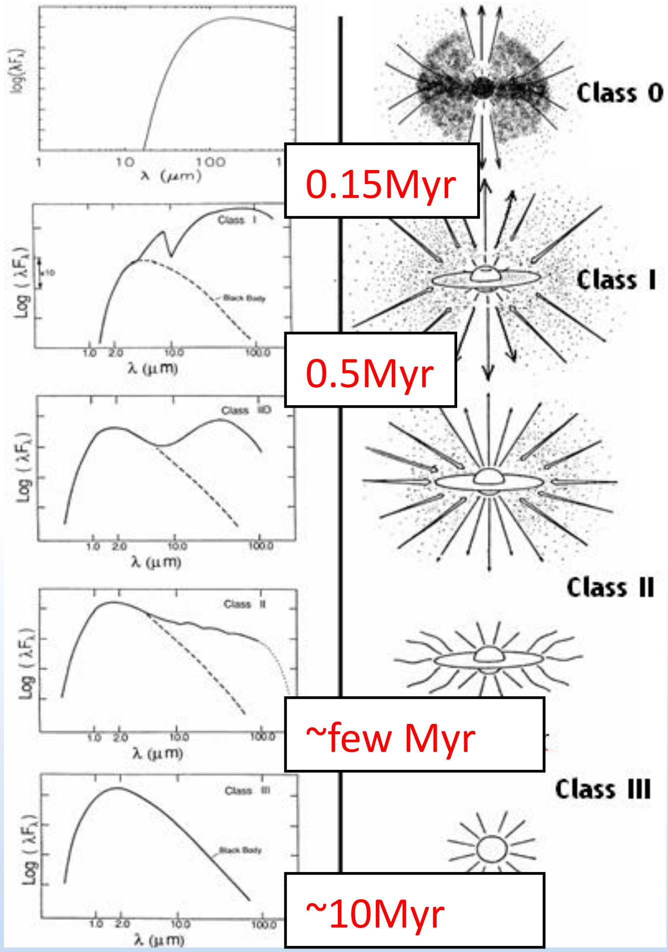
Herschel gas/dust studies of protoplanetary and debris disks

- Background, and questions: why far-IR, why gas?
- FIR in disks before and after Herschel
- GASPS survey
- Initial results – general stats
- Individual objects
- Related Herschel work
- Future - resolving disks

Background

- Early evolution (0-0.5Myr): disk embedded

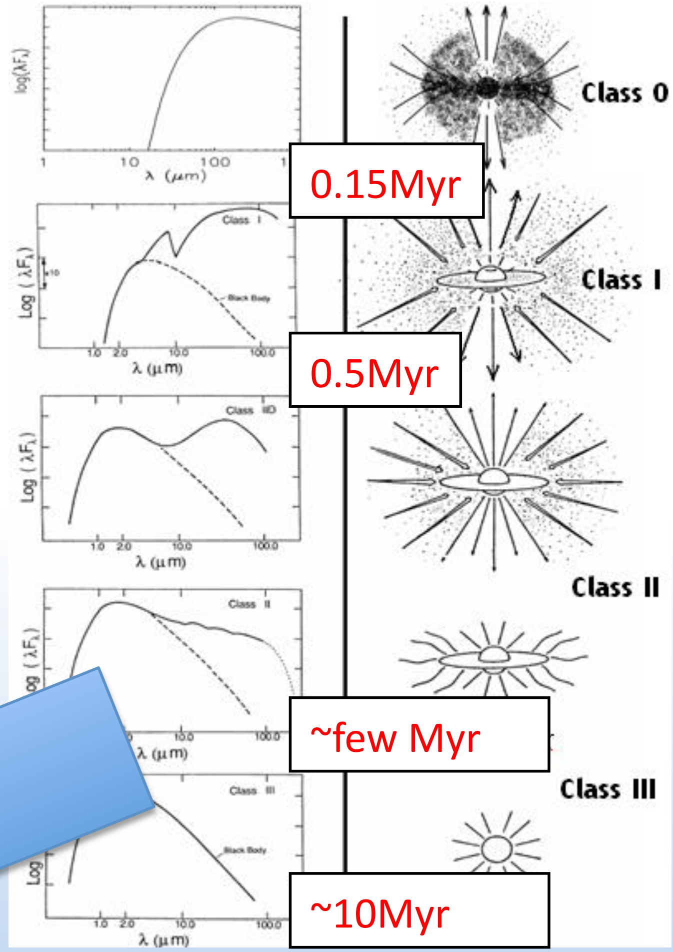


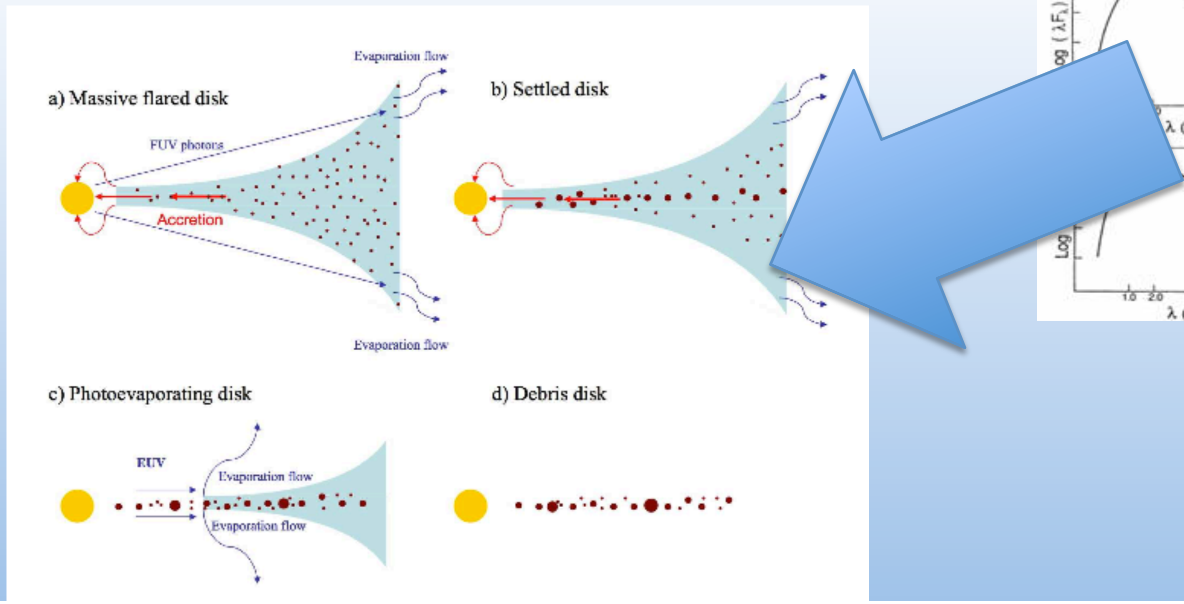
Evans etal 2009
Williams & Cieza 2011

Background

- Early evolution (0-0.5Myr): disk embedded

- Later evolution (0.5-30Myr): star & disk revealed





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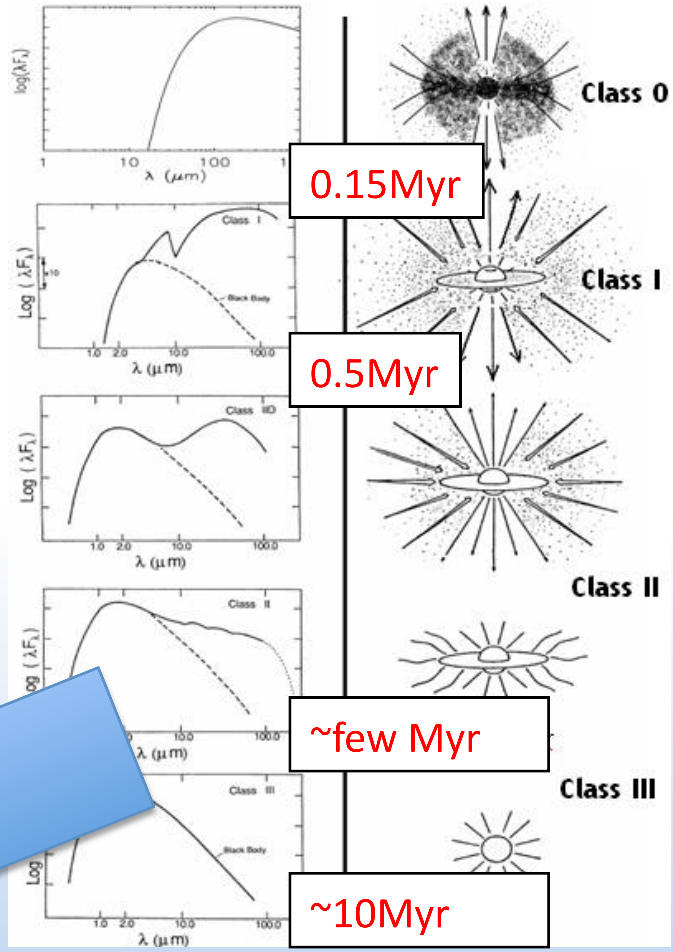
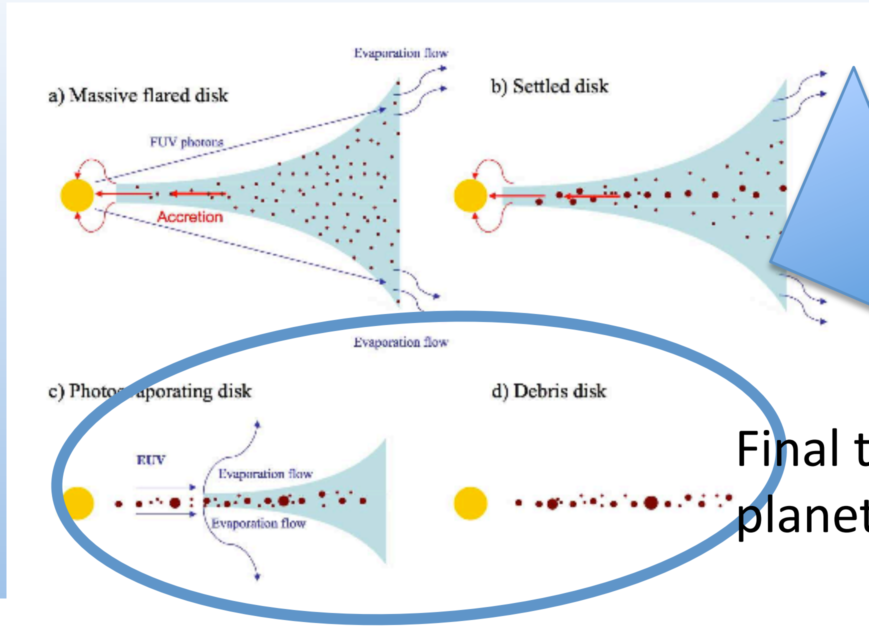
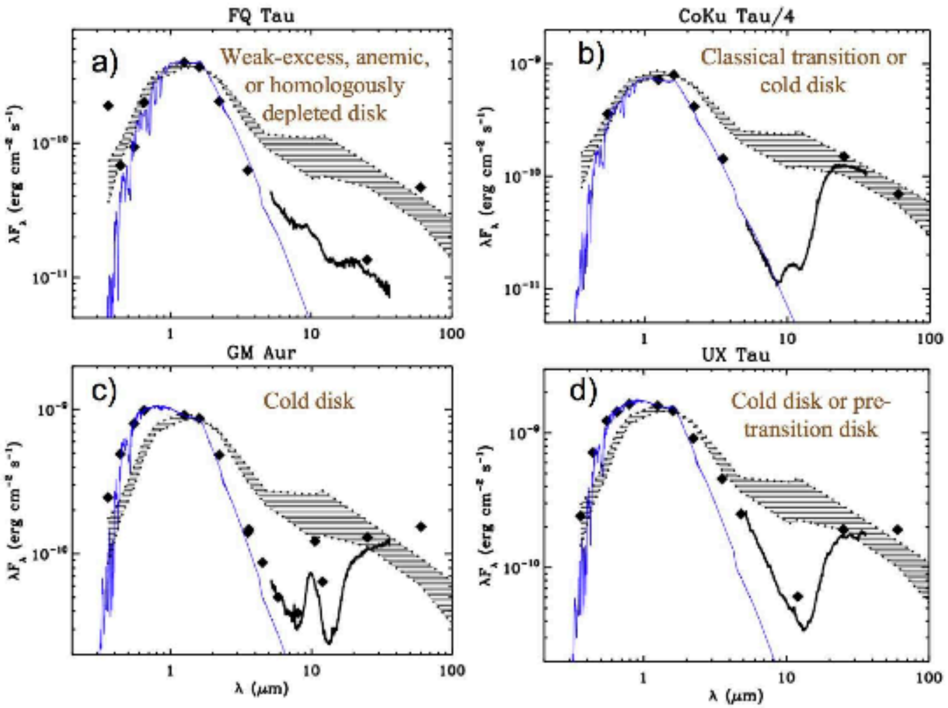


