INTEGRAL Observations of Cataclysmic Variables and Related Objects

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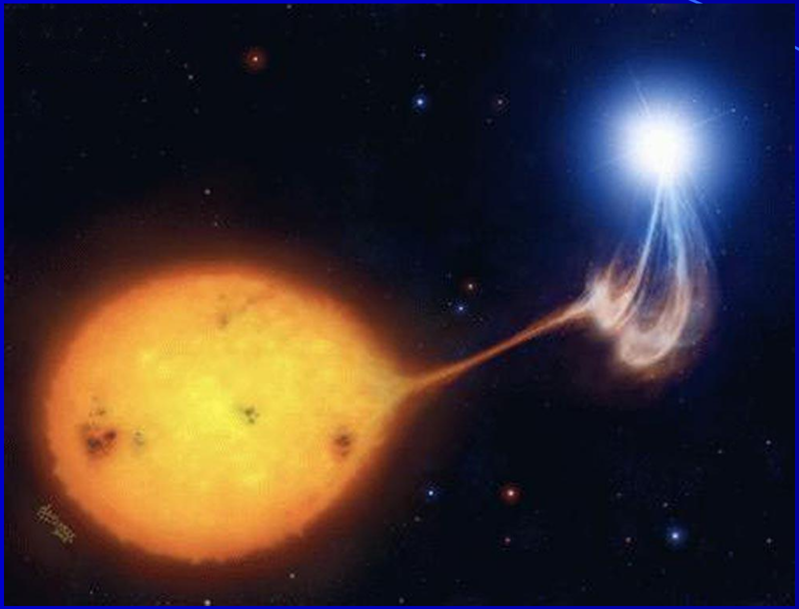
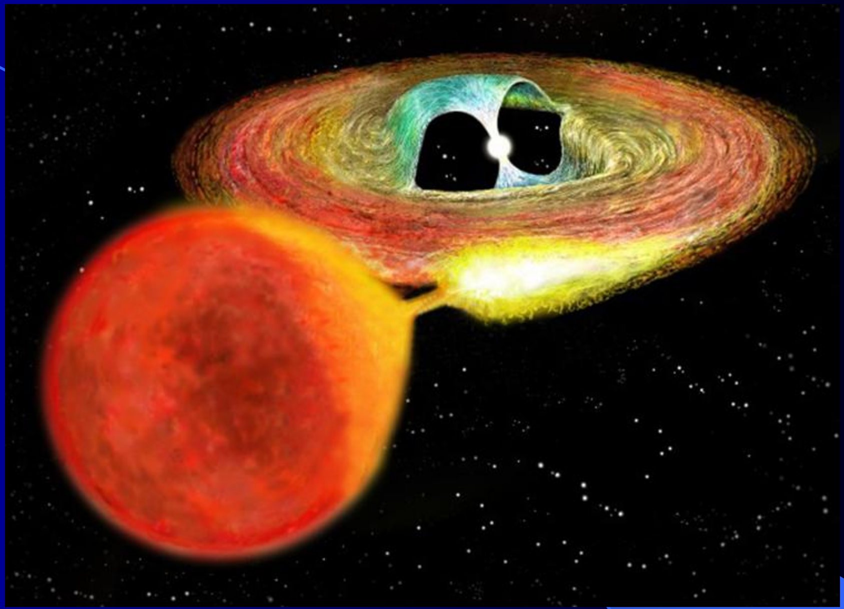
Cataclysmic variables (CVs)

- CVs are close binary systems of a hot white dwarf (WD) and red MS star of spectral type M or K, which fills the volume of its inner Roche lobe and transfers matter to the vicinity of the WD.
- According to strength of WD magnetic field this matter is creating a accretion disk or follows magnetic lines and falls to surface of the WD (polars and intermediate polars (IPs)).
- In IPs, the WD magnetic field (10^6 – 10^7 G) is not strong enough to disrupt disc entirely and simply truncates the inner part of disc. An accretion flow is channelled down towards the magnetic poles and onto the WD surface.

Detected CVs

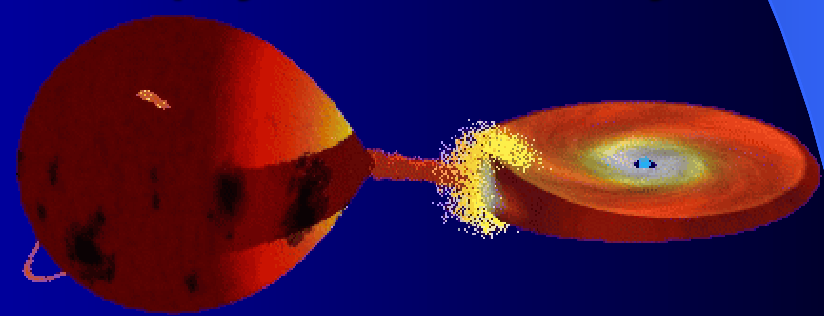
GCVS Name	RA (2000)	DEC (2000)	Object Type
IGR J00234+6141	00:22:57.63	+61:41:07.8	dq
V709 Cas	00:28:48.84	+59:17:22.3	dq
XY Ari	02:56:08.10	+19:26:34.0	dq
GK Per	03:31:12.01	+43:54:15.4	na/dq
V1062 Tau	05:02:27.47	+24:45:23.4	dq
TV Col	05:29:25.52	-32:49:04.0	dq
IGR J05346-5759	05:34:50.60	-58:01:40.7	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 (up to 80 keV): more than expected

More CVs may be among non-classified IGR sources

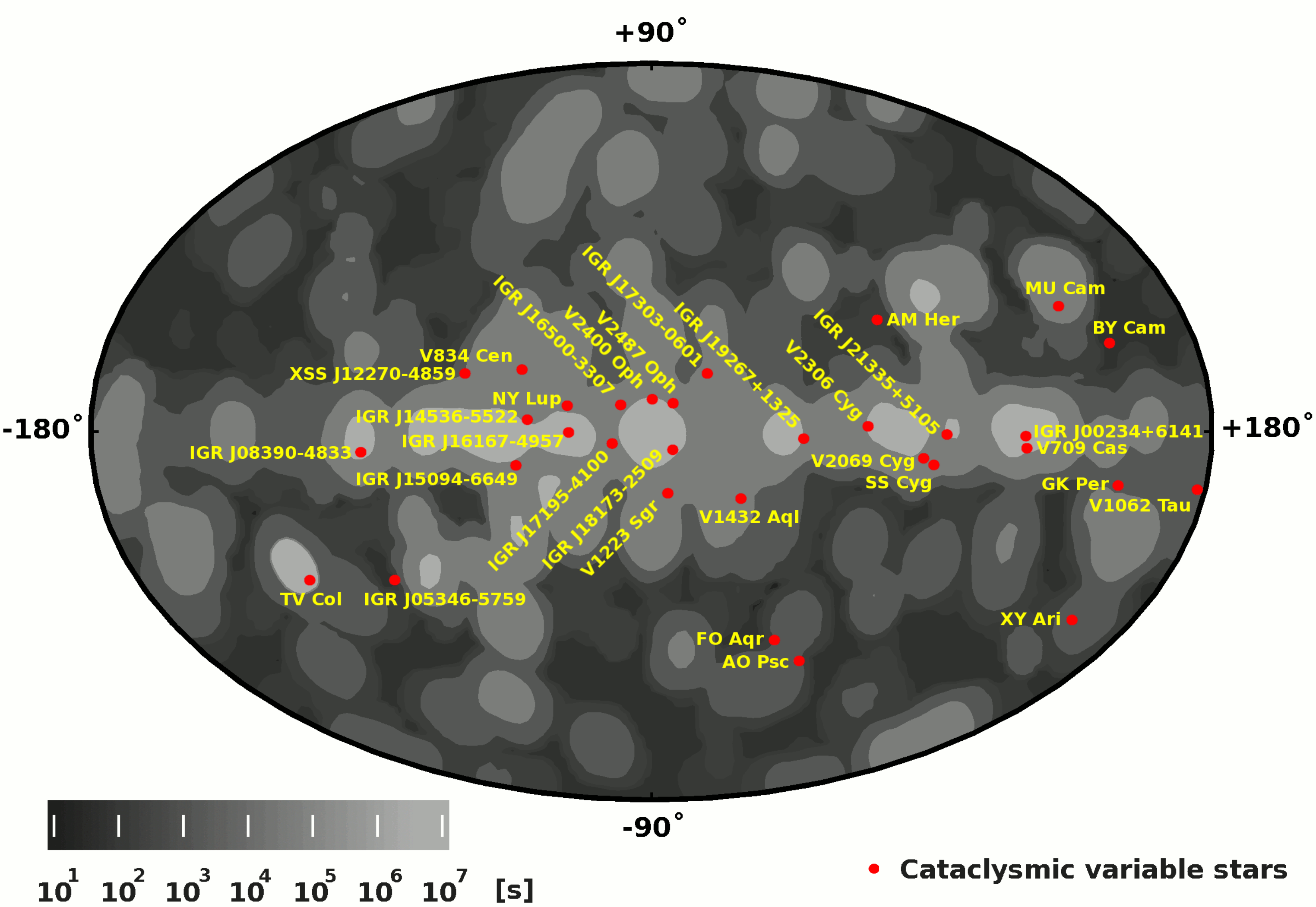
CVs may contribute to galactic X-ray diffuse emission

Cataclysmic Variables as Astrophysical Laboratory



R. Hudec delegated scientist (R_Sci) responsible for this group for the INTEGRAL community

Preview of 32 CVs observed by INTEGRAL – INTEGRAL IBIS sky coverage (up to March 2009)



X-ray emission of IPs

- When material impacts the atmosphere of the WD, a shock will form and hard X-ray/soft gamma-ray emission will result from thermal bremsstrahlung cooling by free electrons in the hot post-shock region (PSR) with kT ≈ 10s of keV.
- In hard X-rays, IPs are more luminous (up to the factor of 10) than polars. It is assumed that, in the strongly magnetized ($B \geq 10^7$ G) polar systems, cyclotron cooling is an important mechanism to suppress the bremsstrahlung high temperature emission.
- IPs have been recently proposed to be the dominant X-ray source population detected near the Galactic center (Ruiter et al. 2006). IPs also contribute significantly to the X-ray diffuse Galactic ridge emission (Revnivtsev et al. 2006, Revnivtsev et al. 2008).

