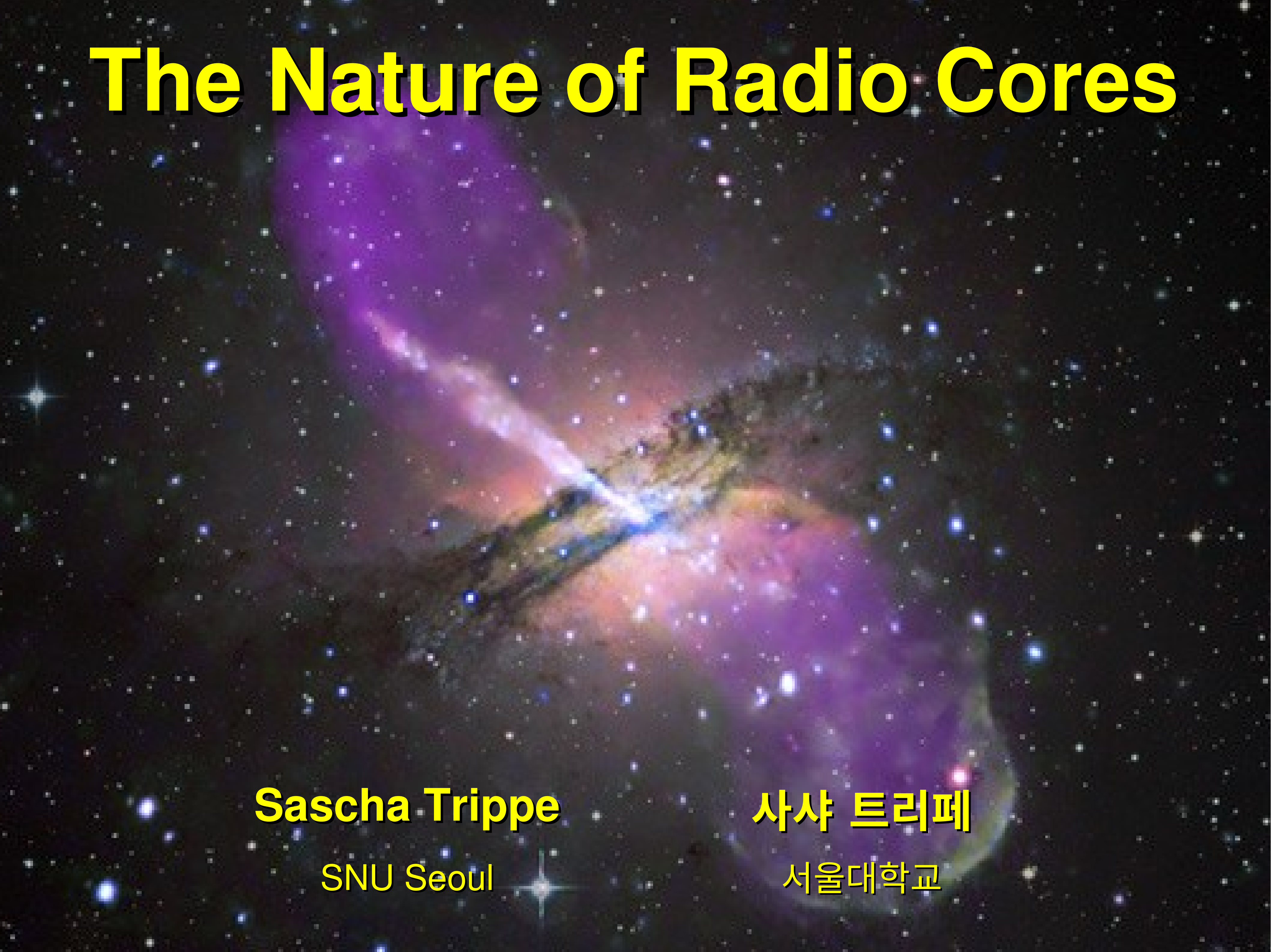
The Nature of Radio Cores



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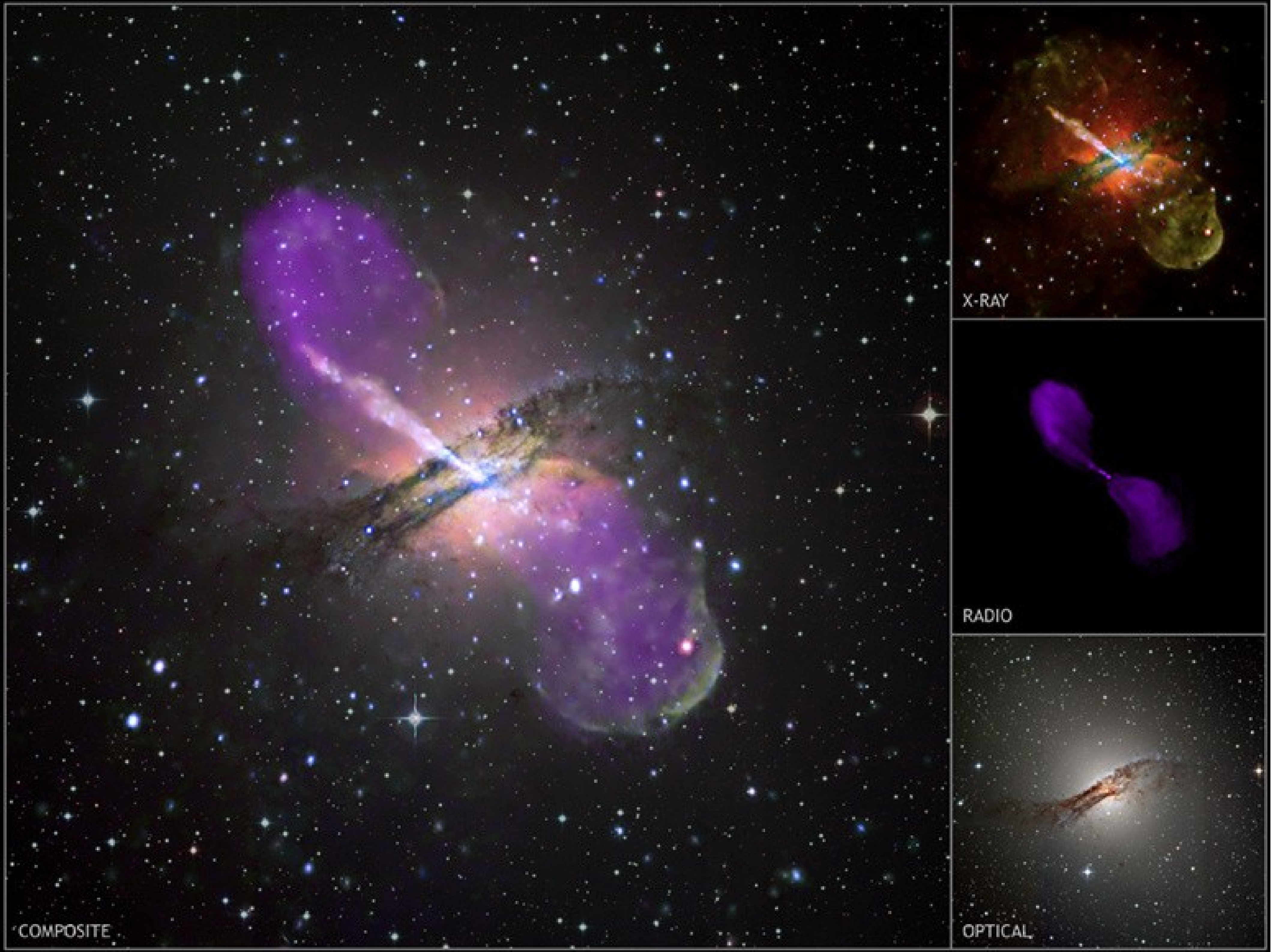
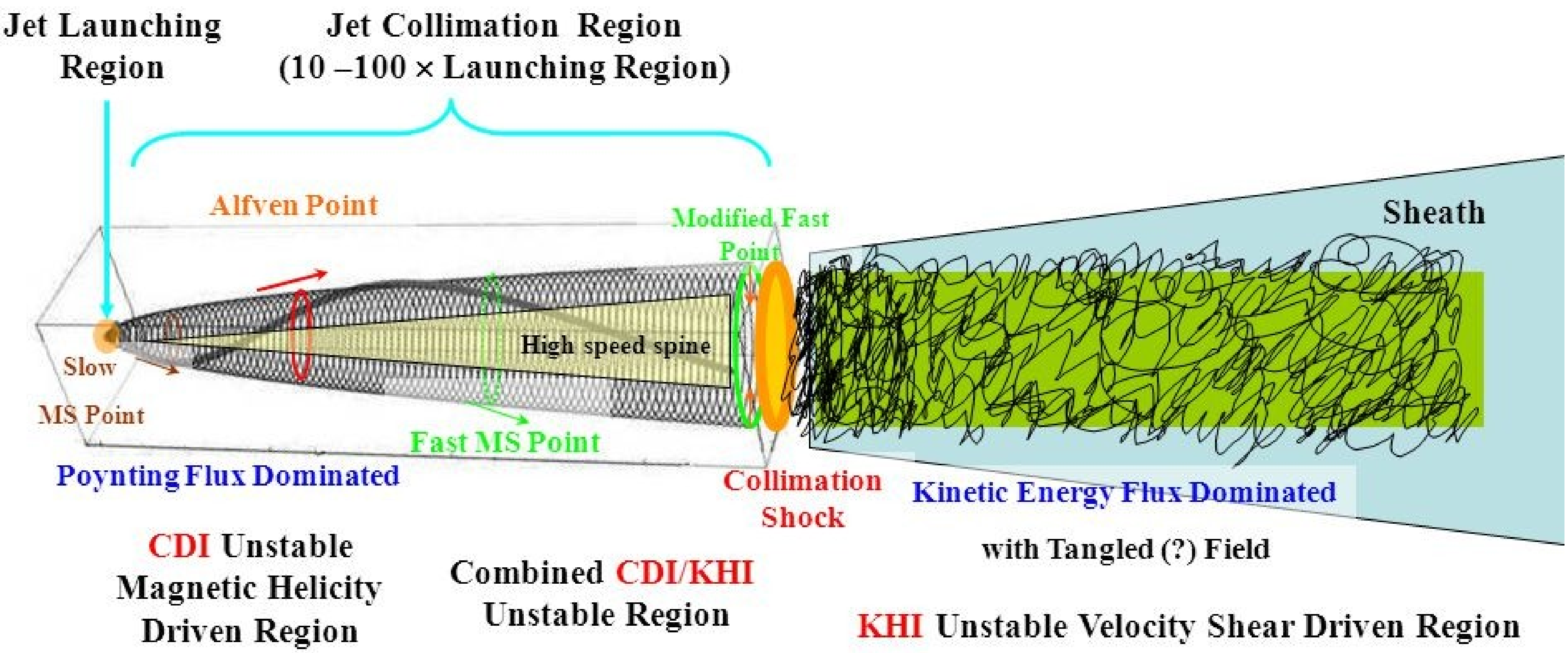

