Innermost regions of the blazar S5 0716+71 from RadioAstron polarimetric observations at 22 GHz

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on behalf of the RA Polarization KSP team

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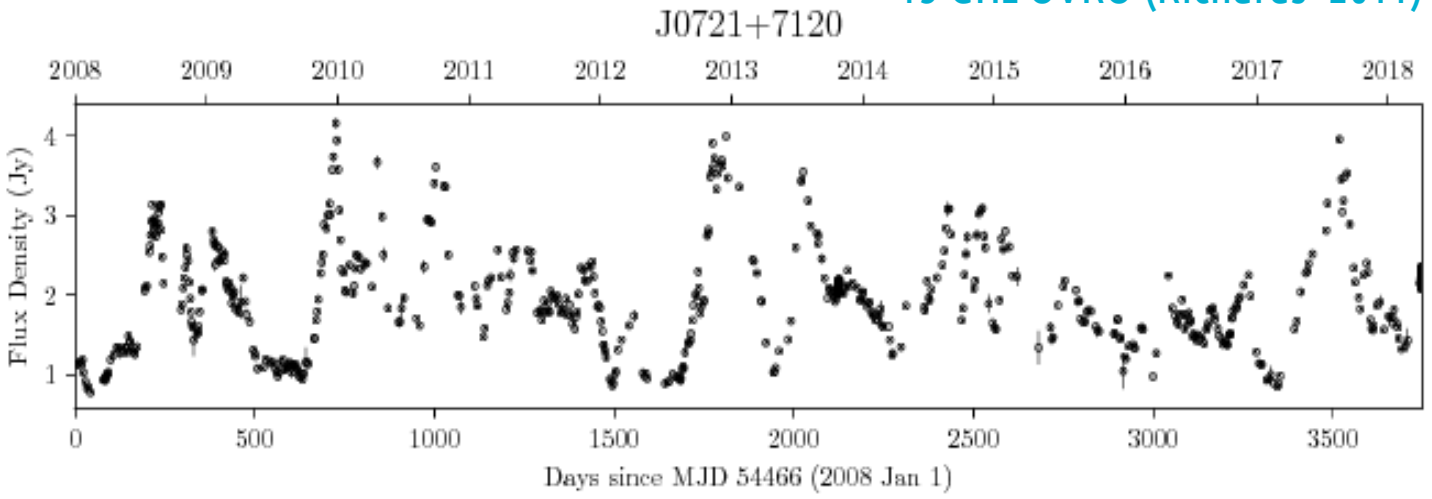
Blazar S5 0716+71

AGN
z ≥ 0.31
βapp ≤ 25c
δ ≤ 25
Θ ≤ 5°

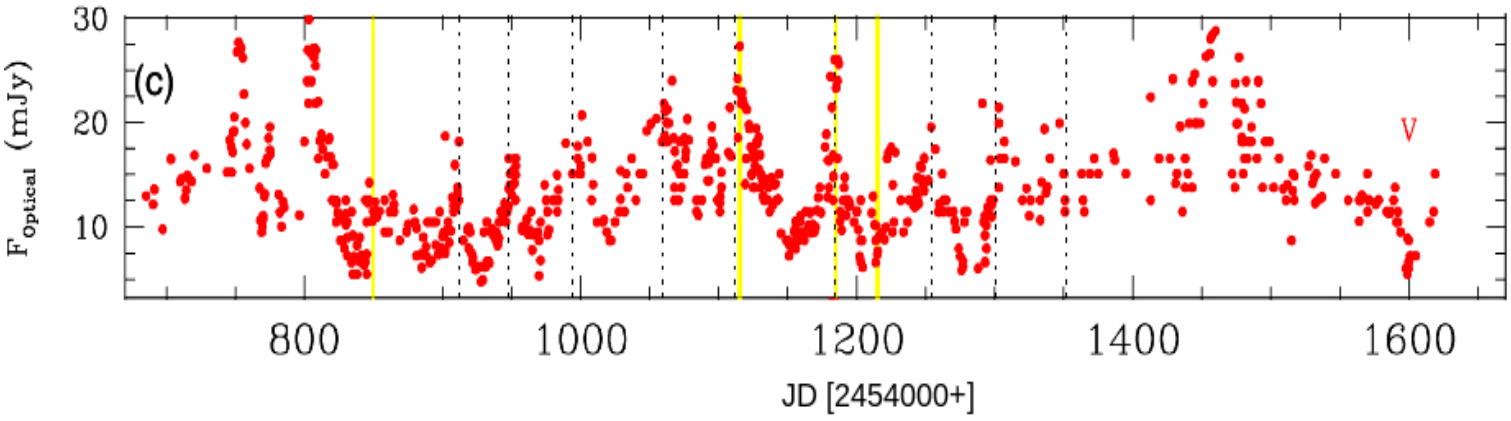
Duty cycle ~ 80-90%,
i.e. blazar is active
almost all the time

Intra-day variability

15 GHz OVRO (Richards+2011)



V (Rani+2014)



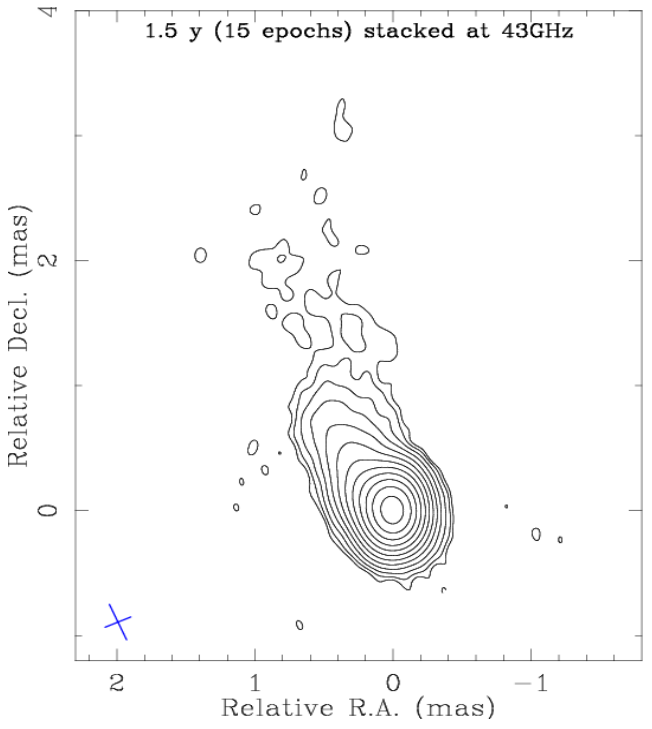
Blazar S5 0716+71

VLBI: significant correlation between γ-ray flux variations and PA variations in the inner 200 μas of the VLBI jet.

Rani+2014

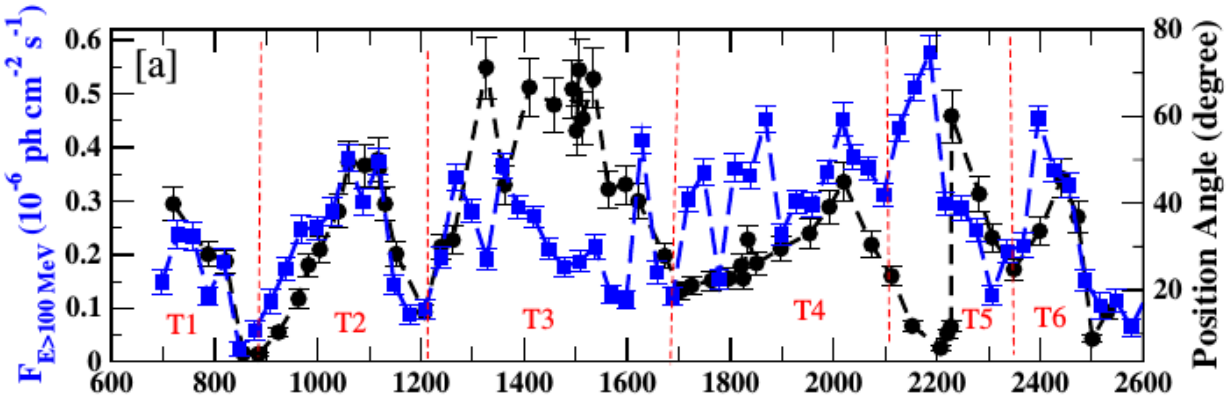
VSOP: variability of ~5% in total intensity and ≤40% in linear polarization in ≤1 day, and is produced in the VLBI core component of the size ≤100 μas.