The summary of CV observations/detections by INTEGRAL

In total, 32 CVs detected (surprise, more than expected, almost 10% of INTEGRAL detections)

•28 detected by IBIS (Barlow et al., 2006, Bird et al., 2007, Kocka et al. 2008, Galis et al., 2008) – correlation of IBIS data and Downes CV catalogue & deep IP survey (our group, 5 new CVs detection)

•4 are CV candidates revealed by optical spectroscopy of IGR sources (Masetti et al., 2006) – new CVs, not in Downes catalogue

Mainly magnetic systems:

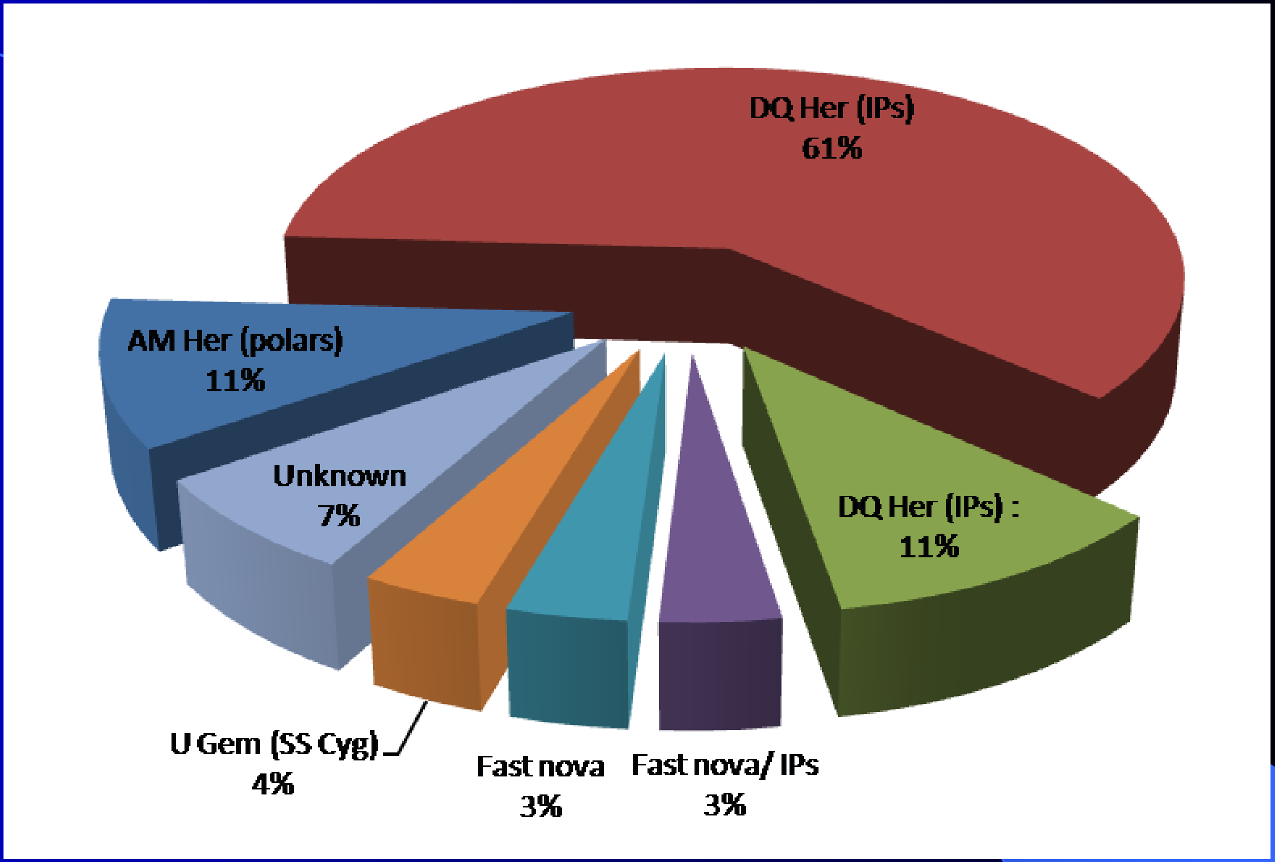
22 confirmed or propable IPs (~25% of all known), 3 polars, 2 dwarf novae, 4 probable magnetic CVs, 1 unknown

Periods:

Vast majority *P*orb > 3 hr, i.e. above the period gap (only one < 3 h). 5 long period systems with *P*orb > 7 hr

Some Statistics

Intermediate polars – only ~2% of the catalogued CVs, but they dominate the group of CVs seen by IBIS



IBIS tends to detect IPs and asynchronous polars: in hard X-rays, these objects seem to be more luminous (up to the factor of 10) than synchronous polars (but detection of more CVs needed for better statistics)

Those IPs not detected despite good coverage may be due to non-activity state

V1223 Sgr

Intermediate polar, bright X-ray source

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

Orbital period: P_{orb} = 3.37 h (Osborne et al. 1985, Jablonski and Steiner 1987)
Rotational period of the white dwarf: P_{rot} = 746 sec (Osborne et al. 1985)
Beat period (combined effect of P_{orb} and P_{rot}): P_{beat} = 794.3 sec (Steiner et al. 1981)

Prominent long-term brightness variations:
- outburst with a duration of ~6 hr and amplitude >1 mag (van Amerongen & van Paradijs 1989)
- episodes of deep low state (decrease by several magnitudes) (Garnavich and Szkody 1988)

Indications for flaring activity

•Seen by IBIS (flare lasting for ~ 3.5 hrs during revolution 61 (MJD 52743), peak flux ~ 3 times of average (Barlow et al., 2006), no simultaneous optical data

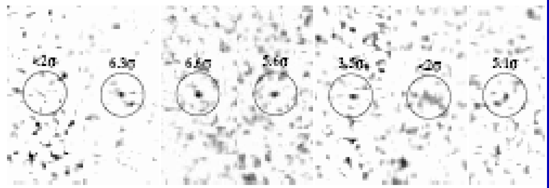


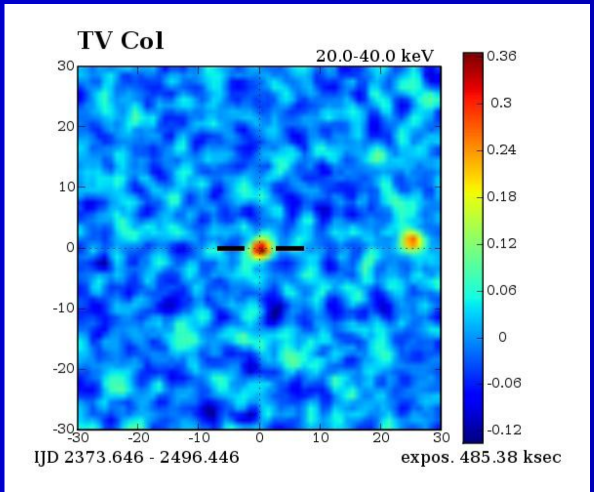
Figure 2. 20–30 keV images of IBIS revolution 61, ScWs 97–103 (left to right). The location of V1223 Sgr is circled and the significances labelled for each ScW.

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. Recently detected also by INTEGRAL IBIS.

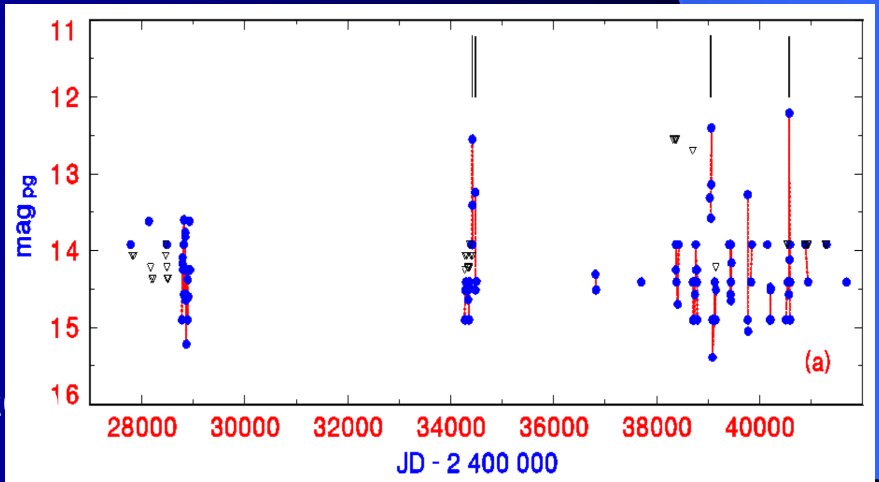
Physics of the outbursts in IPs:

Disk instability or An increase in mass transfer from the secondary

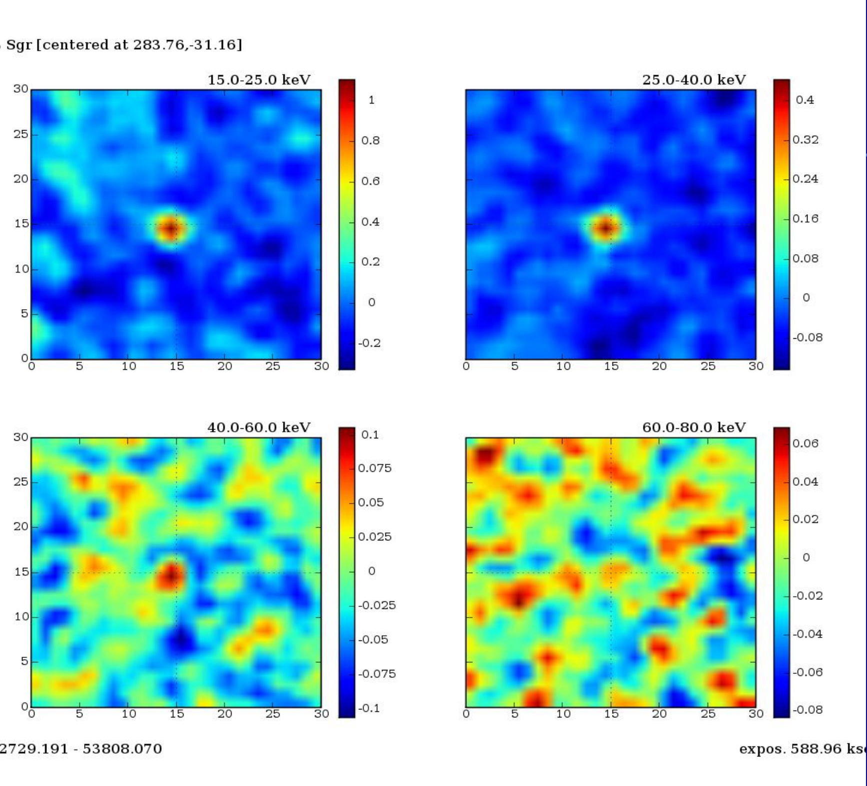


IBIS image

Optical LC (historical)



