Double nuclear structure discovered in 3C84

Junghwan Oh
Jeffrey Hodgson, Sascha Trippe, Sang-Sung Lee,
Thomas Krichbaum, Jae-young Kim, Bindu Rani
IAUS 342, Sicily

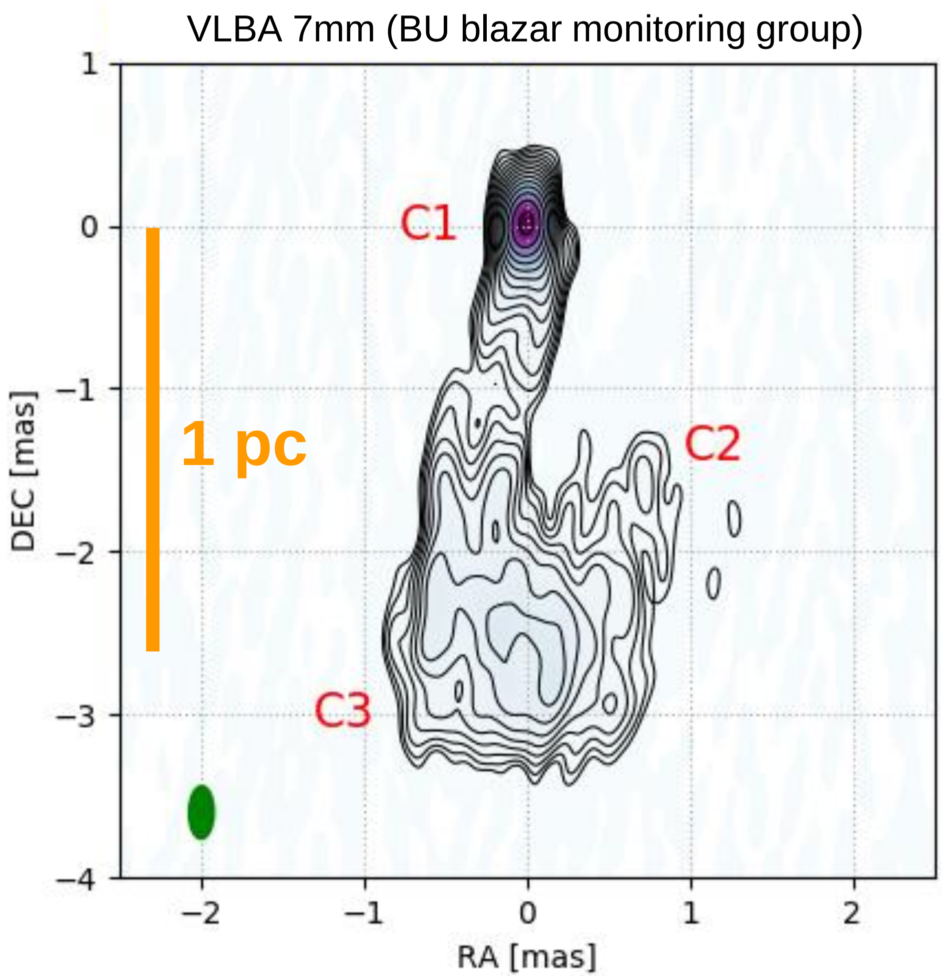
Introduction

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

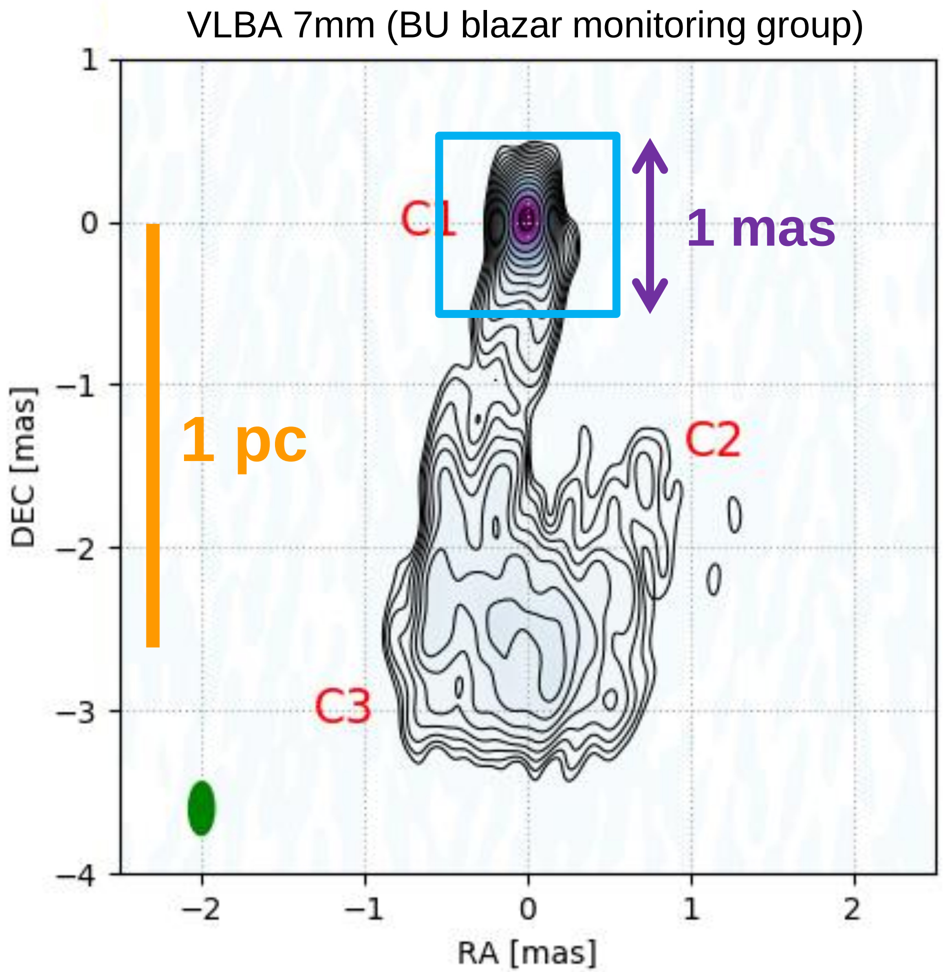
- Highest possible angular resolution
- Nearby target
- High observation frequency

