Observing the activity of X-ray sources by a combination of monitors

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The long-term activity of low-mass X-ray binaries

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

- Transient low-mass X-ray sources:
  - outbursts (a thermal-viscous instability of the accretion disk)
  - usually unpredictable events (duration – weeks, months)
  - variable recurrence time of the outbursts (months – years)

- wide-field monitoring 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

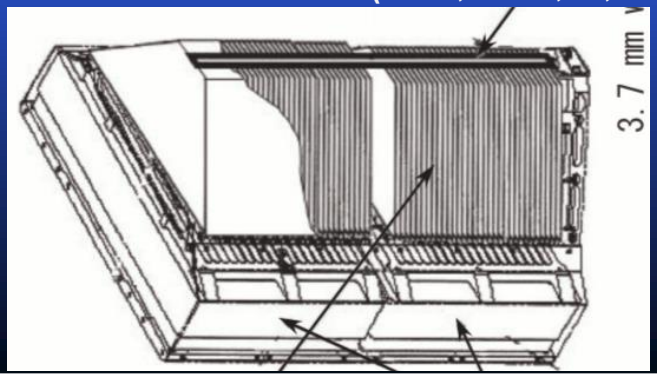
Some X-ray monitors:

- **ASM / RXTE** (1996 – 2012)
- Energy range: 1.5 – 12 keV
  1.5 – 3 keV
  3 – 5 keV
  5 – 12 keV
- Three shadow cameras

Levine et al. (1996, ApJL,469, L33)

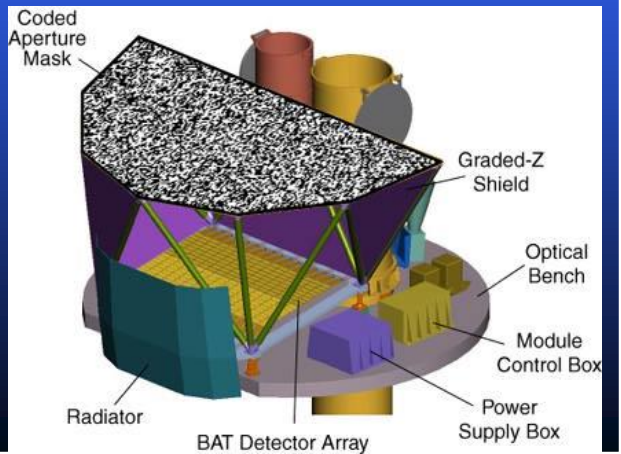
- **MAXI / ISS** (since 2010)
- Slit cameras in 6 units
- Energy range: 2 – 20 keV
  Can be divided !

Matsuoka et al.(2009,PASJ,61,999)
Mihara et al. (2011,PASJ,63,S623)

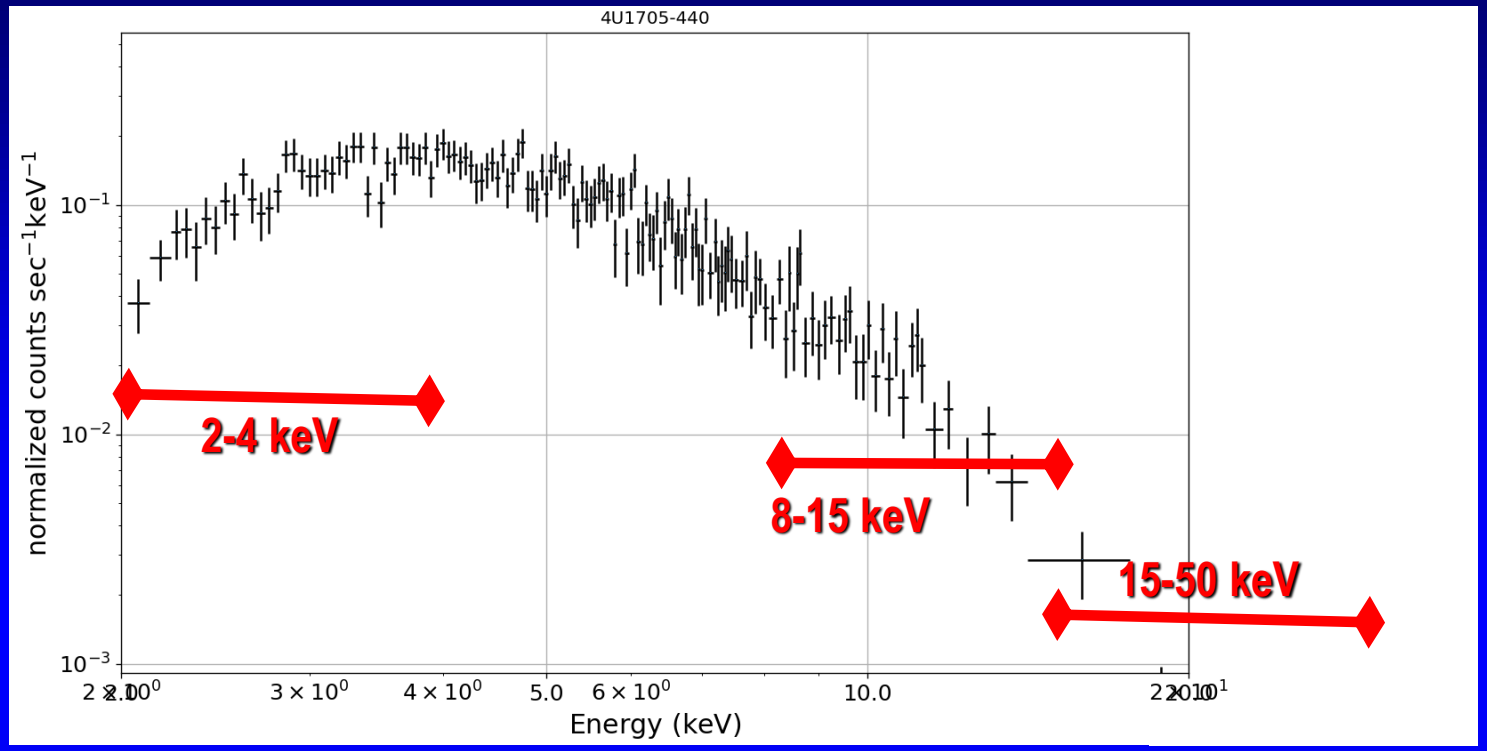


- **BAT/ Swift** (since 2004)
- Coded mask
- Field of view: 1.4 sr (partially-coded)
- Energy range: 15–150 keV
  15-50 keV for monitoring of X-ray sources

Krimm et al. (2013, ApJS,209,id.14)

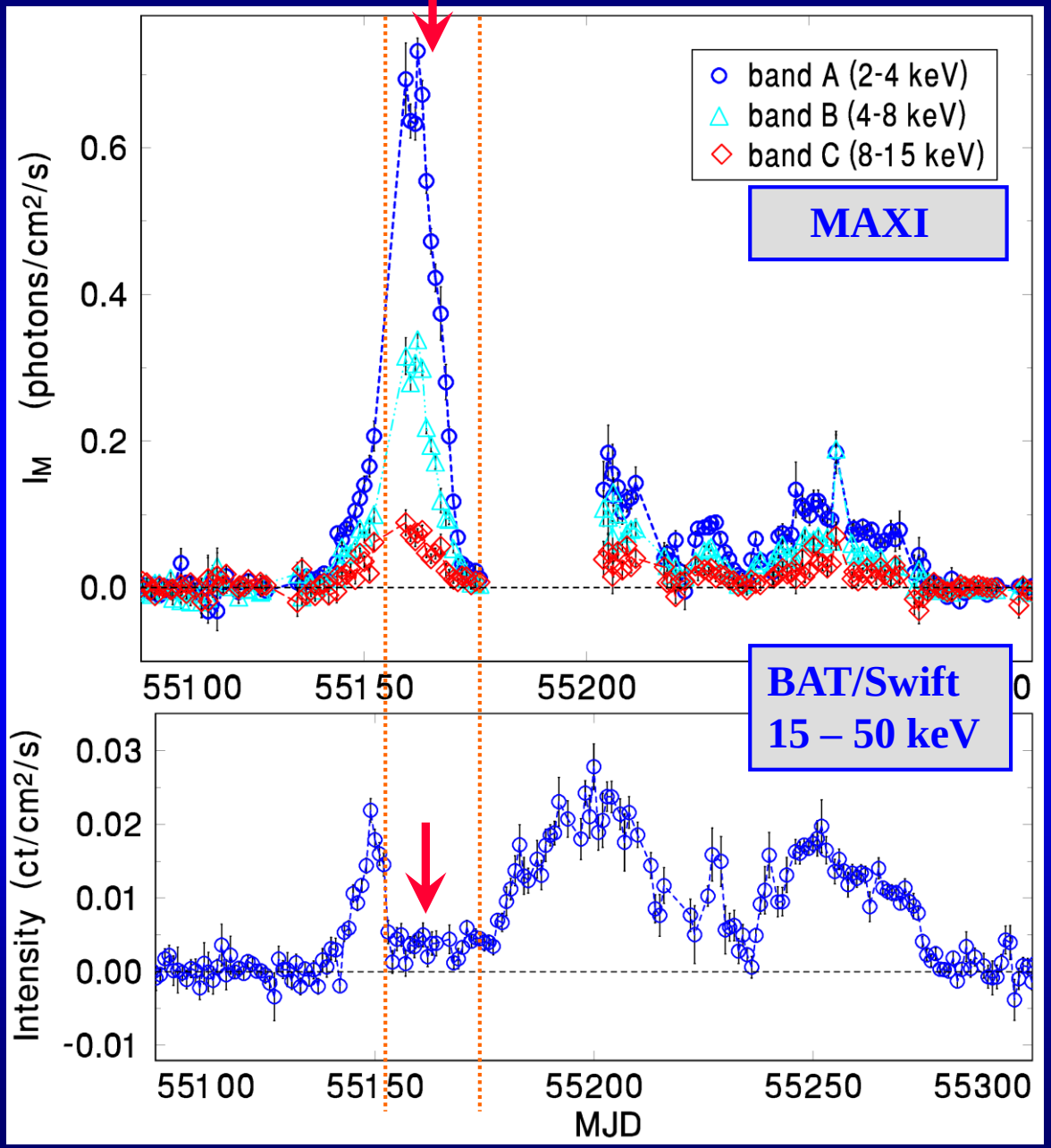


4U 1705-440 – coverage of the spectral regions by the monitors



- MAXI spectrum (E = 2 - 20 keV) of 4U 1705-440 in the high state
- Divided into several bands (2 – 4 keV and 8 – 15 keV in our case)
- The 15 – 50 keV emission: monitored by BAT/*Swift*
- The light curves of the 1-day data means from these monitors and satellites can be compared (most features of the long-term activity vary on timescales longer than several days).

