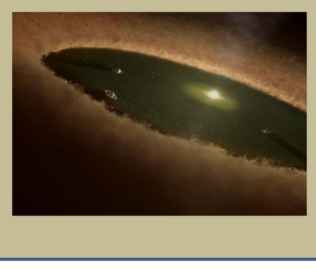
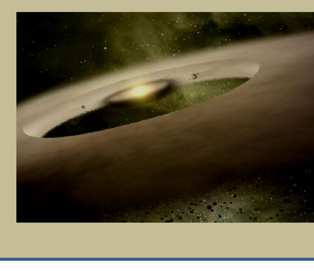
Transitional disks in the Youngest Nearby Star-forming regions: their Trends and Insights on Planet Formation



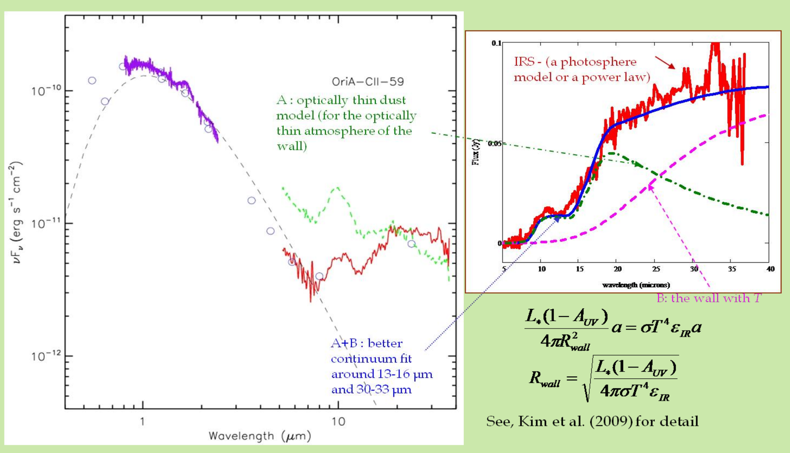
Kyoung Hee Kim and the IRS_Disks team



Introduction

The gaps in transitional disks appear to be cleared by infant giant planets formed in the disk (e.g. Kim et al., 2009, Andrews et al. 2011, Espaillat et al. 2008, 2010), and that our addition of the large sample from Orion, added to the other nearby associations, give us well over 100 TDs of various types, and high statistical significance for any trends among their properties. Here we search for, and analyze, many trends among disk and YSO properties.

Dimensions of gap (R_{wall}) : IRS

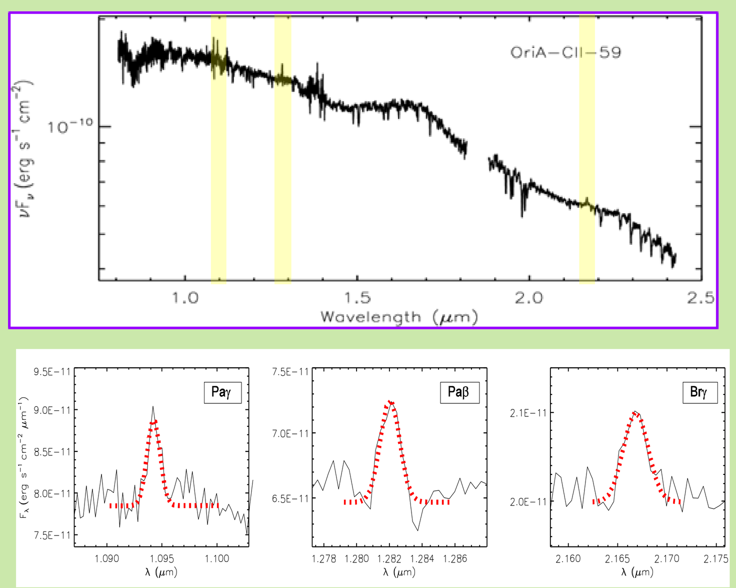


$$\frac{L_*(1-A_{IR})}{4\pi R_{wall}^2} = a = \sigma T^4 \varepsilon_{IR} \alpha$$

$$R_{wall} = \sqrt{\frac{L_*(1-A_{IR})}{4\pi \alpha \sigma T^4 \varepsilon_{IR}}}$$

R_{wall} is the position of the inner wall of an optically thick outer disk. We assume that the wall acts like a blackbody (T), and derive R_{wall} from the radiative equilibrium equation at the wall .

