The Lifetime of Protoplanetary Disks Surrounding Intermediate-mass Stars

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ABSTRACT

☆**Derivation of disk lifetime for intermediate mass (IM-)stars** (1.5–7M⊙)

✓Derivation of IM-star disk fraction (**IMDF**) for many (~20) young (≲10Myr) clusters
using 2MASS JHK (K-disk) and Spitzer IRAC (MIR-disk) data

✓Disk lifetime of IM-stars
$t_{(IM)}$ = 4Myr (innermost K-disk) ／**$t_{(IM)}$ = 6.5Myr** (MIR-disk)

☆**Implication to disk evolution of IM-stars**

✓Significantly earlier innermost disk dispersal (~0.3AU) than inner & outer disk (≳25AU) is suggested (Δt~3Myr)
→ Probably faster dust growth in the innermost disk

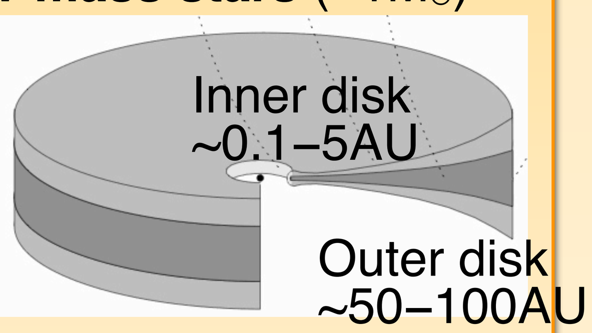
✓IM-stars have much longer transition phase than low-mass stars

Introduction

Disk lifetime of protoplanetary disks

- One of the most fundamental parameters because it directly restricts both star formation and planet formation

- **Estimated to be ~5–10Myr for low-mass stars** (≦1M⊙)
(Williams & Cieza 2011, ARA&A, 49, 67)



✓Inner disk (~0.1–5AU): 5–10Myr
Dust: NIR to MIR
e.g., Haisch+2001, ApJ, 553, 153; Sicilia-Aguilar+2006, ApJ, 638, 897
Gas: Hα (Fedele+2010, A&A, 510, 72)

✓Outer disk (≧50 AU): same as inner disks
Dust: Submm
(e.g., Andrews & Williams 2005, ApJ, 631, 1134)
Gas: FIR [OI] 63µm
(e.g., Meeus+2012, A&A, 544, 78; Mathews+2010, 518, 127)

The entire disk (~0.1–100 AU / gas+dust) disperse almost simultaneously (Δt≤0.5Myr)

- For **Intermediate-mass stars (≧1.5M⊙)**
Qualitatively, suggested *shorter disk lifetime* than low-mass stars
(Hernandez+2005, ApJ, 707, 705; Kennedy & Kenyon 2009, ApJ, 695, 1210)
Quantitative derivation is necessary

Motivation

Mass dependence of disk lifetime
could have a great impact on mechanism of *disk dispersal* and *planet formation*
(e.g., Gorti+2009, ApJ, 705, 1237; Burkert & Ida 2007, ApJ, 660, 845)

