X-ray observing the cosmic sources by the ESA-CAS satellite *SMILE*

Vojtěch Šimon[1,2], R. Hudec[2] & A. Read[3]

[1] *Astronomical Institute, The Czech Academy of Sciences, 25165 Ondřejov, Czech Republic*

[2] *Czech Technical University in Prague, FEE, Prague, Czech Republic*

[3] *University of Leicester, Leicester, UK*

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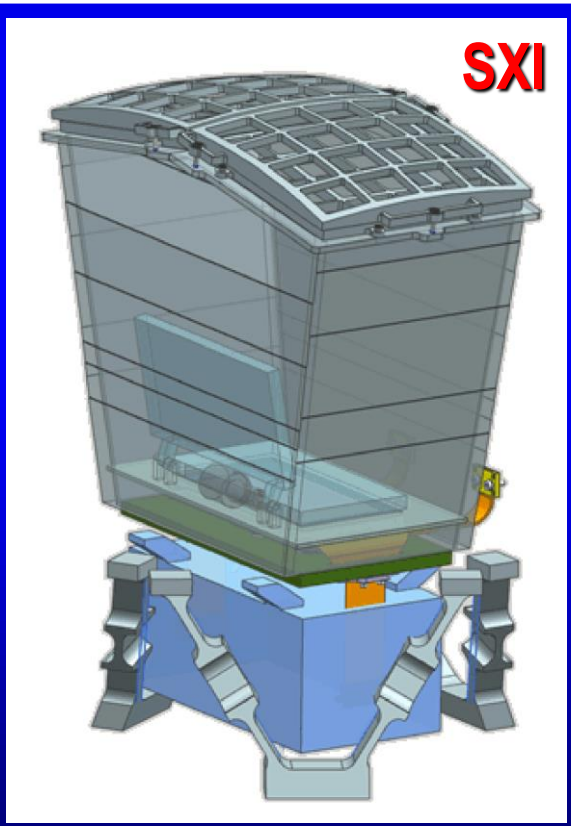
Parameters of SXI/*SMILE*

- SMILE is designed to investigate interaction between the solar wind and the Earth's magnetosphere.

- We show that SXI/*SMILE* is also able to study the long-term activity of cosmic X-ray sources in its field of view.

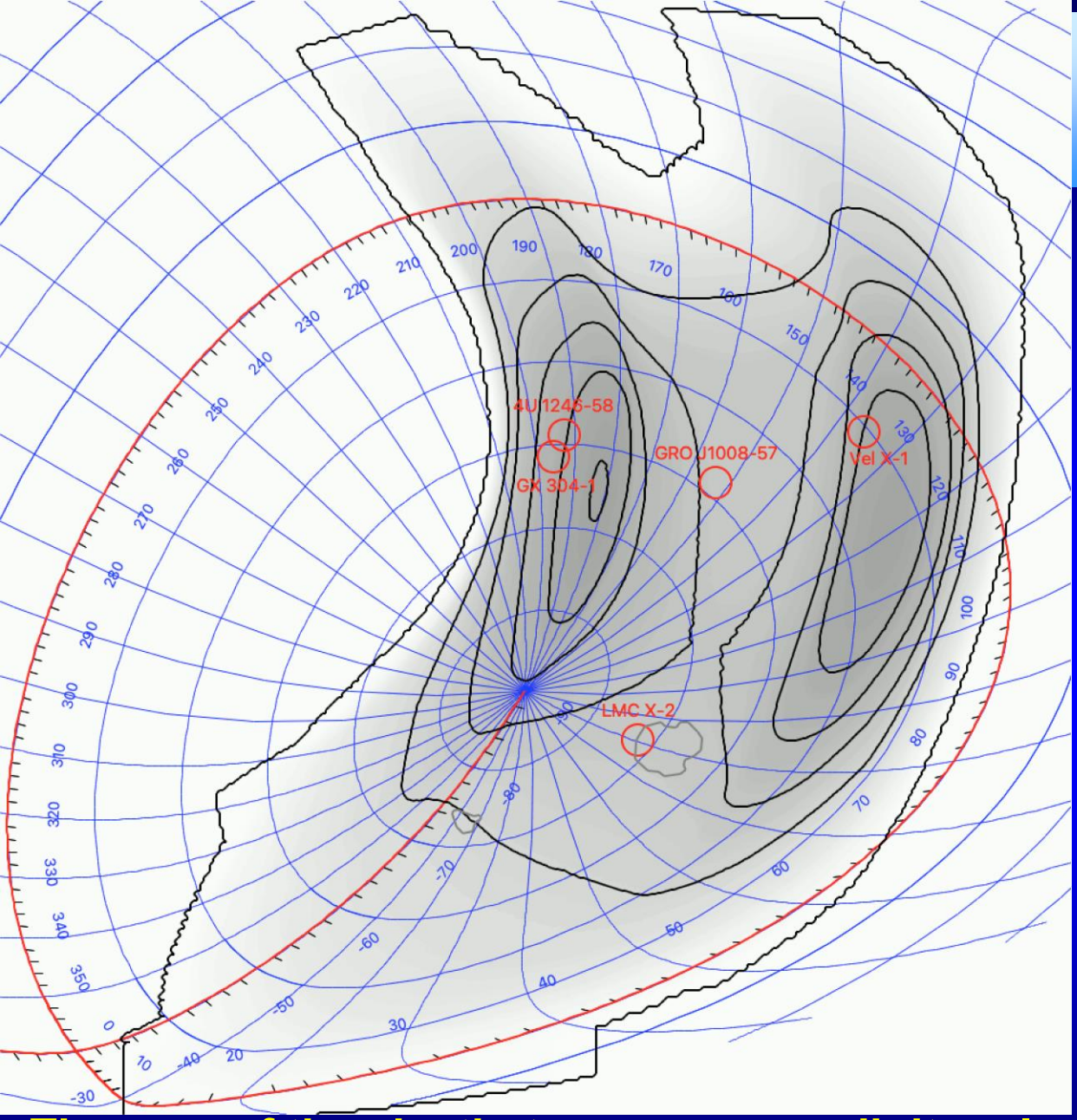


M.R. Soman et al. 2018
JINST 13 C01022

- SXI: a wide-field lobster-eye telescope
- Energy range: ~ 0.2 keV – 3.5 keV
- Field of view: 27 x 16 degrees
- Highly elliptical orbit
- Continuous observing possible for ~40 hours per orbit

https://www.cosmos.esa.int/web/smile/

Area monitored by SXI/*SMILE*



The contours – exposures in the SXI field-of-view over the good SXI observing time in the first year of operations.

The largest area: the lowest non-zero level (> +0 seconds).

- other contours: increase by 1 million seconds each

The area of the sky that passes serendipitously through the SXI/*SMILE* FOV as the magnetosheath is observed.

SXI/*SMILE* and monitoring the long-term activity of X-ray binaries

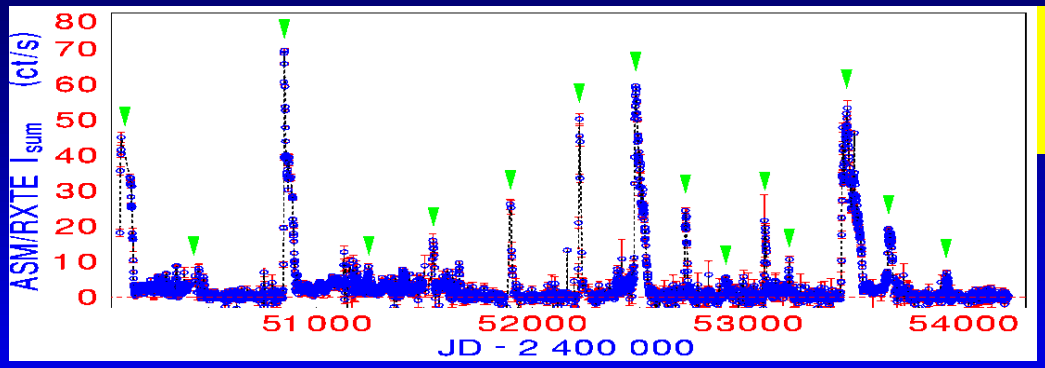
- (Quasi)persistent X-ray sources:
  - transitions between the high/low states (and fluctuations in the high state) are usually fast (~days) and rather unpredictable

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

- 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

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

Increase of the mass transfer rate

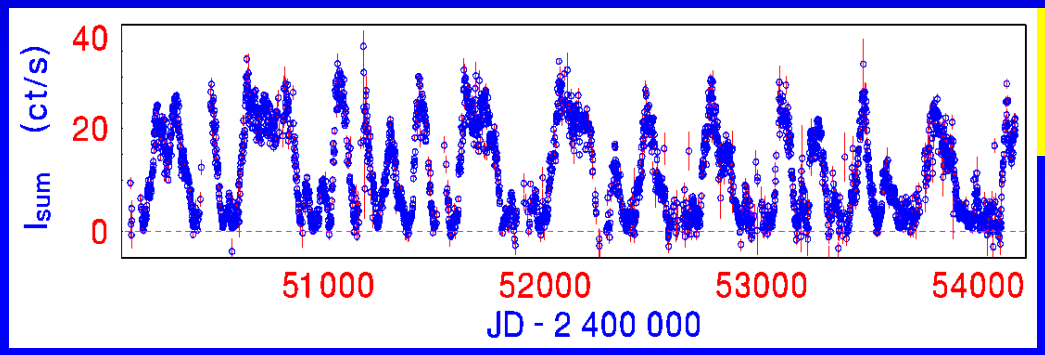


Thermally unstable disk

4U 1608–52

Transient source

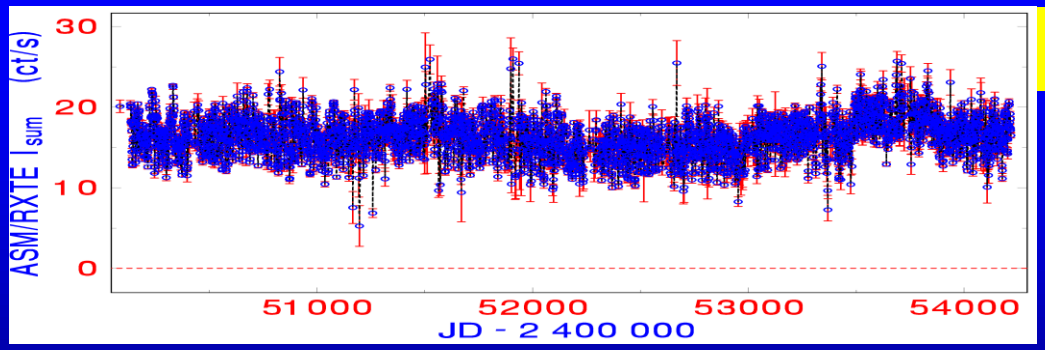
Soft X-ray transient (SXT)



