Investigation of binary X-ray sources with photographic plates

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Prospects for monitoring of activity (I)

Monitoring enables to:

- identify the type of system
- place the events (e.g. outbursts) in the context of the long-term activity of the system
- form the representative ensemble of events (e.g. outbursts) in
  (a) a given system
  (b) in a type of systems

- Transitions between the activity states (e.g. outbursts, high/low states) are often fast and unpredictable – monitors of any type are needed.

Prospects for monitoring of activity (II)

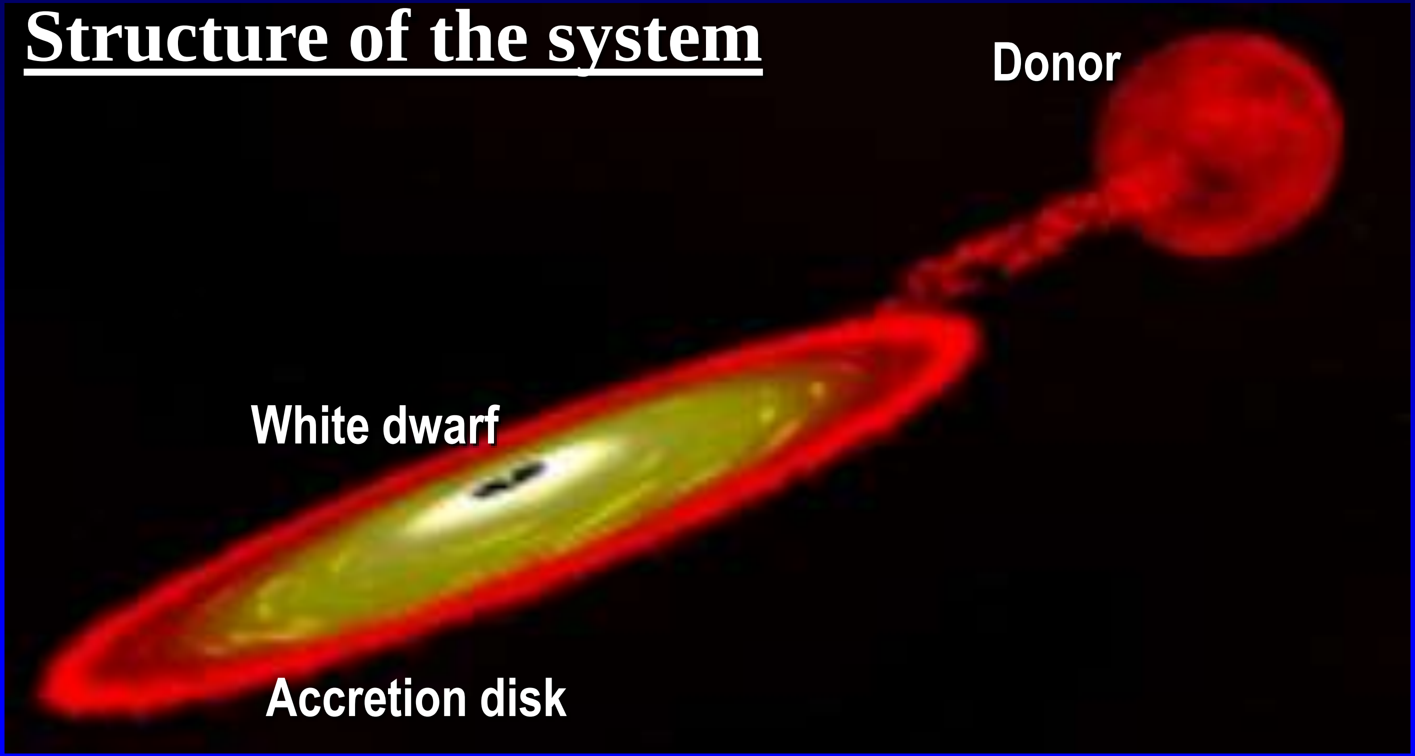
<u>Monitoring of a large part of the sky is needed:</u>

- most transients (objects with outbursts) were discovered only in outburst, not in quiescence before this event – a lot of ‘sleeping’ transients exist

- monitoring is also inevitable for a search for rare, unexpected and unique phenomena.

Cataclysmic variables (CVs) with accretion disks

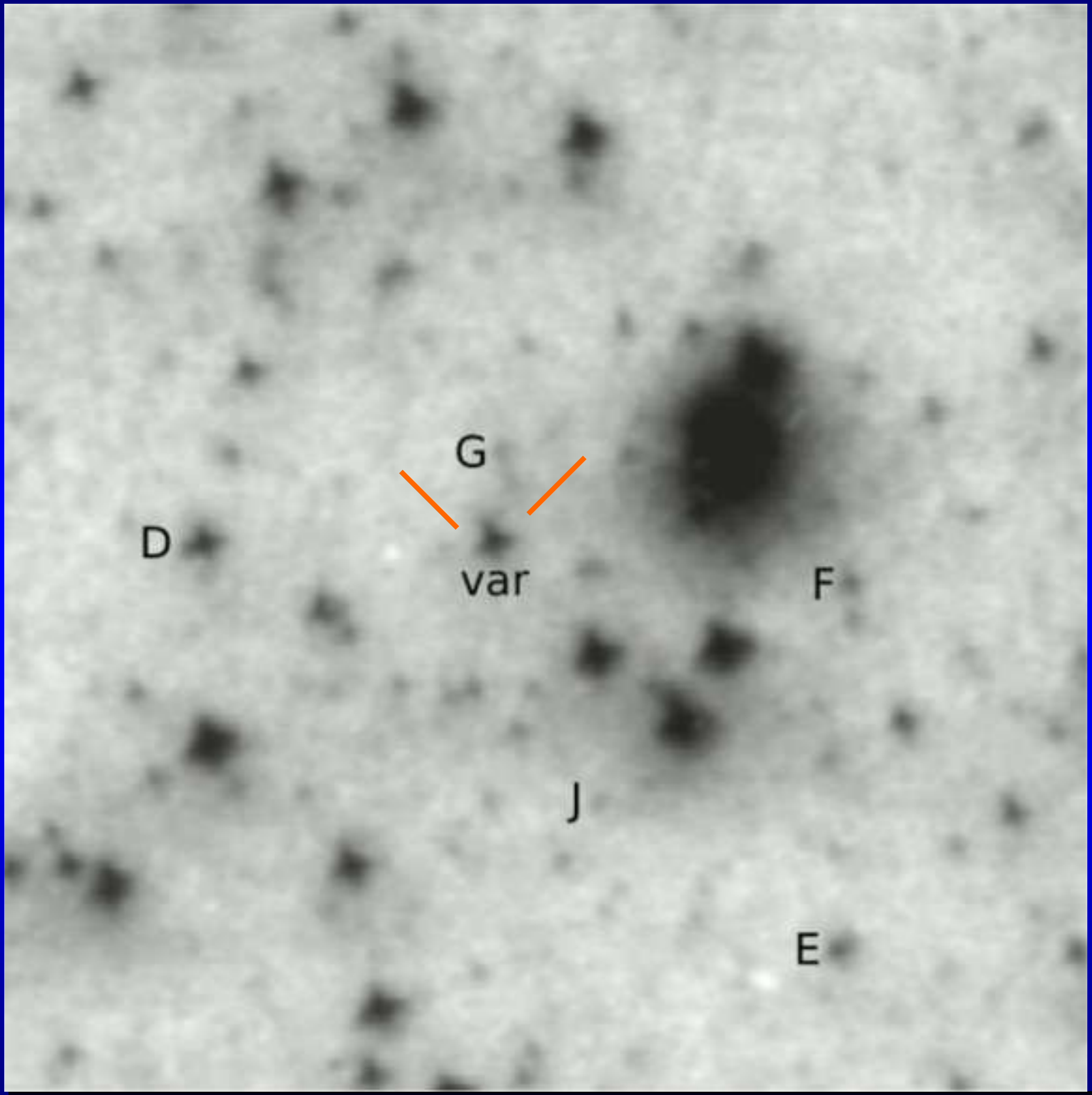
Structure of the system



- Dominant source of luminosity in the optical band: accretion disk (the disk may reach down to the white dwarf (WD) if the WD is non-magnetized)

- The inner part of the disk is missing if the WD is mildly magnetized (intermediate polar)

V1223 Sgr / 1H 1853–312 (the intermediate polar)



Part of the Bamberg plate (JD 2 439 383.24)

V1223 Sgr in its brightest state

Field: 22.2 x 22.2 arcmin

North is up
East to the left

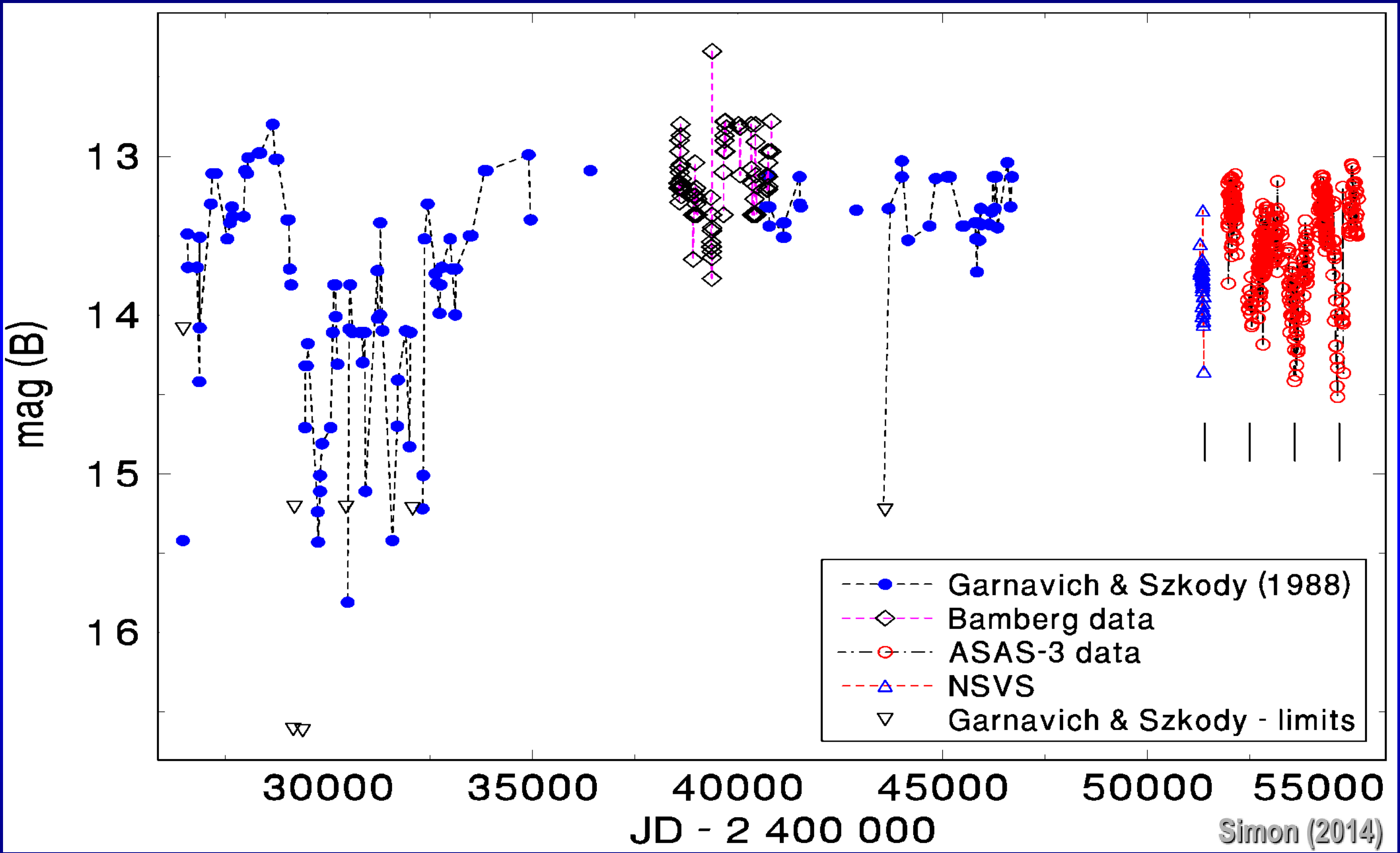
V1223 Sgr : "var"

Comparison stars:
D, E, F, G, J

Simon (2014)

The brightness of V1223 Sgr was measured by Argelander method using microscope.

V1223 Sgr / 1H 1853–312



The long-term activity observed by various methods (photographic and CCD). All measurements were transformed to the *B* band.

