The intense life and fast dispersal of ~~proto-planetary discs~~ astronomers

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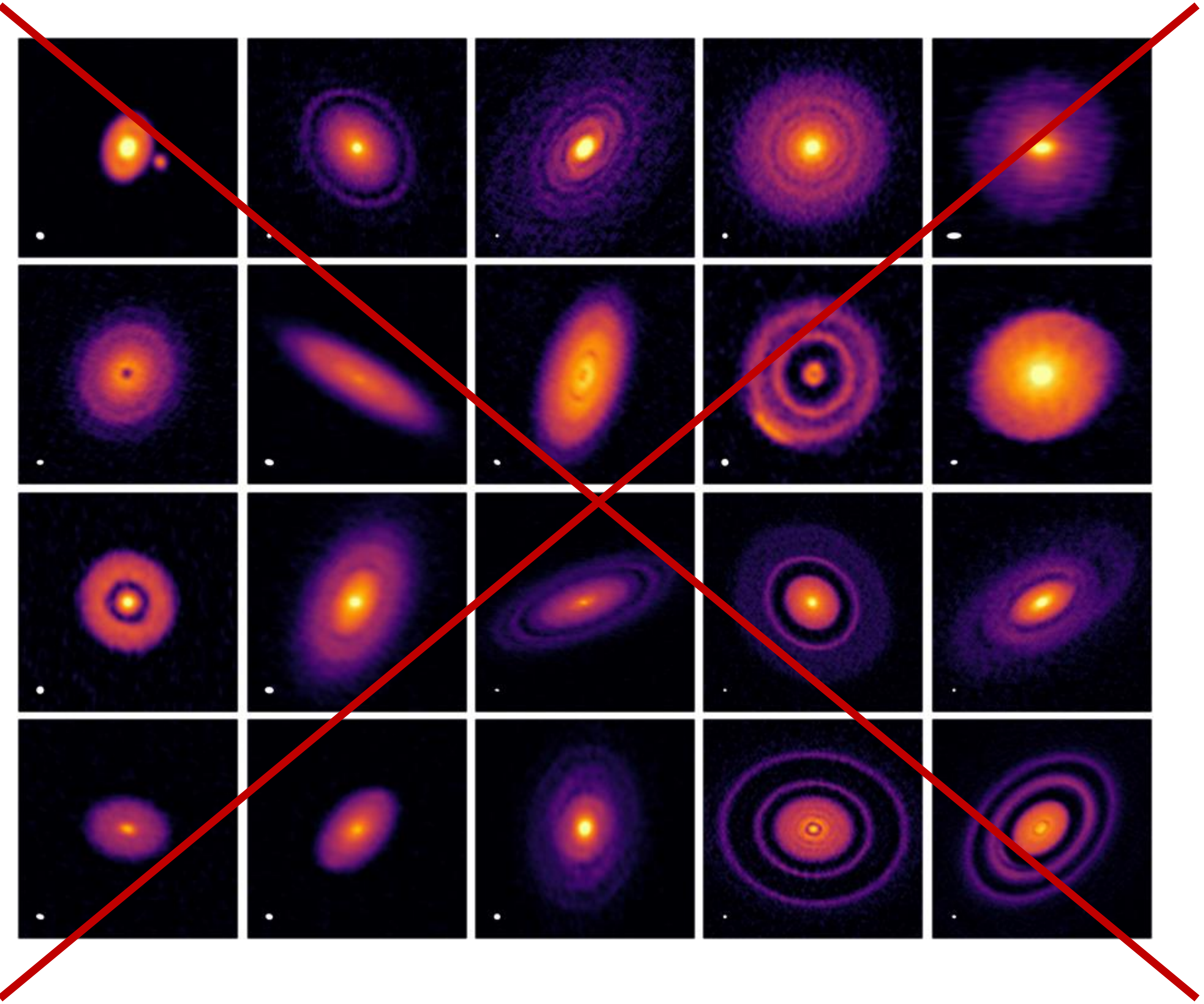
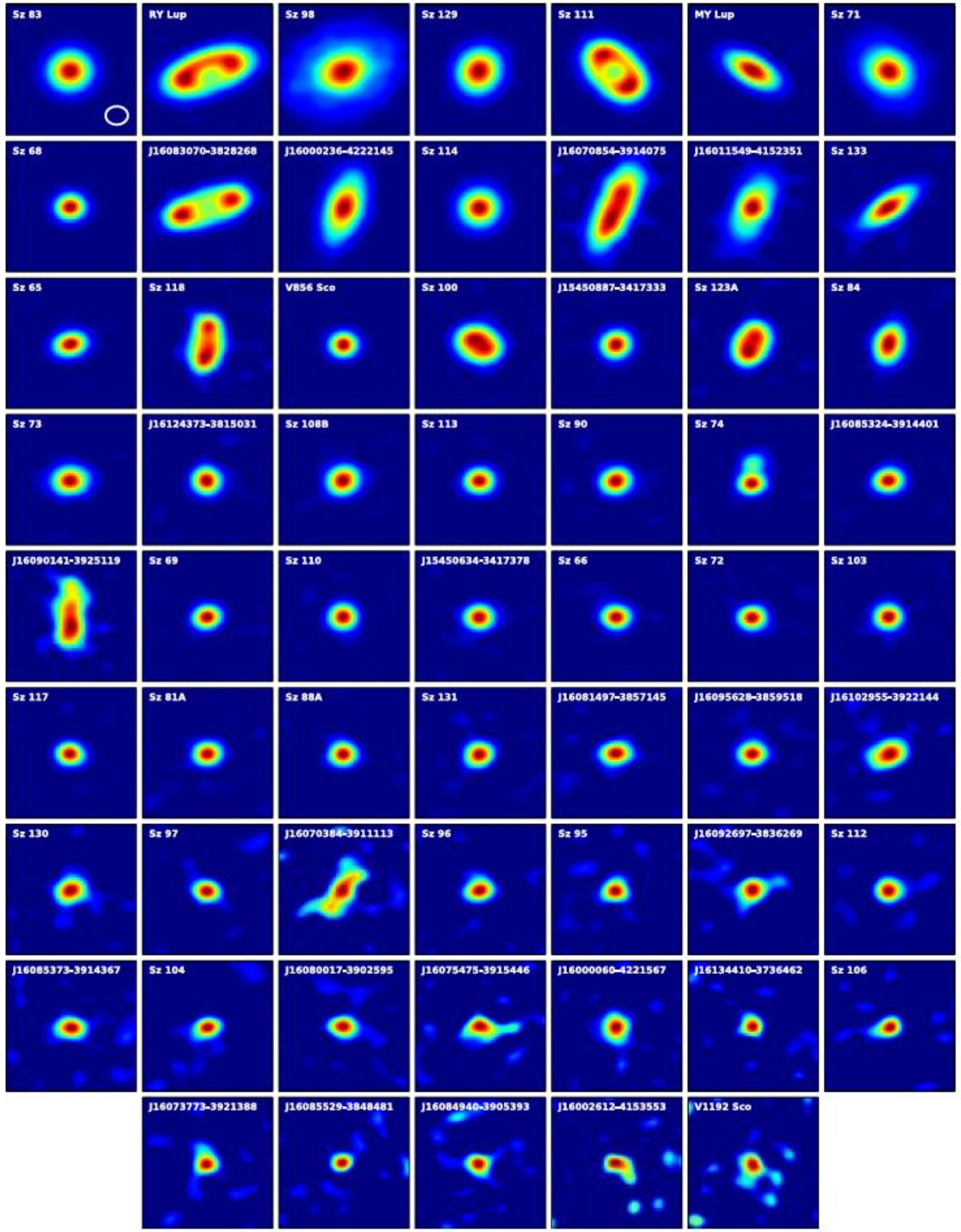
NWO
Veni, Vidi, Vici

An intense life…





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Sz 65
Sz 118
V856 Sco
Sz 100
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Sz 123A
Sz 84
Sz 73
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Sz 108B
Sz 113
Sz 90
Sz 74
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J16090141-3925119
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Sz 72
Sz 103
Sz 117
Sz 81A
Sz 88A
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J16085373-3914367
Sz 104
J16080017-3902595
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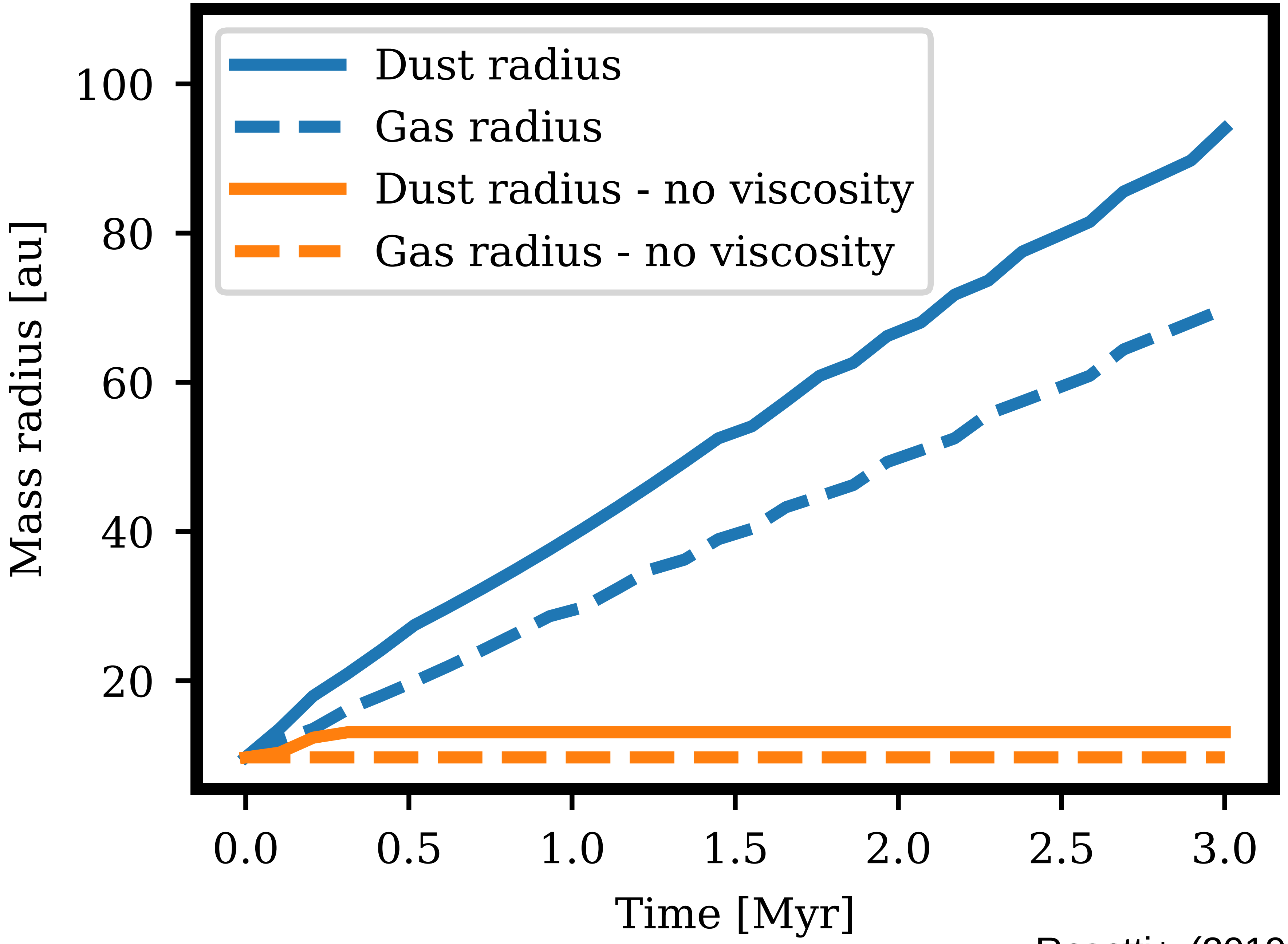
Sz 106
J16073773-3921388
J16085529-3848481
J16084940-3905393
J16002612-4153553
V1192 Sco

Discs get larger…

Lots of small discs

What exactly are we measuring?

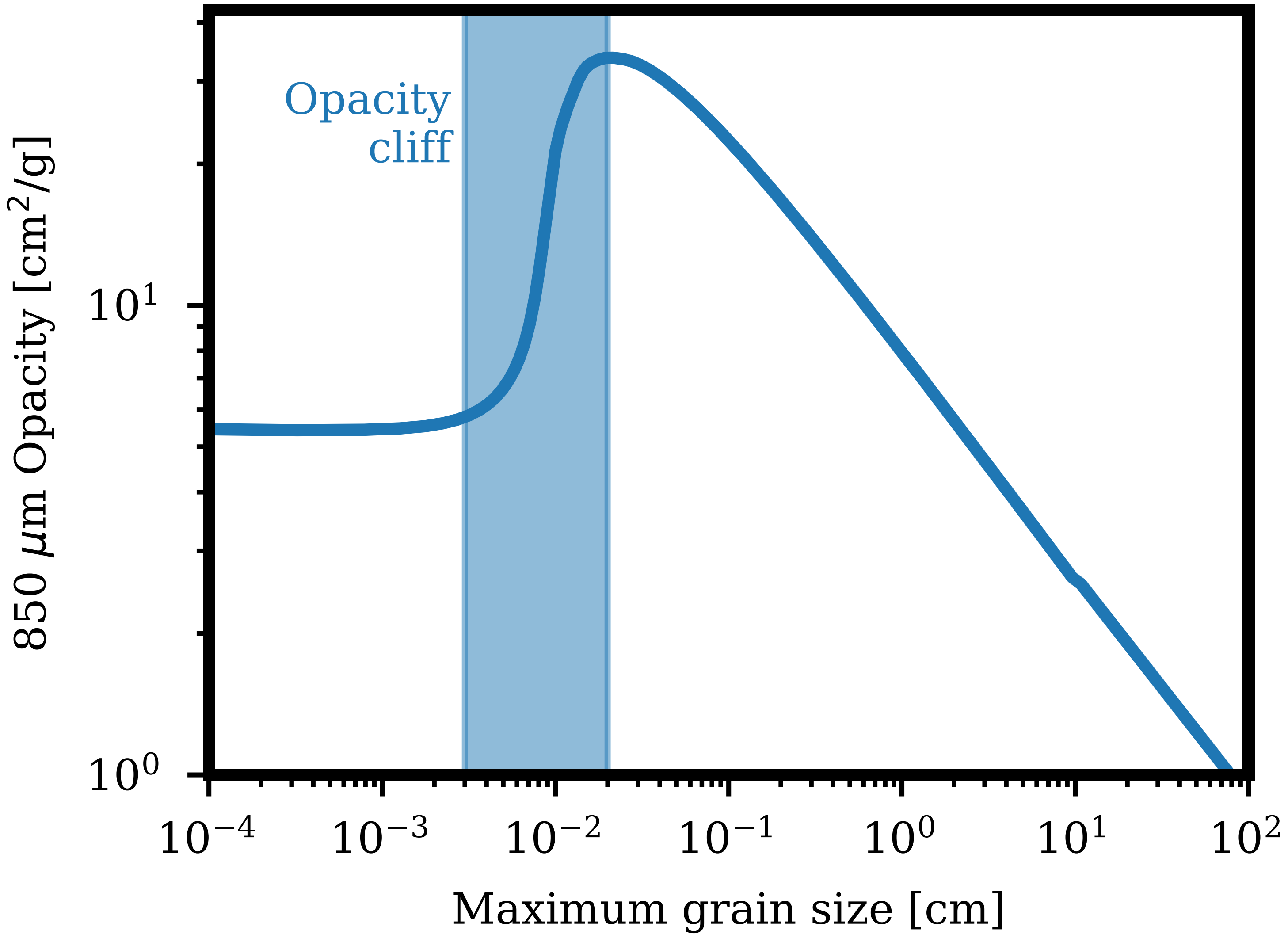
How do they evolve in time?

