A Millimeter-Wave View of the "Transition" Disks

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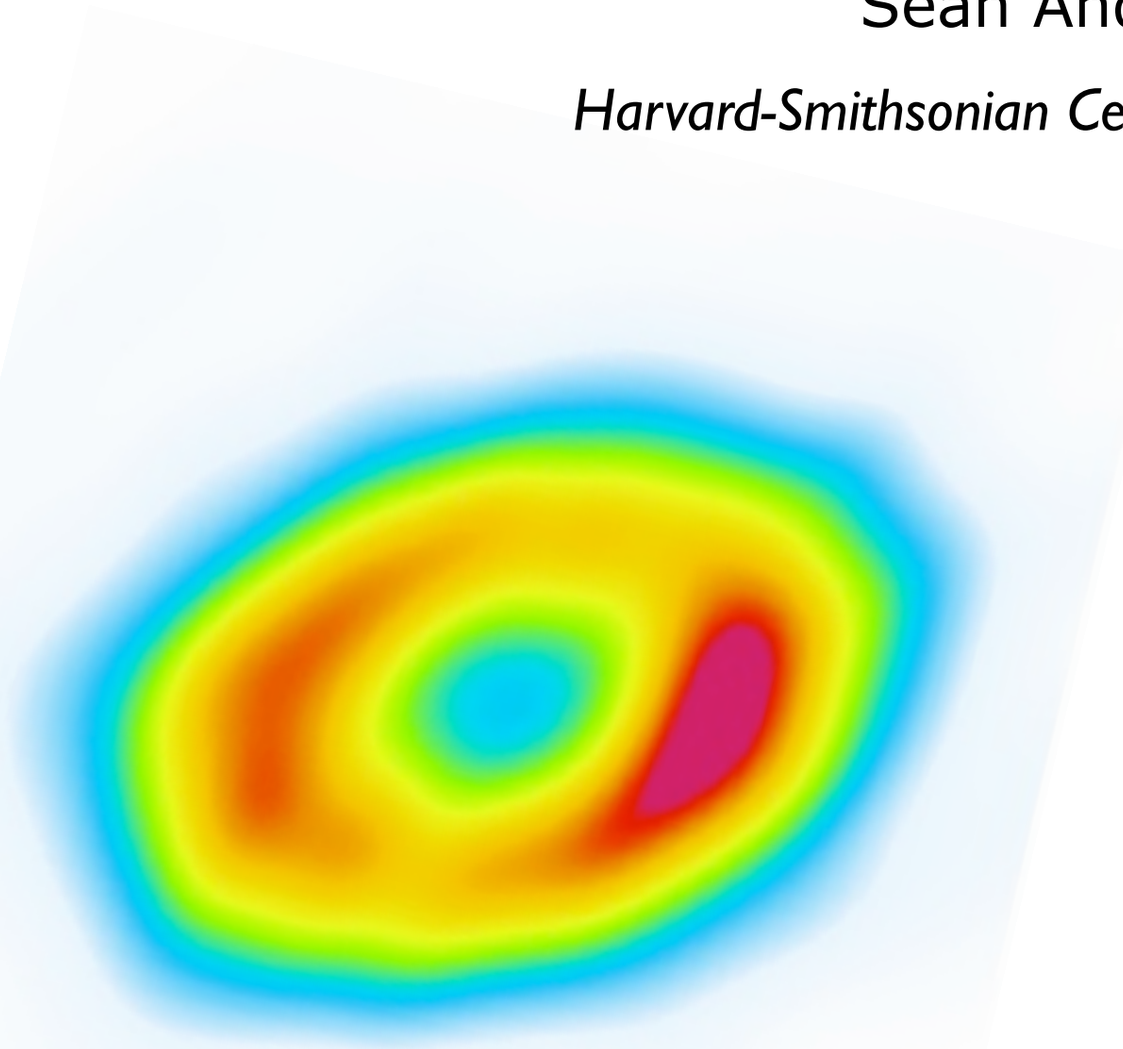
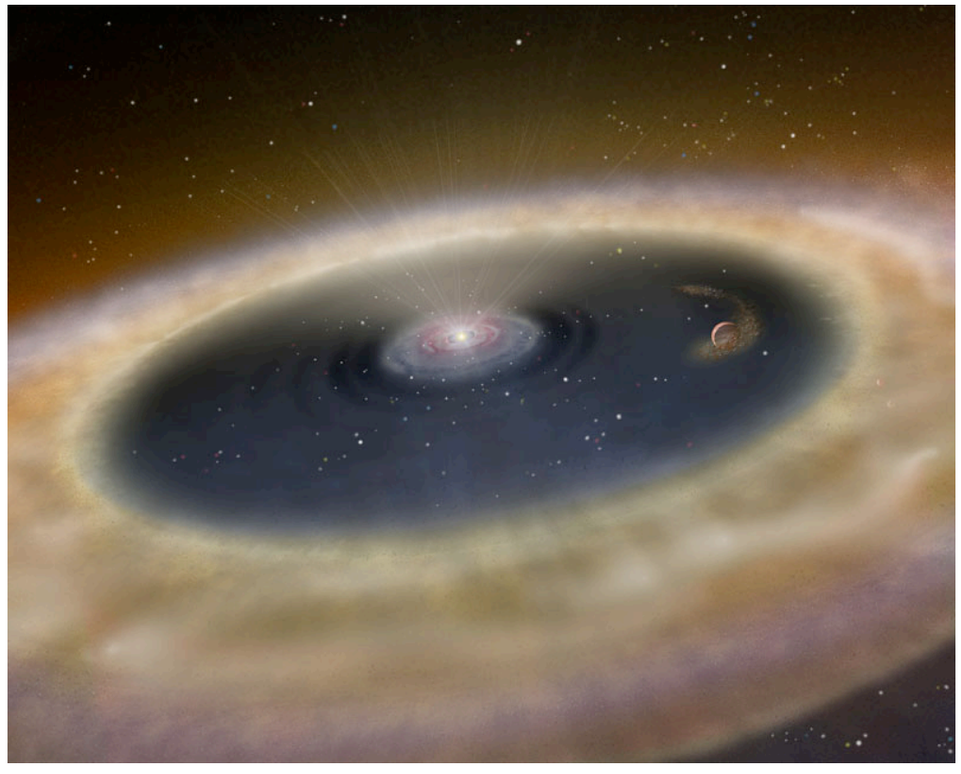
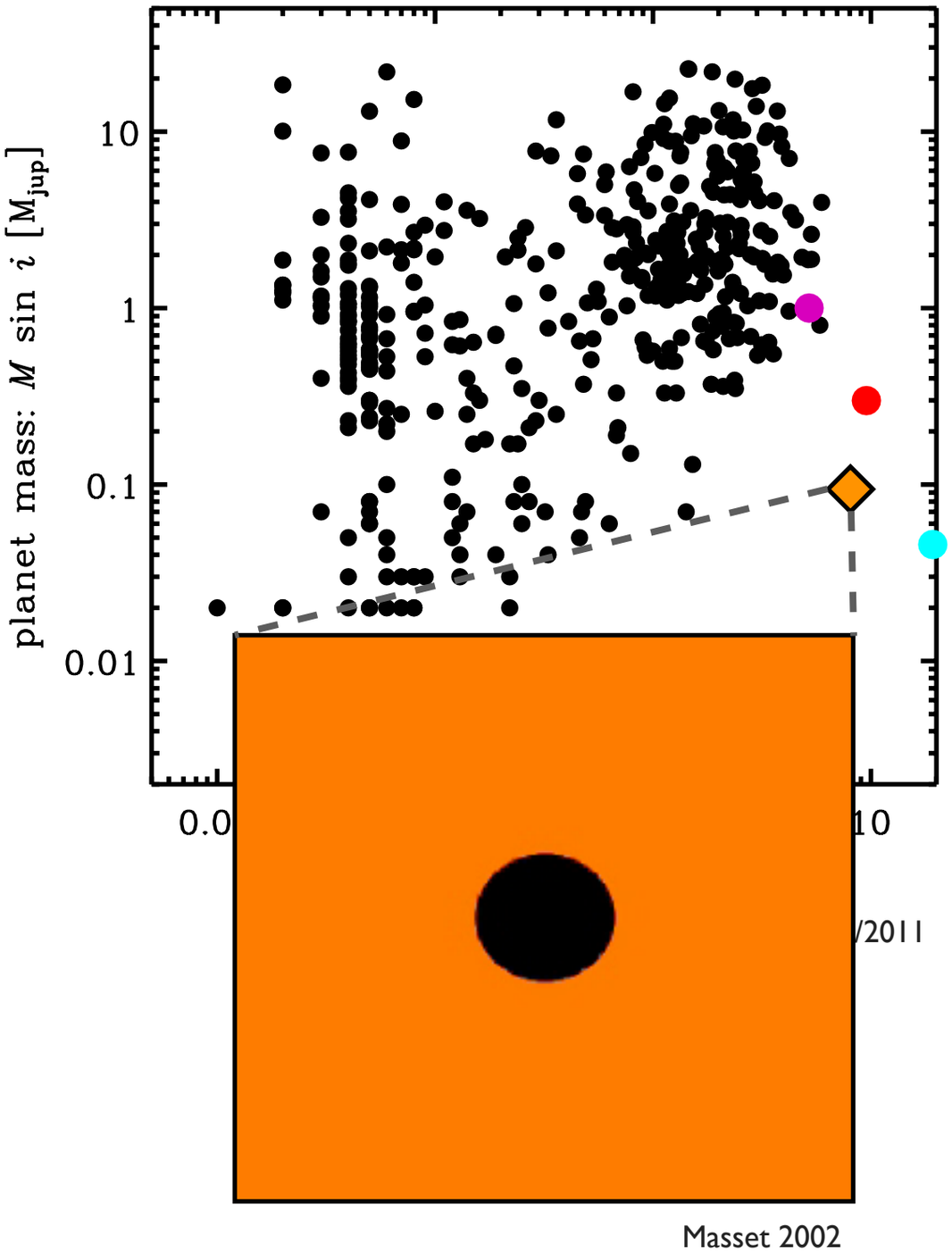


