Models for power of jets: A case for rapidly spinning black holes in elliptical galaxies

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

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Motivation

Need for different and *independent* methods to constrain spins of SMBHs

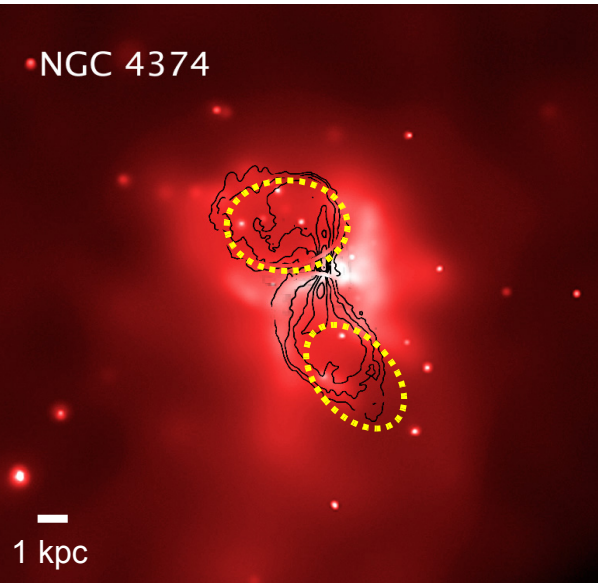
- from X-rays: iron Kα line, QPOs
- from QSO populations: Soltan's argument

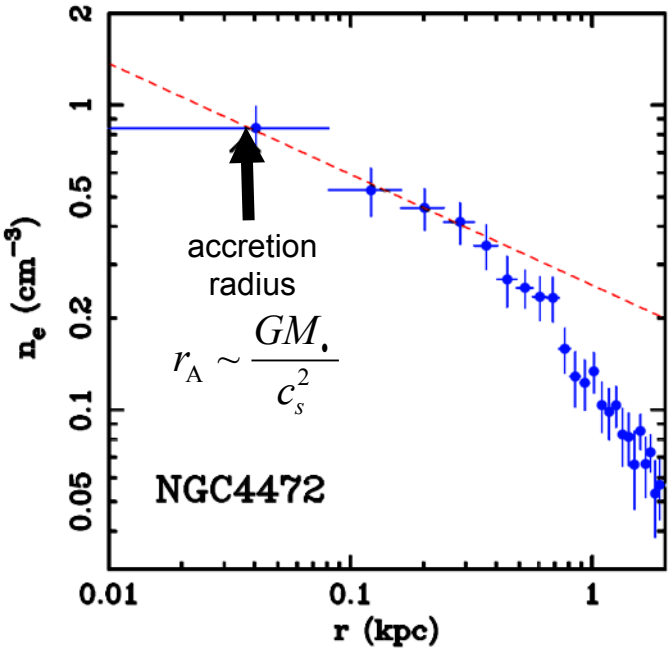
Spin holds the key to *important puzzles*:

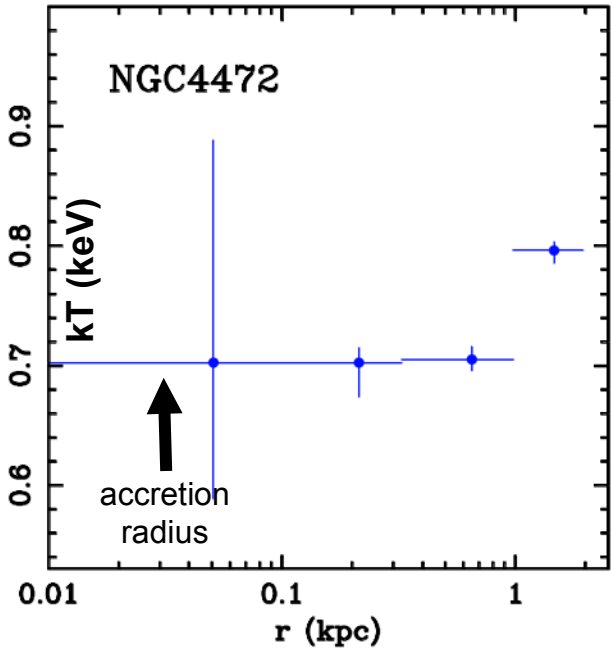
- formation and evolution of BHs
- nature of jets / RL-RQ dichotomy?
- radiative efficiency of QSOs

Chandra observations of nearby radio-loud elliptical galaxies provide jet powers and BH accretion rates

Allen+06 MNRAS: 9 giant ellipticals *with X-ray bubbles/cavities inflated by radio jets* (M87, NGC4696, NGC507, NGC6166, ...)