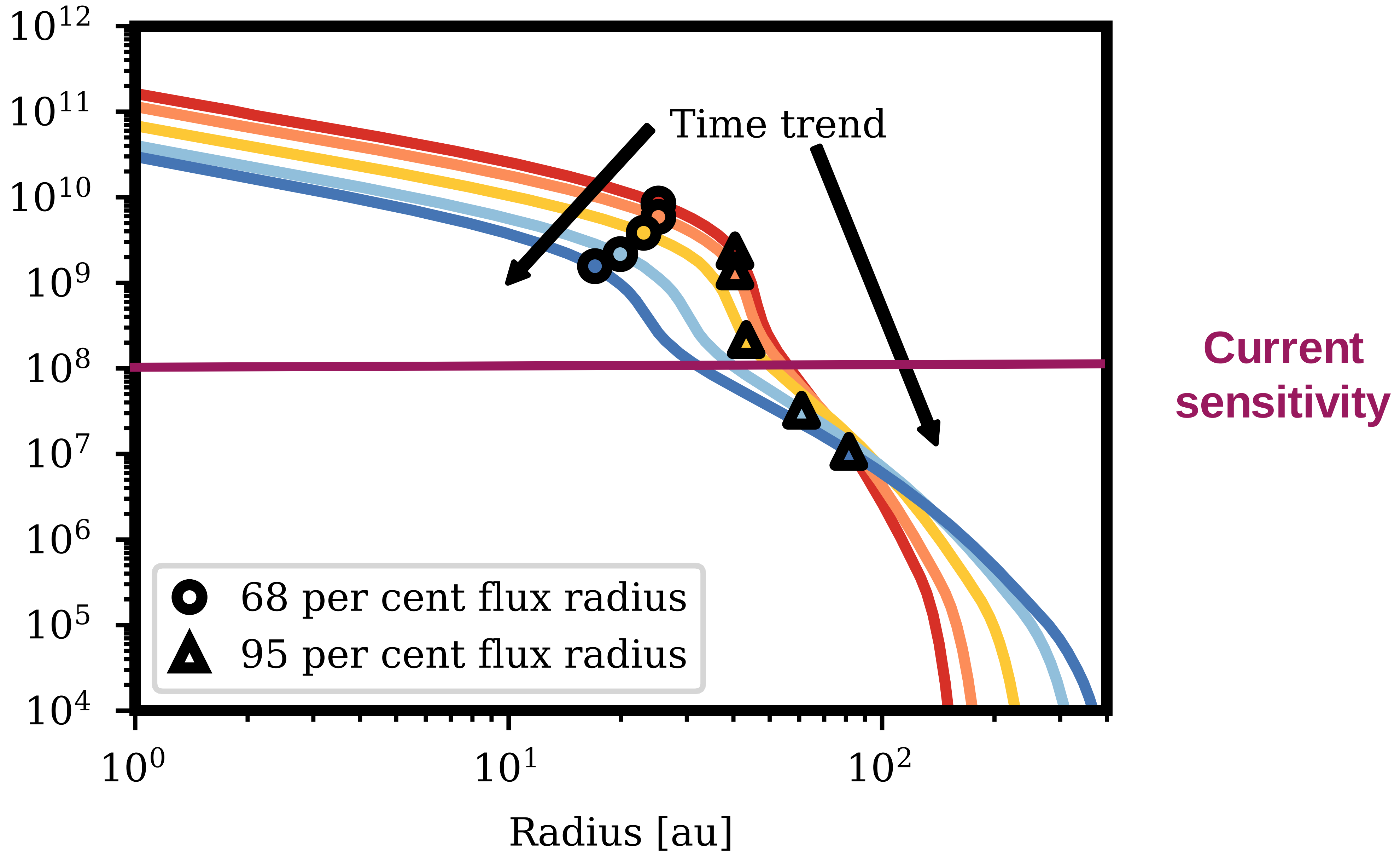


Rosotti+ (2019a)

Viscous spreading (if present) “wins” over radial drift

…but they look smaller!

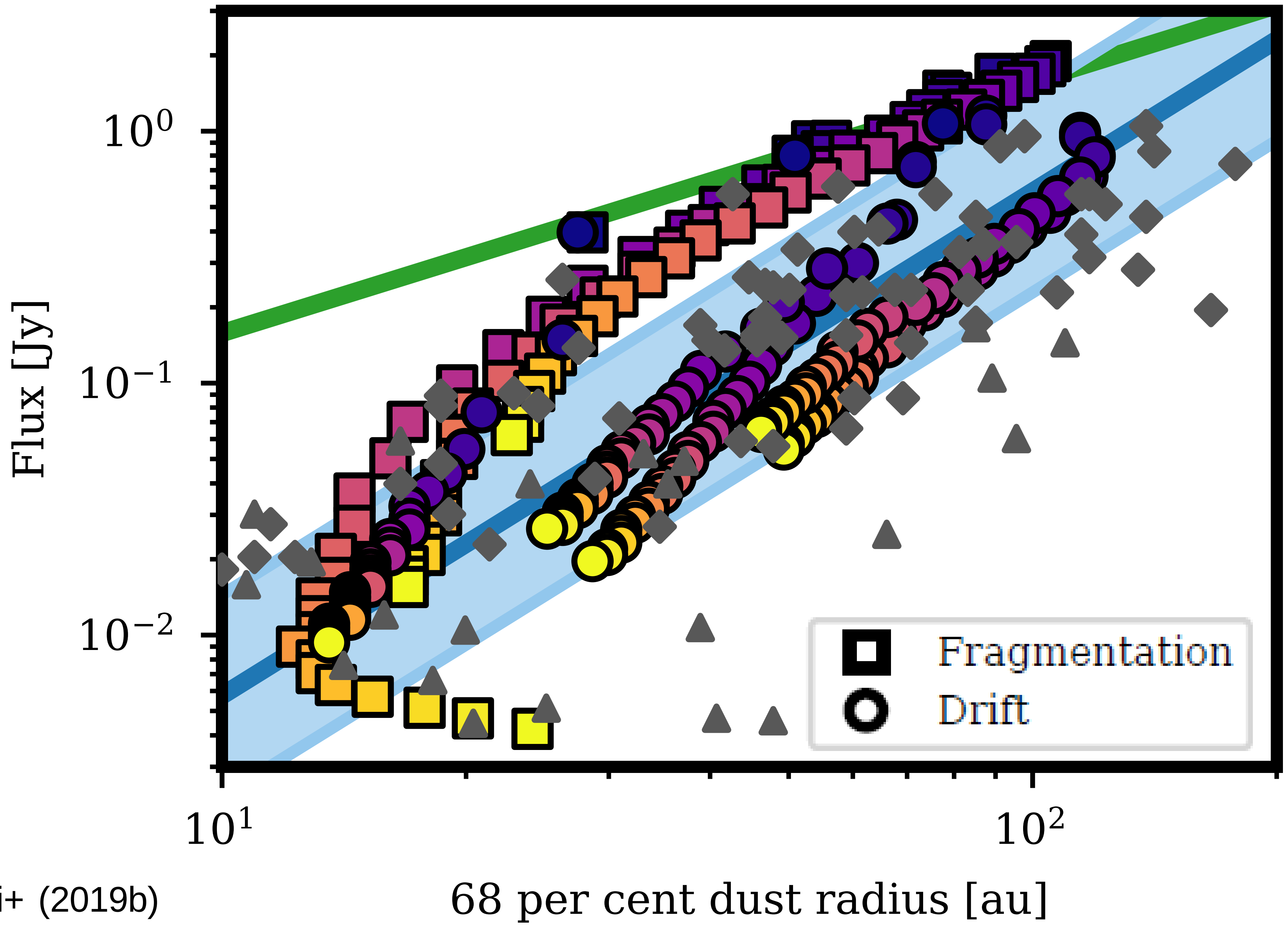




Rosotti+ (2019a)

Small grains are invisible – cannot see the whole disc

Flux-radius relation



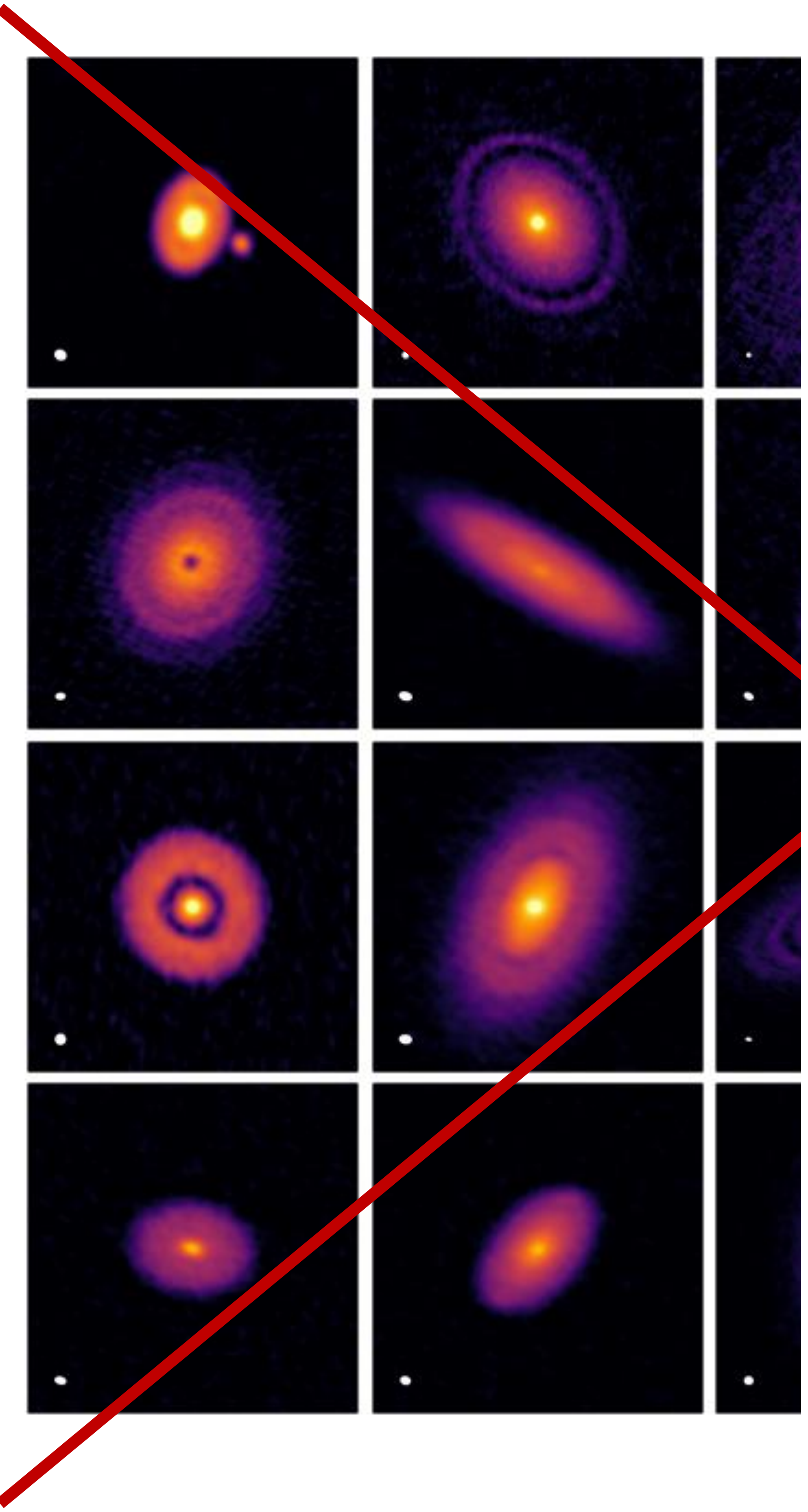
Rosotti+ (2019b)

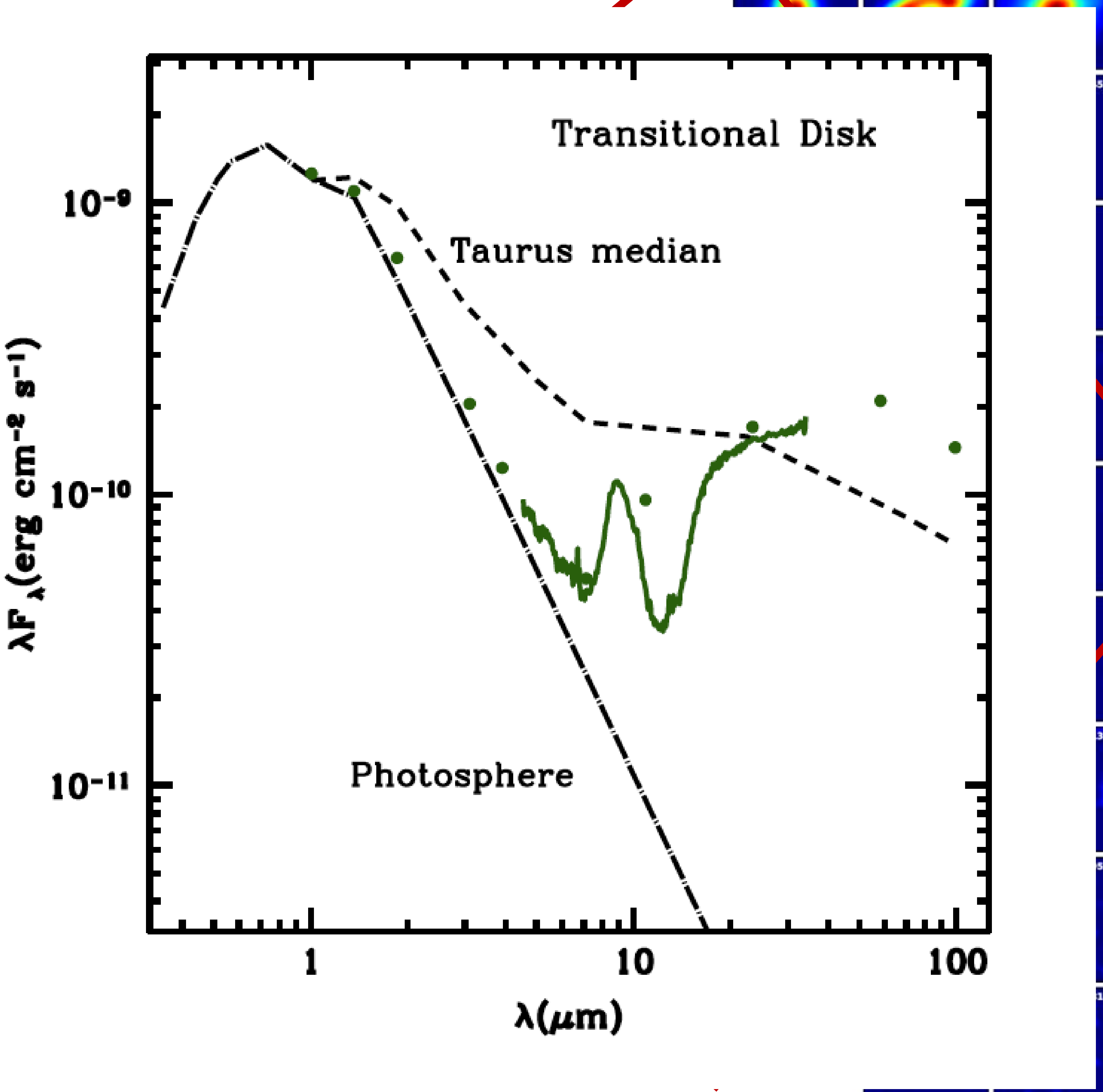
Data from Tripathi (2017), Andrews (2018)

