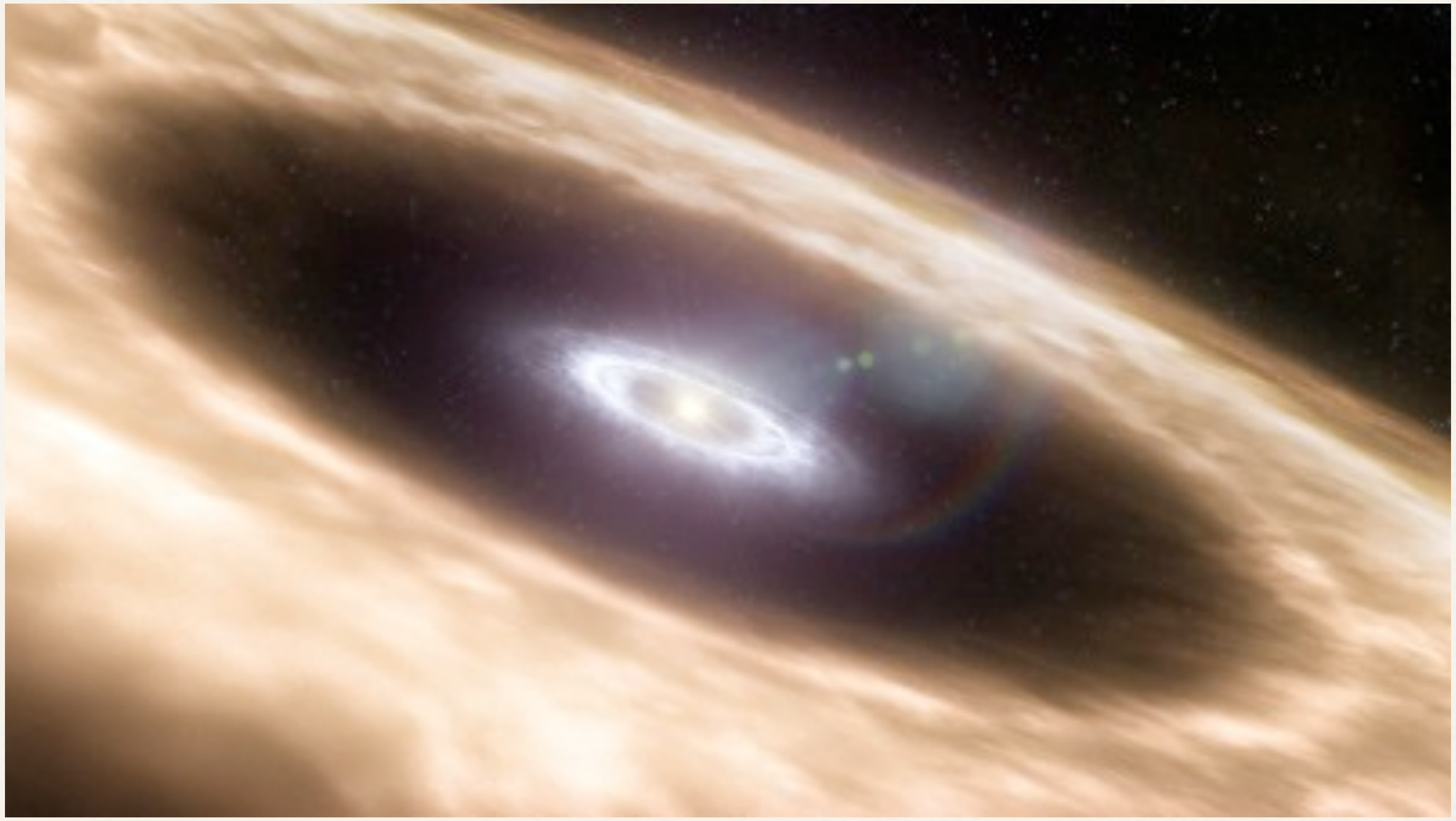
The dispersal of Protoplanetary Discs



Barbara Ercolano
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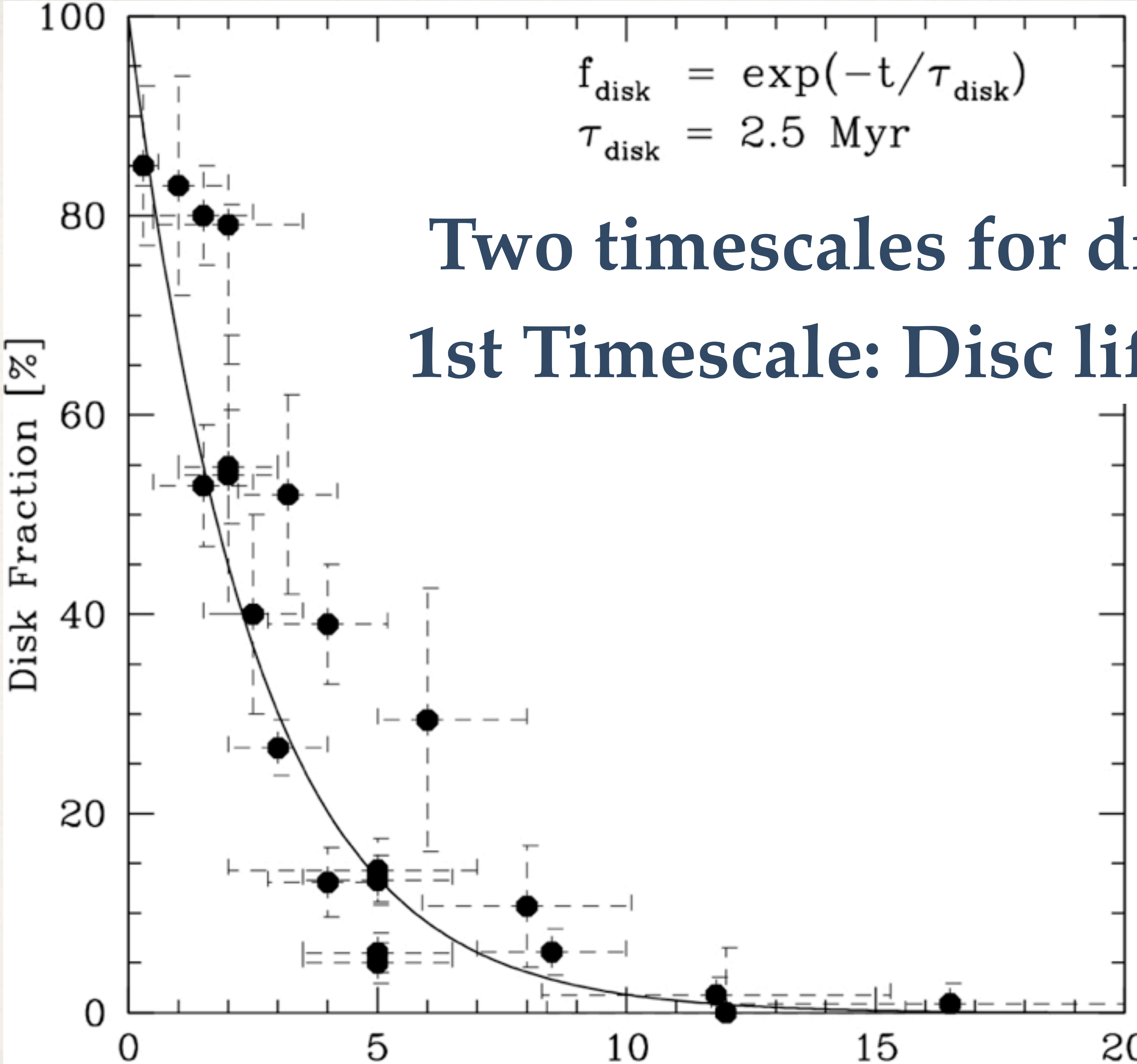
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Universitäts-Sternwarte München

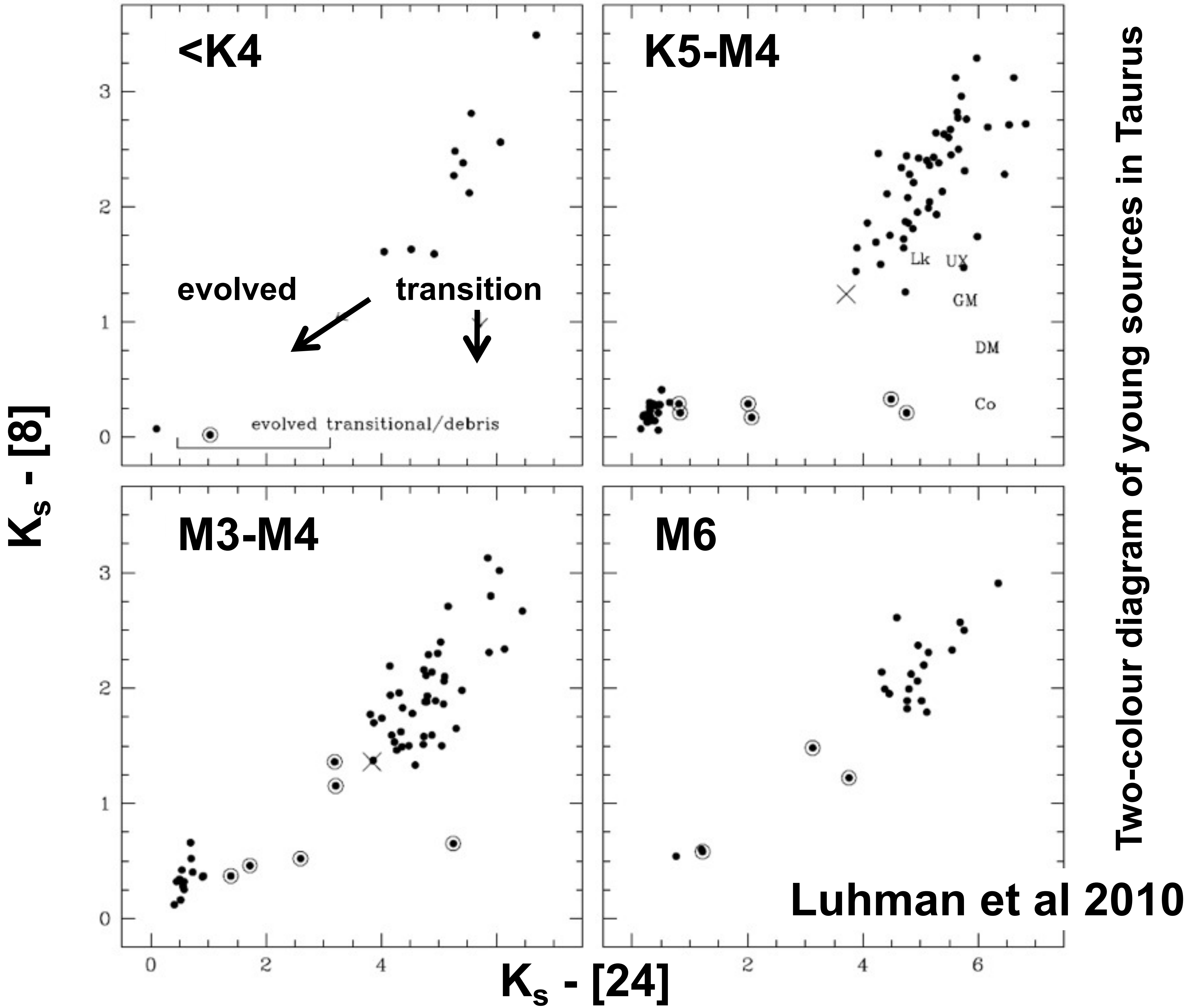
Fakultät für Physik der Ludwig-Maximilians-Universität

Two timescales for dispersal

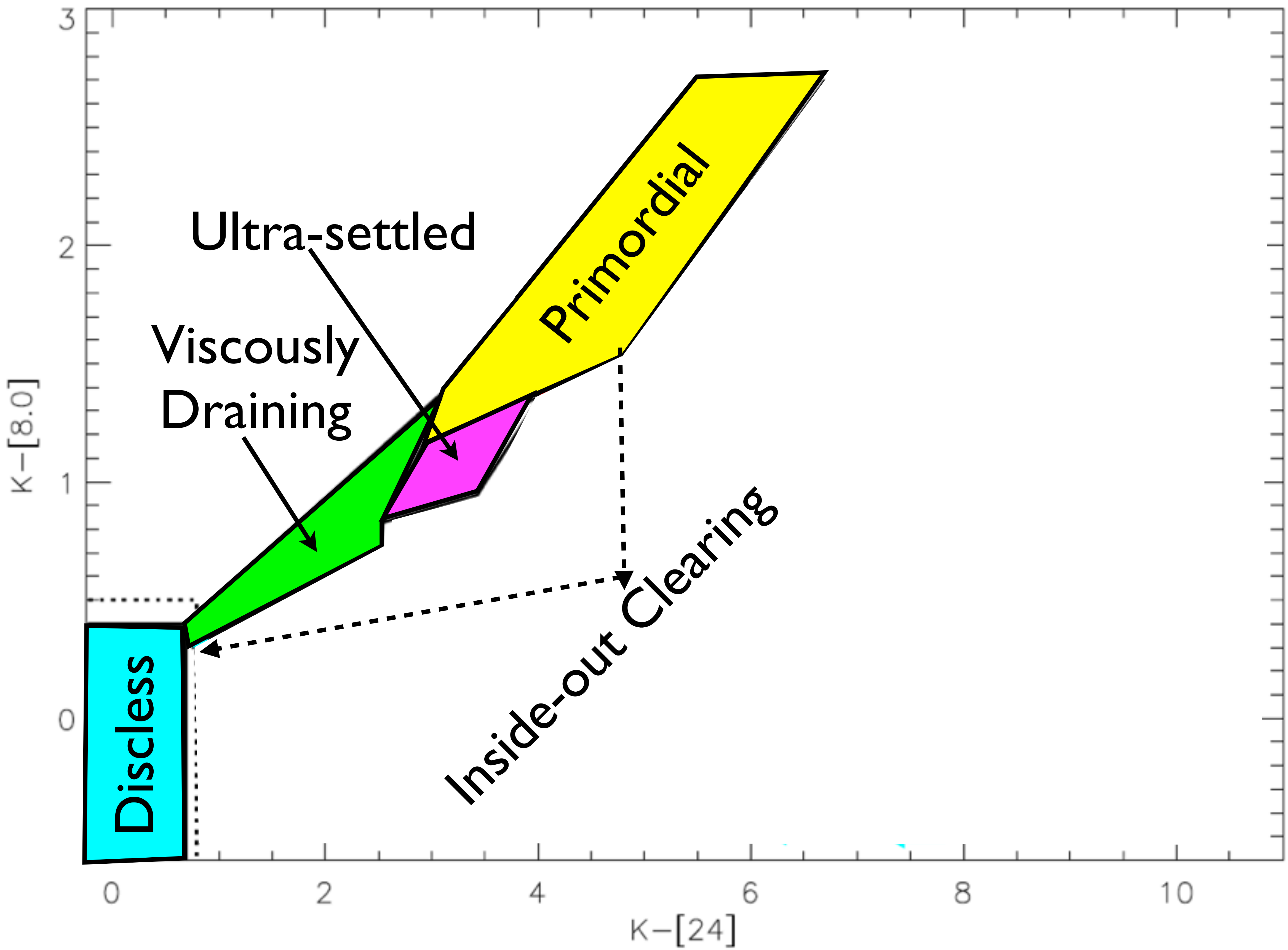
1st Timescale: Disc lifetime



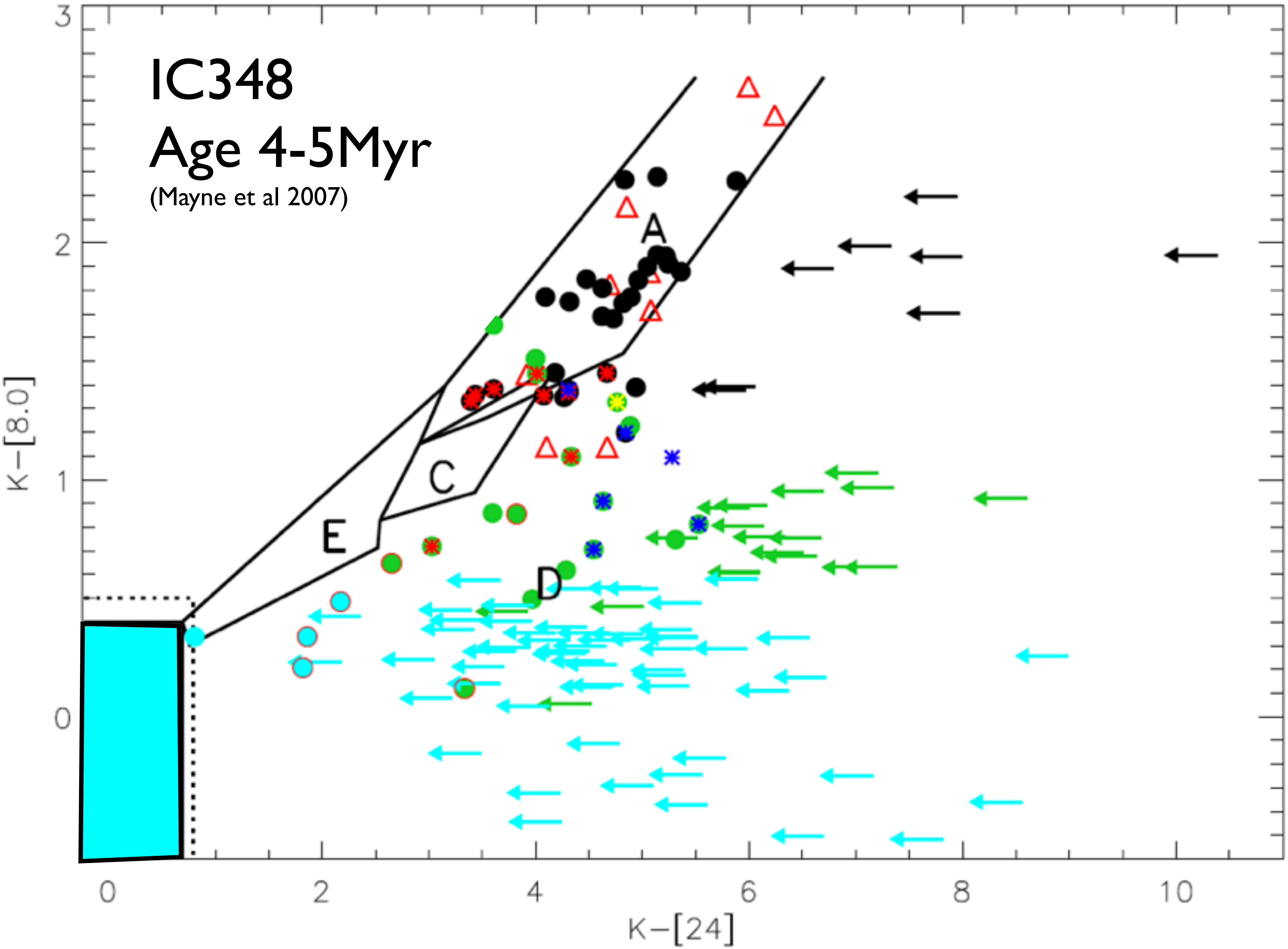
Haisch et al.


