Jets, Shocks, and Magnetic Fields: AGN Polarization with KVN

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The PAGaN Collaboration

Plasma physics of Active Galactic Nuclei

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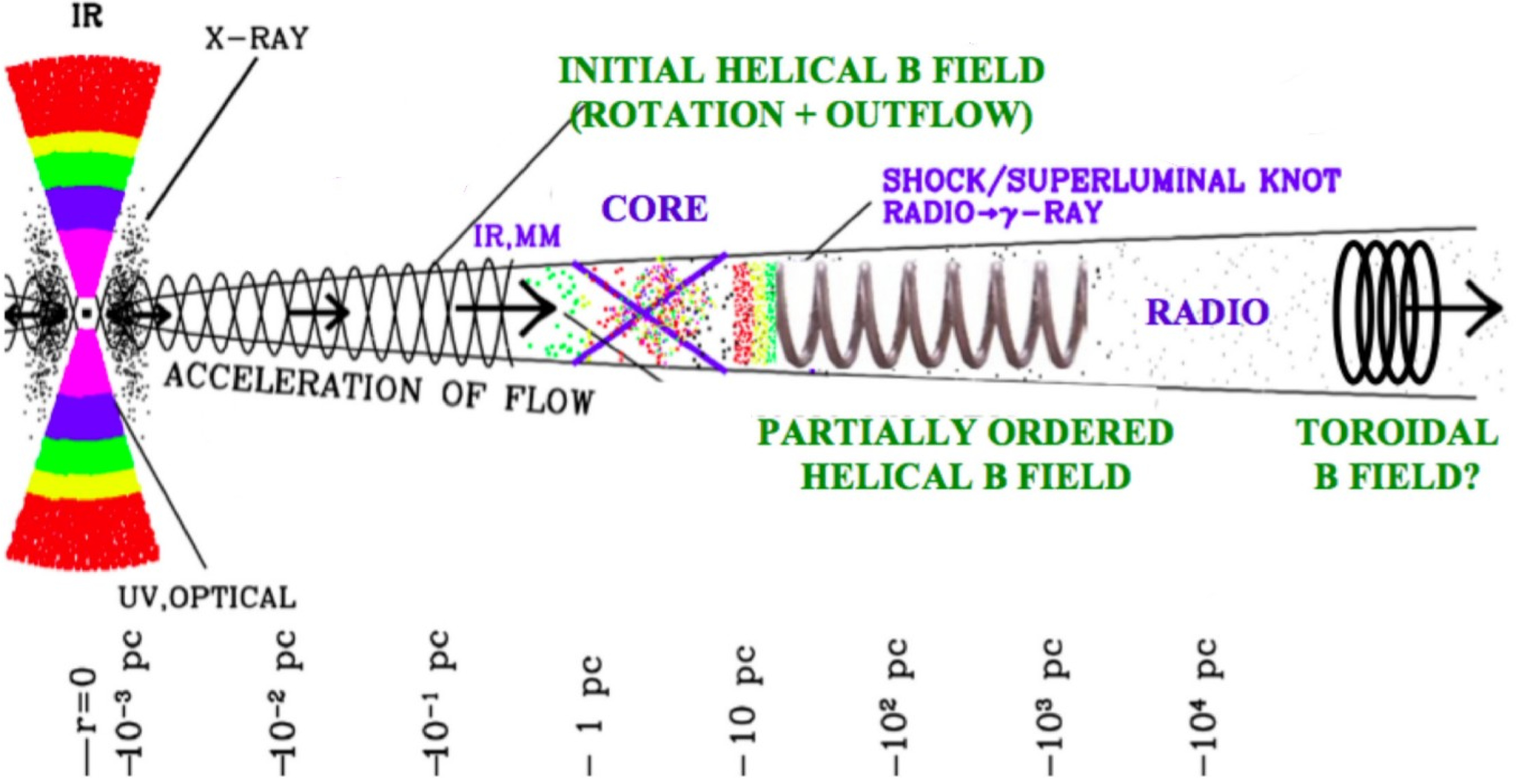
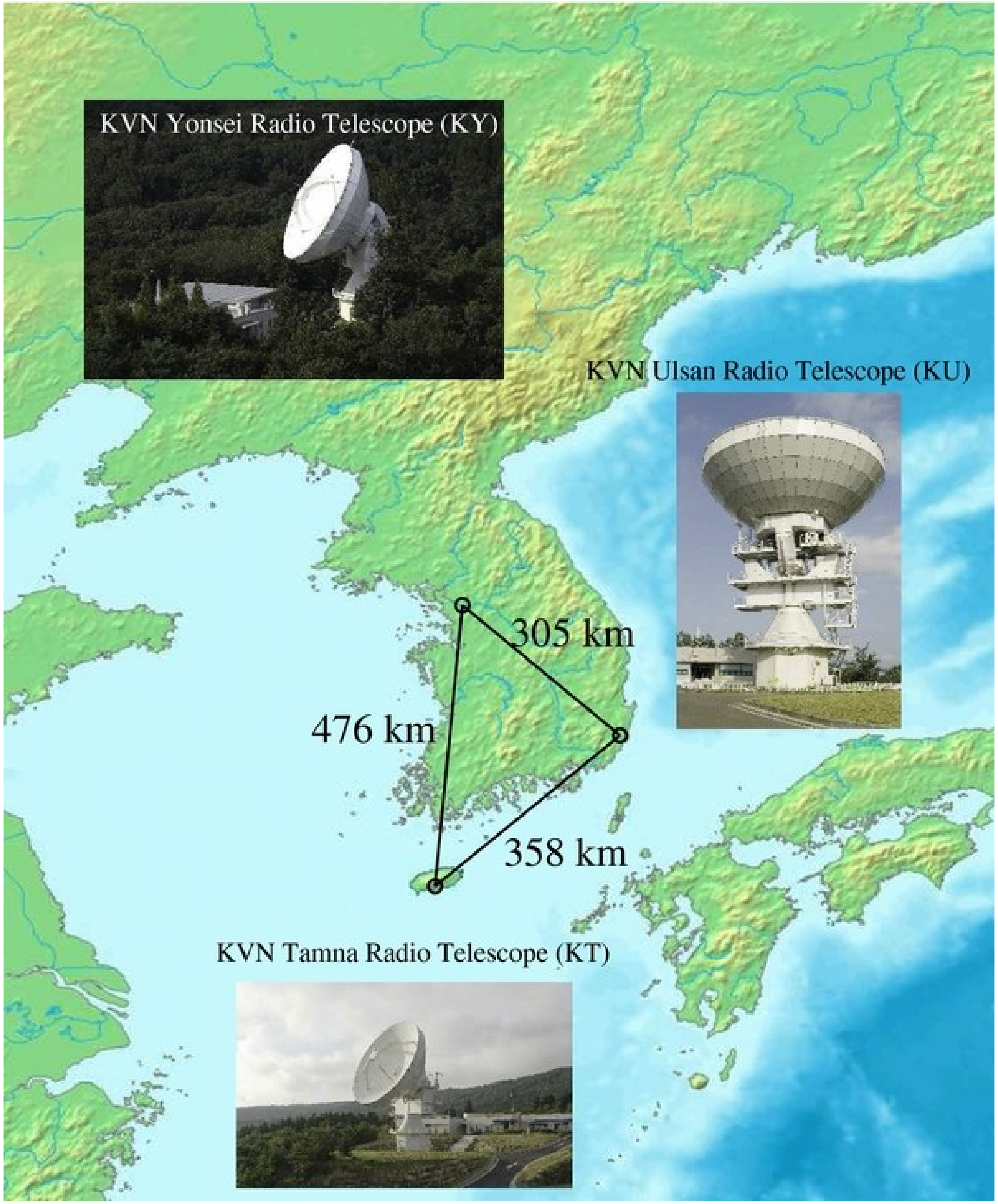
Blazar jets

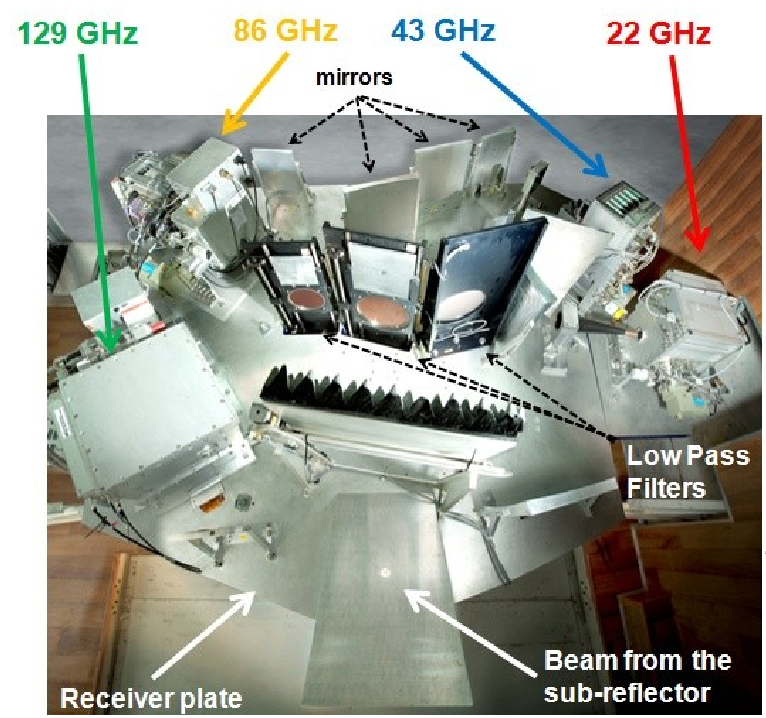


Gabuzda (2017)