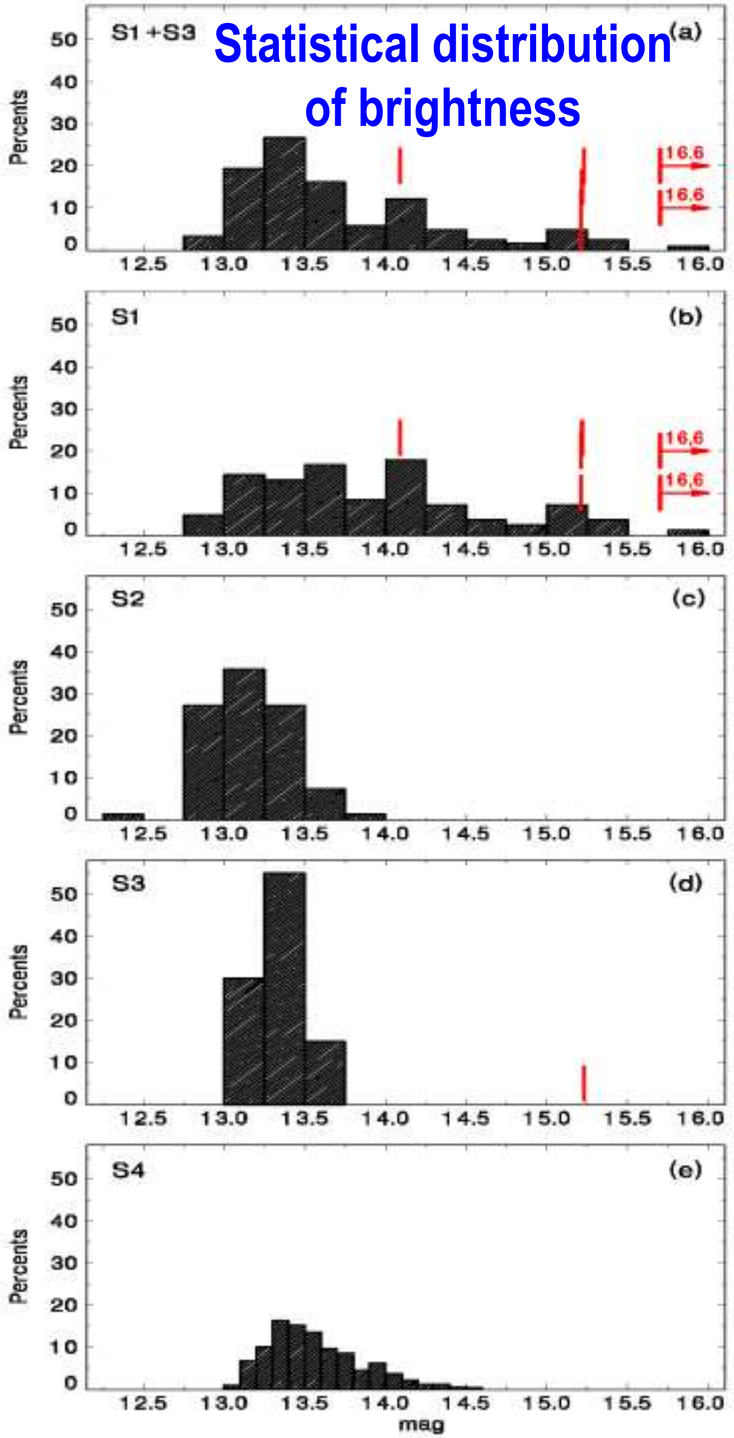
V1223 Sgr / 1H 1853–312

- The statistical distribution of brightness and its parameters (the standard deviation, skewness, excess) may not be very distorted by the sampling of the data (if a long time segment is mapped).

- The statistical distribution of brightness:

➢ description of properties of the long-term activity of CVs.

➢ method for resolving among the types of CVs even in the sampled photometric data.



V1223 Sgr / 1H 1853–312

S1 + S3: JD 2 426 467 – 2 446 698
Harvard plates

Simon (2014)

S1: JD 2 426 467 – 2 436 410
9943 days 84 obs. Harvard plates

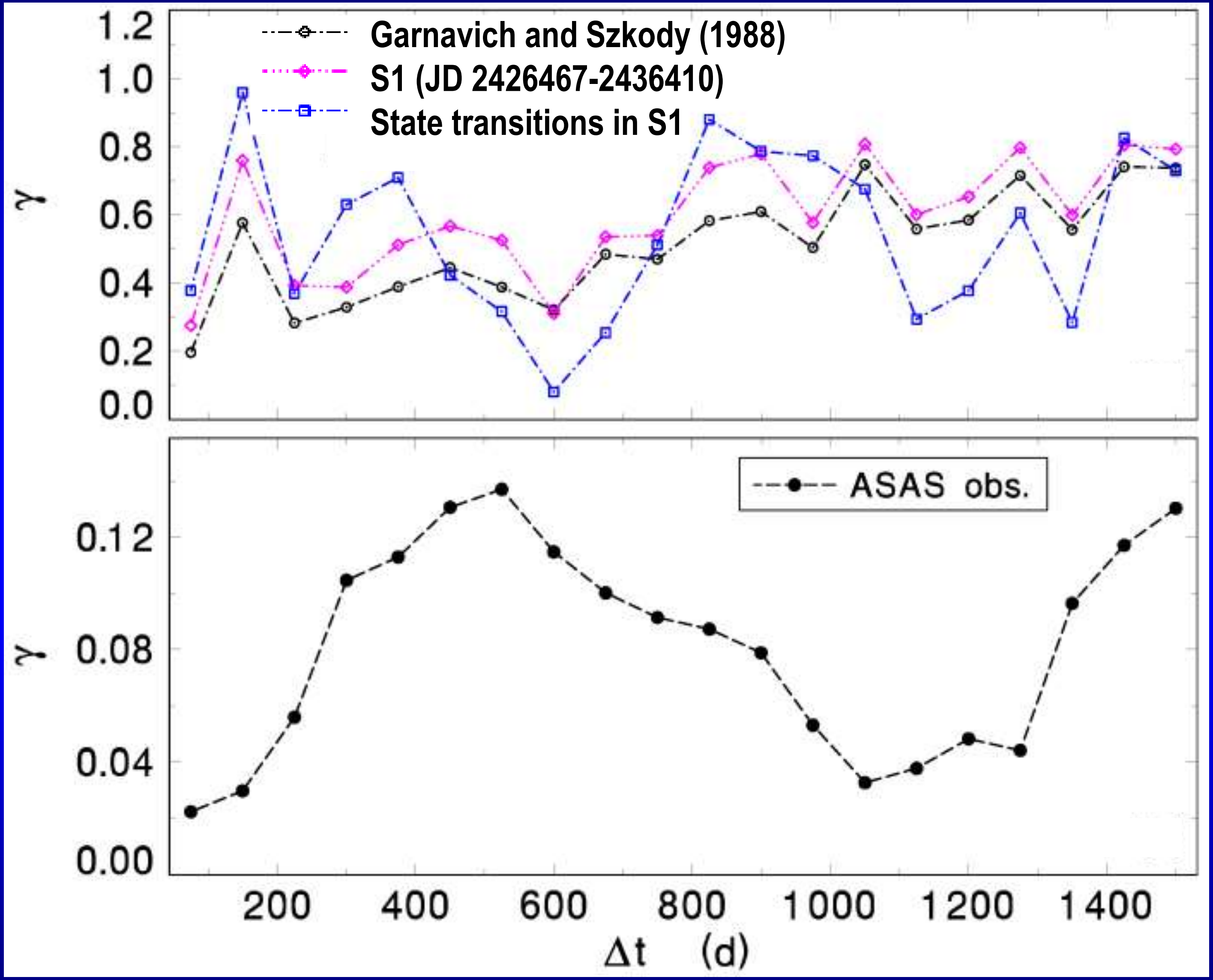
S2: JD 2 438 560 – 2 440 824
2264 days 81 obs. Bamberg plates

S3: JD 2 440 698 – 2 446 698
6000 days 40 obs. Harvard plates

S4: JD 2 451 963 – 2 455 146
3183 days 362 obs. ASAS-3 CCD data

Bar width: 0.25 mag (plates), 0.1 mag (for CCD)

Variograms of V1223 Sgr / 1H 1853–312



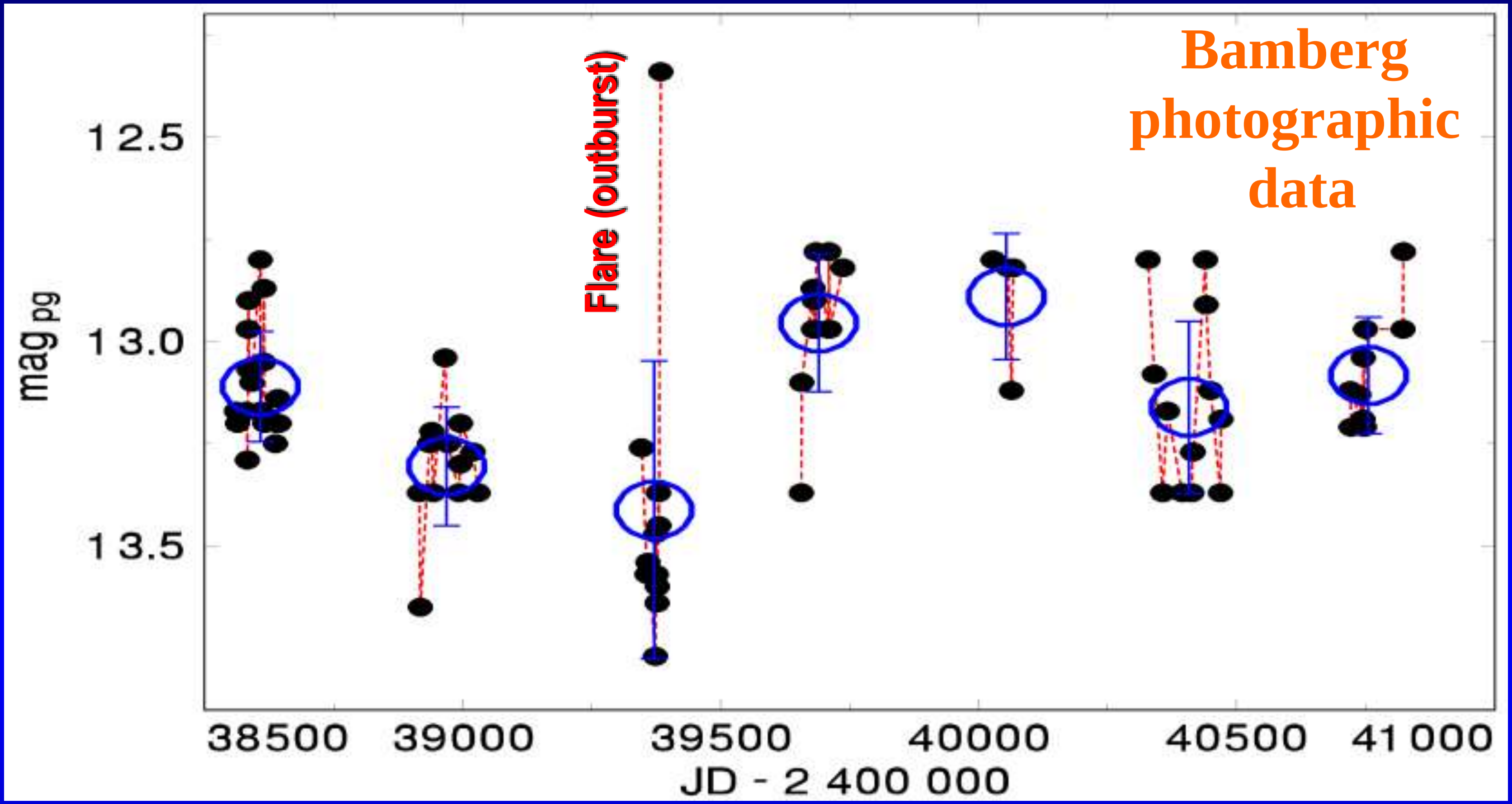
Simon (2014)

Search for typical cycle-lengths of the long-term activity:

variograms for the individual time segments

- Dramatic change of activity between two time segments (several decades apart)

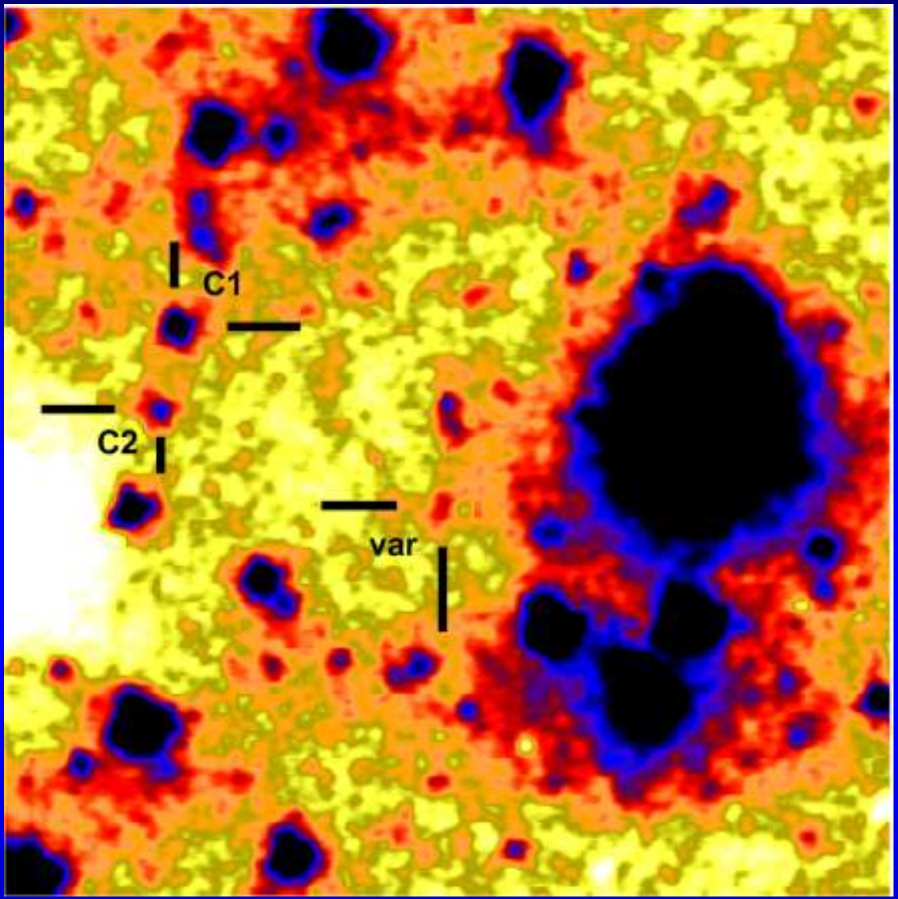
V1223 Sgr / 1H 1853–312



- Open circles: annular means (error bars: annular value of the standard deviation of magnitude)
  - the flare is not included in the annular mean
- The brightness is not stable on the timescales of months and years even in the high state.

