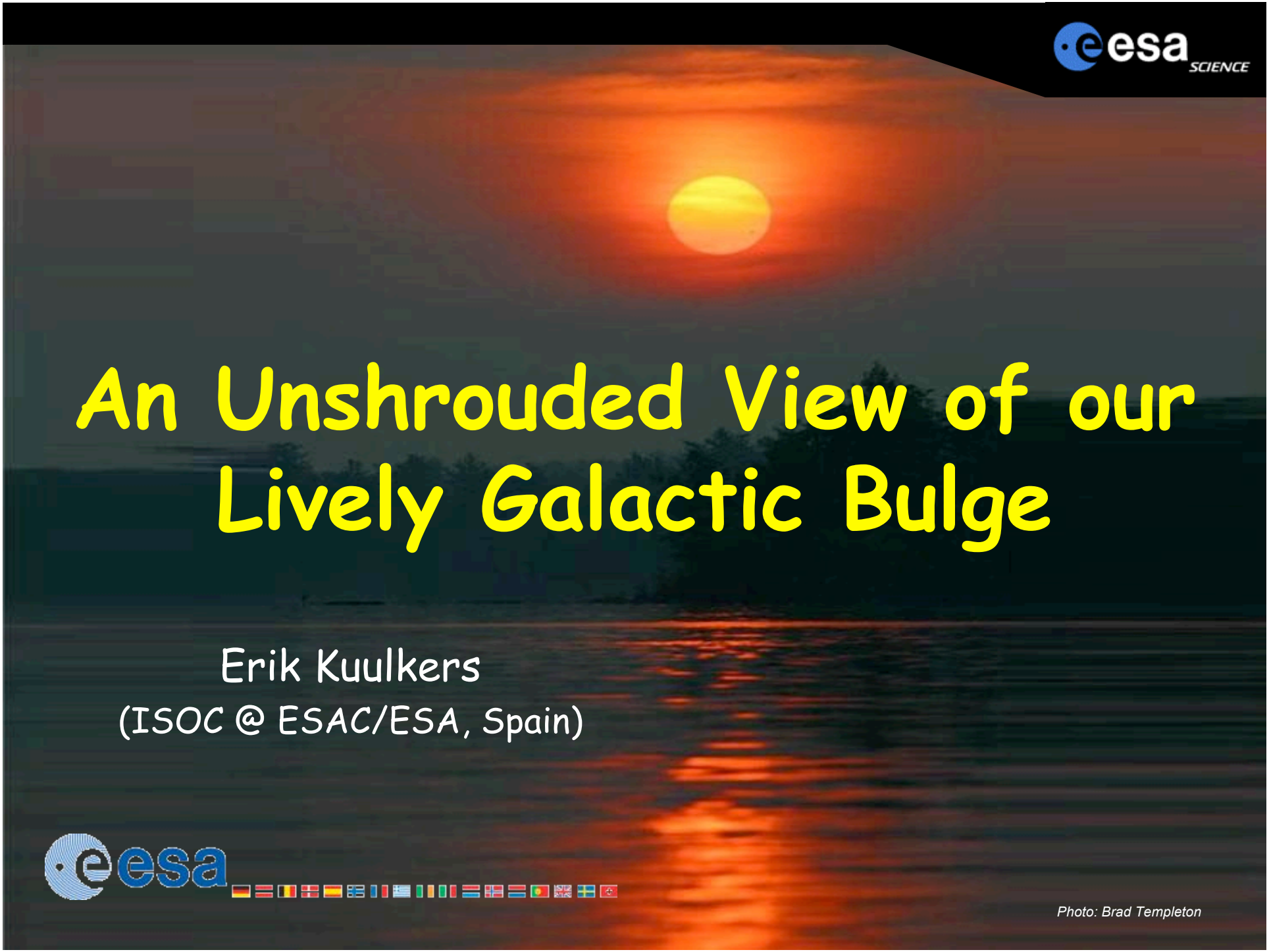


An Unshrouded View of our Lively Galactic Bulge

Erik Kuulkers
(ISOC @ ESAC/ESA, Spain)

Photo: Brad Templeton

With the following players:

Søren Brandt, Jérôme Chenevez, Thierry Courvoisier, Albert Domingo, Ken Ebisawa, Peter Kretschmar, Craig Markwardt, Nami Mowlavi, Tim Oosterbroek, Astrid Orr, Ada Paizis, Daniel Rísquez, Celia Sanchez-Fernandez, Simon Shaw & Rudy Wijnands

Erik Kuulkers
(ISOC @ ESAC/ESA, Spain)

Photo: Brad Templeton

Talk layout

- INTEGRAL
- Galactic Bulge
- Monitoring Program (with focus on hard X-rays)
- Some Results
- To-do list
- Public availability

Integral (International Gamma-Ray Laboratory)

IBIS – The gamma-ray Imager:

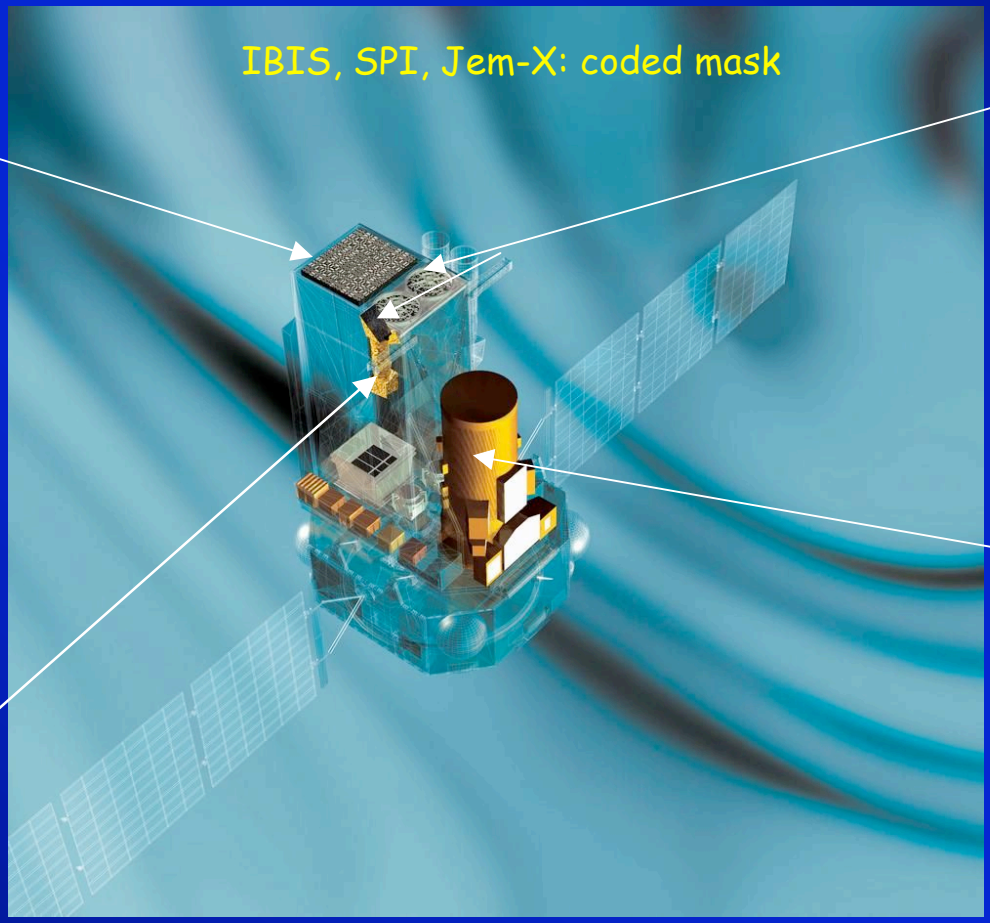
15 keV-10 MeV (ISGRI/PICsIT)

12' FWHM imaging

<30" source location

OMC – Optical Monitor Camera:

500-600 nm



Jem-X – The Joint Euro-pean X-ray Monitor:

3-35 keV

SPI – The gamma-ray Spectrometer:

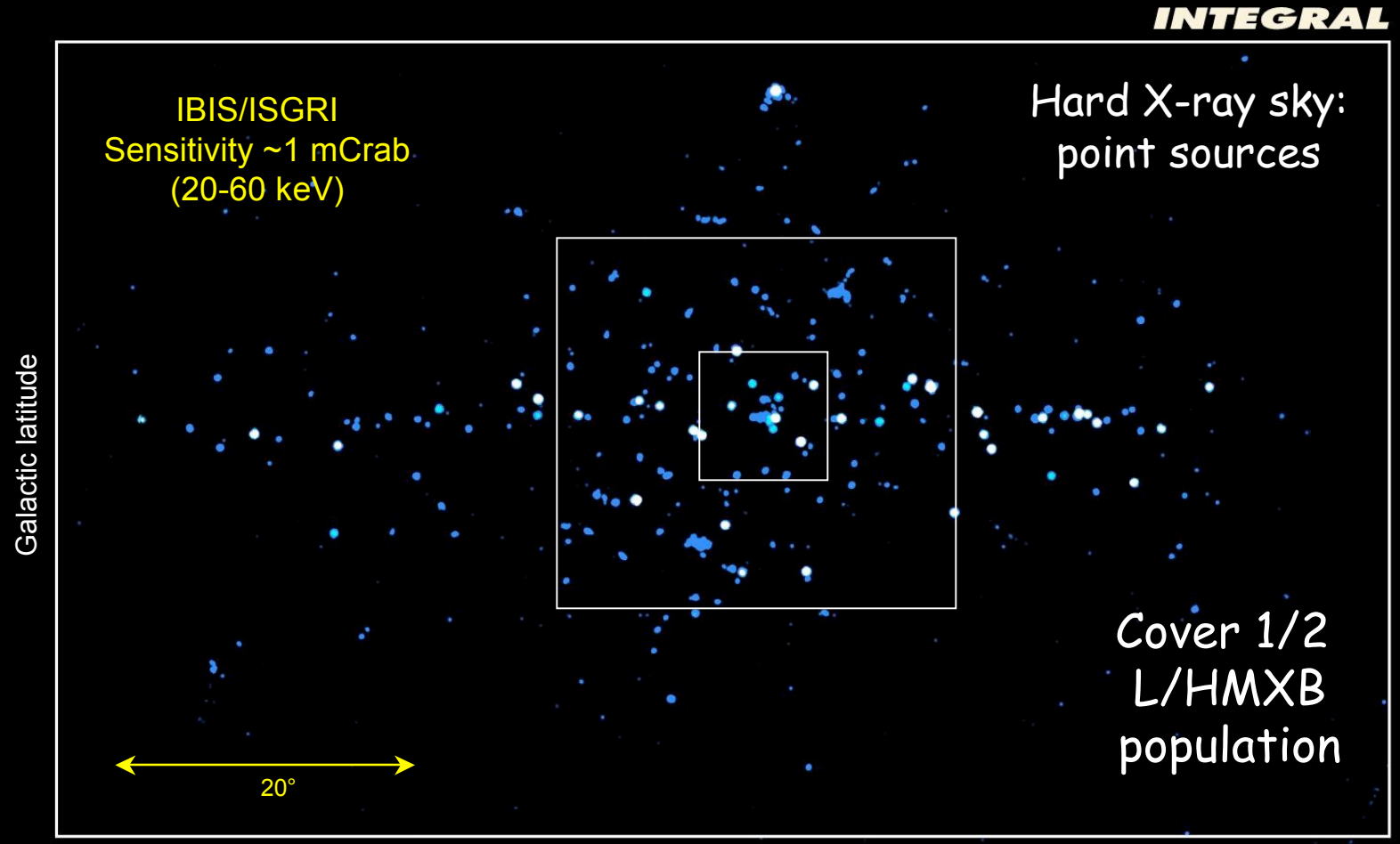
20 keV – 8 MeV

E/DE ~ 500

1.3° source location

See A&A Letters special issue 411 (2003)

Hard X-ray sky



See A&A Letters special issue 411 (2003)

Lebrun et al. 2004
Nature 428, 293

The high-E bulge ZOO

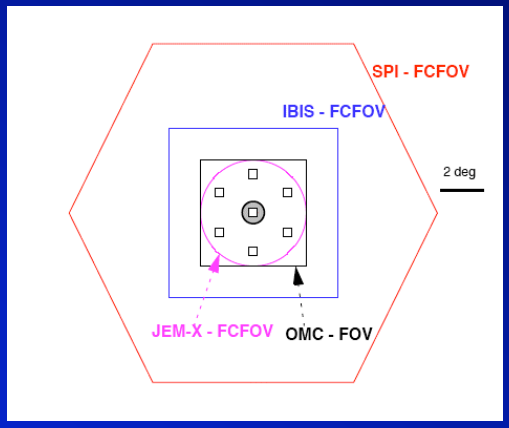
- Low-mass X-ray binaries:
  - persistent with ns (e.g., GX 5-1, GX 3+1)
  - X-ray bursters (e.g., GS 1826-24, GX 354-0)
  - X-ray pulsars (GX 1+4, 2S 1822-371)
  - transient with ns (e.g., MXB 1730-335)
  - persistent with bh (e.g., 1E 1740.7-2942)
  - transient with bh (e.g., GRO J1655-40)
- High-mass X-ray binaries:
  - X-ray pulsars (e.g., OAO 1657-415)
  - highly absorbed IGRs (e.g., IGR J17252-3616)
  - e.g., 4U 1700-377
- SGRs (e.g., SGR 1806-20)
- Cataclysmic variables (e.g., V2400 Oph)
- AGN (e.g., PKS 1830-211)

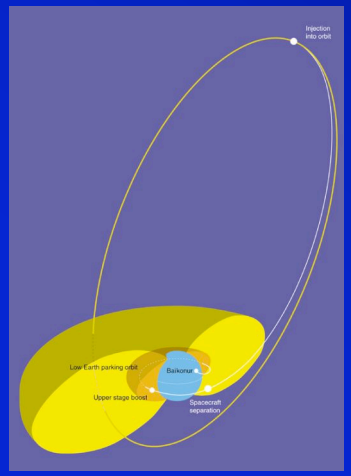
About 1/2 the population of L/HMXBs in the Galactic bulge!