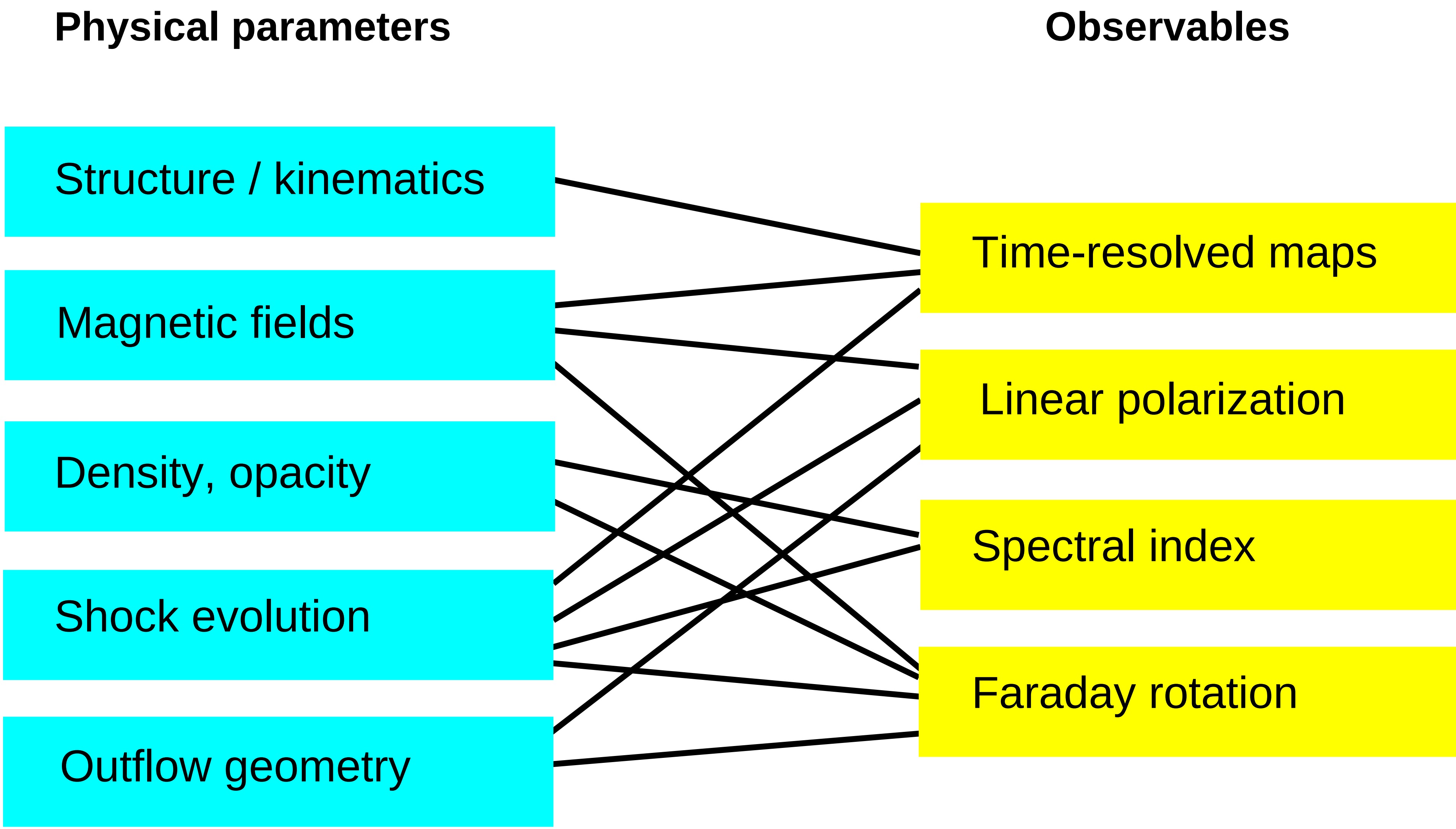
The Korean VLBI Network (KVN)



- Three 21-m antennas
- Full bandwidth 256 MHz – 4 GHz
- Simultaneous observations in 22, 43, 86, 129 GHz bands
- Full polarization observations at two frequencies simultaneously (circularly polarized receivers)



AGN plasma physics



PAGaN I

Scientific motivation:

Accretion, acceleration, collimation, propagation of AGN jets; probing AGN jet models

Technical motivation:

KVN provides multi-frequency full-polarization observations at high radio frequencies

PAGaN I:

Full polarization observations at pairs 22/43 and 86/129 GHz of a sample of 13 blazars + 1 RG, probing the internal structure and physical conditions of the inner jets via polarization distributions and Faraday rotation.

List of targets

Quasars: 8

3C 279 (z~0.158)

3C 345 (z~0.538)

3C 273 (z~0.158)

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)

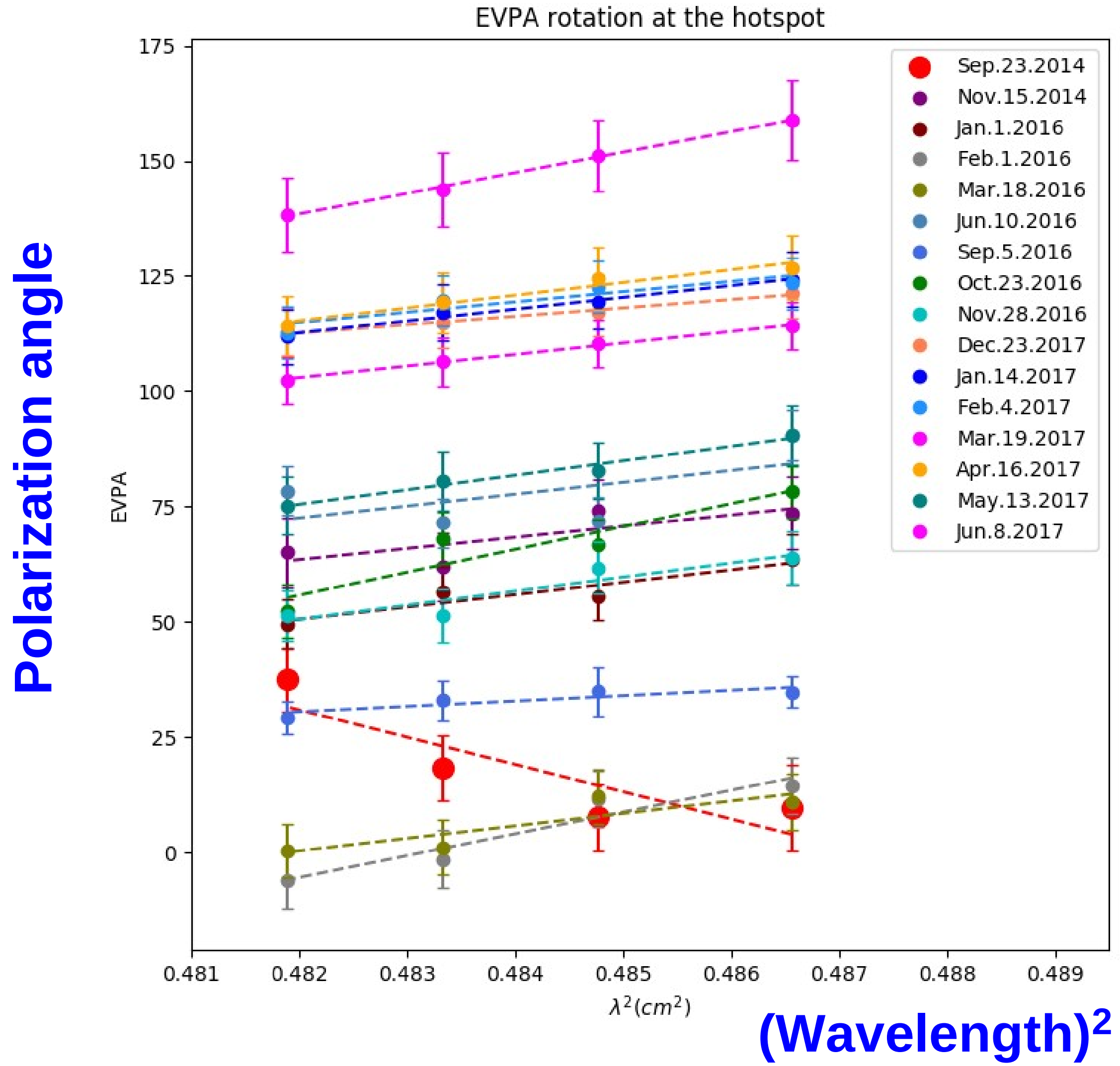
0235+164 (z~0.94)

Radio galaxies: 1

3C 84 (z~0.018)

Total: 14 sources with
– detected polarized flux at >86 GHz
– known γ-ray emission