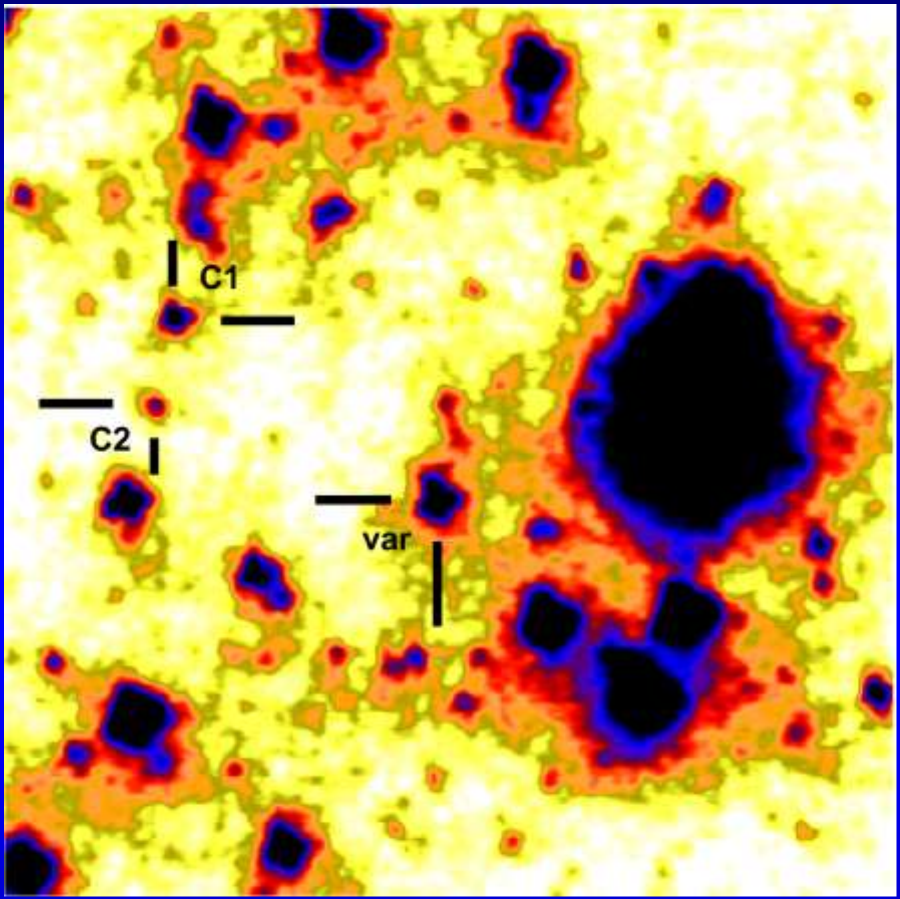
Simon (2014)

Rare flares in the intermediate polars – V1223 Sgr



Sept 11, 1966; JD 2 439 380

"Normal" level



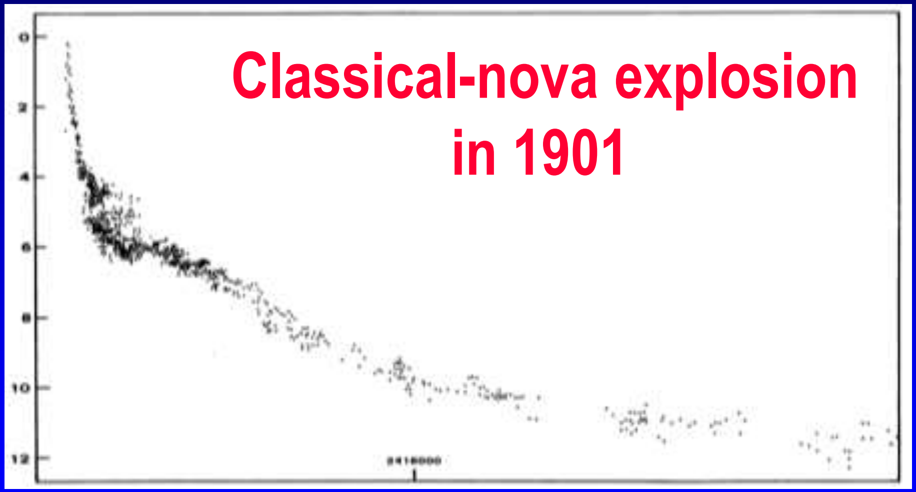
Sept 14, 1966; JD 2 439 383

Time of the peak brightness (flare)

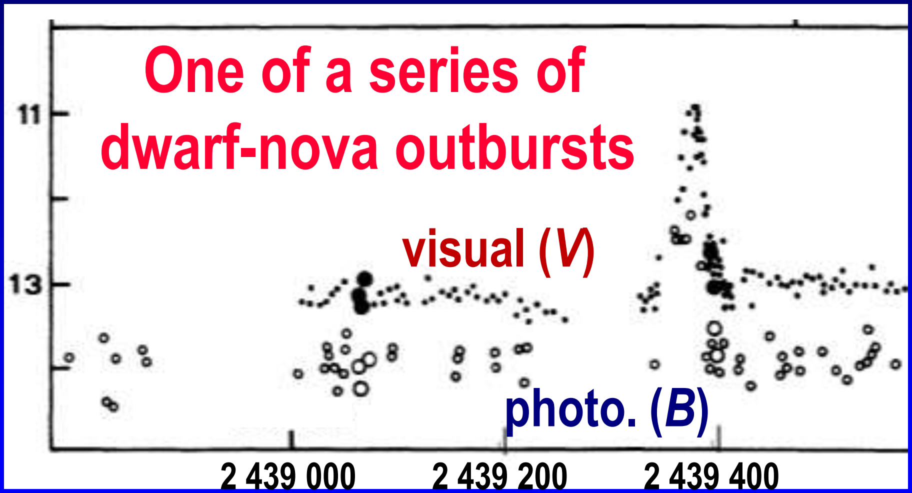
Flare of V1223 Sgr on Bamberg photographic plates (one plate per night)

V1223 Sgr: "var"
Reference stars: "C1" and "C2"
North is at the top, east to the left.

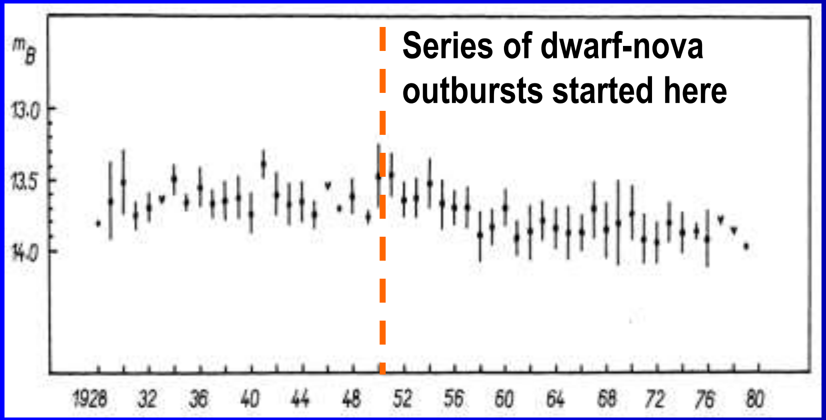
GK Per / 1A 0327+43 (CV – dramatic variations of the type)



Sabbadin & Bianchini (1983)



Sabbadin & Bianchini (1983)



Annular means (brightness averaged over dwarf nova outbursts)

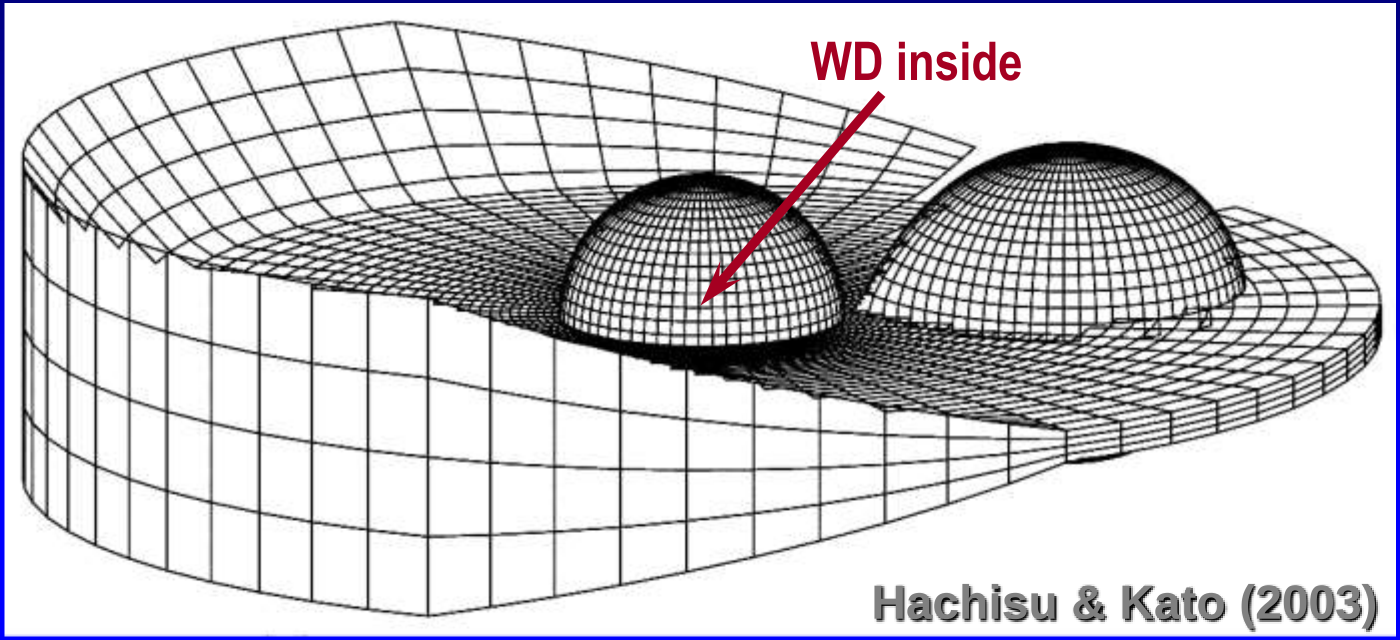
Hudec (1981)

Transition between CV types during less than a century:

classical nova – novalike – dwarf nova (with increasing recurrence time of outbursts)

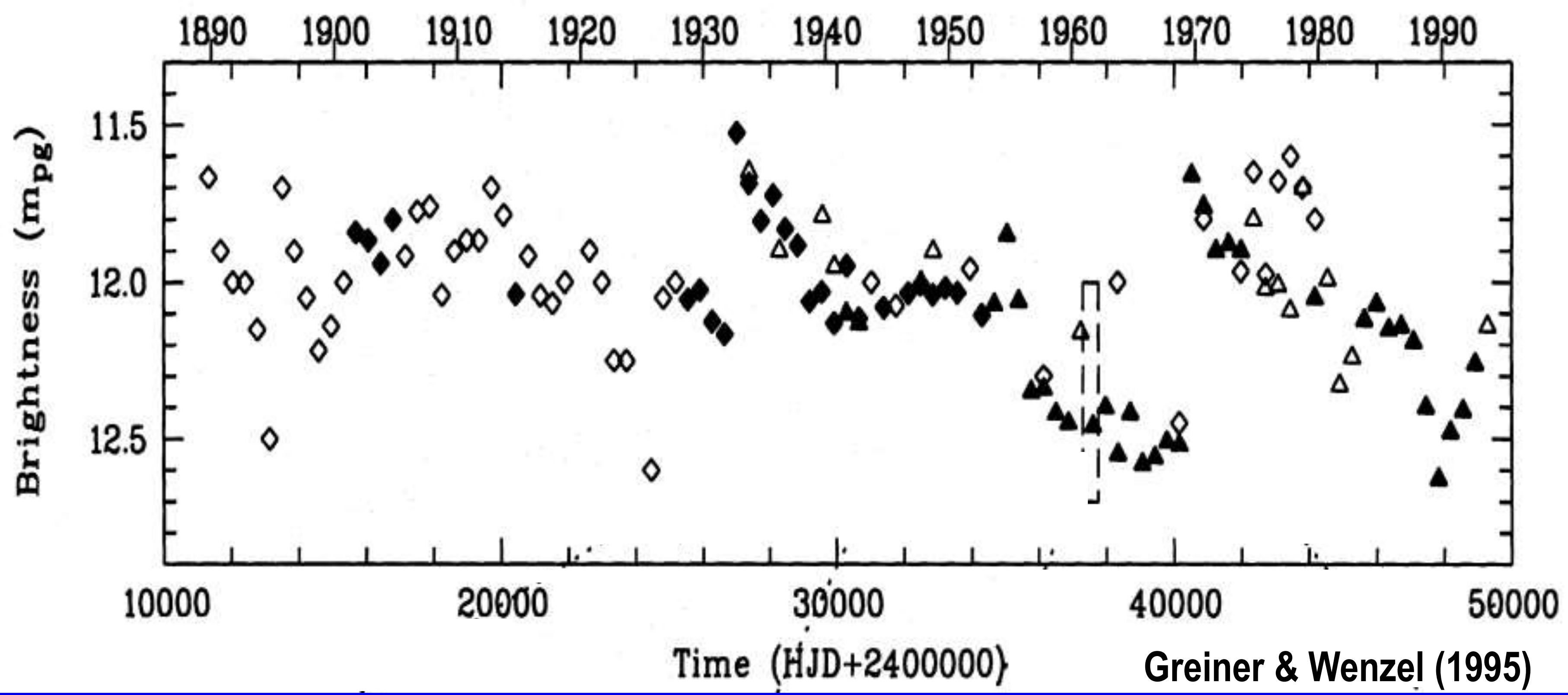
<u>Main common cause:</u> strongly enhanced mass outflow from the donor invoked by strong irradiation during classical nova explosion in 1901 (model by Schreiber et al. 2000)

Supersoft X-ray sources



- Steady-state thermonuclear burning on the white dwarf (WD)
- Strong activity in various spectral bands is common – these objects are thus very promising targets for monitoring
- Detectability of the very soft X-ray emission is strongly dependent on the absorption inside the object – many of these sources remain unrecognized (optical activity may help reveal them)

