Lense-Thirring precession around black holes

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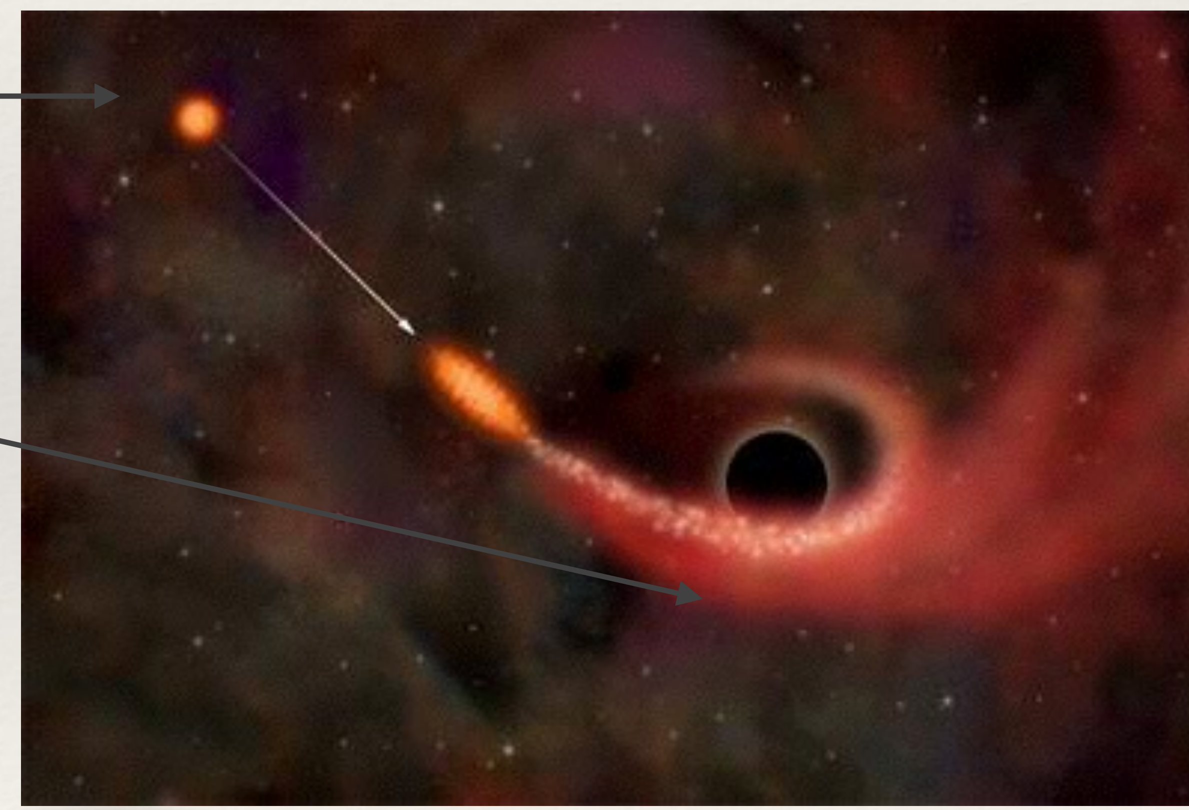
Tidal Disruption Events (TDEs)

Star wanders close enough to a SMBH to be torn apart by its tidal field (Rees 1988). Tidal radius:

$$r_\mathrm{t} \approx 0.47\,\mathrm{au}\,(M_6/m_*)^{1/3} x_*$$

Impact parameter $\beta = r_\mathrm{t}/r_\mathrm{p} \gtrsim 1$ → disruption

star



stellar debris
coming back to pericentre after

$$t_\mathrm{min} \approx 41 M_6^{1/2} m_*^{-1} x_*^{3/2}\,\mathrm{d}$$

$$\dot{M}_\mathrm{fb} = \dot{M}_\mathrm{p} (t/t_\mathrm{min})^{-5/3}$$

TDE accretion disc

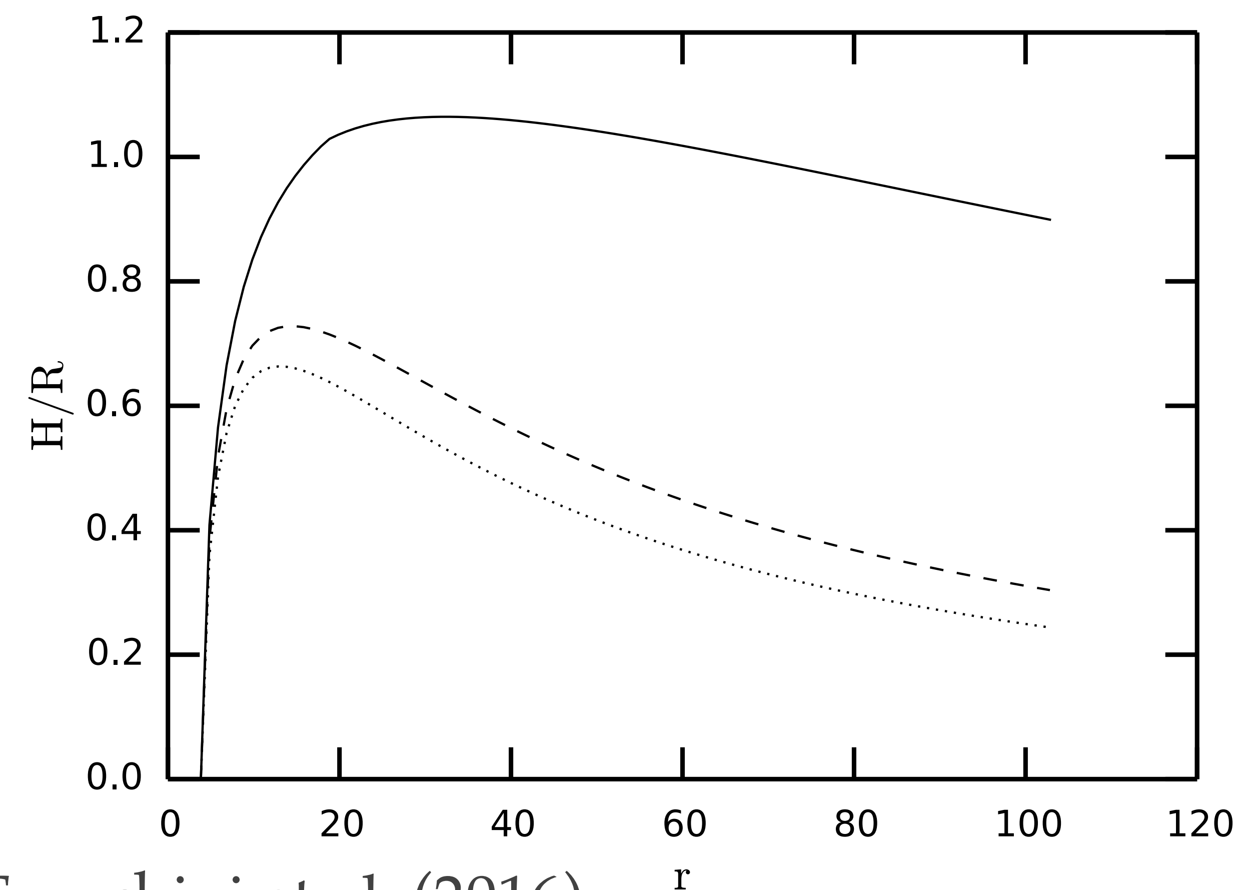
Stellar debris orbits circularize at $r_{\rm c} \simeq 2r_{\rm t}$ and form a **narrow** accretion disc that extends down to the Innermost Stable Circular Orbit

$$\frac{r_{\rm out}}{r_{\rm in}} = 94M_6^{-2/3} r_{\rm ISCO}^{-1} \longrightarrow$$

radiation pressure dominated

Super-Eddington accretion in the early phases $\dot{m} = \dot{M}/\dot{M}_{\rm Edd} > 1$
The disc then **hot** and thus **thick**

