Why Lense-Thirring solid-body precession cannot produce the LFQPOs observed in X-ray binaries

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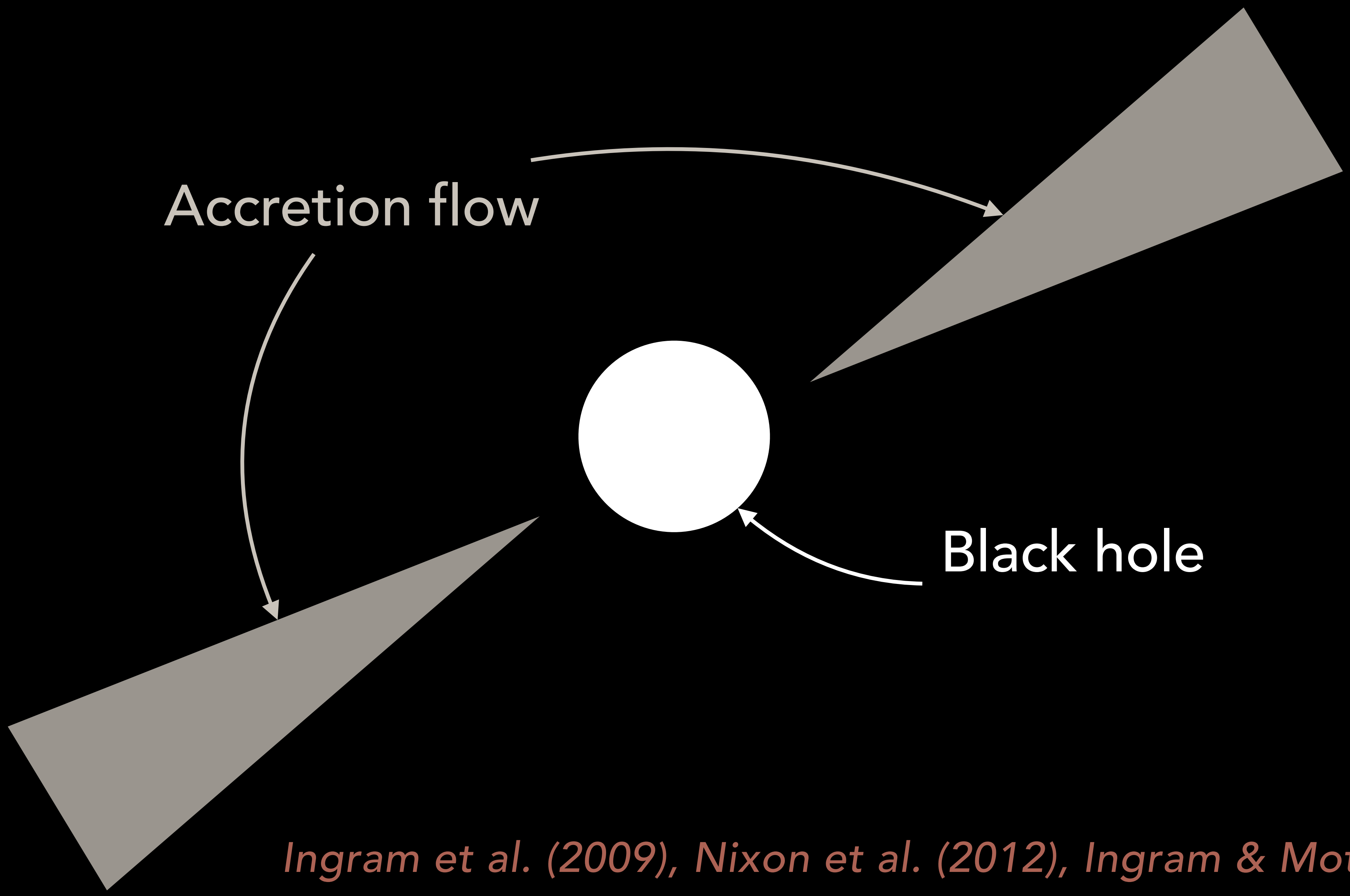
Collaborators: J. Ferreira, P.-O. Petrucci, J. Malzac, C. Reynolds, J. Neilsen, to name a few…

This work was in collaboration with J. Neilsen, see Marcel & Neilsen (2021)

Lense-Thirring precession 101



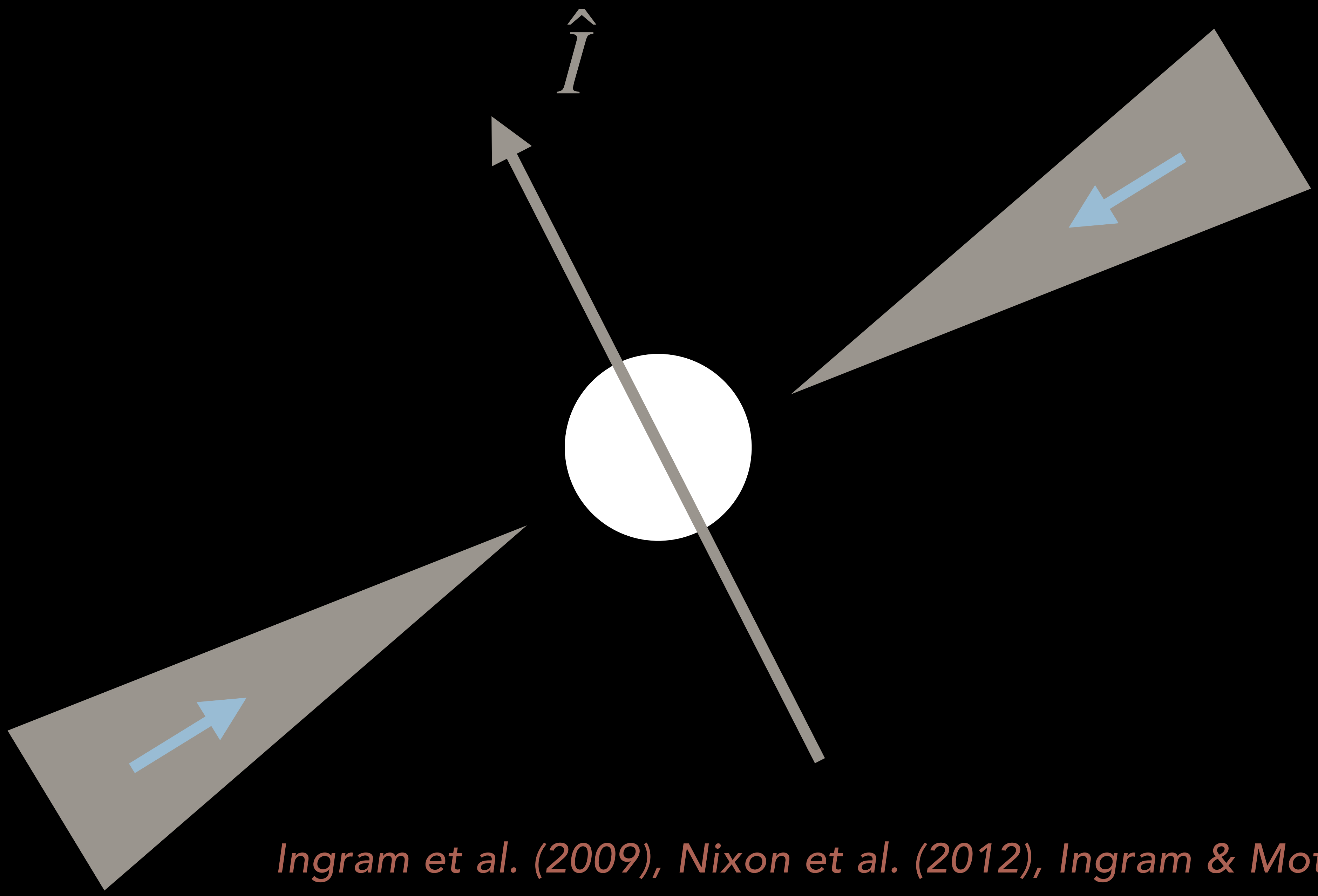
Ingram et al. (2009), Nixon et al. (2012), Ingram & Motta (2020)

