Imaging Transitional Disks with TMT: Lessons Learned from the SEEDS Survey

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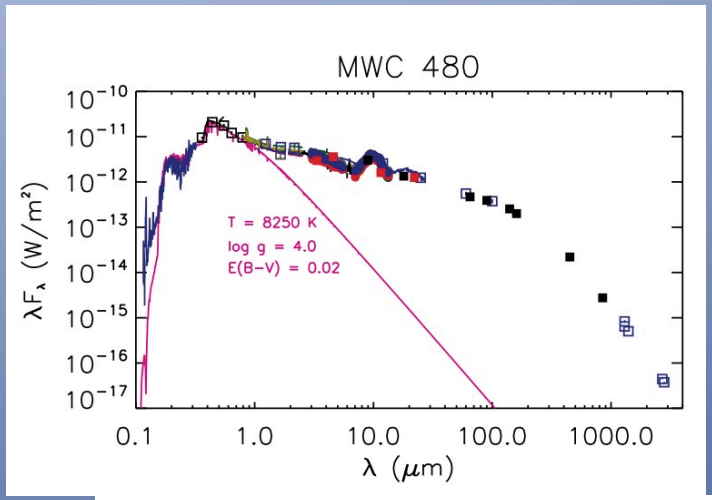
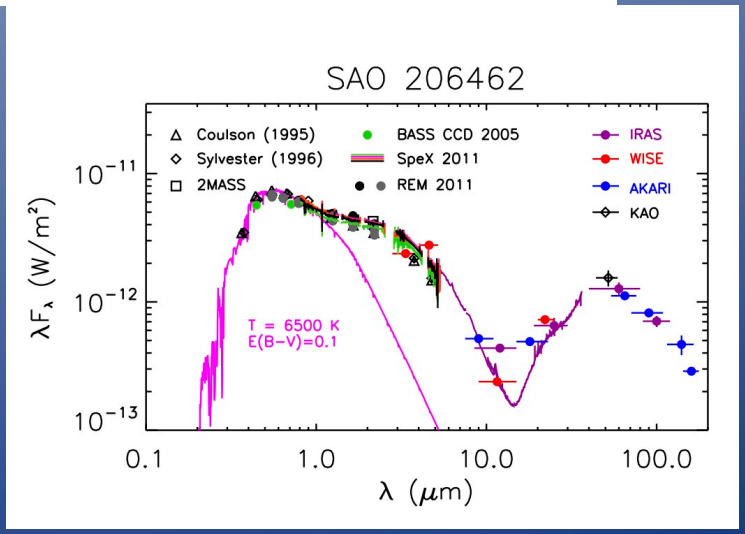
IR SEDS and Imagery for Herbig stars

- HAe stars have 2 distinct types of spectral energy distributions (Meeus et al. 2001; Acke & van den Ancker 04).
- Group II – power law to 200 microns – interpreted as disks with grain growth and settling -Dullemond & Dominik 2004a,b
- Group I fit as power law + BB (Meeus et al. 2001), historically interpreted as flared disks
- Early HST data found scattered light detections were more common (55%), but not universal for group I, and non-detections more common for group II, but again not universal.

