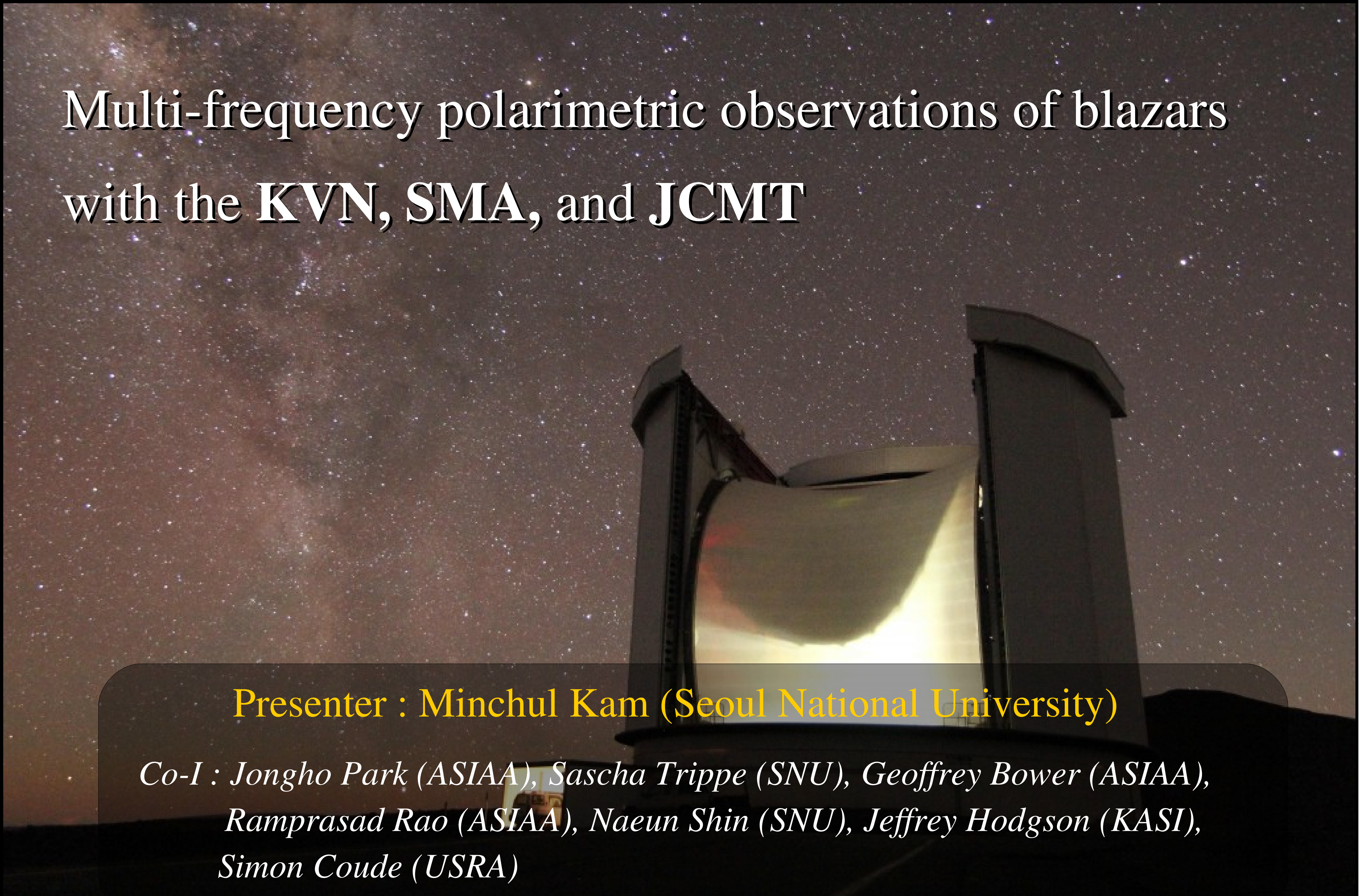
Multi-frequency polarimetric observations of blazars with the **KVN, SMA,** and **JCMT**



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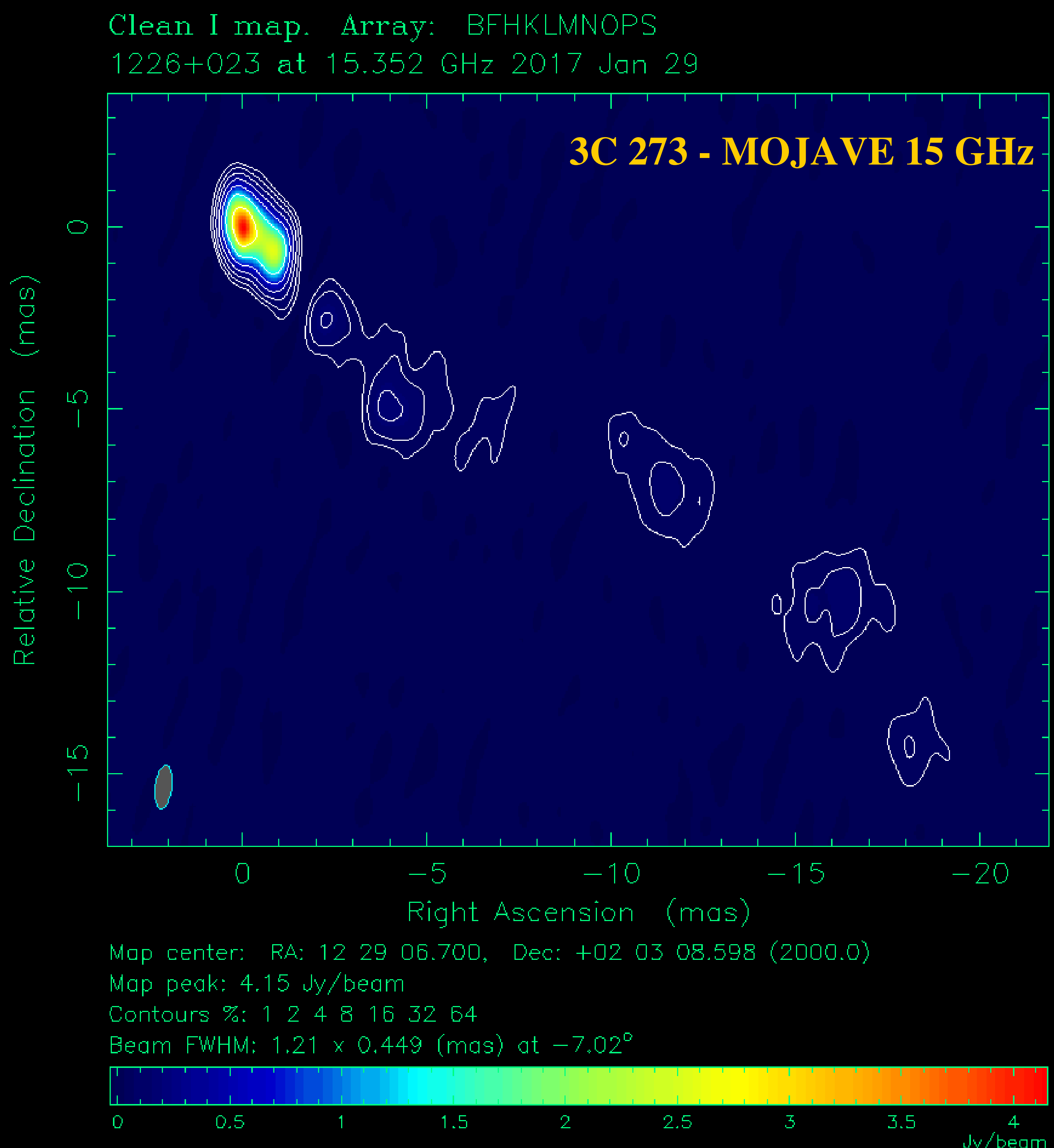
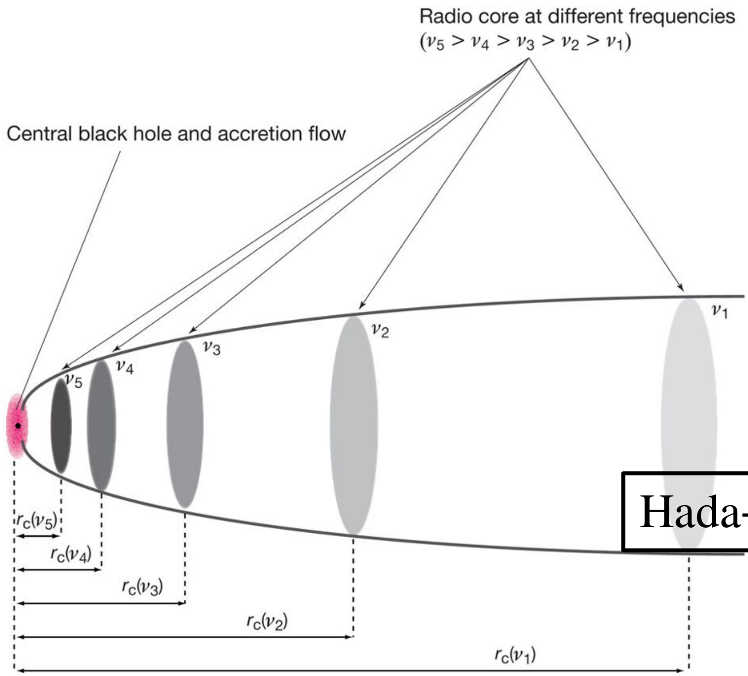
Chris Wilson



