The role of ground-based robotic observatories in satellite projects

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Malaga, May 2009

Modes of observations I

- Satellite campaigns: usually ~days satellite observation, but ~ weeks campaign. Dense coverage during satellite observation required. Magnitudes typically 12-18.
- In addition to that, planned observations of optically variable sources by satellites can be supported by optical ground based observations
- Monitoring for triggering satellite ToO observations: in most cases, 1 point/day is enough. Magnitudes typically 12-18. Example: ToO proposal on blazars

Modes of observations II

- Providing optical data for non-triggered satellite observations (e.g. INTEGRAL 2002-2012). Typically 1 point/day is enough. Magnitudes typically 10 – 18.
- Alert follow-up observations. Need fast response, better (but not necessarily) automated. Even site with non automated instrumentation has chance due to observational/weather constraints. Mostly GRBs. Expected magn 6 – >22.

Modes of observations III

- Verifying suggested identifications. Typical magnitudes 10 – 20. Preferred response within days or a week. Photometry both with good sampling as well as moderate sampling, photometry with filters, spectroscopy (including low dispersion).
- Optical supplementary analyses of HE sources (for complex multispectral analyses) - Typical magnitudes 10 – 20. Photometry both with good sampling as well as moderate sampling, photometry with filters, spectroscopy (including low dispersion).

Need for optical monitoring

- As it will be shown later, very common is the situation when we have satellite (e.g. HE) monitoring data covering up to ~ years, but we do not have simultaneous optical data
- At the same time, the most important goal is to recognize active states of the sources (flares, high states, etc) either to trigger the satellite observations, or, alternatively, to be able to concentrate of archival satellite data for that's periods
- In this aspect, robotic observatories can effectively contribute

The Role of Monitors I

- Some types of astrophysical objects exhibit rare flares for which satellite observations are important
- These events cannot be monitored by satellites itself in most cases
- These events can be effectively monitored by ground based RT generating ToO triggers for satellite with ToO regime

Role of Monitors II

- The monitors, in contrast to alert telescopes, can deliver optical photometric data for objects prior and during the active/flaring states – WF coverage is important to cover as much sources as possible
- Physically important: need to have this mode in robotic telescopes
- RT with reasonably large FOV, doing regular sky surveys, or with an attached WF camera, can serve as a monitoring device.

The Role of Monitors III

- In some cases, even post-flare monitoring is important as shown by magnetar flare in odrer to (1) detect the magnetar flares (2) detect possible recurrence

Role 1

- Identification and Classification of High Energy Sources
- Providing LCs for these sources (in many cases, not available so far)
- For many INTEGRAL gamma ray sources we have gamma ray LCs but not optical

Identification of HE sources

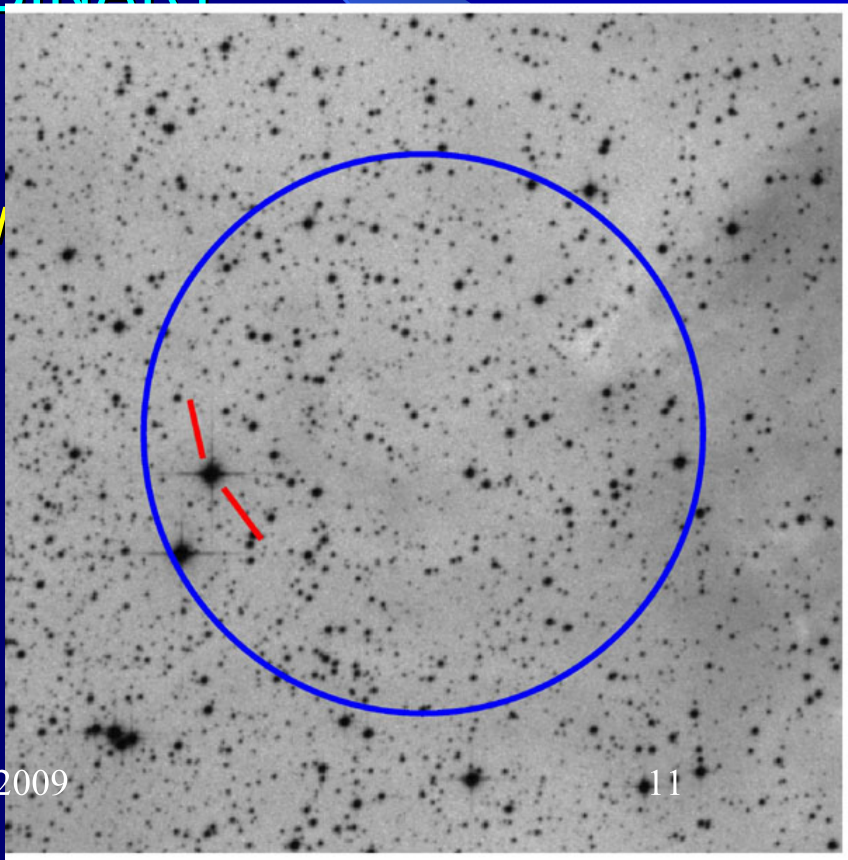
- The RT can also serve as a effective tool in identification and classification of HE sources by optical monitoring and consequent detailed optical analyses of the error box content
- Many of the HE are optically variable and hence can be identified (and classified) by their optical variability

IGR J11305-6256

RA 2000: 11 31 06.9111 [5]
DEC2000: -62 56 48.931 [5]

Class: HIGH MASS X-RAY BINARY
Type: Be/X BINARY

Example how identification w



Recent identification of newly detected INTEGRAL and Swift gamma-ray sources leads to finding new optical counterparts of HE sources. They are in many cases variable.

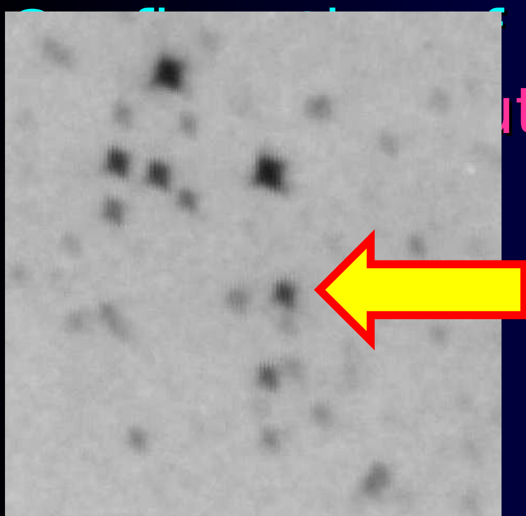
IGR J12349-6434 = RT Cru

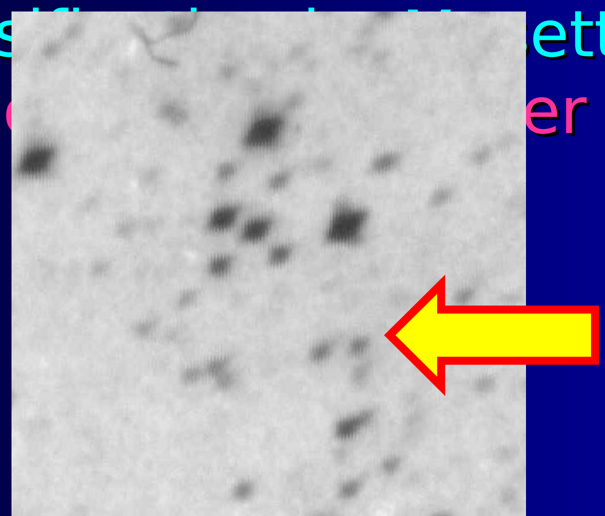
hard X-ray symbiotic star on historical Leiden Franklin Adams Plates

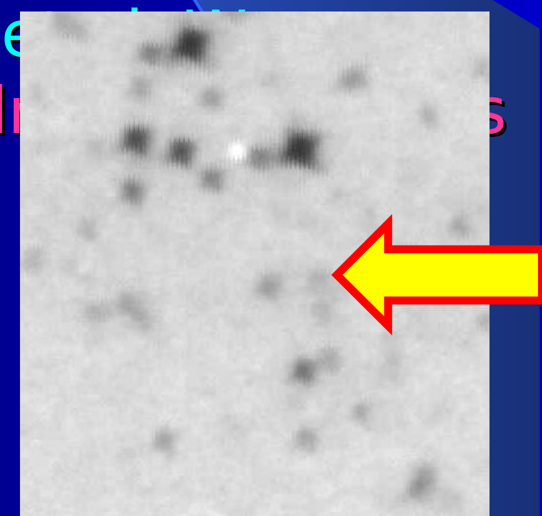
INTEGRAL gamma-ray source visible on astronomical plates taken by 100 years old optical talescope 80 years ago

Violent (amplitude 3 magnitudes) optical brightness variations identified on the historical plates ....

... class... ...etti e... ...ution ... ...er alr... ...s







See poster 1 by Hudec et al for more details on INTEGRAL sources on astronomical archival plates

Role 2

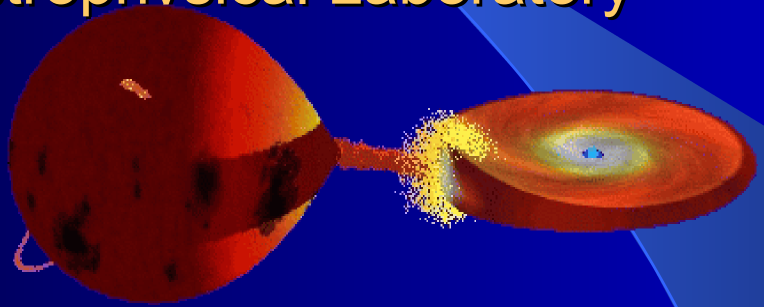
- Delivering Supplementary Optical Data for HE satellites incl. triggering ToO observations
- Example: ESA INTEGRAL

Detected CVs

GCVS Name	RA (2000)	DEC (2000)	Object Type
IGR J00234+6141	00:22:57.63	+61:41:07.8	dq
V709 Cas	00:28:48.84	+59:17:22.3	dq
XY Ari	02:56:08.10	+19:26:34.0	dq
GK Per	03:31:12.01	+43:54:15.4	na/dq
V1062 Tau	05:02:27.47	+24:45:23.4	dq
TV Col	05:29:25.52	-32:49:04.0	dq
IGR J05346-5759	05:34:50.60	-58:01:40.7	vy:
BY Cam	05:42:48.77	+60:51:31.5	am
MU Cam	06:25:16.18	+73:34:39.2	dq
IGR J08390-4833	08:38:49.11	-48:31:24.7	cv
XSS J12270-4859	12:27:58.90	-48:53:44.0	dq
V834 Cen	14:09:07.30	-45:17:16.2	am
IGR J14536-5522	14:53:41.06	-55:21:38.7	dq
IGR J15094-6649	15:09:26.01	-66:49:23.3	dq
NY Lup	15:48:14.59	-45:28:40.5	dq
IGR J16167-4957	16:16:37.20	-49:58:47.5	dq:
IGR J16500–3307	16:49:55.64	–33:07:02.0	dq
V2400 Oph	17:12:36.43	-24:14:44.7	dq
IGR J17195-4100	17:19:35.60	-41:00:54.5	dq:
IGR J17303-0601	17:30:21.90	-05:59:32.1	dq
V2487 Oph	17:31:59.80	-19:13:56.0	na
AM Her	18:16:13.33	+49:52:04.3	am
IGR J18173-2509	18:17:22.25	-25:08:42.9	cv
V1223 Sgr	18:55:02.31	-31:09:49.6	dq
IGR J19267+1325	19 26 27.03	+13 22 03.2	cv
V1432 Aql	19:40:11.42	-10:25:25.8	am
V2306 Cyg	19:58:14.48	+32:32:42.2	dq
V2069 Cyg	21:23:44.84	+42:18:01.8	dq:
IGR J21335+5105	21:33:43.65	+51:07:24.5	dq
SS Cyg	21:42:42.80	+43:35:09.9	ugss
FO Aqr	22:17:55.39	-08:21:03.8	dq
AO Psc	22:55:17.99	-03:10:40.0	dq

32 CVs detected by the ESA INTEGRAL satellite in hard X-rays

Cataclysmic Variables as Astrophysical Laboratory



The optical LC of V834 Cen during the lifetime of INTEGRAL

- **V834 Cen is a polar of AM Her class**

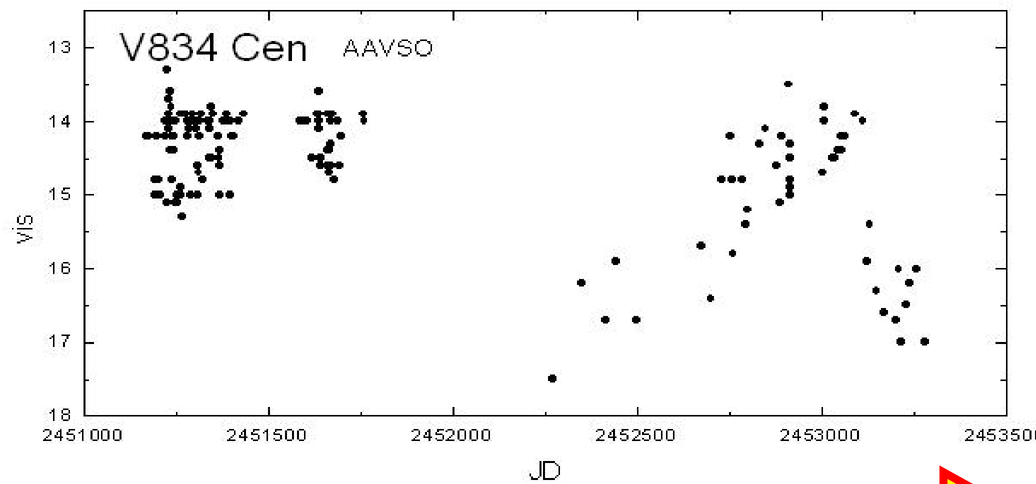
It shows active and inactive states.
Optical monitoring of sources is important as it can indicate active intervals when the object is expected to be active also in gamma-rays

Comparing optical and gamma-ray activity is difficult in

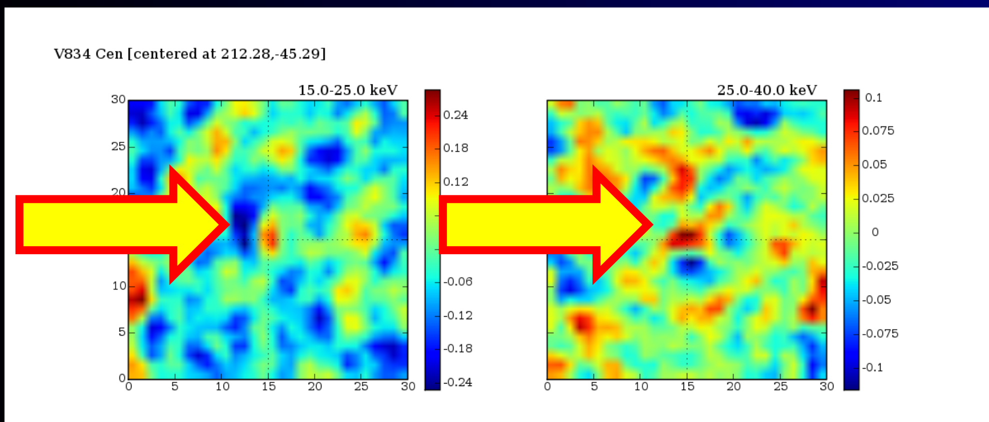
This polar was probably detected by IBIS since it was in high (active) state.

