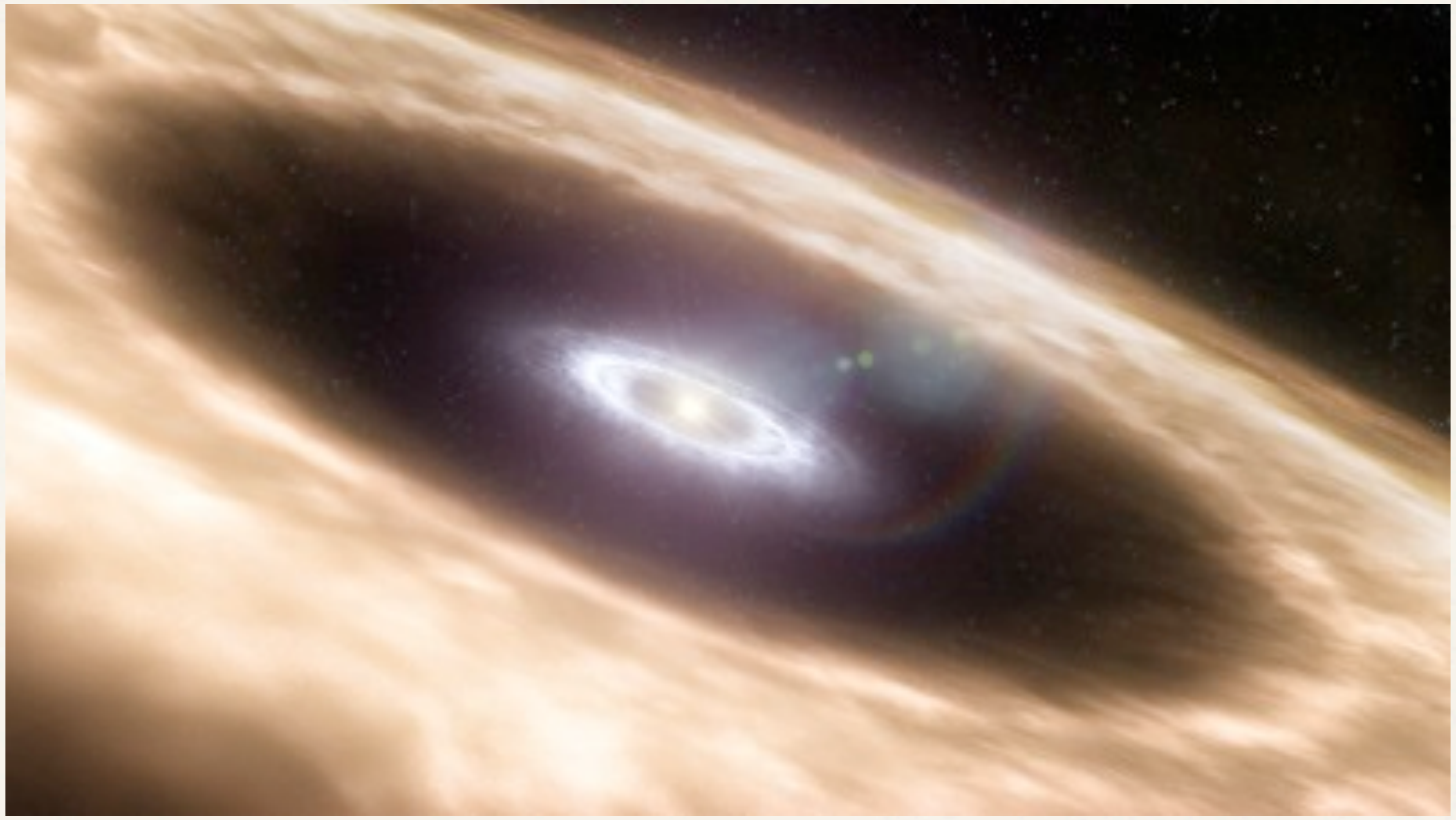
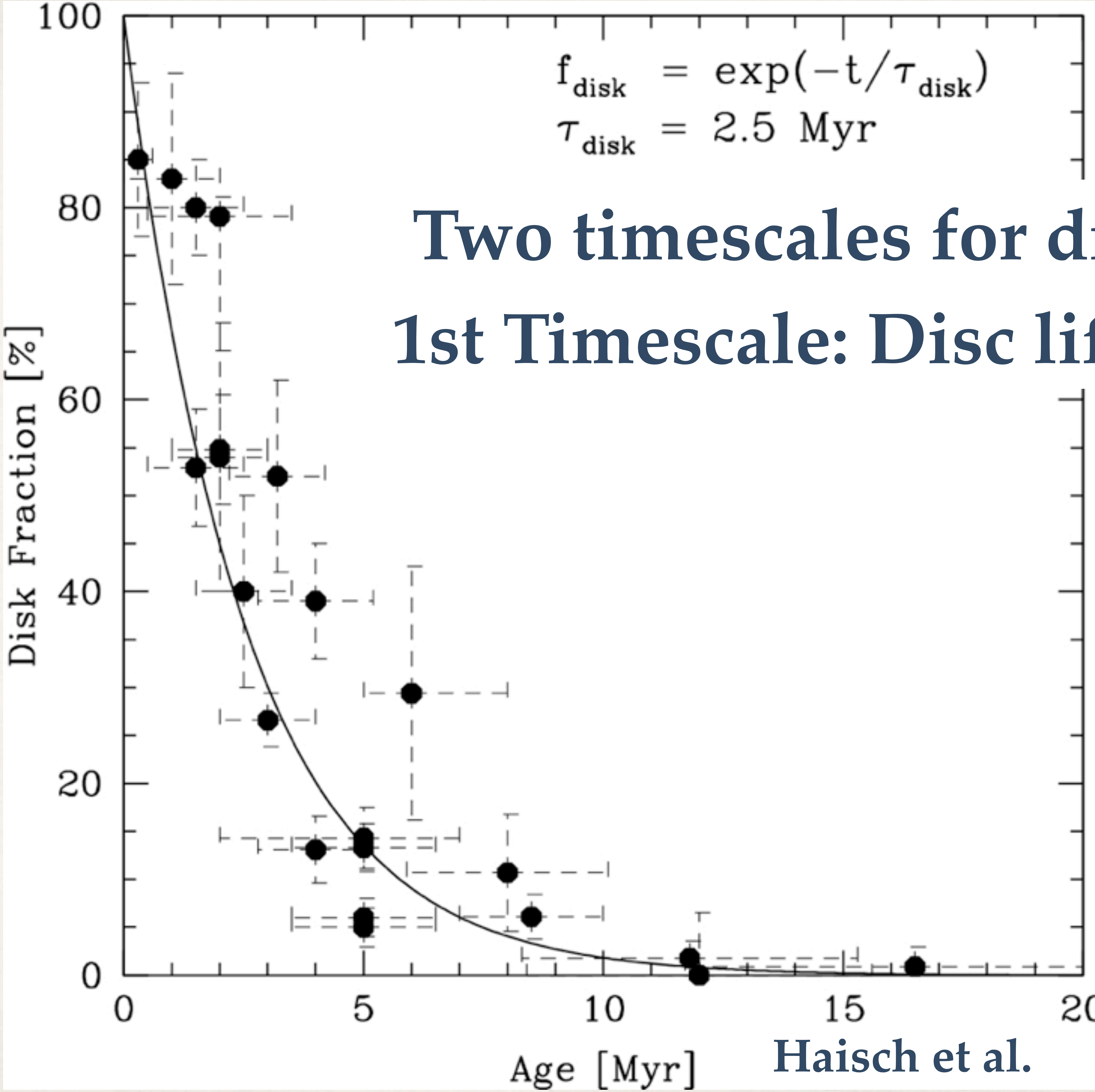
The dispersal of Protoplanetary Discs



Barbara Ercolano
Universitäts-Sternwarte-München
Excellence Cluster "Universe"

Two timescales for dispersal

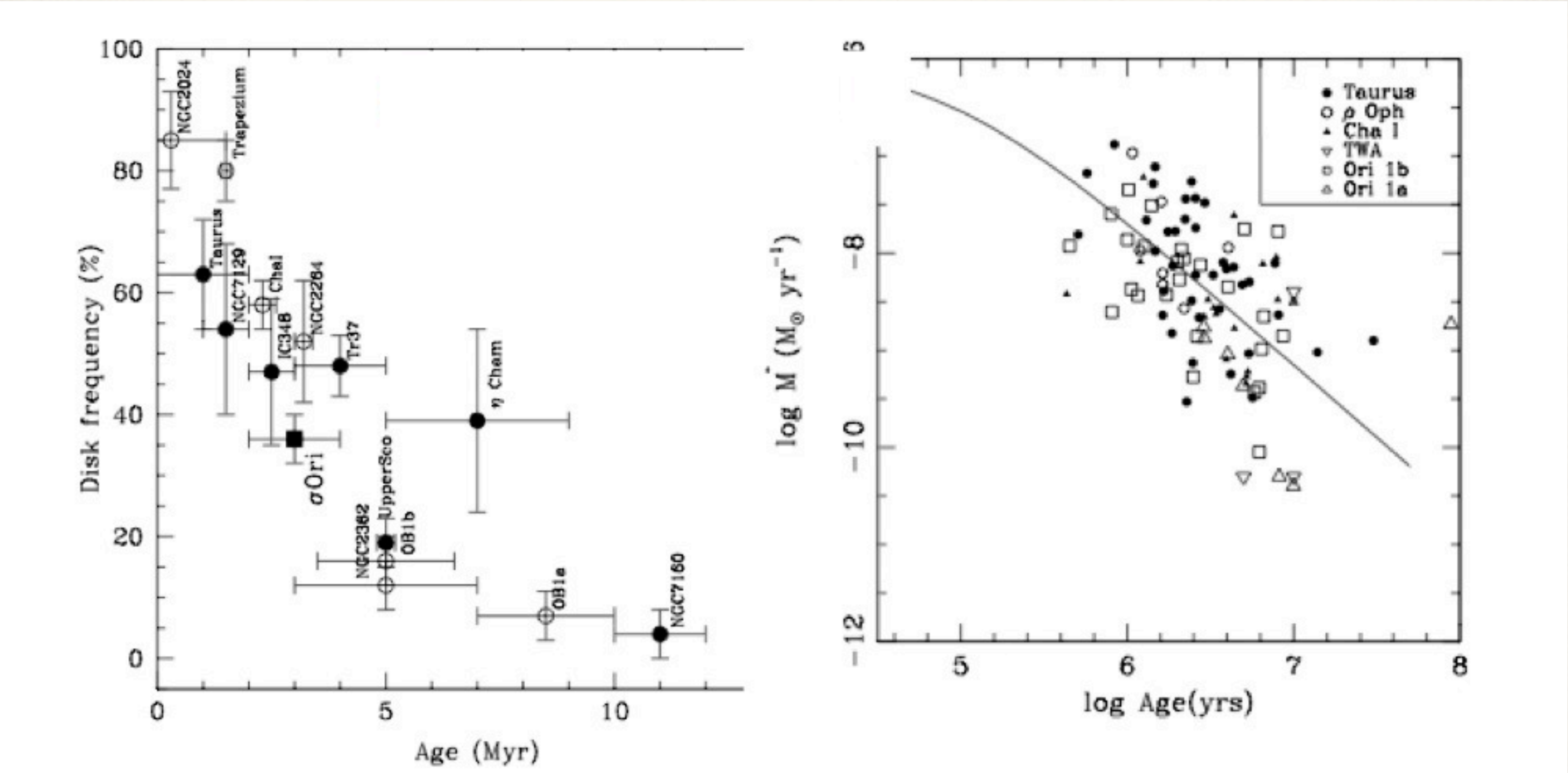
1st Timescale: Disc lifetime



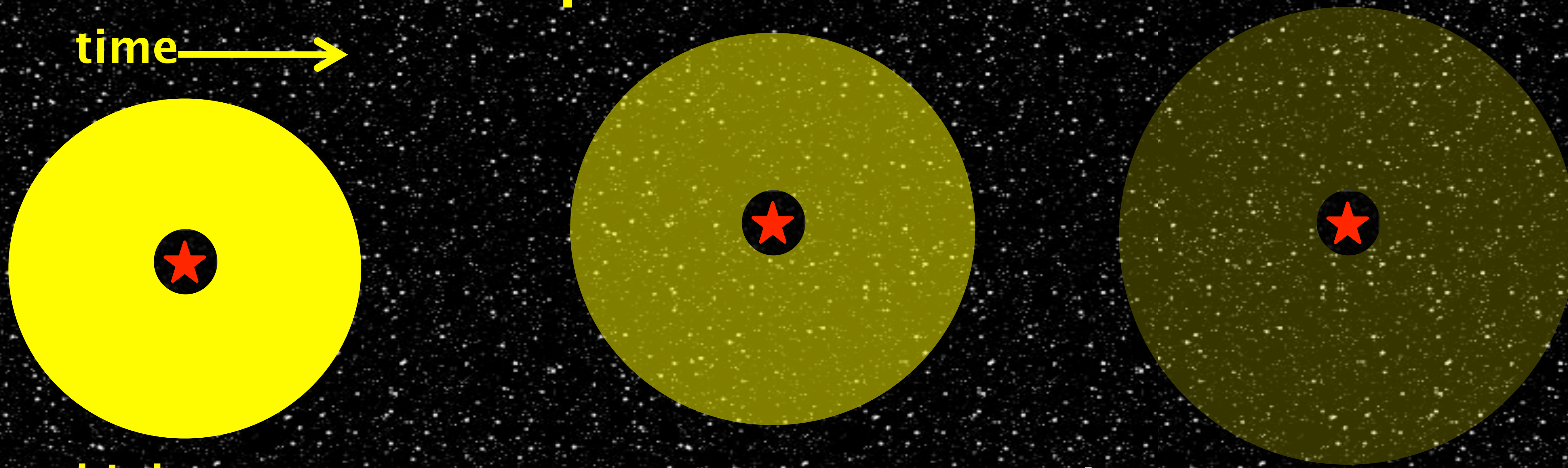
Haisch et al.

What is responsible for disc dispersal?

Viscous accretion is probably at work but is it the whole story???



Viscous evolution predicts....

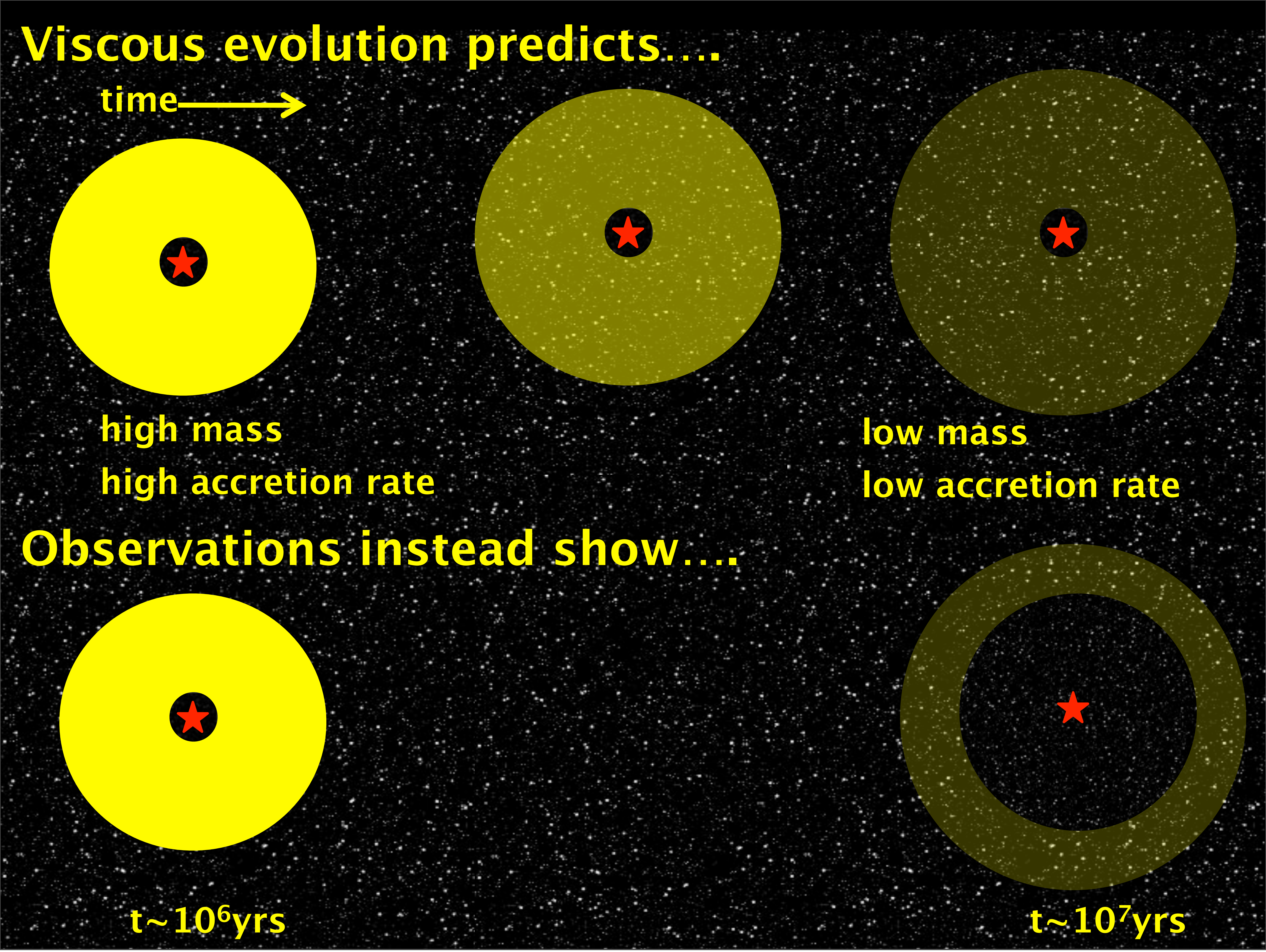


high mass

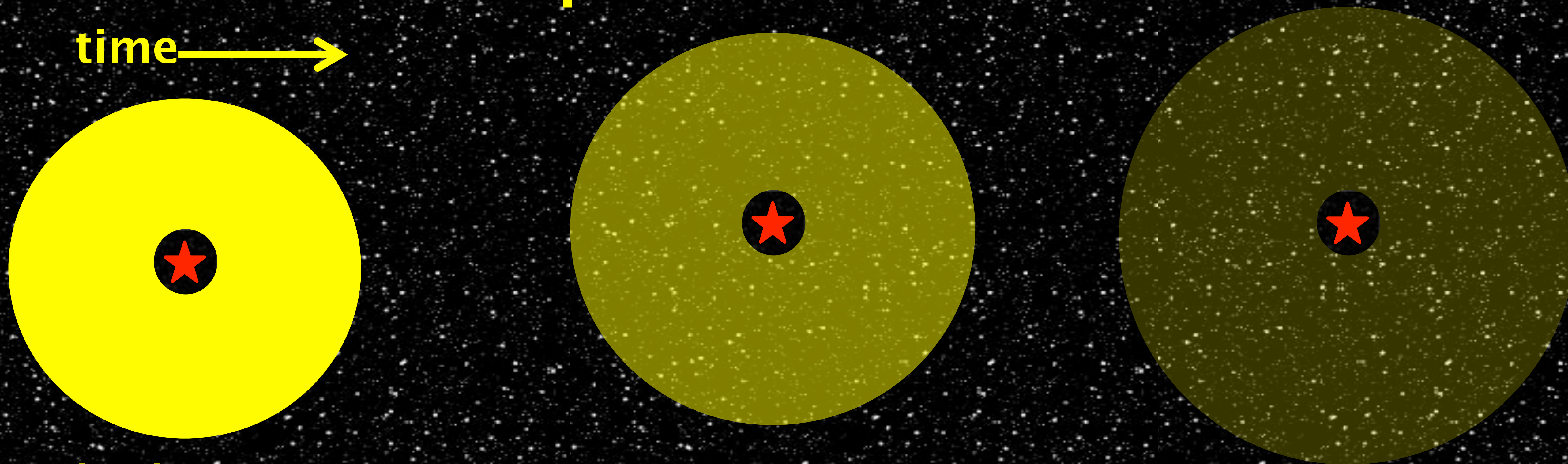
high accretion rate

low mass

low accretion rate


Viscous evolution predicts....
time
high mass
high accretion rate
low mass
low accretion rate
Observations instead show....
t~10^6yrs
t~10^7yrs

