Investigating plasma-physical properties of nearby AGN with KVN and KaVA

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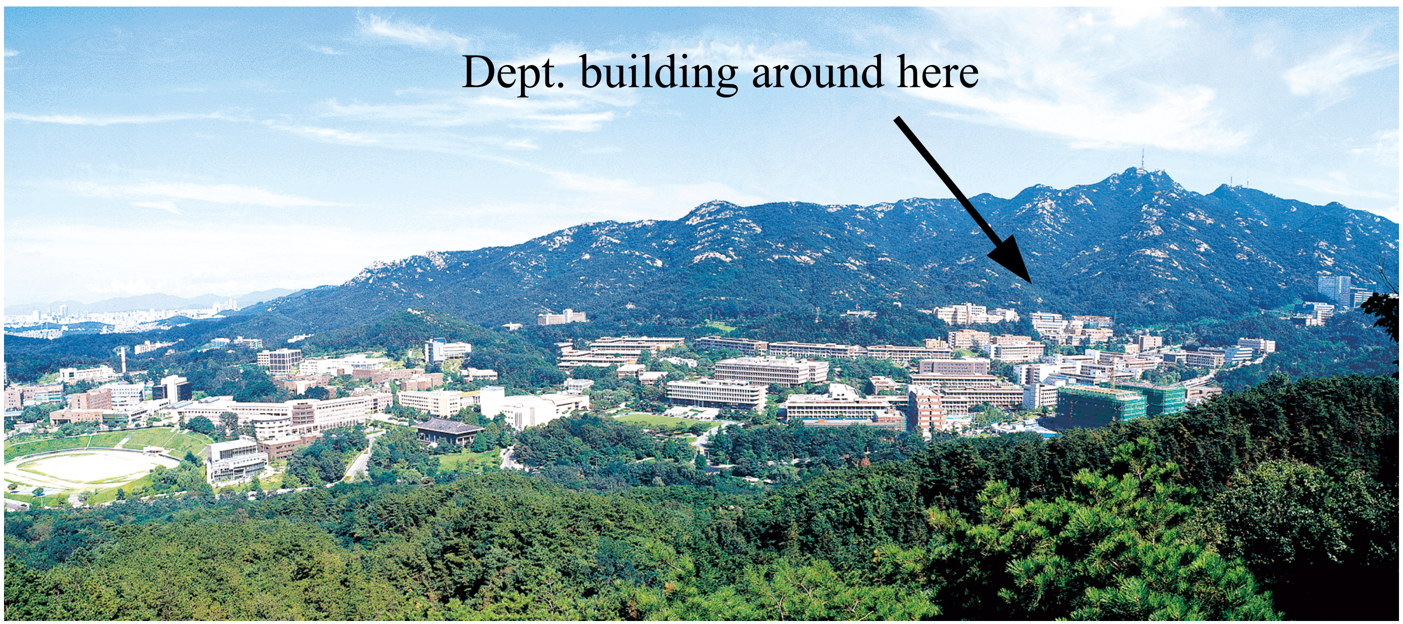
(2) Korea Astronomy and Space Science Institute, Korea

13 Oct 2014 – EATING VLBI workshop at Bologna, Italy

VLBI AGN group at Seoul National University (SNU), Korea



Landscape of SNU

Prof. Sascha Trippe
(working on various subjects)

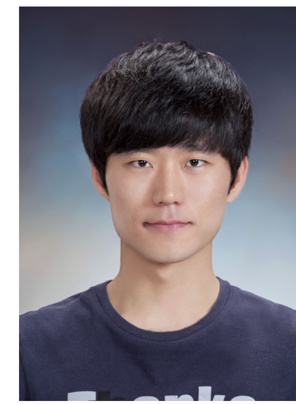
Jong-Ho Park;
Sgr A* obs for G2 cloud event w/ GmVA

Junghwan Oh;
GmVA 86 GHz polarimetry

Taeseok Lee;
KVN Intra-Day Variability study

Me !

At Sapporo, Japan – Aug 2013

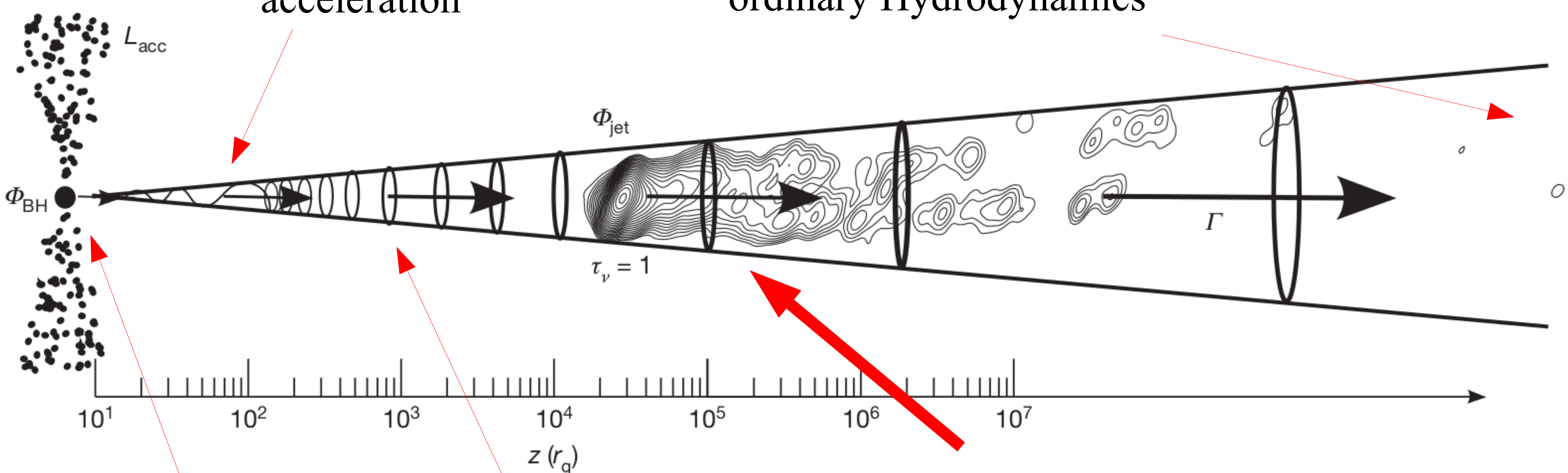


DaeWon Kim;
KVN gamma-ray sources monitoring project

Theoretical understanding about the jet ...

Jet "Nozzle" :
electrodynamic
acceleration

Hot spots & Lobes:
Dominated by
ordinary Hydrodynamics



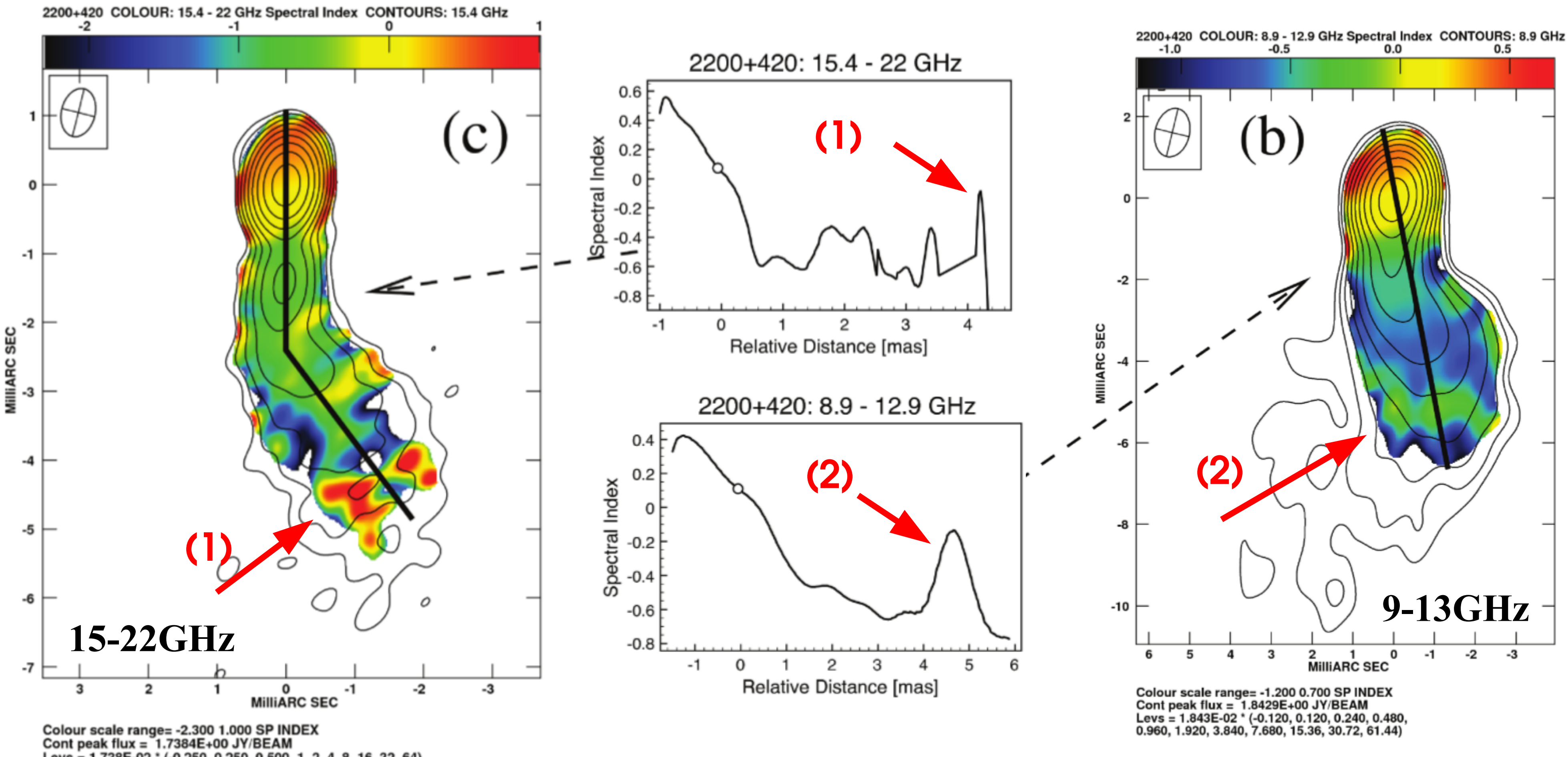
Jet launching site
(BZ or BP mechanism?)

Transition region
(~ 100-1000 Rsch)

Both kinetic & magnetic field energy
play important roles.
VLBI observations explore here !

Summary from Meier 2009;
Image from Zamaninasab, M., et al. 2014

Jet evolution in the structure and particle density

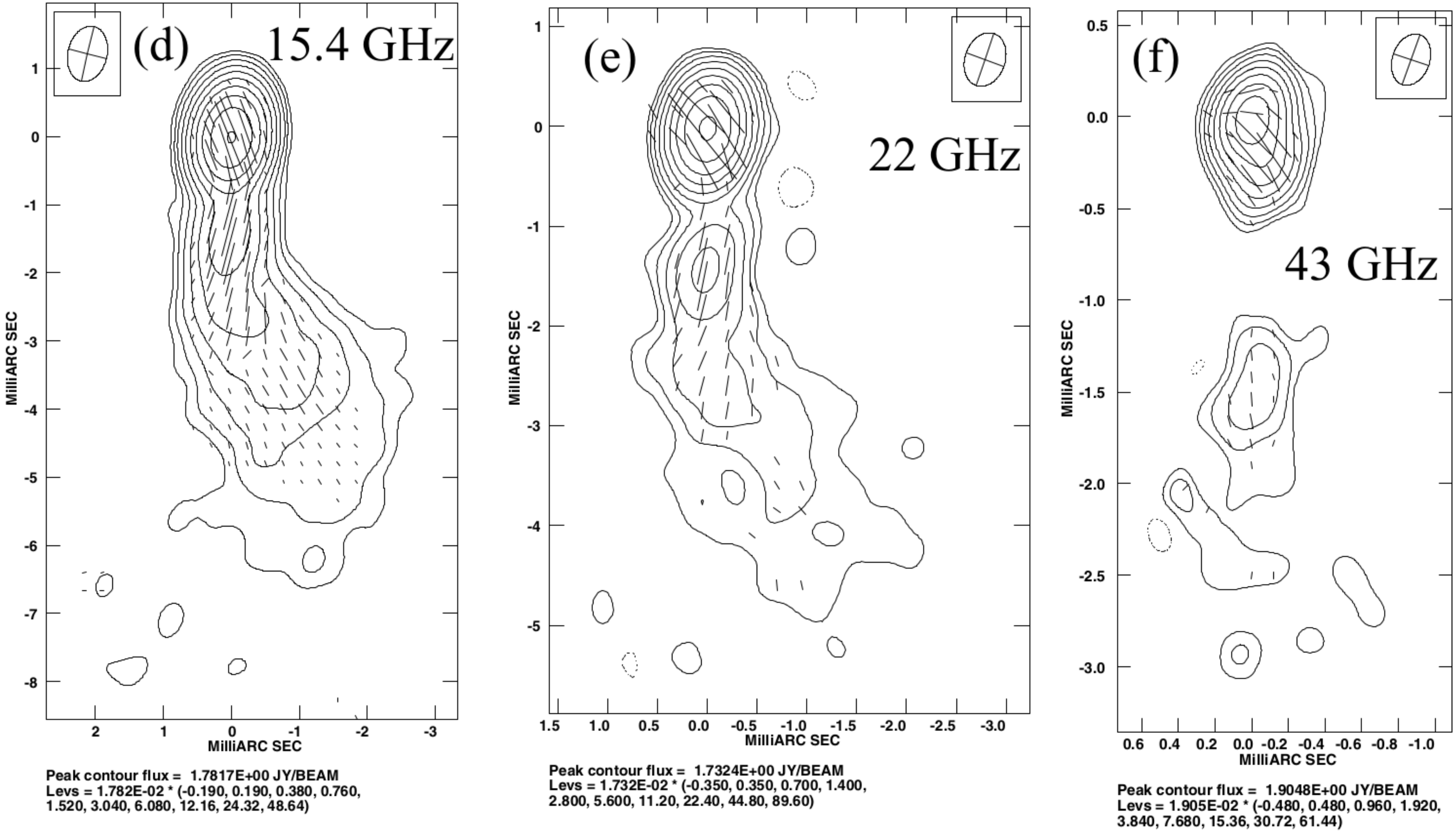


BLLAC Spectral Index map (obs:VLBA)

: Particle re-acceleration or interaction with ISM ?