Data points to drift-dominated regime: $\alpha \leq 10^{-3}$

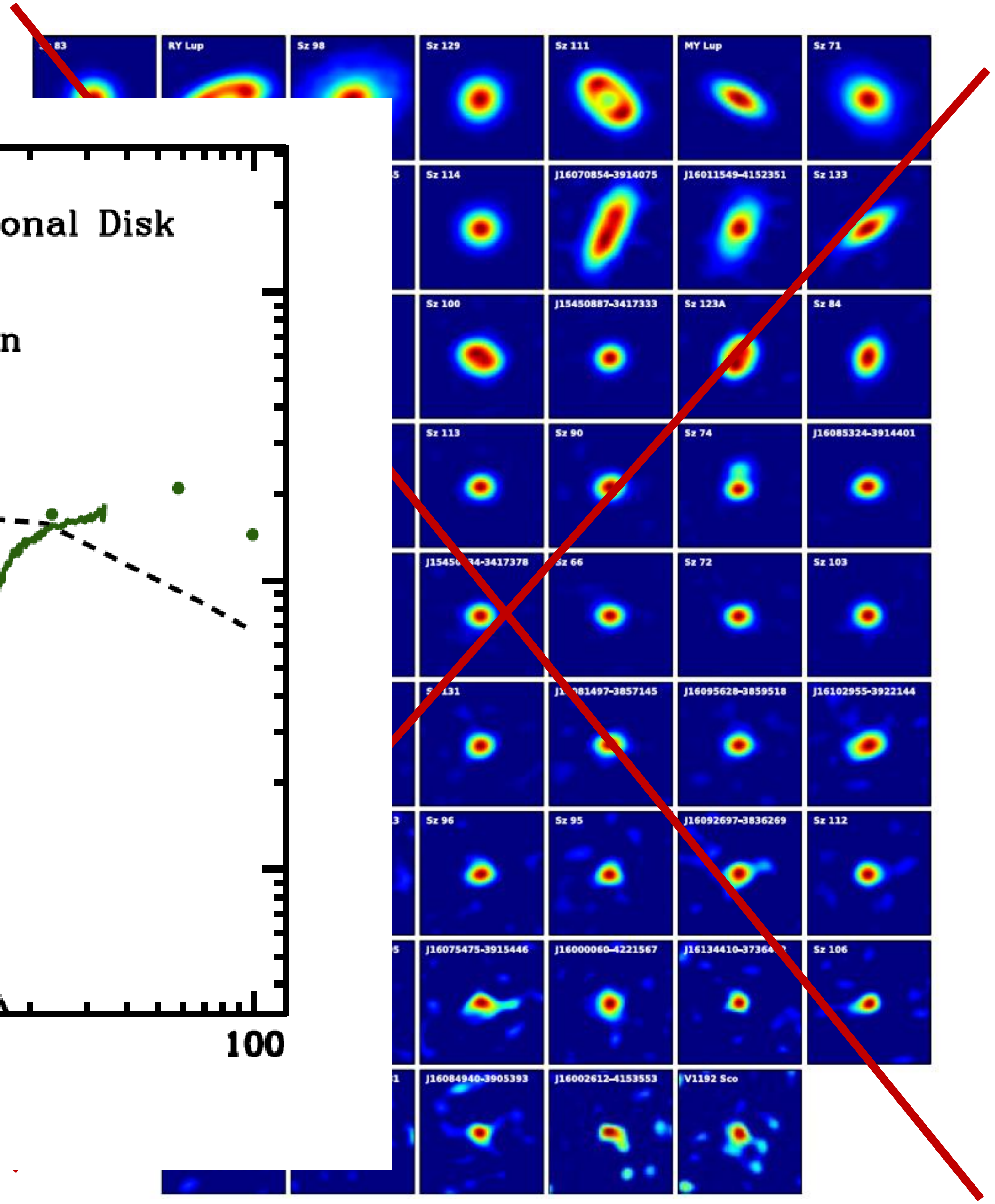
An intense life…

Dispersal





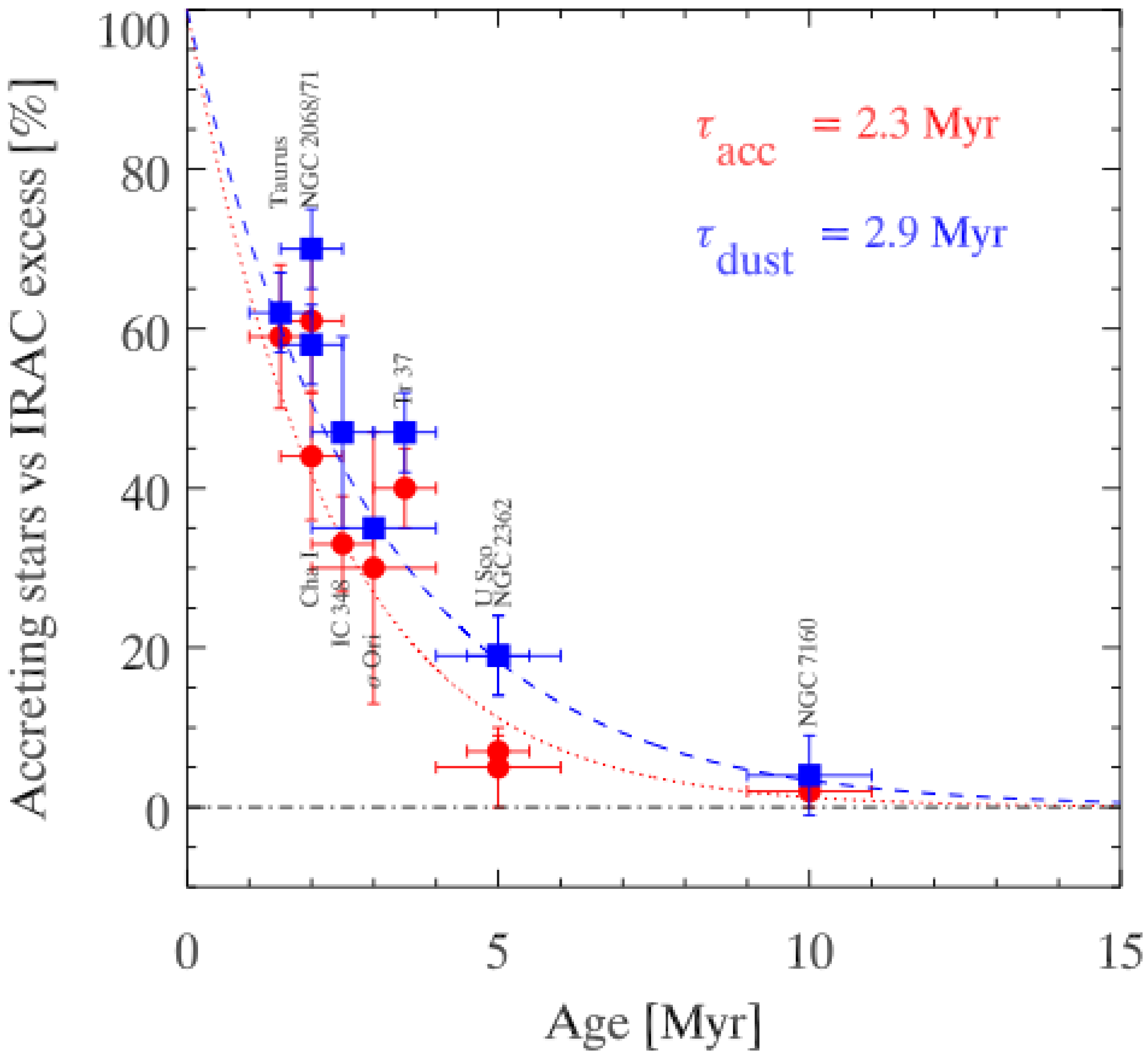
Transitional Disk
Taurus median
Photosphere
λF_λ(erg cm^{-2} s^{-1})
10^{-9}
10^{-10}
10^{-11}
1
10
100
$\lambda(\mu m)$



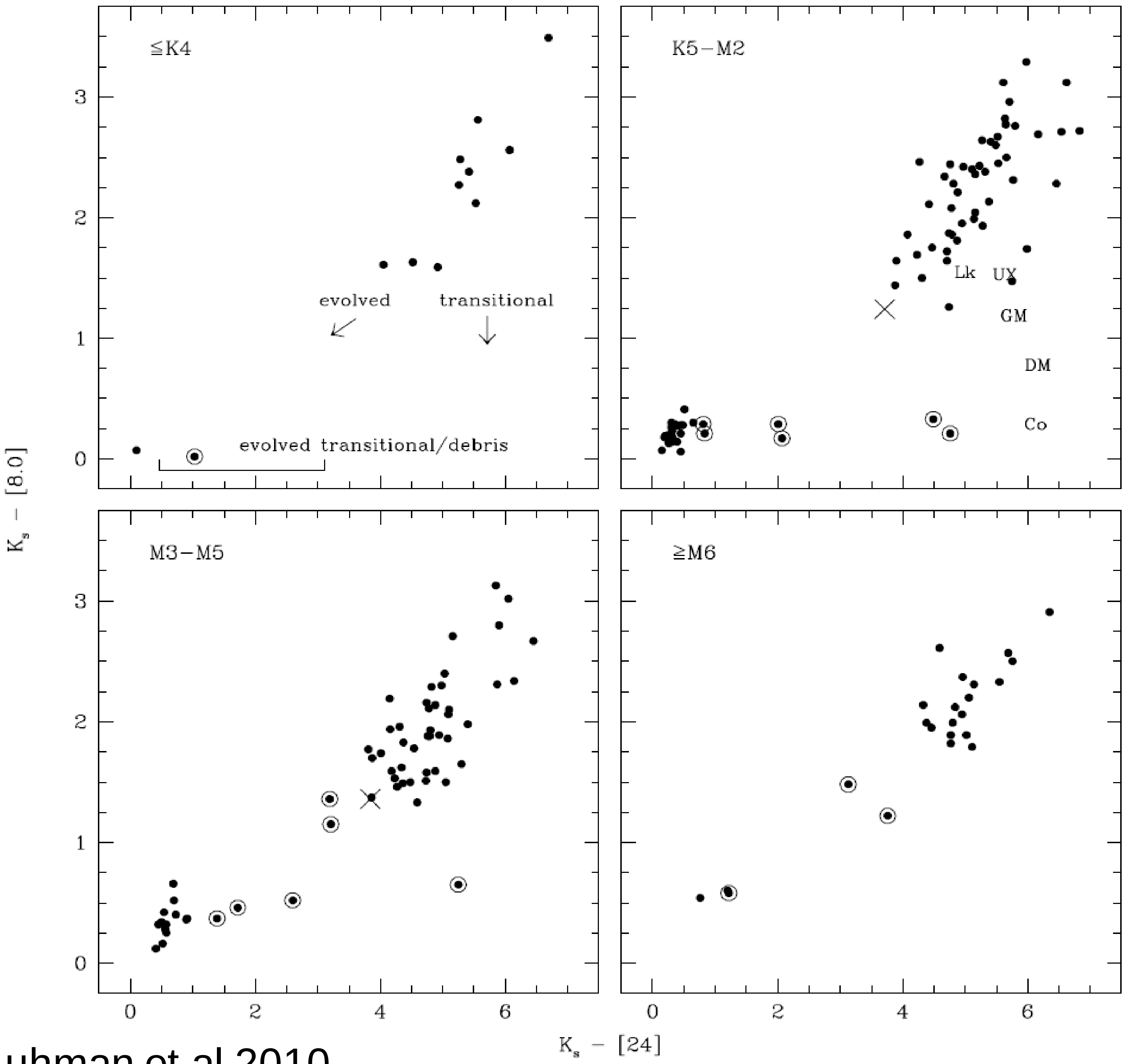
Observational constraints

Median disc lifetime: a few Myr

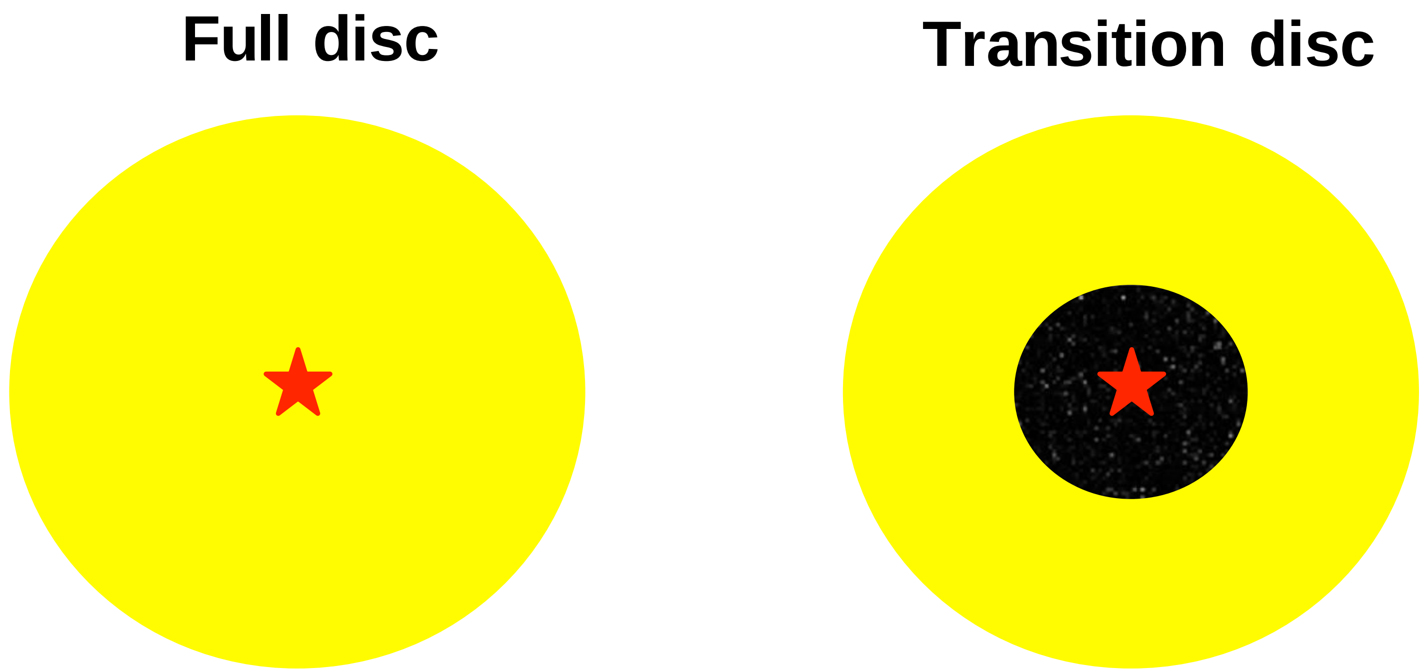
Fedele+ 2010

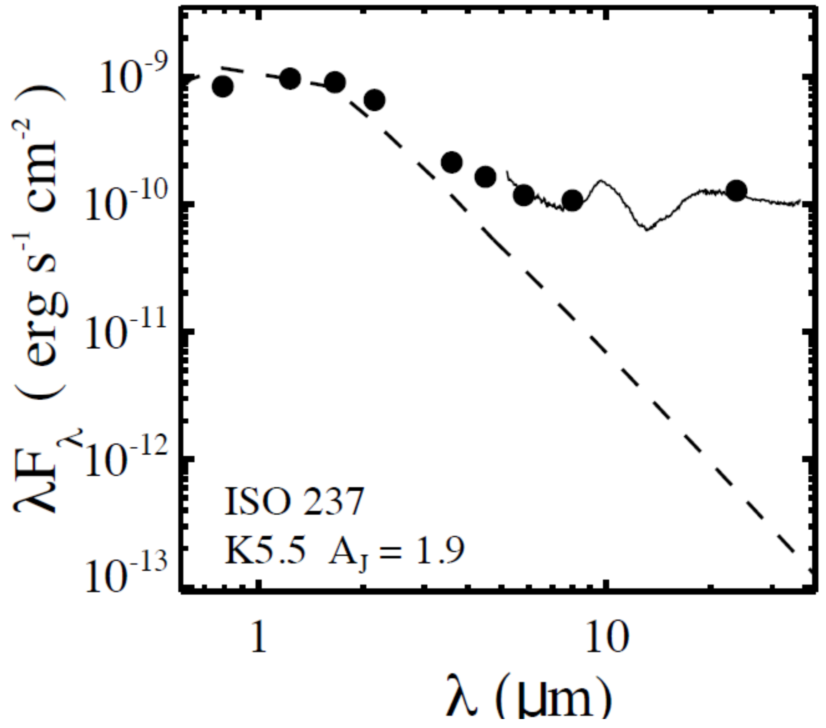


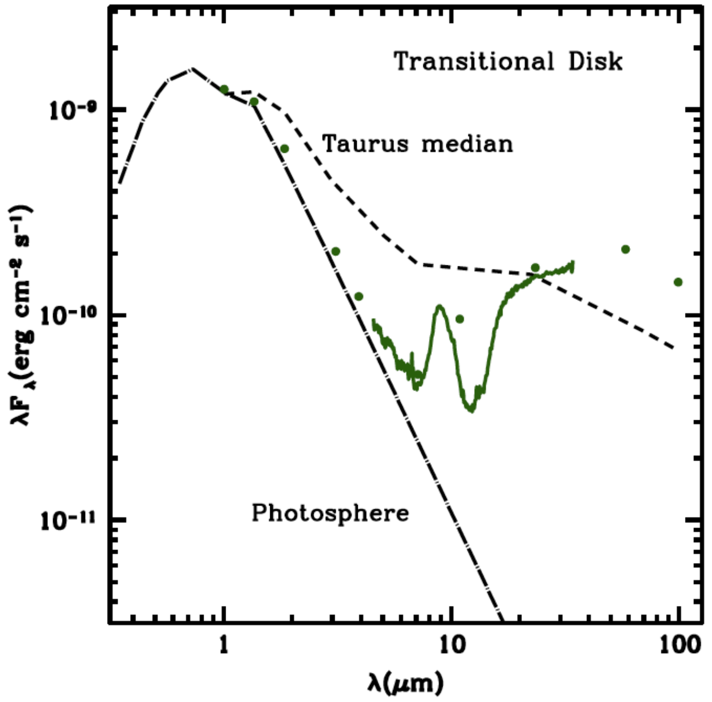
Two-timescale behavior



Luhman et al 2010







Slow quiet phase (10^6 yr/5 days), followed by fast dispersal phase (10^5 yr/24h trip)

Photo-evaporation
(thermal winds)

Photo-evaporation Approaches

Local detailed models

Global evolution on secular timescales

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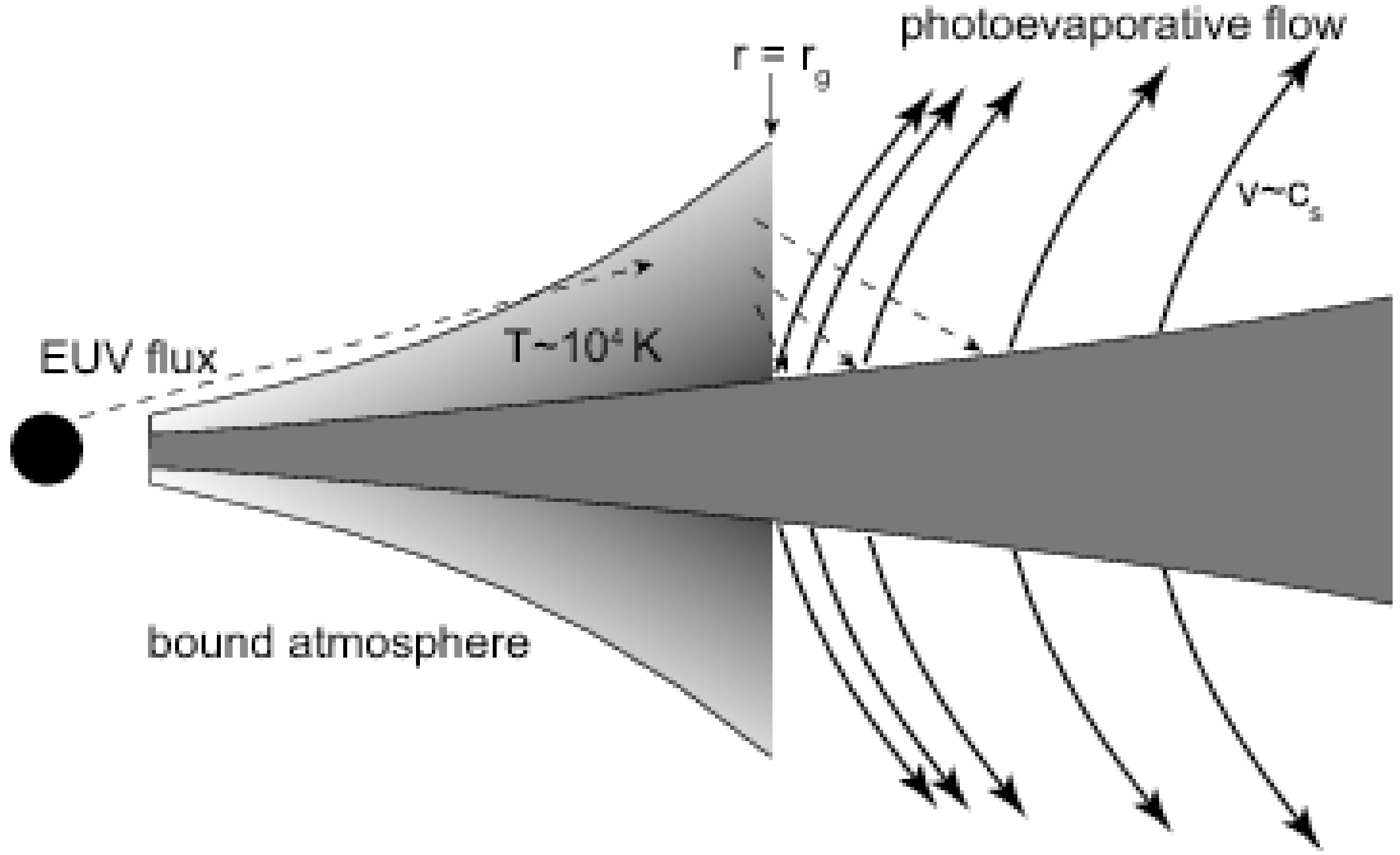
Local detailed models