→ 3C84 is one of the best target sources

Angular scale



Angular scale

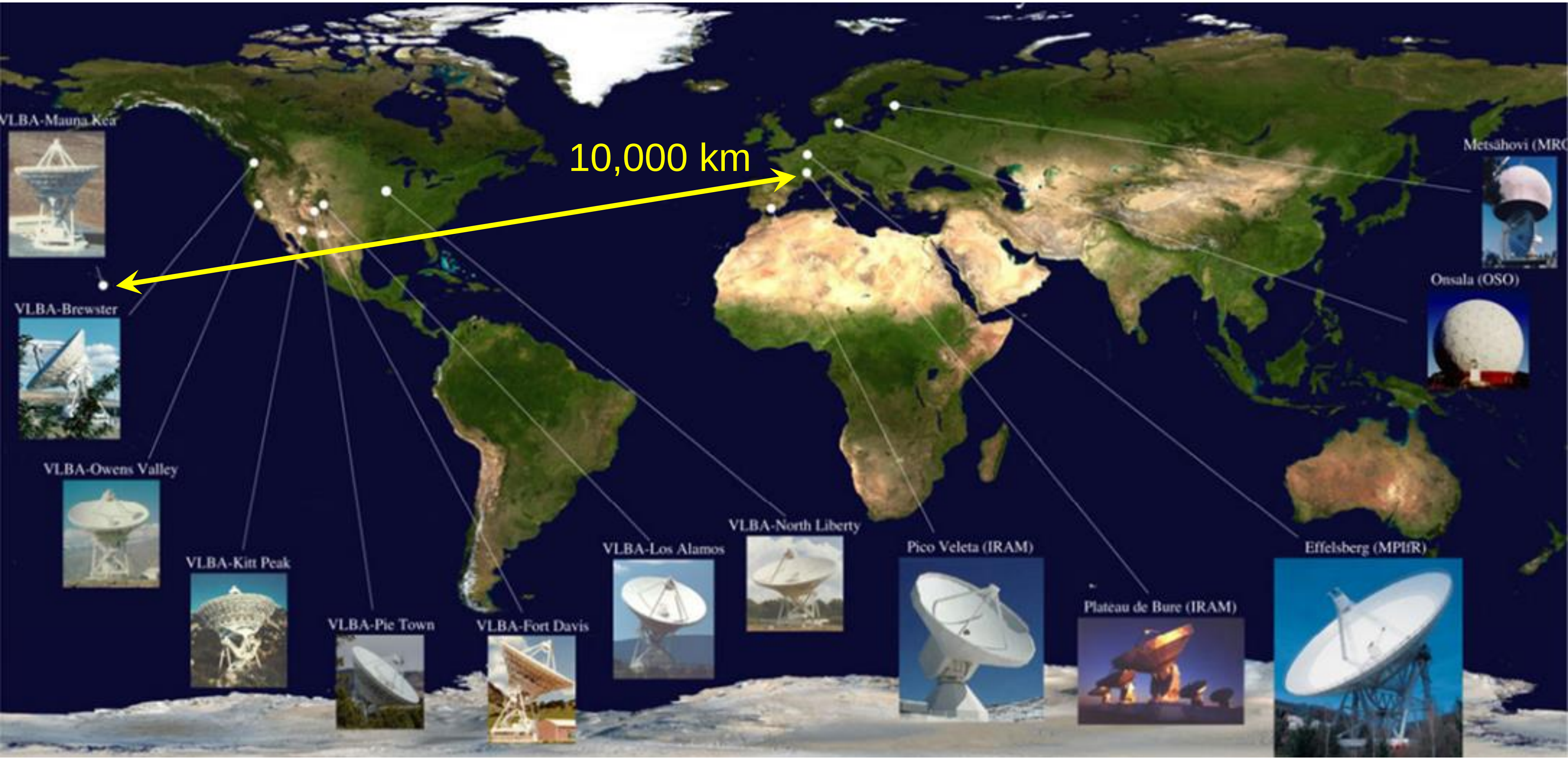


1 mas = 0.36 pc ≈ 11000 R_S

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

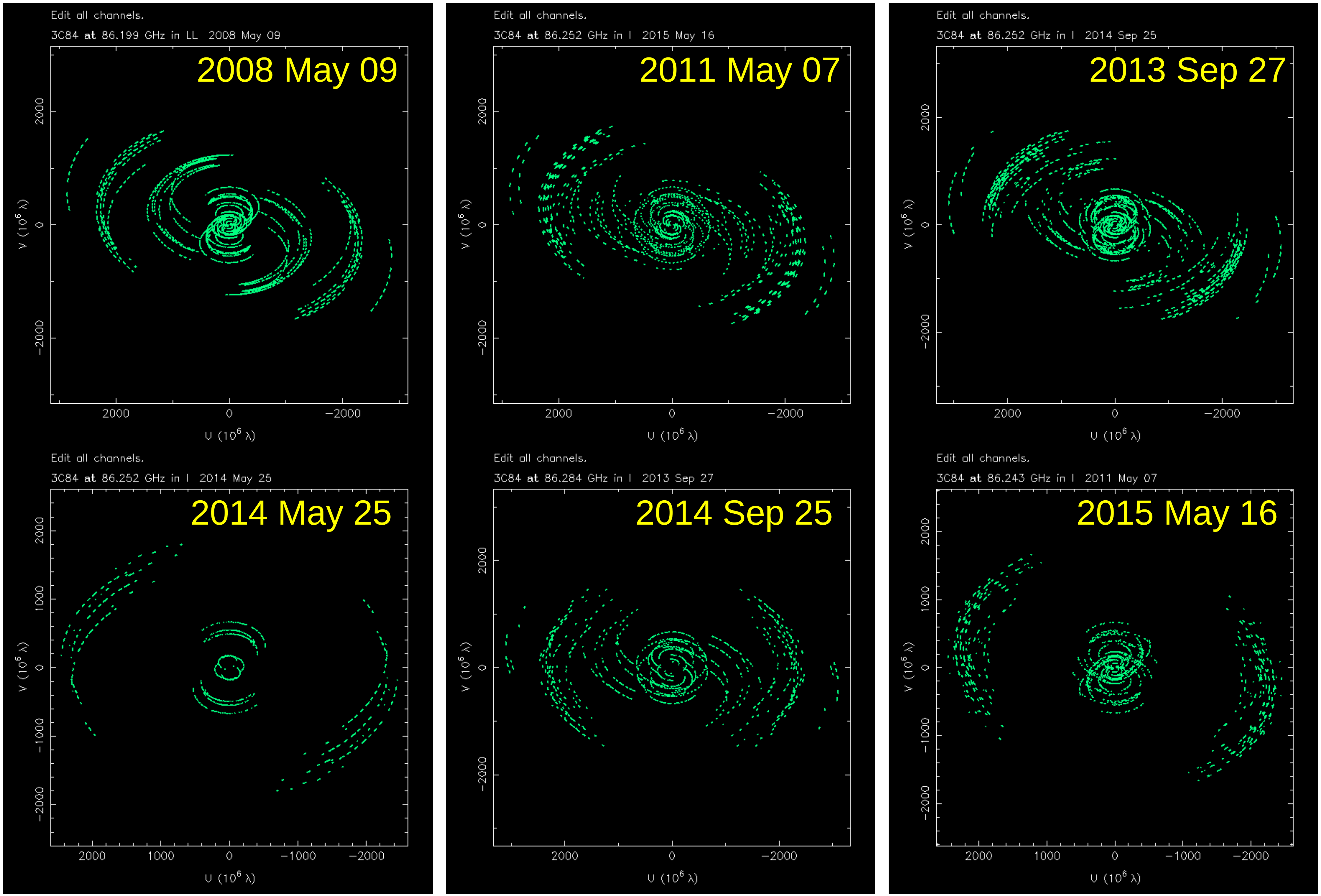
