Blazars & INTEGRAL

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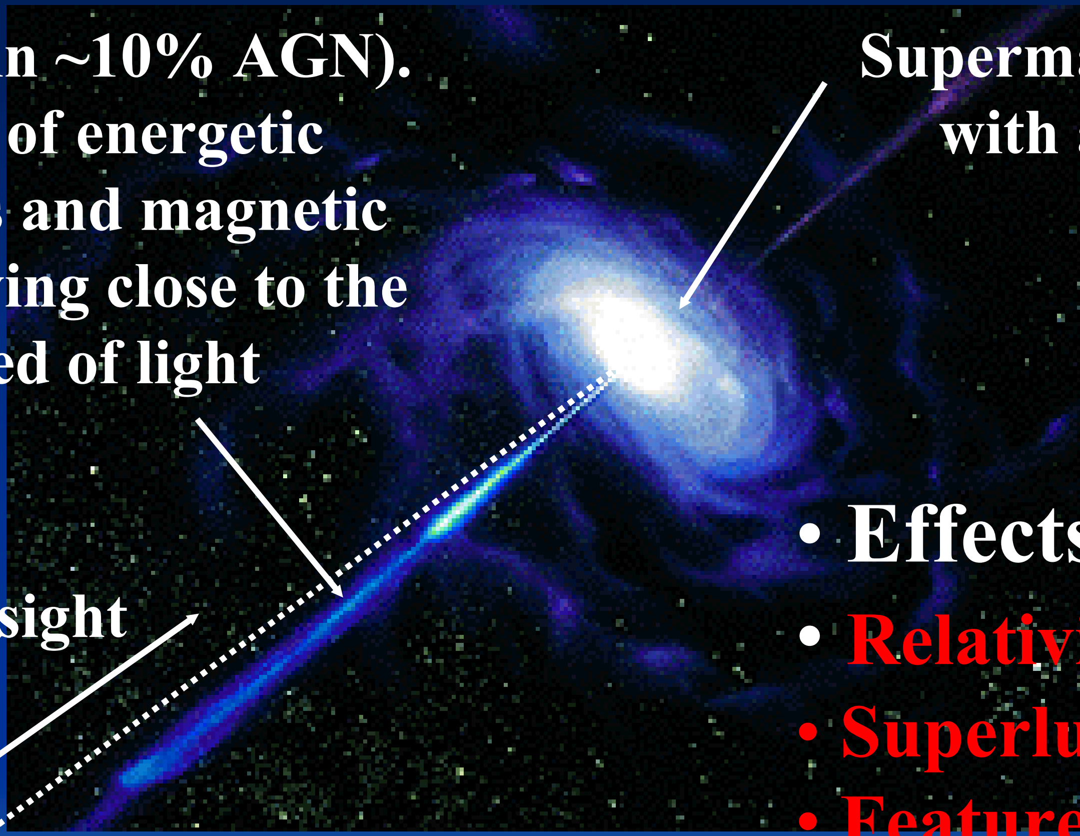
within the AGN CP topics led by Thierry Courvoisier and Loredana Bassani

Blazars & their powerful jets



- **Effects of the jet:**
  - Relativistic beaming
  - Superluminal motion
  - Featureless continuum
  - Gamma rays
  - Rapid variability
  - High luminosity

- Blazars - the most extreme class of active galaxies, powerful and variable
- observed in all wavelength bands - from radio through VHE gamma frequencies
- maximum spectral output and largest variability often at gamma ray energies
- 66 blazars identified as sources of >100 MeV emission by EGRET oboard CGRO (Hartman et al. 1999)
- 16 blazars identified as VHE gamma sources (>350 GeV) by Čerenkov telescopes (recent number)
- suitable targets for INTEGRAL especially during active states (flares)

INTEGRAL and blazars: energy and sky coverage

- INTEGRAL IBIS ISGRI 15 keV – 0.5 MeV, covering upper part of synchrotron peak for HBLs, while in the case of lower-energy blazars this band falls often in the gap between both peaks, with an onset of the second (inverse-Compton) peak in MeV range.

- This is why the EGRET sky was dominated by blazars, INTEGRAL sky is not.

- Moreover, as the INTEGRAl focus on regions along the galactic plane, extragalactic sources as blazars with generally higher absolute galactic latitude fall in the less exposed regions

- Despite of this, ~15 blazars detected so far.

- INTEGRAL adds **unique energy range** to mutispetral picture of blazars, important for model testing

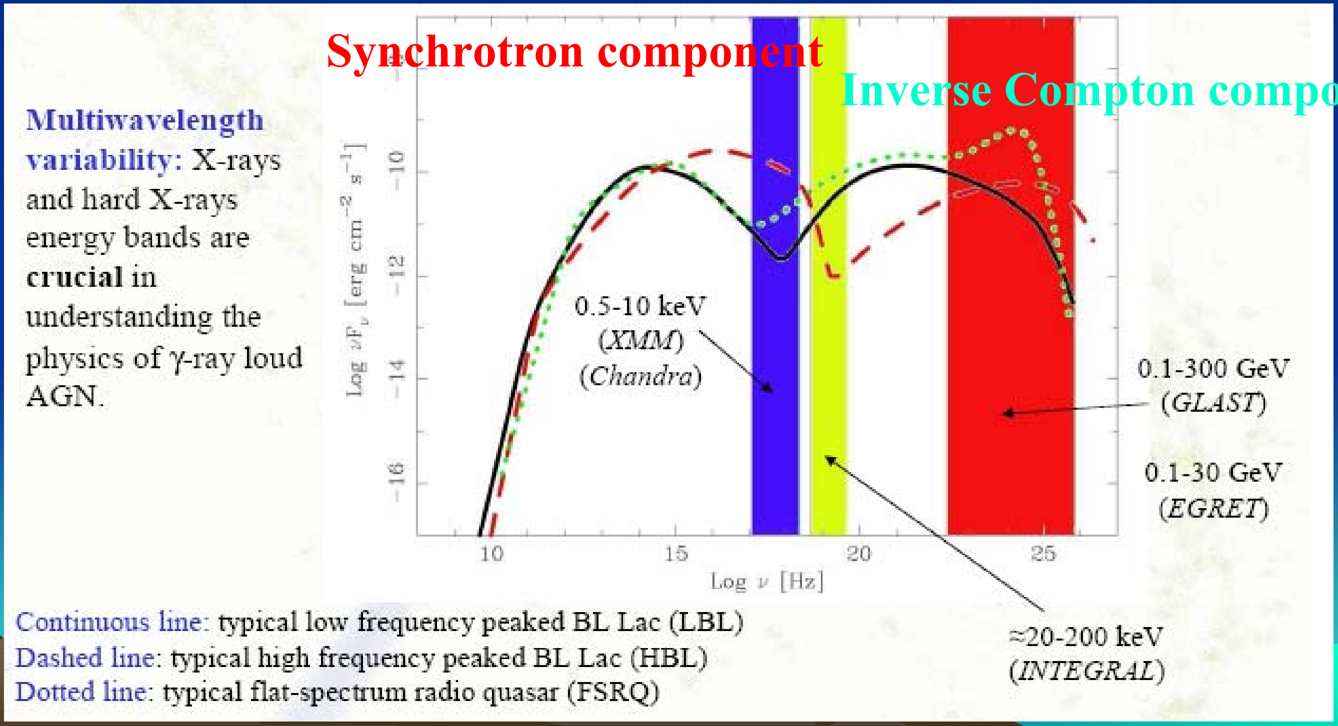
Spectral Energy Distribution

The widest range of all AGN

from radio to gamma TeV, νF(ν) representation - two broad spectral components

Super AGILE

AGILE GRID

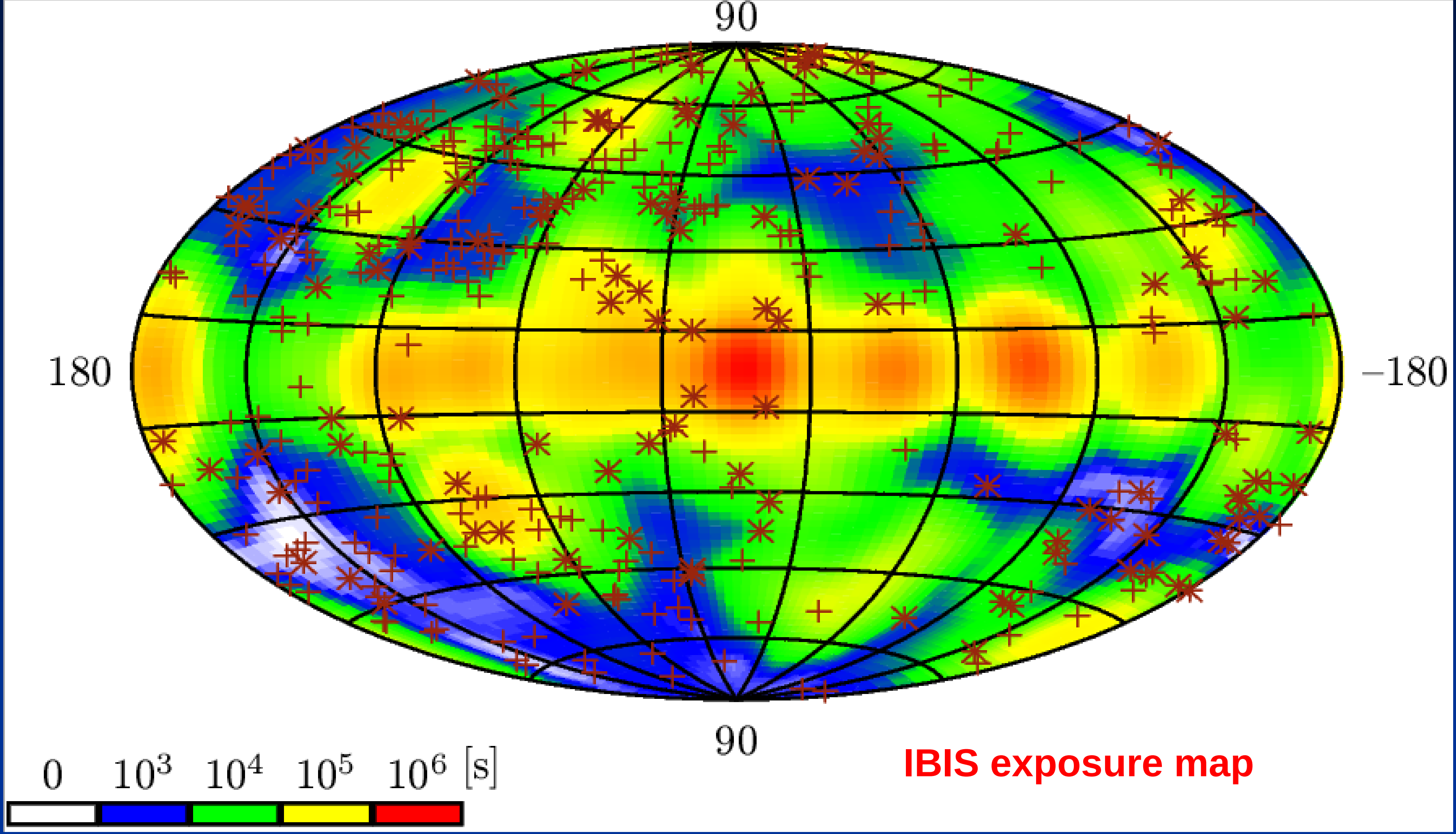


.. and energy coverage of various experiments

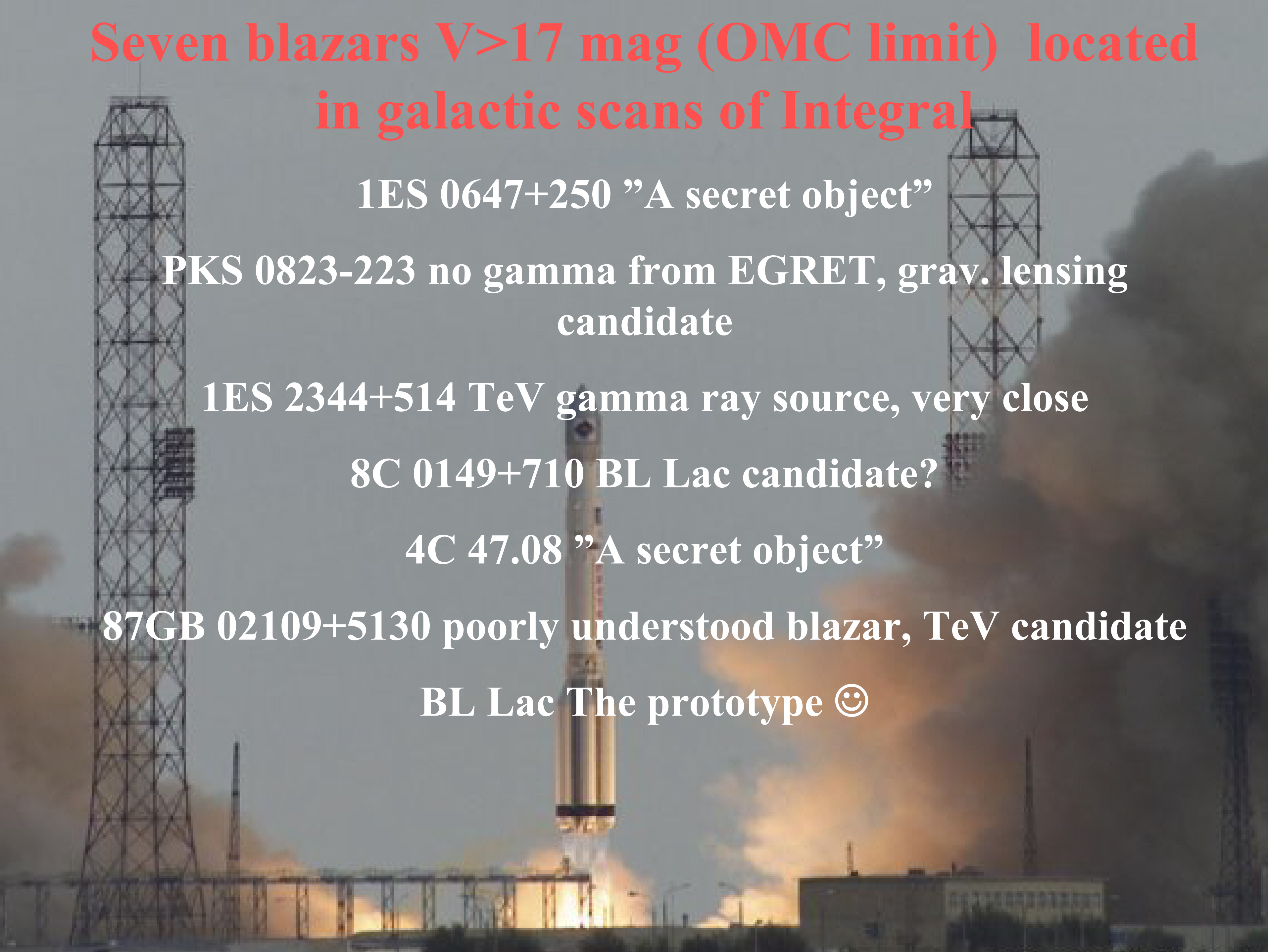
Blazars in the CP/GPS

- GPS zone usually neglected by extragalactic astronomers due to heavy obscuration
- in optical, ~20% of the sky obscured by our Galaxy
- INTEGRAL allows detectability of up to few mCrabs in the most exposed regions

Not always strict classification: e.g.some blazars indicated as blazars in Veron-Cetty catalogue are not noted as blazars in Donato catalogue.