O'Sullivan & Gabuzda 2009a,b

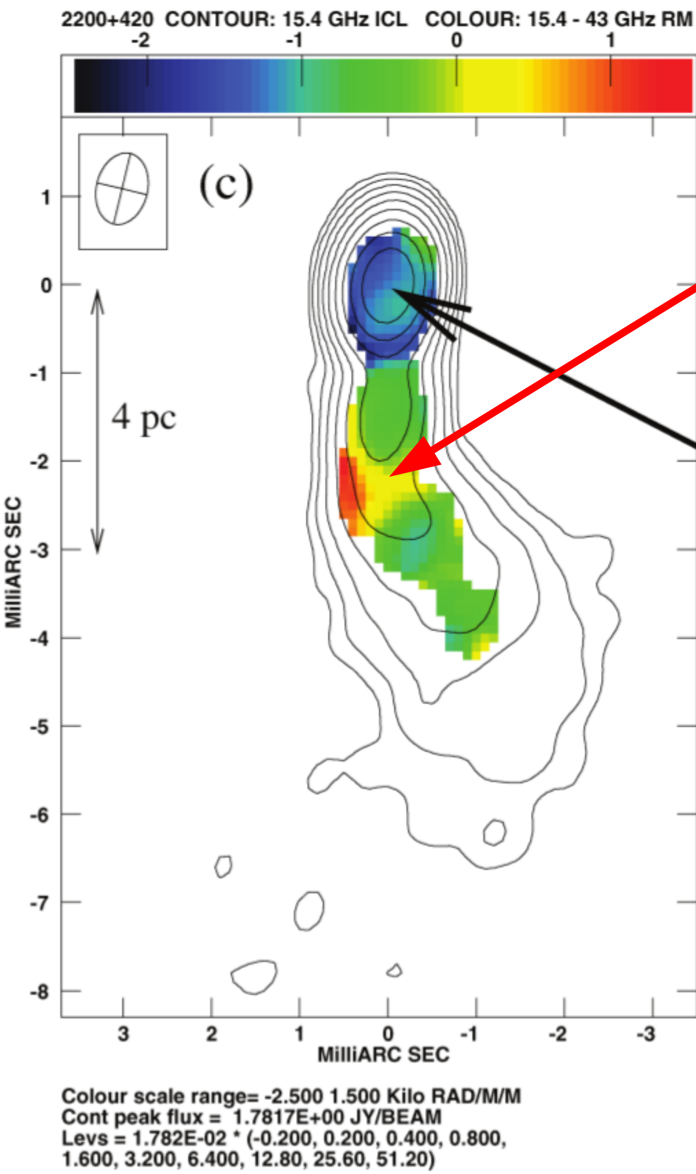
Jet evolution in polarization and large-scale magnetic fields



BLLAC Polarization; strong RM effects due to a sheath of plasma surrounding the jet

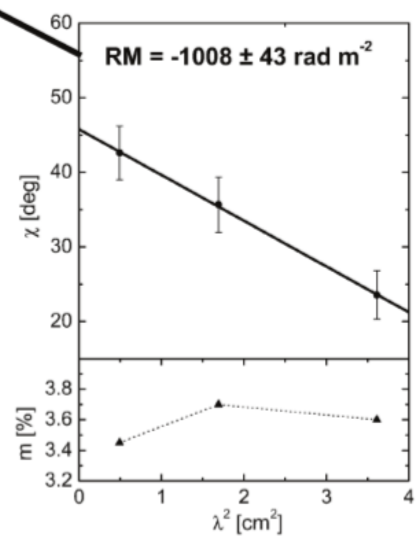
O’Sullivan & Gabuzda 2009a,b

Jet evolution in polarization and large-scale magnetic fields



BLLAC RM map (15-43 GHz)

Variation of RM (– → +)
(indicative of helical B-field geometry ??)



(a) Deep single-epoch
(b) + multi-frequency
(c) + polarimetric VLBI
can provide a lot of
detailed information !

O'Sullivan & Gabuzda 2009a,b

Observations with KVN and KaVA

Source Name	Time [hr]	Freq [GHz]	Polarization	Angular scale
	(For KVN / KaVA , respectively)			
3C 84 (NGC 1275)	10 / 6	22,43,86,129 / 43	L&R / L	0.30 pc/mas
4C +69.21 (1642+690)	10 / 6	22,43,86,129 / 43	L&R / L	7.35 pc/mas
3C 120 (0430+052)	10 / 6	22,43,86,129 / 43	L&R / L	0.65 pc/mas
4C +01.28 (1055+028)	10 / 6	22,43,86,129 / 43	L&R / L	7.78 pc/mas
BL Lac (2200+420)	10 / 6	22,43,86,129 / 43	L&R / L	1.29 pc/mas
DA 55 (0133+476)	10 / 6	22,43,86,129 / 43	L&R / L	7.70 pc/mas
3C 111 (0415+379)	10 / 6	22,43,86,129 / 43	L&R / L	0.95 pc/mas

L/R at 2 freq (simultaneously) for each season

Bright & nearby sources for a detailed study.
Data are still being taken from the observatories.
KVN : Dual L/R pols at 4 freq (3 seasons x 70 hrs)
KaVA : 43 GHz deep imaging (2 seasons x 42 hrs)

Data Reduction & Analysis (mostly AIPS + Difmap)

ACCOR

FRING

APCAL

BPASS

1st CLEAN map (Difmap)

For Stokes I

RLDLY

LPCAL (3C84)

CALIB (w/ I map)

Check V res map

Full Stokes Imaging (modelfit)

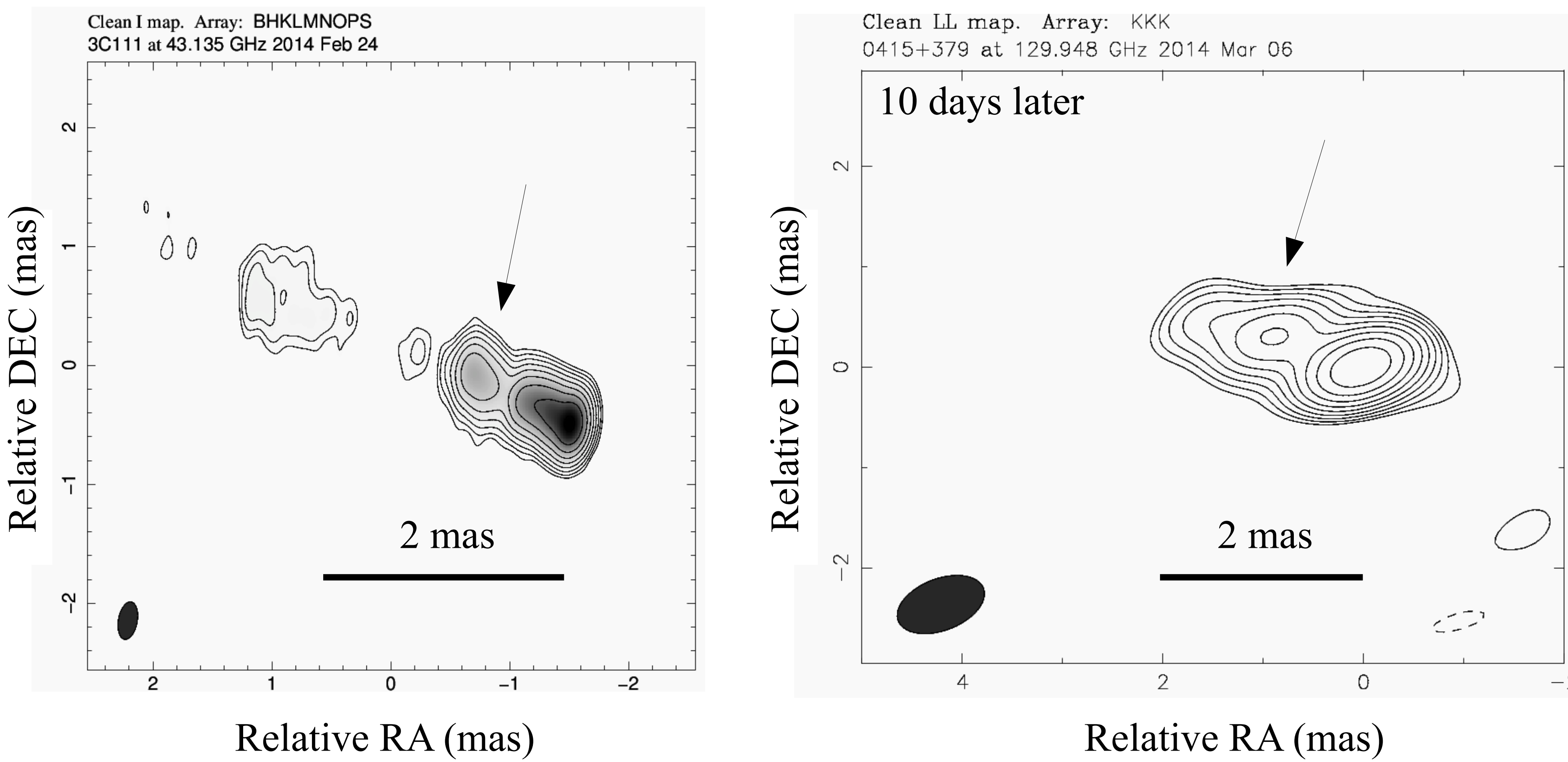
For Stokes Q, U (and V)

(1) Model components analyses
(e.g. Tb,app VS. Distance)

(2) Multi-frequency image analysis with proper alignment
(SPIX & RM map)

For analysis

Illustration of angular resolution

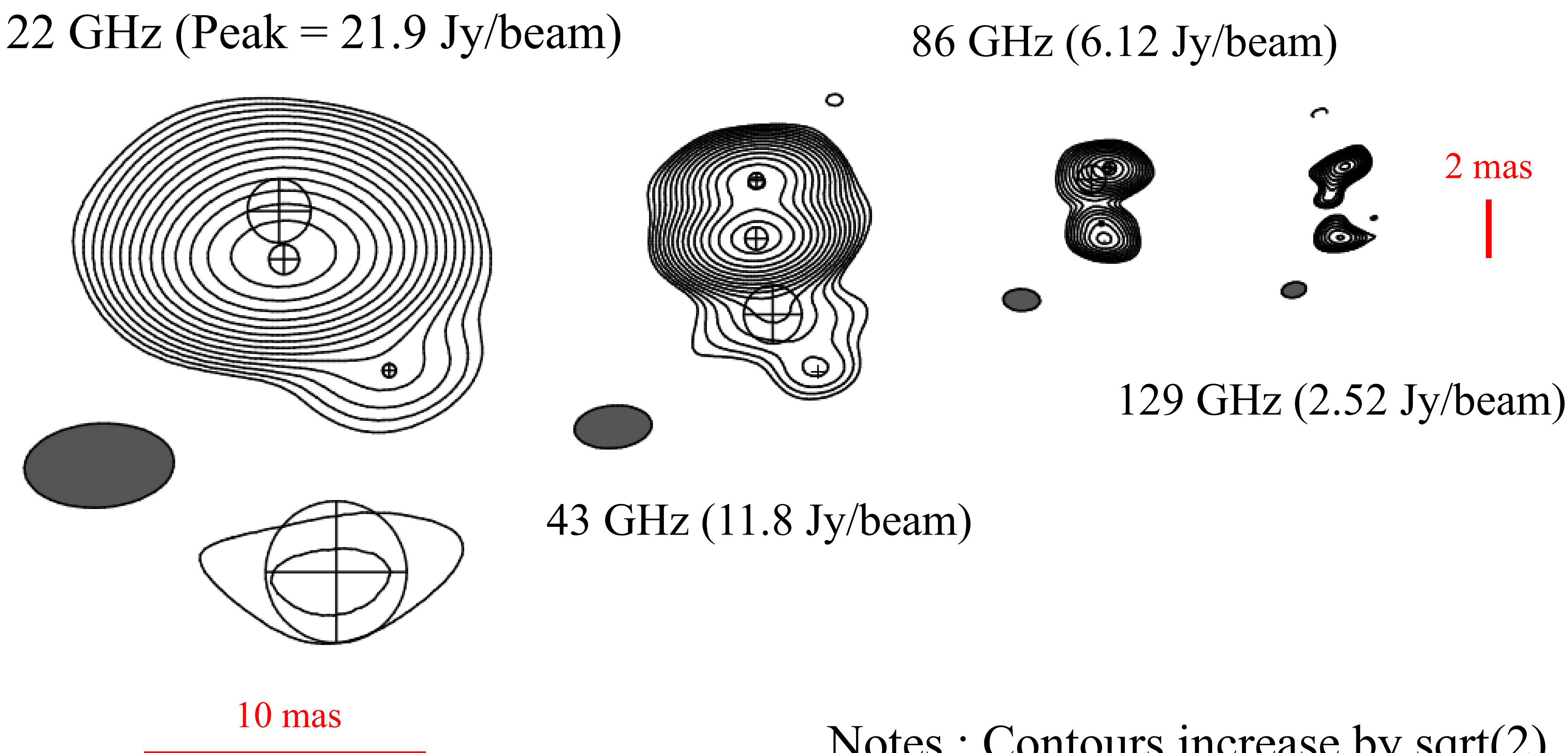


Boston Univ. group's
VLBA 43 GHz 3C111map

Our KVN obs at 129 GHz toward 3C111

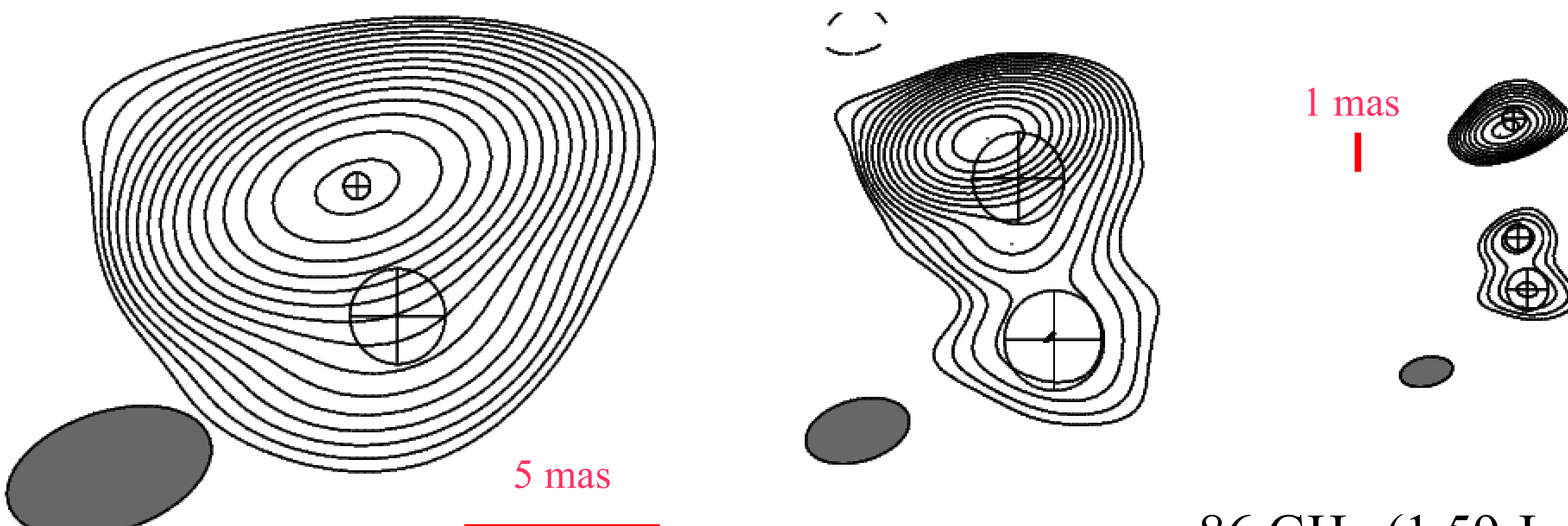
KVN 86 & 129 GHz resolution can be compatible with other powerful arrays.

