Properties of disks around brown dwarfs and very low mass stars

Luca Ricci

California State University, Northridge

Planet-Forming disks: A workshop to honor Antonella Natta

March 7, 2019

My first meeting with Antonella

My first meeting with Antonella

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Science **<u>with friends</u>** is even more fun

My first meeting with Antonella

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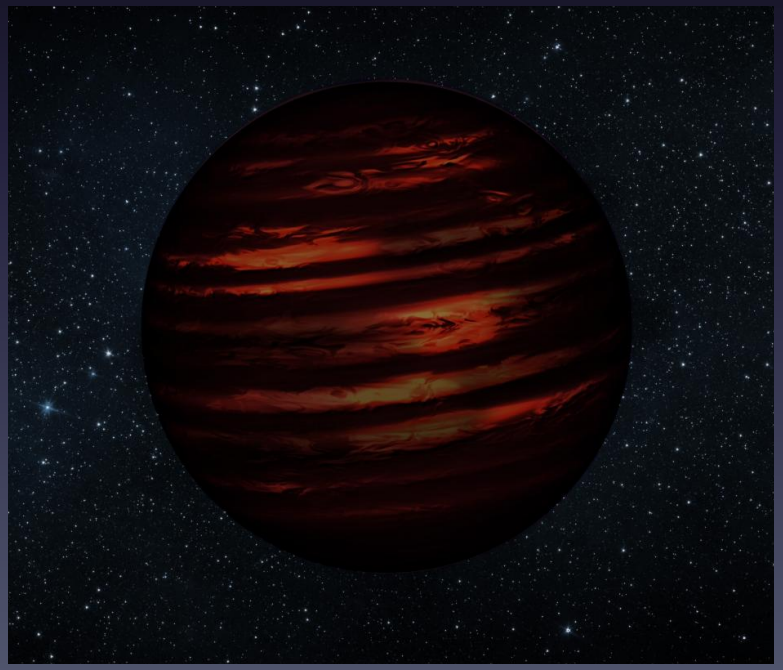


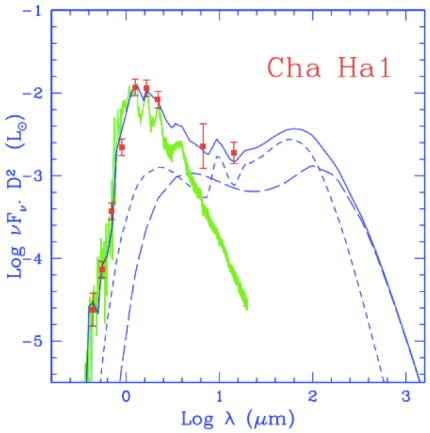
Brown Dwarf disks – IR excess

Exploring brown dwarf disks

A. Natta and L. Testi

Osservatorio Astrofisico di Arcetri, Largo E. Fermi 5, 50125 Firenze, Italy

Received 3 July 2001 / Accepted 24 July 2001



Abstract. We discuss the spectral energy distribution of three very low mass objects in Chamaeleon I for which ground-based spectroscopy and photometry as well as ISO measurements in the mid-infrared are available (Comerón et al. 2000; Persi et al. 2000). One of these stars (Cha Hα1) is a bona-fide brown dwarf, with mass 0.04–0.05 $M_\odot$. We show that the observed emission is very well described by models of circumstellar disks identical to those associated to T Tauri stars, scaled down to keep the ratio of the disk-to-star mass constant and to the appropriate stellar parameters. This result provides a first indication that the formation mechanism of T Tauri stars (via core contraction and formation of an accretion disk) extends to objects in the brown dwarf mass range.

Natta & Testi 2001

(see also Muench+ 01, Natta+ 02, Apai+ 02, Pascucci+ 03, Mohanty+ 04)

(evidence for accretion: Jayawardhana+ 03, Muzerolle+ 03, White & Basri 04, Natta+ 04)

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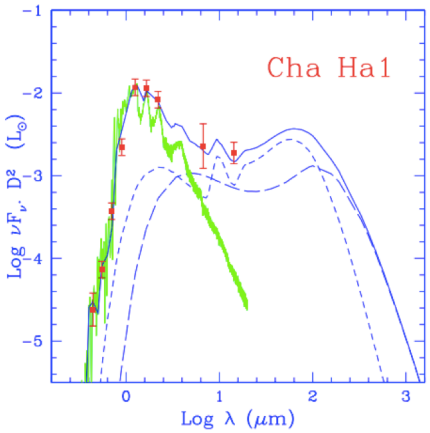

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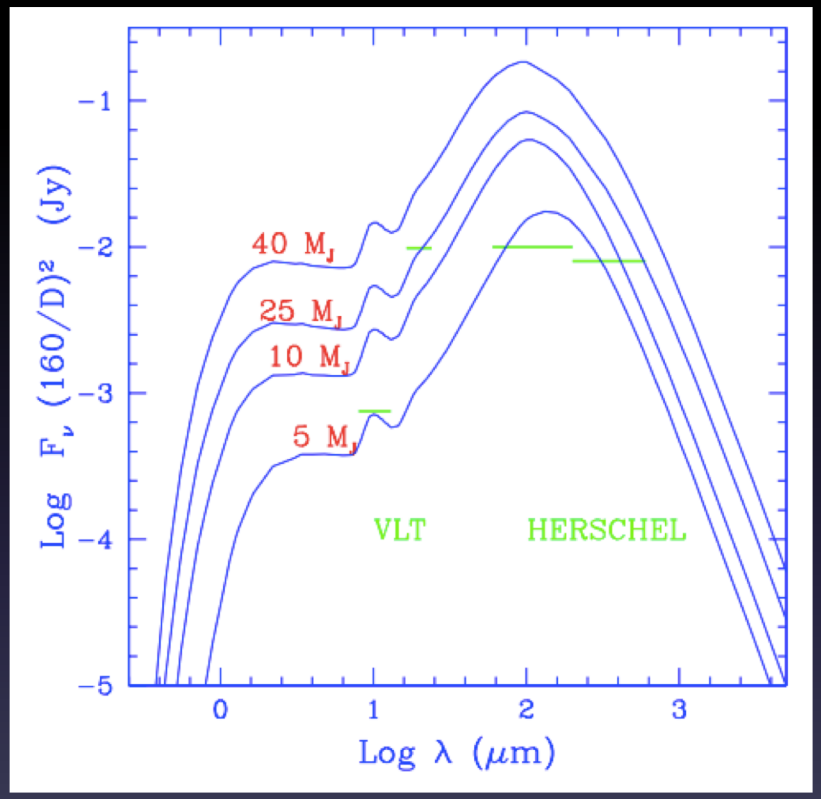


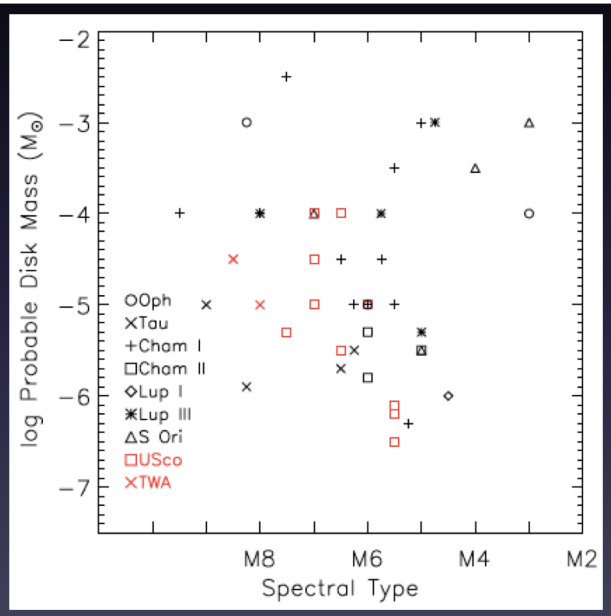
Natta & Testi 2001

Brown Dwarf disks – IR surveys

Table 1
Location of Observed Young BDs

Cloud	Number of BDs	Assumed Distance	Assumed Age	References
Ophiuchus	3	125 pc	1–3 Myr	1
Taurus	4	140 pc	1–3 Myr	2
Chamaeleon I	12	160 pc	1–3 Myr	3
Chamaeleon II	3	178 pc	1–3 Myr	1
Lup I	1	150 pc	1–3 Myr	1
Lup III	5	200 pc	~5 Myr	4
Sigma Ori	7	360 pc	~3 Myr	5
Upper Sco	11	145 pc	~11 Myr	6
TWA	2	54 pc	8–10 Myr	7

SED fitting up to 70 (160) micron



Harvey+ 12a, 12b

(see also Apai+05, Luhman+05, Riaz+06, Scholz+06,07, Liu+15, Daemgen+16, Hendler+17)

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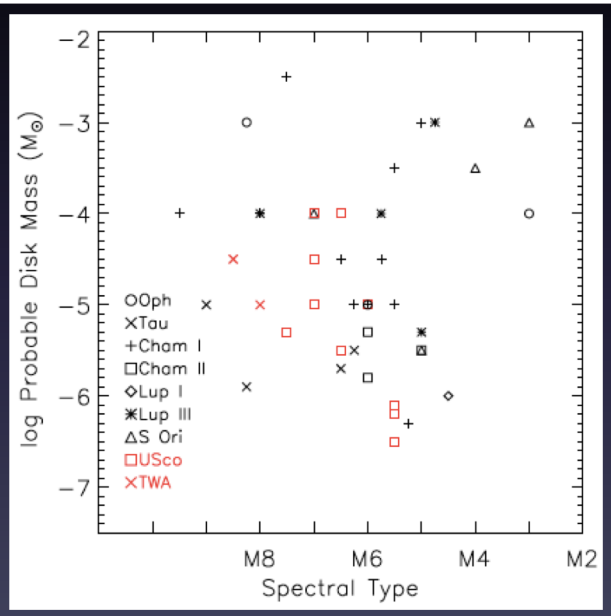

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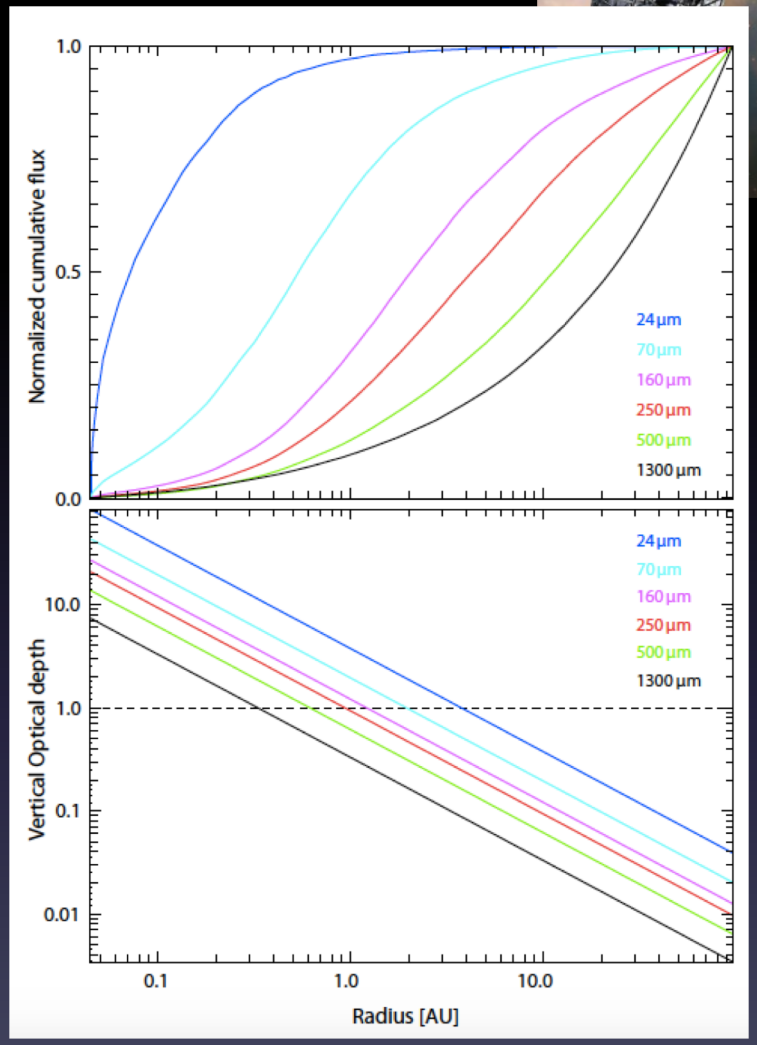
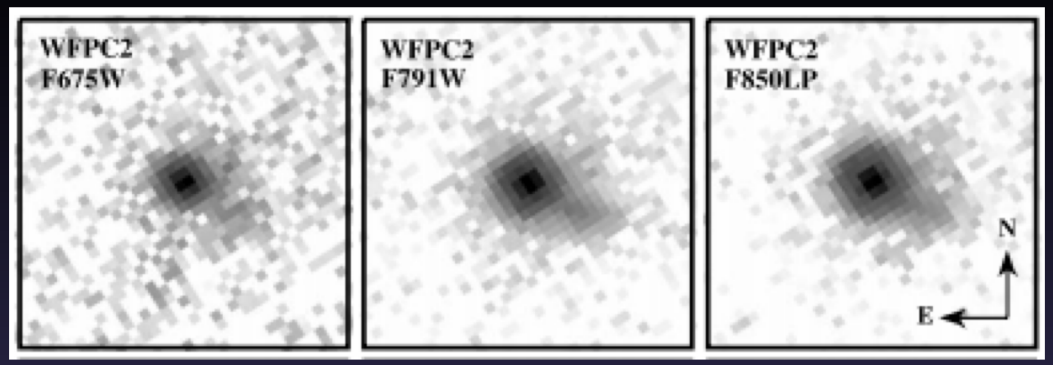


70 micron emission confined to ~ 5 au from BD, significant optical depth

(see also Apai+05, Luhman+05, Riaz+06, Scholz+06,07, Liu+15, Daemgen+16, Hendler+17)