Mass accretion Rates: SXD/SpeX at IRTF



Mass accretion rate measurement from L_{acc} of, Pa γ @ 1.094 μm (Gatti et al. (2008) , Pa β @ 1.282 μm (Muzerolle et al. (1998)), and Br γ @ 2.166 μm (Muzerolle et al. (1998)).

$$\dot{M}_{acc} = \frac{L_{acc} R_*}{G M_*}$$

Data Collection

• We present 70 of the Orion A transitional disks, as well as transitional disks in Taurus (5; 140 pc, 1-2 Myr), Chamaeleon I (8; 160 pc, 2-3 Myr), Ophiuchus (4; 120-160pc, 2-3 Myr), NGC1333 (9; 320pc, <1 Myr).

• The Orion A star-forming region includes Orion Nebular Cluster (ONC) and Lynds 1641 (L1641). The distance is 400-450 pc, and the median age distribution is ~ 1 Myr: ONC < 0.8 Myr; L1641 > 1 Myr

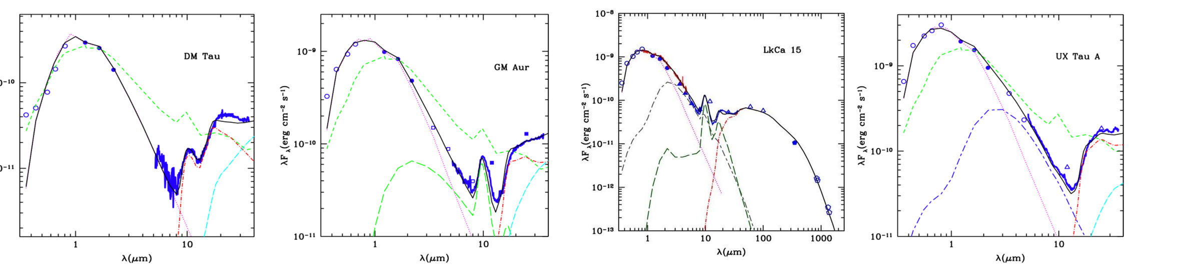
• Among the Orion A transitional disks, 35 objects (2010A semester) and 13 objects (2011A semester) had been observed with SpeX/IRTF.

