Understanding the evolution of mass accretion to explain the evolution of disks

Carlo Felice Manara - *ESO Fellow (ESO Garching)*

With: J. Alcala (INAF), A. Natta (DIAS), G. Rosotti (IoA), L. Testi (ESO), G. Herczeg (KIAA), G. Lodato (UniMI), B. Nisini (INAF), A. Frasca (INAF), D. Fedele (INAF), J. Williams (IfA), I. Pascucci (Arizona), M. Ansdell (Berkley), G. Mulders (Arizona), S. Facchini (MPE), C. Clarke (IoA), T. Prusti (ESA), Jets and Disks at INAF (JEDI) collaboration

Roma - 26.06.2018

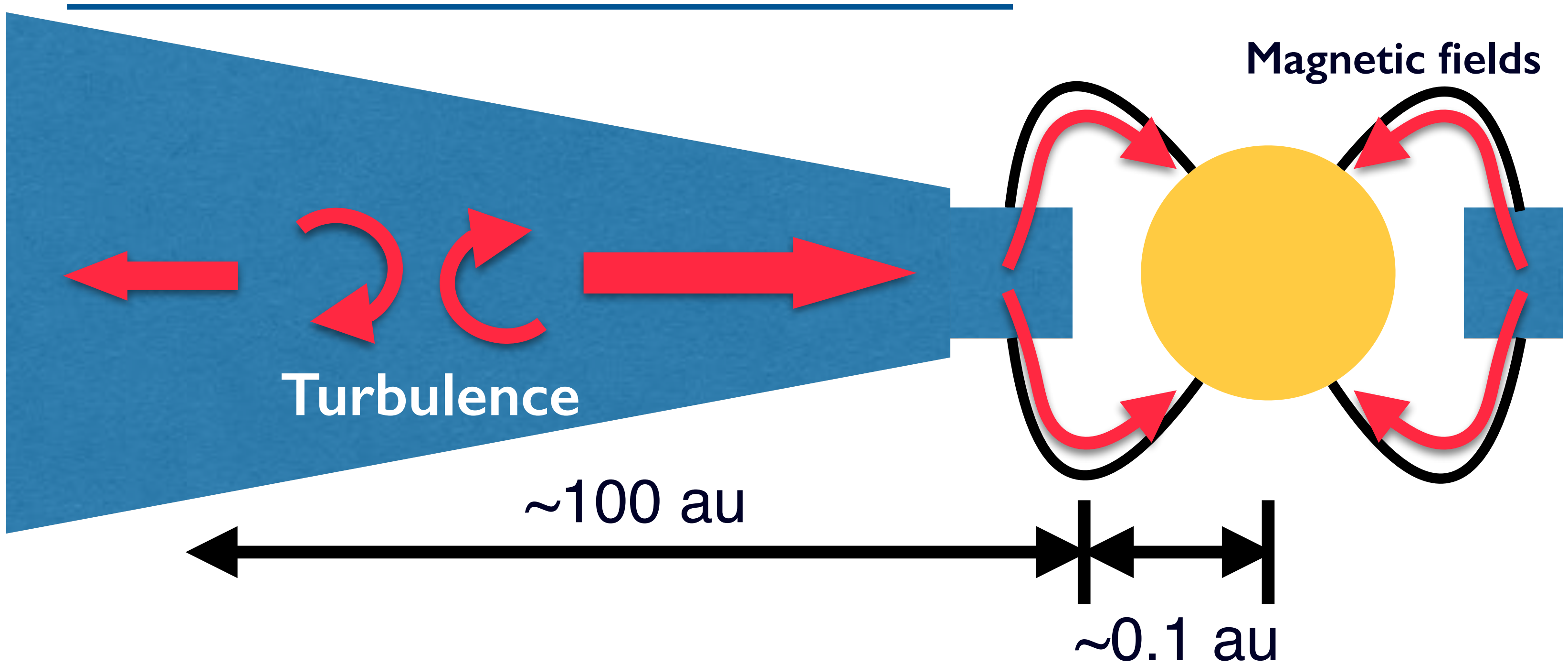
Protoplanetary disks are the place where planets are formed.
Their evolution is **KEY** to understand planet formation

Artist impression. Credits: G. Glasø, Mark A. Garlick, M. Kornmesser

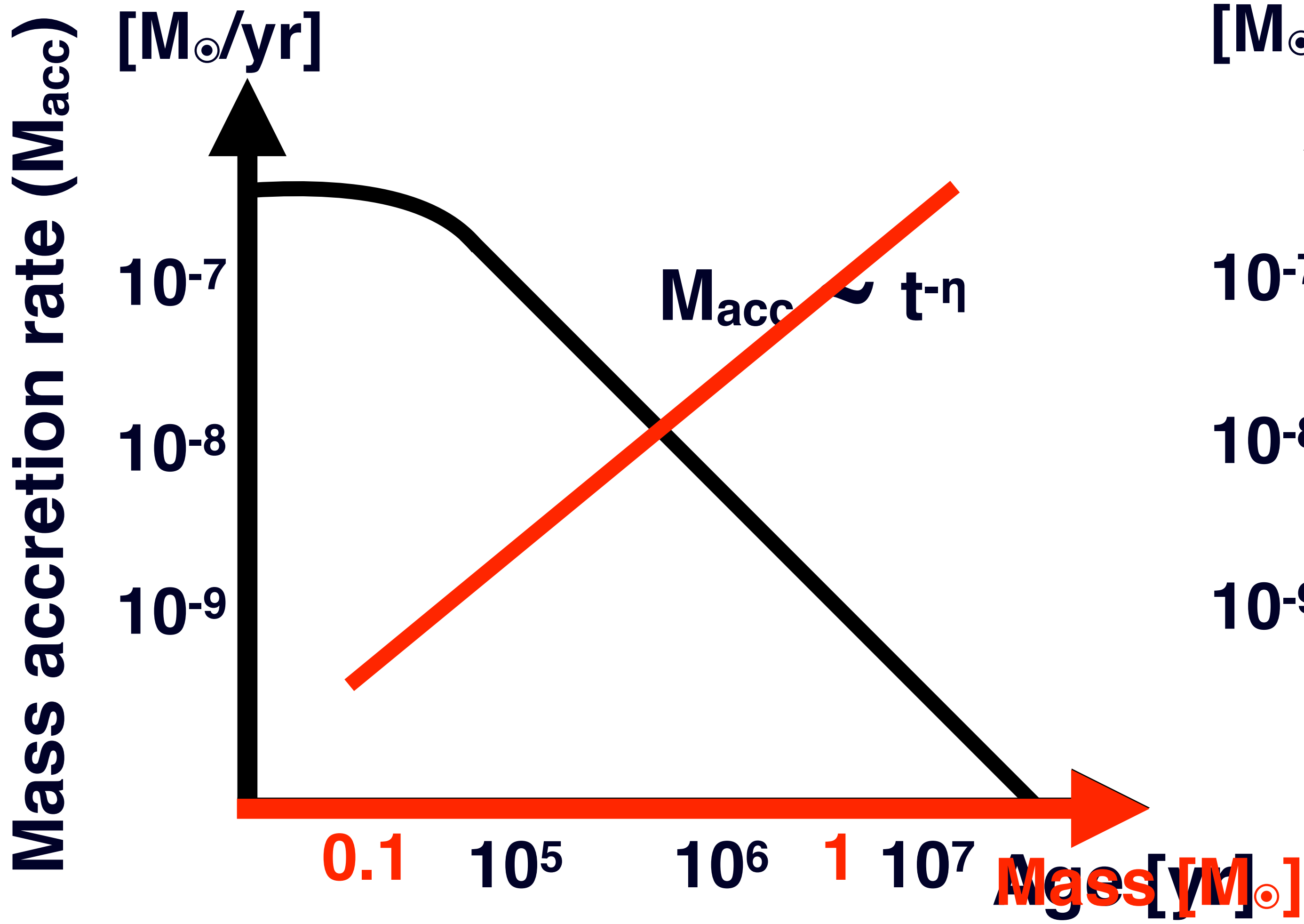
Internal processes driving disk evolution

