

Determination of the spins of supermassive black holes in active galactic nuclei

Alexander Mikhalov.

Special Astrophysical Observatory, Russia

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Black hole



$$a = \frac{cJ}{GM_{BH}^2} \quad M_{BH}$$

$$|a| < 1$$

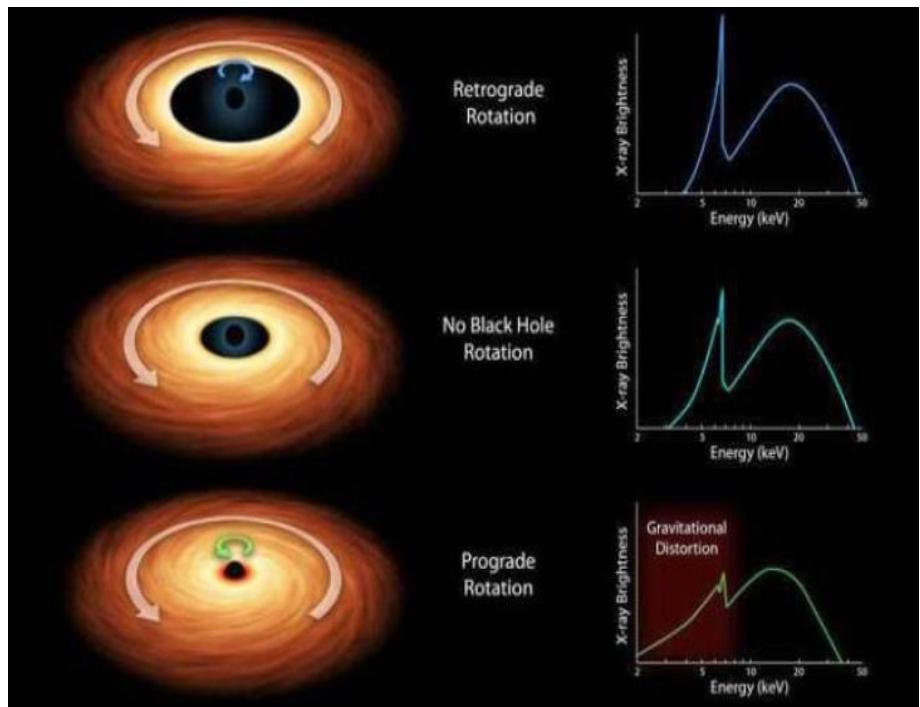
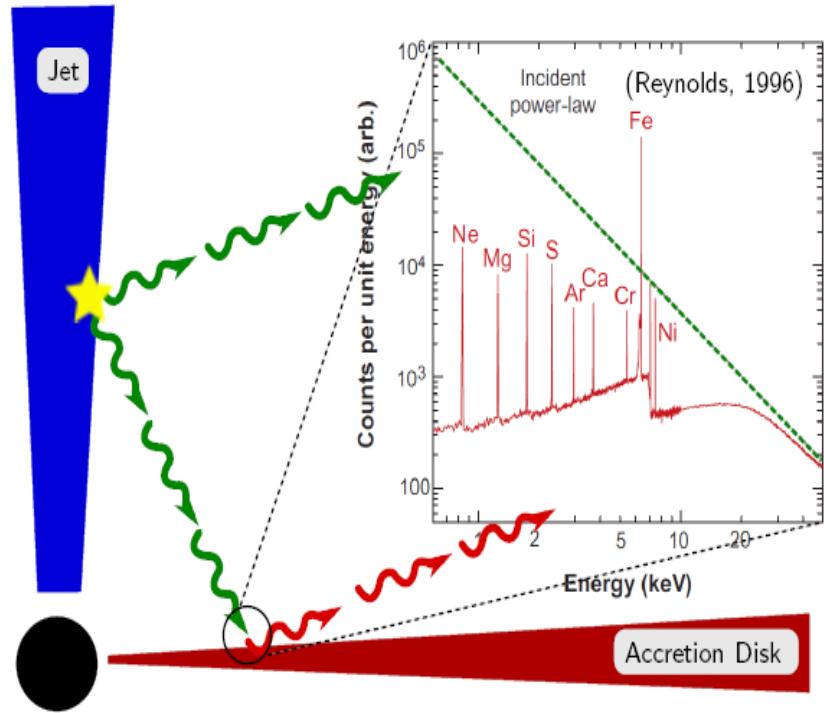
mergers, accretion, removing the angular momentum by jet