Bach+2006



15 BU epochs Stacked @ 43GHz

Rani+2014



AGN

$z \geq 0.31$

$\beta_{app} \leq 25c$

$\delta \leq 25$

$\Theta \leq 5°$

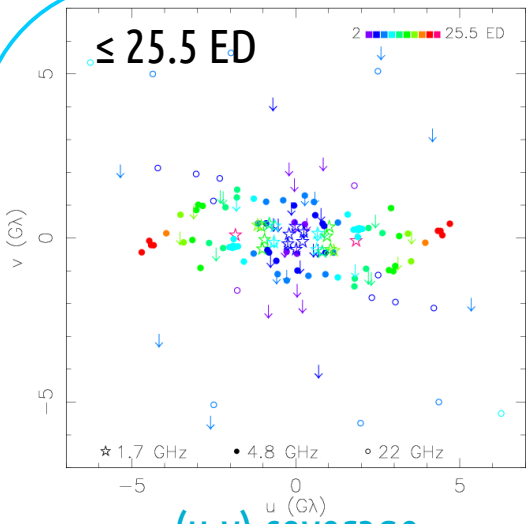
What is structure of the central 100 μas of the VLBI jet?

What produces IDV?

RadioAstron observations of 0716+714

Polarization KSP: 1 global space VLBI imaging run

KSP on AGN Survey & Monitoring: 64 snapshot observations



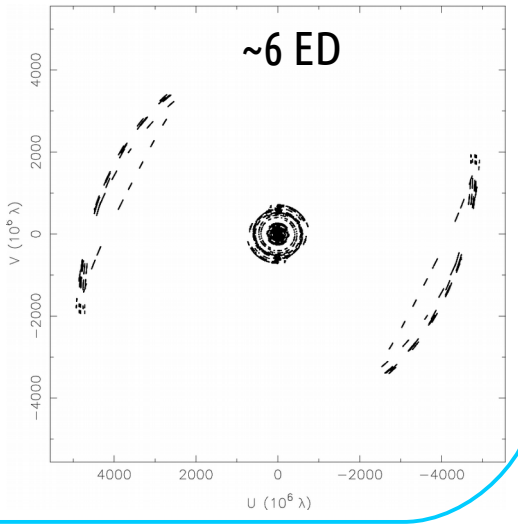
(u,v) coverage

1.7 (L), 4.8 (C) and 22 (K) GHz during 2012 – 2017

Max projected baseline: ≤ 25.5 ED / 324 900 km

Brightness temperature & angular size estimates

(u,v) coverage



2015 January 3-4 / 22 GHz

VLBA (BR, FD, HN, LA, OV, PT), EF, NT, GB, SH, TR + 10-m SRT

Max projected baseline: 5.25 Gλ / 5.6 Earth diameter / 70 833 km

Detailed imaging

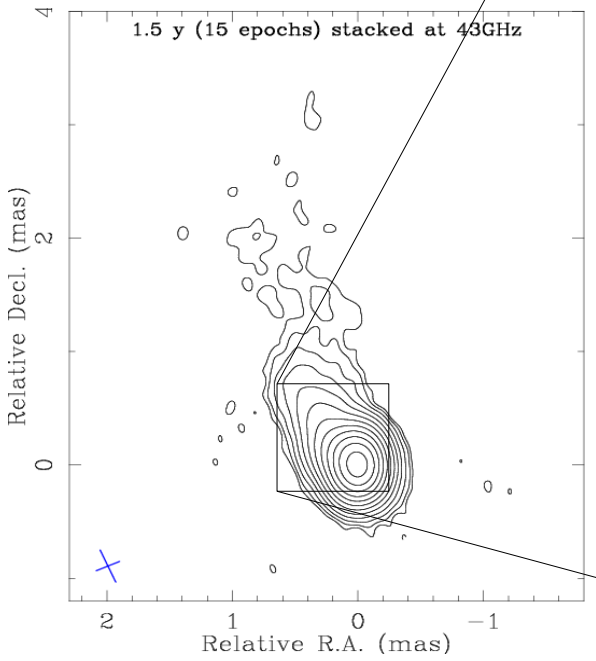
Results: the most detailed image of 0716+714

The finest resolutions of blazar image to date:

Space VLBI: 0.057x0.024 mas /
2015 Jan 3-4, 22 GHz

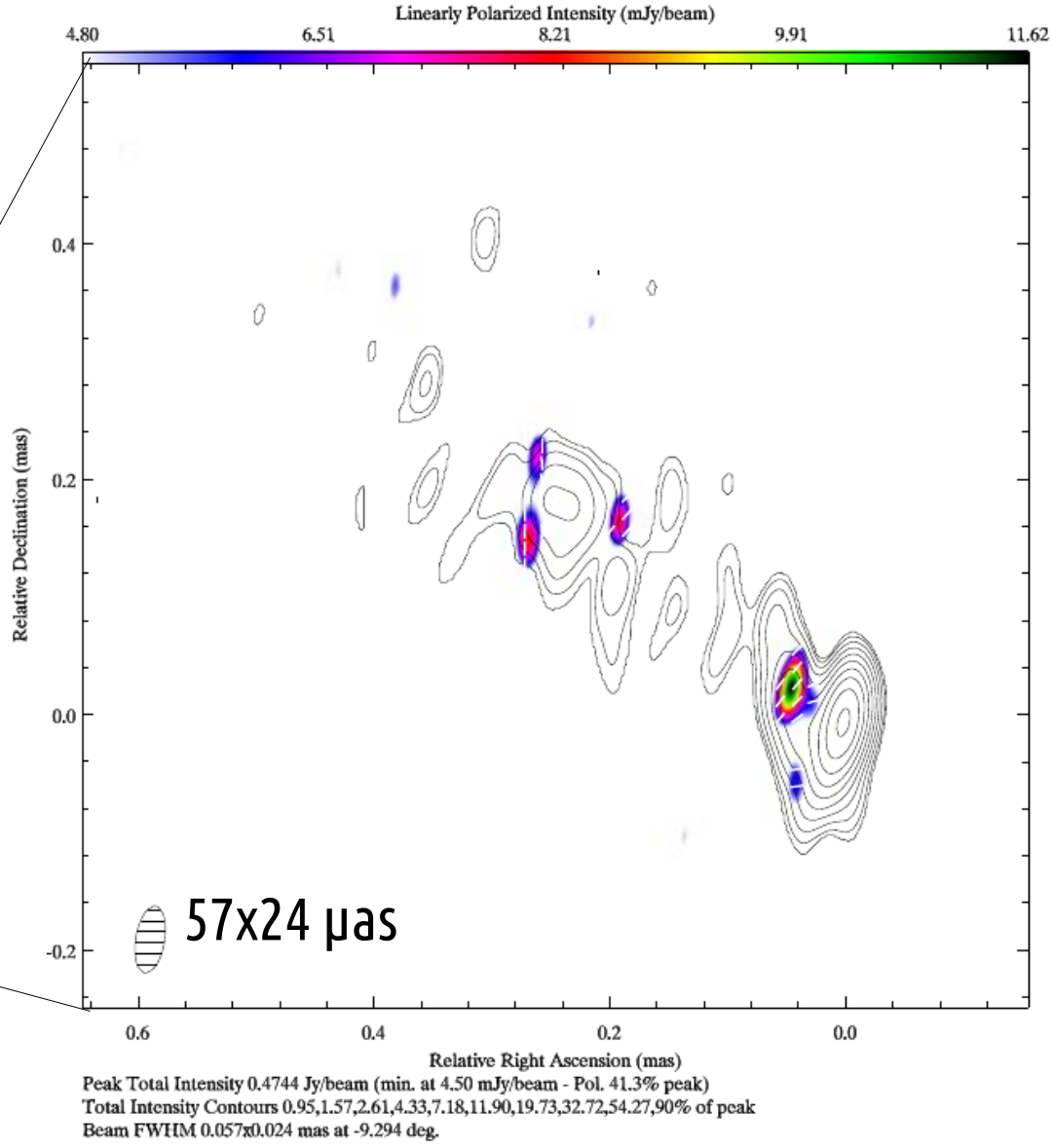
mm-VLBI: 0.076x0.049 mas /
2003 Apr 28, 86 GHz, Bach+2006

