The LOBSTER-EYE monitor – Perspectives of X-ray observing the Galactic center region

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The importance of the long-term coverage

- Transient X-ray sources:
  - wide-field monitoring of the sky is necessary (most transients are discovered only by the first detection of their outburst)
  - outbursts are usually unpredictable – only their mean recurrence time (cycle-length) can be determined from a long (years to decades) series of observations

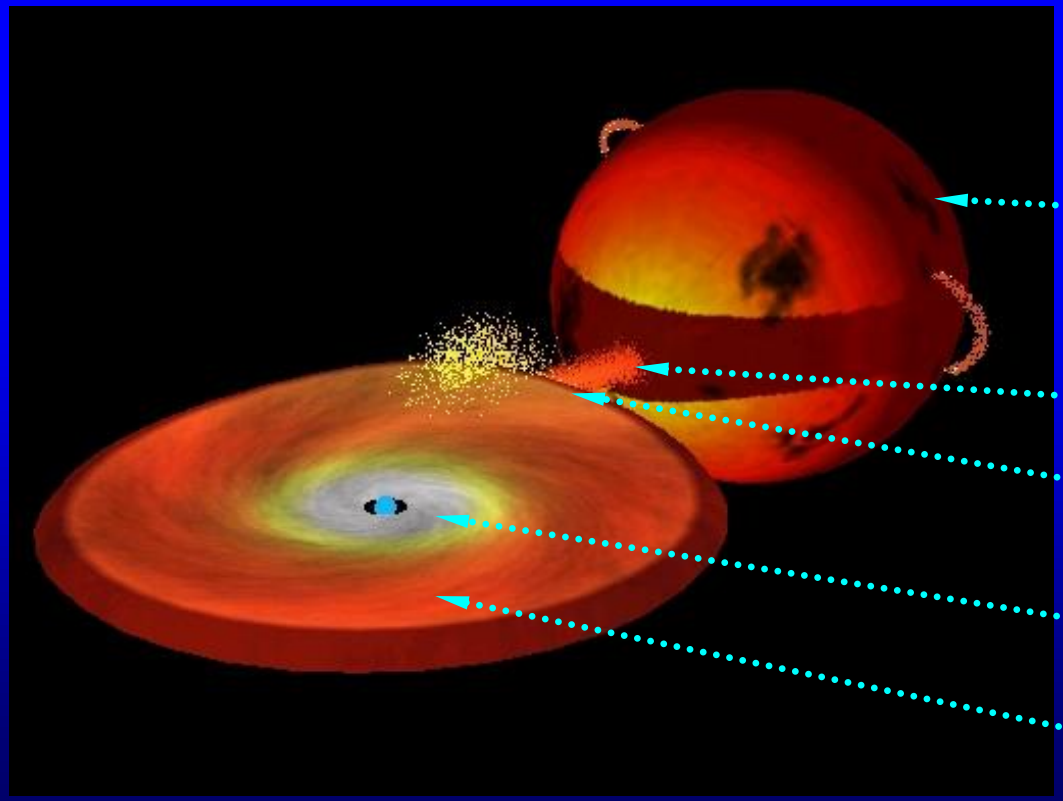
- (Quasi)persistent X-ray sources:
  - transitions between the high/low states (and fluctuations in the high state) are usually fast (~days) and unpredictable

- Superorbital X-ray variations:
  - the timescale of weeks and months
  - stability of the cycle depends on the parameters of the system

Low-mass X-ray binaries (LMXBs)

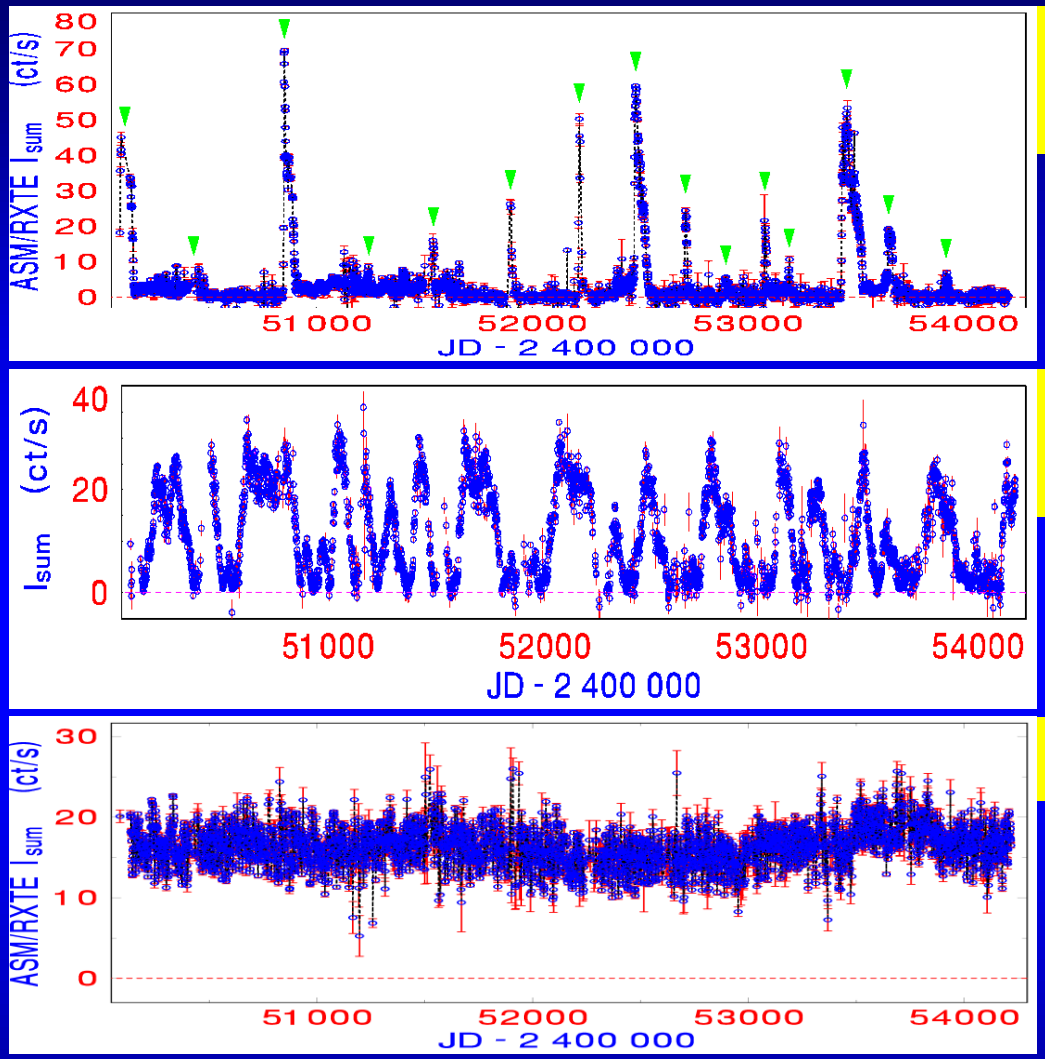
- Donor – thermal radiation (optical, IR)
- Outer disk region – thermal radiation (UV, optical, IR)
- Inner disk region – thermal radiation (soft X-rays (*E* up to several keV))
- Close vicinity of the compact object

  LMXBs: Comptonizing cloud (inverse Compton scattering – hard X-rays)
- Jets: synchrotron (radio, IR?)



Systematics of low-mass X-ray binaries (LMXBs)

Increase of mass transfer rate



Thermally unstable disk

4U 1608–52
Transient source
Soft X-ray transient (SXT)

Thermally unstable disk

4U 1705-44
Transient source

Thermally stable disk

Ser X-1
Persistent source

Change of the long-term activity from large-amplitude, isolated outbursts starting from the baseline quiescent state to the dominant relatively small fluctuations in the high state.
Only systems with neutron star accretor are used.