Viscous evolution predicts....



high mass
high accretion rate

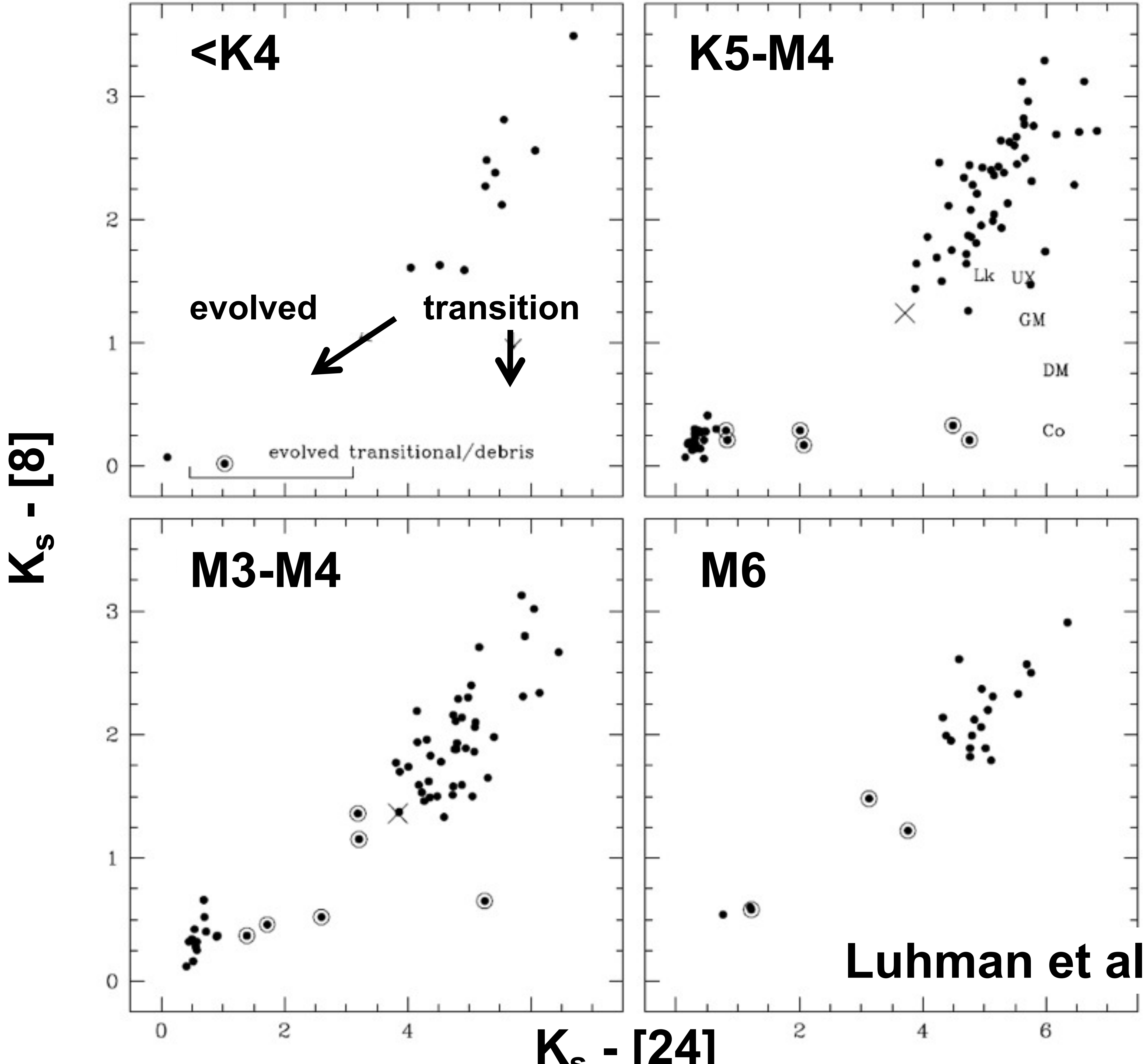
low mass
low accretion rate

Observations instead show....

Rare transition disk

$t \sim 10^6$yrs

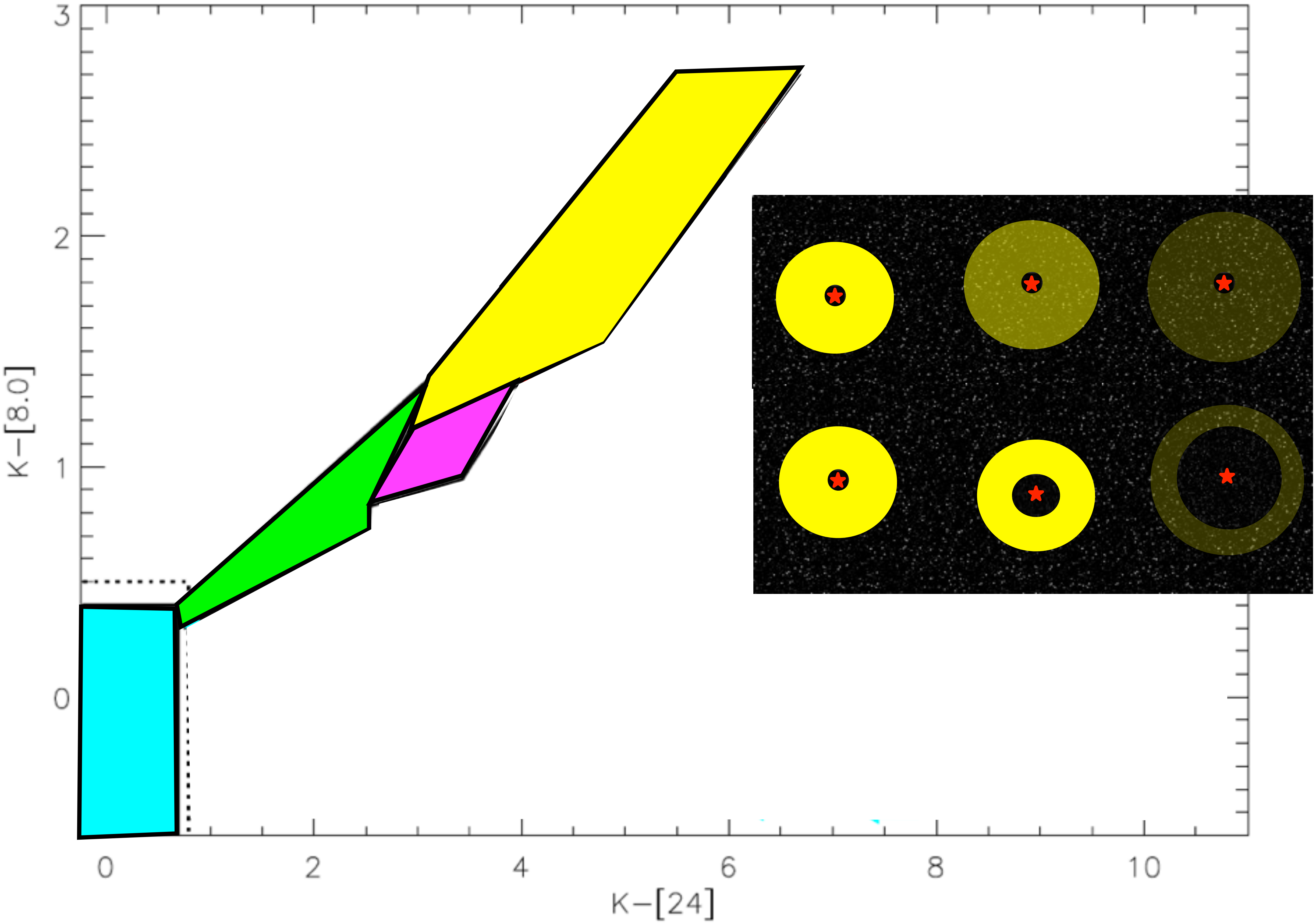
$t \sim 10^7$yrs



Two-colour diagram of young sources in Taurus

Luhman et al 2010

The clearing of discs around late type T-Tauri stars
(Ercolano, Clarke & Hall 2011, MNRAS)



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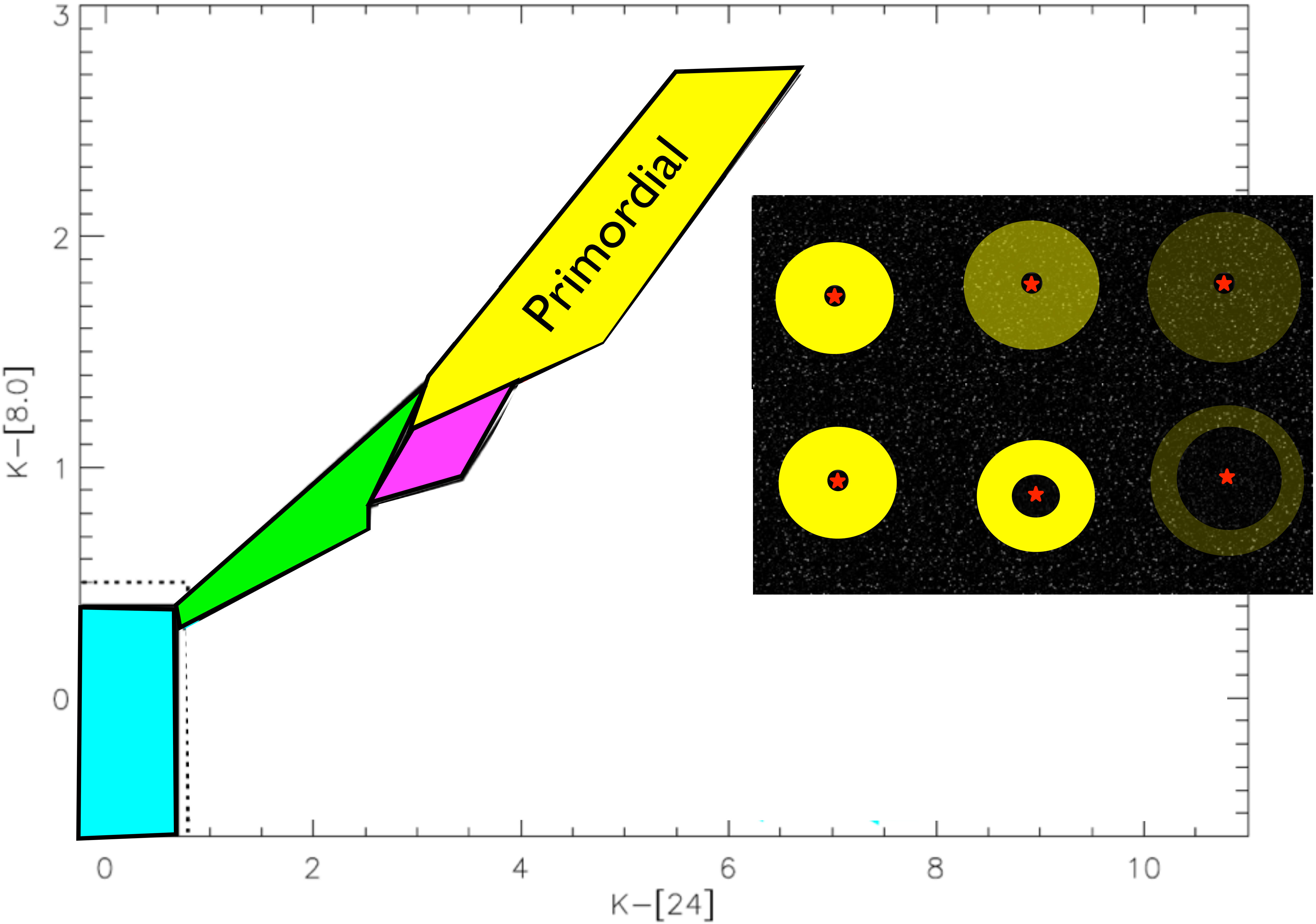

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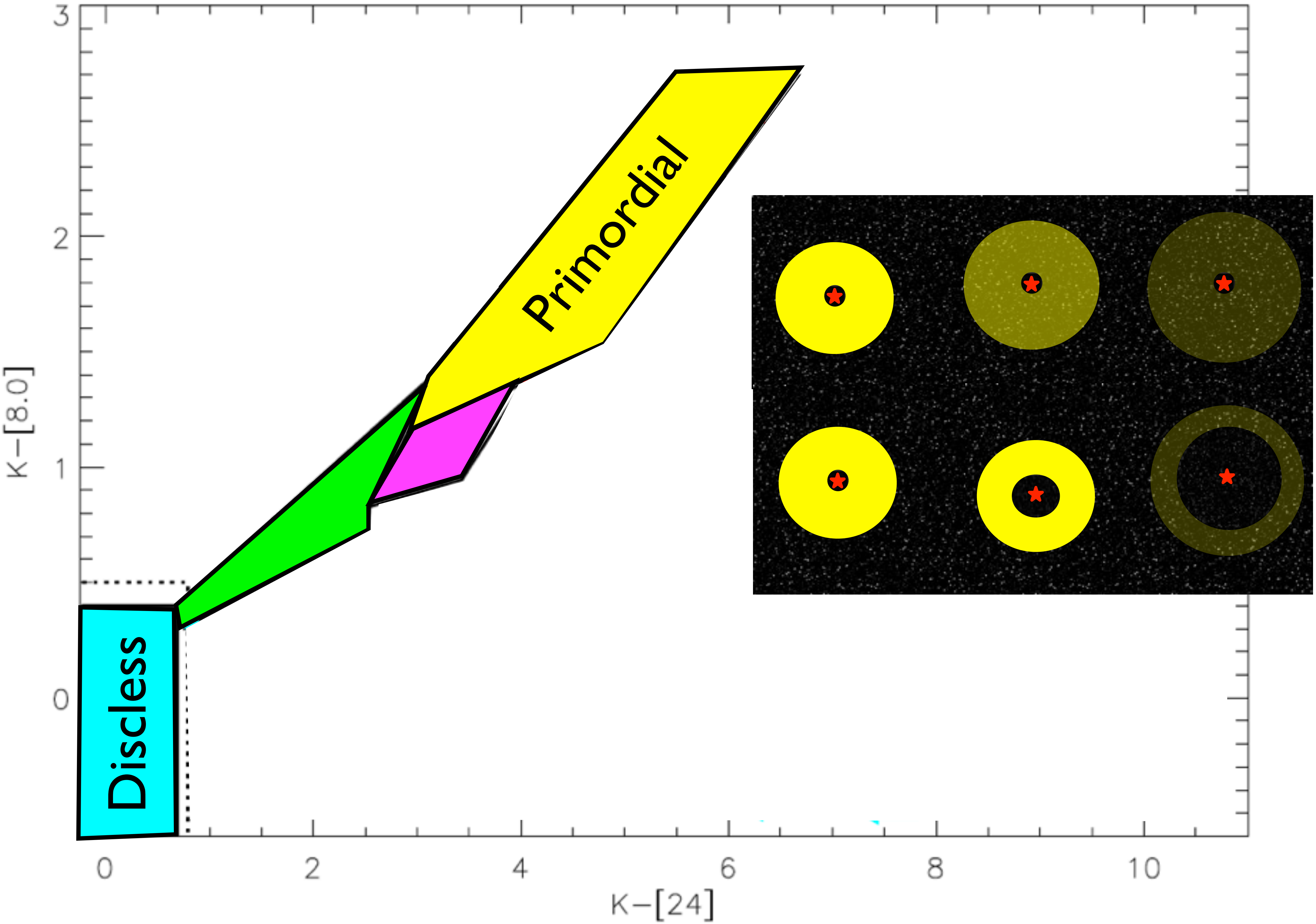

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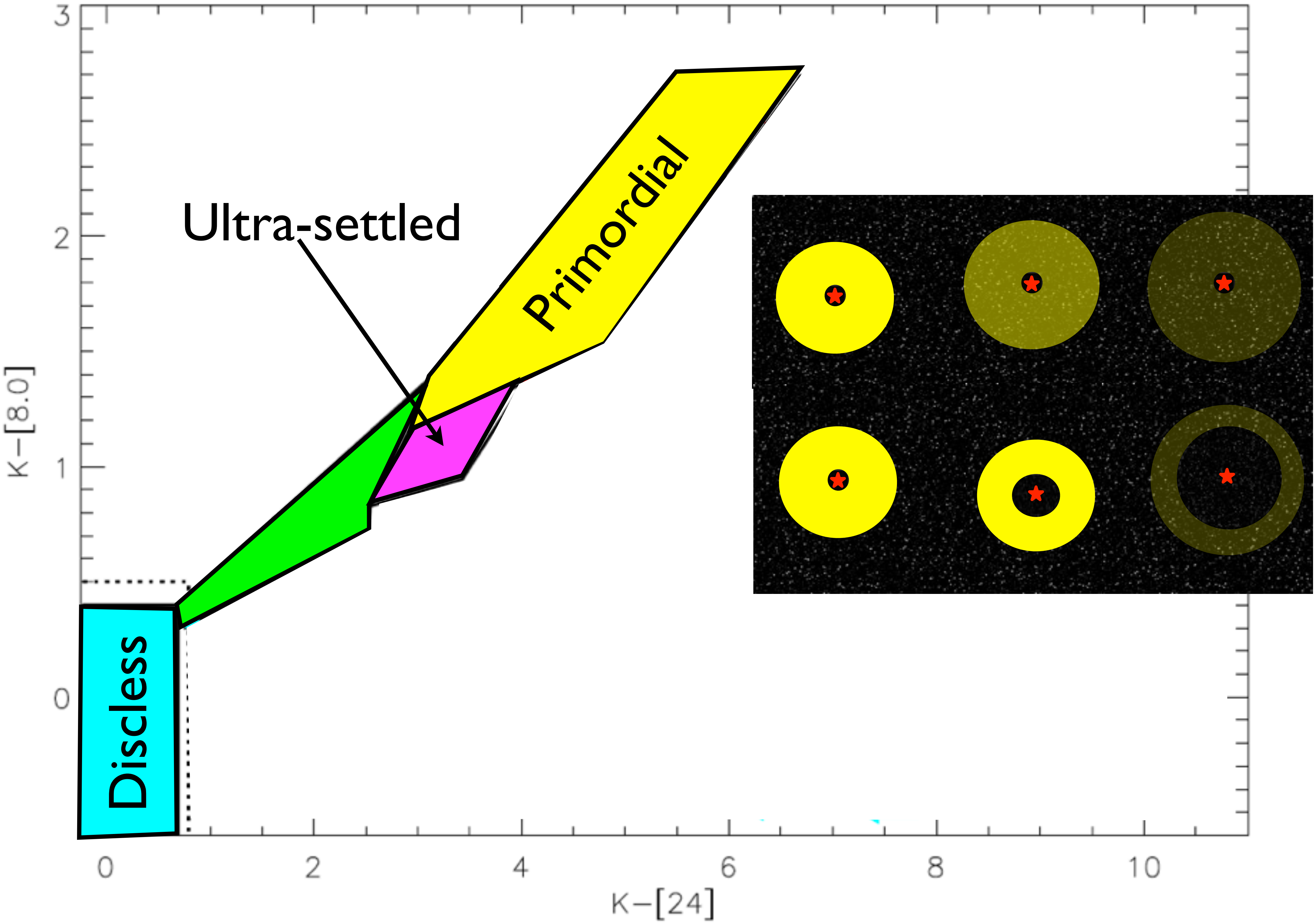