Cataclysmic Variable IP V1223 – the brightest one seen by INTEGRAL

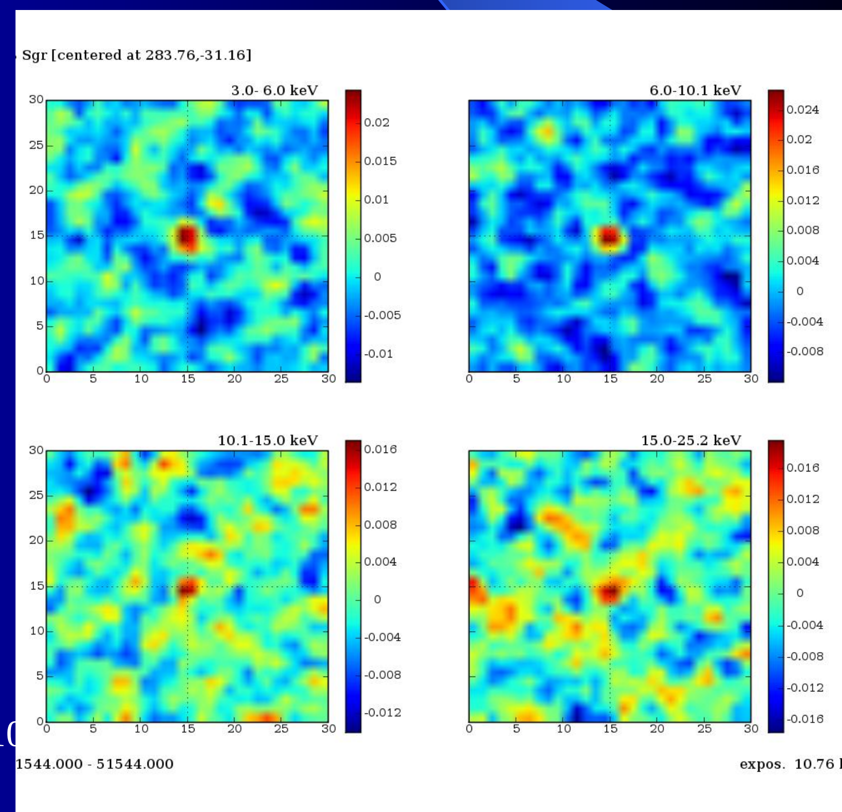


V1223 Sgr IBIS mosaics (co-added frames) all data (589 ks) intensity maps

JD (24..)	Exp. Time	Flux (15 - 25)keV [10^{-12} erg s^{-1} cm^{-2}]	Flux (25 - 40)keV [10^{-12} erg s^{-1} cm^{-2}]	Flux (40 - 60)keV [10^{-12} erg s^{-1} cm^{-2}]	Flux (60 - 80)keV [10^{-12} erg s^{-1} cm^{-2}]
52 710.38 - 52 752.01	109.2	161.00 ± 14.50	57.90 ± 4.88	< 4.93	< 6.26
52 917.17 - 52 926.84	151.1	112.00 ± 11.30	51.10 ± 4.19	21.30 ± 4.24	< 5.48
53 082.07 - 53 119.10	228.1	127.00 ± 8.90	50.00 ± 3.28	23.10 ± 3.48	10.00 ± 4.54
53 267.41 - 53 305.97	134.5	126.00 ± 12.50	55.40 ± 4.46	25.40 ± 4.75	27.70 ± 6.23
53 440.61 - 53 479.81	90.9	155.00 ± 15.20	61.30 ± 5.53	24.10 ± 5.85	< 7.69
53 602.80 - 53 672.88	409.6	< 7.17	31.80 ± 2.65	< 2.82	< 3.78
53 781.06 - 53 809.24	282.1	132.00 ± 10.00	48.50 ± 3.50	13.90 ± 3.56	< 4.69
52 710.38 - 53 809.25	1405.5	103.00 ± 3.90	46.40 ± 1.42	15.10 ± 1.48	12.30 ± 1.97

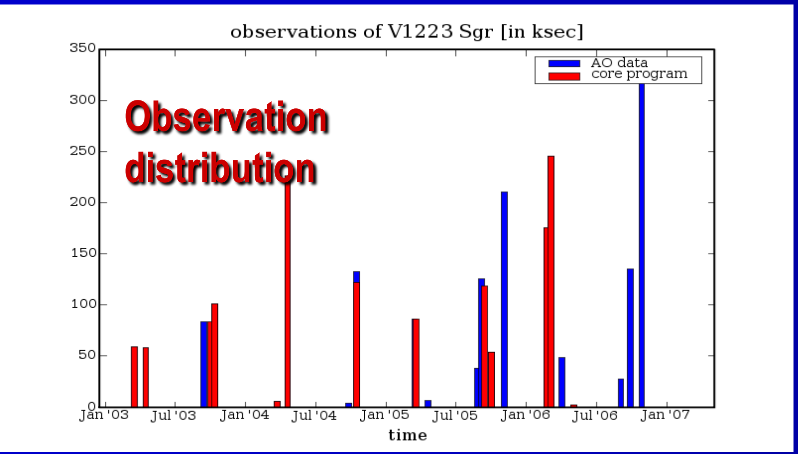
X-ray emisssion extends to >60 keV

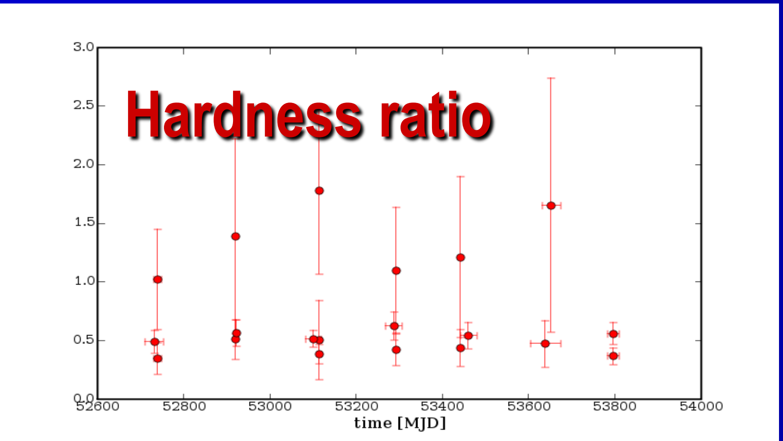
V1223 Sgr JEM-X, OSA7

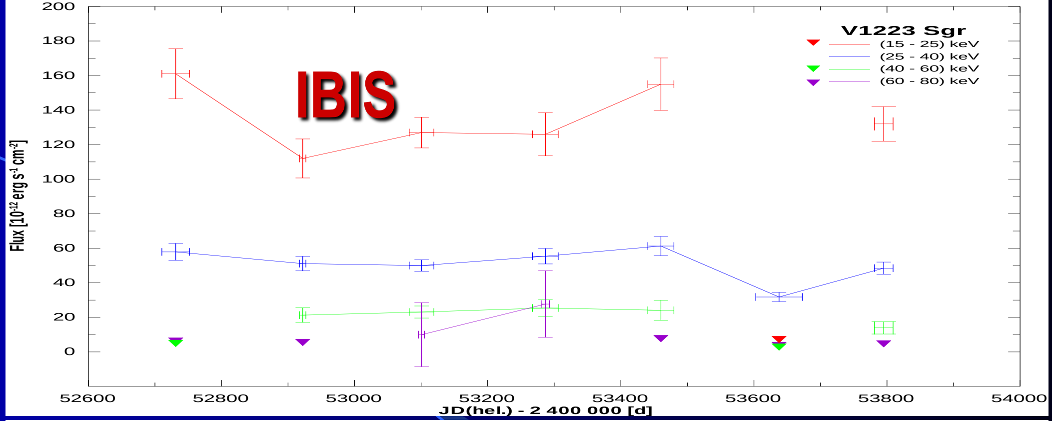


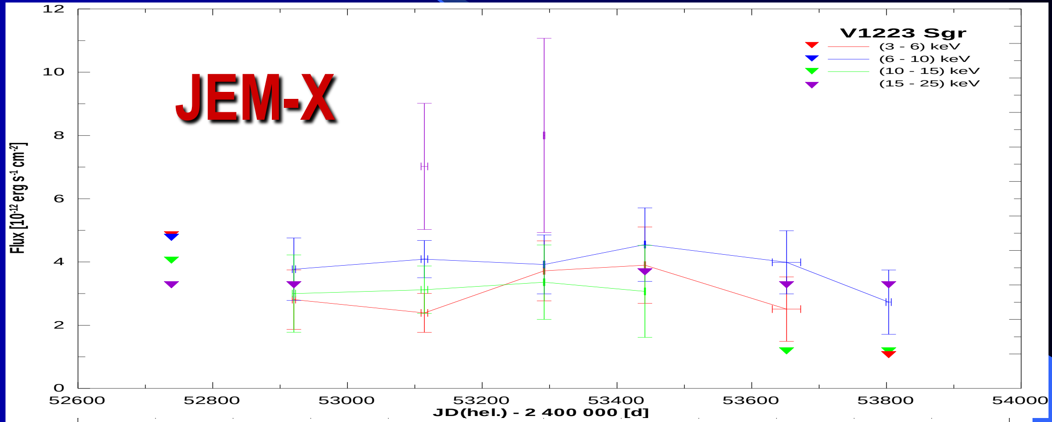
JD (24..)	Exp. Time	Flux (3 - 6)keV [10^{-12} erg s^{-1} cm^{-2}]	Flux (6 - 10)keV [10^{-12} erg s^{-1} cm^{-2}]	Flux (10 - 15)keV [10^{-12} erg s^{-1} cm^{-2}]	Flux (15 - 25)keV [10^{-12} erg s^{-1} cm^{-2}]
52 729.19 - 52 748.22	8.4	4.86 ± 0.99	4.78 ± 1.03	4.06 ± 1.27	< 3.28
52 917.95 - 52 922.93	8.9	2.81 ± 0.94	3.77 ± 0.99	3.00 ± 1.22	< 3.28
53 109.19 - 53 119.10	23.3	2.39 ± 0.61	4.09 ± 0.59	3.12 ± 0.75	7.02 ± 2.00
53 290.73 - 53 292.94	10.8	3.72 ± 0.95	3.92 ± 0.93	3.36 ± 1.18	8.00 ± 3.07
53 440.66 - 53 442.35	7.2	3.90 ± 1.21	4.55 ± 1.16	3.07 ± 1.46	< 3.69
53 630.59 - 53 672.74	11.5	2.51 ± 1.02	3.99 ± 1.00	< 1.19	< 3.28
53 799.35 - 53 807.17	10.6	< 1.07	2.73 ± 1.01	< 1.19	< 3.28

