The Magnetic Field structure in CTA 102 from high-resolution mm-VLBI observations during the flaring state in 2016-2017

Casadio et al., 2018 A&A (accepted), 2018arXiv181202194C

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eXtreme19 - Padova, 22 - 25 January 2019

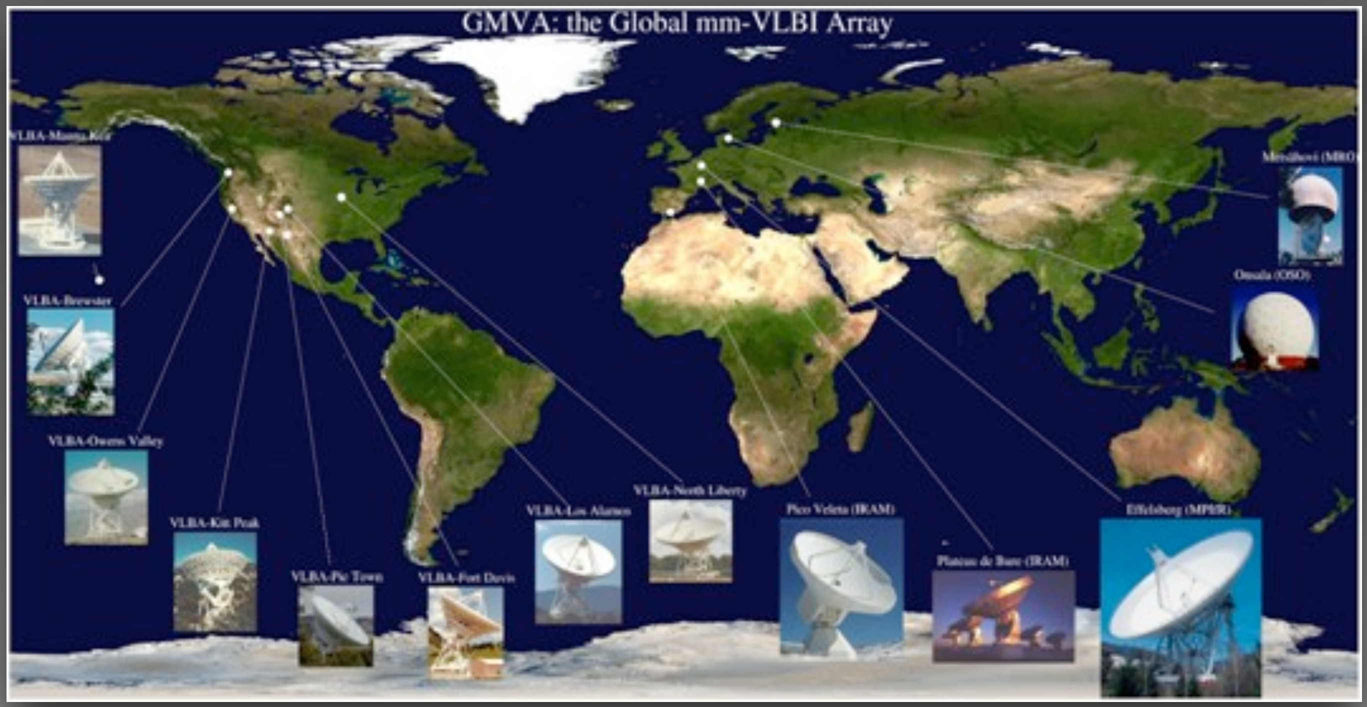
MAX PLANCK INSTITUTE
FOR RADIOASTRONOMY

GMVA observations of gamma-ray bright blazars and radio galaxies

THE SAMPLE

Half of the 37 gamma-ray bright and radio loud AGN from **VLBA-BU-BLAZAR (43 GHz)**:

15 FSRQ and BL Lacs
2 radiogalaxies (3C 120, 3C 111)



86 GHz GMVA polarimetric obs. (PI: Prof. Marscher)

http://www.bu.edu/blazars/vlbi3mm/

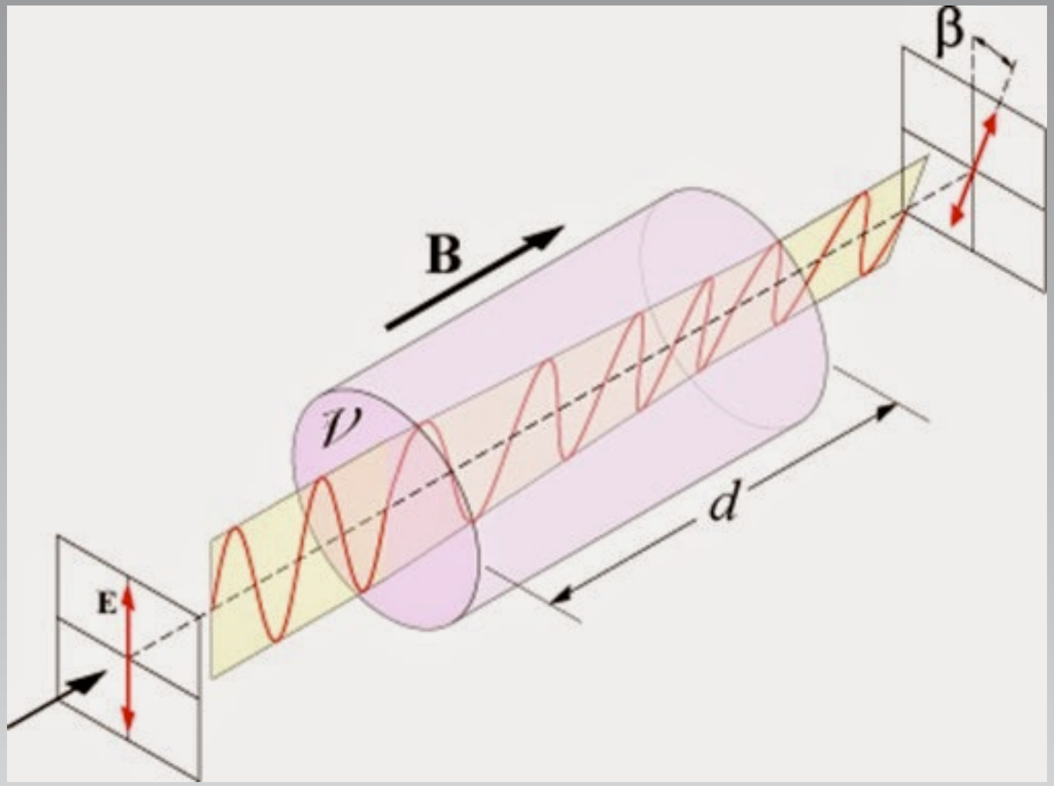
- VLBA, Green Bank, Effelsberg, Onsala, Yebes, Metsahovi, Pico Veleta, Plateau de Bure, KVN stations
- started in 2008.78, ~ every 6 months
- max angular resolution ~ **0.05 mas** → **3 times higher resolution !**

GOALS:

- ✓ Magnetic Field structure in the very inner regions, with unprecedented resolution
- ✓ Variability and physical process occurring during high-energy flares

EVPAs orientation + Faraday Rotation analysis ⟶ 3D map of the magnetic field

EVPAs corrected for Faraday Rotation ⟶ EVPAs intrinsic of the source



$$EVPA = EVPA_0 + \frac{e^3\lambda^2}{8\pi^2\epsilon_0 m^2 c^3}\int n_e \mathbf{B}\cdot dl =$$

$$= EVPA_0 + RM\lambda^2$$

GMVA observations

21 May 2016	30 Sept 2016	31 March 2017
Antennas	**Antennas**	**Antennas**
VLBA + EF + ON + YS + KVN	VLBA (- MK) + EF + ON + YS + MH + GBT + KVN	VLBA + EF + ON + YS + MH + PV + GBT +
Sources	**Sources**	**Sources**
3C111	3C345	3C120
3C120	3C454.3	3C273
3C273	0716+714	3C279
3C345	0954+658	3C345
3C454.3	1055+018	3C454.3
0716+714	1510-089	0716+714
0954+658	1633+382	1510-089
1510-089	1749+096	1633+382
1633+382	BL LAC	1749+096
BL LAC	CTA102	BL LAC
CTA102	OJ287	CTA102
OJ287		OJ287