Andrews et al 2011b; SMA + PdBI (0.88mm)



Kraus et al 2012; illustration by K Teramura

planetary origins: disks as "initial conditions"



1. feasibility (disk properties)

   Q: is there enough stuff(*r*,*t*) ?

   A: yes, probably

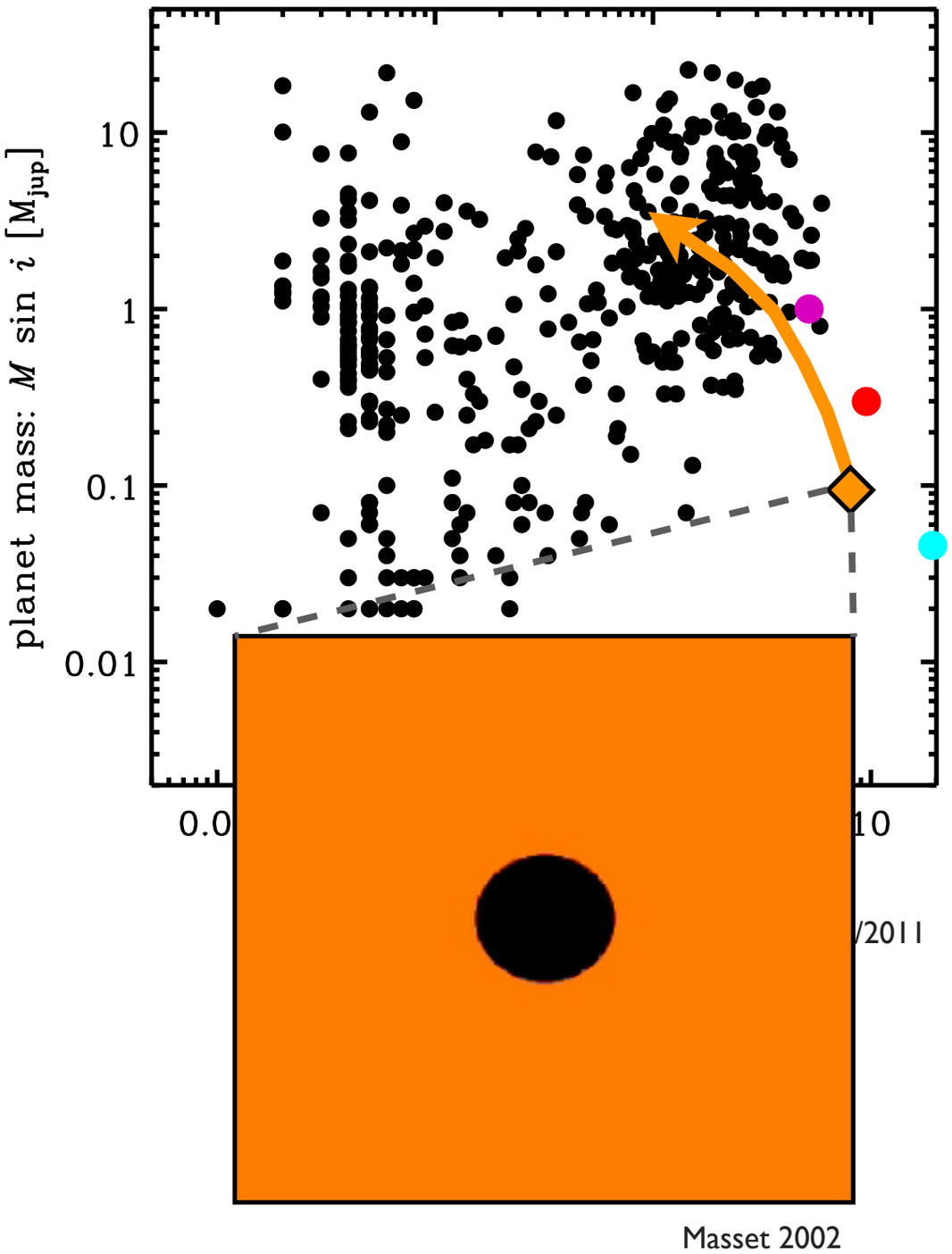
2. early evolution (disk+planets)

   Q: how does planet(*r*,*t*,*disk*) ?

   or disk(*r*,*t*,*planets*) ?

A: ???...

planetary origins: disks as "initial conditions"



1. feasibility (disk properties)

   Q: is there enough stuff(*r*,*t*) ?

   A: yes, probably

2. early evolution (disk+planets)

   Q: how does planet(*r*,*t*,*disk*) ?

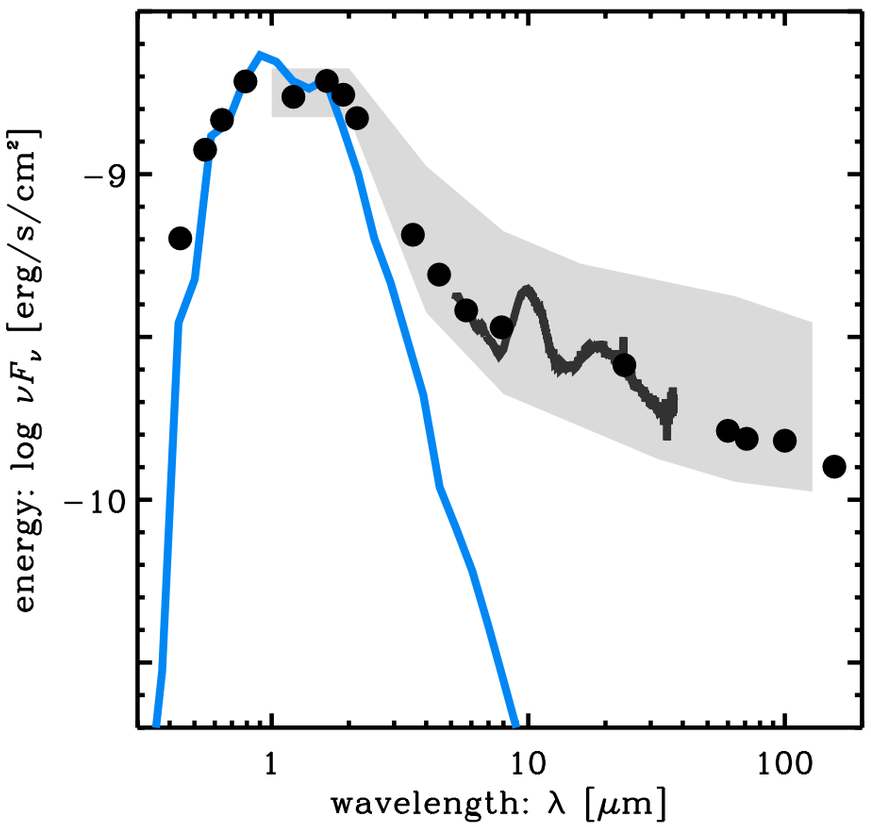
   or disk(*r*,*t*,*planets*) ?