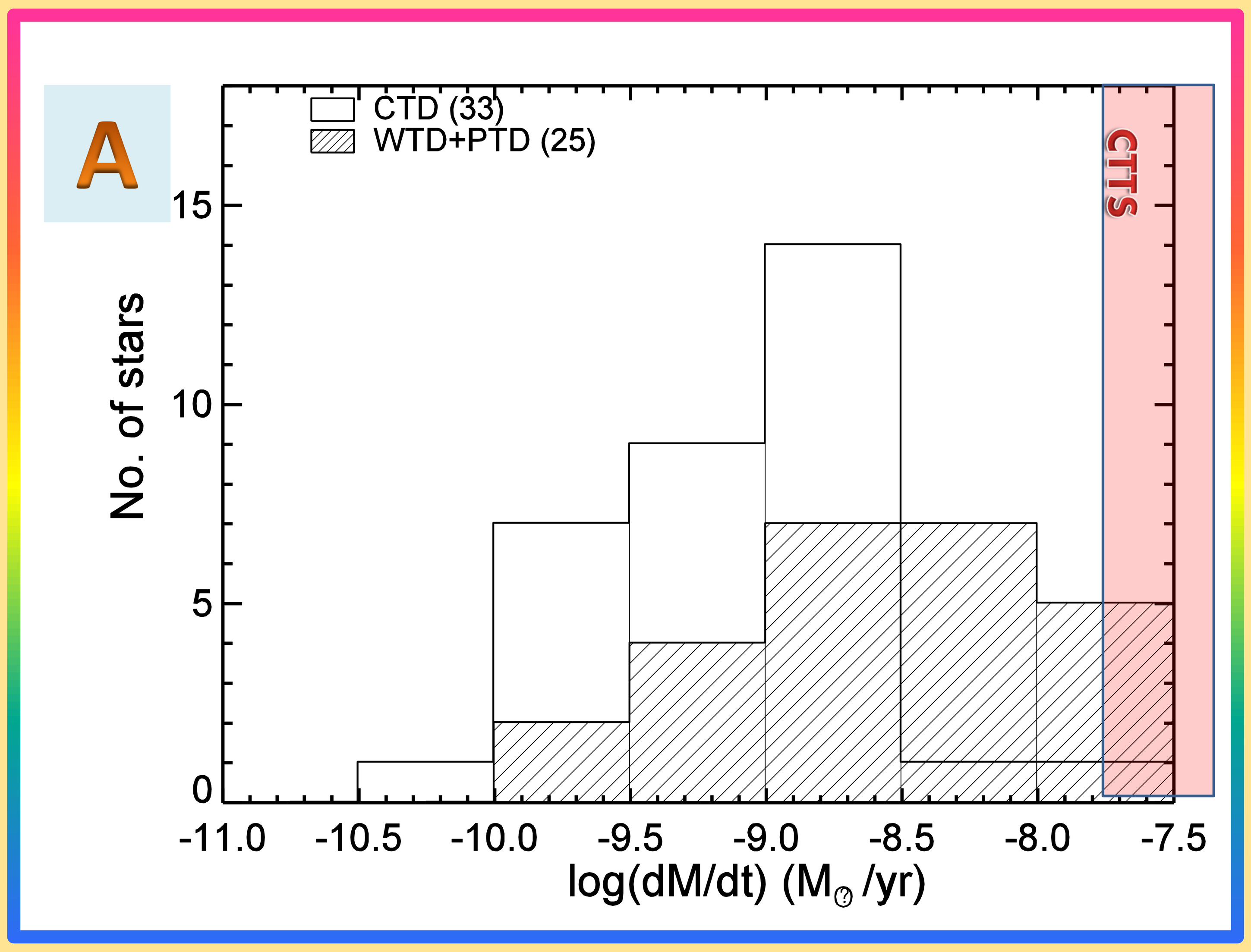
Sub-classification

CTD : Transitional Disk with **Central clearing of zero** excess at 5-8 μm
Archetype: **DM Tau** (Calvet et al. 2005)

WTD : Transitional Disk with **Weak** excess at 5-8 μm
Archetype: **GM Aur** (Calvet et al. 2005)

PTD : **Pre**-Transitional Disk, moderate excess at 5-8 μm
Archetype: **UX Tau A; LkCa 15** (Espaillat et al. 2007, 2008, 2010)