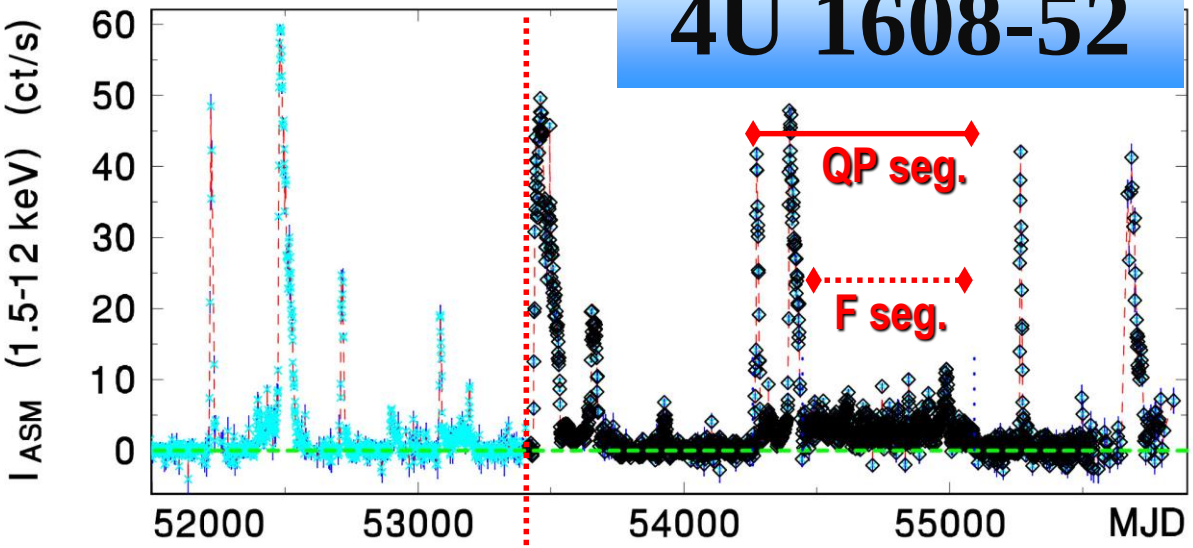
Aql X-1 – evolution of outburst in soft X-ray transient

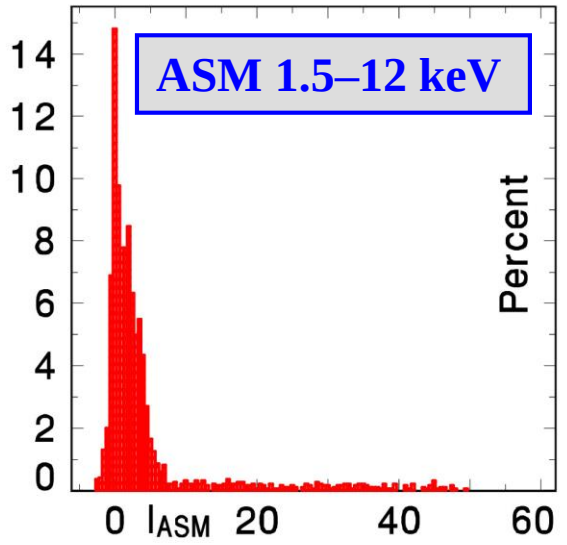


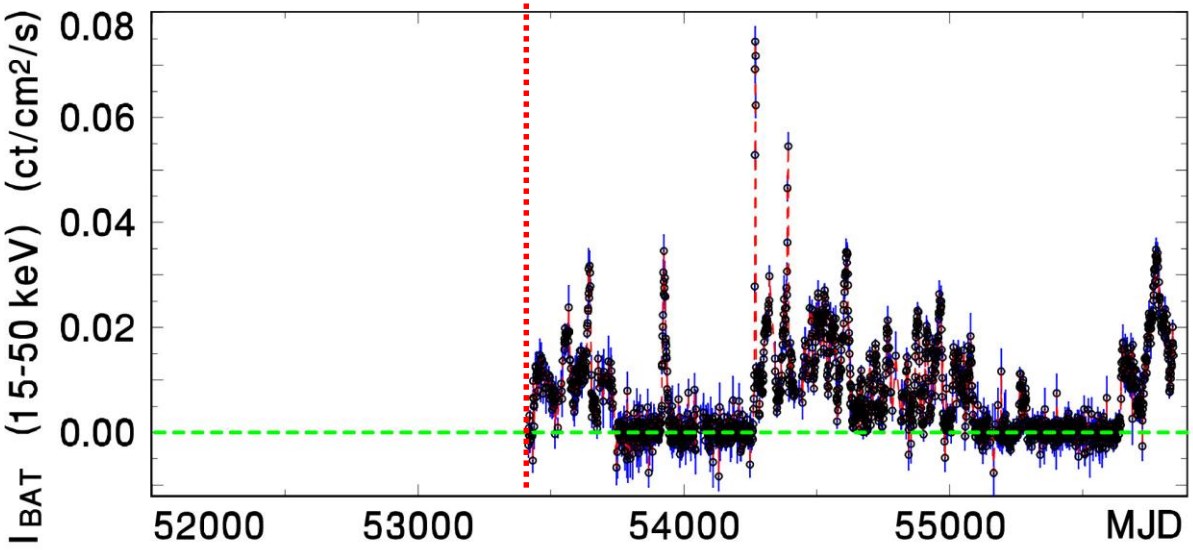
- Profile of the outburst in the BAT/*Swift* band is quite different from that in the softer X-rays.
  Two different emission components:
  - Multicolor accretion disk (soft X-rays)
  - Comptonizing component (hard X-rays)

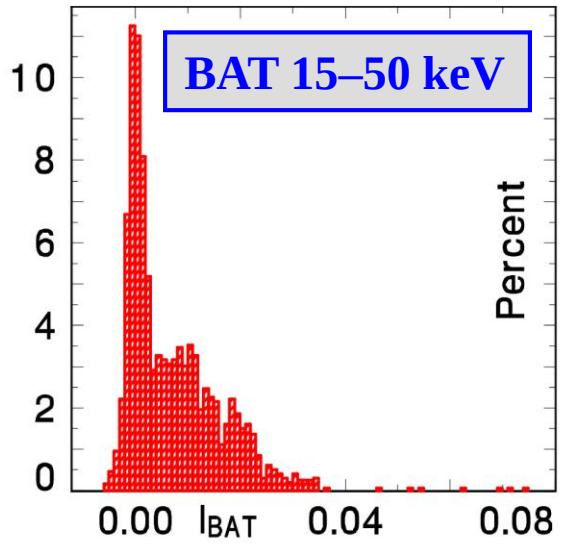
- Strong soft X-ray peak is absent in the BAT data – the disk component dominates