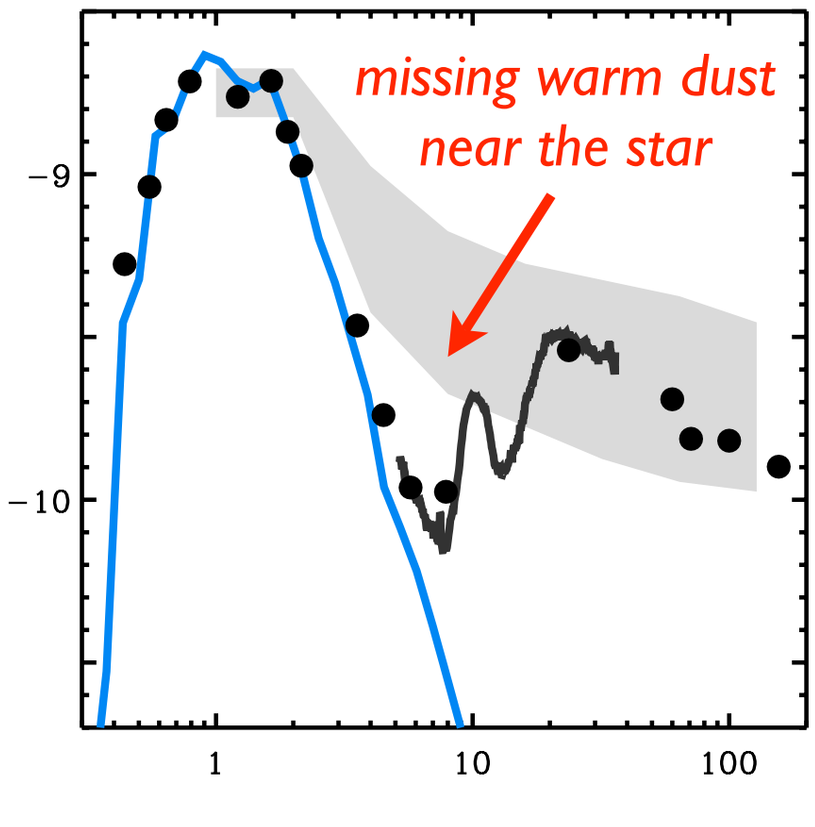
A: ???...

measured planet properties are *not* their initial values

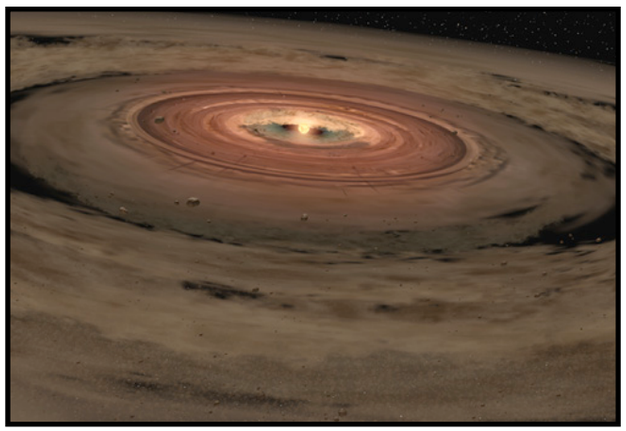
...disk evolution matters...

what is a transition disk?