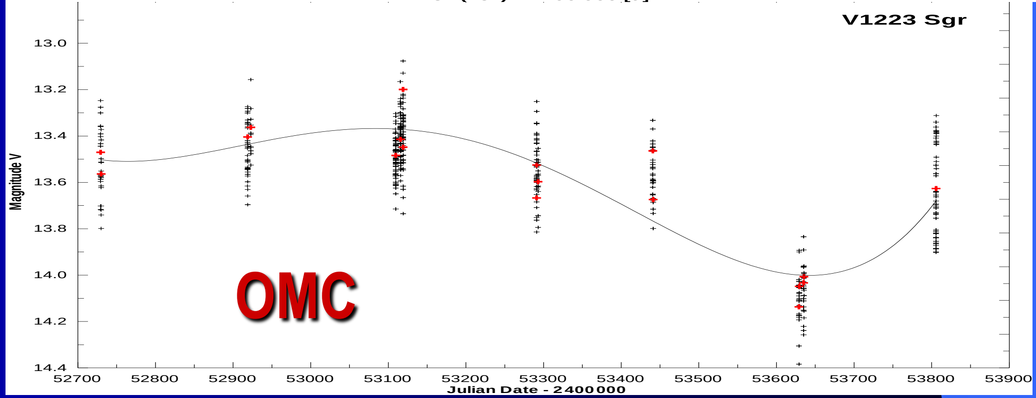
V 1223 Sgr (IBIS, JEM-X & OMC light curves, OSA7) from ALL 4 INTEGRAL instruments







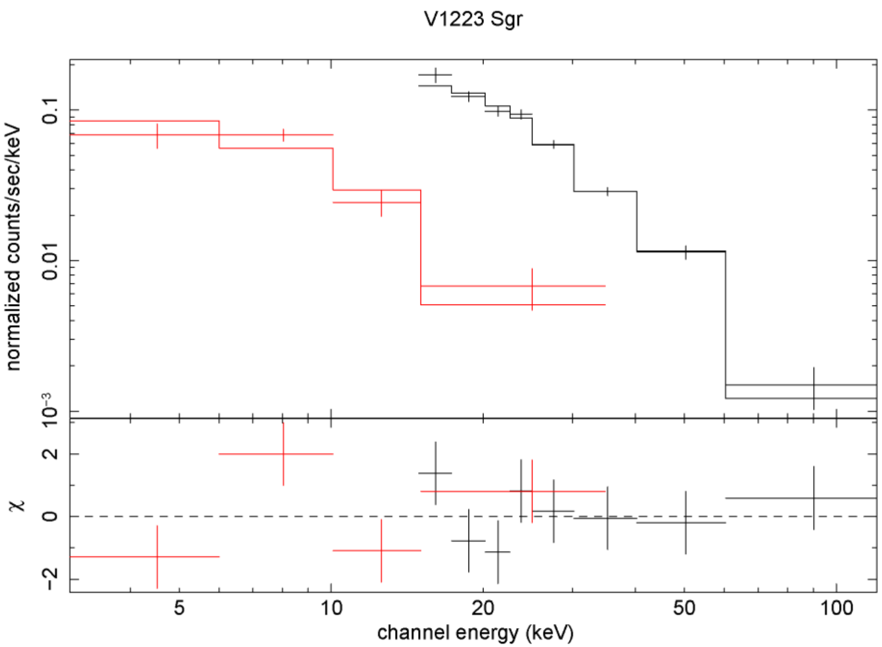


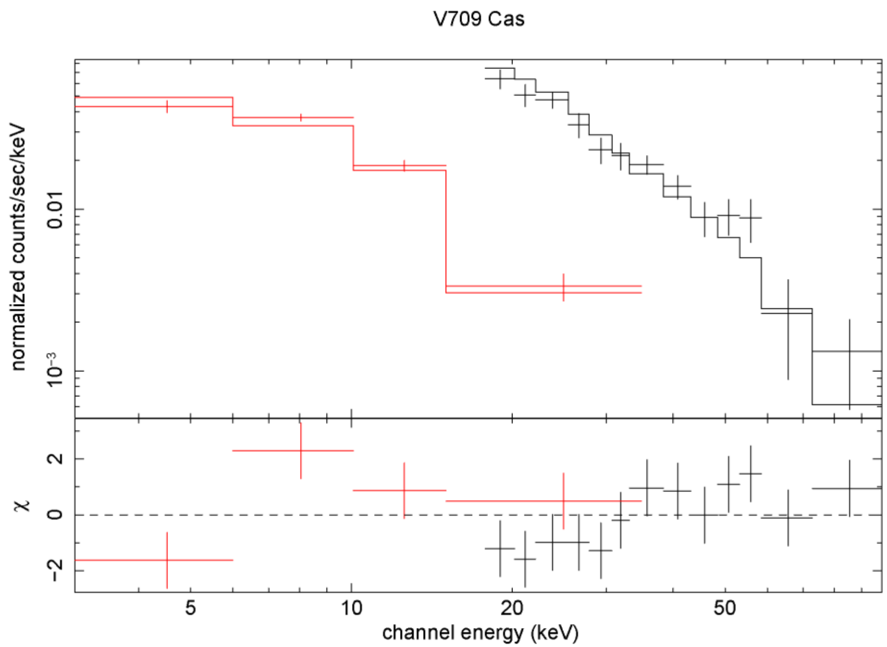


The fluxes especially in (15 - 25) keV and (25 - 40) keV bands are long-term variable with significant drop around MJD ~ 53 650. Optical variations are correlated with the changes in (15 – 25) keV, (25 – 40) keV and (40 – 60) keV spectral bands with correlation coefficient 0. 81, 0. 82 and 0.89, respectively.

Broad-band (3-100) keV spectra

- ***INTEGRAL/JEM-X + IBIS*** **spectra of the studied IPs fitted by a thermal bremsstrahlung model.**





$F_{(20\text{-}40)keV}$ = (48.1 ± 0.7)×10^{-12} erg cm^{-2} s^{-1} (68.2σ)

$F_{(40\text{-}100)keV}$ = (22.1 ± 1.3)×10^{-12} erg cm^{-2} s^{-1}

$$kT = 23.7^{+1.4}_{-1.3}\,\mathrm{keV}$$

χ^2 /d.o.f = 12.4/10

$F_{(20\text{-}40)keV}$ = (27.0 ± 0.3)×10^{-12} erg cm^{-2} s^{-1} (86.1σ)

$F_{(40\text{-}100)keV}$ = (18.3 ± 0.5)×10^{-12} erg cm^{-2} s^{-1}

$$kT = 24.4^{+1.5}_{-1.4}\,\mathrm{keV}$$

χ^2/d.o.f = 22.6/16

Broad-band (3-100) keV spectra

- **Hard X-ray/soft gamma-ray spectra can be well fitted by thermal bremsstrahlung model with temperature of PSR kT ≈ 10s of keV.**
- **Reflection of the bremsstrahlung photons at the WD surface also contributes to the hard X-ray spectrum (van Teeseling, Kaastra & Heise 1996).**
- **In the recent investigations by Canalle et al. (2005) and Saxton et al. (2007) have studied the role of the two-temperature plasma and considered the dipole magnetic funneling.**
- **Suleimanov et al. (2008) showed that the influence of Compton scattering on the broad-band X-ray spectra of IPs is significant only at high accretion rates and large WD masses.**
- **We used all available observational data from *INTEGRAL/JEM-X* and *INTEGRAL/IBIS* detectors to study broad-band spectra of the selected IPs:**
  V 1223 Sgr, V 709 Cas, IGR J16167-4957, GK Per and V 2400 Oph.

Some newly detected INTEGRAL CVs are, in fact, long known X-ray sources
… like this one detected in 1985 by group including INTEGRAL PM Arvind Parmar

TRANSITION IN THE X-RAY LIGHT CURVE OF THE AM HERCULIS SYSTEM V834 CENTAURI (E1405–451): 1985–1986 *EXOSAT* OBSERVATIONS

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The X-ray emission was detected up to 10 keV at that time and now up to 100 keV. Importance of INTEGRAL for study of CVs: extending the range from 0.5-10 keV to 10-100 keV