Global evolution on secular timescales

Classic Photoevaporation model based on EUV (~13.6 eV) radiation



Physics: photoionized gas at disk surface to T ~ 10^4 K, sound speed ~10 km s^{-1}

Where $c_s > v_{esc}$ gas is unbound - escapes as a thermal wind (reminiscent of Parker's wind)

$$r_{escape} = \frac{GM_*}{c_s^2}$$

5-10 AU with this naïve estimate, ~few AU with more sophisticated analysis (Font+ 2004)

$$\dot{\Sigma} \propto \rho c_s$$

Mass loss rate is set by temperature of the flow and density

The key is where the energy comes from

- EUV (ionizing photons): both heating and cooling scale as n^{-2}, giving approximate constant temperature 10^4 K

- FUV (non-ionizing): PDR region

- X-rays: ionize metals

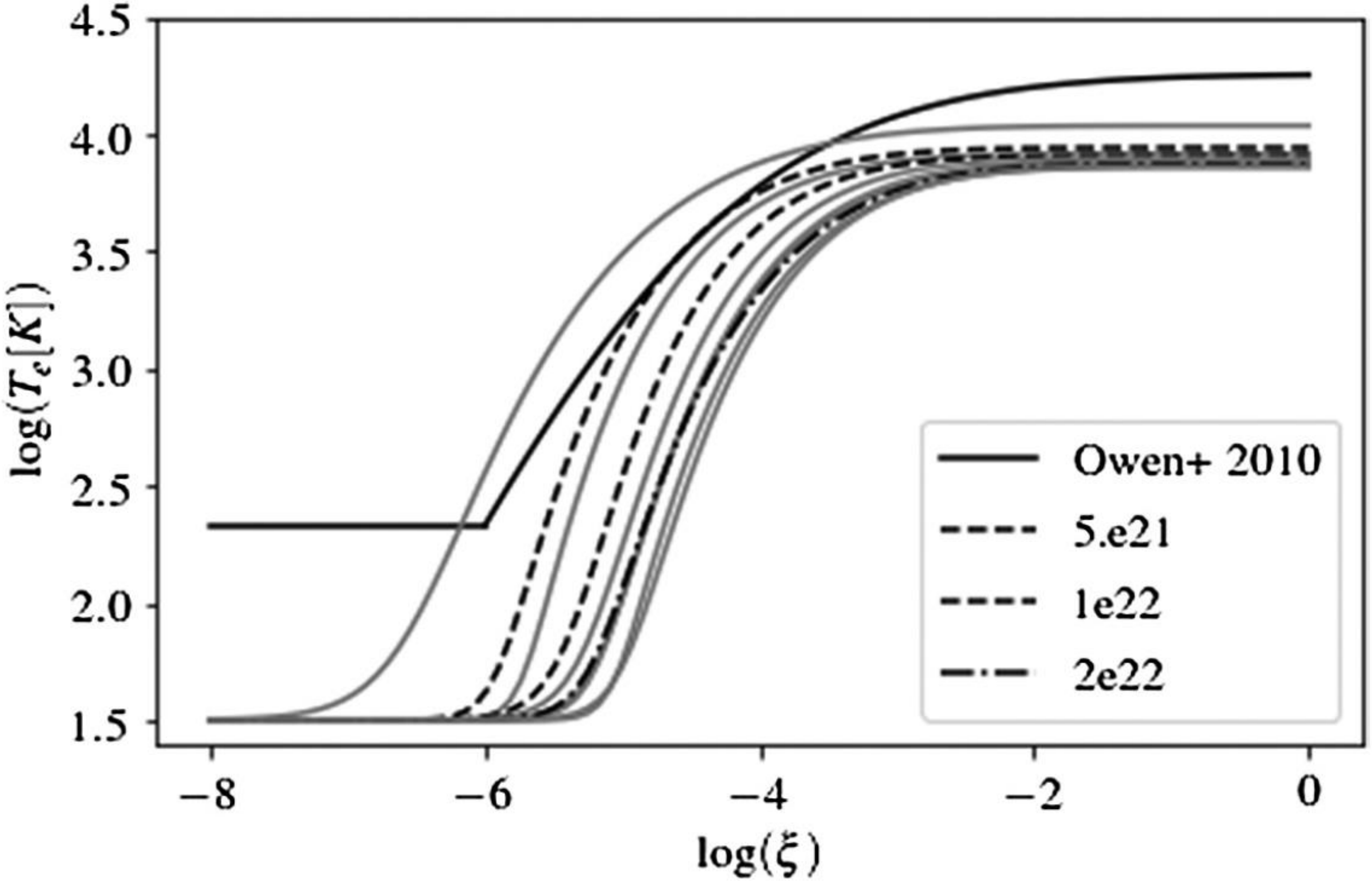
Penetrate deeper

$$\dot{\Sigma} \propto \rho c_s$$

Drive more vigorous winds even if less effective at heating

Talk L. Woelfer

X-ray heating: temperatures



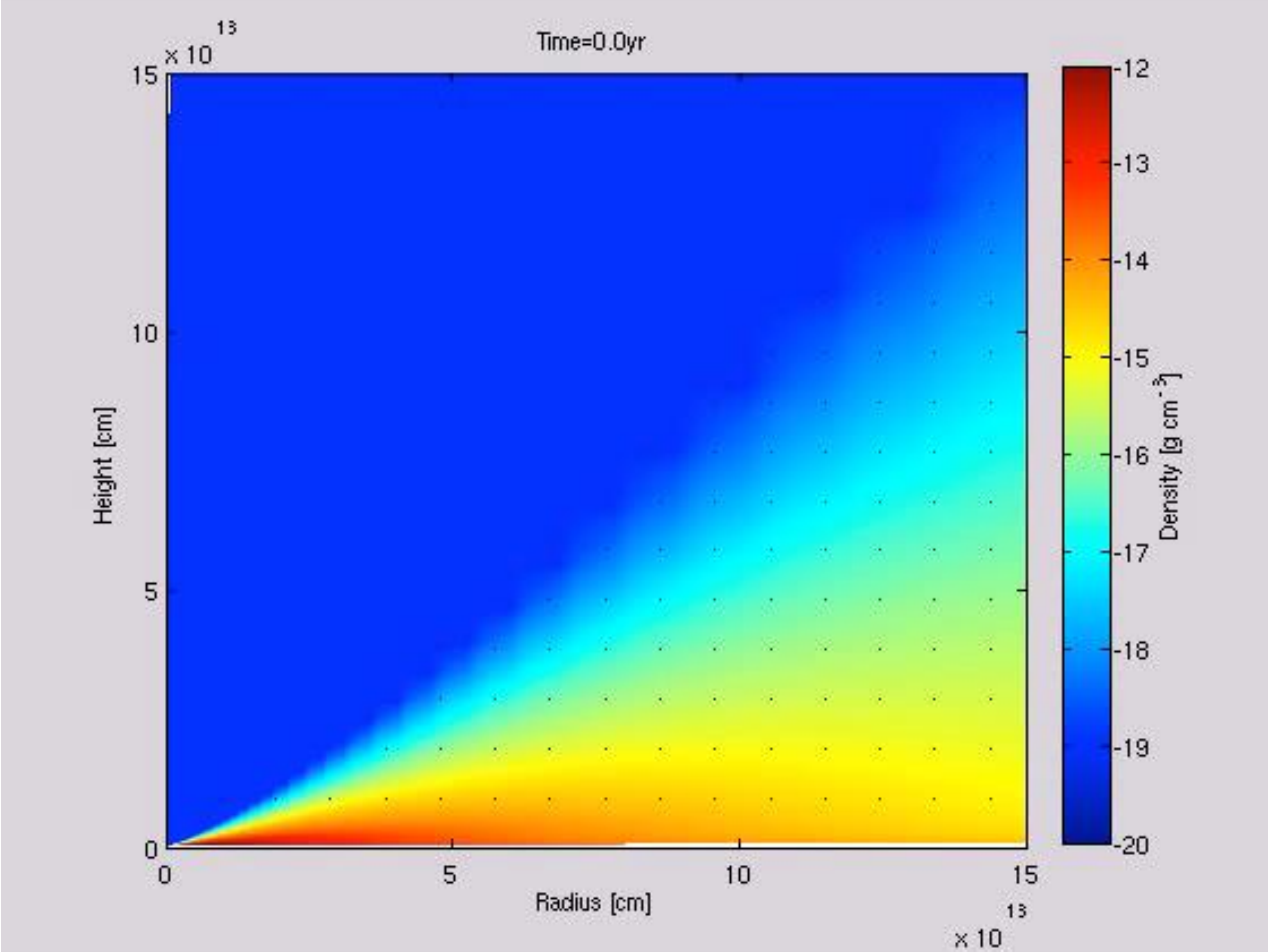
$$\xi = L_X / n r^2$$

Picogna+ 2019

Simple parametrization from detailed static radiative transfer to apply to hydro models

See Wang & Goodman for alternative approach: live, but less accurate, radiative transfer

Hydro-modelling



Owen+ 2010

Critical to derive accurate mass-loss rate

Hydro-static: 10^{-9} $M_{\odot}$/yr

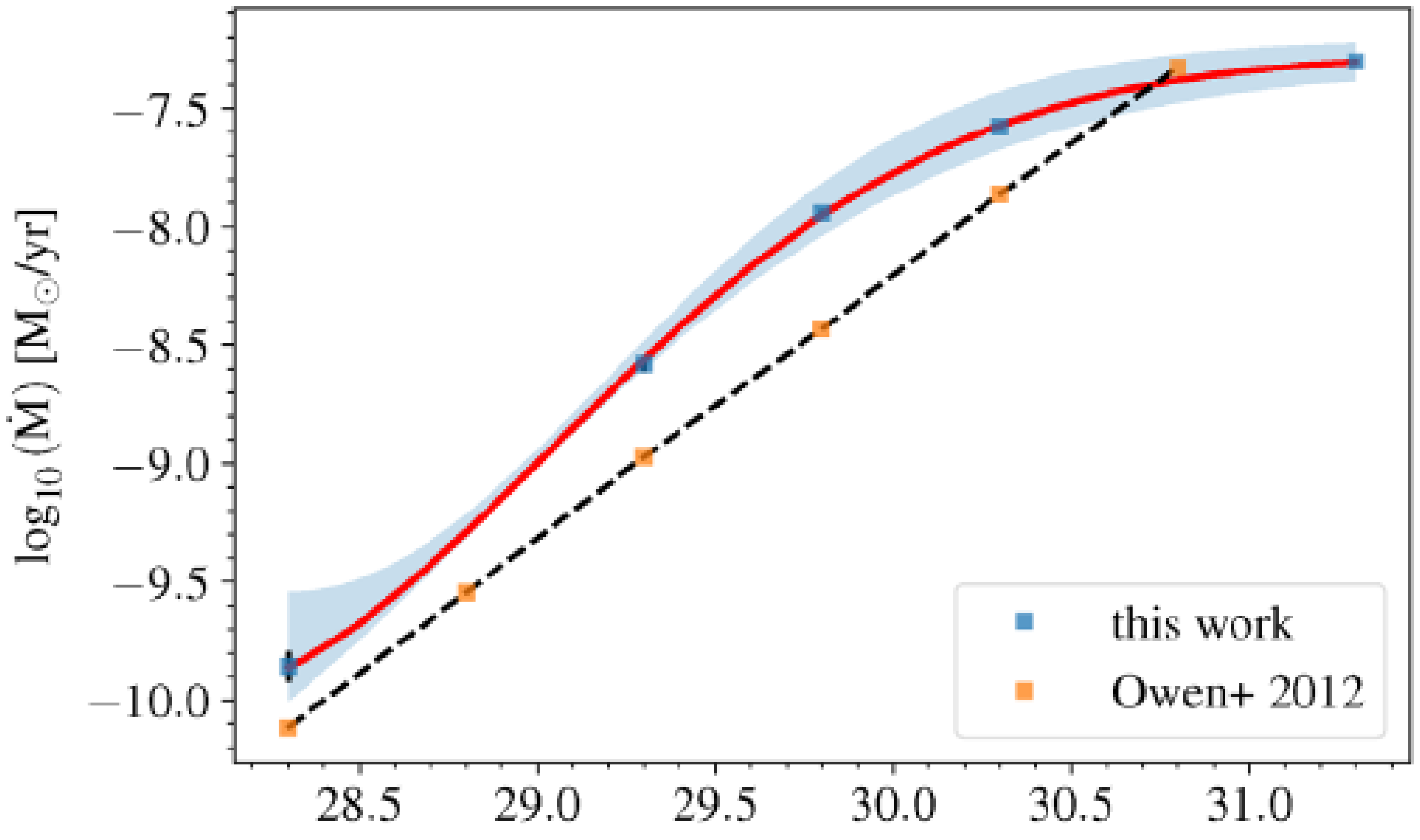
Ercolano 2009

Hydro-dynamic: 10^{-8} $M_{\odot}$/y

Owen+ 2010

Wind properties

Mass-loss rates



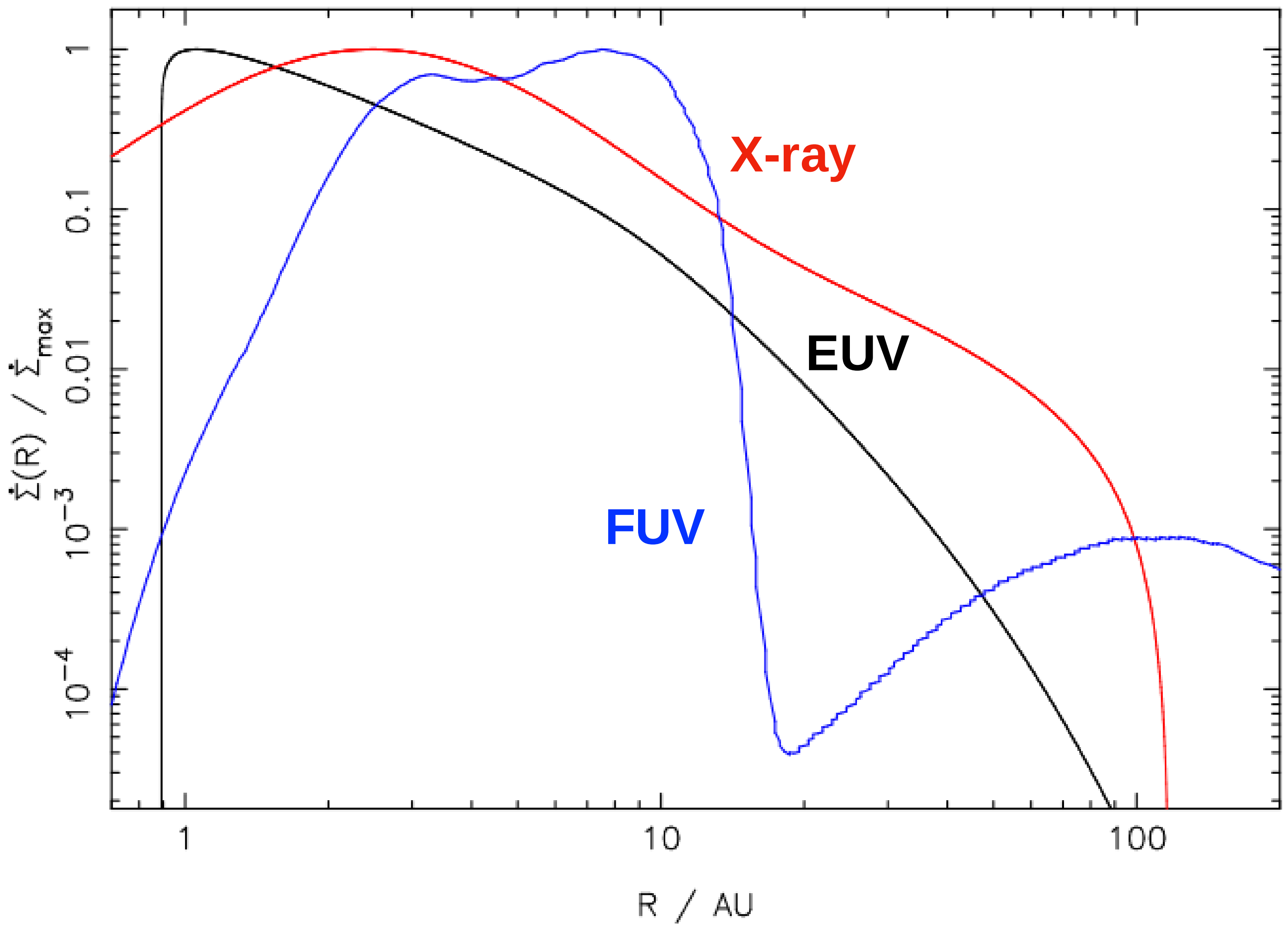
Picogna+ 2019

log(L_x)

$$\dot{M}_{\rm w,EUV} \simeq 1.6 \times 10^{-10} \left(\frac{\Phi}{10^{41}{\rm s}^{-1}}\right)^{1/2} \left(\frac{M_*}{1{\rm M}_\odot}\right)^{1/2} {\rm M}_\odot\,{\rm yr}^{-1}$$