- Extragalactic sources as blazars with generally higher absolute galactic lattitide fall in the less exposed regions, as shown on the map above (stars show positions of known blazars, crosses are other AGNs from Veron-Cetty catalogue)



Seven blazars V>17 mag (OMC limit) located in galactic scans of Integral

1ES 0647+250 "A secret object"

PKS 0823-223 no gamma from EGRET, grav. lensing candidate

1ES 2344+514 TeV gamma ray source, very close

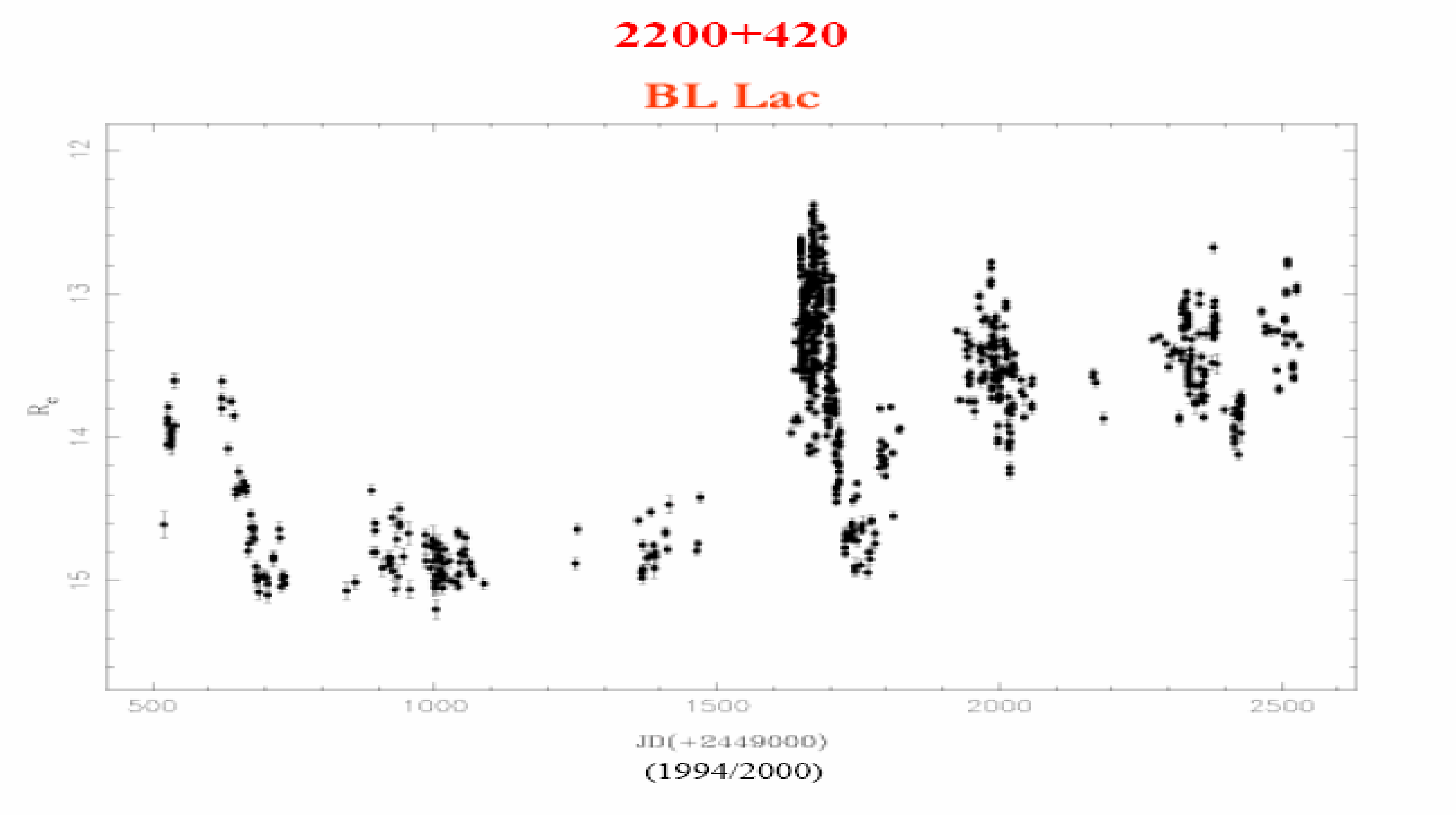
8C 0149+710 BL Lac candidate?

4C 47.08 "A secret object"

87GB 02109+5130 poorly understood blazar, TeV candidate

BL Lac The prototype ☺

Object	z	optical	gamma	X-rays	radio
1ES 0647+250	z=0.20	V=15.3	TeV candidate	ROSAT & Einstein source	0.08 Jy at 5 GHz
PKS 0823-223	z=0.91	V=16.2	not detected by EGRET	?	0.78 Jy at 5 GHz
1ES 2344+514	z= 0.044	V= 15.5	TeV gamma ray source	large variability, spectral changes	0.23 Jy at 5 GHz
8C 0149+710	z=0.022	V=15.5	?	ROSAT	0.64 Jy at 5 GHz
4C 47.08	z=0.475	V=17.0	?	ROSAT	?
87GB 02109+5130	z=0.049	V=16.5	TeV candidate?	ROSAT	0.29 Jy at 5GHz
BL Lac	z=0.069	B=12.5 - 16 polarization	variable/out bursts	both comp. detected	2.94 Jy at 5 GHz, polar.



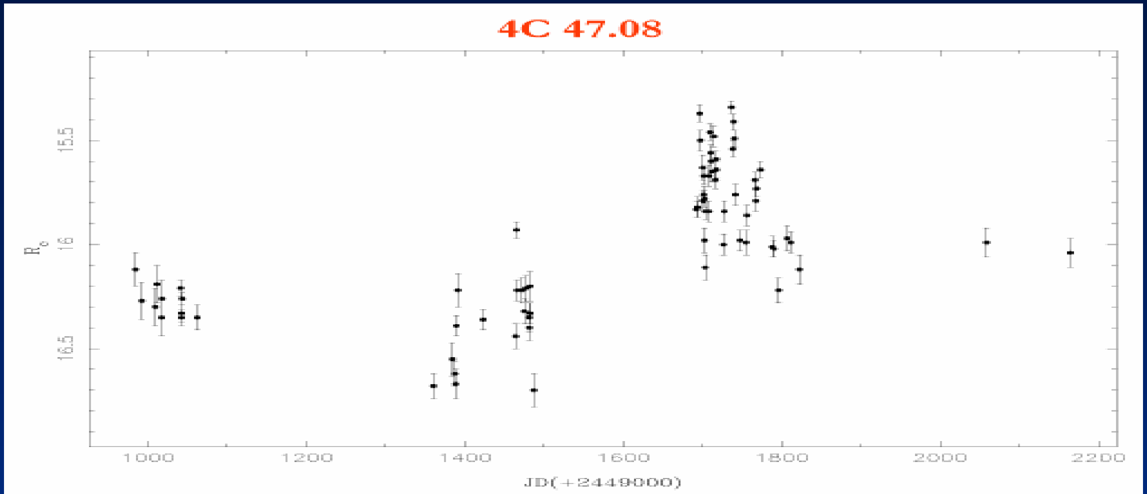
Violent optical variability of BL Lac on a long time time scale

good candidate to be detected at flaring

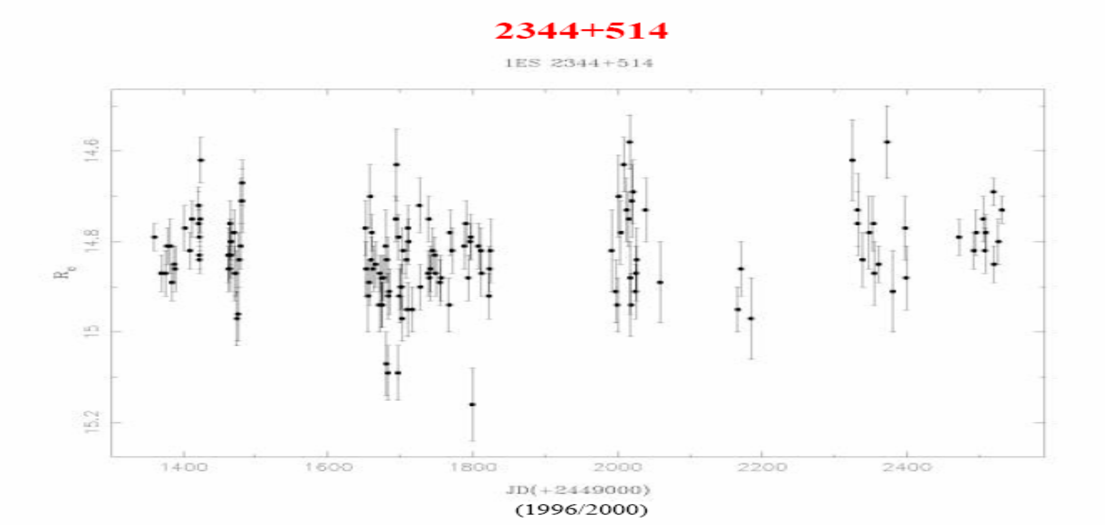
BL Lac is well studied .... but

Most of the GPS blazars are poorly investigated and poorly understood

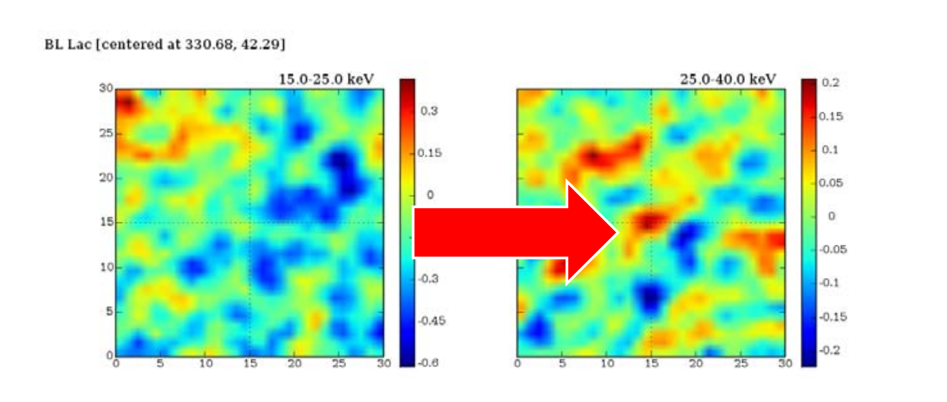
The study with Sonneberg Observatory Archival Plates reveals that most of these objects are optically variable, hence a gamma ray variability can be expected

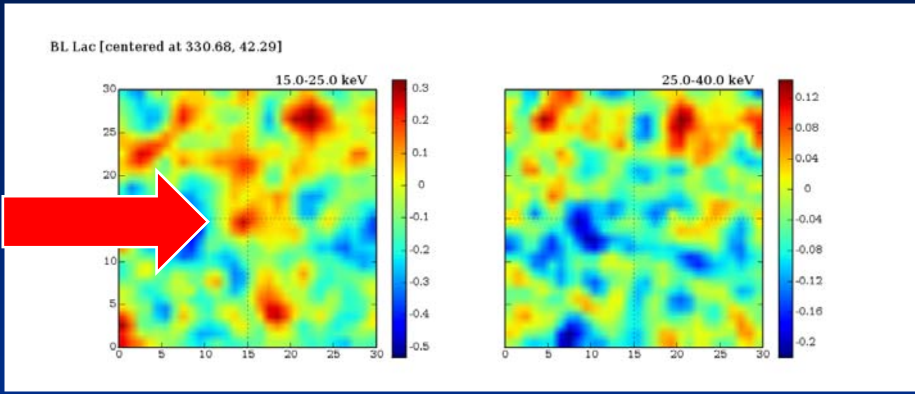


Optical monitoring of GPS blazars (Tosti, Rizzi et al. 2000)



BL Lac, IBIS data





MJD interval 54085.82-54113.01 i.e. 27.19 days size 88×120 [pixels 0.082×0.082] — exposure 280.888 ksec