Brown Dwarf disks – Radii before ALMA

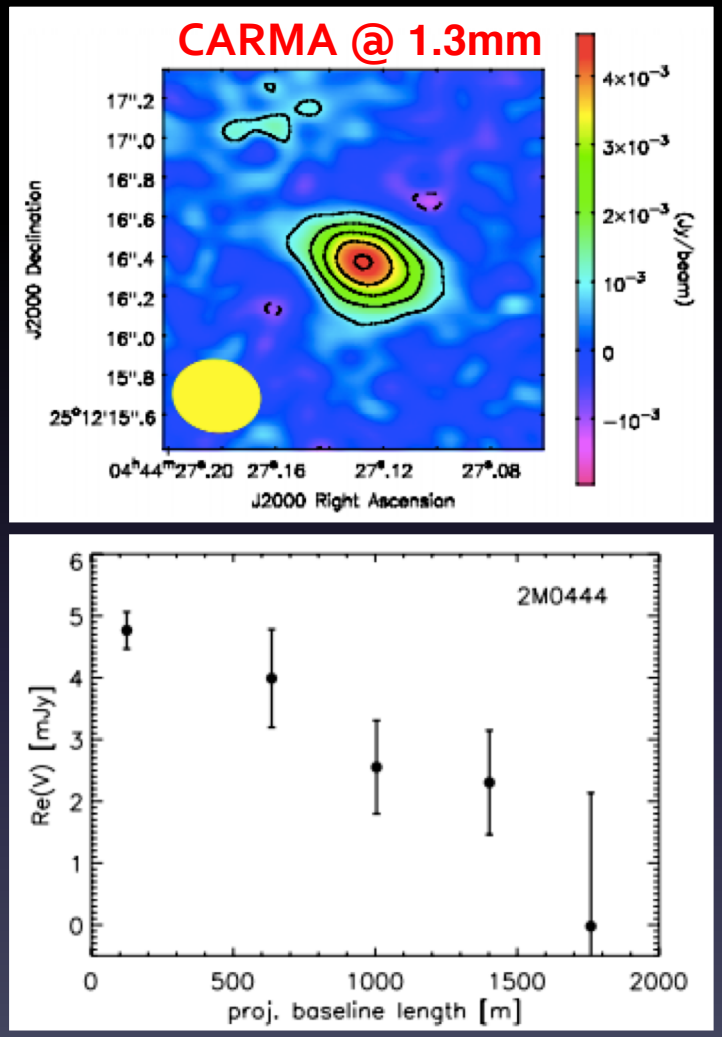
2MASS J04381+2611



Luhman+ 07

$R_{disk} \approx 20 - 40$ au

2MASS J044427+2512



Ricci+ 15

$R_{disk} > 20$ au

"Understanding is seeing well"

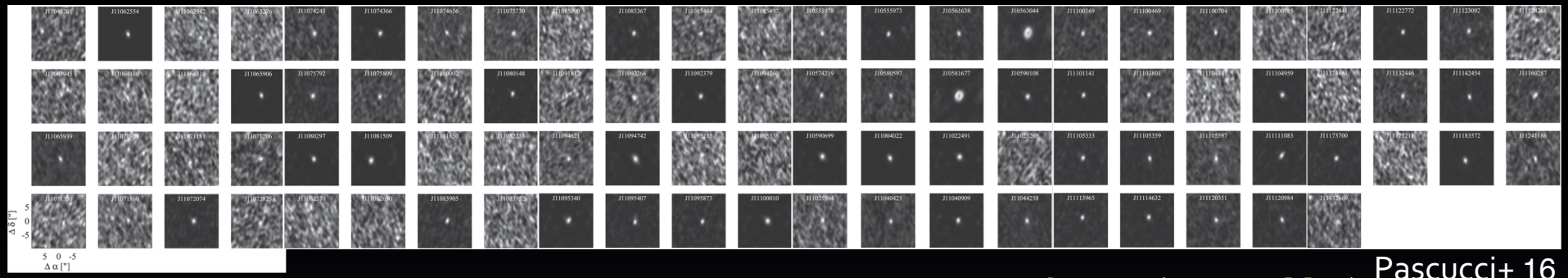
Leonardo da Vinci (1465 - 1519)

"Understanding is seeing well"

Leonardo da Vinci (1465 - 1519)

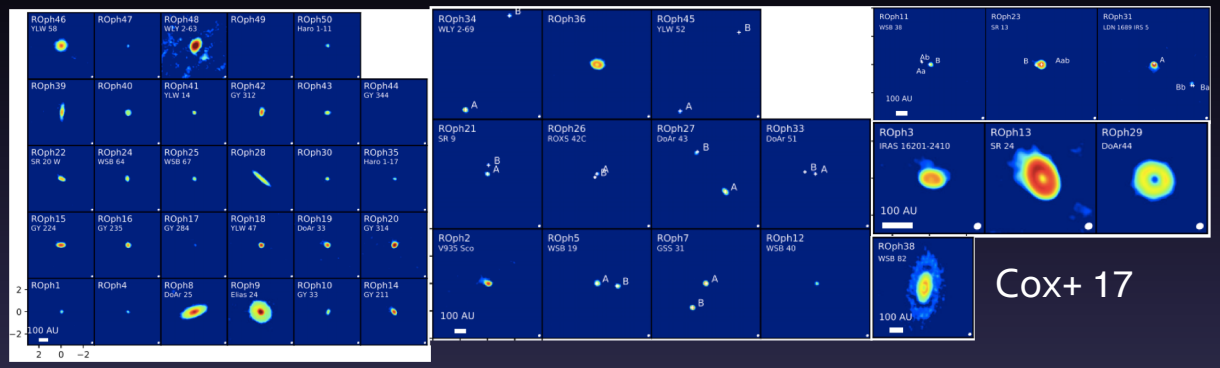
ALMA Disk Surveys in nearby regions (<200 pc)

Chamaeleon I (~ 2 – 3 Myr)



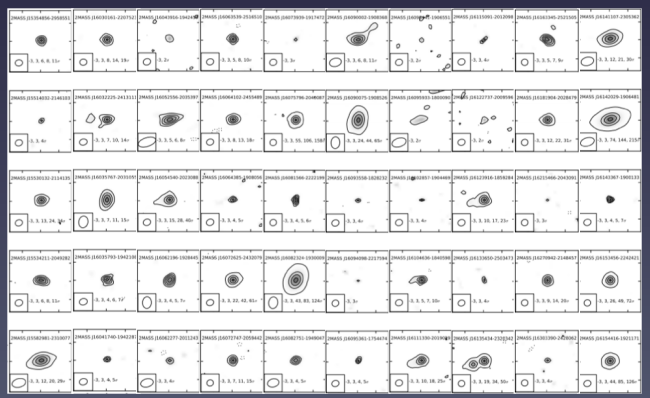
Pascucci+ 16

Ophiuchus (~ 1 – 2 Myr)



Cox+ 17

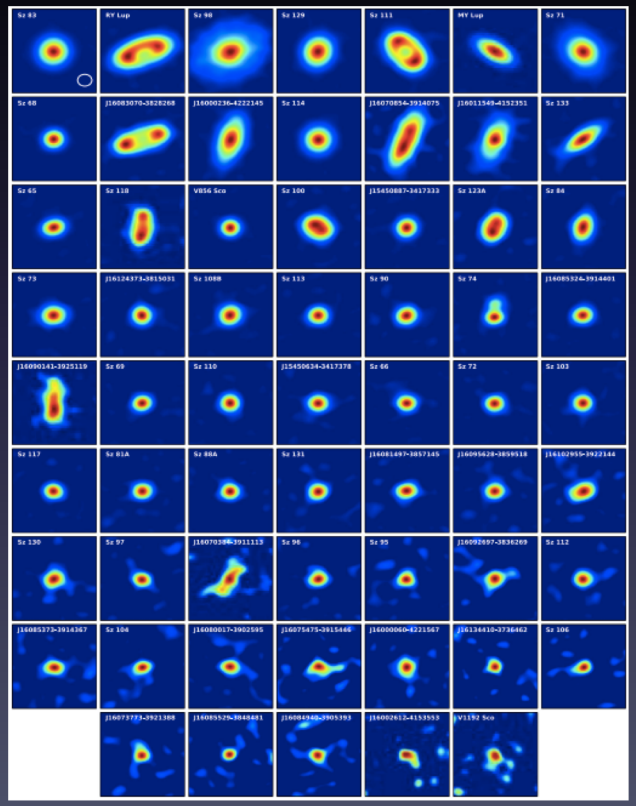
Upper Sco (~ 5 – 10 Myr)



Barenfeld+ 17

Carpenter+ 14

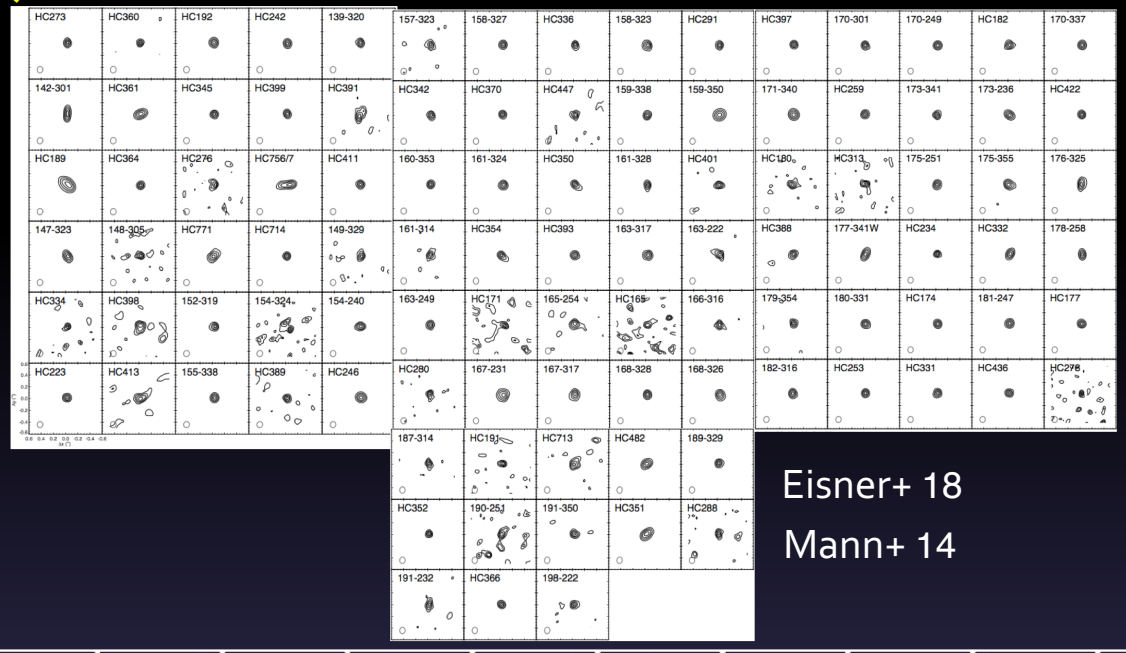
Lupus (~ 1 – 3 Myr)



Ansdell+ 16

ALMA Disk Surveys in denser regions (~400 pc)

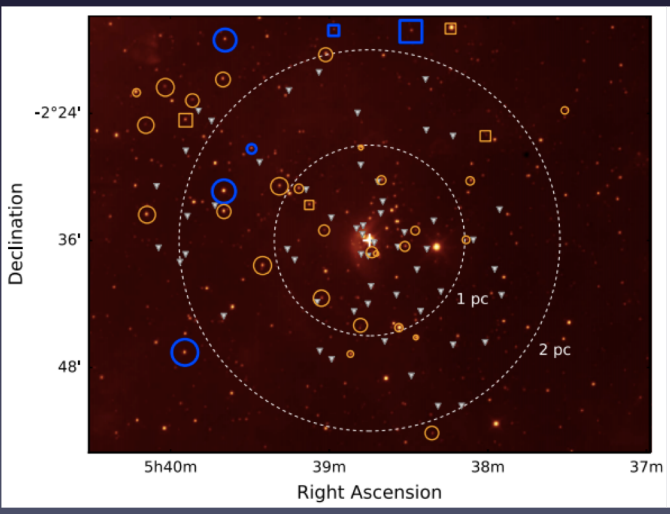
Orion Nebula Cluster (~ 1 – 3 Myr)

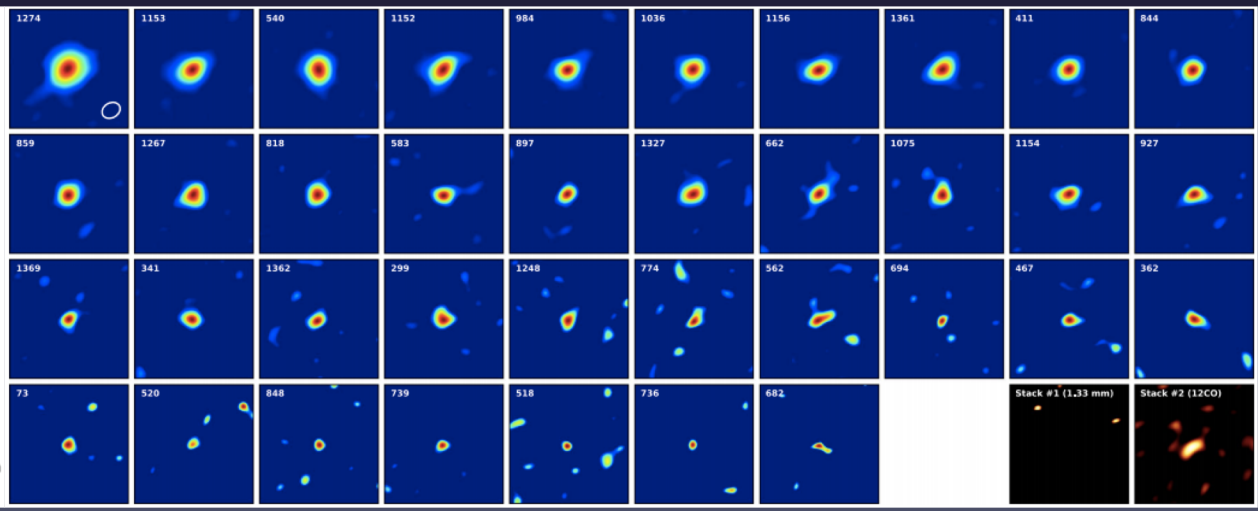


Eisner+ 18

Mann+ 14

σ Orionis (~ 3 – 5 Myr)





