

TMT Science Forum, contributed talk  
Jul. 18, 2014, Loews Ventana Canyon Resort, Tucson, Arizona

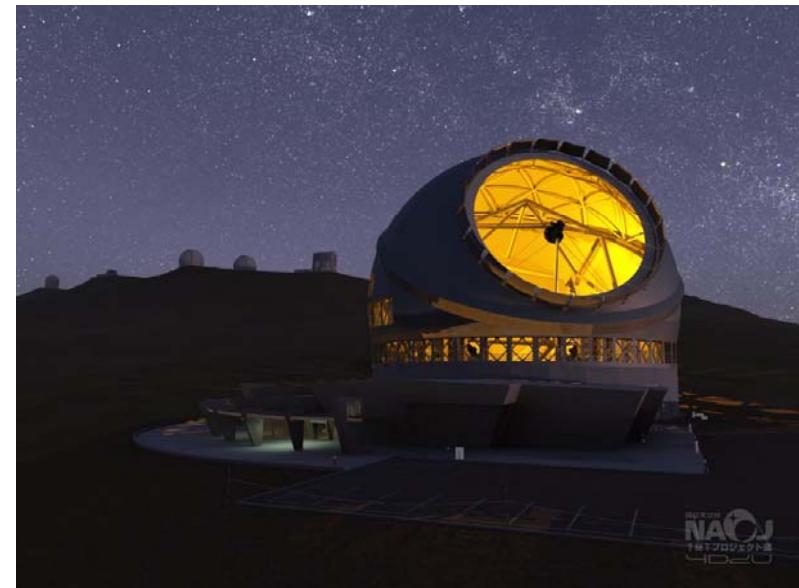


# Direct Imaging Observations of Protoplanetary Disks with TMT

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# High spatial resolution with TMT

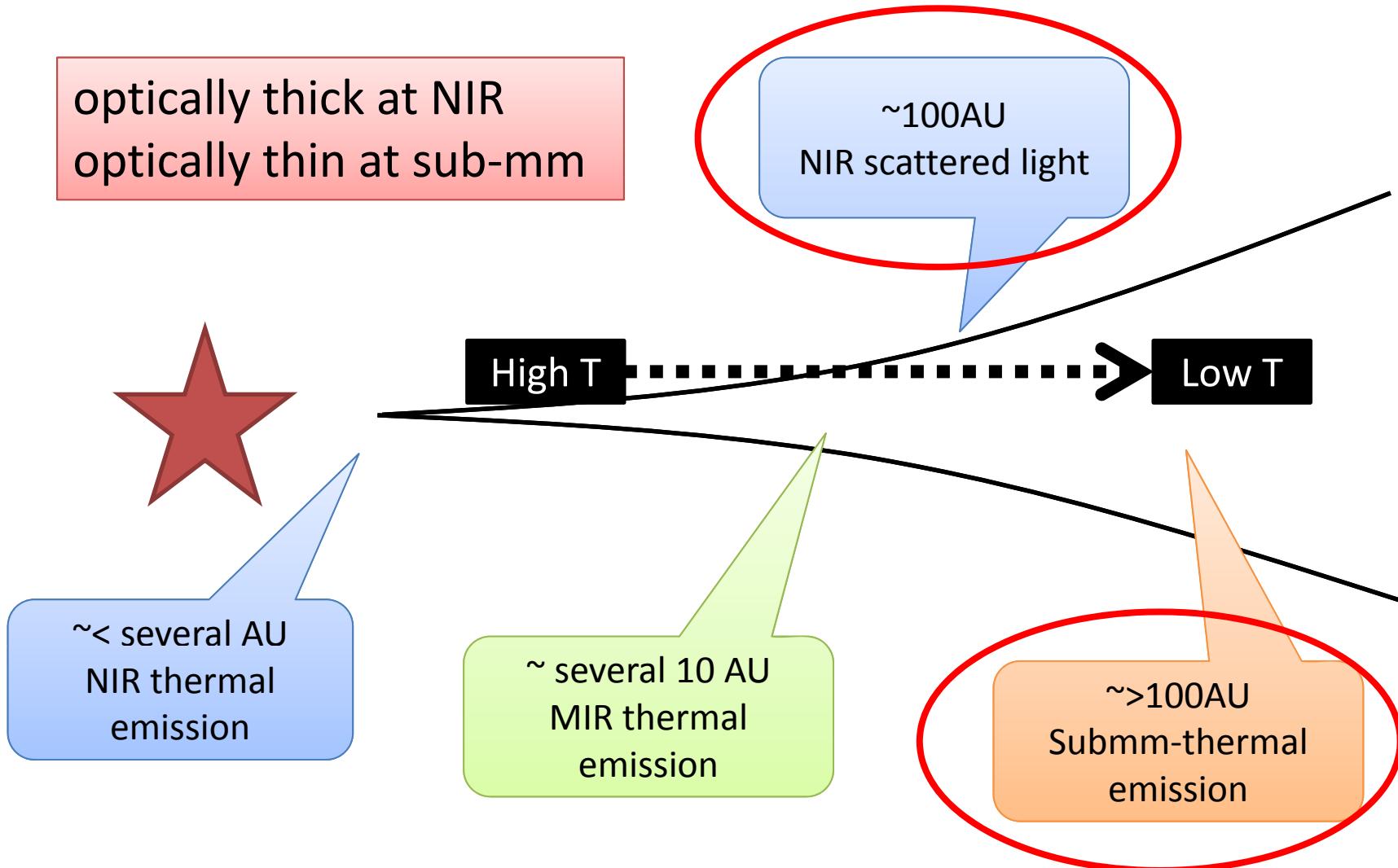
- ~0.02 asec resolution will be available with TMT
  - TMT can resolve structures with several AU scales at  $d \sim 140$  pc (nearby star-forming regions)



