# The importance of monitoring of X-ray sources in the optical passband

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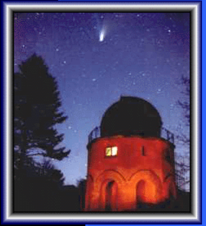
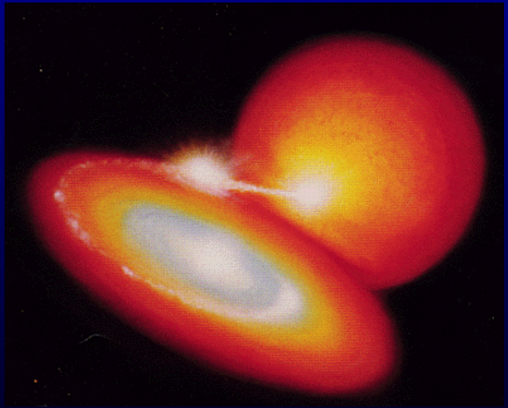


**Talk: Robotic Telescopes, Spain, May 20, 2009**

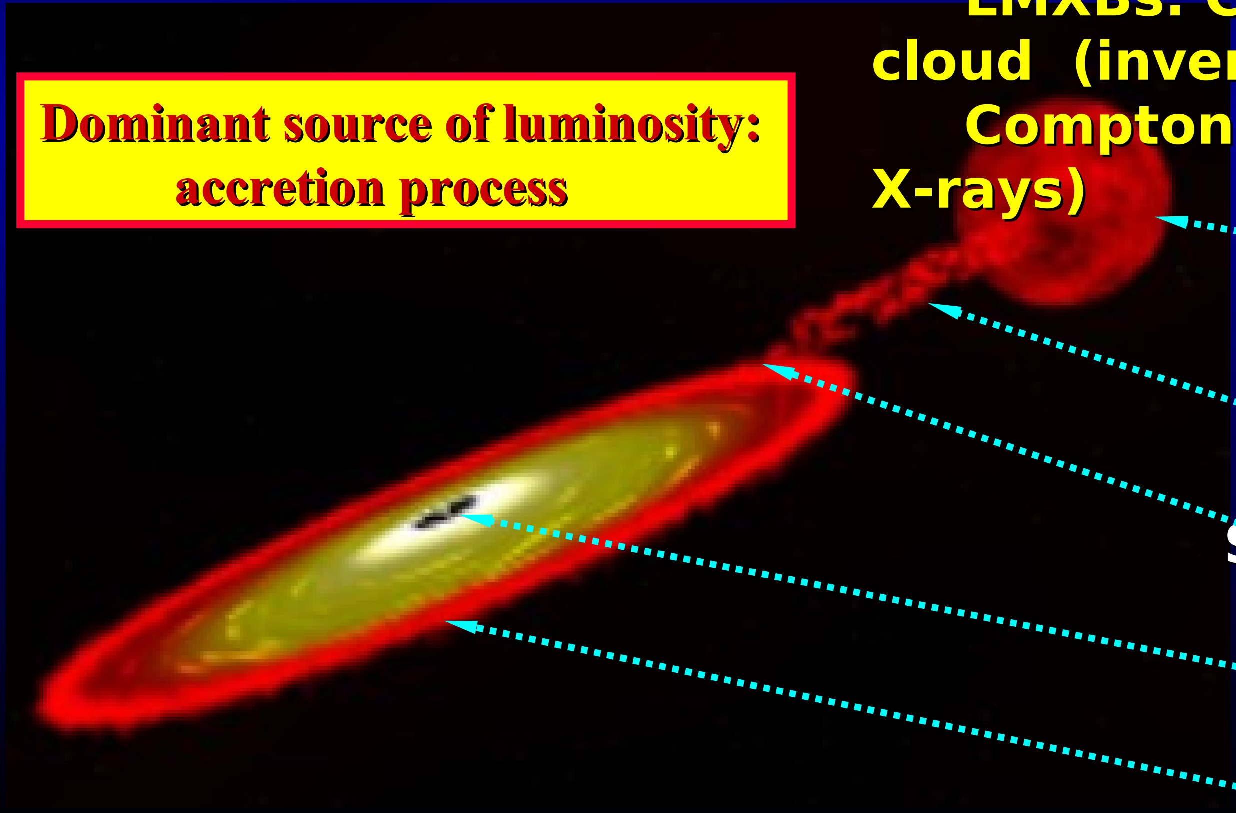
# Binary X-ray sources



# Cataclysmic variables (CVs), Low-mass X-ray binaries (LMXBs)

- Donor – thermal radiation (optical, IR)
- Inner disk region – thermal radiation (f
  UV in CVs, soft X-rays inLMXBs)
- Close vicinity of compact object
  CVs: brehmsstrahlung (X-rays)
  LMXBs: Comptonizing cloud (inverse
  Compton process – hard X-rays)
- Outer disk region – thermal radiation (UV, optical, IR)

**Dominant source of luminosity: accretion process**



# Mechanisms for the long-term activity in CVs and X-ray binaries

- **Changes of mass transfer rate $\dot{m}$ from donor onto compact object** (timescale: days, weeks, months, years)

- **Thermal instability of accretion disk** (timescale: days, weeks, months)

- **Hydrogen burning on white dwarf (in CVs) :**
  - **Episodic:**
    - classical nova explosion (timescale: weeks, months)
    - recurrent novae (timescale: weeks, months)
  - **Steady-state:**
    - supersoft X-ray sources (timescale: days, weeks, months)

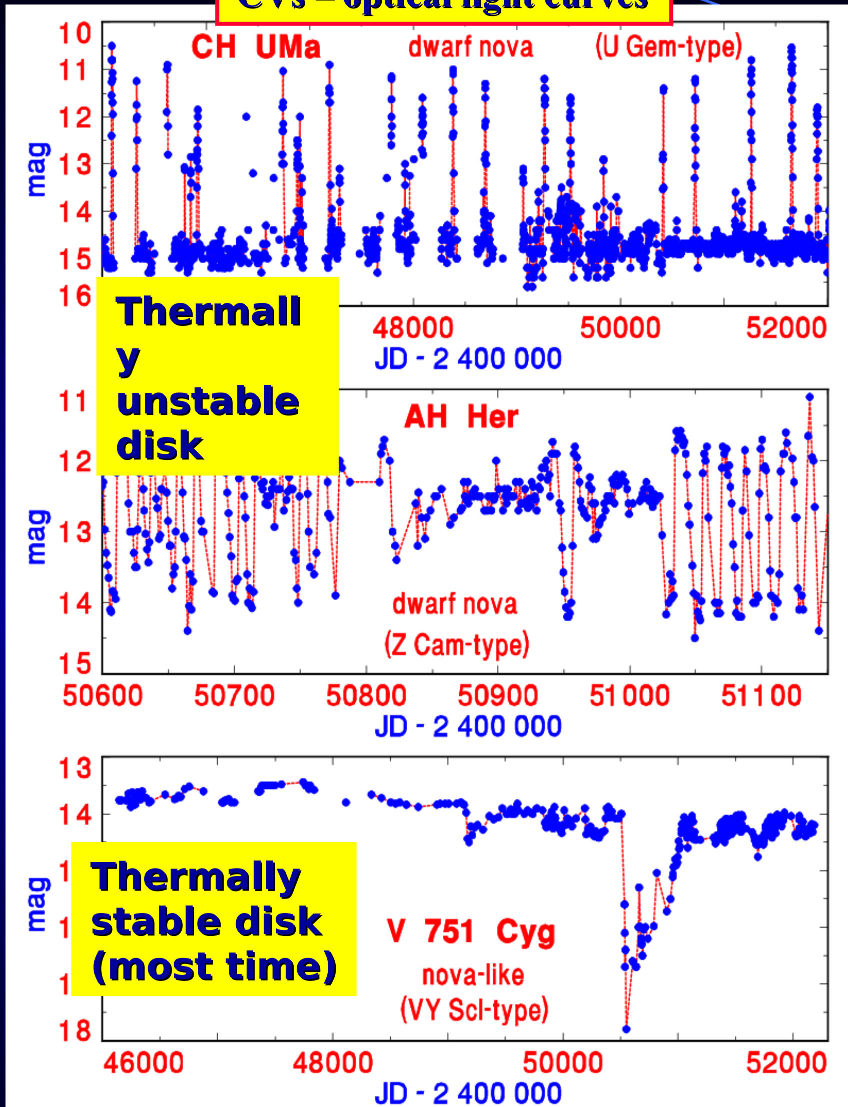
Binary systems with outbursts:

Dwarf novae

Soft X-ray transients (SXTs)

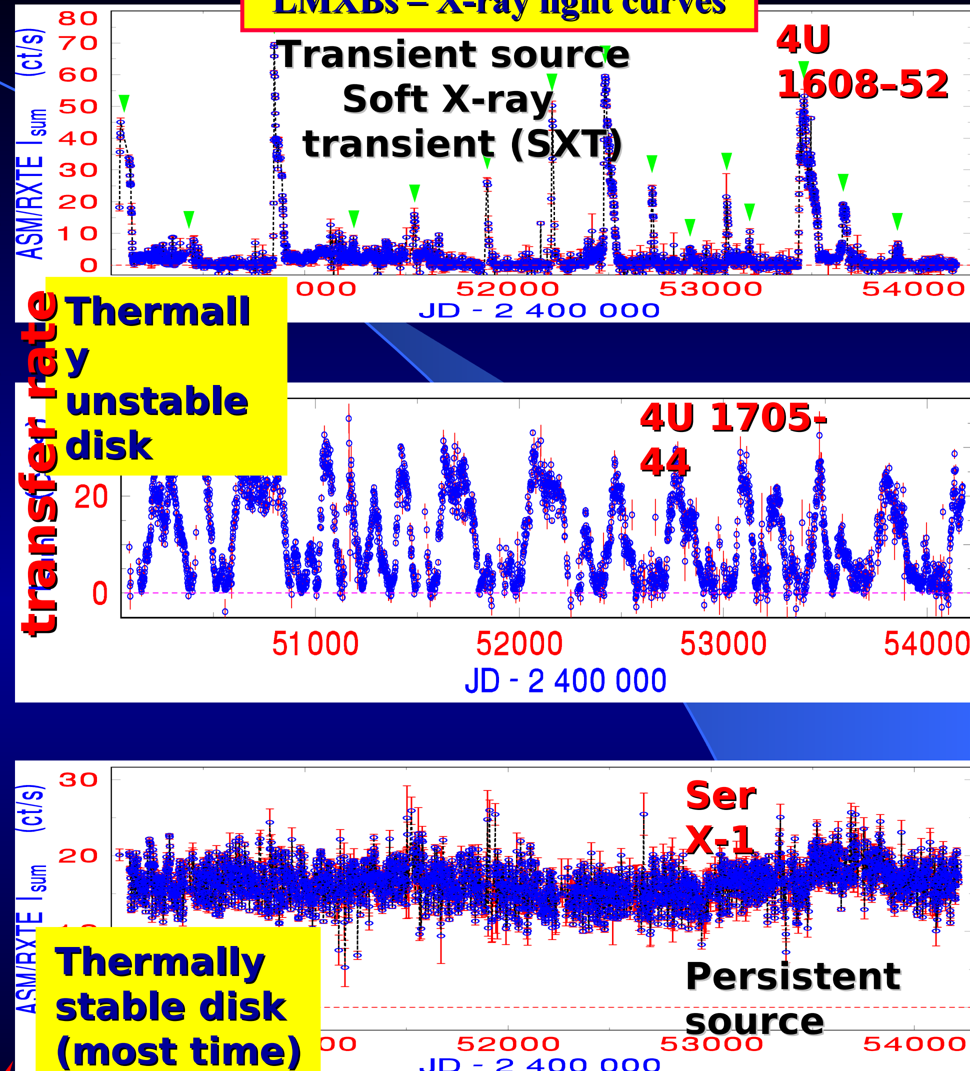
# Systematics of cataclysmic variables (CVs) and low-mass X-ray binaries (LMXBs)

## CVs – optical light curves




Increase of mass transfer rate

## LMXBs – X-ray light curves




**Increasing time-averaged mass accretion rate *m (also increasing***

**Change of long-term activity from large-amplitude, isolated outbursts starting from the baseline quiescent state to the dominant relatively**

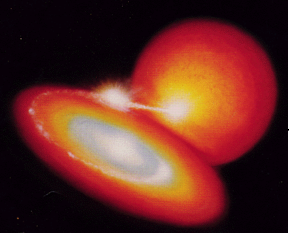
# Problems in long-term coverage

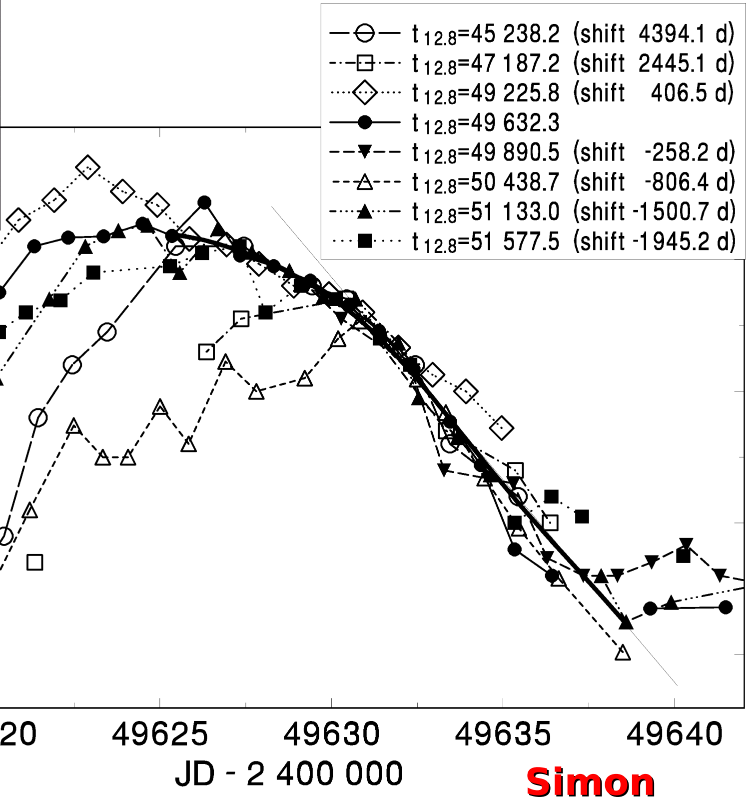
- **X-ray binaries:** often bright in X-rays – easily observable by X-ray monitors, but
  often too faint in the optical (usually fainter than 16-18 mag except infrequent
  outbursts) – optical data are fragmentary or even absent

- **Cataclysmic variables:** bright in the optical, so good long-term coverage is
  available, but X-ray data are fragmentary – too faint for X-ray monitors (with
  only very few exceptions)

- Transitions between activity states (e.g. outbursts, high/low) are often fast and
  unpredictable – monitors with wide field of view are needed to resolve them

# Properties of outburst light curves in dwarf novae – the case of DX And

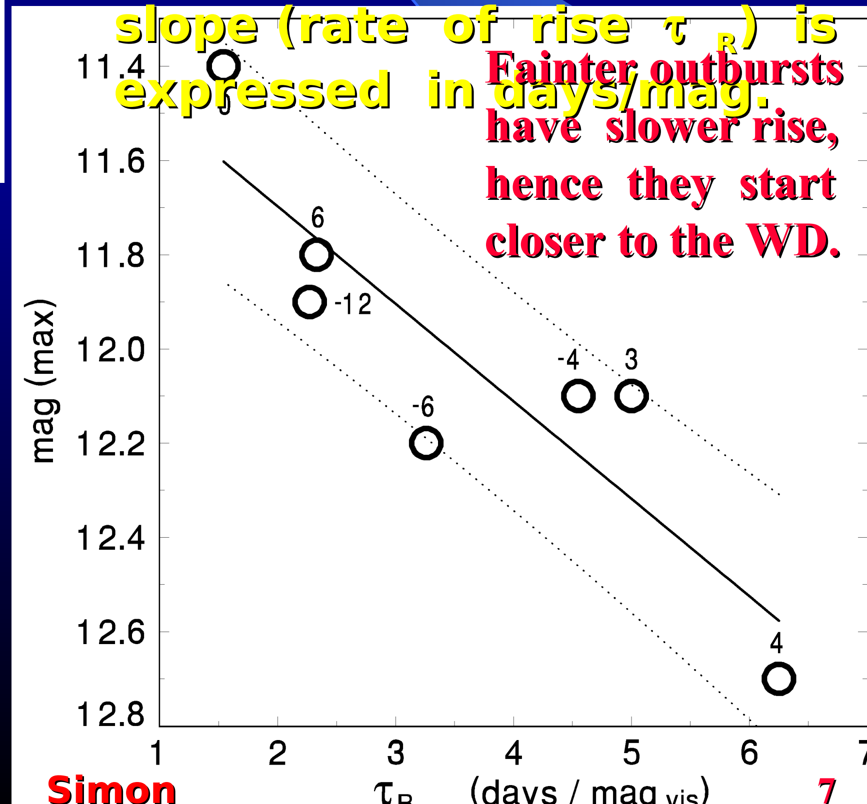





Appearance of the well covered outbursts, shifted along the time axis to match the decaying branch of the template.