Monitoring Program

- Every INTEGRAL orbit (~3 days)
- 7 exposures of 1800 sec; hexagonal dither pattern (source: 1 on-axis, 6 off-axis, 2° apart)
- Data available for analysis after ~2 hrs
- Results publicly available within a day: http://isdc.unige.ch/Science/BULGE/
- 2 visibility windows per year (2 months each)

- Objective: source variability & transient activity on time scales of days-weeks-months at soft and hard X-ray energies
- All sources in one go!
- Any news ➠ Atel





Monitoring Program - 2

- Results are made publicly available as follows on http://isdc.unige.ch/Science/BULGE:
  - Jem-X: 3-10 & 10-25 keV light curves + images
  - IBIS/ISGRI: 20-60 keV & 60-150 keV light curves + images
  - Permanent monitoring of ~80 sources

- IBIS/ISGRI & Jem-X sensitivities:

typically 10-20 mCrab per hexagonal dither; depends on:
  - source position (in fully or partially coded FOV)
  - background (systematics, solar activity)
  - nr of exposures (some are lost)
  - energy (instrument response)

- Started in Feb 2005; results on 1st 3 seasons: Kuulkers et al. 2007

INTEGRAL vs. some others

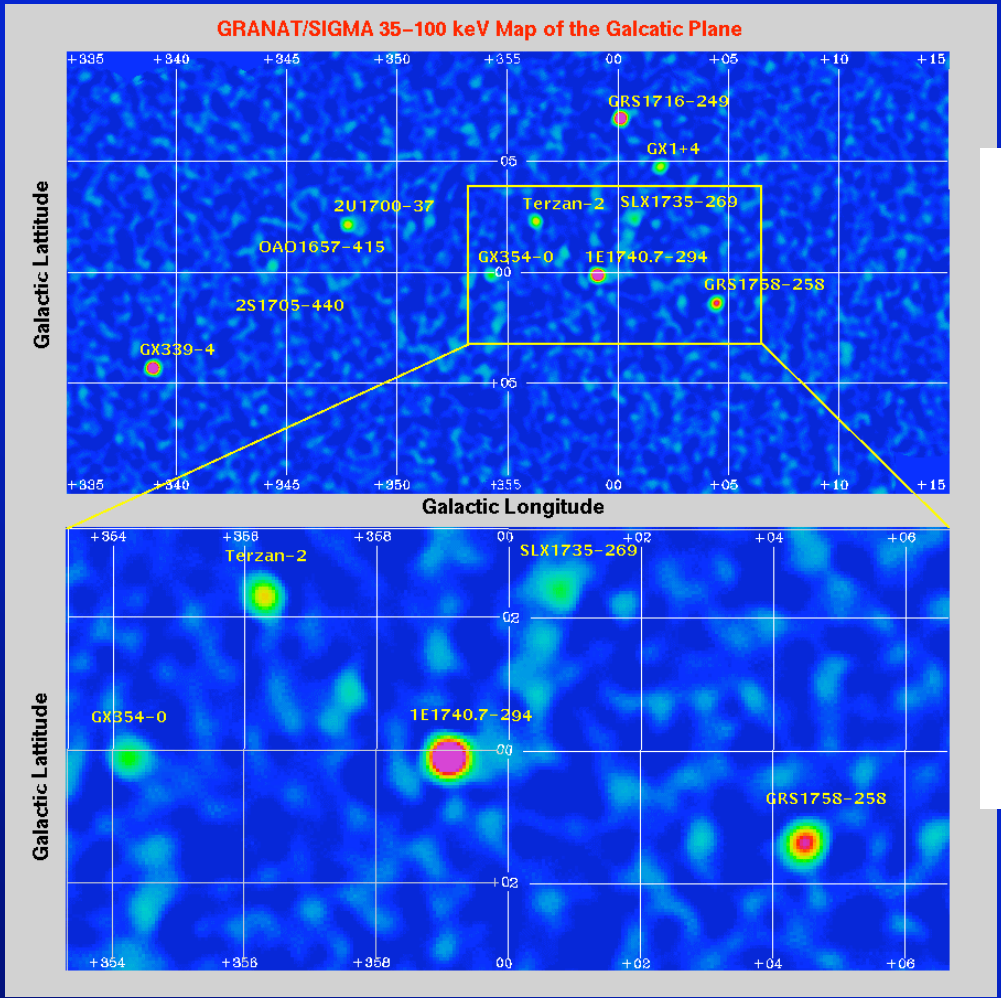
Similar dedicated campaings:

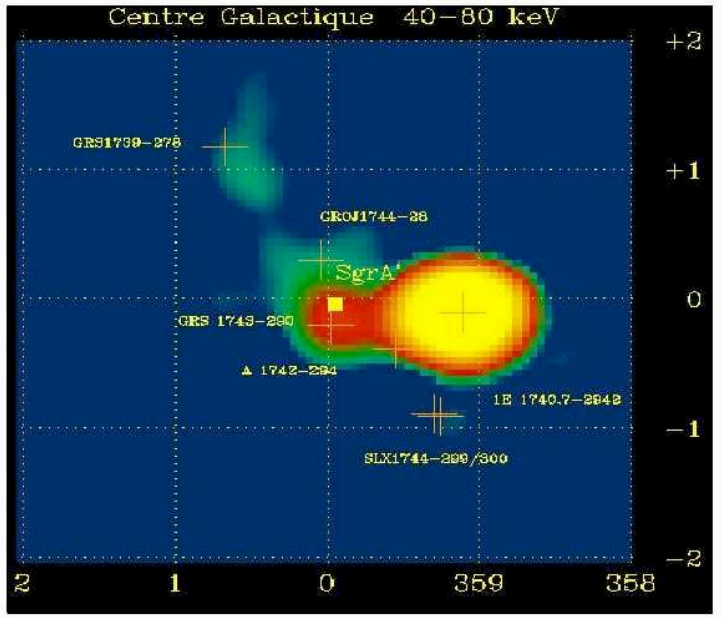
- GRANAT/SIGMA (35-100 keV) - 1990-1998 - e.g. Churazov et al. 1994
- BeppoSAX/WFC (3-35 keV) - 1996-2000 - e.g. in 't Zand 2001
- RXTE/PCA (2-10 keV) - 1996-? - e.g. Swank & Markwardt 2001 (still on-going)

Similar long-term (hard) X-ray light curves:

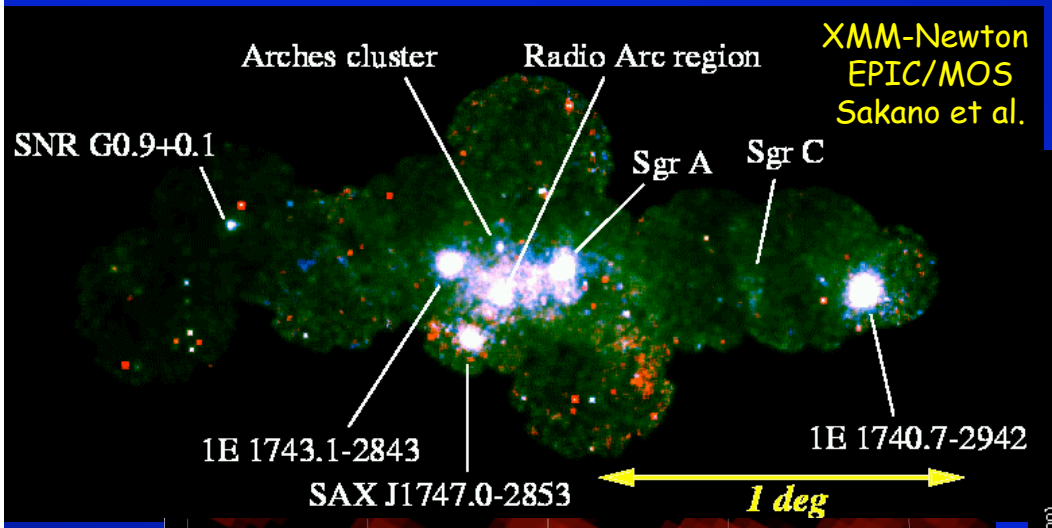
- MIT/OSO-7 (15-40 keV) - 1971-1973 - e.g. Markert et al. 1979
- CGRO/BATSE (20-100 keV) - 1991-2000 - e.g. Harmon et al. 2004
- Swift/BAT (15-50 keV) - 2005-? - e.g. Krimm et al. 2006 (still ongoing)

The past: GRANAT/Sigma



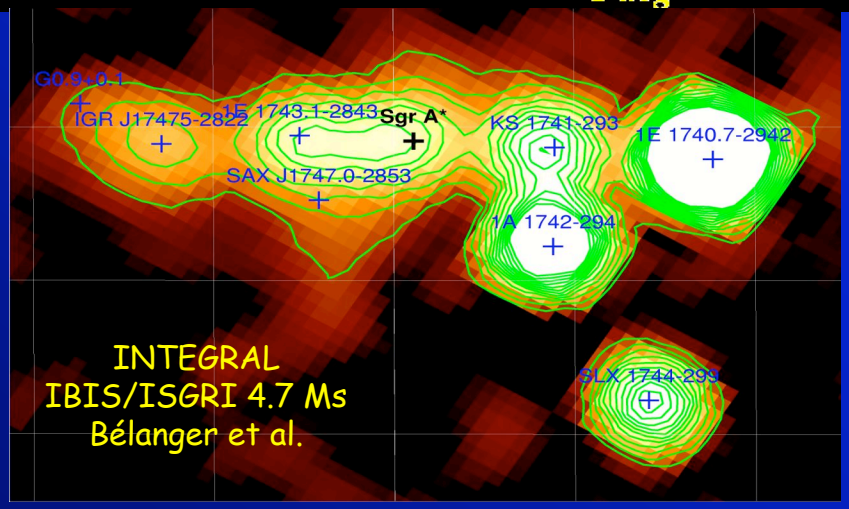


INTEGRAL vs. some others - 2



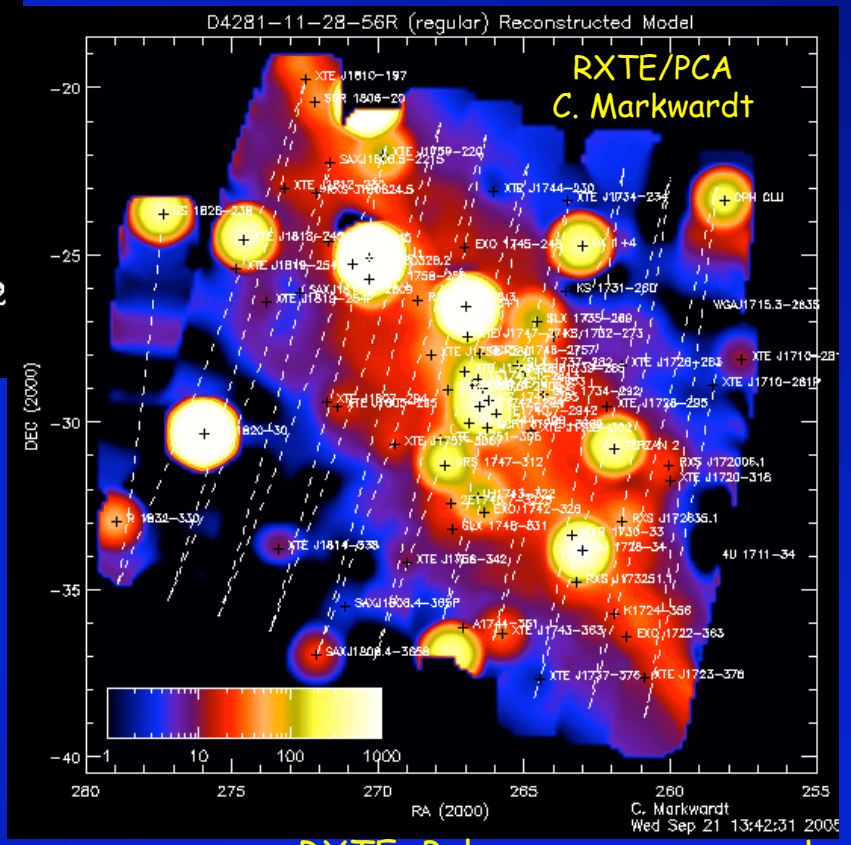
XMM-Newton
EPIC/MOS
Sakano et al.

XMM-Newton & Chandra:
GC exposures few months
(PI: Wijnands)



INTEGRAL
IBIS/ISGRI 4.7 Ms
Bélanger et al.

INTEGRAL: Bulge exposures every ~3 days
(PI: Kuulkers)



RXTE: Bulge scans every week
(PI: Markwardt)

INTEGRAL vs. some others - 3

IBIS/ISGRI:

- 15 keV - 1 MeV, PSF 12', FCFOV 8.3°x8°, PCFOV 29°x29° (zero response)

`Comparable' instruments currently in operation:

Swift/BAT:

- 15-150 keV, PSF 22', FOV 2.0 sr (partially coded)

  But no dedicated GB monitoring + bad resolution in GC

RXTE/HEXTE:

- 15-250 keV, 2° collimator:

  Only GB scans + no imaging

Twinkle, twinkle, little star

- X/γ-ray sources are variable on time scales of millisecond to days (quasi-periodic oscillations, pulsations, [absorption] dips, eclipses, type I and type II X-ray bursts, orbital variations, flares) and weeks to years (orbital variations, outburst cycles, on/off states)

  → the region never looks exactly the same.

