PAGaN II: The evolution of AGN jets on sub-parsec scales

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East-Asia AGN Workshop 2016

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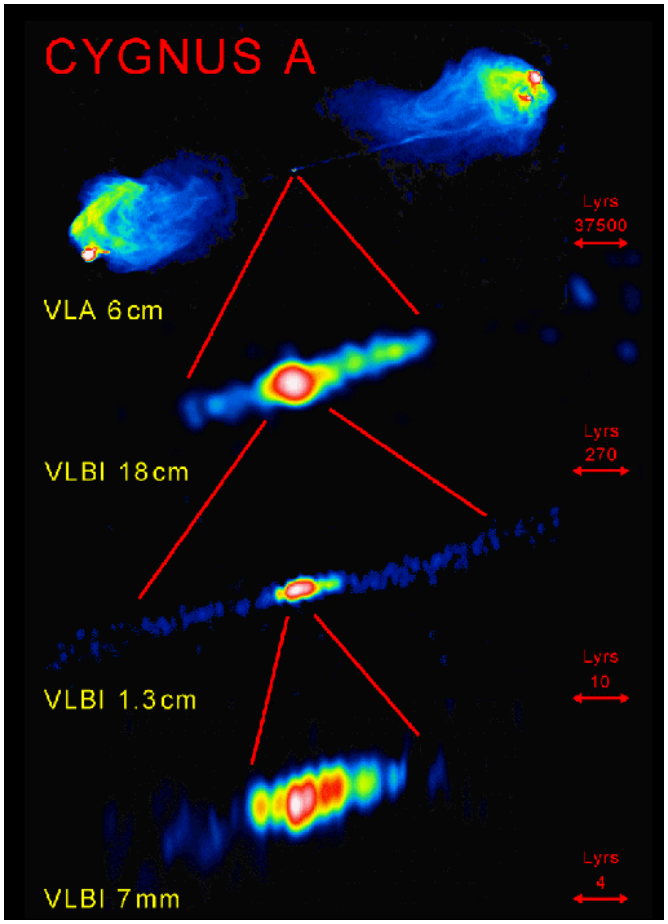
AGN at Radio frequencies – strong jet out flows



- Up to ~Megaparsec
- Synchrotron continuum emission

- Highly collimated
- Superluminal motions of jet components

Plasma-physical conditions of AGN jets

Spatial structure and kinematics	Characteristic variations of optical depth	Strength and orientation of magnetic fields
⇑	⇑	⇑
Tracking bright “knots” by deep high resolution imaging	Spectral index map by 2 (or more) frequencies simultaneous observation	Polarimetric observations

Plasma-physics of Active Galactic Nuclei

Spatial structure and kinematics	Characteristic variations of optical Depth	Strength and orientation of magnetic fields
⇑	⇑	⇑
Tracking bright “knots” by deep high resolution Imaging	Spectral index map by 2 (or more) frequencies simultaneous observation	Polarimetric observations
PAGaN II (KVN+VERA) Oh et al. 2015		PAGaN I (KVN only) Kim et al. 2015

KaVA : KVN and VERA Array

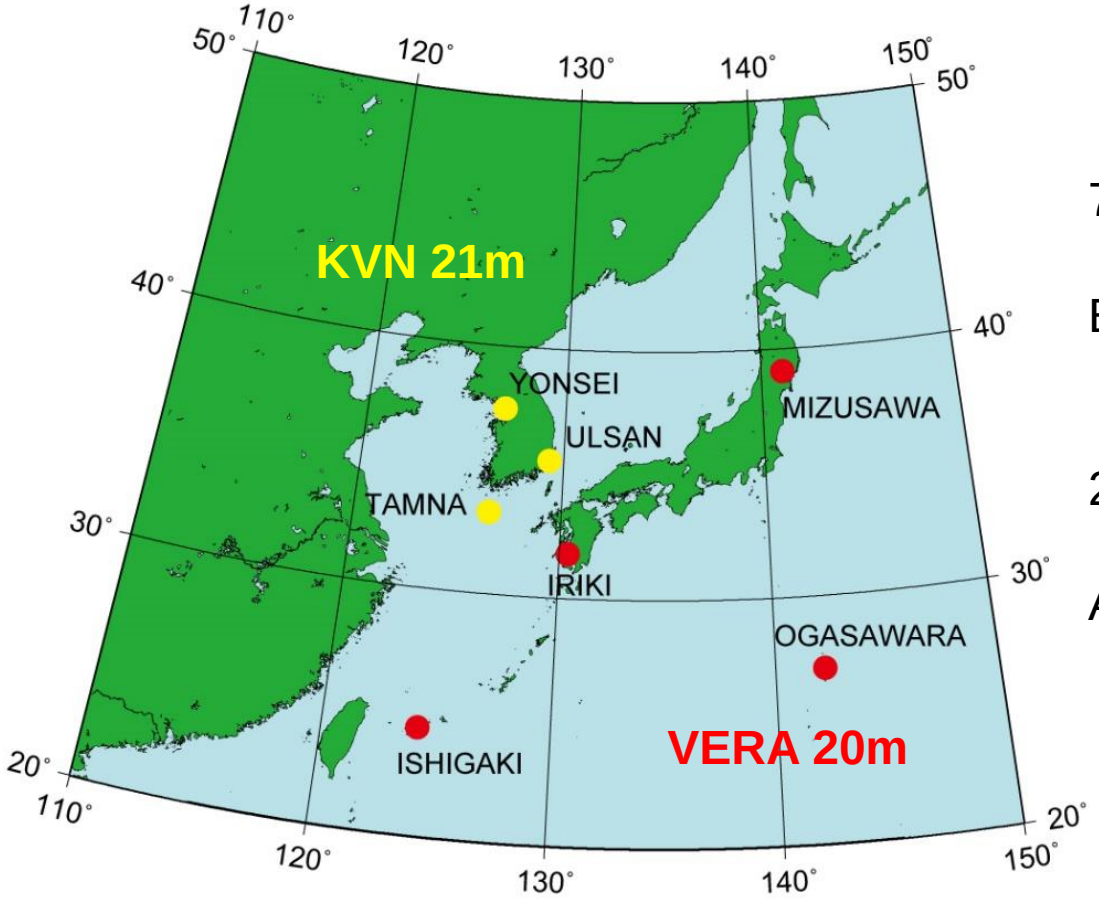


Image taken from http://radio.kasi.re.kr/kava/about_kava.php

7 stations 21 baselines

Baseline length:
305 ~ 2300 km

22 & 43 GHz single polarization

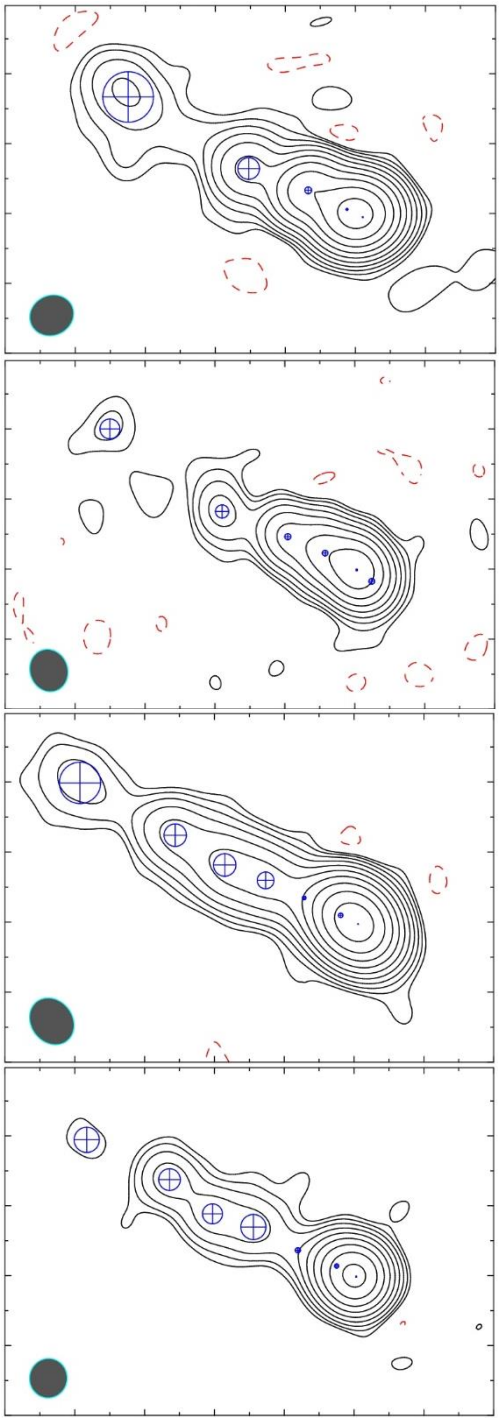
Angular resolution :
~1.2 mas (22 GHz)
~0.6 mas (43 GHz)

Sources & Observations

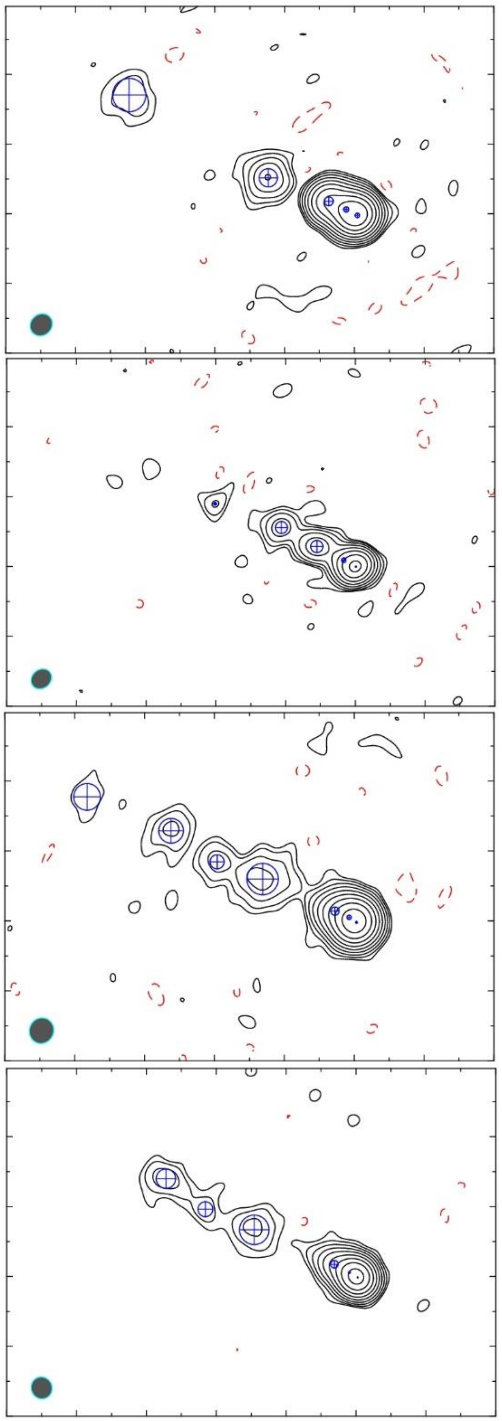
Name	Redshift z	Angular resolution (pc/mas)	Type
3C111	0.0491	0.95	Radio galaxy
3C345	0.593	6.63	Quasar
2200+420	0.0686	1.29	BL Lac object

Date	Obs. Time (hrs / source)	Frequency	Sources
2014 Mar. 15	6	43	3C111
2014 Apr. 17	6	43	2200+420
2014 Oct. 22	7 ~ 8	22	3C111, 2200+420
2015 Mar. 31	7.5 ~ 8	22 & 43	All
2016 Mar. 9	5.5 ~ 6	22 & 43	All
2016 Jun. 3	5.5 ~ 6	22 & 43	All