Multi-frequency I maps (3C 84)



Notes : Contours increase by sqrt(2).
The 22+43 / 86+129 data are obtained at different epochs

Multi-frequency I maps (BL Lac)



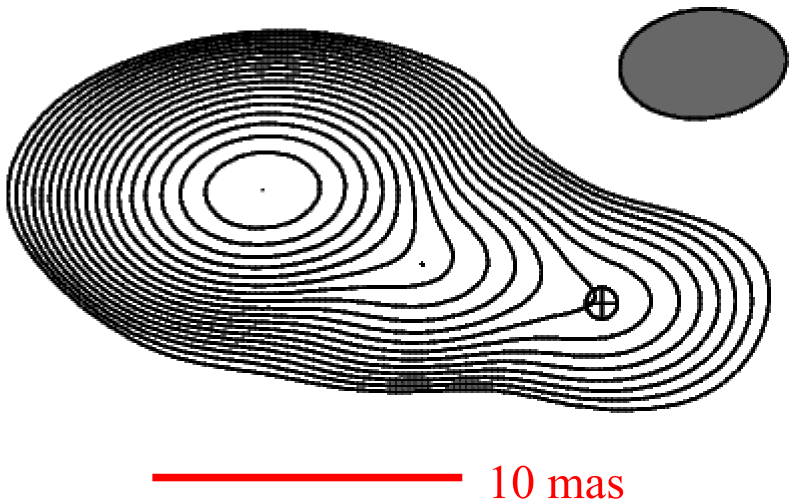
86 GHz (1.59 Jy/beam)

22 GHz (5.16 Jy/beam);
Pol. detected

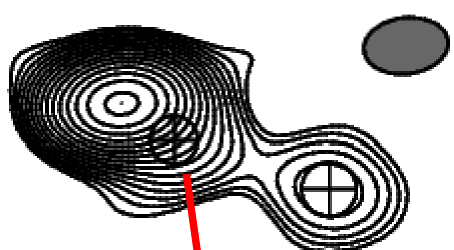
43 GHz (5.17 Jy/beam);
Pol. detected

Note : failed to detect at 129 GHz in our obs

Multi-frequency I maps (3C 120)



22 GHz (Peak = 1.85 Jy/beam)
(Pol. detected)



43 GHz (2.17 Jy/beam)

86 GHz (1.19 Jy/beam; later observation)

Note : failed to detect at 129 GHz in our obs

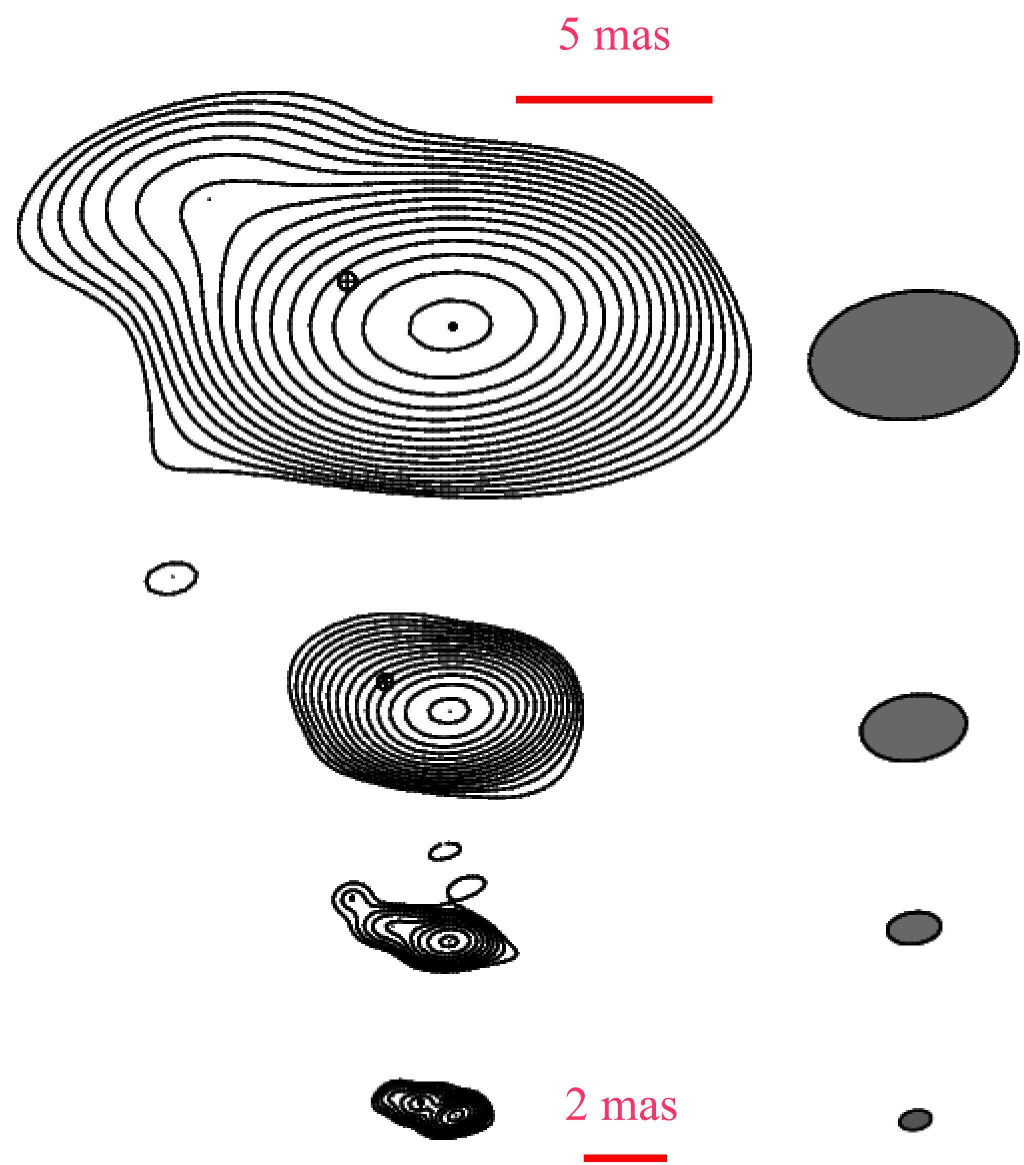
Multi-frequency I maps (3C 111)

22 GHz (3.27 Jy/beam)
Pol. detected

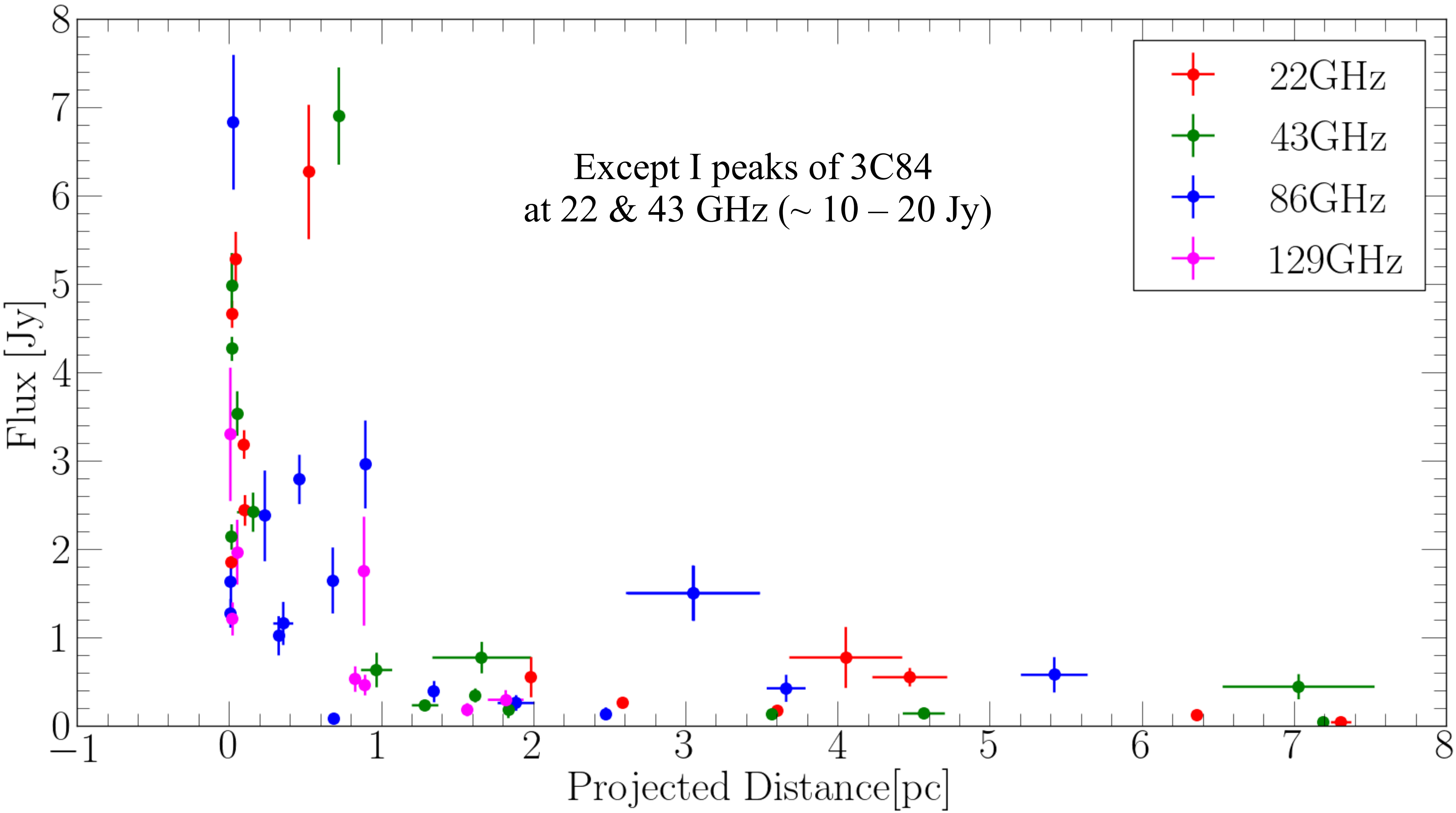
43 GHz (3.6 Jy/beam)

86 GHz (1.64 Jy/beam)

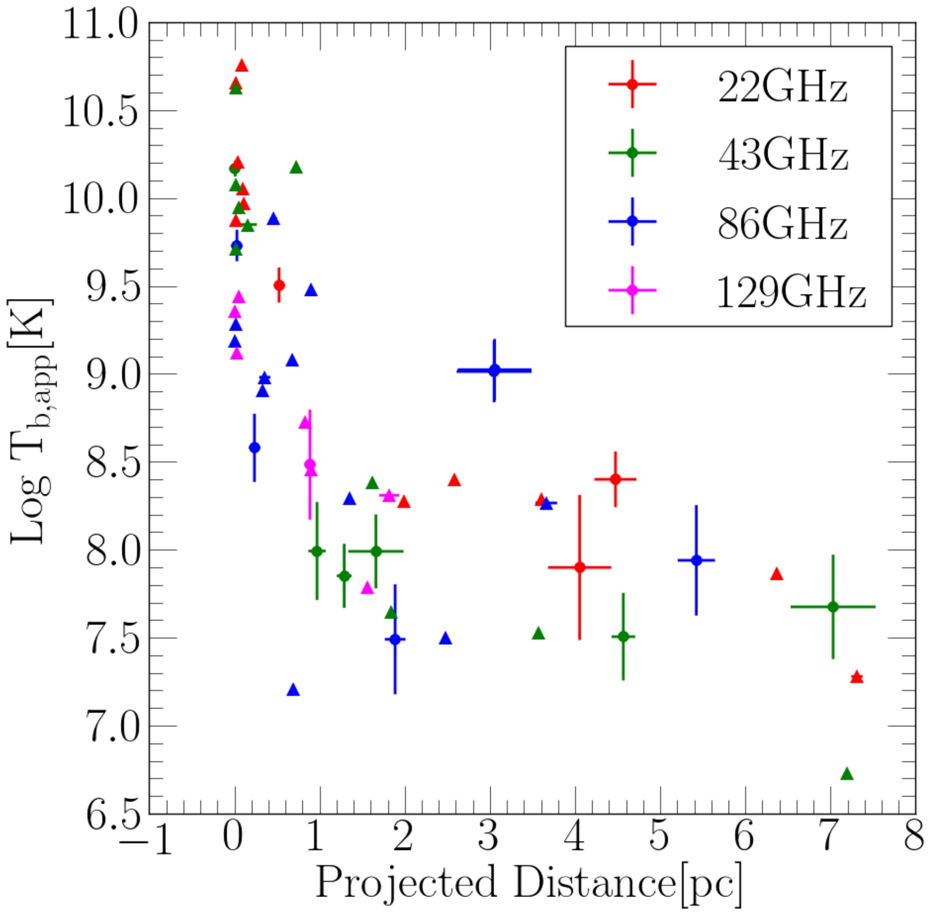
129 GHz (1.21 Jy/beam)