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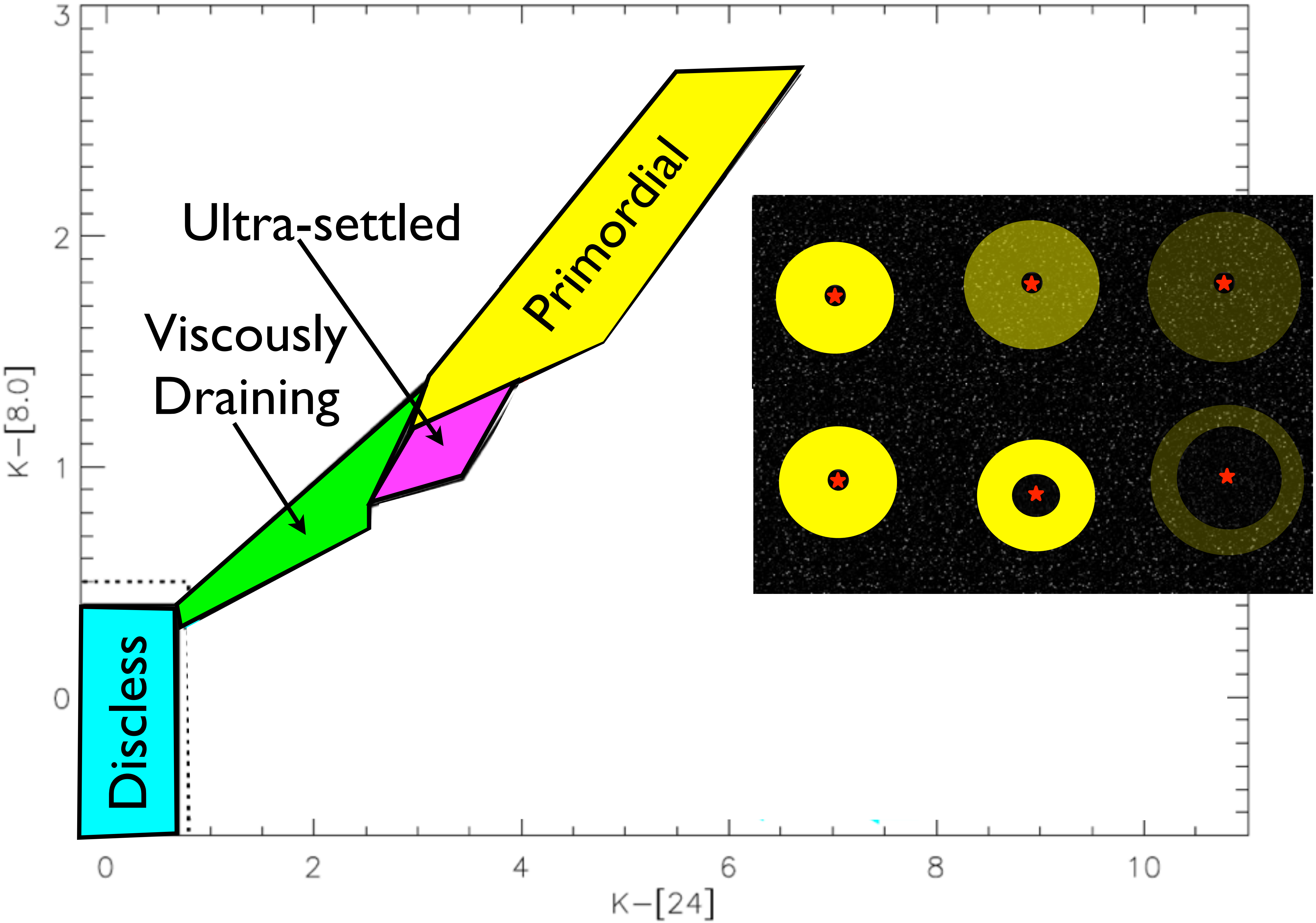

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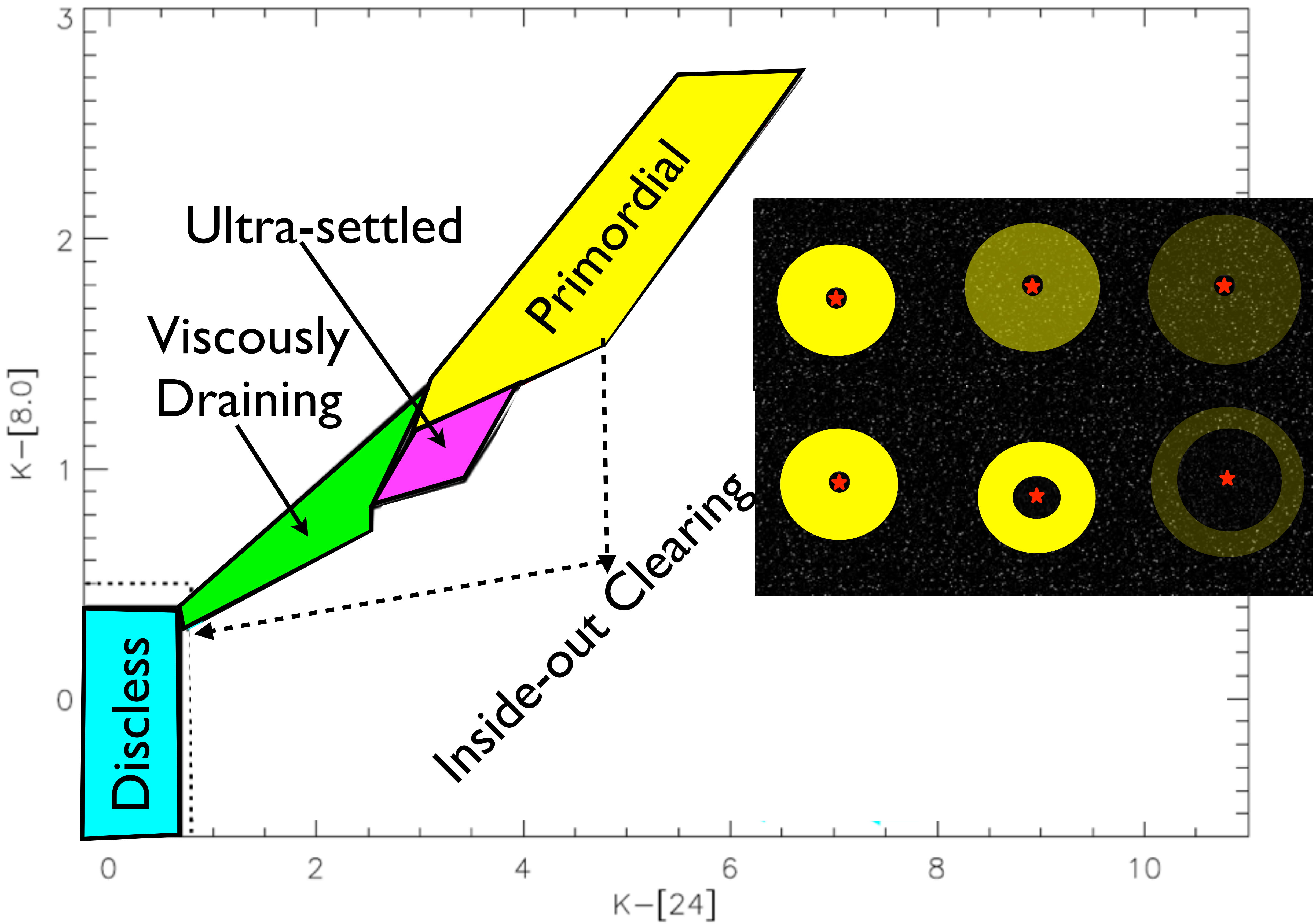

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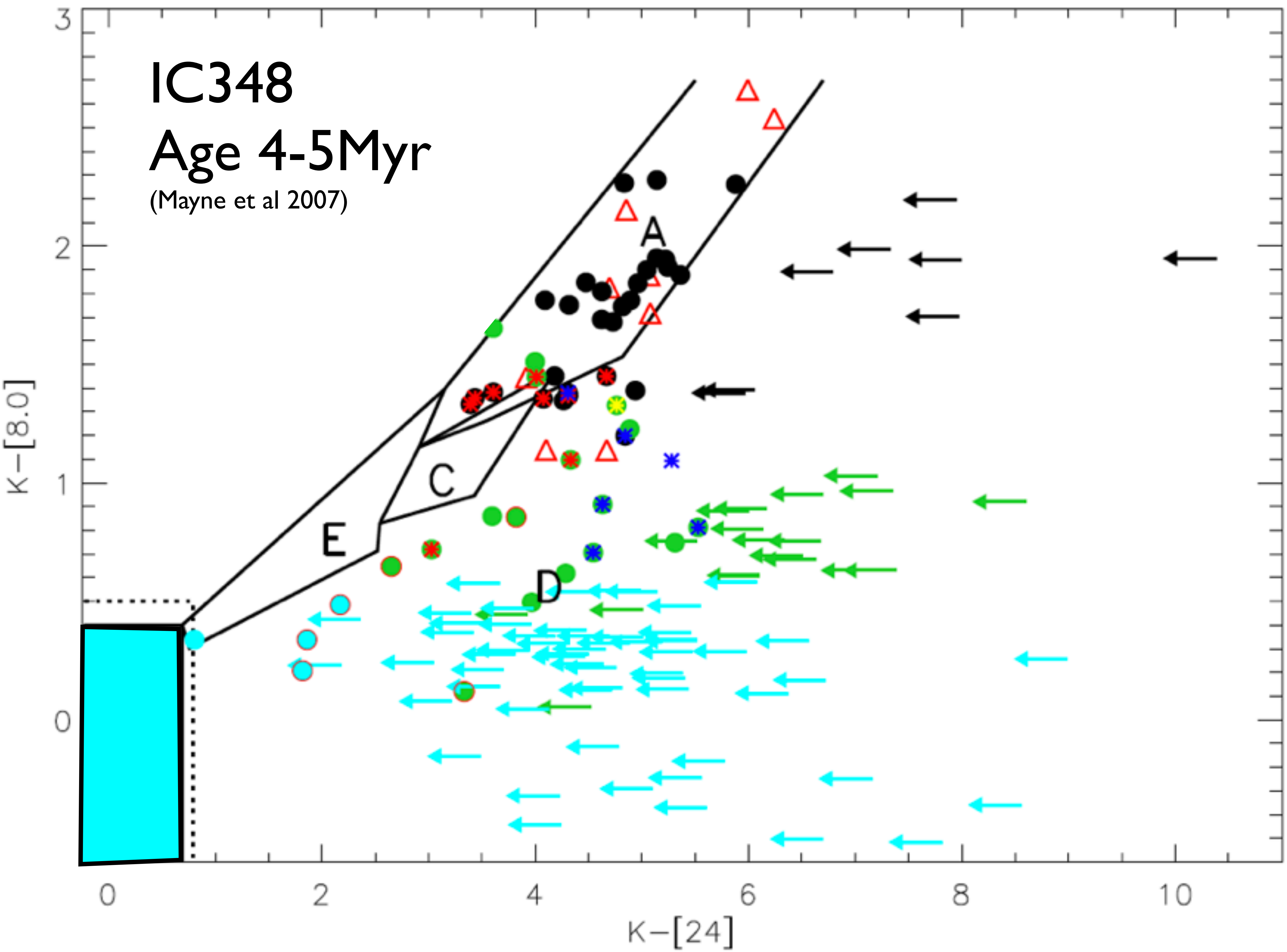
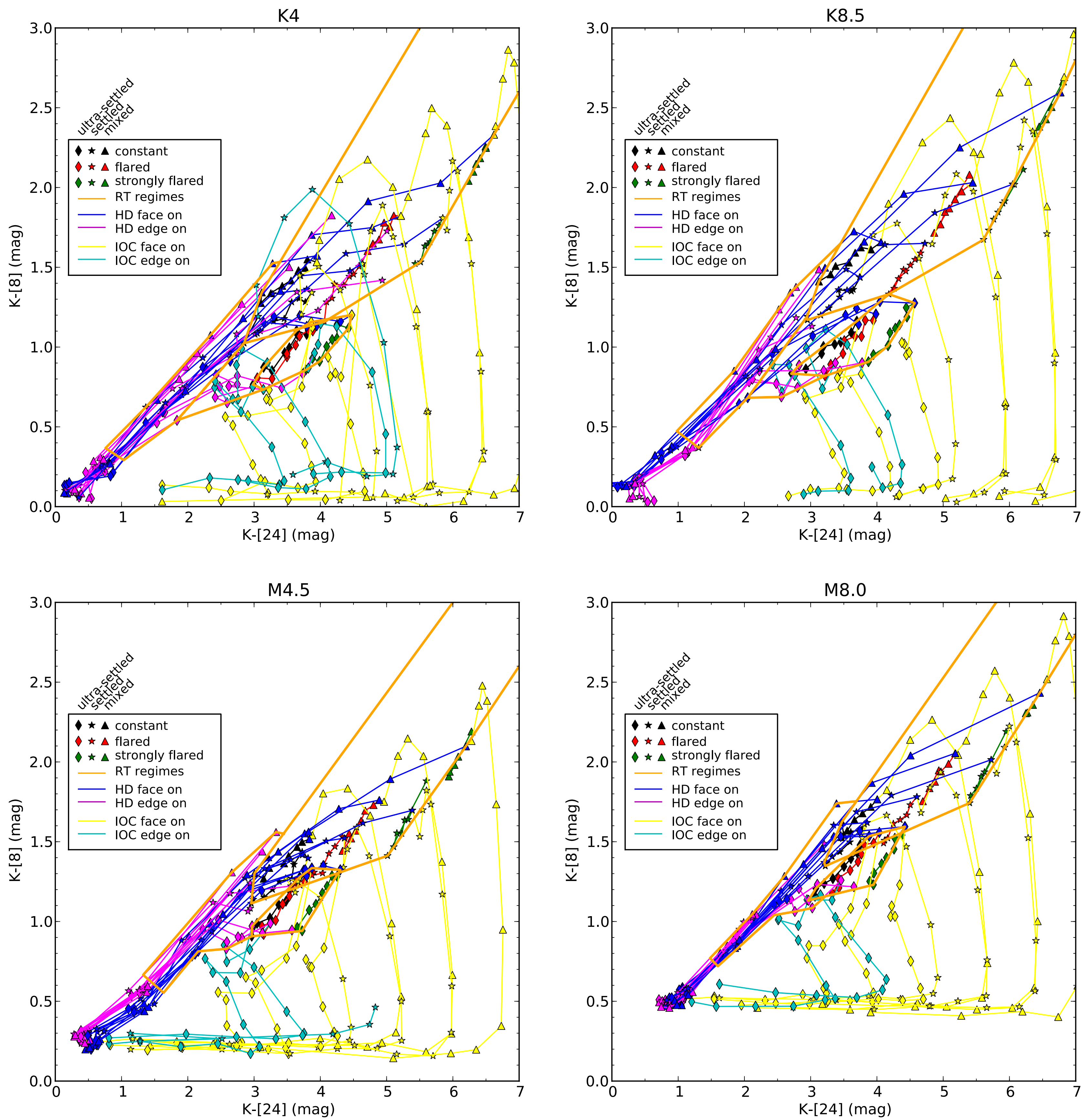


