Monitoring the non-thermal universe, 18 - 21 September 2018 - Cochem

Delving Deeper into Blazar Cores with 3mm GMVA Polarimetric Observations

Carolina Casadio
(MPIfR)

**Alan Marscher, Thomas Krichbaum,
Svetlana Jorstad, Dmitry Blinov, Nicholas MacDonald,
José L. Gómez, Biagina Boccardi, Thalia Traianou, Iván Agudo, Anton Zensus**

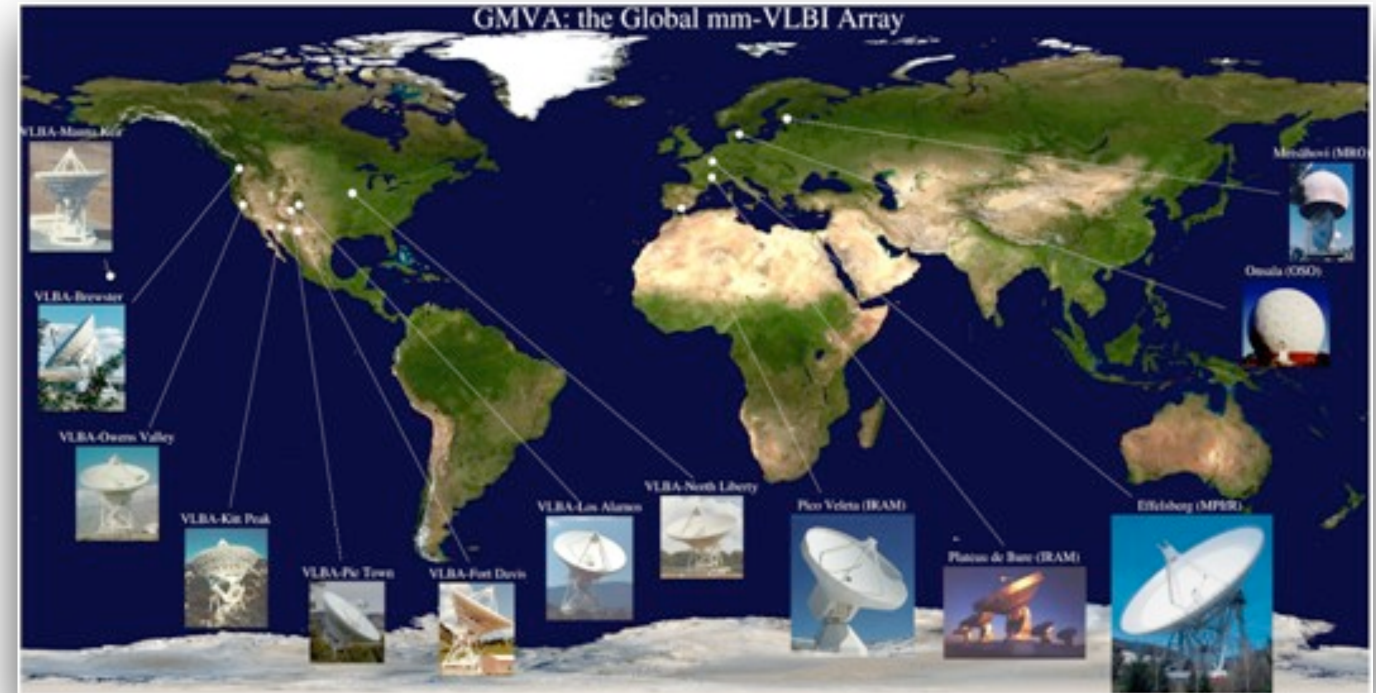
MAX PLANCK INSTITUTE
FOR RADIOASTRONOMY

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 and Requirements

Monitoring at 3mm (86 GHz) : HIGHER resolution + LOWER opacity

Monitoring at 7mm (43 GHz) : HIGH cadence + more extended structure

GOALS:

✓Magnetic Field structure in the very inner regions of AGN jets, with unprecedented resolution

✓Variability and physical process occurring in inner regions during high-energy flares

GMVA observations

21 May 2016

Antennas

VLBA + EF + ON + YS + KVN

Sources

3C111
3C120
3C273
3C345
3C454.3
0716+714
0954+658
1510-089
1633+382
BL LAC
CTA102
OJ287

30 Sept 2016

Antennas

VLBA (- MK) + EF + ON + YS + MH + GBT + KVN

Sources

3C345
3C454.3
0716+714
0954+658
1055+018
1510-089
1633+382
1749+096
BL LAC
CTA102
OJ287

31 March 2017

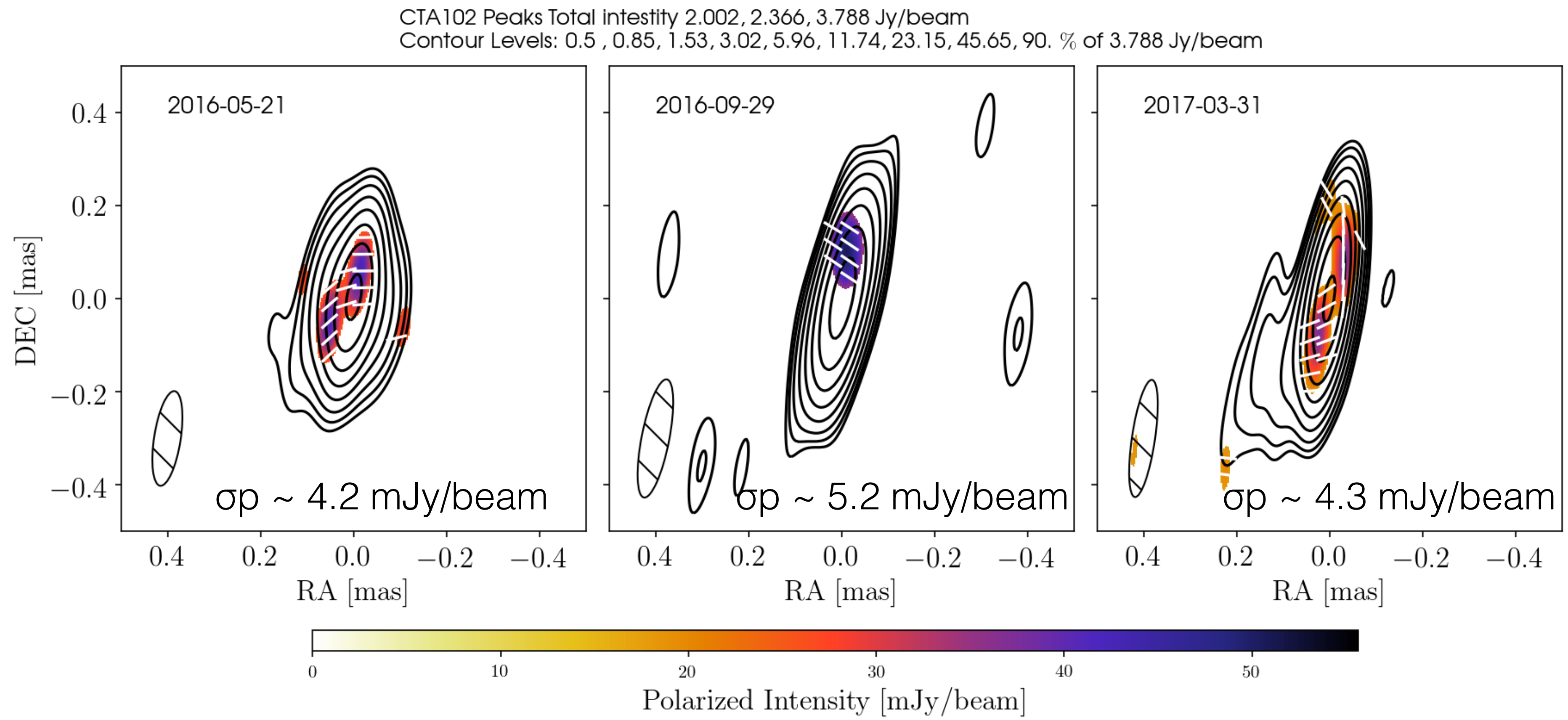
Antennas

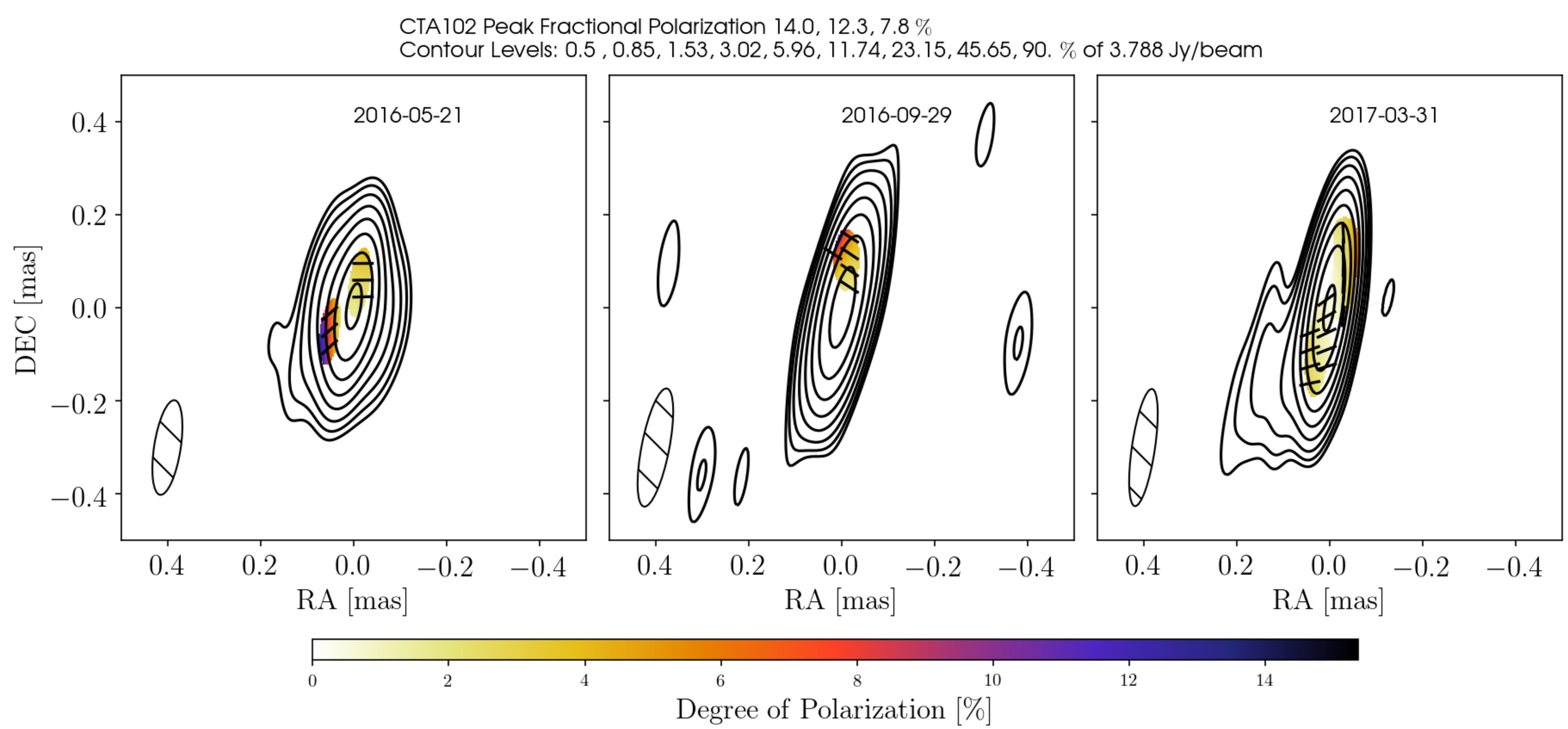
VLBA + EF + ON + YS + MH + PV + GBT +

Sources

3C120
3C273
3C279
3C345
3C454.3
0716+714
1510-089
1633+382
1749+096
BL LAC
CTA102
OJ287

CTA102

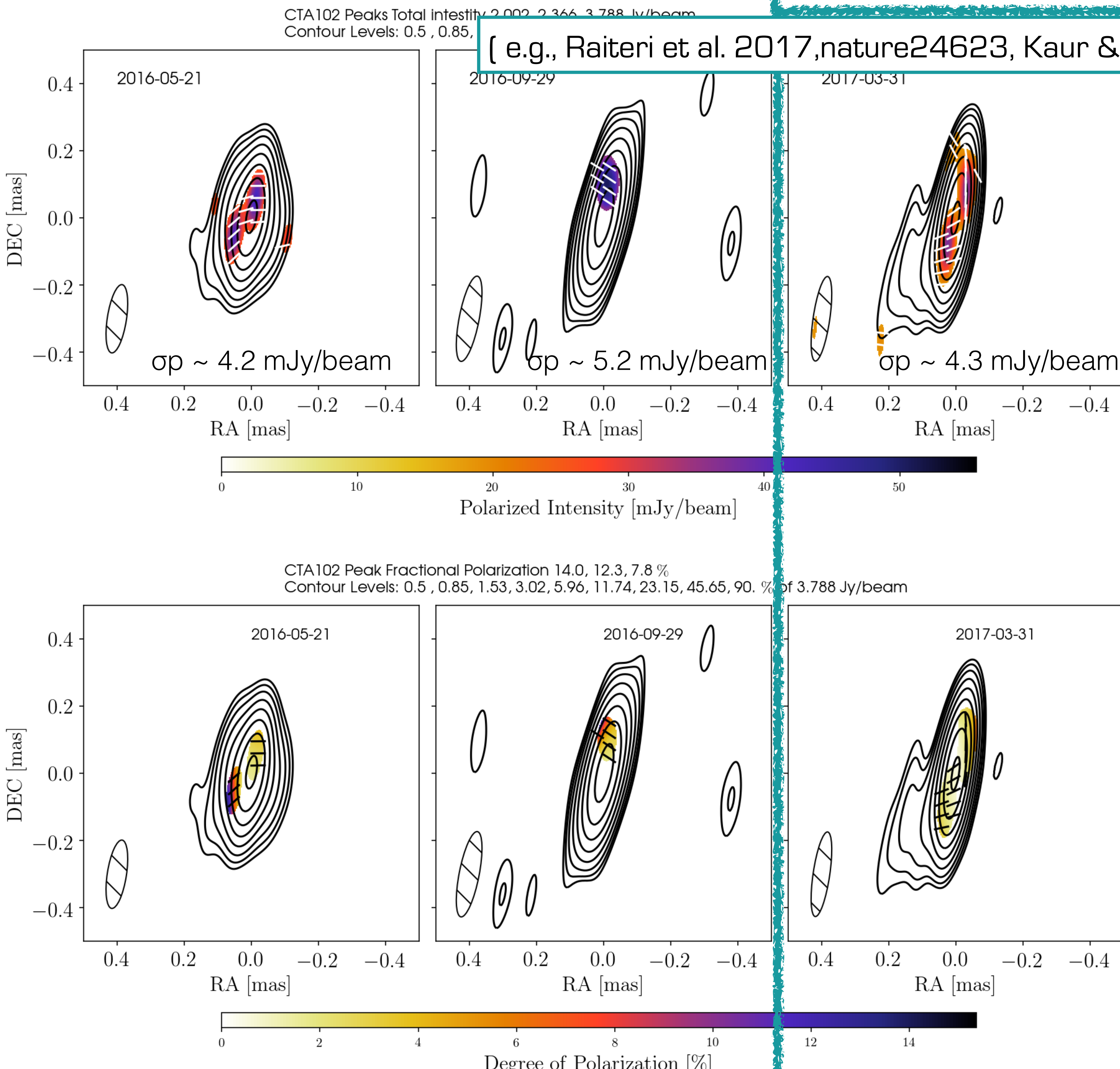

CTA102 Peaks Total intestity 2.002, 2.366, 3.788 Jy/beam
Contour Levels: 0.5 , 0.85, 1.53, 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 3.788 Jy/beam
2016-05-21
2016-09-29
2017-03-31
σp ~ 4.2 mJy/beam
σp ~ 5.2 mJy/beam
σp ~ 4.3 mJy/beam
DEC [mas]
RA [mas]
Polarized Intensity [mJy/beam]