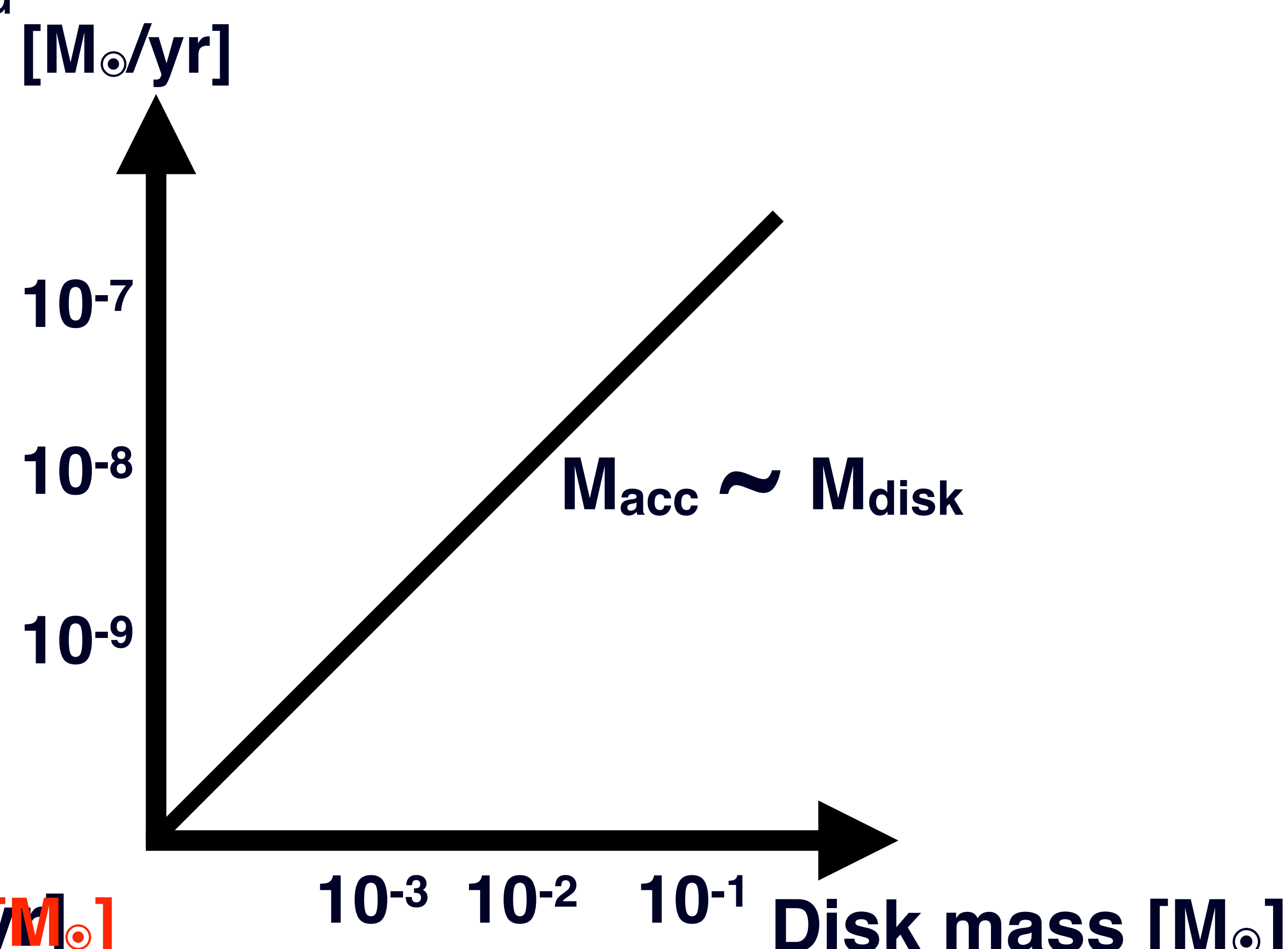
Viscous accretion

e.g., Lynden-Bell & Pringle 1974;
Hartmann et al. 1998

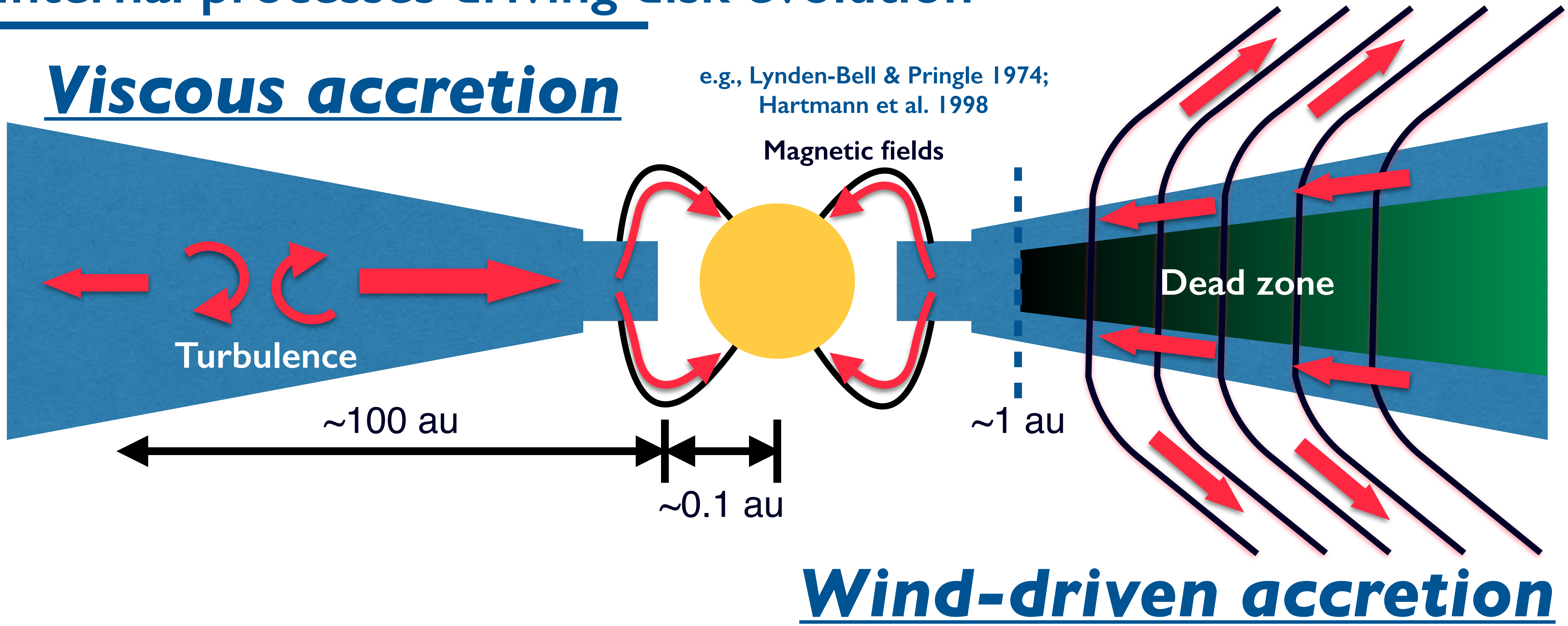


- ? *Origin of turbulence*
- ? *Long timescales*
- ? *Structures in disks*





Internal processes driving disk evolution

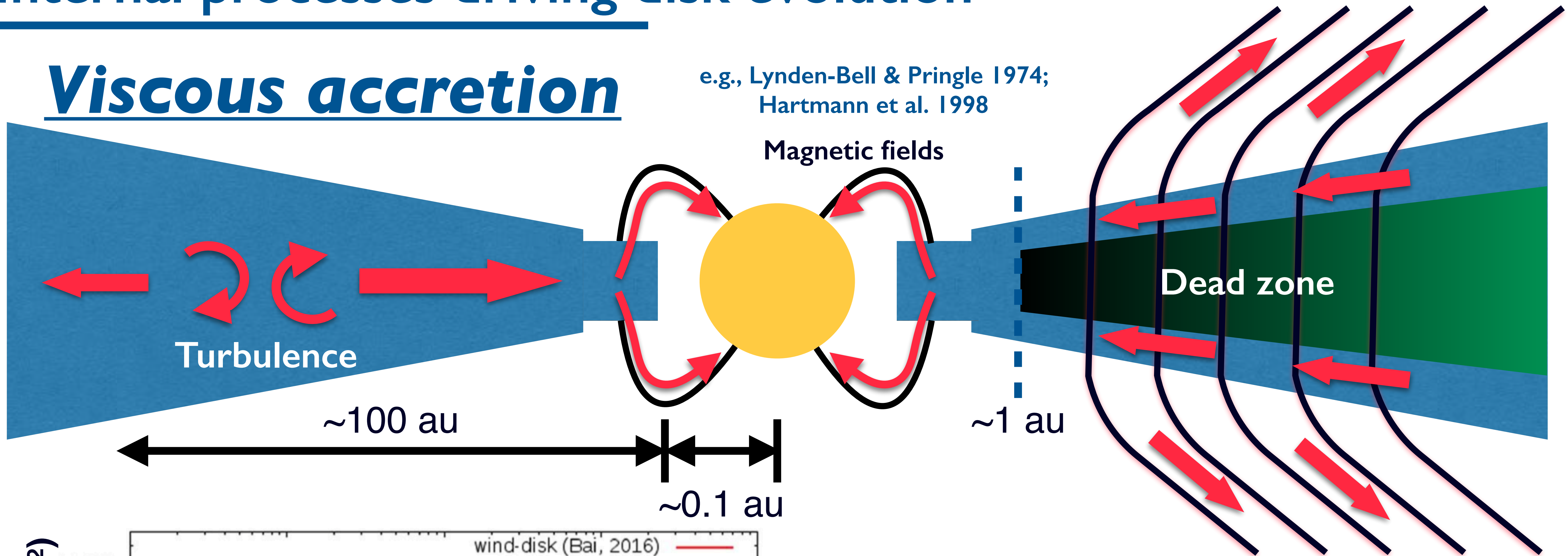


e.g., Armitage et al. 2013,
Bai et al. (2014, 2015, 2016),
Gressel et al. 2015,
Simon et al. 2015

Internal processes driving disk evolution

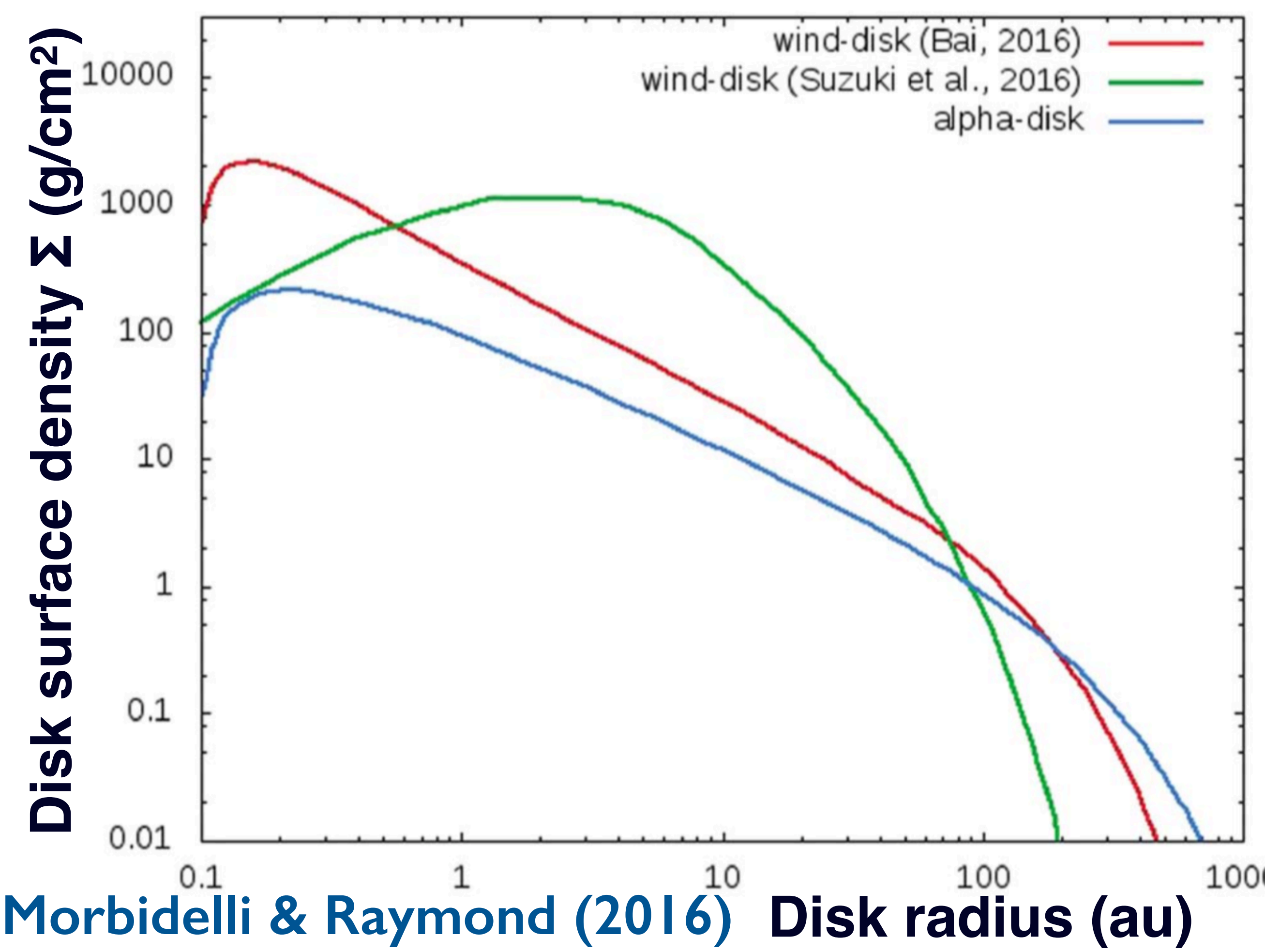
Viscous accretion

e.g., Lynden-Bell & Pringle 1974;
Hartmann et al. 1998



Wind-driven accretion

e.g., Armitage et al. 2013,
Bai et al. (2014, 2015, 2016),
Gressel et al. 2015,
Simon et al. 2015

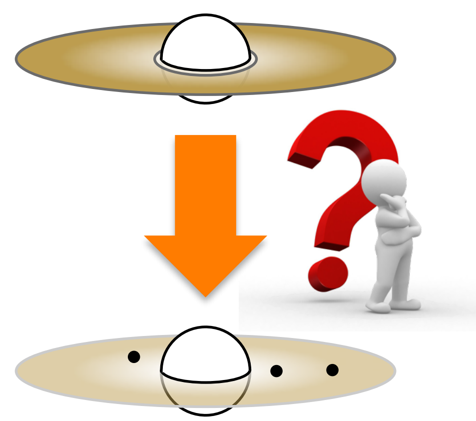


Morbidelli & Raymond (2016)

Impact on planet formation and migration

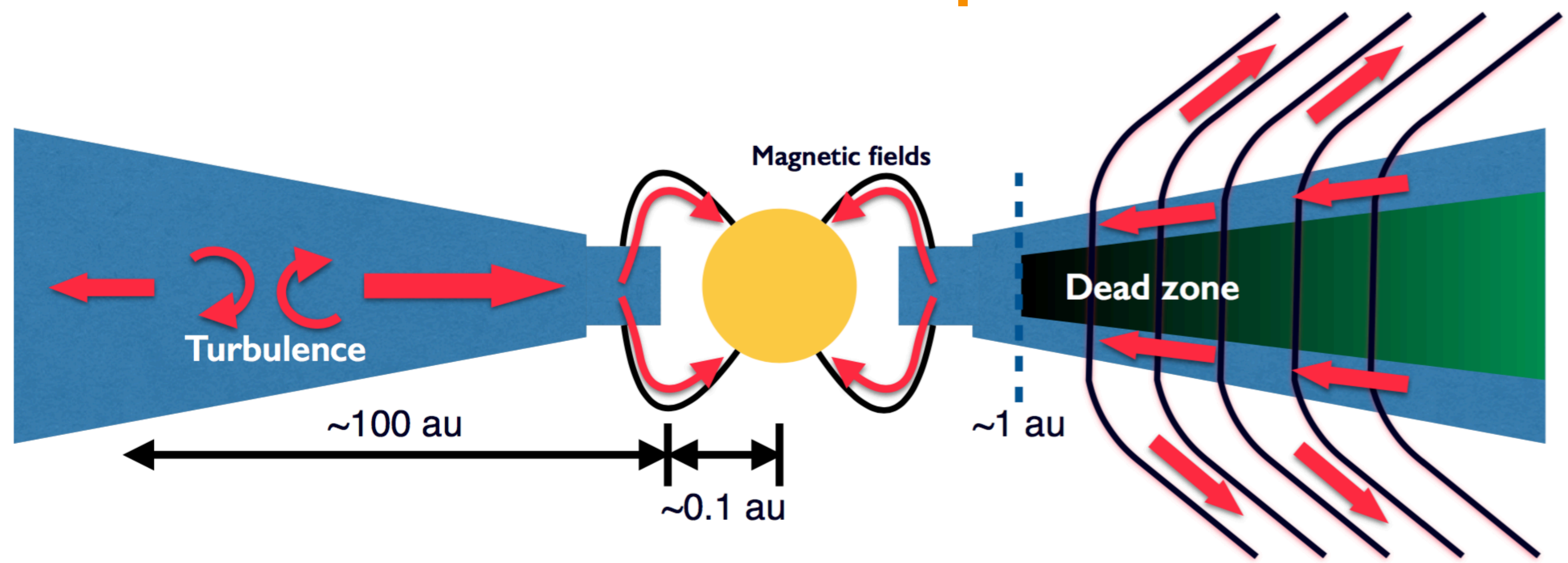
What is the driver of the evolution of protoplanetary disks?

Disk



Star & planets

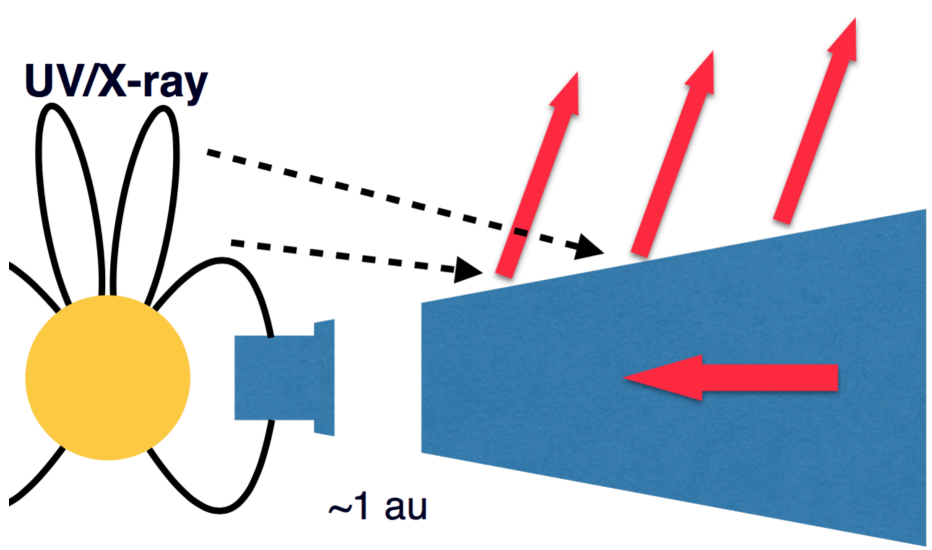
VISCOUS EVOLUTION | DISK WINDS



e.g., Lynden-Bell & Pringle 1974;
Hartmann et al. 1998

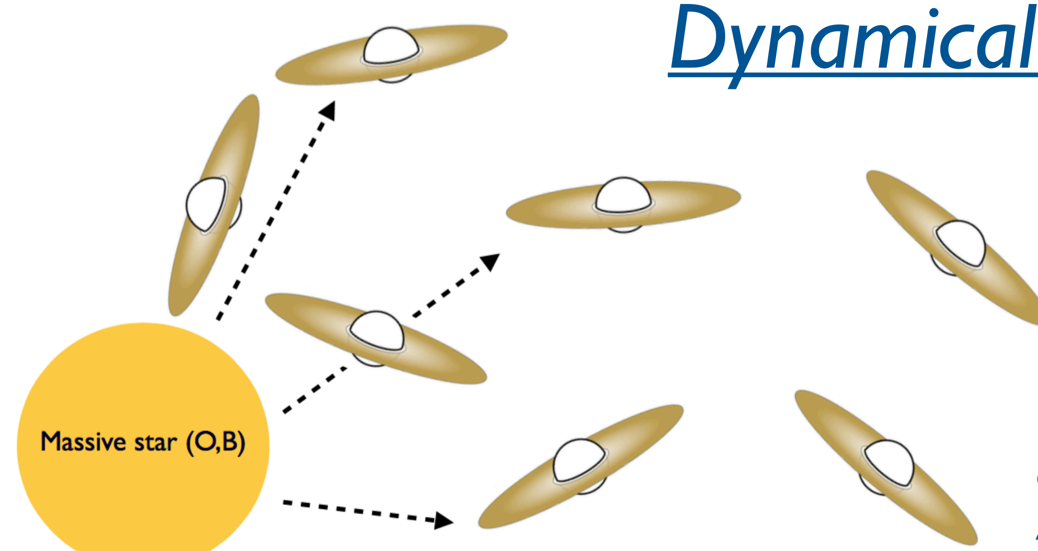
e.g., Armitage et al. 2013, Bai et al. (2014, 2015, 2016),
Gressel et al. 2015, Suzuki et al. 2016

INTERNAL PHOTOEVAPORATION



e.g., Alexander et al. (2014),
Ercolano & Pascucci (2017)

EFFECTS OF ENVIRONMENT - STELLAR CLUSTERS



Dynamical interactions

e.g., Pfalzner et al., 2005;
Clarke et al., 1993, 2008;
Adams 2010,
Winter et al. 2018

External photoevaporation

e.g., Clarke 2007,
Anderson et al. (2013),
Facchini et al. (2016),
Winter et al. (2018)

1 Spectroscopy:

- Stellar properties
- Mass accretion rates
- Wind properties

Talk by L. Venuti, E. Rigliaco, T. Giannini….

