B02班

星惑星形成過程の中心星質量依存性の観測的研究: mass-flow processの時間進化

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1. Introduction
星惑星形成過程の中心星質量依存性

✦星の質量

✓星は質量により一生がほぼ決定される

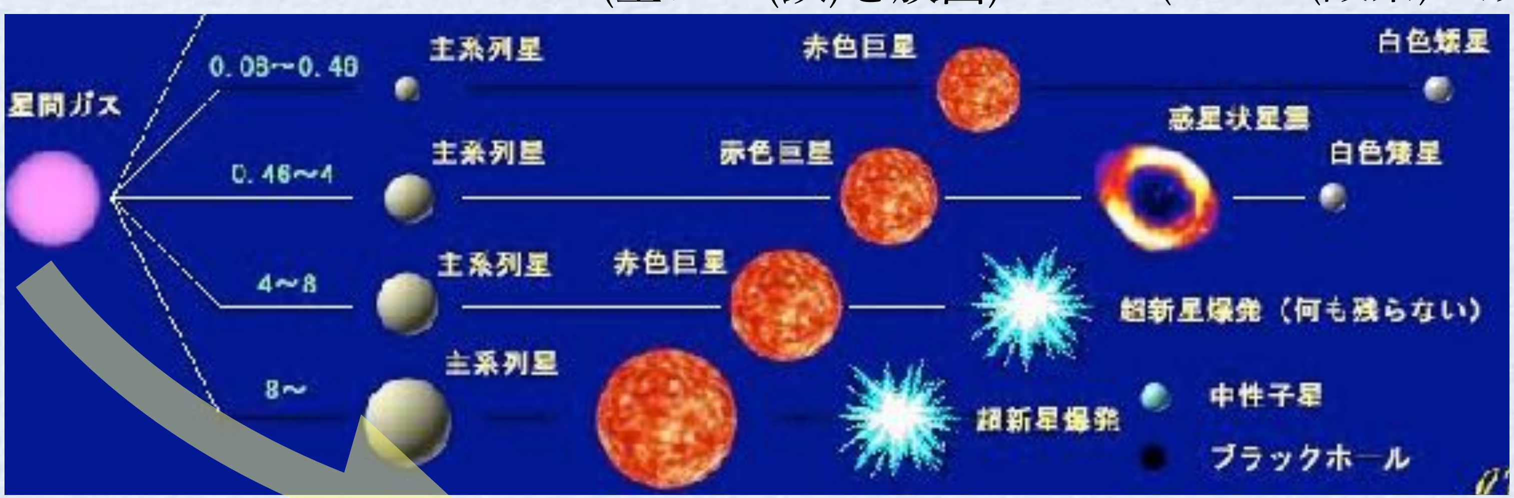
✓重い星ほど進化が速い $t_{MS} \sim 10^{10} \times (M/Msun)^{-2.5}$ yr

小質量星　　中質量星　　大質量星

0.1　　1.5　　8　　星の質量 (太陽質量単位)

星内部の水素核燃焼：p-p chain (0.1〜1.5)　CNO cycle (1.5〜)

超新星の種類：I型 (主にFe(鉄)を放出)　II型 (主にO(酸素)を放出) (8〜)



重い星ほど進化が速い

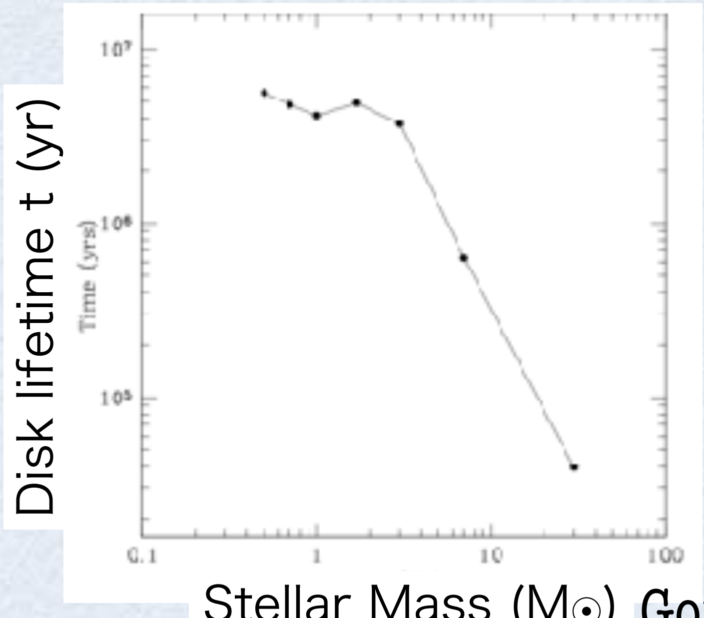
⭐ *Topic of this talk*

Stellar mass dependence of evolution of protoplanetary disks

→**Constraint on disk dispersal mechanism and planet formation process**

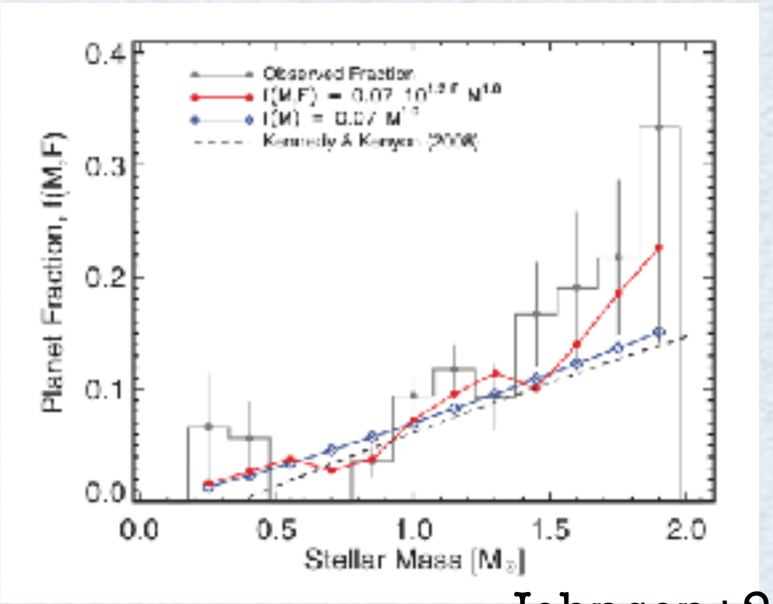
(e.g., Gorti+2009, ApJ, 705, 1237; Kennedy & Kenyon 2009, ApJ, 695, 1210; Burkert & Ida 2007, ApJ, 660, 845)

✓ Theoretical prediction (e.g., FUV photoevaporation)



Gorti+2009

✓ Planet occurrence and stellar mass



Johnson+2010

✦Evolution of protoplanetary disks

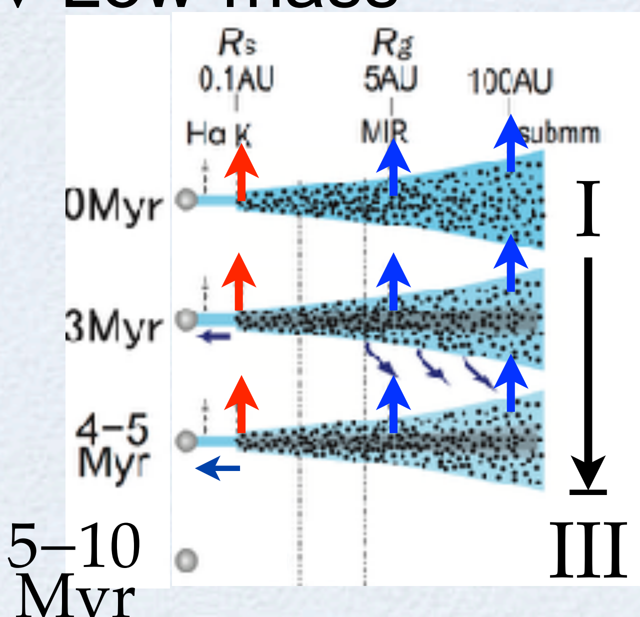
Low-mass stars

Entire disk (gas+dust / from inner to outer) disperse almost simultaneously (Δt~0.5Myr) in 5–10Myr (Williams & Cieza 2011, ARAA).

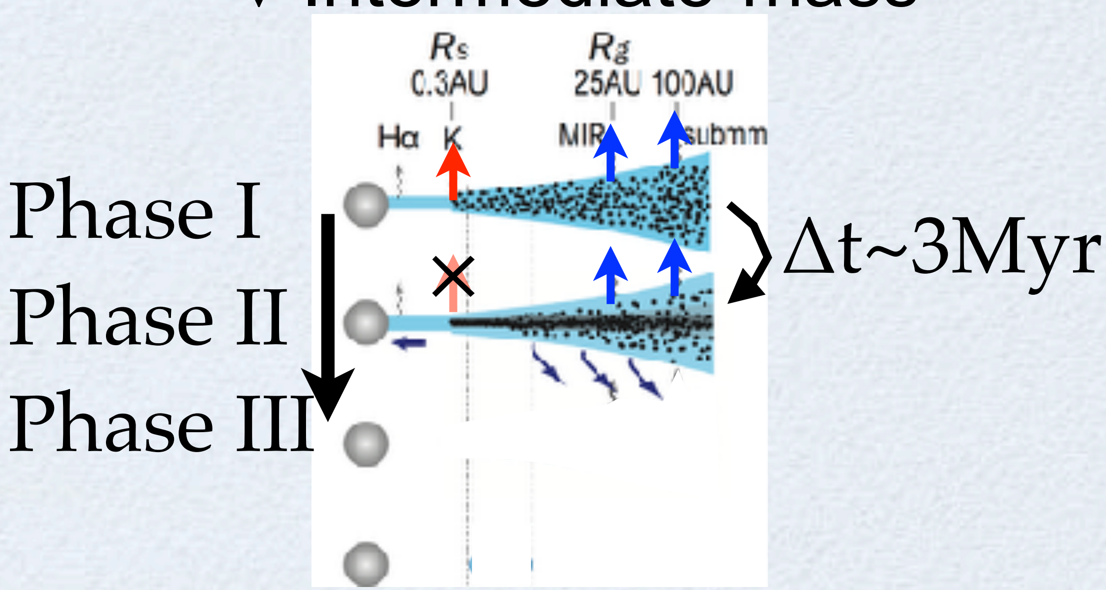
Intermediate-mass stars (IM-stars)

Innermost disks traced with NIR K-band (r~0.3AU) disperse at very early time compared to the outer disks (Δt~3Myr; Yasui+2014, MNRAS, 442, 2543).