Lense-Thirring precession 101

Viscous torque

$$G_\nu = -(2\pi R)\,\nu \Sigma R^2 \frac{\partial \Omega_\phi}{\partial R}$$

with $\nu = \alpha \Omega_\phi H^2$



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Lense-Thirring torque

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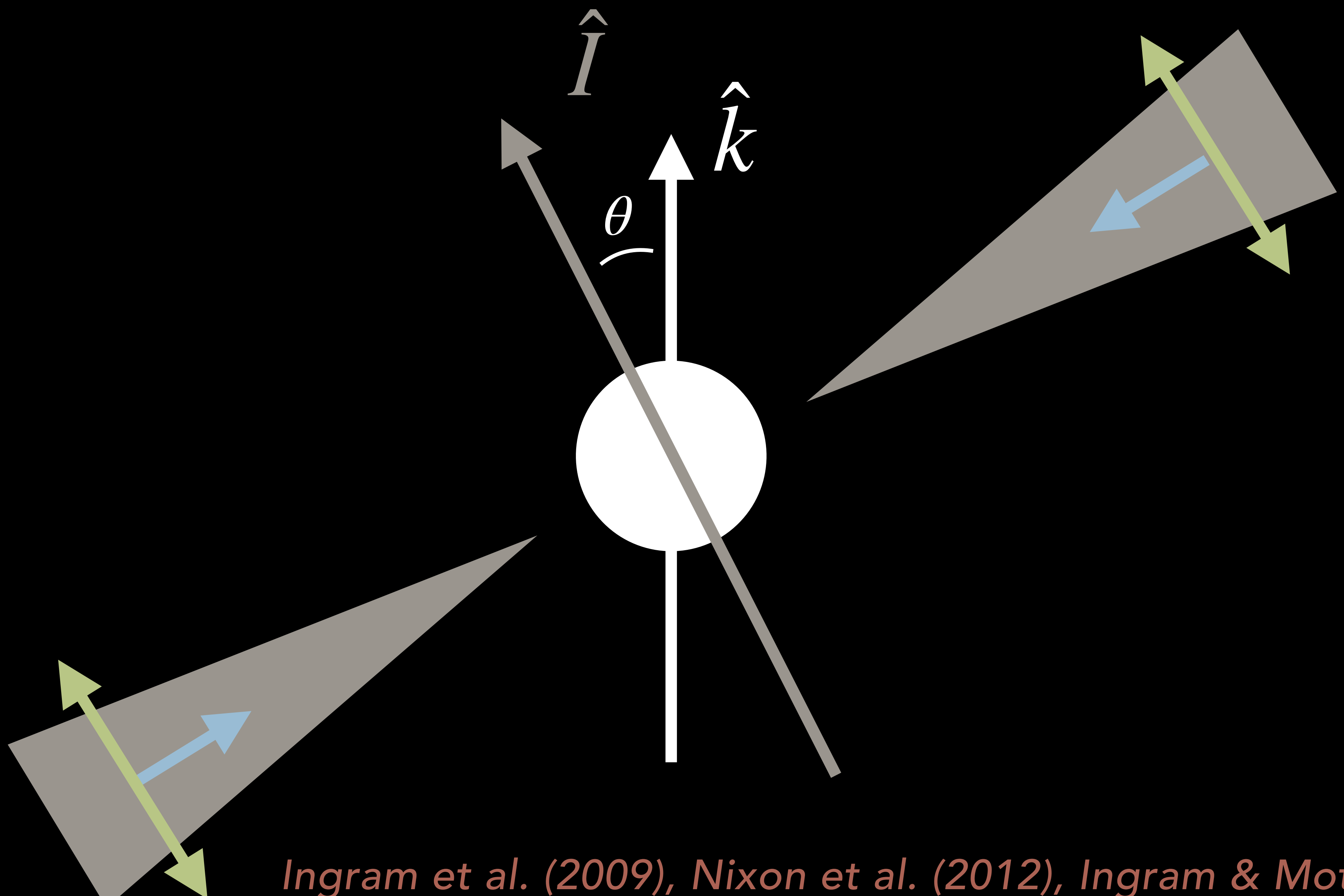

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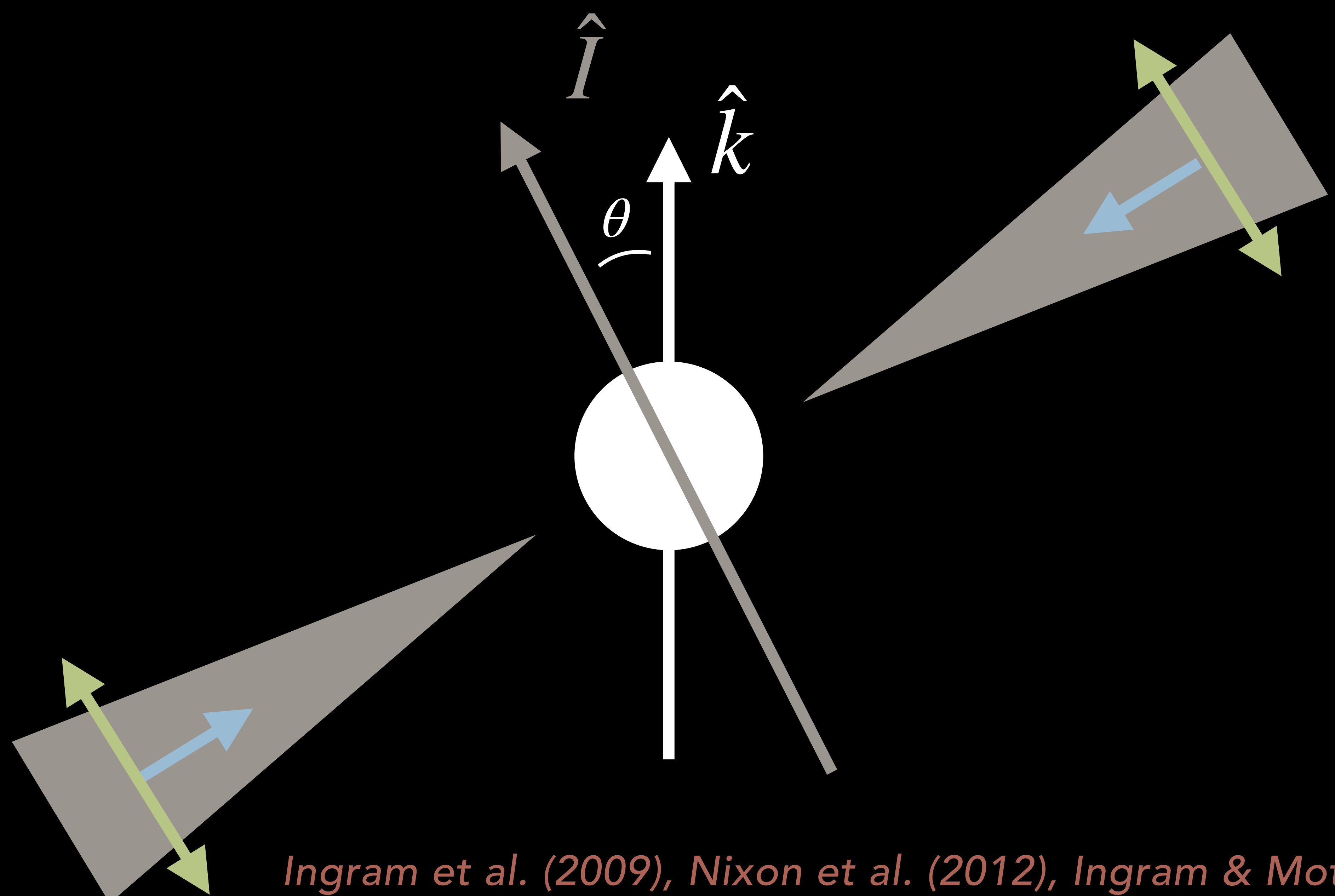