According to van Paradijs (1996)

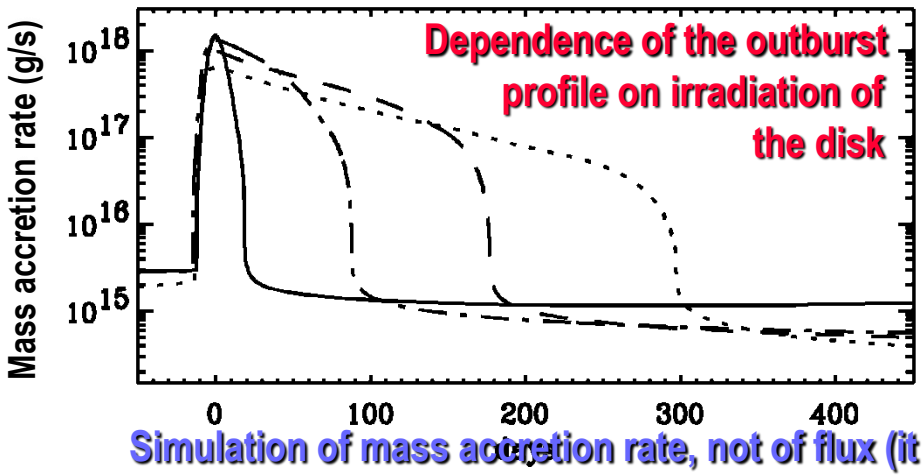
Data: ASM / RXTE (1.5 – 1 2 keV)

What can we expect from data from X-ray monitors?

- Various physical processes produce specific large-amplitude variations of X-ray luminosity on a timescale of days, weeks, to years and decades.

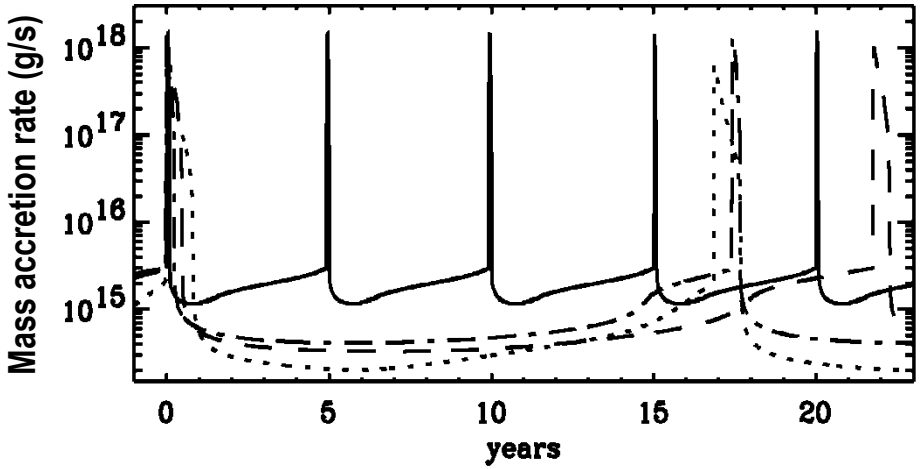
- The characteristic features (e.g., outbursts) can be investigated even in a single-band X-ray light curve (monitors often work with a single band (typically in soft X-rays, a few keV)).
  - Even some model predictions are already available:

Basic properties of the light curves in X-rays (several keV)



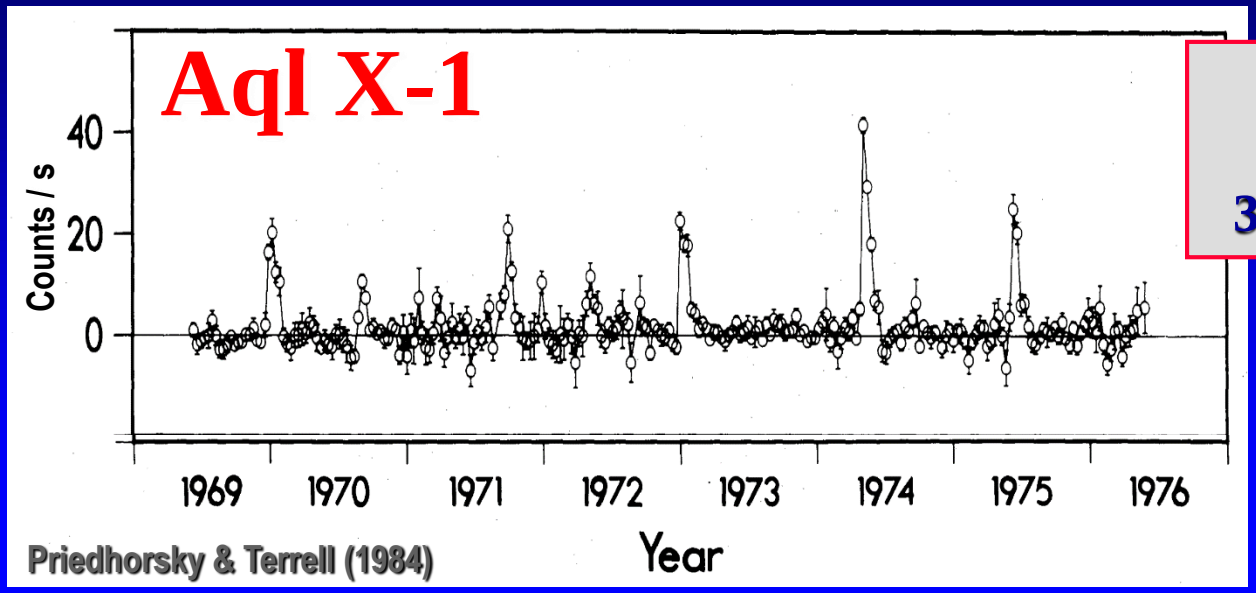
Simulation of mass accretion rate, not of flux (it would depend on X-ray band)

Simulated cycle-length of the outbursts



(model: Dubus et al. 2001)

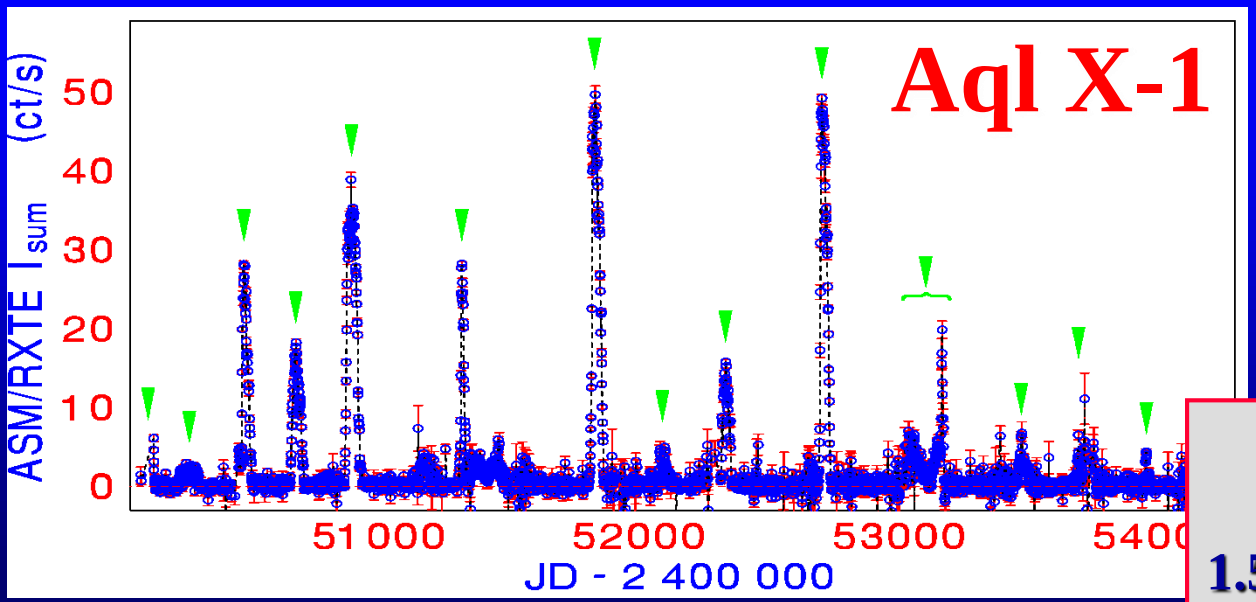
Improving the sensitivity of the X-ray monitor