H_0 = 70 km/s/Mpc

Observations - GMVA

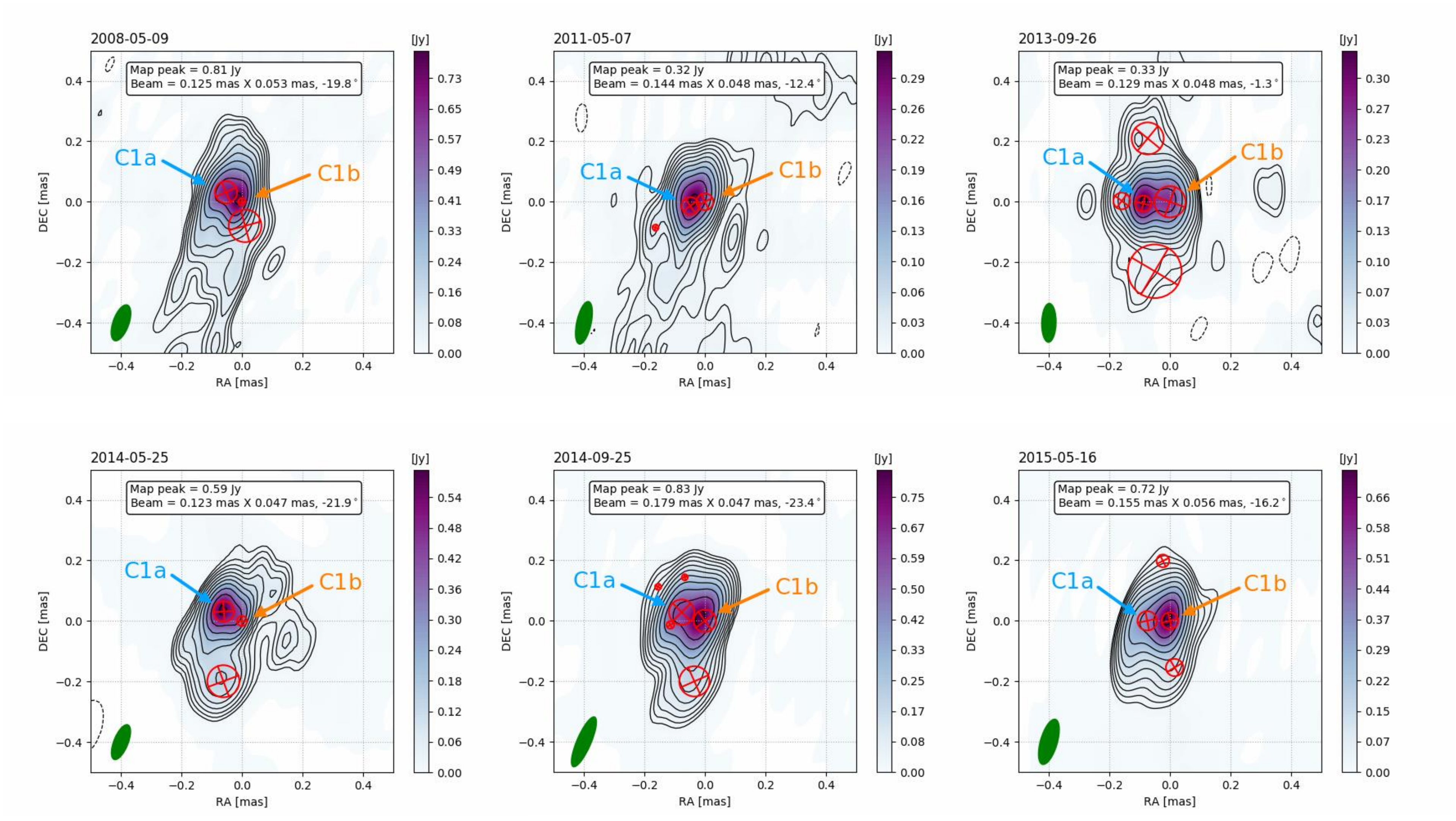


14+ telescopes (+GBT / +KVN)
maximum baseline length : ~10,000 km
Angular resolution : **50 ~ 70 μas**
Operating at **86** GHz (3mm)