3C111



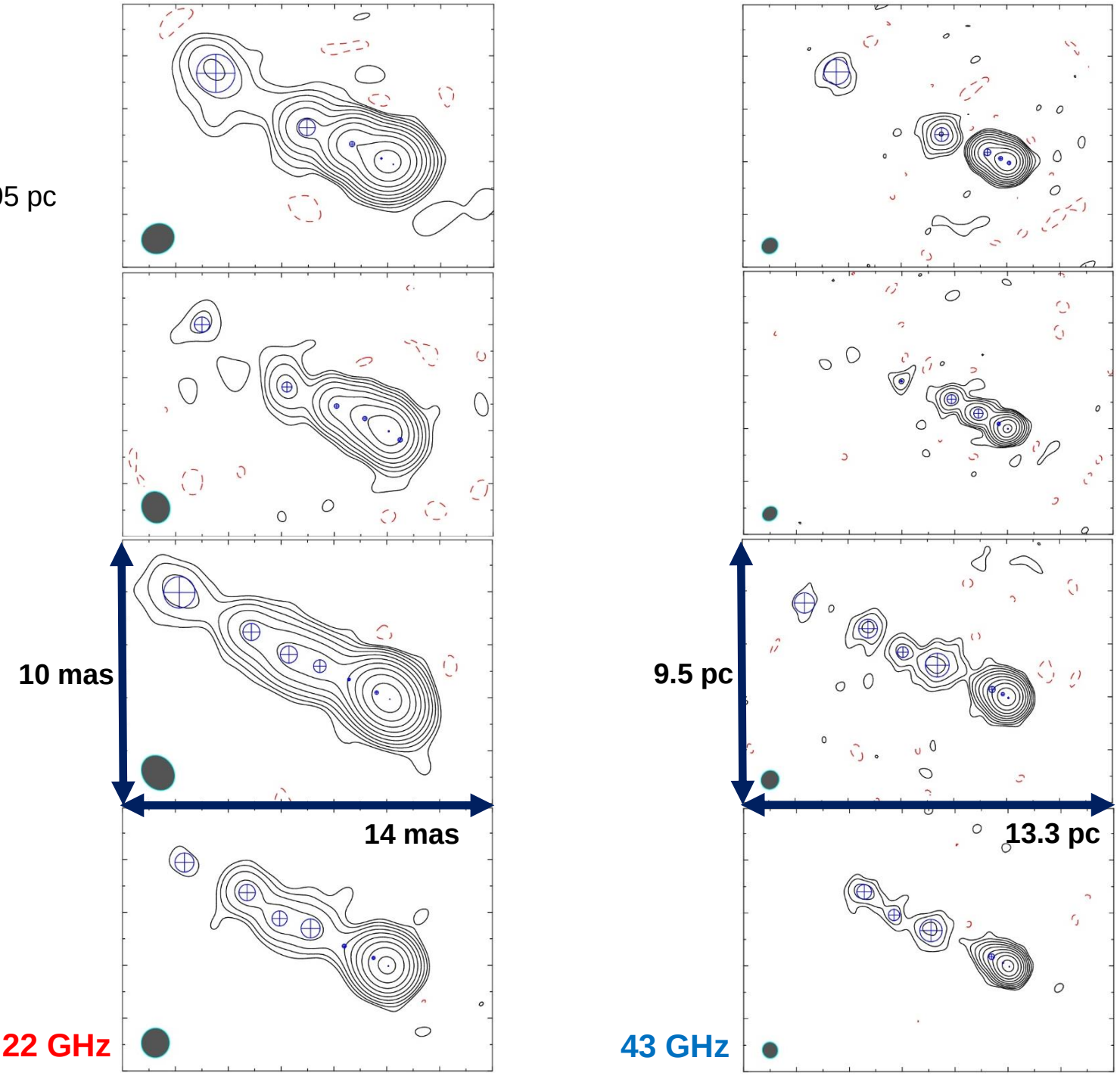
22 GHz



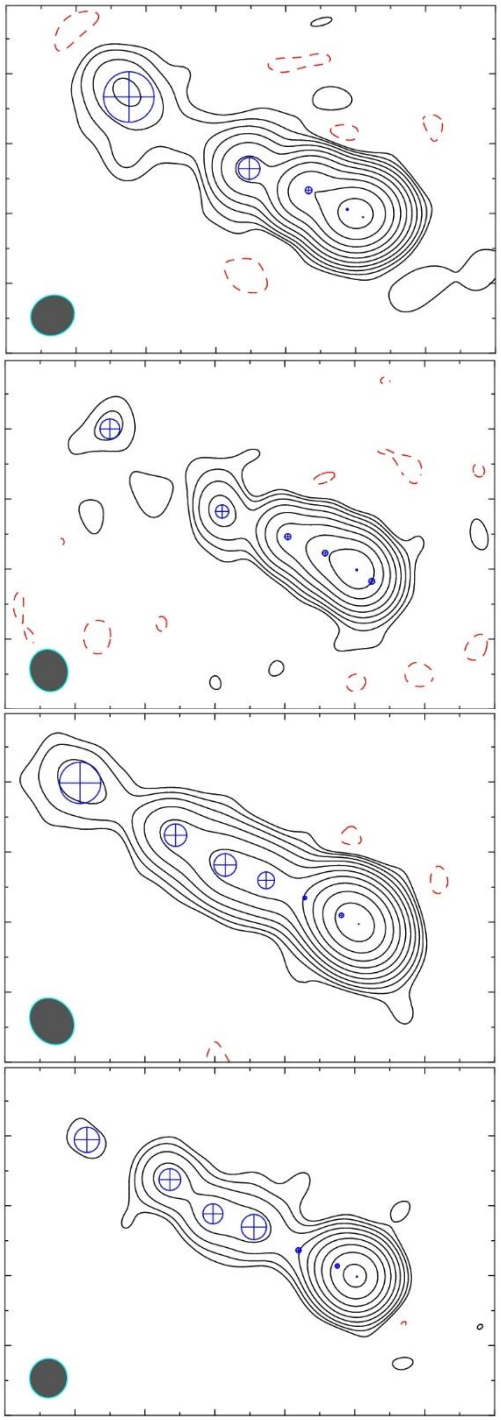
43 GHz

3C111

1 mas = 0.95 pc



3C111



22 GHz

2014 Oct 23

Map peak	2.29 Jy/beam
Image rms	1.05 mJy/beam
Beam size	1.28 x 1.14 (mas)

2015 Apr 1

Map peak	1.45 Jy/beam
Image rms	2.18 mJy/beam
Beam size	1.23 x 1.08 (mas)

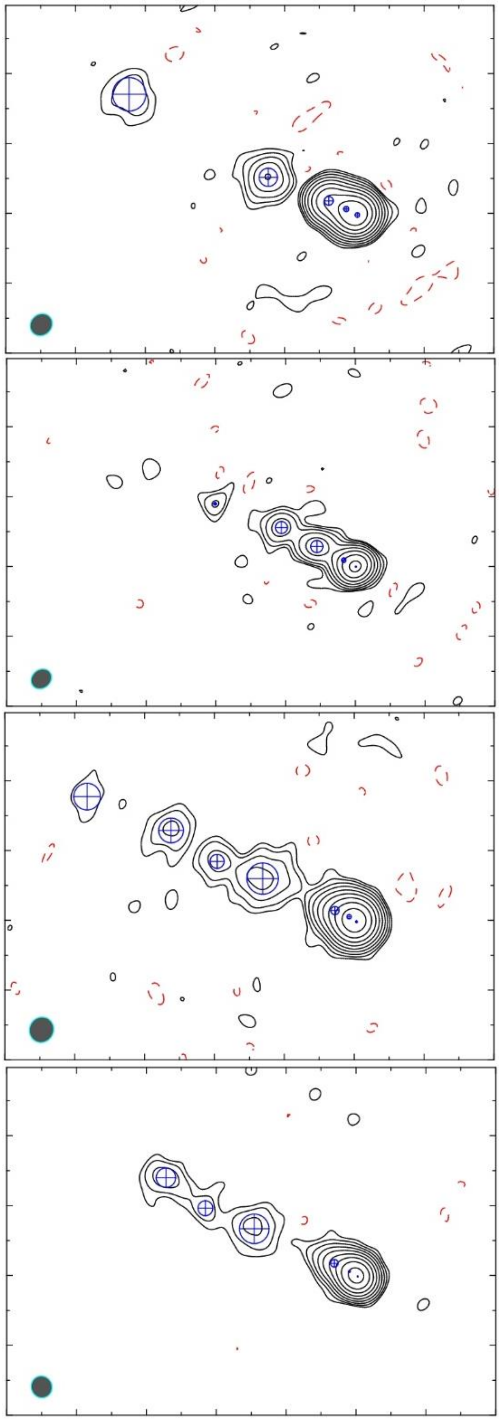
2016 Mar 10

Map peak	1.35 Jy/beam
Image rms	0.57 mJy/beam
Beam size	1.42 x 1.19 (mas)

2016 Jun 3

Map peak	1.27 Jy/beam
Image rms	1.32 mJy/beam
Beam size	1.13 x 1.08 (mas)

3C111



43 GHz

2014 Mar 15

Map peak	1.57 Jy/beam
Image rms	1.01 mJy/beam
Beam size	0.666 x 0.597 (mas)

2015 Apr 2

Map peak	1.25 Jy/beam
Image rms	2.66 mJy/beam
Beam size	0.624 x 0.528 (mas)

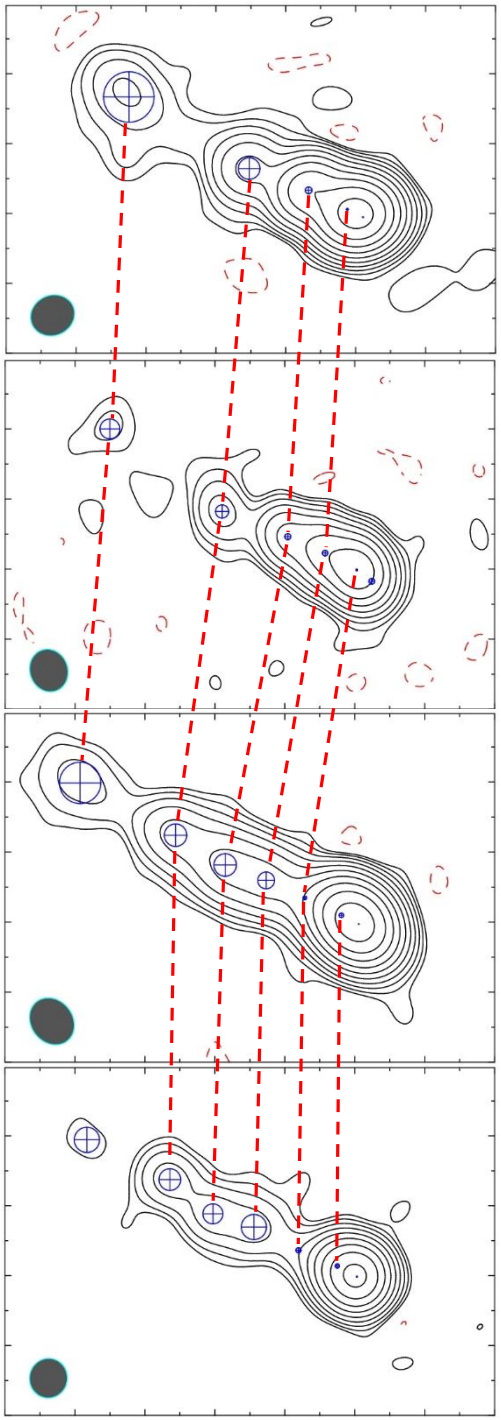
2016 Mar 11

Map peak	0.986 Jy/beam
Image rms	0.74 mJy/beam
Beam size	0.737 x 0.69 (mas)

2016 Jun 4

Map peak	1.03 Jy/beam
Image rms	0.97 mJy/beam
Beam size	0.63 x 0.595 (mas)