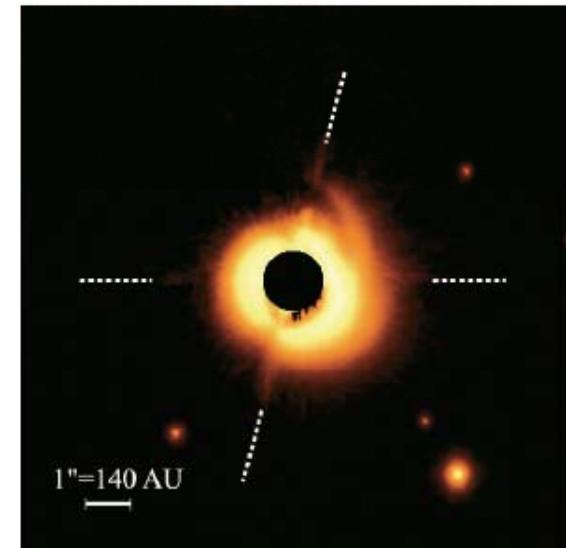
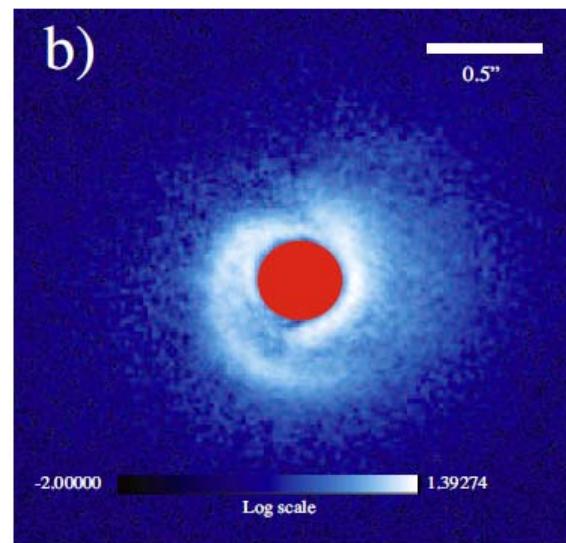
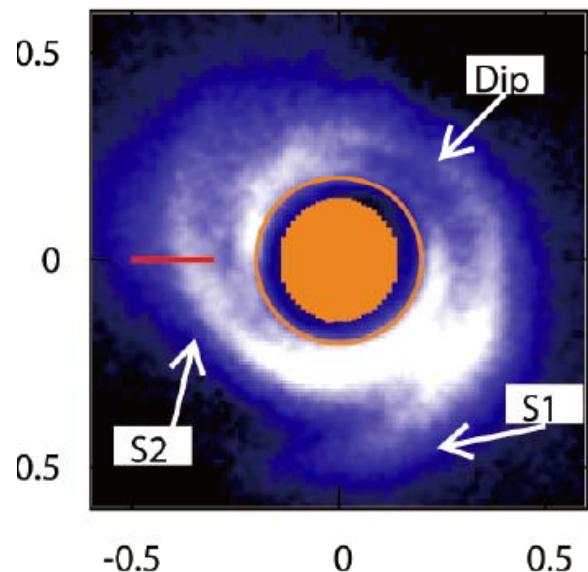
*What can we see with ~0.02 asec spatial resolution?*