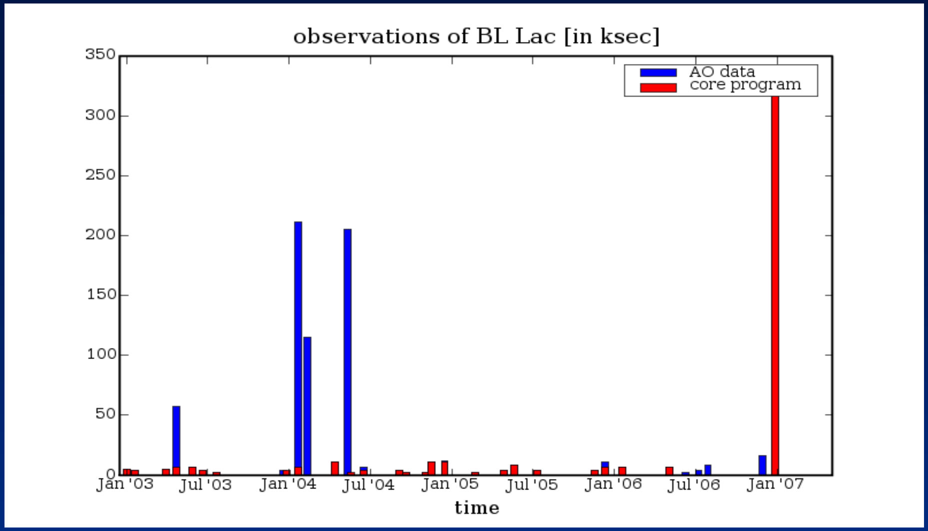
15.0-25.0 keV : no peak - upper limit 0.086ct/s
25.0-40.0 keV : peak 0.193 +- 0.0484ct/s

MJD interval 52985.44-53045.66 i.e. 60.22 days size 88×120 [pixels 0.082×0.082] — exposure 459.019 ksec

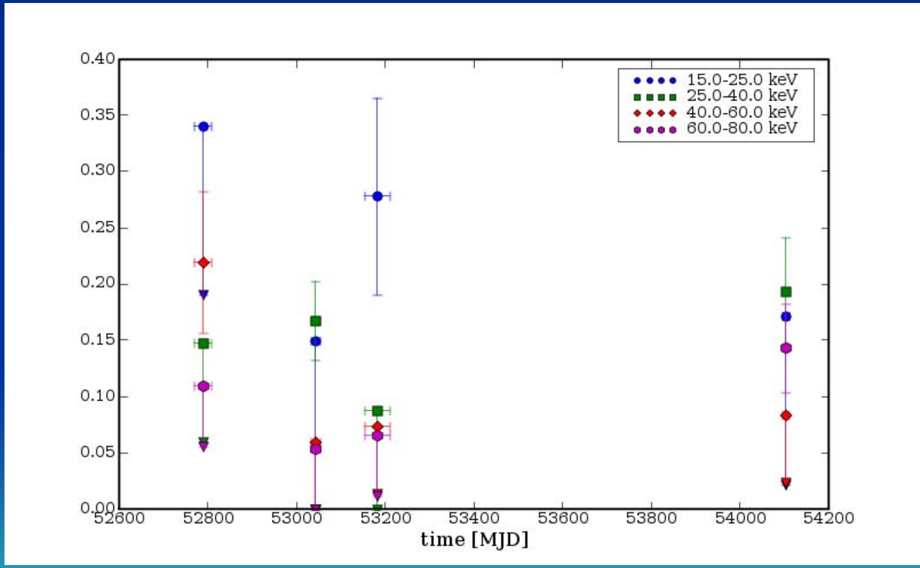
15.0-25.0 keV : peak 0.278 +- 0.0874 ct/s
25.0-40.0 keV : no peak - upper limit 0.088ct/s

Indications for spectral variability

BL Lac cont

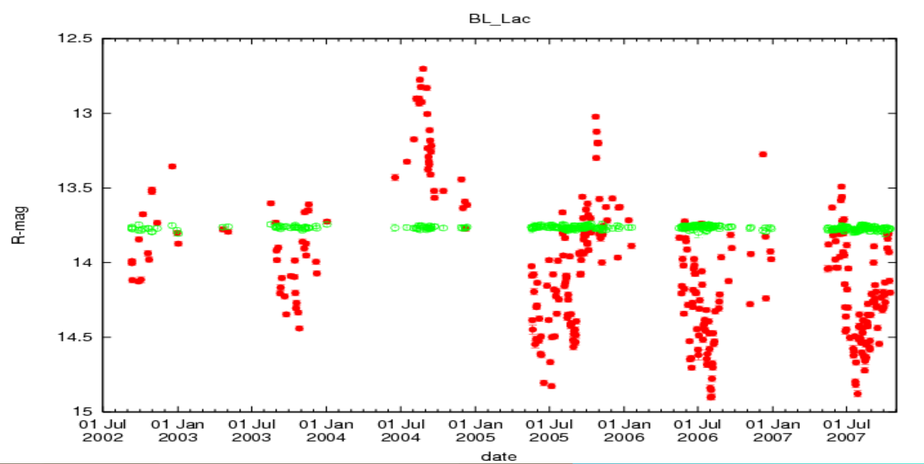


Composition of Integral public data used

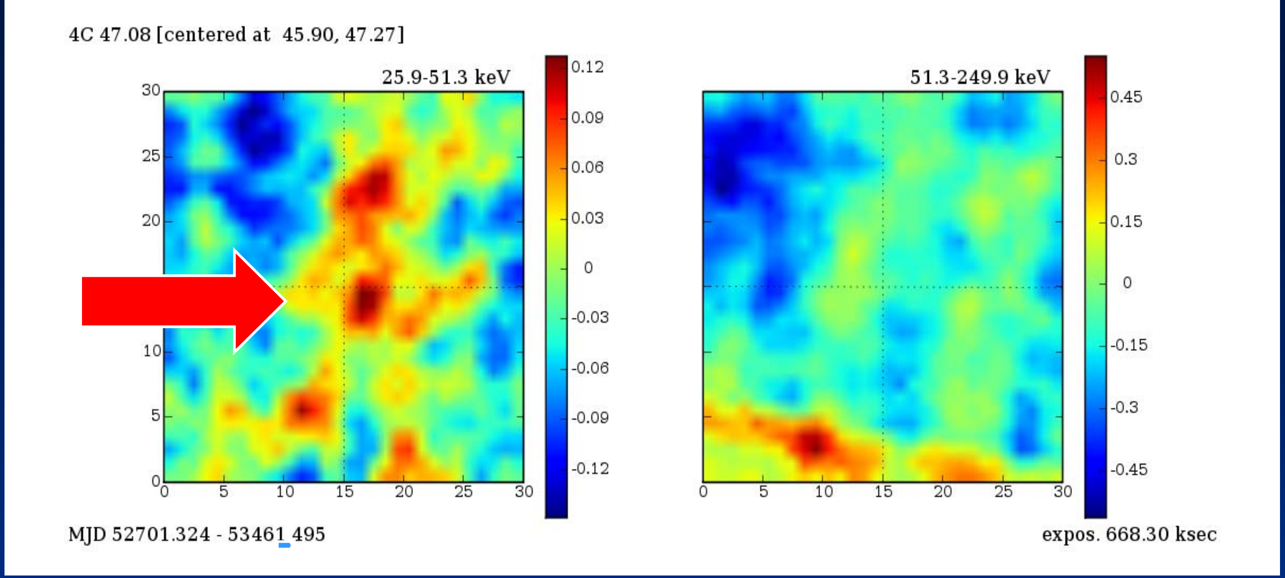


Light curve IBIS

Light curve optical

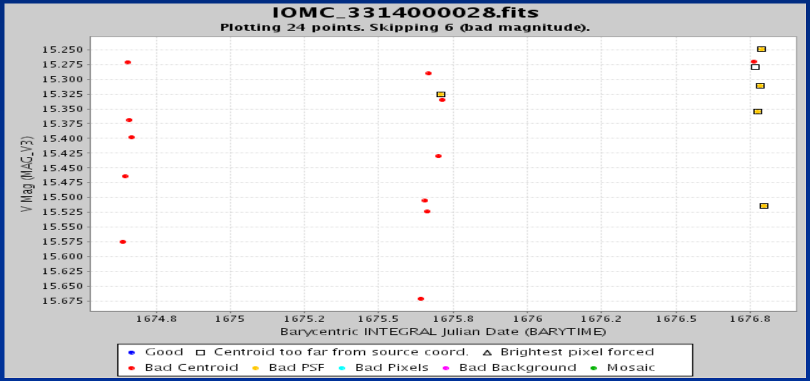


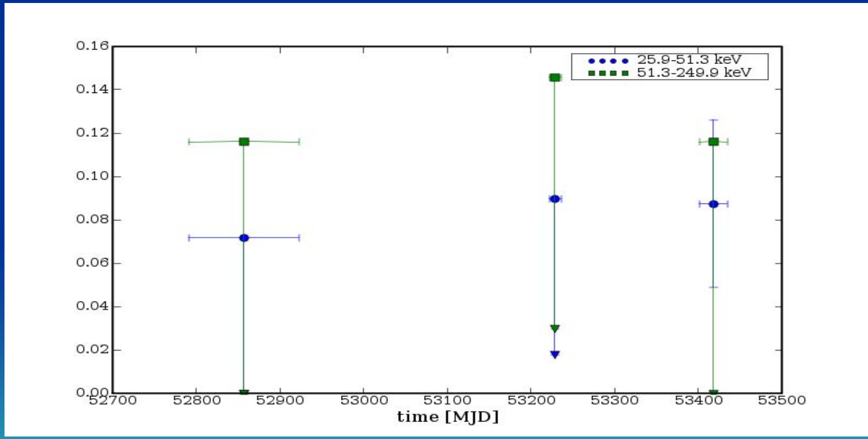
4C47.08 (CP & Public)



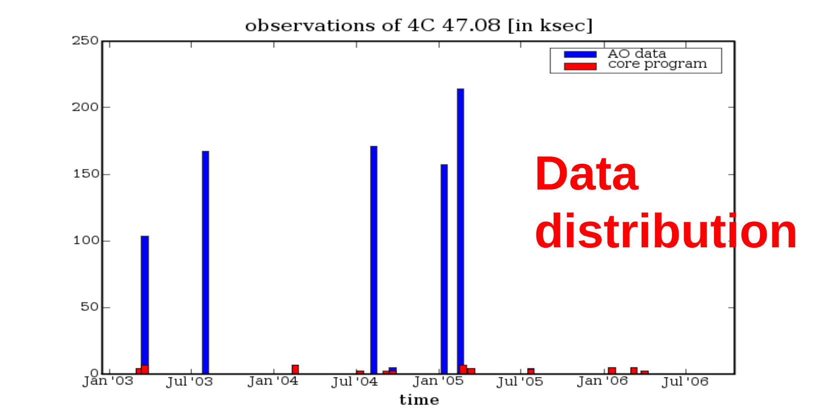
IBIS image

OMC



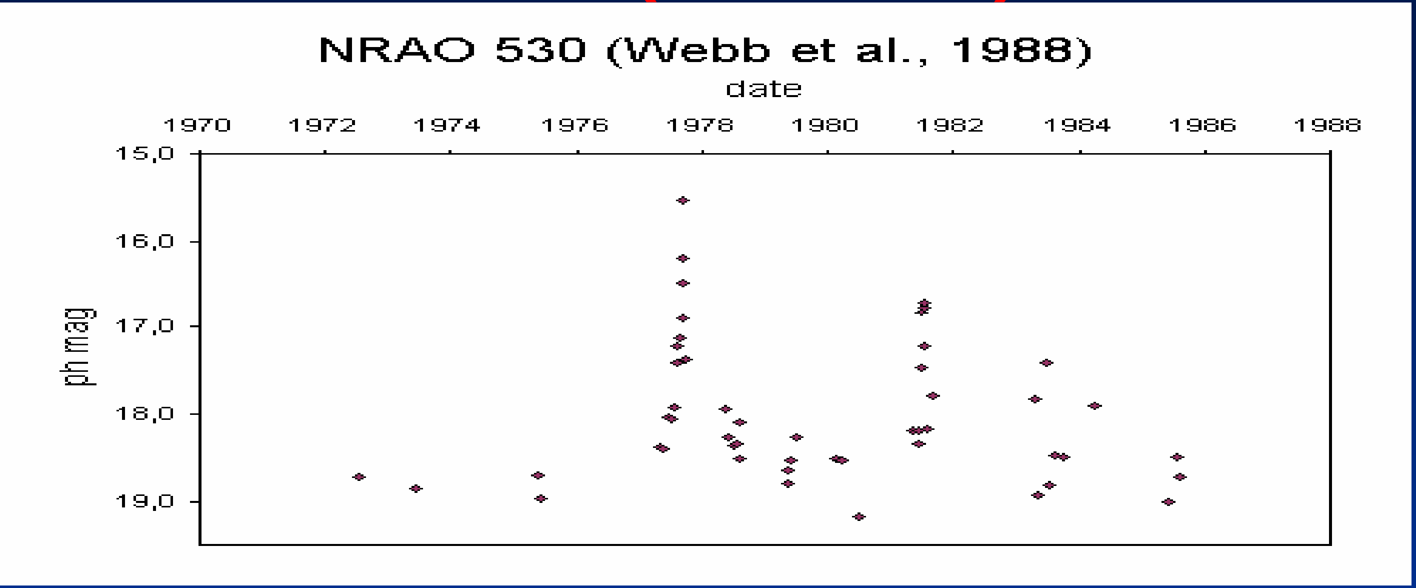


IBIS light curve



Data distribution

NRAO530 (1730- 130)



Historical optical light curve of NRAO530

The source exhibits rare but large amplitude optical flares (Dm~ 4 mag)

- **example of blazar in GPS with violent optical activity (4 mag within 1 month)**
- **Radio, ROSAT and EGRET source in GPS**
- **in flare, the object is expected to be much brighter also in gamma**
- **possible gamma ray flare detected by Foschini et al., 2006, in single INTEGRAL IBIS SW, with no optical data available.**
- **the role of optical monitoring and ToO program - the flare can be recognized by optical monitoring with small (D ~50 cm) telescopes**

The INTEGRAL AO observation of blazars in outburst

proposal by Pian E. et al. (large collaboration)

So far performed twice

E. Pian, L. Foschini, G. Tagliaferri, P. Barr, V. Beckmann, T. Courvoisier, A. De Angelis, G. Di Cocco, N. Gehrels, G. Ghisellini, P. Giommi, P. Grandi, R. Hudec, G. Malaguti, L. Maraschi, A. Marcowith, G. Palumbo, M. Persic, T. Pursimo, C. Raiteri, T. Savolainen, M. Sikora, A. Sillanpää, S. Soldi, L. Takalo, M. Tornikoski, G. Tosti, A. Treves, M. Türler, E. Valtaoja, M. Villata, R. Walter

Strategy

- optical and/or X-ray monitoring (RXTE ASM & others) of flaring activity of a large list of blazars

or, alternatively, soft gamma-ray monitoring by INTEGRAL itself (serendipitous detection of a flaring blazar in the IBIS FOV)