Ansdell+ 17

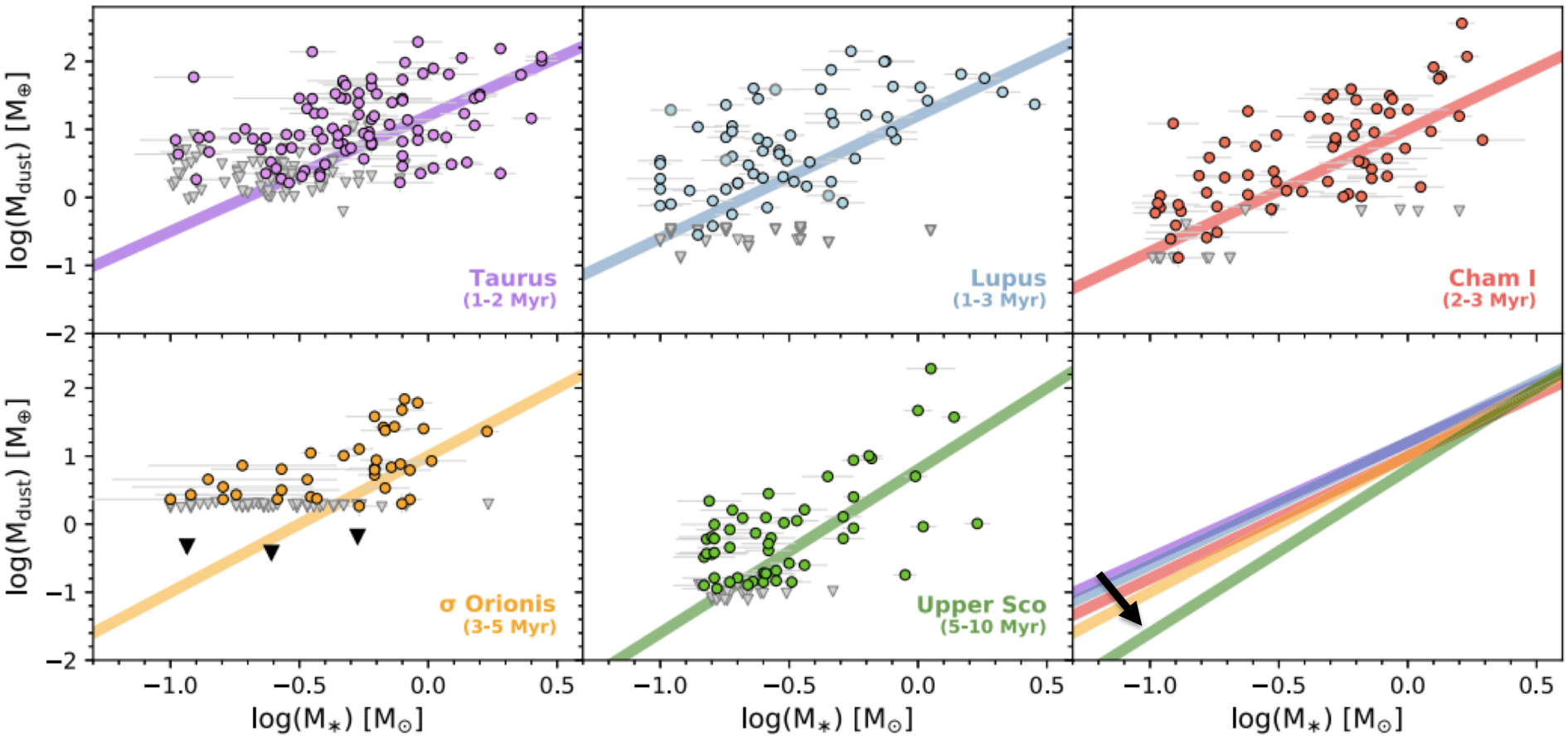
From Flux to Mass

$$M_{dust} = \frac{F_\nu \, d^2}{B_{\nu(T_{dust})} \, \kappa_\nu}$$

Main Caveats:

1) Dust opacities from Beckwith+ 1990, but highly uncertain
2) Dust temperature depends on star and disk properties (flaring, radius, dust opacities, IRF,…)
3) Assumes 100% optically thin emission

Disk Surveys Results – Dust masses



$M_{dust} \propto M_{star}^{1.5 - 2.5}$, large scatter

Hint for steepening of M_{dust} *vs* M_{star} relation with age,
Suggesting faster dust evolution (loss) in VLM/BD disks

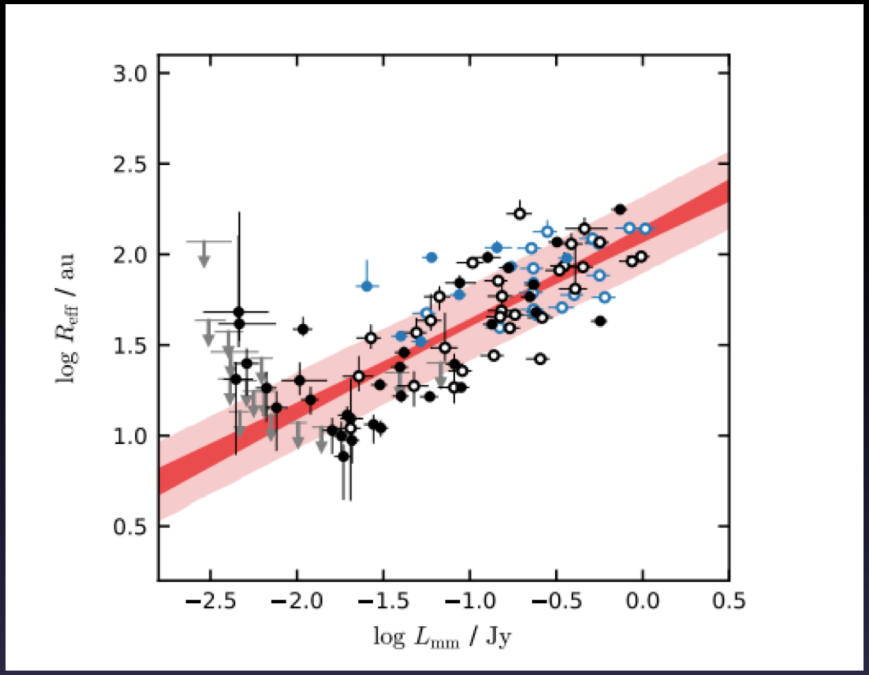
Ansdell+ 17

(Ilaria, Paola's Talks)

Disk Surveys Results – Dust disk sizes

105 disks in nearby regions with ALMA & SMA

Dust "effective radius"
68% of total emission



Andrews+ 18
(see also Tripathi+ 17, Barenfeld+ 17, Tazzari+ 17)

Brighter disks are larger in dust: Initial conditions?

Radial drift? (Giovanni's talk)

$L_{\rm mm} \sim R_{\rm eff}^2$ Significant optical depth? (Marco)

(Ricci, Natta+ 12)

Disk Surveys Results – Dust disk sizes

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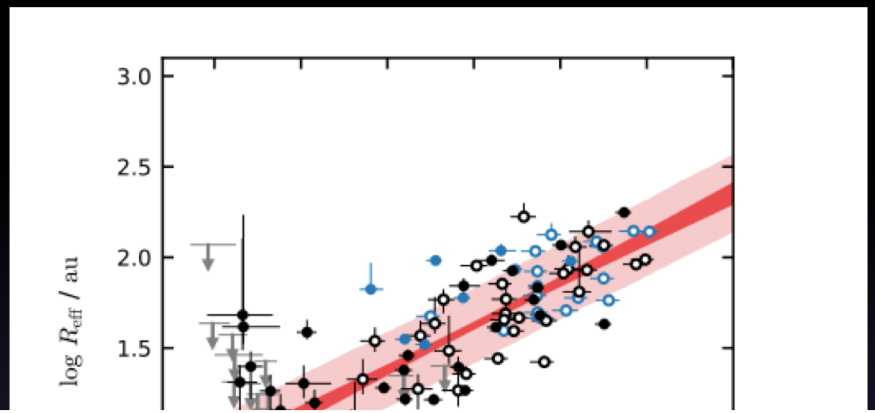


Dust "effective radius"
68% of total emission

A&A 540, A6 (2012)
DOI: 10.1051/0004-6361/201118296

Astronomy & Astrophysics

with τ = 0.6

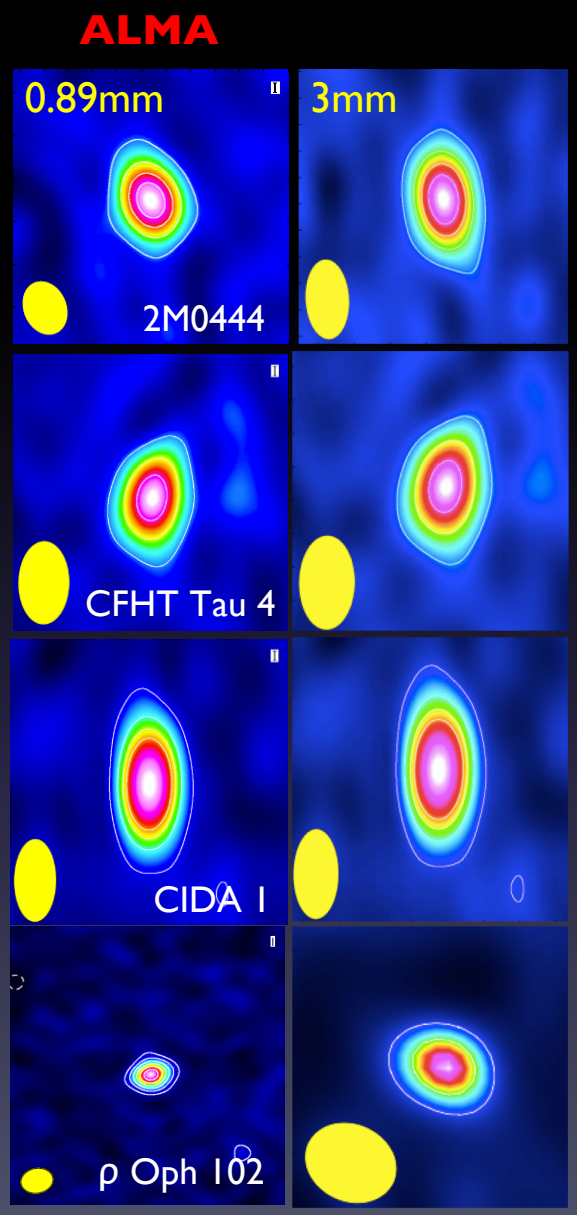
The effect of local optically thick regions in the long-wave emission of young circumstellar disks

L. Ricci[1,2], F. Trotta[1,3], L. Testi[1,3], A. Natta[3,4], A. Isella[2], and D. J. Wilner[5]

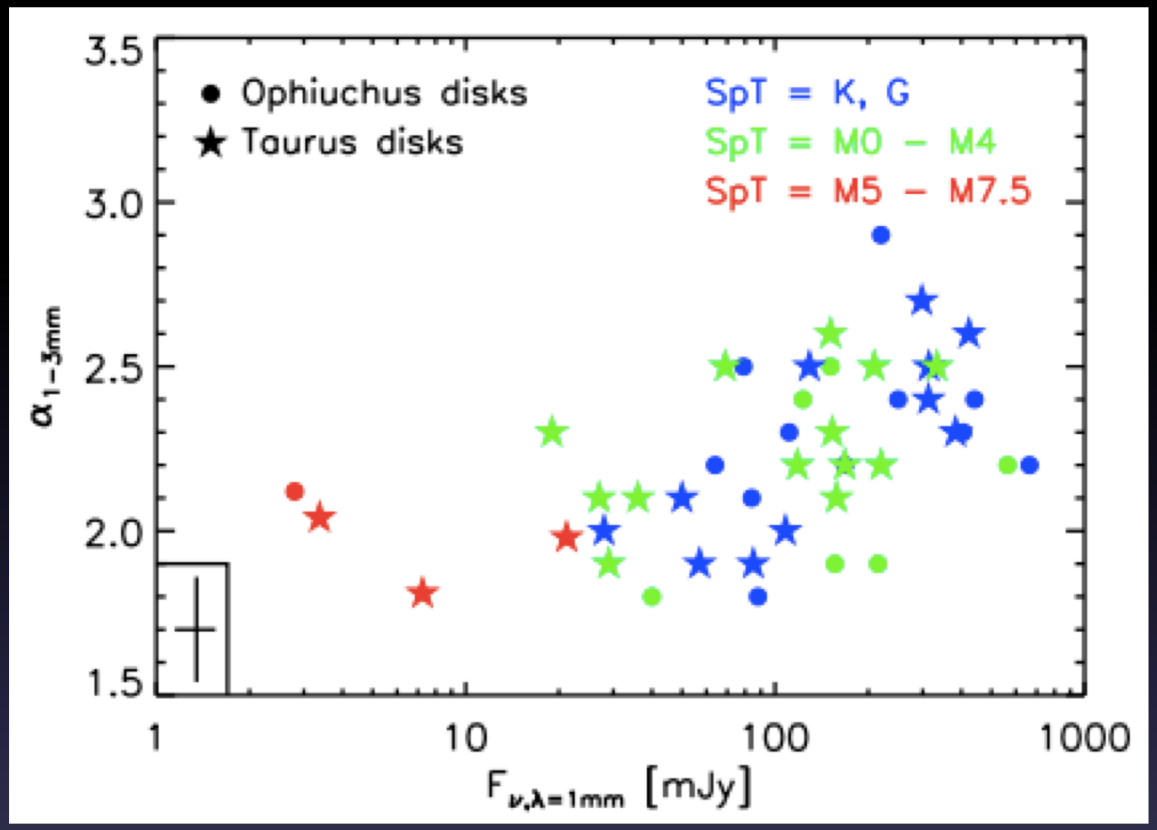
$L_{mm} \sim R_{eff}^2$ Significant optical depth? (Marco)