Alexander+ 2006

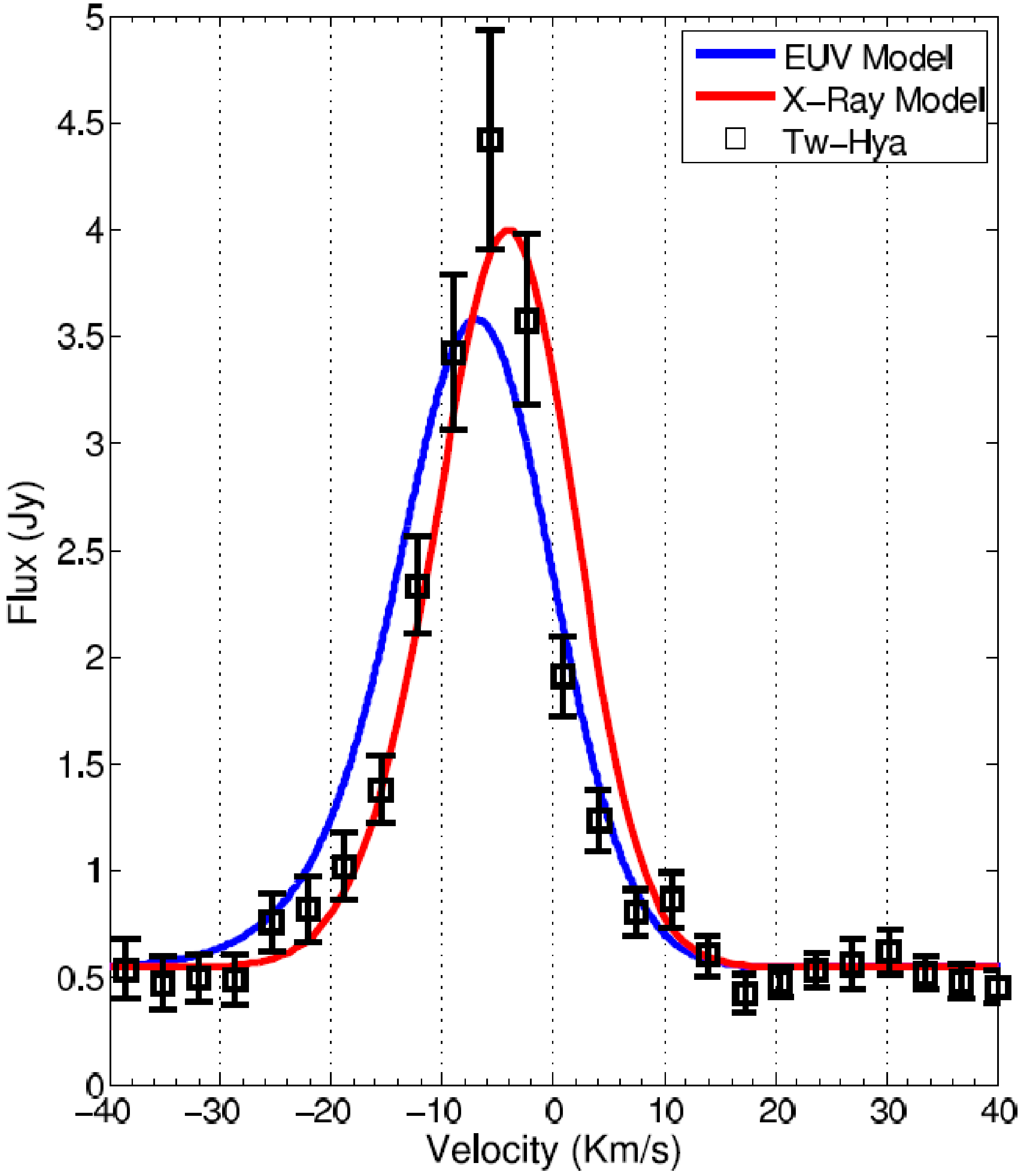
Profiles



Alexander+ 2014; Alexander+ 2006, Owen+ 2009,2010, Gorti+ 2009

Direct observational evidence

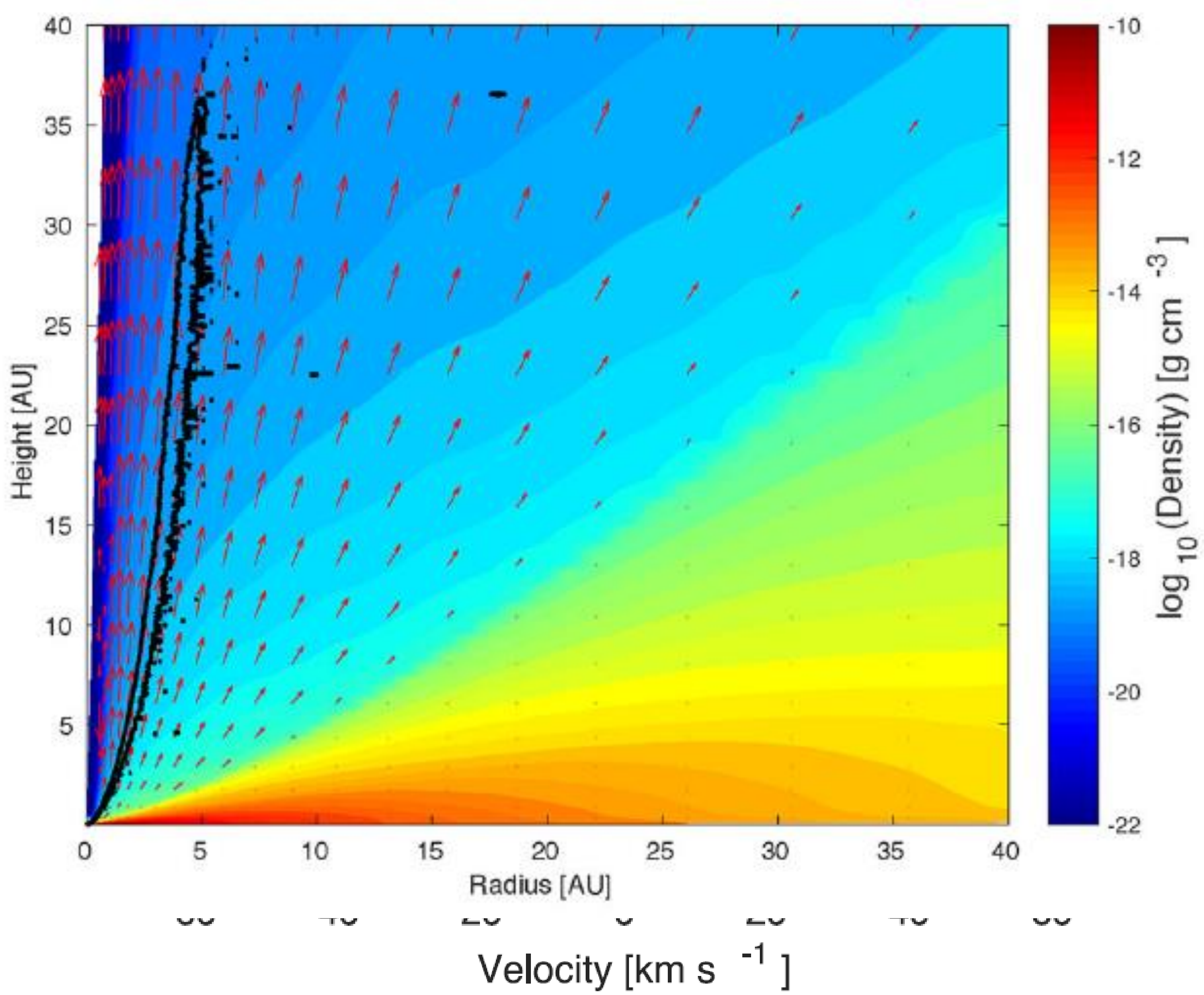
Ne II



Ercolano & Owen 2010; Alexander 2008; Pascucci+ 2009

O I

R=25,000



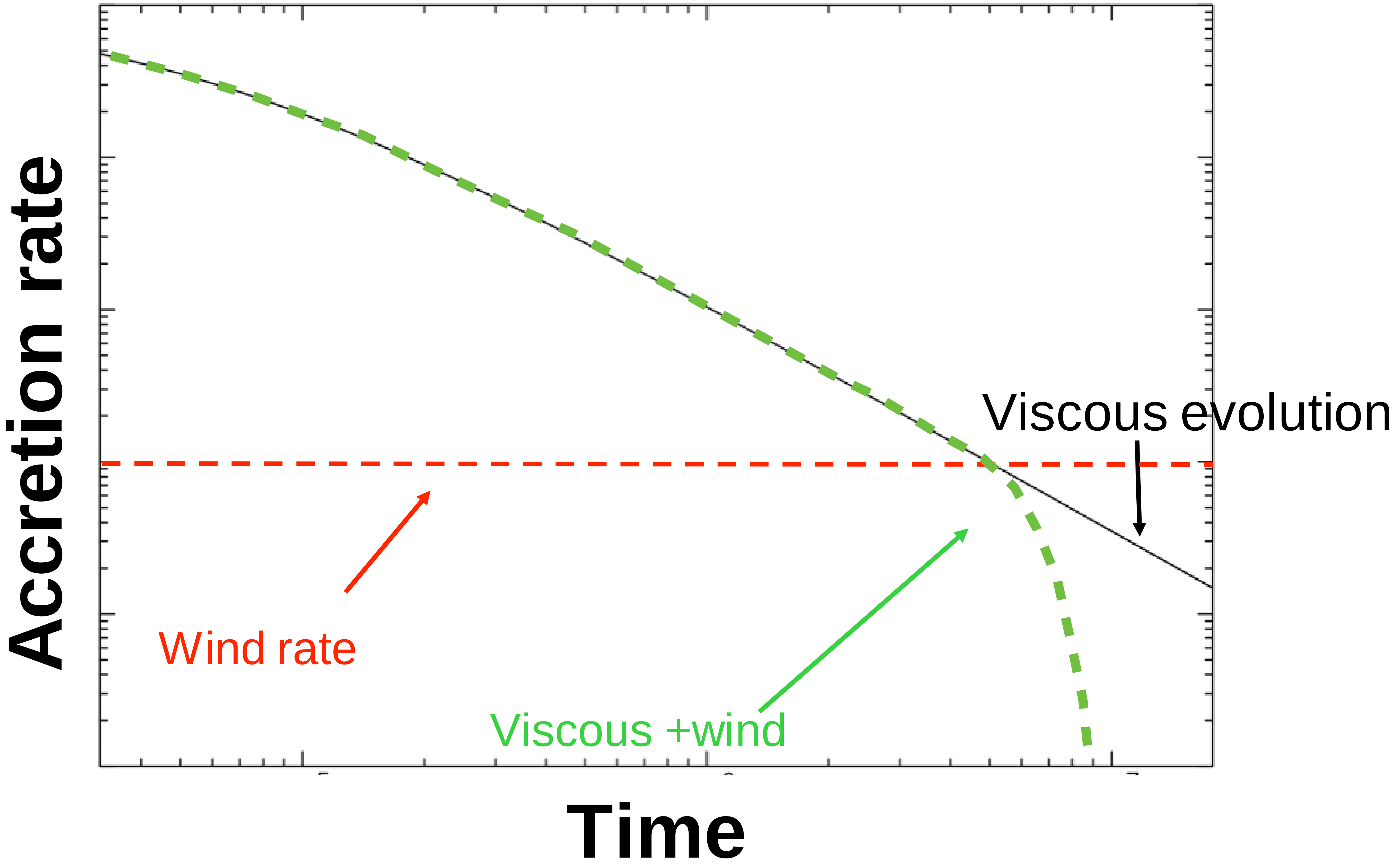
Ercolano & Owen 2016

Photo-evaporation Approaches

Local detailed models

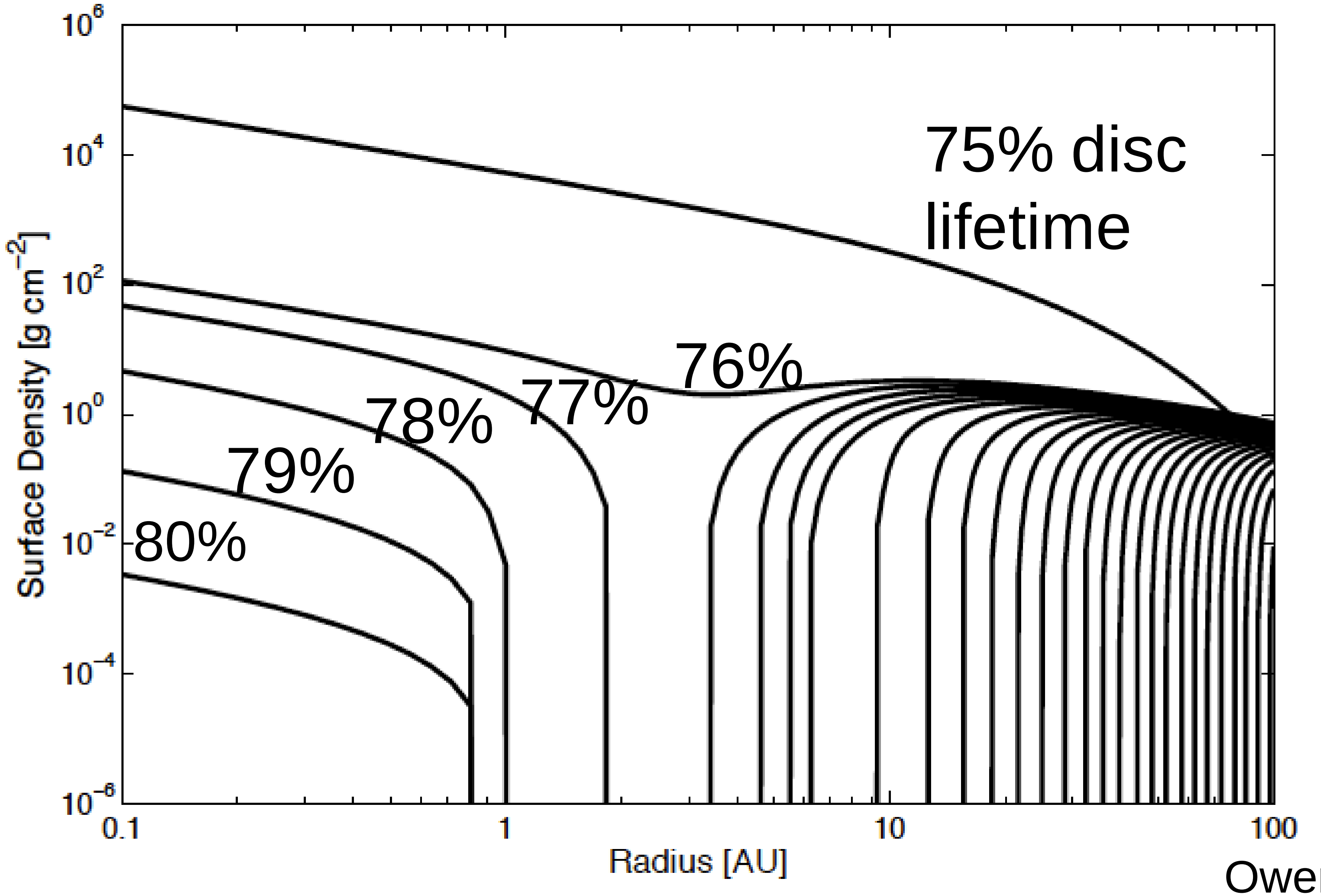
Global evolution on secular timescales

Switch model



Clarke+ 2001

Time evolution



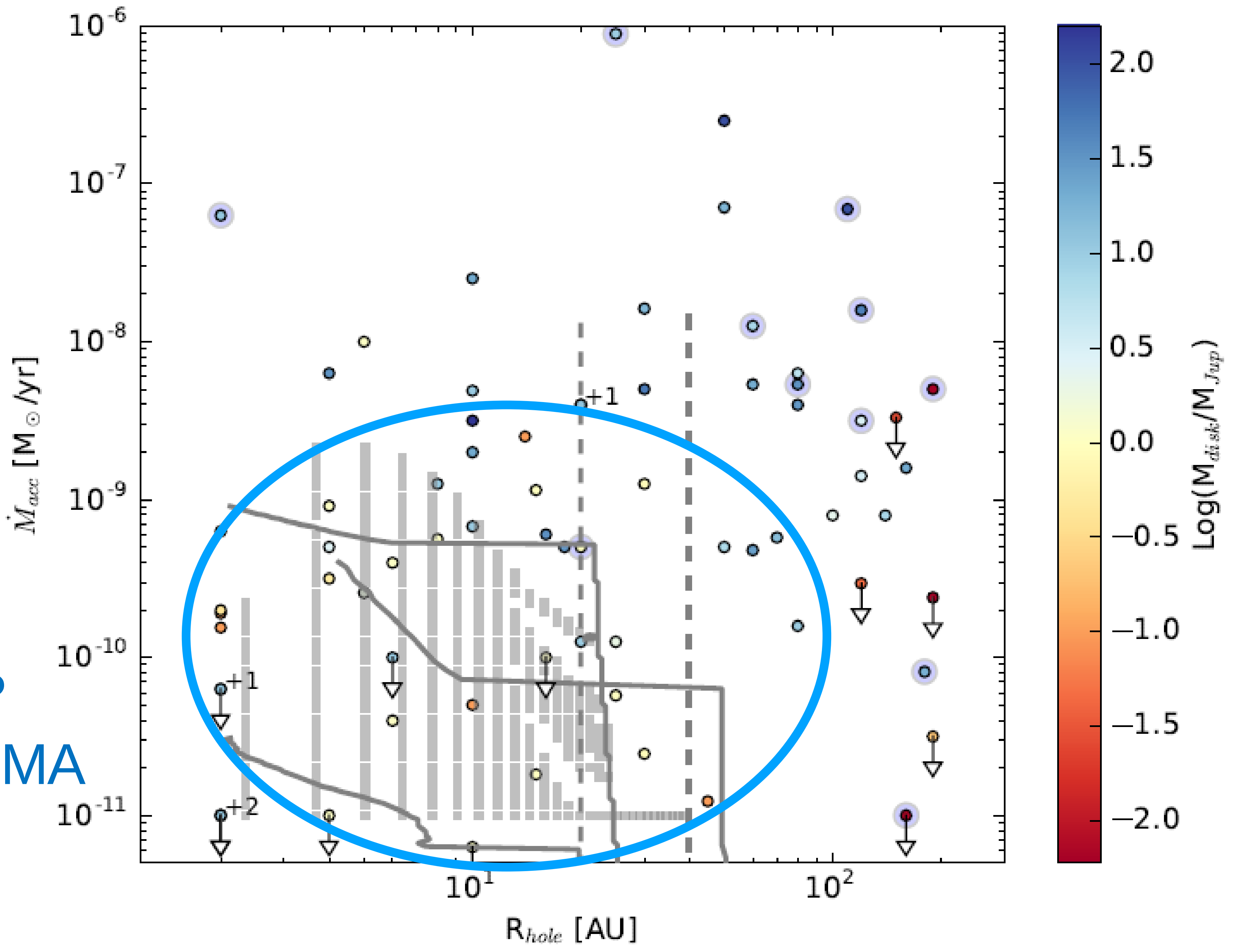
Owen+ 2010

Inside-out dispersal: reproduces two-timescale behaviour

Gap opening stop migrating planets

Talk K. Monsch

Transition discs