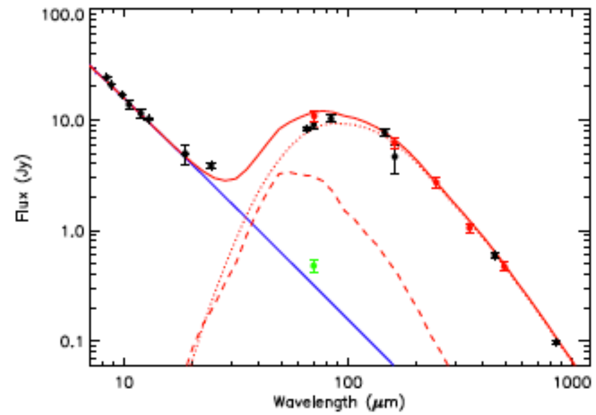


Final transition to ms planetary/debris system

Evans etal 2009
Williams & Cieza 2011

Many flavours of transition objects





Transition objects

Debris disks

Variations on the same theme – inner cleared disks

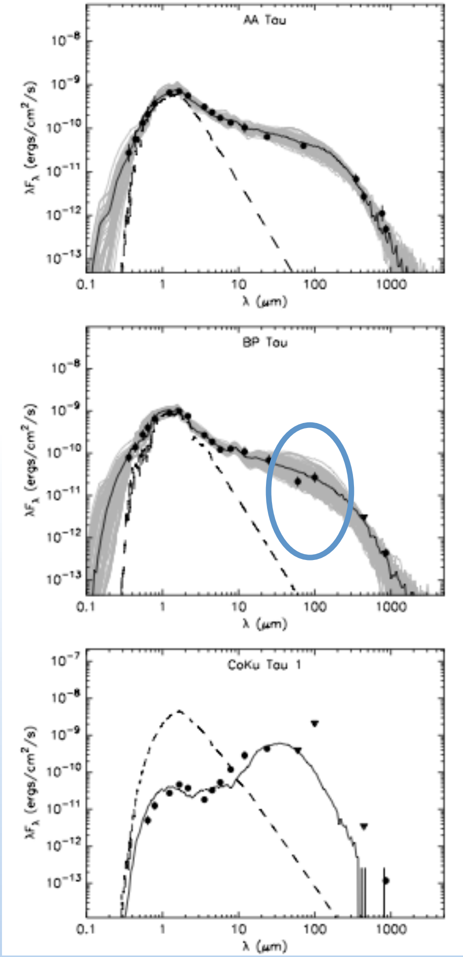
Williams & Cieza 2011
Also "The diskionary" - Evans et al (2011) astro-ph:0901.1691

Questions

- What are disk masses?
- How does gas & dust evolution compare?
- When do (can) planets form?
- Do debris disks contain gas?

Why far-IR, why gas?

- Many continuum surveys exist, mostly 1-70um (eg C2D), and submm
- FIR “gap” – accurate FIR fluxes are needed for models



Robitaille etal 2006

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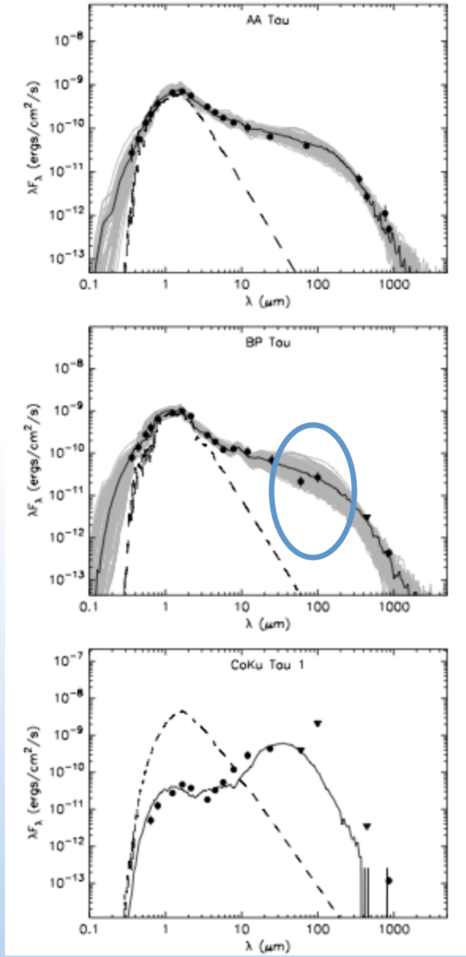
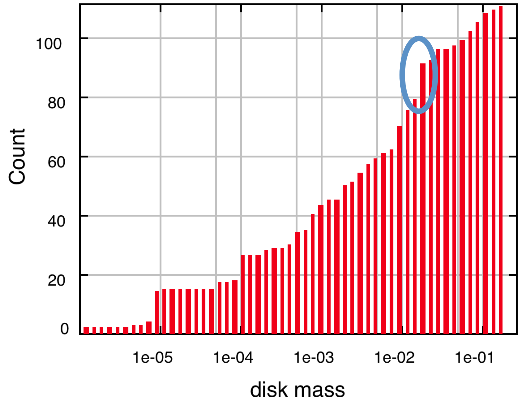
- Submm normally used to derive total mass, but grains grow. $m_{dust} \sim a_{max}^{0.5}$ (eg a_{max}=1m -> 20x mass)
- Global gas/dust ratio may decrease (photoevaporation)
- Gas/dust can increase with radius or height (Andrews etal 2012; Pietu etal)



Robitaille etal 2006

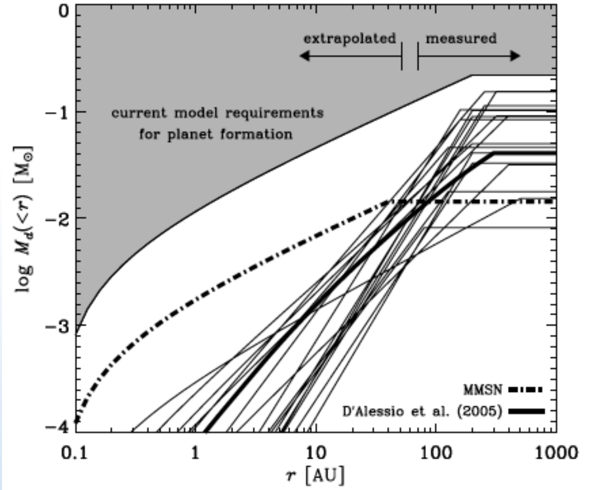
Mass problems?

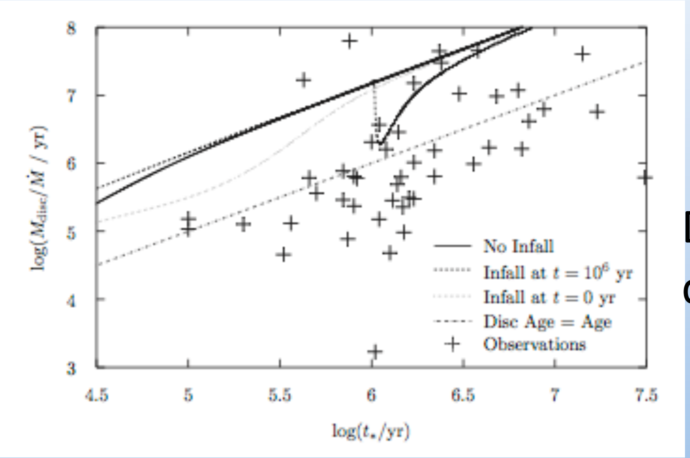


~18% of stars form giant planets

Only ~5% of class II sample have masses of ~30Mj (MMSN)

Resolved submm continuum:
10x lower than planet-forming models require





Disk age vs. stellar age:
disk masses 5x too low

Greaves & Rice, 2009
Andrews & Williams 2007
Jones et al 2011

Why far-IR, why gas?