This may explain why some CVs have been detected by IBIS and some not.

operation

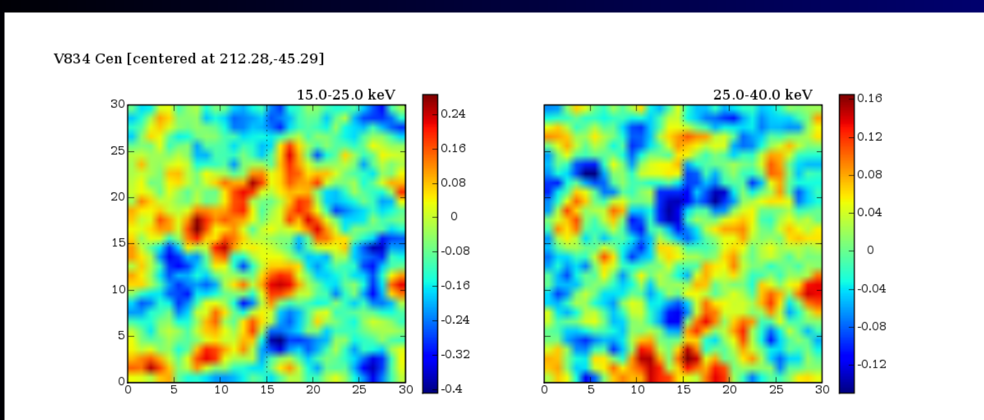


V834 Cen in optical high and low state



IBIS image at optical active state 14 mag

Object detected



IBIS image at optical low state 17 mag

Object not

It can be an explanation why some CV are visible and

V1223 Sgr: Indications for flaring activity:

Most significantly detected CV in the IBIS survey, with a significance of 38 sigma in the 20-40 keV final mosaic

Accretion via disk

Bright X-ray source (4U 1849–31)

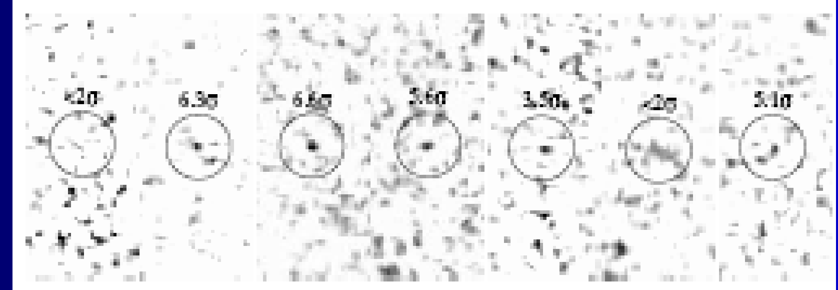


Figure 2. 20–30 keV images of IBIS revolution 61, ScWs 97–103 (left to right). The location of V1223 Sgr is circled and the significances labelled for each ScW.

•Seen by IBIS (flare lasting for ~

during revolution 61 (MJD 52743), peak flux

~ 3 times of average (Barlow et al., 2006)

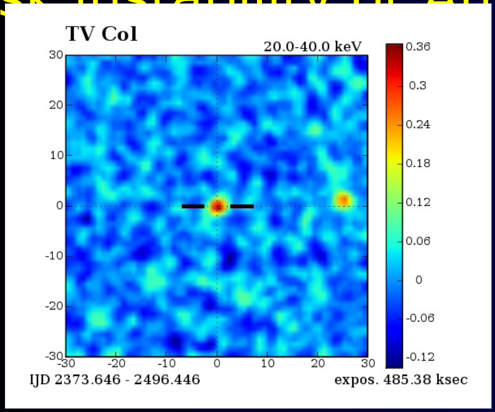
•Seen in optical by ground-based instrument (duration 6-24 hrs), but for other time intervals, Amerrongen & van Paradijs (1989)

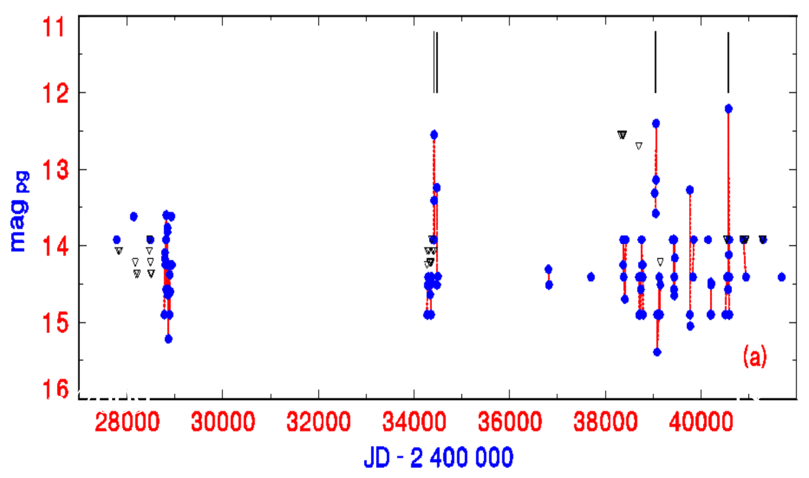
Similar flares known also for another IPs in optical, but not in soft gamma:

Example TV Col (Hudec et al., 2005), where 12 optical flares have been observed so far, five of them on archival plates from the Bamberg Observatory. TV Col is an intermediate polar (IP) and the optical counterpart of the X-ray source 2A0526-328 (Cooke et al. 1978, Charles et al. 1979). This is the first cataclysmic variable (CV) discovered through its X-ray emission.

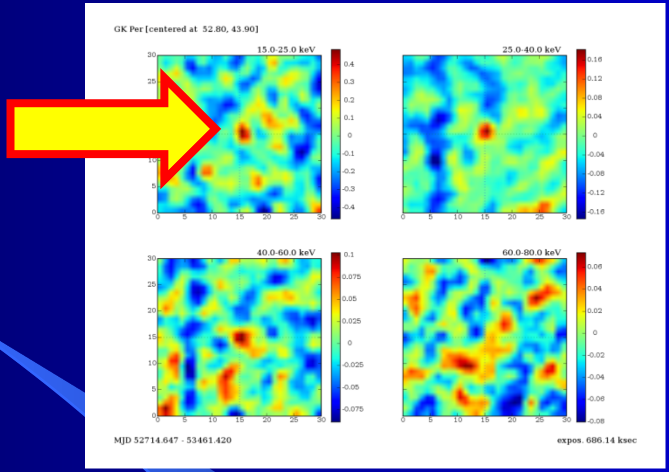
Physics of the outbursts in IPs:

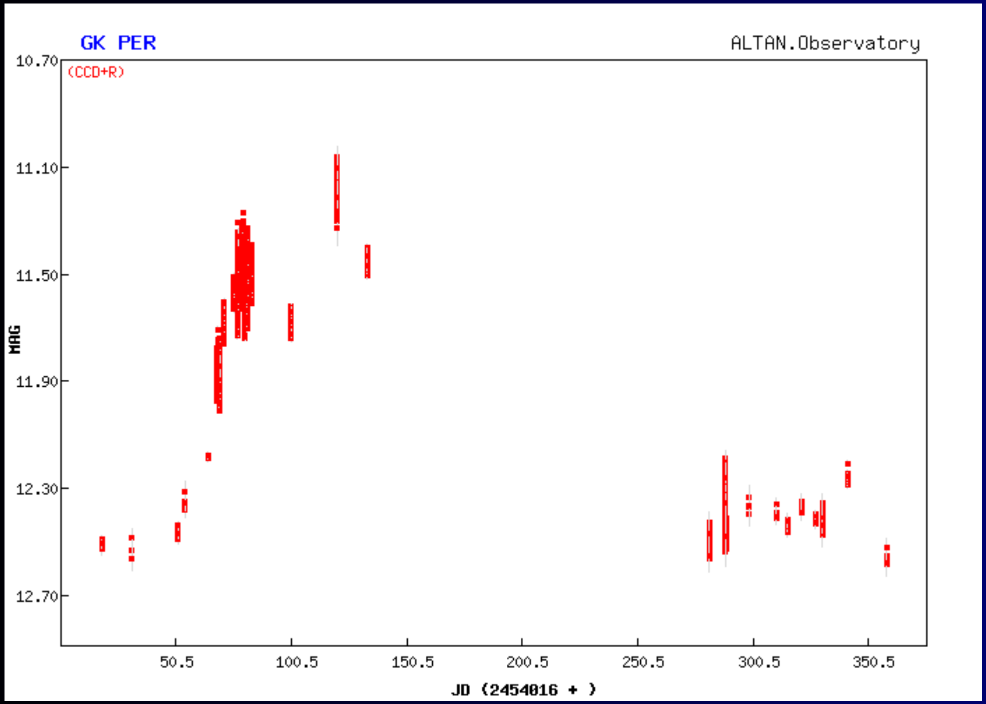
Disk instability or An increase in m





2006 flare of GK Per





Old nova GK Per in dwarf nova-type outburst ATel #965; *L. Brat (Altan Observatory*

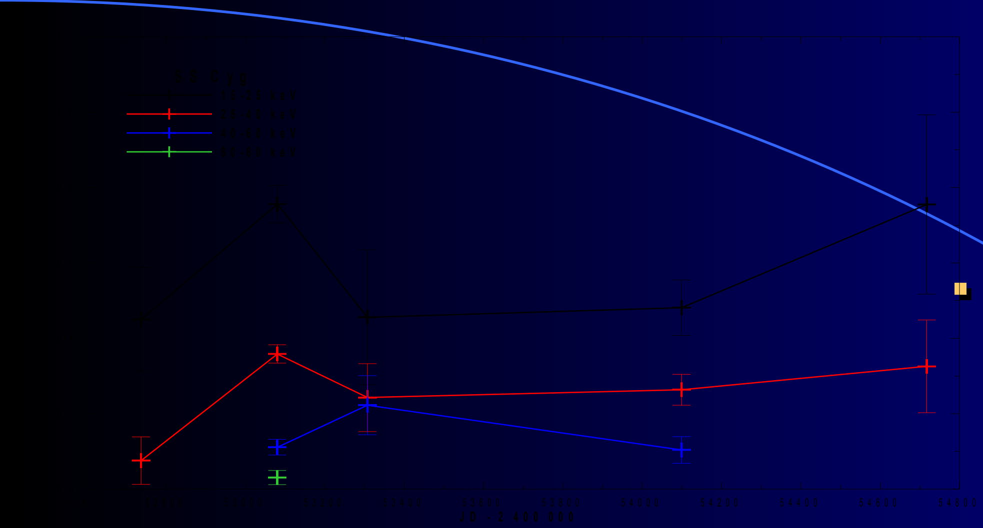
on 18 Dec 2006; 14:28 UT

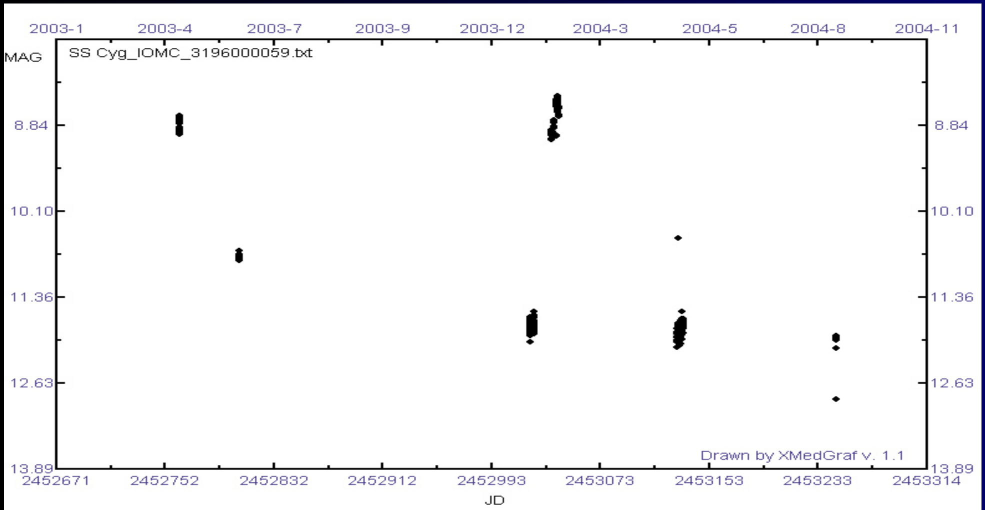
Valuable contributions from Valasske Mezirici, Altan and others