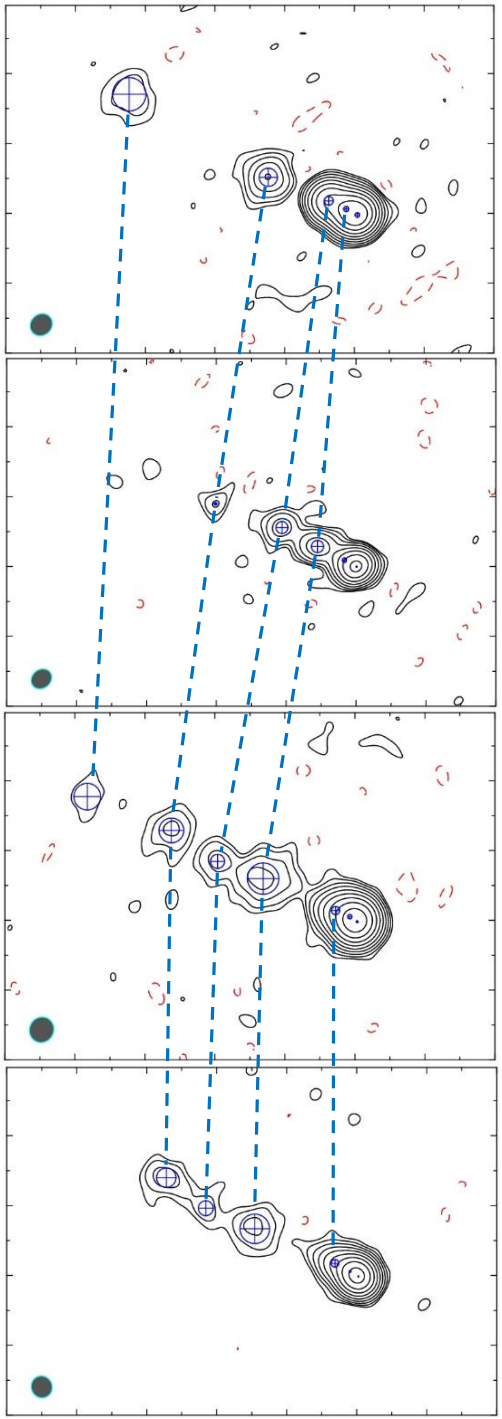
3C111



161 days

345 days

86 days



384 days

345 days

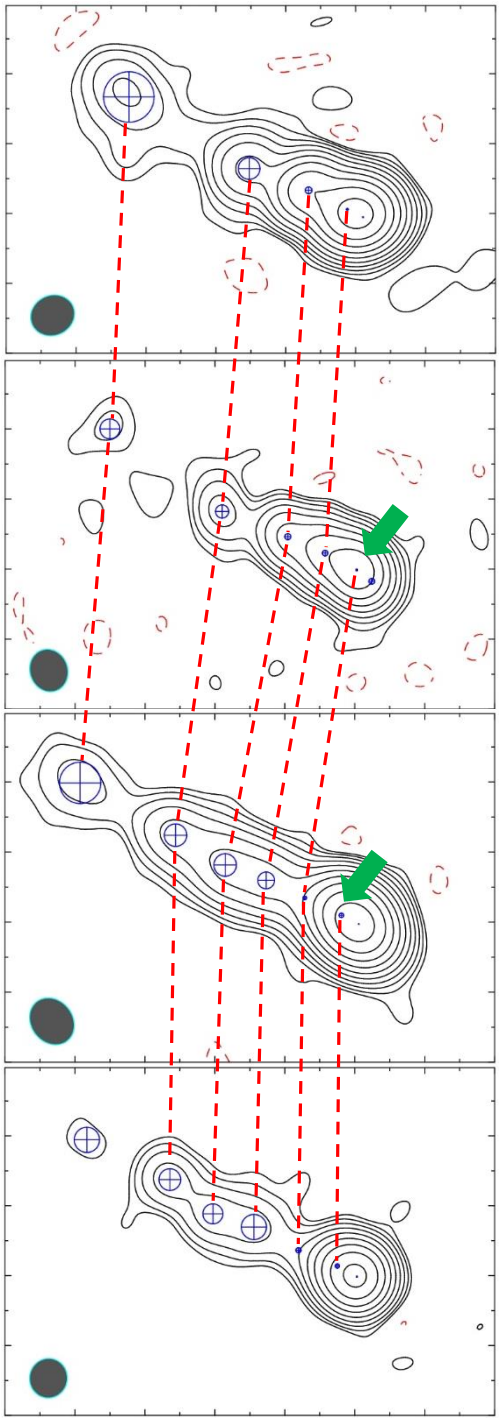
86 days

Apparent speed:
1.07 ~ 6.5 c (22)
0.98 ~ 6.4 c (43)

22 GHz

43 GHz

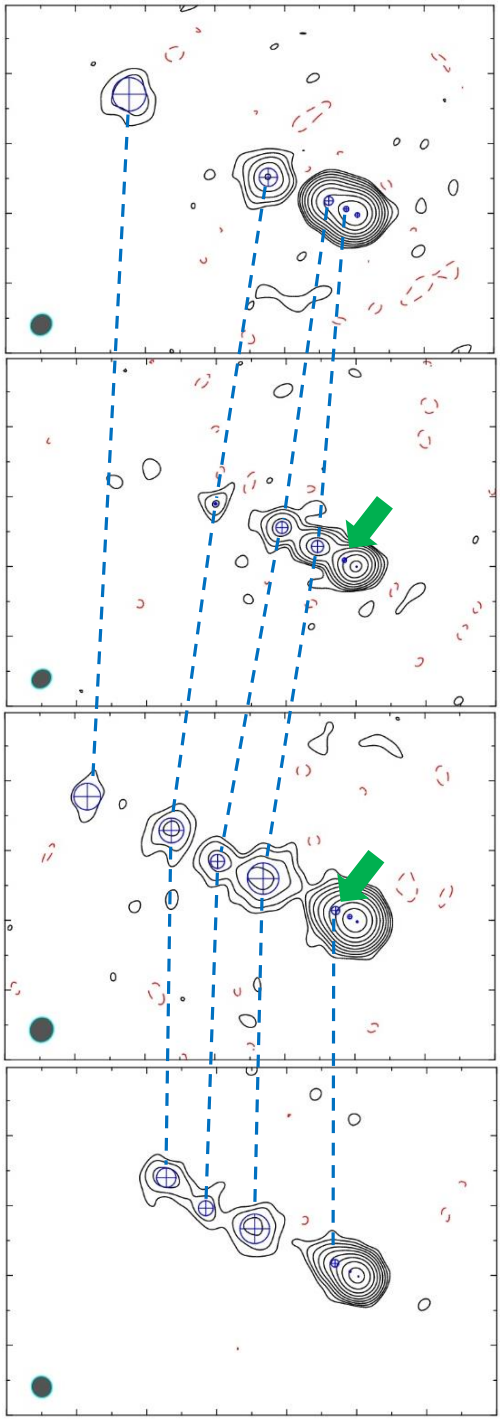
3C111



161 days

345 days

86 days



384 days

345 days

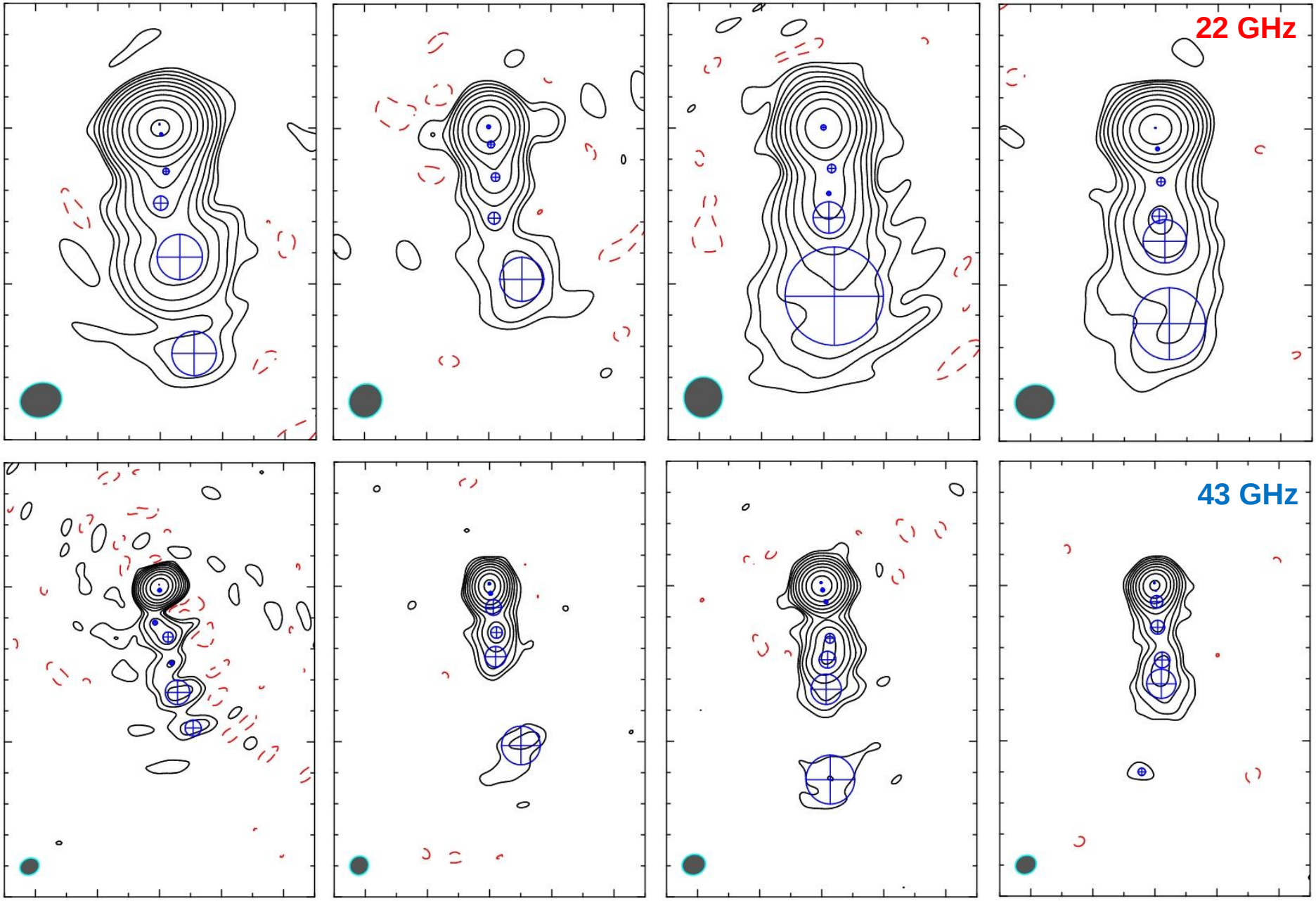
86 days

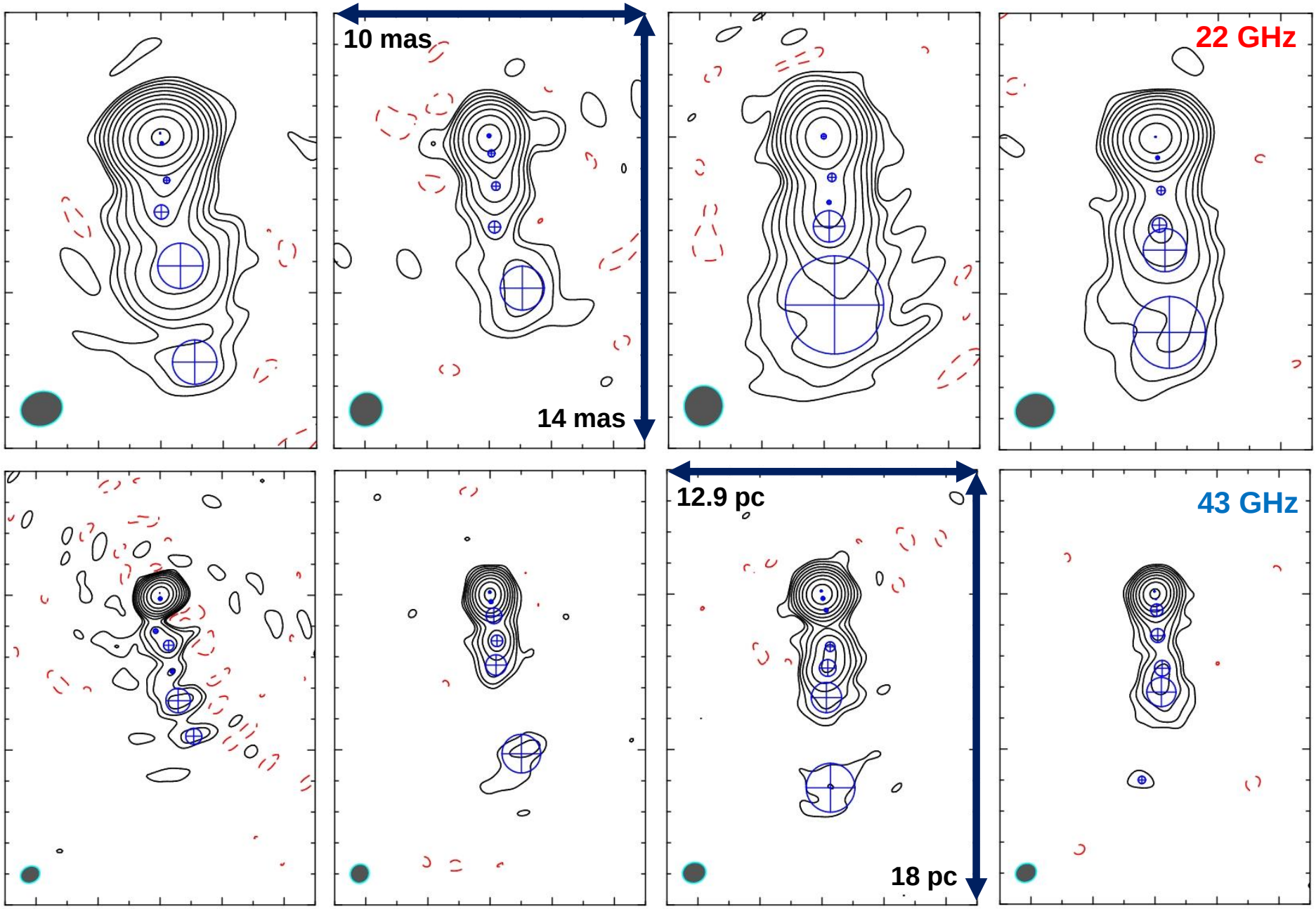
Apparent speed :
1.07 ~ 6.5 c (22)
0.98 ~ 6.4 c (43)