✦ Low-mass



✦ Intermediate-mass



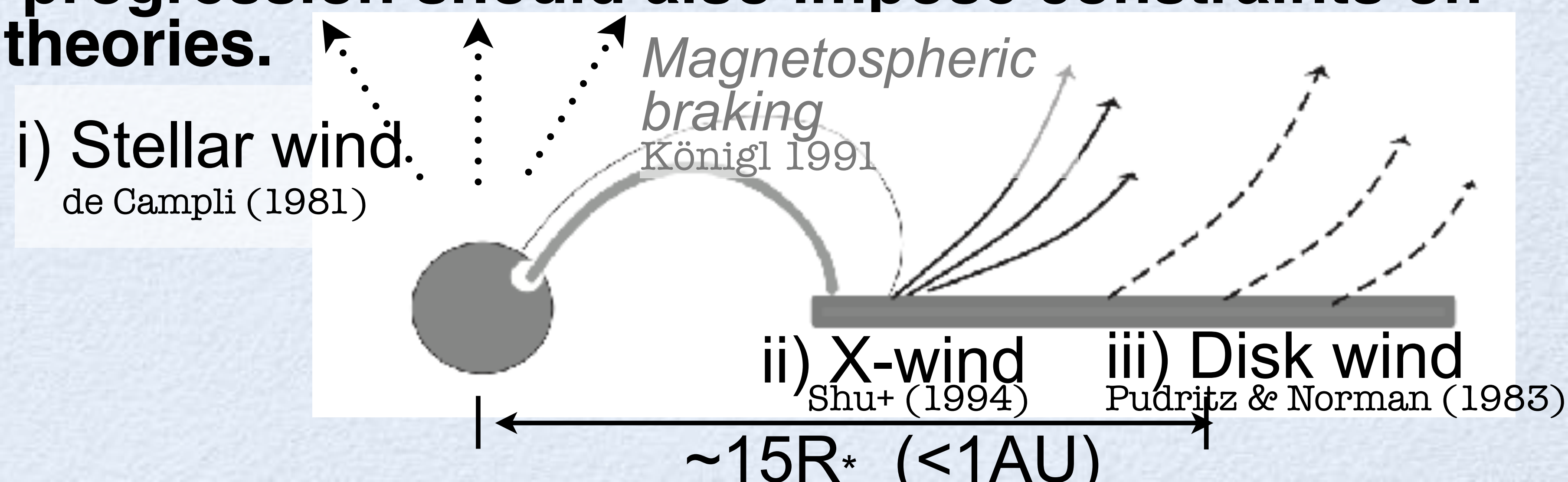
mass-flow processの時間進化

⭐ Introduction

✦Mass-flow processes close to central stars (≲1au)

- Essential processes for star and planet formation
- The some mechanisms of outflowing gas have been proposed, e.g., stellar wind, disk wind, and X-wind.
  However, the actual mechanics of outflowing gas have not yet been completely elucidated.
- Direct imaging for the separations is very difficult
  High resolution spectroscopy is effective for diagnosing the nature or location of the wind-launching region.

The progression should also impose constraints on the theories.



✦Method: spectroscopy

✓ Conventional methods: Optical spectroscopy

e.g, Hα, NaD, CaII, MgII (Mundt 1984)

- Redshifted absorption

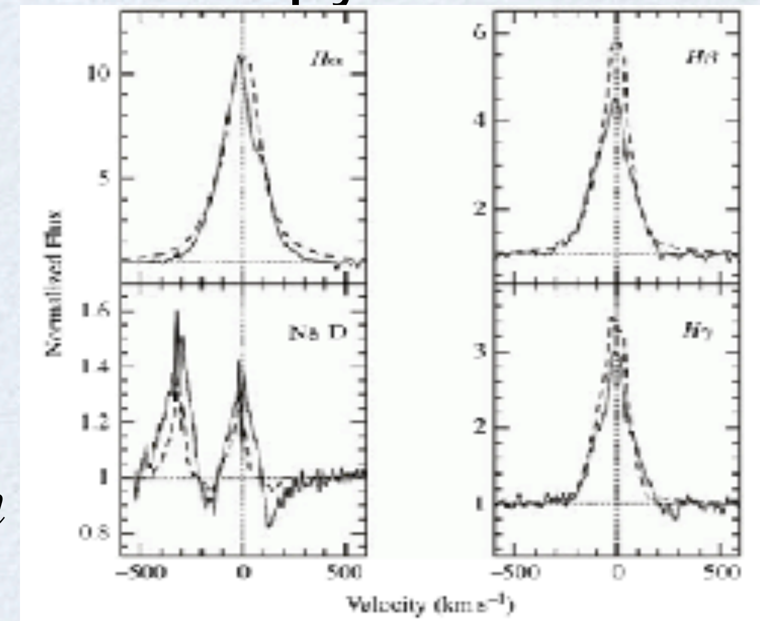
  Sensitive to magnetospheric accretion

- Blueshifted absorption

  Sensitive to inner winds (Calvet+1997)

However, superimposed on broad emission features

→ *Little information on the nature or location of the wind-launching region*



Muzerolle+2001

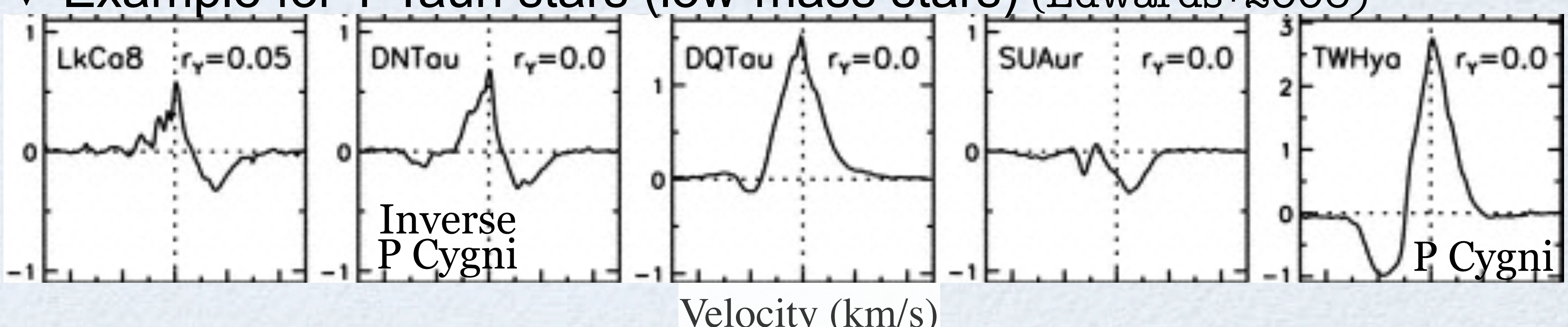
✓ **HeI λ10830**

Very high exciting temperature: T>15,000K (21eV)

- Blueshifted/redshifted absorption

  Sensitive to both winds/magnetospheric accretion

  ✦ Example for T Tauri stars (low-mass stars) (Edwards+2006)



Detected various types of line profiles with high probability
but, no clearly correlated parameters with line profiles

✦Evolution of protoplanetary disks

<u>Low-mass stars</u>

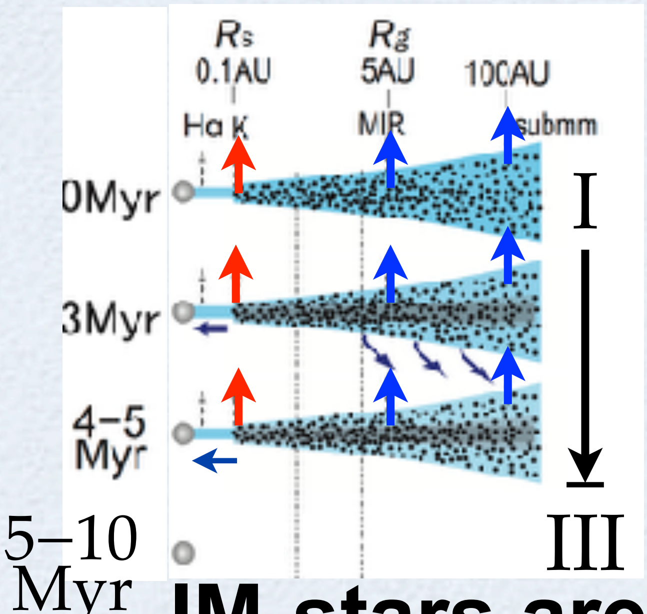
Entire disk (gas+dust / from inner to outer) disperse almost simultaneously (Δt~0.5Myr) in 5–10Myr

(Williams & Cieza 2011, ARAA).