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)

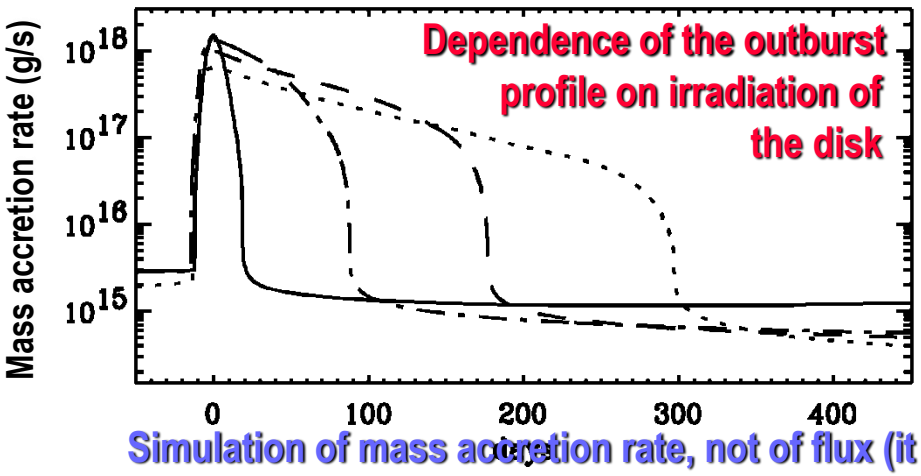
Data: ASM / RXTE (1.5 – 1 2 keV)

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.

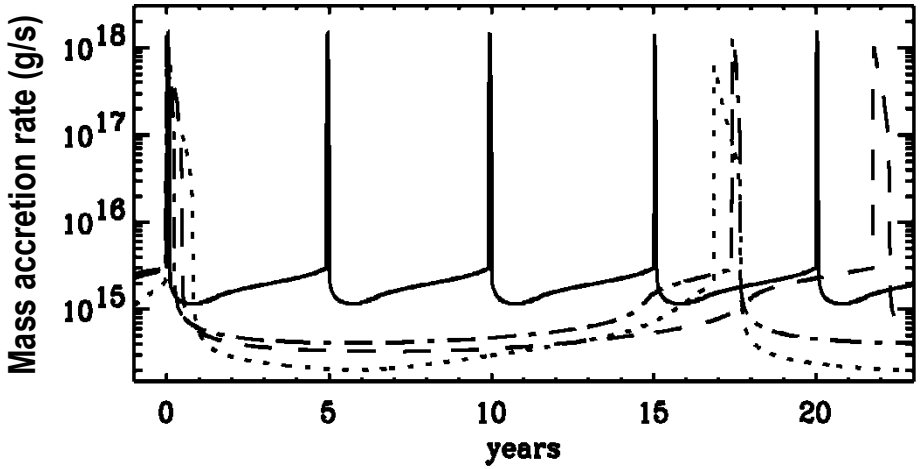
- The characteristic features (e.g., outbursts) can be investigated even in a single-band X-ray light curve (monitors often work with a single band (typically in soft X-rays, a few keV)).
  - Even some model predictions are already available:

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)

Data from X-ray monitor used for simulating SXI/*SMILE* observations of X-ray binaries:

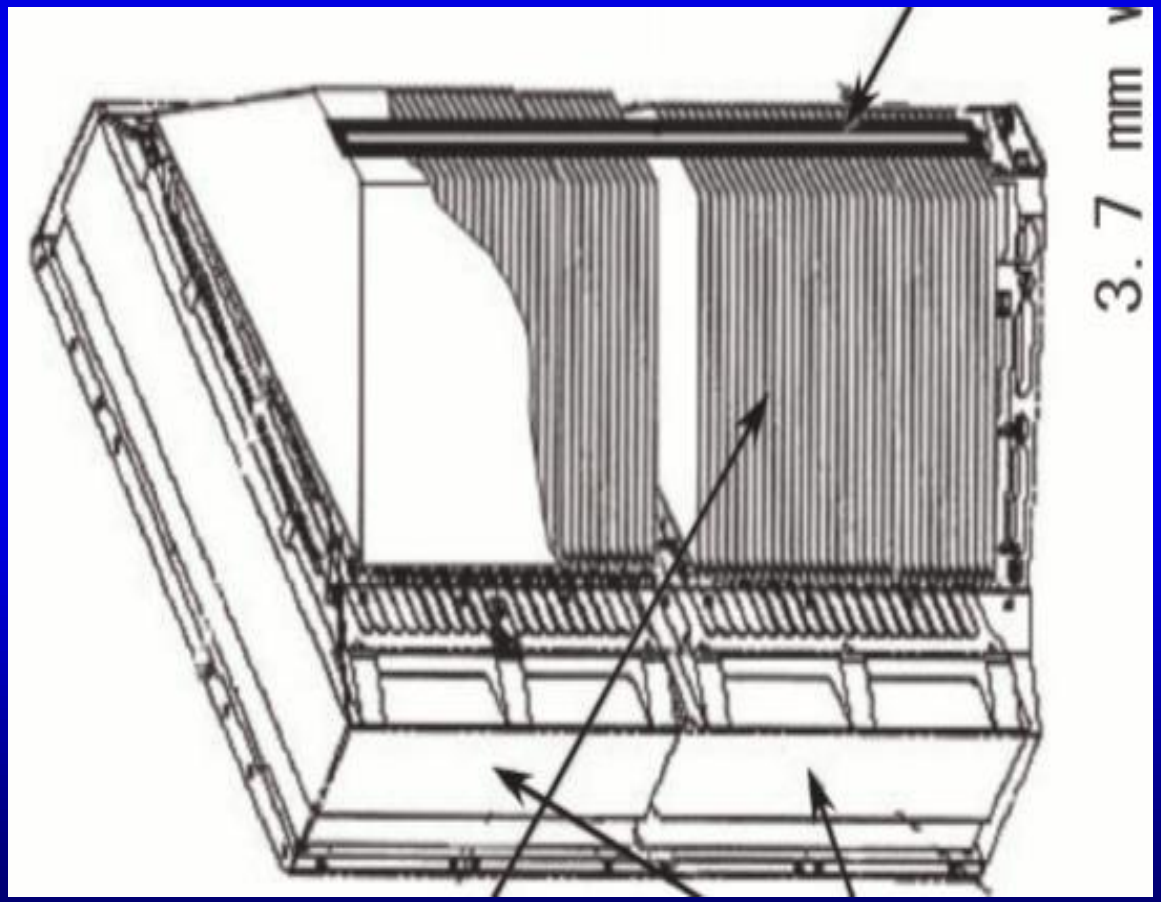
- **MAXI / ISS** (since 2010)

