X-ray irradiated protoplanetary discs

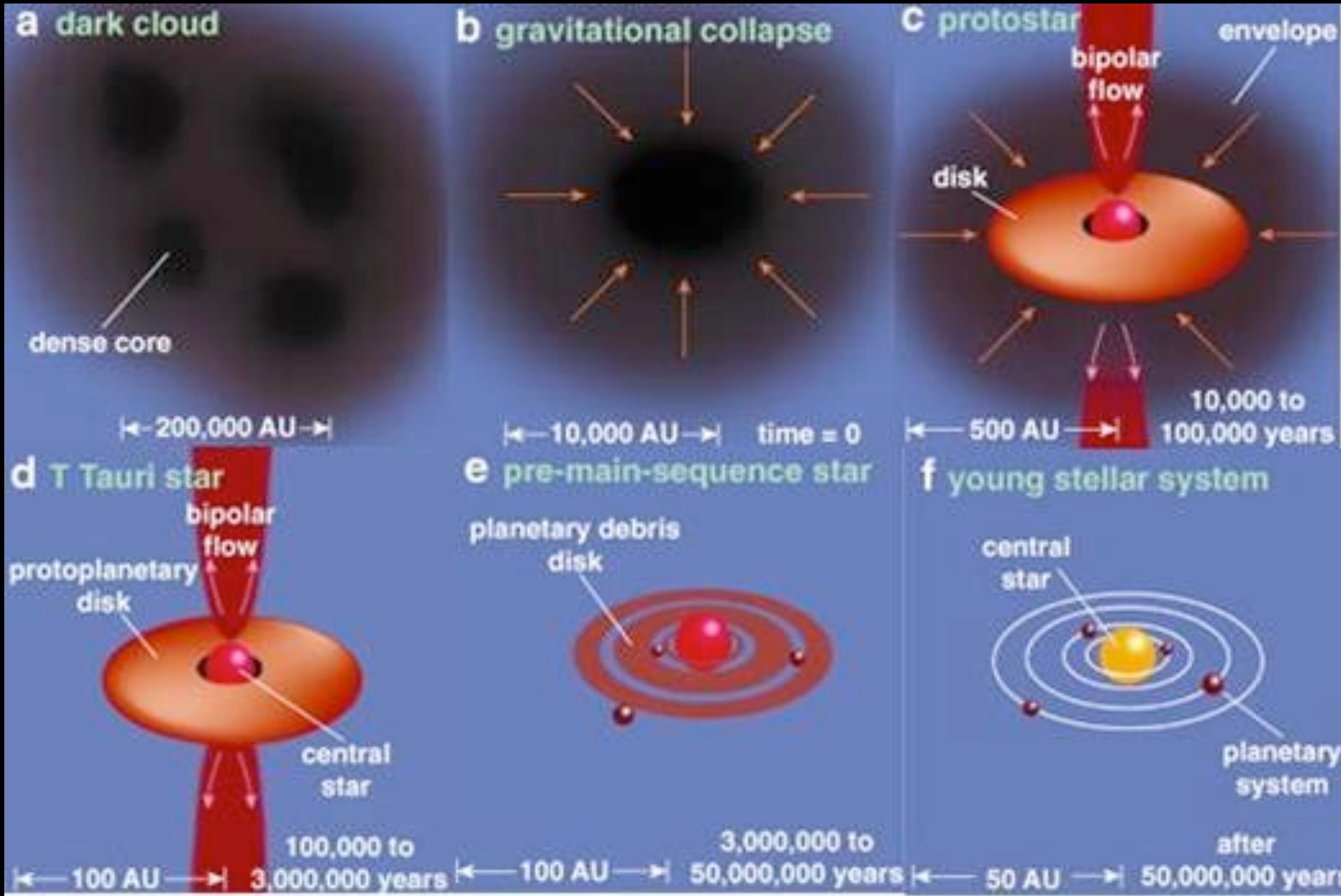
Barbara Ercolano

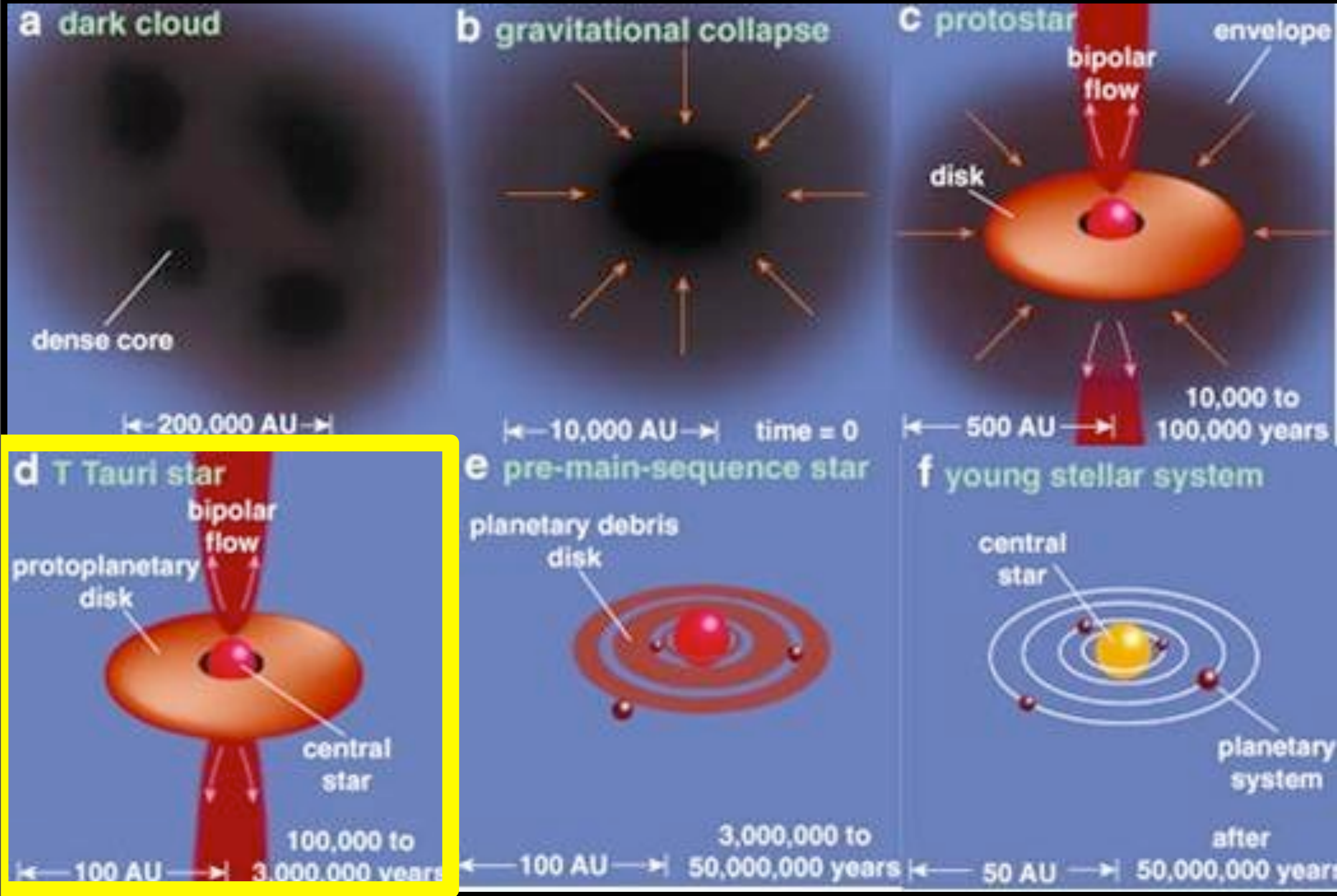
University of Exeter

Thanks to:

James Owen, C. Clarke (IoA); A. Glassgold (Berkeley);

S. Mohanty (Imperial); N. Turner (JPL); J. Drake, J. Raymond (CfA)


a dark cloud
dense core
200,000 AU
b gravitational collapse
10,000 AU
time = 0
c protostar
bipolar flow
envelope
disk
500 AU
10,000 to 100,000 years
d T Tauri star
bipolar flow
protoplanetary disk
central star
100 AU
100,000 to 3,000,000 years
e pre-main-sequence star
planetary debris disk
100 AU
3,000,000 to 50,000,000 years
f young stellar system
central star
planetary system
50 AU
after 50,000,000 years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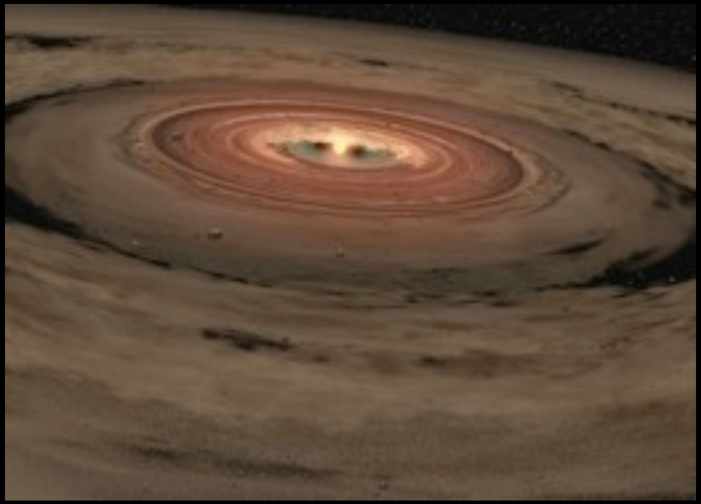
X-ray Feedback on Low Mass Star & Planet Formation



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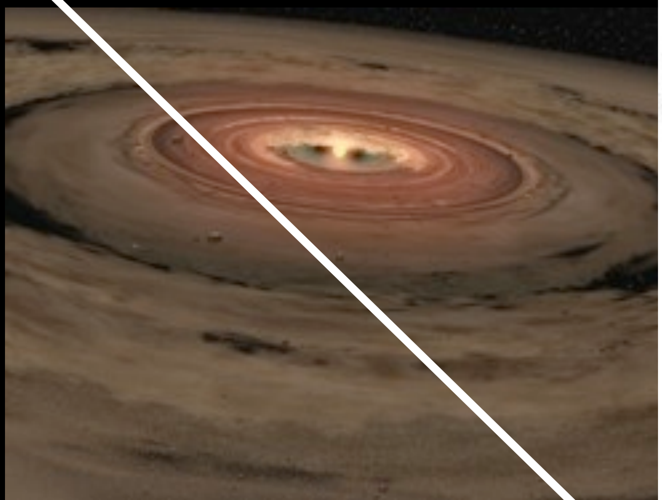
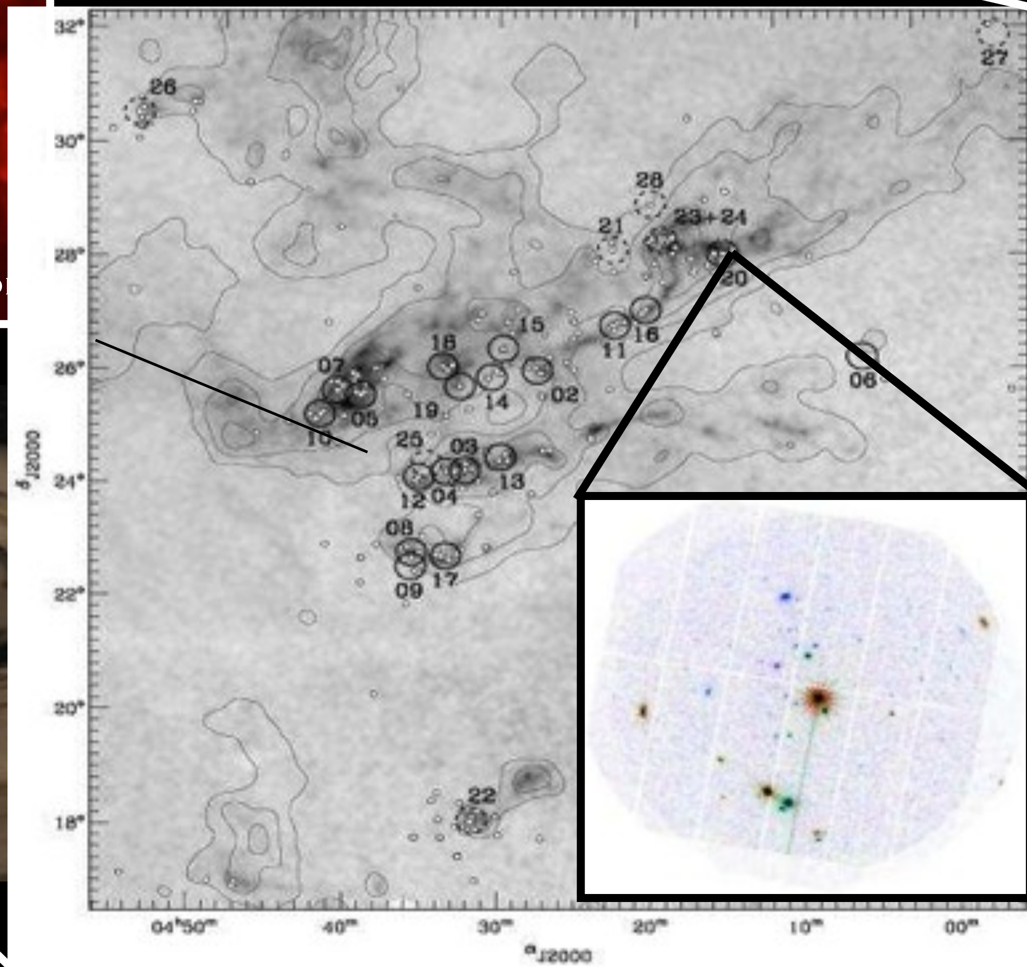
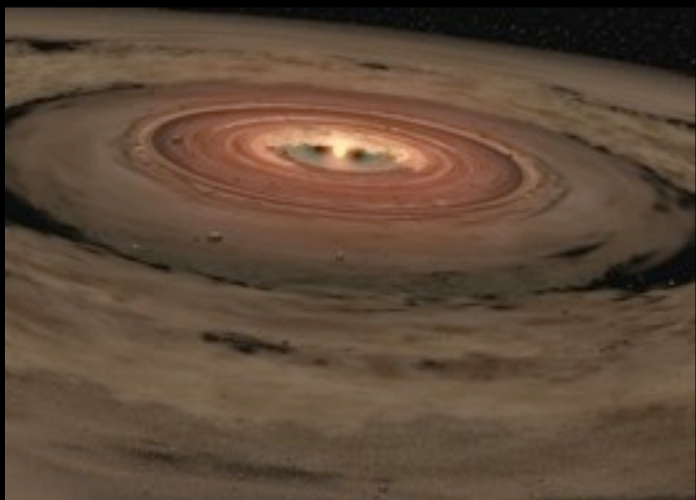