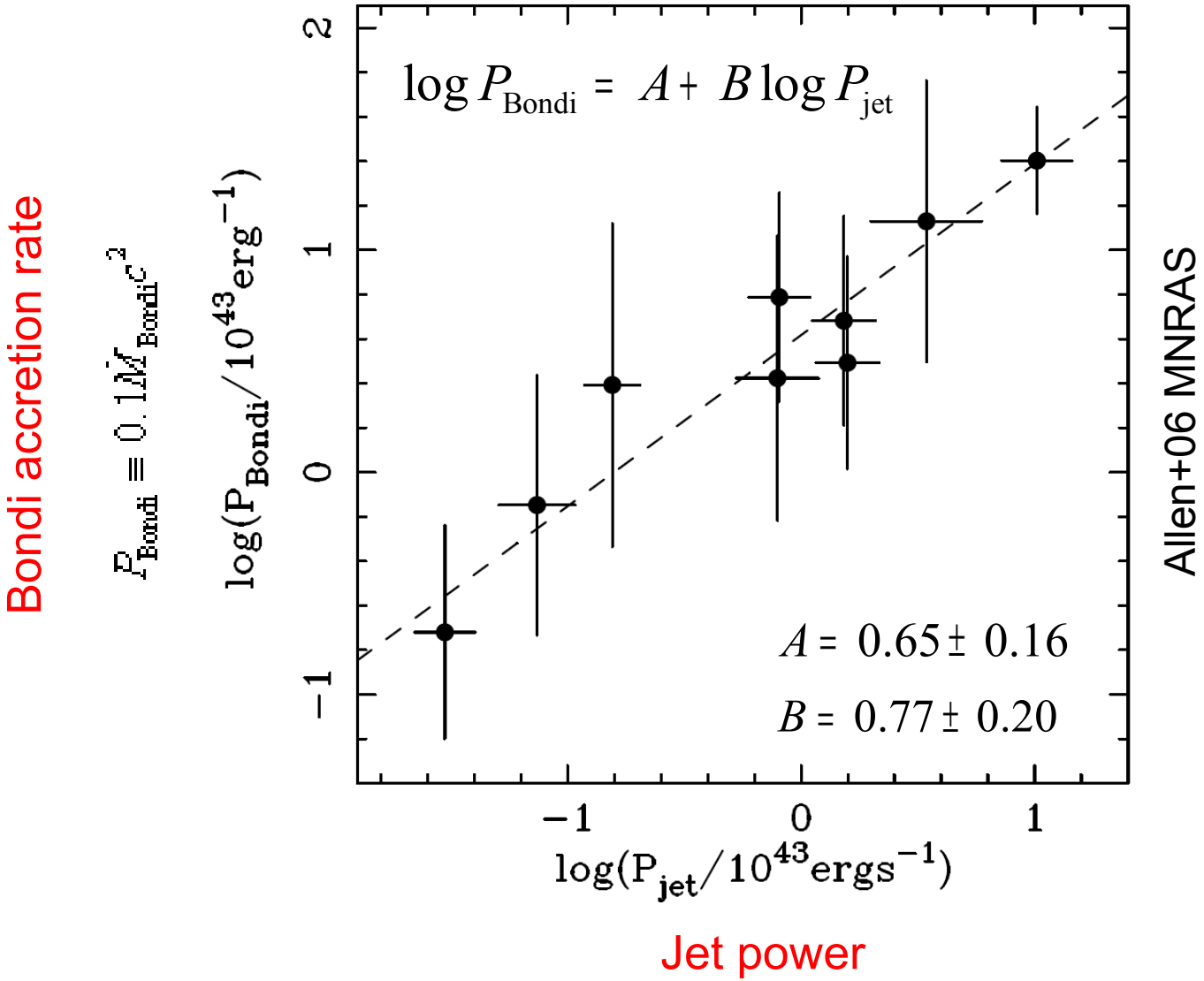
BH accretion rate → ● ← Jet power

$$\dot{M}_{\rm Bondi} \approx 0.1 M_9^2 T_{0.8}^{-3/2} n_{0.17}\ M_\odot {\rm yr}^{-1}$$

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

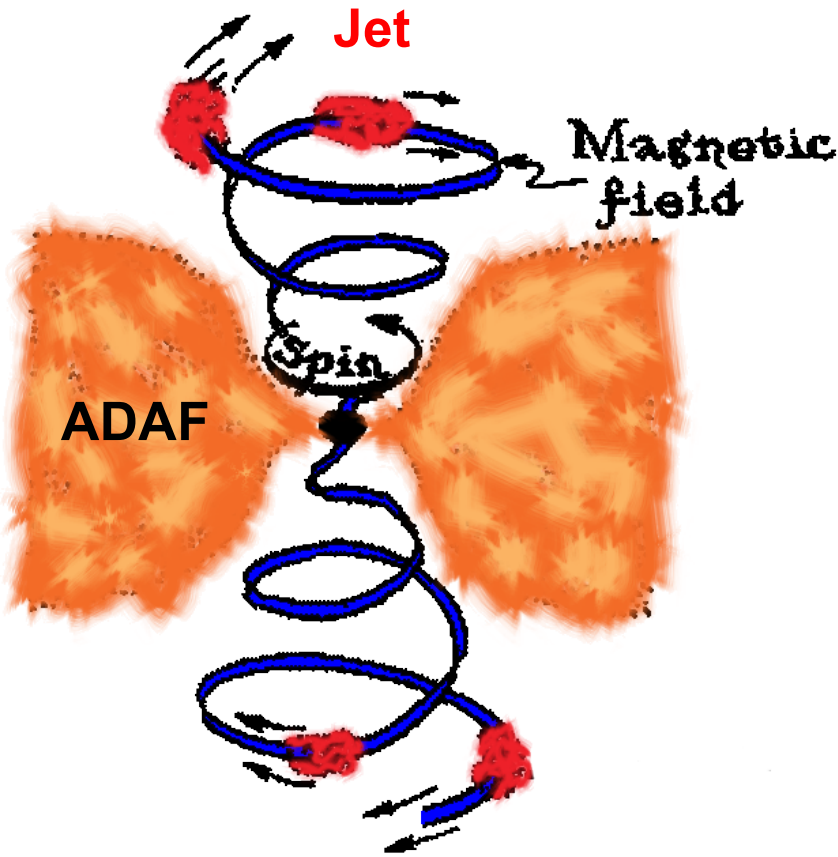
$(4PV_{\rm bub})$ $(R_{\rm bub} / c_s)$

Chandra observations of nearby radio-loud elliptical galaxies suggest tight correlation $\dot{M}_{\rm Bondi} \propto P_{\rm jet}$