GMVA observations

21 May 2016

Antennas

VLBA + EF + ON +
YS + KVN

Sources

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VLBA (- MK) + EF +
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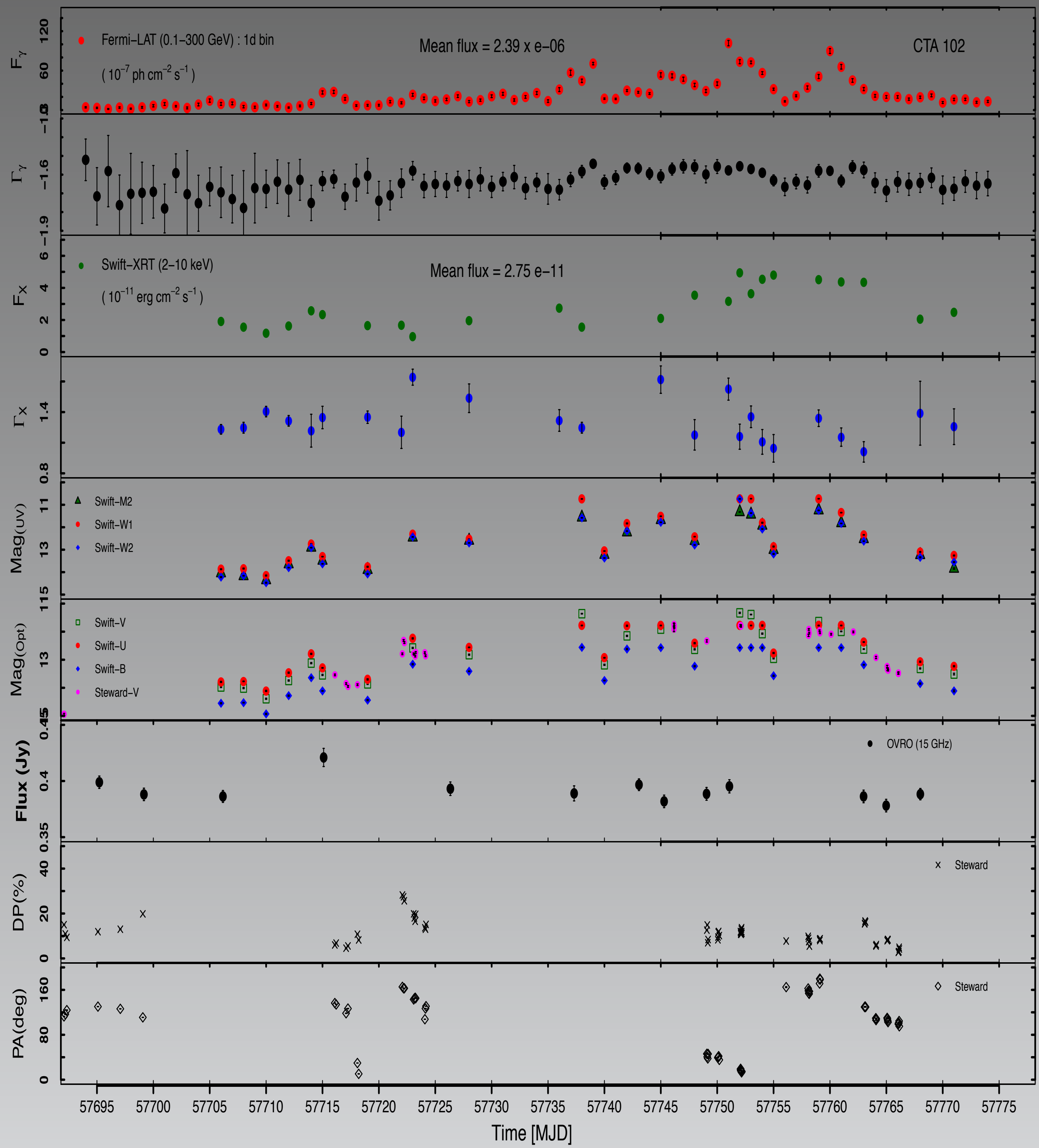
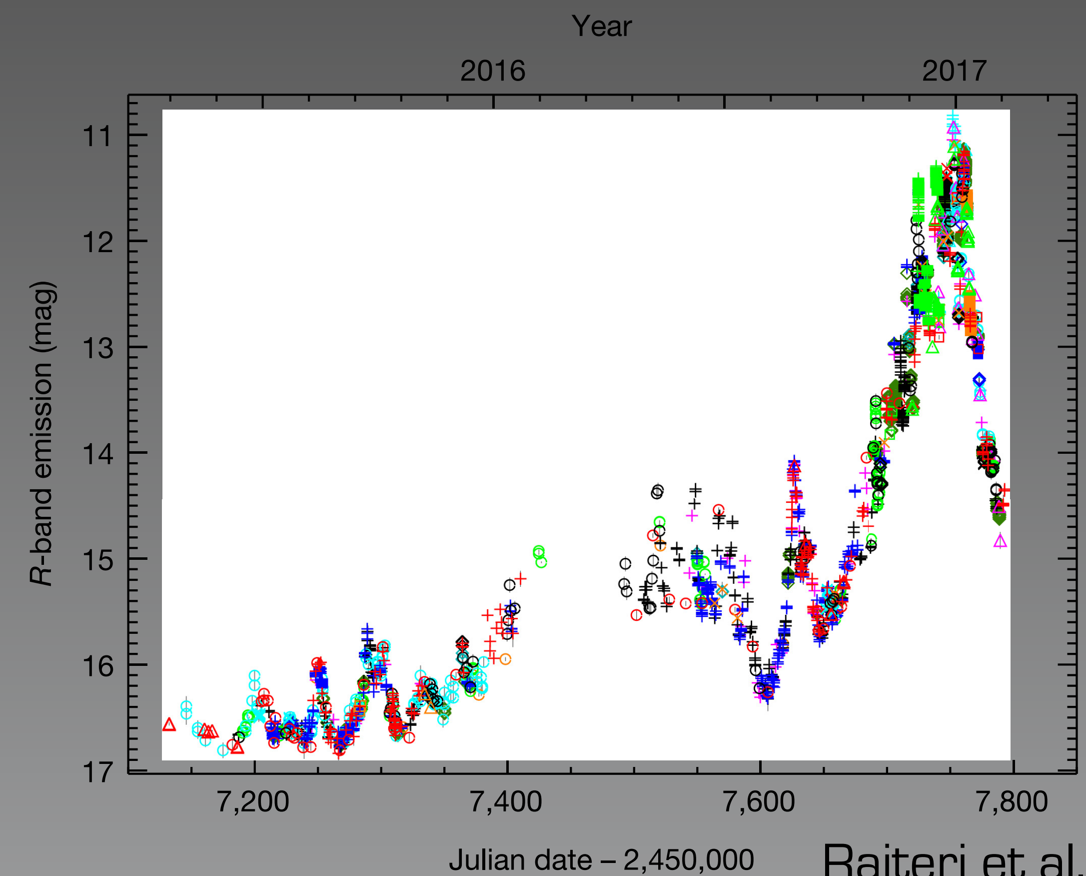
The multi-wavelength bright flare in December 2016 - January 2017

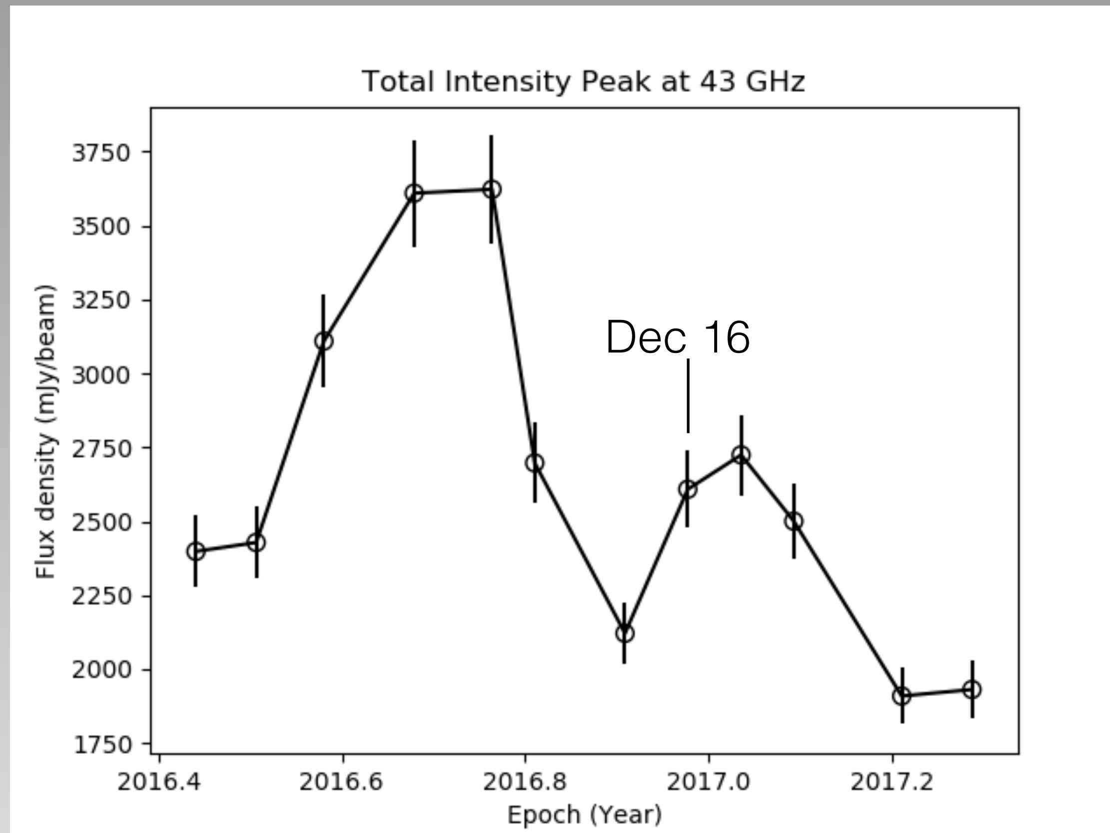
Multi-wavelength flare in December 2016 - January 2017



Kaur et al., 2018

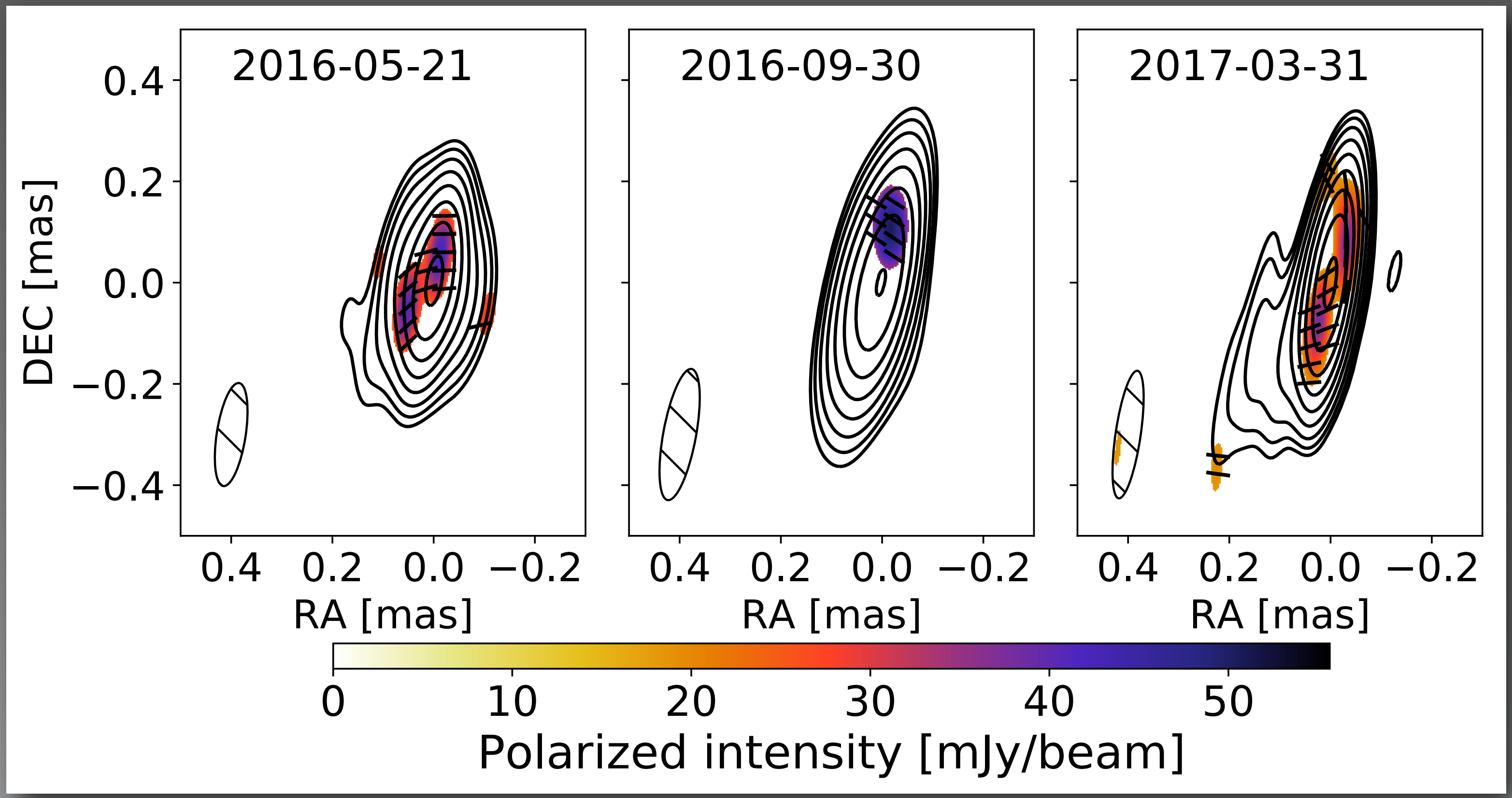


Raiteri et al., 2017



Rotation Measure analysis: the case of CTA 120

Casadio et al., 2018 A&A (accepted)
2018arXiv181202194C



GMVA - 3mm

beam ~ 0.25 X 0.05 mas

Total Intensity peaks:
2.0, 1.8, 3.8 Jy/beam

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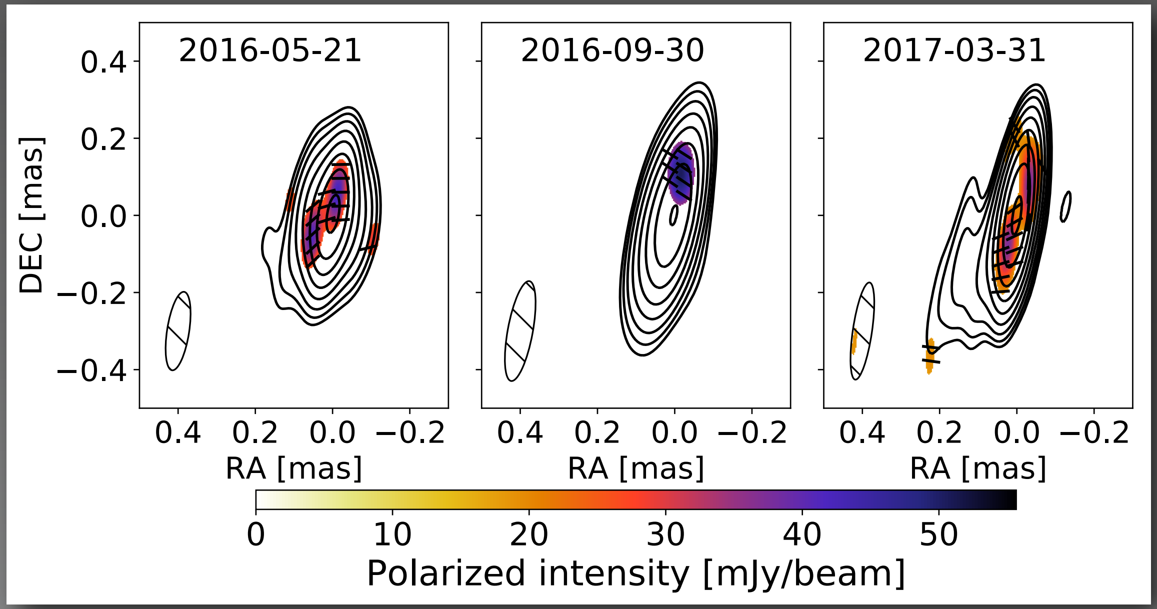

