Linking spin-down and long-term variability in YSOs

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NWO

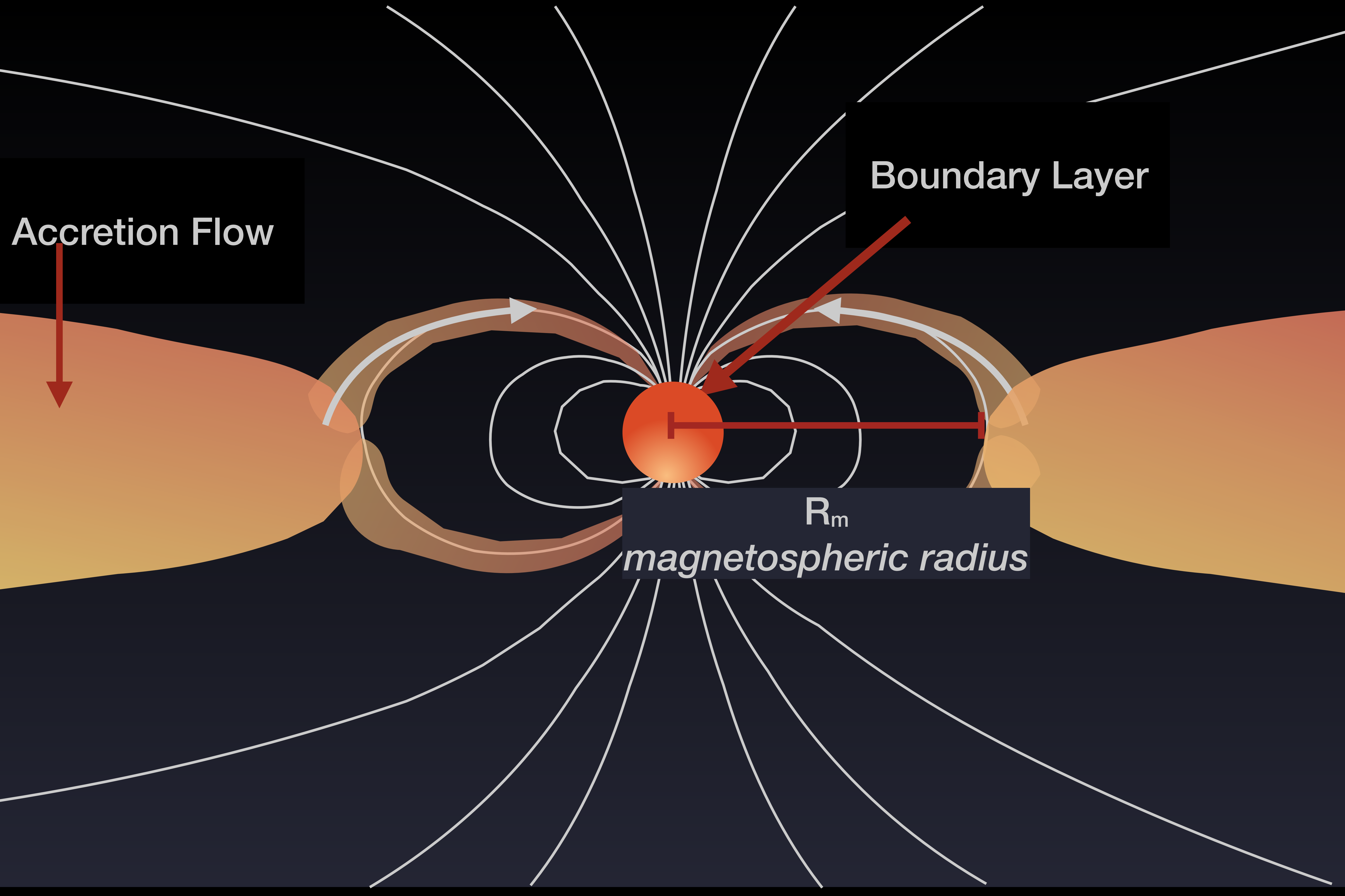
THIS WORK:

Fridriksson, J. K.; Messenger, C.; **Archibald, A M.**; **Bogdanov, S**; **Patruno, A**; **Jaodand, A.,** Hessels, J. W. T.; Deller, Adam T.; Bassa, Cees; Janssen, Gemma H.; Kaspi, Vicky M.; Lyne, Andrew G.; Stappers, Ben W.; Tendulkar, Shriharsh P.; Wijnands, Rudy; Maitra, D.; Russell, D.; Curran, P; Middleton, M.;

How do YSOs regulate spin?

- YSOs are slow rotators, depends on B field configuration (cf. talks on Tuesday)
- YSOs with discs rotate more slowly than without
- Potential angular momentum sinks: stellar wind, mass ejections/propeller, accretion disc

MAGNETOSPHERIC ACCRETION



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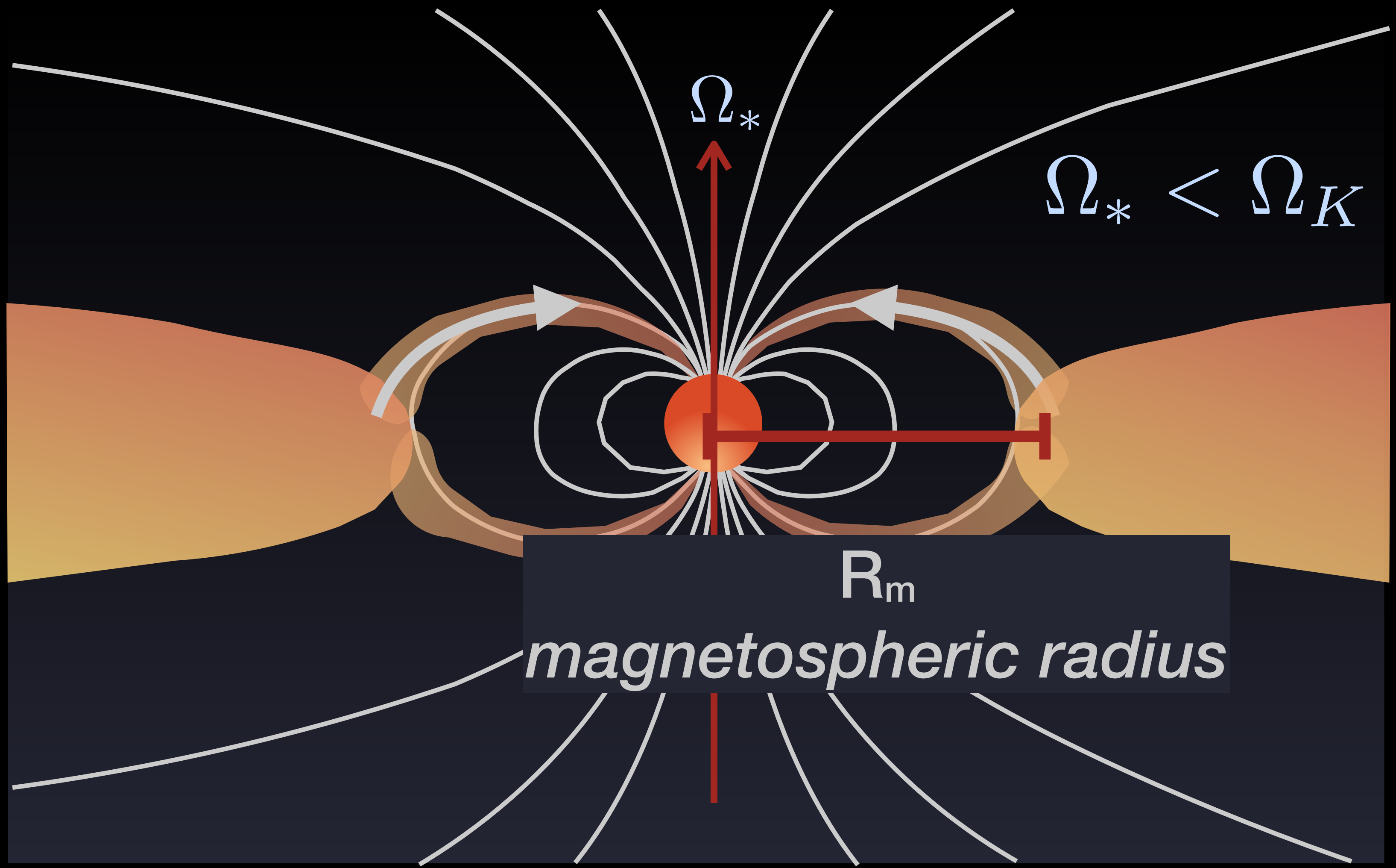
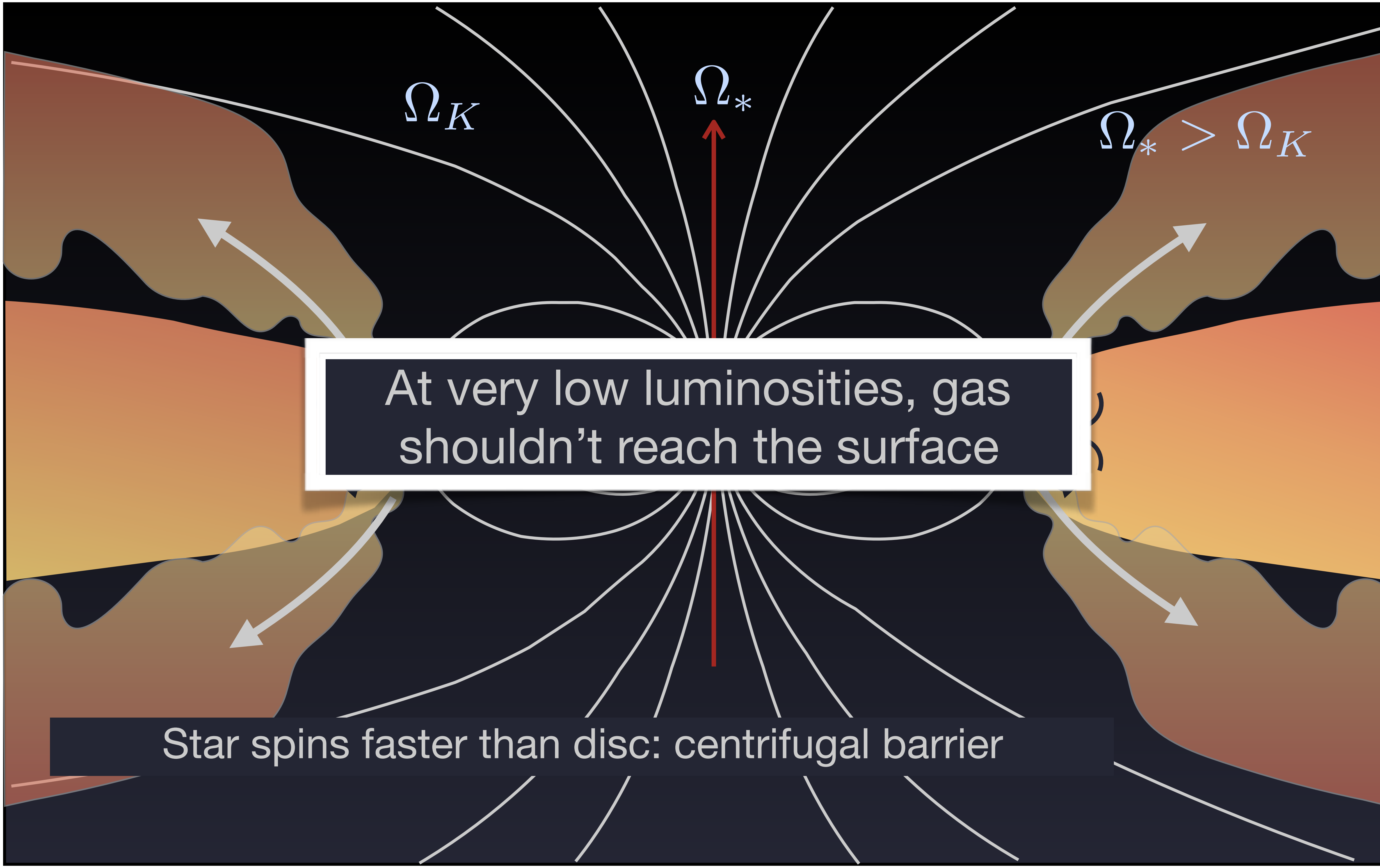