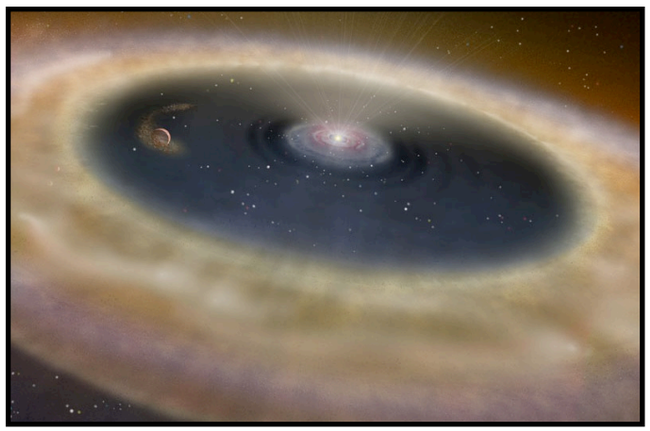




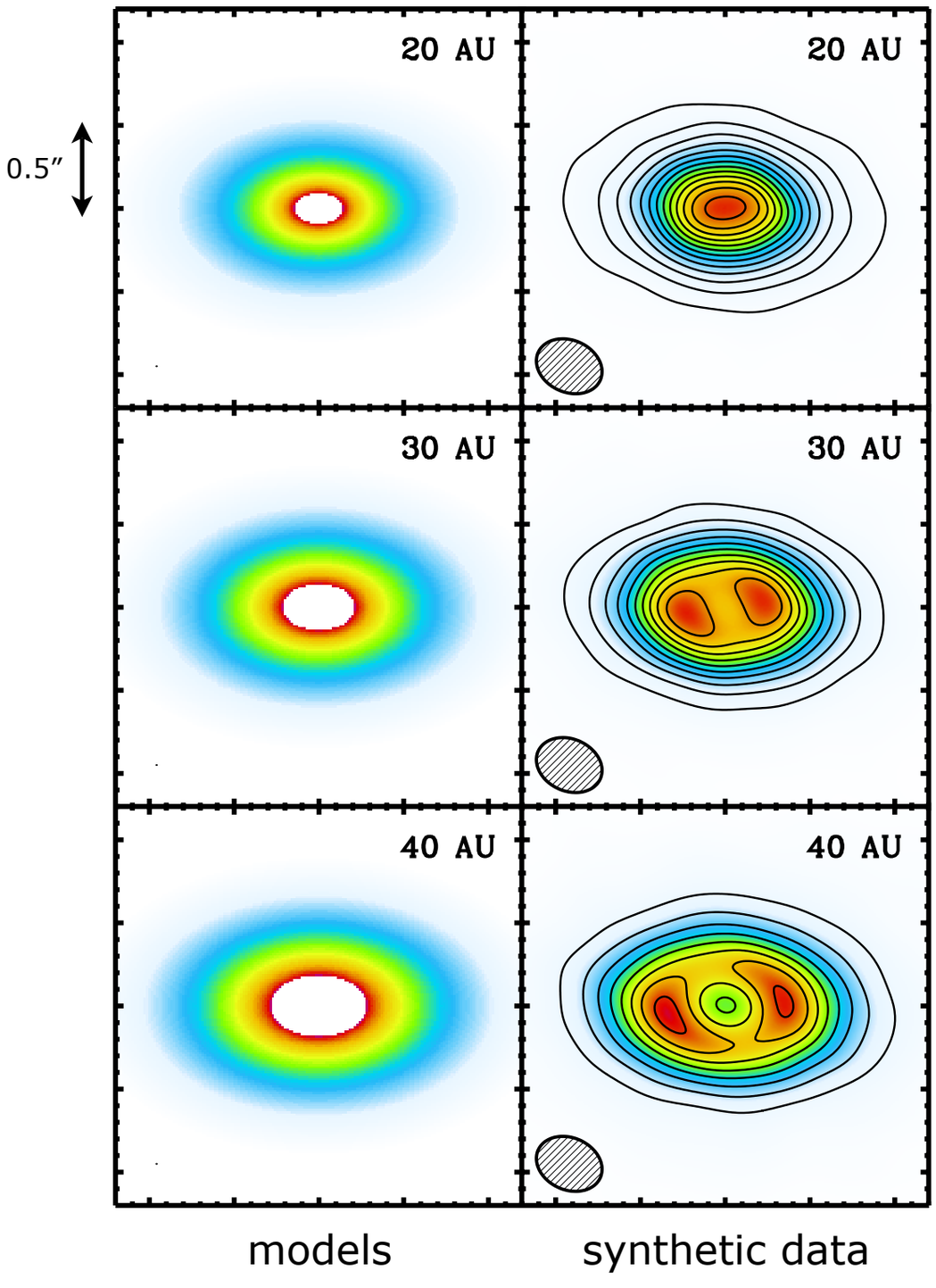
"normal" disk



"transition" disk

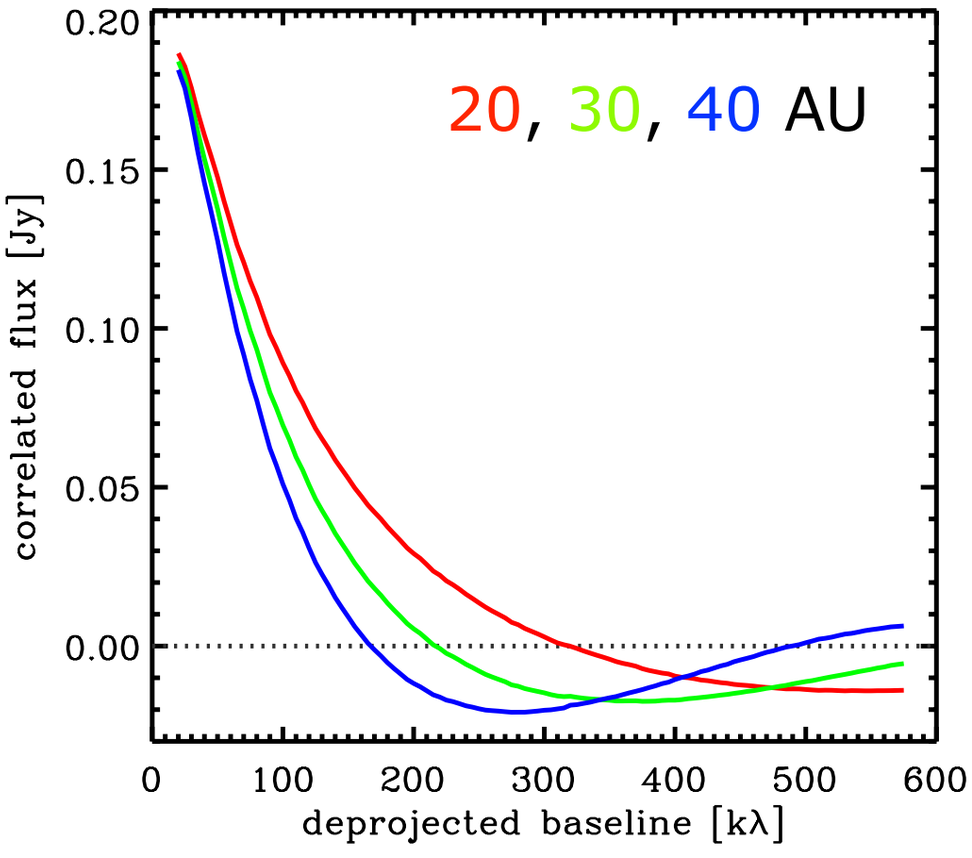


mm-wave imaging of transition disk "cavities"

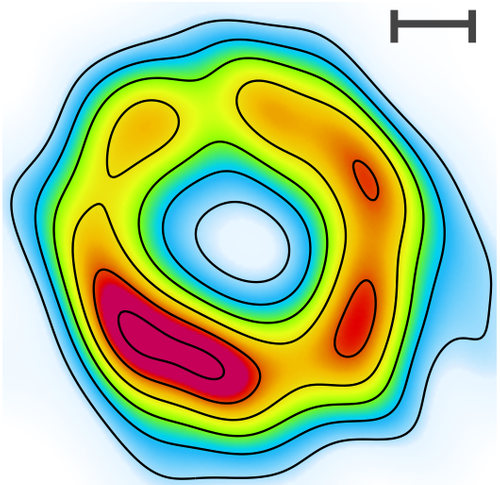


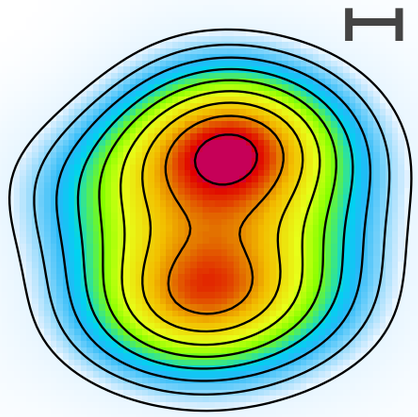
observing requirements:

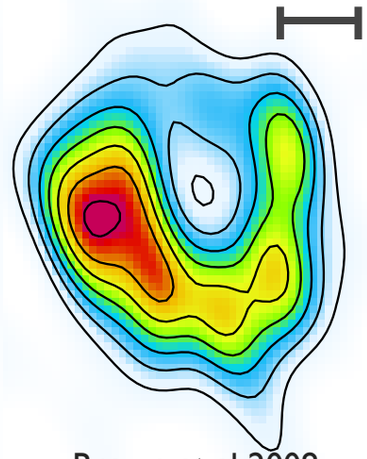
- high angular resolution (<0.5")
- good sensitivity (>100 mJy)
- (helps to know viewing geometry)