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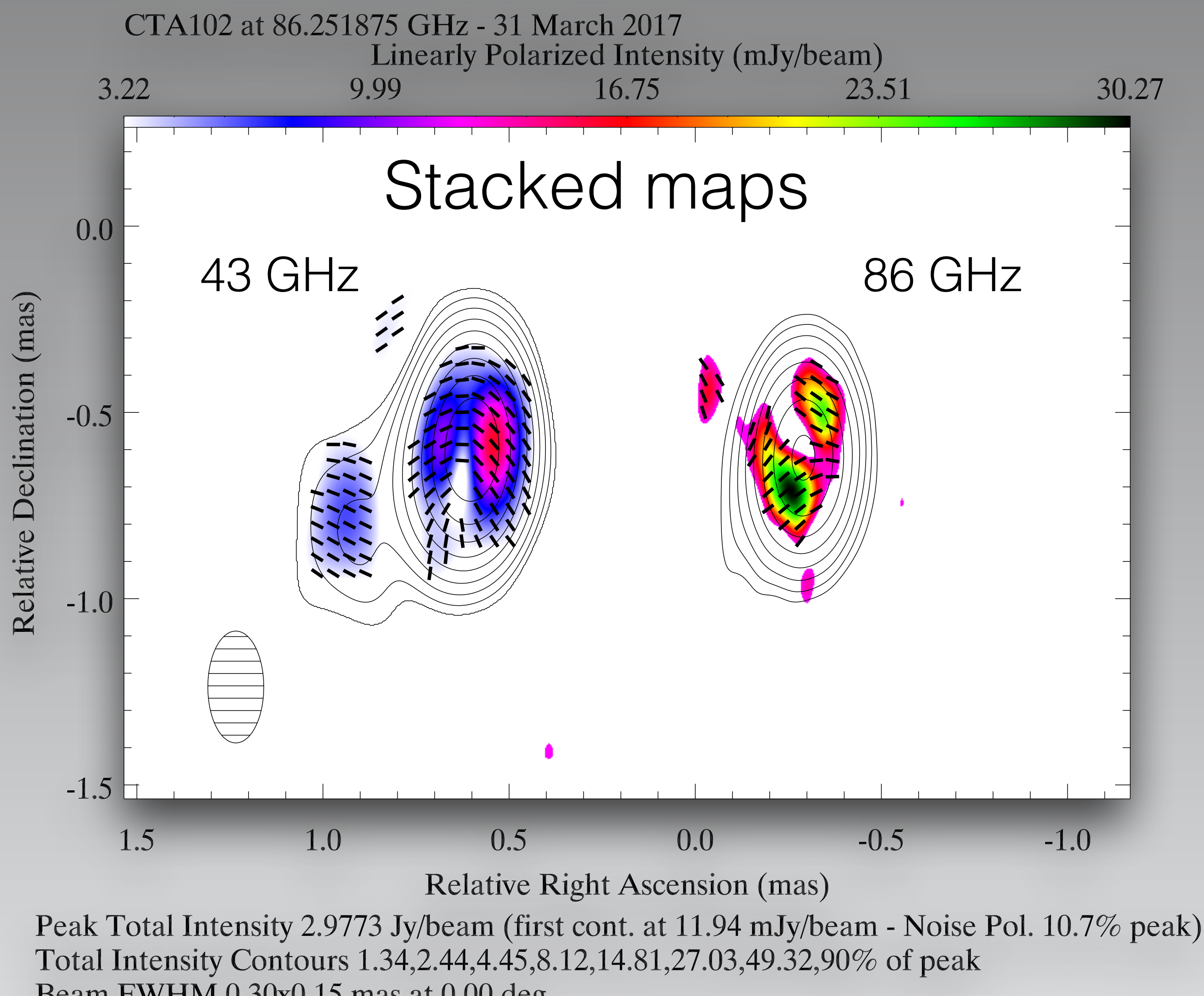

Stacked map at 43 GHz : June 2016 - April 2017

Stacked at 86 GHz : May, Sept 2016 and March 2017

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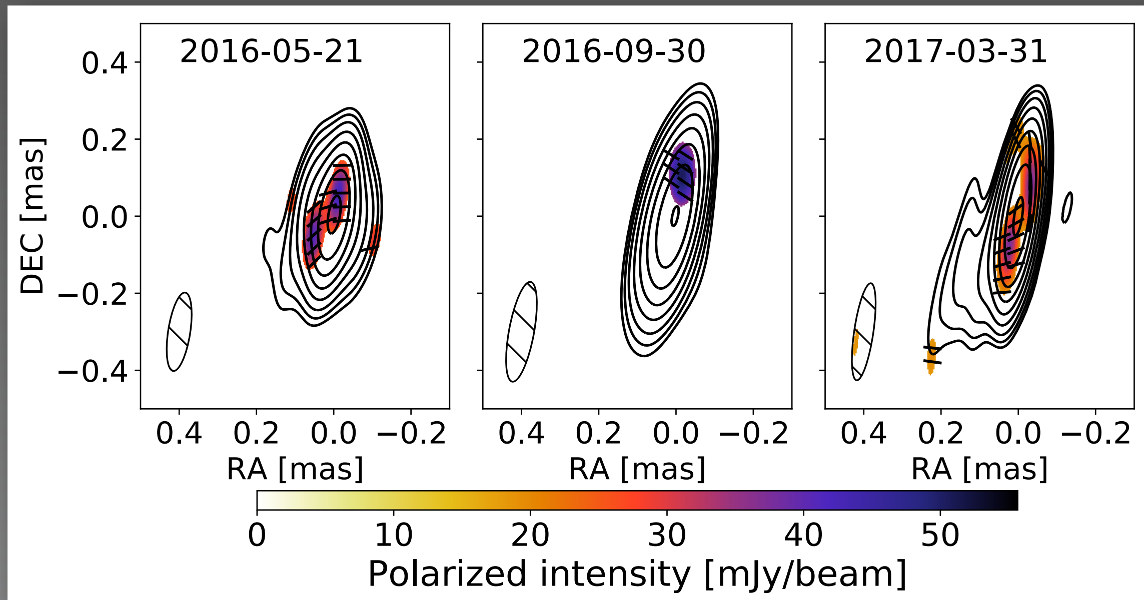

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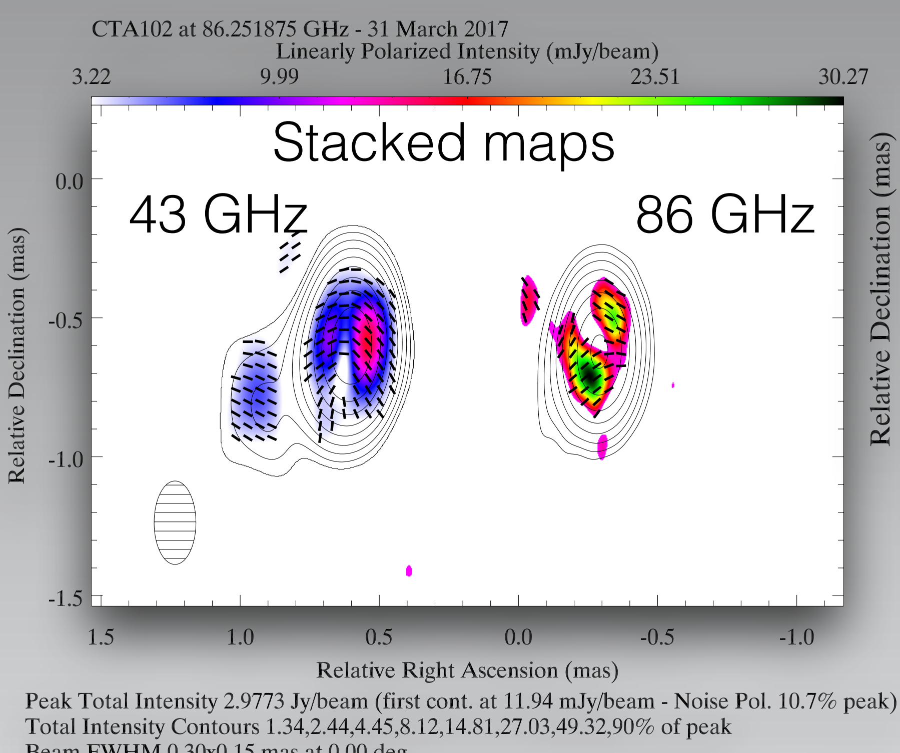

