Double nuclear structure discovered in 3C84

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Introduction

- Probing jet launching mechanism (BZ vs BP) by direct imaging of jet launching region (jet morphology)

  - Highest possible angular resolution
  - Nearby target
  - High observation frequency

→ **3C84** is one of the best target sources
Angular scale
Angular scale

1 mas = 0.36 pc ≈ 11000 $R_S$

$M_\bullet = 3.2 \times 10^8 M_\odot$ (Park & Trippe 2017)

$H_0 = 70$ km/s/Mpc
14+ telescopes (+GBT / +KVN)
maximum baseline length : ~10,000 km
Angular resolution : 50 ~ 70 μas
Operating at 86 GHz (3mm)
Observations – uv coverage

2008 May 09
3C84 at 86.199 GHz in LL 2008 May 09

2011 May 07
3C84 at 86.252 GHz in L 2011 May 07

2013 Sep 27
3C84 at 86.252 GHz in L 2013 Sep 27

2014 May 25
3C84 at 86.284 GHz in L 2014 May 25

2014 Sep 25
3C84 at 86.284 GHz in L 2014 Sep 25

2015 May 16
3C84 at 86.243 GHz in L 2015 May 16
Consistent double nuclear structure in all 6 epochs
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- No significant motion over 8 years
- Separation $\sim 70 \mu\text{as}$
- Brightness temperature
  - $C_{1a} : 1.0 \times 10^{11} \text{ K}$
  - $C_{1b} : 1.3 \times 10^{11} \text{ K}$
- Continued to Limb-brightened jet structure
• Distance between C1a and C1b
  \(\sim 800 \, R_S\) (~1 light-month, for \(M_{\text{BH}} = 3.2 \times 10^8 \, M_\odot\))

• If C1a + C1b is jet base, we have Blandford–Payne mechanism at work (Blandford–Znajek requires <10 \(R_S\))
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- But the size is probably even too large for an accretion disk

- Accretion disk size vs. black hole mass (Morgan+ 2010)

  \[
  \log \left( \frac{R_{2500}}{cm} \right) = (15.78 \pm 0.12) + (0.80 \pm 0.17) \log \left( \frac{M_{BH}}{10^9 \, M_\odot} \right)
  \]

- Expected for 3C84: \( \sim 54 \, R_S \)
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- Expected for 3C84 : ~54 \( R_S \)

- High brightness temperature (>10^{11} \, K) indicates non-thermal emission
Relative locations: $r: R_s$

$T_B [\times 10^{10} \text{ K}]$

C1a

C1b
- $T_B$ – PA and $S_v$ – PA correlation
- $T_B$ varies by factor of $\sim 6$

→ Emitters moving on a helical path

- Possible physical processes
  1. Doppler boosting
  2. Intrinsic evolution of the jet plasma
- $T_B - PA$ and $S_v - PA$ correlation
- $T_B$ varies by factor of $\sim 6$

→ Emitters moving on a helical path

- Possible physical processes
  1. Doppler boosting
  2. Intrinsic evolution of the jet plasma

$T_B^{obs} \leq 2 \times 10^{11} K$

Equi-partition limit (Singal 2009)

$T_B^{em} \leq \sim 10^{11} K$

$\delta \approx 1 \quad \rightarrow \quad \beta \ll 1$
Intrinsic evolution of jet plasma

- Assuming all emission is synchrotron radiation
- No correlation of flux with time
- Multiple individual emitters cooling down rapidly
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The cooling time scale:

\[ \tau_{\text{cool}} = 7.74 \left( \frac{\delta}{1 + z} \right)^{-1} B^{-2} \gamma^{-1} \text{ seconds} \]

- \( \delta \approx 1, B \approx 10\mu T, \gamma \approx 10000, z = 0.0176 \)
- \( \sim 3 \) months
- Typical blazar-like value (Hodgson+ 2016)
Where is the Black Hole?

- Jet profile using multiple slices on stacked map
- Found local maxima
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\[ \text{BH\_parabola: (-0.006, 0.017)} \]
\[ \text{BH\_conical: (-0.004, 0.161)} \]

\[ \sim 1800 \, R_S \]
\[ \sim 190 \, R_S \]
Where is the Black Hole?

- If jet plasma is expanding and cooling, SMBH must be between C1a and C1b
- Viewing angle in C1 < 45°?
- Parabolic fit is more consistent
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- Viewing angle in C1 < 45°?
- Parabolic fit is more consistent

Abdo et al. (2009) ~ 25°
γ-ray SED fitting

Fujita & Nagai (2017) ~ 65°
Jet / counter-jet

- γ-ray emission from C1 region (Hodgson et al. 2018)
- Viewing angle changed from the nuclear region to the extended structure?
An east-west oriented “double” nuclear structure in C1 region

The brightness temperature of C1a and C1b, in the order of $10^{11}$K and shows a trend of increasing brightness temperature to the north for C1a and to the south for C1b. This behavior is consistent with a helical expanding jet sheath.

The behavior of the nuclear emission appears to be broadly consistent with that of a blazar.

We placed limits of the true location of the SMBH assuming either a parabolic or conical jet to between 190 $R_S$ and 1800 $R_S$.
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