Double nuclear structure discovered in 3C84

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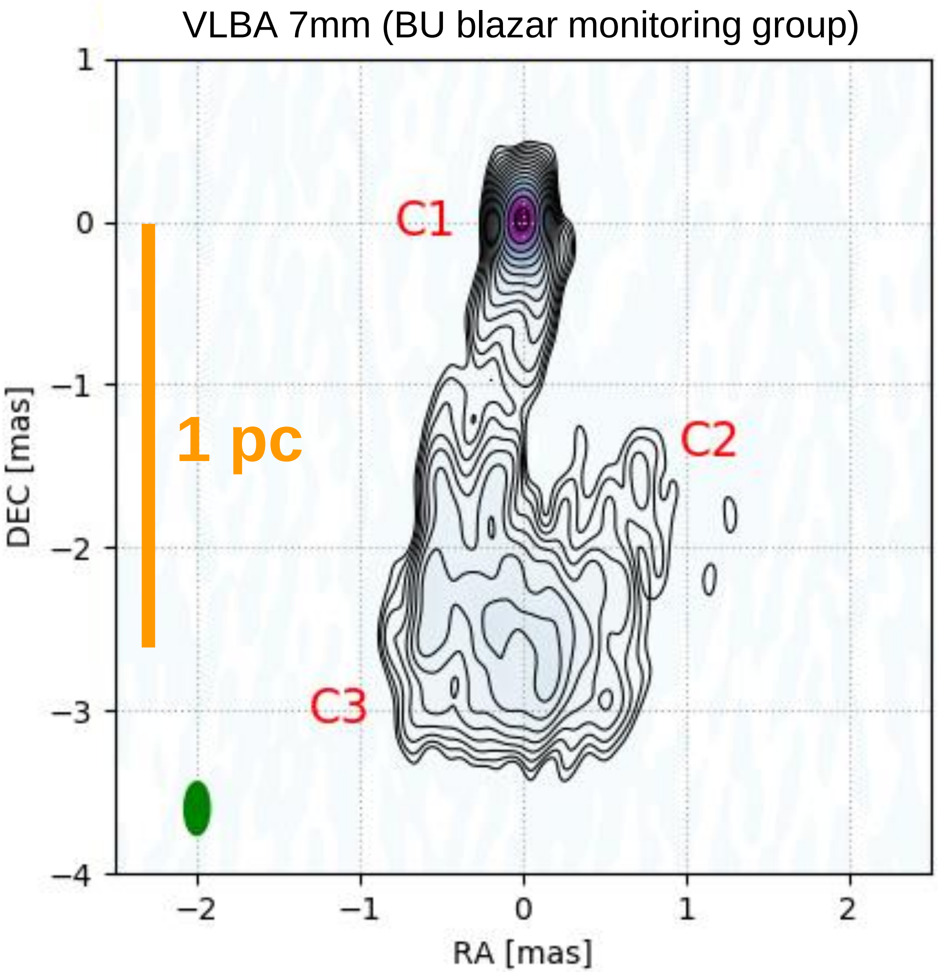
Introduction

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

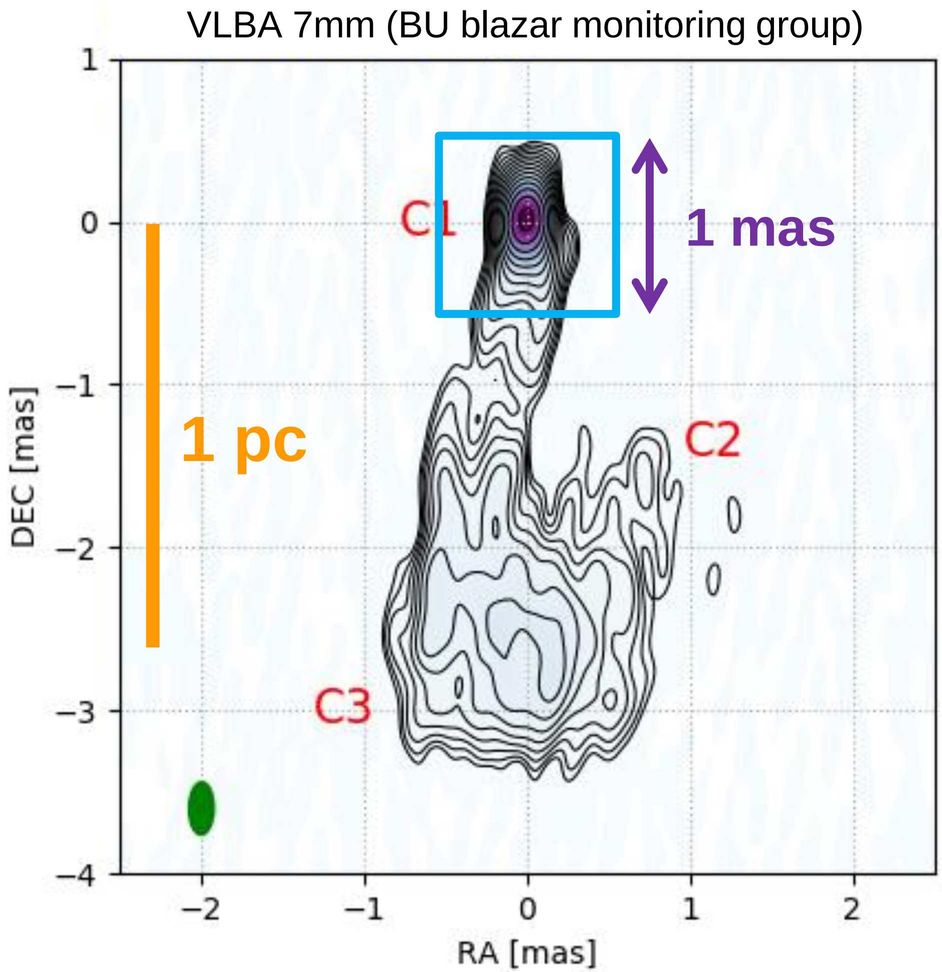
➢ Highest possible angular resolution
➢ Nearby target
➢ High observation frequency