(Ricci, Natta+ 12)

VLM/BD disks – physical structure

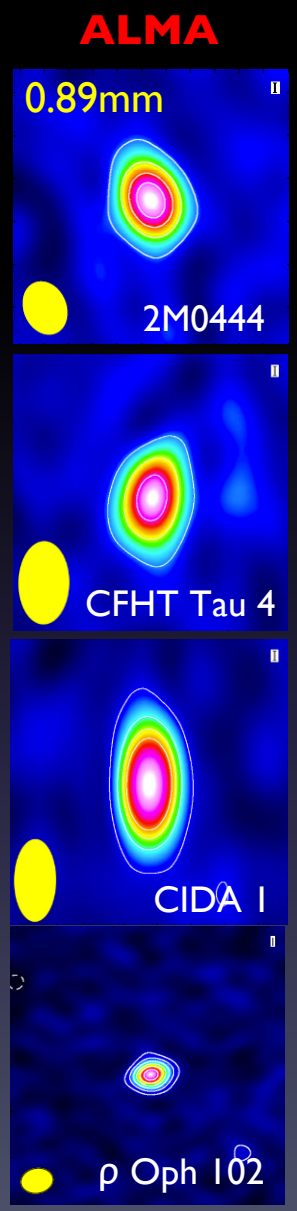


Ricci, Testi, Natta+ 12, 14

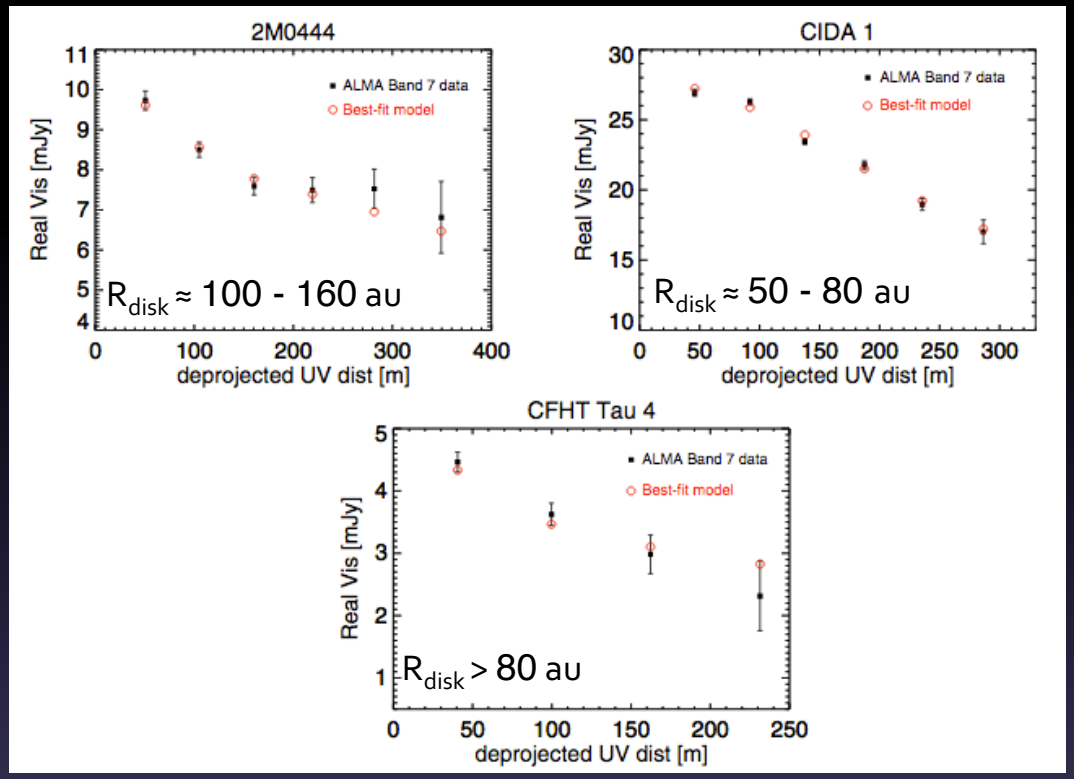


mm-spectral indices similar to those in T Tauri disks, test to models of dust evolution in disks (see Paola's talk)

VLM/BD disks – physical structure



Ricci, Testi, Natta+ 12, 14



Ricci+ 14

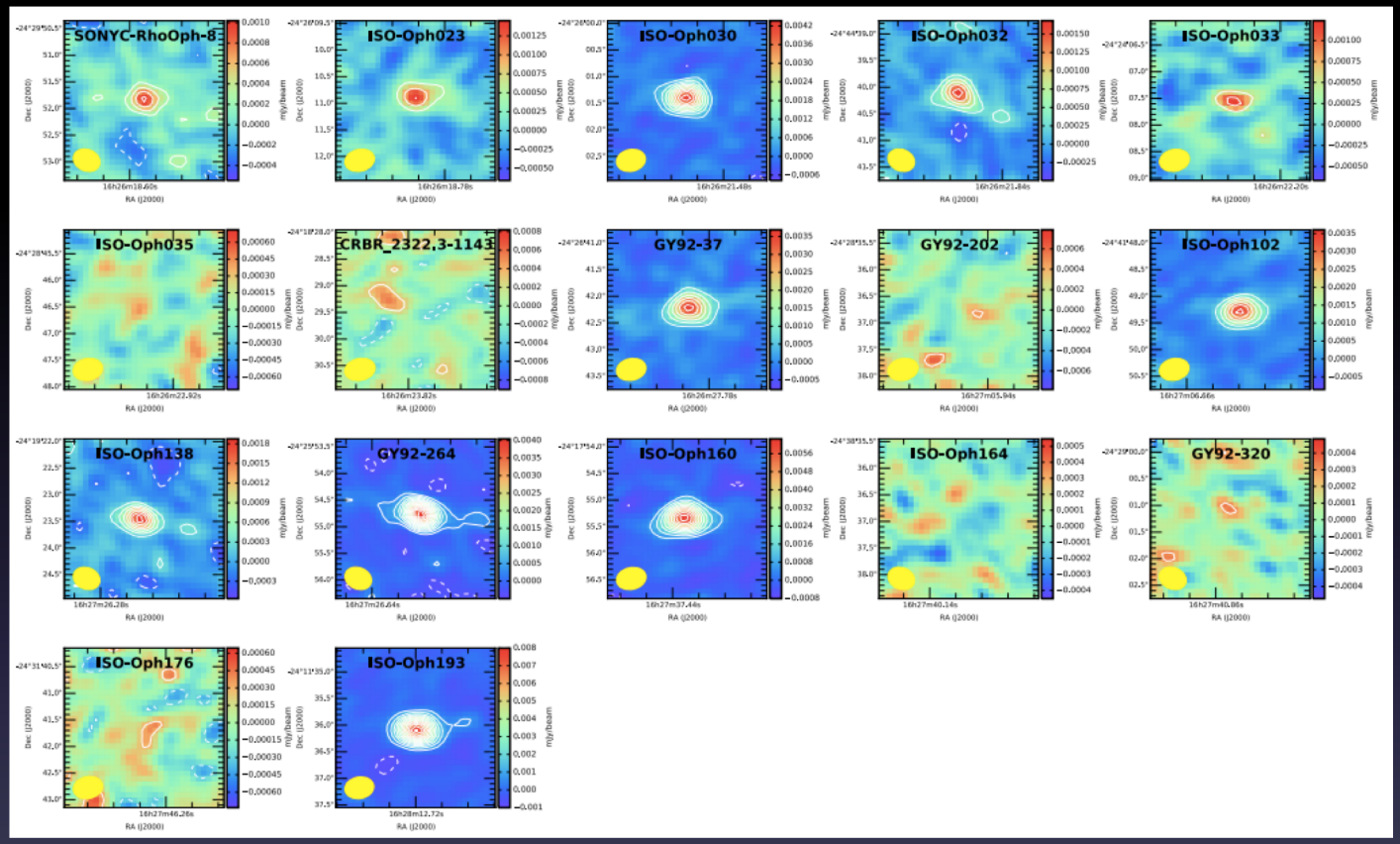
Brightest disks in Taurus around M5-M7.5

VLM/BDs as large as stellar disks

Disk in Ophiuchus is smaller, $R_{disk} < 30$ au

VLM stars/BDs surveys

17 disks around M5- M8 in Ophiuchus

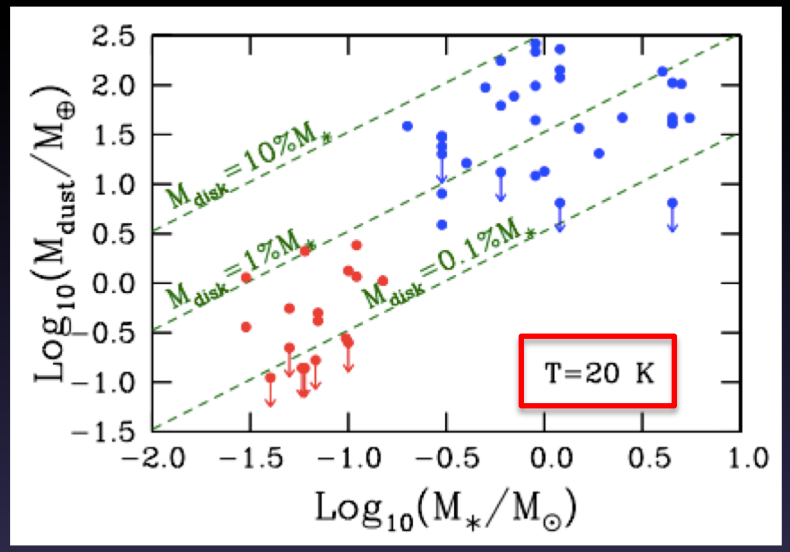


Testi, Natta, ...Ricci+ 16

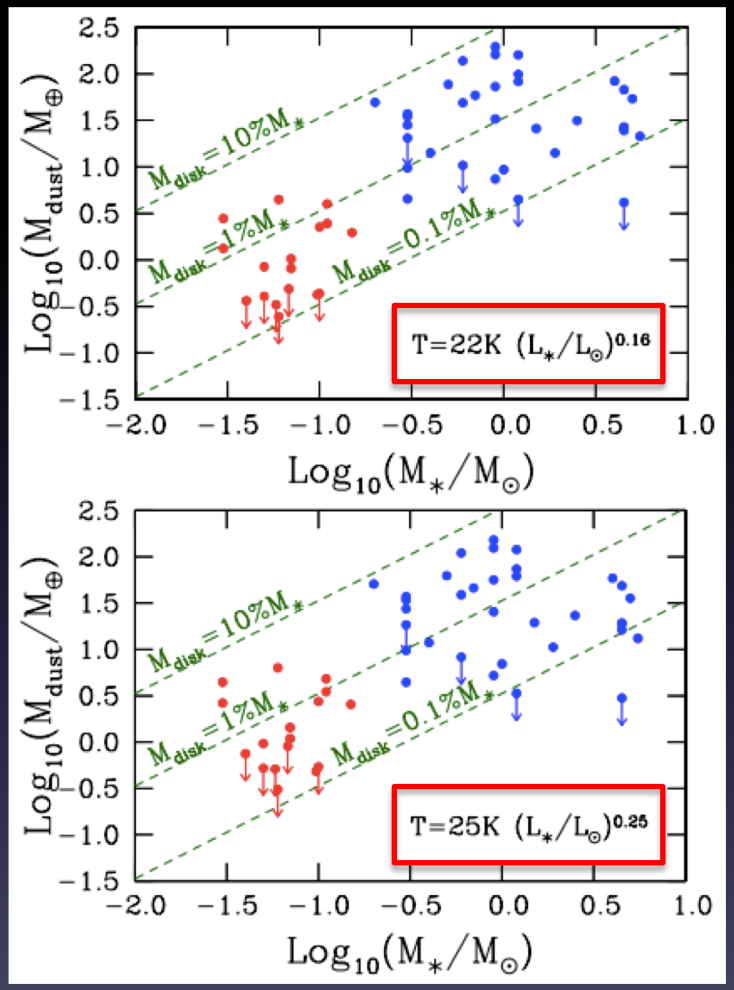
All detected disks have sizes < 0.3″, or < 20 au in radius:
BD formation ejection? Efficient radial drift?