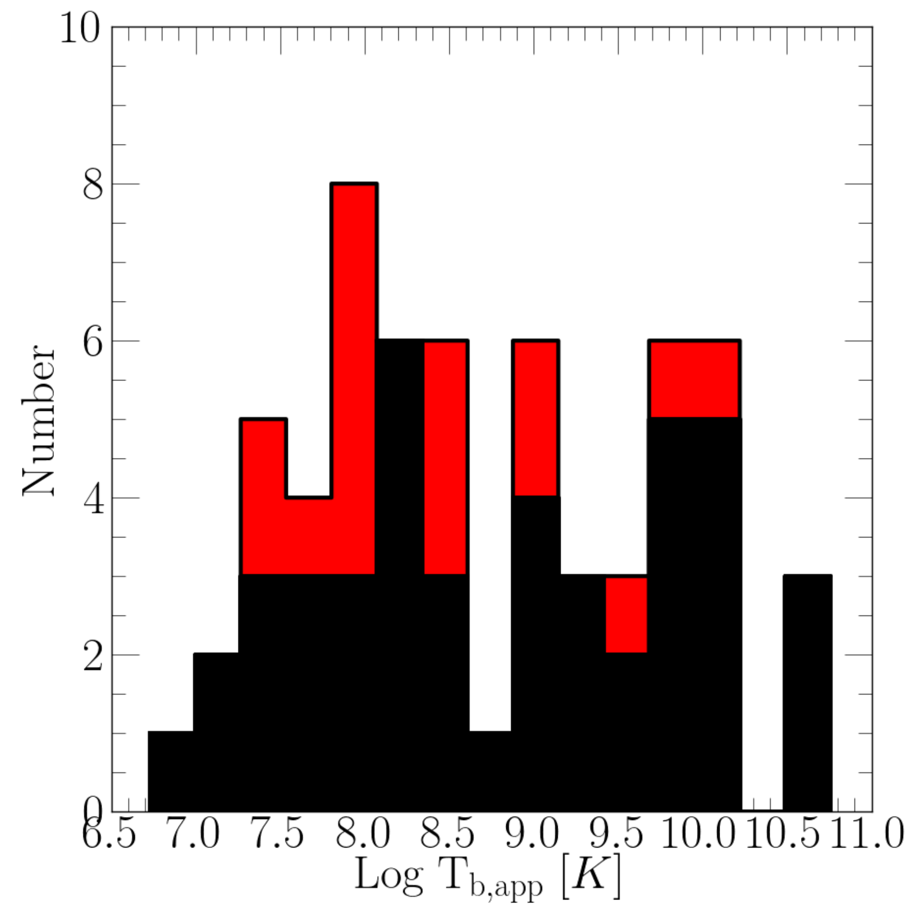


Flux distributions of the components



Apparent $T_{brightness}$ Distributions





▲ : Lower limit (unresolved)

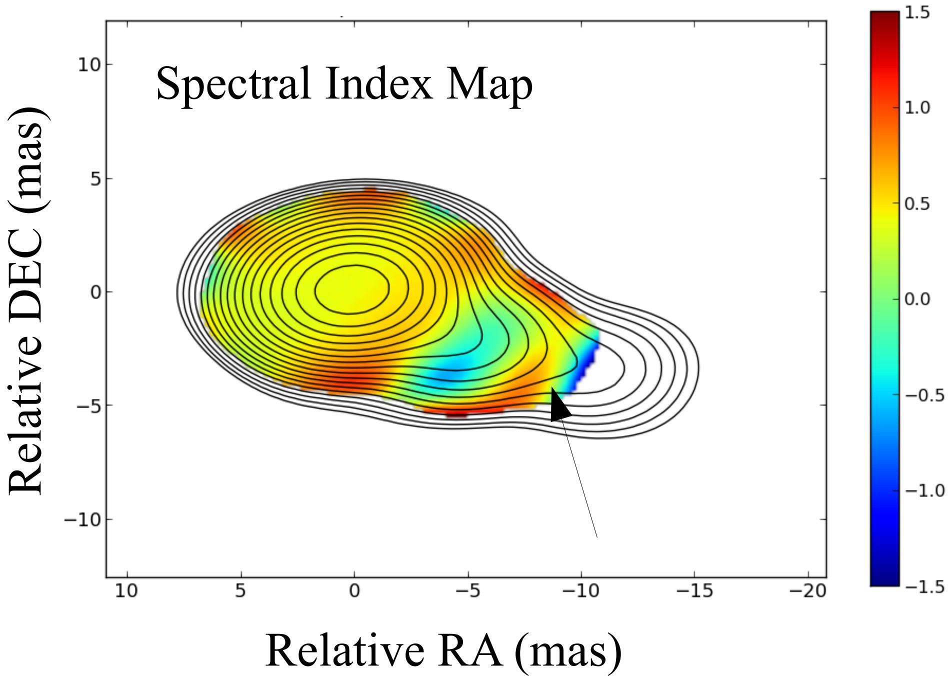
(Red)Black : (Un)resolved

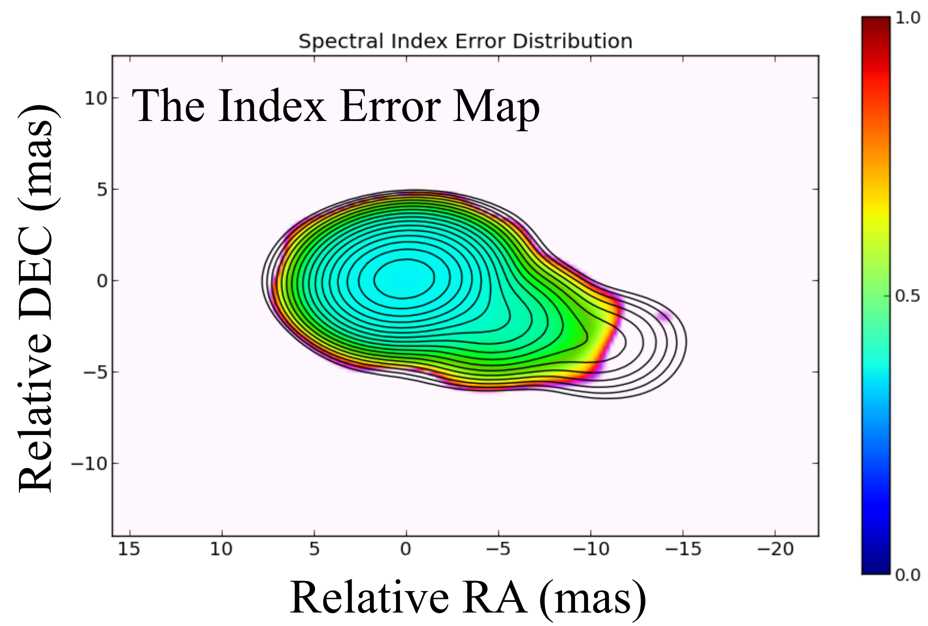
Wide range of $T_{b,app}$ in mm wavelengths;
Deriving the Doppler factor will be next job.

Spectral Index Map (3C 120 at 22 – 43 GHz)

$$\sigma_{\nu,ij} = \delta_\nu I_{\nu,ij} + RMS_{\nu,ij} \longrightarrow Err(\alpha_{\nu_{1,2},ij}) = \frac{1}{\log(\nu_2/\nu_1)} \times \left[\frac{\sigma^2_{\nu_{1,ij}}}{I^2_{\nu_{1,ij}}} + \frac{\sigma^2_{\nu_{2,ij}}}{I^2_{\nu_{2,ij}}}\right]^{1/2}$$

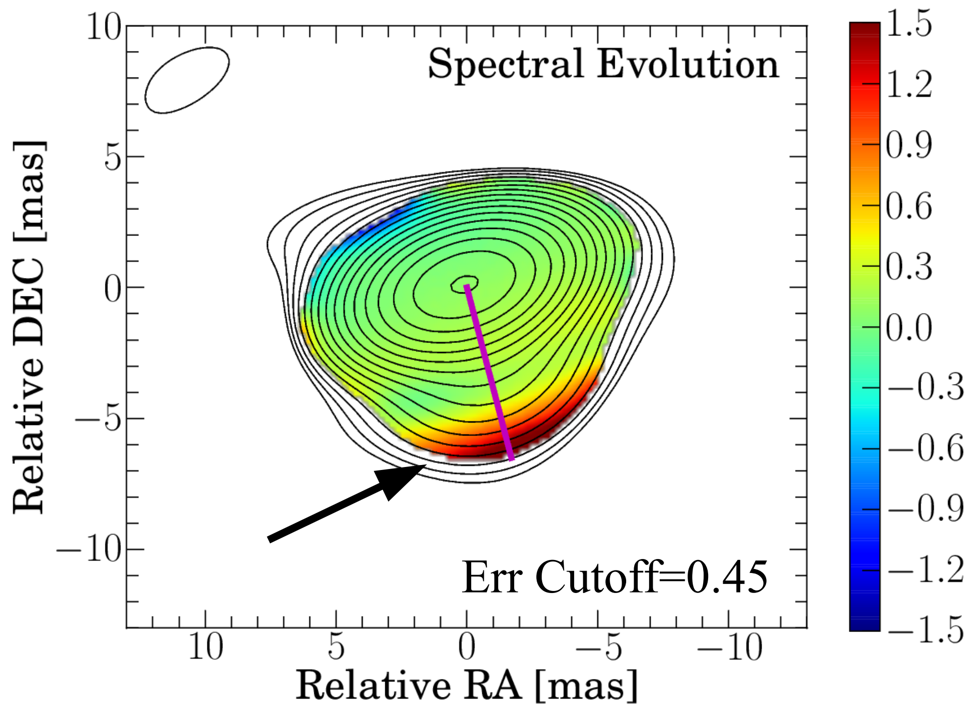
Systematical flux uncertainty ~ assumed 10% for KVN

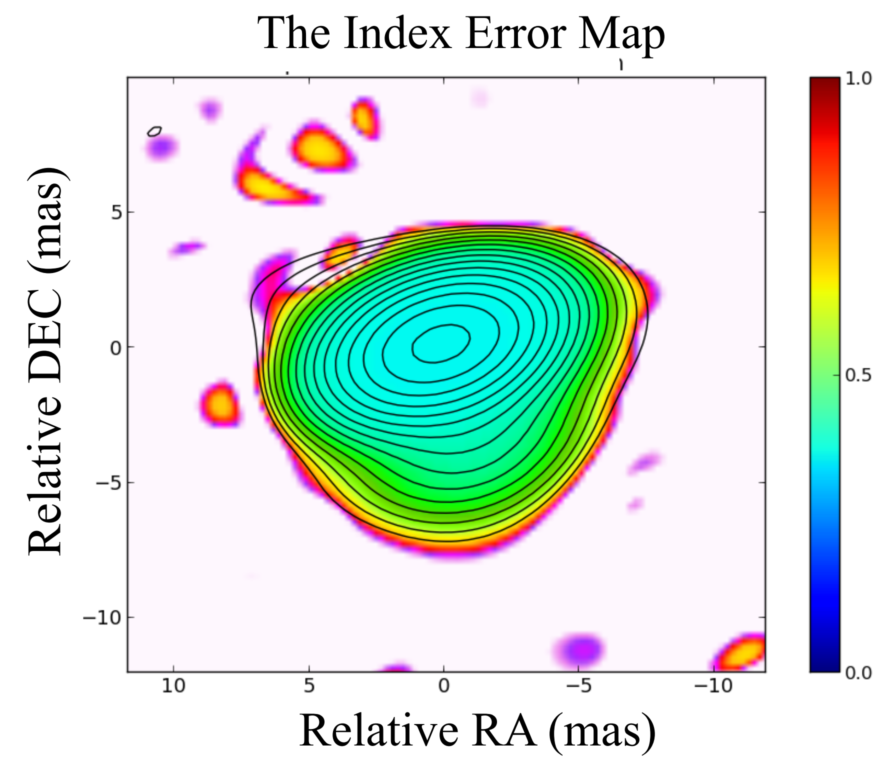


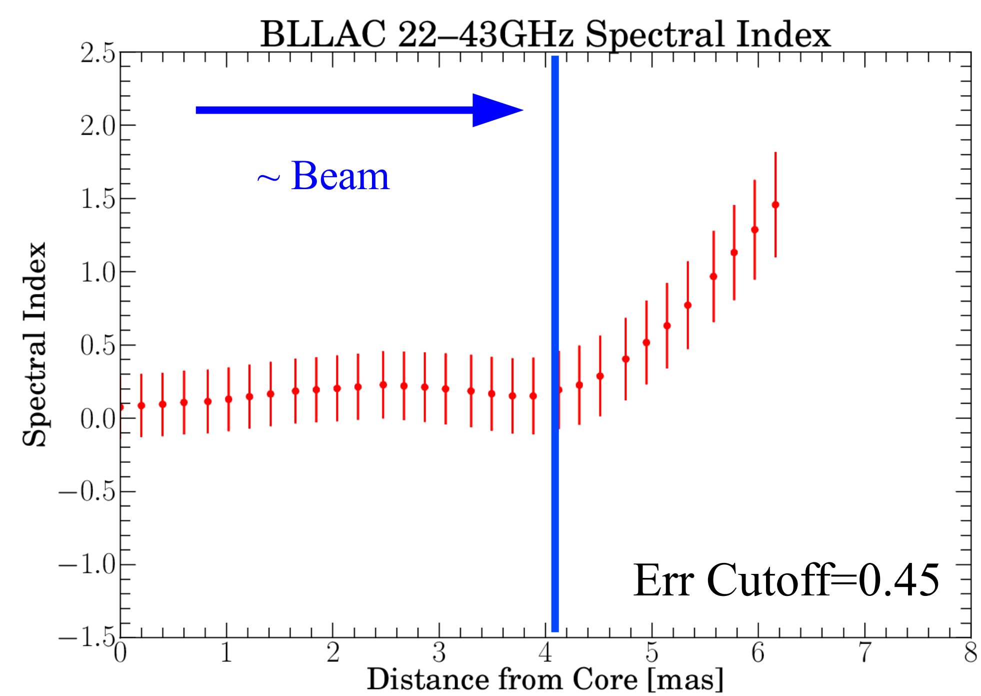


Note : the core-shifts at these frequencies may be too small (~a few micro arcsecs); Phase self-cal and/or blending of source structures may affect the results.