Main goal: constrain spins of SMBHs in radio-loud giant elliptical galaxies

How? *New method of estimating spins:* modelling correlation $\dot{M} \propto P_{\rm jet}$ with theory of jet production



Ingredients for jet production in LLAGN:

- Kerr black hole
- hot accretion flow (ADAF or RIAF)
- large scale magnetic fields (threading BH/inner flow)

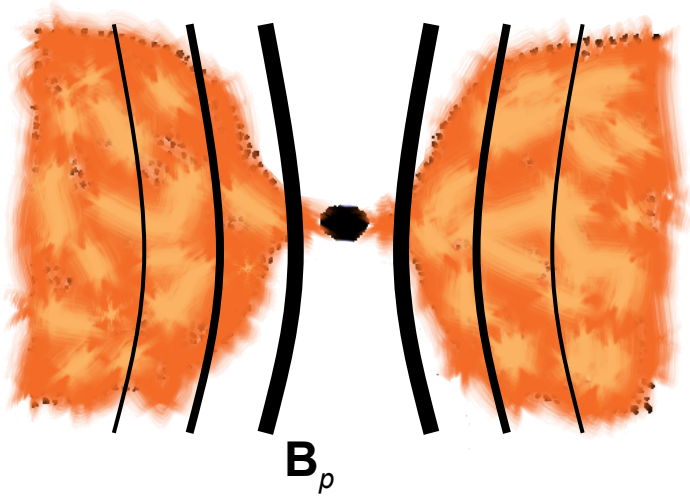
Why ADAF? Favored accretion mode for low-luminosity AGN

LLAGNs: low accretion powers, unusual SEDs (Ho 08, Yuan 07)

Mag. fields in ADAFs more “conducive” to jet formation than thin accr. disks
(Rees+82, Meier 01, Ballantyne 07)

LLAGNs have high jet powers (Körding+08, Heinz+07)

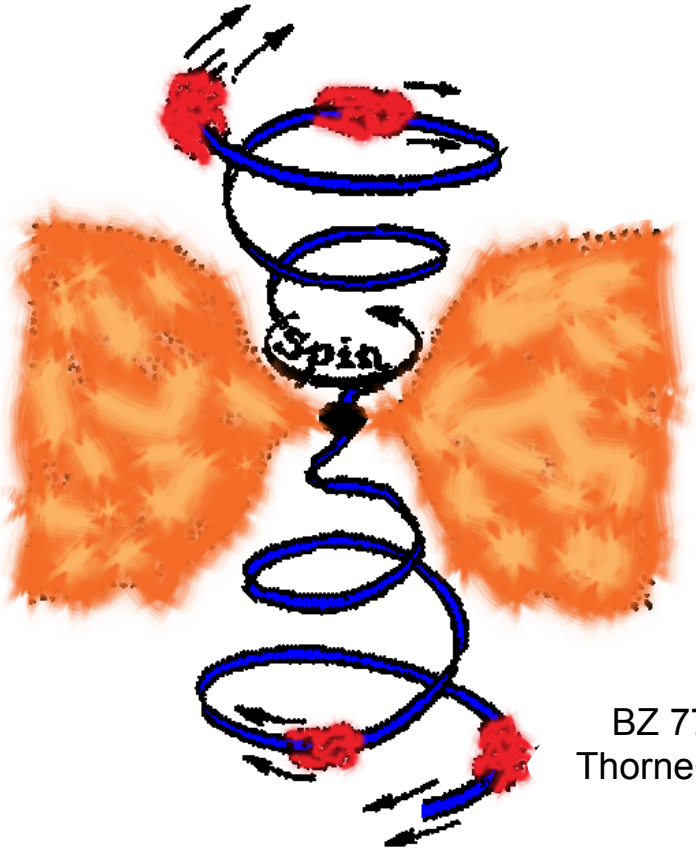
Jet needed to explain radio part of LLAGN SEDs (poster 323 by Nemmen)