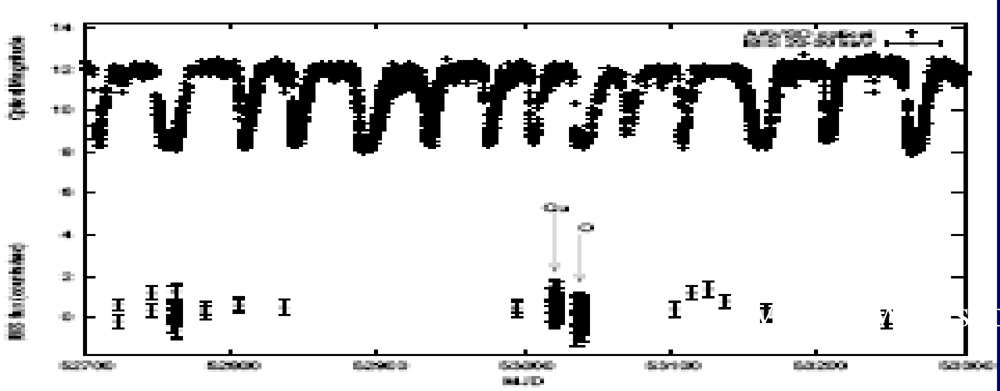
755 d from last outburst

1992, 1996, 1999, 2002, and 2004 : between 1091 and 1333 d, but before rouhly

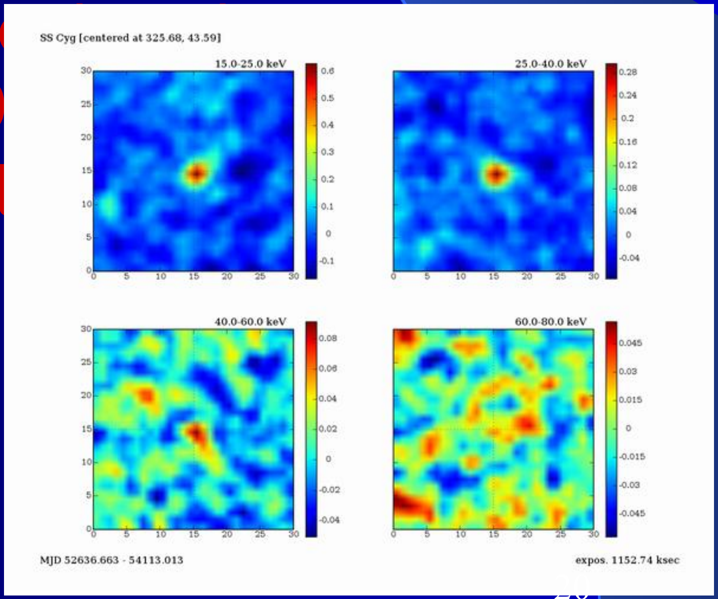
SS Cyg



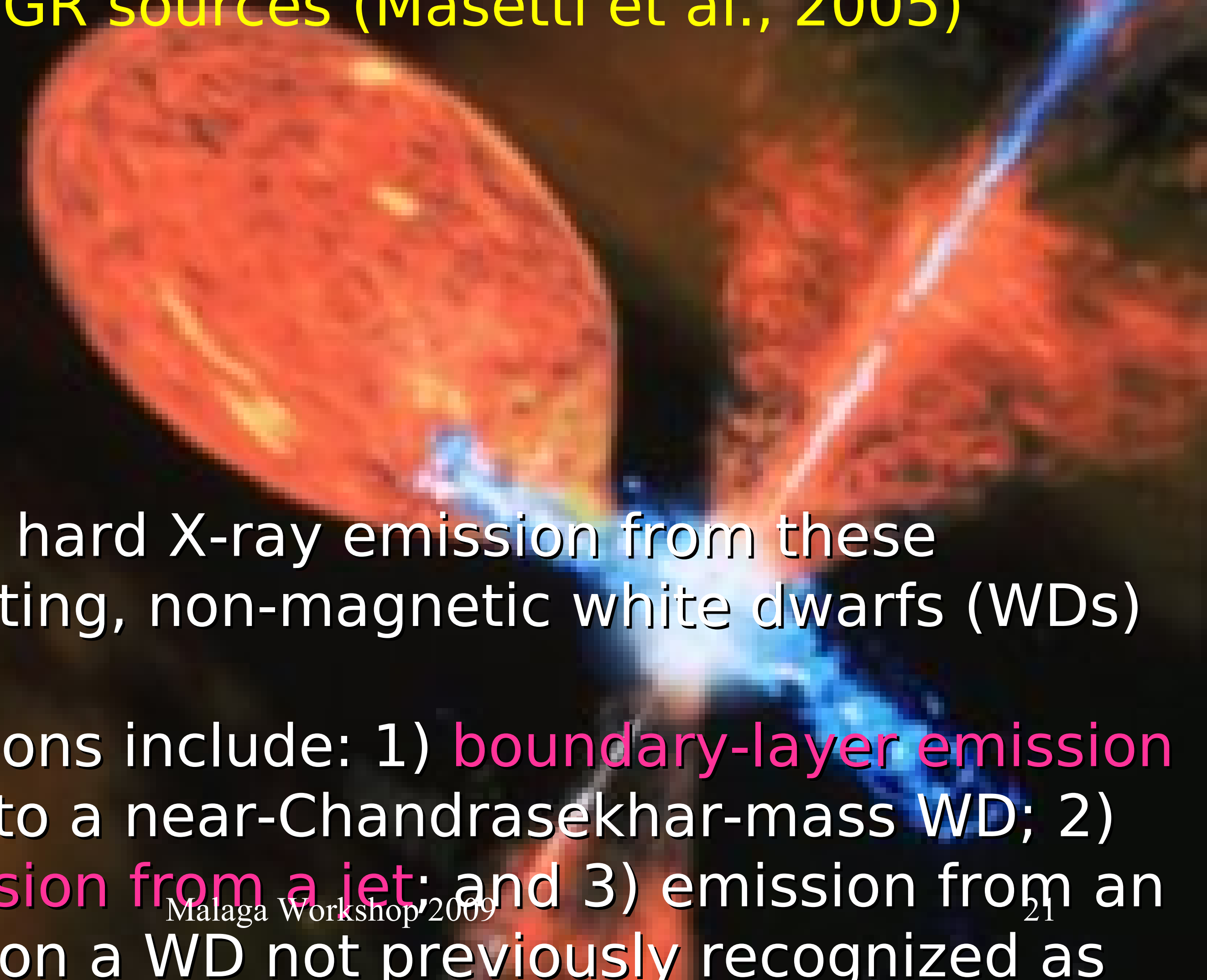




- INTEGRAL gamma ray LC (IBIS) and optical LC (OMC)
- Consistent with anti-correlation known from soft X-rays
- Optically bright DN with
optic
~40
12 t



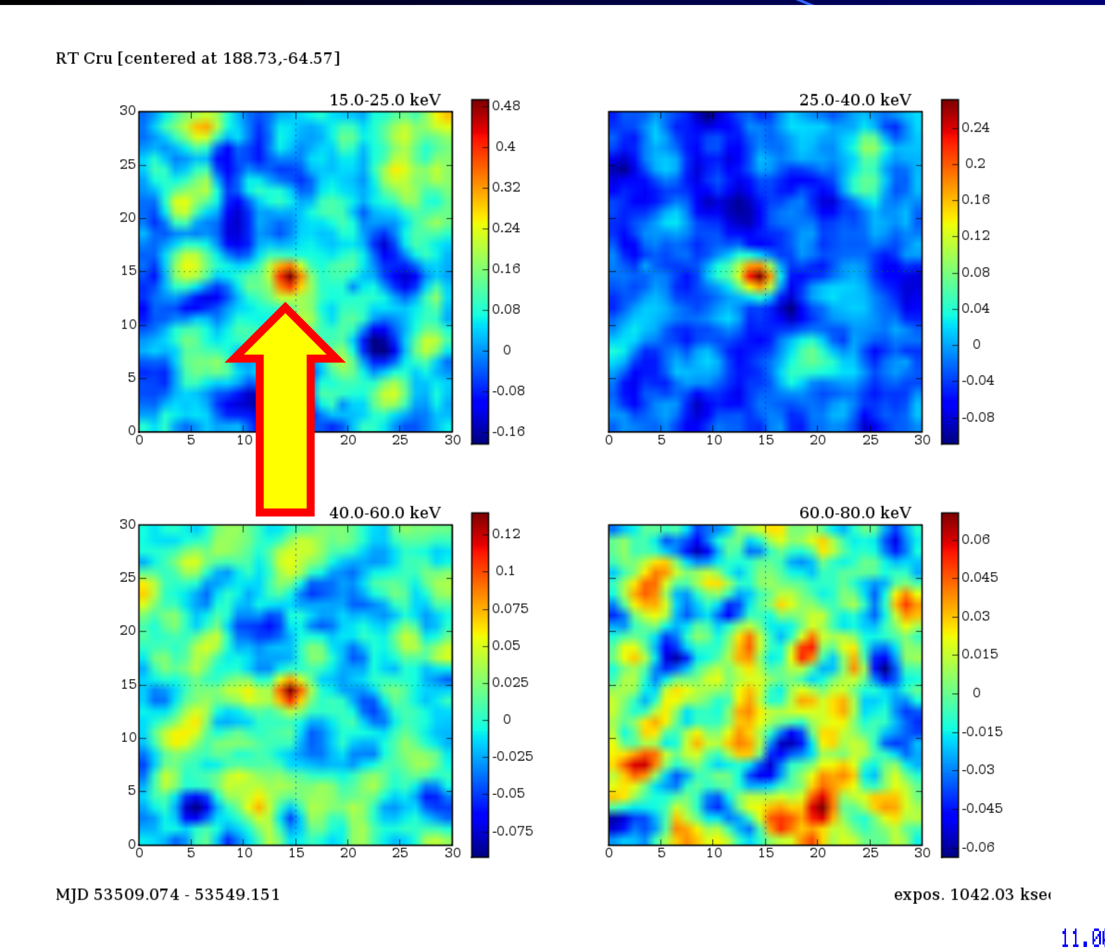
Symbiotic stars as Hard-X-ray emitters seen by INTEGRAL : RT Cru and CD -57 3057 identified with IGR sources (Masetti et al., 2005)



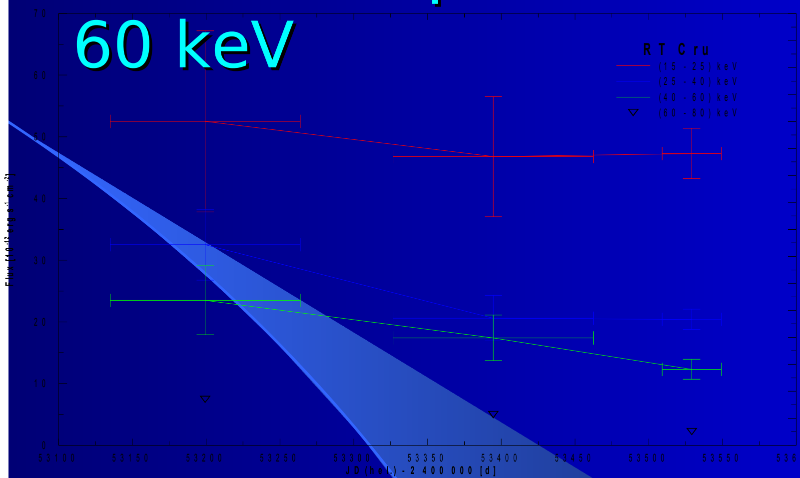
The origin of such hard X-ray emission from these presumably accreting, non-magnetic white dwarfs (WDs) is a mystery.

Possible explanations include: 1) boundary-layer emission from accretion onto a near-Chandrasekhar-mass WD; 2) non-thermal emission from a jet; and 3) emission from an accretion column on a WD not previously recognized as

RT Cru IBIS

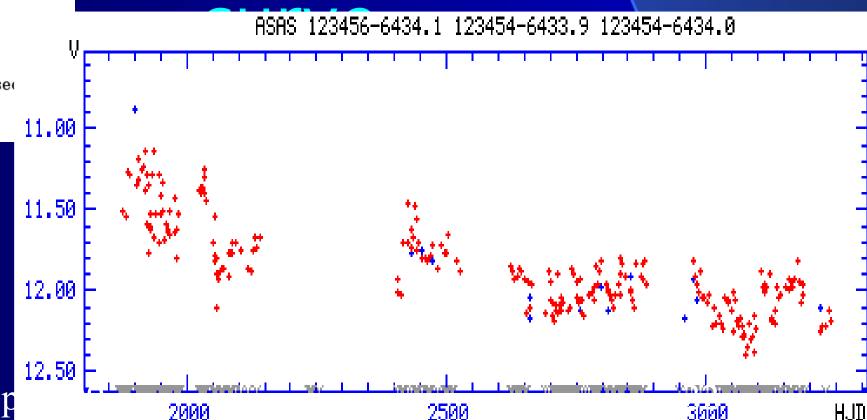


Detected up to 60 keV



IBIS light curve

Optical light



0.5 cts/s 15-25 keV

0.3 cts/s 25-40 keV

0.2 ctss/s 40-60 keV

<0.1 cts/s 60-80 keV

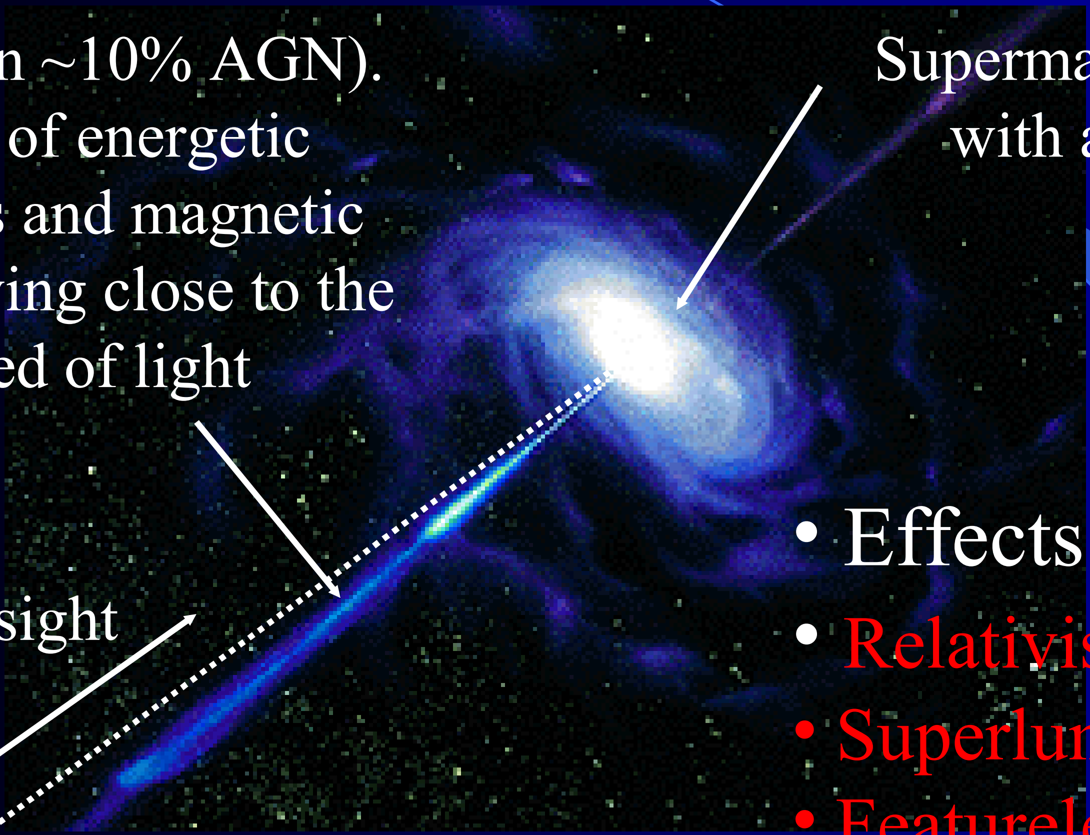
In optical very bright source

mag 11-12

Blazars & their powerful jets

Jet (within ~10% AGN). Beam of energetic particles and magnetic field moving close to the speed of light

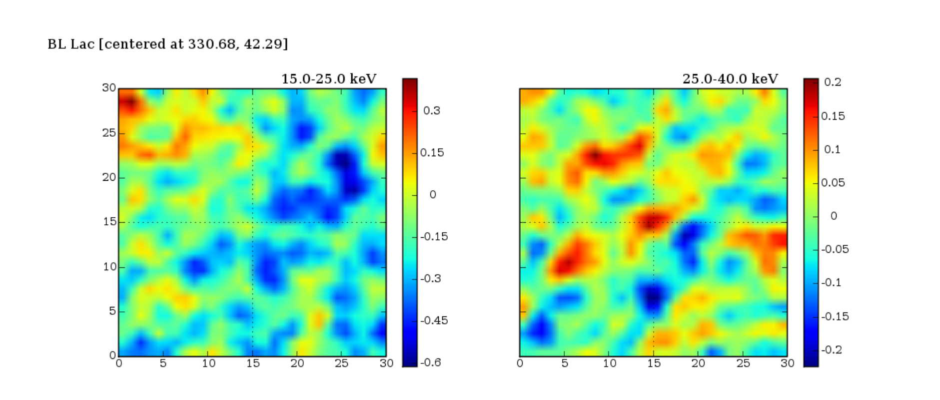
Supermassive black hole with accretion disc