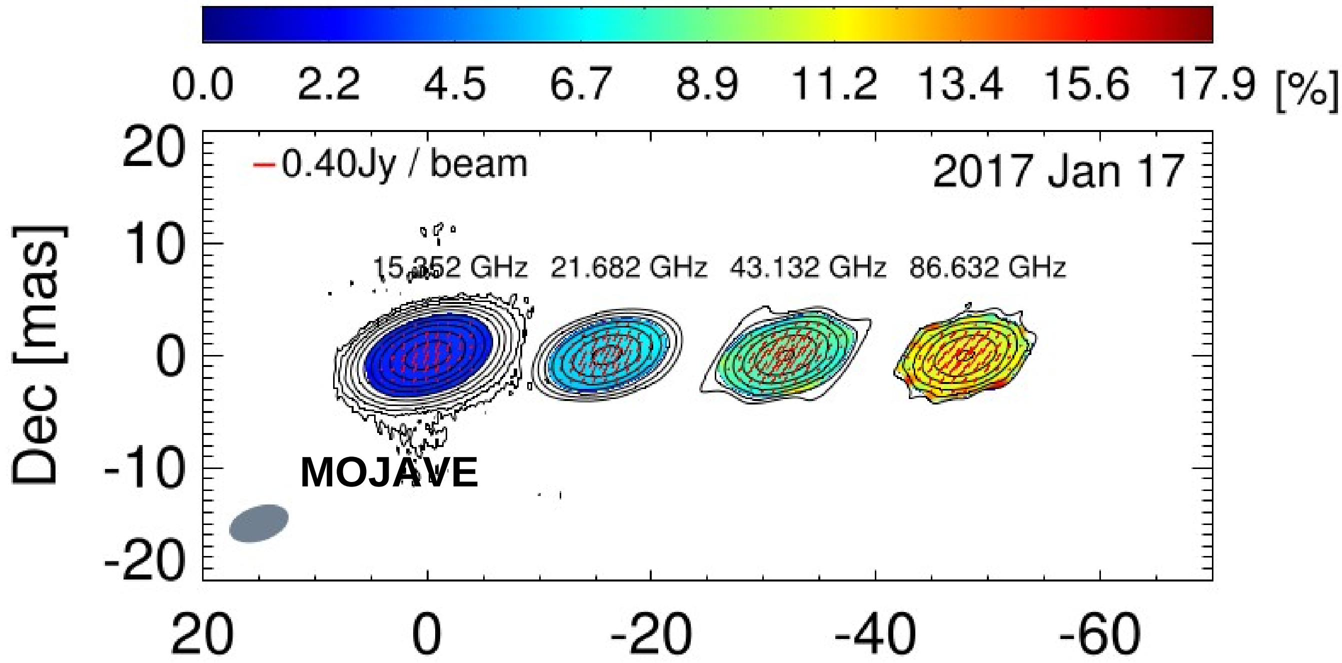
Faraday rotation

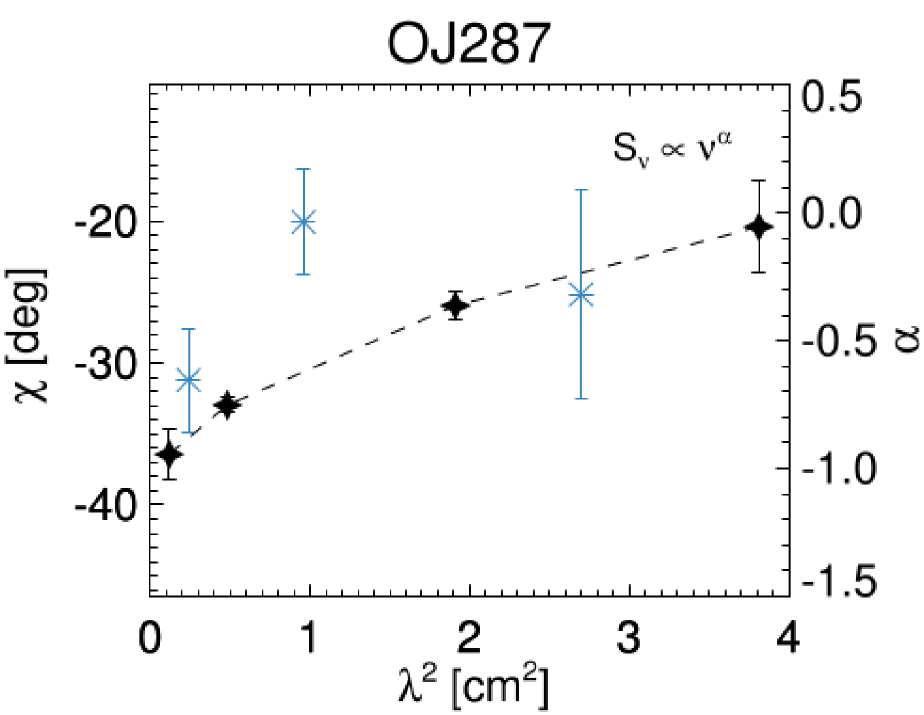


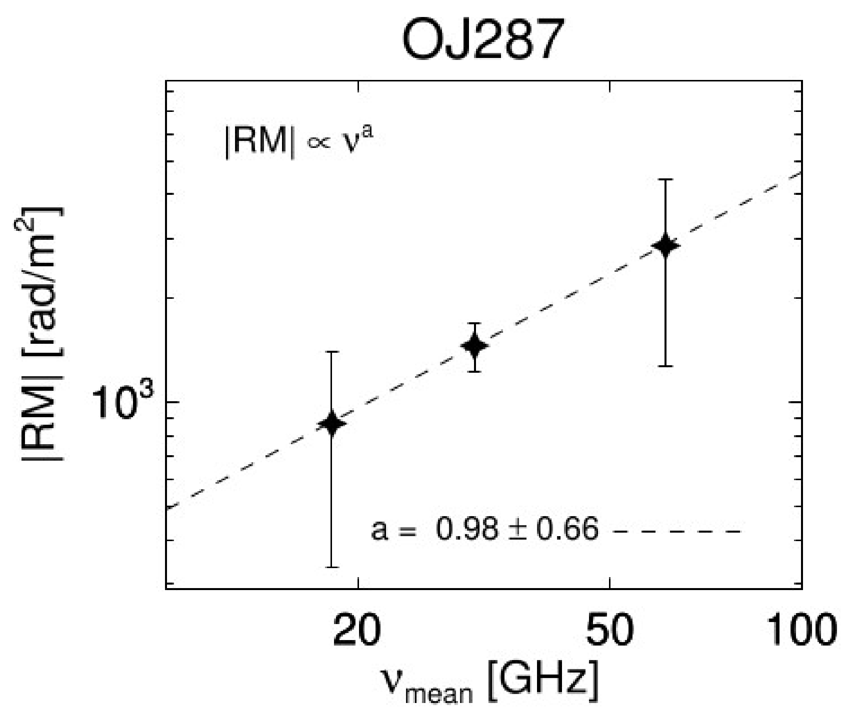
$$\text{(observed angle)} = \text{(intrinsic angle)} + \text{(rotation measure)} \times \text{(wavelength)}^2$$

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

AGN cores: KVN polarization maps (here: OJ 287)