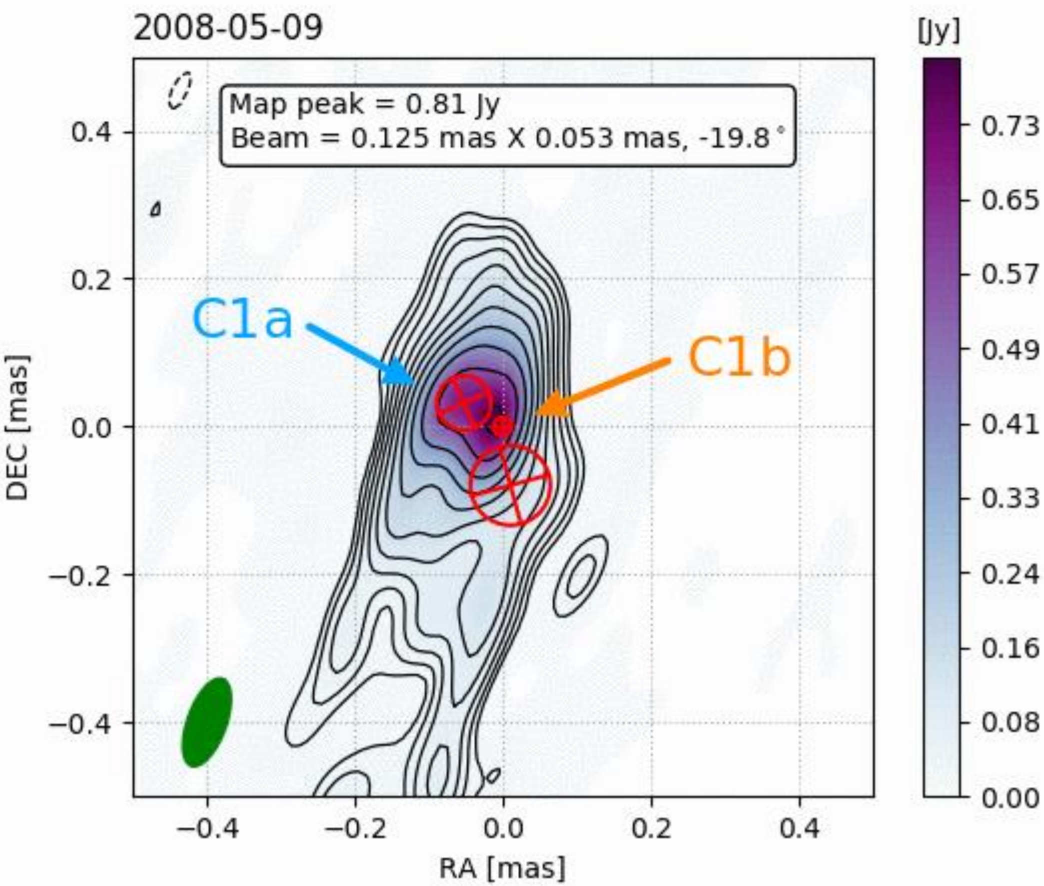
Observations – uv coverage



Consistent double nuclear structure in all 6 epochs



Consistent double nuclear structure in all 6 epochs



- **No significant motion over 8 years**
- **Separation ~70 μas**
- **Brightness temperature**
  C1a : 2.4 x 10^{10} K
  C1b : 4.1 x 10^{10} K
- **Continued to Limb-brightened jet structure (Nagai+ 2014)**

- 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)

- 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)

- 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

- 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)

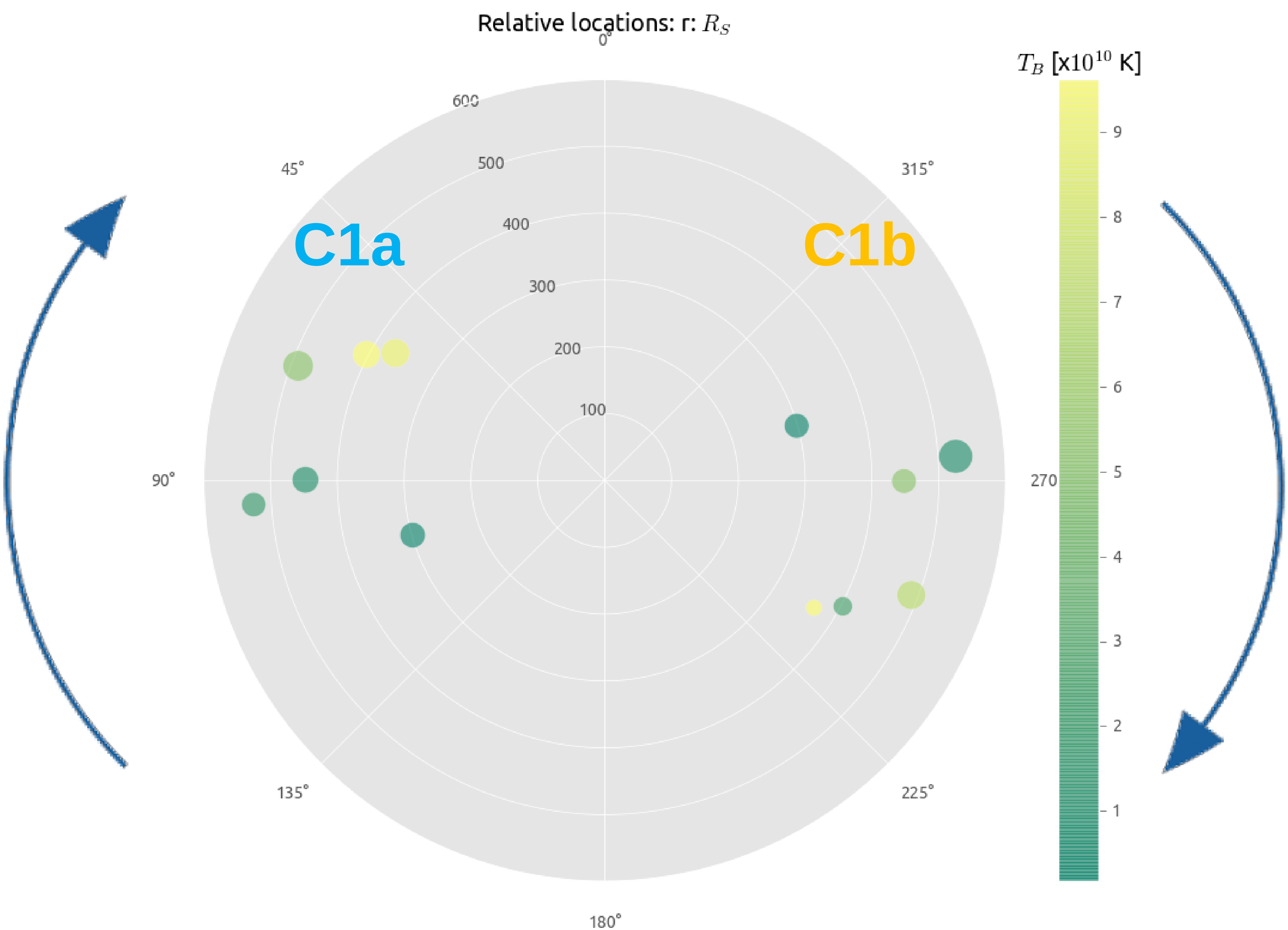
- But the size is probably even too large for an accretion disk

