Misaligned Accretion: ADAFs, Slim Discs, QPOs and Jets

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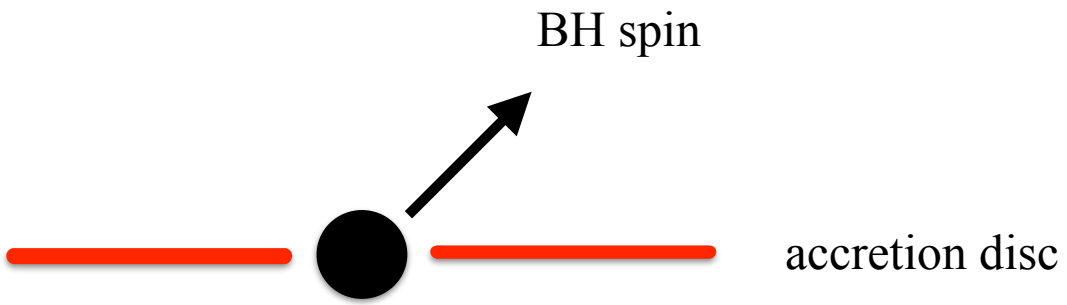
misalignment is generic for all accretion



obvious for AGN accretion - accretion plane set at large distance from SMBH

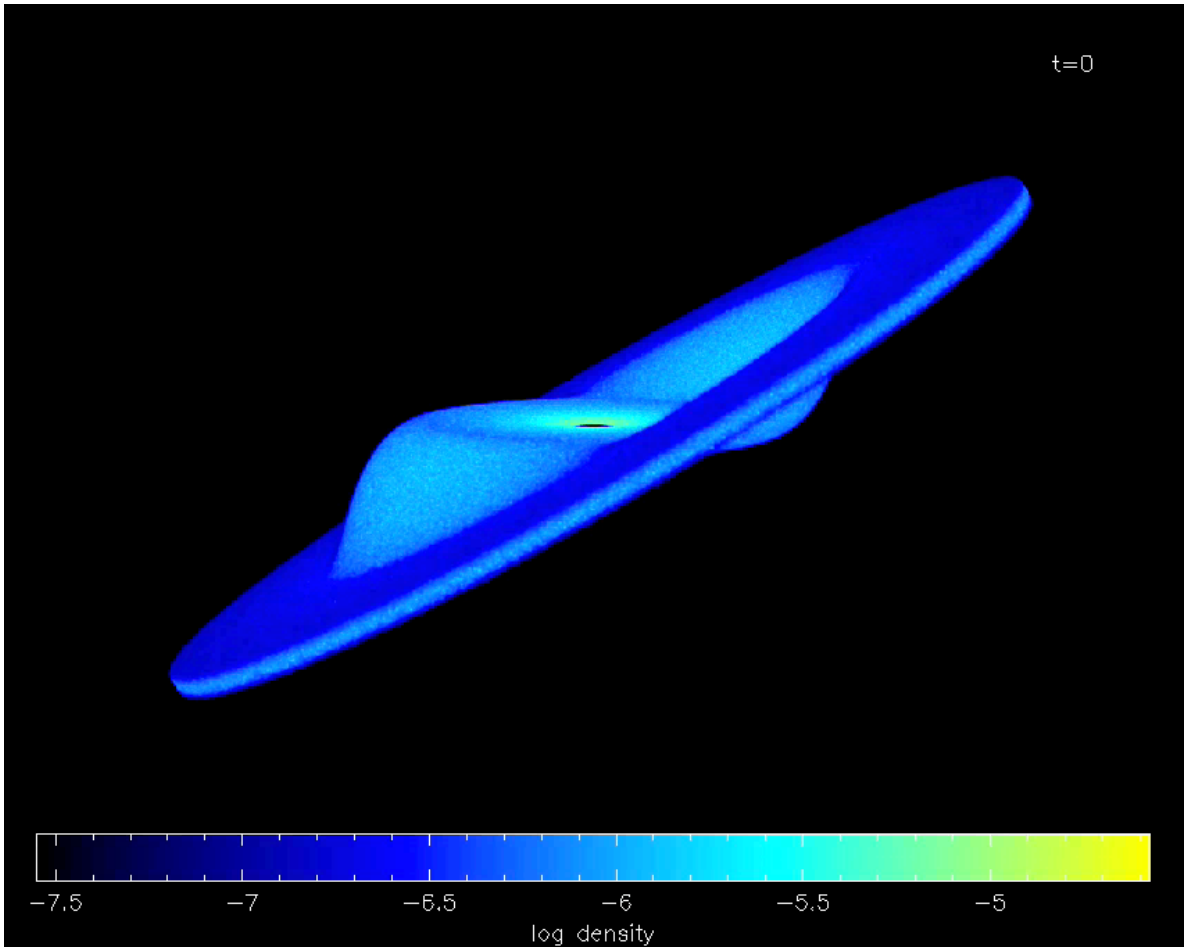
no good reason for alignment in high-mass X-ray binaries