finite thickness disc

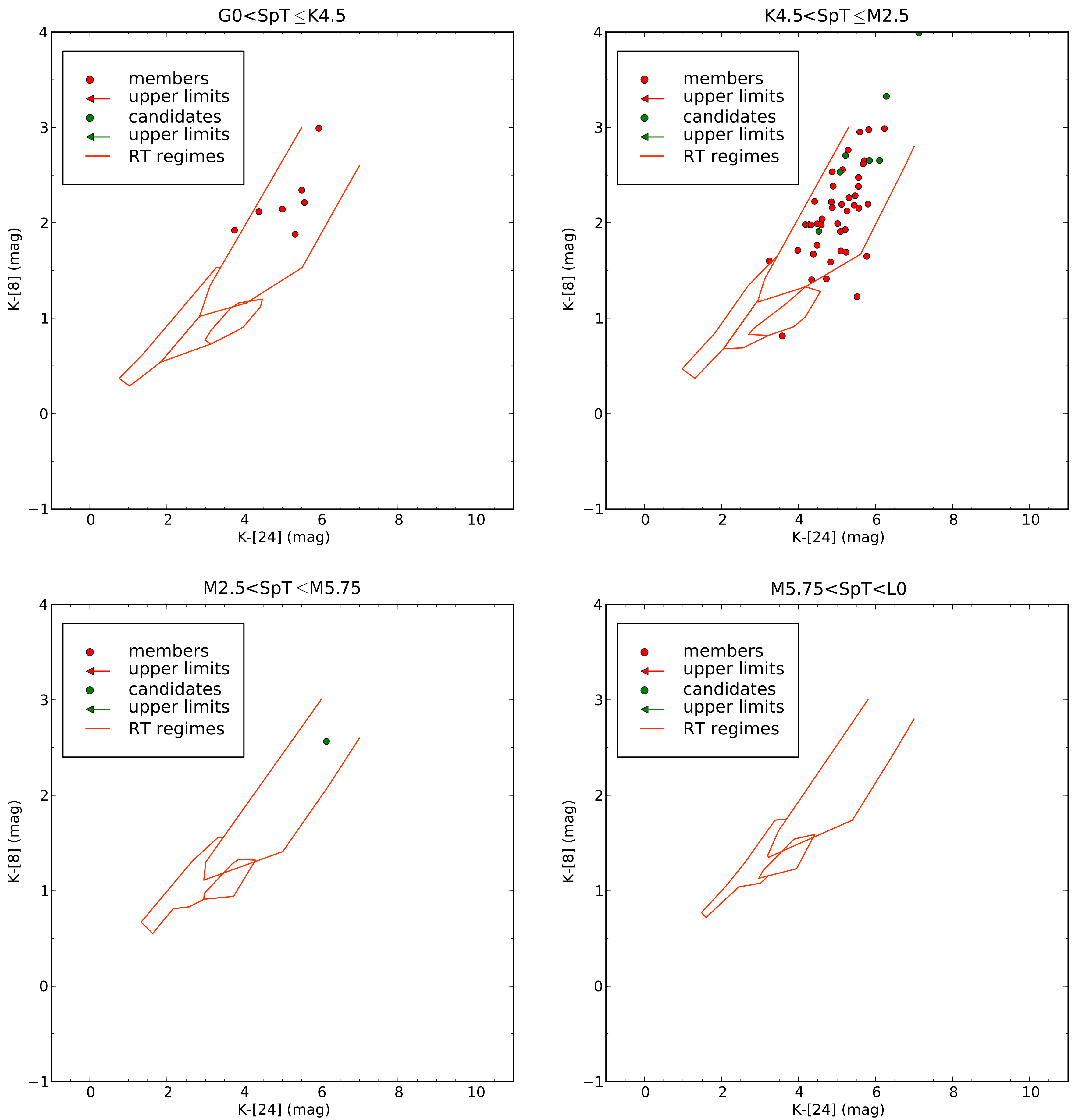
Koepferl, Ercolano et al. 2012



Koepferl, Ercolano et al. 2012

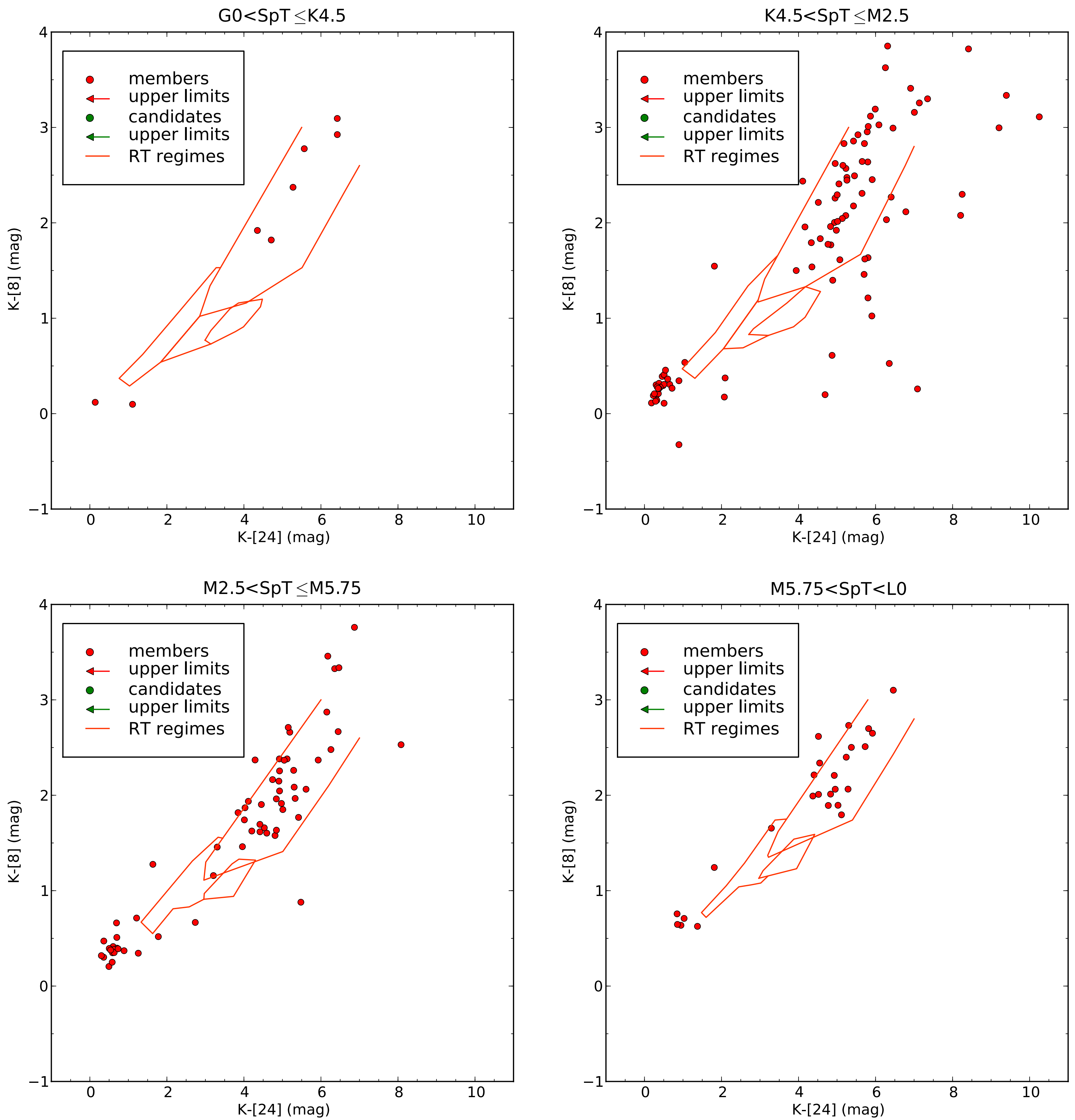
Tr37

Koepferl, Ercolano et al. 2012



Taurus (Luhman)

Koepferl, Ercolano et al. 2012



cluster	SpT	τ_{SpT} [Myr]	$<\tau_{SpT}>$ [Myr]	τ_c [Myr]
IC348	all	-	1.78 ± 1.05	1.75 ± 0.60
IC348	I	1.67 ± 1.14	-	-
IC348	II	1.51 ± 0.72	-	-
IC348	III	1.85 ± 0.71	-	-
IC348	IV	2.12 ± 1.65	-	-
Taurus^L	all	-	0.12 ± 0.10	0.14 ± 0.05
Taurus^L	I	0.13 ± 0.18	-	-
Taurus^L	II	0.22 ± 0.09	-	-
Taurus^L	III	0.06 ± 0.04	-	-
Taurus^L	IV	0.07 ± 0.07	-	-
Taurus^R	all	-	[illegible] $\pm$ 0.11	0.21 $\pm$ [illegible]
Taurus^R	I	0.30 ± 0.16	-	-
Taurus^R	II	0.18 ± 0.08	-	-
Taurus^R	III	0.12 ± 0.07	-	-
Taurus^R	IV	0.31 ± 0.15	-	-
Tr 37	all	-	[illegible]	[illegible]
Tr 37	I	-	-	-
Tr 37	II	0.33 ± 0.24	-	-
Tr 37	III	-	-	-
Tr 37	IV	-	-	-
Upper Sco	all	-	0.41 ± 0.35	0.38 ± 0.19
Upper Sco	I			
Upper Sco	II			
Upper Sco	III			
Upper Sco	IV			
OB1bf	all	-	1.55 ± 1.86	1.54 ± 1.35
NGC1333	I	-	-	-
NGC1333	II	1.00 ± 0.81	-	-
NGC1333	III	0.83 ± 0.65	-	-
NGC1333	IV	0.60 ± 0.93	-	-

cluster	SpT	τ_{SpT} [Myr]	$<\tau_{SpT}>$ [Myr]	τ_c [Myr]
NGC2068/71	all	-	0.34 ± 0.38	0.30 ± 0.23
NGC2068/71	I	0.44 ± 0.51	-	-
NGC2068/71	II	0.24 ± 0.25	-	-
NGC2068/71	III	-	-	-
NGC2068/71	IV	-	-	-
NGC2264	all	-	1.04 ± 0.57	1.15 ± 0.27
NGC2264	I	1.23 ± 0.39	-	-
NGC2264	II	1.10 ± 0.33	-	-
NGC2264	III	1.[illegible] $\pm$ 0.43	-	-
NGC2264	IV	[illegible]	-	-
η Cha	all	-	0.67 ± 0.96	0.43 ± 0.59
η Cha	I	-	-	-
η Cha	II	-	-	-
η Cha	III	0.67 ± 0.96	-	-
η Cha	IV	-	-	-
Cha I	all	-	[illegible]	[illegible] $\pm$ 0.19
Cha I	I	[illegible]	-	-
Cha I	II	0.19 ± 0.28	-	-
Cha I	III	0.28 ± 0.43	-	-
Cha I	IV	-	-	-
Cha II	all	-	0.47 ± 0.68	0.33 ± 0.34
Lup III	all	-	1.00 ± 1.37	0.88 ± 0.74
Serpens	I	0.57 ± 1.07	-	-
Serpens	II	1.05 ± 1.03	-	-
Serpens	III	0.80 ± 0.98	-	-
Serpens	IV	-	-	-

L: Data from Luhman et al. (2010)
R: Data from Rebull et al. (2010)

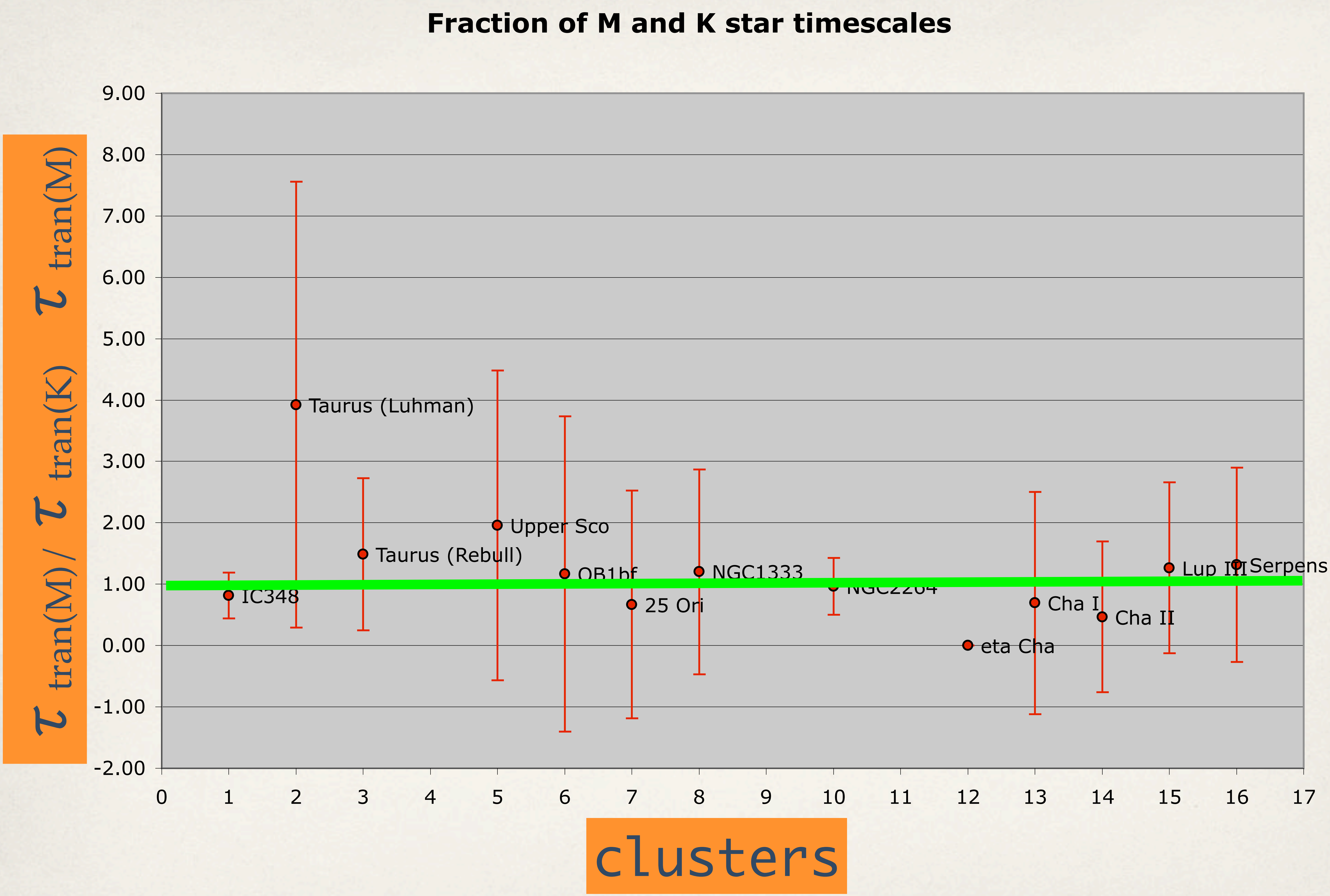
I $\in$ $[G0; K4.5]$
II $\in$ $]K4.5; M2.5]$
III $\in$ $]M2.5; M5.75]$
IV $\in$ $]M5.75; L0[$

$\tau_{tran} \sim 10^5$ yr

no evidence for homogeneous draining

Two timescales for dispersal

2nd Timescale: Transition timescale / mode



Koepferl, Ercolano et al. 2012

(see also Ercolano et al. 2011)

Disk Dispersal: a two-timescale problem

What is responsible for the rapid dispersal???

Disk Dispersal: a two-timescale problem

- Gaseous disks are seen healthy and optically thick generally up to ages of a few Myrs
- At ~10 Myr they are almost gone (debris disks)
- Only a few are 'caught in the act' (transition disks) – roughly 10%
- Transition phase must be extremely quick (~10^5 yrs)

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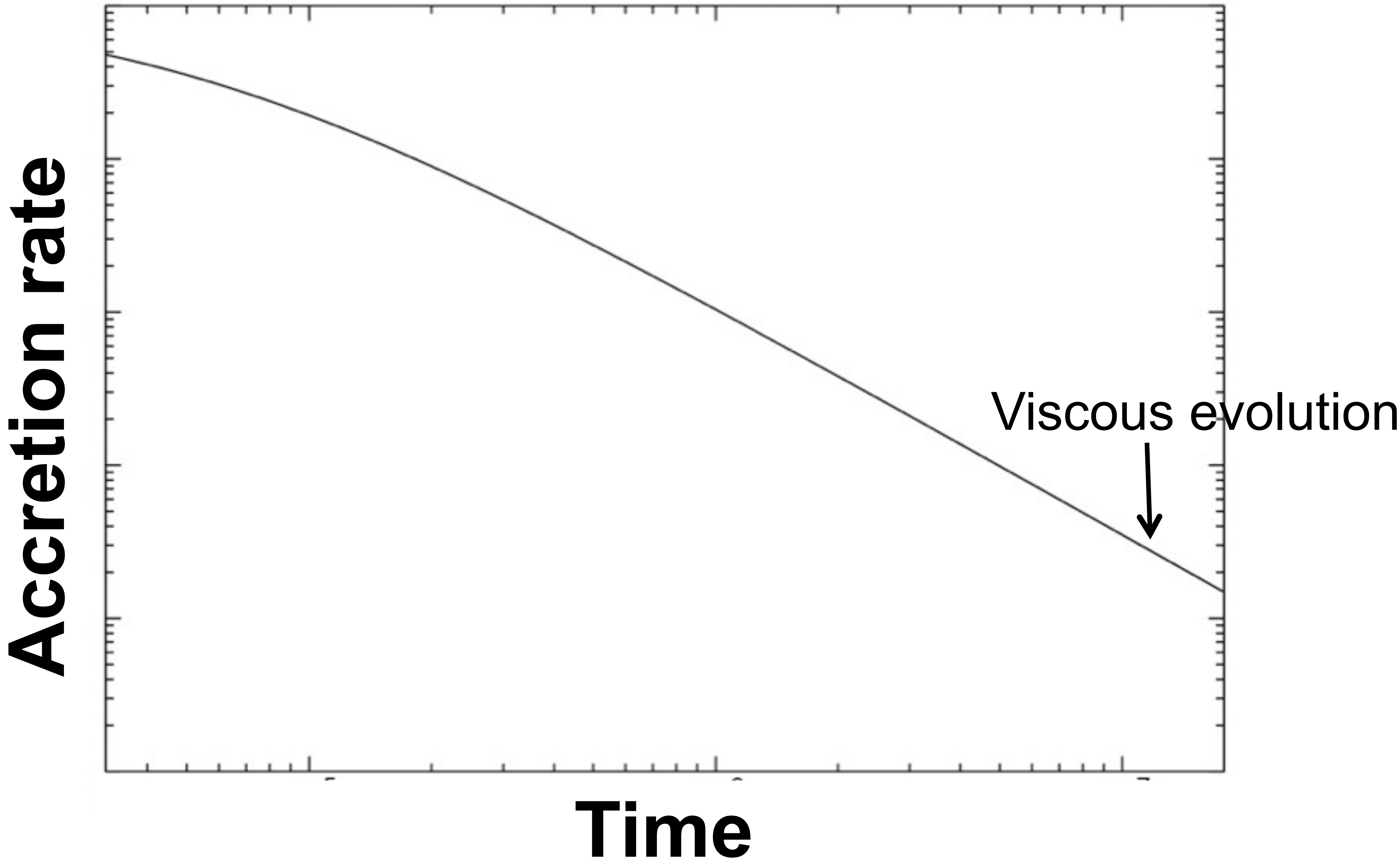
X-ray switch model