CTA102 Peak Fractional Polarization 14.0, 12.3, 7.8 %
Contour Levels: 0.5 , 0.85, 1.53, 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 3.788 Jy/beam
2016-05-21
2016-09-29
2017-03-31
DEC [mas]
RA [mas]
Degree of Polarization [%]

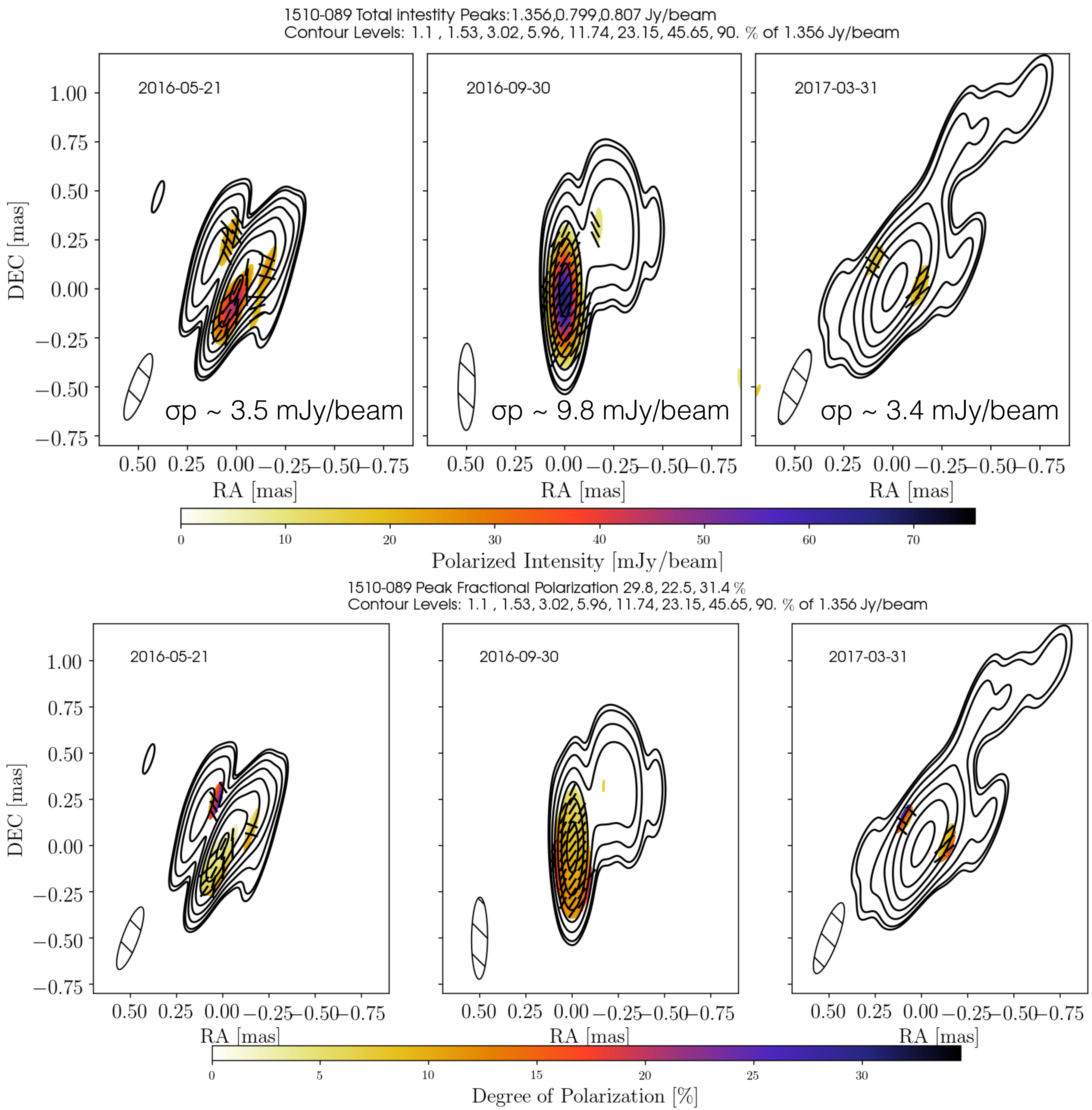
CTA102

gamma-ray, optical and X-ray flare

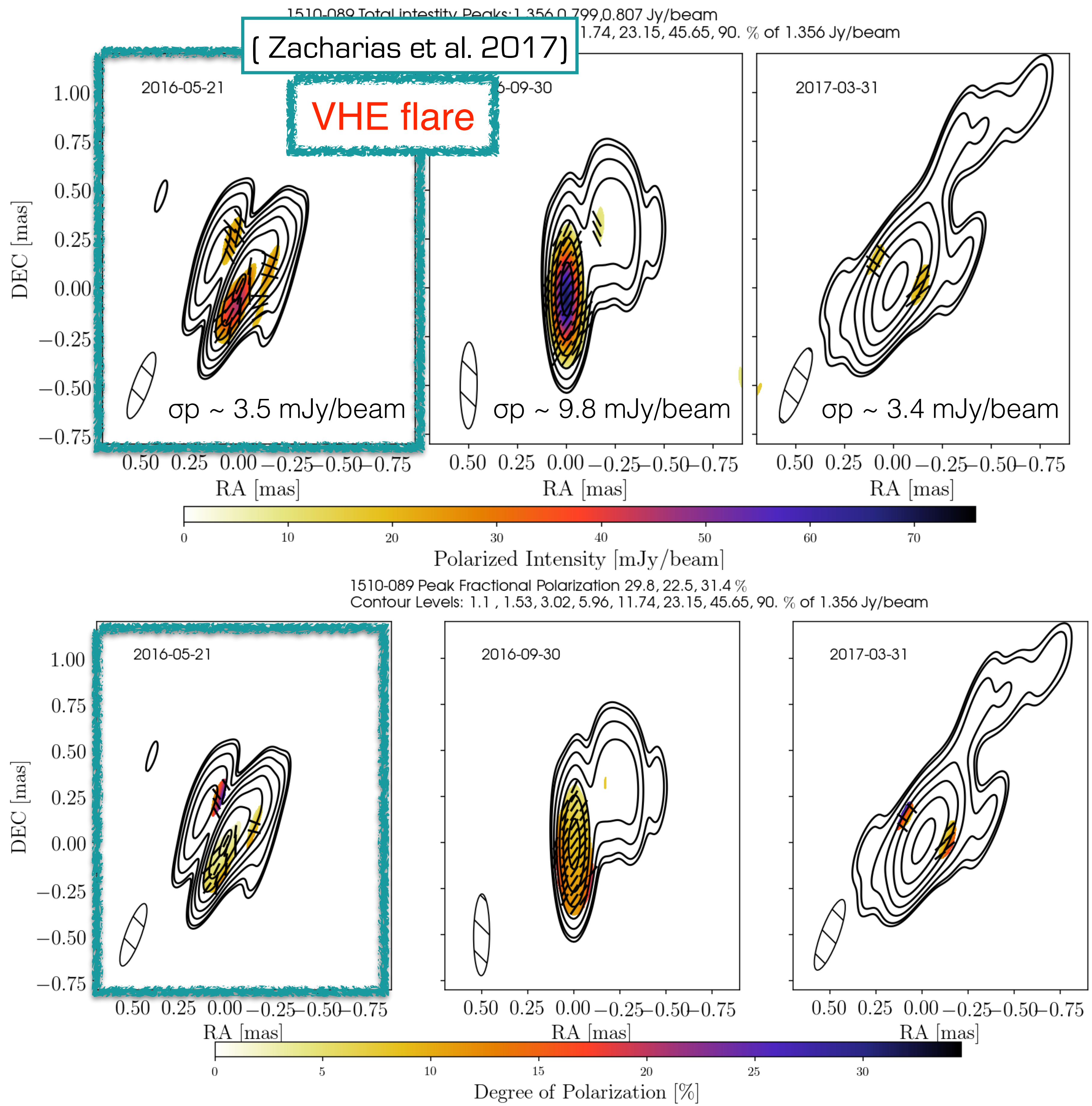
(e.g., Raiteri et al. 2017,nature24623, Kaur & Baliyan 2018)



1510-089

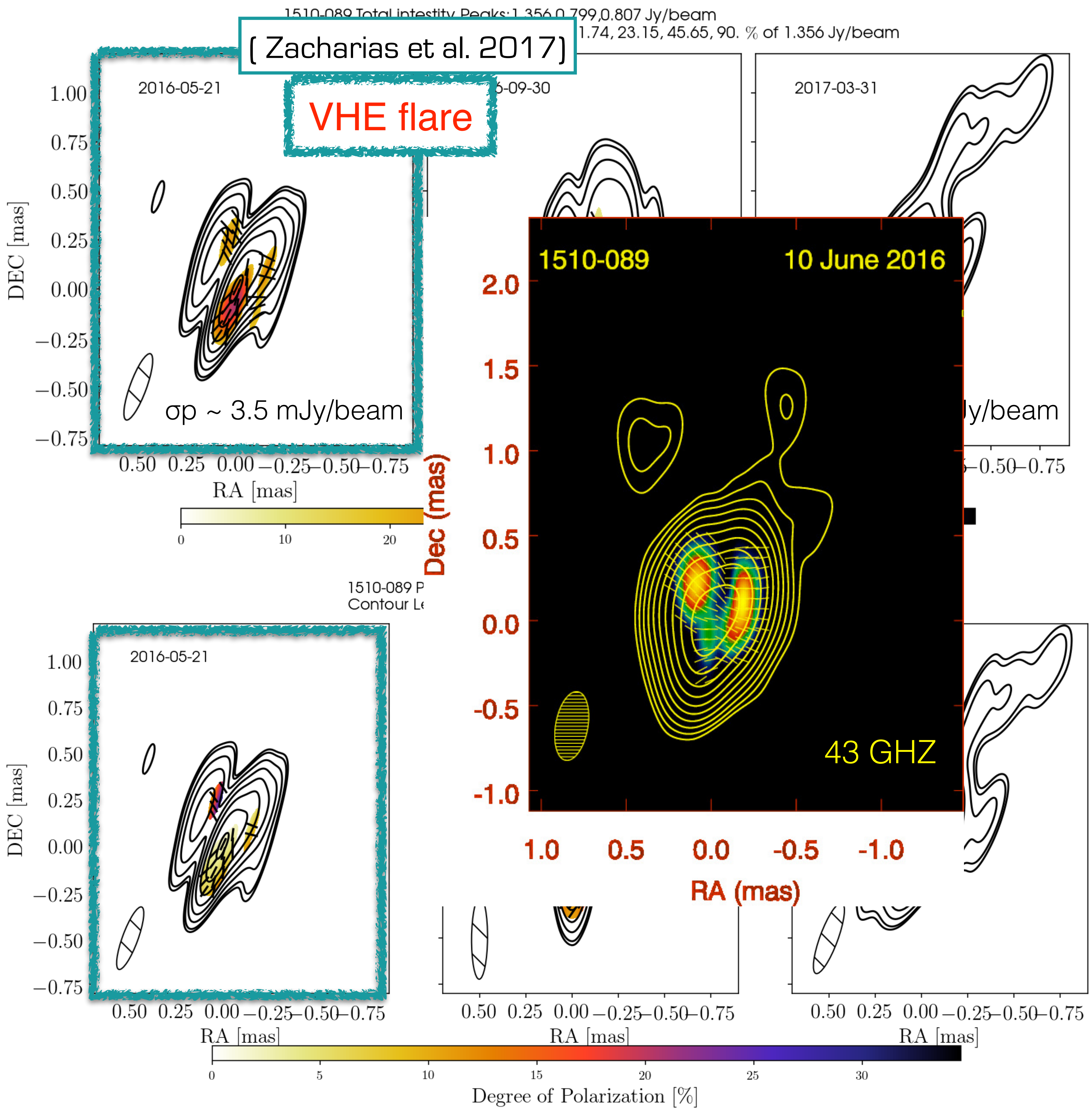

1510-089 Total intestity Peaks:1.356,0.799,0.807 Jy/beam
Contour Levels: 1.1 , 1.53, 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 1.356 Jy/beam
2016-05-21
2016-09-30
2017-03-31
σp ~ 3.5 mJy/beam
σp ~ 9.8 mJy/beam
σp ~ 3.4 mJy/beam
DEC [mas]
RA [mas]
Polarized Intensity [mJy/beam]
1510-089 Peak Fractional Polarization 29.8, 22.5, 31.4 %
Contour Levels: 1.1 , 1.53, 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 1.356 Jy/beam
Degree of Polarization [%]

1510-089



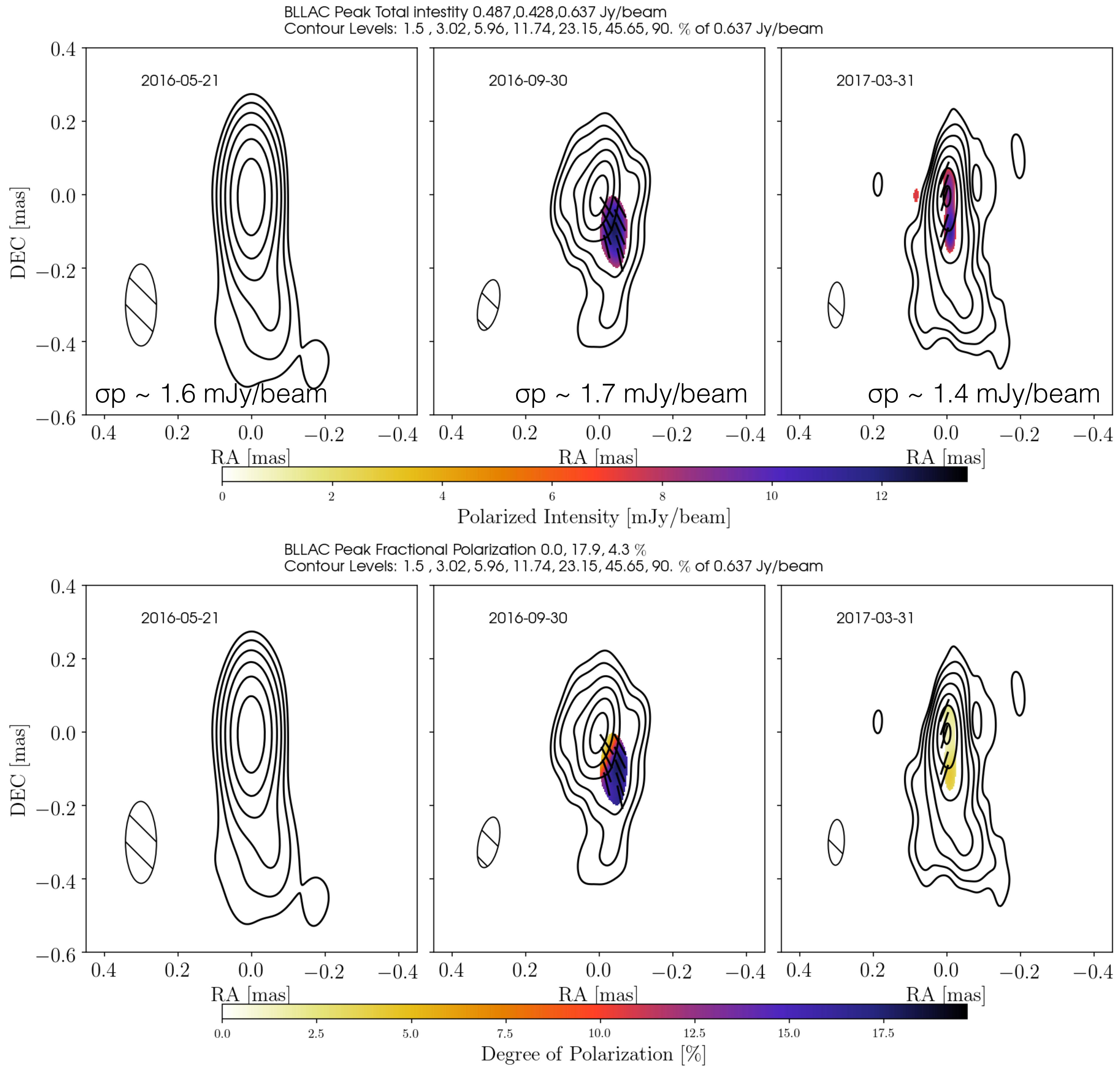
1510-089 Total Intensity Peaks: 1.356,0.799,0.807 Jy/beam
1.74, 23.15, 45.65, 90. % of 1.356 Jy/beam
(Zacharias et al. 2017)
VHE flare
2016-05-21
2017-03-31
σp ~ 3.5 mJy/beam
σp ~ 9.8 mJy/beam
σp ~ 3.4 mJy/beam
DEC [mas]
RA [mas]
Polarized Intensity [mJy/beam]
1510-089 Peak Fractional Polarization 29.8, 22.5, 31.4 %
Contour Levels: 1.1 , 1.53, 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 1.356 Jy/beam
2016-05-21
2016-09-30
2017-03-31
DEC [mas]
RA [mas]
Degree of Polarization [%]