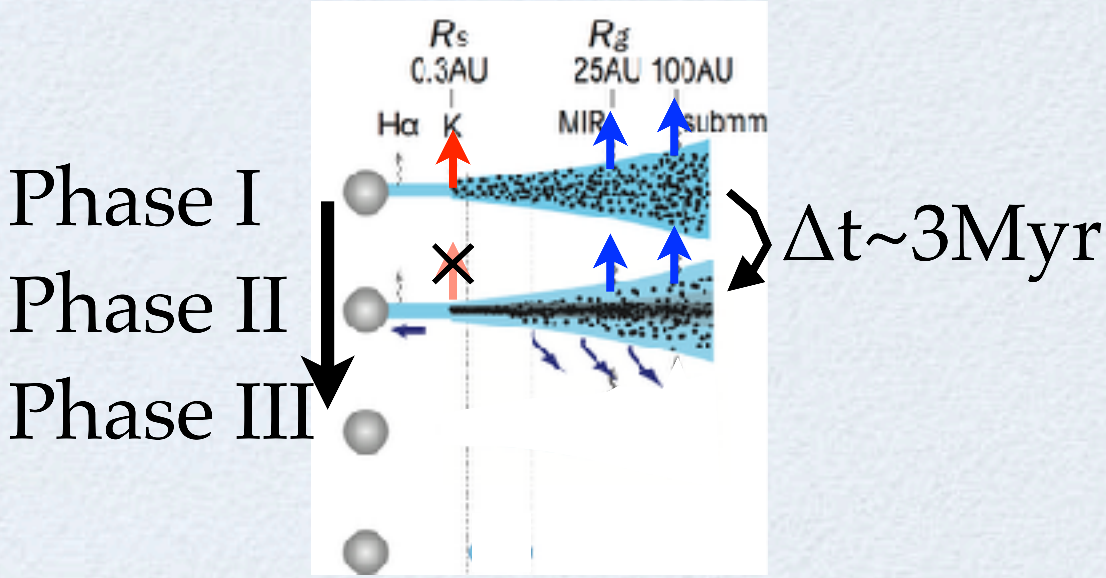
<u>Intermediate-mass stars (IM-stars)</u>

Innermost disks traced with NIR K-band (r~0.3AU) disperse at very early time compared to the outer disks (Δt~3Myr; Yasui+2014, MNRAS, 442, 2543).

✦ Low-mass



✦ Intermediate-mass



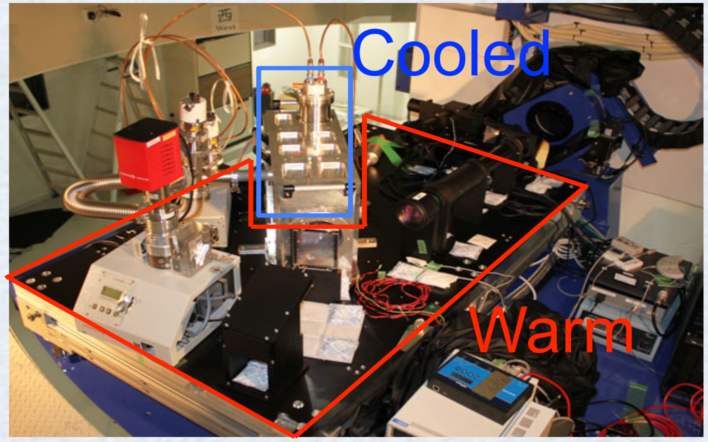
IM-stars are suitable targets for identifying evolutionary stages

Observation

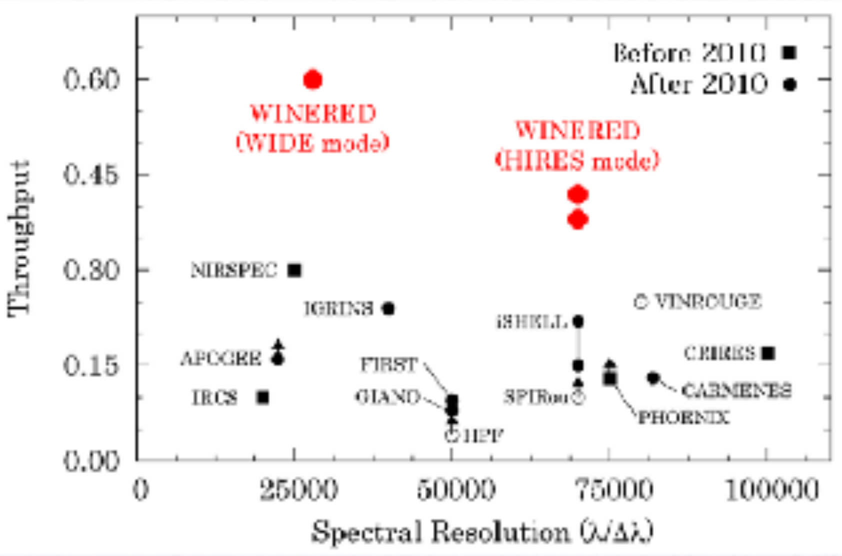
✦NIR high-resolution spectroscopy

WINERED (Ikeda+2018 SPIE)

Warm Infrared Echelle spectrograph for Realizing Decent infrared high-resolution spectroscopy



- High spectral resolution: R=30,000
  Very high throughput (50%)
- Wavelength range: λ=0.91-1.35 μm
- Attached to the Araki 1.3m telescope
  WINERED was Attached to NTT in 2017-2018, and will move to Magellan in 2020
- Observation period:
  Feb 2013-Oct 2014

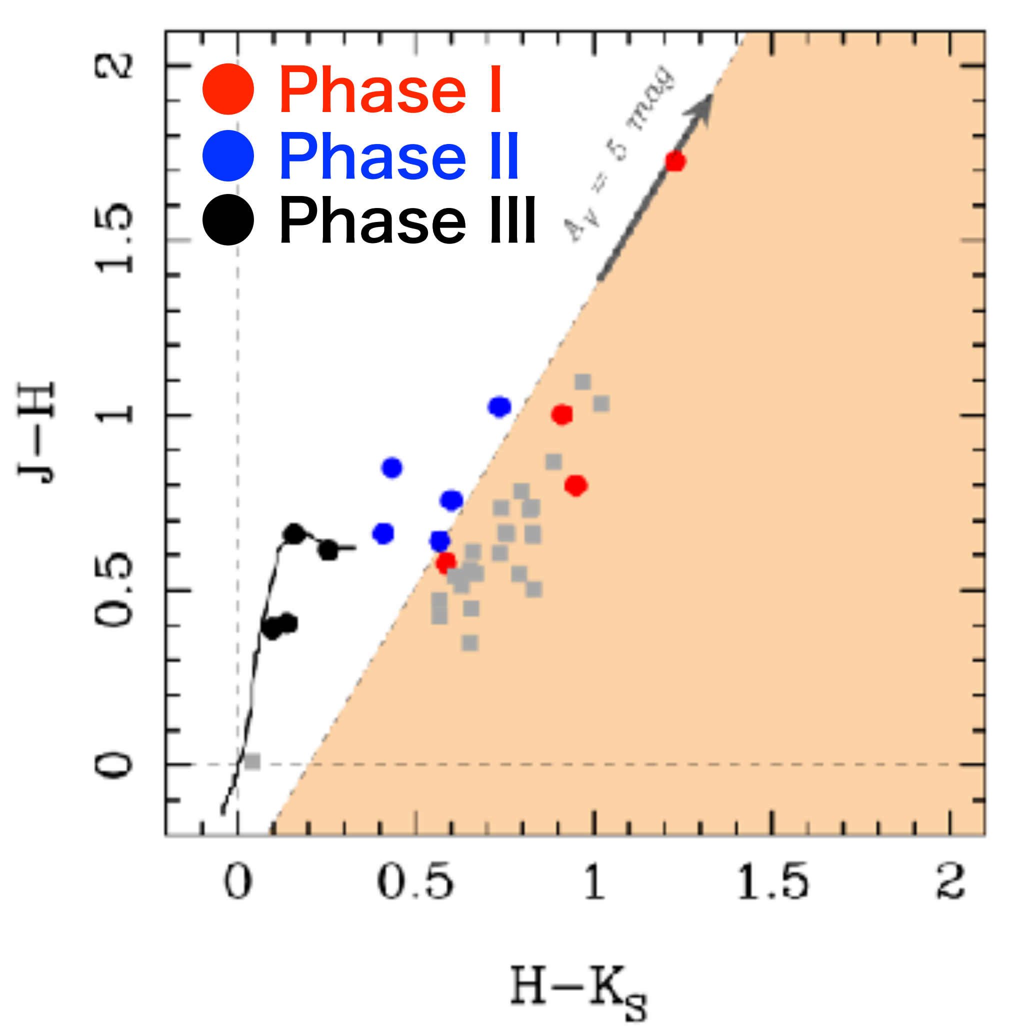


✦Target selection

- Intermediate-mass stars in the Taurus star-forming region
- Different evolutionary phases of dust disks
- Sensitivity limits: J < 9mag