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

Angular scale



Angular scale

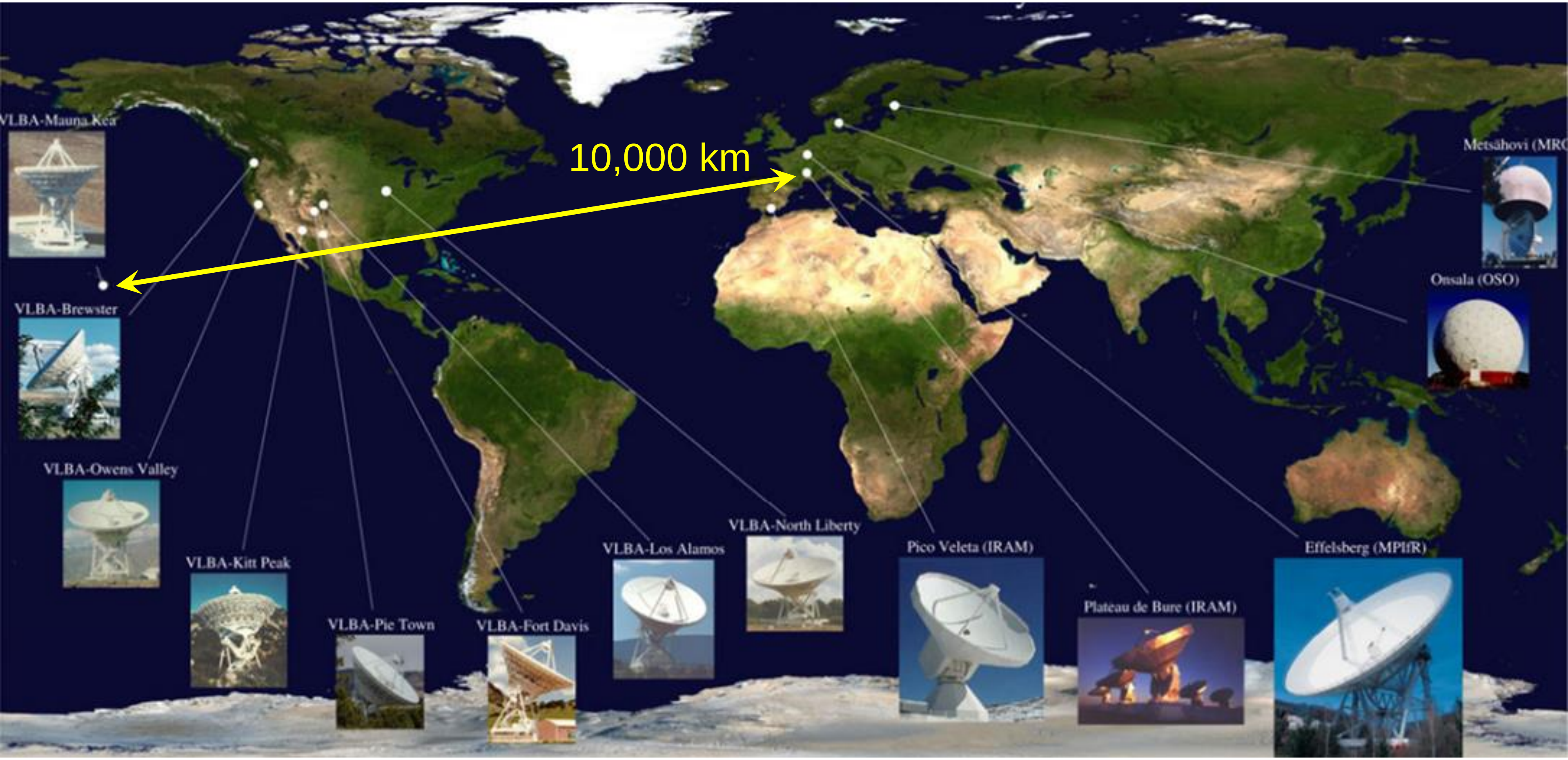


1 mas = 0.36 pc ≈ 11000 R_S

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

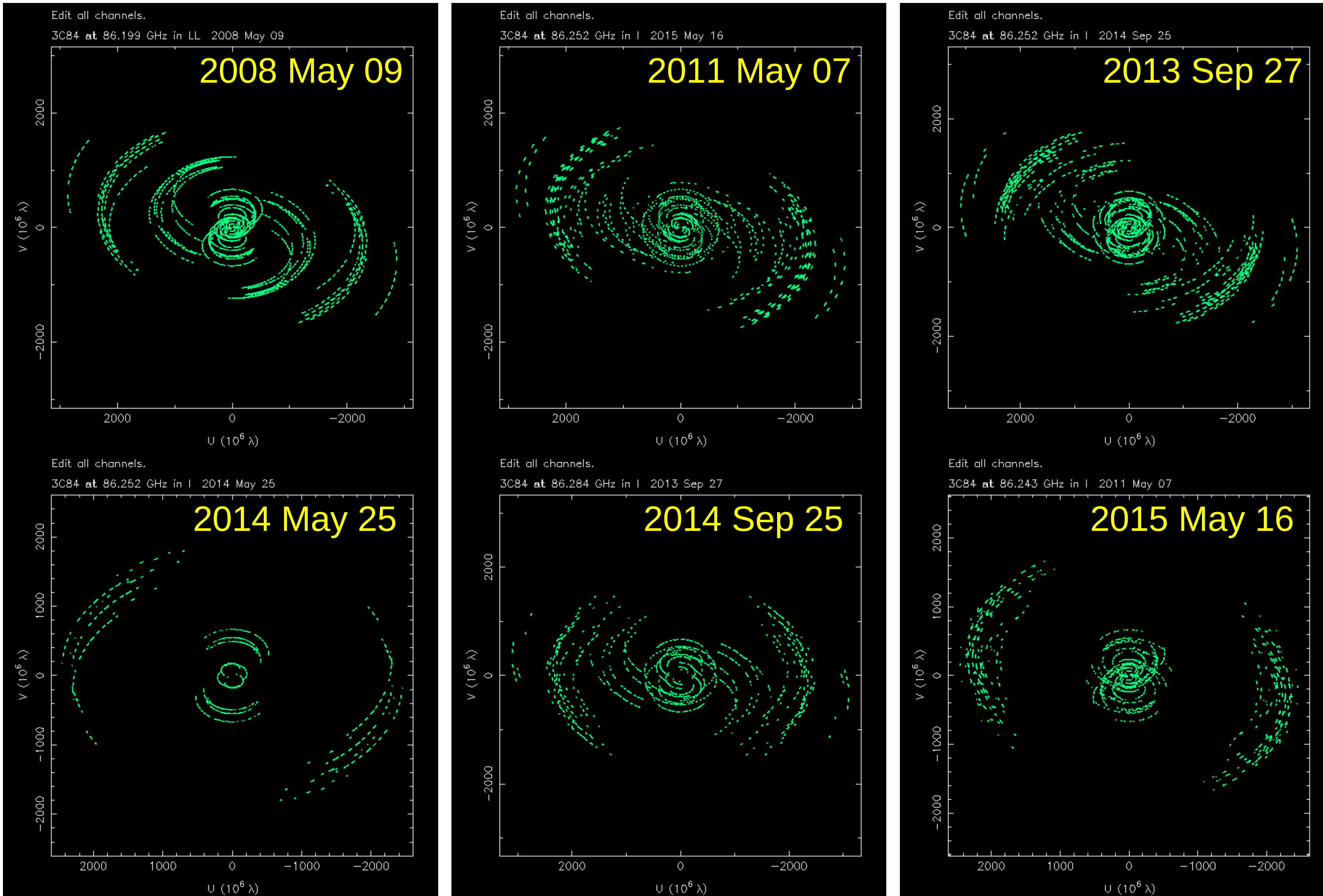
H_0 = 70 km/s/Mpc

Observations - GMVA

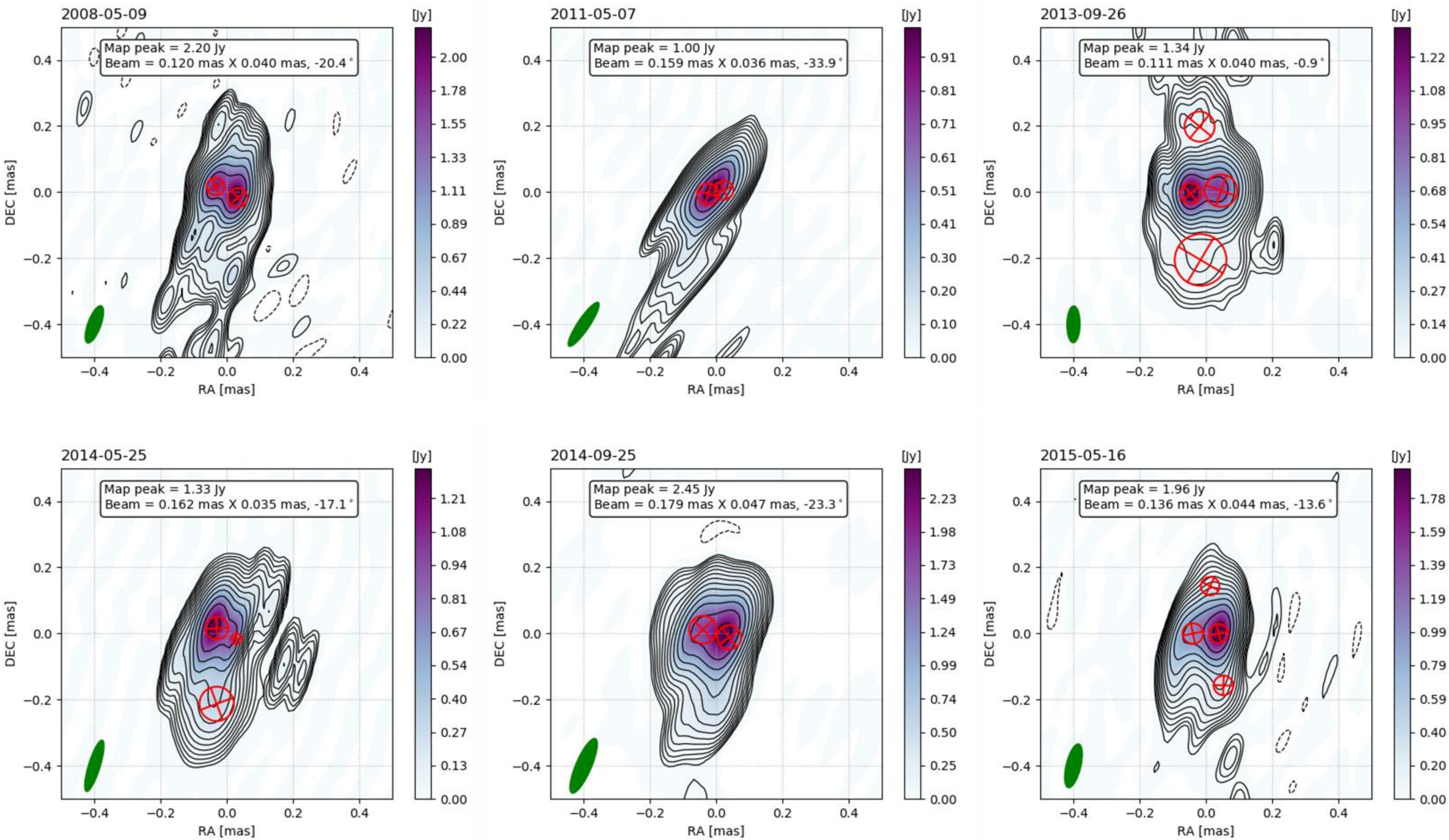


14+ telescopes (+GBT / +KVN)
maximum baseline length : ~10,000 km
Angular resolution : **50 ~ 70** **μas**
Operating at **86** GHz (3mm)