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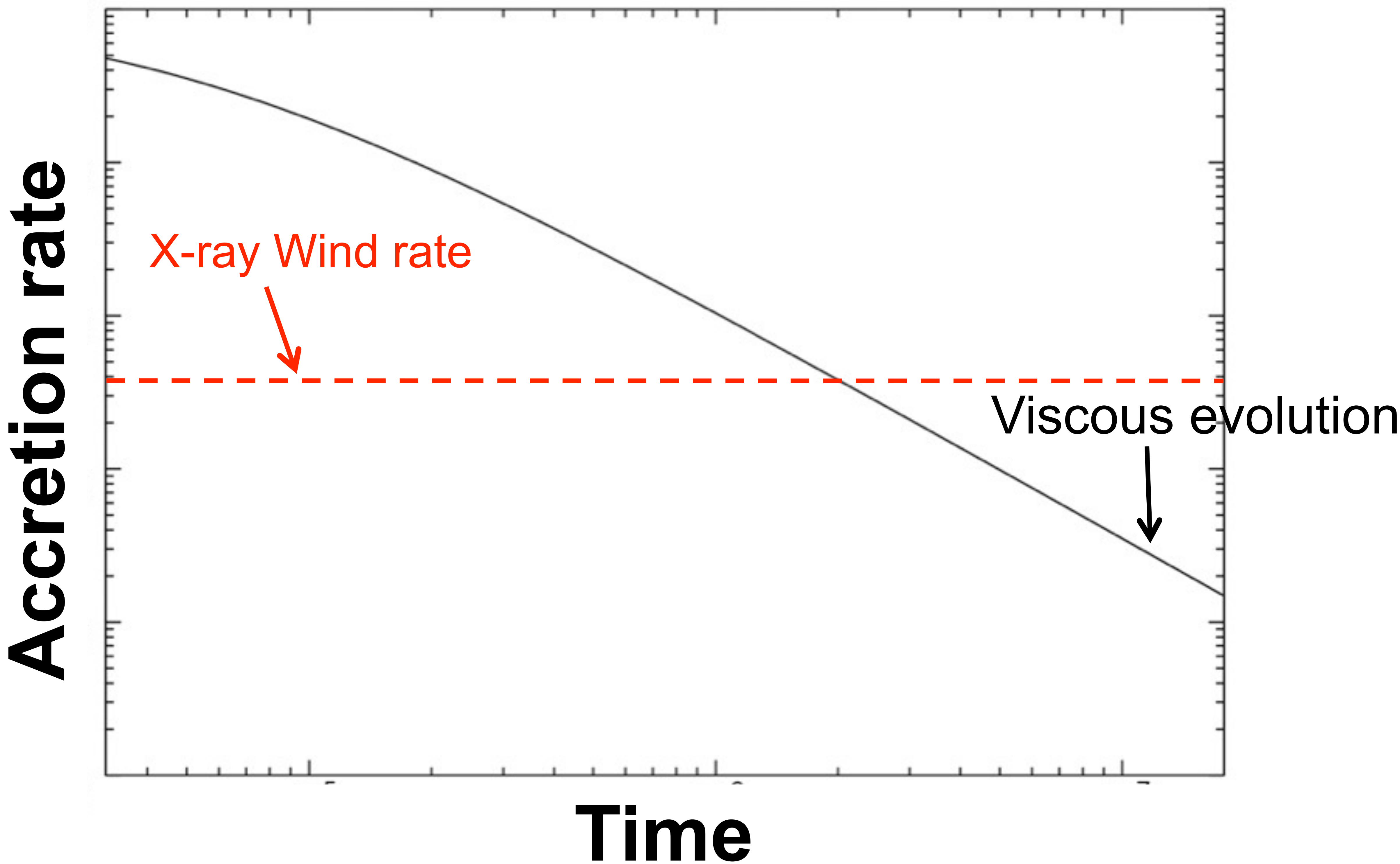
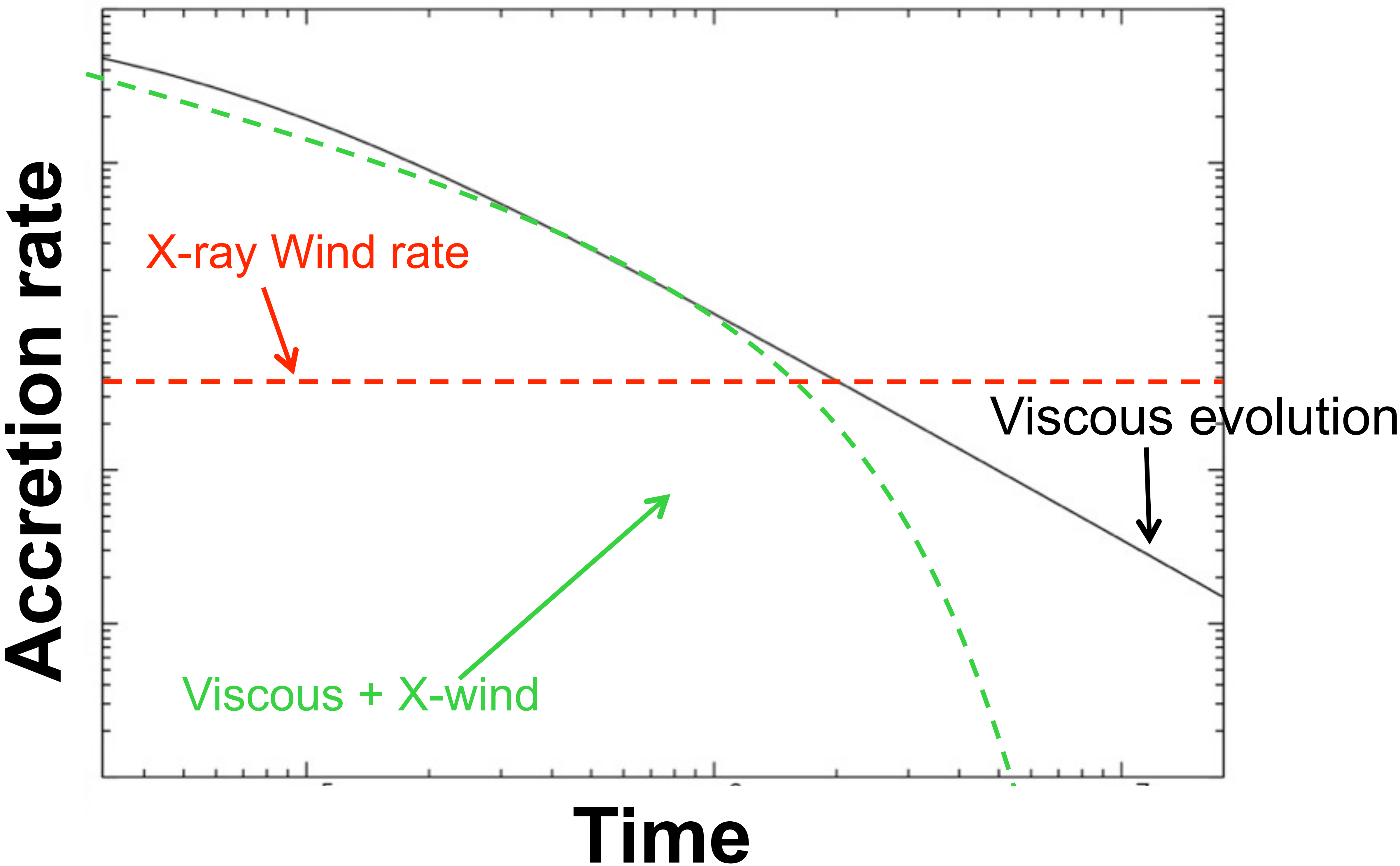
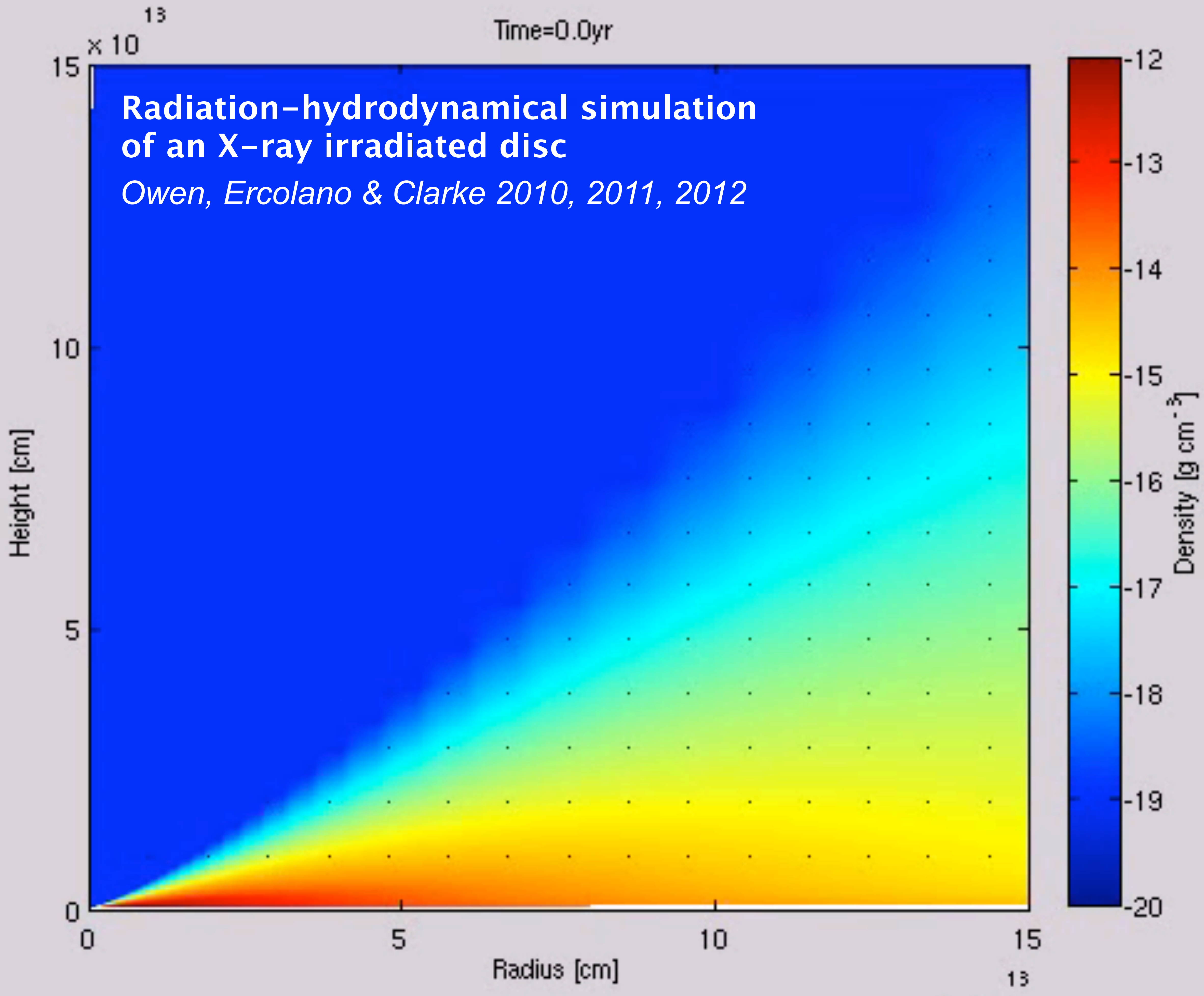
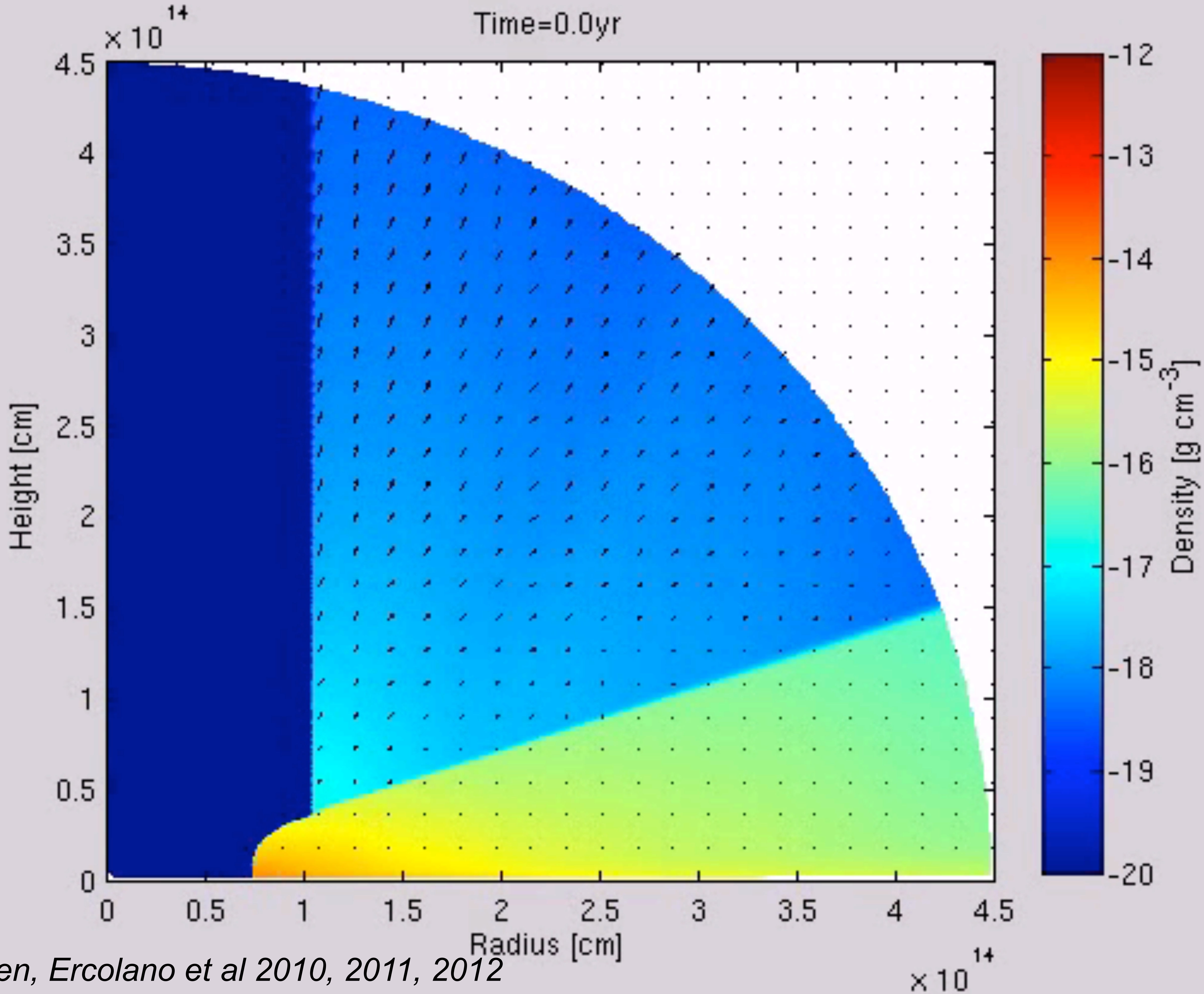


X-ray switch model

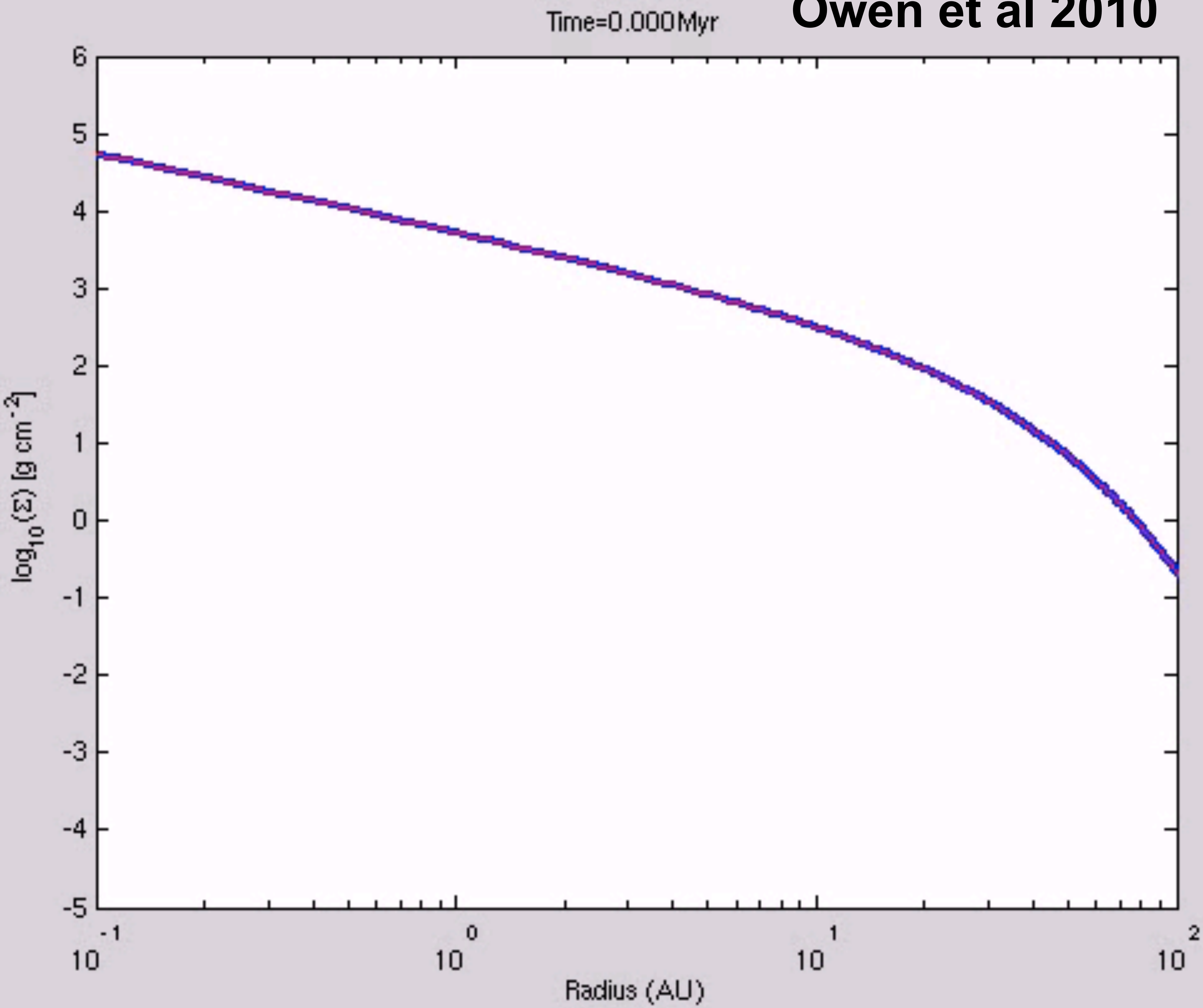



Radiation-hydrodynamical simulation
of an X-ray irradiated disc
Owen, Ercolano & Clarke 2010, 2011, 2012
Time=0.0yr
× 10^13
15
10
5
0
Height [cm]
Radius [cm]
× 10^13
-12
-13
-14
-15
-16
-17
-18
-19
-20
Density [g cm^-3]



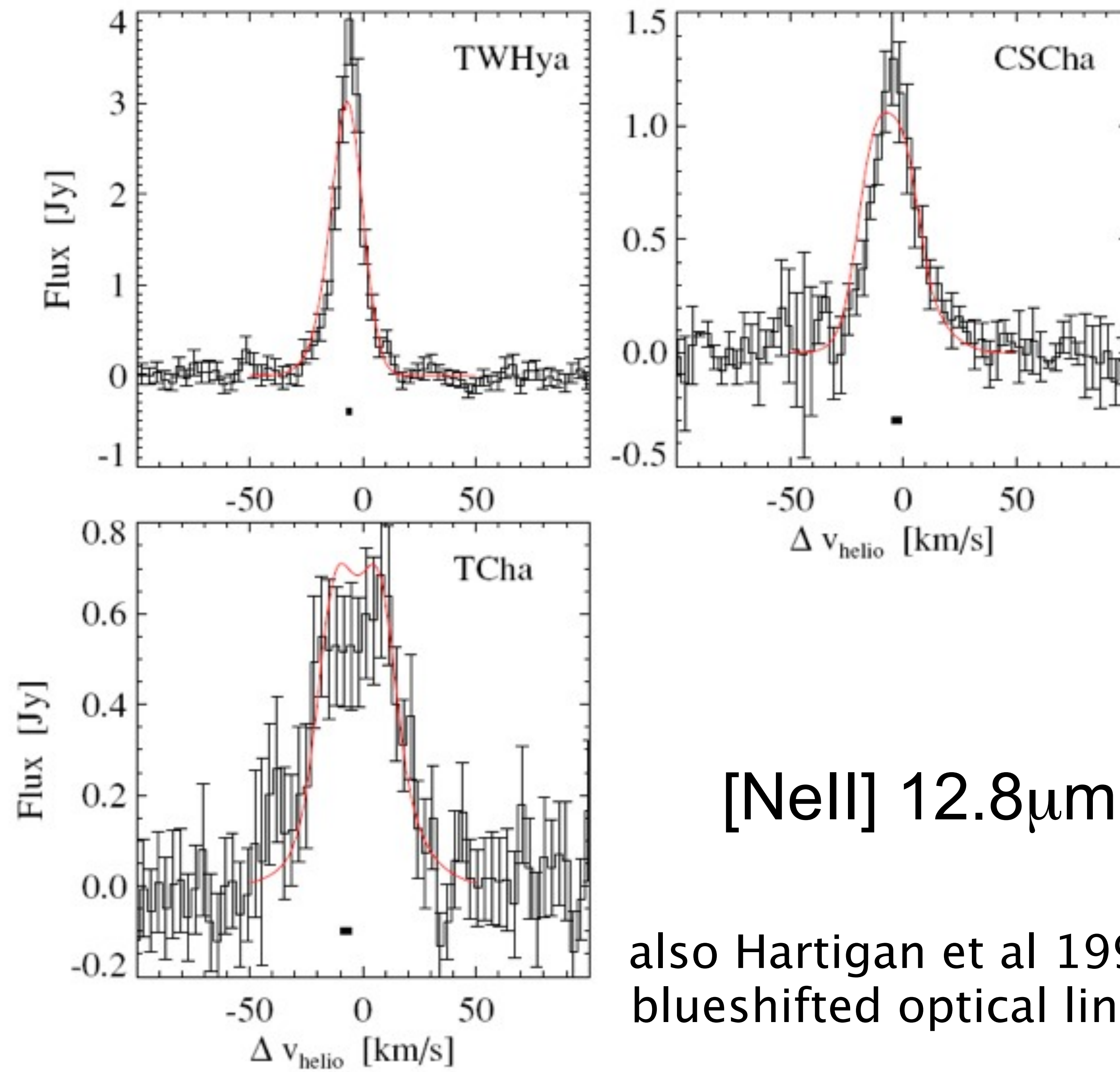
Owen, Ercolano et al 2010, 2011, 2012

Owen et al 2010



Can we 'see' the wind??