- Small-scale asymmetries (spirals) at ~10-30 AU
- Water snow line at surface

# Protoplanetary Disks Observations



# Spirals in PP Disks

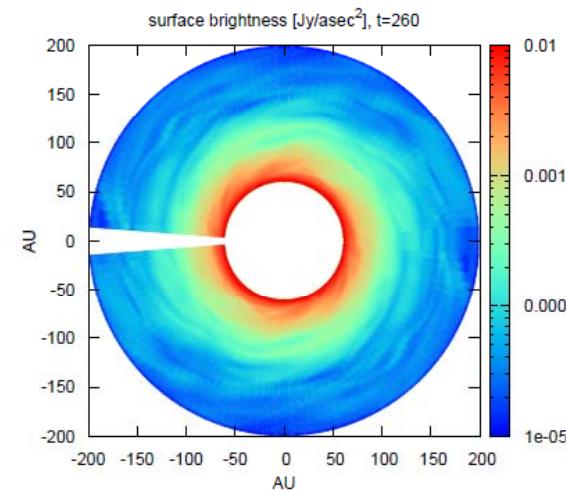
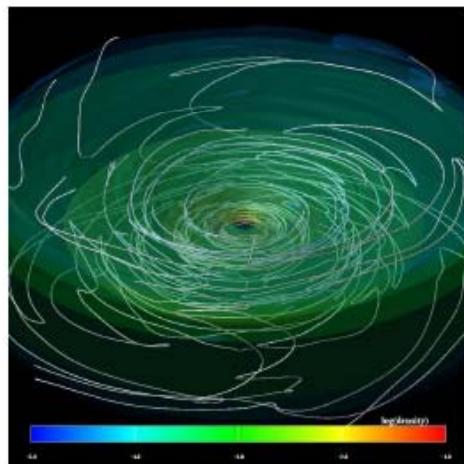


Muto et al. 2012, Grady et al. 2013, Fukagawa et al. 2006

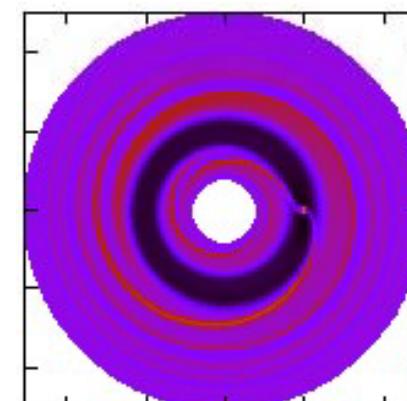
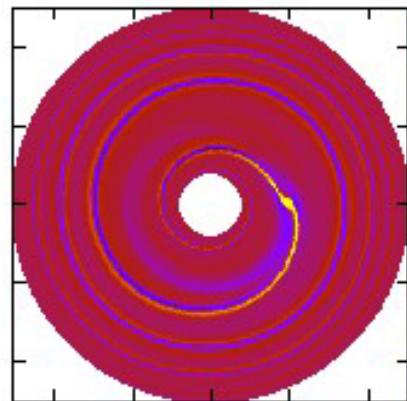
# Dynamical Processes in Protoplanetary Disks

Turbulence:  
gravitational instability / magnetorotational instability / others...