Vela 5B
(10-day means)
3 – 12 keV 1969 - 1976

Effect of increase of the monitor's sensitivity (similar spectral bands):

- **Better-defined features of the intense outbursts**
- **Minor outbursts can be resolved (important for the assessment of the activity of the object)**



ASM / RXTE
(one-day means)
1.5 – 12 keV 1996 - 2008

X-ray monitor used for simulating LOBSTER-EYE observations:

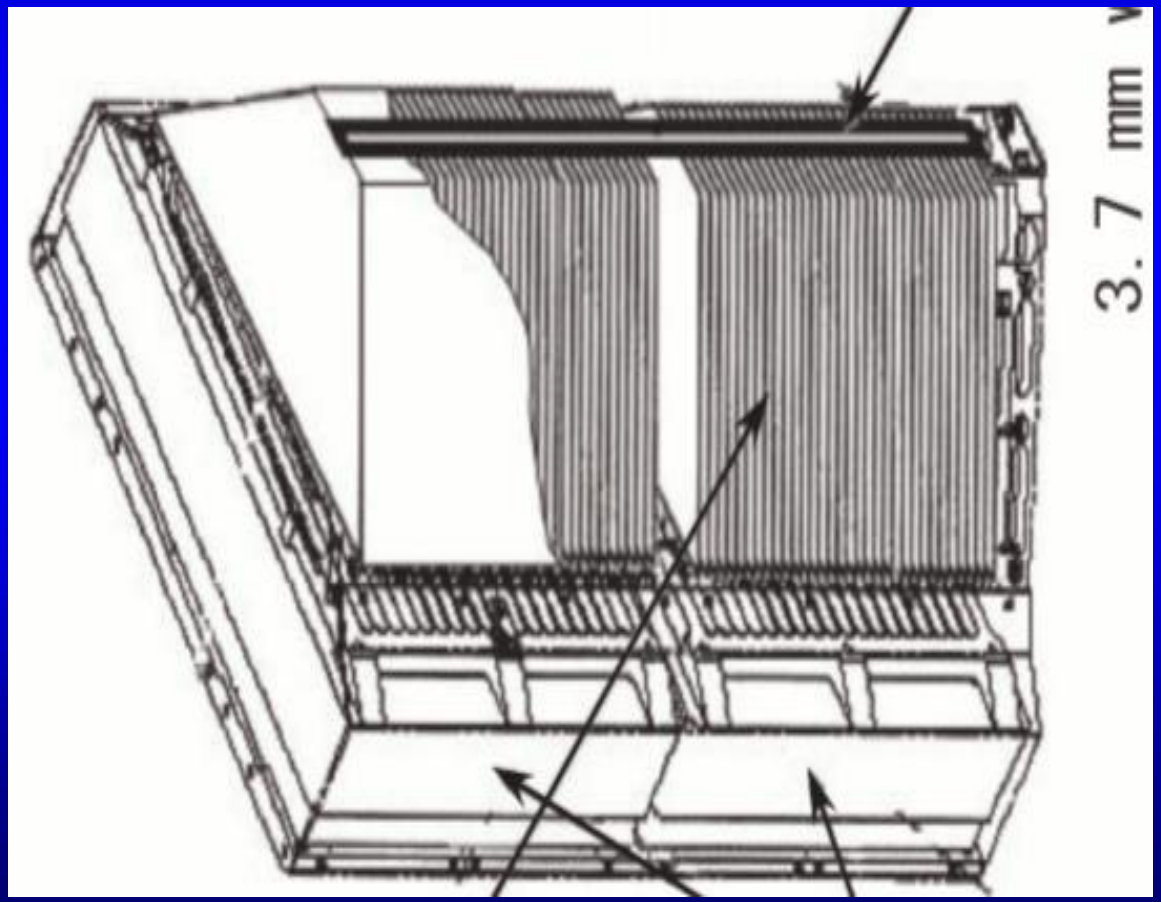
- **MAXI / ISS** (since 2010)

Matsuoka et al. (2009)
Mihara et al. (2011)

- Slit cameras in 6 units

- Energy range: 2 – 20 keV

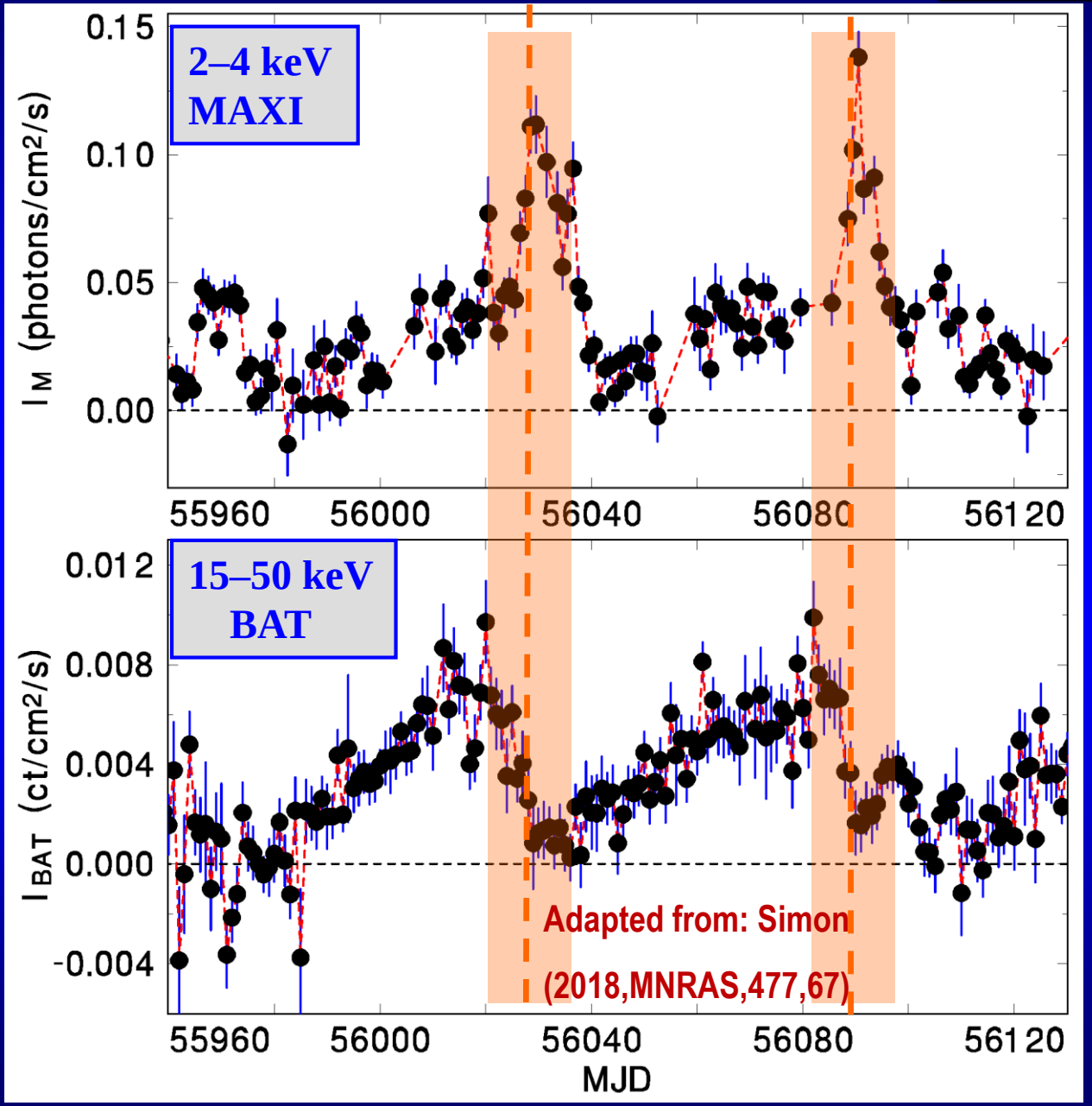
Possibility to modify division into sub-bands:
e.g., 2 – 4 keV and
4 – 8 keV in our case