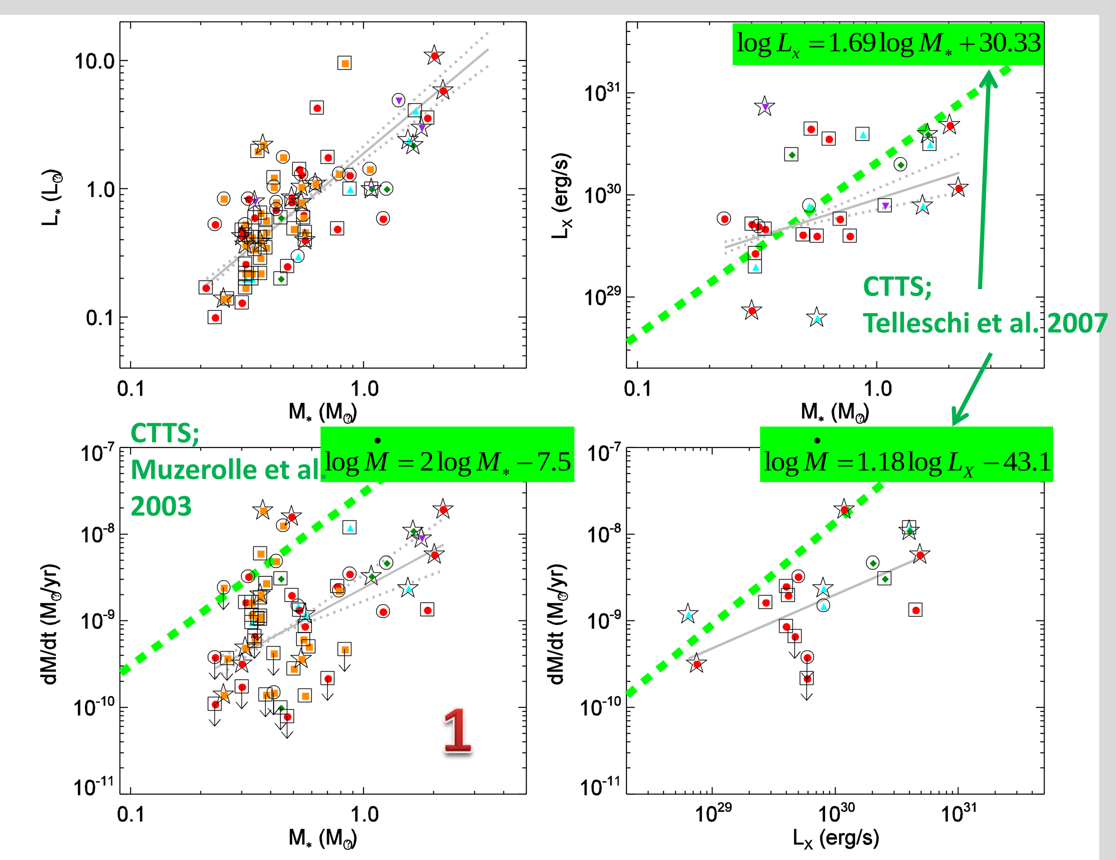
Mass Accretion Rate distribution

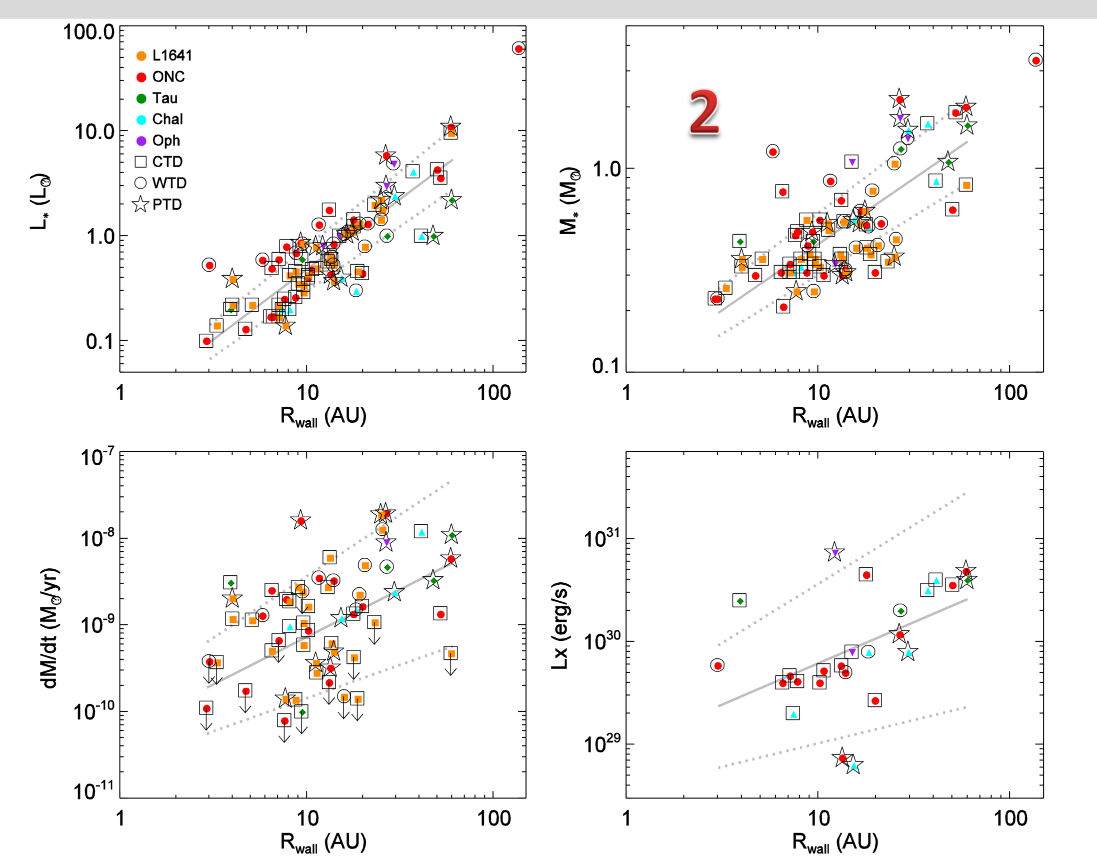
• *dM/dt* distribution of Transitional disks, divided by subclass of TDs in two categories:
(1) Central clearing (CTD); (2) Gaps (WTD+PTD) .