Suzuki &  
Inutsuka 2014



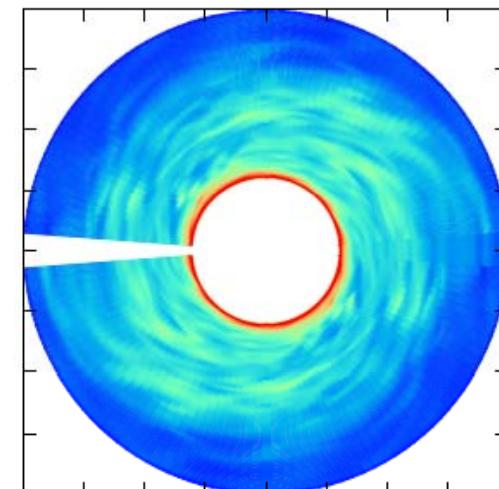
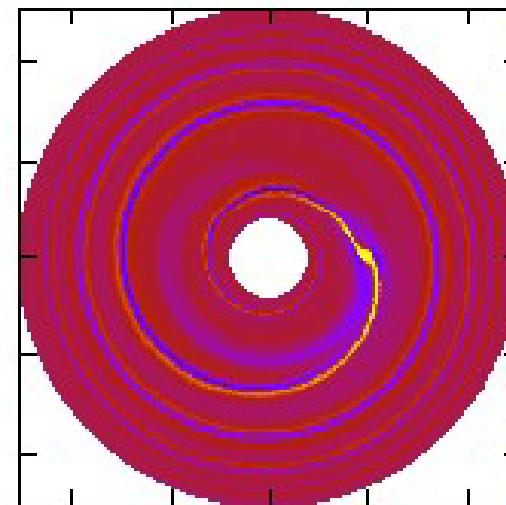
Disk-planet interaction: spiral wave, gap-opening...



FARGO simulation

# Spiral Wave as an Indicator of Dynamical Activity in a Disk

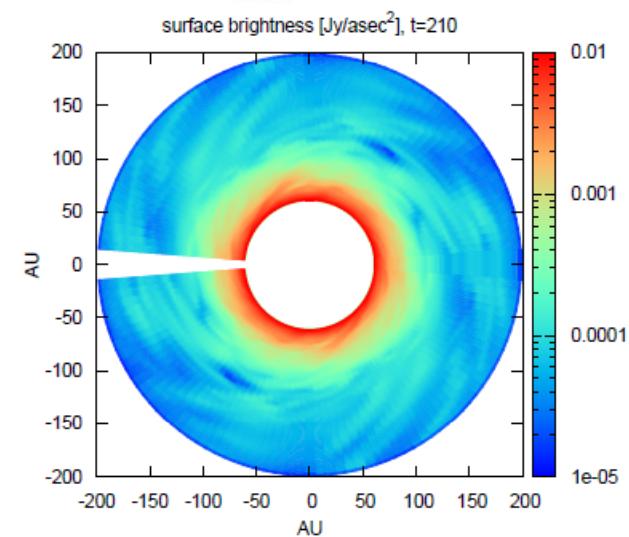
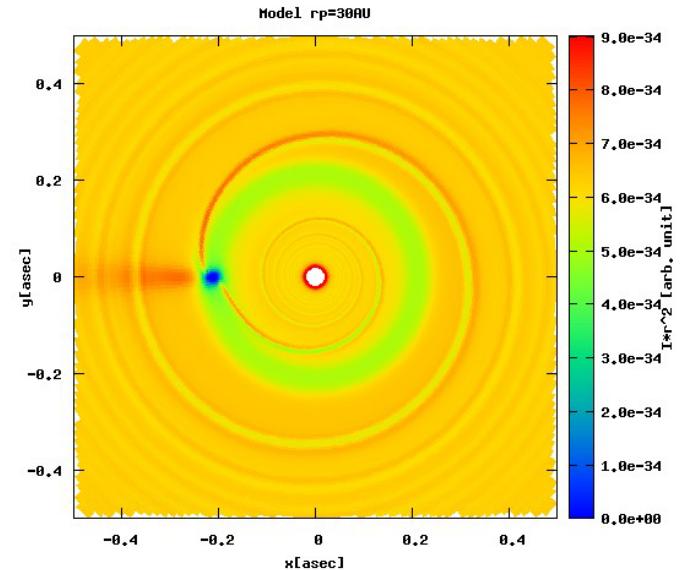
- Spiral structures are expected quite generally in dynamically active disks
- Spiral *density* wave
  - (non-axisymmetric) sound wave excited in a disk
  - Any perturbation can cause non-axisymmetric structures