Observations – uv coverage



Consistent double nuclear structure in all 6 epochs



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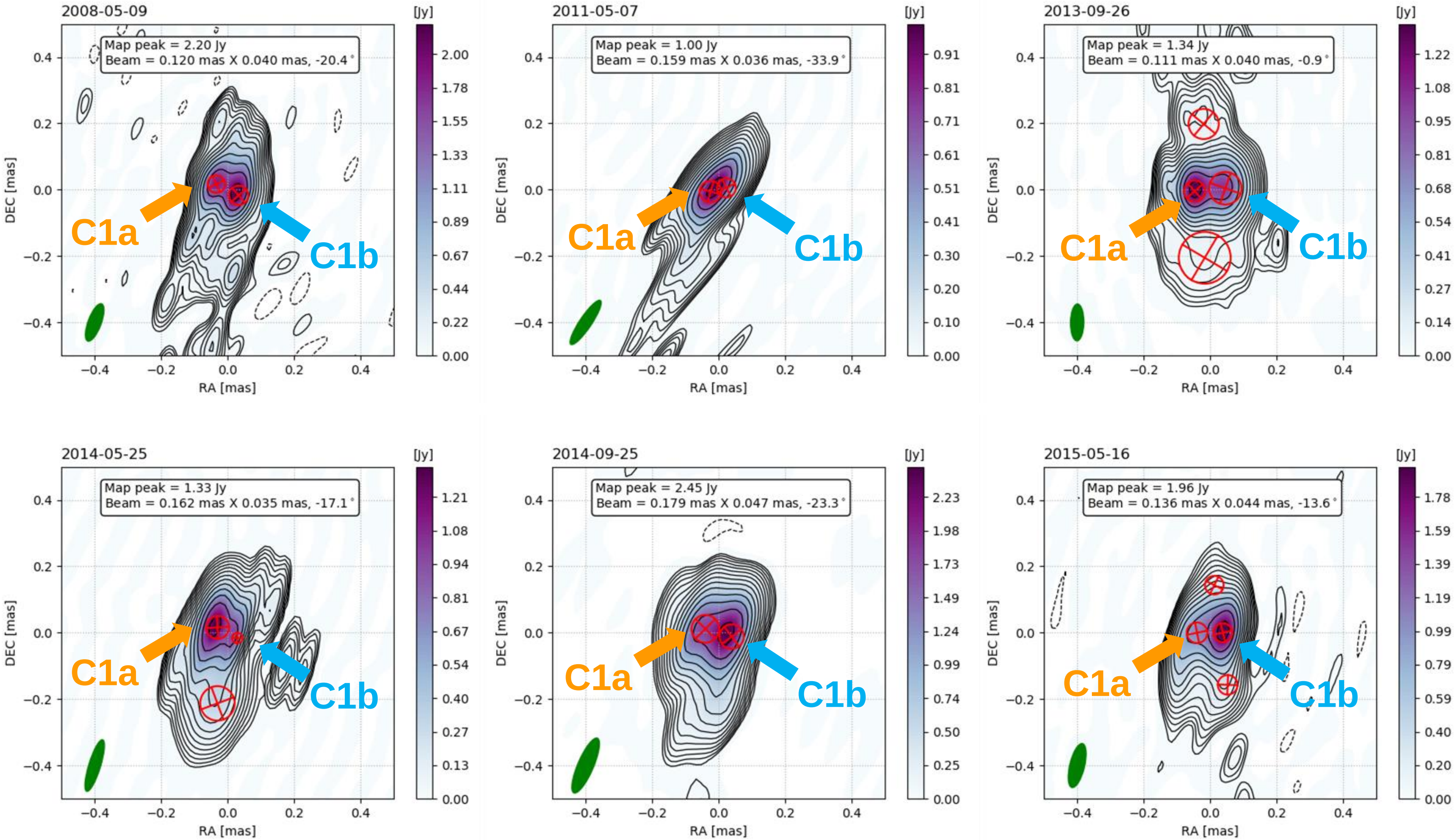

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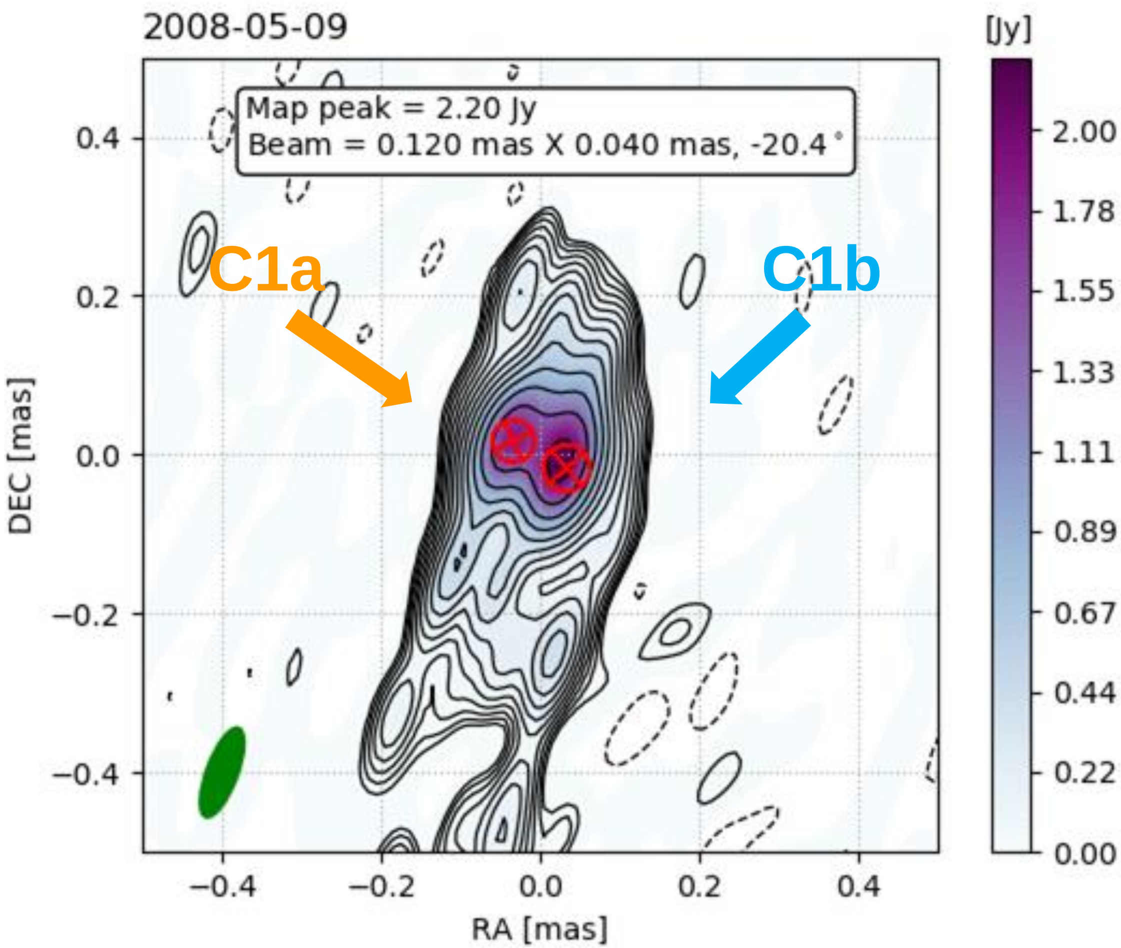
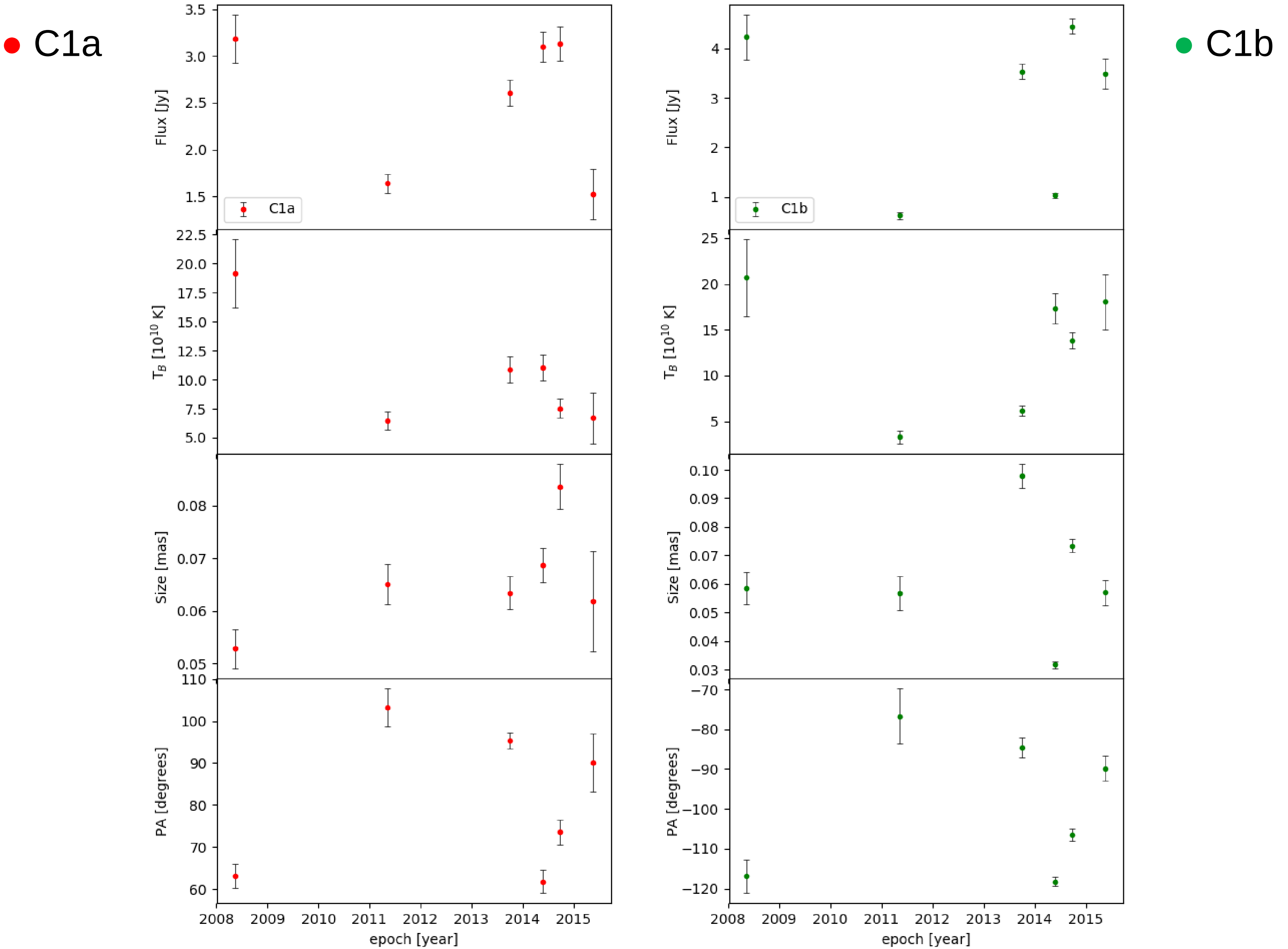


