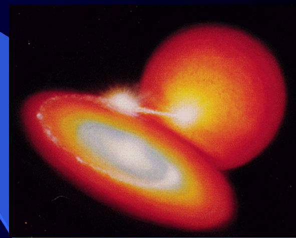
Observations of cataclysmic variables with *INTEGRAL*



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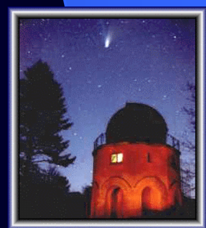
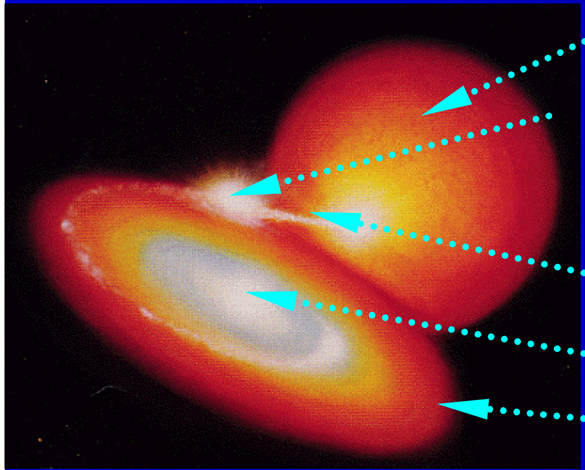


Non-magnetic cataclysmic variable (CV)

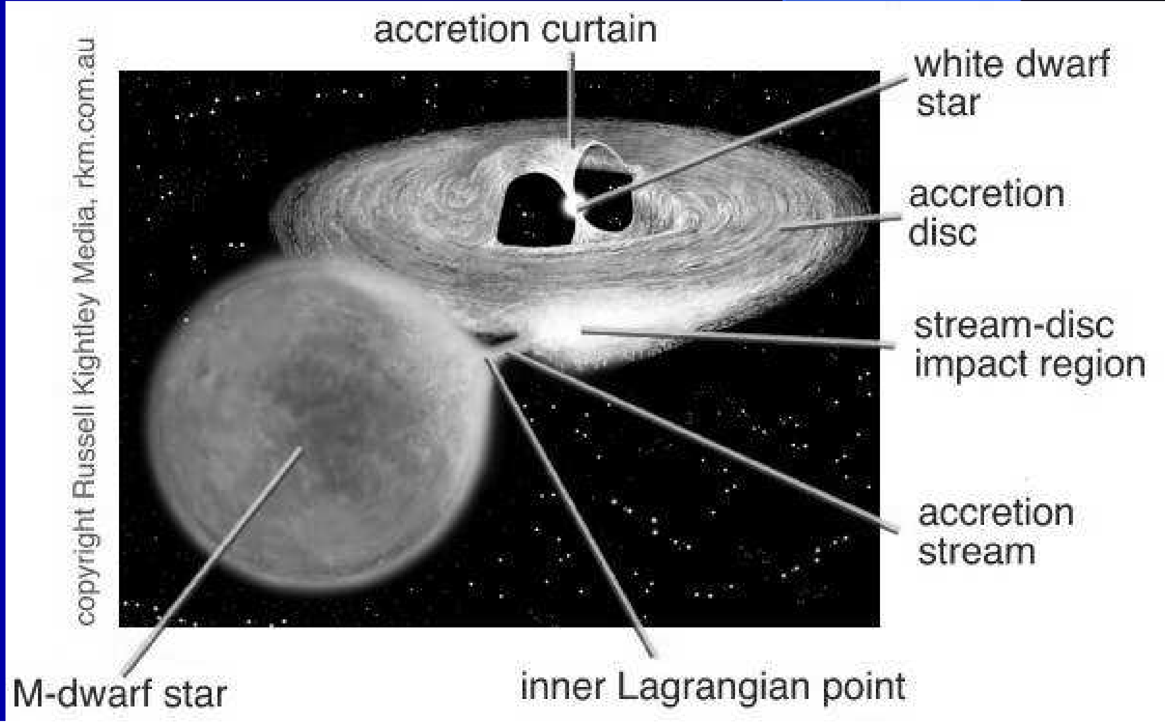


- Accretion disk – thermal radiation (UV, optical, IR)
- Opt. thick, geom. thin boundary layer (therm. rad. - soft X-rays) (high $\dot{m}$)
- Opt. thin, geom. thick boundary layer (bremsstrahlung – hard X-rays) (low $\dot{m}$)

Dominant source of luminosity: accretion process

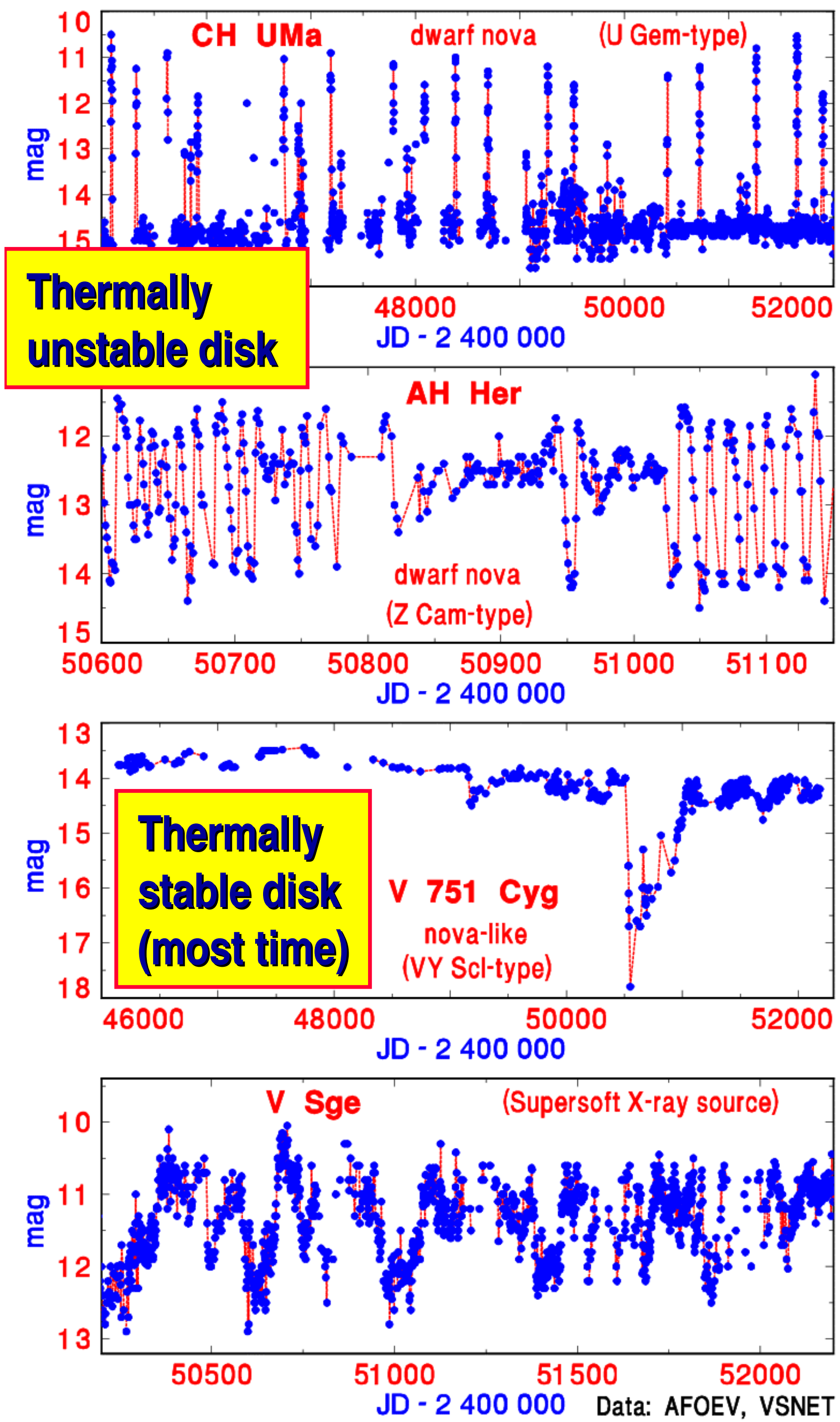
Intermediate polar – mildly magnetized white dwarf

- Impact region near the magnetic pole of the WD (bremsstrahlung – hard X-rays)

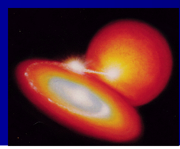


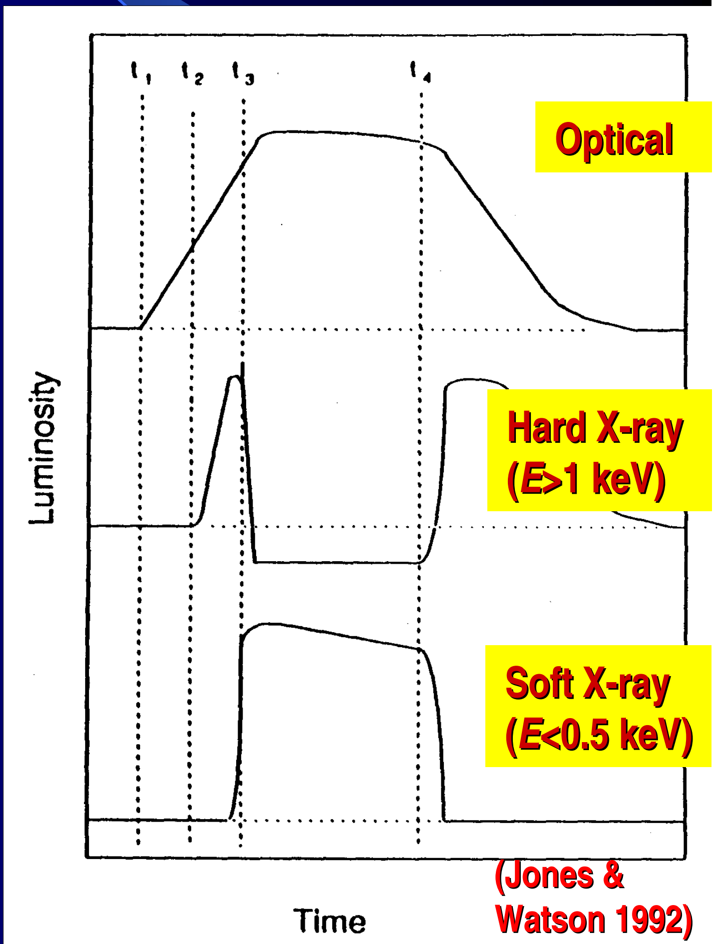
Non-magnetic CVs

Boundary layer changes from optically thin, geom. thick to optically thick, geometrically thin during outburst