X-RAY
RADIO
OPTICAL
COMPOSITE

Going really deep into blazar jets



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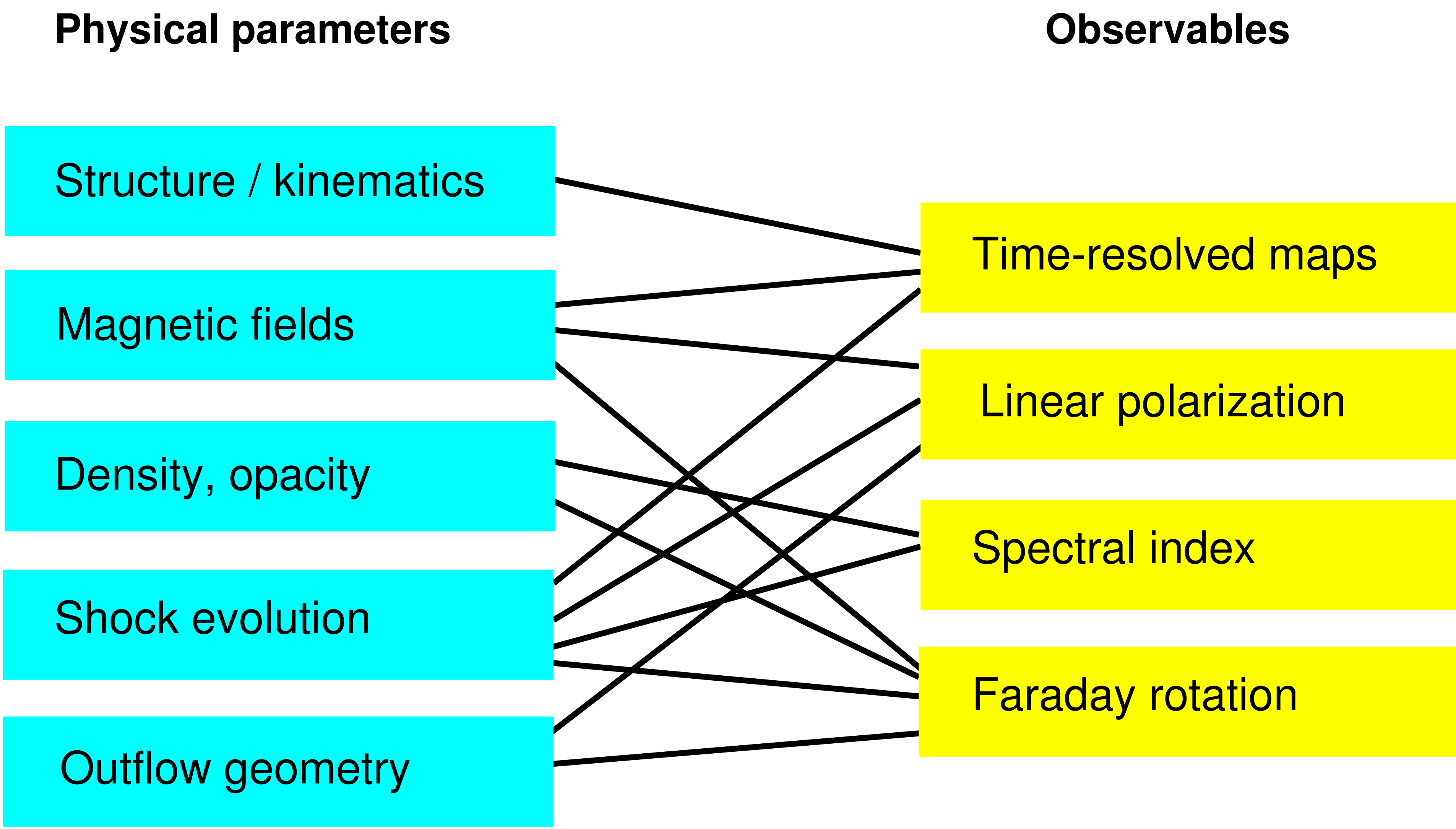
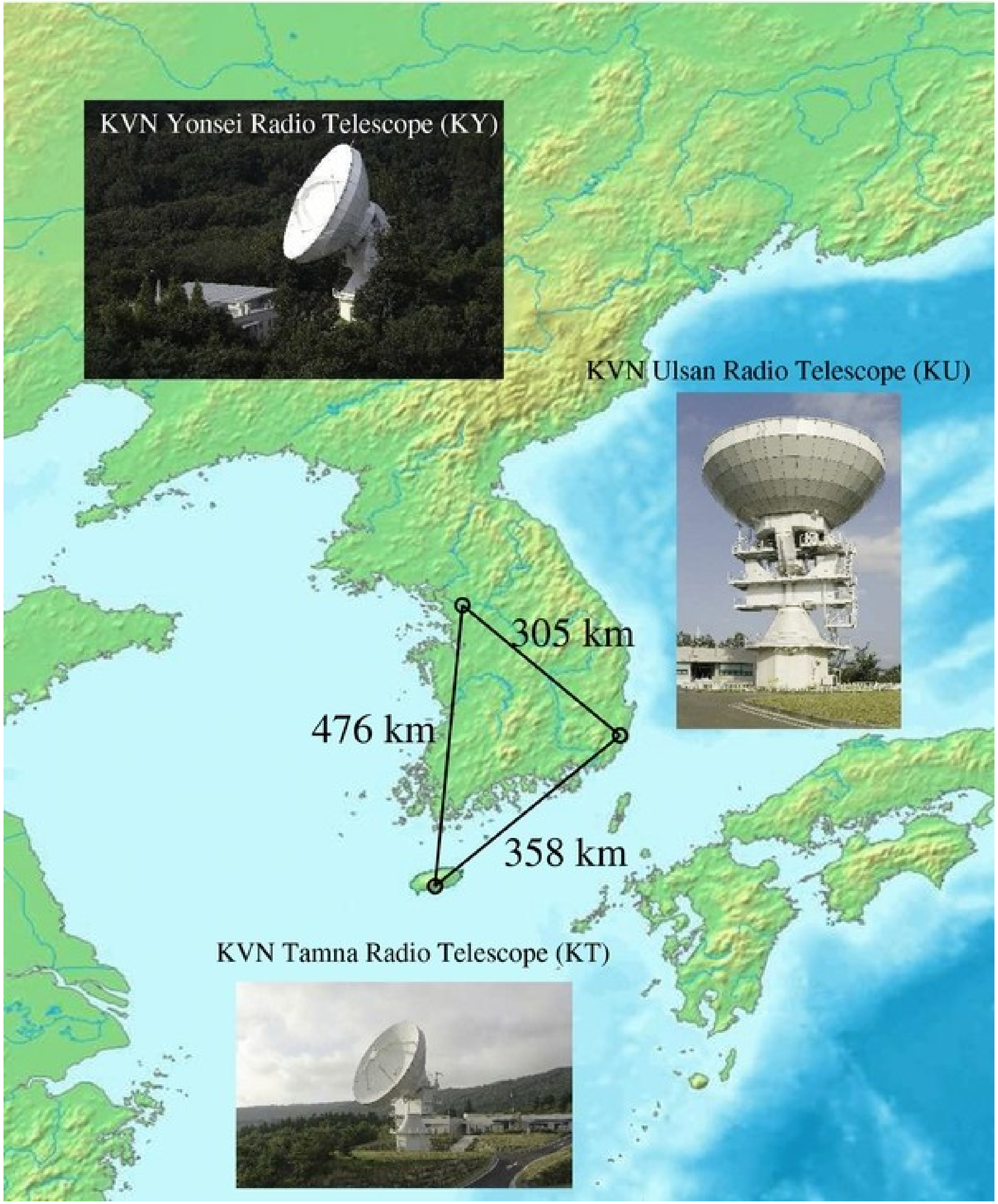
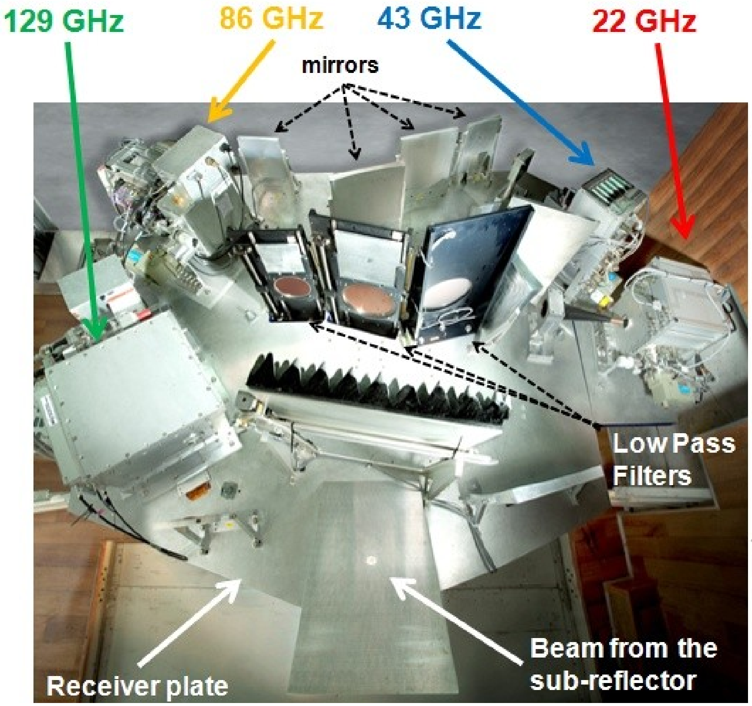
AGN plasma-physics



The Korean VLBI Network (KVN)



- Three 21-m antennas
- Full bandwidth 256 MHz
- Simultaneous observations at 22, 43, 86, 129 GHz
- Full polarization observations at two frequencies simultaneously



Target selection criteria

1. Total and polarized emission should be bright enough to be detected by KVN.

Polarized emission should be detectable at least at 86 GHz.

2. γ-ray emitters: all targets are monitored by Fermi-LAT

(to probe the connection γ-ray $\leftrightarrow$ radio flux and polarization)

3. Cover both quasars (FSRQs) and BL Lacs (for source type statistics)

Final target selection needed some trial and error

Observations so far

p16st01i (22 & 86 GHz), p16st01j (43 & 129 GHz) / Dec 9, 10 (2016)

p17st01a (22 & 86 GHz), p17st01b (43 & 129 GHz) / Jan 16, 17

p17st01c (22 & 86 GHz), p17st01d (43 & 129 GHz) / Feb 26, 27

p17st01e (22 & 86 GHz), p17st01f (43 & 129 GHz) / Mar 22, 23

p17st01g (22 & 86 GHz), p17st01h (43 & 129 GHz) / Apr 21, 22

p17st01i (22 & 86 GHz), p17st01j (43 & 129 GHz) / Jun 1, 2

p17st02a (22 & 86 GHz), p17st02c (43 & 129 GHz) / Sep 24, 25

p17st02d (22 & 86 GHz), p17st02e (43 & 129 GHz) / Oct 25, 26

p17st02f (22 & 86 GHz) , p17st02g (43 & 129 GHz) / Nov 17, 18

In 2017: 24 hrs x 2 days x 8 months = total 384 hrs

(3 more observing days coming in December)

Final list of targets

Quasars: 8

3C 279 (z~0.158)

3C 345 (z~0.538)

3C 273 (z~0.595)

3C 454.3(z~0.859)

NRAO530 (z~0.902)

CTA102 (z~1.037)

NRAO150 (z~1.51)

1633+38 (z~1.814)

BL Lacs: 5

BL Lac (z~0.069)

0716+714 (z~0.3)

OJ287 (z~0.306)

1749+096 (z~0.322)

0235+164 (z~0.94)

Radio galaxies: 1

3C 84 (z~0.018)

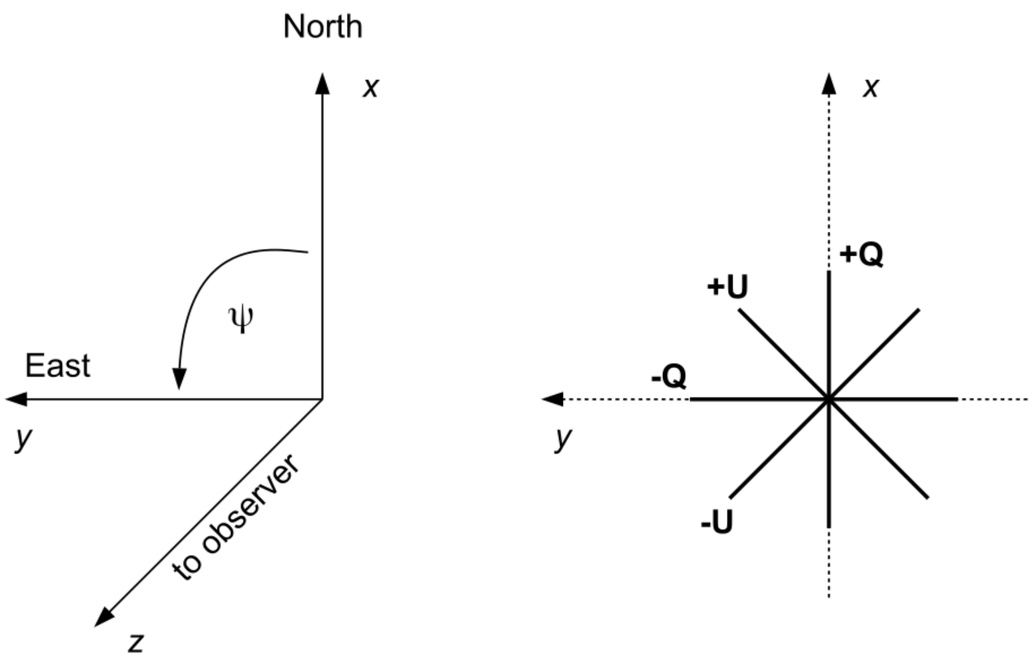
Total: 14 sources

	DEC (9)	JAN (9)	FEB (11)	MAR (11)	APR (16)	JUN (10)
3C84	O	O	O	O	O	O
3C273	O	O	O	O	O	O
3C279	O	O	O	O	O	O
OJ287	O	O	O	O	O	O
3C454.3	O	O	O	O	O	O
CTA102	O	O	O		O	O
3C345	O	O	O		O	
1510-089	O	O	O	O	O	O
1749+096	O	O	O	O		O
BLLAC			O	O	O	
1055+018			O	O	O	
1611+343					O	
1633+382				O		
0235+164				O	O	O
NRAO 530					O	
0716+714					O	O
3C120					O	
0336-019					O	

K, Q, W

K, Q, W, D

The Stokes parameters



Trigonometric notation

$$
\begin{aligned}
I &= \langle E_R^2 \rangle + \langle E_L^2 \rangle \\
Q &= 2\,\langle E_R E_L \cos\delta' \rangle \\
U &= 2\,\langle E_R E_L \sin\delta' \rangle \\
V &= \langle E_R^2 \rangle - \langle E_L^2 \rangle
\end{aligned}
$$