Discs in dispersal?
Not yet imaged by ALMA

Ercolano & Pascucci 2017, tracks from Owen+ 2011 and GR+ 2013

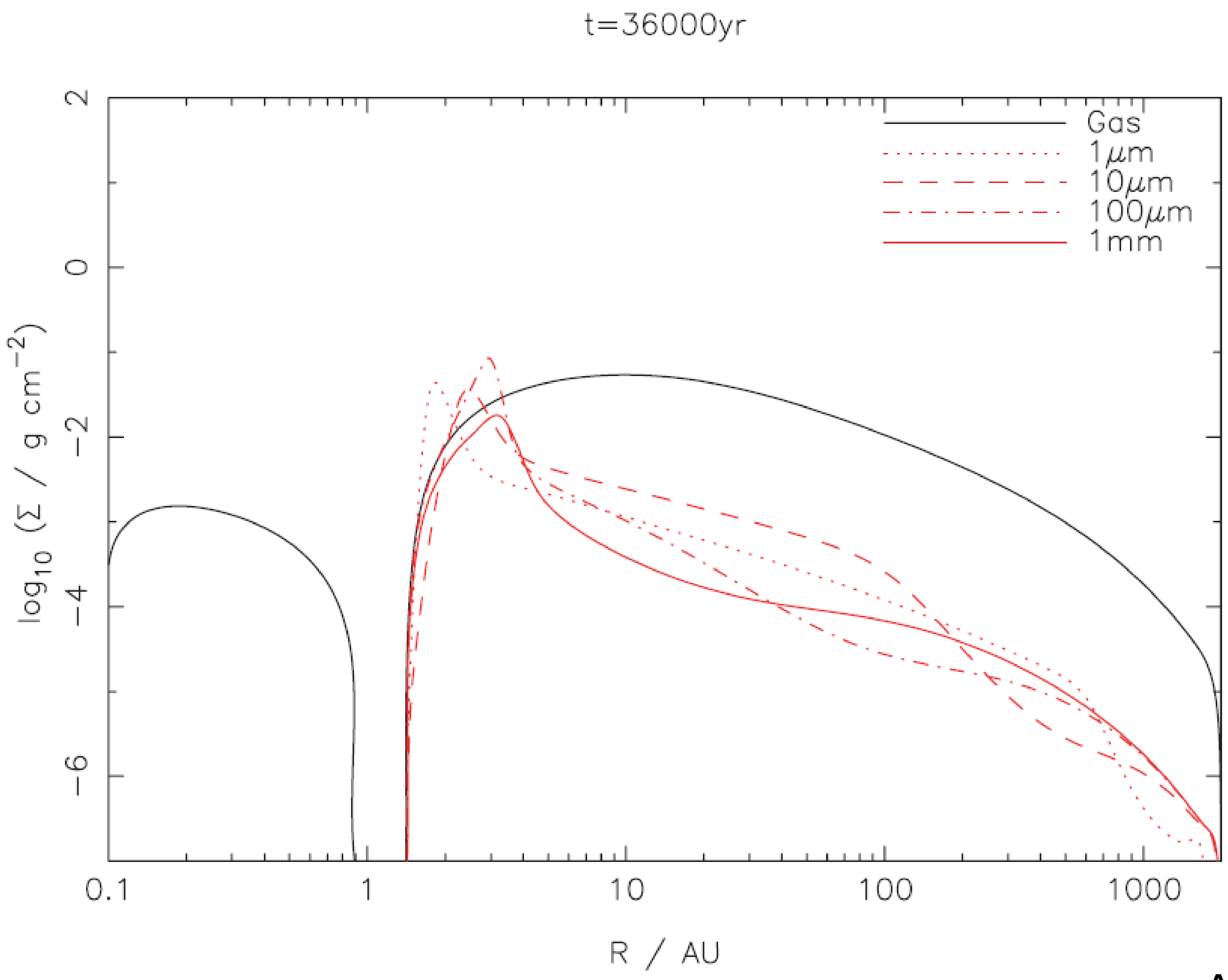
Two classes of transition discs?

An intense life…

Dispersal

Debris discs

Dust behaviour



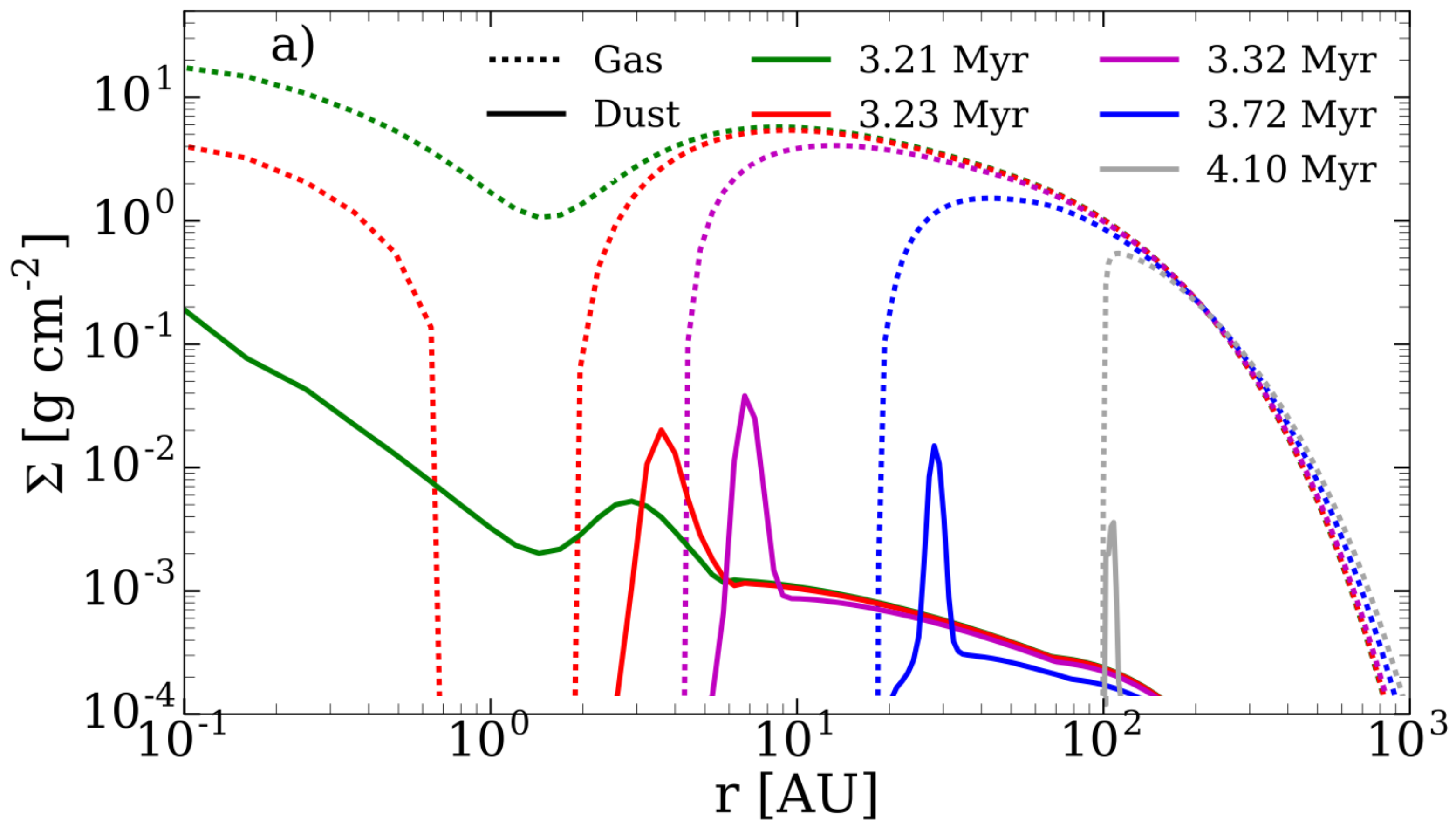
Alexander & Armitage 2007

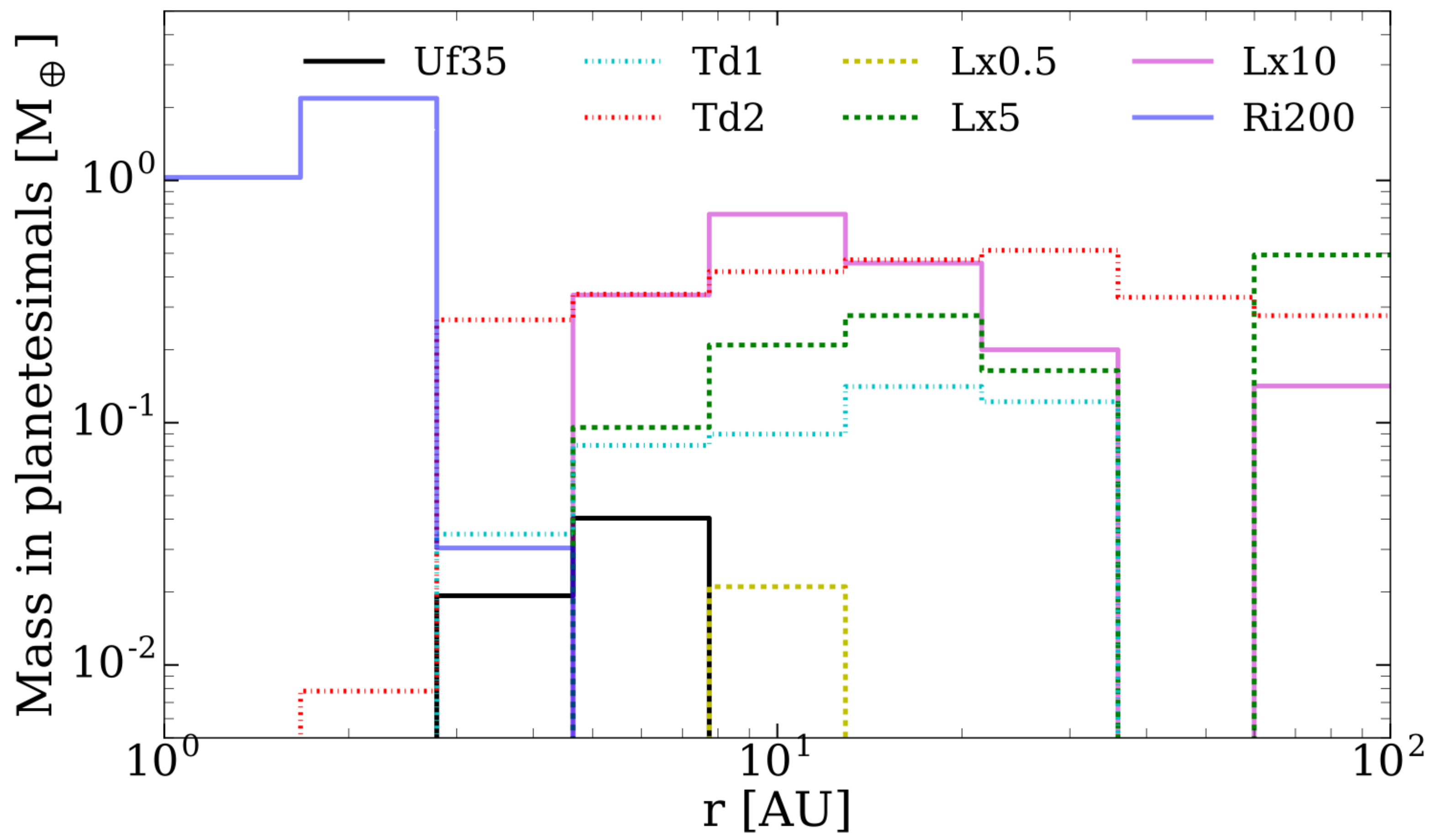
Inner disc disappears

Dust outside piles up in a trap

Does photo-evaporation trigger the streaming instability?

Ercolano, Jennings & GR 2017

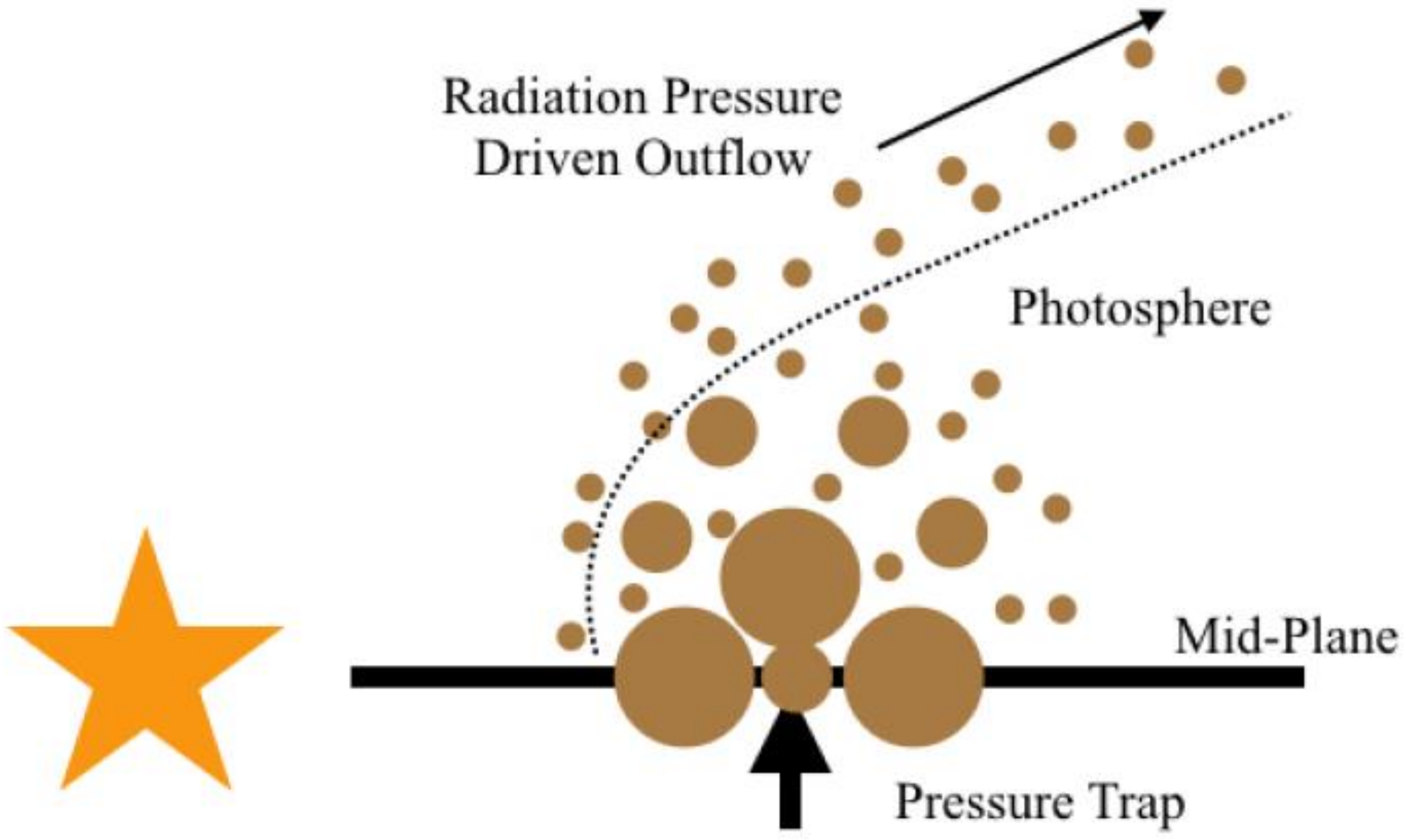




Yes, but too little mass is produced to form terrestrial planets

FUV photo-evaporation more successful (Carrera+ 2017), but only in the outer disc (~100 AU)