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- Global gas/dust ratio may decrease (photoevaporation)
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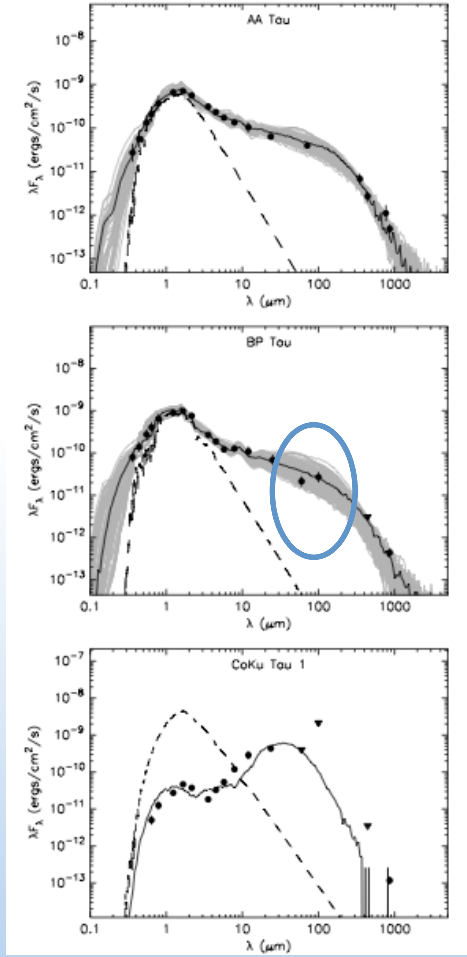
- Gas important for accretion, solid body dynamics & planetary composition

=> need for a complementary gas survey

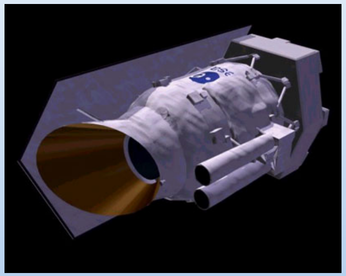
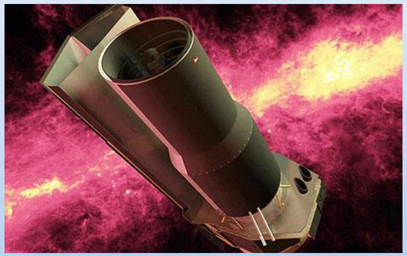
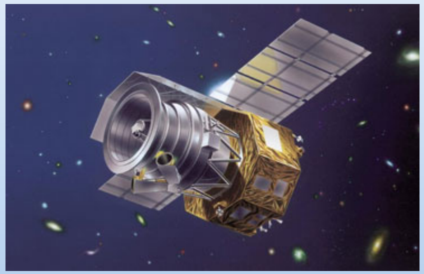


Robitaille etal 2006

FIR before Herschel

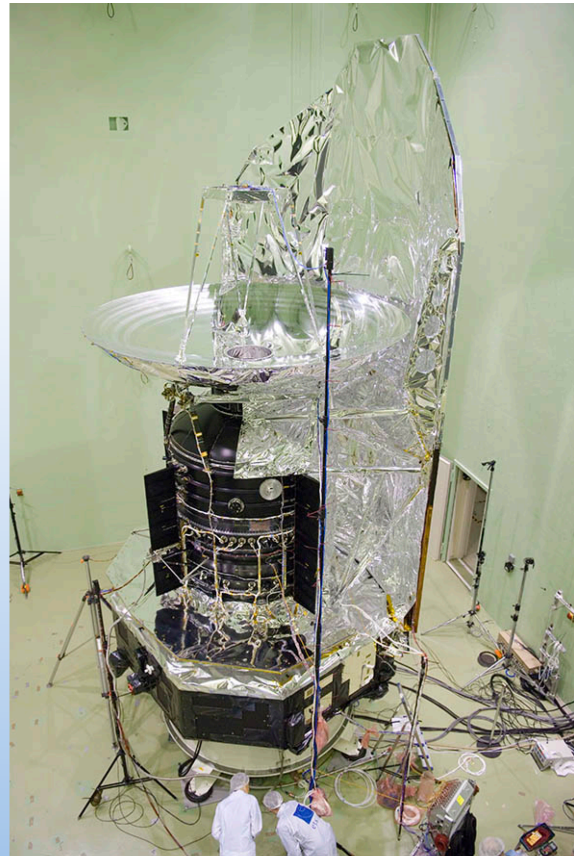
- KAO(0.9m), IRAS (0.6m), ISO (0.6m), Spitzer (0.8m), AKARI (0.7m), SWAS, ODIN
- Extensive dust continuum surveys
- Limited spectroscopy

  =>Need for sensitivity and resolution

Herschel & PACS

- Herschel – 3.5m passively cooled telescope
- 3 instruments: SPIRE (250-550um), HIFI (heterodyne spectrometer) & PACS (70-200um)

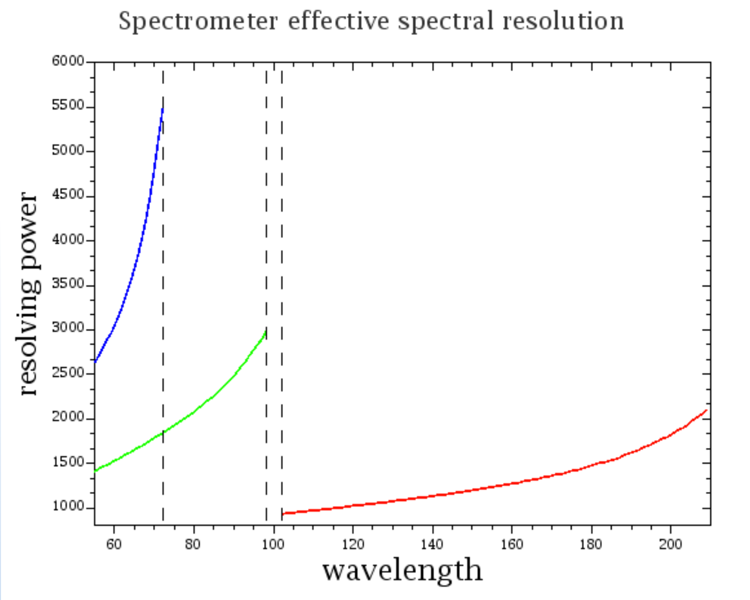


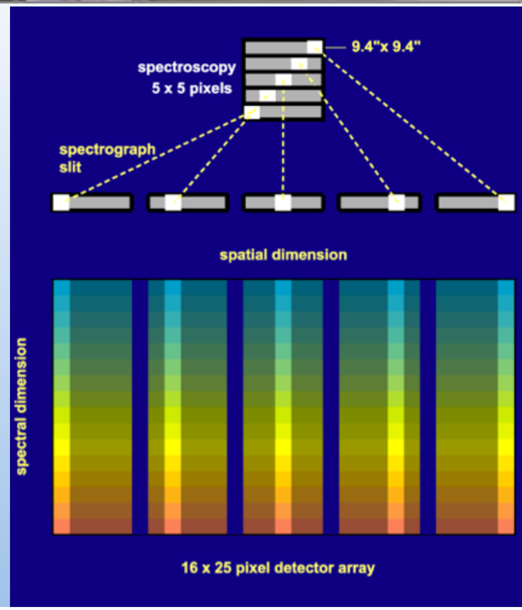
- Launched May 2009

  -- Feb 2013

Herschel/PACS capabilities

- Spatial resolution: 5-12” with 9.4”pixels in IFU
- Spectral resolution: 1000-4000 (88km/s at 60um)
- Sensitivity 100x improvement





BUT…

Largest pp disk ~5”

Keplerian velocity ~10km/s

=> most disks are unresolved

Herschel disk projects

- GASPS (this talk)
- DIGIT (see later talk)
- WISH
- DUNES
- DEBRIS
- + many others on individual objects

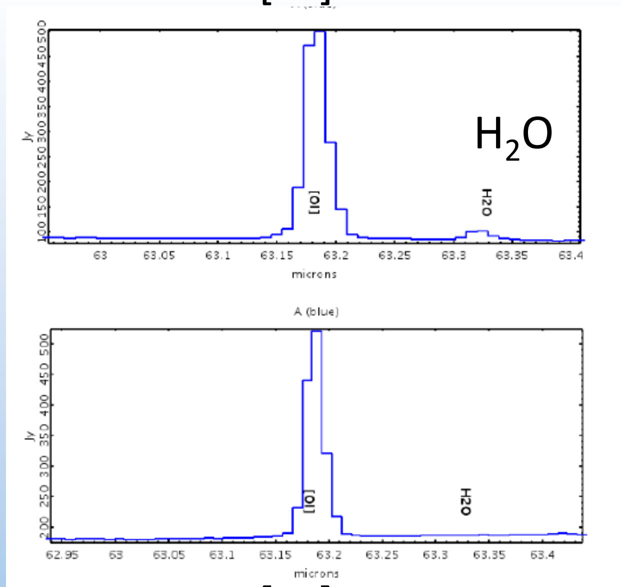
GASPS survey

- Only brightest FIR lines & continuum
- [OI]63/145, [CII], CO, H2O, OH
- 70/110/170um photometry
- From class II, TO, III, debris
- 0.5-30Myr
- Nearby (<150pc) [Taurus, ChaII, upper Sco, ηCha, βPicMG, TWA, TucHor]
- T Tauri and Herbig AeBe stars
- Range of Lx, binarity, disk
- Use latest disk models, in a systematic way

Lines detected

- [OI] 63,145um   *[OI]63 is by a factor of ~10, brightest FIR line*
- [CII] 157um
- H2O   8 lines, from Eu=115-1300K
- OH
- CO   4 lines, from J-18-17 to J=36-35
- CH+

[OI]