Lobster-eye will be most sensitive in the softest band of MAXI.

HETE J1900.1-2455

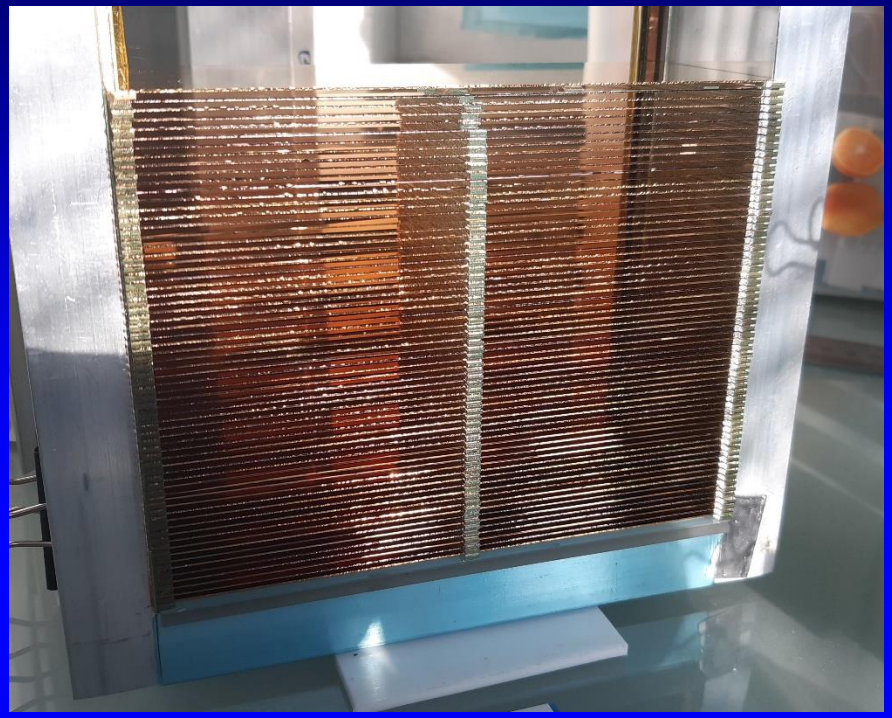
A more general relation of the light curves in the soft and hard X-rays



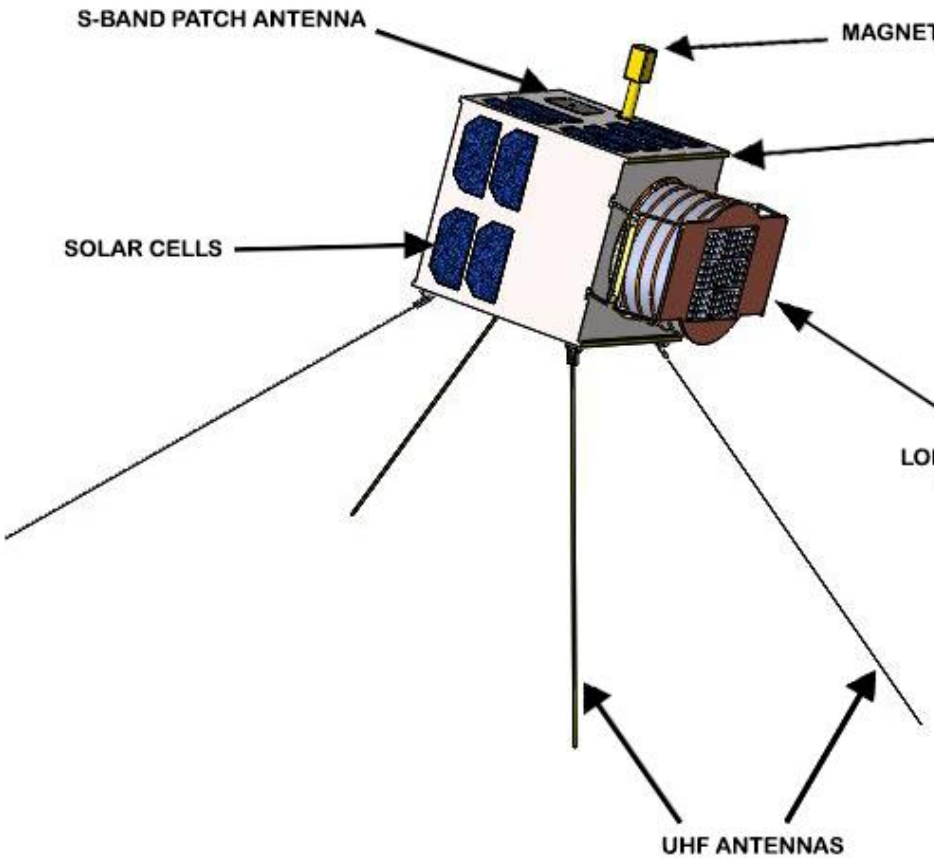
- Peaks in the soft X-ray flux are accompanied by dips in the hard X-ray band.
- Changes of the structure of the emitting region(s)
  – Comptonizing comp. fades during disk emission peak

Lobster-eye will observe in the soft X-ray band (3 - 9 keV)

The already existing lobster-eye telescopes

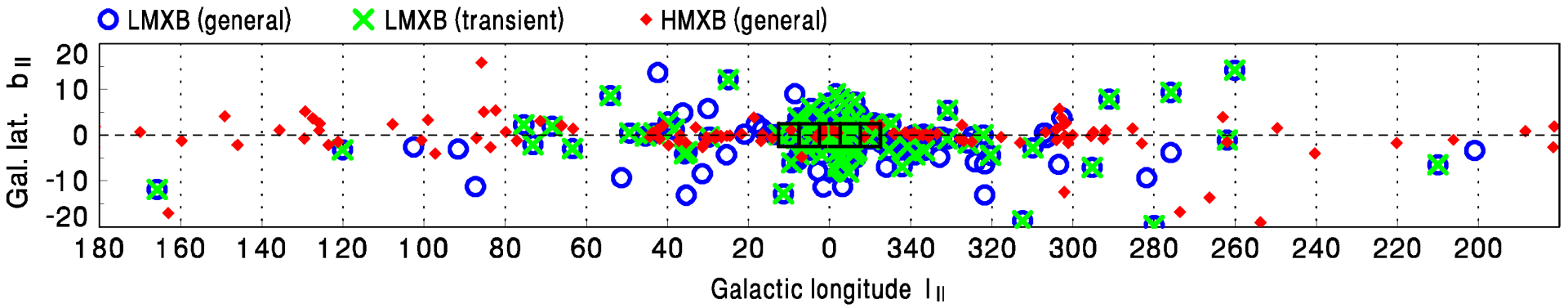


- The assembled examples of lobster-eye modules in Schmidt arrangement.
- They were designed in various dimensions: apertures ranging from 3 x 3 mm to 30 x 30 cm.