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

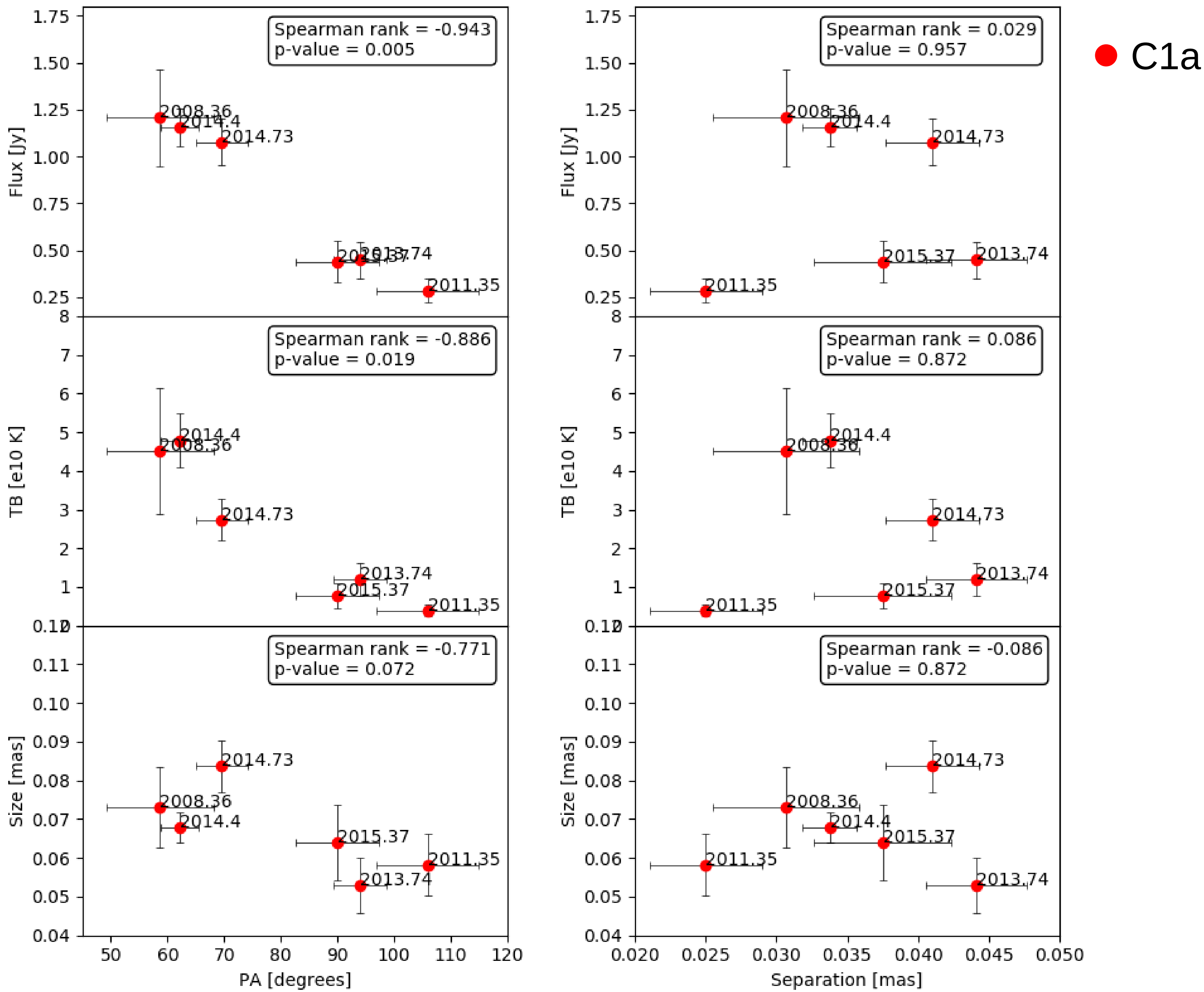
$$\log\left(\frac{R_{2500}}{cm}\right) = (15.78 \pm 0.12) + (0.80 \pm 0.17) log\left(\frac{M_{BH}}{10^9\ M_\odot}\right)$$