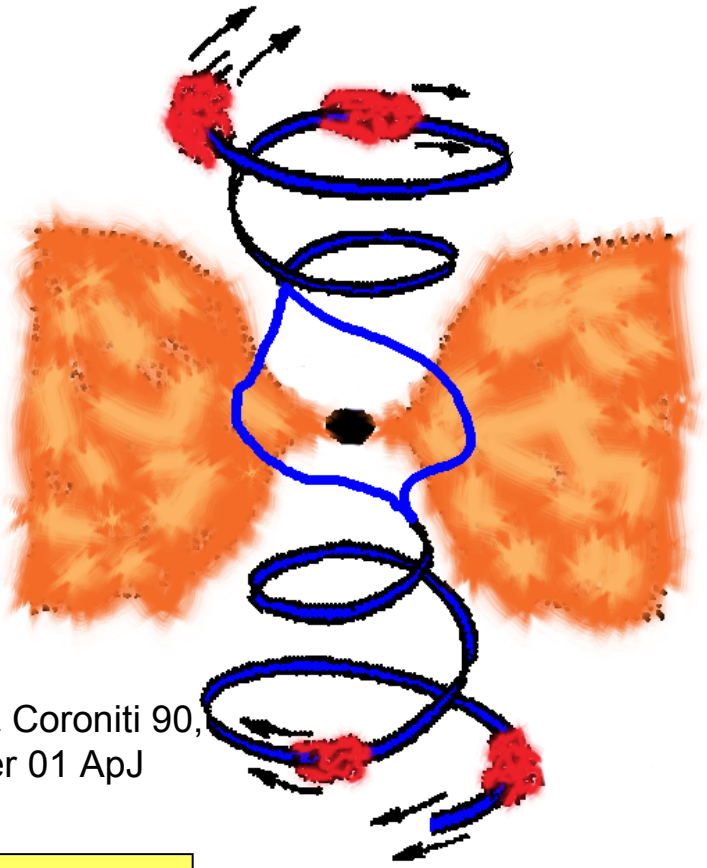
$$P_{\rm jet} \propto B_p^2$$

$$B_p \propto \frac{H}{R}$$

Models of jet powering:
(1) Blandford-Znajek (2) ersgospheric "winds" (hybrid)



BZ 77,
Thorne+86



Punsly & Coroniti 90,
Meier 01 ApJ

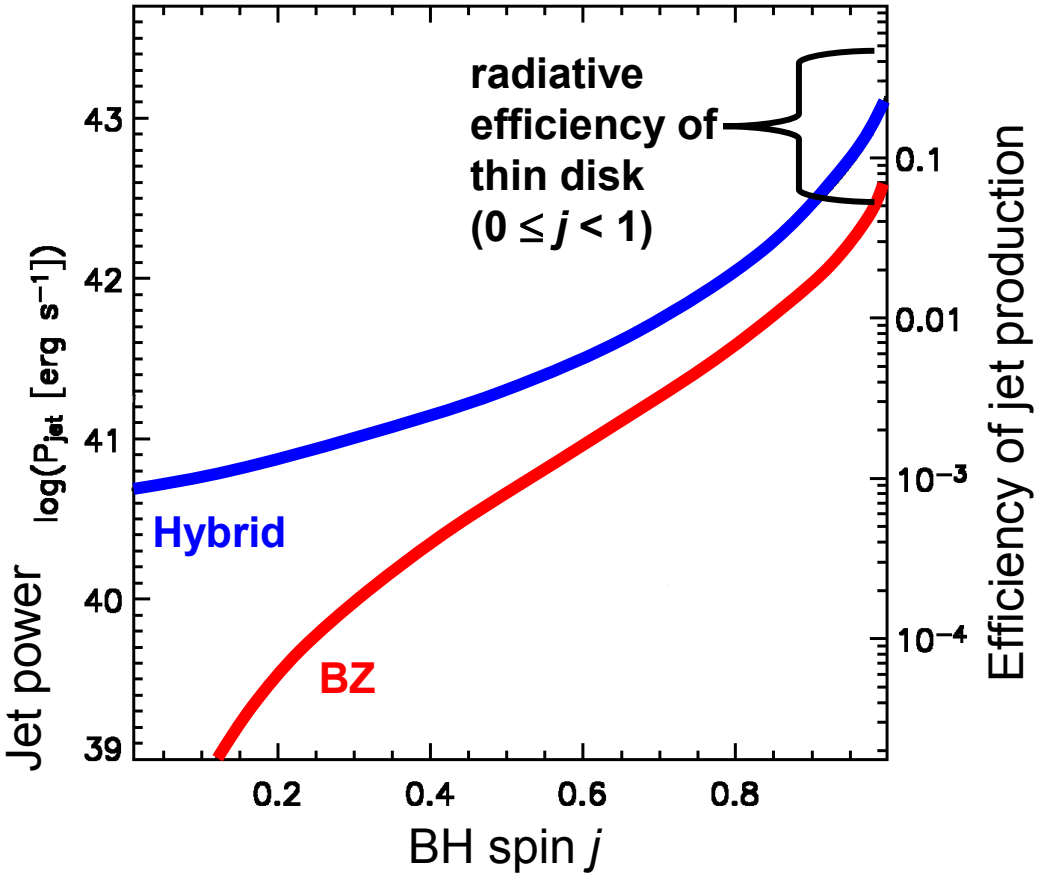
Basic model parameters:
M, black hole spin ($j=a/M$), α