MAGNETIC FIELD COUPLES DISC AND STAR: ANGULAR MOMENTUM EXCHANGE

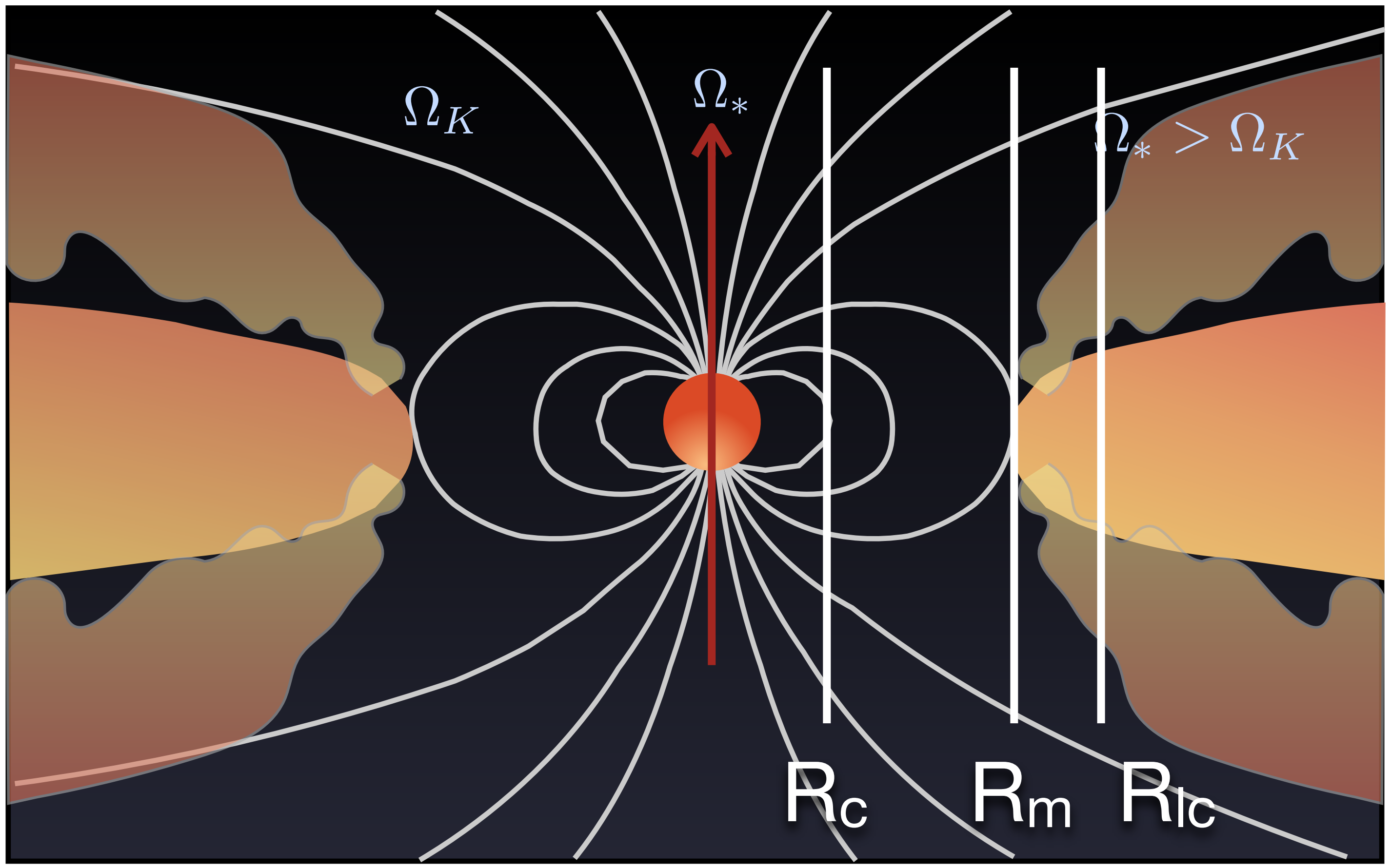
SPIN UP/SPIN DOWN DEPENDS ON *CO-ROTATION RADIUS*

$$r_c = \left(\frac{GM_*}{\Omega_*^2} \right)^{1/3}$$



Ω_K
Ω_*
$\Omega_* > \Omega_K$
At very low luminosities, gas shouldn't reach the surface
Star spins faster than disc: centrifugal barrier

Faint accreting pulsar: J1023+0038

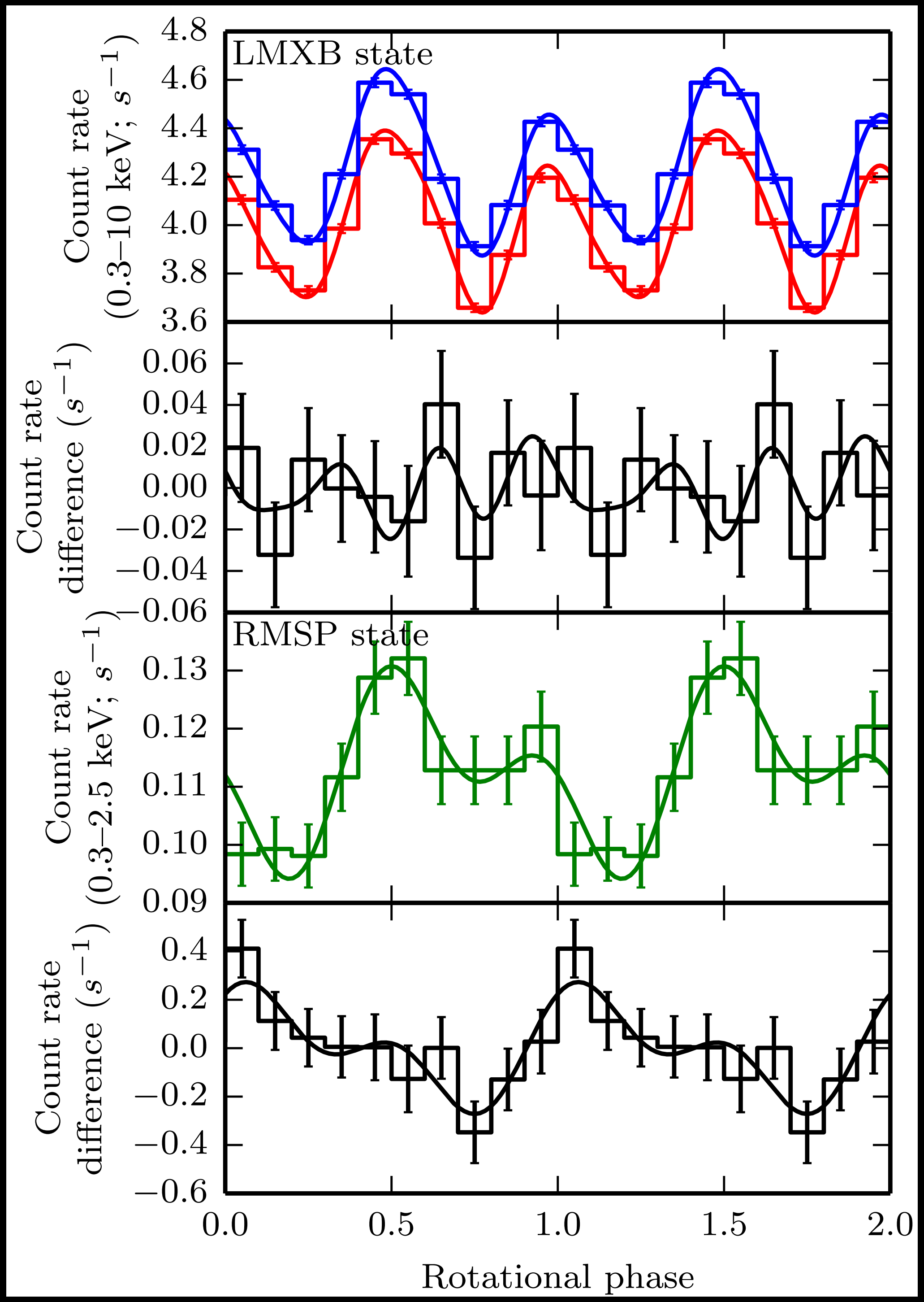


- Accreting X-ray pulsar
- Weakly magnetic B~10^8G
- Spin period: 592 Hz
- X-ray 'bright' state:
  - L_x 10^{32}-10^{34} erg/s (very faint)
  - R_c: 2.4x10^6 cm
  - R_m: 6x10^6 cm