- Expected for 3C84 : ~54 R_S

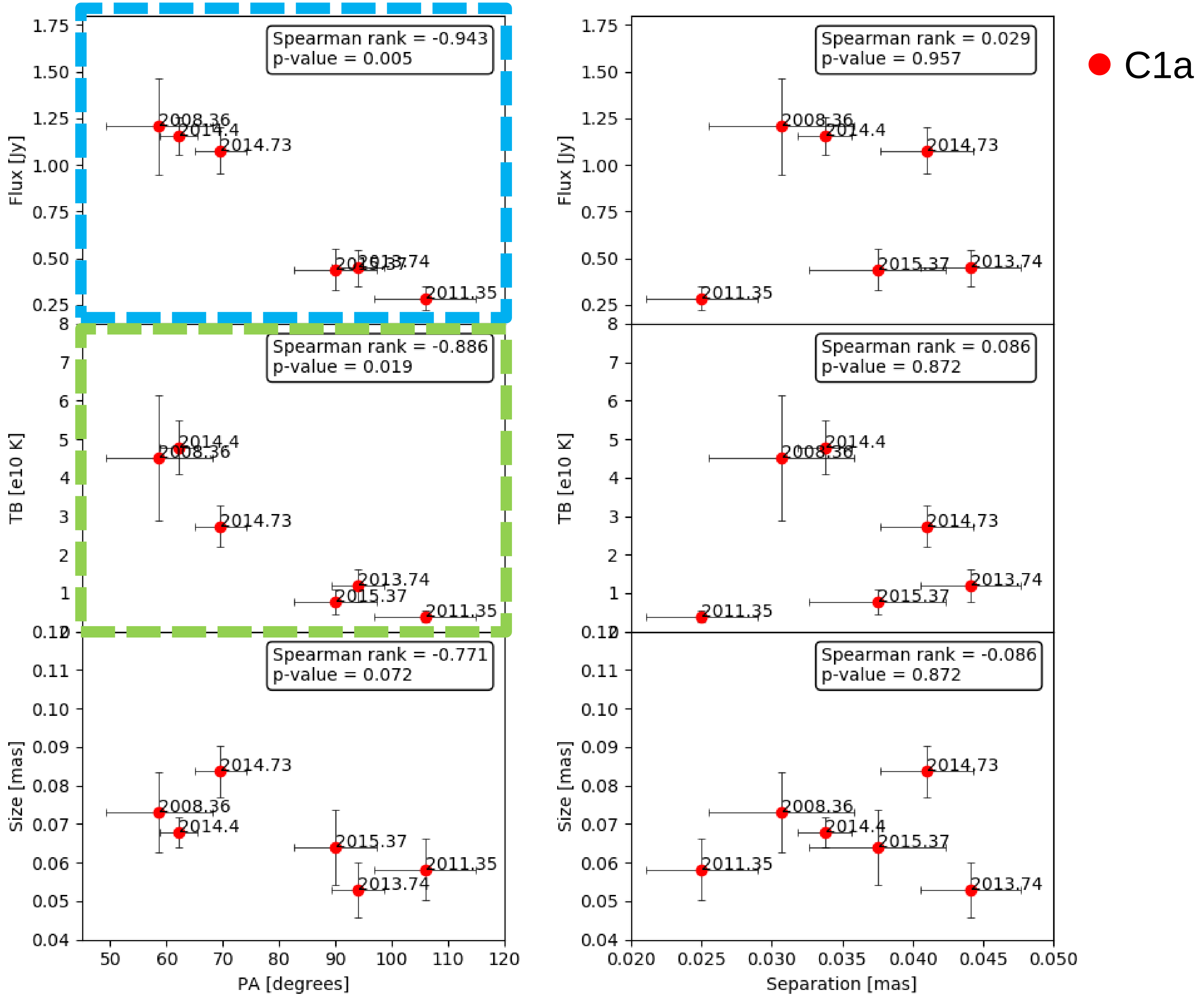
- High brightness temperature (>10^{10} K) indicates non-thermal emission



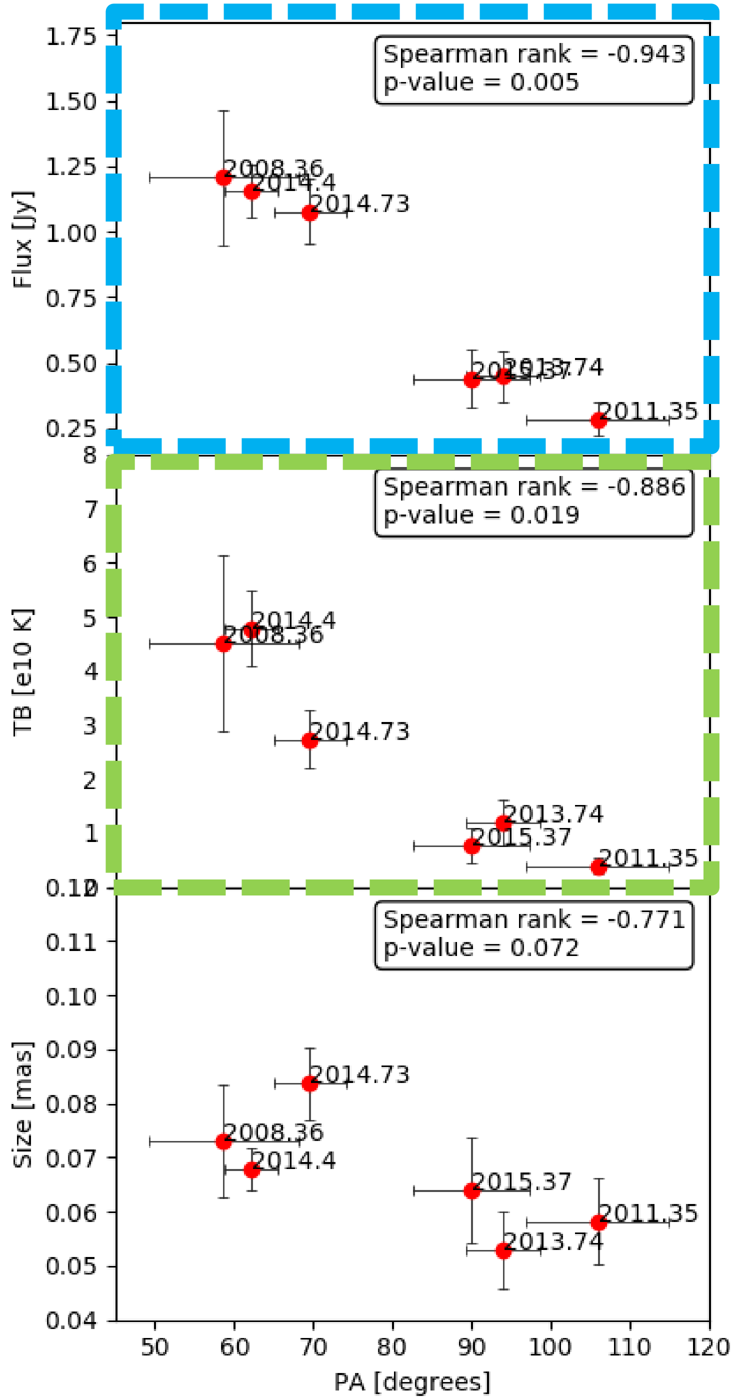
Relative locations: r: R_S
0°
45°
90°
135°
180°
225°
270
315°
100
200
300
400
500
600
C1a
C1b
T_B [x10^{10} K]
1
2
3
4
5
6
7
8
9