2 mm-interferometry:

- Disk mass
- Disk morphology
- Surface density

Talk by L. Testi, A. Miotello, M. Tazzari, D. Fedele, C. Favre…

3 IR-interferometry & spectroscopy:

- Inner disk morphology
- Inner disk composition

Talk by R. Garcia-Lopez, A. Garufi

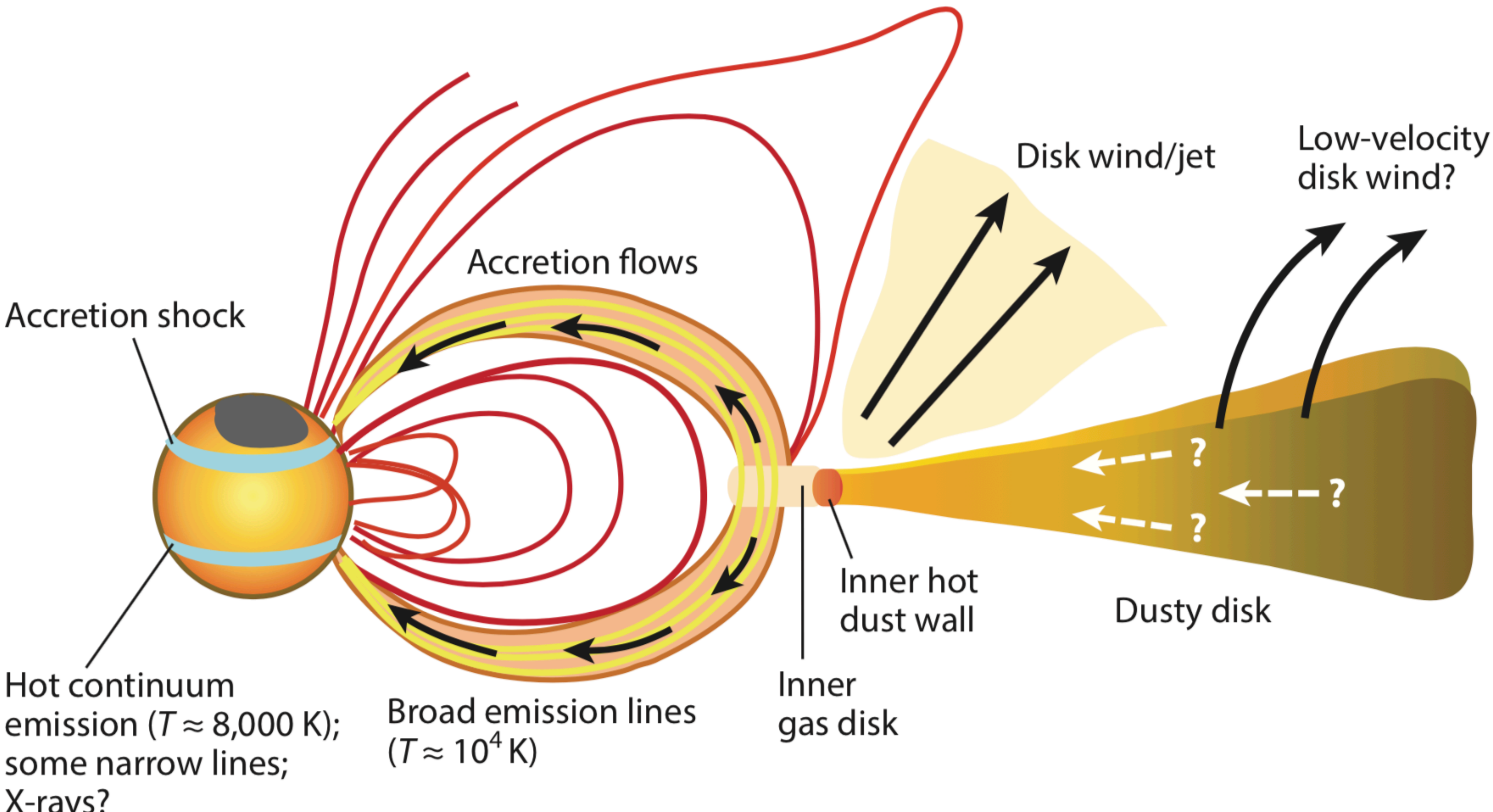
4 Astrometry:

- Distances
- Kinematic membership
- Dynamical properties

Poster by CFM

Artist impression. Credits: G. Glasø, Mark A. Garlick, M. Kornmesser

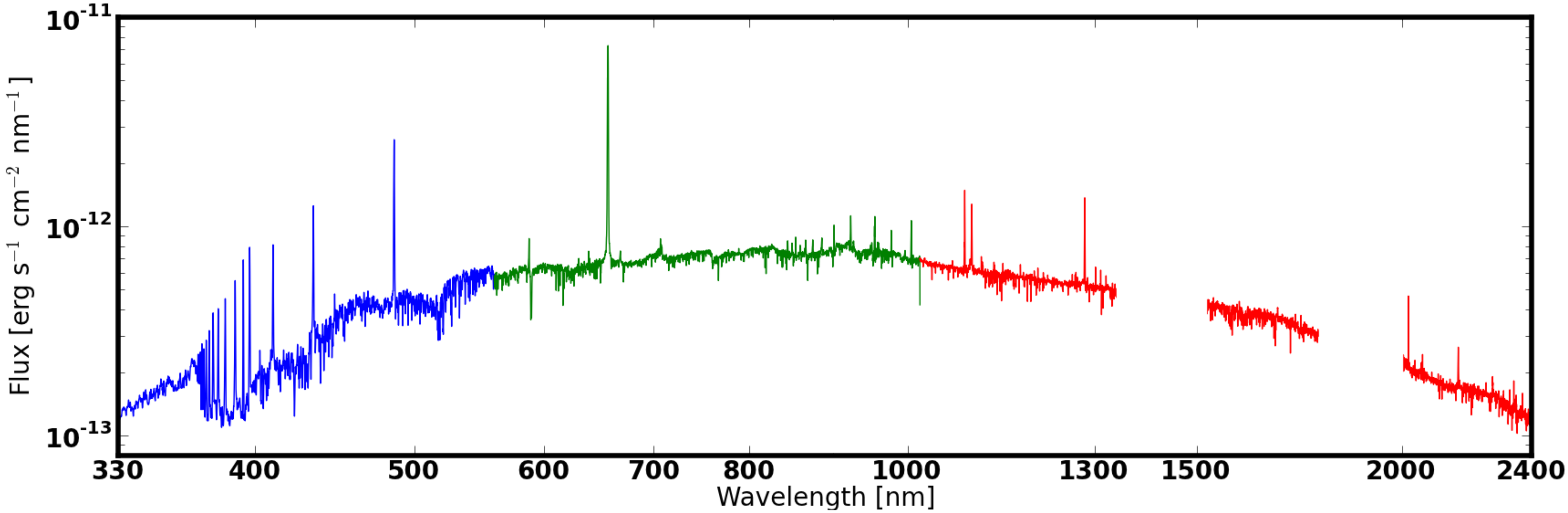
Accretion onto Pre-Main-Sequence stars



- UV-excess
- Emission lines

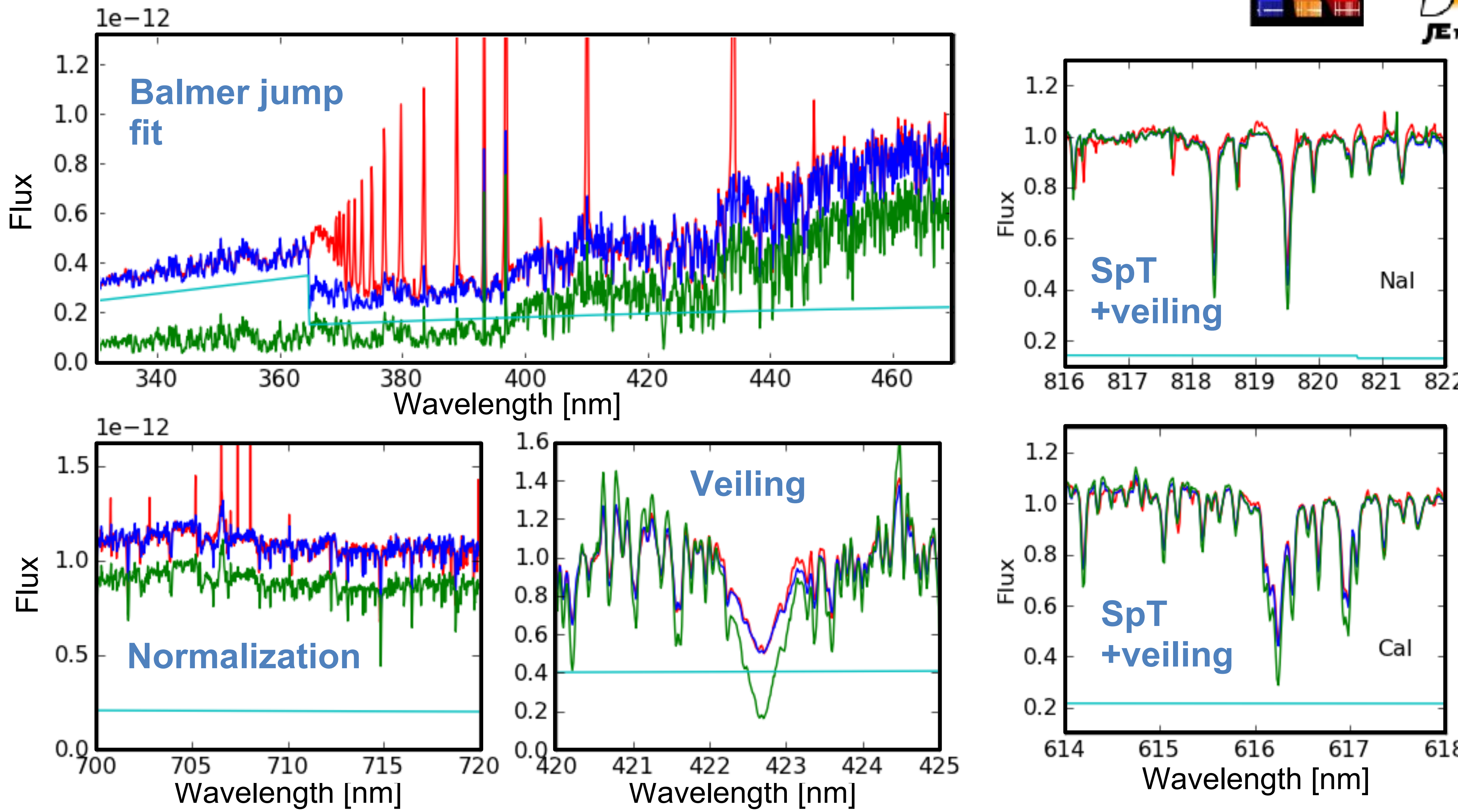
Hartmann, Herczeg and Calvet, 2016, ARAA

VLT/X-Shooter



- Medium resolution and high-sensitivity
- Simultaneous observation from ~300 nm to ~2500 nm
  - UV-excess
  - Many accretion diagnostics (emission lines)
  - Photospheric features

Accretion and stellar properties determination



Manara et al. 2013b

- Photospheric templates: Class III YSOs (*Manara et al. 2013a, 2017b*) ➜ SpT, $L_\star$
- Isothermal hydrogen slab model for the accretion shock spectrum ➜ L_{acc}
- Extinction values + reddening law ➜ A_V

ACCRETION & STELLAR PROPERTIES DETERMINATION

X-Shooter surveys: aiming for completeness

95% complete

Chal (PI Testi)
$M_\star/M_\odot<1$
44 Class II
(Manara, Testi et al. 2017)

95% complete

Lupus (PI Alcala)
$M_\star/M_\odot< 2$
37 Class II
(Alcala, Manara, Natta et al. 2017)

Chal (PI Antoniucci)
$M_\star/M_\odot\sim 1$
8 Class II
(Manara, Testi et al. 2017)

ρ-Oph (PI Testi)
$M_\star/M_\odot<0.2$
17 Class II
(Manara, Testi, Natta, & Alcala 2015)

Lupus
$M_\star/M_\odot<1.2$
36 Class II
(Alcala, Natta, Manara+2014)

Cha I (PI Herzceg)
$M_\star/M_\odot<2$
31 Class II
(Manara, Fedele, Herczeg & Teixeira 2016)

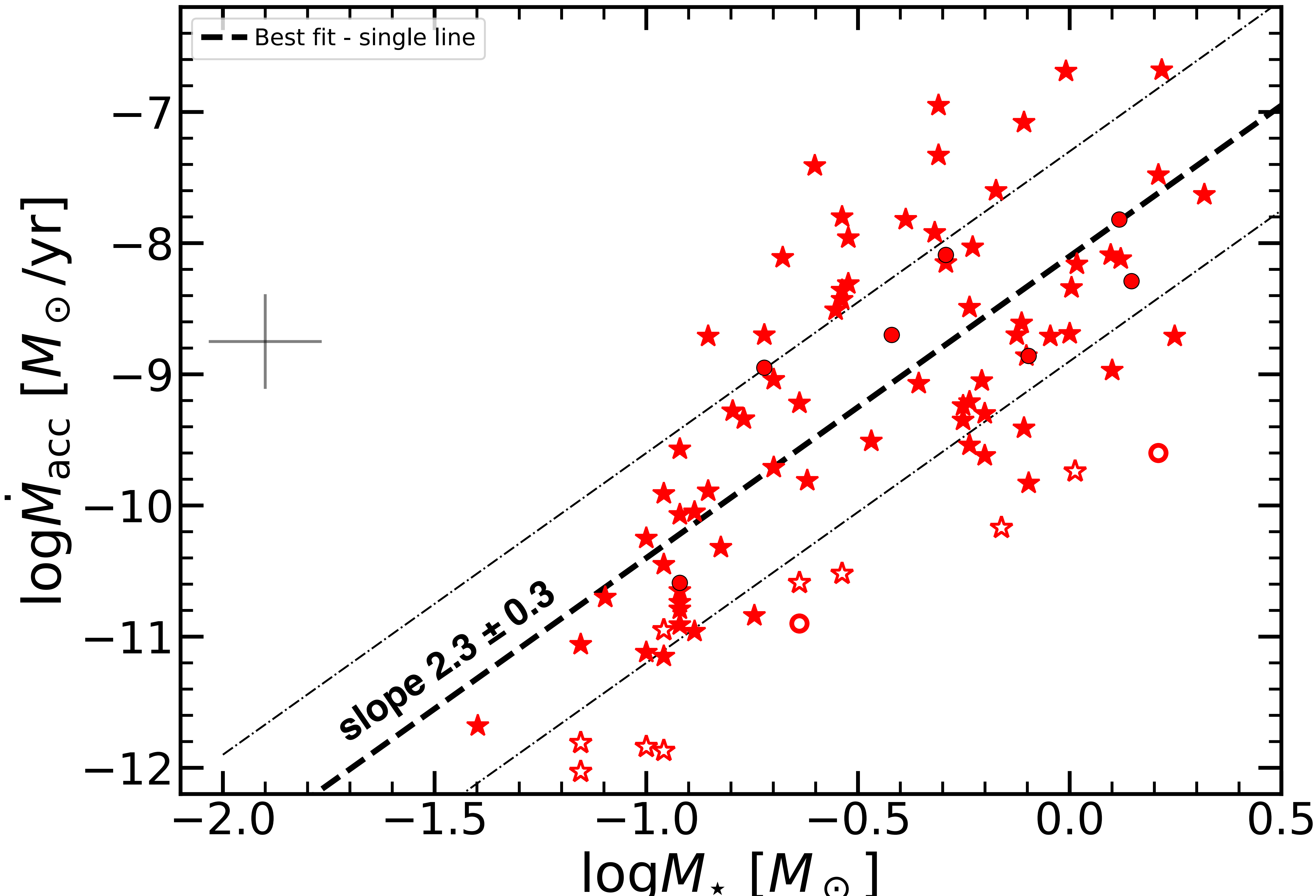
σ-Orionis
$M_\star/M_\odot<0.3$
8 Class II
(Rigliaco et al. 2012)