Clean I map. Array: BFHKLMNOPS
1226+023 at 15.352 GHz 2017 Jan 29
3C 273 - MOJAVE 15 GHz
Relative Declination (mas)
0
−5
−10
−15
−20
Right Ascension (mas)
Map center: RA: 12 29 06.700, Dec: +02 03 08.598 (2000.0)
Map peak: 4.15 Jy/beam
Contours %: 1 2 4 8 16 32 64
Beam FWHM: 1.21 x 0.449 (mas) at −7.02°
0
0.5
1
1.5
2
2.5
3
3.5
4
Jy/beam

- The nature of the VLBI core

1. τ=1 surface (Blandford & Königl jet)



Hada+ 2011

The core location is dependent of ν due to SSA

→ the core-shift effect is observed.

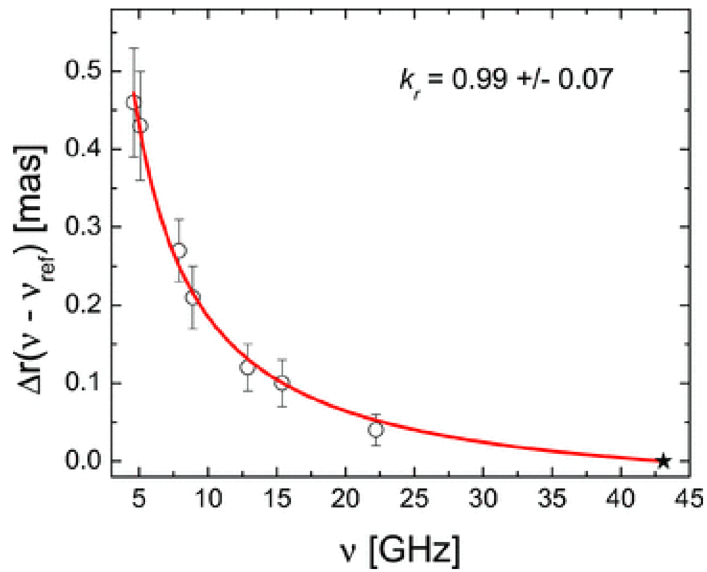


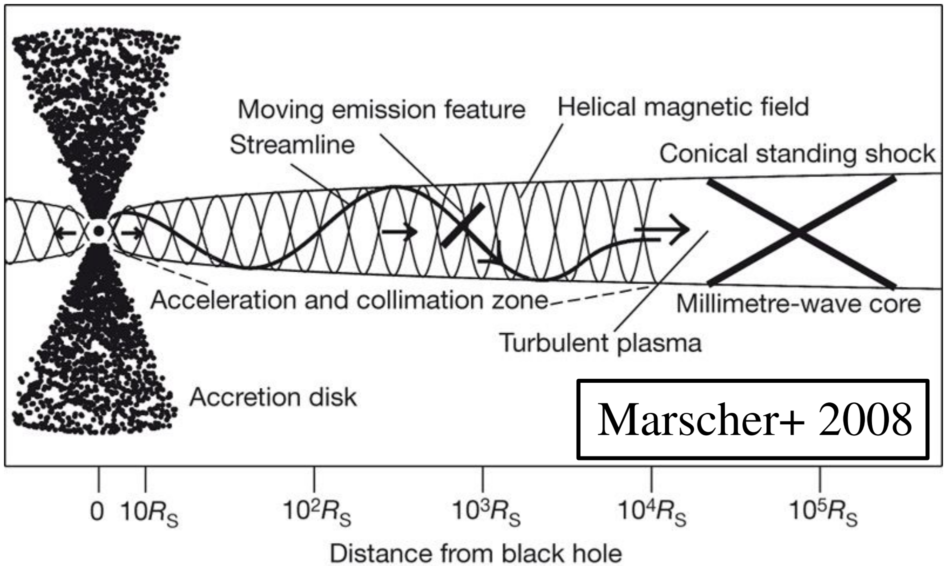
Table 3. Averaged core-shifts using 43 GHz as the reference frequency for 2200+420, plotted in Fig. 3.

ν (GHz)	Δr (mas)	$\Delta r_{\rm projected}$ (pc)	Fraction of beam (per cent)
4.6	0.46 ± 0.07	0.60 ± 0.09	17
5.1	0.43 ± 0.07	0.56 ± 0.09	17
7.9	0.27 ± 0.04	0.35 ± 0.05	16
8.9	0.21 ± 0.04	0.27 ± 0.05	14
12.9	0.12 ± 0.03	0.16 ± 0.04	11
15.4	0.10 ± 0.03	0.13 ± 0.04	10
22.2	0.04 ± 0.02	0.05 ± 0.03	5