13 IM-stars selected

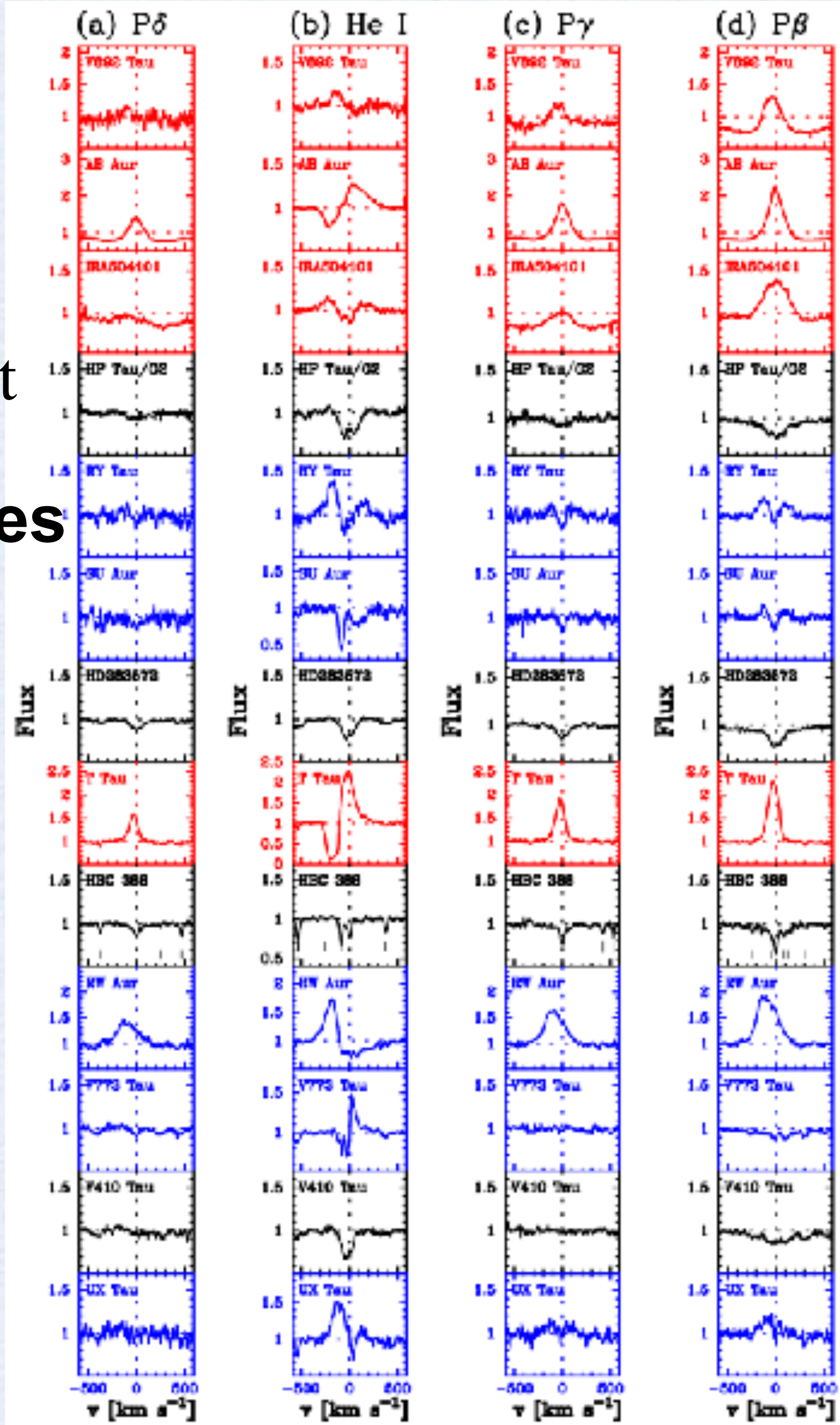
Object	SpT	Phase
V892 Tau	B9	I
AB Aur	A0	I
IRIS 04101+3103	A1	I
HP Tau/G2	G0	III
RY Tau	G1	II
SU Aur	G1	II
HD 283572	G5	III
T Tau	K0	I
HBC 388	K1	III
RW Aur	K3	II
V773 Tau	K3	II
V410 Tau	K3	III
UX Tau	K5	II



Results & Discussion

- **Obtained spectra**
  - ✓HeI λ10830
  - ✓Hydrogen Paschen lines
    Paβ features are most prominent

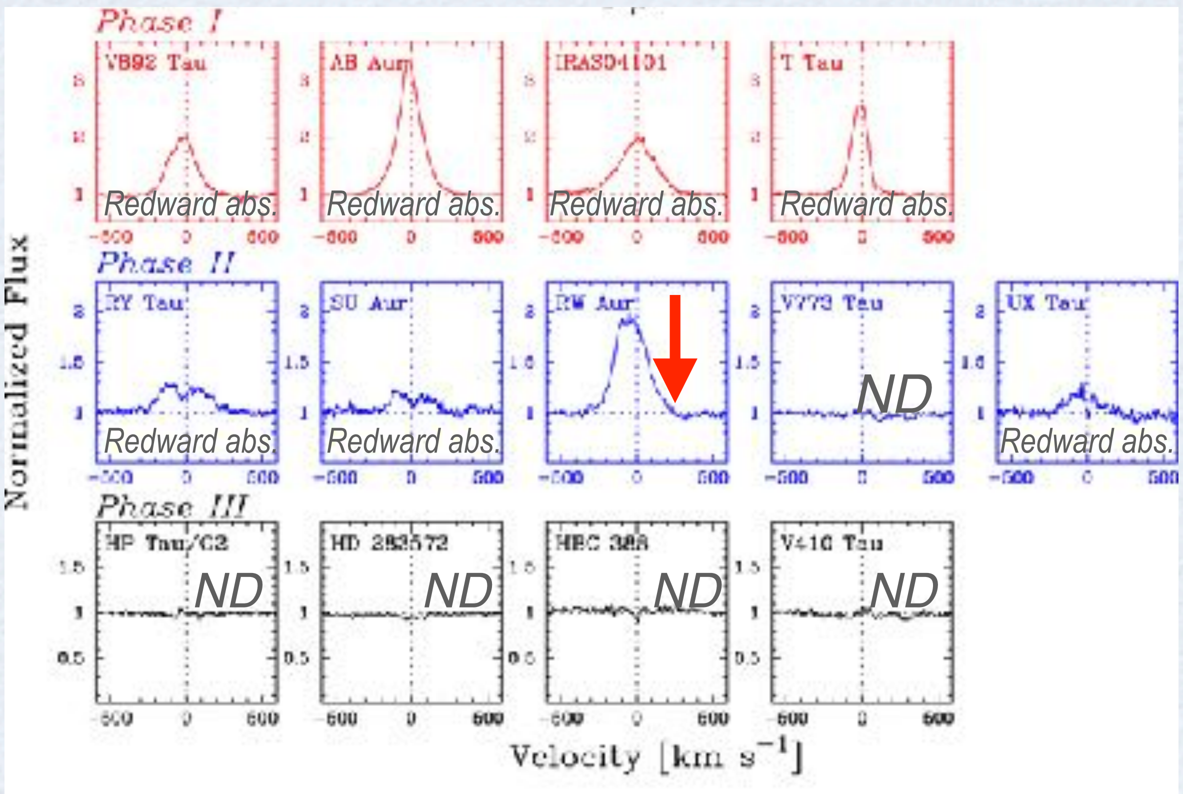
- **Remove photospheric features**
  v_{broad}, RV, veiling estimations



✦Detection and Interpretations of Pβ and HeI λ10830 line profile morphologies

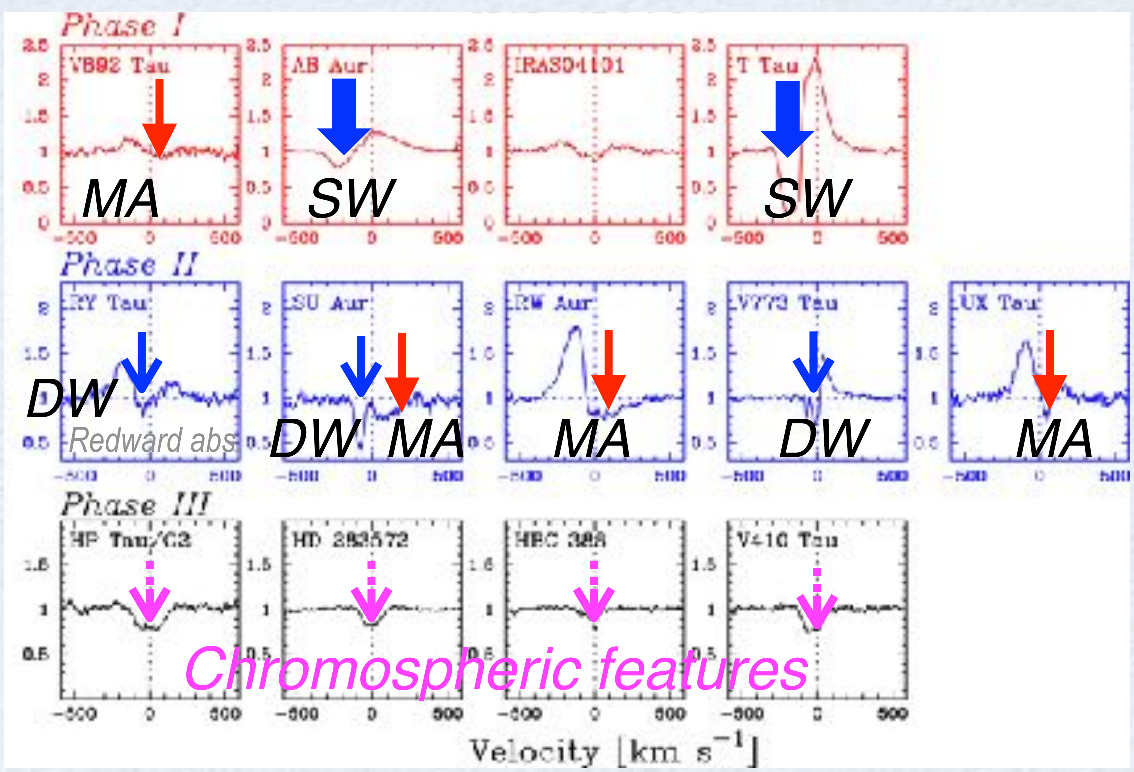
Pβ

- Detection in Phase I and II, while non-detection in Phase III
- **Redshifted abs. features**↓ can be used as diagnostics for **MA signature** (e.g., Fischer+2008, ApJ, 687, 1117), detected in one source; redward abs. features suggest that MA are functioning (e.g., Muzerolle+1998, ApJ, 492, 743 for Brγ), detected in most of Phase I and II sources.