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

- Slit cameras in 6 units

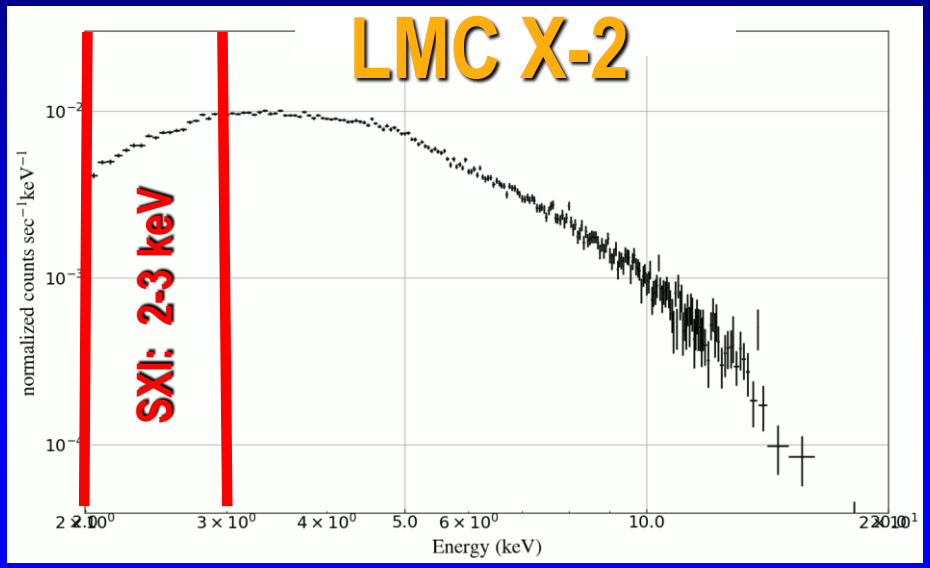
- Energy range: 2 – 20 keV

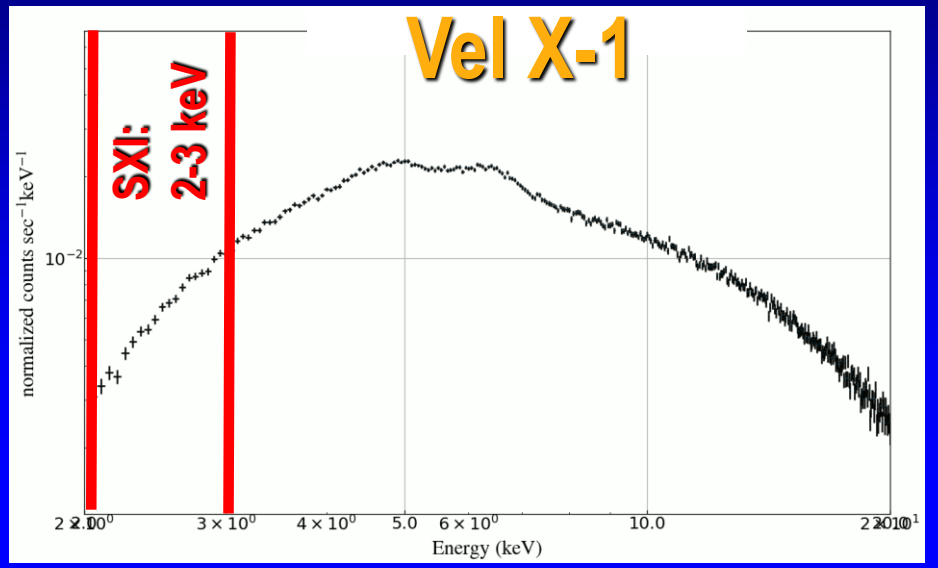
Possibility to modify division into sub-bands or use a specific band:
e.g., 2 – 3 keV in our case



The softest part of MAXI overlaps with SXI/*SMILE*.

Typical X-ray spectra of X-ray binaries (MAXI 2-20 keV)



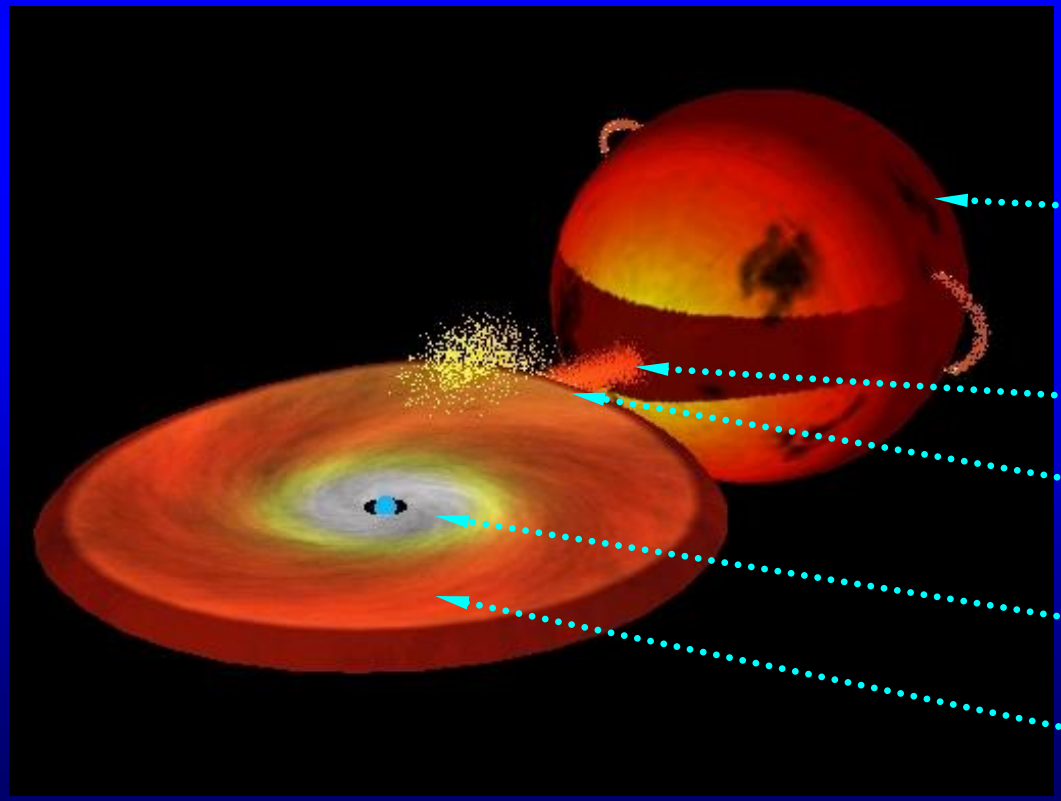


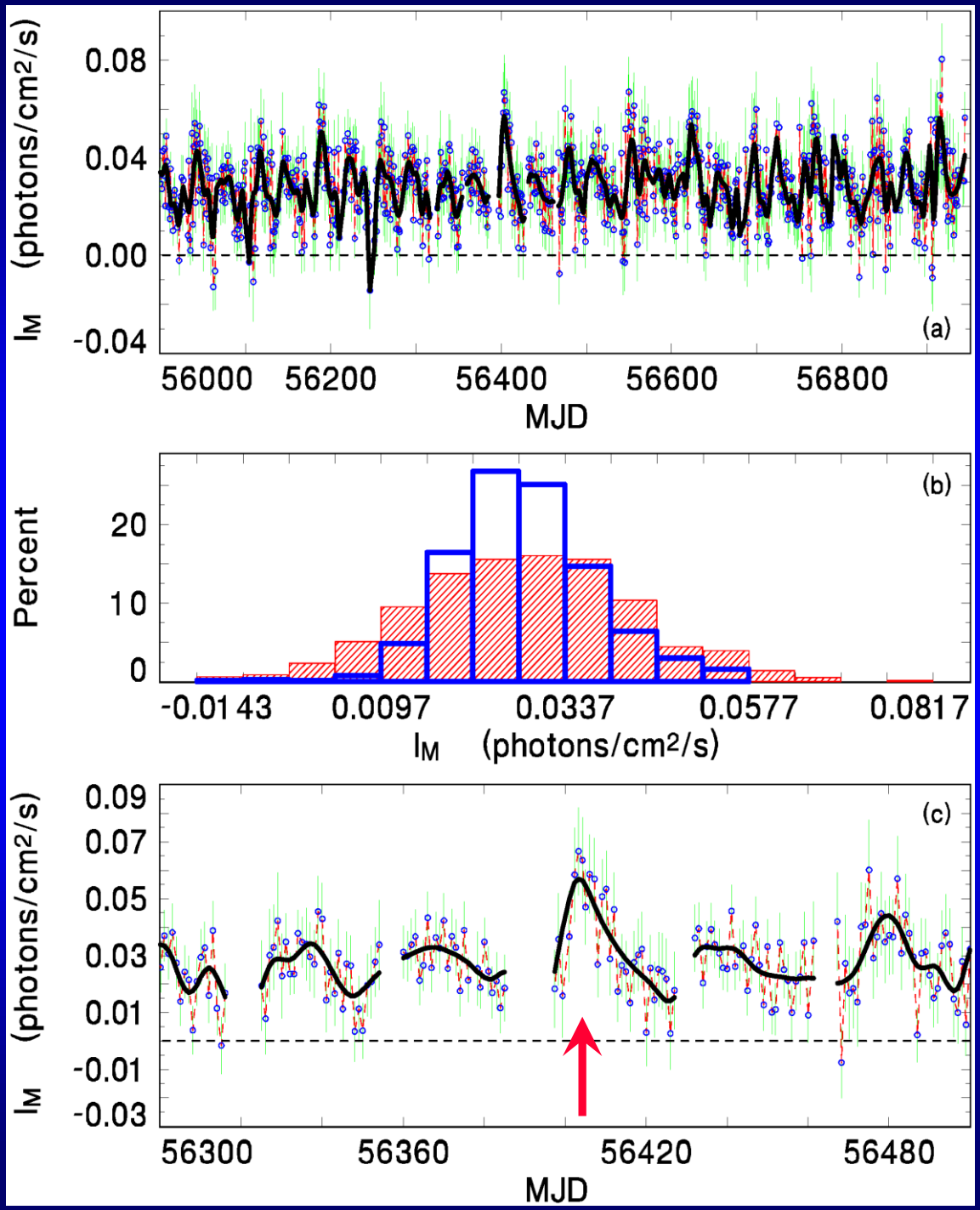
- Smooth spectra of X-ray binaries – flux varies only gradually with energy
- SXI/*SMILE* observations will cover the spectral band partly overlapping with the MAXI//*SS* band (X-ray binaries with smooth spectra will be detectable with SXI extending to 0.2 keV).
- It is not very important for detecting X-ray binary in which energy the spectral coverage exactly begins and finishes.

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?)