Complex exponential notation

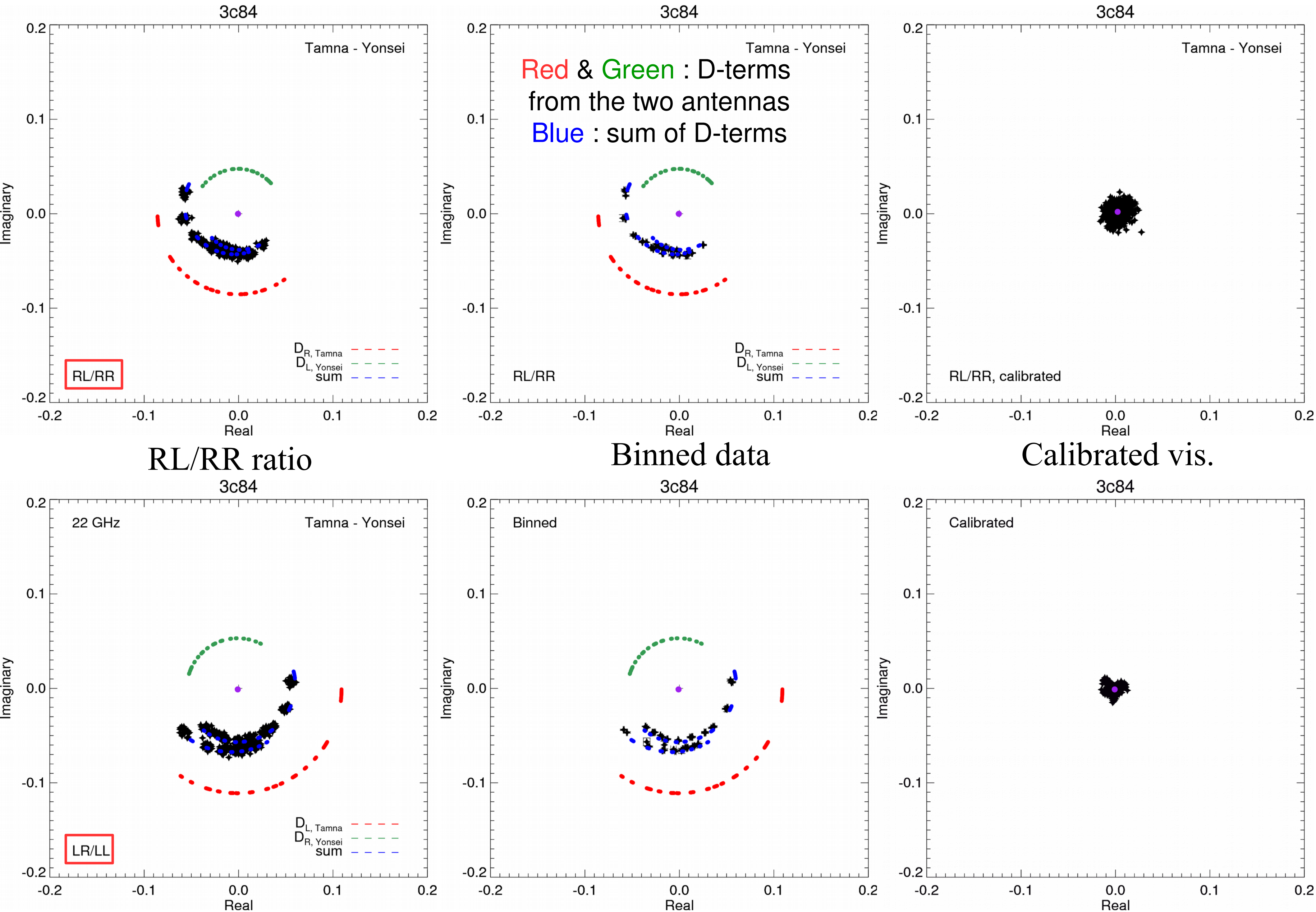
Total intensity

Linear polarization

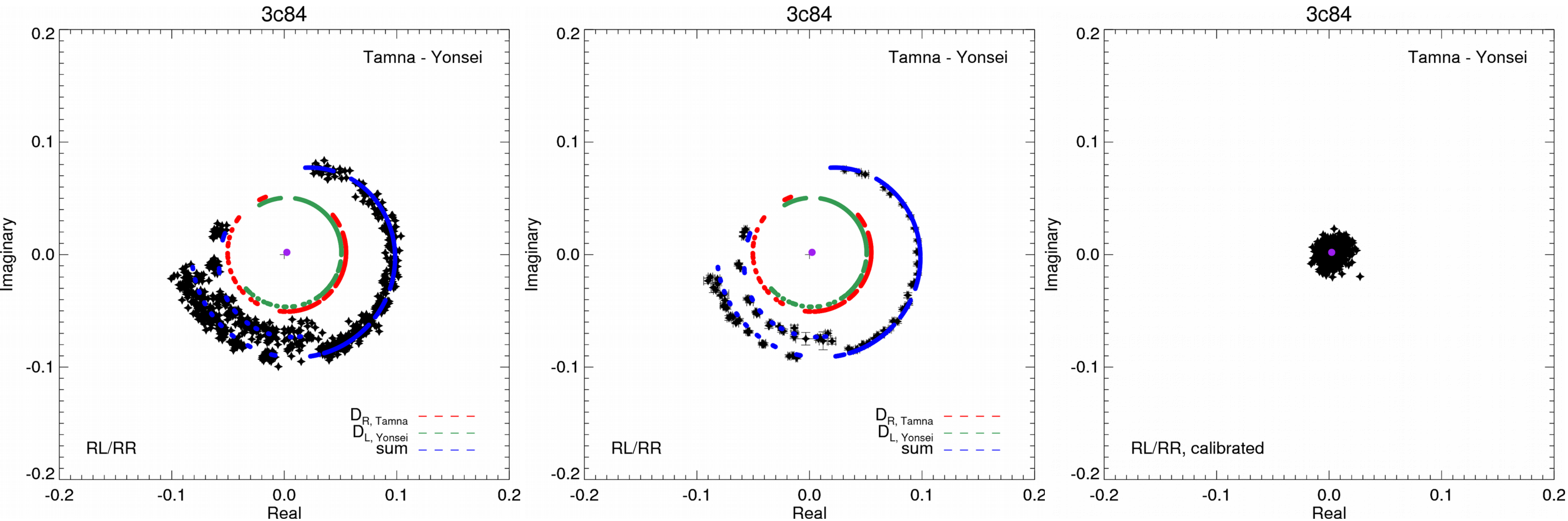
Circular polarization

$$
\begin{aligned}
I &= \langle E_R E_R^* \rangle + \langle E_L E_L^* \rangle \\
Q &= \langle E_R E_L^* \rangle + \langle E_L E_R^* \rangle \\
U &= -i\,[\langle E_R E_L^* \rangle - \langle E_L E_R^* \rangle] \\
V &= \langle E_R E_R^* \rangle - \langle E_L E_L^* \rangle\ .
\end{aligned}
$$