Guedel et al., 2007

X-ray Feedback on Low Mass Star & Planet Formation

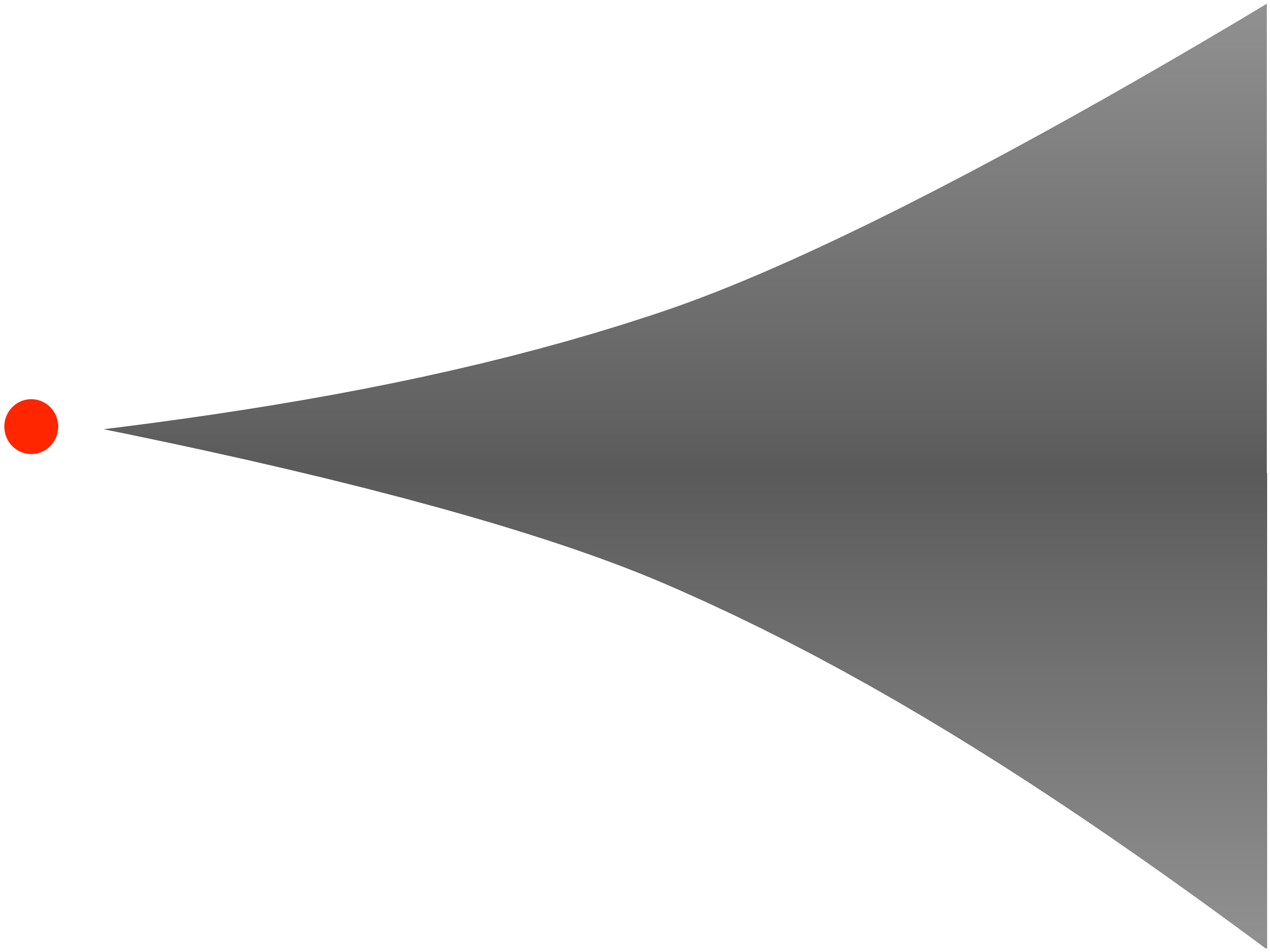
Taurus – Spitzer Space Telescope

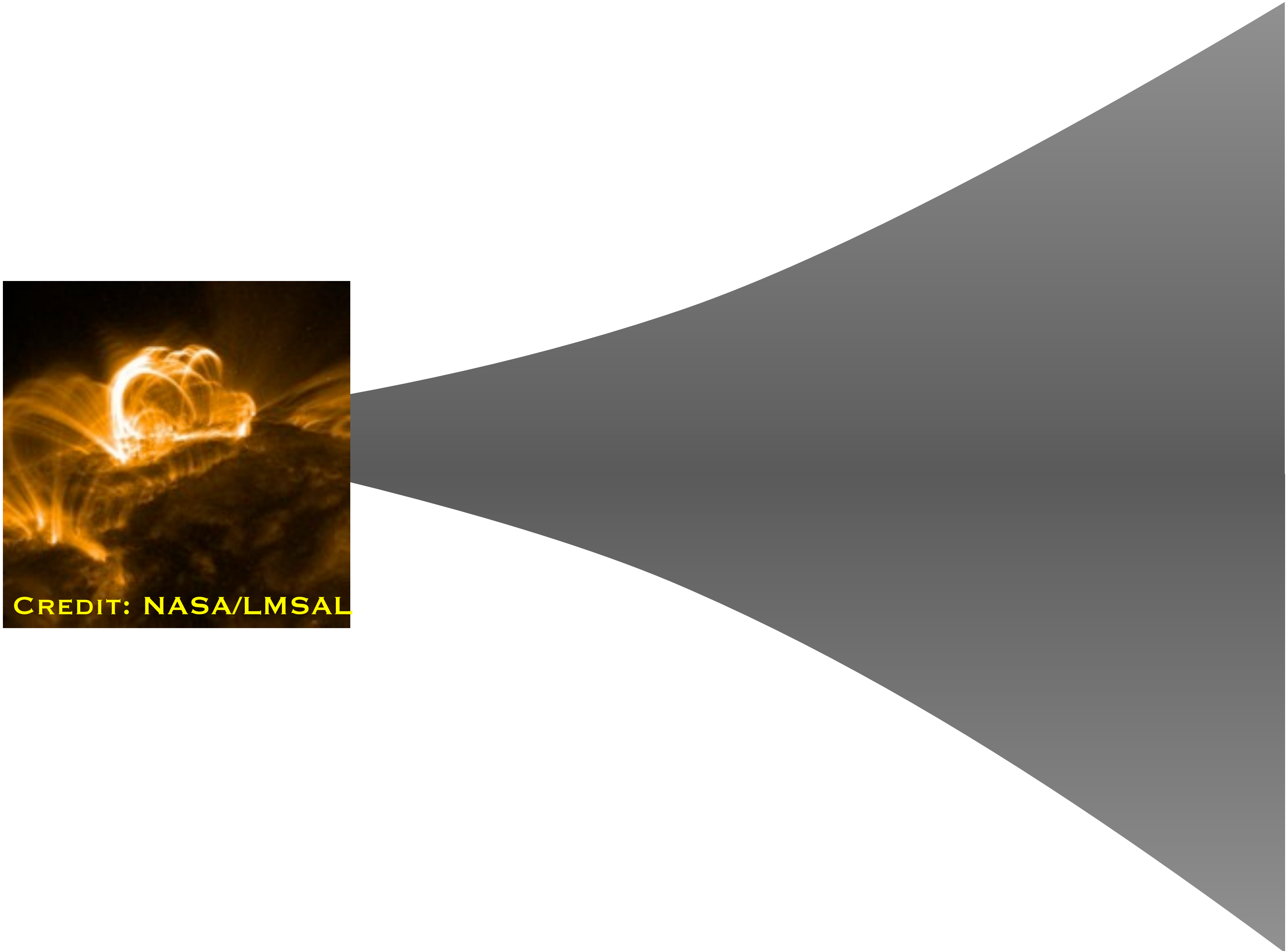


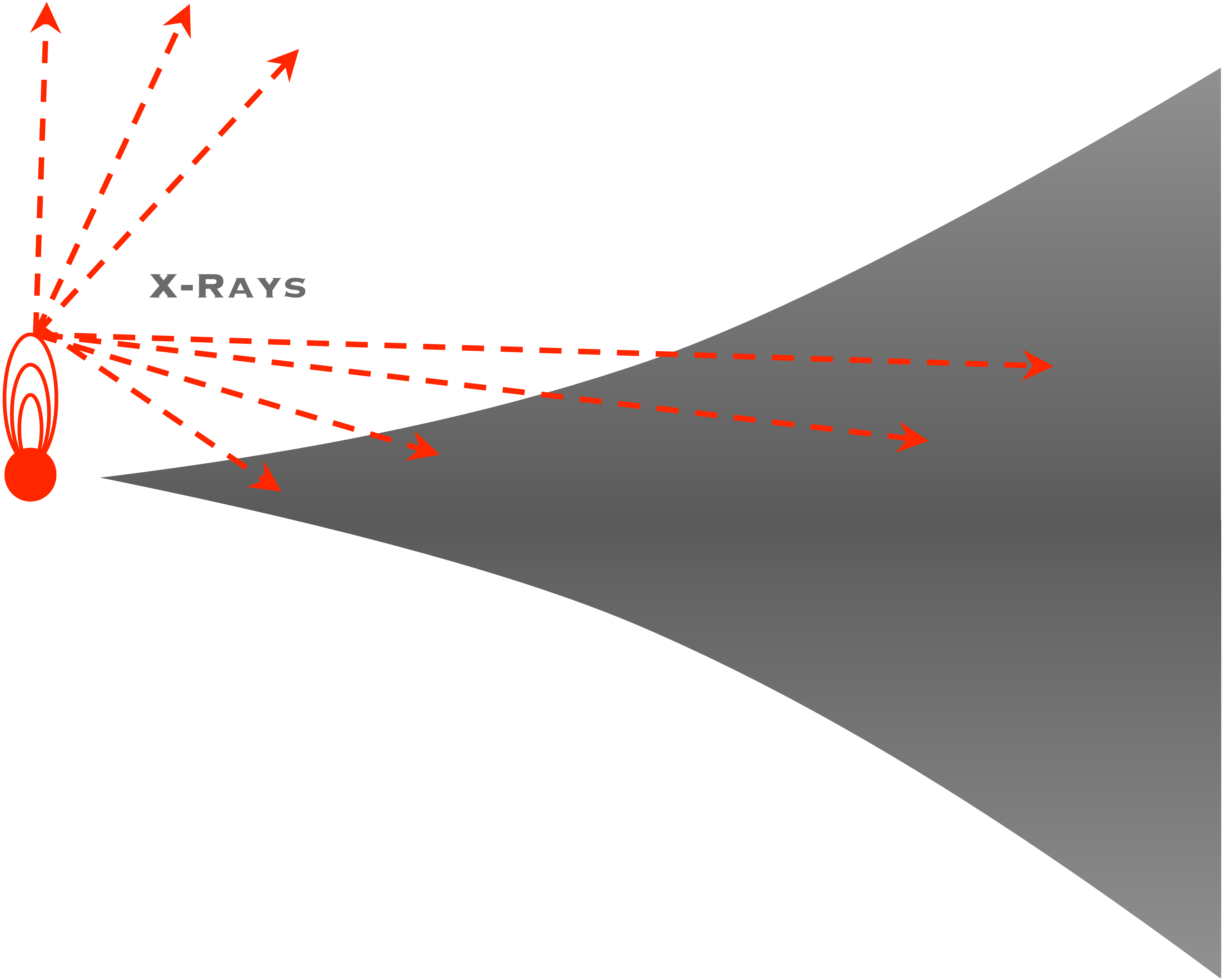
What drives the dispersal of disks? On what timescales?

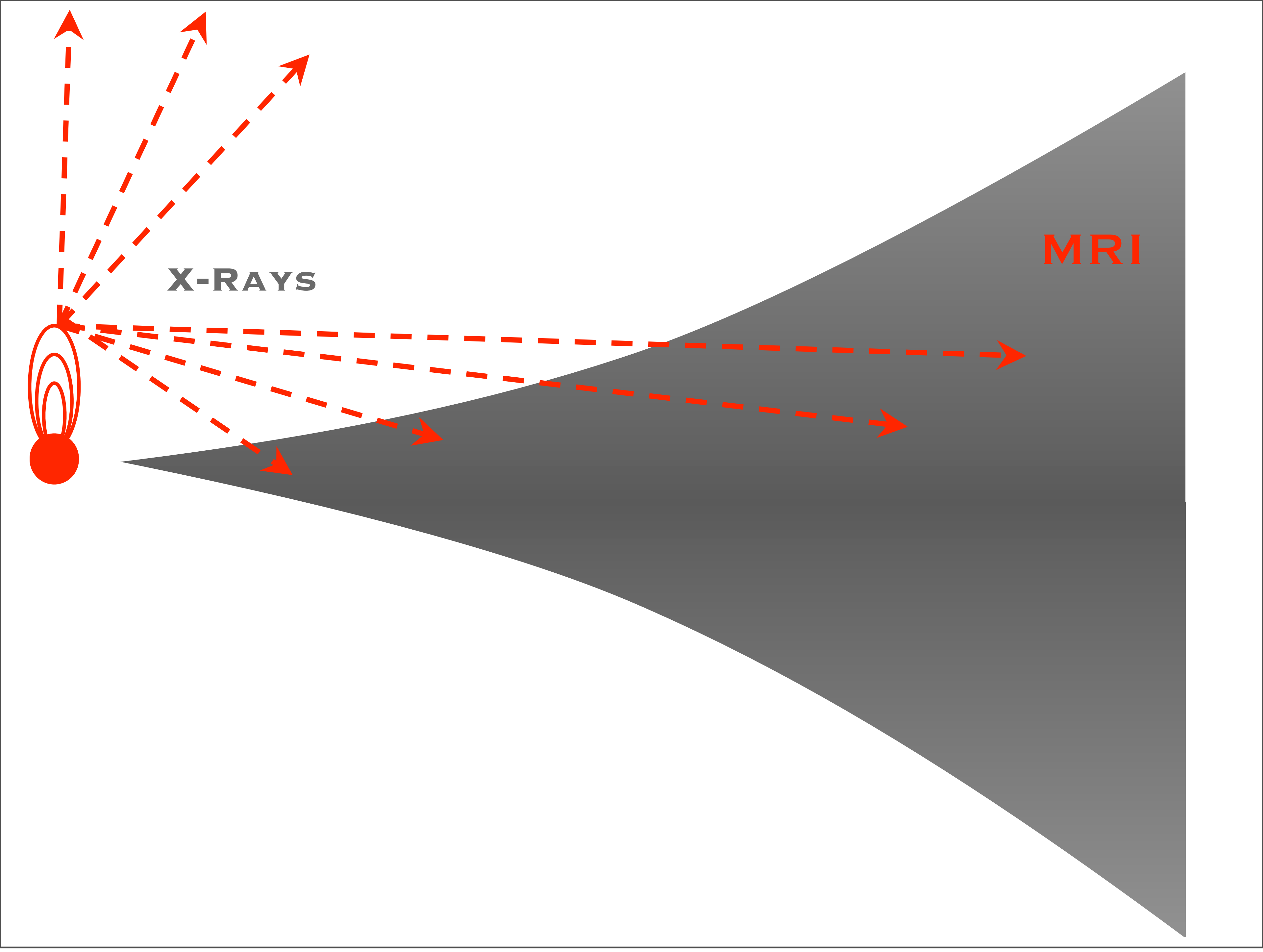
What environments are favourable to the formation of terrestrial and giant planets?