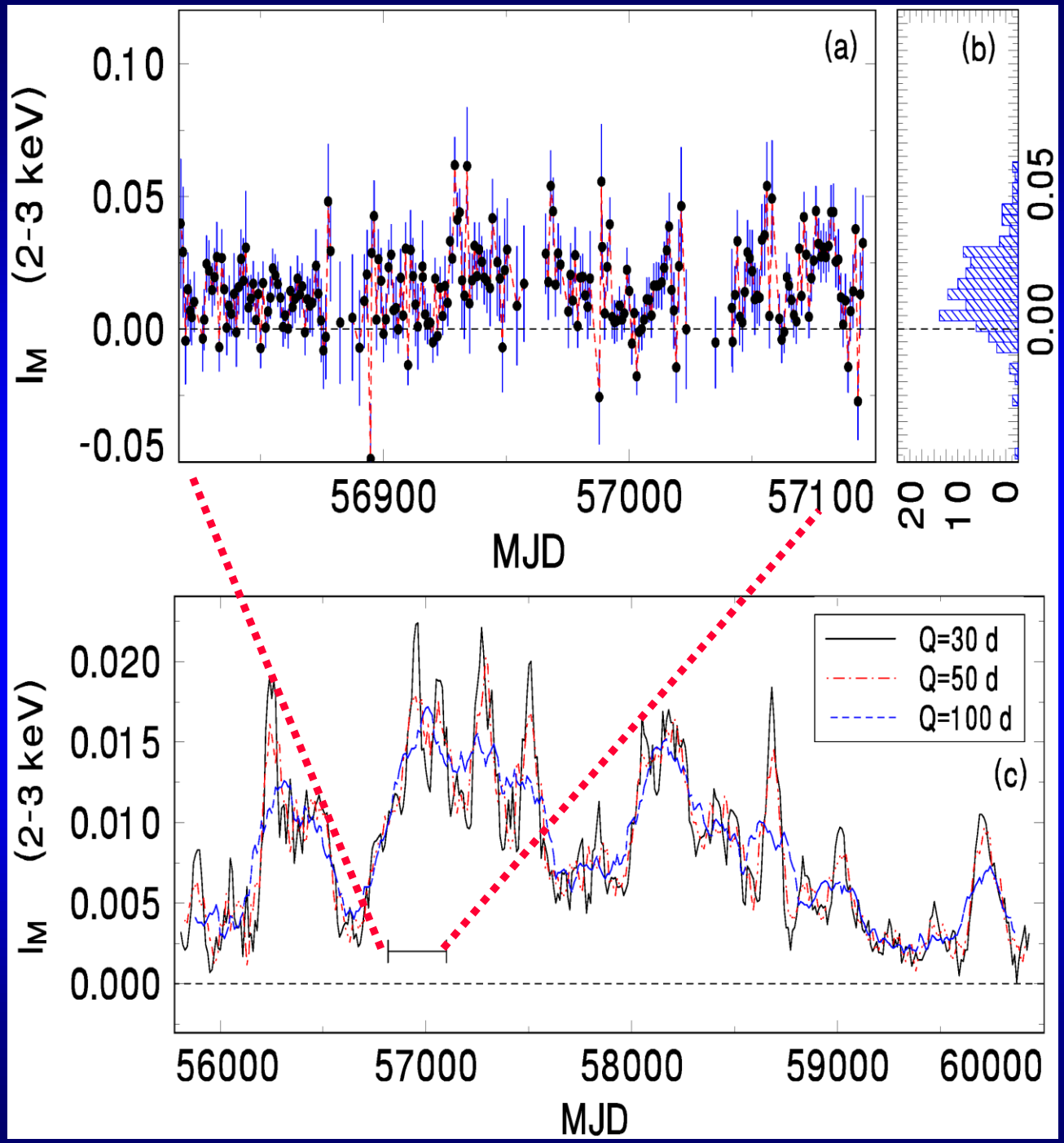


Z-source LMXB (low-mass X-ray binary) LMC X-2

(MAXI 2-3 keV data)

- The MAXI one-day means + the HEC13 fits (cyclic changes of flux)
- Histograms of flux (the 1-day means (hatched bars); the HEC13 fit (empty bars)
- A detail of the light curve (a fit runs through a broad belt (real rapid variations)) - a flare several days long

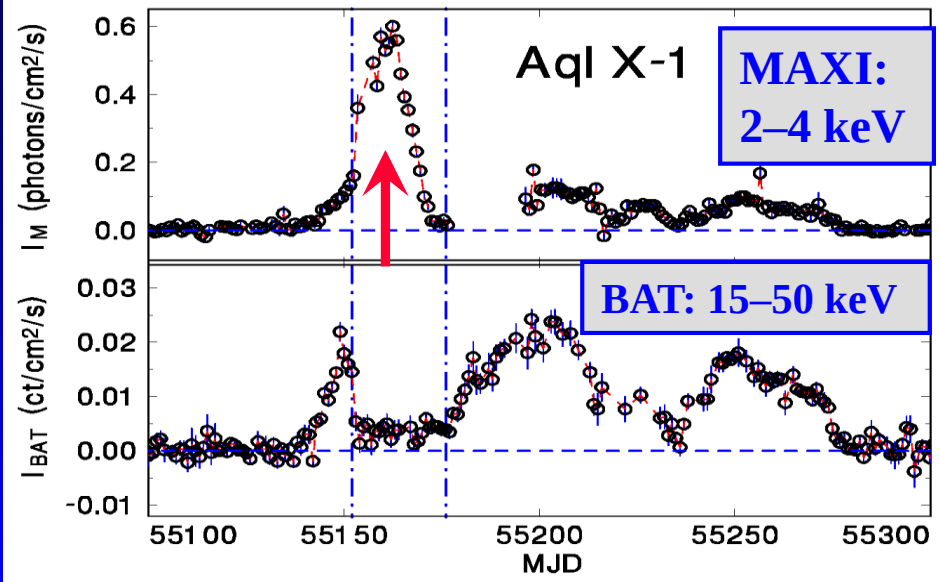
Ultracompact LMXB 4U 1246-58 (MAXI 2-3 keV)

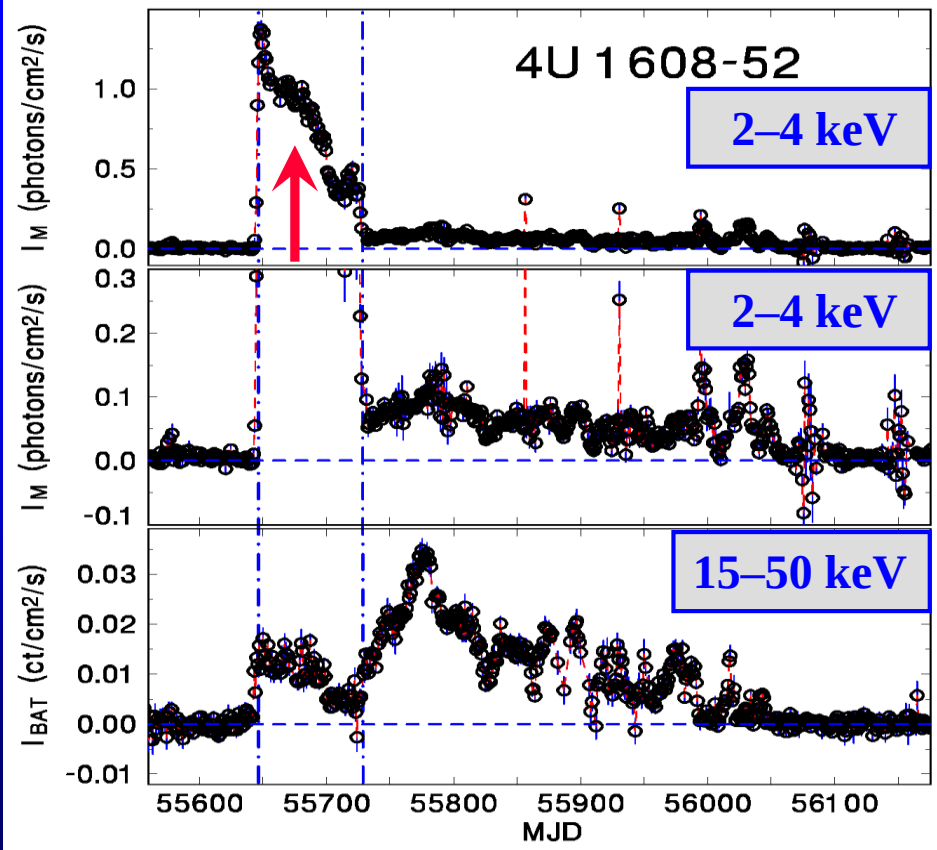


(a) A cluster of flares

(b) Histogram of flux in this series in (a) (the bar size is in %).

(c) The moving averages with various half-widths Q
– The horizontal bar: the cluster in (a) - near the highest flux





Dependence of the light curve of outburst of soft X-ray transient (SXT) on the X-ray band

- The light curve of the outburst of an SXT depends on the X-ray band (structural changes of the emitting regions (the inner disk regions?))
- The properties of the observed outbursts are often determined for soft X-rays (at most a few keV)

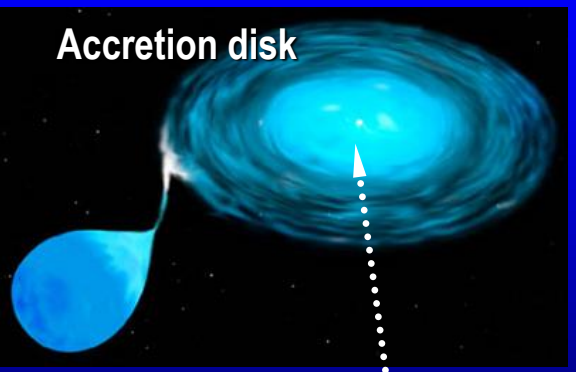
- An SXT in outburst can appear in any place of the sky – the SXT is usually discovered only during such outburst

High-mass X-ray binaries (HMXBs)

- Donor – thermal radiation (UV, optical, IR) – often dominant in the optical
- Disk (if exists) embedding the compact object – thermal rad. (spectral band in which it is detected differs from system to system)
- Close vicinity of the compact object: inverse Compton process, brehmsstrahlung (X-rays)
- Colliding winds: inverse Compton process, brehmsstrahlung (X-rays)
- Jets: synchrotron (radio, IR?)