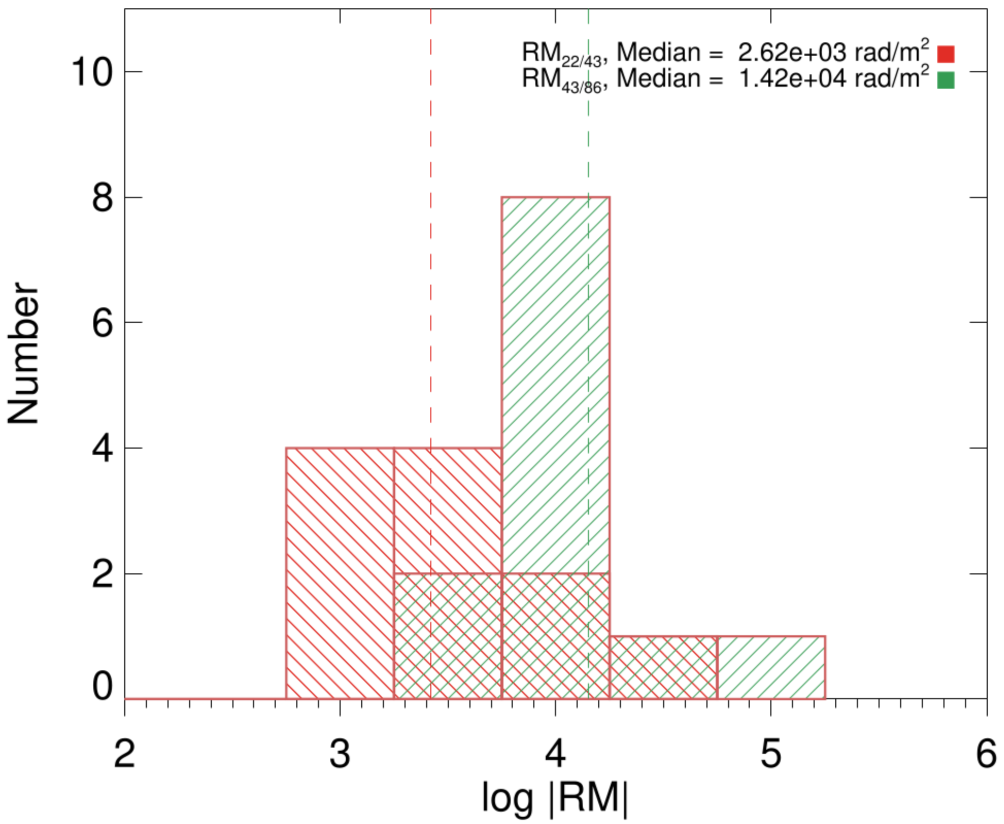


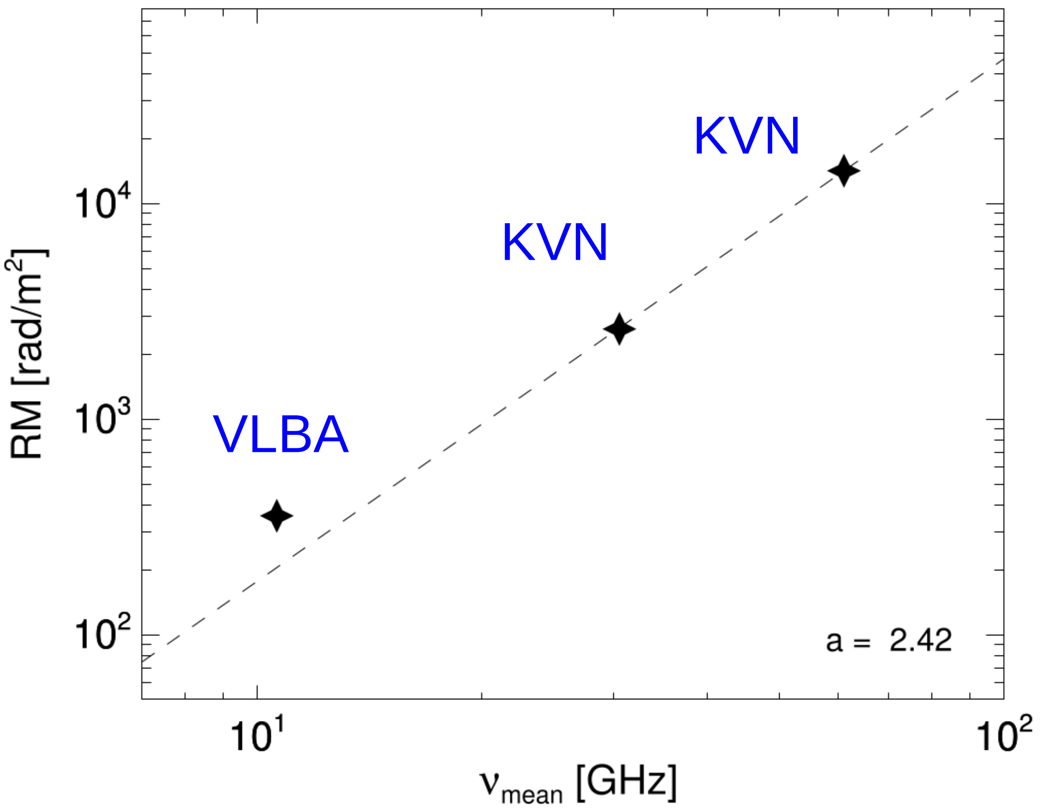




Park et al. 2018, ApJ, 860, 112

AGN cores: Median RM increases with frequency

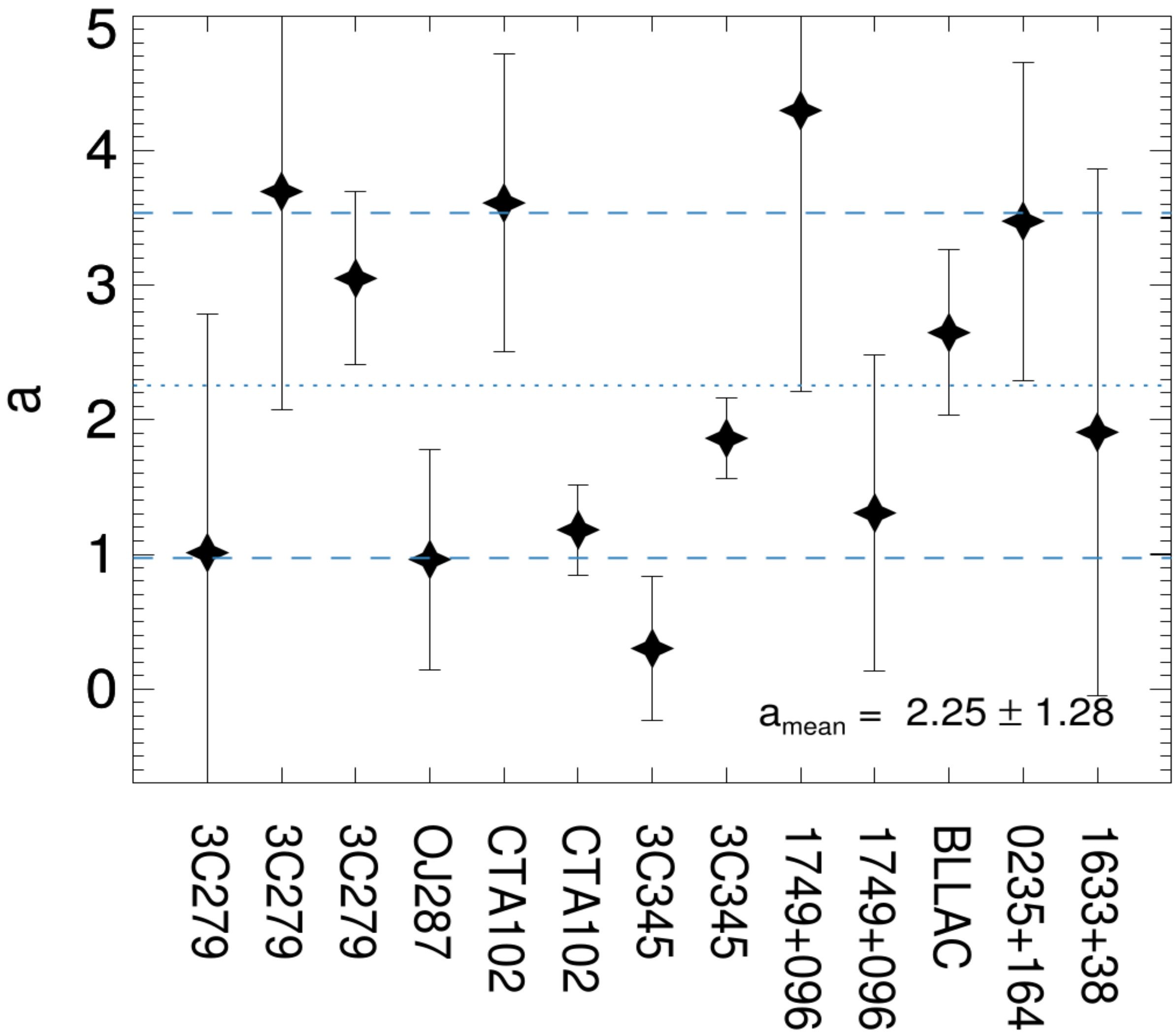




$$|RM| \propto \nu^{a}$$

Park et al. 2018, ApJ, 860, 112

AGN cores: Variable B-field / outflow geometries