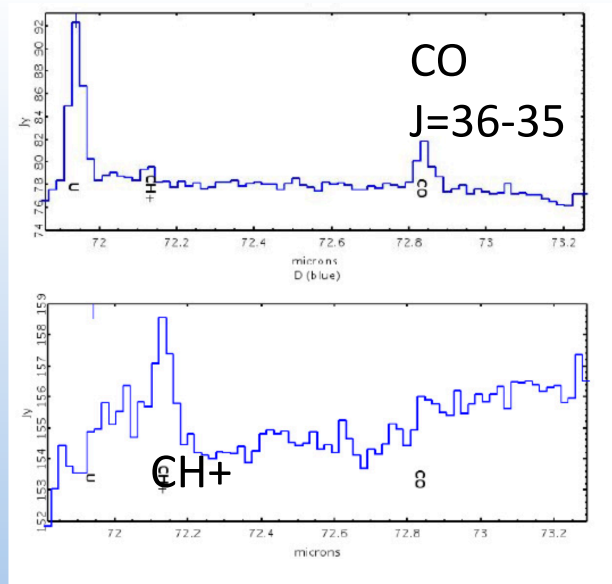


[OI]

T Tauri

HD100546

H_2O



Line detection rates

Broadly similar for different spectral types

	[OI]63	[OI]145	[CII]157	H_2O	CO 18-17
Percent of total	50 (6)	38 (8)	25 (6)	16 (5)	36 (8)
Percent HAeBe stars	80 (18)	22 (10)	24 (10)	4 (4)	33 (12)
Percent T Tauri stars	42 (6)	49 (11)	25 (6)	24 (9)	39 (11)

Line detection rates

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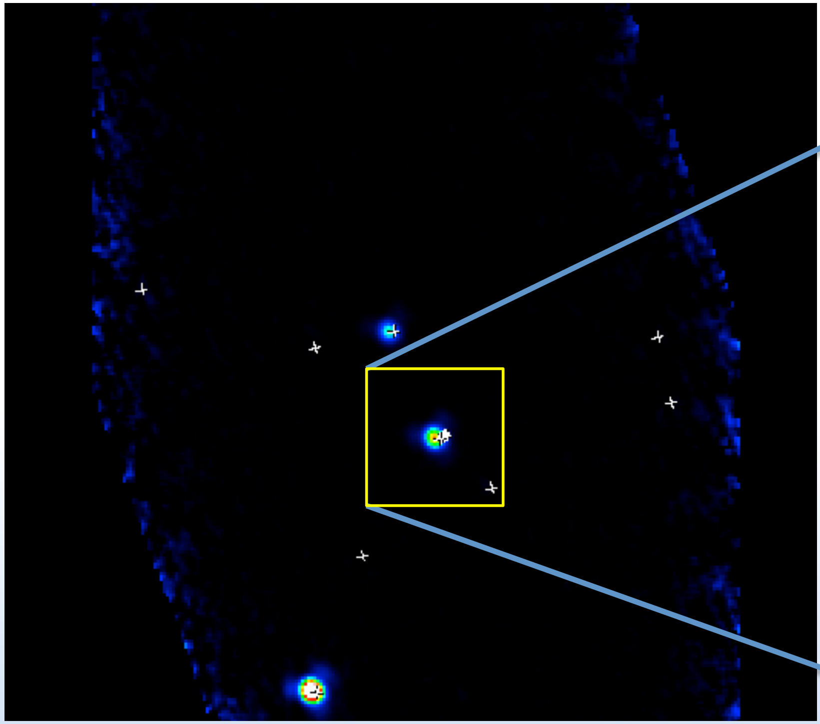
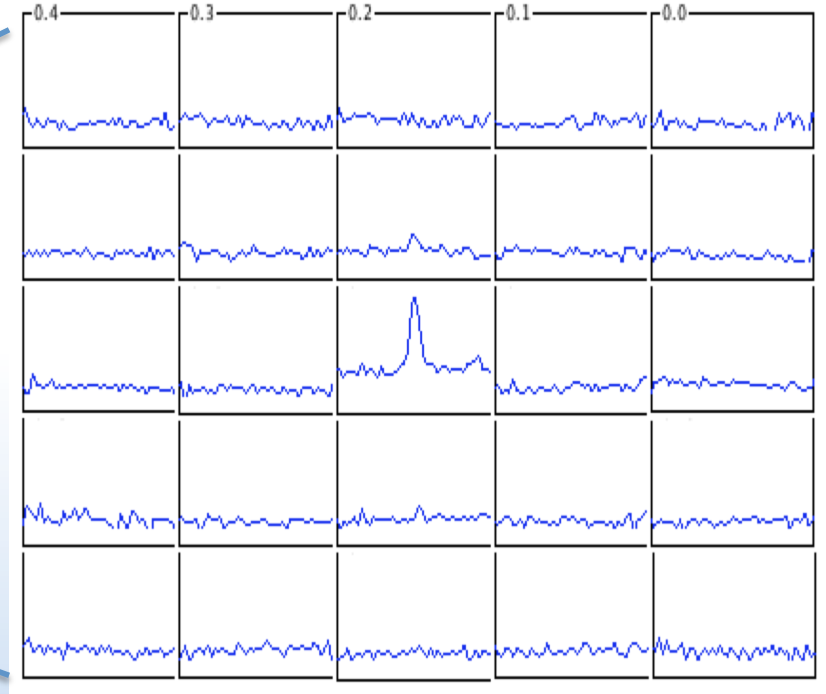
[OI]145 is high for TTS compared with HAeBes