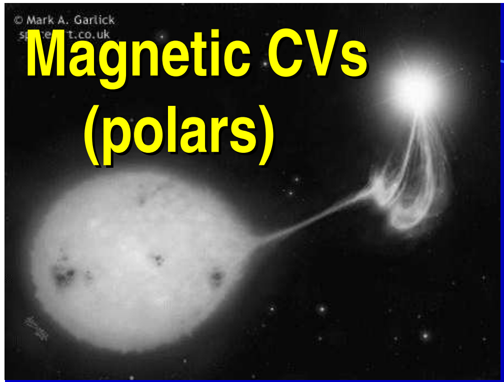


Increasing time-averaged mass accretion rate $\dot{m}$

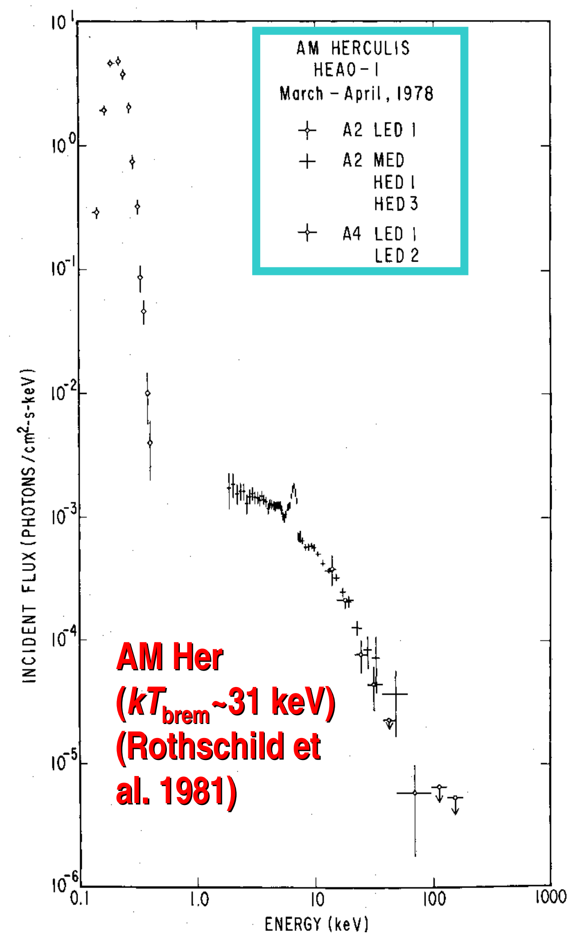




Magnetic CVs (polars)



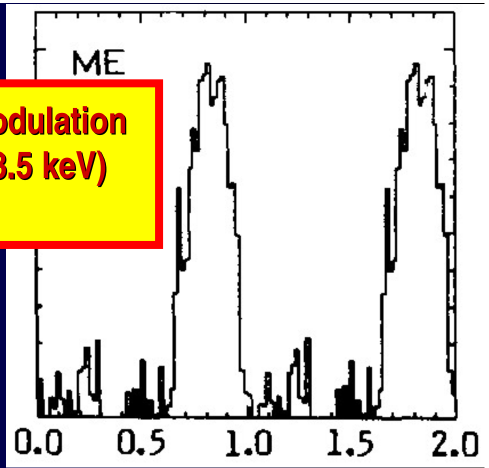
- cyclotron em. from accretion column (mainly optical and UV)
- bremsstrahlung from shocks above impact region on the WD (X-rays)



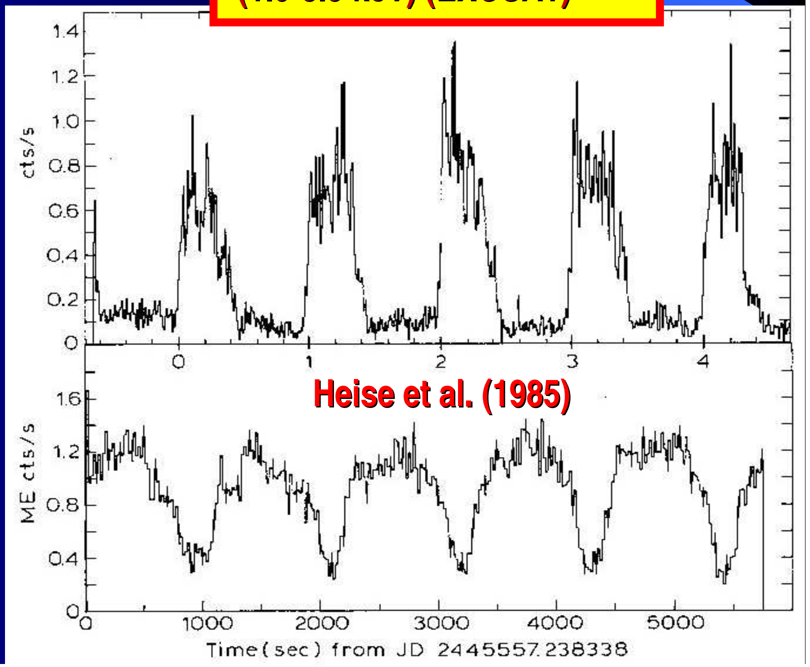
AM Her (kT_{brem}~31 keV) (Rothschild et al. 1981)

ST LMi – orbital modulation in hard Xrays (1.9-8.5 keV) (*EXOSAT*)

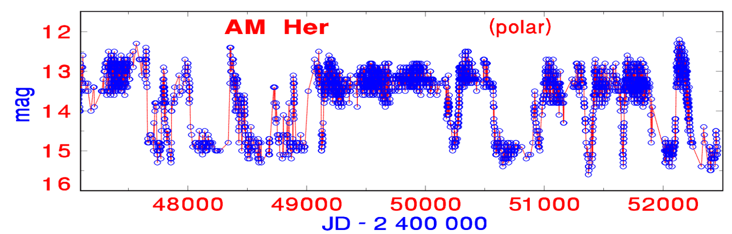
Mason (1985)

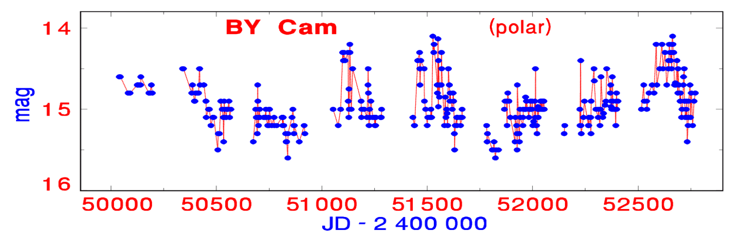


AM Her – orbial modulation top – soft X-rays (40-120 A) bottom- hard X-rays (1.9-8.5 keV) (*EXOSAT*)

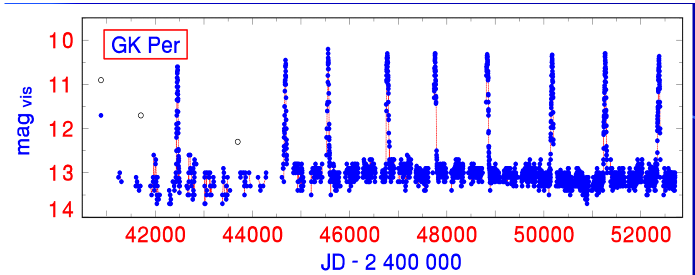


Heise et al. (1985)





GK Per

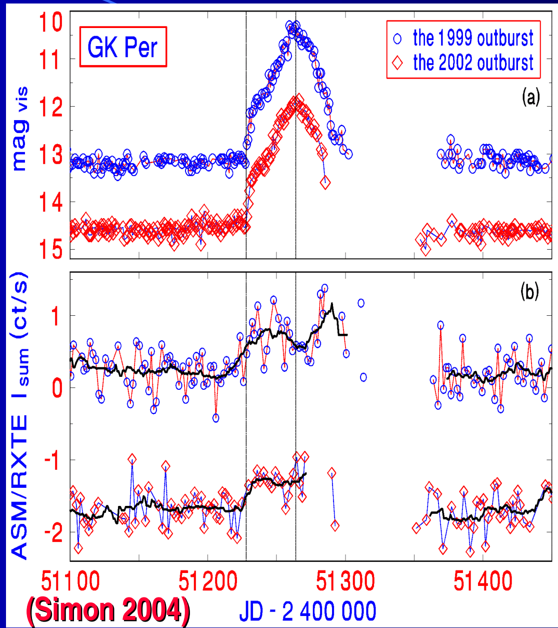


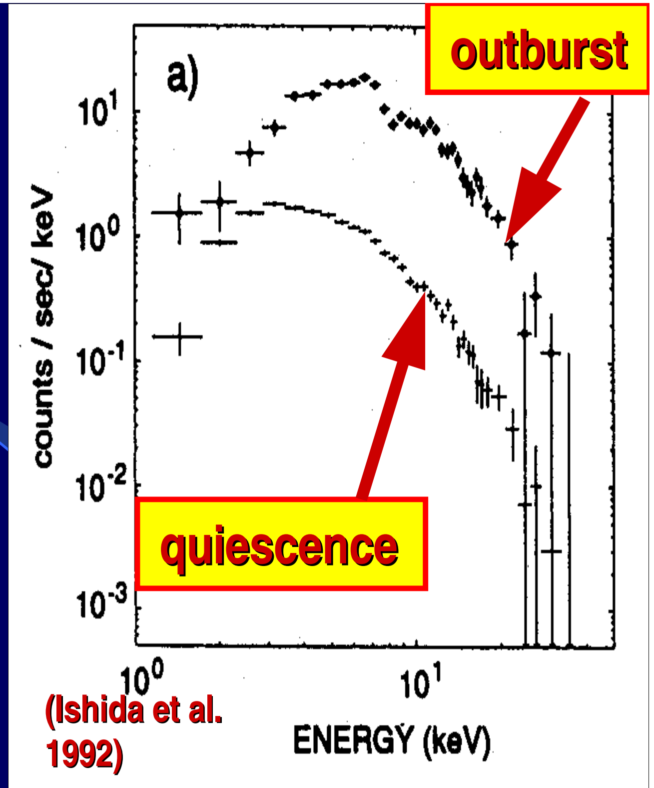
Intermediate polar with dwarf nova outbursts

Relation between profile of optical and X-ray outburst

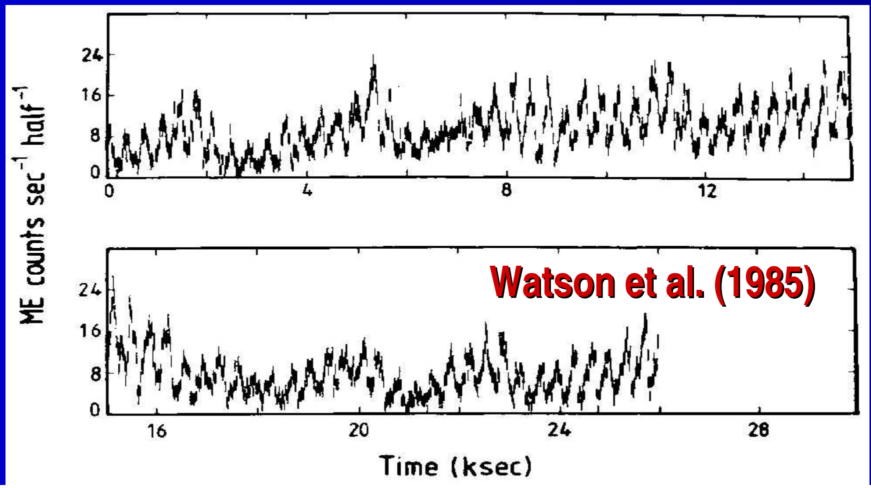
X-ray start can precede the optical start by up to 40 days (Binachini & Sabbadin 1985)

Models: up to 80 – 120 days (Kim et al. 1992)