Spearman rank = -0.943
p-value = 0.005
Spearman rank = 0.029
p-value = 0.957
Spearman rank = -0.886
p-value = 0.019
Spearman rank = 0.086
p-value = 0.872
Spearman rank = -0.771
p-value = 0.072
Spearman rank = -0.086
p-value = 0.872
C1a
Flux [Jy]
TB [e10 K]
Size [mas]
PA [degrees]
Separation [mas]
2008.36
2014.4
2014.73
2015.37
2013.74
2011.35



Spearman rank = -0.943
p-value = 0.005
Spearman rank = 0.029
p-value = 0.957
Spearman rank = -0.886
p-value = 0.019
Spearman rank = 0.086
p-value = 0.872
Spearman rank = -0.771
p-value = 0.072
Spearman rank = -0.086
p-value = 0.872
C1a
Flux [Jy]
TB [e10 K]
Size [mas]
PA [degrees]
Separation [mas]
2008.36
2014.4
2014.73
2015.37
2013.74
2011.35



- T_B – PA and S_v – PA correlation
- T_B varies by factor of ~10
- S_v varies by factor of ~5

→ Emitters moving on a helical path

- Possible physical processes

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

Doppler Boosting in helical jet

- Jet tilted by ~65° (Fujita & Nagai 2017)
- Scaling of T_B : $T_B^{obs} = T_B^{em}\delta$
- Doppler factor : $\delta = [\gamma(1 - \beta\cos\theta)]^{-1}$

$$\frac{\delta_{max}}{\delta_{min}} \approx 10 \Longrightarrow \beta \geq 0.8$$

- Inconsistent with the bulk speed ($\beta \ll 1$)

Doppler Boosting in helical jet

- Jet tilted by ~65° (Fujita & Nagai 2017)
- Scaling of T_B : $T_B^{obs} = T_B^{em} \delta$
- Doppler factor : $\delta = [\gamma(1 - \beta \cos\theta)]^{-1}$

$$\frac{\delta_{max}}{\delta_{min}} \approx 10 \Longrightarrow \beta \geq 0.8$$

- Inconsistent with the bulk speed ($\beta \ll 1$)

$$T_B^{obs} \leq 5 \times 10^{10} K$$

$T_B^{em} \leq 5 \times 10^{10} K$ Equipartition limit (Readhead 1994)