H2O is low (~1) for HAeBes compared with TTS

Lines & continuum are normally unresolved

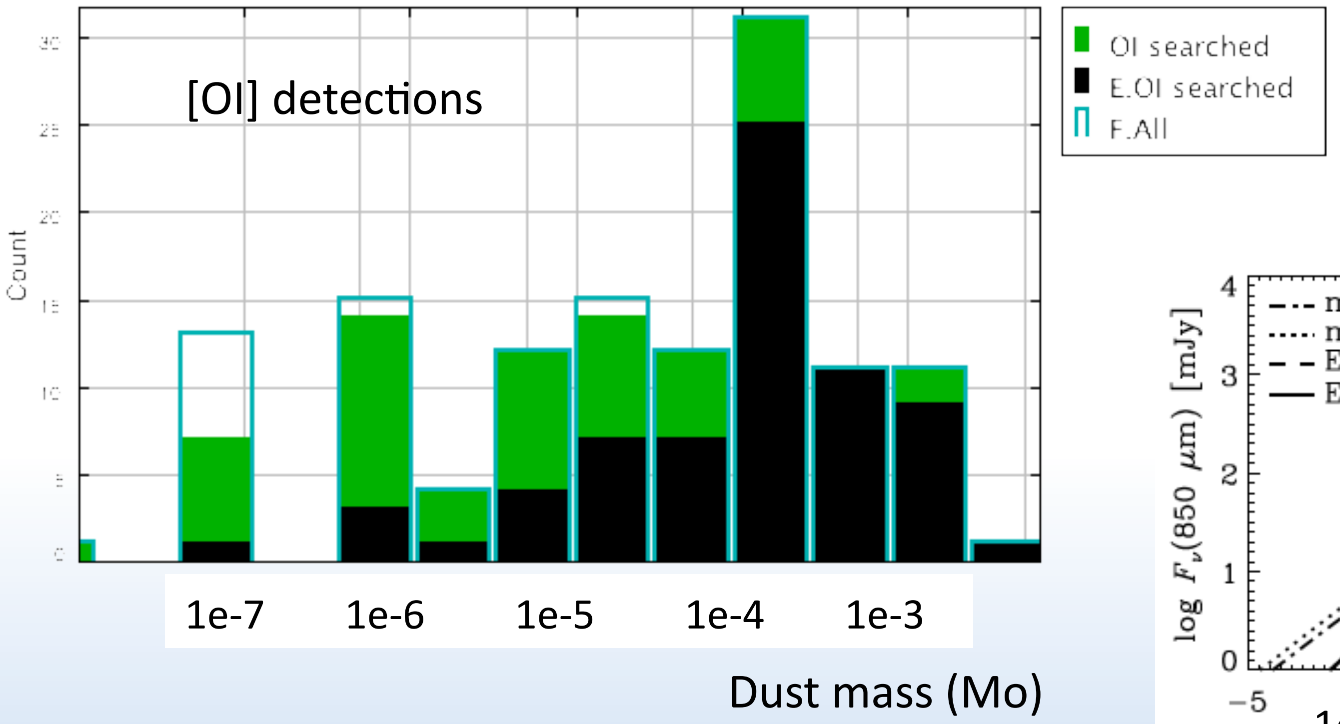


110um

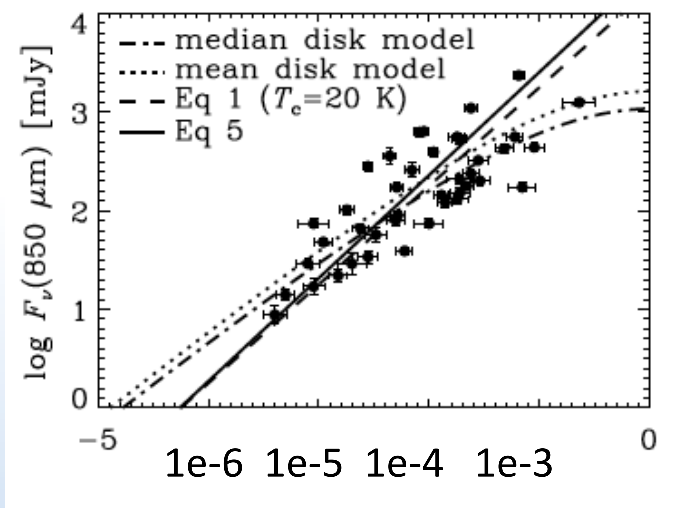


[OI]63

Disk mass limit for [OI]63 detection



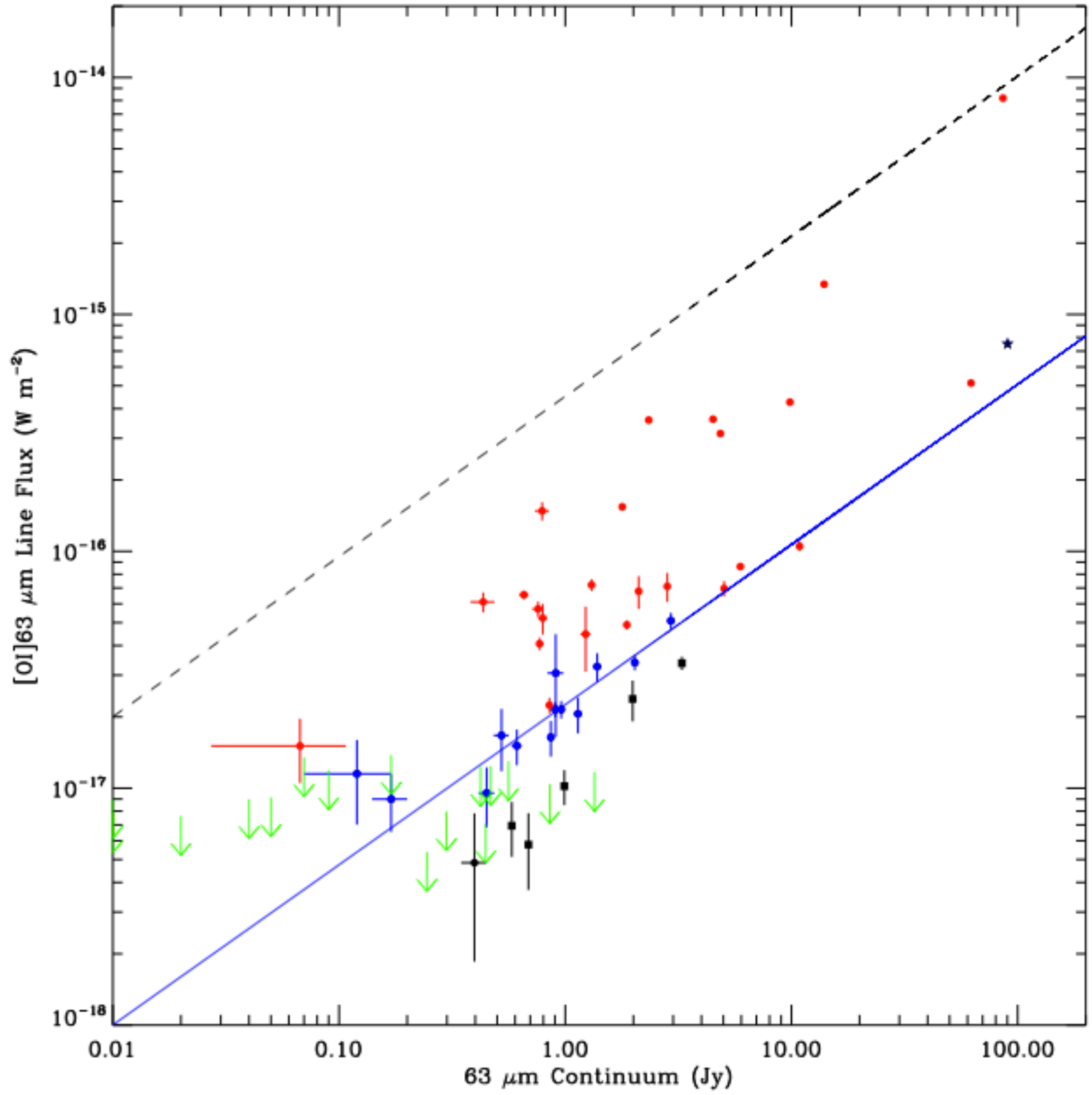
Submm continuum detections



=> [OI]63 is detecting >50% of systems above 1e-5Mo (in dust)
(similar to submm surveys)

(Andrews & Williams, 2005)

[OI]63 correlated with FIR continuum



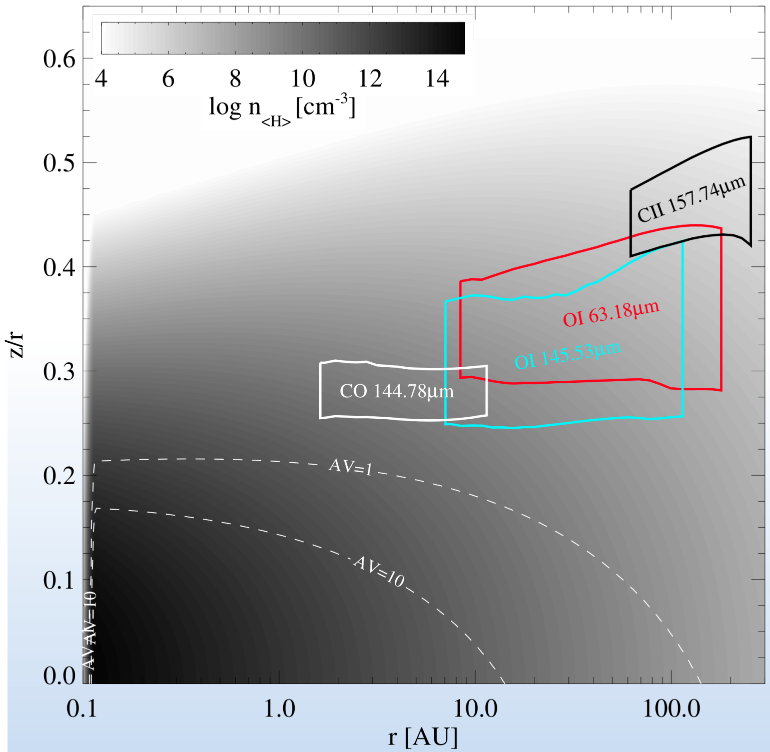
Only Taurus:
Blue => passive disks
Black => transition objects

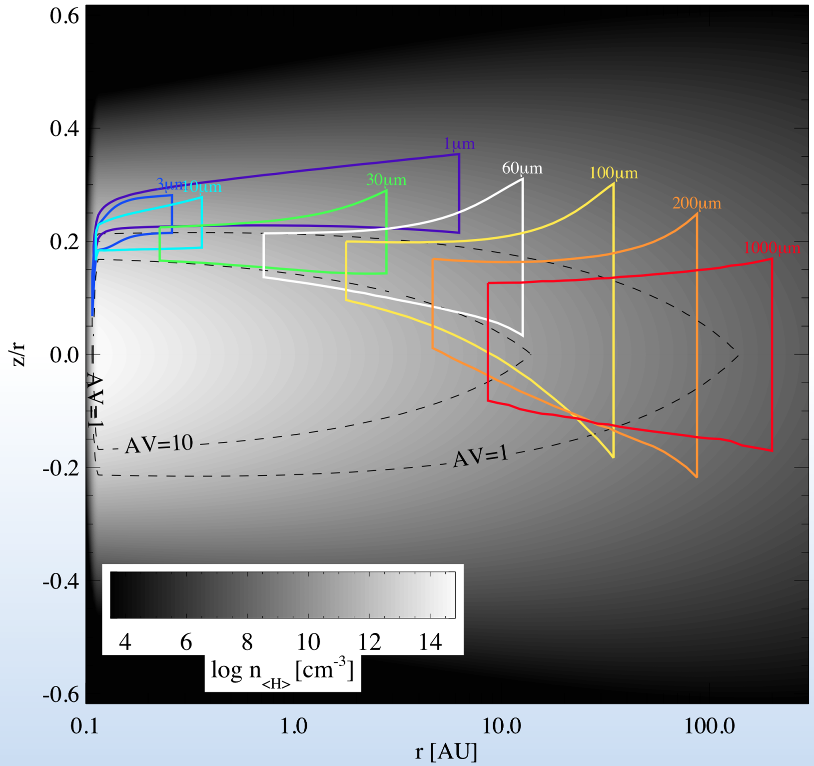
Red => outflow source
(mostly borderline class I-II)

[OI]63 correlated with FIR continuum for non-outflow systems
Outflows enhance [OI] above this

Where does [OI] and 63um arise in disks?

ProDiMo models (Woitke etal 2009)





[OI]63 mostly from disk surface at 10-100AU

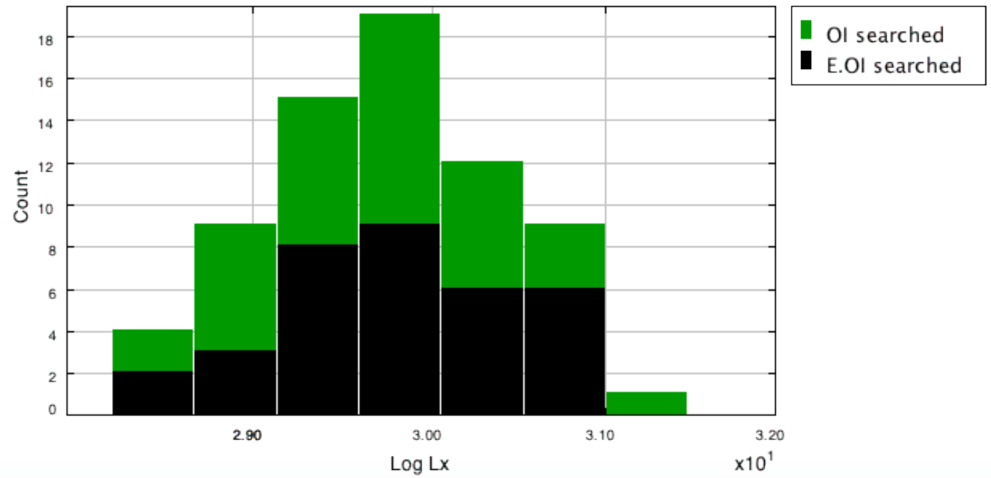
63um continuum mostly from disk surface at 1-10AU

Not the same region. How can there be a correlation?