GMVA: 0.117 x0.053 mas /
2013 Feb 13, 86 GHz, Rani+2016

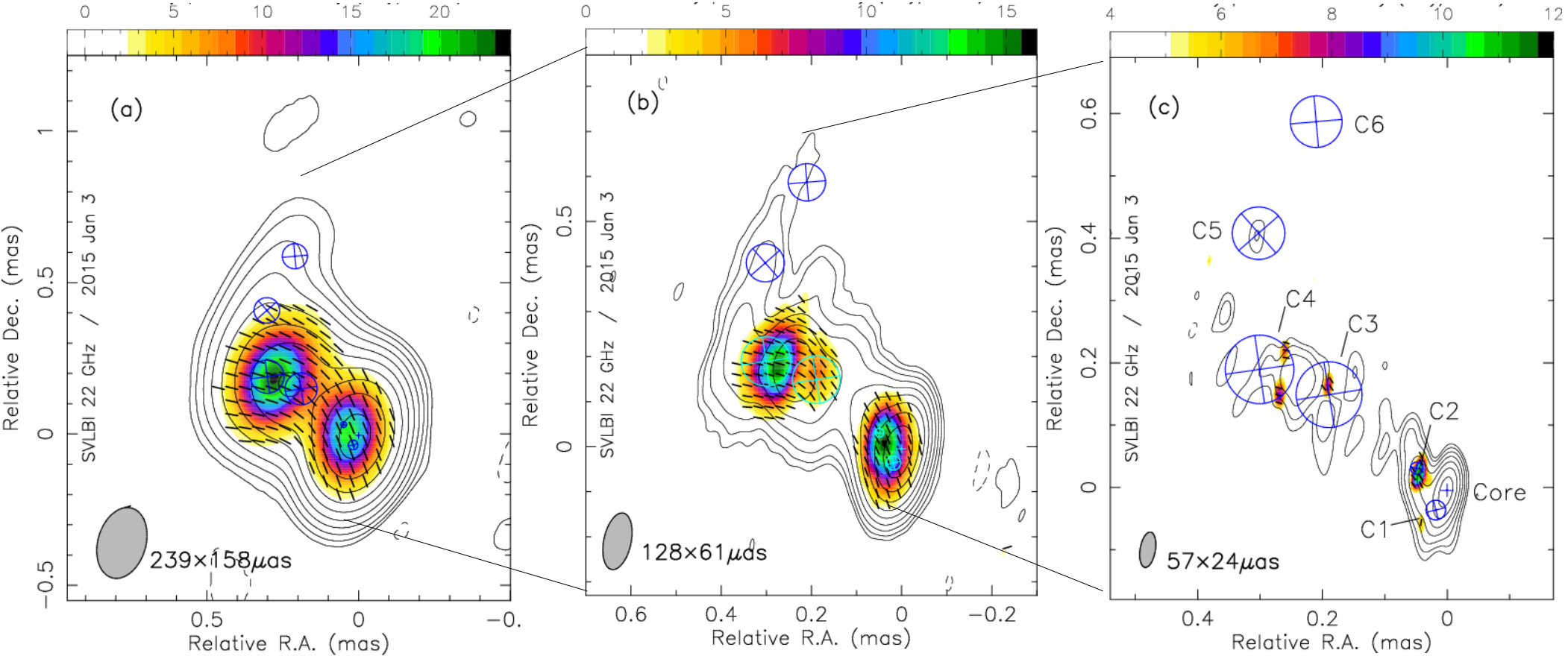


15 BU epochs Stacked @ 43GHz

Space total and linearly polarized intensity contours @ 22GHz, super uniform weighting



The jet of 0716+714 at different scales

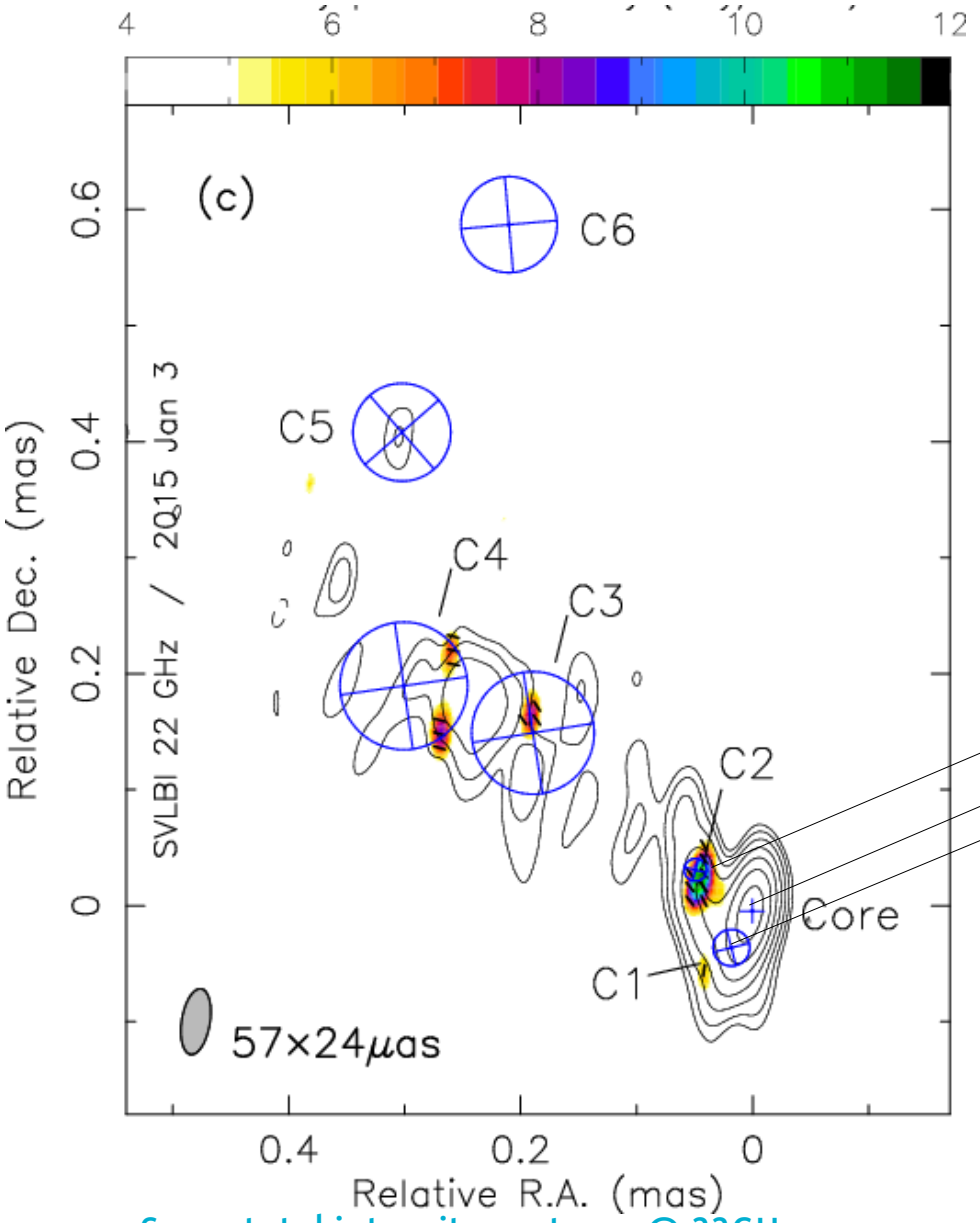


natural weighting

uniform weighting

super uniform weighting

Structure of the innermost 100 μas of 0716+714 jet



Space total intensity contours @ 22GHz
super uniform weighting

Brightness temperature:

Core: < 12x5 μas / $T_{b,obs} \geq 2.2 \times 10^{13}$ K

C1: ~30 μas / $T_{b,obs} \sim (7.0 \pm 0.2) \times 10^{11}$ K

C2: ~19 μas / $T_{b,obs} \sim (1.2 \pm 0.1) \times 10^{12}$ K

60 μas

40 μas

$T_{b,observed} = \delta\, T_{b,intrinsic}$

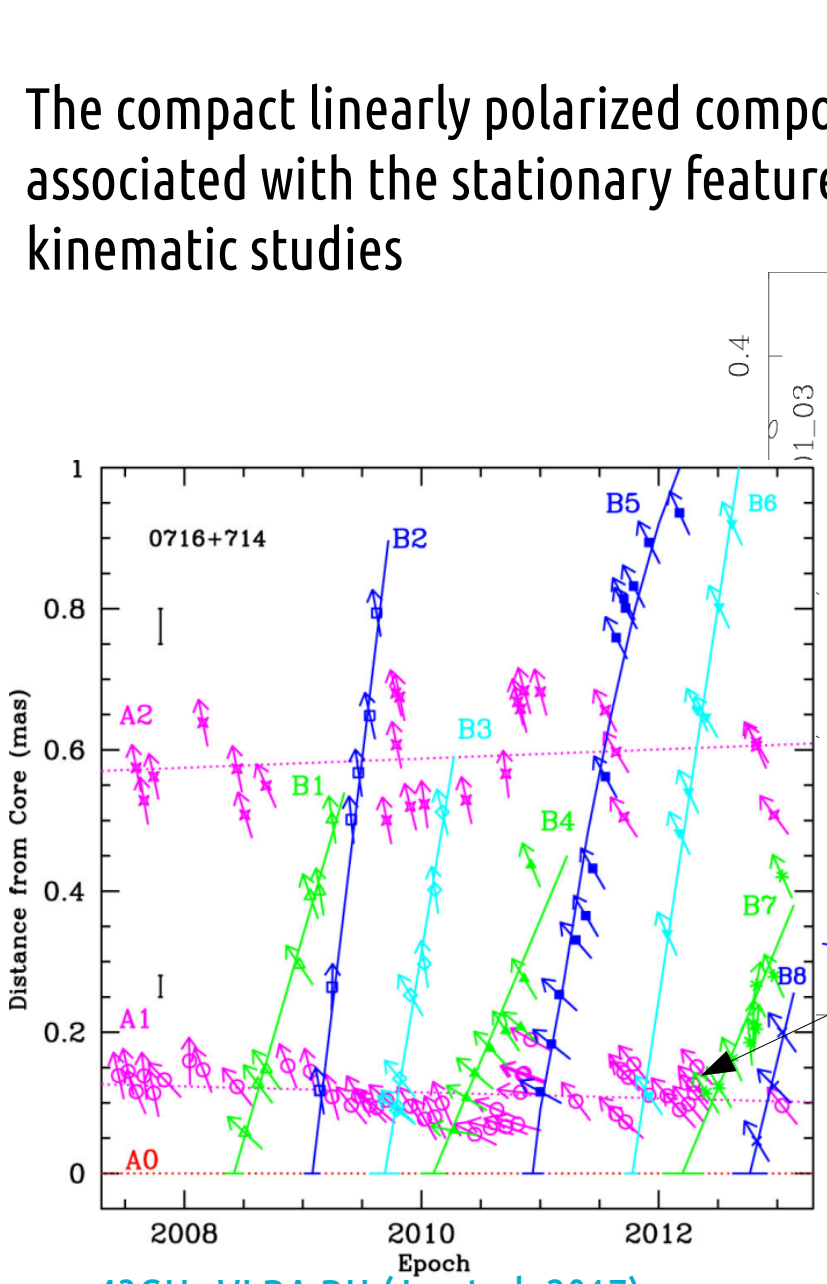
For $\delta \sim 25$ and $T_{b,obs} \geq 2.2 \times 10^{13}$ K, $T_{b,intrinsic} \sim 10^{12}$ K

Compact polarized component at C2

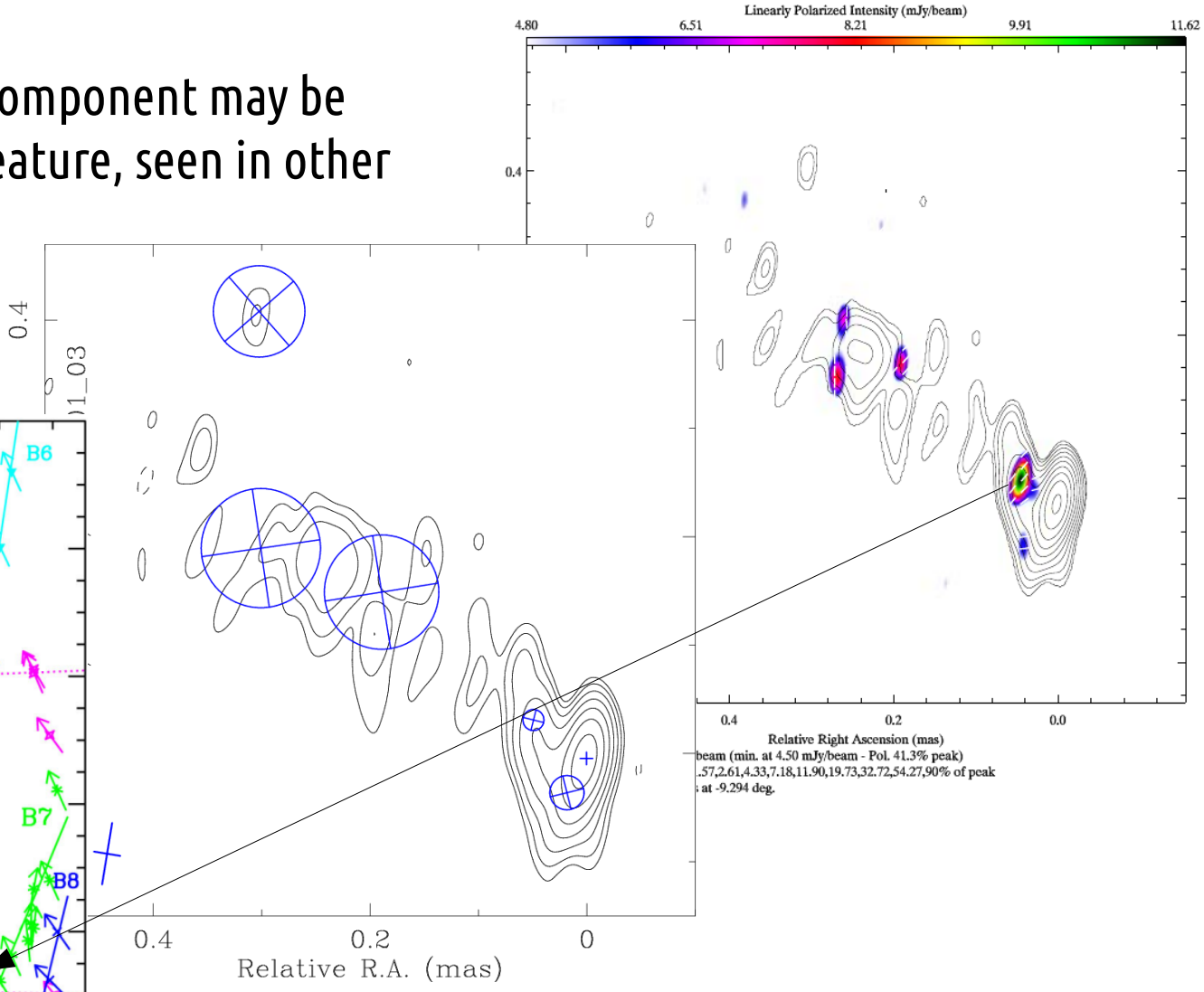
Degree of linear polarization ~ 15%

Component C2 of the inner S5 0716+71 jet

The compact linearly polarized component may be associated with the stationary feature, seen in other kinematic studies



43GHz VLBA BU (Jorstad+2017)