TW Hydrae
$M_\star/M_\odot<0.6$
~10 Class II
(Stelzer et al. in prep)

1 Myr — 2-3 Myr — 3-5 Myr — >5 Myr

STELLAR AGE

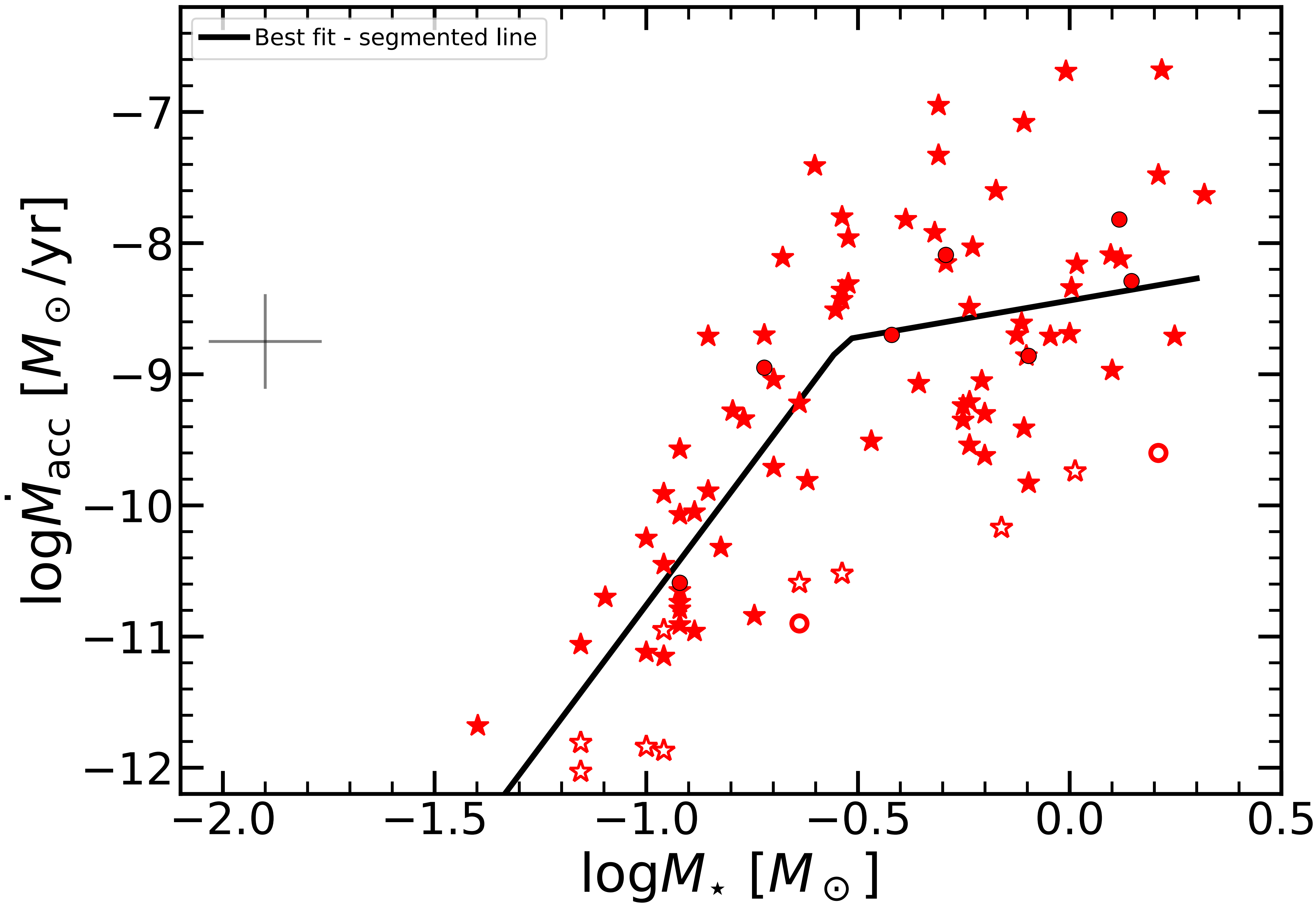
X-Shooter survey: Chamaeleon I



Manara, Testi, Herczeg et al. 2017a
and Manara, Fedele, Herczeg et al. 2016a

Single power-law: result of initial conditions (e.g., *Alexander & Armitage 2006, Dullemond et al. 2006*), Bondy-Hoyle accretion (*Padoan et al. 2005*), photoevaporation (e.g., *Clarke & Pringle 2006, Ercolano et al. 2014*)?

X-Shooter survey: Chamaeleon I

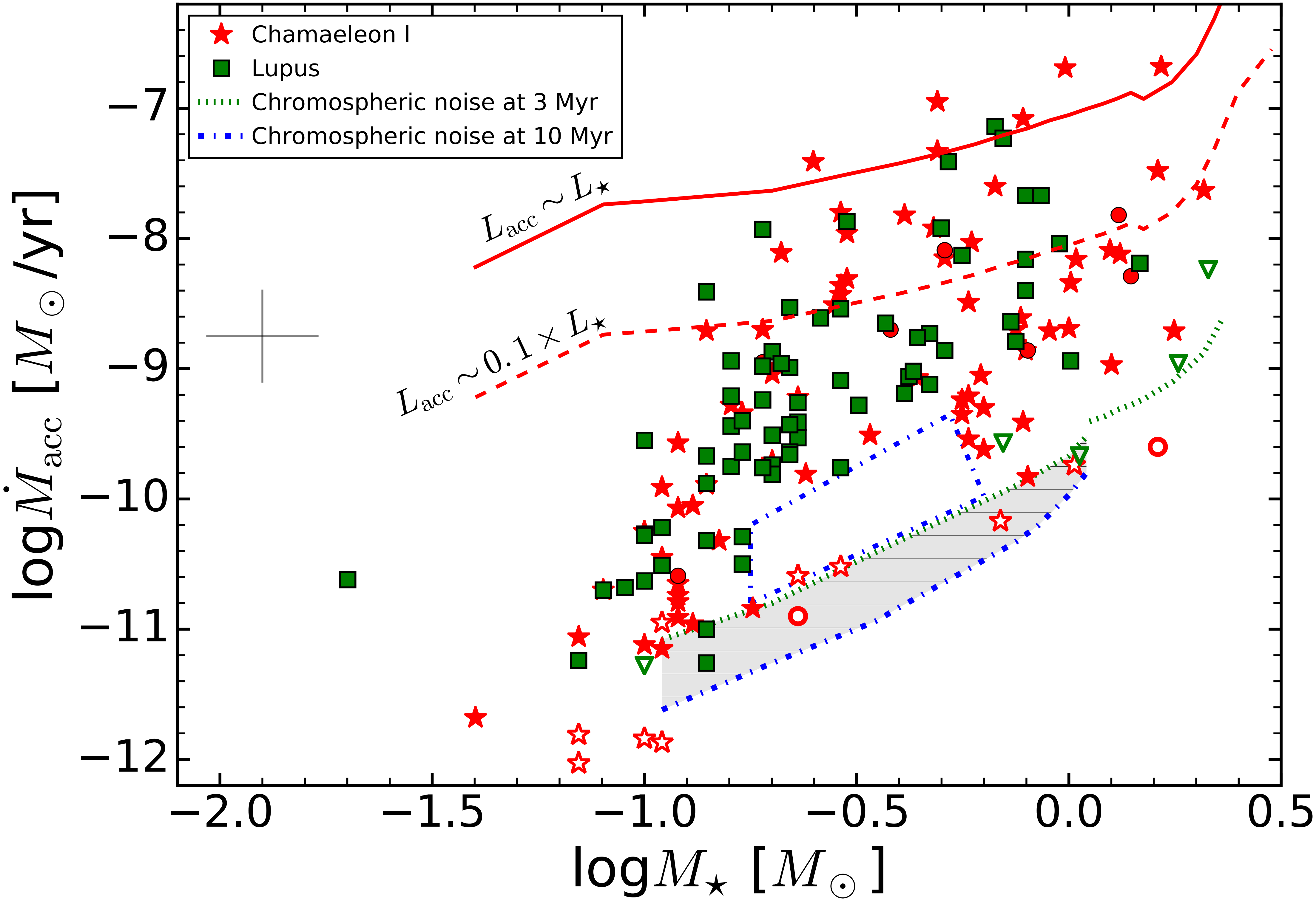


Manara, Testi, Herczeg et al. 2017a
and Manara, Fedele, Herczeg et al. 2016a

Drop at log(M★/M⊙)~-0.5:

two accretion regimes *(Vorobyov & Basu 2009)* or faster evolution at lower masses?

Macc vs Mstar: Lupus & Chameleon I



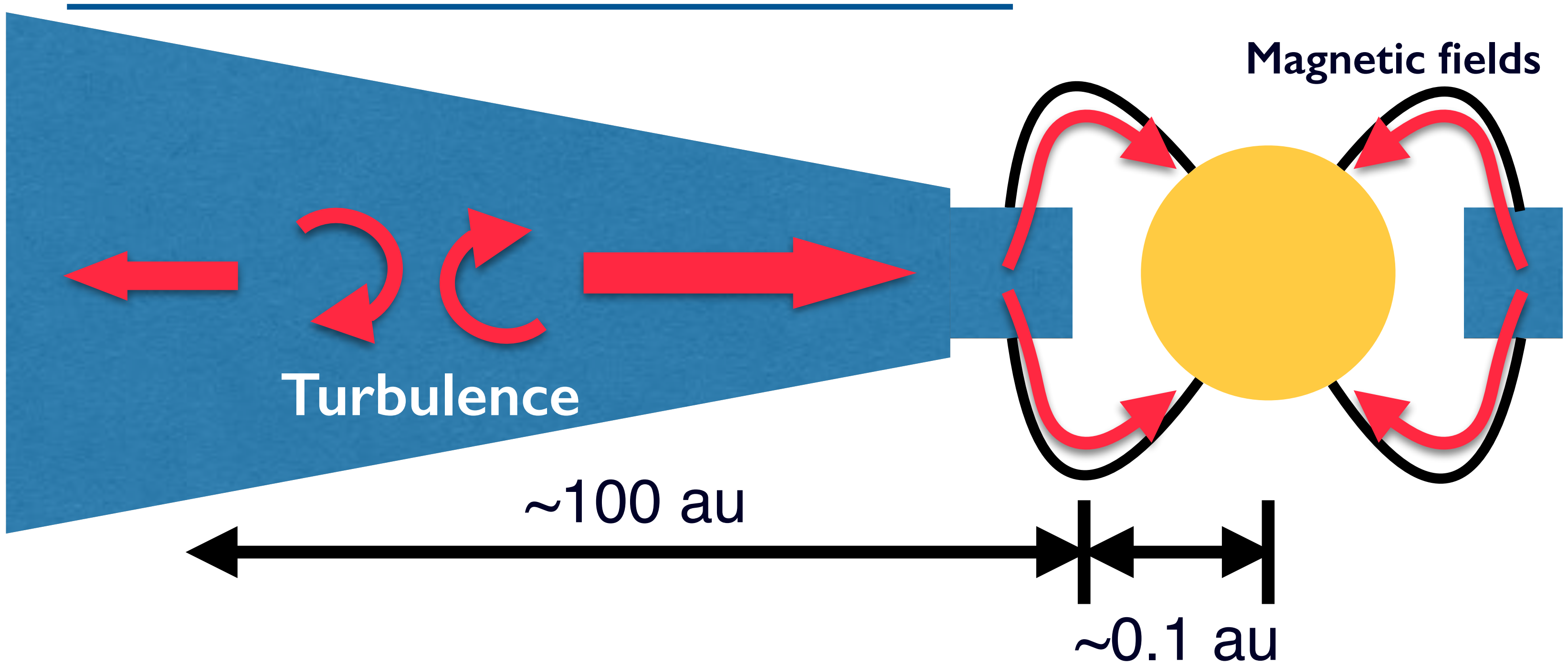
data from: Manara, Testi et al. 2017a, Manara, Fedele et al. 2016a, Alcala, Manara, Natta et al. 2014, 2017

Empty region compatible with internal photoevaporation?