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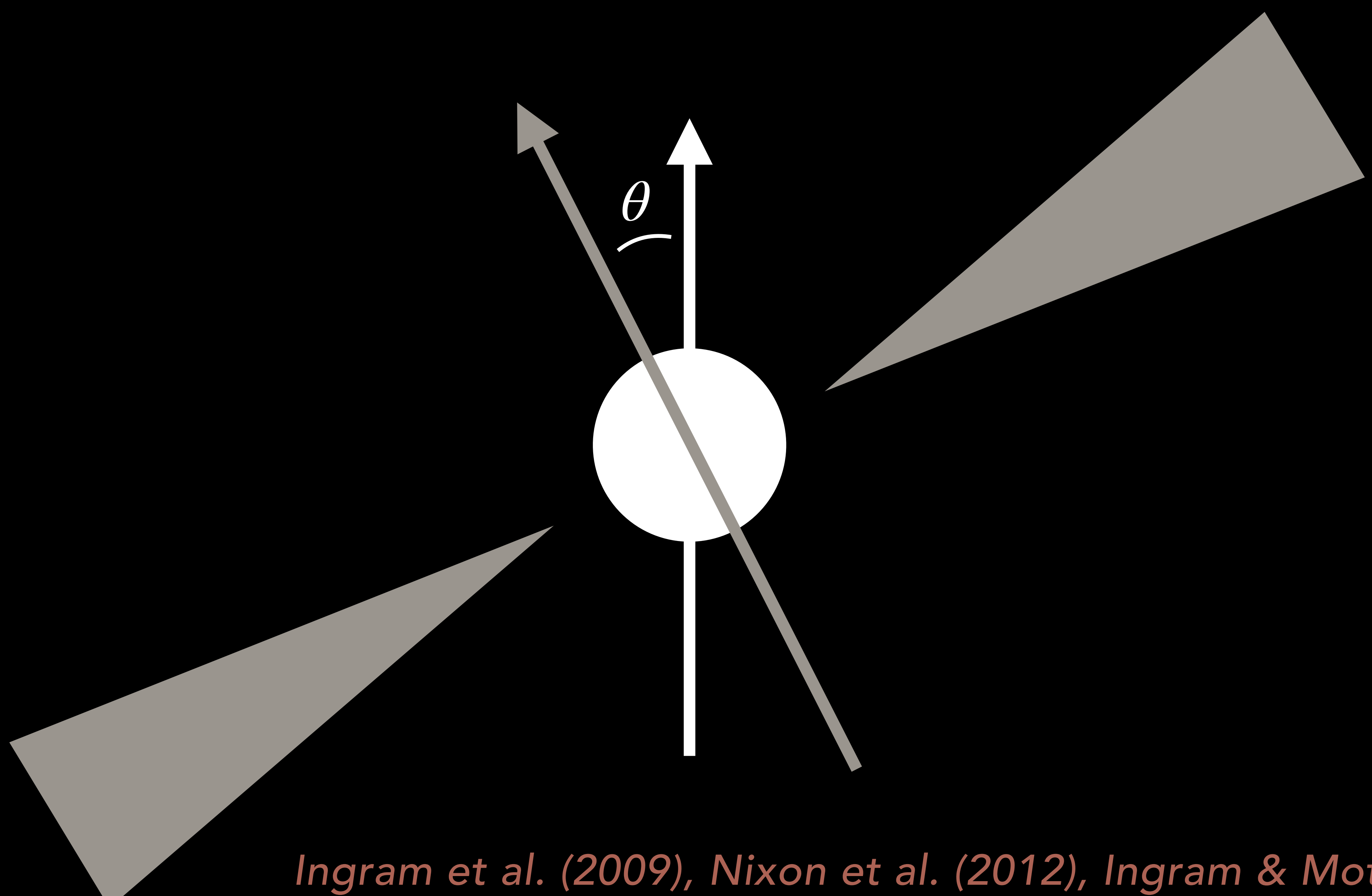
$$\frac{G_{LT}}{G_\nu} = \frac{4}{3} \frac{a\,|\sin(\theta)\,|}{\alpha\epsilon} (R/R_g)^{-3/2}$$



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Lense-Thirring precession 101

Black hole spin and inclination

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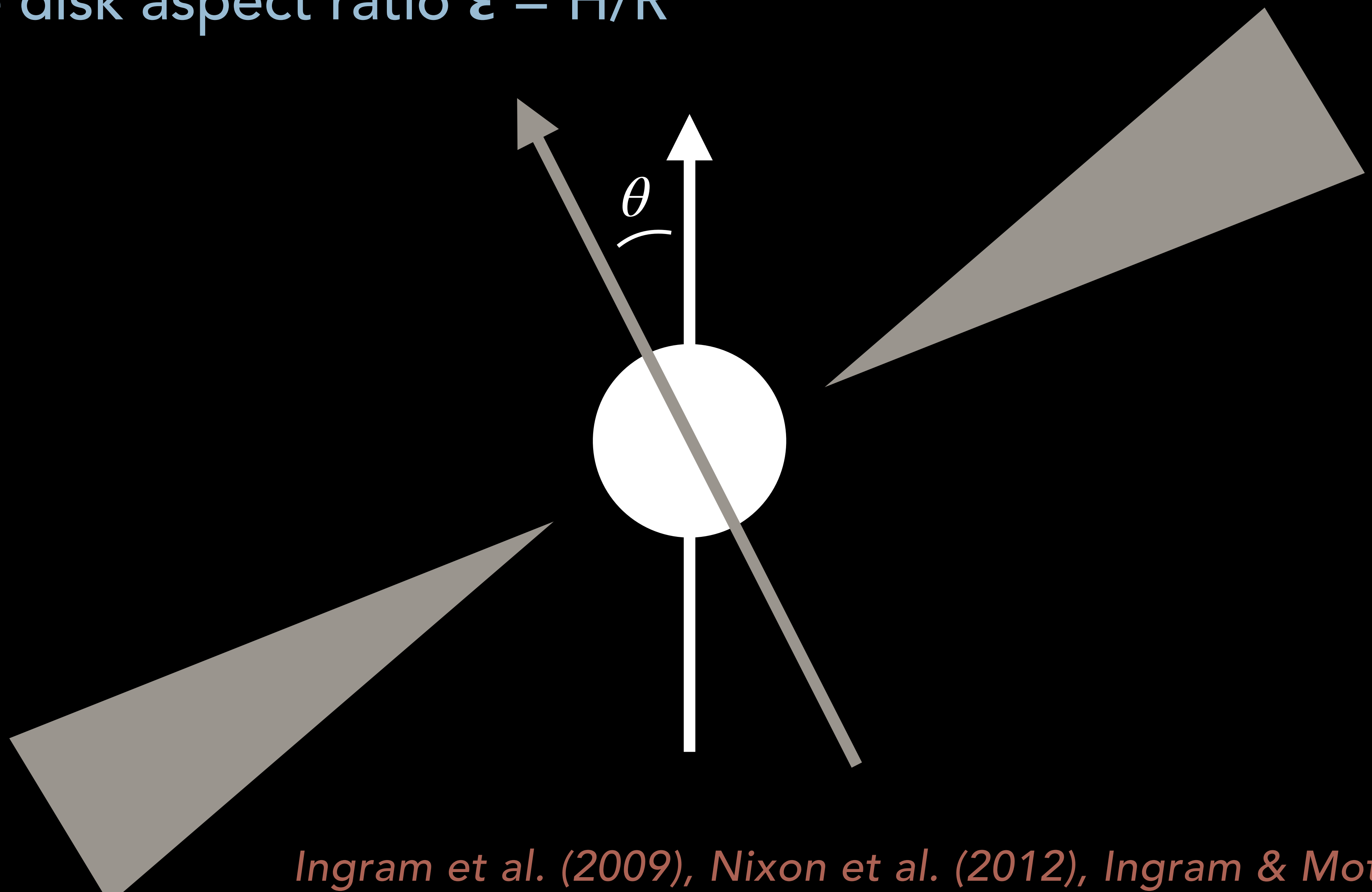
Depends on both the viscosity **α** and the disk aspect ratio **ε** = H/R



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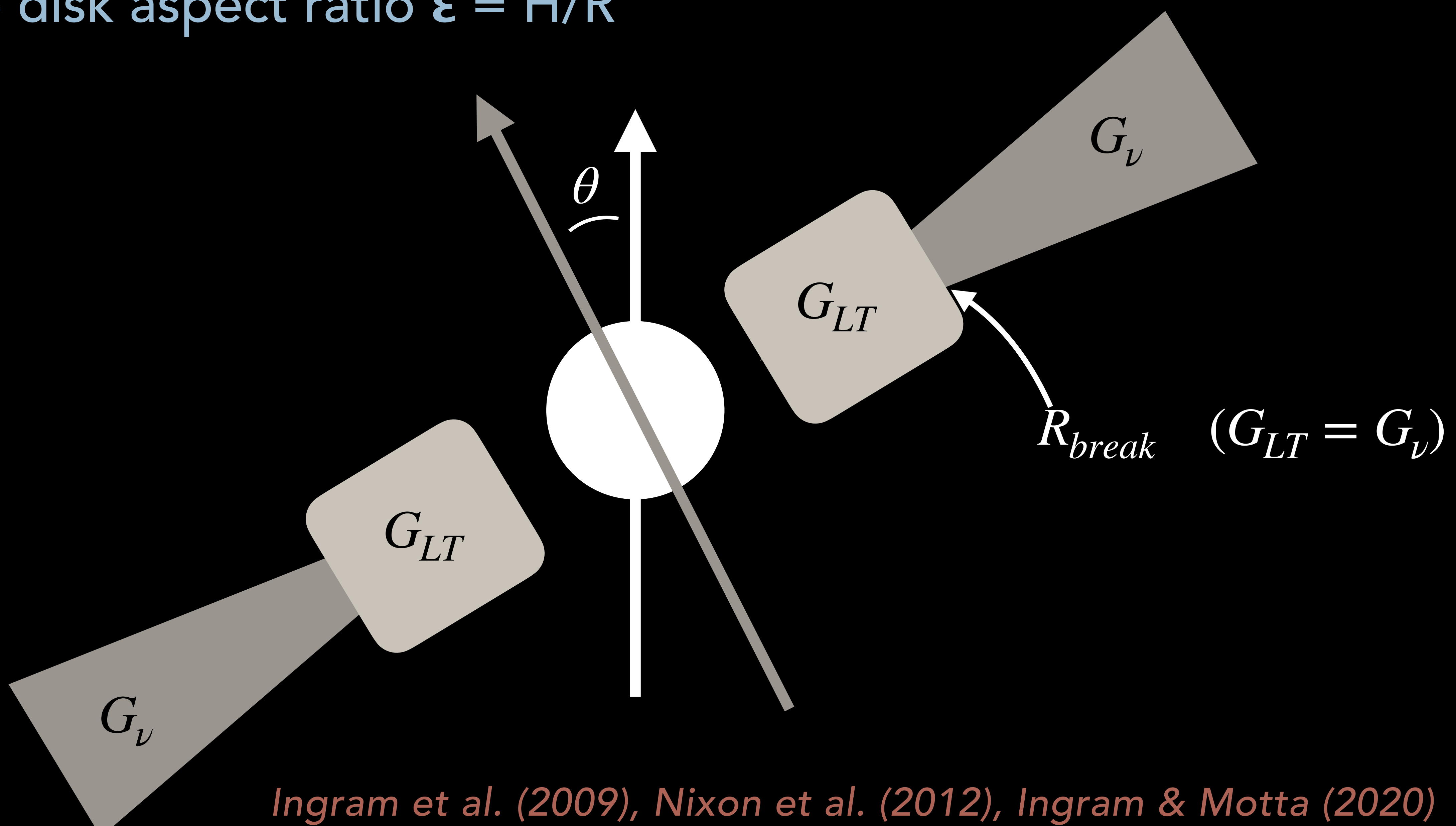