Decaying branch – the most stable part of outburst, slope independent of peak outburst luminosity

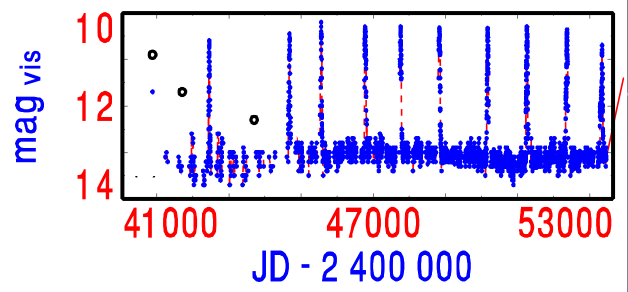
Relation between peak magnitude of the outburst and the slope of its rising branch. The slope (rate of rise $\tau_R$) is expressed in days/mag.



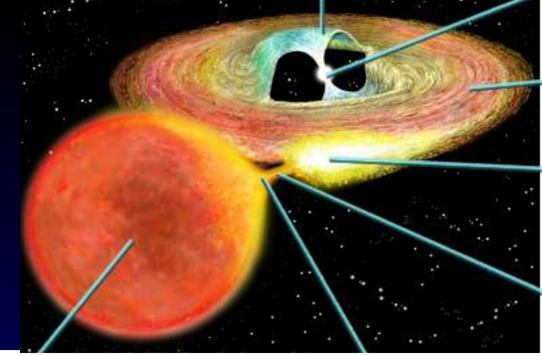

Fainter outbursts have slower rise, hence they start closer to the WD.

Monitoring is necessary to obtain sufficient number of well-mapped outbursts in a given dwarf nova to determine a meaningful ensemble of outbursts

Simon




# Cataclysmic variables – dwarf nova GK Per Complicated relation between the optical and X-ray profile of outburst



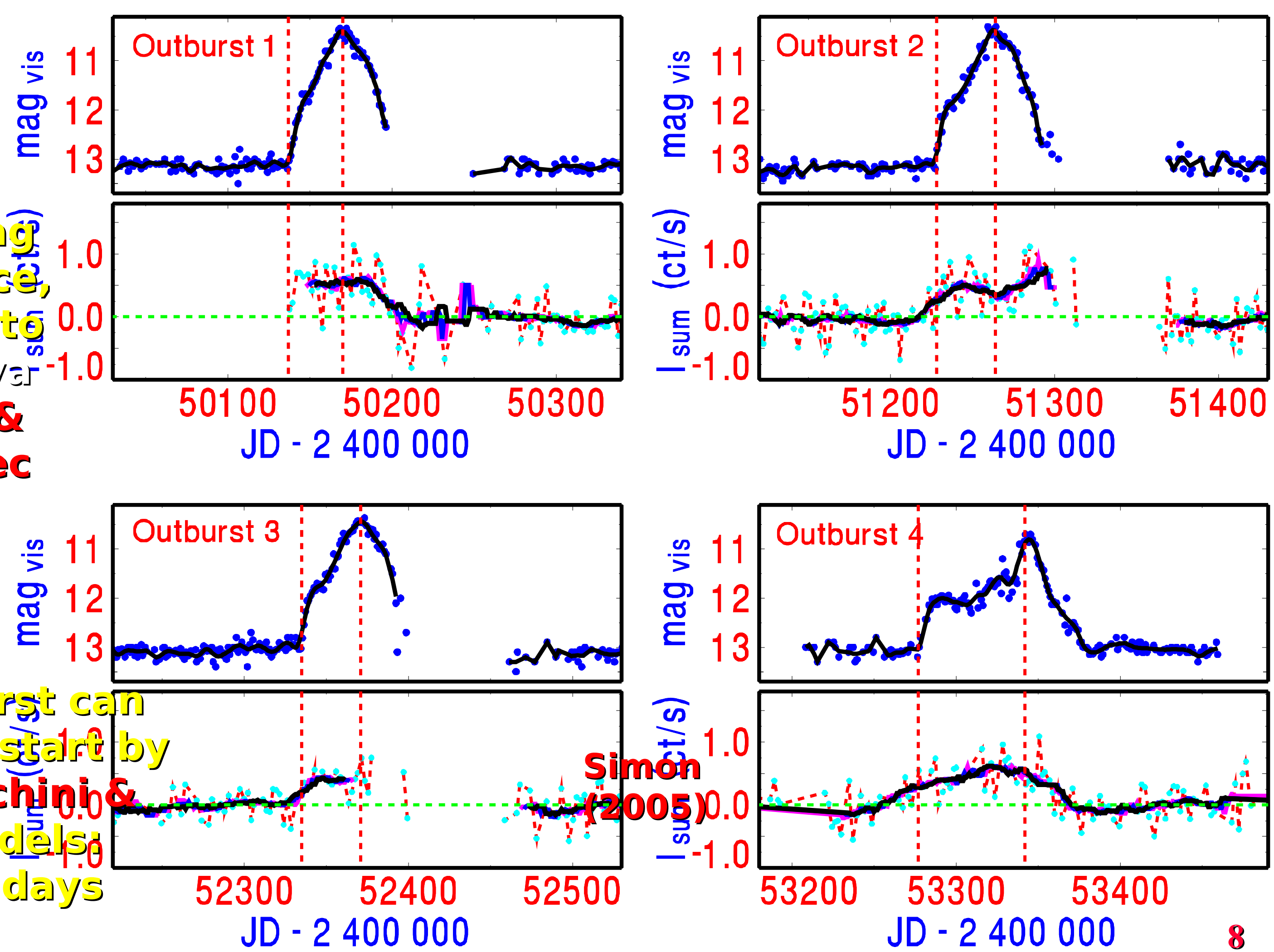
ermediate polar
y long $P_{orb}$=1.99 d
ampton et al. 1986)

loded as classical
a in 1901

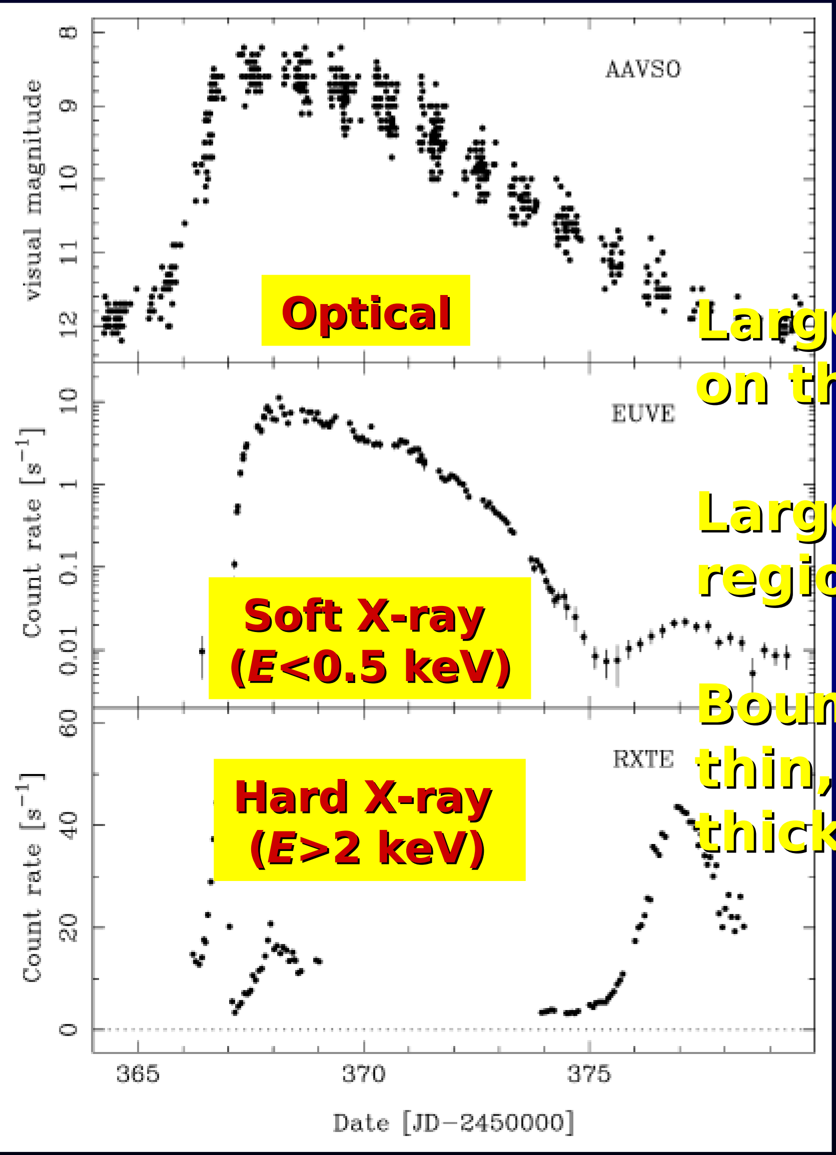
ctuations by ~1 mag
er return to quiescence,
er they developed into
equent dwarf nova
bursts (Sabbadin &
nchini 1983, Hudec
1)

of very few CVs
cted by *ASM/RXTE*

X-ray start of outburst can precede the optical start by up to 40 days (Binachini & Sabbadin 1985). Models: even up to 80 – 120 days (Kim et al. 1992)



# Cataclysmic variables – dwarf nova SS Cyg
# Complicated relation between the optical and X-ray profile of outburst



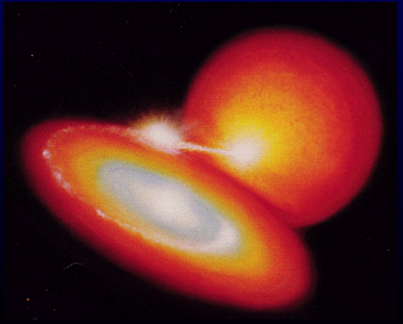

Wheatley et al. (2003)

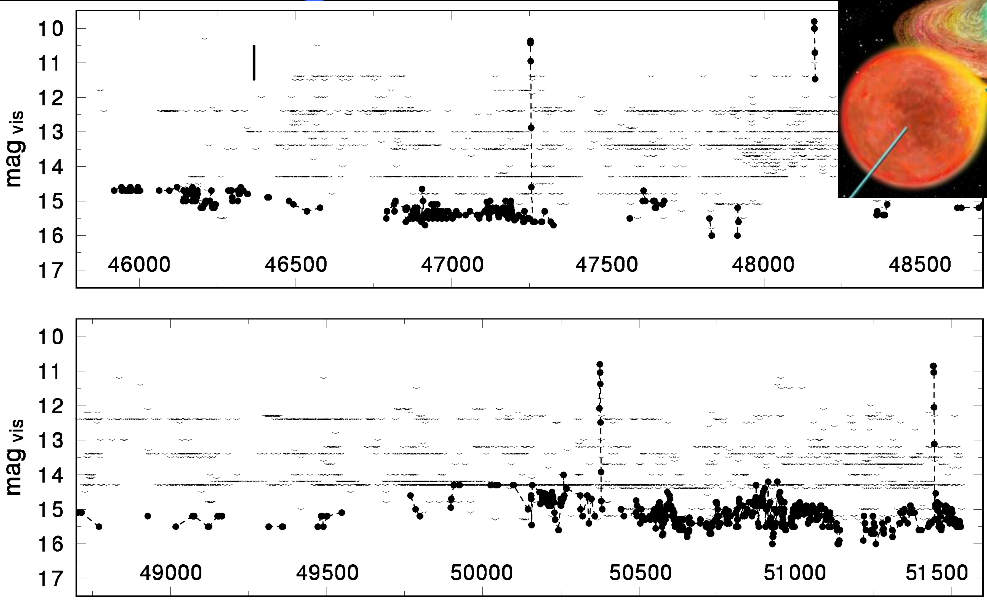
**Optical – accretion disk**
**X-ray – boundary layer**

Large dependence of the outburst prof on the passband

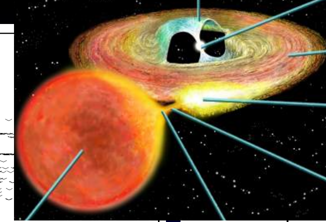
Large structural changes of the emitti regions during outburst

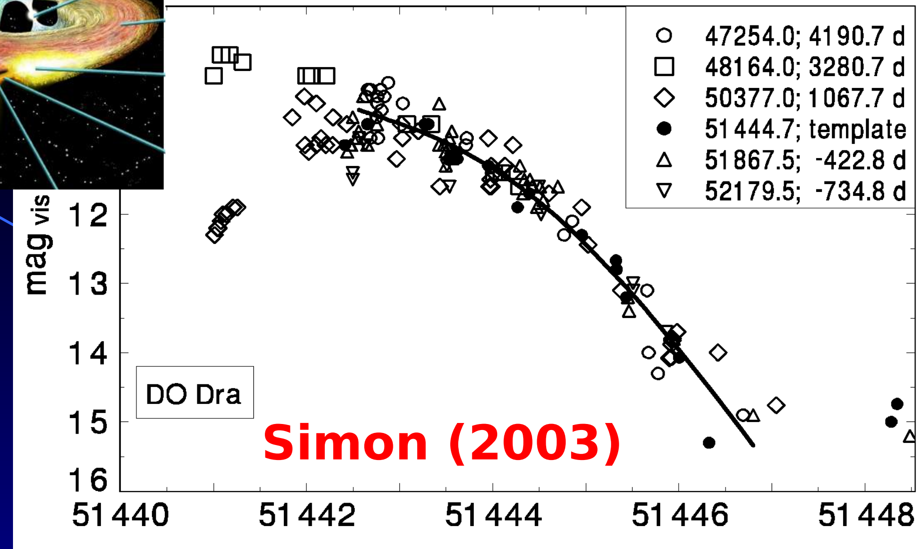
Boundary layer changes from optical thin, geometrically thick to optica thick, geometrically thin during outbur






Simon (2000)

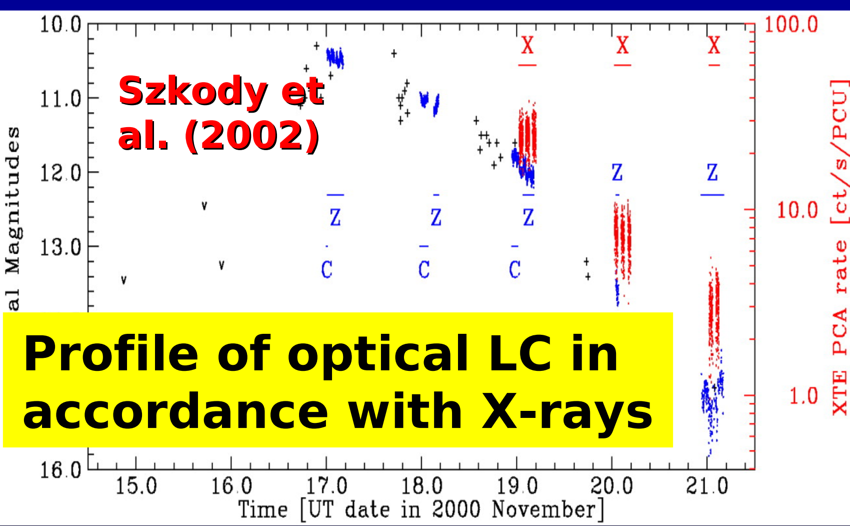




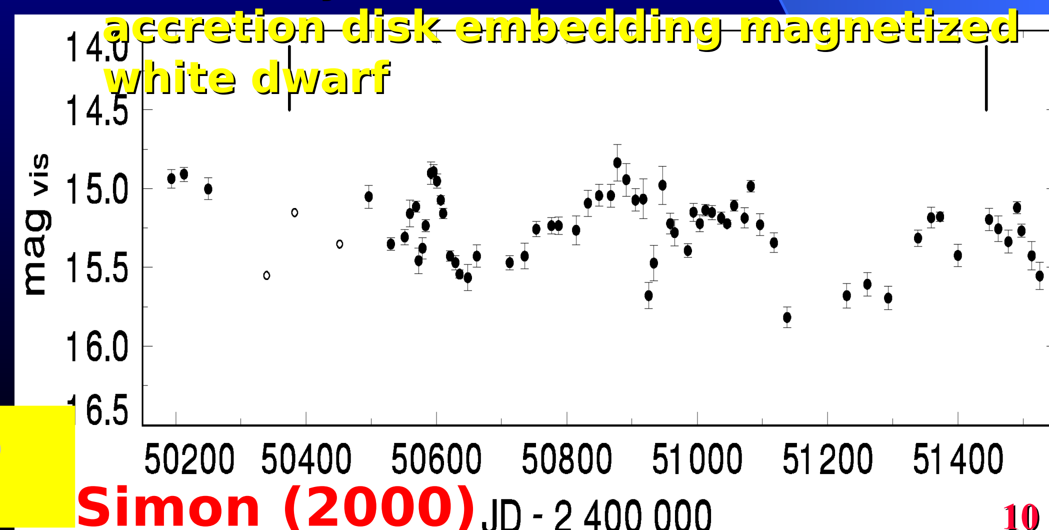

Simon (2003)

