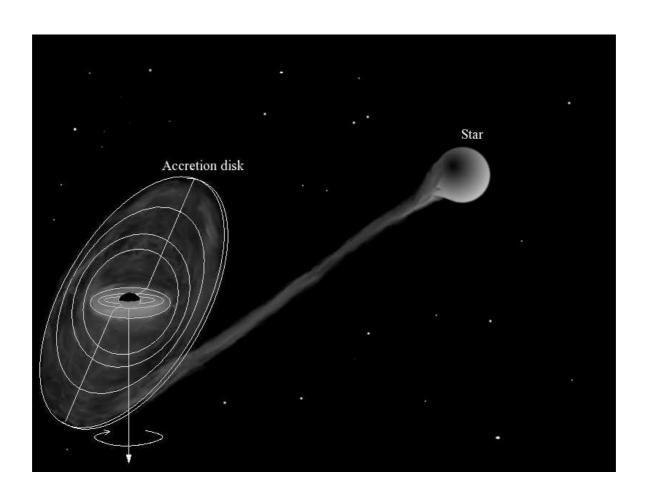
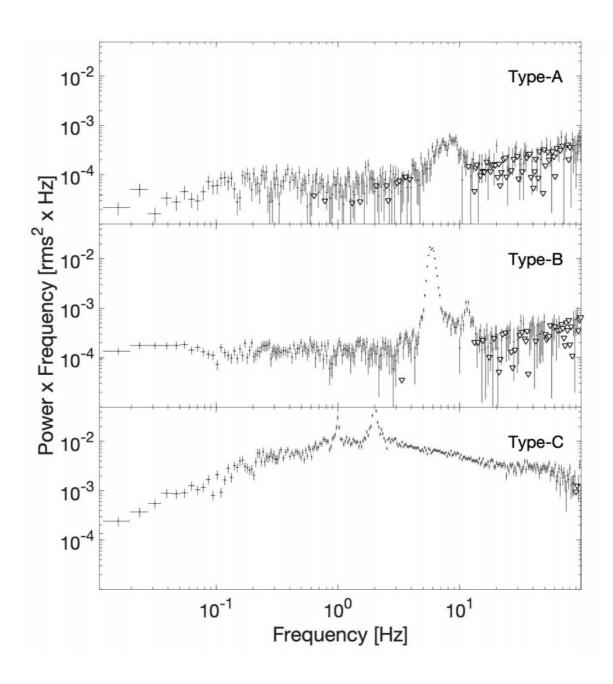
## **Tilted Accretion Disks around Black Holes**