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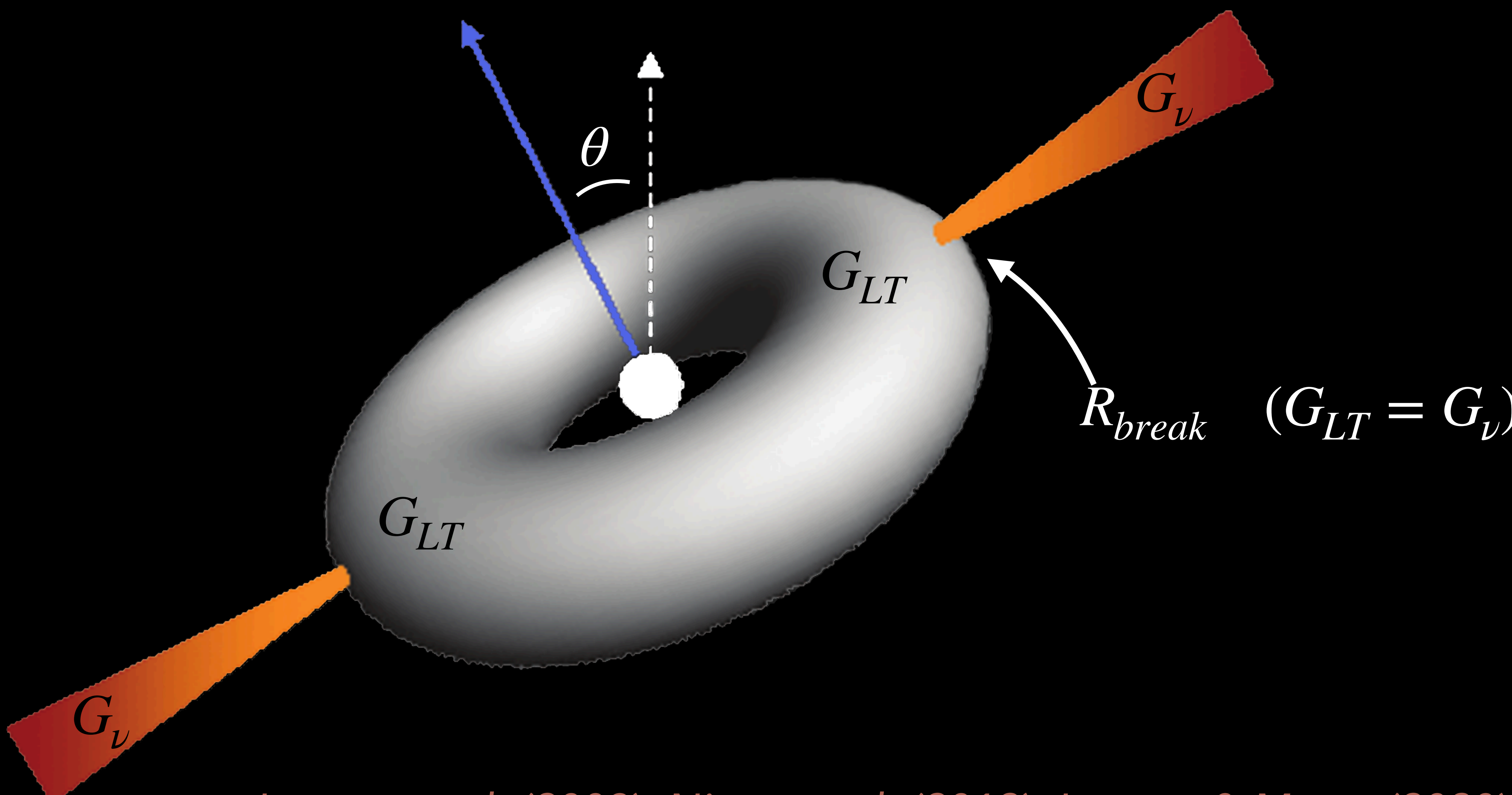

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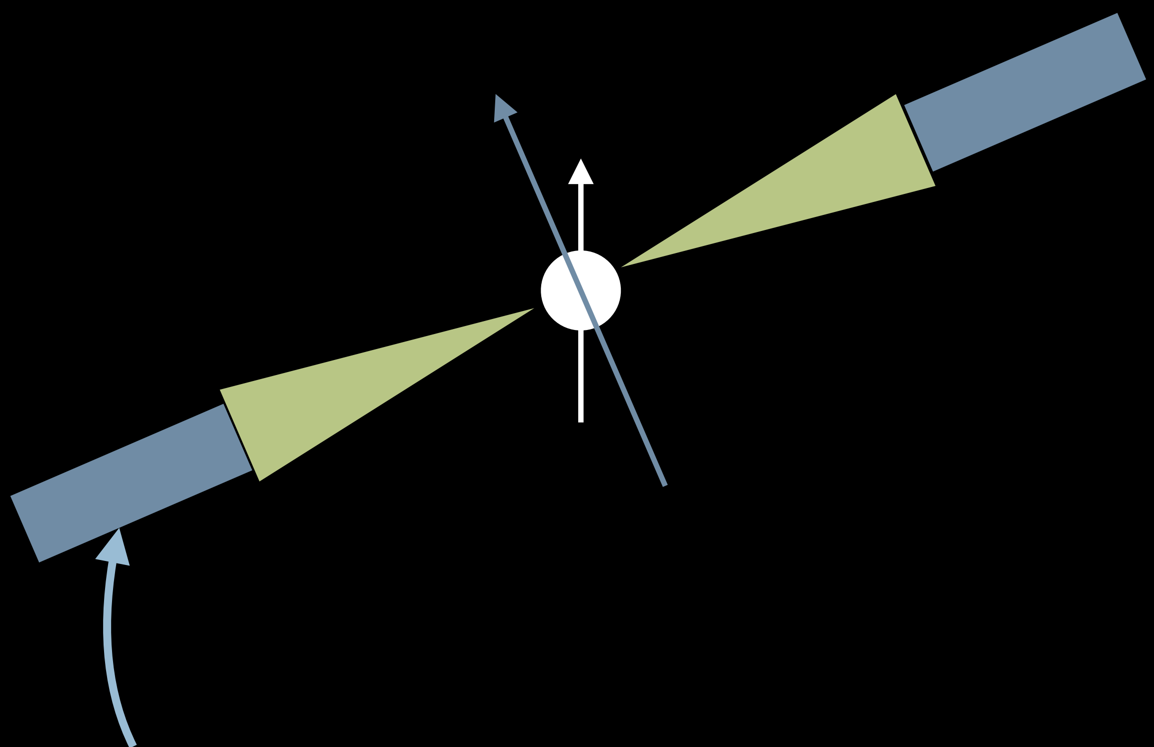
Assuming $\frac{G_{LT}}{G_{\nu}} > 1$ in the green region

