Transitional disks and their host stars

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Star and planet formation

- Class II => III:
  - Transitional disk
  - Dust/gas dissipation
  - Hole/gap

Hogerheijde 1997
Transitional disks

Indirectly:
SED modeling

Merin et al 2010
Transitional disks

Direct imaging: Interferometry with SMA

Brown et al 2009
Transitional disks

- Asymmetries (ALMA)
Transitional disks

- Mechanisms dust clearing:

  Grain growth
  Photoevaporation
  Stellar companion
  Forming planet?

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Transitional disks

- Understanding disk evolution and planet formation

=> statistical studies: large sample!
Goals of thesis

- An (unbiased) sample of transitional disks
- Analysis of hole sizes and global disk structure using RADMC SED modeling
- Derivation disk properties and constraining origin of the dust hole
- Link exoplanetary systems to transitional disks
**Finding transitional disks**

- Basic tool: looking at the SED in IR
- Literature & Selection criteria
- Spitzer mission: lots and lots of IR mapping:
  - IRAC: 3.6, 4.5, 5.8 and 8.0 μm
  - MIPS: 24, 70 (and 160) μm
  - Some targets IRS: spectra 5-34 μm
- Full analysis of Spitzer maps: catalogs
Finding transitional disks

- C2d + GB: local star forming regions
- >3000 YSOs have been found
- How to find transitional disks?
Finding transitional disks

- Study Bruno Merin to develop color criteria: how to identify transitional disk candidates with SED photometric fluxes?
- 33 targets
- Opt+IR+mm photometric fluxes + IRS spectrum
- full SED modeling

Merin et al 2010
Finding transitional disks

+ * Disk with hole
△ Edge on disk
◇ Disk without hole

Color criteria:
Regions A/B select disks with holes!
(no need for modeling)
Finding transitional disks

Sz84: 55 AU hole and falls outside Region A

=> additional set of criteria using MIPS2 (70 µm)
(van der Marel et al., in prep.)
Finding transitional disks

- Selection criteria on c2d and GB in combination with MIPS2 (70 μm) > 40 mJy: bright disks!
- > 100 new candidates found!
  + ~ 70 candidates and confirmed TD from literature
- **Additional data** required to determine properties and confirm TD!
Finding transitional disks

- Requirements before SED modeling

- SpT for $A_v$
- Flux measurements @JCMT/APEX/SMA
- Submm fluxes
- IRS-Spitzer/WISE/VISIR
- 10-15 micron (dip)
- Optical/NIR spectroscopy@WHT
- Opt/IR fluxes
- Catalogs Spitzer/2MASS/WISE
- Also: accretion!
- Flux measurements @JCMT/APEX/SMA
Stellar properties

- Important for SED: $T_{\text{star}}(\text{BB}) \Rightarrow \text{SpT}$
Stellar properties

- Spectral types: (OB) AFGKMK
- Temperature: 10 000 – 2000 K
- Classification using optical/NIR spectroscopy
  - Atomic/molecular lines
  - Photometry
- ISIS/LIRIS spectroscopy with WHT
- Also: accretion rate $dM/dt$
Stellar properties

• Two main problems:
  – Accretion shock: veiling
    => excess continuum towards blue
    continuum more blue, lines less visible
  – Interstellar matter: extinction
    => suppression continuum towards blue
    continuum more red

• Both effects to be taken into account!
Stellar properties

- What could happen with wrong SpT...
Stellar properties

- Approach: fitting routine of optical/NIR spectra which fits temperature, extinction and veiling (accretion) simultaneously (Manara et al. 2013)
- Accretion important property as well:
  => photoevaporation only possible when accretion is low!
Finding transitional disks

- SED modeling >150 transitional disk (candidates): hole sizes ~ 0.5 – 150 AU
- Follow-up resolved dust imaging SMA/ALMA
- Construct robust sample TDs (10-15) => largest holes (>5-10 AU) which can be resolved in gas
Transitional disks

- Mechanisms dust clearing:

  Grain growth  Photoevaporation  Stellar companion

  Forming planet?

⇒ What about the gas?

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Transitional disks

- Mechanisms dust clearing:
  - Grain growth
  - Photoevaporation
  - Stellar companion

⇒ Need to know the gas distribution and mass < 50 AU ⇒ ALMA
ALMA

- Atacama Large Millimeter Array
- Atacama desert, Chile (5000 m altitude)
- Built and operated by Europe (ESO), North-America (NRAO) and East-Asia (NAOJ)
- Total cost ~1.3 billion $US
**ALMA**

- **Freq bands:** 315 µm - 3 mm (80-950 GHz)
ALMA

- Final array 66 antennas:
  - 50 12-m (25 EU and 25 US)
  - 16 (12 7-m) Short spacings (East Asia):
- Baselines up to 16 km (0.005” at 650 GHz)
- State of the art wide-band receivers and high resolution correlator
- ALMA allows measurement of gas distribution on <20 AU scales
- Early Science programs (2012-2014) on TDs
ALMA

- First target (observed in 2012): Oph IRS 48
- Asymmetry: interpreted as dust trapped in vortex => important step in planet formation

Van der Marel e.a. 2013/Bruderer e.a in prep.
**ALMA next cycles**

- Future ALMA: increase resolution and sensitivity
- Observe unbiased sample of transitional disks:
  - Resolve gas distribution range of Tds

\[\Rightarrow\] Large, broad sample of TD's with known distribution of gas and dust
**ALMA next cycles**

- With knowledge of gas, dust and accretion:
  
  Grain growth  Photoevaporation  Stellar companion
  
  Forming planet?

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Future possibilities

- More molecules: **chemistry**
- Other frequencies: **temperature**
- Substructure in holes: **planet orbits?**
- Comparison with other samples of TTS and debris disks: **evolution**
- Comparison hole size distribution with exoplanetary systems: **planet formation**

\( (+) \text{ planet (exoplanet.eu 2009)} \)

\( (*, \Diamond, \bullet \) \text{ Transitional disks (Merin et al 2010, Kim et al 2009, Brown et al 2007)} \)
Questions?