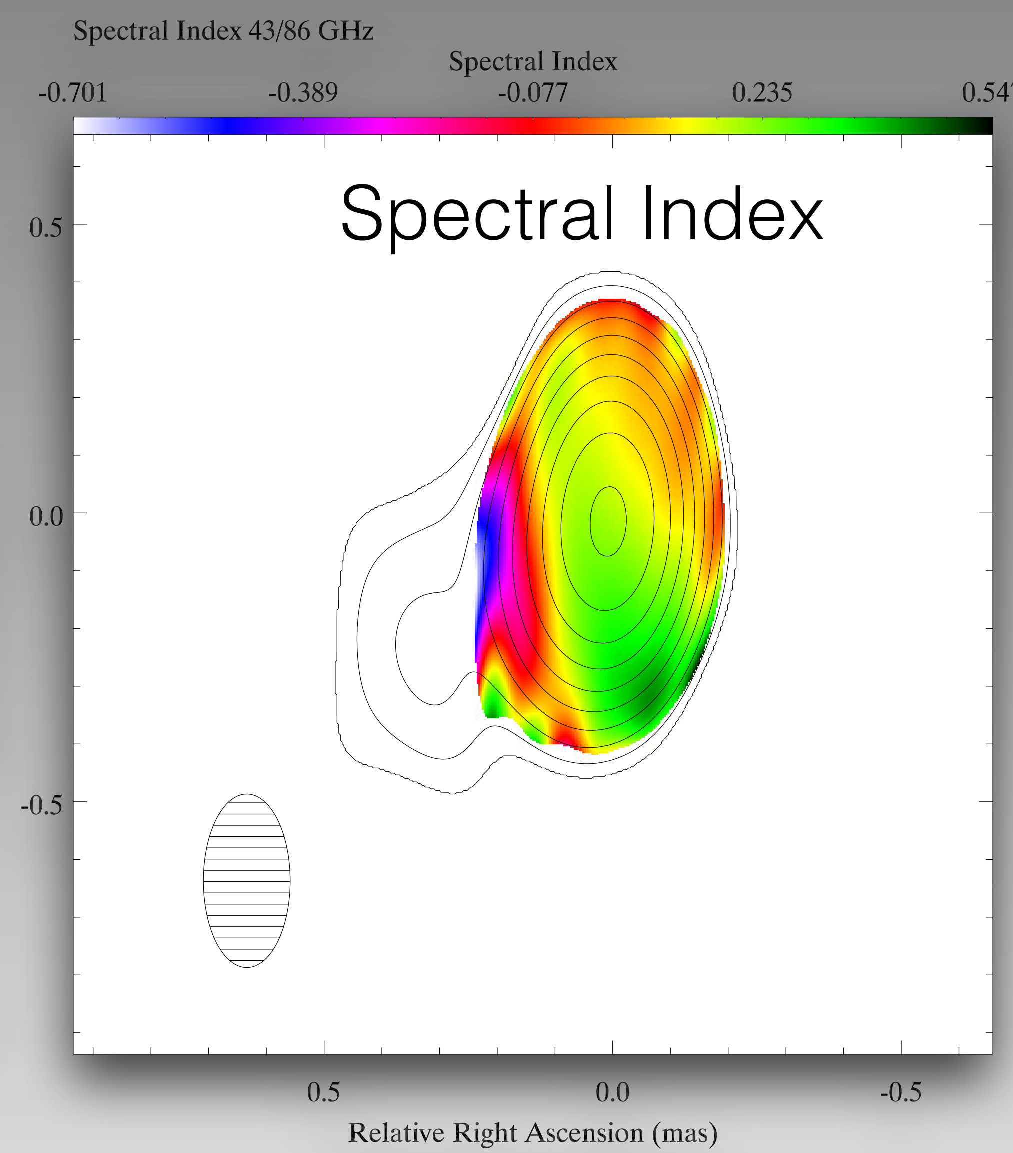

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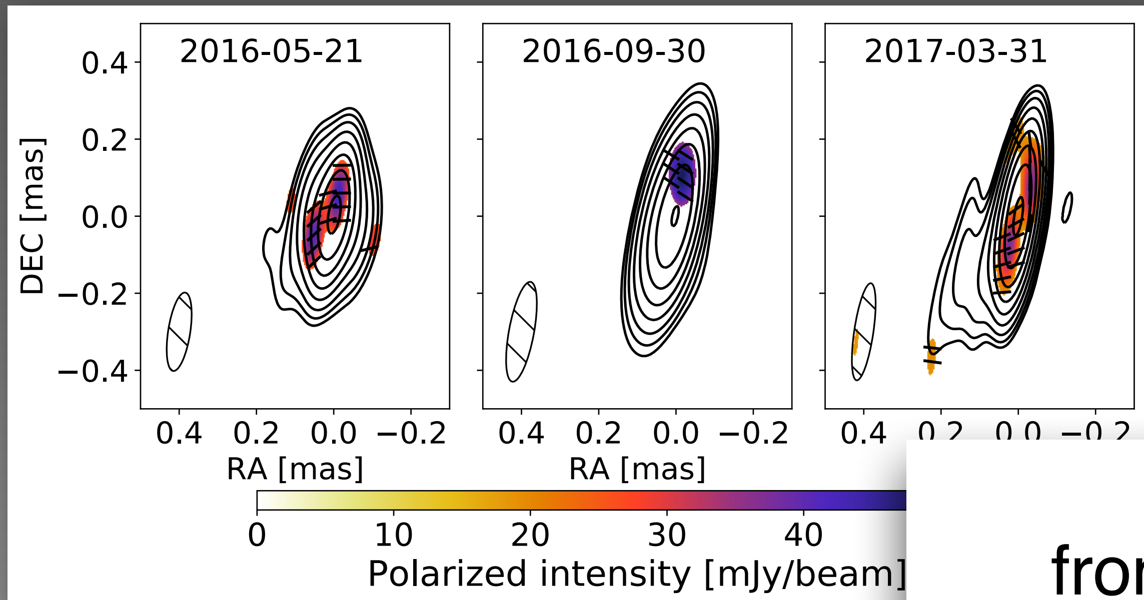

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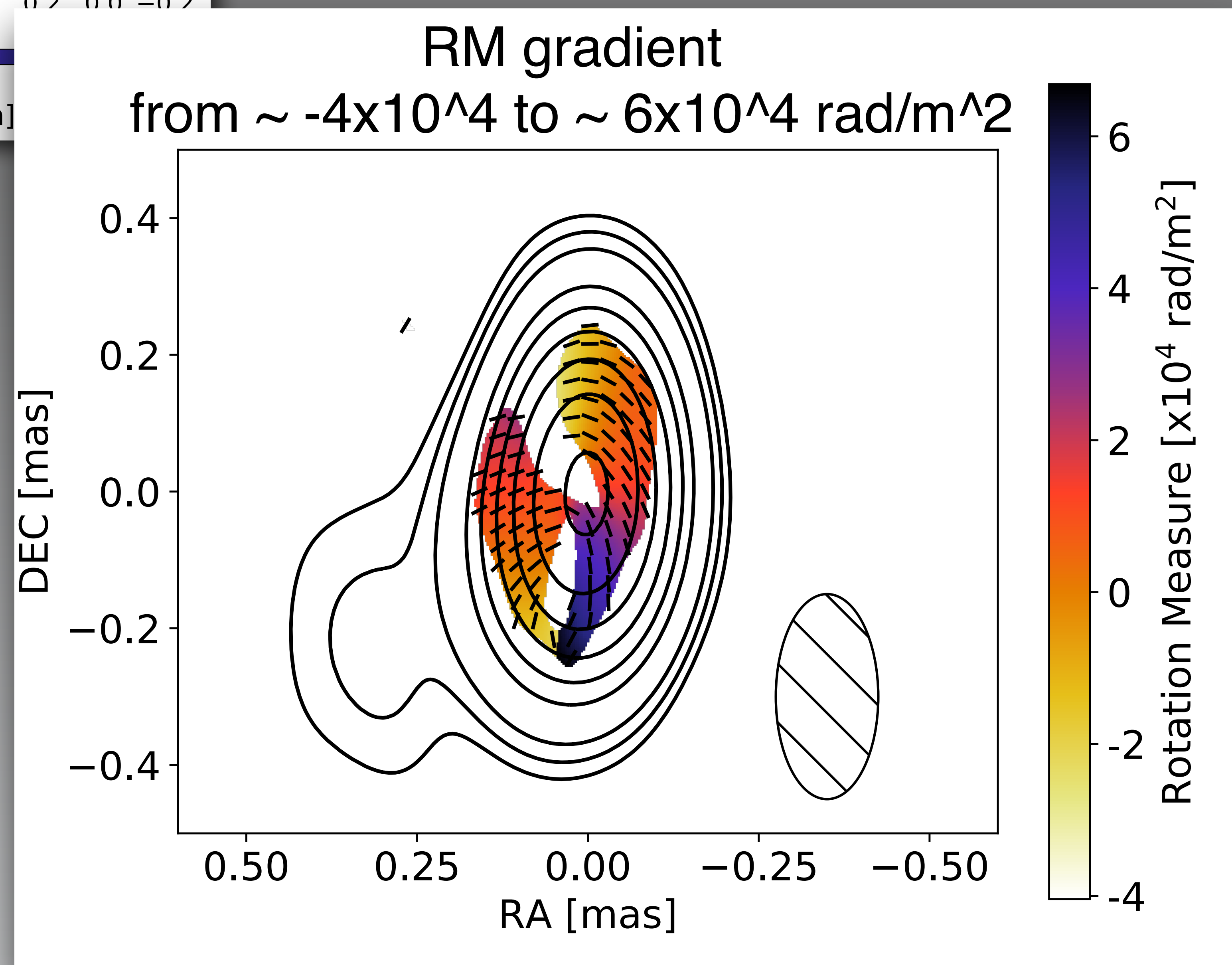