Diffusive regime $(\alpha \gg \epsilon)$



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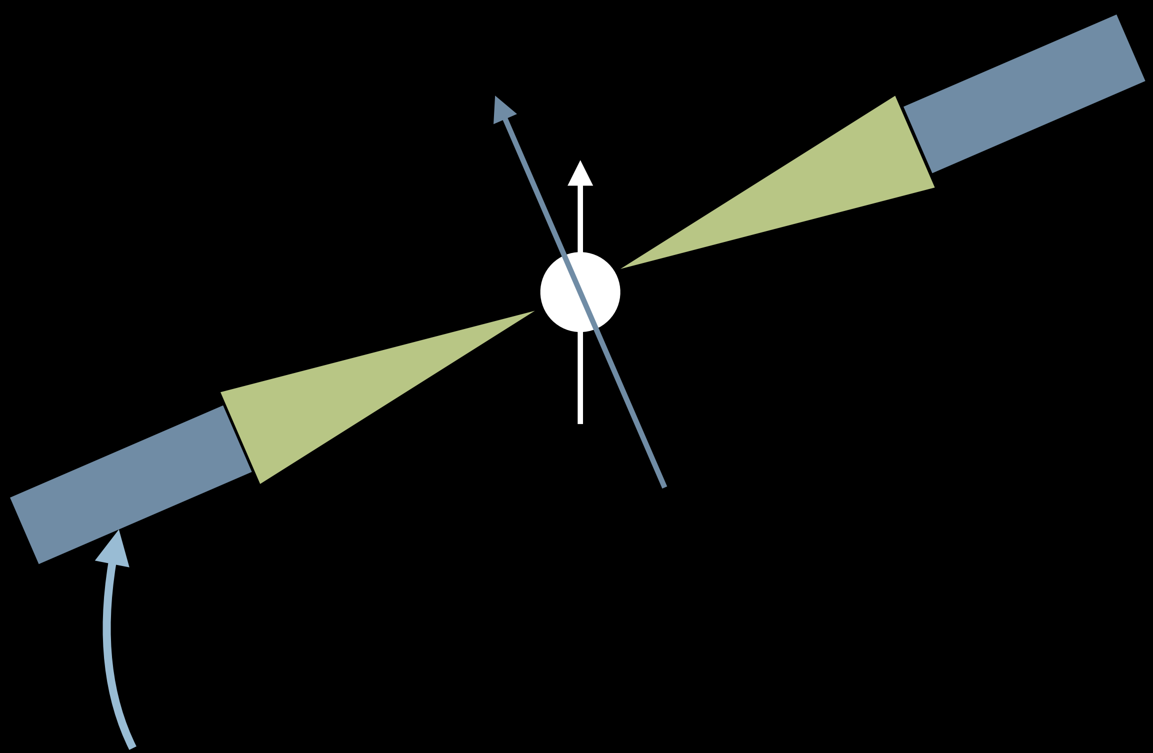

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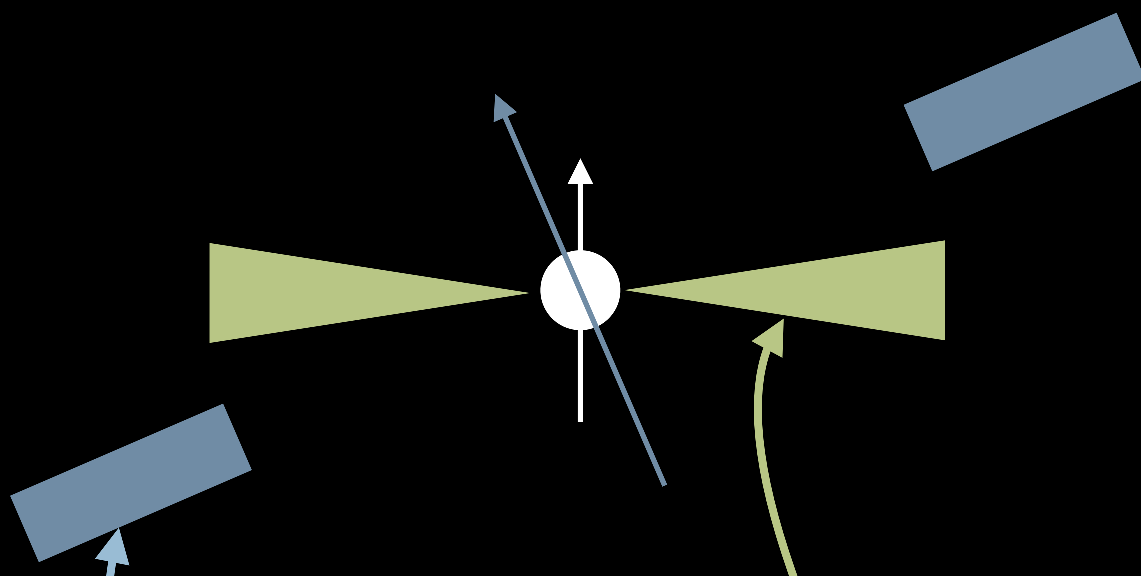

Bardeen-Petterson configuration

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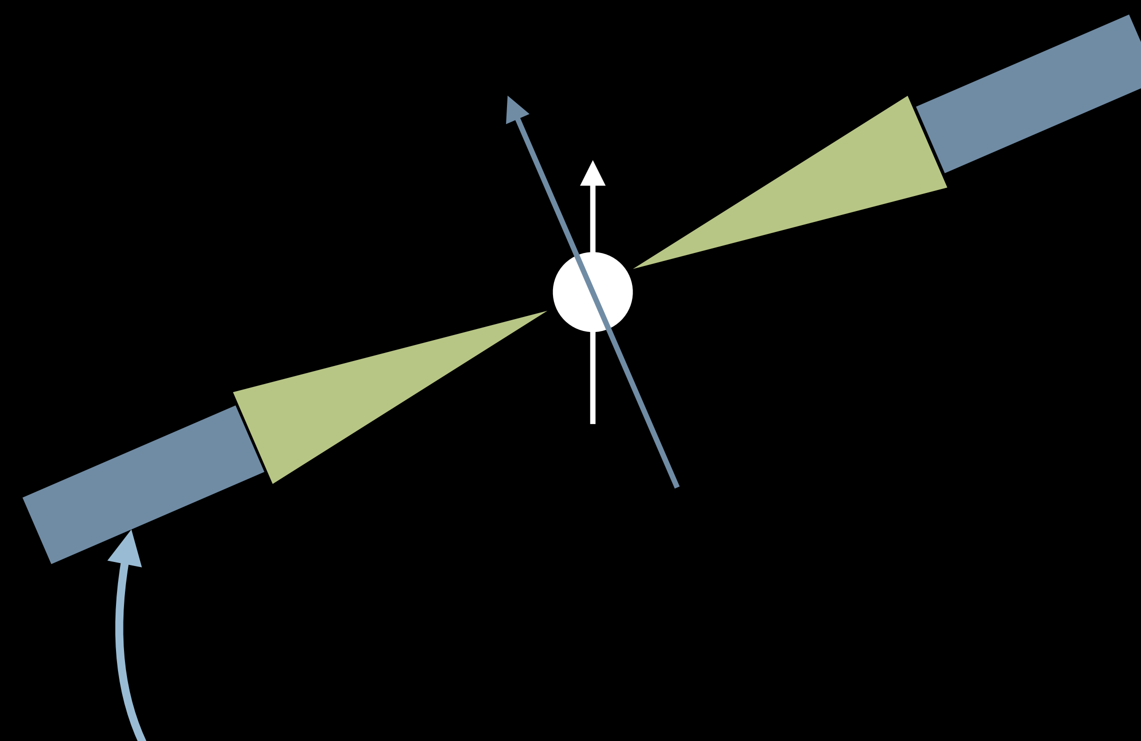

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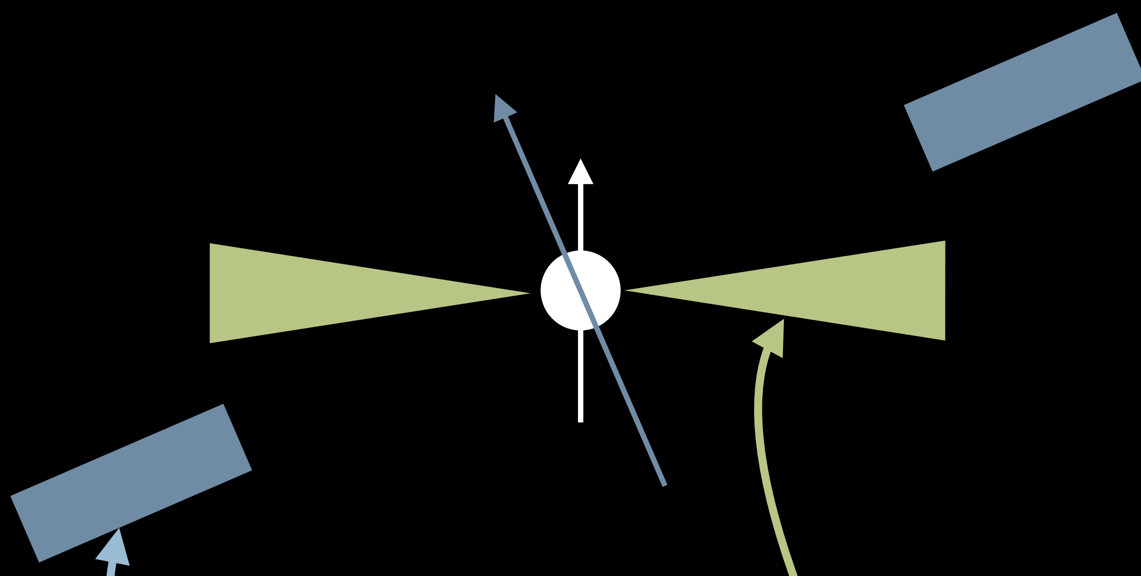