# Cataclysmic variables – outbursts of intermediate polar DO Dra

**Rare outbursts caused by thermal instability of accretion disk embedding magnetized white dwarf**



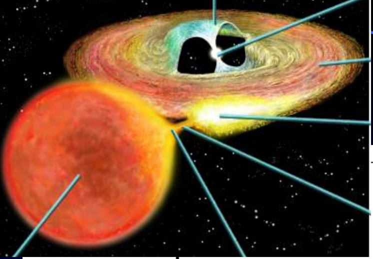

**Profile of optical LC in accordance with X-rays**

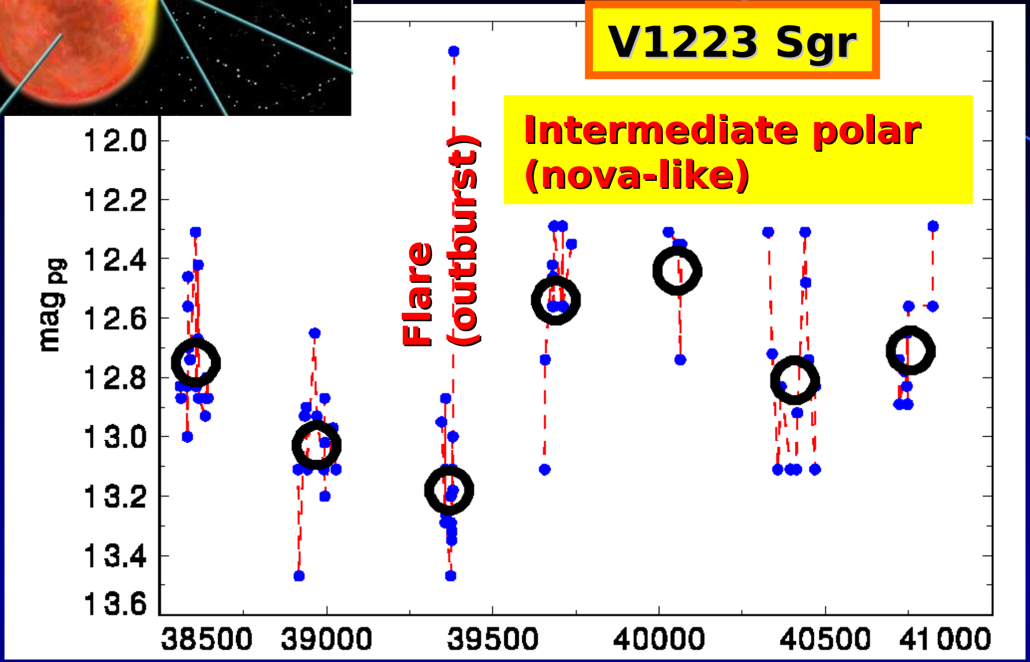


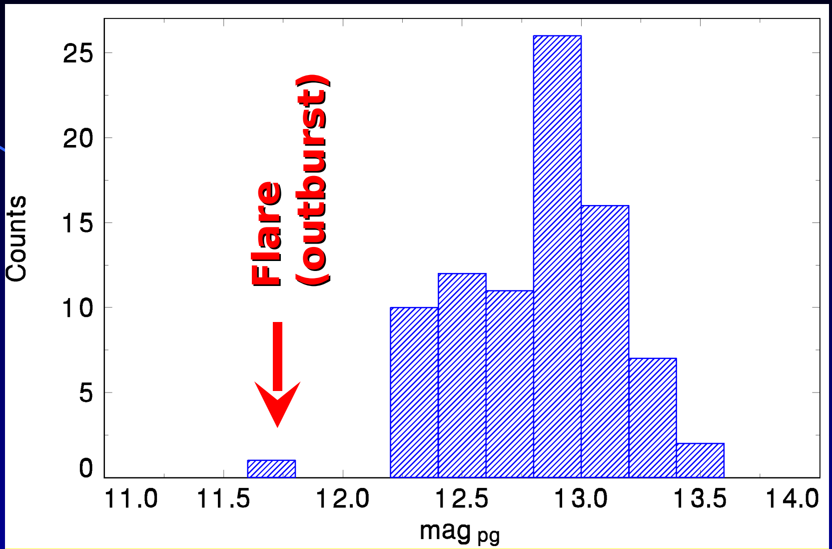

Simon (2000)

**Variations in quiescence between two outbursts (means)**

# Rare flares in cataclysmic variables



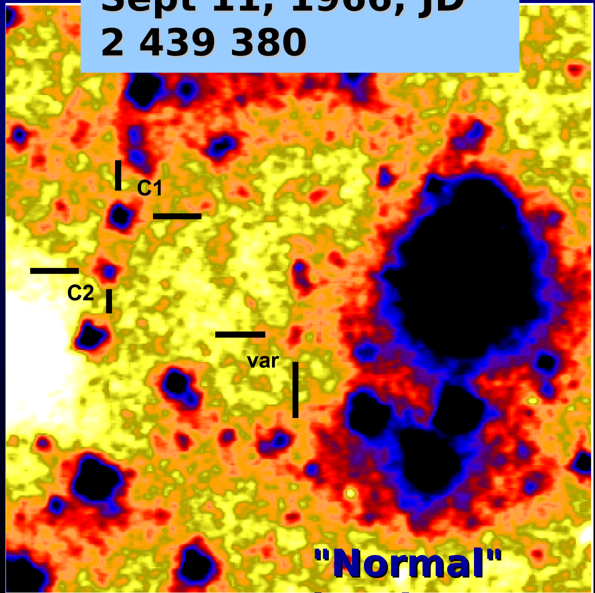


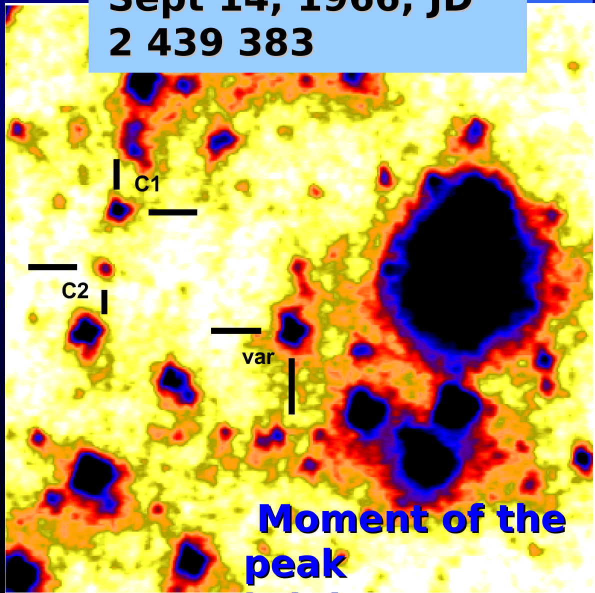

**Statistical distribution for brightness can reveal rare, short brightenings even in sampled data**

**Outburst of V 1223 Sgr on Bamberg photographic plates (one plate per night)**

**Sept 11, 1966, JD 2 439 380**

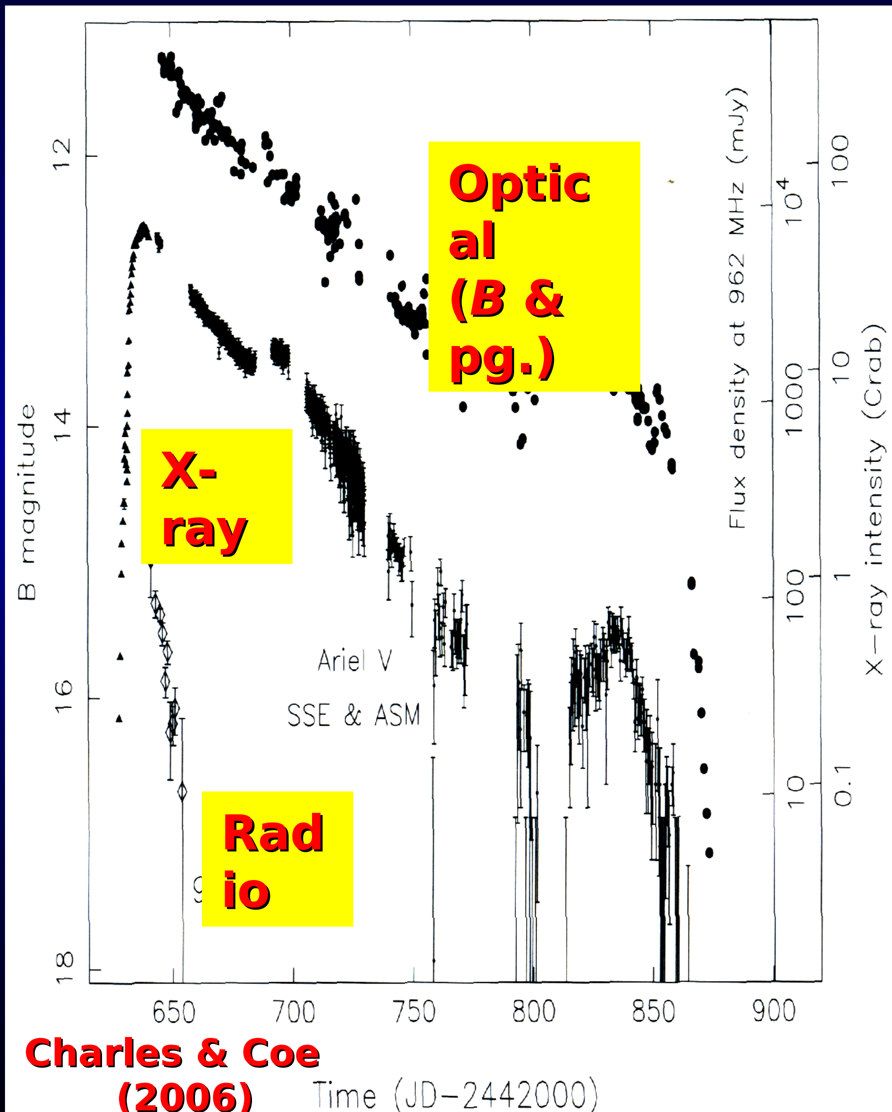



**Sept 14, 1966, JD 2 439 383**

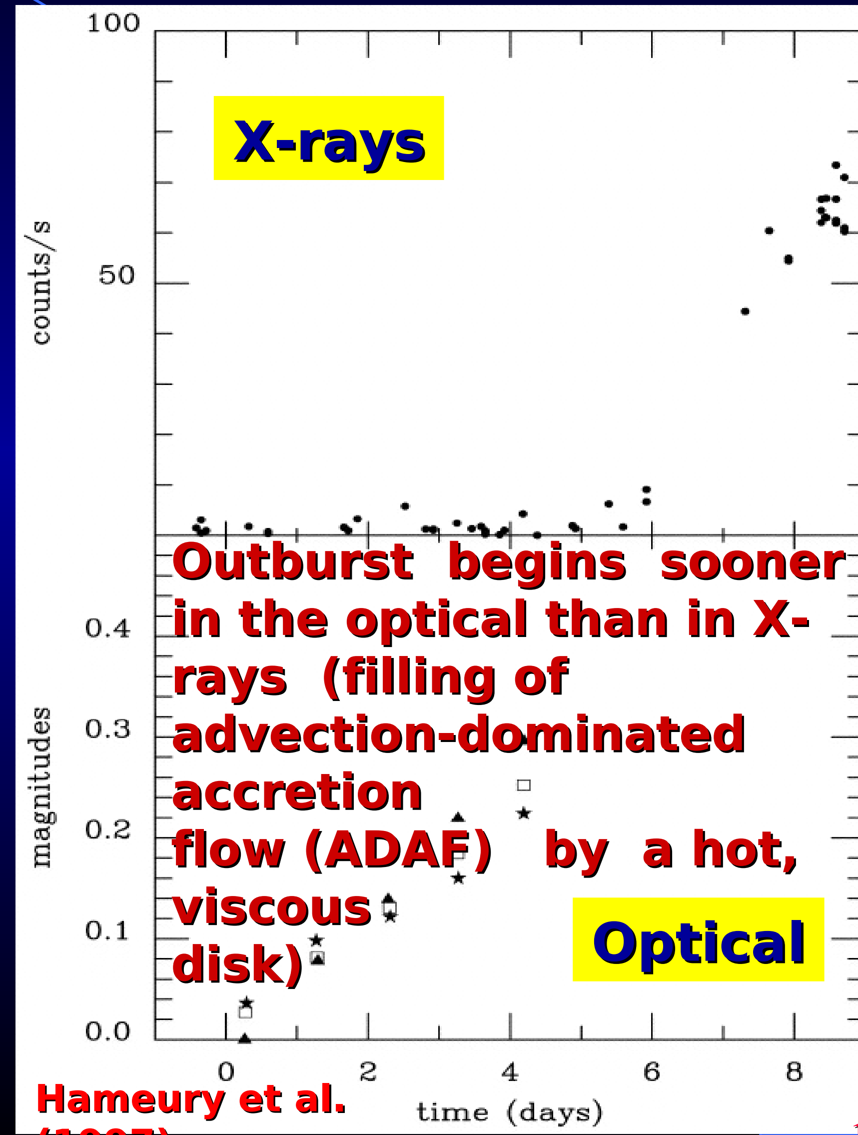



V1223 Sgr: "var"
Reference stars: "C1" and "C2"
North is at the top.