# What can we learn from spirals?

$$\phi(r) \sim \pm \frac{r}{H}$$

- The shape of the spirals indicate the *wave propagation speed*
  - ***disk temperature*** if the spiral is sound wave
  - ***disk B-field*** (?) if the spiral is MHD turbulence
- Possible indicator of newly-born planet
  - ***We can spot where the planet is.***



# Spatial Resolution Required

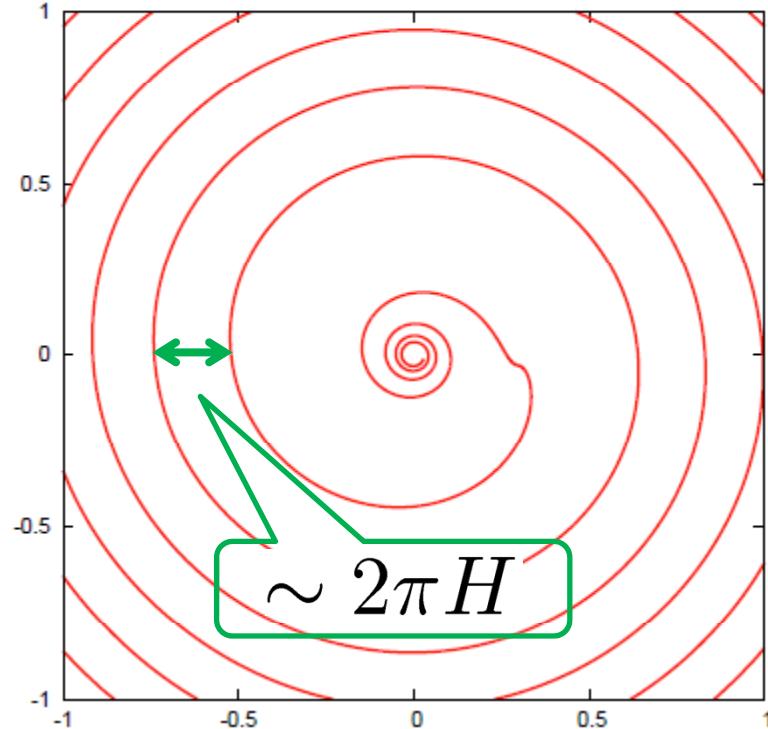