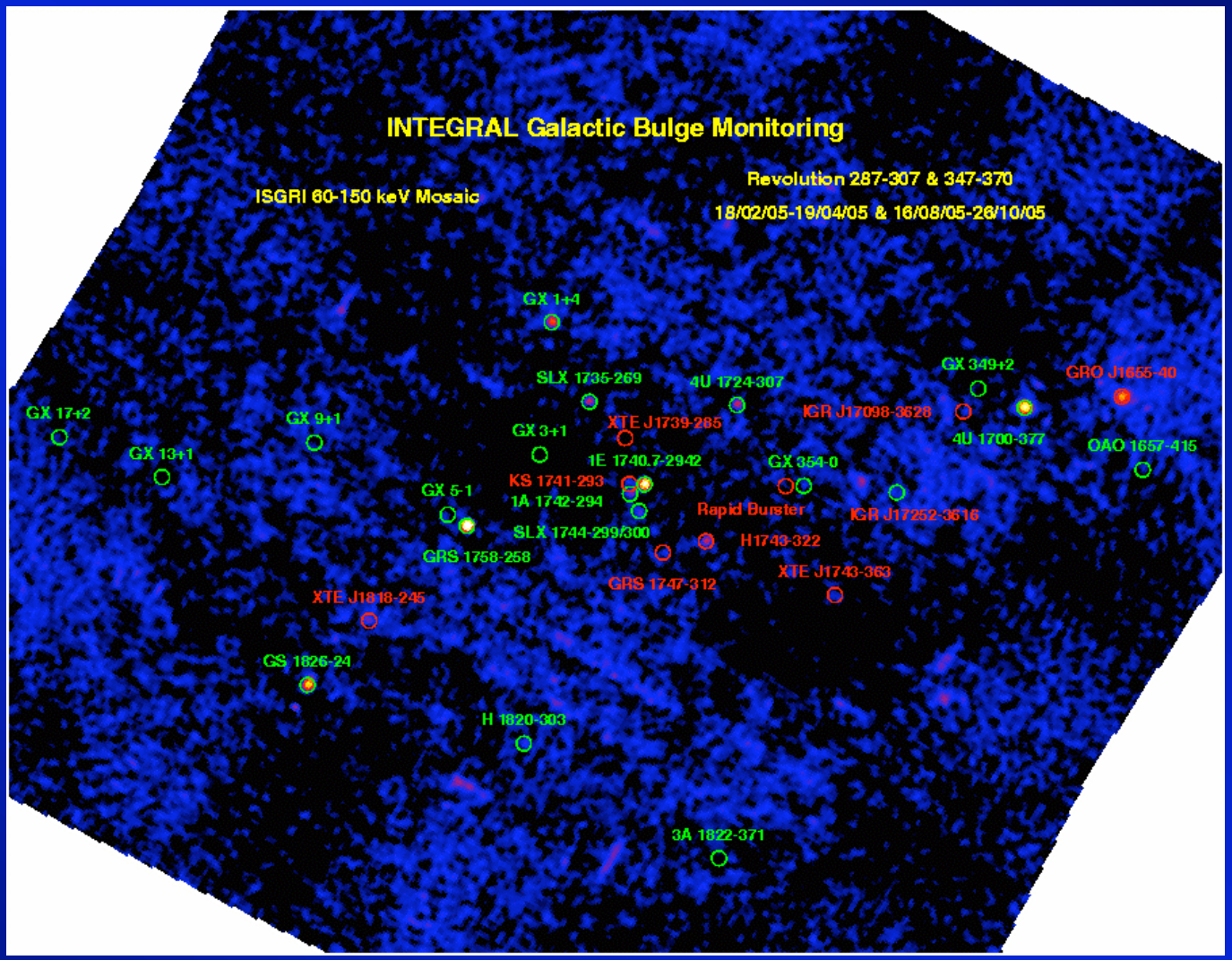
- Today: focus on the short (hour), medium (month) and long-term (year) variability in hard X-rays (20-60 keV and 60-150 keV).
  When available, also discuss soft X-rays (2-10 keV)

Some results

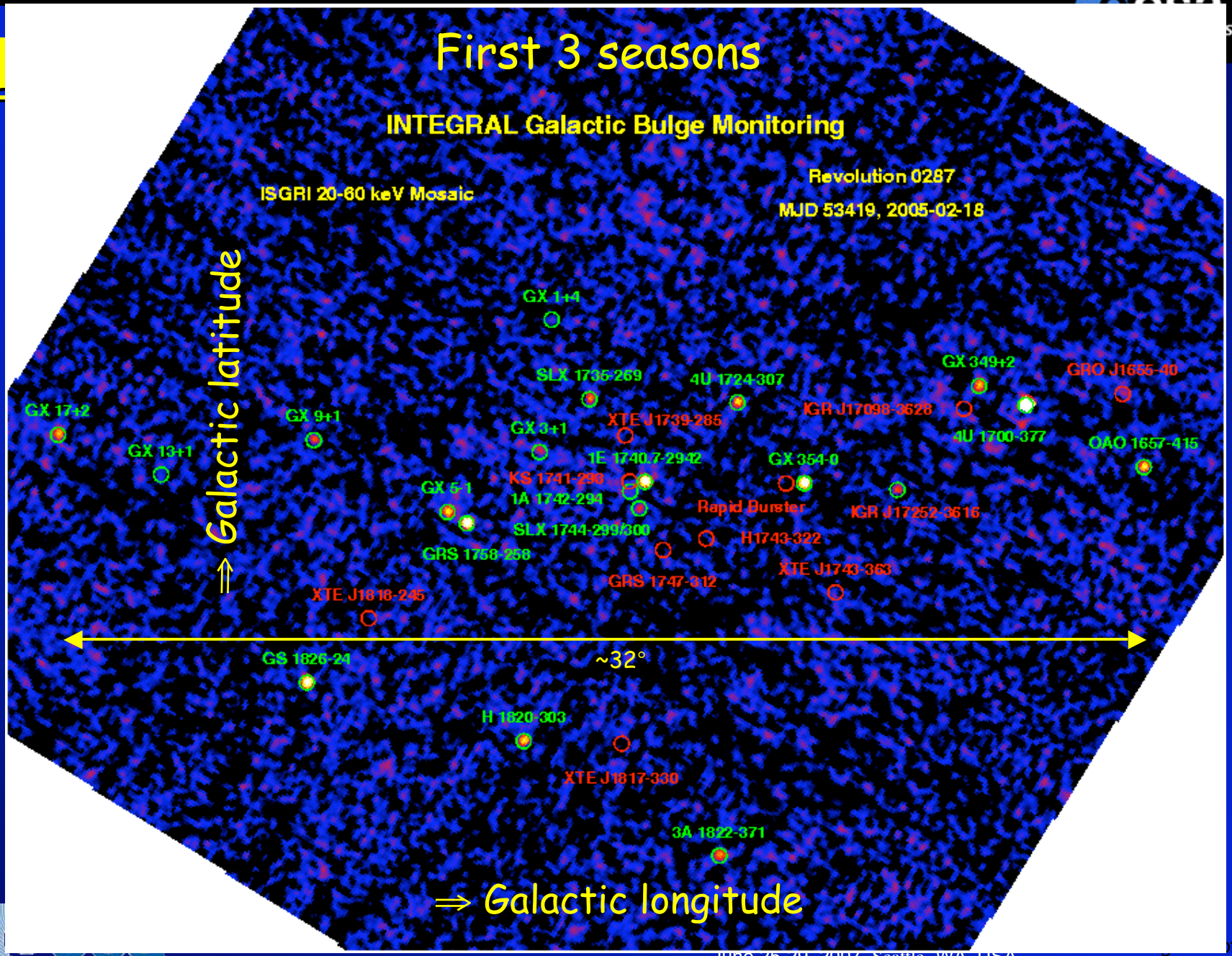
- Simultaneous monitoring of various compact binaires, i.e., low-mass and high-mass X-ray binaries containing either a neutron star or black hole at low energies ... and high energies:

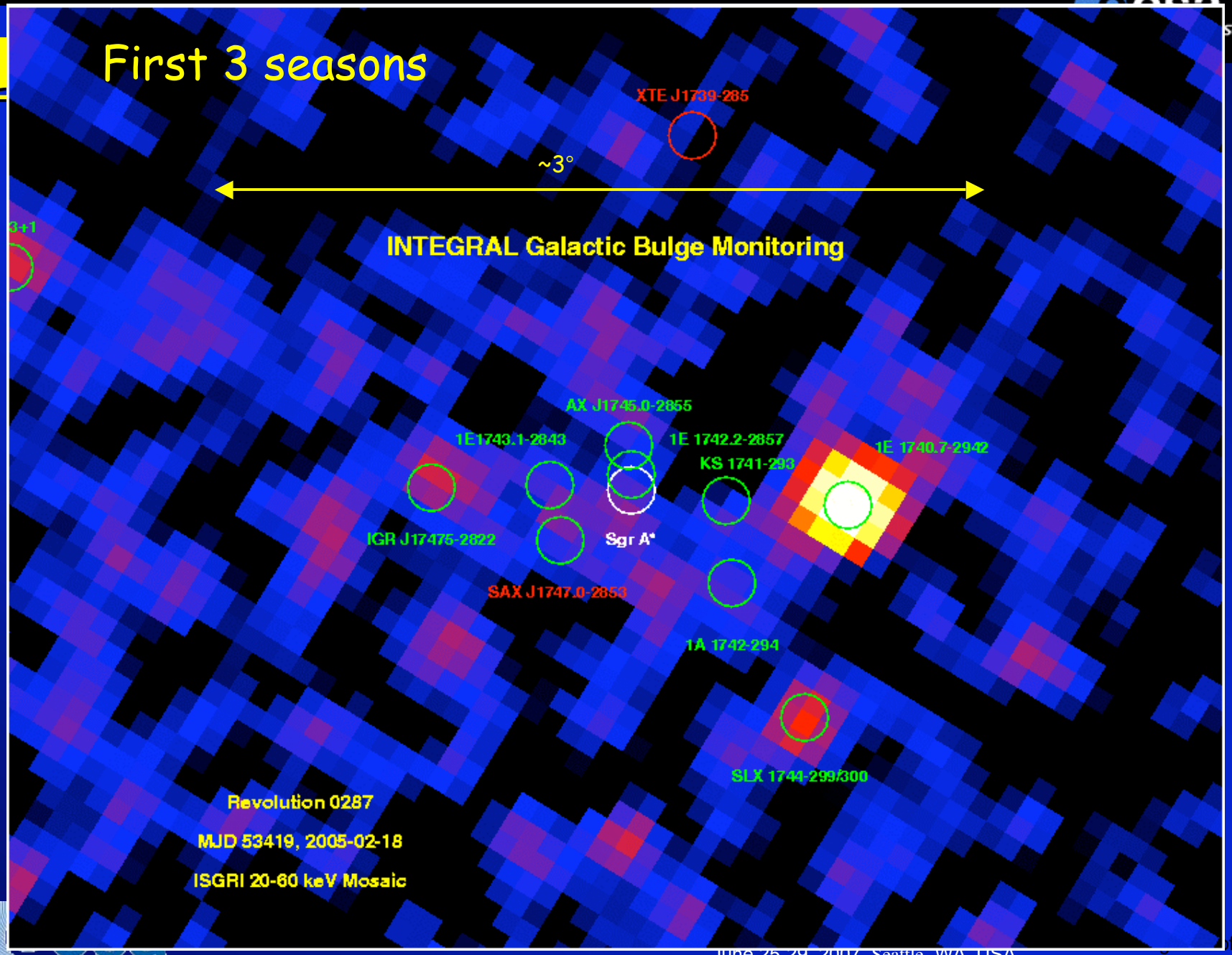
20-150 keV

20-60 keV

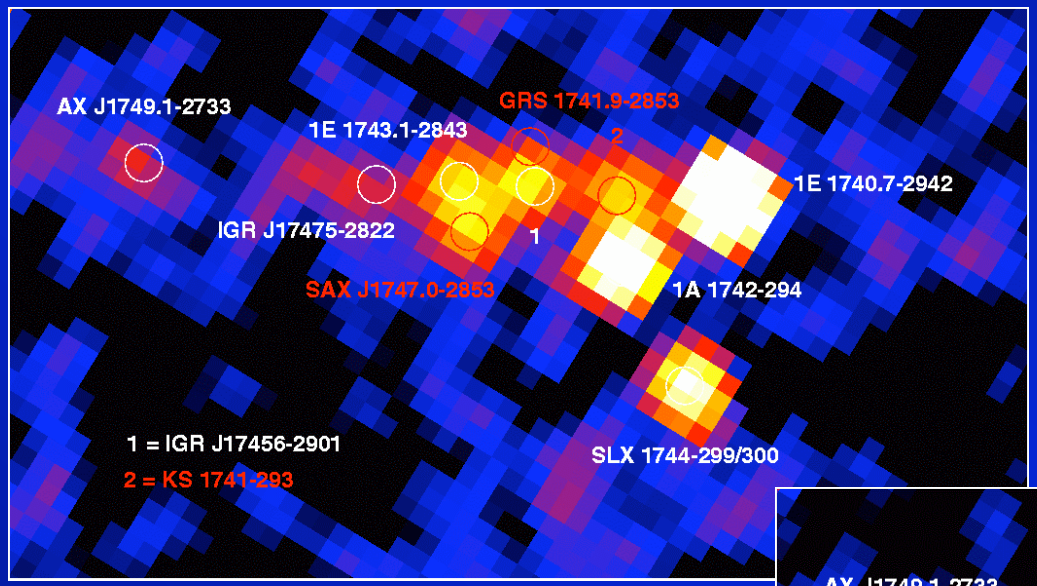


- 3 seasons


First 3 seasons
INTEGRAL Galactic Bulge Monitoring
ISGRI 20-60 keV Mosaic
Revolution 0287
MJD 53419, 2005-02-18
⇒ Galactic latitude
GX 1+4
SLX 1735-269
4U 1724-307
GX 349+2
GRO J1655-40
GX 17+2
GX 9+1
XTE J1739-285
IGR J17098-3628
4U 1700-377
OAO 1657-415
GX 13+1
GX 3+1
1E 1740.7-2942
GX 354-0
KS 1741-293
GX 5-1
1A 1742-294
Rapid Burster
IGR J17252-3616
SLX 1744-299/300
H1743-322
GRS 1758-258
XTE J1743-363
GRS 1747-312
XTE J1818-245
~32°
GS 1826-24
H 1820-303
XTE J1817-330
3A 1822-371
⇒ Galactic longitude