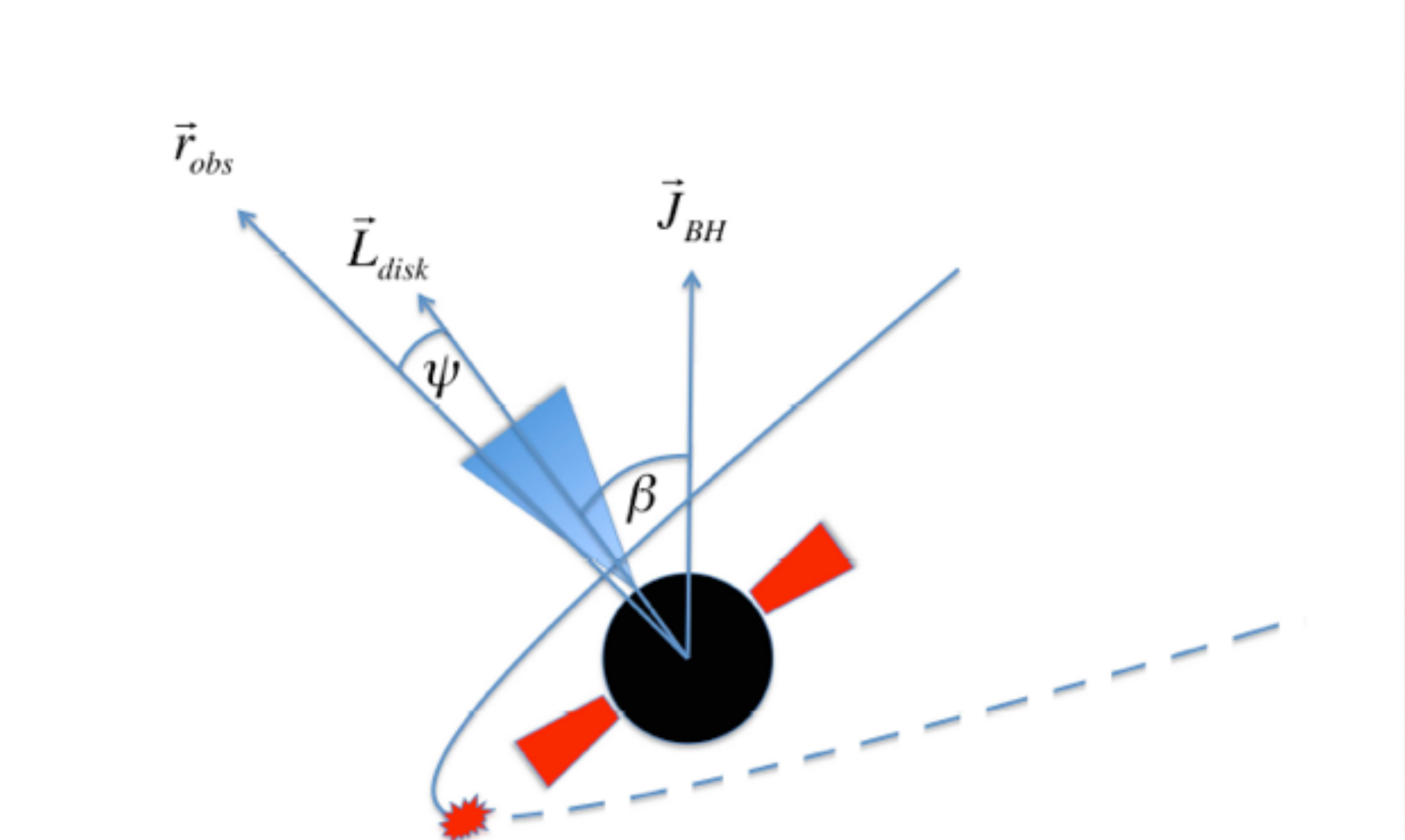
$$\frac{H}{R} \sim 1$$



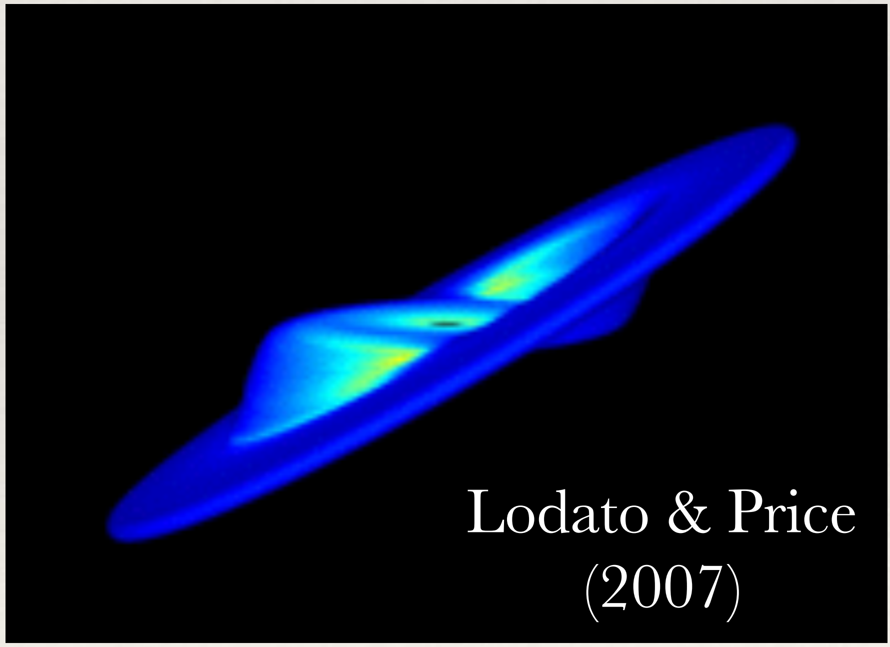
Franchini et al. (2016)

Lense-Thirring effect

Orbit inclined with respect to the black hole equatorial plane leads to the Lense-Thirring (nodal) precession of the orbit around the central object.
The Lense-Thirring precession frequency is $\Omega_{\rm LT} \propto R^{-3}$