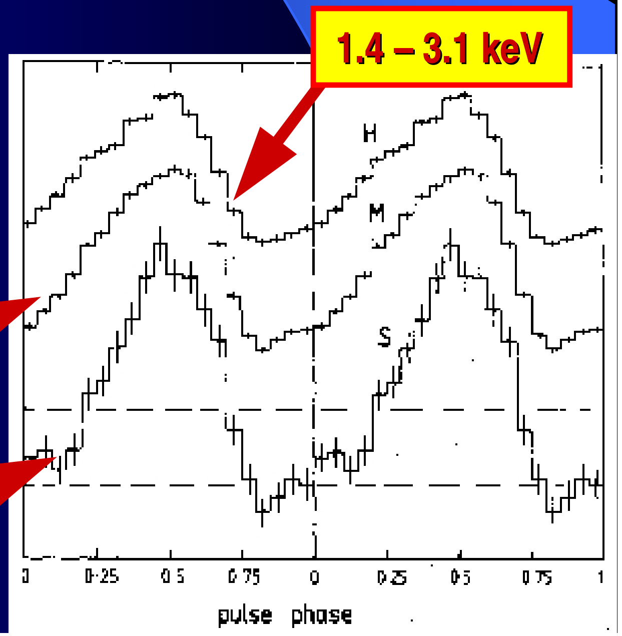


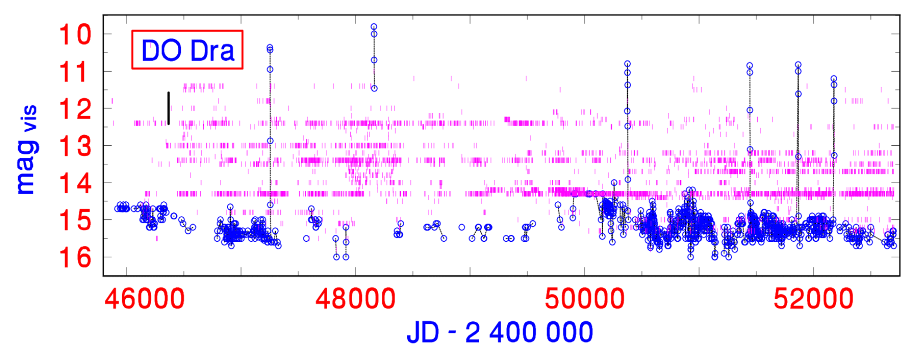


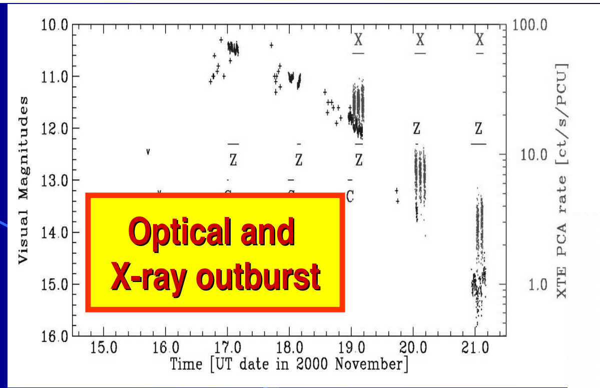
X-ray (2.5 – 11 keV) spin modulation – 351 s (*EXOSAT*) during optical outburst



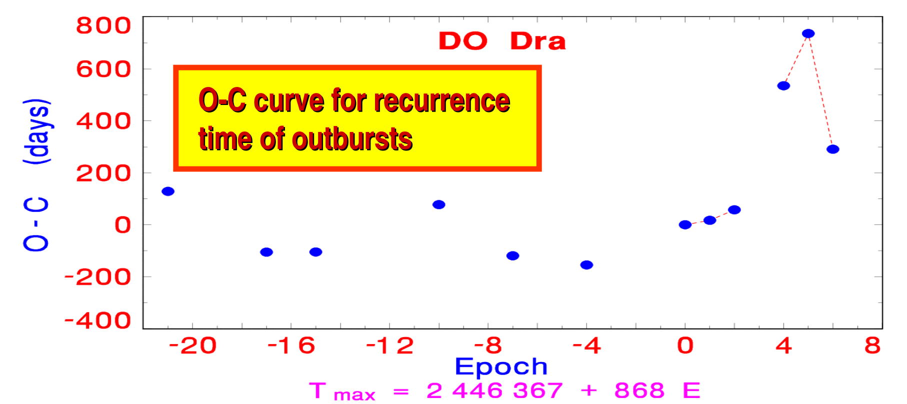
Data folded with spin phase (*EXOSAT*)



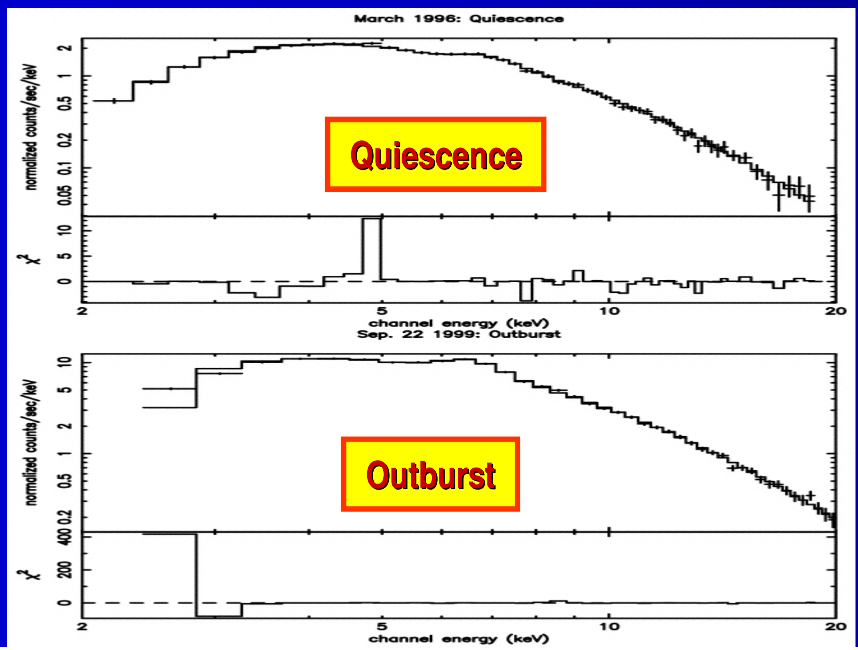




X-ray spin modulation (529.31 s)



DO Dra
3A 1148+719



Intermediate polar

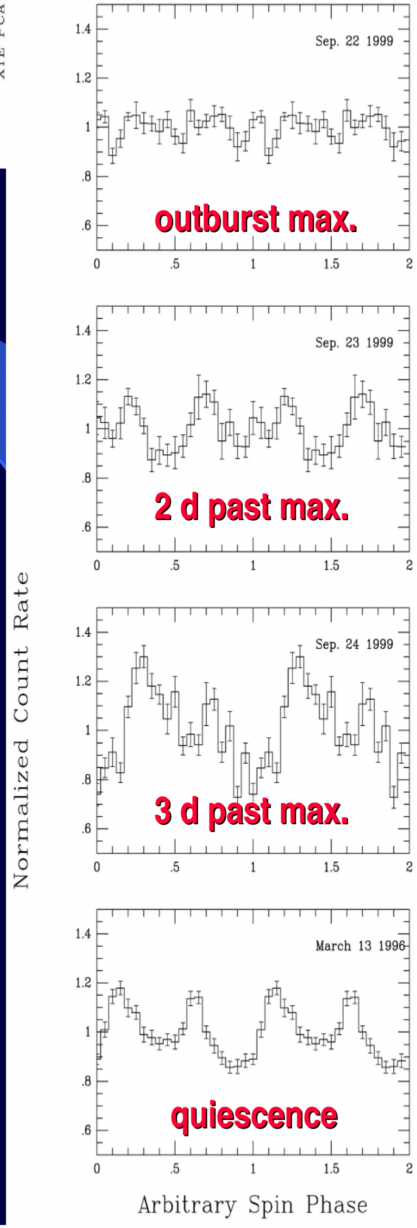
P_{orb}=3.96 hr (Mateo et al. 1991)

P_{spin}=529 sec (Haswell et al. 1997)

Hard X-ray source 3A 1148+719 (Patterson et al. 1982)

Infrequent short outbursts; variations in quiesc. ~1 mag

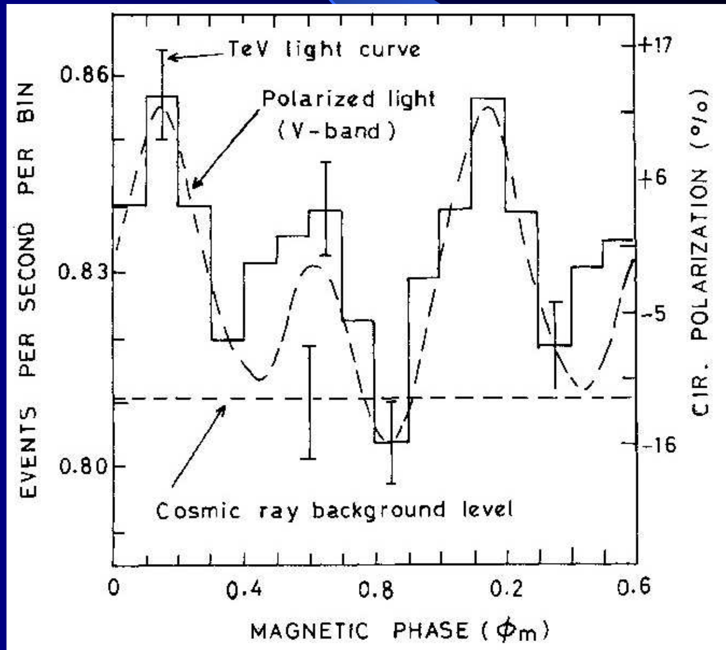
(Szkody et al. 2002)



Production of gamma-rays in CVs

Acceleration of particles by the rotating magnetic field of the WD in intermediate polars in the propeller regime – AE Aqr – detected by ground-based Cherenkov telescopes in the TeV passband (e.g. Meintjes et al. 1992)

TeV emission from the polar AM Her detected by ground-based Cherenkov telescopes (Bhat et al. 1991)



Detection in the keV – MeV passbands by *INTEGRAL* may be also possible

CVs and *INTEGRAL*:

- In total, ~ 335 CVs brighter than 17.5 mag(*V*) at least during maxima of their long-term activity and located within $-14^o < b_{II} < +14^o$ are contained in the latest version of *The Catalog and Atlas of CVs* (Downes et al. 2001) (this number excludes classical novae brighter than 17.5 mag(*V*) only during explosion and steadily fainter than 17.5 mag(*V*) after return to quiescence).

- Also CVs with a slightly larger b_{II} are expected to be scanned because of the large field of view.

- Currently the best coverage for CVs lying toward the Galactic center.

- Some CVs far from the Galactic plane lie in the fields scheduled for obs. of other kinds of object.

- Simultaneous information in the optical, medium X-ray, hard X-ray, and gamma spectral region (or at least a suitable upper limit) for each CV in each scan or field.

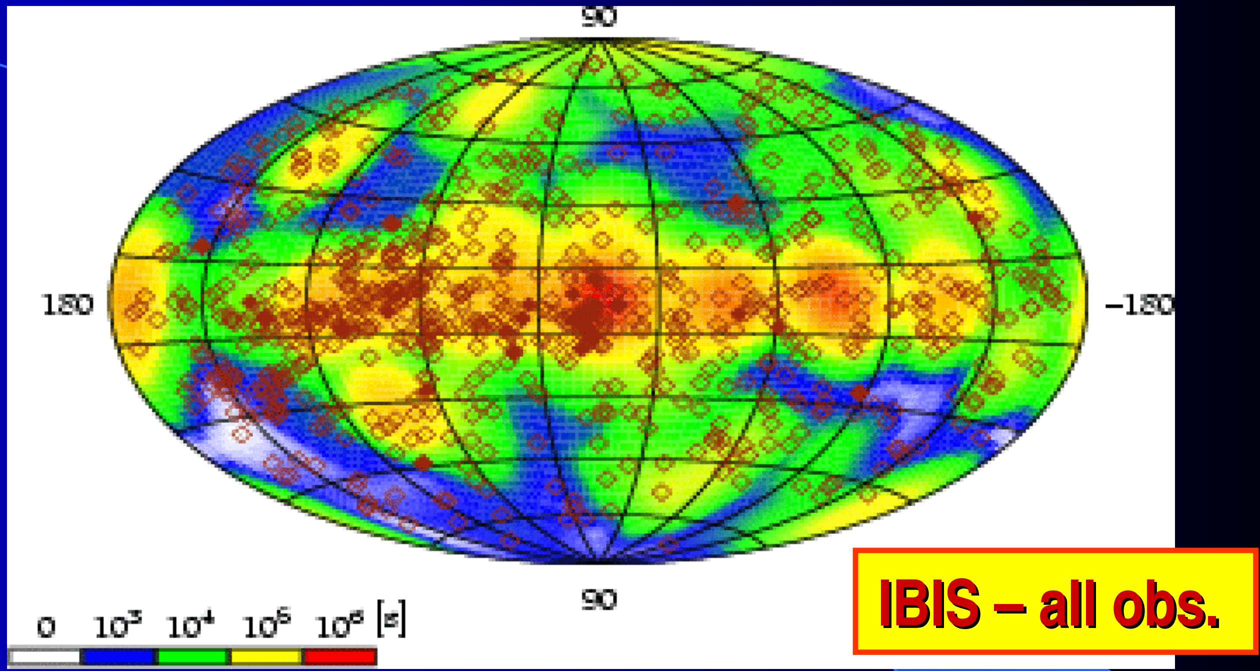
Modes of observation:

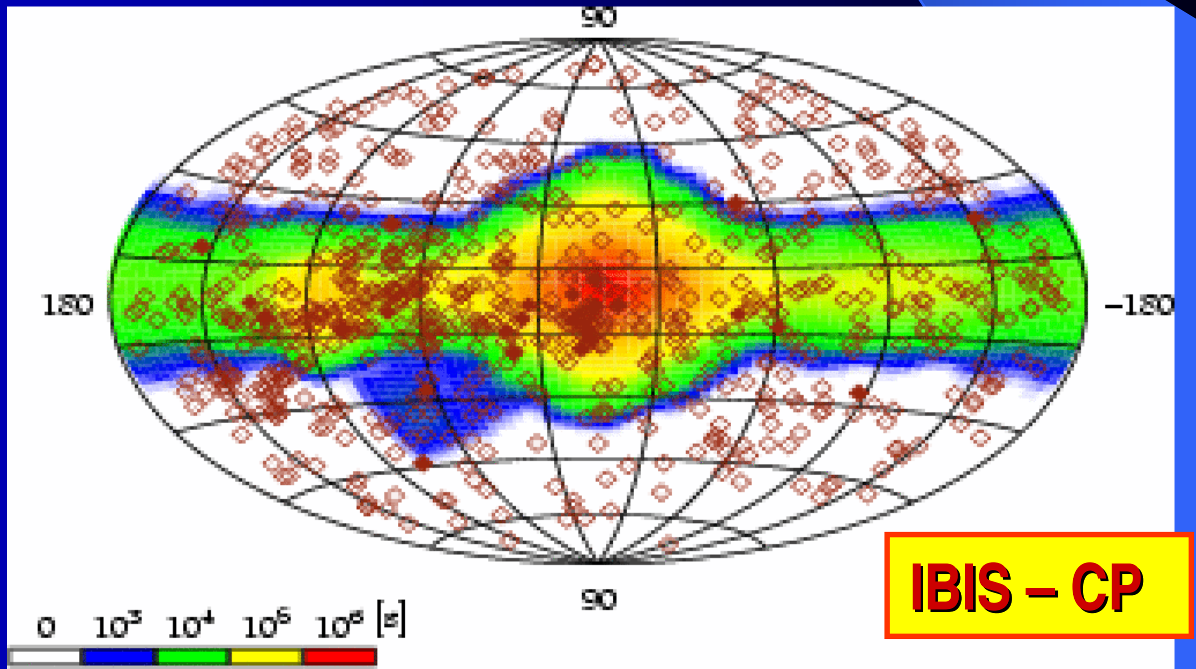
Galactic Plane Scans (GPS) ($-14^o < b_{II} < +14^o$) – most important for CVs !

Pointed observations

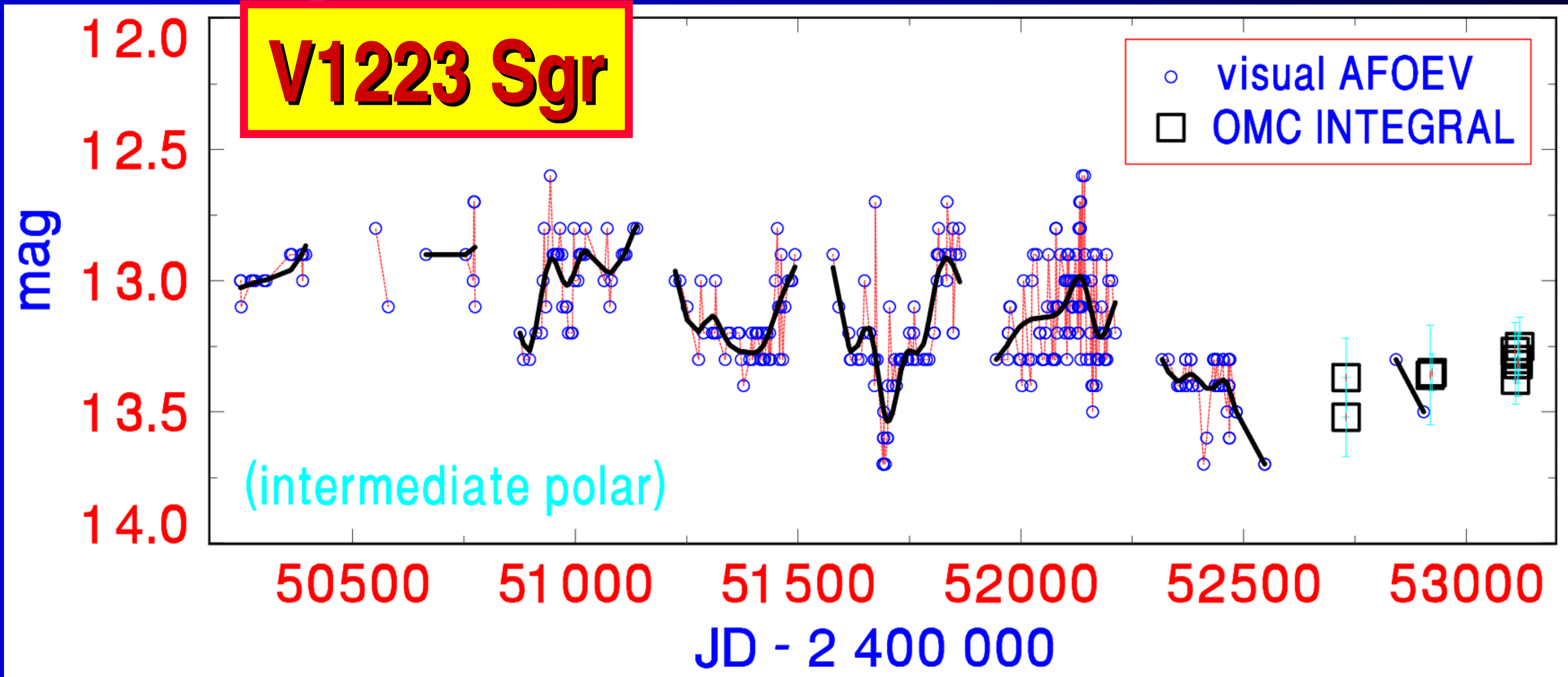
Targets of opportunity

Total exposure times of IBIS.



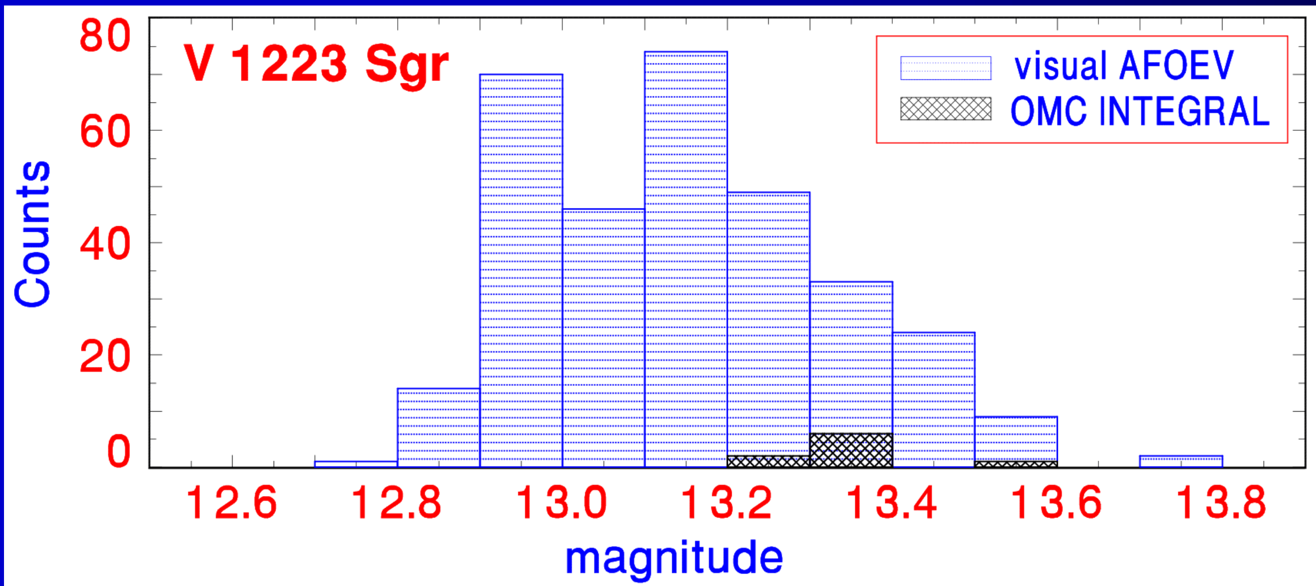


Known CVs:
The Catalog and Atlas of Cataclysmic Variables (Downes et al. 2001) .



Long-term brightness variations

Means for each sci. window



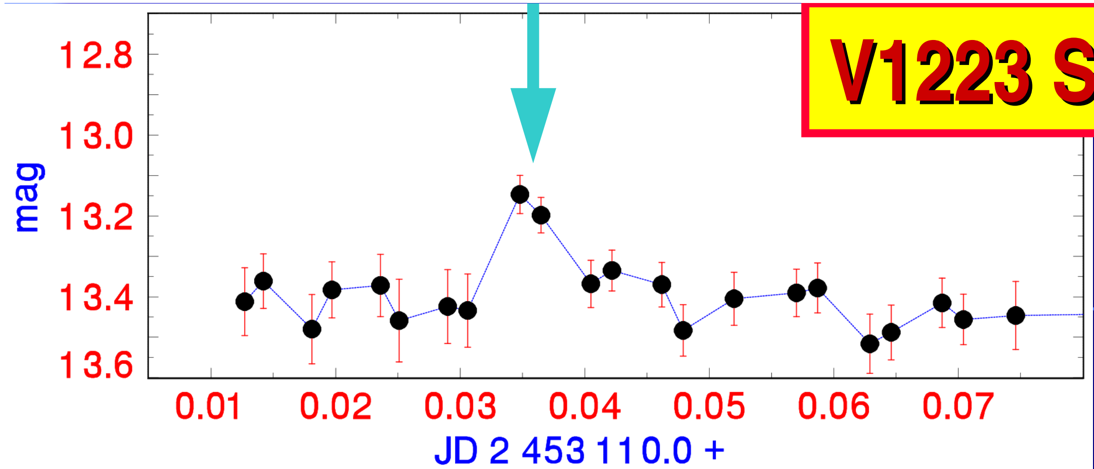
Statistical distribution of brightness

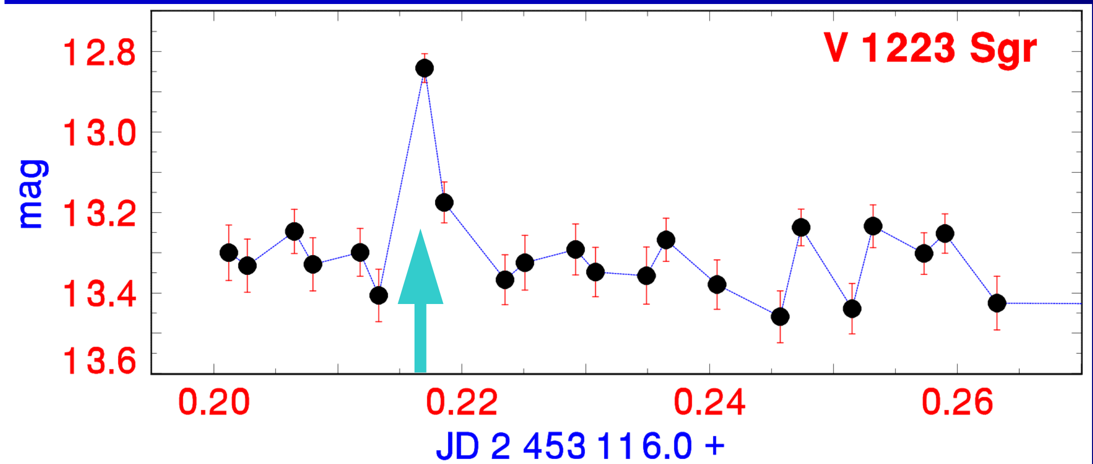
INTEGRAL observations in lower than average level of brightness