D-Term correction: 22 GHz, 3C 84



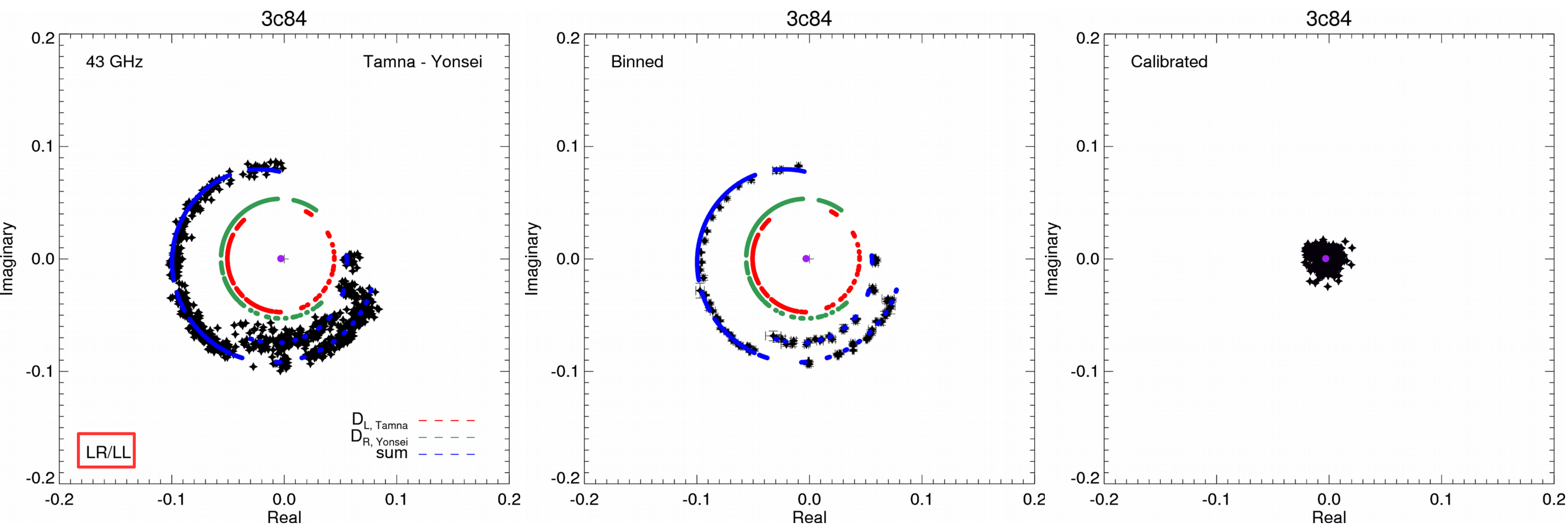
D-Term correction: 43 GHz, 3C 84



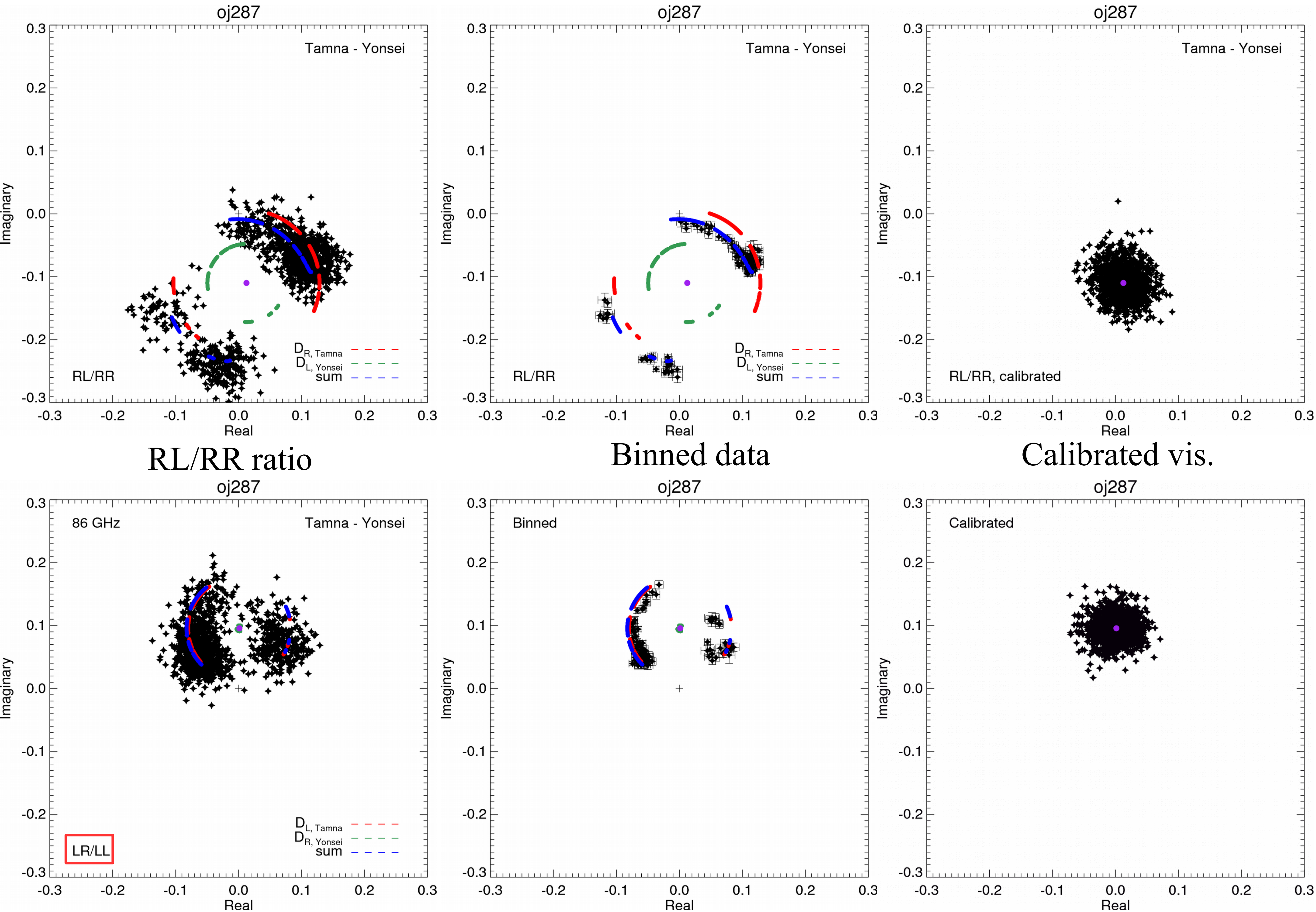
RL/RR ratio

Binned data

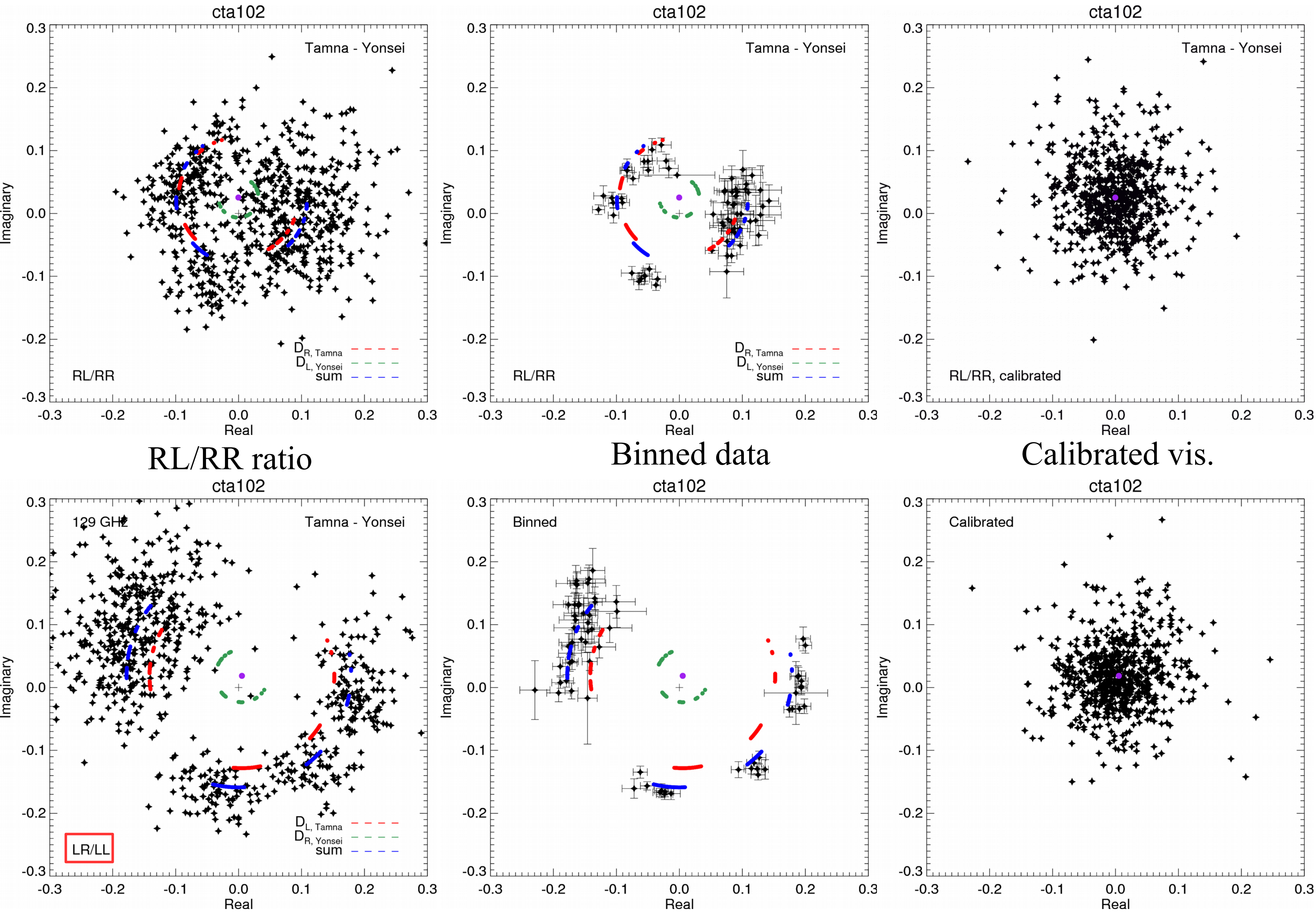
Calibrated vis.



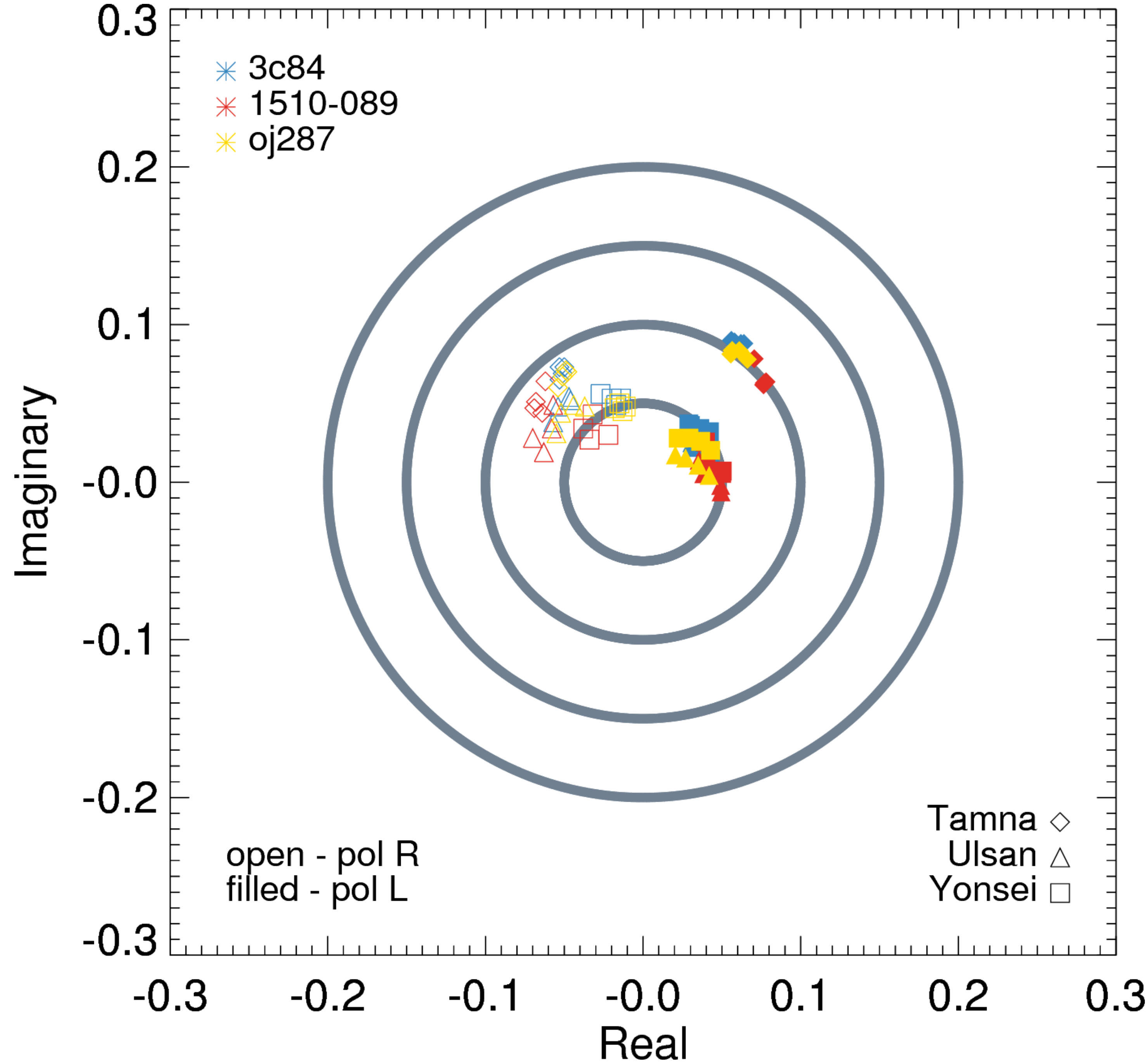
D-Term correction: 86 GHz, OJ 287



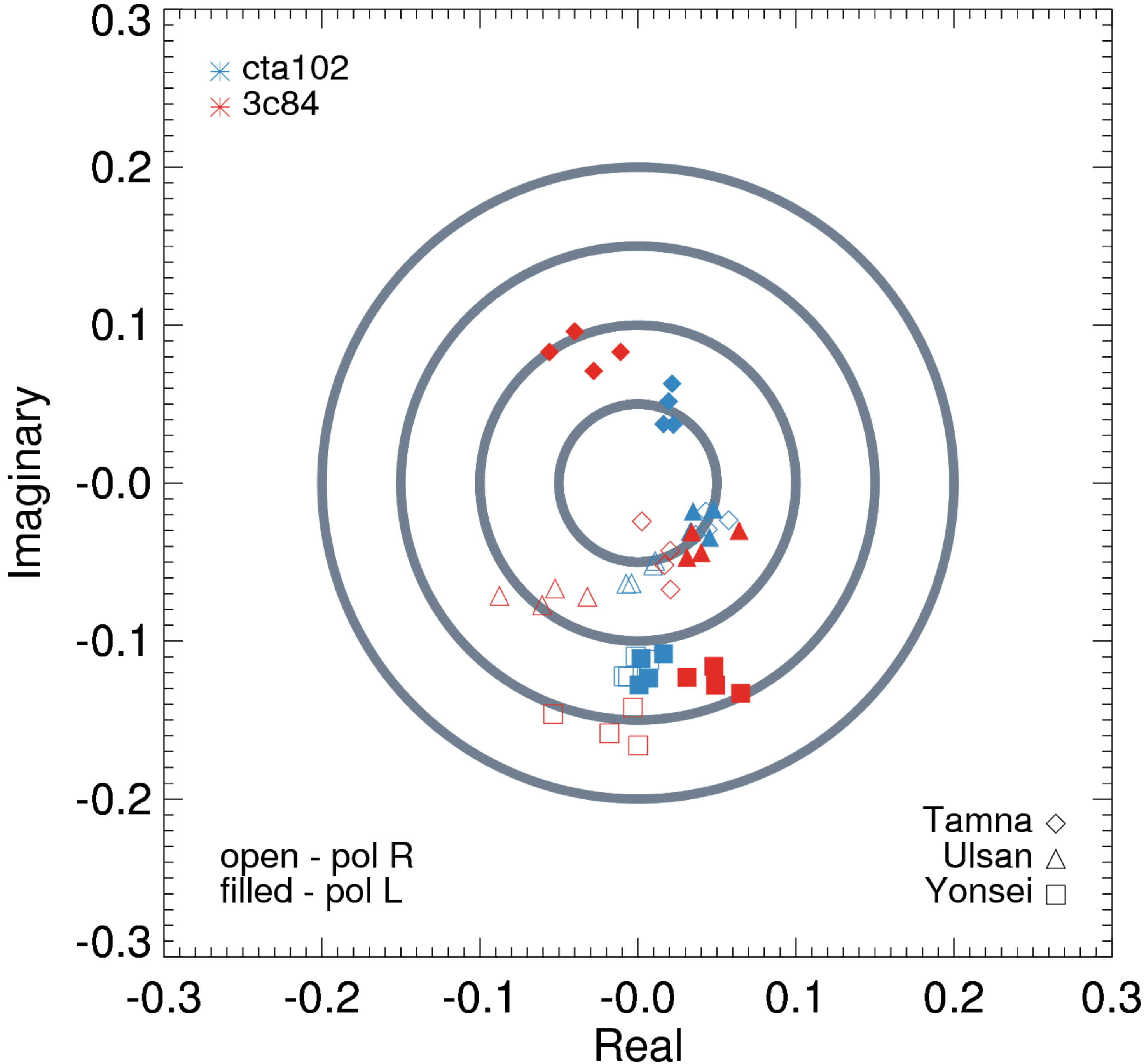
D-Term correction: 129 GHz, CTA 102



D-Term accuracy – 22 GHz

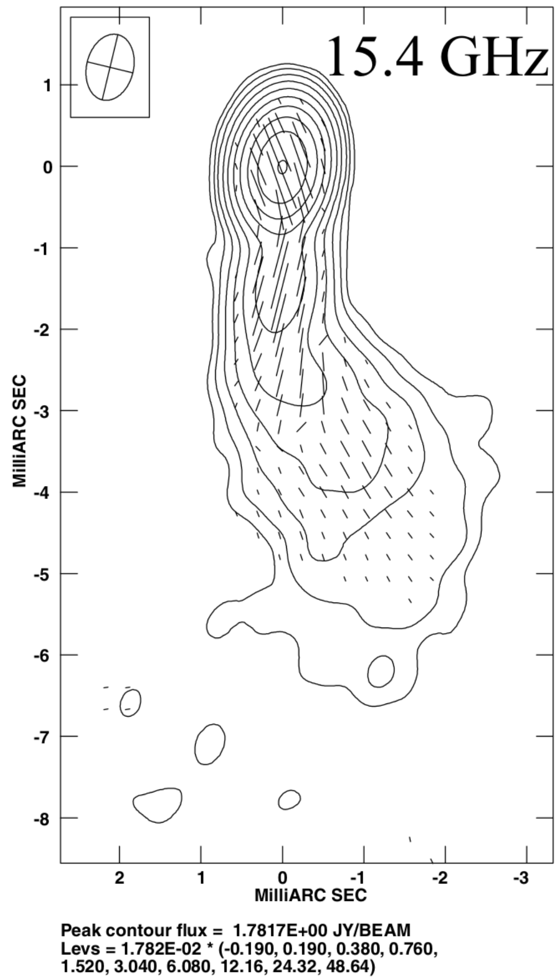


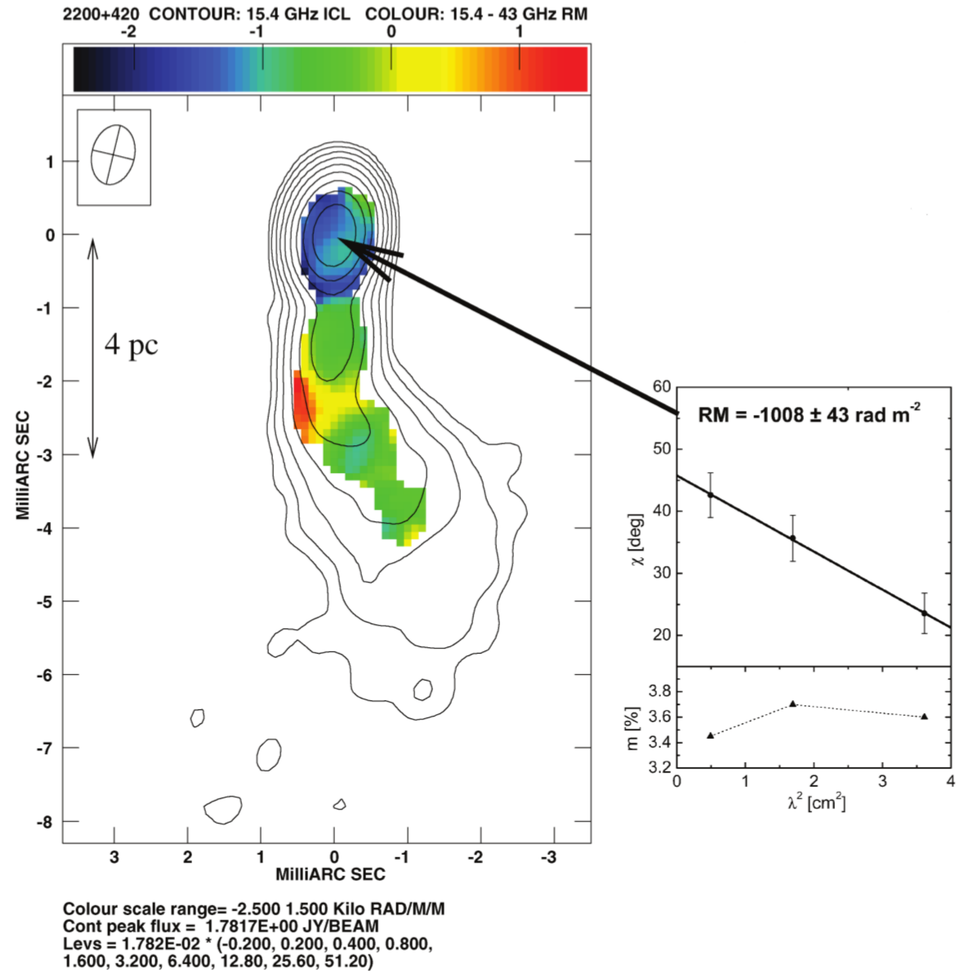
D-Term accuracy – 129 GHz



Faraday rotation

O'Sullivan & Gabuzda (2009a)





$$\text{(observed angle)} = \text{(intrinsic angle)} + \text{(rotation measure)} \times \text{(wavelength)}^2$$

$$\text{(rotation measure)} \propto \int_{\text{l.o.s.}} \text{(l.o.s. magnetic field strength)} \times \text{(electron density)} \times \text{d(path)}$$