Line of sight

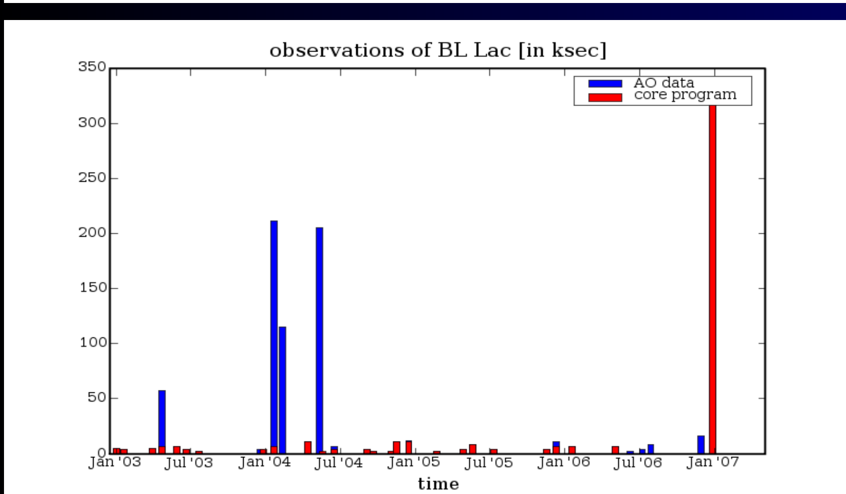
Blazar observer

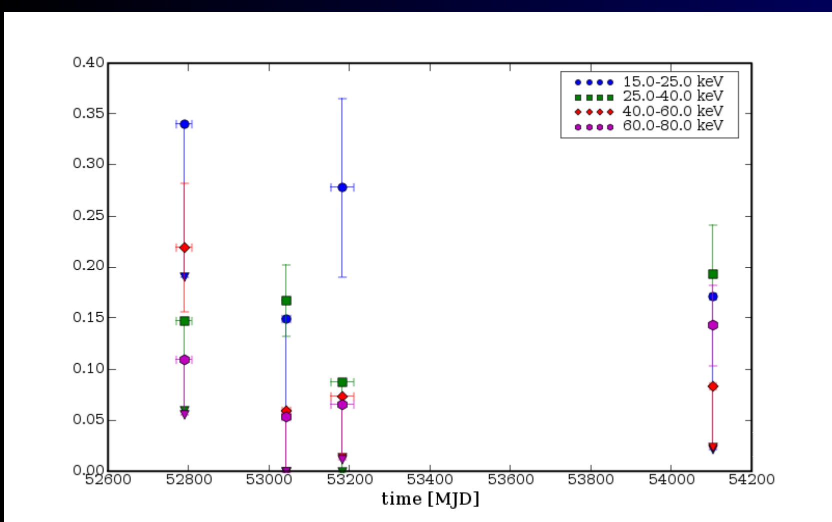
- Effects of the jet:
- Relativistic beaming
- Superluminal motion
- Featureless continuum
- Gamma rays
- Rapid variability
- High luminosity

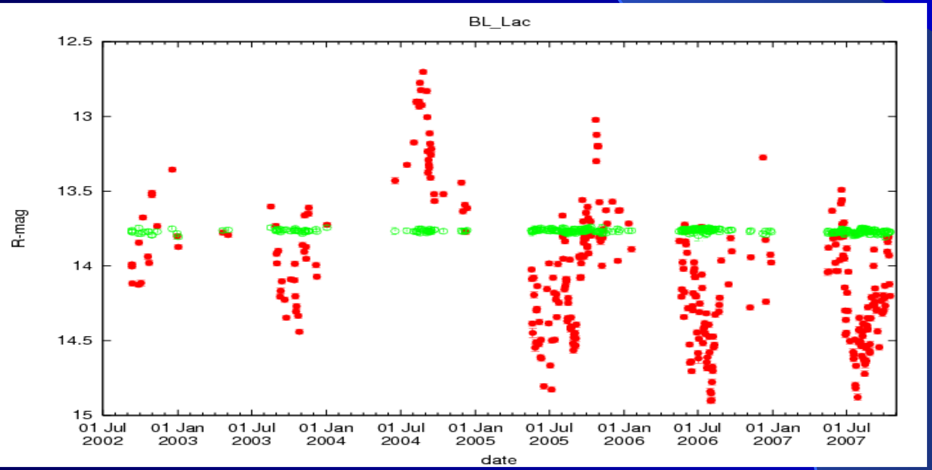


BL Lac

- Composition of Integral public data used
- Light curve IBIS
- Light curve optical



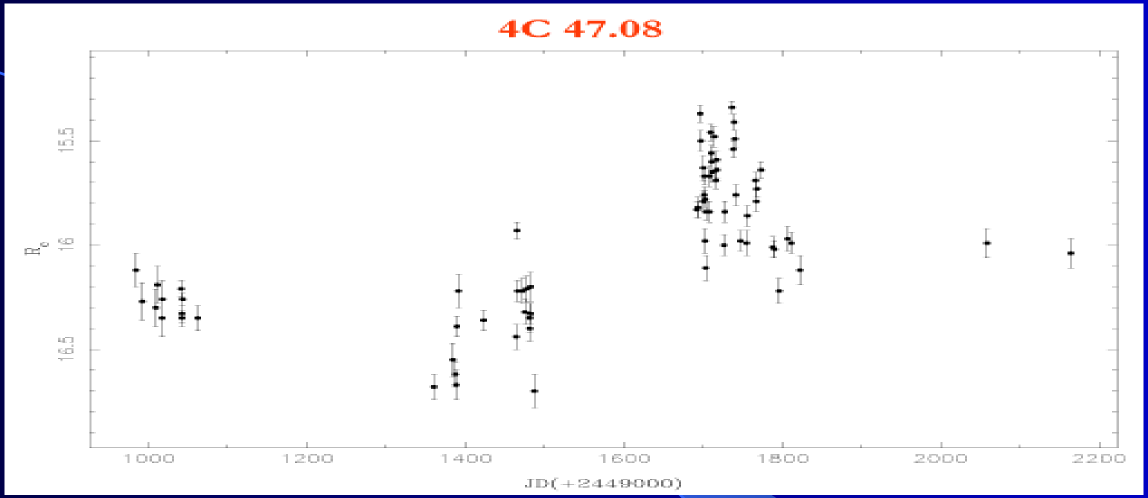




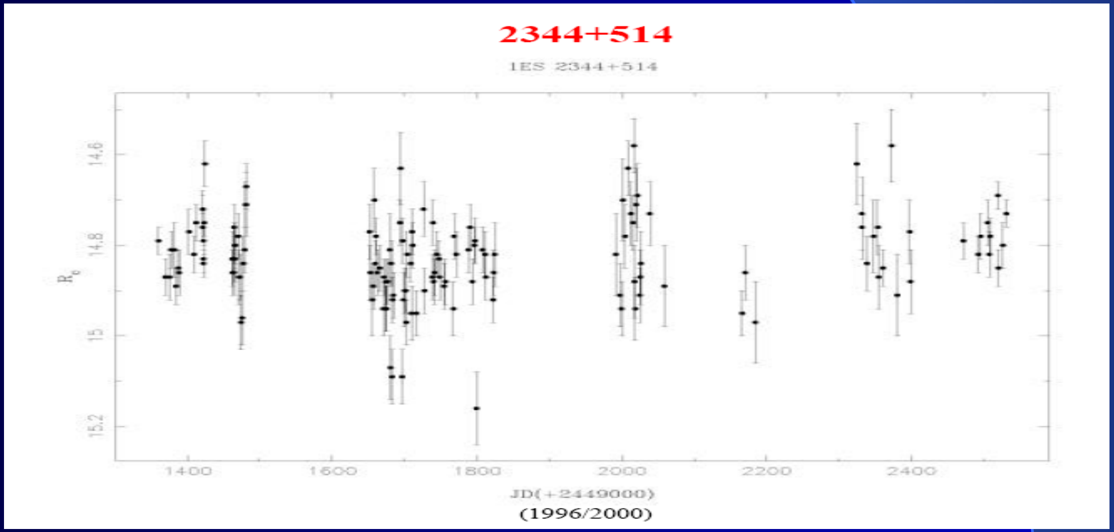
BL Lac is well studied .... but

Most of the GPS blazars are poorly investigated and poorly understood

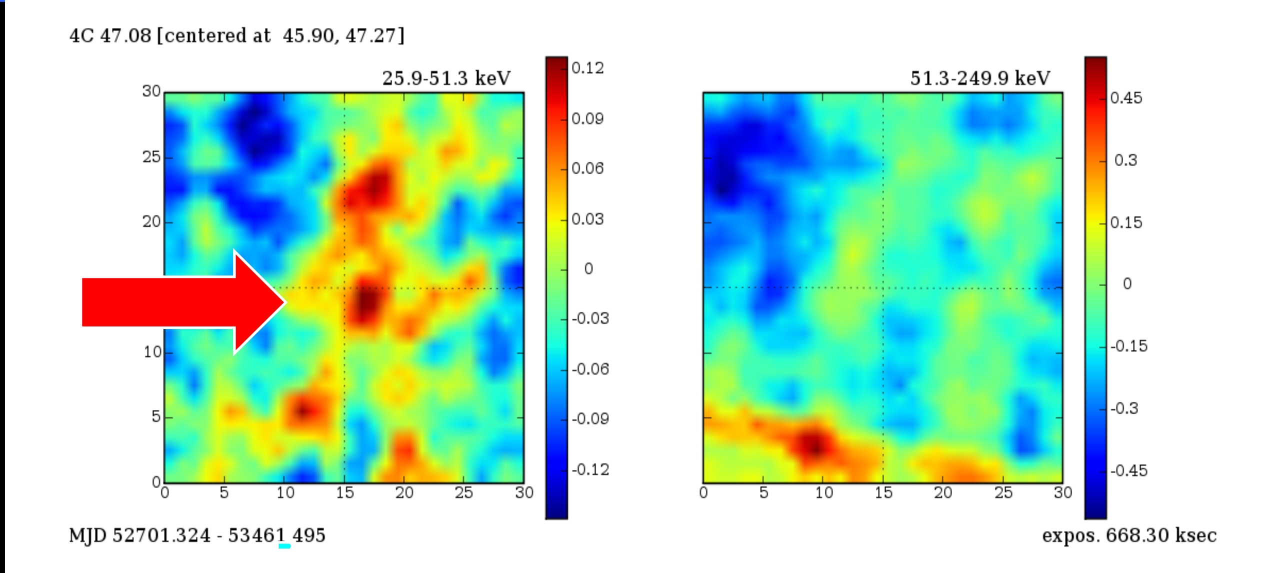
The study with Sonneberg Observatory Archival Plates reveals that most of these objects are optically variable, hence a gamma ray variability can be expected - the LCs may be revealed by RTs



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

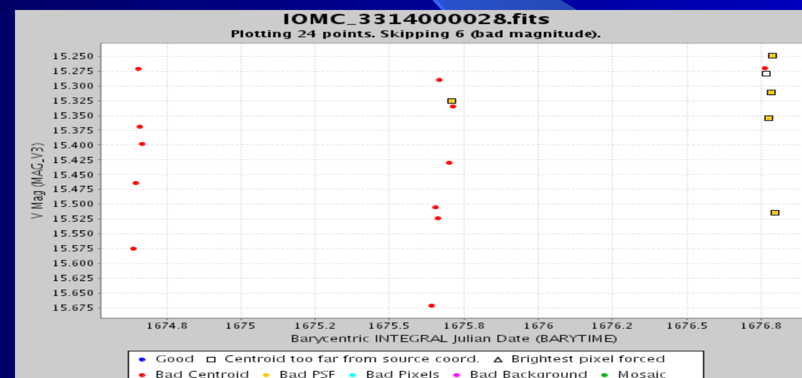


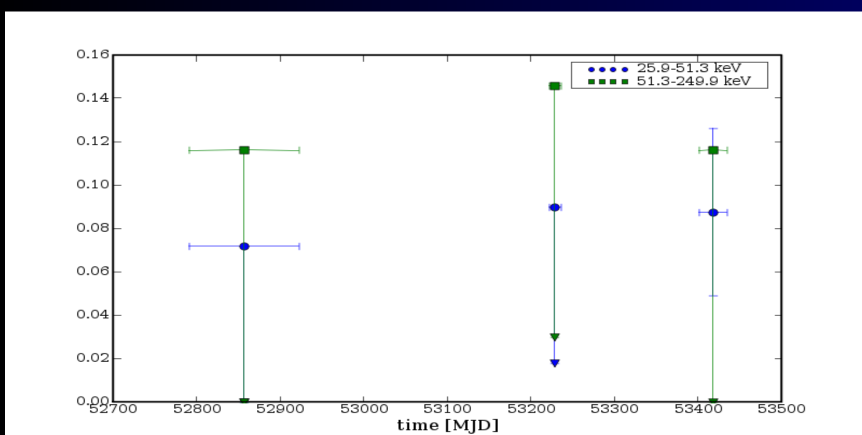
4C47.08 (CP & Public)