Definition of IMDF

IMDF= disk fraction for intermediate-mass stars

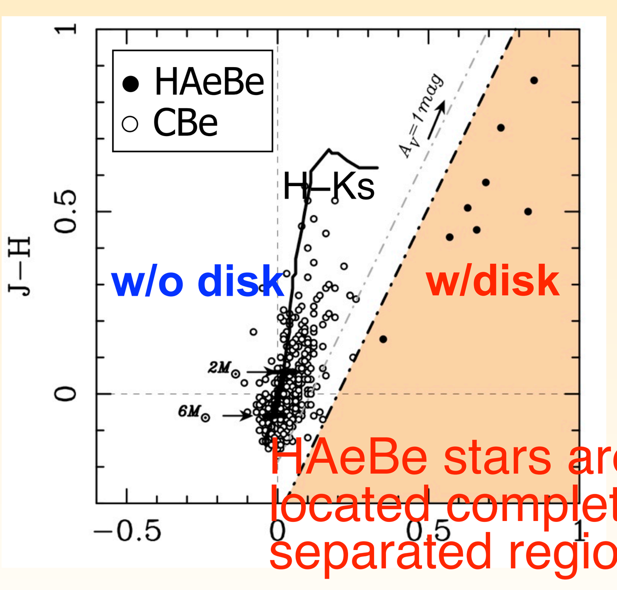
Mass range setting

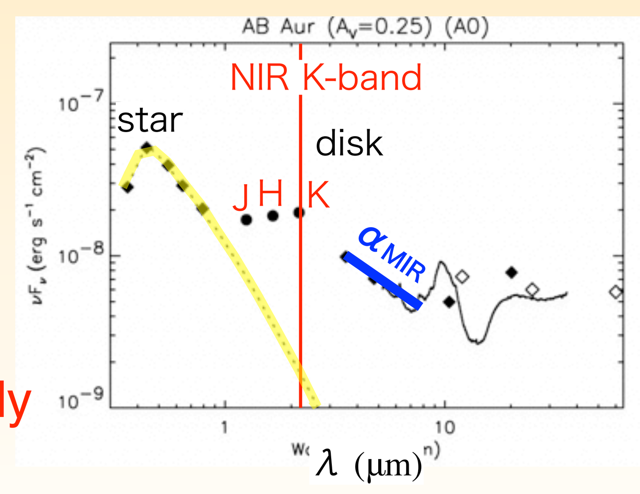
- Set mass range as ~1.5–7M⊙
- Pick up stars based on spectral types with cluster ages
(PMS isochrone model from Siess+2000, A&A, 358, 593)

Disk excess

✓JHK IMDF
HAeBe stars have large H-K excess

✓MIR IMDF
From MIR SED slope
$\alpha_{MIR} \geq -2.2$: w/disk
$\alpha = d \ln \lambda F\lambda / d \ln \lambda$
Spitzer IRAC (3.6–8µm data)





Results

IMDF derivation

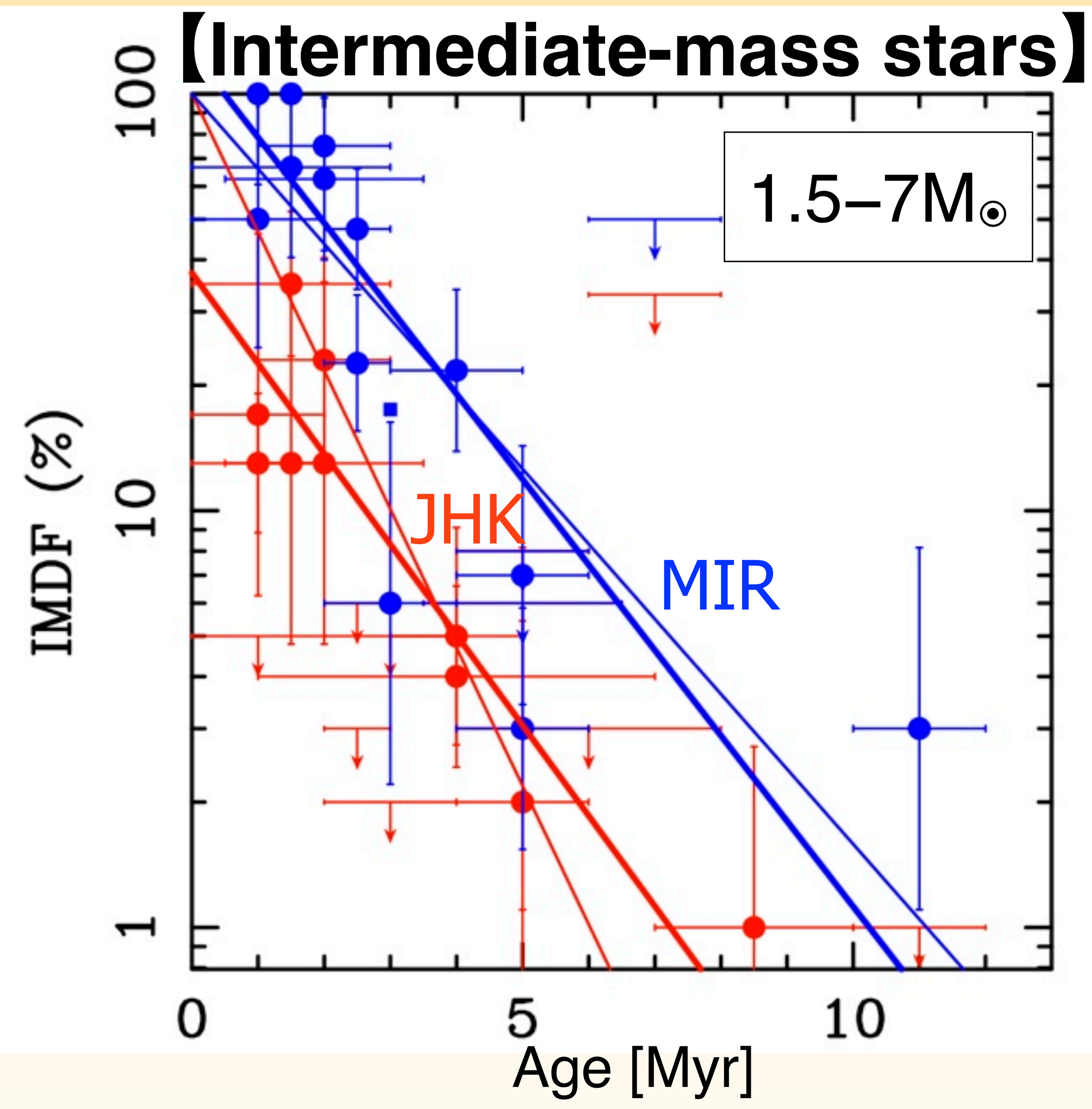
Target clusters
Almost all of the well-known clusters (N≅20)
- Nearby: D ≦ 2kpc
- Young: Age ≲ 10Myr
~20 young clusters used
Basically the same targets for JHK and MIR
(JHK: 2MASS, Spitzer: IRAC 8µm)