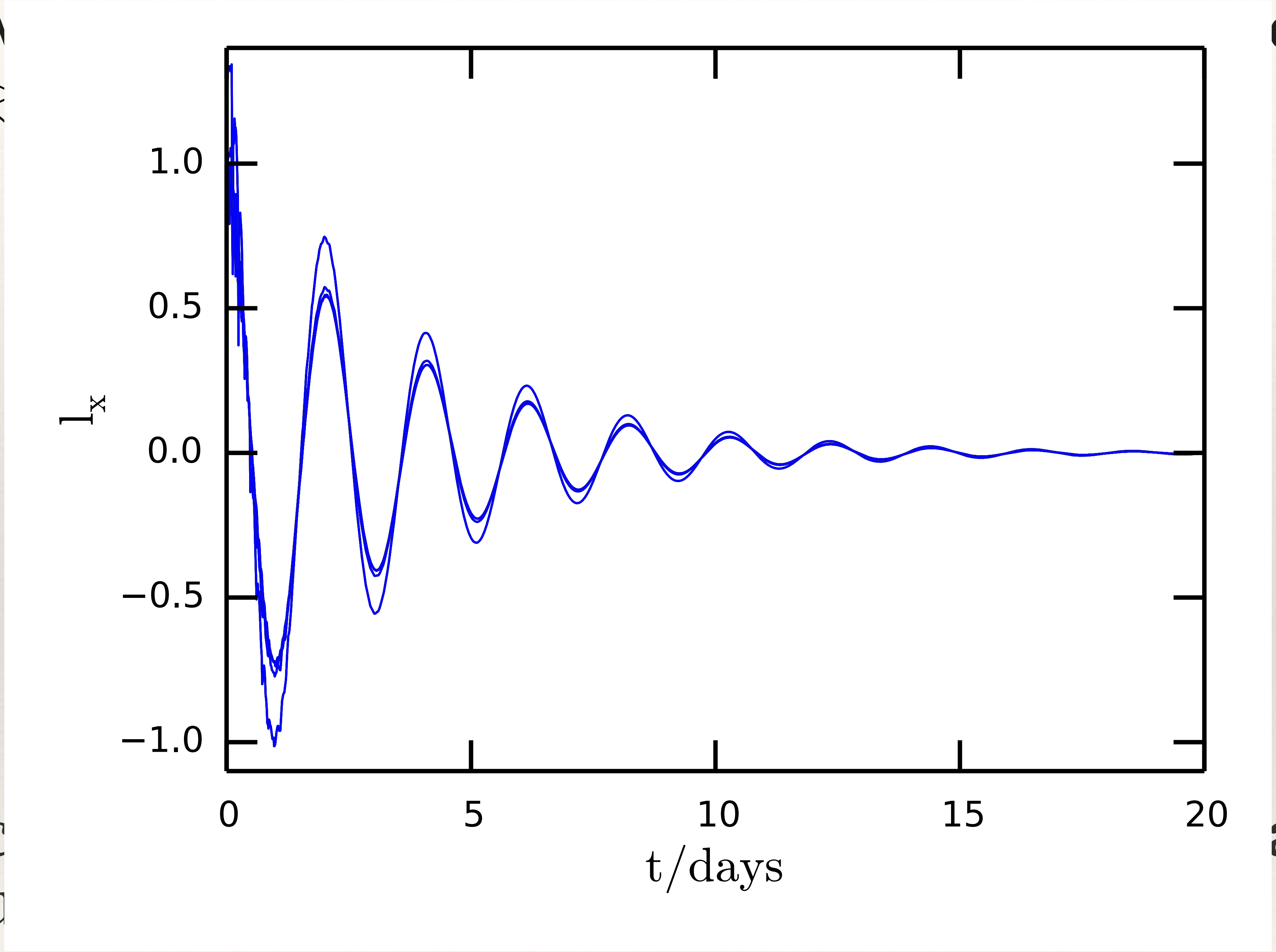


Stone & Loeb (2014)


Lodato & Price (2007)

Disc rigid precession

Bending w e a thick disc ($H/R \gtrsim$

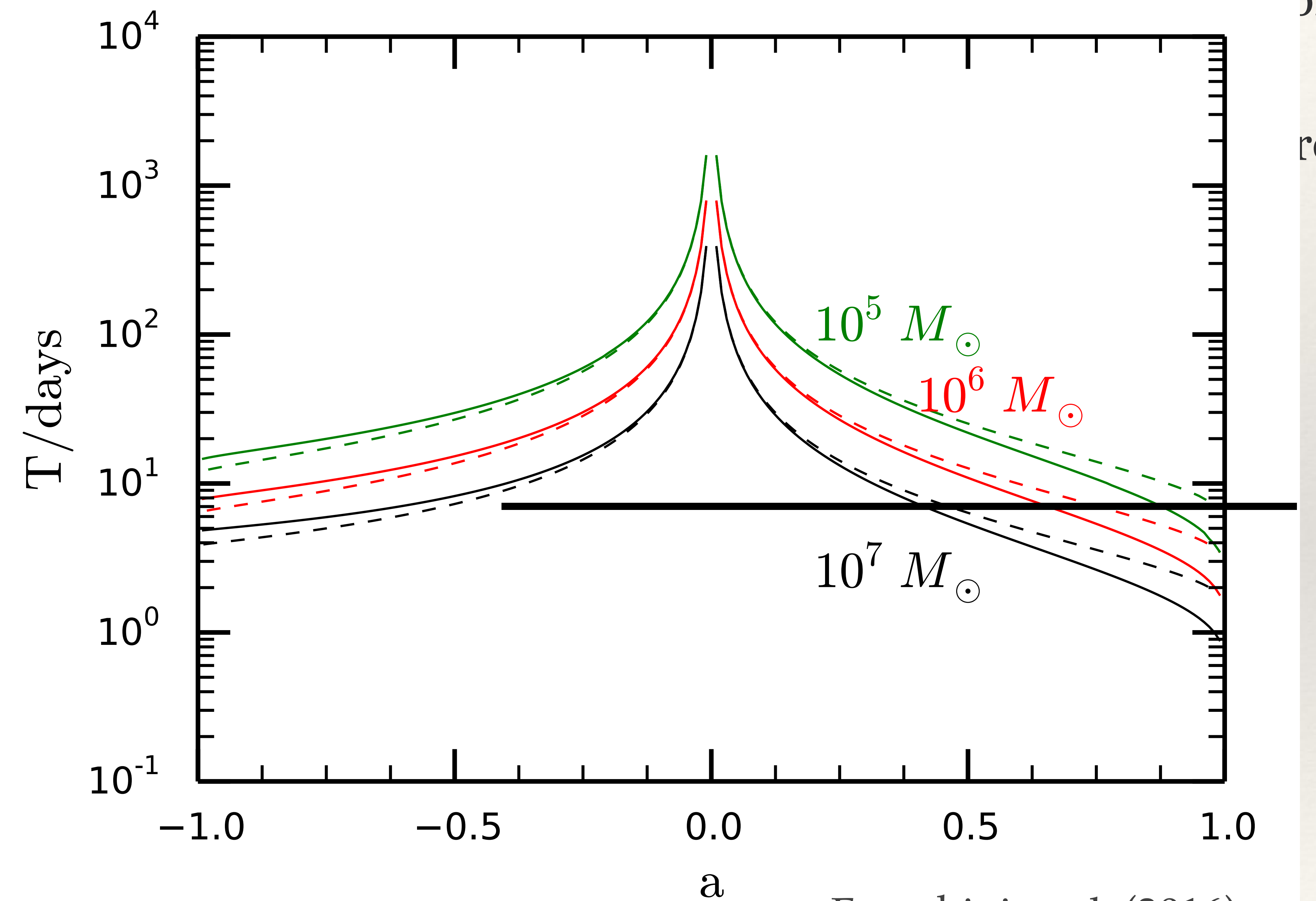


If the disc as a rigid body arou

TDE disc rigid precession period

Disc formed after a TDE can rigidly precess around the SMBH. This might lead to the preces[…] of the event.