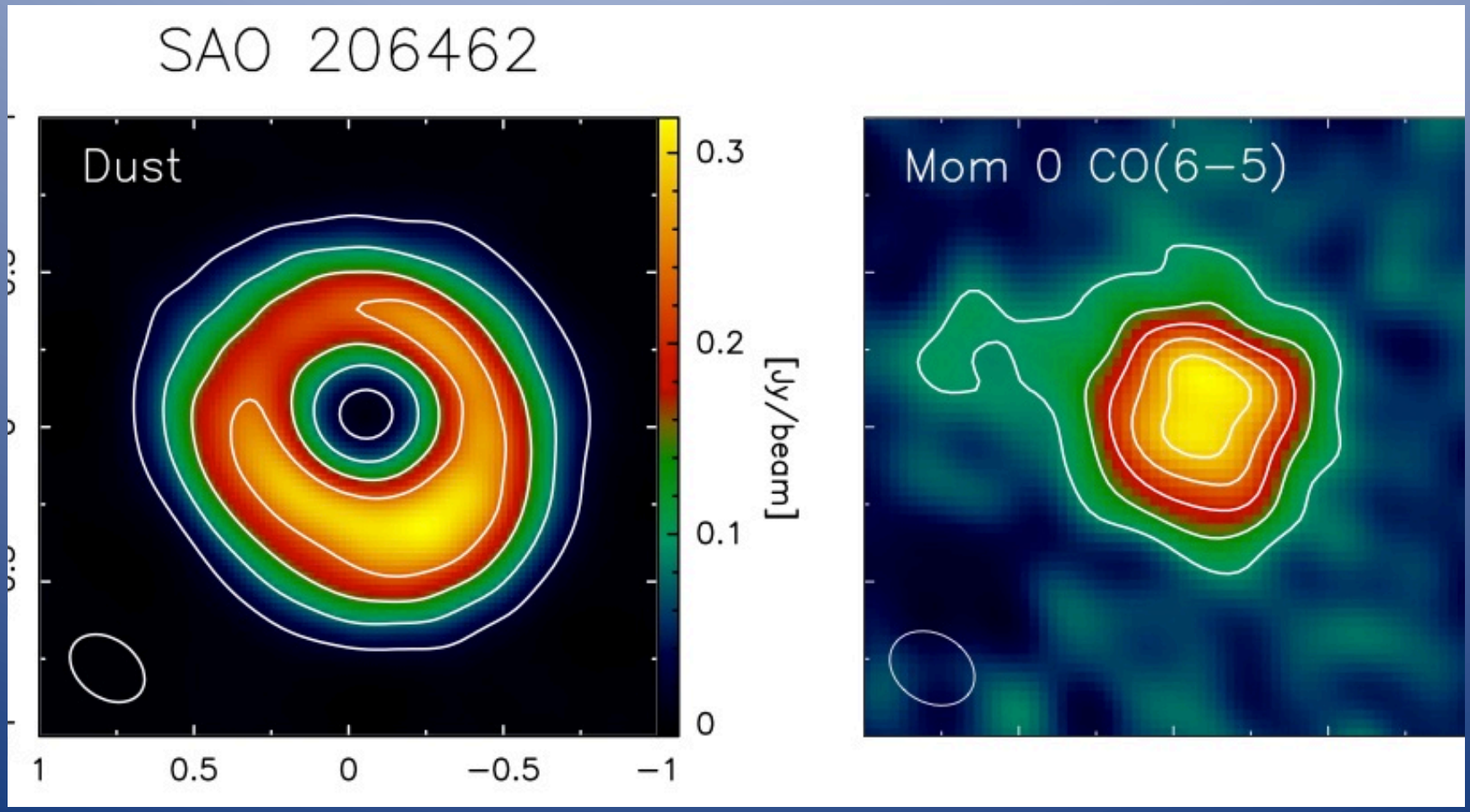




Are Meeus I Disks the missing Herbig Transitional Disks?

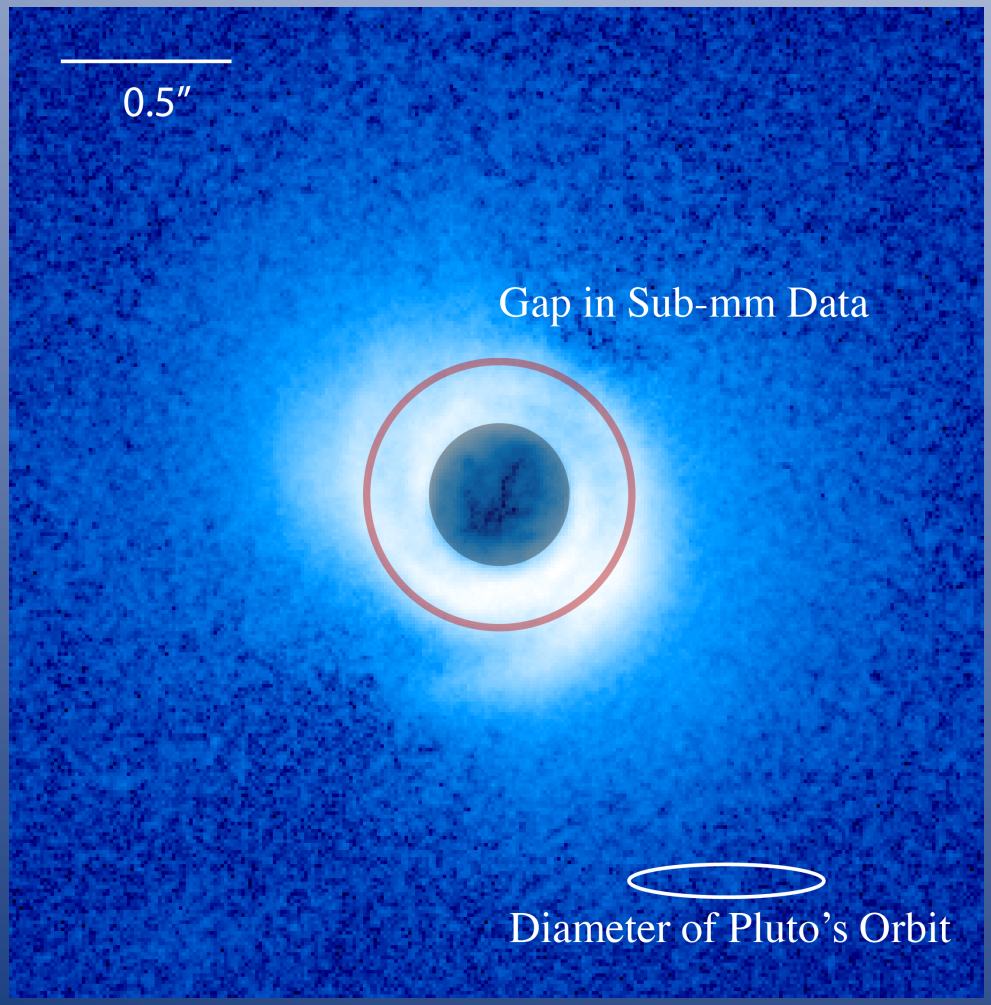
- Originally interpreted as flared, primordial disks.
- Honda et al. (2012) suggest that these are transitional disks, and specificially ones with inner disk components (pre-transitional in notation of Espaillat et al. (2010).
- Sub-millimeter, mid-IR data show central cavities or gaps up to tens of au wide.
- TD defined as having distinctive SED dip, cavities in sub-mm continuum, and associated gas structure…