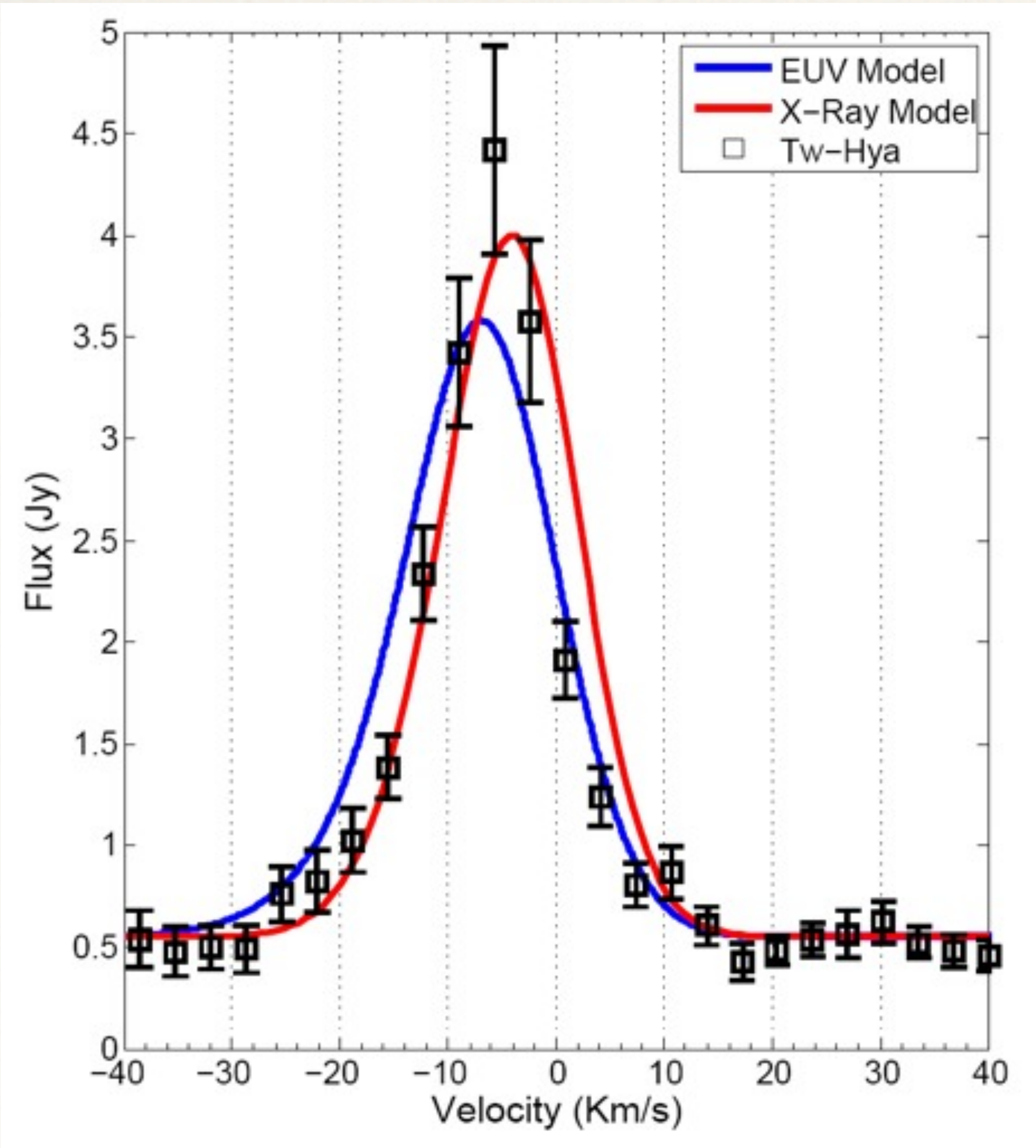
Pascucci & Sterzik, 2009



[NeII] 12.8μm

also Hartigan et al 1995
blueshifted optical lines

Emission lines formed in the wind will appear blueshifted as the material moves radially towards the observer for specific lines of sight



Ercolano & Owen 2010

EUV – M ~ $10^{-10} M_{\odot}$ /yr

X-ray – M ~ $10^{-8} M_{\odot}$ /yr

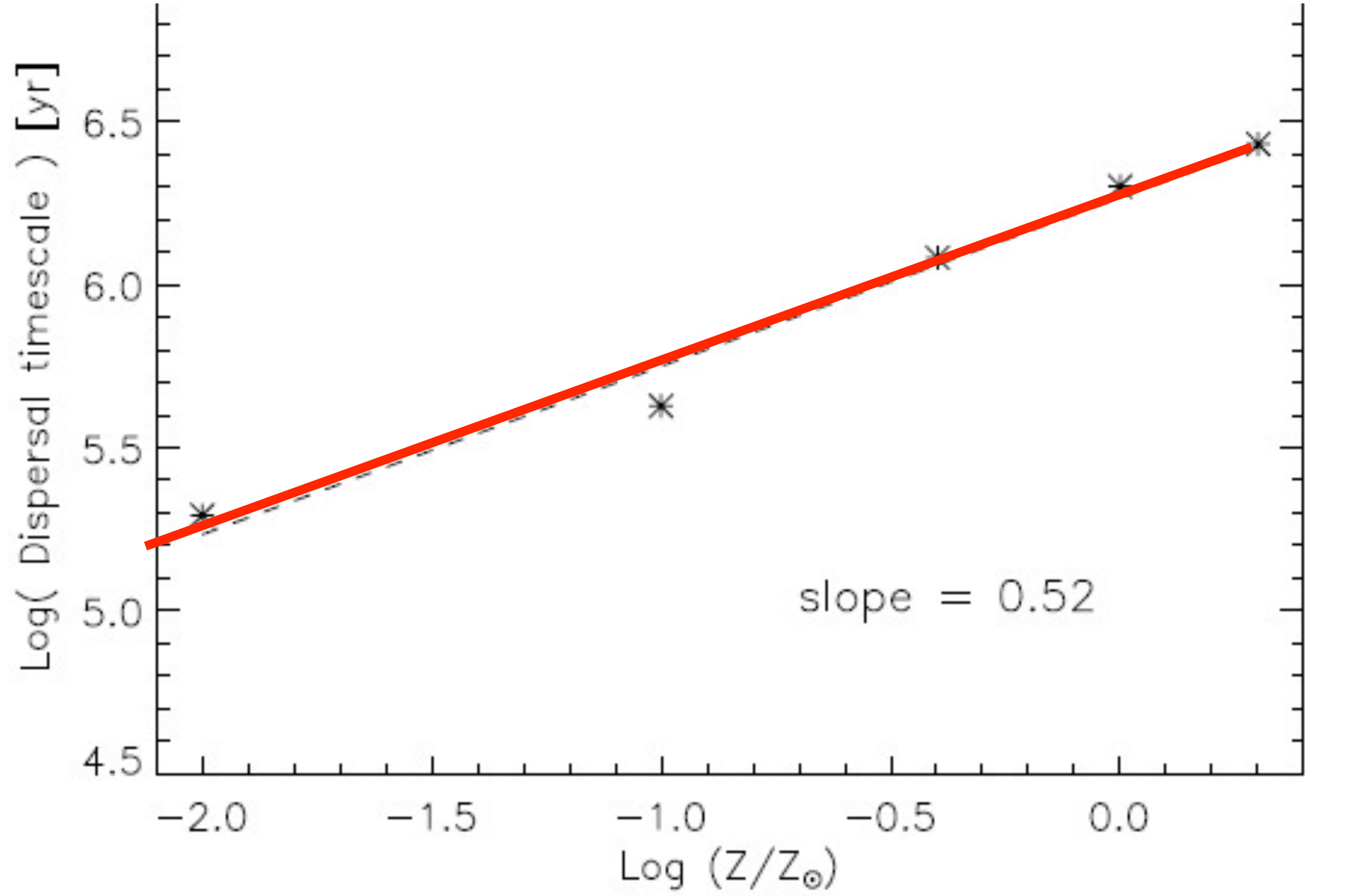
Dependence of wind rates on metallicity

▪

Ercolano & Clarke 2010

Dependence of wind rates on metallicity

$$M_W \propto Z^{-0.77}, \; t_{dis} \propto Z^{+0.52}$$



Ercolano & Clarke 2010

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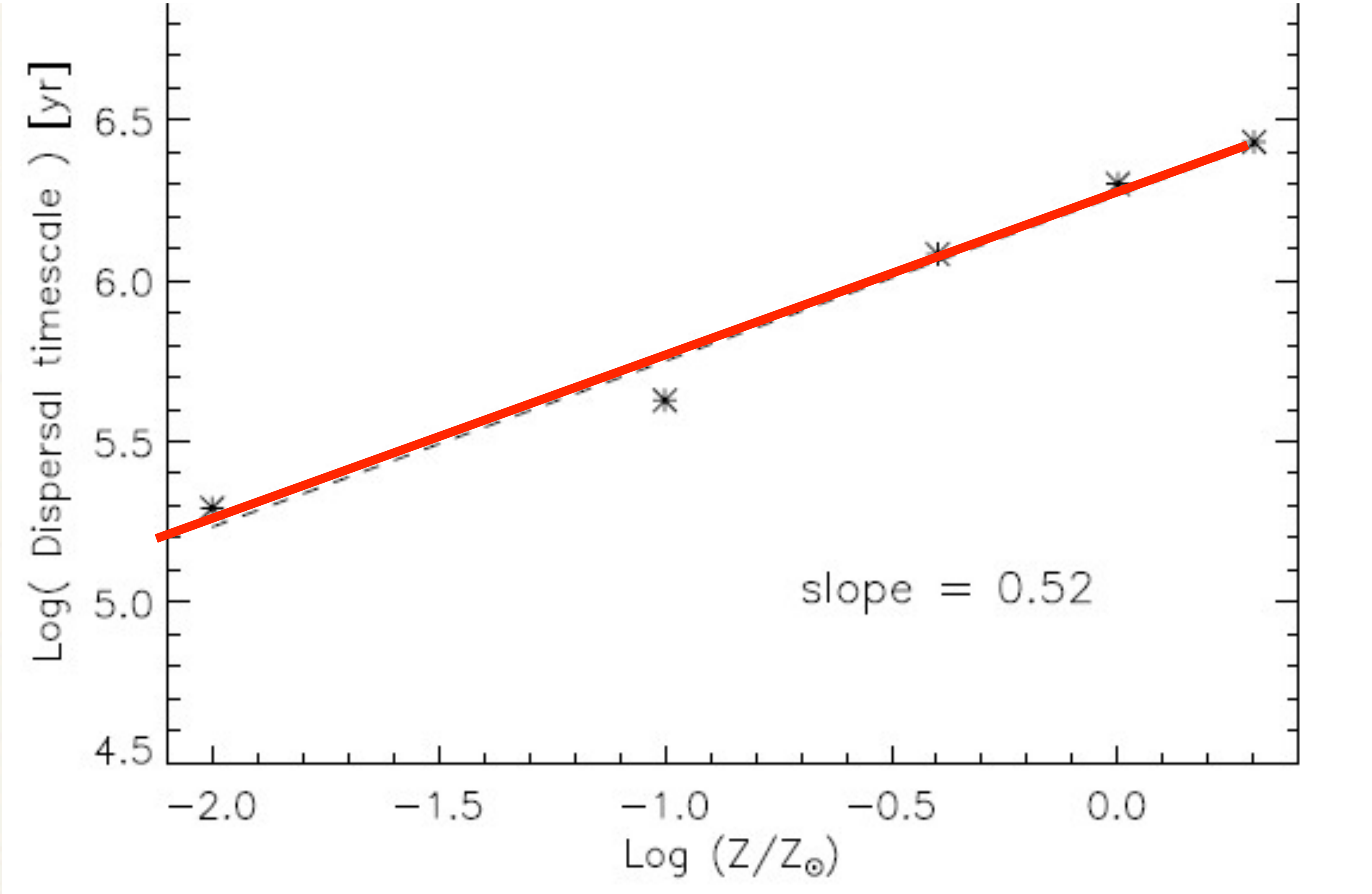

Ercolano & Clarke 2010

Dispersal by planet formation: $t_{dis} \propto Z^{\alpha}$

α = −2.5, −5, −7.5 or −32 !!!

Dependence of wind rates on metallicity

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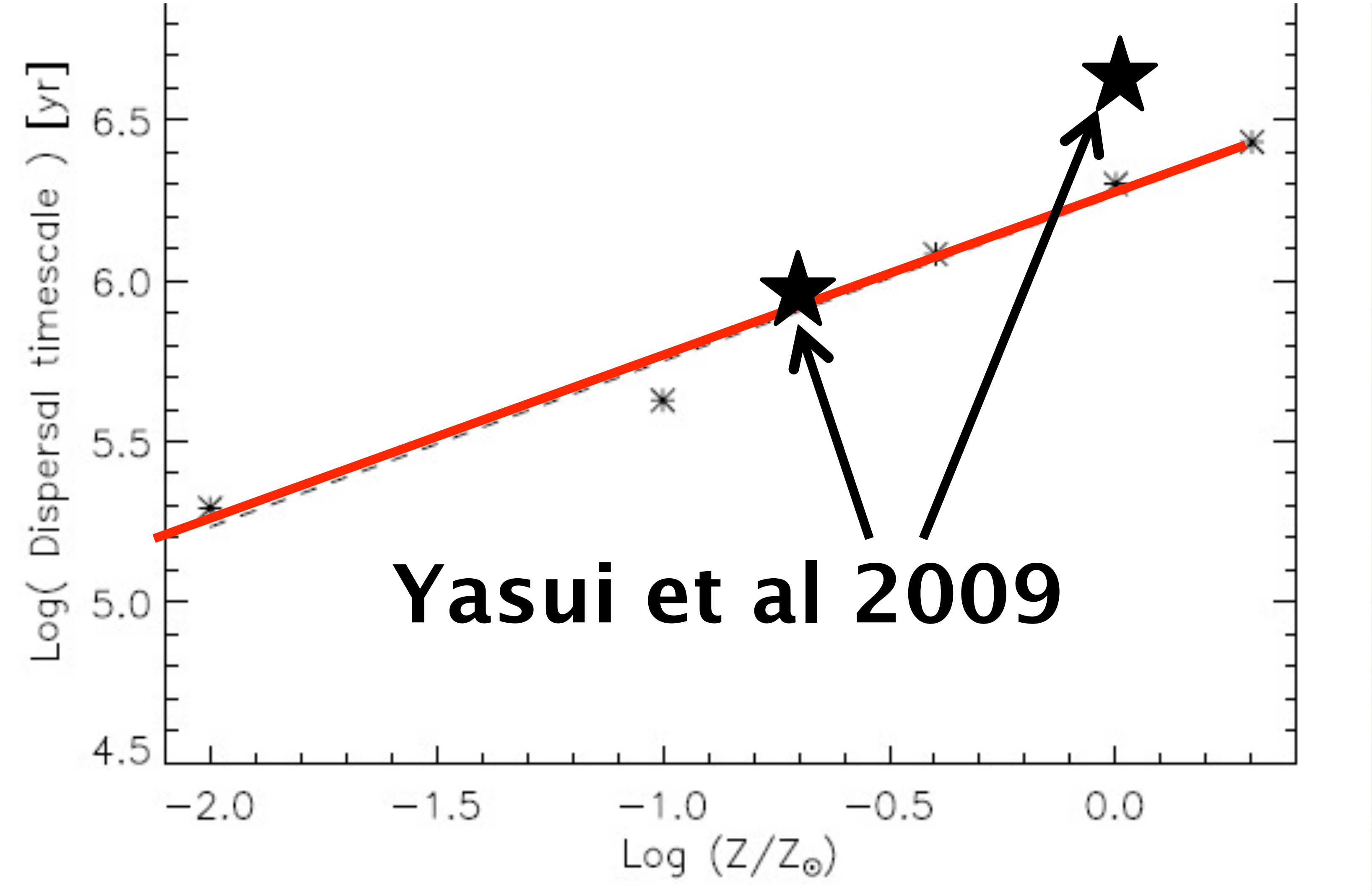