<K4
K5-M4
M3-M4
M6
evolved
transition
evolved transitional/debris
Lk
UX
GM
DM
Co
0
1
2
3
0
2
4
6
K_s - [8]
K_s - [24]
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)



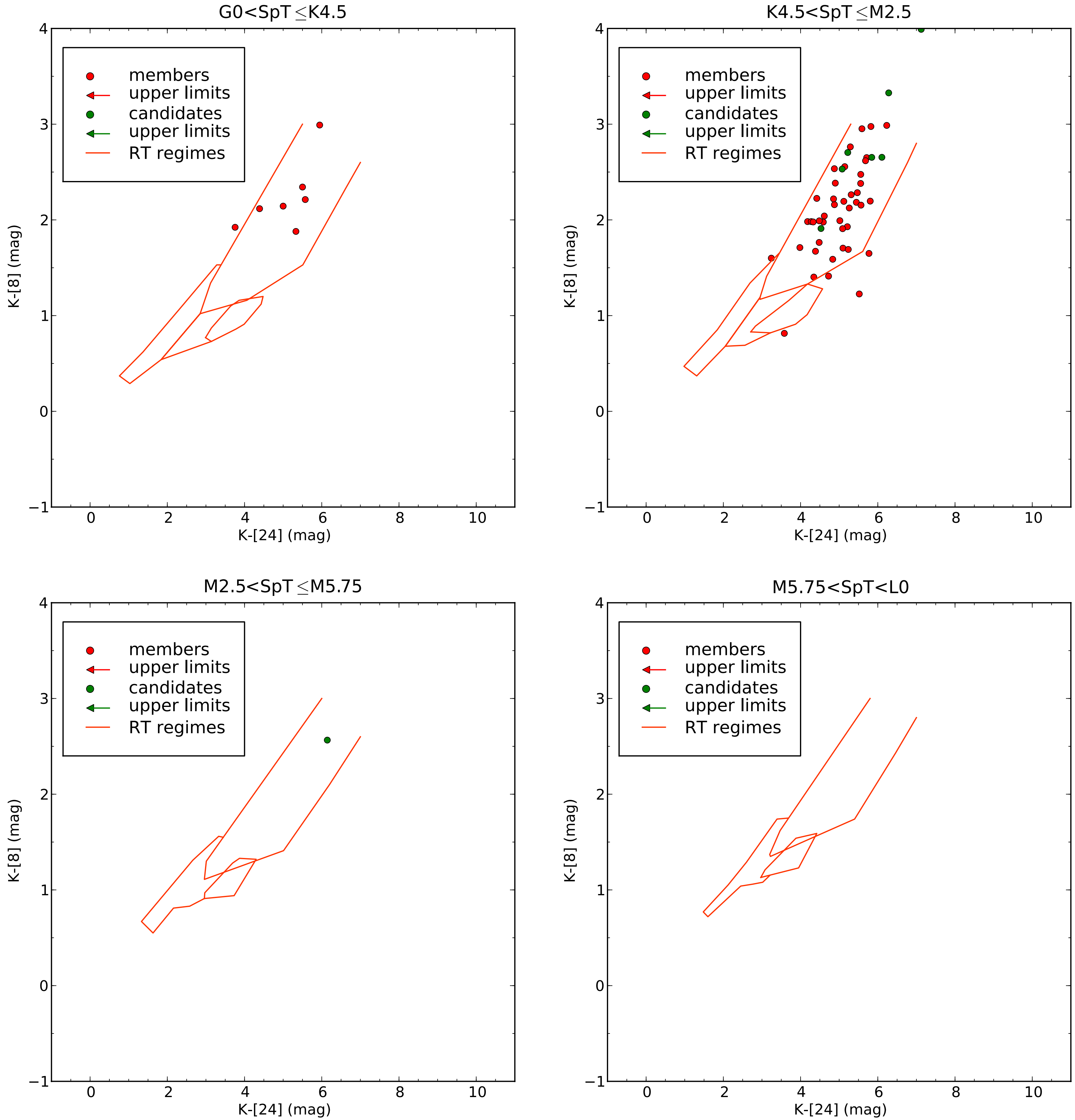
The clearing of discs around late type T-Tauri stars
(Ercolano, Clarke & Hall 2011, MNRAS)



Koepferl, Ercolano et al. 2013

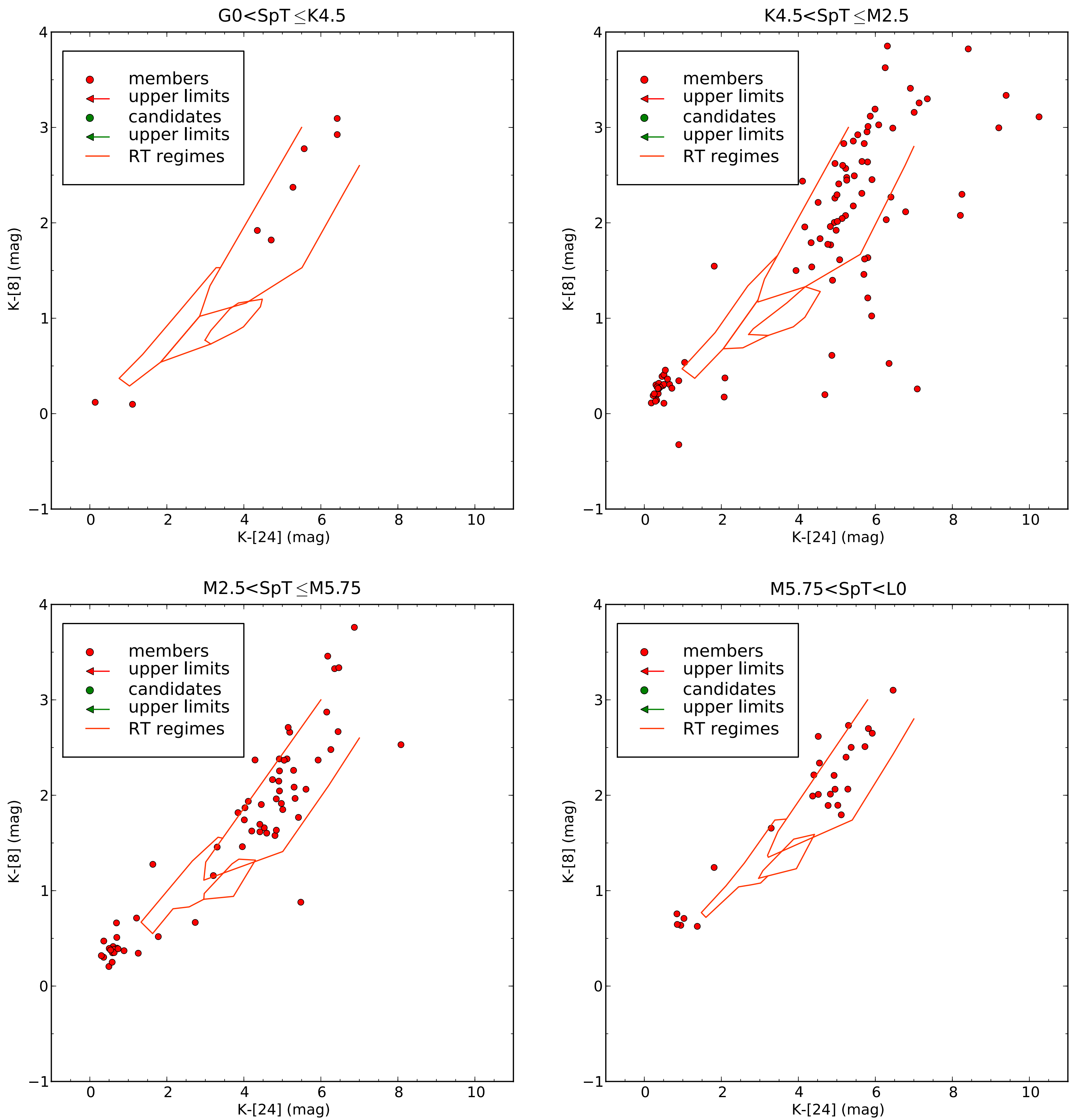
Tr37

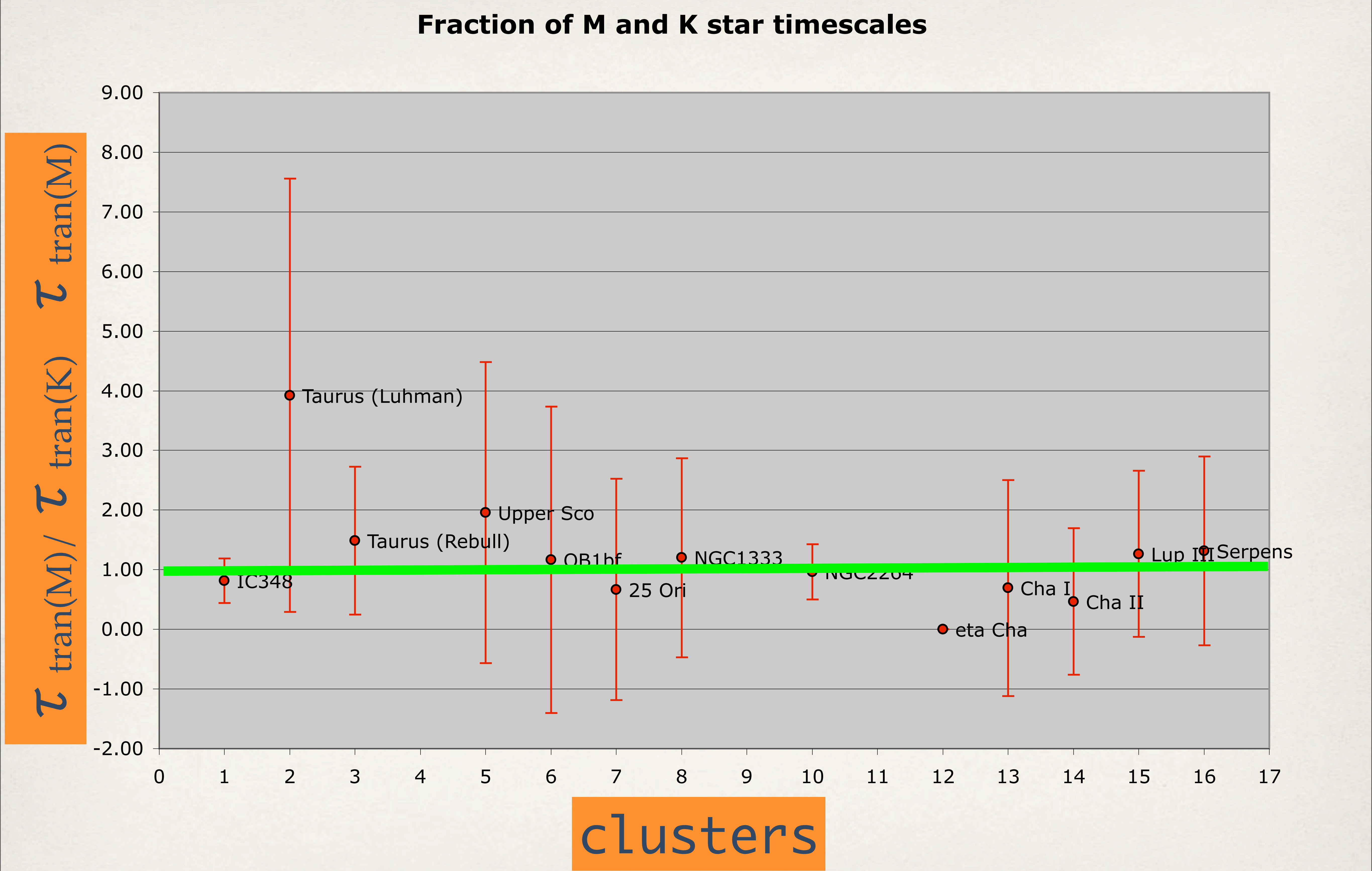
Koepferl, Ercolano et al. 2013



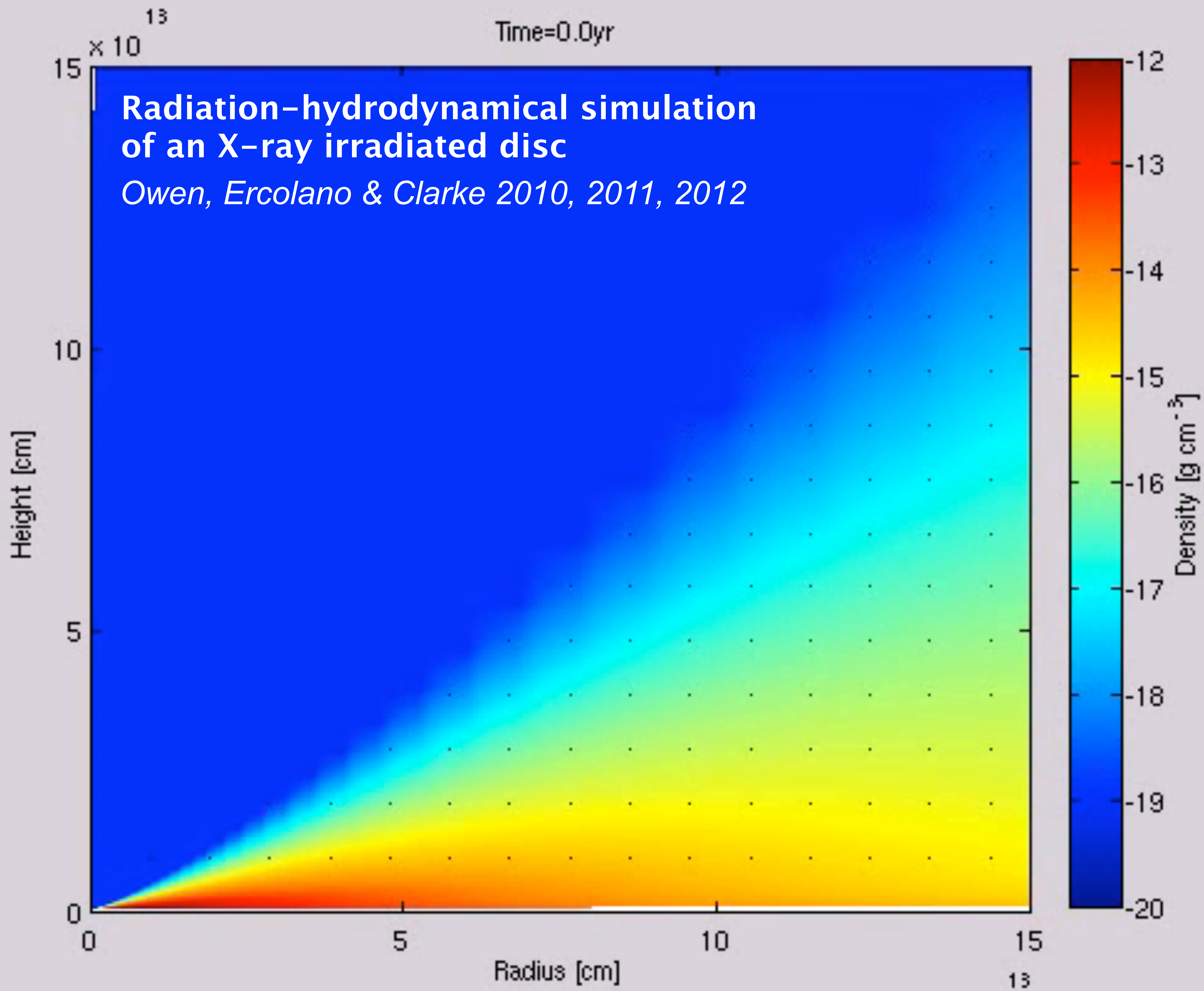
Taurus (Luhman)

Koepferl, Ercolano et al. 2012

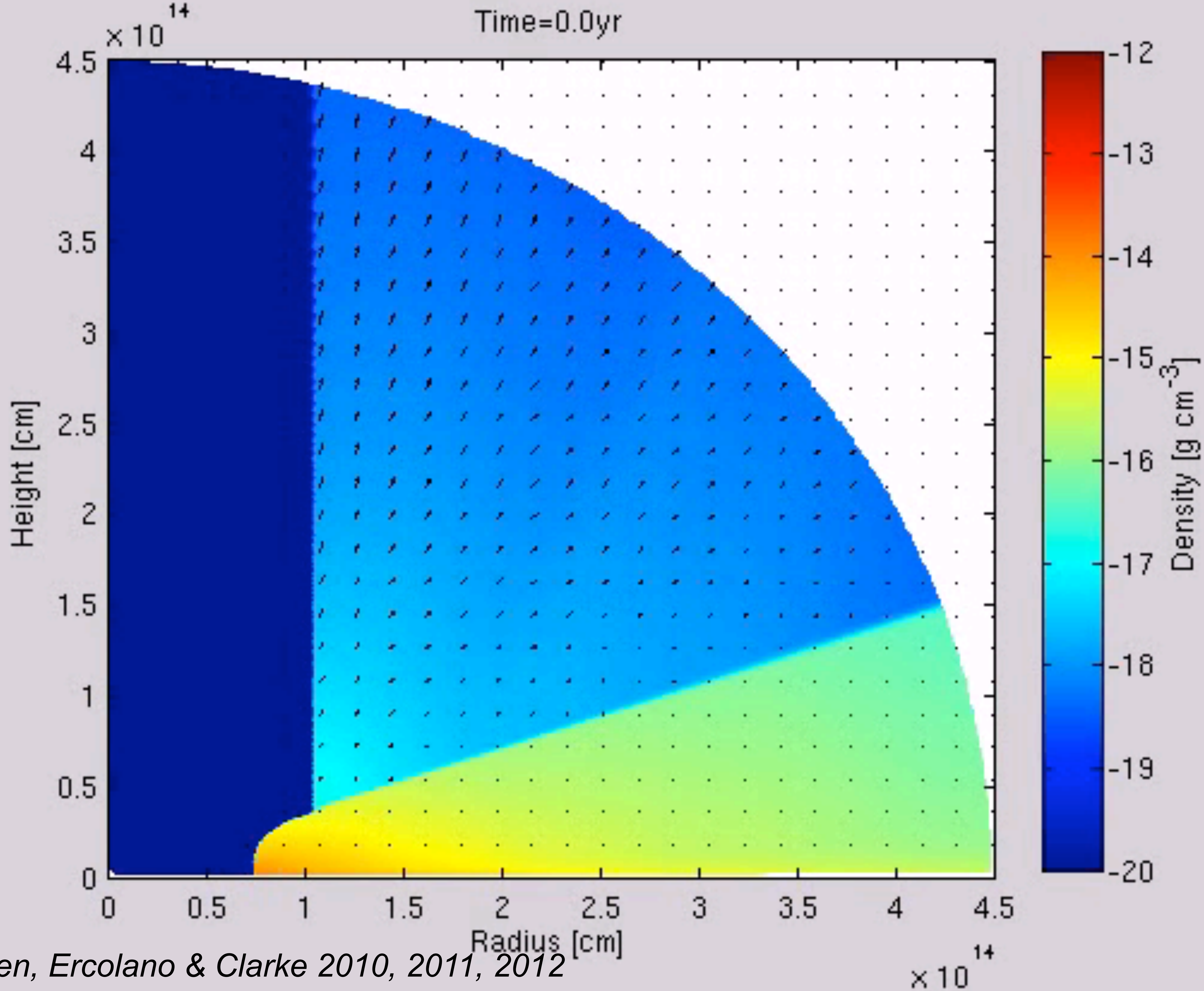




Koepferl, Ercolano et al. 2012 (see also Ercolano et al. 2011)



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]
0
5
10
15
Radius [cm]
13
-12
-13
-14
-15
-16
-17
-18
-19
-20
Density [g cm^-3]



Owen, Ercolano & Clarke 2010, 2011, 2012

What is the main driver of photoevaporation?

- Classical EUV models - rates 10^{-10} Msun/yr

  (e.g. Alexander et al 2006)

- FUV model - rates up to 10^{-8} Msun/yr

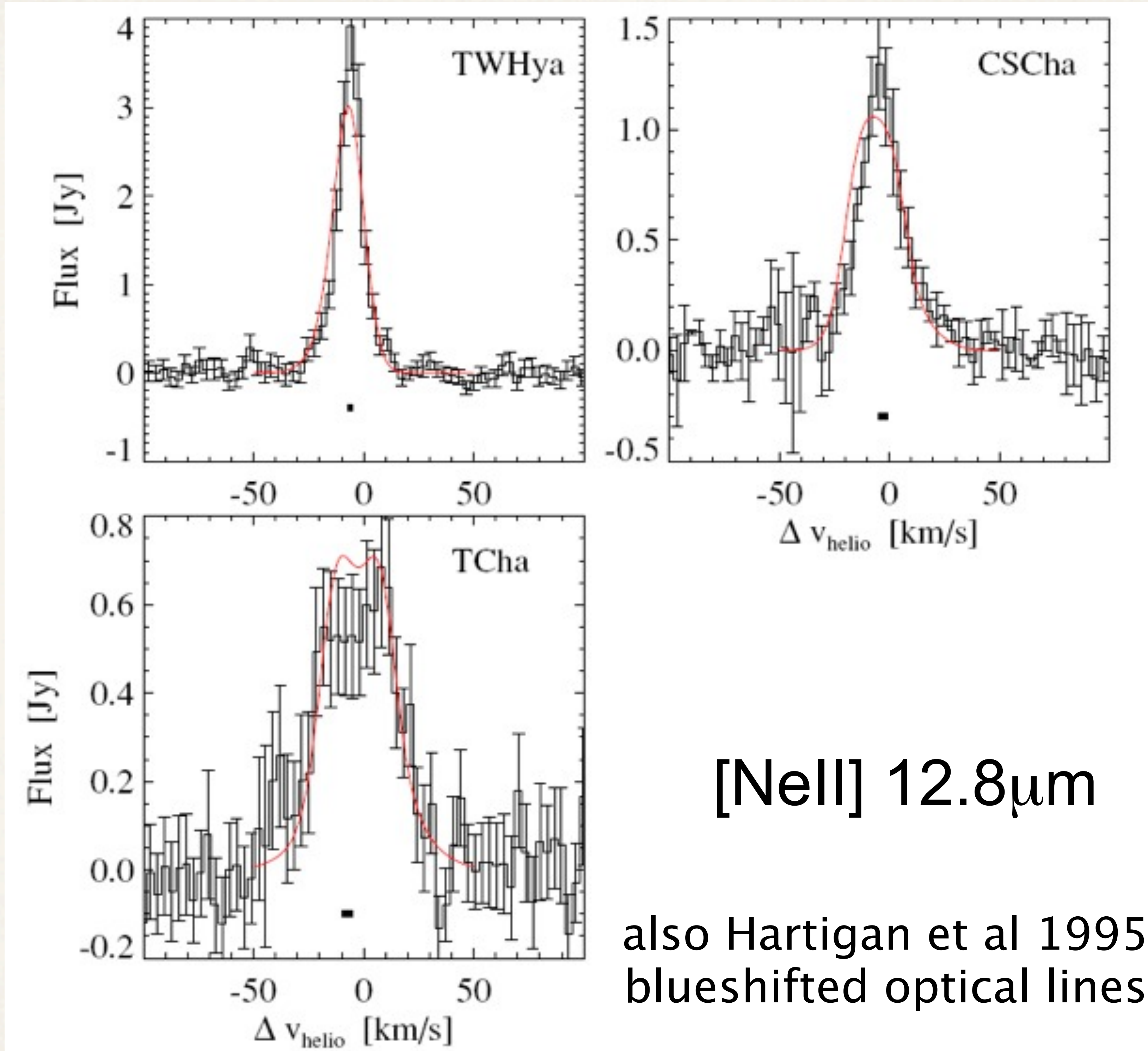
  (Gorti et al. 2009)

- X-ray model - rates 10^{-10} - 10^{-8} Msun/yr

  (Ercolano et al 2009; Owen et al. 2010)

Can we 'see' the wind??