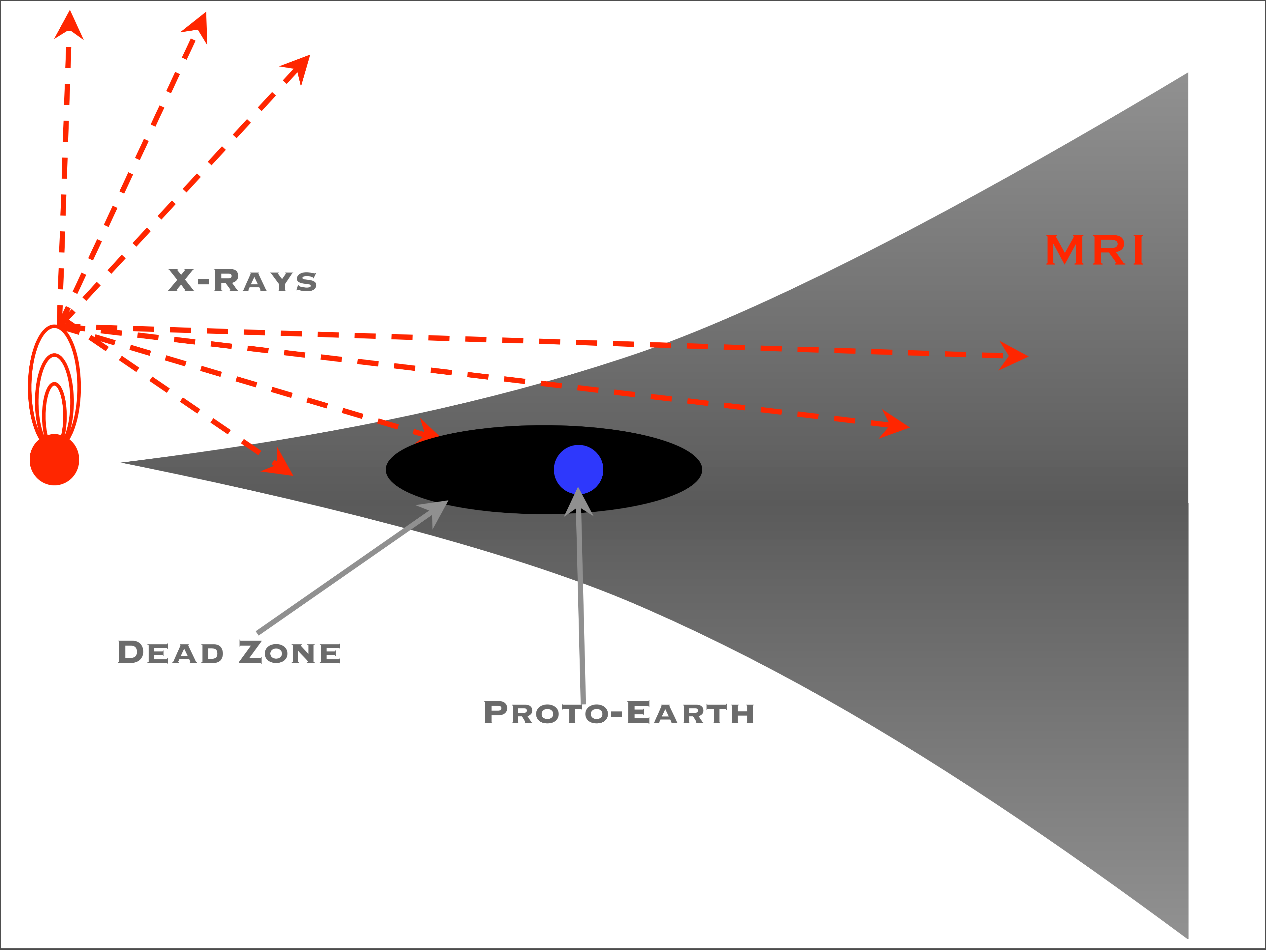
What is the effect of irradiation on planetary atmospheres?

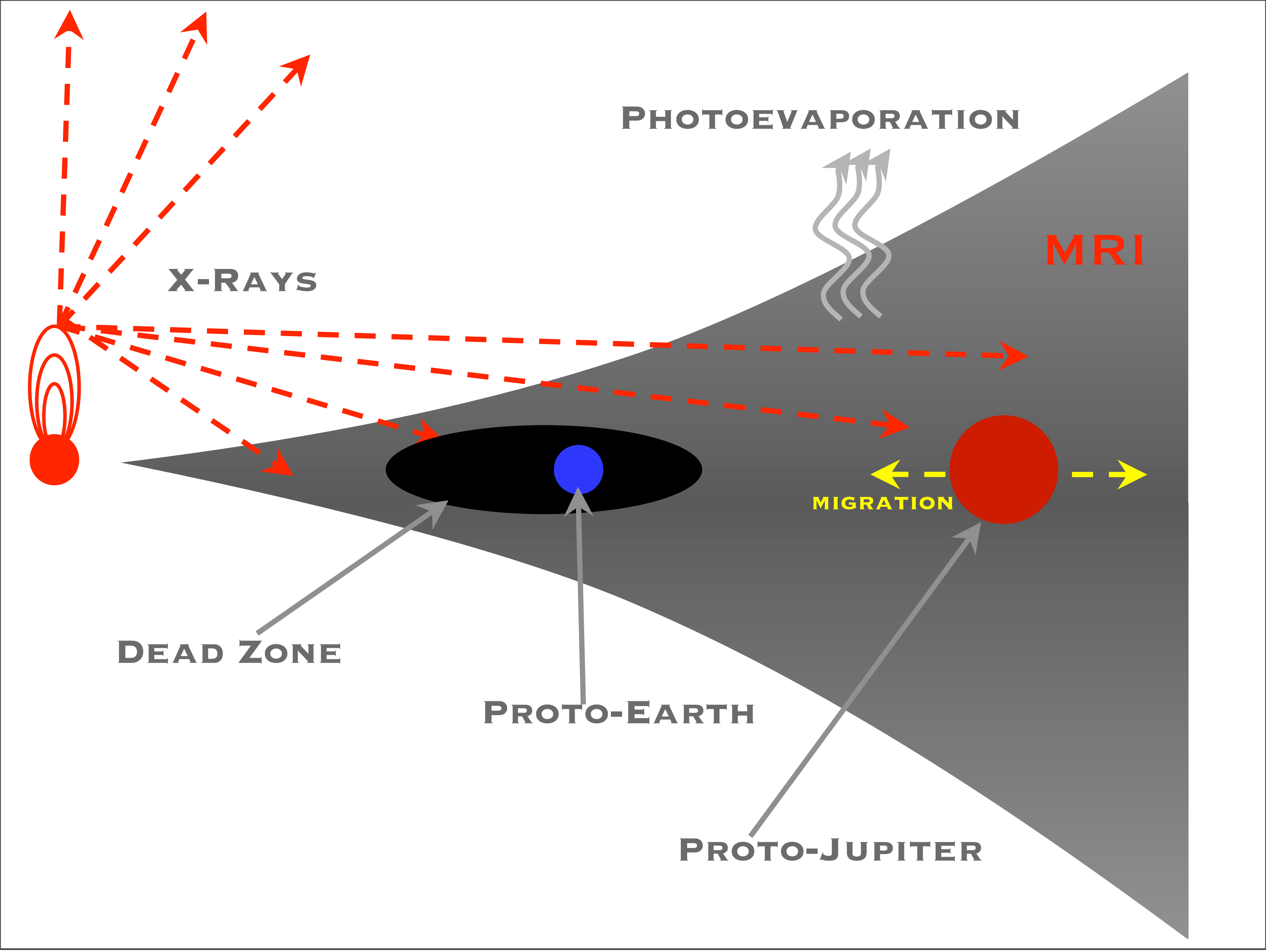



Credit: NASA/LMSAL


X-Rays


X-Rays
MRI


MRI
X-Rays
Dead Zone
Proto-Earth


Photoevaporation
MRI
X-Rays
migration
Dead Zone
Proto-Earth
Proto-Jupiter

Overview

- ‘Hard’ X-rays: MRI and Dead Zones
- ‘Soft’ X-rays: Disc photoevaporation

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'Hard' : E > 1 keV

'Soft' : 0.1 < E < 1 keV

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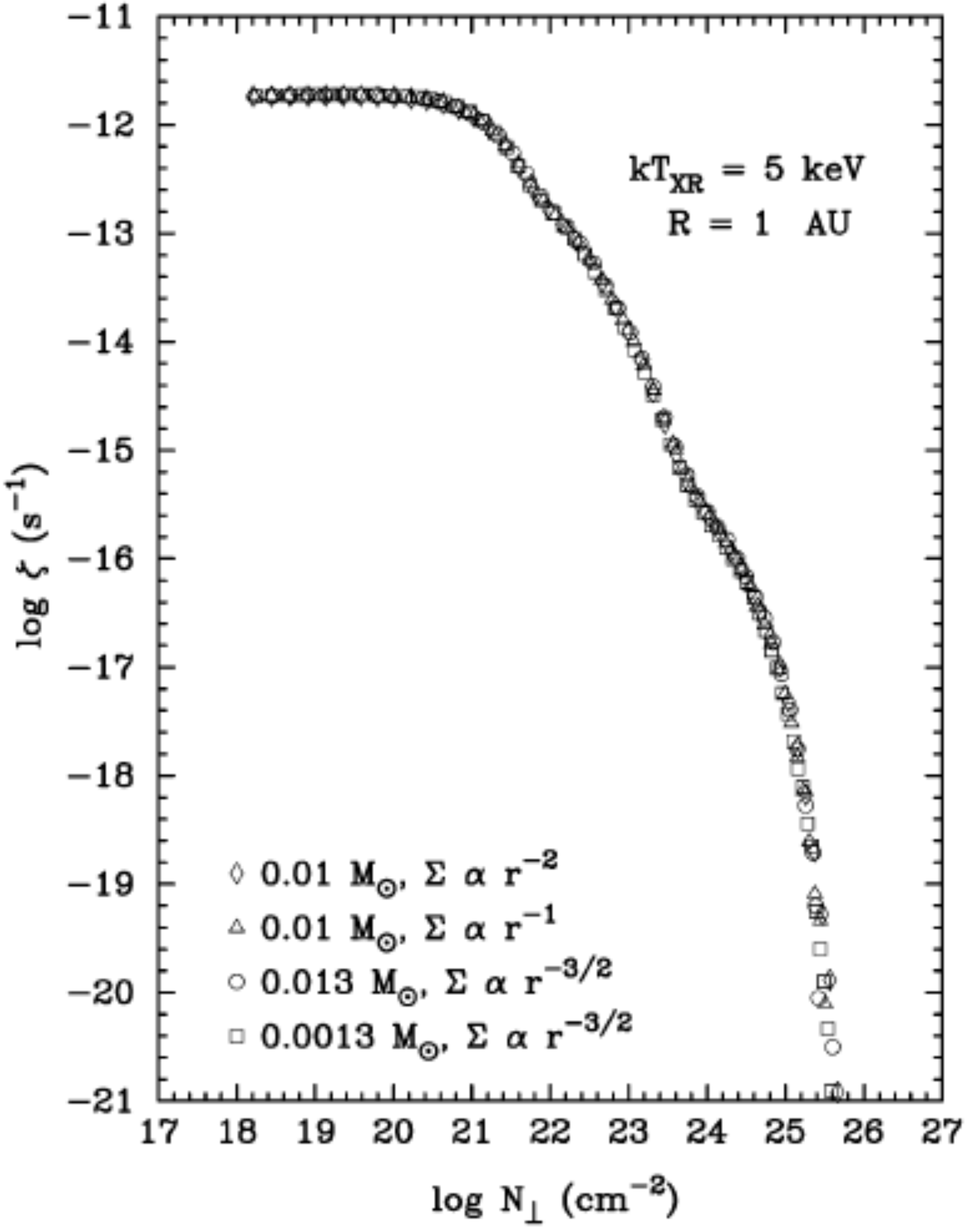
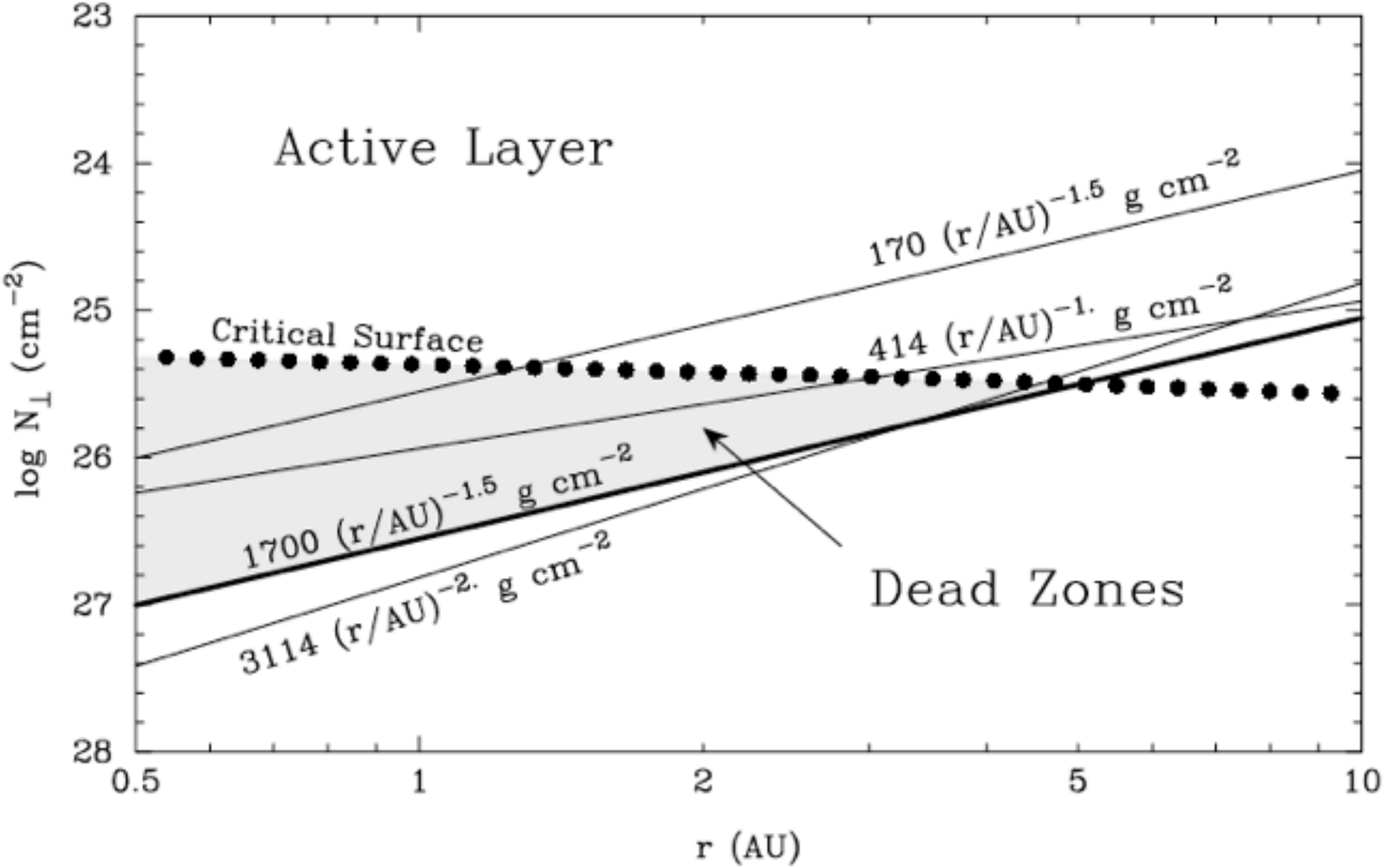


