Transitional Disks Associated With Intermediate-mass Stars: Results of the SEEDS YSO survey

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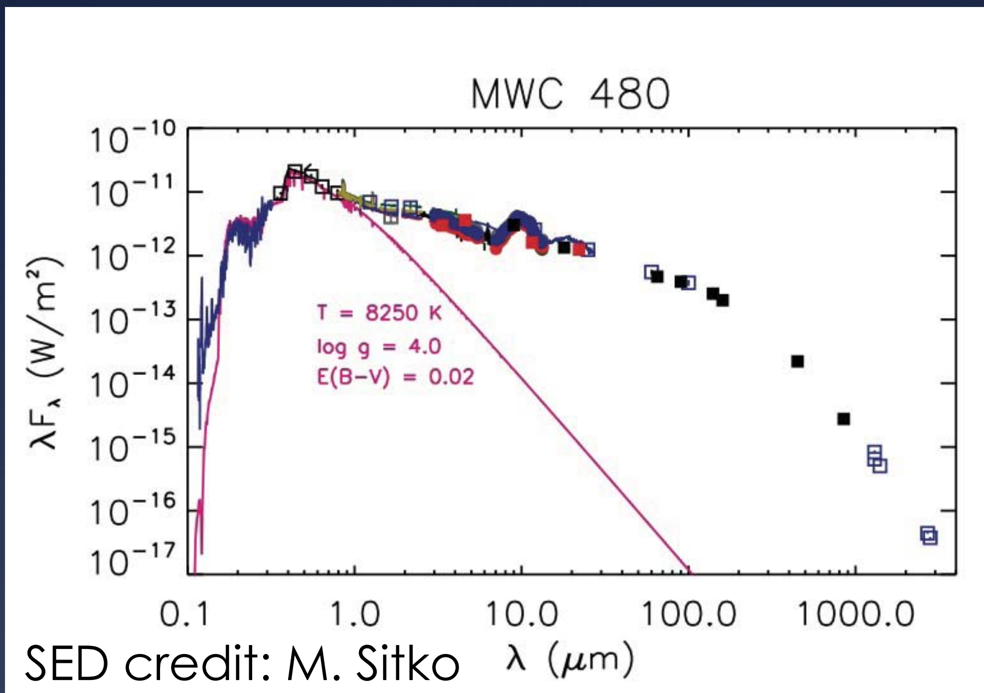
Talk Roadmap

- 1. IR SEDs for Intermediate-mass stars
- 2. The SEEDS Survey –
- 3. Transitional Disks Imagery and Interferometry
- 4. The path forward

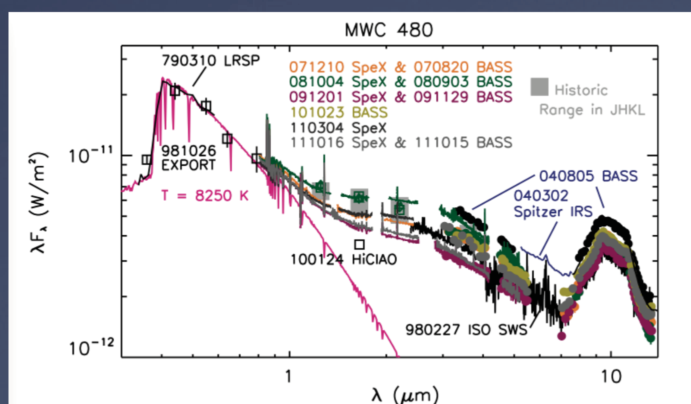
The SEEDS YSO Survey

- 1-10 Myr old objects, both single and binary/multiple stars
- 210 objects which are to be searched for both disks and the presence of planets in/near the disks.
- Bulk of stars studied at H-band using Polarimetric Differential Imaging (Hinkley et al. 2009) + Angular Differential Imaging (Thalmann et al. 2010).
- Focus in this talk on disks associated with stars of spectral types B-G.
- IR SEDs for these stars come in 2 flavors from 1-200 μm: power law only (Meeus et al. 2001, Group II) and powerlaw + blackbody (Meeus Group I)