HeI λ10830

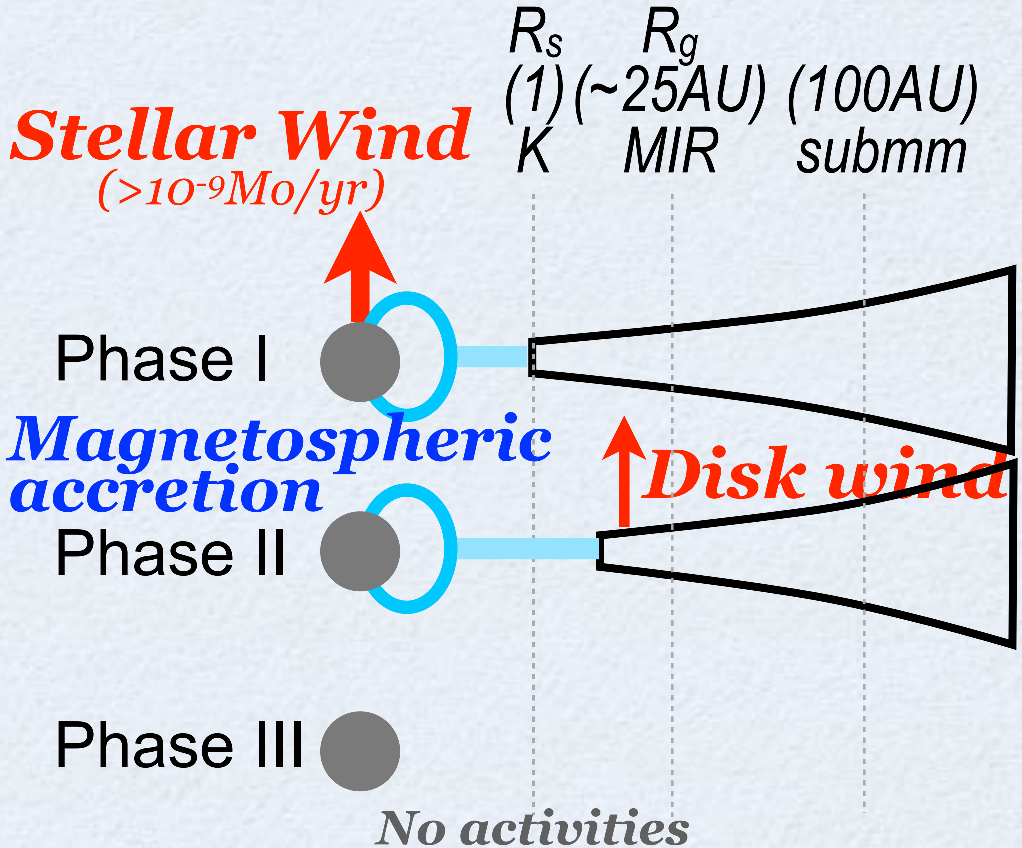
- Combination of emi. and abs. features are detected in Phase I and II, while pure abs. features are detected in Phase III.
- **Redshifted abs. features** can be used as diagnostics for **MA signature**, detected in four sources; reward abs. features suggest MA activities, detected in one source.
- **Blueshifted abs. features** can be used as diagnostics for **inner winds**: *Narrow blueshifted abs. component is caused by a disk wind, while wider component is caused by a stellar wind* (Kwan+2007, ApJ, 657, 897; Kurosawa+2011, MNRAS, 416, 2623).



✦Progression of dominant processes

- Phase I: *Stellar wind* + magnetospheric accretion
- Phase II: *Disk wind* + magnetospheric accretion
- Phase III: No activity for inner winds and MA

A clear progression for inner winds is suggested.

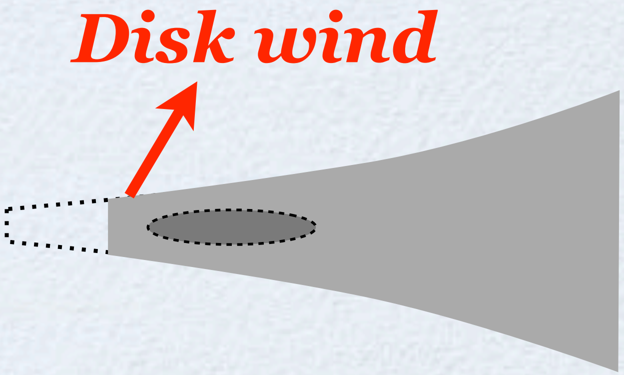


Implication to theories of mass-flow processes

The signature of disk wind is see in Phase II, whereas it is not seen in Phase I.

- Phase I: High opacity in the innermost disk, but without substantial dust settling or growth → Low ionization
- Phase II: Low opacity in the innermost disk probably due to dust settling or growth → High ionization

Suggested that opacity in protoplanetary disks plays an important role on deciding dominant mass flow processes



✦Comparison with previous studies

<u>Previous studies for HAeBes</u> (= Phase I sources)

Cauley&Johns-Krull (2014)

Mass range of HAe stars is roughly comparable to our targets.

✓HAe stars show evidence for stellar wind, whereas they show no evidence of disk wind

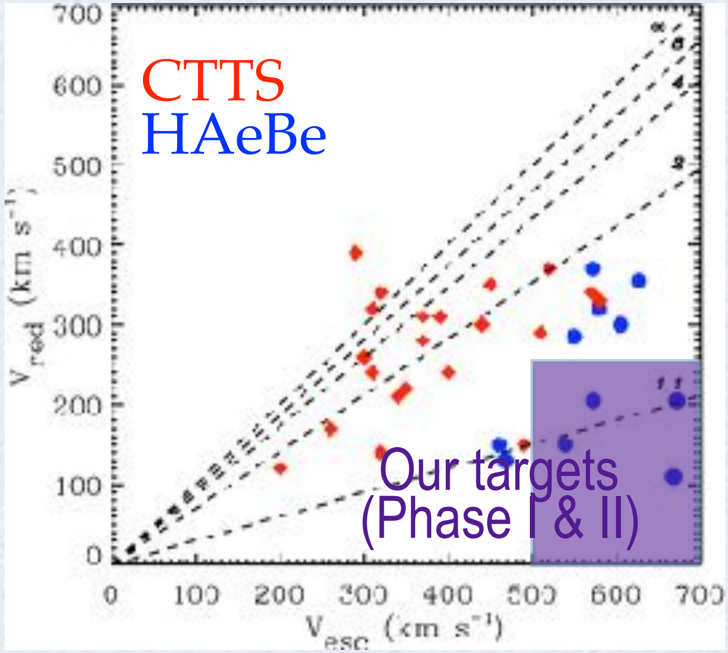
Consistent with the results for Phase I, but inconsistent with Phase II.

✓Small magnetospheres are confirmed from maximum redshifted abs. velocities

The same trends are seen for our targets (both Phase I and II).

✓The <u>smaller magnetospheres</u> as a result of smaller magnetic fields was indicated to be the reason for the lack of their disk wind signatures.

The signature is seen in Phase II sources despite that smaller magnetospheres are suggested generally for IM stars.



Cauley&Johns-Krull (2014)

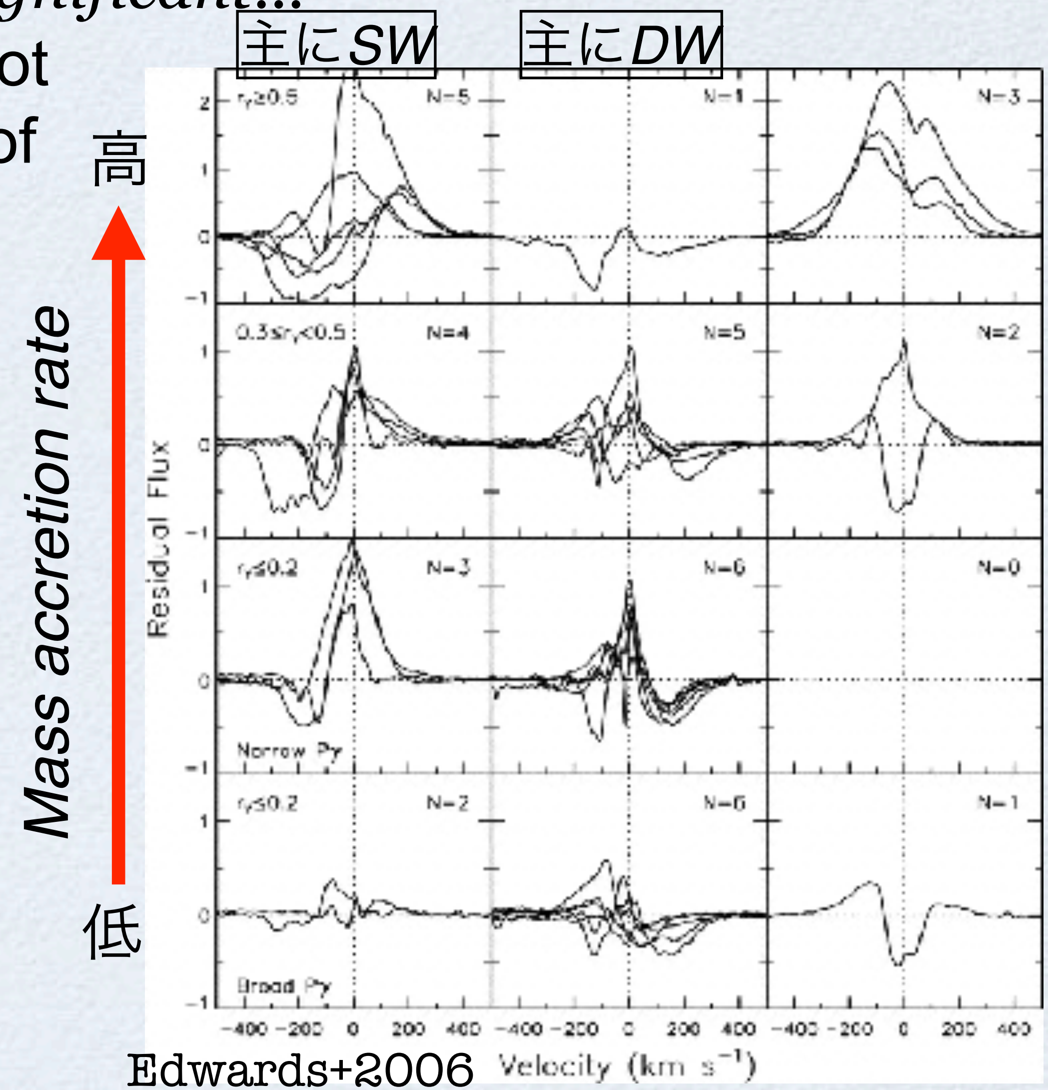
<u>Studies for CTTS</u> (Edwards+2006, Kwan+2007, Fischer+2008)