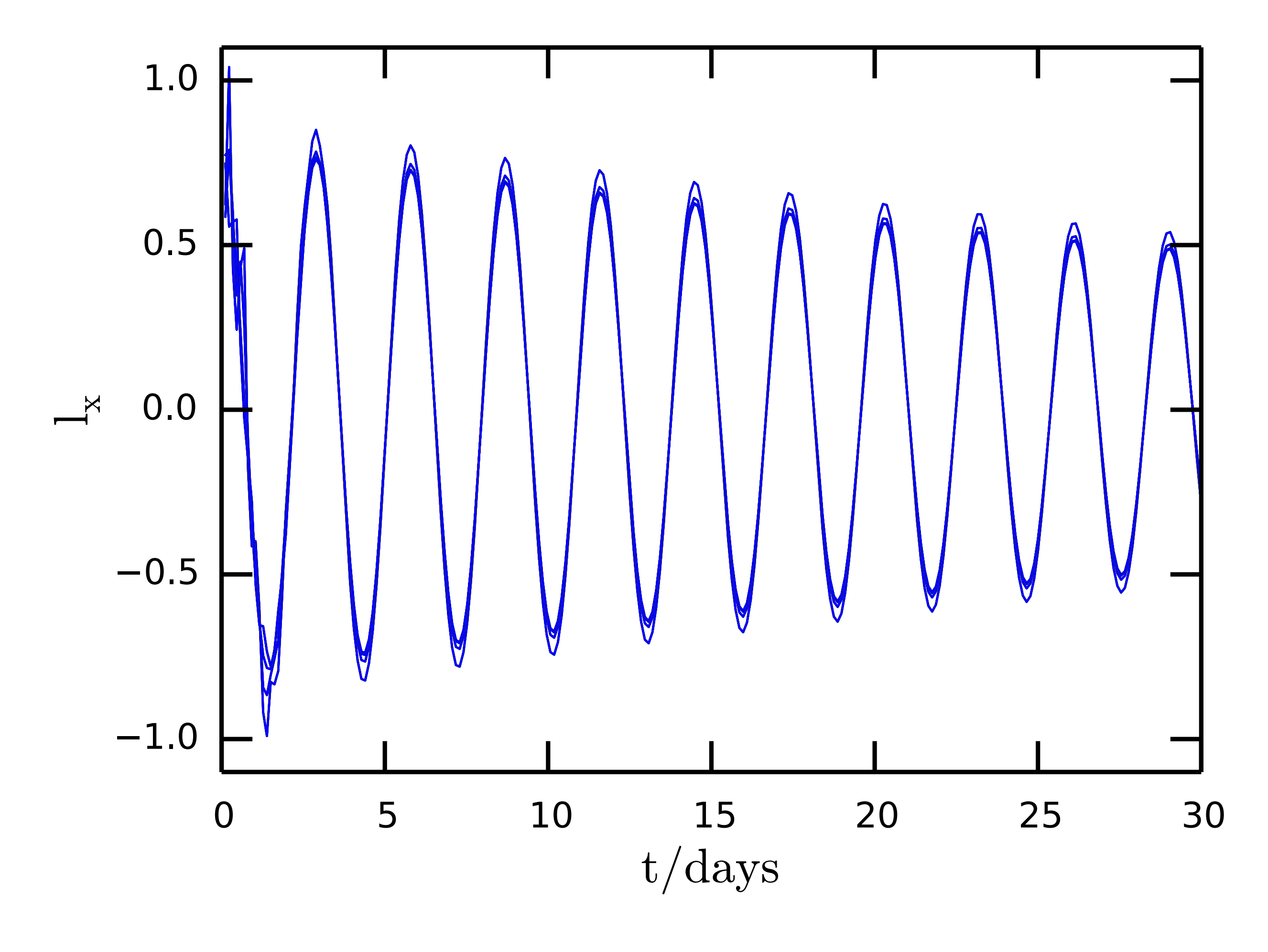
From the […] red.



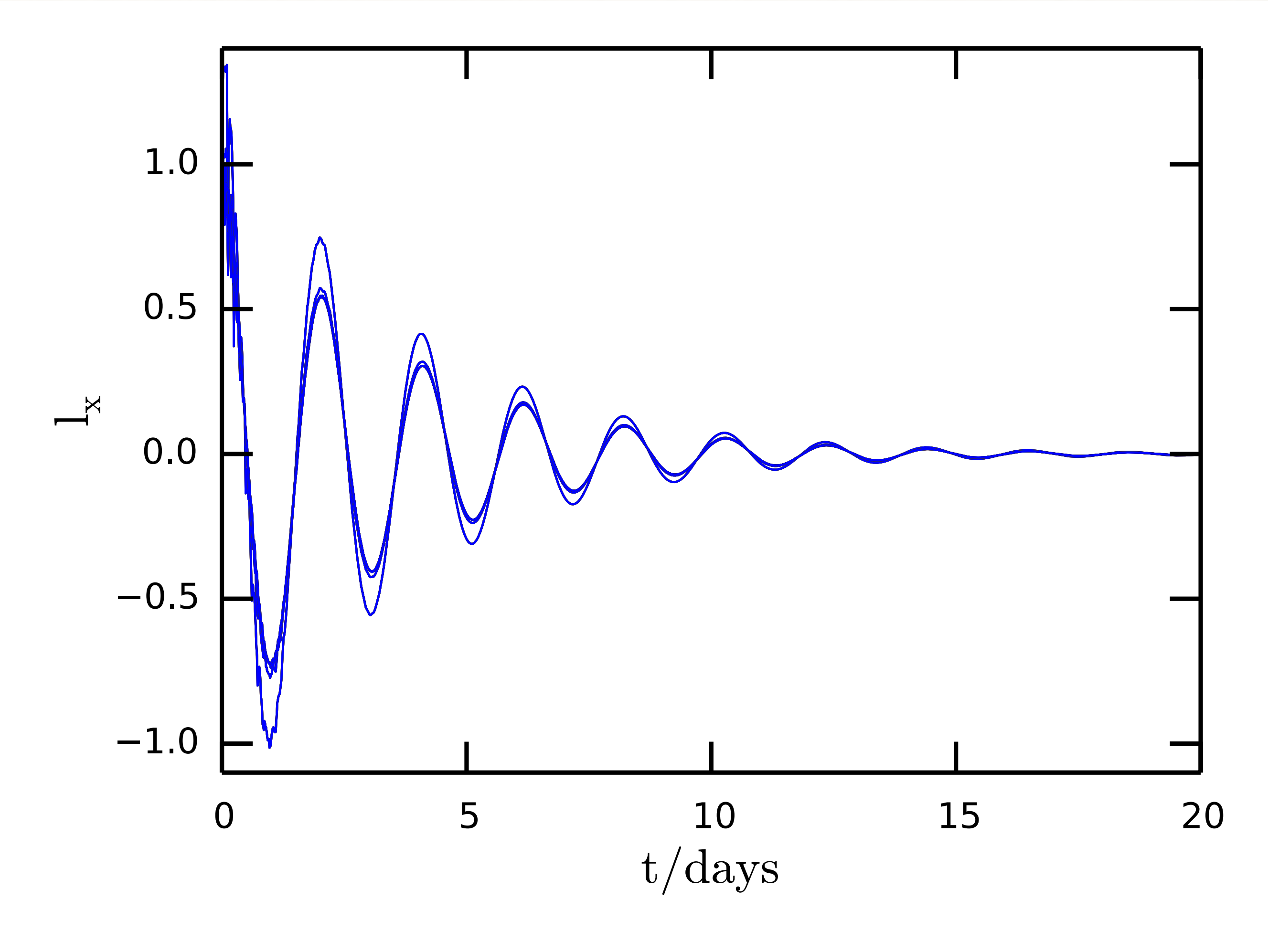
Franchini et al. (2016)

