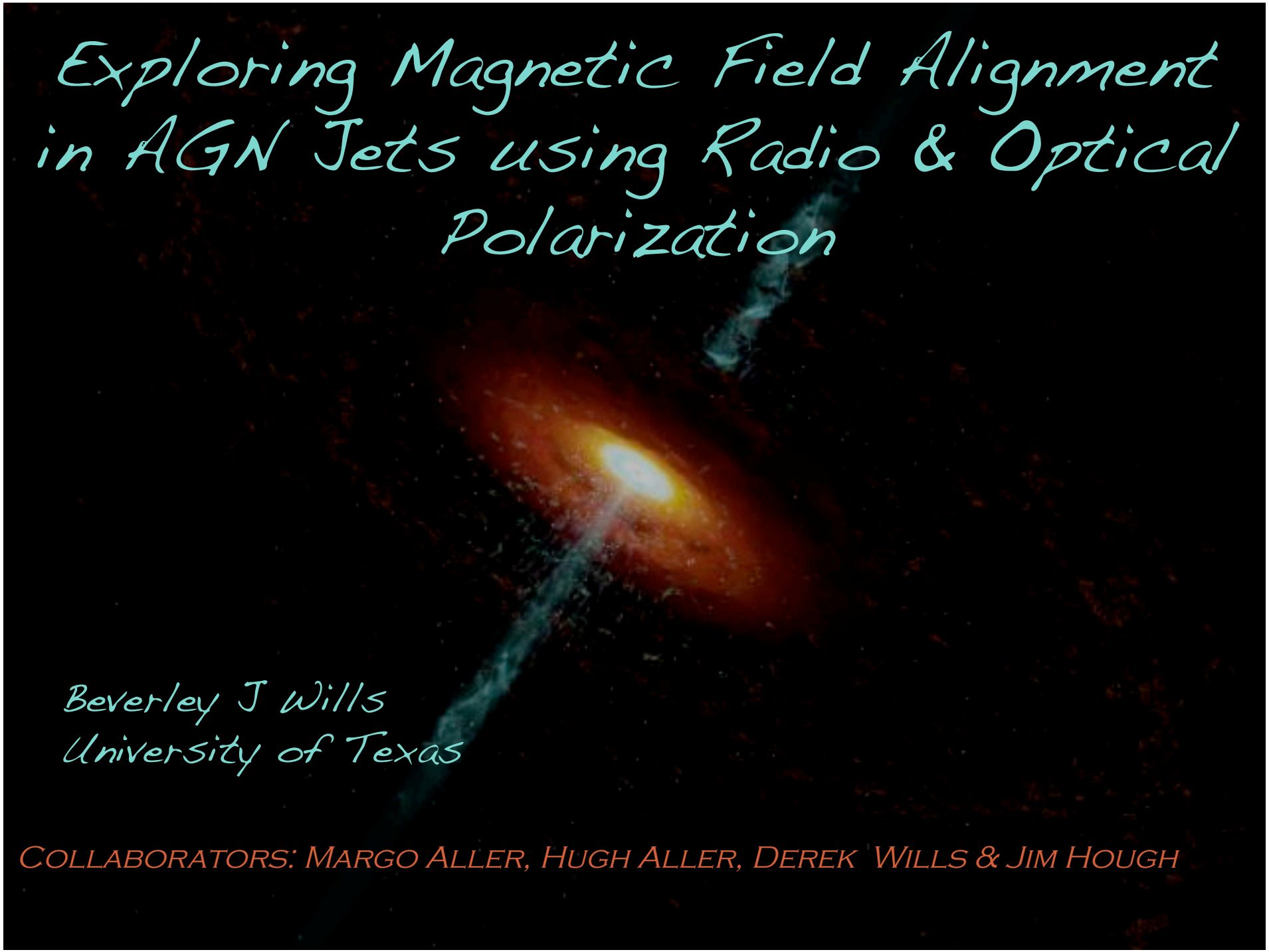
# Exploring Magnetic Field Alignment in AGN Jets using Radio & Optical Polarization



Beverley J Wills
University of Texas

Collaborators: Margo Aller, Hugh Aller, Derek Wills & Jim Hough

My sincere thanks to the organizing committee for inviting me – especially to Preeti Kharb and Prajval Shastri.

Motivation:

Simultaneous optical-radio polarization challenging.
Much optical pol data exist in literature, but time coverage is sparse. The existence of extensive radio monitoring at 4.5, 8, 14.5 GHz from UMRAO allows comparison of simultaneous data. We compare EVPA over 30-40 years. In addition I measured inner jet position angles from databases & literature to compare with EVPA.

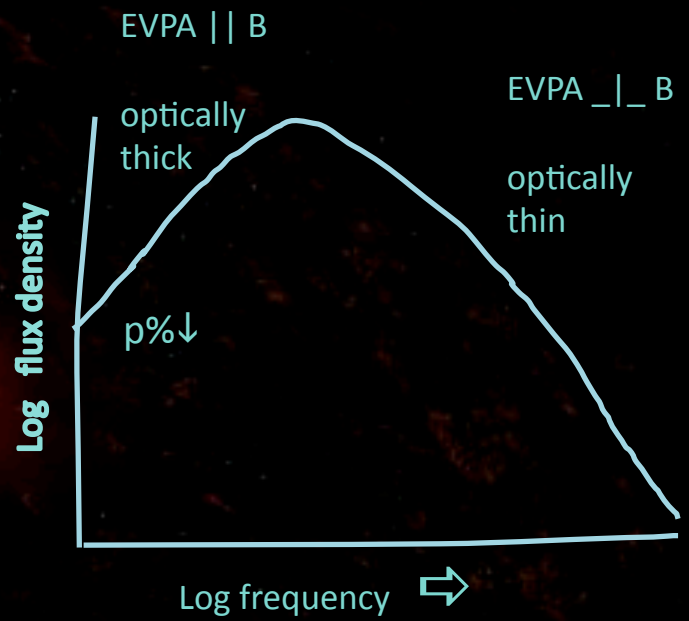
The Ledlow-Owen diagram suggested that a comparison of FR I and FR II jet properties might be fundamental to the central engine of AGN…… or at least its near environment.

# Comparing position angles of radio & optical polarization, 1964 – 1994.

What can we learn from polarization position angles?

1. Synchrotron PA = EVPA is perpendicular (optically thin case) to B. p% can be up to 50% -the higher the more well-ordered is B.

2. Optically thick case:




3. Faraday rotation (FR) in intervening ionized (thermal) plasma

FR = RM x $\lambda^2$ (radian)

where rotation measure RM = 8100 x $n_e$ $B_{l-o-s}$ $\ell$ (slab, rad/m$^2$)

## Optical data

p% and EVPA from 1964 to 1993, from my observations with several collaborators, and from the literature.

pros: extends over long time, EVPA can be accurately compared among observers.

cons: often sparsely sampled, does not resolve jet (but not many do – needs HST).

## Radio data

From University of Michigan Radio Astronomy Observatory, since late 1970's, Hugh & Margo Aller have been monitoring flux density, p% and EVPA every few days, where possible, for many blazars. UMRAO uses 4.8 GHz, 8 GHz & 14.5 GHz. We have extended coverage to earlier times using literature data, but those data are sparse. Large beams cover all VLBI structure – a limitation of course.

The dense UMRAO coverage enables our polarization comparison despite the sparse optical coverage.

**Inner jet structure position angles** are from VLBI databases and the literature. I also obtained Kpc-scale jet/lobe position angles – another big task. This also enabled investigation of the Pearson-Readhead (1988) 90° misalignment between pc and Kpc jet directions.

**FR I – FR II Class:** (1) by radiative efficiency, & (2) jet morphology & $L_{rad}$

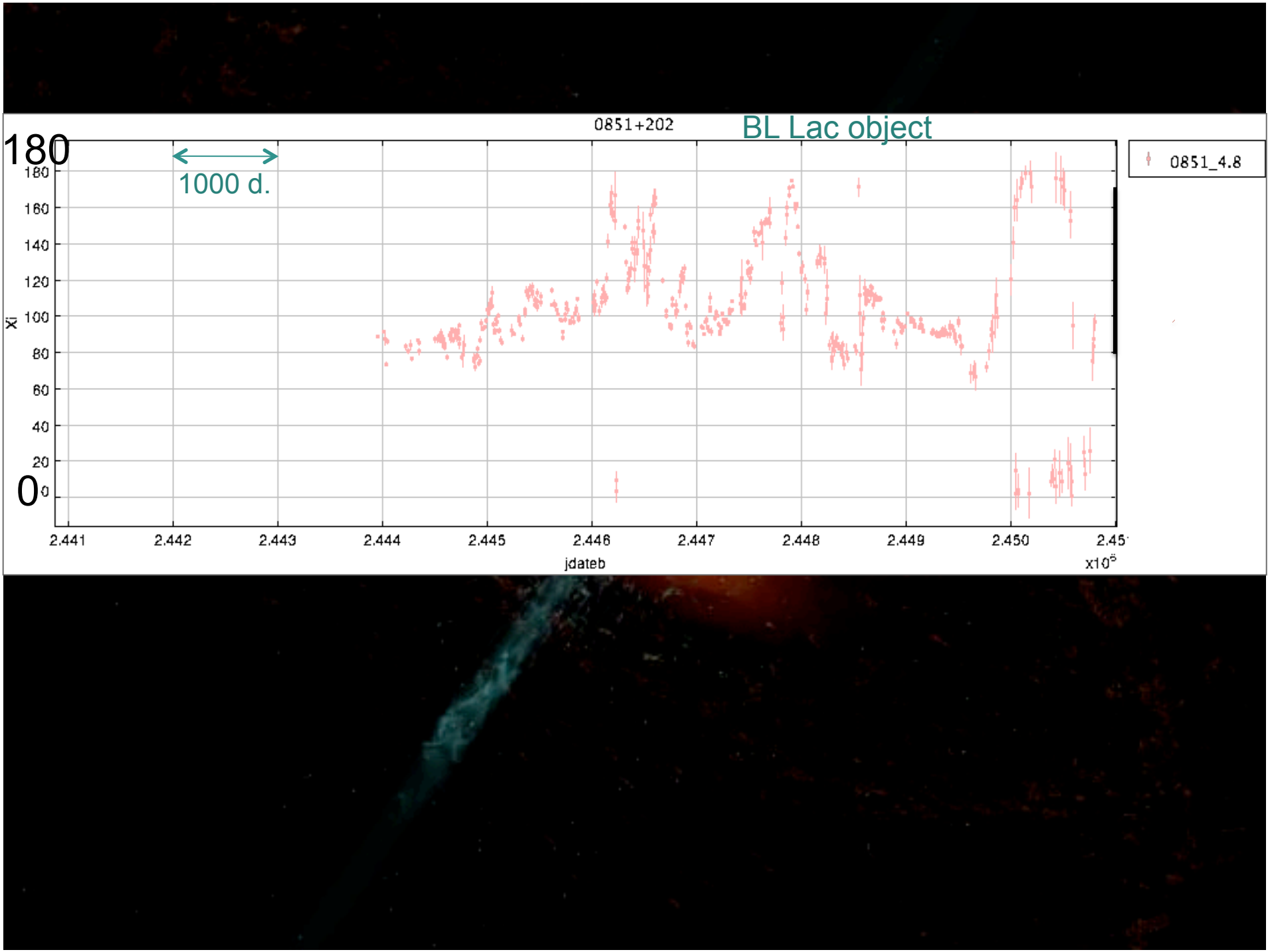
# Sample:

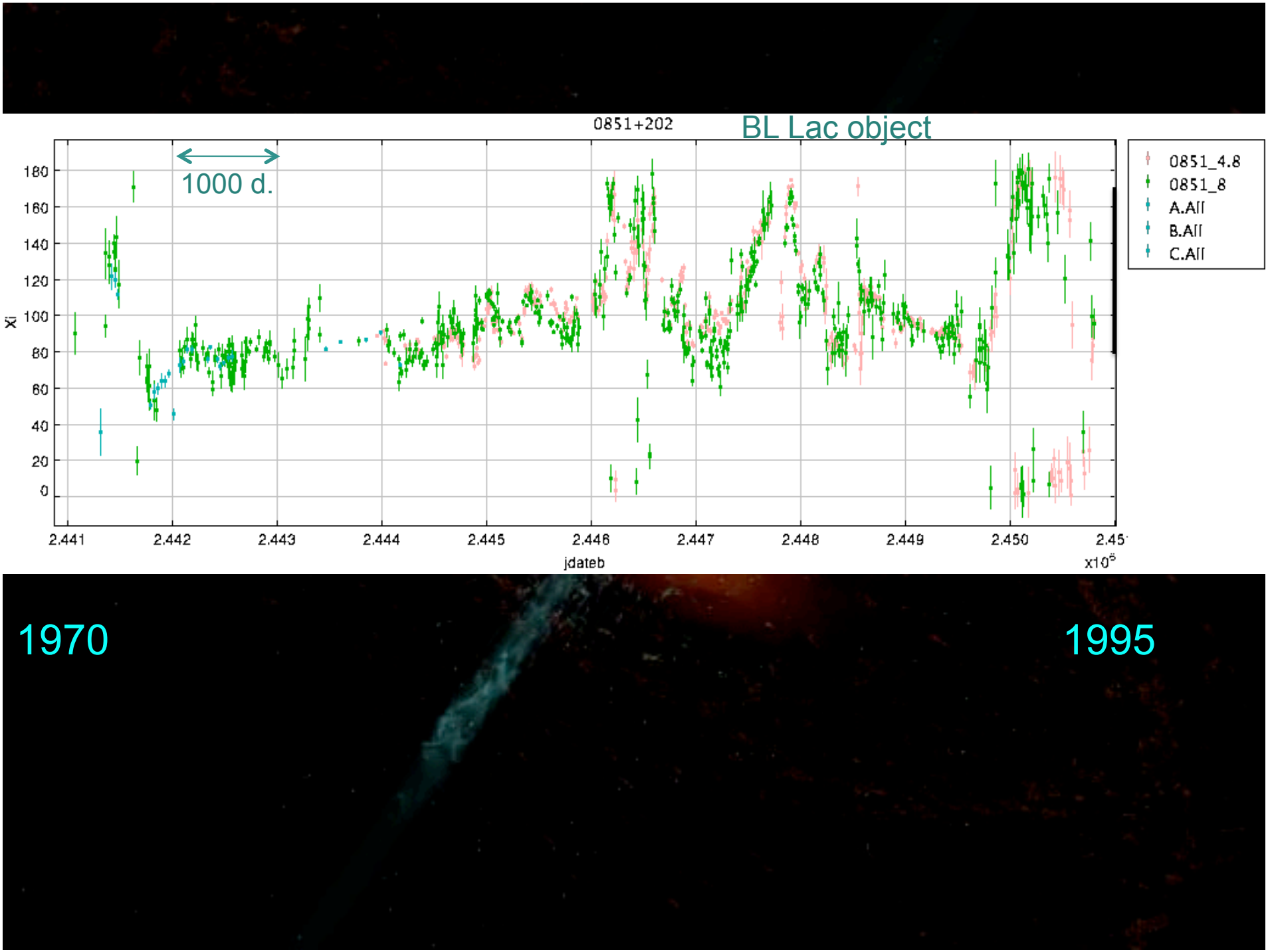
About 160 blazars, but then require radio polarization (UMRAO).
Optical polarization observations range from one! to many.

Unique contributions of this project:

1. Use of the optical polarization to define the INTRINSIC B field direction at the origin of the emission – enabling comparison with direction of radio, that, in direct interpretation of data can be affected by optical depth effects.

2. The search for patterns over long timescales of 20-30 years in blazars with a range of accretion properties (radiatively efficient and inefficient), and a range of jet properties.