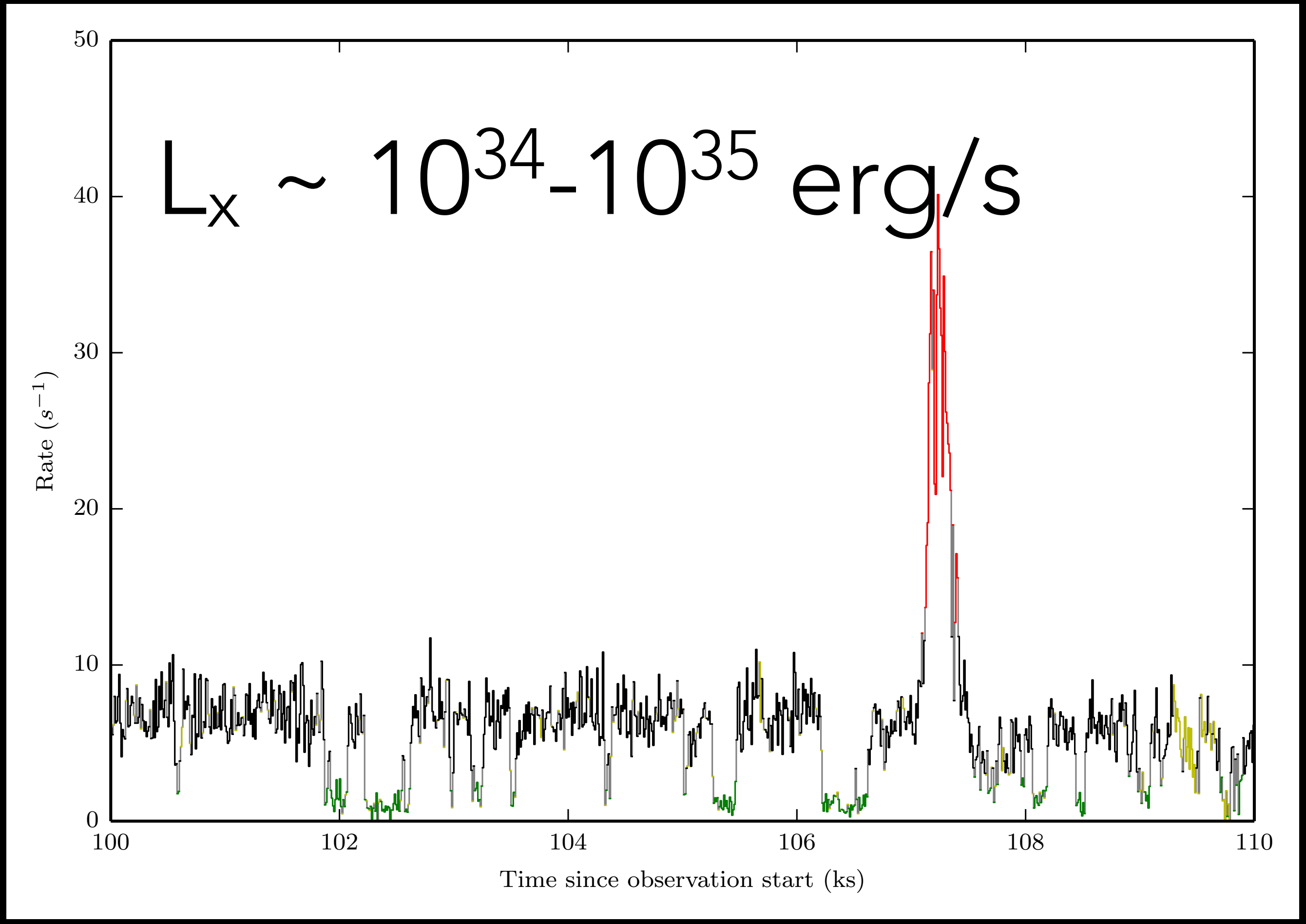
It therefore seems more likely that infalling matter did not reach the NS surface, but instead underwent what is known as "propeller-mode accretion" (*20*): infalling matter entered the light cylinder but was stopped by magnetic pressure outside the corotation radius, which prevented it from falling further inward. This process also has a minimum accretion rate and minimum

Archibald et al. 2009

PULSATIONS: ACCRETION ONTO SURFACE

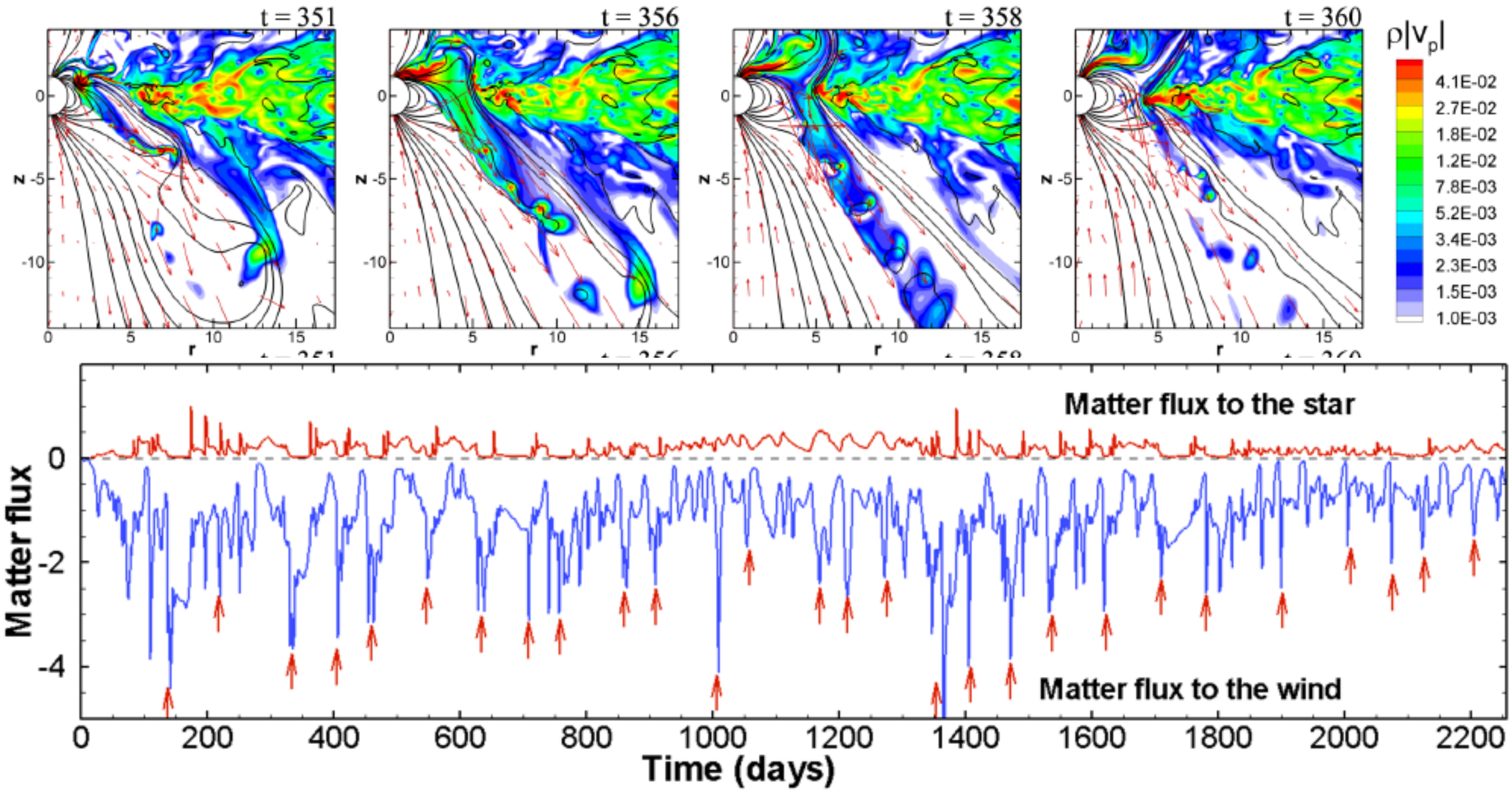


Archibald et al., 2015



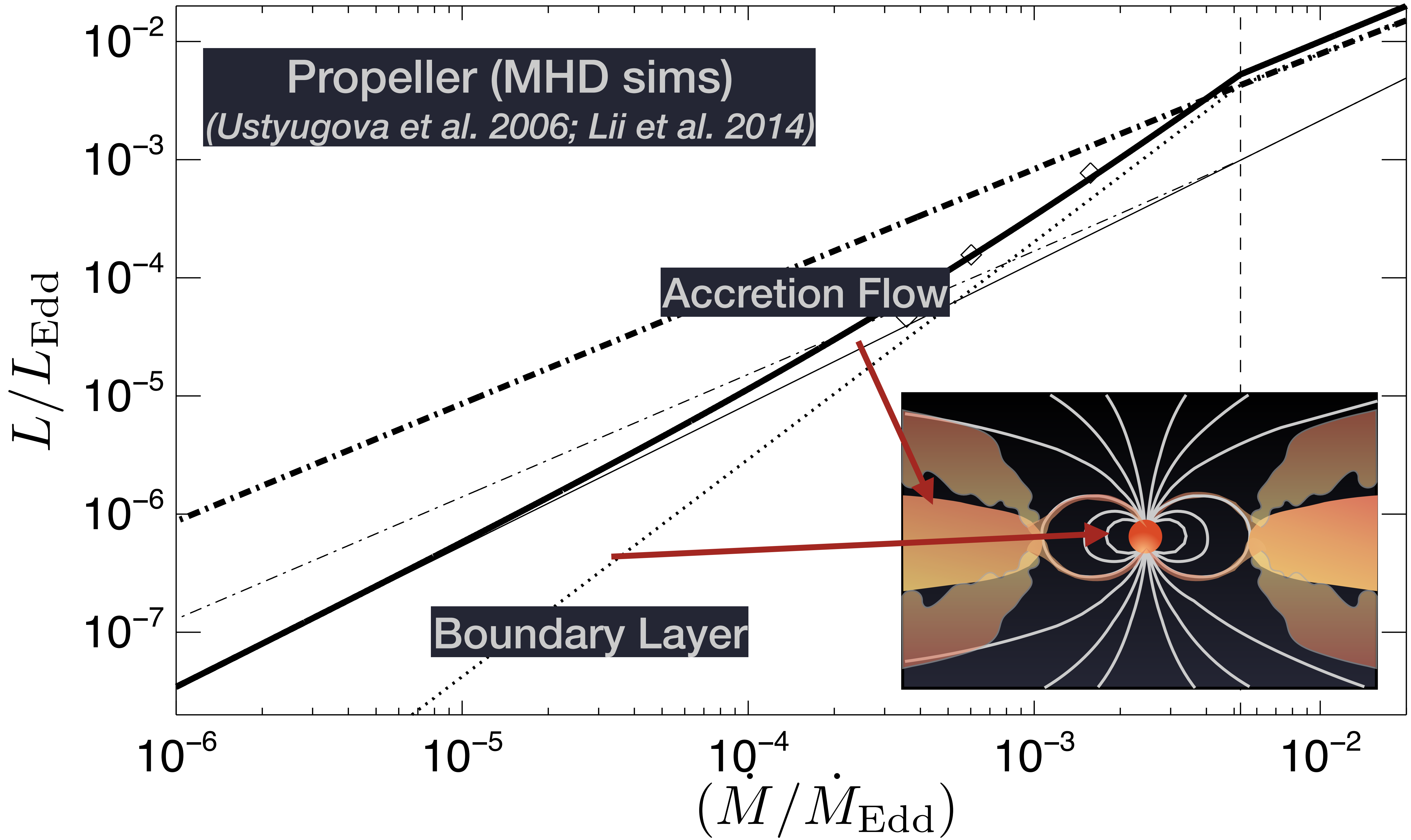
Archibald et al., 2015

X-ray pulsations found in X-ray bright state: inefficient propeller?