22 GHz

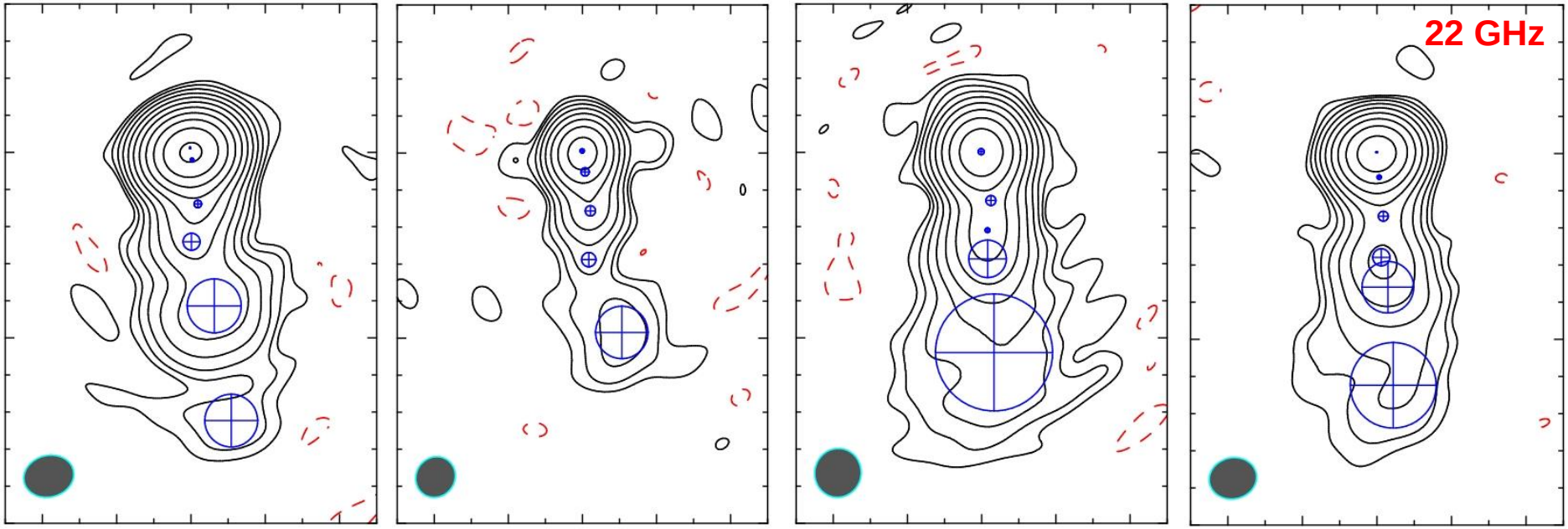
43 GHz

2200+420 (BL LAC)




2200+420 (BL LAC)
1 mas = 1.29 pc
10 mas
14 mas
22 GHz
12.9 pc
18 pc
43 GHz

2200+420 (BL LAC)



2014 Oct 22

Map peak	3.53 Jy/beam
Image rms	1.0 mJy/beam
Beam size	1.36 x 1.12 (mas)

2015 Mar 31

Map peak	1.92 Jy/beam
Image rms	3.46 mJy/beam
Beam size	1.12 x 1.04 (mas)

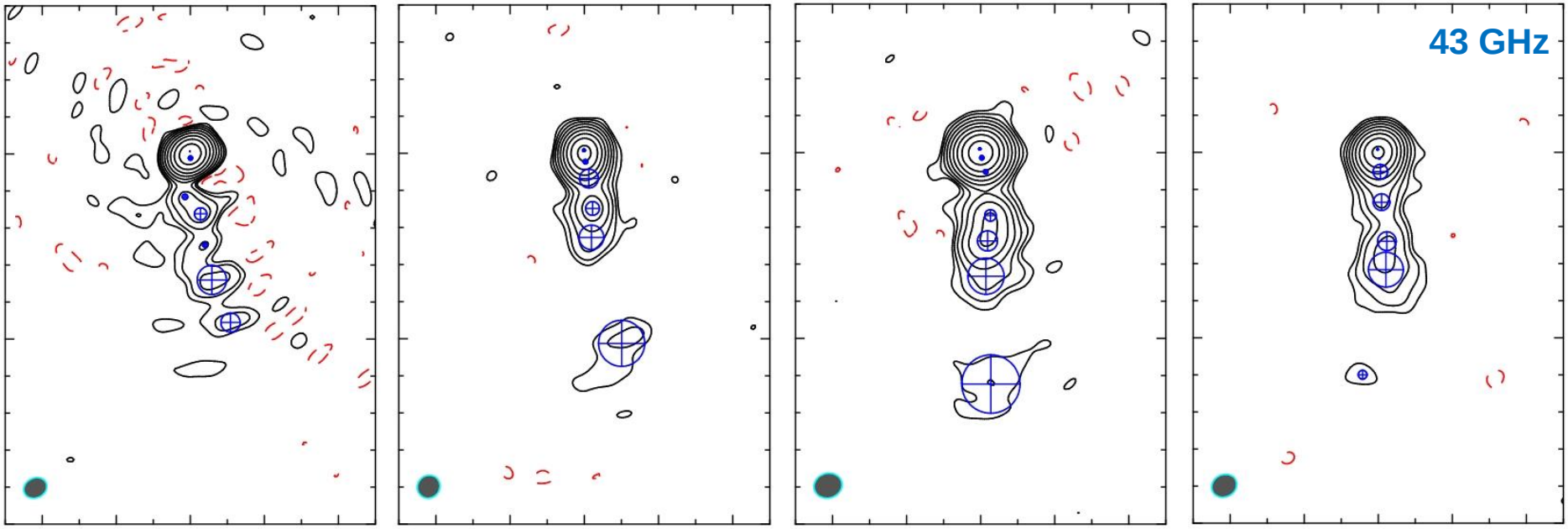
2016 Mar 9

Map peak	1.29 Jy/beam
Image rms	0.93 mJy/beam
Beam size	1.32 x 1.25 (mas)

2016 Jun 3

Map peak	1.08 Jy/beam
Image rms	0.9 mJy/beam
Beam size	1.28 x 1.11 (mas)

2200+420 (BL LAC)



2014 Apr 17

Map peak	4.1 Jy/beam
Image rms	2.93 mJy/beam
Beam size	0.647 x 0.53 (mas)

2016 Mar 10

Map peak	1.02 Jy/beam
Image rms	0.8 mJy/beam
Beam size	0.764 x 0.663 (mas)

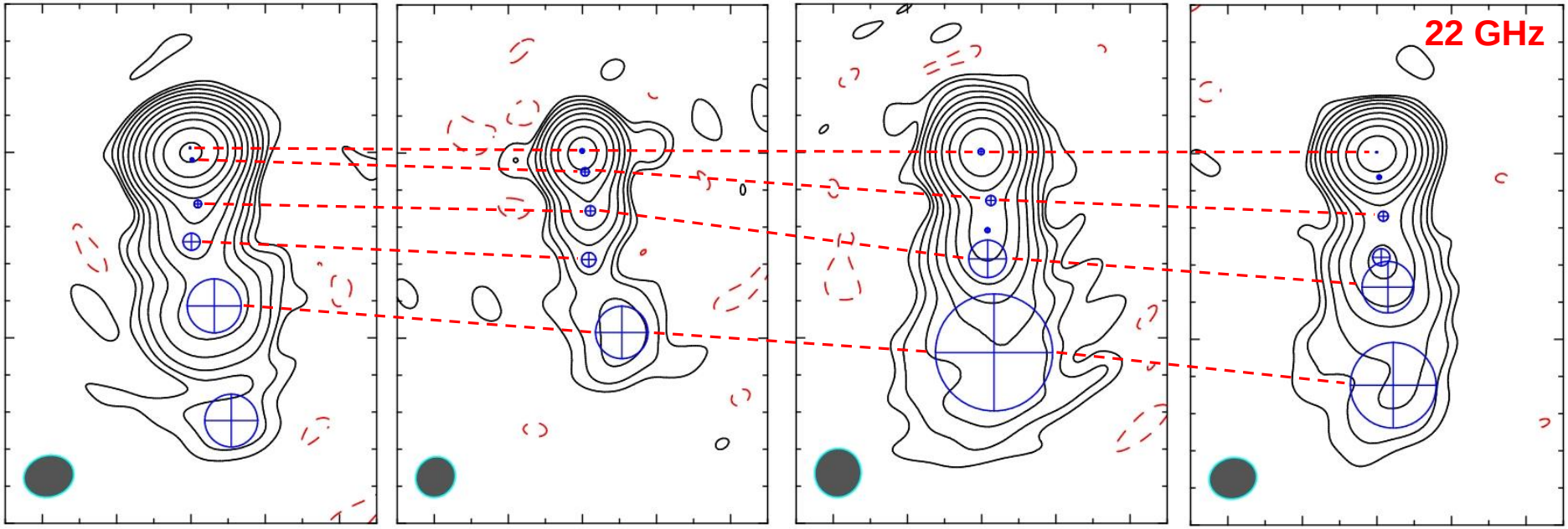
2015 Apr 1

Map peak	1.76 Jy/beam
Image rms	1.82 mJy/beam
Beam size	0.633 x 0.596 (mas)

2016 Jun 04

Map peak	0.926 Jy/beam
Image rms	1.03 mJy/beam
Beam size	0.696 x 0.598 (mas)

2200+420 (BL LAC)