0851+202
BL Lac object
180
1000 d.
0851_4.8
xi
0
jdateb
x10^5


0851+202
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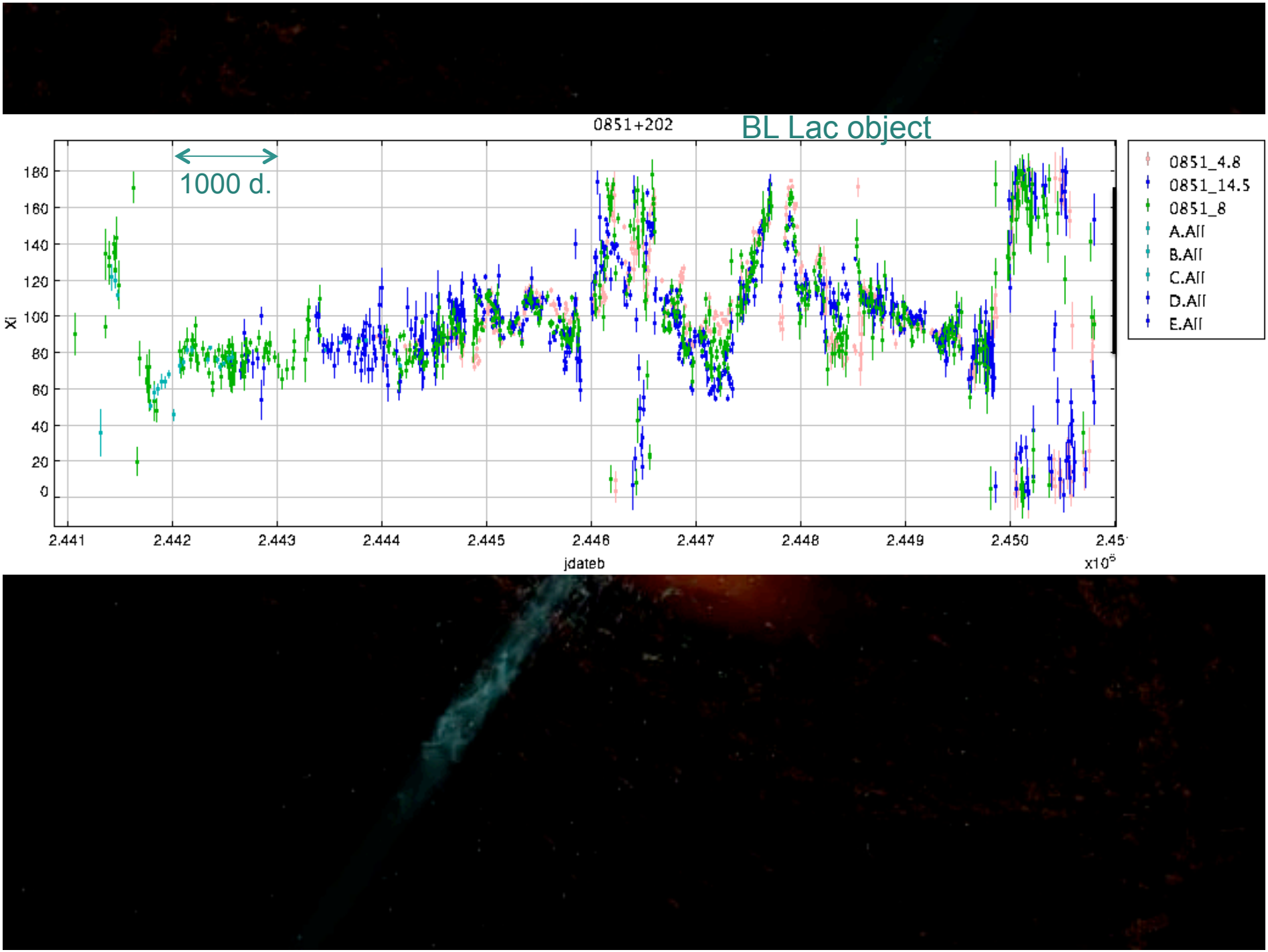
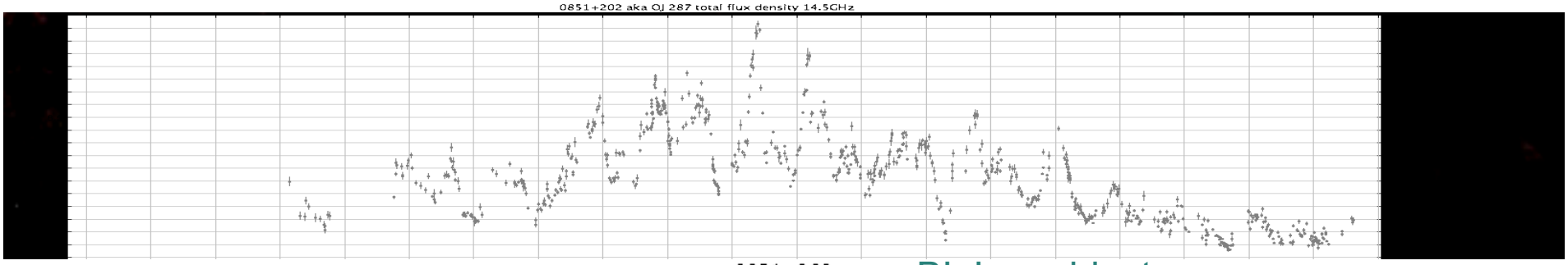
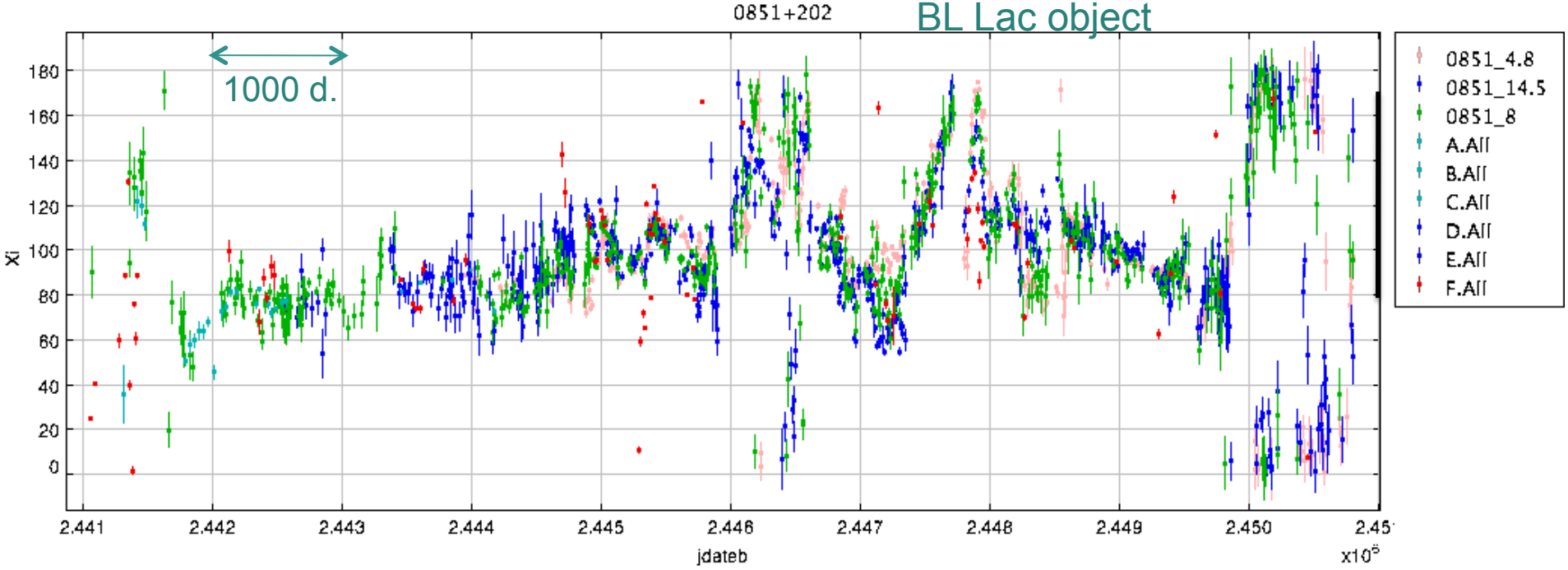
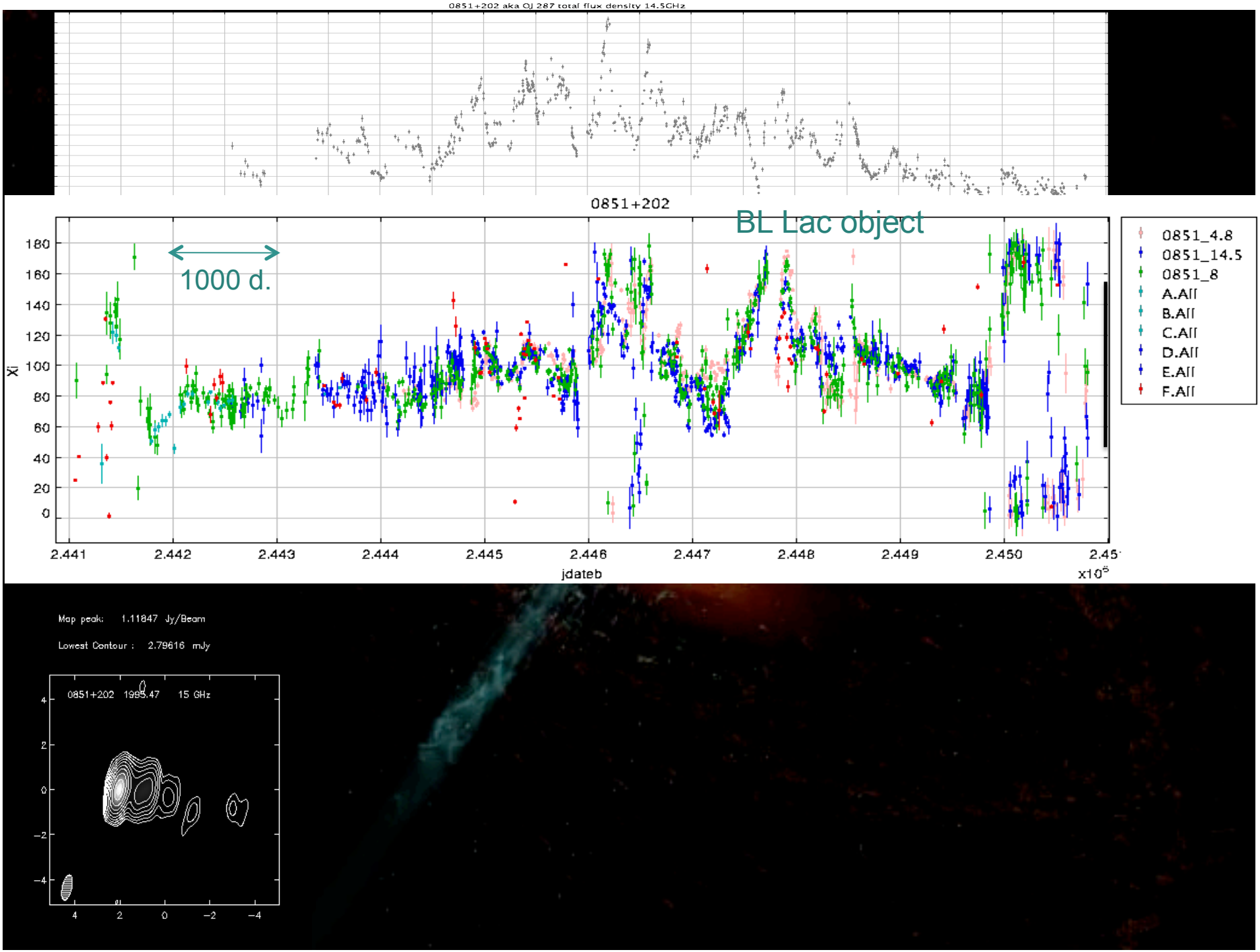
0851_4.8
0851_8
A.All
B.All
C.All
xi
jdateb
x10^5
1970
1995

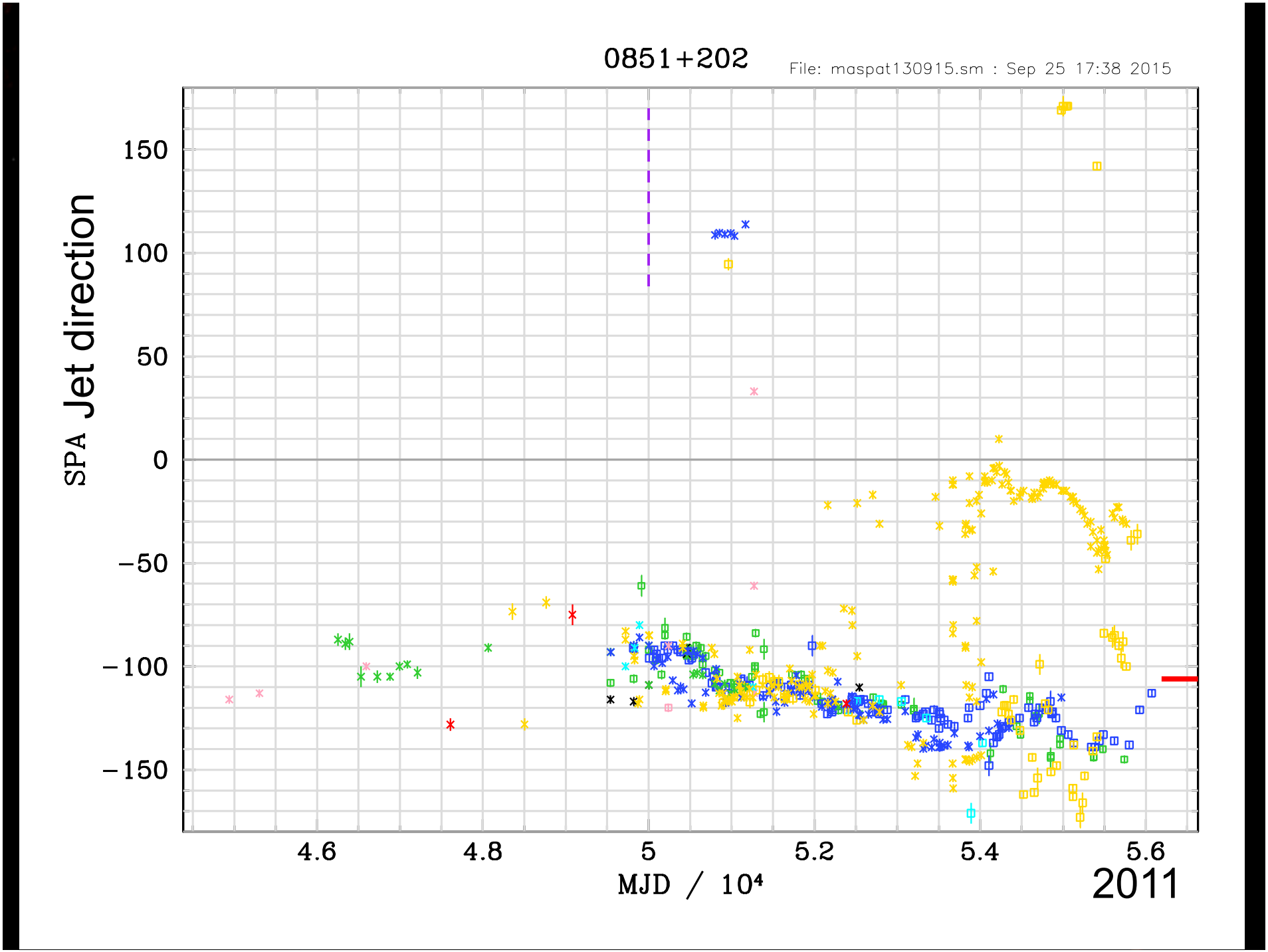

0851+202
BL Lac object
1000 d.
0851_4.8
0851_14.5
0851_8
A.All
B.All
C.All
D.All
E.All
Xi
jdateb
x10^5


0851+202 aka OJ 287 total flux density 14.5GHz


0851+202
BL Lac object
1000 d.
Xi
jdateb
x10^5
0851_4.8
0851_14.5
0851_8
A.All
B.All
C.All
D.All
E.All
F.All


0851+202 1995.47 15 GHz


0851+202 aka OJ 287 total flux density 14.5GHz
0851+202
BL Lac object
1000 d.
0851_4.8
0851_14.5
0851_8
A.All
B.All
C.All
D.All
E.All
F.All
Xi
jdateb
x10^5
Map peak: 1.11847 Jy/Beam
Lowest Contour : 2.79616 mJy
0851+202 1995.47 15 GHz


0851+202
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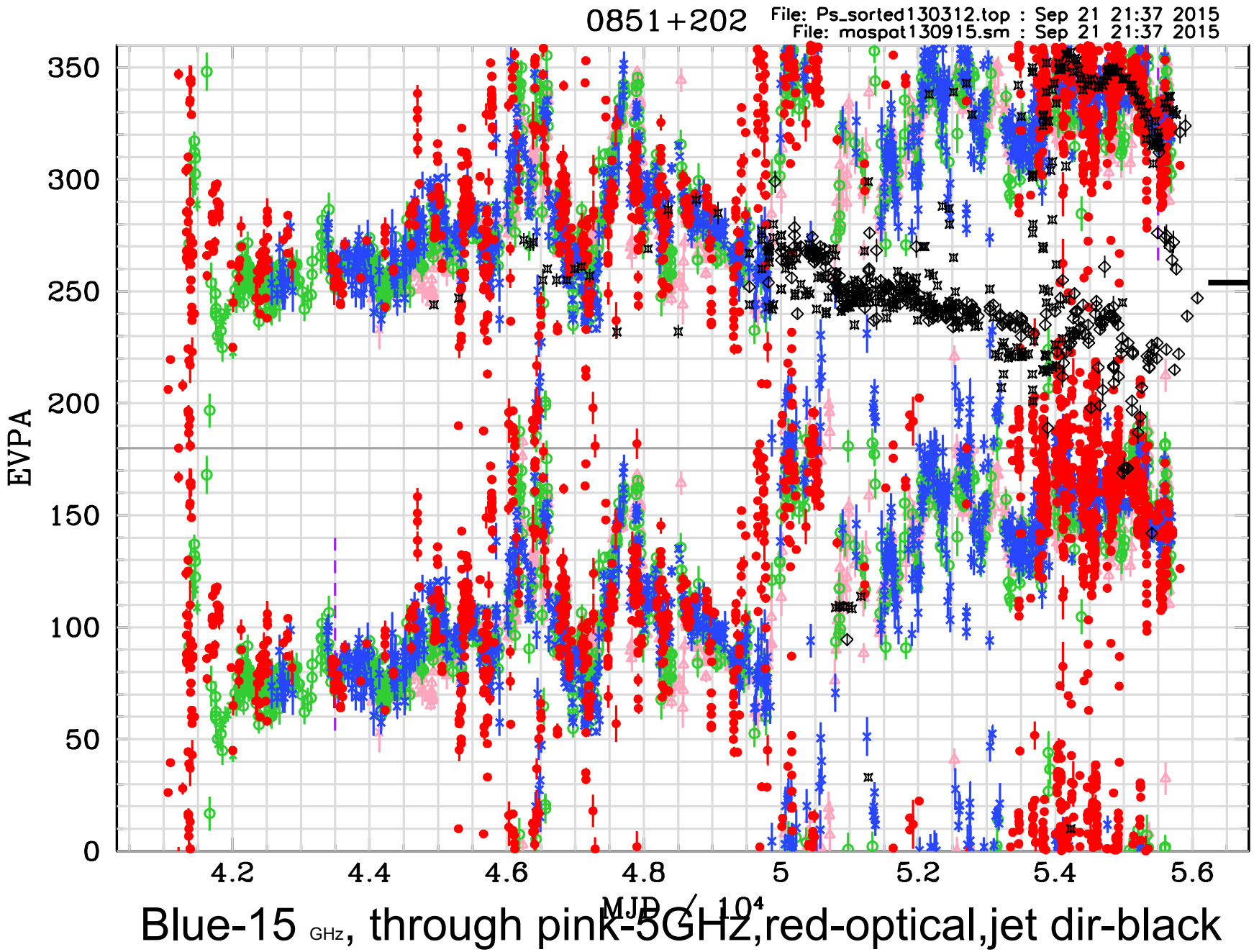
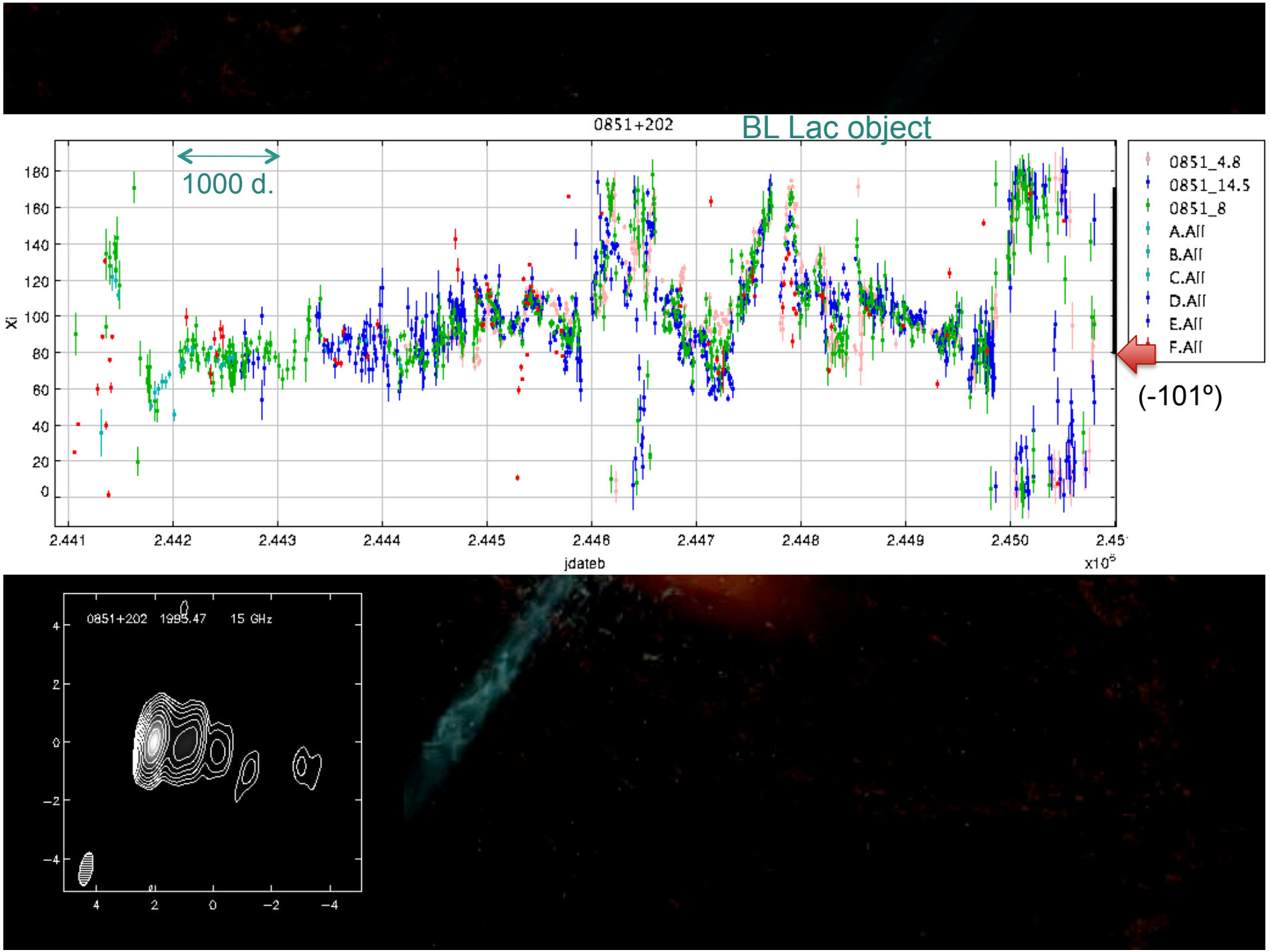
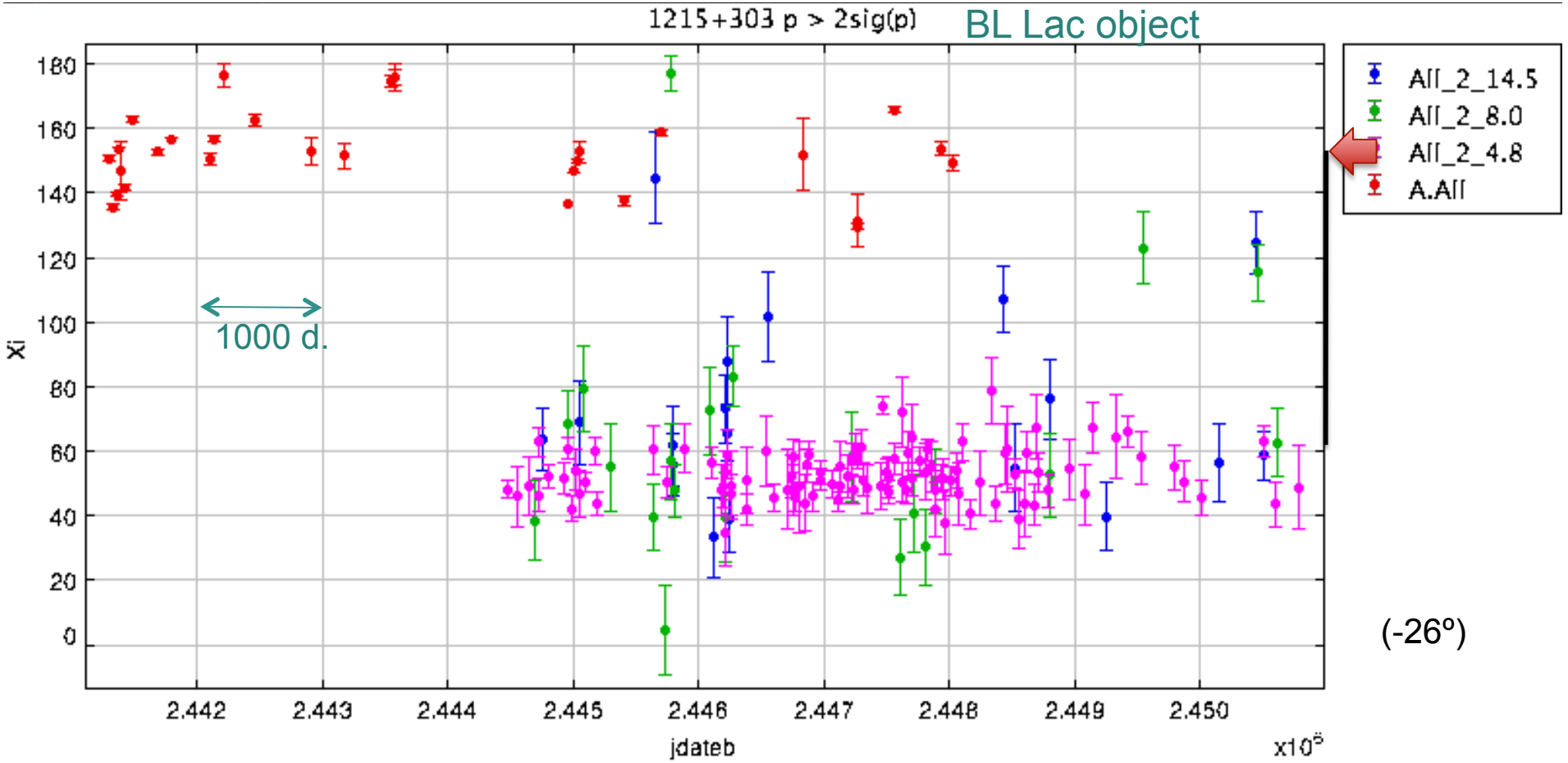
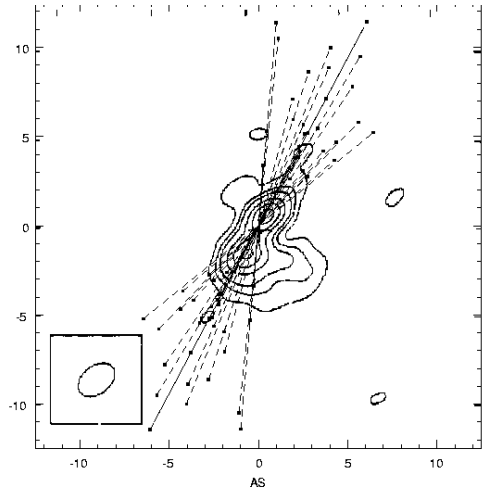
SPA Jet direction
150
100
50
0
−50
−100
−150
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴
2011