• median (*dM/dt*) of CTTSs is about $10^{-7.5}$ M_{sun}/ yr.
median $(dM/dt)_{(WTD+PTD)}$/median$(dM/dt)_{CTTS}$ ~ 0.1
➔ similar results from Najita et al. 2007

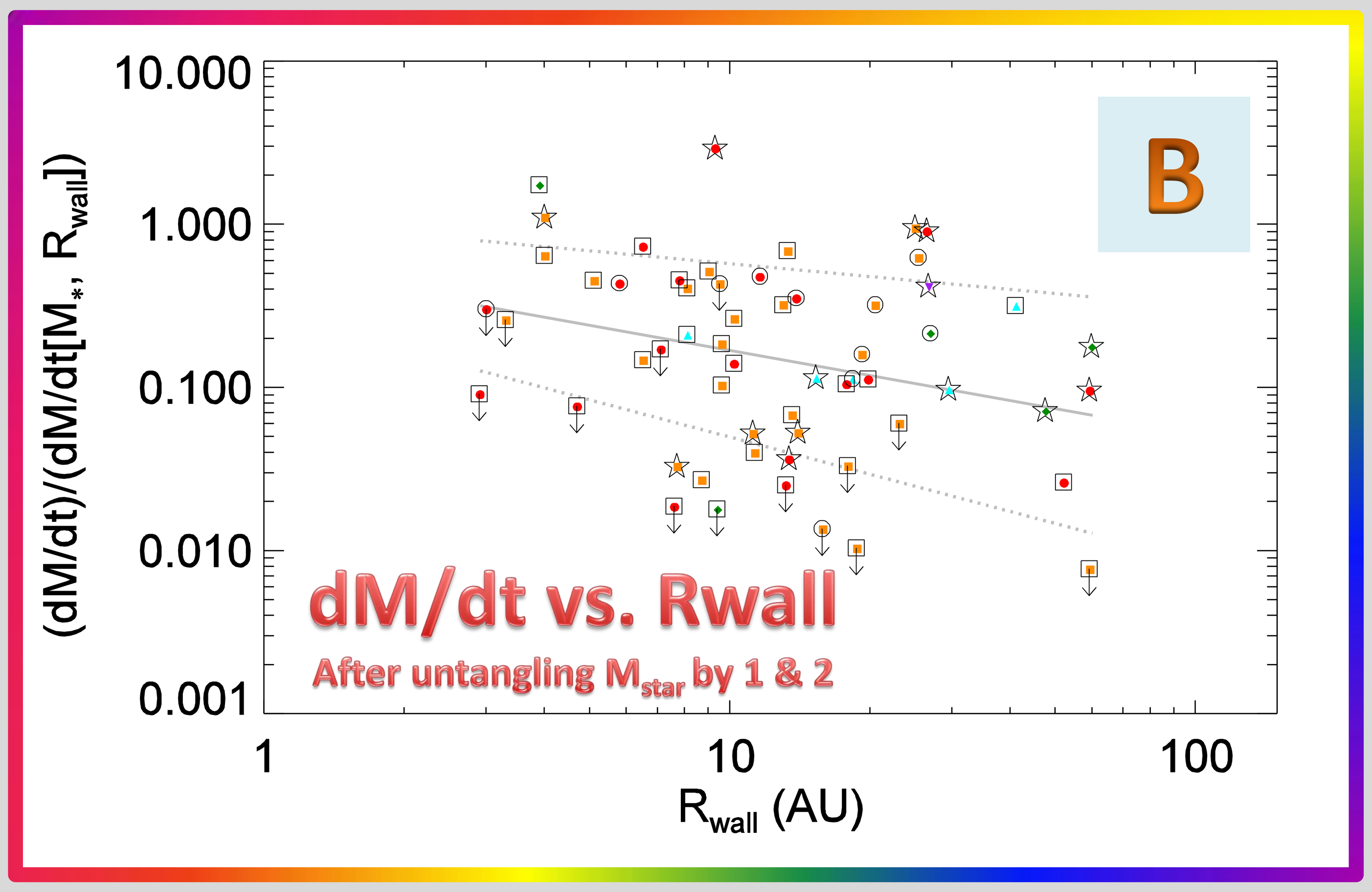
• CTDs and WTD+PTDs show different distribution; WTD+PTDs have still comparable *dM/dt* to CTTSs; *dM/dt* of CTDs is truncated at some upper level, but there are many CTDs with still considerable *dM/dt* .
median$(dM/dt)_{CTD}$ /median $(dM/dt)_{(WTD+PTD)}$~ 0.1