C2: ~19 μas / $T_{b,obs}$~$(1.2\pm0.1)\times10^{12}$K

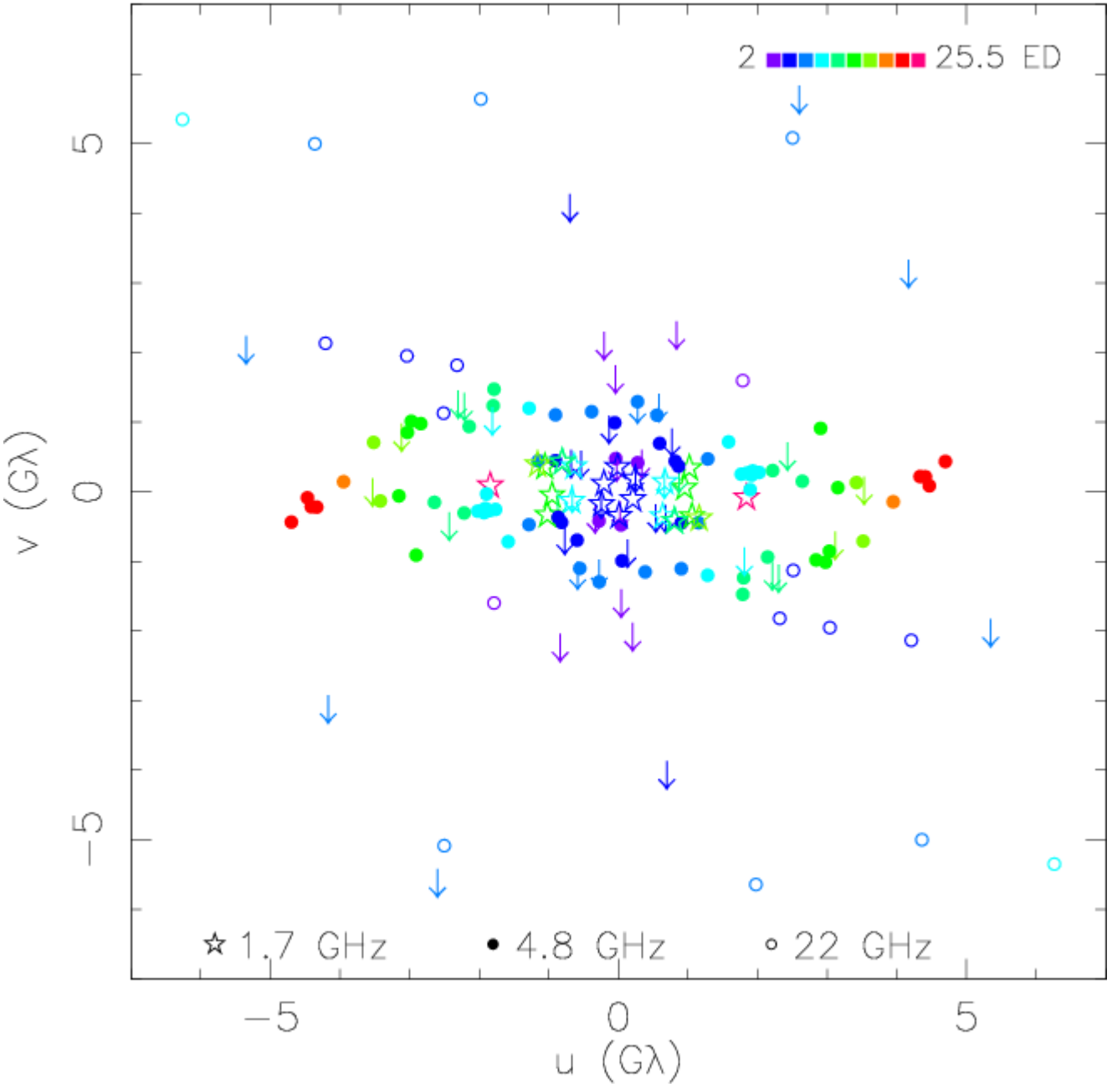
Degree of linear polarization ~ 15%

Taking δ~25, θ=19μas, light crossing time ~5.5days

0716+714 RadioAstron brightness temperatures

64 x 20m-1h observations
at 1.7, 4.8 and 22 GHz

The longest proj.baseline:
25.5 Earth diameters / 1.7 GHz / 324 900 km



0716+714 RadioAstron brightness temperatures

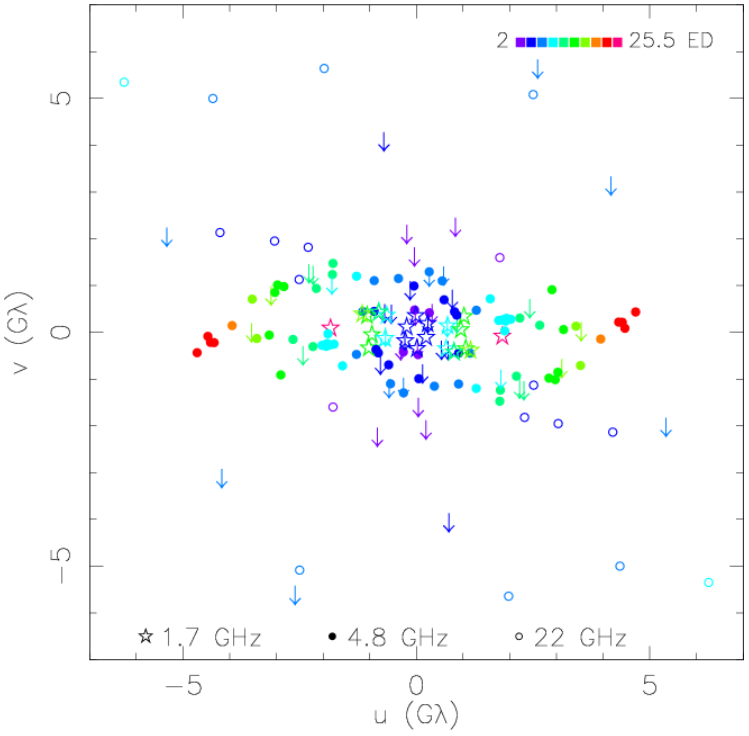
64 x 20m-1h observations
at 1.7, 4.8 and 22 GHz

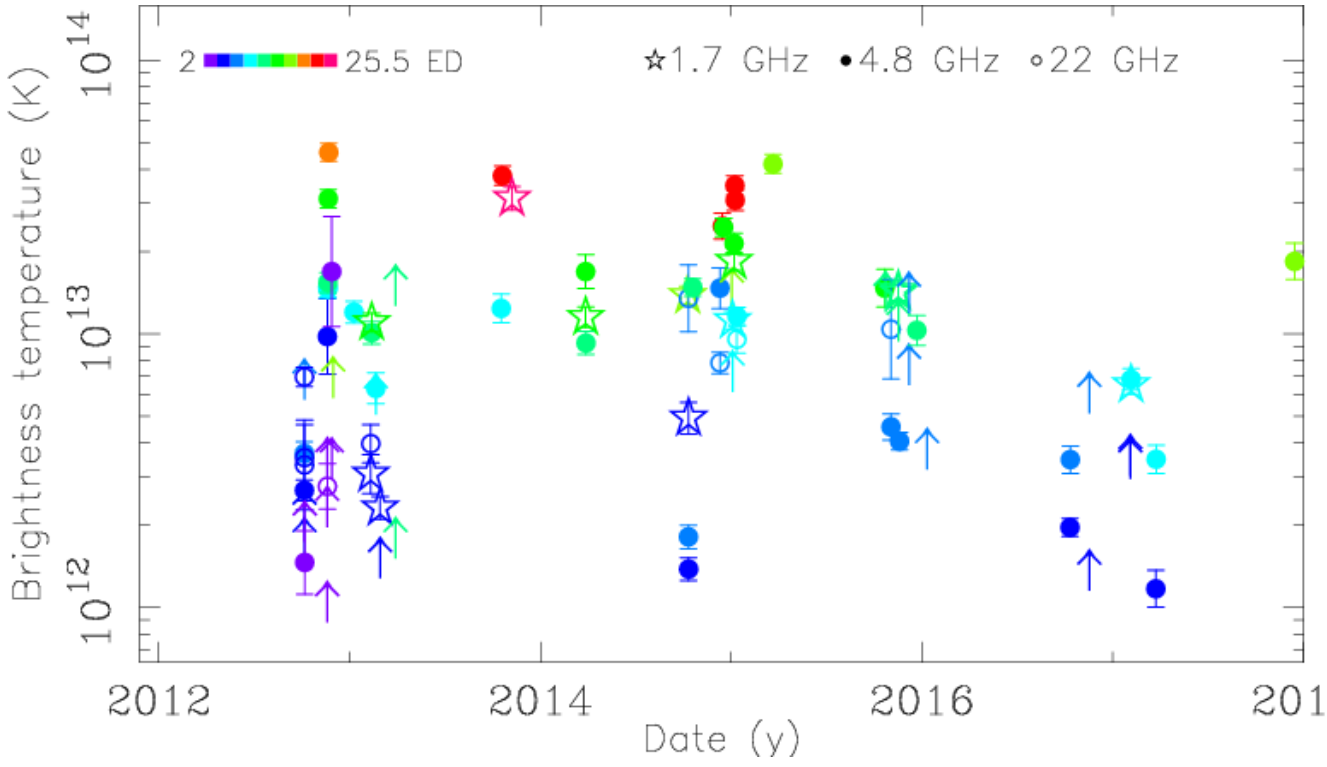
$$T_{\mathrm{b,est}} = (1+z)\frac{\pi}{2k}\frac{B^2 V_0}{\ln(V_0/V_{\mathrm{b}})}$$

$$\theta = \frac{2\sqrt{\ln 2}}{\pi}\frac{\lambda}{B}\sqrt{\ln(V_0/V_{\mathrm{b}})}.$$

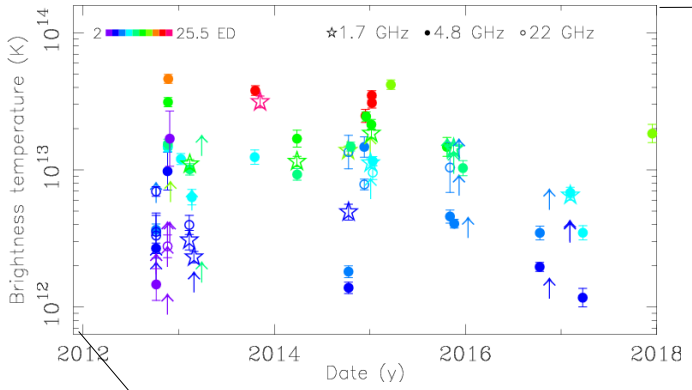
The longest proj.baseline:
25.5 Earth diameters / 1.7 GHz / 324 900 km