changes spin



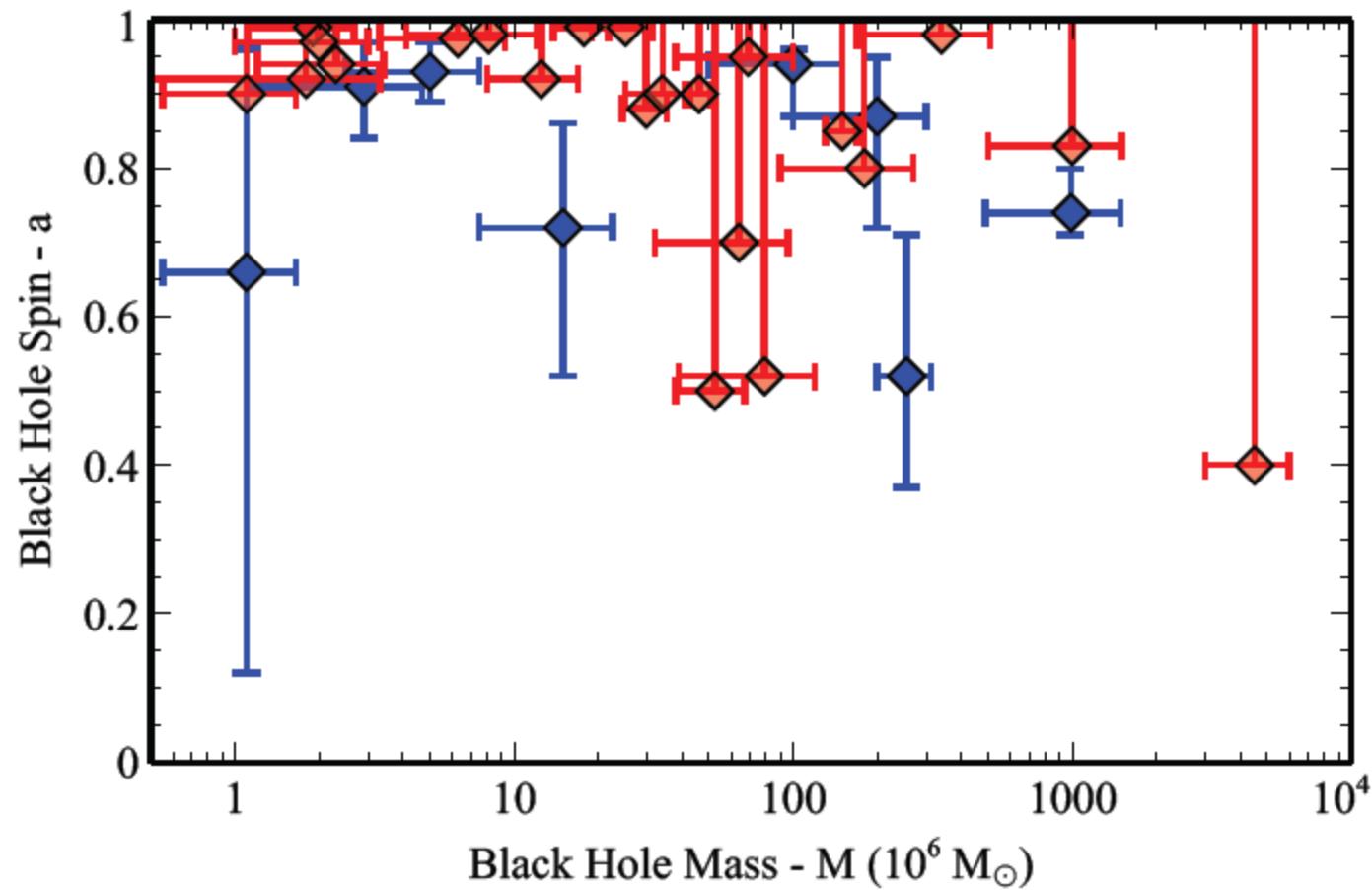
It is necessary to construct the diagram "mass-spin"