$$\delta \approx 1 \Longrightarrow \beta \ll 1$$

Intrinsic evolution of jet plasma

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

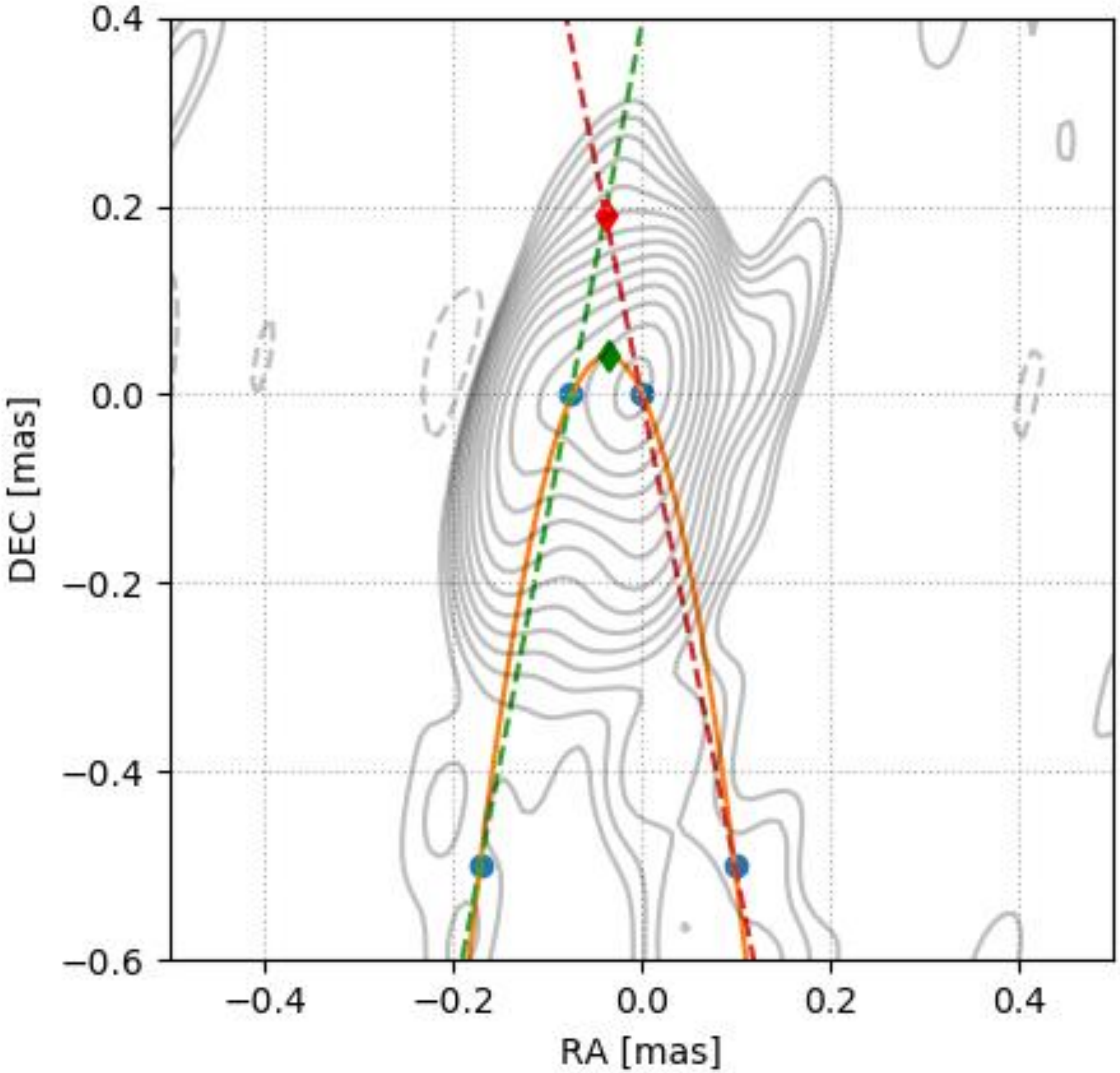
Intrinsic evolution of jet plasma

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

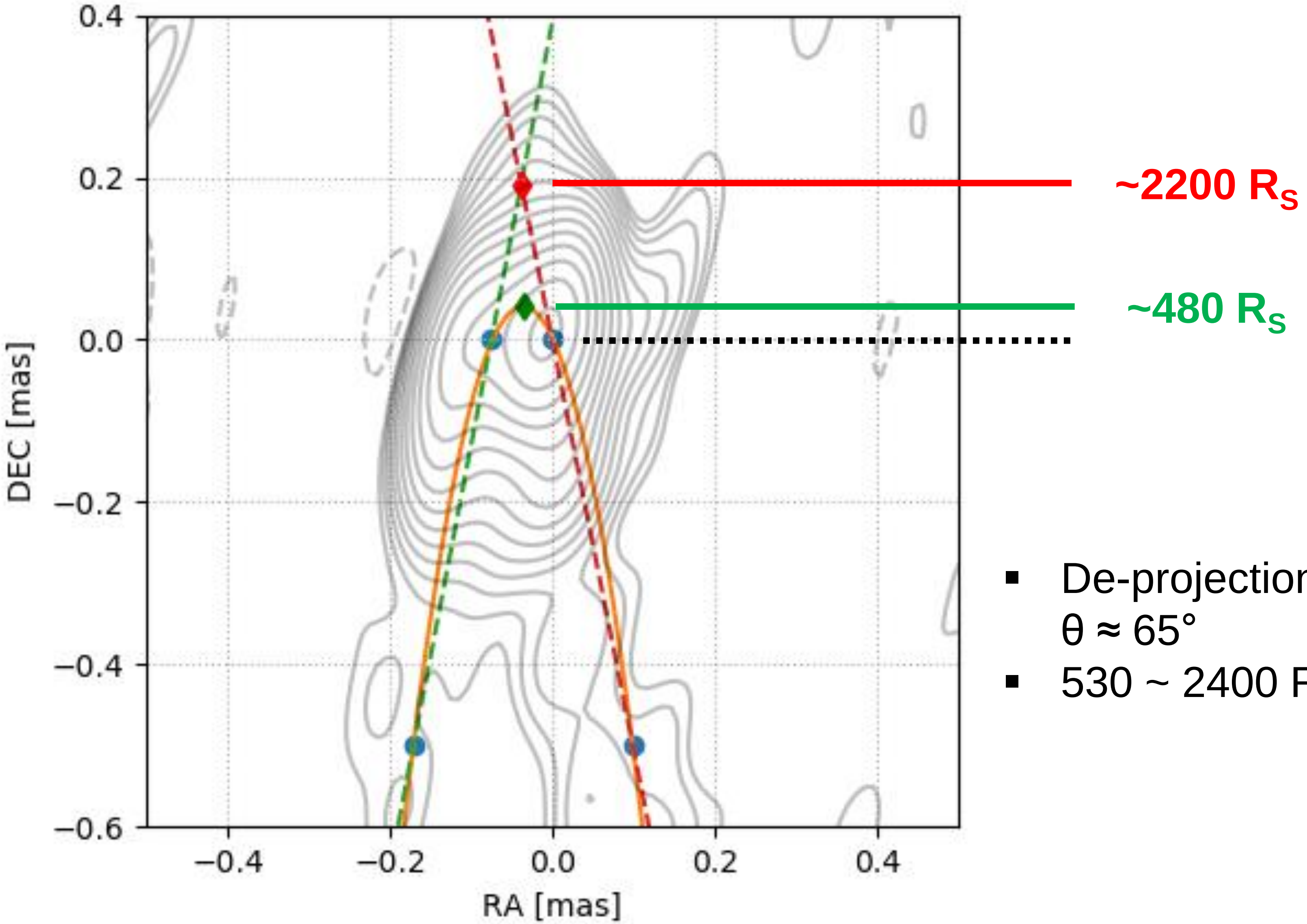
$$\tau_{cool} = 7.74 \left[\frac{\delta}{1+z}\right]^{-1} B^{-2}\gamma^{-1}\ seconds$$

- $\delta \approx 1, B \approx 10\mu T, \gamma \approx 10000, z = 0.0176$
- ~3 months
- Typical blazar-like value (Hodgson+ 2016)

Black Hole location



Black Hole location



- De-projection with $\theta \approx 65°$
- 530 ~ 2400 R_S

Summary

- An east-west oriented “double” nuclear structure in C1 region
- The brightness temperature of C1a and C1b, in the order of 10^{10}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.
- Using the jet profiles of 3 mm and 7 mm VLBI data, we placed limits of the true location of the SMBH assuming either a parabolic or conical jet to between 480 R_S and 2200 R_S