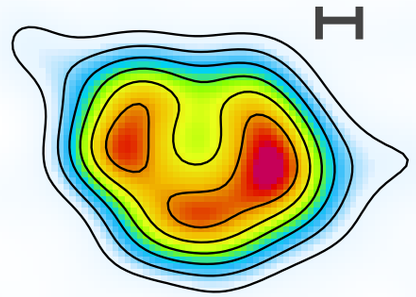


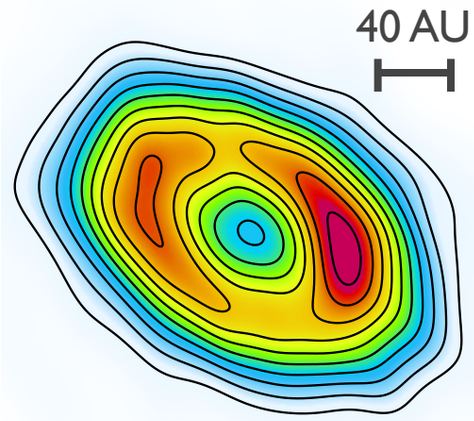
mm-wave transition disk images


Mathews et al 2012

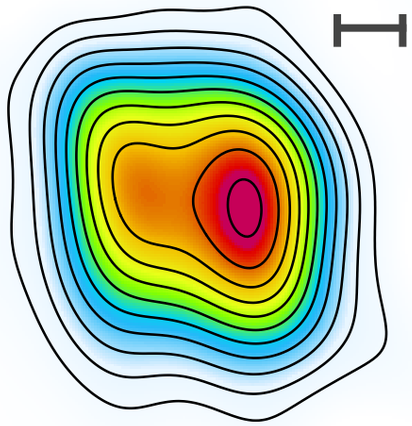

Isella et al 2010b

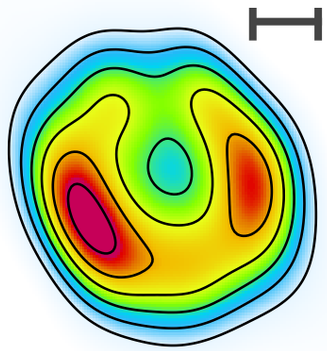

Brown et al 2008

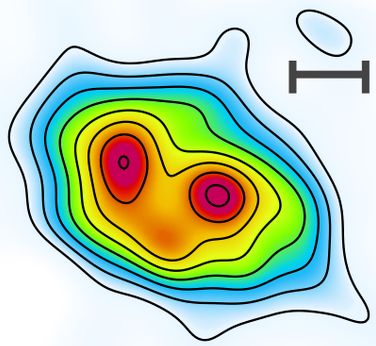

Brown et al 2008

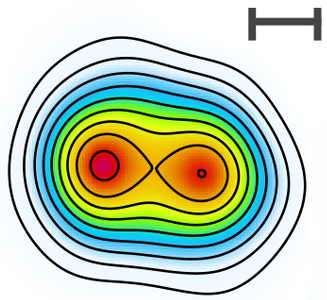


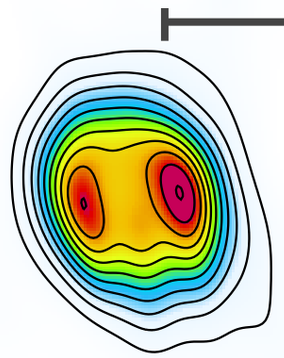
Andrews et al 2011b

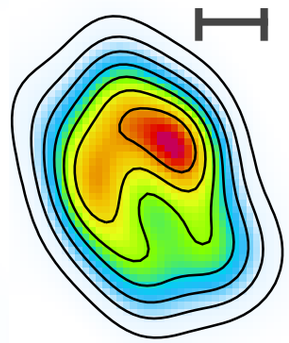

Andrews et al 2009

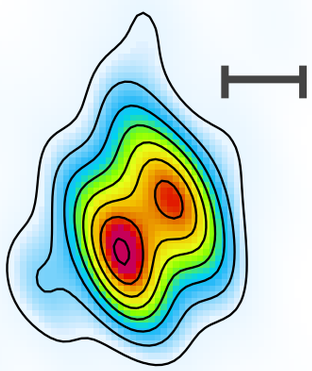

Andrews et al 2009

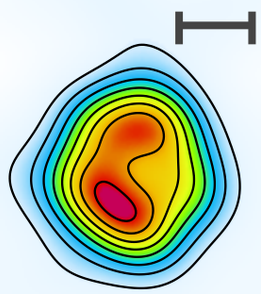

Hughes et al 2009

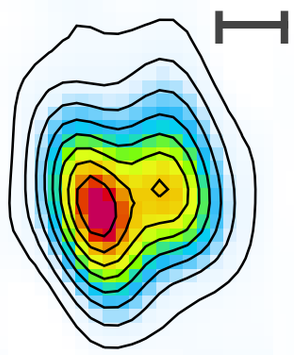

Cieza et al 2012

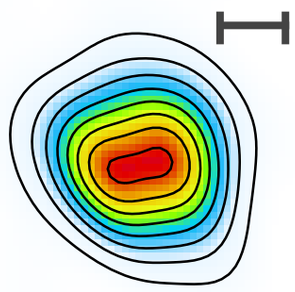

Rosenfeld et al 2012

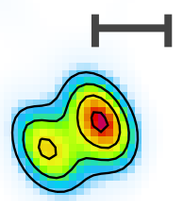

Andrews et al 2010

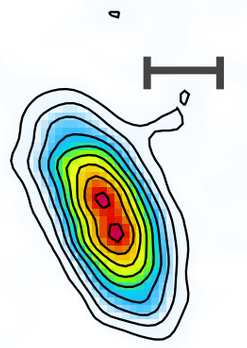

Andrews et al 2011a


Andrews et al 2011a

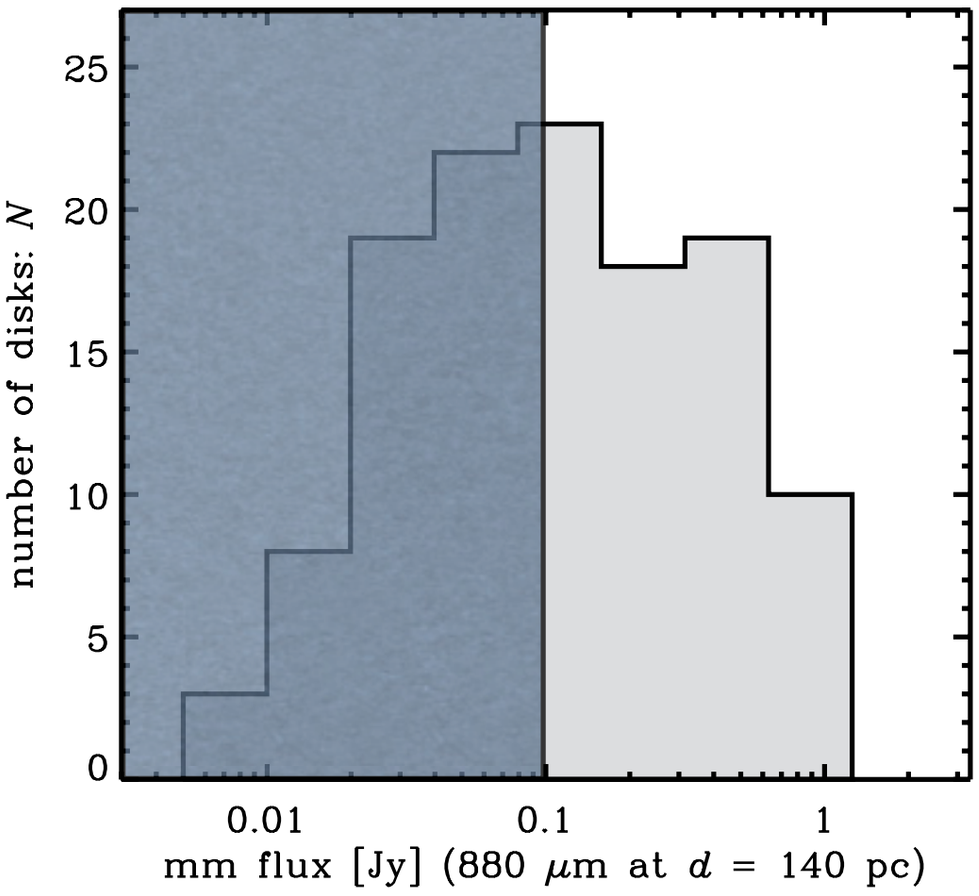

Andrews et al 2009


Brown et al 2012


Andrews et al 2011a


Isella et al 2010a

how common is the transition disk phenomenon?



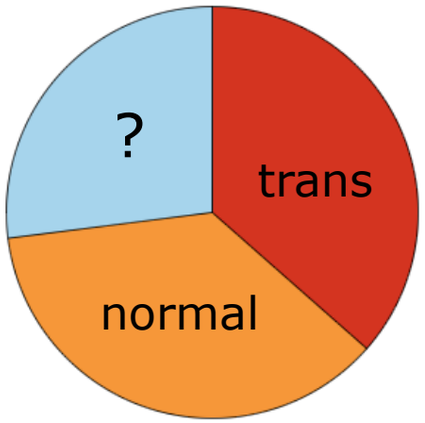
Andrews & Williams 2005, 2007; Nurnberger et al 1998

3/4 of bright disks have been imaged at <0.5" resolution

Andrews et al 2009-2012

Isella et al 2009-2012

Guilloteau et al 2012



>1/3 of bright disks have large cavities (R > 15 AU)