V834 Cen, old X-ray spectra from EXOSAT 1985-86

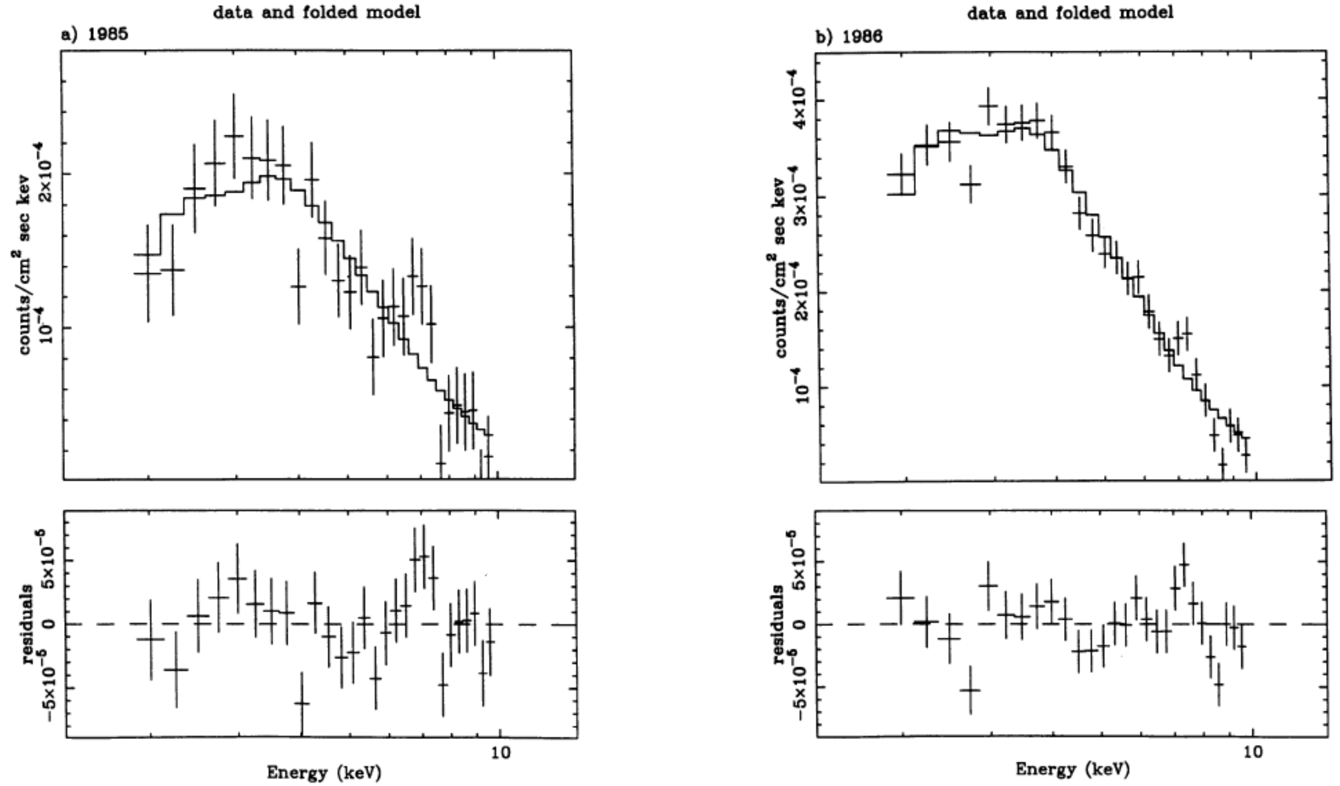


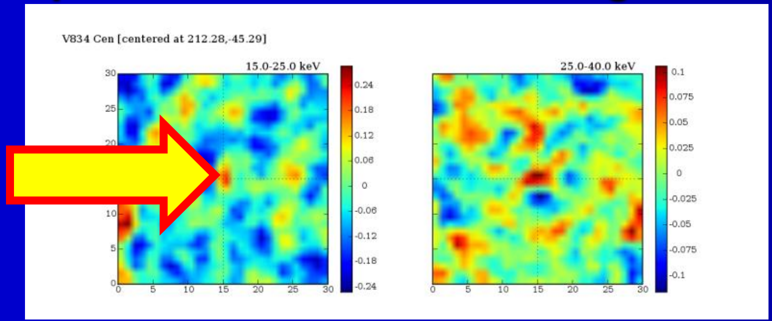
FIG. 4.—1985 and 1986 ME spectra. (*top*) Observed spectra and bremsstrahlung folded model. (*bottom*) The residuals of the fit.

The emission ends at 10 keV due to constraints of used X-ray telescope, not due to source itself

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

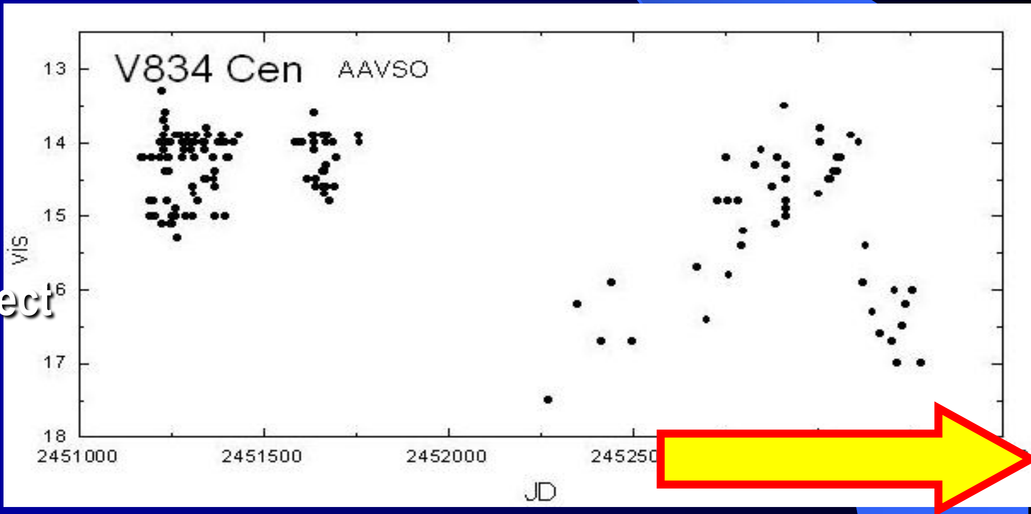


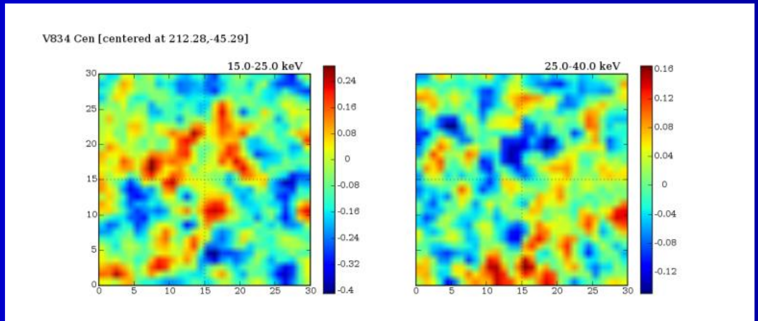
IBIS image at optical active state 14 mag Object detected

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.

arrow: time period of INTEGRAL observation

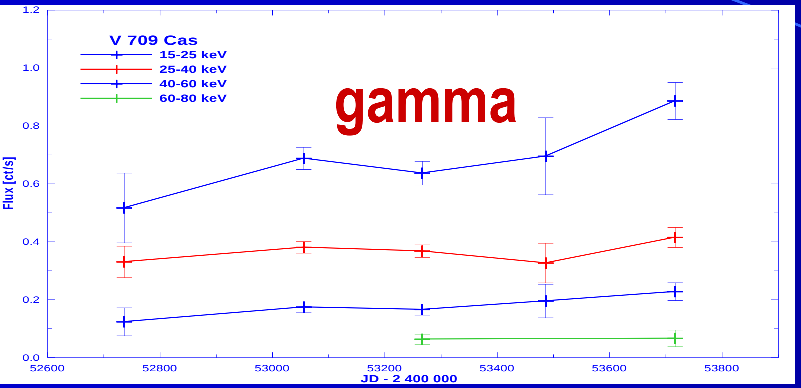


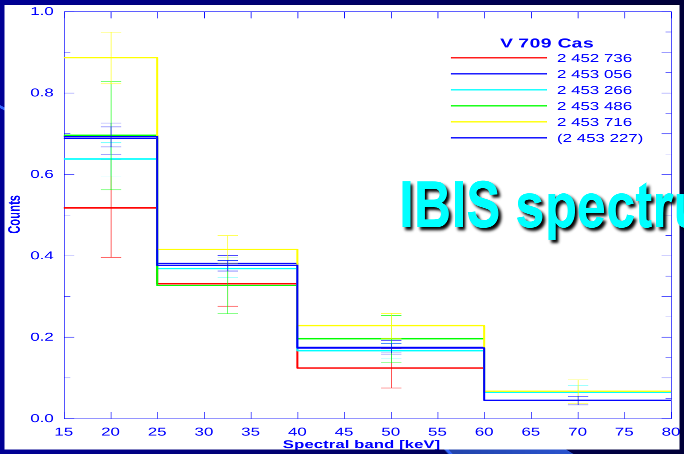


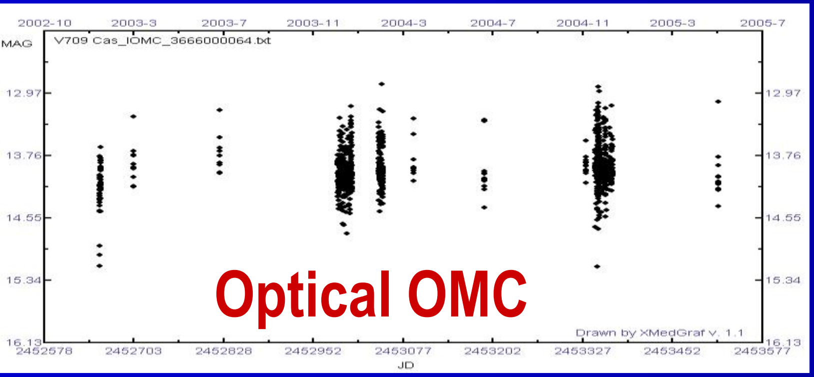
IBIS image at optical low state 17 mag

Object not detected

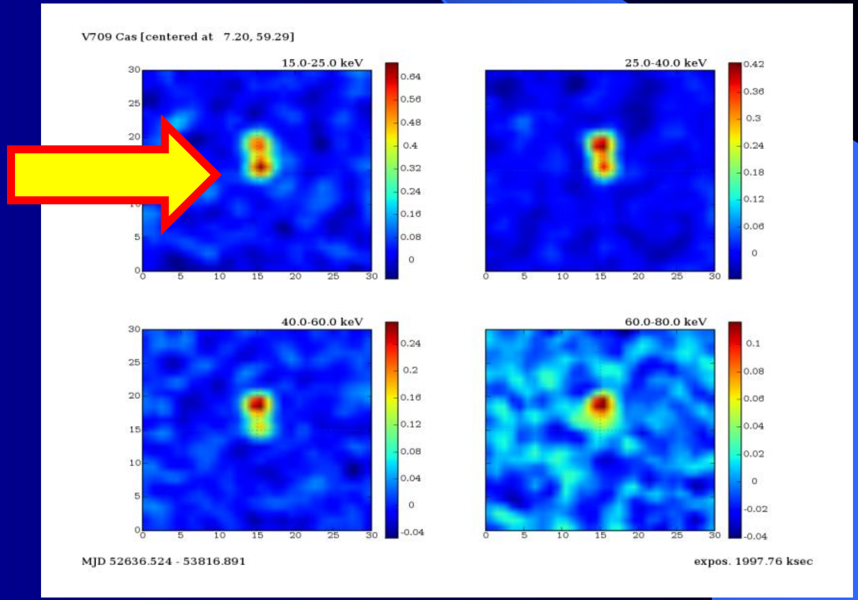
V 709 Cas IBIS gamma-ray and OMC optical light curves