- **No significant motion over 8 years**
- **Separation ~70 μas**
- **Brightness temperature**
  C1a : 1.0 x 10^{11} K
  C1b : 1.3 x 10^{11} K
- **Continued to Limb-brightened jet structure**



C1a
C1b
Flux [Jy]
T$_B$ [10^{10} K]
Size [mas]
PA [degrees]
epoch [year]
2008
2009
2010
2011
2012
2013
2014
2015

- Distance between C1a and C1b
  ~800 R_S (~1 light-month, for $M_{BH} = 3.2 \times 10^8\ M_{\odot}$)

- 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 : ~54 R_S

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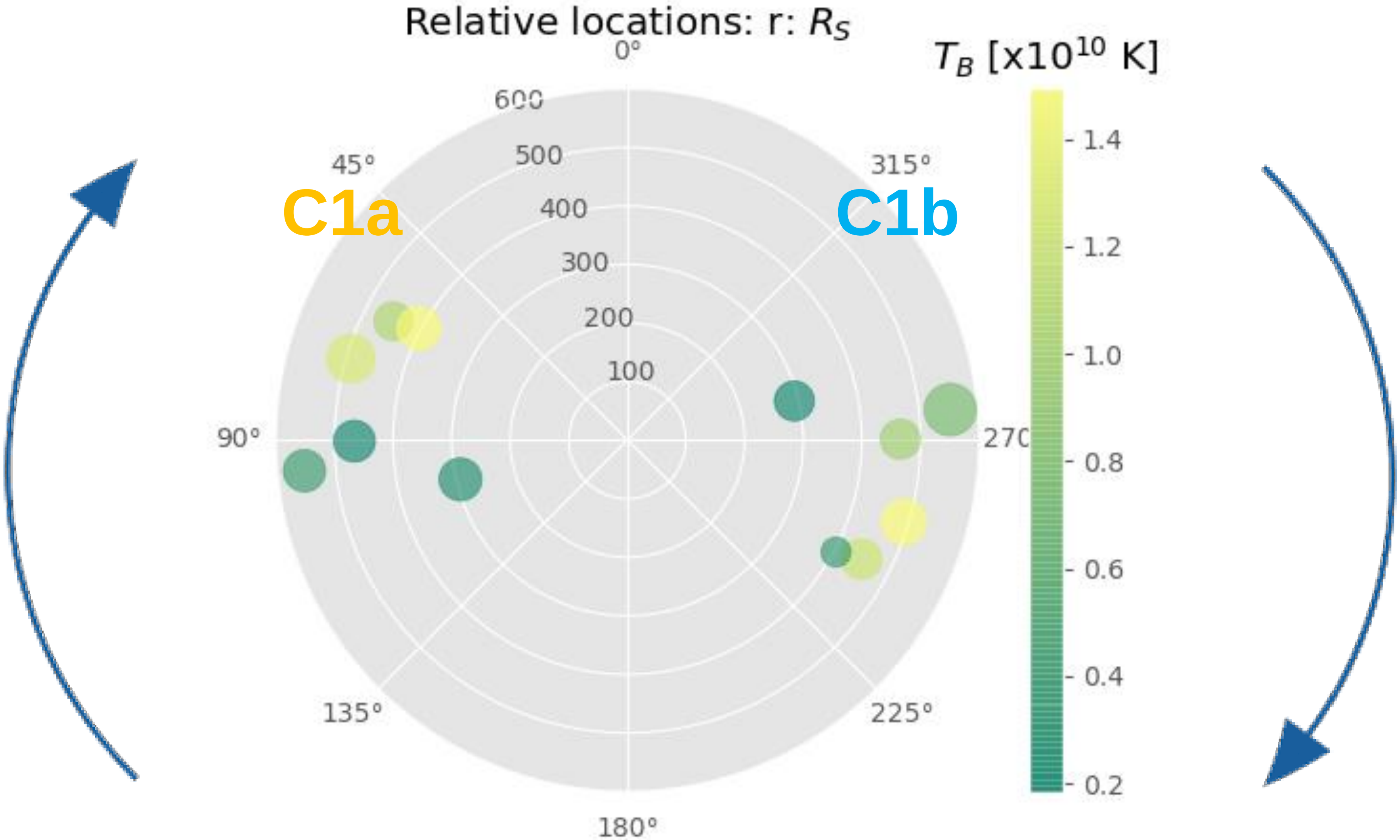
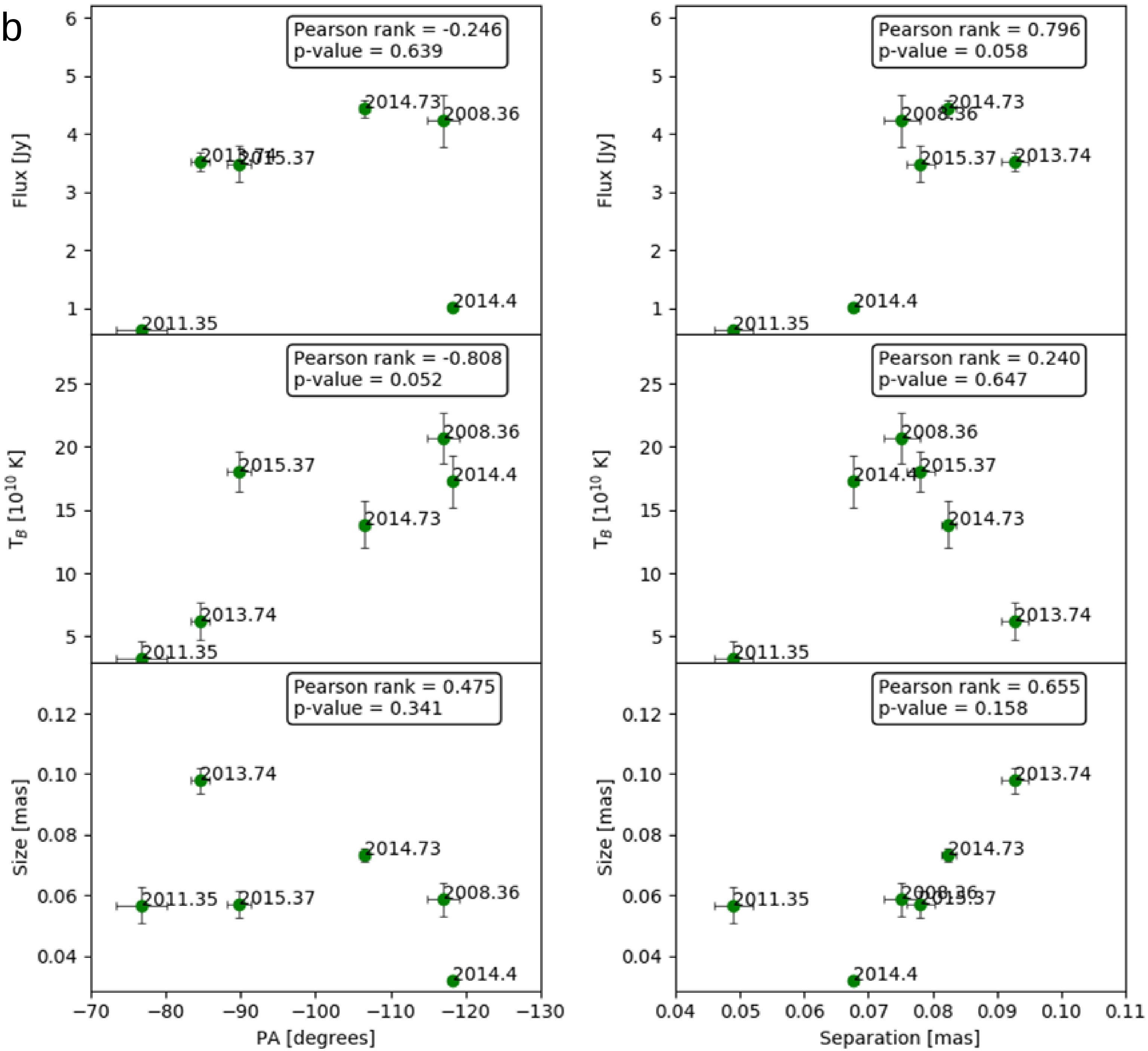
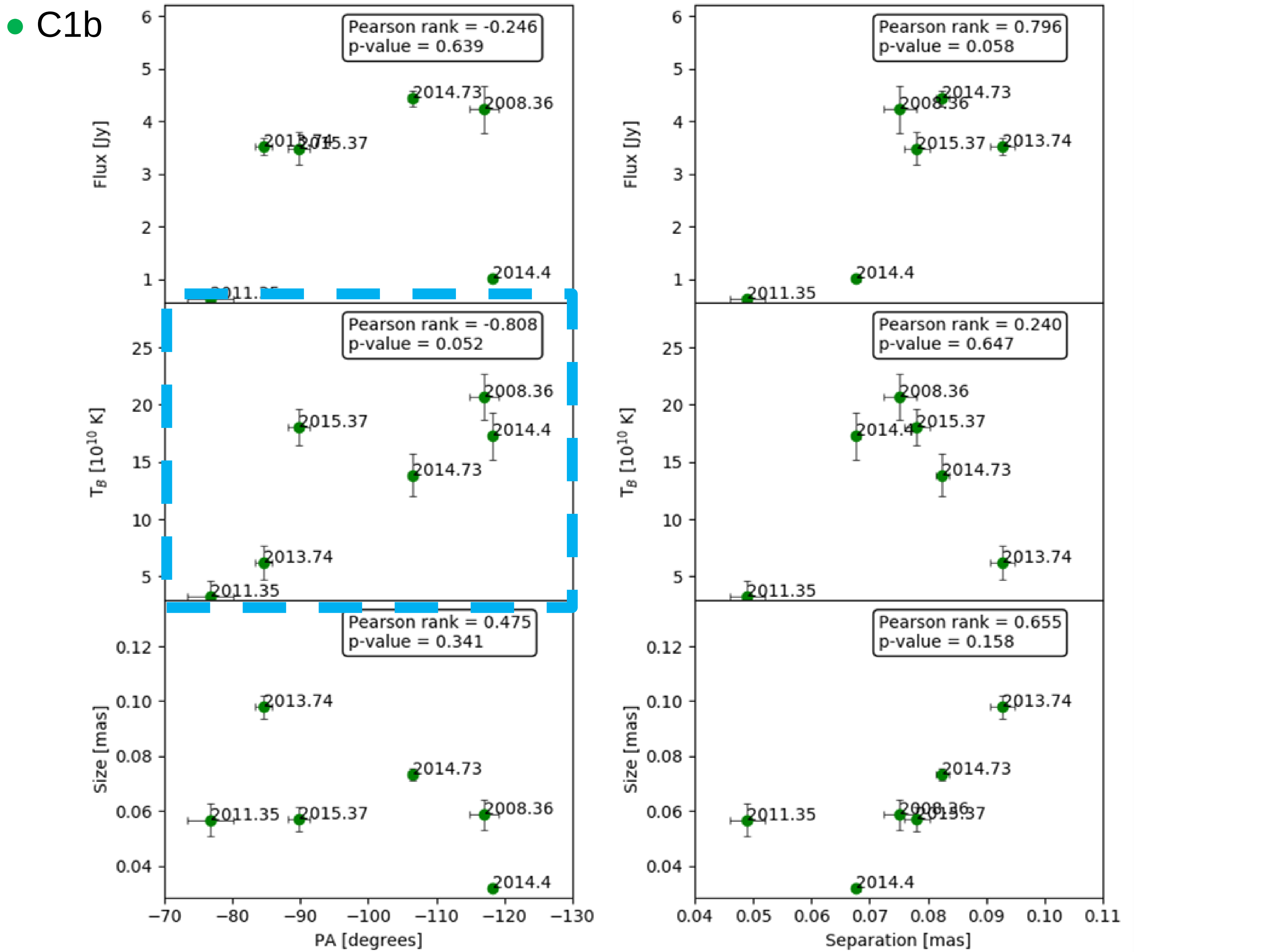
- High brightness temperature (>10^{11} K) indicates non-thermal emission