Alignment

$a = 0.7\, M = 10^7 M_\odot$

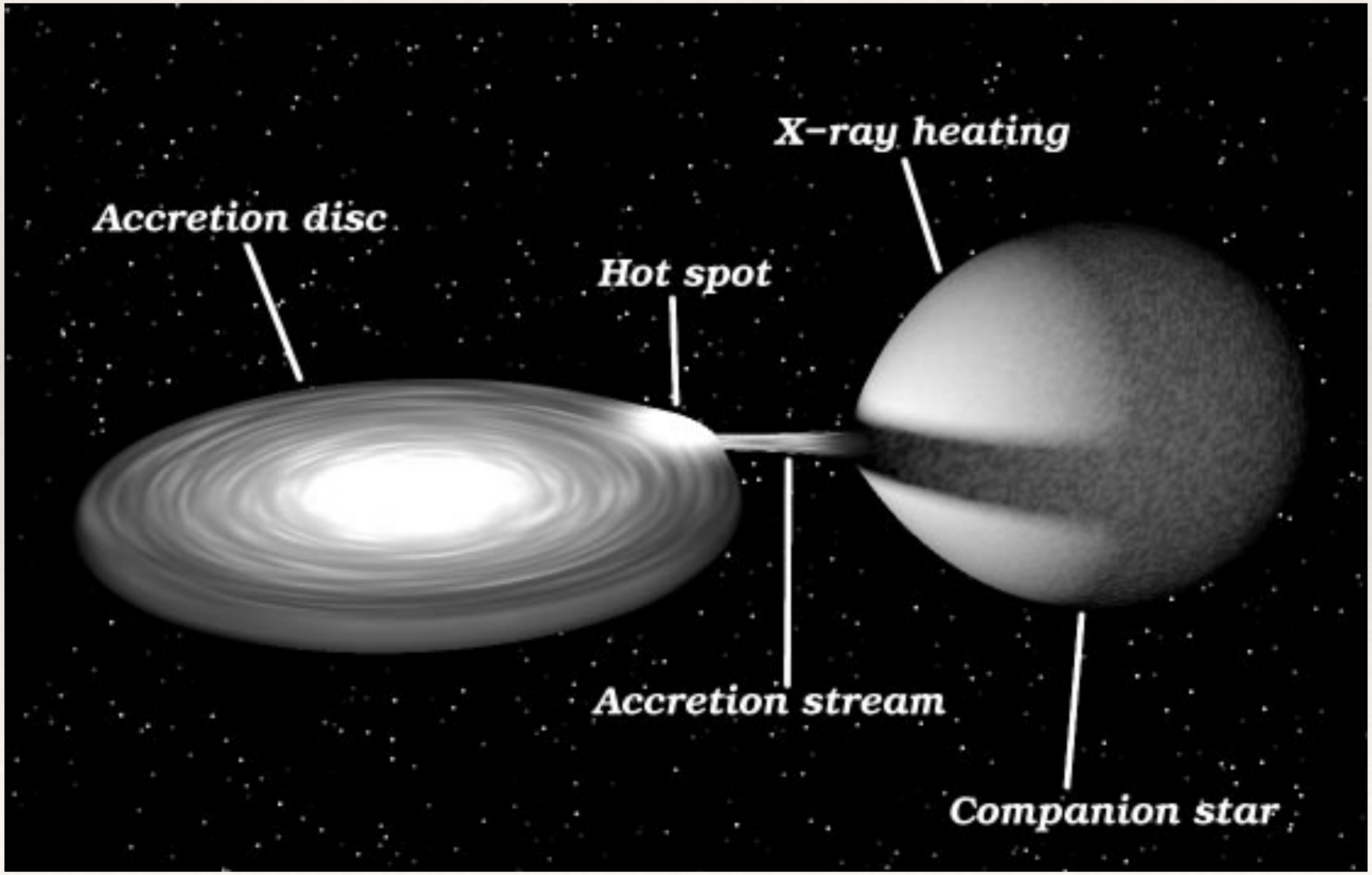


$a = 0.9\, M = 10^6 M_\odot$

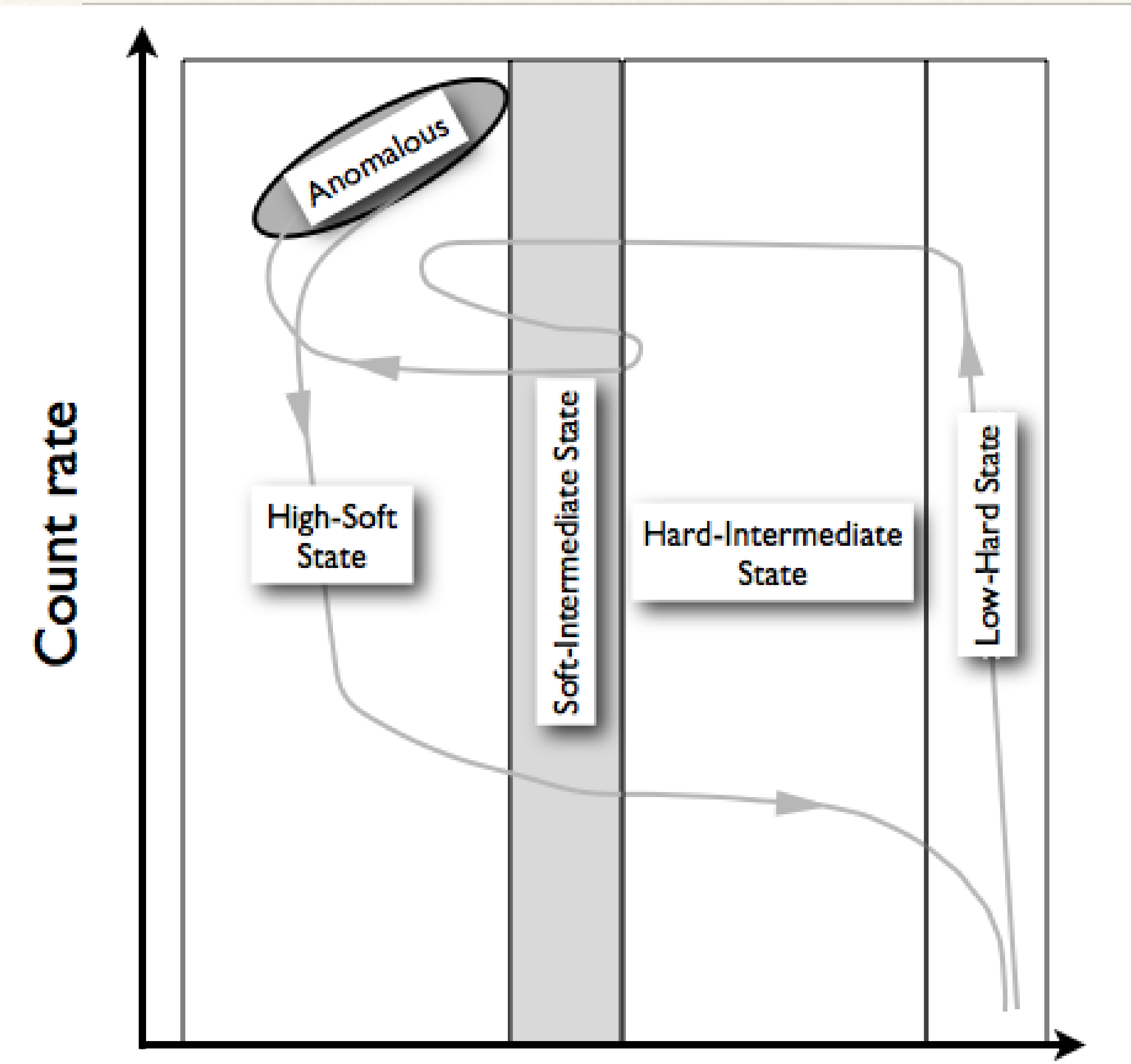


X-ray binaries

XRBs are double systems composed by a compact object that accretes matter from the companion through an accretion disc.
Transients systems: long quiescence and short outbursts (weeks to months).
Significant **variability on human accessible timescales**