ToO INTEGRAL observation activated meeting the "trigger criteria" (major flaring event)

coordinated with XMM Newton ToO program

Triggering criteria:

1) > 20 mCrab for 3 consecutive days in 15-50 keV or 20-60 keV, or

2) > 50 mCrab at any time in the same bands as in the point (1), or

3) > 2e-6 photons/s/cm2 in the GLAST/LAT band

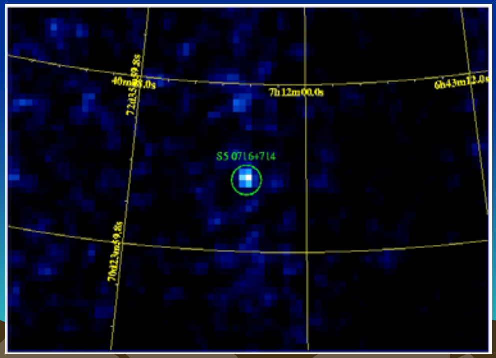
I. Blazar S5 0716+714

- a BL Lac object
- monitored at radio and optical wavelengths by Whole Earth Blazar Telescope (> 40 telescopes, Villata et al. 2004)
- ToO triggered by optical activity - 2 outbursts up to the extreme level of R =12.1 mag (historical maximum, light increase by 1 mag in 2 weeks and 2 magnitudes in 4 months)
- ToO performed 2003 April 2-7

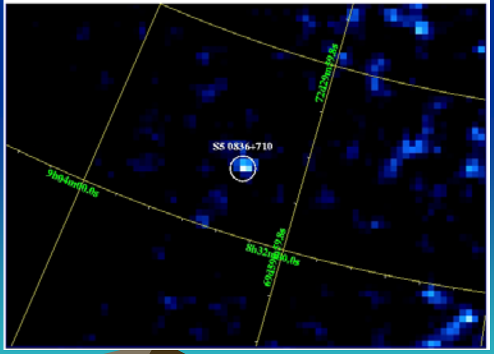
•INTEGRAL observation: S5 0716+714 detected only by IBIS ISGRI at 4.5 sigma, 30-60 keV band, for a count rate of 0.11 counts/s (exposure 280 ksec).

•observed at somewhat higher (2x) gamma-ray state when in Oct 2000 (BeppoSAX ToO, Tagliaferri et al., 2003) (R=12.5 versus 12.1)

•S5 0836+710 (high z blazar of the FSRQ sub-class) observed by chance in the FOV up to 100 keV

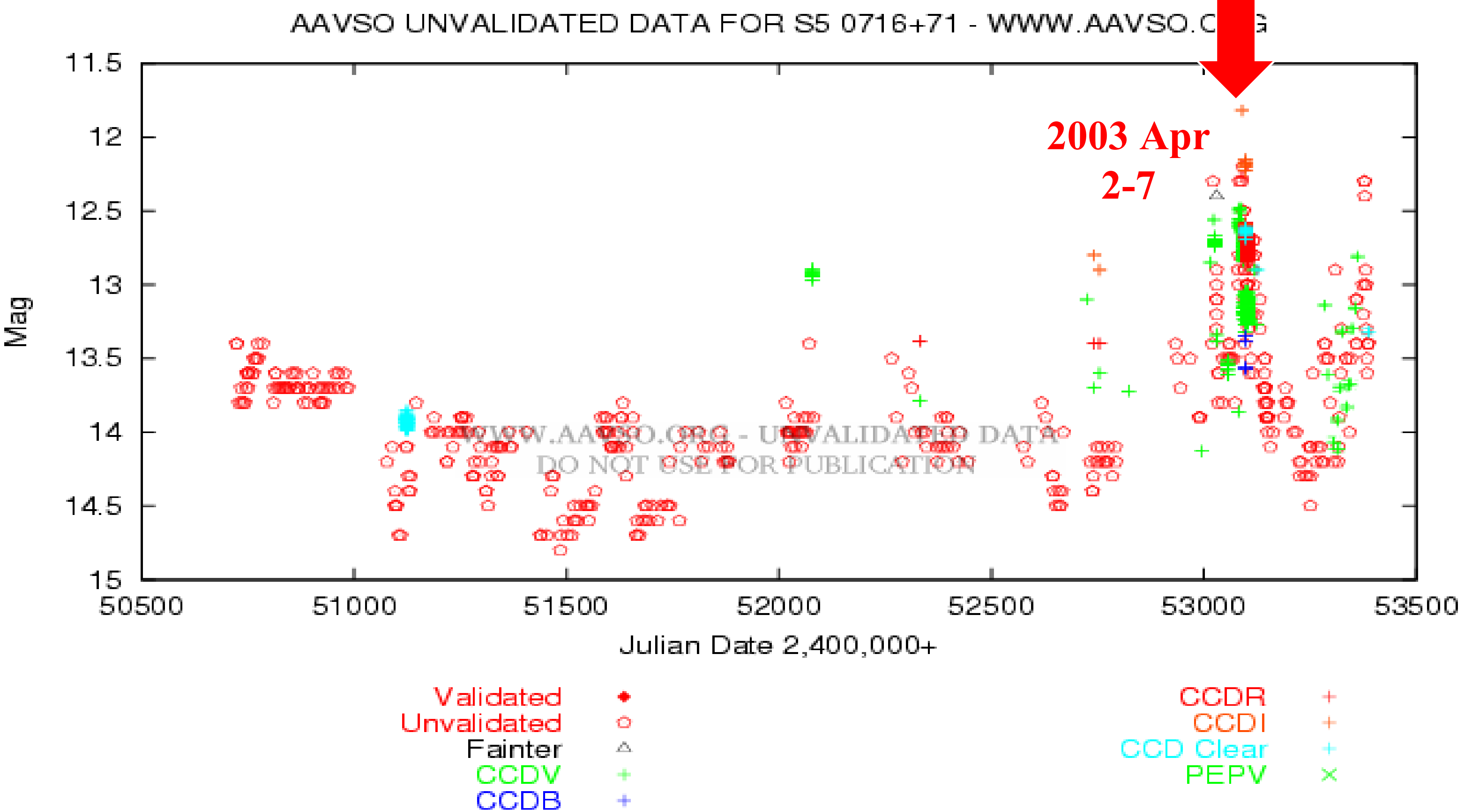


S5 0716+714



S5 0836+710

INTEGRAL ToO Observation



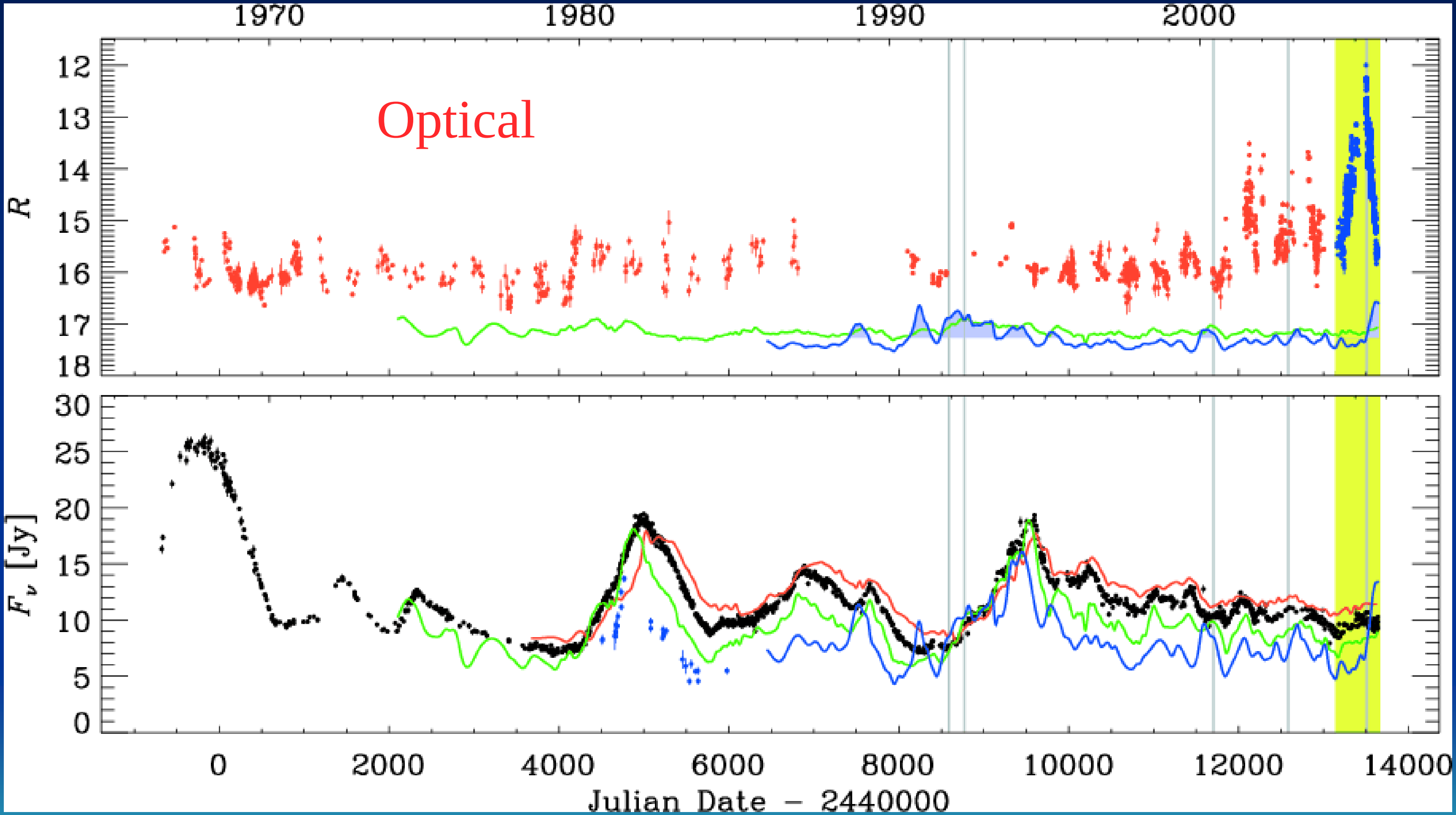
II. INTEGRAL AO-3 ToO observation of 3C454 (z=0.859, Foschini et al. 2005, Pian et al. 2006, PI E. Pian @ large collaboration)

ToO triggered by high optical (T. Balonek, VSNET alert) and X-ray (BAT Swift) activity

INTEGRAL observation started 2005 May 15, at 18:40 UT, exposure 200 ksec

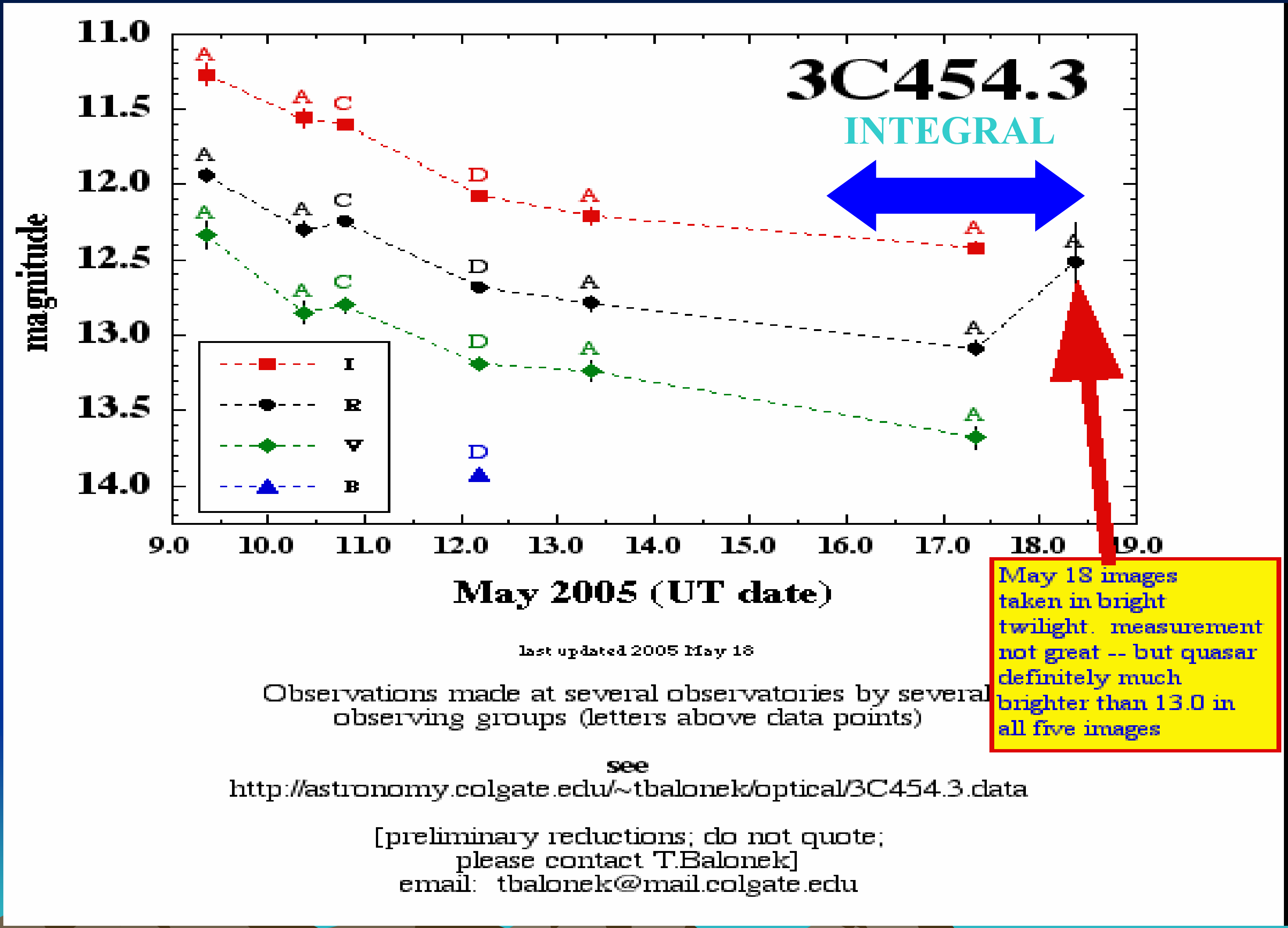
source clearly detected by IBIS/ISGRI in the 20-40 and 40-100 keV energy bands, with a significance of 20 and 15 sigma