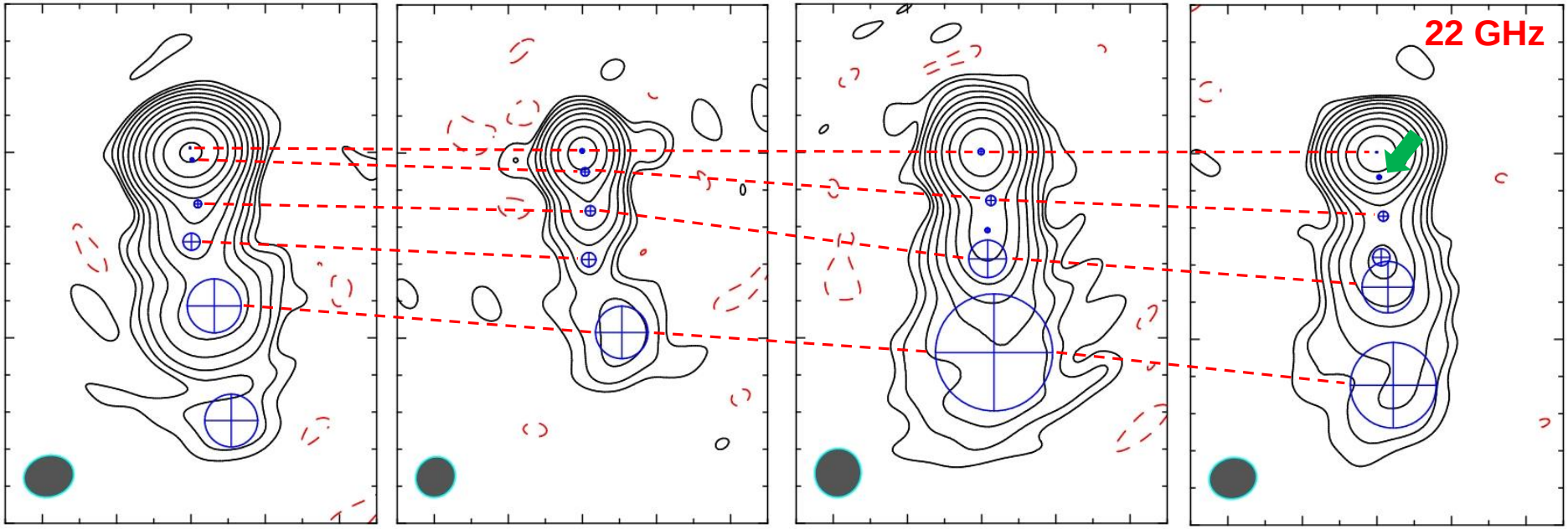
161 days

345 days

85 days

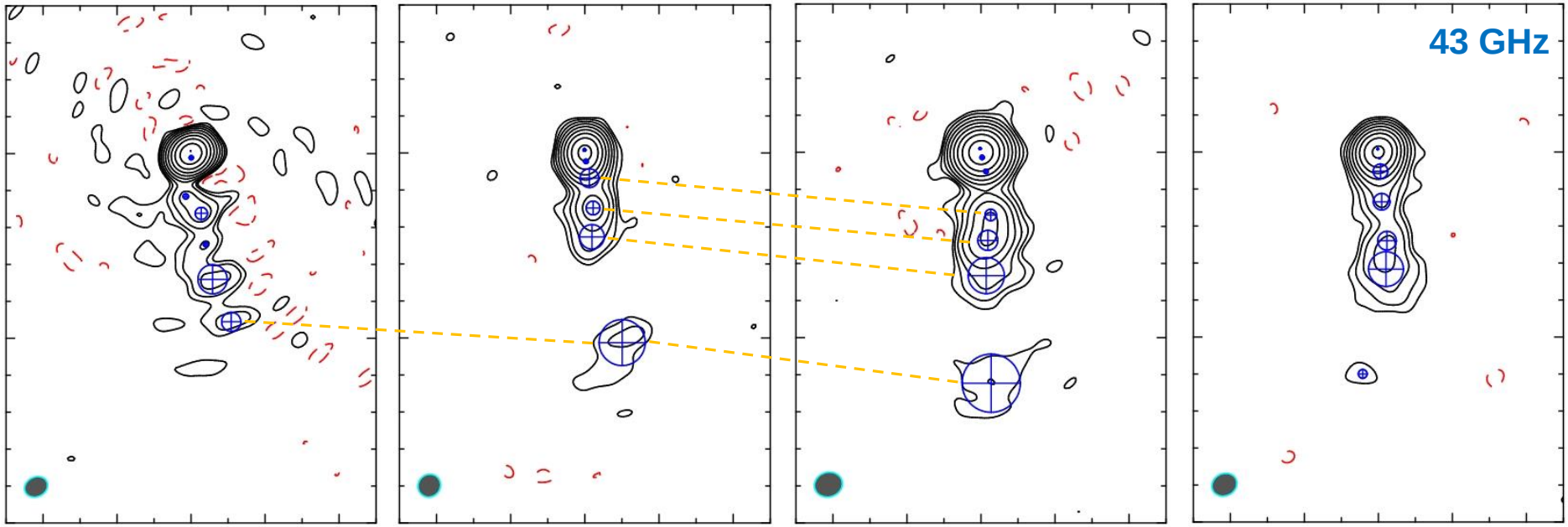
Apparent speed :
1 ~ 4 c

2200+420 (BL LAC)



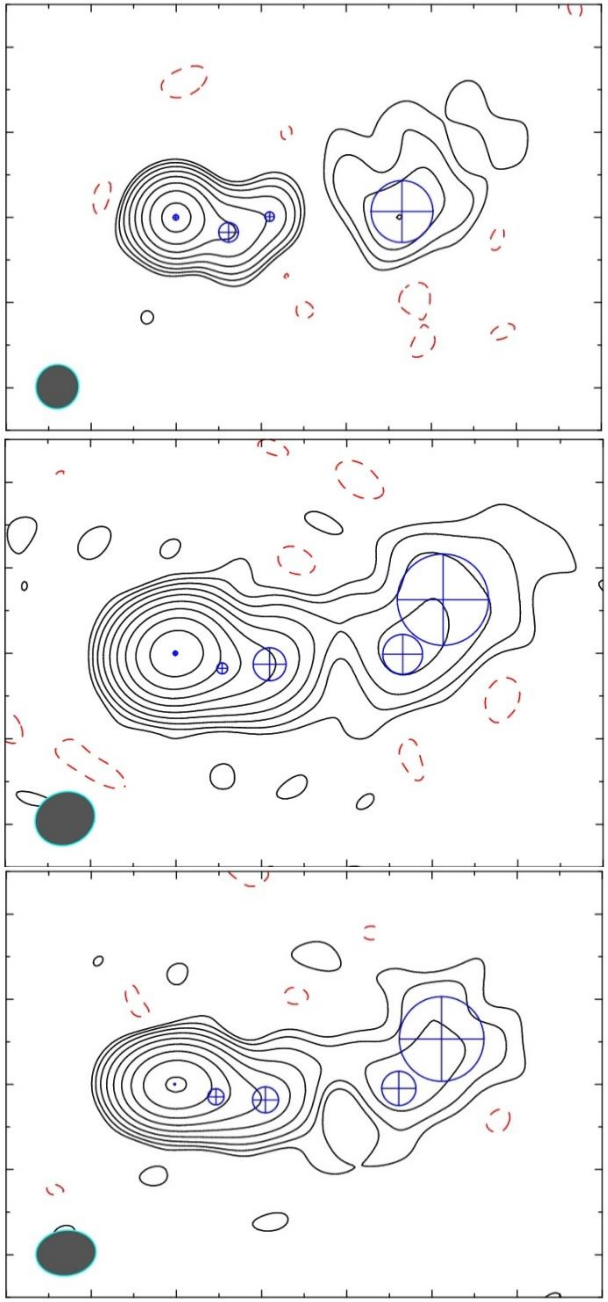
Apparent speed :
1 ~ 4 c

2200+420 (BL LAC)