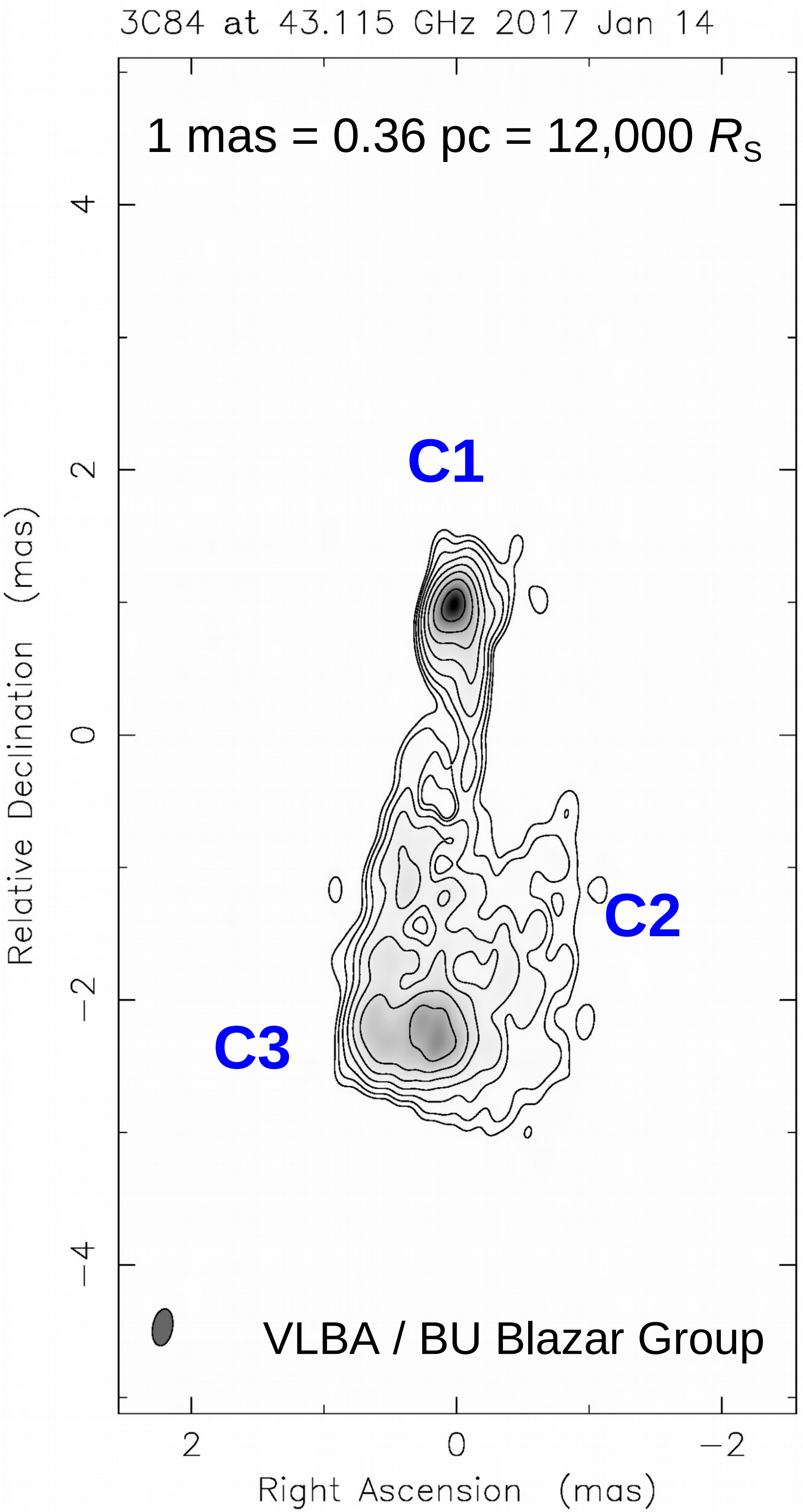
Park et al. 2018, ApJ, 860, 112

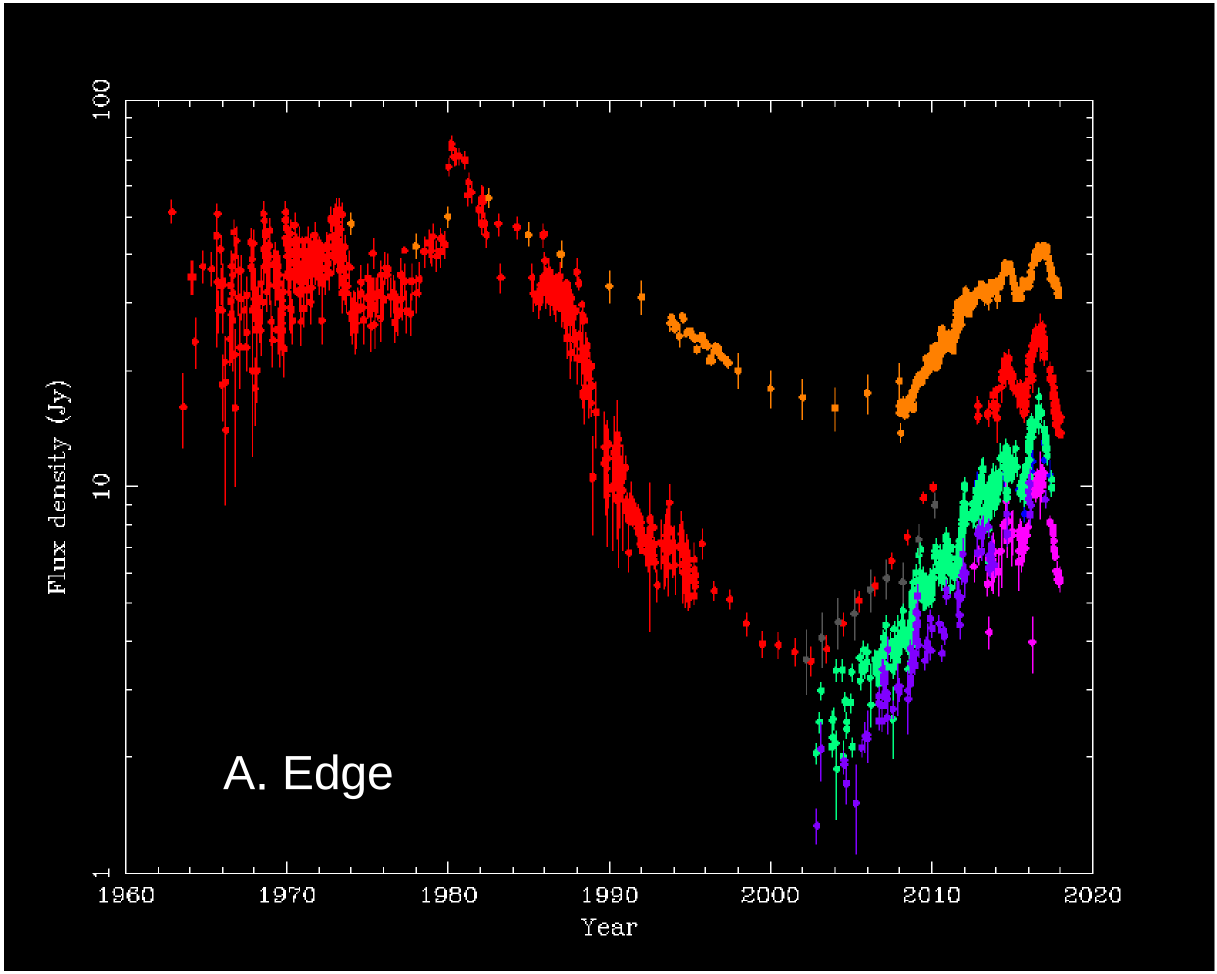
Core shift
+ conical (or spherical) density distribution
+ azimuthal *B* field dominating

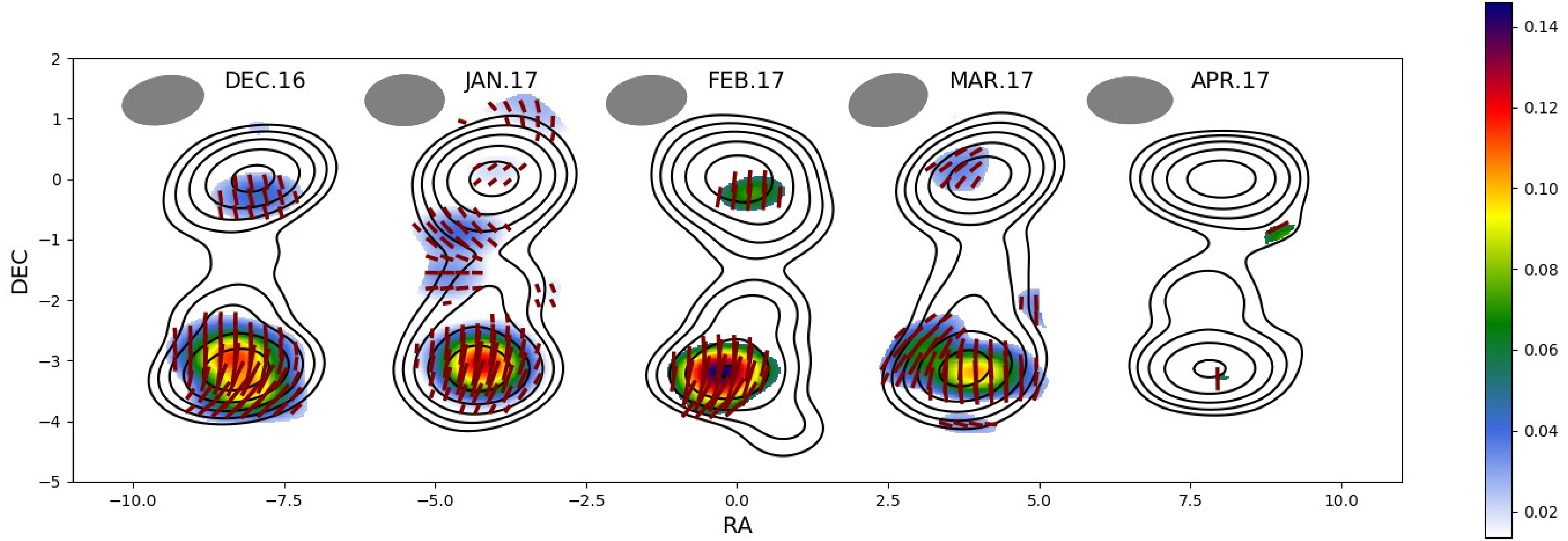
} $a = 2$

3C 84 (NGC 1275)