Methods for determination of the BH spin (XRS, TCF)



High quality X-rays spectra are required → constraints of the SMBH spin are obtained for ~ 40 nearby AGNs

Summary of SMBH spin measurements (rev. C. Reynolds 2021)

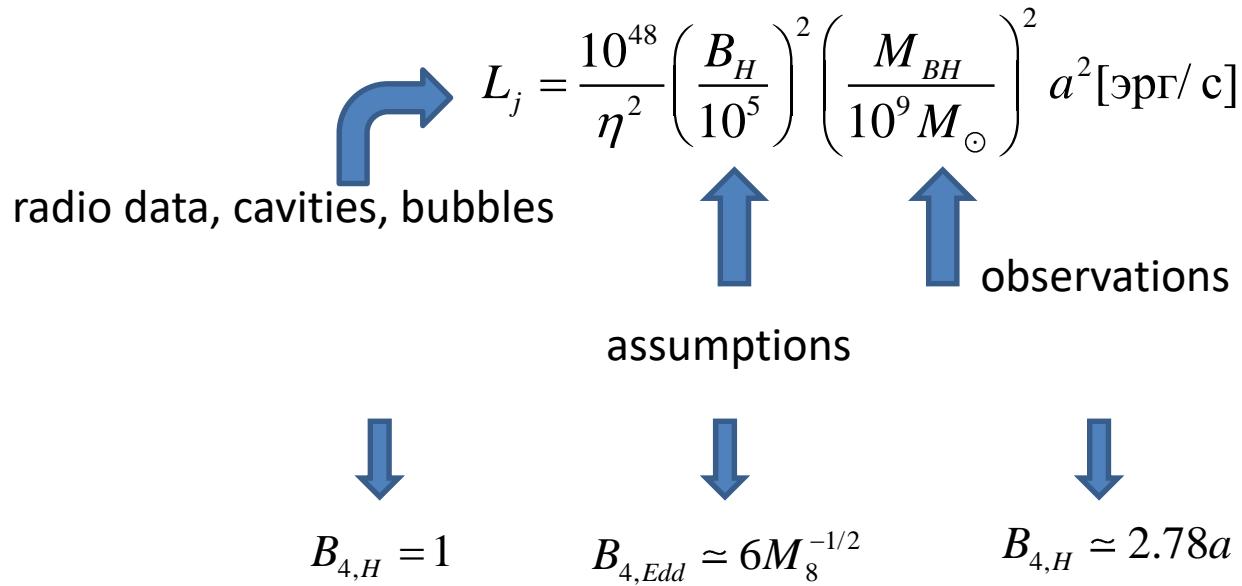


Methods of the spin determining based on jet models

Hybrid models:

Blandford-Znajek and Blandford-Payne mechanisms

R. Daly 2009, R. Daly & T. Sprinkle 2014:



Results: constraints of the spins for 130 SMBH in AGN mainly FRII radio morphology

Our approach

The hybrid model of Meier
D. Meier 1999, R. Daly 2009

$$L_j = \frac{10^{48}}{\eta^2} \left(\frac{B_H}{10^5} \right)^2 \left(\frac{M_{BH}}{10^9 M_\odot} \right)^2 a^2 [\text{erg/s}]$$