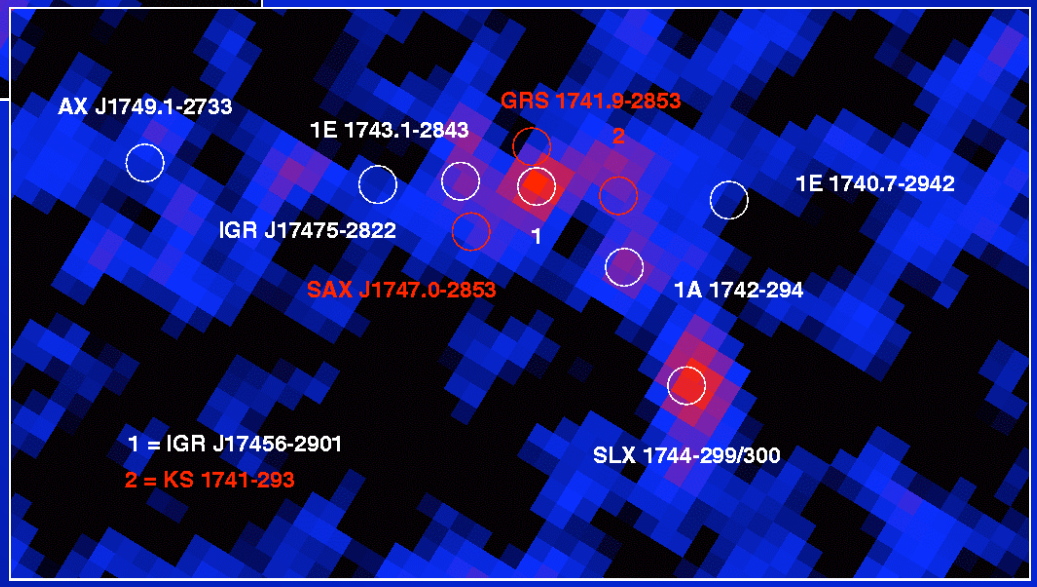

First 3 seasons
XTE J1739-285
~3°
INTEGRAL Galactic Bulge Monitoring
AX J1745.0-2855
1E1743.1-2843
1E 1742.2-2857
KS 1741-293
1E 1740.7-2942
IGR J17475-2822
Sgr A*
SAX J1747.0-2853
1A 1742-294
SLX 1744-299/300
Revolution 0287
MJD 53419, 2005-02-18
ISGRI 20-60 keV Mosaic

The GC region playing hide and seek



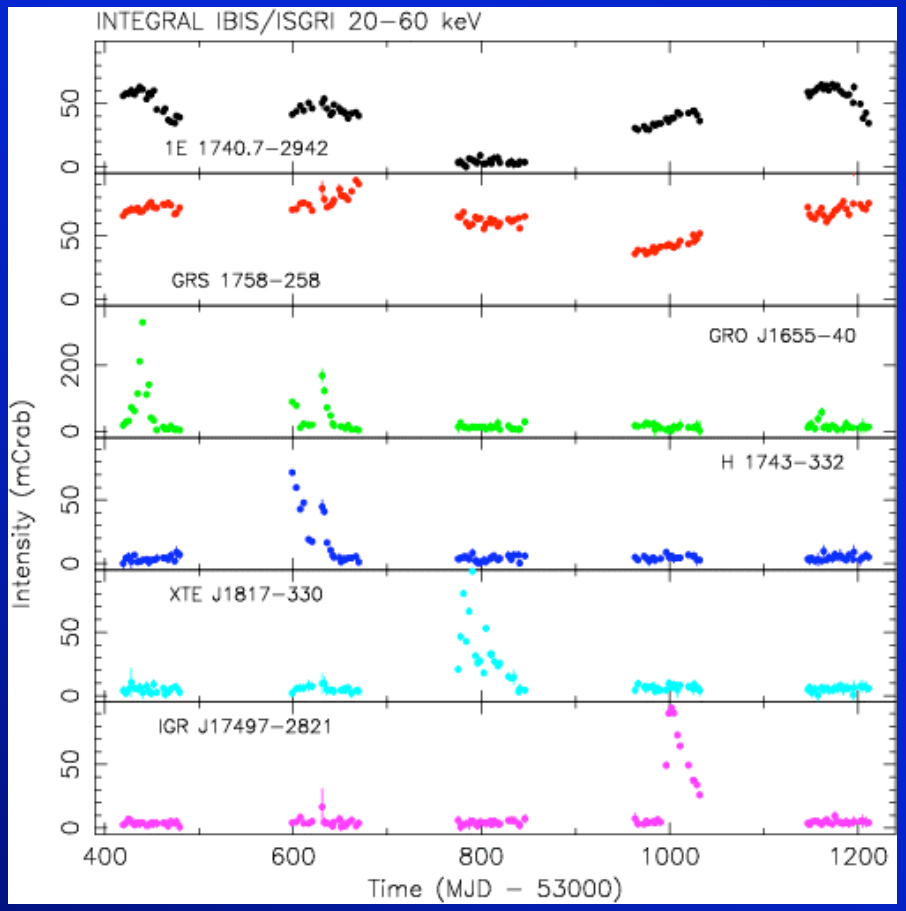
April 2006
69 ksec

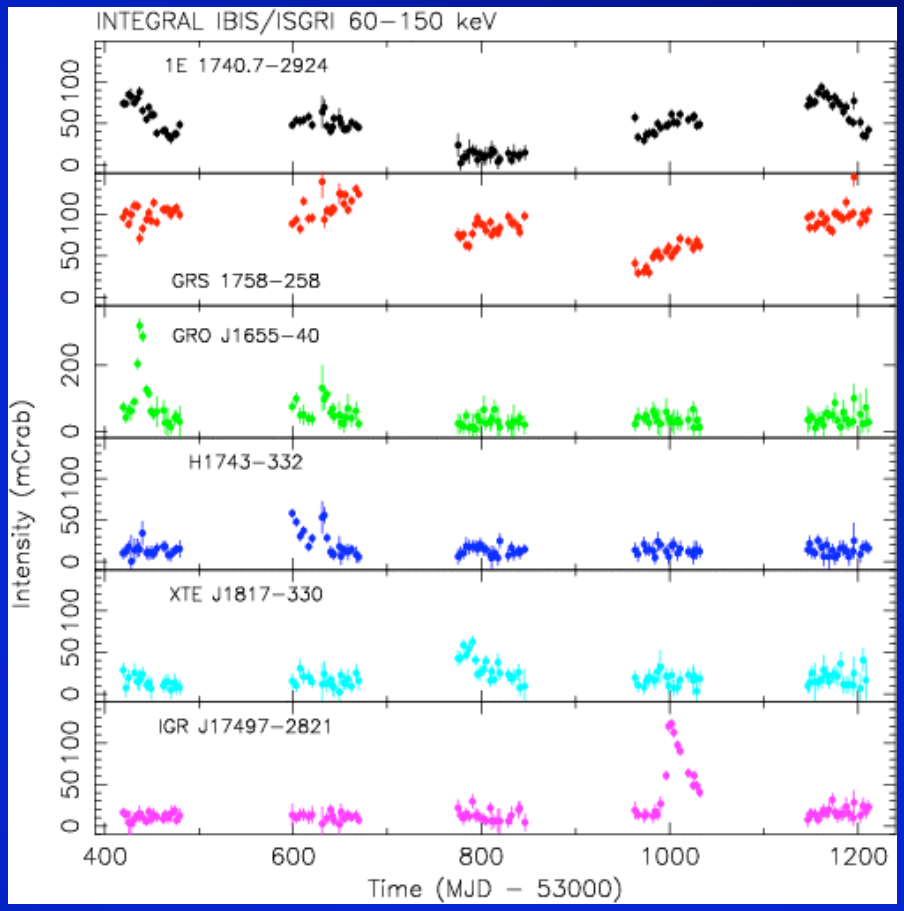
3 seasons
727 ksec



Same scale;
no magic...