O'sullivan & Gabuzda+ 2009

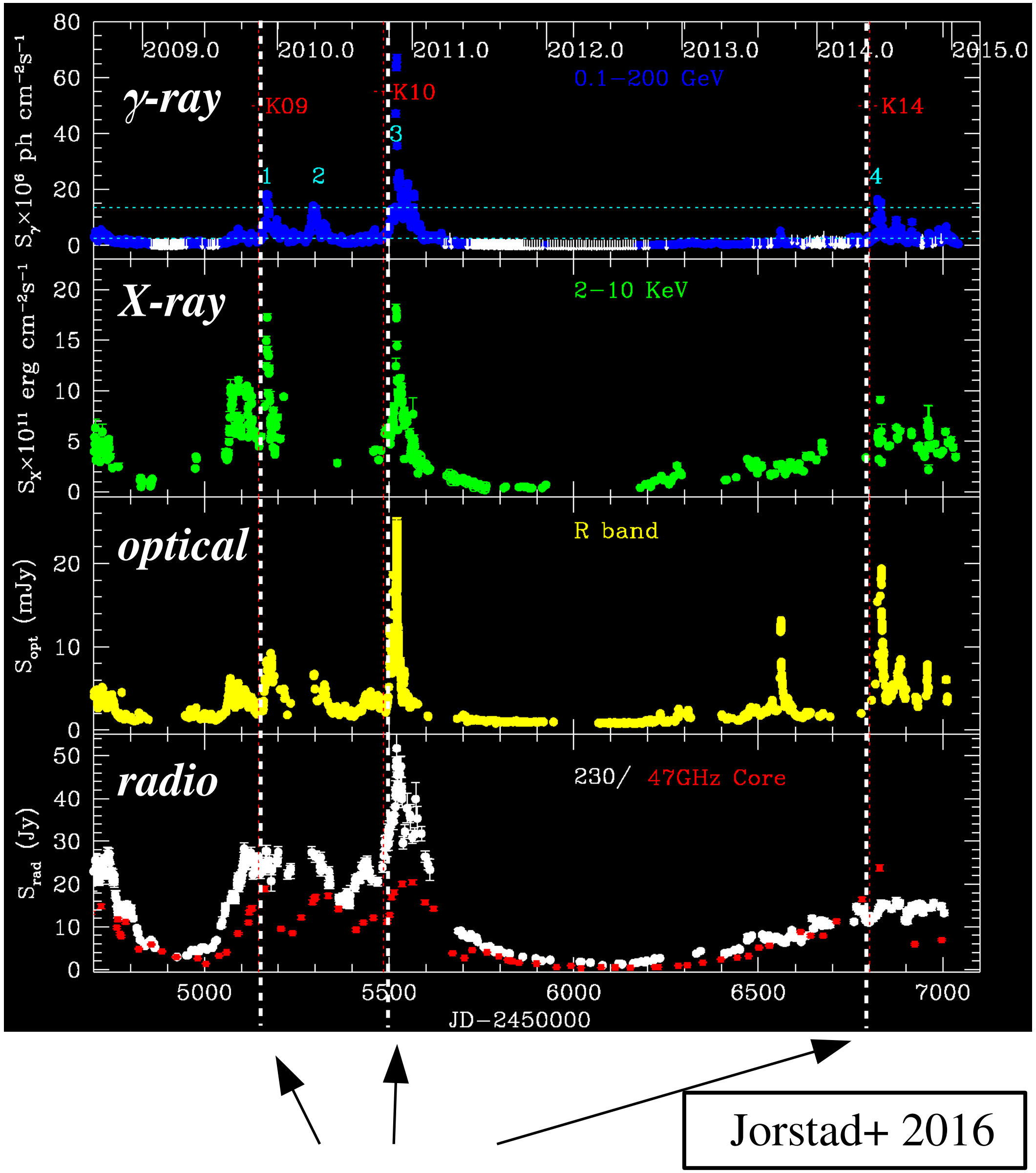
• The nature of the VLBI core

2. Standing (recollimation) shock



The core location is independent of ν when ν is high enough

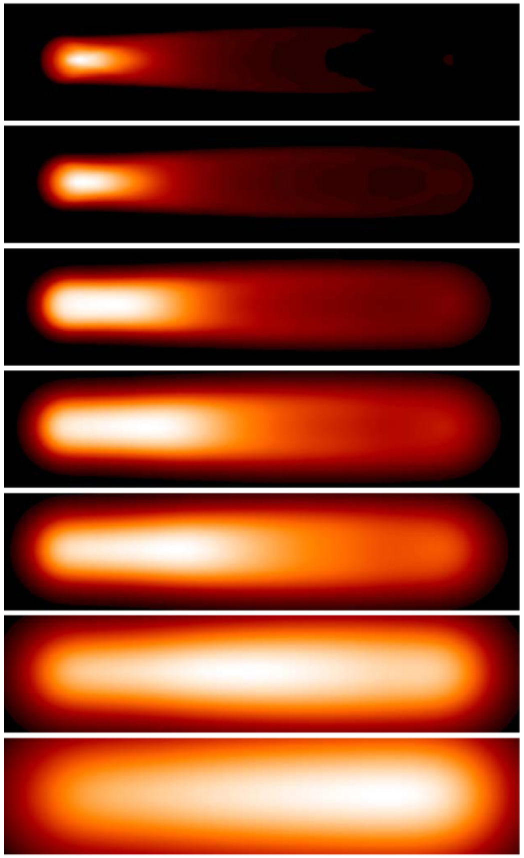
→ the core-shift effect is not expected.

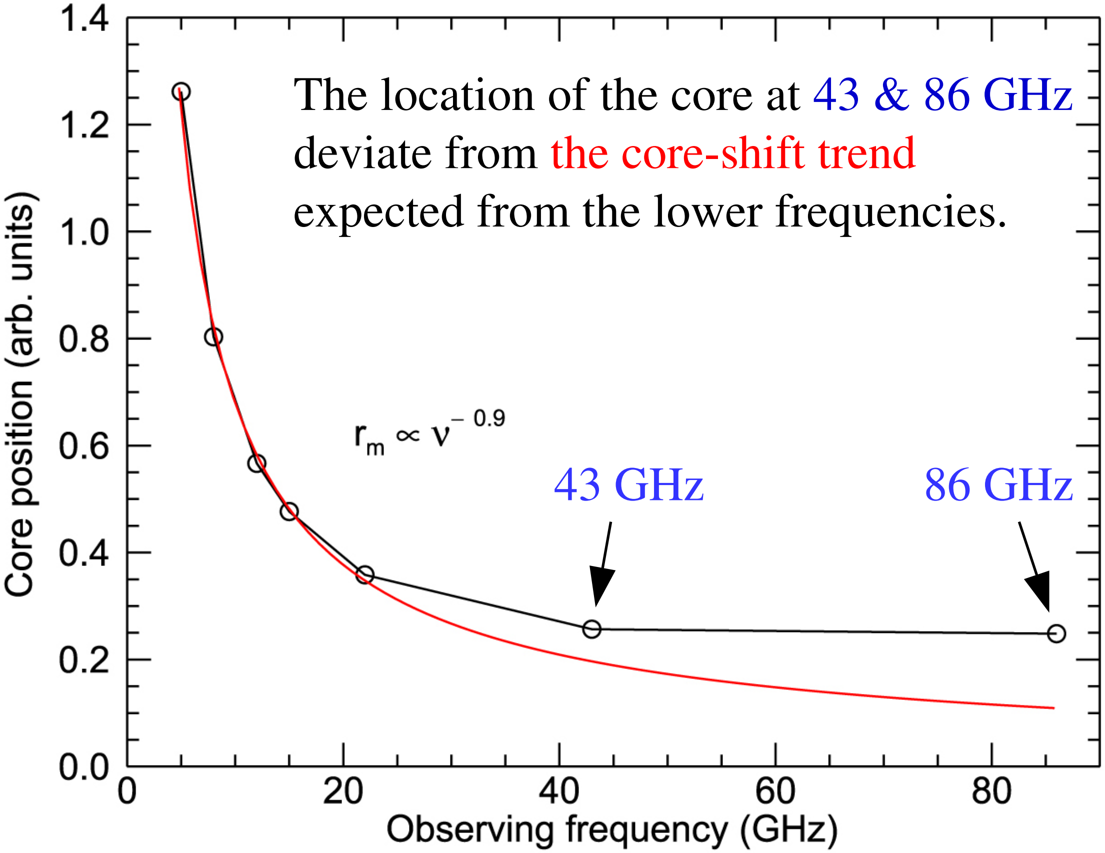


when a new jet component is ejected from the core

- The nature of the VLBI core

→ Standing (recollimation) shock located upstream of the Blandford & Königl jet





Dodson+ 2017

- Rotation measure (RM) of the core

$$RM \propto \int N_e B_{LoS} \, dl$$

assumptions (Jorstad+ 2007) :

1. conical jet geometry : $l \propto d$
2. a power-law N_e distribution : $N_e \propto d^{-a}$
3. helical B-field : $B_{LoS} \propto d^{-1}$

$$B_r \propto d^{-2} \quad B_\varphi \propto d^{-1}$$

➡ $|RM| \propto d^{-a}$ (a=2 when conical)

core-shift effect : $d_{core,\nu} \propto \nu^{-1}$

$$|RM| \propto \nu^{a}$$ (a=2)

$\nu\uparrow \rightarrow$ distance from the SMBH $\downarrow$

$\rightarrow$ n$\uparrow$, B$\uparrow$

$\rightarrow$ RM$\uparrow$

If there is core-shift effect, a~2

If there is no core-shift, a ~ 0

- The **K**orean **V**LBI **N**etwork (**KVN**)

1. Frequency : 22 / 43 / 86 / 129 GHz

(14 / 7 / 3.5 / 2.3 mm)