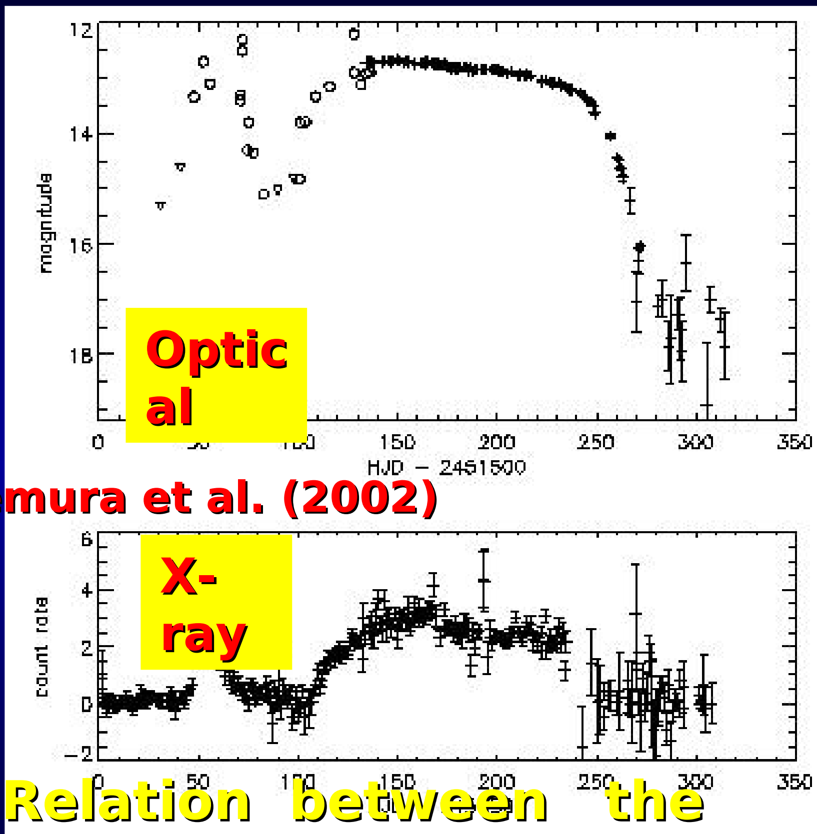
## Outburst of SXT in various passbands – the case of A0620–00 / V616 Mon



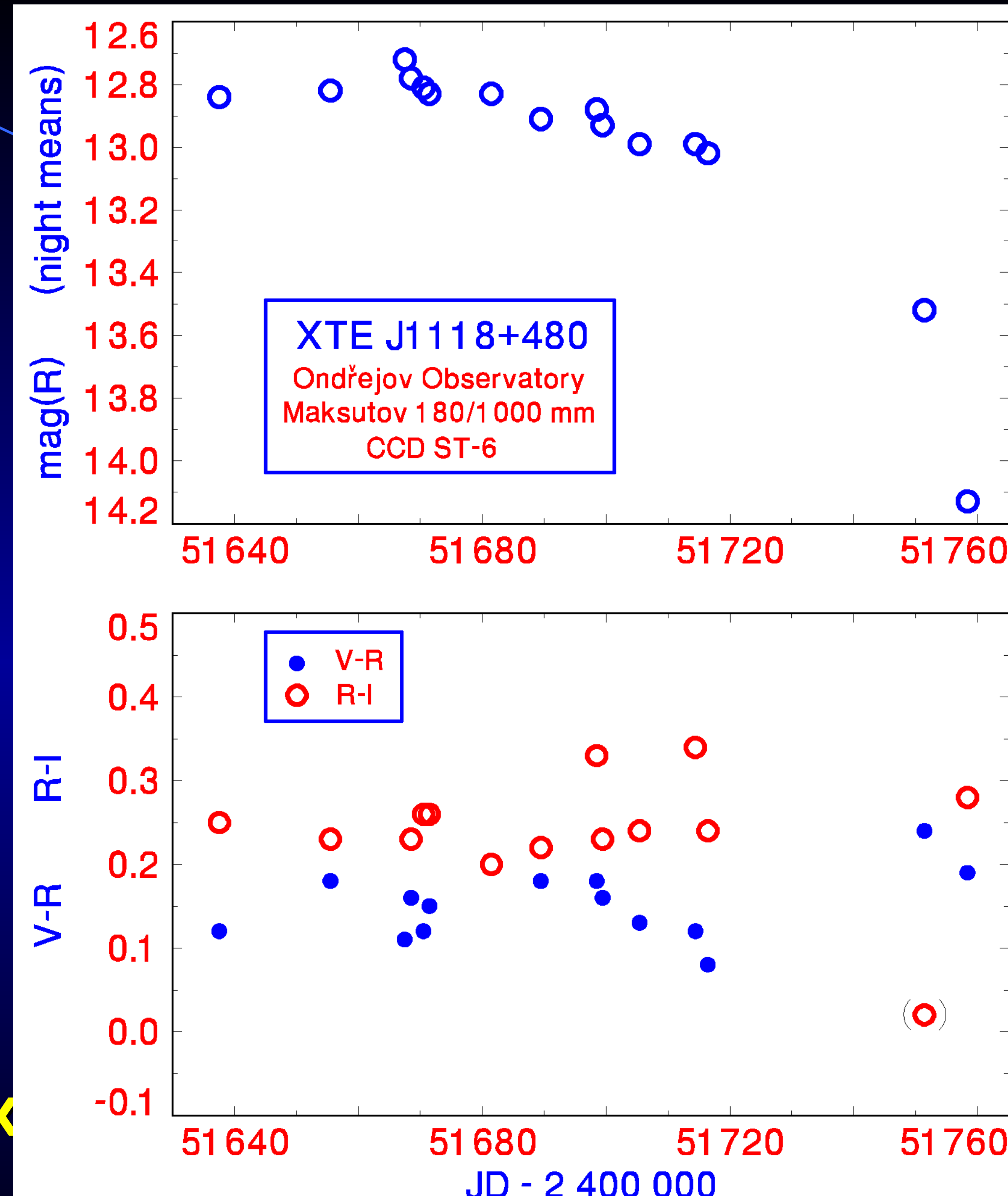

## Influence of the inner disk region on the outburst rise in SXT – the case of GRO J1655–40



# Low-mass X-ray binary – black hole SXT: XTE J1118+480/KV UMa



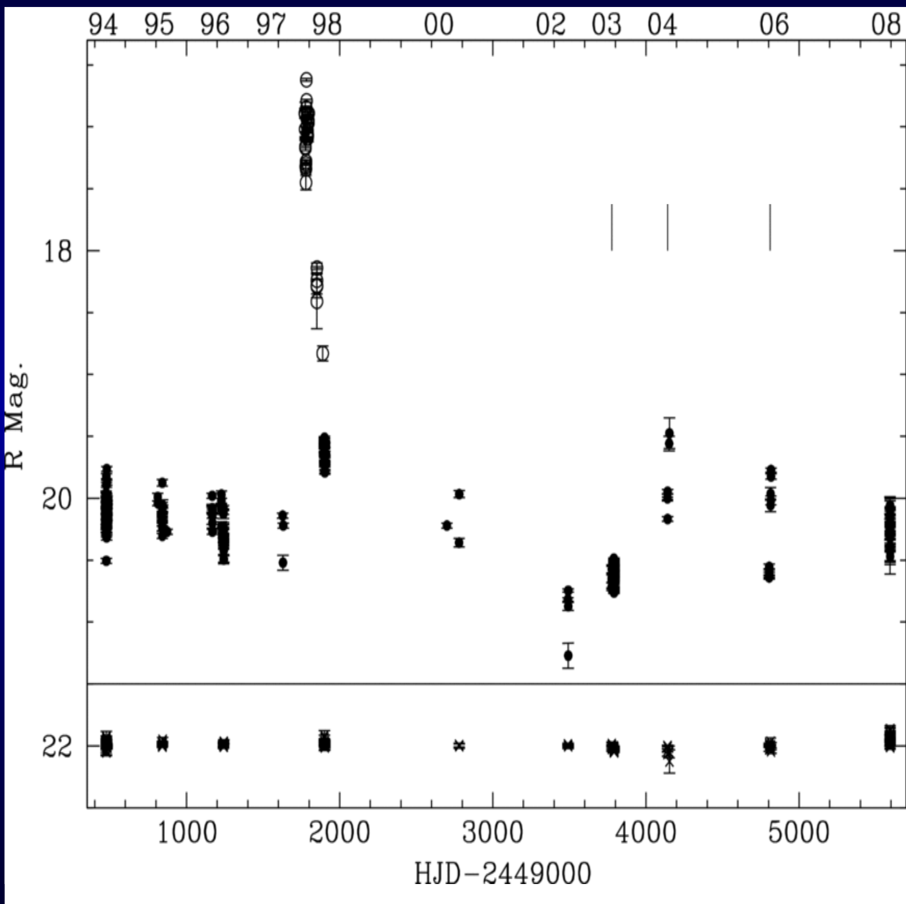

Relation between the evolution of the optical magnitude and X-ray flux (1.5-12 keV) during the 2000 outburst




magnitude and color indices during the

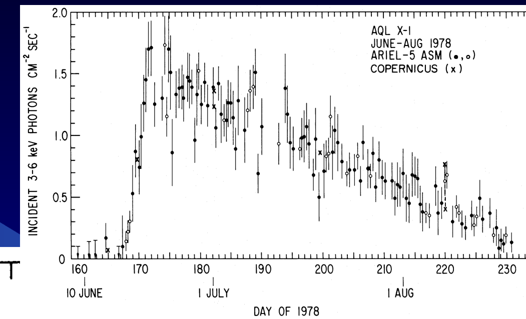
## Long-term optical variations of SXT in quiescence – the case of GS 1354–64 / BW Cir

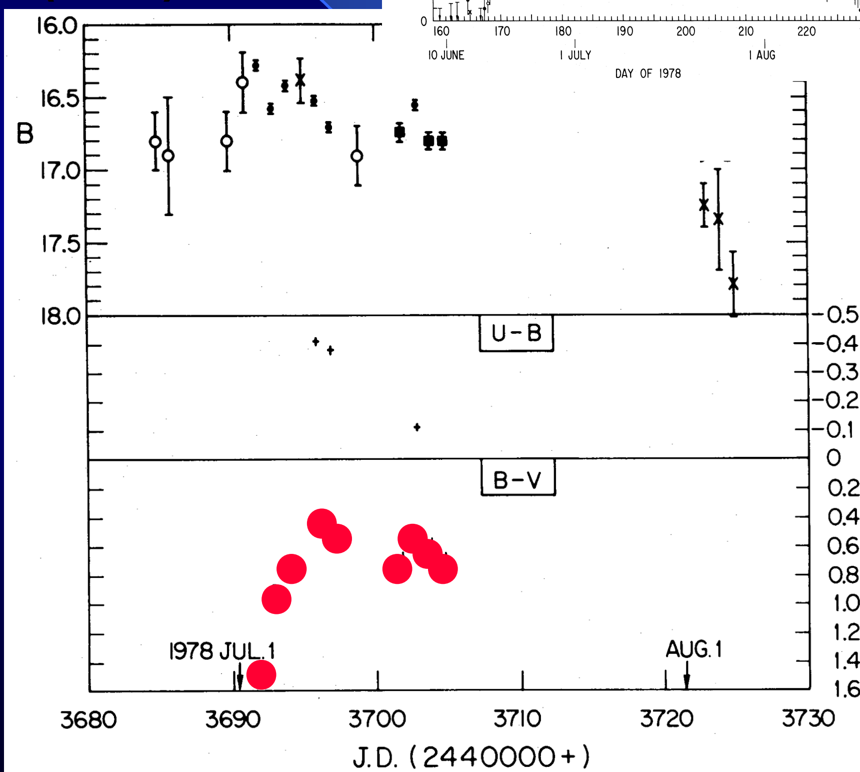
## Episodes of anomalous color indices in outburst – the case of Aql X-1 / V1333 Aql




Casares et al. (2009)

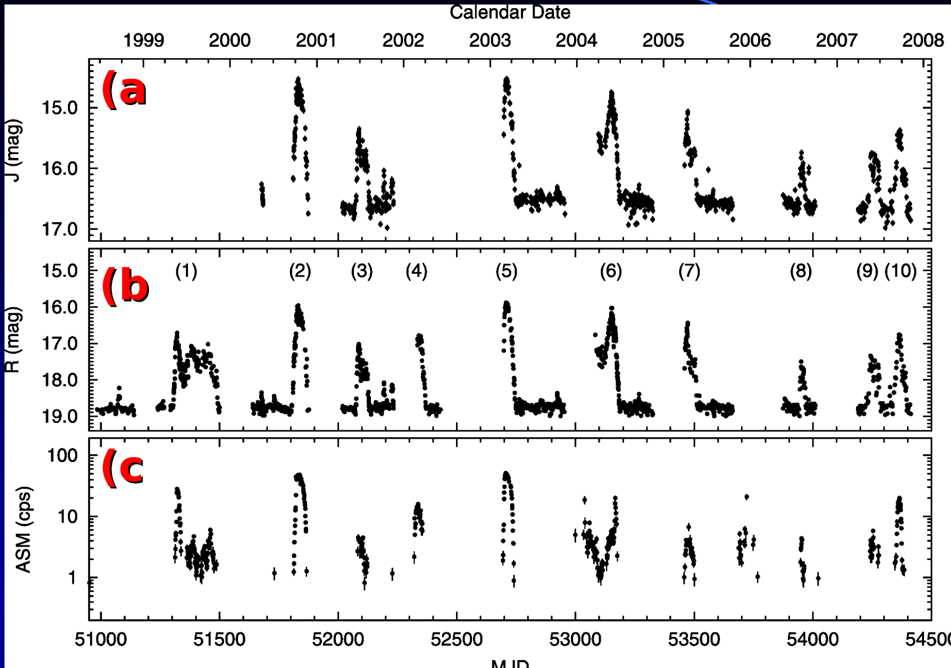
Charles et al. (1980)

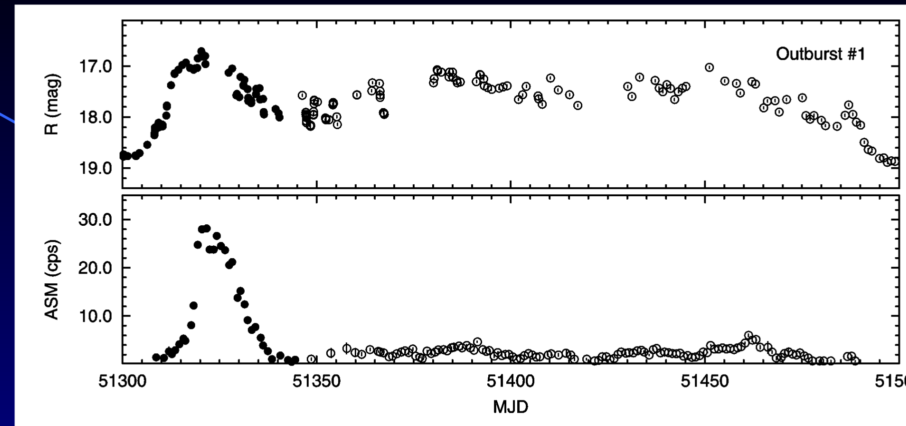


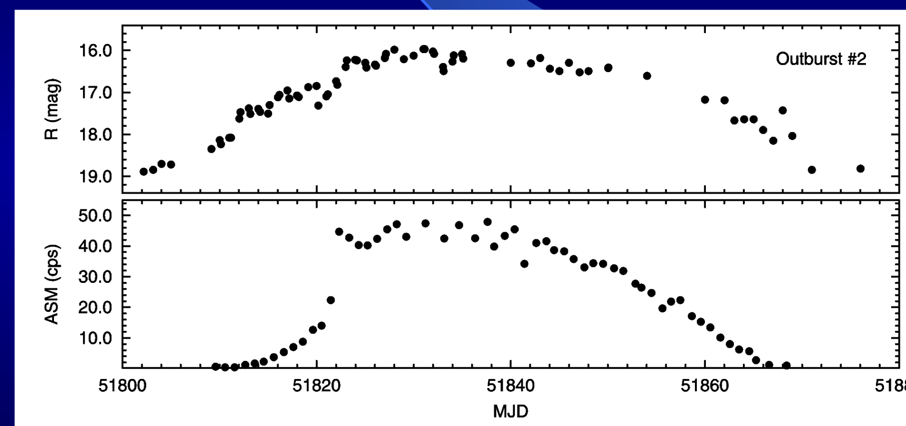




**Episodic reddening of the B-V inxes – launch of synchrotron-emitting jet?**

# Properties of outburst light curves in SXTs – the case of Aql X-1




**Multiwavelength long-term monitoring**

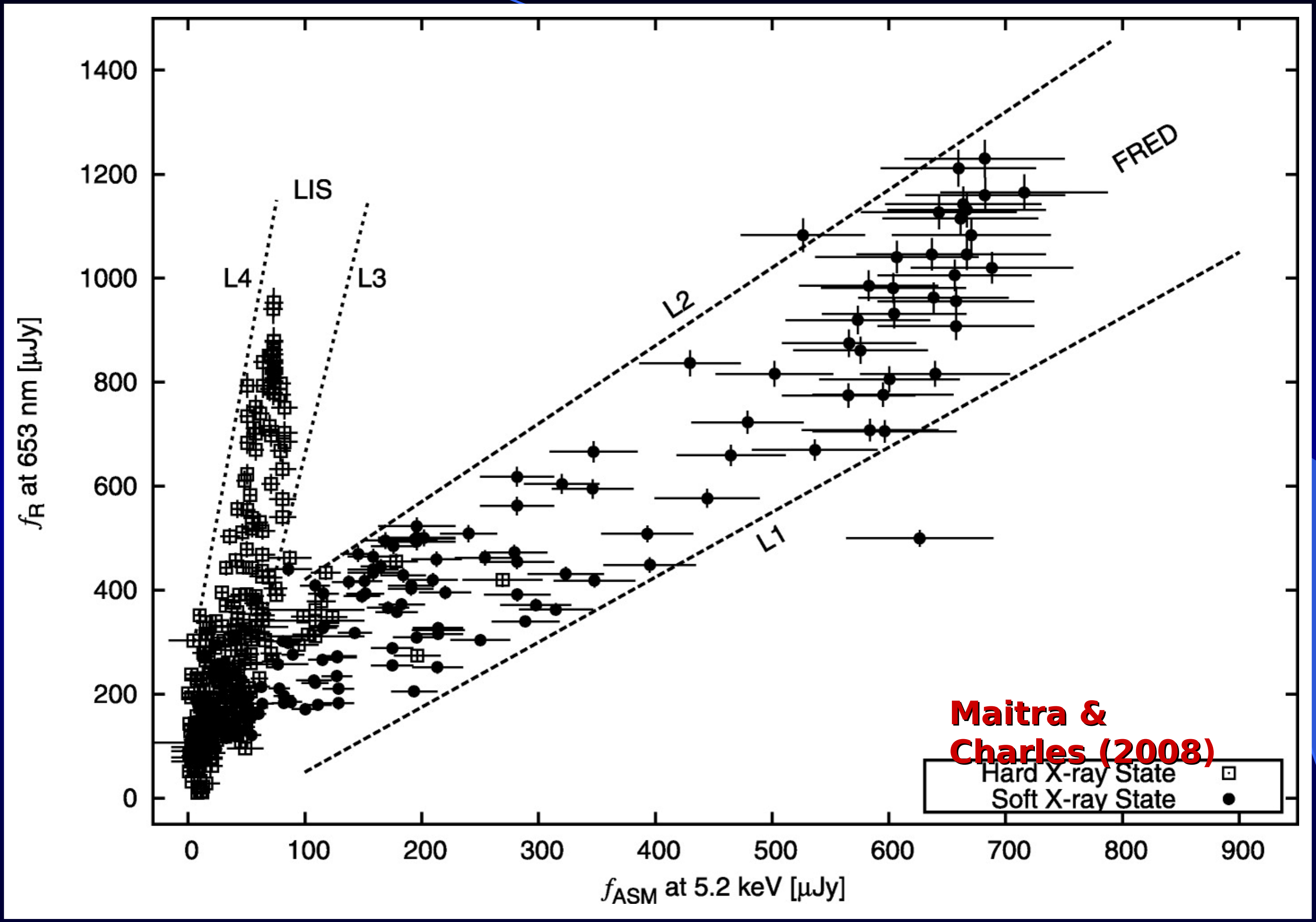
- **(a) Near-IR *J*-band light curve (Aql X-1 + contaminating star)**
- **(b) Optical *R*-band light curve (Aql X-1 + contaminating star)**
- **(c) Logarithm of soft X-ray (1.5-12 keV) count rate (ASM/RXTE)**