ALMA data reveal… they are!



Perez et al. 2014

HiCIAO's view



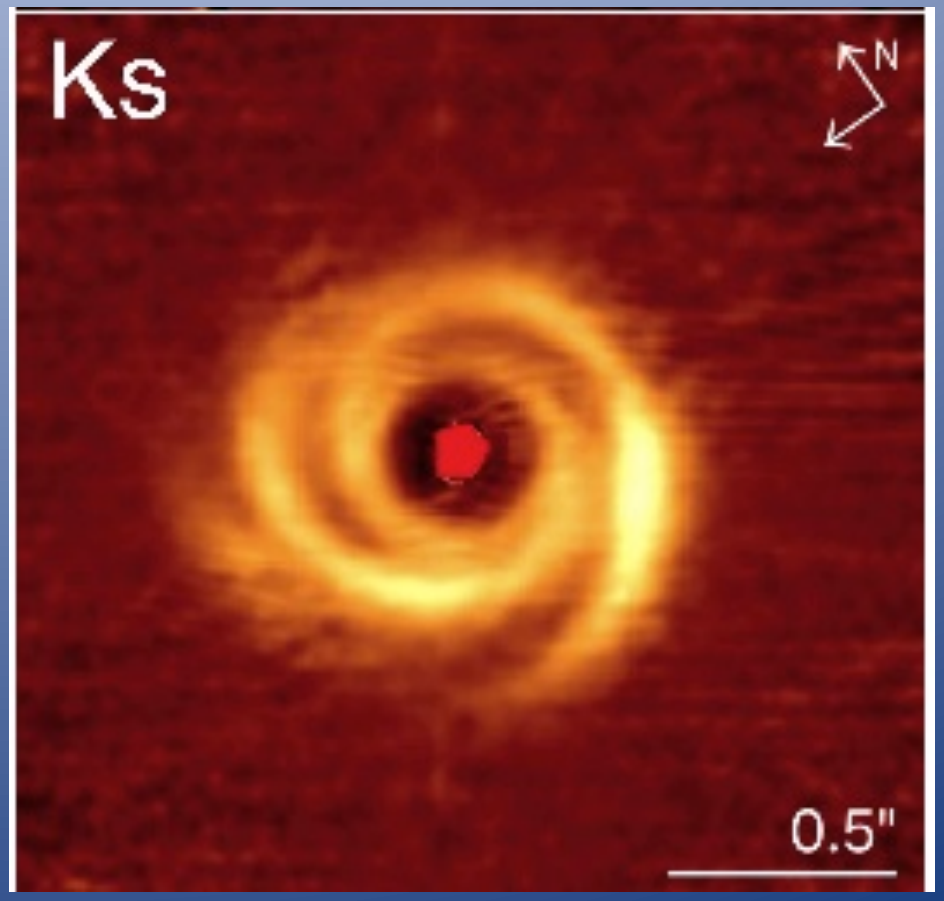
- material in region of SMA & ALMA gap
- disk is not ~circular in Scattered light
- trailing spiral arms
- central dark region is coronagraphic obscuration