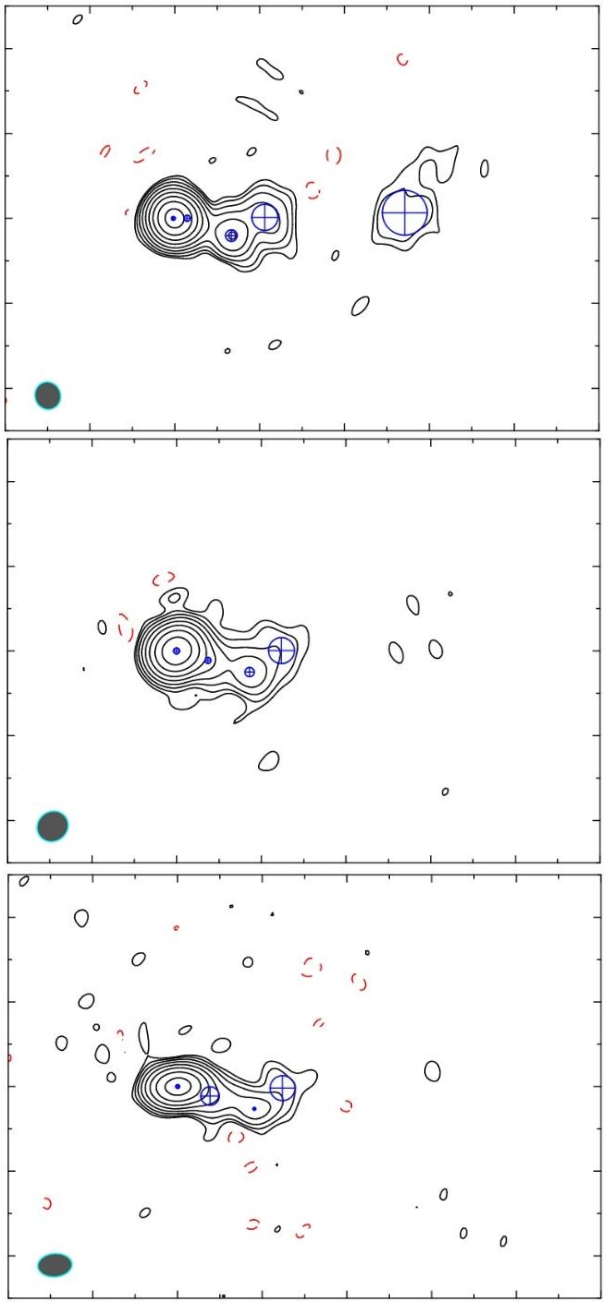


Apparent speed :
4.0 ~ 5.9 c

3C345



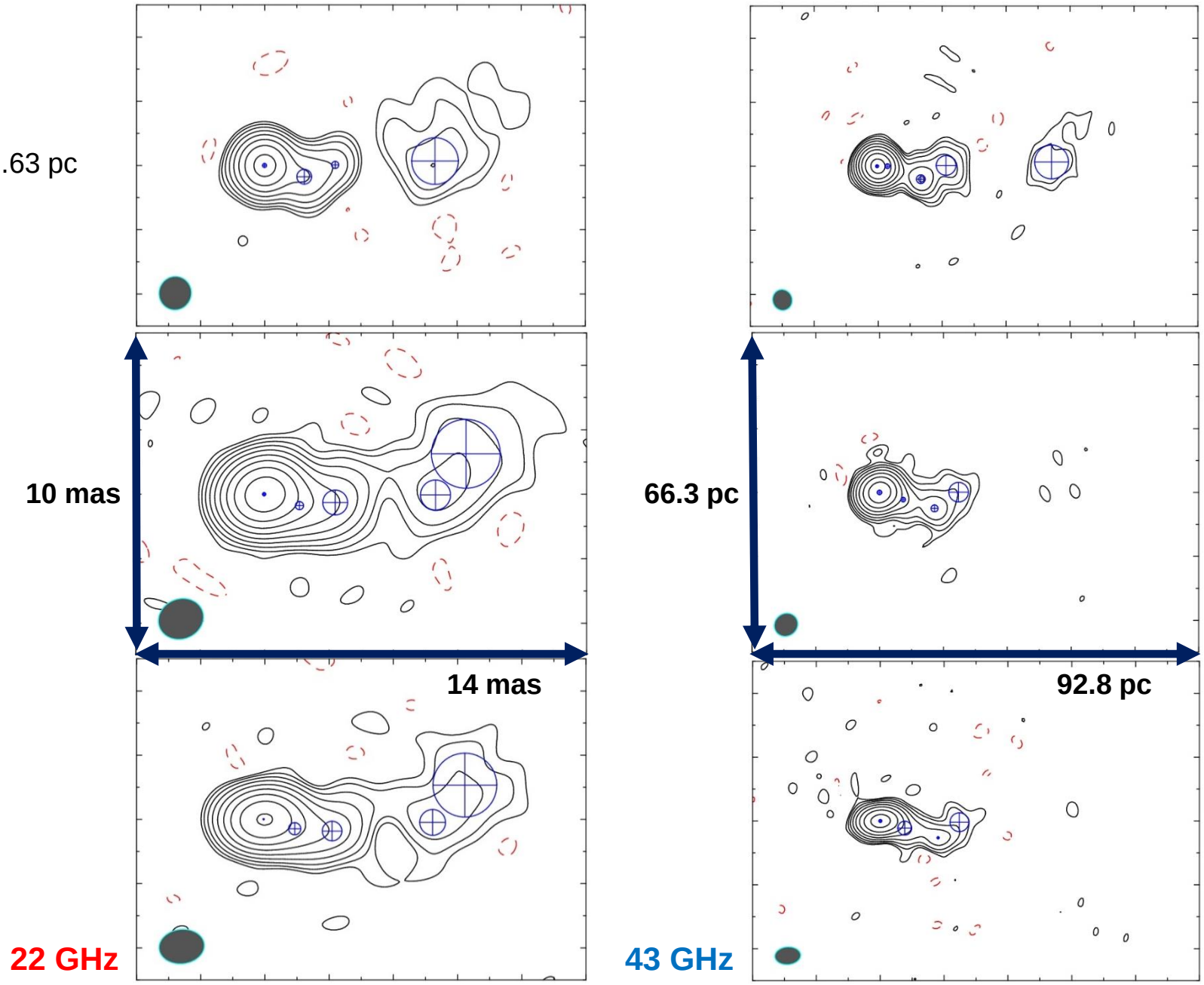
22 GHz



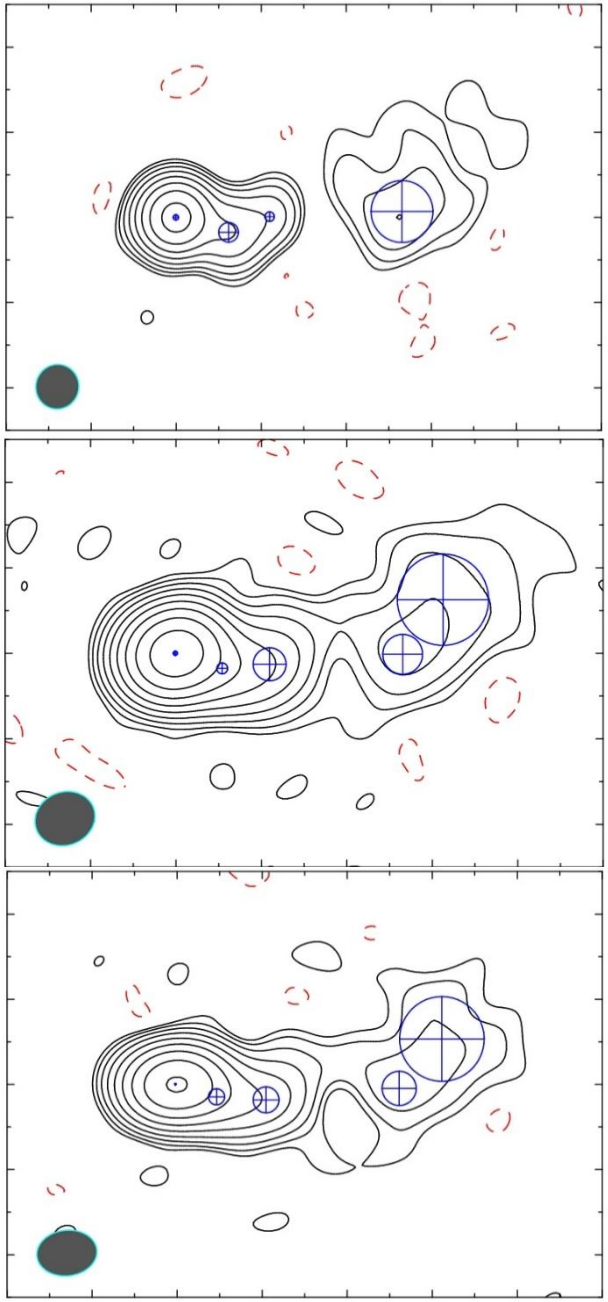
43 GHz

3C345

1 mas = 6.63 pc



3C345



22 GHz

2015 Mar 31

Map peak	2.35 Jy/beam
Image rms	4.57 mJy/beam
Beam size	1.05 x 1.01 (mas)

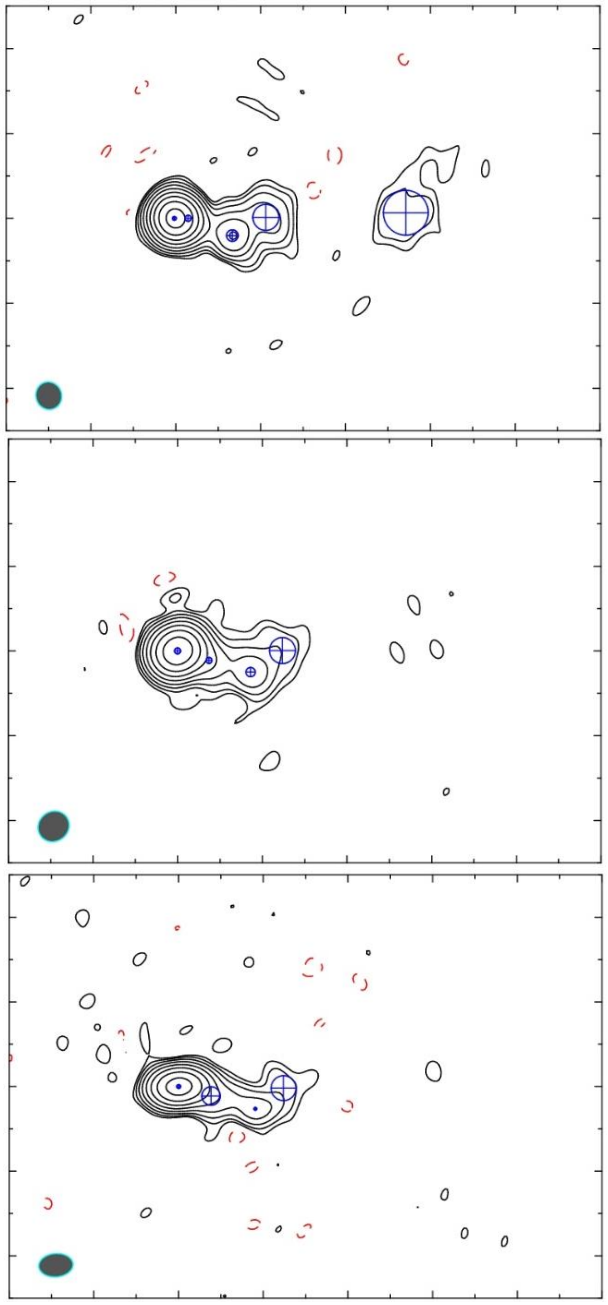
2016 Mar 9

Map peak	3.37 Jy/beam
Image rms	2.66 mJy/beam
Beam size	1.43 x 1.24 (mas)

2016 Jun 3

Map peak	3.06 Jy/beam
Image rms	3.7 mJy/beam
Beam size	1.42 x 1.07 (mas)

3C345



43 GHz

2015 Apr 1

Map peak	2.0 Jy/beam
Image rms	1.87 mJy/beam
Beam size	0.654 x 0.607 (mas)

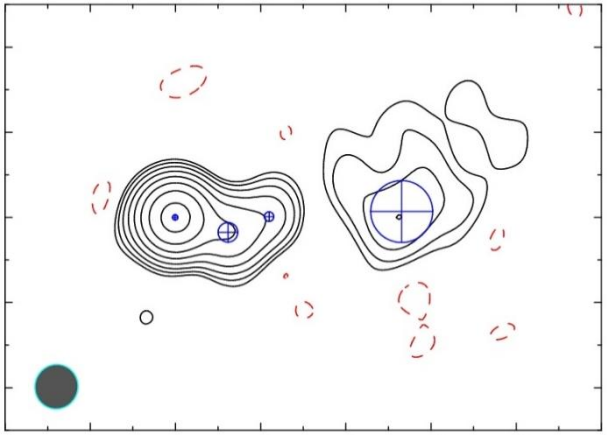
2016 Mar 9

Map peak	2.0 Jy/beam
Image rms	3.0 mJy/beam
Beam size	0.759 x 0.697 (mas)

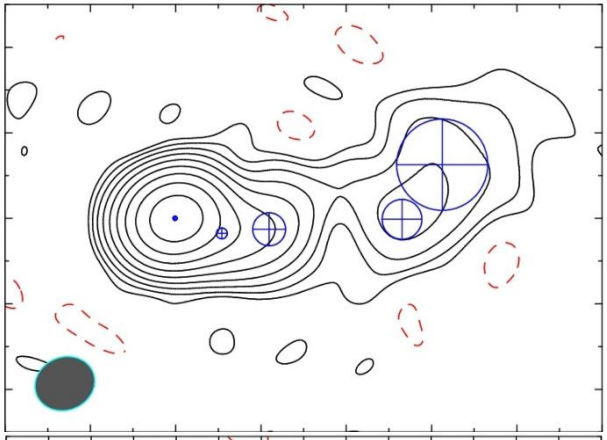
2016 Jun 3

Map peak	2.46 Jy/beam
Image rms	4.47 mJy/beam
Beam size	0.81 x 0.552 (mas)