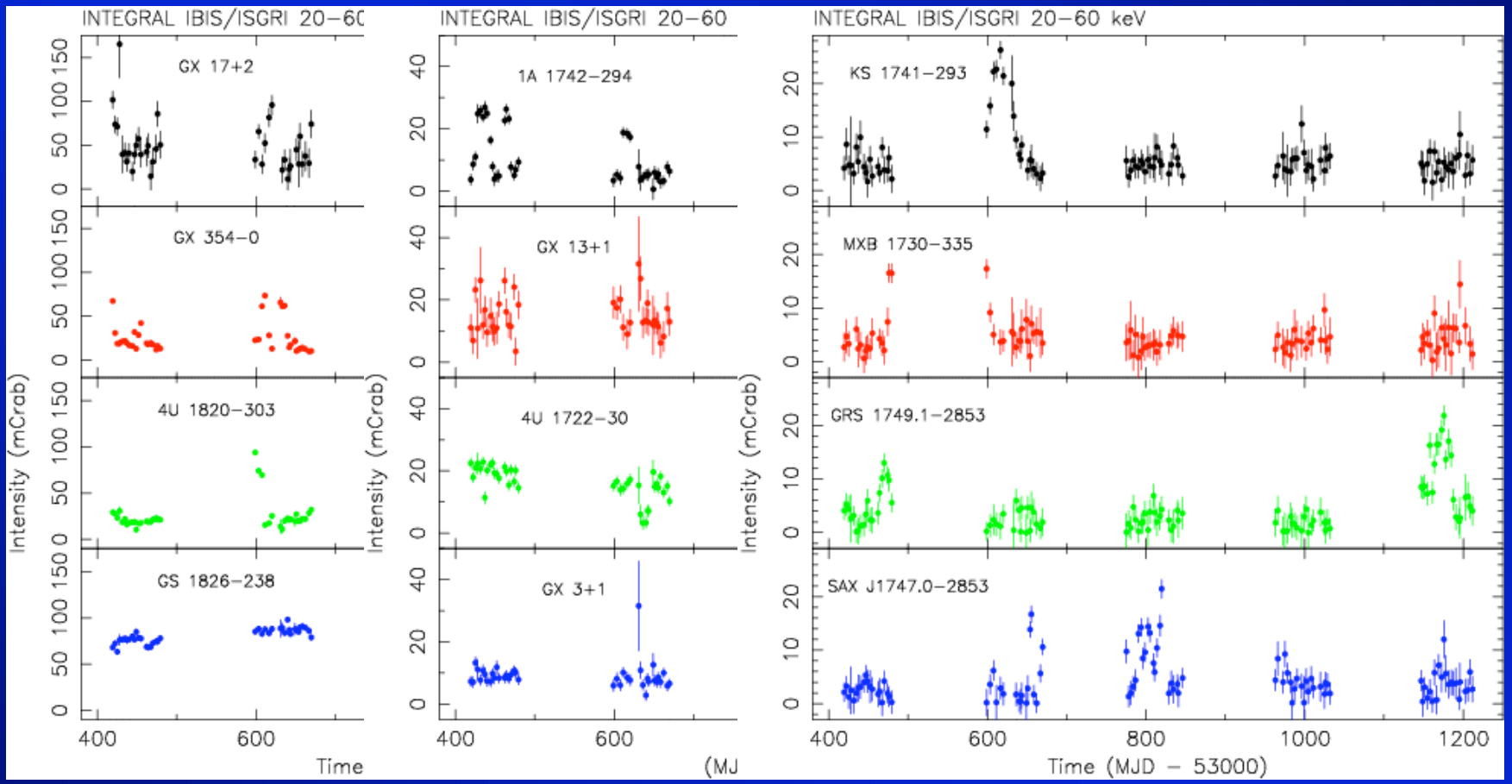
IBIS/ISGRI light curves - BHC





20-60 keV 5 seasons 60-150 keV

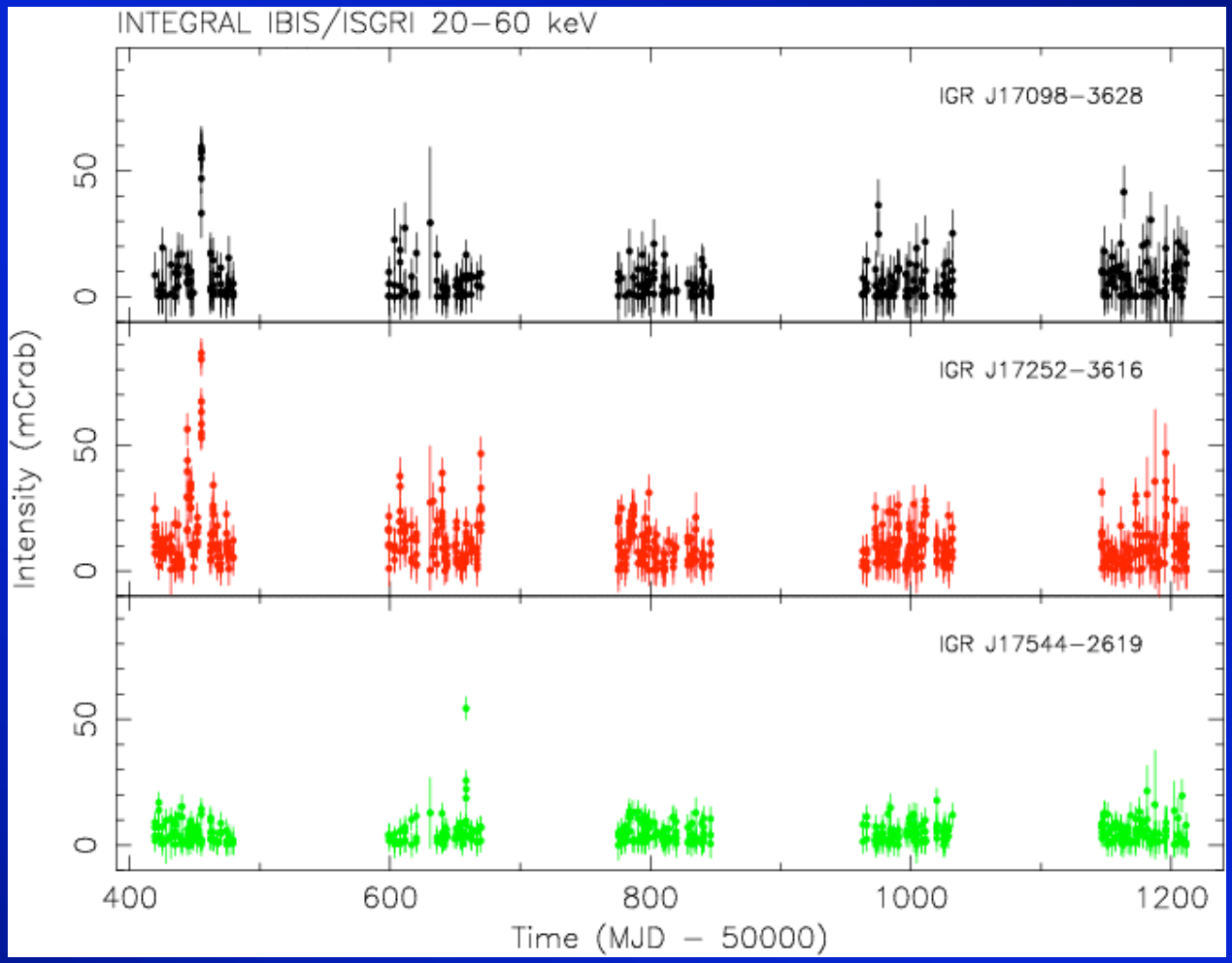
IBIS/ISGRI light curves - XRB



5 seasons

20-60 keV

IBIS/ISGRI light curves - IGRs



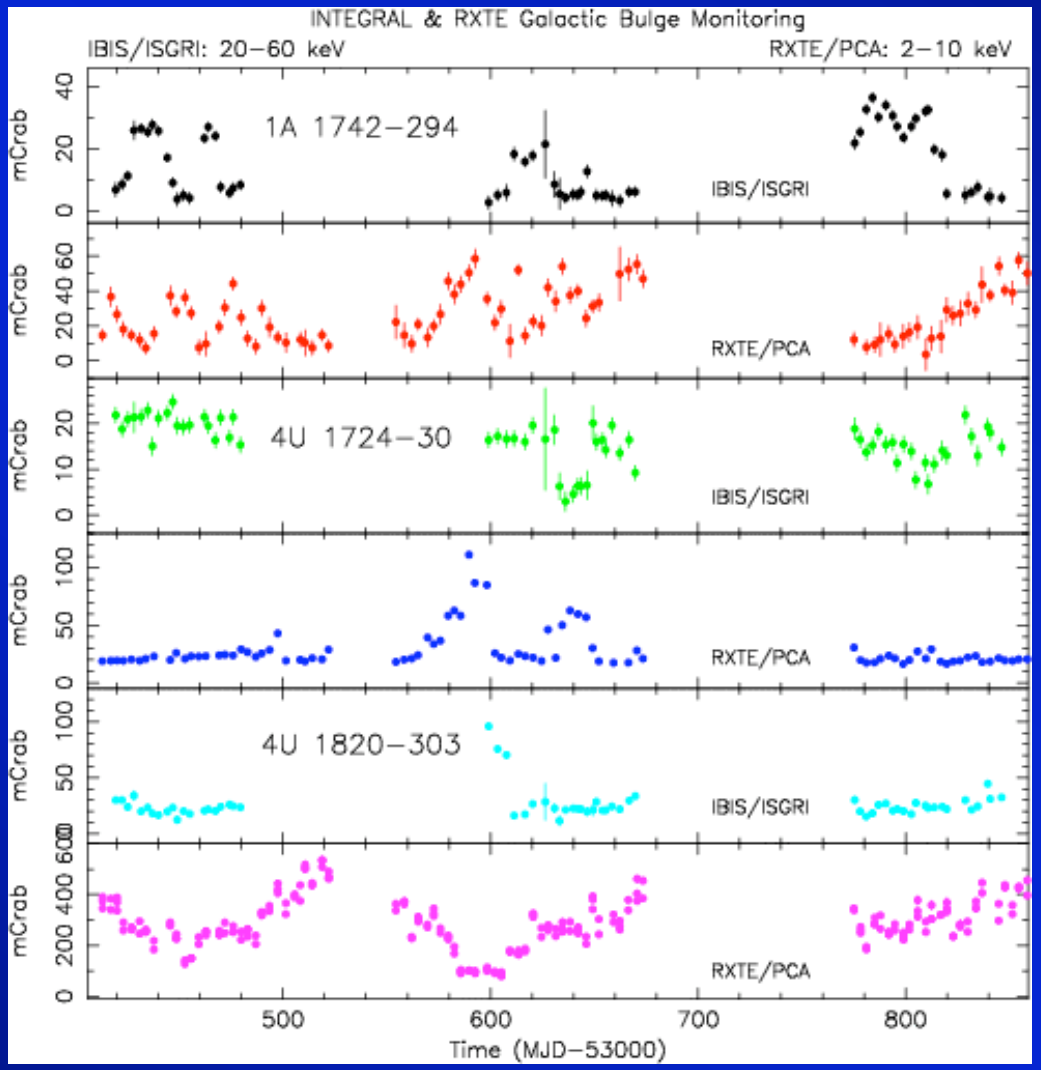
20-60 keV

5 seasons

Hard X-ray vs. soft X-ray light curves

IBIS/ISGRI:
20-60 keV

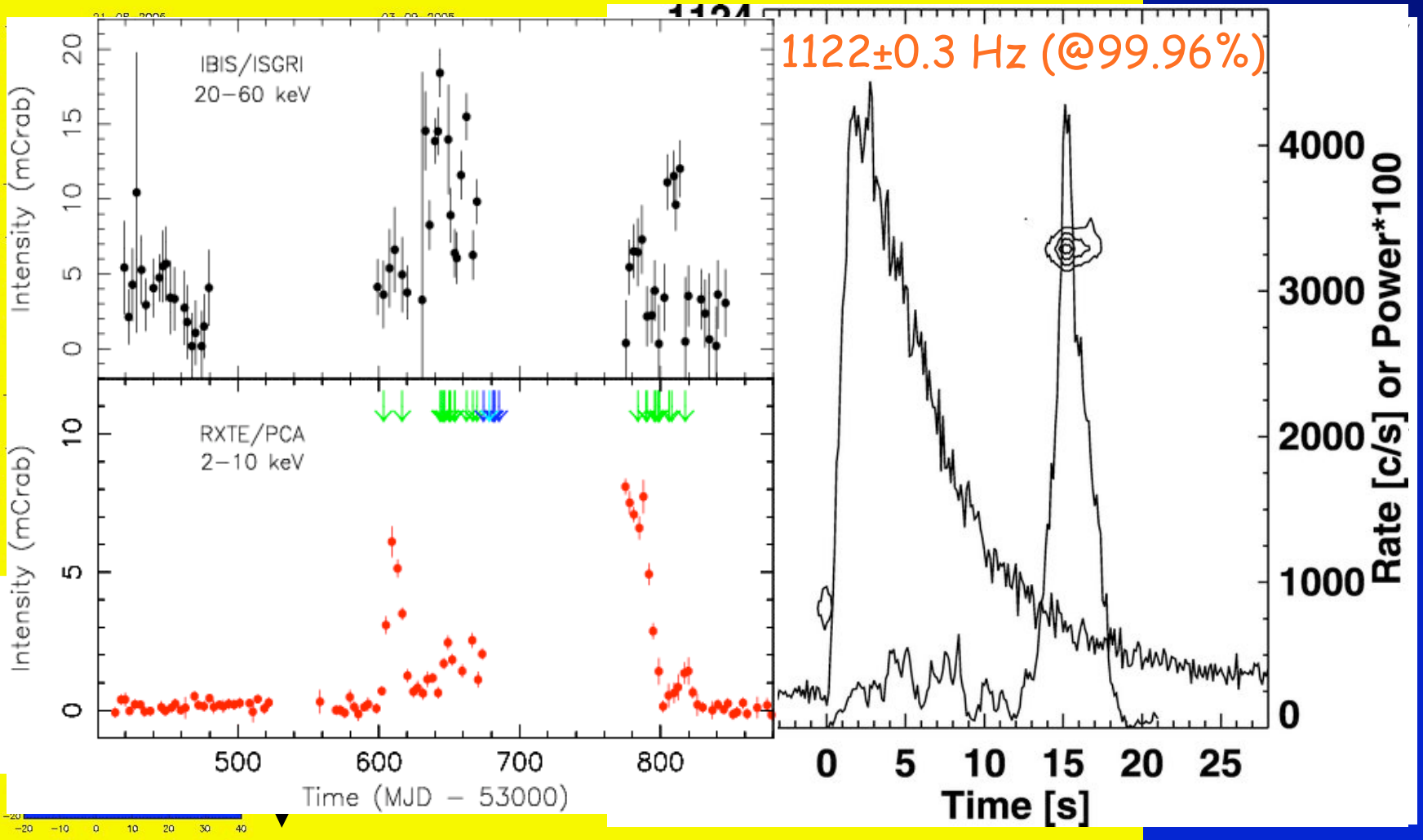
RXTE/PCA:
2-10 keV



Anti-
correlation

3 seasons

XTE J1739-285 (new XRB)



Executive Summary (Kuulkers et al. 2007)

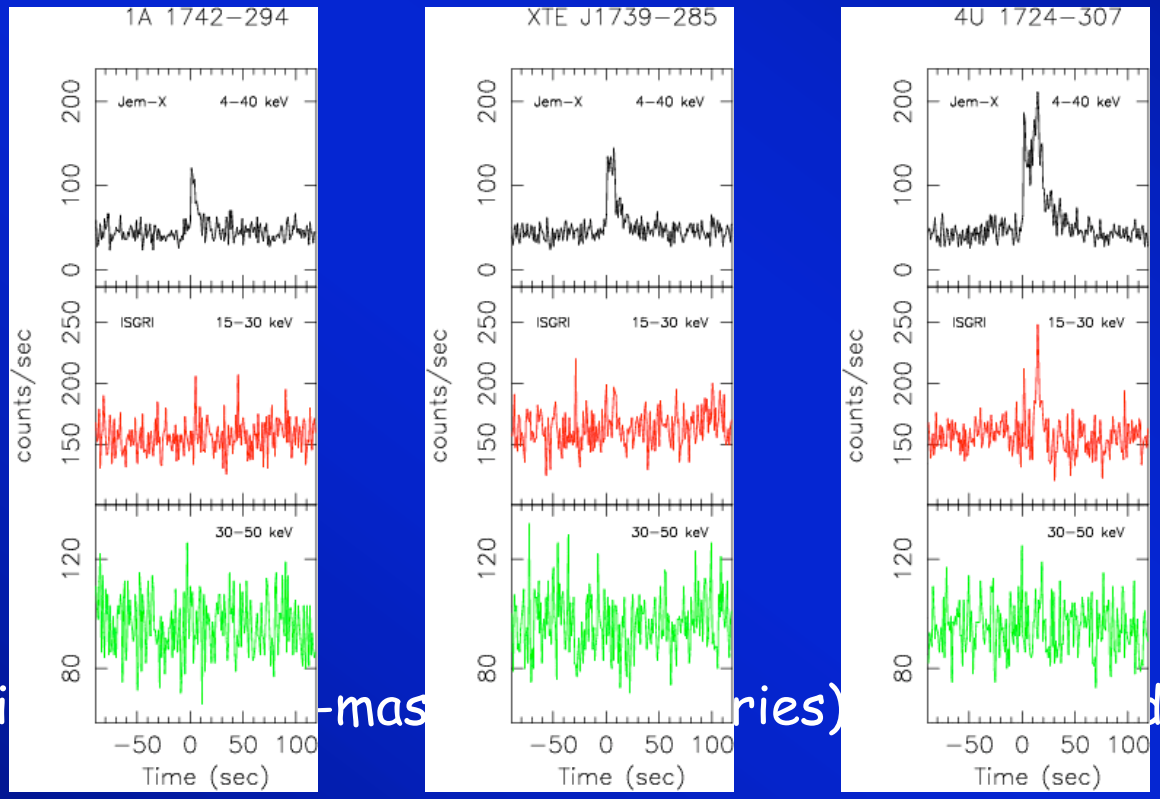
• Per visibility season we detect ~30 sources at 20-60 keV; 1/3 of these also at 60-150 keV (transient/persistent black-hole candidate sources, X-ray bursters, high-mass X-ray binaries; see also Bazzano et al. 2006)

• On average per visibility season :
- 1 active bright (>~100 mCrab, 20-60 keV) black-hole candidate X-ray transient
- 3 active weaker (<~25 mCrab, 20-60 keV) neutron star X-ray transients
- 1 fast X-ray transient (up to ~100 mCrab, 20-60 keV)

• Most of the time: clear anti-correlation can be seen between the soft and hard X-ray emission in some of the X-ray bursters:
- hard X-ray flares or outbursts (~weeks) accompanied by soft X-ray drops
- hard X-ray drops can be accompanied by soft X-ray flares/outbursts

To-do list

- Light curves/variability (down to min/sec); e.g. type I X-ray bursts, superbursts --> Martin Willitsch (pre-graduate student at ESAC)



Jem-X
4-40 keV

IBIS/ISGRI
15-30 keV

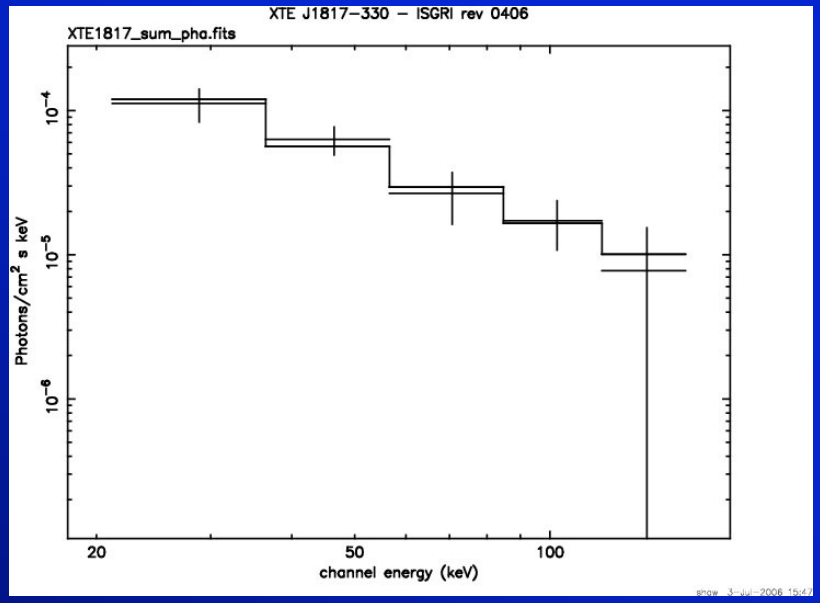
IBIS/ISGRI
30-50 keV

- Pulse timi -mas ries) dent next week

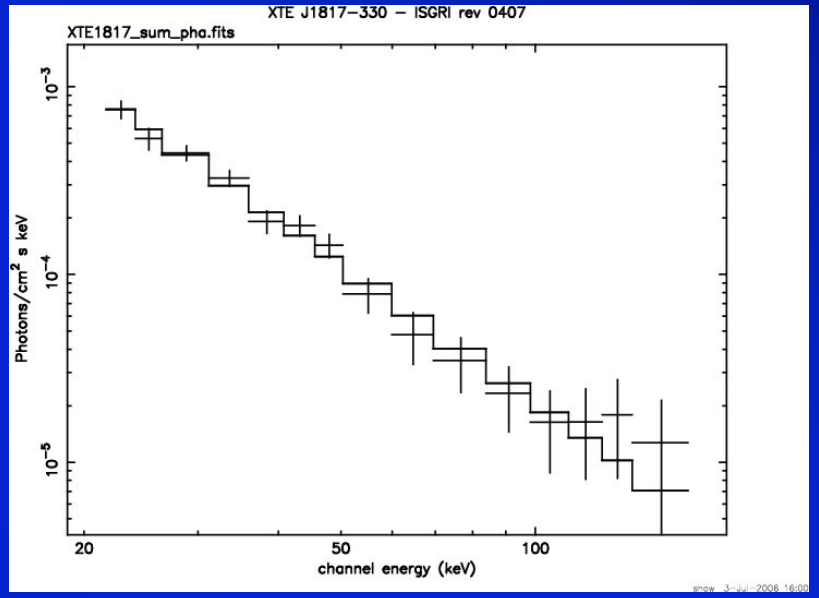
To-do list - 2

- Spectra, for all sources, each Hex observation + simple modeling
--> Laura Barragan (pre-graduate student at ESAC)