Pascucci & Sterzik, 2009

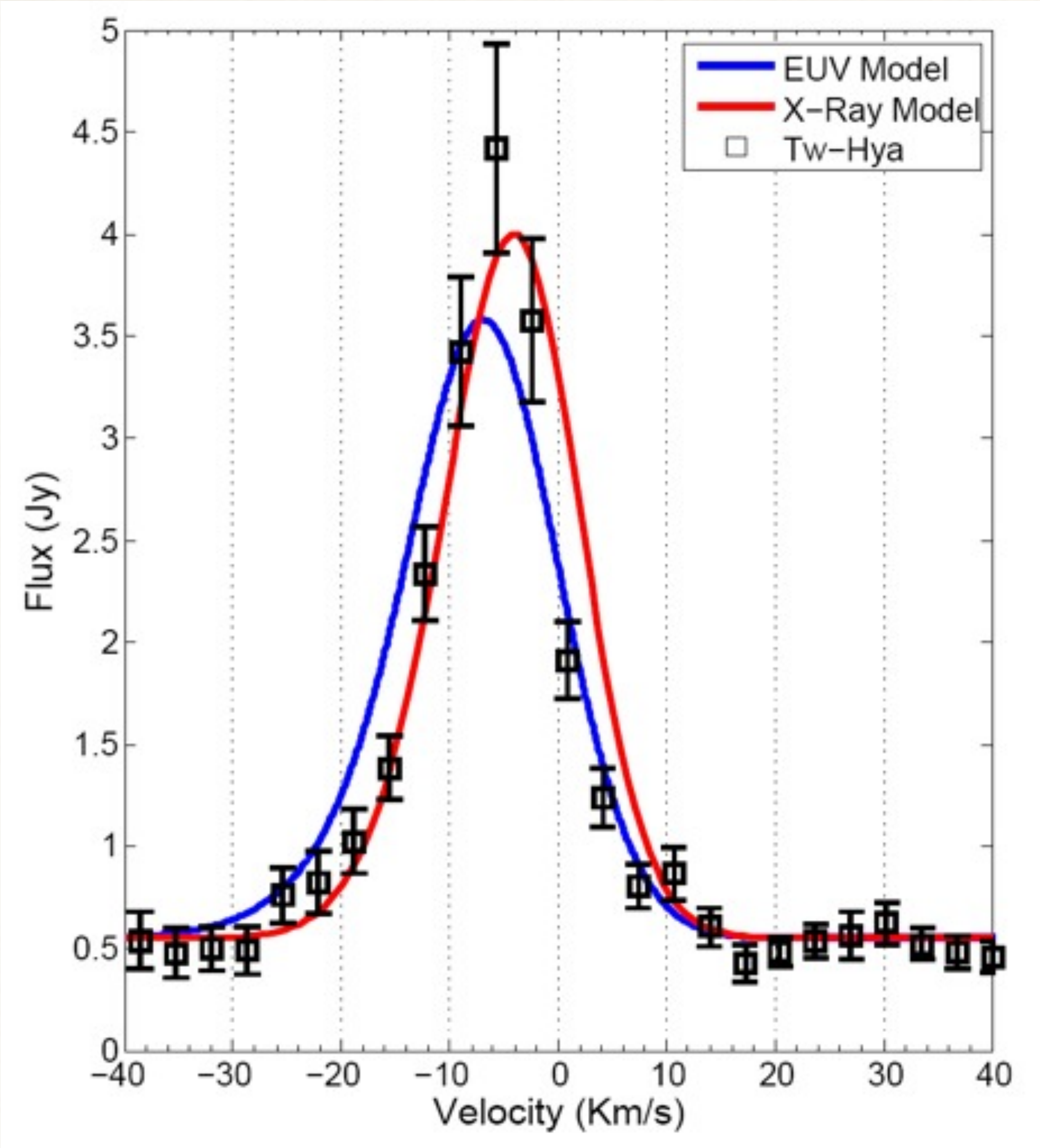


[NeII] 12.8μm

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

Can we 'see' the wind??

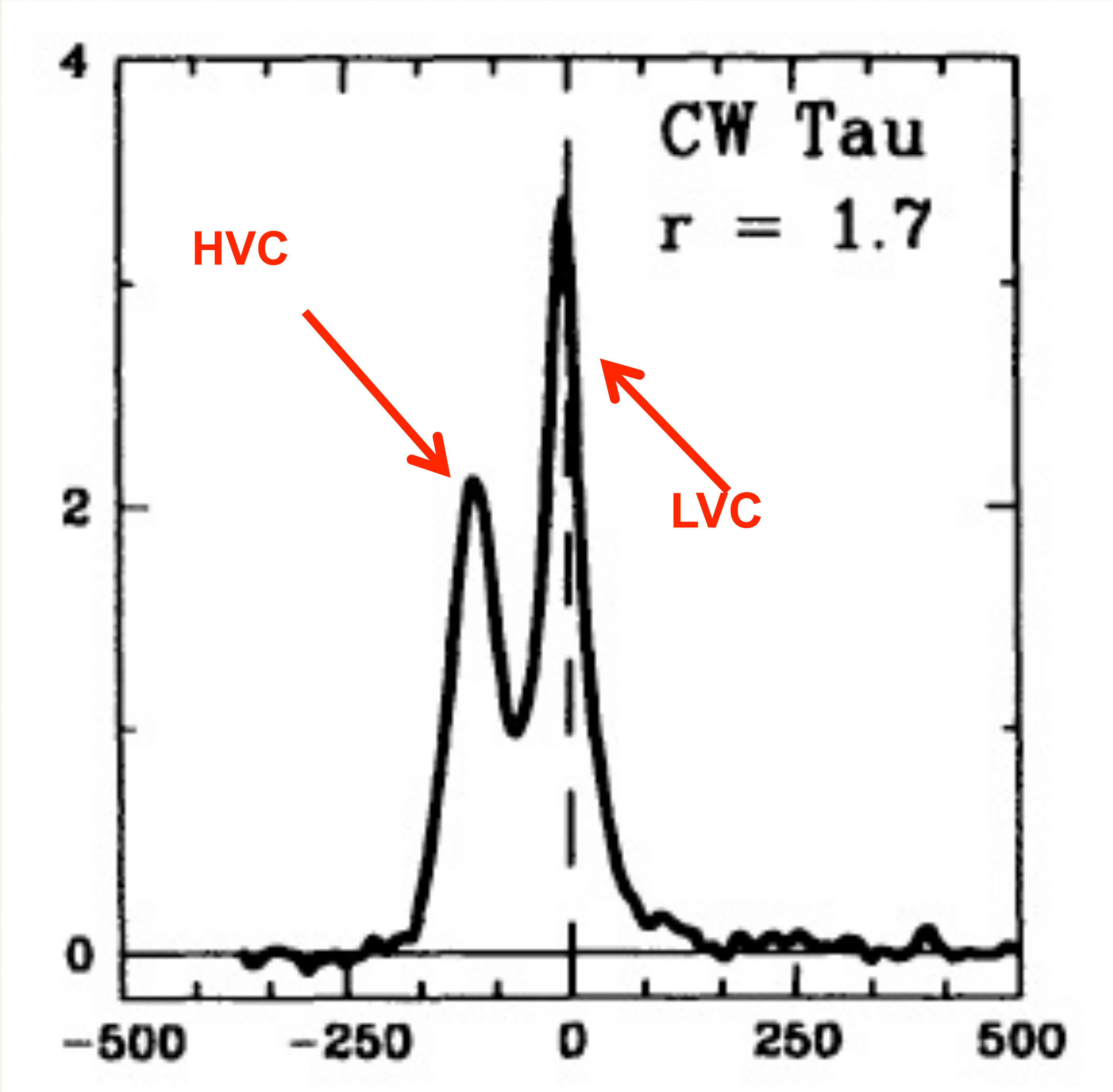


Ercolano & Owen 2010

EUV – M ~ $10^{-10} M_\odot$ /yr

X-ray – M ~ 10^{-10}-$10^{-8} M_\odot$ /yr

[OI] 6300A to the rescue!



Hartigan et al 1995

But see also Gorti et al. OH dissociation?

[OI] 6300A to the rescue!

L(LVC) ~ 10^{-5}-10^{-4} $L_\odot$

blueshifted by a few km/s

EUV wind is fully ionised

L([OI]) < 10^{-6} $L_\odot$

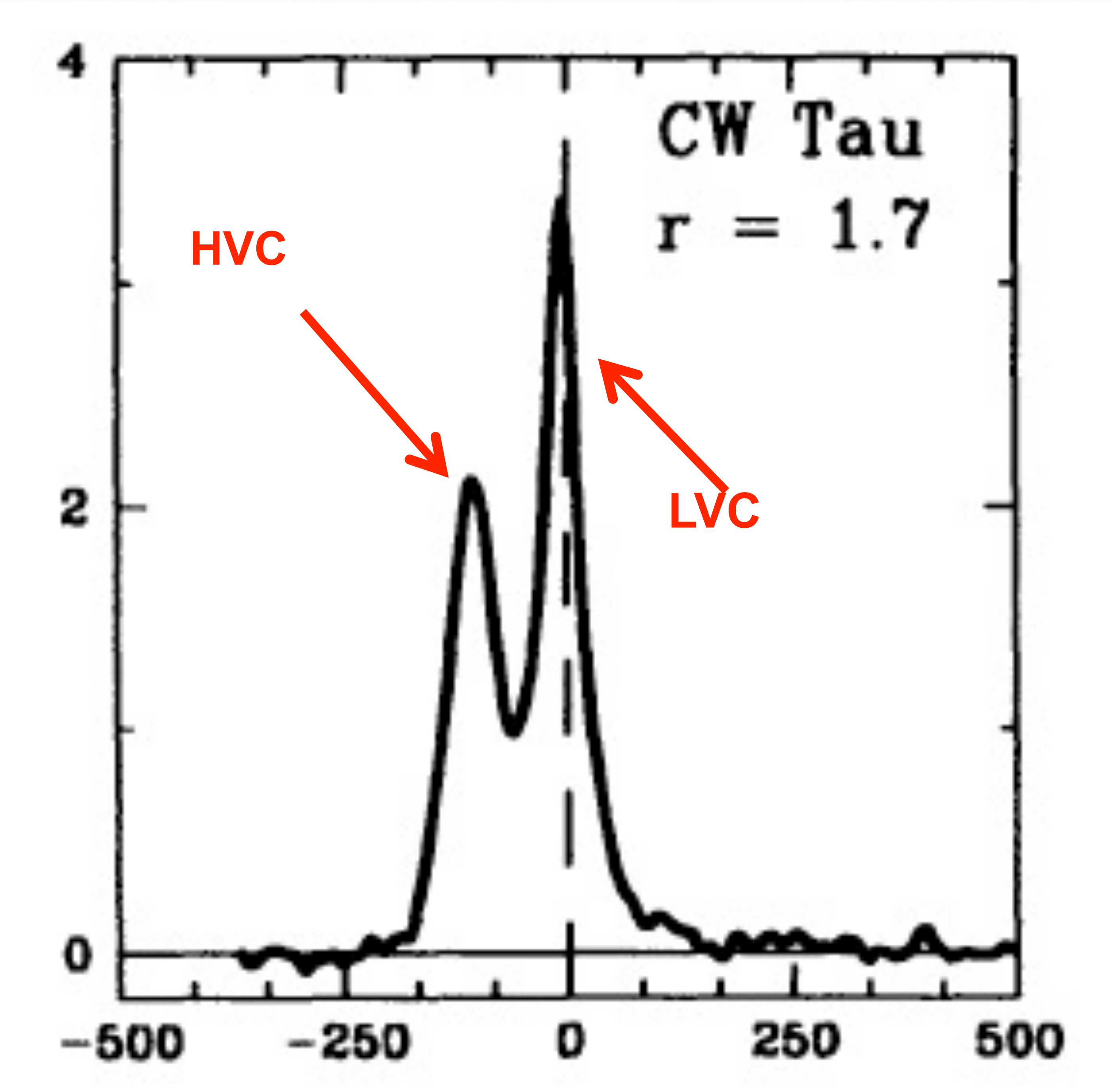
(Font et al 2004)

X-ray wind is quasi-neutral

L([OI]) > 10^{-5} $L_\odot$

(Ercolano & Owen 2010)

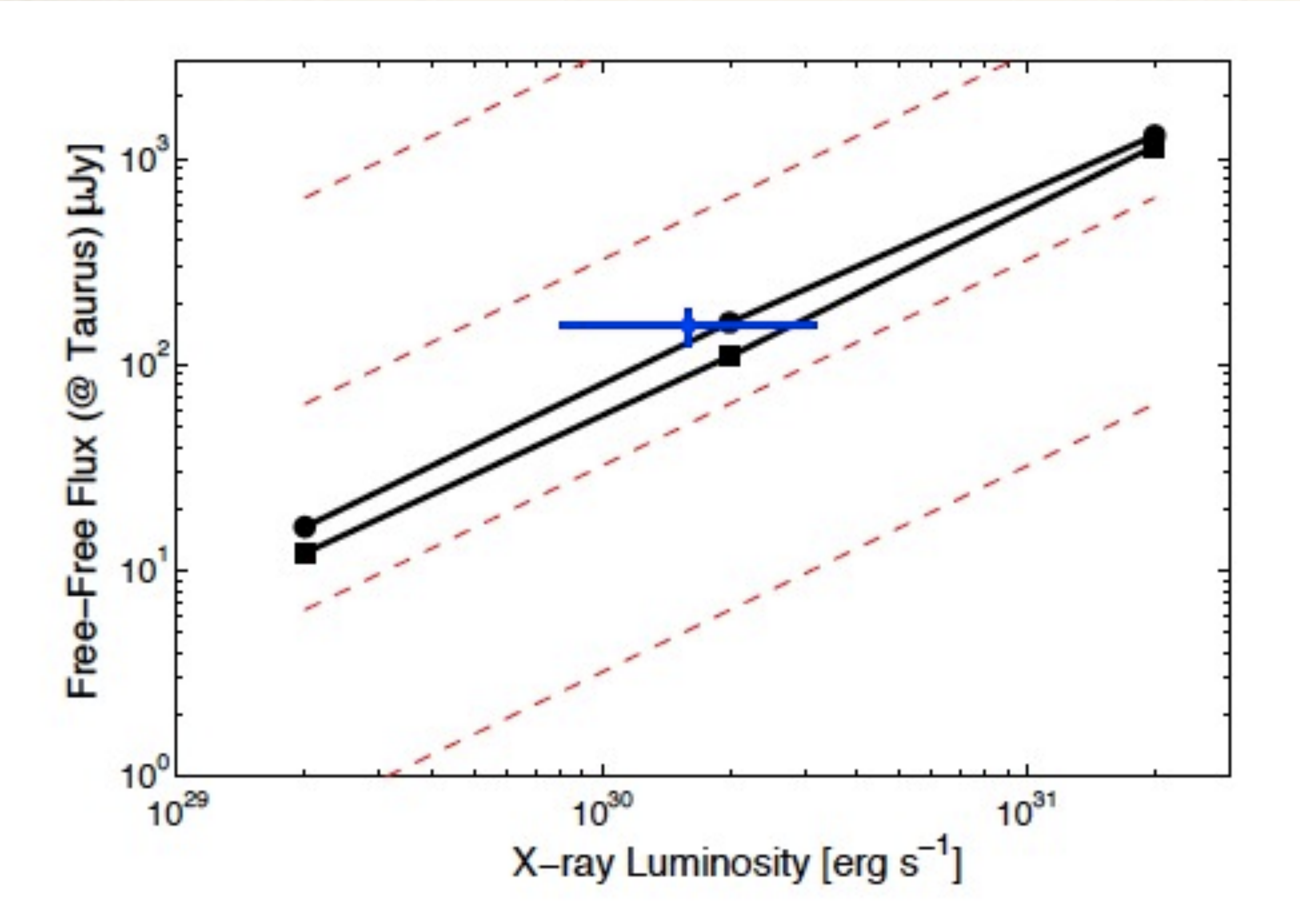
But see also Gorti et al. OH dissociation?

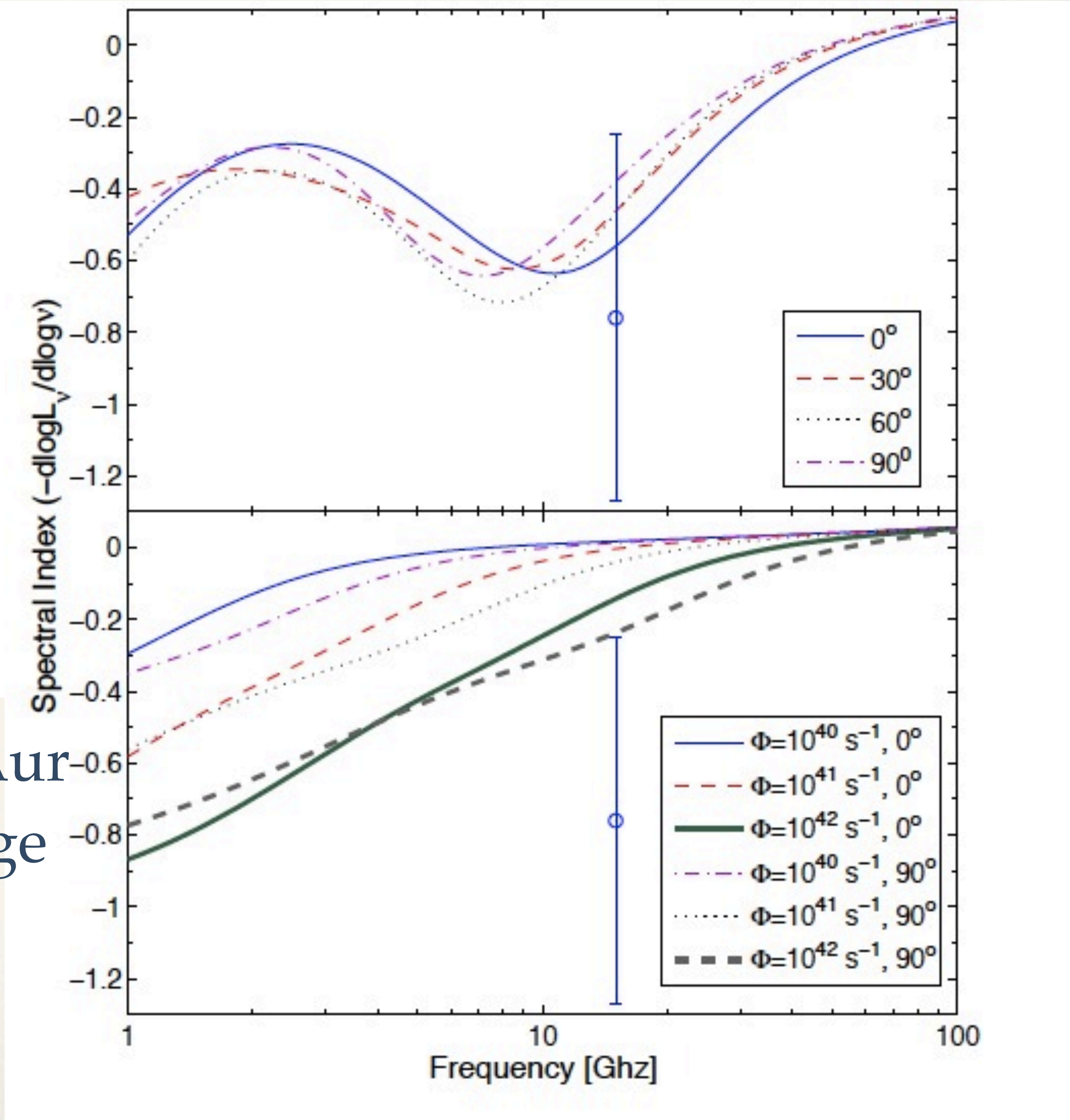


Hartigan et al 1995

Can we 'see' the wind??