- covers from cm to mm
- 2 freq. simultaneously

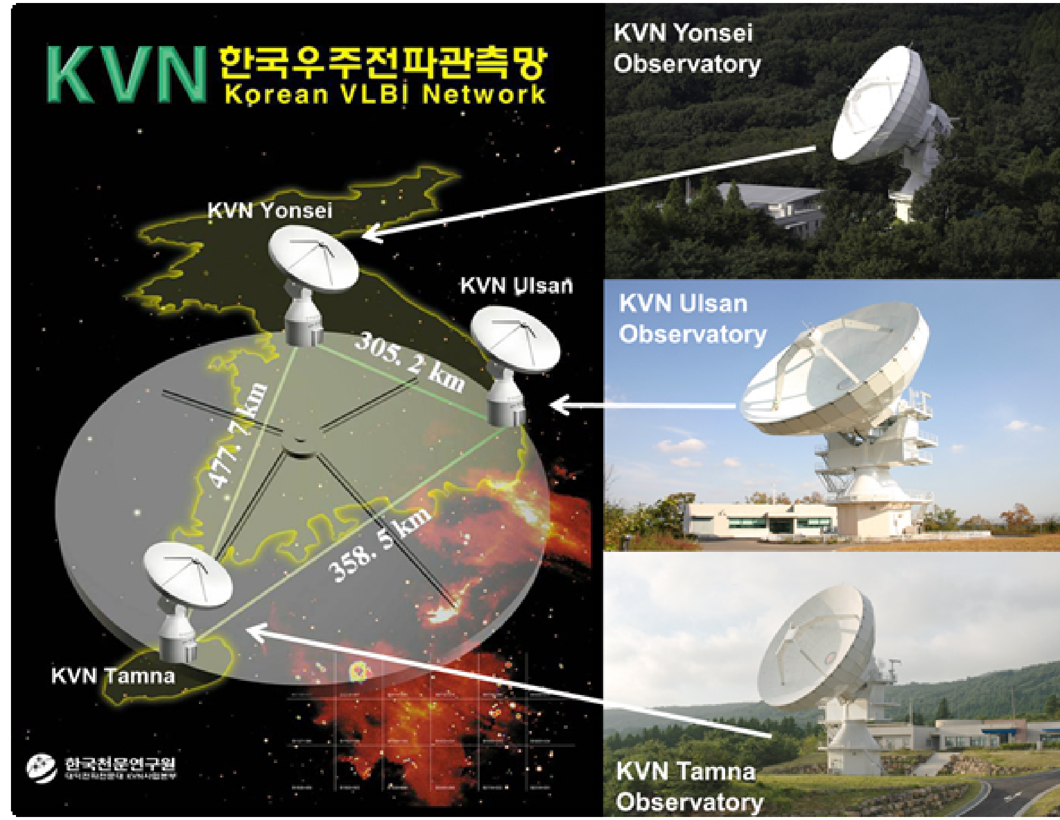
(4 freq. within 2 days!)

→ avoid rapid variability

2. KSP : monthly monitoring program

→ Dec. 2016 ~

→ number of targets : 15



Targets of the KVN monitoring program

[Quasars – 10]

3C 273 (z~0.158)

1510-089 (z~0.361)

3C 279 (z~0.538)

3C 345 (z~0.595)

3C 454.3 (z~0.859)

1055+018 (z~0.893)

NRAO530 (z~0.902)

CTA102 (z~1.037)

NRAO150 (z~1.51)

1633+38 (z~1.814)

[BL Lac – 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 galaxy – 1]

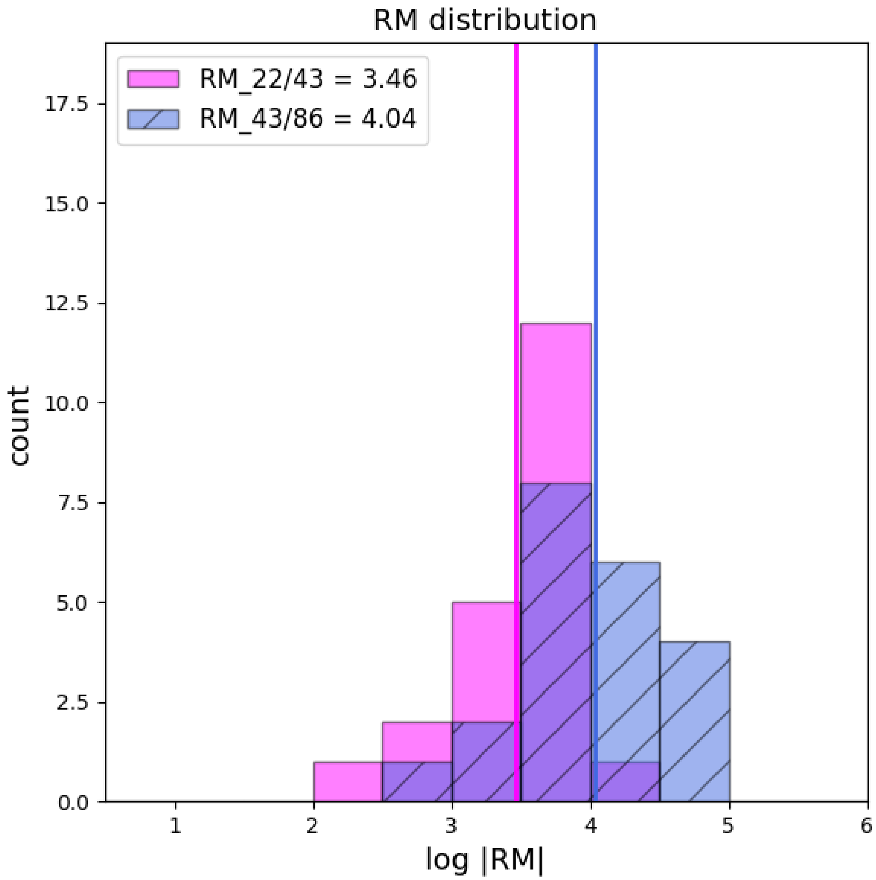
3C 84 (z~0.018)

cover wide redshift range → wide frequency range in the source frame!

Result I : RM distribution

Result II : RM $\leftrightarrow$ frequency

- Result I : RM distribution



RM (22 ↔ 43 GHz) ~ $2900\, rad/m^2$

RM (43 ↔ 86 GHz) ~ $11000\, rad/m^2$

RM increases at higher frequency!

~~3C 273~~, 3C 279, 3C 345, ~~3C 454.3~~, ~~OJ287~~, BLLAC, CTA102, 0235+164, 0336-019, 0716+714, 1055+018, ~~1510-089~~, 1611+343, 1633+38, 1749+096, ~~NRAO530~~

→ excluded the sources with complex polarization structures near the core

Result I : RM distribution

Result II : RM $\leftrightarrow$ frequency

- Rotation measure (RM) of the core

$$RM \propto \int N_e B_{LoS} \, dl$$

assumptions (Jorstad+ 2007) :

1. conical jet geometry : $l \propto d$
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$B_r \propto d^{-2}$ $B_\varphi \propto d^{-1}$

➡ $|RM| \propto d^{-a}$ (a=2 when conical)