Andrews+ 2011; Brown+ 2008, 2012

Isella+ 2010, 2012; Cieza+ 2012

Mathews+ 2012; Rosenfeld+ 2012

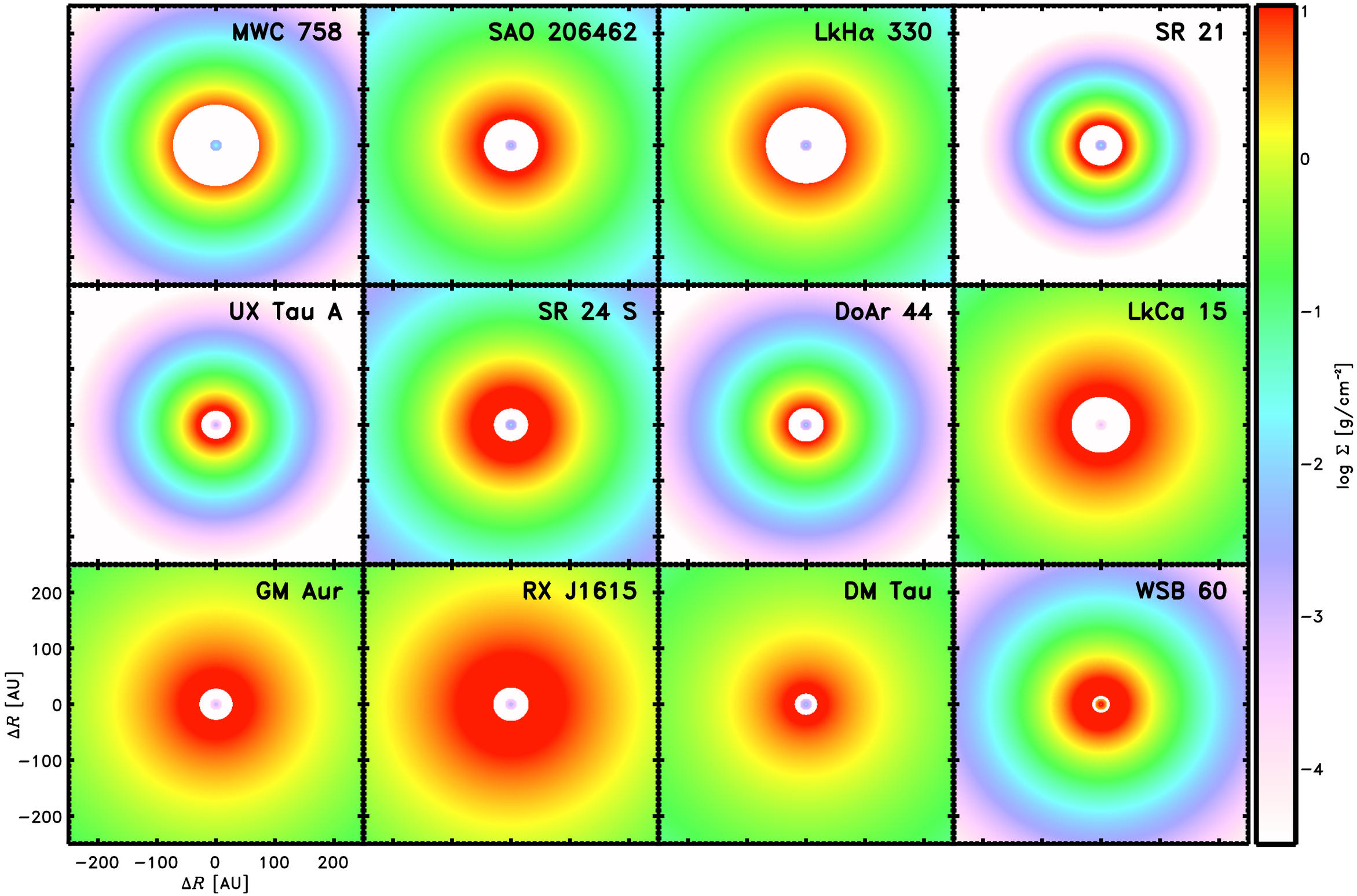
what fraction have cavities?

a disk mass threshold?

preferential stellar properties?

correlations with cavity size?

modeling transition disk structures



Andrews et al 2011a

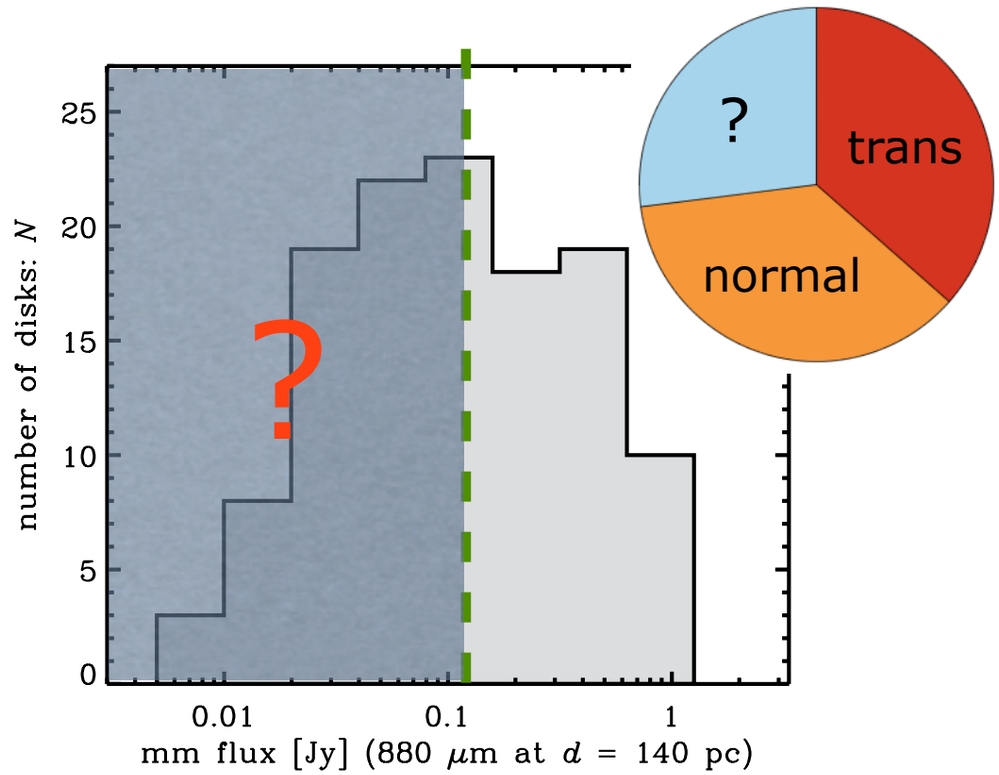
basic transition disk properties

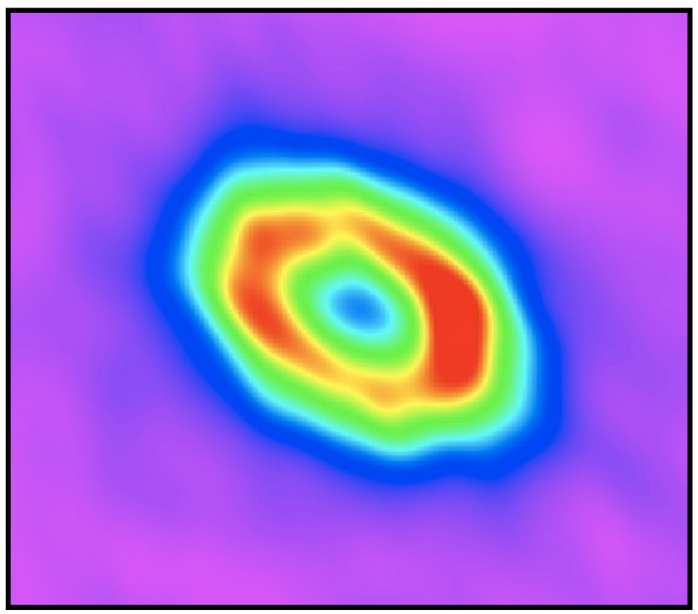
1. transition disks are *common*
   - >1/3 of bright (massive) disks
   - bias: large, tenuous cavities

2. observed cavities are *large*
   - radii of 15-75 AU (or more)

3. cavities are *depleted*
   - tau(IR) down by $10^{3\text{-}5}$x
   - tau(mm) down by >100x
   - but they are *not* empty