Accretion modes:

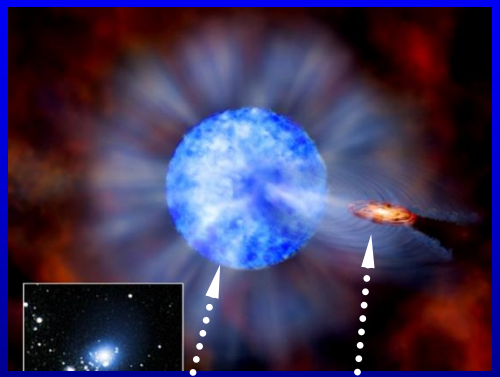
Roche lobe overflow



Donor, filling its lobe

Compact object (NS, BH, WD)

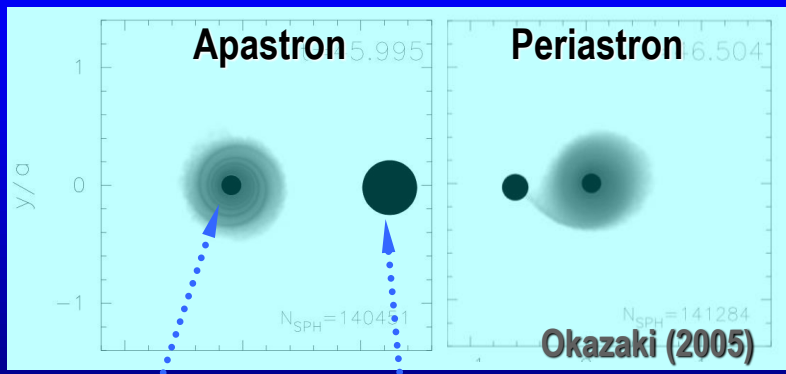
Wind accretion



Donor, underfilling its lobe

Compact object (NS, BH, WD)

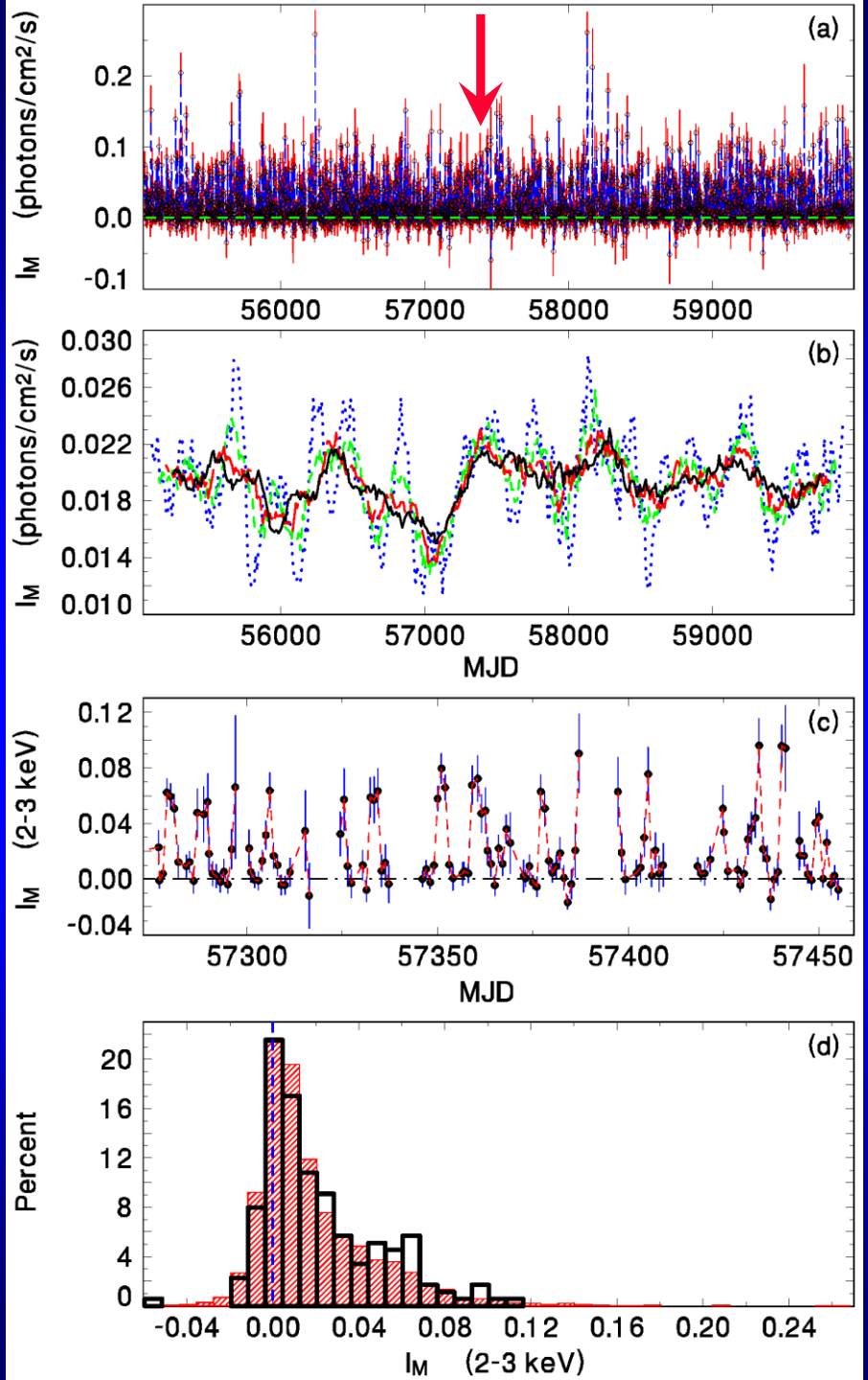
Periastron passage



Donor, underfilling its lobe

Lobe size of the compact object

Vel X-1 – wind accretor (MAXI 2-3 keV)

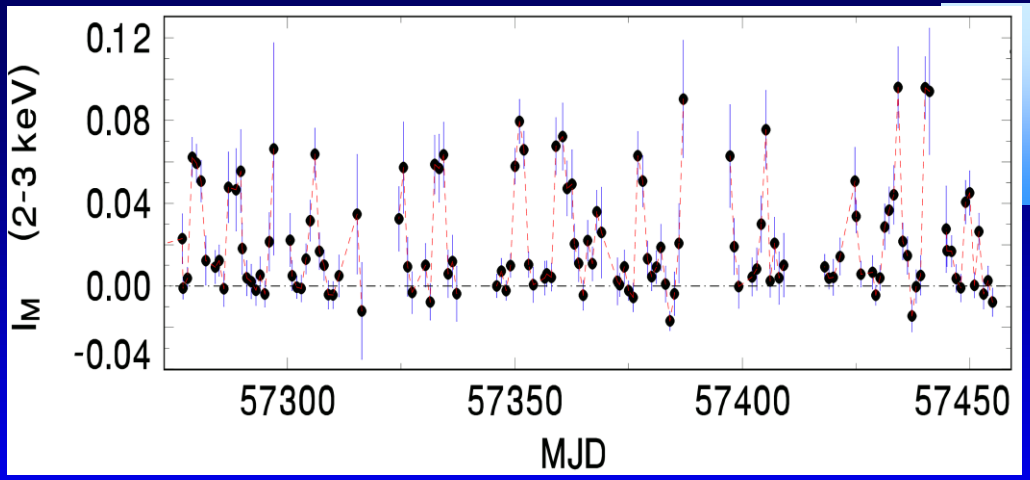


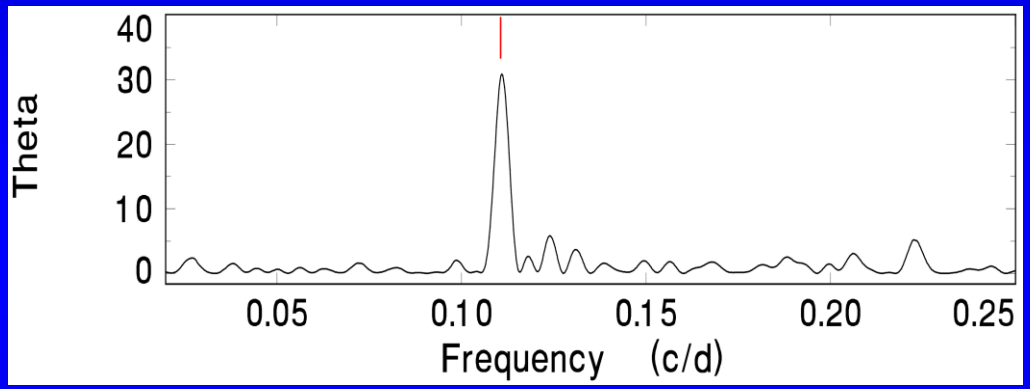
- (a) The light curve (1-d means).
- (b) Moving averages with various half-widths *Q* (*Q* = 50 d (dotted), *Q*= 100 d (long-dashed), *Q*= 150 d (short-dashed), *Q* = 200 d (solid))
- (c) A segment of the light curve – flares from a faint basic level
- (d) Histograms of X-ray flux:

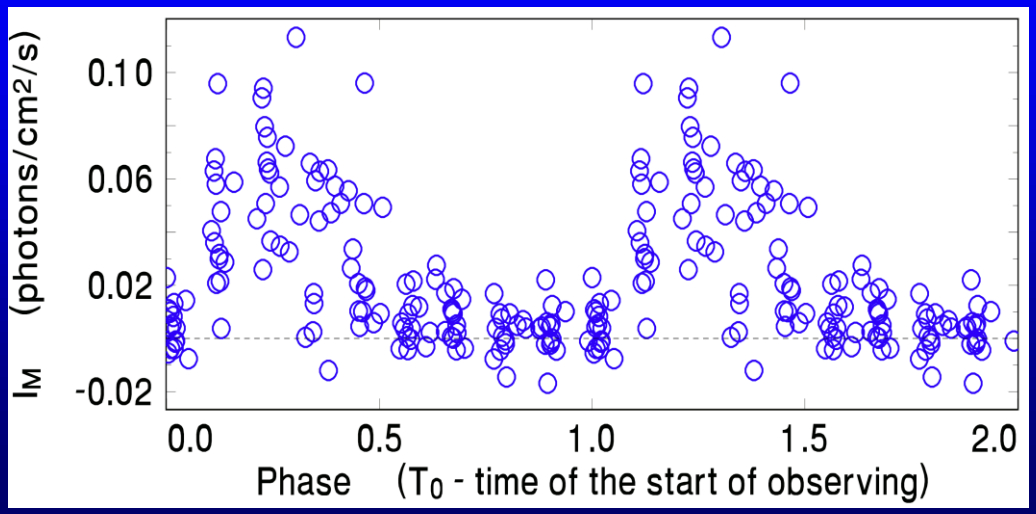
The hatched bars – the whole data set

The empty bars – a the time segment from (c)

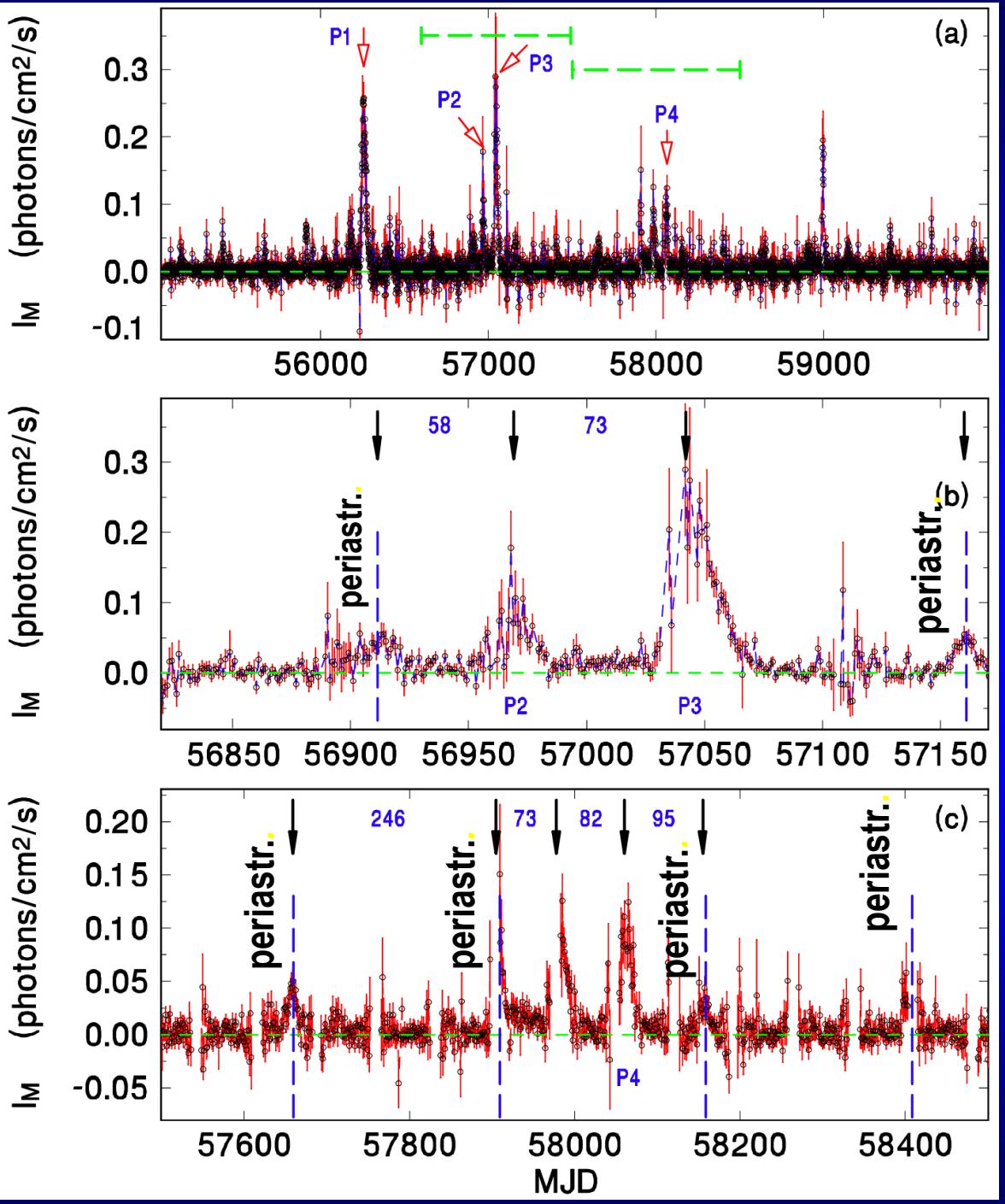
Vel X-1 – wind accretor (MAXI 2-3 keV)







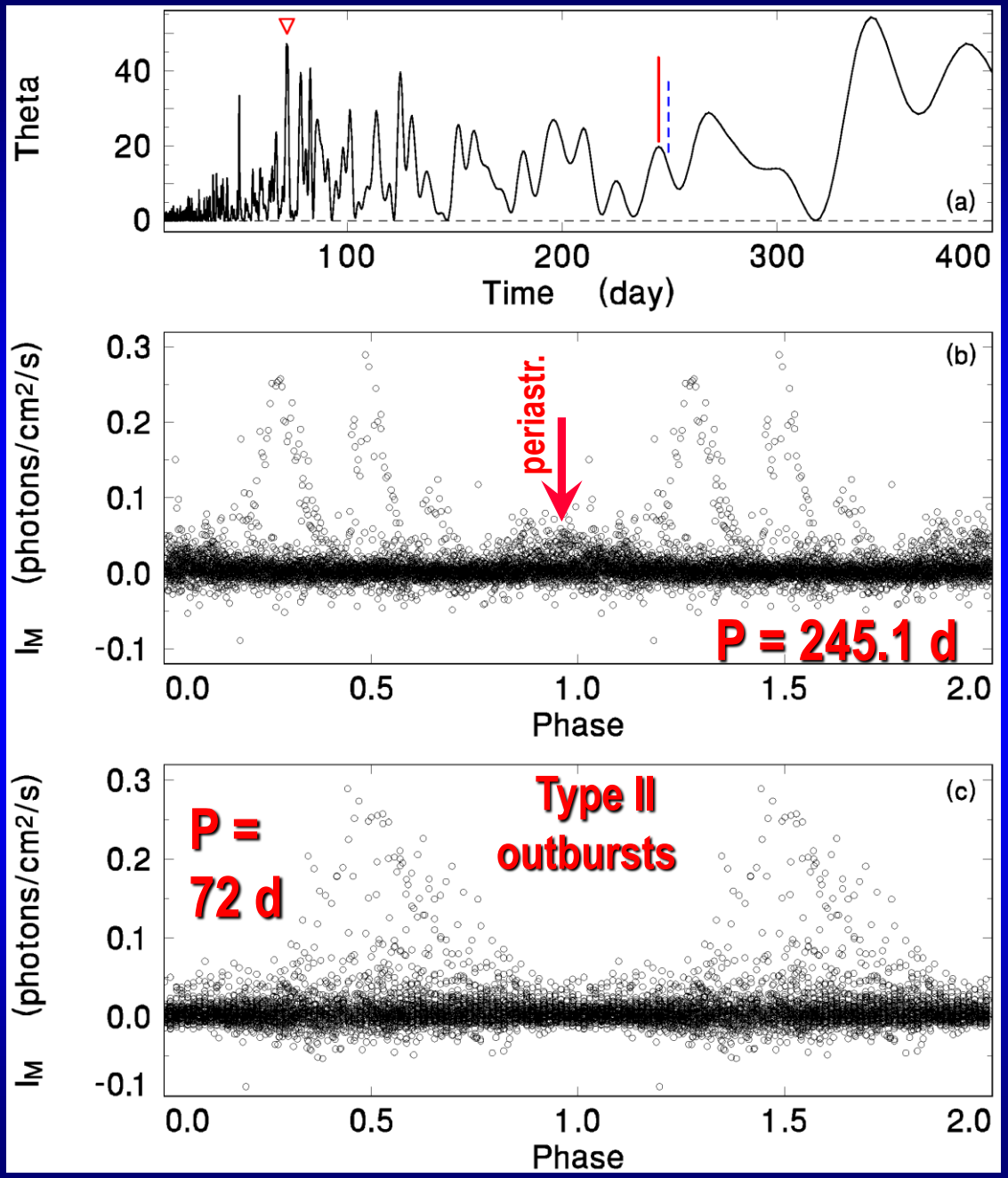
- A segment of the light curve – flares from a faint basic level
- Periodogram (a Lomb-Scargle method)
  – period of X-ray bumps corresponds to the orbital period
- Folded X-ray light curve:
  – The peak flux and width of the bump differ for the individual epochs