+

$$B_H = \frac{1}{R_H} \sqrt{\frac{2 \dot{M} c}{\beta}}$$



$$f(a) = \frac{|a|}{\sqrt{\varepsilon(a)} \left(1 + \sqrt{1 - a^2} \right)} = 1.77 \times \sqrt{\beta} \left(\frac{L_j}{L_{bol}} \right)^{1/2}$$

$$\beta = 1$$



Equipartition

The flux-trapping model (FT)
D. Garofalo 2009, D. Garofalo et al. 2010

$$L_j = 2 \times 10^{47} \alpha \gamma^2 \left(\frac{B_d}{10^5} \right)^2 \left(\frac{M_{BH}}{10^9 M_\odot} \right)^2 a^2 [\text{erg/s}]$$



$$\frac{\beta_1 B_d^2}{8\pi} = \frac{L_{bol}}{4\pi c R_{in}^2}$$



$$X(a) = 16.48 \beta_1 \frac{L_j}{L_{bol}}$$

$$\beta_1 = 1$$

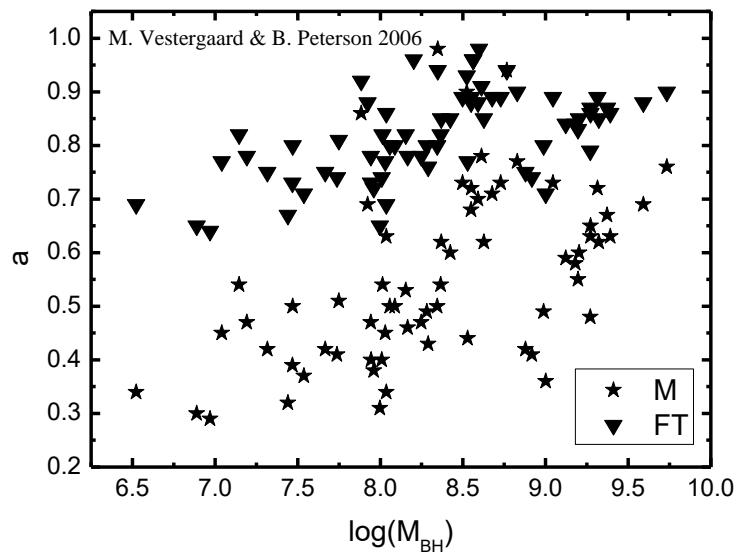
Lower limit spin

Comparison with the XRS method

Name	spin (XRS)	spin (M)	spin (FT)
MCG-6-30-15	$0.91^{+0.06}_{-0.07}$	$0.49^{+0.25}_{-0.17}$	$0.79^{+0.11}_{-0.12}$
Fairall 9	$0.52^{+0.19}_{-0.15}$	$0.88^{+0.12}_{-0.26}$	$0.93^{+0.05}_{-0.07}$
SWIFT J2127.4+5654	$0.72^{+0.14}_{-0.20}$	$0.61^{+0.29}_{-0.19}$	$0.85^{+0.08}_{-0.10}$
1 H0707-495	> 0.94	$0.38^{+0.21}_{-0.14}$	$0.72^{+0.12}_{-0.14}$
Mrk 79	> 0.50	$0.88^{+0.12}_{-0.26}$	$0.93^{+0.05}_{-0.07}$
Mrk 335	> 0.99	$0.56^{+0.27}_{-0.19}$	$0.83^{+0.09}_{-0.11}$
NGC 3783	> 0.88	$0.83^{+0.17}_{-0.24}$	$0.92^{+0.05}_{-0.08}$
Ark 120	> 0.85	$0.94^{+0.06}_{-0.27}$	$0.94^{+0.04}_{-0.07}$
3C 120	> 0.95	$0.52^{+0.27}_{-0.17}$	$0.81^{+0.10}_{-0.11}$
1 H0419-577	> 0.98	$0.35^{+0.21}_{-0.12}$	$0.70^{+0.13}_{-0.15}$
Ark 564	> 0.90	$0.70^{+0.30}_{-0.22}$	$0.88^{+0.07}_{-0.09}$
Mrk 110	> 0.99	$0.63^{+0.30}_{-0.20}$	$0.86^{+0.08}_{-0.10}$
Ton S180	> 0.98	$0.31^{+0.18}_{-0.12}$	$0.66^{+0.14}_{-0.16}$
RBS 1124	> 0.80	$0.64^{+0.31}_{-0.20}$	$0.86^{+0.08}_{-0.10}$
Mrk 359	$0.66^{+0.30}_{-0.54}$	$0.56^{+0.27}_{-0.19}$	$0.83^{+0.09}_{-0.11}$
Mrk 841	> 0.52	$0.48^{+0.24}_{-0.17}$	$0.79^{+0.10}_{-0.13}$
IRAS13224-3809	> 0.975	$0.42^{+0.22}_{-0.15}$	$0.75^{+0.11}_{-0.14}$
NGC 4051	> 0.99	> 0.73	$0.95^{+0.04}_{-0.06}$
NGC 1365	> 0.97	$0.83^{+0.17}_{-0.24}$	$0.92^{+0.05}_{-0.08}$