Output: Jet power P_{jet}

Models imply that jet power strongly depends on the BH spin

$\alpha = 0.3$

$\dot{M}(\mathrm{isco}) = 10^{-3} M_{\odot}\ \mathrm{yr}^{-1}$



For $j \geq 0.9$: jet efficiency

$$\frac{P_{jet}}{\dot{M}_{\mathrm{isco}} c^2} \sim 10\%$$

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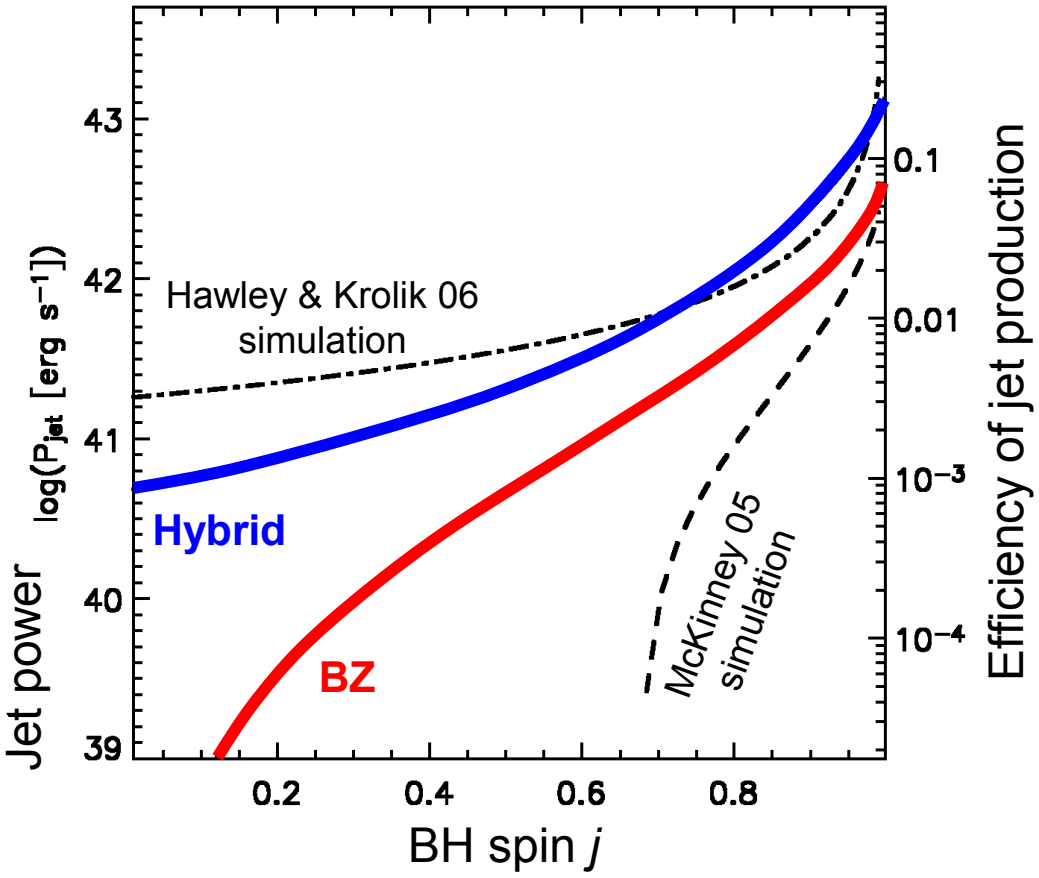

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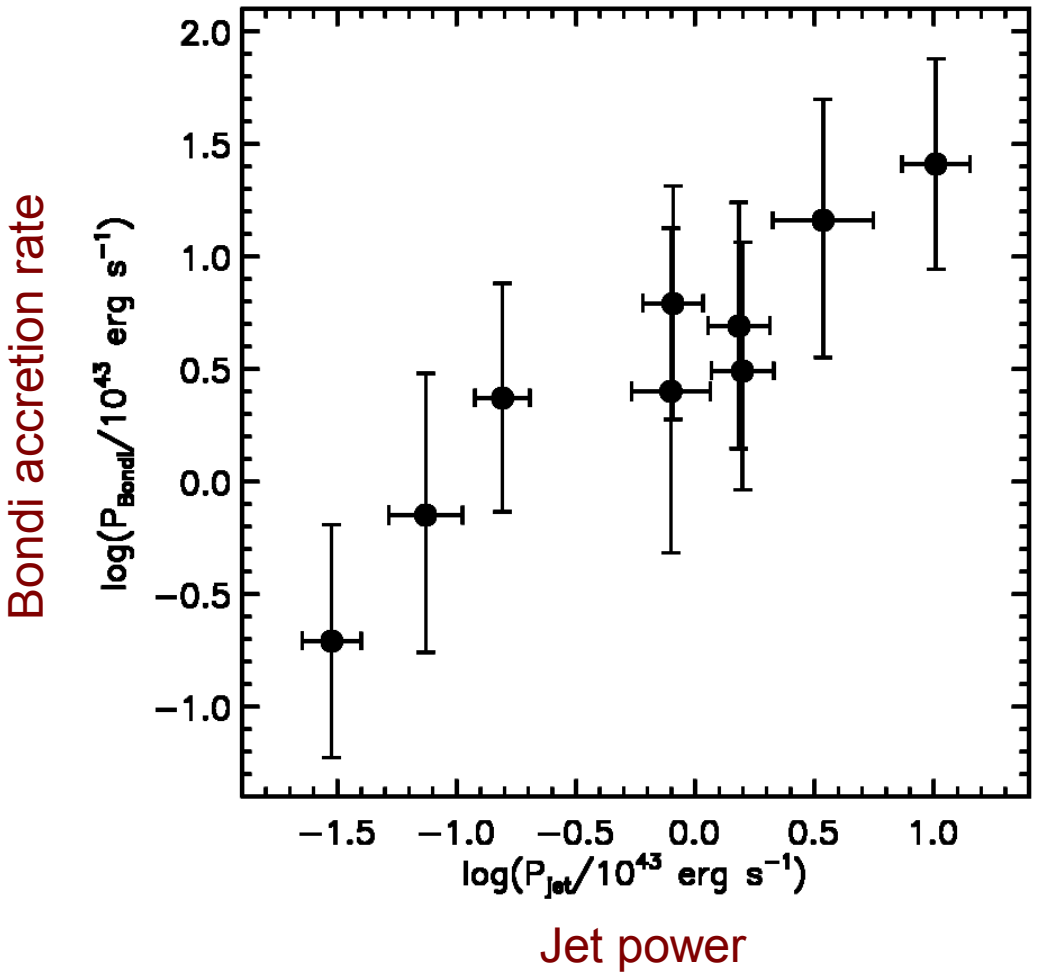
Jet models predict $P_{\rm jet} \propto \dot{M}_{isco}$