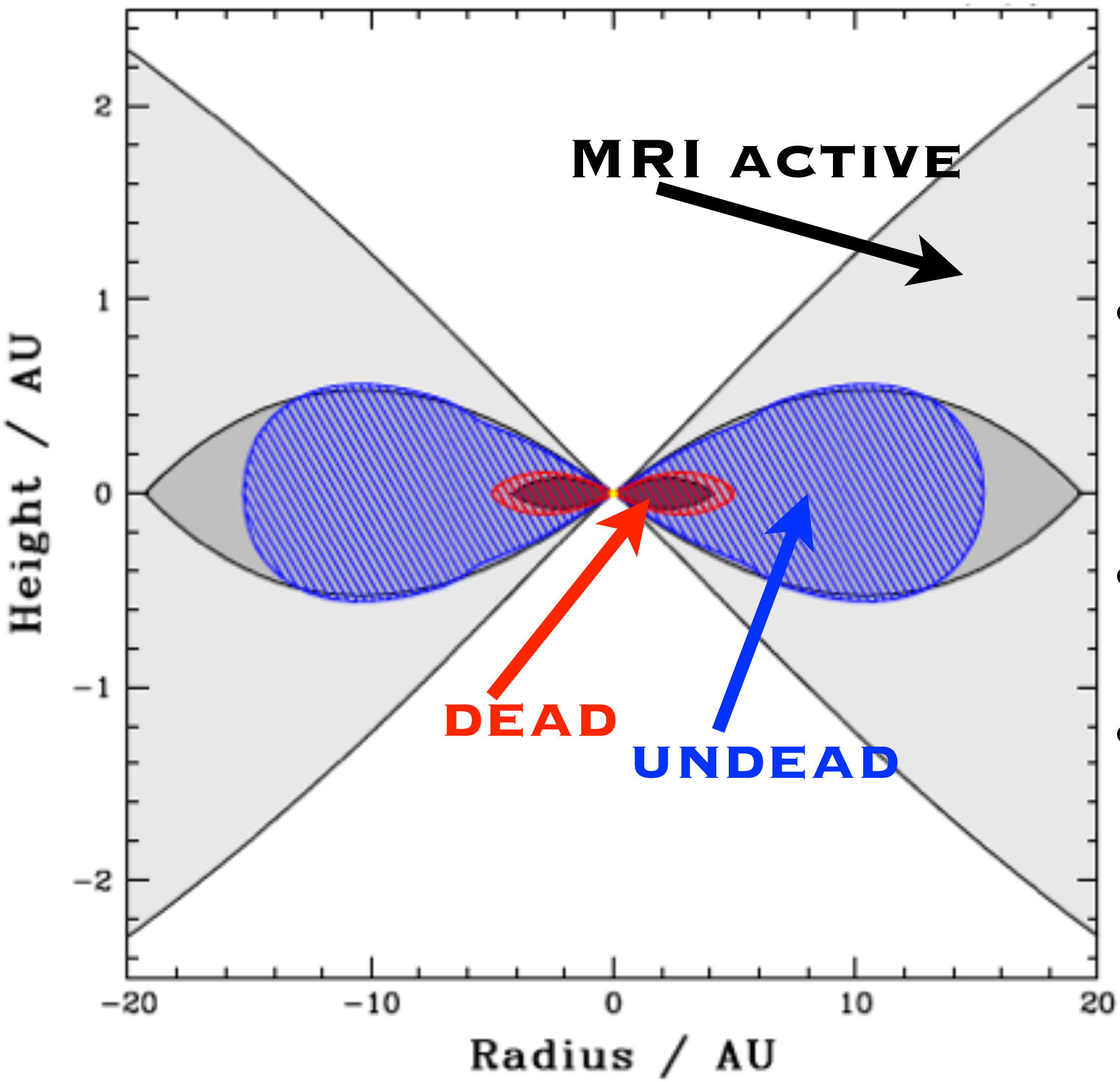
MRI and Dead Zones

Igea & Glassgold 1999

- X-rays from YSO dominate the disc ionisation structure
- Discs around solar-type stars mostly MRI active
- Dead-zone should extend to aprrox 5 AU



Igea & Glassgold 1999



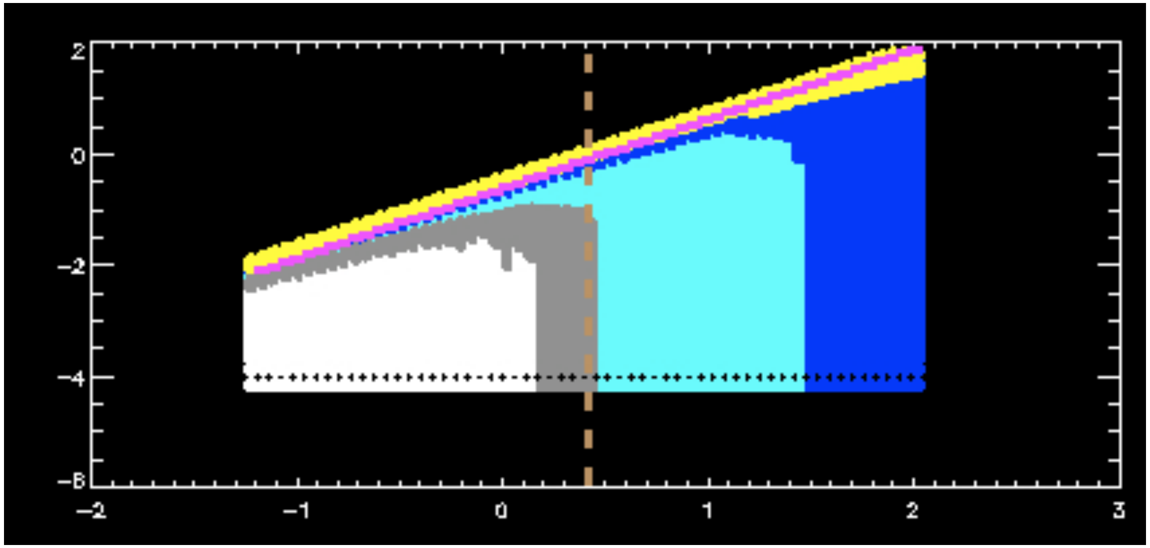
Dead or Undead?

Turner & Sano 2008
Turner & Drake 2009

- Use IG99 ionisation rates for stellar X-ray & consider other ionisation processes in the MMSN
- Dead zones basically always present
- Undead zones important?

MRI & (Un)Dead Zones in YSO Discs

Mohanty, Ercolano & Turner 2010 in prep



- New ionsation rates calcs with MOCASSIN
- Chemical network to account for recombinations on grains
- Parameter space investigation

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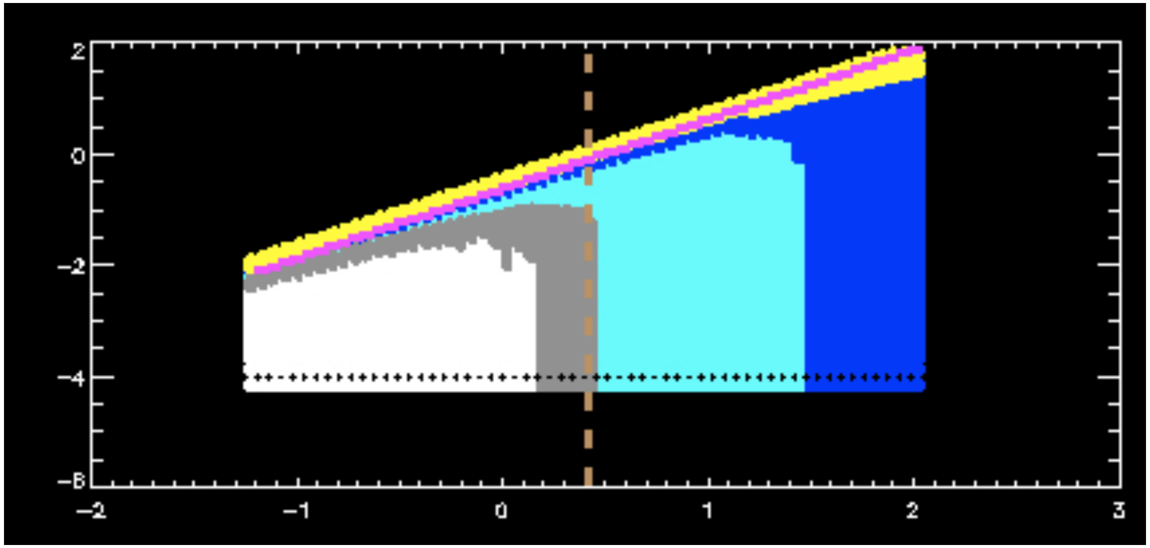


- New ionsation rates calcs with MOCASSIN
- Chemical network to account for recombinations on grains →
- Parameter space investigation

- DZ present in all discs with $M_D > 1\% \ M_*$
- MRI is reduced for discs with small grains or low densities
- Grains play a major role in determining accretion in discs

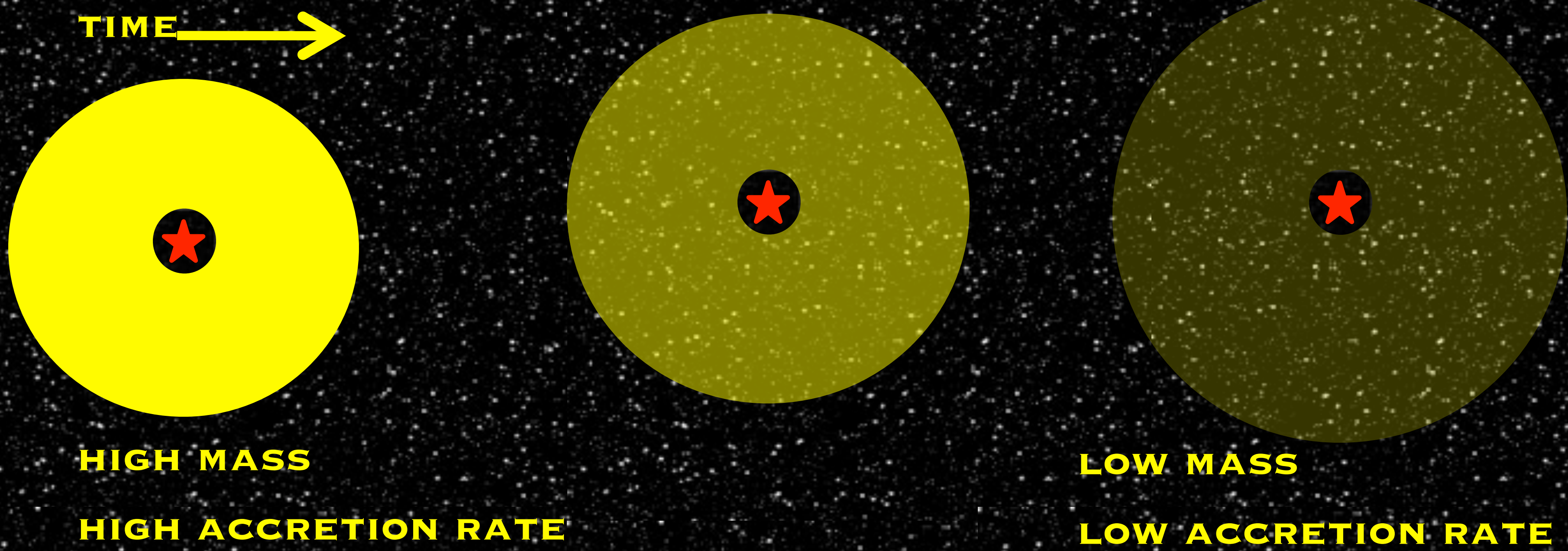
Overview

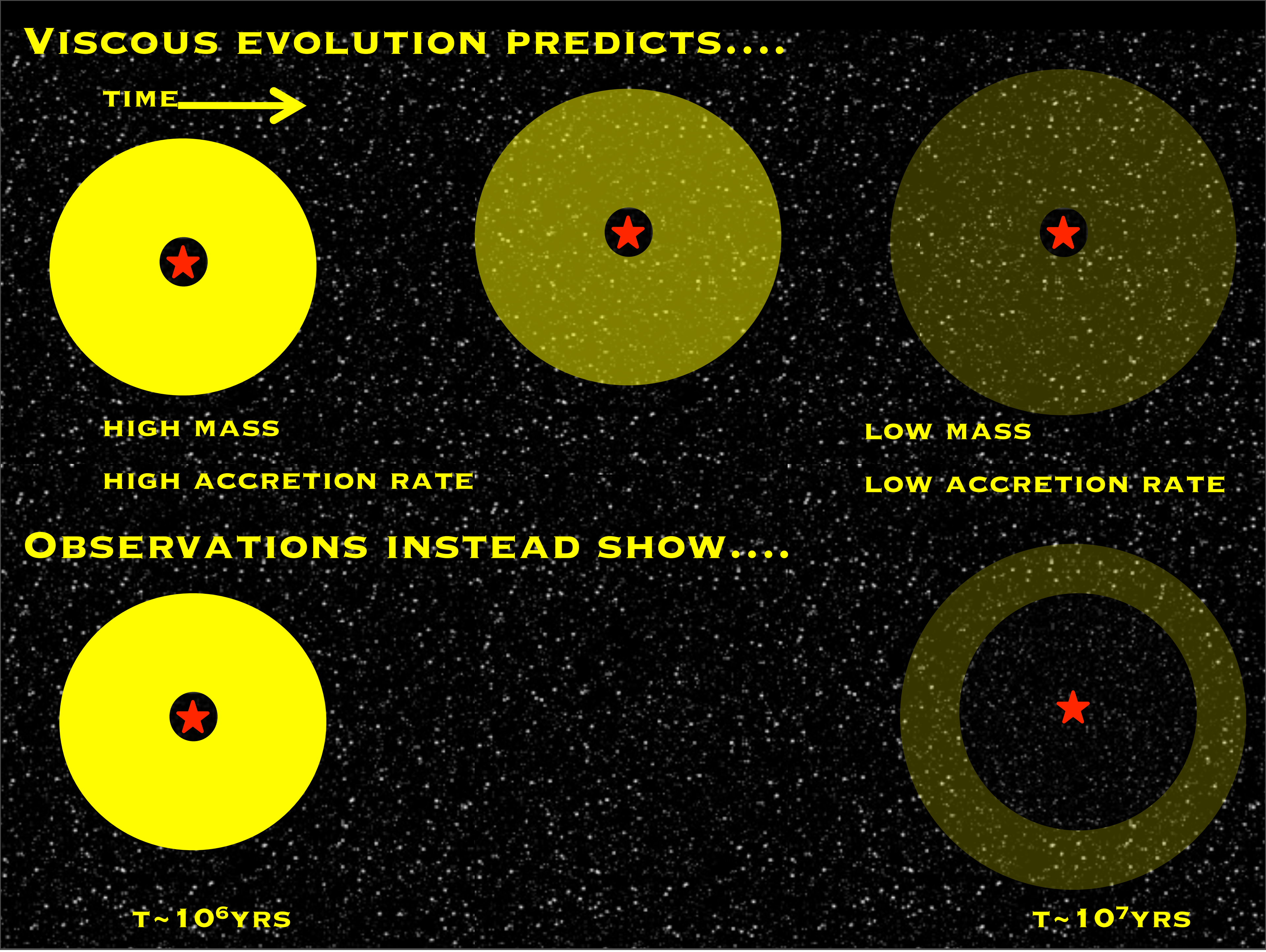
- 'Hard' X-rays: MRI and Dead Zones
- 'Soft' X-rays: Disc photoevaporation