1510-089



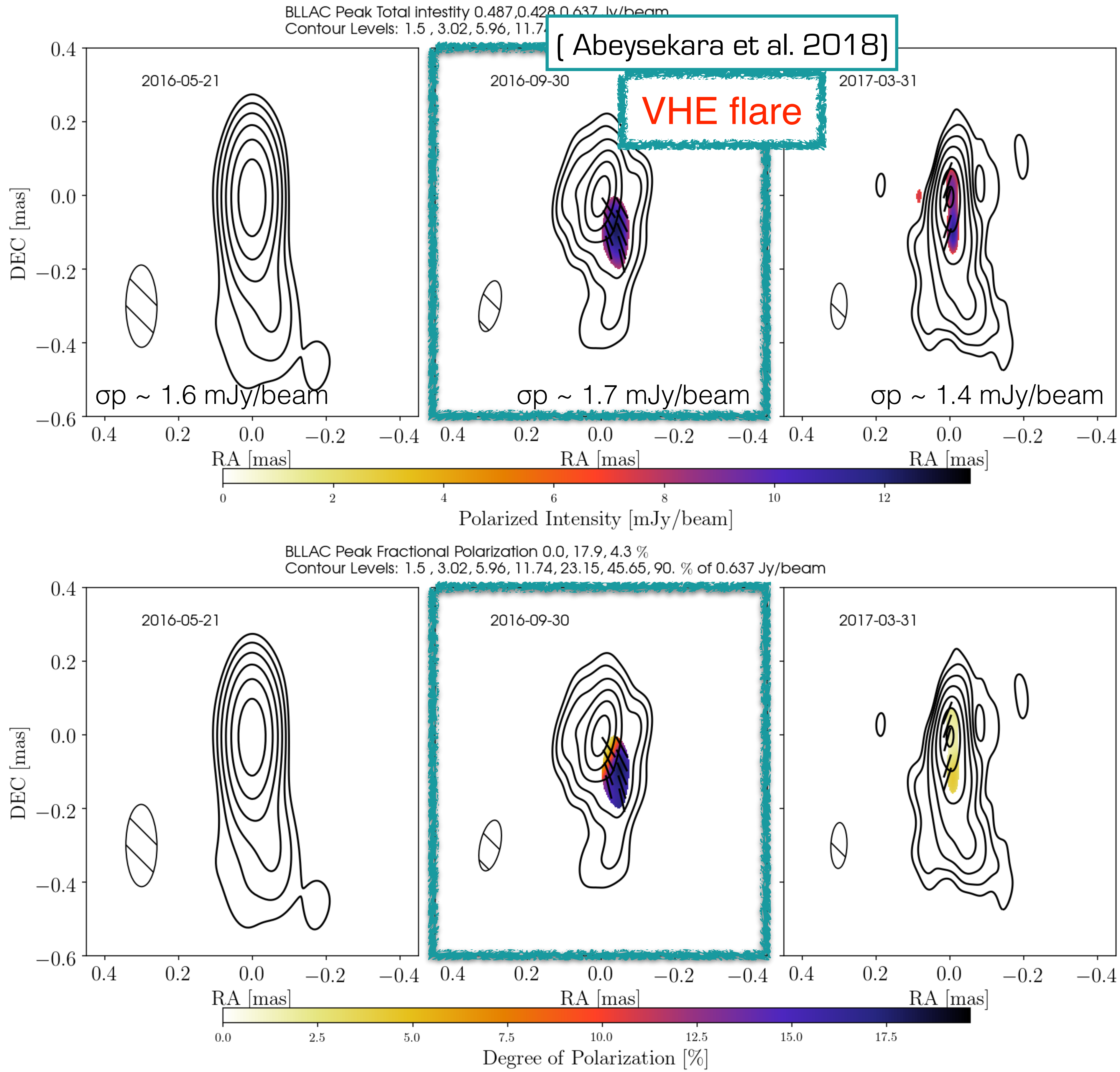
[Zacharias et al. 2017]
VHE flare
2016-05-21
σp ~ 3.5 mJy/beam
DEC [mas]
RA [mas]
1510-089
10 June 2016
43 GHZ
Dec (mas)
RA (mas)
Degree of Polarization [%]

BL LAC

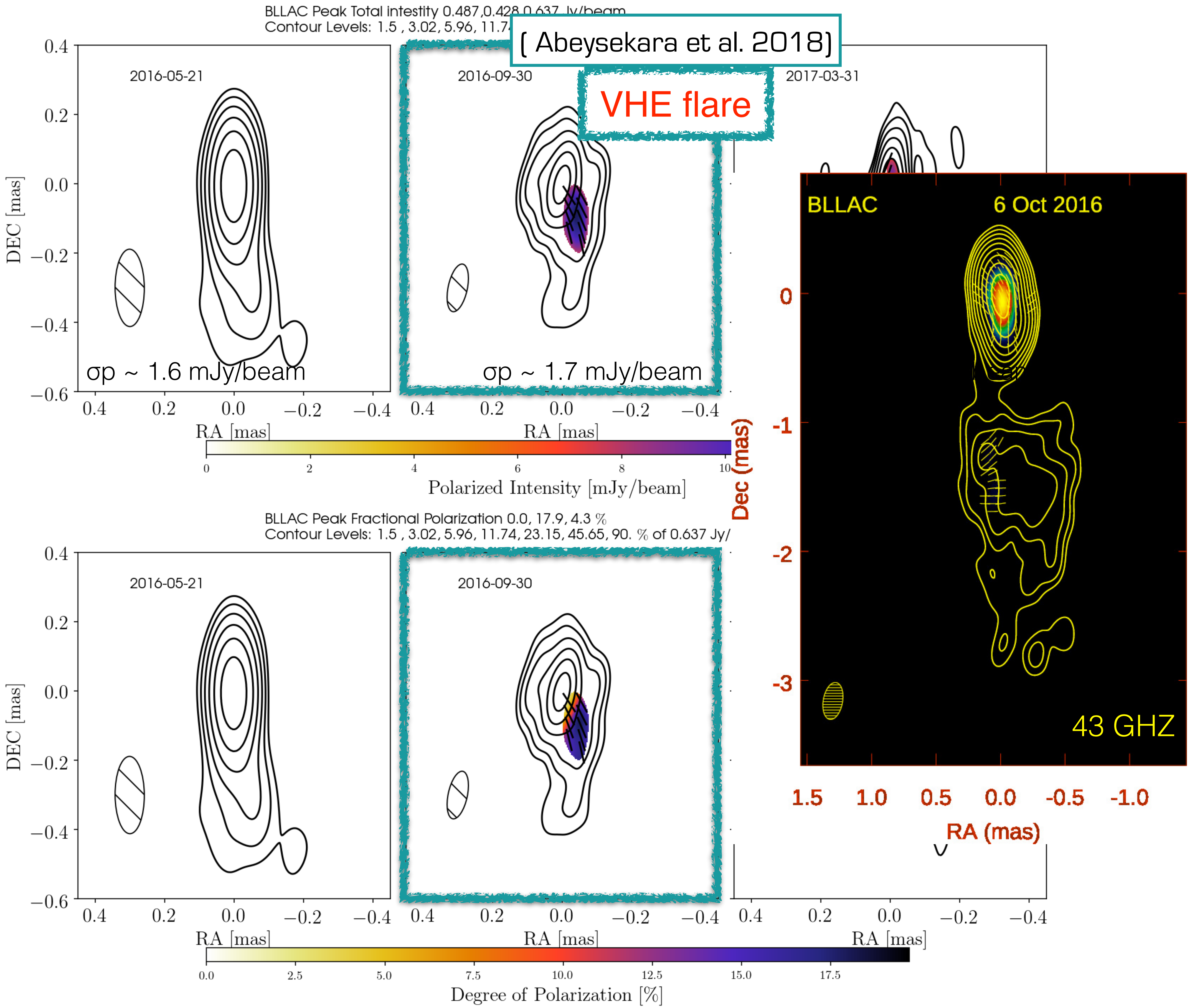


BLLAC Peak Total intestity 0.487,0.428,0.637 Jy/beam
Contour Levels: 1.5 , 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 0.637 Jy/beam
2016-05-21
2016-09-30
2017-03-31
σp ~ 1.6 mJy/beam
σp ~ 1.7 mJy/beam
σp ~ 1.4 mJy/beam
DEC [mas]
RA [mas]
Polarized Intensity [mJy/beam]
BLLAC Peak Fractional Polarization 0.0, 17.9, 4.3 %
Contour Levels: 1.5 , 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 0.637 Jy/beam
Degree of Polarization [%]

BL LAC


BLLAC Peak Total intestity 0.487,0.428,0.637 Jy/beam
Contour Levels: 1.5 , 3.02, 5.96, 11.74
(Abeysekara et al. 2018)
VHE flare
2016-05-21
2016-09-30
2017-03-31
σp ~ 1.6 mJy/beam
σp ~ 1.7 mJy/beam
σp ~ 1.4 mJy/beam
DEC [mas]
RA [mas]
Polarized Intensity [mJy/beam]
BLLAC Peak Fractional Polarization 0.0, 17.9, 4.3 %
Contour Levels: 1.5 , 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 0.637 Jy/beam
Degree of Polarization [%]

BL LAC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(Abeysekara et al. 2018)
VHE flare
2016-05-21
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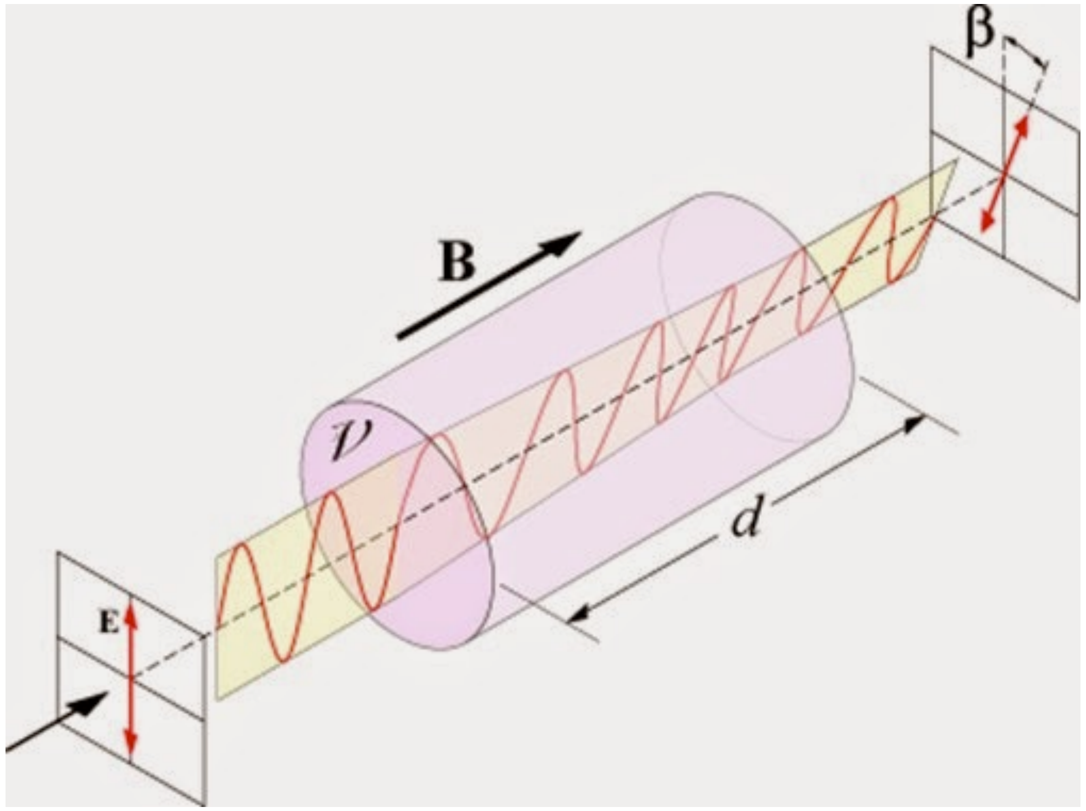
2017-03-31
σp ~ 1.6 mJy/beam
σp ~ 1.7 mJy/beam
DEC [mas]
RA [mas]
Polarized Intensity [mJy/beam]
BLLAC Peak Fractional Polarization 0.0, 17.9, 4.3 %
Contour Levels: 1.5 , 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 0.637 Jy/
Degree of Polarization [%]
BLLAC
6 Oct 2016
43 GHZ
Dec (mas)
RA (mas)