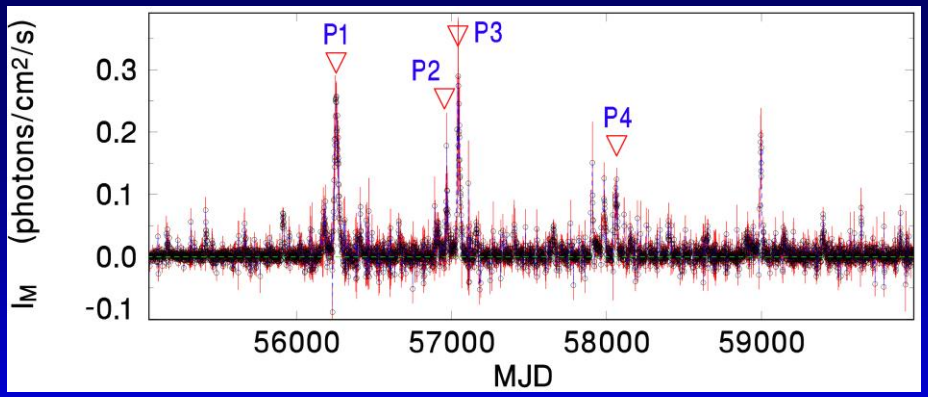
HMXB GRO J1008-57 (MAXI 3-6 keV)

- Periastron passages of the neutron star with the orbital period 249.5 d
- The prominent peaks P1, P2, P3, P4 – brightenings far from the periastron passages
- P1…P4 – possible transitions of the NS through short-lived clouds of matter (they disappear during less than 1 orbital epoch)

GRO J1008-57 (MAXI 3-6 keV)

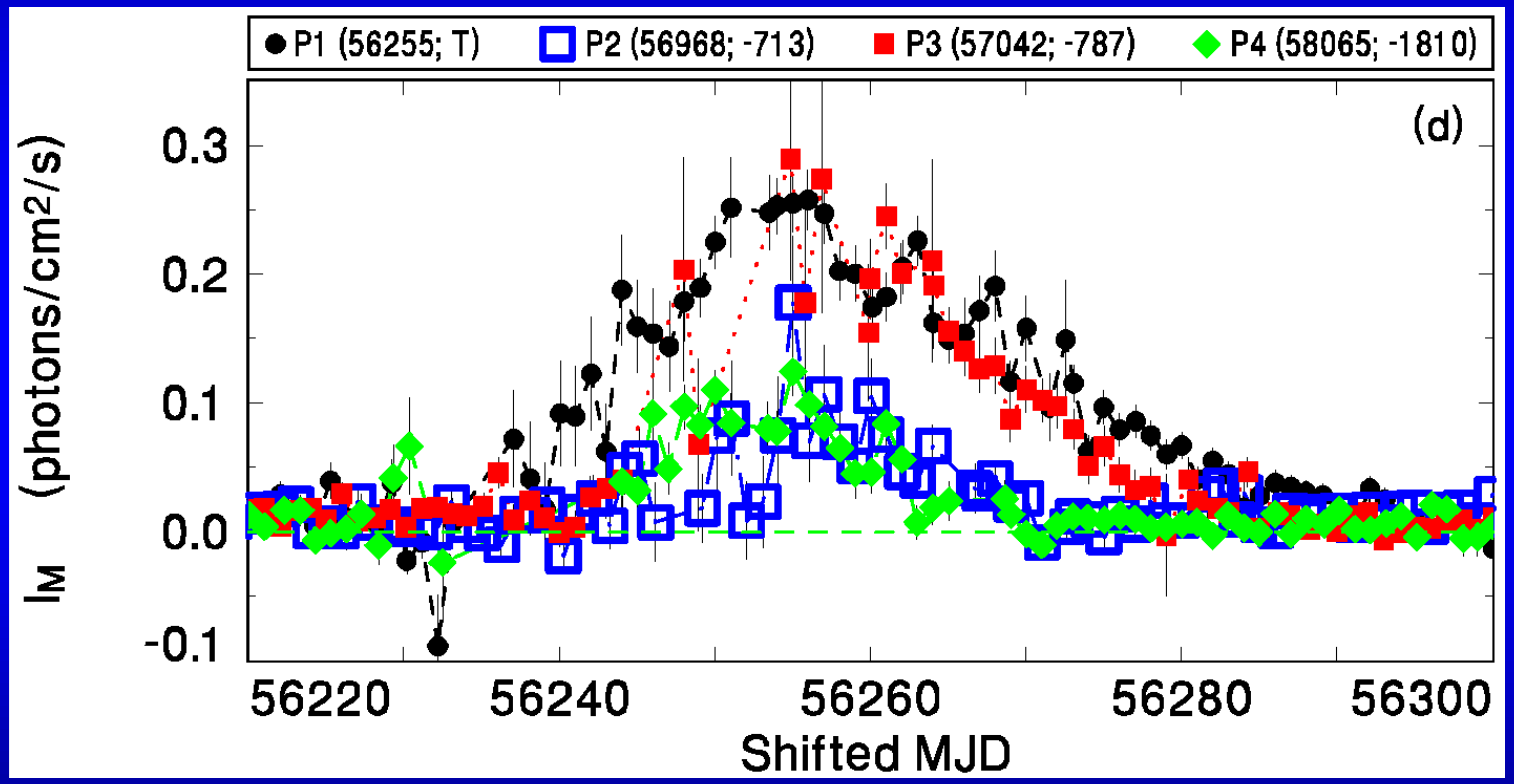


- Periodogram of the flux variations (the Lomb-Scargle method)
- The solid line: P= 245.1 d
- The dashed line: a period found by Kuhnel et al.(13)
- The triangle: the peak of a cluster (a period of 72 d)
- A foggy peak near phase 0 (a periastron passages)



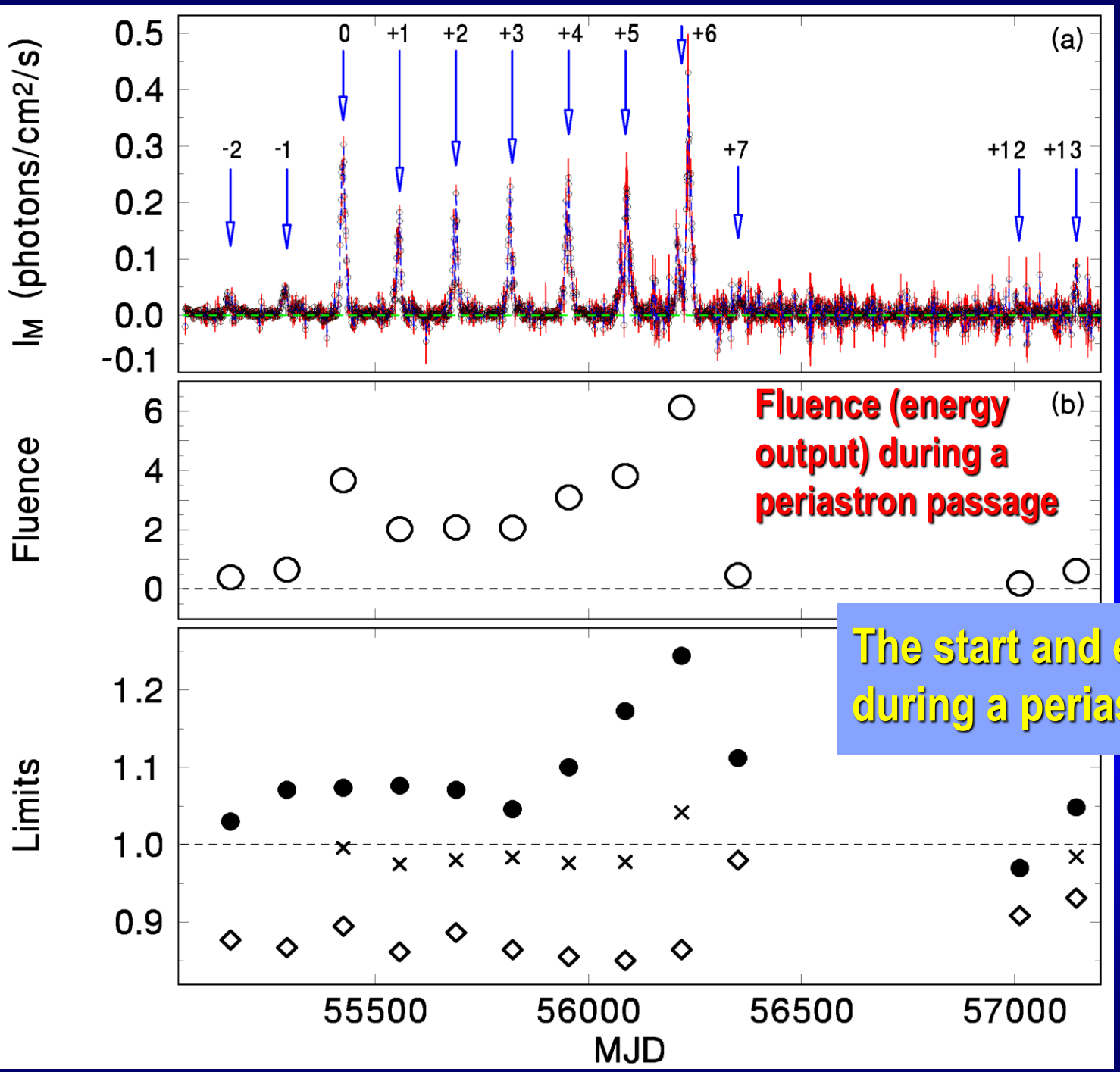
GRO J1008-57 (3-6 keV)