3C454.3 since 1966

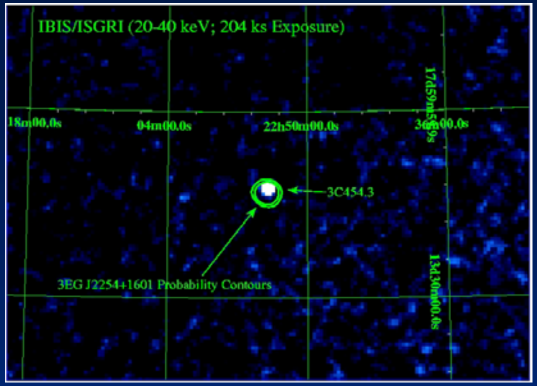


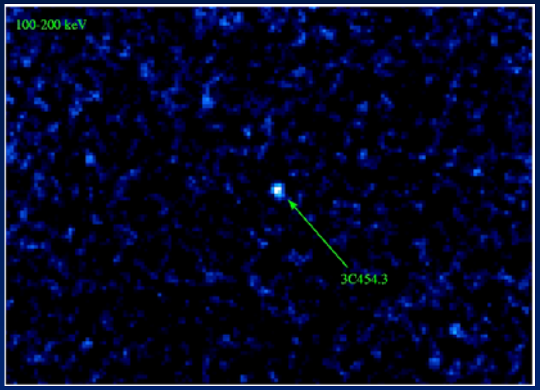
May 2005

Villata et al. 2006

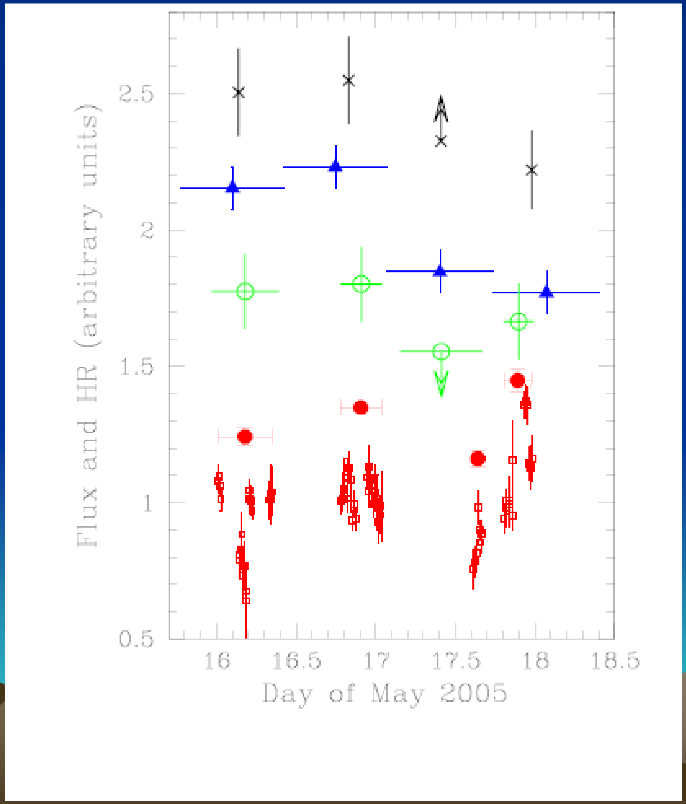


3C454 was at the time of INTEGRAL observation already 1 mag below maximum but still bright





INTEGRAL IBIS/ISGRI images, 20-40 (left) and 100-200 keV (right)



IBIS (blue), JEM-X (green) and OMC (red) LCs of 3C454.3

Observed spectrum: flat, photon index 2.2 +-0.2, normalization 0.13 (+0.10 -0.06) phcm-2s-1keV-1

Allocated 200ks were not enough to detect the object up to 400 keV, > 400ks would be necessary ...

Further INTEGRAL observations of blazars

•3C 279 within AO-1 by Collmar et al. in a deep low-activity state (faintest R mag in 10 years, 3 mag fainter than average)

•3C273 by Courvoisier et al. 2003 (2 very bright blazars)

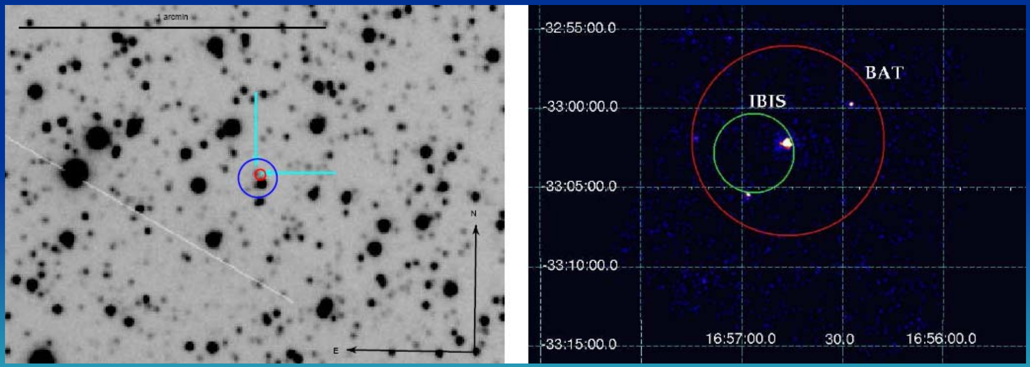
•PKS1830-211 confirmed as a blazar by INTEGRAL CP (Bassani et al., 2004) ... broad band energy spectrum confirms the blazar nature (low-energy - MeV - peaked or red blazar). One of farthest objects detected so far by INTEGRAL (z=2.5)

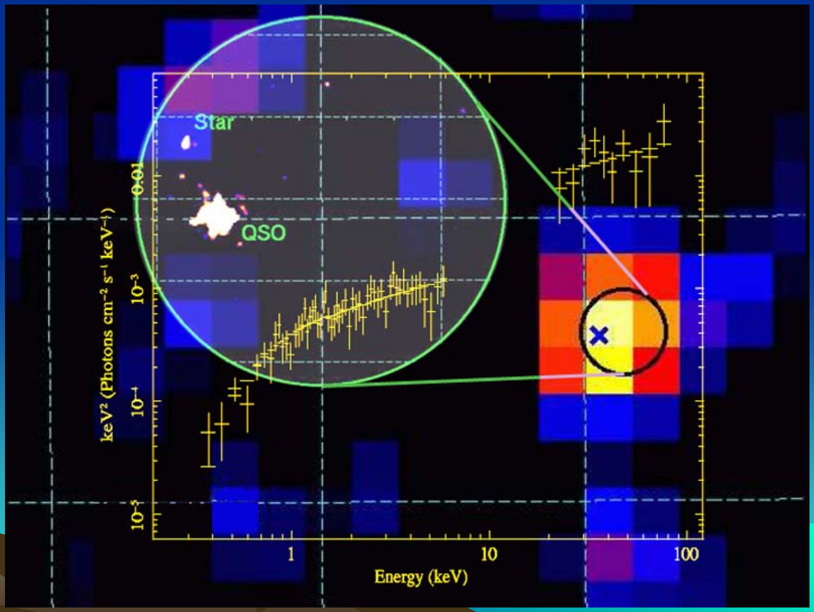
•S5 0716+714 AO-1 observation by Wagner et al. (in optically low state, no detection, Ostrorero et al. 2007)

•Mrk421 AO-4 observation. TeV blazar (Lichti et al. 2007, Bottacini et al., poster this conference)

INTEGRAL and high redshift Universe

detection of 4 high z blazars (S5 0836+710 at z=2.17 , PKS 1830-21 at z=2.51, Swift J1656.3-33-02 (z=2.40), IGR J22517+2218 (peculiar QSO with blazar features) at 3.67) (- the most distant objects seen by INTEGRAL so far - INTEGRAL can also play a role in investigation of high z Universe

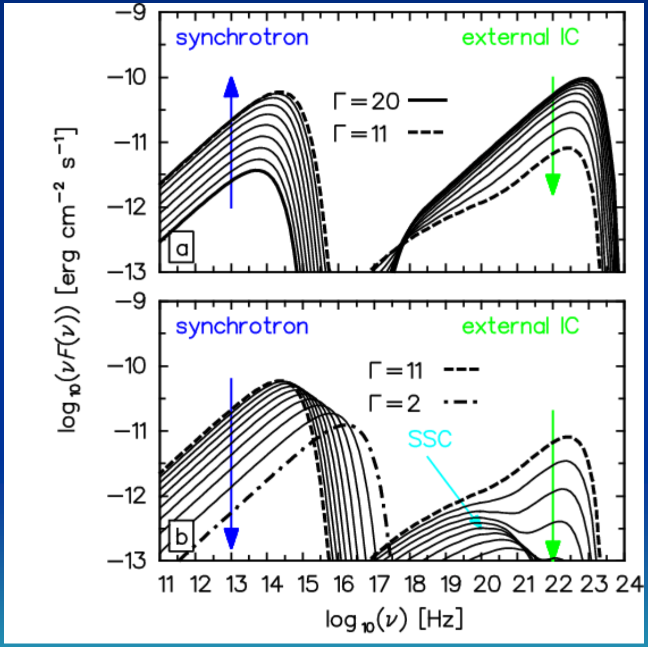




Masetti et al. 2007, Bassani et al., 2007

INTEGRAL & testing blazar models

Testing the "economic" jet model (Katarzynski & Ghisellini 2007): the same bolometric energy budget can produce *very* different multiwavelength states (Pian et al. 2006).



Blazar multiwavelength spectra as predicted by the "economic" model

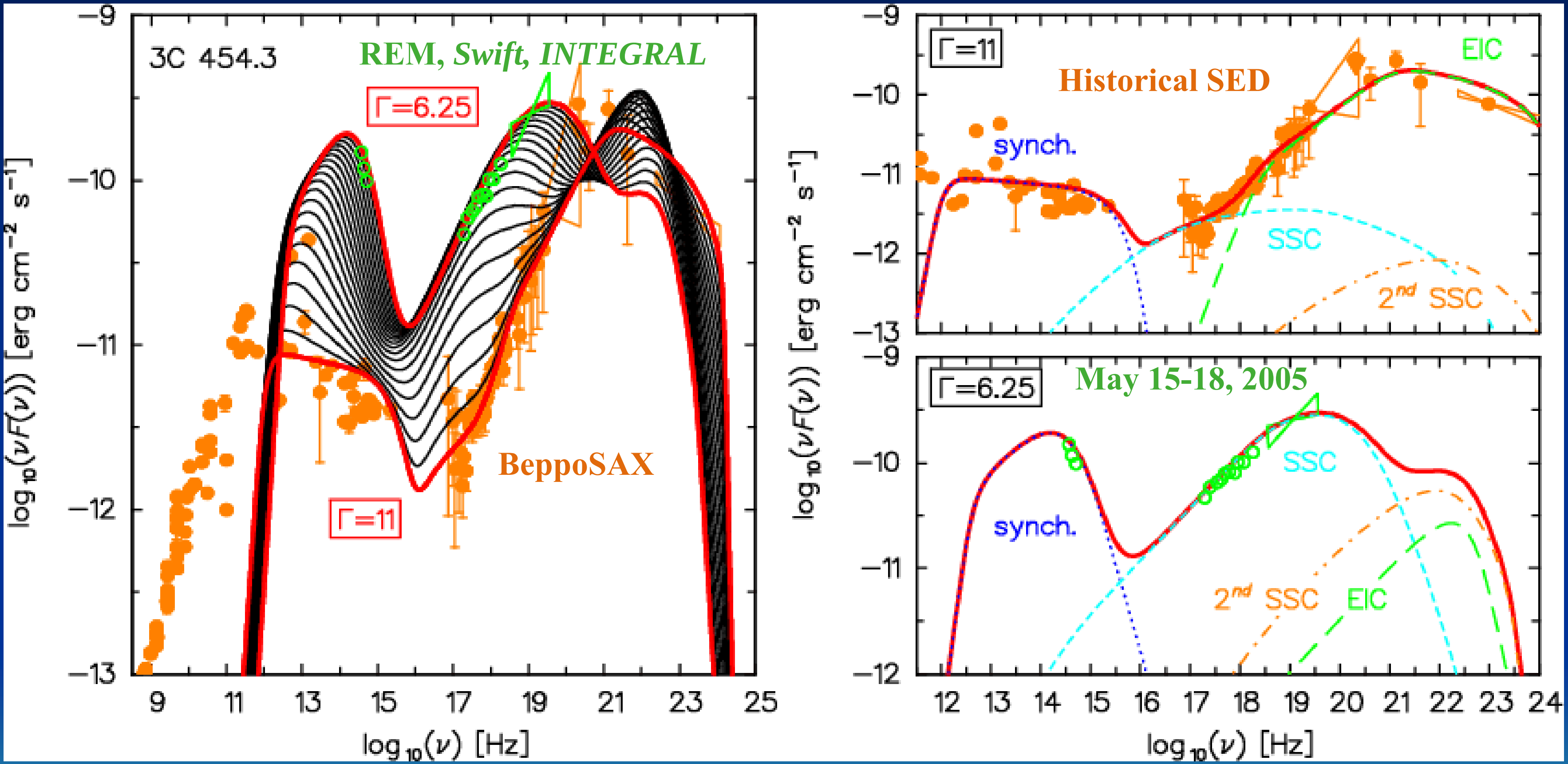
METHOD:

Accurate multiwavelength monitorings of blazars

3C 454.3: 15-18 May 2005, *INTEGRAL*, *Swift* and REM

PKS0537-441: Jan-Feb, July, November 2005: *Swift* and REM

3C454.3 (z = 0.859): 15-18 May 2005 (green) and historical



Pian et al. 2006; Giommi et al. 2006; Fuhrmann et al. 2006; Villata et al. 2006; Katarzynski & Ghisellini 2007