Goal: We want to study the magnetic field structure

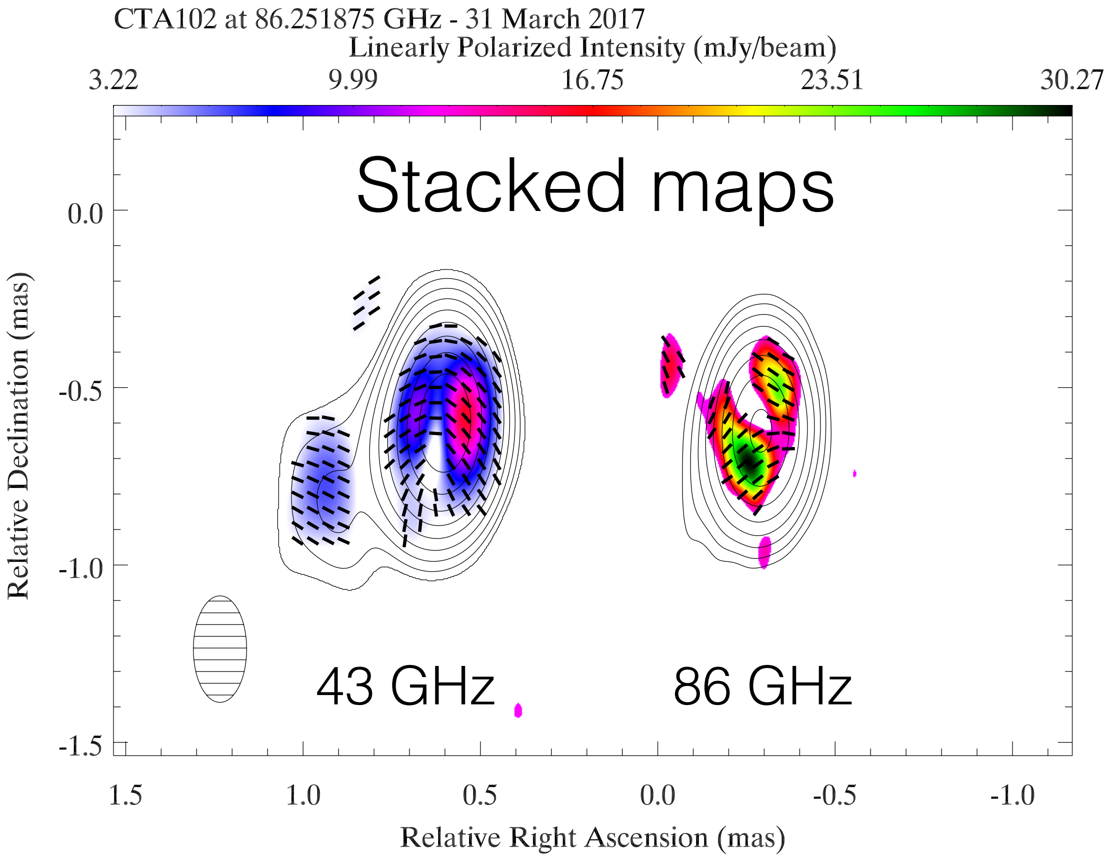
EVPAs orientation + Faraday Rotation analysis ⟶ 3D map of the magnetic field

EVPAs corrected for Faraday Rotation ⟶ EVPAs intrinsic of the source



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

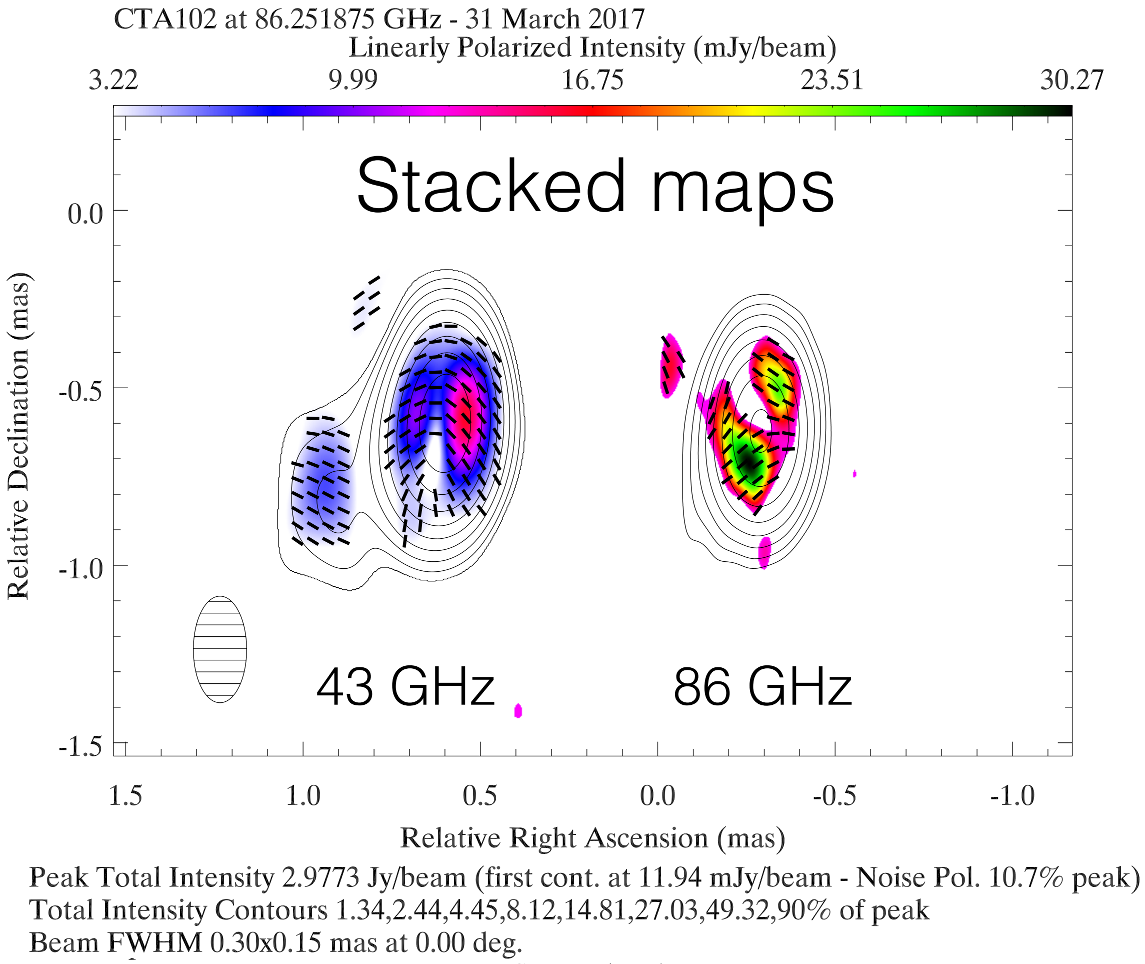
$$= EVPA_0 + RM\lambda^2$$

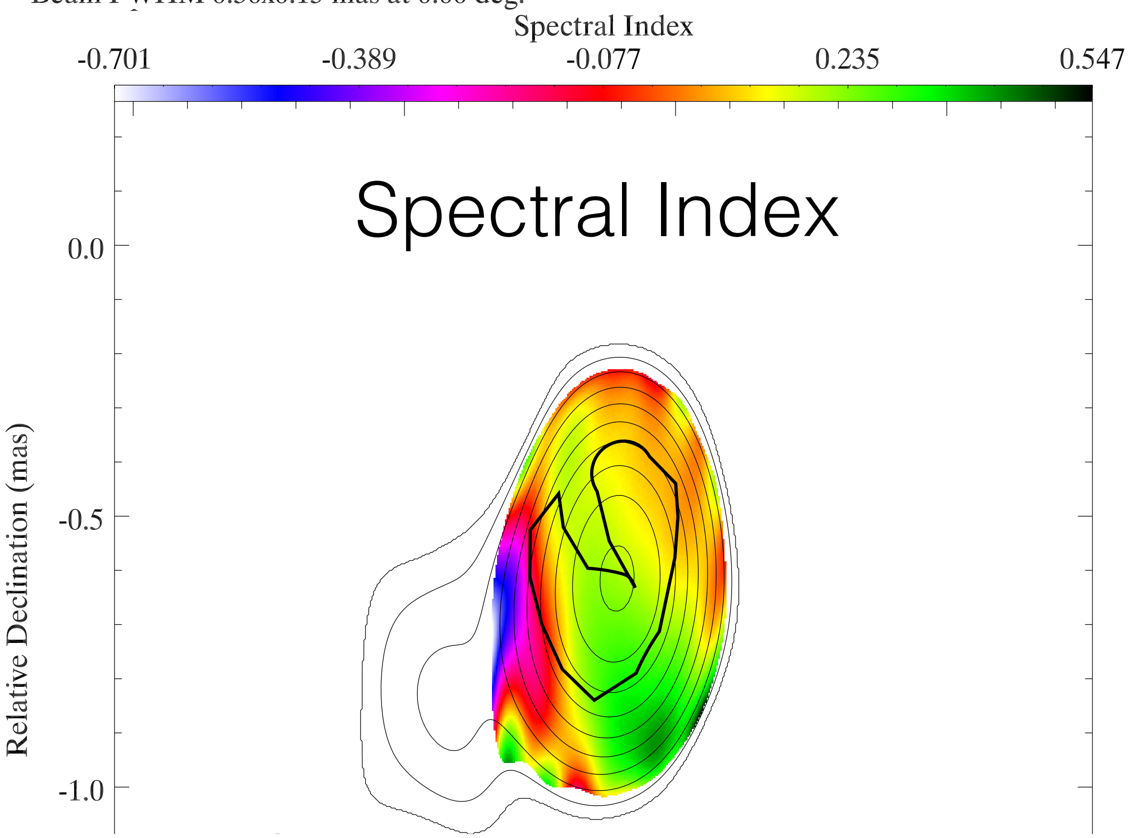


Peak Total Intensity 2.9773 Jy/beam (first cont. at 11.94 mJy/beam - Noise Pol. 10.7% peak)
Total Intensity Contours 1.34,2.44,4.45,8.12,14.81,27.03,49.32,90% of peak
Beam FWHM 0.30x0.15 mas at 0.00 deg.

Stacked map at 43 GHz : June 2016 - April 2017

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

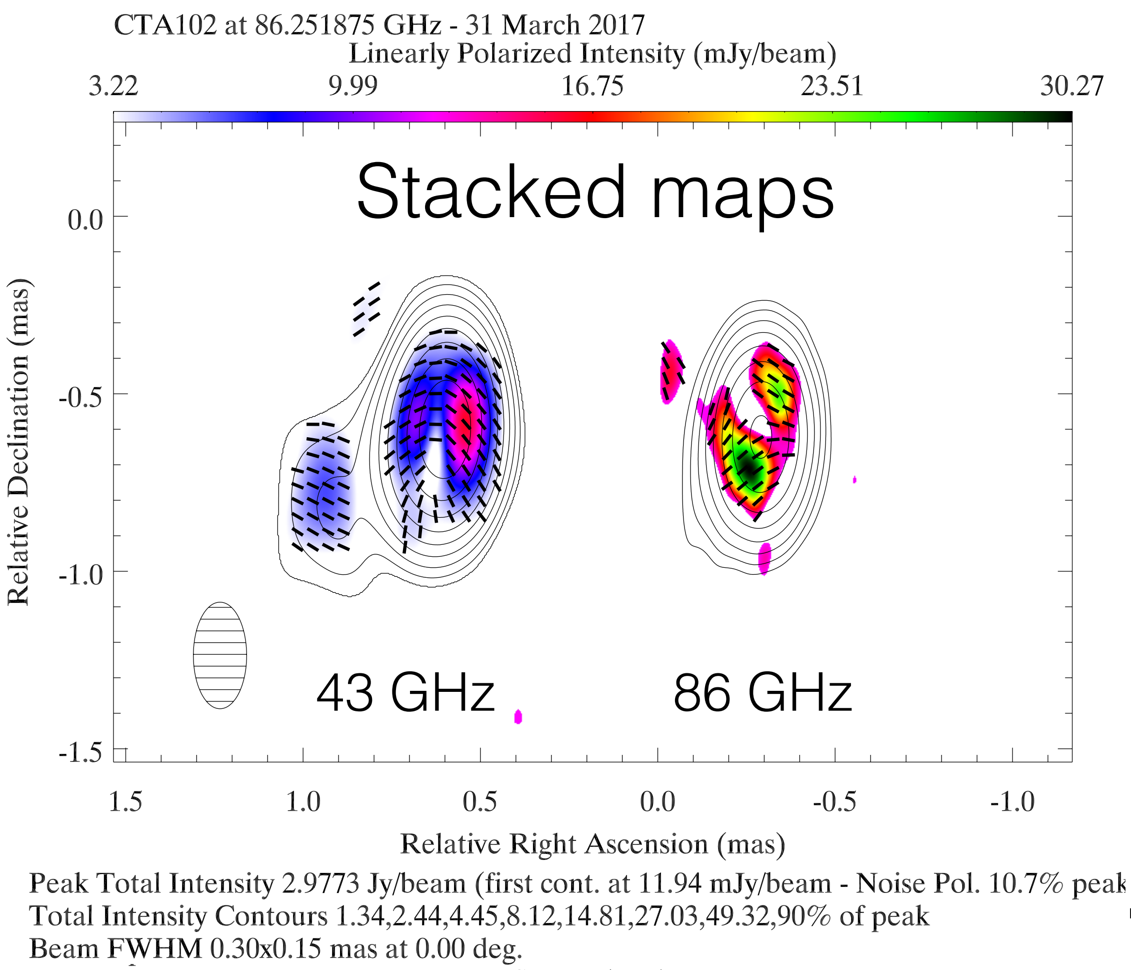


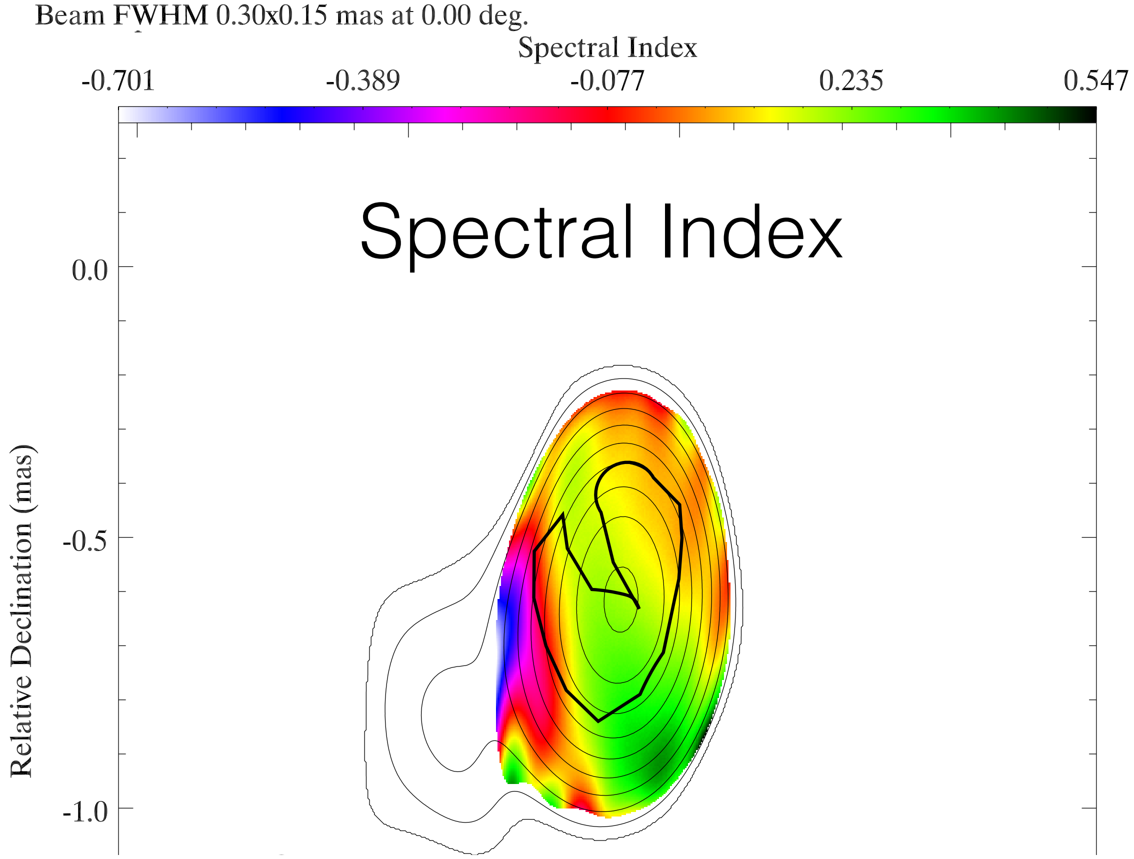


Stacked map at 43 GHz : June 2016 - April 2017

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

Rotation Measure analysis: the case of CTA 120 Casadio et al., in prep.