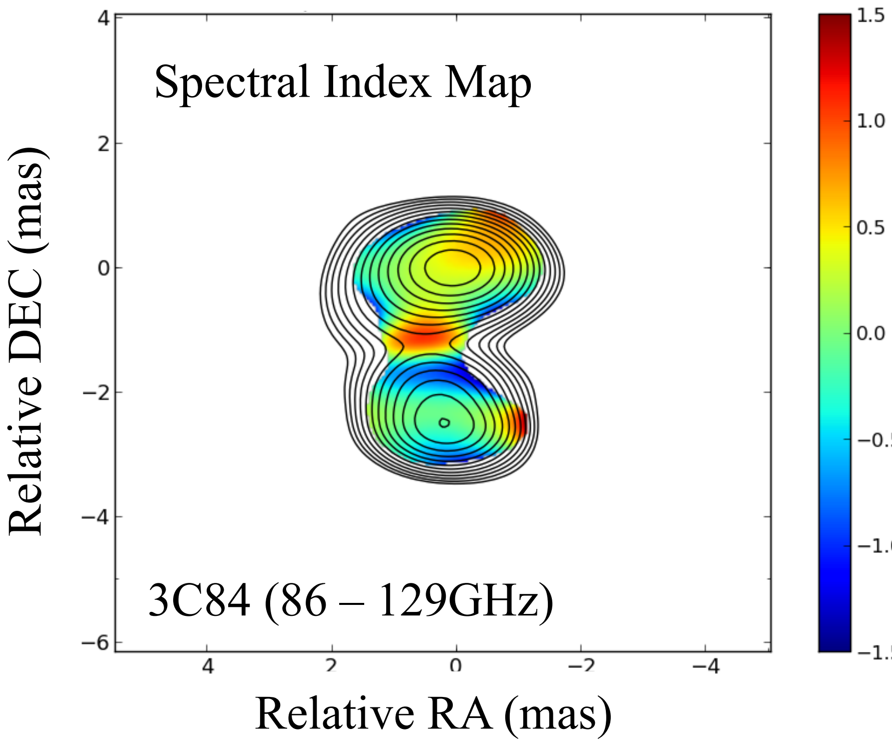
Spectral Index Map
(BL Lac at 22 – 43 GHz)

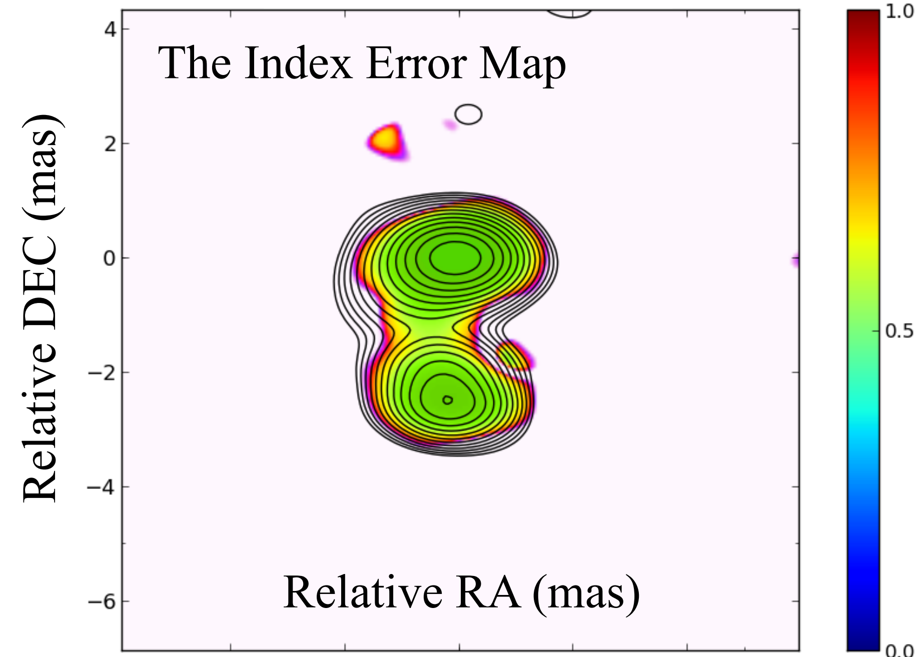


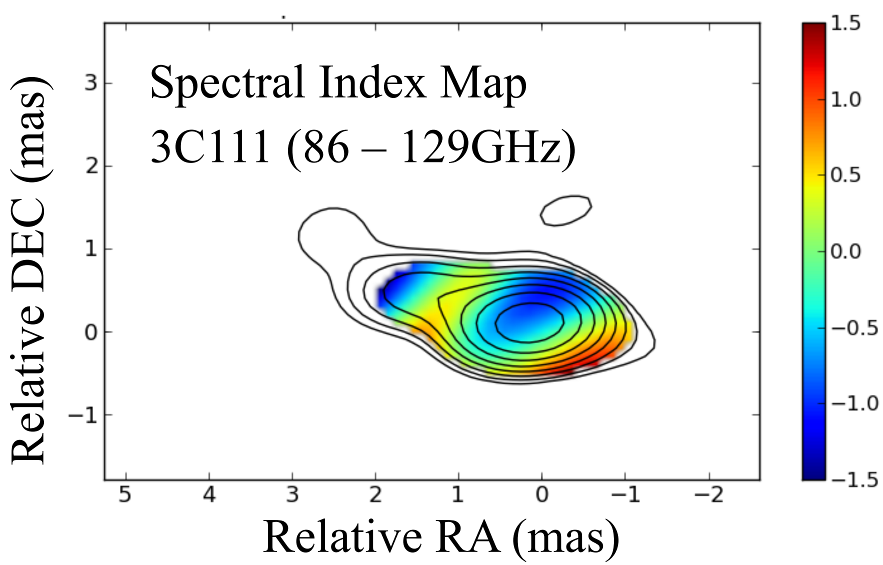


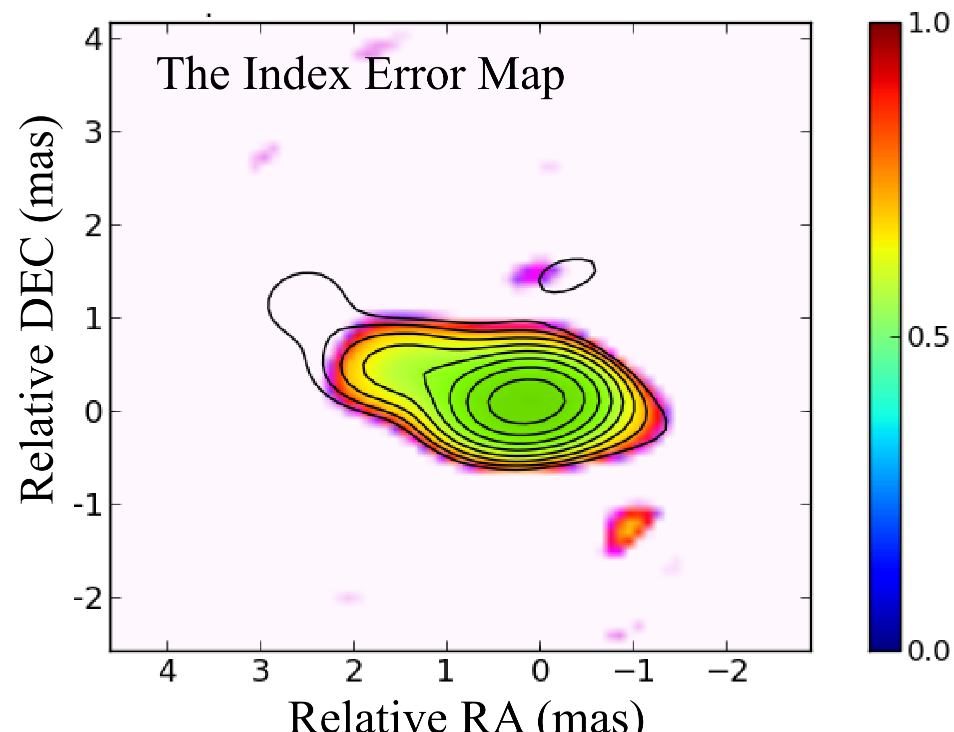


Relative shifts did not changed the index values so much.



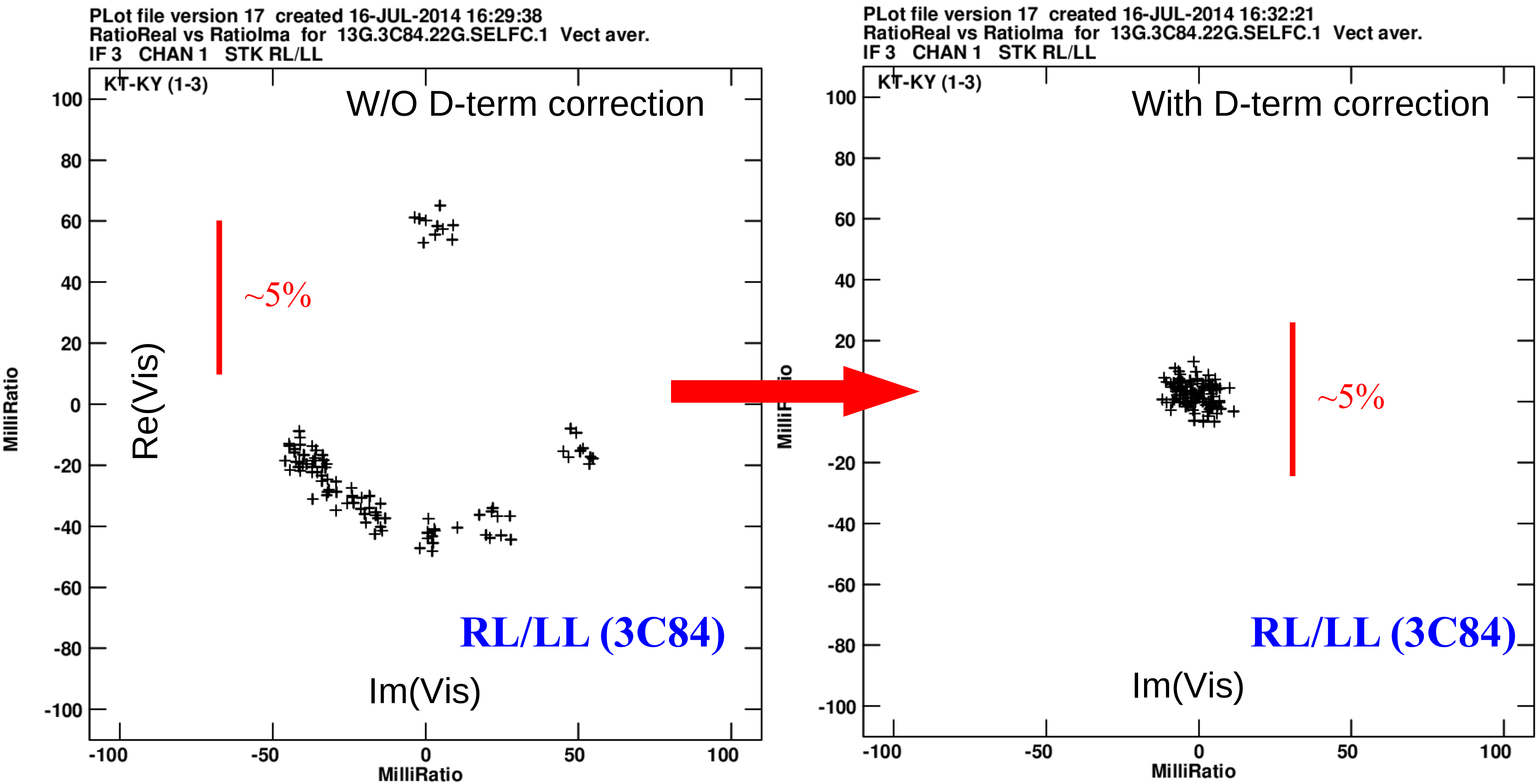






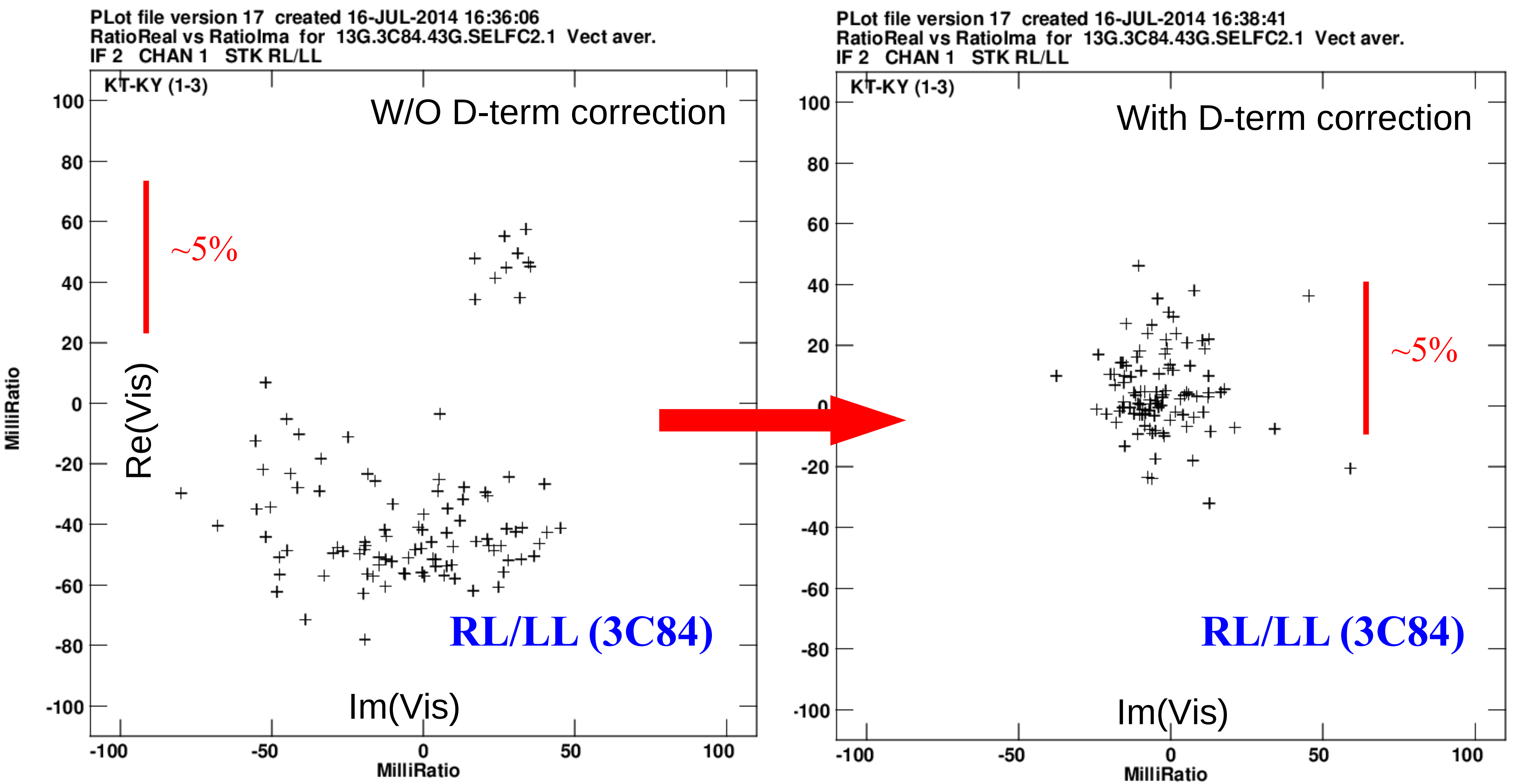
Still preliminary results at higher frequencies ...