$$\phi(r) \sim \pm \frac{r}{H}$$

Need to resolve  
structure with scale  $\sim H$

$$d = 140\text{pc}$$

$$R = 100\text{AU}, H \sim 10\text{AU}$$

$$R = 30\text{AU}, H \sim 3\text{AU}$$

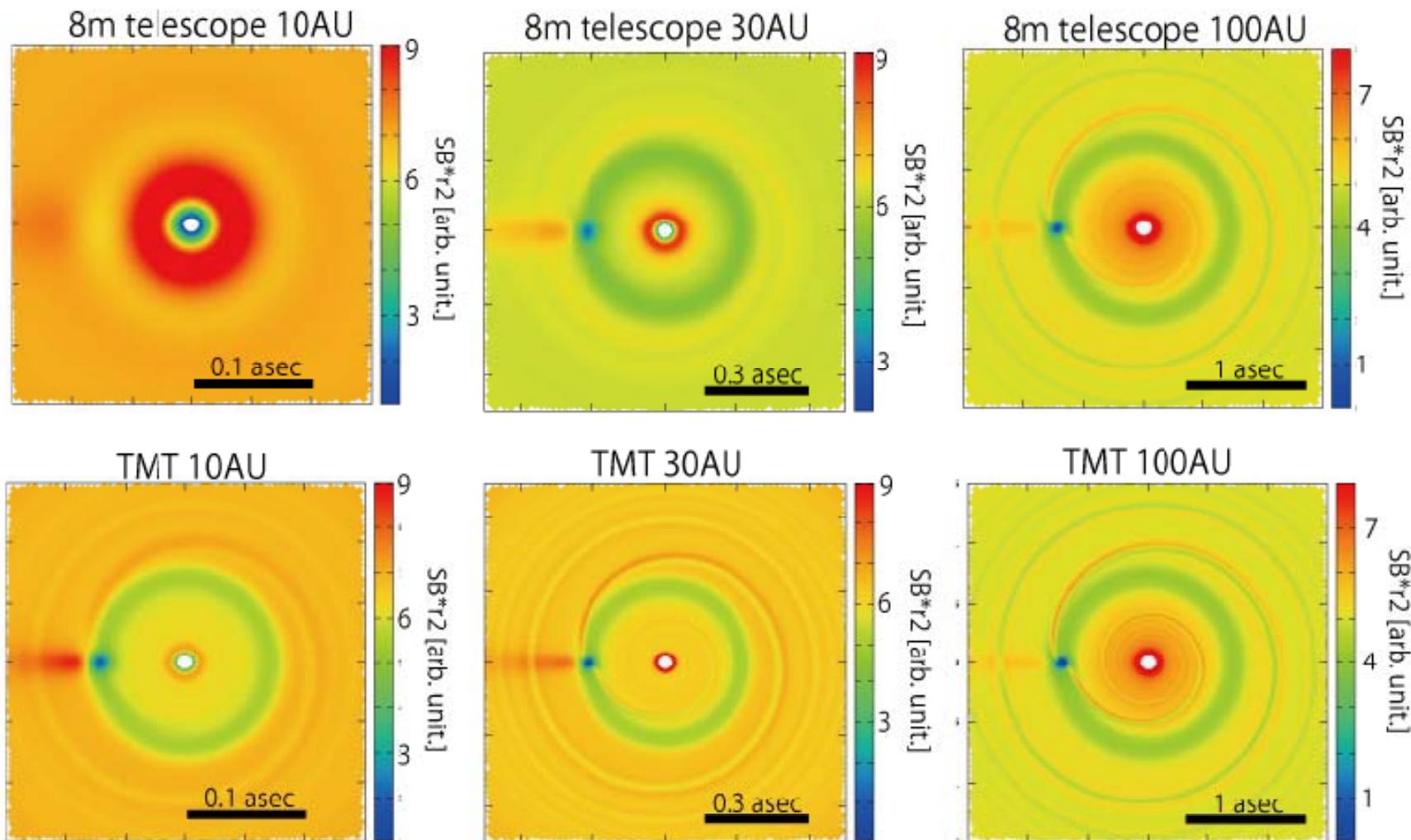


To observe spirals at  $\sim 100\text{AU} \rightarrow 0.1\text{asec}$  resolution (8m-telescopes)  
To observe spirals at  $\sim 30\text{AU} \rightarrow 0.01\text{asec}$  resolution (TMT)