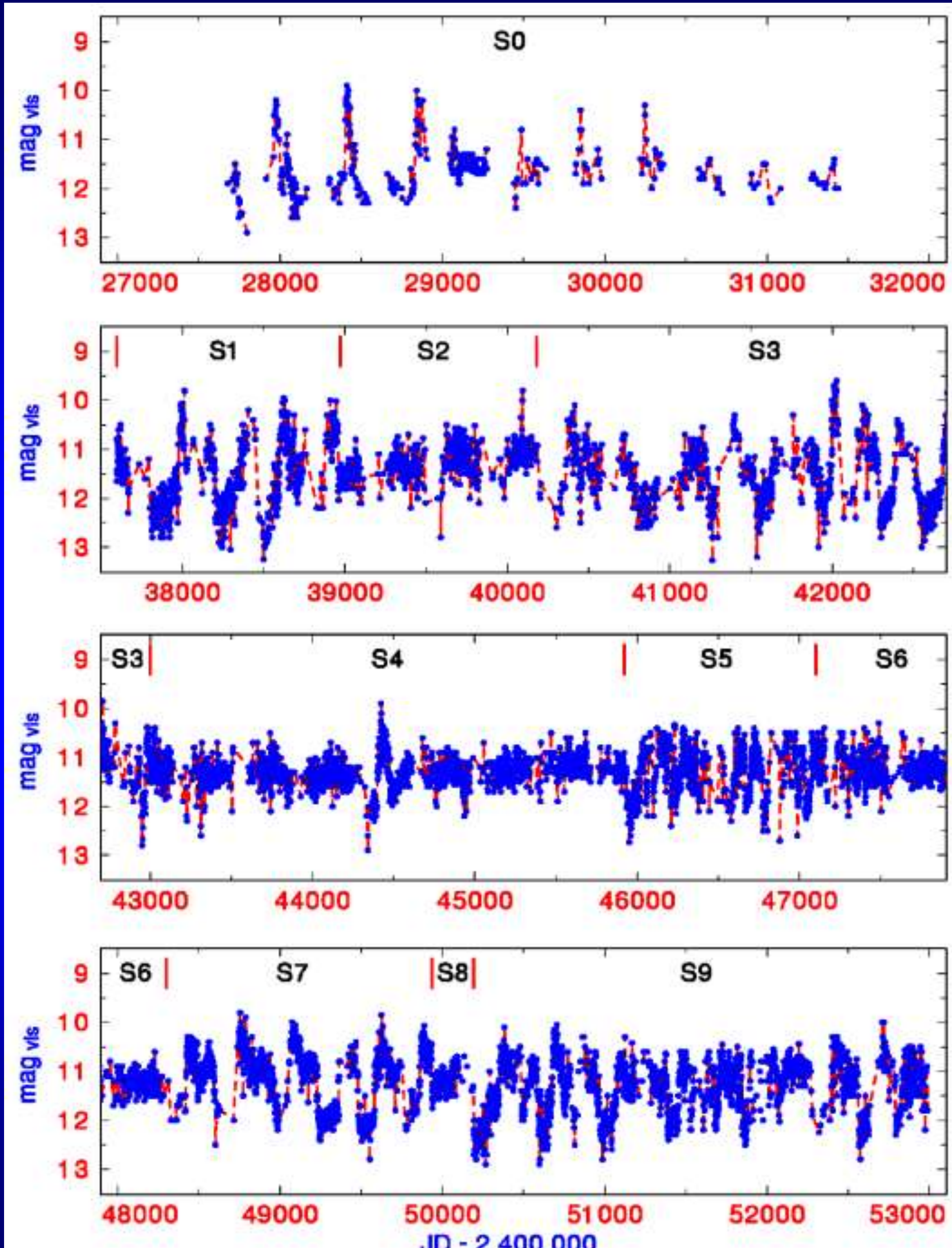
QR And / 1RXS J001950.0+215651



Greiner & Wenzel (1995)

Long-term activity – Harvard and Sonneberg photographic plates

- The activity on long timescales is mapped only in the optical region.
- Most photographic data map the time before the discovery of the object (it was first discovered in X-rays, only later in the optical band (Beuermann et al. 1995))
- X-ray observations are only very sparse snapshots.



V Sge / 2E 2018.0+2056

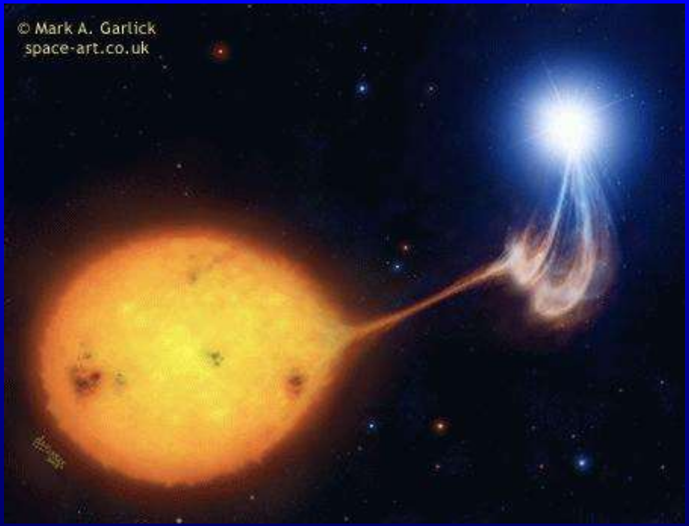
- Unique type of X-ray sources
- Very complicated long-term activity and its evolution (from the optical data so far):

➢ outbursts (segment S0)
➢ high/low state transitions (segments S1, S3, S5, S7, S9)
➢ flat segments (segments S2, S4, S6, S8)

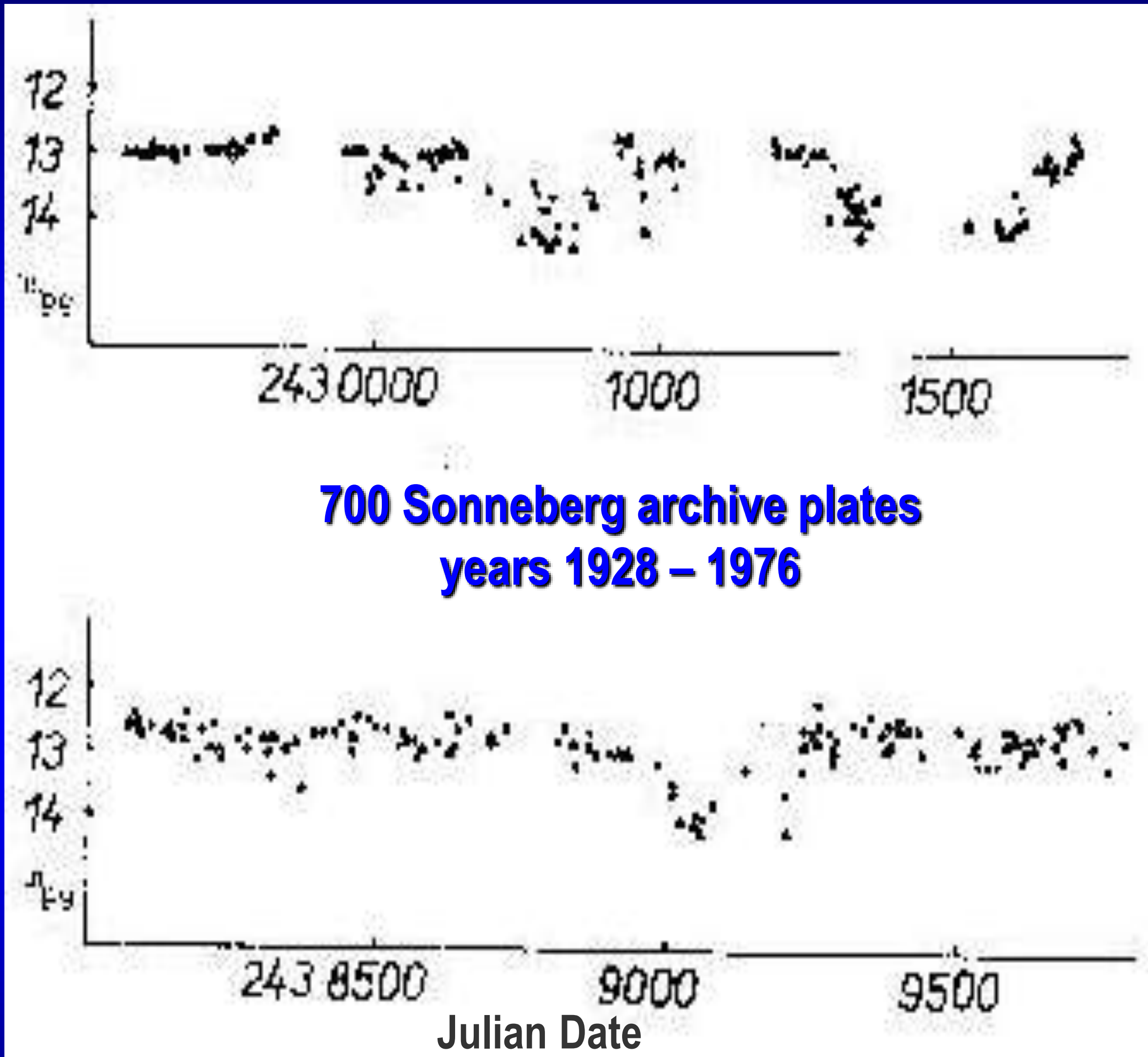
Simon & Mattei (1999, 2002, 2006)

Discless magnetic cataclysmics – polars

- Strongly magnetized white dwarf ($B \sim 10^9$ Gauss)
- Accretion of matter directly onto the region(s) of the magnetic pole(s)



AM Her / 4U 1814+50



- Long-term activity: alternating high and low states on the timescale of months
- Transitions between the states: shorter than the durations of the states (the plates often catch the system in a given state)
- Study of this optical activity even for the epoch preceding the discovery of this object and its classification as the X-ray emission
- Activity easily detectable on archival photographic plates

Hudec & Meinunger (1976)

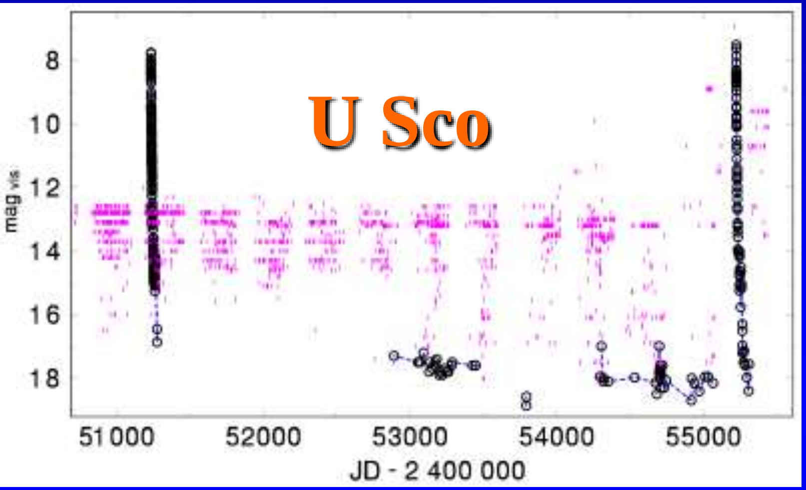
Explosions of classical novae

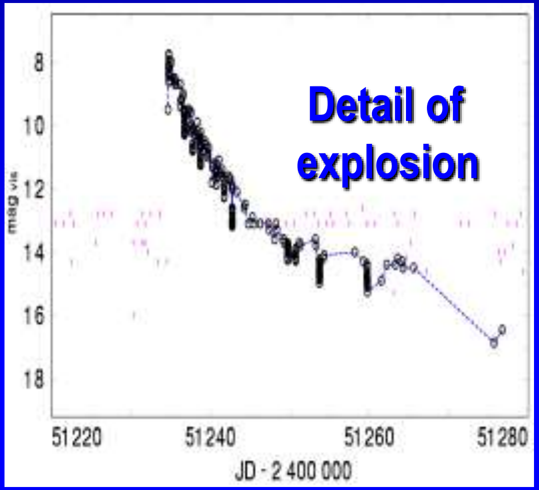
Classical novae – rare thermonuclear explosions of accreted matter on the WD in almost all types of CVs

Typical duration of explosion: **weeks to months**

Typical amplitude of explosion: **12-15 mag**

Recurrence time of explosion: **from decades (recurrent novae) to 10^4 years**

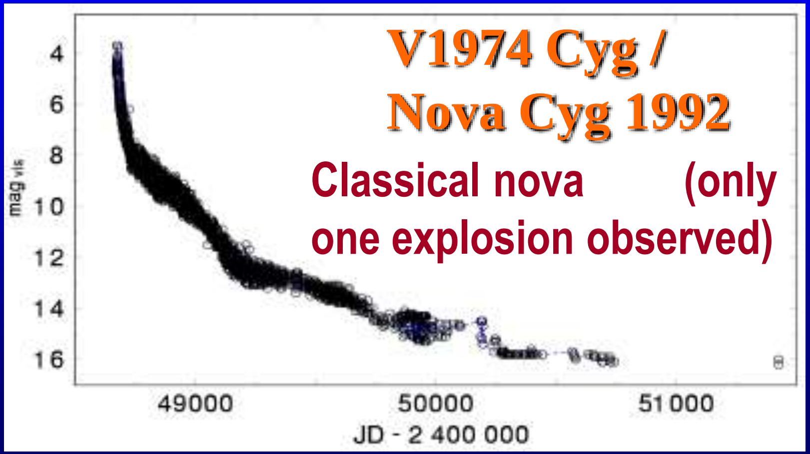




Upper limits constrain the duration of the fast rise to the peak of explosion (badly covered!)