Correcting instrumental polarization; 22GHz



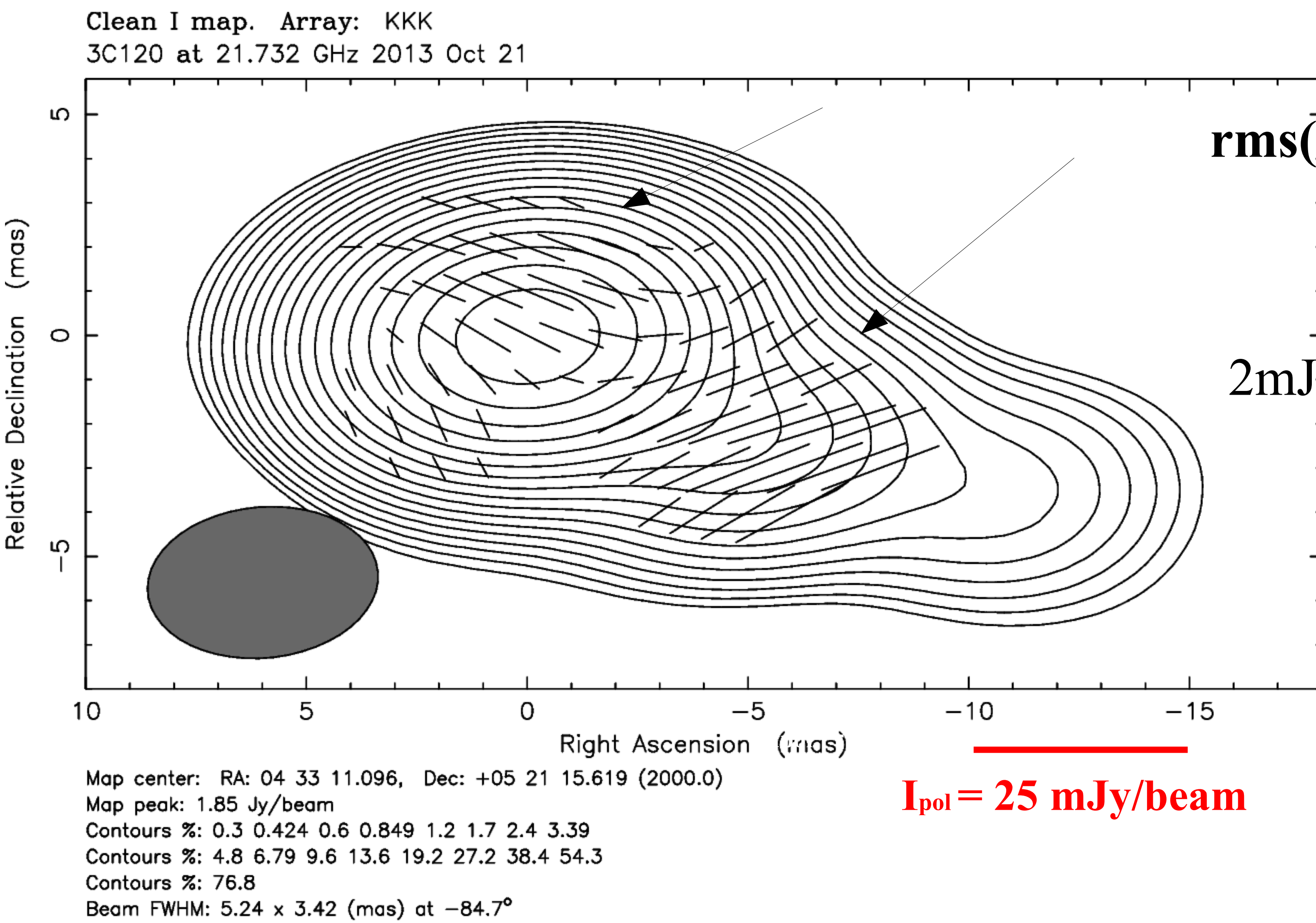
Successfully obtained D-terms using unpolarized source, **3C84**.

Correcting instrumental polarization; 43GHz



A bit larger scatter. Sometimes D-term corrupted source polarization.

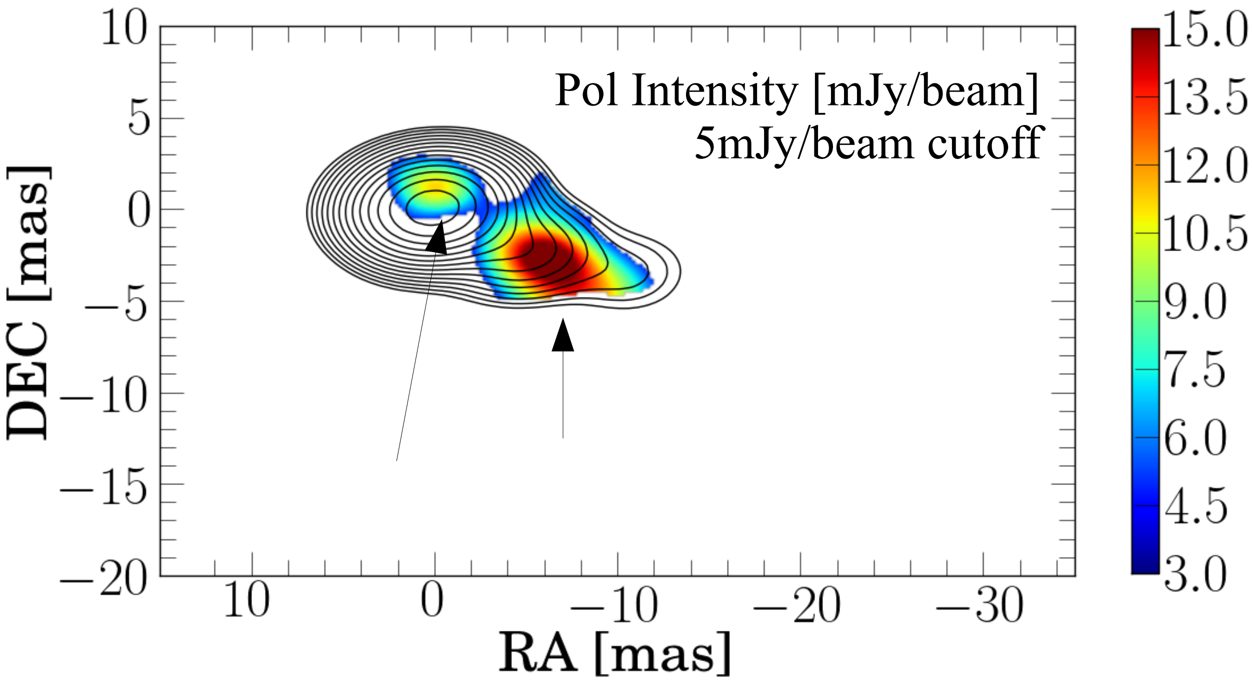
Polarization of 3C120 at 22 GHz



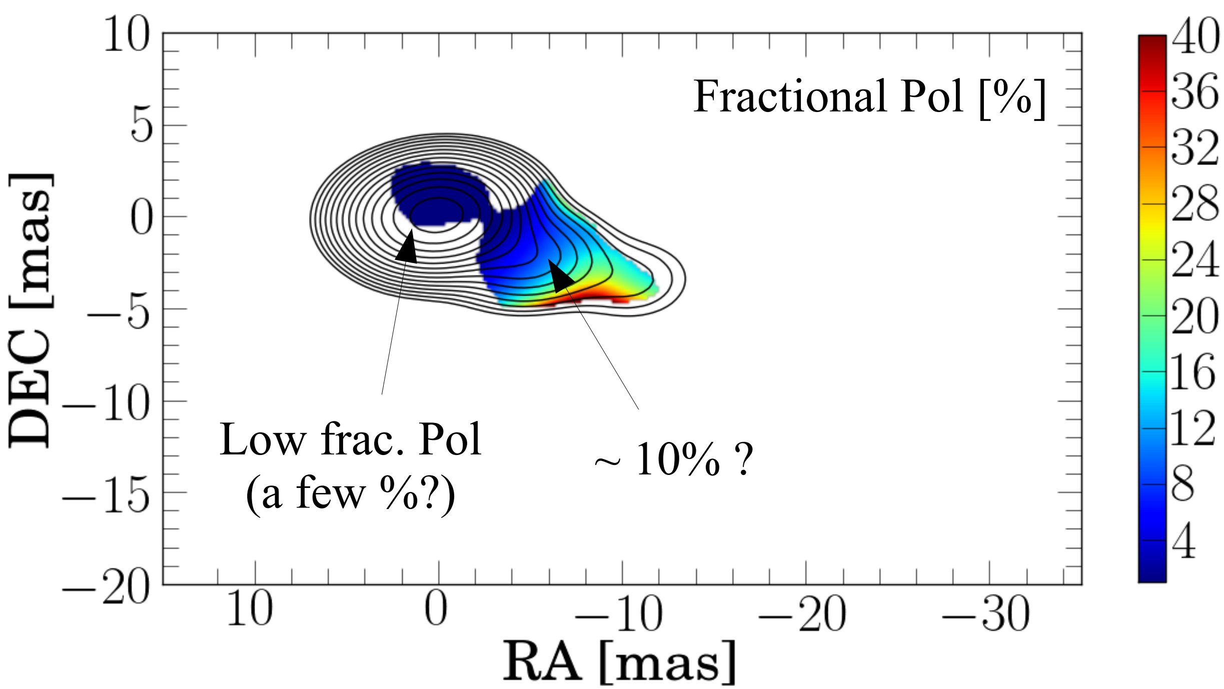
rms(Stokes V res.) ~ 0.5 mJy/beam

rms(I_{pol}) ~ 2mJy/beam (=cutoff)

Note : Pol angle calibration is not made yet.



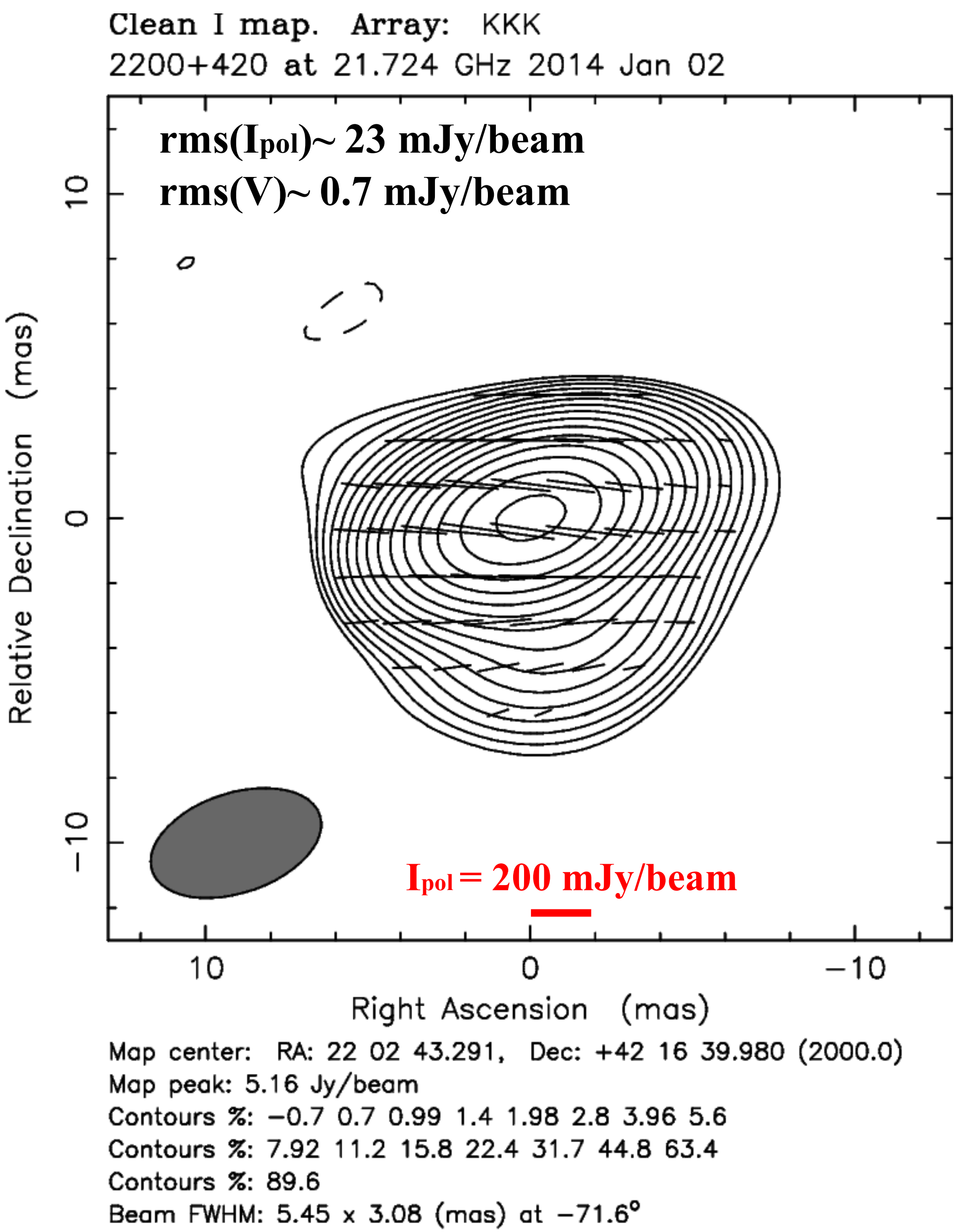
Pol intensity shows two distinguished components