Romanova et al. 2013

Luminosity v. Accretion Rate
Magnetic Propeller



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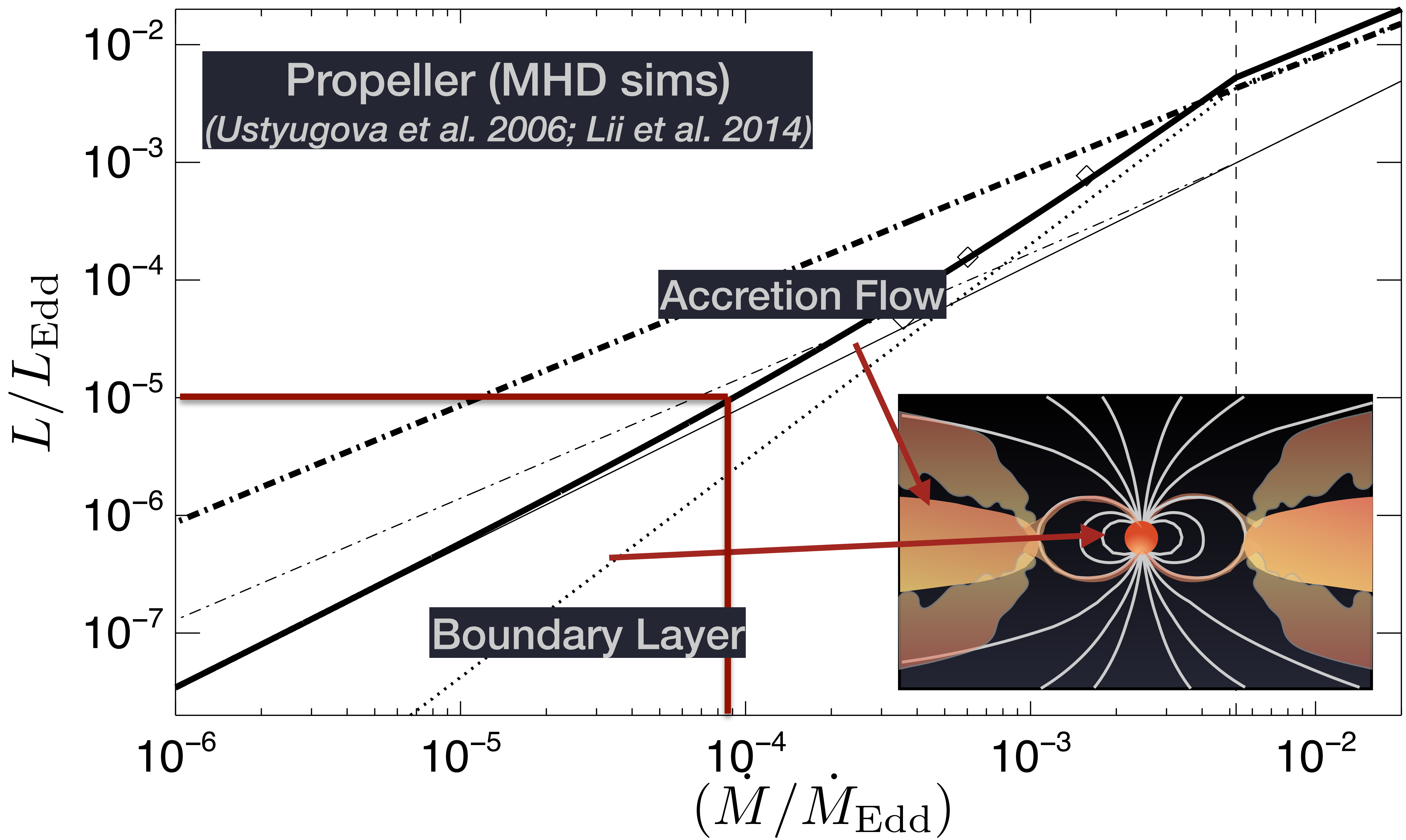
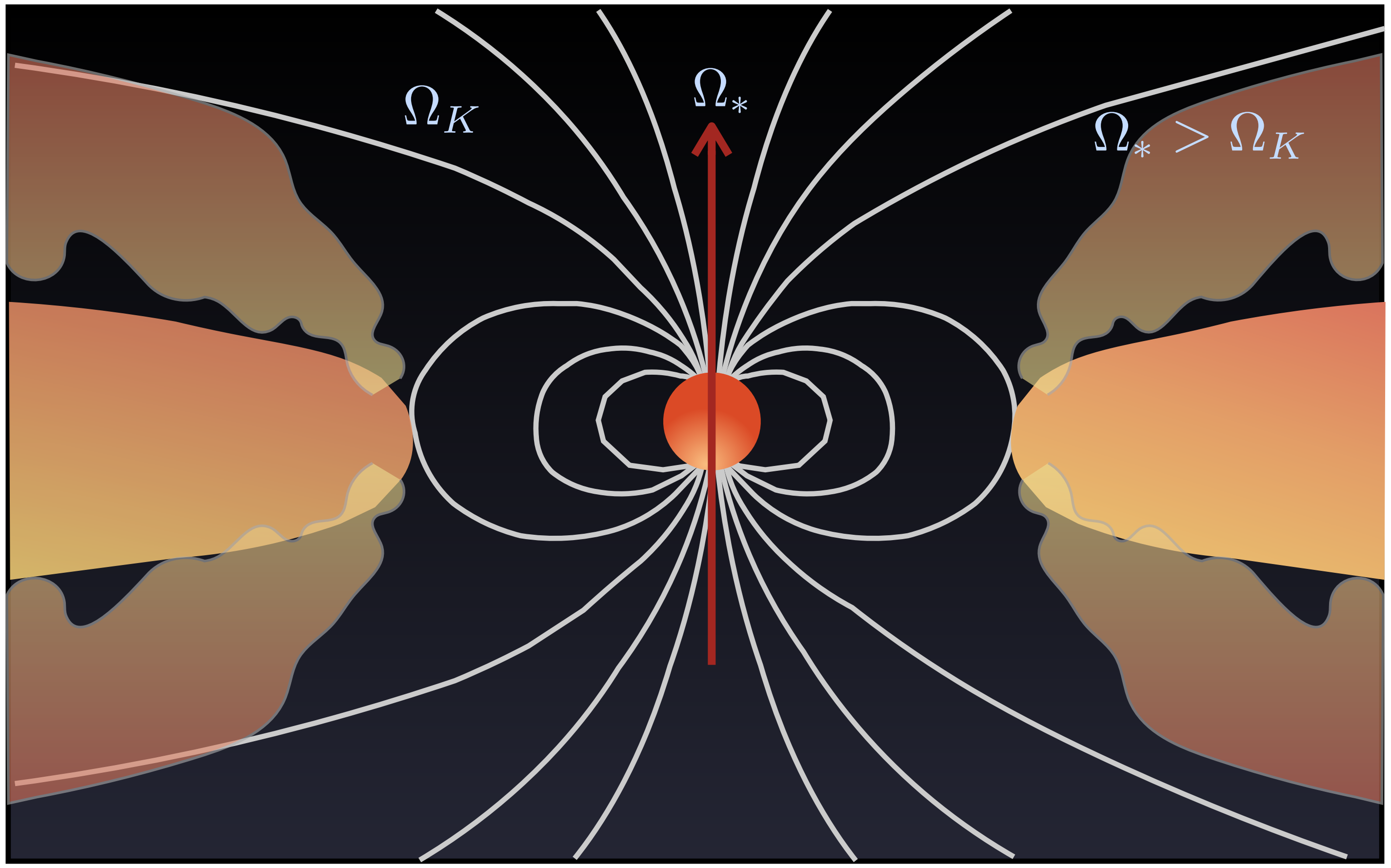


Spin-down limits



- Jaodand et al. (2015) report *phase connected* timing solution
- J1023 shows modest spin-down

'Propeller' simulations predict 10-20 times higher spin-down rate

CENTRIFUGAL BARRIER TO ACCRETION

$R_m > R_c$: star spins faster than disc

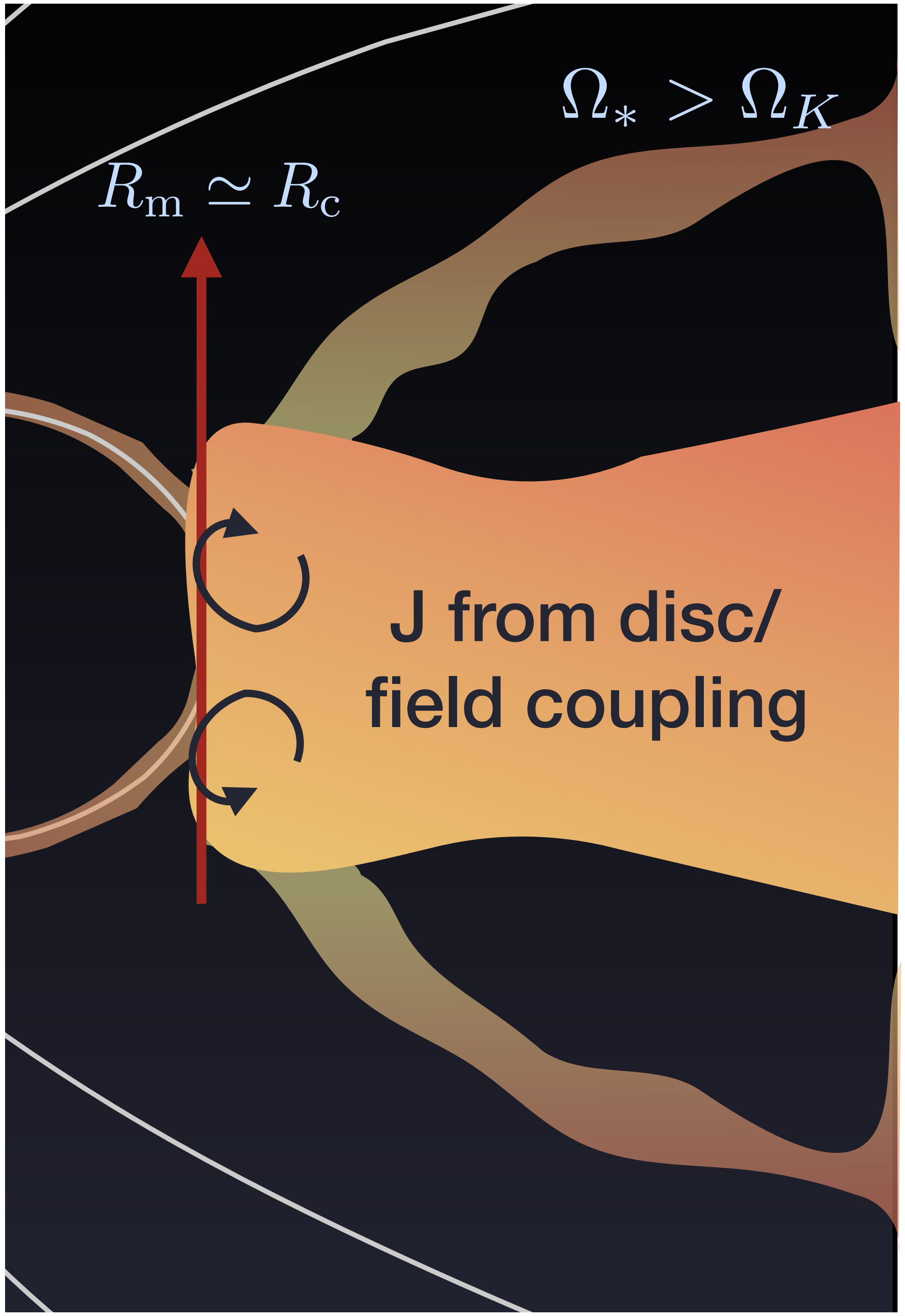
Illarianov & Sunyaev (1975)

vs.