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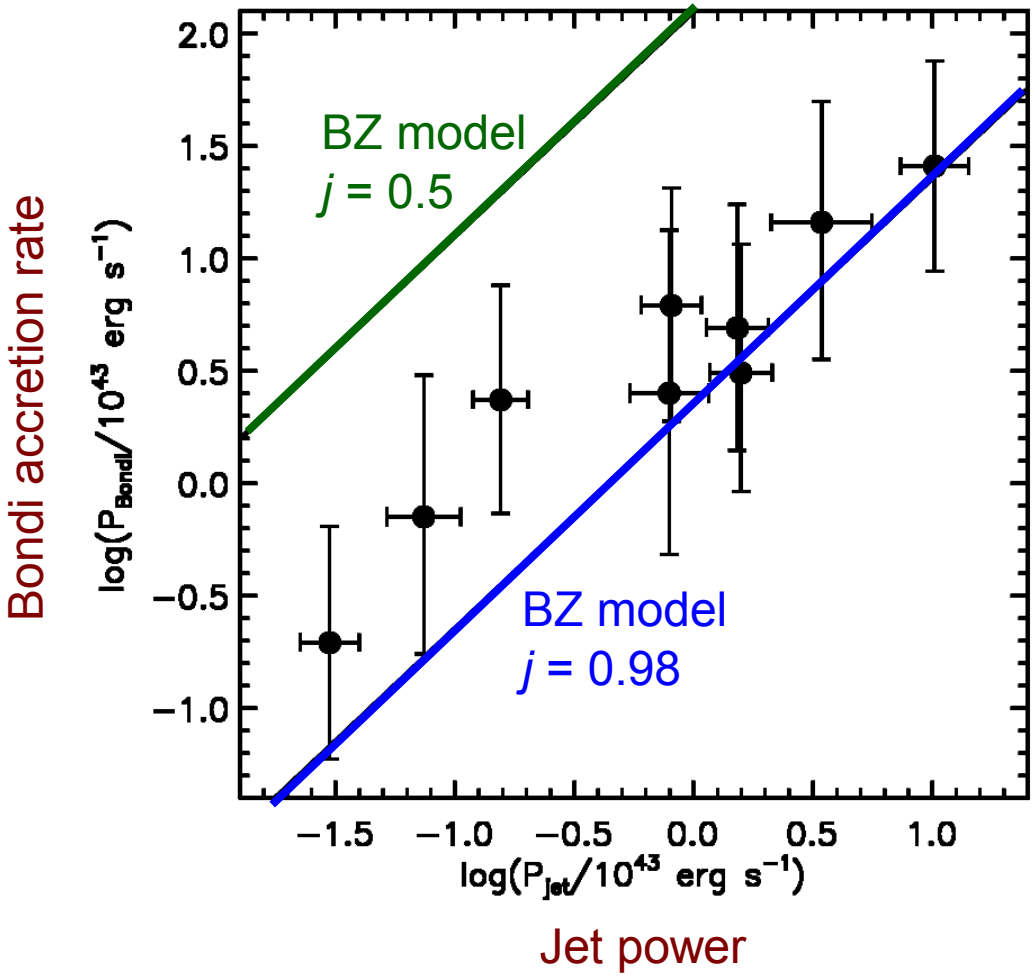