Monitoring is necessary to obtain sufficient number of well-mapped outbursts in a given SXT to determine a meaningful ensemble of outbursts

**Simultaneous observations of the outburst in the optical and X-ray passbands – duration of the outburst in various passbands and X-ray/optical ratio may differ substantially – mass outflow from the inner disk region?**

Maitra & Charles (2008)

# Properties of outburst light curves in SXTs – the case of Aql X-1



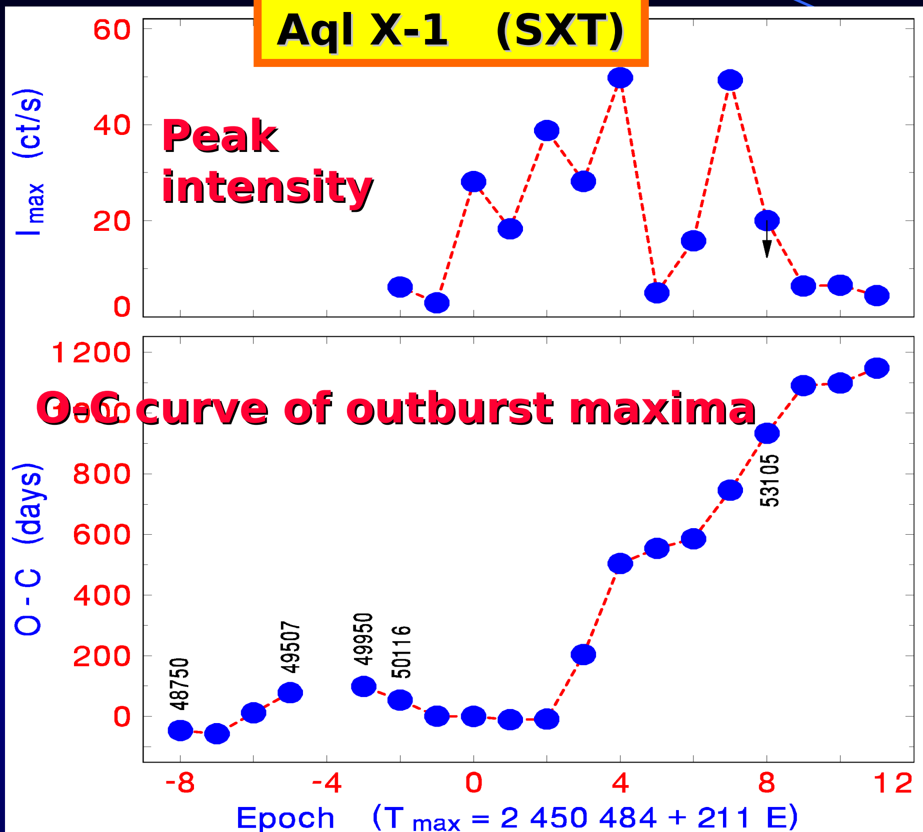

**Optical vs. soft X-ray correlation during a set of outbursts**

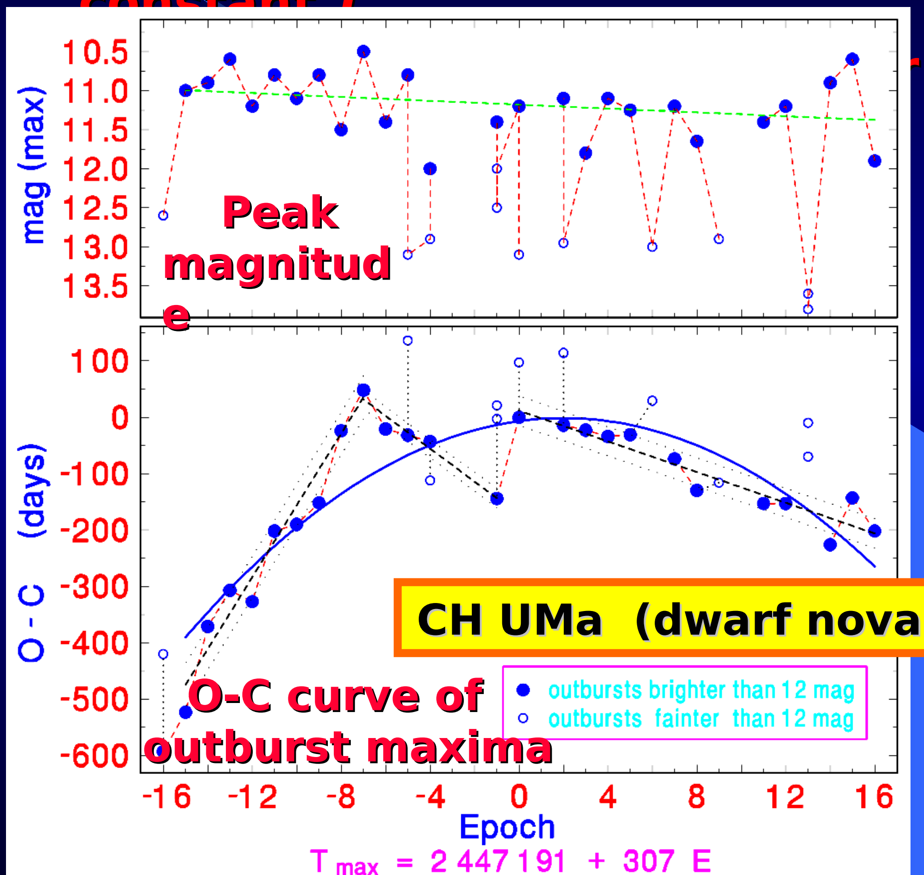
**Monitoring is necessary to obtain sufficient number of well-mapped outbursts in a given SXT to determine a meaningful ensemble of outbursts**

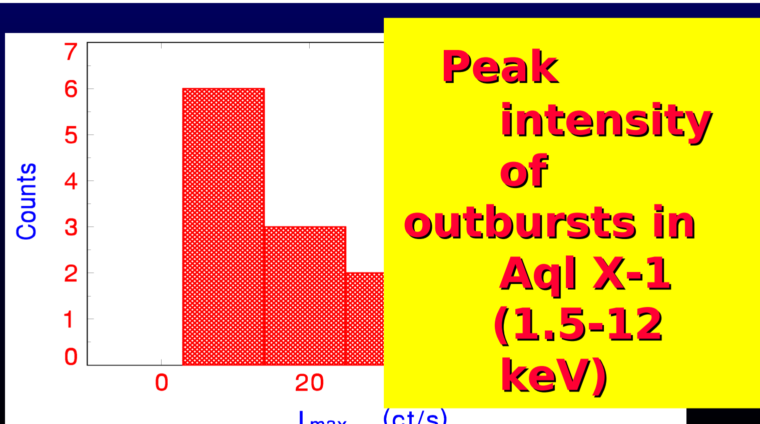
# Variations of the outburst recurrence time in dwarf novae and SXTs

**Relation between O-C curve and $T_c$:**

**Linear profile of O-C curve – constant $T_c$**



## Properties of outbursts in dwarf novae and SXTs – possibilities to investigate various phenomena

- Profiles of outbursts – very large variety of profiles exists (even outbursts in a single system display largely different profiles). Search for the common features is needed.

- Search for the relation between the outburst properties in the long-term activity of a given system.

- Parameters of irradiation of disk (mainly in SXTs). Evolution of irradiating body during outburst.

- Analysis of a possible shielding of outer disk region by a structure (mainly in SXTs).

- Role and evolution of spiral arms that may appear in disk during outburst (observations versus models).

# Evolution of activity in dwarf novae and SXTs – current status

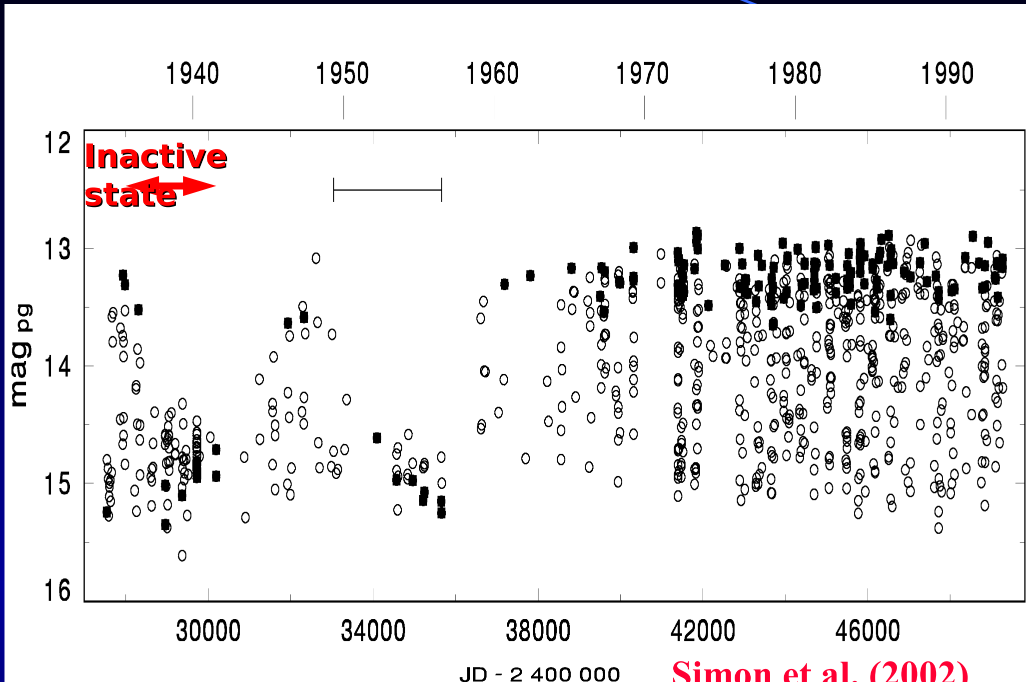
- **Variations of the recurrence time of outbursts, $T_c$, of SXTs are large, but not chaotic – long-term trends can be clearly resolved – individual outbursts depend on each other in a given SXT. This behavior of SXTs can be compared with that of dwarf novae determined from the optical data.**

- **Behavior of $T_c$ in SXTs is quite similar to dwarf novae (e.g. Vogt 1980, Simon 2000, Simon 2002ab). Mean $T_c$ of some SXTs can be even as short as those in dwarf novae with long orbital period $P_{orb}$ (CH UMa, DX And, GK Per).**

- **Available observations suggest that the individual outbursts in a given system are dependent on each other.**

- **$T_c$ shows large jumps and/or cyclic variations (dependent**

# Low-mass X-ray binary HZ Her/Her X-1




**Remarkably different profile of the orbital modulation with respect to the active state:**

- **Much smaller amplitude**
- **Appearance of secondary minimum**
- **Flat profile outside primary and secondary minima**

**Sonneberg photographic data (one plate per night)**

Hudec &Wenzel (1976)

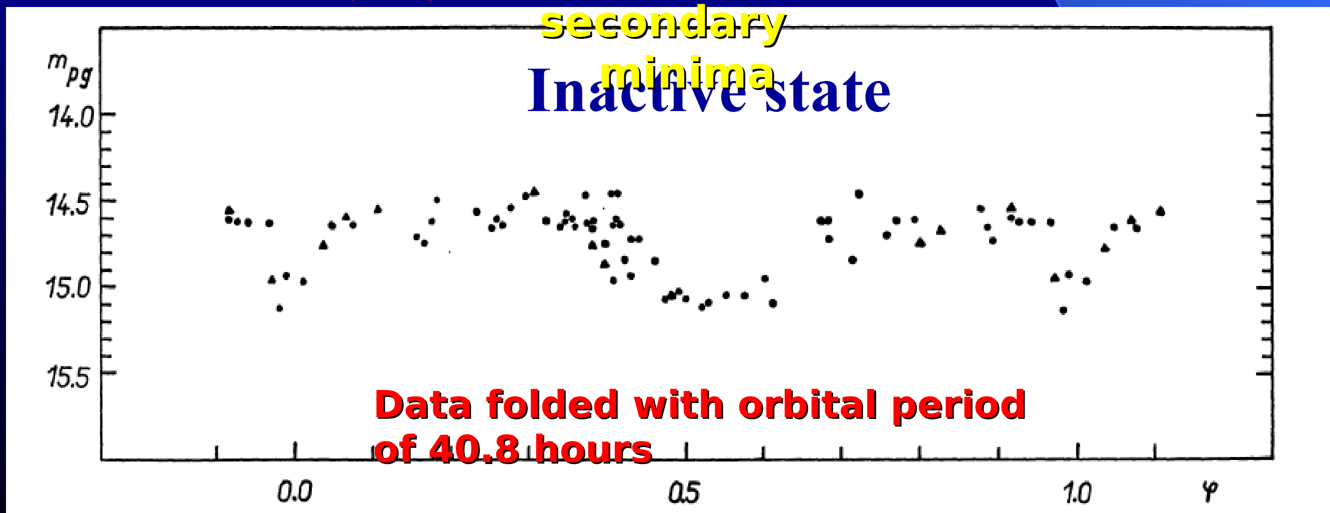
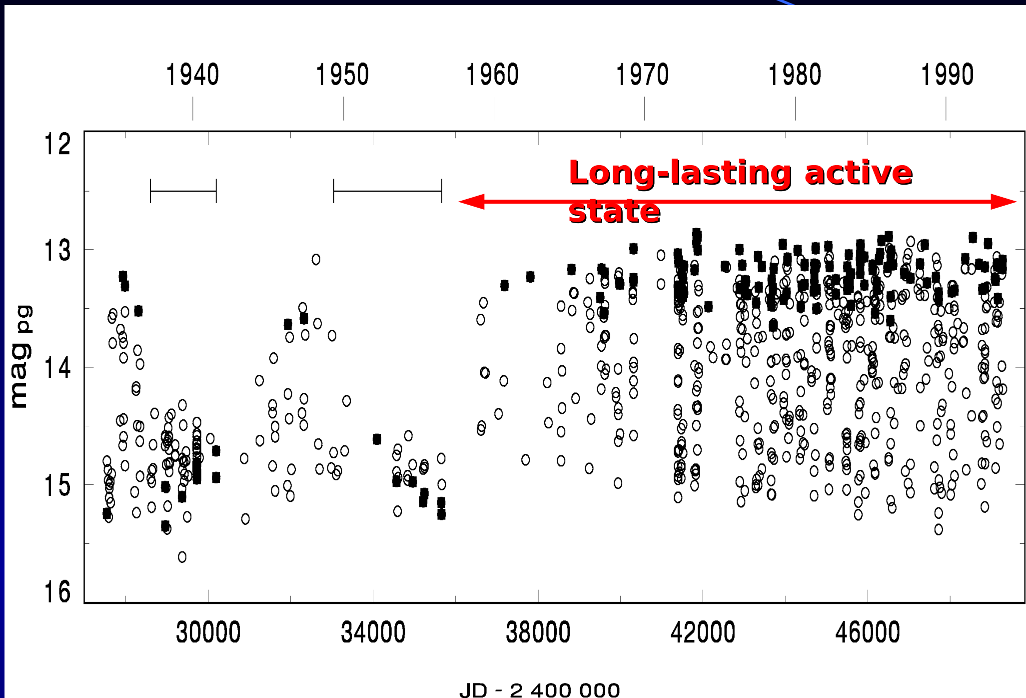