Relative locations: r: R_S
T_B [x10^{10} K]
0°
45°
90°
135°
180°
225°
270
315°
100
200
300
400
500
600
C1a
C1b
1.4
1.2
1.0
0.8
0.6
0.4
0.2

● C1b


Pearson rank = -0.246
p-value = 0.639
Pearson rank = 0.796
p-value = 0.058
Pearson rank = -0.808
p-value = 0.052
Pearson rank = 0.240
p-value = 0.647
Pearson rank = 0.475
p-value = 0.341
Pearson rank = 0.655
p-value = 0.158
Flux [Jy]
T_B [10^{10} K]
Size [mas]
PA [degrees]
Separation [mas]
2014.73
2008.36
2013.74
2015.37
2014.4
2011.35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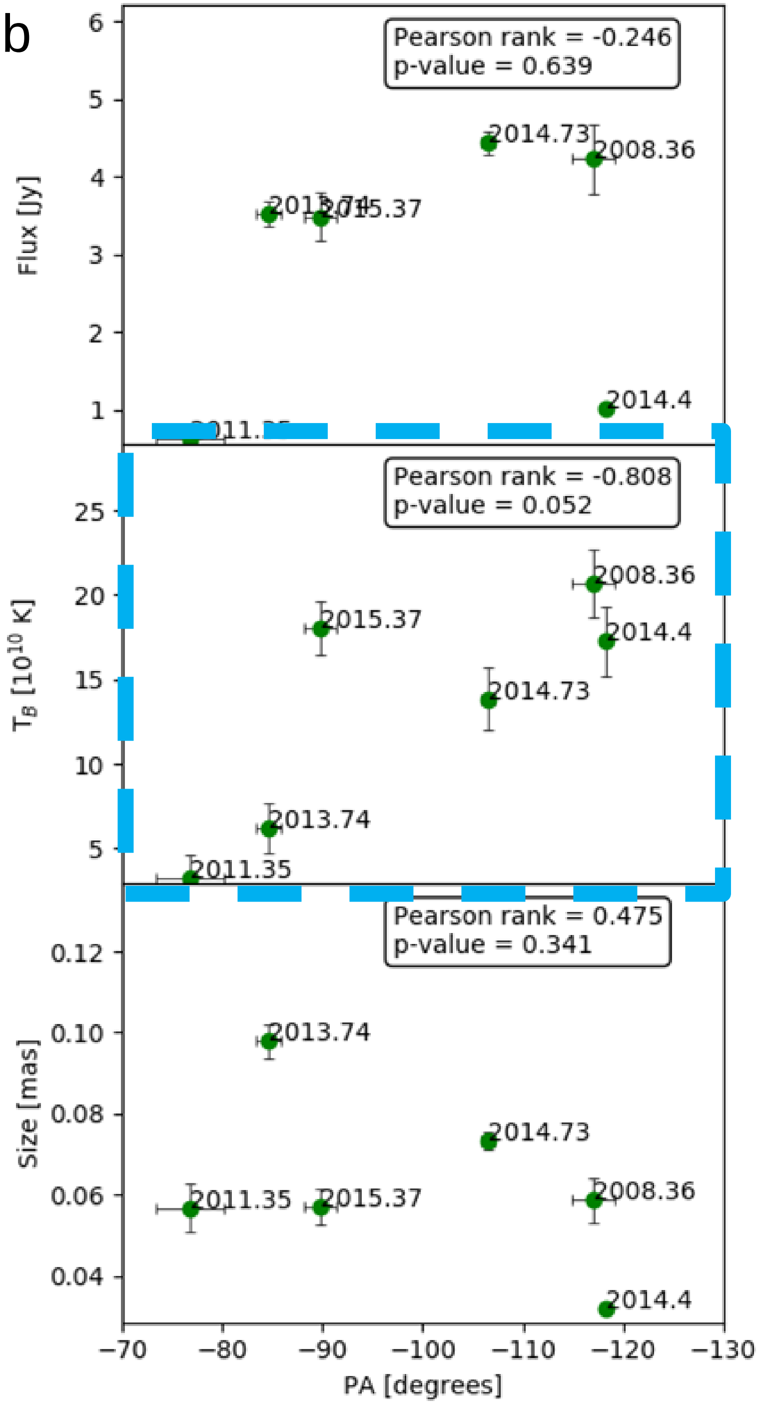


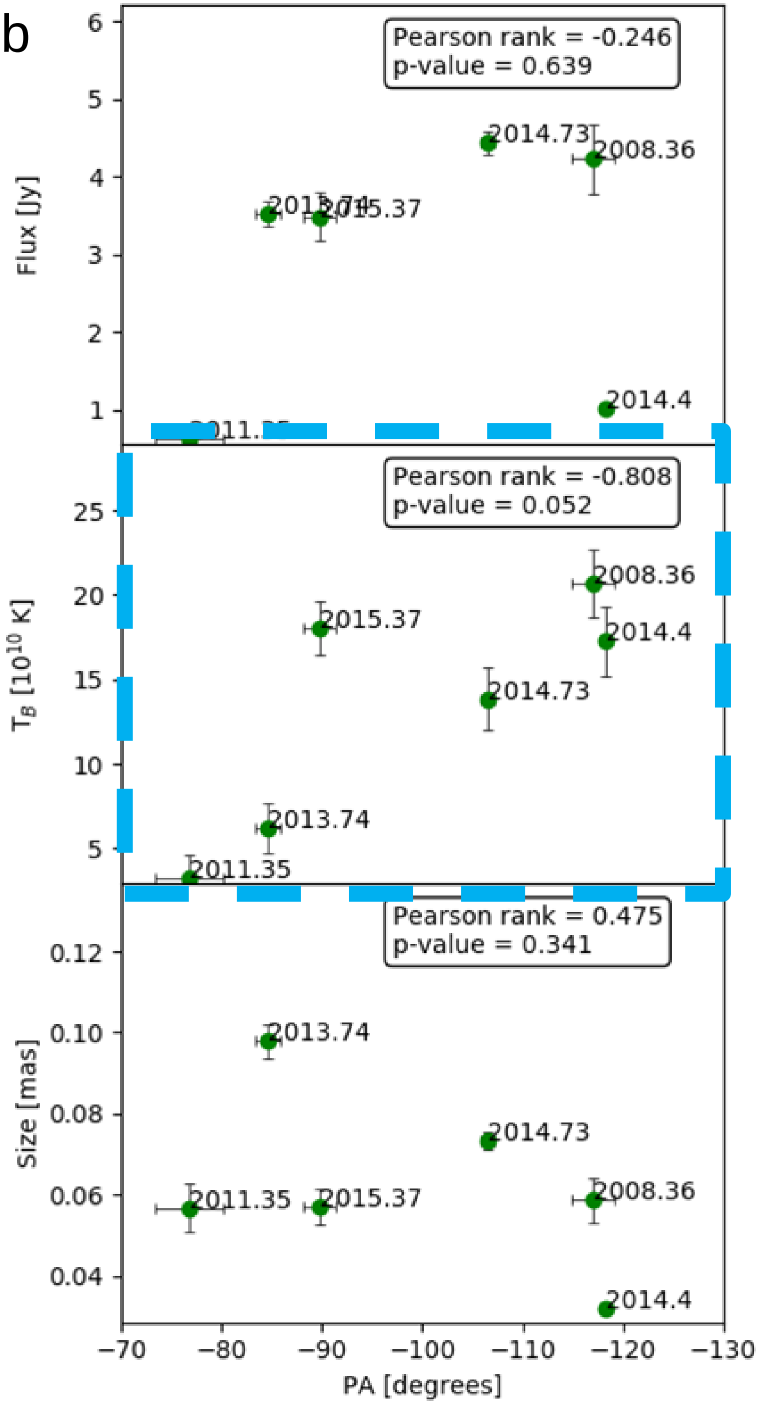
- T_B – PA and S_ν – PA correlation
- T_B varies by factor of ~6