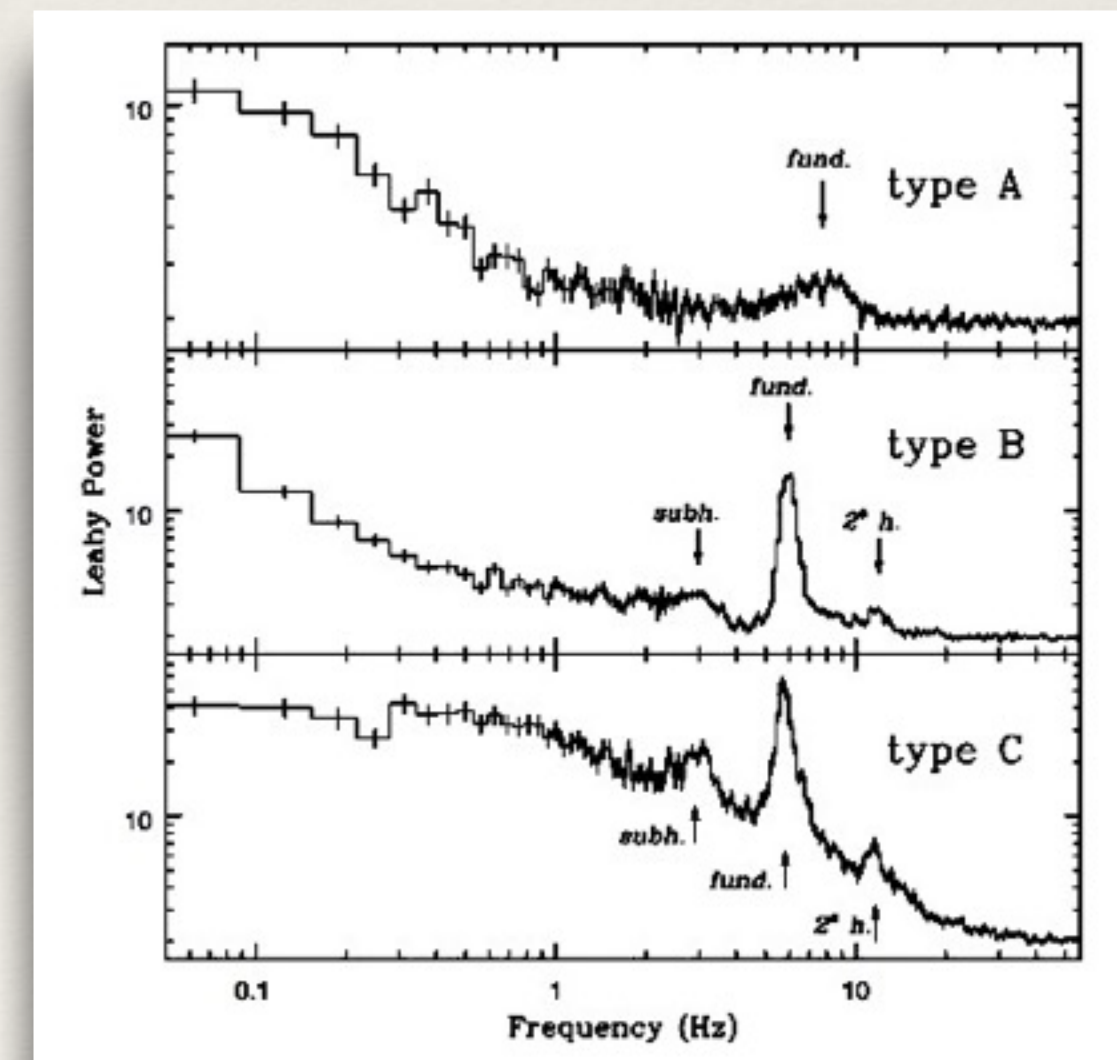
Low mass X-ray Binaries (LMXBs)



Homan et al. 2001

Classification through the analysis of the fast time variations in the power density spectra (PDS).

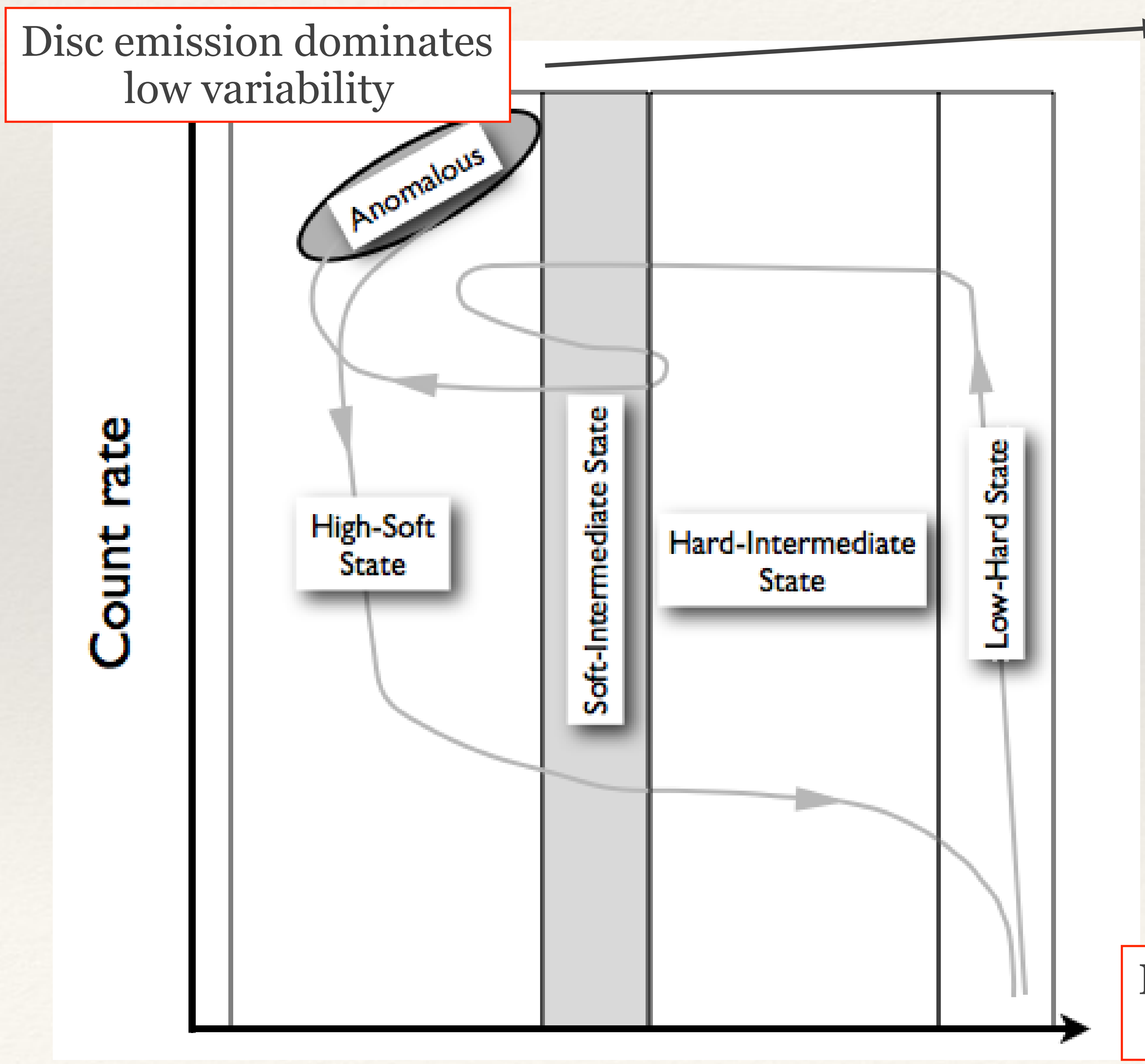
Quasi-periodic oscillation (QPO)
types (narrow peaks in the power spectrum)