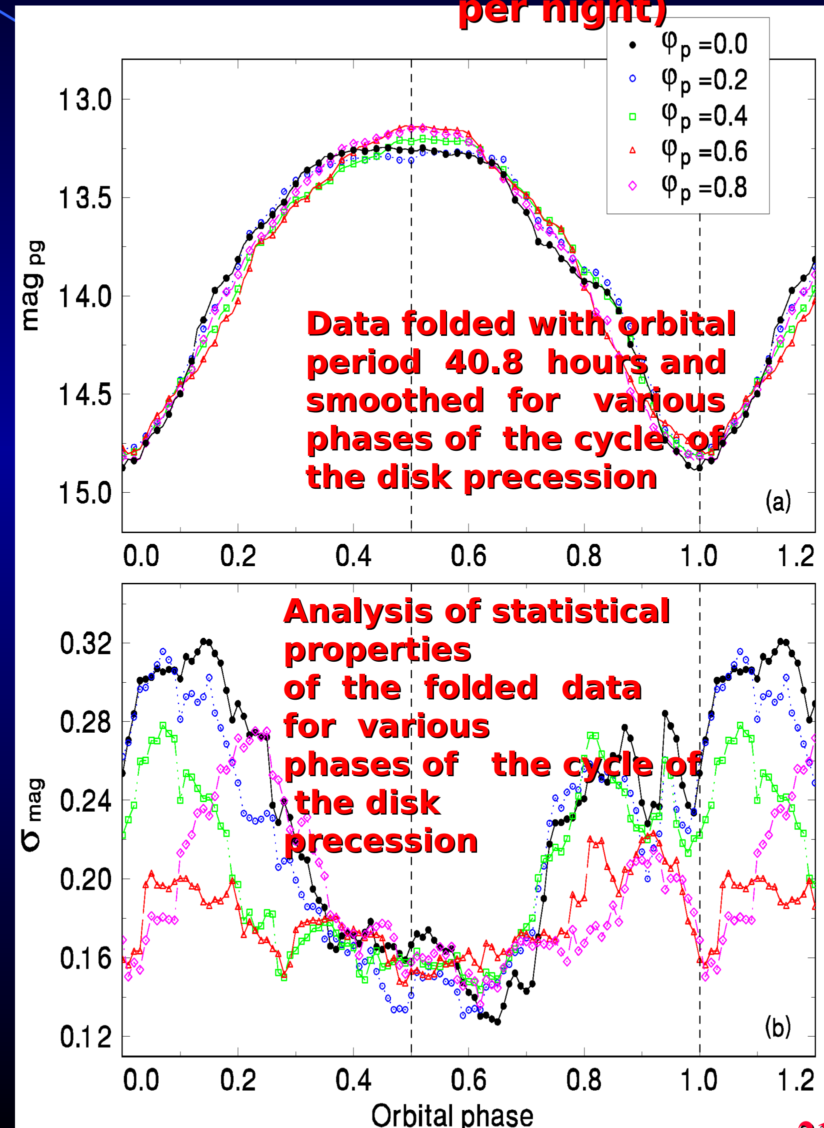

Fig. 9. The inactive state light curve of HZ Her. The circles = J. D. 242 8630 … 9789, the triangles = J. D. 242 7543 … 7657.

# Low-mass X-ray binary HZ Her/Her X-1

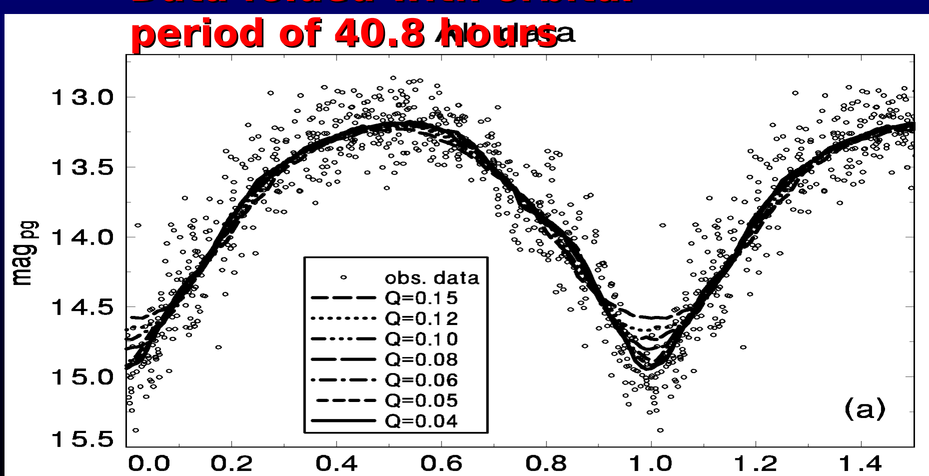



Simon et al. (2002)

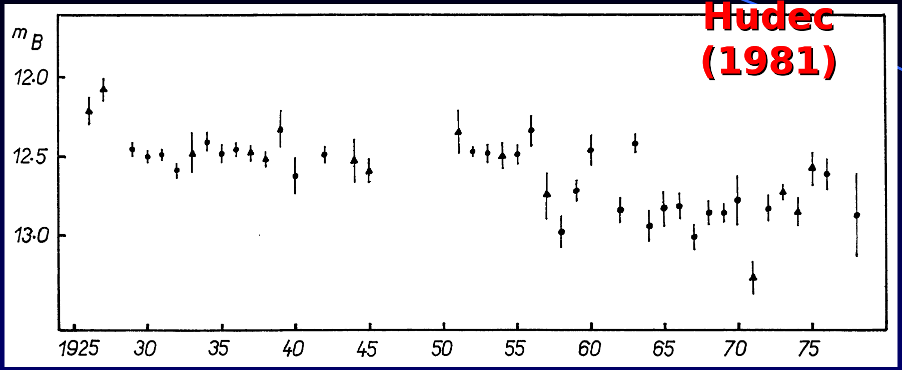
Sonneberg photographic data (one plate per night)




Data folded with orbital period of 40.8 hours



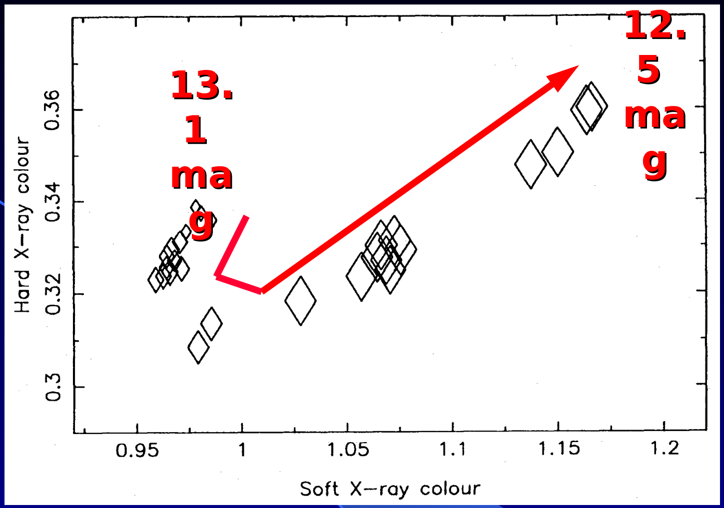
# Low-mass X-ray binaries – Sco X-1



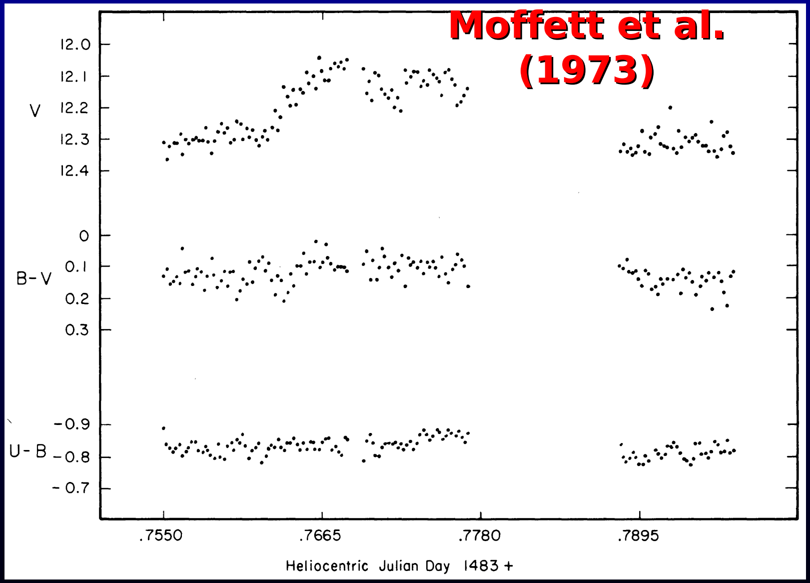

erm light curve in blue light. Annular means
ermined from archival photographic plates.

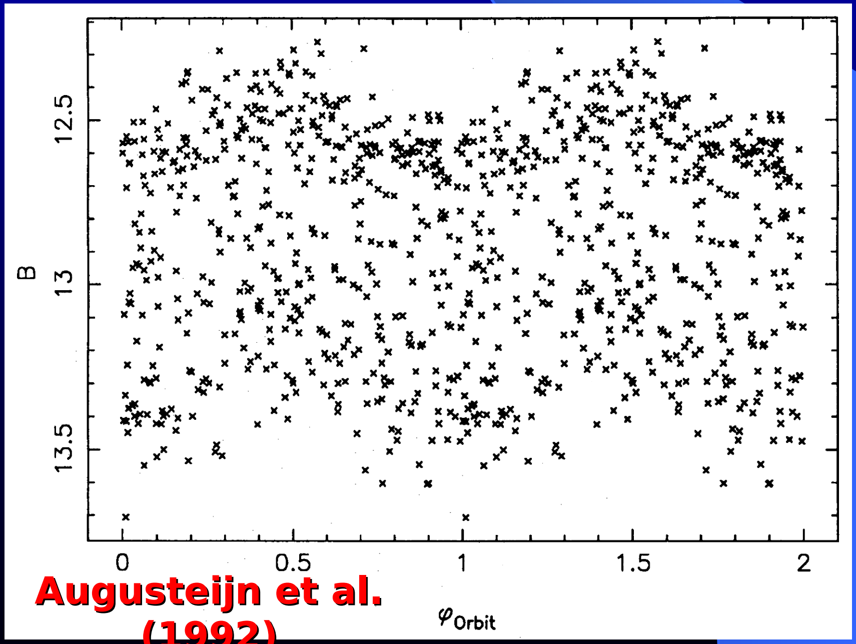
nt variations are composed of the rapid and
rm activity.

Augusteijn et al. (1992)




X-ray spectral changes vs. *B* band magnitude



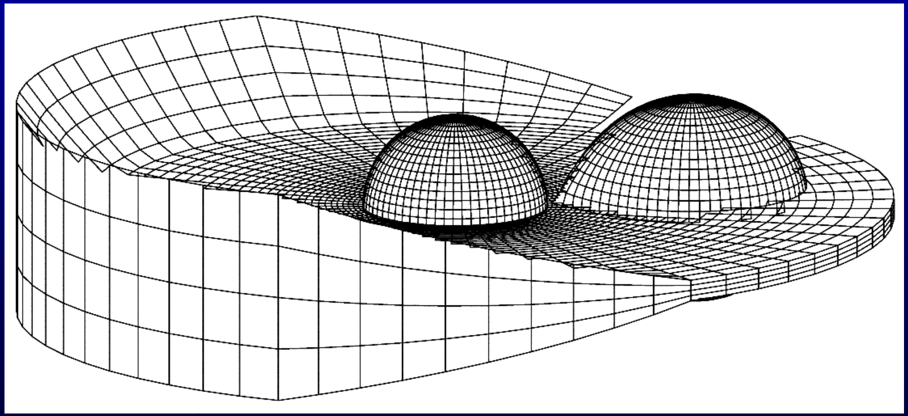




Augusteijn et al. (1992)

brightness variations during a single night.

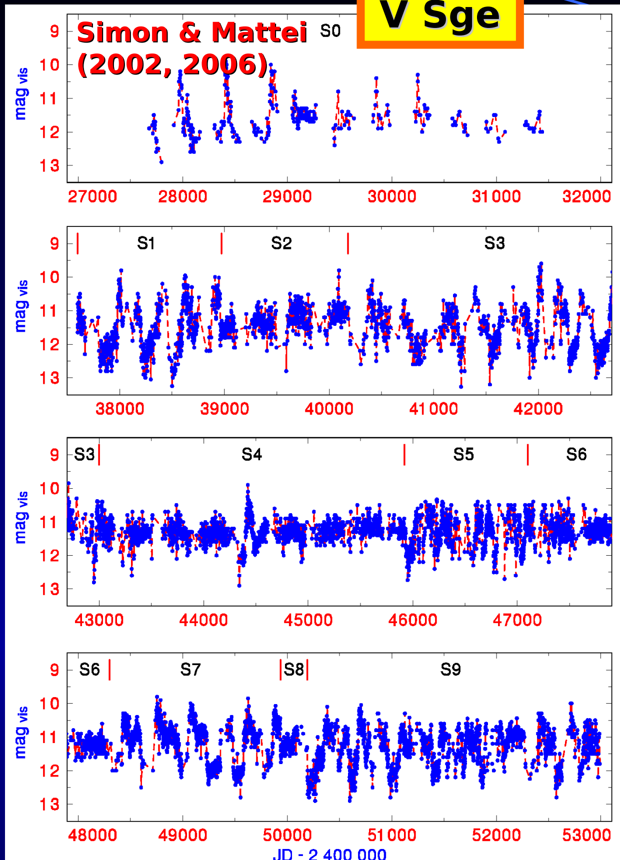
Orbital variation from 150 nights in 1971–1

# Supersoft X-ray sources



# Supersoft X-ray sources

**V Sge**



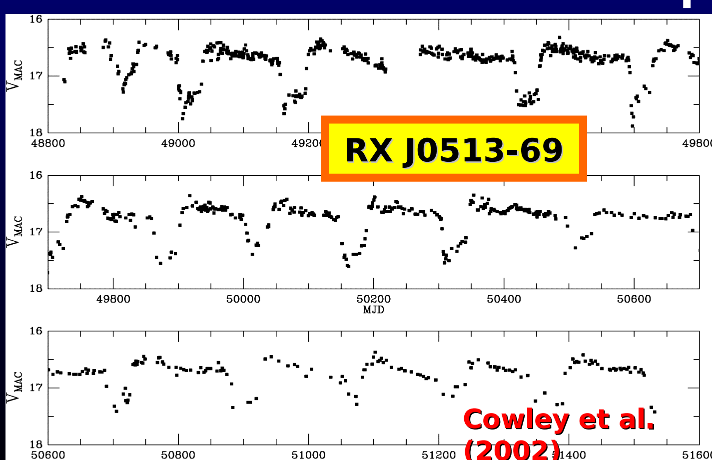

## Unique type of X-ray sources

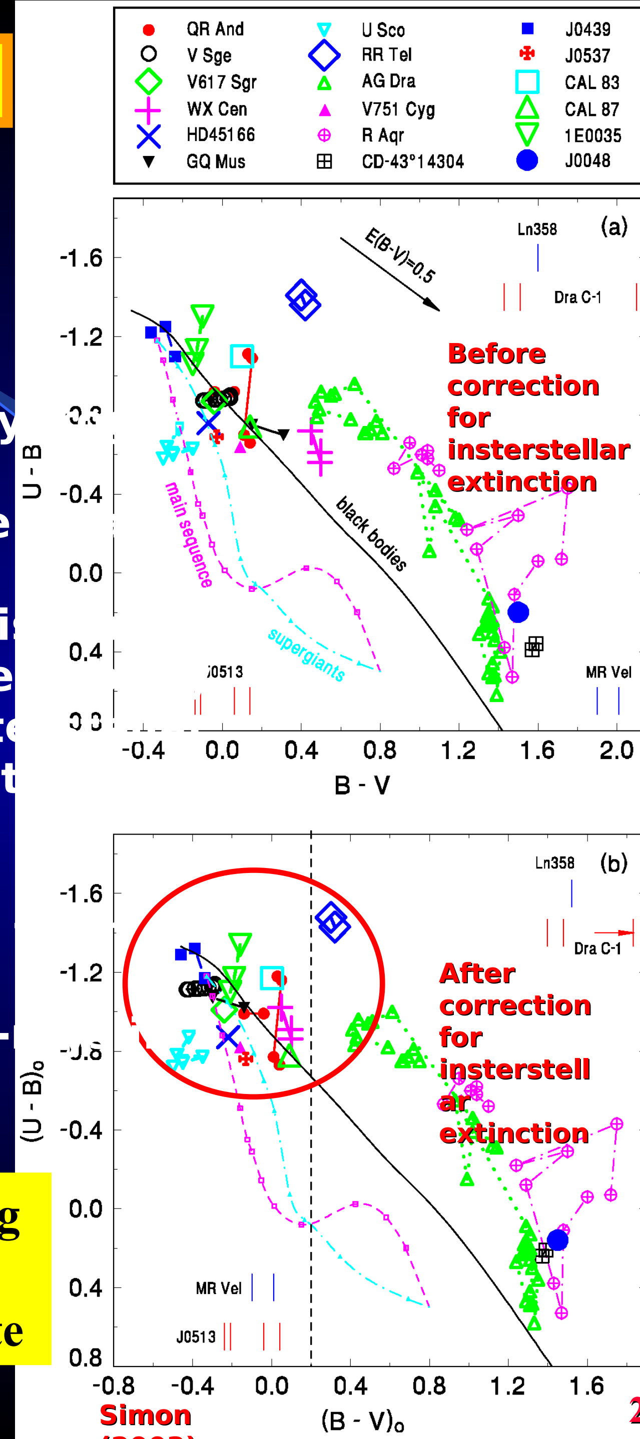
(Quasi)steady-state thermonuclear burning of accreted hy… on the surface of the white…

Intense soft X-ray emi… produced, but its dete… depends on the inte… extinction and metallicit… source.

