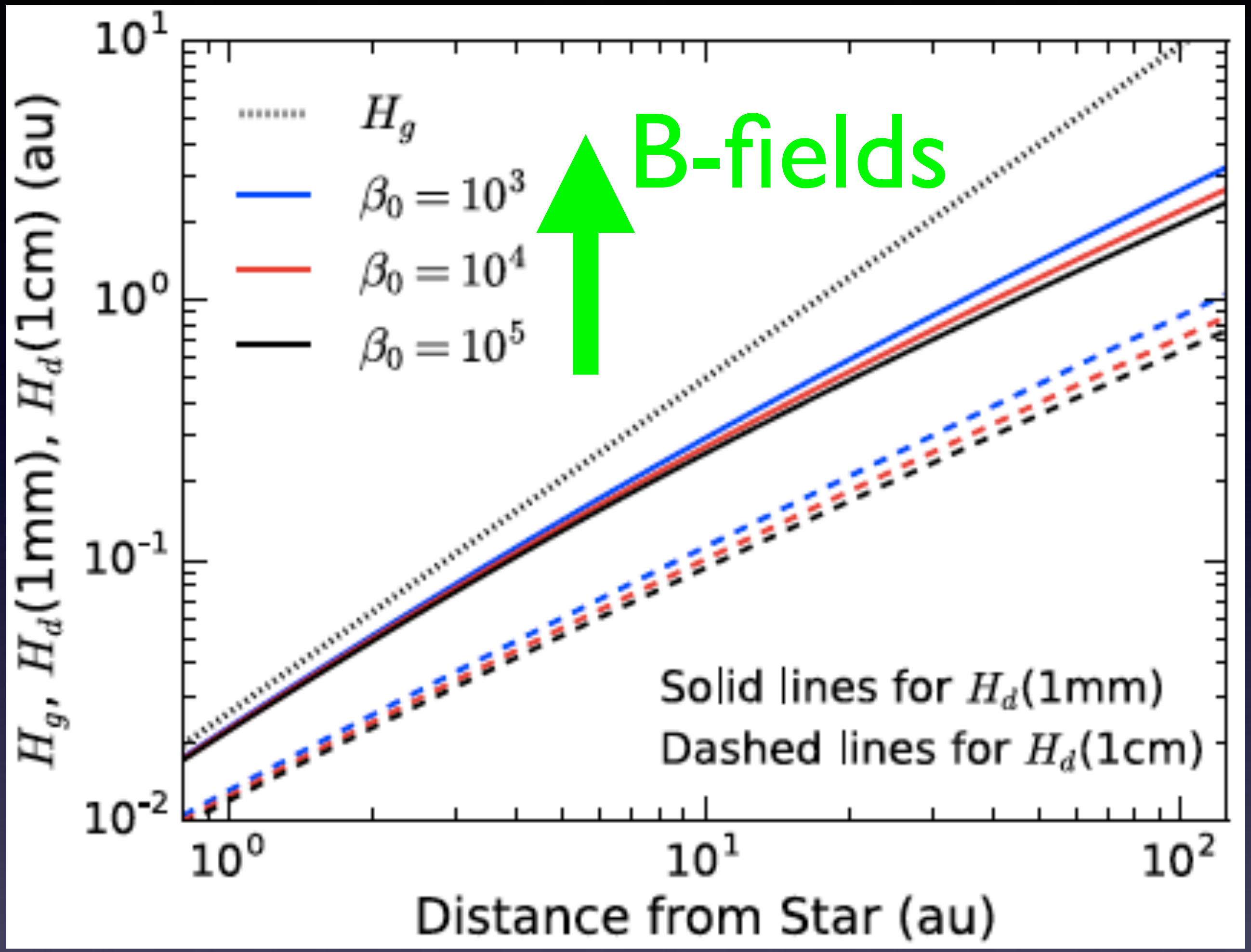
Summary

Hasegawa et al 2017, ApJ, 845, 31

- ALMA observations of the HL Tau disk can advance our understanding of disk evolution
- Subsequent radiative transfer modeling suggests a higher degree of dust settling for the actively accreting disk
- Developed the simple, semi-analytical model, taking into account magnetically induced disk winds
- Our results indicate the importance of magnetically induced disk winds to fully reproduce the global configuration
- Followup work will be performed to obtain a better understanding of the birthplace of planets and to fully identify the origins of observed multiple gaps in the HL Tau disk

Resulting Disk Structures with Disk Winds





As B-fields are stronger, surface density decreases due to disk winds

Dust scale heights are independent of B-fields

Results are obtained for given values of disk accretion rate, disk temperature

1) Comprehensive Examination of Planet Formation Covering the Full Size Range

First Stage | **Second** | **Third Stage**

~ micron — ~ mm — ~ m — ~ km — $\sim 10^3$ km — Size

JPL Postdoc -> JPL Scientist

2) Fill out the Gap in Research between Solar and Extrasolar Systems