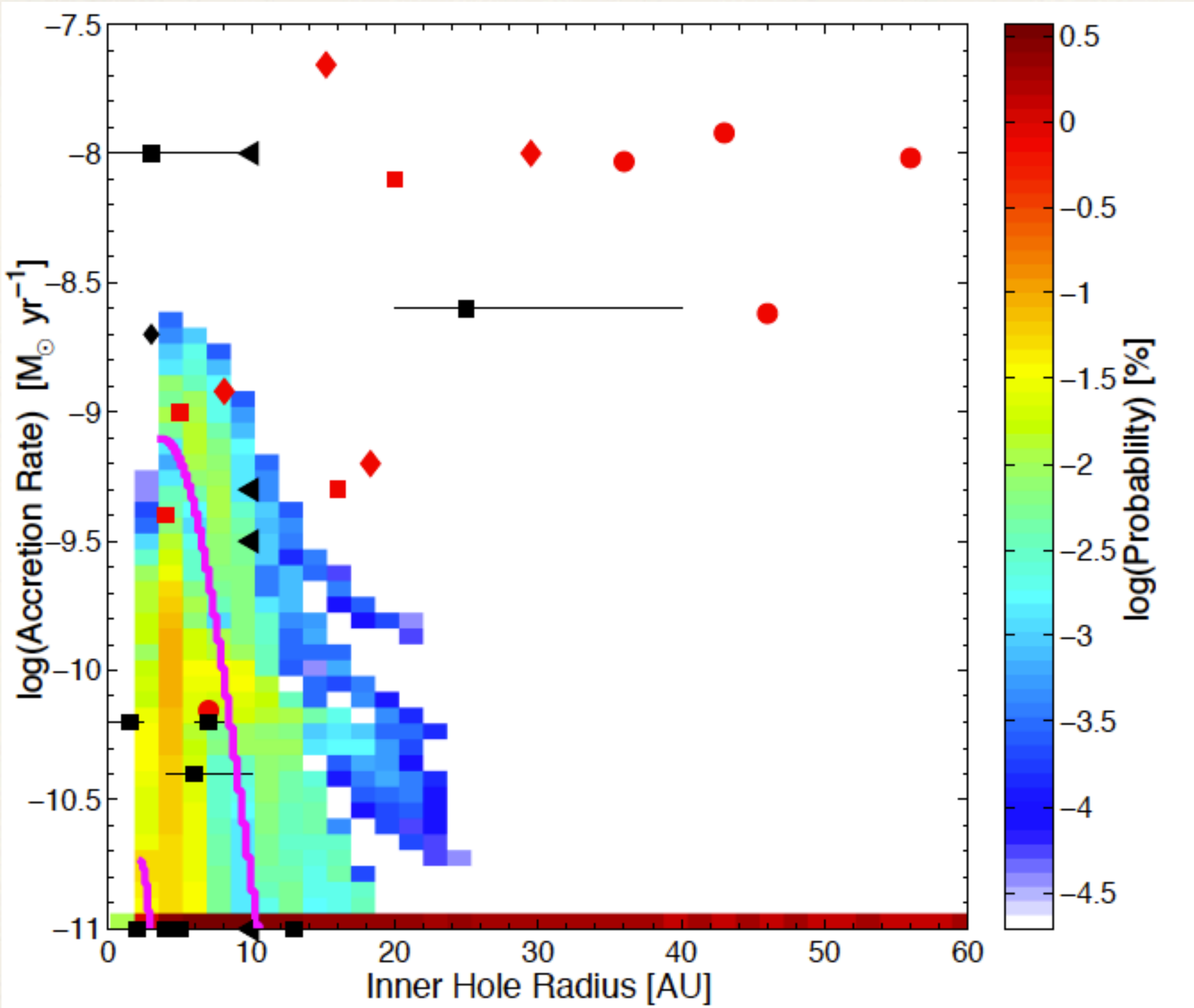
Free-free emission from the wind should be detectable
(Pascucci, Gorti & Hollenbach, 2012)





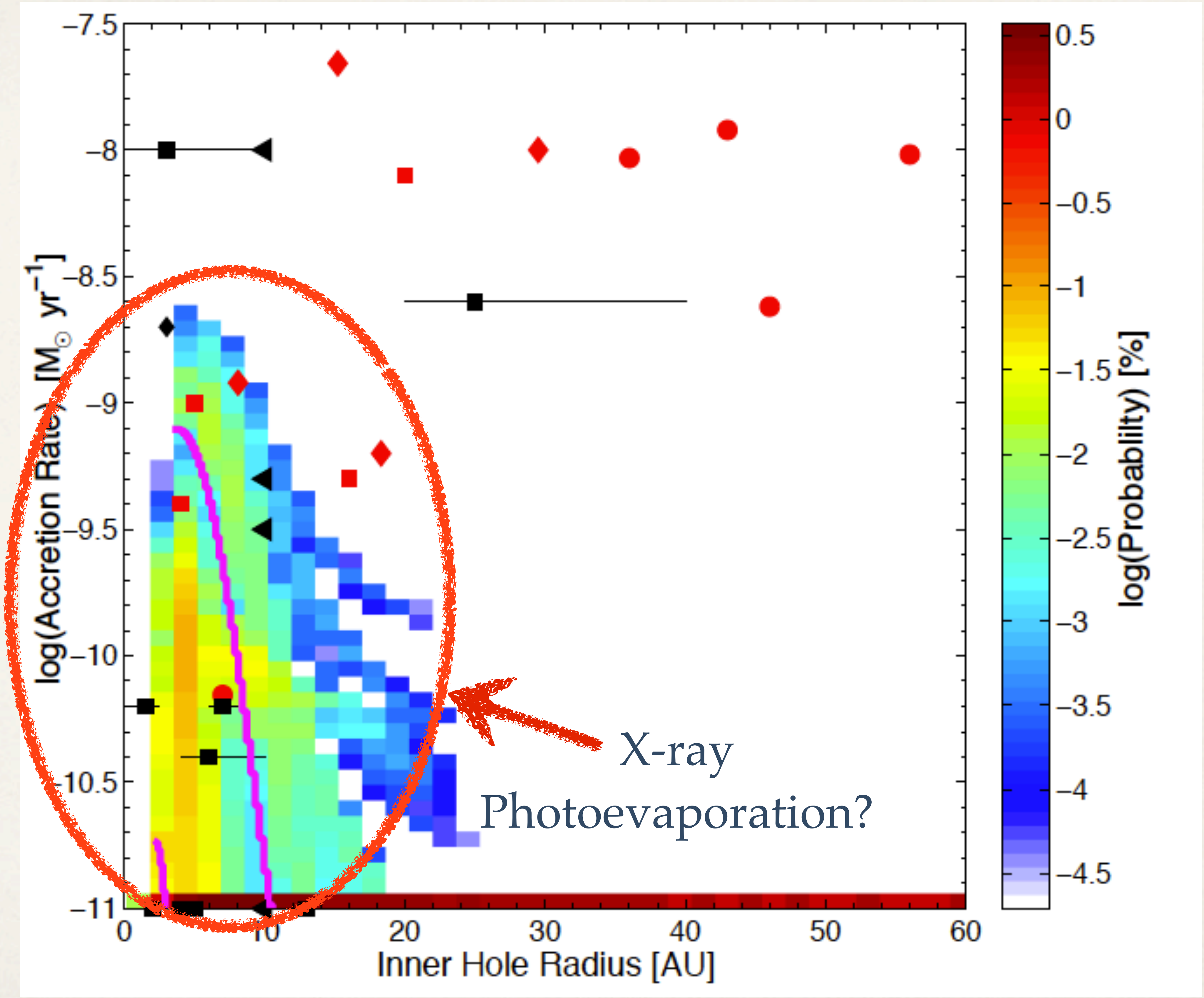
Free-free emission detected in GM Aur
with AMI-LA at Mullard, Cambridge
Owen, Scaife & Ercolano, in prep

X-ray photoevaporation & Transition Discs



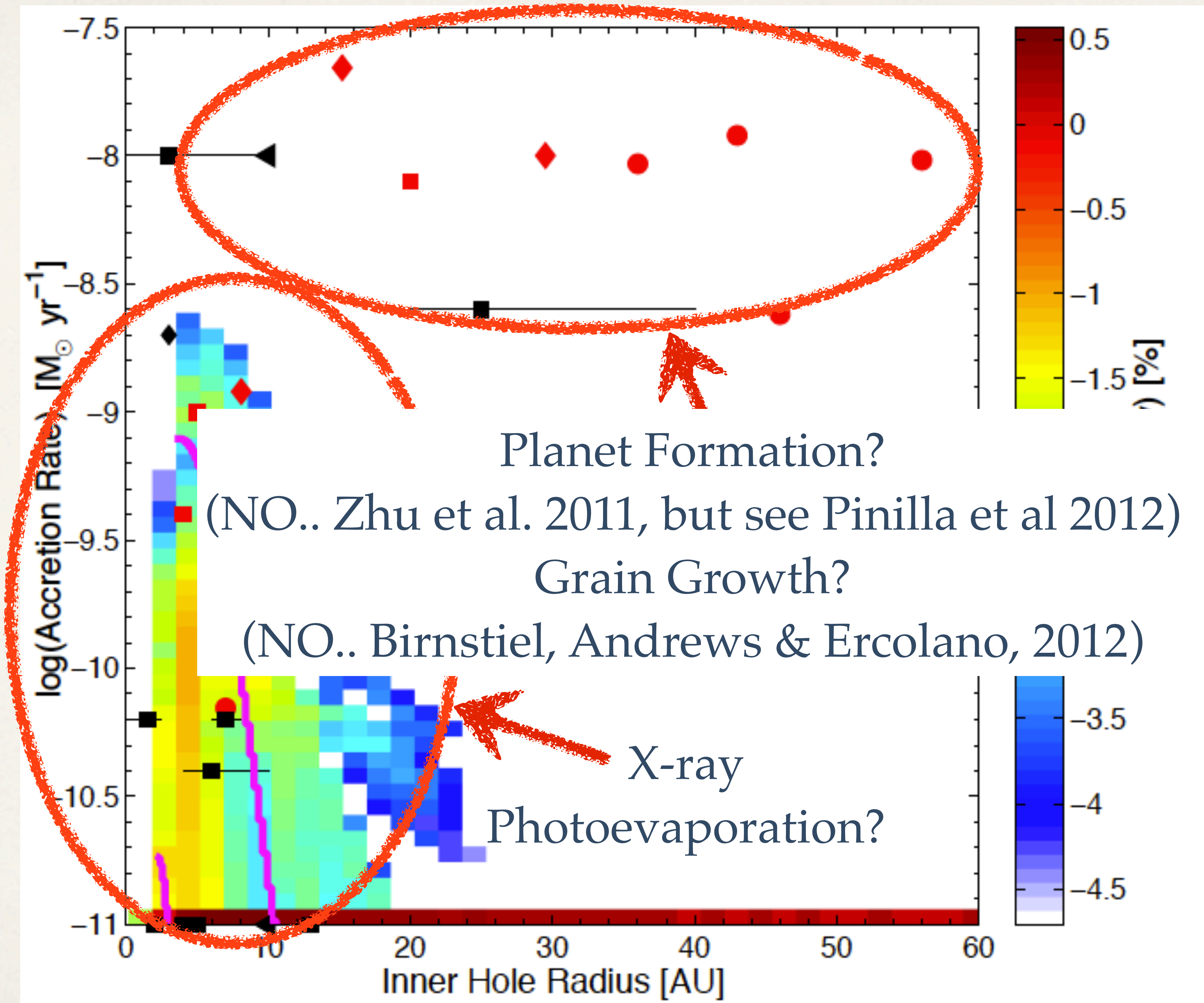
Owen, Ercolano & Clarke 2011

X-ray photoevaporation & Transition Discs



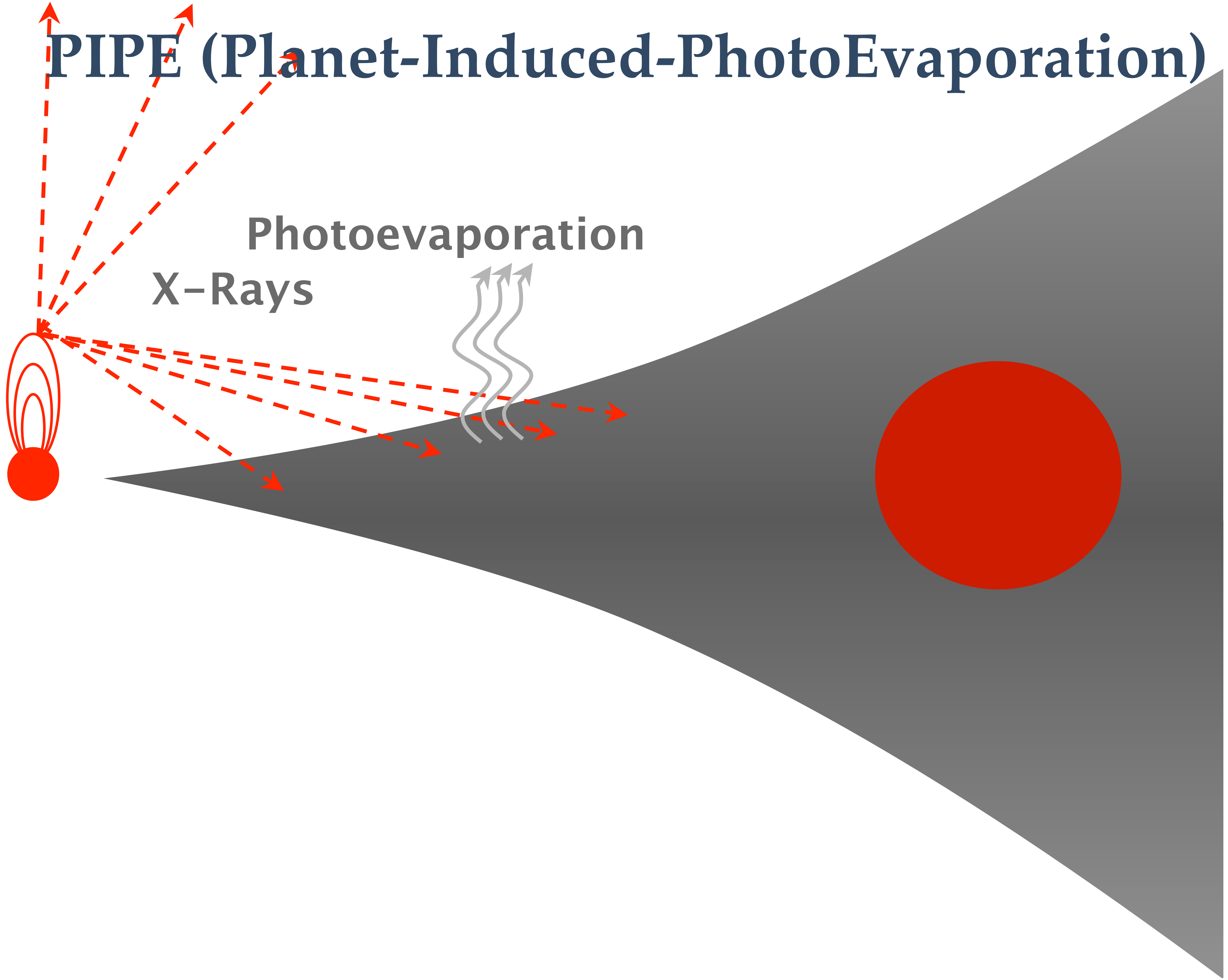
Owen, Ercolano & Clarke 2011

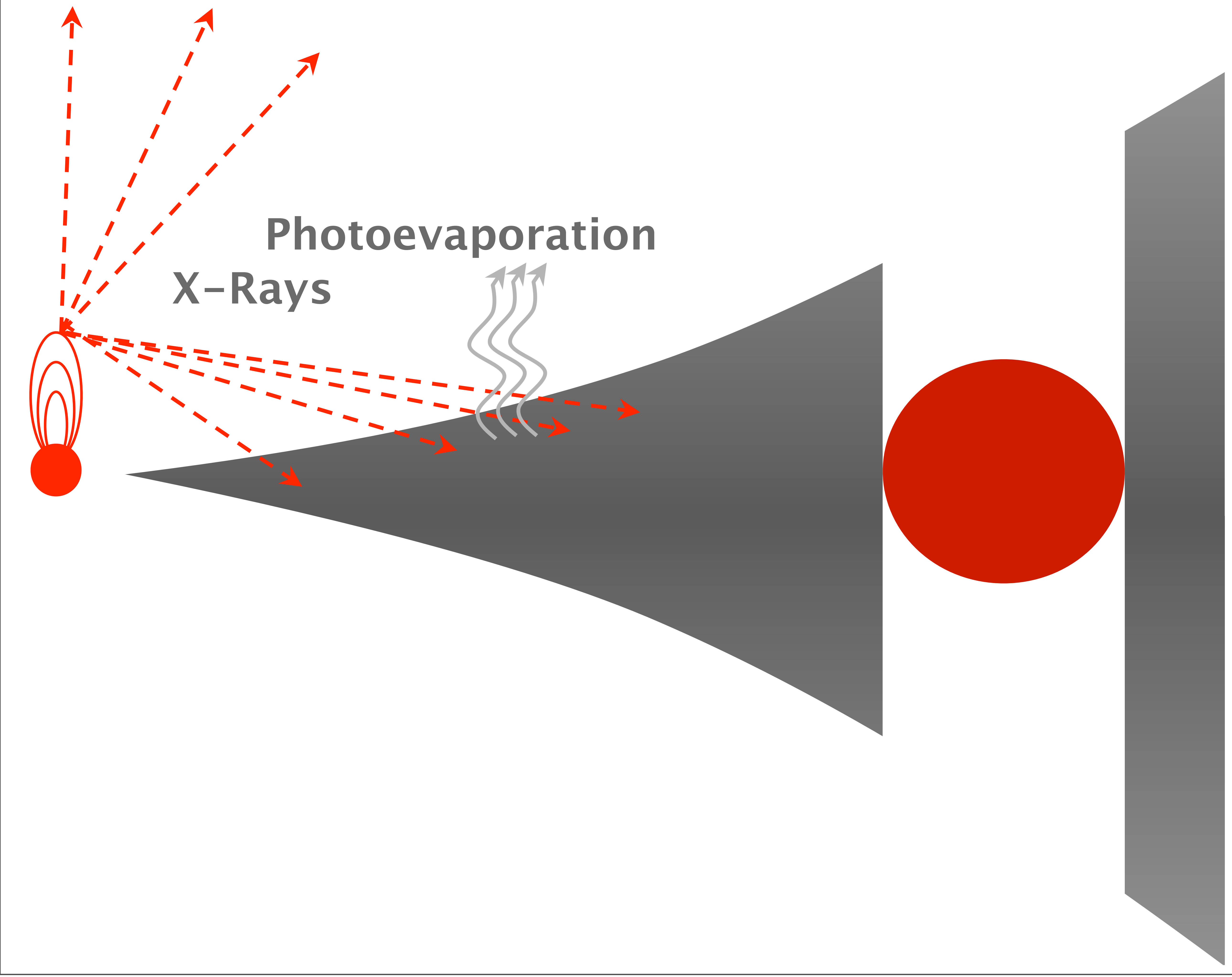
X-ray photoevaporation & Transition Discs