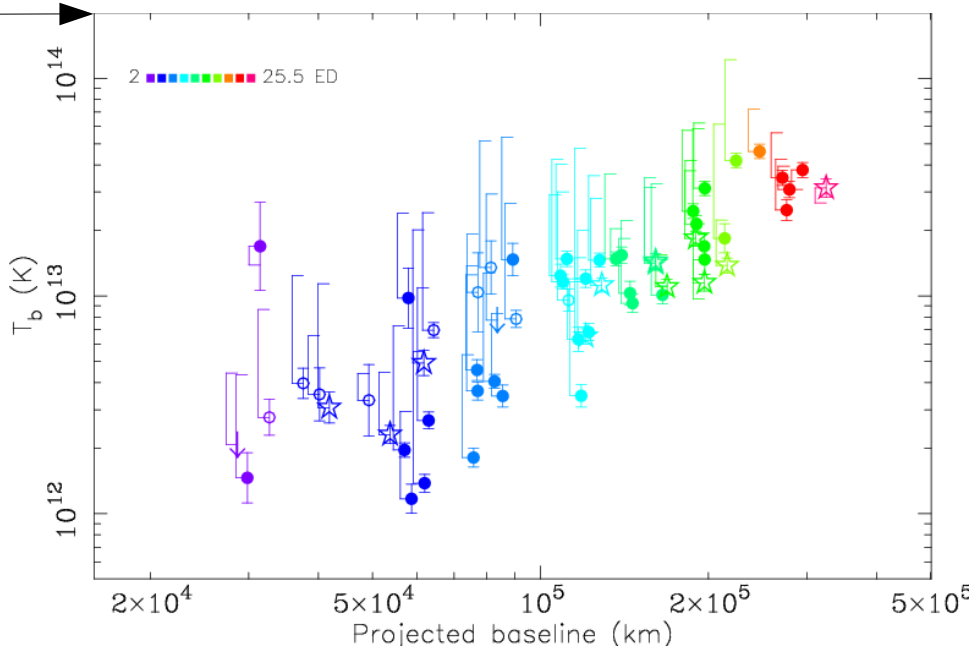
Lobanov 2015





0716+714 RadioAstron brightness temperatures





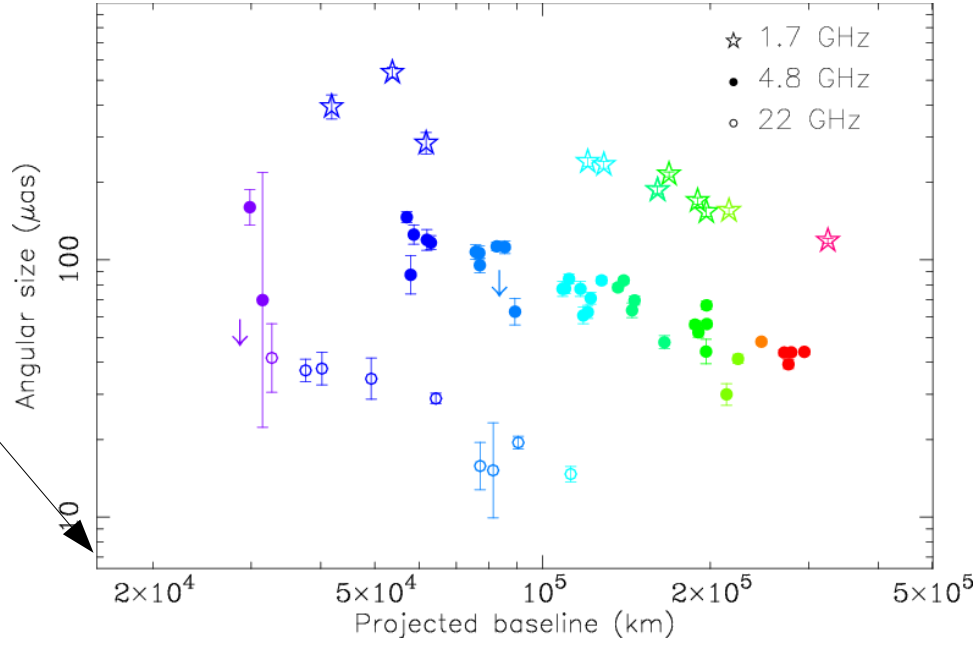
$$T_{\rm b,est} = (1+z)\frac{\pi}{2k}\frac{B^2 V_0}{\ln(V_0/V_{\rm b})} \qquad \theta = \frac{2\sqrt{\ln 2}}{\pi}\frac{\lambda}{B}\sqrt{\ln(V_0/V_{\rm b})}.$$

Tb,observed = δ Tb,intrinsic
For δ~25 and Tb,obs=(4.61±0.35)x10^{13}K then
Tb,intrinsic~2x10^{12}K

There is an indication that high Tb are connected with injection of new jet components

The shortest detected variability scale is ≤4 hours (C,K-bands)

Do these measures correspond to observations on Earth?

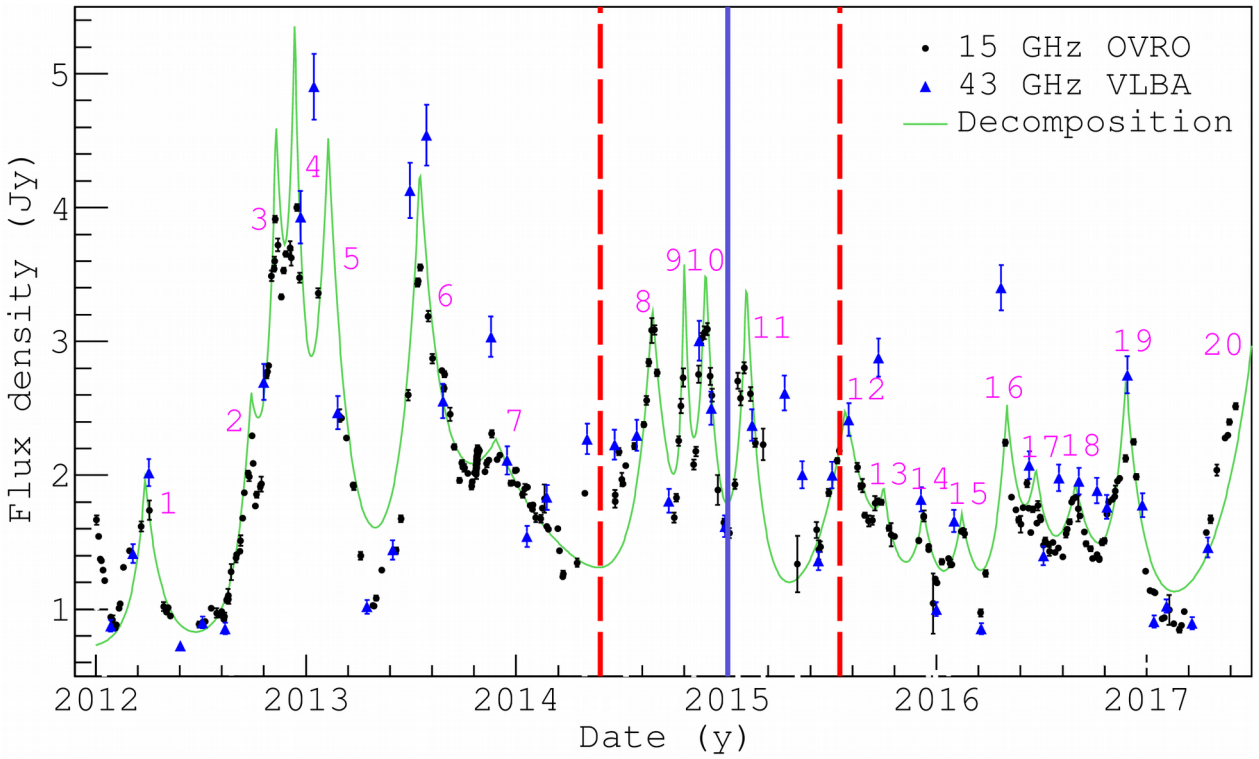


Ground-based 0716+714 brightness temperatures

Total flux density @ 15 and 43 GHz

$$T_{\mathrm{b,var}} = \delta_{\mathrm{var}}^{3} T_{\mathrm{b,int}}$$

$$T_{\mathrm{b,obs}} = \delta\, T_{\mathrm{b,int}}$$



Decomposition of the 15 GHz radio light curve into individual flares and combination with the modelled structure of the VLBA jet images at 43 GHz