Optical emission comes … th… reprocessing of X-… …k and from the disk …cosity.

**RX J0513-69**

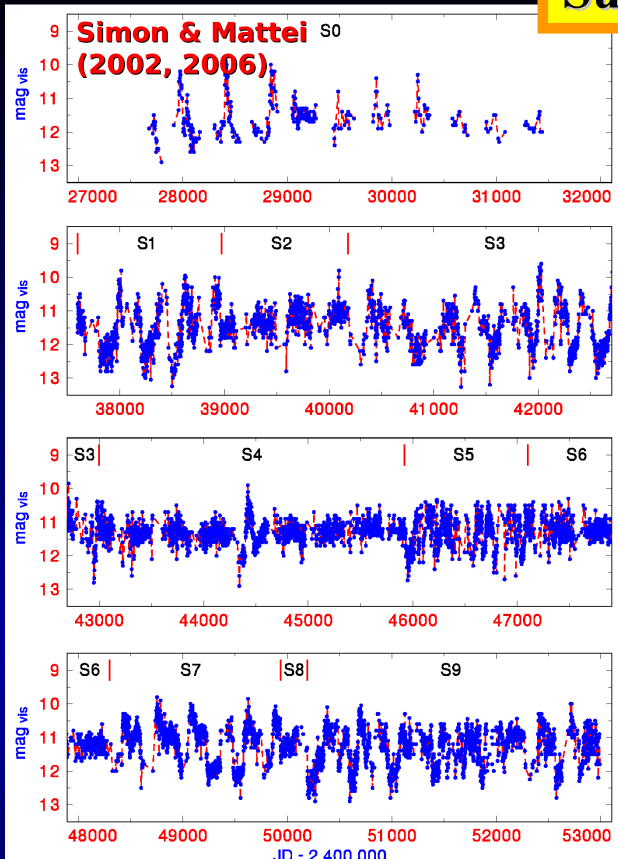


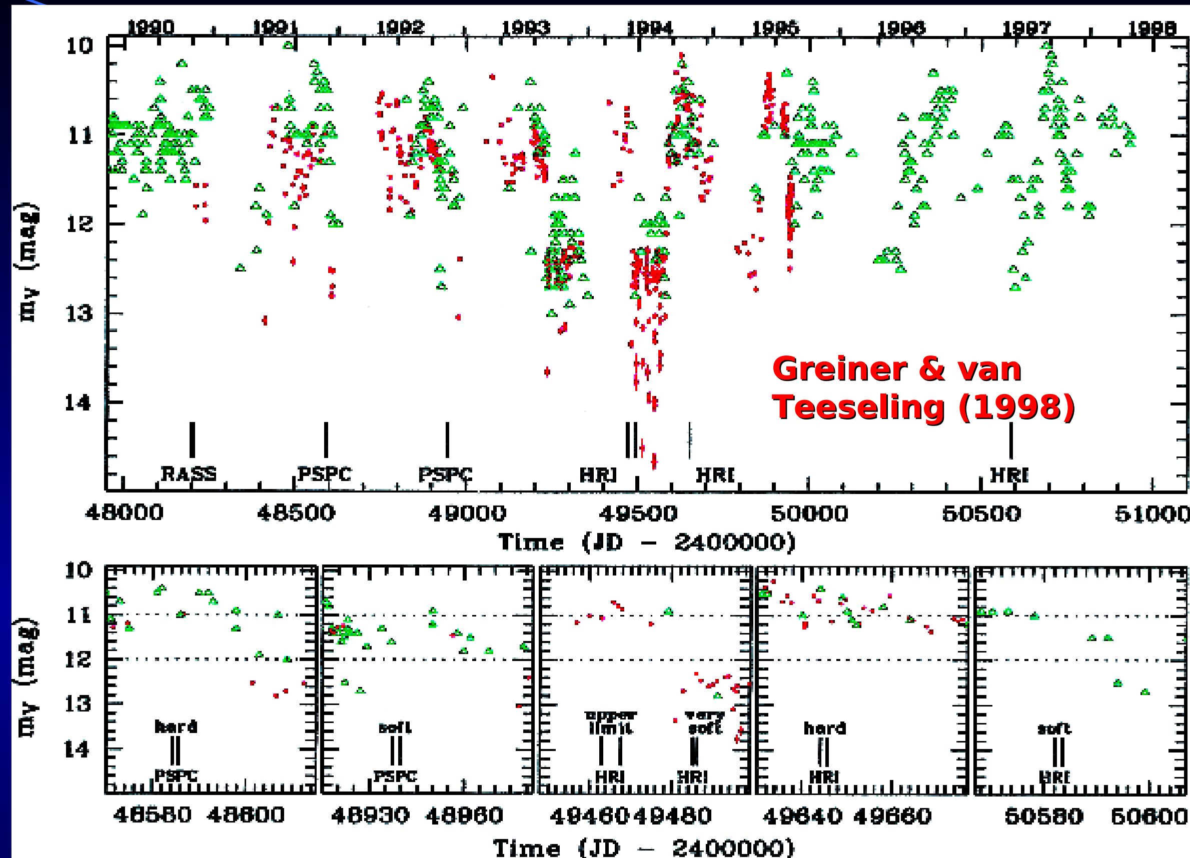




**Specific clustering of color indices during active state**

# Supersoft X-ray sources – V Sge

Unique type of X-ray sources

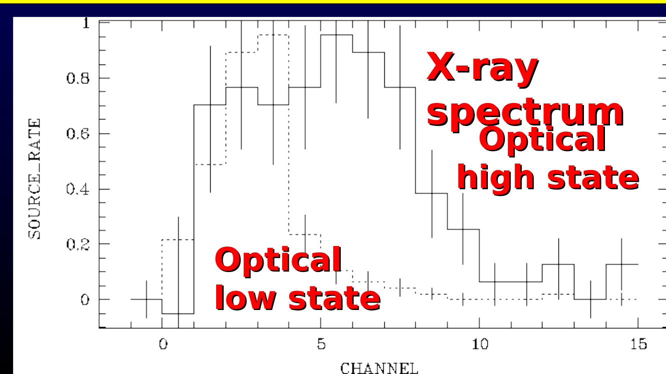


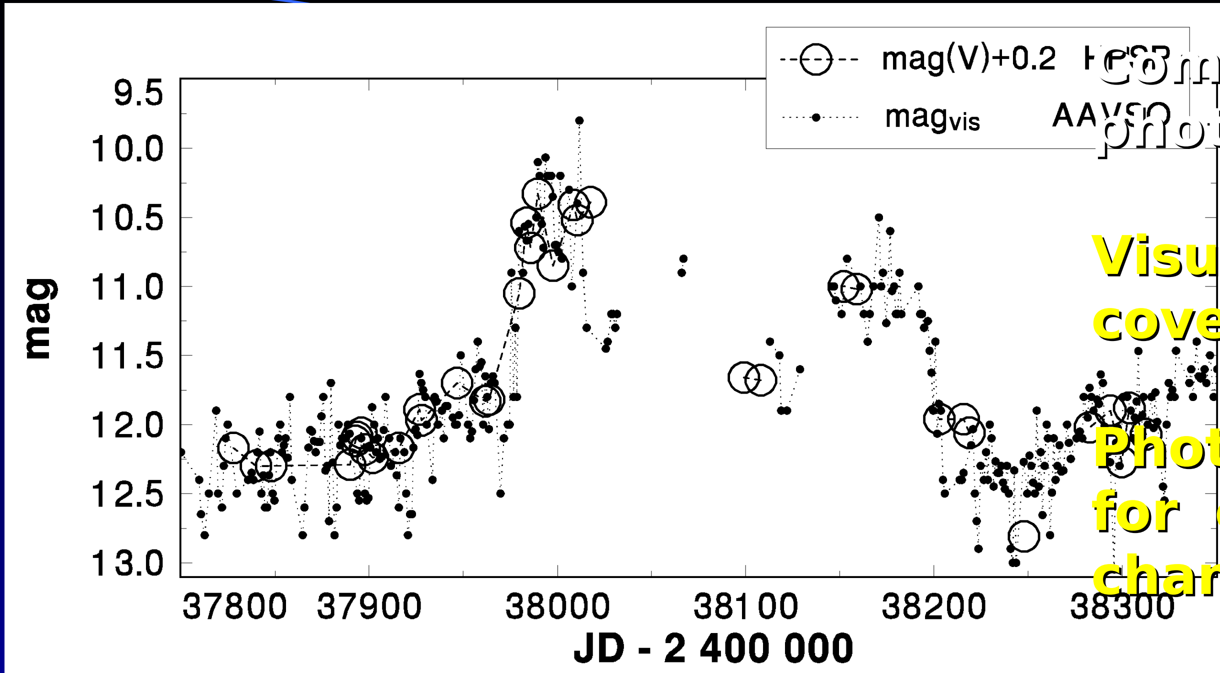

(Quasi)steady-state thermonuclear burning of accreted hydrogen on the white dwarf surface

Intense soft X-ray emission is produced, but its detectability depends on the interstellar extinction, temperature of white dwarf, and metallicity of the source (these are the causes of

Optical changes in antiphase with X-rays



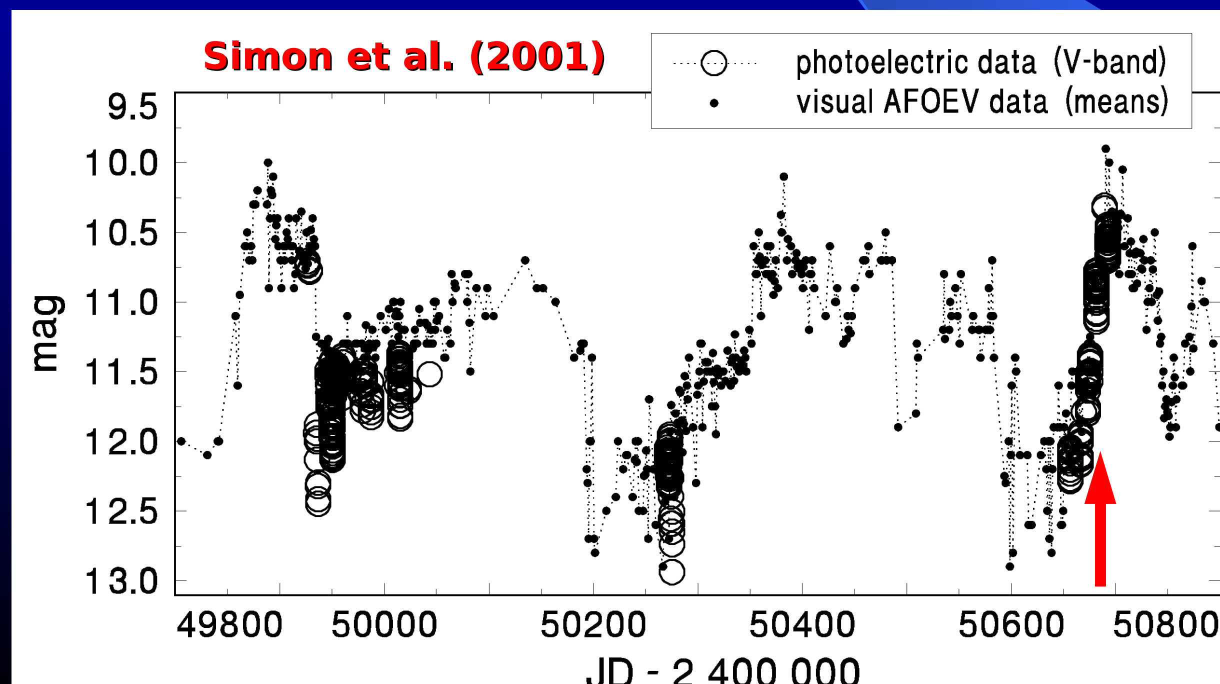

Greiner & van Teeseling (1998)




## Comparison of visual and photoelectric (CCD) obs.:

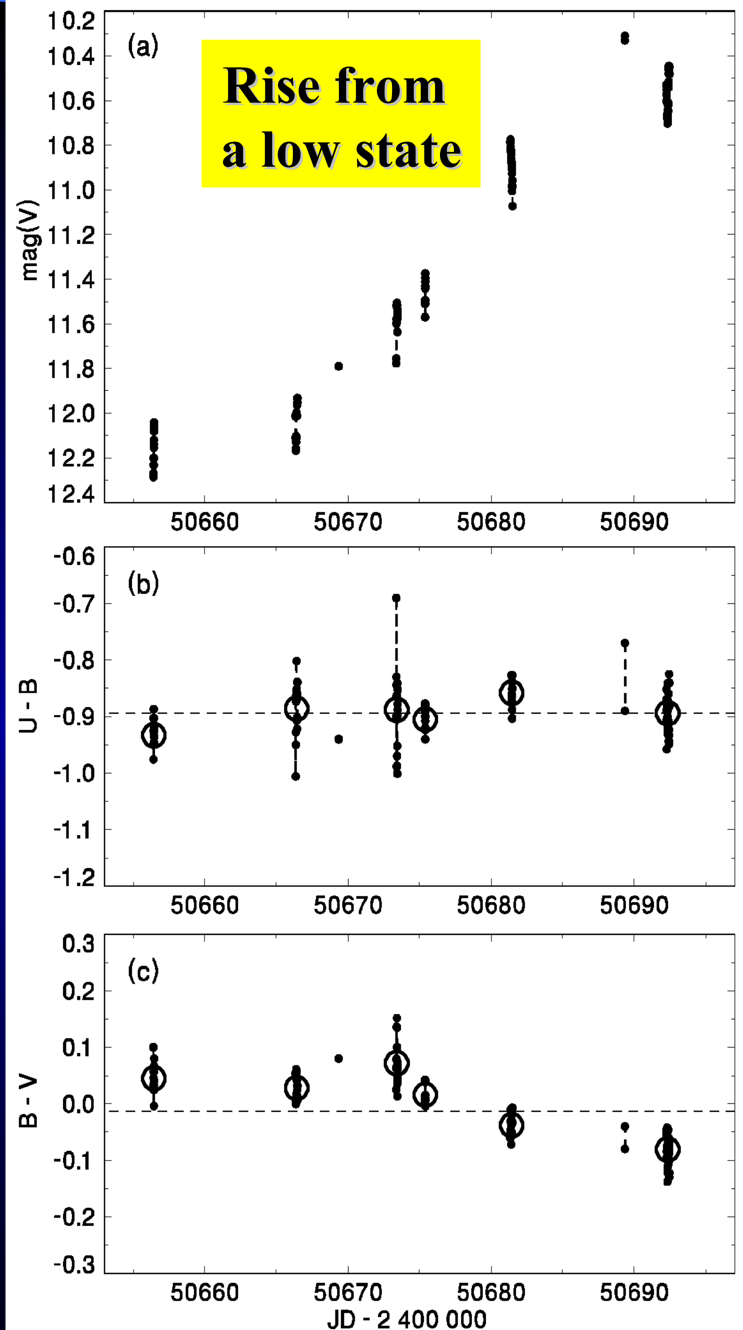
**Visual data make dens covered long-term light cu**