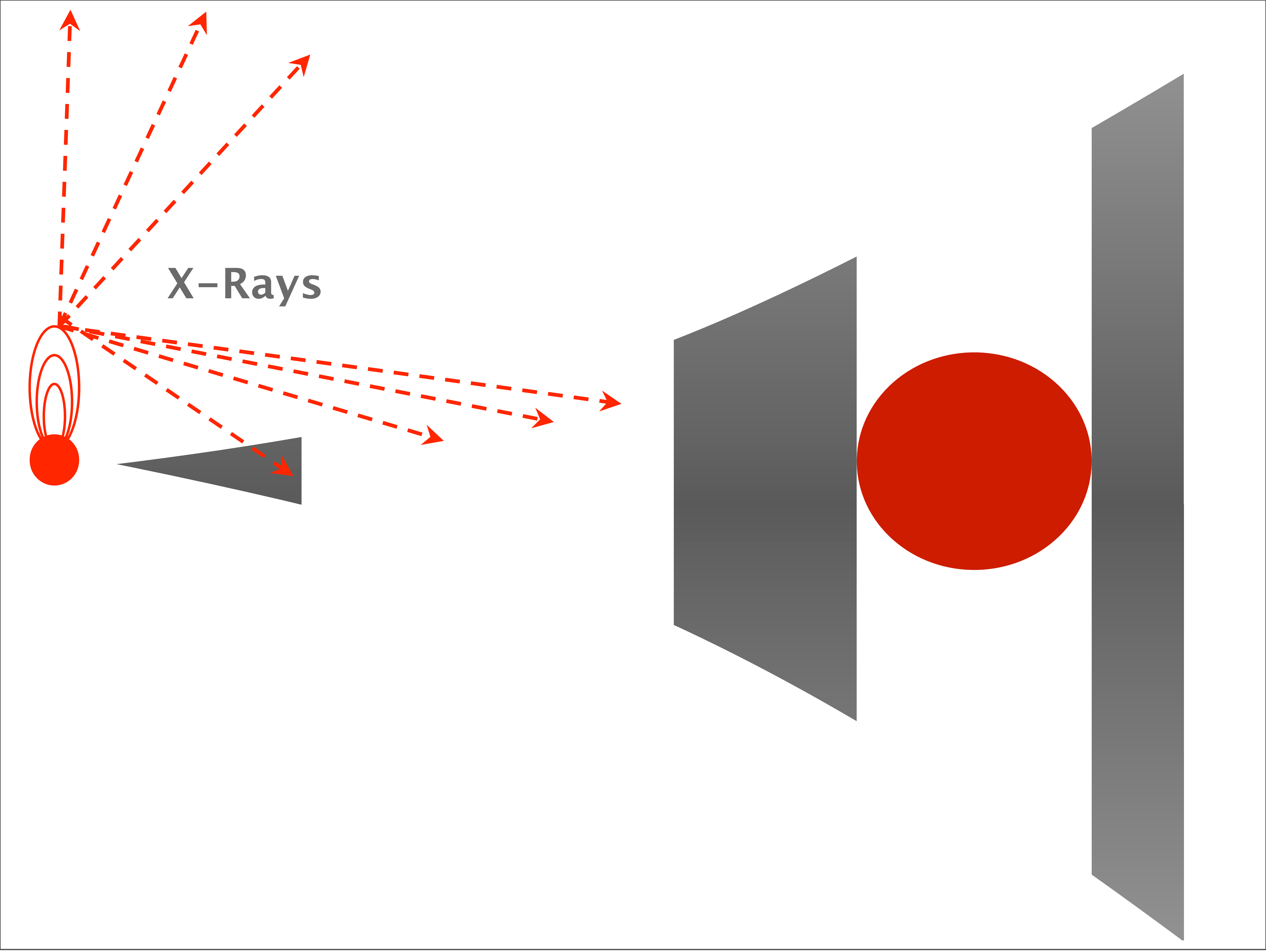


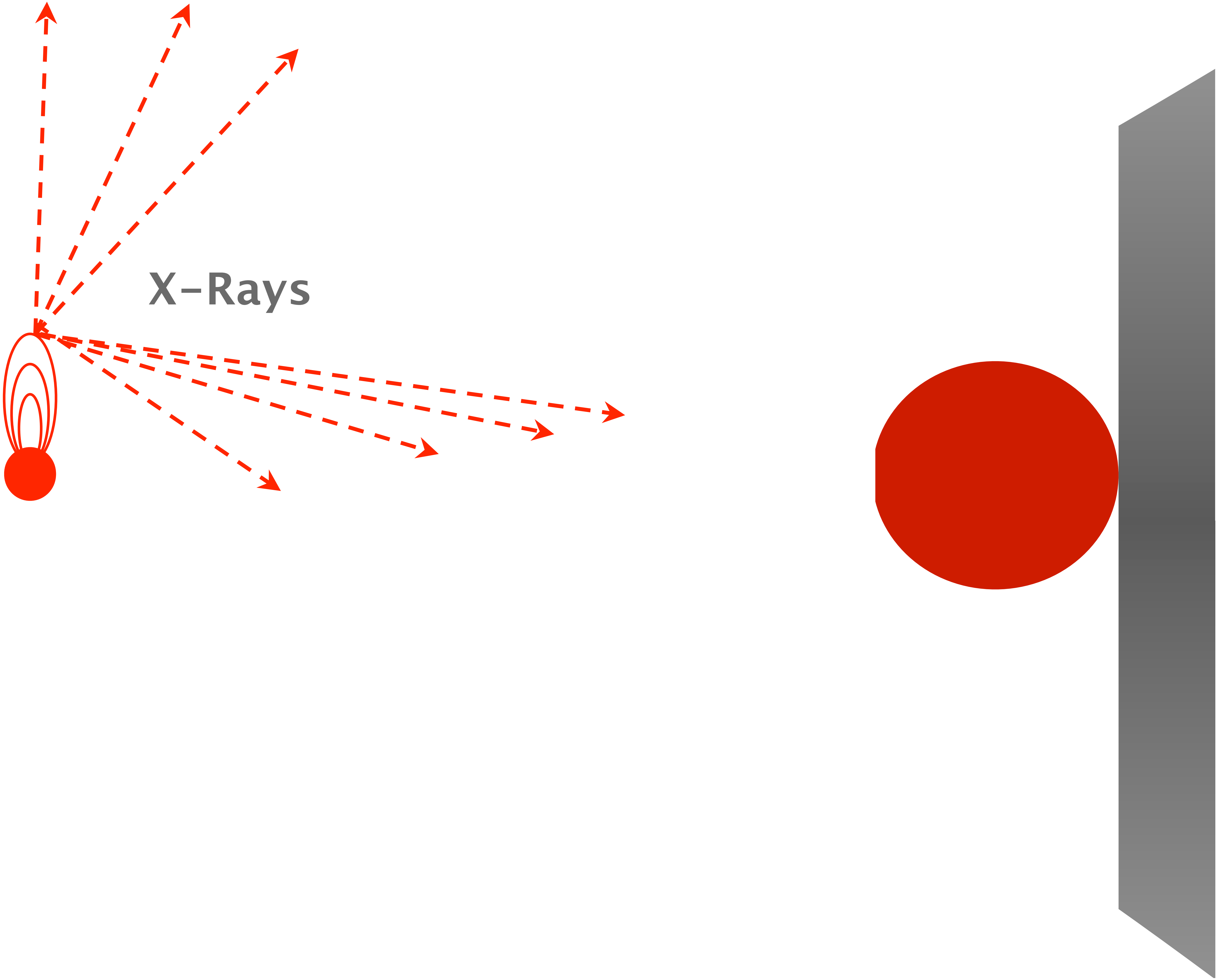
Owen, Ercolano & Clarke 2011

PIPE (Planet-Induced-PhotoEvaporation)



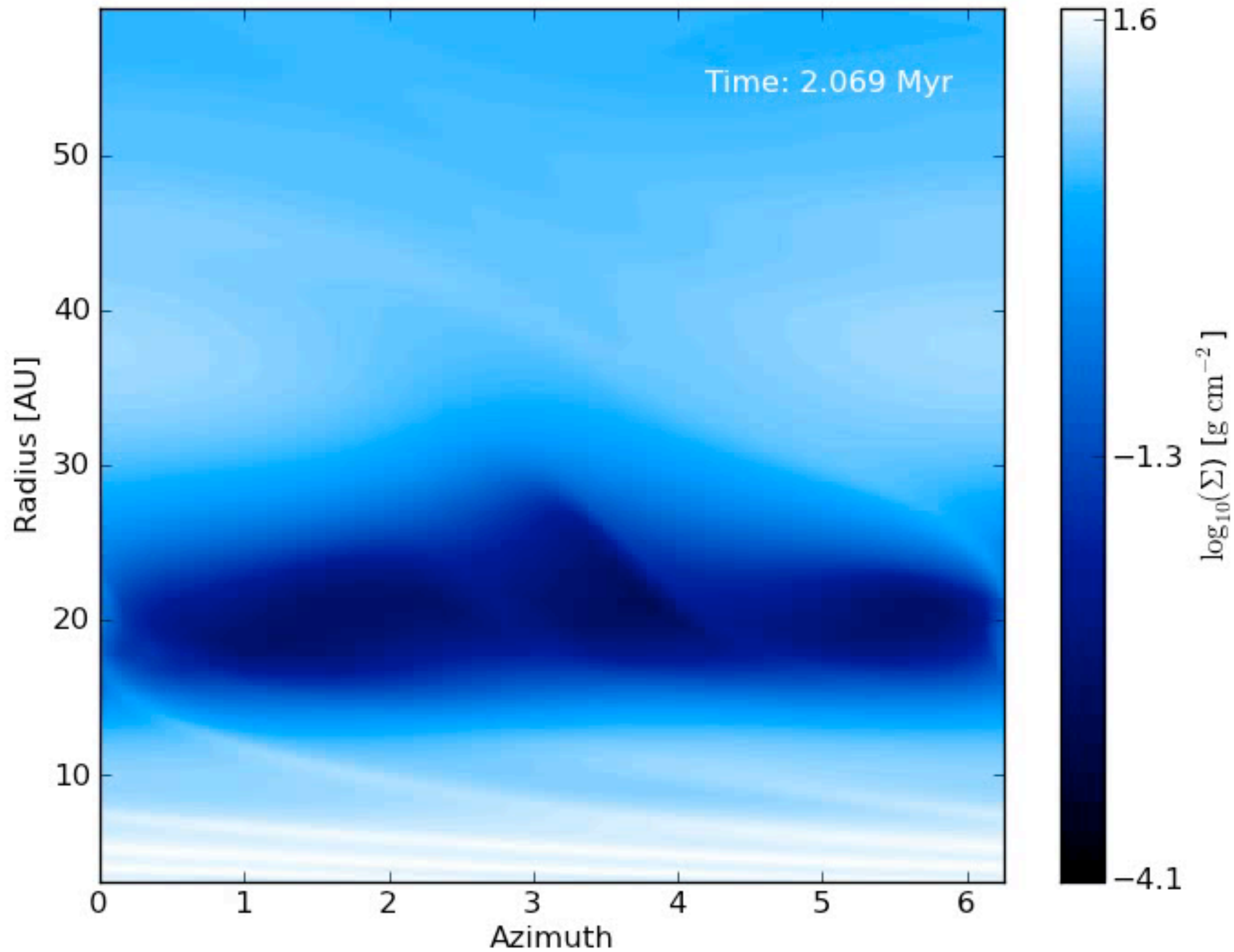

Photoevaporation
X-Rays


X-Rays


X-Rays

PIPE (Planet-Induced-PhotoEvaporation)

Rosotti, Ercolano, Owen & Armitage (2013)



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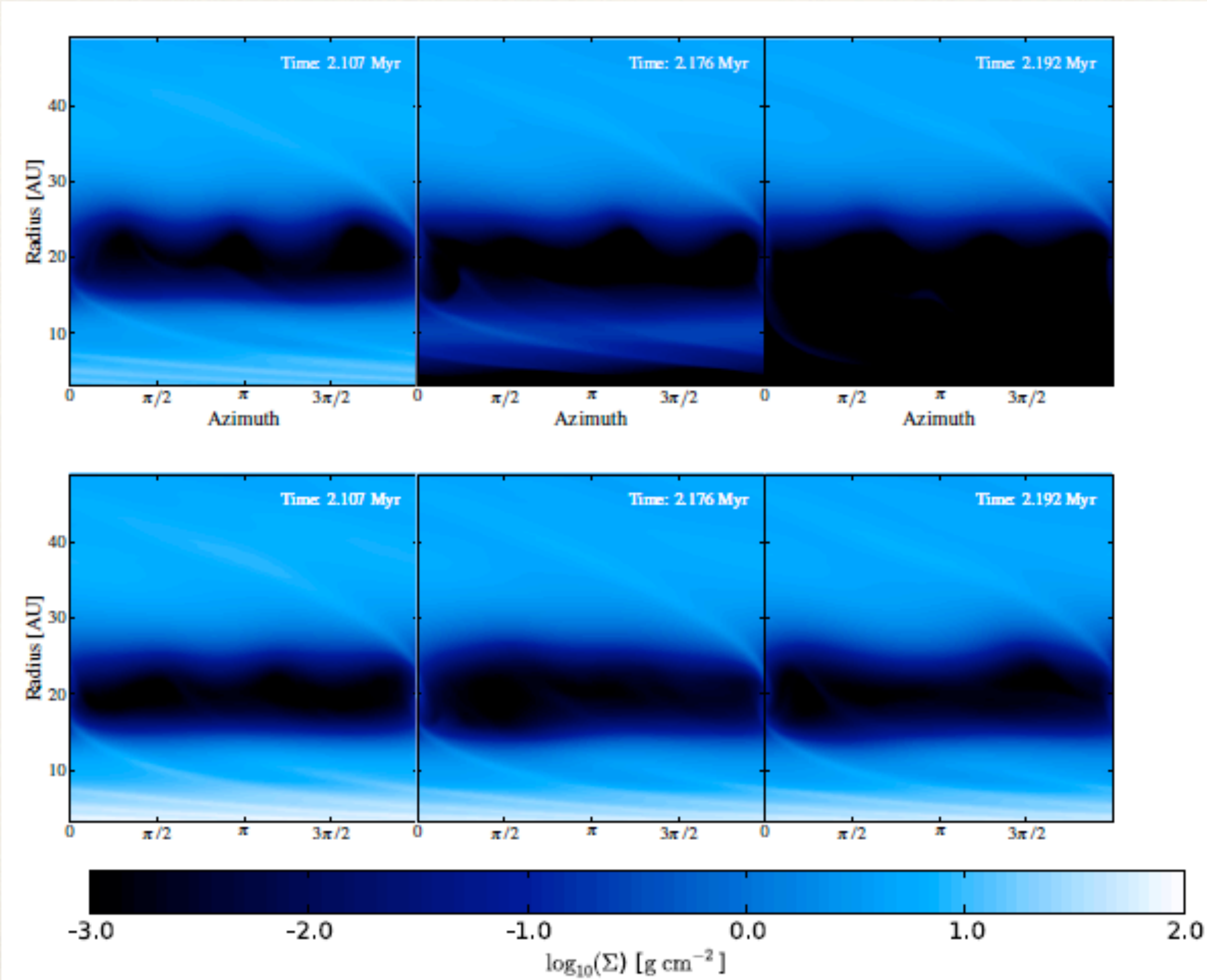

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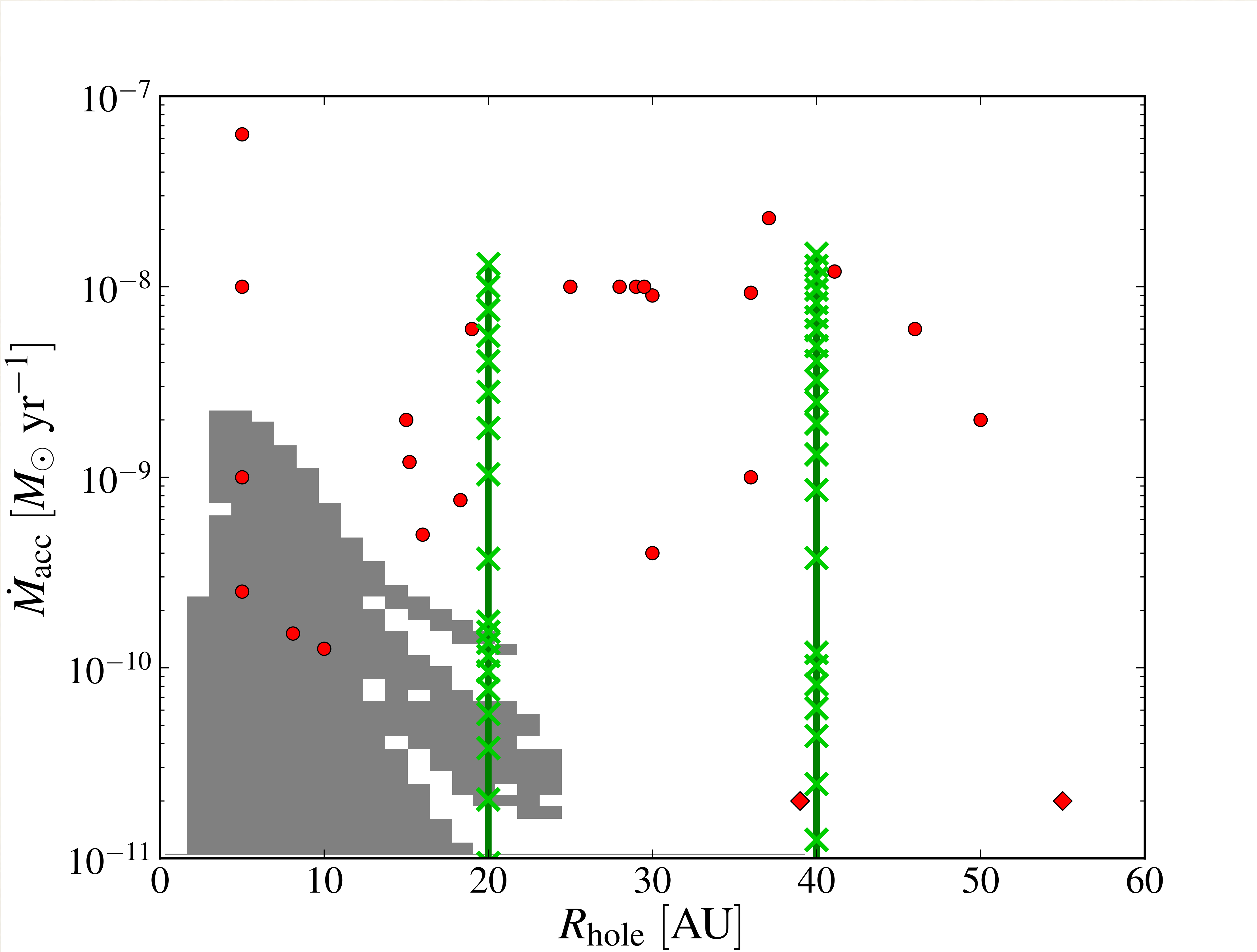

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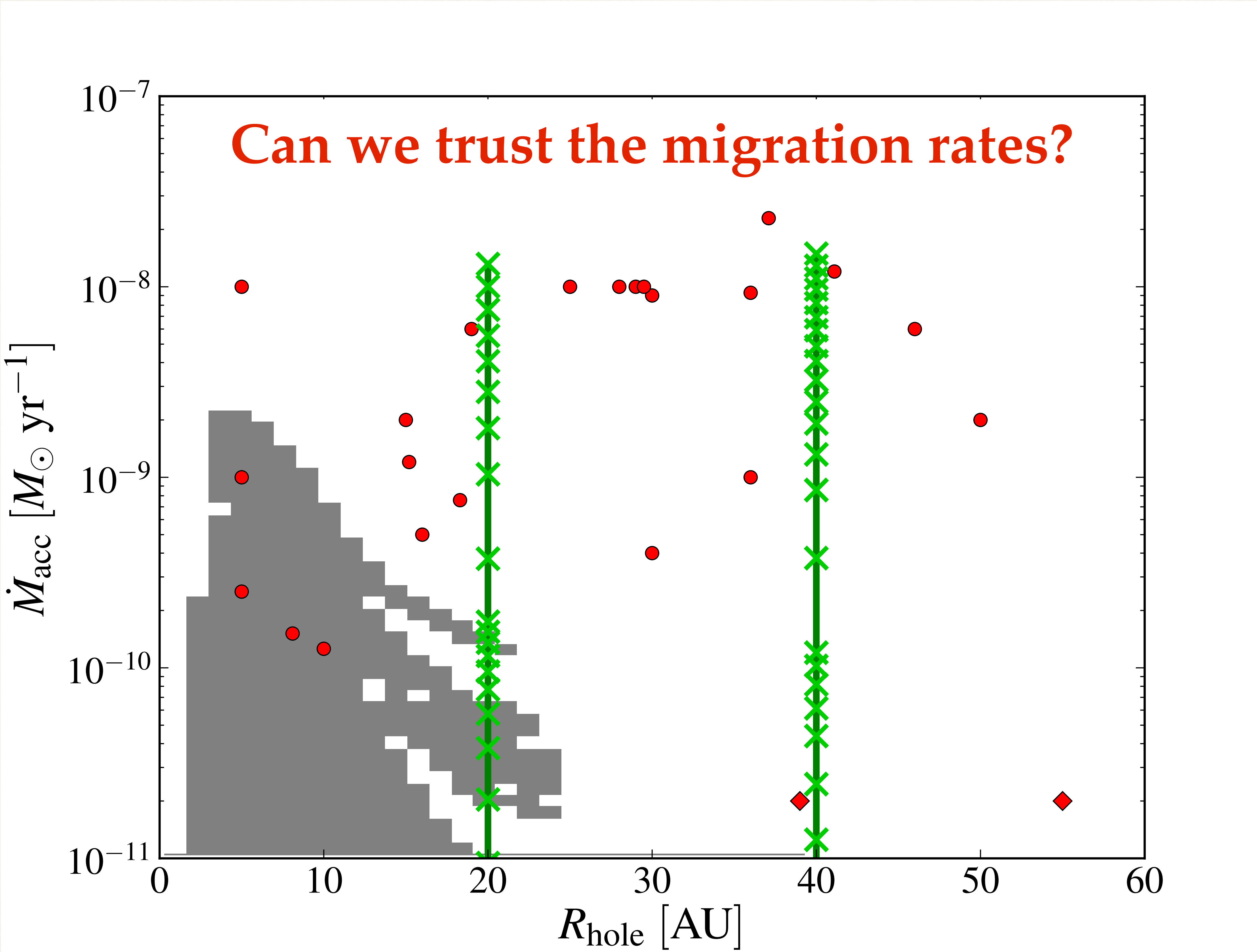
Rosotti, Ercolano, Owen & Armitage (2013)



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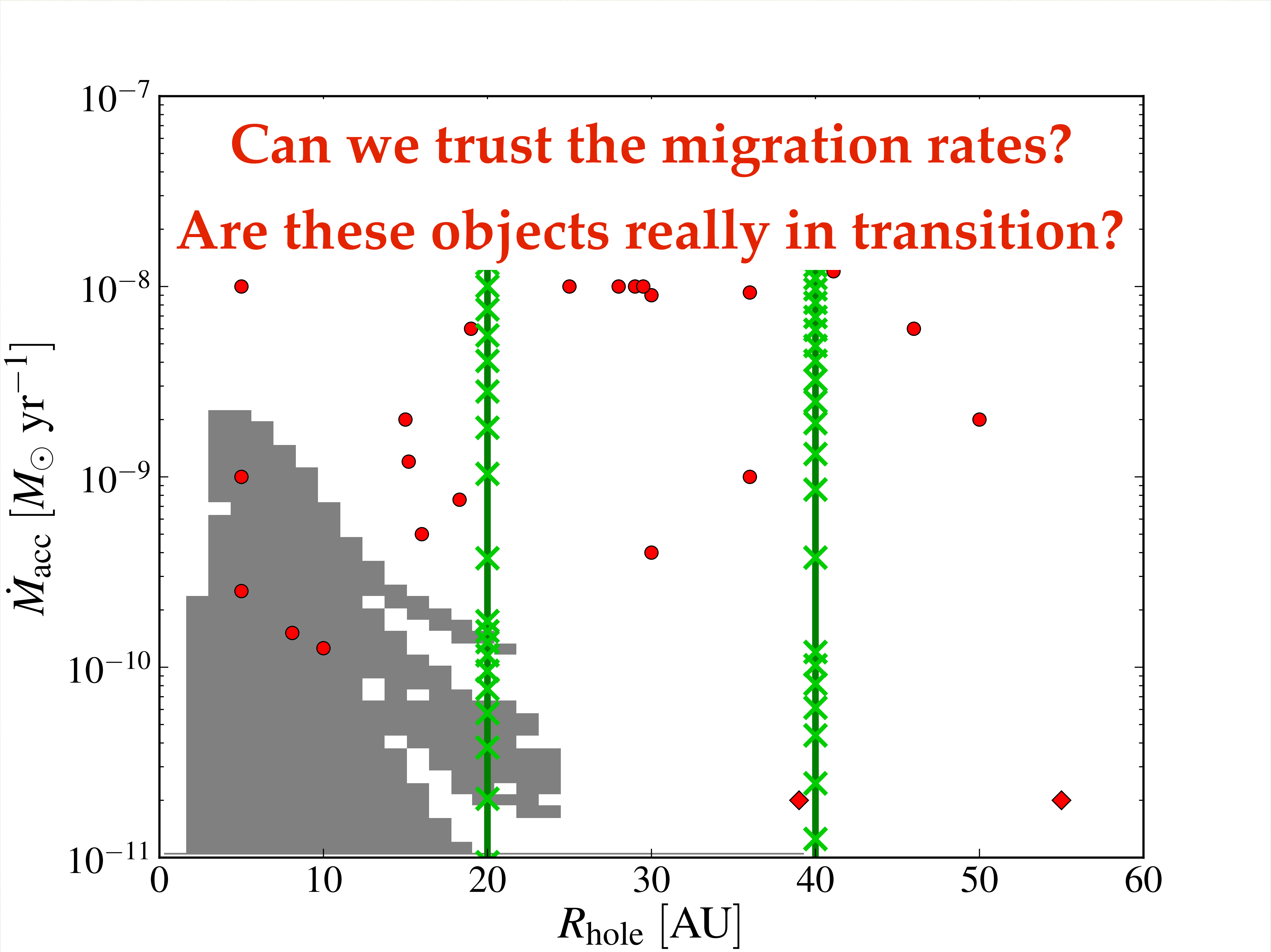
Rosotti, Ercolano, Owen & Armitage (2013)