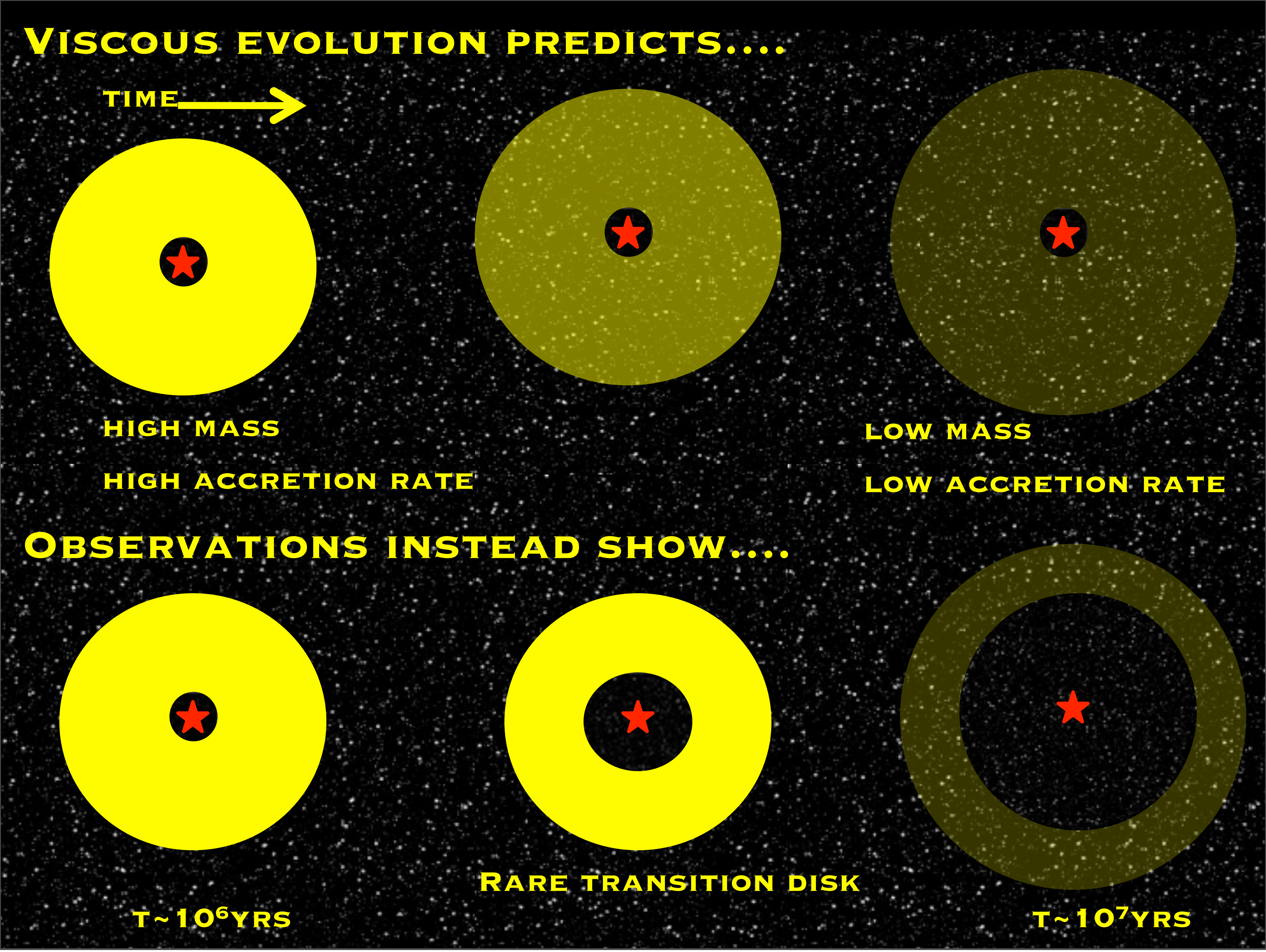
'Hard' : E > 1 keV

'Soft' : 0.1 < E < 1 keV

Viscous evolution predicts....



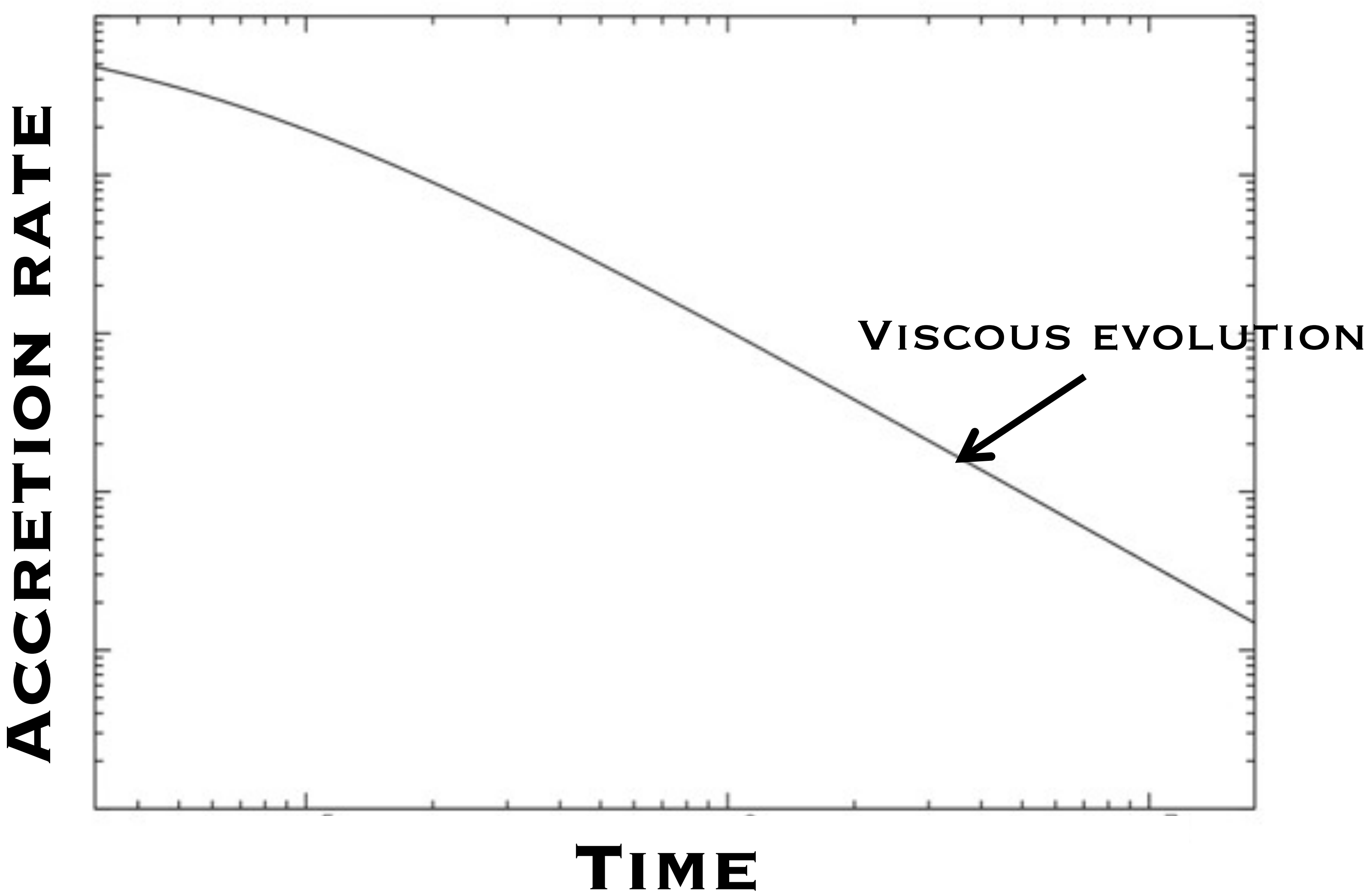

Viscous evolution predicts....
time
high mass
high accretion rate
low mass
low accretion rate
Observations instead show....
t~10^6yrs
t~10^7yrs



Tuesday, 27 July 2010

The Classical EUV switch model

Clarke et al. (2001); Matsuyama et al. (2003); Ruden (2004)



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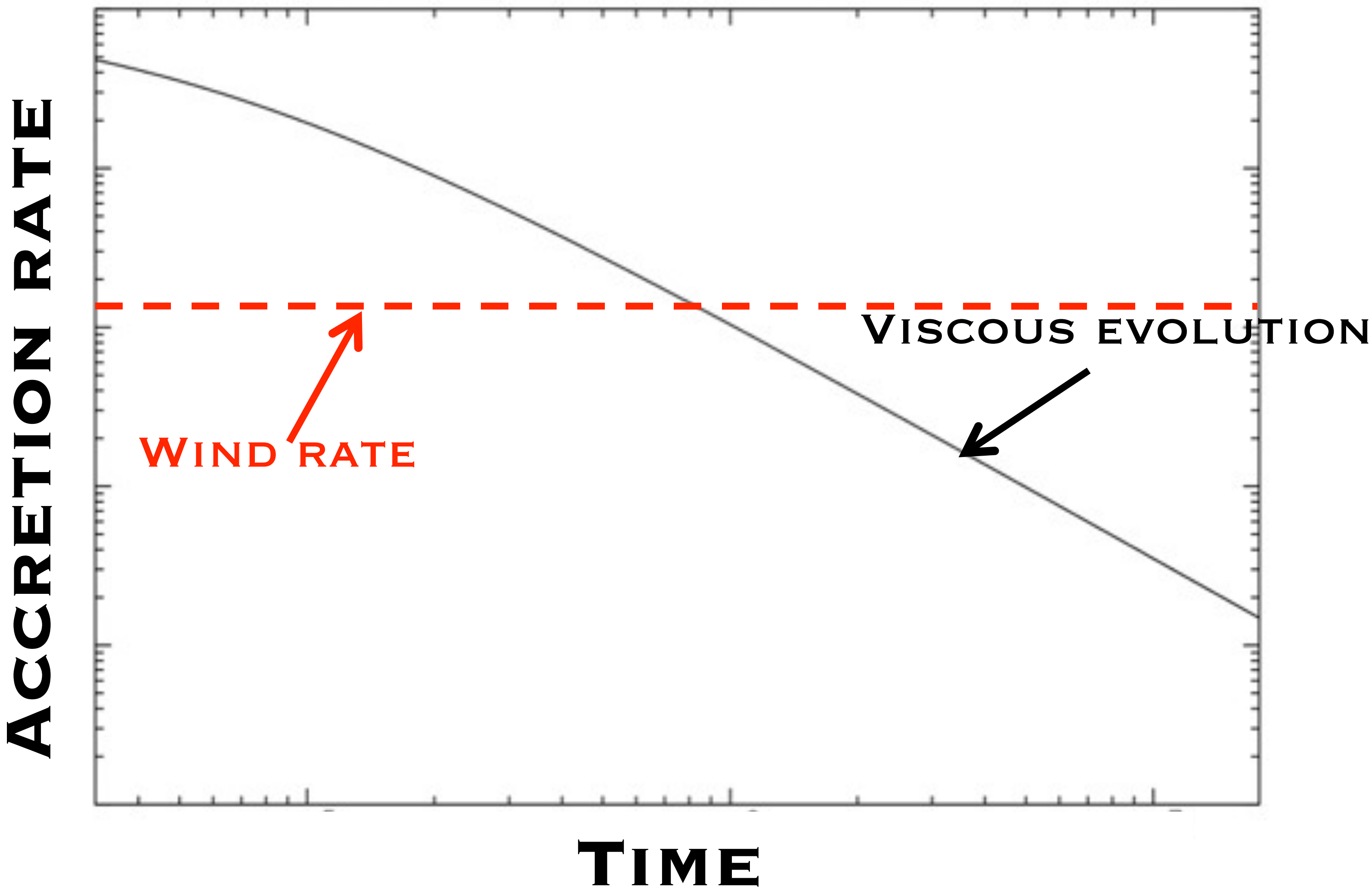