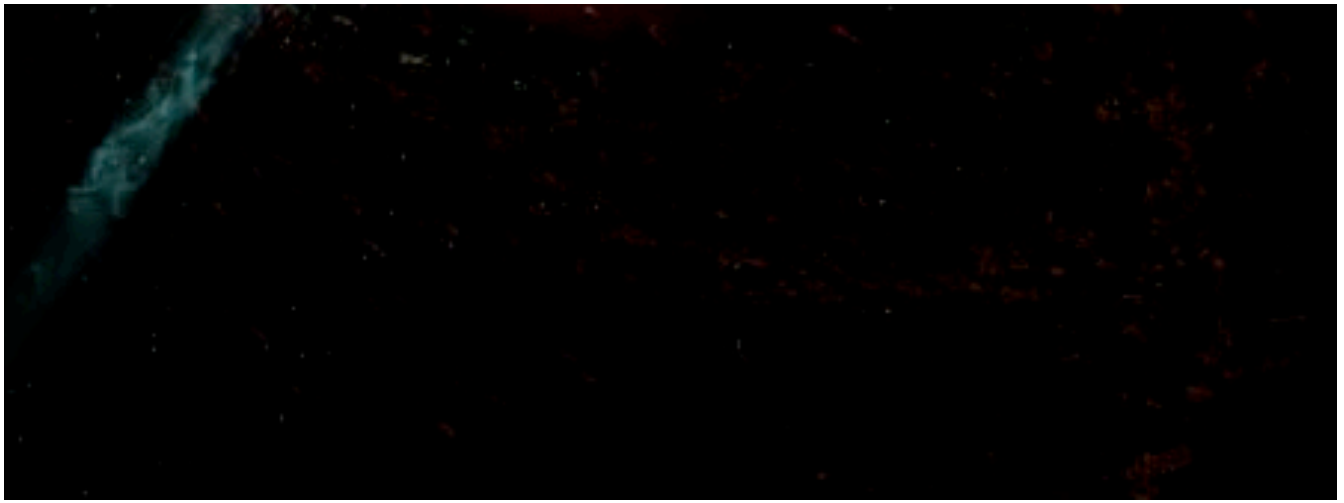

0851+202
File: Ps_sorted130312.top : Sep 21 21:37 2015
File: maspat130915.sm : Sep 21 21:37 2015
EVPA
350
300
250
200
150
100
50
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴
Blue-15 GHz, through pink-5GHz,red-optical,jet dir-black

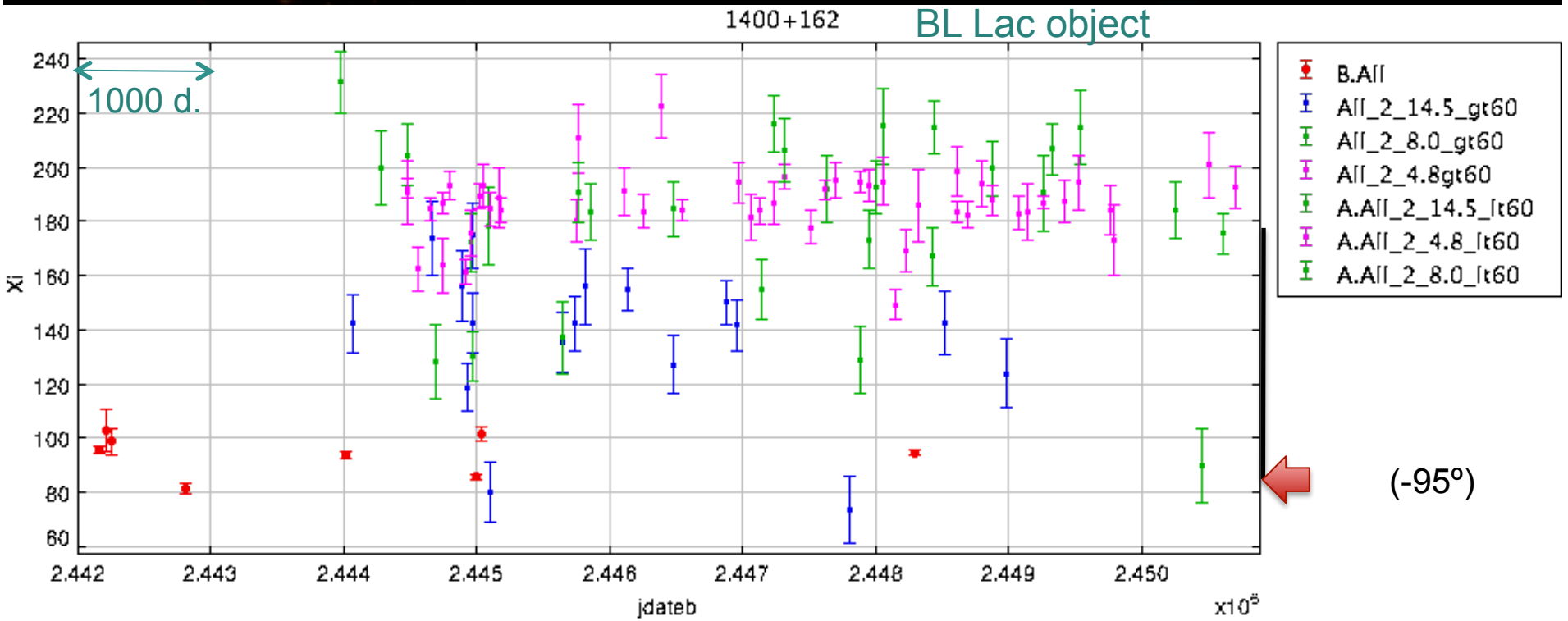

0851+202
BL Lac object
1000 d.
0851_4.8
0851_14.5
0851_8
A.All
B.All
C.All
D.All
E.All
F.All
(-101º)
Xi
jdateb
x10^5
0851+202 1995.47 15 GHz

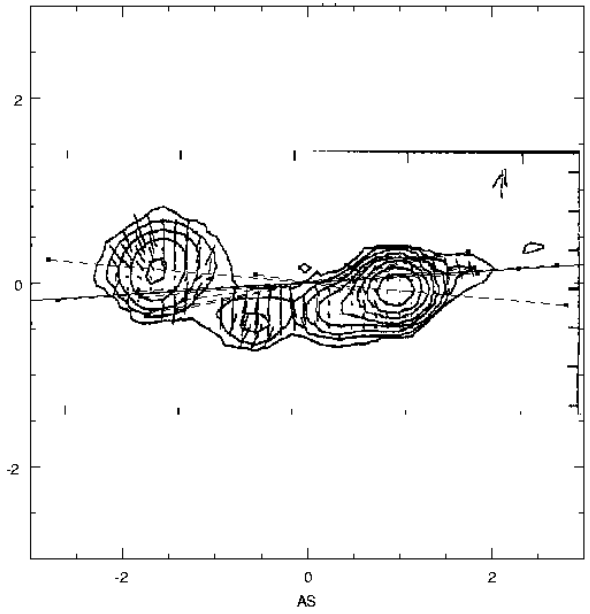

1215+303 p > 2sig(p)
BL Lac object
All_2_14.5
All_2_8.0
All_2_4.8
A.All
1000 d.
Xi
jdateb
x10^5

(-26º)


AS




1400+162
BL Lac object
1000 d.
Xi
jdateb
x10^5
B.All
All_2_14.5_gt60
All_2_8.0_gt60
All_2_4.8gt60
A.All_2_14.5_lt60
A.All_2_4.8_lt60
A.All_2_8.0_lt60
(-95°)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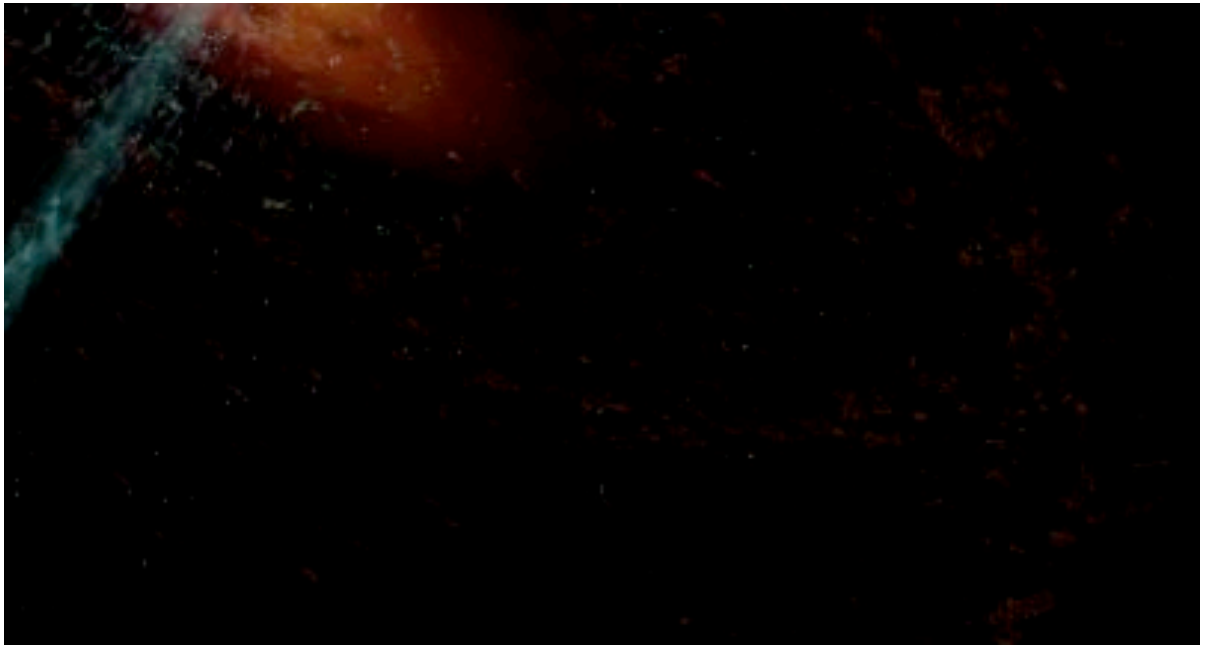
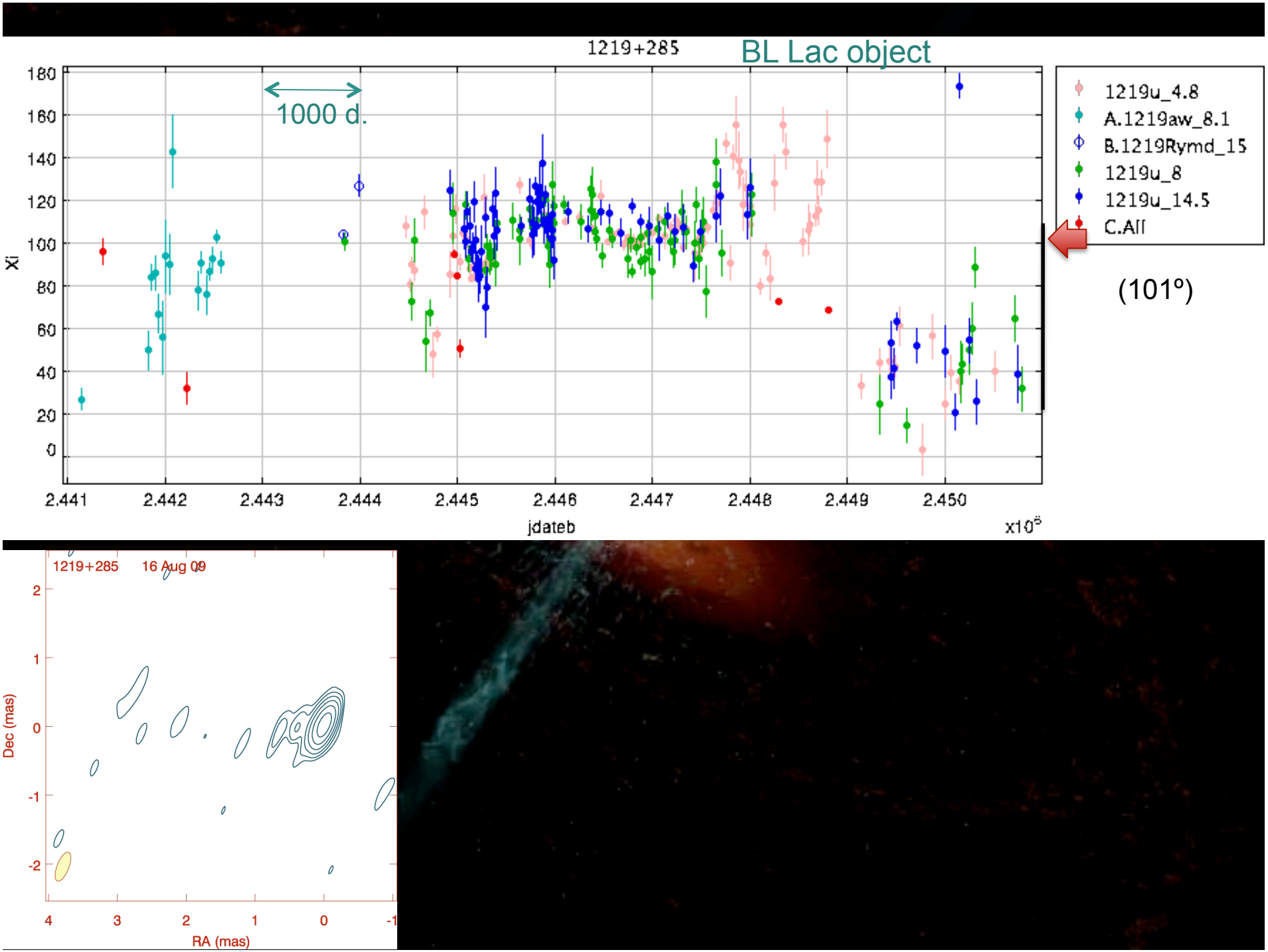
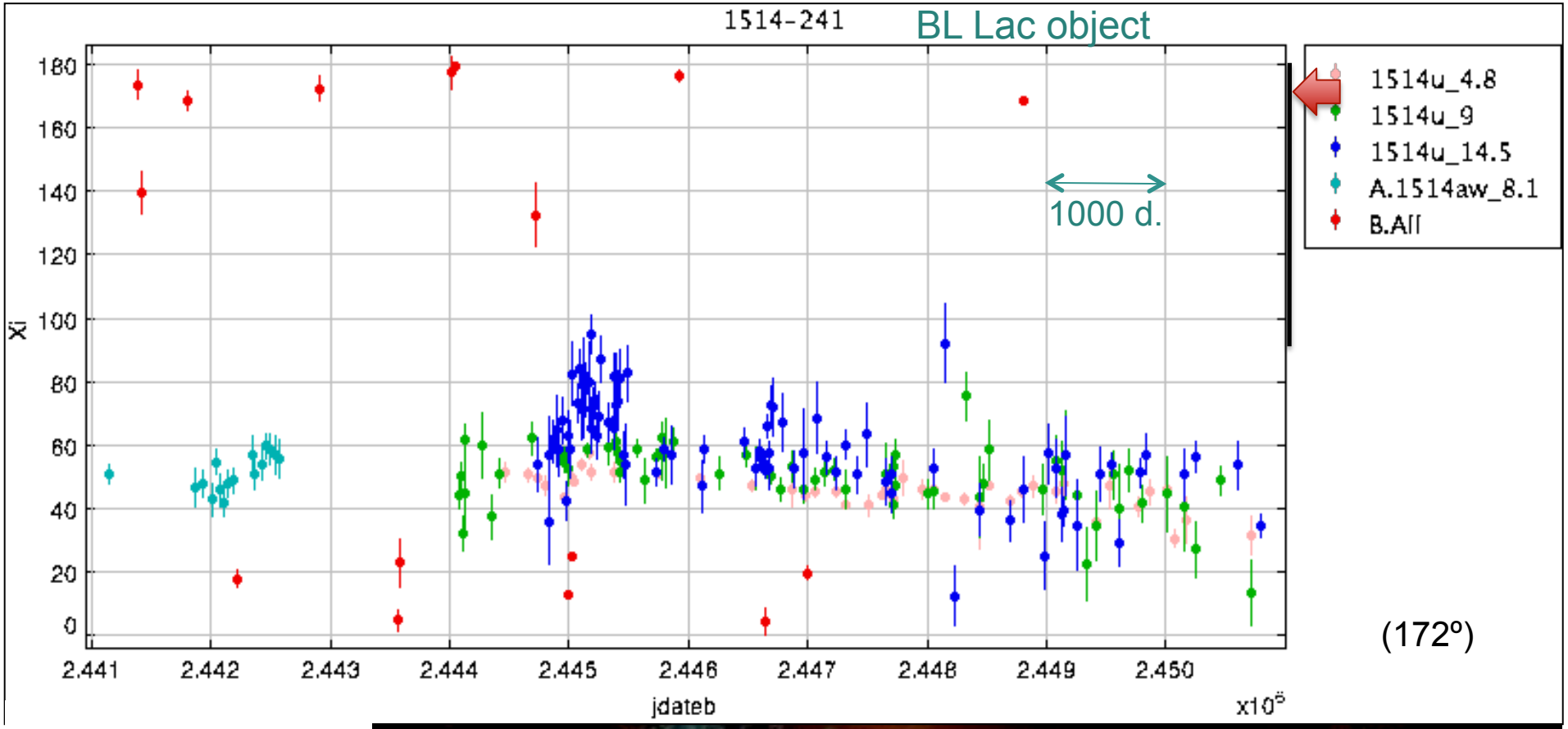
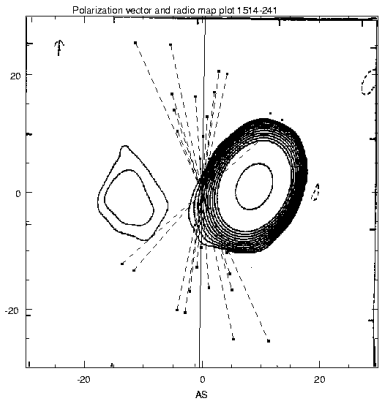
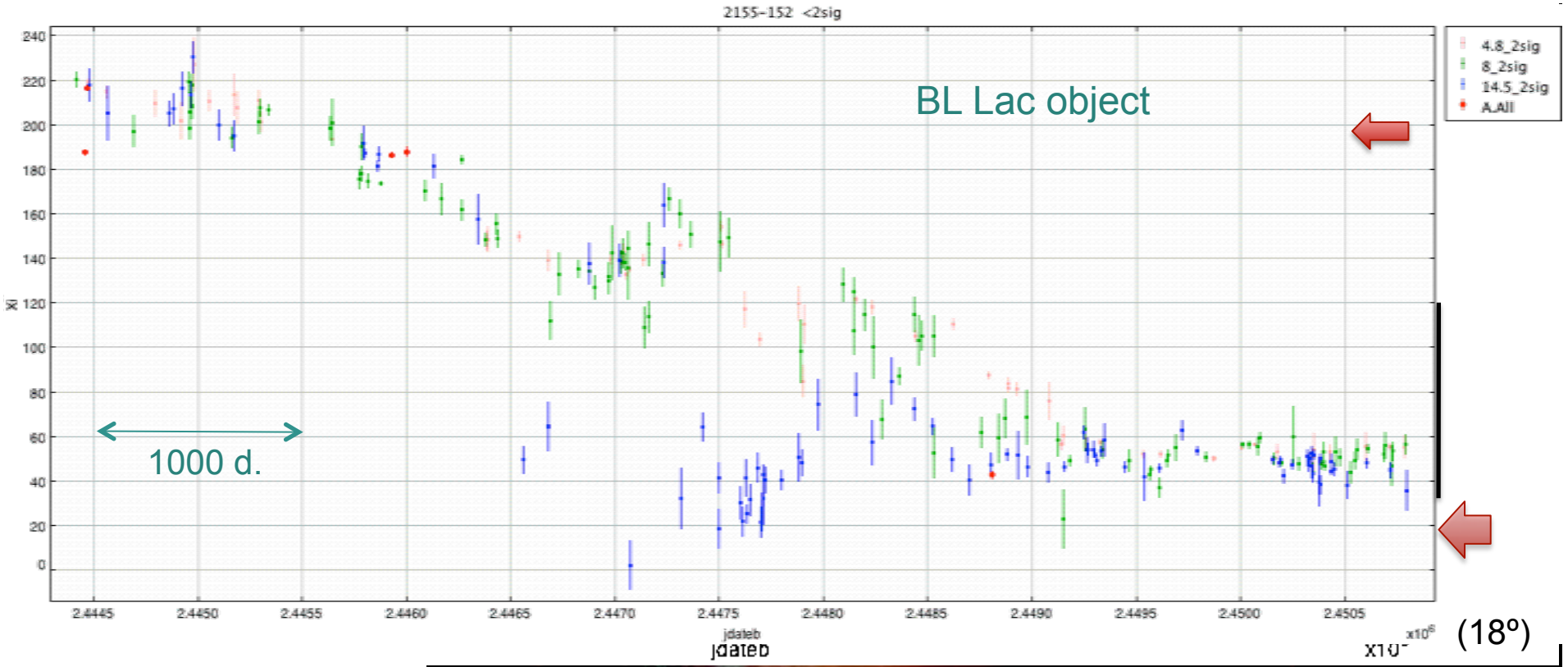