→ Emitters moving on a helical path

- Possible physical processes

1. Doppler boosting
2. Intrinsic evolution of the jet plasma

● C1b



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

Equipartition limit (Singal 2009)

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

$\delta \approx 1 \longrightarrow \beta \ll 1$

Intrinsic evolution of jet plasma

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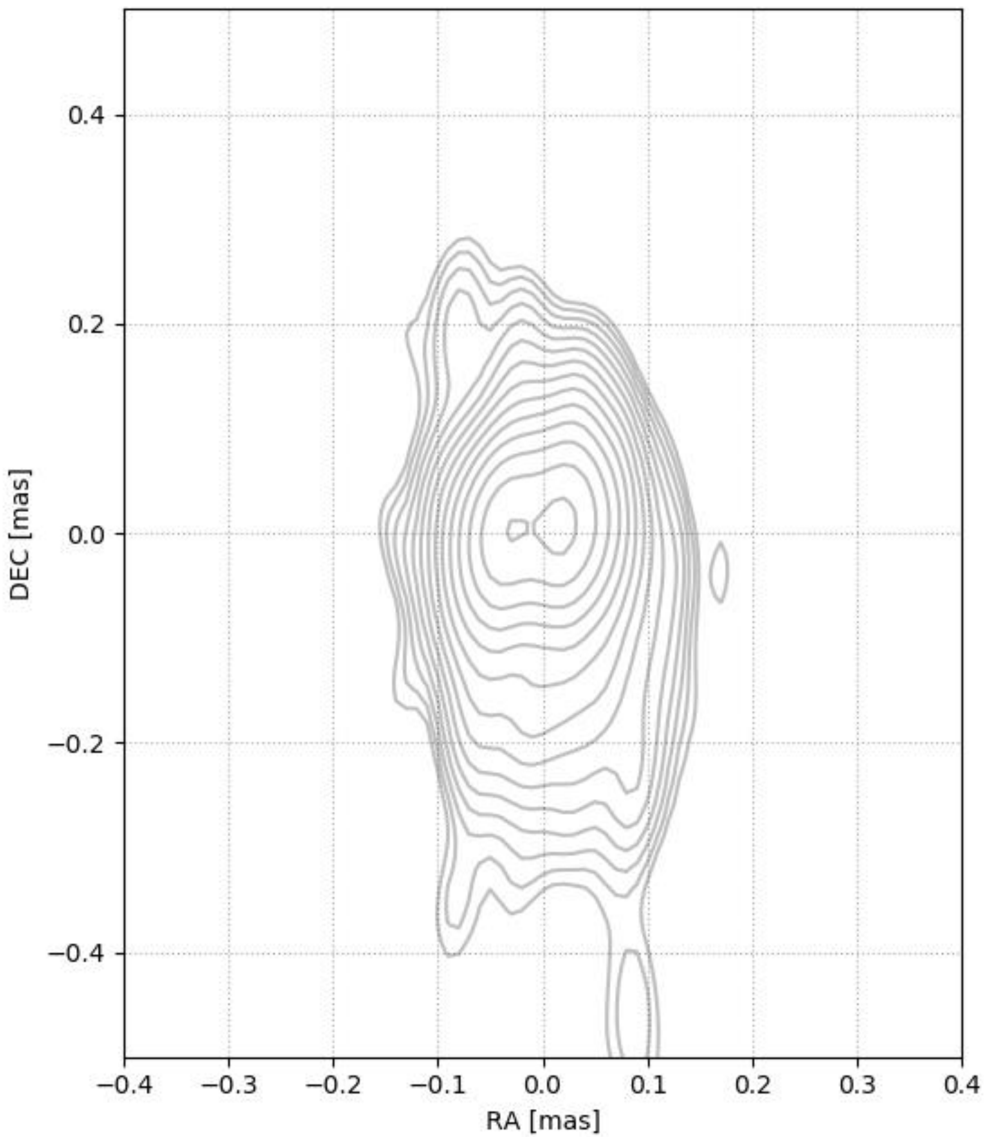
- No correlation of flux with time
- Multiple individual emitters cooling down rapidly
- The cooling time scale :

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

- $\delta \approx 1, B \approx 10\mu T, \gamma \approx 10000, z = 0.0176$
- ~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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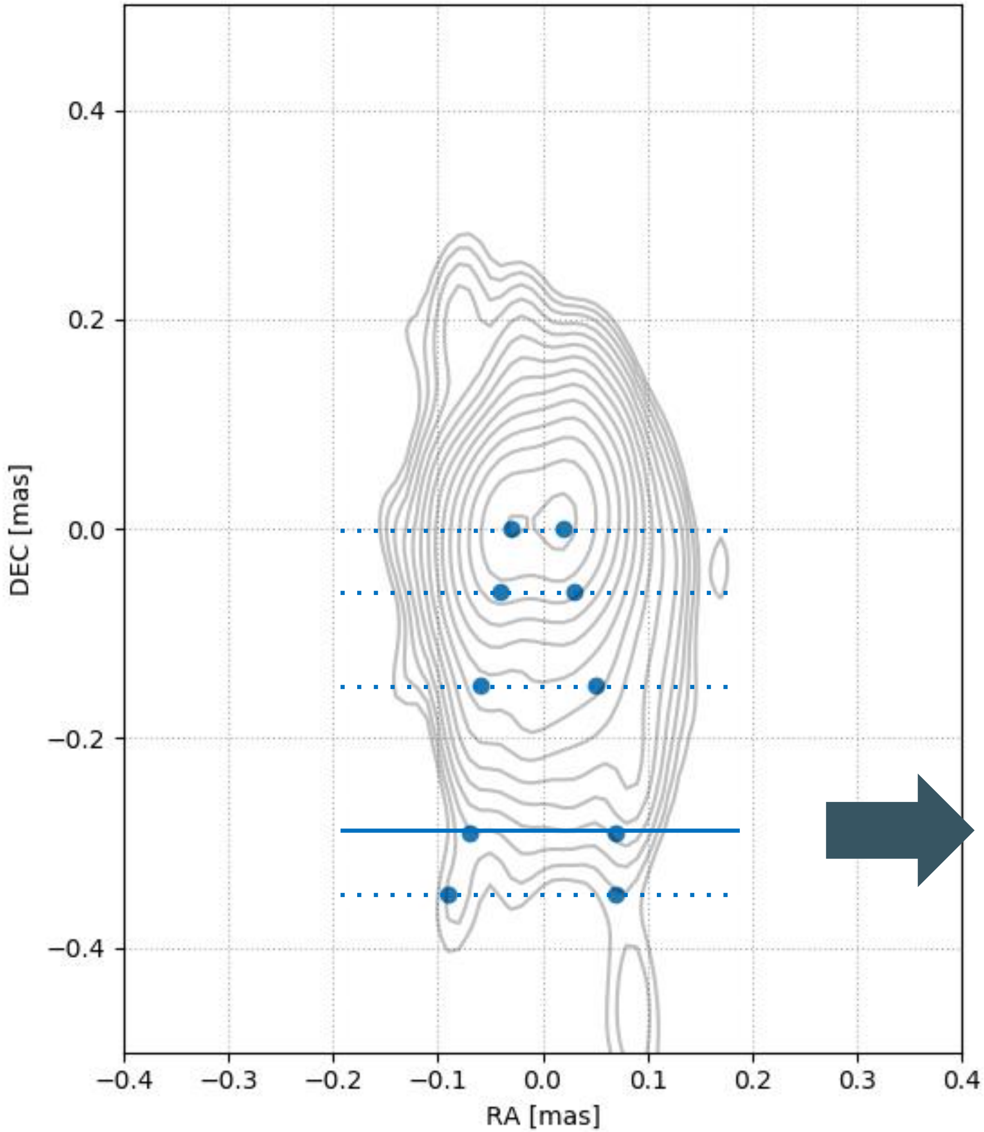