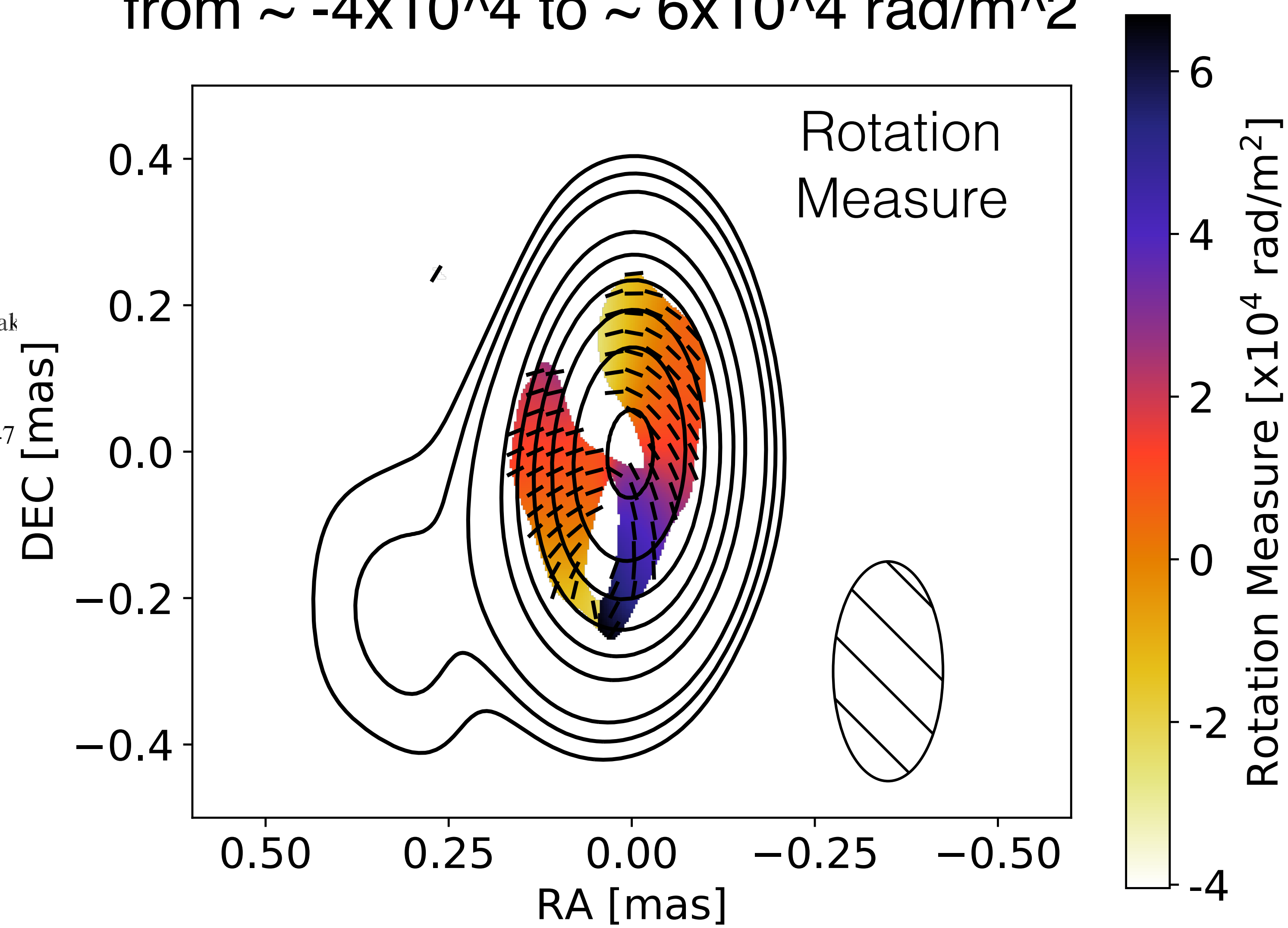




Stacked map at 43 GHz : June 2016 - April 2017

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

RM gradient
from ~ -4x10^4 to ~ 6x10^4 rad/m^2



In agreement with Park et al., 2018

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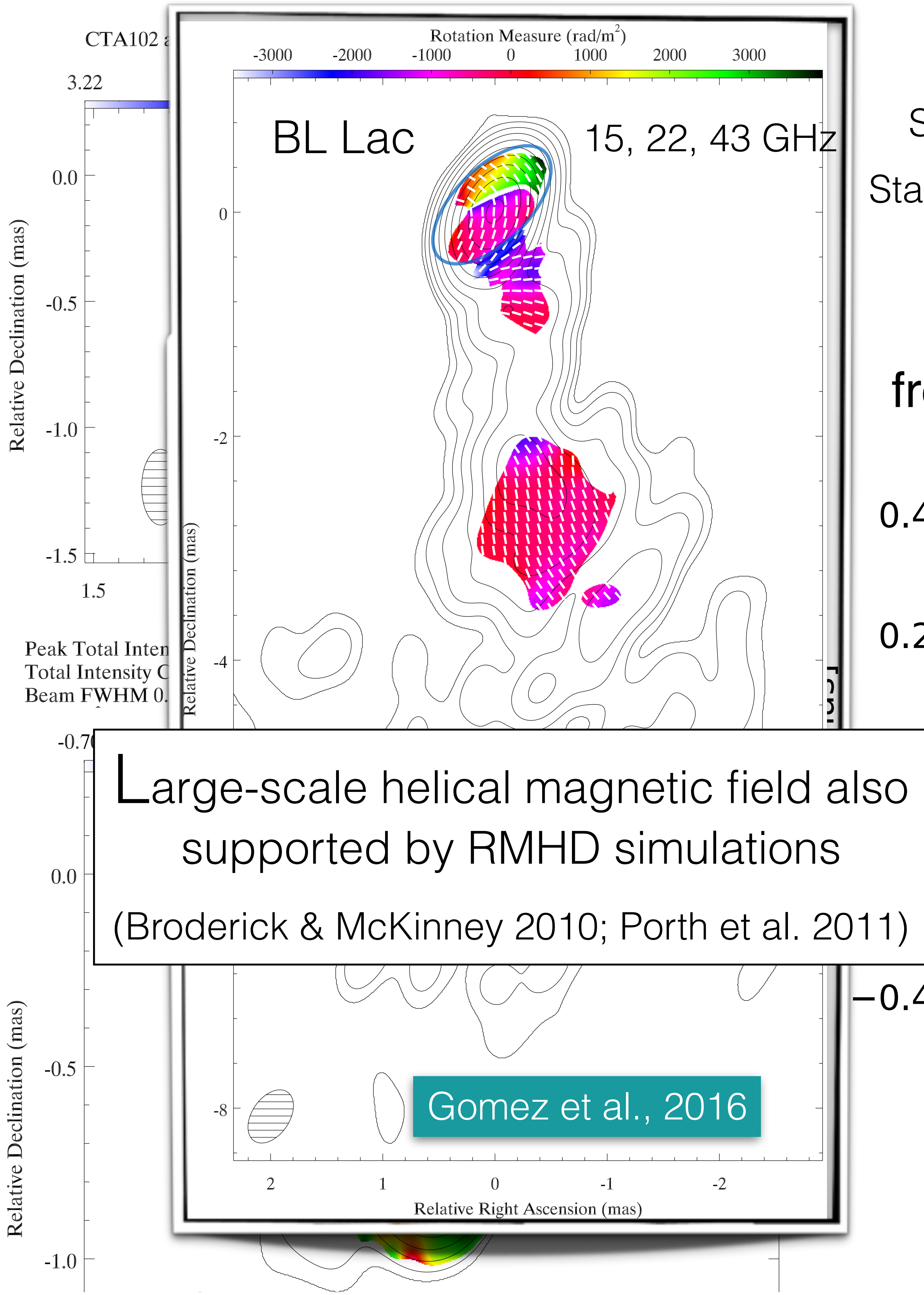


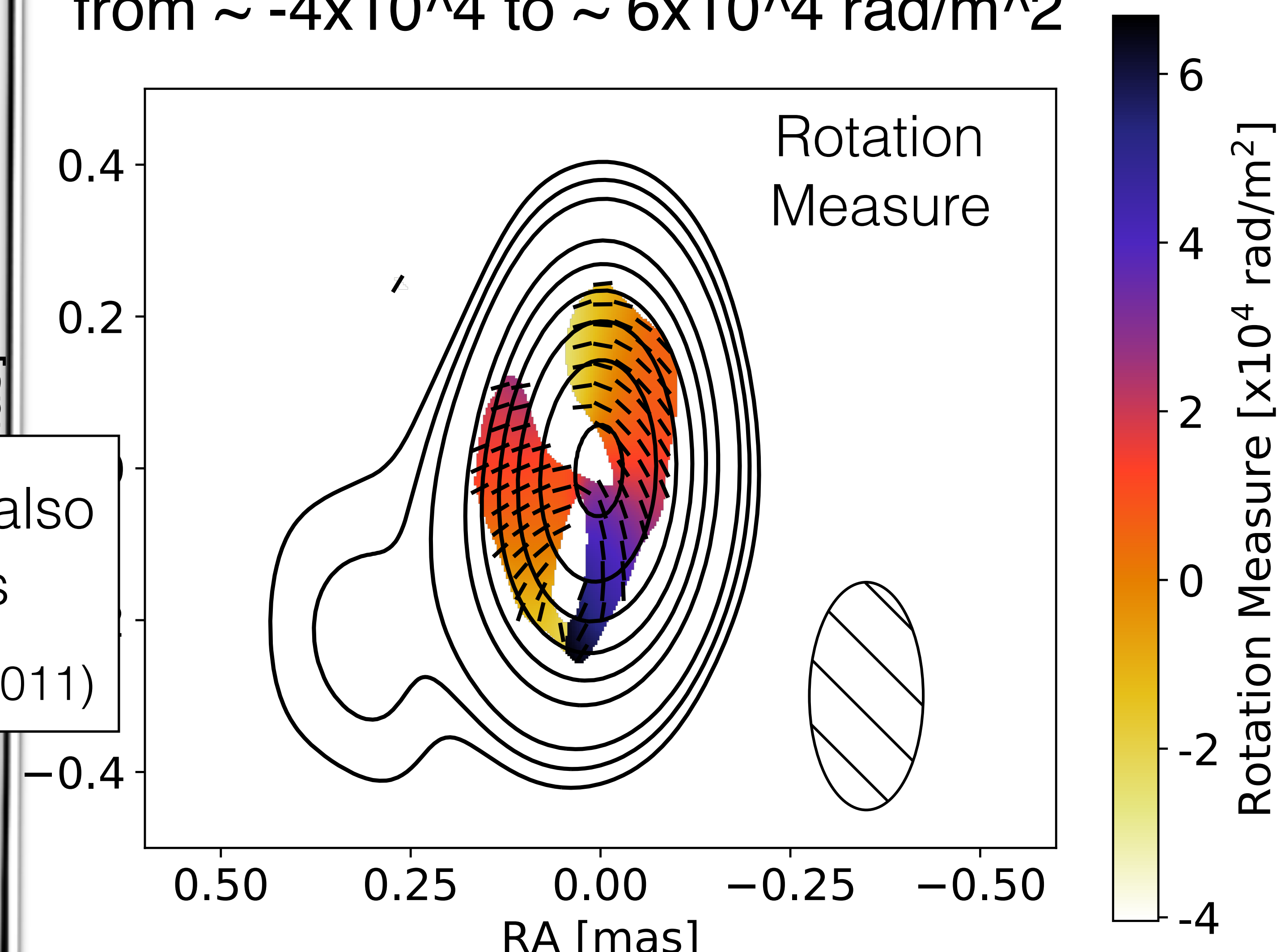
Large-scale helical magnetic field also supported by RMHD simulations

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

Stacked map at 43 GHz : June 2016 - April 2017

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

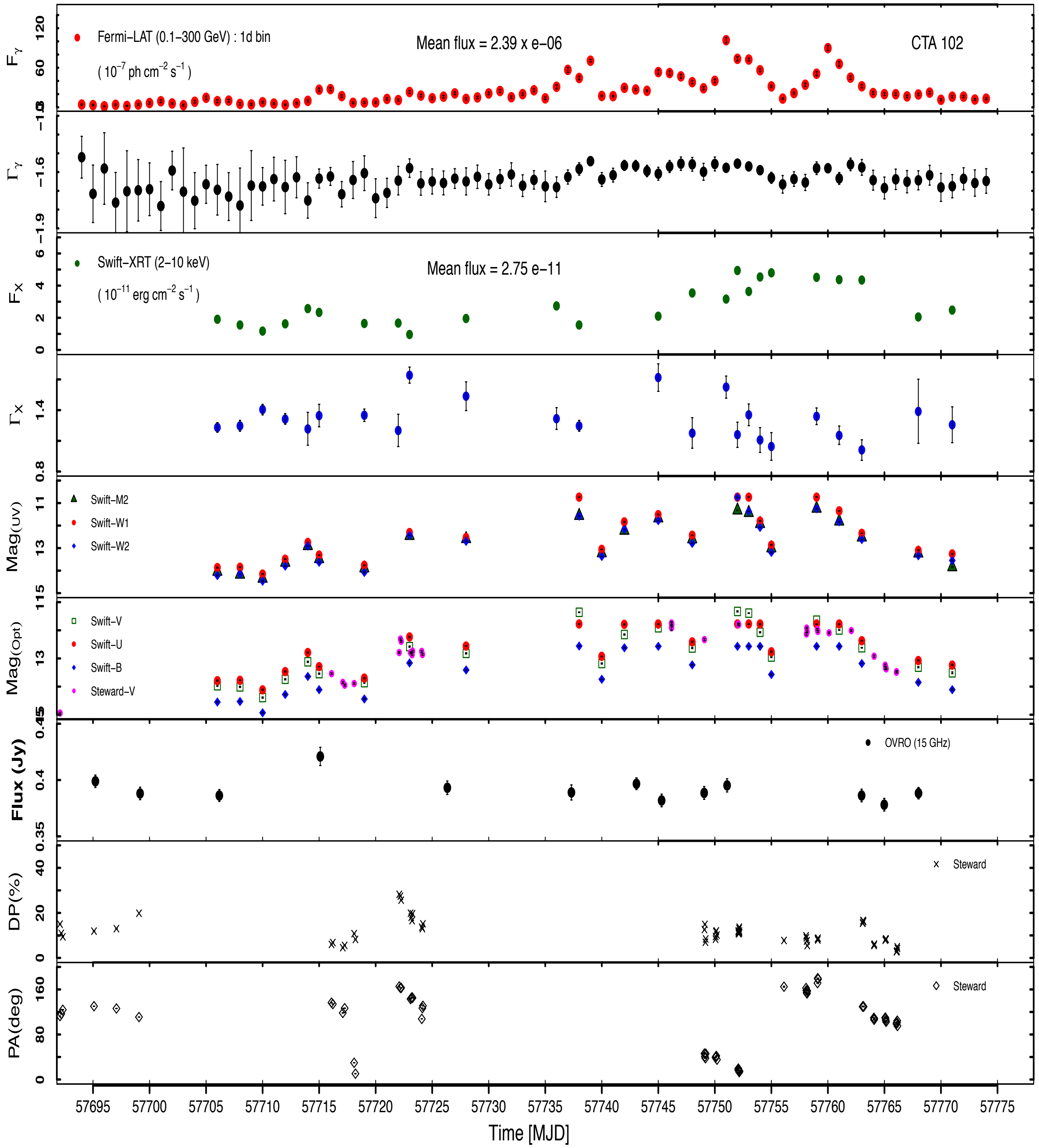
RM gradient
from ~ -4x10^4 to ~ 6x10^4 rad/m^2