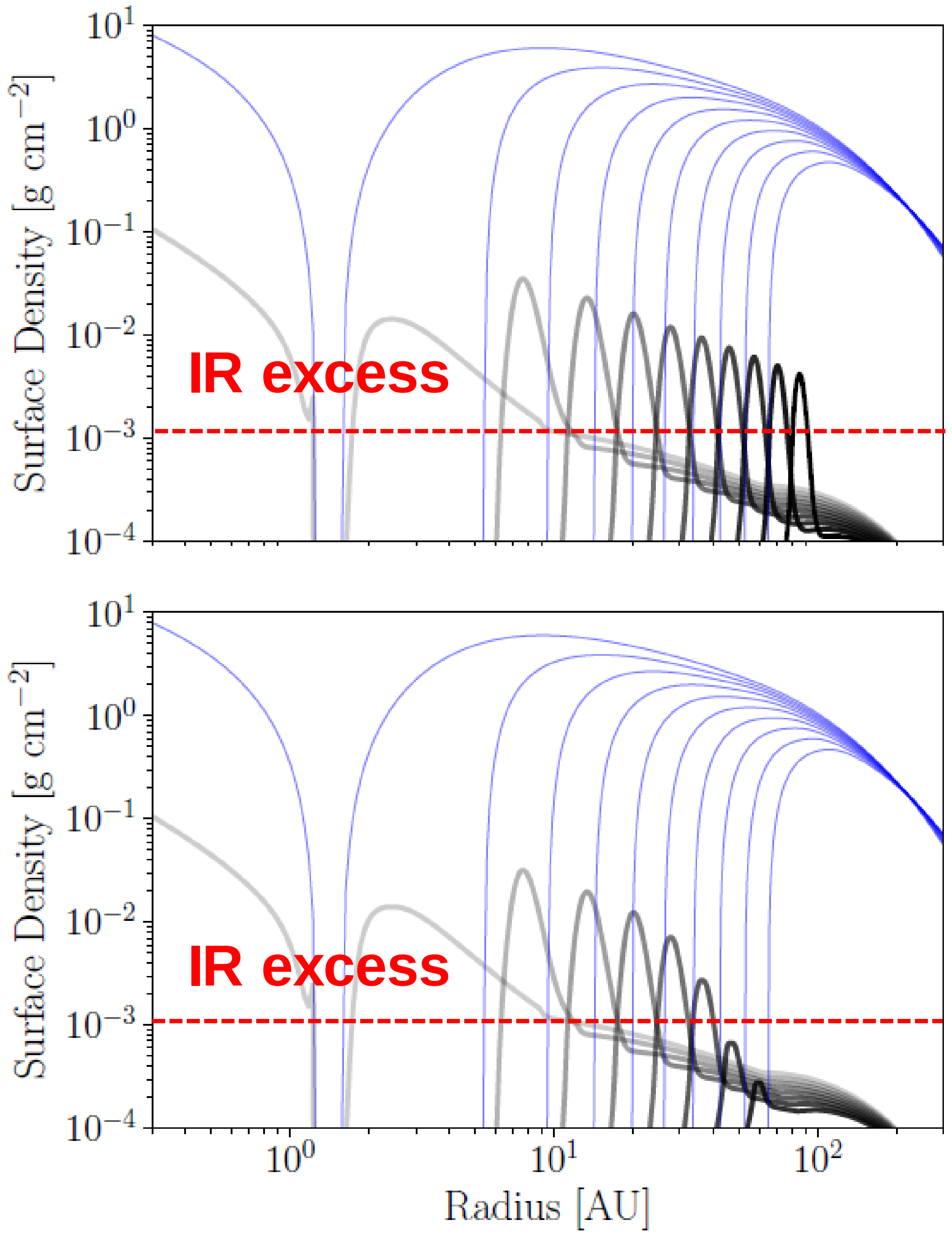
Dust clearing by radiation pressure



Owen & Kollmeier 2019

No radiation pressure

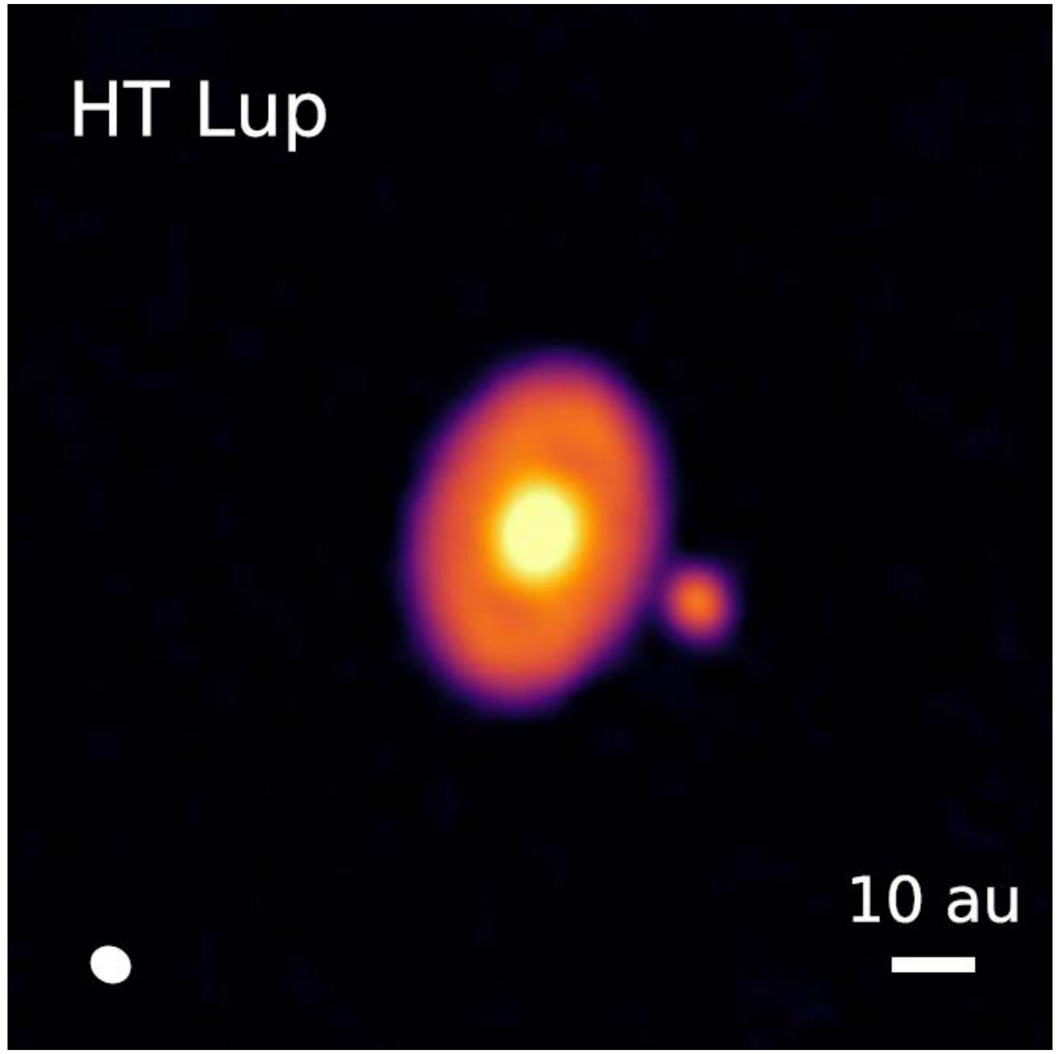
With radiation pressure



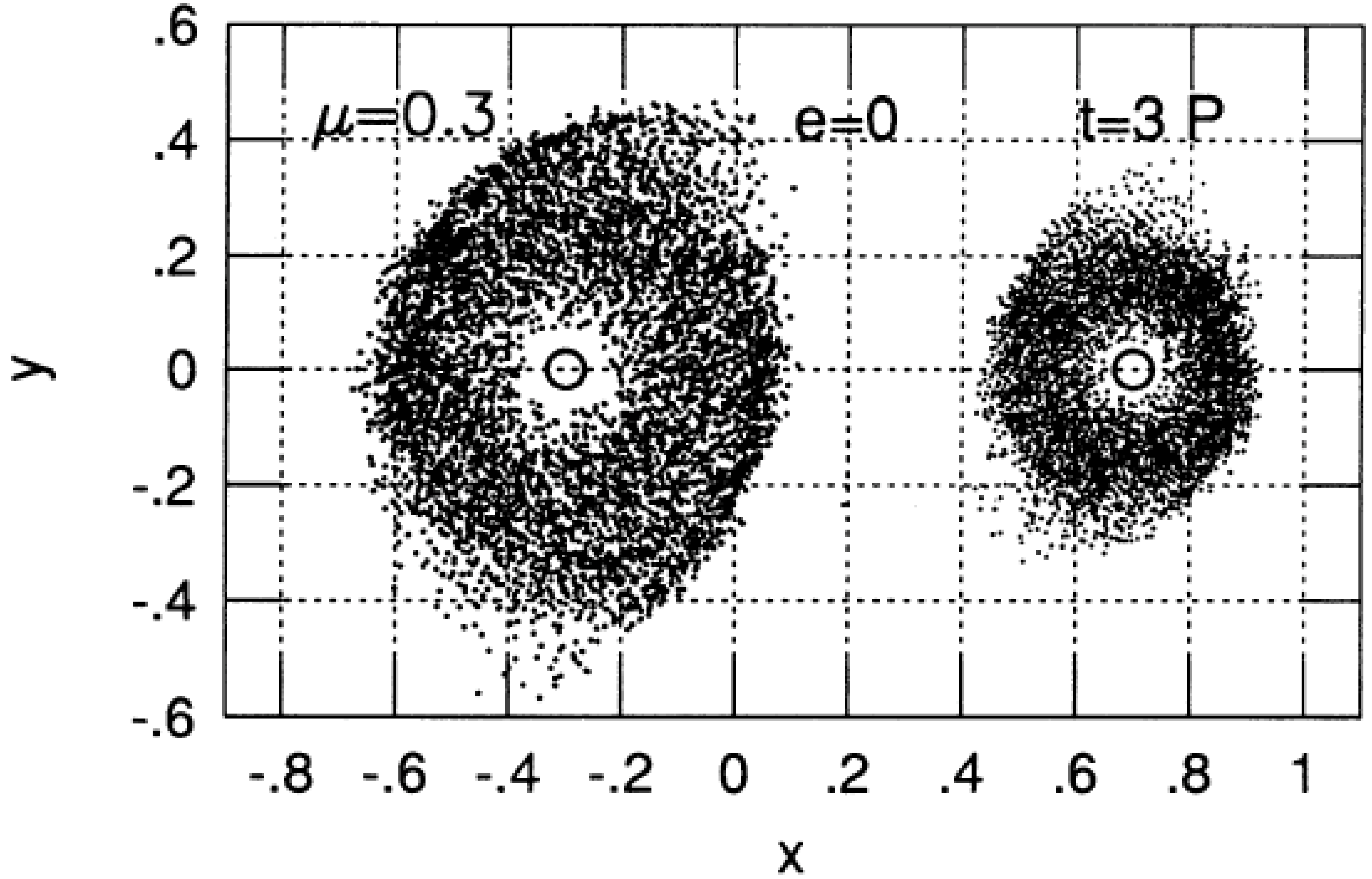
Predicts gas-rich debris discs

Discs in binary systems

Companions truncate discs



Andrews+ 2018, DSHARP

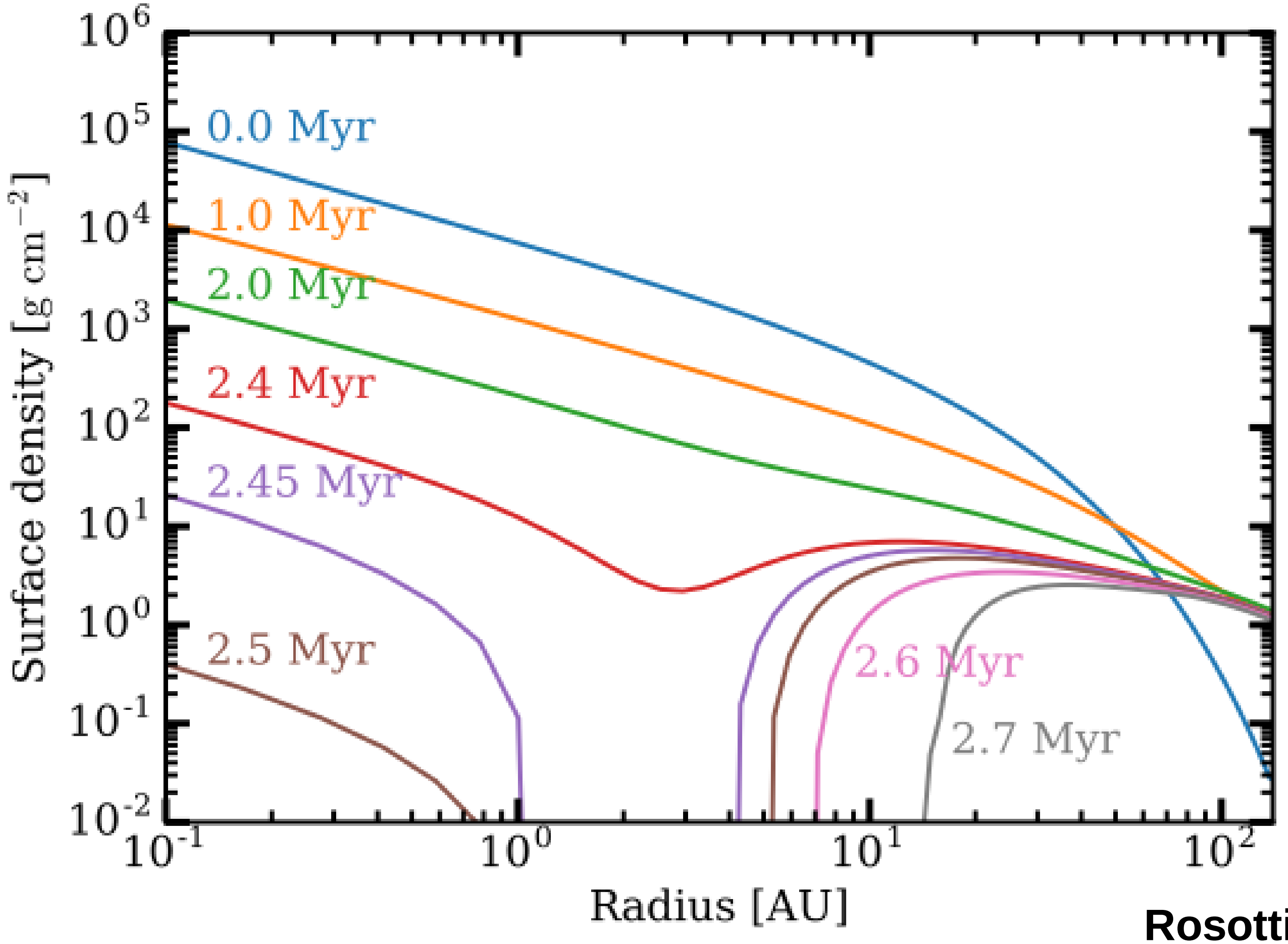


Simulation, Artymowicz & Lubow 1994

How does this feedback on the evolution?