even in low-mass X-ray binaries, accretion can only dilute misalignment after SN, but supplies too little angular momentum to remove it

assuming alignment is a singular limit removing many effects

how does misaligned accretion proceed?

standard assumption: disc warps (Bardeen-Petterson)

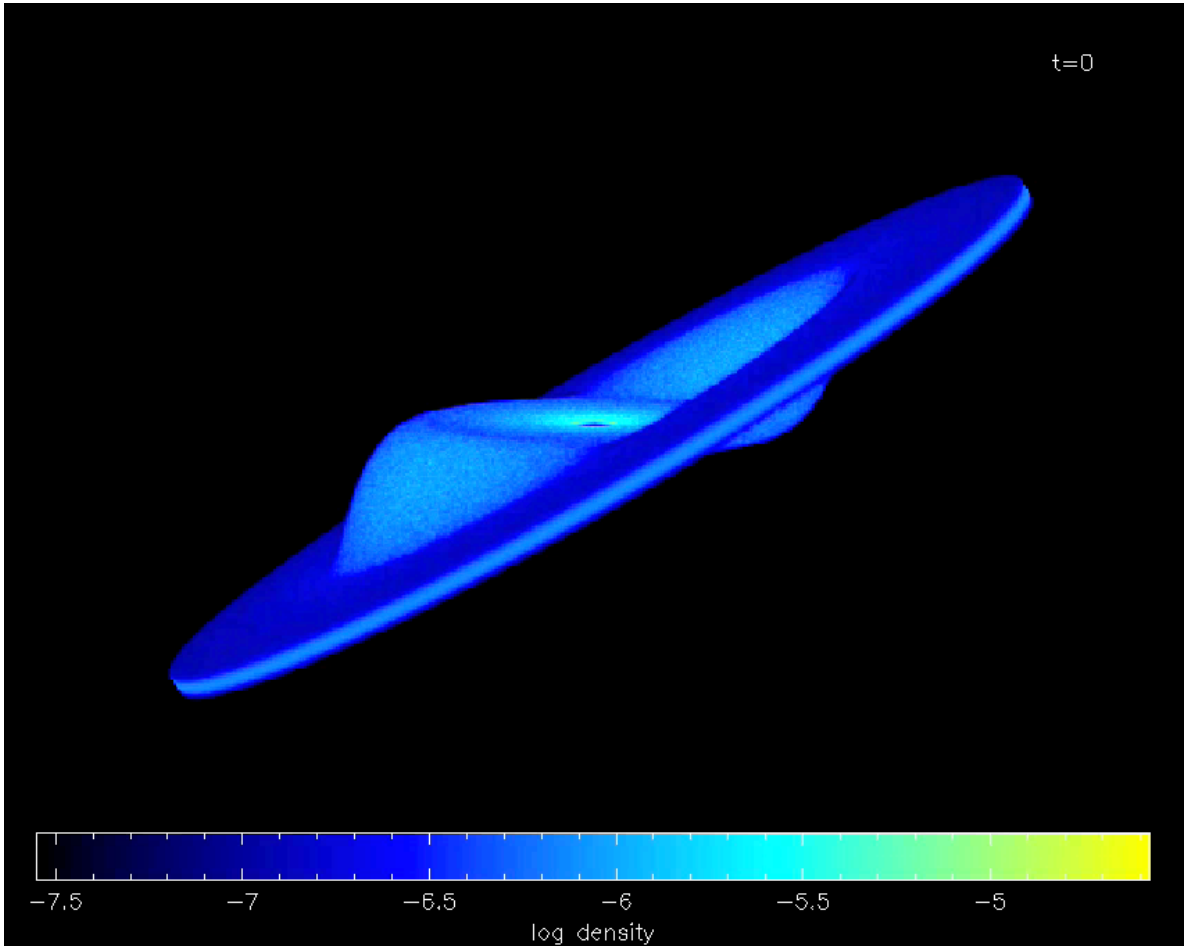