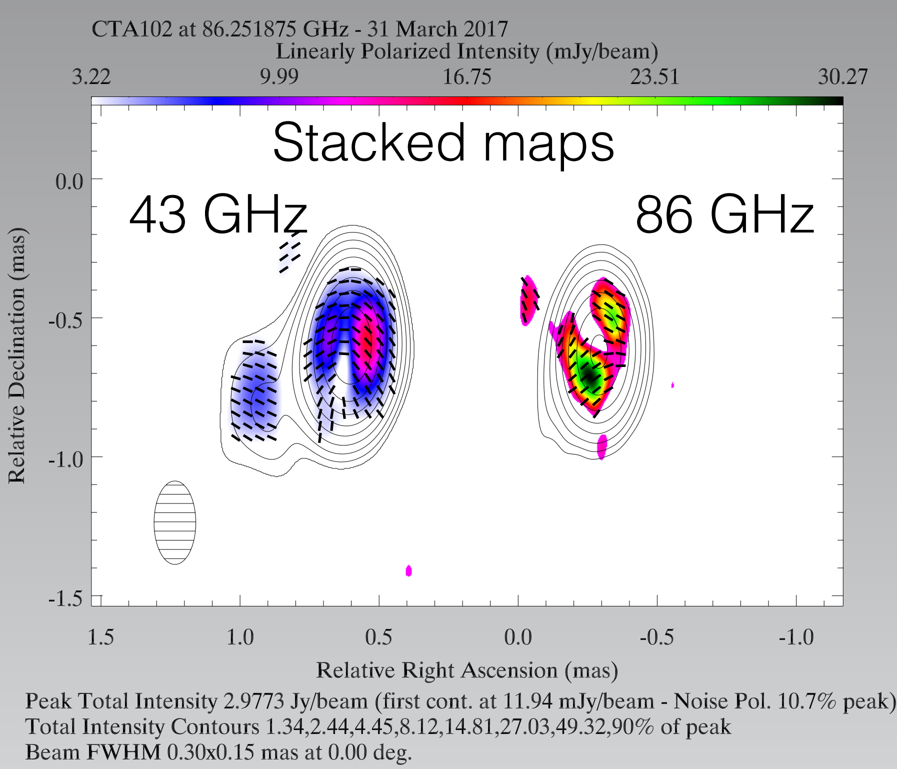

In agreement with Jorstad et al. 2017 and Park et al., 2018

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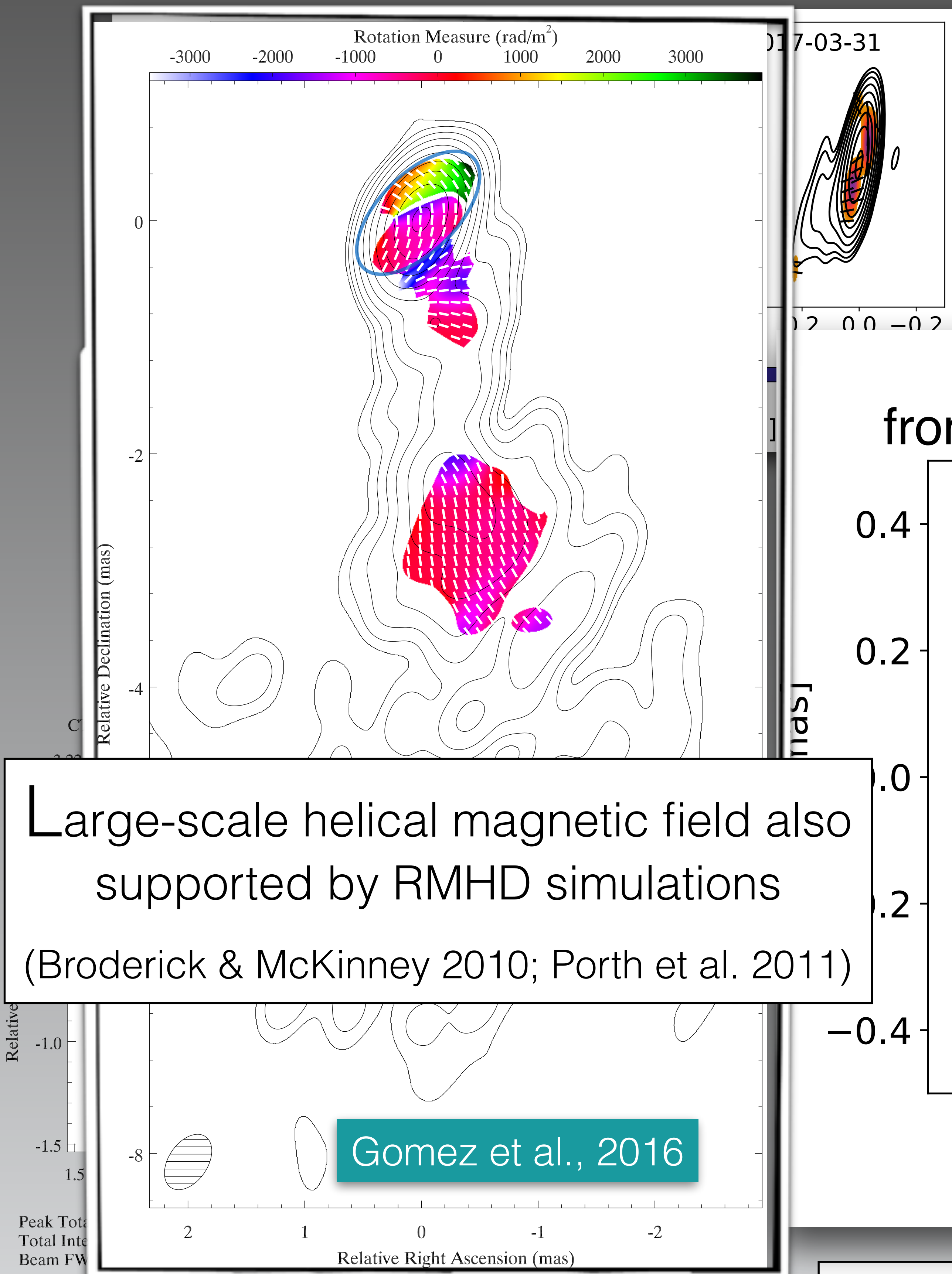
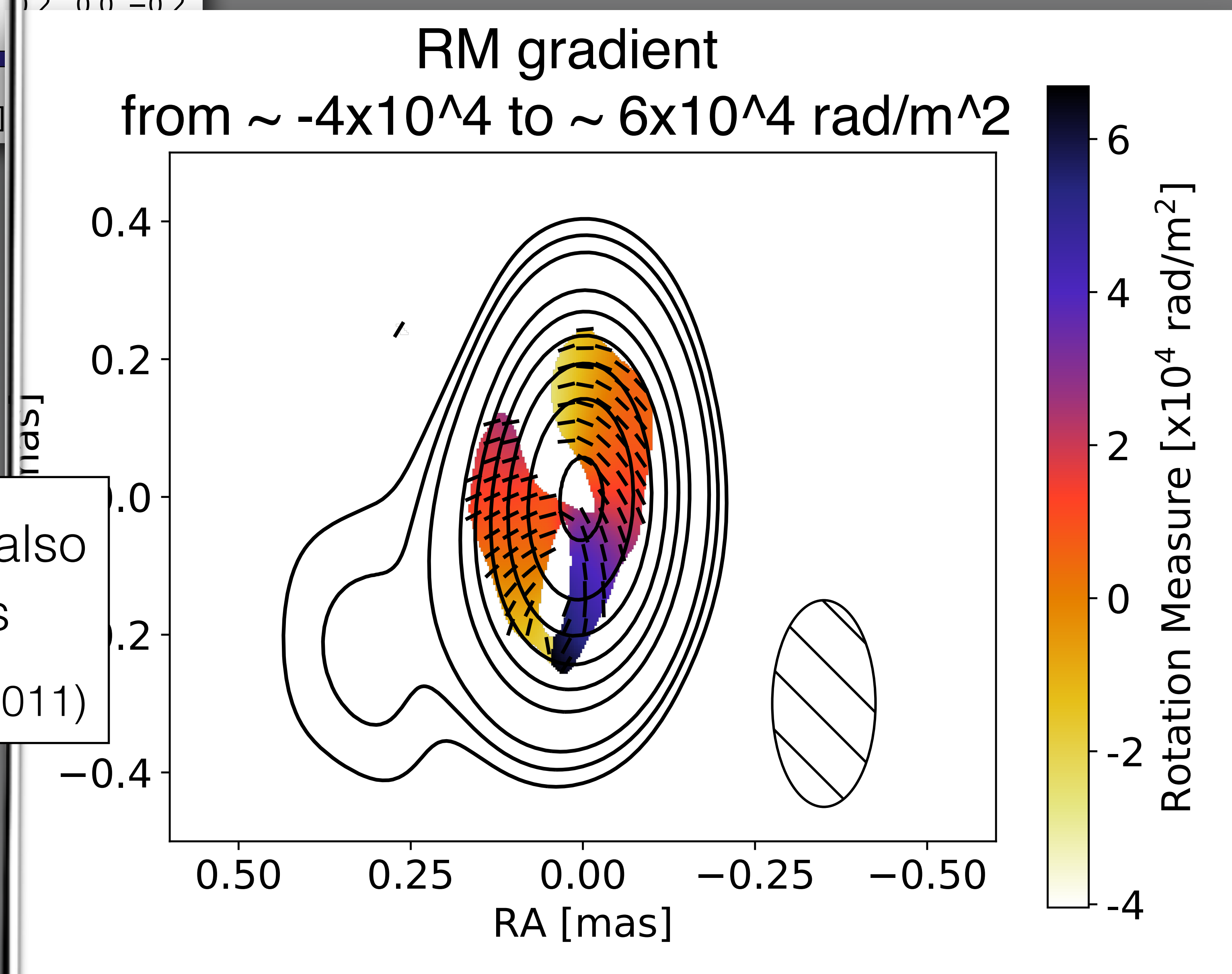


Large-scale helical magnetic field also supported by RMHD simulations

(Broderick & McKinney 2010; Porth et al. 2011)

Gomez et al., 2016



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High-energy flares

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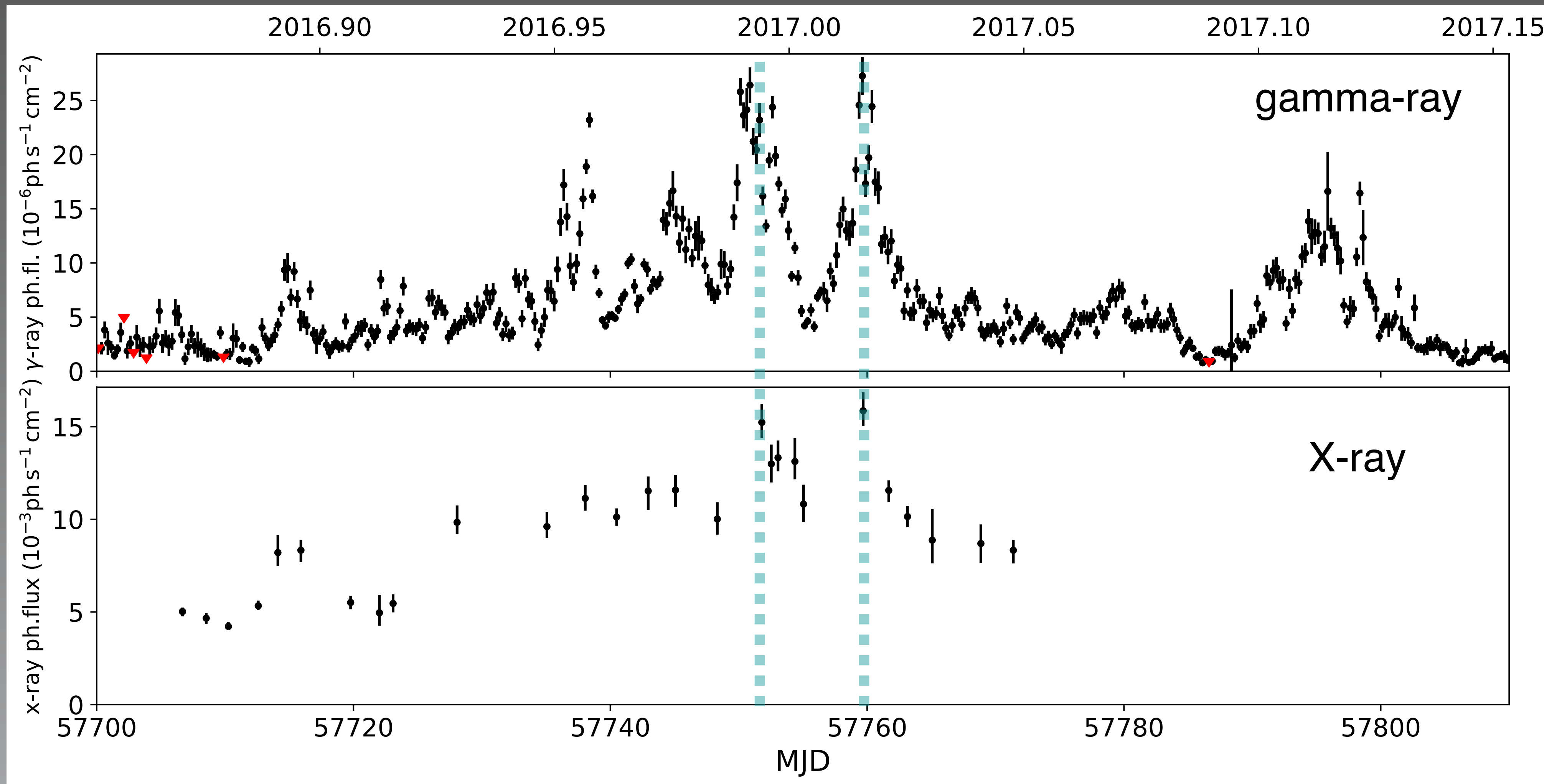