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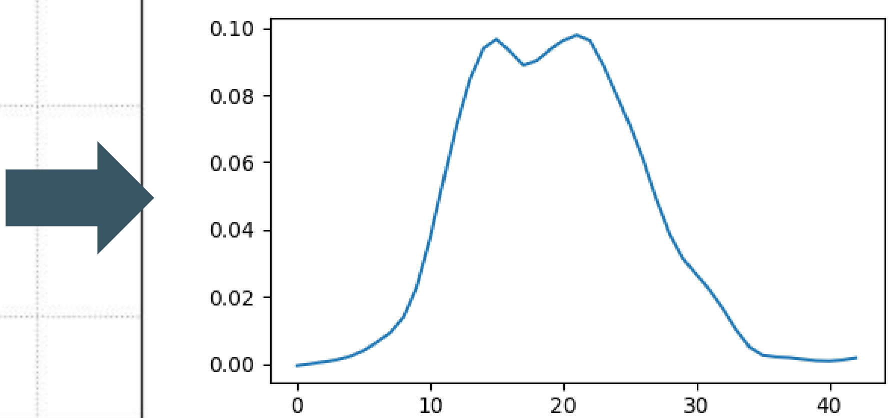

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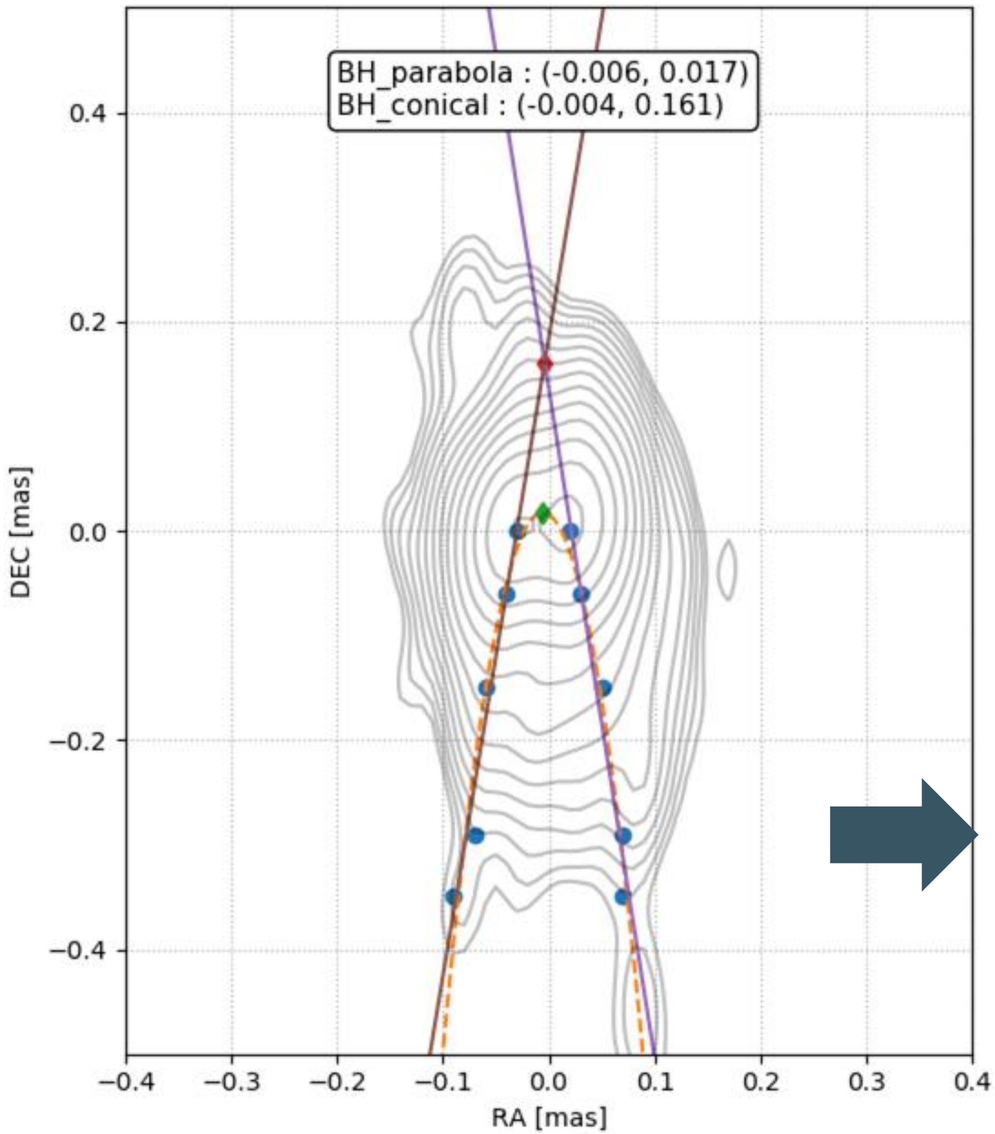

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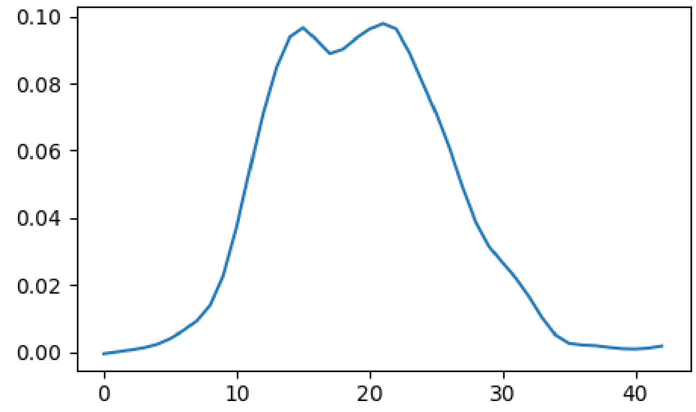

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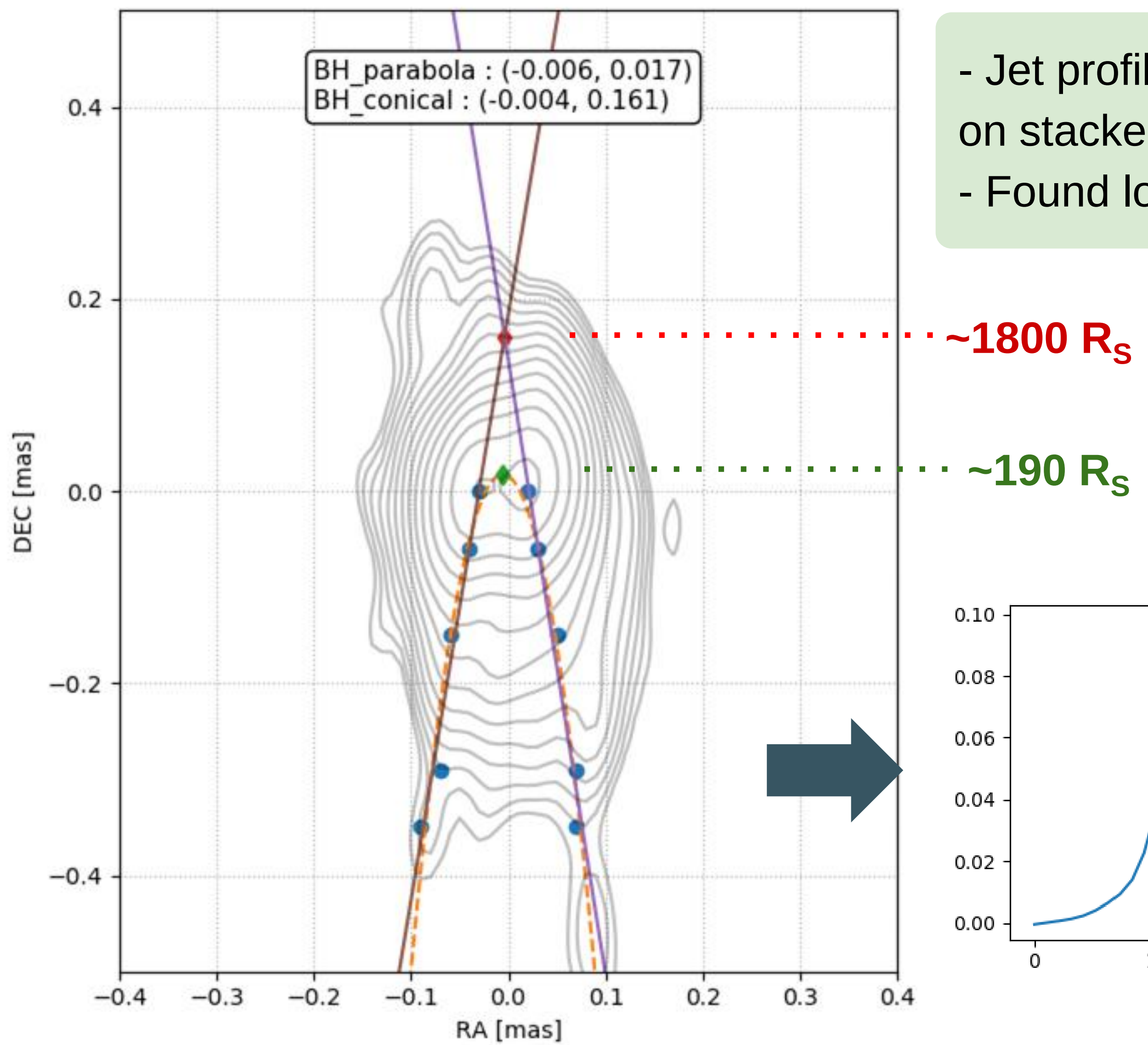