AFOEV data

Recurrent nova – several explosions observed



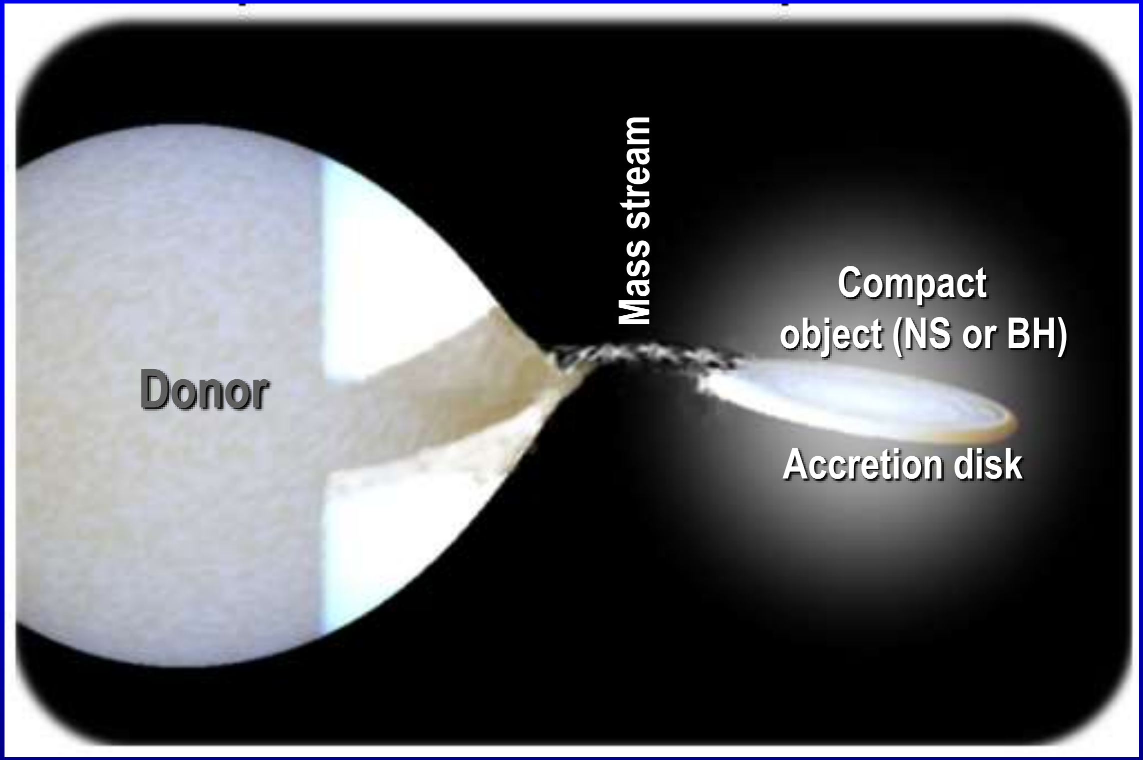
Detection of explosion on the archival plates:

- New object in an "empty" position
- Novae are usually faint in quiescence (they are discovered by the outburst)
- Pre-explosion activity (and search for the previous explosions) can be studied on the plates

Low-mass X-ray binaries (LMXBs)

Typical structure

- Donor (lobe-filling star)
- Compact mass-accreting object: neutron star (NS) or black hole (BH)
- Accretion disk embedding the compact object



Gerend & Boynton (1976)

Lewin et al. (1995)

- Dominant part of the optical emission from the accretion disk and the irradiated part of the donor

Her X-1

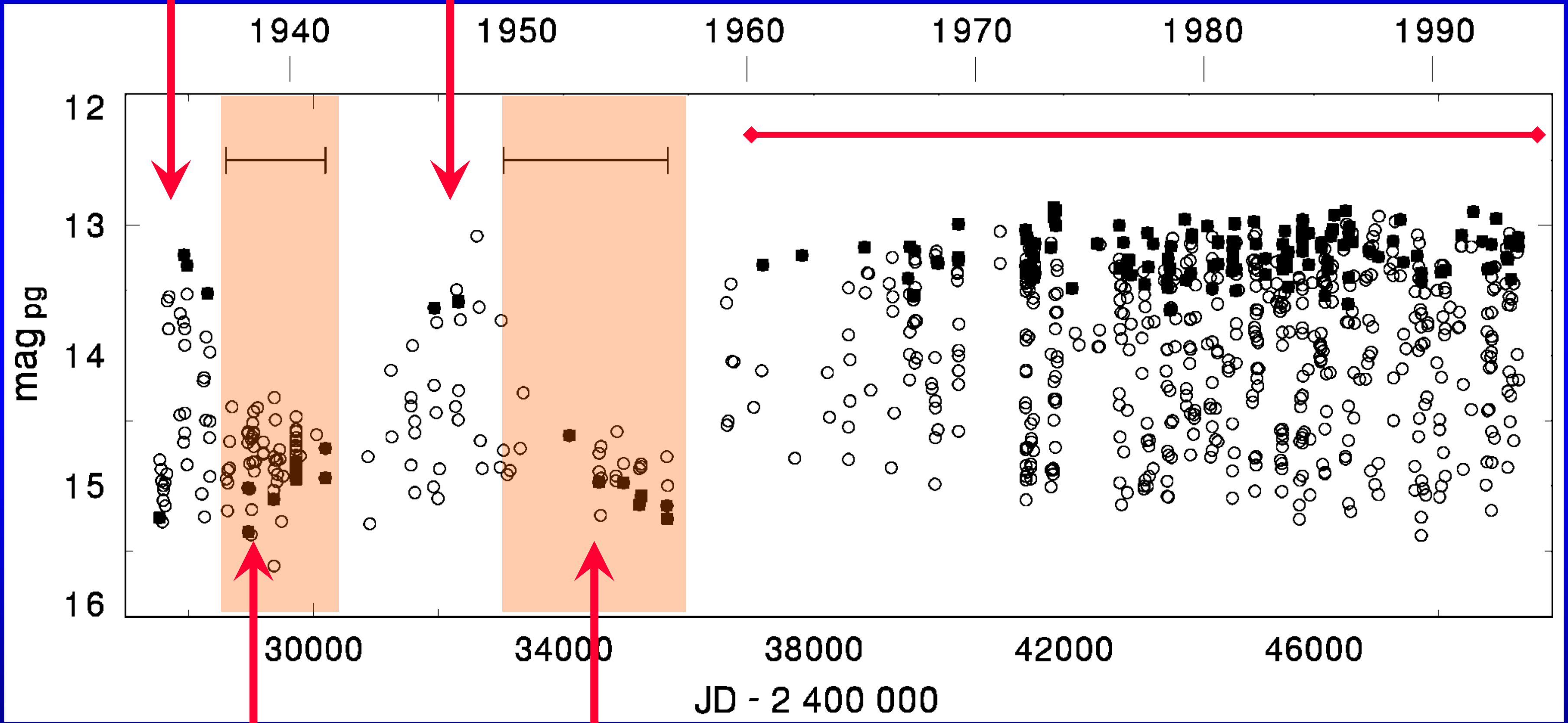
Long-term activity in the optical band (even before the era of X-ray astronomy)

Active state

Active state

Sonneberg photographic data (one plate per night)

Active state



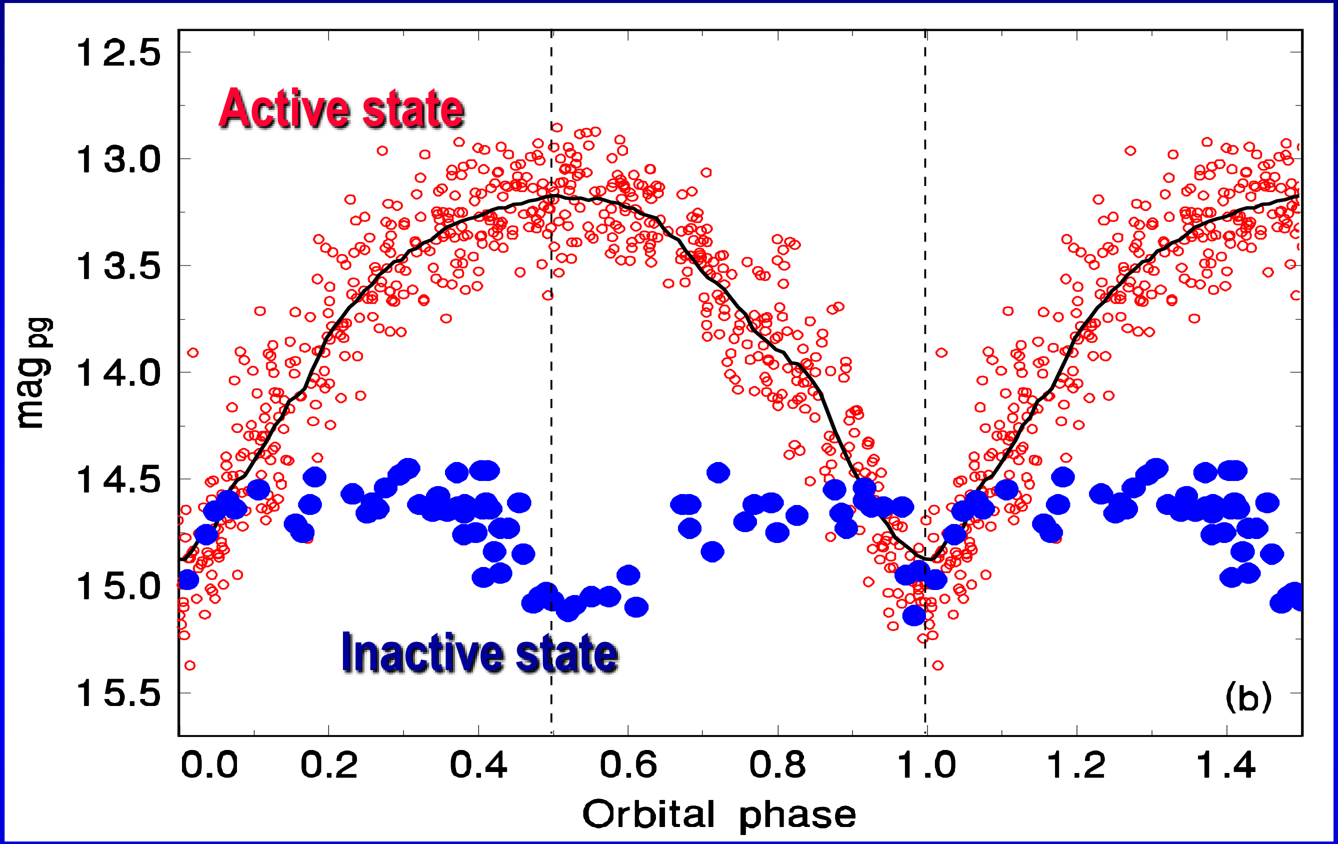
Inactive state

Inactive state

Solid points: data within the orbital phases 0.4-0.6

Simon et al. (2002)

Her X-1 – the unique nature of the orbital modulation



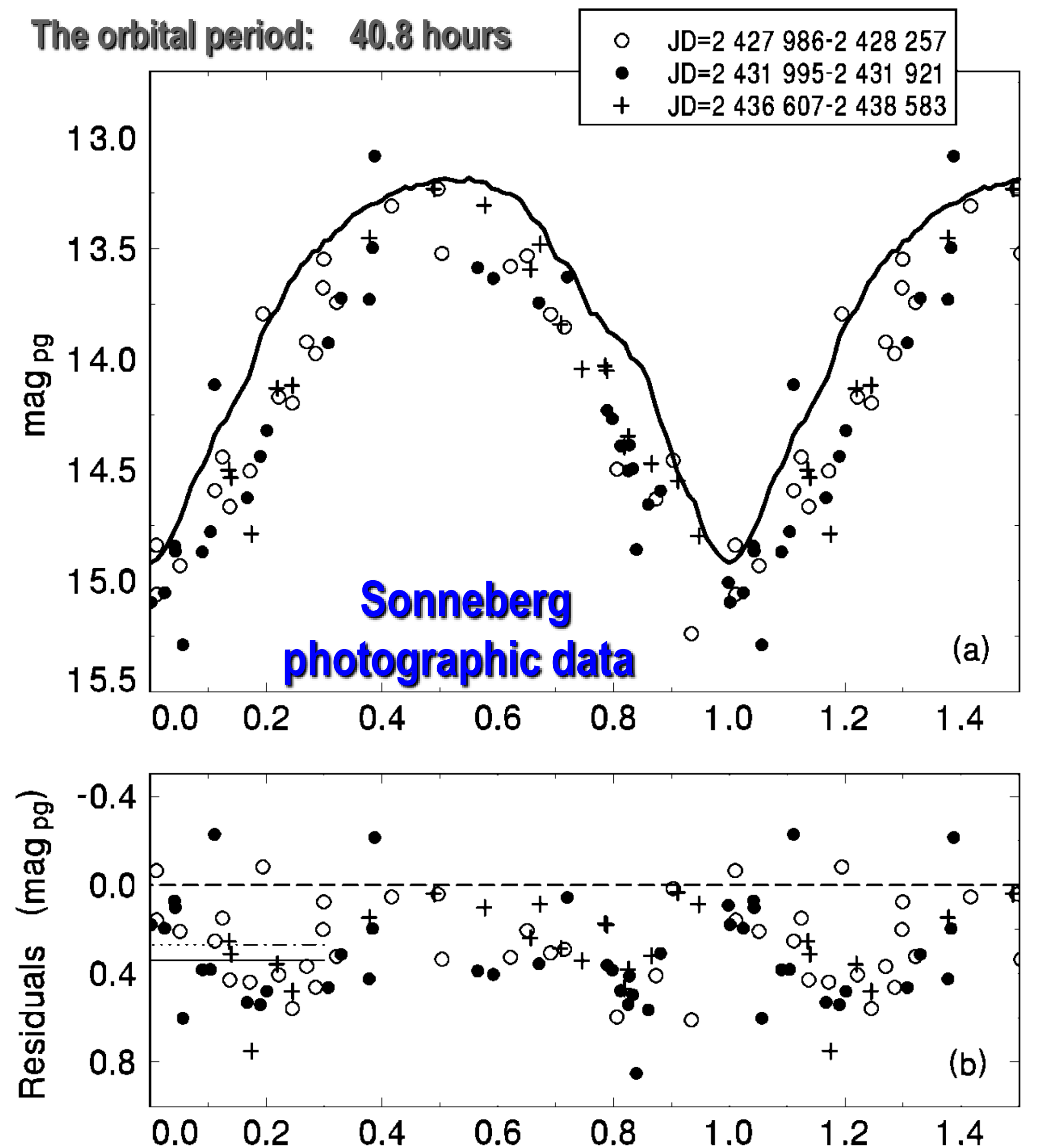
Sonneberg photographic data (one plate per night)

Hudec &Wenzel (1976)
Simon et al. (2002)

The orbital period: 40.8 hours

- Dominant part of the optical emission in the active state – reprocessing off X-rays on the donor (Gerend & Boynton 1976)
- Inactive state – temporary decrease of irradiation of the donor
  Observed only prior to the X-ray astronomy era.