Searches for faint blazars in IBIS data: procedure developed and tested

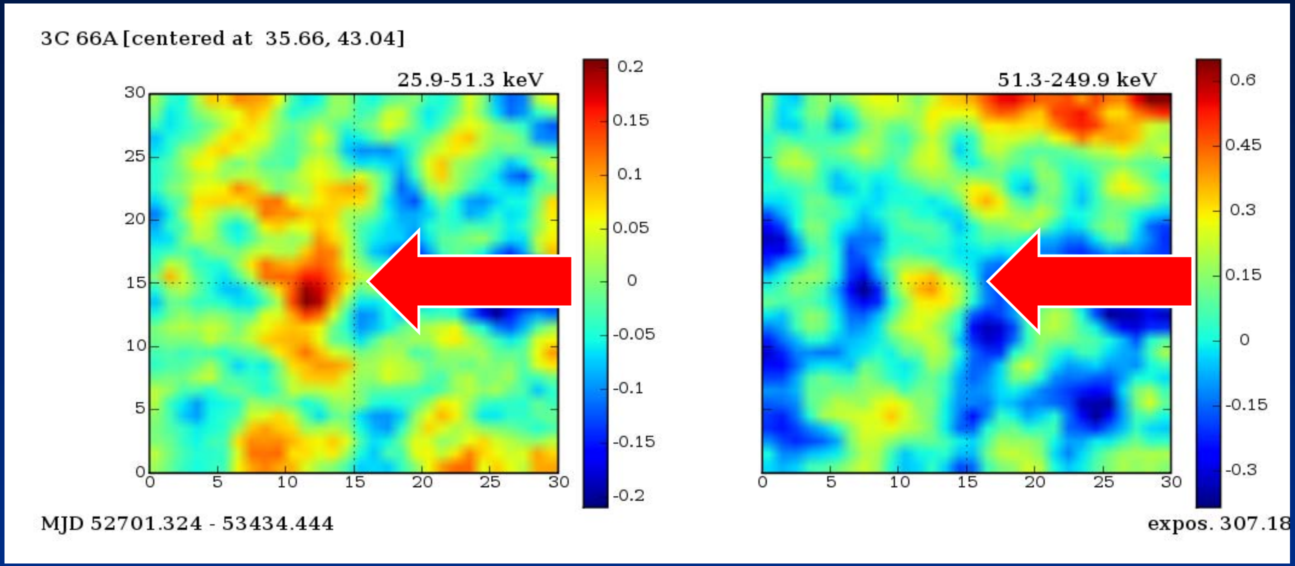
Images limited to 60×60 pixels around the source position and fine spectral binning (12 bands between 13 and 520 keV) is combined in just 2 bands – 25-51 keV and 51-250 keV – to reach maximal sensitivity.

Distribution of background values checked: images with too large background fluctuations rejected. This gives an improvement of this process compared to previously used method of cut-outs from larger mosaics where no such selection was possible.

Individual images are combined using varmosaic procedure (by K. Ebisawa) from HEATOOLS (since standard OSA mosaicing tool are not applicable to the cut-outs described).

Final mosaics are centered at the exact catalog position of the source. Total exposure is divided into periods spanning typically less than 2 months and a sub-mosaic is created for each of them. This approach gives better sensitivity to variable sources (that could be averaged out in overall mosaics).

A cumulative mosaic is then created (the sub-mosaics being aligned) by simple summing.

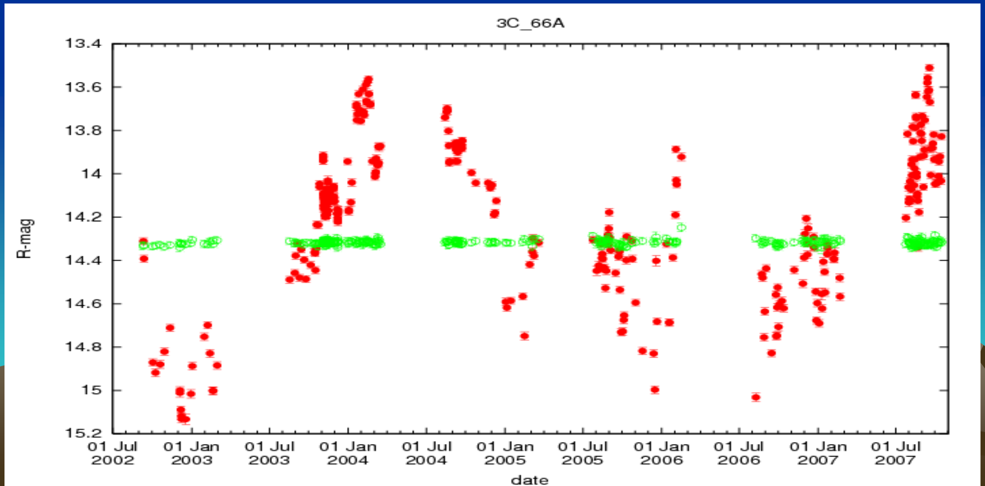


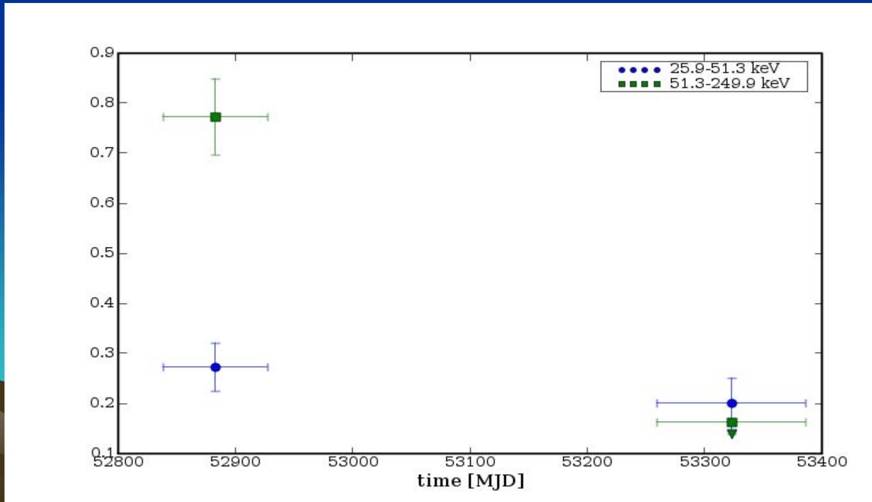
3C 66A

Visible by IBIS only during the optical flare shown below

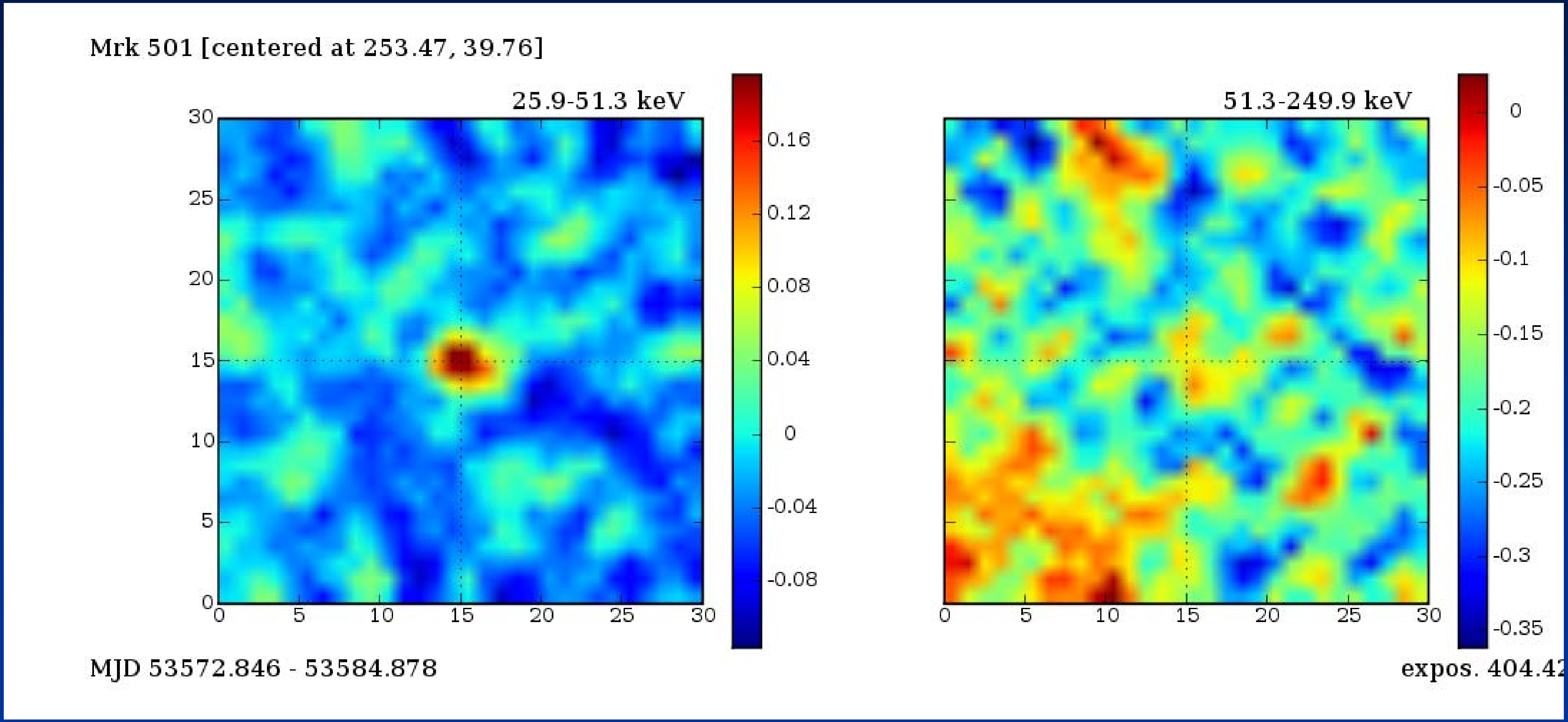
Invisible other times

MJD interval 52701.32-52849.62 i.e. 148.30 days [Mar 2004 - Jul 2004]
time mean 1294.368 +- 44.479
size 60×60 [pixels -0.082×0.082] — exposure 128.563 ksec **The flux is (1.66 +- 0.285) 10-11erg/cm2/s** **Clearly variable**



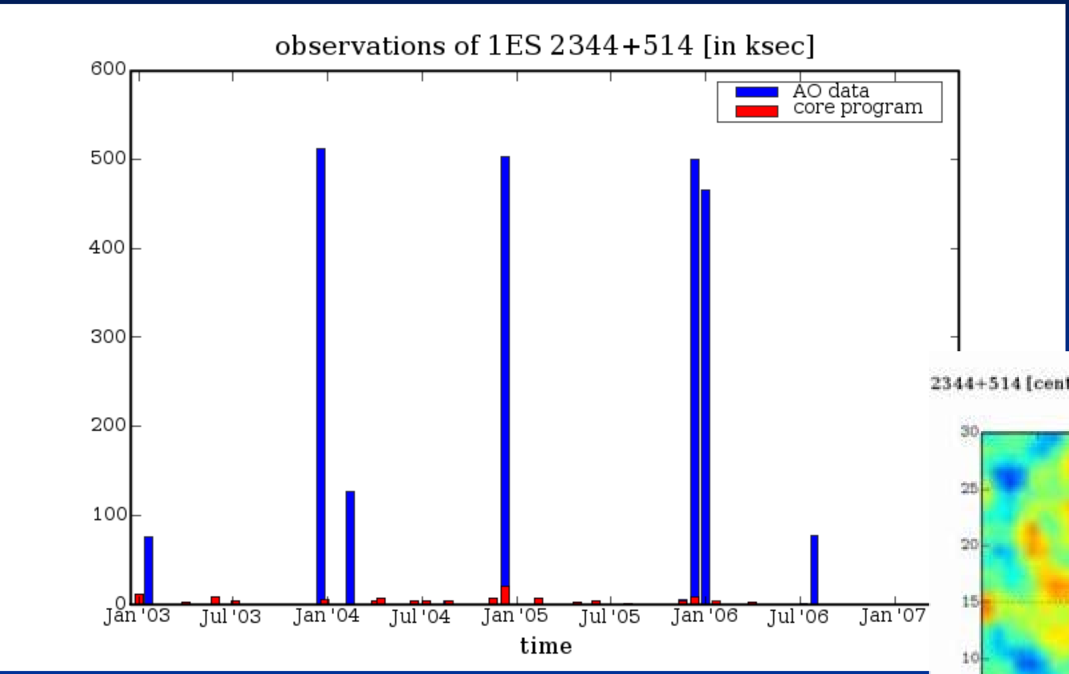


Mrk 501

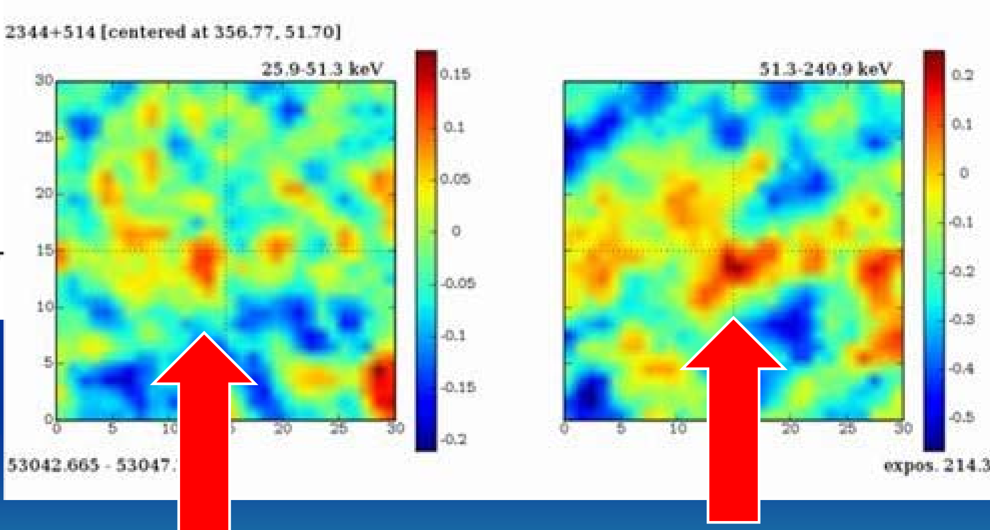


The most significant result of the procedure described. The flux corresponding to the excess in lower spectral band for Mrk 501 is (1.57 ± 0.24) 10-11erg/cm2/s. The coordinates of the images are given in pixels, one pixel being 4.9 arcmin; mosaics are centered on the catalogue position of the source.