By C. Fragile & M. Liska

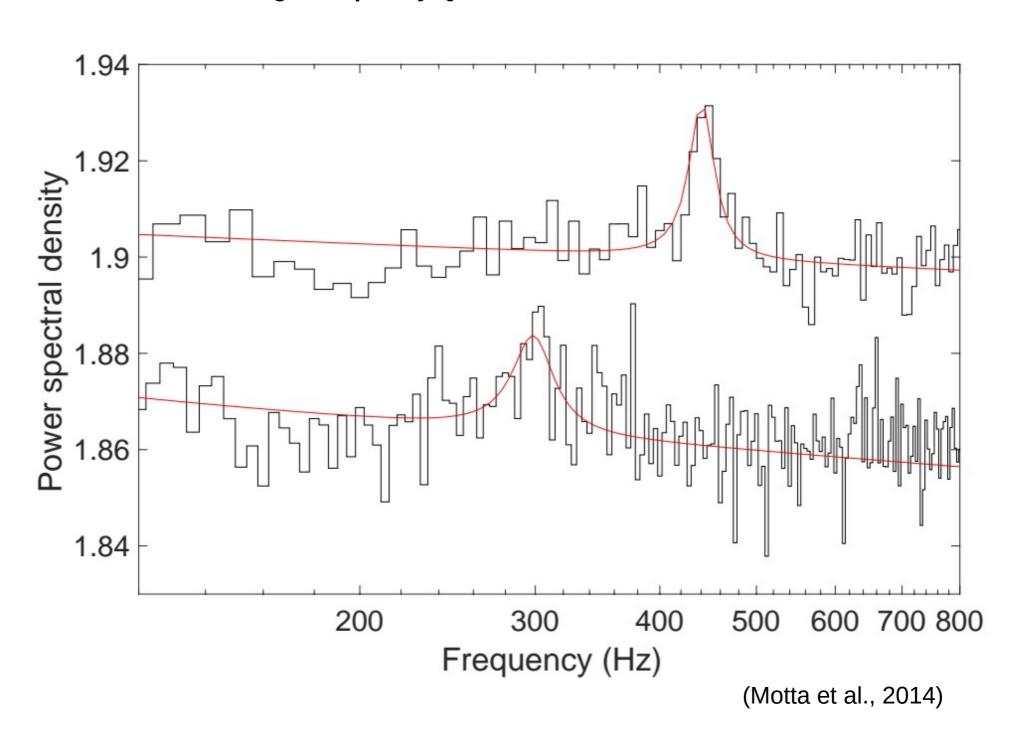


Oct 23, 2024

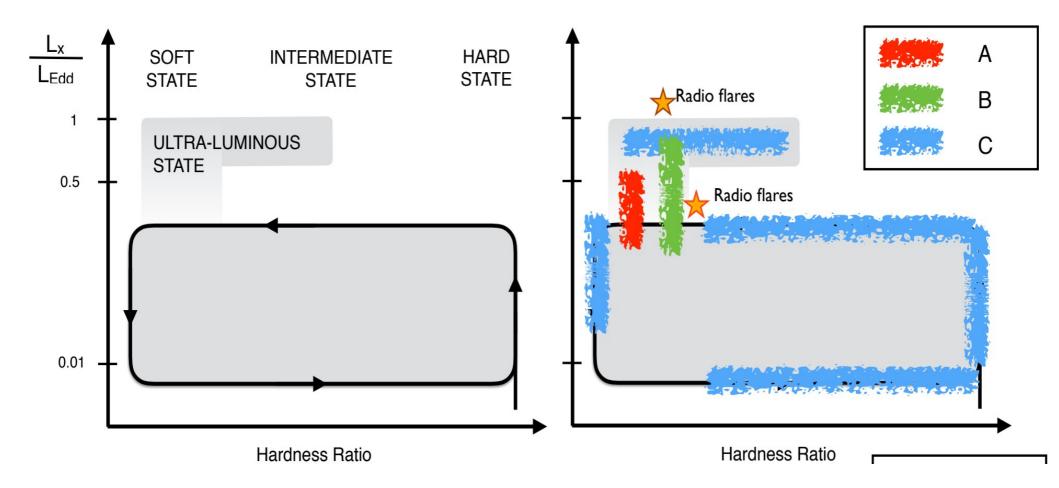
## **Low Frequency QPOs from BH XRBs**



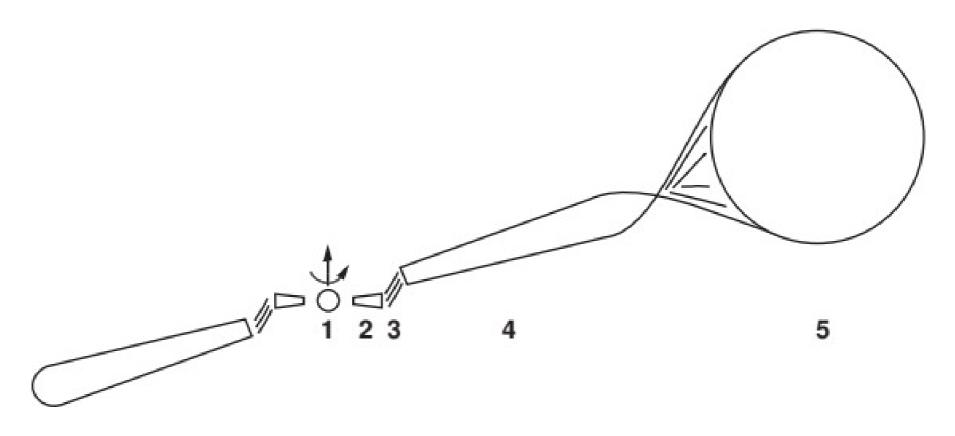
## **High Frequency QPOs from BH XRB GROJ1655-40**