Lodato & Price, 2010

OK if inclination is moderate

how does misaligned accretion proceed?

but if inclination is large, or viscosity weaker, disc breaks!



Lodato & Price, 2010

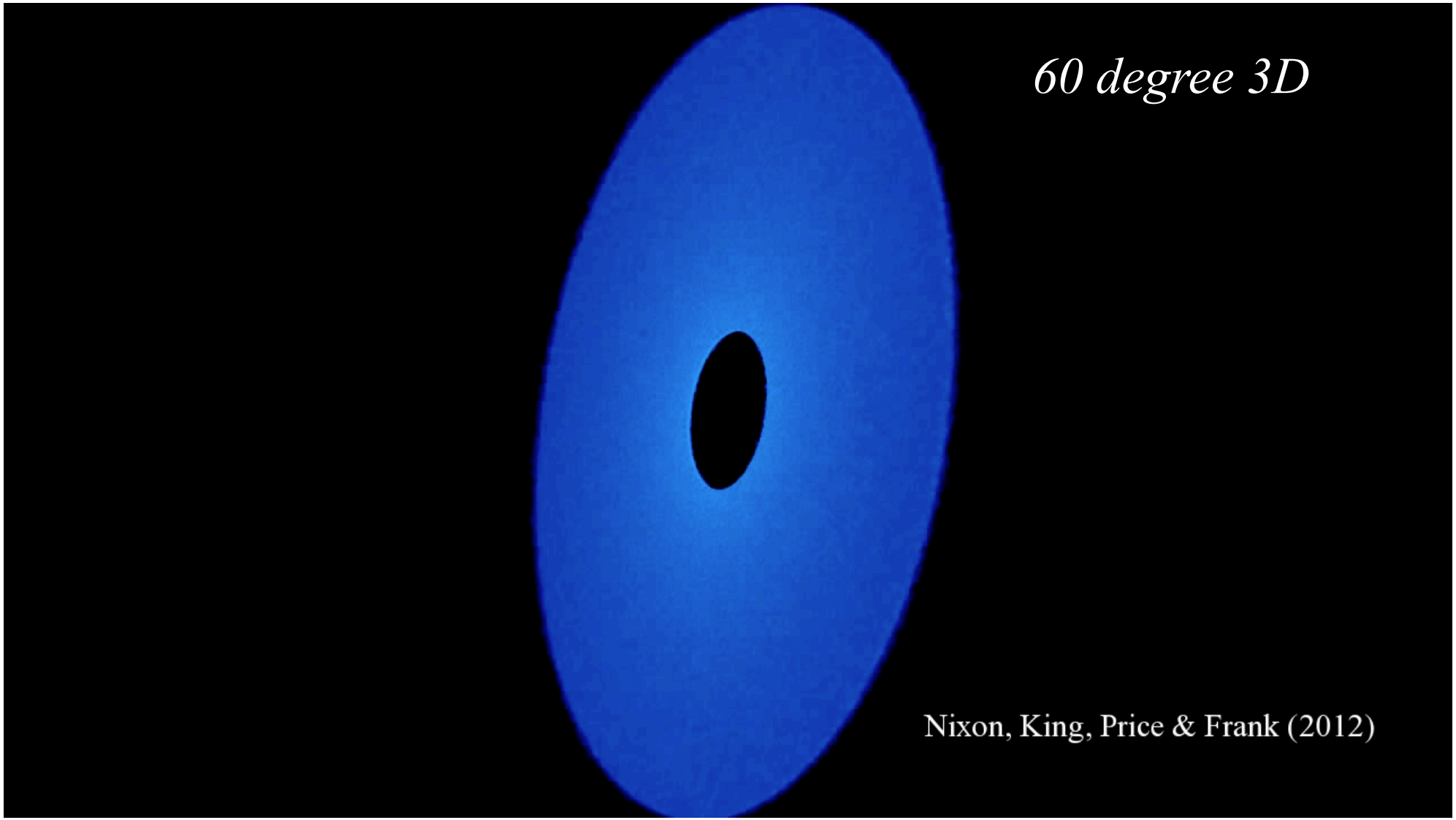
predicted by Papaloizou & Pringle, 1983; Ogilvie, 1999, 2000
also recently found using GRMHD (Liska+, 2018)