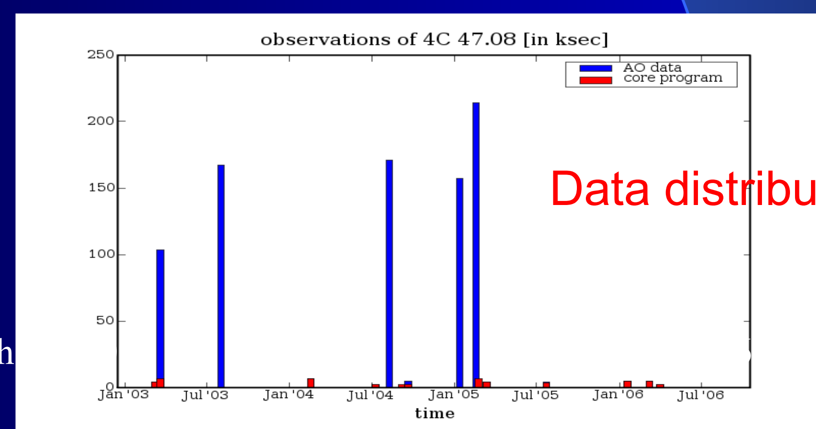
IBIS image

OMC



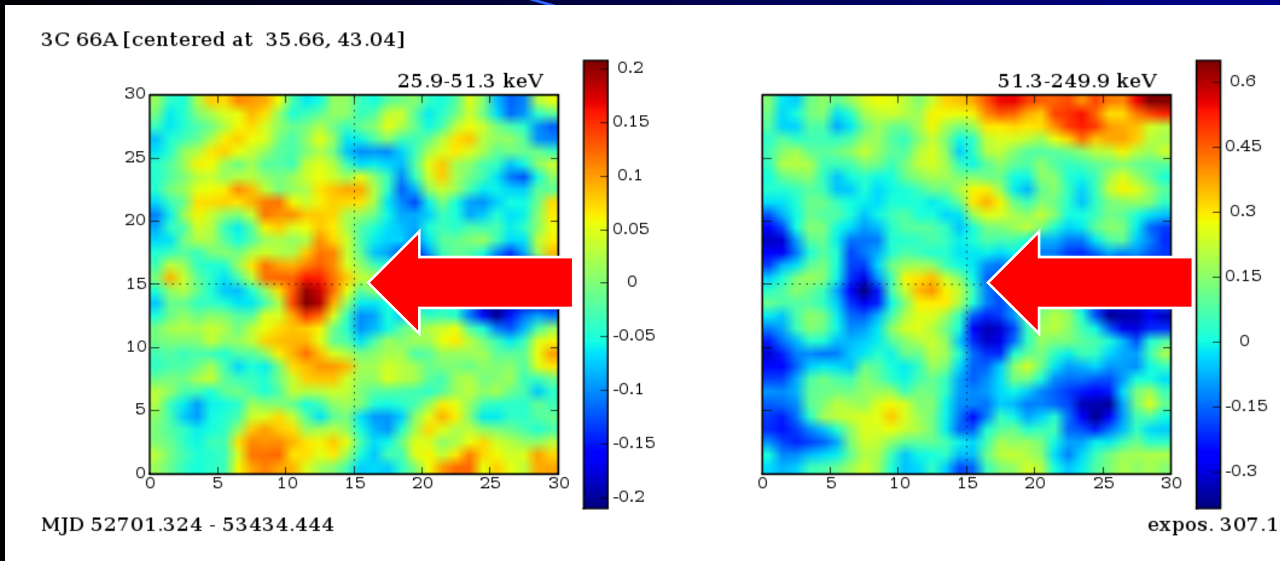


IBIS light curve



Data distribution

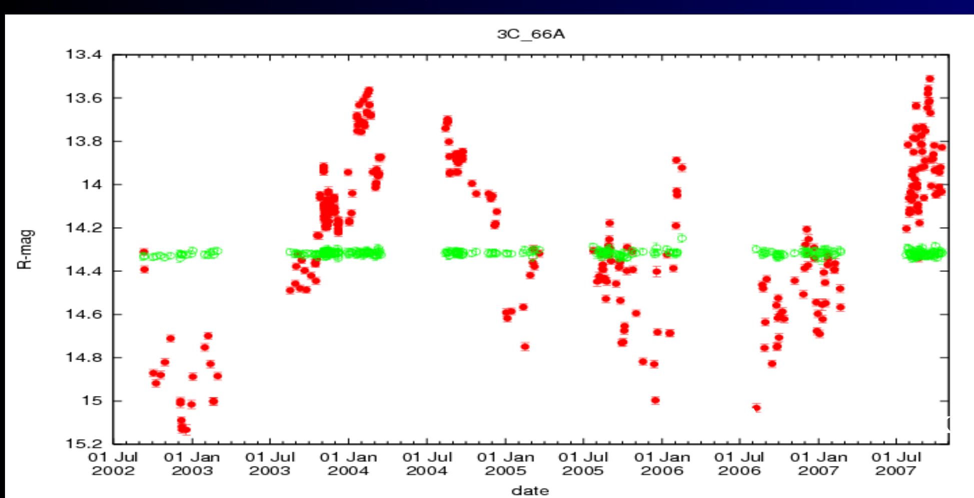
3C 66A

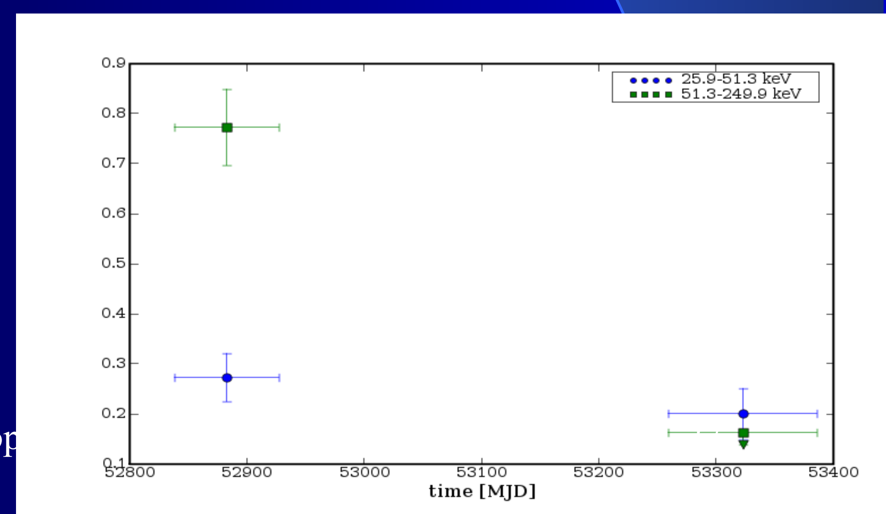


Visible by IBIS only during the optical flare shown below

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





The INTEGRAL AO observation of blazars in outburst

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

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

optical and/or X-ray monitoring (RXTE ASM, others)

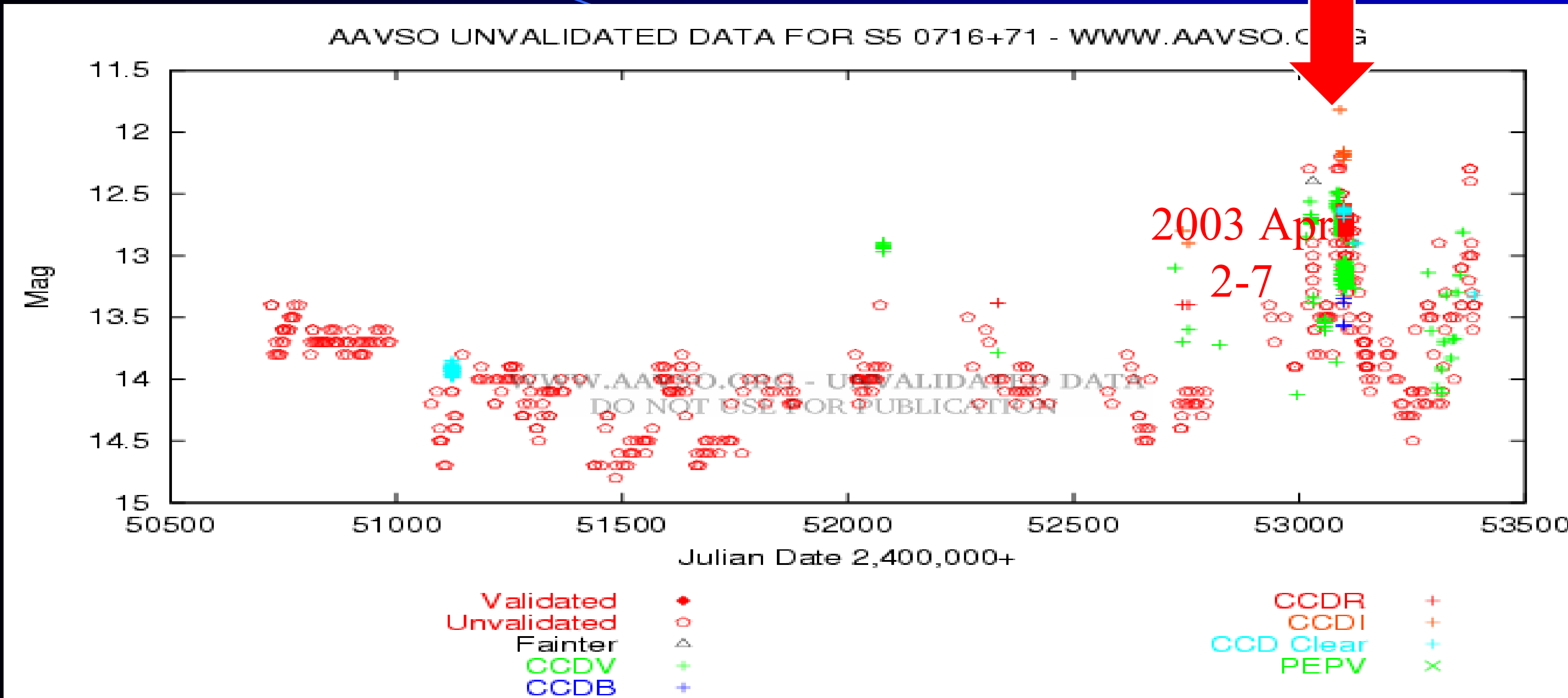
of flaring activity of a large list of blazars

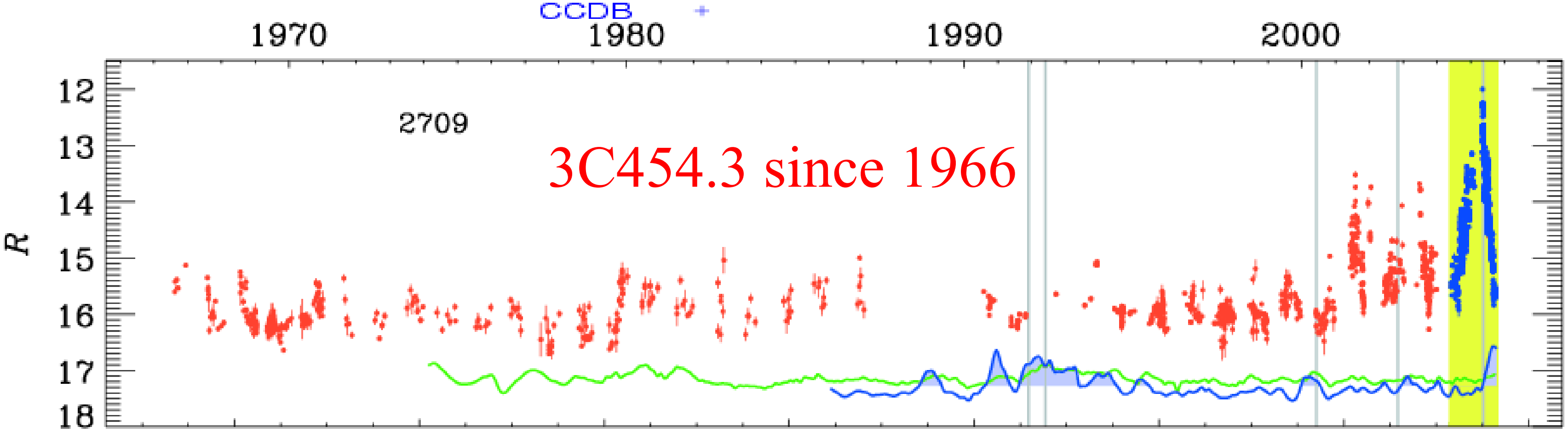
or, alternatively, soft gamma-ray monitoring by INTEGRAL itself (serendipitous detection of a flaring blazar in the IBIS FOV)

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

coordinated with XMM Newton ToO program

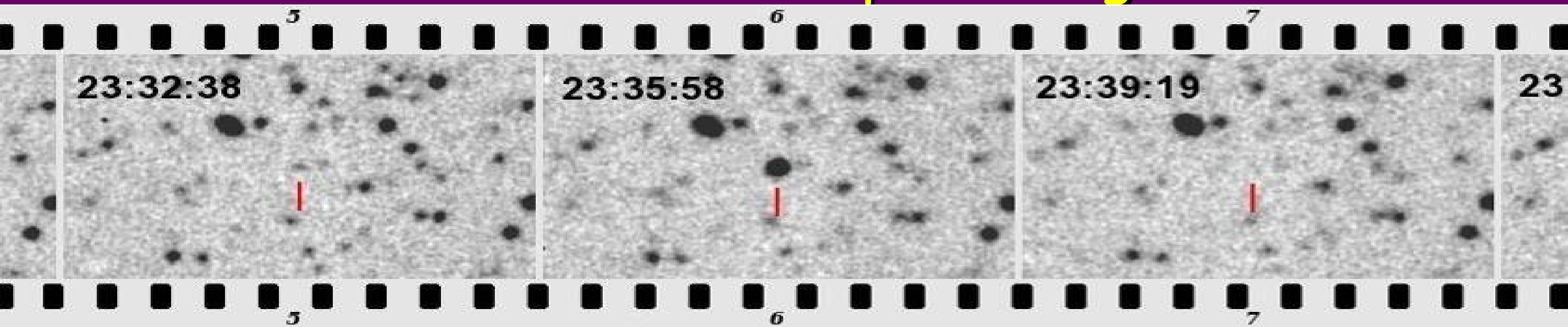
INTEGRAL ToO Observation



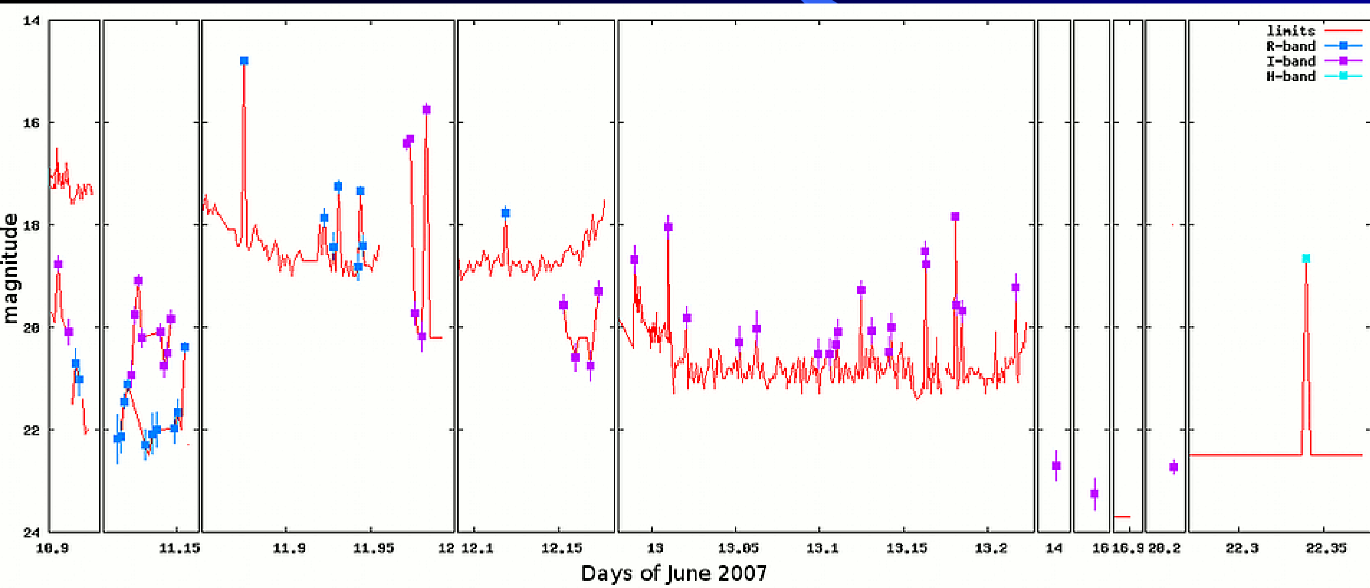


New Types of Optically Variable Objects

GRB 070610: Flares from a peculiar galactic burst



The missing link between magnetars and DINs ?
Castro-Tirado et al, Nature 2008



40 flare episodes
Up to I~16, timescales of ~20sec - 7 min
Amplitudes over 4 magnitudes

A *new* magnifestation of magnetar activity, becoming one of the few hundred Galactic ones becoming active in 10^4 yr

… and what this means for robotic observations

- New type of optical variable object (“star”) manifested
- Short (~1 to 2 mins) intense (up to mag 7) numerous (~40 in 2 days) flares
- Peak magnitude I ~ 14.8 accessible by a digital CCD camera & lens
- Expected recurrence – but cannot be predicted
- Occurs in Galactic plane
- Monitoring of microquasars
- Visible variable sky changes! We can see magnetars but also objects up to billions light years far (naked eye GRBs)

Role 3

- Delivering Supplementary Optical Data for non-HE satellites
- Example: ESA Gaia

Gaia: ESA Mission

Unraveling the chemical and dynamical history of our Galaxy

Albeit focusing on astrometry, Gaia will also provide Spectrophotometry for all objects down to mag 20 over 5 years operation period. Typically 30 to 300 measurements per object Including optical counterparts of HE sources.

