NEW CONSTRAINTS ON THE BLACK HOLE SPIN IN RADIO LOUD QUASARS

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Active Galactic Nuclei (AGN) Zoo

- QSO/quasar
- Seyfert galaxy
- Blazar, FSRQ, BL Lac
- Radio galaxies
- FR I / FR II
- HERG / LERG
- LINERS

Alexander & Hickox (2012)
AGN Unification: Radio properties?

What causes AGN to be radio-loud (RL) or radio quiet (RQ) / have relativistic jets?

- Black hole mass $M_{BH}$
- Eddington ratio $\lambda = L_{bol} / L_{edd}$
- BH spin

Urry & Padovani (1995)
RL/RQ dichotomy

$$R = f_{6\text{cm}} / f_{2500} > 10$$

~ 10% of AGN are radio loud

➢ RL/RQ dichotomy

White et al. (2007)  
Balokovic et al. (2012)
Radio loud fraction changes with BH mass and Eddington ratio (e.g. Laor 2000, Kratzer et al. 2015)

RL fraction highest at high BH mass and low Eddington ratio

Parameter dependence of RL fraction
Radio loudness governed by $M_{\text{BH}}$ and $\lambda$?

- BH mass and Eddington may play a role but are not sufficient to produce RL quasar
- Even at high $M_{\text{BH}}$, low $\lambda$ majority of population is RQ

- What else?
  - BH spin
The spin paradigm

- Energy can be extracted from a spinning black hole e.g. via the Blandford-Znajek process (Blandford & Znajek 1977)
- Magnetic field extracts spin energy

⇒ Collimation of radio jets
⇒ radio loud AGN

NASA/JPL-Caltech
Radiative efficiency as tracer of BH spin

- $L_{bol} = \varepsilon \dot{M}_{AD} c^2$
- BH spin sets inner edge of accretion disk (ISCO)
- sets radiative efficiency $\varepsilon$
  - For thin-disk accretion $\varepsilon \sim 0.05-0.42$ (for non-spinning – max.-spin BH)
  
  ⇒ Focus on luminous, radiatively efficient type-1 QSOs (thin accretion disks)

Madau et al. (2014)
**SED for RL and RQ QSOs**

- At fixed optical luminosity, difference in SED in EUV regime expected as function of BH spin
- EUV cannot be directly probed
- Use [OIII] as average tracer of $L_{\text{bol}}$ via probing the peak of SED in UV regime

![Graph showing the log rest frequency vs log $V F_{\nu}$ with [OIII] (5007A) emission peaks at different BH spins]
Sample of RL and RQ quasars

- Focus on luminous type-1 QSOs from SDSS

**Sample:**
- SDSS DR7 QSO catalog, uniform target within FIRST footprint
- $i<18.9$ (to match optical depth and FIRST depth for RL/RQ classification)
- $0.3<z<0.84$
- measured BH mass from Hbeta and measured [OIII] luminosity
- Accretion rates from Wu et al. (2013)

RL: 757  RQ: 7187

⇒ Control RL and RQ sample for BH mass, Luminosity, $\dot{M}_{AD}$
  (1) match on grid  (2) match individual objects

⇒ Do RL and RQ have same average radiative efficiency?

$$L_{\text{bol}} = \epsilon \dot{M}_{AD} c^2$$
Enhanced $L_{\text{OIII}}$ in RL quasars

Difference in $L_{\text{OIII}}$ between RL and RQ QSOs in grid on $M_{\text{BH}}, L_{5100}$ or $M_{\text{BH}}, \dot{M}_{\text{AD}}$

⇒ Radio loud QSOs have enhanced $L_{\text{OIII}}$

Schulze et al. (in prep.)
Enhanced $L_{\text{O}III}$ in RL quasars

➢ Compare RL QSOs and matched RQ sample, in $z$, $M_{\text{BH}}$ and $L_{5100}$
➢ Mean offset in log $L_{\text{O}III}$ distributions of 0.18 dex => factor 1.5
⇒ KS-test: $D=0.188$, $p=5.204\times10^{-20}$
⇒ Result independent of definition of RL
Narrow emission lines in spectral stack

Stack of RL and RQ matched QSO samples

**OIII profile:**
⇒ enhancement due to core emission
⇒ trend is not driven by outflows/shocks
⇒ same enhancement present in all high excitation narrow lines
Broad emission lines in spectral stack

- Low ionization broad lines of Balmer lines and MgII show no strong difference between RL and RQ stack

- High ionization broad line of HeII **does** show enhancement in RL stack, similar to narrow lines
RL quasars have higher BH spin

⇒ RL quasars have higher $L_{\text{bol}}$ at a given $\dot{M}_{\text{AD}}$

$L_{\text{bol}} = \varepsilon \dot{M}_{\text{AD}} c^2$

⇒ have average radiative efficiency factor 1.5 higher than RQ quasars

⇒ RL quasars have higher average BH spin

⇒ different BH spin distributions

assume:
RQ: $\varepsilon = 0.1 \Rightarrow a = 0.67$
RL: $\varepsilon = 0.15 \Rightarrow a = 0.89$


Thank you!