breaking can lead to tearing

broken parts of discs precess separately and interact

if they have precessed more than 180 degrees they are partially opposed

=> INFALL



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precession by more than 180 degrees => partially opposed => infall

could this make an ADAF?

misaligned accretion - BH spin inclined to external magnetic field (King & Lasota 1977)

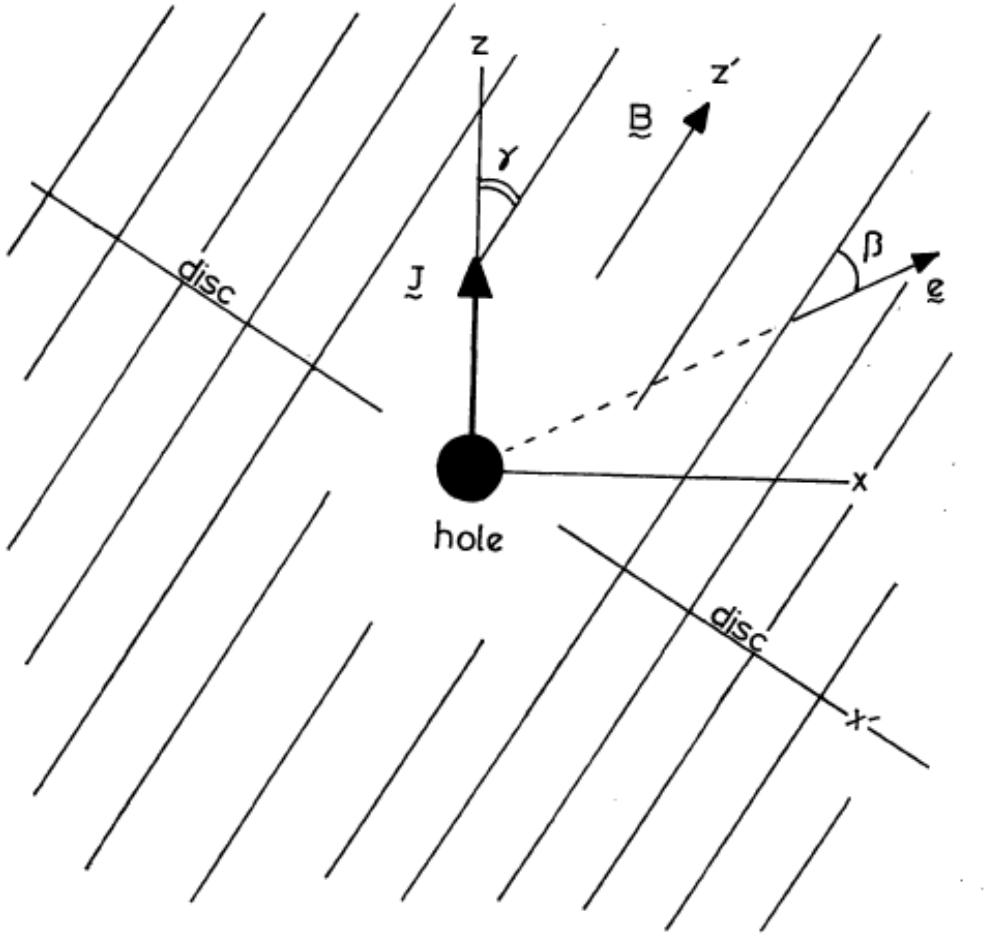

Fig. 1. Black hole of angular momentum ***J*** immersed in a magnetic field ***B*** which becomes uniform far from the hole. The y and y' axes are identical and point into the paper, and ***e*** is a radially pointing unit vector. Part of the disc considered in III of the text is shown in section (not to scale)