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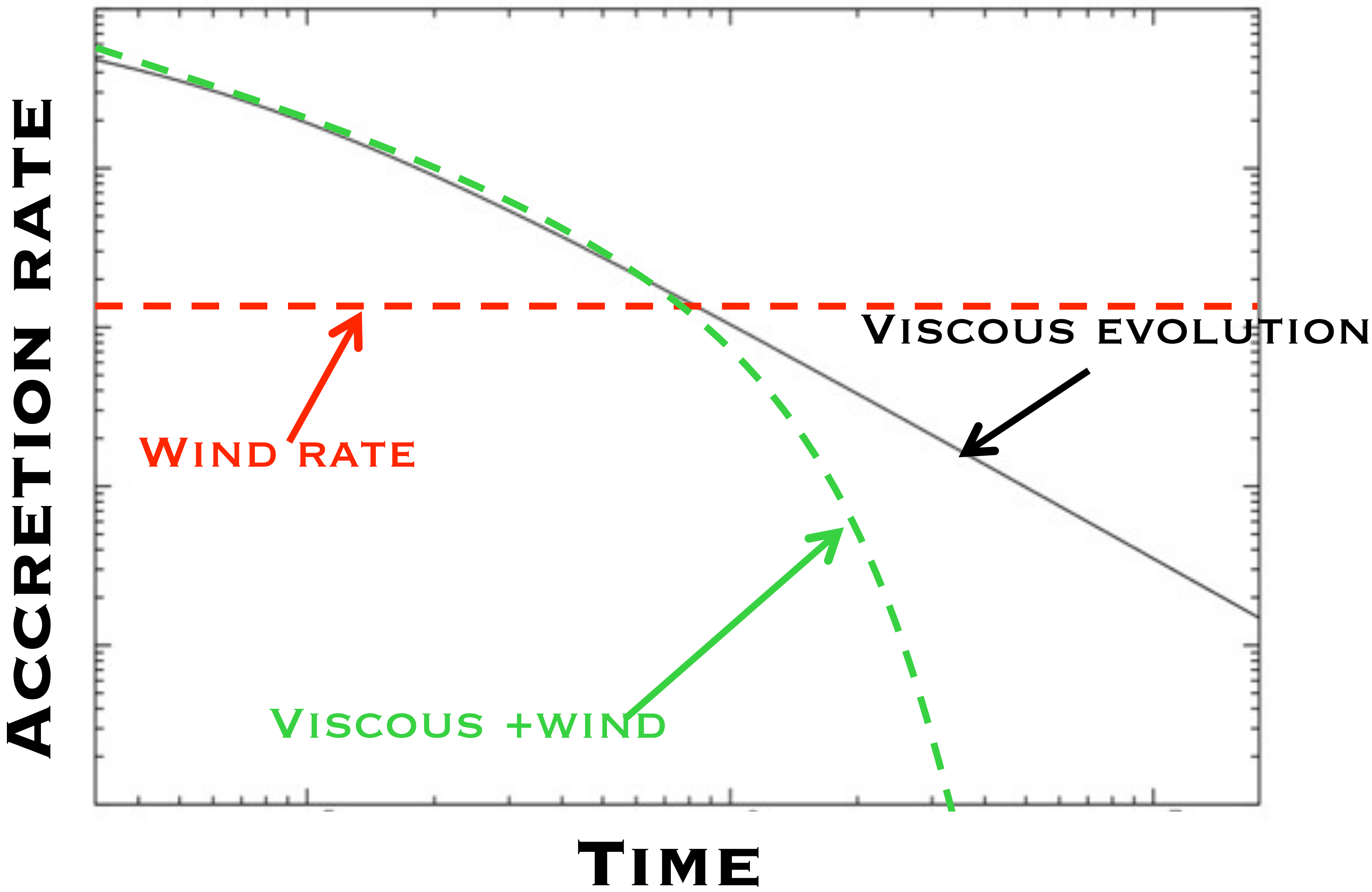
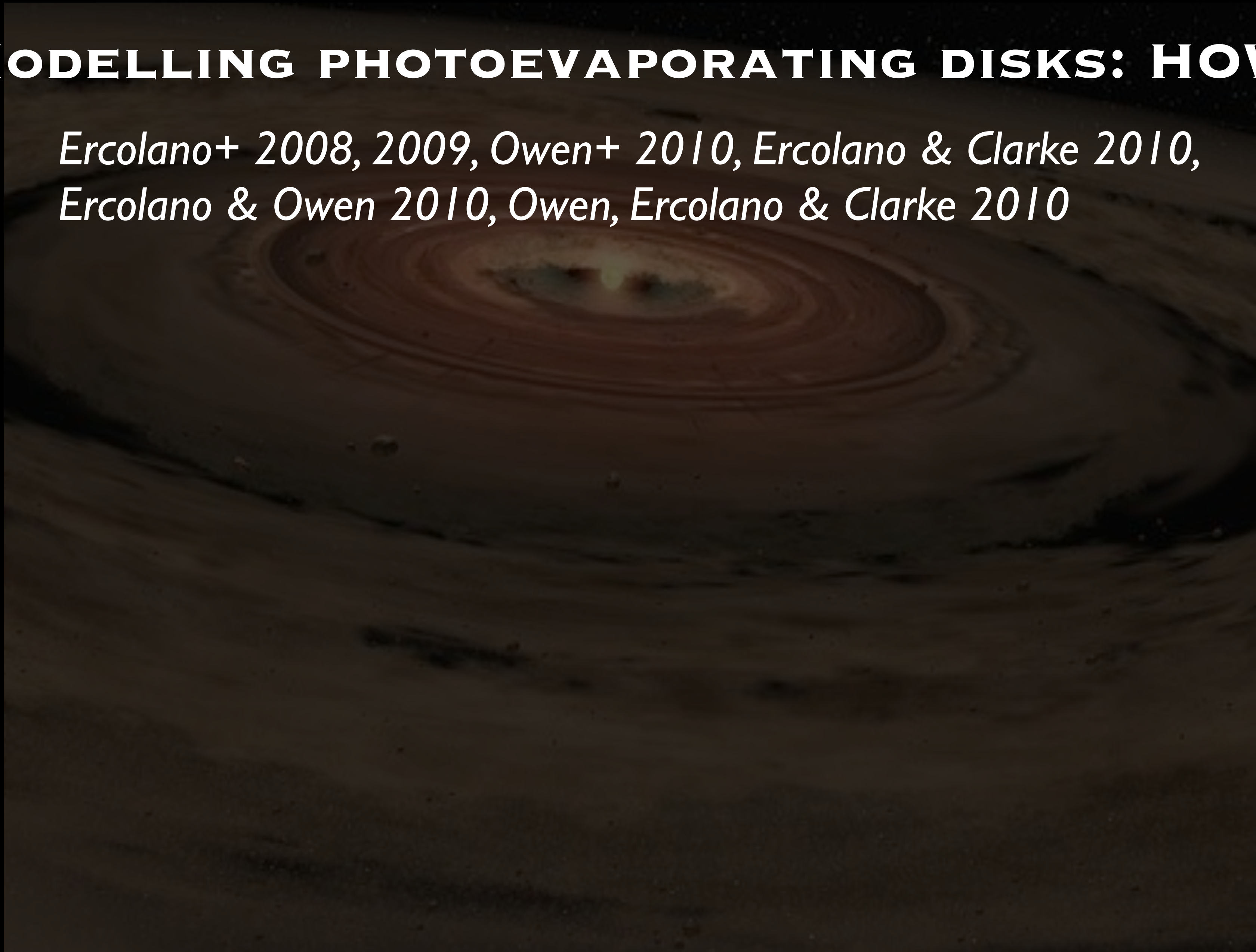


Modelling photoevaporating disks: HOW?

Ercolano+ 2008, 2009, Owen+ 2010, Ercolano & Clarke 2010, Ercolano & Owen 2010, Owen, Ercolano & Clarke 2010



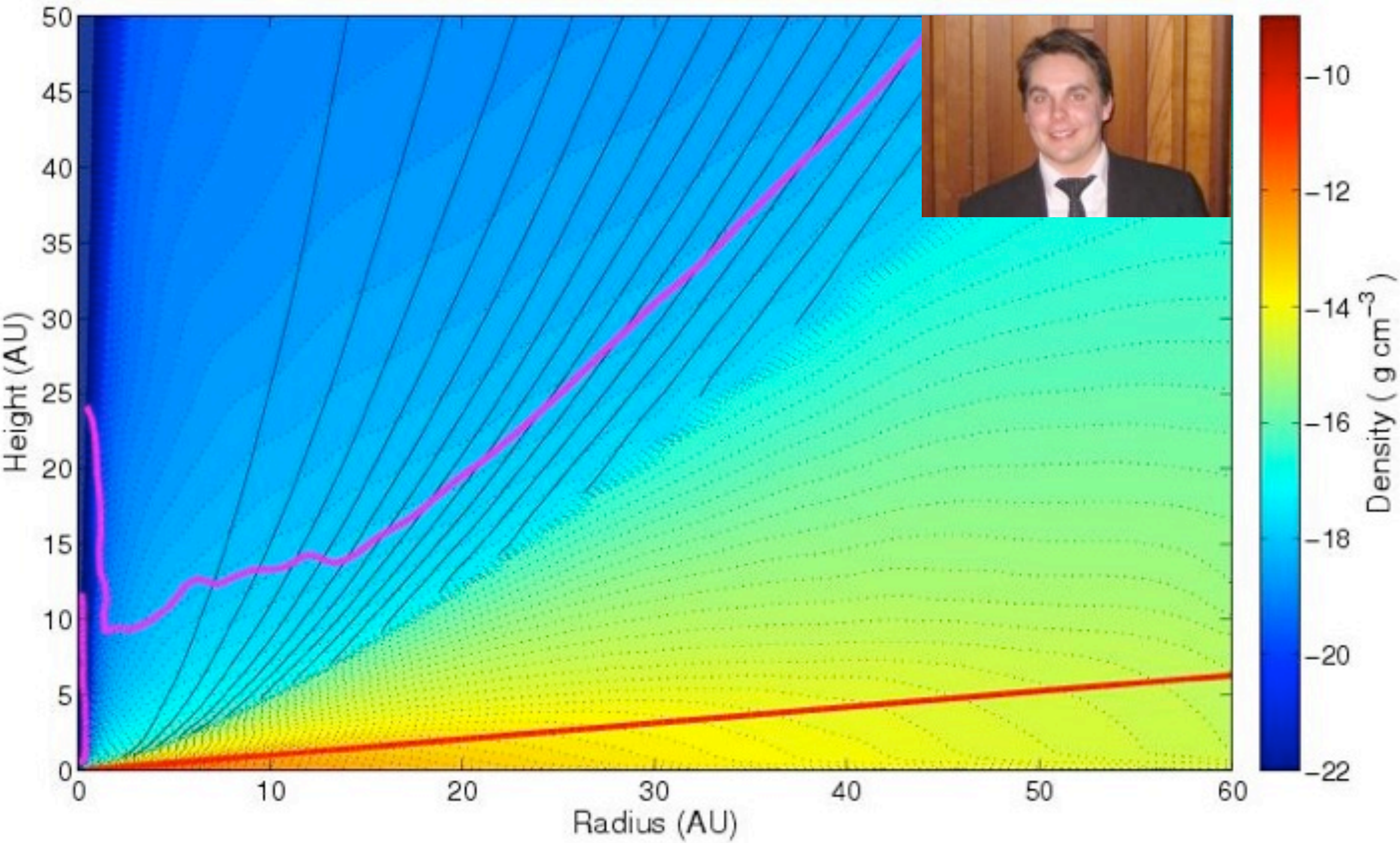
Modelling photoevaporating disks: HOW?

Ercolano+ 2008, 2009, Owen+ 2010, Ercolano & Clarke 2010, Ercolano & Owen 2010, Owen, Ercolano & Clarke 2010

1) Radiative Transfer (MOCASSIN)
   a) 2D (at least)
   b) gas (photoionisation) + dust

2) Hydrodynamics (ZEUS)

3) Viscous Evolution

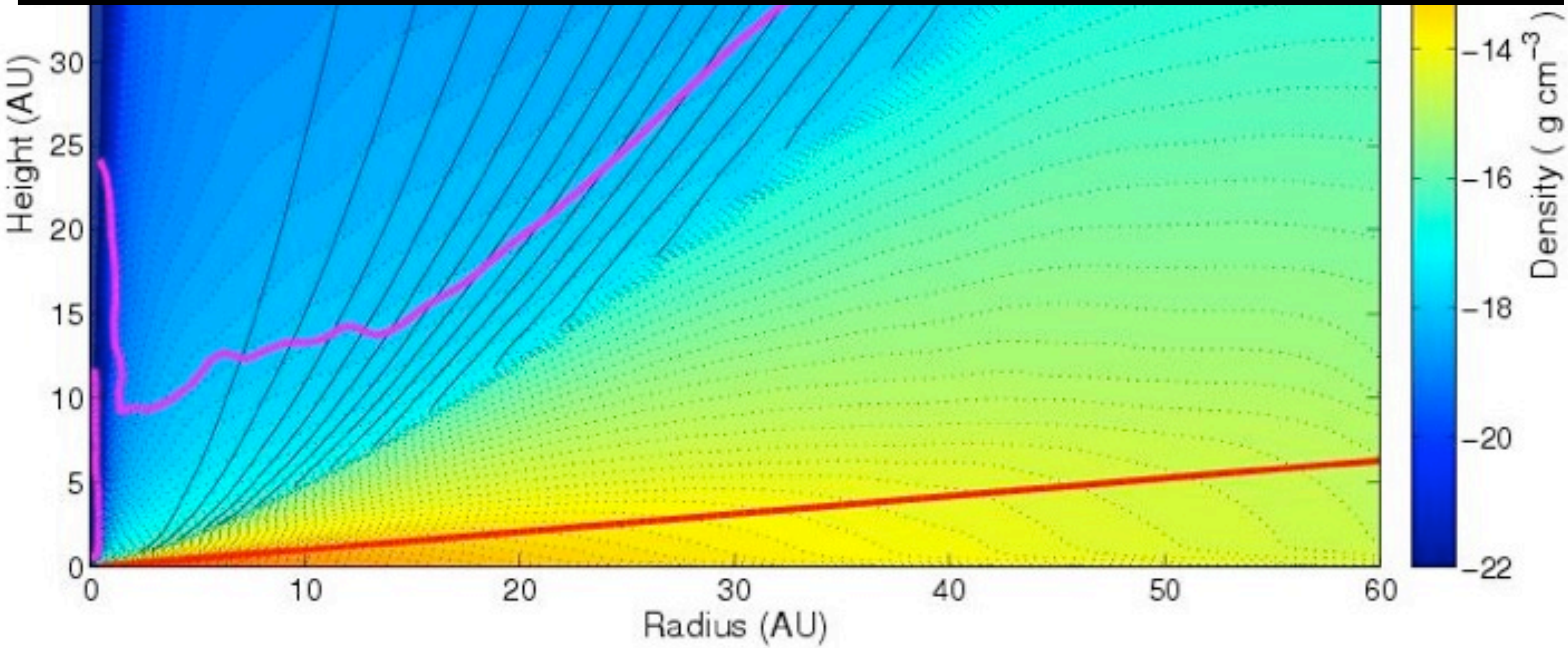


Owen, Ercolano, Clarke & Alexander, 2010

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

(for L_x = 2e30erg/sec)