XTE J1817-330



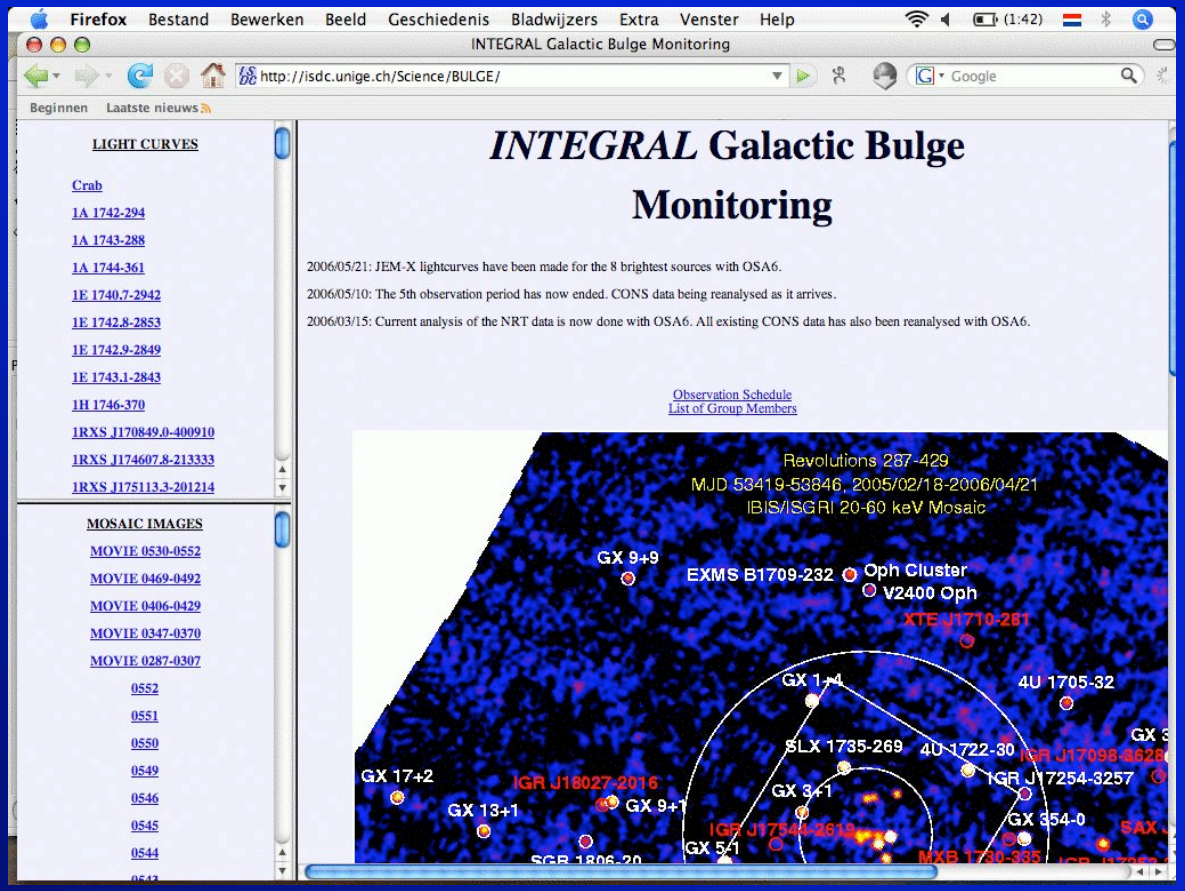
Rev 406; Γ~1.5
9 feb 2006



Rev 407; Γ~2.4
11 feb 2006

Watch this space

- Galactic bulge monitoring program to be continued



http://isdc.unige.ch/Science/BULGE

or e-mail us at:

gb-group@isdcmail.unige.ch

Bob's quest

What one thing would you like the nuclear theorists to take away from your talk ?

Bugger...

Take away

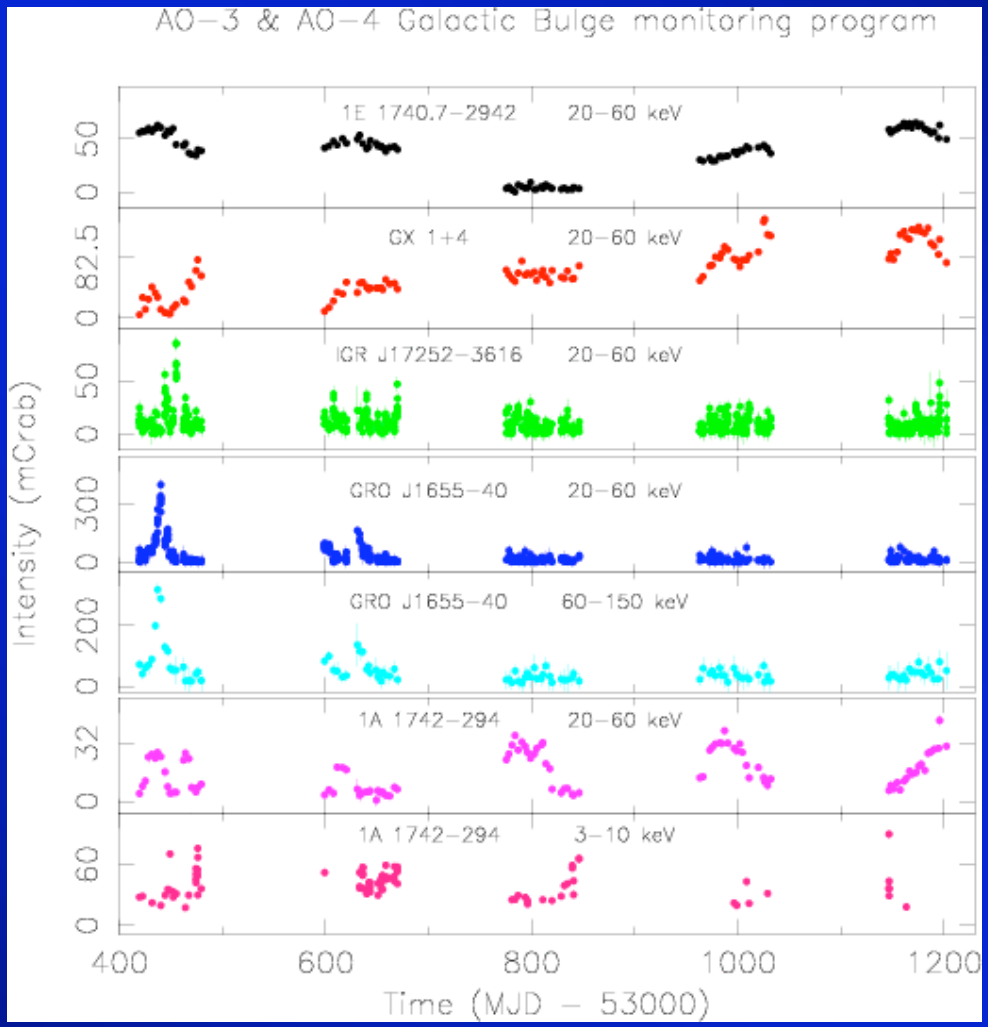
Google: `Top Ten Myths About Evolution'

1. *Humans evolved from monkeys*
2. *It's Only A Theory*
3. *If nobody saw it, we can't be sure it happened*

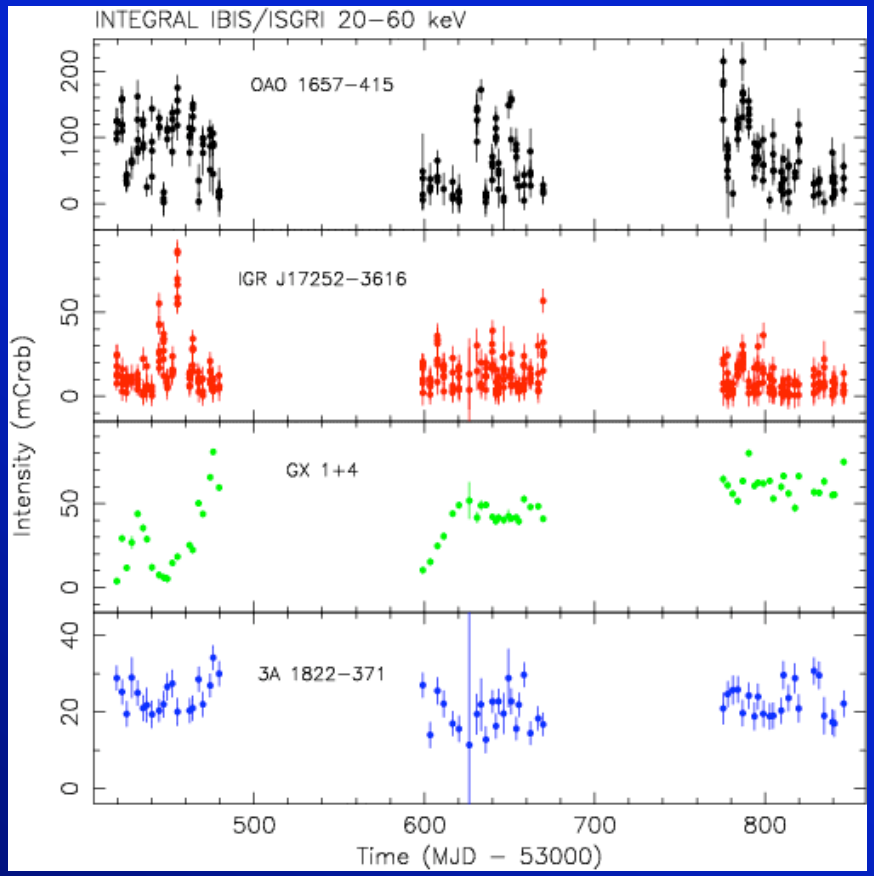
etc...

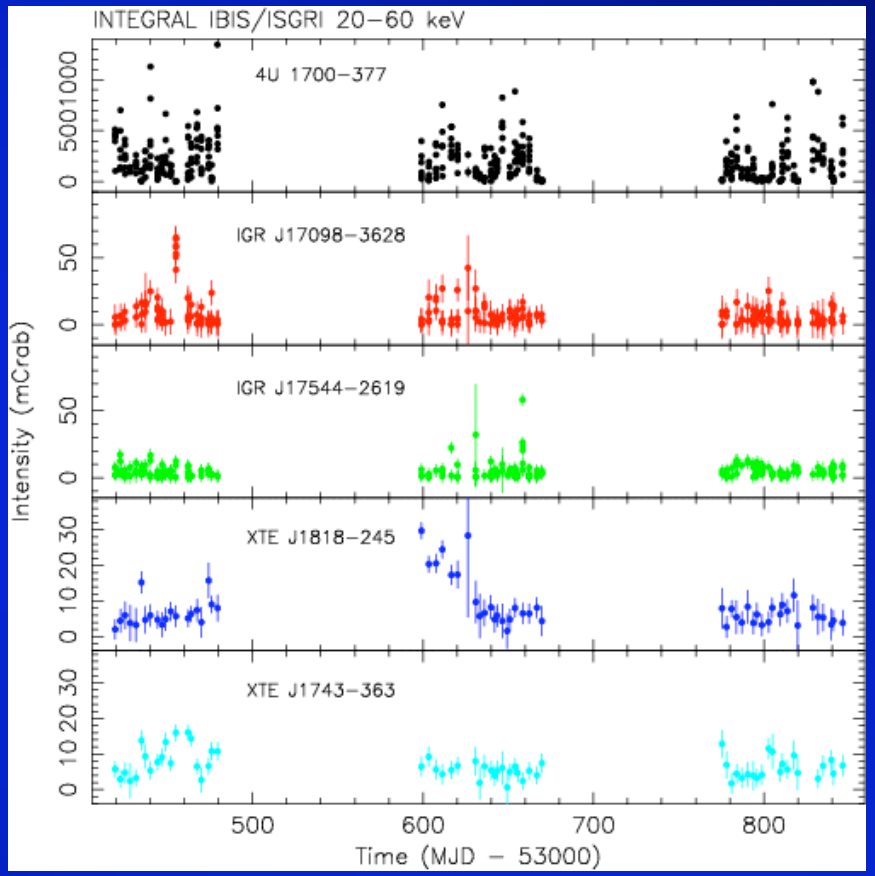
The high-energy sky changes from time to time.