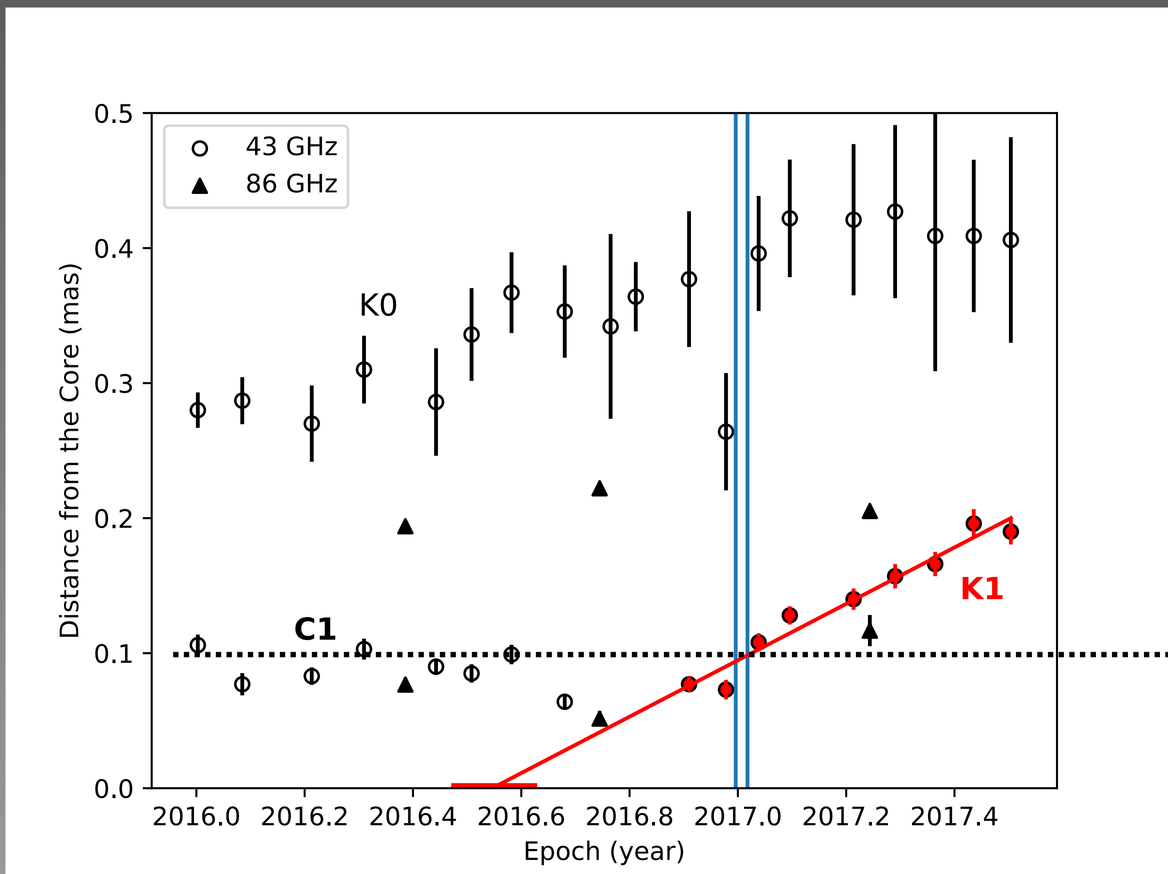
$$\delta \geq \left[5 \times 10^{-4} (1+z)^{-(4+2\alpha)} (1+z-\sqrt{1+z})^{-2} h_{75}^{2} \, T_5 \times \left(\frac{F_{\mathrm{keV}}}{\mu\mathrm{Jy}}\right)^{-1} \left(\frac{E_\gamma}{\mathrm{GeV}}\right)^{-\alpha} \right]^{-(4+2\alpha)^{-1}} .$$

Mattox et al. 1993

57754 MJD $\delta \geq 17$
57760 MJD $\delta \geq 15$

MJD	α	h_{75}	T_5	F_{keV}	E_γ
57754	0.17	0.9	0.58	3.22	100
57760	0.29	0.9	1.72	4.14	100

Kinematics and Flux density variability at 43 GHz - VLBA-BU-BLAZAR program

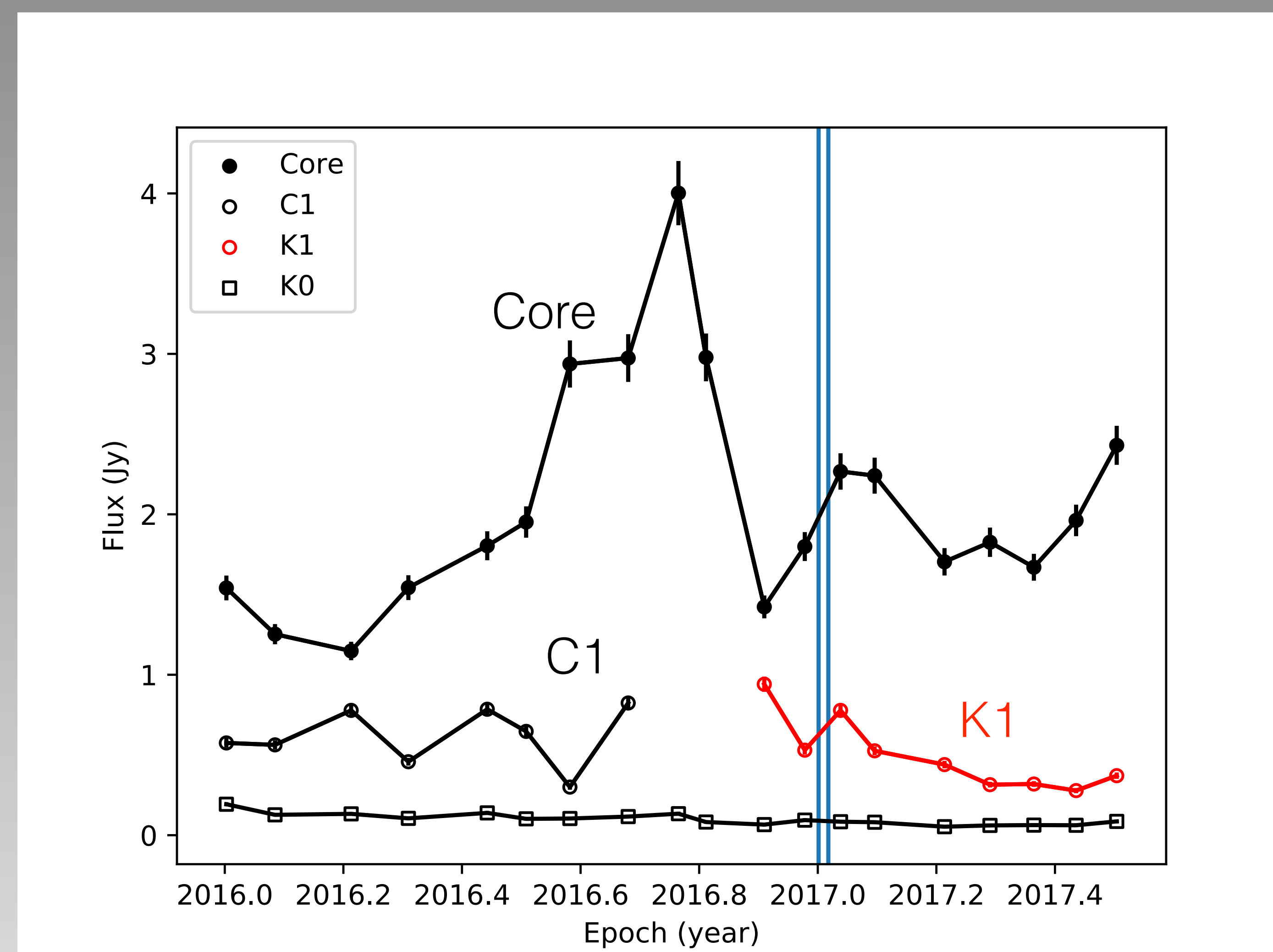


A new component (K1) has been ejected in July 2016 and it takes till November 2016 to exit from the core

$\beta_{app} = 11.5 \pm 0.9$ c

Stationary component at ~ 0.1 mas reported in previous studies (Jorstad et al., 2001,2005) and interpreted as a recollimation shock (From et al., 2013; Casadio et al., 2015)

Small increase in flux when K1 crosses the component at 0.1 mas



Using the method in Jorstad et al. 2005:

$\delta_{var} \sim 34 \pm 4$

$\Theta_{var} \sim 0.9 \pm 0.2 \quad \Gamma_{var} \sim 20.9 \pm 1.9$

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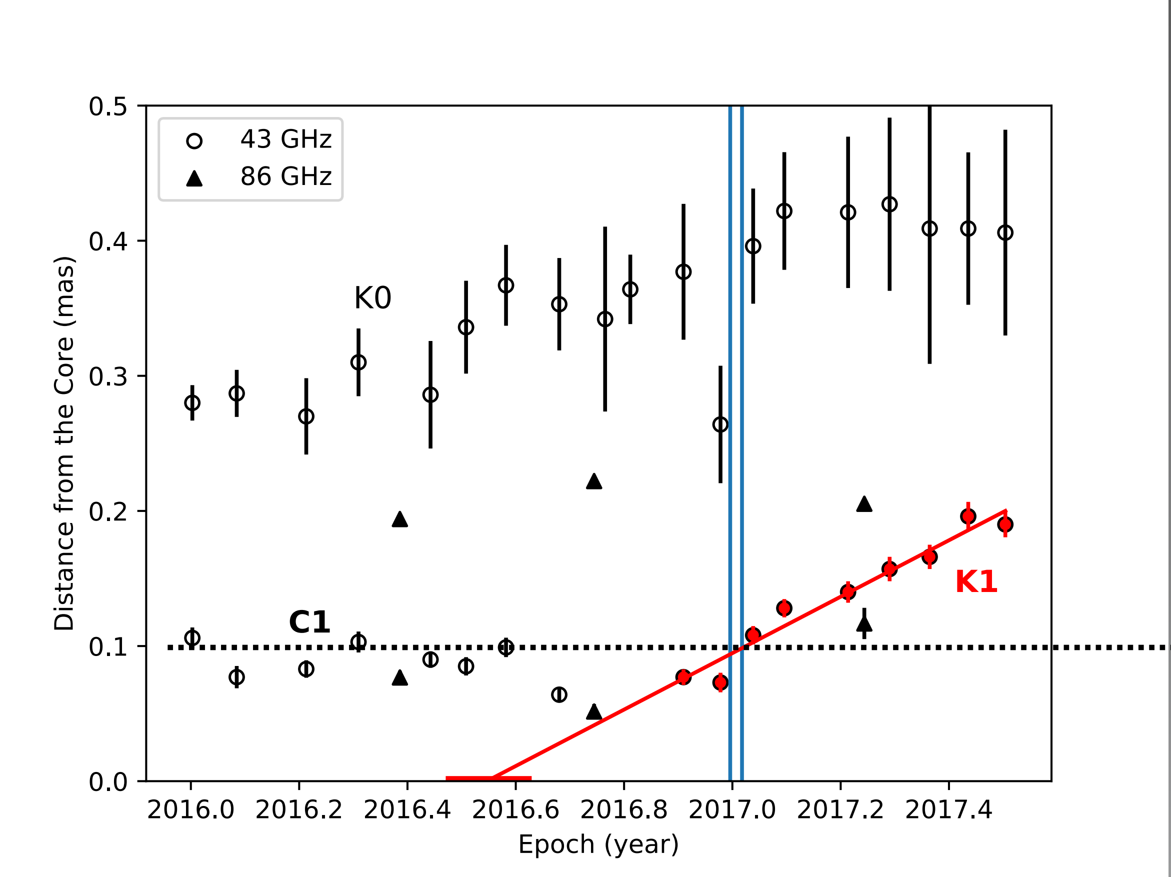

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$\delta_{var} \sim 34 \pm 4$