core-shift effect : $d_{core,\nu} \propto \nu^{-1}$

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

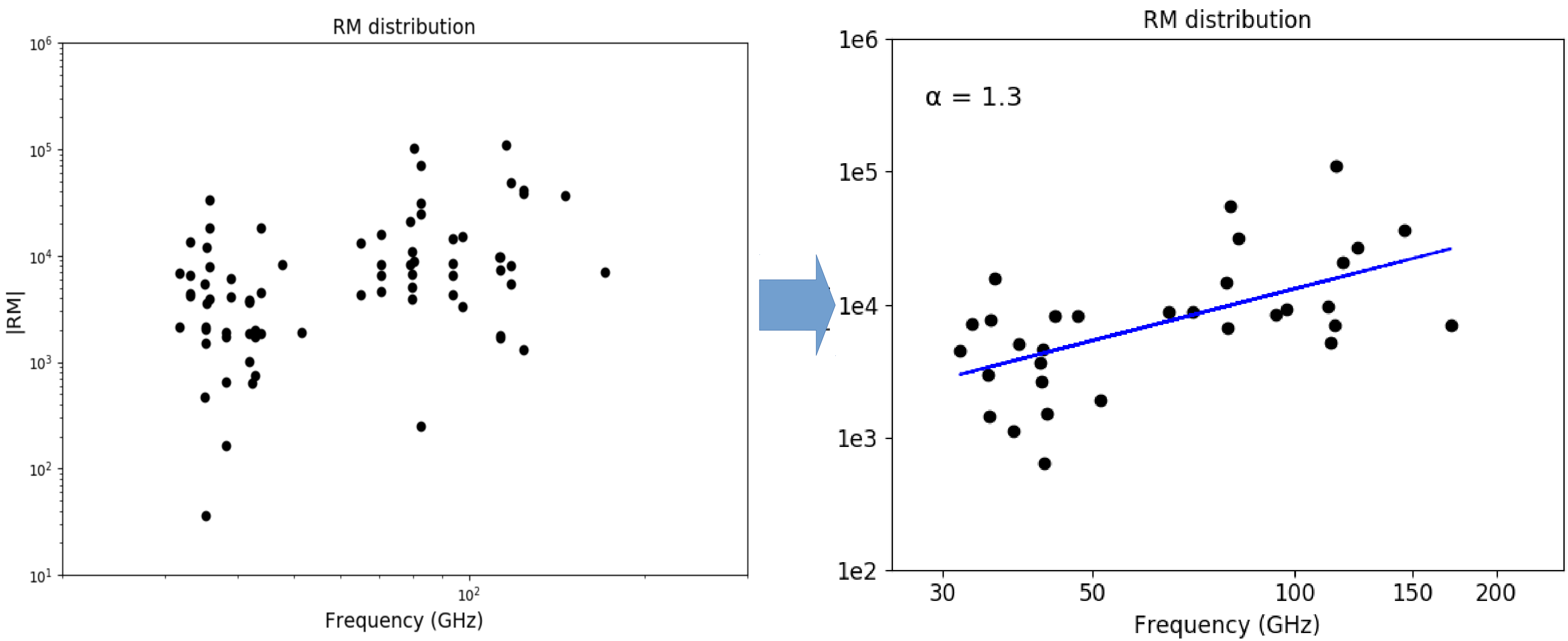
low freq (cm) → a ~ 2

high freq (mm/sub-mm) → a < 2

KVN 22 / 43 / 86 GHz (1.4 / 0.7 / 0.35 cm)

→ a = ?

- Result II : $RM \propto \nu^{a}$ with a~1.3



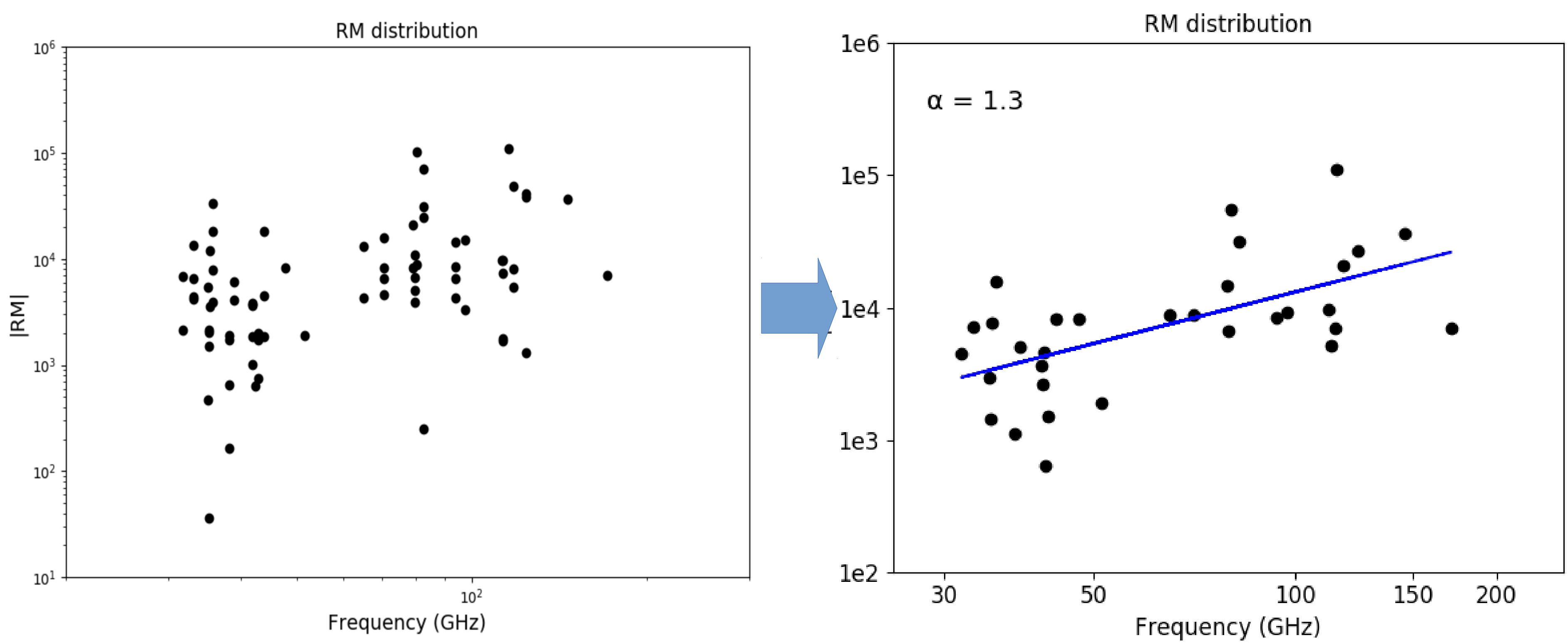
different redshift → different observing frequencies in the rest frame

α~1.3 : smaller than 2 → deviates from the BK conical jet assumption !

→ smaller α at higher frequency?

→ Will the RM be saturated at some point?

- Result II : $RM \propto \nu^{a}$ with a~1.3



different redshift → different observing frequencies in the rest frame

α~1.3 : smaller than 2 → deviates from the BK conical jet assumption !

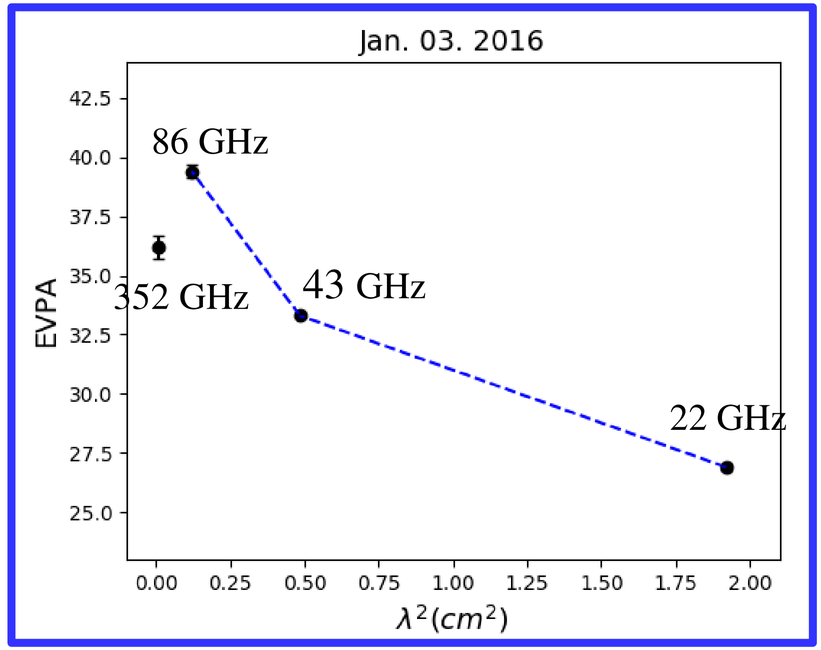
→ smaller α at higher frequency?

→ Will the RM be saturated at some point?

→ higher frequencies are necessary !!