Spruit & Taam (1993); D'Angelo & Spruit (2010)
Archibald et al., 2015

Most gas is not necessarily expelled!

A PROPELLER DOESN'T HAVE TO FORM



- (r_m<1.3 r_c): angular momentum not enough to expel most gas in outflow (weak propeller)
- gas piles up in disc
- accretion onto star continues
- "Trapped disc" (inner edge trapped near R_c)

[Spruit & Taam 1993, D'Angelo & Spruit 2010,2011,2012]

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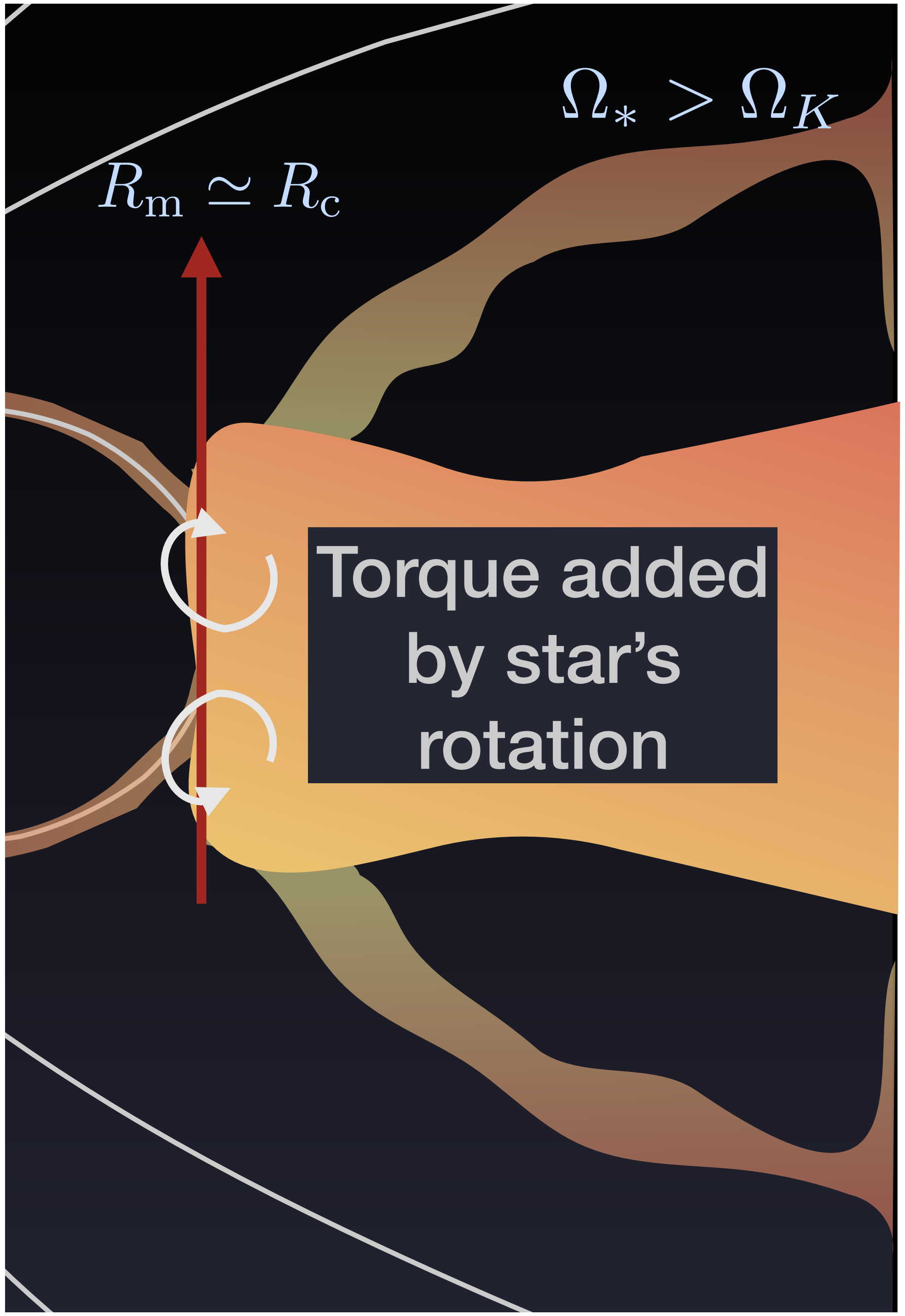

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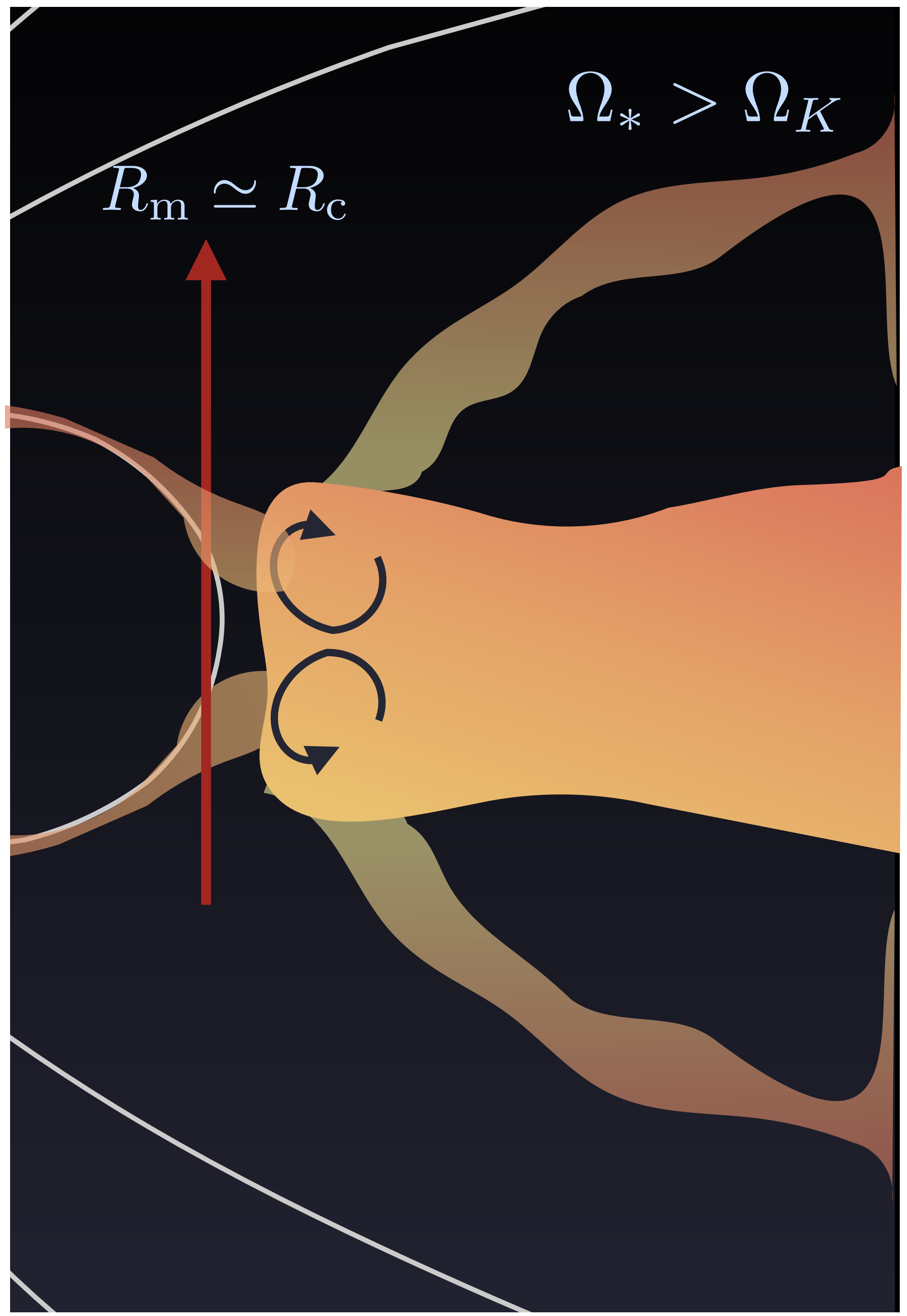

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‘Propeller’	Trapped disc
Strong outflow dominates	Weaker outflow; gas accretes
Narrow range of $\dot{M}$ leads to surface accretion	**Always** get accretion onto star
Inefficient spin regulation for strongly variable accretion rates	**Spin-down** efficiency high for variable accretion rates

Surface Accretion and spin change in J1023+0038 implies a trapped disc is present