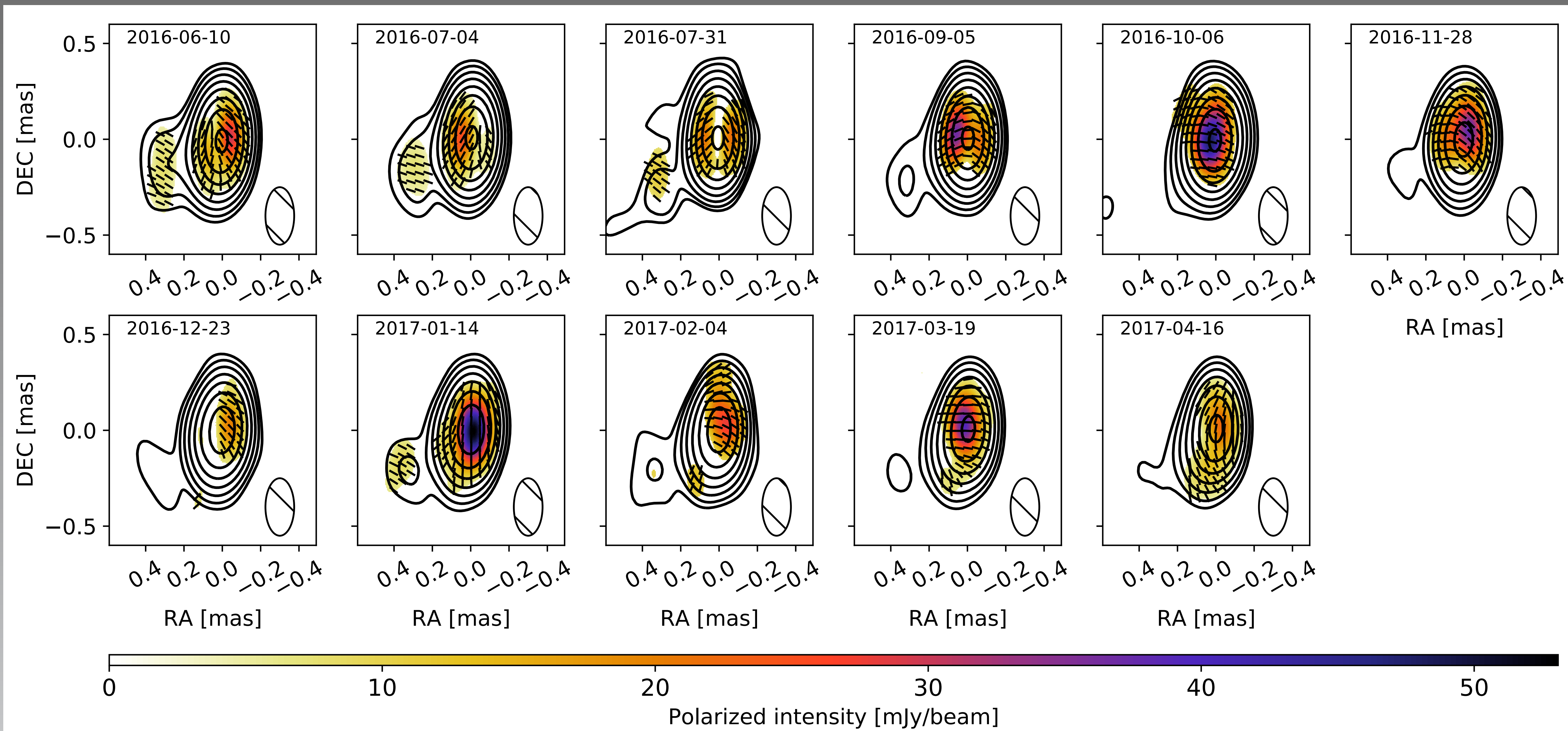
$\delta \gtrsim$ 17 to explain the X- and γ-ray emission

$\delta \sim 30$ to explain the optical flare

(Raiteri et al., 2017)

$\Theta_{var} \sim 0.9 \pm 0.2$ $\Gamma_{var} \sim 20.9 \pm 1.9$

Polarization variability from 43 GHz VLBA images



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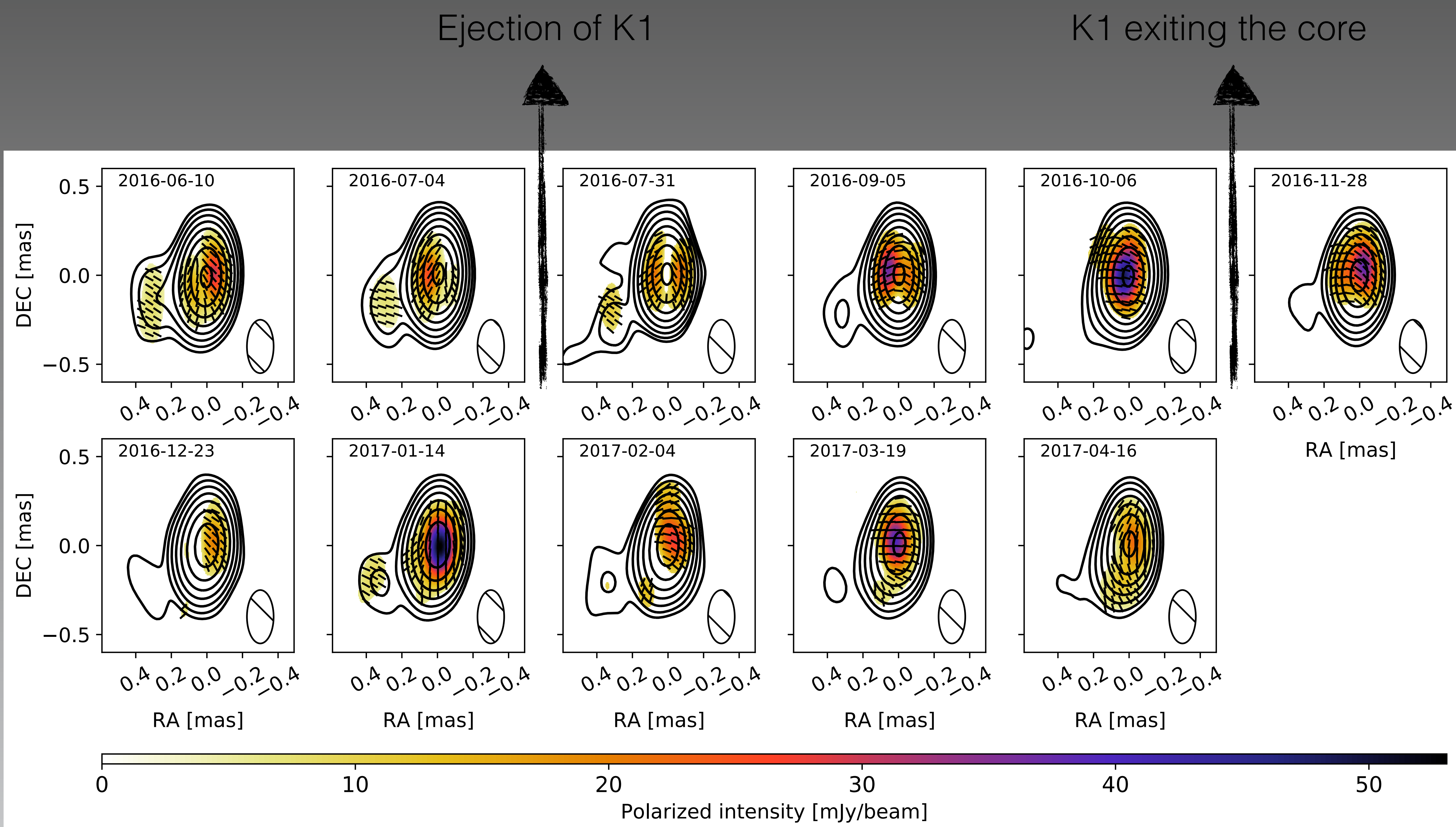

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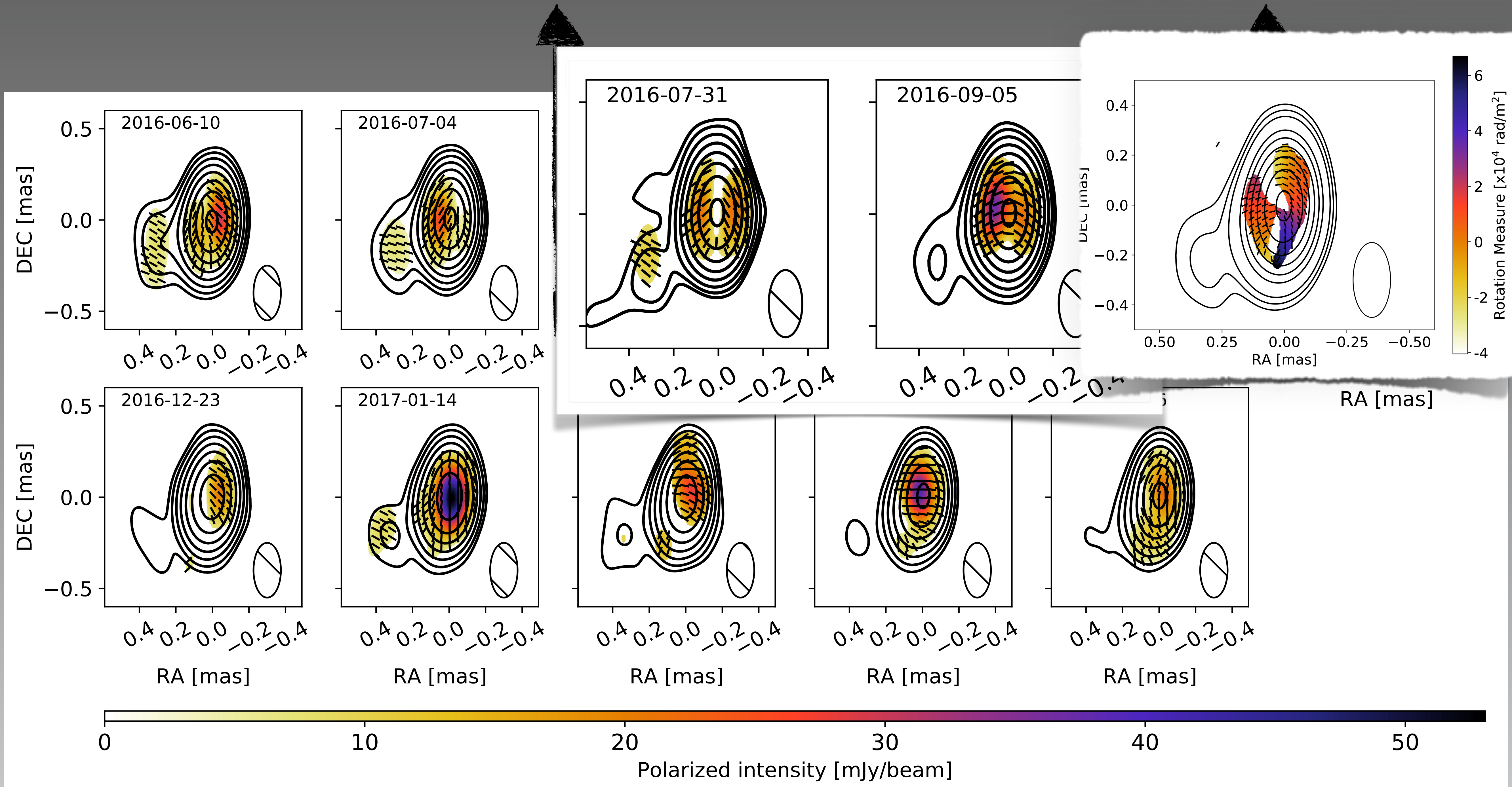
Ejection of K1