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aligns by killing off the misaligned component of $\mathbf{J}$ while aligned component stays fixed:

$$J_{||} = \text{constant}, \quad J_{\perp} = J_{\perp\,0} e^{-t/t_h}, \text{with}$$

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alignment utterly negligible except for very strong fields (GRBs?)

alignment torque extracts energy from hole spin

=> gravitational and EM radiation

if we set $\boldsymbol{\mu} = R_g^3 \boldsymbol{B}$, $\boldsymbol{\omega} = \boldsymbol{J}/MR_g^2$

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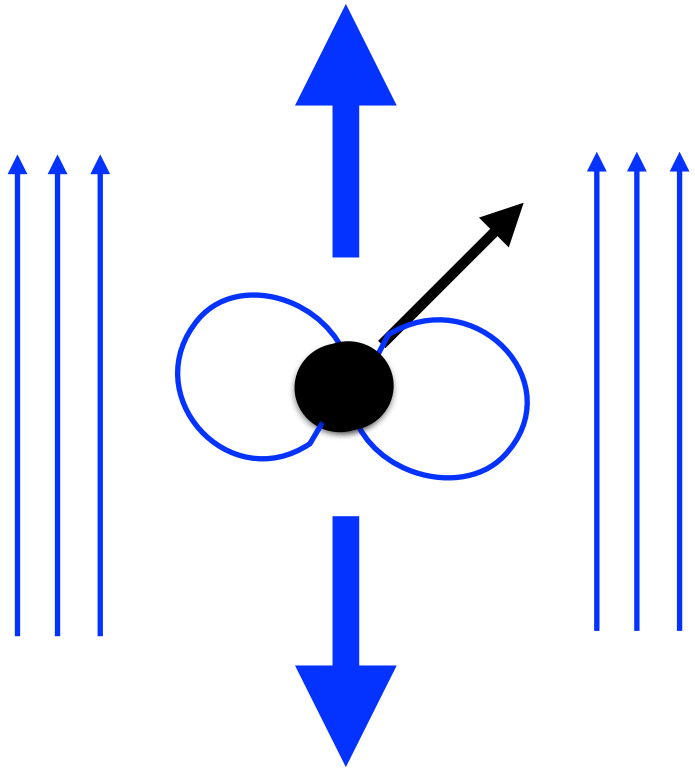
magnetic dipole radiation

circular polarization carries off spin angular momentum

magnetic field induces a dipole near BH horizon
this is forced to corotate inside the ergosphere

=> dipole radiation



more interesting case - MRI field anchored in accretion disc rings: spin now fixed and they move: misalignment => Lense-Thirring precession