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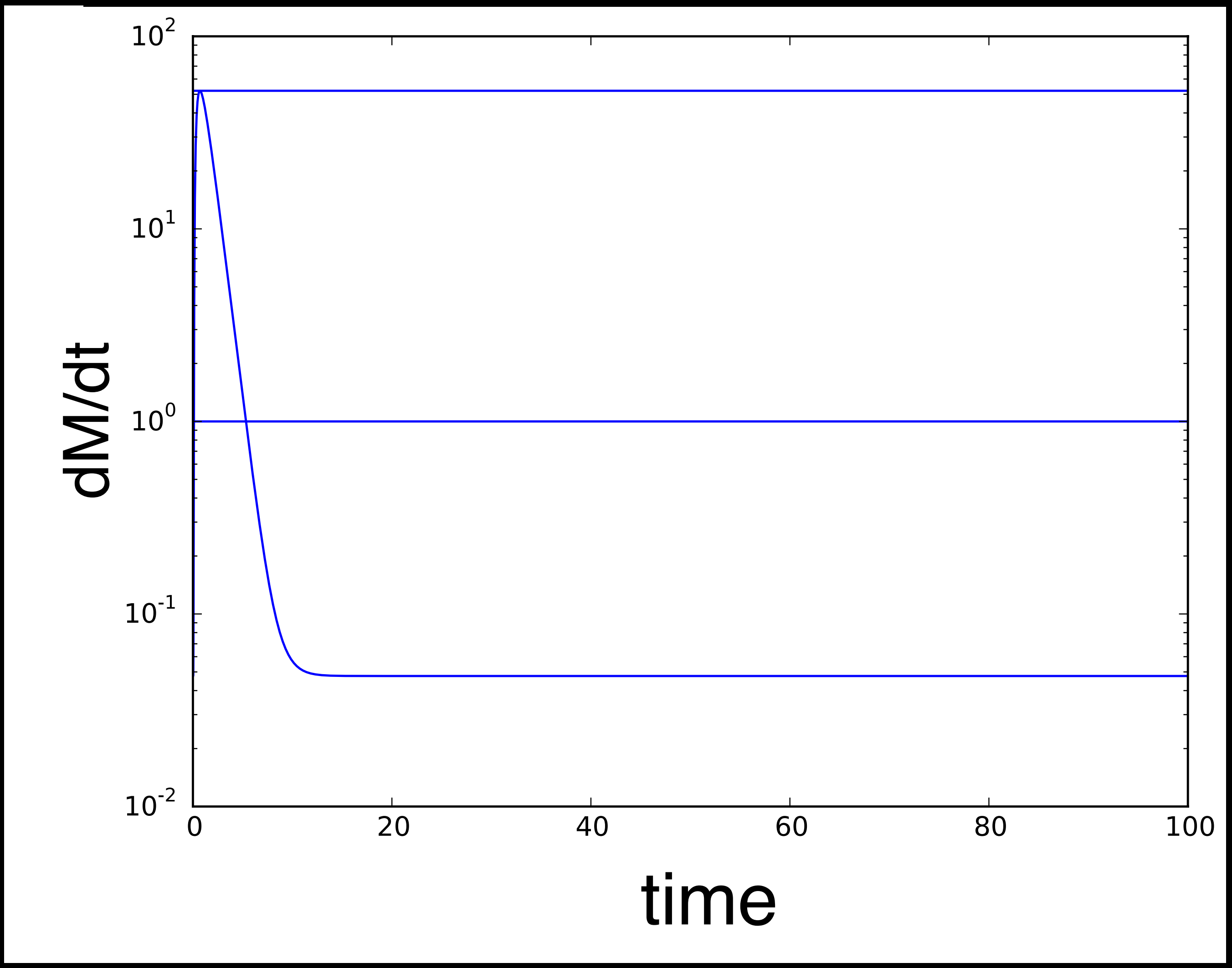
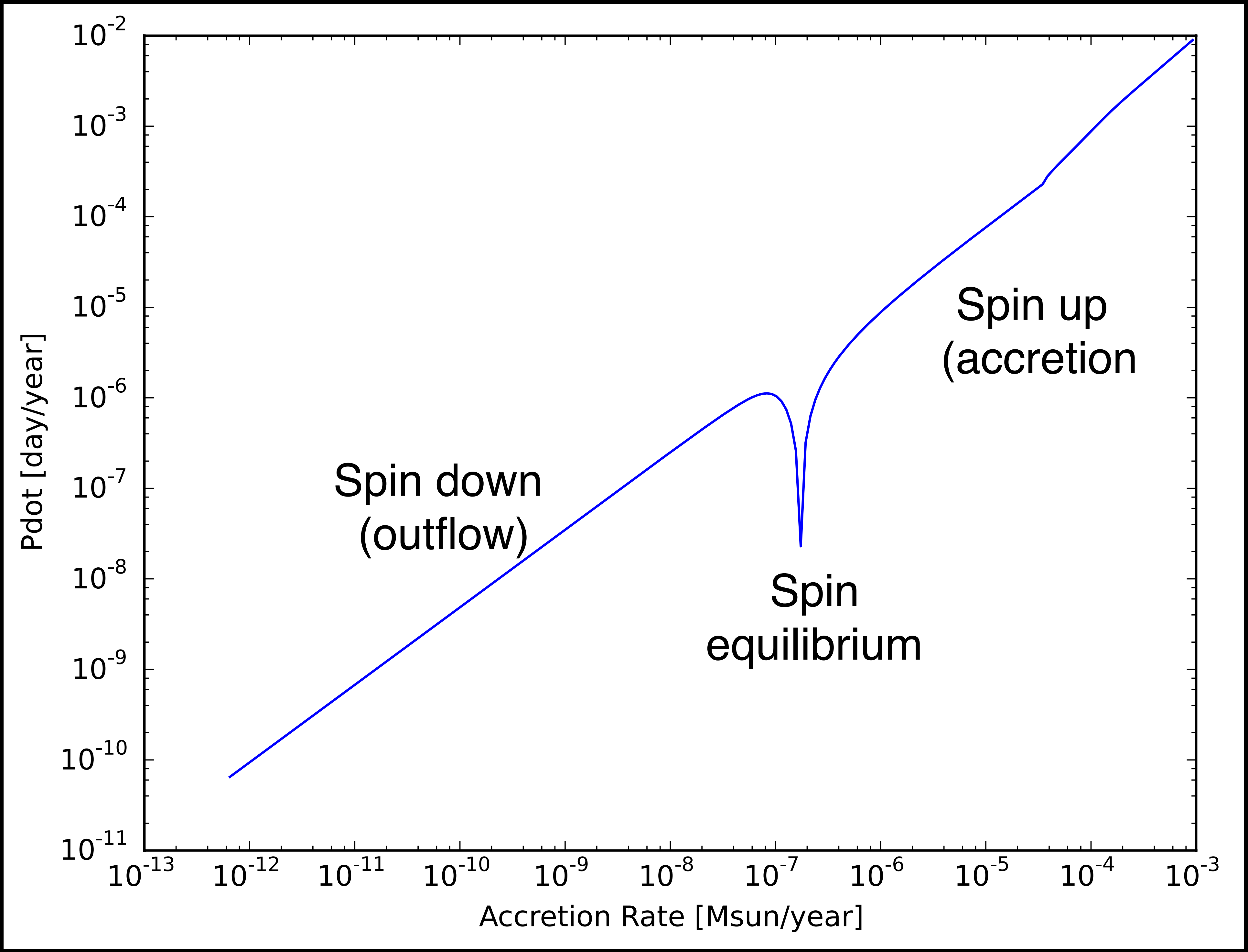
How do FU Ori outbursts affect spin evolution in YSOs?

- Young TTauri stars show FU Ori-type outbursts: ~1000x change in luminosity,~1/100 duty cycle?

- How do these large changes affect spin evolution?



Accretion/Propeller Spin regulation



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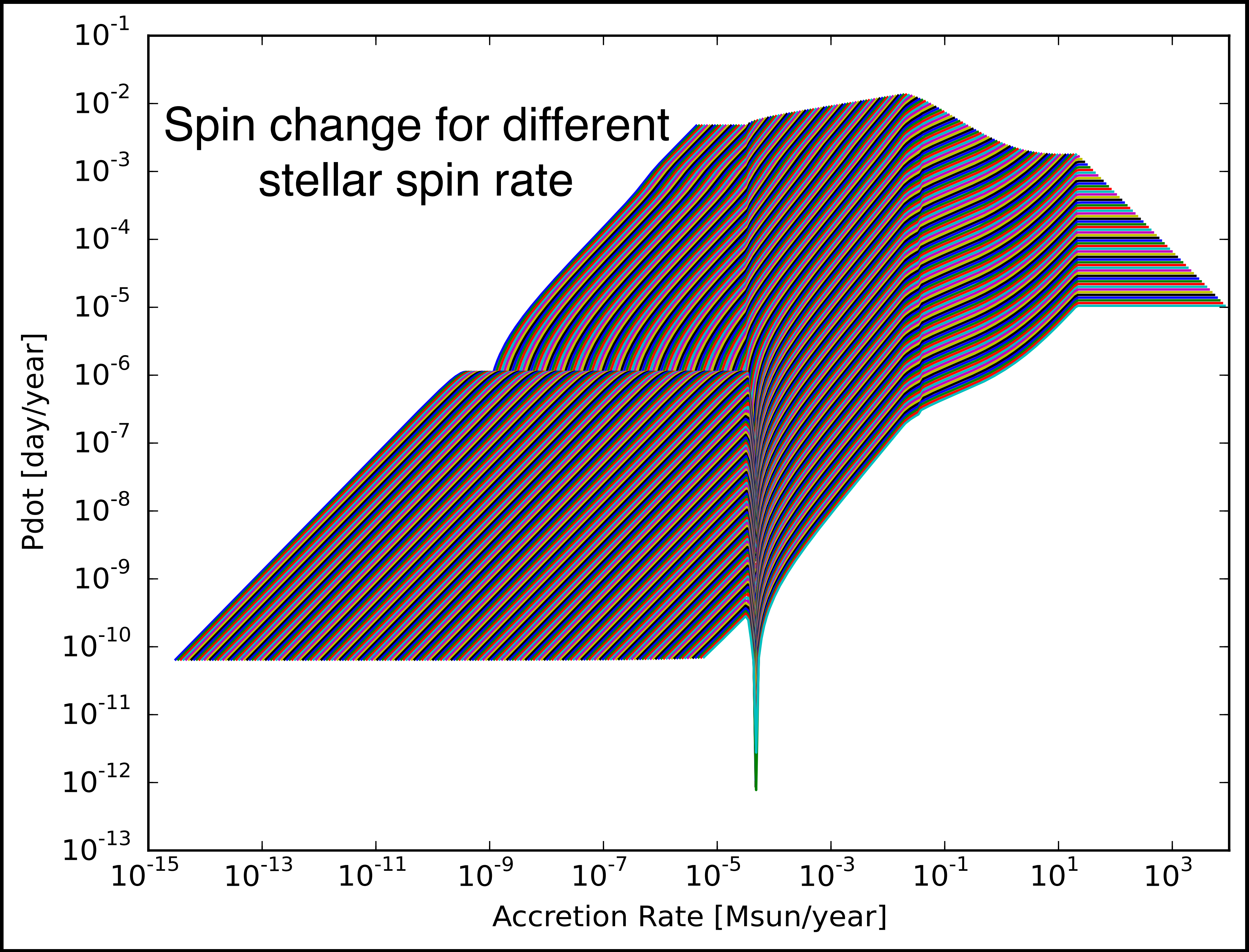
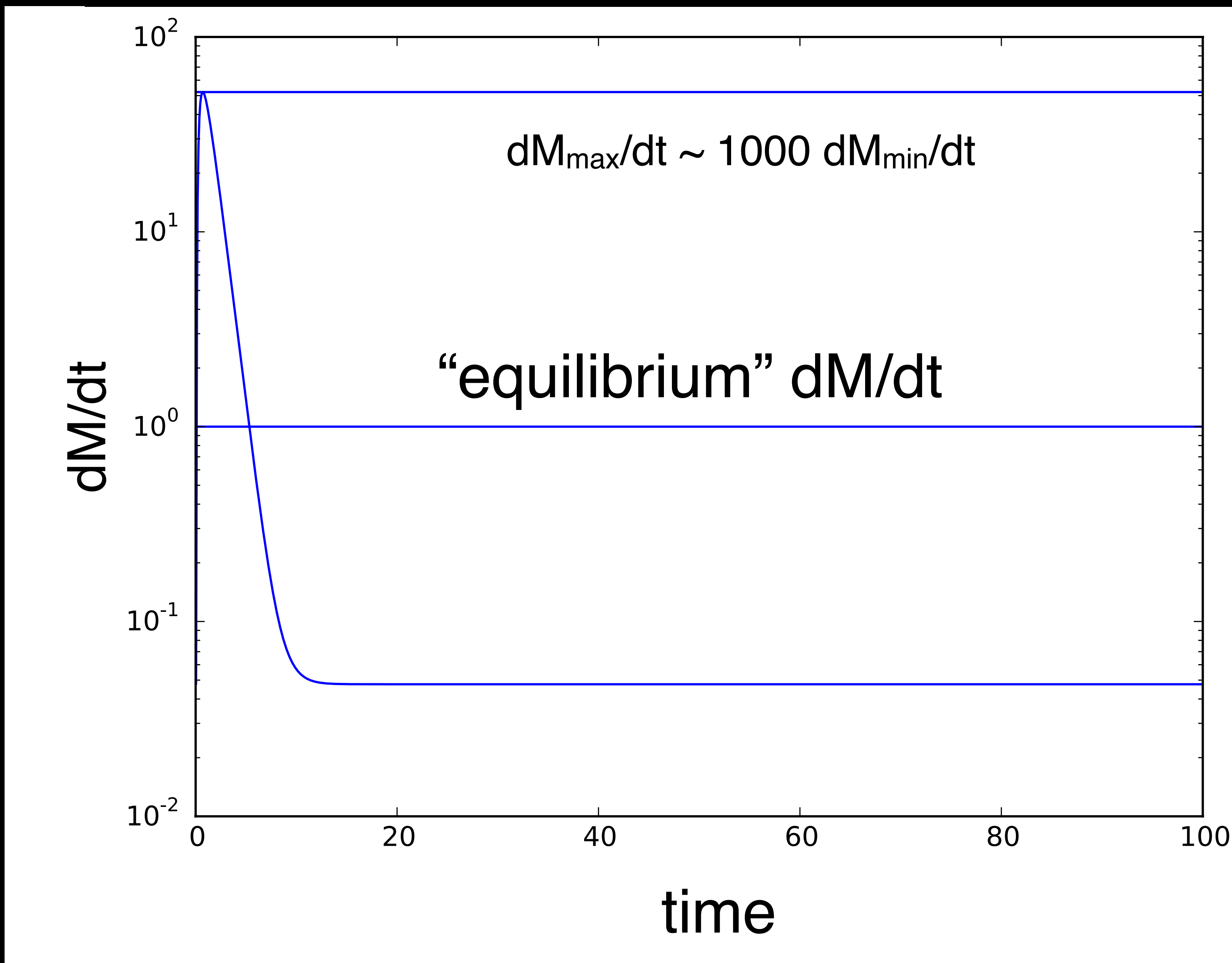
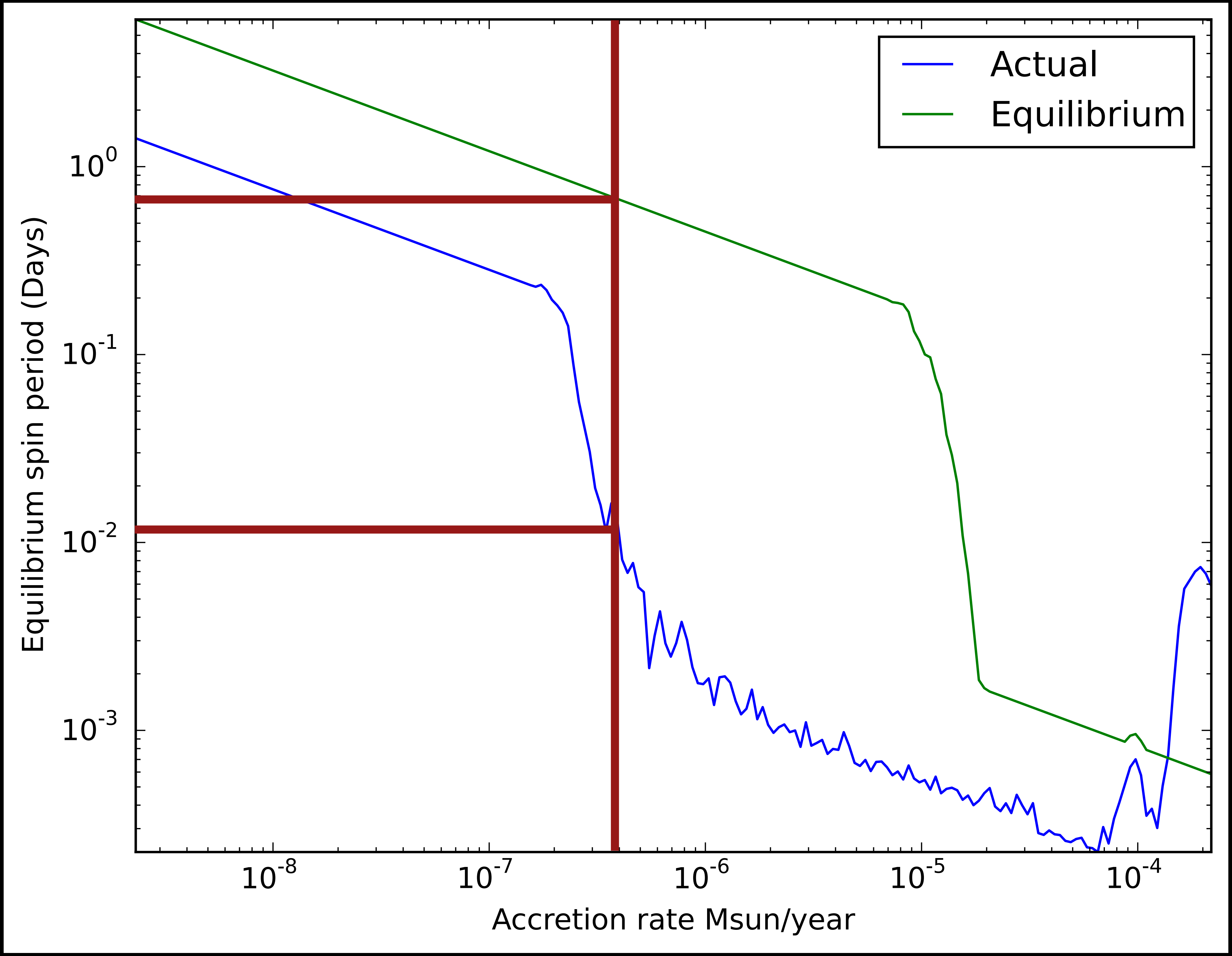