5 seasons

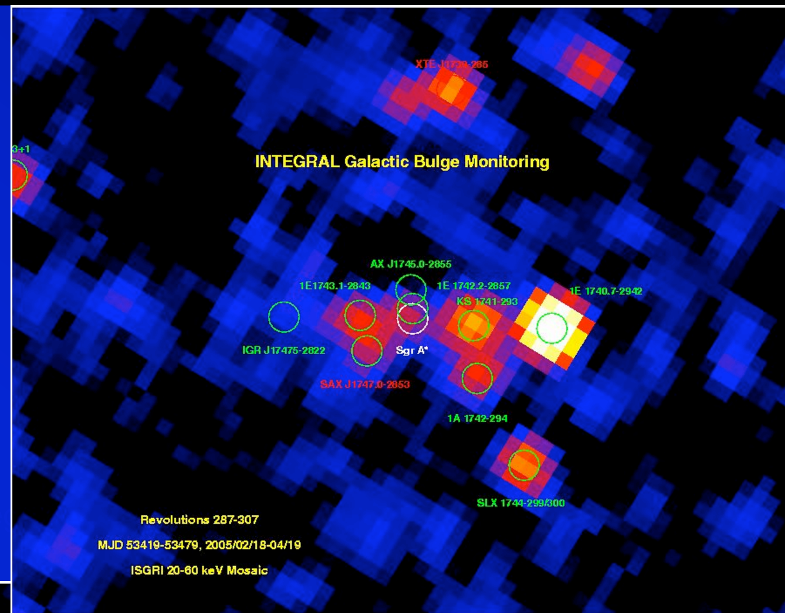

AO−3 & AO−4 Galactic Bulge monitoring program
1E 1740.7−2942 20−60 keV
GX 1+4 20−60 keV
IGR J17252−3616 20−60 keV
GRO J1655−40 20−60 keV
GRO J1655−40 60−150 keV
1A 1742−294 20−60 keV
1A 1742−294 3−10 keV
Intensity (mCrab)
0 50
0 82.5
0 50
0 300
0 200
0 32
0 60
400
600
800
1000
1200
Time (MJD − 53000)

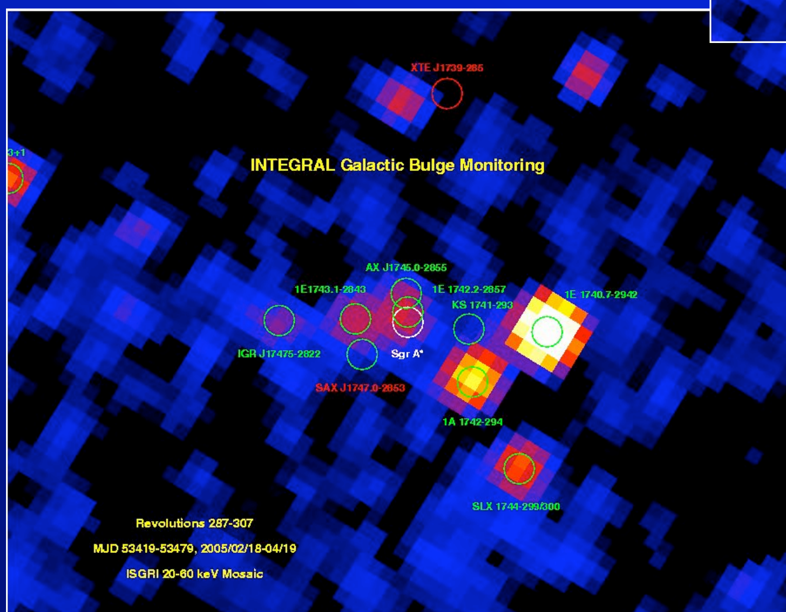
More IBIS/ISGRI light curves...





3 Seasons


INTEGRAL Galactic Bulge Monitoring
XTE J1739-285
AX J1745.0-2855
1E1743.1-2843
1E 1742.2-2857
KS 1741-293
1E 1740.7-2942
IGR J17475-2822
Sgr A*
SAX J1747.0-2853
1A 1742-294
SLX 1744-299/300
Revolutions 287-307
MJD 53419-53479, 2005/02/18-04/19
ISGRI 20-60 keV Mosaic


XTE J1739-285
INTEGRAL Galactic Bulge Monitoring
AX J1745.0-2855
1E1743.1-2843
1E 1742.2-2857
KS 1741-293
1E 1740.7-2942
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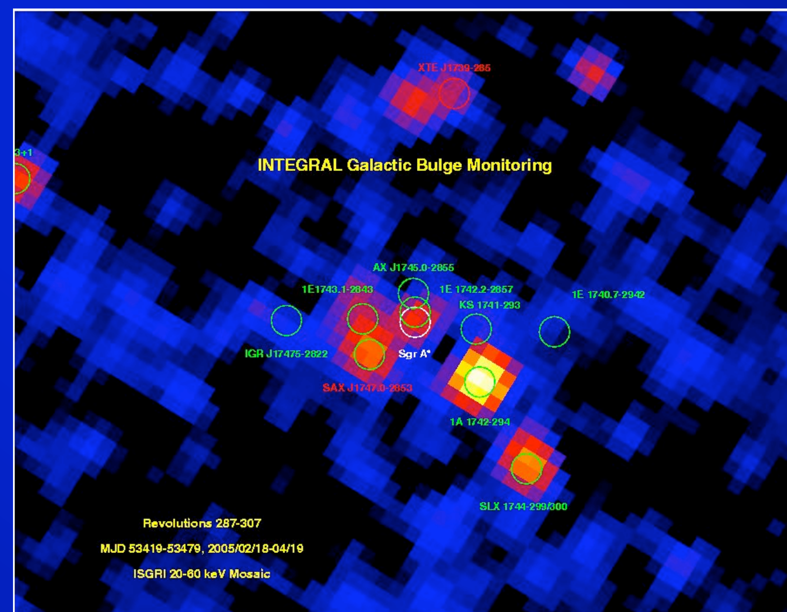
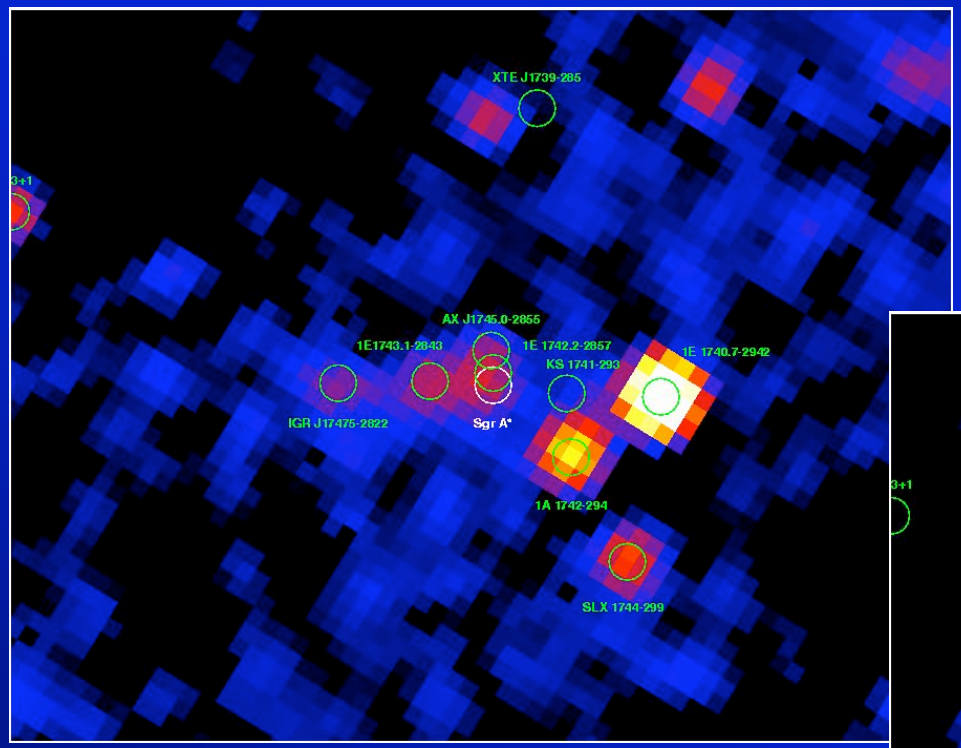
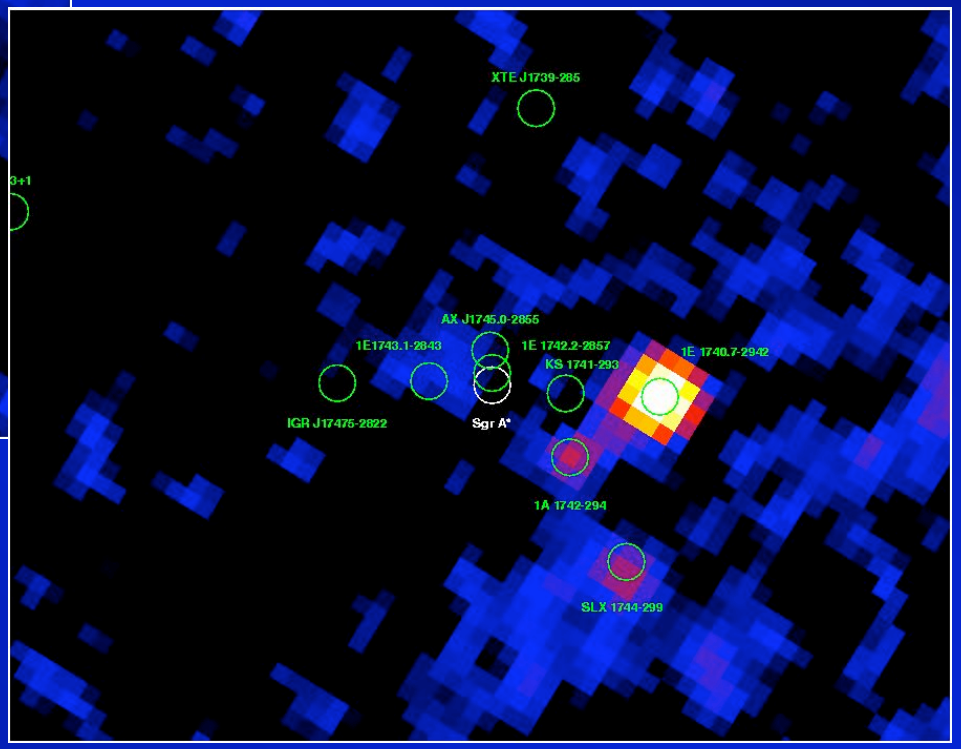
Sgr A*
SAX J1747.0-2853
1A 1742-294
SLX 1744-299/300
Revolutions 287-307
MJD 53419-53479, 2005/02/18-04/19
ISGRI 20-60 keV Mosaic


XTE J1739-285
INTEGRAL Galactic Bulge Monitoring
AX J1745.0-2855
1E1743.1-2843
1E 1742.2-2857
KS 1741-293
1E 1740.7-2942
IGR J17475-2822
Sgr A*
SAX J1747.0-2853
1A 1742-294
SLX 1744-299/300
Revolutions 287-307
MJD 53419-53479, 2005/02/18-04/19
ISGRI 20-60 keV Mosaic