- KVN S/D + JCMT + optical (3C 279 / Jan. 2016)

	Freq	EVPA	
		03.Jan.16	14.Jan.16
KVN (S/D)	22 GHz	26.9 ± 0.1	26.2 ± 0.2
	43 GHz	33.3 ± 0.1	33.9 ± 0.3
	86 GHz	39.4 ± 0.3	41.9 ± 0.8
JCMT	352 GHz	36.2 ± 0.5 (04.Jan.16)	38.2 ± 1.3 (12.Jan.16)
Steward	optical	-	65.2 ± 0.3 (12~14.Jan.16)



KVN 22/43/86 GHz : Jan. 3 / Jan. 14

JCMT 352 GHz : Jan. 4 / Jan. 12

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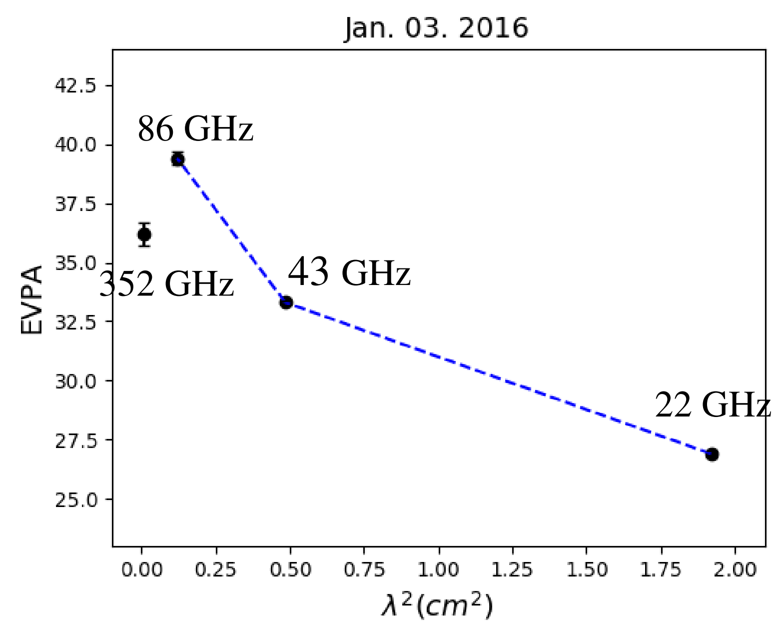
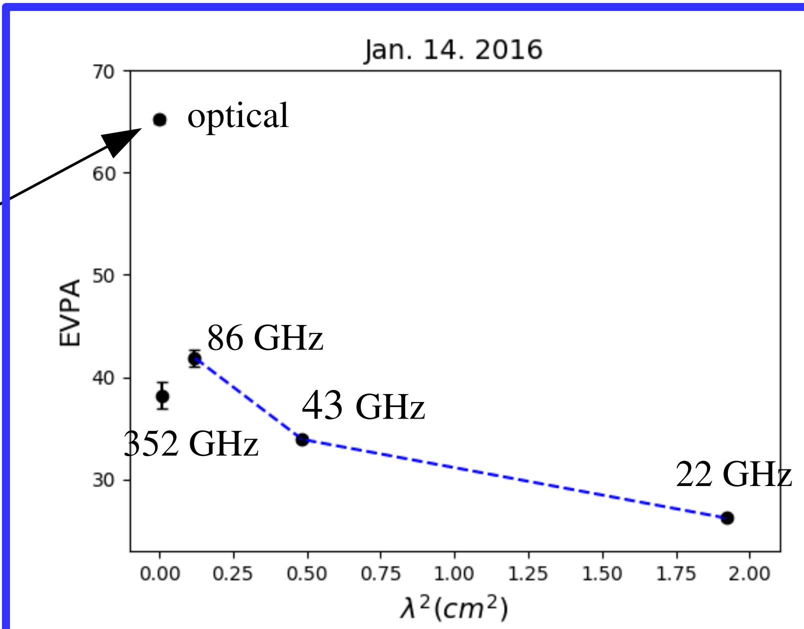


KVN 22/43/86 GHz : Jan. 3 / Jan. 14

JCMT 352 GHz : Jan. 4 / Jan. 12

Optical : 12,13,14 Jan (weighted mean)

Faraday rotation doesn't seem to continue to the 352 GHz & optical !



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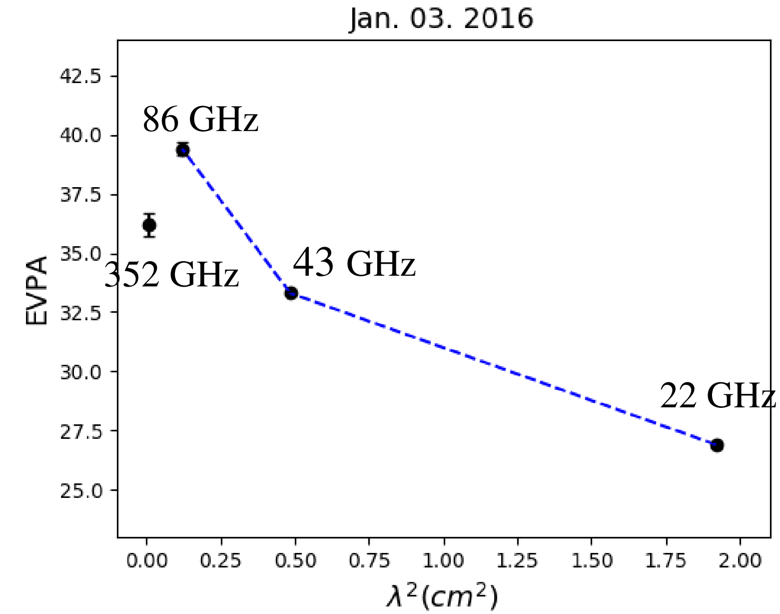

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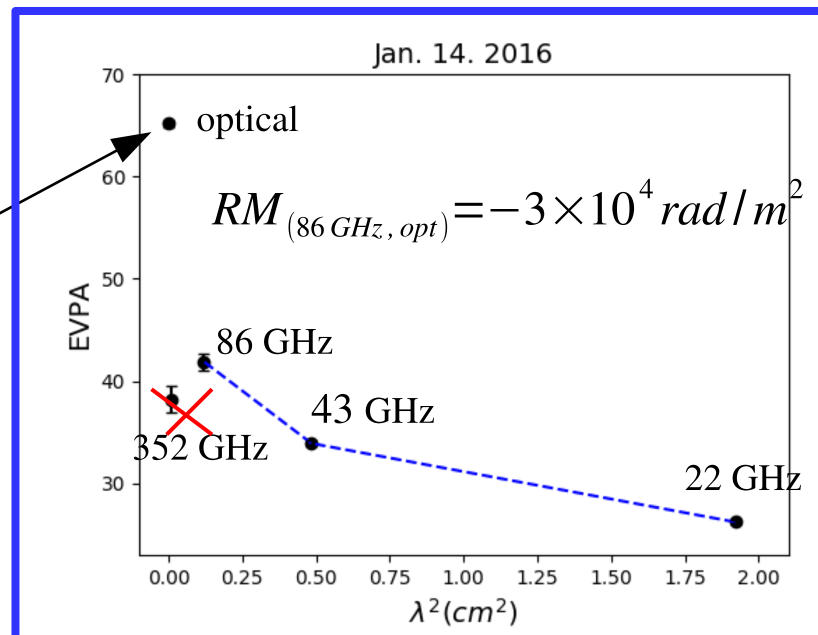

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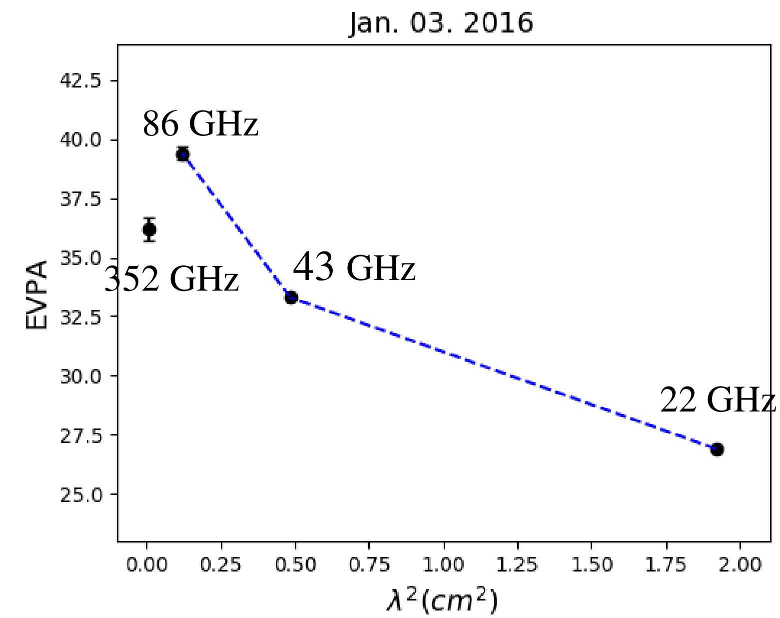