Track spin change over time for outbursting YSO

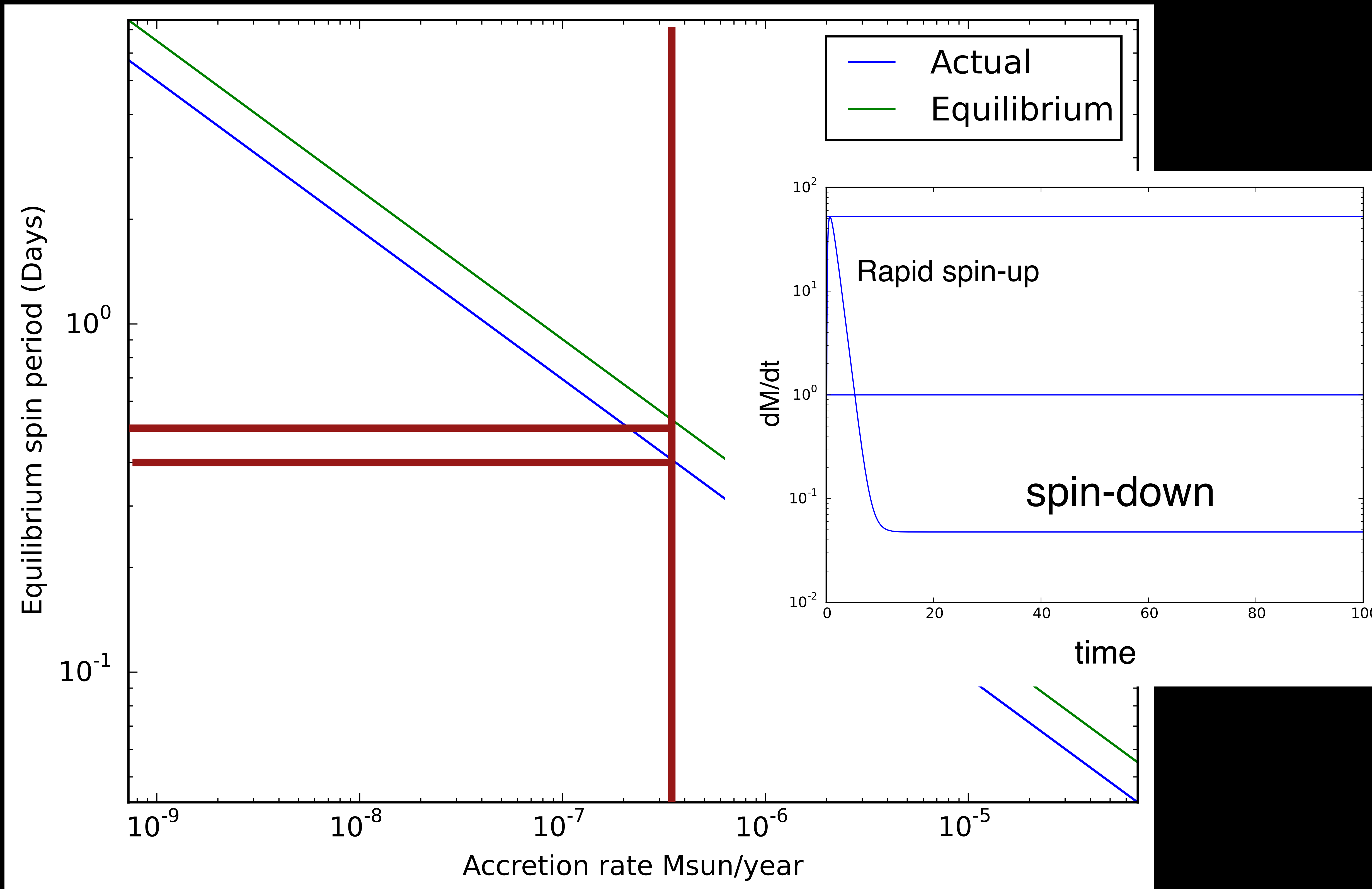


- $B \sim 1500$ G, $M \sim 0.5\ M_{sun}$
- Calculate spin change for different average accretion rates and spin-regulation models
- Consider effect of outbursts on spin evolution
- Evolve star to 'spin equilibrium' for different accretion rates