Gaia: Complete, Faint, Accurate

	Hipparcos	Gaia
Magnitude limit	12	20 mag
Completeness	7.3 – 9.0	20 mag
Bright limit	0	6 mag
Number of objects	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance	1 kpc	1 Mpc
Quasars	None	5×10^5
Galaxies	None	$10^6 – 10^7$
Accuracy	1 milliarcsec	7 μarcsec at V = 10 10-25 μarcsec at V = 15 300 μarcsec at V = 20
Photometry	2-colour (B and V)	Low-res. spectra to V = 20
Radial velocity	None	15 km/s to V = 16-17
Observing	Pre-selected	Complete and unbiased

- detection and dating of all spectral types and Galactic populations
- detection and characterisation of variability for all spectral types

Payload and Telescope

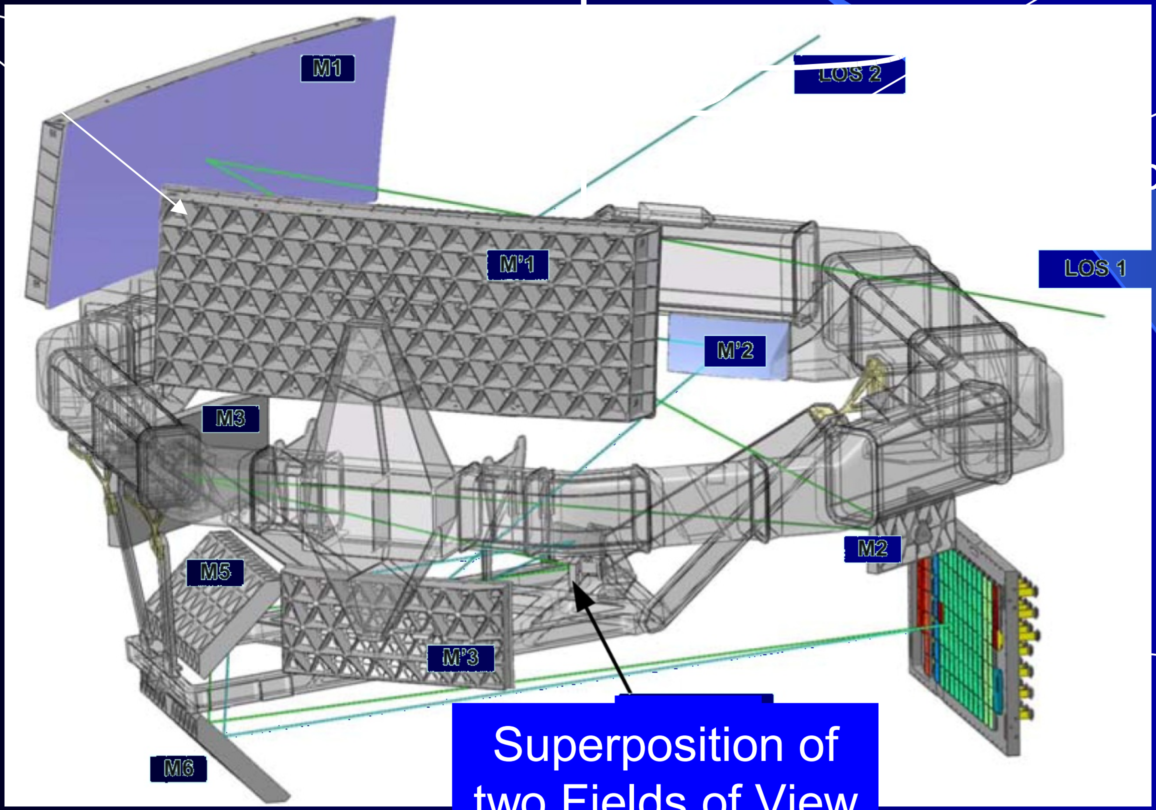
Two SiC primary mirrors
1.45 × 0.50 m² at 106.5°

Rotation axis (6 h)

Basic angle
monitoring system

SiC toroidal
structure
ptical bench)

- ESA-only mission
- Launch date: 2011
- Lifetime: 5 years
- Launcher: Soyuz–Fregat from CSG
- Orbit: L2



Superposition of
two Fields of View
(FoV)

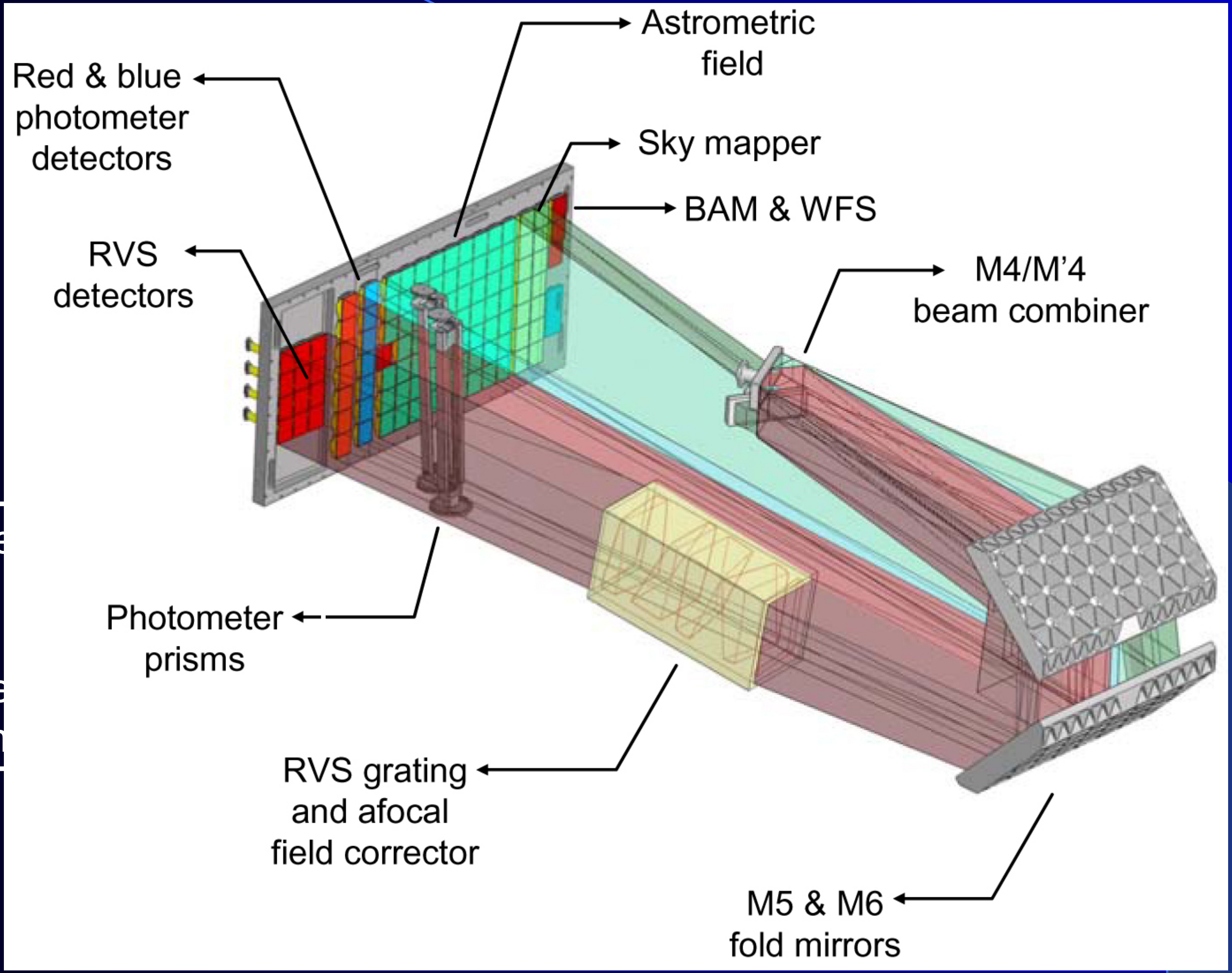
Combined
focal plane
(CCDs)

Figure courtesy EADS-Astrium

Photometry Measurement Concept

Blue photomete
330–680 nm

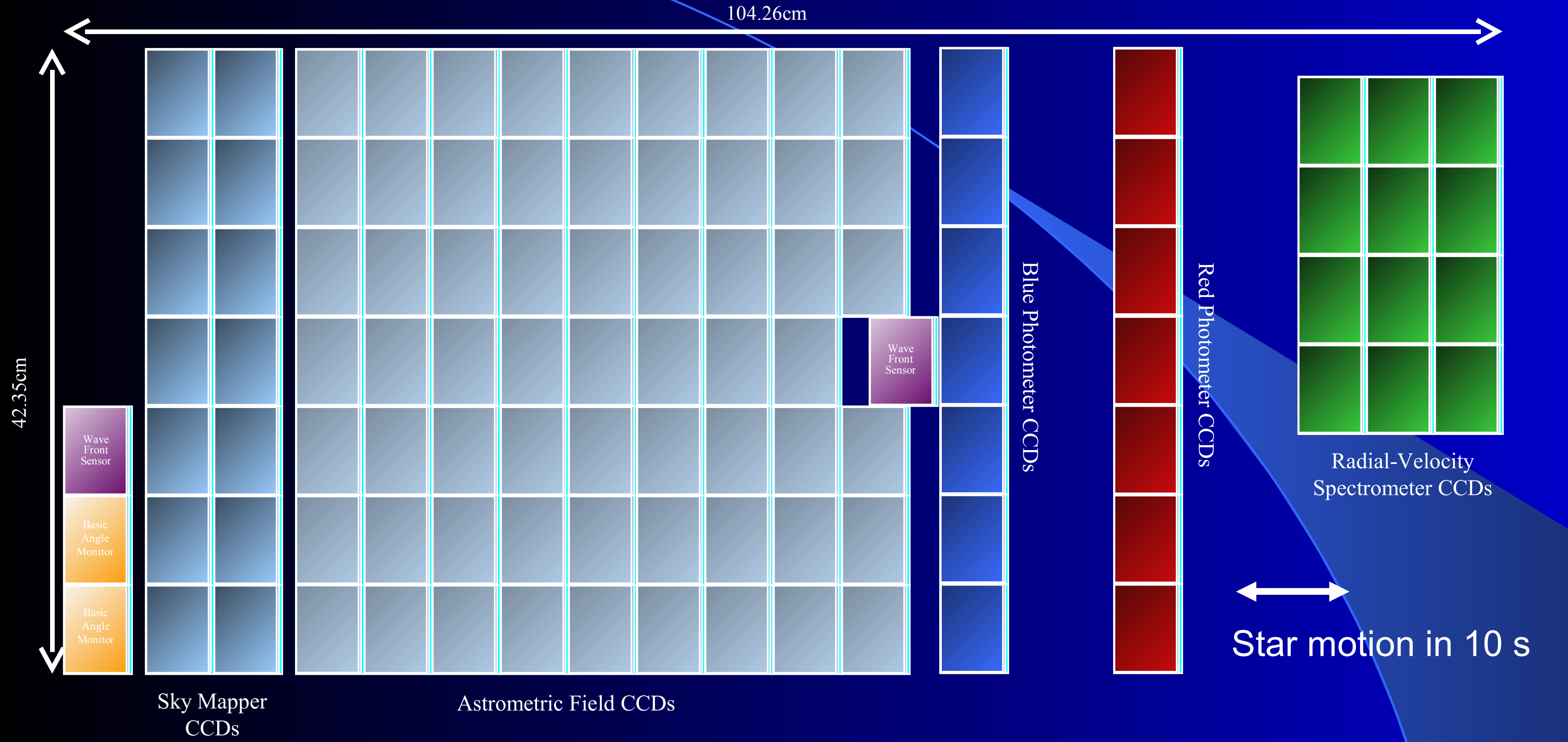
Red photomete
640–1000 nm



Figures courtesy EADS-Astrium

Focal Plane

Figure courtesy Alex Short



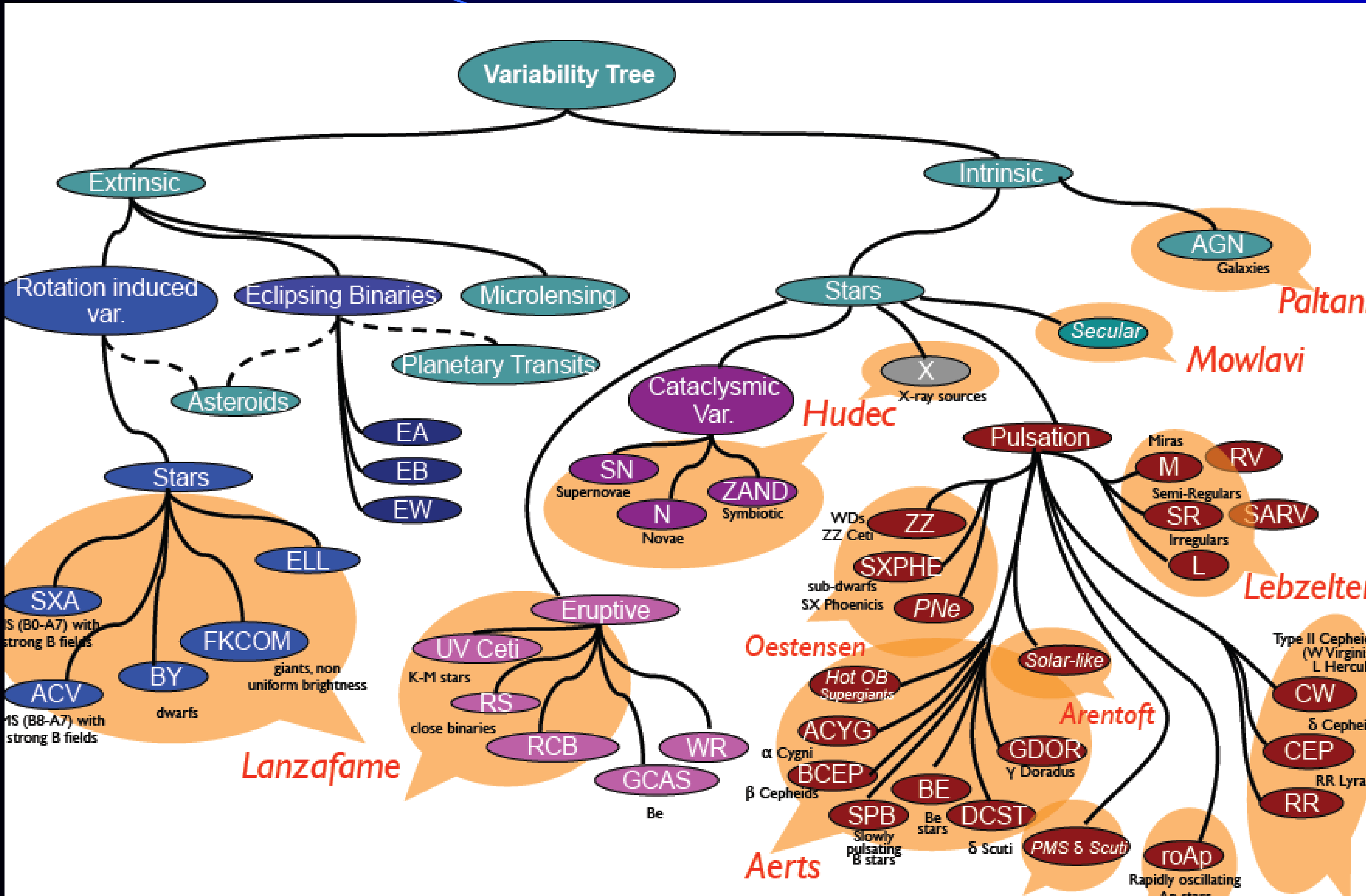
Total field:
- active area: 0.75 deg^2
- CCDs: 14 + 62 + 14 + 12
- 4500 x 1966 pixels (TDI)
- pixel size = 10 µm x 30 µm = 59 mas x 177 mas

Sky mapper:
- detects all objects to 20 mag
- rejects cosmic-ray events
- FoV discrimination

Astrometry:
- total detection noise: 6 e^-

Photometry:
- two-channel photometer
- blue and red CCDs

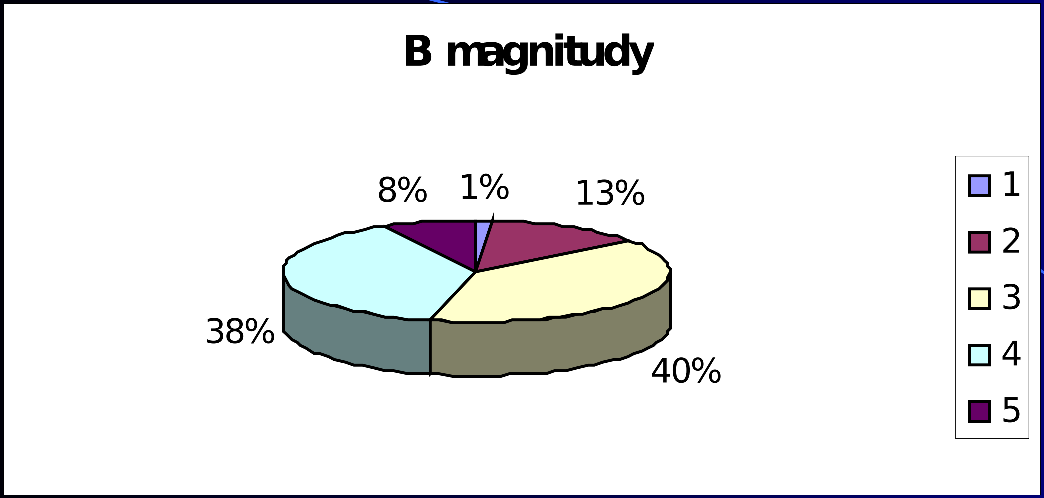
Spectroscopy:
- high-resolution spectra
- red CCDs



- Oestensen mentions compact binaries?