## Behaviour of BH in a Hardness-Intensity diagram

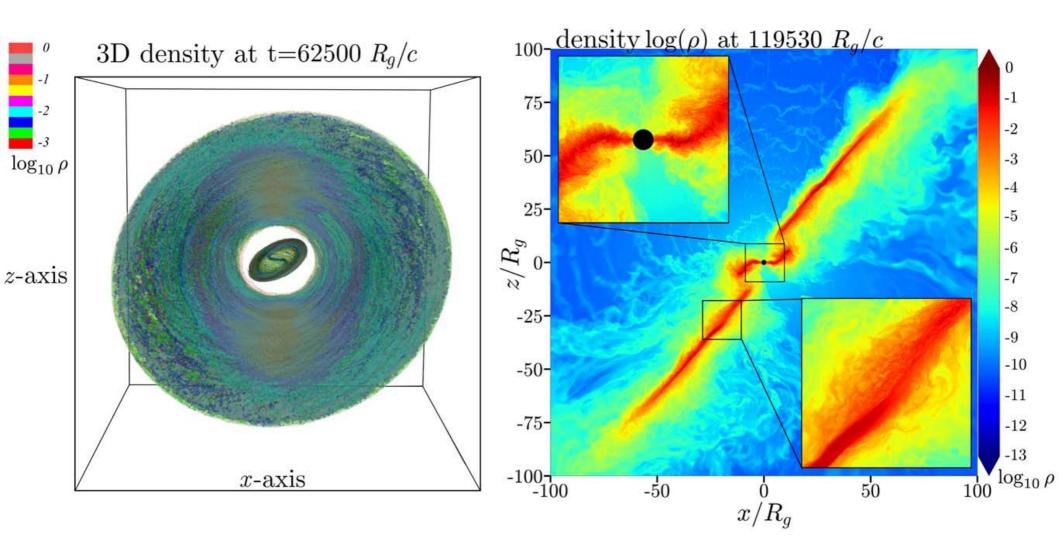


Schematic diagram of the Bardeen-Petterson effect in a black hole X-ray binary showing (1) the central rotating black hole, (2) the inner, aligned accretion disk, (3) the transition region, (4) the outer, tilted accretion disk, and (5) the companion star.



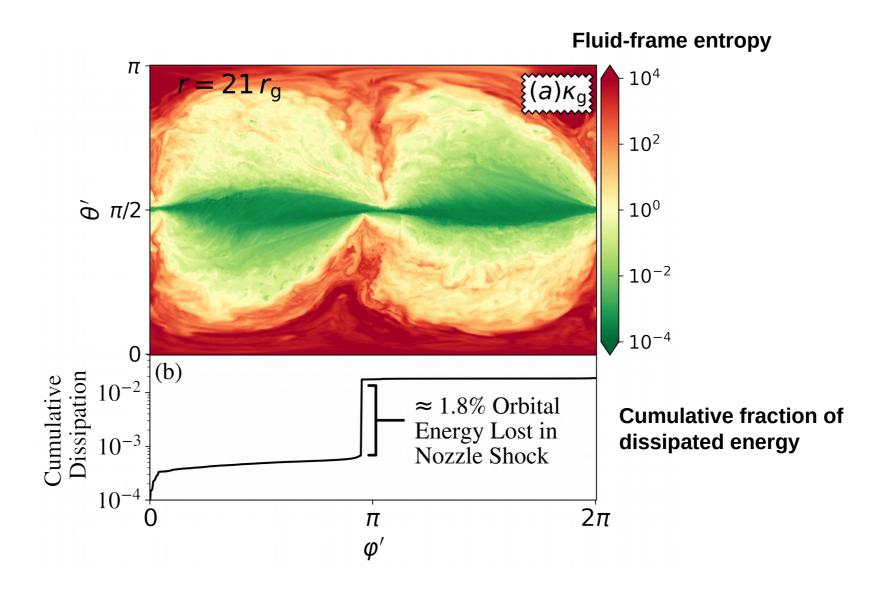
GRMHD simulation of a thin accretion disk which tears apart into an outer, non-precessing disk and inner, precessing one.