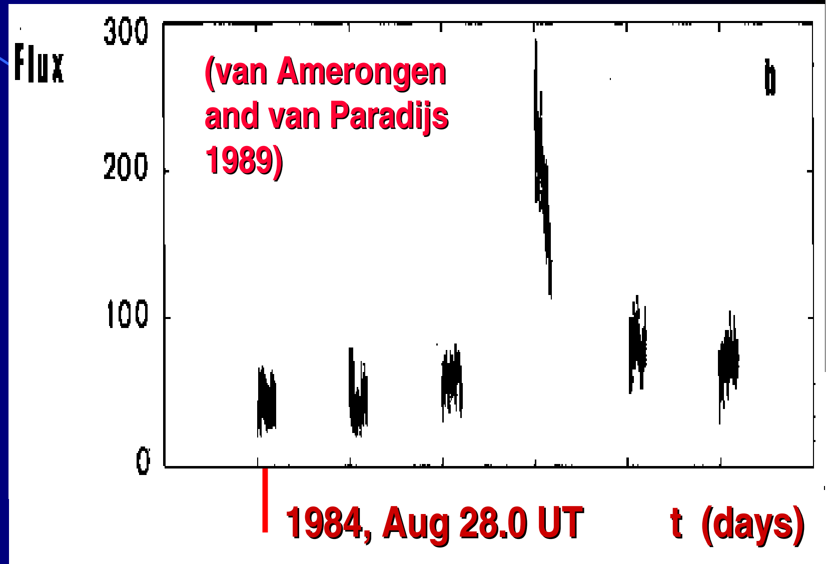
V1223 Sgr

OMC light curves (100 sec exp. only)

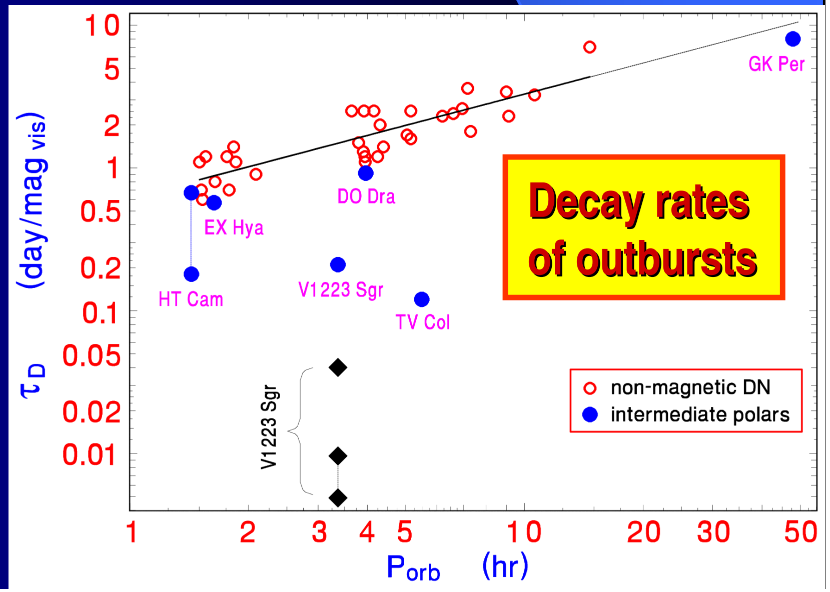
Short-duration flares

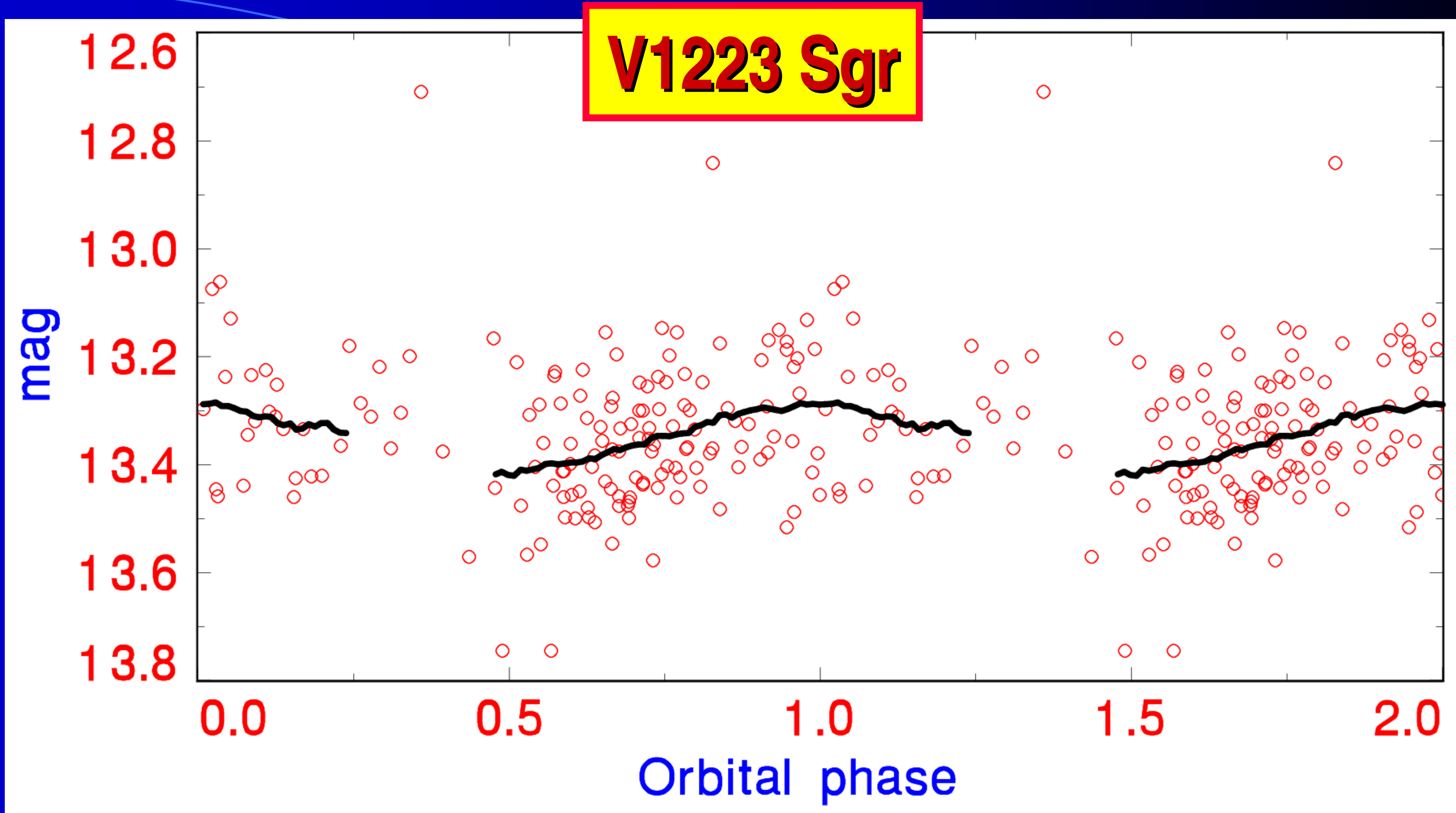






These 2 outbursts (flares) in V1223 Sgr possess faster decay rate than the 1984 more luminous outburst (van Amerongen and van Paradijs 1989)