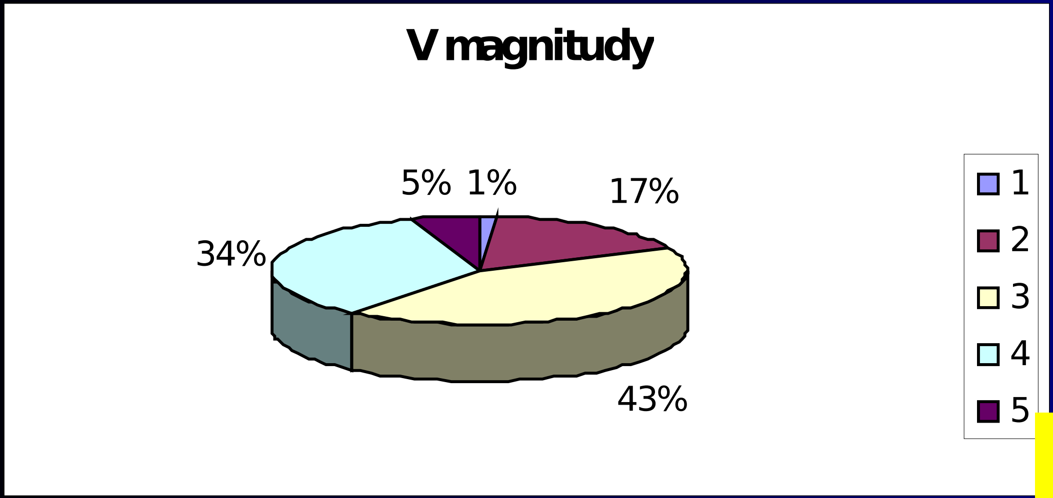
Gaia CU7 Sub-workpackages on Optical Counterparts of High-Energy Sources and on CVs

René Hudec & Collaborator



Even gamma-ray sources do have optical counterparts accessible by Gaia

Legend - B
1 = 2,29 - 5
2 = 5 -10
3 = 10 - 15
4 = 15 - 20
5 = 20 - 23



Legend - V
1 = 2,39 - 5
2 = 5 -10
3 = 10 - 15
4 = 15 - 20
5 = 20 - 21

>90% accessible with Gaia

Optical B and V magnitudes of optically identified INTEGRAL gamma-ray sources ... most are brighter than mag 20, and more than half are brighter than mag 15

Some examples

- LMXRB
- HMXRB
- Optical Afterglows and Optical Transients of GRB

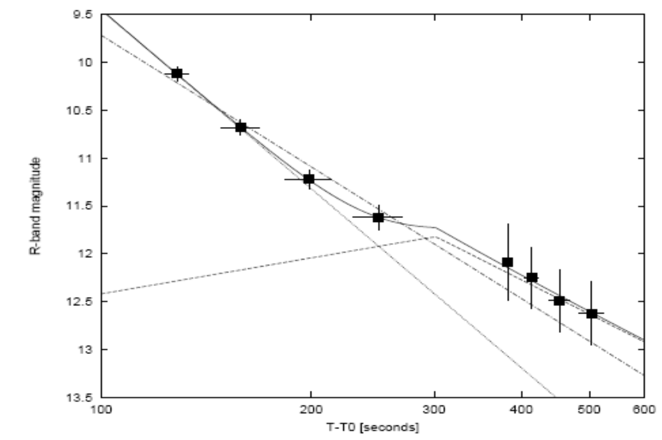


Fig. 3. The R-band afterglow lightcurve of GRB 060117. The lightcurve is fitted as a superposition of reverse shock (dotted line) and forward shock (dashed line). The linear fit is plotted by a dot-and-dash line.

Optical LC of OT of GRB060116, Jelinek et al. 2006

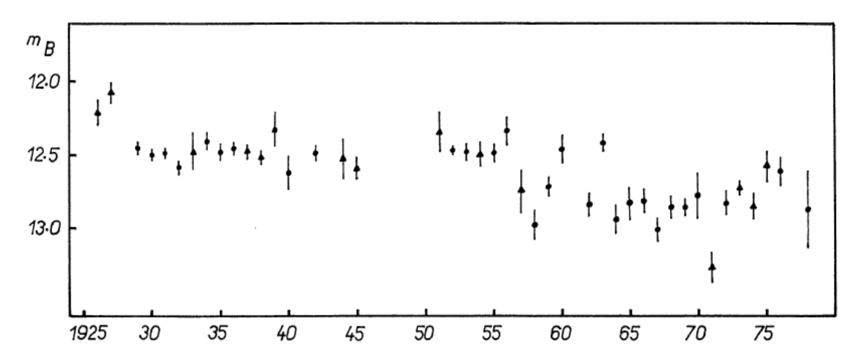


Fig. 3. Annual mean values of the V 818 Sco system. Error bars show the standard deviation of the mean.

Long-term optical changes of Sco X-1/V818 Sco, Hudec 1981

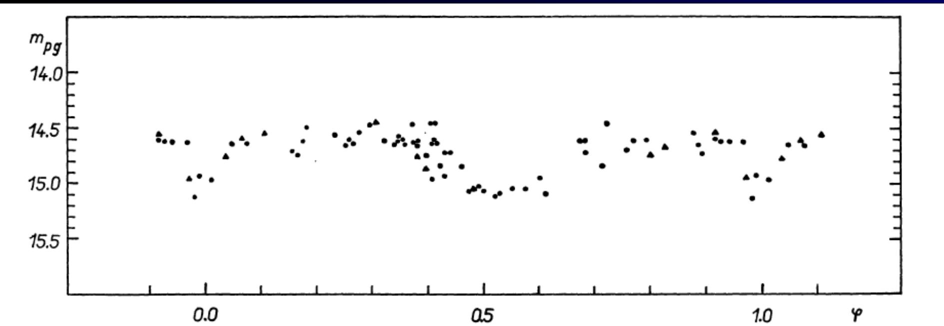


Fig. 9. The inactive state light curve of HZ Her. The circles = J. D. 242 8630 ... 9789, the triangles = J. D. 242 7543 ... 7657.

Inactive state optical LC of Her X-1/HZ Her, Hudec and Wenzel 1976

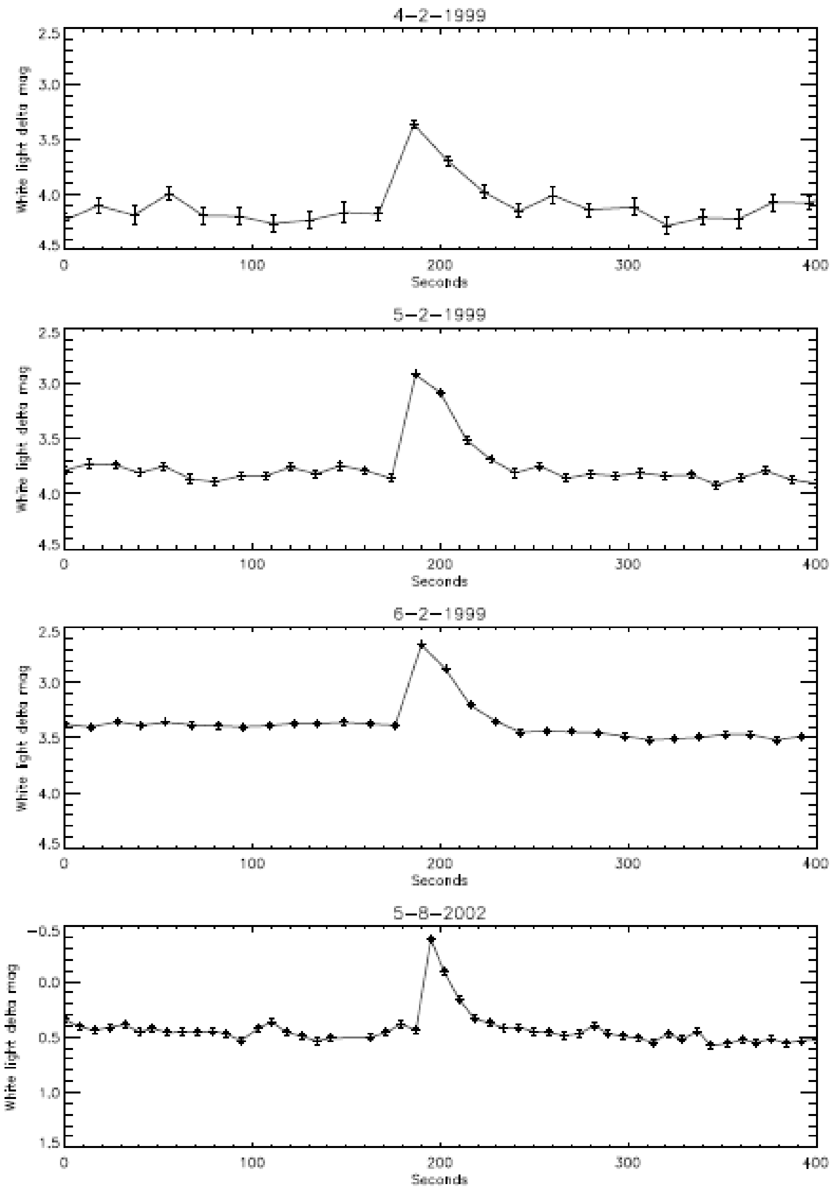


Fig. 1. Optical bursts in the light curves of UW CrB.

Rapidly evolving light curves of some LMXRB, Muhli et al., 2004

Thermonuclear bursts related to NS?

Gaia: Optically faint LMXB often suffer by poor optical coverage/analyses, especially on long-term time scales. Here can Gaia provide important inputs.

RT support for Gaia:

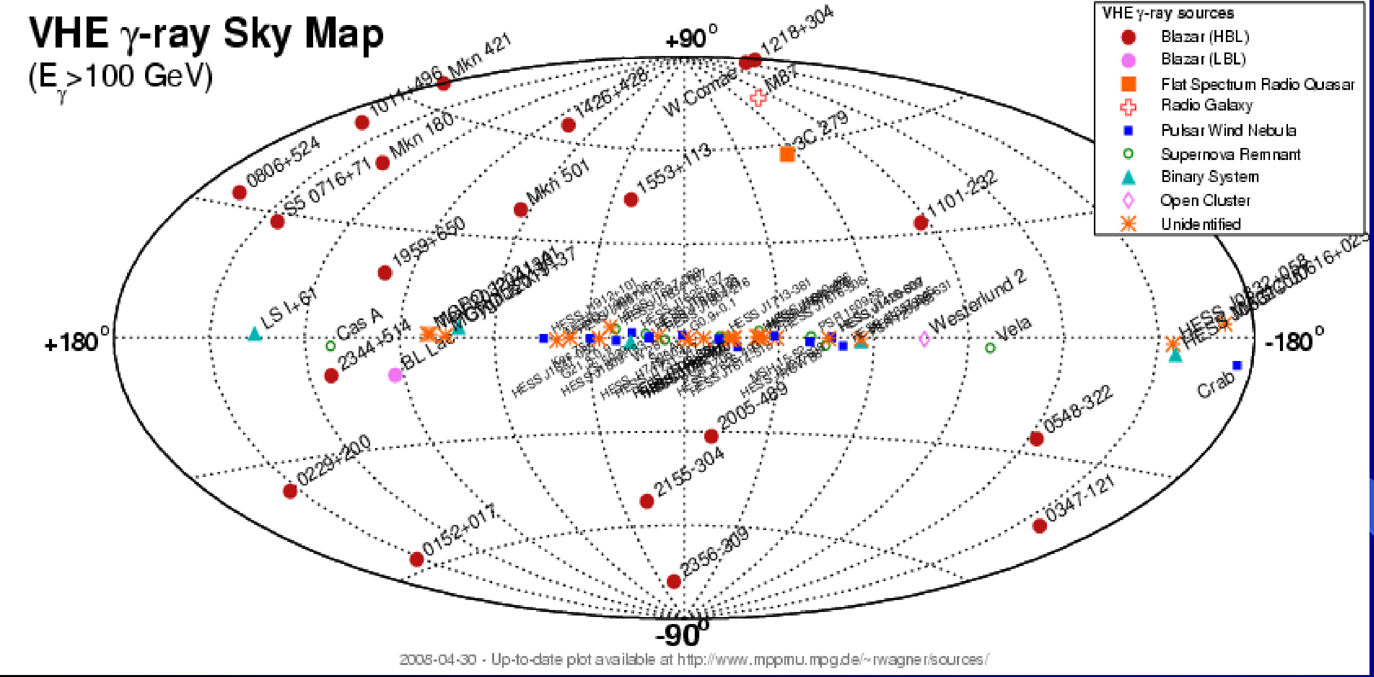
Supplementary ground-based observations

Involved: BART. BOOTES, FRAM, …

Goal: 1. To confirms events found by satellite 2. To deliver supplementary photometric data (better sampling)

Role 4

- Delivering Supplementary Optical Data for CTA
- The CTA Cerenkov Telescope Array, albeit not being a satellite, is in many aspects similar to satellite projects (see also CTA effort at ISDC)
- Need robotic monitoring of VHE sources, and alert system for TeV flaring triggers