Internal processes driving disk evolution

Viscous accretion

e.g., Lynden-Bell & Pringle 1974;
Hartmann et al. 1998



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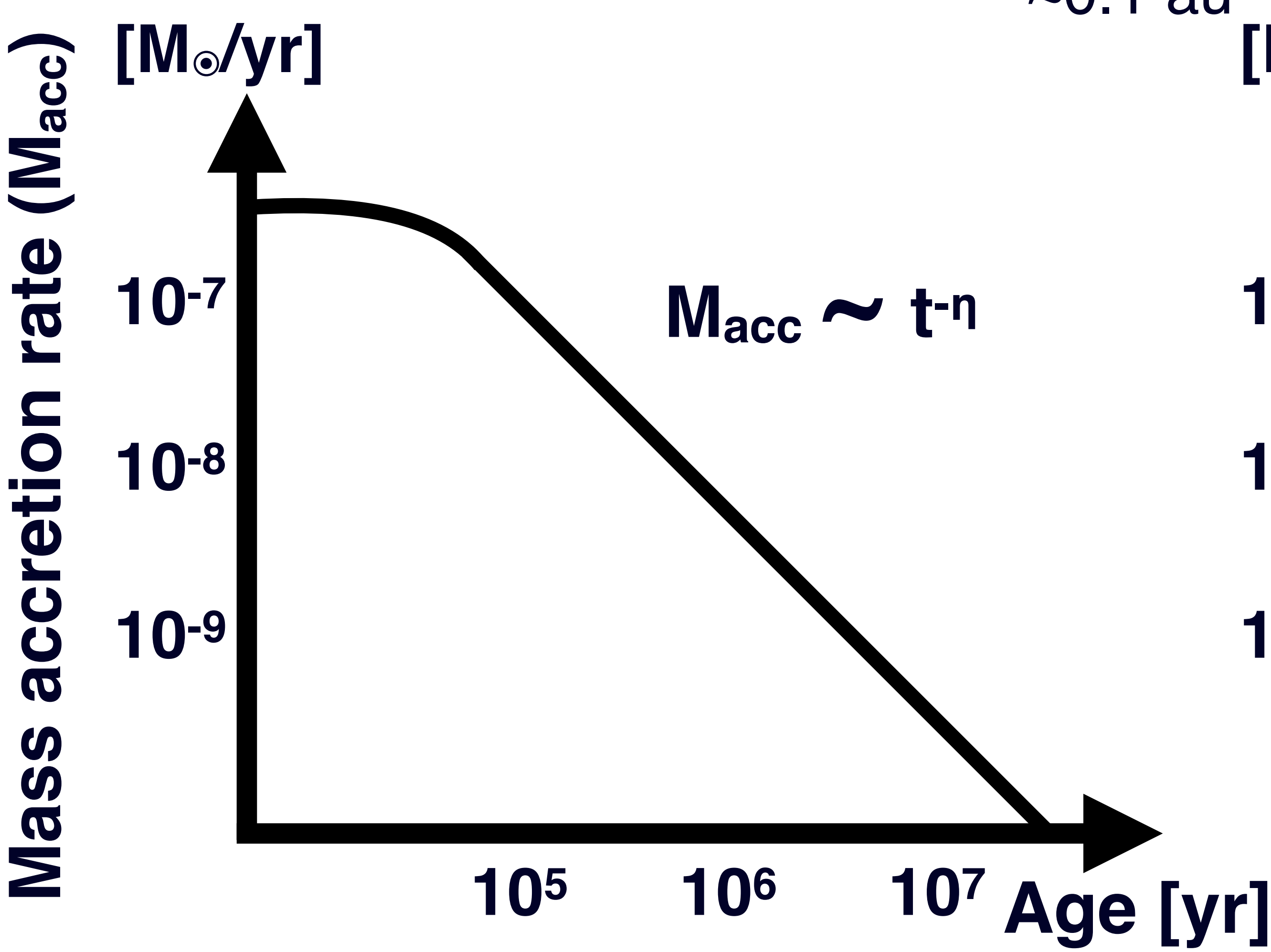
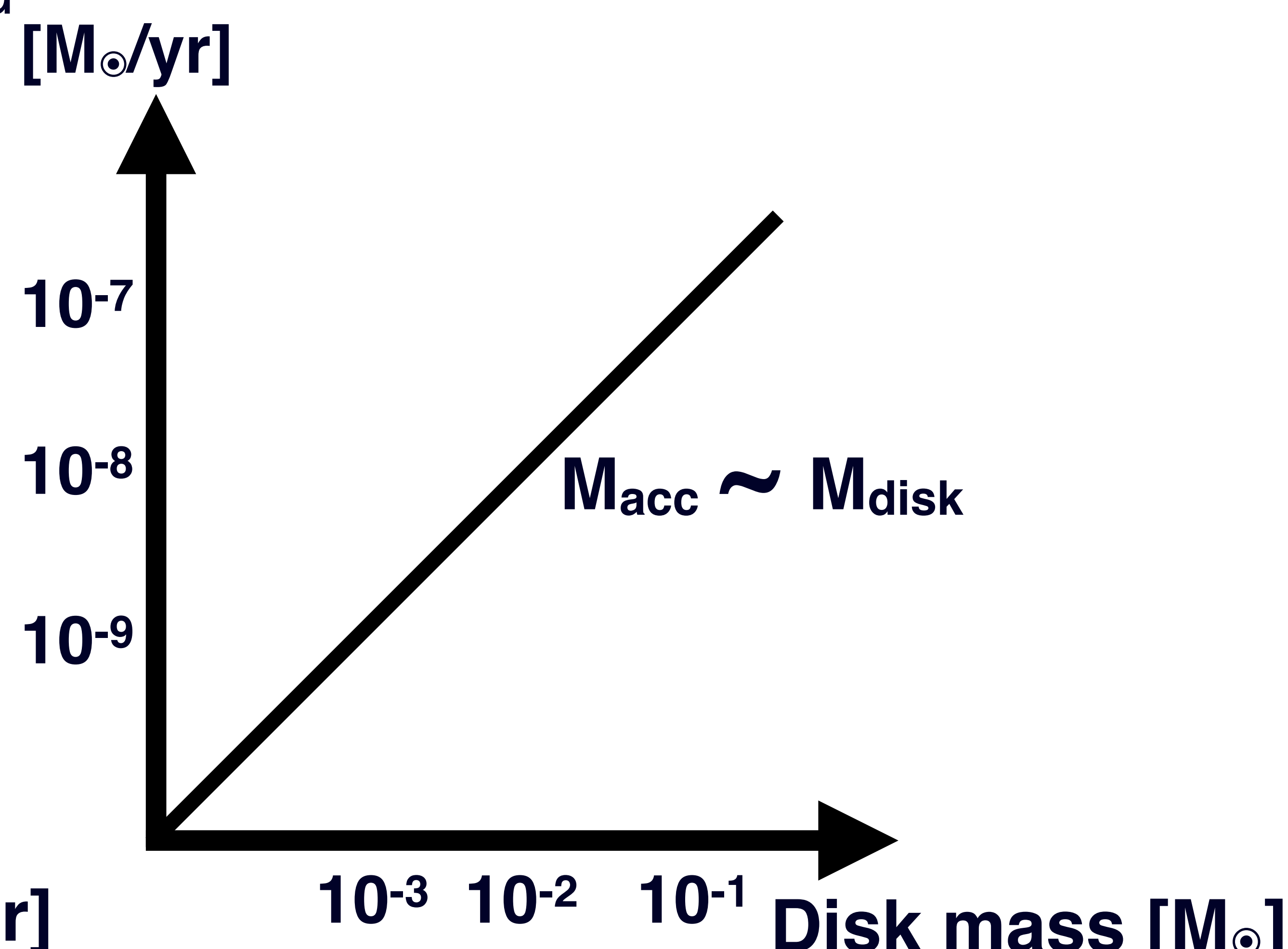
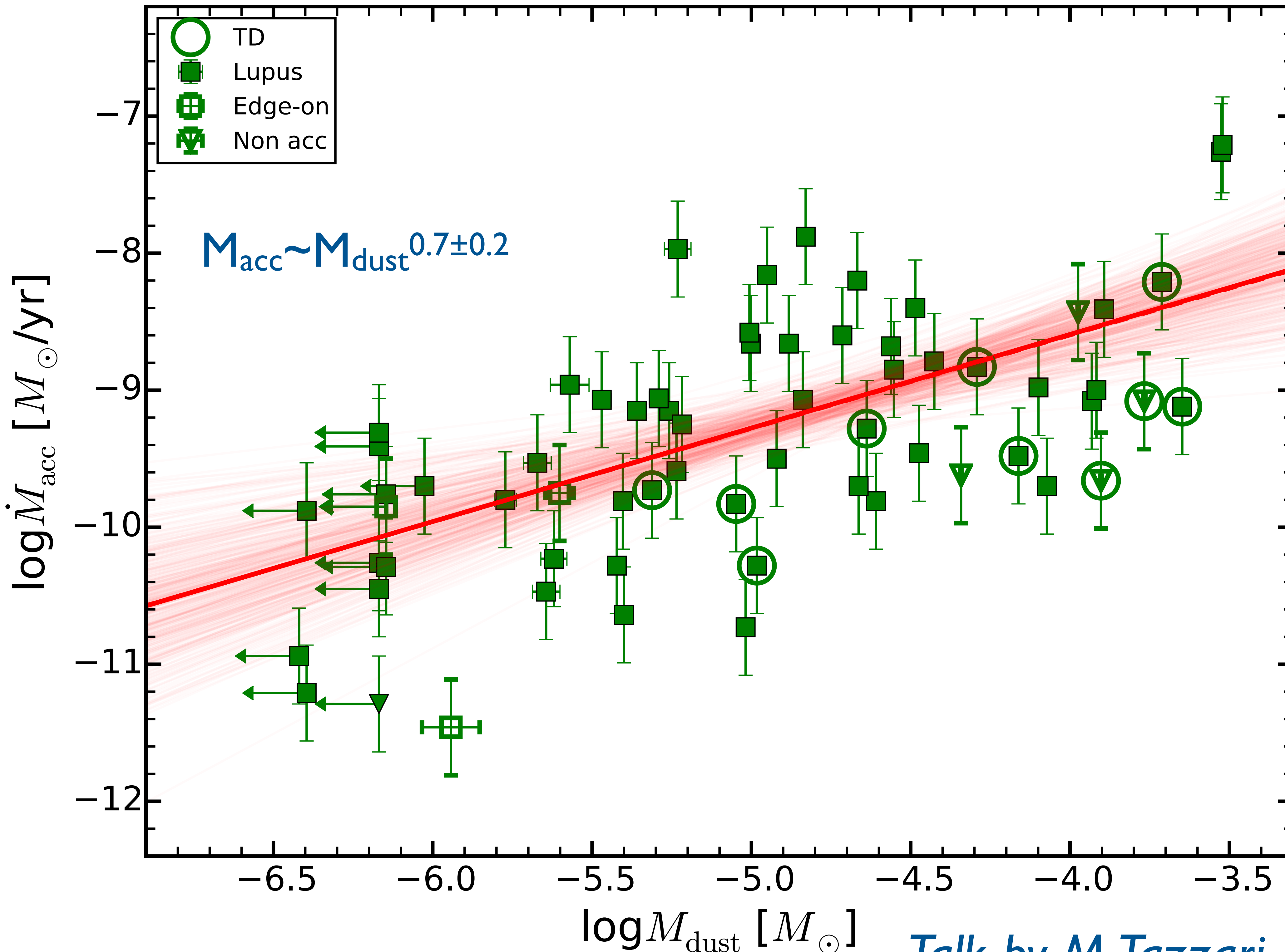