4U 1608-52

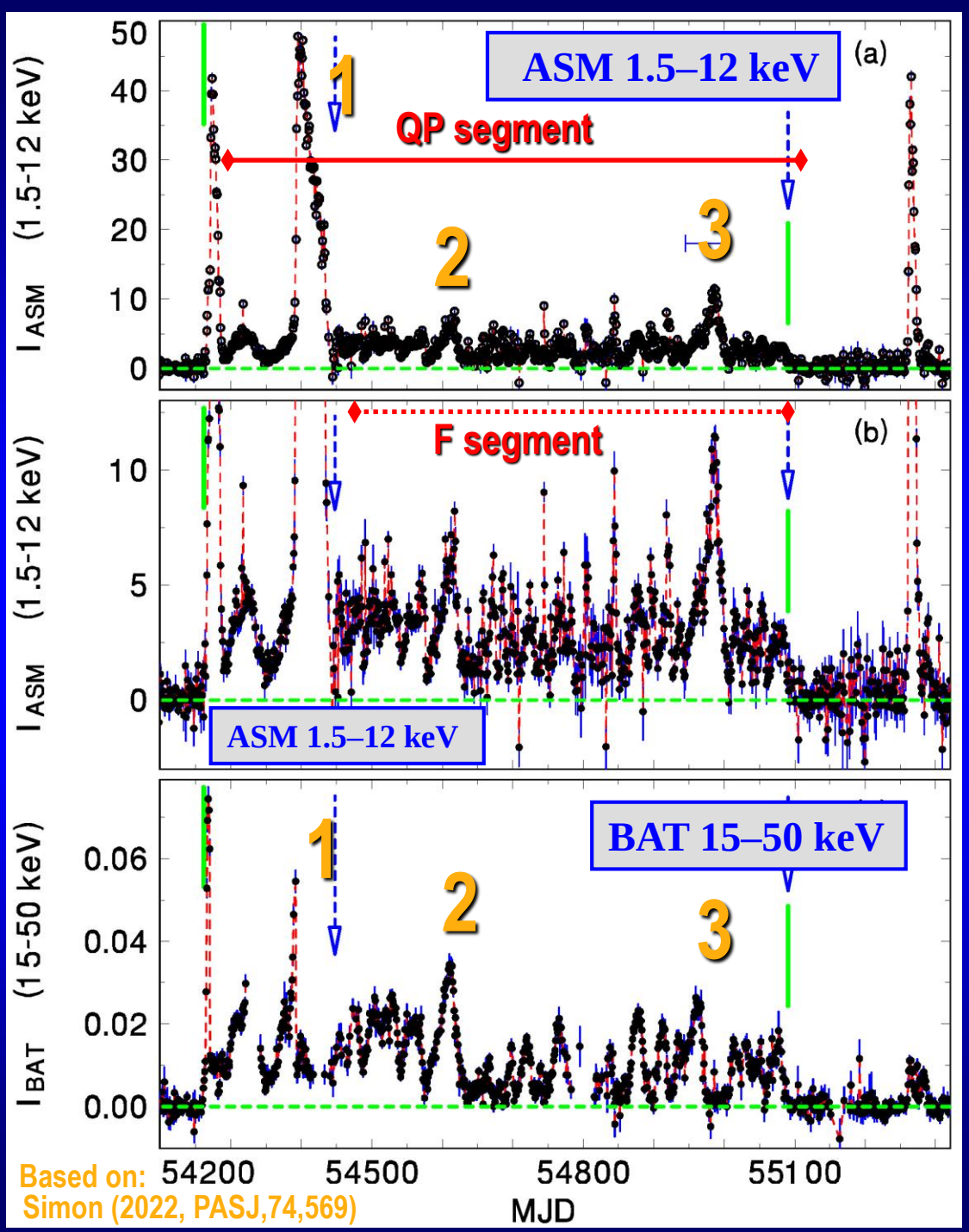








- A series of outbursts (very strong soft X-ray (I_{ASM}) peaks)
- X-ray flux is below the observing limit in quiescence
- QP segment: the source behaves as quasi-persistent.



4U 1608-52

- *QP segment (quasi-persistent source):*

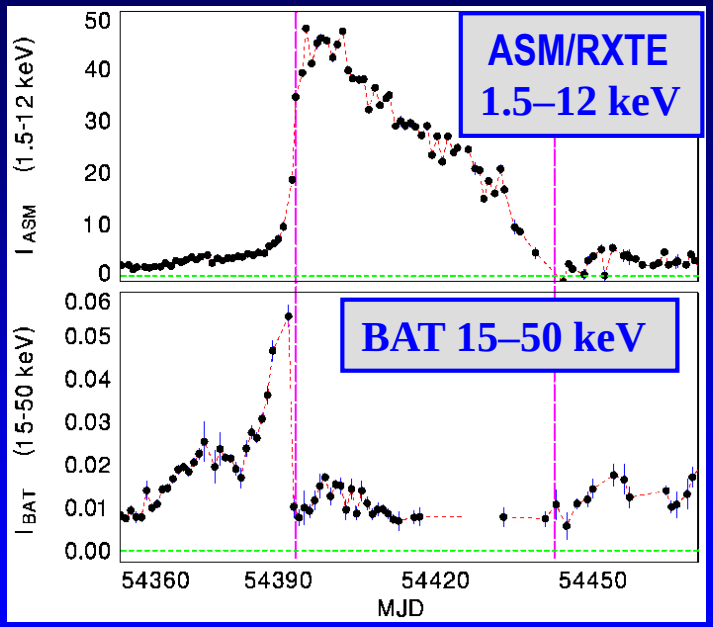
This object remains active between the consecutive outbursts

- **Normal outbursts – a thermal-viscous instability of the accretion disk**

(Dubus et al. 2001,A&A,373,251)

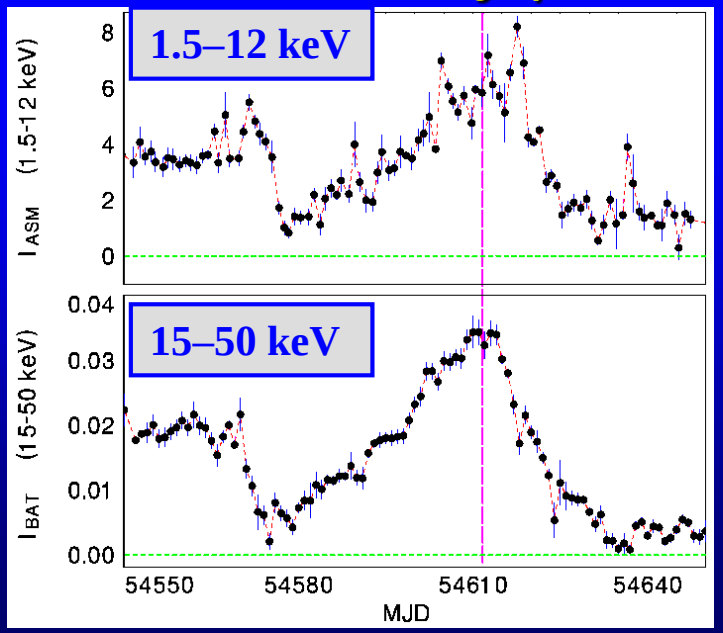
- **A series of short small-amplitude fluctuations (e.g. 2 and 3) in various X-ray bands (structural changes of the emitting regions?)**

Quasi-persistent 4U 1608-52 – details

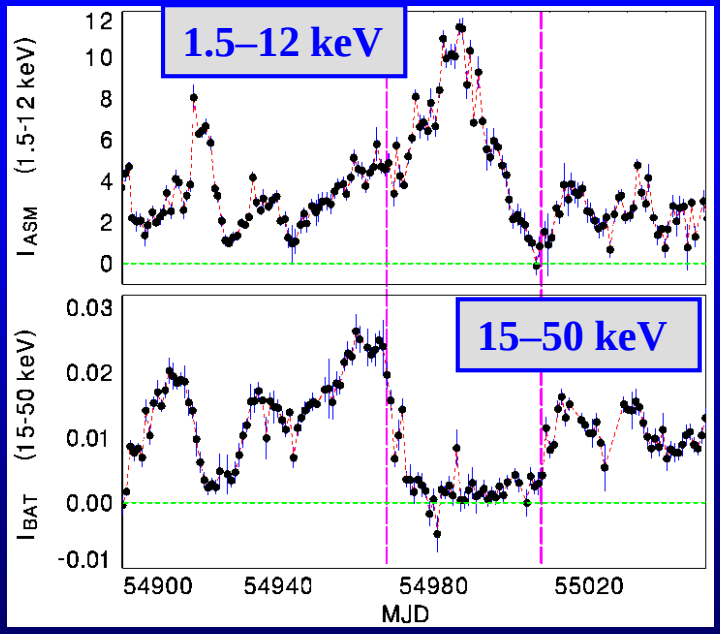


1 – main outburst
(hard peak in the start of the event)
– a steep decay of I_{BAT} – structural changes
(heating front in the disk)

2 – fluctuation (a peak in hard and soft X-rays)