1ES2344+514

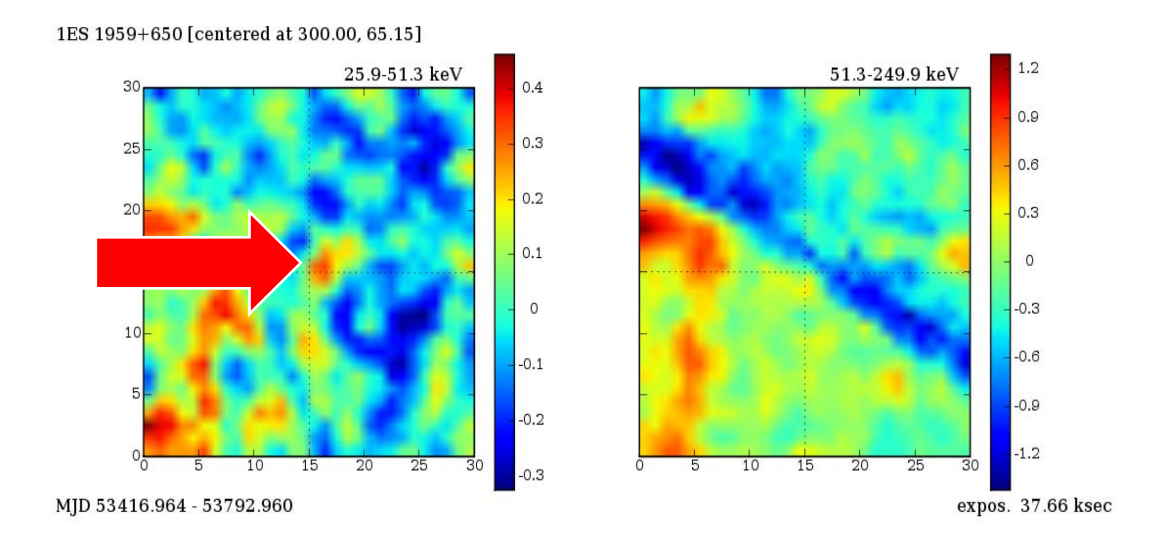


INTEGRAL IBIS data mining for faint variable objects

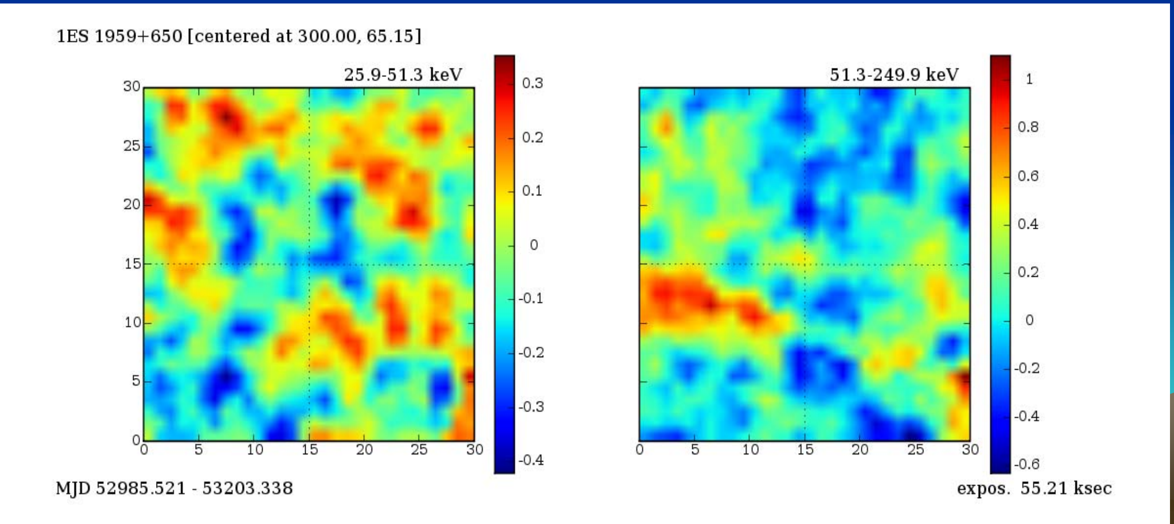


The distribution of observations in time for the most exposed target, AO data are those covered by a proprietary period) and a sub-mosaic is created for each of them. This approach gives us better sensitivity to variable sources (that could be averaged out in overall mosaics) and also is less prone to processing problems, when only a shorter (and quite fast) part of calculations has to restarted. A cumulative mosaic is then created (the sub-mosaics being aligned) by simple summing.

1ES 1959+650 variable object visible in 2006 only, invisible in total mosaics and/or other periods

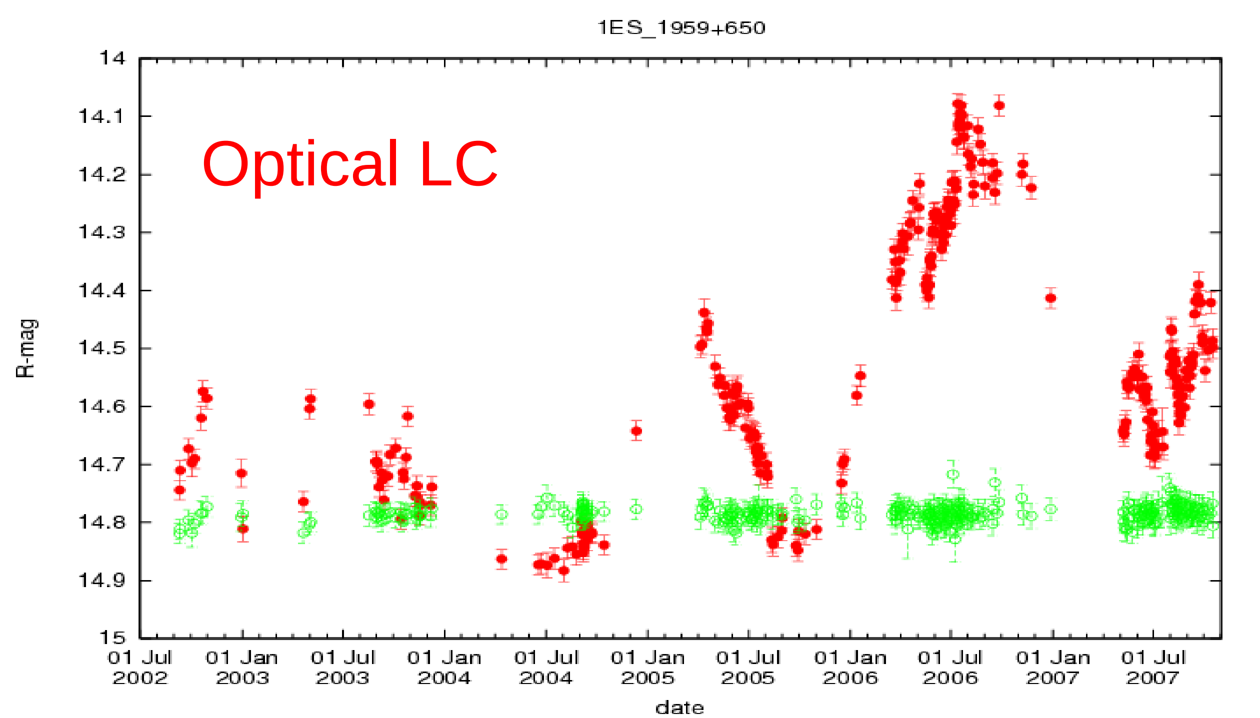


MJD interval 53416.96-53792.96 i.e. 376.00 days [Feb 2006 - Feb 2007]
time mean 2042.517 +- 123.373
size 60×60 [pixels 0.082×0.082] — exposure 37.662 ksec
25.9-51.3 keV : 0.335 +- 0.0991 ct/s

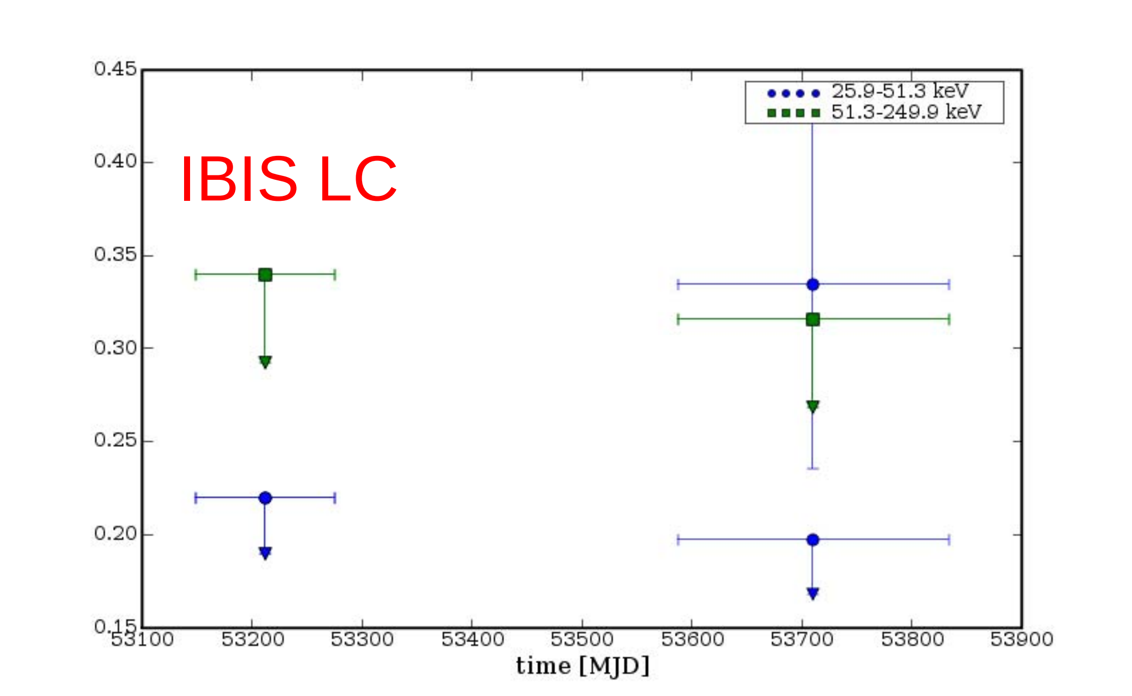


MJD interval 52985.52-53203.34 i.e. 217.82 days [Dec 2004 - Jul 2005]
time mean 1604.384 +- 63.512
size 60×60 [pixels 0.082×0.082] — exposure 55.206 ksec
25.9-51.3 keV : <0.2 +- 0.1 ct/s

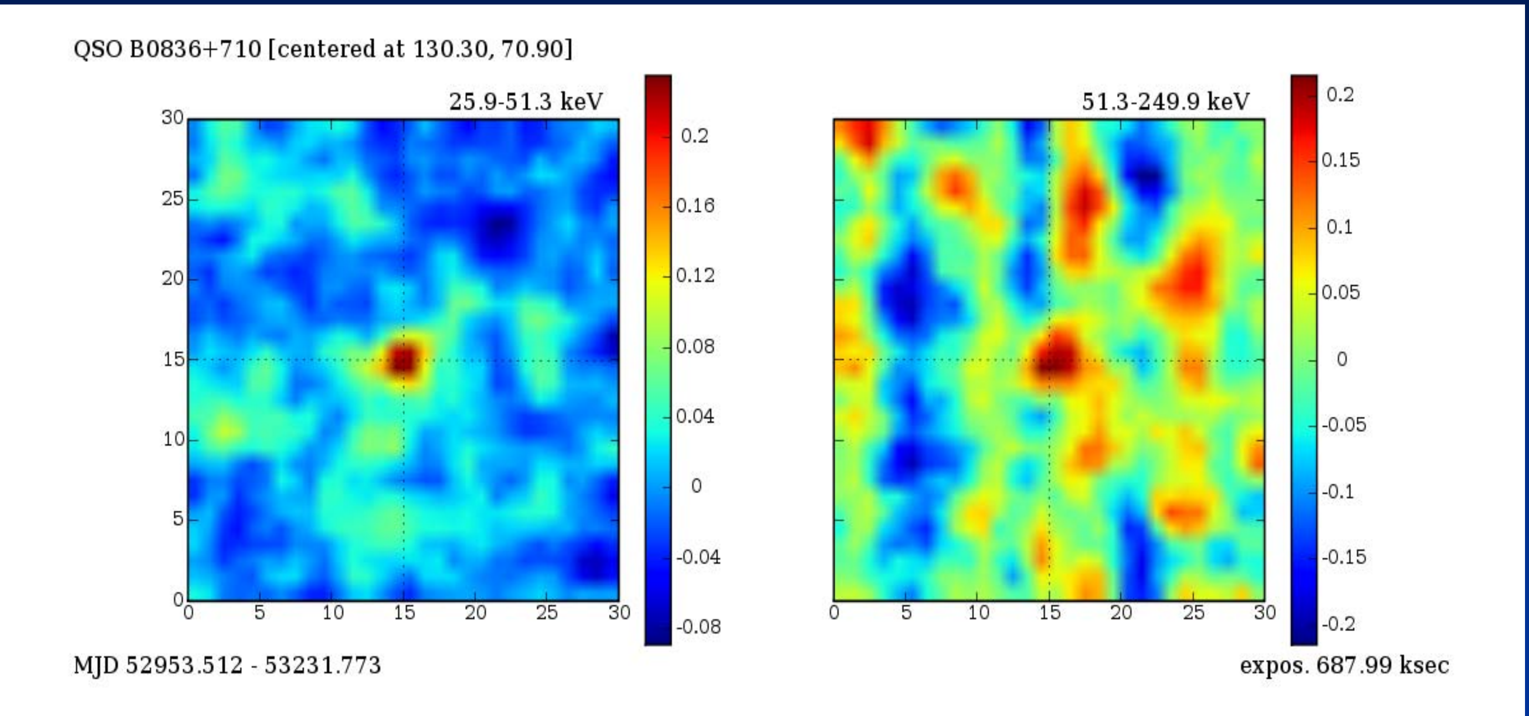
1ES 1959+650



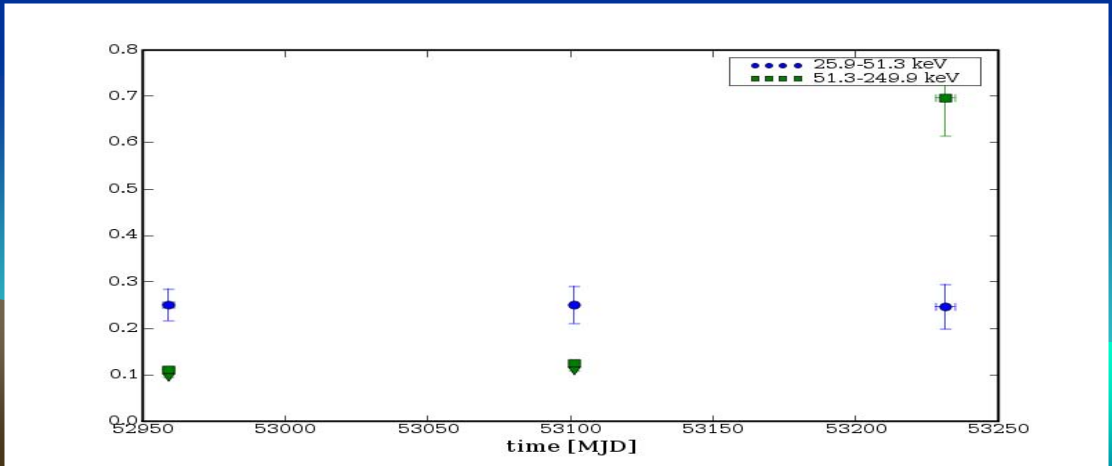
- Blazar is in IBIS visible only in data set corresponding to optical flare