Muto et al. 2012

Inner Working Angle Critical for interpretation

IWA matters…

- Smaller IWA of NaCo
- Reveals gap in small
- Dust ~ same size as
- CO gap (Perez et al.
- 2014)

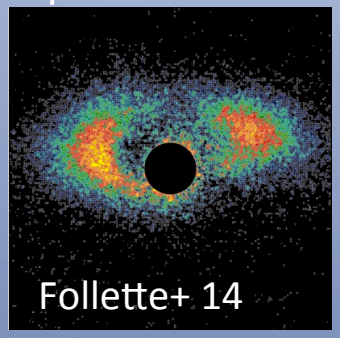


Garufi et al. 2013

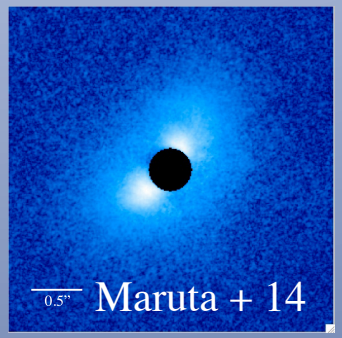
SAO 206462 is not unique

AB Aur

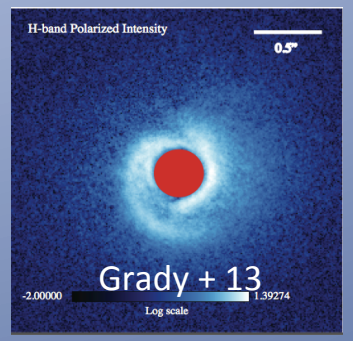
Oph IRS 48



HD 34282

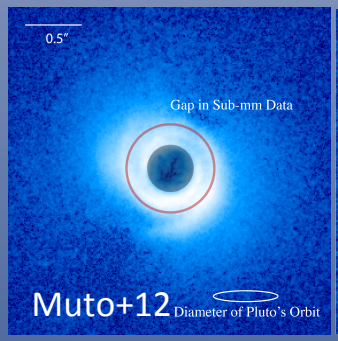


MWC 758

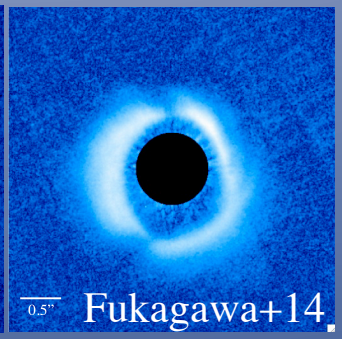


HD 169142

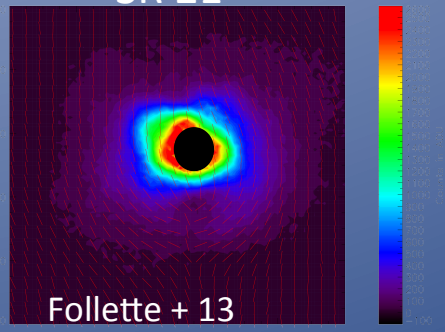
SAO 206462

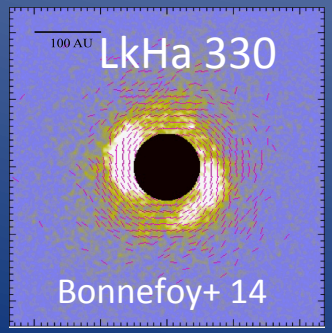


HD 142527



SR 21





Grady et al. 2014

Meeus I disks are Diverse

- Some HST non-detections are due to angular size of disk (HD 34282, HD 179218),
- PI detection rate ≥92%
- NIR gap or cavity size is often smaller than seen in the sub-millimeter continuum.
- 45% have spiral arms/features at some wavelengths – may rise with higher contrast provided by extreme AO systems
- 35% of the HiCIAO sample have eccentric gaps

Mechanisms

- Grain growth and settling – would put sub-mm continuum in region of NIR gap – NOT SEEN
- Photoevaporation: hard to achieve for systems with inner, optically thick dust belts, cannot produce disks with pericenter offsets
- Dynamical sculpting by a companion: required for dust trap mechanism to work; can produce pericenter offsets, and crisp edges to NIR dust and sub-mm gas disks.