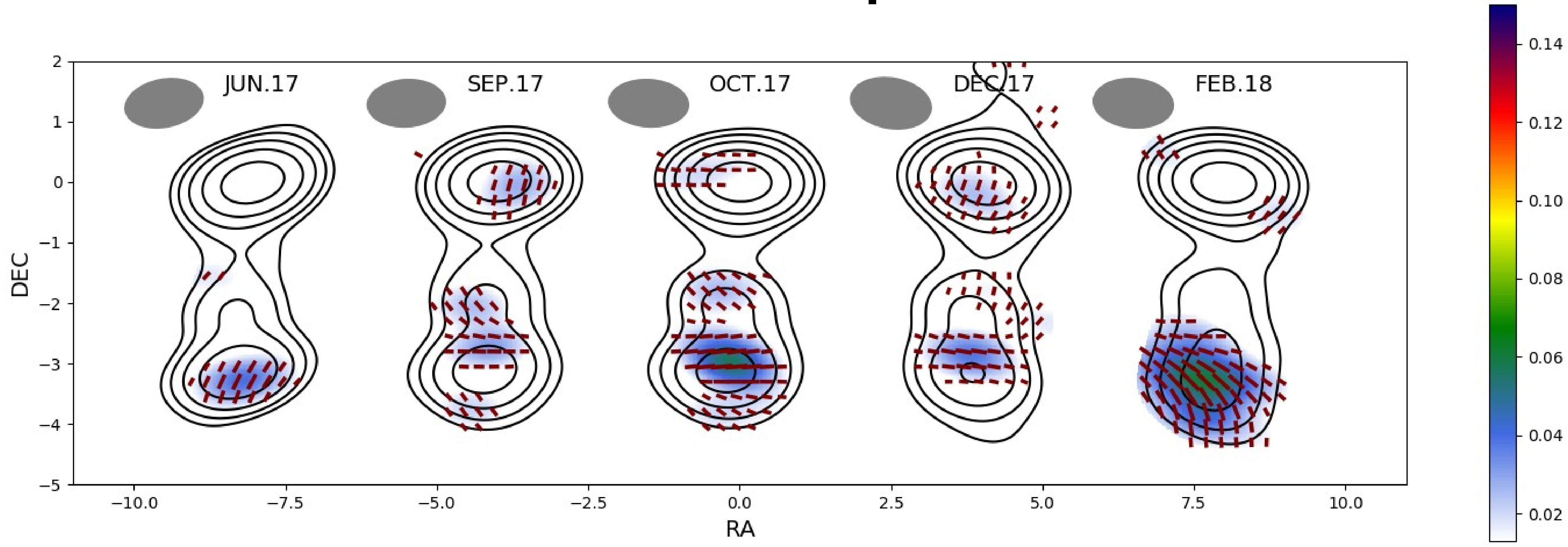
- z = 0.0176 (~75 Mpc)
- Radio galaxy / Seyfert 1.5
- γ-ray bright





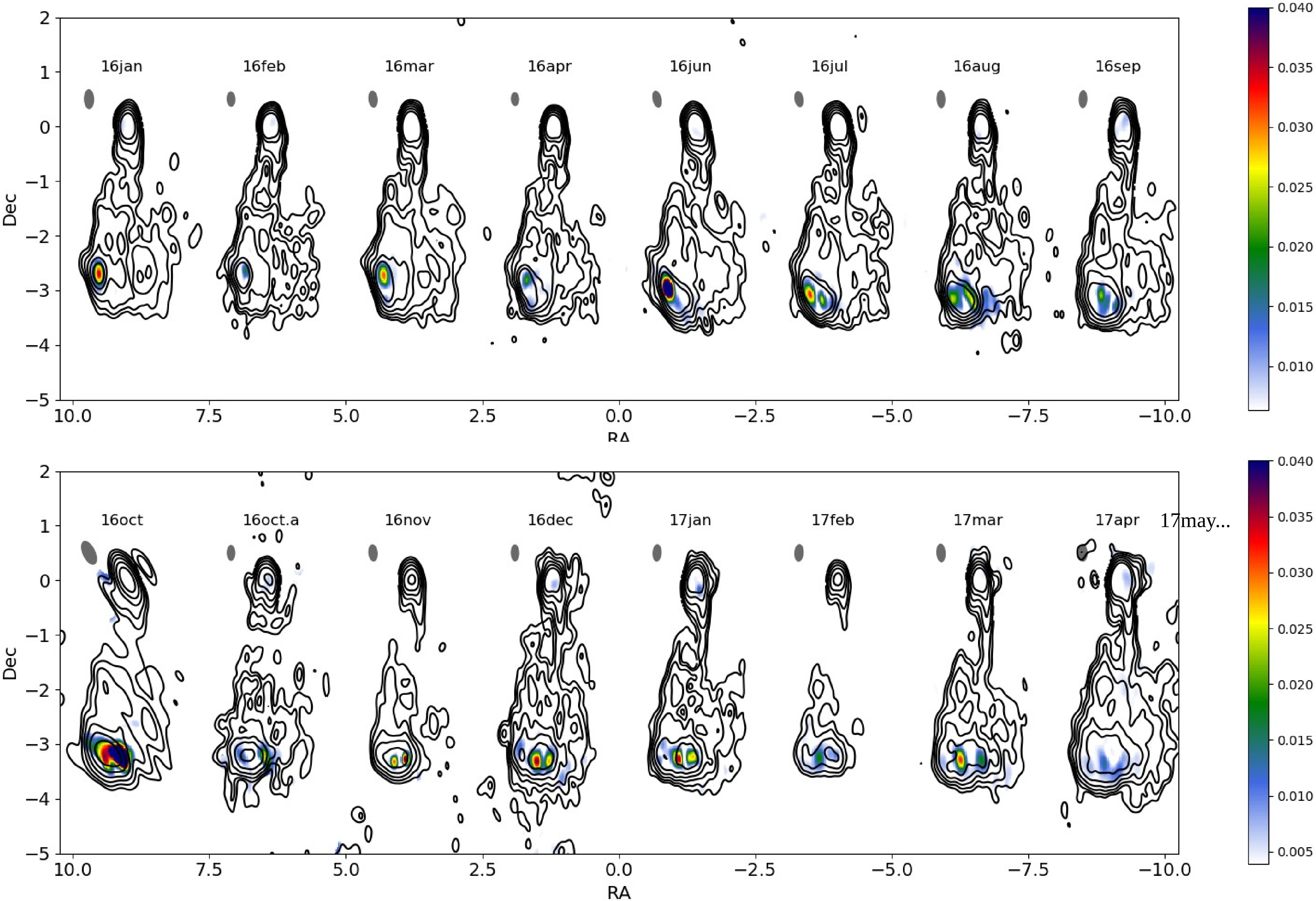


3C 84: KVN 86 GHz polarization

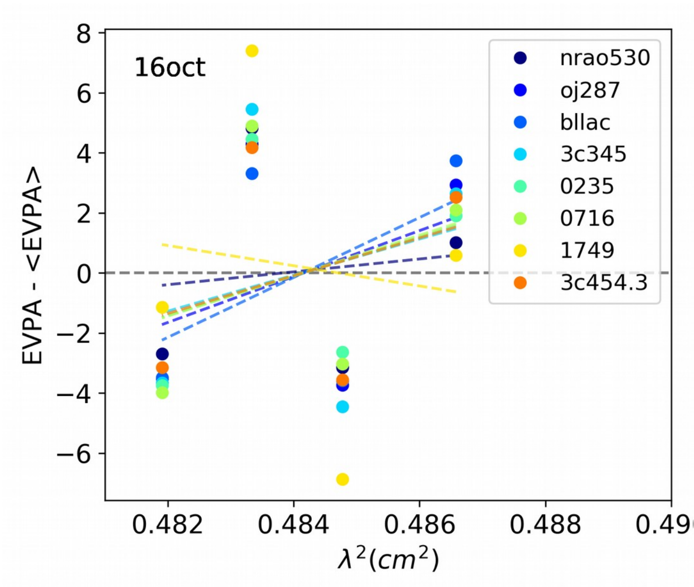


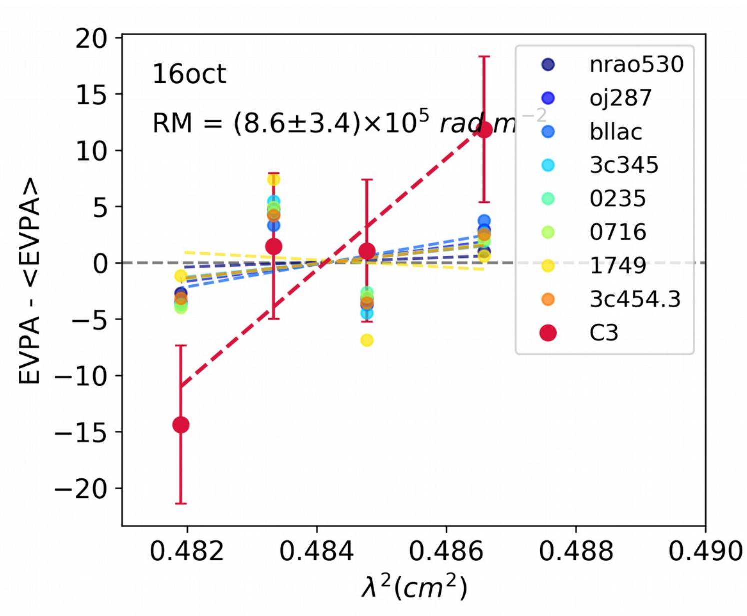
3C 84: VLBA 43 GHz polarization

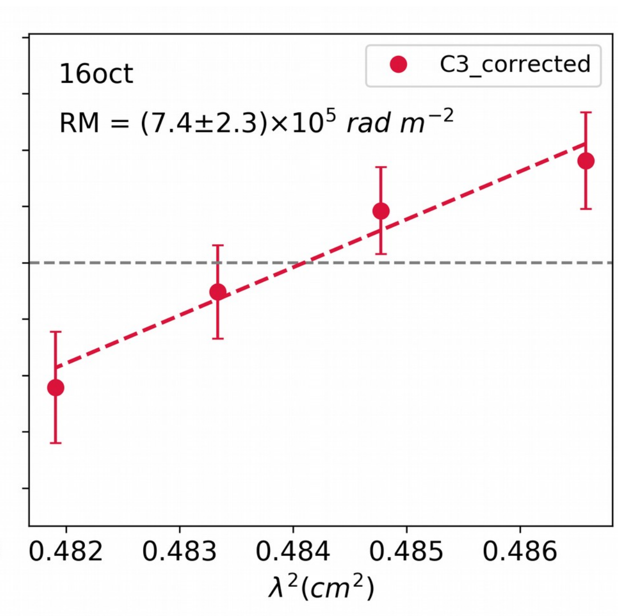
(Data: BU Blazar Group)