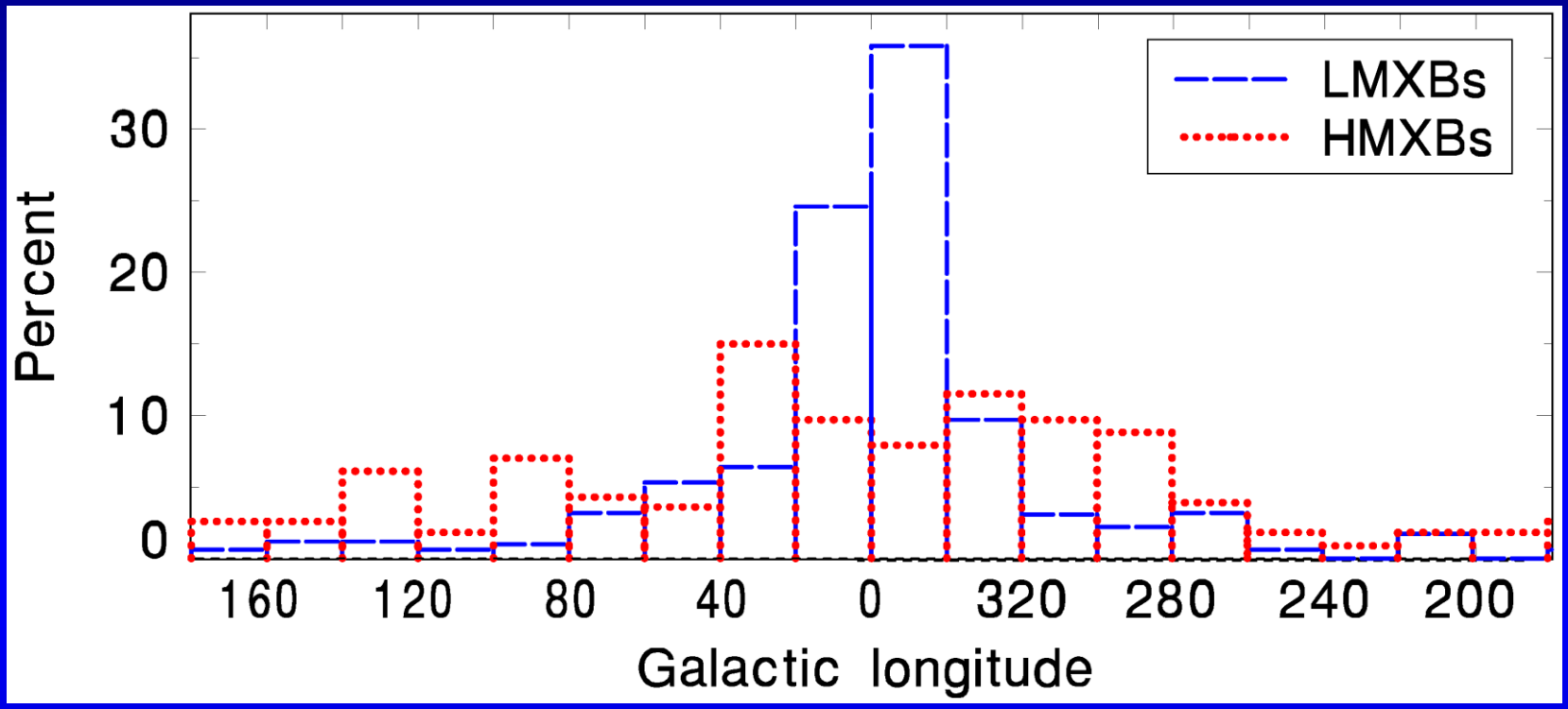
- **The proposed CubeSat with lobster-eye sky telescope/monitor**

Distribution of low-mass X-ray binaries (LMXBs) and high-mass X-ray binaries (HMXBs) in the sky

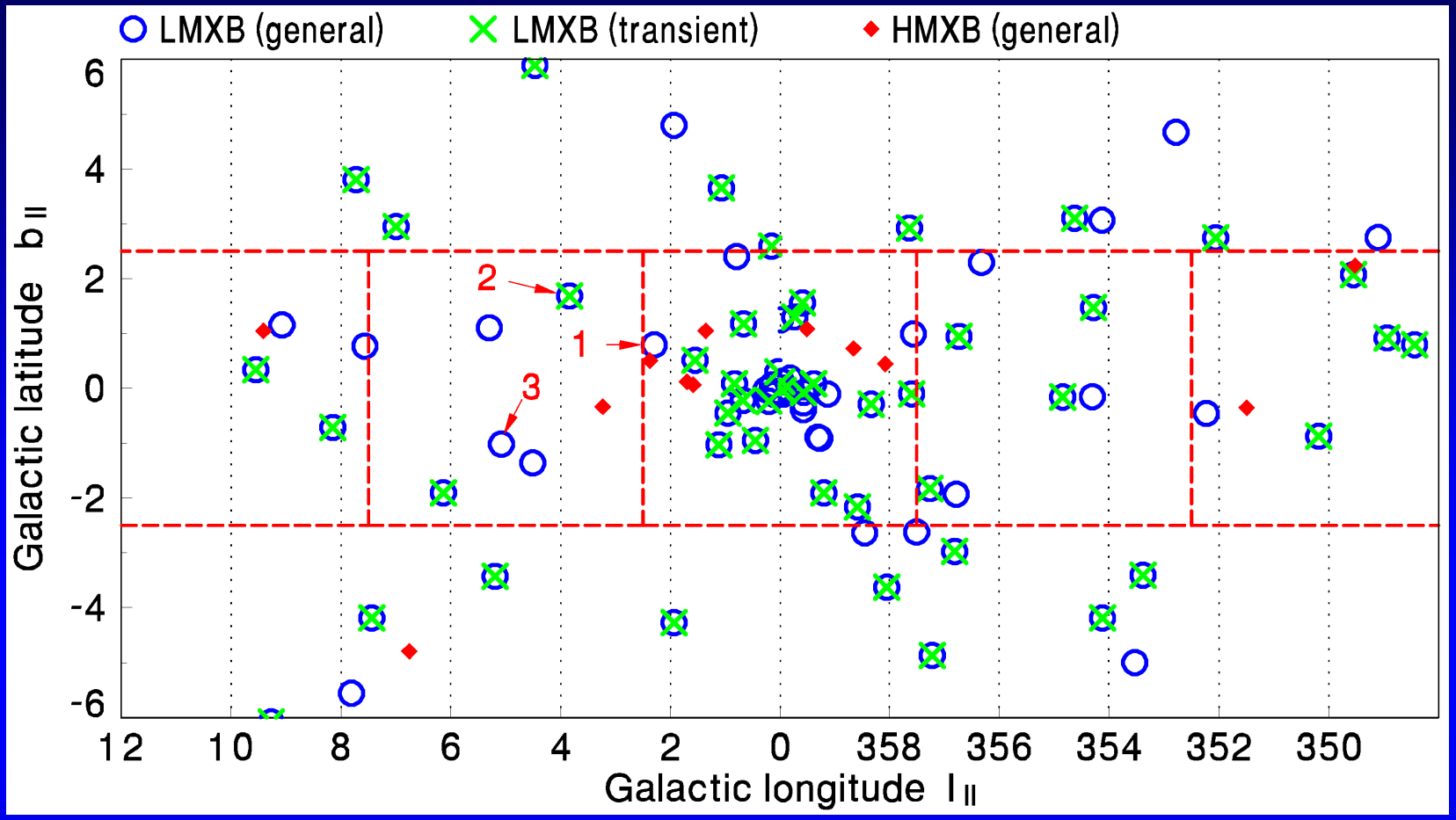


- A belt in which most such known X-ray sources are located. The direction toward the Galaxy center is in the center of the plot.
- The data from the catalogs of Liu et al. (2007,A&A,469,807) and Liu et al. (2006,A&A,455,1165) were used.
- The solid lines (squares) mark the planned field of view of the proposed lobster-eye telescope in the field in which X-ray binaries are concentrated.