CONCLUSIONS

The lifetimes of discs are characterised by two timescales:

Global (~ Myr)

Dispersal (~10^5)

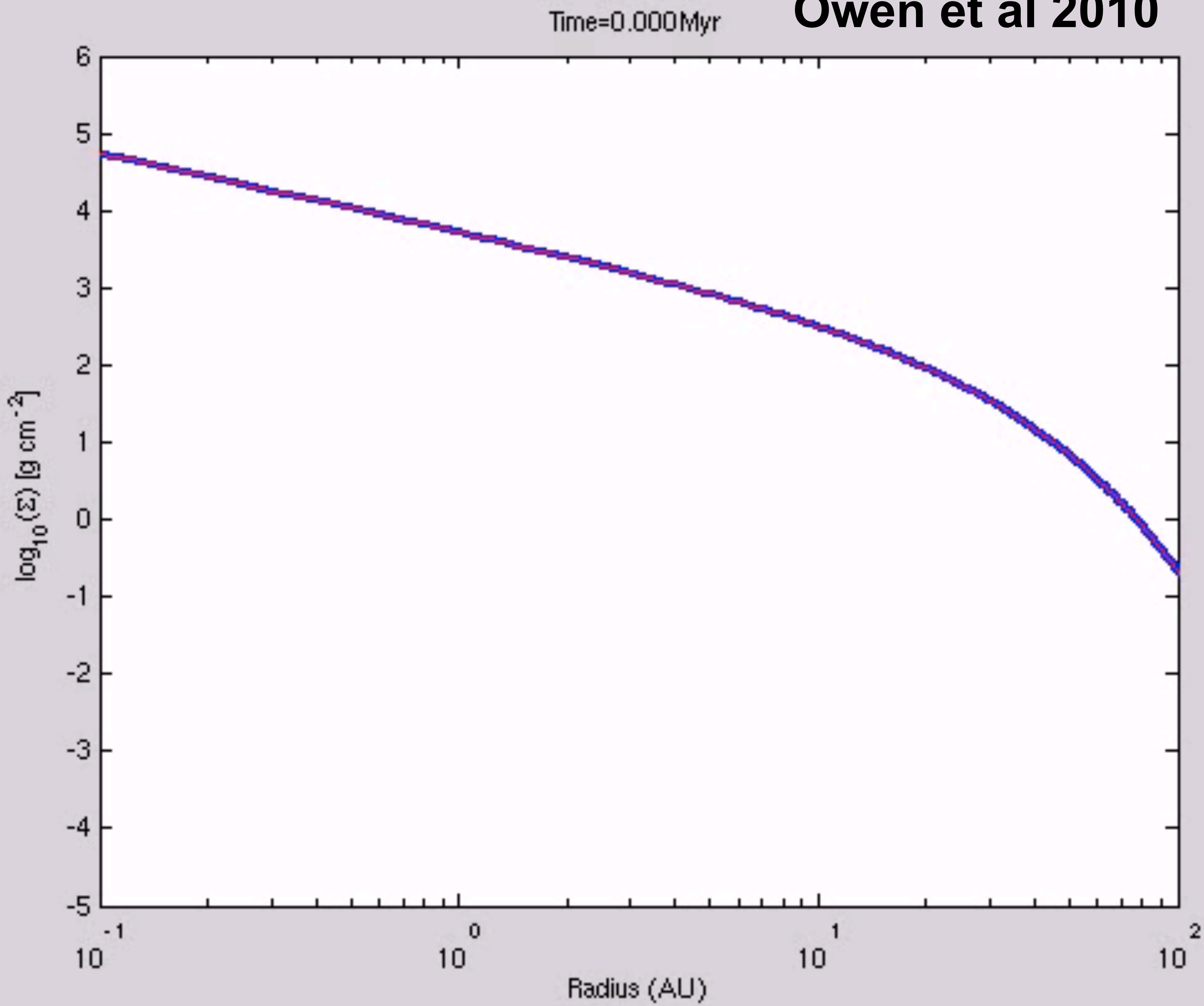
Dispersal is rapid and proceeds from the inside-out

X-ray photovaporation can reproduce the observed dispersal timescales and spectroscopic signatures

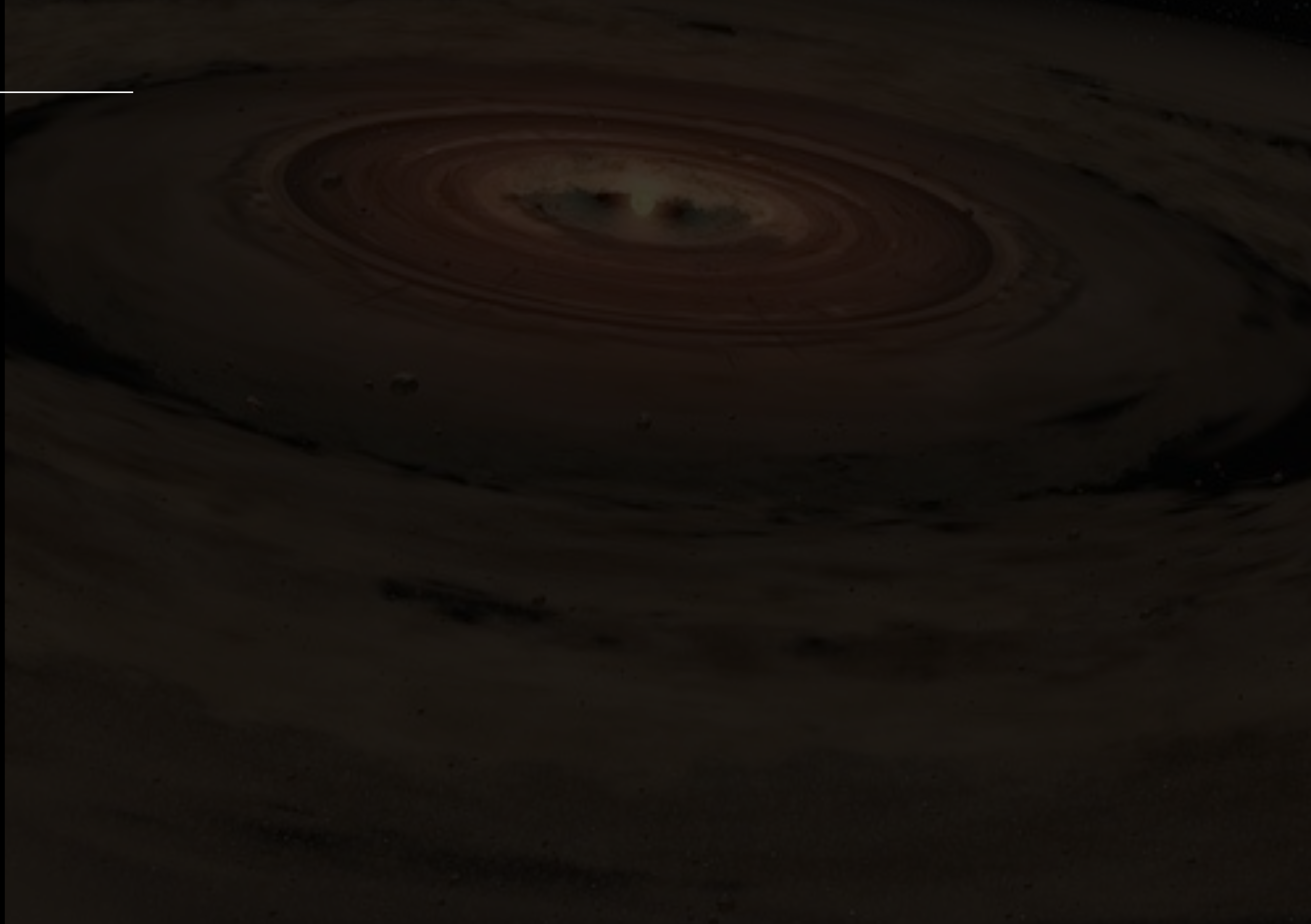
Photoevaporation or planet formation alone cannot explain all of the observed transition discs

PIPE could provide a mechanism to produced large hole strongly accreting transition discs but problems remain

Owen et al 2010



Disc Dispersal: Models vs Observations



Disc Dispersal: Models vs Observations

Observ. / Models							
Viscous Accretion-only							
EUV-only Photoevap.							
FUV-Photoevap.							
X-ray Photoevap.							
Planet Formation							

Disc Dispersal: Models vs Observations

Observ. / Models	Fast inside-out						
Viscous Accretion-only	✗						
EUV-only Photoevap.	✓						
FUV-Photoevap.	✓						
X-ray Photoevap.	✓						
Planet Formation	✓						

Disc Dispersal: Models vs Observations

Observ. / Models	Fast inside-out	Massive Trans. Discs					
Viscous Accretion-only	✗	✗					
EUV-only Photoevap.	✓	✗					
FUV-Photoevap.	✓	✓					
X-ray Photoevap.	✓	✓					
Planet Formation	✓	✓					

Disc Dispersal:
Models vs Observations

Observ. / Models	Fast inside-out	Massive Trans. Discs	Accret. Trans. Discs				
Viscous Accretion-only	✗	✗	✗				
EUV-only Photoevap.	✓	✗	✗				
FUV-Photoevap.	✓	✓	✓ ?				
X-ray Photoevap.	✓	✓	✓ ?				
Planet Formation	✓	✓	✓				

Disc Dispersal: Models vs Observations

Observ. / Models	Fast inside-out	Massive Trans. Discs	Accret. Trans. Discs	Metall. dependance			
Viscous Accretion-only	✗	✗	✗	✓ ?			
EUV-only Photoevap.	✓	✗	✗	✗			
FUV-Photoevap.	✓	✓	✓ ?	✗			
X-ray Photoevap.	✓	✓	✓ ?	✓ ?			
Planet Formation	✓	✓	✓	✗			

Disc Dispersal: Models vs Observations

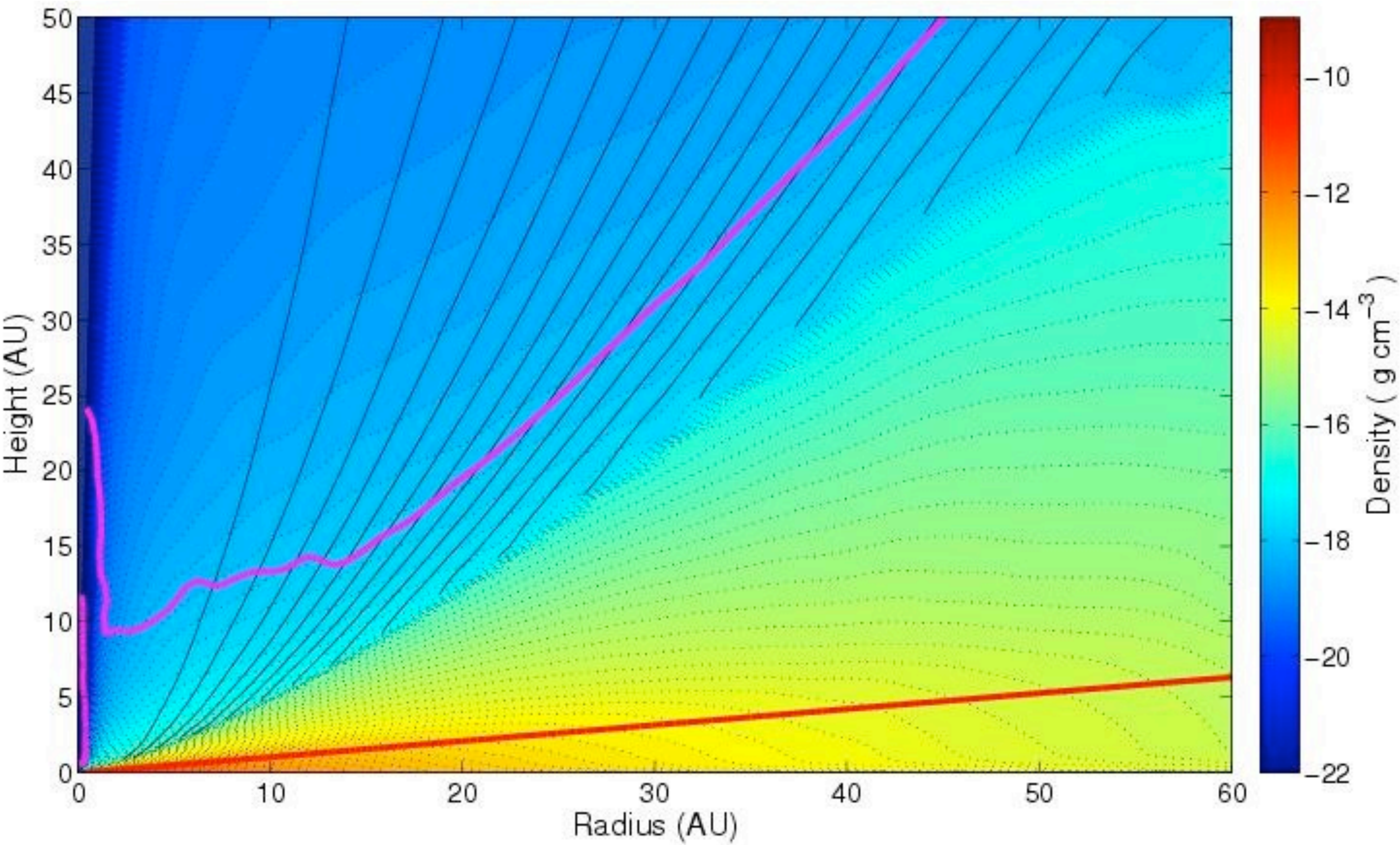
Observ. / Models	Fast inside-out	Massive Trans. Discs	Accret. Trans. Discs	Metall. dependance	Blueshifted [NeII]		
Viscous Accretion-only	✗	✗	✗	✓?	✗		
EUV-only Photoevap.	✓	✗	✗	✗	✓		
FUV-Photoevap.	✓	✓	✓?	✗	?		
X-ray Photoevap.	✓	✓	✓?	✓?	✓		
Planet Formation	✓	✓	✓	✗	✗		

Disc Dispersal: Models vs Observations

Observ. / Models	Fast inside-out	Massive Trans. Discs	Accret. Trans. Discs	Metall. dependance	Blueshifted [NeII]	Blueshifted [OI]	
Viscous Accretion-only	✗	✗	✗	✓?	✗	✗	
EUV-only Photoevap.	✓	✗	✗	✗	✓	✗	
FUV-Photoevap.	✓	✓	✓?	✗	?	?	
X-ray Photoevap.	✓	✓	✓?	✓?	✓	✓	
Planet Formation	✓	✓	✓	✗	✗	✗	

Disc Dispersal: Models vs Observations

Observ. / Models	Fast inside-out	Massive Trans. Discs	Accret. Trans. Discs	Metall. dependance	Blueshifted [NeII]	Blueshifted [OI]	free-free emission
Viscous Accretion-only	✗	✗	✗	✓?	✗	✗	✗
EUV-only Photoevap.	✓	✗	✗	✗	✓	✗	?
FUV-Photoevap.	✓	✓	✓?	✗	?	?	?
X-ray Photoevap.	✓	✓	✓?	✓?	✓	✓	✓?
Planet Formation	✓	✓	✓	✗	✗	✗	✗

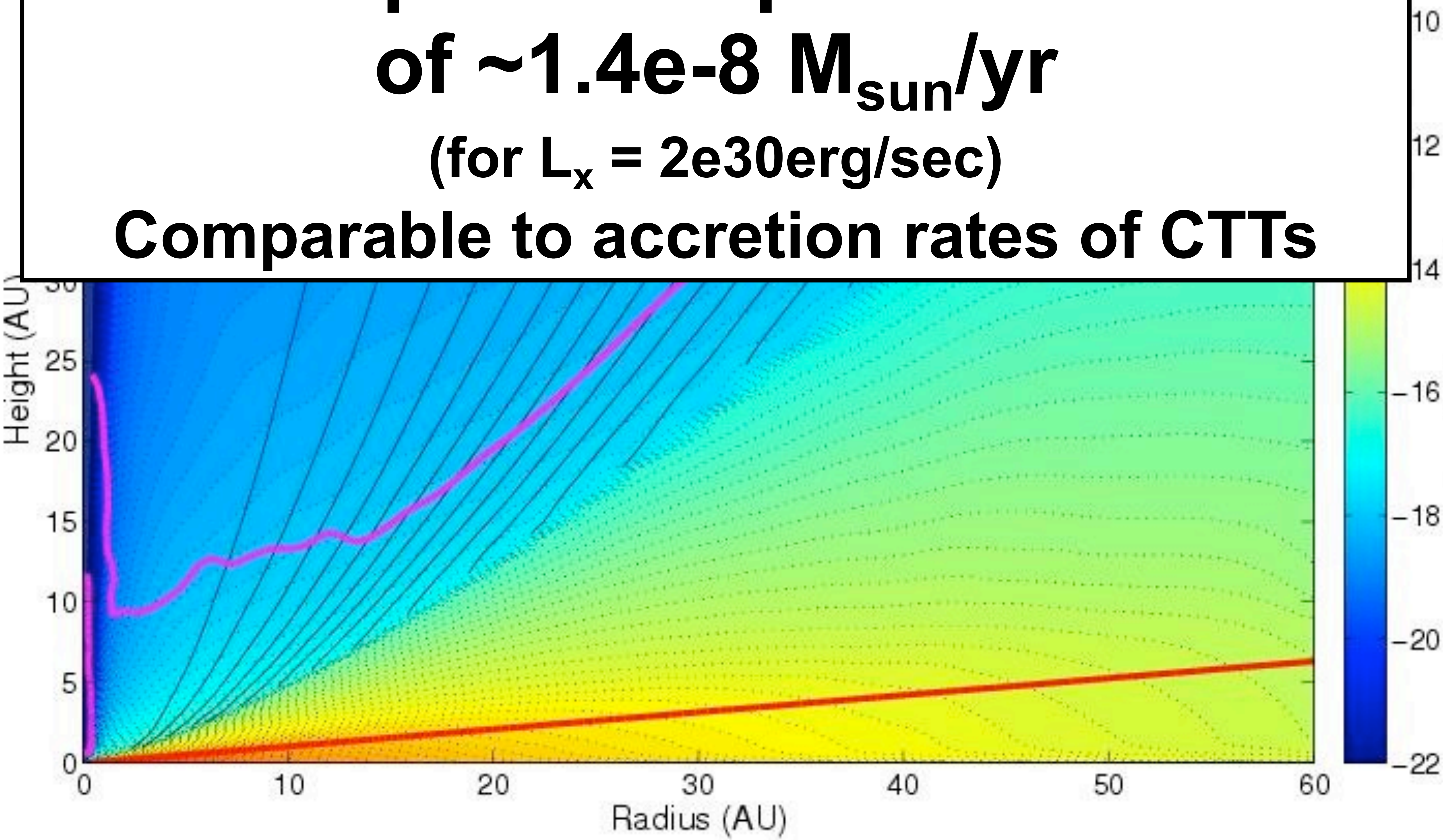


Owen, Ercolano, Clarke & Alexander, 2010, MNRAS

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:

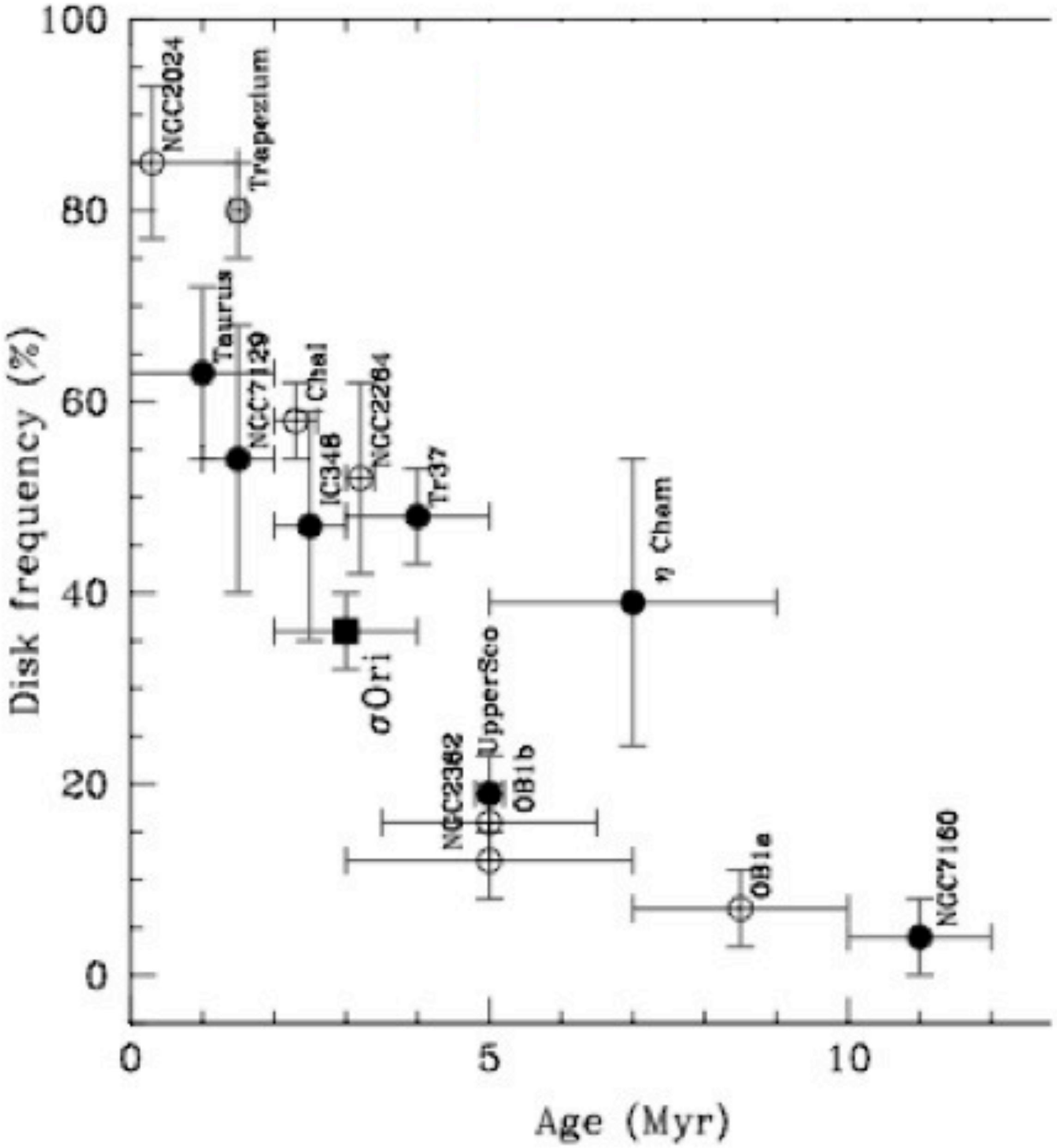
39% primordial discs
31% inside-out dispersal
22% discless sources
2% homogeneous draining
6% unclassified

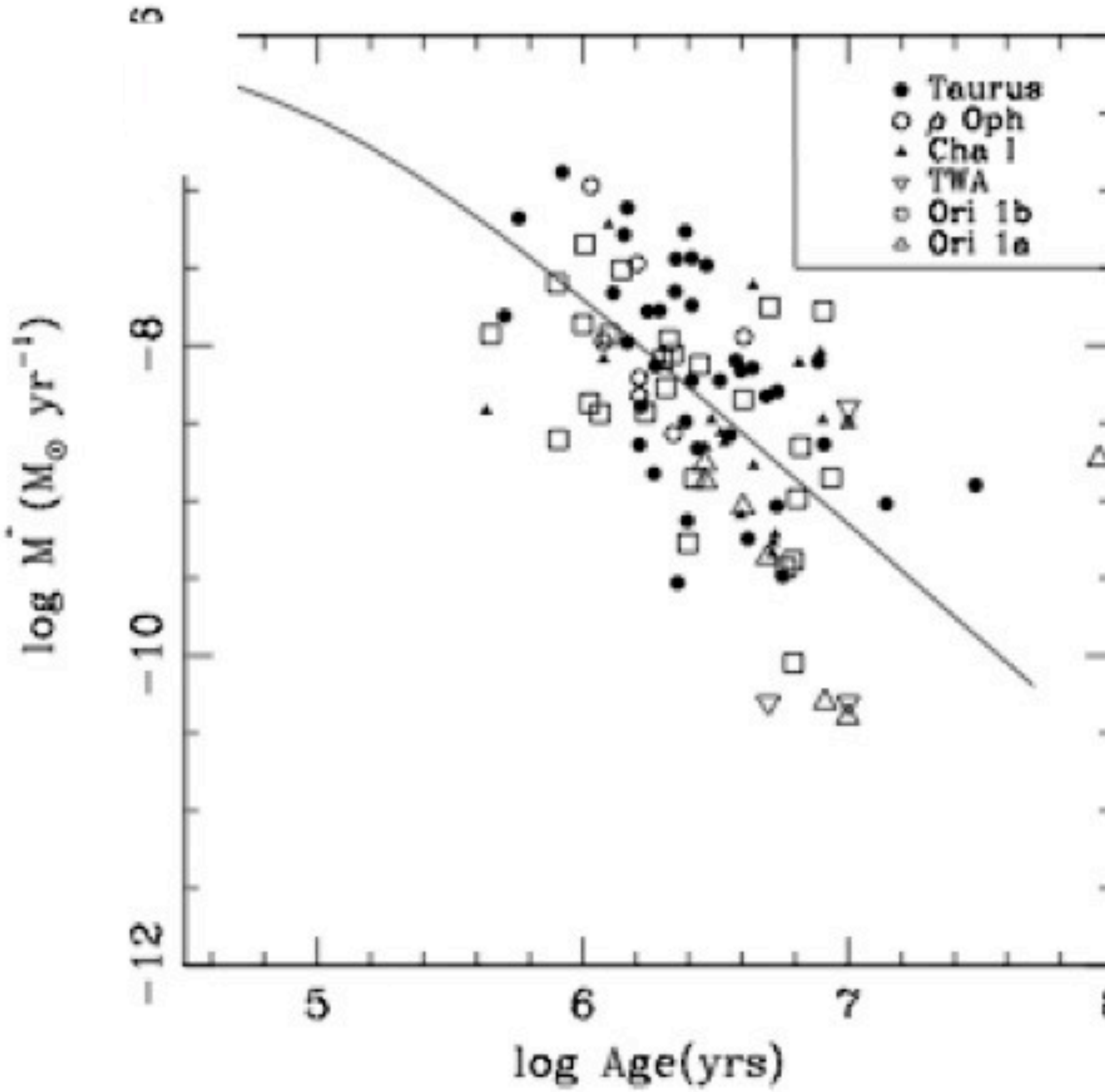
similar results apply to all spectral types

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

What is responsible for disc dispersal?

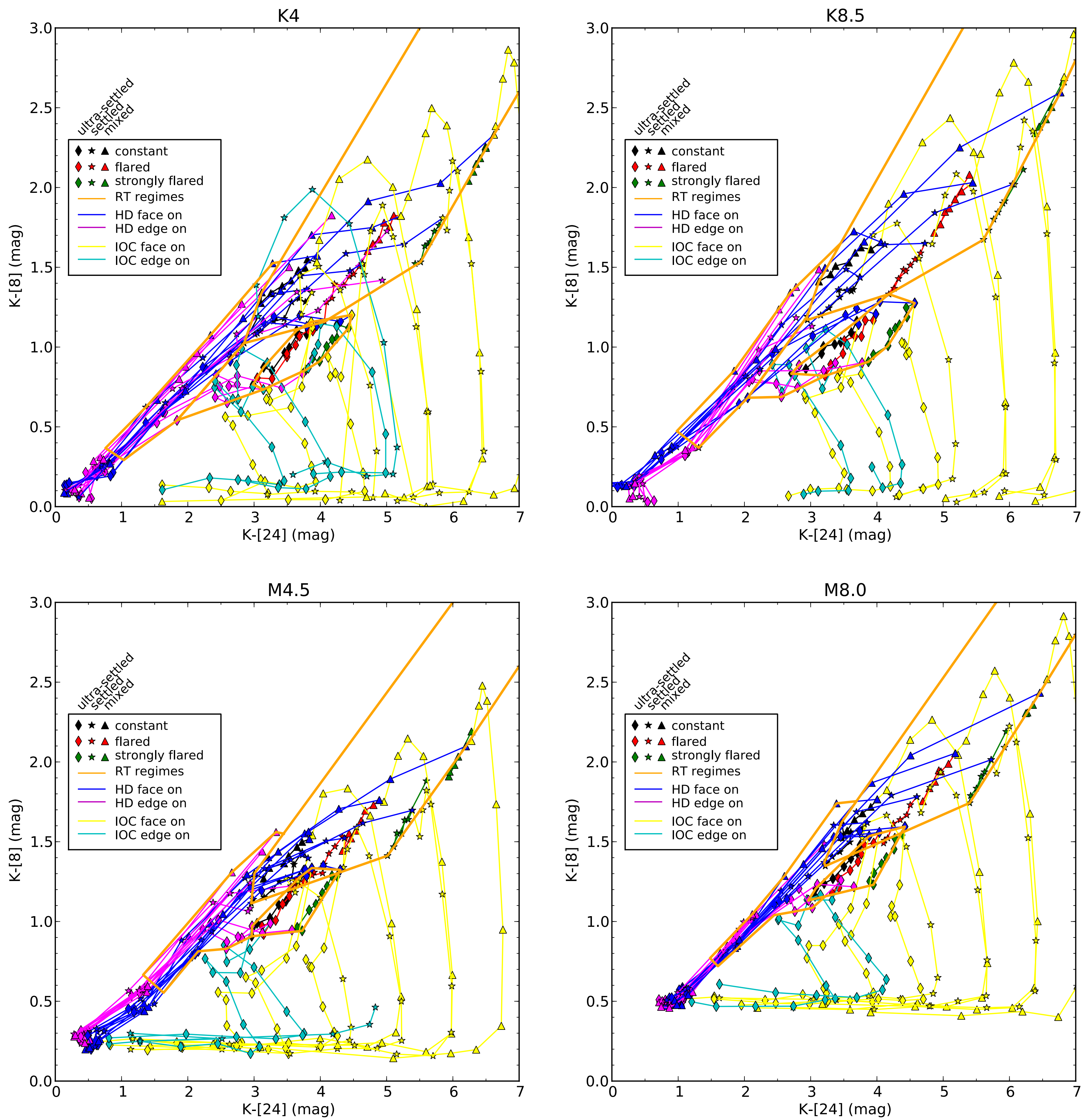
Viscous accretion is probably at work but is it the whole story???



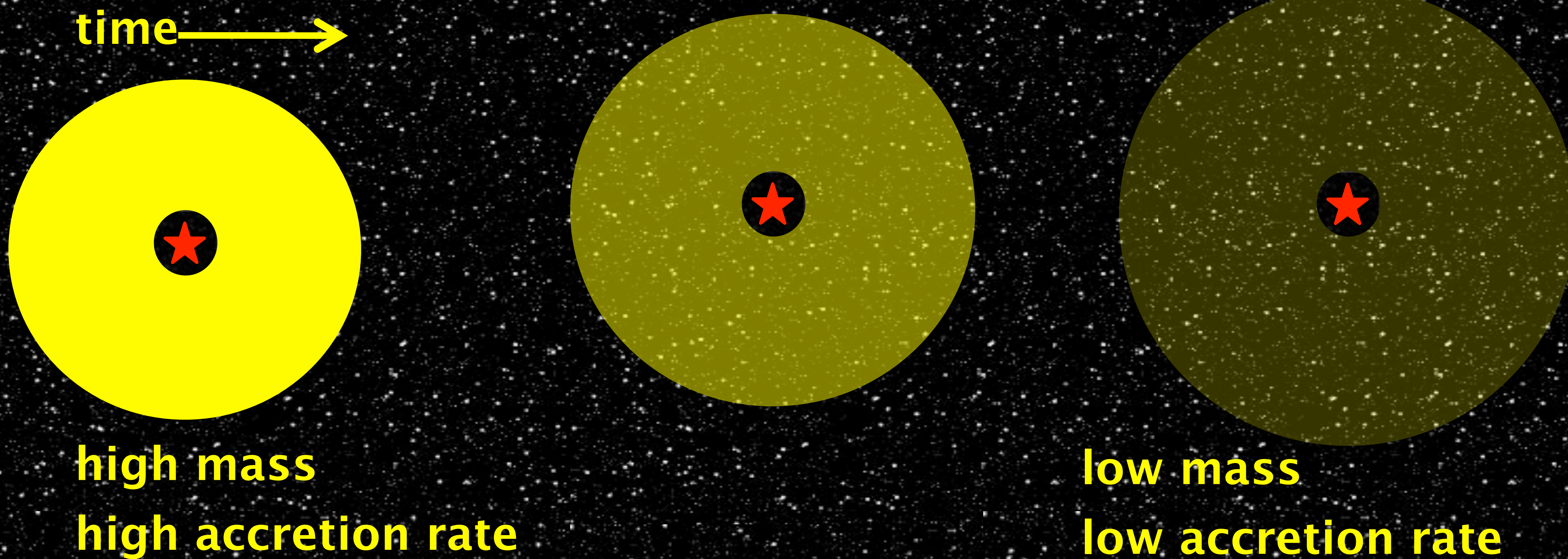


finite thickness disc

Koepferl, Ercolano et al. 2012

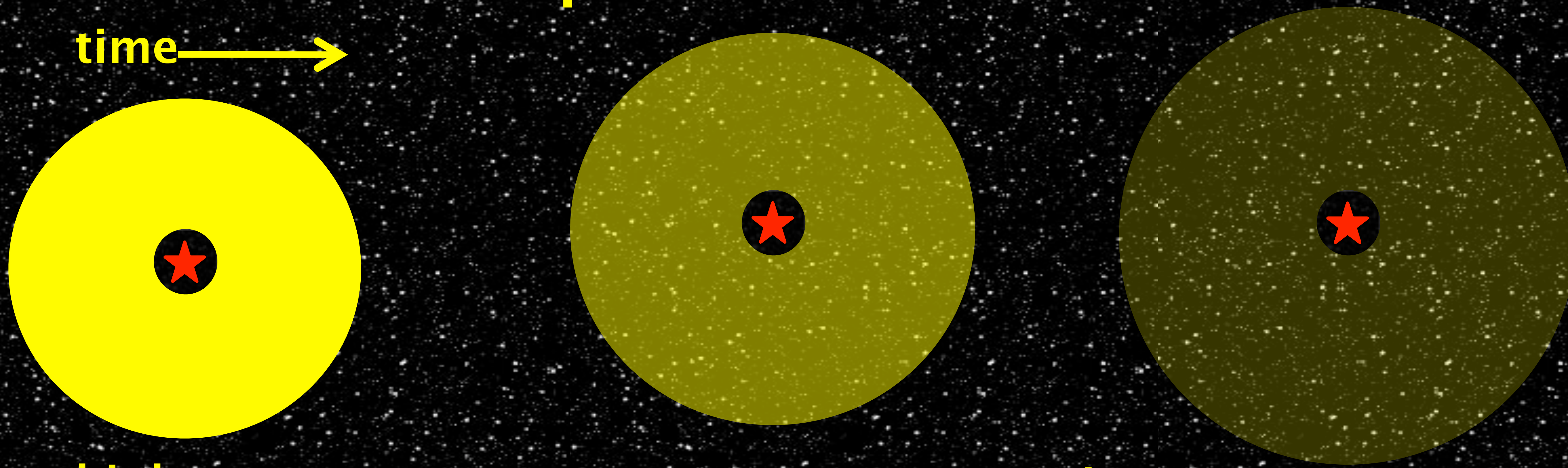


Viscous evolution predicts....



Viscous evolution predicts....

time ⟶



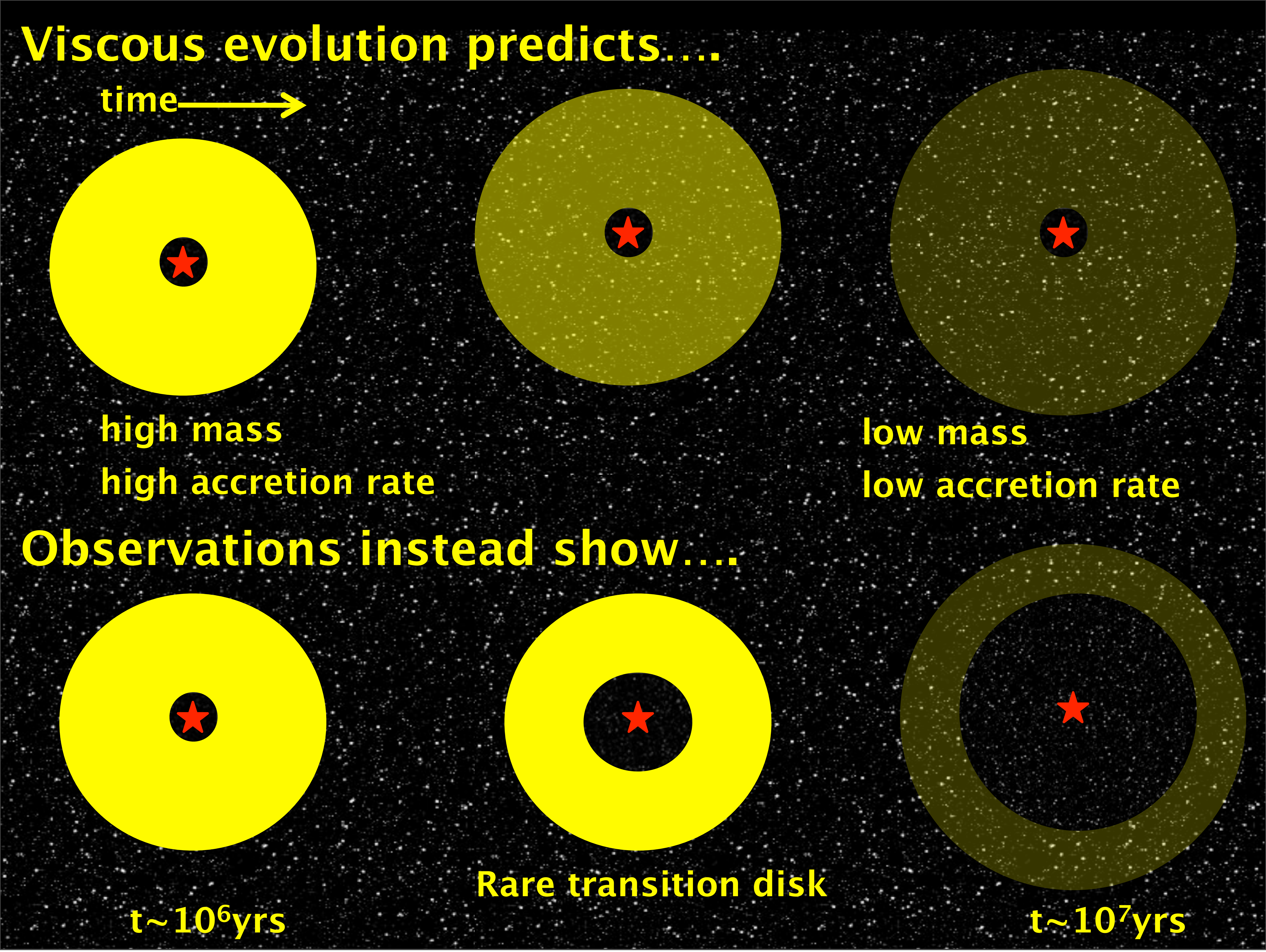
high mass
high accretion rate

low mass
low accretion rate

Observations instead show....

$t \sim 10^6$yrs

$t \sim 10^7$yrs


Viscous evolution predicts....
time
high mass
high accretion rate
low mass
low accretion rate
Observations instead show....
t~10⁶yrs
Rare transition disk
t~10⁷yrs

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

no evidence for homogeneous draining

Two timescales for dispersal

2nd Timescale: Transition timescale / mode

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]	[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]	[illegible]
Tr 37	I	[illegible]	[illegible]	[illegible]
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	[illegible]	[illegible]	[illegible]
Upper Sco	II	[illegible]	[illegible]	[illegible]
Upper Sco	III	[illegible]	[illegible]	[illegible]
Upper Sco	IV	[illegible]	[illegible]	[illegible]
OB1bf	all	-	[illegible]	[illegible]
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	[illegible]	-	-
NGC2068/71	IV	[illegible]	-	-
NGC2264	all	-	1.04 ± 0.57	1.15 ± 0.27
NGC2264	I	1.23 ± 0.39	-	-
NGC2264	II	1.10 ± 0.33	-	-
NGC2264	III	[illegible]	-	-
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]
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
Cha II	I	[illegible]	-	-
Cha II	II	[illegible]	-	-
Cha II	III	[illegible]	-	-
Cha II	IV	[illegible]	-	-
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 $\in$ $]M5.75; L0[$

Disk Dispersal: a two-timescale problem

What is responsible for the rapid dispersal???