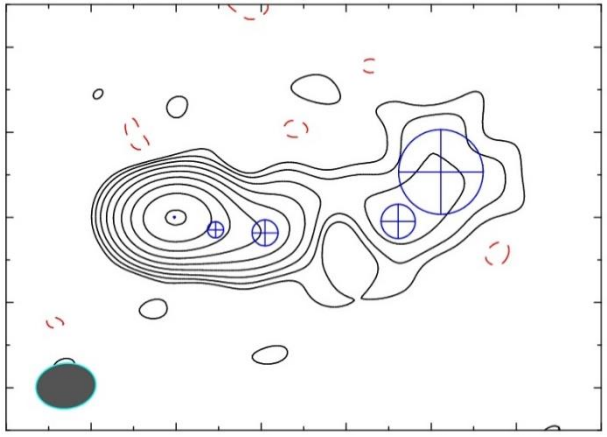
3C345



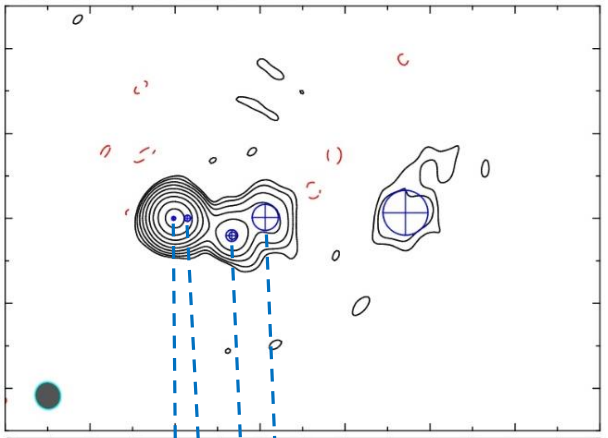
345 days



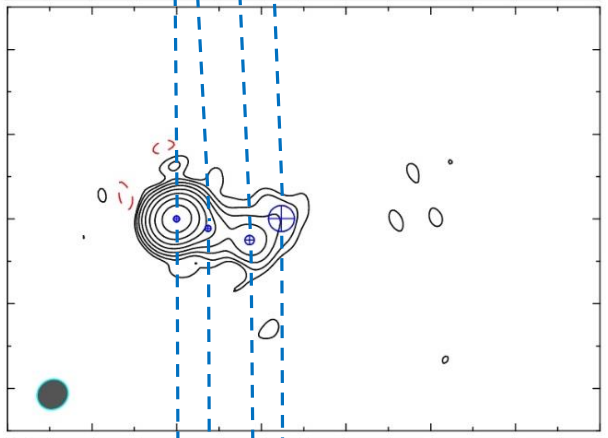
85 days



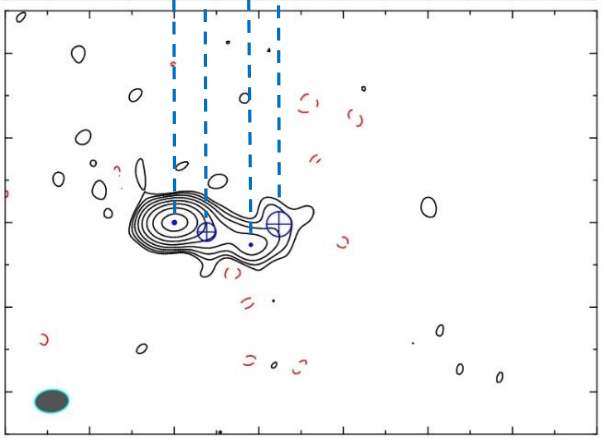
22 GHz



345 days



87 days

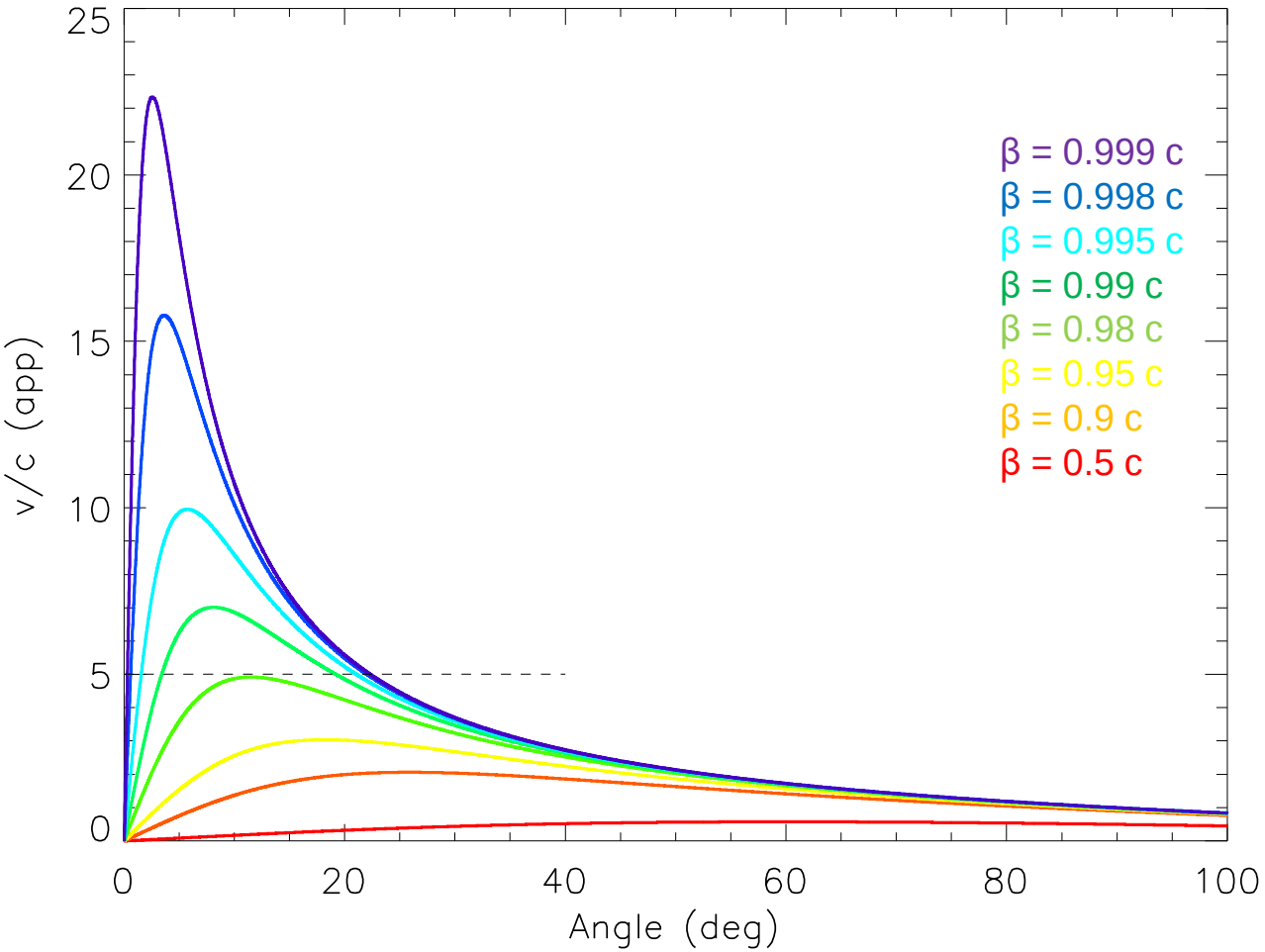


43 GHz

Apparent speed : 1.97 ~ 10.8 c (43)

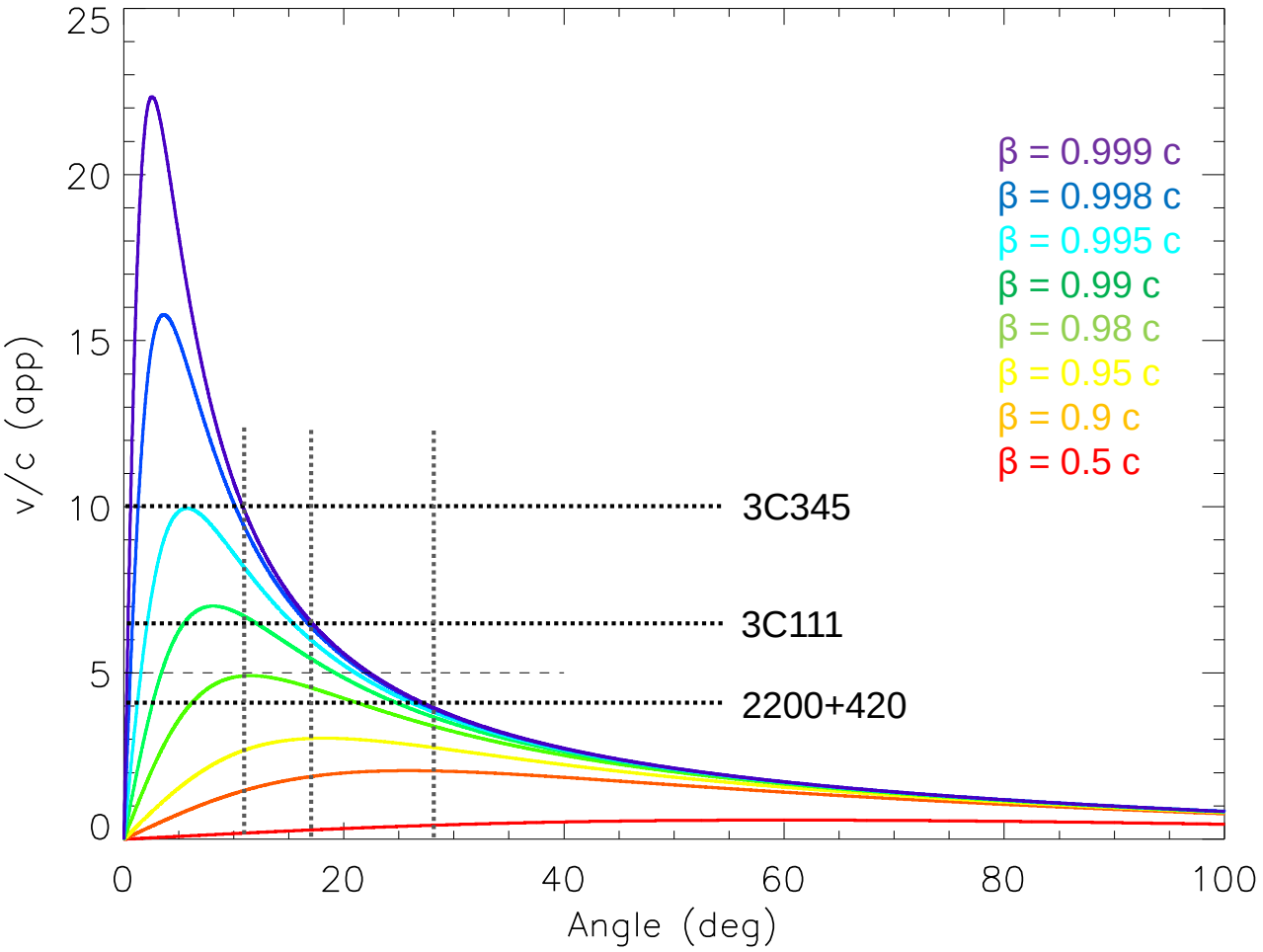
Viewing angle

$$\beta_{\rm app} = \frac{\beta \sin\theta}{1 - \beta \cos\theta}$$

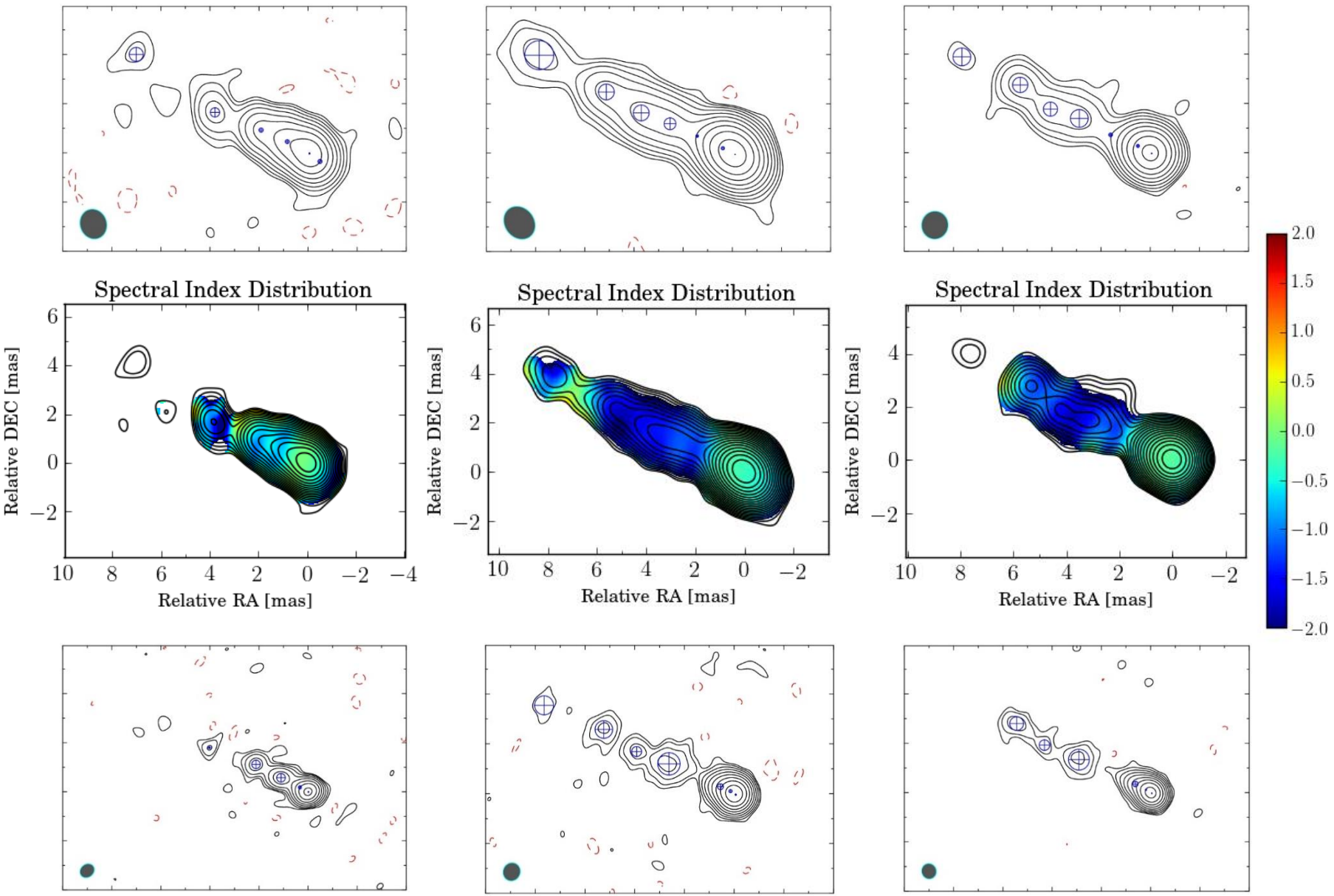


Viewing angle

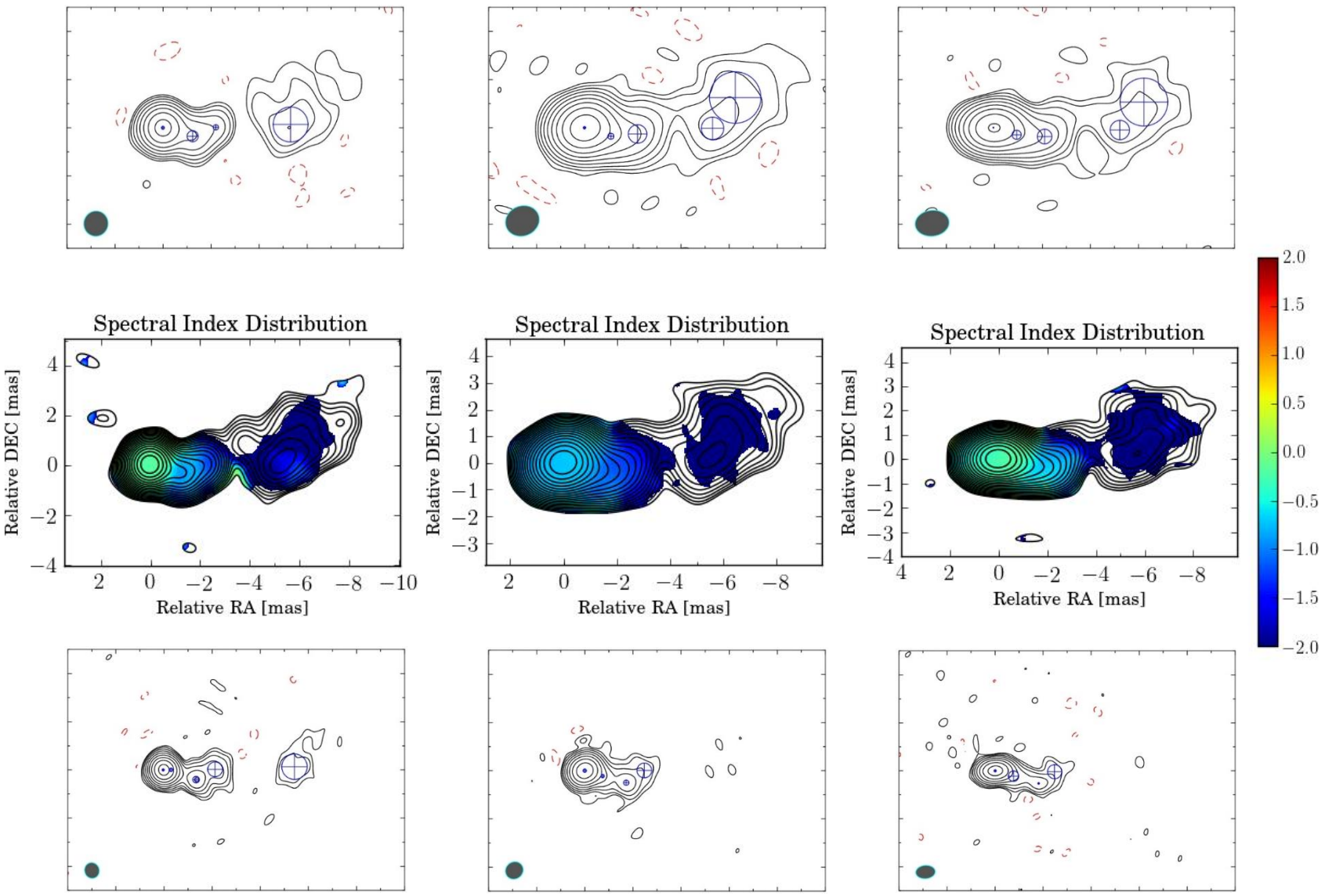
$$\beta_{\rm app} = \frac{\beta \sin\theta}{1 - \beta \cos\theta}$$