1219+285
BL Lac object
1000 d.
1219u_4.8
A.1219aw_8.1
B.1219Rymd_15
1219u_8
1219u_14.5
C.All
(101º)
Xi
jdateb
x10^5
1219+285
16 Aug 09
Dec (mas)
RA (mas)

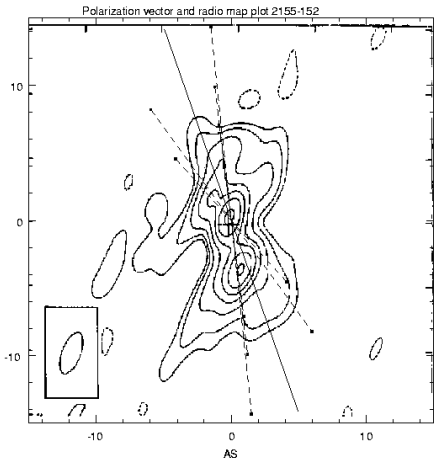

1514-241
BL Lac object
1514u_4.8
1514u_9
1514u_14.5
A.1514aw_8.1
B.All
1000 d.
Xi
jdateb
x10ö
180
160
140
120
100
80
60
40
20
0
2.441
2.442
2.443
2.444
2.445
2.446
2.447
2.448
2.449
2.450

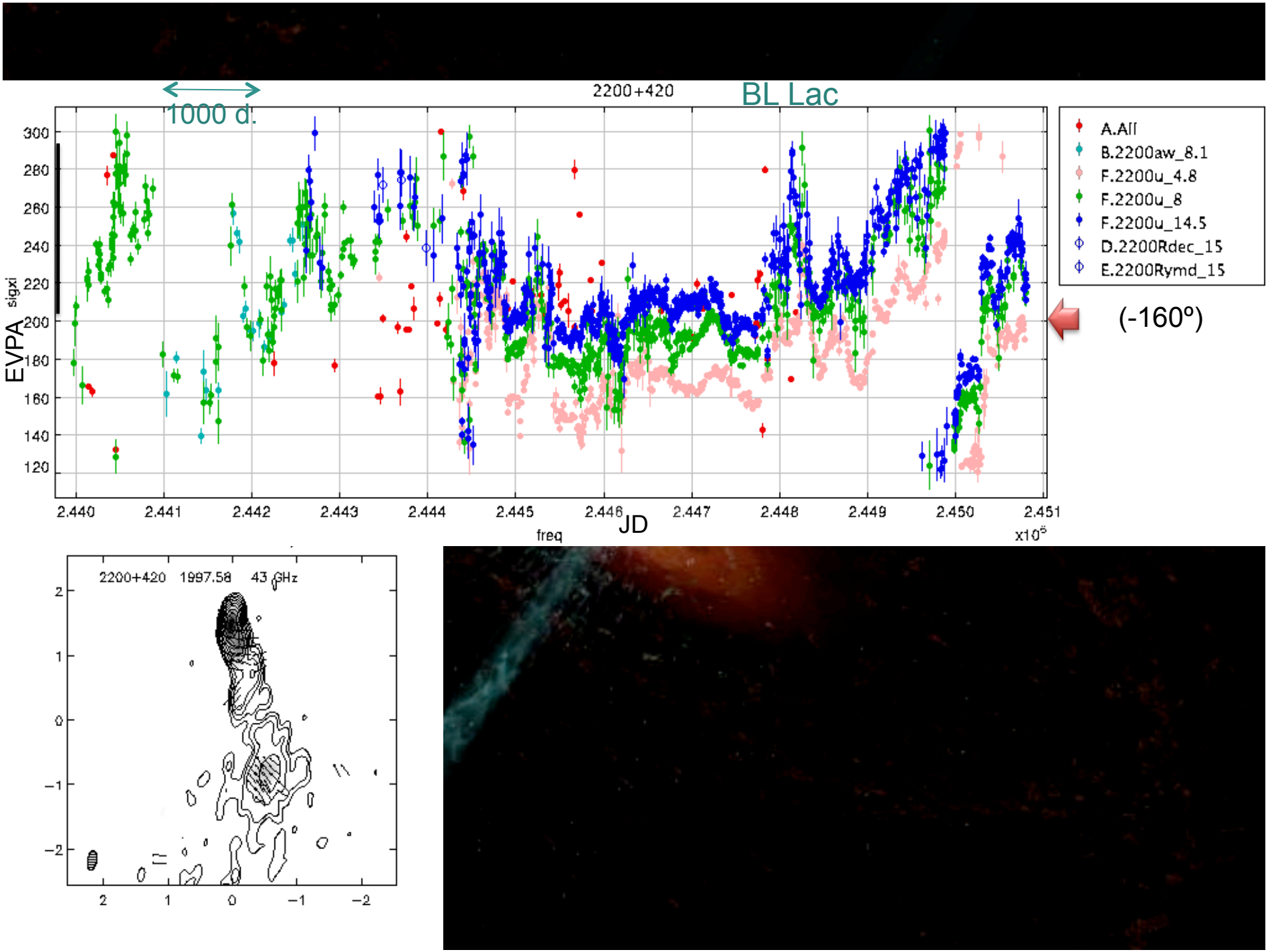
(172º)

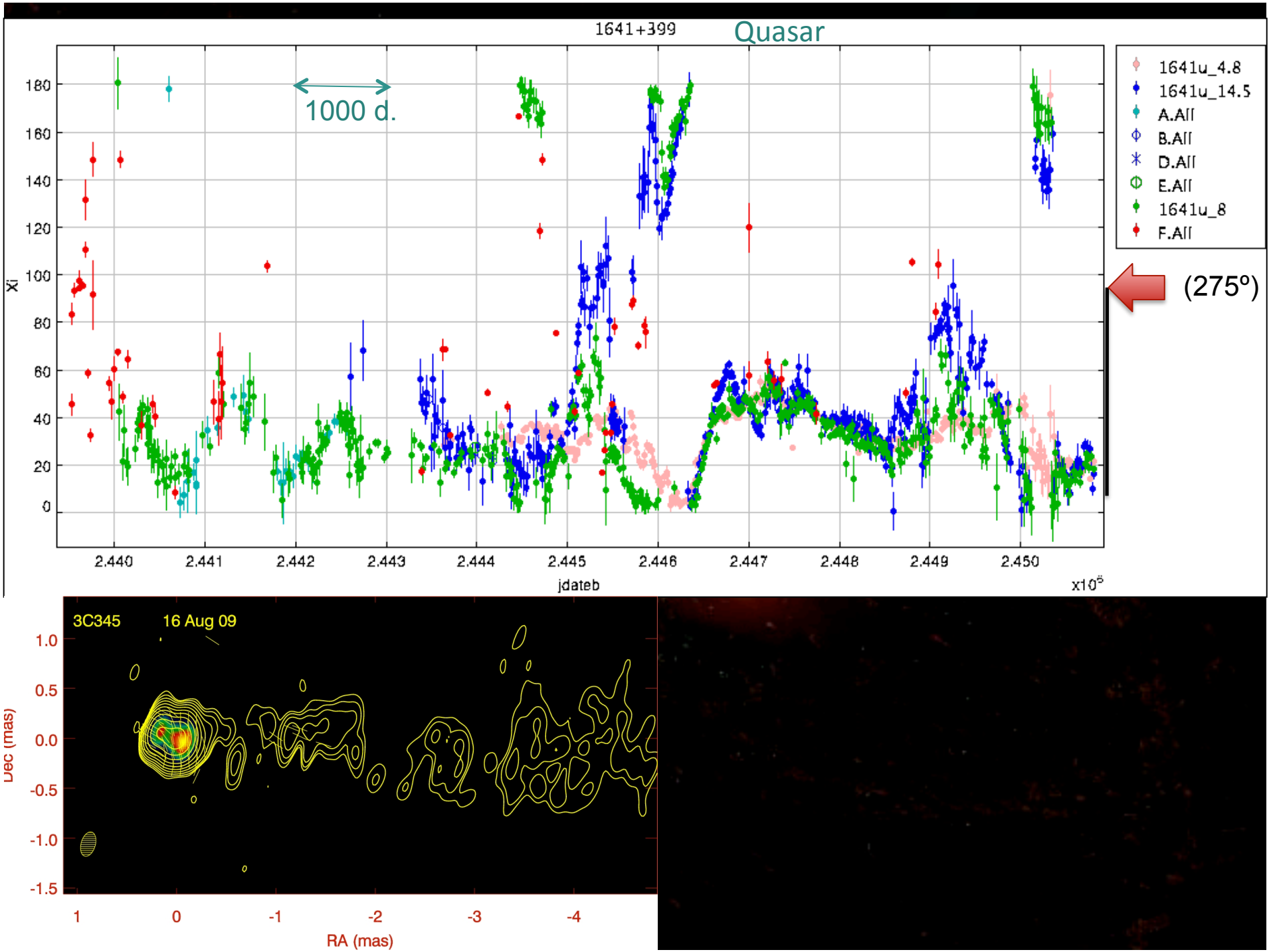

Polarization vector and radio map plot 1514-241
20
0
-20
-20
0
20
AS

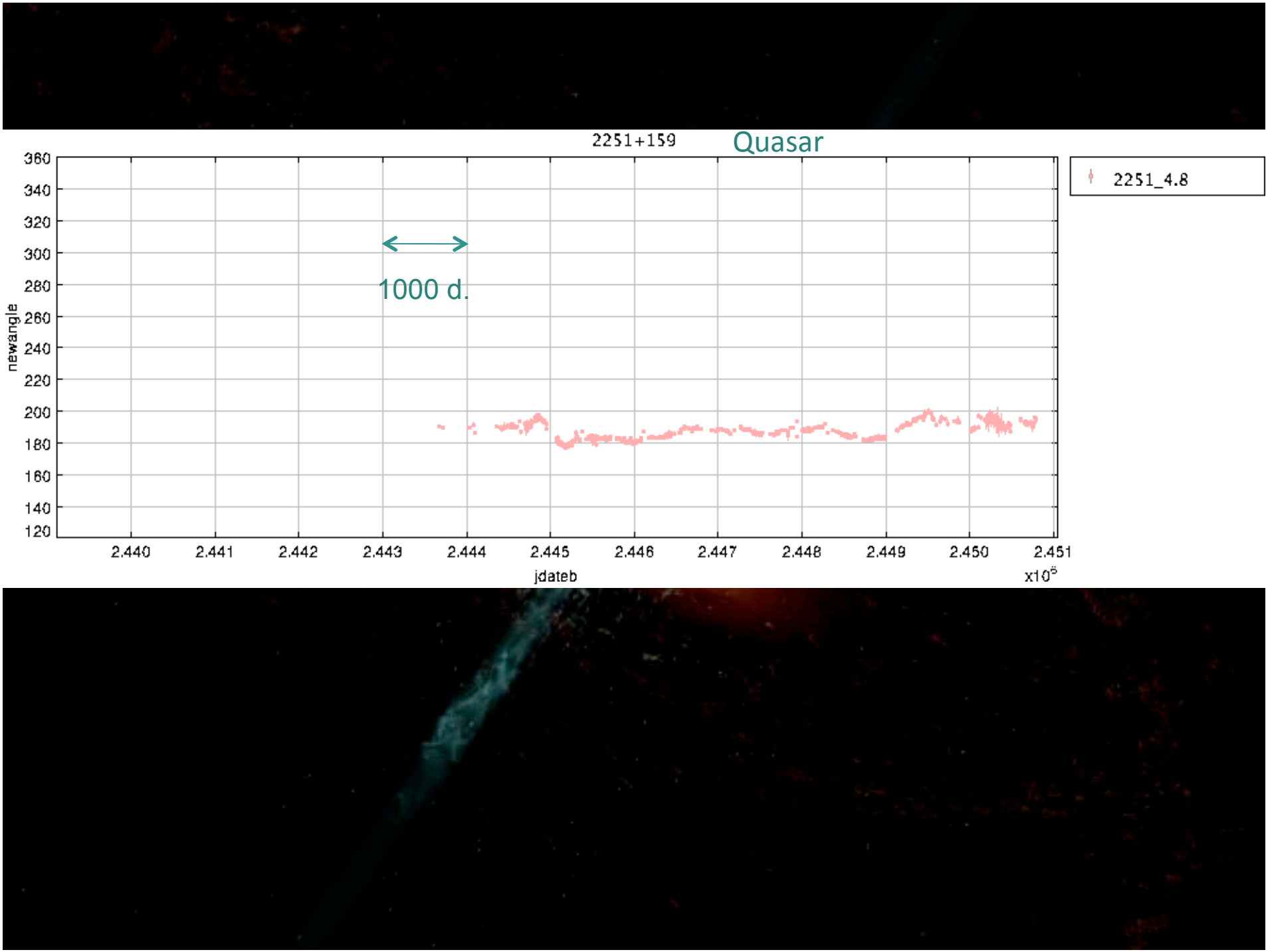

2155-152 <2sig
BL Lac object
1000 d.
4.8_2sig
8_2sig
14.5_2sig
All
jdateb

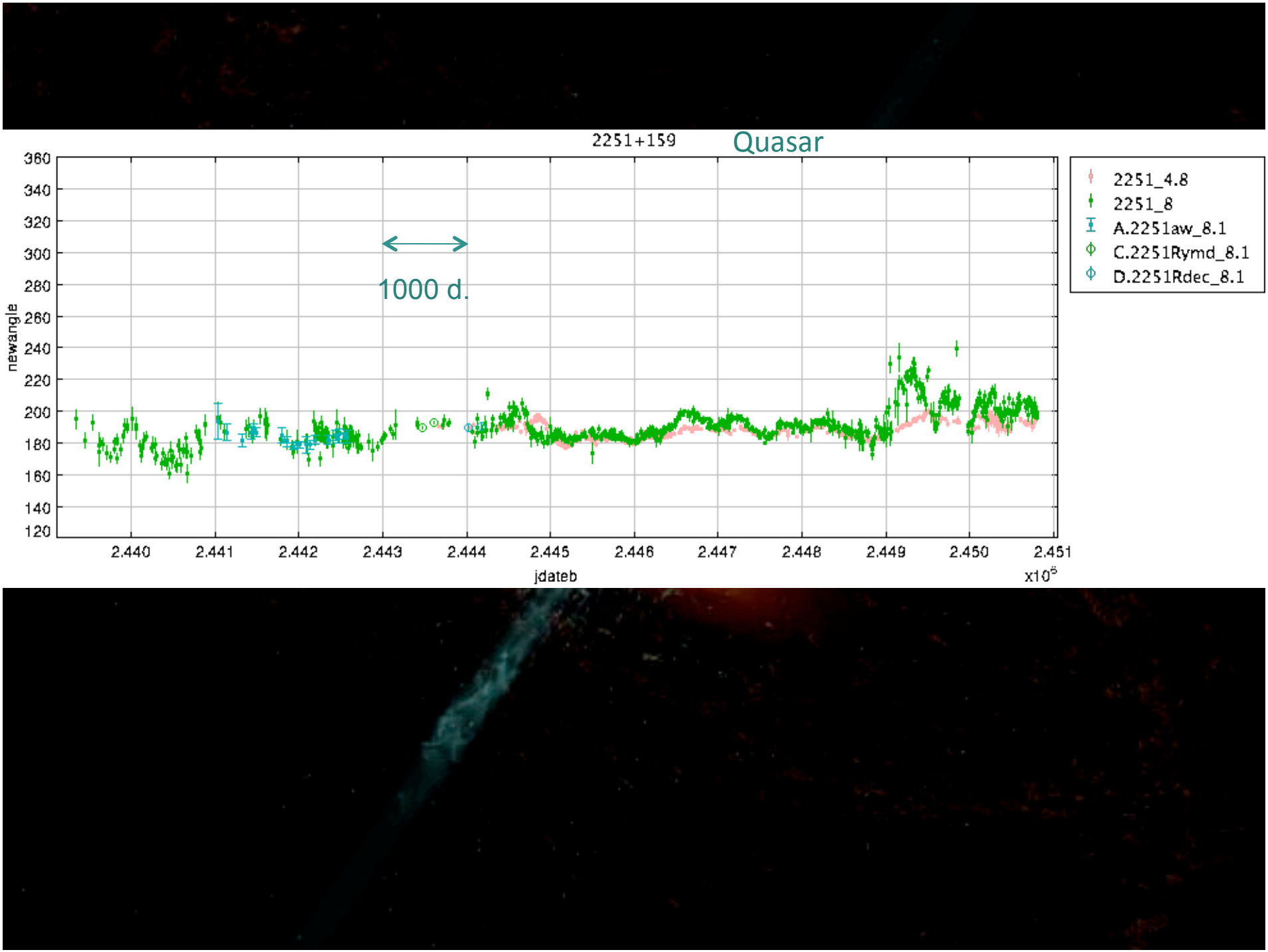
(18º)

