Models for jet power in elliptical galaxies: support for rapidly spinning black holes

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Nemmen et al., 2007, MNRAS, 377, 1652

Goals

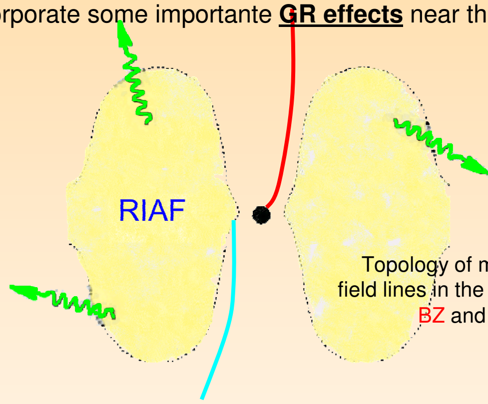
Improve existing analytic models for the jet power (Blandford-Znajek-like)

Apply these models to giant elliptical galaxies, to explain the empirical correlation $\dot{M}_{\rm Bondi} \times P_{\rm jet}$ and constrain the spins of the central supermassive black holes

Models of jet power

Blandford-Znajek-like models: used the original BZ model (BZ 77) and an hybrid version of BZ and Blandford-Payne model (as in Meier 2001 ApJ)

Improvements: (A) model the accretion flow as **ADAF** (advection-dominated accr. flow) (or **RIAF**), **(B)** incorporate some importante **GR effects** near the BH.

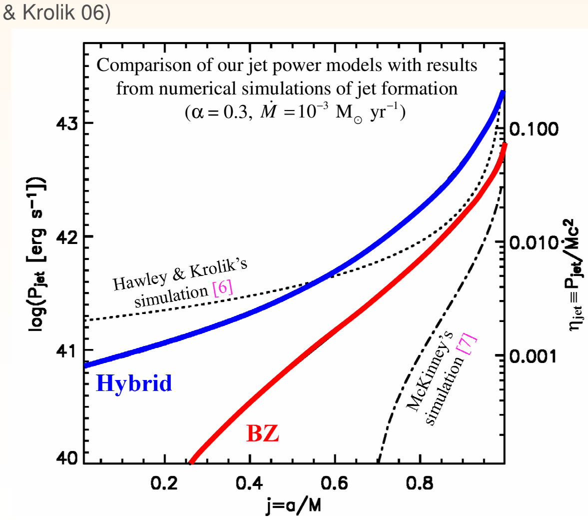


Topology of magnetic field lines in the models: BZ and "hybrid"

Results (part I)

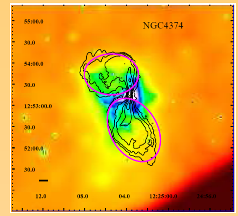
Jet efficiencies predicted from models for high *j* (=*a*/*M*) are comparable to the thin disk radiative efficiency

The *j*-dependence of $P_{\rm jet}$ is very steep, resembling the results of complex MHD simulations (McKinney 05, Hawley & Krolik 06)



Data

From S. Allen et al. 06 (MNRAS): Chandra observations of 9 nearby X-ray luminous elliptical galaxies, with clear X-ray cavities inflated by jets



Chandra X-ray images 0.5 - 8 keV (colour), VLA radio 1.5 GHz (contours), cavities (ellipses)

NGC507
NGC4374
NGC4472
M87
NGC4552
NGC4636
NGC4696
NGC5846
NGC6166

Accretion rates: Bondi rate

$$\dot{M}_{\rm Bondi} = 4\pi r_{\rm A}^2 \rho_{\rm A} c_s(r_{\rm A})$$

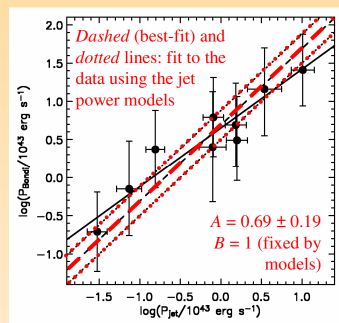
$$r_{\rm A} \sim \frac{GM}{c_s^2}$$ Bondi radius

Jet powers: from energies and timescales required to inflate the cavities

$$P_{\rm jet} = E_{\rm bubble} / t_{\rm age}$$

$$E_{\rm bubble} = 4PV$$

$$t_{\rm age} = R / c_s$$



Main result from Allen+06: **Tight correlation** between accretion rates and jet powers!

$$\log \frac{P_{\rm Bondi}}{10^{43}\,{\rm erg\,s^{-1}}} = A + B \log \frac{P_{\rm jet}}{10^{43}\,{\rm erg\,s^{-1}}}$$

$$P_{\rm Bondi} \equiv 0.1 \dot{M}_{\rm Bondi} c^2$$

Results (part II)
Constraints on black hole spins

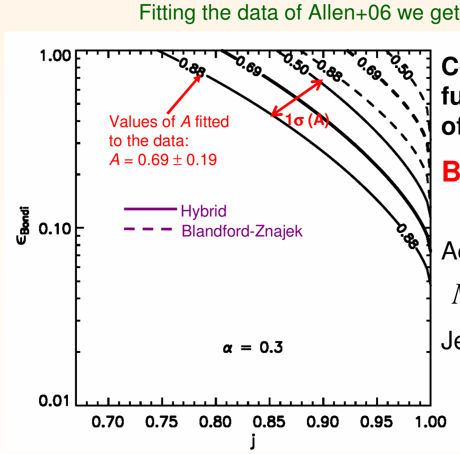
Jet models predict $P_{\rm jet} \propto \dot{M}_{\rm isco}$

$\varepsilon_{\rm Bondi}$ parameter is introduced: $\dot{M}_{\rm isco} = \varepsilon_{\rm Bondi} \dot{M}_{\rm Bondi}$

because Bondi formula *is not ok* for ADAFs, and there may be *winds* in the disk

Models *then* predict $A = \log\left[0.1/\left(\varepsilon_{\rm Bondi}\eta_{\rm jet}(\alpha, j)\right)\right]$, $B = 1$

Fitting the data of Allen+06 we get A: can constrain the spin *j*!



Constraints on fundamental parameters of the AGNs:

Black hole spins:

$$j \approx 0.75 - 1$$

Accretion rates:

$$\dot{M}_{\rm isco} \approx (0.04 - 1)\dot{M}_{\rm Bondi}$$

Jet efficiencies:

$$\eta_{\rm jet} \approx (2 - 48)\%$$

High values of *j* agree with theory/obs.:

- Cosmological simulations of spin evolution (Volonteri+05,+07)
- "Soltan's argument" applied to quasar populations (Soltan 82, Yu & Tremaine 02, Wang+06)