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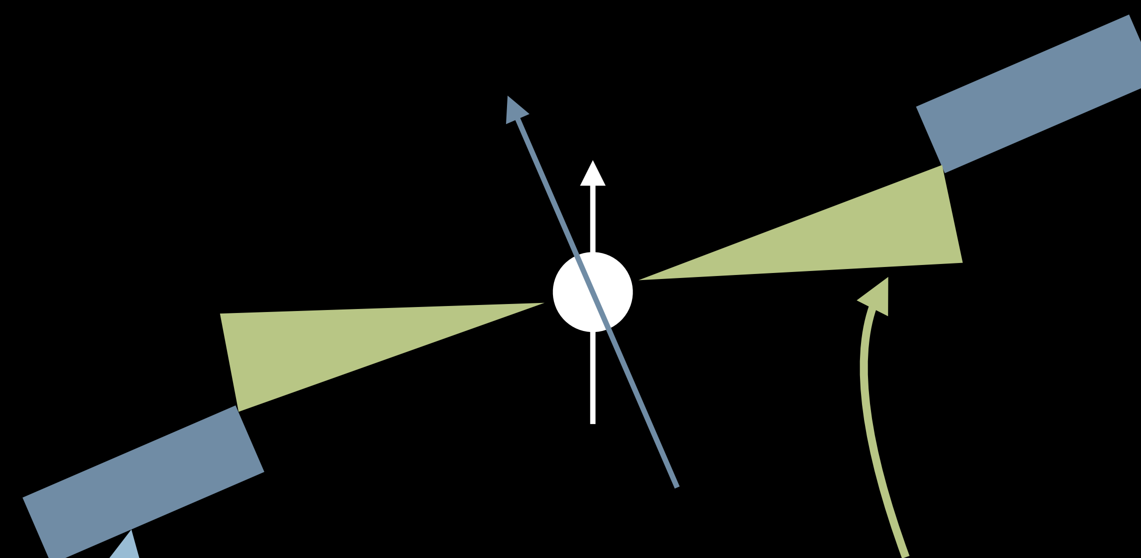

solid-body precession

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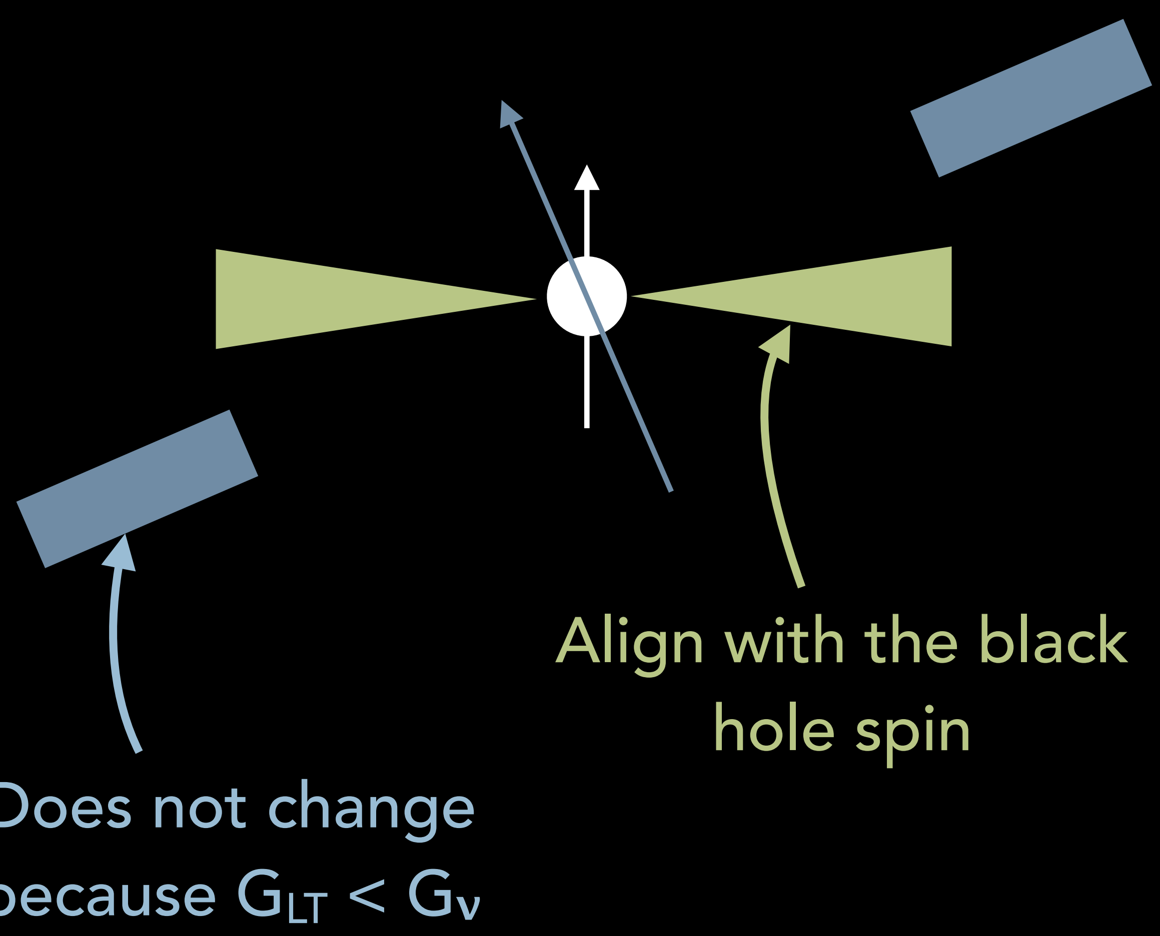

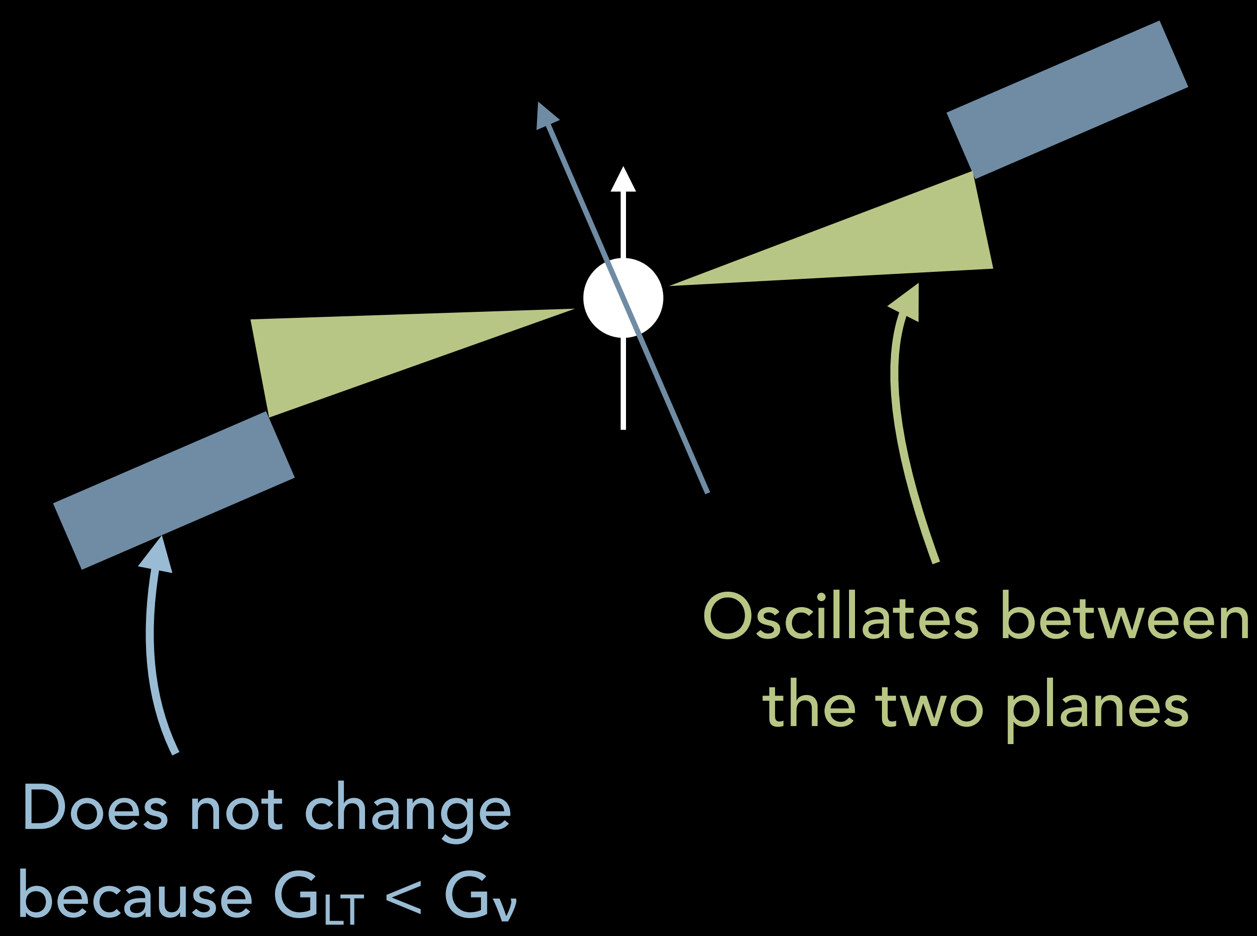

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solid-body precession

The LT precession has shown unprecedented results…
but are we in the right conditions?