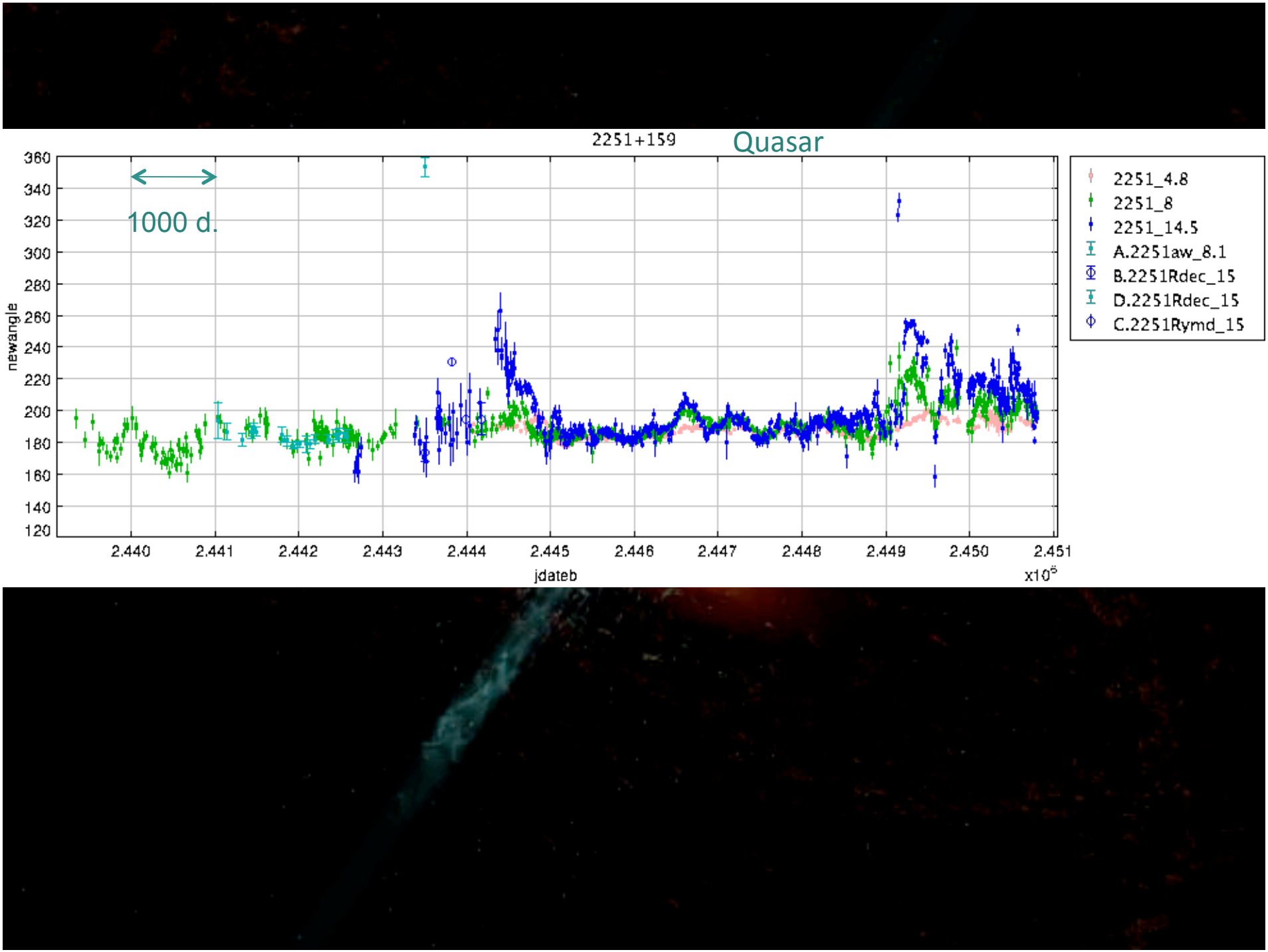

Polarization vector and radio map plot 2155-152
AS


1000 d.
2200+420
BL Lac
EVPA
sigxi
300
280
260
240
220
200
180
160
140
120
2.440
2.441
2.442
2.443
2.444
2.445
2.446
2.447
2.448
2.449
2.450
2.451
freq
JD
x10^6
A.All
B.2200aw_8.1
F.2200u_4.8
F.2200u_8
F.2200u_14.5
D.2200Rdec_15
E.2200Rymd_15
(-160º)
2200+420 1997.58 43 GHz
2
1
0
−1
−2


1641+399
Quasar
1000 d.
1641u_4.8
1641u_14.5
A.All
B.All
D.All
E.All
1641u_8
F.All
(275°)
Xi
jdateb
x10^5
3C345
16 Aug 09
Dec (mas)
RA (mas)


2251+159
Quasar
2251_4.8
1000 d.
newangle
jdateb
x10^5


2251+159
Quasar
1000 d.
2251_4.8
2251_8
A.2251aw_8.1
C.2251Rymd_8.1
D.2251Rdec_8.1
newangle
jdateb
x10^5


2251+159
Quasar
1000 d.
newangle
jdateb
x10^5
2251_4.8
2251_8
2251_14.5
A.2251aw_8.1
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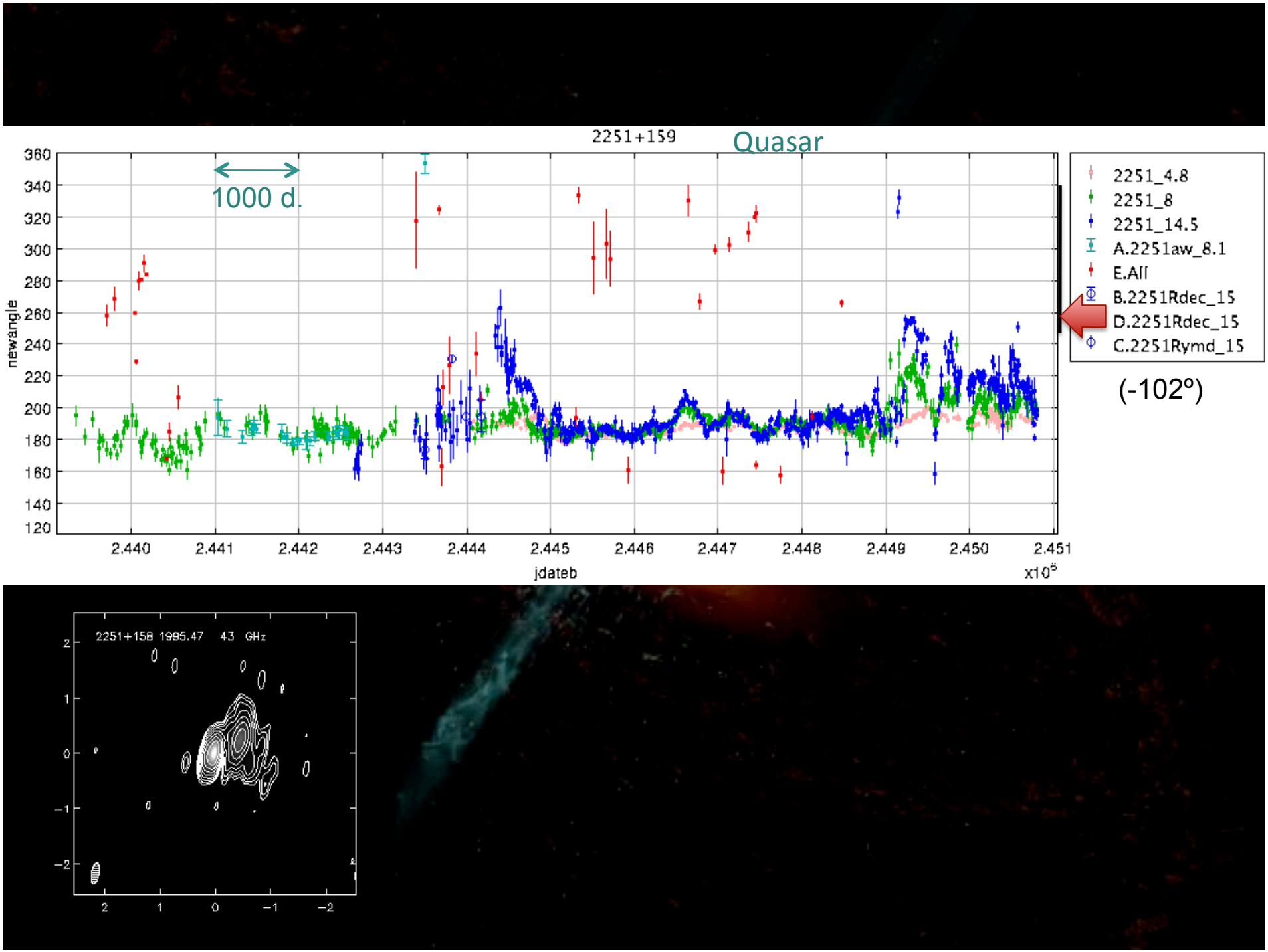
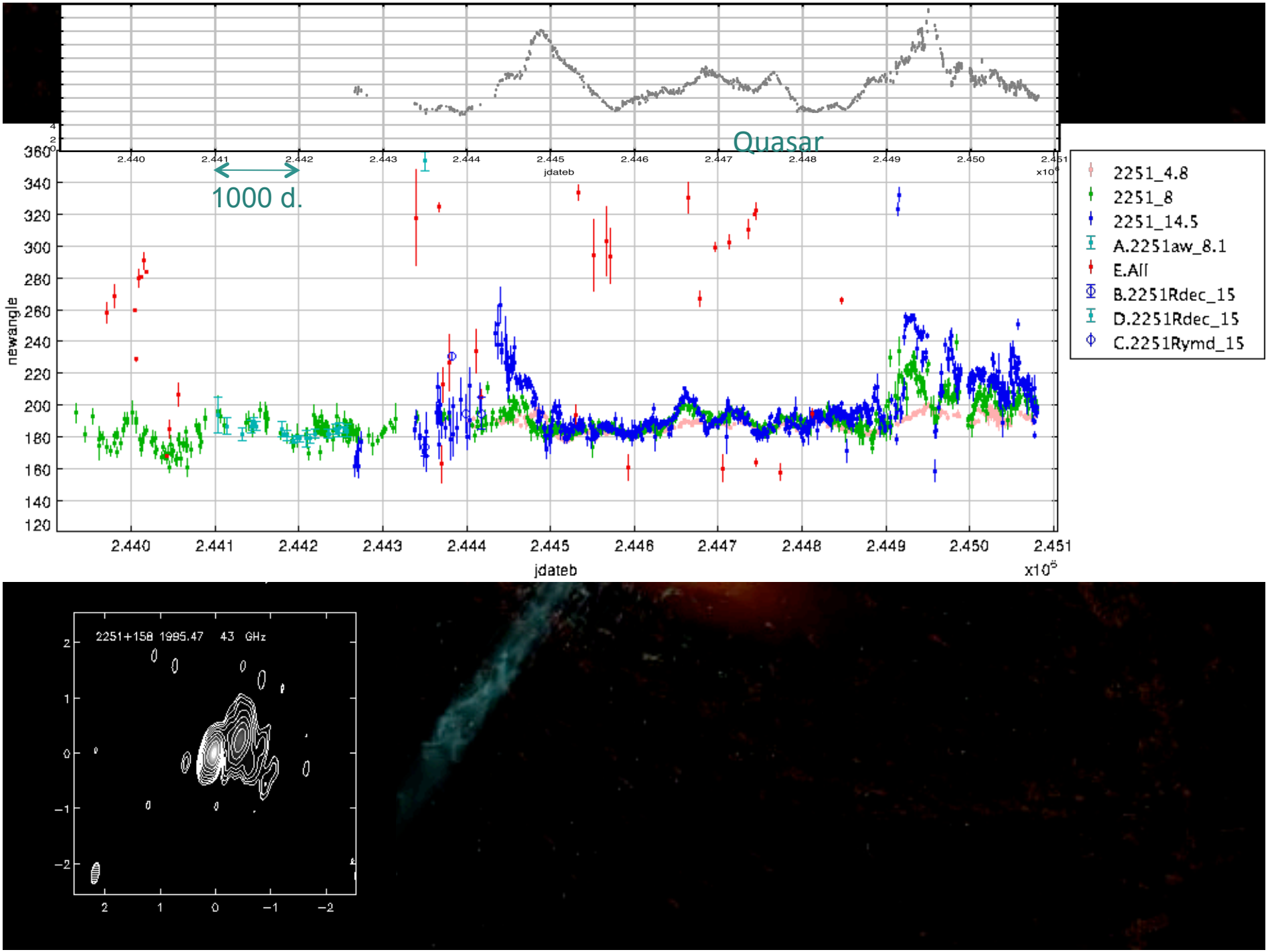
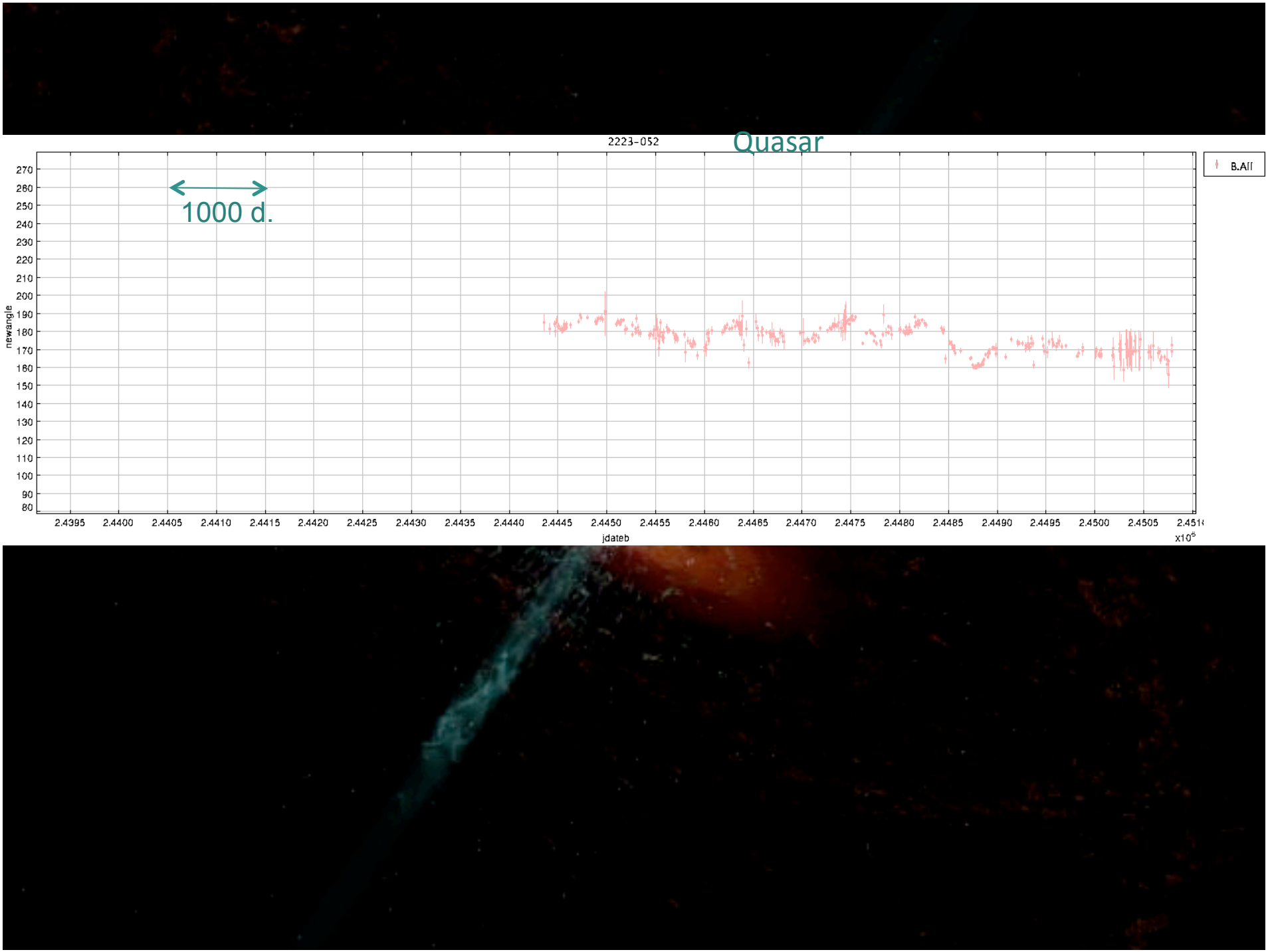
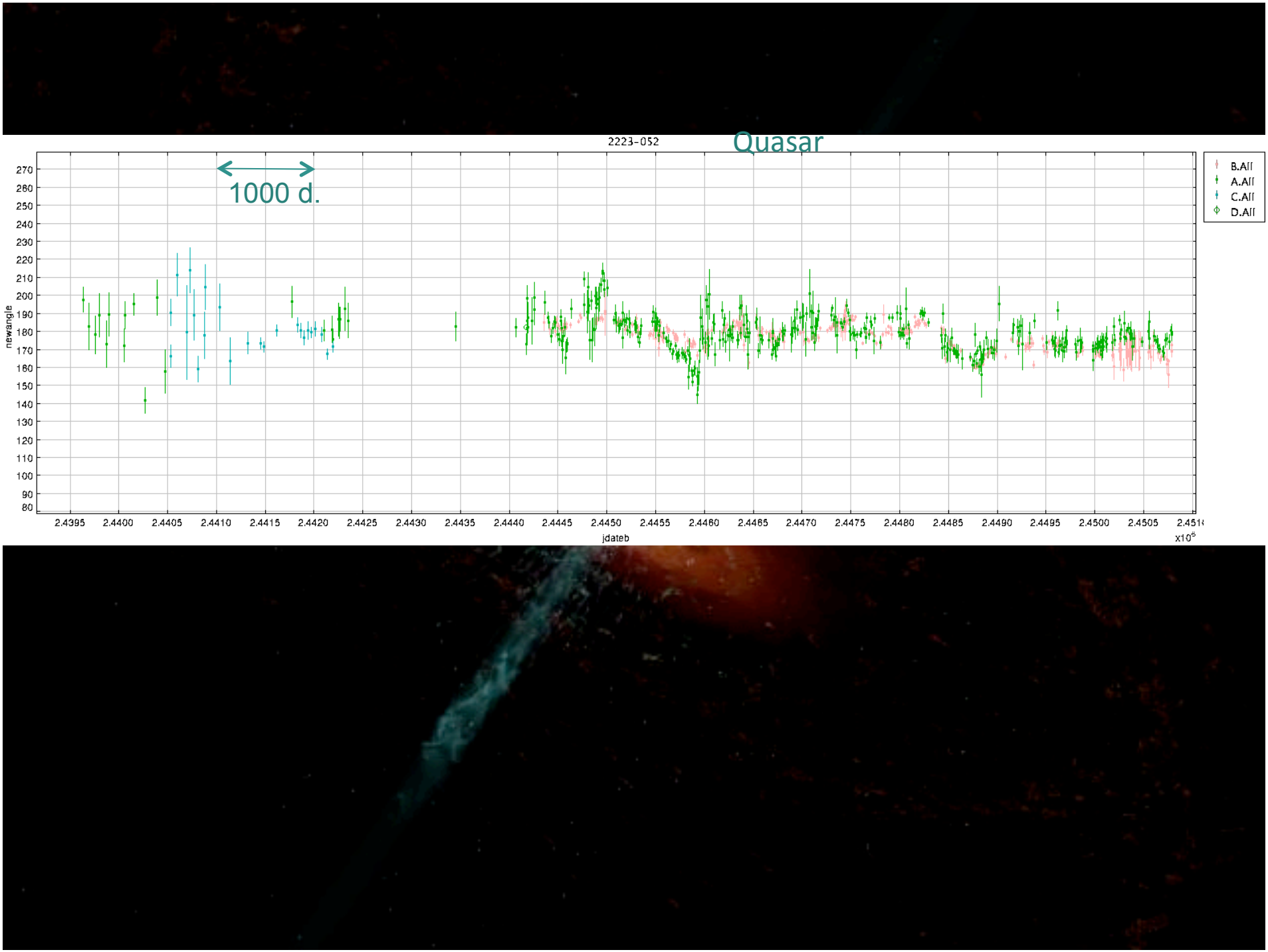
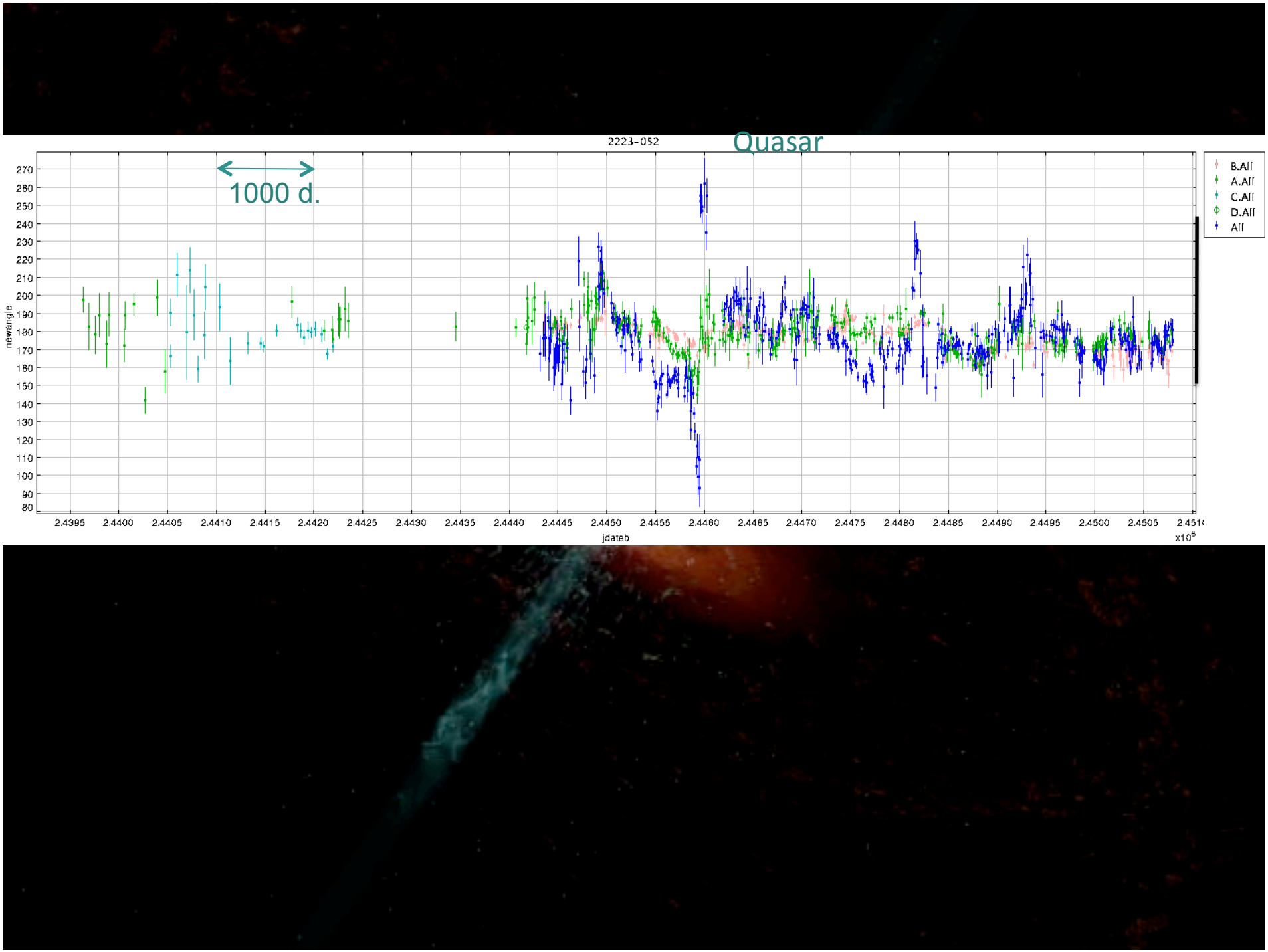
D.2251Rdec_15
C.2251Rymd_15