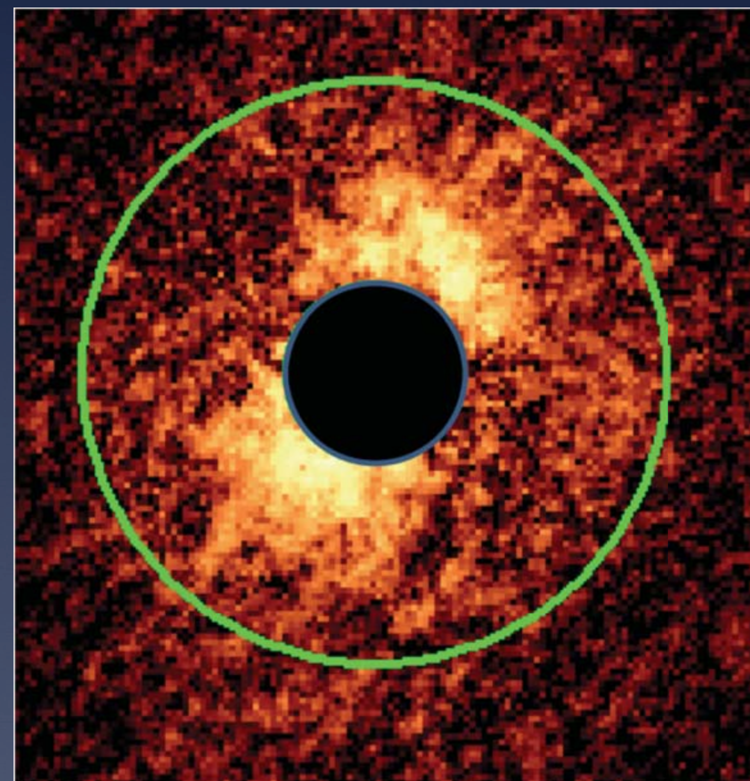
2. IR SEDS– Meeus Group II



SED credit: M. Sitko

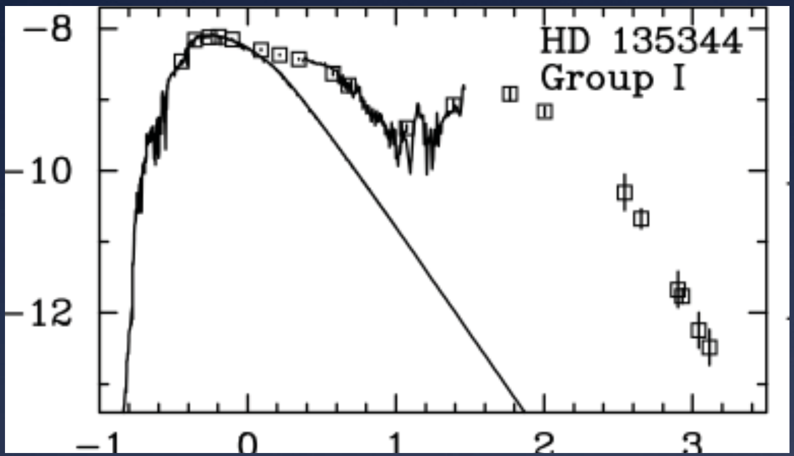


Kusakabe et al. 12

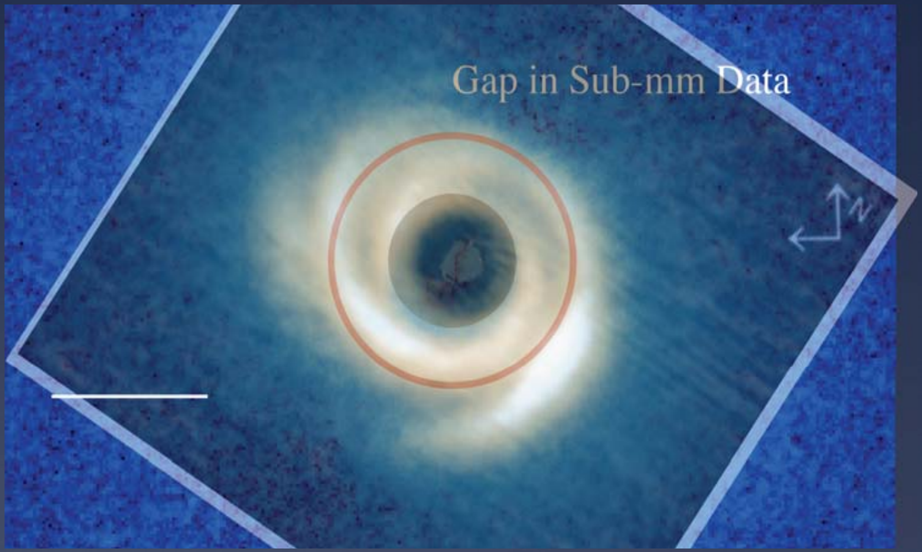


H band PI, Kusakabe et al. 2012

IR SEDS- Meeus Group I



Acke & van den Ancker 04

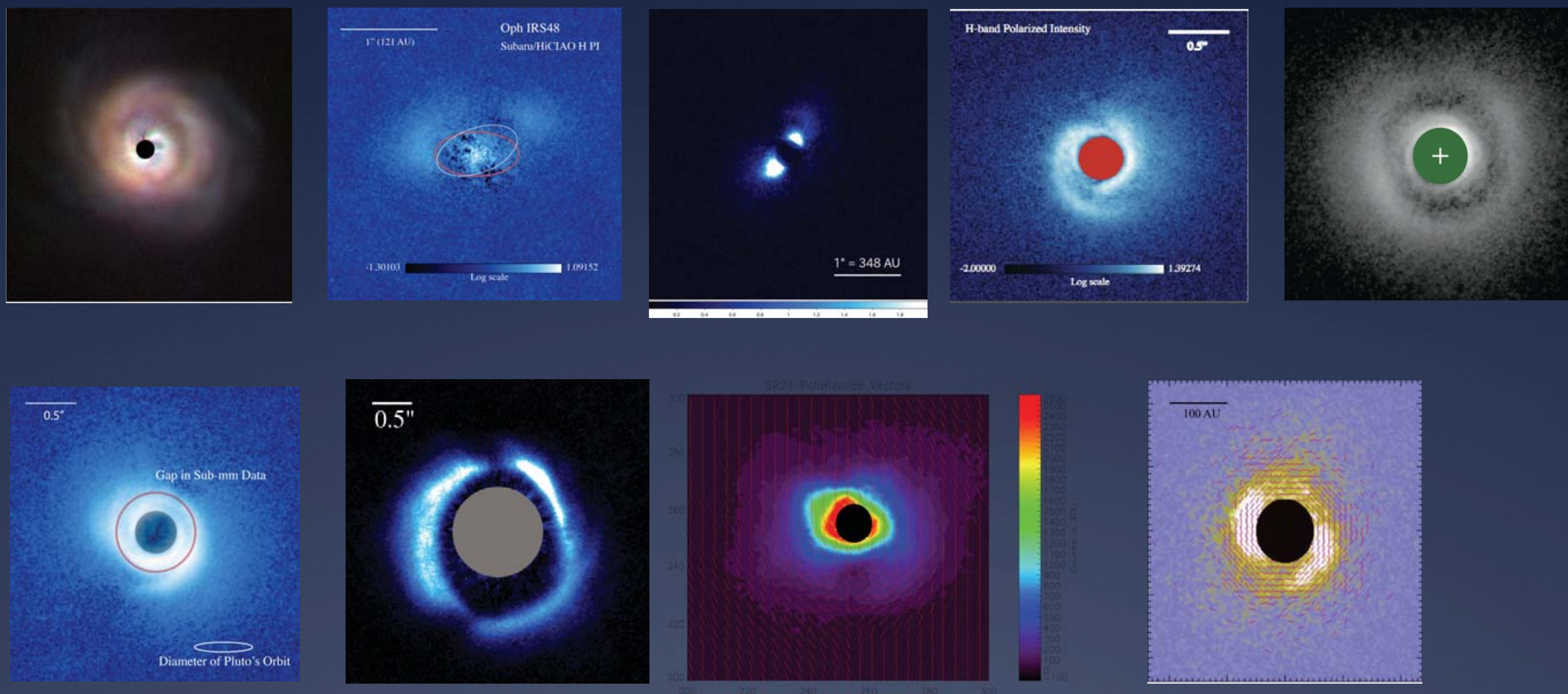


Muto et al. 2012 H PI, Garufi et al. 2013 Ks PI

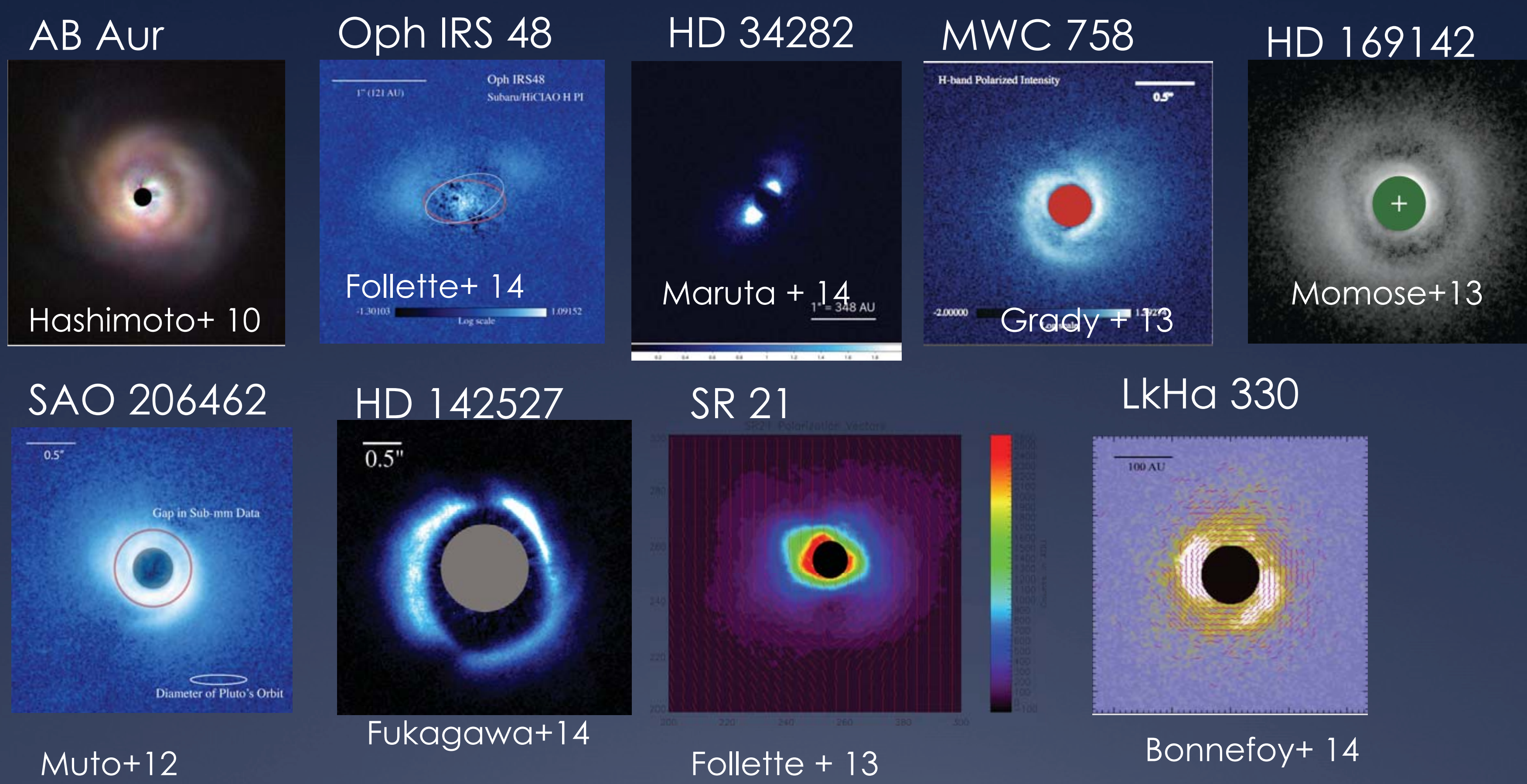
Stars in the Survey

* HD 179218 (ND), HD 100546 (NaCo), HD 97048 (NaCo), AB Aur, Oph IRS 48, HD 34282
* MWC 758, HD 169142 (HiCIAO and NaCo), SAO 206462 (HiCIAO and NaCo), CQ Tau (ND)