Her X-1 – the unique nature of the orbital modulation

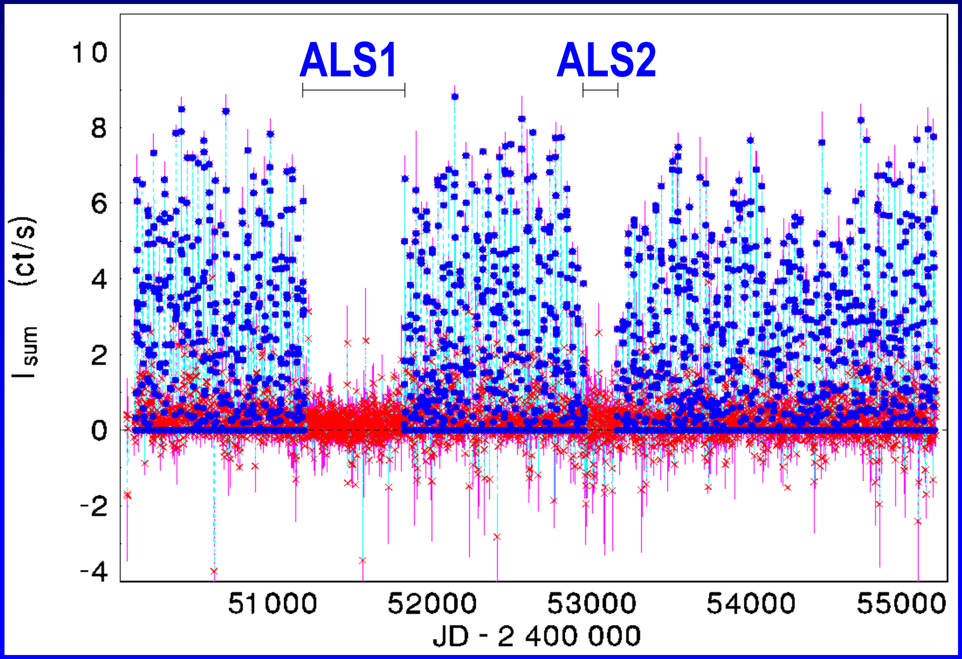


Simon et al. (2002)

- Two short active states:
  years 1934–1937 (empty circles)
  years 1941–1949 (solid circles)
- Smooth curve – moving averages of the active state in 1959–1993
- Residuals of observations of short active states from the smooth curve in 1959-1993.
- Short active states were fainter than the long-lasting state in 1959 – 1993.

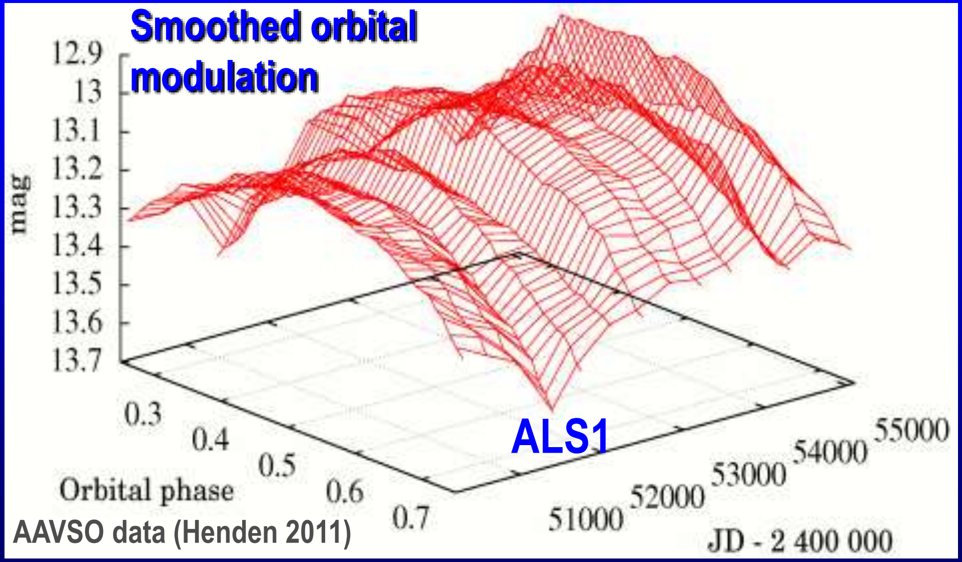
Her X-1 …in the recent years

Relation between the optical and X-ray log-term activity



X-rays (ASM/*RXTE* 1.5 – 12 keV)
(One-day means)

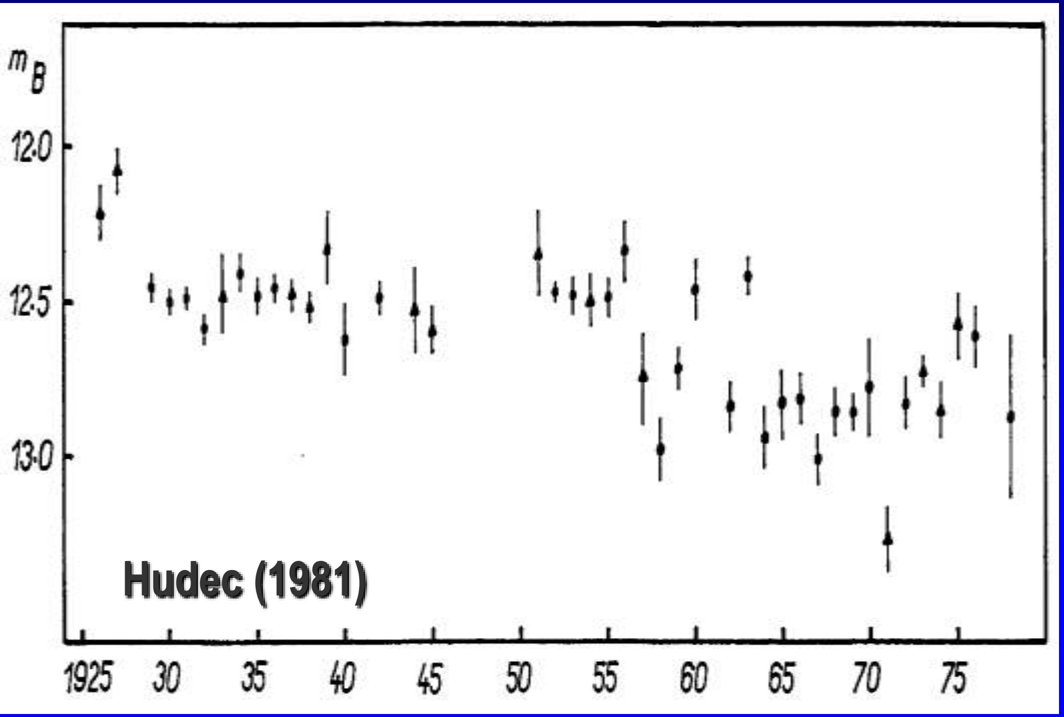
On and Off-states do not form a clear light curve (but two anomalous low states ALS1 and ALS2 can be resolved).

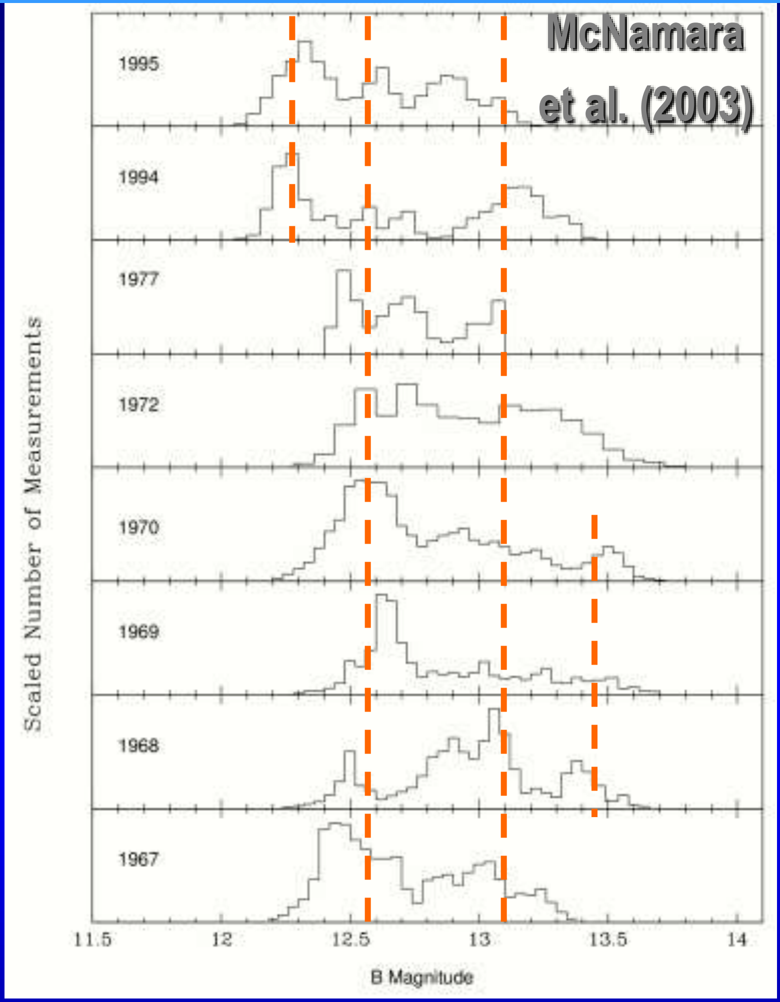


Optical (AAVSO)

- **ALS1 state – decrease of the optical brightness accompanied the fall of the X-ray intensity.**
- **Optical modulation caused by X-ray irradiation of the donor remained**

Sco X-1 / V818 Sco (LMXB)





Long-term light curve in blue light

One-year means from archival photographic plates

The light variations are composed of rapid and long-term activity (episodes of high and low states could occur during a given year).

Differences in the *B*-mag histograms:

Explanation: variations in the mass accretion rate and the relatively short time period typically covered by optical observations

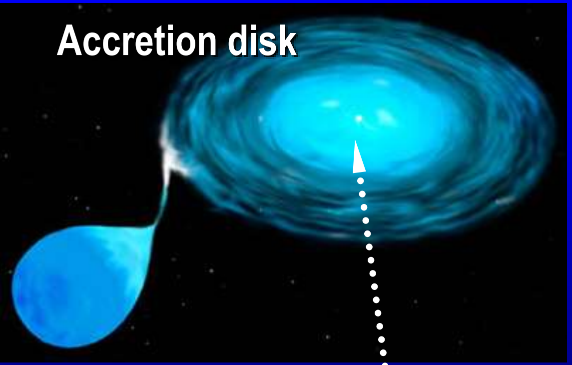
Examples of the optical activity of high-mass X-ray binaries (HMXBs)

High-mass X-ray binaries (HMXBs)

- Donor – thermal radiation – often dominant in the optical
- Accretion disk (if exists) embedding the compact object (neutron star or black hole) – thermal radiation
- Vicinity of the compact object, colliding winds: inverse Compton process, bremsstrahlung (X-rays)

Accretion modes for the large-amplitude changes of brightness:

Roche lobe overflow



Donor, filling its lobe

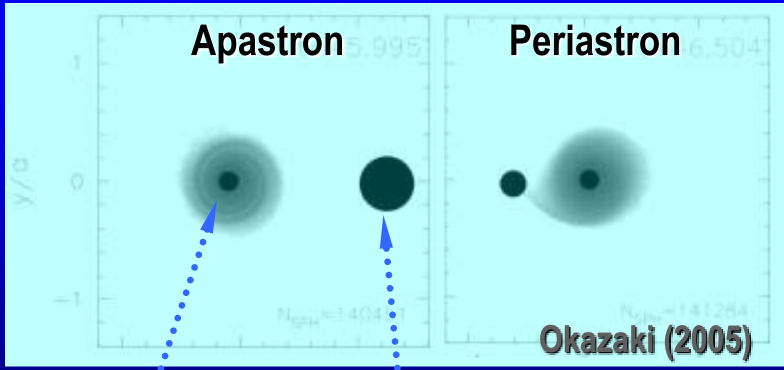
Compact object (NS, BH, WD)

Wind accretion

Donor, underfilling its lobe

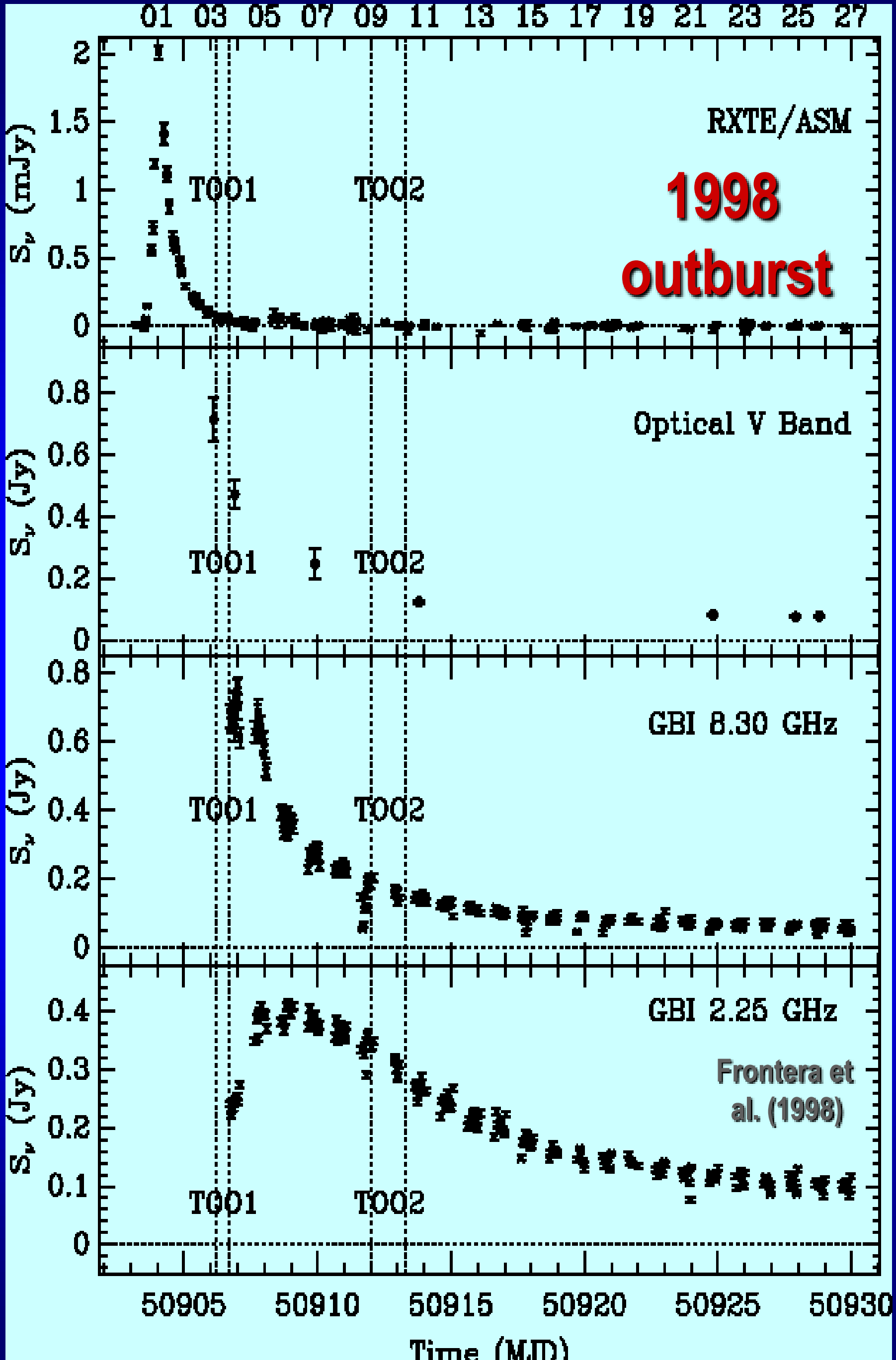
Compact object (NS, BH, WD)

