Spin estimation of the Supermassive Black Hole of III Zw 2

"Joint XMM-Newton and NuSTAR observations of the reflection spectrum of III Zw 2"

Wara Chamani, Karri Koljonen and Tuomas Savolainen
Aalto University Metsähovi Radio Observatory, Finland

AGN Jet Workshop January 2020
Tohoku University, Sendai
Black hole spin observations

→ 22 robust spin values measured using X-ray reflection method.
→ No Spin vs BH mass correlation.

Reynolds 2019.
Motivation of this work

→ A wide radio-loudness ($R$) distribution in AGN.
→ at least 4 orders of magnitude of accretion rate difference!

What creates a powerful black hole jet?

Powerful jet → High black hole spin?
Weak jet → Low black hole spin?

Which other parameter can dominate besides the spin?
Motivation of this work

Magnetic flux threading the black hole → that launch powerfull jets. "Magnetic flux paradigm" → may explain the $R$ dichotomy (Sikora & Begelman 2007).

Magnetically Arrested Disk (MAD) (Narayan + 2003; Tchekhovskoy + 2011; McKinney + 2012) explains the powerful jets.

Jet magnetic flux versus $L_{\text{acc}}^2 M_{\text{BH}}$ for FSRL+RG+Low Luminosity Radio Loud AGN. Solid line is the MAD prediction. (Zamaninasab+2014)
Motivation of this work

Magnetic flux threading the black hole → that launch powerfull jets. “Magnetic flux paradigm” → could explain the $R$ dichotomy (Sikora & Begelman 2007)


Physical parameters MAD model: BH spin (X-rays) + Jet’s Magnetic field flux (VLBI).


Jet magnetic flux versus $L_{\text{acc}}^1 M_{\text{BH}}$ for FSRL+RG+Low Luminosity Radio Loud AGN. Solid line is the MAD prediction. (Zamaninasab+2014)
A RIQ, it certainly emits radiation from radio to gamma-ray wavelengths.

- Highly variable in radio band emissions.
- Li+2010: Quasi periodic activity. Outburst period ~ 5 years at 22 and 37 GHz. This might be due to the rotation of the helix in the jet.
VLBI observations of III Zw 2

It has a compact radio core.

Core dominated flat radio spectrum

VLA-A configuration 1.4 GHz image in the MOJAVE sample (Cooper+2017).

MOJAVE archive.

- A jetted source with a apparent superluminal motion :1.58±0.29c (Lister et al. 2019).
- Maximum jet’s viewing angle: 41° (Brunthaler+2000).
X-ray reflection spectrum

Direct Power-law

Observer

"Reflection" spectrum

Accretion

BH

disk

X-ray reflection spectrum

Direct Power-law

Observer

"Reflection" spectrum

Accretion BH disk

Soft excess – broad iron line – Compton hump

Credits: Fabian 2016.

Black hole spin, FeK line at 6.4 keV

Image taken from NASA pictures.
Black hole spin, FeK line at 6.4 keV

X-ray Reflection spectrum

Image taken from NASA pictures.

Credits: Fabian+2000.
Simultaneous X-ray satellite observations of III Zw 2

- Our observations were made on 11.12.2017

**XMM-Newton**  
11.94 hours of exposure

**NuSTAR**  
26.03 hours of exposure

= Broad Band energy X-ray observations (0.2 – 70 keV)

- Data reduction: running different pipelines and checking of pileups.
- Data analysis with the ISIS (Interactive Spectral Interpretation System) package.
Reflection spectrum of III Zw 2

- Our observations taken in 2017 gathered more X-ray data.
- Hard X-ray detections > 10keV.
- XMM archival data of 2000.
- X-ray flux increases after 17 years by a factor of ~2.
Search for the presence of FeK line

Residuals of Power Law fit to the spectra

Energy of the FeK line: 6.4 keV
Residuals of Power Law (PL) fit to the spectra

Search for the presence of FeK line

FeK line detection

Energy of the FeK line: 6.4 keV
Search for the presence of FeK line

Residuals of a Power law + Black Body fit

- A good improvement on the fitting of the 2017-soft excess.
- Soft-excess still visible on the 2000 data.
- Black body temperatures: $136-144$ eV $>>$ standard disk temperature ($\sim 10$ eV).
- Which mechanism is driving the soft-excess?