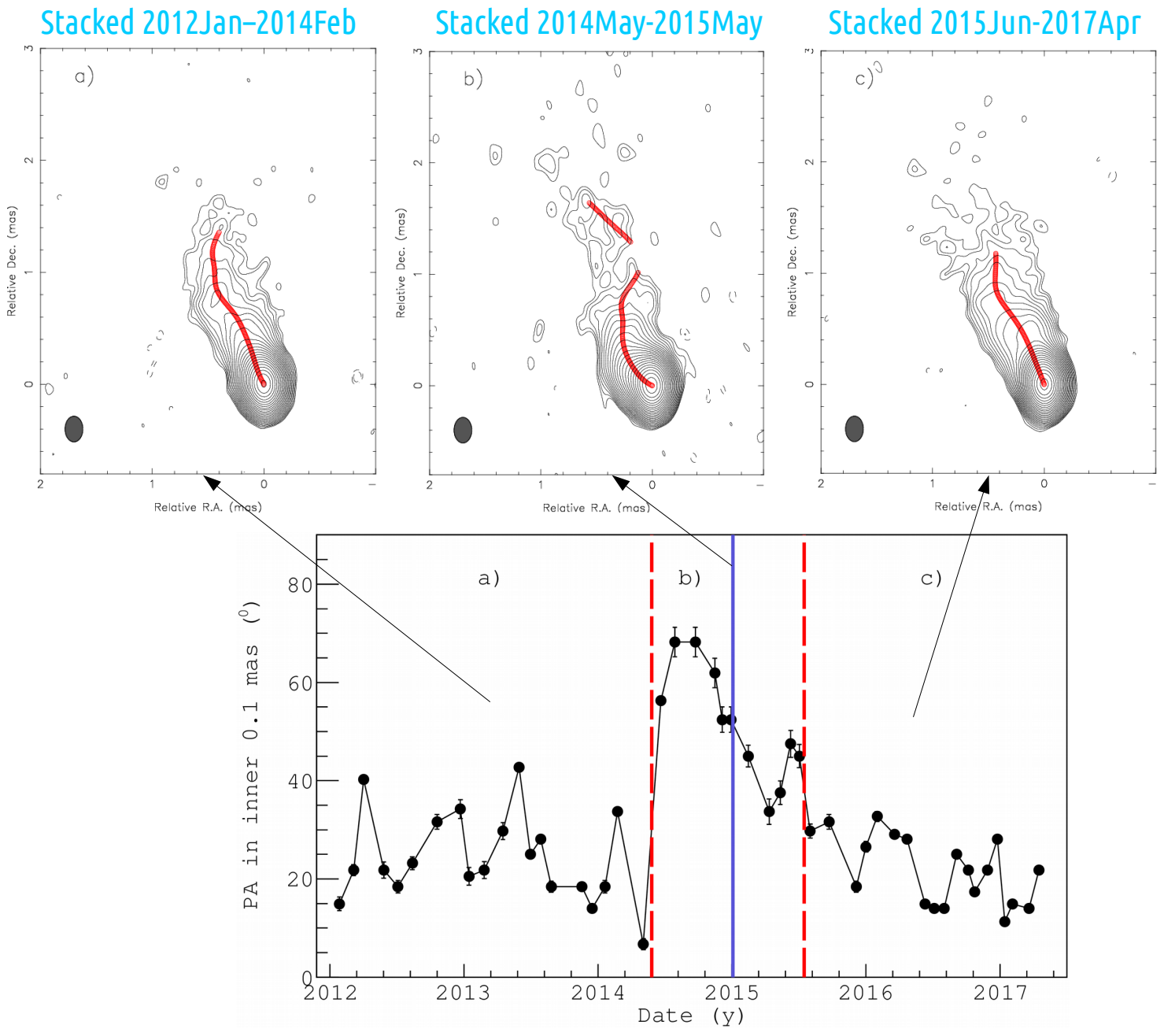
The results are $2 \le \delta \le 32$ and $7\times10^{10}\mathrm{K} \le T_{b,int} \le 2\times10^{12}\mathrm{K}$ with median $4\times10^{11}\mathrm{K}$ which is close to expected value of $10^{11.5}\mathrm{K}$ for inverse Compton losses

Kellermann & Pauliny-Toth 1969

RadioAstron: $T_{b,obs}=(4.61\pm0.35)\times10^{13}\mathrm{K}$ and $T_{b,intrinsic}\sim2\times10^{12}\mathrm{K}$

Variability of the 0716+714 jet position angle

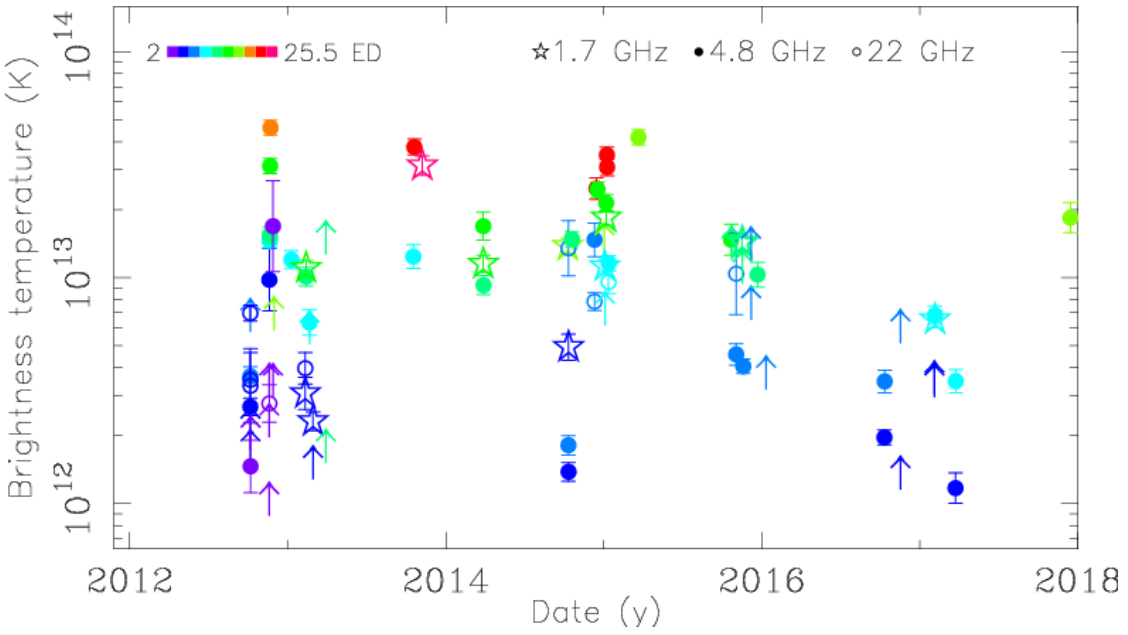
The PA of the inner 100 μas varies significantly in time, as seen from 5 years of blazar monitoring with BU@43GHz