Distribution of low-mass X-ray binaries (LMXBs) and high-mass X-ray binaries (HMXBs) in the sky

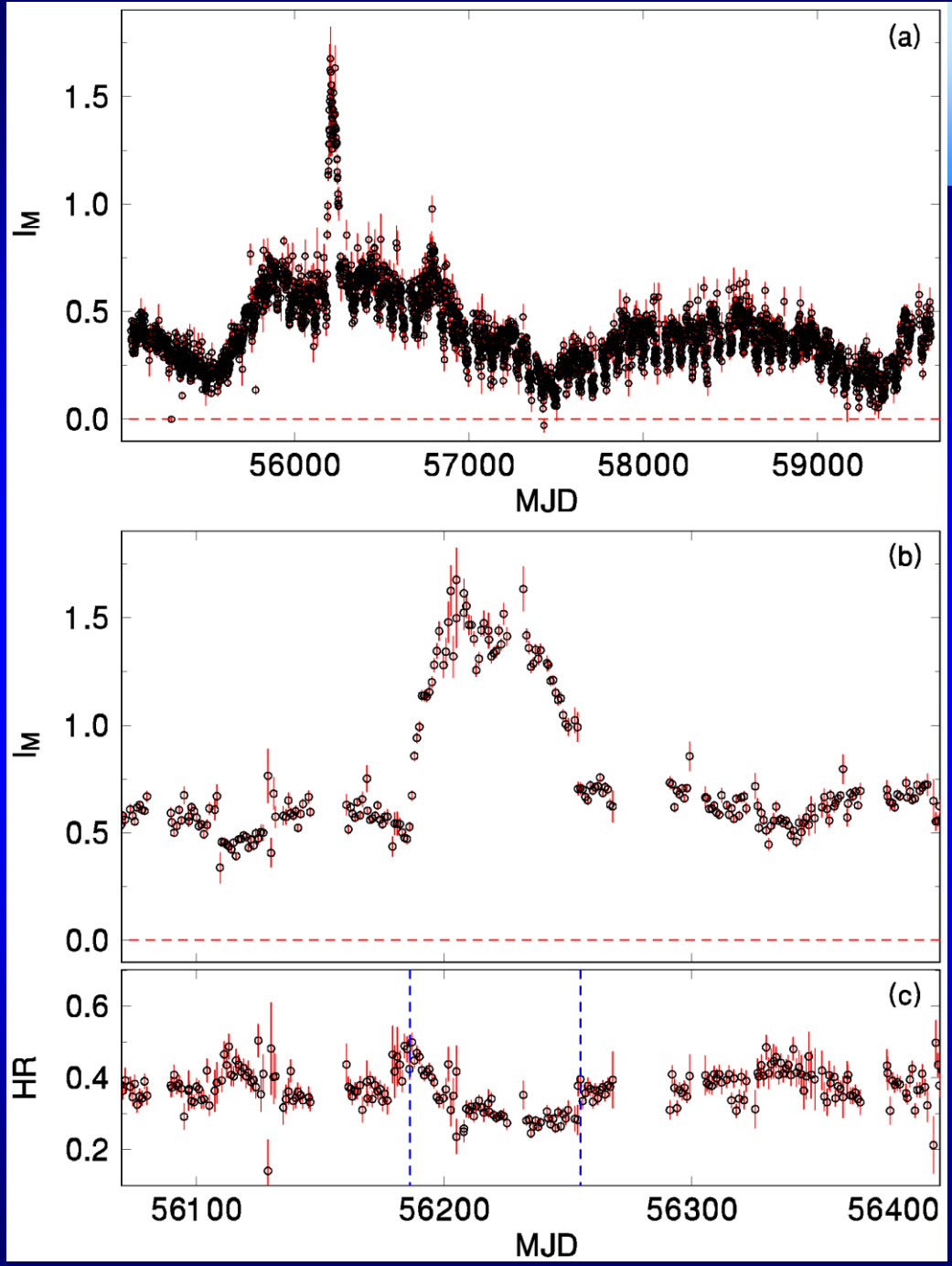


- Histogram of numbers of X-ray binaries at various Galactic longitudes.
- The direction toward the Galaxy's center is the best for monitoring and searching for X-ray transients.
- The data from the catalogs of Liu et al. (2007,A&A,469,807) and Liu et al. (2006,A&A,455,1165) were used.



- Fields (5 x 5 deg) proposed for monitoring with the lobster-eye telescope.
- The data from the catalogs of Liu et al. (2007,A&A,469,807) and Liu et al. (2006,A&A,455,1165) were used.
- The arrows and numbers: the promising objects (low-mass X-ray binaries) for monitoring with lobster-eye.

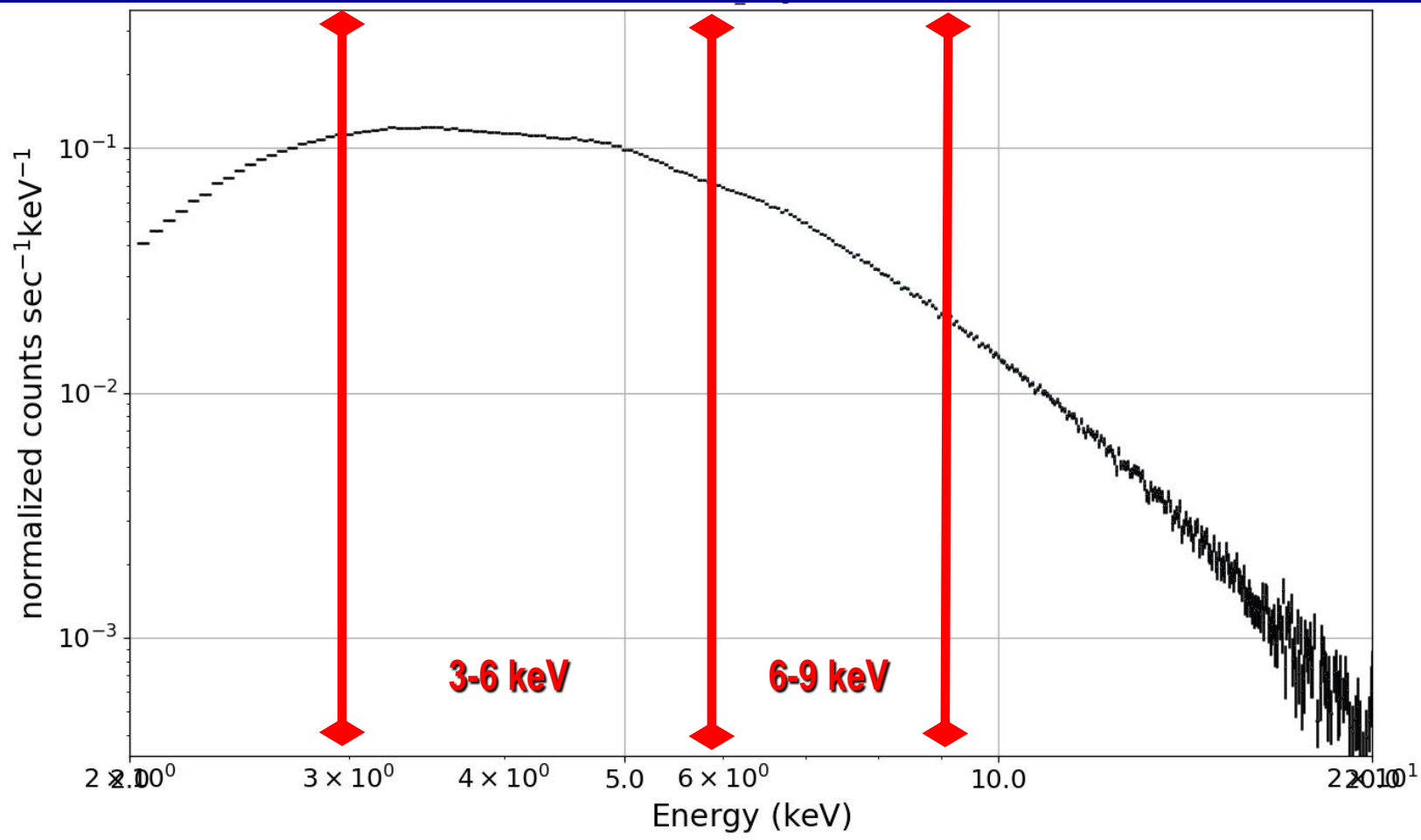
LMXB GX 3+1 (MAXI 3-6 keV)