Energy of the FeK line: 6.4 keV
X-ray relativistic reflection models

RELXILL model (Garcia +2014).

RELXILL-LP (Lamp-post) model (Dauser+2013).

RELXILL code =

XILLVER code (reflected spectrum) +

RELLINE code (relativistic blurring effects)

Images credits: Chauvin+2018
X-ray relativistic reflection models

Physical parameters:

- Spin: $a$
- Reflection fraction: $R$
- Disk Inclination: $\theta$
- Ionization parameter: $\xi$
- Iron Abundance: $A_{\text{Fe}}$
- Power Law photon index: $\Gamma$

RELXILL model (Garcia +2014).
RELXILL-LP (Lamp-post) model (Dauser+2013).

Images credits: Chauvin+2018
Fitting the data with RELXILL
Spin ‘a’ and other parameters obtained with a joint-fit

- $a > 0.98$.
- $\theta \sim 41^\circ$ (pegged to the limit)
- $R_{2000} \sim 2 \times R_{2017}$
## Relxill joint-fit results for different disk inclination

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$a$</th>
<th>$\Gamma_{2000}$</th>
<th>$\Gamma_{2017}$</th>
<th>$\log(\xi)$ (erg cm s$^{-1}$)</th>
<th>$A_{Fe}$ (solar)</th>
<th>$R_{2000}$</th>
<th>$R_{2017}$</th>
<th>$\chi^2$/d.o.f</th>
</tr>
</thead>
<tbody>
<tr>
<td>5°</td>
<td>$\geq 0.976$</td>
<td>1.78$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.73$^{+0.04}_{-0.01}$</td>
<td>2.71$^{+0.50}_{-0.52}$</td>
<td>1.04$^{+0.18}_{-0.16}$</td>
<td>0.55$^{+0.07}_{-0.05}$</td>
<td>777/599 (1.30)*</td>
</tr>
<tr>
<td>10°</td>
<td>$\geq 0.978$</td>
<td>1.78$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.73$^{+0.04}_{-0.03}$</td>
<td>2.67$^{+0.50}_{-0.52}$</td>
<td>1.04$^{+0.18}_{-0.12}$</td>
<td>0.56$^{+0.06}_{-0.05}$</td>
<td>772/599 (1.29)*</td>
</tr>
<tr>
<td>22°</td>
<td>$\geq 0.983$</td>
<td>1.78$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.73$^{+0.03}_{-0.05}$</td>
<td>2.47$^{+0.51}_{-0.53}$</td>
<td>1.07$^{+0.18}_{-0.16}$</td>
<td>0.56$^{+0.06}_{-0.05}$</td>
<td>746.8/599 (1.25)*</td>
</tr>
<tr>
<td>35°</td>
<td>$\geq 0.986$</td>