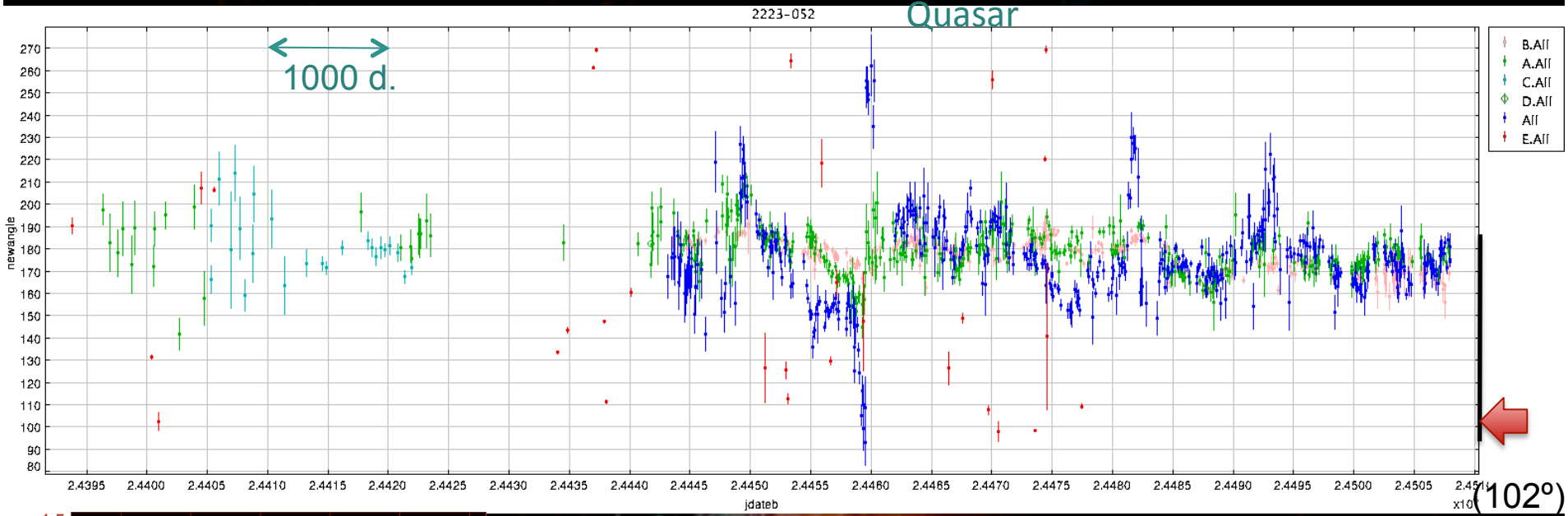

2251+159
Quasar
1000 d.
newangle
jdateb
x10^6
2251_4.8
2251_8
2251_14.5
A.2251aw_8.1
E.All
B.2251Rdec_15
D.2251Rdec_15
C.2251Rymd_15
(-102º)
2251+158 1995.47 43 GHz


Quasar
1000 d.
2251_4.8
2251_8
2251_14.5
A.2251aw_8.1
E.All
B.2251Rdec_15
D.2251Rdec_15
C.2251Rymd_15
newangle
jdateb
x10^6
2251+158 1995.47 43 GHz

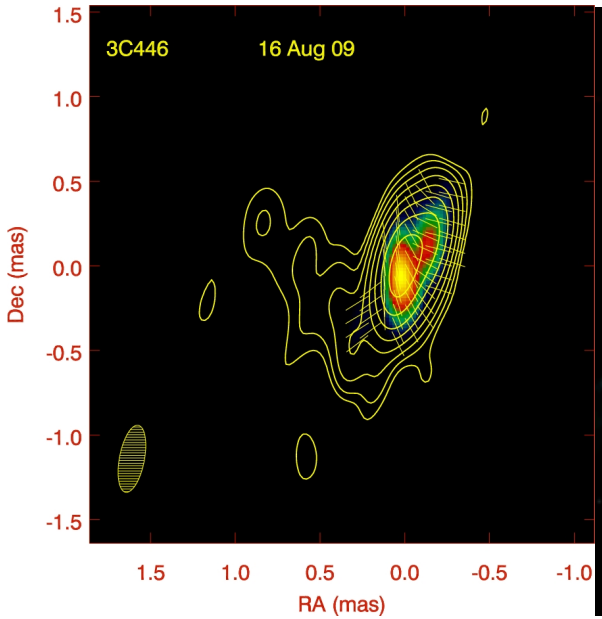

2223-052
Quasar
1000 d.
B.All
newangle
jdateb
x10^5

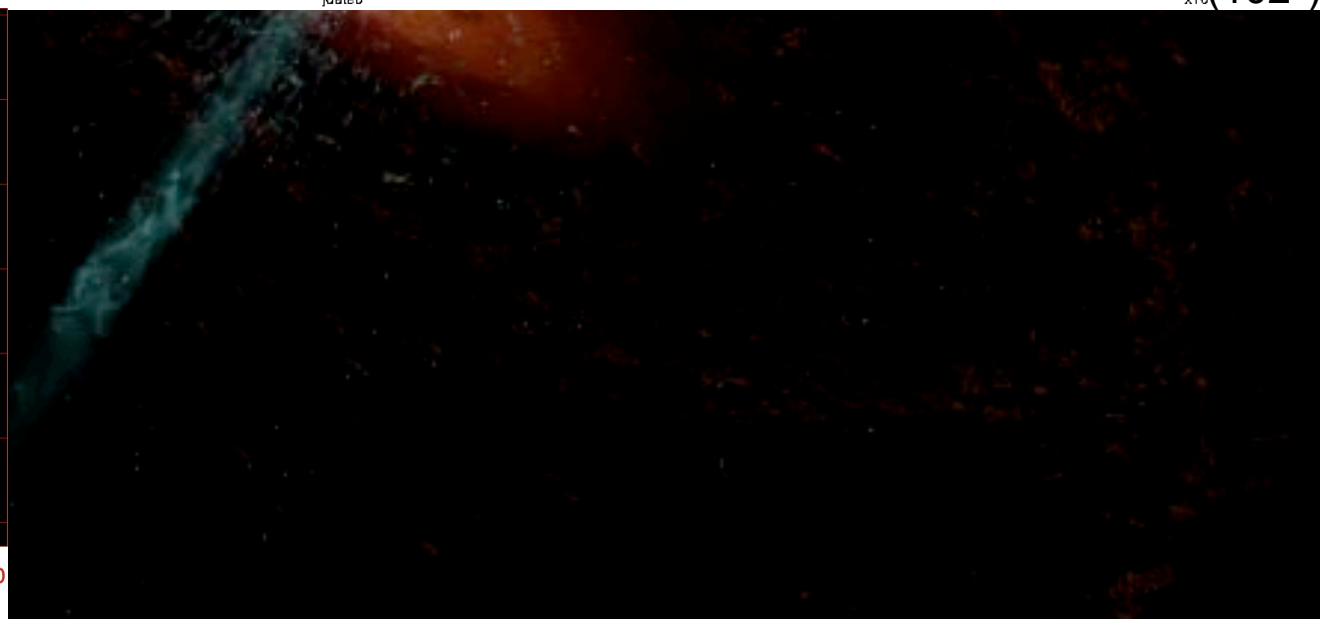

2223-052
Quasar
1000 d.
B.All
A.All
C.All
D.All
newangle
jdateb
x10^5

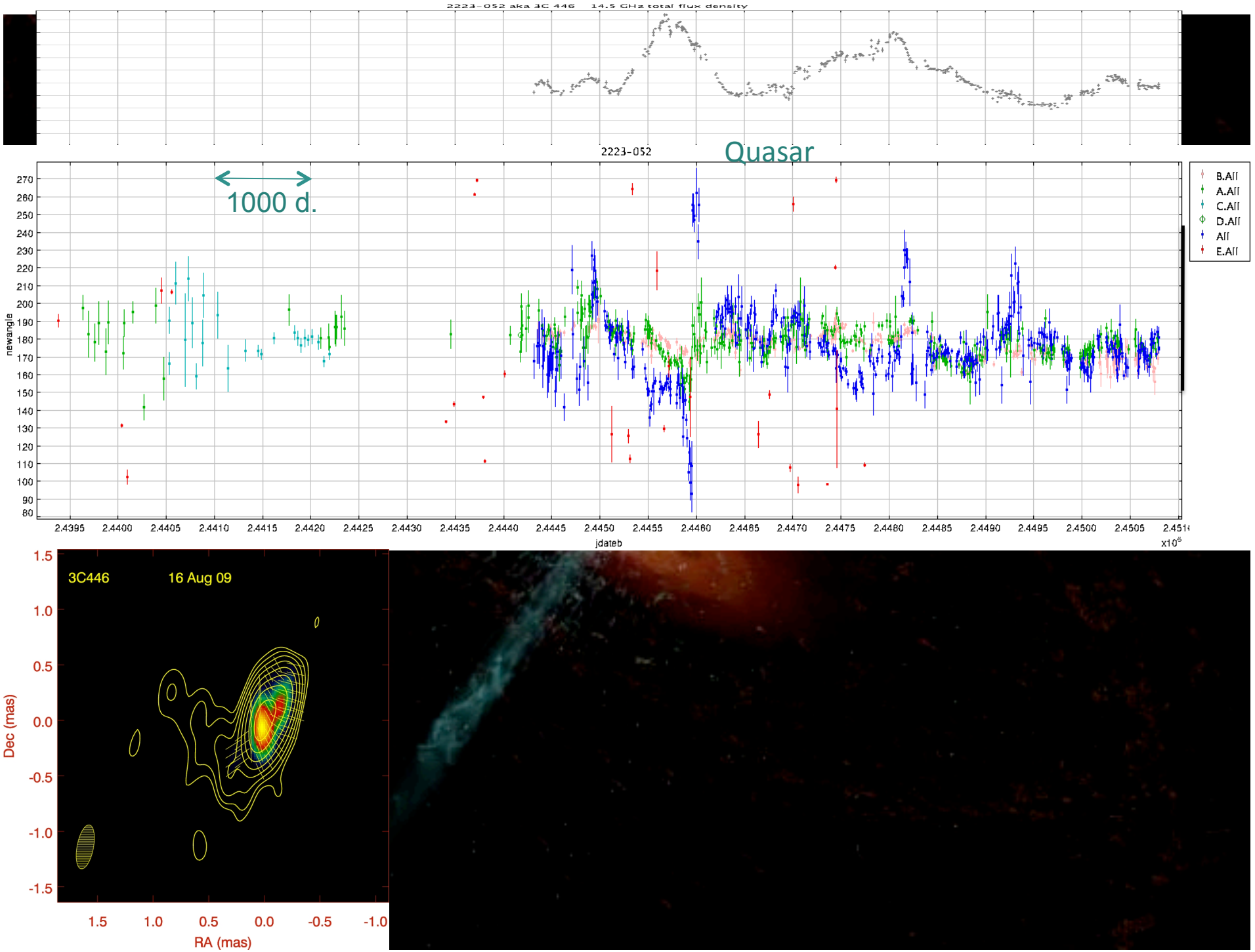

2223-052
Quasar
1000 d.
B.All
A.All
C.All
D.All
All
newangle
jdateb
x10^5

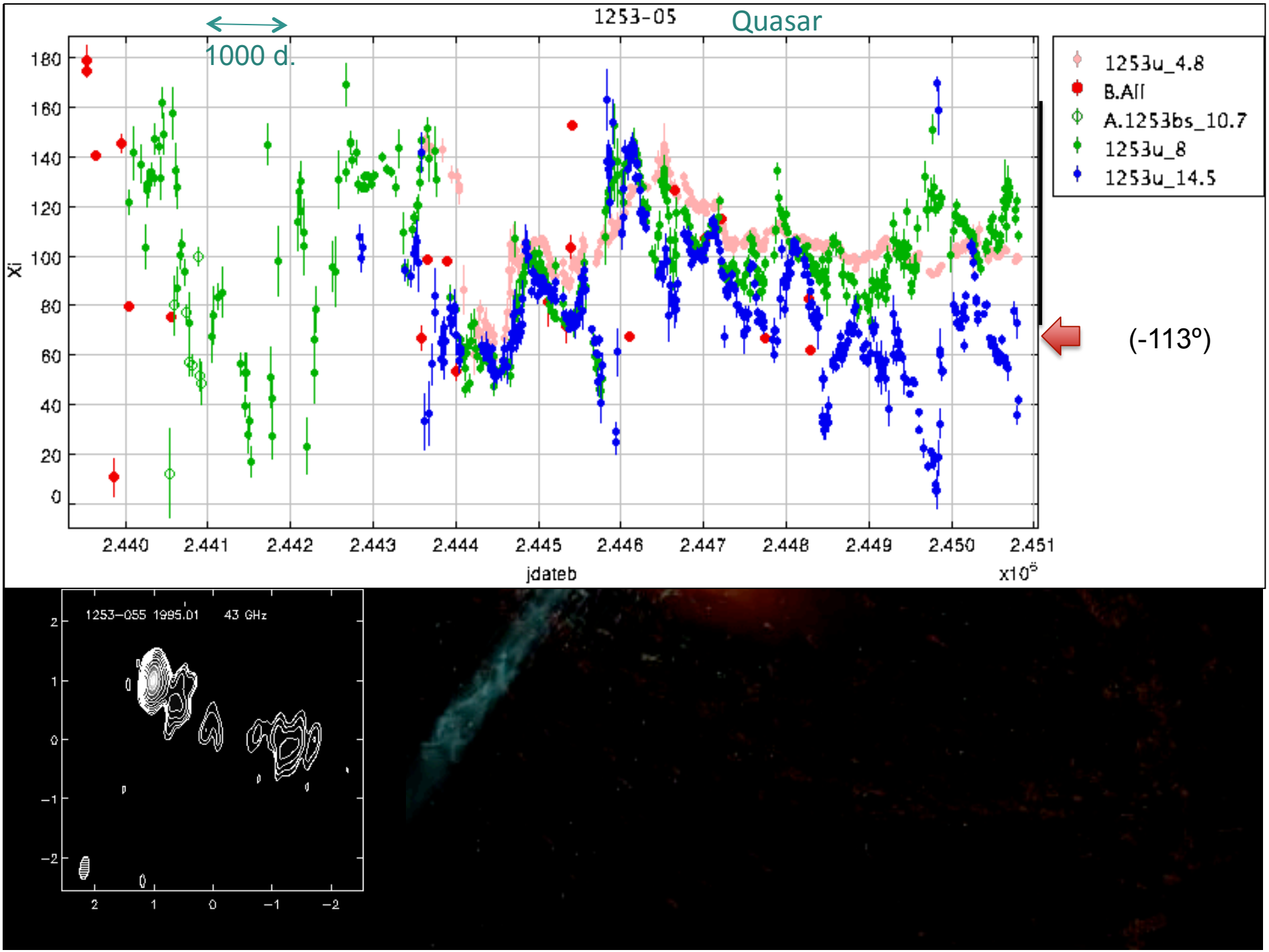

2223-052
Quasar
1000 d.
B.All
A.All
C.All
D.All
All
E.All
newangle
jdateb
x10⁴

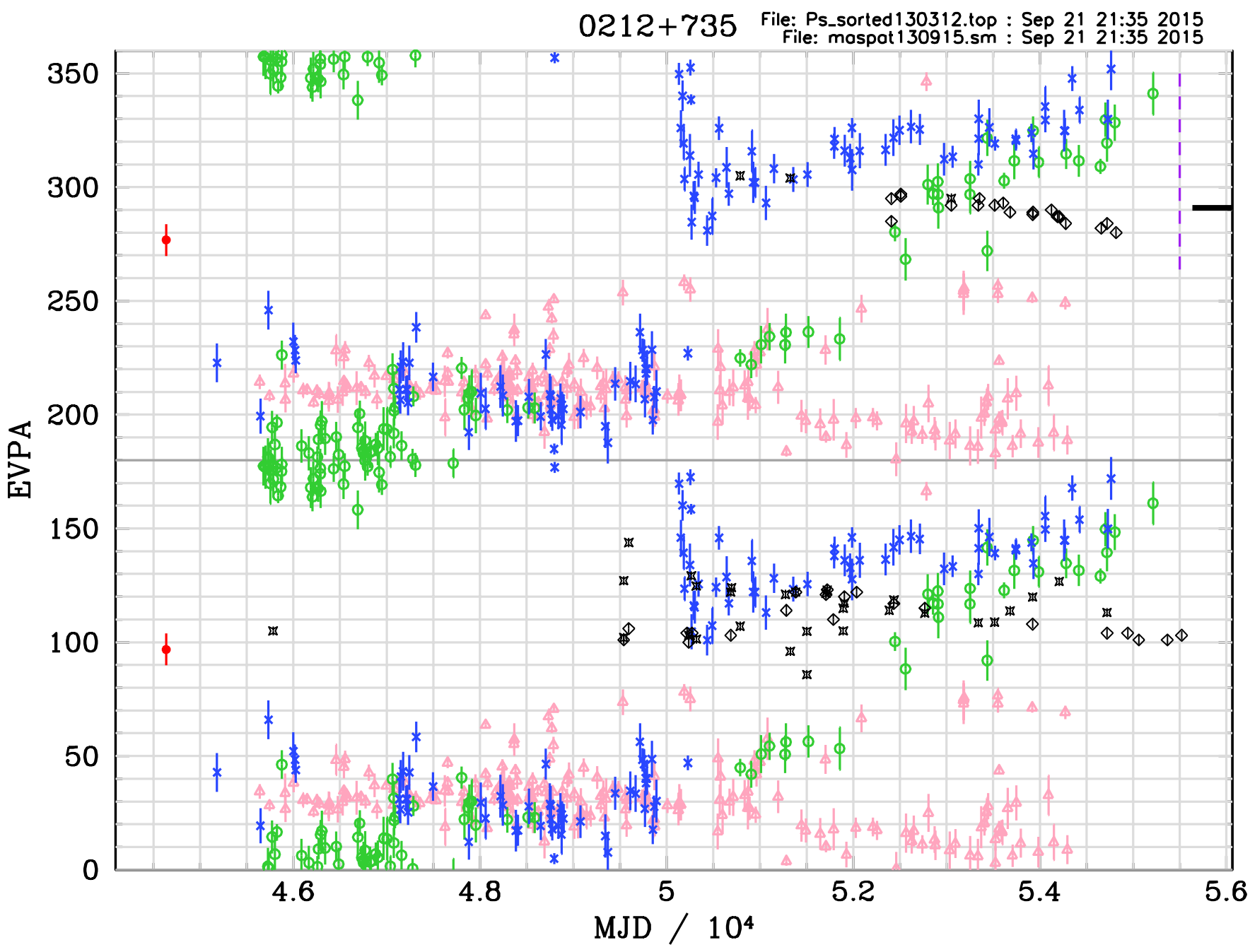
(102º)