K1 exiting the core



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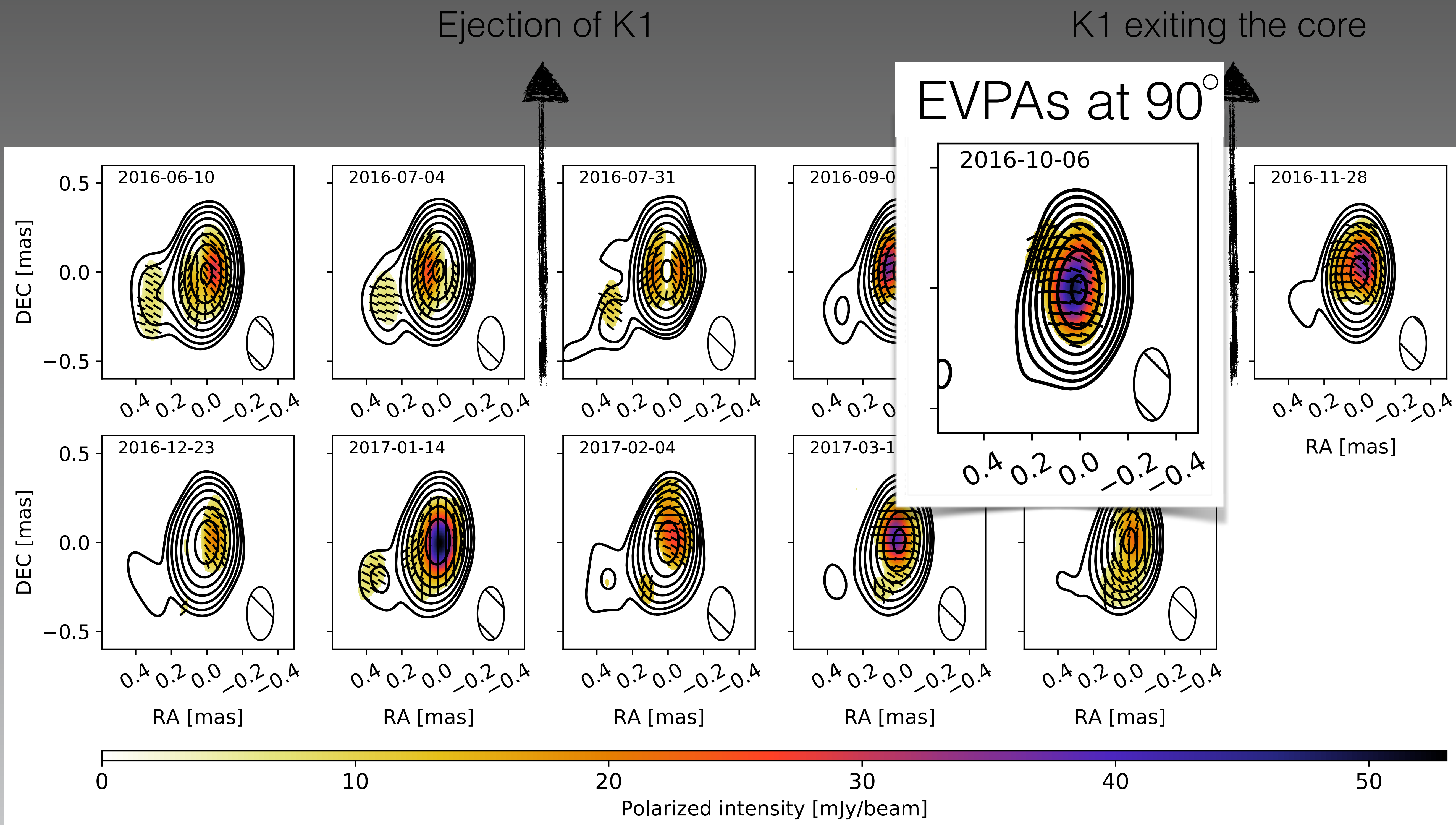

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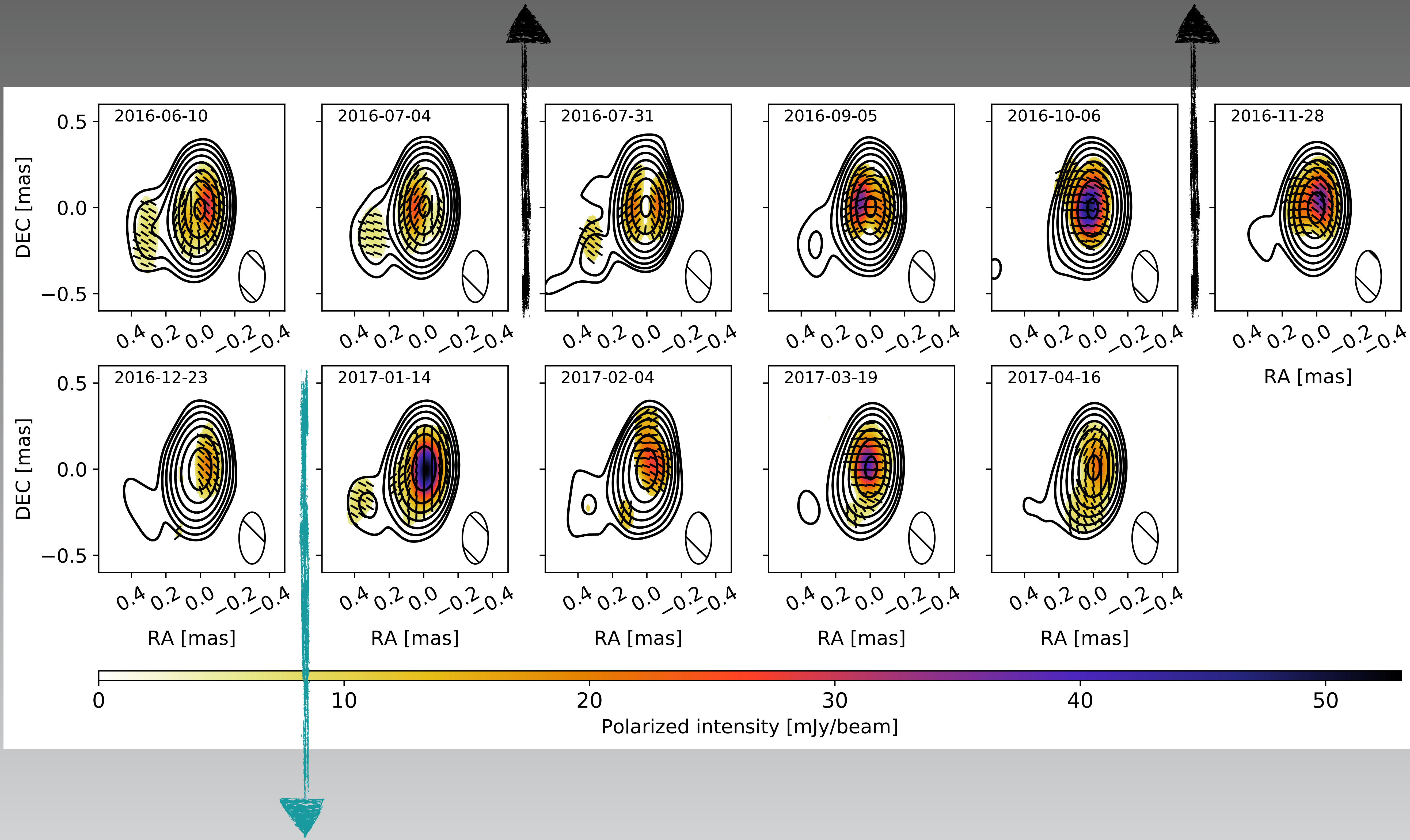

high-energy flares

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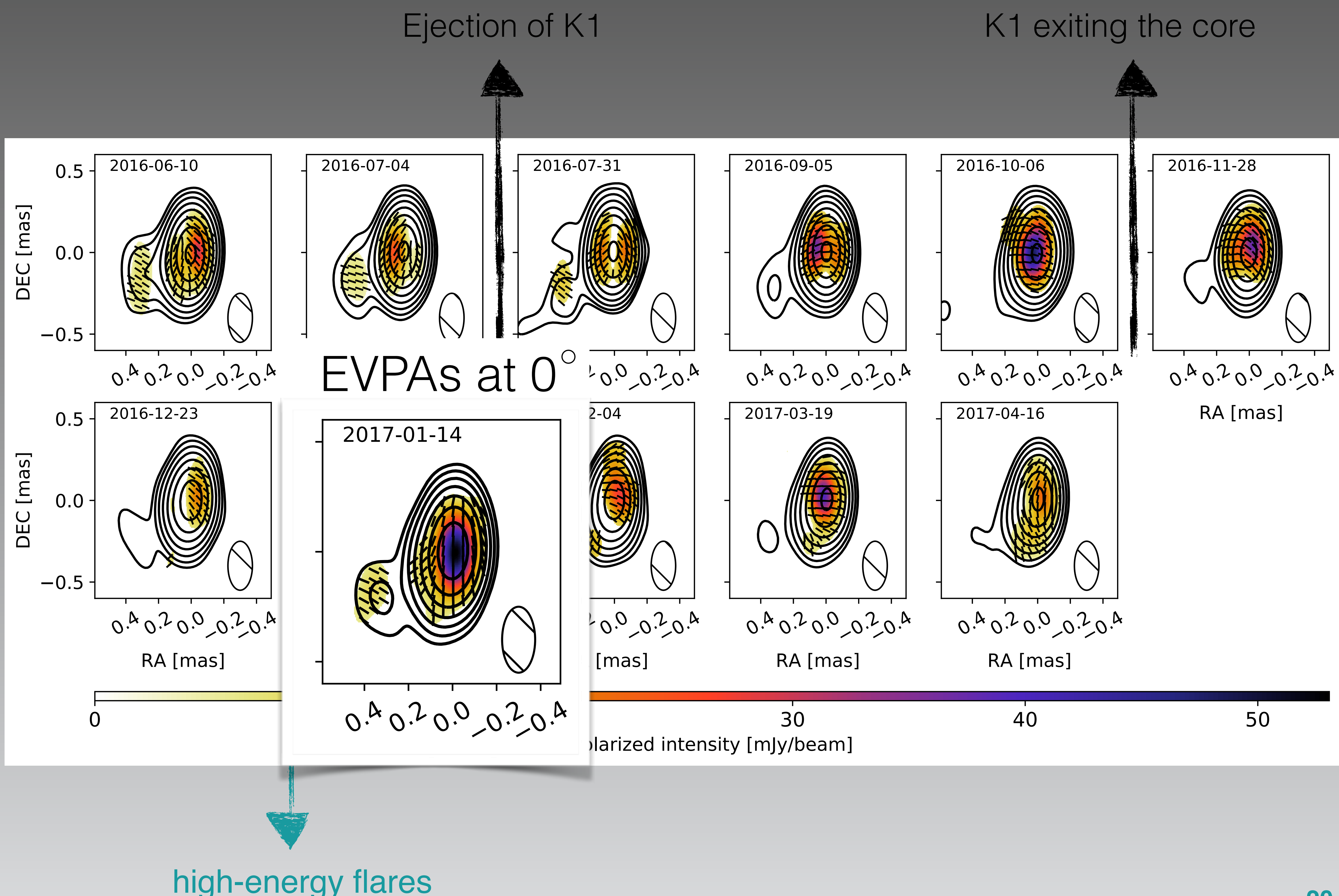

CONCLUSIONS

We present mm-VLBI polarimetric images of the FSRQ CTA 102 with the highest possible resolution currently achievable (50 μas), using 86 GHz GMVA data obtained in May 2016, September 2016, and March 2017.

Collecting 43 GHz VLBA data in the same time range we performed the *Faraday rotation* analysis between 43 and 86 GHz:

→ RM gradient from ~ -4x10^4 to 6x10^4 rad/m^2 around the centroid of the core and a change of sign

→ The intrinsic EVPAs rotate around the centroid of the core

Hints for large-scale helical magnetic field in the innermost regions

Comparing mm-VLBI data with X- and γ-ray, we obtained:

→ the high-energy flares in Dec 2016 - Jan 2017 were triggered by the passage of a new superluminal component through the recollimation shock at 0.1 mas

From the evolution of the 43 GHz polarised emission when the new component travels along the jet, we have:

→ when the component travels across the core region the EVPA orientation resembles the intrinsic orientation as obtained in the RM map;

→ the EVPAs have a different orientation when the component exits the core (EVPAs ~ 90°) and the recollimation shock (EVPAs ~ 0°)