VLM stars/BDs surveys

17 disks around M5- M8 in Ophiuchus



Testi, Natta, ...Ricci+ 16

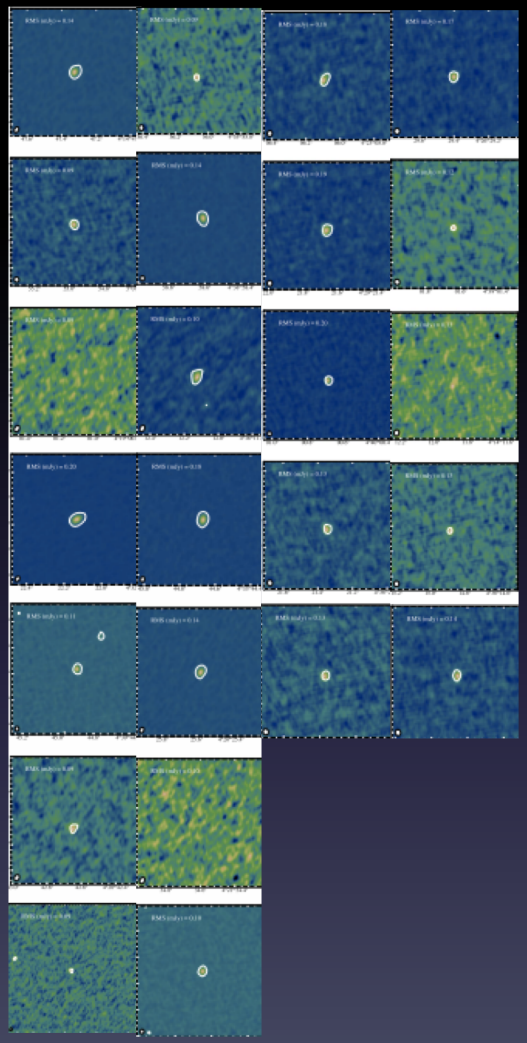


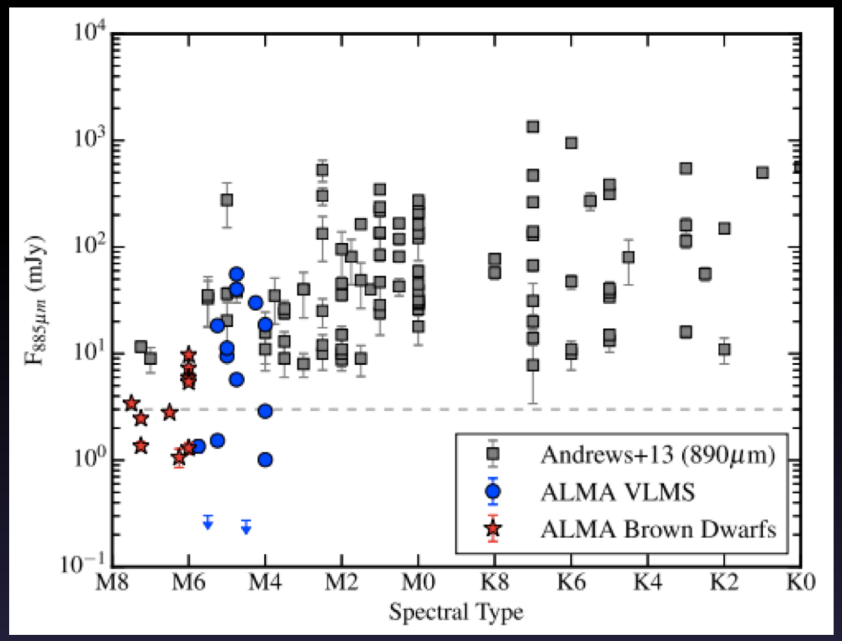
$$M_{dust} = \frac{F_\nu \, d^2}{B_\nu(T_{dust}) \, \kappa_\nu}$$

Strong effect of T_{dust} vs L_* relation on M_{dust} vs M_* across the HBL

VLM stars/BDs surveys

M4 - M7.75 in Taurus





Ward-Duong+ 18

VLM stars/BDs surveys

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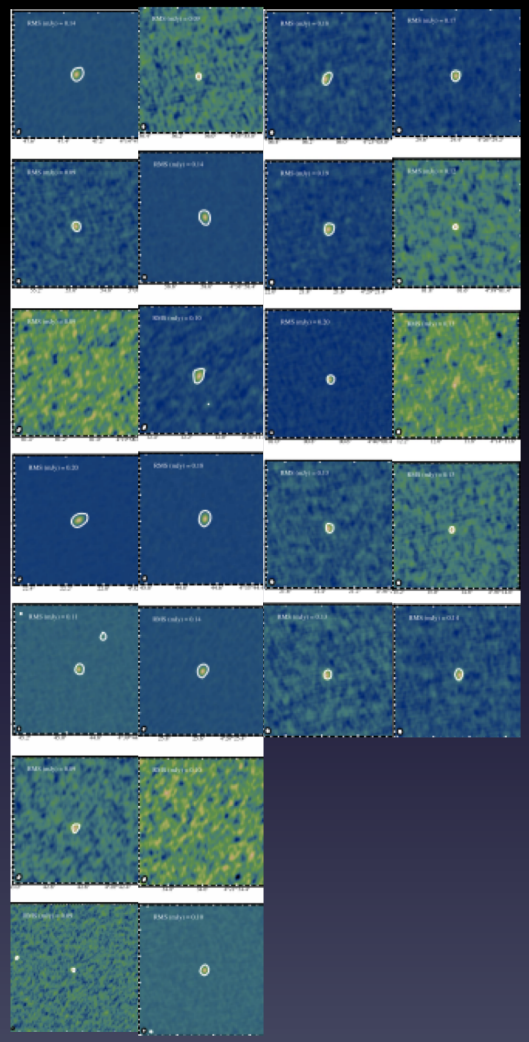
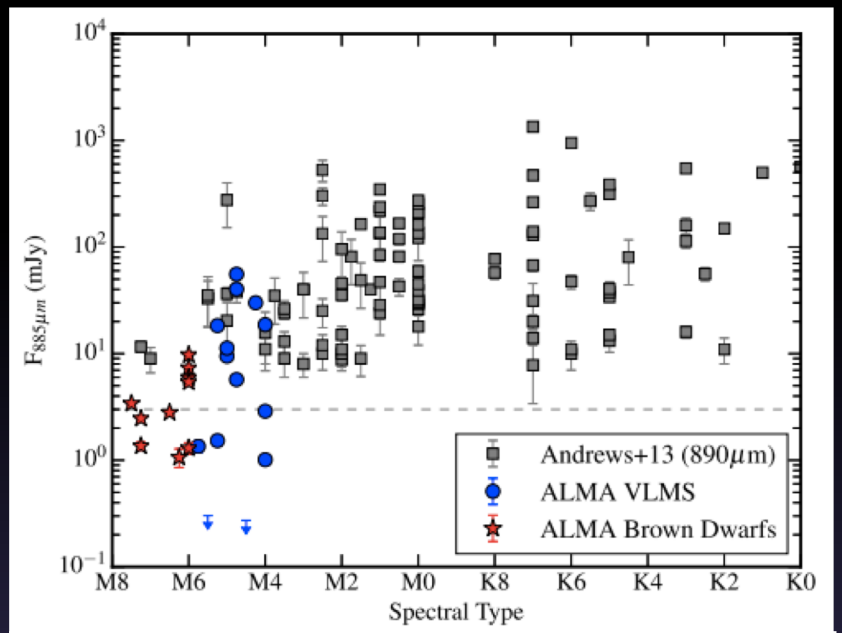
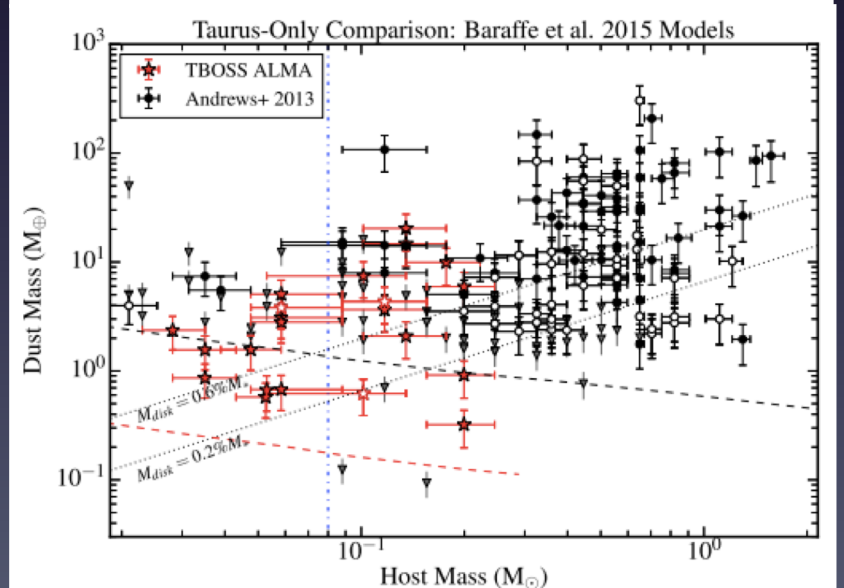




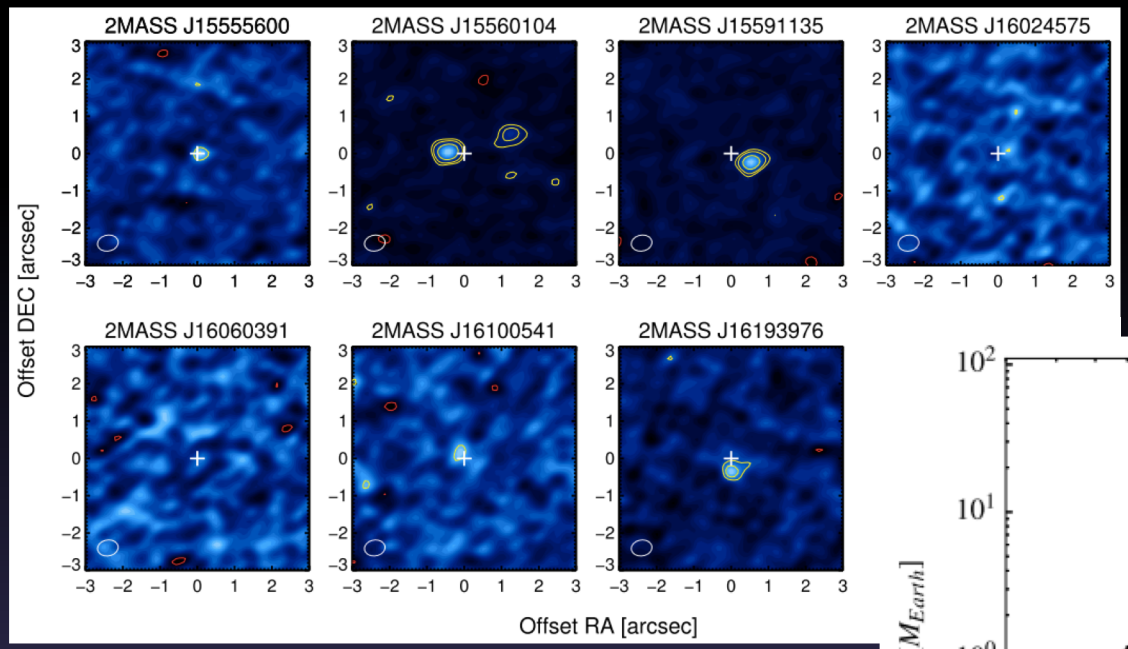


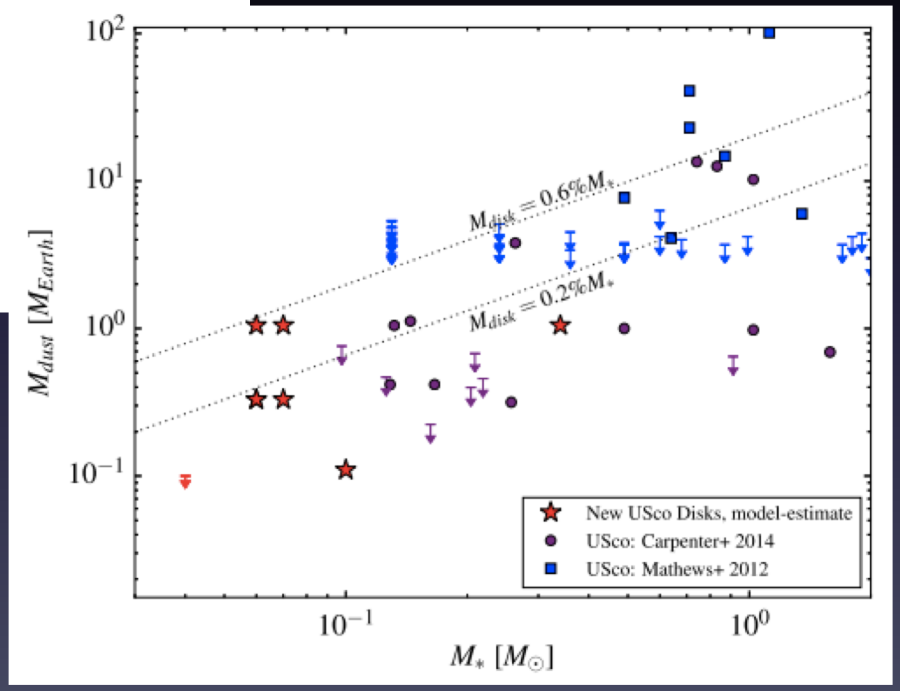
No break/knee at ~ HBL

Ward-Duong+ 18

VLM stars/BDs surveys

7 disks around M5.5 - M7.5 VLM/BDs in Upper Sco

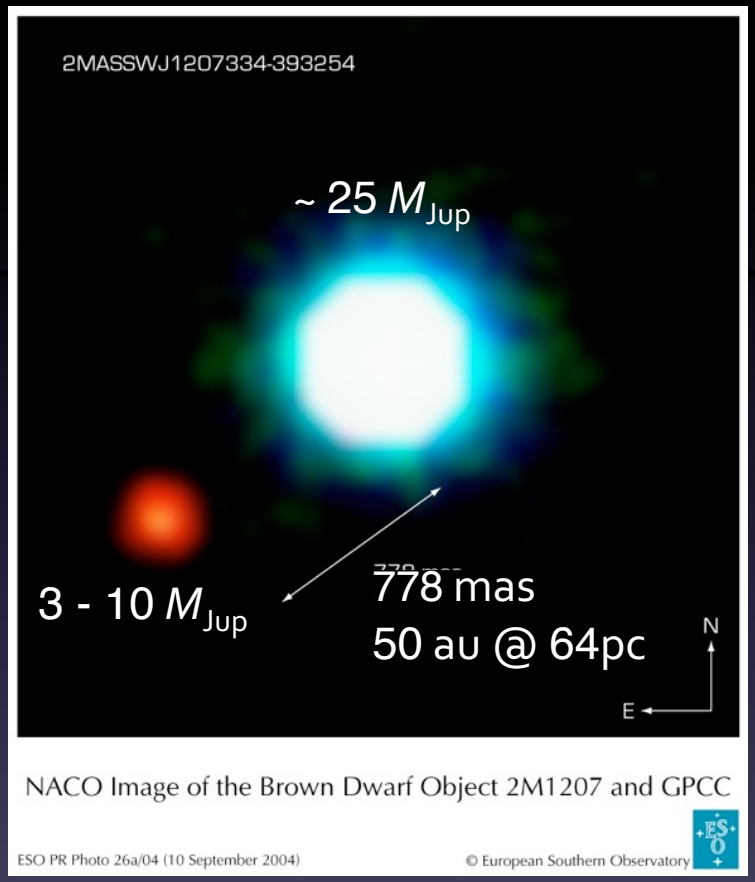




van der Plas+ 16

See Talk by Enrique Sanchis-Melchor for ALMA survey of Lupus BDs

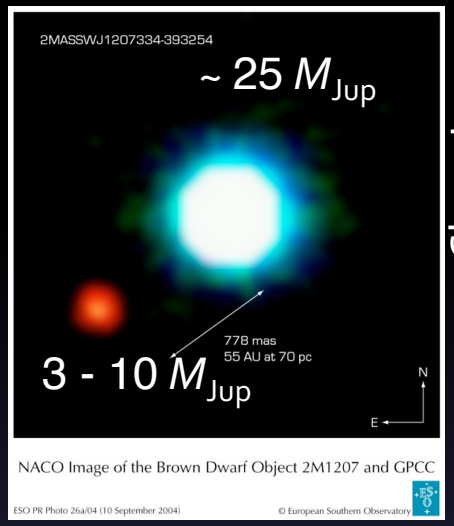
BD disks with ALMA: how low in mass?