Applications

PG quasars, $0 < z < 0.5$



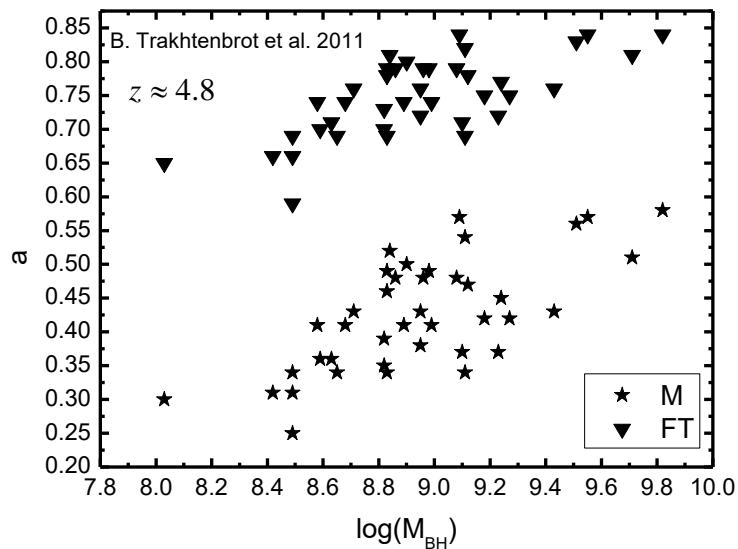
Merloni & Heinz 2007:

$$\log \frac{L_j}{L_{\text{Edd}}} = (0.49 \pm 0.07) \log l_E - (0.78 \pm 0.36)$$

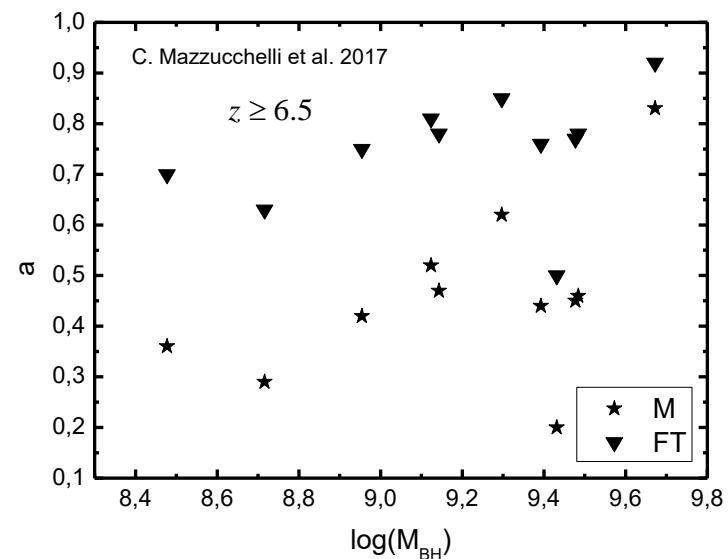
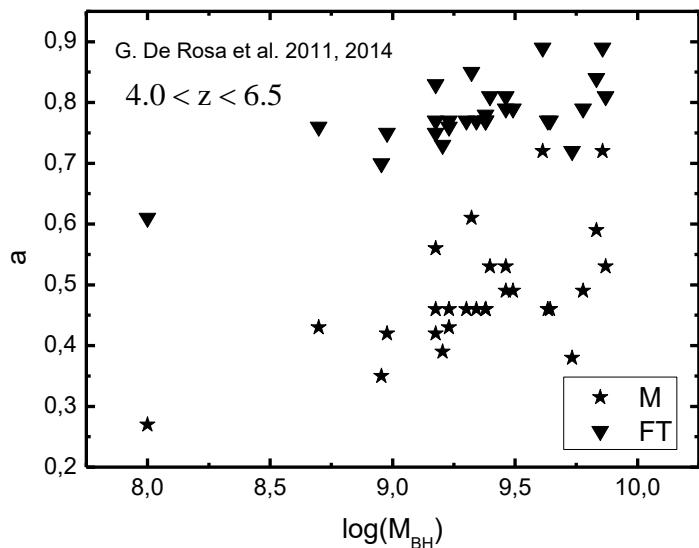


cavities, bubbles

Applications



$$\log \frac{L_j}{L_{\text{Edd}}} = (0.49 \pm 0.07) \log l_E - (0.78 \pm 0.36)$$

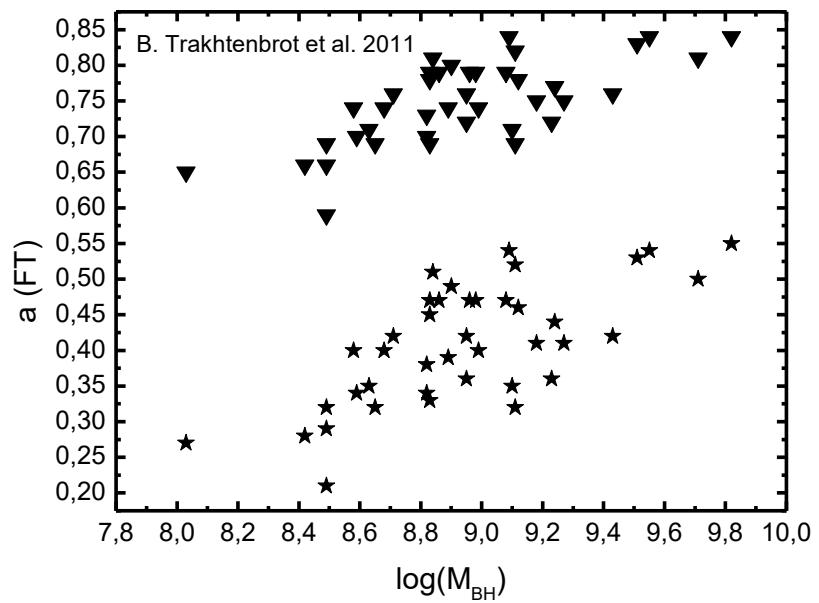
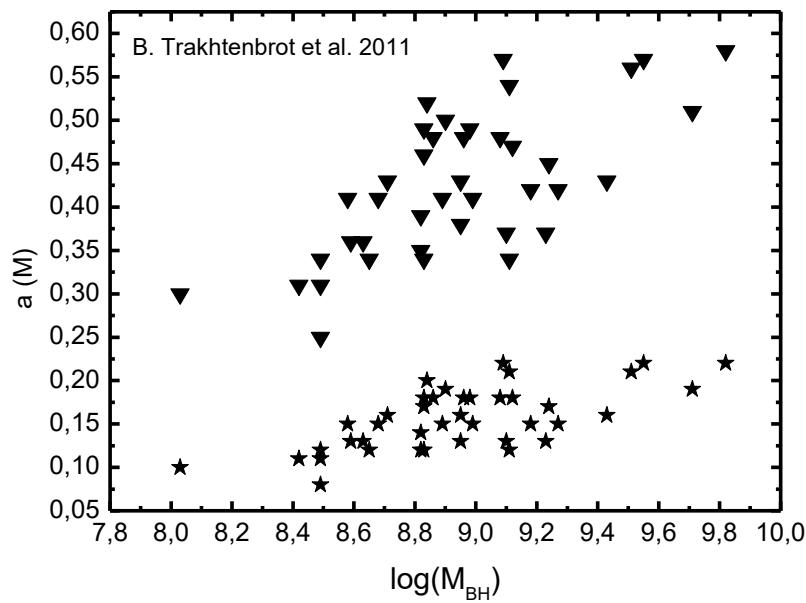