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- 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)
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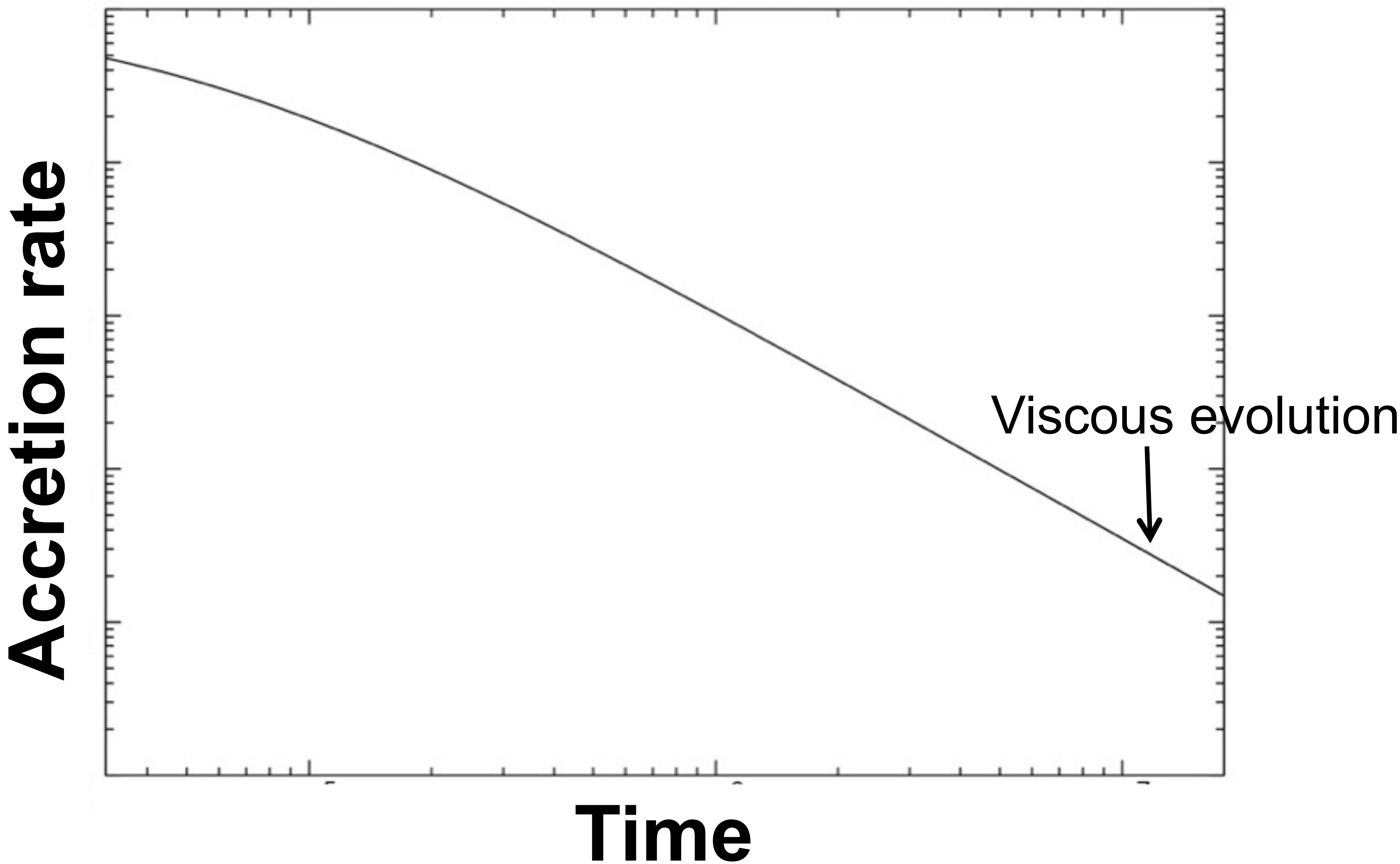
X-ray switch model



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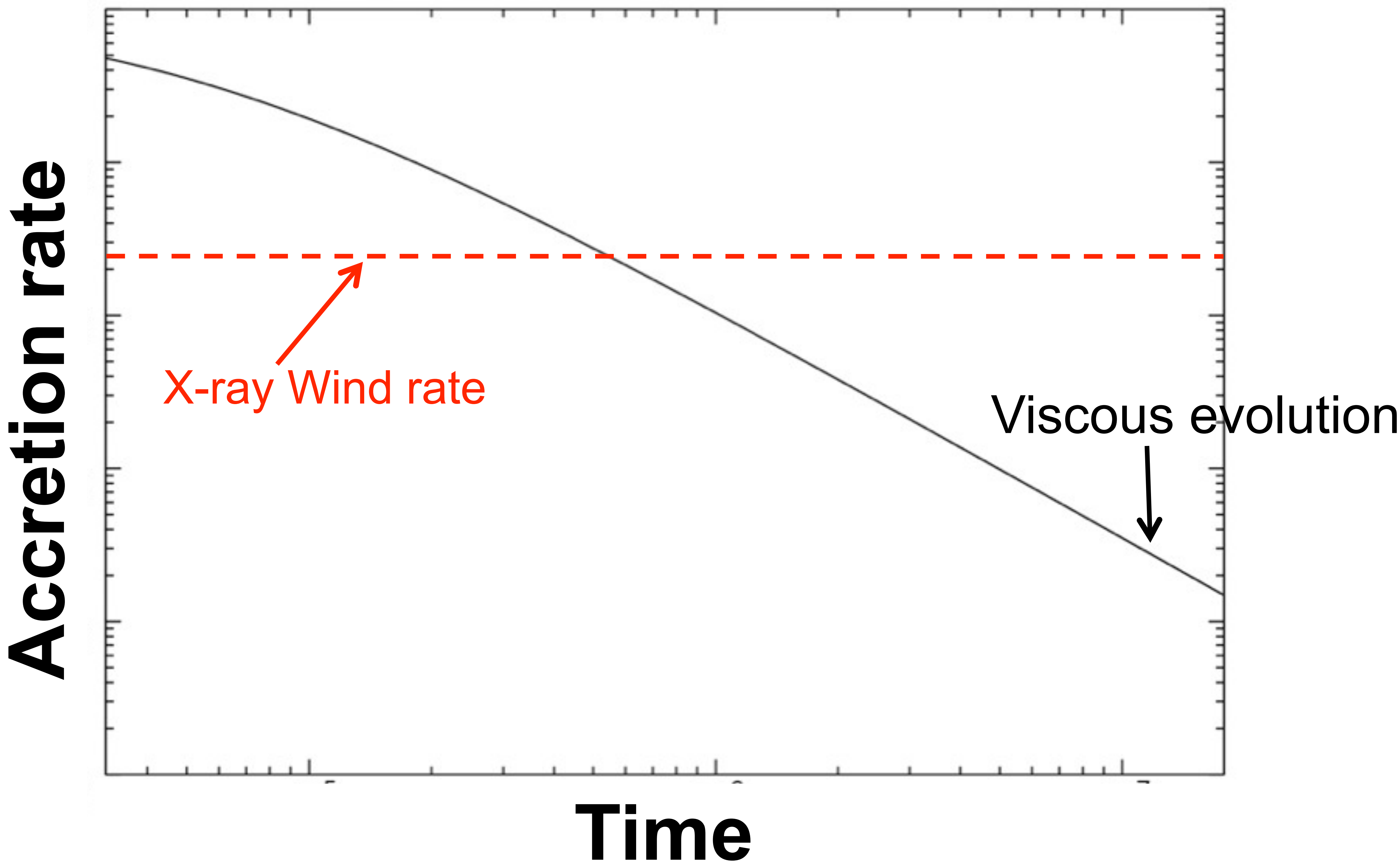

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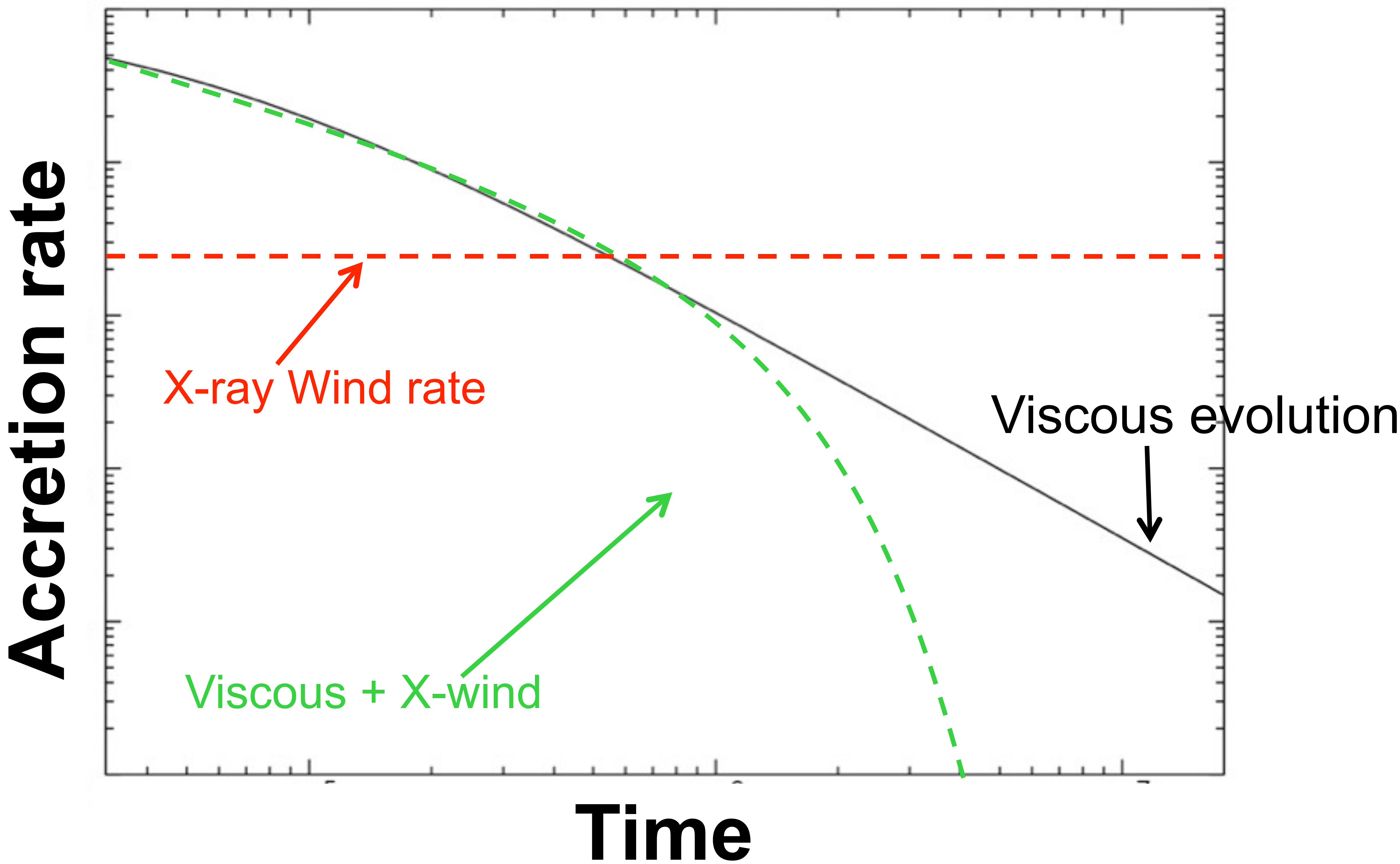

Dependence of wind rates on metallicity

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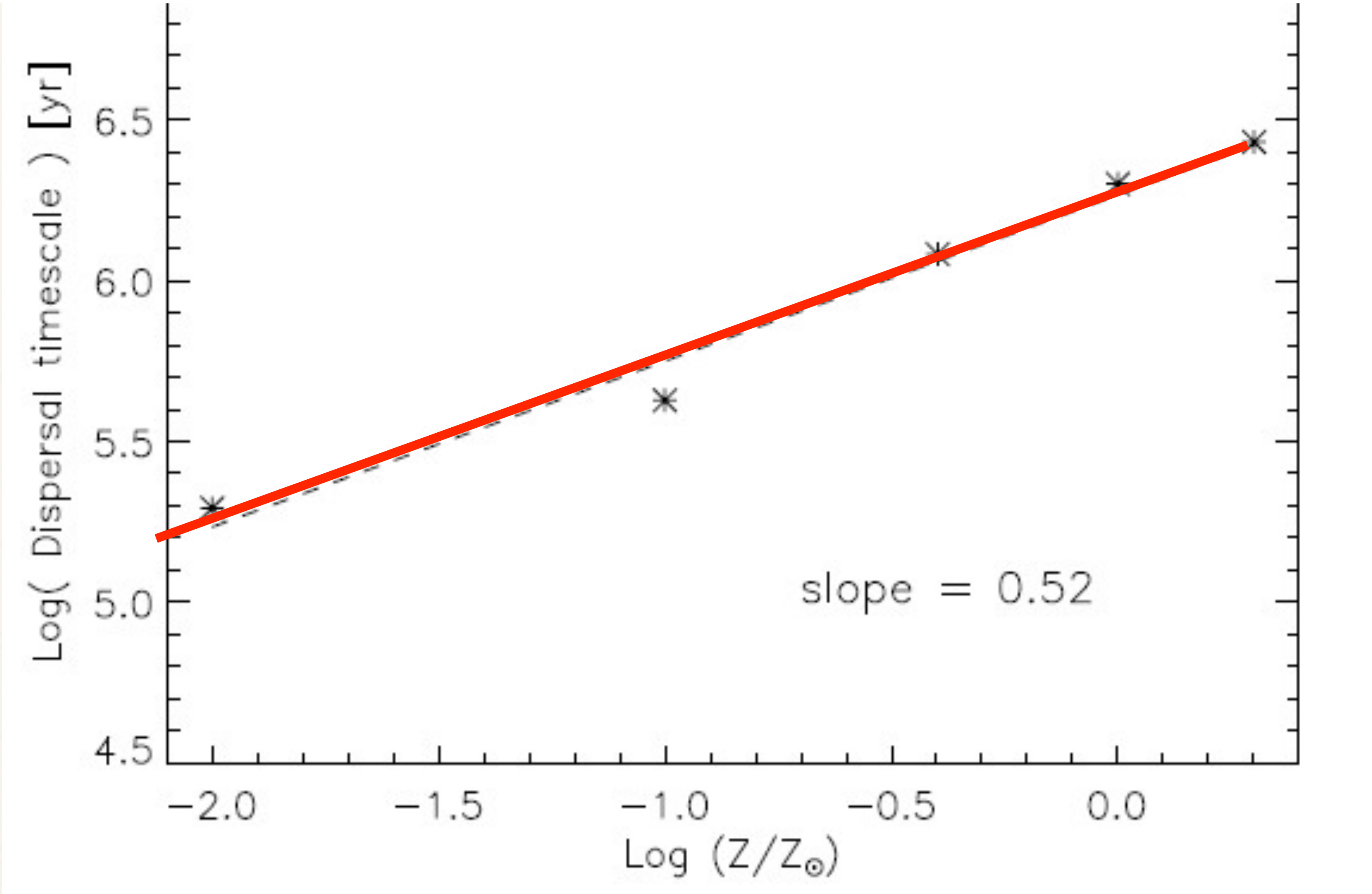
Ercolano & Clarke 2010

Dependence of wind rates on metallicity

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



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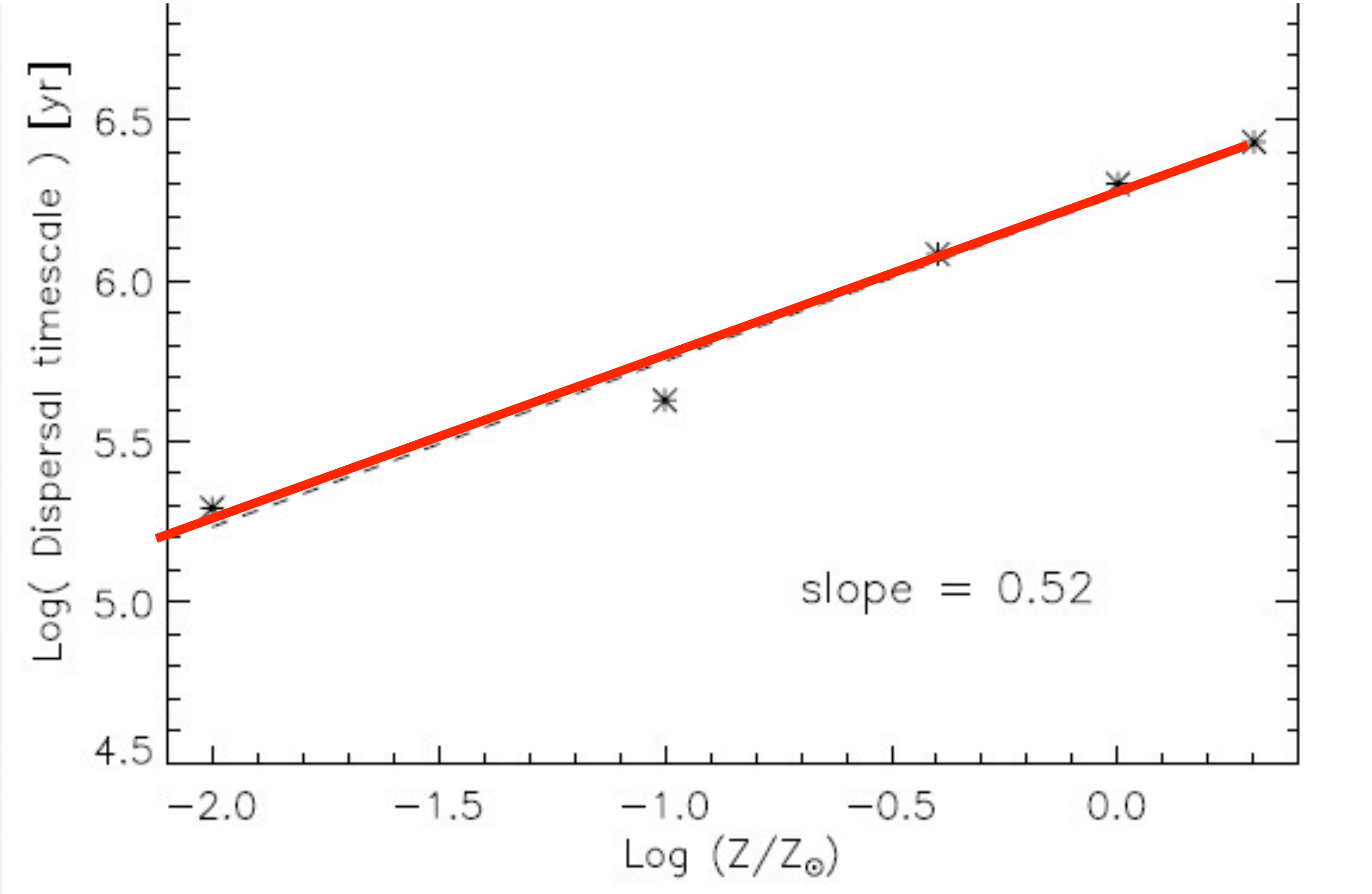

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Dispersal by planet formation: $t_{dis} \propto Z^{\alpha}$

$\alpha = -2.5, -5, -7.5$ or -32 !!!

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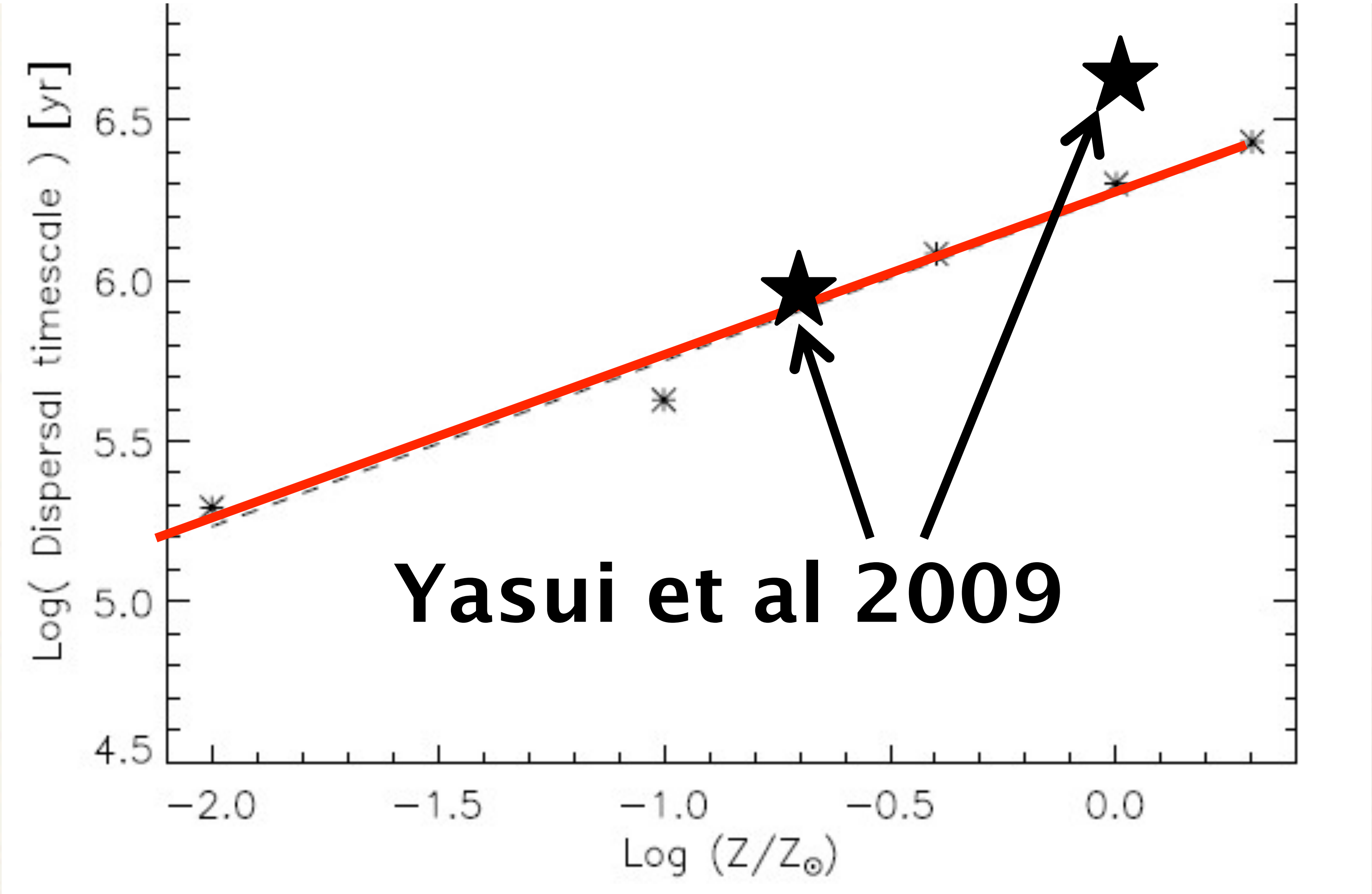

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