Rotation measure in VLBI cores (jet bases)

Rotation measures in the jet base of AGN increase as function of observing frequency:

$$\mathrm{RM} \propto \int N_e B_\| dl$$

$$l \propto d$$

Conical geometry

$$N_e \propto d^{-a}$$

$$B_\| \propto d^{-1}$$

Dominated by B_Φ

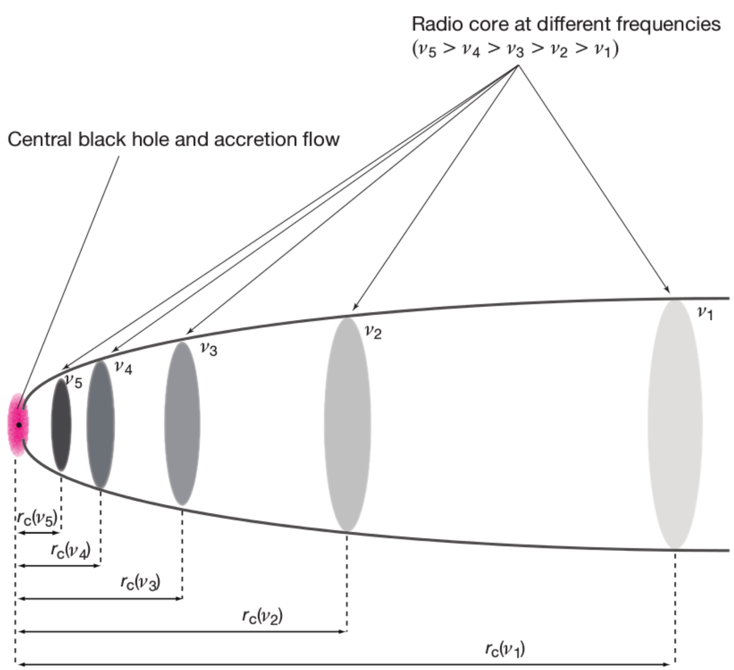
Power-law assumption;
$a = 2$: Conical or
Spherical Jets

$$B_z \propto d^{-2} \qquad B_\phi \propto d^{-1}$$

Prediction of helical
B-field geometry

$$|\mathrm{RM}| \propto d^{-a}$$

"Core-shift"



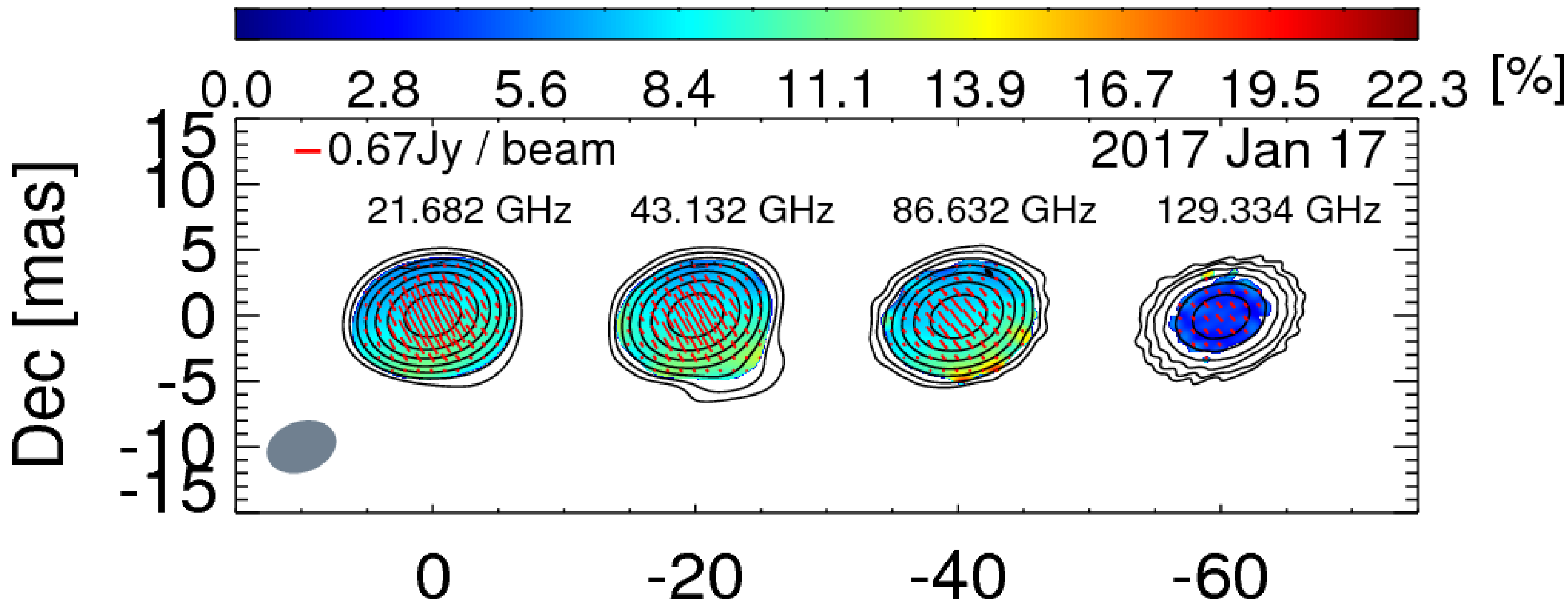
$$d_{\mathrm{core},\nu} \propto \nu^{-1}$$

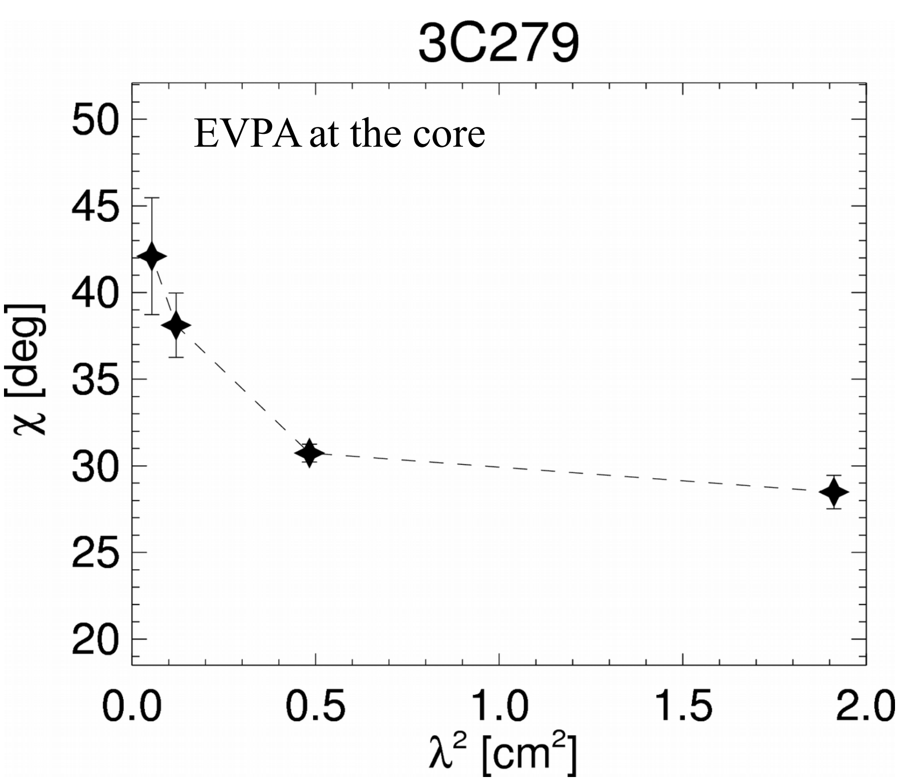
$$|\mathrm{RM}_{\mathrm{core},\nu}| \propto \nu^{a}$$

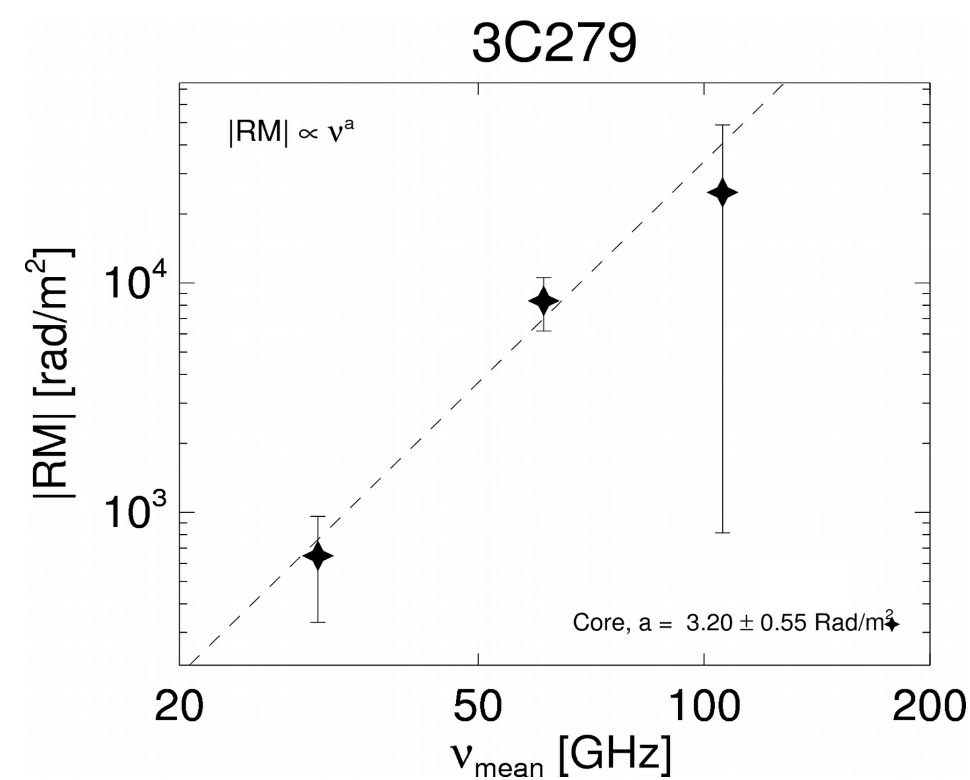
$a = 0.9 \sim 3.8$: O'Sullivan & Gabuzda 2009
$a \sim 1.8$: Jorstad et al. 2005
$a \sim 1.9$: Trippe et al. 2012
$a \sim 3.6$: Algaba et al. 2013

→ indicates that B-field and particle density increase as one goes "deep" into the jets.