Vertical slice through the density with the black hole spin pointing vertically



(Liska et al. 2022)

### Vertical compression in simulations of warped, thin disks



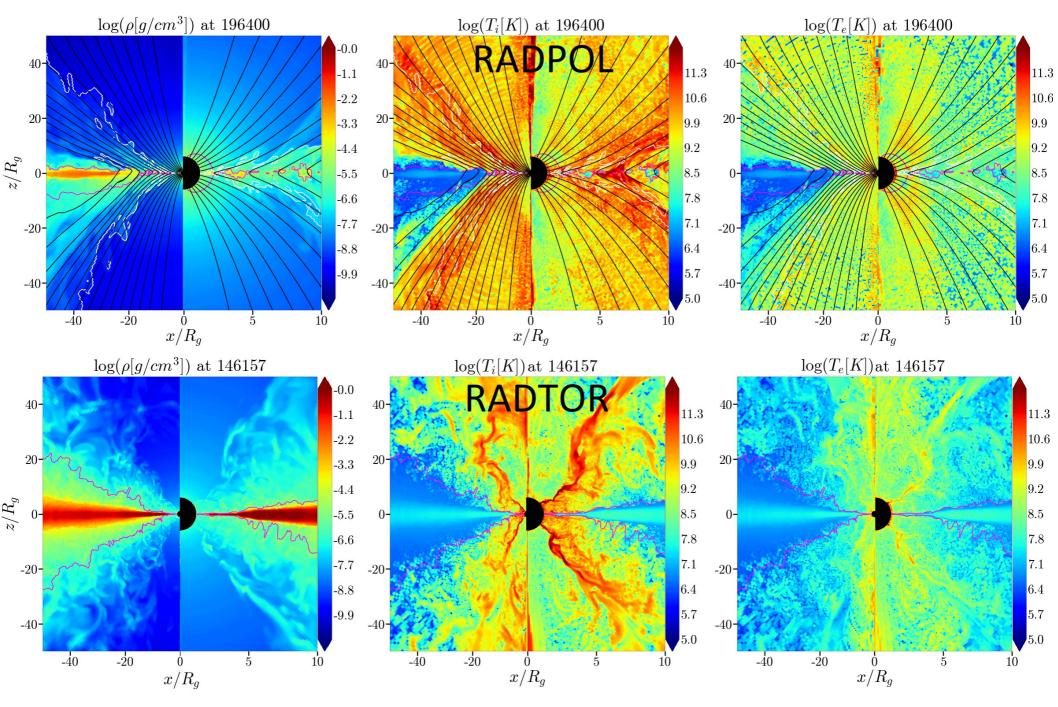
Warping of ST causes the disk to tear apart: a precessing, inner disk and a non-precessing, outer one.