Periastron passage



Donor, underfilling its lobe

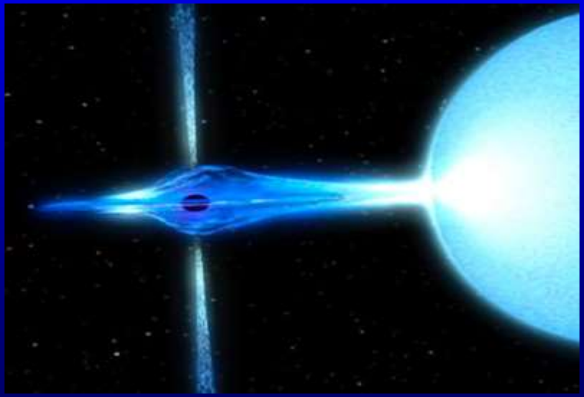
Lobe size of the compact object



CI Cam / XTE J0421+560

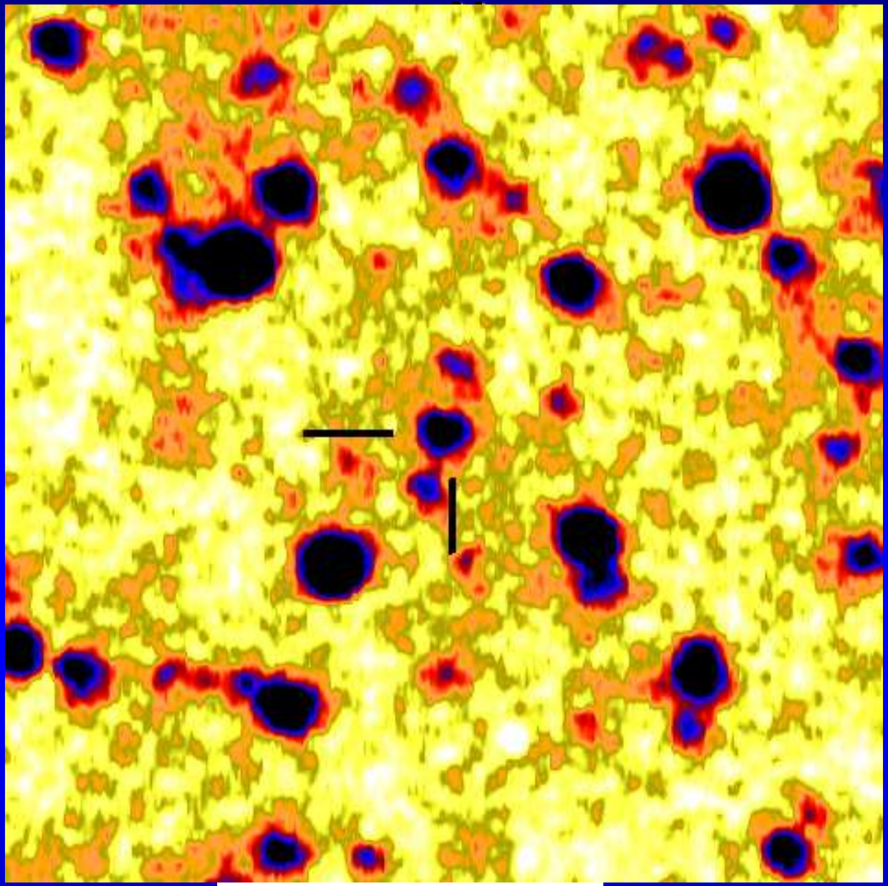
Remarkable system (microquasar)
(Lamers et al. 98; Belloni et al. 99; Robinson et al. 02; Hynes et al. 02; Barsukova et al.02)

Outburst:
- **thermal instability of a small, wild-fed accretion disk**
- **mechanism of this event is analogous to outbursts of soft X-ray transients** (Simon et al. 06)



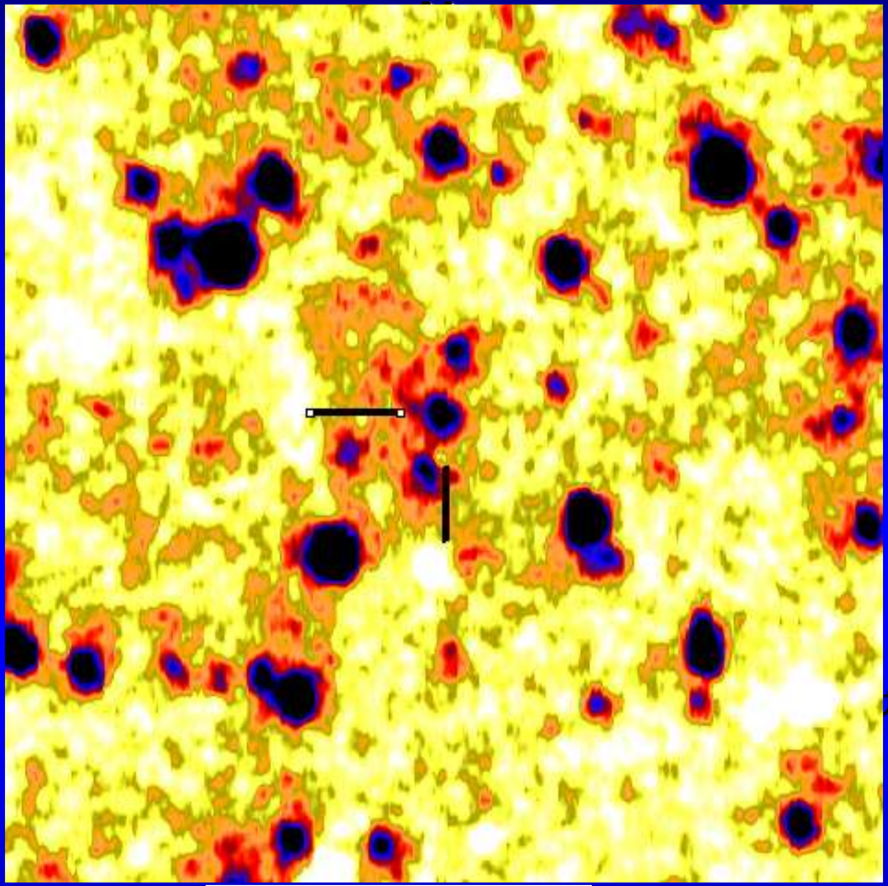
CI Cam/XTE J0421
Archival Bamberg plates

Sept 13, 1936
JD 2 428 424



Brighter state

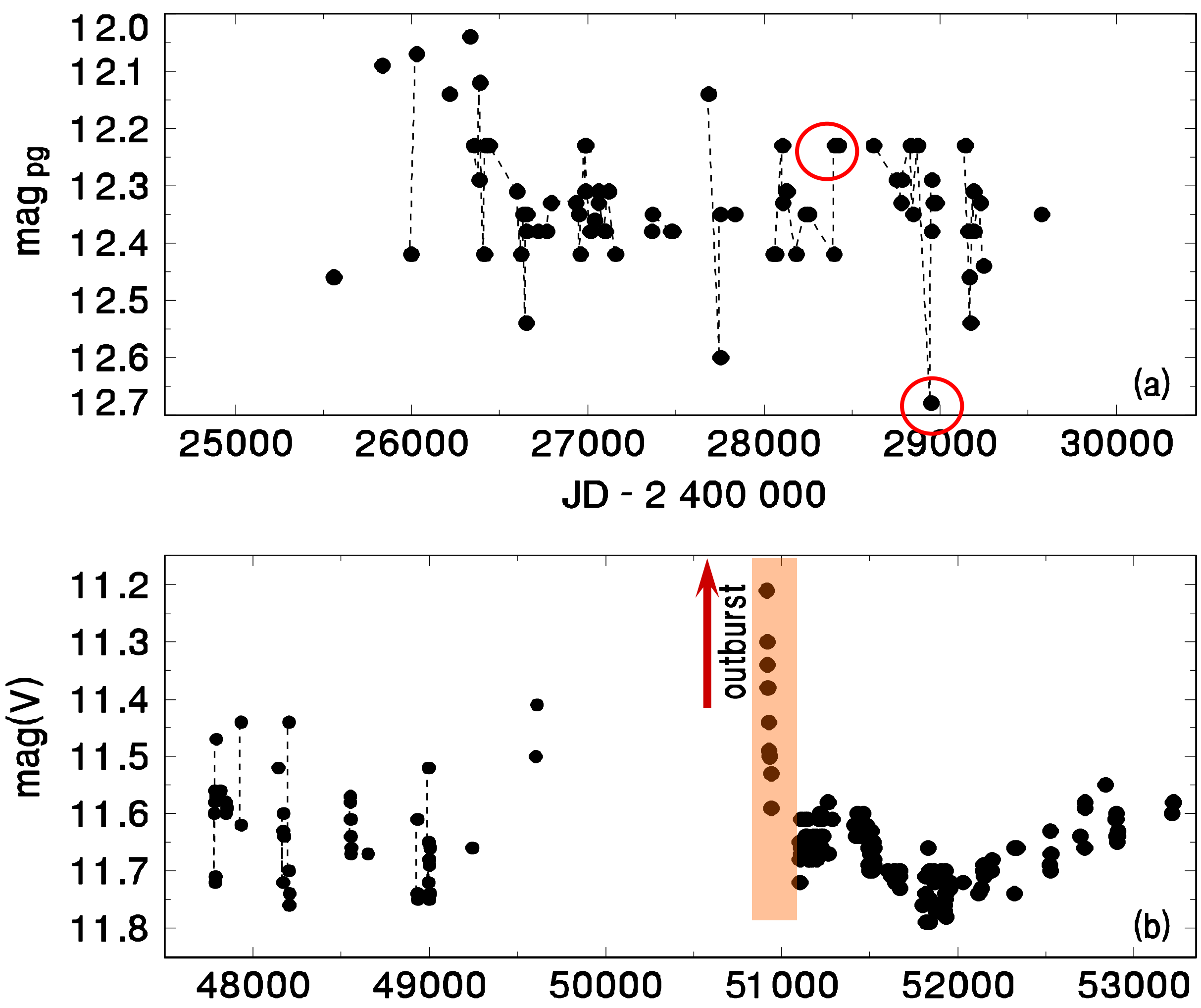
Feb 19, 1938
JD 2 428 949



Fainter state

CI Cam on the plates in various states. North is up, east to the left.
Field size: 36 x 36 arcmin. Fluctuations of brightness occurred.

CI Cam / XTE J0421 Activity on timescales of decades



Simon et al. (2007, 2008)

Bamberg photographic obs. in the blue band (similar to the *B* band) (years 1928 – 1939)

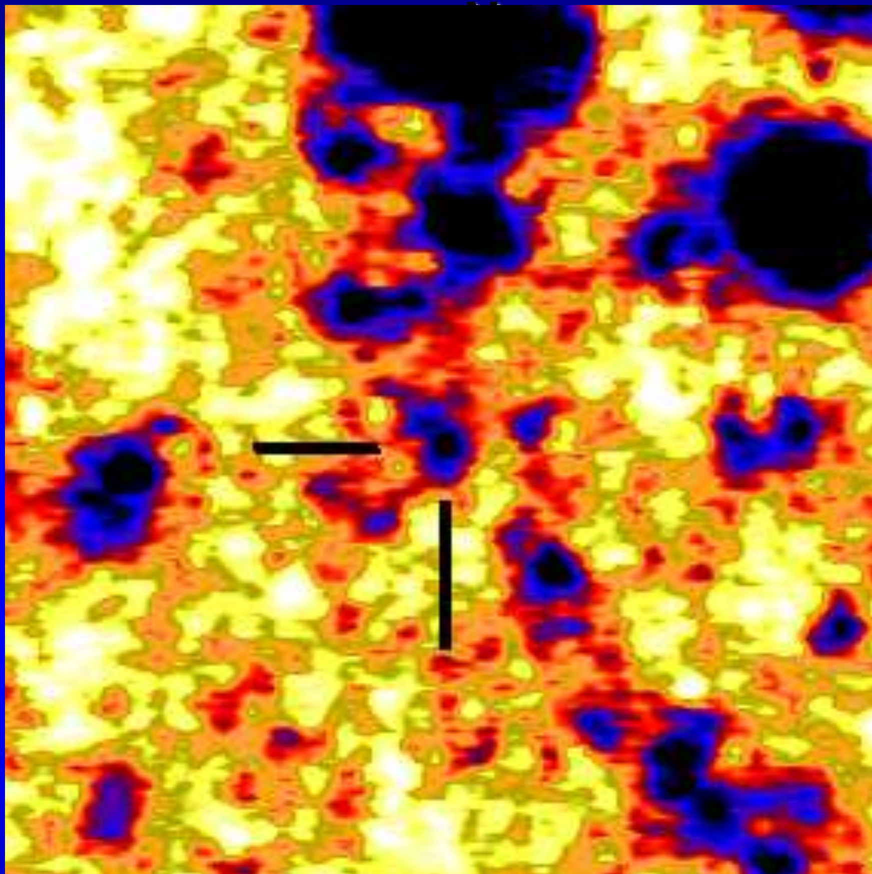
Typical uncertainty: 0.09 mag

Recent activity (photoel. and CCD obs.) (Bergner et al.1989, Simon et al. 2007) (years 1985 – 2004)