4. outer regions like normal disks
   - typical density profiles, sizes





Andrews et al 2011a, b

low-mass (planetary?) companions

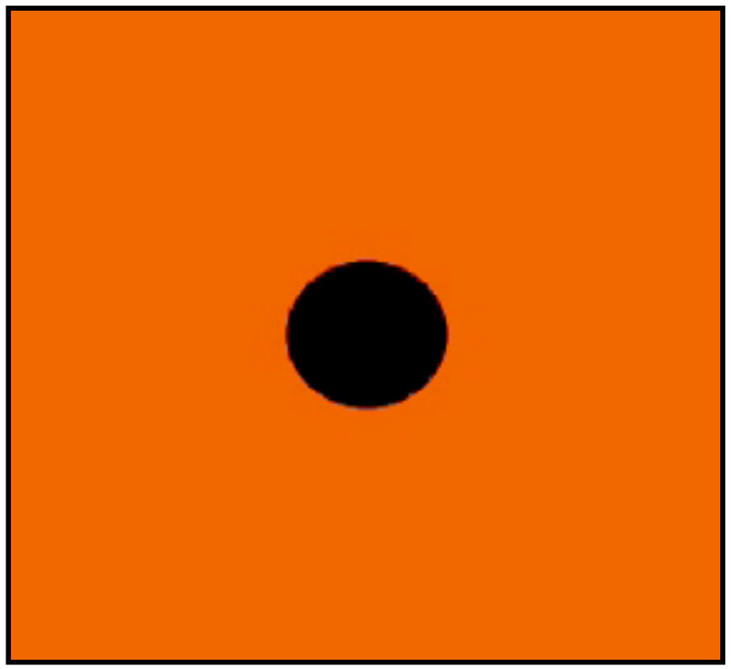
resonant torques make waves

gap opens; pressure bump

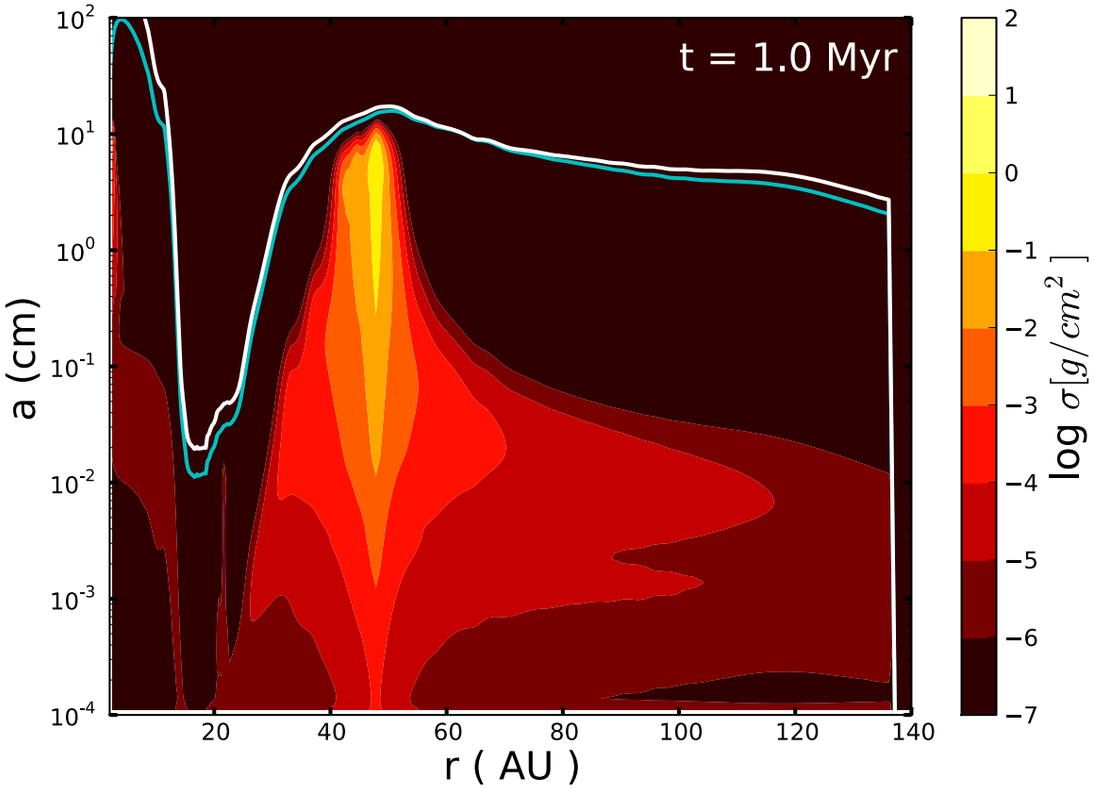
Lin & Papaloizou 1979; Bryden et al 1999

key issue: *dust/gas flow across gap*

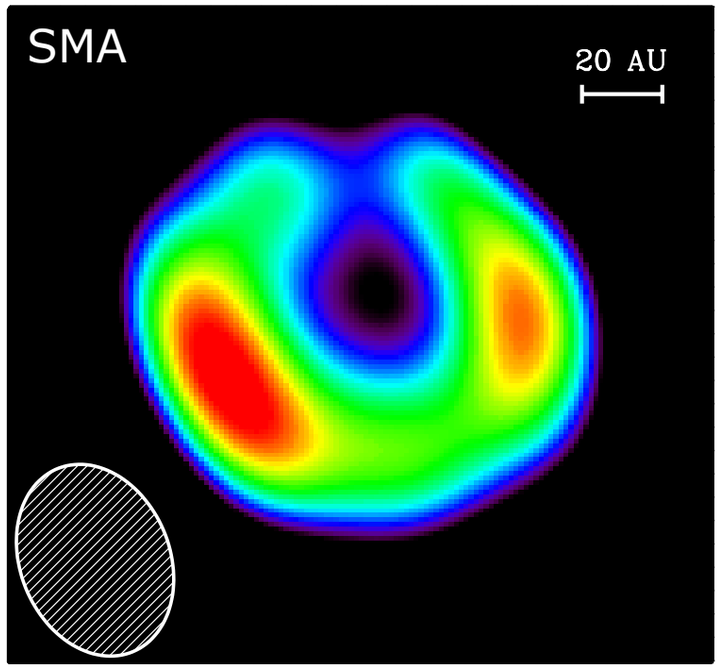
we ought to reconsider modeling formalism