Influence of empirical relations on results

$$\log L_X = 9.86 + 0.75 \log L_{bol}$$

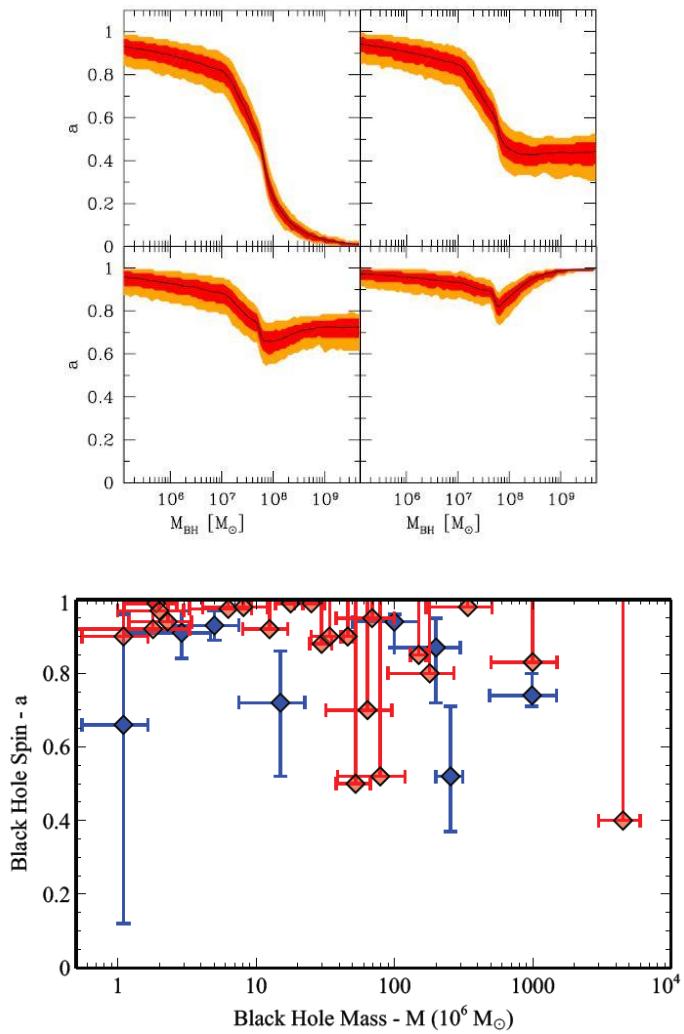
$$\log \frac{L_j}{L_{Edd}} = (0.49 \pm 0.07) \log l_E - (0.78 \pm 0.36) \quad \log L_R = (0.60 \pm 0.11) \log L_X + (0.78^{+0.11}_{-0.09}) \log \frac{M_{BH}}{M_\odot} + 7.33^{+4.05}_{-4.07}$$