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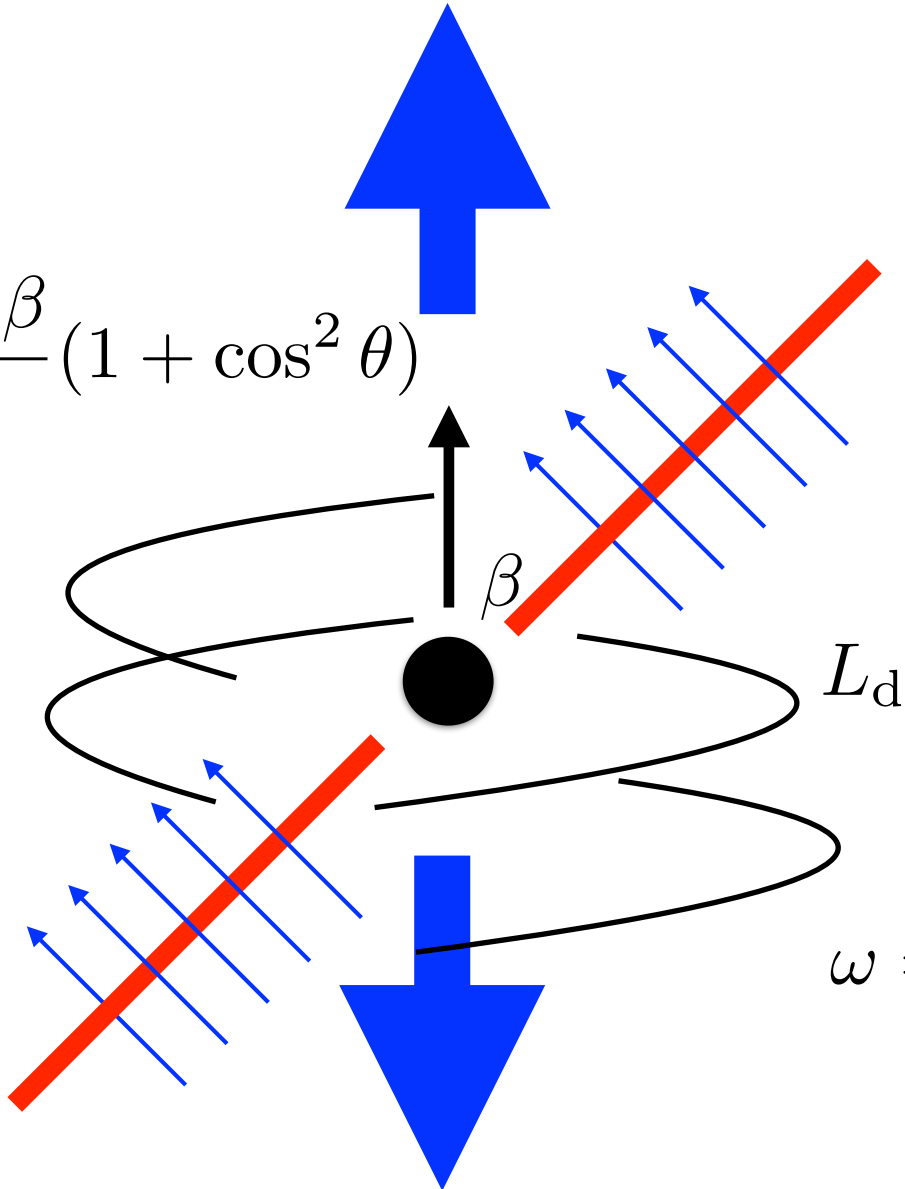
$$\frac{\mathrm{d}L_{\rm dip}}{\mathrm{d}\Omega} = \frac{\omega^4 \mu^2 \sin^2\beta}{8\pi c^3}(1+\cos^2\theta)$$



$$L_{\rm dip} = \frac{2\omega^4 \mu^2 \sin^2\beta}{3c^3}$$

$$\omega = \omega_{\rm LT} \simeq \frac{2ac}{R_g r^3}$$

King & Nixon
ApJL 2018

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further:

this effect works *whatever* the nature of the accretor - if this is not a black hole, precession is driven by stellar quadrupole moment

dipole emission goes as $\mu^2\omega^4 \propto B^2 r^{-6}$ so dipole emission sharply peaked towards disc inner edge (ISCO for BH)

$$L_{\rm dip} = \frac{128}{9\alpha}\left(\frac{R}{H}\right)\left(\frac{v_A}{c_s}\right)^2 \frac{\dot{M}c^2}{r^{17/2}}\left(1-\frac{1}{r^{1/2}}\right)^{11/20} a^4 \sin^2\beta$$

$$\frac{L_{\rm dip}}{L_{\rm acc}} = \frac{128}{9\eta\alpha}\left(\frac{R}{H}\right)\left(\frac{v_A}{c_s}\right)^2 \frac{a^4\sin^2\beta}{r^{15/2}}\left(1-\frac{1}{r^{1/2}}\right)^{11/20}$$