<td>1.77$^{+0.03}_{-0.01}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.71$^{+0.02}_{-0.05}$</td>
<td>2.18$^{+0.52}_{-0.56}$</td>
<td>0.99$^{+0.17}_{-0.14}$</td>
<td>0.52$^{+0.06}_{-0.05}$</td>
<td>710.4/599 (1.19)</td>
</tr>
<tr>
<td>40°</td>
<td>$\geq 0.988$</td>
<td>1.77$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.04}_{-0.05}$</td>
<td>2.05$^{+0.54}_{-0.56}$</td>
<td>0.93$^{+0.15}_{-0.14}$</td>
<td>0.49$^{+0.05}_{-0.04}$</td>
<td>698.3/599 (1.17)</td>
</tr>
<tr>
<td>50°</td>
<td>$\geq 0.992$</td>
<td>1.76$^{+0.02}_{-0.06}$</td>
<td>1.86$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.02}_{-0.06}$</td>
<td>1.56$^{+0.54}_{-0.57}$</td>
<td>0.83$^{+0.15}_{-0.11}$</td>
<td>0.43$^{+0.05}_{-0.04}$</td>
<td>691.3/599 (1.15)</td>
</tr>
<tr>
<td>60°</td>
<td>$\geq 0.993$</td>
<td>1.73$^{+0.02}_{-0.01}$</td>
<td>1.84$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.02}_{-0.06}$</td>
<td>1.19$^{+0.65}_{-0.23}$</td>
<td>0.56$^{+0.08}_{-0.09}$</td>
<td>0.31$^{+0.03}_{-0.09}$</td>
<td>693/599 (1.17)*</td>
</tr>
<tr>
<td>70°</td>
<td>$\geq 0.993$</td>
<td>1.85$^{+0.02}_{-0.01}$</td>
<td>1.92$^{+0.02}_{-0.17}$</td>
<td>1.30$^{+0.08}_{-0.22}$</td>
<td>0.72$^{+0.23}_{-0.22}$</td>
<td>0.48$^{+0.07}_{-0.05}$</td>
<td>0.31$^{+0.03}_{-0.04}$</td>
<td>708/599 (1.18)*</td>
</tr>
<tr>
<td>80°</td>
<td>$\leq 0.298$</td>
<td>1.82$^{+0.01}_{-0.02}$</td>
<td>1.89$^{+0.01}_{-0.01}$</td>
<td>1.11$^{+0.20}_{-0.09}$</td>
<td>0.64$^{+0.26}_{-0.14}$</td>
<td>0.29$^{+0.01}_{-0.05}$</td>
<td>0.18$^{+0.03}_{-0.02}$</td>
<td>729.6/599 (1.22)*</td>
</tr>
<tr>
<td>55° ± 2°</td>
<td>$\geq 0.992$</td>
<td>1.74$^{+0.02}_{-0.05}$</td>
<td>1.85$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.02}_{-0.05}$</td>
<td>1.57$^{+0.51}_{-0.46}$</td>
<td>0.64$^{+0.15}_{-0.09}$</td>
<td>0.35$^{+0.05}_{-0.03}$</td>
<td>685.2/598 (1.15)</td>
</tr>
</tbody>
</table>
Relxill joint-fit results for different disk inclination