Estimating the accretion speed in the hot flow

Frank et al. (2002),
Marcel & Neilsen (2021)

$$\dot{M} = 2\pi R \,|\, u_R \,|\, \Sigma$$

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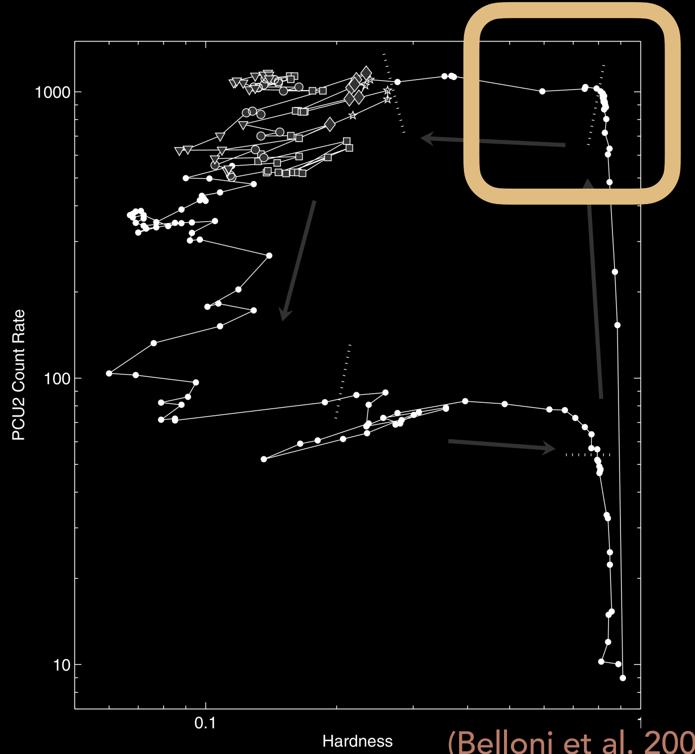

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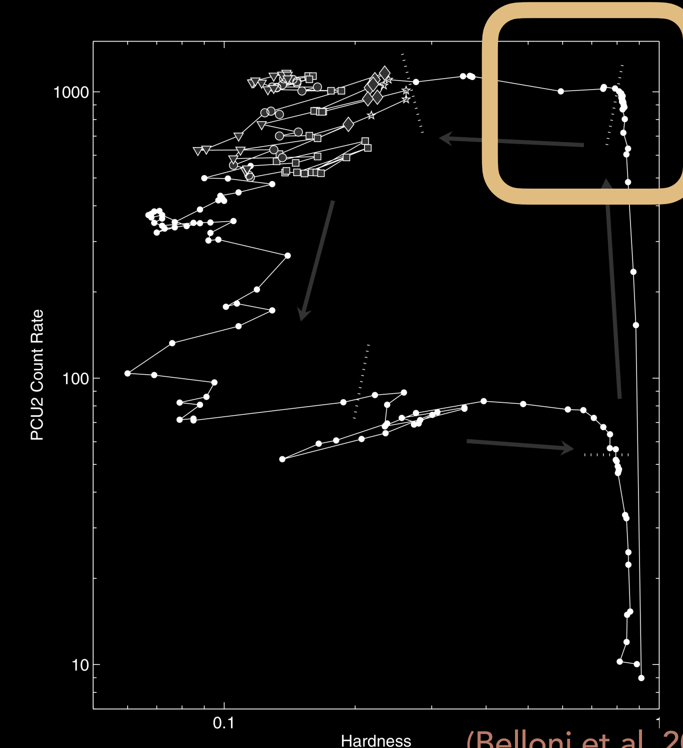

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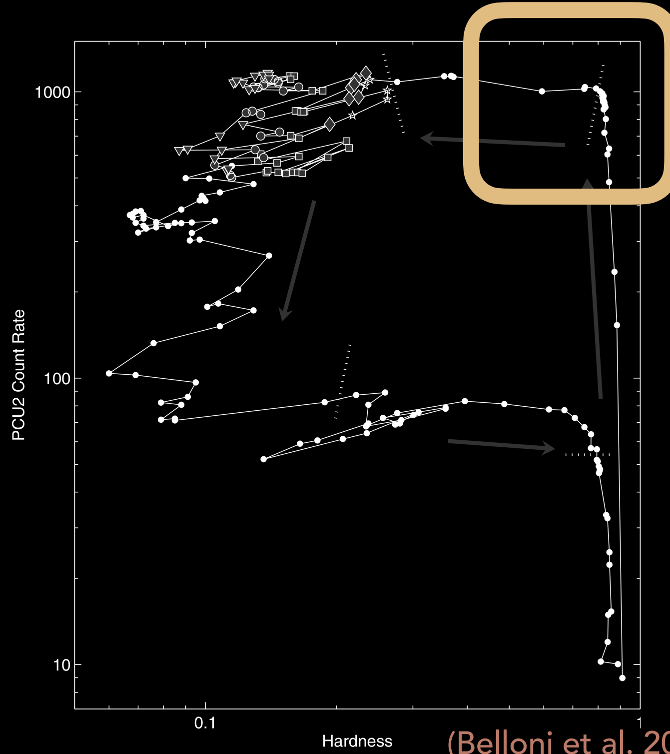

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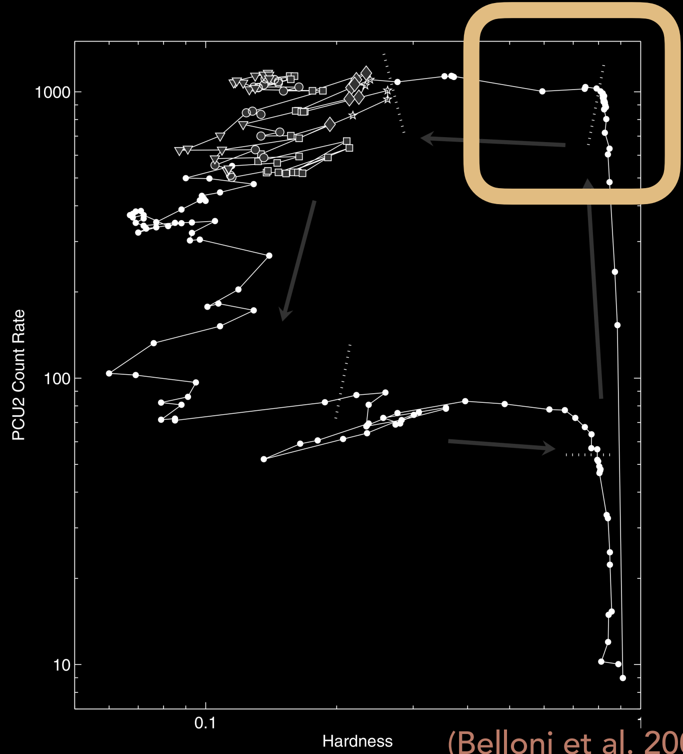