Comparable to accretion rates of CTTs



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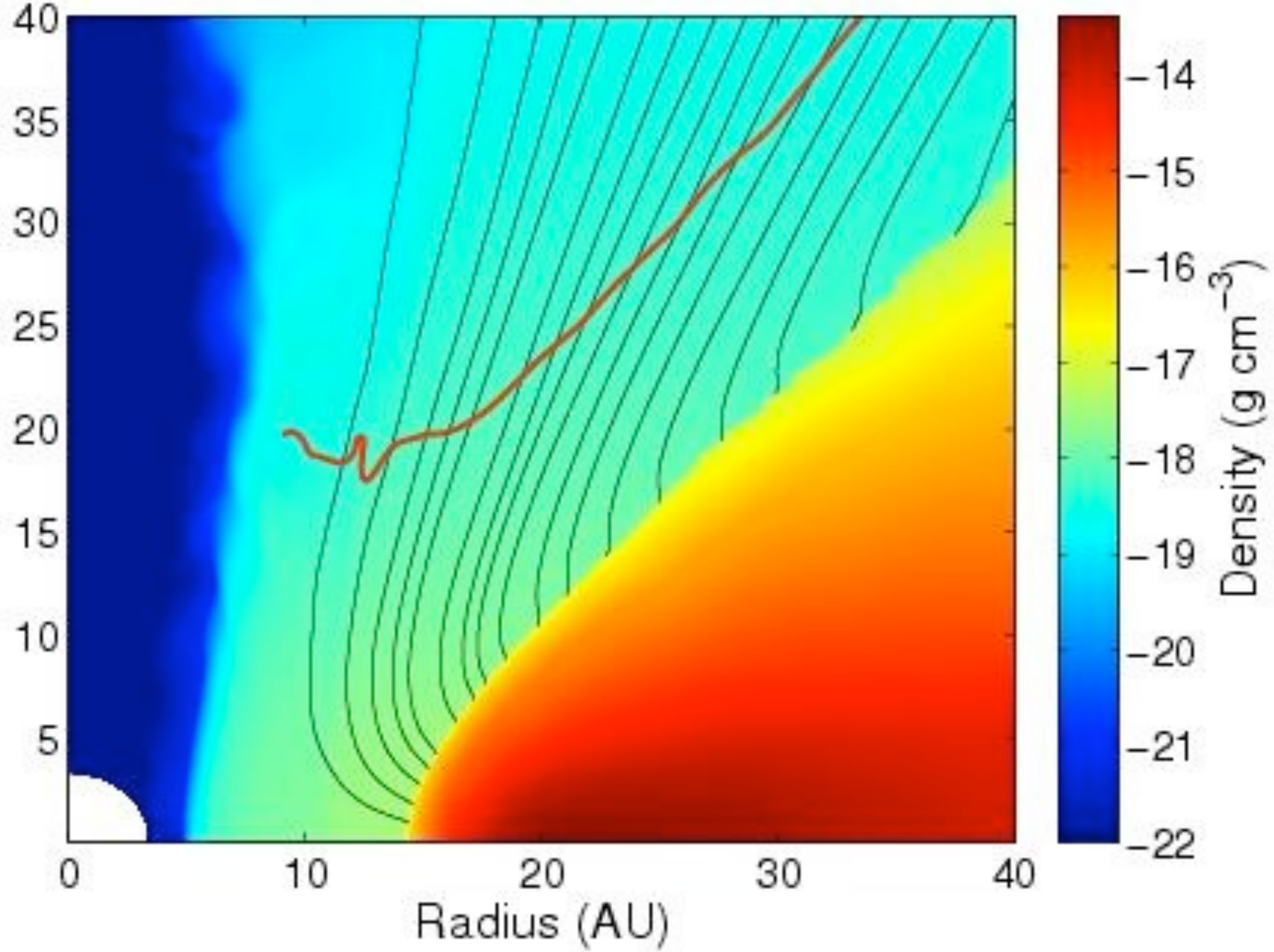
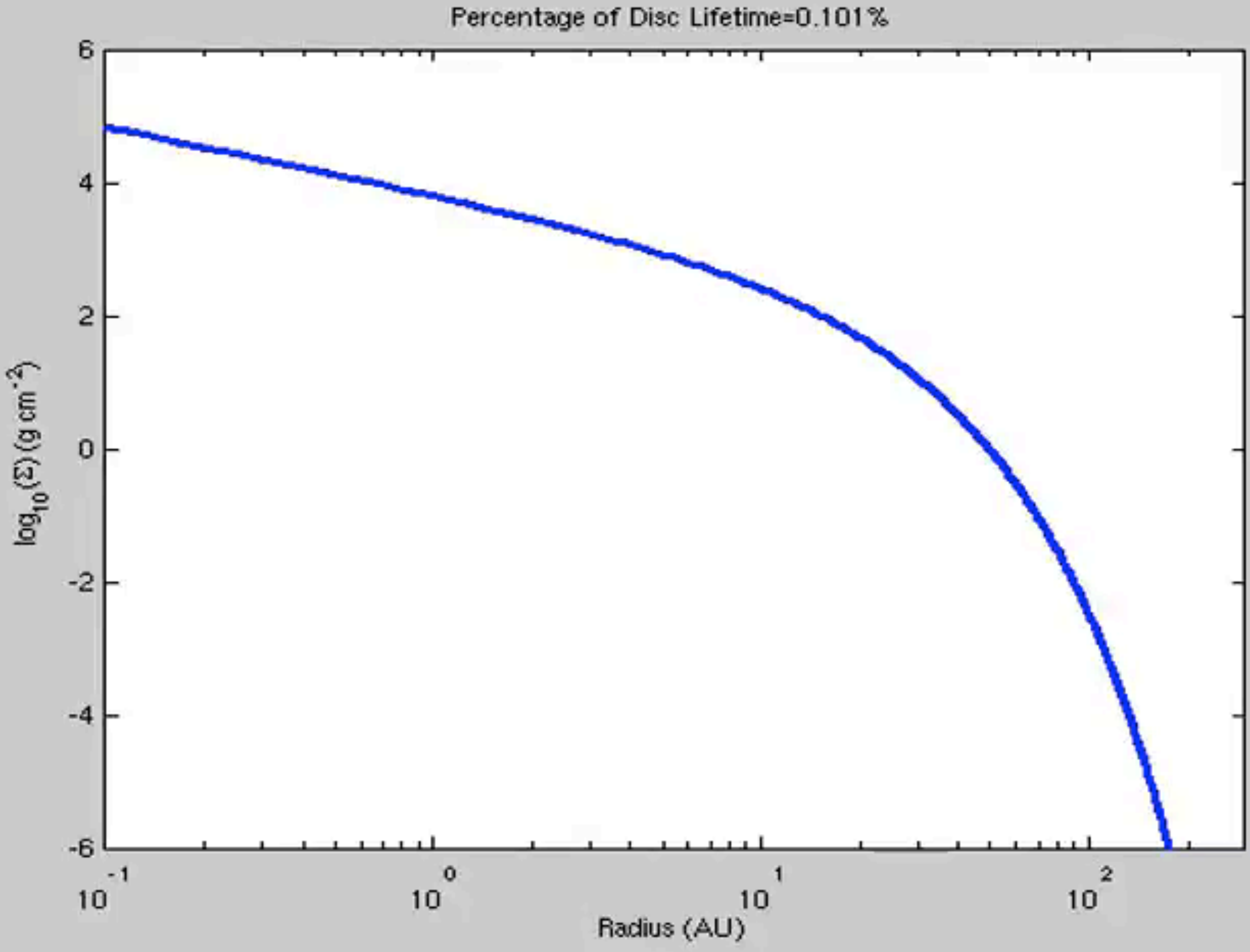
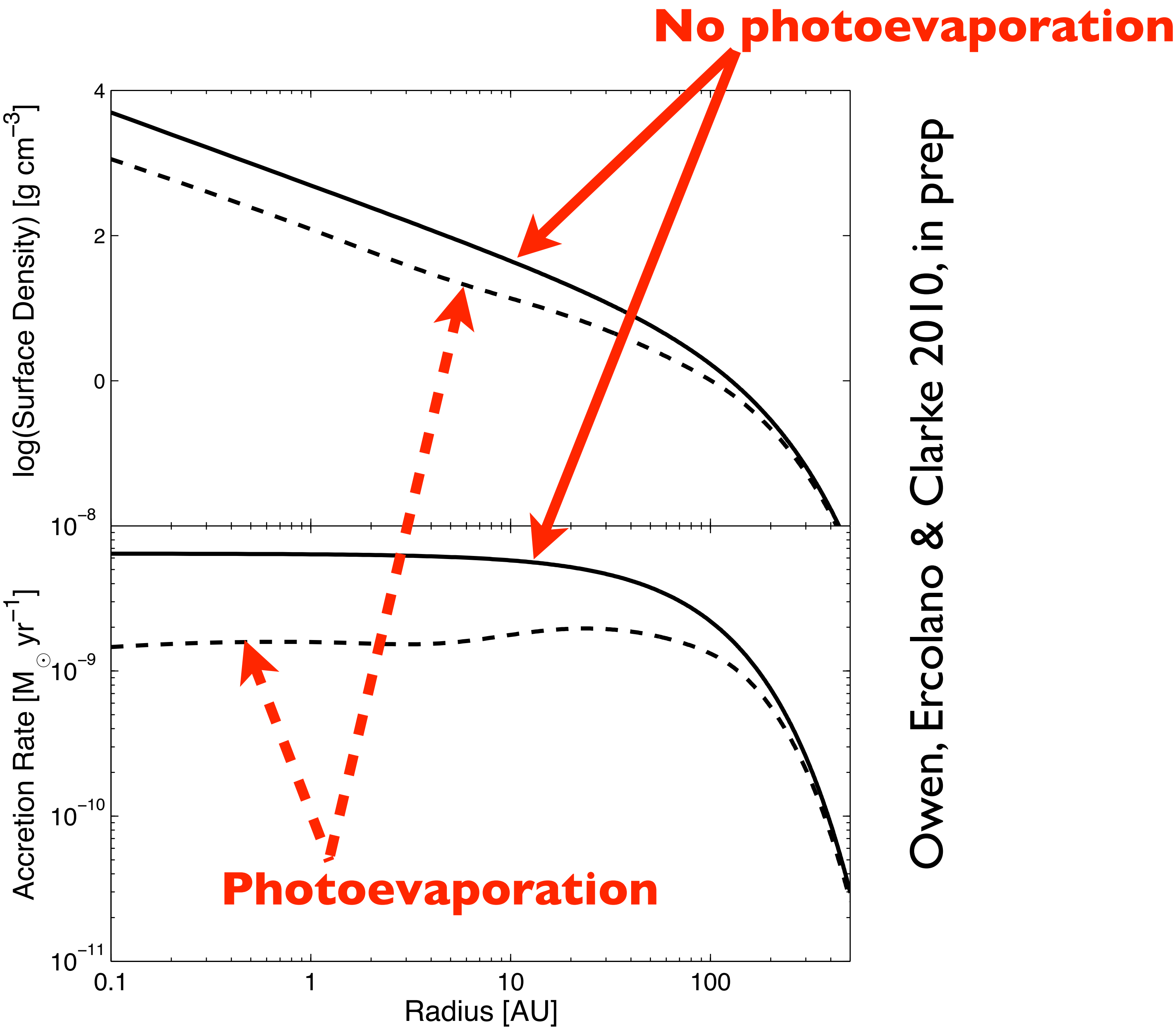


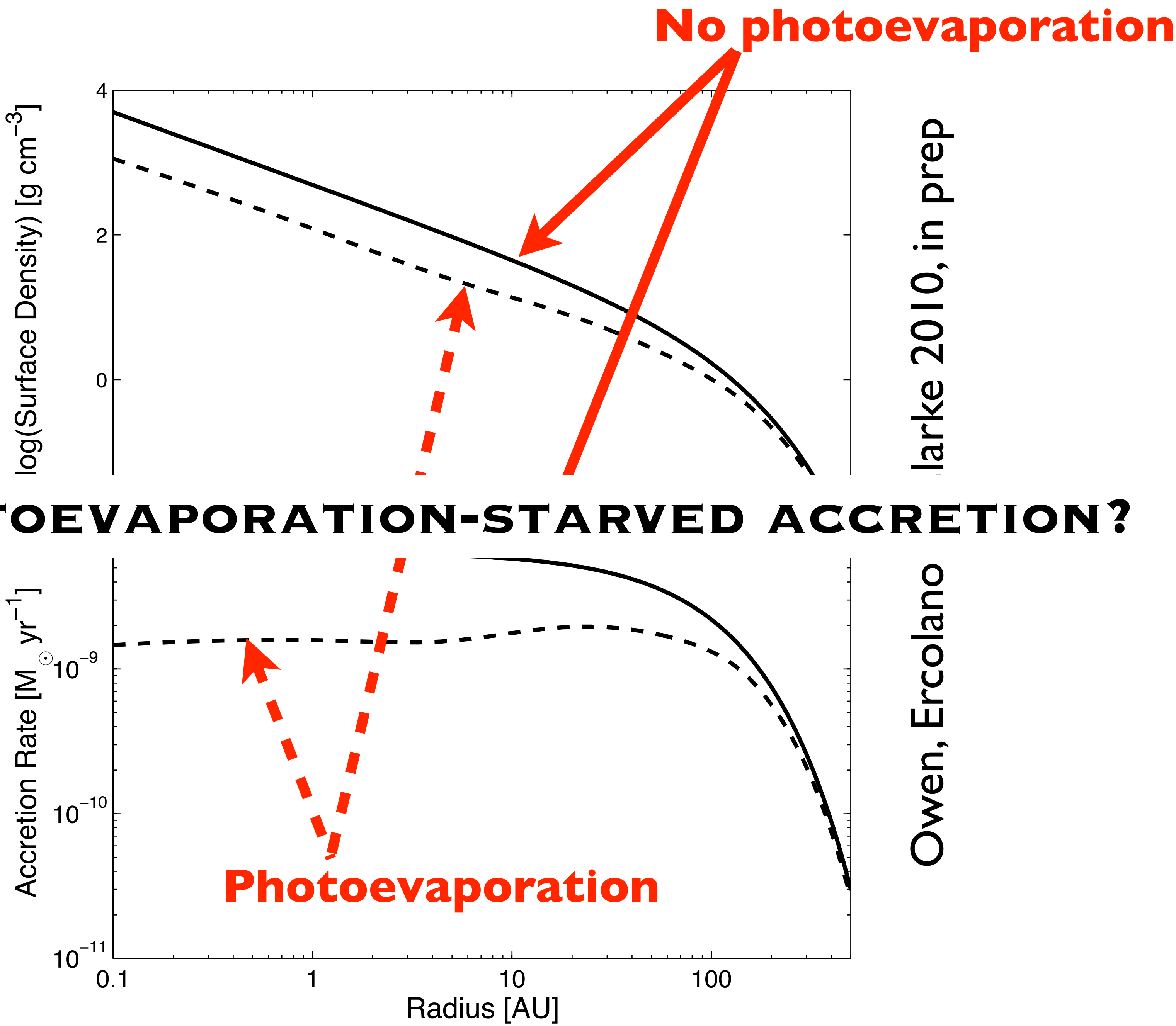
OWEN, ERCOLANO, CLARKE & ALEXANDER, 2010


Percentage of Disc Lifetime=0.101%
6
4
2
0
-2
-4
-6
$\log_{10}(\Sigma)$ (g cm^{-2})
10^{-1}
10^{0}
10^{1}
10^{2}
Radius (AU)