- (a) The MAXI data (one-day means) with the band similar to the one of the proposed lobster-eye telescope
- (b) The surroundings of a prominent brightening.
- (c) Hardness ratio (HR) variations. The dashed vertical lines: boundaries of the brightening episode.

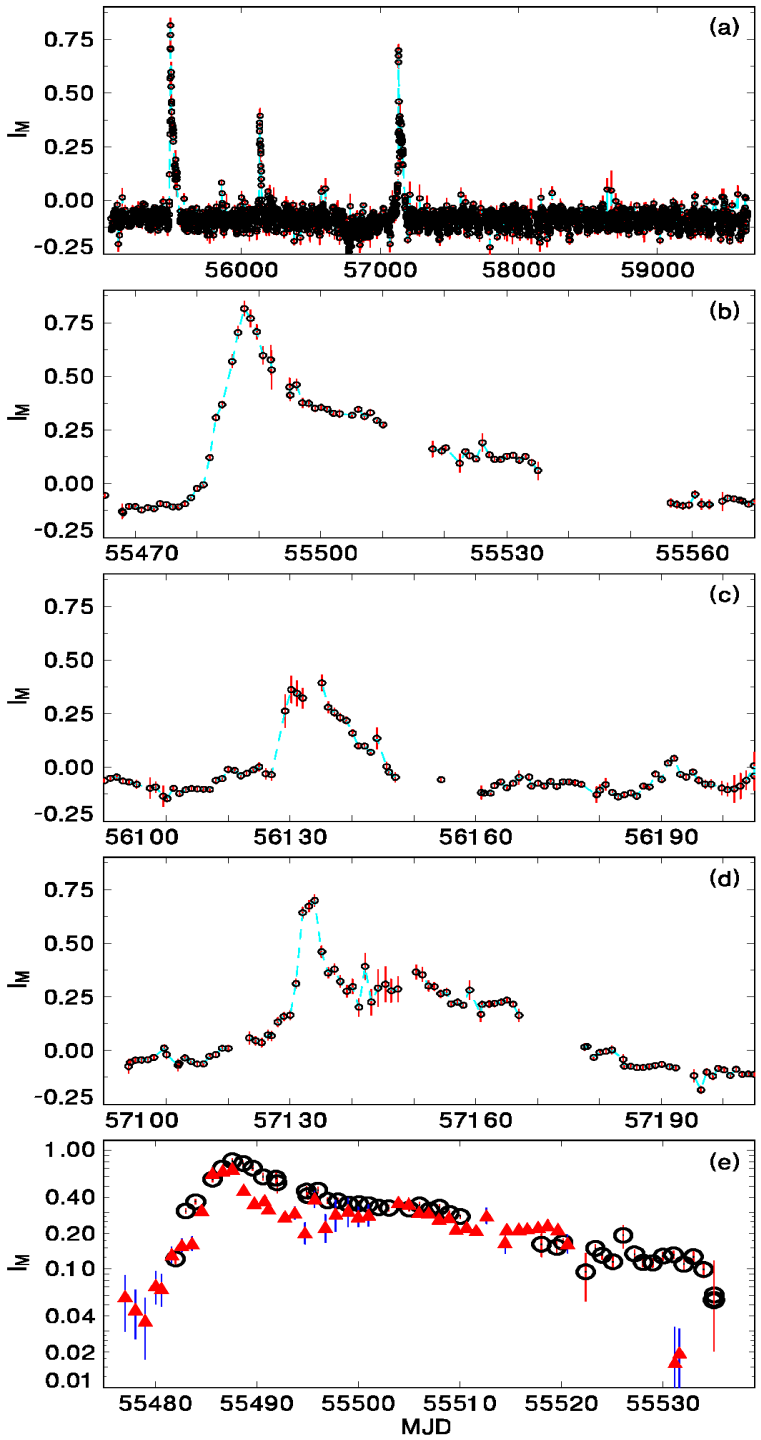
HR = I(6-9 keV / I(3-6 keV))

A mean X-ray spectrum of GX 3+1 (MAXI 3-6 keV and 6-9 keV)



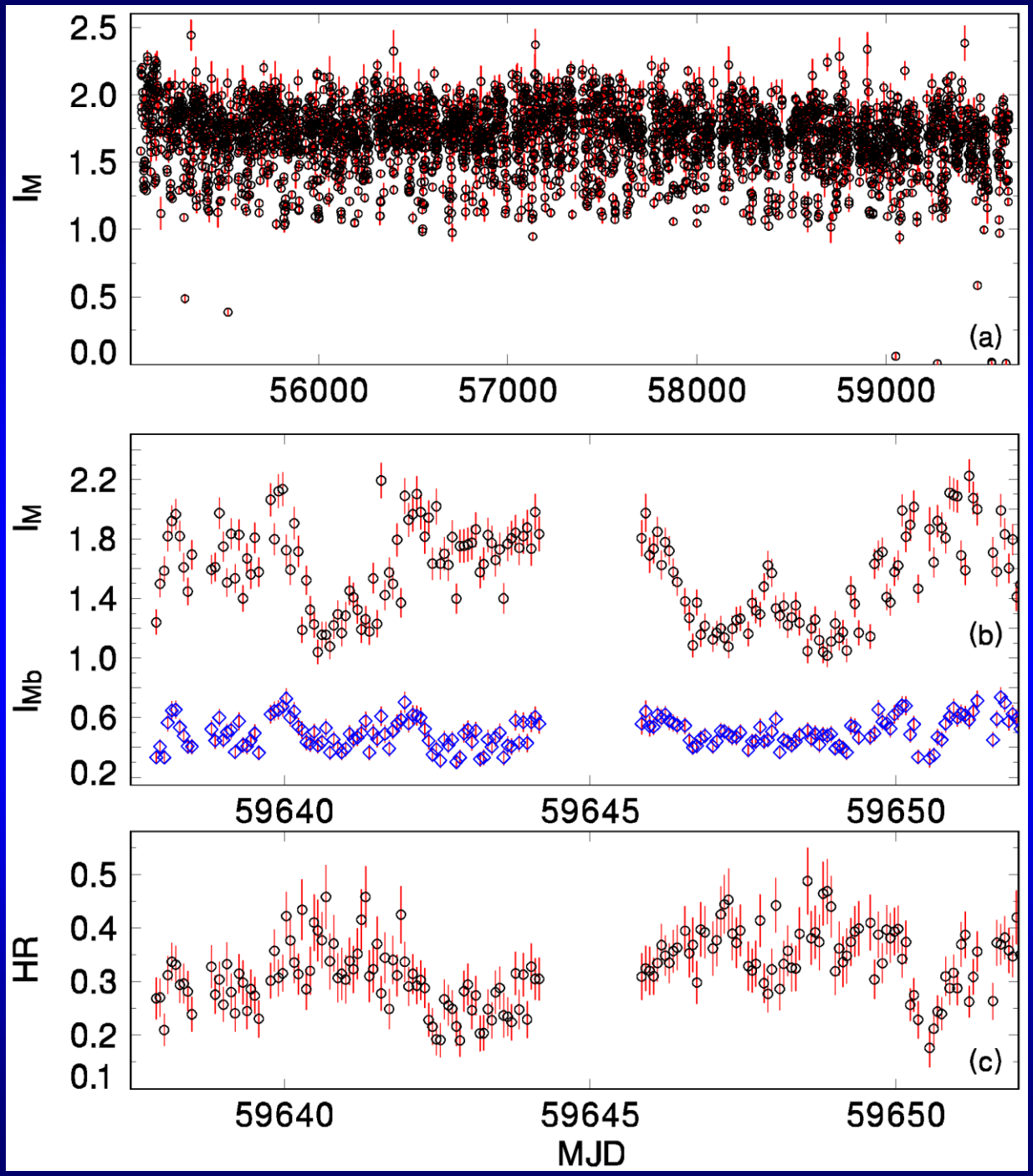
- Lobster-eye observations in the 3-9 keV band will cover the spectral band containing the highest flux of GX 3+1 (this situation will also be similar for other low-mass X-ray binaries).