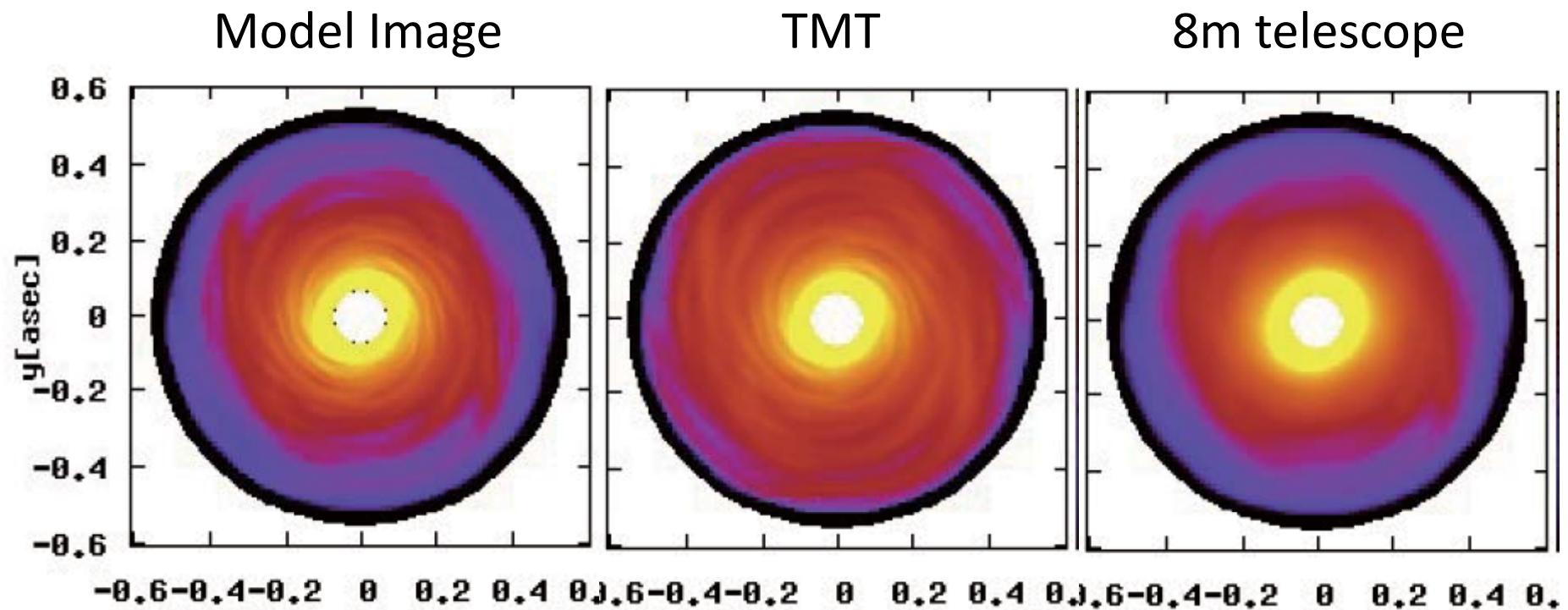
More tightly-wound spirals in colder disks (T Tauri disks)

← see Grady's talk

# Spirals by a planet in disk



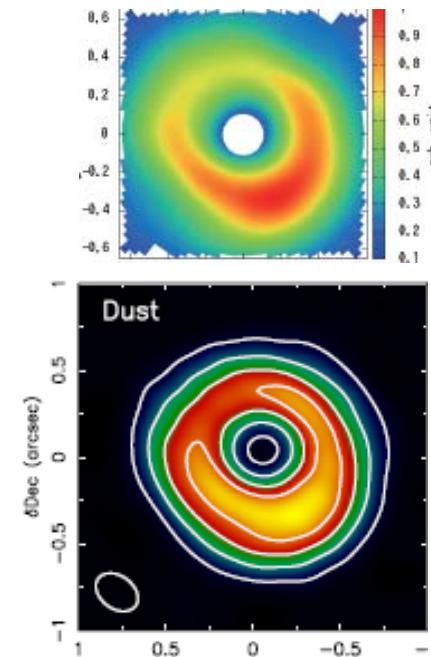
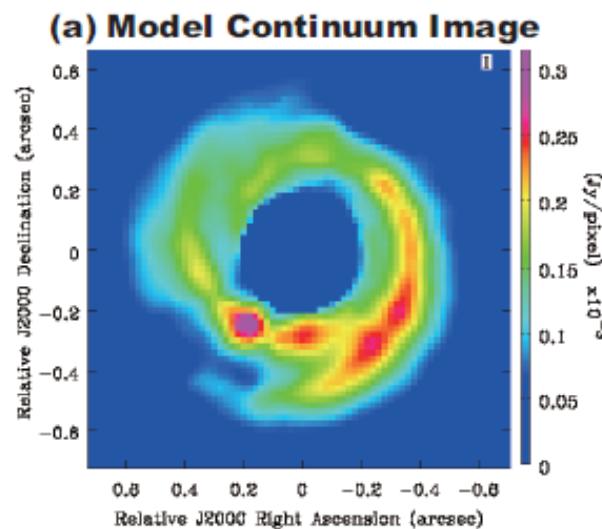
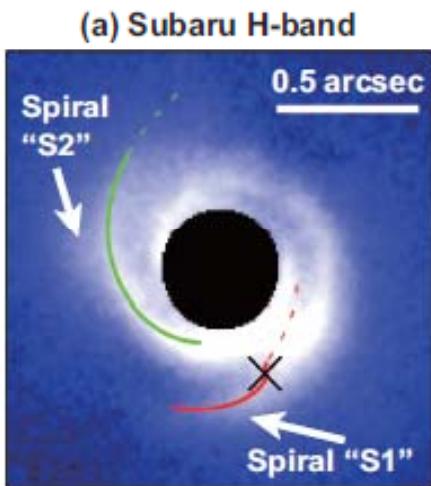
# Disk Turbulence