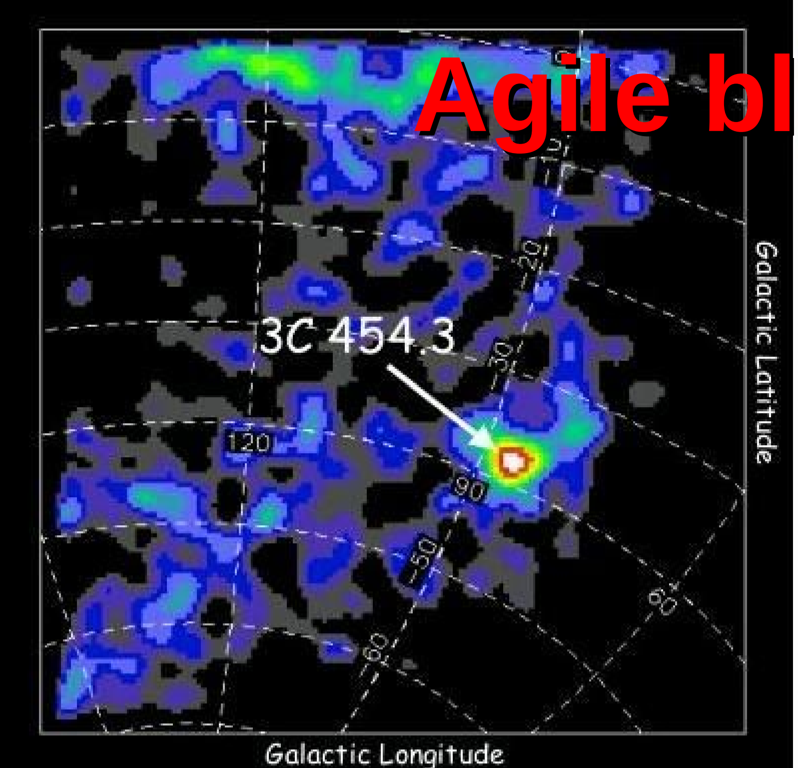
Blazar QSO B0836+701

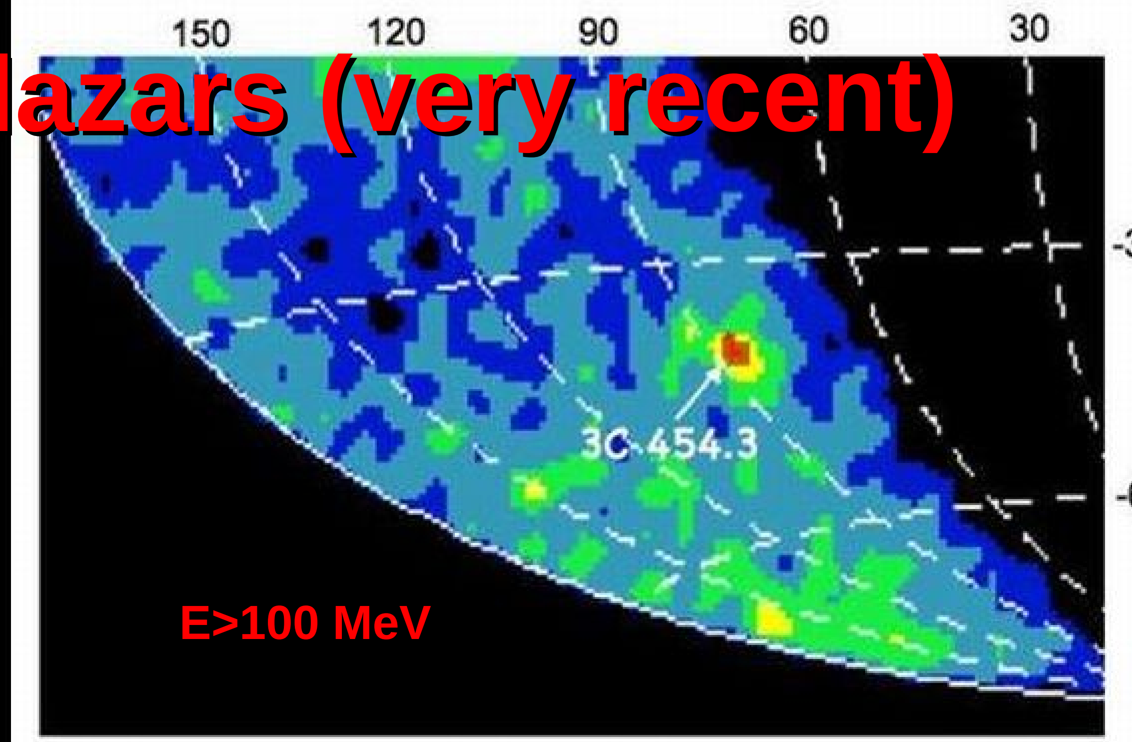


- MJD interval 52953.51-53231.77 i.e. 278.26 days [Nov 2004 - Aug 2005]
- time mean 1508.734 +-107.722
- size 60×60 [pixels 0.082×0.082] — exposure 687.993 ksec



Agile blazars (very recent)





3C 254.3 Rough estimate (calibration still ongoing) (3+/-1)*10E-6 ph/cm2/s for E>100 MeV. http://agile.iasf-roma.inaf.it/

S5 0716+714

Found bright in gamma rays >100MeV and small optical corresponding brightening found (ATEL 1221, 1223)

3C273, 3C279 (two very bright blazars)

AGILE versus INTEGRAL IBIS

Comparing AGILE versus INTEGRAL: AGILE more suitable to see gamma-loud blazars

Integral IBIS

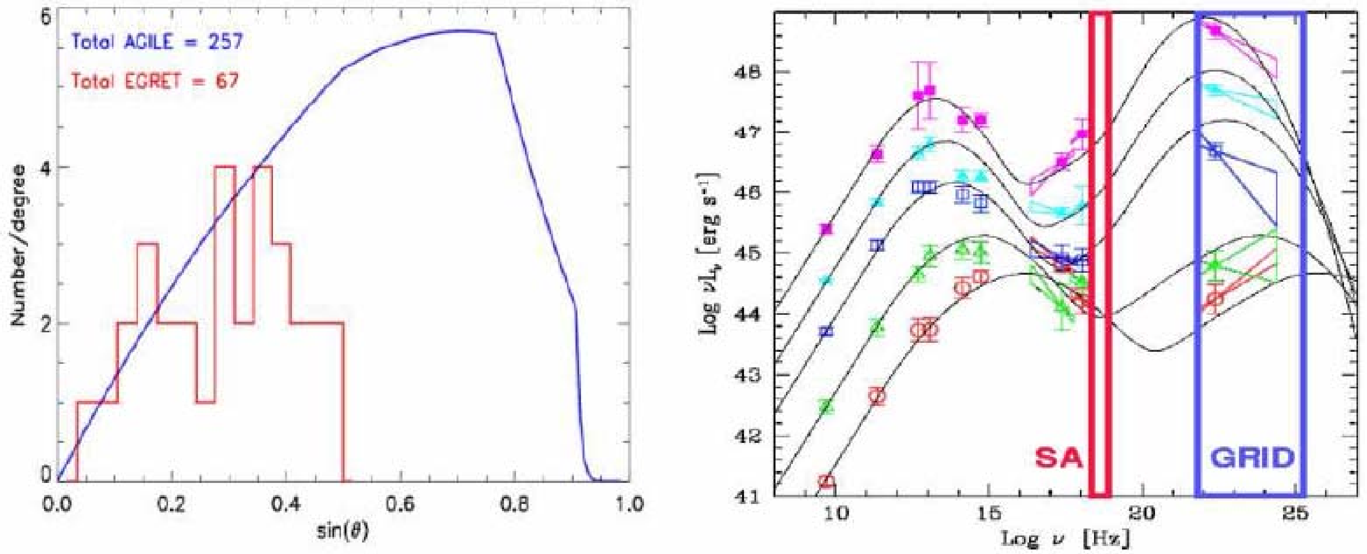
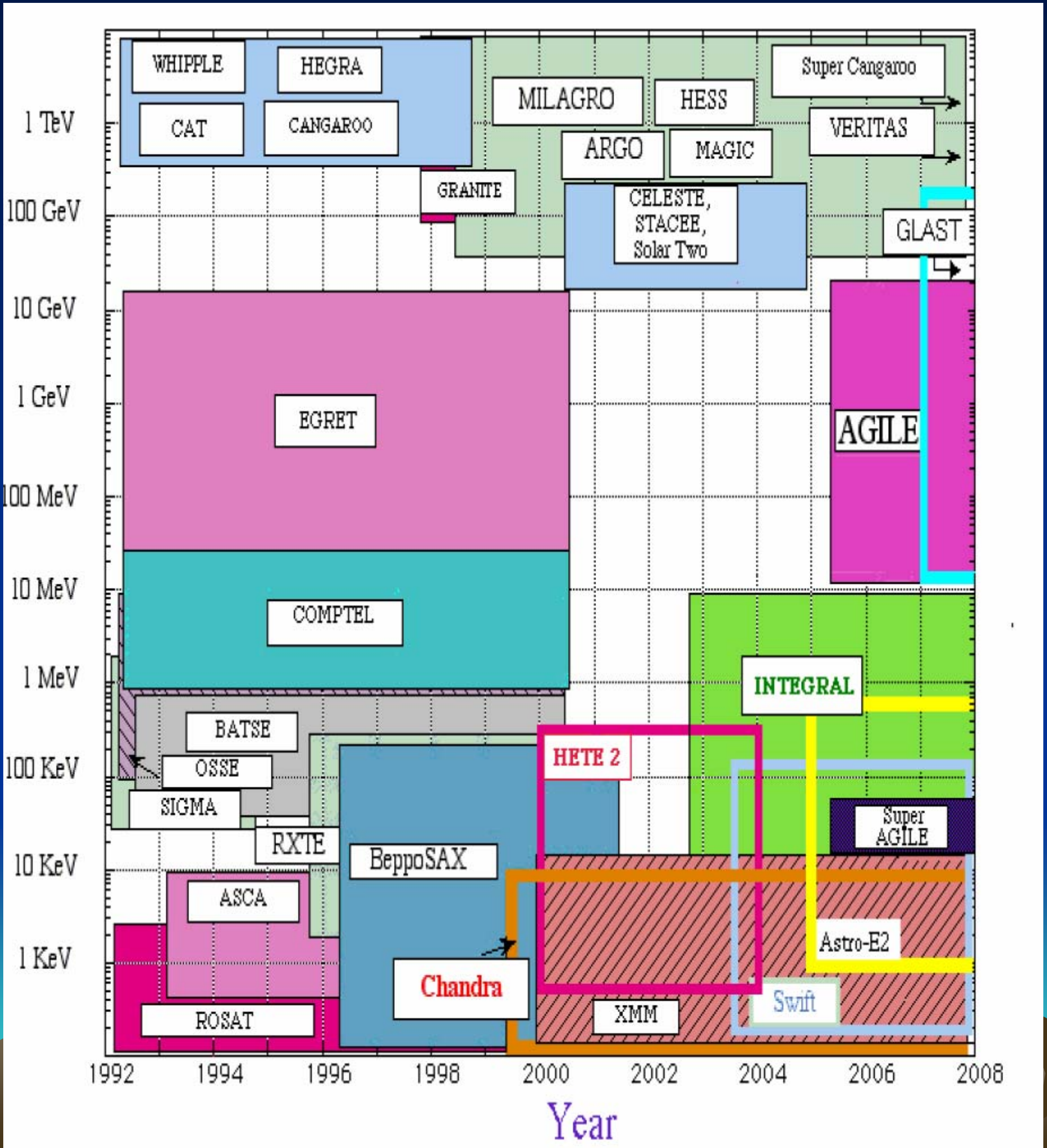


Figure 1: (**Left panel:**) Simulation of the EGRET and AGILE detectable blazar distribution as a function of the sine of the off-axis angle θ. (**Right panel:**) Broad-band spectral coverage of AGILE compared to different classes of blazar emission.



Comparison of high-energy space experiments

http://agile.iasf-roma.inaf.it/

Conclusion

- Albeit the INTEGRAL sky is NOT dominated by blazars, there are ~20 detections so far
- New approaches allow data mining for hidden faint blazar detections
- Best results come from ToO type observations for flaring blazars
- INTEGRAL gives coverage in little investigated E bands. This gives important piece of information for multispectral analyses
- Tests of models possible
- Best science from collecting real multispectral data from all energy bands
- Careful data mining in public INTEGRAL data may still yield valuable scientific results

The End