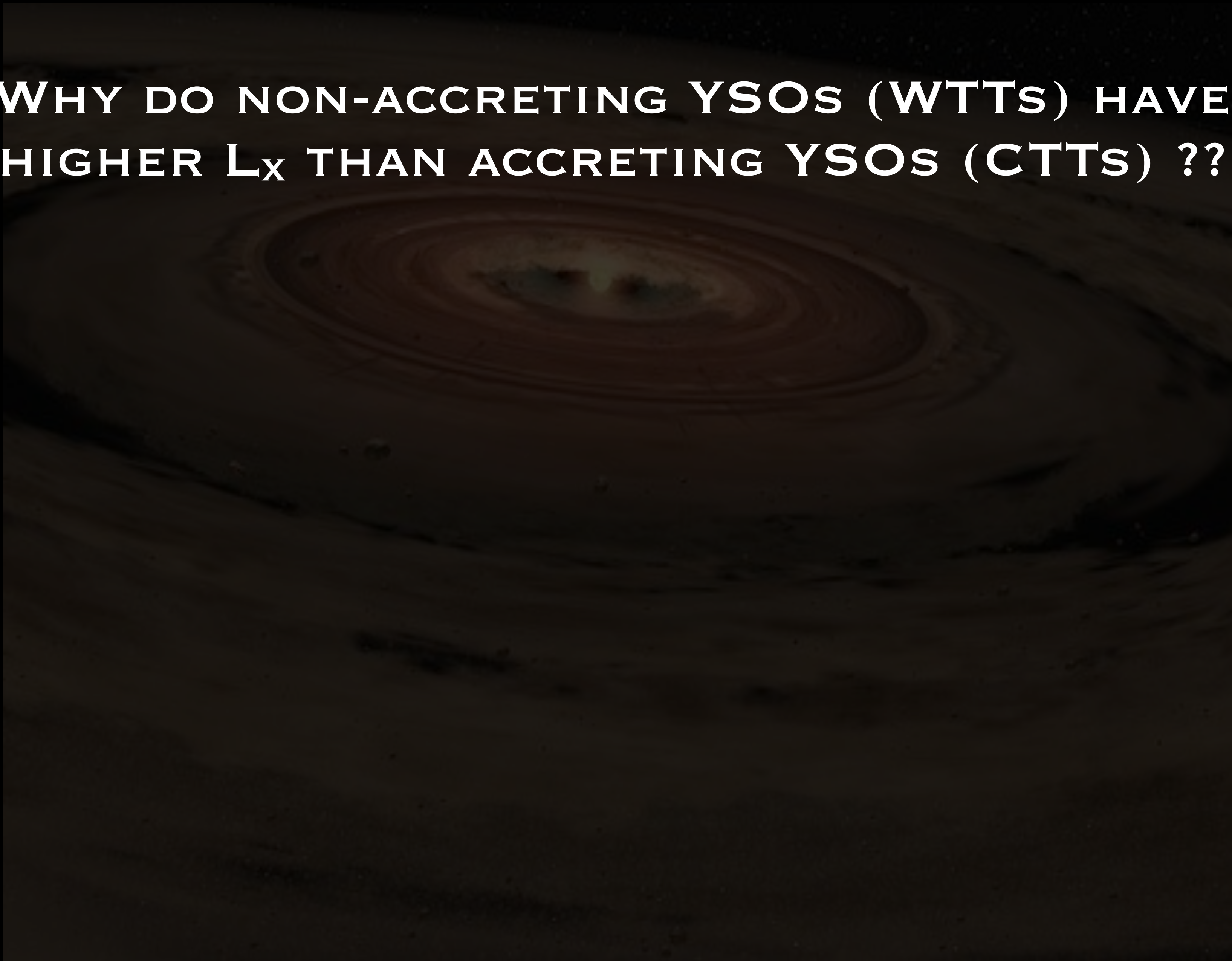


Owen, Ercolano & Clarke 2010, in prep

Photoevaporation-starved accretion?



Why do non-accreting YSOs (WTTs) have higher L_X than accreting YSOs (CTTs) ??



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Accretion 'disturbs' X-ray emission

(e.g. Flaccomio et al 2003, Stassun et al 2004, Preibisch et al 2005, Jardine et al 2006, Guedel et sl 2007, Gregory et al 2007)

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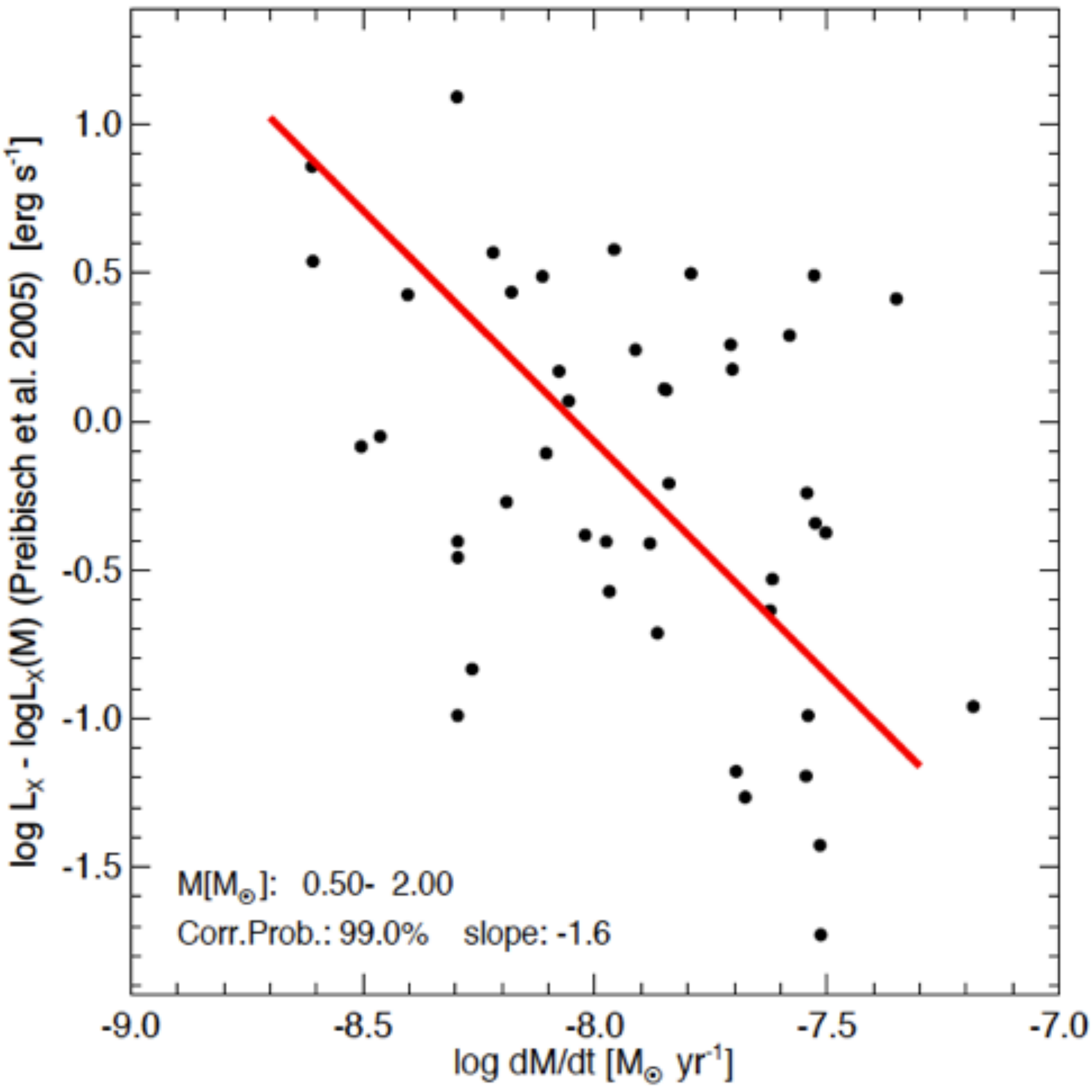
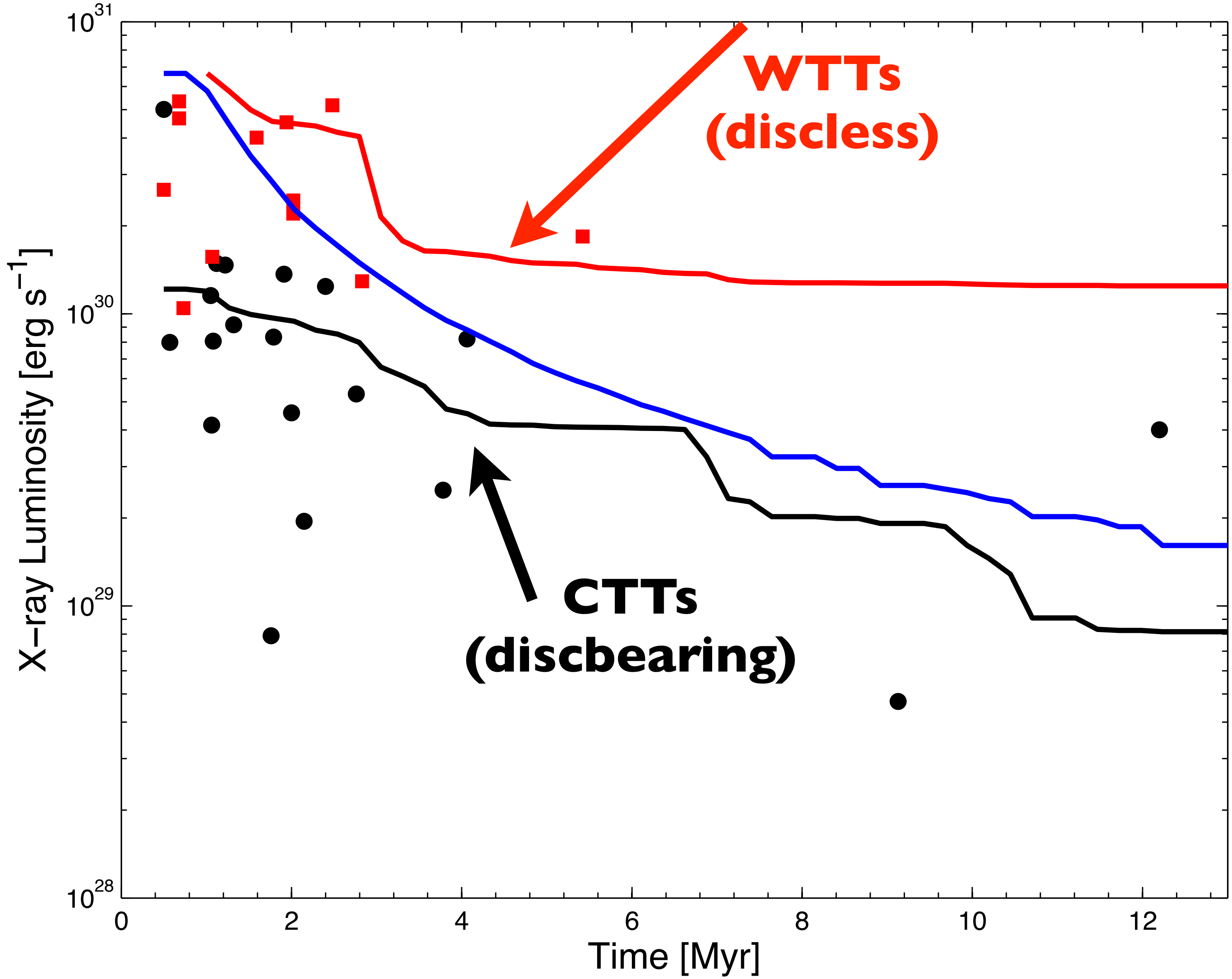
X-rays modulate accretion?
X-ray photoevaporation-starved accretion

(Drake et al 2009)

Drake et al 2009



Data points from Taurus (Guedel et al 2007)



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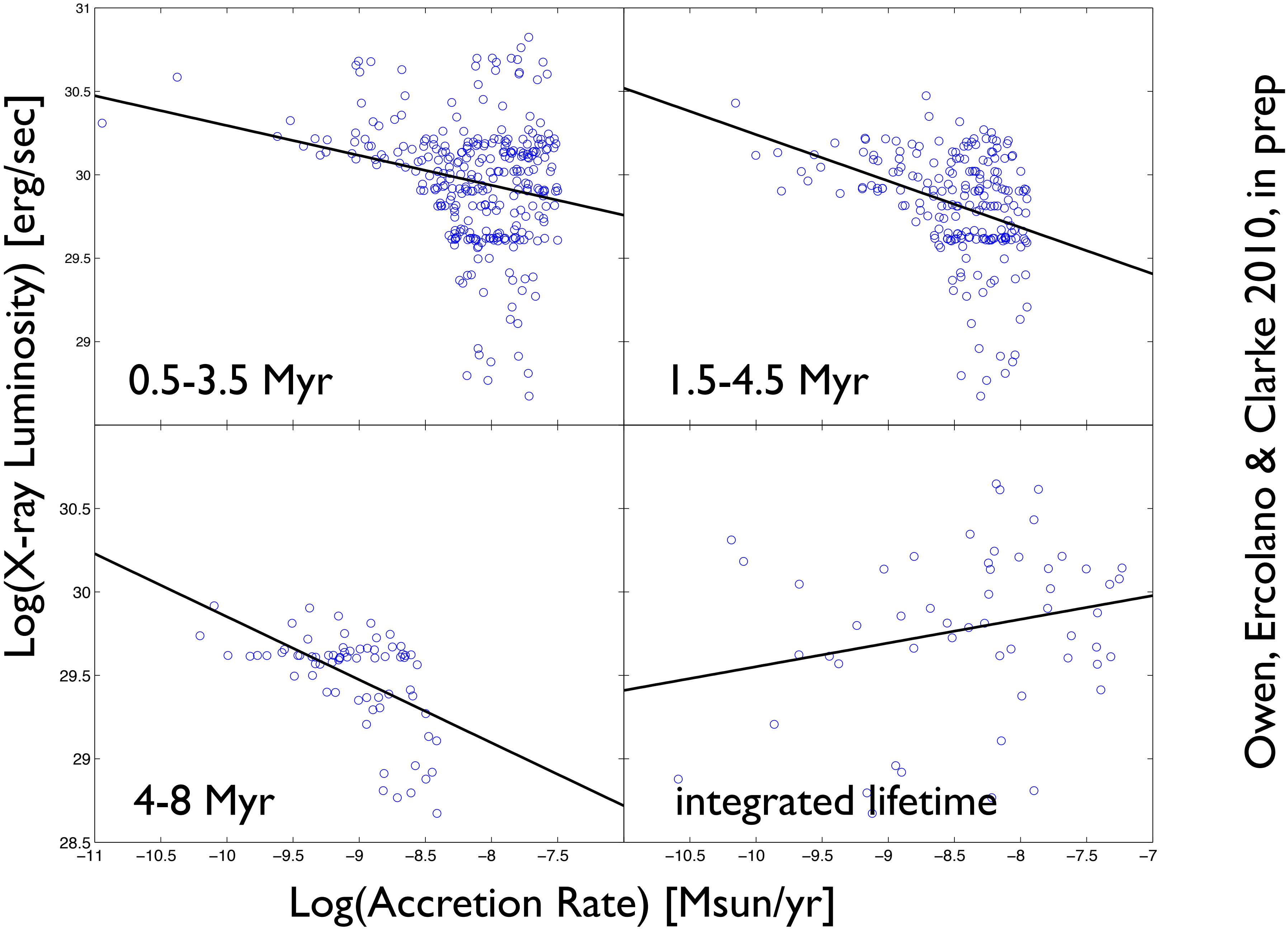

Log(X-ray Luminosity) [erg/sec]
Log(Accretion Rate) [Msun/yr]
0.5-3.5 Myr
1.5-4.5 Myr
4-8 Myr
integrated lifetime
31
30.5
30
29.5
29
28.5
−11
−10.5
−10
−9.5
−9
−8.5
−8
−7.5
−7
Owen, Ercolano & Clarke 2010, in prep

Conclusions

X-rays control the evolution & dispersal of protoplanetary discs & affect planet formation through:

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X-rays control the evolution & dispersal of protoplanetary discs & affect planet formation through:

- Ionising the discs thus allowing MRI to work ('hard' x-ray)
- Driving a photoevaporative wind that erodes the disc from the inside-out ('soft' X-ray)
- (Possibly) modulating accretion through photoevaporation-starved accretion ('soft' X-ray)

Thank You!