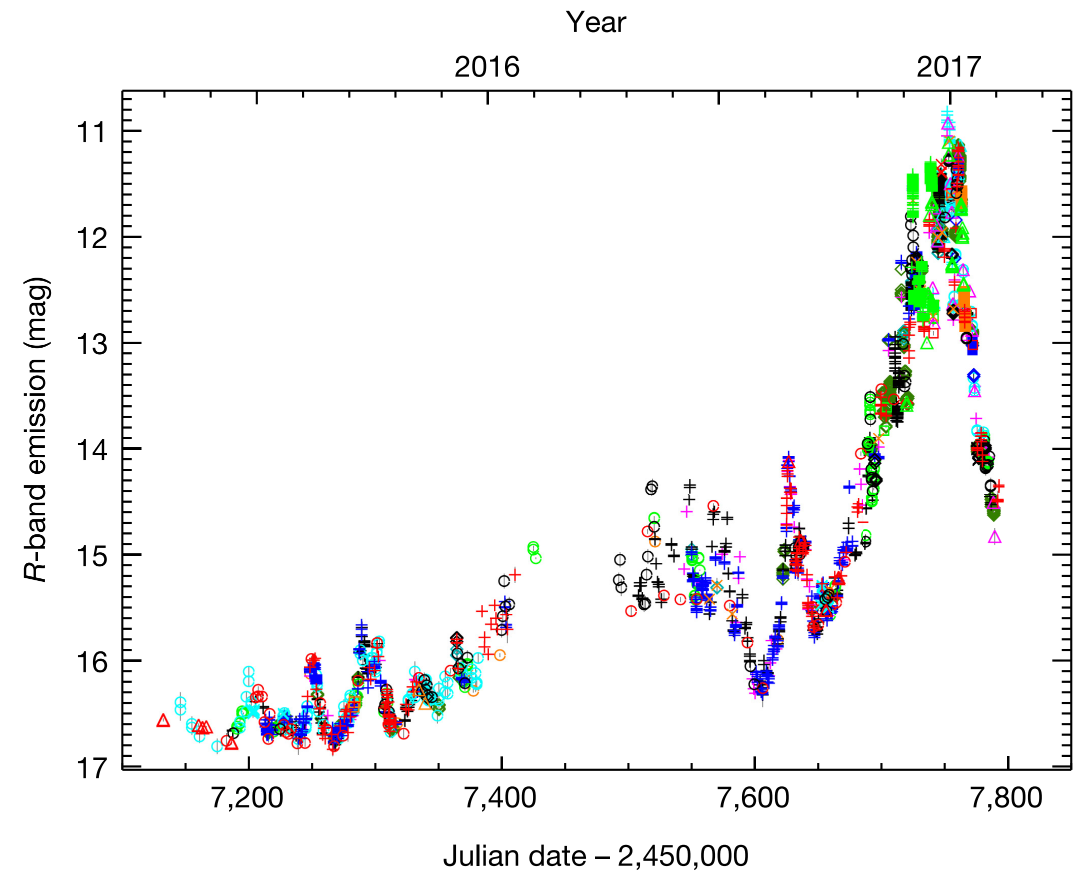
In agreement with Park et al., 2018

The multi-wavelength bright flare in December 2016 - January 2017

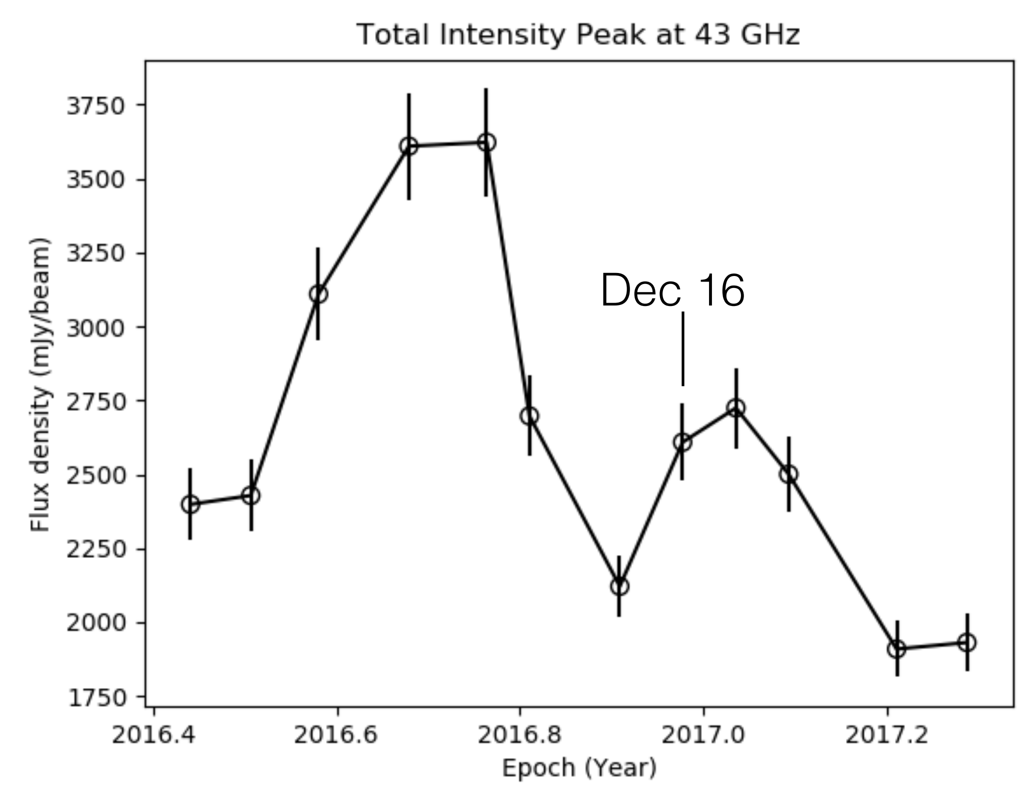
Multi-wavelength flare in
December 2016 - January 2017



Kaur et al., 2018

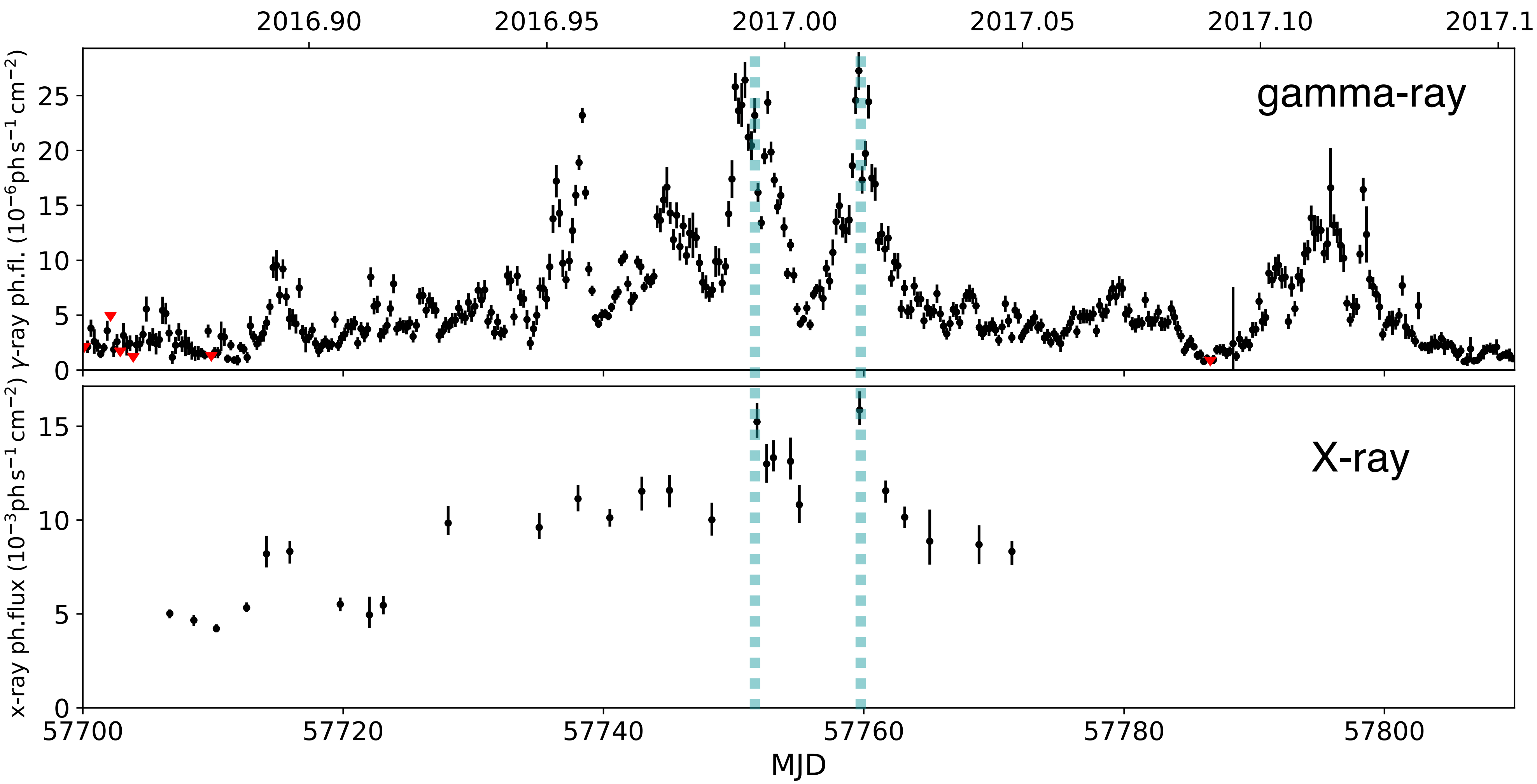


Raiteri et al., 2017



High-energy flares

Casadio et al., in prep.



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

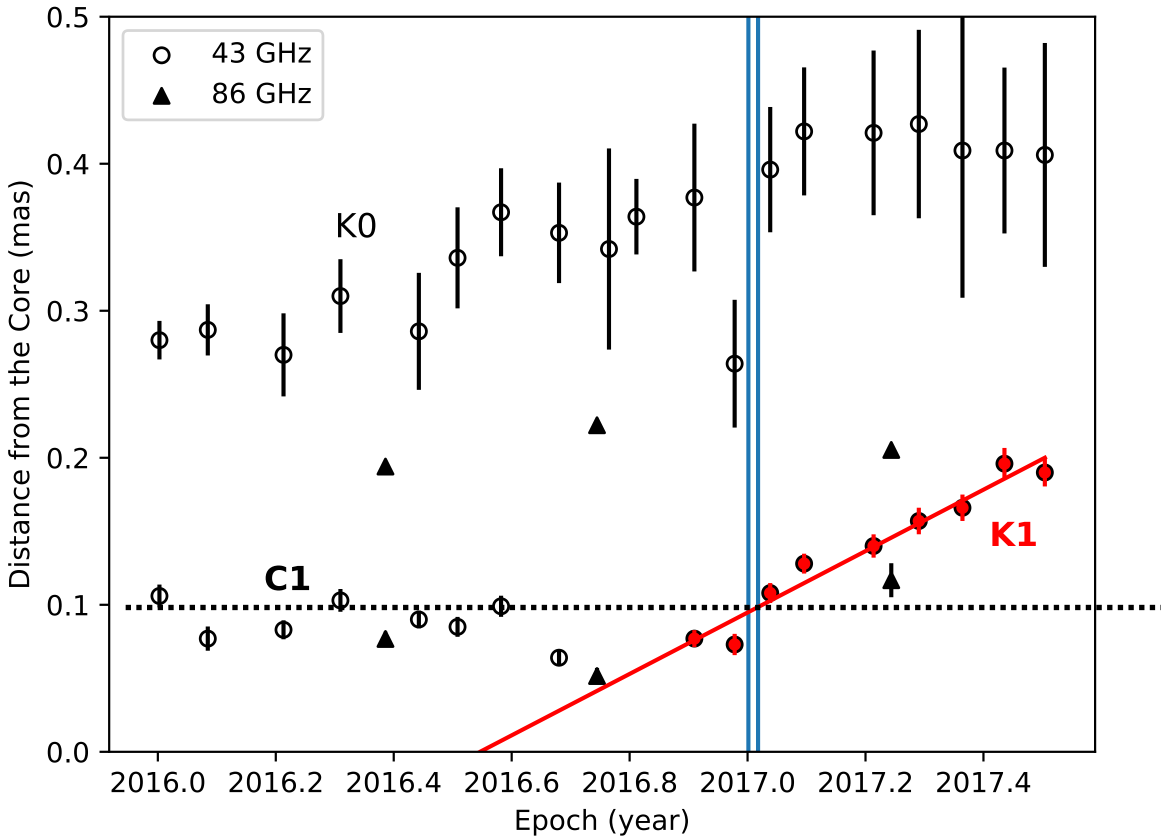
Mattox et al. 1993

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

57754 MJD $\delta \geq 17$

57760 MJD $\delta \geq 15$

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



credit: S. Jorstad

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

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

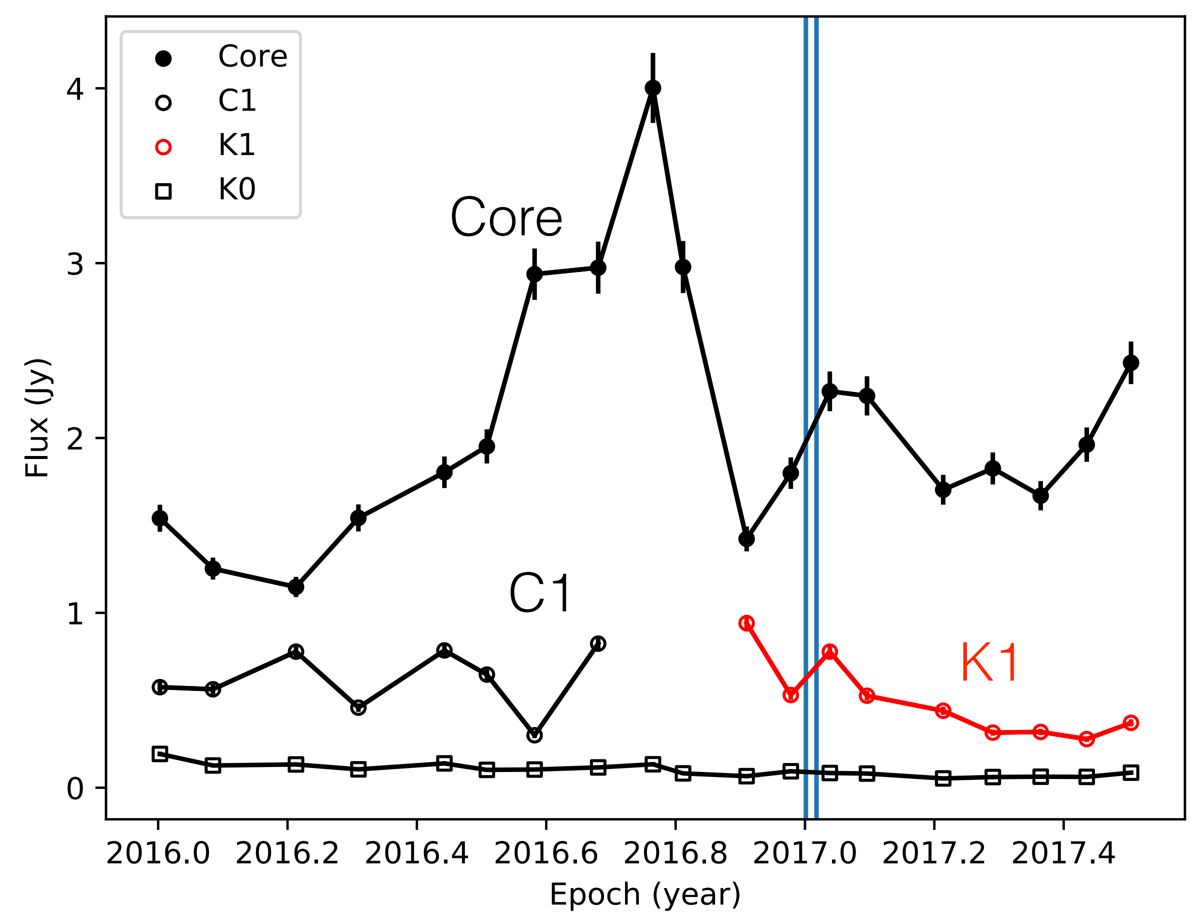
A stationary component at ~ 0.1 mas reported in previous studies (Jorstad et al., 2001,2005) and interpreted as a recollimation shock (From et al., 2013; Casadio et al., 2015)