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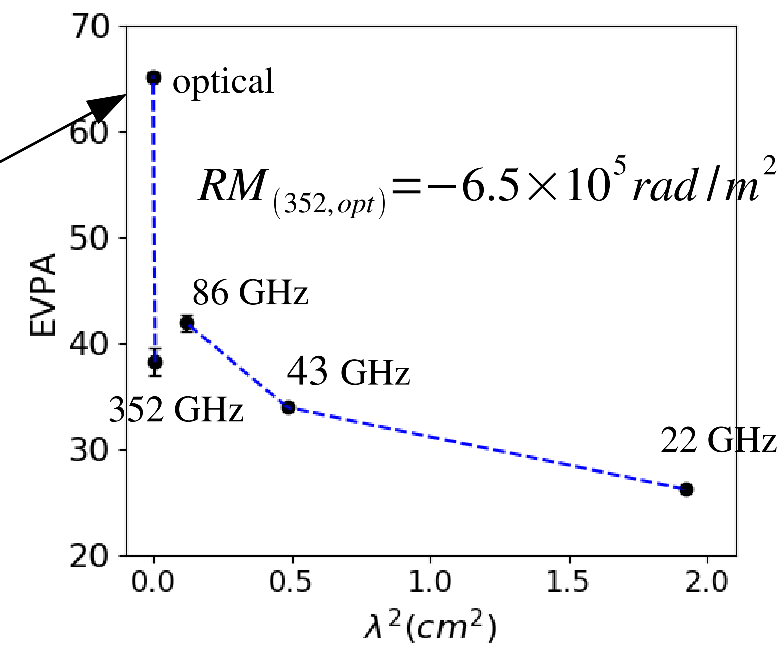

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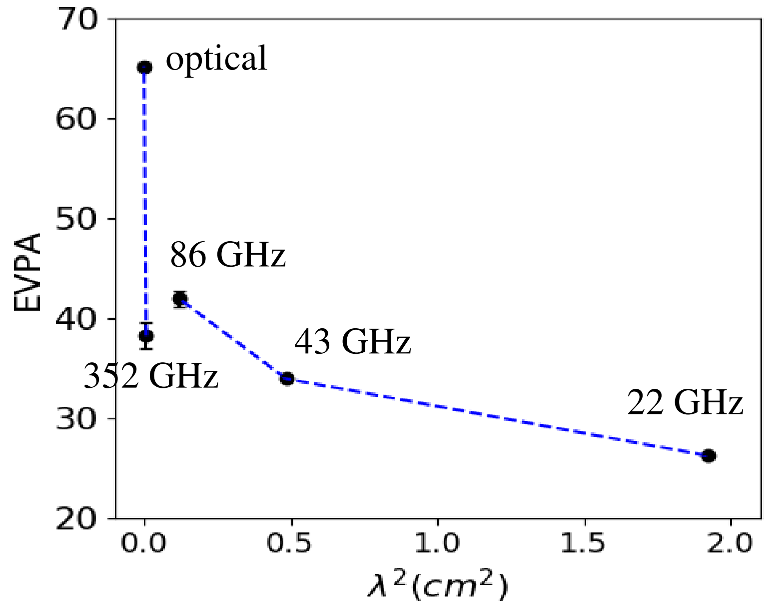
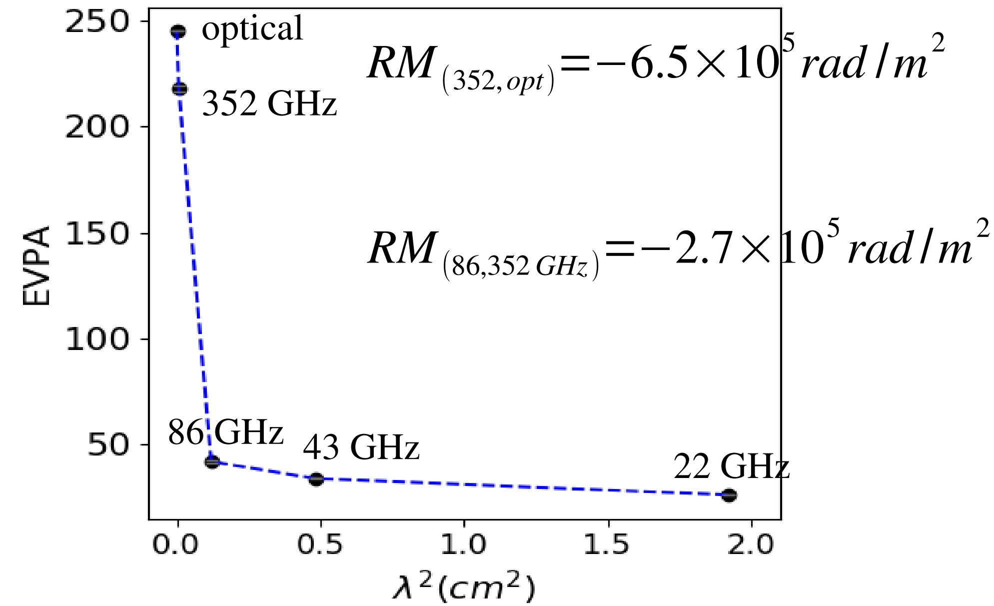


no nπ-ambiguity between 86 ↔ 352 GHz



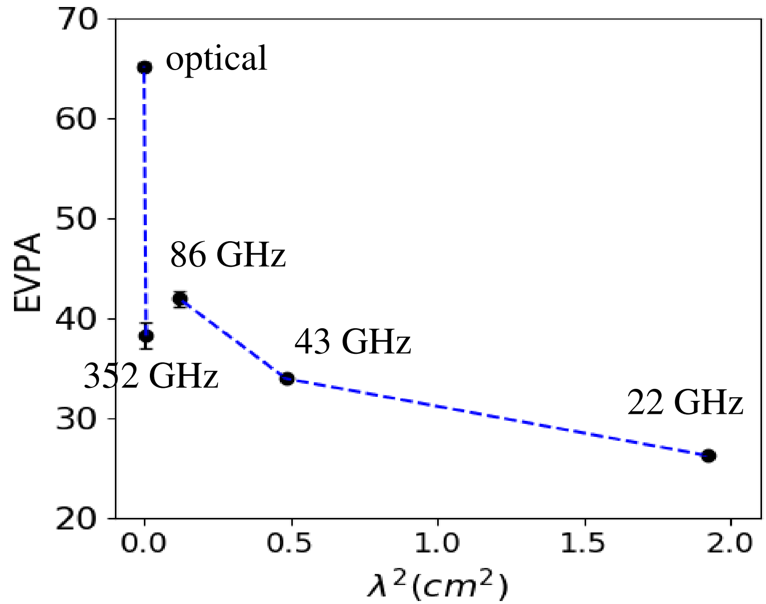
1π applied to EVPA at 352 GHz & optical

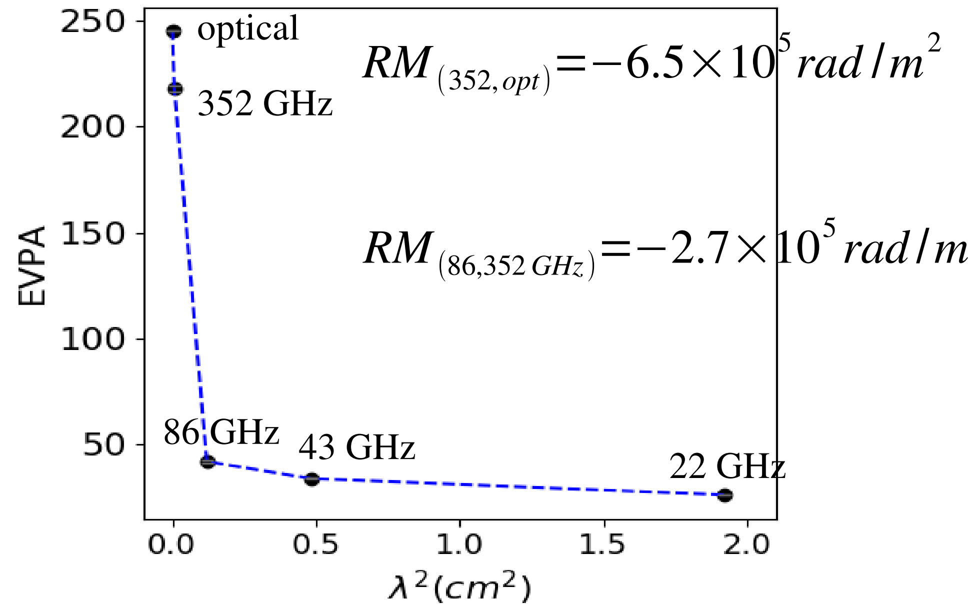
We don't know how many times the polarization angle rotates! (n-π ambiguity)

→ need additional frequencies between 86 GHz ↔ optical!