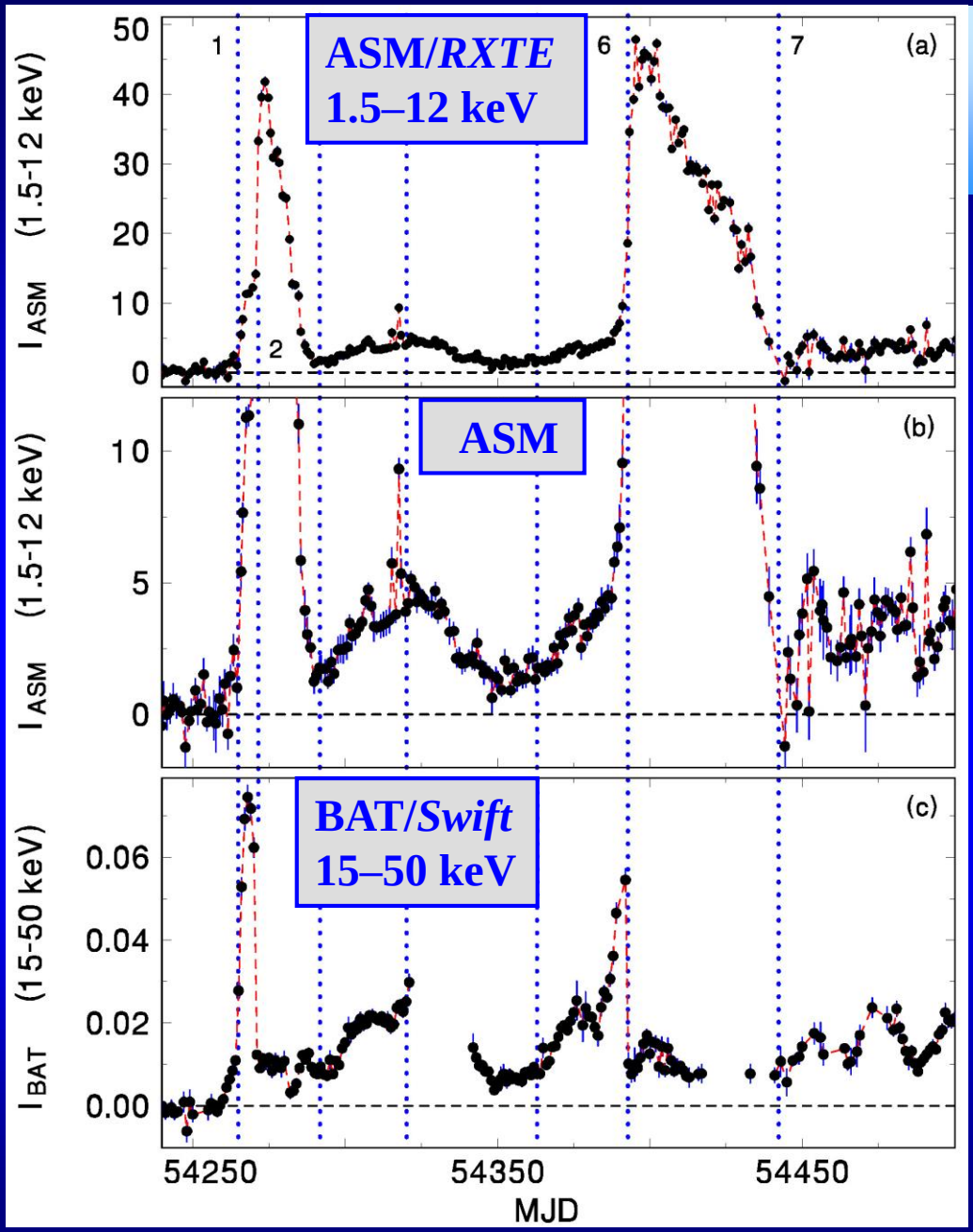


3 – fluctuation (hard X-rays in depression)
(heating and cooling fronts in the disk)



Based on:
Simon (2022, PASJ,74,569)

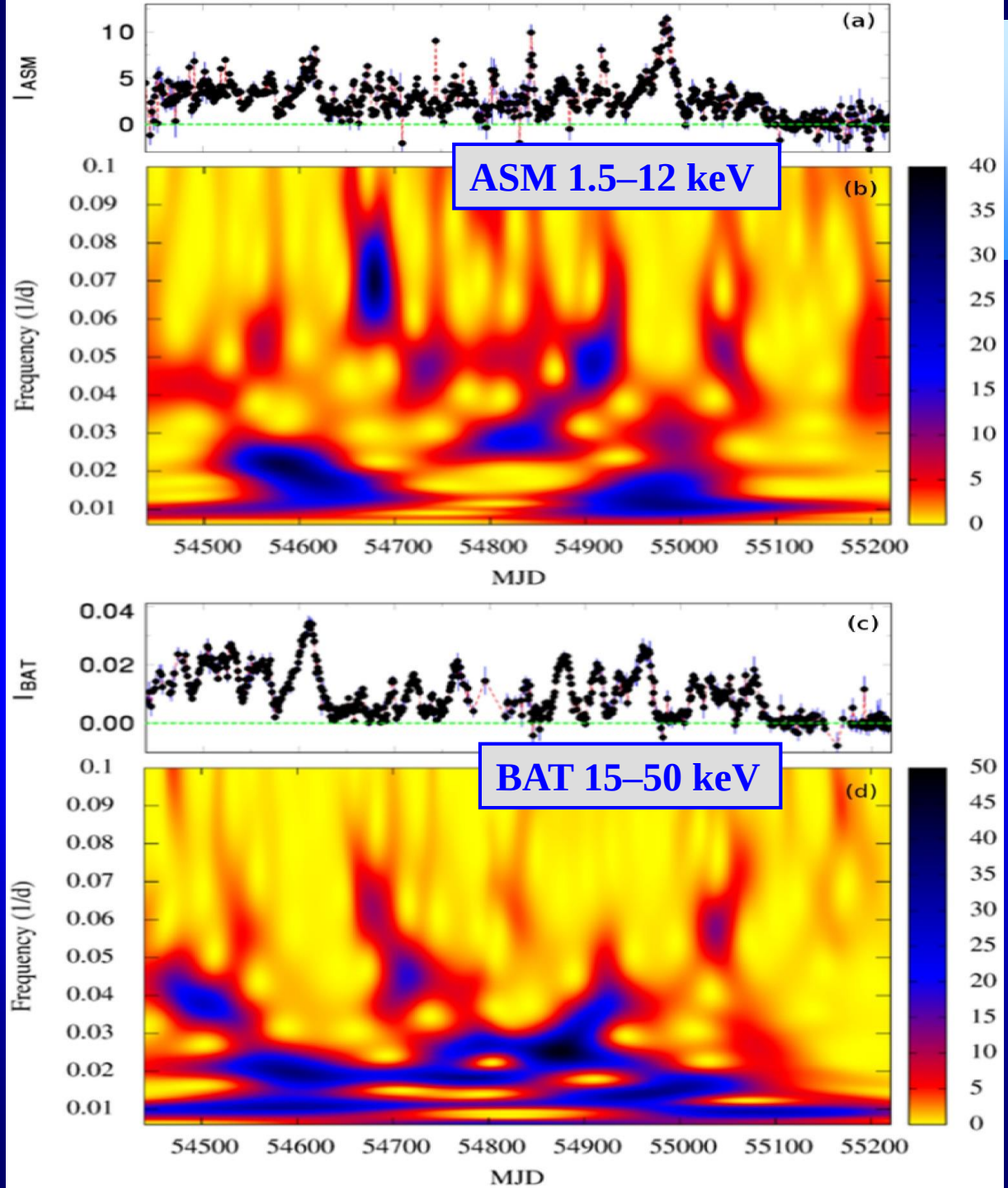
Start of quasi-persistent (QP) phase in 4U 1608-52



- A combination of monitors shows significant structure changes:
  - The start of the outburst is the same for the soft and hard X-ray bands
  - The hard X-ray outburst already ends at the peak of the soft X-ray outburst
- Significant waves of X-ray flux are always present (even between these outbursts).

Based on: Simon (2022,PASJ,74,569)

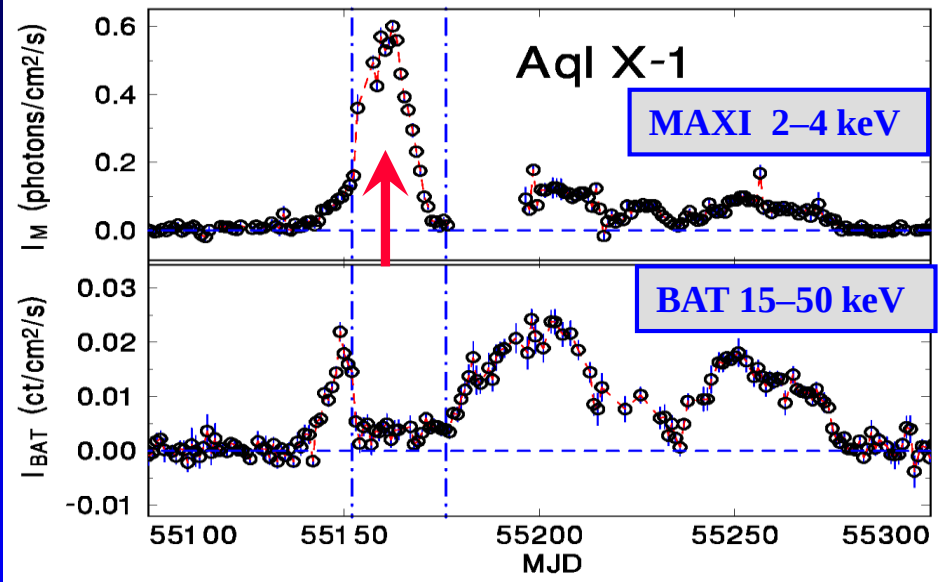
4U 1608-52 – time evolution in various energy bands

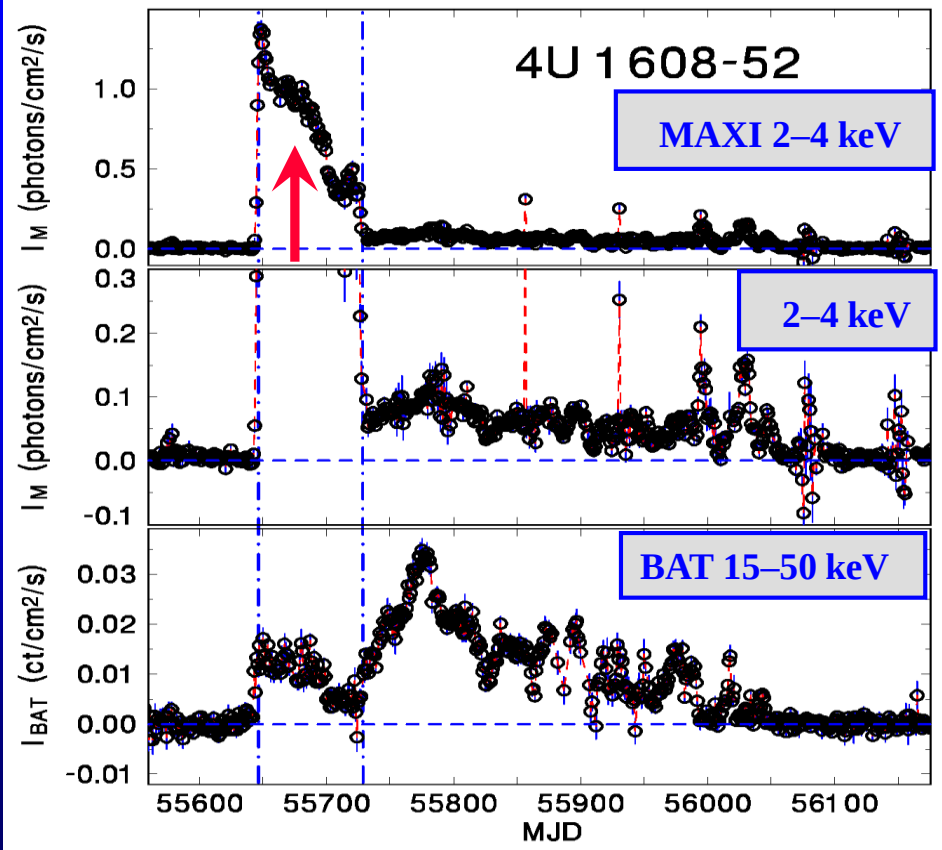


WWZ-transform (method of Foster (1996, AJ, 112, 1709))