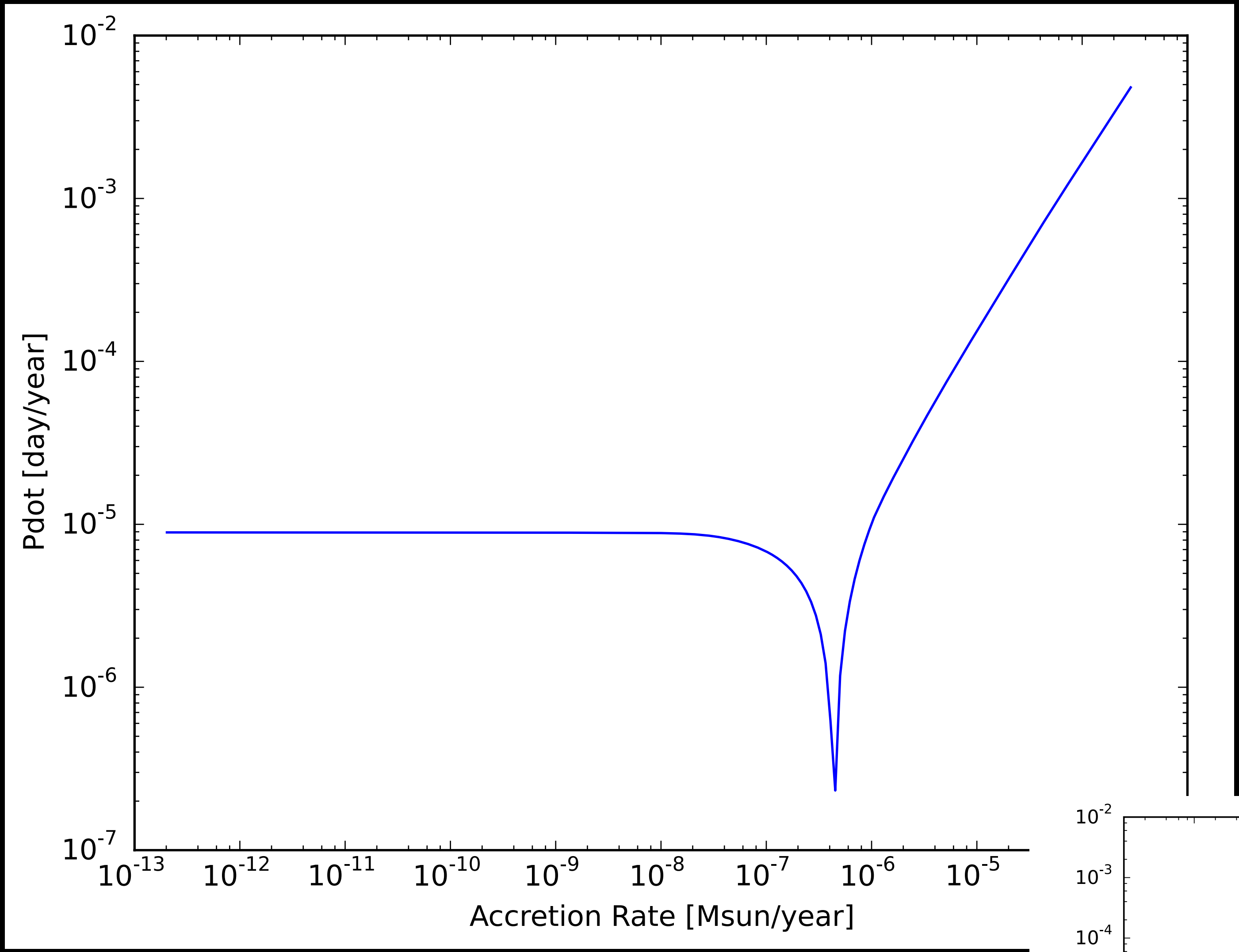
Strong propeller: inefficient spin down

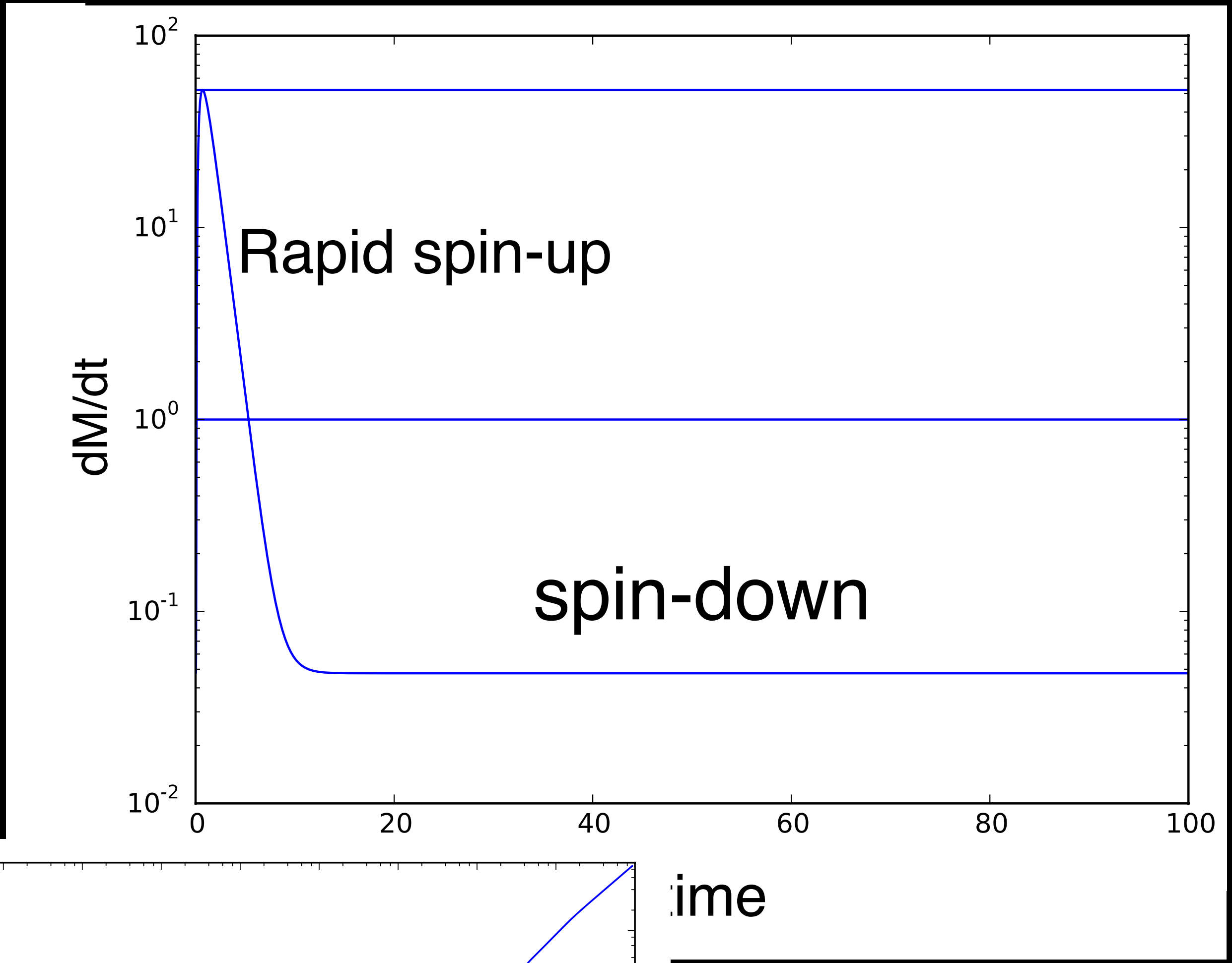


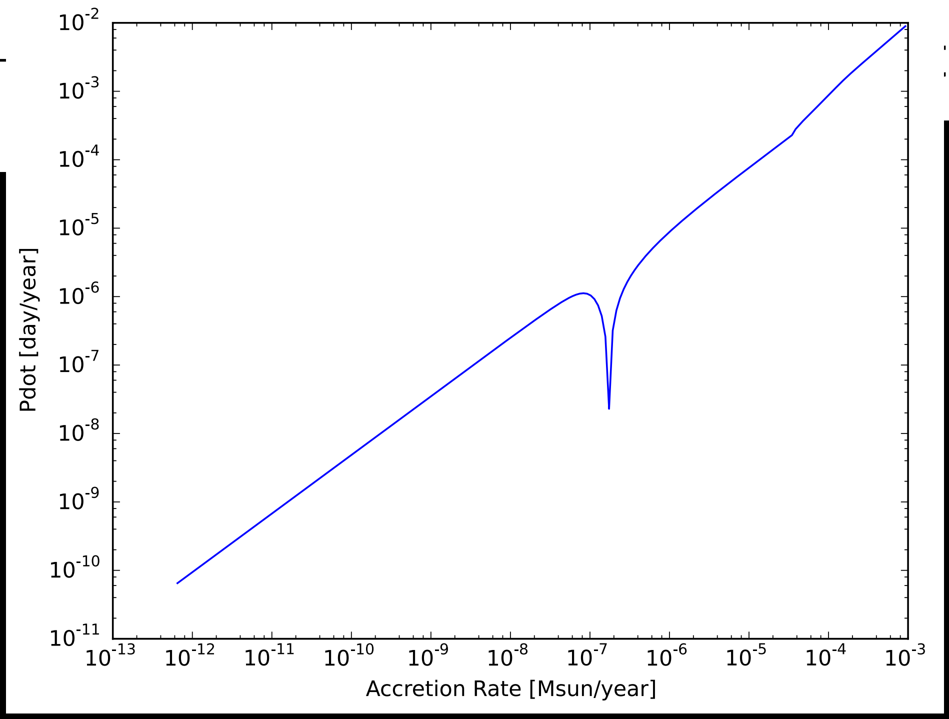
Trapped Disc: Efficient spin down



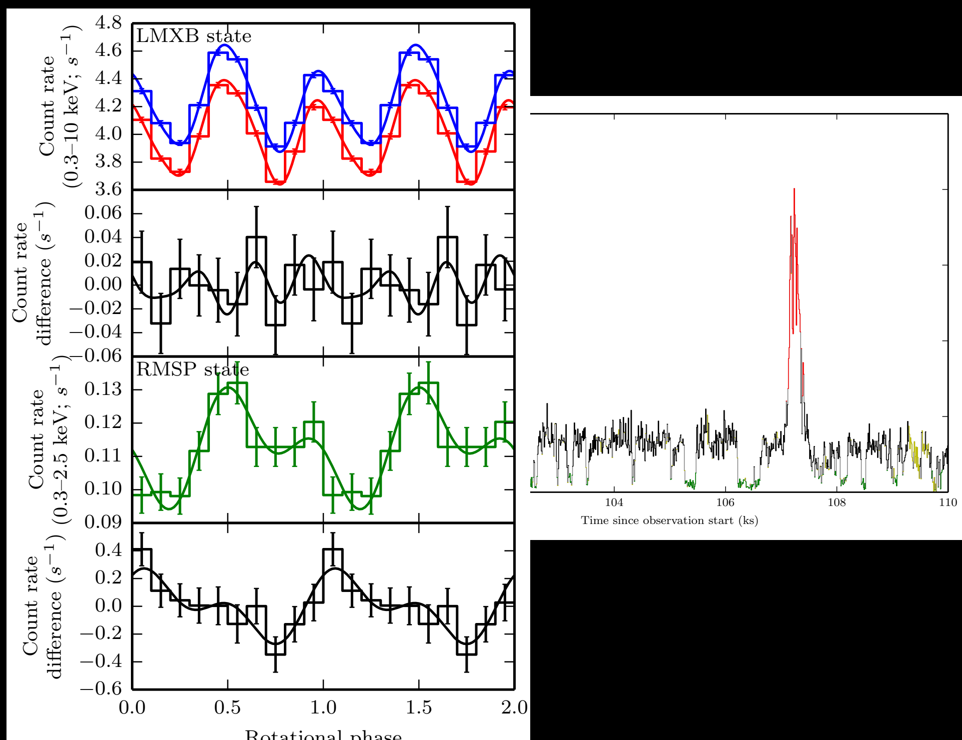
Spin regulation in trapped disc







Summary



Studying spin regulation in neutron stars can also shed light on young stars

Faint star J1023 does *not* have a strong propeller

Strong changes in accretion rate (FU Ori-type events) can strongly influence spin change, depending on spin model — may be able to use to distinguish spin-down mechanism