Disk lifetime

- χ² fitting with an exponential function
- The disk lifetime is defined as the timescale of disk fraction to fall down to 5%

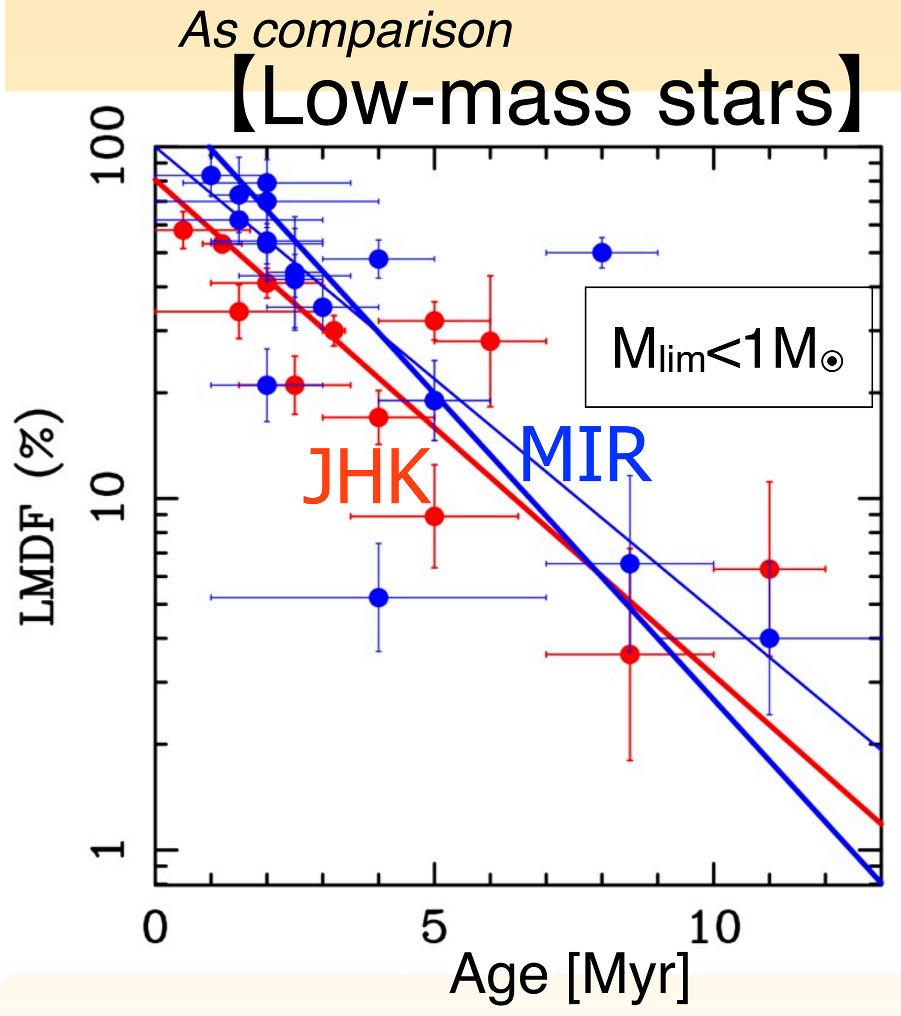
	Mass (M⊙)	t_{JHK} (Myr)	t_{MIR} (Myr)
IM	~2.5	4.4±0.9	6.9±1.0
LM	~0.5	9.7±1.1	8.6±0.7
Mass dependence		$M_*^{-0.5\pm0.2}$	$M_*^{-0.1\pm0.1}$

Tab. 1 Disk lifetime and stellar mass



Suggested that MIR IMDF is systematically larger by ~3 times than JHK IMDF

As comparison



JHK and MIR LMDF seem to disperse almost simultaneously.