3C 84: Intra-band RM measurements at 43 GHz







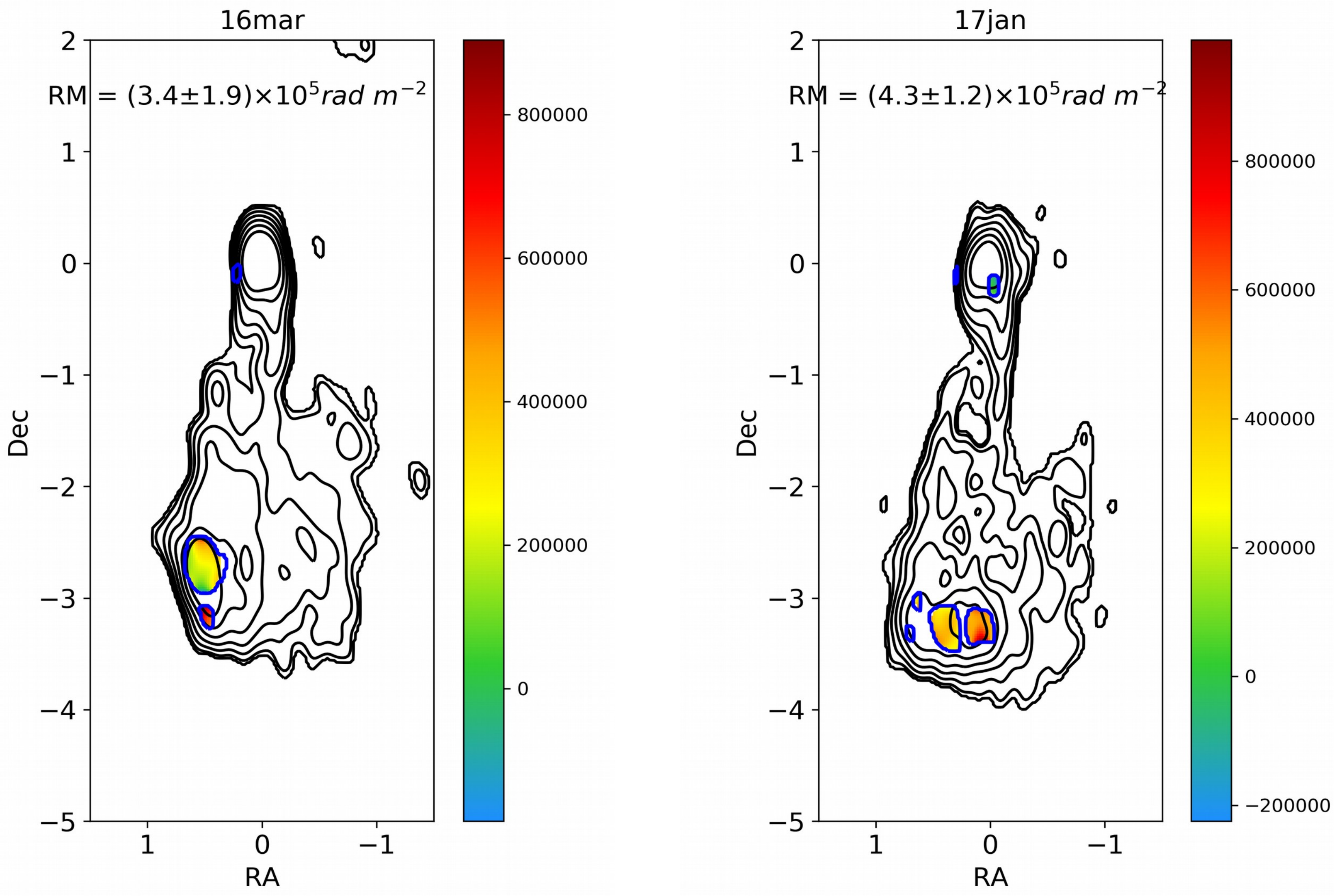
1. Use multiple reference sources to check for systematic EVPA offsets between IFs; systematics are obvious for many epochs.

2. Subtract ensemble-averaged EVPA offset from all data in each IF, including 3C 84 (C3).

3. Subtraction gives corrected EVPAs for each IF.

Kam et al. (in prep.)

3C 84: Strong, variable Faraday rotation



Kam et al. (in prep.)

– High RM indicates shock interaction with (inhomogeneous?) ambient matter
– RM maps show signs of a temporary contact discontinuity structure

PAGaN II

Scientific motivation:

Search for systematic differences between BLOs and FSRQs needs better statistics = larger samples

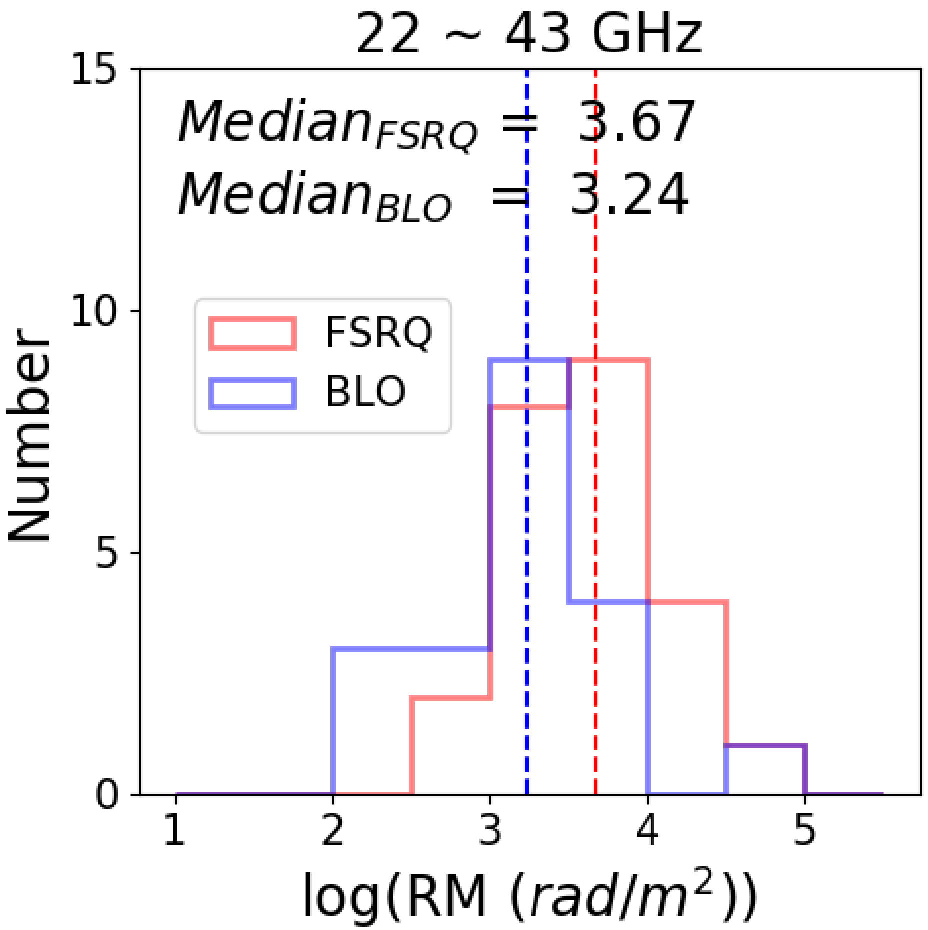
Technical motivation:

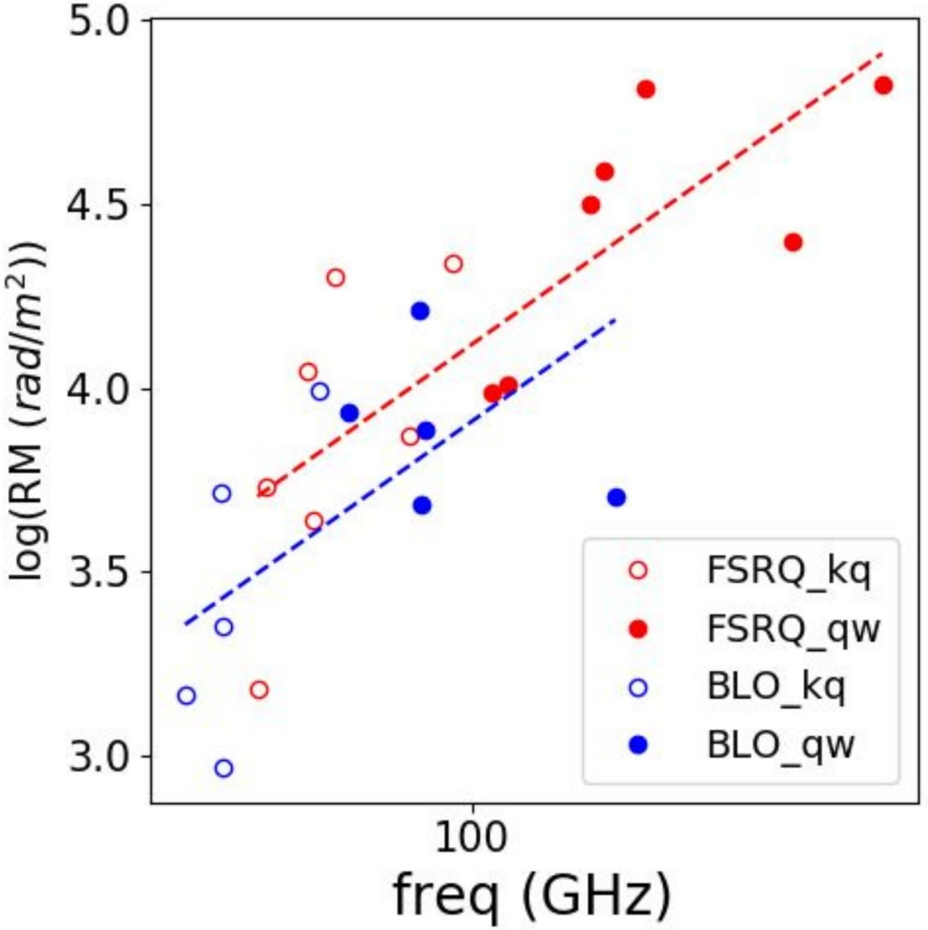
New KVN 16-Gbps recording system allows full polarization observations at all 4 frequencies simultaneously

PAGaN II:

Full polarization observations at 22, 43, 86, 129 GHz of a sample of 32 blazars + 1 RG, allowing for the first time for a statistical search for systematic differences between these blazar classes as well as for systematic trends within each source class.

Blazars: Stronger Faraday rotation in FSRQs?





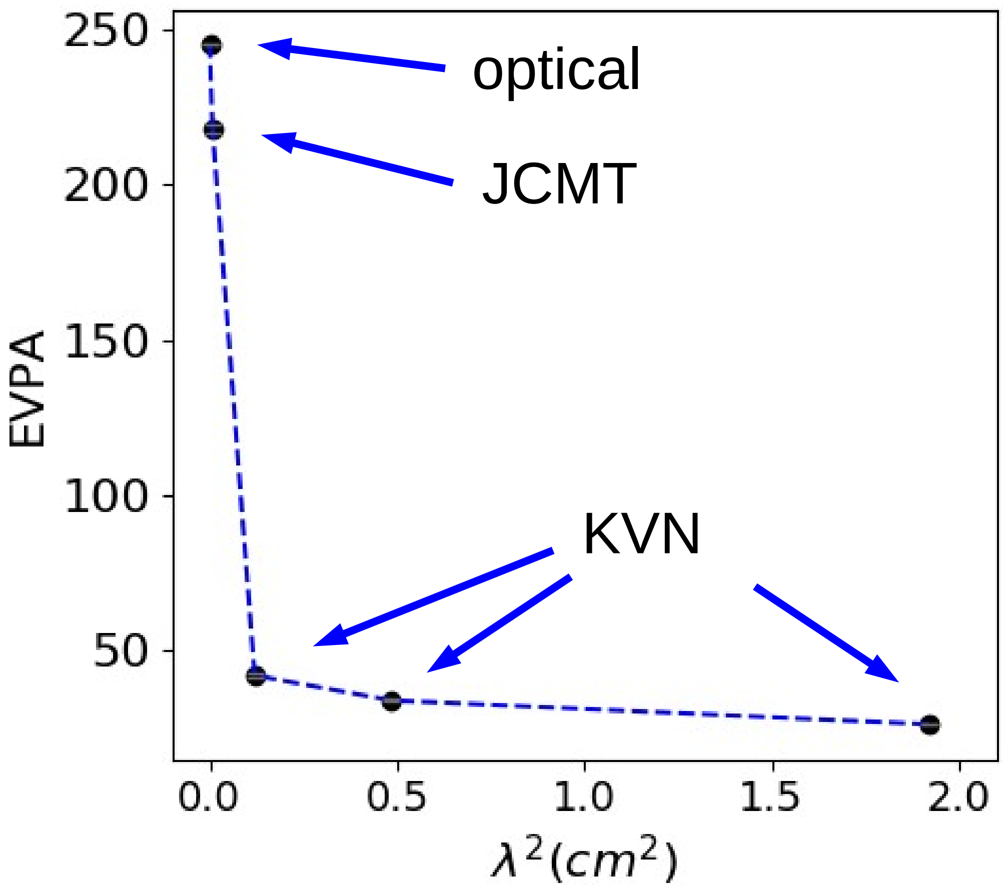
$|RM|_{FSRQ} \approx 3\times|RM|_{BLO}$

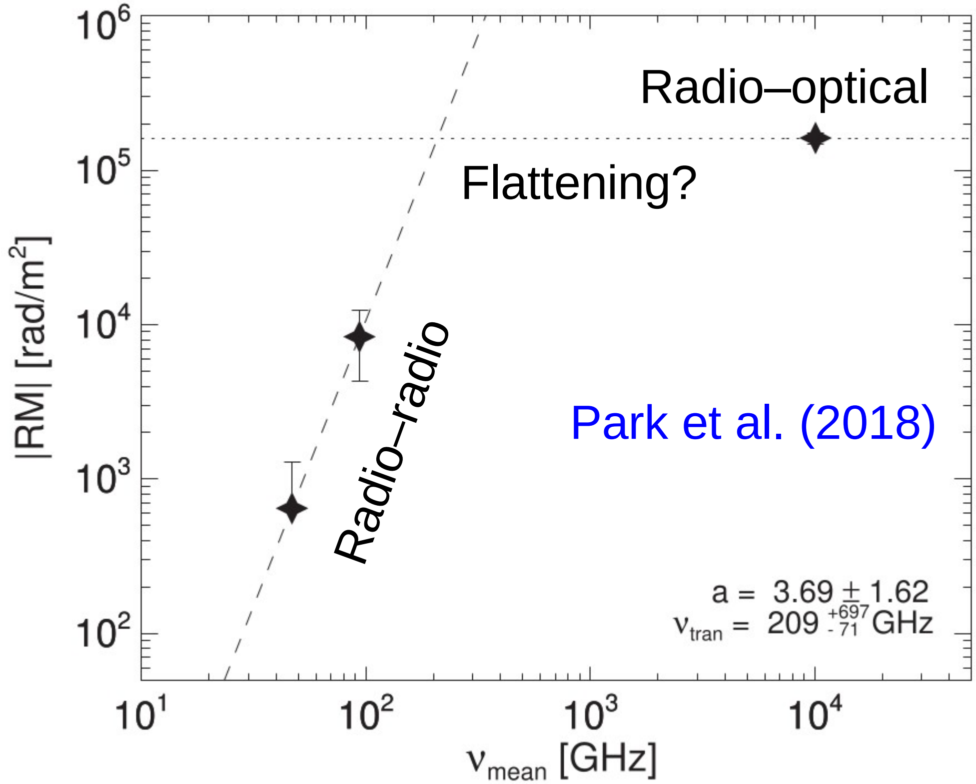
– Does not look like pure redshift effect
– Limited by low-number statistics ➔ PAGaN II

Shin et al. (in prep.)

Blazars: Are radio cores shocks at high frequencies?

Search for flattening of RM–ν scaling relation with SMA, JCMT





3C 279, January 2016:
$|RM|_{86–365\ GHz} \approx 300{,}000$ rad/m^2

M. Kam & N.-E. Shin

27 targets selected so far

[FSRQ – 18]

3C 273 (z~0.158)

1928+738 (z~0.302)

1510-089 (z~0.361)

3C 279 (z~0.538)

3C 345 (z~0.595)

1655+077 (z~0.621)

0059+581 (z~0.644)

1642+690 (z~0.751)

0336-019 (z~0.852)

3C 454.3 (z~0.859)

1055+018 (z~0.893)

NRAO530 (z~0.902)

0235+164 (z~0.94)

0420-014 (z~0.916)

CTA102 (z~1.037)

NRAO150 (z~1.51)

1633+38 (z~1.814)

0836+710 (z~2.218)

[BL Lac – 8]

BL Lac (z~0.069)

0716+714 (z~0.3)

OJ287 (z~0.306)

1749+096 (z~0.322)

0003-066 (z~0.347)

0954+658 (z~0.367)

1538+149 (z~0.606)

1823+568 (z~0.664)

[Radio galaxy – 1]

3C 84 (z~0.018)

Observations started in October 2020

Summary

– PAGaN is a KVN Key Science Program dedicated to multi-frequency polarimetry of blazars (and 3C 84), initially 14 sources (PAGaN I)

– Rotation measures of blazar cores increase with increasing frequency, scaling is consistent with conical “standard” outflows but are variable over time and between sources

– 3C 84 jet (C3) shows “hot spot” with high, variable RM consistent with shock interaction with ambient matter

– FSRQs might show stronger (rest frame) Faraday rotation than BLOs on average, but more sources needed

– Combination of KVN with 230/345 GHz SMA and JCMT data probes RM–frequency scaling, might identify radio cores as standing shocks

– New KVN broad-band mode allows for doubling the number of targets (PAGaN II)