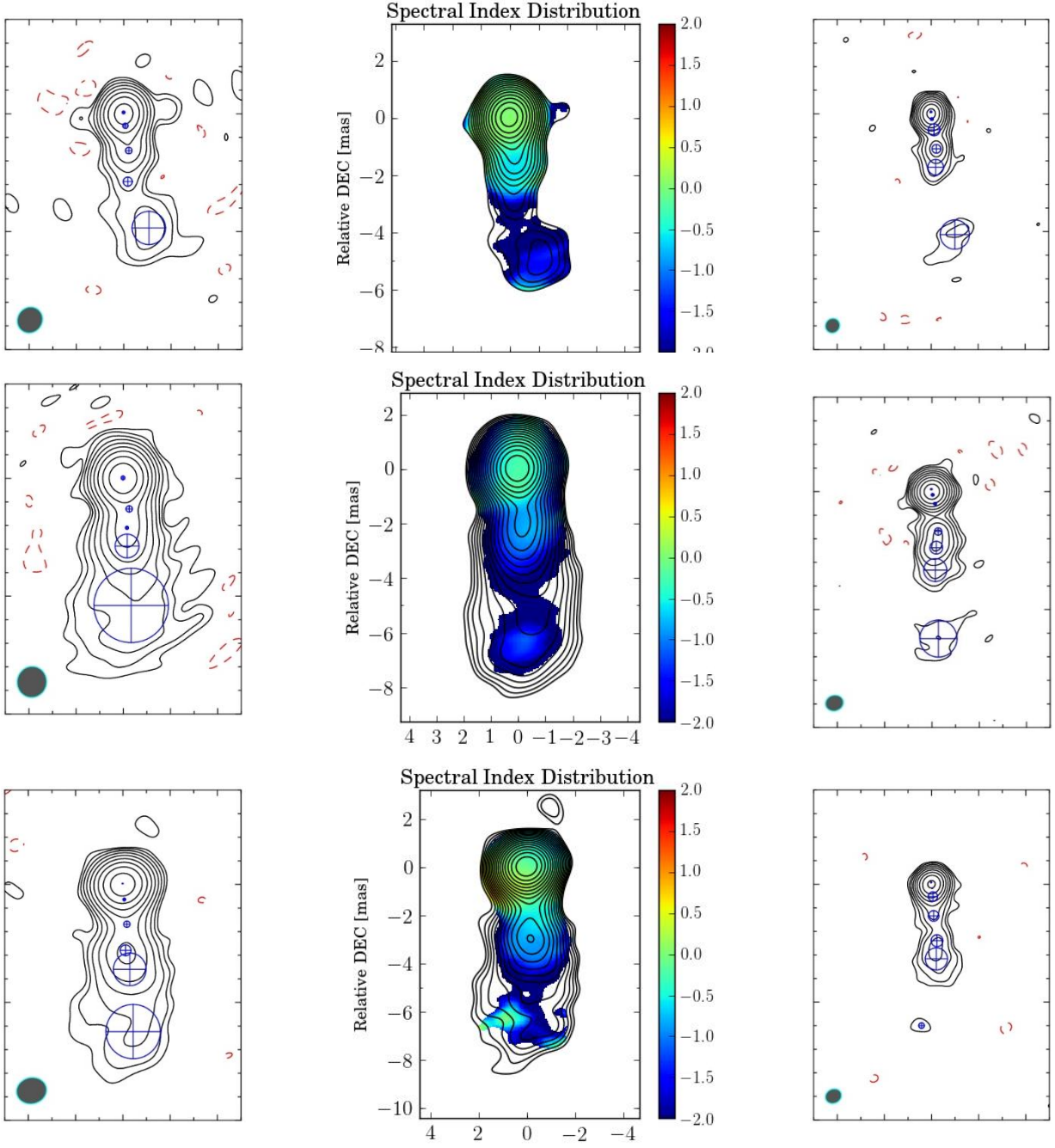
3C111

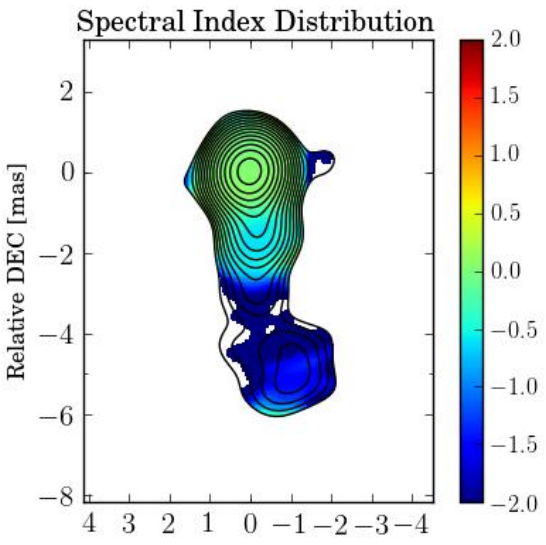

Spectral Index Distribution
Spectral Index Distribution
Spectral Index Distribution
Relative DEC [mas]
Relative RA [mas]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

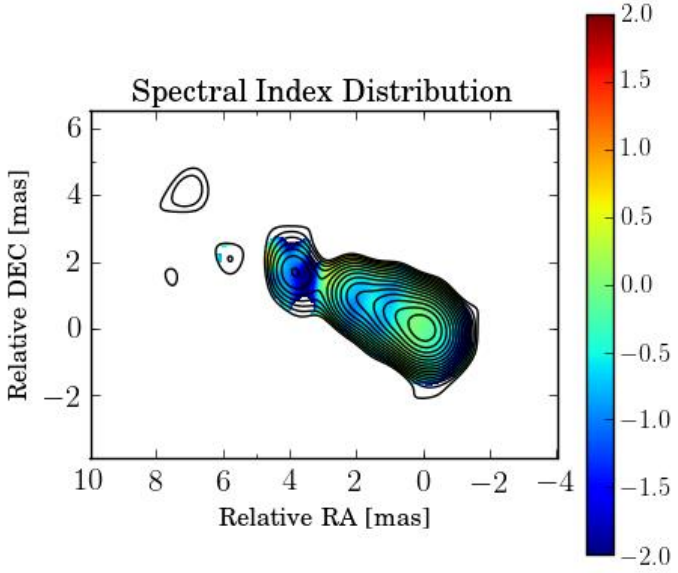
3C345

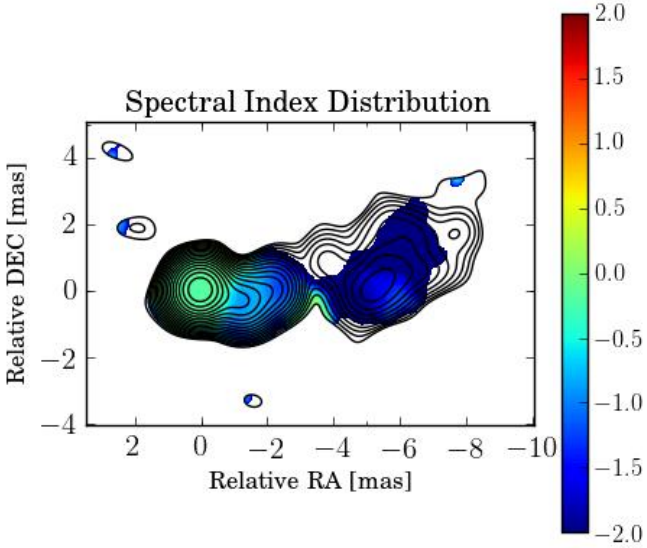

Spectral Index Distribution
Spectral Index Distribution
Spectral Index Distribution
Relative DEC [mas]
Relative RA [mas]
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0

2200+420

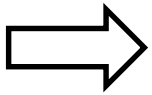

Spectral Index Distribution
Relative DEC [mas]
Spectral Index Distribution
Relative DEC [mas]
Spectral Index Distribution
Relative DEC [mas]



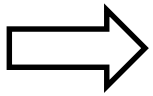




BL Lac object
(flat)



Radio galaxy
(moderate steep)



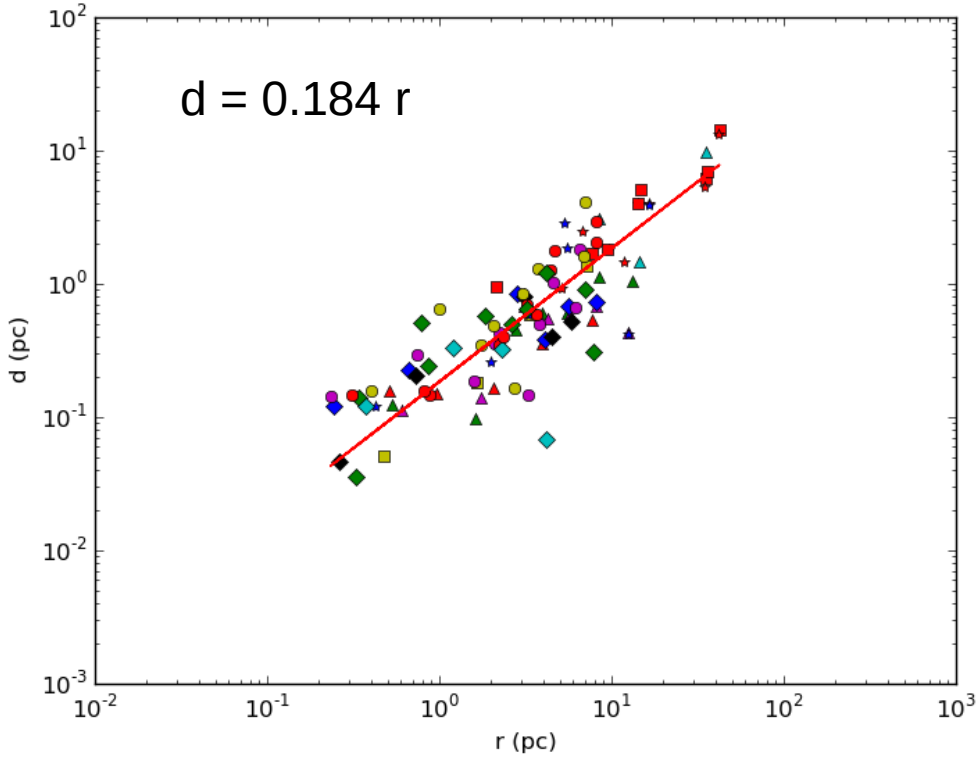
Quasar
(steep)

Jet expansion (preliminary)

- Distance (pc) vs Radius (pc)
- All jet components except core of all sources
- Linear fit
- Errors not estimated

Jet expansion (preliminary)

- Distance (pc) vs Radius (pc)
- All jet components except core of all sources
- Linear fit
- Errors not estimated



Summary

- We obtained interferometric maps sufficient to identify individual source components.

- We observed significant proper motions of jet components in 3C111, 2200+420 and 3C345. In all sources, we found superluminal apparent jet speeds up to about 10 c.

- The spectral index maps for 3C 111, 2200+420 and 3C 345 show a tendency for an increasingly fast steepening of the spectral index as function of core distance in the order BL Lac object → radio galaxy → quasar. This is probably caused by systematic differences in viewing angle.

- Jet components show systematically larger diameters d at larger core distances r. the components of our targets all follow the same universal relation $d \approx 0.184\ r$.