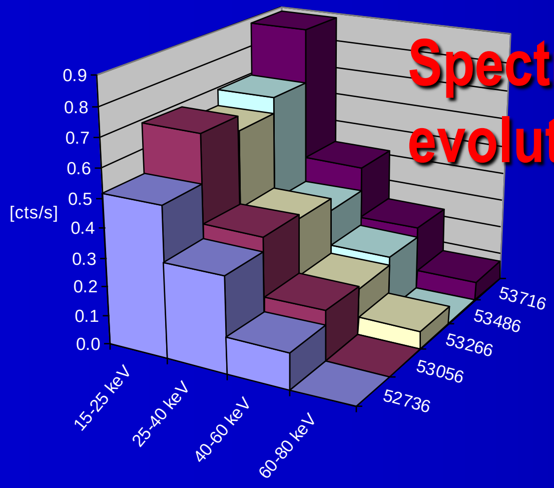






V709 Cas IBIS image



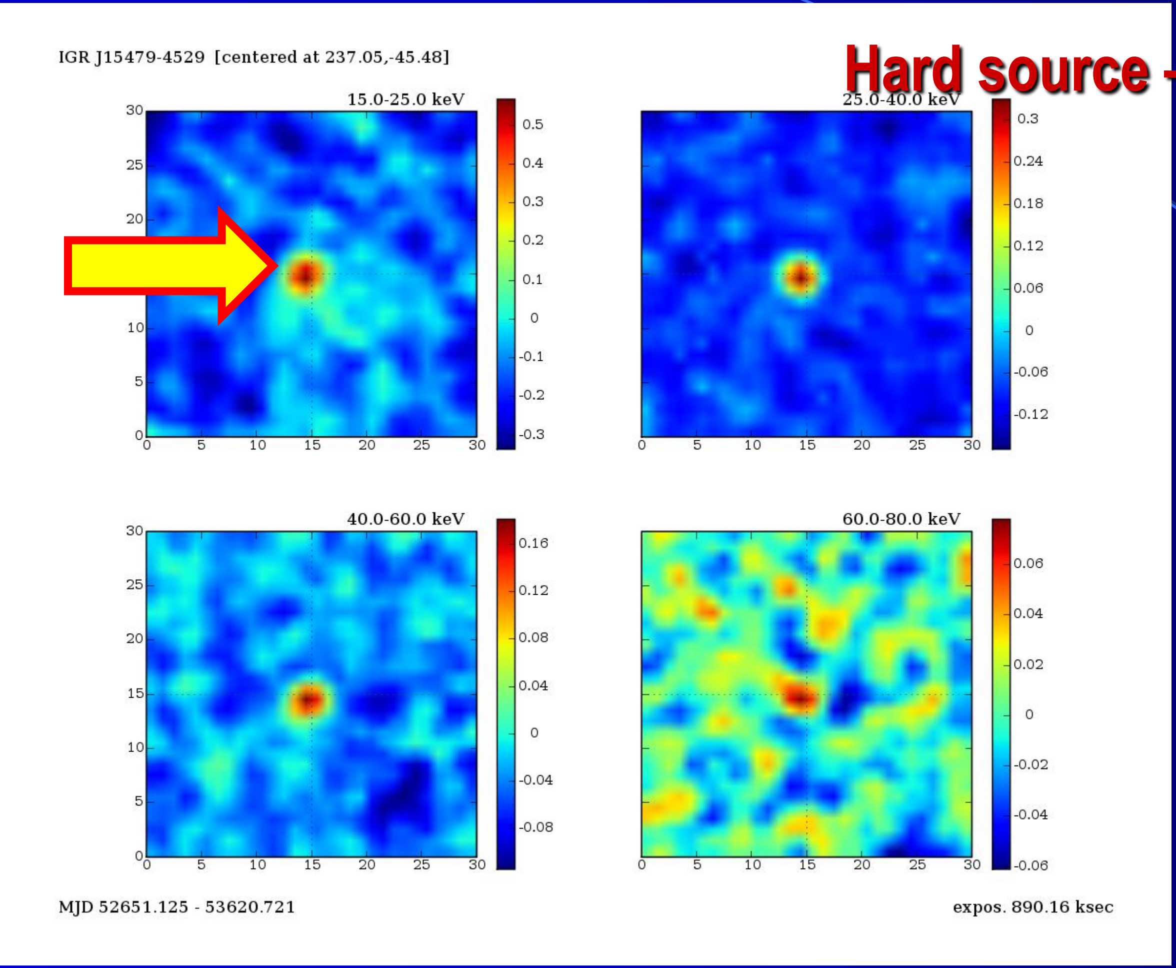


Spectral temporal evolution (IBIS)

MJD interval 52636.52-53816.89 i.e. 1180.37 days time mean 1689.171 +- 292.267 size 36×72 — exposure 1997.76 ksec

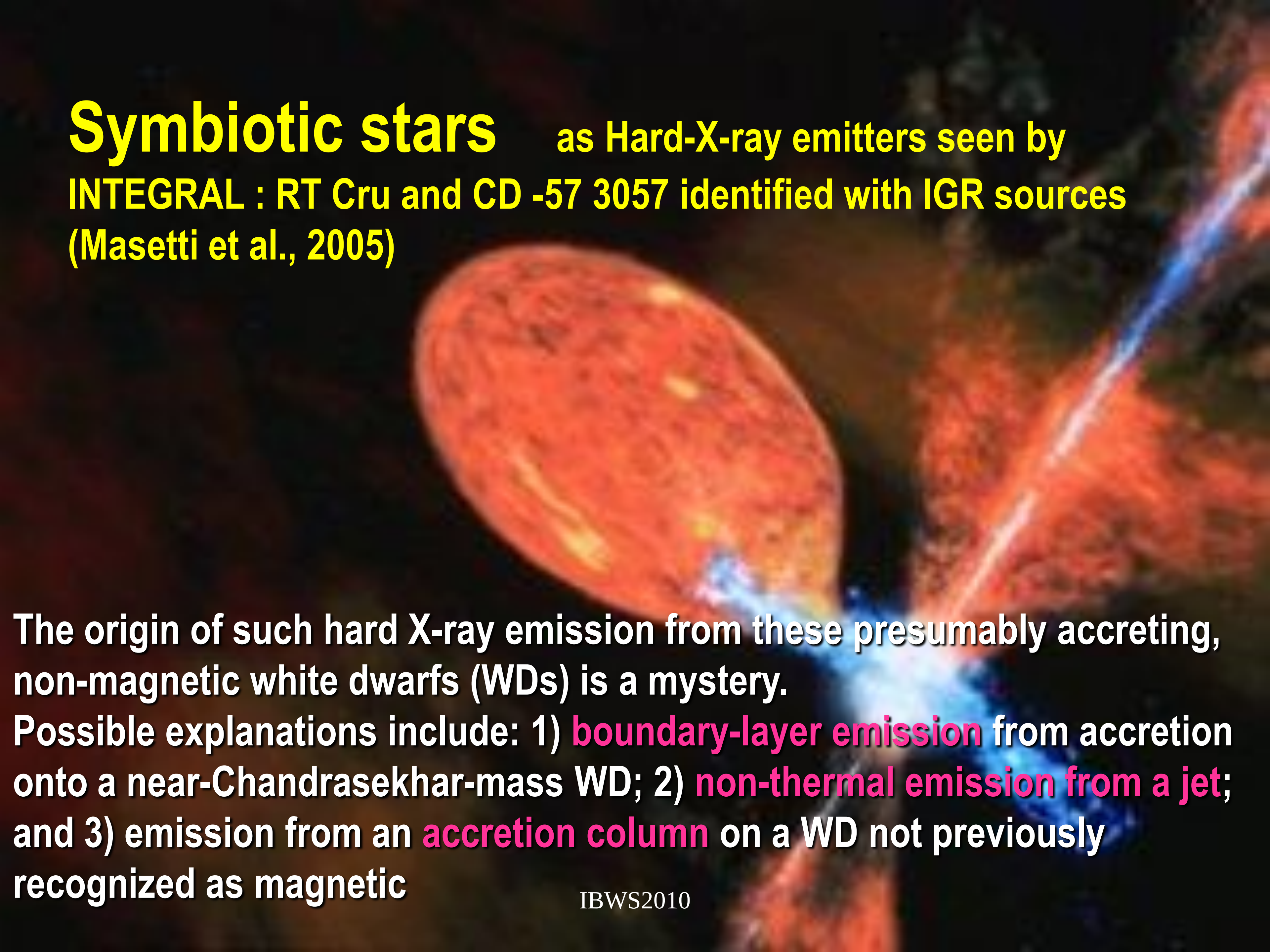
IGR J15479-4529

Hard source – emission up to 60-80 keV



MJD interval 52651.12-53620.72 i.e. 969.60 days
time mean 1661.355 +- 388.437
size 84×120 — exposure 890.159 ksec

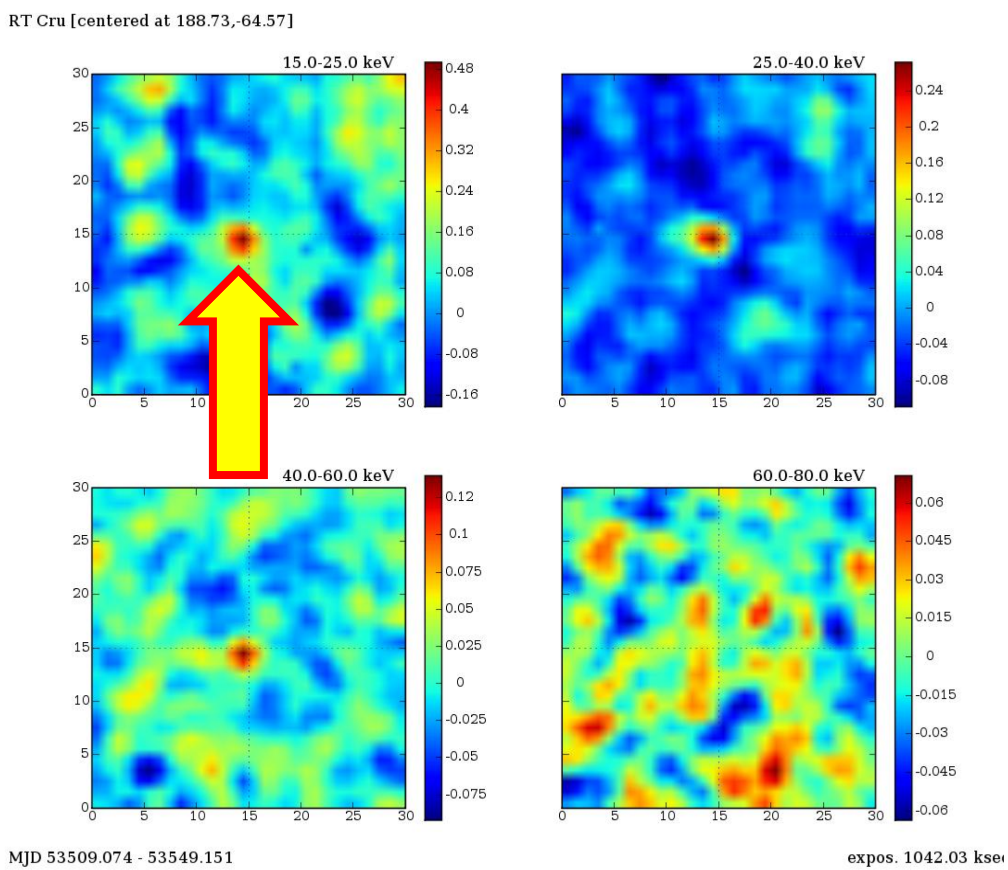
15.0-25.0 keV : peak 0.567 +- 0.044 ct/s [width 1.18], 1.3 pix. off = 12.90 σ
25.0-40.0 keV : peak 0.329 +- 0.0214 ct/s [width 0.81], 1.3 pix. off = 15.39 σ
40.0-60.0 keV : peak 0.181 +- 0.0182 ct/s [width 0.86], 1.4 pix. off = 9.97 σ
60.0-80.0 keV : peak 0.0781 +- 0.0162 ct/s [width 1.55], 2.3 pix. off = 4.82 σ