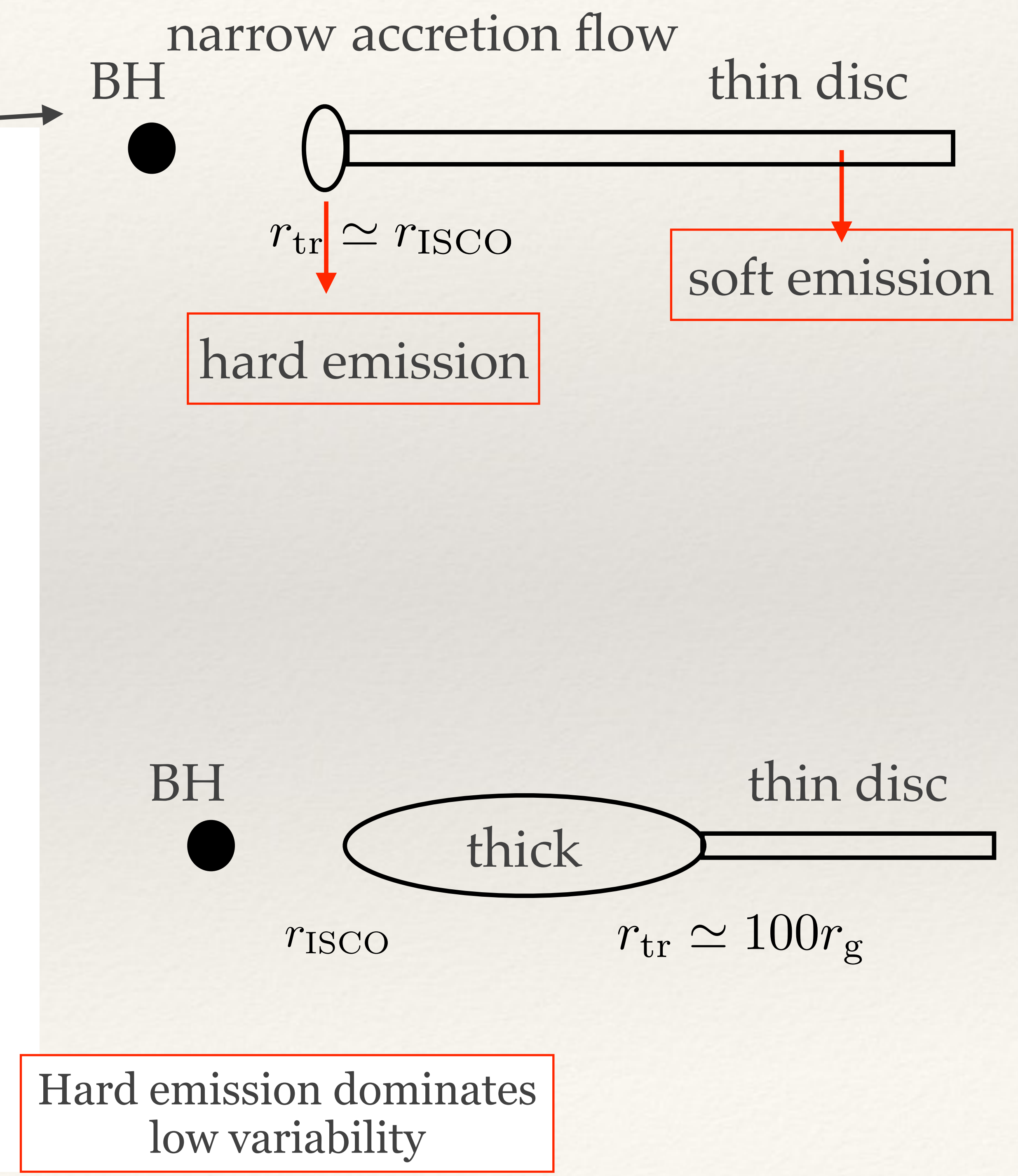


Motta et al. (2014)

The soft state

Emission dominated by a strong thermal component associated to an accretion disc whose inner radius reaches ISCO (innermost stable circular orbit). Very low variability.





The Relativistic Precession Model (RPM)

Test particle orbiting the black hole ⟶ relativistic effects involving the misalignment between the accretion flow and the BH spin. (Stella & Vietri 1998,1999, Ingram & Motta 2014)

$$\nu_\phi = \pm \frac{c^3}{2\pi GM} \frac{1}{r^{3/2} \pm a}$$

Keplerian frequency

upper HFQPO

$$\nu_{\rm per} = \nu_\phi \left[1 - \left(1 - 6r^{-1} \pm 8ar^{-3/2} - 3a^2r^{-2} \right)^{1/2} \right]$$

Periastron precession frequency

lower HFQPO

$$\nu_{\rm nod} = \nu_\phi \left[1 - \left(1 \mp 4ar^{-3/2} + 3a^2r^{-2} \right)^{1/2} \right]$$

Lense-Thirring precession frequency

Type C QPO

- three frequencies
- two frequencies and an independent mass measurements
- **limits placed with at least one QPO at ISCO**

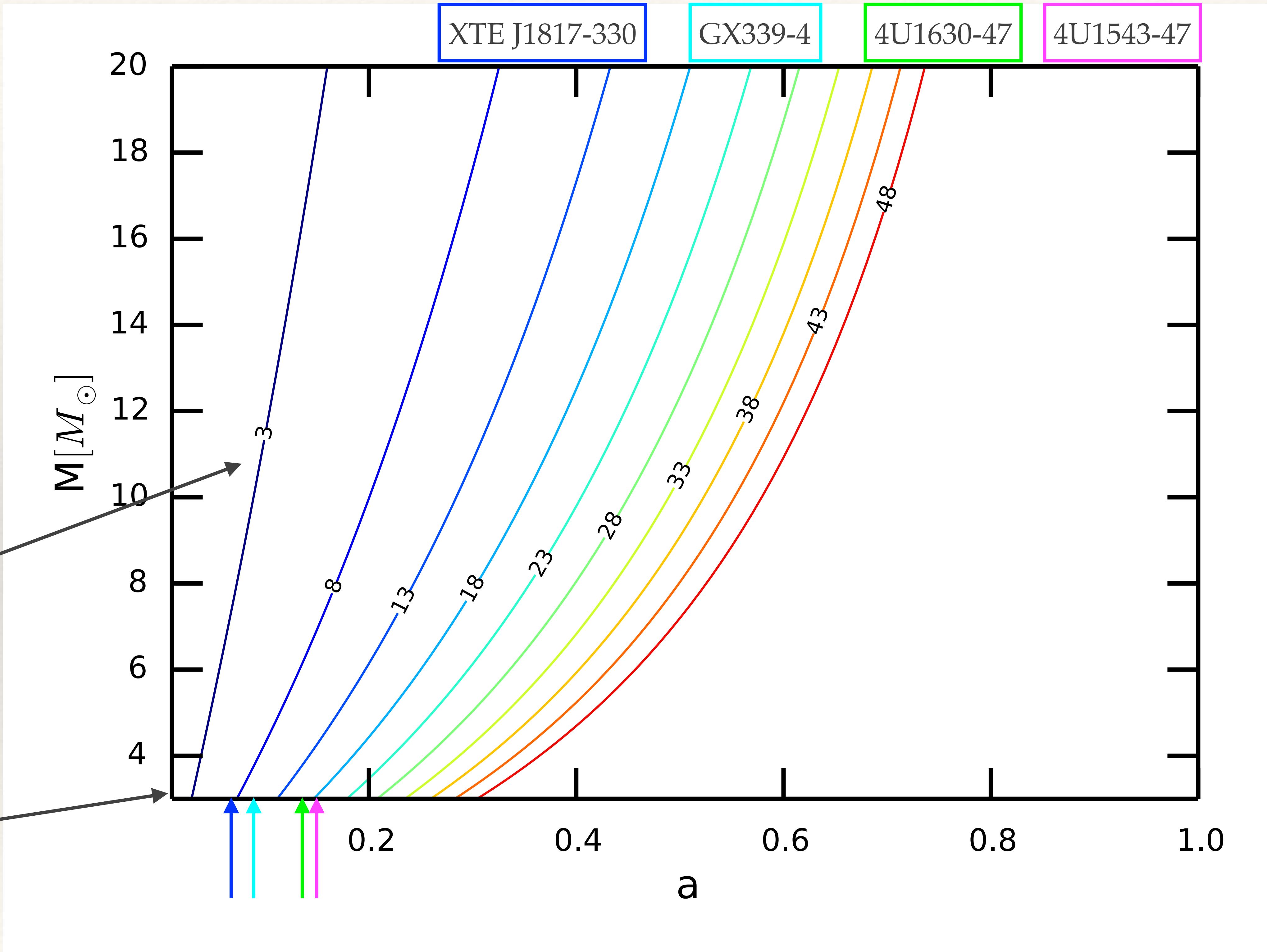
Placing spin limits

In the soft state we can
assume that the frequencies are those of a test particle at the ISCO