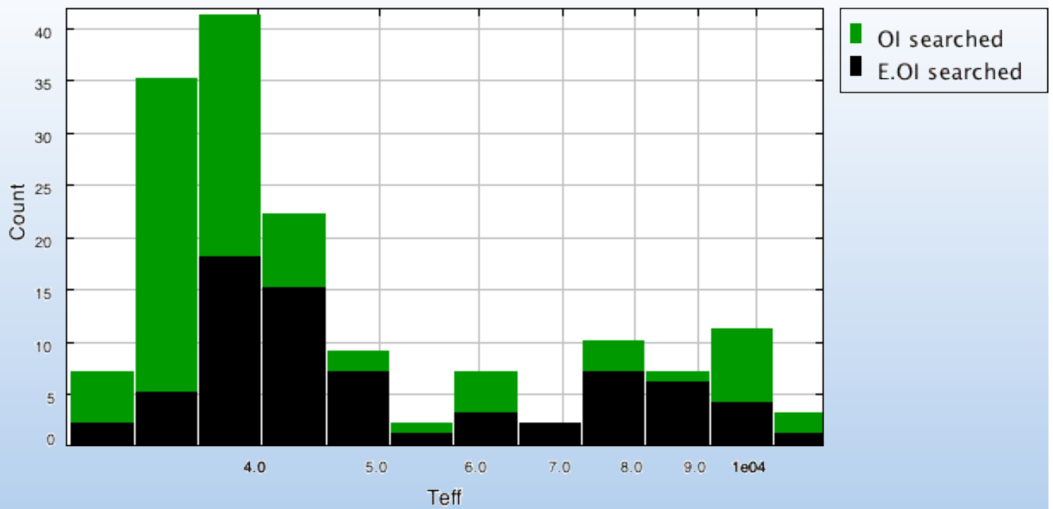
⇒ Similar disk structures

What affects [OI] detections?

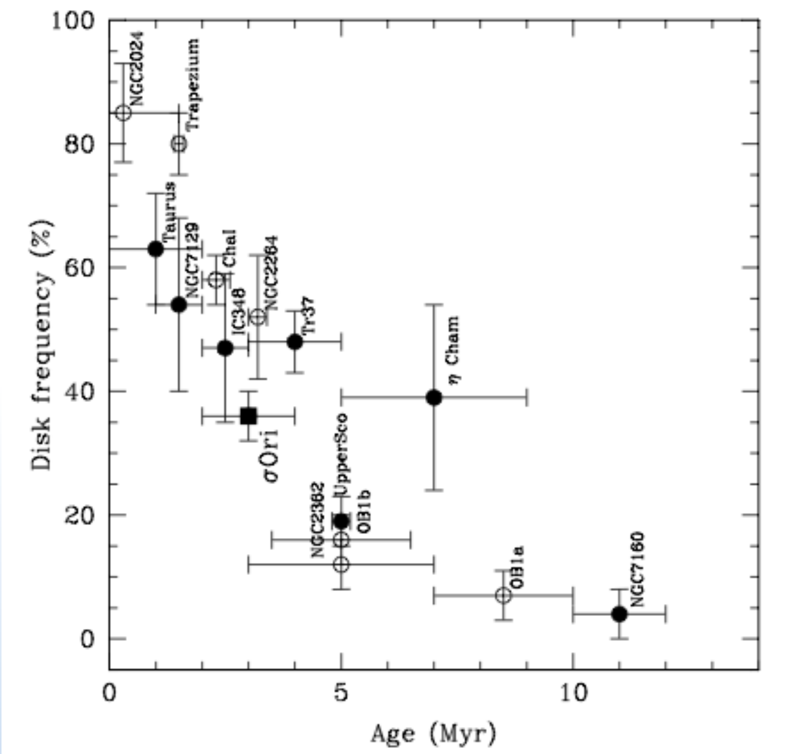
X-ray luminosity does not affect [OI]



Higher [OI] line detection rate for stars Earlier than K5



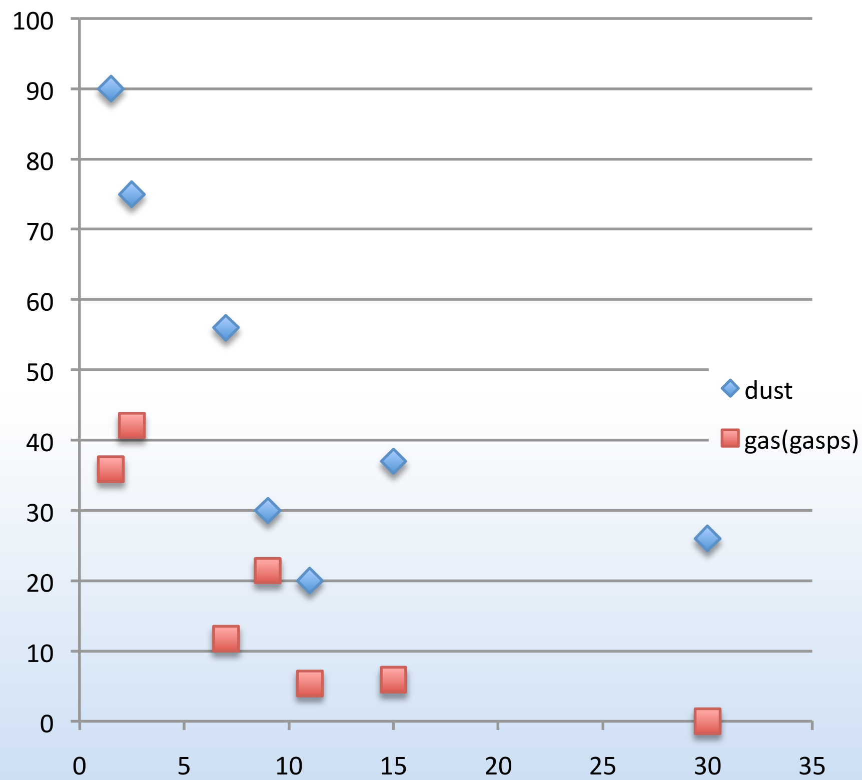
How long do most disks last?



NIR continuum ½-life : 3Myr

(Hernandez etal, 2007)

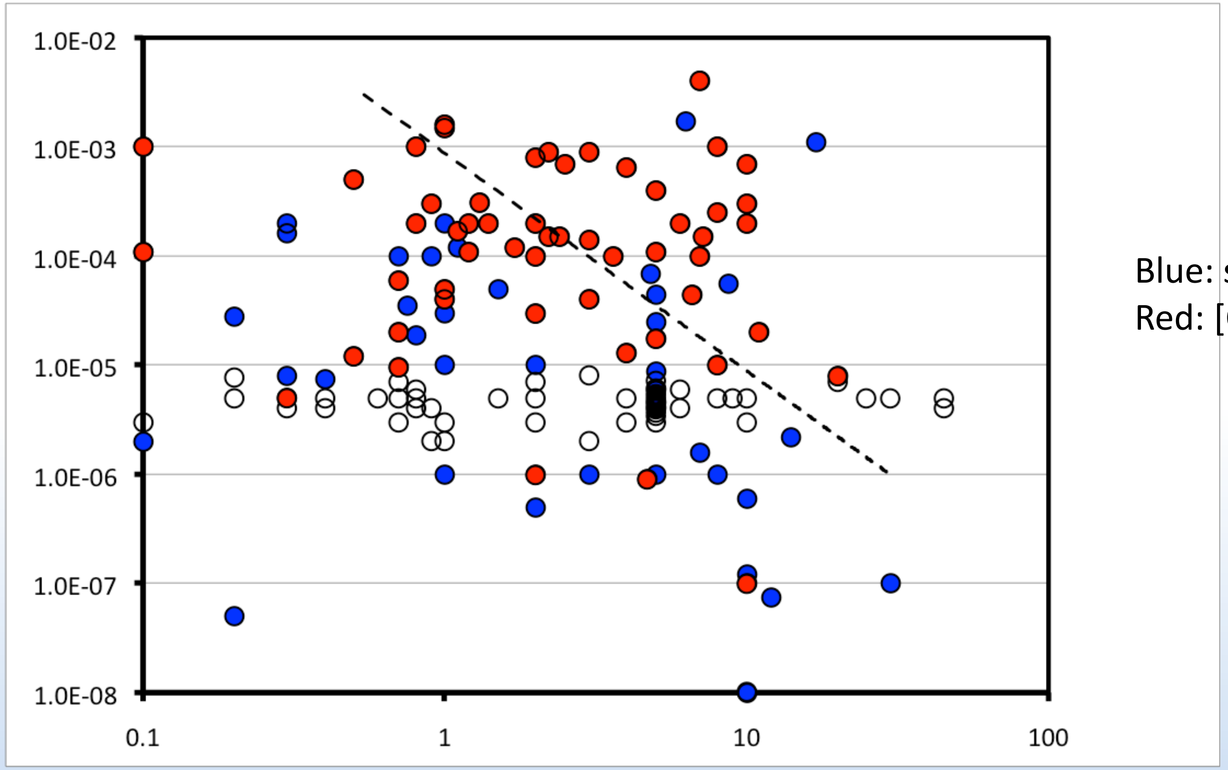
GASPS-only clusters



FIR/submm continuum ½-life : 5-10Myr

Gas [OI] ½-life : 3-5Myr

Individual disks differ



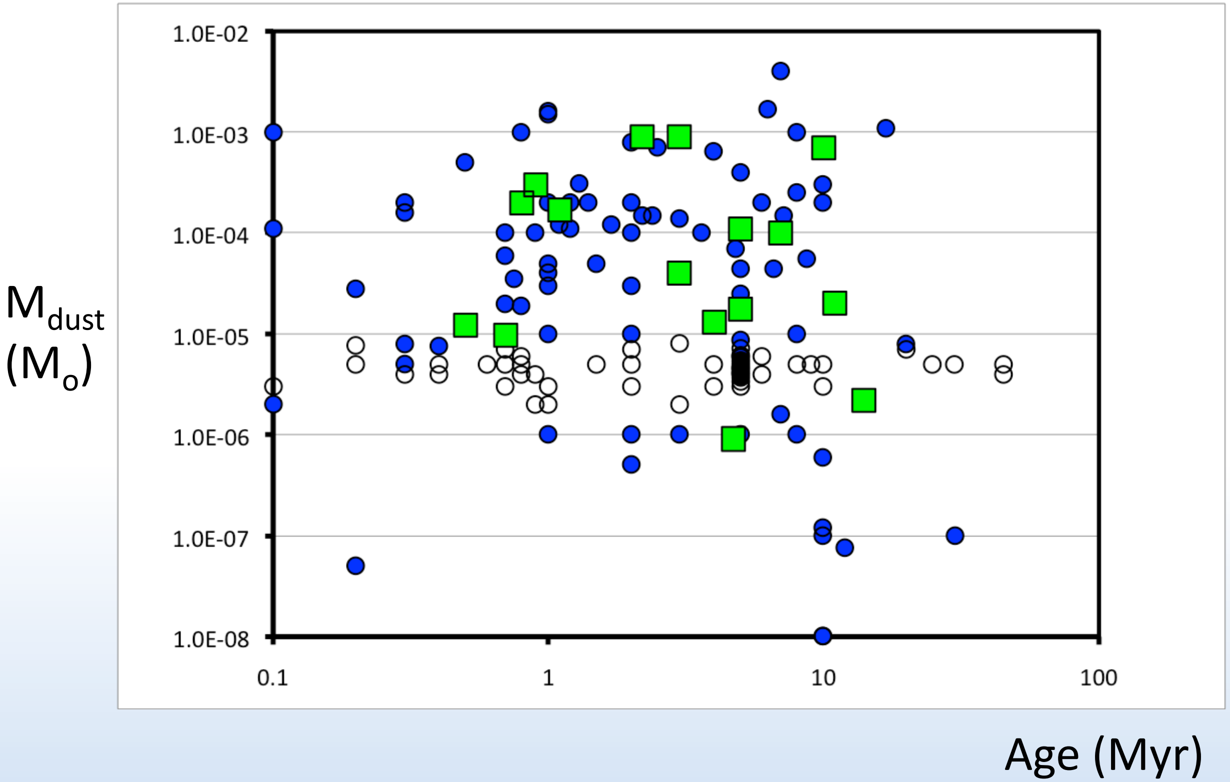
M_{dust} (M_o)