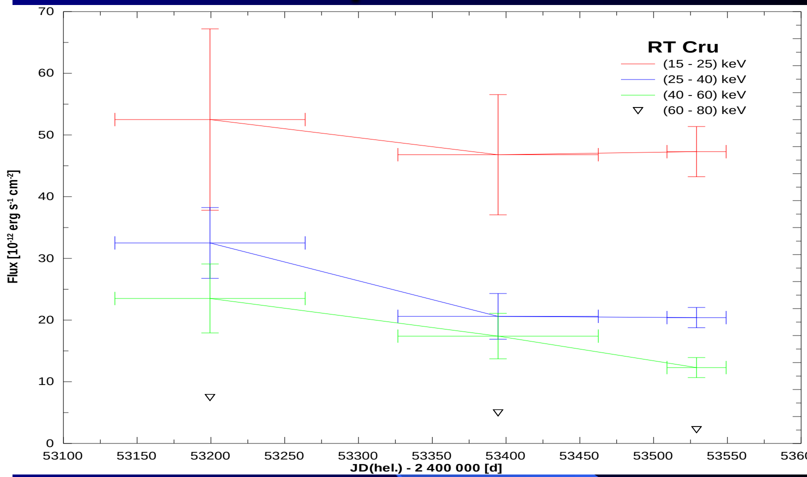
Symbiotic stars as Hard-X-ray emitters seen by INTEGRAL : RT Cru and CD -57 3057 identified with IGR sources (Masetti et al., 2005)

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 magnetic

RT Cru IBIS

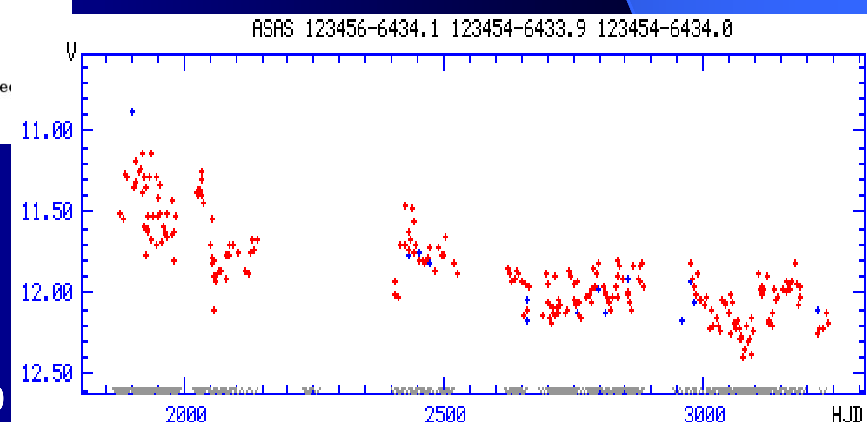


Detected up to 60 keV



IBIS light curve

Optical light curve



- 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

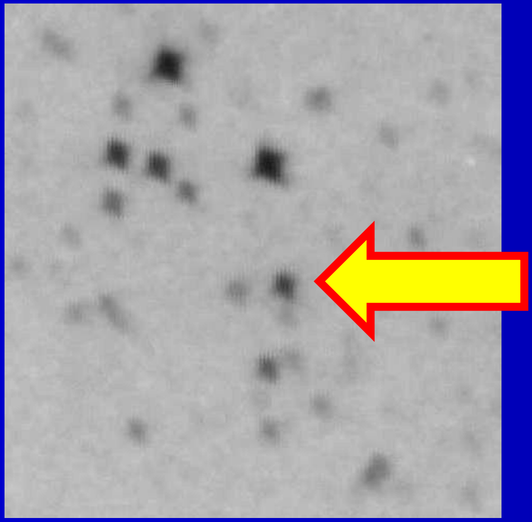
mag 11-12

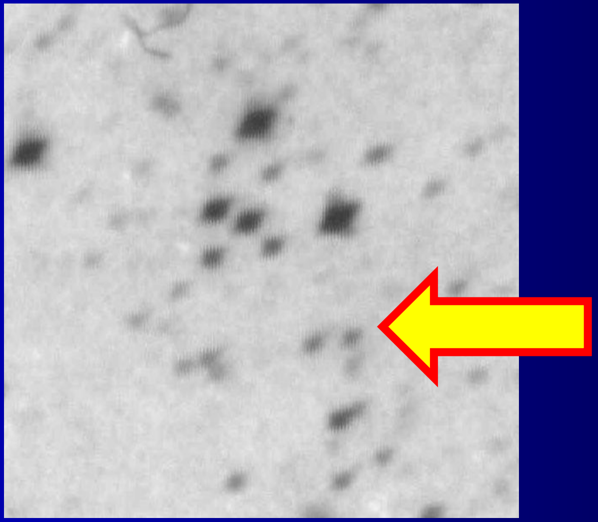
IGR J12349-6434 = RT Cru

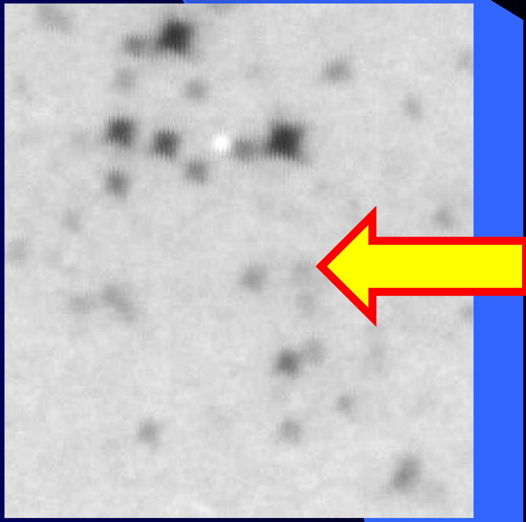
hard X-ray symbiotic star on historical Leiden Franklin Adams Plates

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 …. Confirmation of classification by Masetti et al. We can follow the evolution of the source over almost 100 years







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

Deep IPs survey

- Now, the sample of IPs detected in (20-40) keV energy band has 23 members, which represents around 25% of all known IPs.

- Nevertheless, some IPs are not detectable even we have significant exposure time (more than 4Msec) for these sources. This fact can be related with activity state of these close interacting binaries. So, in the next investigation we concern in correlation between the activity state and X-ray emission of the IPs.

- Analogous deep survey done also for blazars, see Poster by Hudec et al.

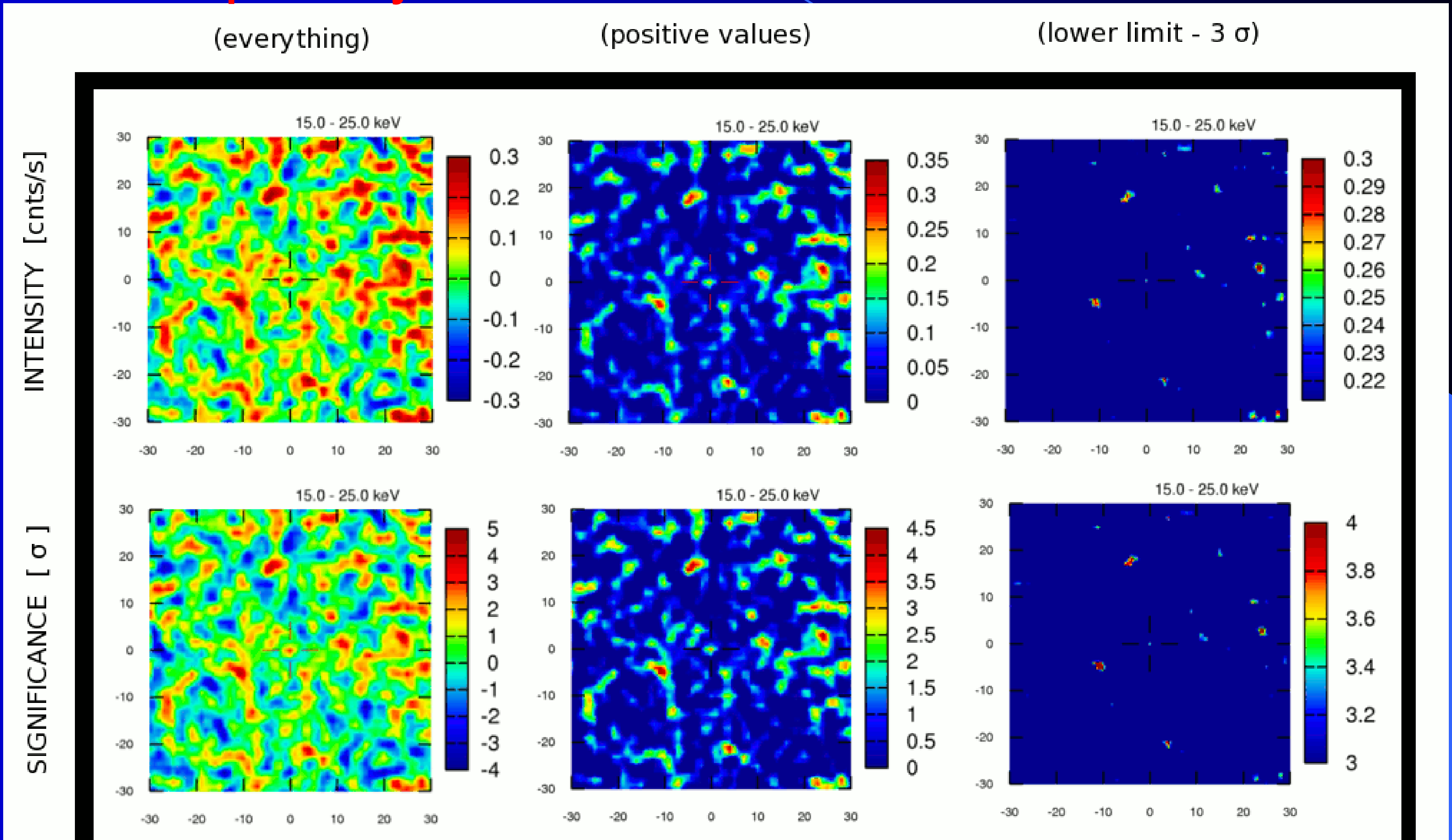
Deep IPs survey: hard X-ray detection of additional 5 IPs