*turbulence is the driver of disk evolution*

statistical analysis is essential for turbulence  
→ need to resolve small-scale structures

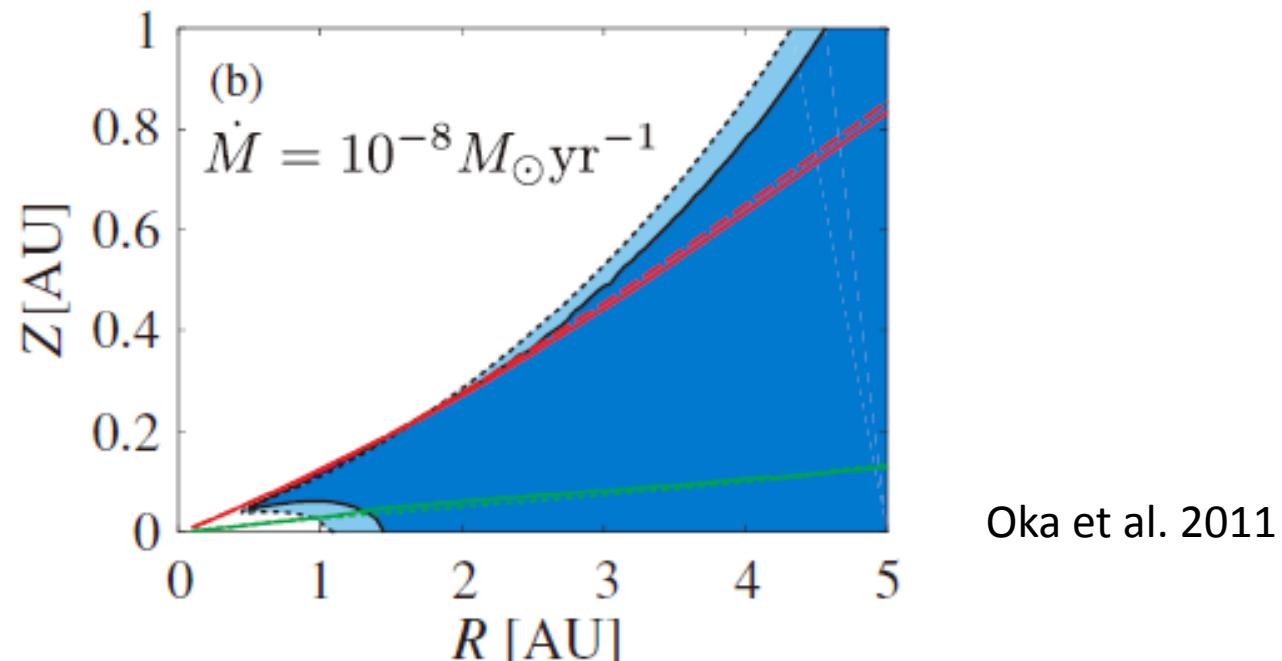
# Possible Synergy with ALMA



- ALMA and TMT are complementary to each other
  - (small) grains at the surface (TMT)
  - (large) grain distribution at mid-plane (ALMA)
  - Molecular gas distribution / velocity (ALMA)
- Spatial resolution with full ALMA is comparable with TMT

# (Surface) Snow Line

- Snow line: sublimation boundary for ice
- Snow line exists at:
  - Disk midplane
  - Disk surface ← can be traced with NIR scattered light



# The location of snow line

- Classical value  $\sim$  2-3 AU (at midplane)
  - Surface snow line locates farther than classical location
  - Probably observed with the high resolution
- The main composition of dust particles change drastically across the snow line
  - Water ice will reflect light more effectively than silicate

# Summary

- TMT can resolve structures at several AU scale in protoplanetary disks
- TMT can resolve spiral structures at ~30 AU (Neptune distance) from the central star
  - Synergy with ALMA will give useful information on disk dynamics and possibly the location of forming planets
- TMT can resolve disk-scale structures at snow-line regions