Accretion rates scale with (dust) disk mass

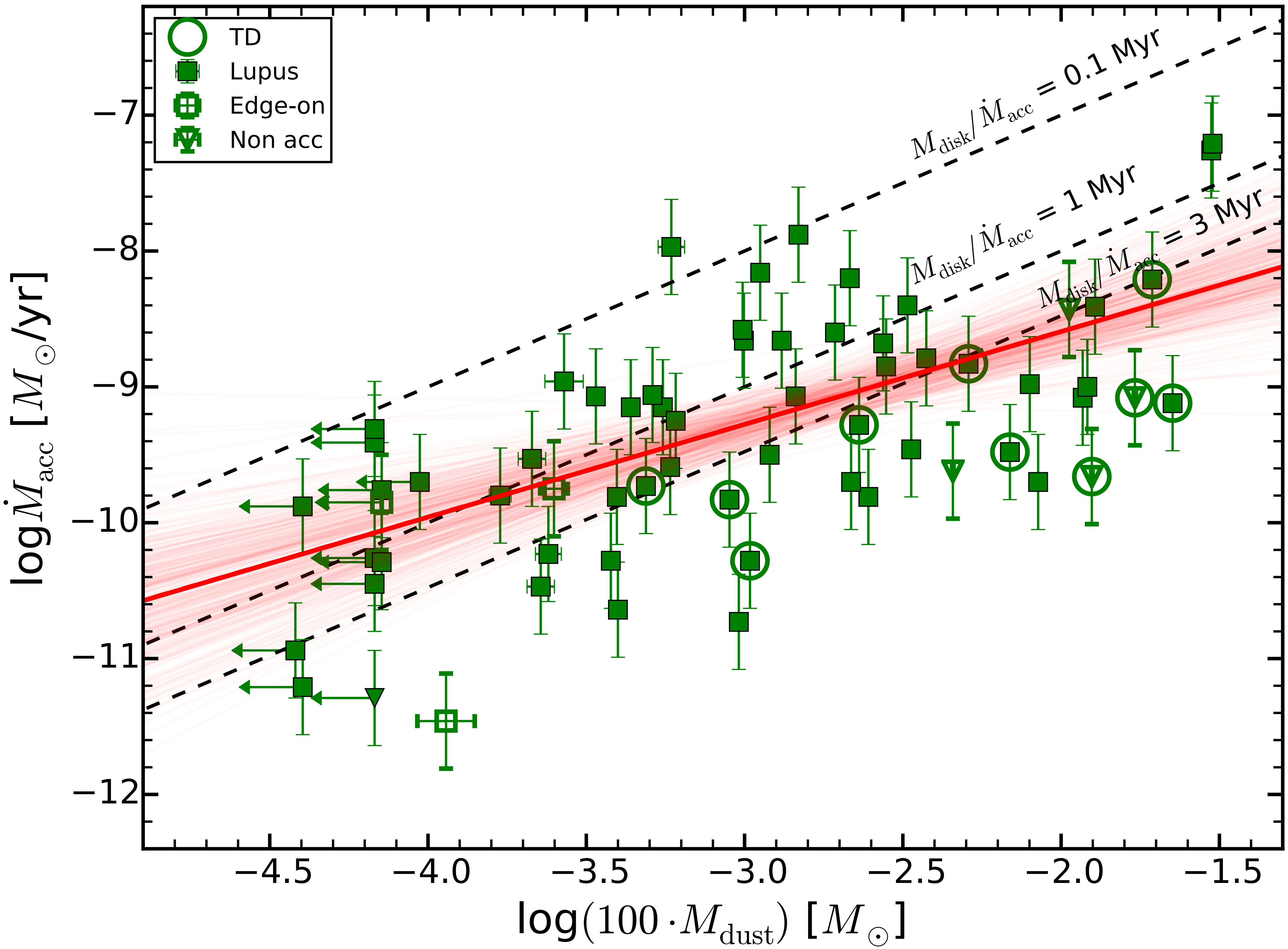


Manara, Rosotti, Testi, Natta et al. 2016b

Talk by M. Tazzari, A. Miotello

M_{acc} correlates ~linearly with M_{dust}, no correlation with M_{CO}

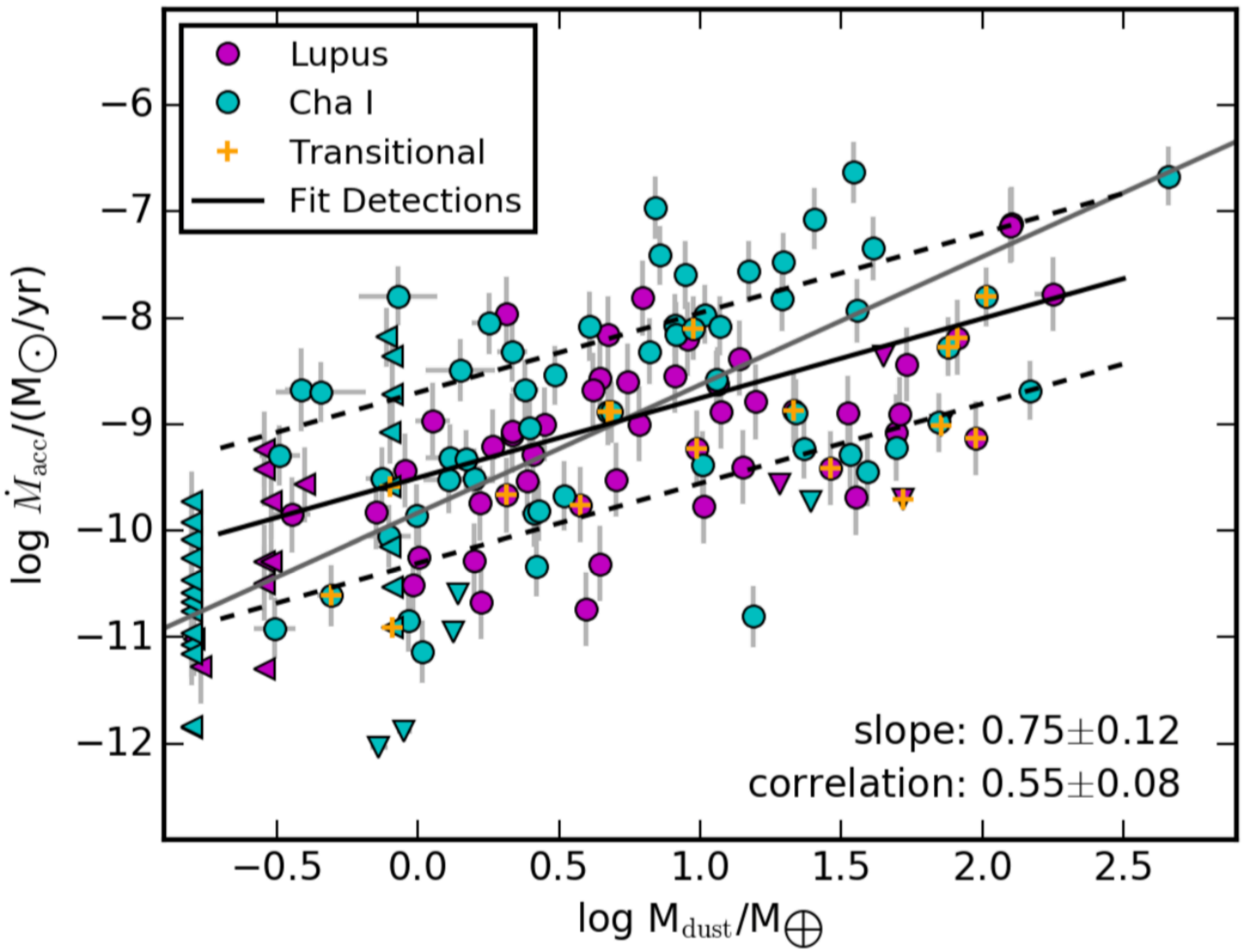
Accretion and outer disk mass



Manara, Rosotti, Testi, Natta et al. 2016b

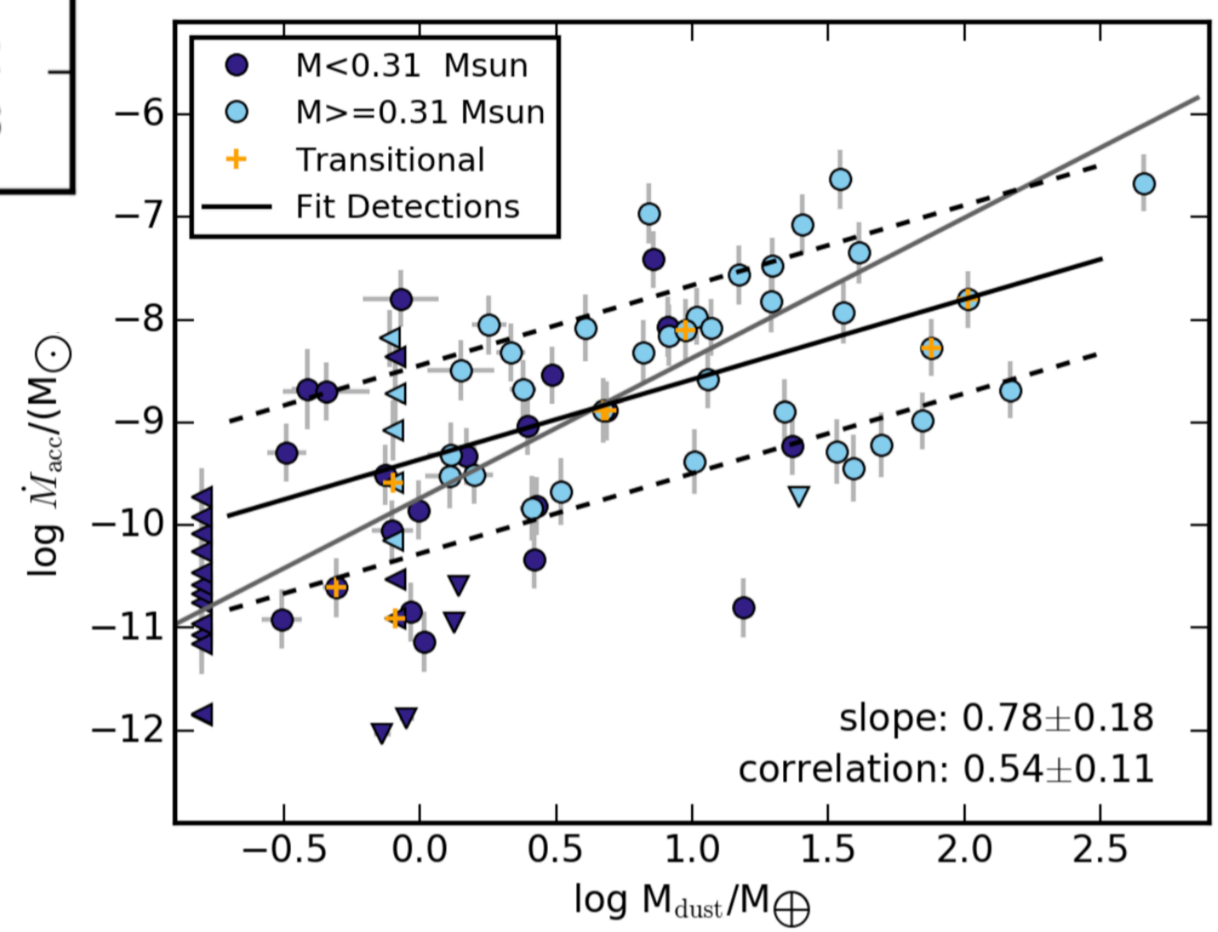
Using M_{dust} and a gas-to-dust ratio of 100 to get M_{disk}
the results are in general agreement with viscous evolution models

Accretion and outer disk mass



A similar result is obtained with the data in the Chamaeleon I region and combining the two datasets

(data from Manara et al. 2016a, 2017a; Pascucci et al. 2016; Alcala, Manara et al. 2014, 2016; Ansdell et al. 2016)

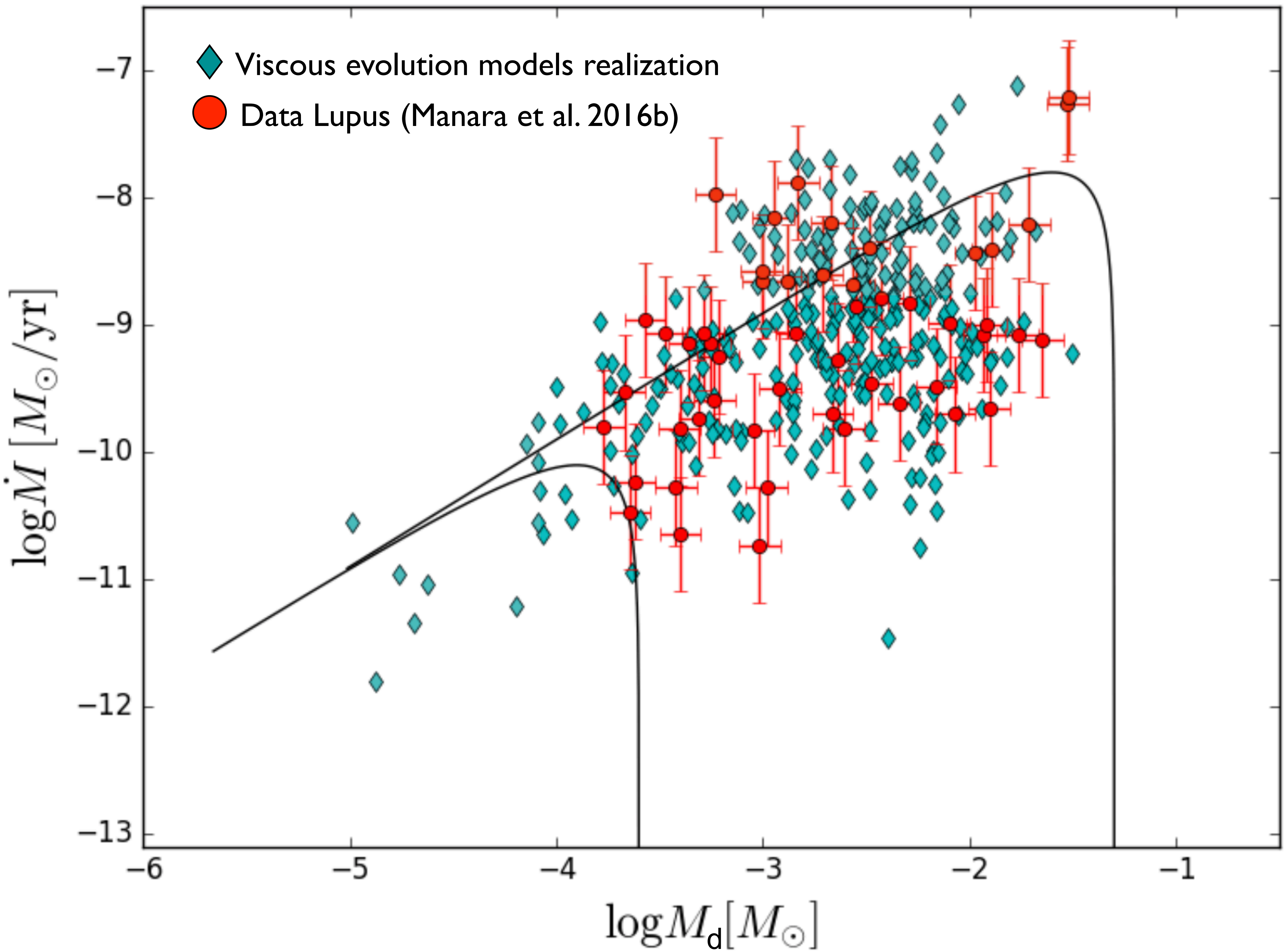


Observations support a ***correlation with the DUST mass*** that is ***compatible with linear***

Manara et al. 2016b

Mulders, Pascucci, Manara et al. 2017

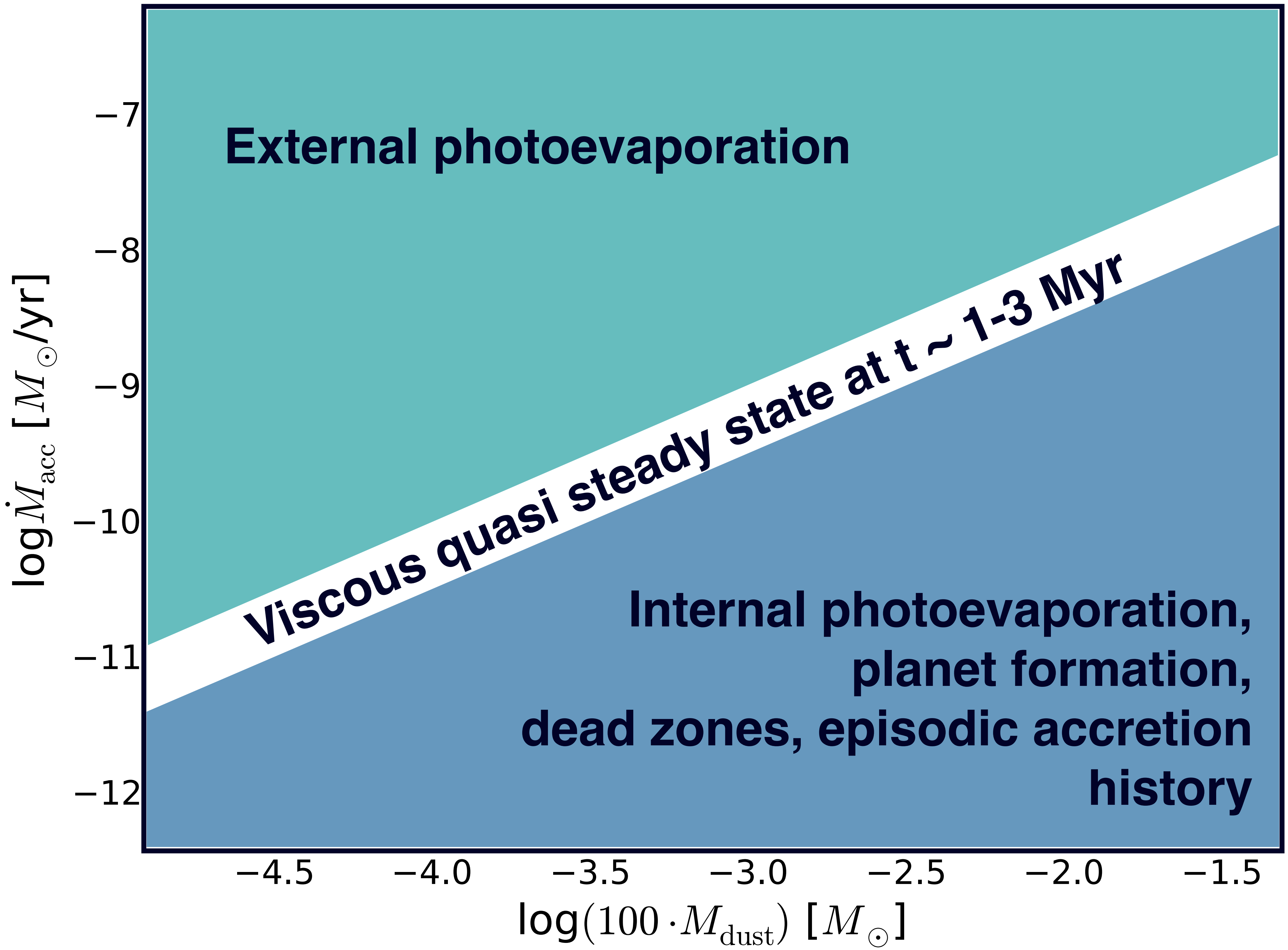
Can viscous evolution explain the observations?