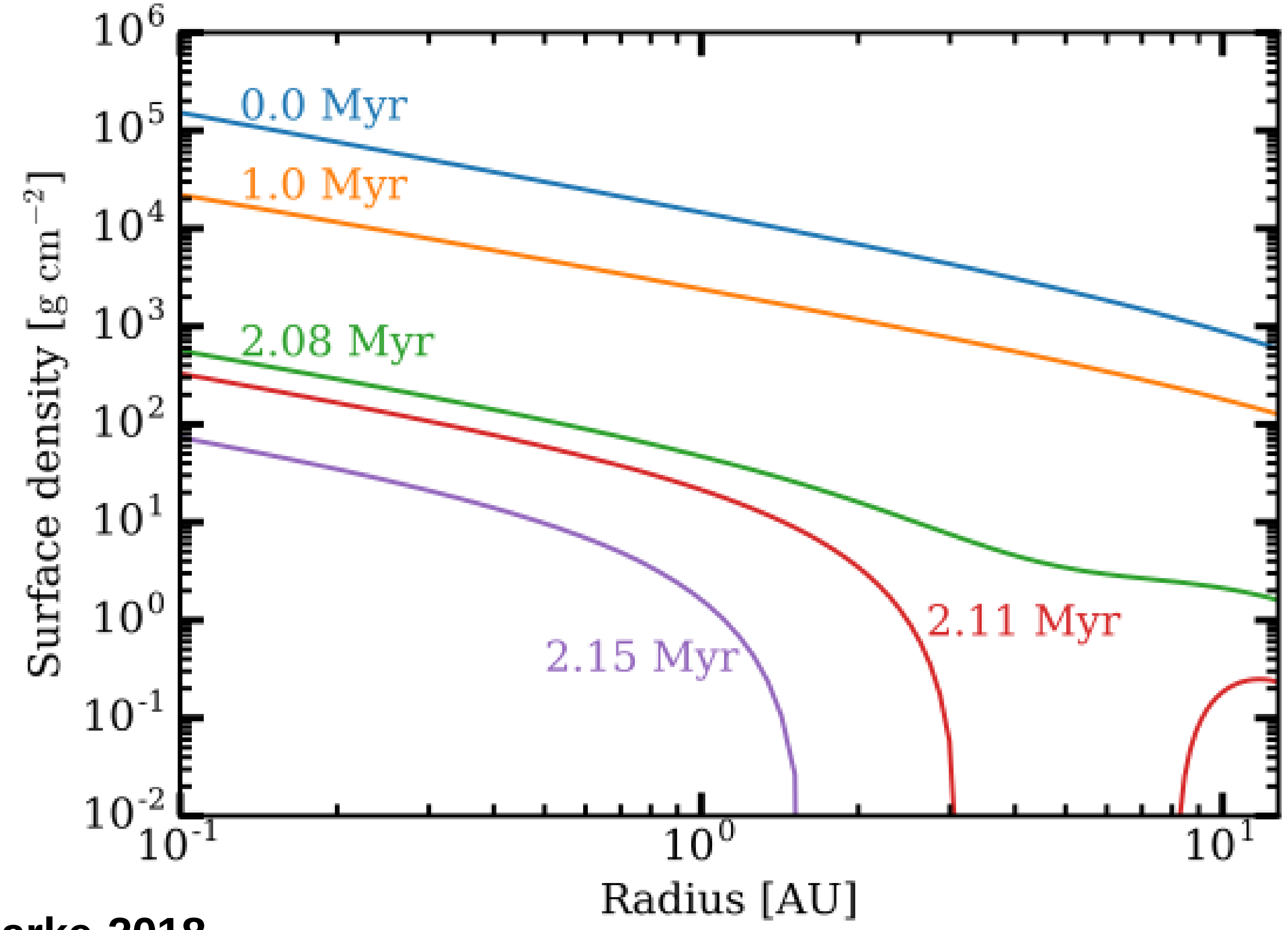
Qualitative behaviour

Separation 300au



Inside out dispersal

Separation 30au

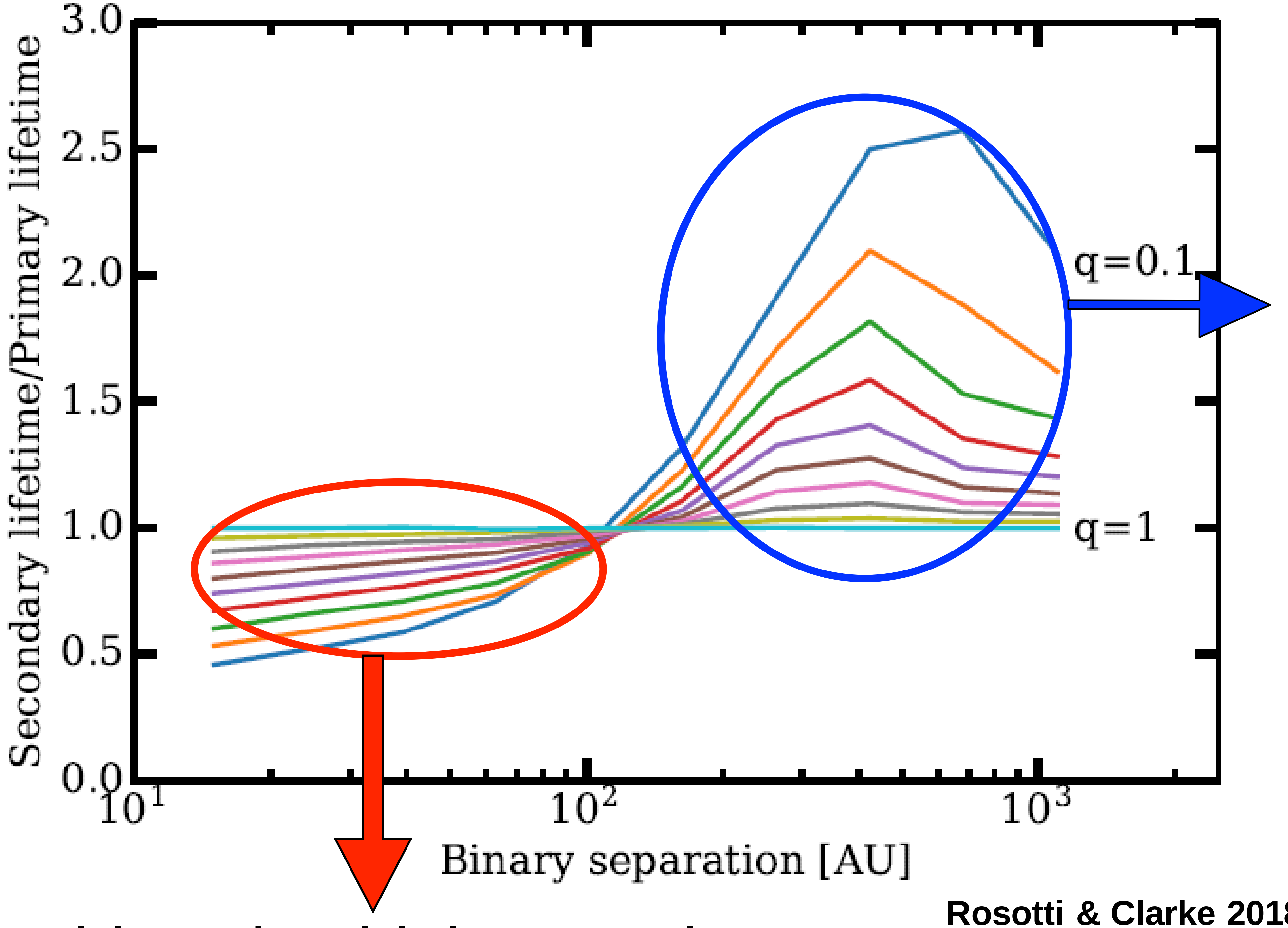


Rosotti & Clarke 2018

Outside in dispersal

Driven by tidal truncation

Disc lifetime is affected



driven by photo-evaporation rate

Can be used to measure disc lifetime as a function of stellar mass

driven by tidal truncation

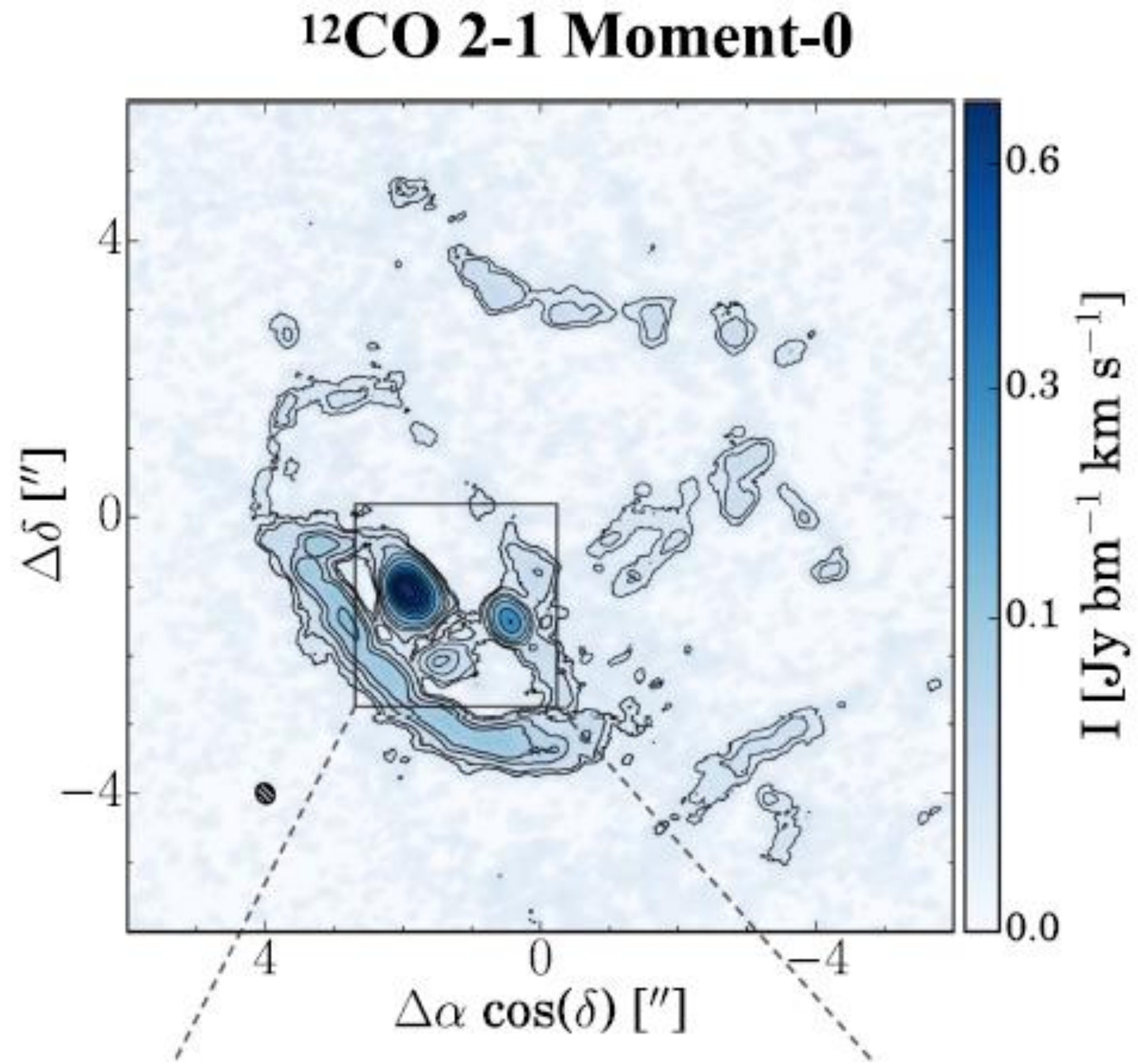
Rosotti & Clarke 2018

Effects of the environment

Two mechanisms

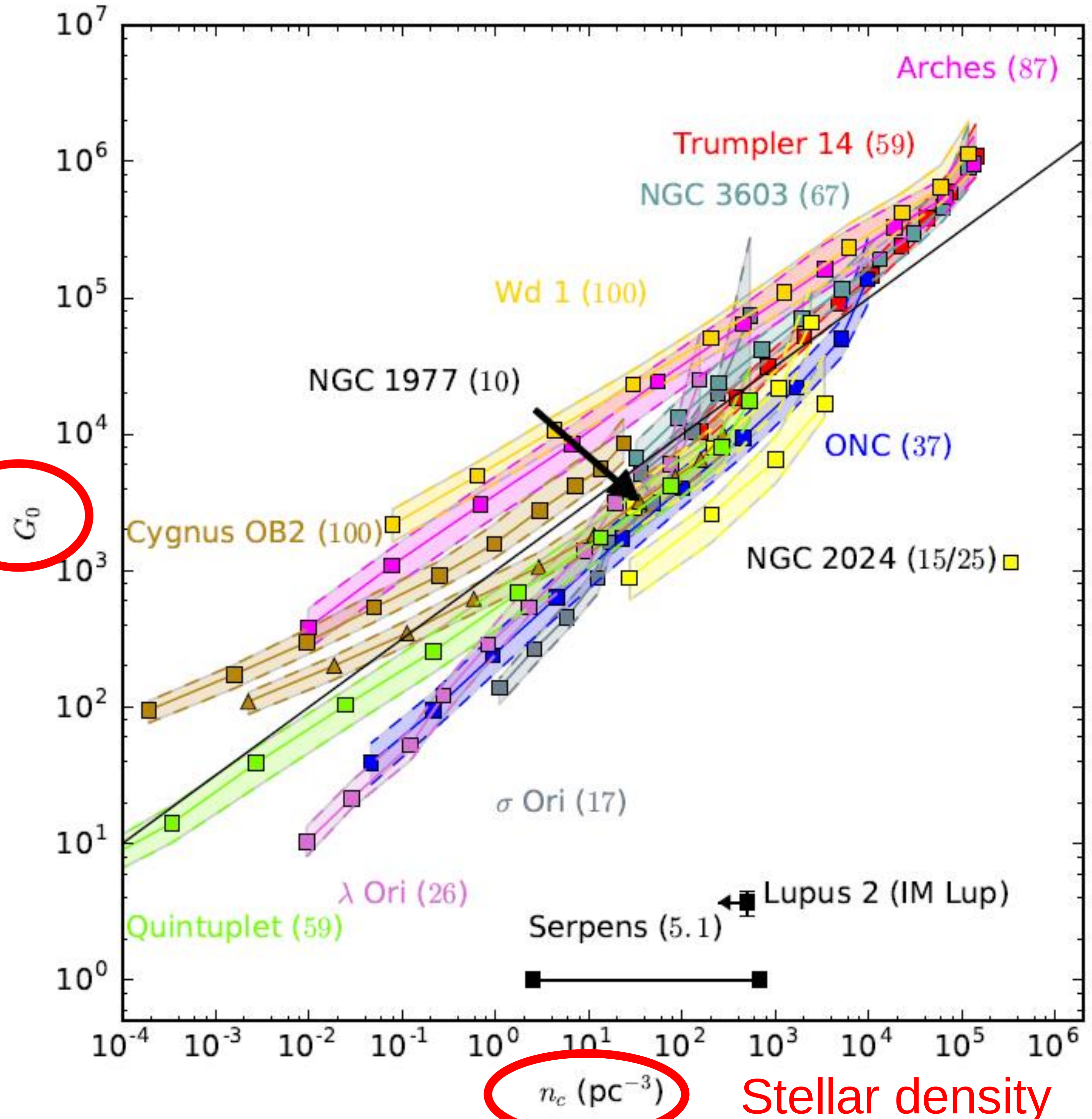
External photo-evaporation

Encounters



RW Aur, Rodriguez+ 2018

Encounters or irradiation?

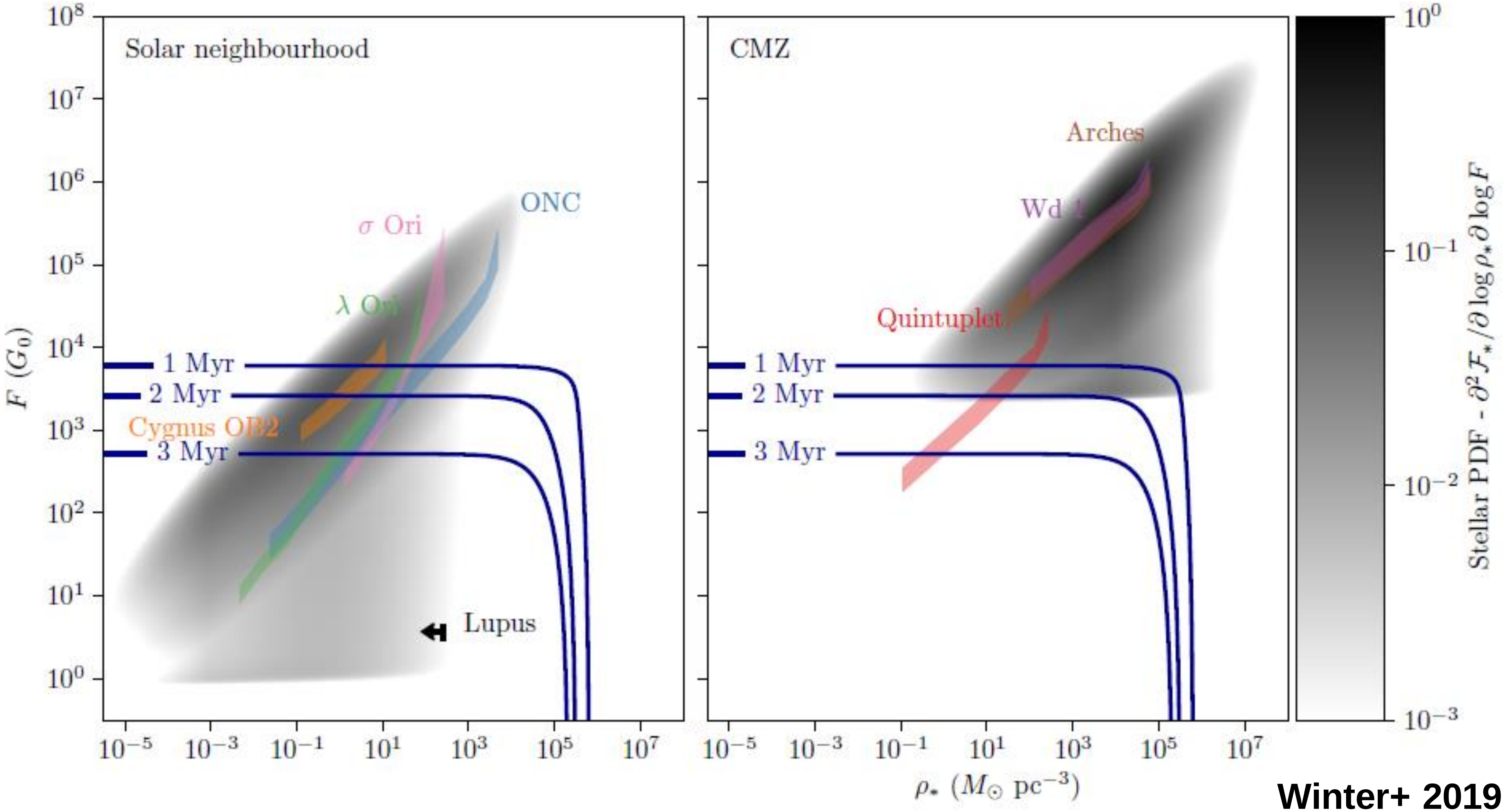


Level of irradiation

Stellar density

Winter, Clarke, GR+ 2018
Using external photo-evaporation models from Facchini+ 2016 and Haworth+ 2018

Where did the average star form?



Winter+ 2019

Talk A. Winter

50% (in the solar neighbourhood) in regions affected by external photo-evaporation

Thus:

a) The average disc is NOT from Taurus or Lupus
b) Reinforces idea that planet formation is fast

Conclusions

- Photo-evaporation is the most established disc dispersal mechanism
- In binaries, either viscous evolution (enhanced by tidal truncation) or photo-evaporation is dominant depending on separation
- In a massive environment, external photo-evaporation always dominates over encounters
- The average star (and planetary system) formed in a region significantly affected by the environment. Planet formation must be really fast!