Trends





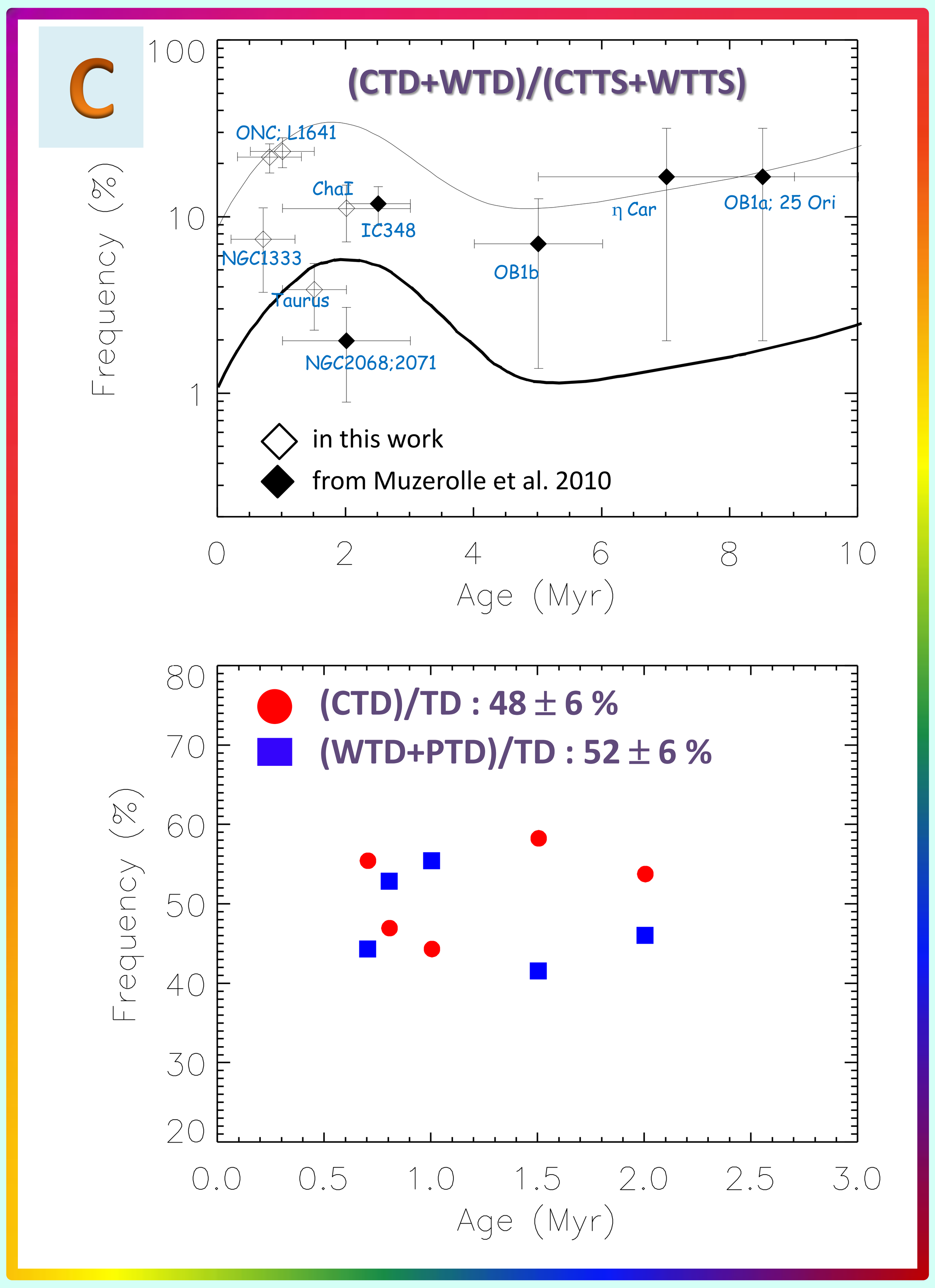
N: number of sample
α : an intersection in logY; β: a slope of a correlation
corr: a linear correlation coefficient between *logX* and *logY*
P: a probaility of getting *corr* in random distribution.