$$r = r_{\rm ISCO}$$

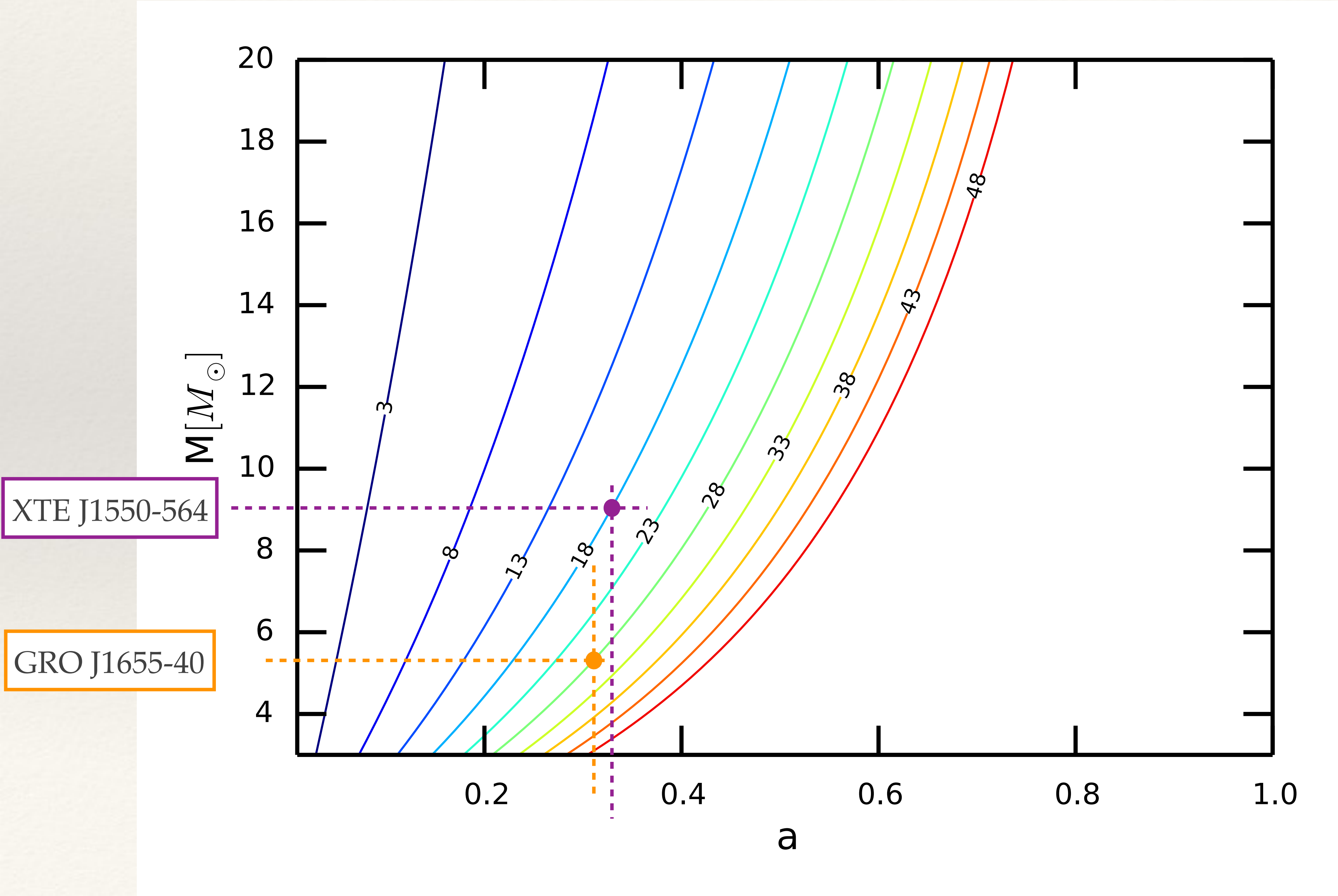
Type-C QPO highest frequency

$$M = 3M_{\odot}$$



With a dynamical mass estimate

For the sources XTE J1550-564 and GRO J1655-40 we have independent mass measurements (Motta et al. 2014a,b and references therein). Respectively $9.1 \pm 0.6 M_{\odot}$ and $5.4 \pm 0.3 M_{\odot}$.
——> very narrow spin range using the RPM at the ISCO.



Spin lower and upper limits

Target	ν_{max} (Hz)	New QPOs	HSS	spin limits
GX 339-4	10.6 ± 0.8	1	yes	0.16 - 0.38
4U 1630-47	14.8 ± 0.1	2	yes	0.12 - 0.46
4U 1543-47	15.37 ± 0.18	3	yes	0.13 - 0.47
XTE J1859+226	8.56 ± 0.06	0	no	0.07
XTE J1650-500	6.84 ± 0.05	0	no	0.06
XTE J1817-330	9.6 ± 0.2	1	yes	0.08 - 0.36
XTE J1748-288	31.55 ± 0.13	0	no	0.23
XTE J1752-223	6.46 ± 0.13	0	no	0.06
XTE J1550-564	18.10 ± 0.06	0	yes	0.31 - 0.34
MAXI J1543-564	5.72 ± 0.04	0	no	0.05
H1743-322	9.44 ± 0.02	0	no	0.08
GRO J1655-40	27.51 ± 0.13	1	yes	0.28 - 0.32

If the highest type-C QPO was detected in the HSS, we can place both lower and upper limits on the spin because in this state the accretion disc extends down to or close to the ISCO.

If the highest type-C QPO was NOT detected in the HSS, we can place only a conservative lower limit.

Table 1. Spin limits inferred from the highest frequency type-C QPO at ISCO according to the RPM. Both limits are evaluated assuming a black hole mass in the range $3 - 20 M_\odot$. In the case of GX339-4 the lower limit corresponds to $6 M_\odot$. For XTE J1550-564 and GRO J1655-40 the limits correspond to the measured masses $9.1 \pm 0.6 M_\odot$ and $5.4 \pm 0.3 M_\odot$ respectively (Muñoz Darias et al. 2010; Motta et al. 2014a,b). The third columns is the number of new QPOs found in this work and the fourth indicates whether the highest type-C QPO has been detected in the HSS or not. The last column contains the spin limits.

Franchini et al. (2016, submitted)

Summary

Tidal disruption events:

- The Lense-Thirring effect can be used to *infer the SMBH spin value from the rigid precession period of TDE discs.*
- The estimate of the alignment timescale allows to break the degeneracy in mass and spin values

Low mass X-ray Binaries:

- Looking for type-C QPOs in the soft state
- Applying the Relativistic Precession Model assuming that the highest type-C QPO in the soft state is that of a test particle at the ISCO
- *Place limits on the BH spin assuming a conservative range of masses*