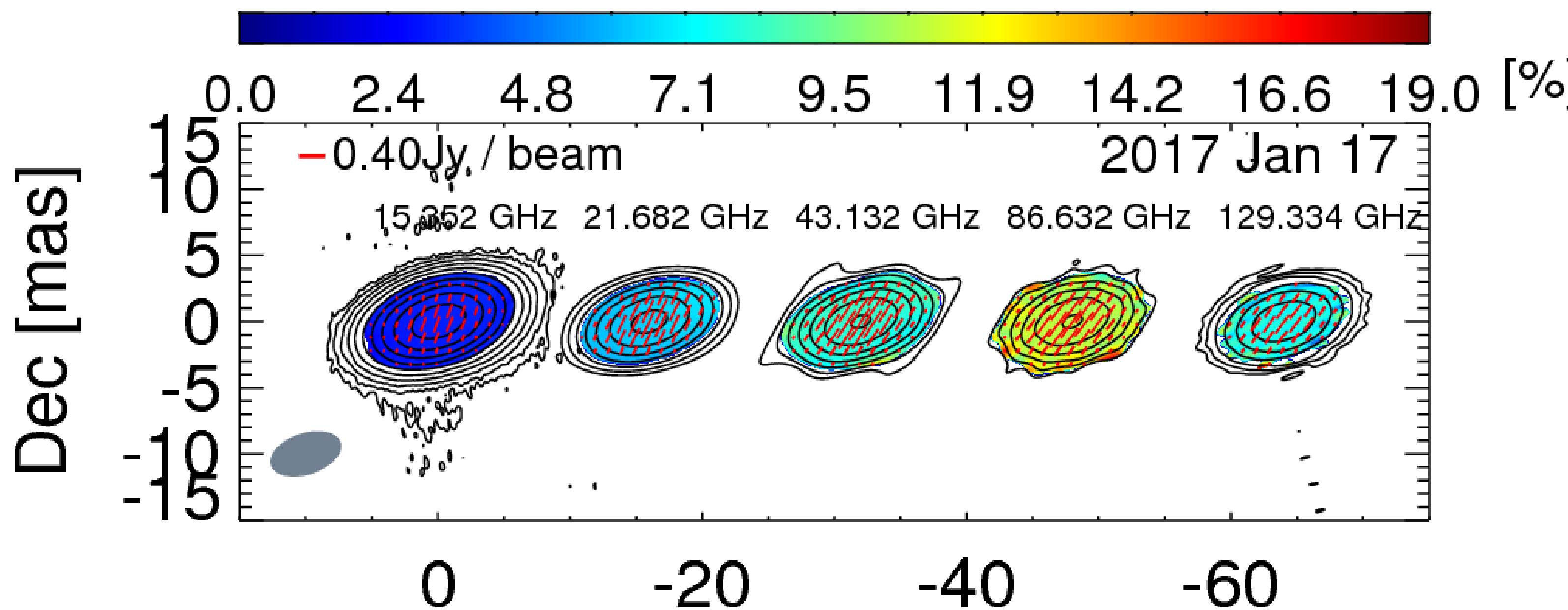
KVN polarization maps: 3C 279

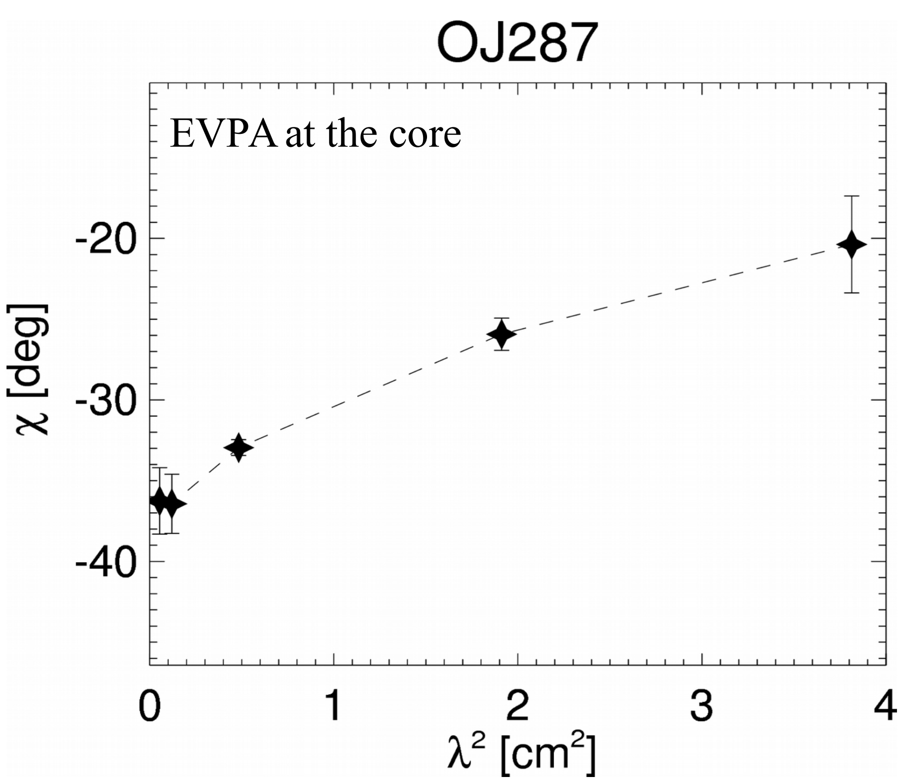


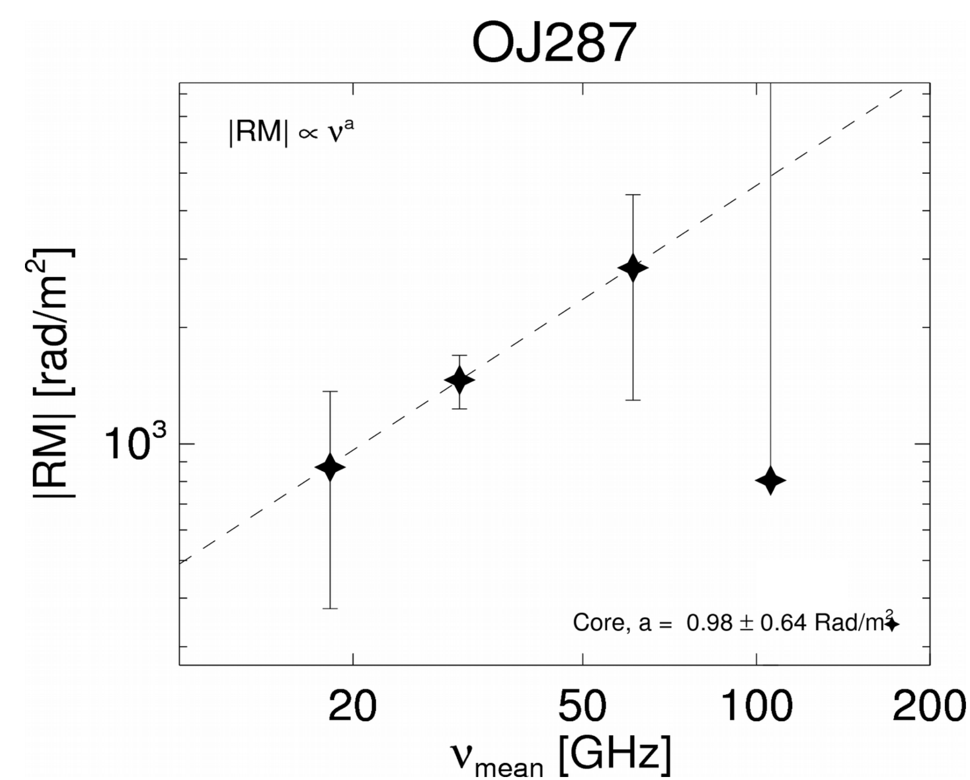




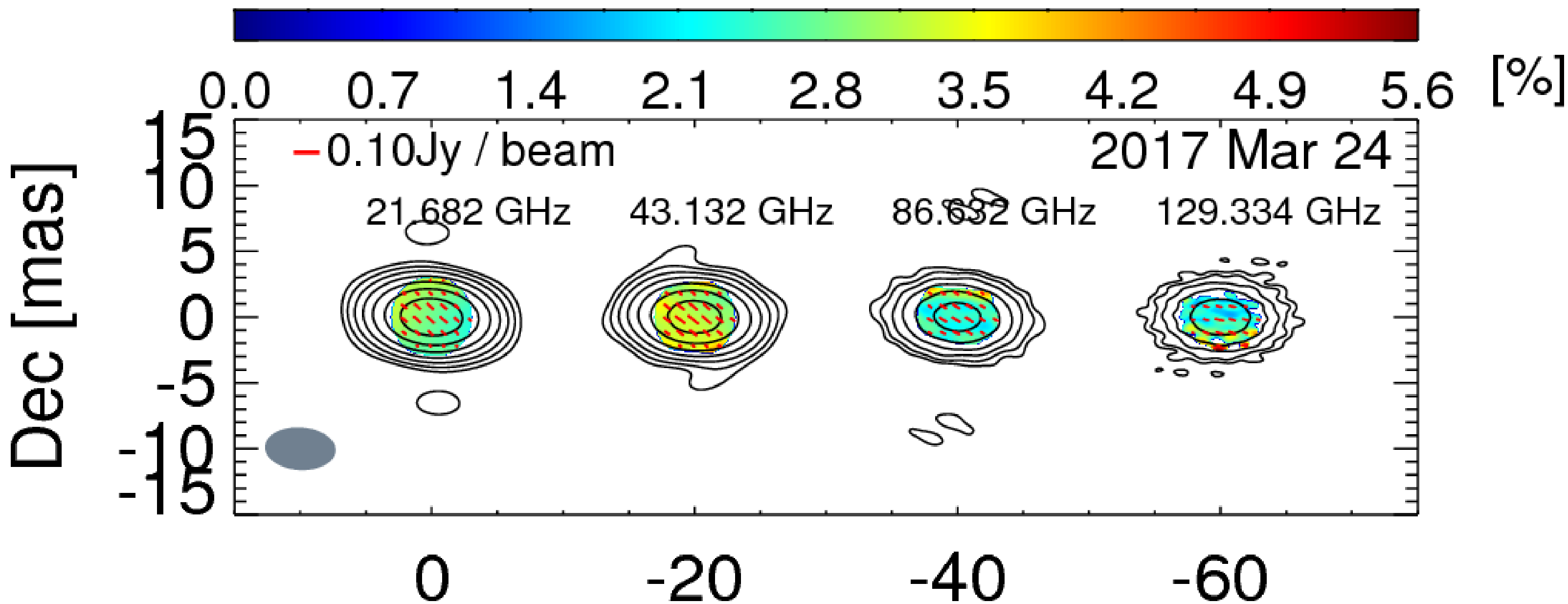
KVN polarization maps: OJ 287

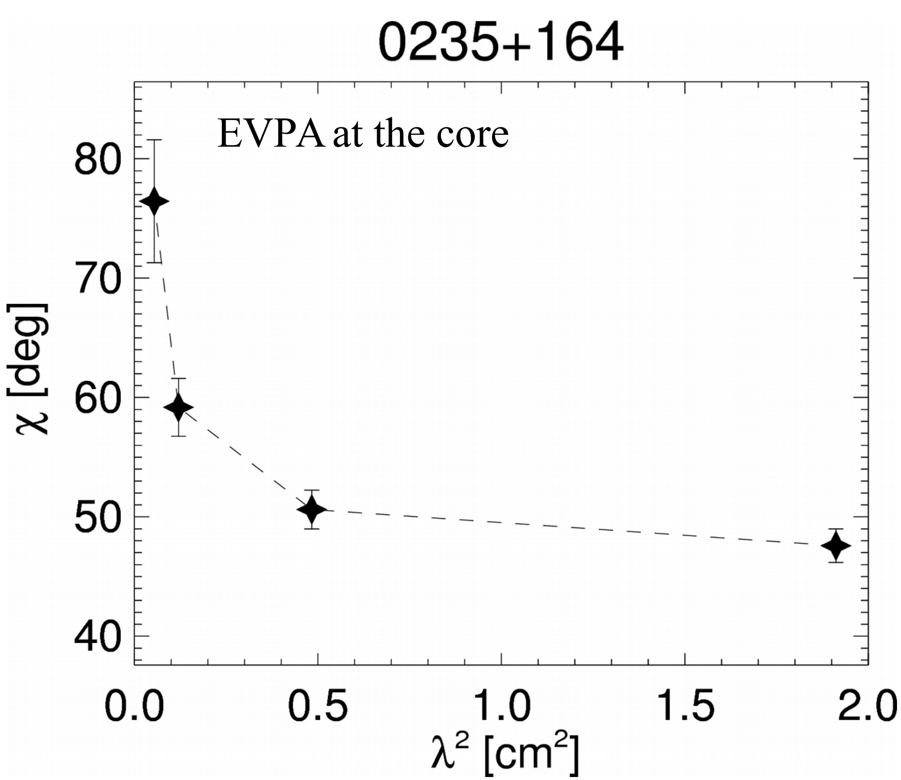


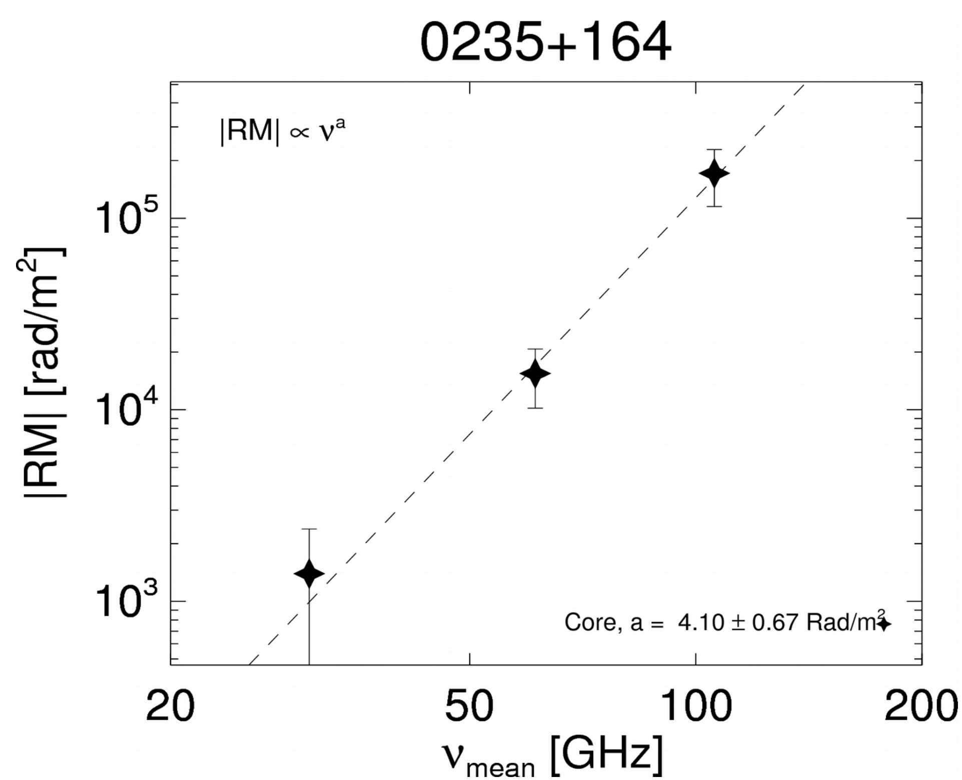




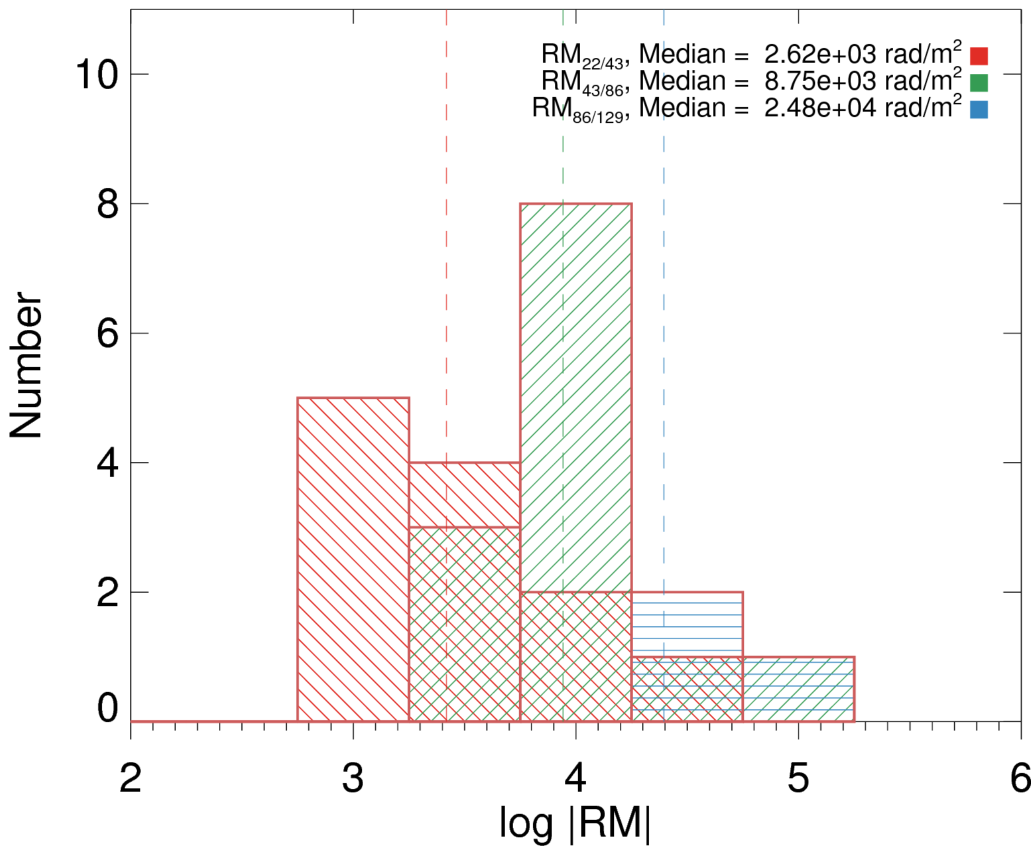
KVN polarization maps: 0235+164

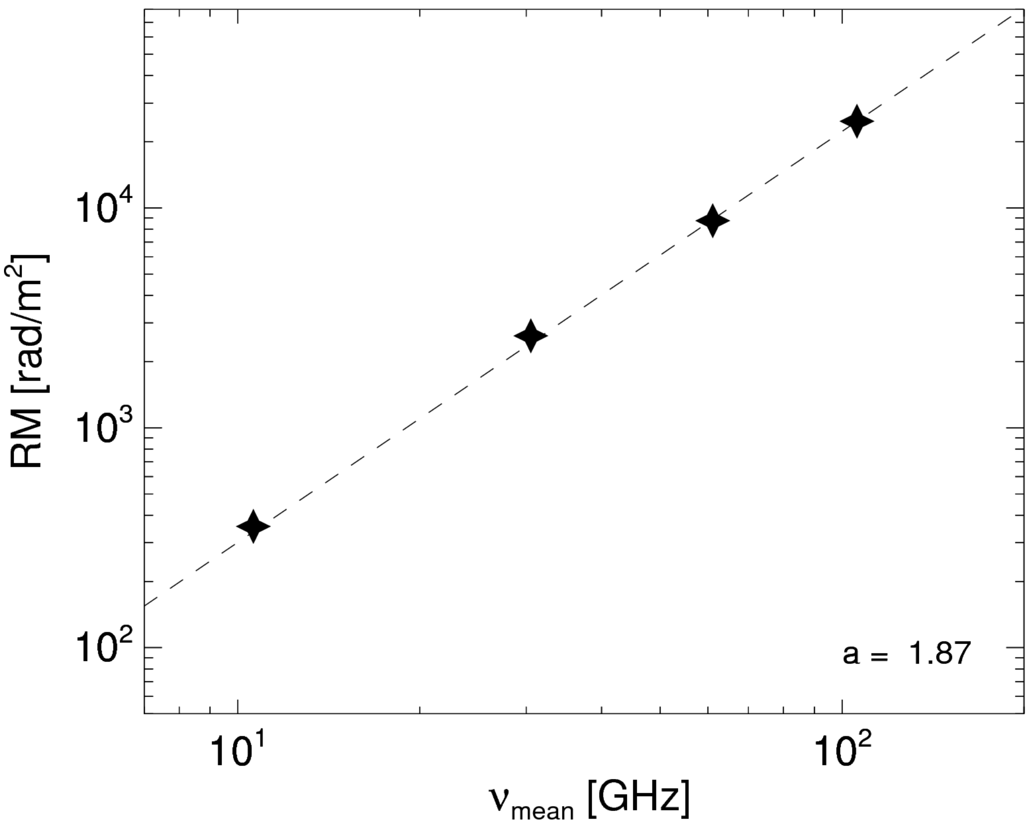




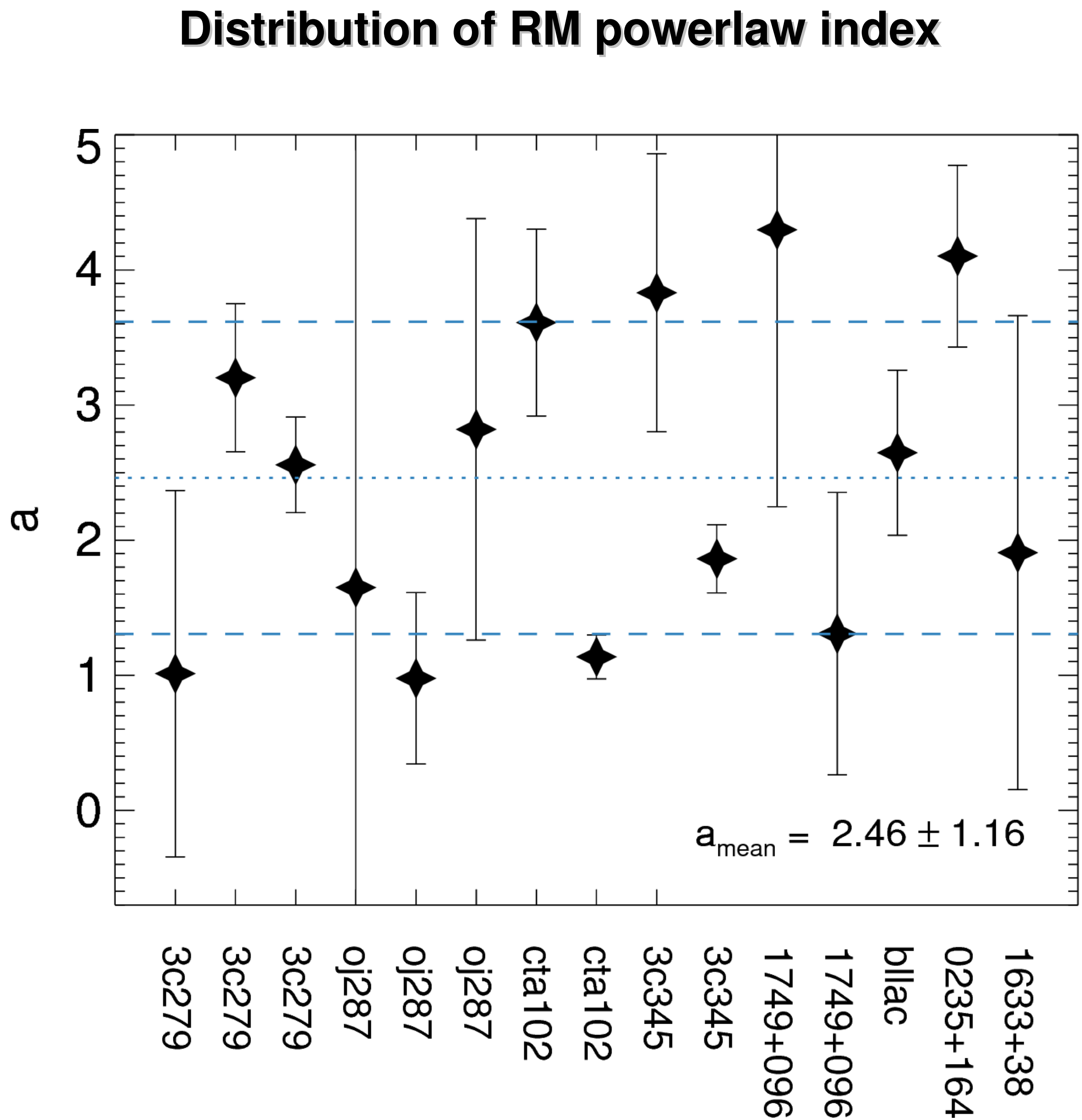


Median rotation measure as function of frequency

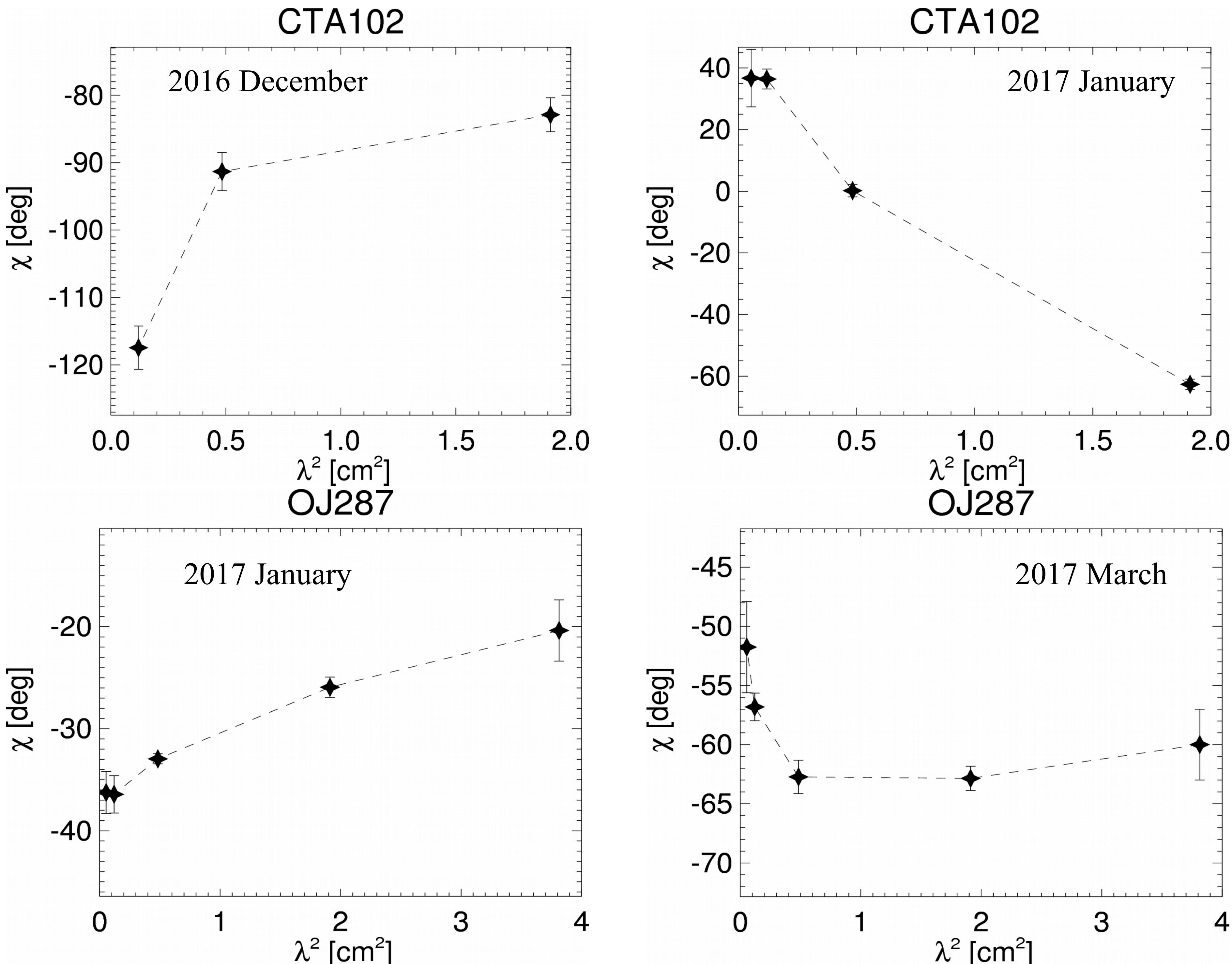




$$\mathrm{RM} \propto \nu^{a}$$

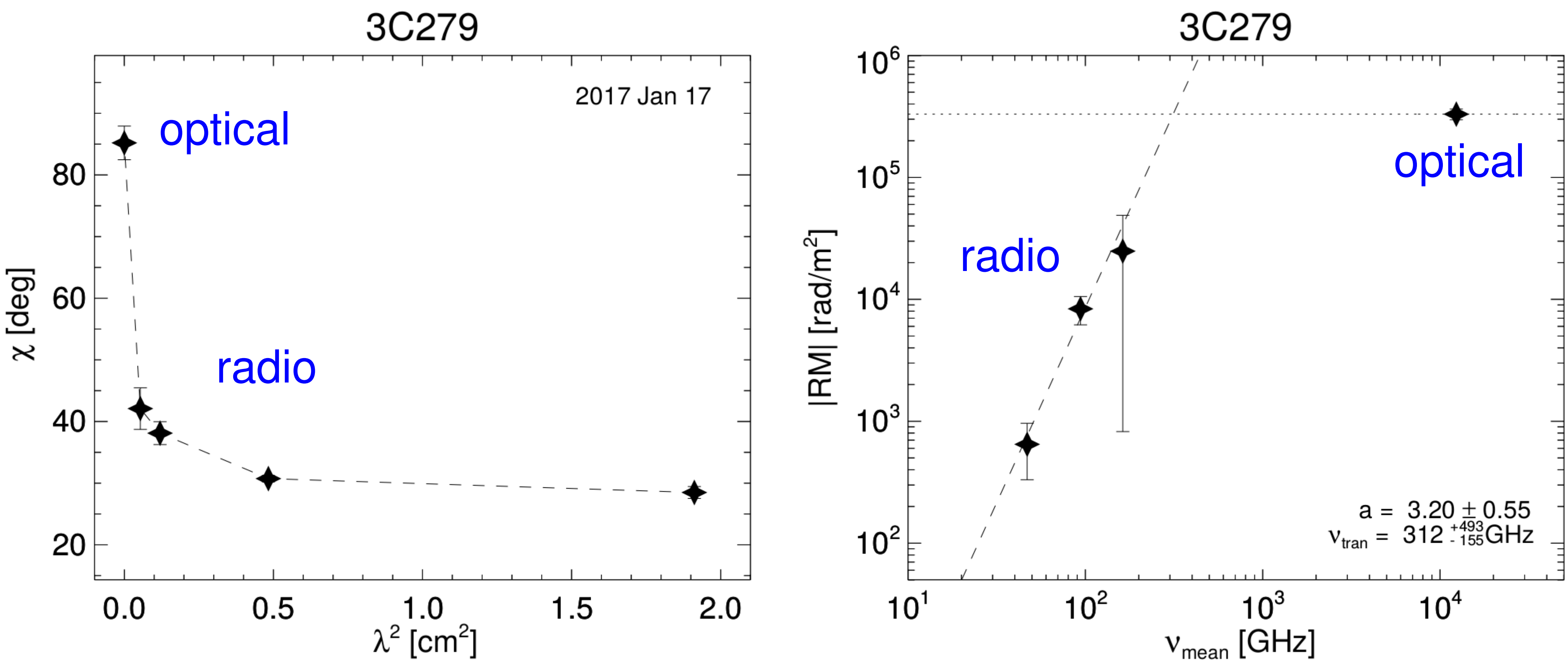