✓Focused on another indicator of disk evolutionary phase: veiling (≒mass accretion rate)

✓Suggested that stars with high disk accretion rates are more likely to have stellar wind signatures than disk wind signatures.

However, the trend is not so significant...

The mass accretion rate, cannot be necessarily clear indicator of disk evolution?



Edwards+2006

✦Chromospheric activities in YSOs

First detection of HeIλ10830 absorption features associated with chromospheric activities

- Observed pure absorption lines in Phase III sources are likely to be *stellar intrinsic features* from broader absorption features for sources with larger rotation velocities.
- The HeI absorption features associated with chromospheric activities have not been previously reported for YSOs.

He I absorption features associated with chromospheric activities even in such young phases may be characteristics of intermediate-mass stars.

Excitation mechanisms

Transition between lower metastable level of 2^3S and the upper level of 2^3P

- Two main mechanisms are proposed: Photoionization-recombination (PR) mechanism via EUV and X-ray radiations, and electron collisional excitation.
- From the non-correlation between HeI EW and L_x/L_{bol}, the dominant mechanism is suggested to be electron collisions.

The larger rotation velocities ($v\sin i \sim 100\mathrm{kms^{-1}}$) **may be the possible cause for the detection of HeI absorption in Phase III sources.**

⭐Summary

Yasui, C. et al. 2019, *ApJ,* 886, 115.

✦Observation with high-resolution NIR spectrograph"*WINERED*"

✓Obtained spectra for 13 intermediate-mass stars in different evolutionary phases of protoplanetary disks

✓High S/N was achieved

with R=30,000, 1m-class telescope, and short exposure time

S/N>100 for J=6mag with 20min exposure

✦Star-disk interaction in intermediate-mass stars

✓Detected HeI only in stars having disks

✓Showing differences in HeI line profiles with disk evolution

Phase I: Stellar wind

Phase II: Magnetospheric accretion + disk wind

Phase III: No activities

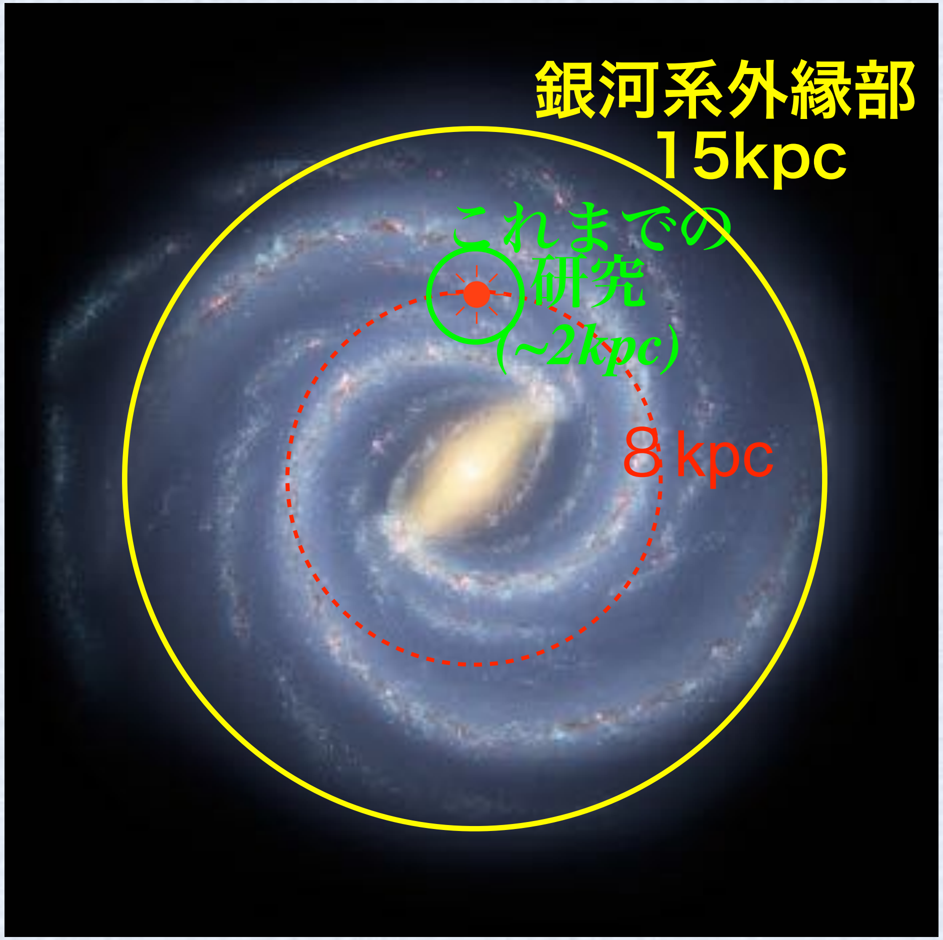
The first clear suggestion of progression

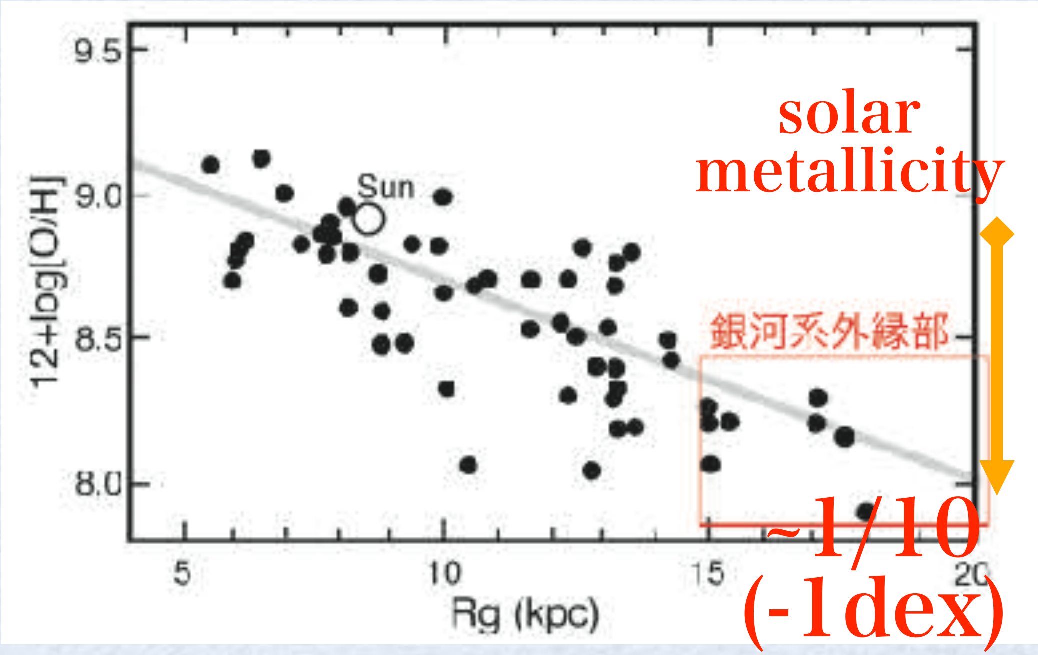
Suggested that *<u>opacity in protoplanetary disks</u>* play an important role on mass flow processes.