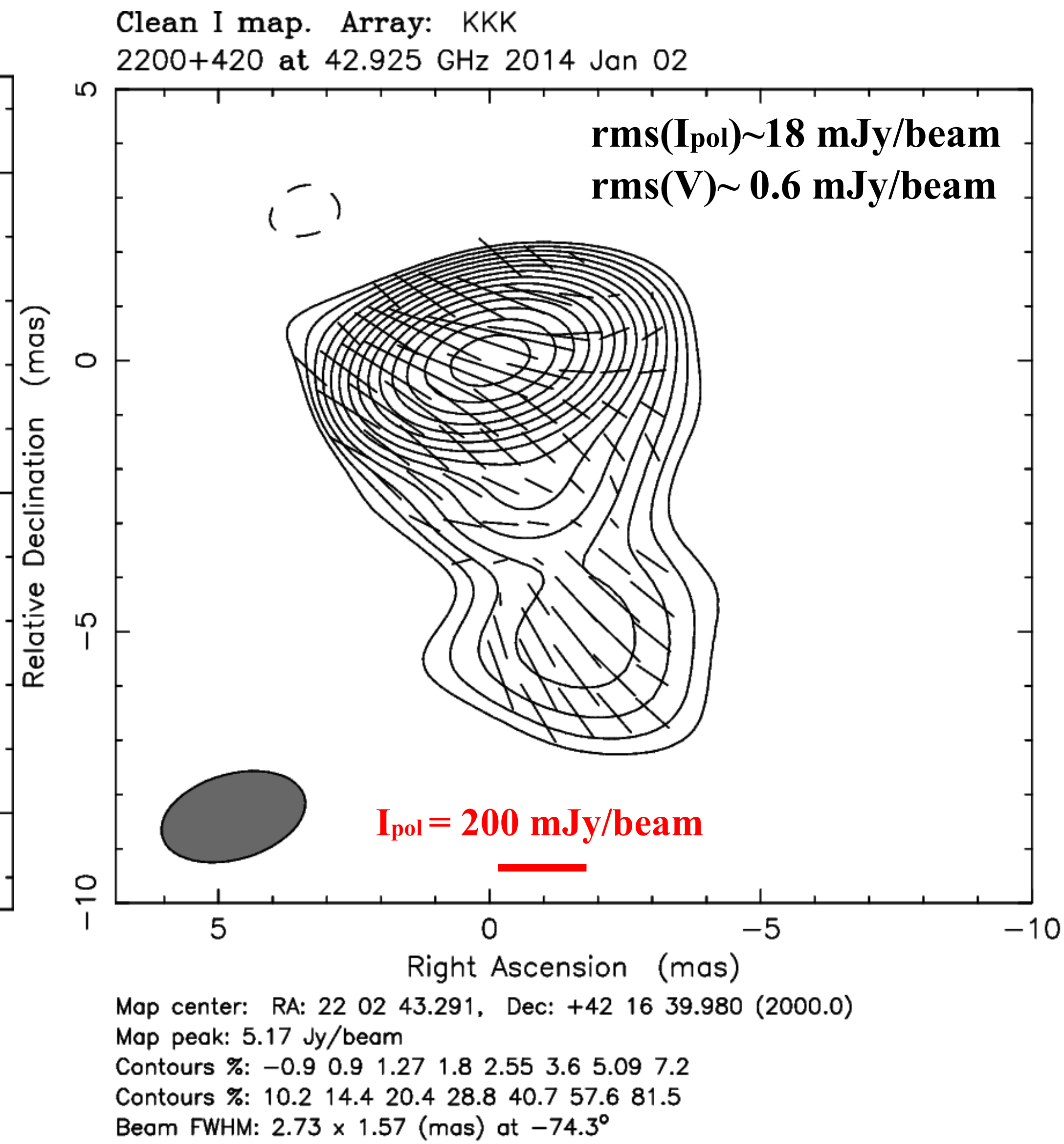


Level of core polarization is only a few percent;

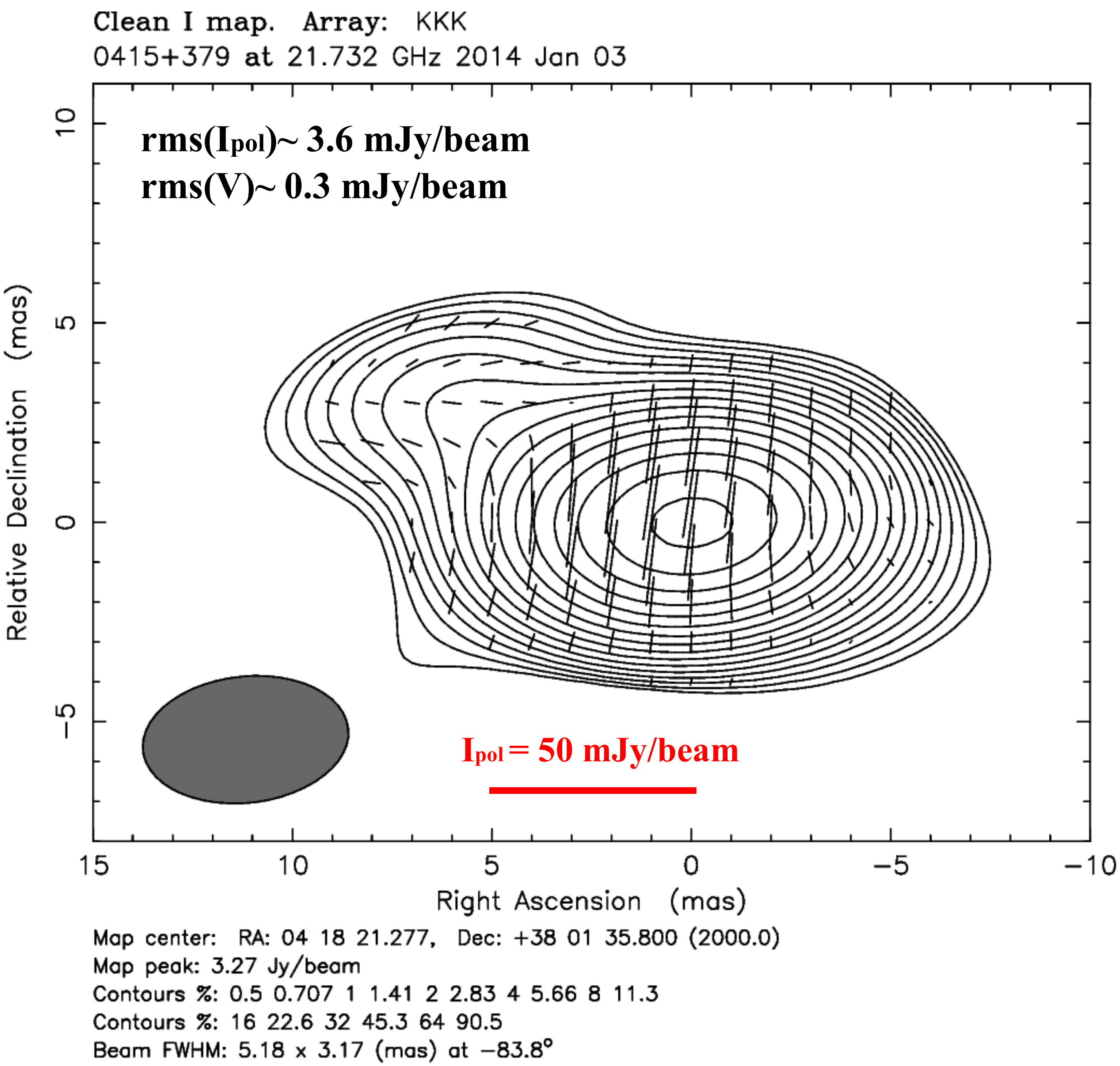
Pol canceling effect by the observing beam? Or other physical origins for this ?

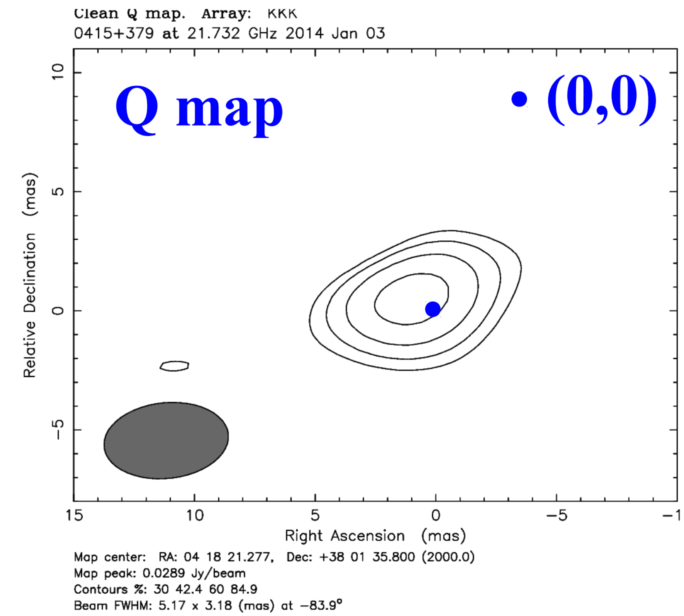
Polarization of BL Lac (22/43 GHz)