Lodato, Scardoni, Manara, Testi 2017
Mulders, Pascucci, Manara et al. 2017

Yes, but only **IF** the viscous timescale is of the order of the age of the region (~1 Myr)

Mdisk/Macc as a proxy of disk evolution processes

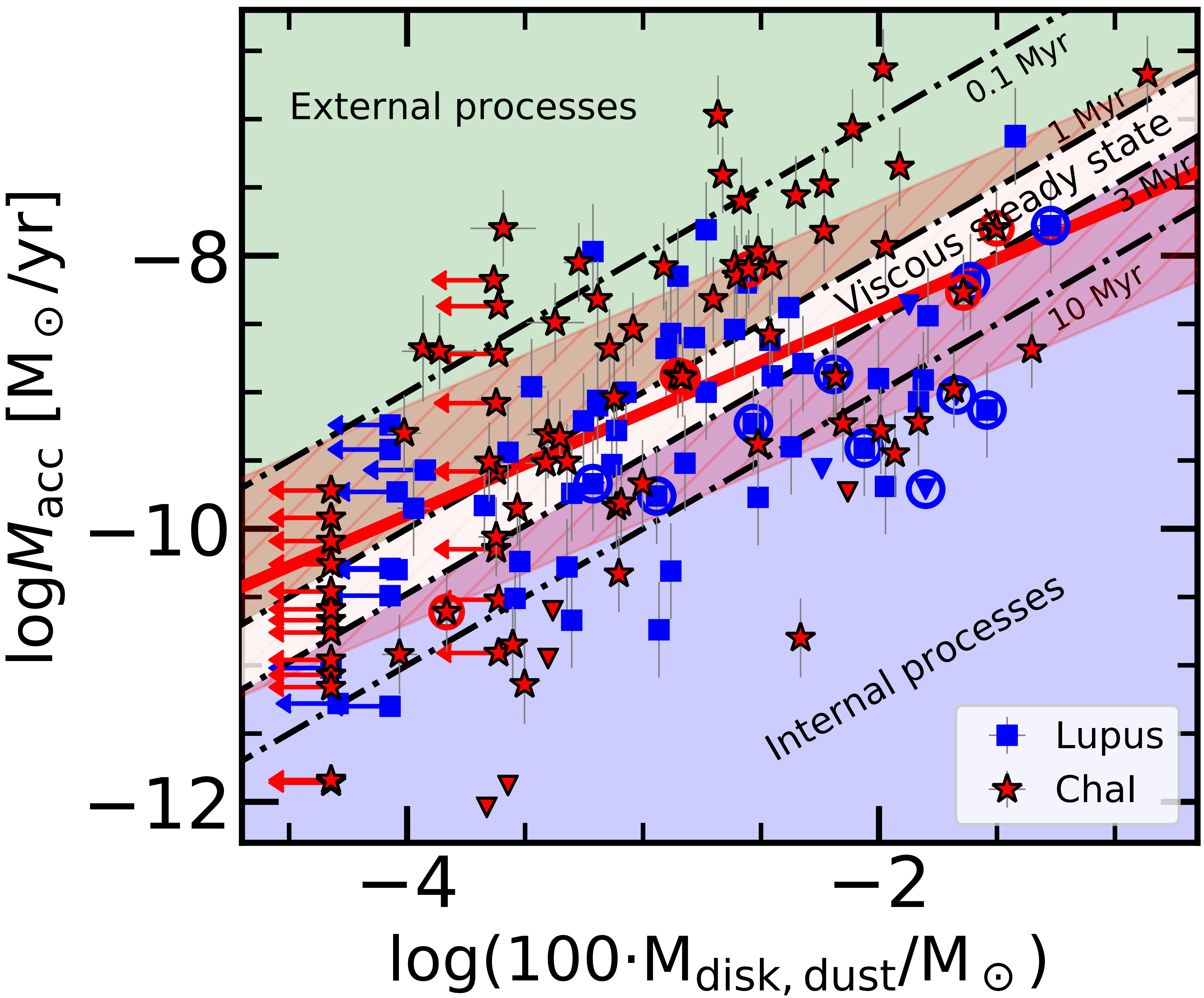


Rosotti, Clarke, Manara, Facchini 2017

Viscous models predict a **tight correlation** between mass accretion rates and disk masses

See also Hartmann et al. 1998, Jones et al. 2012, Lodato et al. 2017

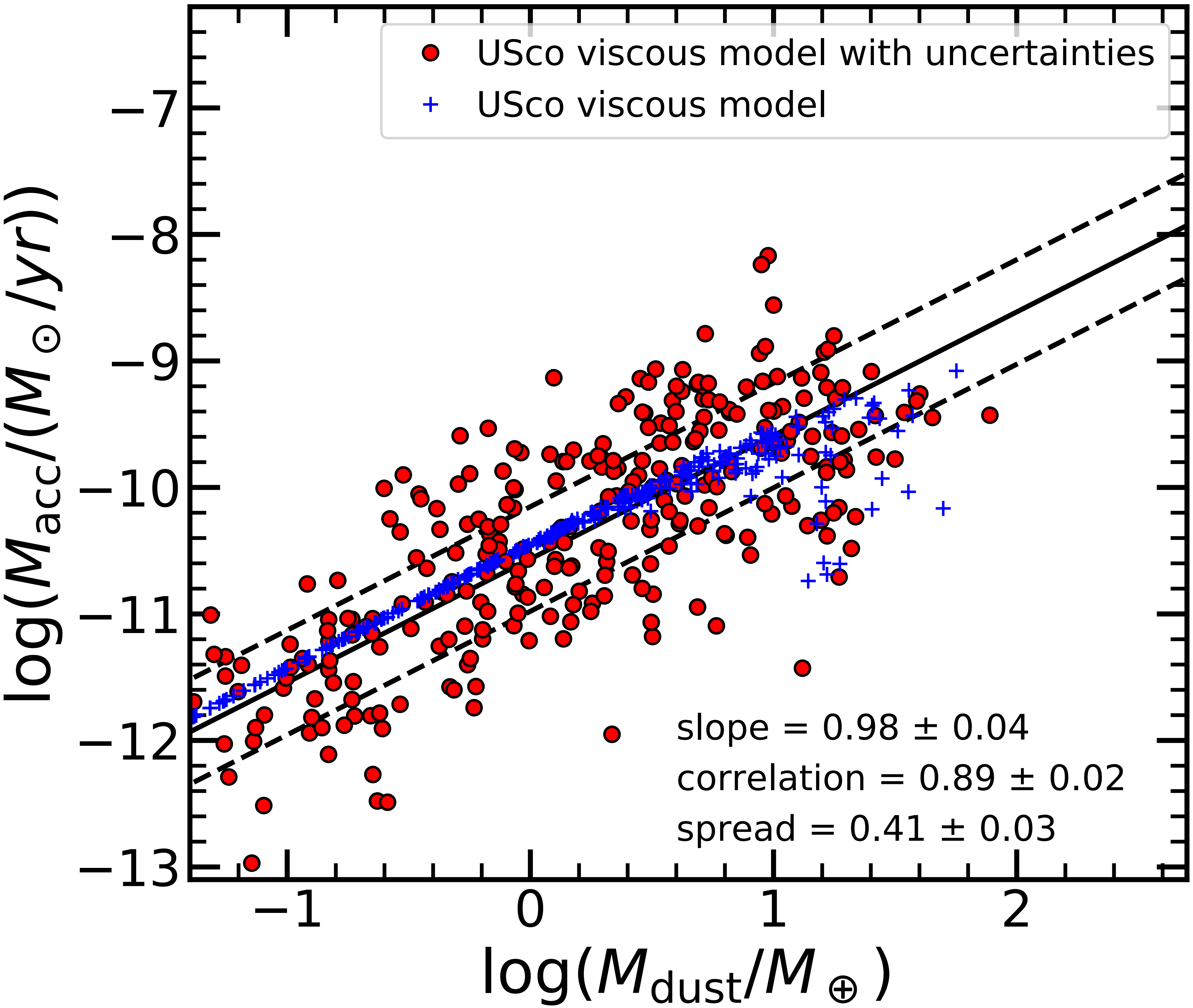
Mdisk/Macc as a proxy of disk evolution processes



Manara, Rosotti, Testi, Natta et al. 2016b
Rosotti, Clarke, Manara, Facchini 2017
Mulders, Pascucci, Manara et al. 2017
Lodato, Scardoni, Manara et al. 2017

To be tested with objects at different AGES and evolutionary stages
⇒ input for disk evolution, planet migration and formation models

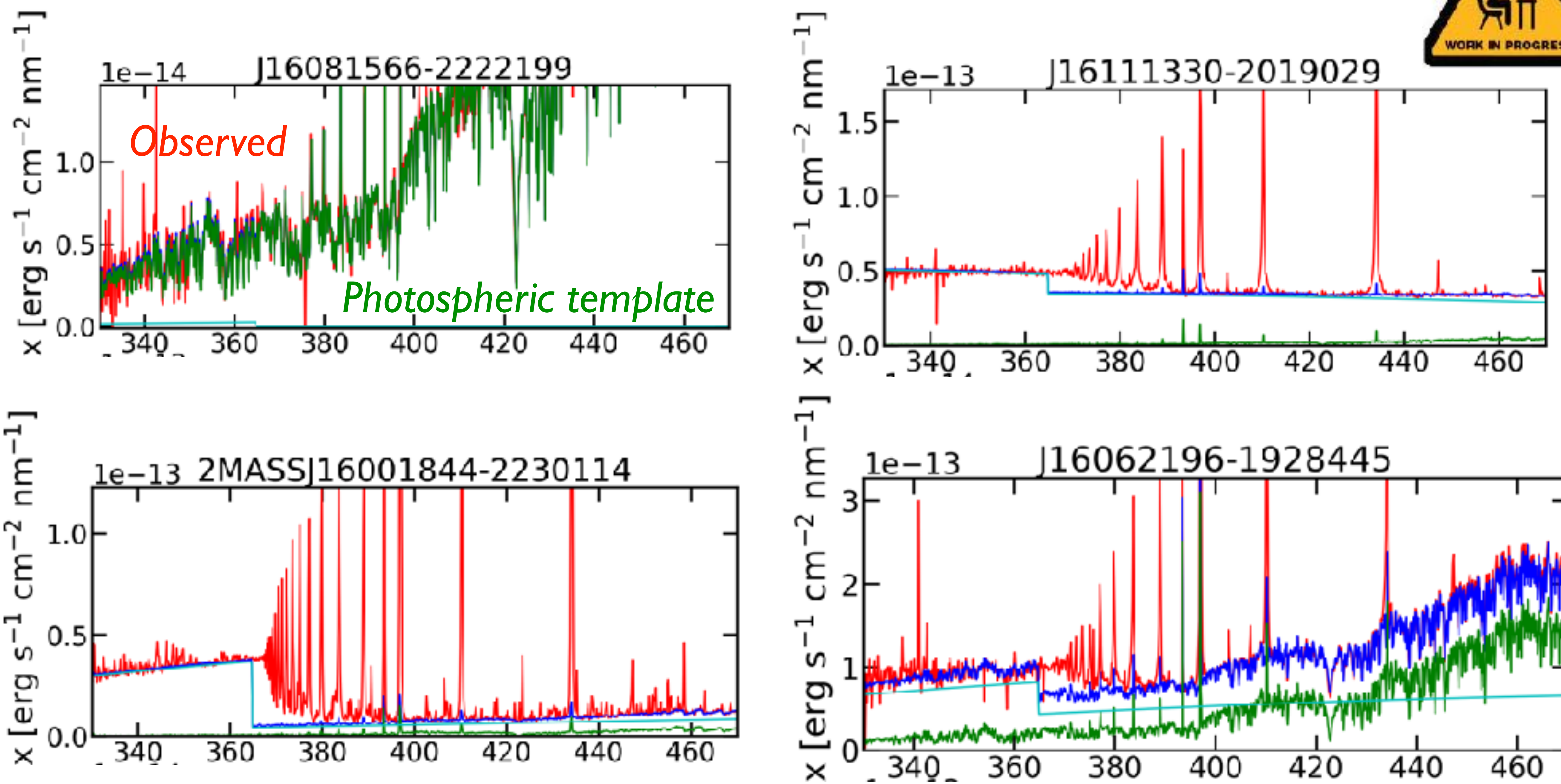
How does the Macc/Mdisk relation looks at 10 Myr?