The VHE Sky

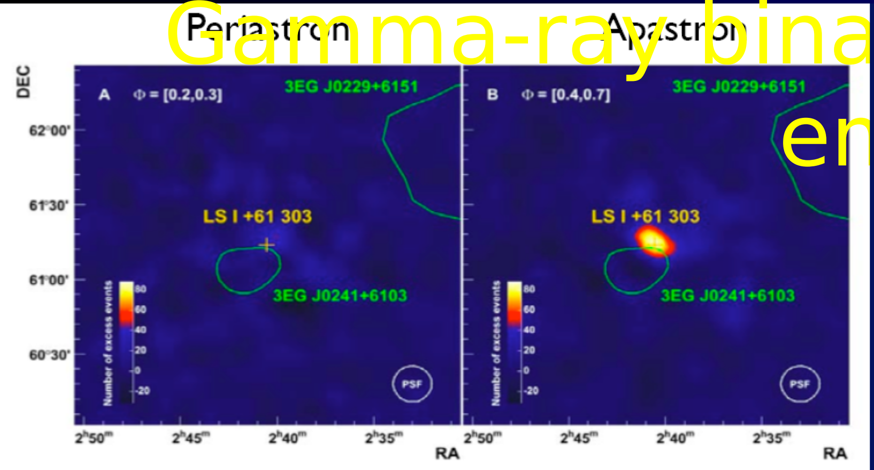
….. and some optical magnitudes

LSI +61 303	mag_v 10
HESS J0632+058	mag_v 9.08
Centaurus X3	mag_v 13.2
PSR B1259-63	mag_v 10.6
HESS J1747-281	mag_v 9.25
HESS J1825-137	mag_v 11.4
LS 5039	mag_v 11.23

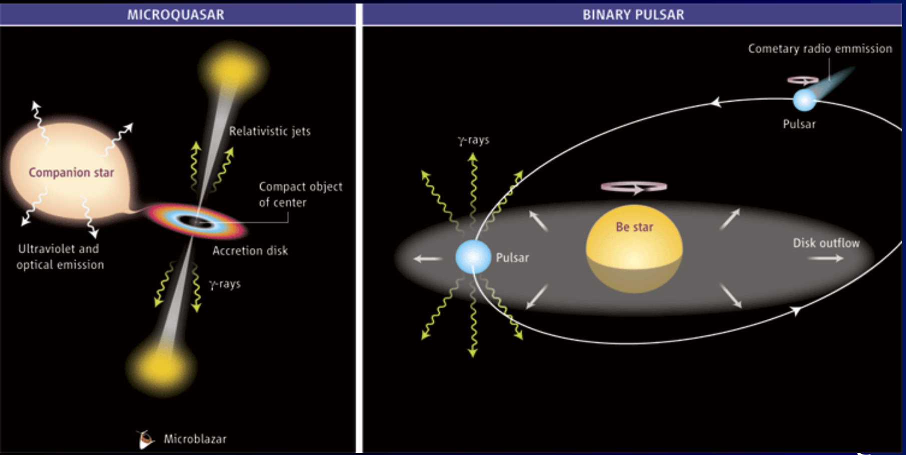
The VHE sky is dominated by objects which are (in many cases) also sources of optical emission

LSI +61 303: TeV source, optical mag 10

Gamma-ray bina … en



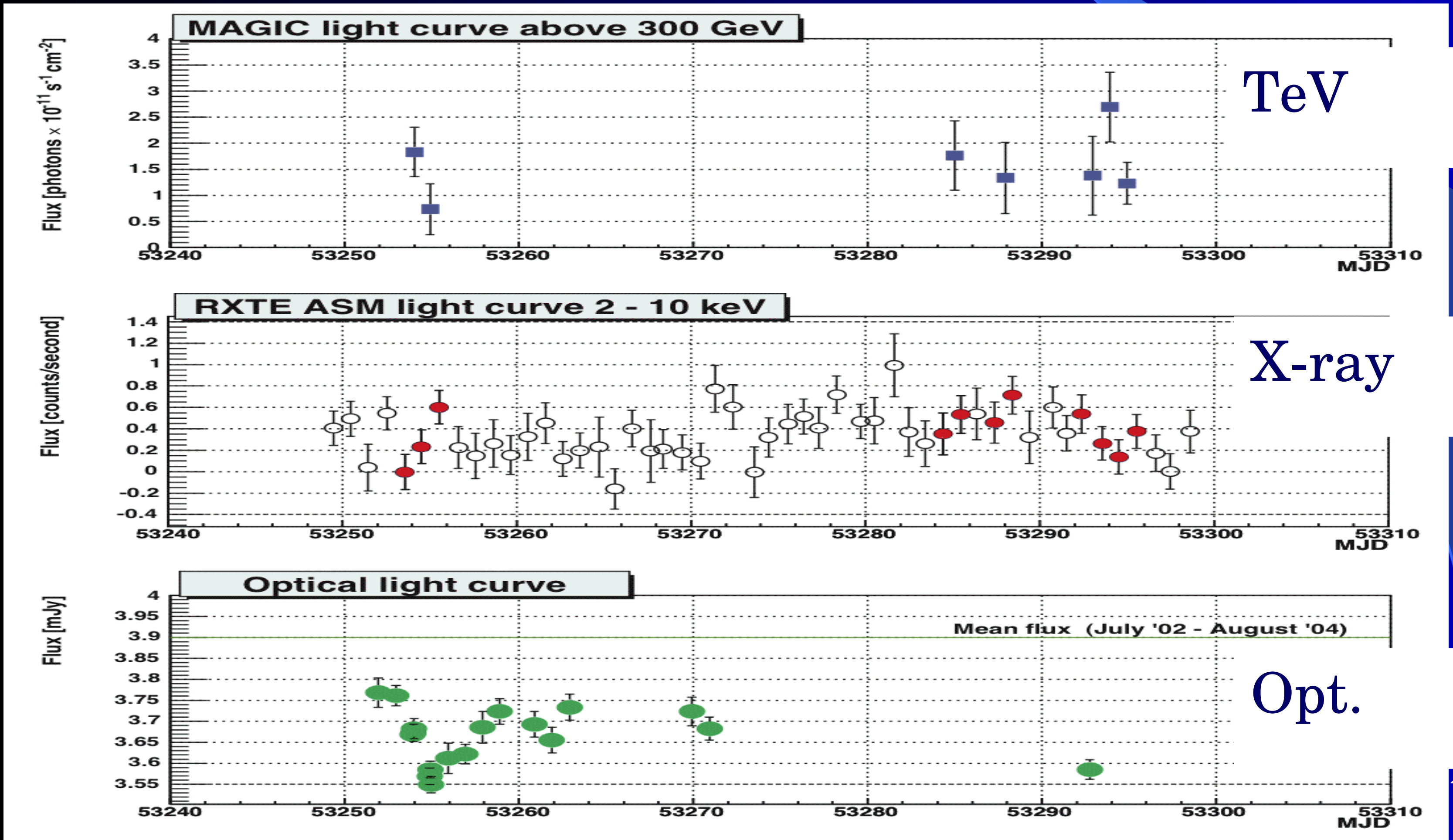
MAGIC images of LS I +61 303 showing time variability, astro-ph/0605549



- High Mass x-ray binary at a distance of 2 kpc
- Optical companion is a B0 Ve star of 10.7 mag with a circumstellar disc
- Compact object probably a neutron star
- High eccentricity or the orbit (0.7)
- Modulation of the emission from radio to x-rays with period 26.5 days attributed to orbital period
- Secondary modulation of period 4 years attributed to changes in the Be star equatorial disc

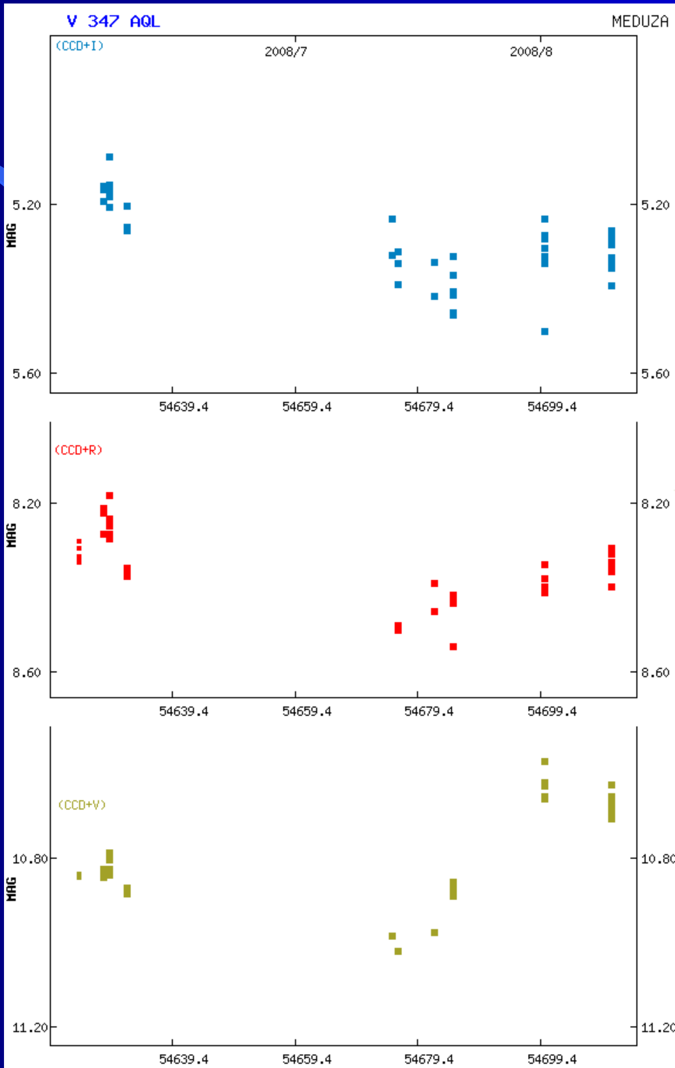
1ES1959+650(z=0.047)

- Blazar famous for the orphan flare in 2002
- MAGIC: Significant signal in only 6h of effective obs. time ApJ, 639 (2006), 761



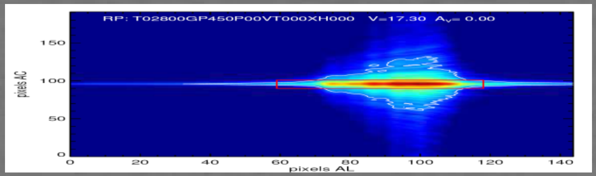
Unknown Discoveries

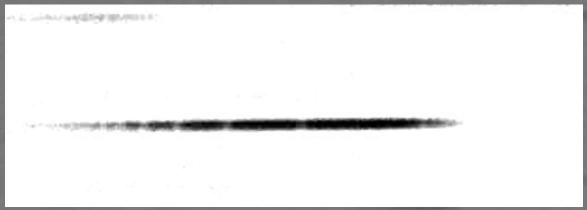
- Puzzling poorly investigated Variable stars at positions of UHE sources
- the variable M6 star V* V347 Aql,   with coordinates J2000.0 ICRS position of RA=19h08m01.3s, DEC=+06d18'27 B 11.5 mag
- Within the error box of the new VHE source HESS J1908+063
- T Tauri star?
- Oxygen rich irregular variable? IRAS source
- LC unknown …… object at B 11 ….. Good target for optical monitoring and investigations by RTs



Note

- The role of focal devices: a spectral alternative





Simulated low dispersion Gaia spectrum

Real low dispersion spectrum from digitised Schmidt spectral plate

Digitized spectral Schmidt telescope plate, Sonneberg Observatory

Spectral Type Variability of Cepheids, Miras & Peculiar Stars

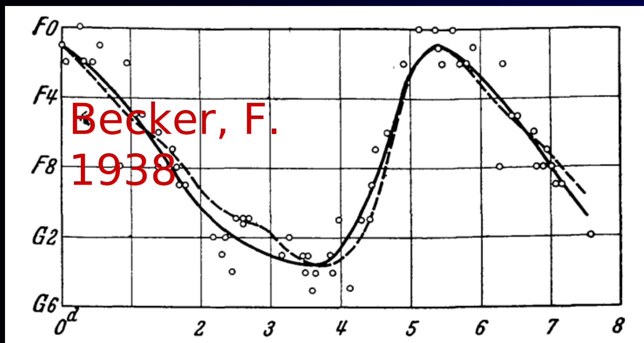


Abb. 1. Mittlere Spektralkurve und visuelle Lichtkurve (gestrichelt) von δ Cephei.

All classical Cepheids definitely vary their spectral types. At maximum, they all have types around F5-F8. At minimum, the longer the period, the later is the spectral type (to K2) (Samus, 2008)

Spectral ty
changes o
peculiar
stars: FG
Sagittae
changed its
spectral typ
from B to M
(Chalonge
al 1977)

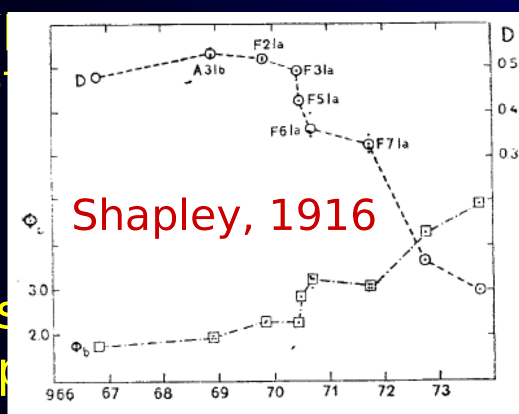
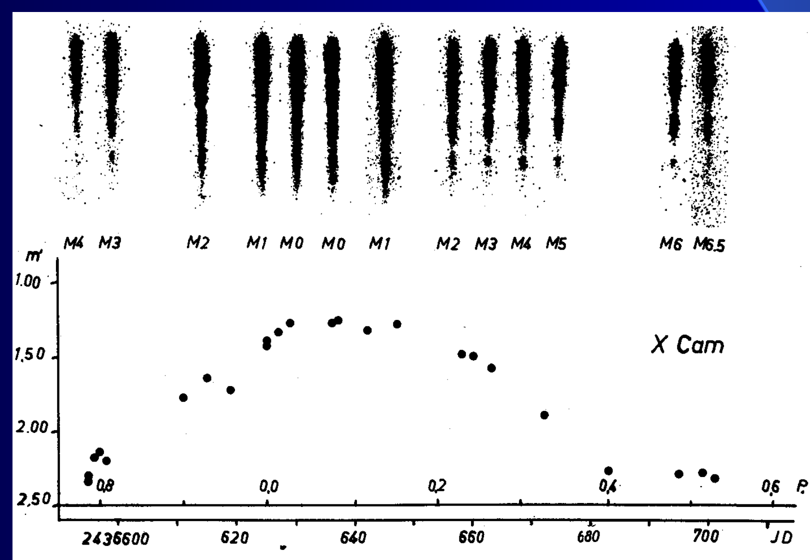


Fig. 1. D and Φ_b as a function of time. The corresponding BCD spectral types are indicated. The 1966 values are from Roark, 1968. Small black dots: individual measurements.



Jarzebowski, 1959 X Cam

MiraVariable

Spectral Variations M0 to M6.5

Amplitude 1.4 mag in R

Conclusions

- The HEA objects in many cases exhibit optical (and variable emission) accessible by ground based RTs
- The optical data are important for multispectral analyses of the sources
- Despite of many RTs available there is still lack of optical LCs for satellite triggers
- Even small apertures may contribute as some sources are brighter than mag 12
- The RTs play a important role even in satellite projects
- in visible light (Gaia)
- Not just photometry but also low dispersion spectroscopy is important

The End