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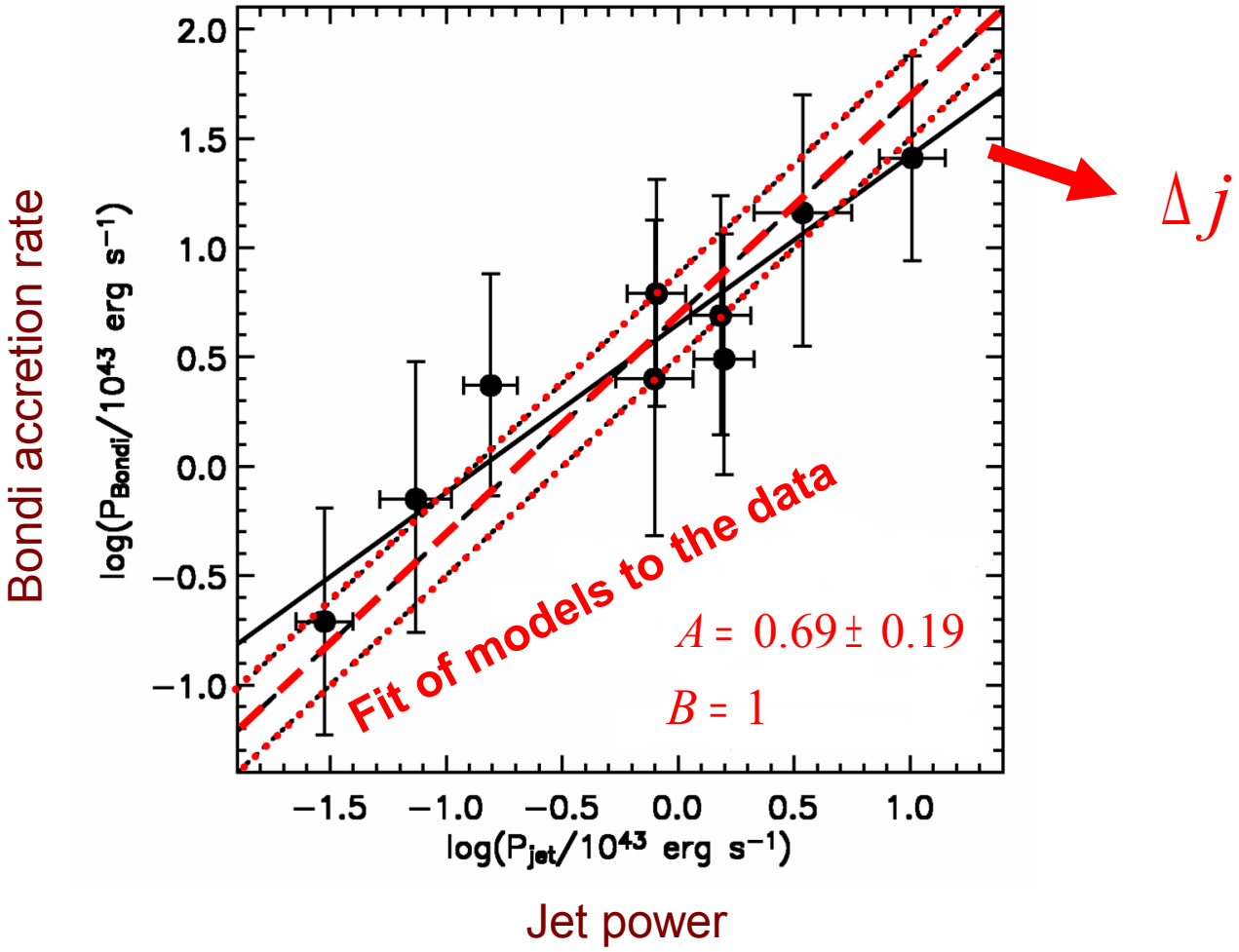
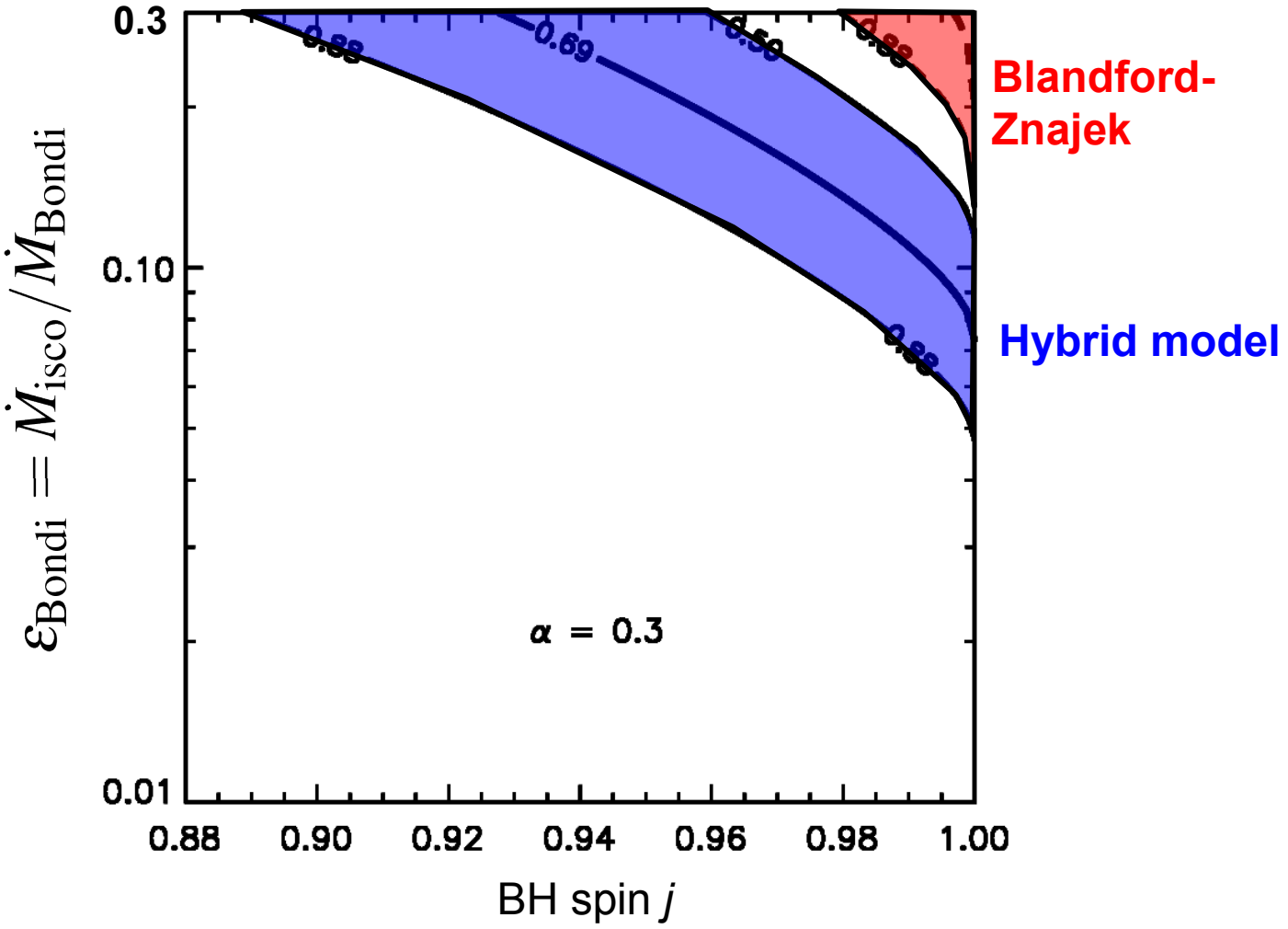