4. Current progress and future prospects
現在進行中の研究

☆金属量依存性の観測的研究

銀河系内での金属量勾配



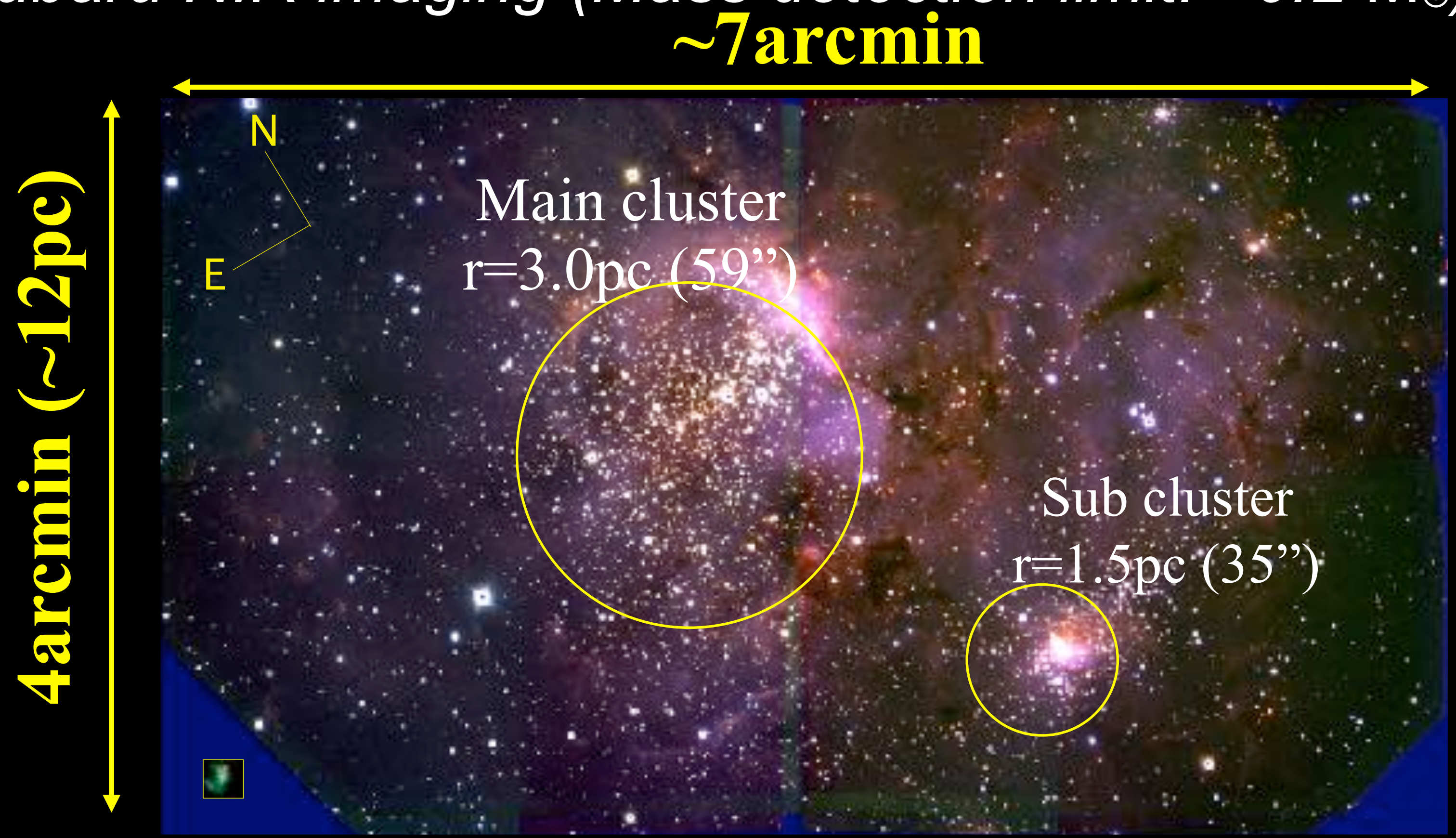


Smartt & Rolenston (1997)

銀河系外縁部での金属量は
太陽近傍の~1/10 (z≈2に相当)

◆Sh 2-209 @ Rg=17.5 kpc [O/H]=-0.6

Subaru NIR imaging (Mass detection limit: ~0.2 M$_\odot$)



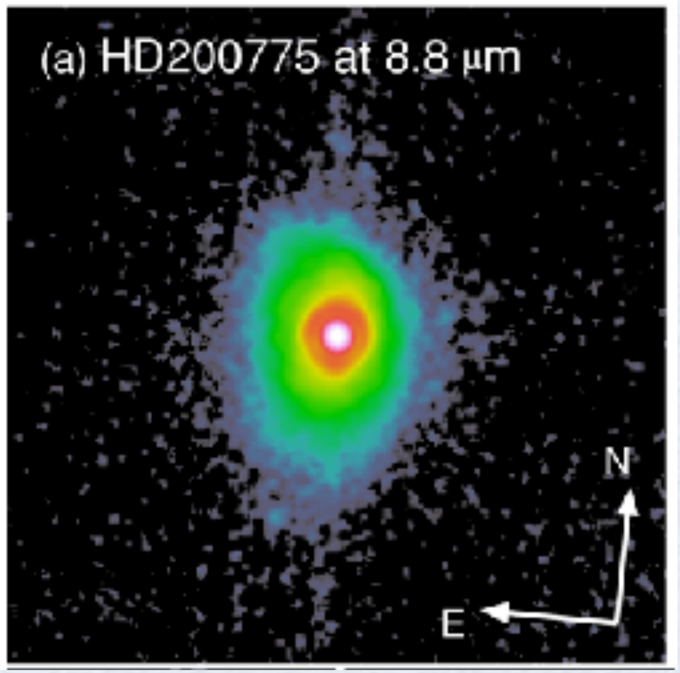
Yasui+2010, ApJL, 723, 113

One of the largest star-forming regions in the outer Galaxy (N*~1500, r=3pc → ONC-like cluster)

sub stellar massまでのIMFの導出が初めて可能に

⭐中心星質量依存性の観測的研究

- ✦中質量星におけるphotoevaporation検出の可能性
  - ✓Target: HD200775 (HBe) = 空間分解して観測される円盤を持つ星の中で、最大の質量を持つ天体 ($10M_{\odot}$)
  - ✓観測: 近赤外線高分散分光 (R=30,000, 70,000)
  - ✓結果: 複数の禁制線を検出 (一部は、YSOにおいて初検出)
    lineの性質(中心速度v_C~-10kms^{-1}, 速度幅Δv_{FWHM}~10kms^{-1}, critical density N_e ~ 10^5-10^7[cm^{-3}])より、
    photoevaporationの検出か (京産大、加藤卒業研究2020)



Okamoto+2009

4. *Current progress and future prospects*
今後の展望

⭐円盤散逸過程の中心星質量・金属量依存性

引き続き、近赤外線高分散分光観測を進める

着目するパラメータ①: 中心星質量 (& 時間進化)

これまでの研究ではターゲット数が少なかった

Taurus星生成領域のYSO (Edwards+2006, Yasui+2014)

HAeBe stars (Cauley & Johns-Krull (2014)

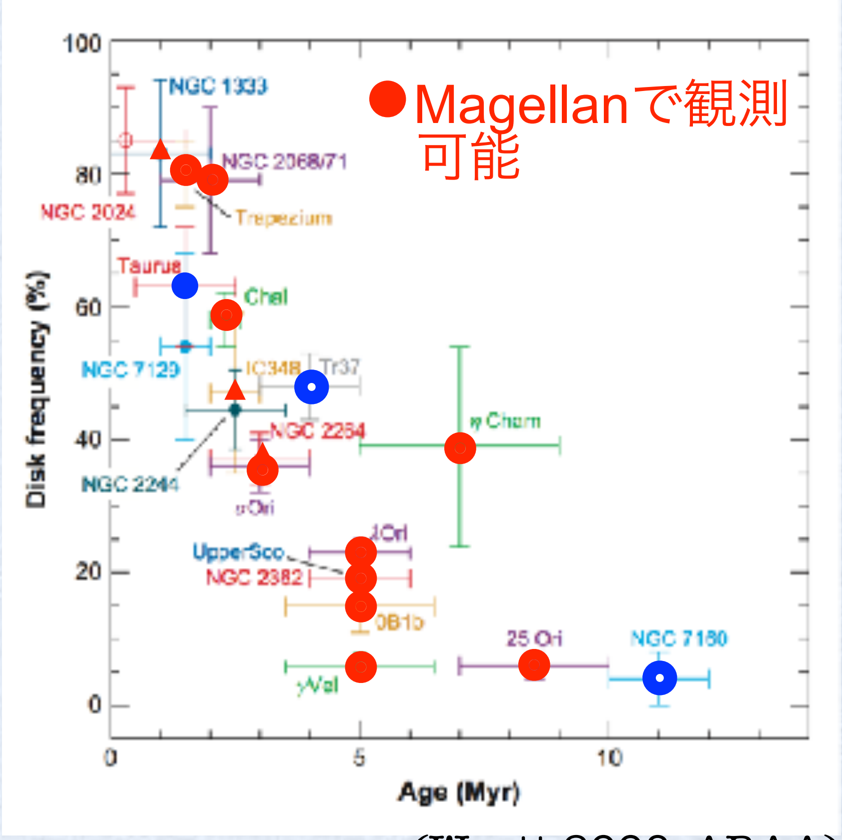
✓ターゲット: 太陽近傍の星生成領域

<1Myrから10Myrの幅広い年齢範囲

✓感度: J=15mag (*R*=28,000, S/N=50)

近傍天体(D~500pc)であれば、

~0.1M$_\odot$まで到達可能



(Wyatt 2008, ARAA)