* HD 142527(HST NICMOS, NIRI, NaCo, HiCIAO), LkHa 330, SR 21

Meeus I disks are diverse



Meeus I disks are diverse



Are Meeus I Disks the missing Transitional Disks?

* 66% of the HiCIAO sample have inner cavities seen in sub-millimeter interferometry
* 55% have gaps seen in the NIR either with HiCIAO or VLT/NaCo (smaller IWA)
* Gap non-detections include the more distant systems – NIR detection rate is clearly sensitive to IWA and proximity of the disk.
* Conclude that the majority of the well-studied Herbig stars with Meeus I SEDS are transitional disks – same conclusion reached by Maaskant et al. (2013).

Statistics for Meeus I disks

- 9 disks in HiCIAO sample, 11 if include VLT/NACO imagery in the literature; scattered light detection rate ~85% detection rate
- Featureless disks: up to 3 – 25% of sample – may reflect Strehl ratio of data… or distance to star
- Gapped disks visible in NIR – 44% of HiCIAO sample, rises with smaller IWA
- Broken powerlaw systems: 0 – these would be hard to find, given other structure
- 45% have spiral arms/features at some wavelengths
- 35% of the HiCIAO sample have eccentric gaps

Statistics (con't)

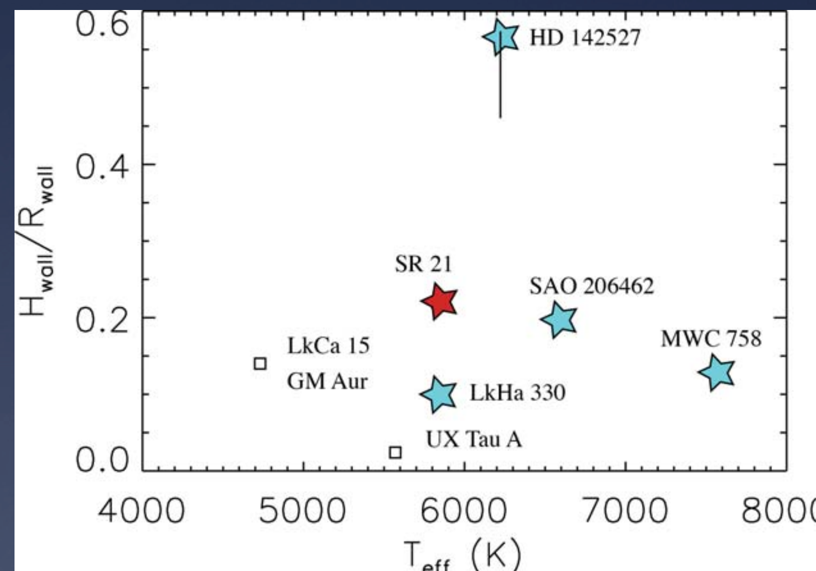
* Disk detection rate in scattered light is high compared with Meeus II disks (hit or miss with HST and NIR ground-based surveys)

* Diverse grain properties: Some disks can be fit with MCRT codes using compact grains (HD 142527), others require porous grain aggregates (Oph IRS 48), and some can be modeled using either.

* 2 flavors of spiral – some dominated by ISM-like grains (AB Aur) and extend beyond mm disk – envelope material, others seen throughout NIR and clearly associated with disks.