Blue: submm mass
Red: [OI] det

Age (Myr)

- *Dust (submm) and gas [OI] can last similar times.*
- *So far, no significant population of gas-rich or gas-poor older systems (apart from known debris disks)*
- *unclear what affects lifespan*

[CII]



[CII] not correlated with disk mass or age.

Suggests it's from low-density remnant compact envelopes/outer diffuse disk.
Unclear why it sometimes can last 10Myr

Individual objects modeled

- TW Hya: [OI]63um – gas/dust ratio 0.1x ISM (Thi etal 2010). Also H2O in disk, but weak (Hogerheijde etal 2010; Kamp etal in prep)
- HD169142: large classical HAeBe disk with ~ISM gas:dust ratio (Meeus etal 2010)
- ET Cha: low disk dust mass & size (10AU) with bright [OI]63. High gas:dust ratio >10x ISM (Woitke etal 2011)
- HD181327: no gas. Marginally resolved (Lebreton etal)
- HD163296: 0.1-1x ISM (Tilling etal 2012)

=> No single value for gas/dust can be used

Future work

- Derive disk models in a systematic way across complete sample
- Compare with dust (SED, some resolved)
- Global gas/dust ratios, evolution

Resolution!

Statistical approach with models provides basic info

BUT…

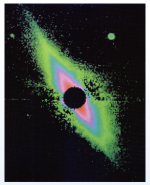
Resolution (spatial and spectral) is the key

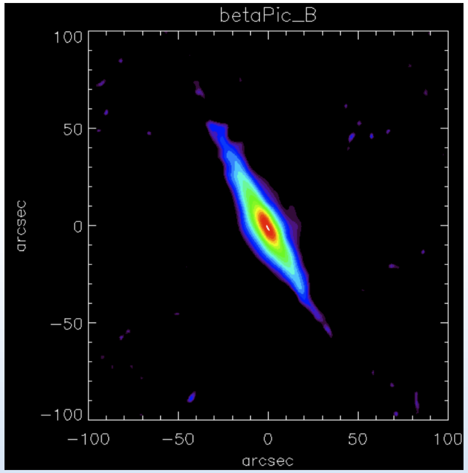
Protoplanetary disks are all <5”
5-10AU region = 0.05arcsec

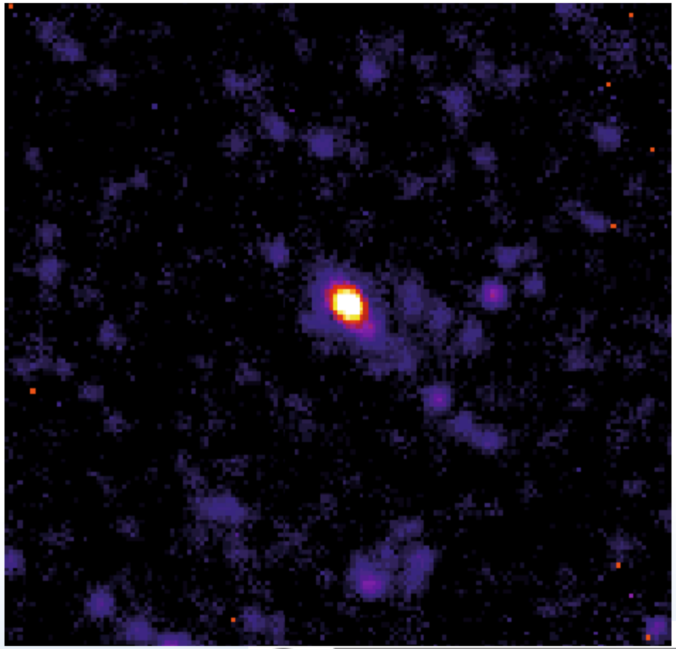
Debris disks <20pc are resolvable now

Herschel resolved disks

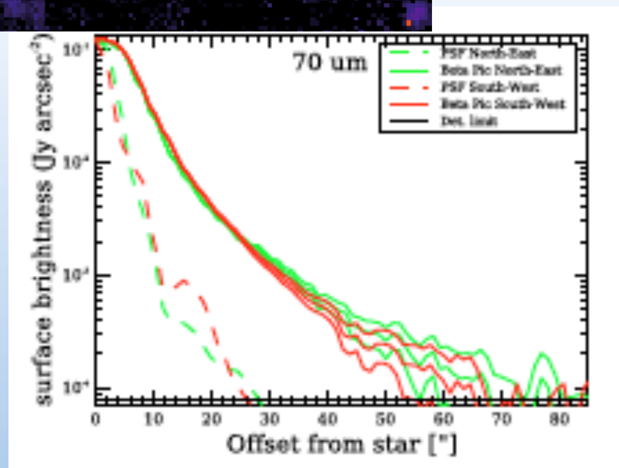
1) Beta Pic, 19pc







250um: 10x10arcmin
50 background objects



70um extends smoothly to ~60"
Closely follows optical scattered light
β~0.3 => large grains

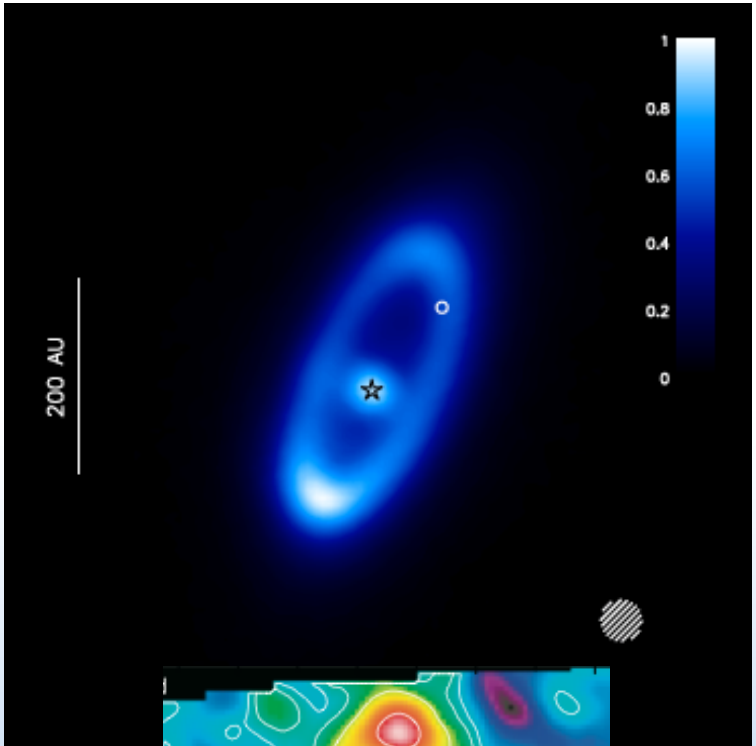
Vandenbussche et al 2010
Kalas & Jewitt 1995

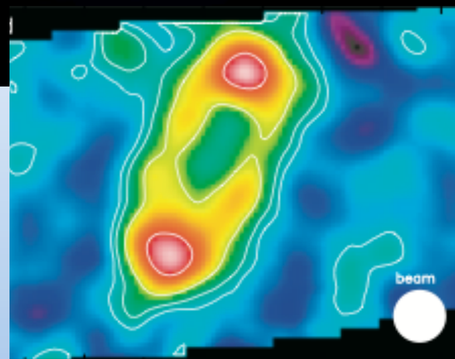
Herschel resolved disks

2) Fomalhaut, 7.8pc

At 70um, continuous smooth ring.
Eccentric, so see a pericentre glow at 70um.
No perturbation near the planet.

+ excess on the star.