Constraints on the spins of central SMBHs



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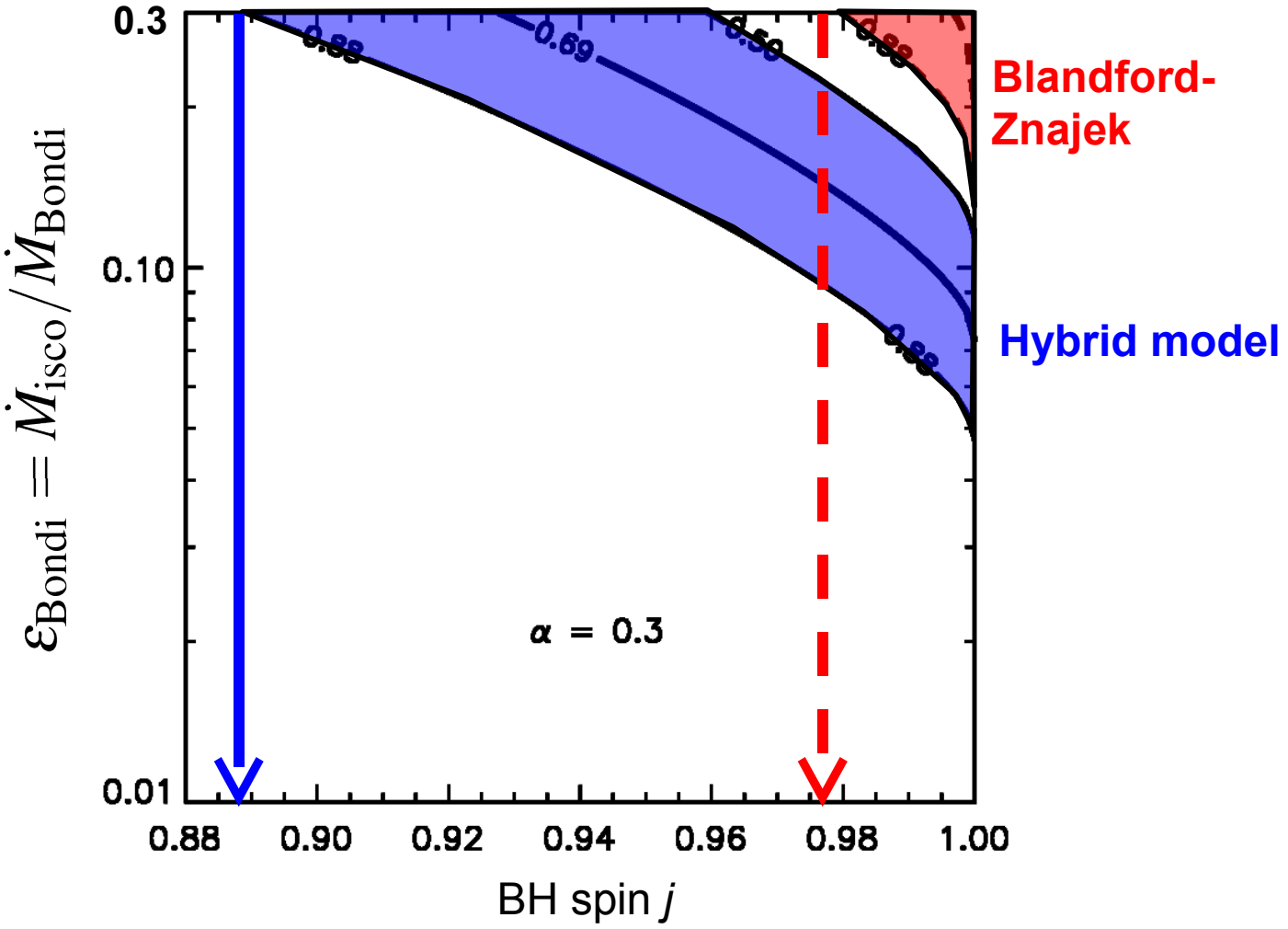

Tight correlation $\dot{M} \propto P_{\rm jet}$ → Black hole *spins*: ***j*** **≈ 0.9 – 1**

Conclusions

Developed models for jet power in LLAGNs: ADAF + Kerr BH

New way of estimating BH spins: modelling correlation $\dot{M}_{\rm Bondi} \propto P_{\rm jet}$

SMBHs in many radio-loud giant elliptical galaxies are rapidly rotating

Future research:

- probe accretion mode in LLAGNs: SEDs
- correl. $\dot{M} \propto P_{\rm jet}$: enlarge sample of ellipticals
- more spin determinations for SMBHs!
- improve understanding of jet production (theory/simulations)