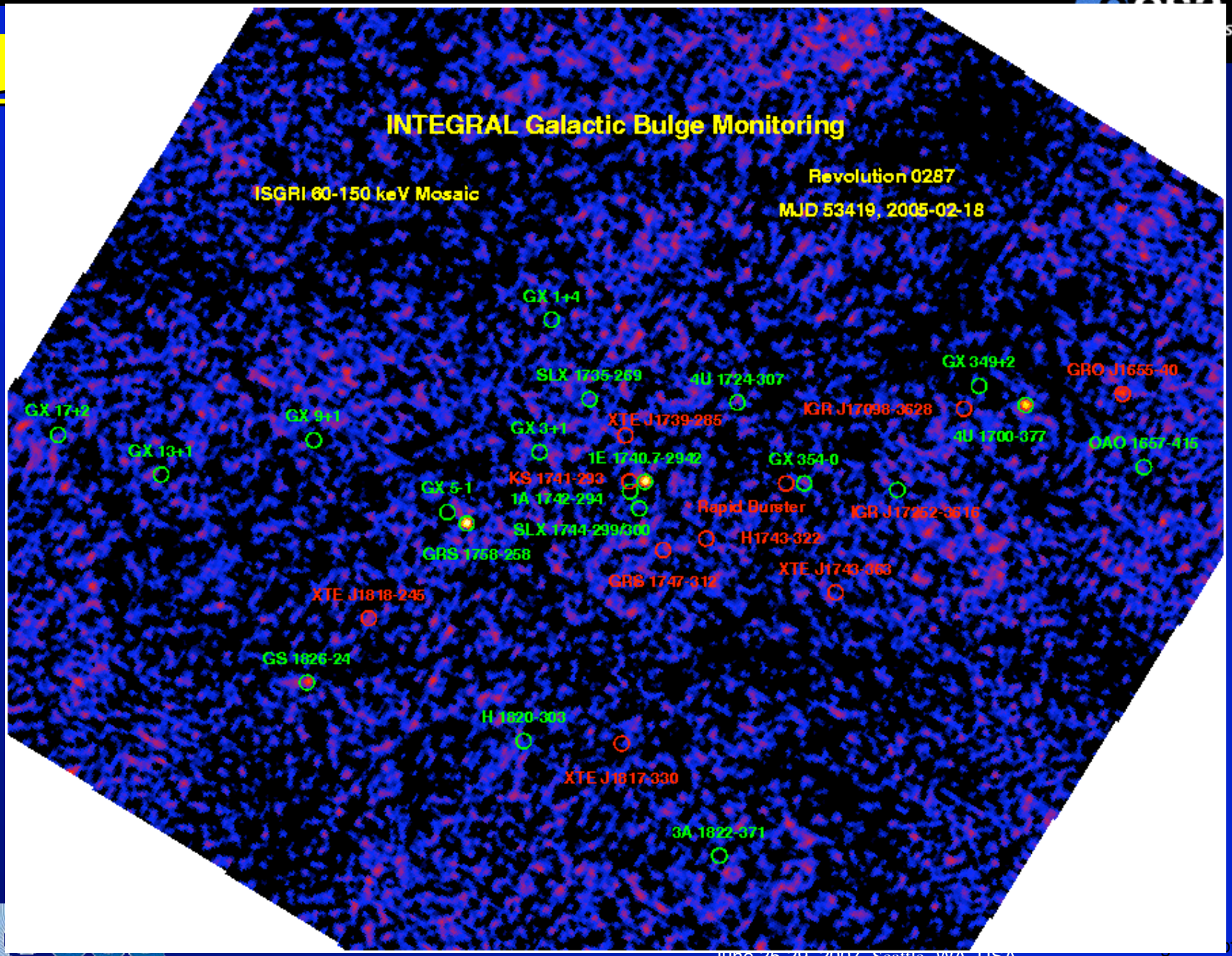
Zoom in on the GC



IBIS/ISGRI 20-60 keV



IBIS/ISGRI 60-150 keV


INTEGRAL Galactic Bulge Monitoring
ISGRI 60-150 keV Mosaic
Revolution 0287
MJD 53419, 2005-02-18
GX 1+4
SLX 1735-269
4U 1724-307
GX 349+2
GRO J1655-40
GX 17+2
GX 9+1
XTE J1739-285
IGR J17098-3628
4U 1700-377
GX 3+1
GX 13+1
1E 1740.7-2942
OAO 1657-415
GX 354-0
KS 1741-293
GX 5-1
1A 1742-294
Rapid Burster
IGR J17252-3616
SLX 1744-299/300
H1743-322
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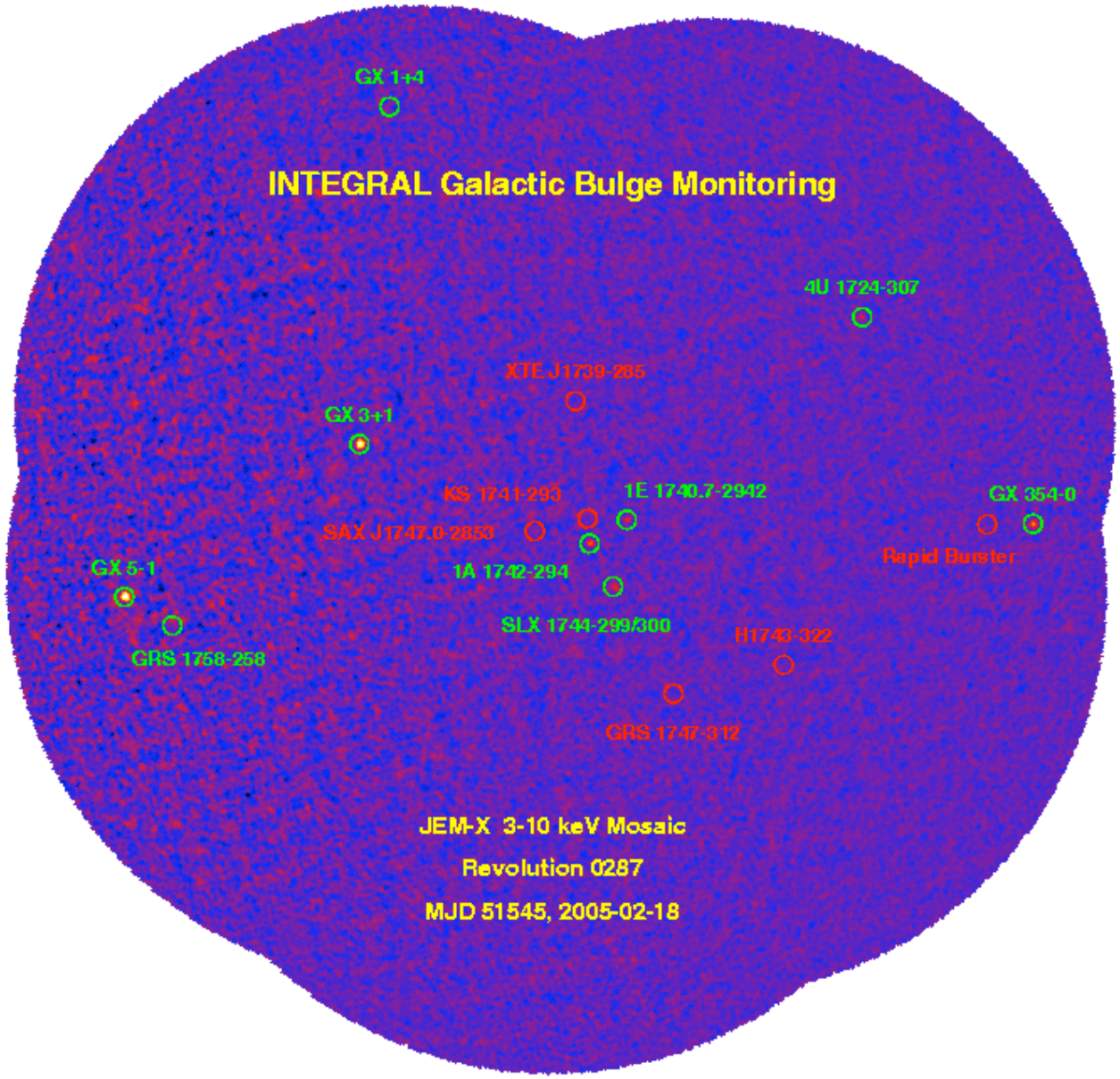
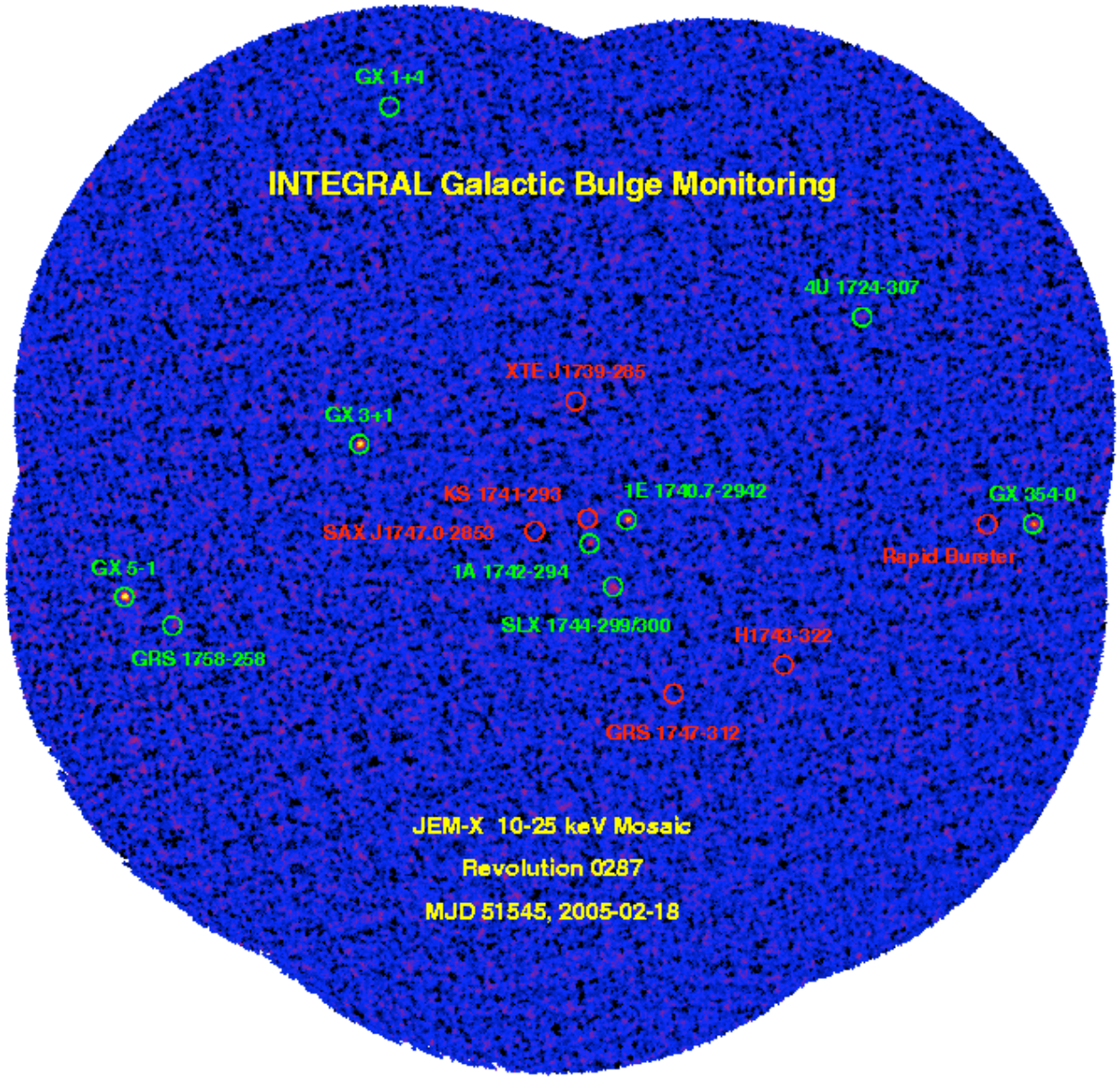
XTE J1743-363
GRS 1747-312
XTE J1818-245
GS 1826-24
H 1820-303
XTE J1817-330
3A 1822-371

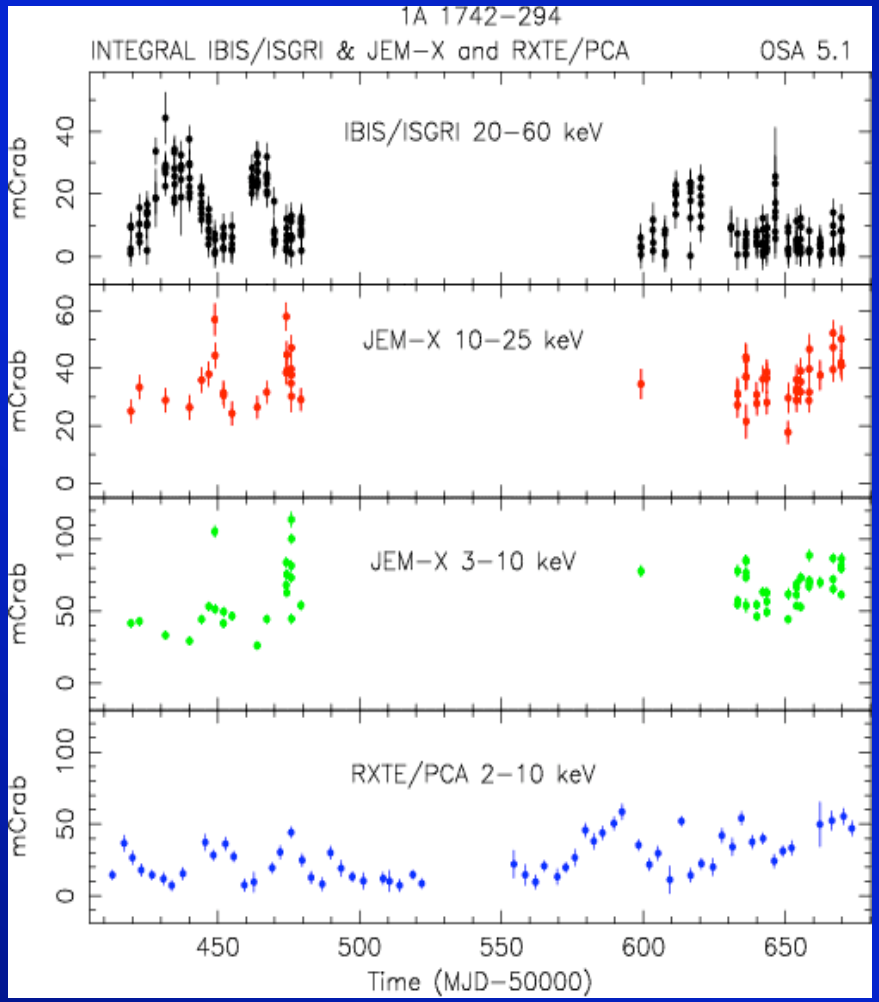


Jem-X
3-10 keV;
FOV 4.8°
(per exposure)

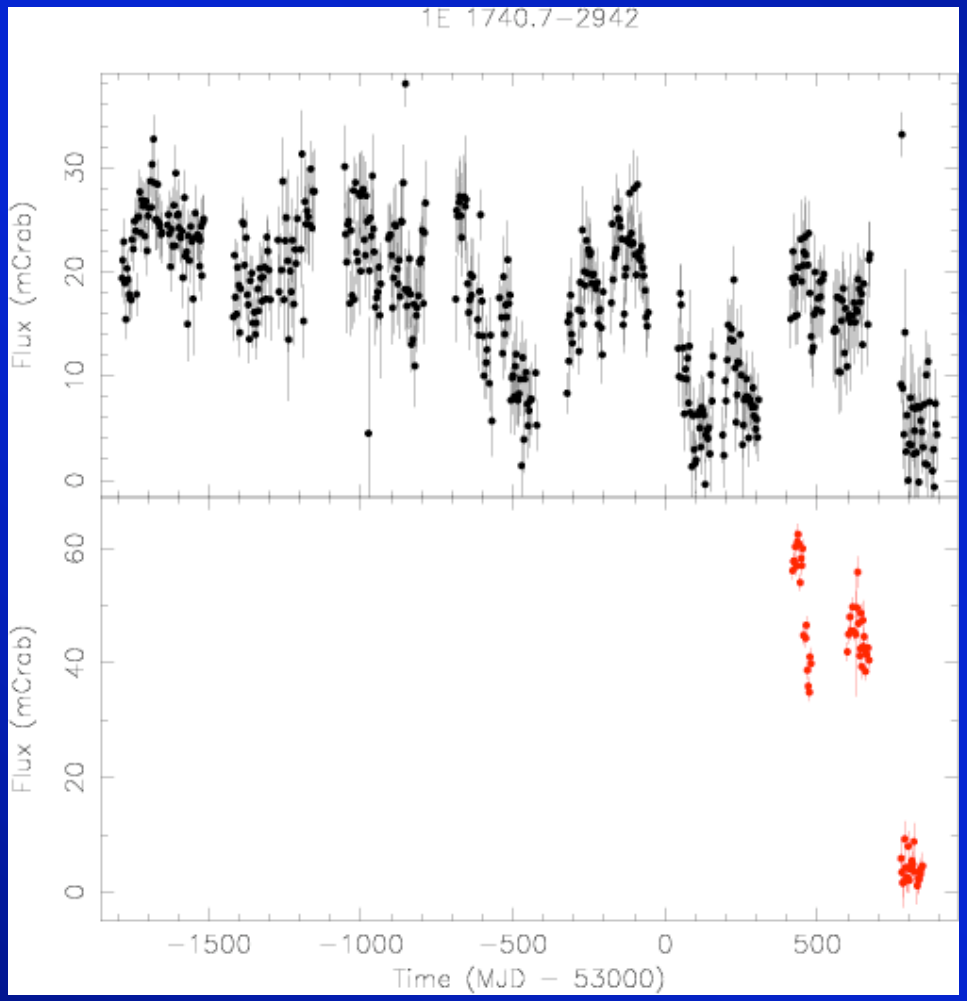


Jem-X
10-25 keV;
FOV 4.8°
(per exposure)

IBIS/ISGRI + PCA/Jem-X light curves



1E 1740.7-2942 went off...



RXTE/PCA
2-10 keV

IBIS/ISGRI
20-60 keV

XTE J1817-330 (new BHC)