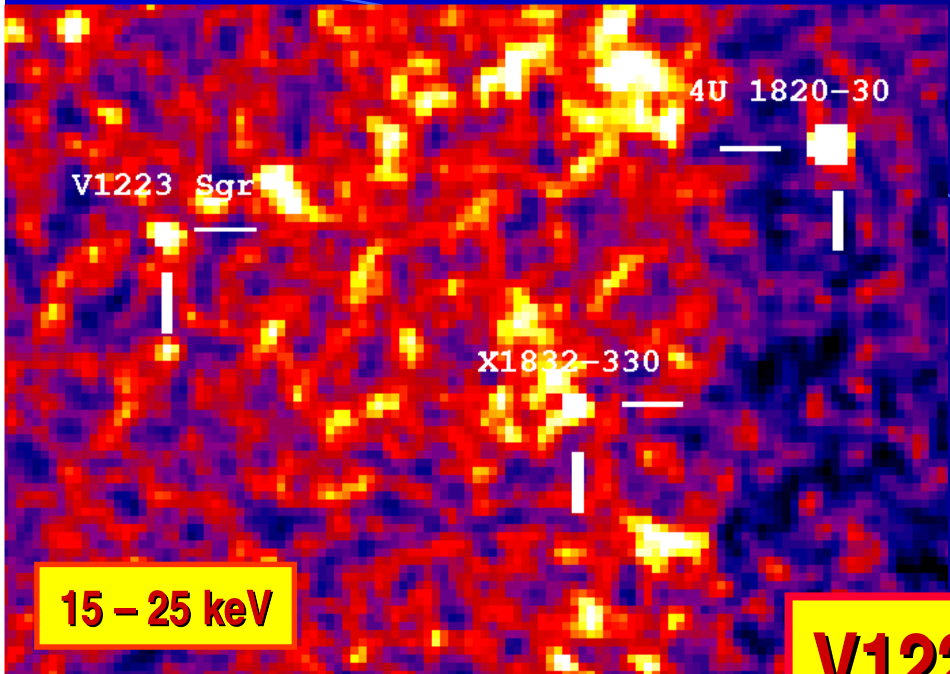


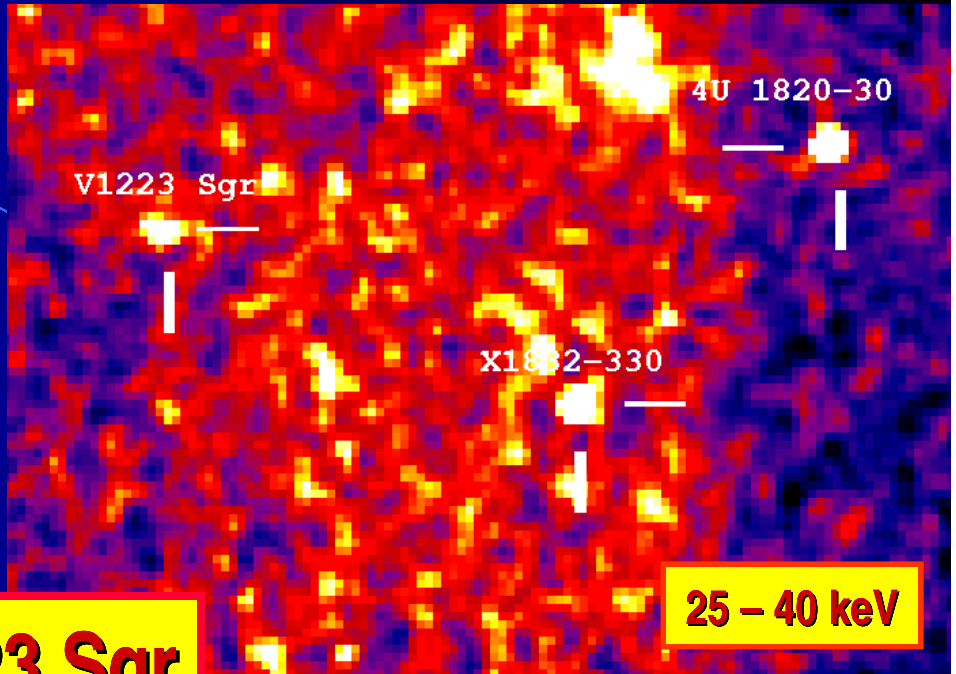


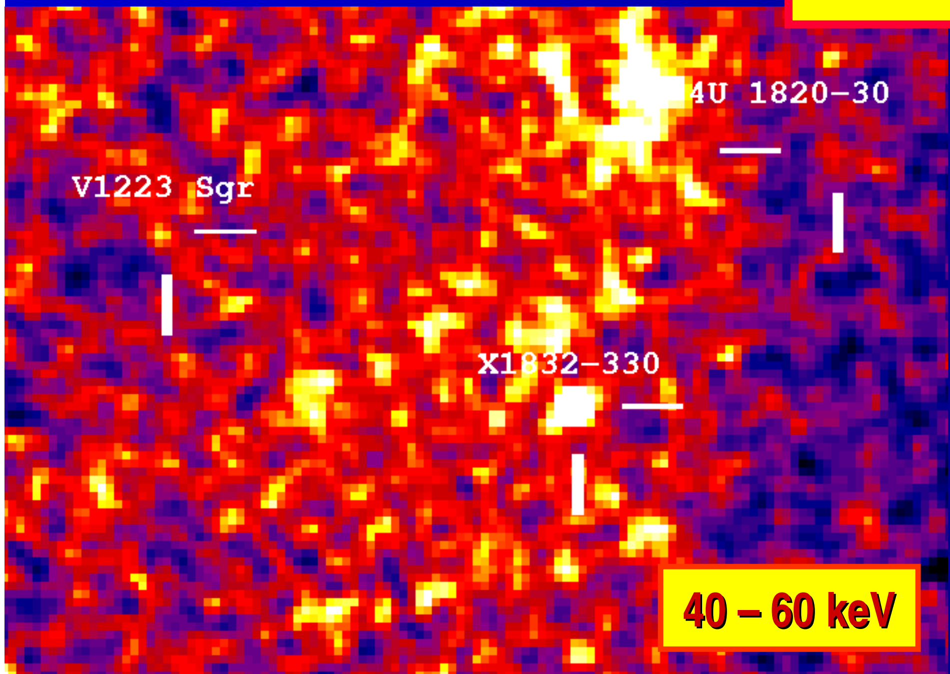
Orbital modulation in folded OMC data (100 sec exp. only)
(ephemeris of Jablonski and Steiner (1987)) P_{orb} = 3.37 hr

Smooth curve: moving averages – orb. modul. clearly visible
Ocurrence of brightenings is independent on the phase
Scatter – rotational modulation of the white dwarf contributes!
OMC is able to provide important data for such objects

V1223 Sgr

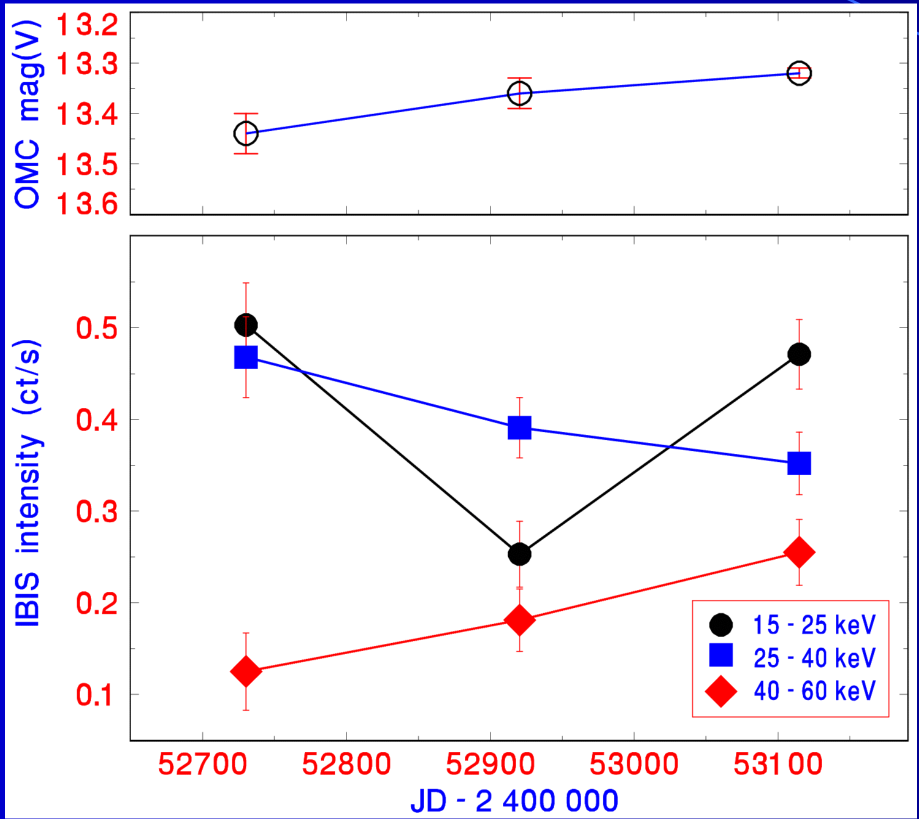






Field of the intermediate polar V1223 Sgr. Co-added frames from IBIS. mid exp. JD 2452730.1680; exp. 115548 sec (32.8 hr). Size of the field: 9.1°x7.1°. North is up, East to the left.

V1223 Sgr



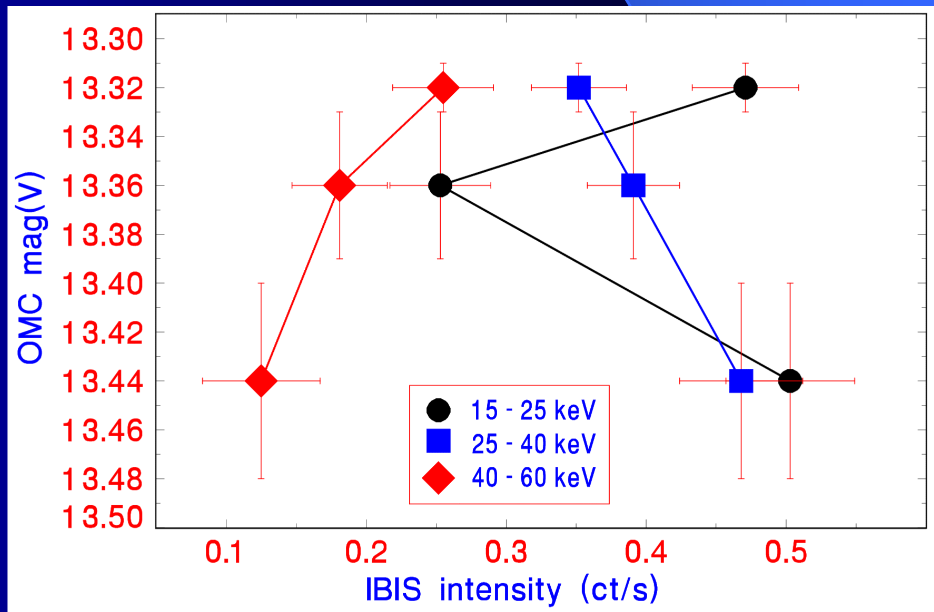
Relation between hard X-ray flux and optical magnitude

Relating processes in different regions:

Disk (optical)

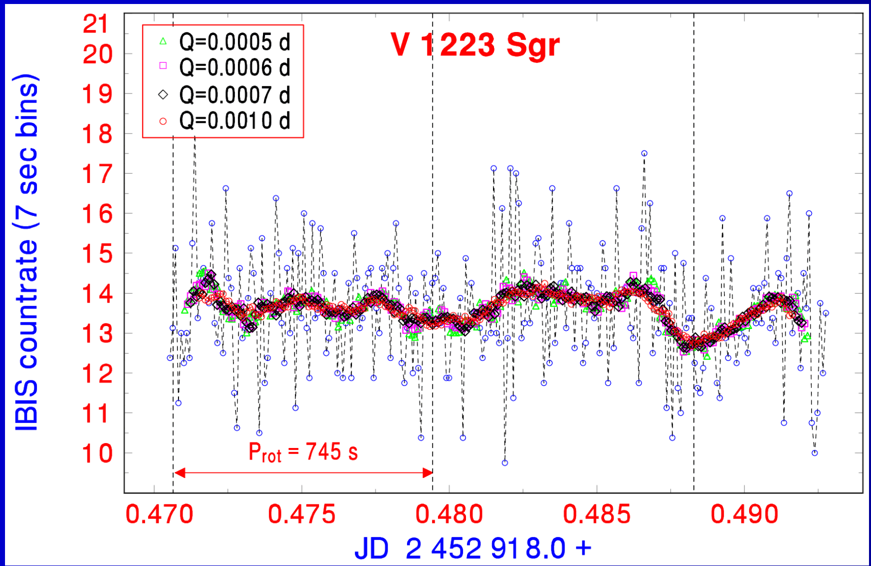
Impact region near magnetic pole of white dwarf (X-ray)

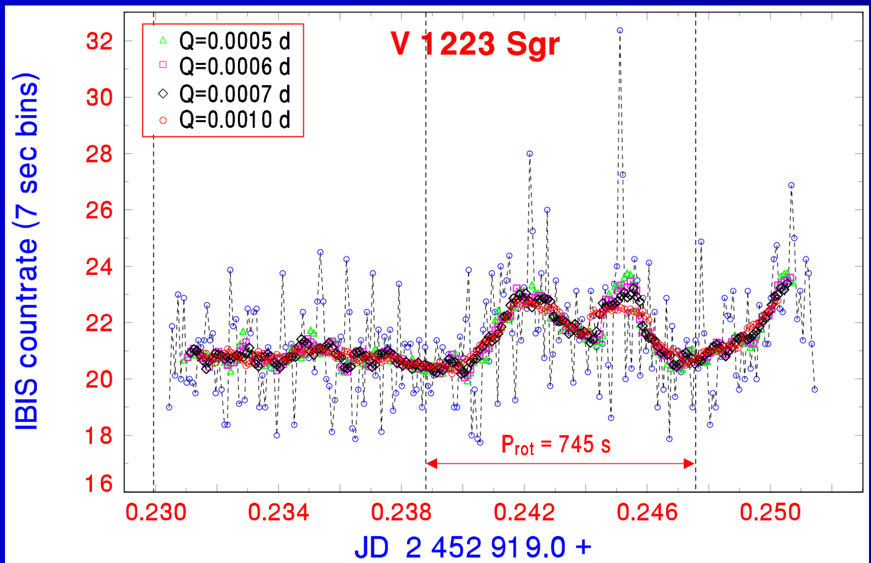
Spectrum in 25 – 60 keV hardens with time



V1223 Sgr

Rotational modulation of white dwarf in 15 – 40 keV region (IBIS) and its fits by moving averages