1. SMA 230 GHz and JCMT 352 GHz fill the frequency gap between 86 and the optical.

- KVN S/D + JCMT + optical (Jan. 2016)





no nπ-ambiguity between 86 ↔ 352 GHz

1π applied to EVPA at 352 GHz & optical

We don't know how many times the polarization angle rotates! (n-π ambiguity)

→ need additional frequencies between 86 GHz ↔ optical!

1. SMA 230 GHz and JCMT 352 GHz fill the frequency gap between 86 and the optical.
2. We can space the LSB and USB up to 16 GHz → two frequencies around 230 GHz.
3. We obtained 25.1° and 31.4° at each LSB and USB (227.5 ↔ 243.5 GHz) on Nov. 26. 2018.

→ $RM = -5.0 \times 10^5\ rad/m^2$ in the observing frame.

→ support this case

The SMA & JCMT are essential to obtain the reliable RM!

[Quasars – 10]

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[BL Lac – 5]

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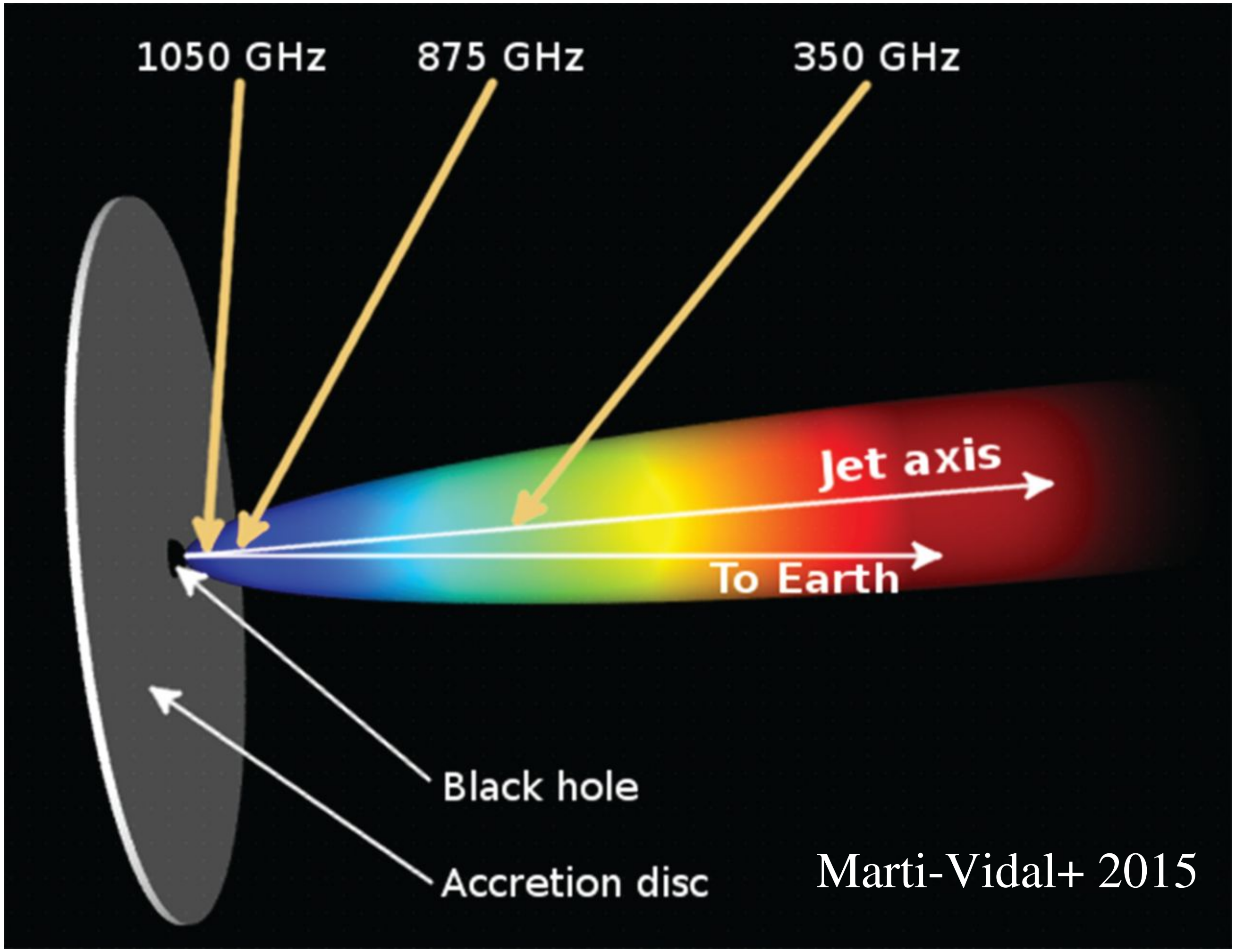
[Radio galaxy – 1]

- 3C 84 (z~0.018)

KVN : 22 ~ 129GHz → 23.5 ~ **260** GHz

KVN / SMA / JCMT : 22 ~ 352 GHz → 23.5 ~ **700** GHz !!

- A new view on the core of blazar jets!



Marti-Vidal+ 2015

→ PKS 1830-211 (z~2.5)

→ ALMA 100~300 GHz

→ $RM \sim 10^8 \, rad/m^2$

Hovatta+ 2018

→ 3C 273 (z~0.158)

→ ALMA 223~243 GHz

→ $RM \sim 3 \times 10^5 \, rad/m^2$

KVN / SMA / JCMT can cover **23~1000 GHz** in the rest frame!

Thank you.

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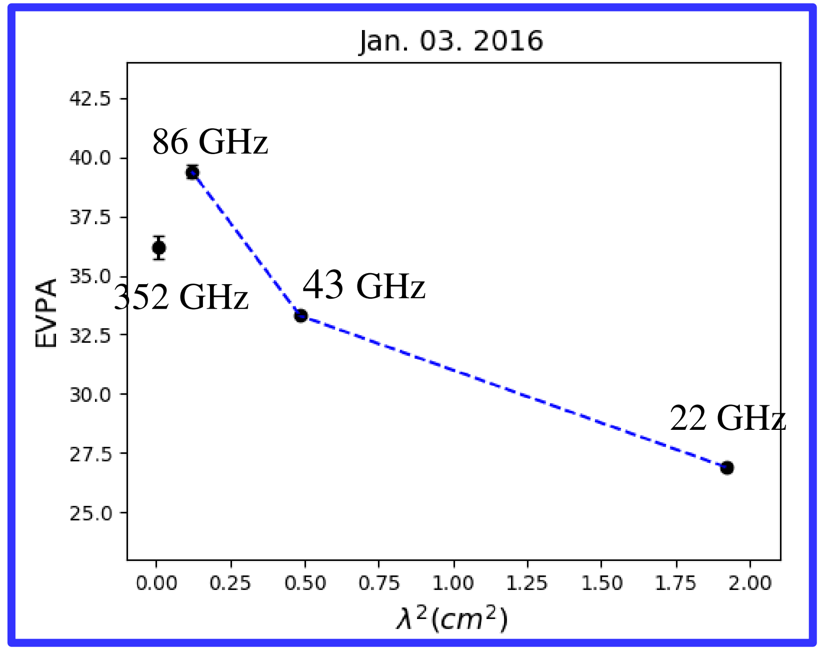

KVN 22/43/86 GHz : Jan. 3 / Jan. 14

JCMT 352 GHz : Jan. 4 / Jan. 12

$$RM \propto slope$$

$$RM \propto \int N_e \overrightarrow{B_{LoS}} \cdot d\vec{l}.$$