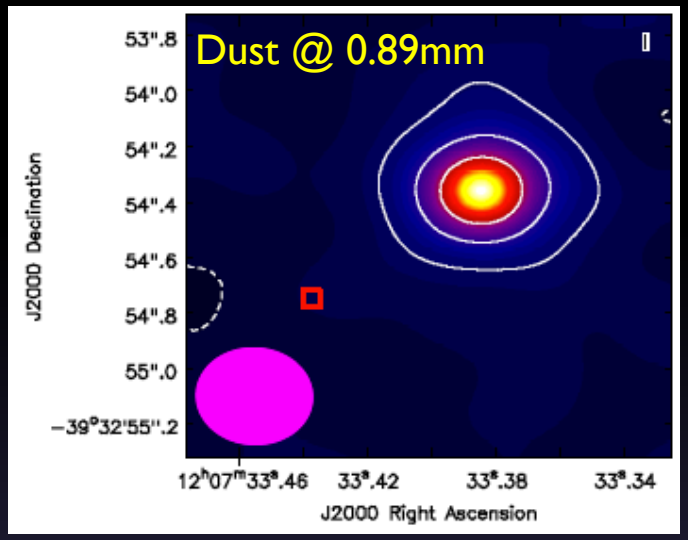
Chauvin+ 04

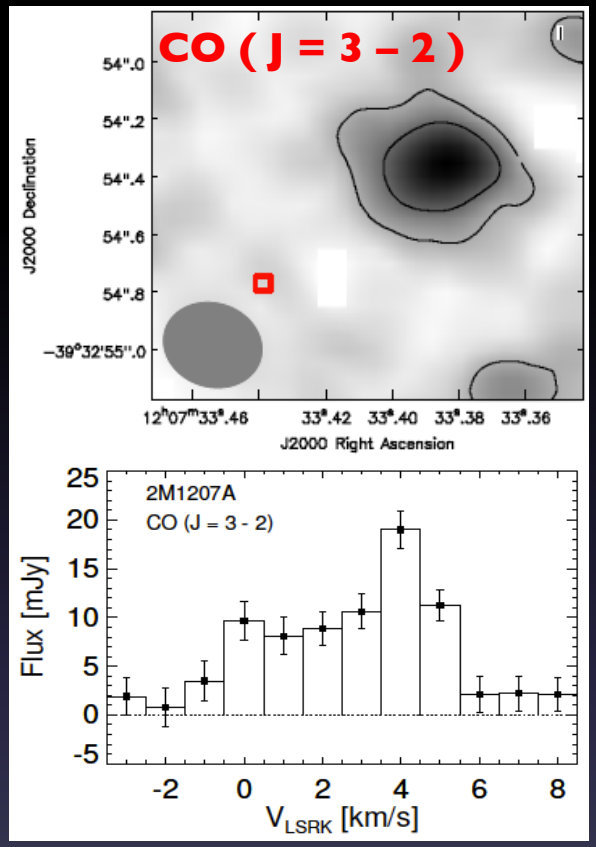
2M1207: age ~ 5 - 10 Myr, closer than all younger systems

BD disks with ALMA: how low in mass?



Chauvin+ 04





Ricci+ 17

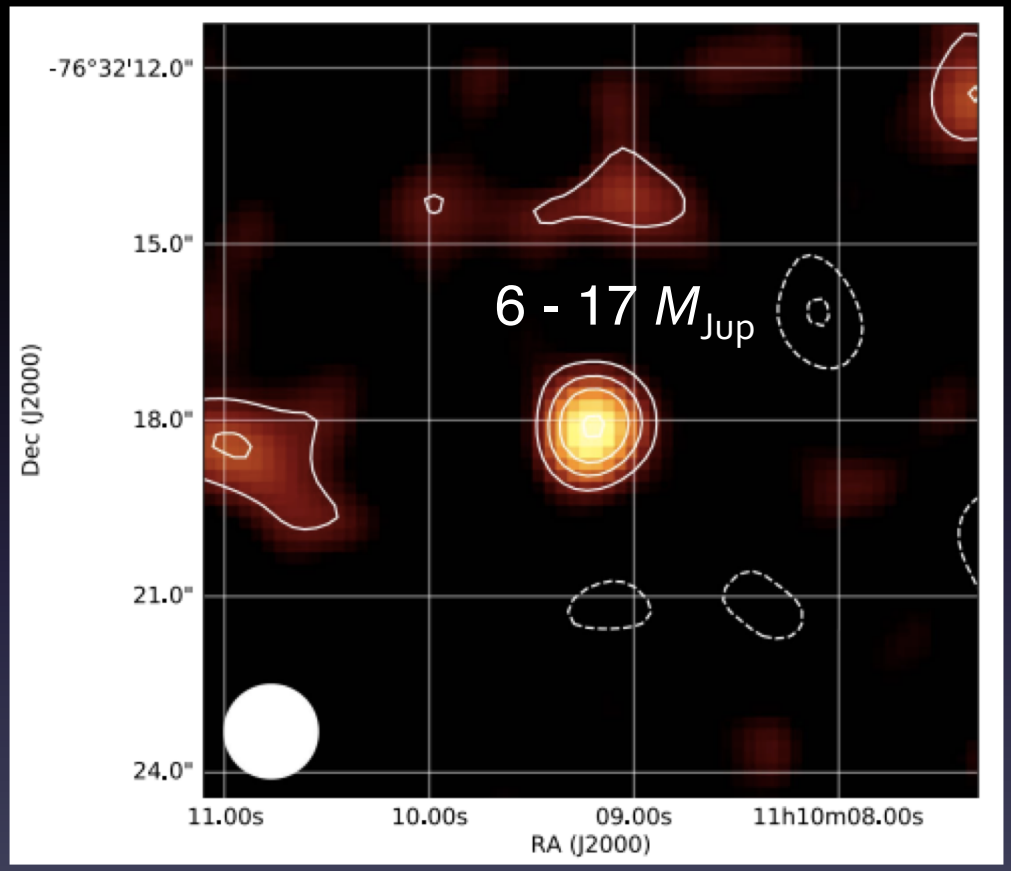
Dusty, gas-rich disk down to ~ 2 x deuterium burning limit

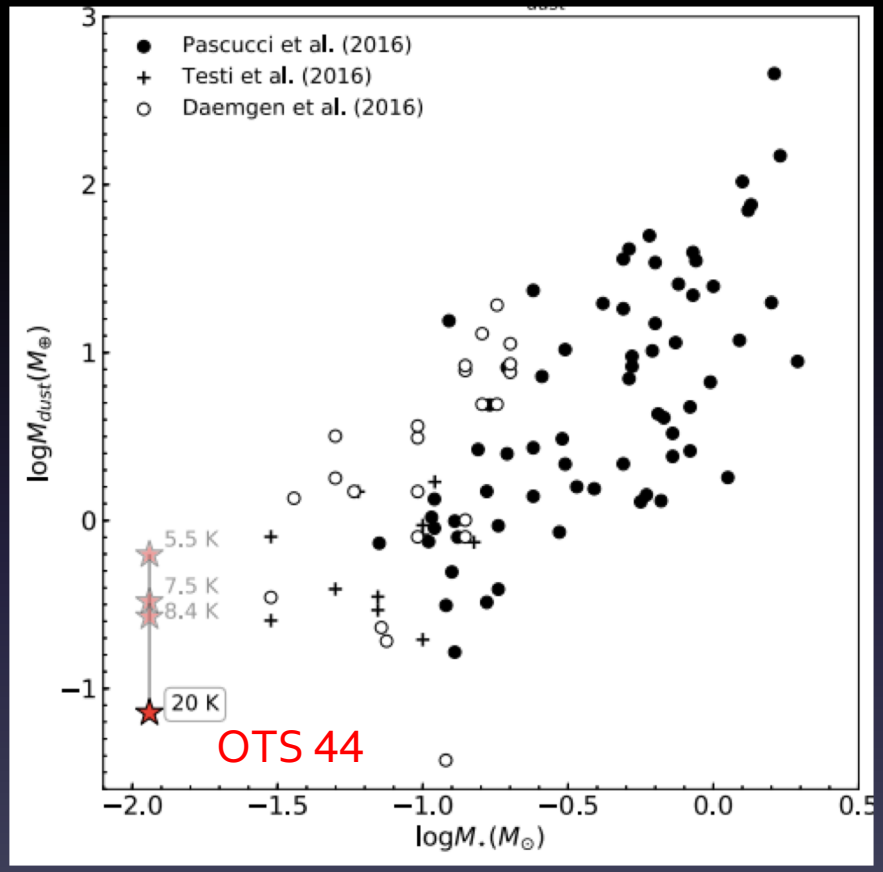
M_{dust} (BD) ~ 10 M_{Moon} , M_{dust} (planet) < 1 M_{moon} (opt thin)

R_{disk} (planet) < 0.5 au (opt thick)

BD disks with ALMA: how low in mass?