Masset 2002

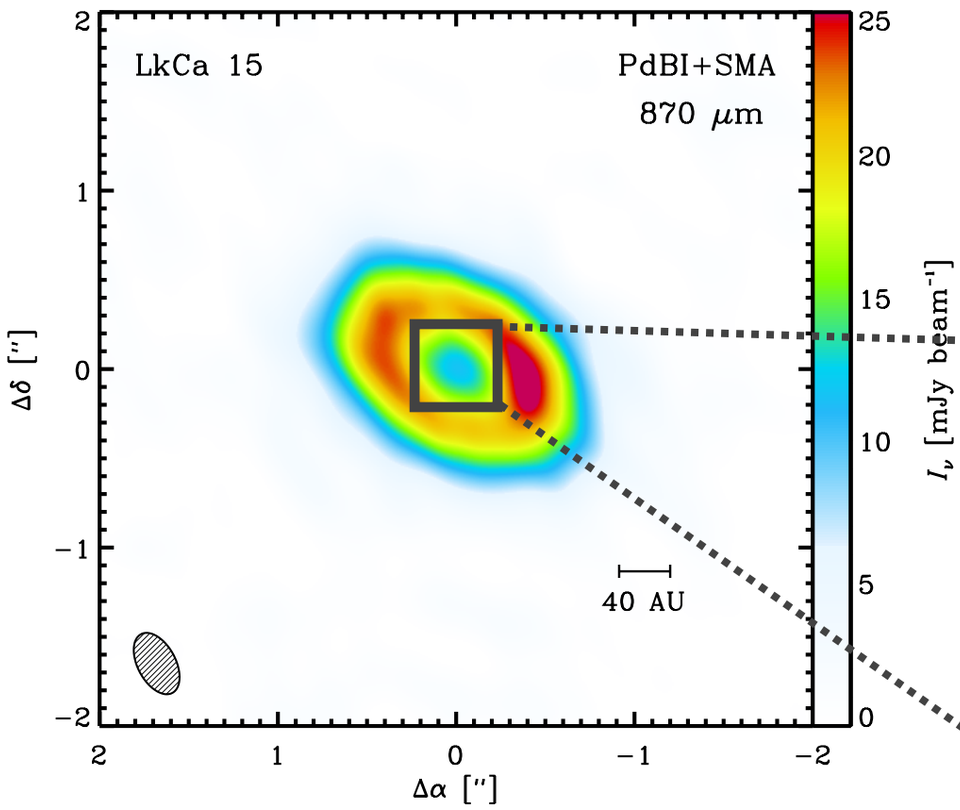


Pinilla, Benisty, & Birnstiel 2012



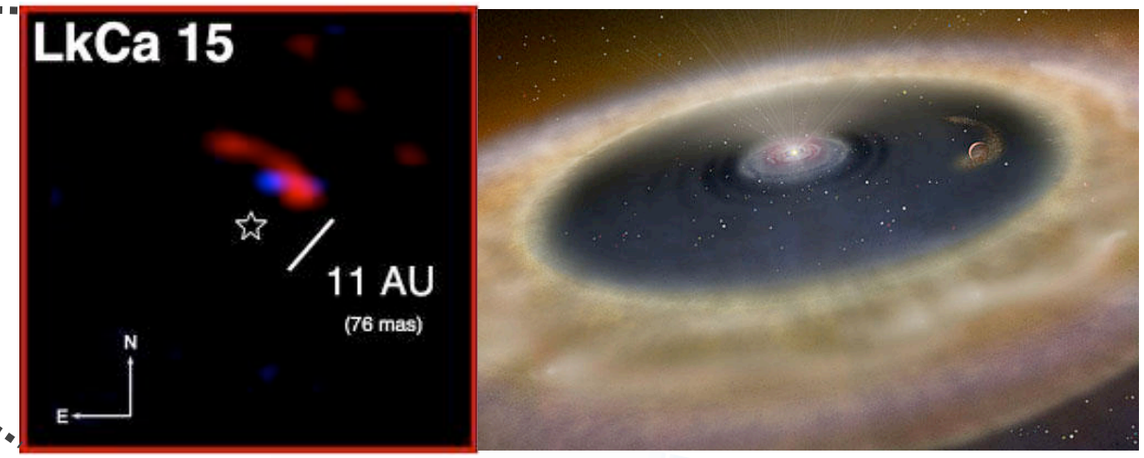
Andrews et al 2009

a (large) population of very young exoplanets?

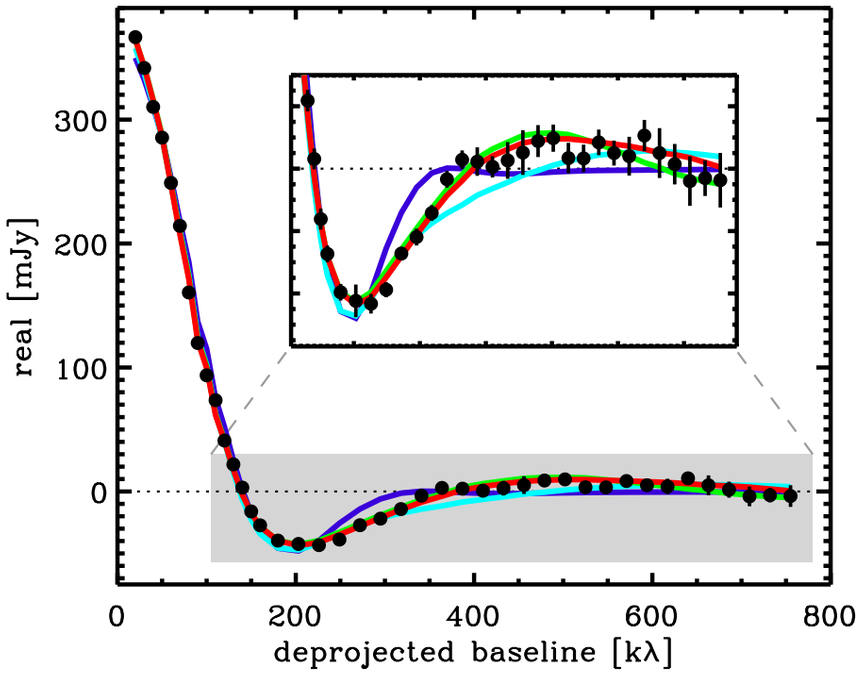


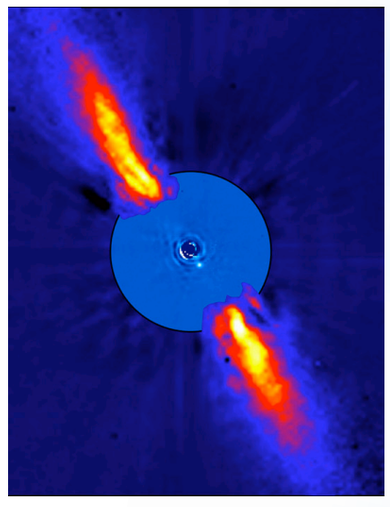
semi-analytic disk gap model:
4-9 M_{Jup} planet orbiting at ~16 AU

Andrews, **Rosenfeld**, et al 2011

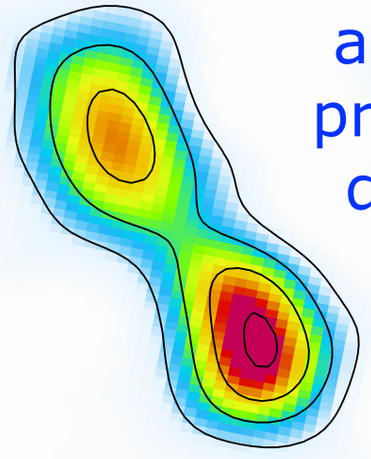


Kraus & Ireland 2012





Lagrange et al 2009



Wilner, Andrews, & Hughes 2011

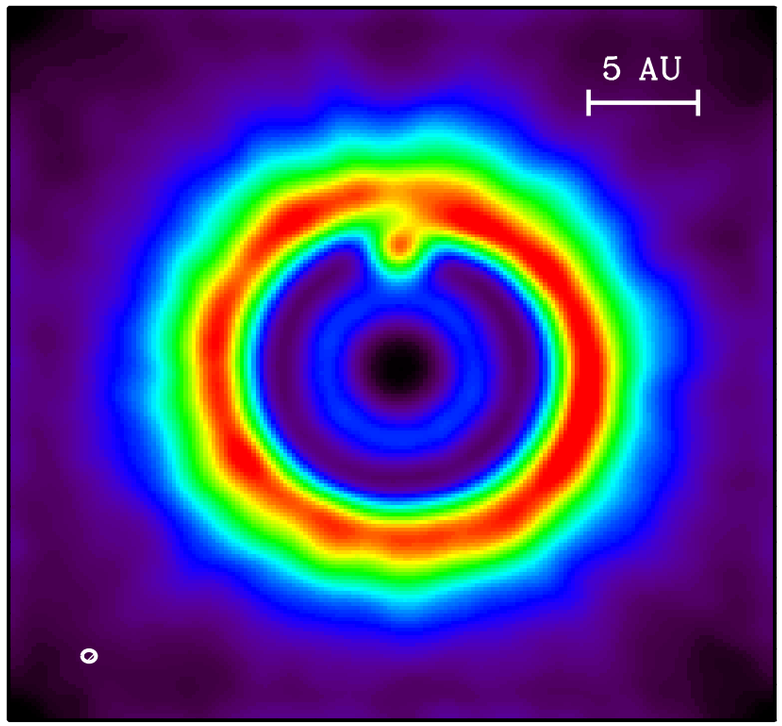
are these the progenitors of debris disks?

SUMMARY:

transition disks host young planetary systems (?)

1) transition disks have low optical-depth dust cavities:

imaging is critical; best at mm



2) a "transition" phase:

common, at least for massive disks

3) likely due to tidal interactions with faint companion(s)

mm/radio imaging can (indirectly) find/characterize young planets

cavity size ~ planet orbit

depletion + $\dot{M}$ ~ planet mass

bright future with ALMA

many thanks to:

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Andrea Isella
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Geoff Mathews