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

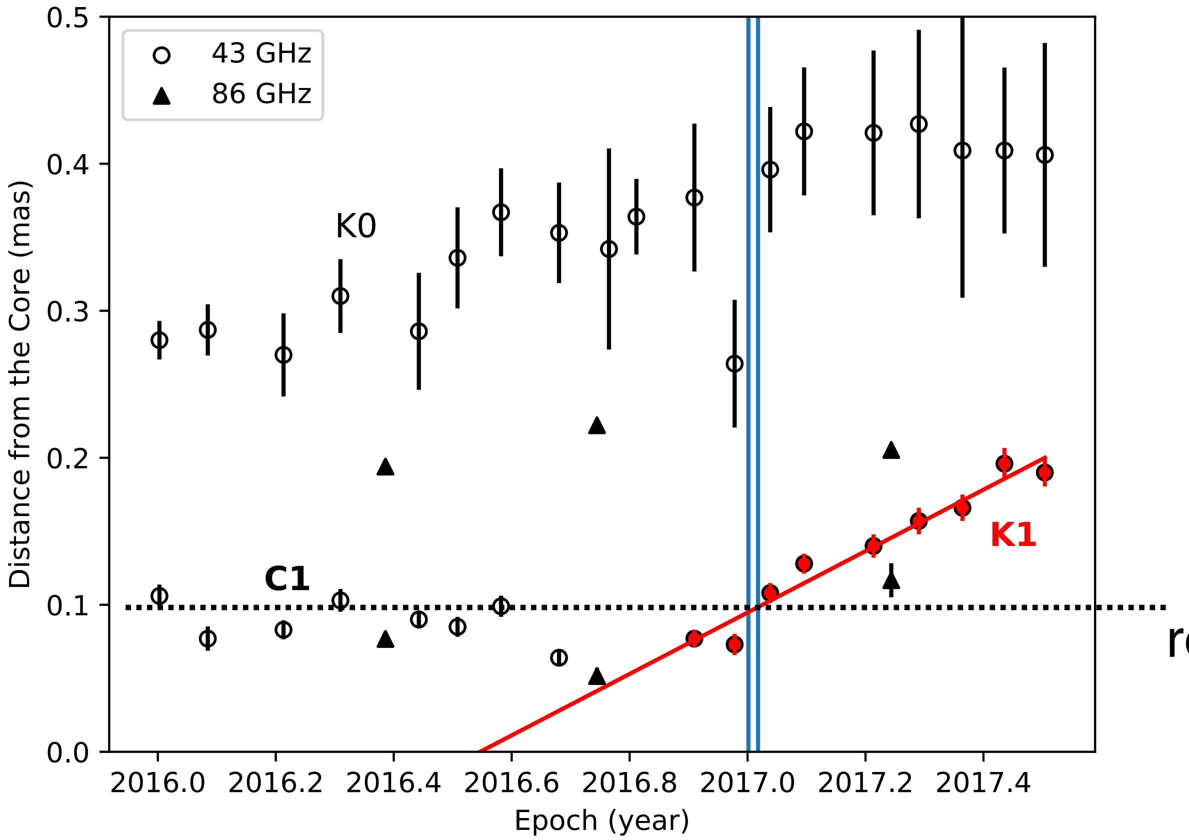
Using the method in Jorstad et al. 2005:

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

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



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



credit: S. Jorstad

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Using the method in Jorstad et al. 2005:

$\delta_{var} \sim 34 \pm 4$ $\Theta_{var} \sim 0.9 \pm 0.2$ $\Gamma_{var} \sim 20.9 \pm 1.9$

In agreement with:

- δ_{var} in Casadio et al., 2015, Jorstad et al., 2017
- **δ to explain the optical flare** (Raiteri et al., 2017)
- cloud ablation scenario (M.Zacharias talk); ~~mins scale gamma-ray variability~~ (A.Shula talk)

CONCLUSIONS

We have analysed polarimetric 86 GHz GMVA data of a sample of ~ 12 bright gamma-ray blazars and radio galaxies in 3 observing epochs (May 2016, September 2016 and March 2017)

→ We produced polarimetric images (θ ~ 0.05 mas) that allow us to distinguish more substructures than in 43 GHz images, also in coincidence with High Energy Flares,

CTA102

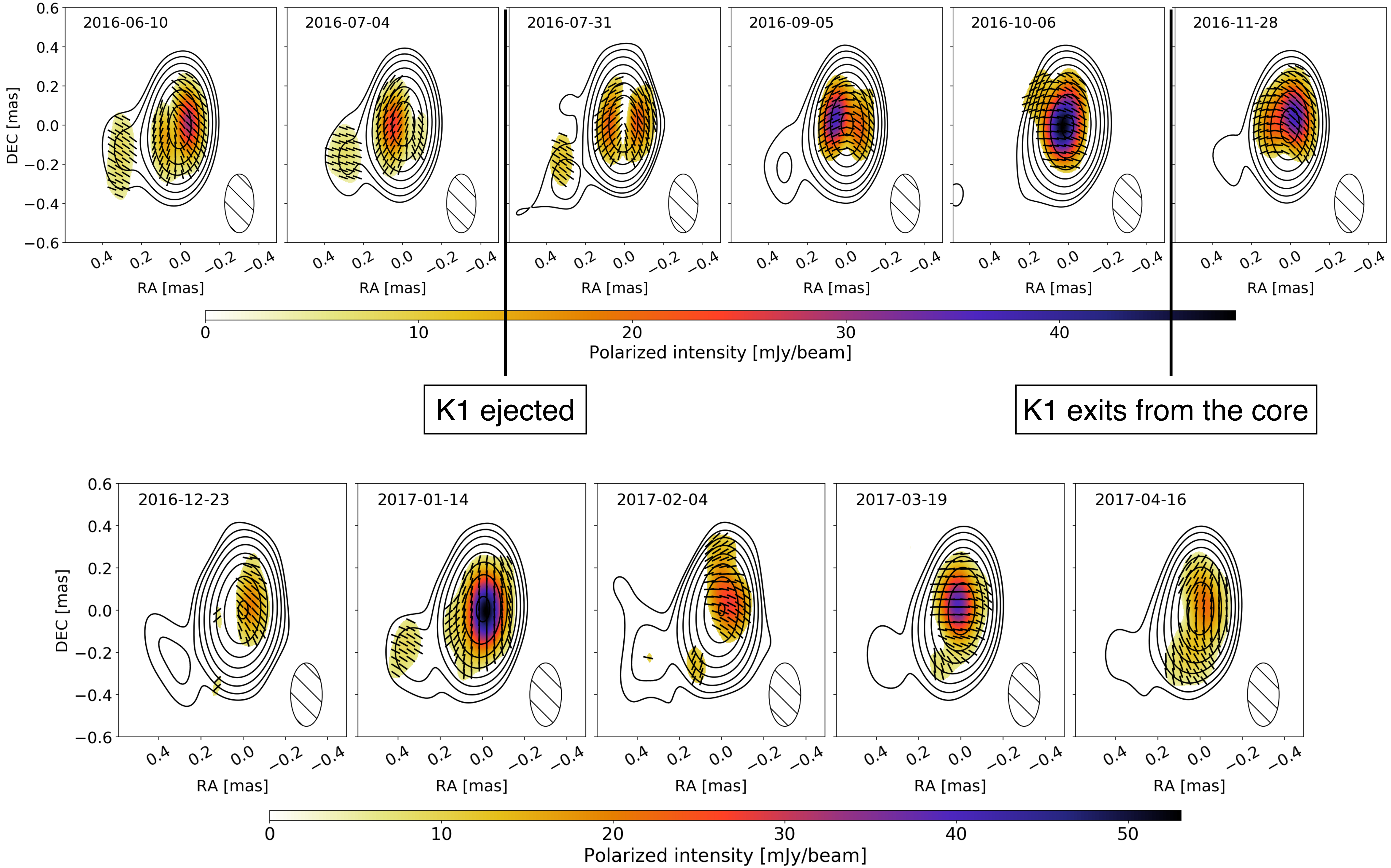
→ We have obtained the *Rotation Measure maps* between 43 and 86 GHz

- → The RM at 86 GHz shows a gradient from ~ -4x10^4 to 6x10^4 rad/m^2 around the centroid of the core and a change of sign
- → The intrinsic EVPAs displays a peculiar rotation around the core

Hints for large scale helical magnetic field in the innermost regions

→ the bright multi-wavelength flare in Dec 2016 - Jan 2017 is triggered by the passage of a new superluminal component through the recollimation shock at 0.1 mas

Evolution of Polarized emission at 43 GHz data Casadio et al., in prep.



Evolution of Polarized emission at 43 GHz data

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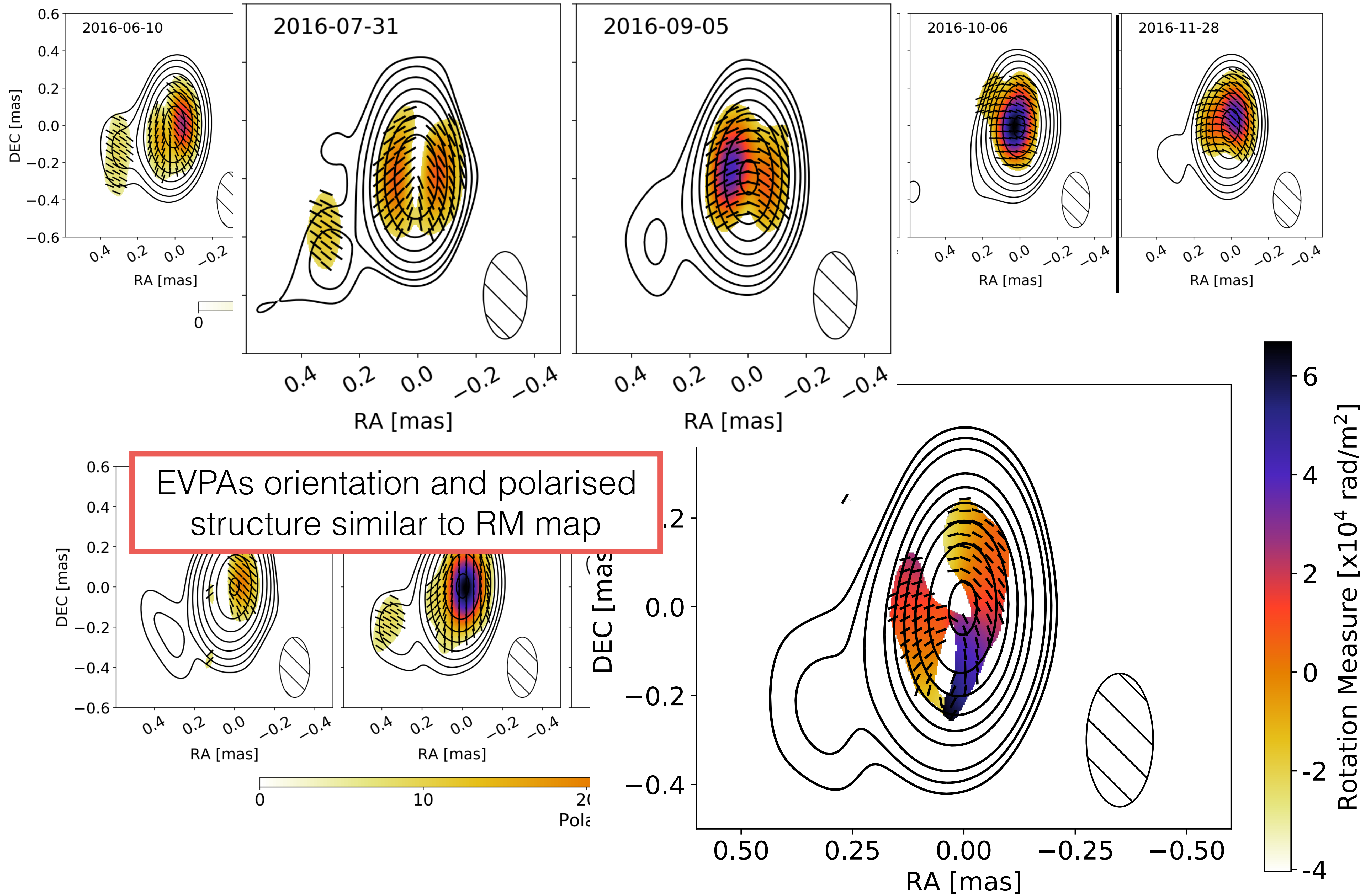