Dominant type II outbursts



- Aligning the bumps P1, P2, P3, and P4 according to their peak flux times
- The legend: the time of this peak and the shift with respect to the template T

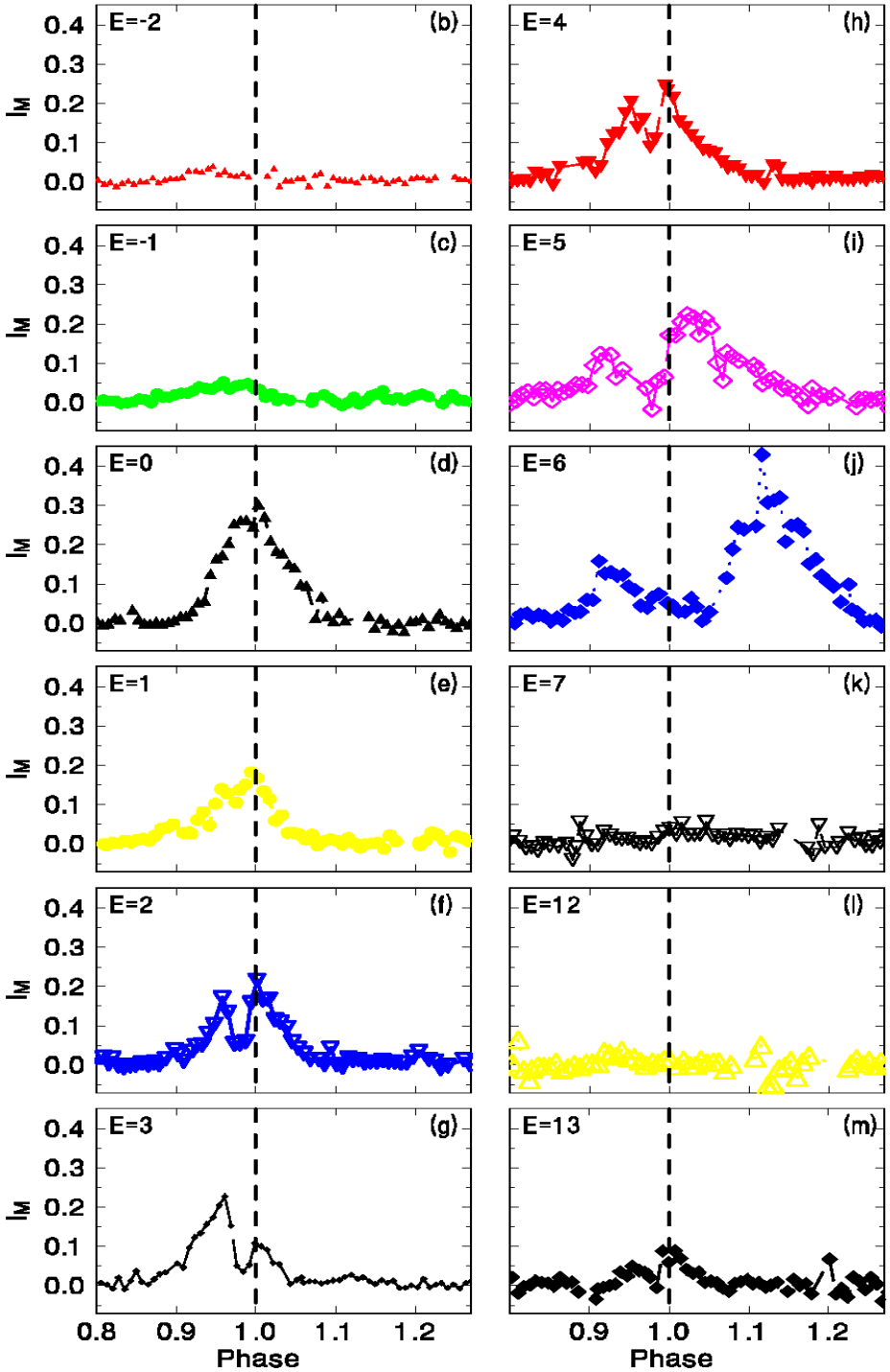
HMXB GX 304-1



- A series of periastron passages of the NS

The start and end of the bump during a periastron passage

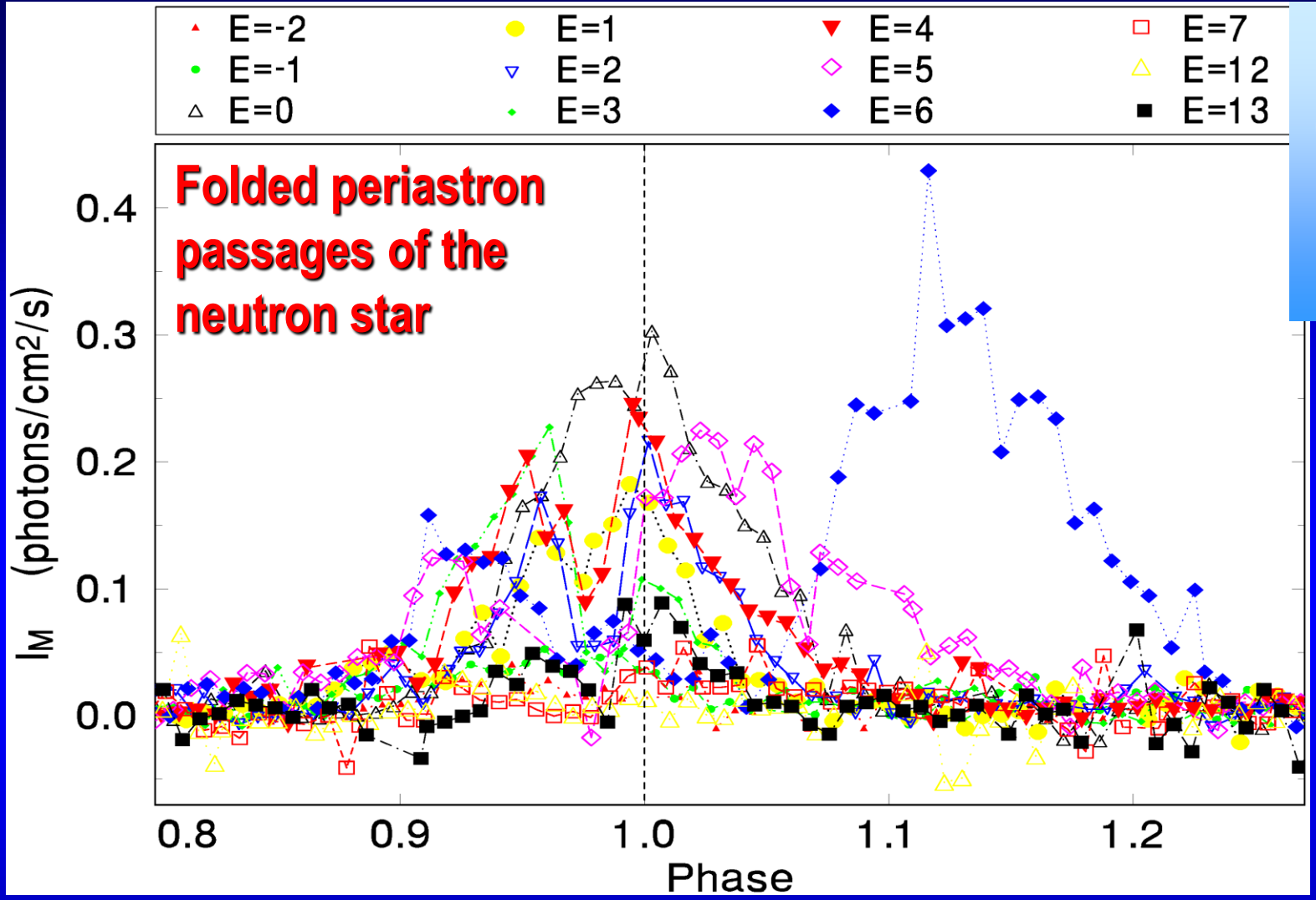
- Not every periastron passage gives X-ray brightening



HMXB GX 304-1 (MAXI 2-3 keV)

- Evolution of activity – a series of bumps (periastron passages of the NS)
- Extension of the circumstellar medium embedding the early-type donor varied.
- Changes from a narrow and single - peaked to a double-humped with increasing length

HMXB GX 304-1 (MAXI 2-3 keV)



All bumps (some of them multipeaked) in the X-ray light curve folded with *P*orb (ephemeris of Sugizaki et al.(2015): To = MJD 55 ,425.6 + 132.189 x *E*

The trailing side of the disk embedding the donor is less stable than the leading side (see also the precessing disk in Kuhnel et al. (2017))

Conclusions

- We describe the scientific potential of a Soft X-ray Imager (SXI) onboard the ESA-CAS satellite *SMILE* for investigating cosmic X-ray sources of various types.

- SXI, designed for X-ray imaging of solar wind interaction with the magnetosheath and the cusps, is also essential for astrophysics.

- SXI is able to provide wide-field (27 x 16 degrees) imaging of the sky in the soft X-ray region – also outbursts of transient sources (not known when in quiescence) will be detectable.

- X-ray sources with continuous X-ray spectra observable by MAXI/*ISS* enabled us to assess which object types and activity will be detected by SXI/*SMILE* and studied.

- The accreting compact sources (mainly neutron stars) are the most promising targets for observing their long-term activity with SXI.

Acknowledgements:

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