- **Using all publicly available observational data (over 8000 individual pointings, total exposure time over 23 Msec) we constructed the (20-40) keV *INTEGRAL/IBIS* mosaics for all known 72 IPs (Downes, 2006, Bird et al., 2007, Kniazev et al. 2008, Masetti et al. 2008).**
- **We are not able to find significant detection of the X-ray emission in the mosaics for 43 known, but in 5 cases, namely XY Ari, V1062 Tau, TV Col, V2306 Cyg and AO Psc we can declare new, previously unreported detection of the X-ray emission in the (20-40) keV.**

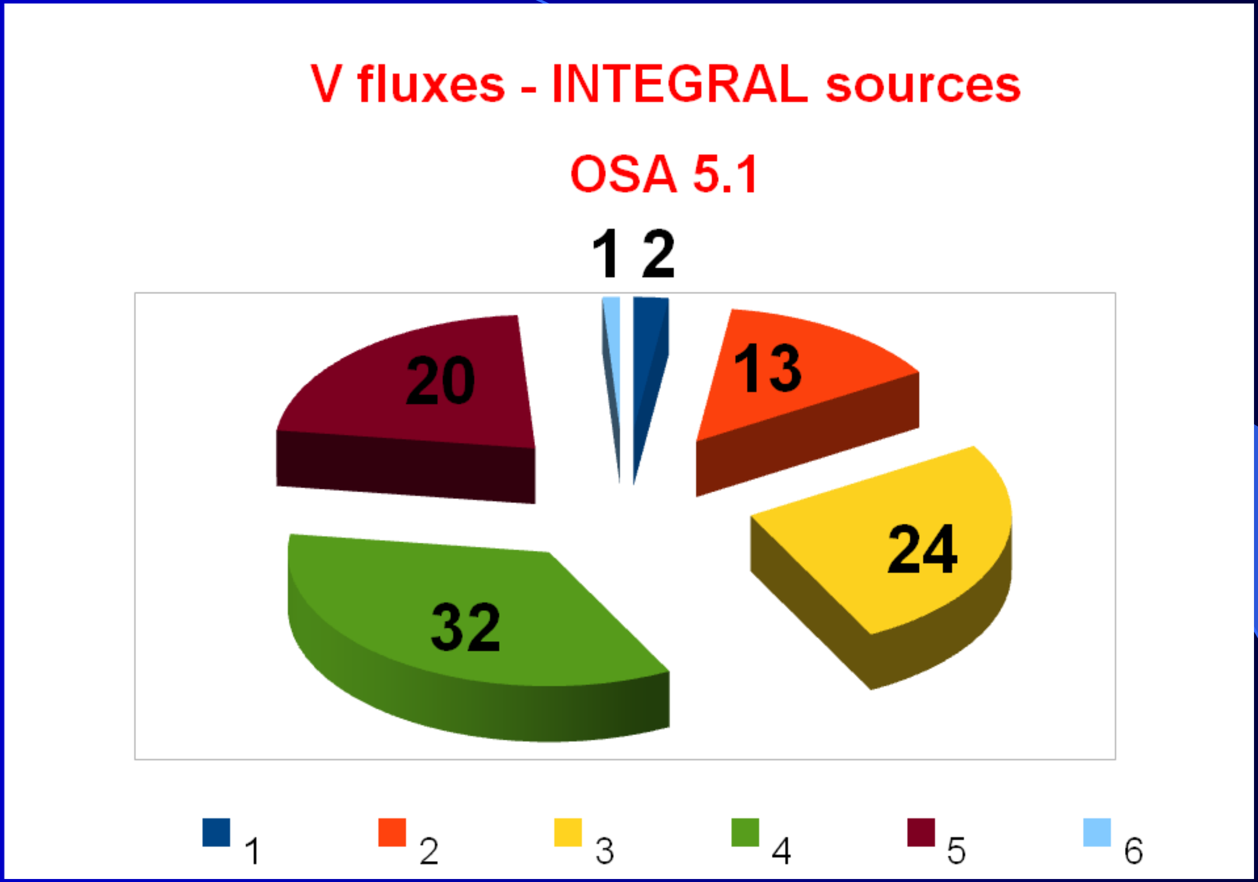
GCVS Name	RA (2000)	DEC (2000)	$F_{(20-40)keV}$ [10^{-12}erg $cm^{-2}s^{-1}$]	$F_{(40-100)keV}$ [10^{-12}erg $cm^{-2}s^{-1}$]	Sign.	Exp. time
XY Ari	02:56:08.10	+19:26:34.0	17.8 ± 4.7	< 38.1	3.9	42.0
V1062 Tau	05:02:27.47	+24:45:23.4	11.9 ± 1.5	< 14.0	7.8	462.0
TV Col	05:29:25.52	-32:49:04.0	28.4 ± 1.1	9.1 ± 1.6	25.9	990.0
V2306 Cyg	19:58:14.48	+32:32:42.2	7.2 ± 0.5	< 6.8	12.9	1713.0
AO Psc	22:55:17.99	-03:10:40.0	16.1 ± 1.8	< 18.1	8.7	273.0

XY Ari (IP, example of a new detection)

Comparison of the visualization methods – noise reduction. For more details see poster by Blažek and Hudec



IGR sources as optical emitters



The distribution of optical V magnitudes of optically identified INTEGRAL gamma-ray sources. Most are brighter than mag 20, and more than half are brighter than mag 15. *Legend* 1 = mag 2 – 6, 2= mag 5 -10, 3 = mag 10 – 14, 4 = mag 14 – 18, 5 = mag 18 – 22, 6 = mag 22-26. The numbers in the plot indicate number of objects with optical V magnitude within the indicated range

New: Optical Monitoring by D50 RT

- Motivation: IBIS data indicate correlation of hard gamma and optical luminosity
- Very difficult to find optical photometric data for INTEGRAL CVs over the INTEGRAL years 2002-now
- Observable (northern) CVs added to list of targets of the automated D50 Ondřejov telescope
- Brighter southern targets added to Polish 4pi of the sky monitor

Conclusions

•INTEGRAL is an effective tool to analyse CVs and symbiotics – 32 CVs and 3 SSs detected, with increase in time

•INTEGRAL opens new X-ray observational window 10-100 keV with only very limited access before

•The X-ray emisssion of some CVs and SSs extends to 80 keV

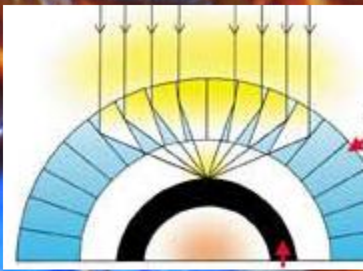
•INTEGRAL is an effective tool to find new CVs, mainly IPs

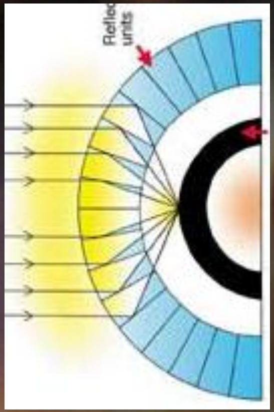
•ToO and AO observations of bright (in hard X-rays) CVs should be considered

•Example: AM Her, not covered by CP observations, AO proposed twice but always rejected - now confirmed as IBIS source

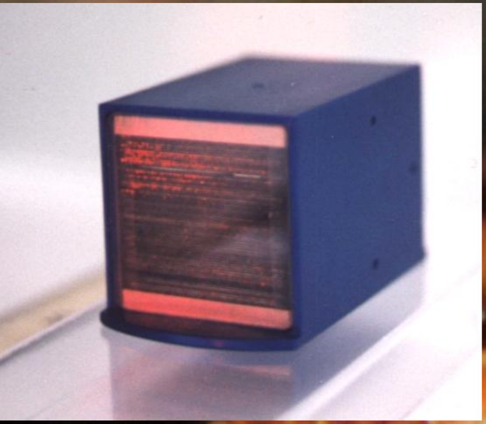
LOBSTER EYE X-ray All Sky Monitor

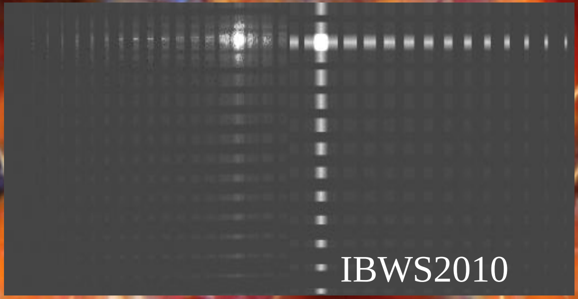
The refractive eyes of a lobster

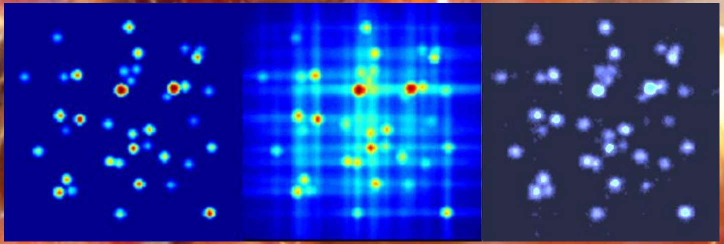




- X-ray binaries ~ 700 triggers
- Cataclysmic Variables ~ 200 triggers
- stars ~ 600 triggers
- AGN ~ 4 000 triggers
- Daily sampling! Energy range 1-10 keV







News

- V407 Cygni detected by Fermi as very hard gamma-ray source, March 2010
- During major flare in optical
- Symbiotics/Mira with Nova outburst
- Details in the Hot News Session Sunday morning

The End