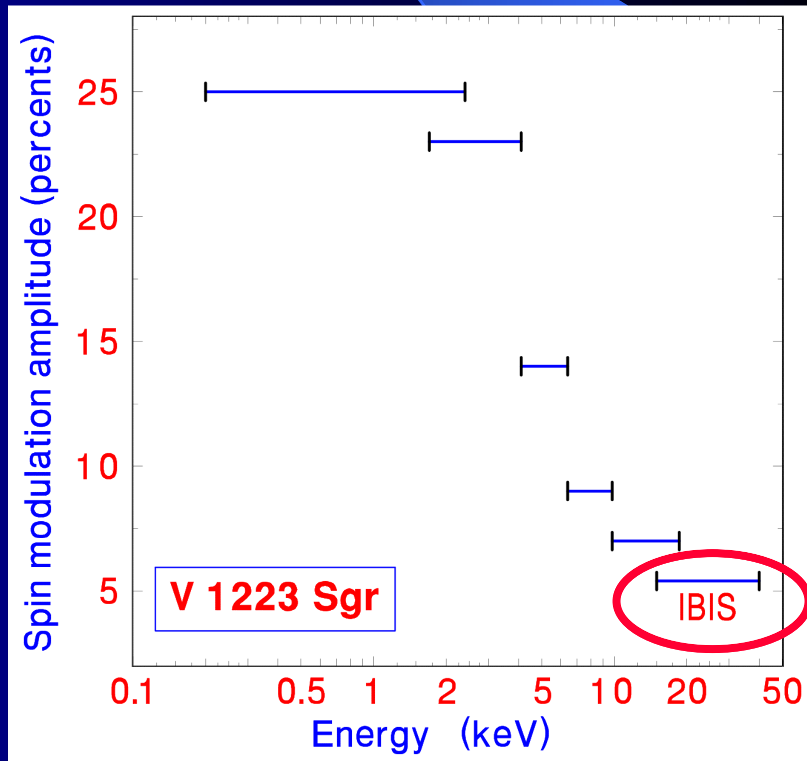


Profile of rot. modulation in 15 – 40 keV region different from previous obs. in softer passbands:

0.2 – 18.6 keV: ~sinusoidal profile

15 – 40 keV: flat-topped profile, narrower minima

Full amplitude of spin mod.:
$A = (I_{max} - I_{min}) / (I_{max} + I_{min})$



Exp. time: 186 891 sec
100 scw (62 scw March – May 2003, 36 scw Sept – Oct 2003, 2 scw March 2004)

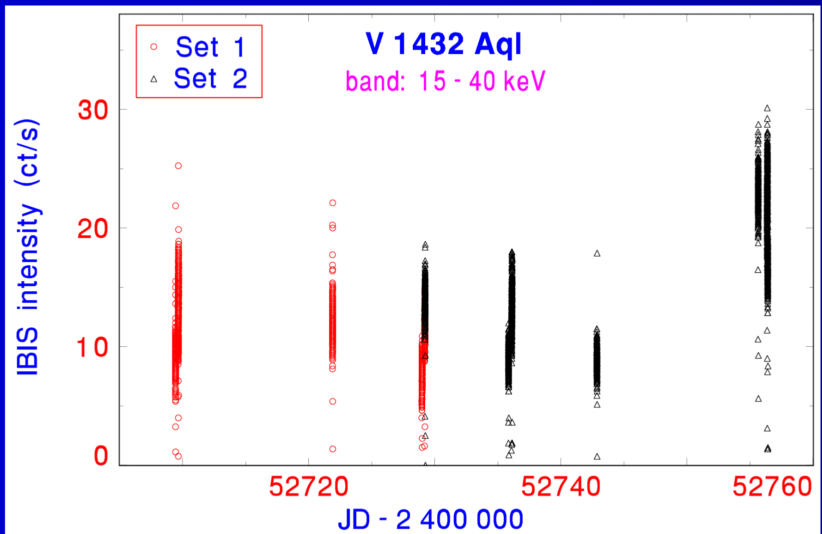
V 1432 Aql

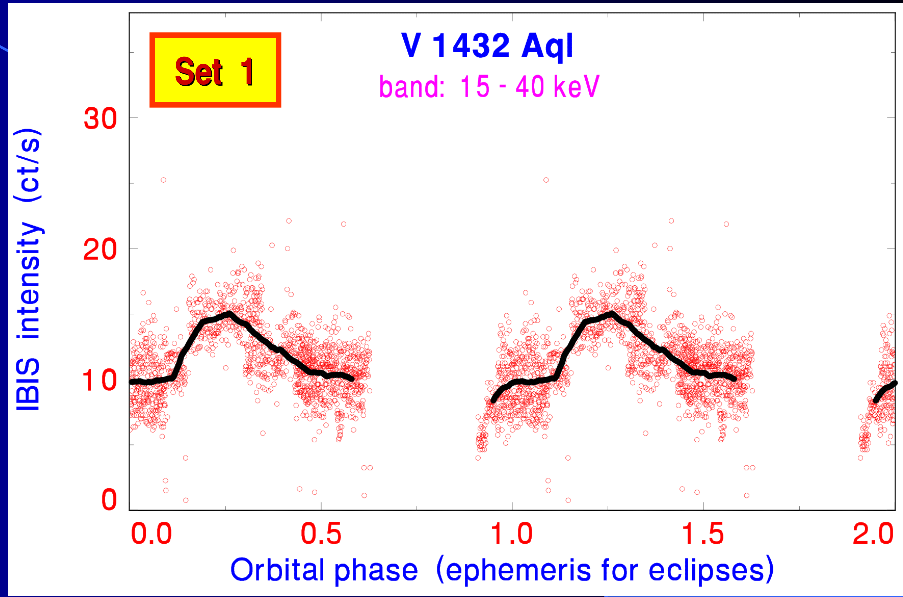
Prominent orbital modulation – variable aspect of the impact region on the WD

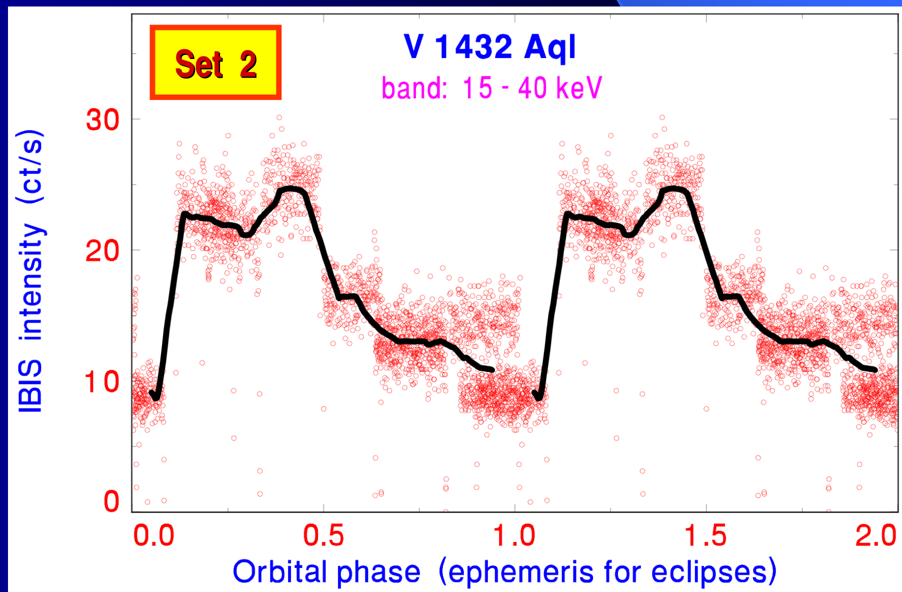
Fit to co-added IBIS image:

15 – 40 keV: flux = 0.318 +/- 0.045 ct / s
(significance: 7 sigma)

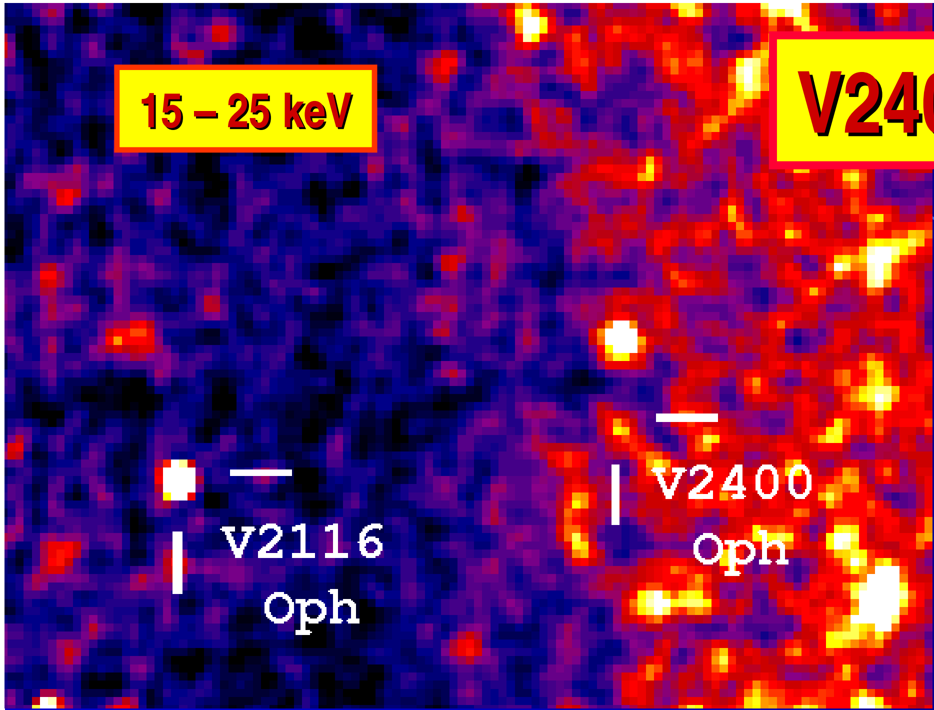
40 – 80 keV: flux = 0.109 +/- 0.044 ct / s
(significance: 2.5 sigma)