Striking difference in activity before and after the outburst – even optical activity itself can indicate the influence of the X-ray outburst on the character of the long-term activity – <u>outbursts of CI Cam thus appear to be very rare (decades?).</u>

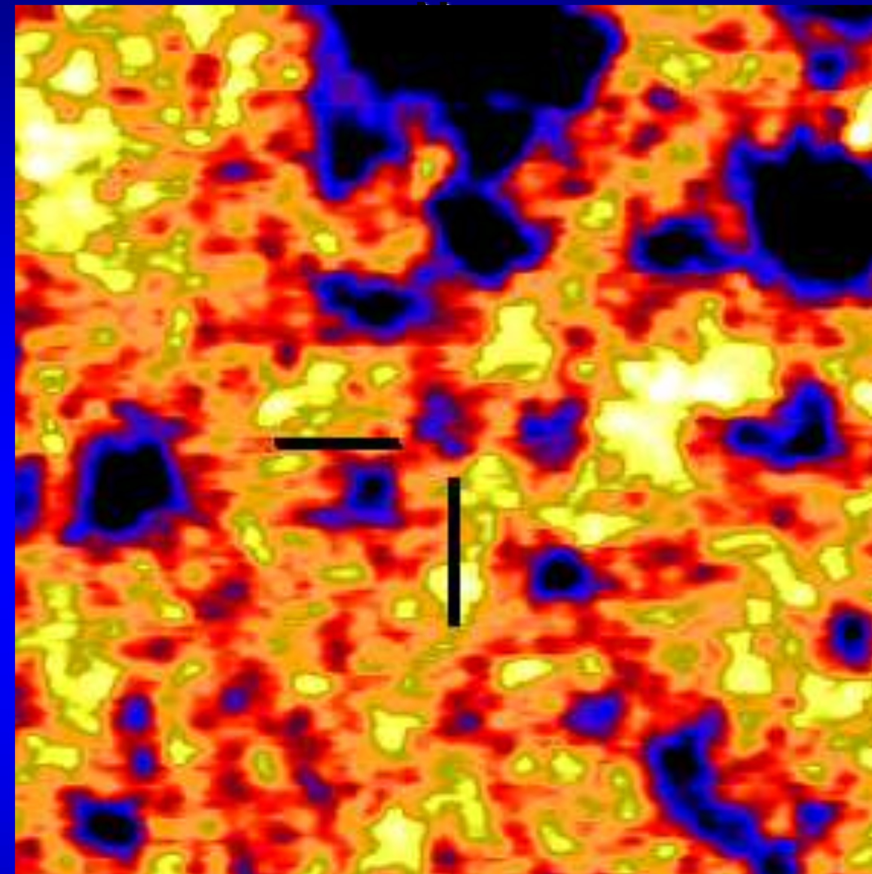
V4641 Sgr/XTE J1819 – 254
Archival Bamberg plates

Jun 28, 1965
JD 2 438 940



Bright state

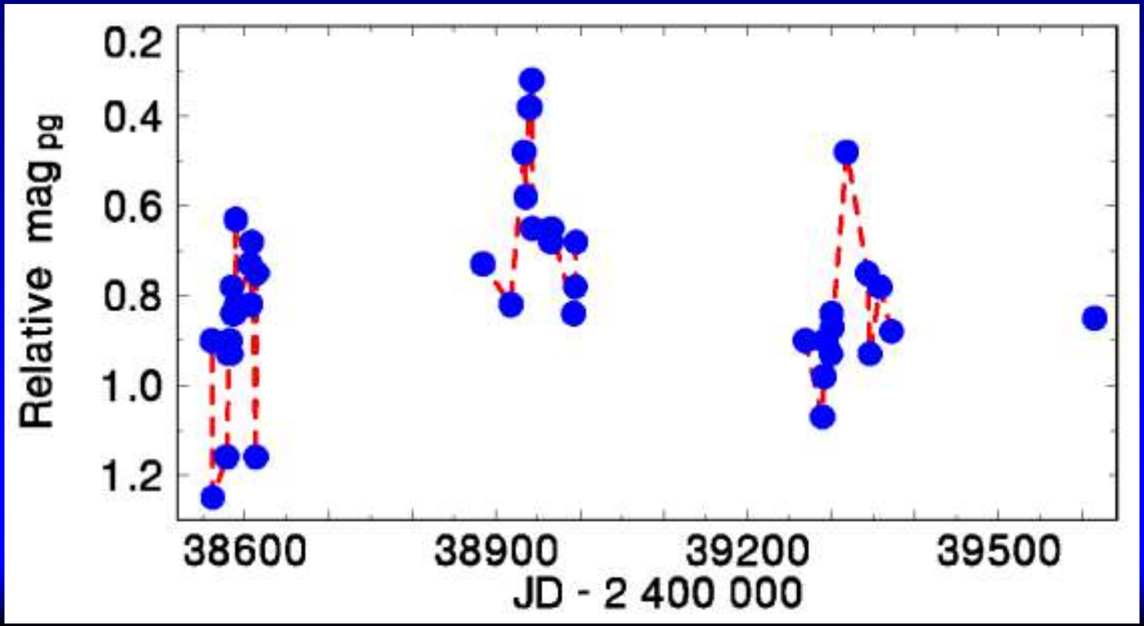
Jun 12, 1966
JD 2 439 289



Faint state

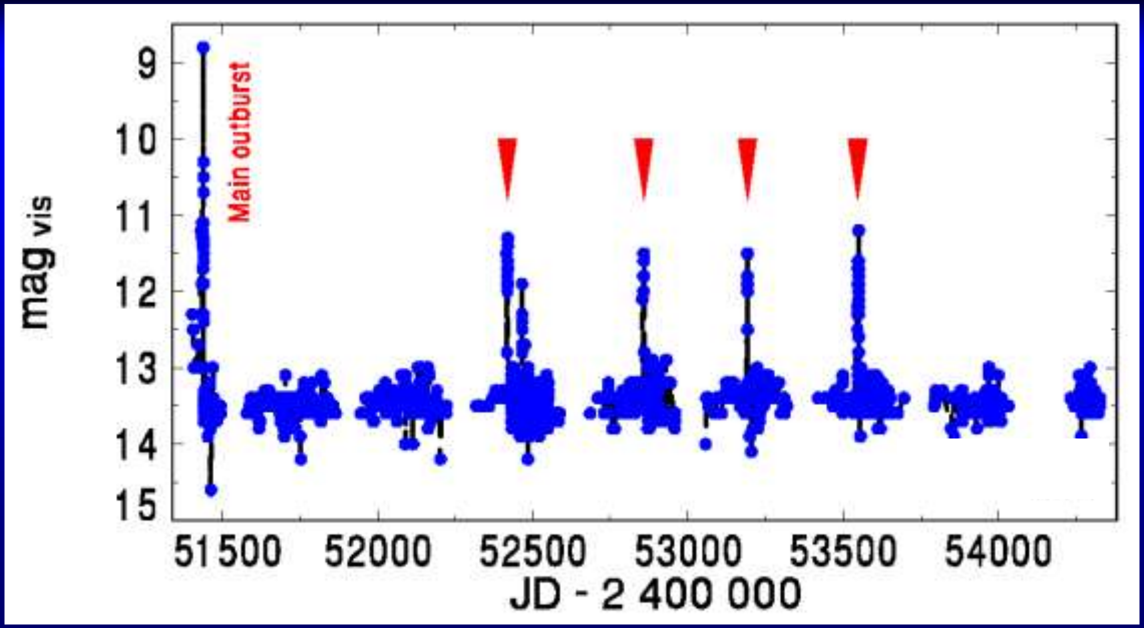
V4641 Sgr on the plates in various states. North is up, east to the left.
Field size: 8.4 x 8.4 arcmin. Fluctuations of brightness occurred.

V4641 Sgr / XTE J1819–254 (microquasar)



Photographic light curve – Bamberg plates (1964 – 1967)

(relative mag in the blue band – similar to the *B* band)



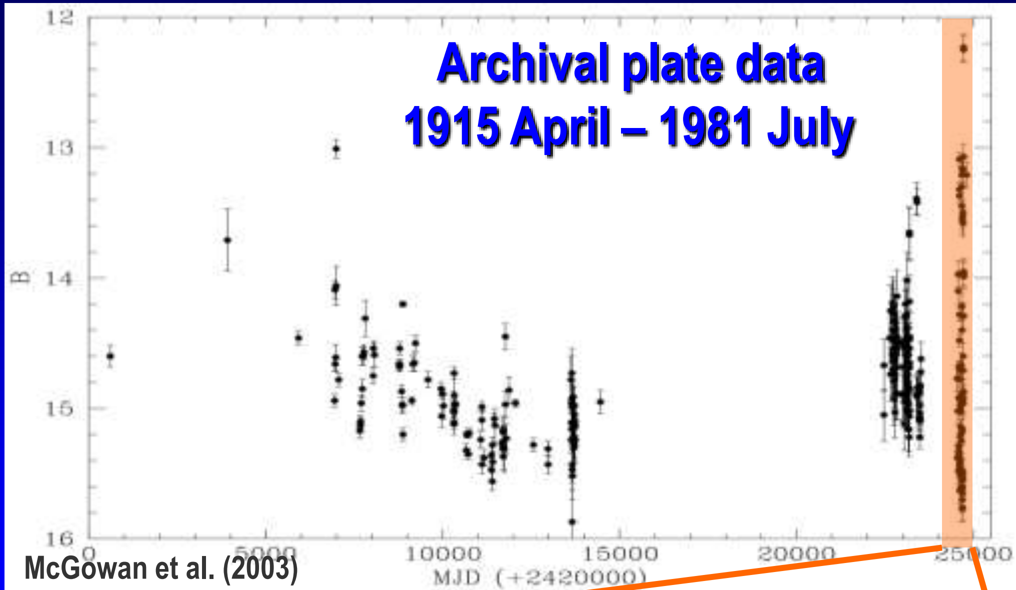
AVVSO light curve

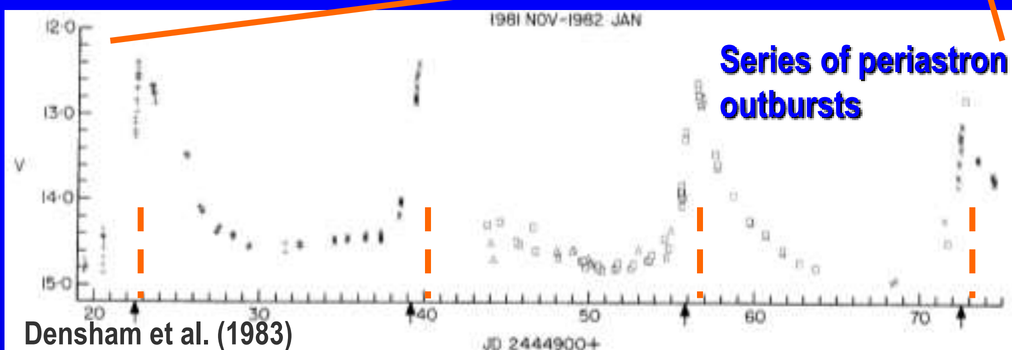
The 1999 main outburst and a series of the echo outbursts

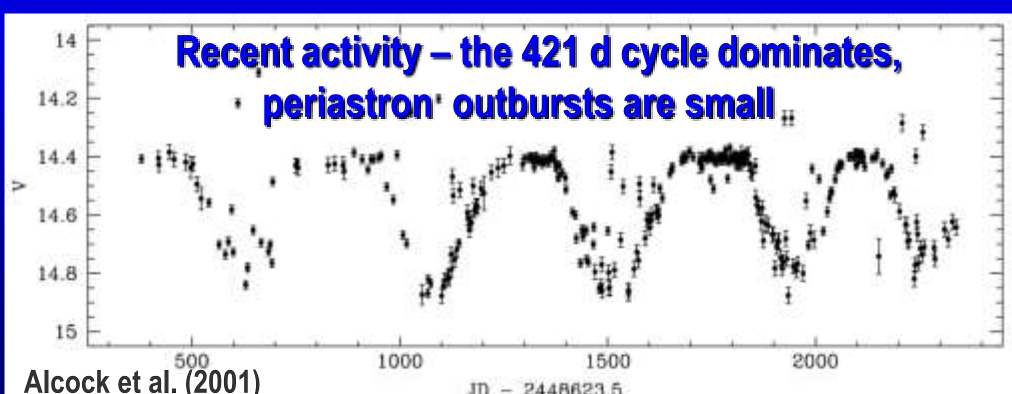
(visual data, the sensitivity approximately of the *V* band)

Simon & Henden (2008)

A0538 – 66 (HMXB)







- Recurrent X-ray transient in the Large Magellanic Cloud (White & Carpenter 1978)
- Outbursts: periastron passages of the compact object (NS) in a highly eccentric orbit ($e \sim 0.7$) (Charles et al. 1983)
- Compact accretor: neutron star (Skinner et al. 1982)
- Donor: high-mass, type B (~12 M_{Sun}) (Charles et al. 1983)

Conclusions

- Activity of some X-ray binary systems undergoes large changes on the timescale of decades – photographic data can significantly extend the mapped time interval, and to discover such changes.
- Photographic data enable us to study the optical counterparts even in the time intervals before the discovery of such objects (even many decades before!).
- Unpredictable and rare events (flares, outbursts, transitions between the states) can be discovered on the archival photographic plates.
- Transients with the large-amplitude brightenings (e.g. novae) can be discovered on the photographic plates.
- The large-amplitude activity of such objects can be studied even on the non-digitized photographic plates (e.g. by Argelander method + microscope).
- It is possible to combine the photographic archival data with the newer CCD observations – also transformations to the same band (e.g. *V*) are possible.

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