P101 succesfull proposal, PI Manara

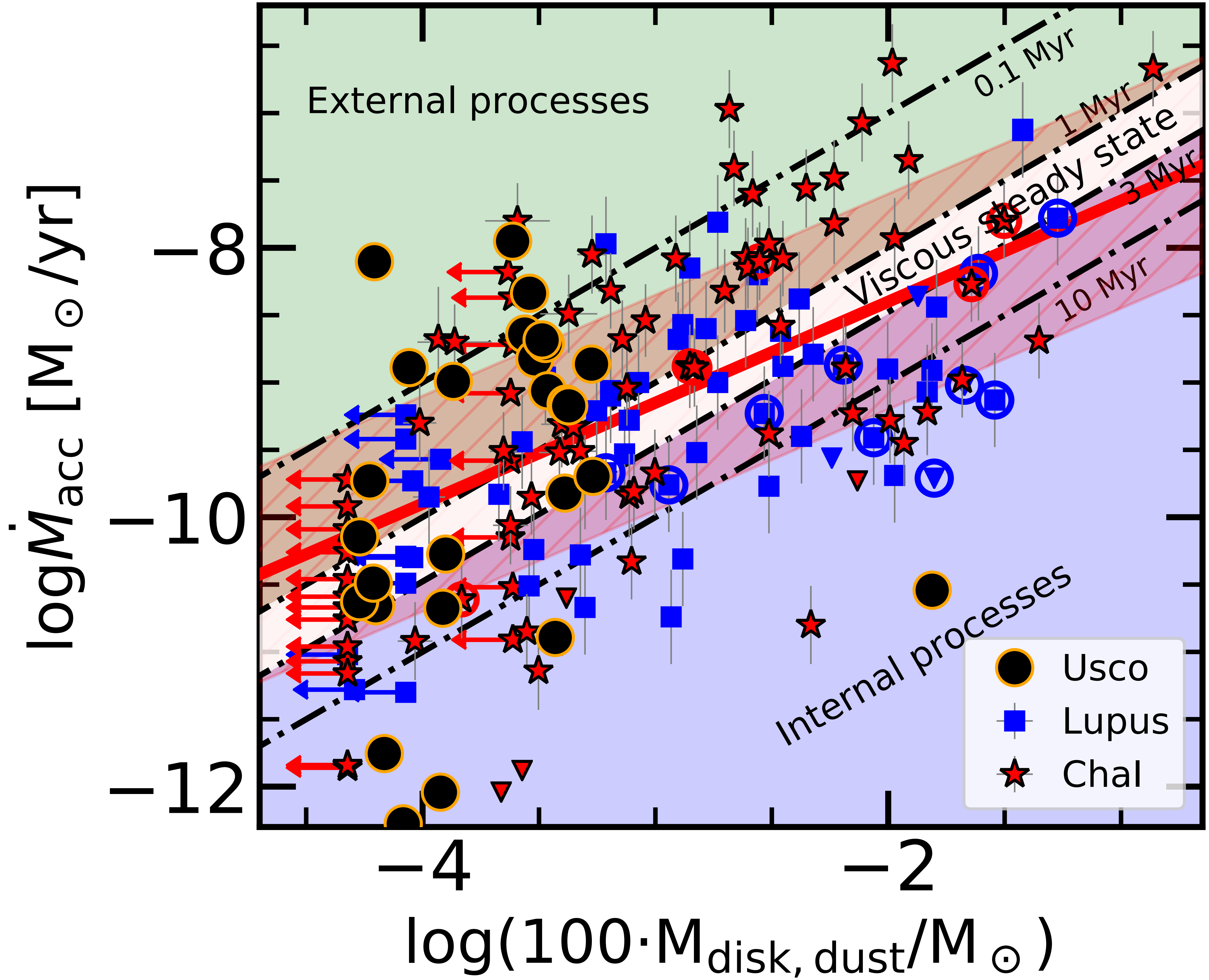
To be tested in Upper Scorpius, VLT/X-Shooter visitor run May 19-20 2018

Examples of Balmer excess in Upper Scorpius



There are strong accretors in Upper Scorpius (5-11 Myr old)!!!

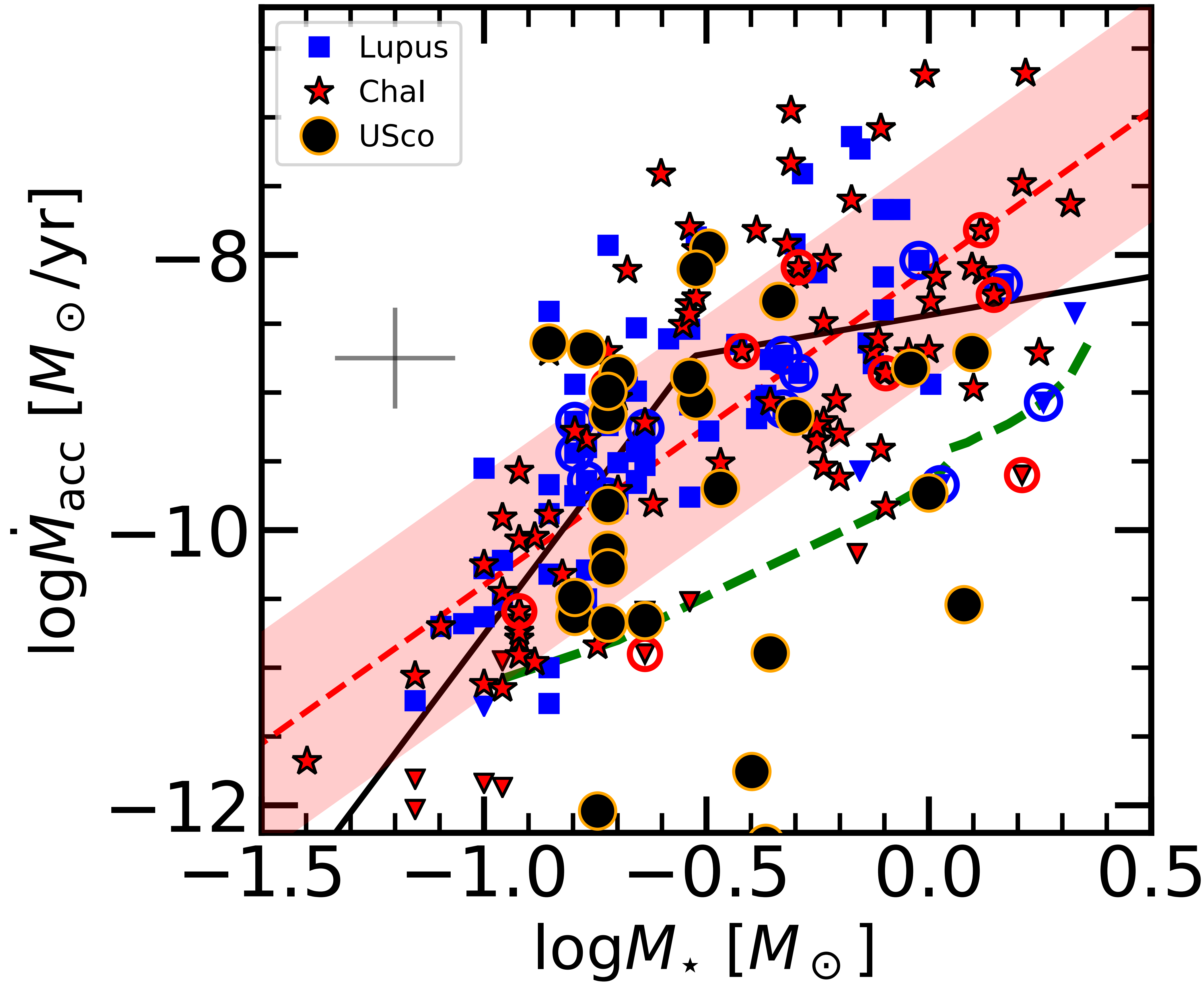
Initial results in the 5-10 Myr old Upper Scorpius region



Manara et al. in prep

Still large spread, and several strongly accreting disks!

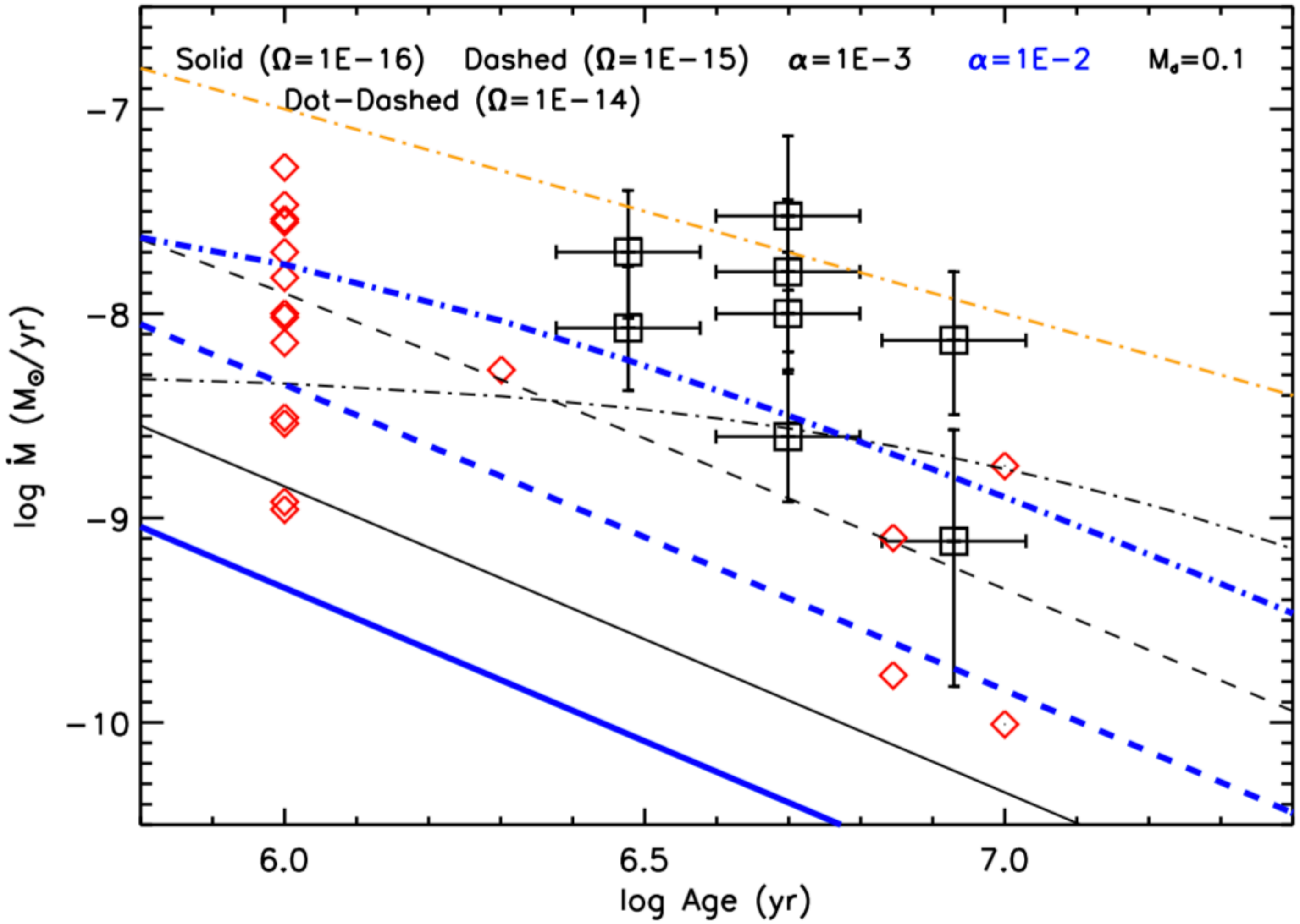
Initial results in the 5-10 Myr old Upper Scorpius region



Manara et al. in prep

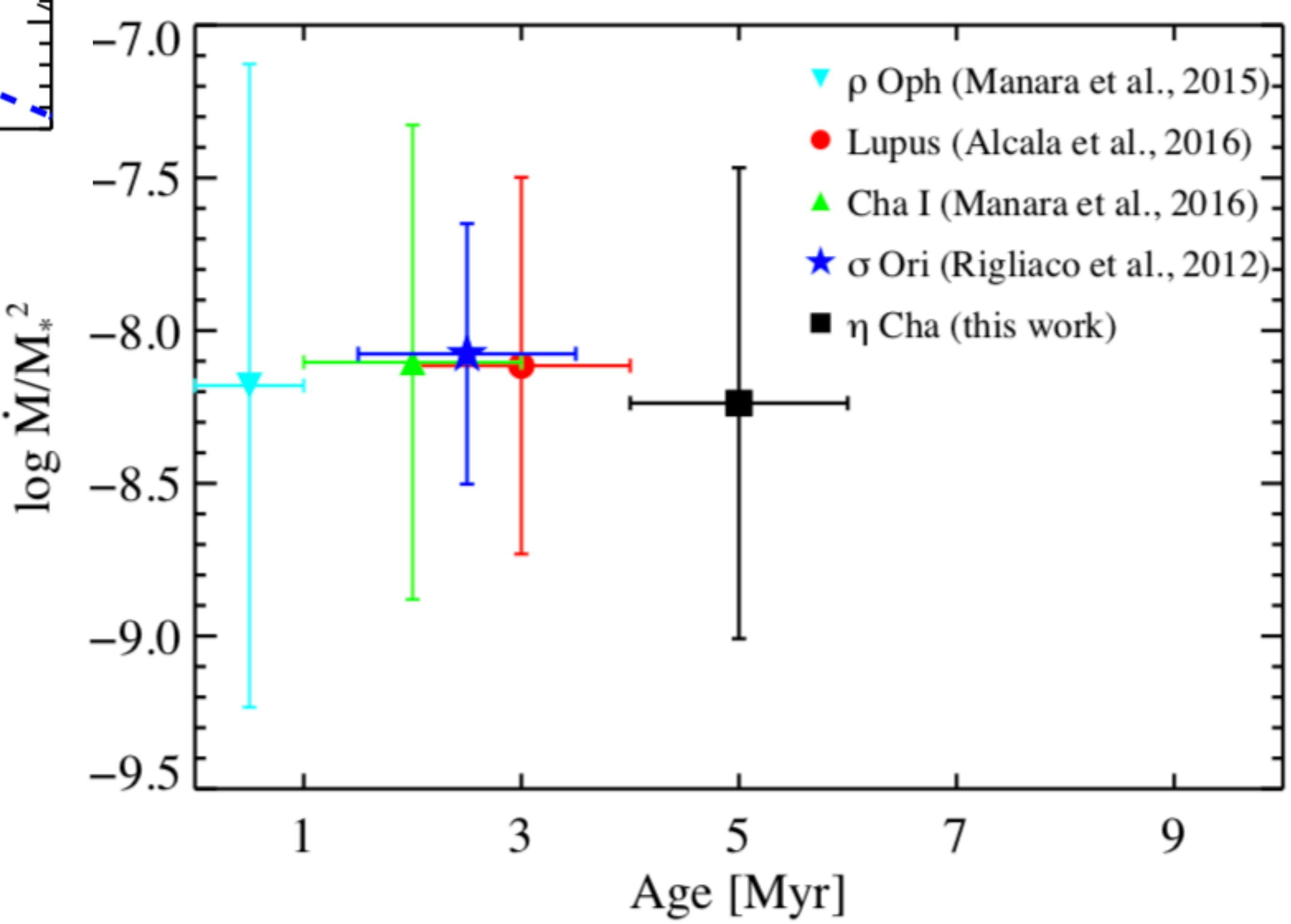
Most of the accreting objects follow the same distribution as the younger ones

Initial data on old and strongly accreting objects



Ingleby et al. 2014

Rugel, Fedele, Herczeg 2017



There are STRONG accretors at 10 Myr!!!

Talk L.Venuti for more

TAKE HOME

1 BIMODAL distribution of M_{acc} vs M_{star} at all ages, and with a large spread of values.

2 M_{acc} scales linearly with M_{dust}, but with a large scatter, even at older (???) ages. Ruling out viscous evolution?

Carlo Felice Manara (ESO Fellow)

15–19 October 2018

ESO HQ, Garching bei München, Germany

https://www.eso.org/sci/meetings/2018/tcl2018.html

TAKE A CLOSER LOOK

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Barbara Ercolano	(LMU Munich, Germany)
Bruno Lopez	(OCA Nice, France)
Antonella Natta	(DIAS Dublin, Ireland)

Main Topics

Close-in exoplanets | Inner regions of protoplanetary discs | Disc-star interaction | Evolution of protoplanetary