#### **Vertical projection** h/rat 37026 $R_a/c$ $\log(\Sigma[g/cm^2])$ at 37026 $R_g/c$ Volume rendering 4.93 4.23 a = 0.940.16 3.53 0.14 $L = 0.35 L_{edd}$ 2.83 0.12 2.13 Res: 6720x2304x4096 0.10 1.43 0.08 0.73 0.06 0.03 -20-0.04 -0.670.02 -1.370.00 $x/R_q$ $x/R_q$ **BH Spin** $\log(T_e[K])$ at 37026 $R_g/c$ $\log(T_i[K])$ at 37026 $R_g/c$ Nozzle shock Evolving tear radius 20-Tearing shock Shock-driven viscosity is strong $y/R_g$ 6.5 7.0 6.2 Turbulence-driven viscosity is weak 10 5.9 5.6 Nozzle shock $x/R_a$ $x/R_a$ $r[r_g]$

Shock-induced effective viscosity ( $\alpha_{eff}$ ) orders of magnitude larger than the turbulent viscosity seeded by MRI turbulence ( $\alpha_m$ )

(Kaaz et al. 2023; Liska et al. 2023)

#### Presence of large-scale poloidal magnetic flux leads to the development of a two-phase medium



(Liska et al. 2022)

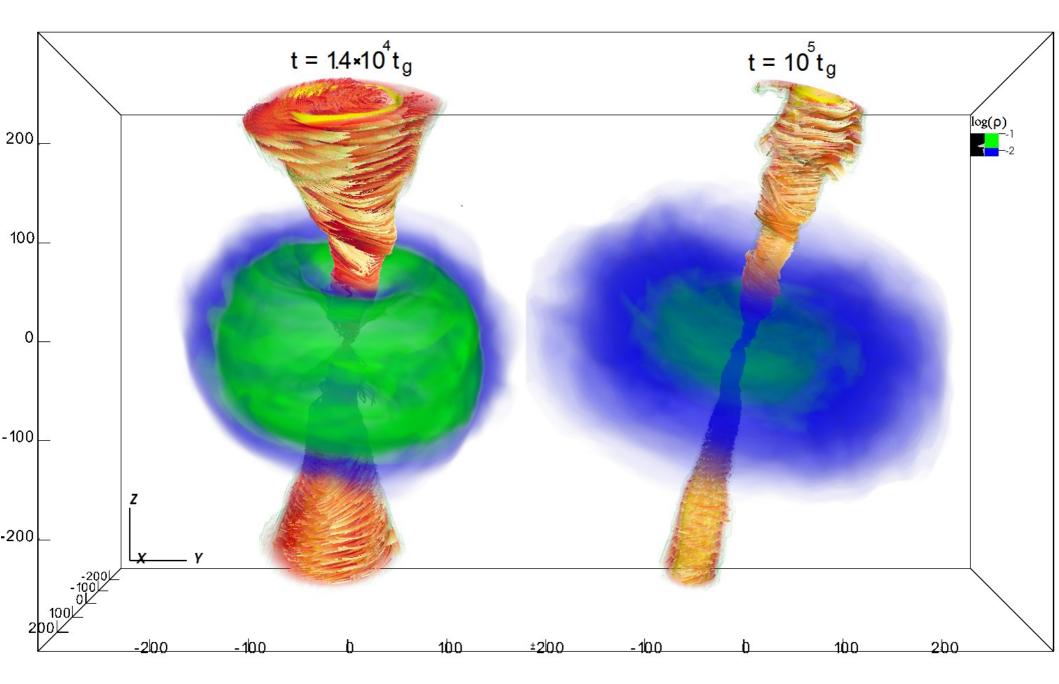
## Inside a Black Hole's Jet Engine As a spinning black hole pulls in matter, it creates a rotating "accretion disk" of charged particles. The motion generates twisted magnetic fields that accelerate particles into two thin jets. "SANE" MODEL Weak and turbulent magnetic fields in the accretion disk. **Twisted** magneticfield Jet Black hole Black hole Accretion disk Accretion disk Black hole "MAD" MODEL Strong and coherent magnetic fields in the disk. Recent observations support this model.