- The fluctuations are not quite random – a cycle exists in the QP segment
- Discrepancy of soft and hard X-ray activities

Based on: Simon (2022, PASJ,74,569)





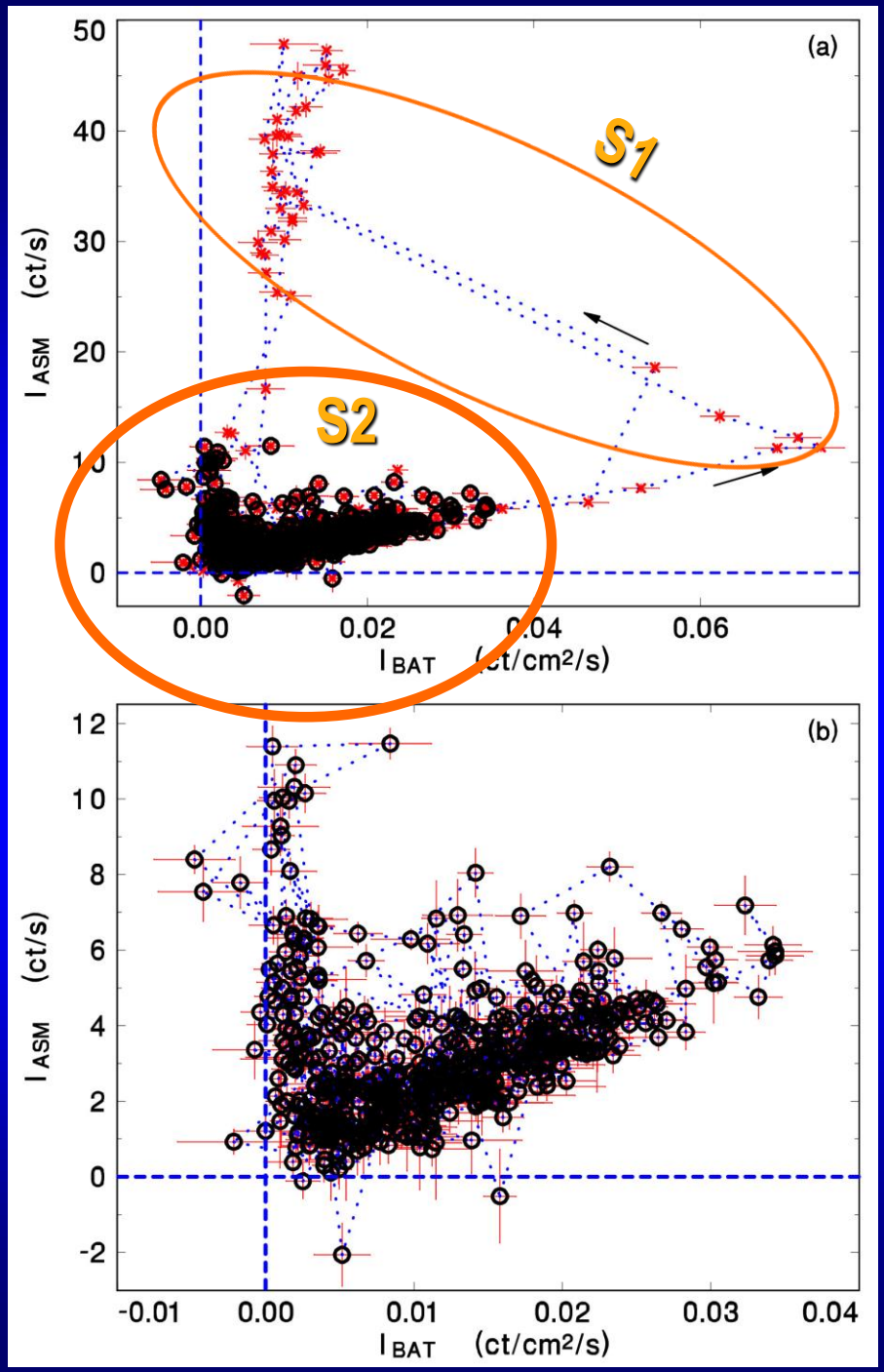
Dependence of the light curves of the outbursts of SXTs on the X-ray band

- The light curve of the outburst largely depends on the X-ray band (large structural changes of the emitting regions (disk?))
- The strongest peak dominates only in the soft X-rays (although the accretion is longer)

Such spectral changes will be observable also with THESEUS / XGIS.

Adapted from: Simon (2018,MNRAS,477,67)

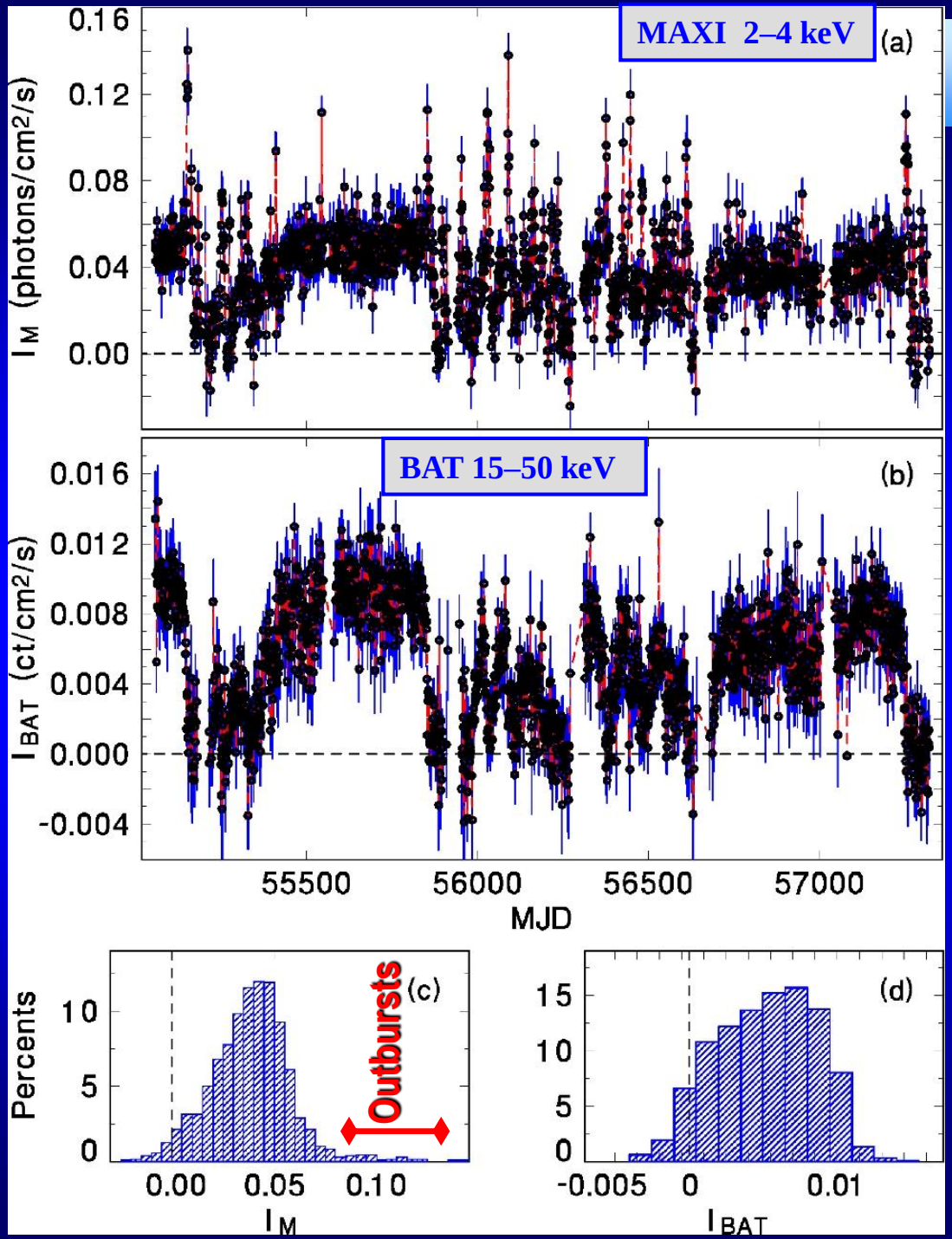
4U 1608-52



- Relation between fluxes in various X-ray bands in the QP segment
- S1: A rise to the outburst peak
- S2: Fluctuations in segment F
- The arrows and the lines connecting the points – the time evolution

Based on: Simon (2022, PASJ,74,569)