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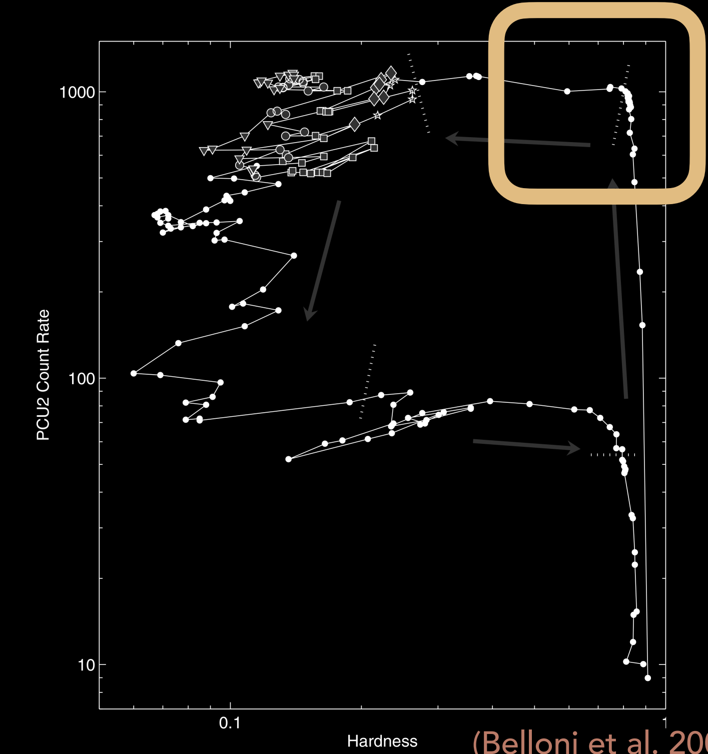

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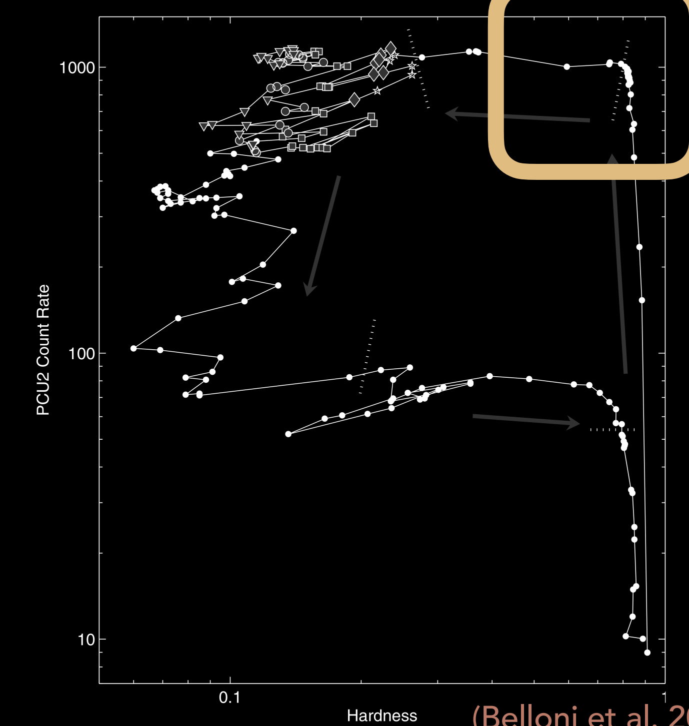

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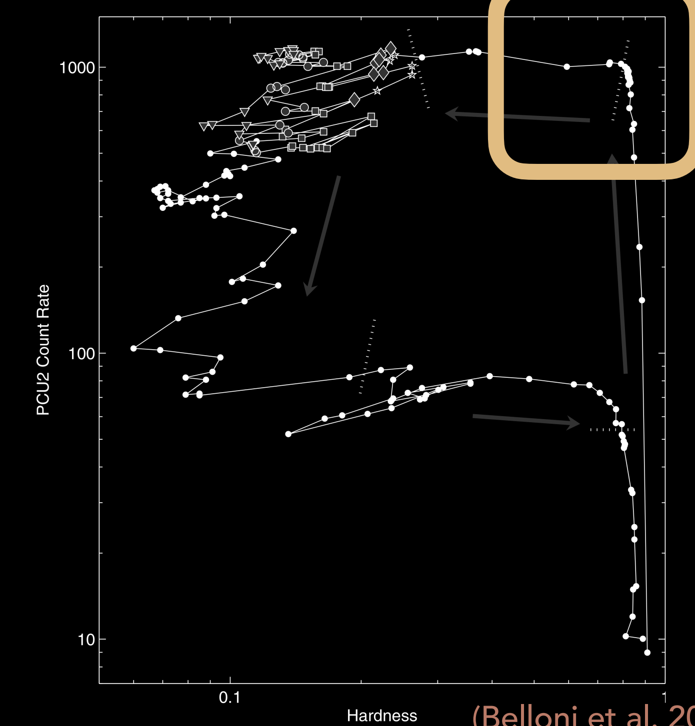

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Estimating the accretion speed in the hot flow

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→ ADAF/ADIOS/CDAF/SANE: $u_R/u_{sound} \ll 1$
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→ MAD: $u_R/u_{sound} \gtrsim 1$
(Narayan et al. 2012)

→ JED: $u_R/u_{sound} \approx 1$ by definition
(Ferreira et al. 1993a,b, 1995, Marcel et al. 2018a,b)

How about the viscosity $\boldsymbol{\alpha}$?

Assume that accretion is generated by the turbulent viscosity ν

Frank et al. (2002),
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Result 2: If the hot flow is turbulent, the expected viscosity is **α~5**

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Frank et al. (2002),
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$$\left.\begin{aligned} \nu &= \alpha \Omega_\phi H^2 \\ \nu \Sigma &= \frac{\dot{M}}{3\pi} \end{aligned}\right\} \quad \alpha = \frac{2}{3} \frac{|u_R|}{u_{sound}} \frac{R}{H} = \frac{2}{3} \frac{|u_R|}{u_{sound}} \frac{1}{\epsilon}$$

$$\alpha = 5.3 \times \left(\frac{\dot{M}c^2}{L_{Edd}}\right) \cdot \left(\frac{0.2}{\epsilon}\right)^2 \cdot \left(\frac{1}{\tau}\right) \cdot \left(\frac{10\, R_g}{R}\right)^{1/2}$$

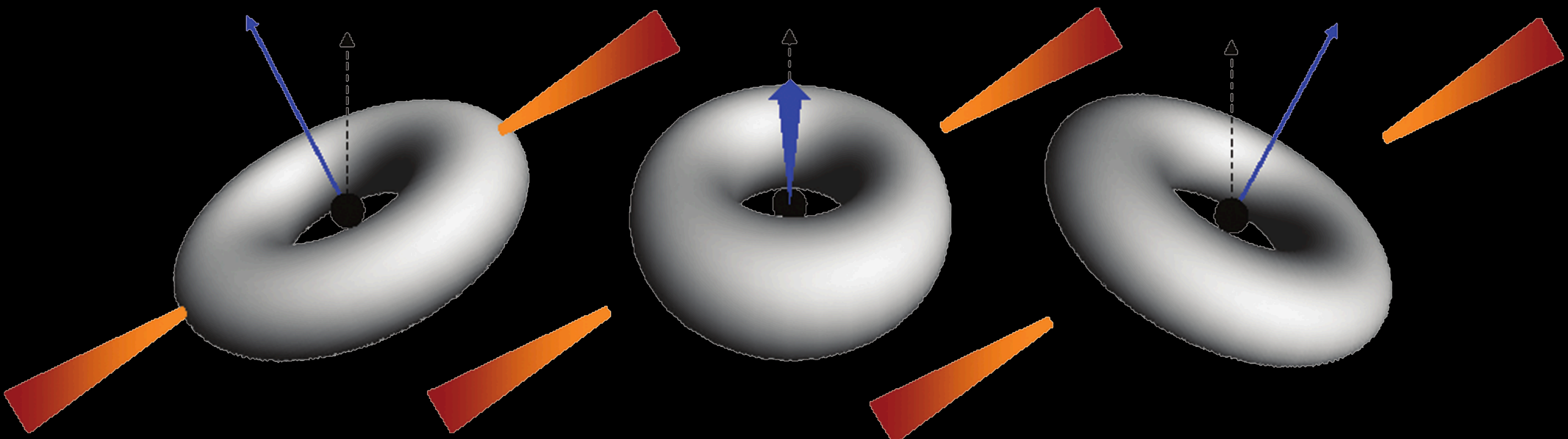
Result 2: If the hot flow is turbulent, the expected viscosity is **α~5**

This is an extreme value… is the hot flow really a 'viscous' flow?

Conditions for solid-body precession of the hot flow

Condition n°1 : $\frac{G_{LT}}{G_\nu} = \frac{4}{3} \frac{a\,|\sin(\theta)|}{\alpha\epsilon} (R/R_g)^{-3/2} > 1$

Condition n°2 : $\alpha \ll \epsilon$



Ingram et al. (2009), Nixon et al. (2012), Ingram & Motta (2020)

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Result 3: The conditions for LT solid-body precession are not fulfilled in the luminous hard states…

Ingram et al. (2009), Nixon et al. (2012), Ingram & Motta (2020)

Conclusions

Marcel & Neilsen (2021)

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1 - The inner hot flow needs to accrete at (super)sonic speeds *in the luminous hard states*. Only magnetized flows (MAD & JED) are able to reach these velocities.

Marcel & Neilsen (2021)

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—> Address the impact of the high sound speed and the new torque on the bending waves

Marcel & Neilsen (2021)