Correlation $\log Y = \alpha + \beta \log X$	N	α	β	*corr*	*P*	photo-evaporation	MRI	massive companion	Infant Giant Planet
$L_☆$ vs. $M_☆$	78	0.29	1.52	0.82	<0.001%				Y
	77	0.24	1.39	0.79	<0.001%				
L_X vs. $L_☆/L_⊙$	25	29.97	0.75	0.59	0.191				Y
$L_X/L_☆$ vs. $M_☆$	25	-3.67	-0.30	-0.18	38.925				Y
L_X vs. $M_☆$	25	30.13	0.88	0.46	2.069				Y
dM/dt vs. $M_☆$	58	-8.61	1.46	0.45	0.039	N		N	Y
dM/dt vs. $L_☆/L_⊙$	58	-8.88	0.74	0.46	0.028				Y
dM/dt vs. L_X	19	-27.24	0.62	0.57	1.084				Y
dM/dt vs. $L_X/L_☆$	19	-7.73	0.28	0.24	32.233				Y
$L_☆$ vs. R_{wall}	78	-1.64	1.34	0.91	<0.001%				Y
	77	-1.55	1.25	0.89	<0.001%				
$M_☆$ vs. R_{wall}	78	-1.01	0.65	0.79	<0.001%				Y
	77	-0.98	0.62	0.76	<0.001%				
dM/dt vs. R_{wall}	58	-10.22	1.10	0.48	0.014	N			Y
L_X vs. R_{wall}	25	28.99	0.80	0.50	1.092				Y
(dM/dt)/(dM/dt[$M_☆$-R_{wall}]) vs. R_{wall}	58	-0.26	-0.51	-0.29	2.723	N	N		Y
$L_X/L_X[M_☆-R_{wall}]$ vs. R_{wall}	25	29.00	0.79	0.50	1.092				Y
(dM/dt)/(dM/dt[L_X]) vs. L_X	19	17.11	-0.60	-0.62	0.463				Y
PTDs exists!						N	Y?	N?	Y

NOTE: grain-growth and settling is a nonstarter in explaining TDs, because of the sharpness of the gap edges and the mere existence of PTDs.

Frequency



The solid lines in the two upper panels are the disk dissipation models with t_{hole}=0.1 Myr (thick line) and t_{hole}=1 Myr (thin line) (Muzerolle et al. 2010). The ratio of TD types are similar between central clearings and gaps.

Conclusions:

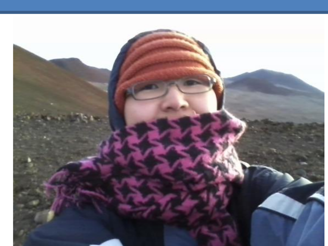
A Outer disk materials accrete to the host star even there are gaps or holes in the disk. *dM/dt* of TDs are less than 10 times of that of CTTSs ➔ **Giant Planet formation** expects it; Photoevaporation cannot explain this.

B No strong correlation between *dM/dt* and R_{wall} found after eliminating strong M_{star}-dM/dt-R_{wall} relation ➔ Inside-out disk clearing by MRI cannot explain this.

C Gap opening and disk clearing happen even at very early age (< 1 Myr) ➔ **Infant Giant Planet** formation starts at < 1 Myr? The fraction of TDs with gaps and that with holes are similar through 1-3 Myr.

For further investigation, homogeneous L_X data and Mass of disks of transitional disks needed

1. This work is based on observations made with the Spitzer Space Telescope, which is operated by the Jet Propulsion Laboratory, California Institute of Technology under NASA contract 1407. Support for this work was provided by NASA through Contract Number 1257184 issued by JPL/Caltech, and Cornell subcontracts 31419-5714 to the University of Rochester.
2. Visiting Astronomer at the Infrared Telescope Facility, which is operated by the University of Hawaii under Cooperative Agreement no. NNX-08AE38A with the National Aeronautics and Space Administration, Science Mission Directorate, Planetary Astronomy Program.
3. This research has made use of data obtained from the Chandra Source Catalog, provided by the Chandra X-ray Center (CXC) as part of the Chandra Data Archive.



Contact: Kyoung Hee Kim
khkim@pas.rochester.edu
University of Rochester