Ercolano & Clarke 2010

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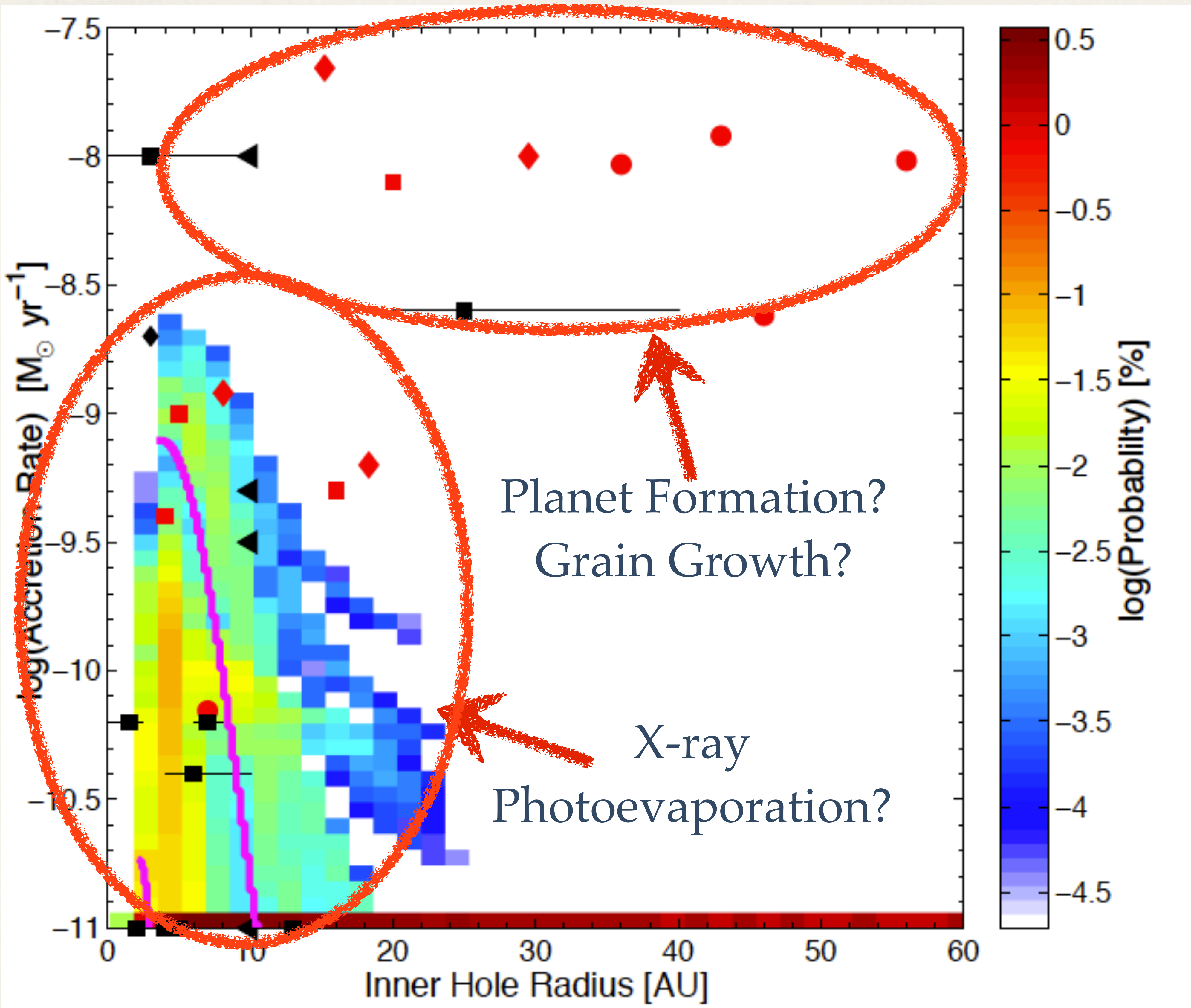
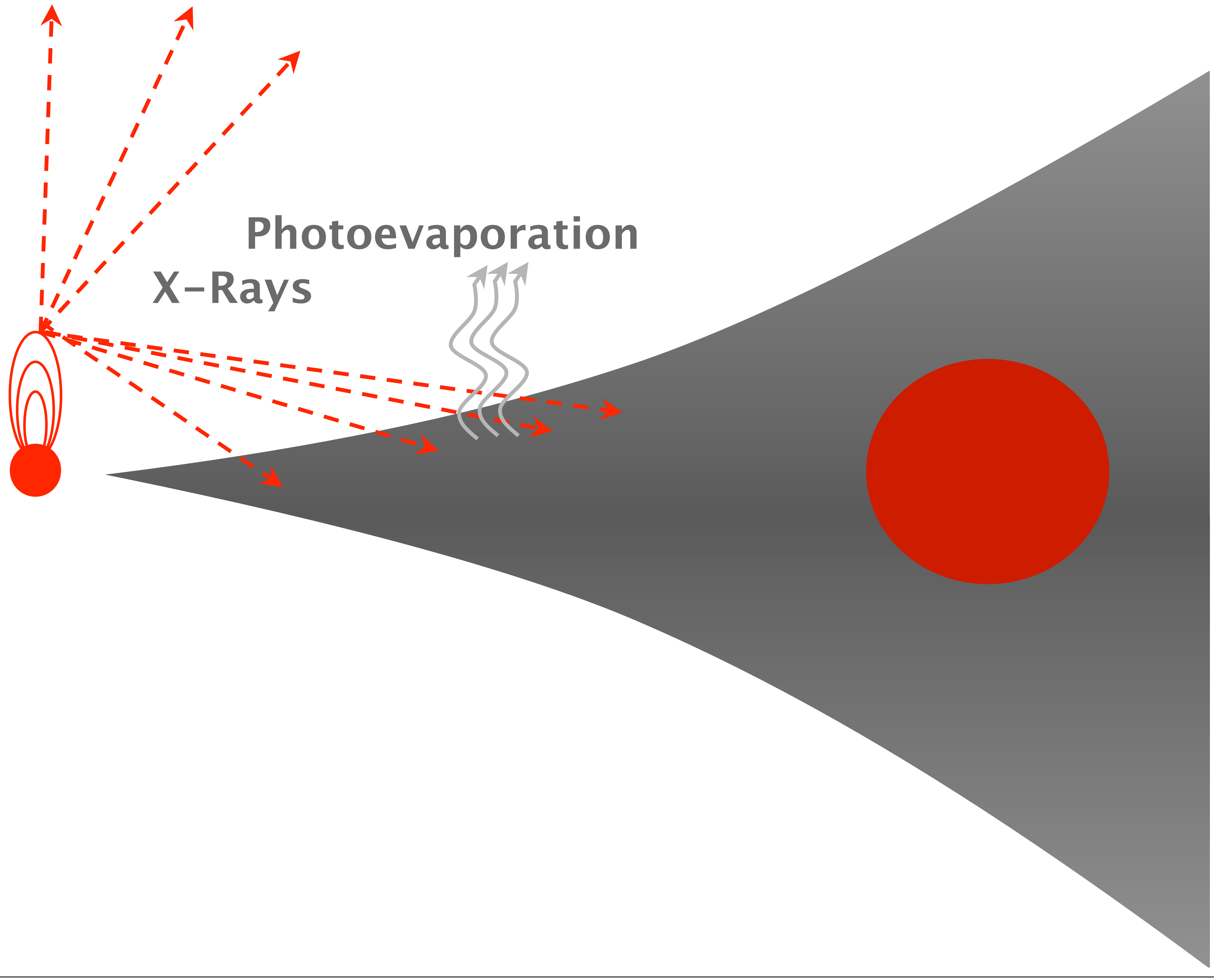
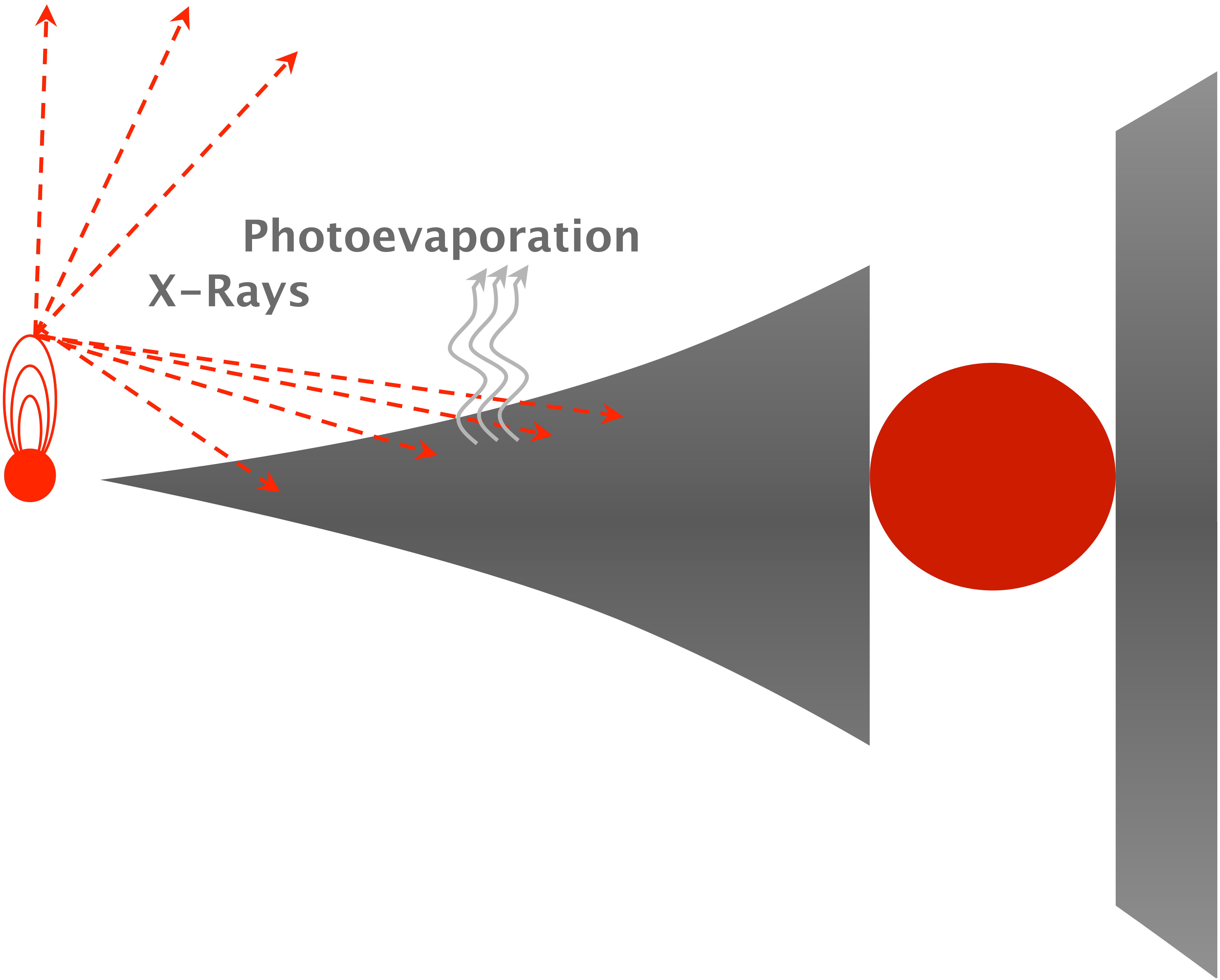
X-ray photoevaporation & Transition Discs



Owen, Ercolano & Clarke 2011


Photoevaporation
X-Rays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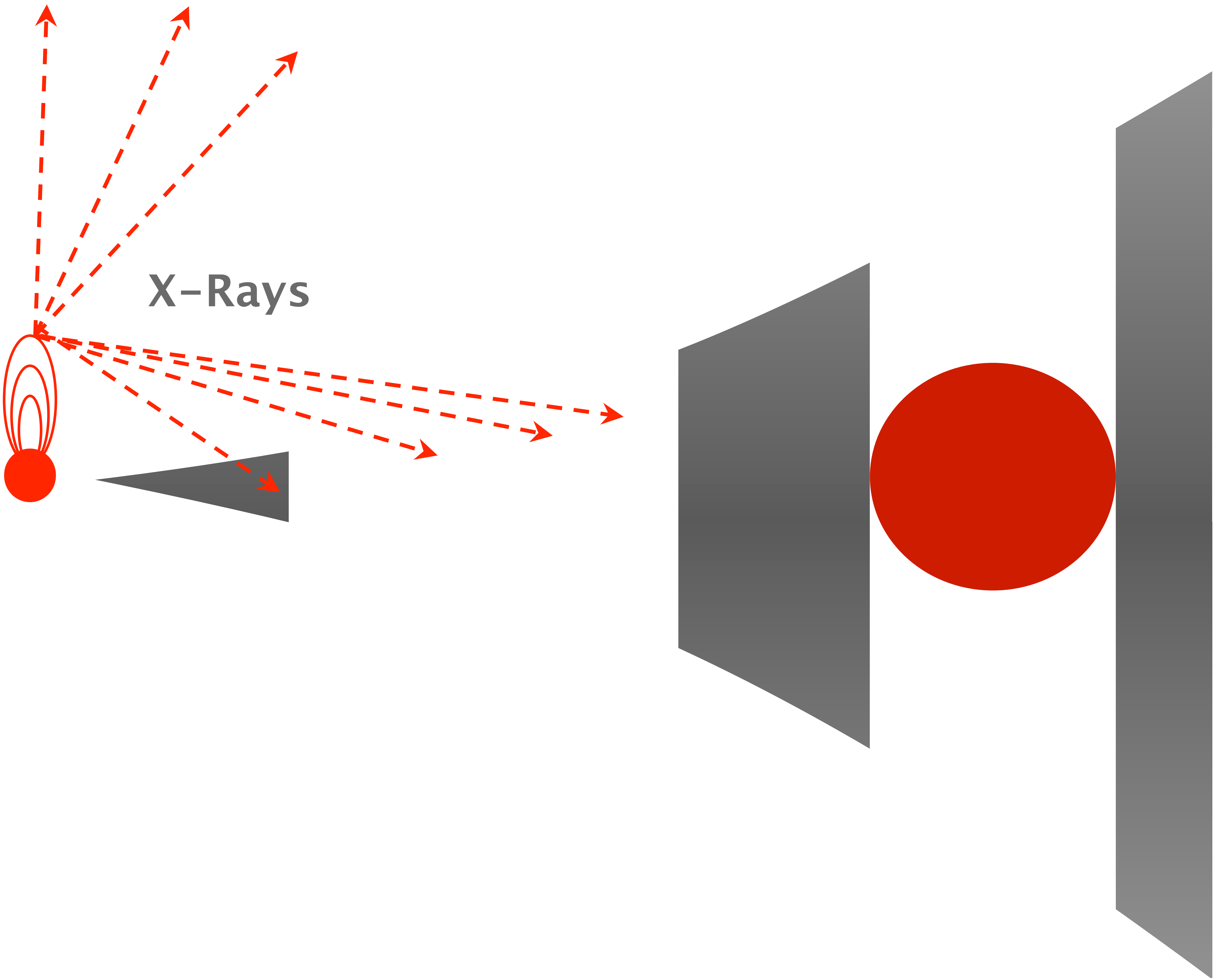
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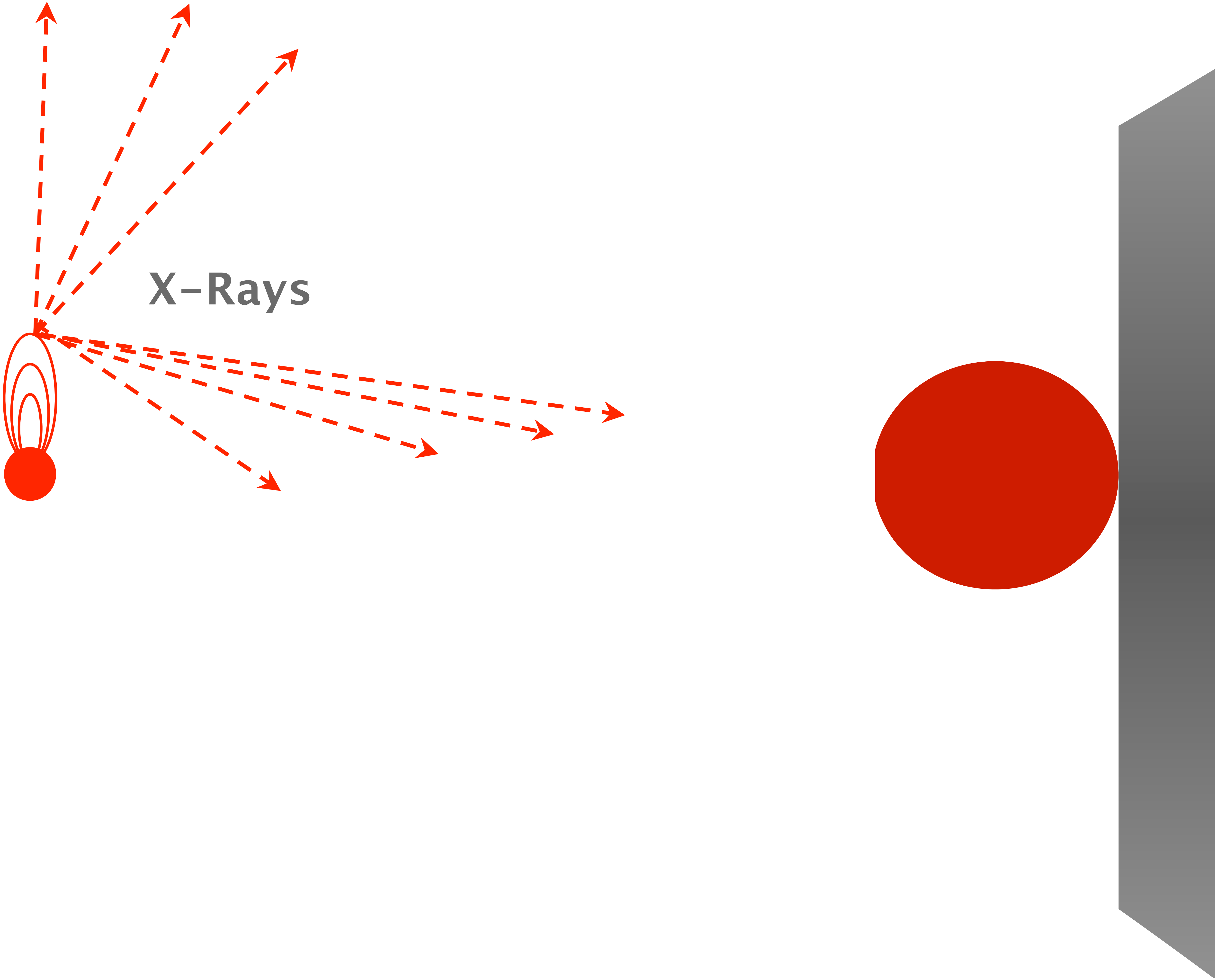
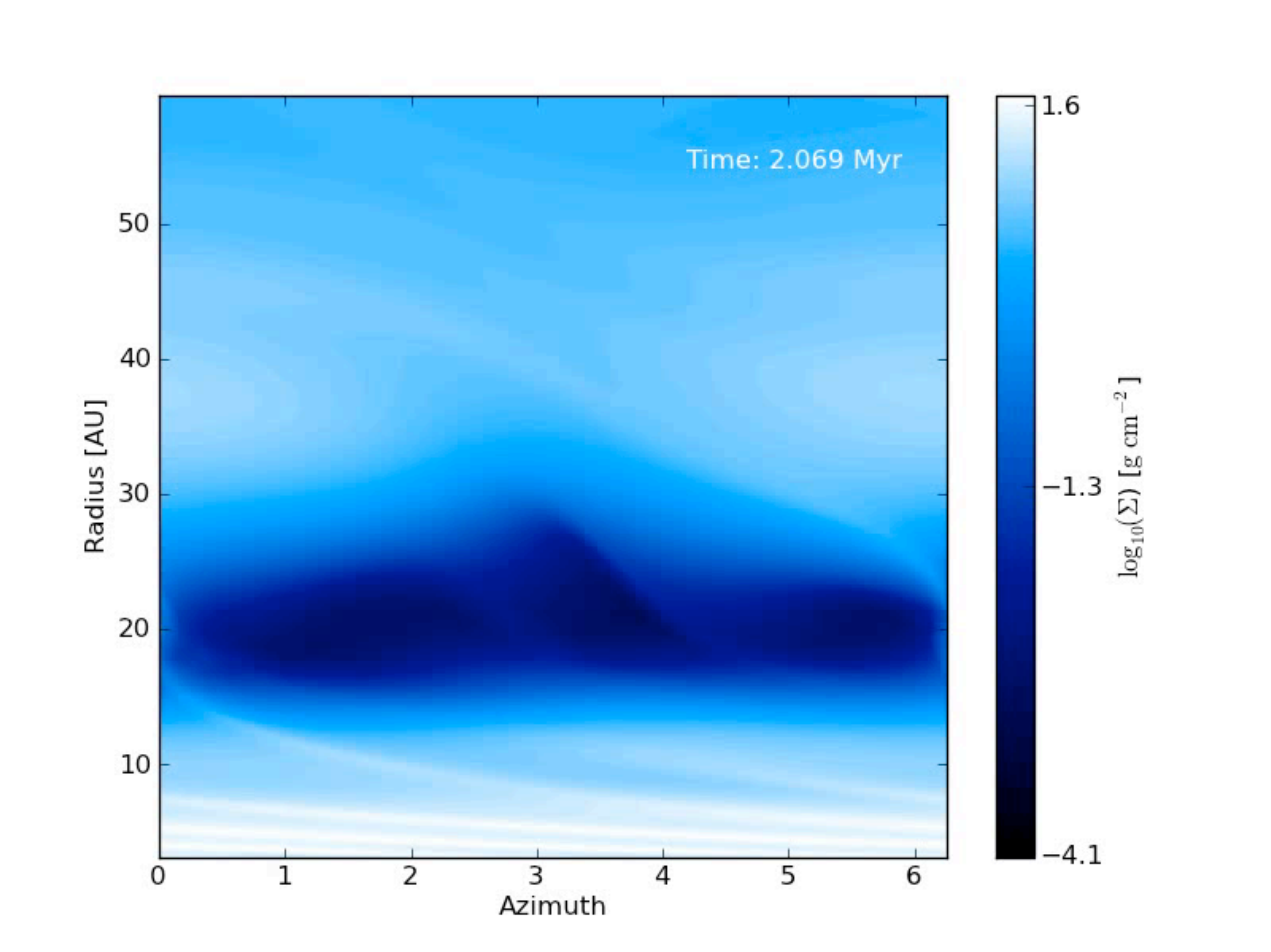