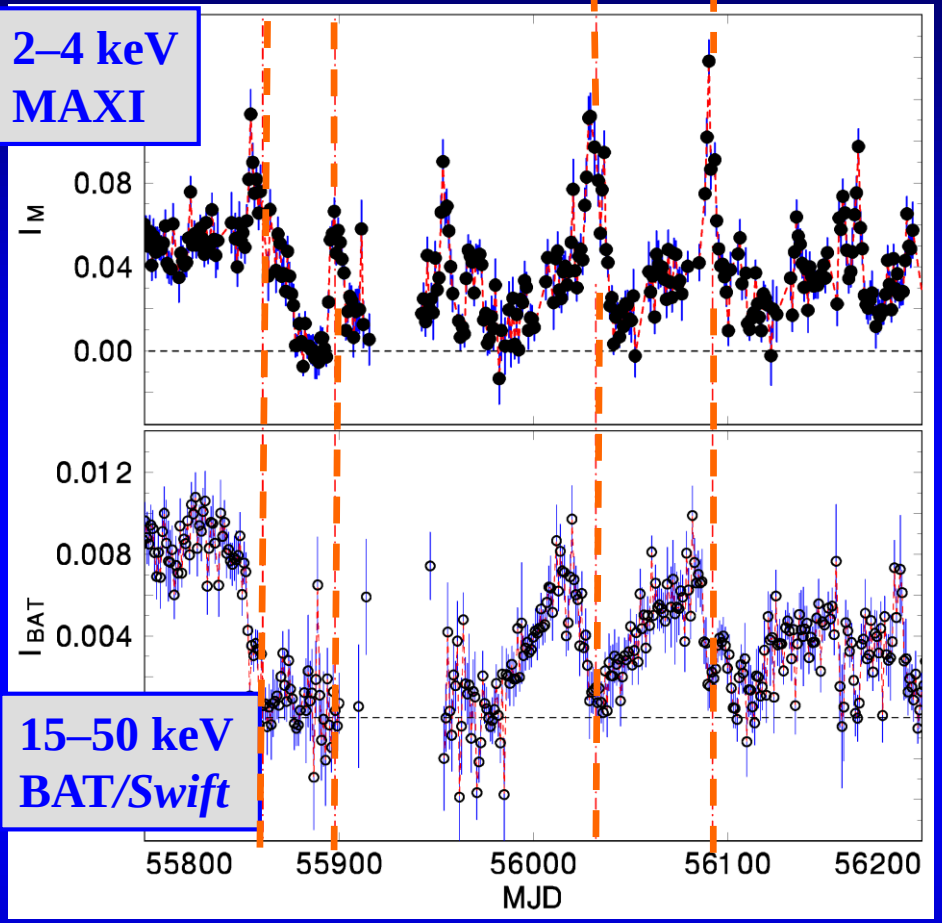
HETE J1900.1-2455



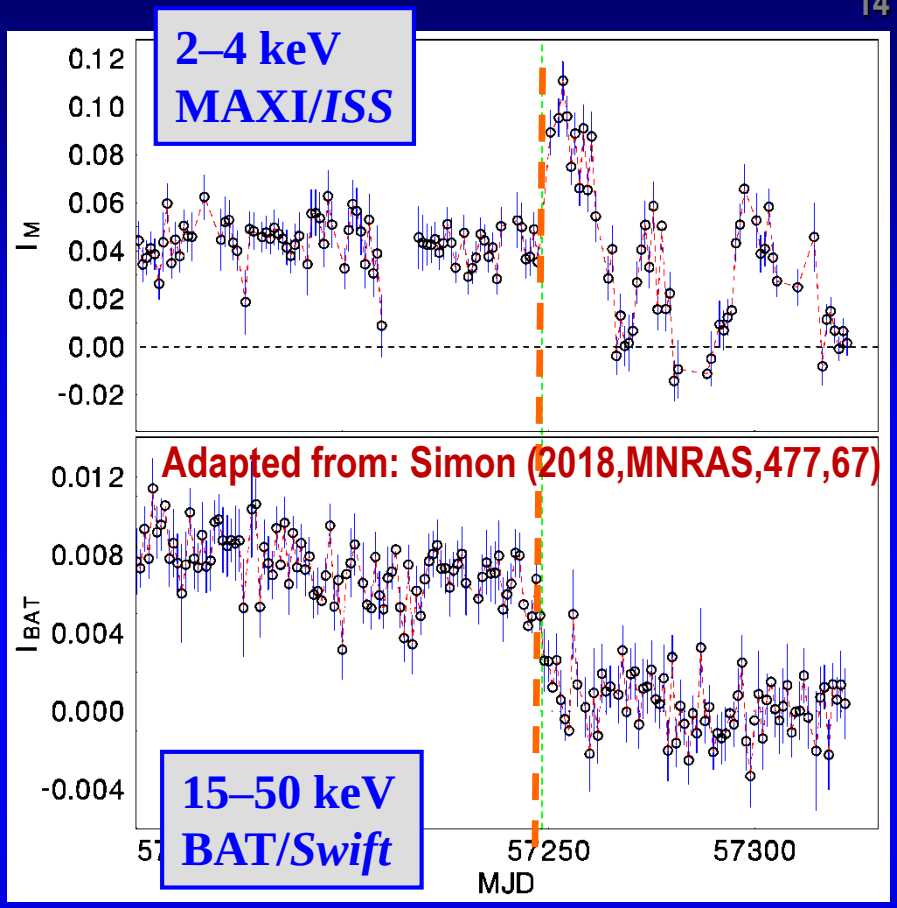
- The active state in the 15 – 50 keV band largely differs from that in softer X-rays.
- The activity simultaneously observed by *ISS*/MAXI and *Swift*/BAT
  – short outbursts (flares) only in the soft band
- Comparison of histograms of I_M and I_{BAT} in this active state

from: Simon (2018,MNRAS,477,67)

HETE J1900.1-2455



Properties of the ensemble of outbursts



- Peaks of the soft X-ray outbursts are accompanied by dips in the hard X-ray band ➡ changes of the structure of the emitting region(s) in the disk

- End of the active state

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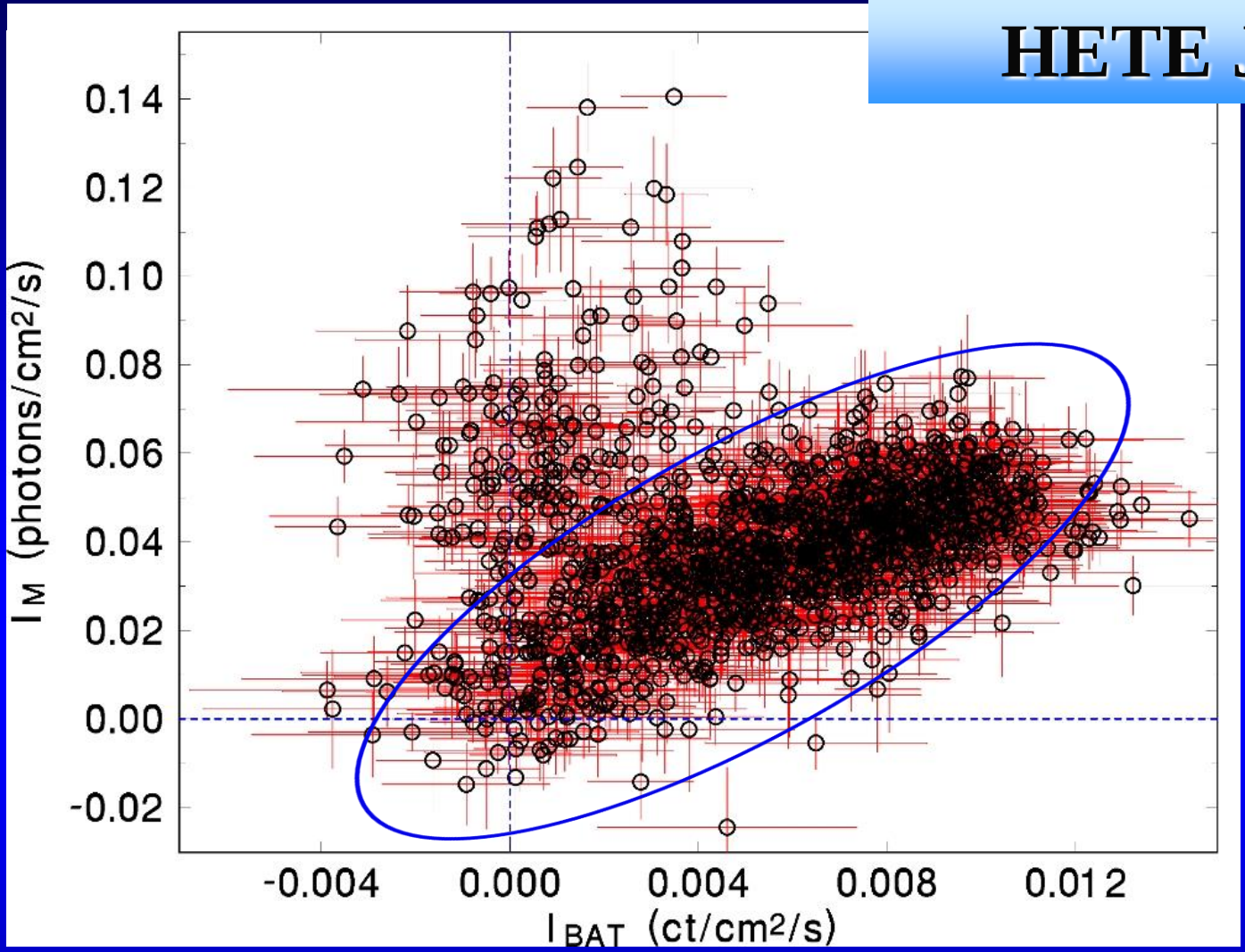
Such spectral changes will be observable also with THESEUS/XGS.

from: Simon (2018,MNRAS,477,67)