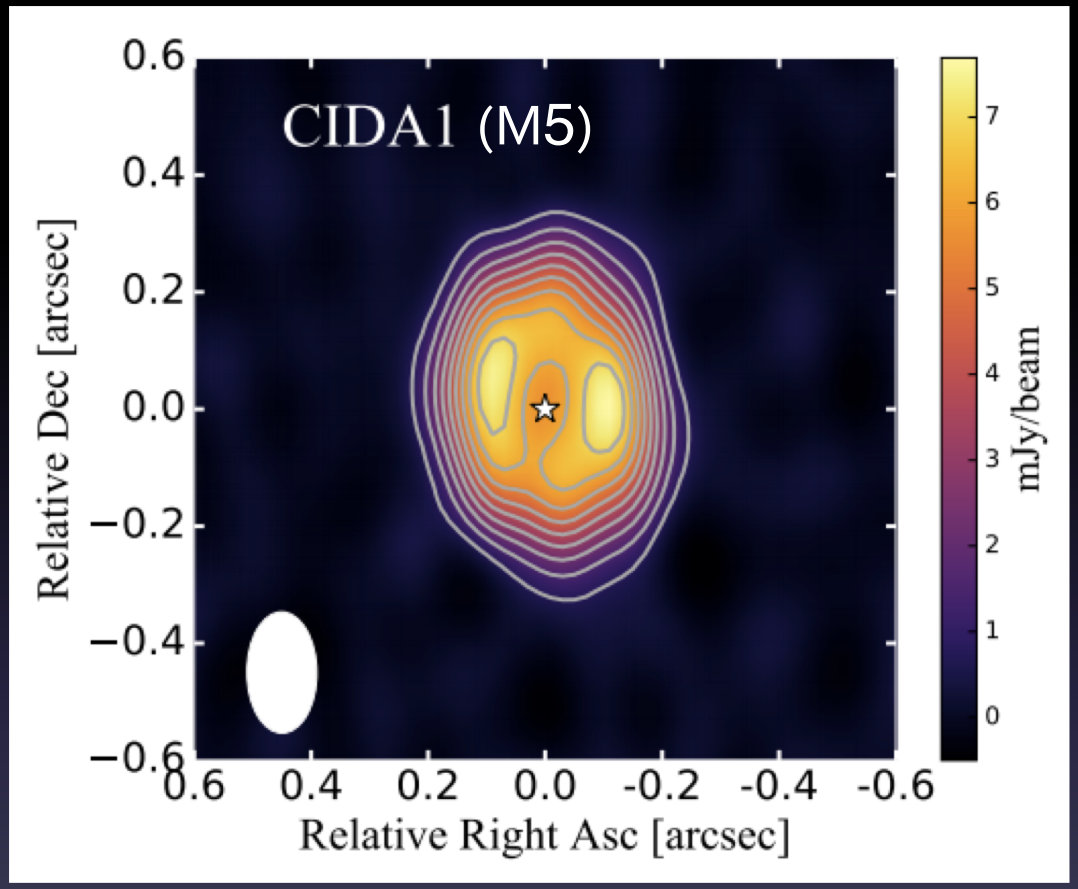
OTS 44, SpT M9.5

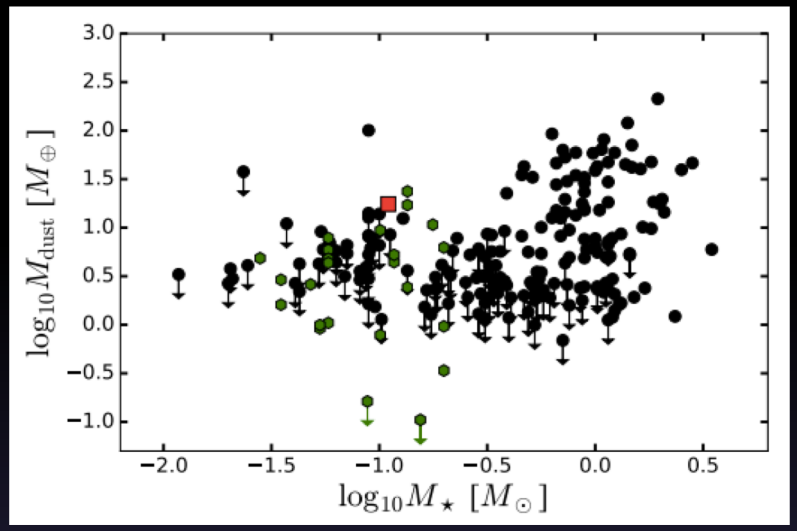


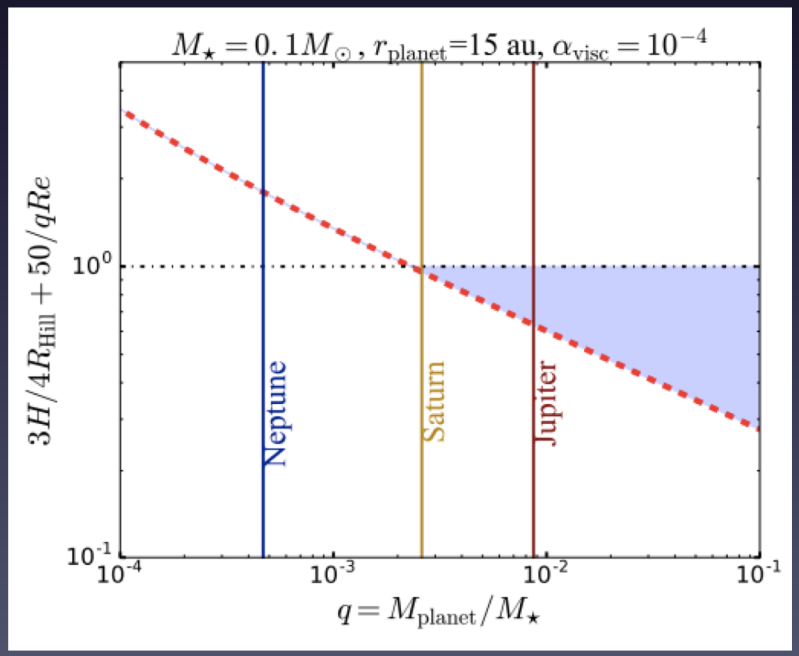


Bayo+ 17

Substructures in a VLM disk





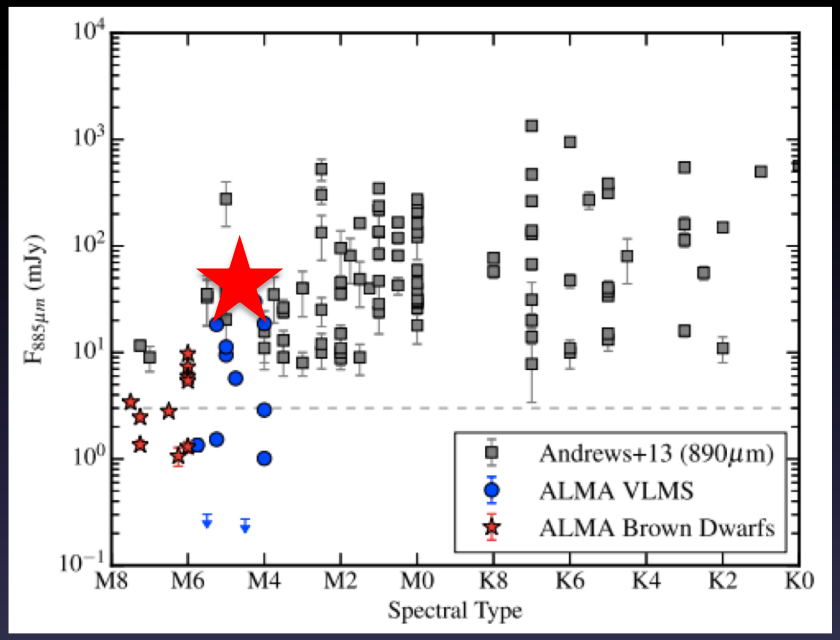


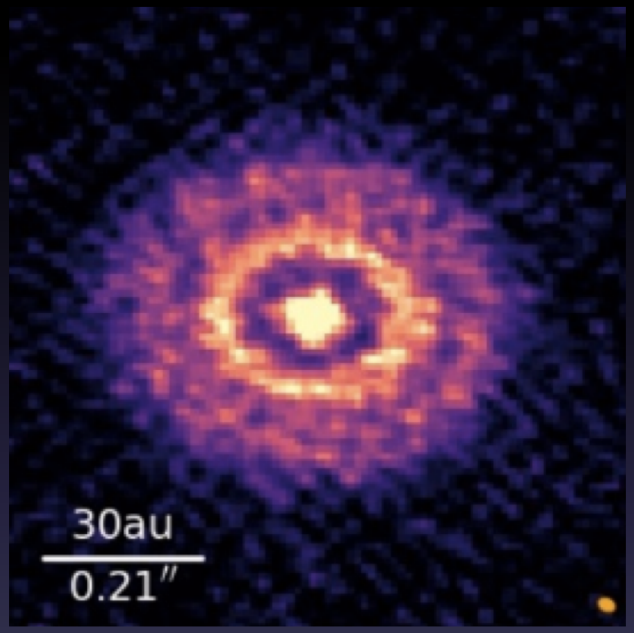
Inner cavity at ~ 20 au

Giant Planet (> Saturn) can open it

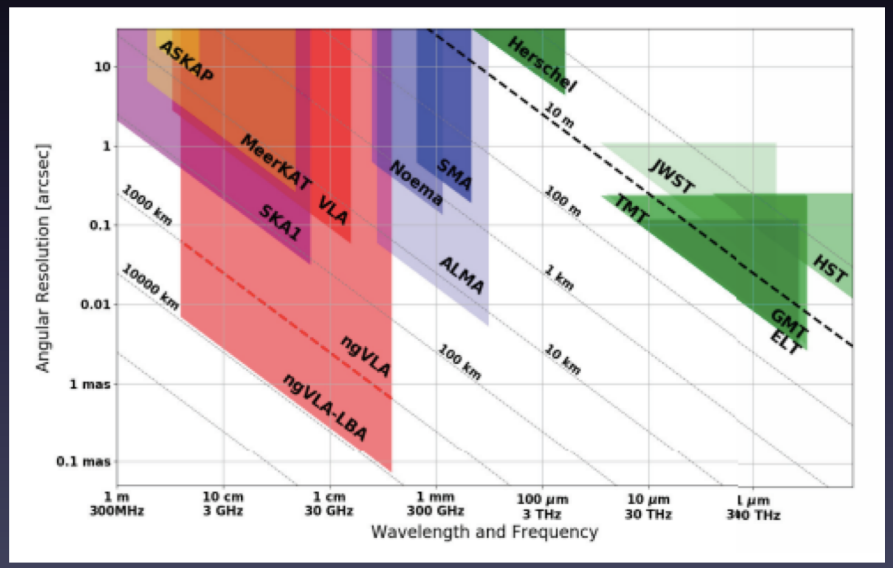
Pinilla, Manara, Natta, Ricci+ 18

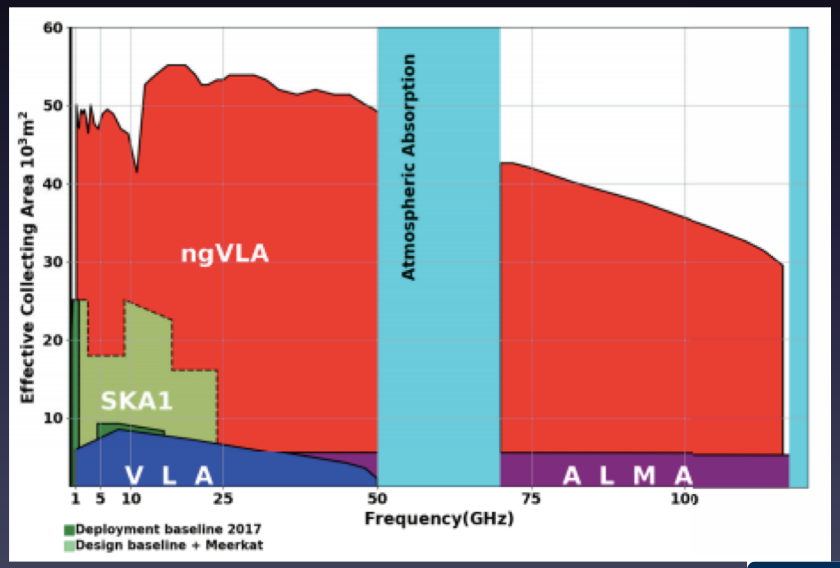
Gaps in VLM/BD disks?





Next Generation Very Large Array (ngVLA)

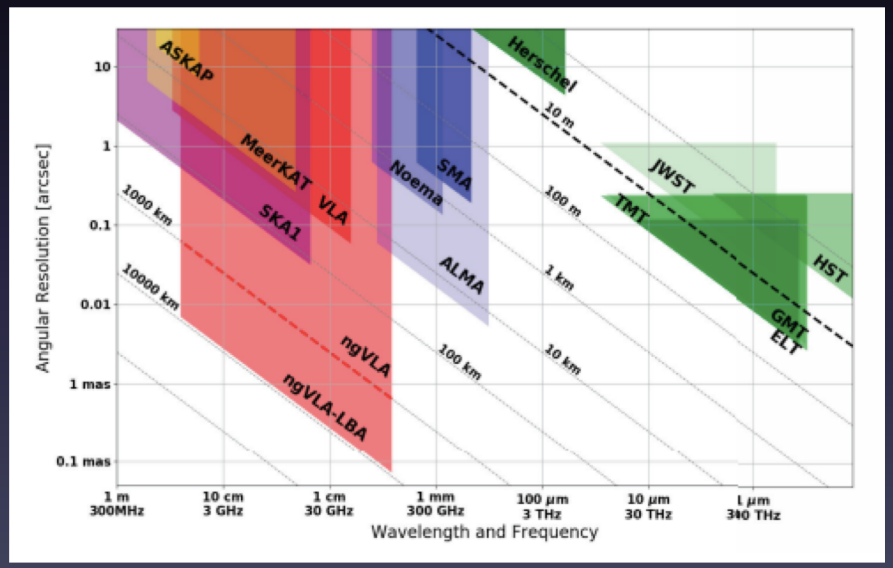


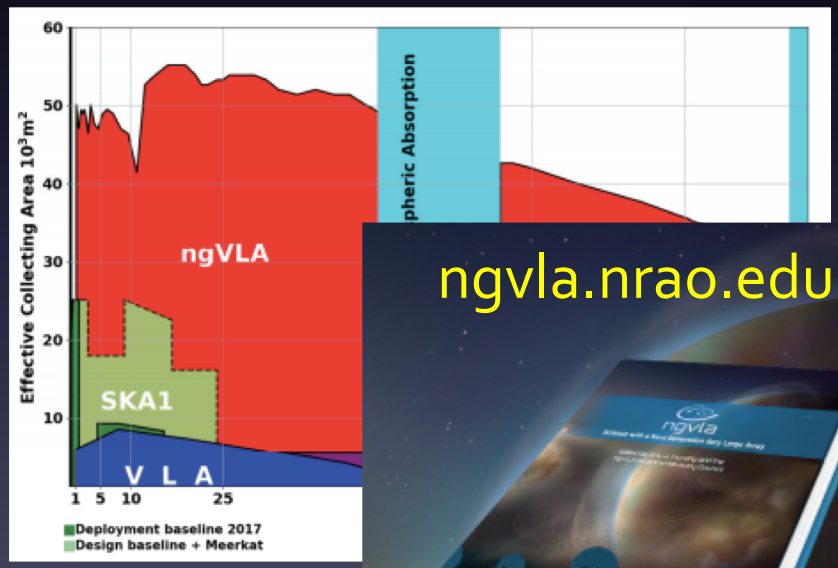


~ 1 mas resolution at 3mm, 0.2 au at 200 pc, 1 au at 1 kpc

NRAO

Next Generation Very Large Array (ngVLA)

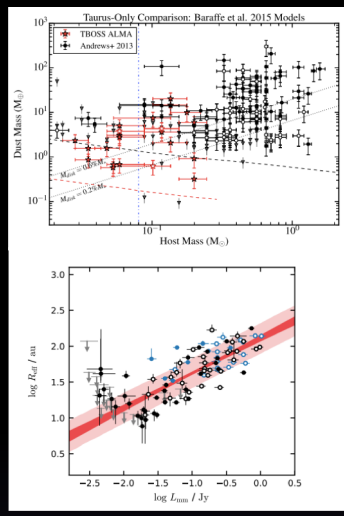




~ 1 mas resolution at 3mm, 0.2 au at 200 pc, 1

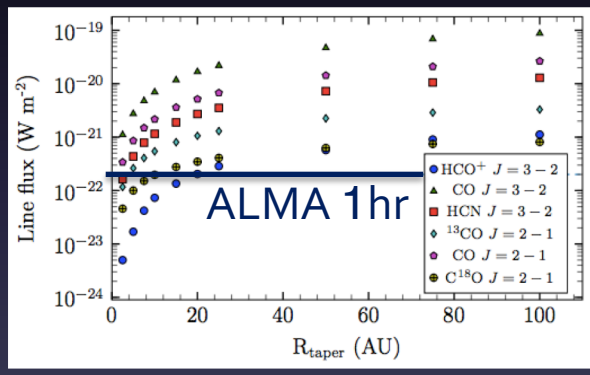
Take away messages

The scaling relations established by ALMA between stellar and disk properties <u>extend "smoothly" across the HBL and down to the DBL</u>, although obs constraints much more limited than for stellar disks



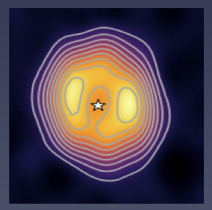
Ward-Duong+ 18
Andrews+ 18

Nearly all ALMA obs of VLM/BD disks are snapshot: <u>Longer integrations</u> needed to constrain <u>the radial dust density</u>, and <u>molecular gas</u>; <u>multi-wavelength</u> observations important for optical depths; critical for shedding light on the scaling relations



Greenwood+ 17

ALMA will likely detect substructures only in the brightest VLM/BD disks (ALMA 2030? ngVLA?)