3C446
16 Aug 09
Dec (mas)
RA (mas)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5




2223-052 aka 3C 446 14.5 GHz total flux density
2223-052
Quasar
1000 d.
B.All
A.All
C.All
D.All
All
E.All
newangle
jdateb
x10^5
3C446
16 Aug 09
Dec (mas)
RA (mas)


1253-05
Quasar
1000 d.
1253u_4.8
B.All
A.1253bs_10.7
1253u_8
1253u_14.5
Xi
jdateb
x10^5
(-113º)
1253−055 1995.01 43 GHz


0212+735
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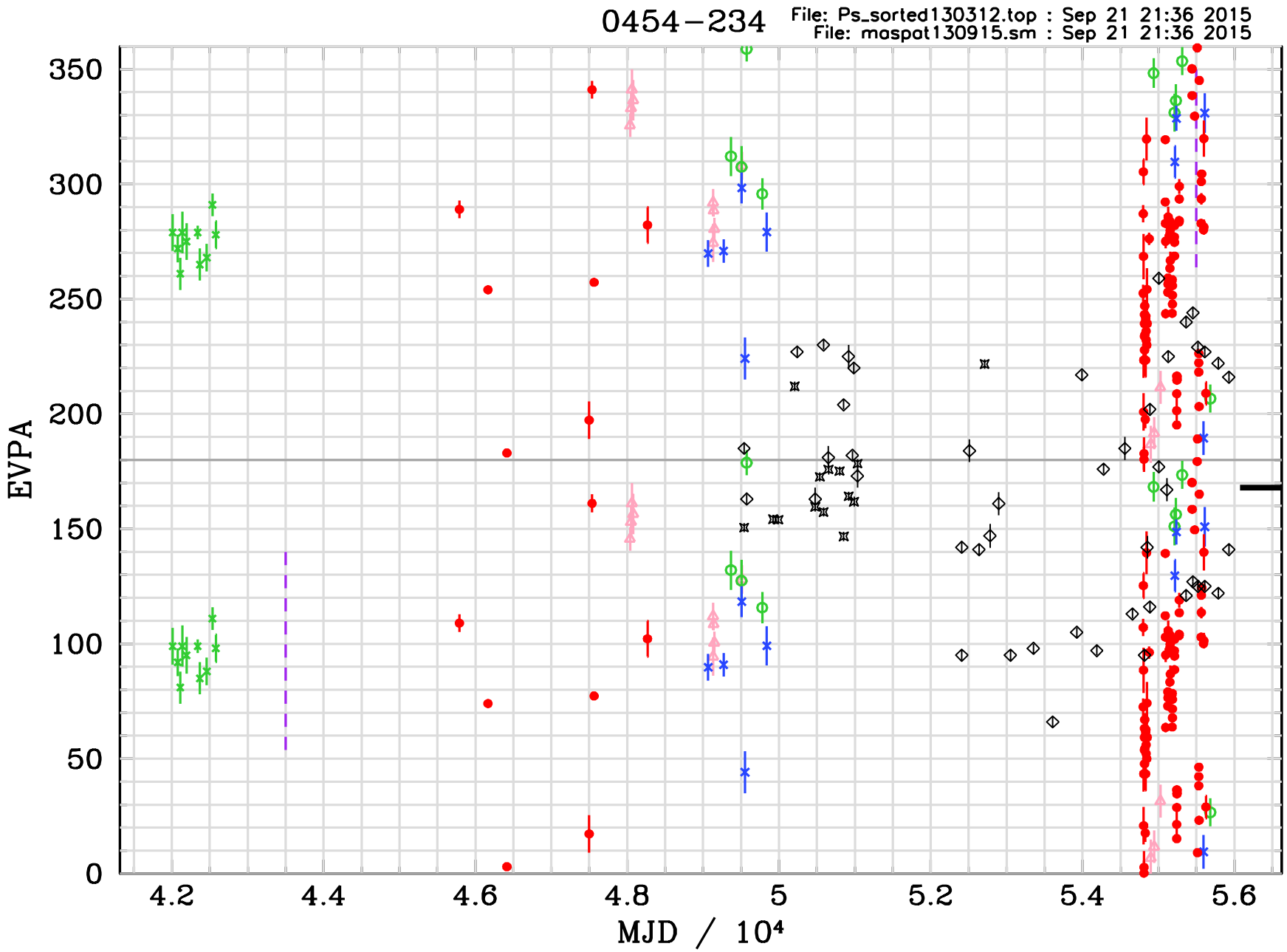
EVPA
350
300
250
200
150
100
50
0
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴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100
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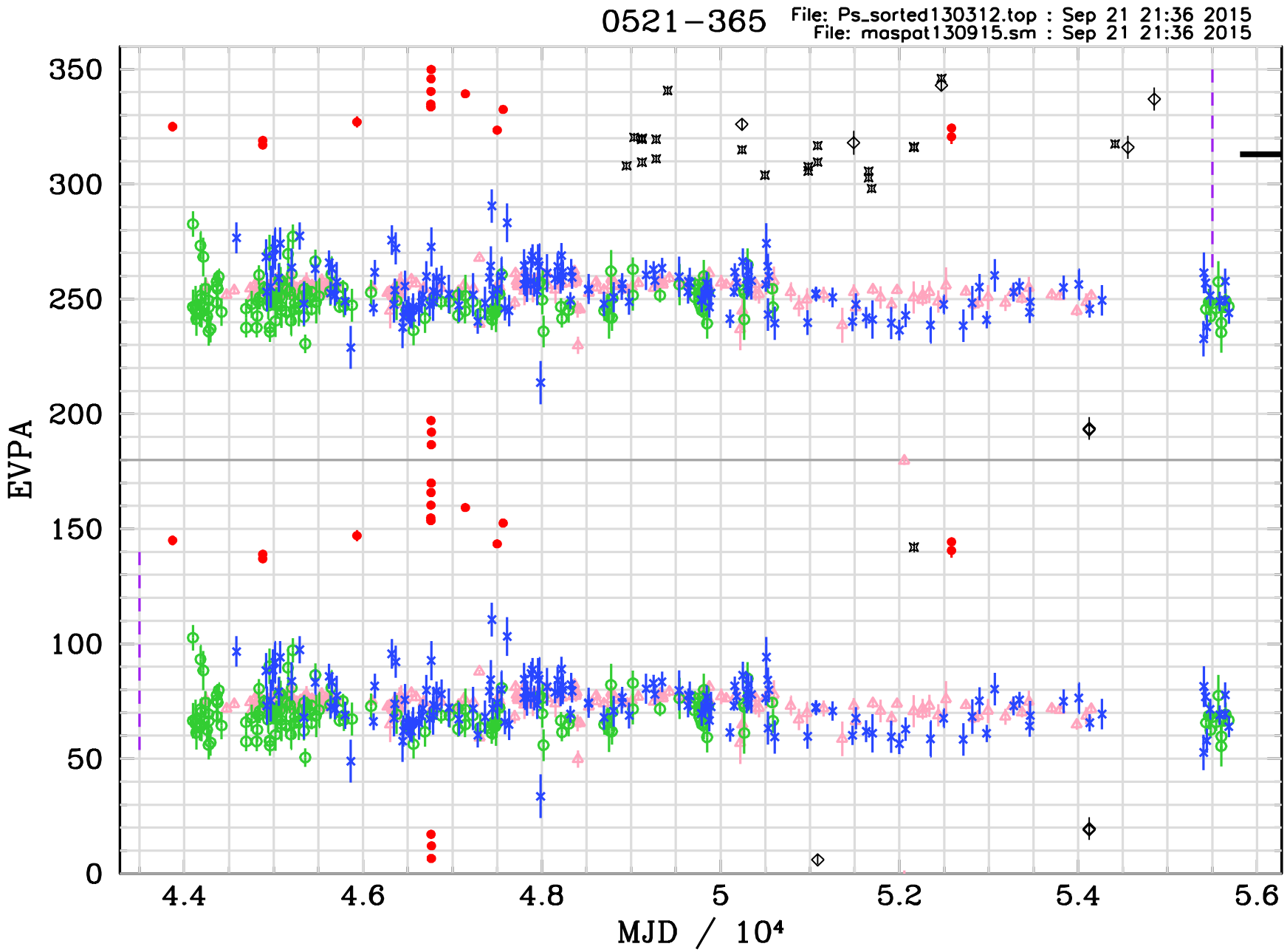
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴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200
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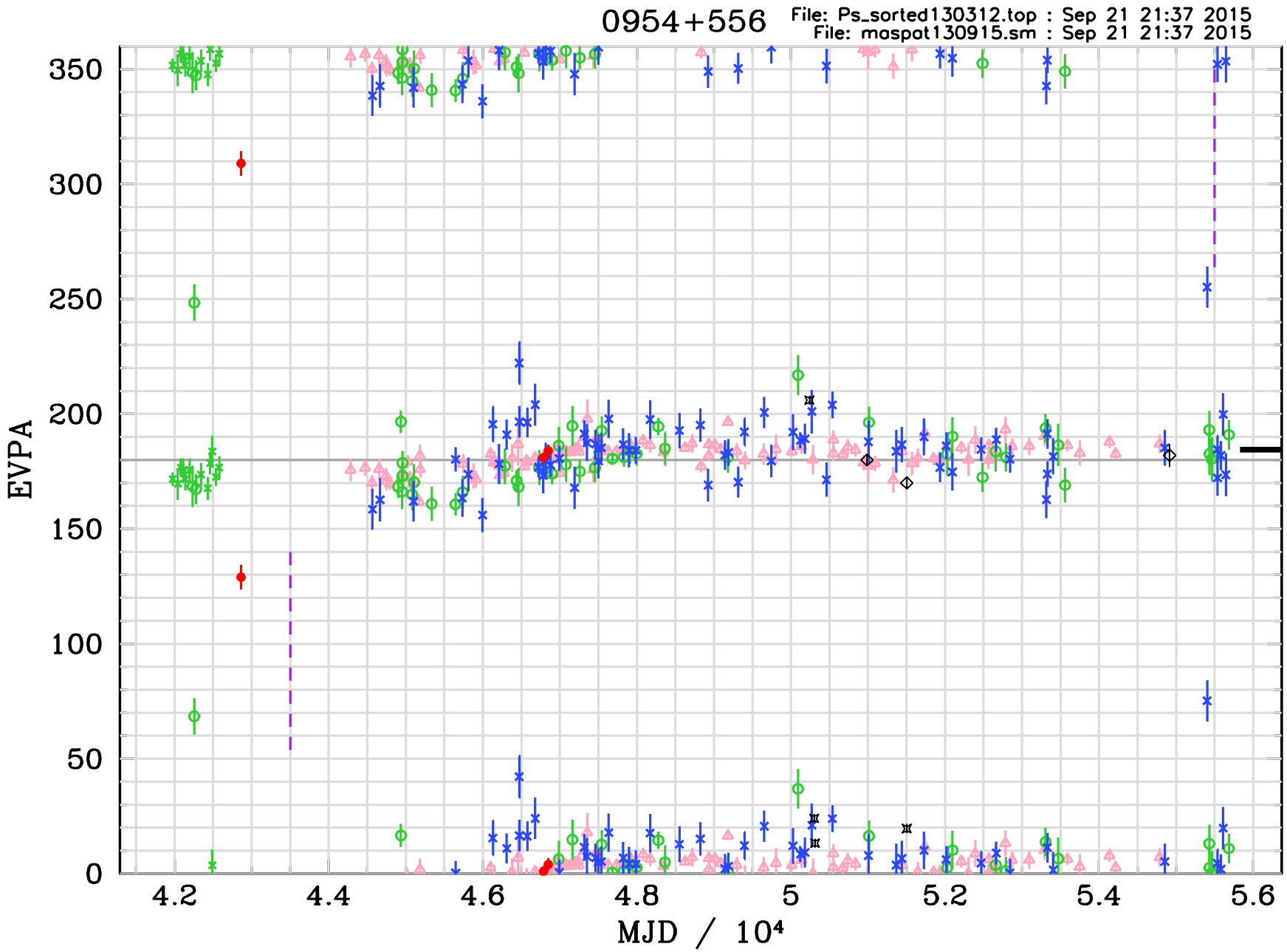
100
50
0
4.4
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴


0954+556
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EVPA
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300
250
200
150
100
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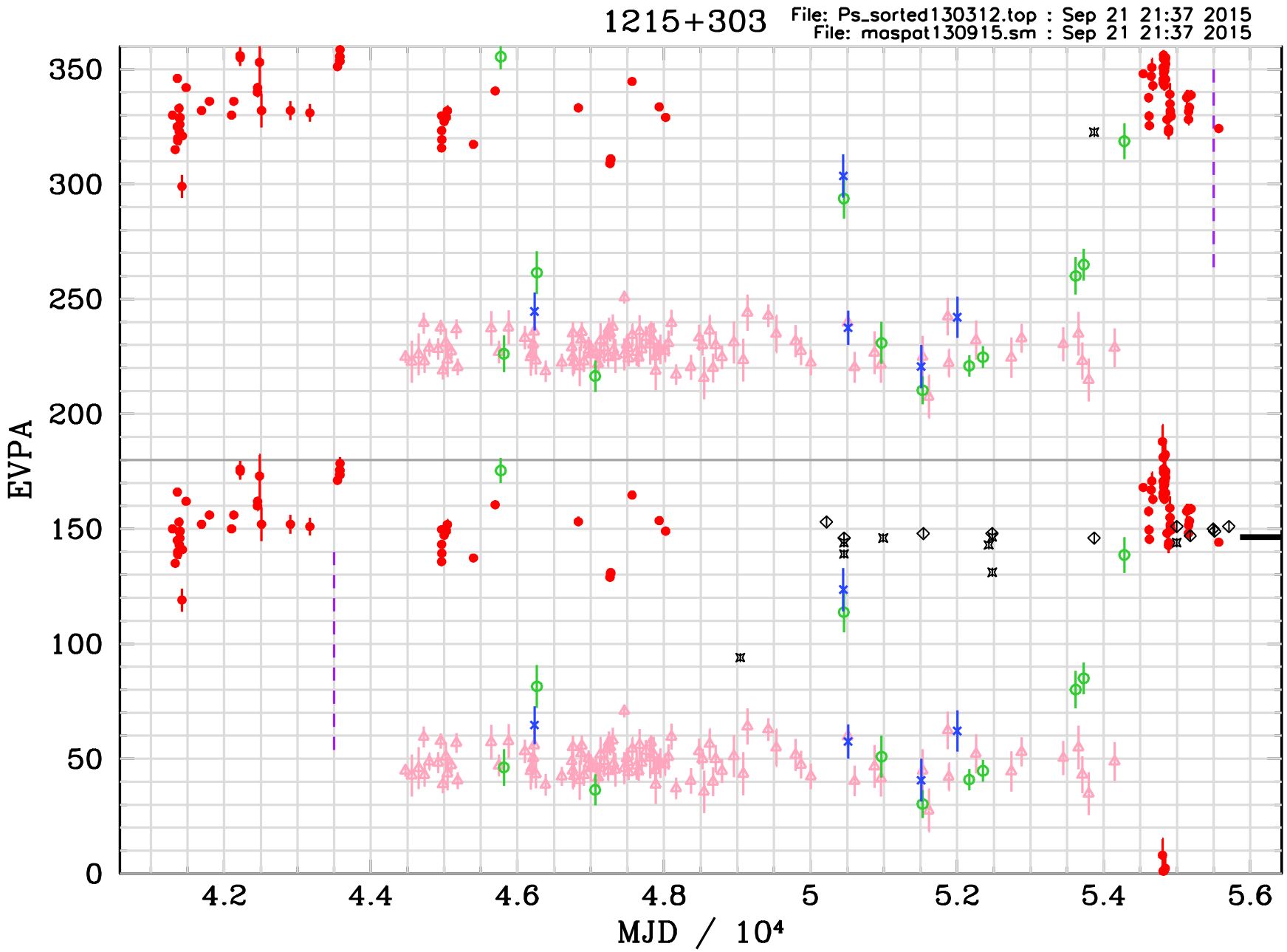
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴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300
250
200
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100
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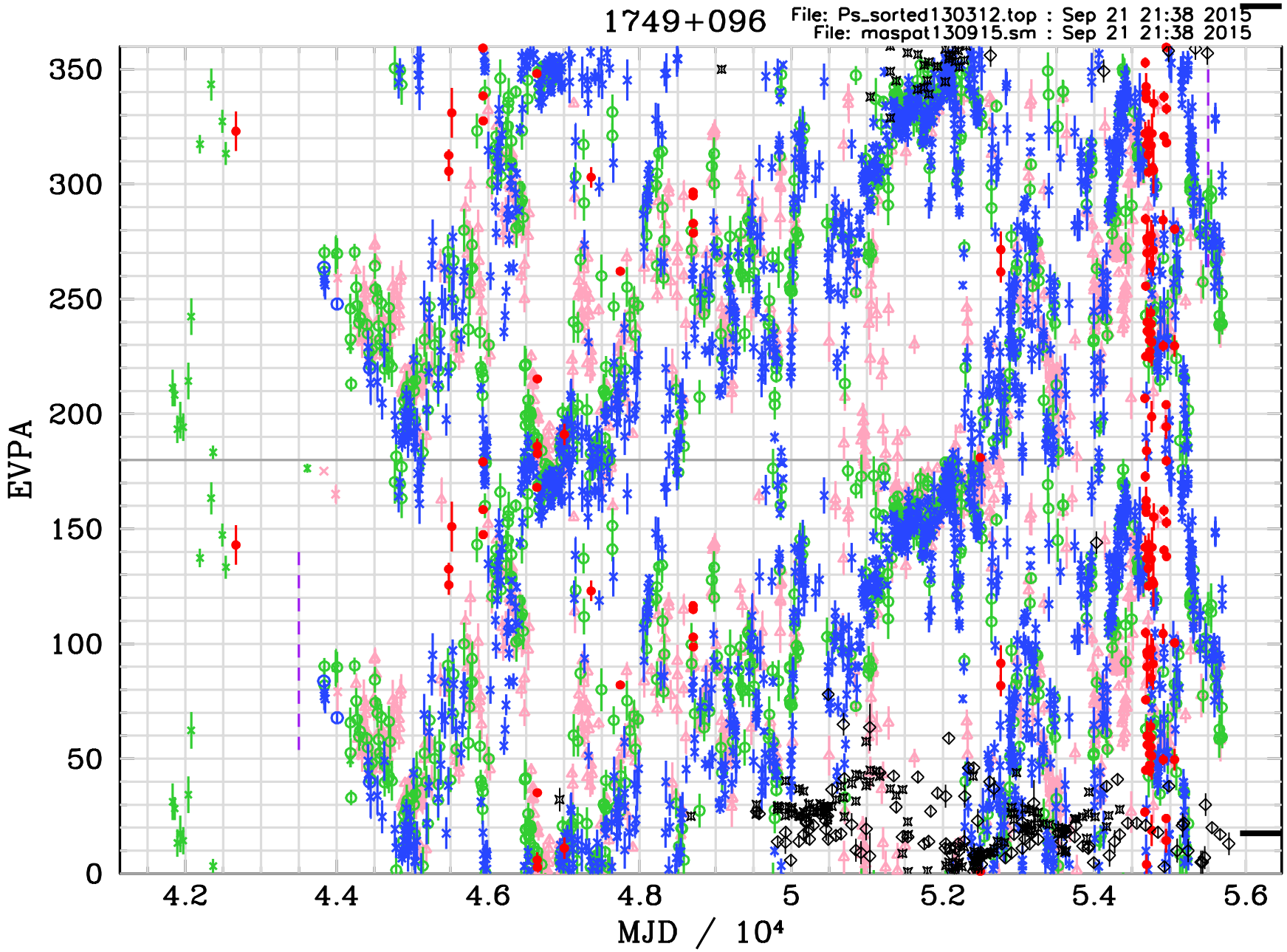
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴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EVPA
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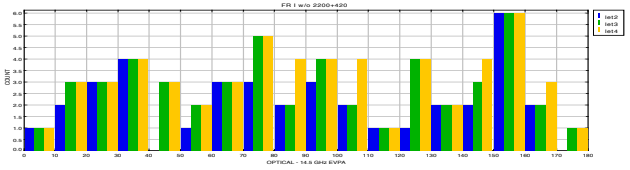
300
250
200
150
100
50
0
4.2
4.4
4.6
4.8
5
5.2
5.4
5.6
MJD / 10⁴