HETE J1900.1-2455

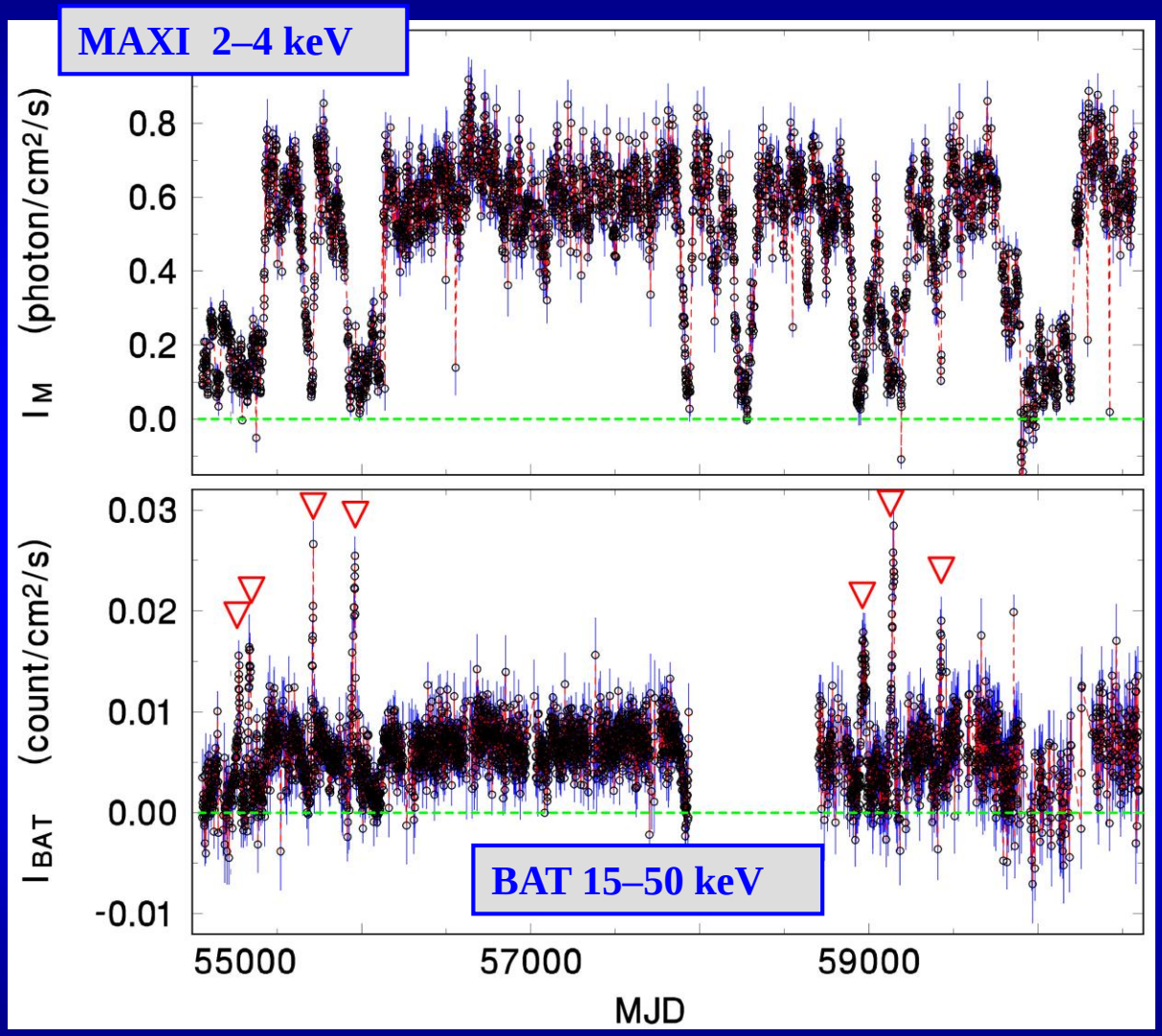


X-ray color-color diagram for the active state

from: Simon (2018, MNRAS,477,67)

- MAXI I_M corelates with Swift I_{BAT} during most time (variations of the mass transfer rate?).
- The biggest values of I_M deviate – (a thermal-viscous instability of the accretion disk).

4U 1705 – 440

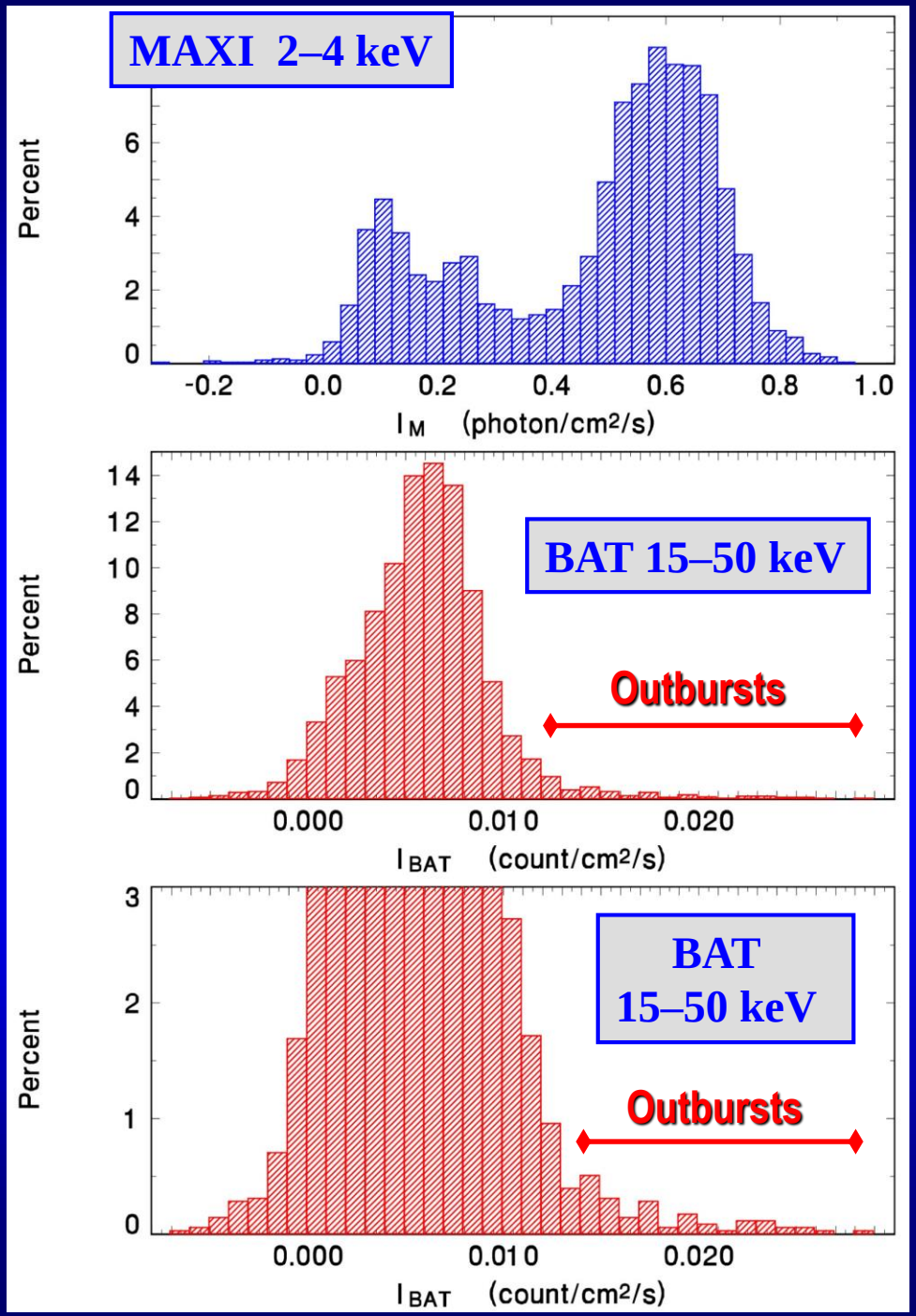


- Big discrepancy of soft and hard X-ray activities
- Soft X-rays: transitions between the high and low states
- Hard X-rays:

– state transitions only barely visible

– outbursts (flares) only in some low-state episodes of soft X-rays

4U 1705 – 440



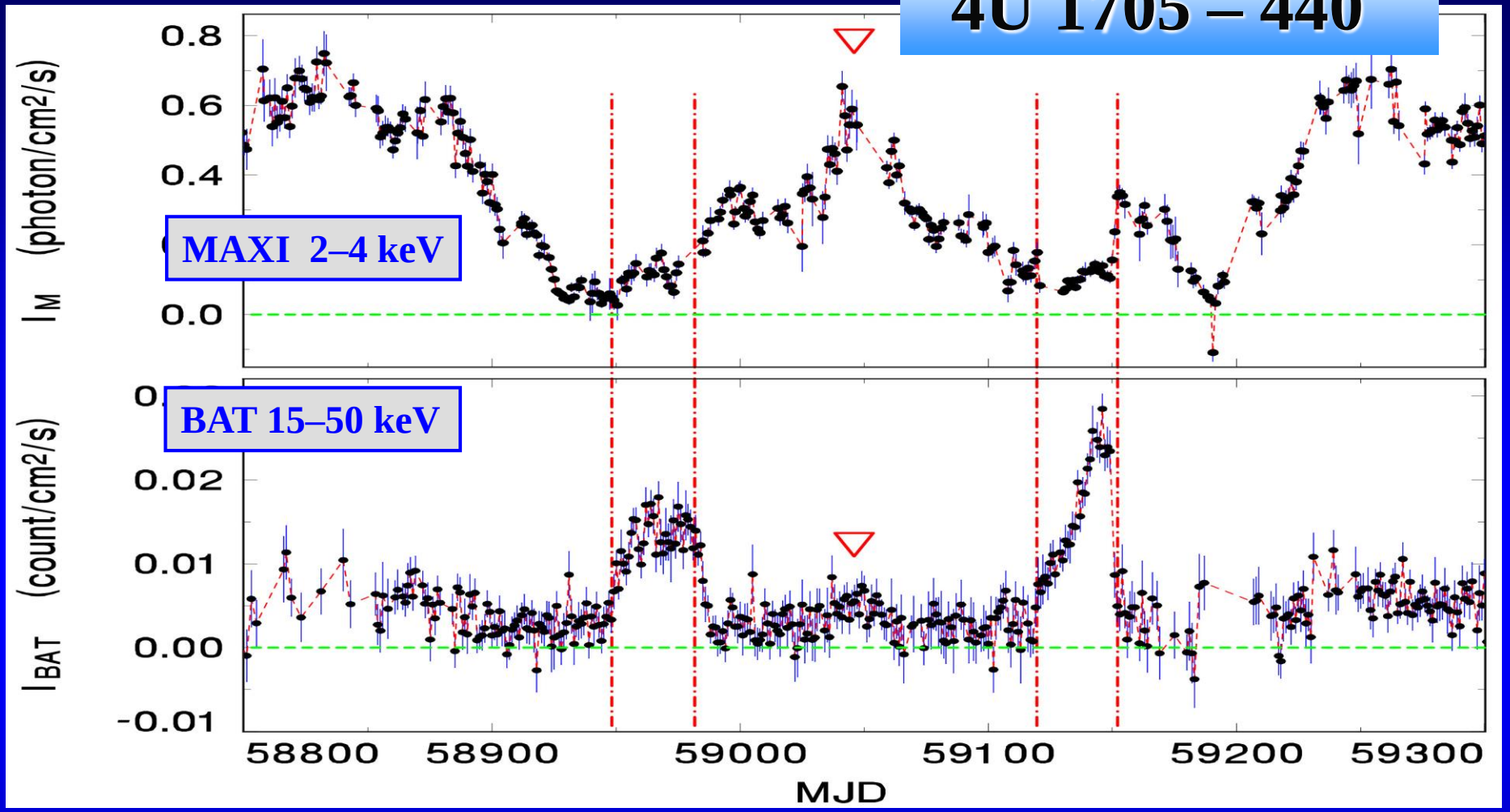
- Comparison of histograms of I_M and I_{BAT}

– Bimodal histogram only in the soft X-ray band
(the high states are separated from the low states)

– the low states are only a tail in the hard X-ray band

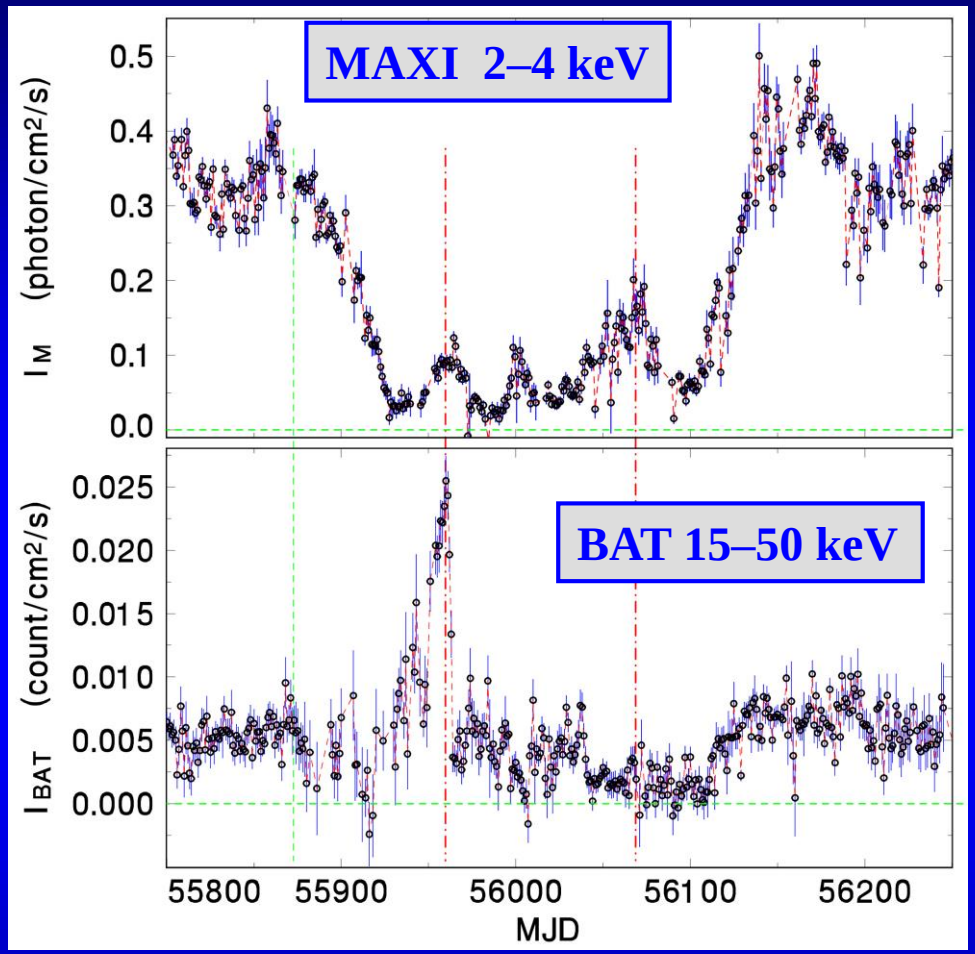
– Short outbursts (flares) only in the hard X-ray band
(a long tail)

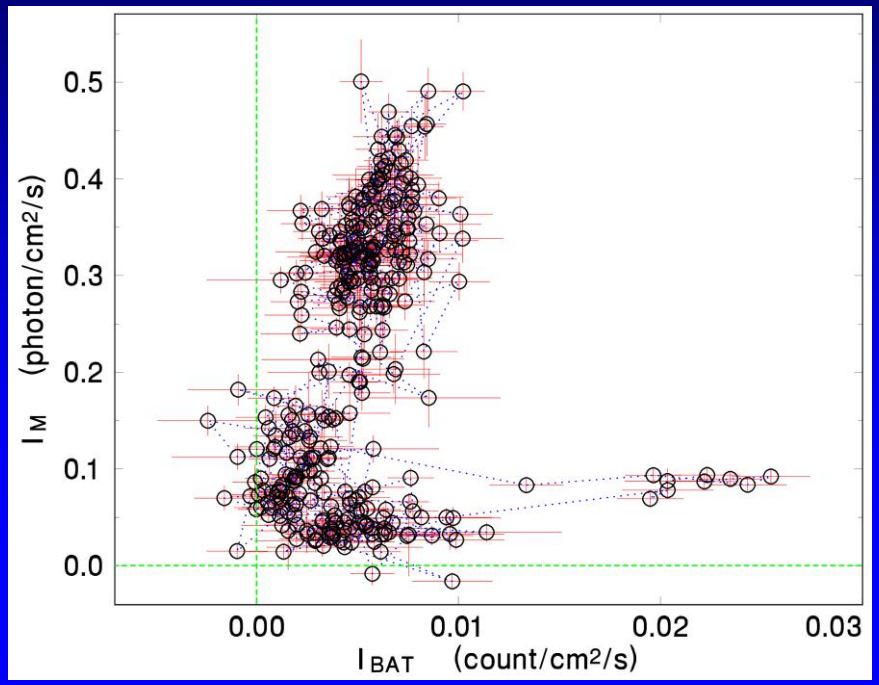
4U 1705 – 440



- Changes of absorption cannot explain the steep decrease of the hard X-ray emission (I_{BAT}) at the peak of the soft X-ray bump.
- The hard X-ray emission (I_{BAT}) is the most intense only in the transition from a low state to a high state (but not vice versa).

4U 1705 – 440





- A very intense hard X-ray peak only in some rising branches of the soft X-ray brightenings

- Hysteresis in the soft (I_M) X-ray versus hard (I_{BAT}) X-ray flux occurs in some transitions of this LMXBs from low state to high state

  – similar to the outbursts of soft X-ray transients

Conclusions

- Combining the observations (1-day bins) of various X-ray monitors with different energy bands onboard different satellites – helpful for investigating the features of the long-term activity of X-ray binaries

- Combinations of data from MAXI/*ISS* and BAT/*Swift* enable the investigation of long-term activity at energies between 2 keV and 50 keV.

- 1-day binning – sufficient for resolving the typical features of activity

- Combinations of the data from these monitors reveal large structural changes in the emitting regions that occur during these features.

- This combination of X-ray monitors has the scientific potential to investigate the role of various physical mechanisms on long timescales.

A combination of X-ray monitors in the time of *THESEUS*

XGIS / *THESEUS* (Amati et al. 2019): **the profiles in of the X-ray light curves in the 2 – 30 keV (similar to a combination of MAXI and BAT)**

SXI / *THESEUS* **(0.3 - 5 keV)** (Amati et al. 2019): **extension of the spectral coverage to a very soft X-ray band – search for possible very soft X-ray components and absorption intrinsic to the sources**

- **A series of X-ray monitors:** **necessary to obtain long-term light curves (e.g., outbursts, state transitions) in a broad energy range.**

- **Big satellites:** **needed to obtain detailed observations (spectra, rapid variations)**
  - **in a broad energy range**
  - **in specific and essential phases of activity**

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