Outer Disk Partial Shadowing

- Demonstrated for SAO 206462, MWC 758 and now HD 142527 (Christiaens +14)
- Indicates that the arm/shadowing structures are at high altitude: for HD 142527 wall H/R=0.42, in outer disk more like 0.1
- Optically thick = cast shadows
- May account for some of the prior HST non-detections (MWC 758 with STIS)
- Can't assume that shape of disk in scattered-light imagery reliably informs on geometry

Synergy with data from other wavelengths

- Sub-mm continuum shows where dust mass is concentrated, not full extent of dust disk
- NIR continuum subject to asymmetric shadowing, complicates measurement of inclination, outer radius, etc.
- Shadowing may produce time-dependent chemistry (or asymmetric detection of species) in disk
- May need multiple measures of a disk's properties in dust and gas

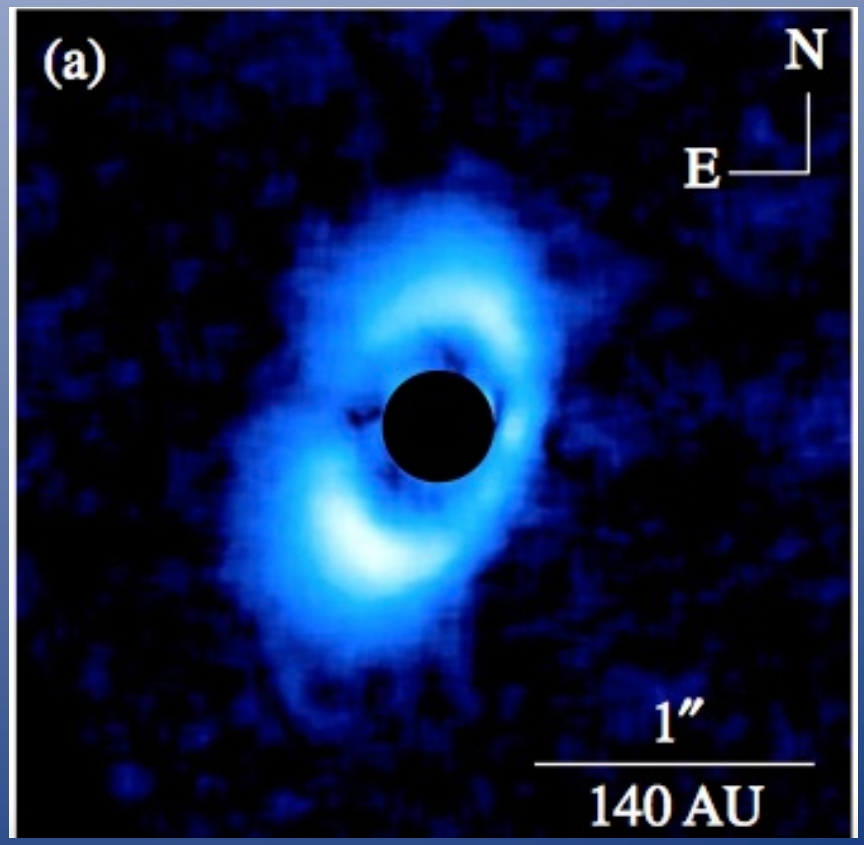
Limitations of Extreme AO on 8m-class telescopes

- Wavefront sensing typically done at R or I: can't use LGS with GPI or Sphere
- Excludes observing of highly reddened systems, fainter systems, and disks around young solar or sub-solar analogs

T Tauri Transitional Disks

- Transitional disks with large cavities are known
- Typically do not exihibit spiral arms at Strehl 0.2-0.3 with 8m-class telescopes
- SED modeling indicates the disks are dynamically colder (Andrews et al. 2011)
- Expect arms to be more tightly wound (talk by Muto)

PDS 70 Hashimoto et al. (2014)



T Tauri transitional disks

- Too faint for optimal performance of extreme AO systems on 8m-class telescopes Also likely to host dust traps
- offset in inner radius SMA and NIR dust observed PDS 70 (Hashimoto et al. 2014)
- Due to status as disks around young, Solar analogs, these are natural targets for TMT and its AO system.

Discovery space for TMT

- A T Tauri transitional disk survey should be a priority as early in TMT operations as feasible.
- Such a survey, looking at young Solar analogs and young Jupiter analogs would have high EPO potential, public interest, and would naturally highlight what TMT can do that the 8m-class telescopes have not been able to do.

Summary

- NIR polarized light imagery of disks has revealed remarkable diversity in Herbig Ae disks and allowed us to identify the Meeus Group I disks as transitional (mostly pre-transitional) disks
- Similar data to that starting to come from extreme AO systems on 8m-class telescopes for brighter Herbig stars should be feasible for T Tauri transitional disks early in TMT operations.