$$r = R/R_g$$

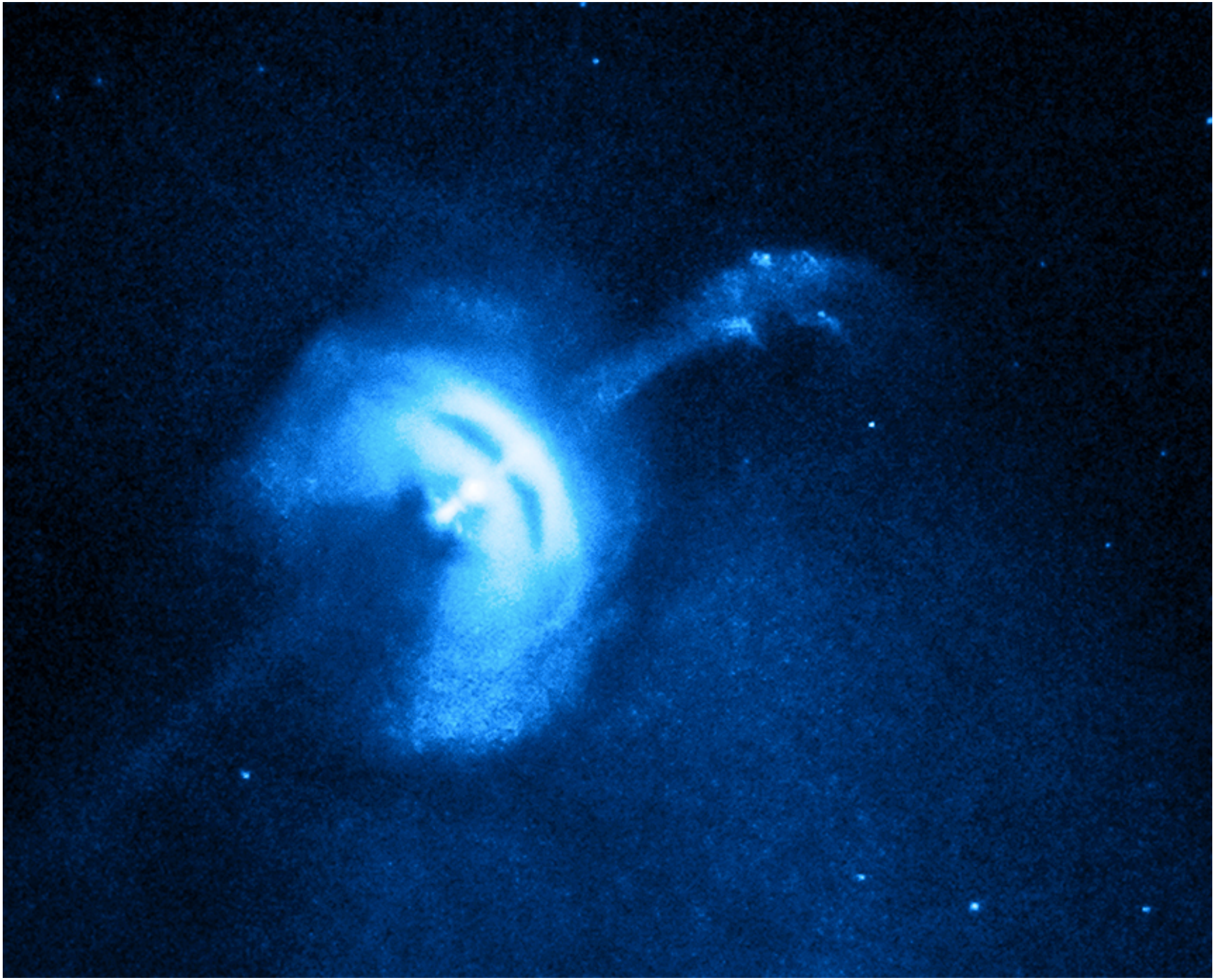
competition between alignment and accretion

emission is coherent at $\omega < 2c/R_g \sim 4 \times 10^4$ Hz for $10 M_\odot$ black hole

so below plasma frequency, not directly observable

accretion/alignment competition => QPOs at $\sim \omega$ (kHz)

as in radio pulsars, emission must drive outflow as jets along spin axis



Summary

misaligned accretion + MRI =>

QPOs, and JETS along spin axis, for all accretors

MHD, GRMHD (even `radiation' GRRMHD)

do not capture this, as displacement current set to zero:

no matter - radiation coupling