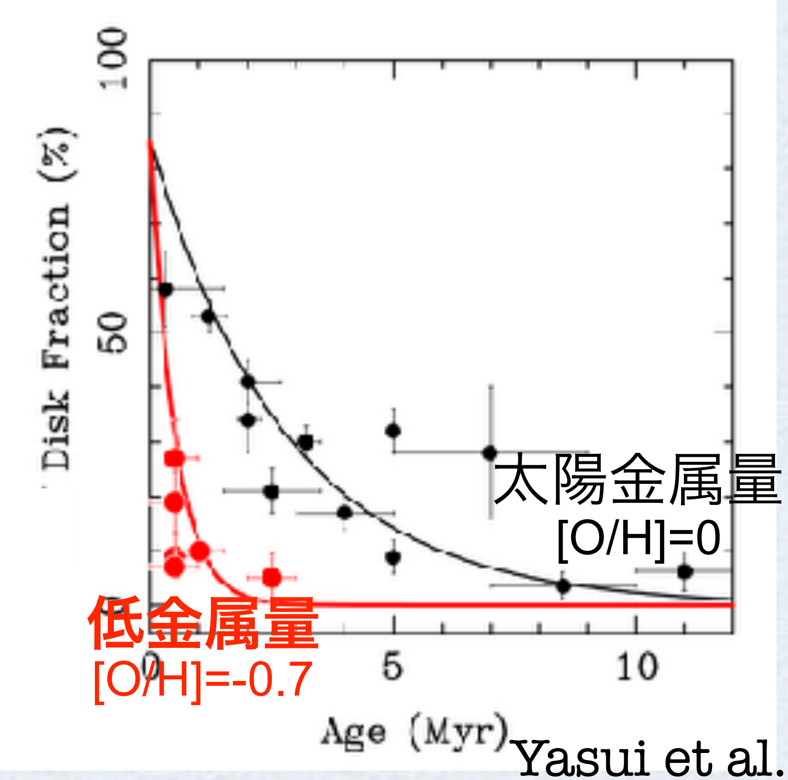
着目するパラメータ②: 金属量依存性

近赤外線観測より示唆された円盤寿命の金属量依存性を説明しうる円盤散逸メカニズムについての直接観測

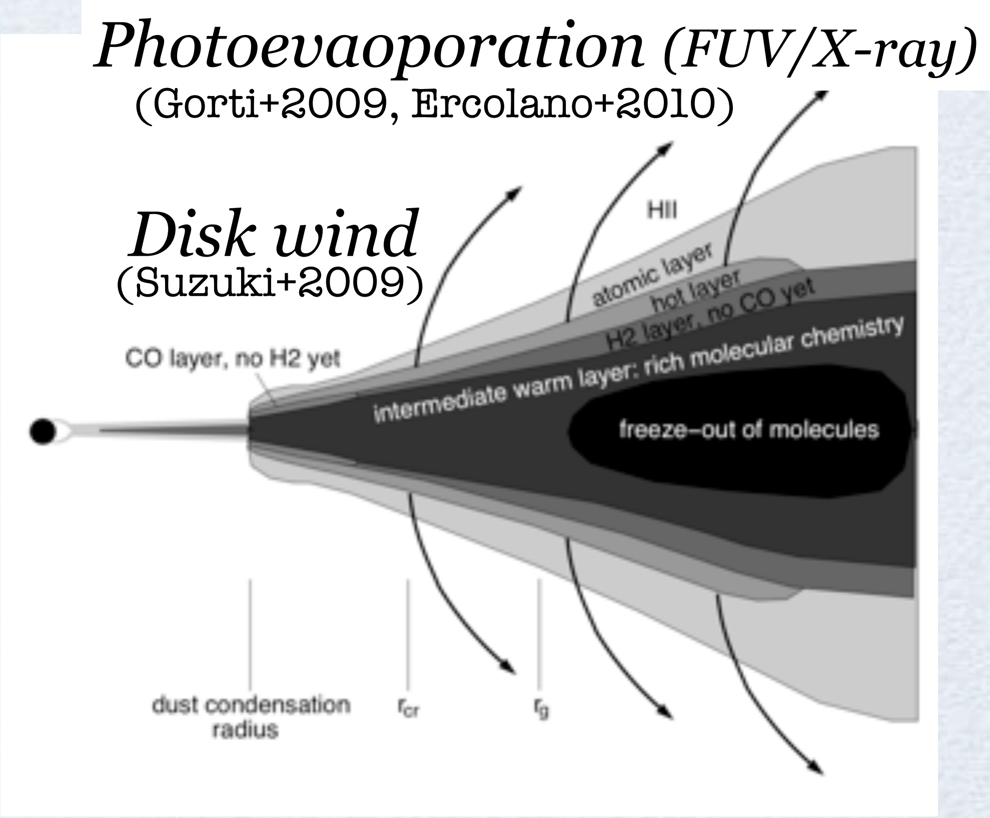
✓ターゲット: 低＆高金属量領域のYSO

~-1dexから+0.3 dexの幅広い金属量範囲

✓感度: J=14mag (R=68,000; S/N=50) まずは、中質量星(~10M$_\odot$)



Yasui et al. 2010



(From Dullemond+2005)

⭐星惑星形成過程の金属量依存性 *From late 2021 to early 2023?*

✦JWST GT observations (PI: M. Ressler (JPL))

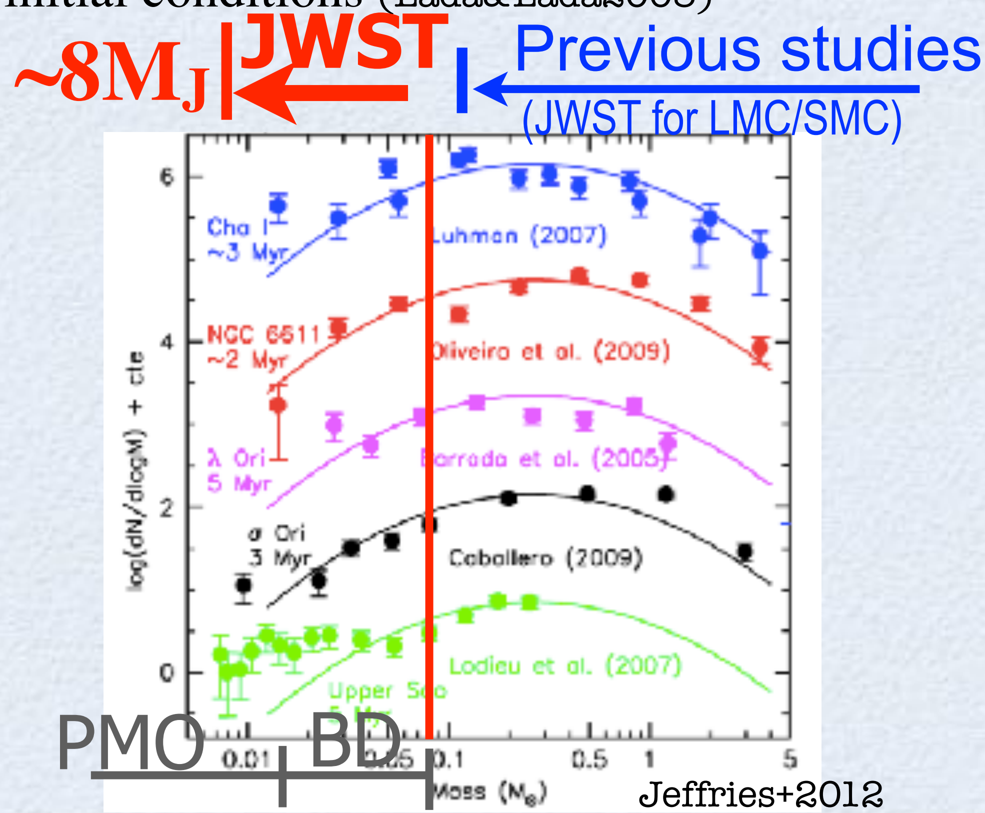
NIR/MIR imaging (1.15-21μm)

<u>IMF</u>

The low-mass end IMF down to planetary-mass objects (PMO)

Are free-floating objects common in low-metallicity environments?

The substellar IMF may be a sensitive function of formation environment and/or initial conditions (Lada&Lada2003)

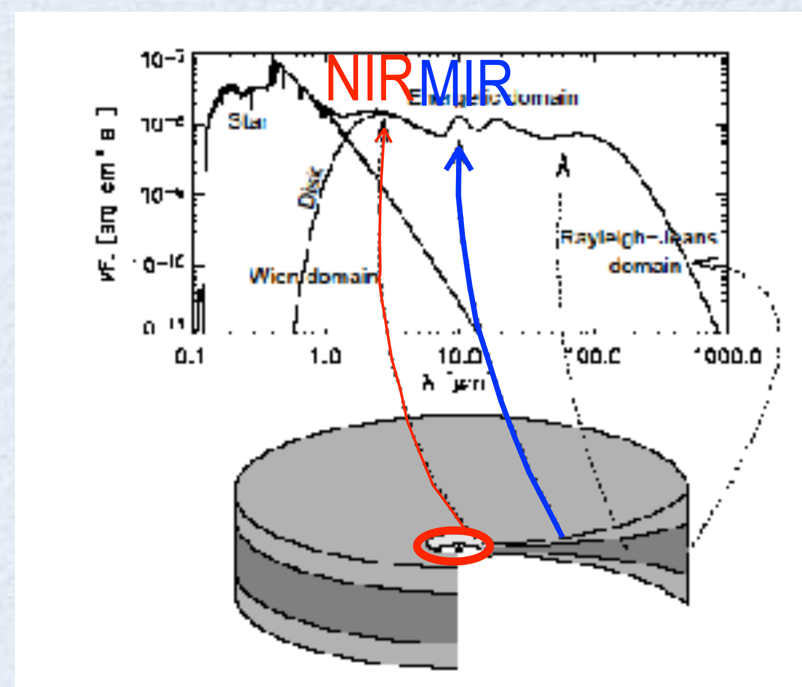


Jeffries+2012

<u>Disk evolution</u>

✓Protoplanetary disks
 For low-mass stars (**~0.5M☉**)
- *Outer* disk lifetime
- Disk properties
 e.g., M_{disk}, M_{acc}
- Dust growth & settling

✓Debris disk
 For intermediate-mass stars



(Figure by Dullemond et al. 2007 PPV)