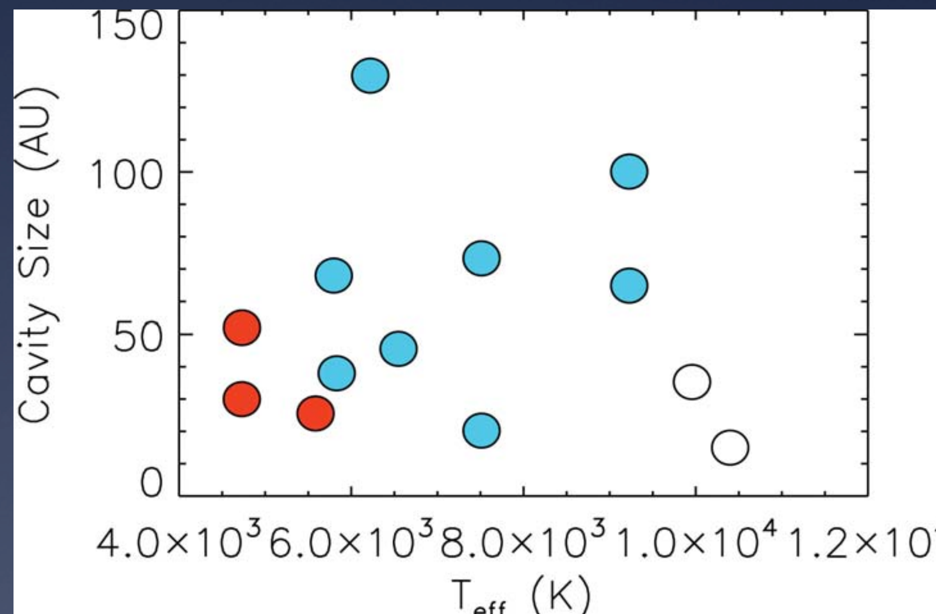
Why and When are we seeing structured disks?

- Andrews et al. (2011 - same model for T Tauri and Hae transitional disks - Hwall/R_wall
- Expect loosely wrapped arms for dynamically warm disks – easier to image
- Some of our non-detections (SR 21) have large H/R and were obtained at low Strehl ratio.
- Some of the non-detections are for systems viewed at 50-55° inclination – projection effect?



Gap Properties for Meeus I disks

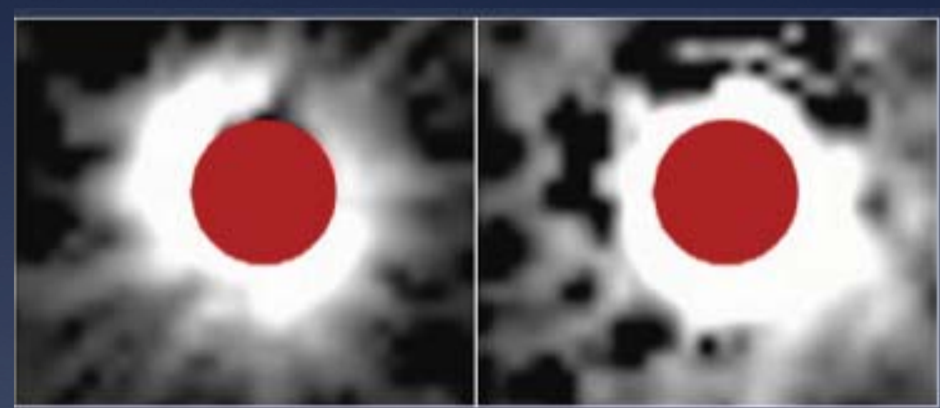
- All disks are pre-transitional
- Gap size is
  - uncorrelated with FUV radiation field.
  - Uncorrelated with system age
- Dynamical origins are suggested by the fact that one of these systems hosts 2 exoplanet candidates.