Distribution of RM powerlaw index
a
5
4
3
2
1
0
a_{mean} = 2.46 ± 1.16
3c279
3c279
3c279
oj287
oj287
oj287
cta102
cta102
3c345
3c345
1749+096
1749+096
bllac
0235+164
1633+38

RM signs can change within a few months



RM seems to saturate at high frequencies

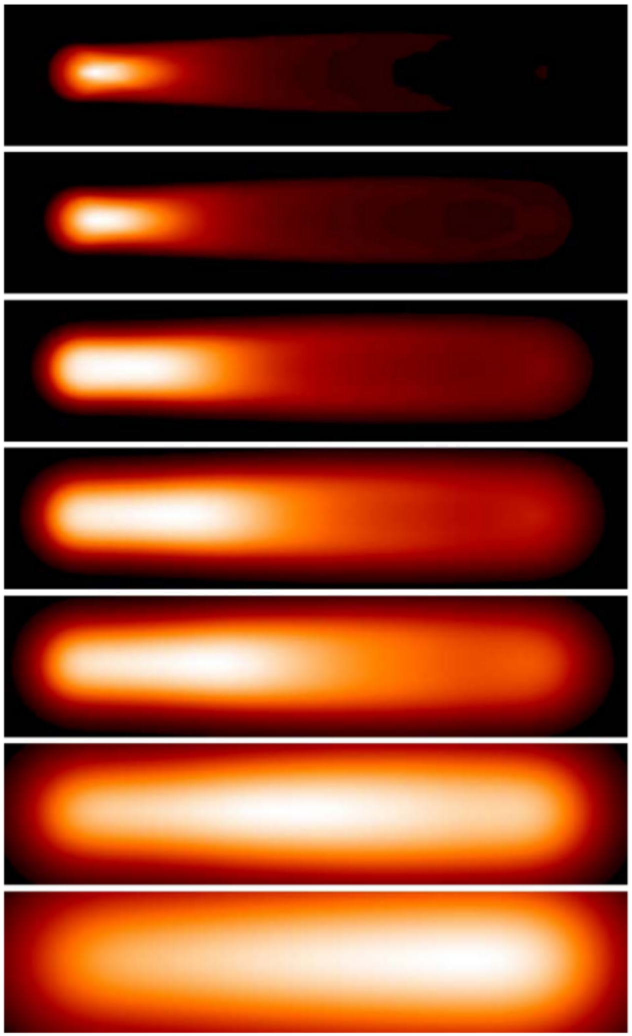
Optical data: Steward Observatory monitoring program



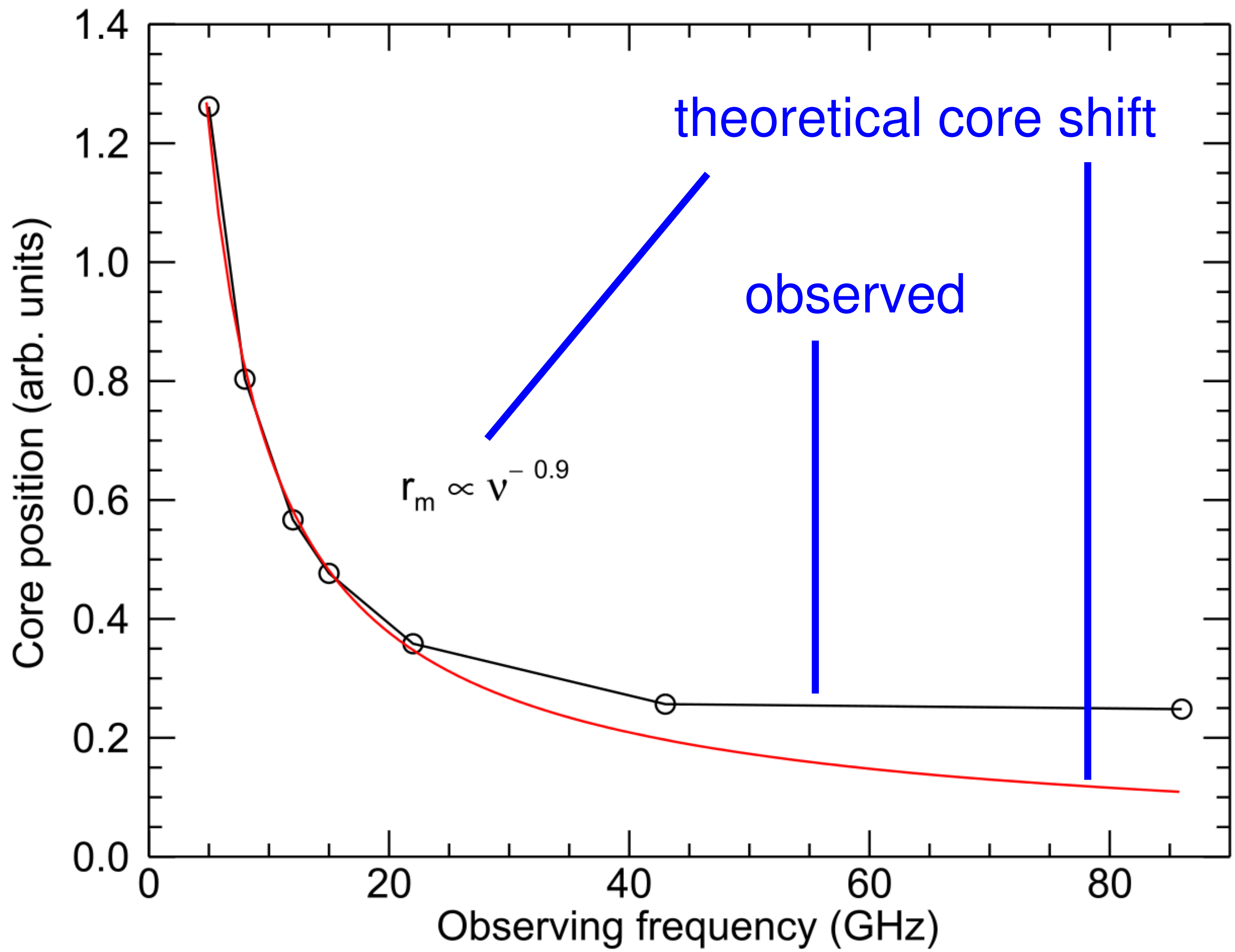
The radio core as re-collimation shock

The case of BL Lac

Simulation



Core shift data

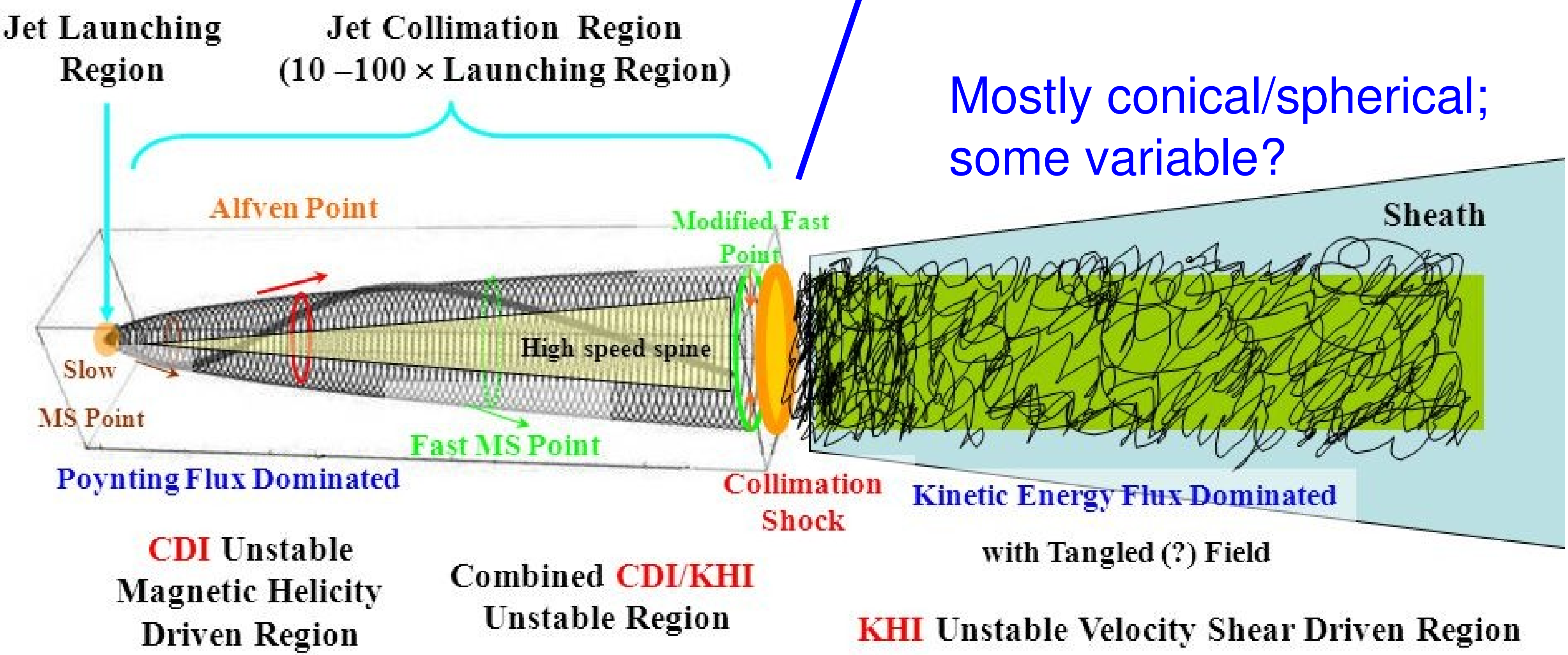


Dodson+ (2017); also: Kim+ (2017)

Going really deep into blazar jets

Visible at (sub)mm?

Mostly conical/spherical; some variable?



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Summary

- We started a systematic KVN polarimetric monthly monitoring campaign of 14 radio-loud AGN
- Observed levels of polarizations are up to about 30% (in 3C 273)
- Faraday rotation measures are of order 10^3 to 10^5 rad/m^2 and increase with frequency, can be highly variable in a given source
- RM–frequency scaling laws have power law indices *a* of order 2, consistent with conical/spherical outflows, but seem to be variable
- Saturation of RM might point toward the radio cores becoming optically thin at (sub)mm, cores could be re-collimation shocks