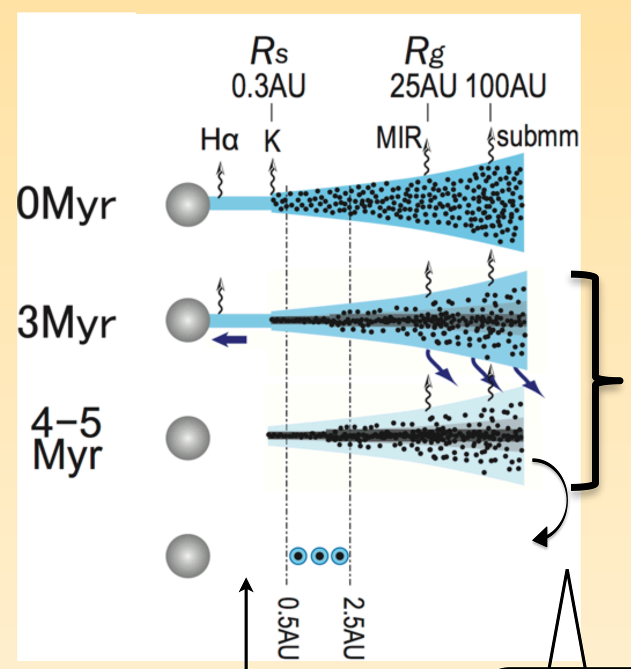
(Data: MIR IMDF: mainly from Kennedy & Kenyon 2009, ibid;
MIR LMDF: mainly from Roccatagliata+2011, ApJ, 733, 113;
JHK LMDF data: from Yasui+2009, ApJ, 705, 54; Yasui+ 2010, ApJ, 723, L133)

Discussion

Disk evolution sequence

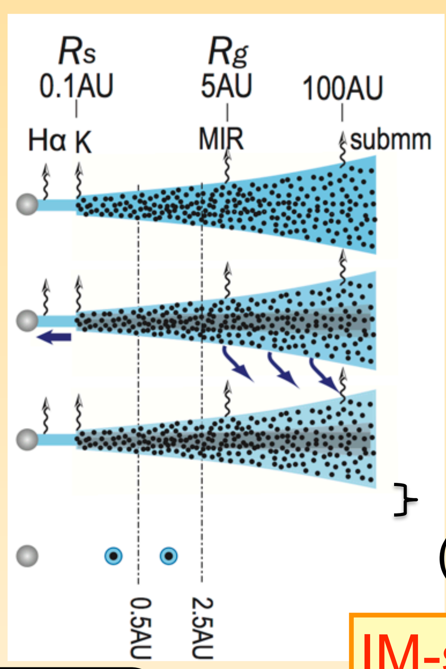
Suggestions from comparison of JHK vs. MIR disk evolution

✦ IM stars (2–6M⊙)



Transition disk phase (Δt~3Myr)

✦ LM stars (Mlim<1M⊙)



Transition disk phase (Δt≲0.5Myr)

Cause for the lack of close-in planet?

MIR-disks and sub-mm disks are strongly correlated both for IM and LM stars
(e.g., Andrews & Williams 2005, ApJ, 631, 1134)

IM-stars may have a substantially long "transition disk phase"
(Cf. For LM-stars ≲20%; Muzerolle+2010, ApJ, 708, 1107)

Possible cause for the time-lag

Possibility① Disk dispersal

Different disk dispersal mechanism compared to low-mass stars?

✓Inner disk edge ... *determined by dust sublimation*
Not changed (In radiative equilibrium condition)

✓Inner disk dispersal ... *mainly by accretion*
Not changed (Tracer (Hα) exist)

✓Outer disk dispersal ... *mainly by photoevaporation*
Not directly related

→ Seems unlikely

Possibility② Dust growth (settling)

According to analytical calculation
$t_{grow} \sim \Sigma_g/\Sigma_d \cdot h_d/z \cdot T_K$ (e.g., Nakazawa+1981, Icarus, 45, 517)
Σ: surface density
T_K: Kepler orbital period ∝ r^3/2

→Consistent with faster dust growth in inner disks
However, difference between IM and LM inner disk evolution cannot be explained

Simply calculated t_grow appears much shorter (e.g., a few 100 yr) than actually observed
Additional processes are proposed (e.g., turbulence, two-layer disk model)
These processes may be less effective in IM-stars.