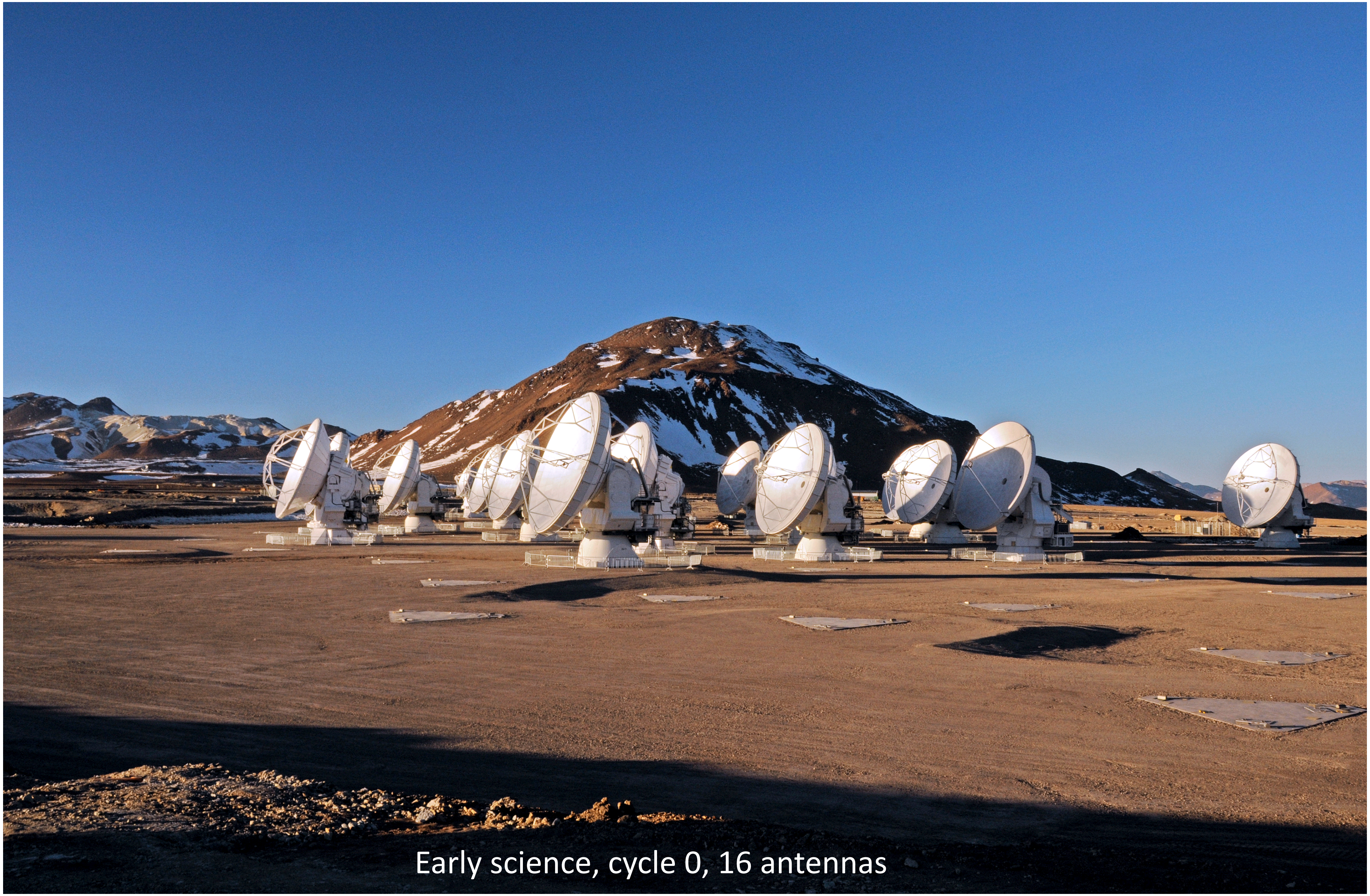




(350um/CSO)

Acke et al 2012 A&A
Marsh et al 2005

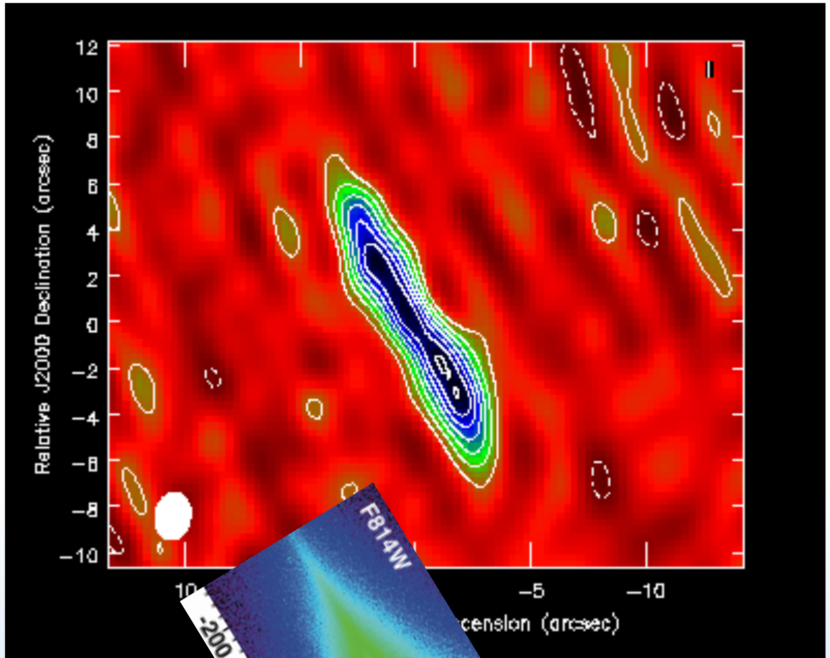
ALMA

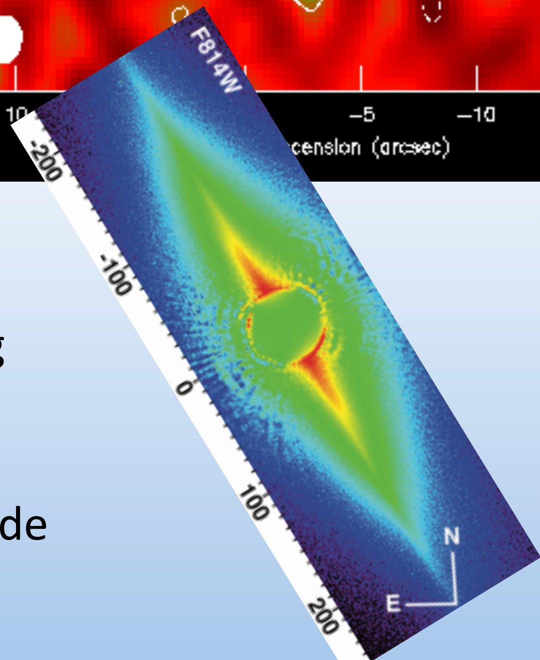


ALMA and debris

1) Beta Pic

Taken during test phase, with 5-6 antennas
850um, 1.5arcsec resolution





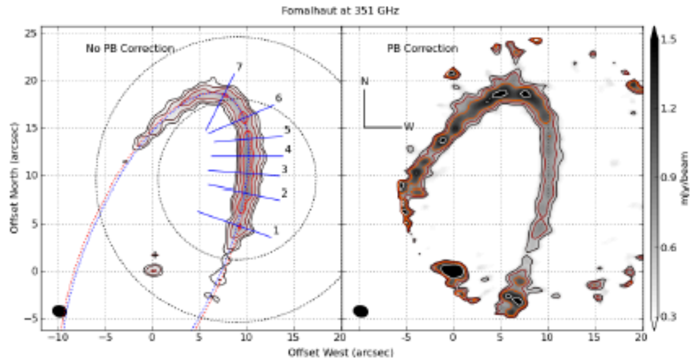
Double-peaked structure: ring radius 75AU
Negligible emission inside ring.
Radius corresponds to size of proposed 2nd inclined ring and change in scattered light gradient.

=> delineates orbit of parent bodies in collisional cascade

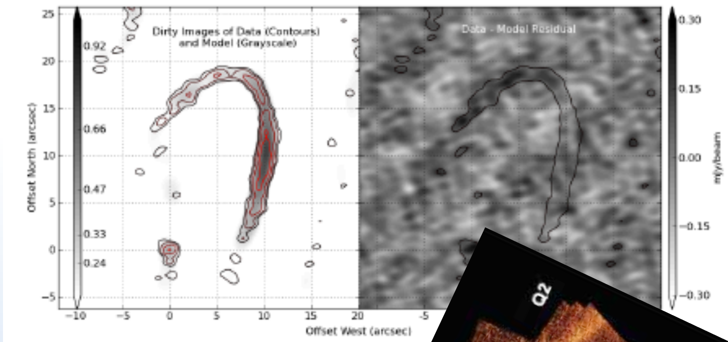
Golimowski etal 2006 (HST)

ALMA and debris

2) Fomalhaut

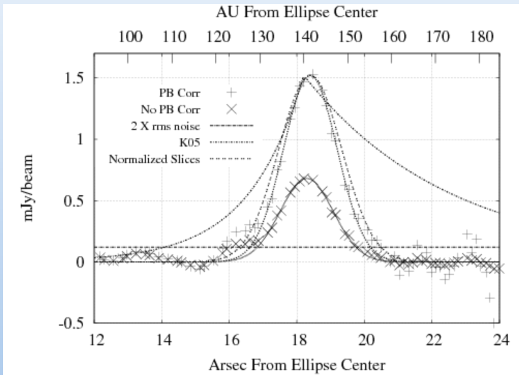


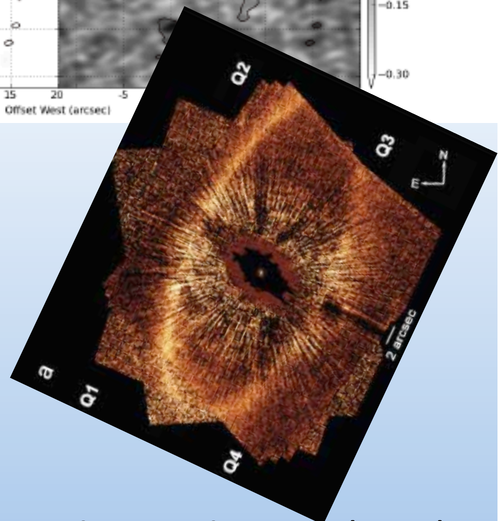
Taken in Dec & Jan, Early Science, 15-16 antennas, 850um, 60uJy rms, 1.5"resolution



Sharp ring, radius 140AU, width 16AU.
Negligible emission in/outside.
M_{mm}~$10^{-7}M_{o}$
•Optical - µm grains, blown out by radiation pressure
•mm grains, delineate orbit of parent bodies in collisional cascade

Why is ring so narrow?
=> Shepherding planets inside and outside





Kalas etal 2005 (HST)
Boley et al (2012) (about to be submitted)

Summary

Unresolved survey

- FIR line/continuum survey - Class II through to debris
- [OI]63 brightest - detect disks of 10^{-5}Mo (dust)
- Traces exposed surface of disk at 10-100AU, and outflows in early systems
- gas/dust ratio not constant (10x higher or lower)
- Can't rely on submm dust continuum to measure total mass
- [OI] correlated with FIR continuum
- Gas disk lifetimes ~4Myr

Resolved imaging

- Debris disks in submm are actually thin rings
- Planet shepherding may be common

- ALMA will reach 10AU resolution in nearby star formation regions in ~1yr