Standard And Normal Evolution (SANE)

Magnetically Arrested Disk (MAD)

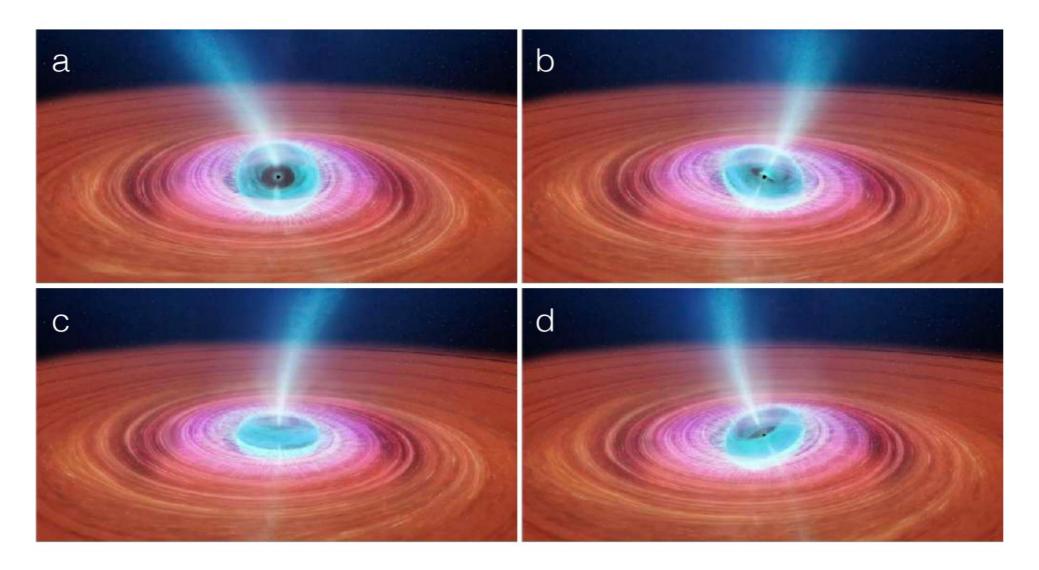
(Image credit: Quanta Magazine)

## Standard And Normal Evolution (SANE) in thick disks: Jets precess in phase with the disk



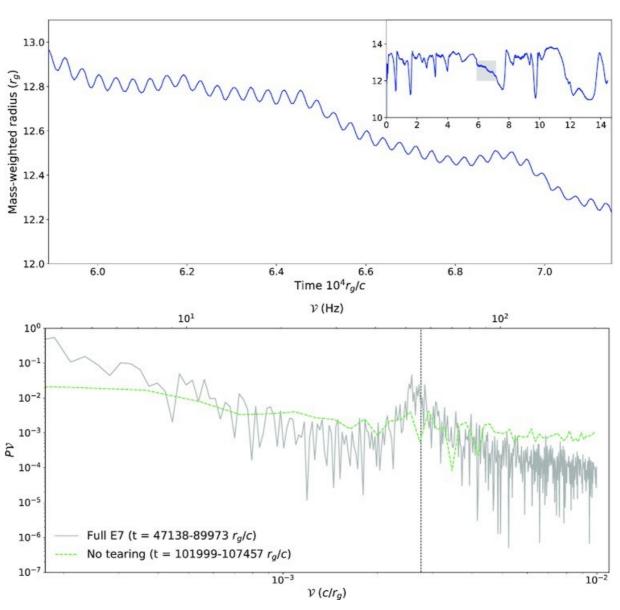
(Liska et al. 2018)

**Precessing inner flow model**: The disc (orange) remains stationary, whilst the inner flow (blue torus) and the jet precess around the BH spin axis (which is pointing upwards and slightly towards the observer in this example). Here, precession and disc rotation are both anticlockwise.



(Miller-Jones et al. 2019)

## Radial oscillations of the inner sub-disk in a tearing-disk simulation



(Musoke et al. 2023)

## **Current/Future simulations**

Broader range of tilts

Broader range of spins

Wider variety of starting conditions

SANE & MAD

(Adapted from last slide of C. Fragile at the Simon Foundations in January 2024)

The trouble with people is not that they know so little, but that what they know is largely not true. ~ Mark Twain

# Thank you.