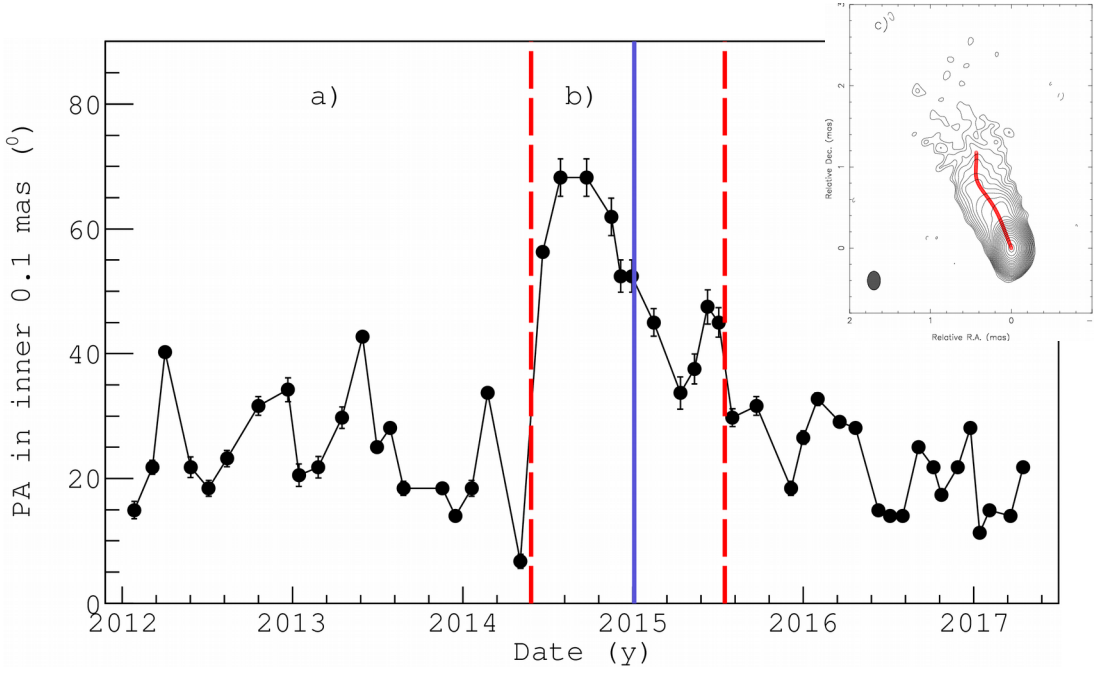


Tb – jet PA connection for 0716+714

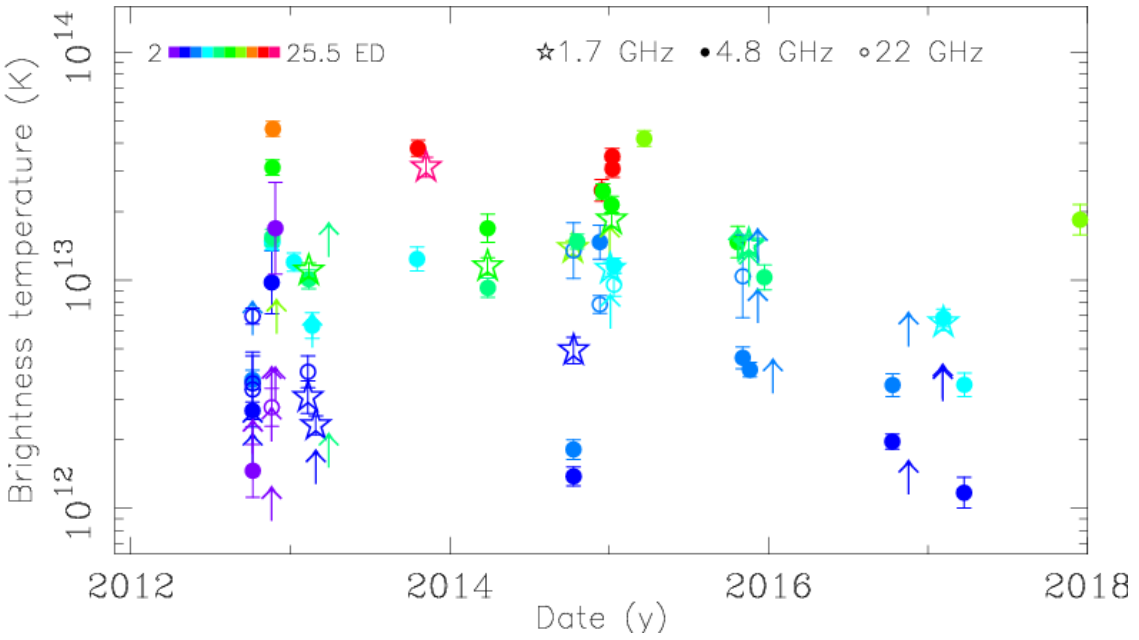
The PA of the inner 100 μas varies significantly in time, as seen from 5 years of blazar monitoring with BU@43GHz

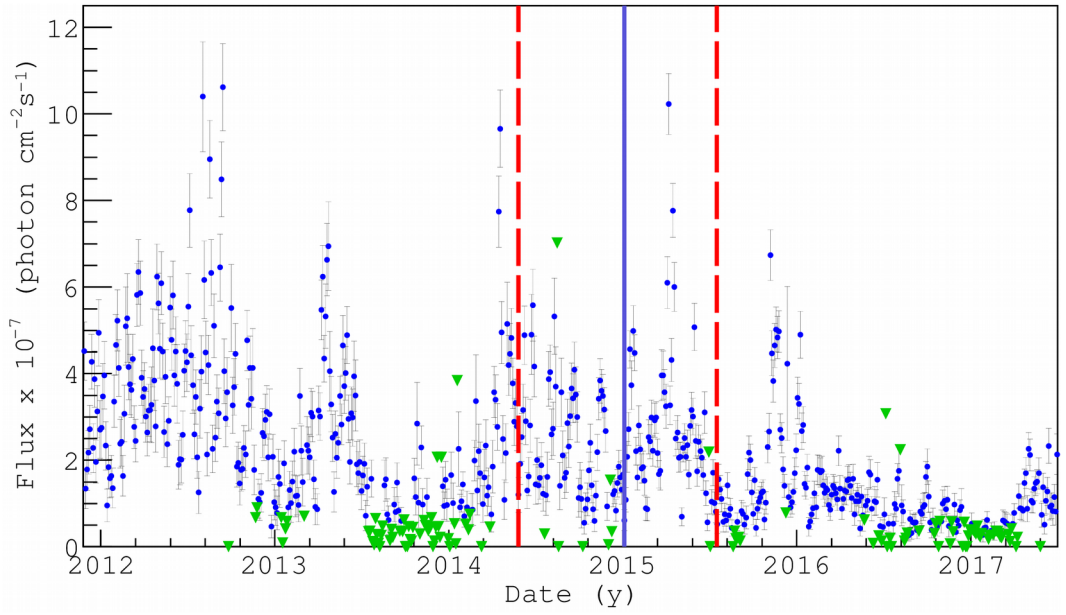
Tb variability originates at scales ≤ 100 μas





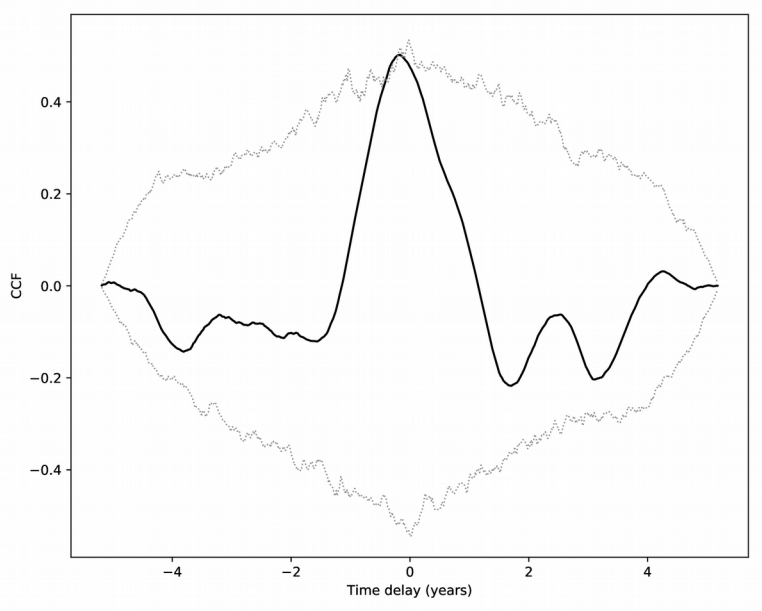
Tb – gamma-ray flux connection for 0716+714





γ-ray emission correlates with the long-term variations of Tb with ~ 90% confidence

γ-ray variations lead that of Tb by ~ 0.2 years, which applies that distance between γ-emission production zone and place, where radio emission at 4.8GHz originates is ~14 pc.



Results

- We present space-VLBI observations of the blazar 0716+714, obtained by RadioAstron mission. The source has been detected on baselines ≤25.5 ED (~325,000 km) in total intensity, and on the baselines ≤5.6 ED (70,833 km) in polarized intensity.

- We obtain full-polarimetric image of 0716+714 with the maximum angular resolution of ~24 μas, highest for the source to date, and found complex bent structure in the central 0.1 mas core of the blazar jet. Still, our probes do not resolve the core < 12x5 μas, having $T_{b,int} \geq 9 \times 10^{11}$K in excess of predicted limits.

- We suggest that 15%-polarized component of the size 19 μas, located within ~60 μas from the core, can represent recollimation or standing shock in the jet. This feature might be responsible for weekly variability of the blazar in polarized intensity. Meanwhile, other strongly polarized components can be presented upstream the jet, where we see significant curvature, and may produce intrinsic IDV. Probably, different orientation and hence Doppler boosting is not allow us to probe these very compact regions.

- The highest observed brightness temperature of the blazar on space-ground baselines reaches 4.6×10^{13}K. This applies, that some of the compact jet region, seen by RadioAstron are far from the equipartition regime between radiating particles and the magnetic field. There is an indication, that highest Tb states are connected with injection of new components into jet. High Tb states correlate with gamma-emission, implying that distance between γ-emission production zone and the site where radio emission at 4.8 GHz originates is of 14 pc.