X-Rays

PIPE (Planet-Induced-PhotoEvaporation)

Rosotti, Ercolano, Owen & Armitage (2012, submitted)



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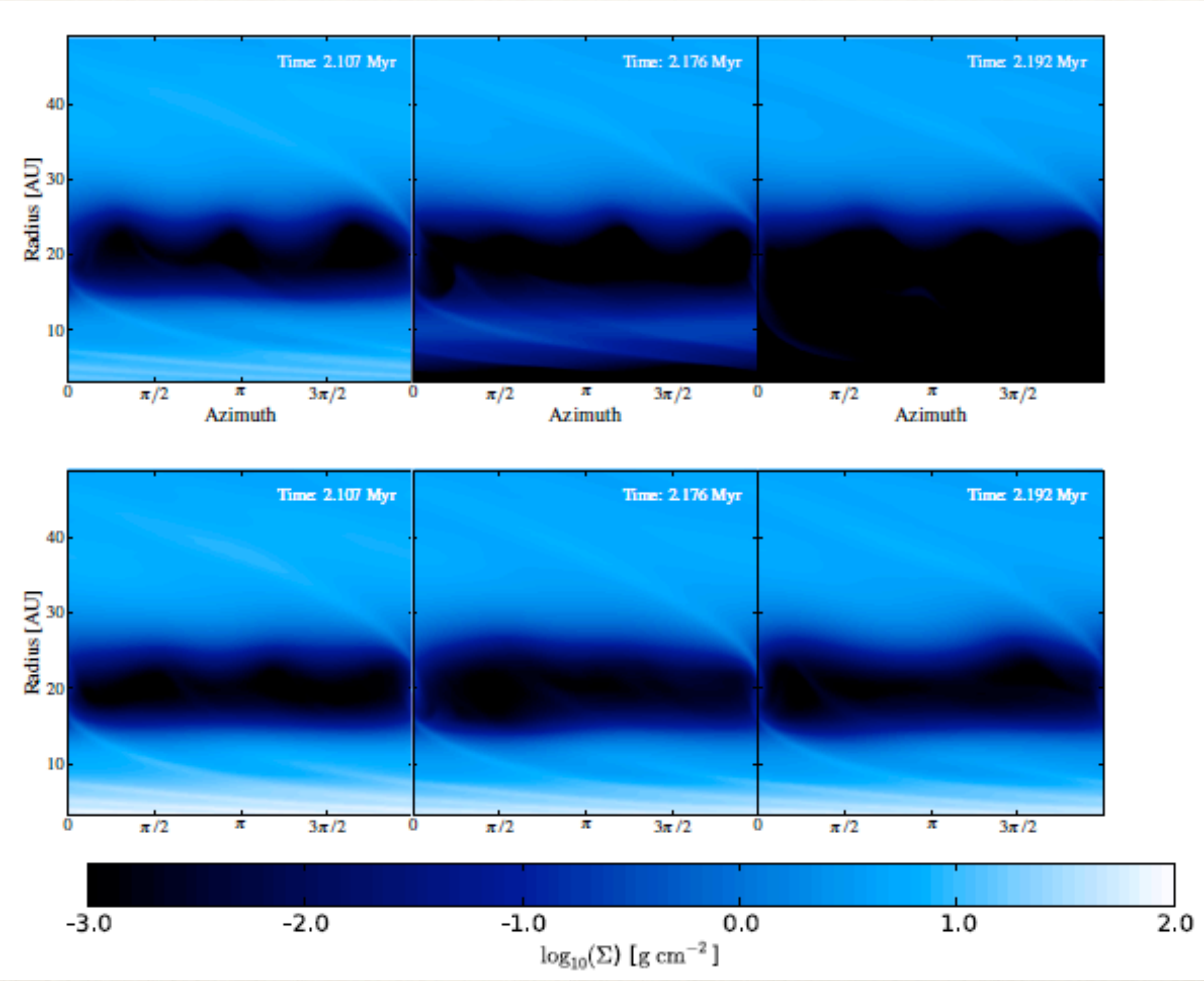

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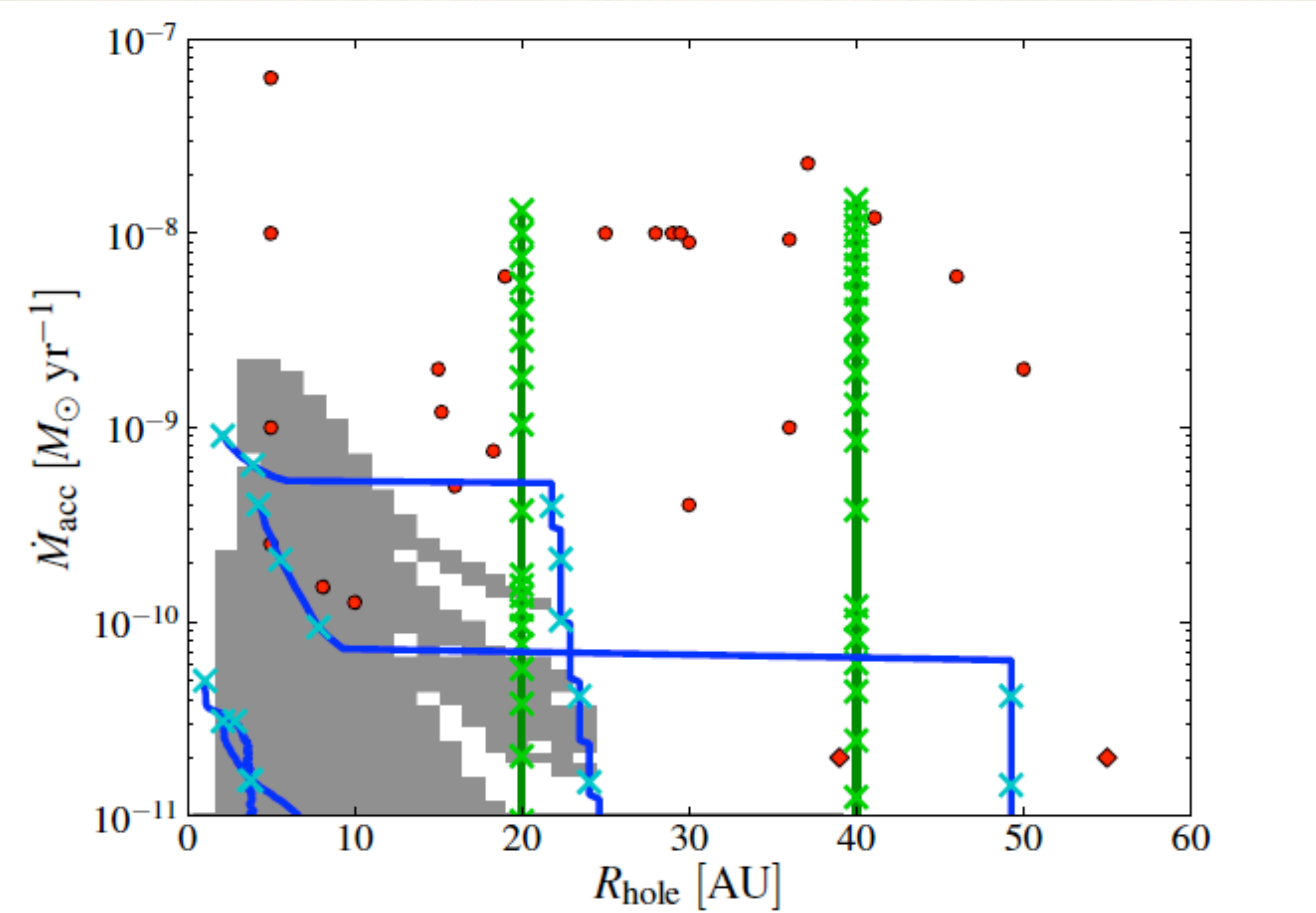


CONCLUSIONS

The lifetimes of discs are characterised by two timescales:

Global (~ Myr)

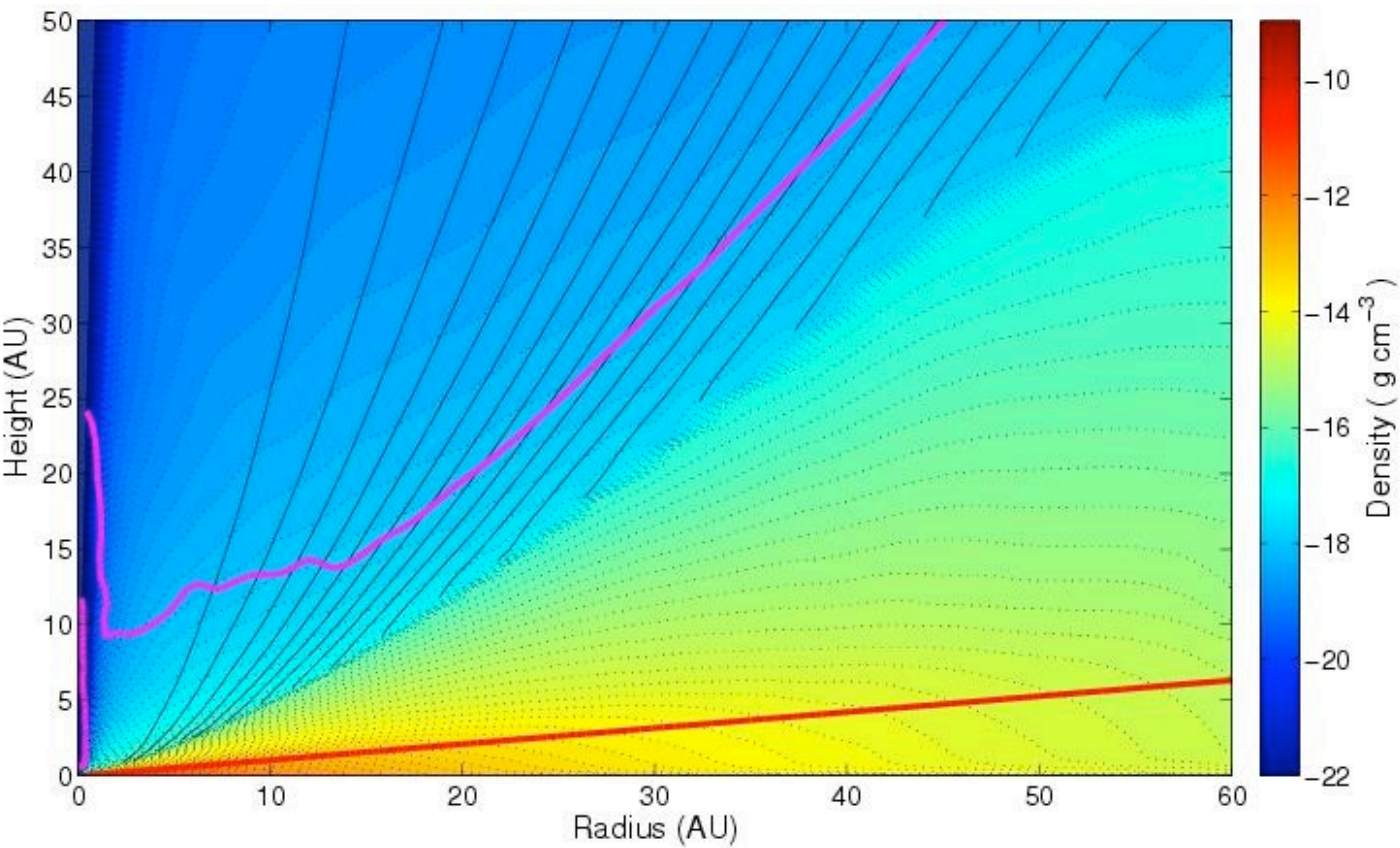
Dispersal ($\sim 10^5$)

Dispersal is rapid and proceeds from the inside-out

X-ray photovaporation can reproduce the observed dispersal timescales

Photoevaporation or planet formation alone cannot explain all of the observed transition discs

Planet induced photoevaporation could provide a mechanism to produced large hole strongly accreting transition discs

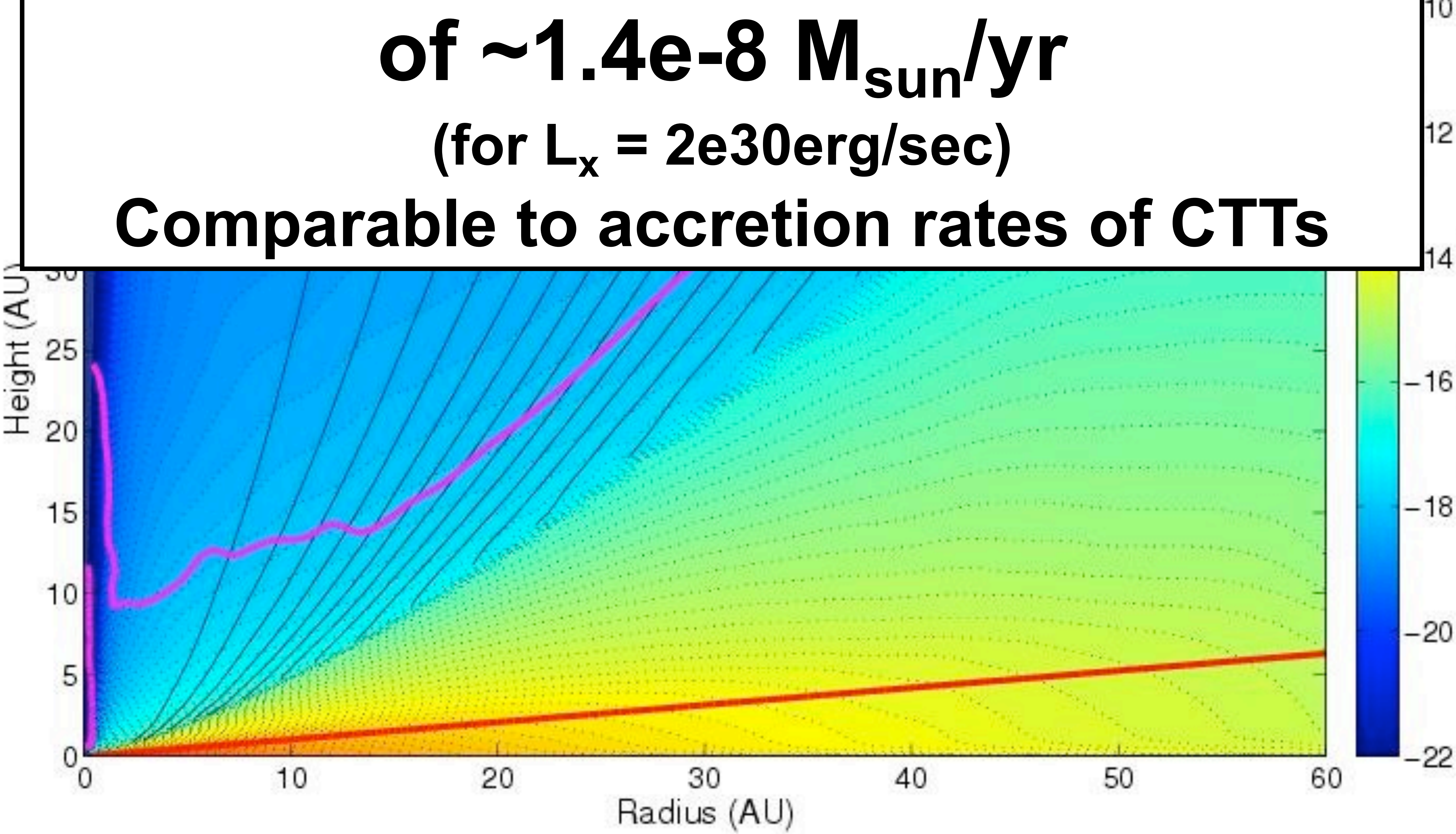


Owen, Ercolano, Clarke & Alexander, 2010, MNRAS

Total photoevaporation rate of ~1.4e-8 M_{sun}/yr

(for L_x = 2e30erg/sec)

Comparable to accretion rates of CTTs



Owen, Ercolano, Clarke & Alexander, 2010, MNRAS

1529 YSOs in 15 Star Forming Regions:

39% primordial discs
31% inside-out dispersal
22% discless sources
2% homogeneous draining
6% unclassified

similar results apply to all spectral types

τ_{disc} *and* τ_{trans} *do not depend on spectral type*