LMXB EXO 1745-248 (MAXI 3-6 keV)



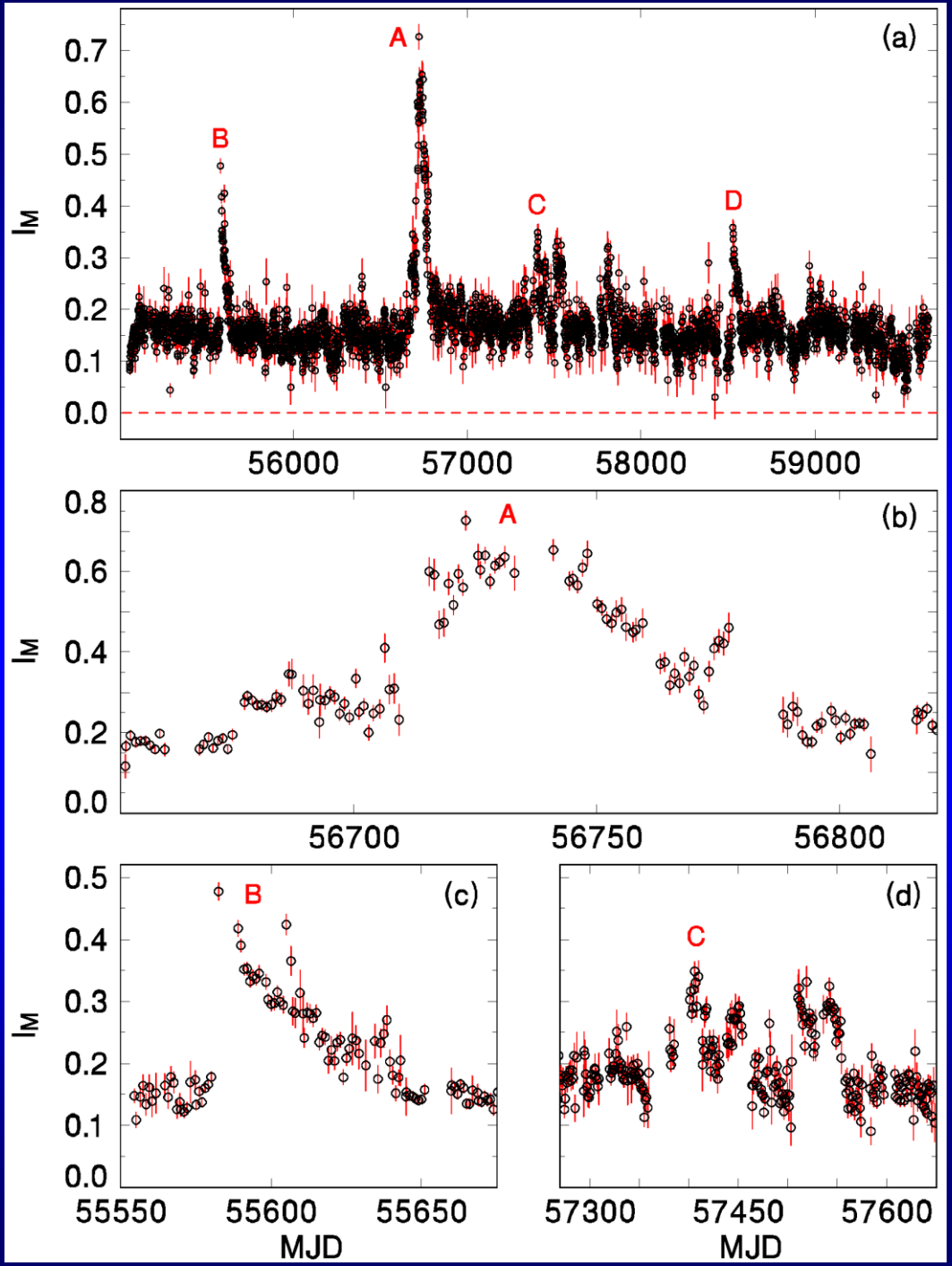
- One-day means of the MAXI data
- (b,c,d) The dramatically different light curves of the individual outbursts
- (e) Superposition of the outbursts from panels (b-circles) and (d-triangles), aligned according to their times of the peak flux

LMXB GX5-1 (MAXI 3-6 keV and 6-9 keV)



- (a) One-day means of the MAXI data
- (b) A segment of the 1 orbit light curves.
  - The black empty circles: I_M (the 3-6 keV data)
  - The empty blue diamonds: I_{Mb} (the 6-9 keV obs.)
- (c) The hardness ratio (HR) variations

The dense cluster of X-ray sources (MAXI 3-6 keV)



- Activity of the dense cluster of X-ray sources, dominated by 1A 1742-294 (1-d means)
- (b) An episode of a powerful brightening
- (c) Outburst with a steep rise and gradual decay
- (d) A series of brightenings (outbursts?).

Lobster-eye will resolve these objects and their light curves.

Conclusions (I)

- We show the lobster-eye (LE) monitor's perspectives and the observing plan based on a small LE telescope on a small (CubeSat-like) satellite platform.

- Instrument able to provide wide-field X-ray imaging

- We present the possibilities of monitoring the Galactic center region in the relatively soft X-ray energy band (constrained by the detector).

- **Reason:** Many X-ray binaries (especially those with a low-mass lobe-filling secondary and mostly the neutron star accretor) concentrate in the bulge surrounding the center of our Galaxy.

- Several X-ray binaries are expected to be present in our monitor's field of view (a square of about 5 x 5 degrees).

Conclusions (II)

- The long-term activity of X-ray binaries located in this region can be reliably observed even with sufficiently long exposure times.
- The typical features of such objects' long-term X-ray activity (e.g., outbursts and state transitions) can be reliably observed with our lobster-eye monitor. The observed data will be essential and valuable for scientific analyses.
- Observing in the soft X-ray band is the most promising because the X-ray intensity of these objects is the highest in this band.

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