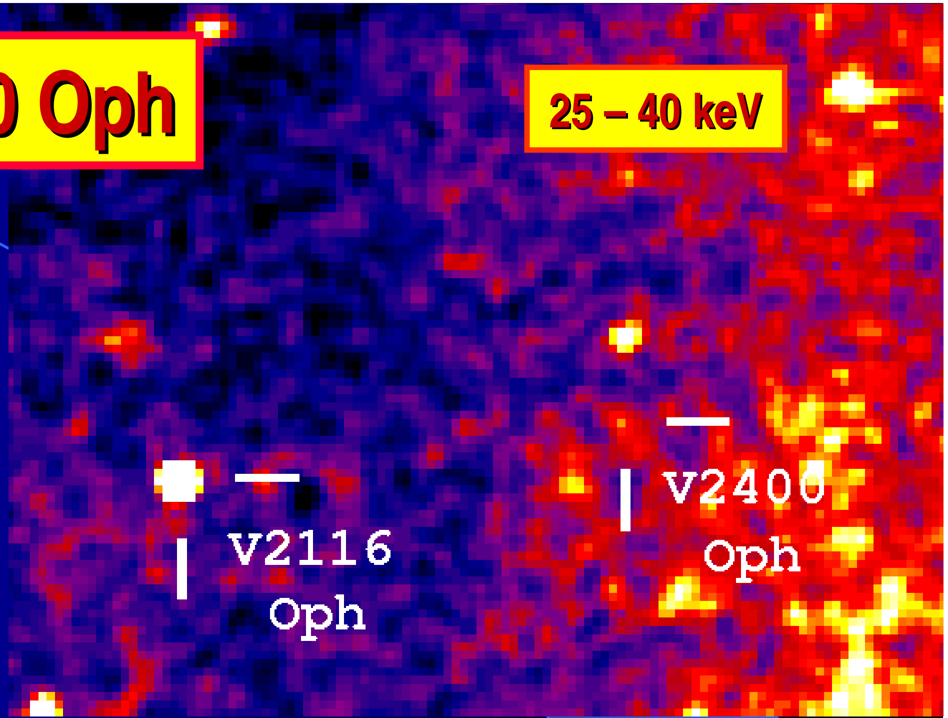


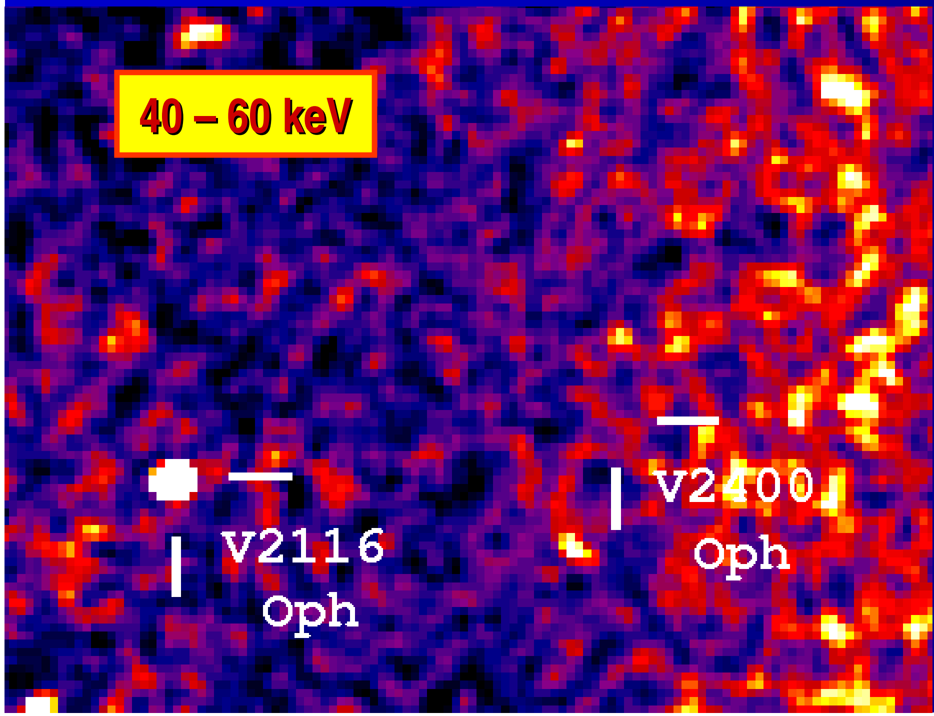




V2400 Oph

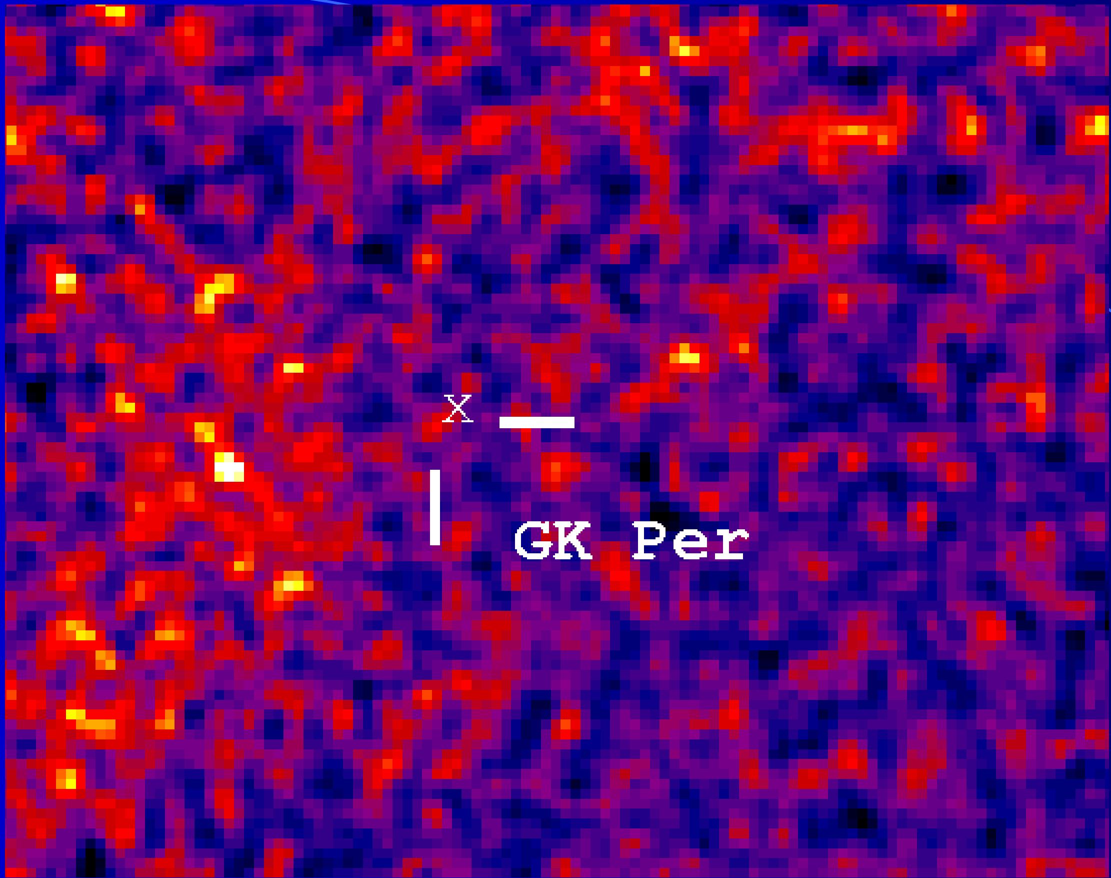


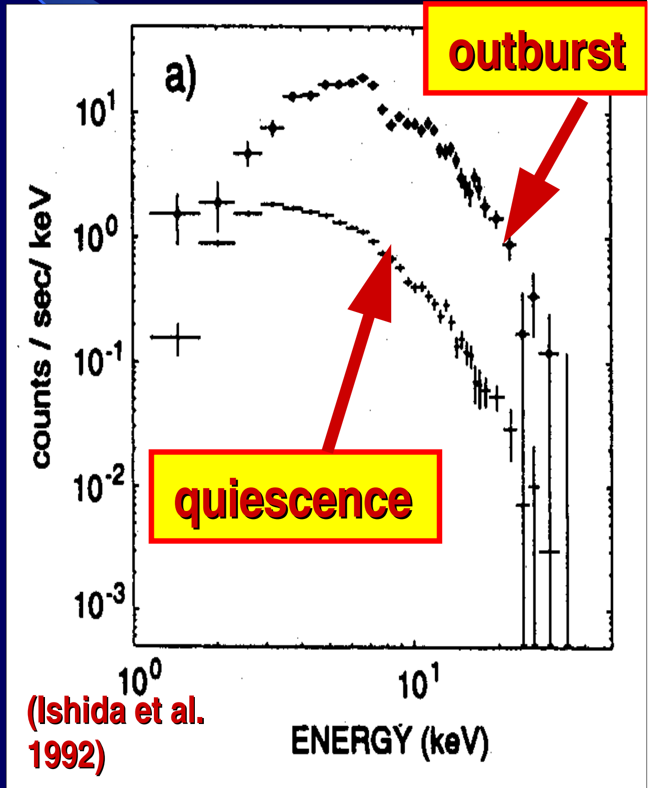




Field of the intermediate polar V2400 Sgr. Co-added fully coded images from IBIS:JD 2452732.6 + JD 2452920.0 + JD 2453054.4. exp. 243018 sec (68.9 hr). Size of the field: 9.1ºx7.1º. North is up, East to the left.

GK Per

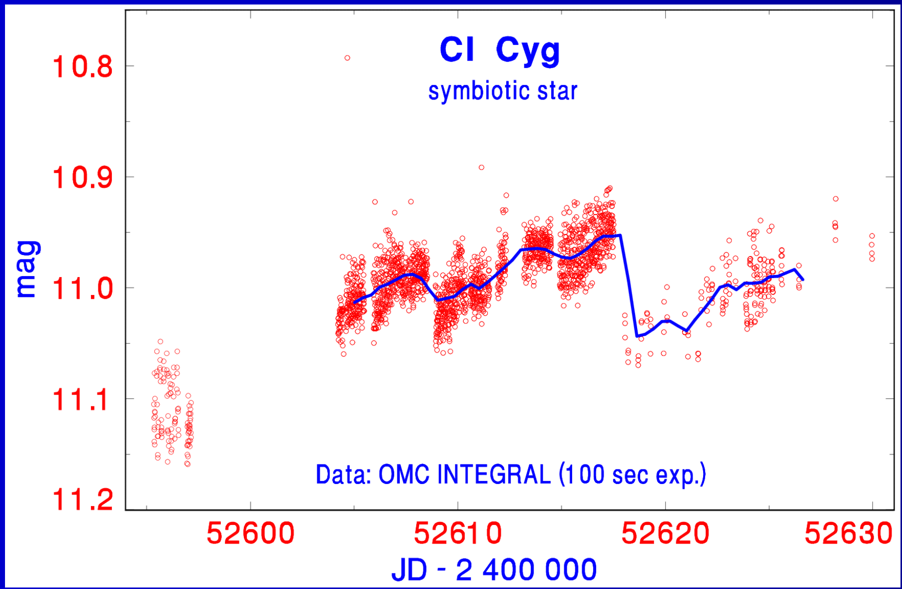




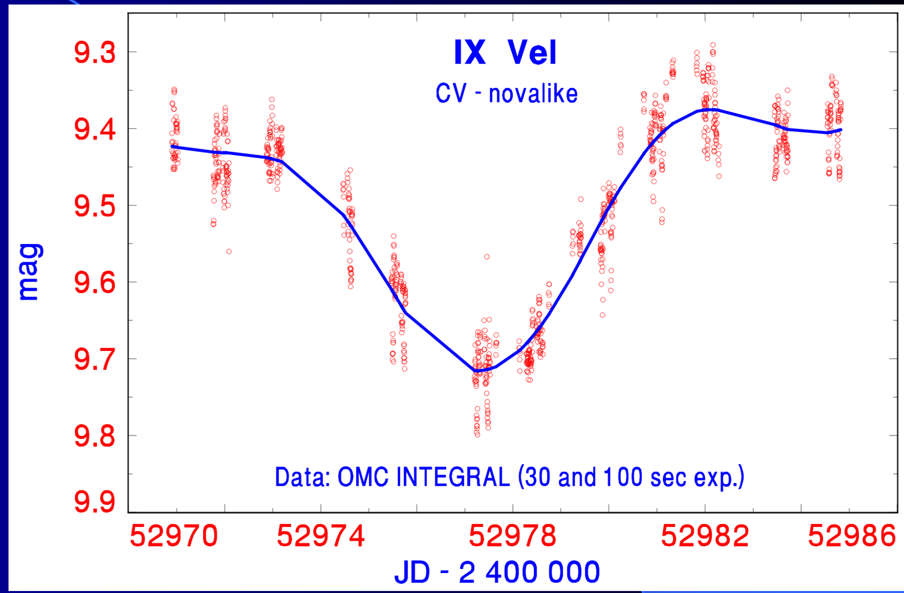
IBIS (15 – 40 keV) image of the intermediate polar GK Per (267 950 sec exp. (~74.4 hr). Co-added images: 19 March 2003, 27 – 29 July 2003. Size of field: 9.1ºx7.1º. North is up, East to the left.

Examples of OMC light curves

CI Cyg



IX Vel



Search for rapid variations

Low-amplitude changes on time scale of a few days may be present

Two rapid jumps of mean magnitude: real features or instrumental effect?

Short-lived episode of shalow low state

Rapid variations (flickering) superimposed on the long-term changes

Results for CV observations with *INTEGRAL* and perspectives

- Proof that CVs can be successfully detected and observed in hard X-rays with *INTEGRAL (for most CVs much harder passbands than possible previously!)*

- Confirmation of our prediction that magnetic CVs are promising targets

- More CVs (and in harder passbands) will be detectable with increasing integration time Also increasing probability of detecting the objects in outbursts, high and low states…

- Simultaneous hard X-ray and optical observations (or at least suitable upper limits)

- Long-term variability of CVs (GPS) – will be increasingly even more valuable with increasing time

- Analysis of the properties of rotational and orbital modulation in magnetic CVs

- Covering the gap between TeV energies (obs. by Cherenkov tel.) and X-rays obs. by previous satellites

Acknowledgements:

This study was supported by the project ESA PRODEX INTEGRAL 14527. We acknowledge using the curve-fitting code HEC13 written by Dr. Harmanec. We thank P. Sobotka for a search in OMC database.