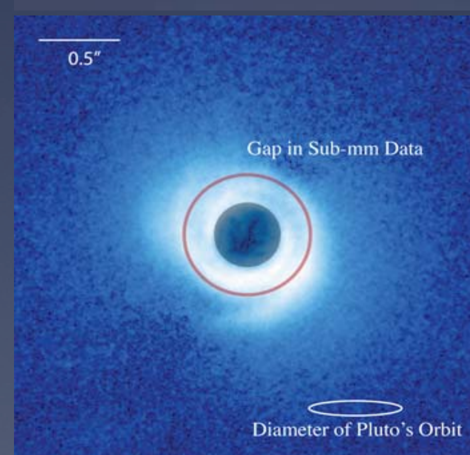


Potential of Extreme AO

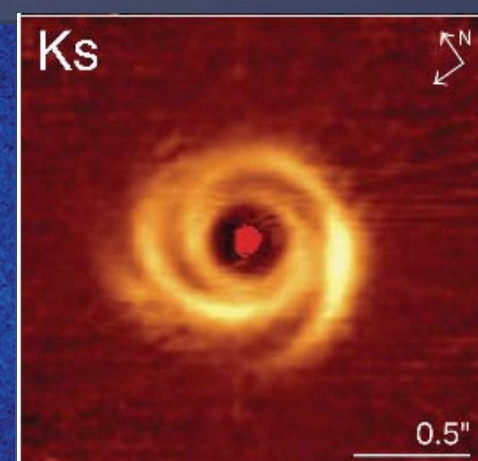
- SCExAO - smaller IWA – 4x better than HiCIAO, 2x better than NACO - image in to 7AU at d=140pc
- More stable PSF – may be able to get I images to go with PI data from HiCIAO – probe of grain properties
- Classification of disks can change with IWA – case in point is SAO 206462 – would classify as a filled disk with spiral arms from HiCIAO, but NaCo data clearly demonstrate a cavity which is smaller than seen in the sub-mm.

HST NICMOS



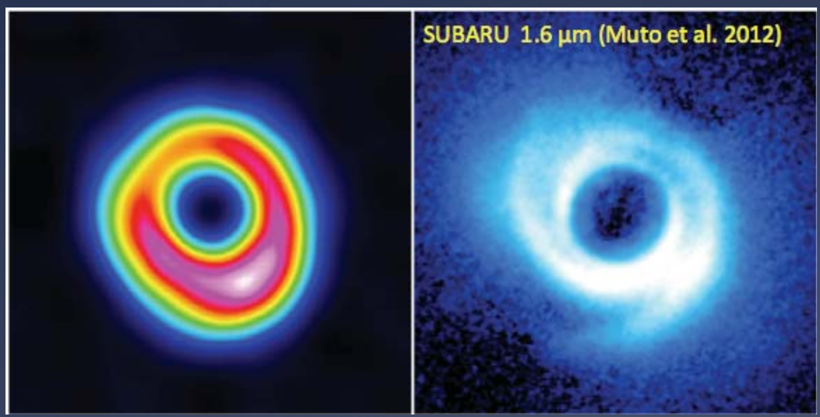


Muto et al. 2012



Garufi et al. 2013

Synergy between scattered light imagery and ALMA



Perez et al. 2012

- Band 9 ALMA continuum for SAO206462 has a gapped ring, similar to SMA, but places the gap and the flux maximum at different locations in the disk.
- SE "wall" coincides with SE arm.
- Gapped ring morphology appears typical for the transitional disks in the sub-mm continuum.
- Can expect ALMA data to evolve as interferometer comes fully on-line.

Conclusions

- Structure in the form of spiral arms, gaps, etc. extremely common in Intermediate-mass transitional disks. Easier to see in dynamically warm disks, and can be washed out if the image quality is low.
- Gap size and visibility in the scattered light imagery does not correlate with stellar properties (mass, luminosity). Excludes photoevaporation, and suggests an independent process, such as exoplanet formation.
- Expect disks around lower-mass stars to show structure as the IWA, Strehl ratio, and contrast of the imaging data improve.
- Next phase of study will be searches for indirect signatures of exoplanets in these disks such as rotation of planet-induced spiral arms, and direct imaging searches for the exoplanets and/or their accretion luminosity.
- Please See Posters: Baille, Follette, Garufi, Hanawa, Kanagawa, Matter, Takahashi, S., Tsukamoto, Wisniewski, and Yasui