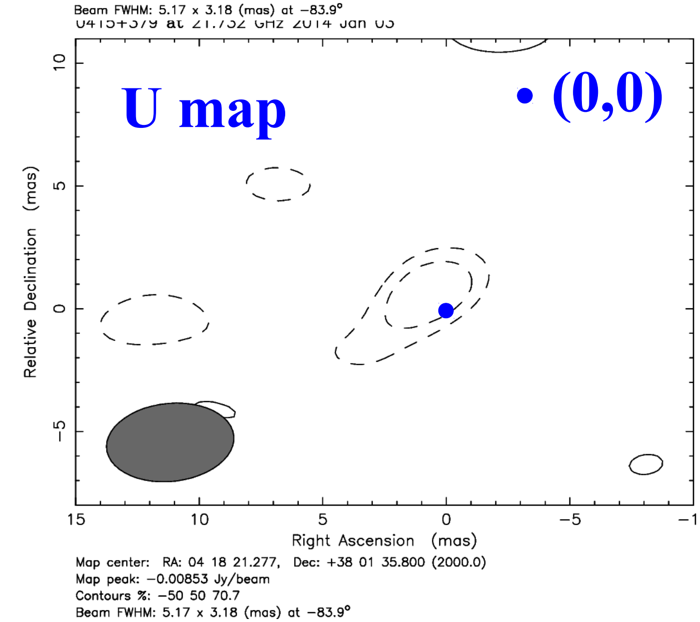




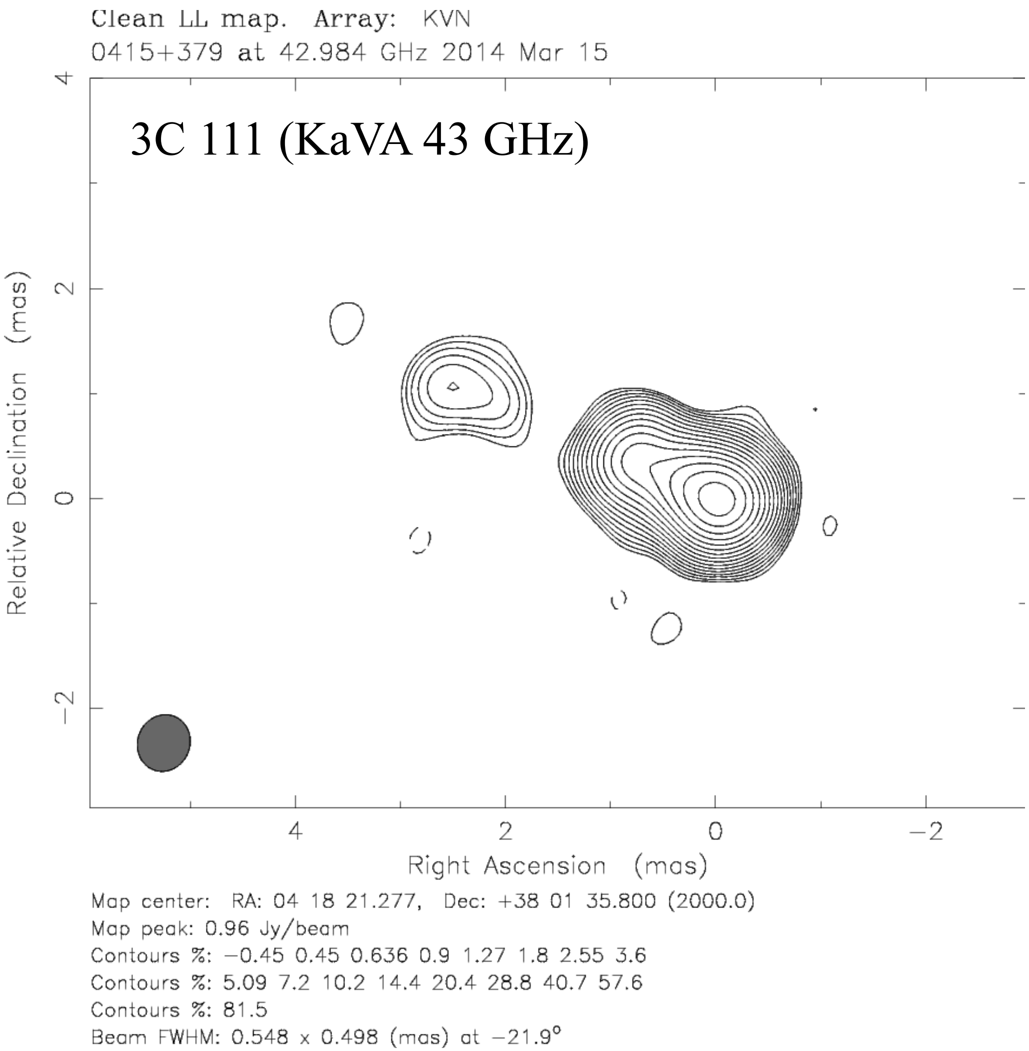
Polarization of 3C111 at 22 GHz

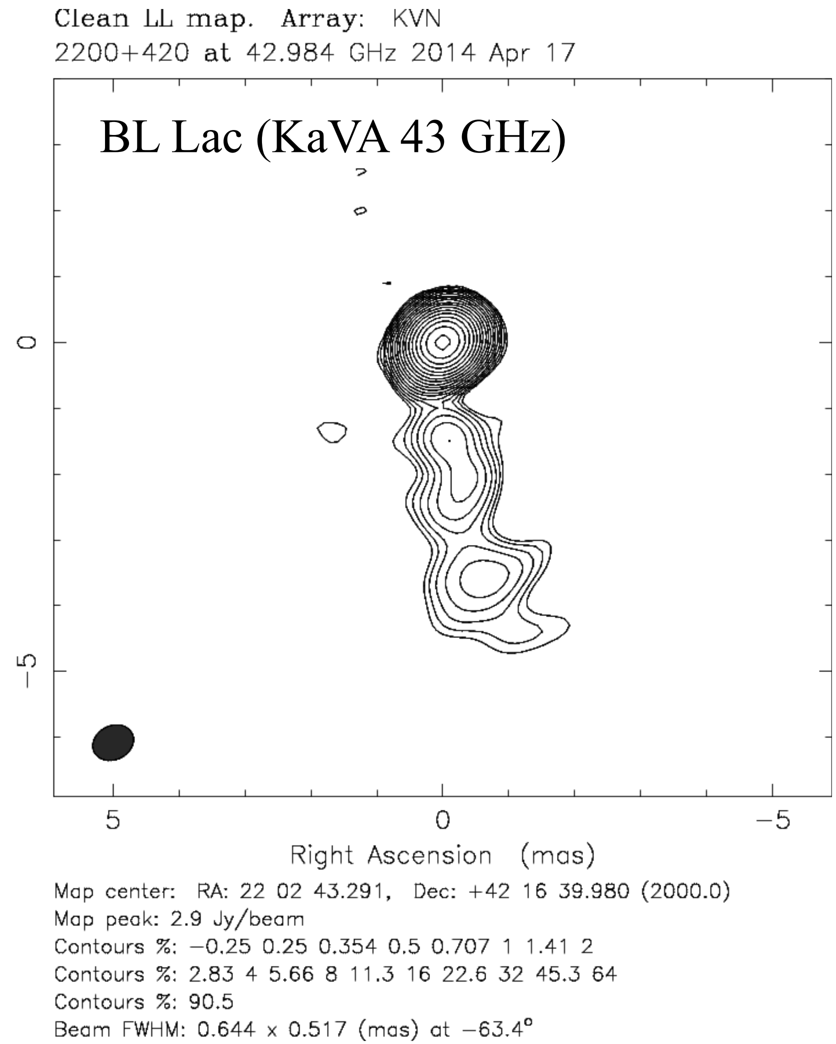






What's next ? KaVA observations (also KaVA polarimetry at 22 GHz soon ?)





Niinuma, K., et al. 2014, arXiv:1406.4356 for more information about KaVA array

Thank you for your patience.

Any questions and comments are welcome.

Backup Materials

Errors for model components

$$\sigma_{\rm peak} = \sigma_{\rm rms}\left(1 + \frac{S_{\rm peak}}{\sigma_{\rm rms}}\right)^{1/2},$$

$$\sigma_{\rm tot} = \sigma_{\rm peak}\left(1 + \frac{S_{\rm tot}^2}{S_{\rm peak}^2}\right)^{1/2},$$

Assumptions on
errors for parameters
of a model component

$$\sigma_d = d\,\frac{\sigma_{\rm peak}}{S_{\rm peak}},$$

$$\sigma_r = \frac{1}{2}\sigma_d,$$

$$\sigma_\theta = \mathrm{atan}\left(\frac{\sigma_r}{r}\right),$$

$$d_{\rm min} = \frac{2^{1+\beta/2}}{\pi}\left[\pi a b \ln 2 \ln \frac{\rm (S/N)}{\rm (S/N) - 1}\right]^{1/2},$$

Limiting angular scale determined by S/N (Lee et al. 2008 and references therein)

D-term estimation

Ratio of cross-to-parallel hand visibility is used to evaluate effects of the D-term calibration (AIPS LPCAL on 3C84). (Roberts & Wardle 1994; Aaron 1997)

Parallactic angle

$$\frac{R_1 L_2}{L_1 L_2} \propto M_{12} e^{-2i\phi_1} + D_{1R} + D_{2L} e^{-2i\phi_{12}}$$

Source Polarization;
un-pol source (=3C84) is desired.

Instrumental Polarization

Spectral index maps

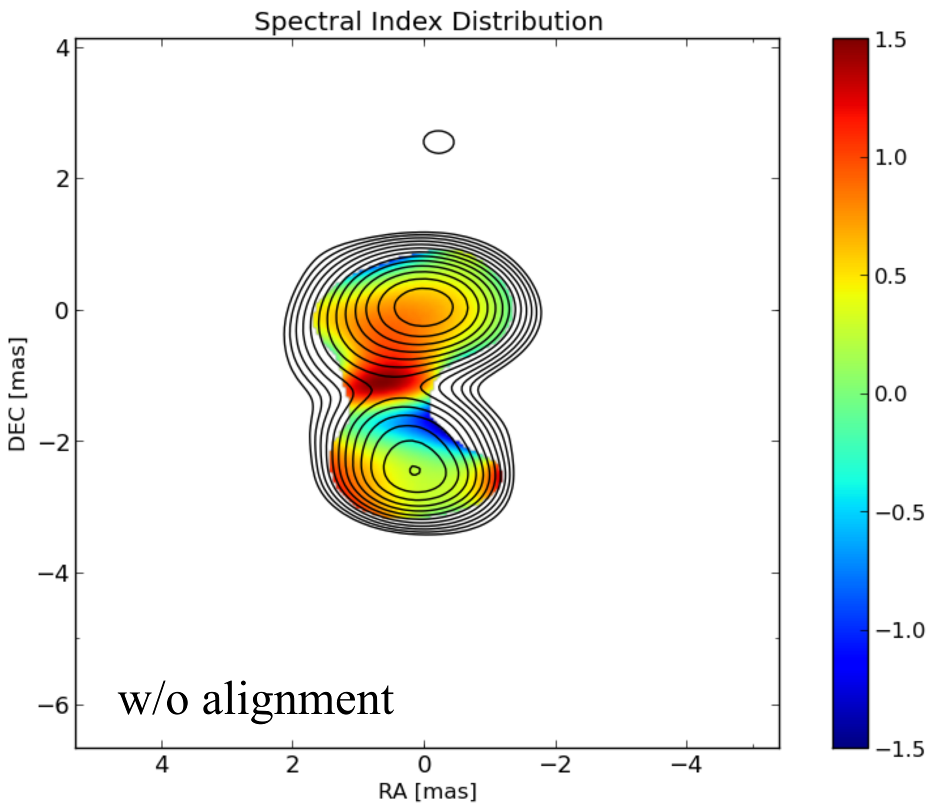
Image alignment is the key to achieve the best result;
It is usually be done via

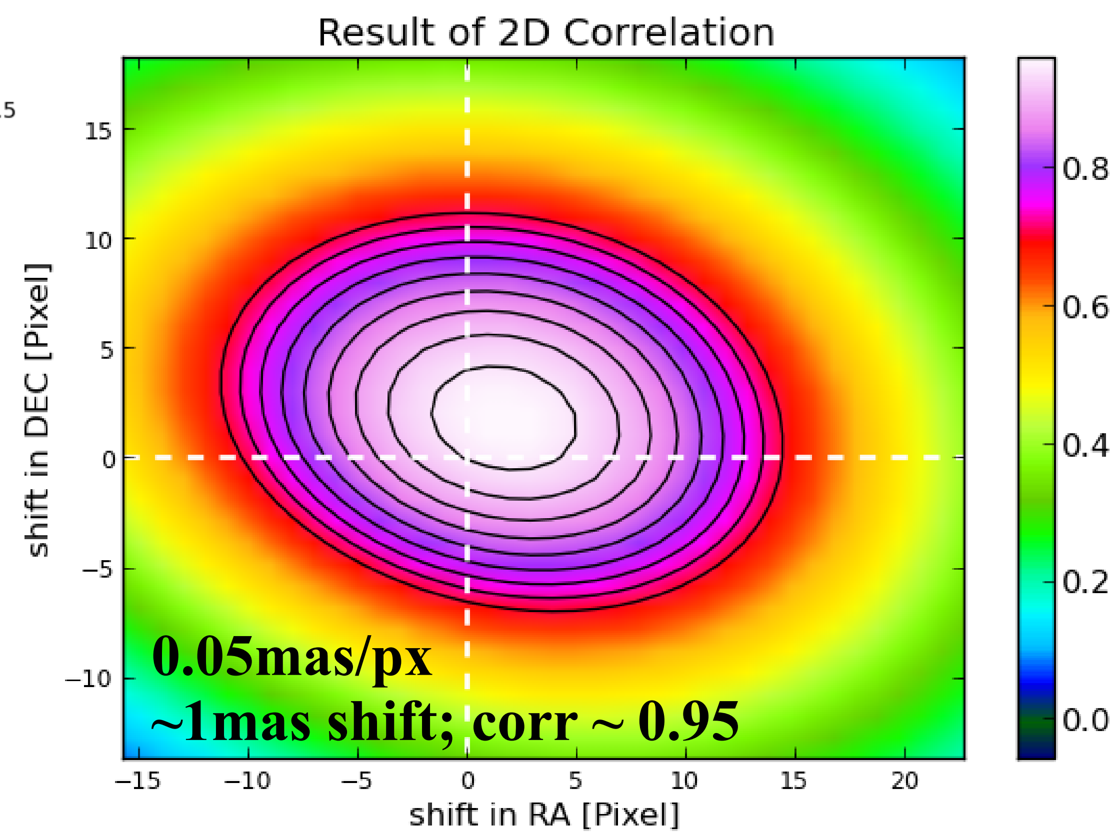
(1) Component-based approach
(Kameno et al. 2003; Kadler et al. 2004)

(2) 2D cross-correlation method.
(Walker et al. 2000; Croke & Gabuzda 2008; Kim & Trippe in prep.)

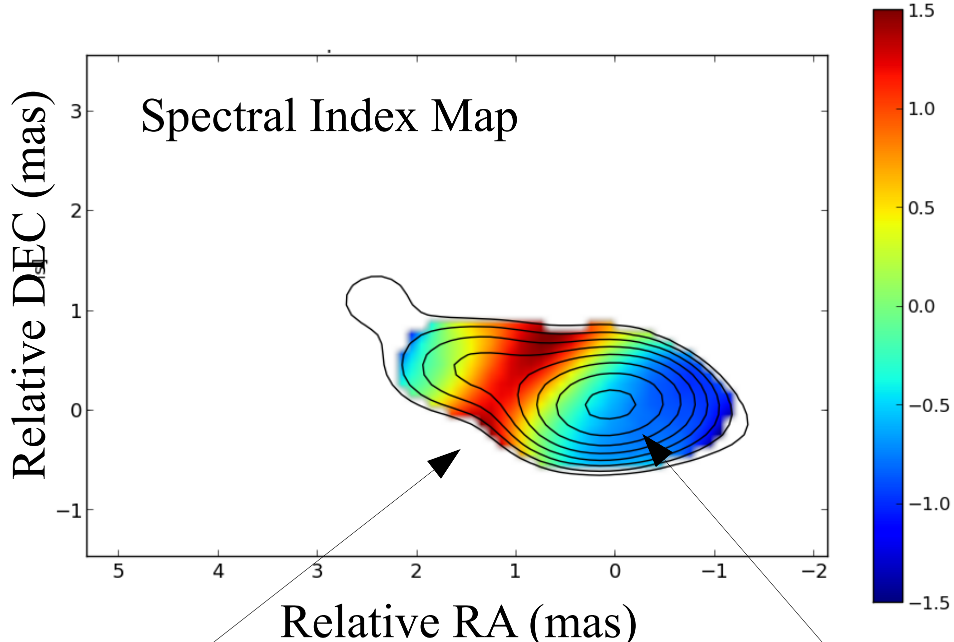
The core-shifts may be negligible (since it would be micro-arcsecs in this high frequency regime); also, due to the large beam sizes cores at low frequencies could be regarded as reference positions.

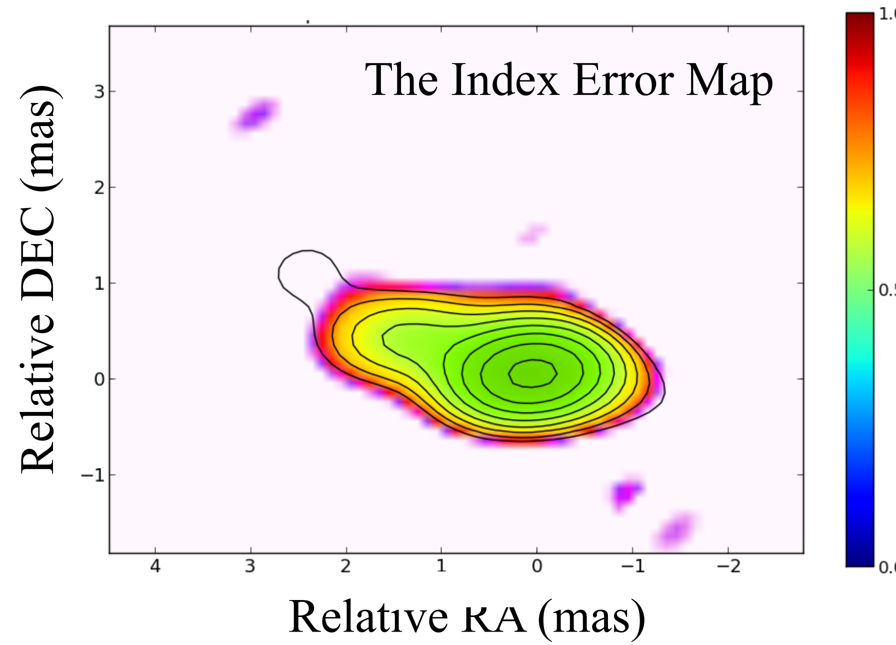
Spectral Index Map
(w/o correction)





Spectral Index Map (w/o correction)





Overdensity in the outflow ?

Steeper index at core than 22 – 43 GHz interval

Currently we are careful about spectral index maps of high frequency pairs; Phase unstability at 129 GHz might affect the results.