<table>
<thead>
<tr>
<th>$\theta$</th>
<th>$\alpha$</th>
<th>$\Gamma_{2000}$</th>
<th>$\Gamma_{2017}$</th>
<th>$\log(\xi)$ (erg cm s$^{-1}$)</th>
<th>$A_{\text{Fe}}$ (solar)</th>
<th>$R_{2000}$</th>
<th>$R_{2017}$</th>
<th>$\chi^2$/d.o.f</th>
</tr>
</thead>
<tbody>
<tr>
<td>5°</td>
<td>$\geq 0.976$</td>
<td>1.78$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.73$^{+0.04}_{-0.01}$</td>
<td>2.71$^{+0.50}_{-0.52}$</td>
<td>1.04$^{+0.18}_{-0.16}$</td>
<td>0.55$^{+0.07}_{-0.05}$</td>
<td>777/599 (1.30)$^*$</td>
</tr>
<tr>
<td>10°</td>
<td>$\geq 0.978$</td>
<td>1.78$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.73$^{+0.04}_{-0.03}$</td>
<td>2.67$^{+0.50}_{-0.52}$</td>
<td>1.04$^{+0.18}_{-0.12}$</td>
<td>0.56$^{+0.06}_{-0.05}$</td>
<td>772/599 (1.29)$^*$</td>
</tr>
<tr>
<td>22°</td>
<td>$\geq 0.983$</td>
<td>1.78$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.73$^{+0.03}_{-0.05}$</td>
<td>2.47$^{+0.51}_{-0.53}$</td>
<td>1.07$^{+0.18}_{-0.16}$</td>
<td>0.56$^{+0.06}_{-0.05}$</td>
<td>746.8/599 (1.25)$^*$</td>
</tr>
<tr>
<td>35°</td>
<td>$\geq 0.986$</td>
<td>1.77$^{+0.03}_{-0.01}$</td>
<td>1.87$^{+0.02}_{-0.01}$</td>
<td>2.71$^{+0.02}_{-0.05}$</td>
<td>2.18$^{+0.52}_{-0.56}$</td>
<td>0.99$^{+0.17}_{-0.14}$</td>
<td>0.52$^{+0.06}_{-0.05}$</td>
<td>710.4/599 (1.19)</td>
</tr>
<tr>
<td>40°</td>
<td>$\geq 0.988$</td>
<td>1.77$^{+0.02}_{-0.03}$</td>
<td>1.87$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.04}_{-0.05}$</td>
<td>2.05$^{+0.54}_{-0.56}$</td>
<td>0.93$^{+0.15}_{-0.14}$</td>
<td>0.49$^{+0.05}_{-0.14}$</td>
<td>698.3/599 (1.17)</td>
</tr>
<tr>
<td>50°</td>
<td>$\geq 0.992$</td>
<td>1.76$^{+0.02}_{-0.01}$</td>
<td>1.86$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.02}_{-0.06}$</td>
<td>1.56$^{+0.54}_{-0.57}$</td>
<td>0.83$^{+0.15}_{-0.11}$</td>
<td>0.43$^{+0.05}_{-0.04}$</td>
<td>691.3/599 (1.15)</td>
</tr>
<tr>
<td>60°</td>
<td>$\geq 0.993$</td>
<td>1.73$^{+0.02}_{-0.02}$</td>
<td>1.84$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.02}_{-0.07}$</td>
<td>1.19$^{+0.65}_{-0.23}$</td>
<td>0.56$^{+0.08}_{-0.09}$</td>
<td>0.31$^{+0.03}_{-0.09}$</td>
<td>693/599 (1.17)$^*$</td>
</tr>
<tr>
<td>70°</td>
<td>$\geq 0.993$</td>
<td>1.85$^{+0.02}_{-0.01}$</td>
<td>1.92$^{+0.02}_{-0.01}$</td>
<td>1.30$^{+0.08}_{-0.17}$</td>
<td>0.72$^{+0.23}_{-0.22}$</td>
<td>0.48$^{+0.07}_{-0.11}$</td>
<td>0.31$^{+0.03}_{-0.04}$</td>
<td>708/599 (1.18)$^*$</td>
</tr>
<tr>
<td>80°</td>
<td>$\leq 0.298$</td>
<td>1.82$^{+0.01}_{-0.02}$</td>
<td>1.89$^{+0.01}_{-0.01}$</td>
<td>1.11$^{+0.20}_{-0.09}$</td>
<td>0.64$^{+0.26}_{-0.14}$</td>
<td>0.29$^{+0.01}_{-0.05}$</td>
<td>0.18$^{+0.03}_{-0.02}$</td>
<td>729.6/599 (1.22)$^*$</td>
</tr>
<tr>
<td>55° ± 2°</td>
<td>$\geq 0.992$</td>
<td>1.74$^{+0.02}_{-0.01}$</td>
<td>1.85$^{+0.01}_{-0.01}$</td>
<td>2.70$^{+0.02}_{-0.05}$</td>
<td>1.57$^{+0.51}_{-0.46}$</td>
<td>0.64$^{+0.15}_{-0.09}$</td>
<td>0.35$^{+0.05}_{-0.03}$</td>
<td>685.2/598 (1.15)</td>
</tr>
</tbody>
</table>

Chamani+2019, submitted to A&A
Summary and discussion

- Soft -excess observed in the XMM 2000 and 2017 data sets.

- A prominent Fe Kα line detected in the XMM 2000 data set (Salvi + 2002; Piconcelli + 2005; Gonzalez + 2018).

- The relxill fits favour fast rotating black hole \( a \sim 0.9 \) in III Zw 2, but it has a weak jet!

- High spins does not produce necessarily powerful jets.

- Do III Zw 2 jet is below the MAD level? We will measure the magnetic flux with VLBI observations (in collaboration with Hada-san).
Thanks for your attention!