Evolution of Polarized emission at 43 GHz data

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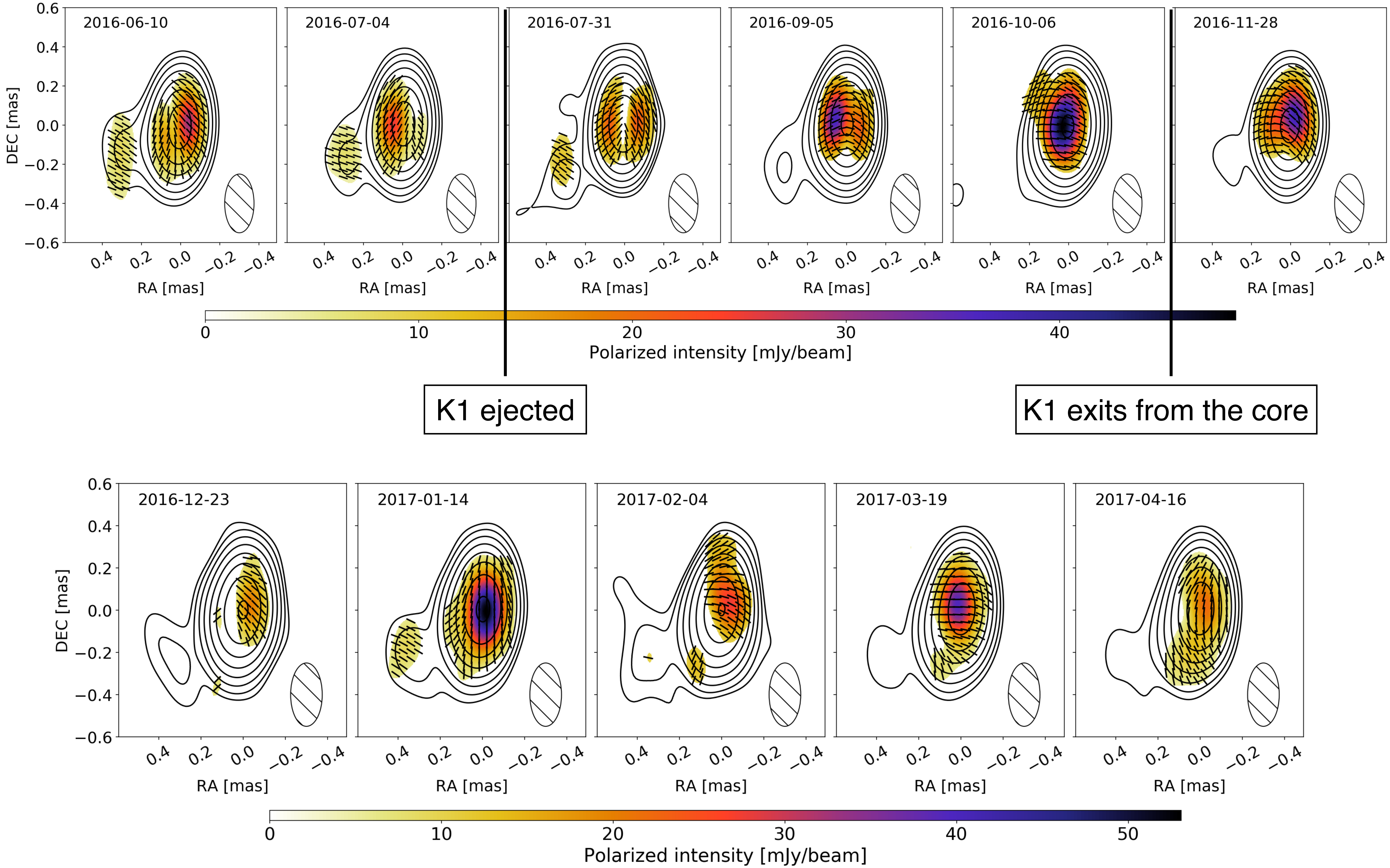
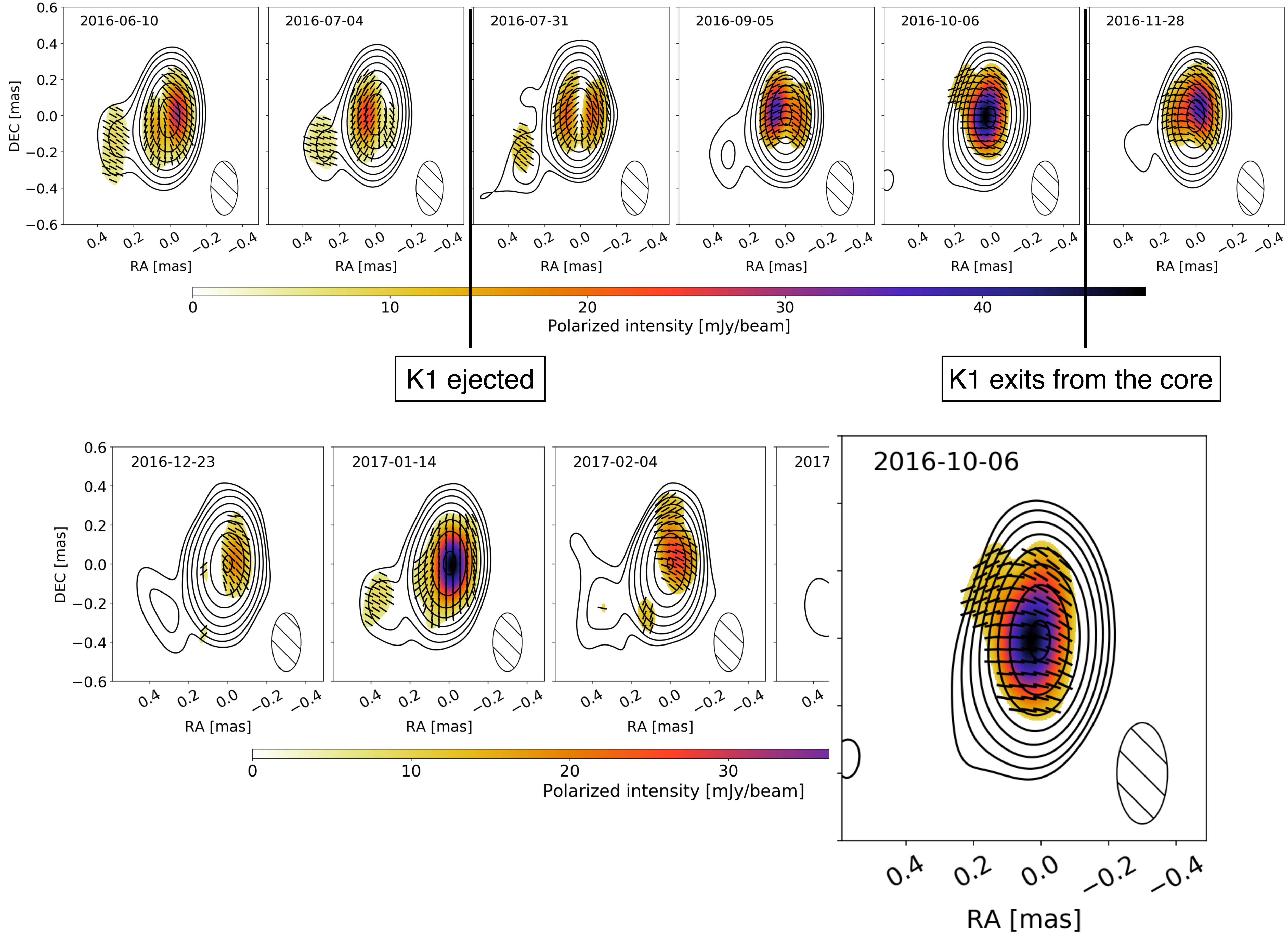


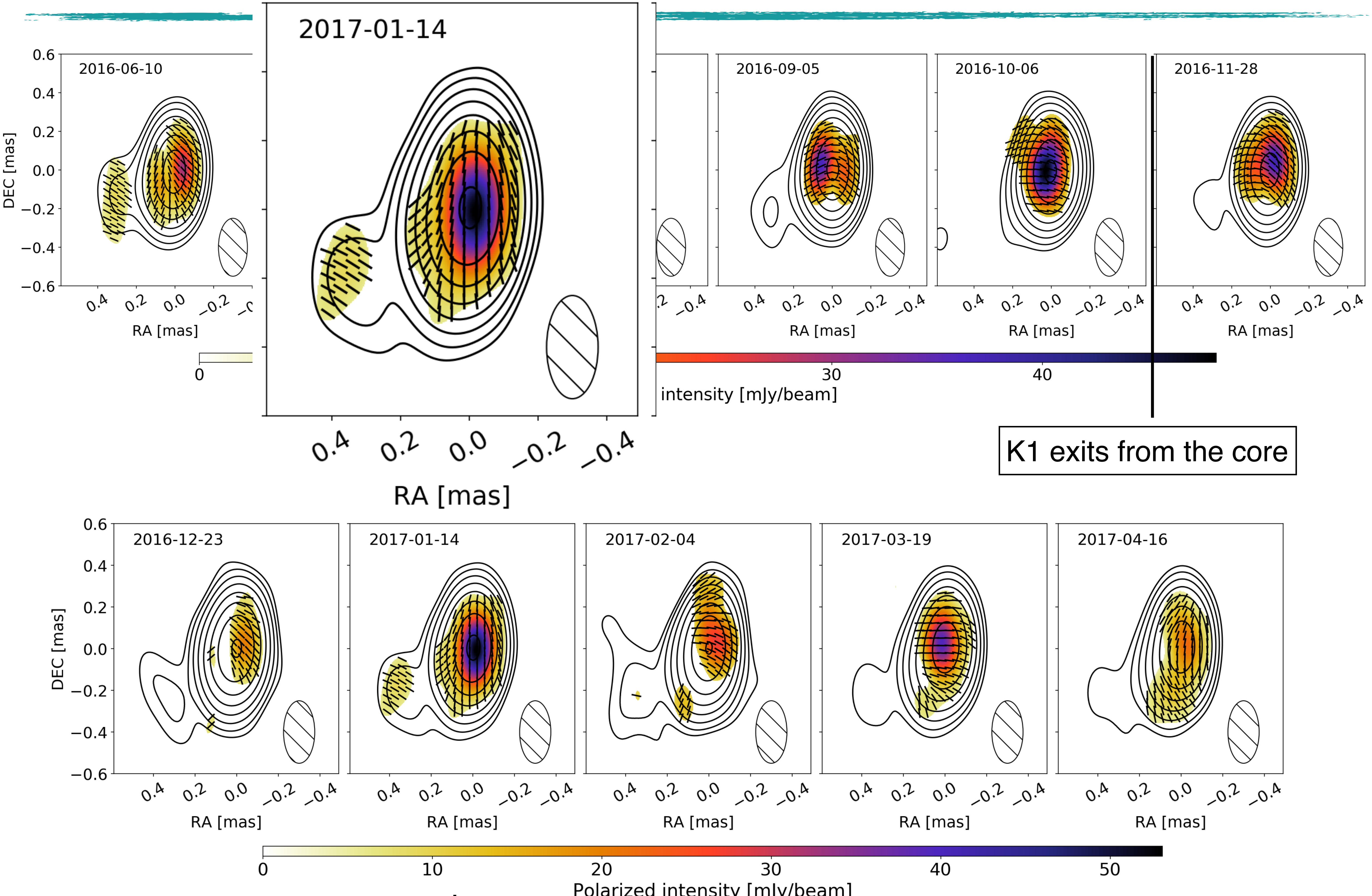
Evolution of Polarized emission at 43 GHz data

Casadio et al., in prep.



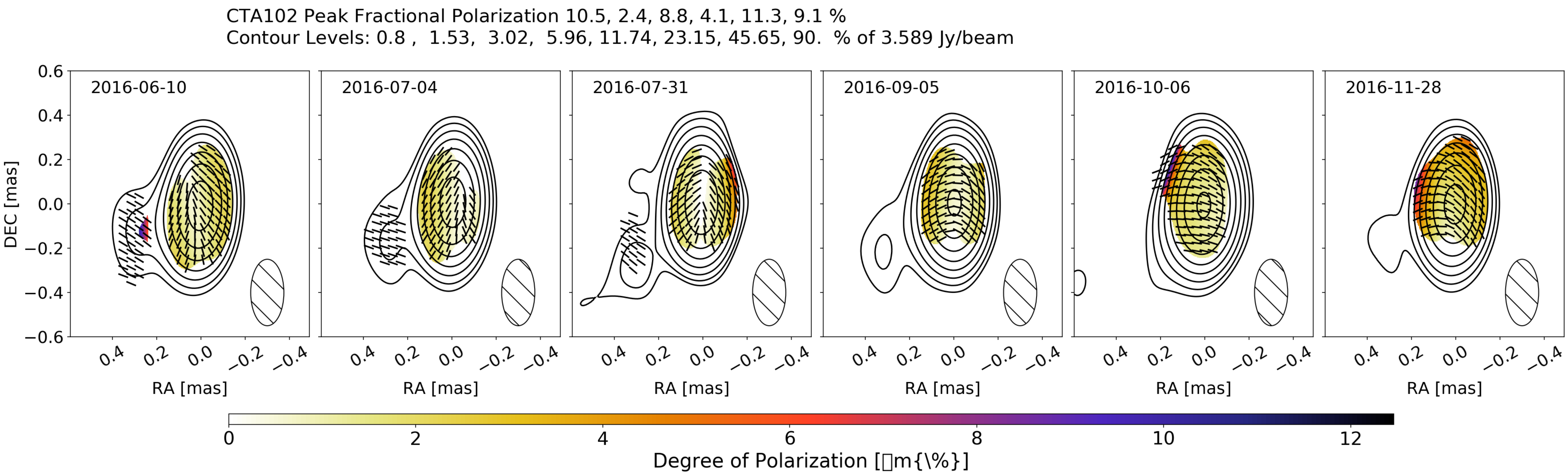
Evolution of Polarized emission at 43 GHz data

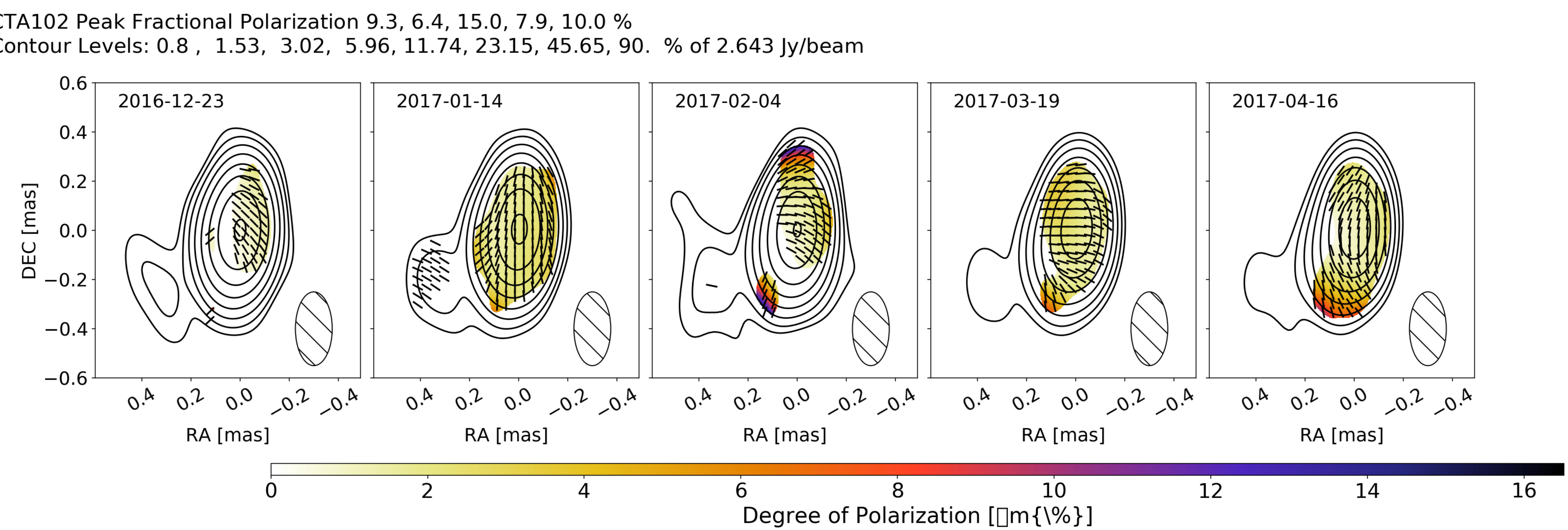
Casadio et al., in prep.



K1 exits from the core

K1 crosses the stationary feature at ~ 0.1 mas


CTA102 Peak Fractional Polarization 10.5, 2.4, 8.8, 4.1, 11.3, 9.1 %
Contour Levels: 0.8 , 1.53, 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 3.589 Jy/beam
2016-06-10
2016-07-04
2016-07-31
2016-09-05
2016-10-06
2016-11-28
DEC [mas]
RA [mas]
Degree of Polarization [□m{\%}]


CTA102 Peak Fractional Polarization 9.3, 6.4, 15.0, 7.9, 10.0 %
Contour Levels: 0.8 , 1.53, 3.02, 5.96, 11.74, 23.15, 45.65, 90. % of 2.643 Jy/beam
2016-12-23
2017-01-14
2017-02-04
2017-03-19
2017-04-16
DEC [mas]
RA [mas]
Degree of Polarization [□m{\%}]