FR I w/o BLLac



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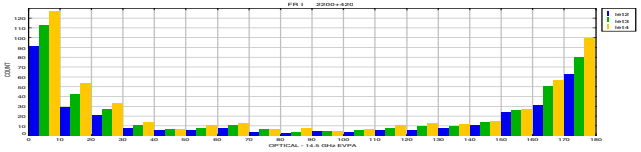

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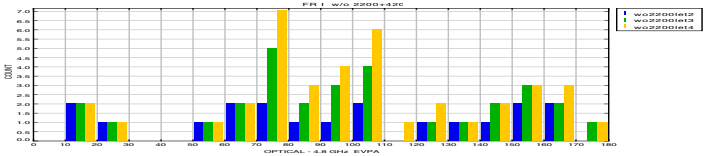

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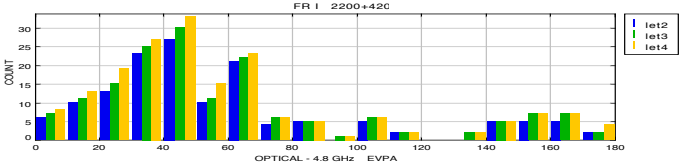
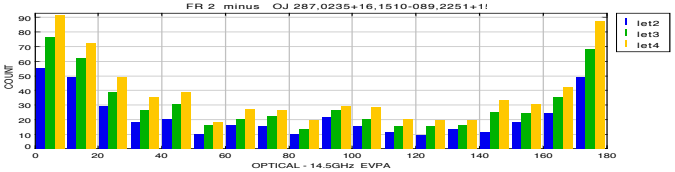
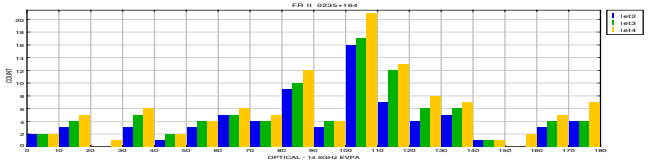
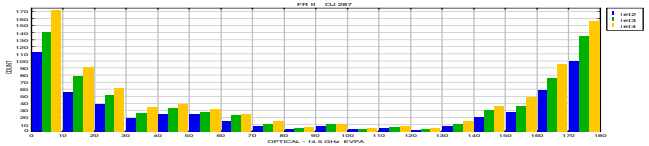
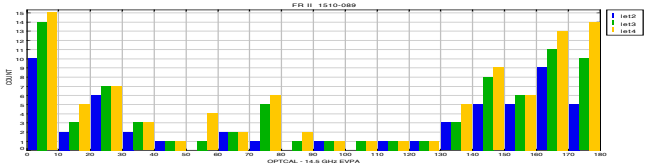


FR II









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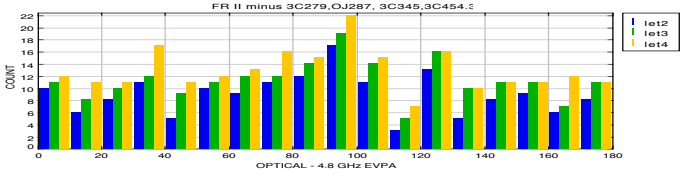
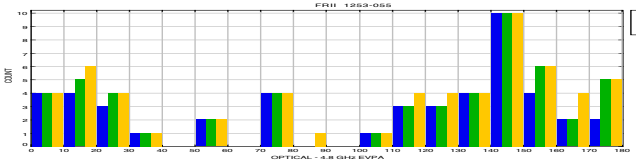
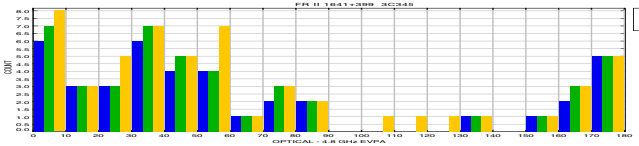
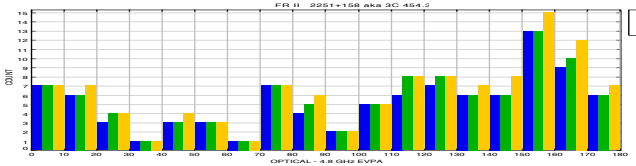








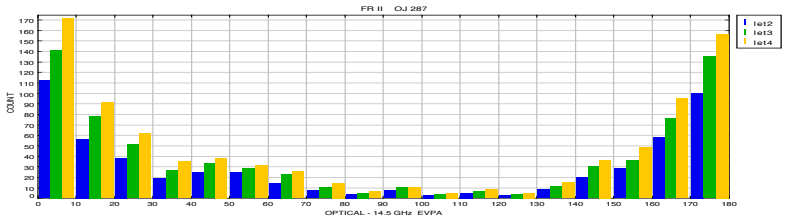
Optical – 14.5 GHz EVPA

0 º 90 º 180 º

Optical – 4.8 GHz EVPA

Separations 2,3,4 days

# FR II

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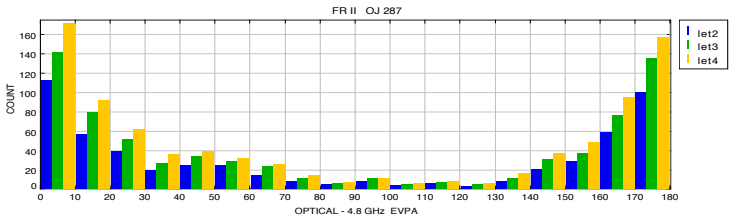
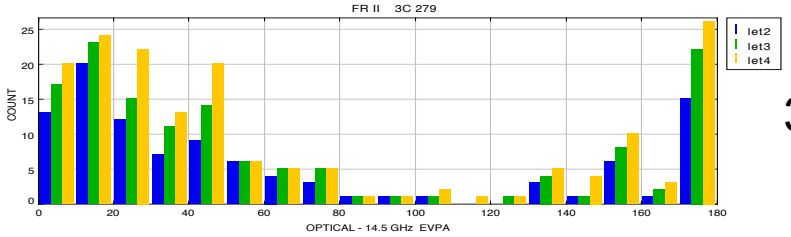
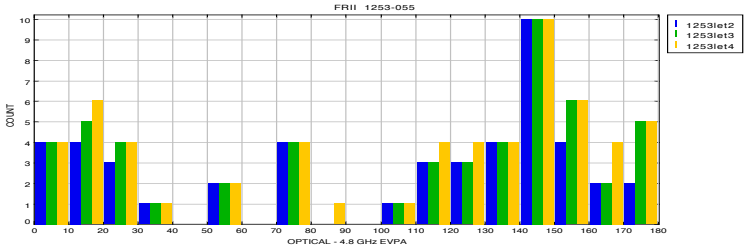
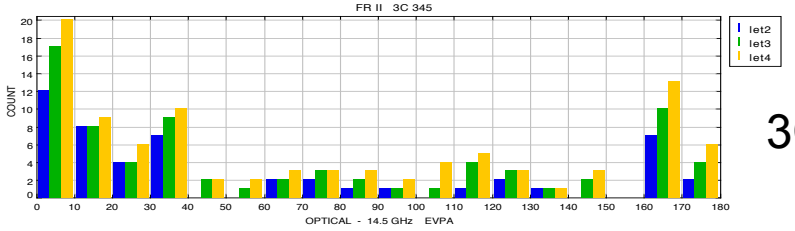


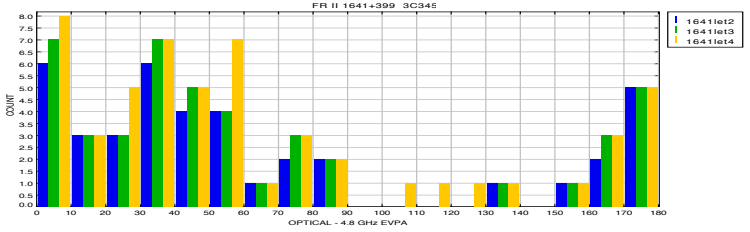



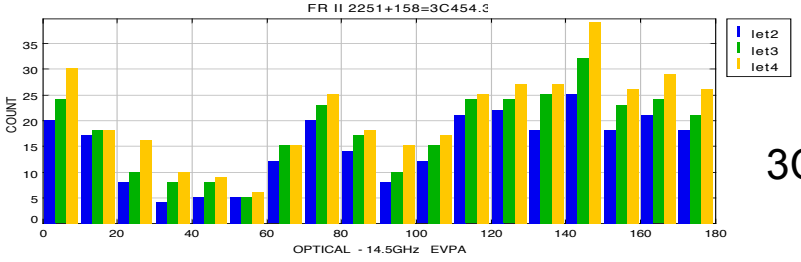

3C279




3C345

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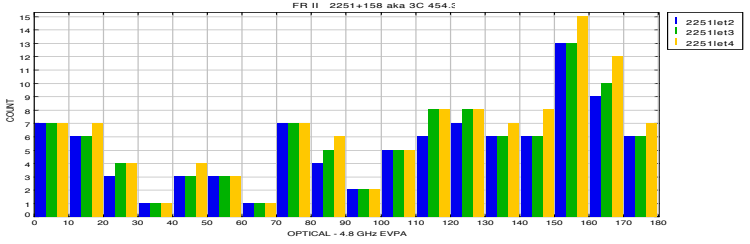
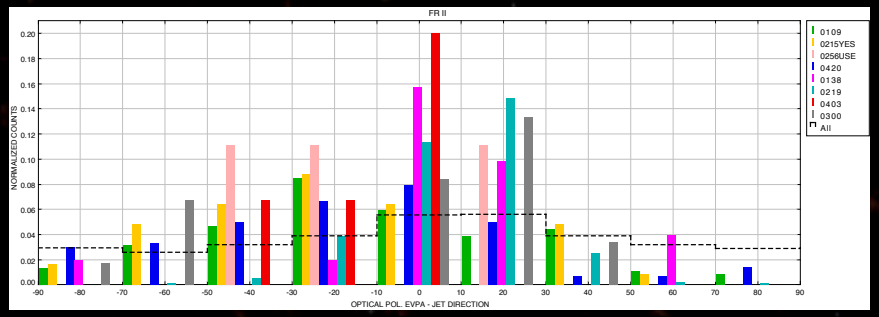


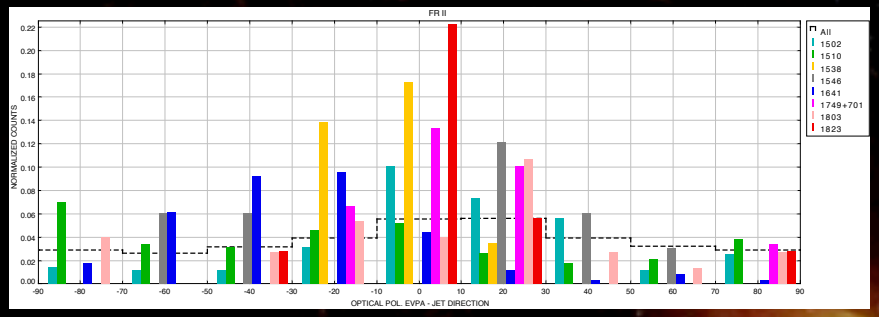

0 º 90 º 180 º

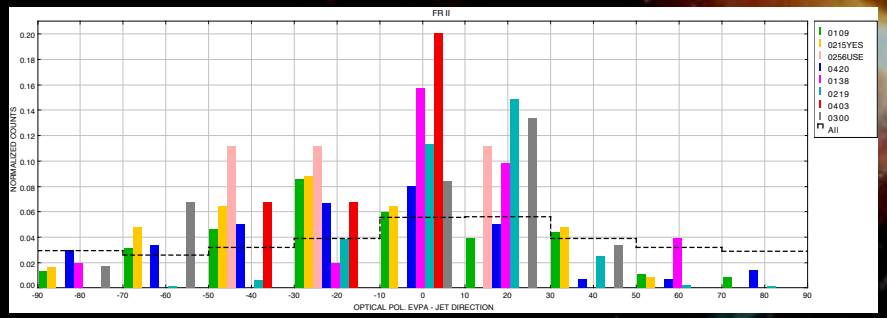
Optical – 14.5 GHz EVPA

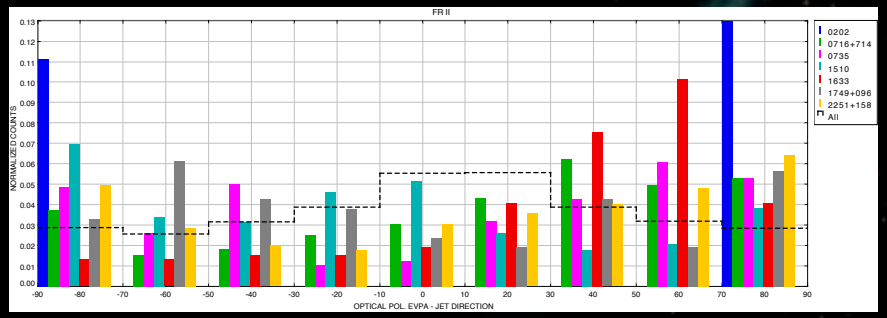
Optical – 4.8 GHz EVPA

Separations 2,3,4 days

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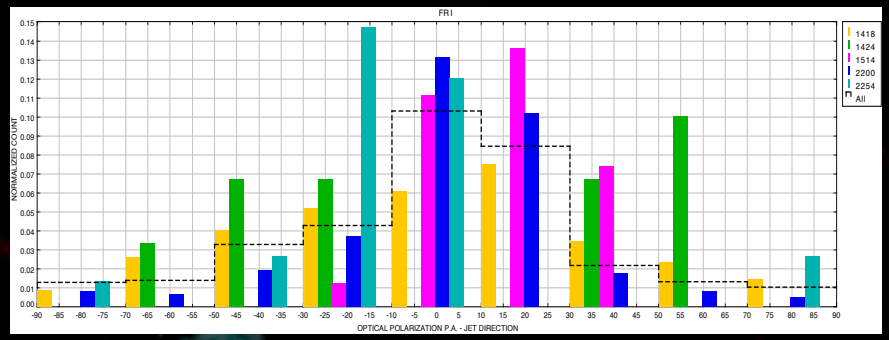


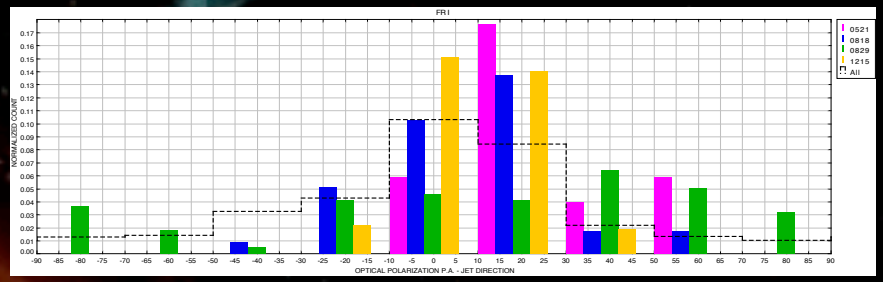


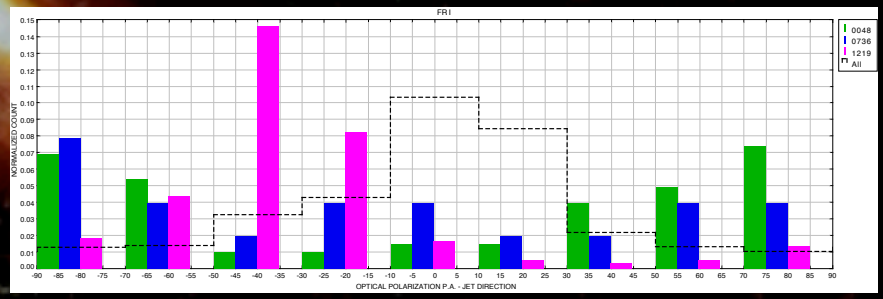


-90° 0° 90°

Optical polarization EVPA – Jet direction

(for individual sources)

FR I

## Some Results

Different EVPAs for different frequencies are consistent with a dependence on optical depth, with Tau ~ 1 occuring for > 14.5 GHz to < 4.8 GHz.
P% & flux density light curves could test this.

There are 'light curves' of rather different character – long-term rotations and scatter.

VLBI result: BL Lac objects tend to have stable optically thin EVPA in jet direction. This means B is perpendicular to the jet flow. B compressed in shocks (VLBI knots), or toroidal component of helical B field.
BL Lac objects sometimes have optical EVPA ||, sometimes _|_ to the radio EVPA.

Quasar-blazars show optical EVPA || to jet in some objects, _|_ in others. 90 deg flips of optical relative to radio occur half the time. Optical depth &/or different origin? Radio EVPA can flip and be accompanied by optical flip, suggesting close in space. The overall jet direction doesn't change much, so these may be shocks, with optical originating at higher energies.

We do not find such a clear distinction between FSRQs and BLLac objects. Could be differences in sample,or radio beam size, e.g. (to be investigated).

For both BL Lac objects & quasars, the scatter in EVPA usually increases from low frequencies (4.8 GHz) through 14.5 GHz through optical. This is similar to the trend seen for longer time scale variations in polarization and flux. Different frequencies don't have same origin, as also indicated by optical depth effects.

The close relationships between optical and radio EVPA can rule out Faraday Rotation in many cases.

What next?

..a summary picture, with individual results in order of lobe luminosity (increasing up.....

THANKS FOR A WONDERFUL CONFERENCE

File: latestYoptet.lt11.5.sm : Sep 26 21:24 2015