$$\log L_j = (0.81 \pm 0.11) \log L_R + (11.9 \pm 4.1)$$

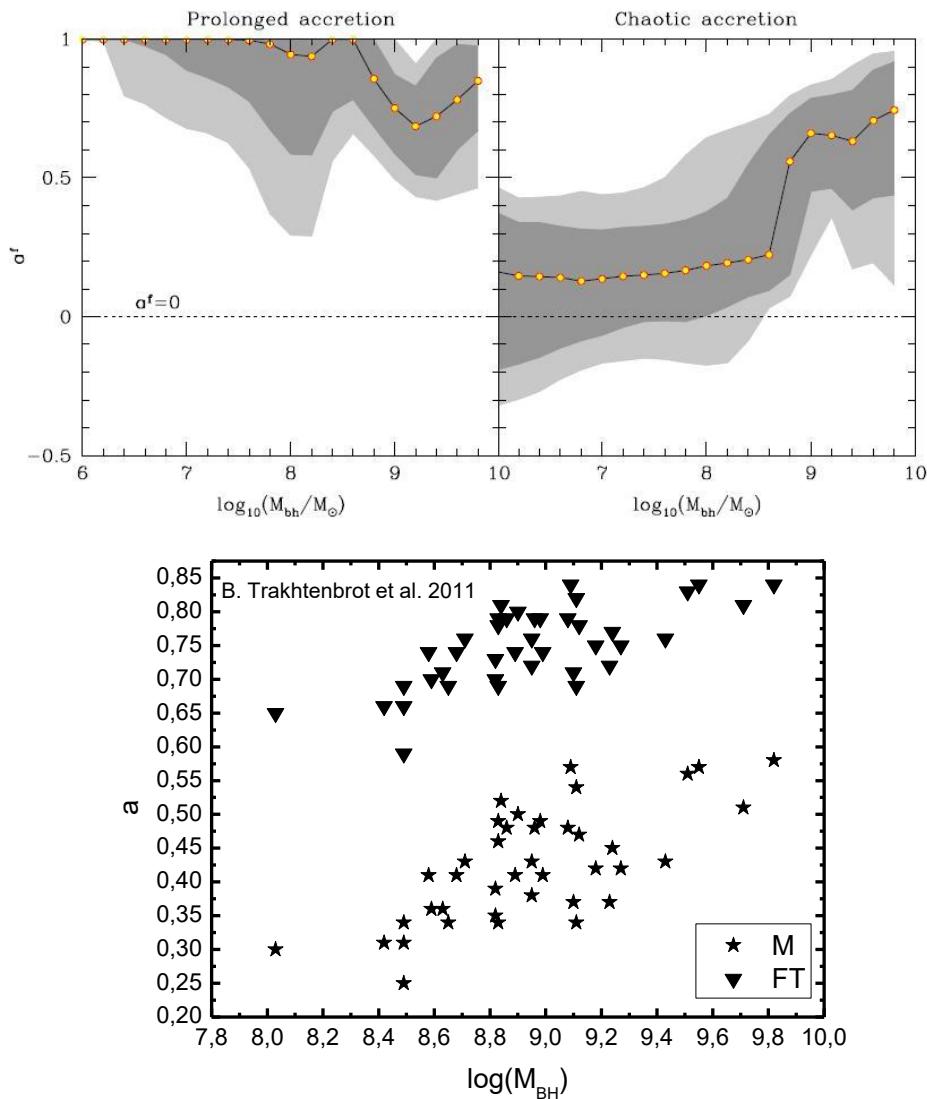


The modeling evolution of SMBH by mergers and accretion processes

Dotti et al. 2013



Fanidakis et al. 2011



Conclusions

- It is necessary to develop methods for determining the magnetic field close to BH
- The assumption equipartition is reasonable for systems with thin accretion disk
- The obtained diagrams "mass-spin" can be used for study the accretion processes onto SMBH

Thanks for your attention!