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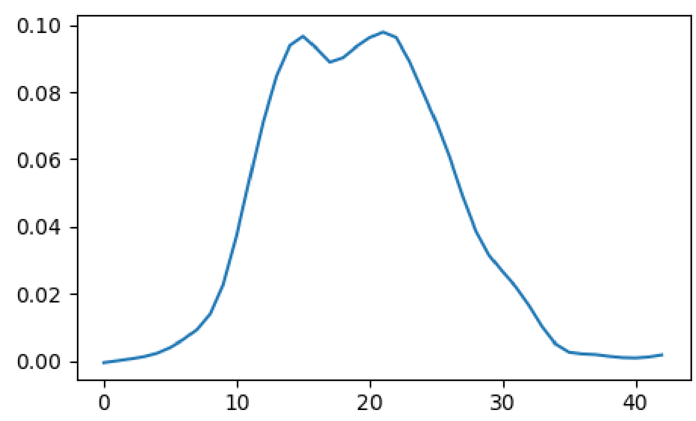

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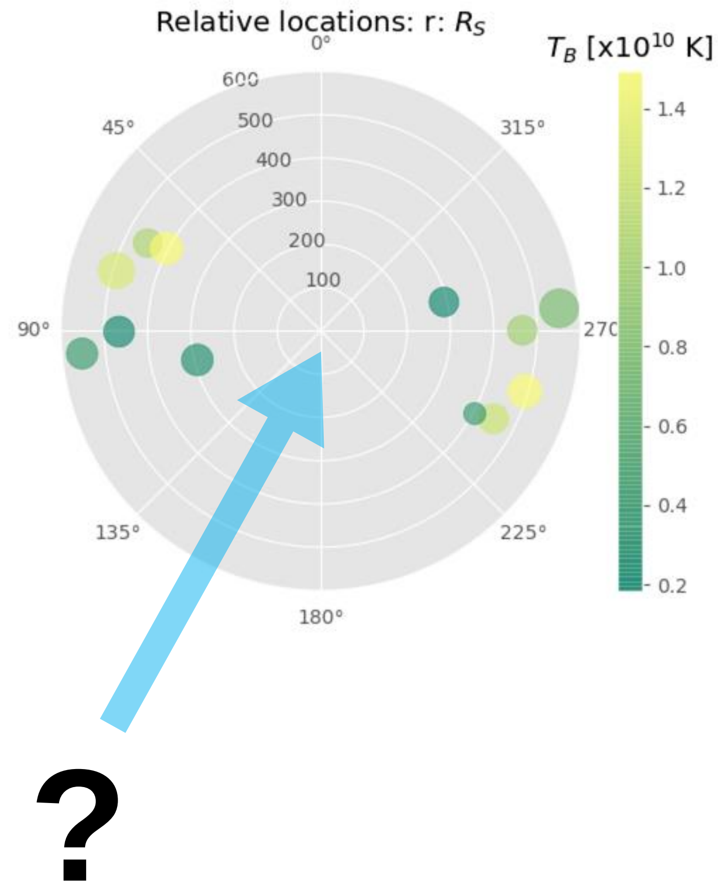

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- Viewing angle in C1 < 45° ?
- Parabolic fit is more consistent

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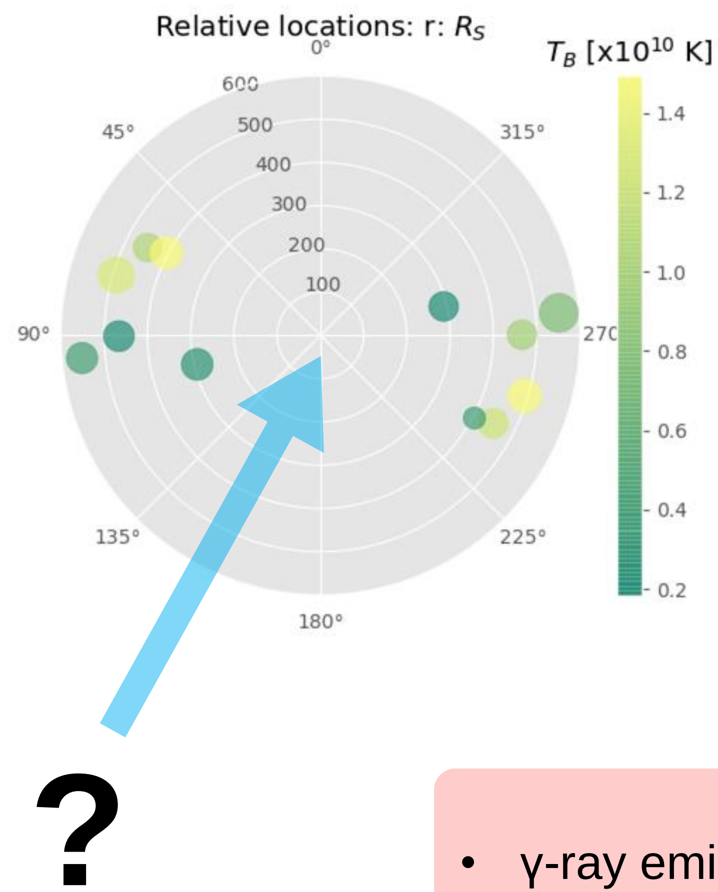

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Abdo et al. (2009)	Fujita & Nagai (2017)
~ 25 °	**~ 65 °**
γ-ray SED fitting	Jet / counter-jet

- γ-ray emission from C1 region (Hodgson et al. 2018)
- Viewing angle changed from the nuclear region to the extended structure?

Summary

- 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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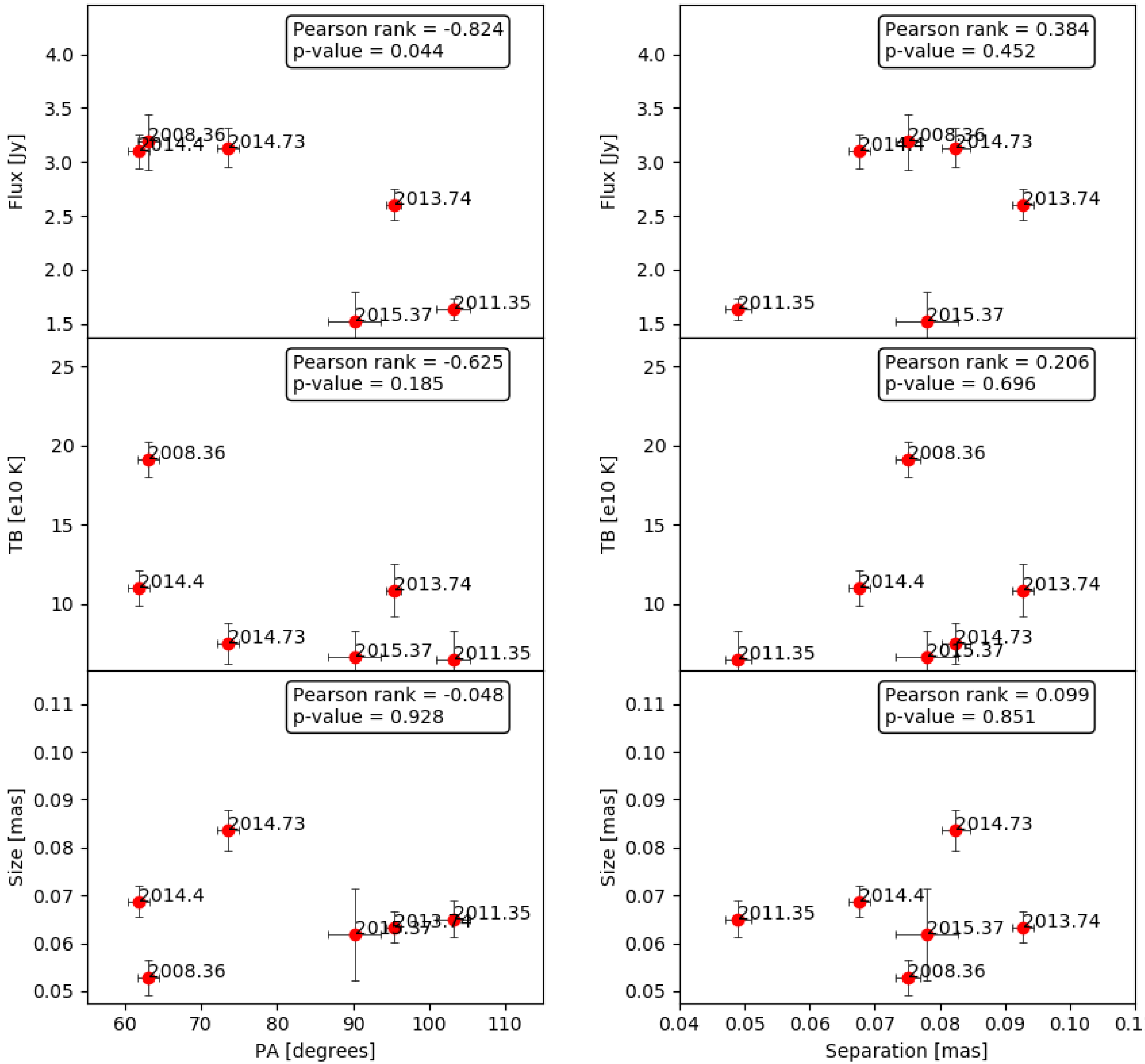
Thank you for listening!



Pearson rank = -0.824
p-value = 0.044
Pearson rank = 0.384
p-value = 0.452
Pearson rank = -0.625
p-value = 0.185
Pearson rank = 0.206
p-value = 0.696
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Pearson rank = 0.099
p-value = 0.851
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