Pinilla+ 18

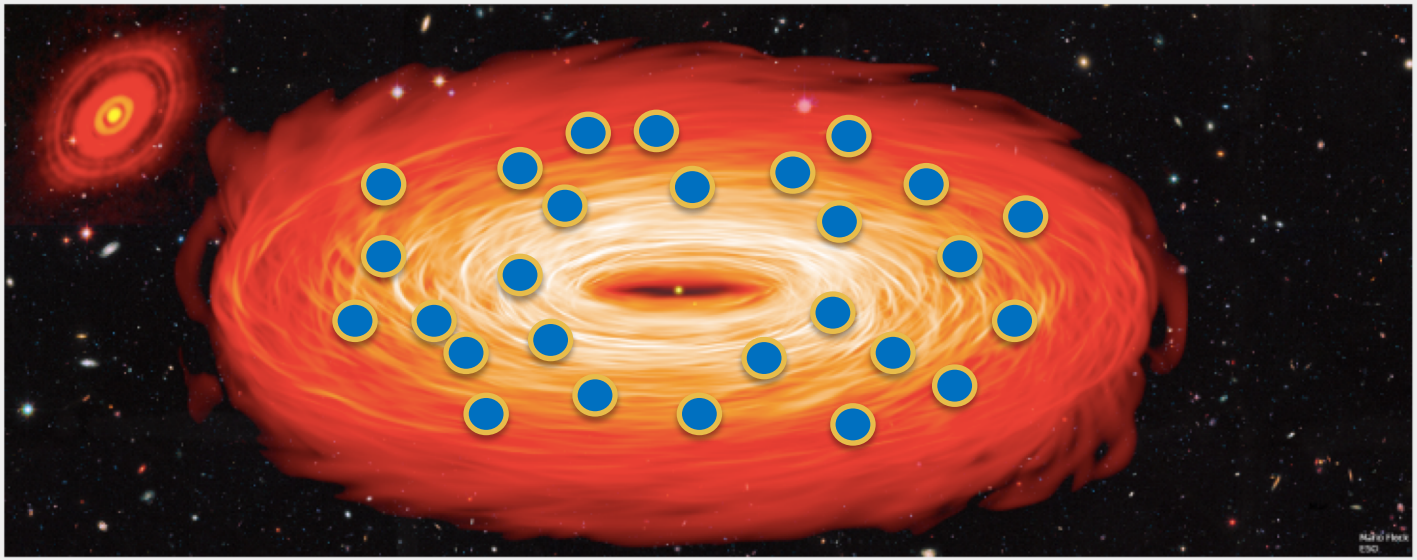
Planet-Forming

τ = 0.6 Clumps

A theoretical workshop to honor Leonardo Testi

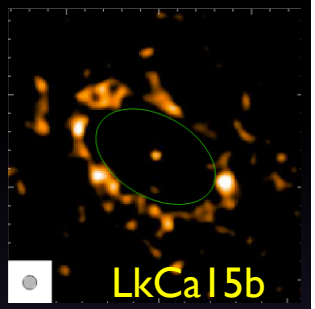
March 4-8, 2039 Villa Vigoni, Italy

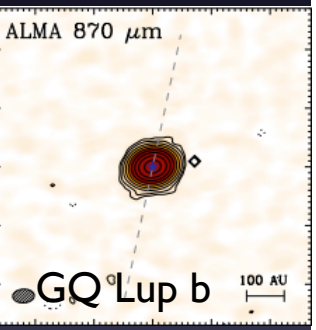
- Home
- Program
- Participants
- Logistics
- Code of conduct

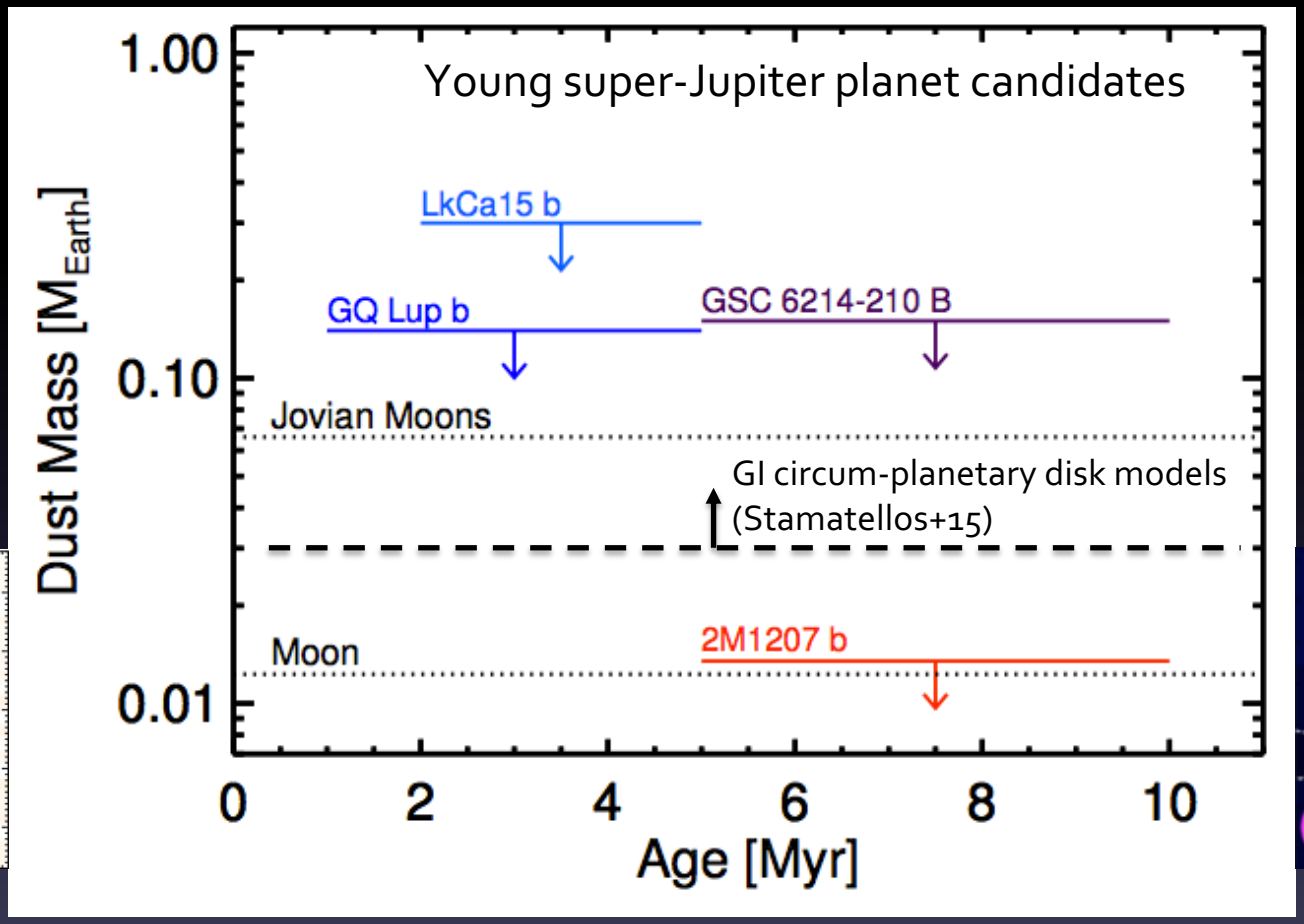


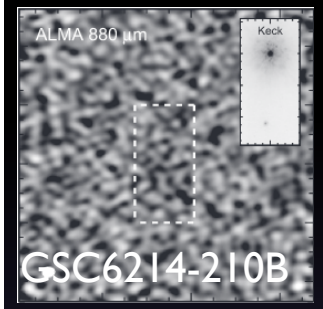
Thank you!

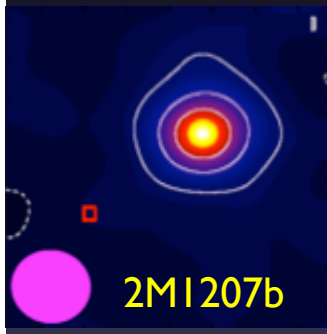
Circumplanetary disks









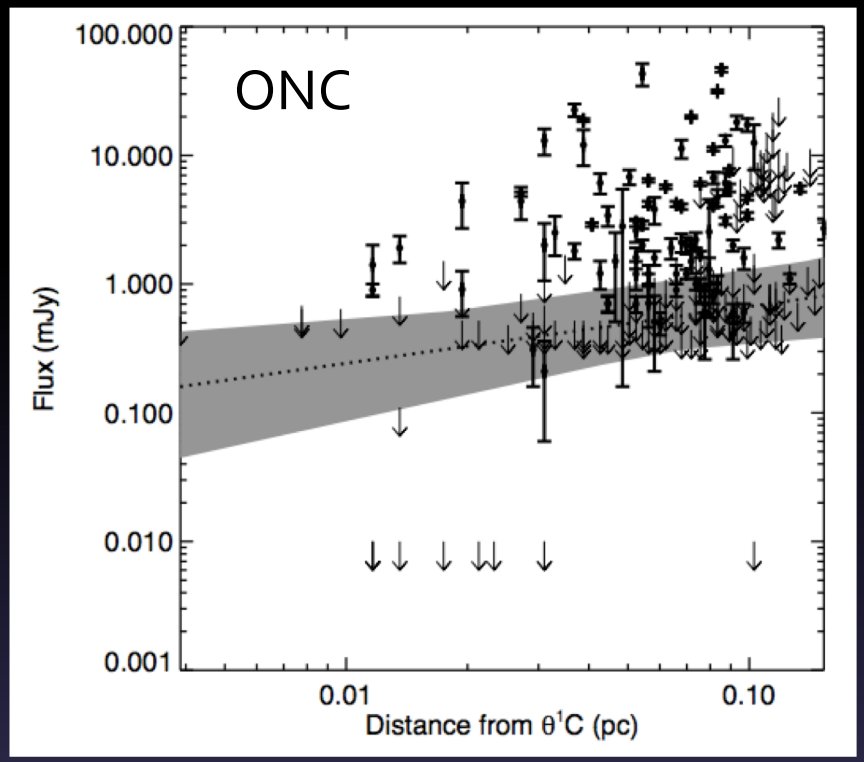


Isella+14, Bowler+15, MacGregor+16, Ricci+ 17

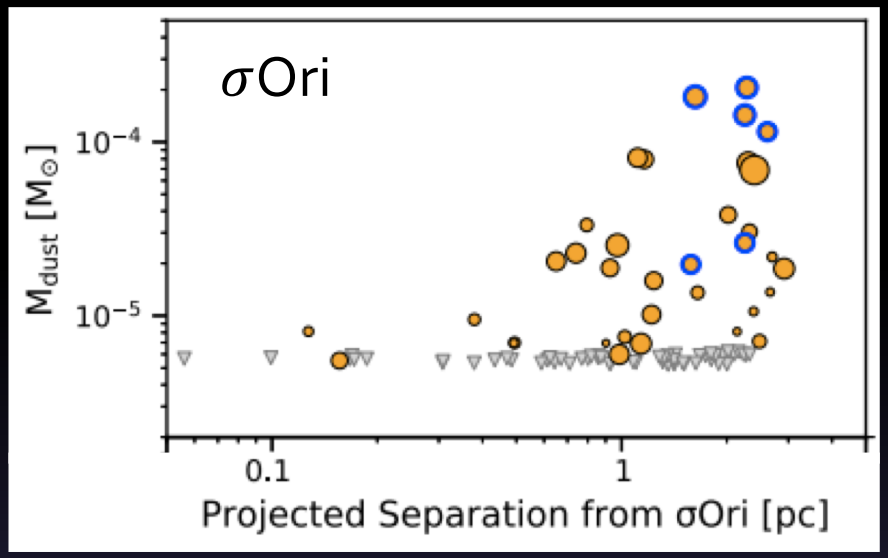
Very little dust around young super-Jupiter planets (or very small disks, $<< 0.1 - 1\ R_{\mathrm{Hill}}$)

(fast formation of satellites/Moons around massive giant planets?)

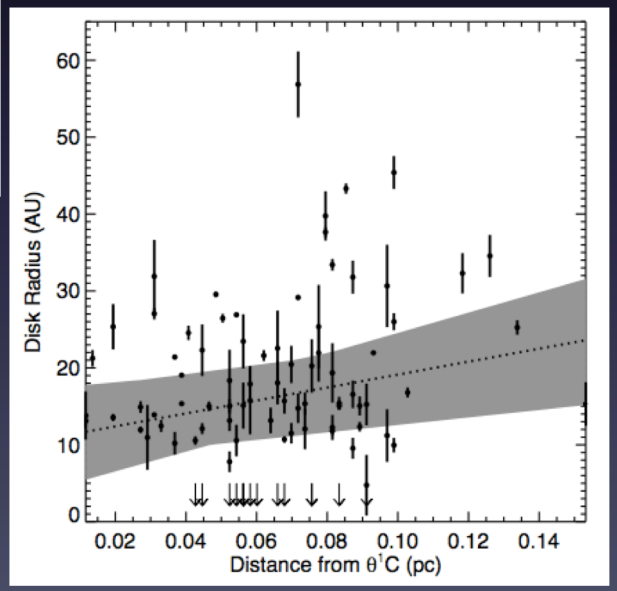
Disk Surveys Results 4 Environment



Eisner, Ricci+ 18



Ansdell+ 17



External photoevaporation by O stars draining mass off the disk