**Photoelectric data are suita for color variations and ra changes (orbital modulatio**



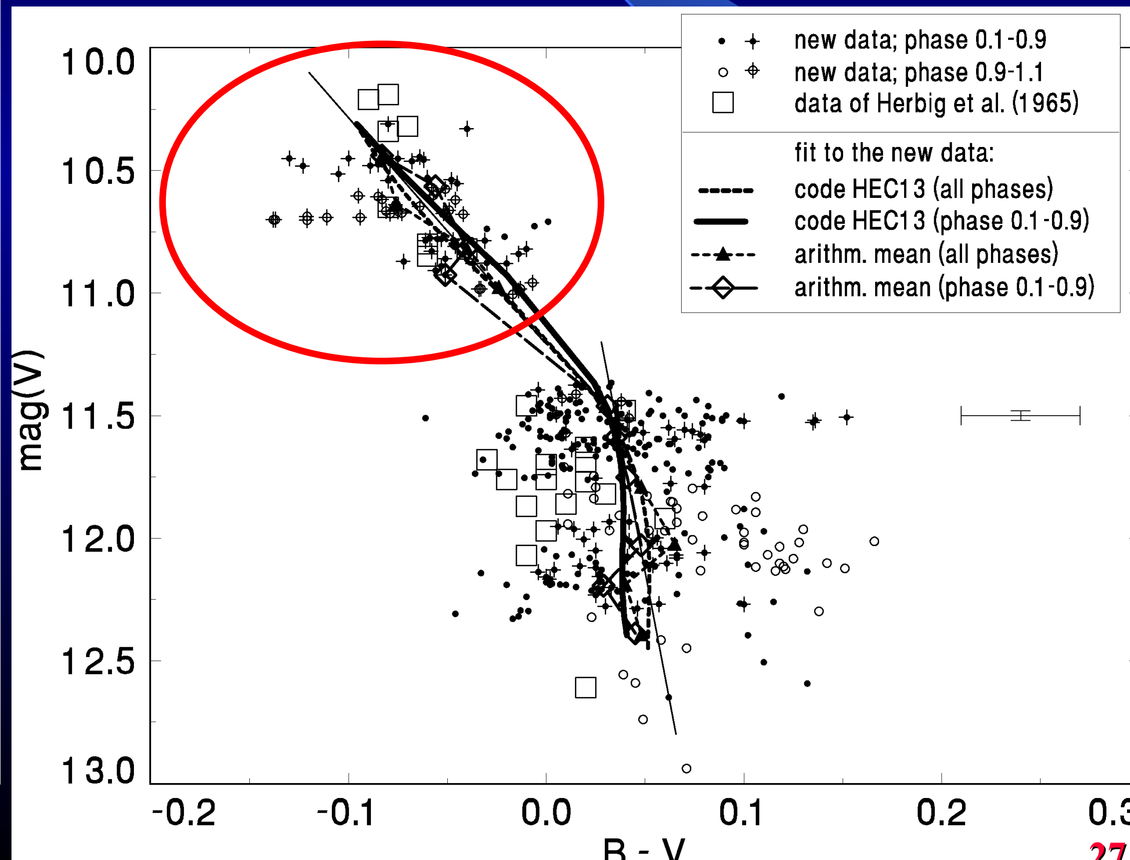

**Supersoft X-ray sources – V Sge**

# Supersoft X-ray sources – V Sge




- *U-B* **constant**
- *B-V* **decreases in the upper part of the transition**

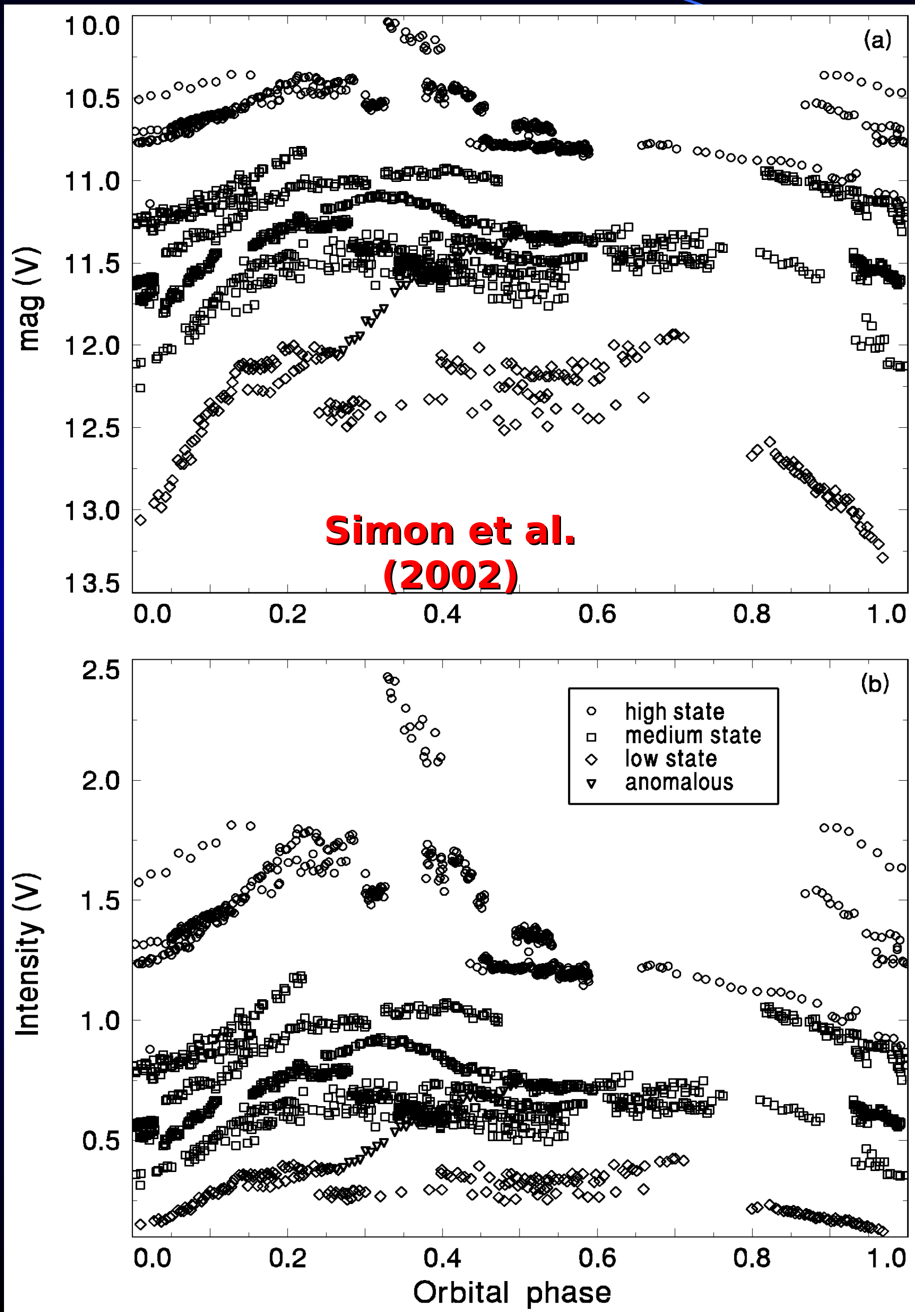
## Color – magnitude diagram

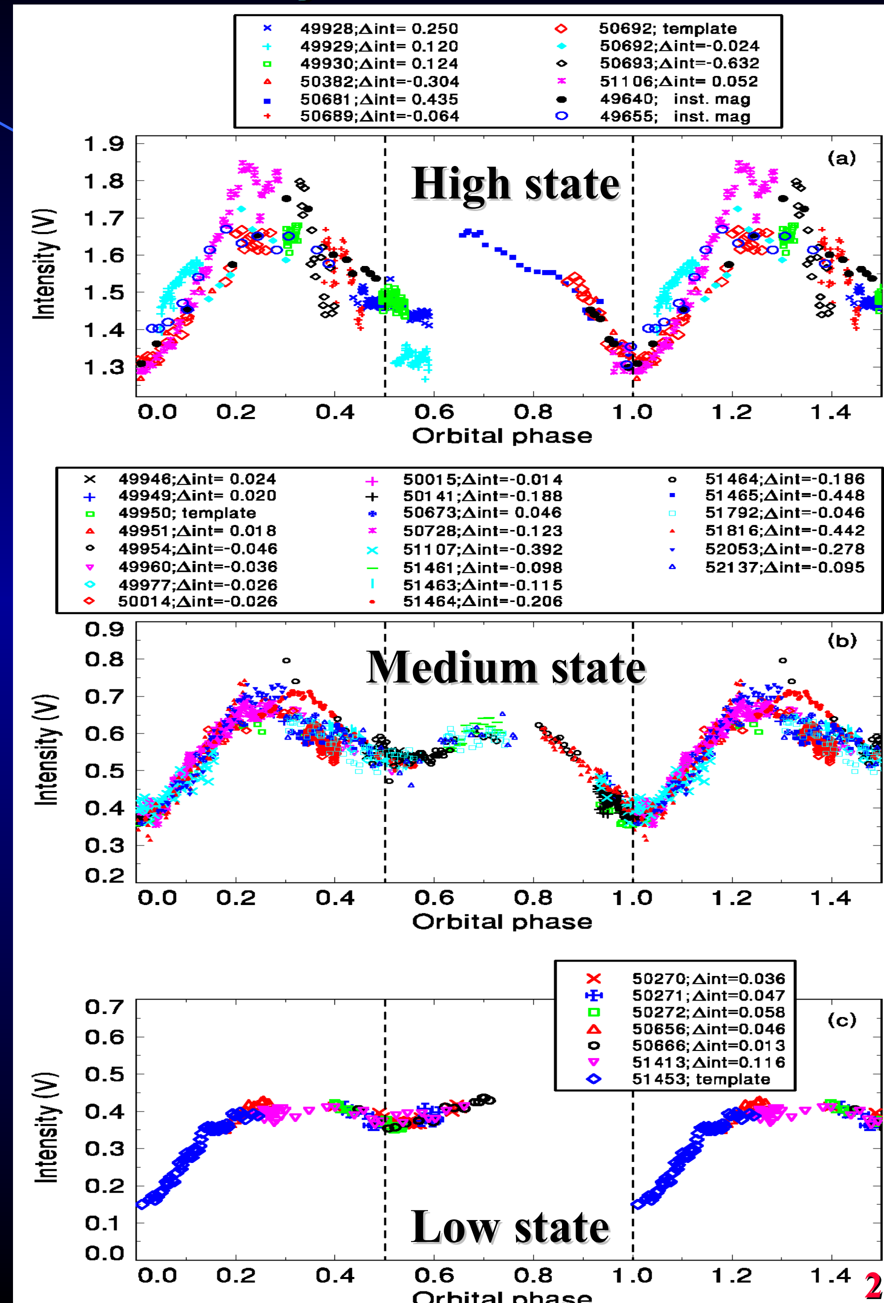



Simon et al. (2001)

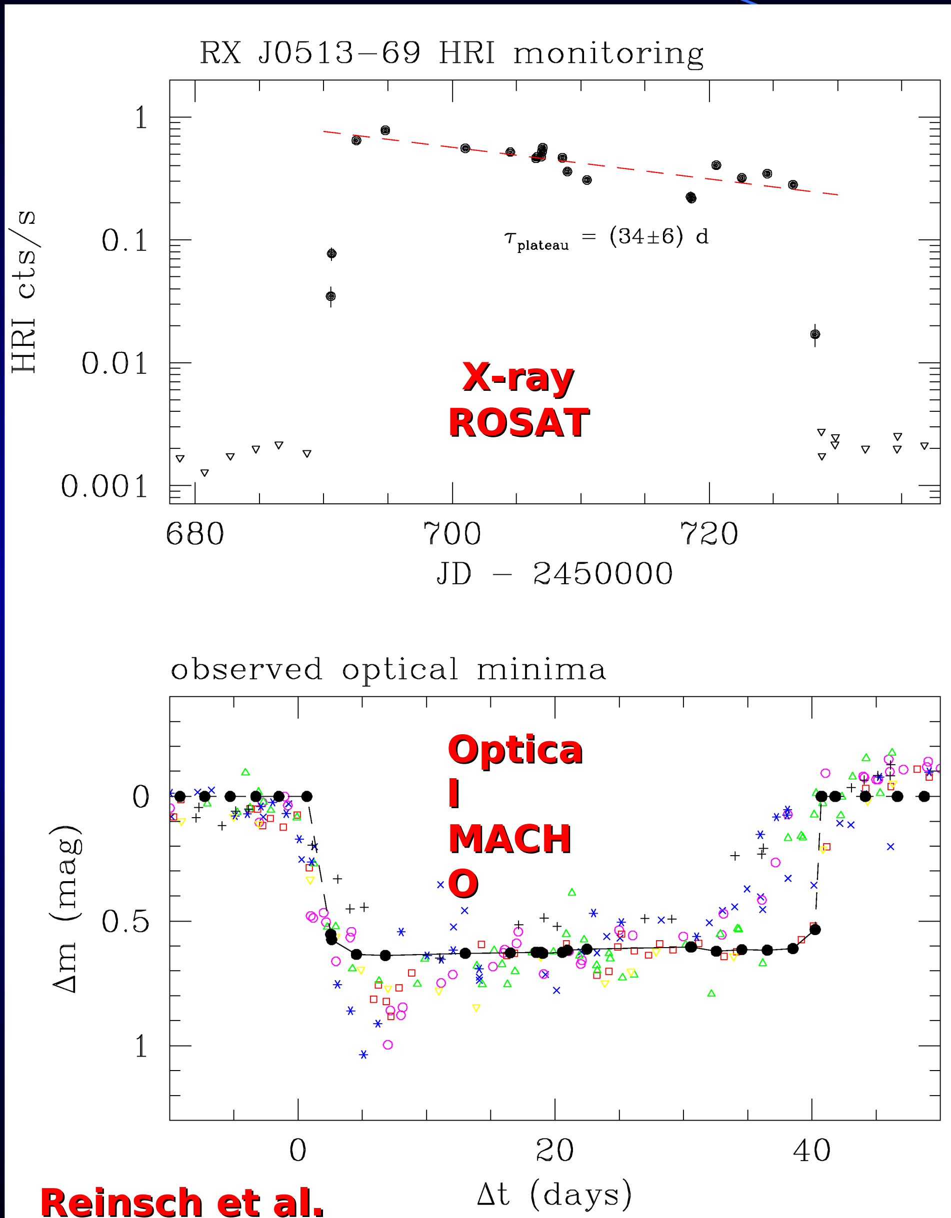
# Supersoft X-ray sources – V Sge

## long-term activity and orbital



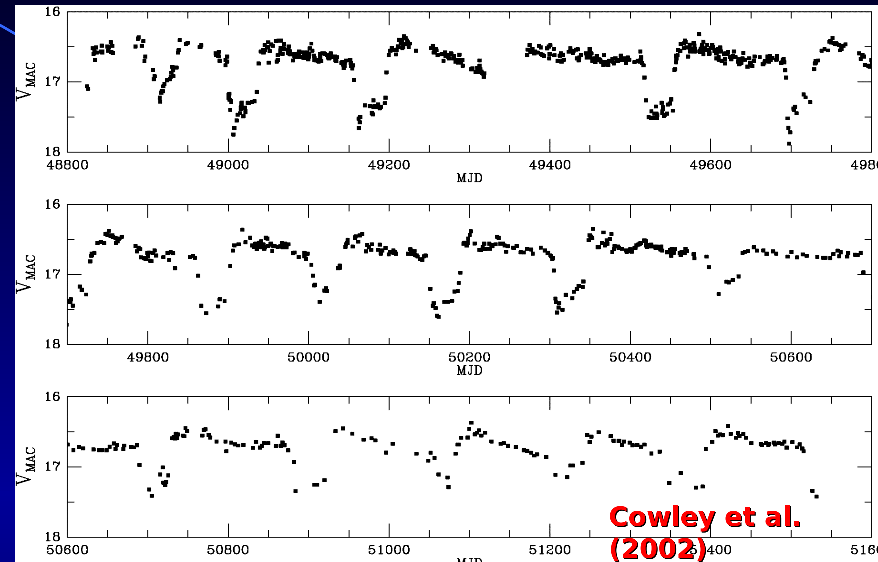



# Supersoft X-ray sources – RX J0513–69




Reinsch et al. (2000)

## Unique type of X-ray sources

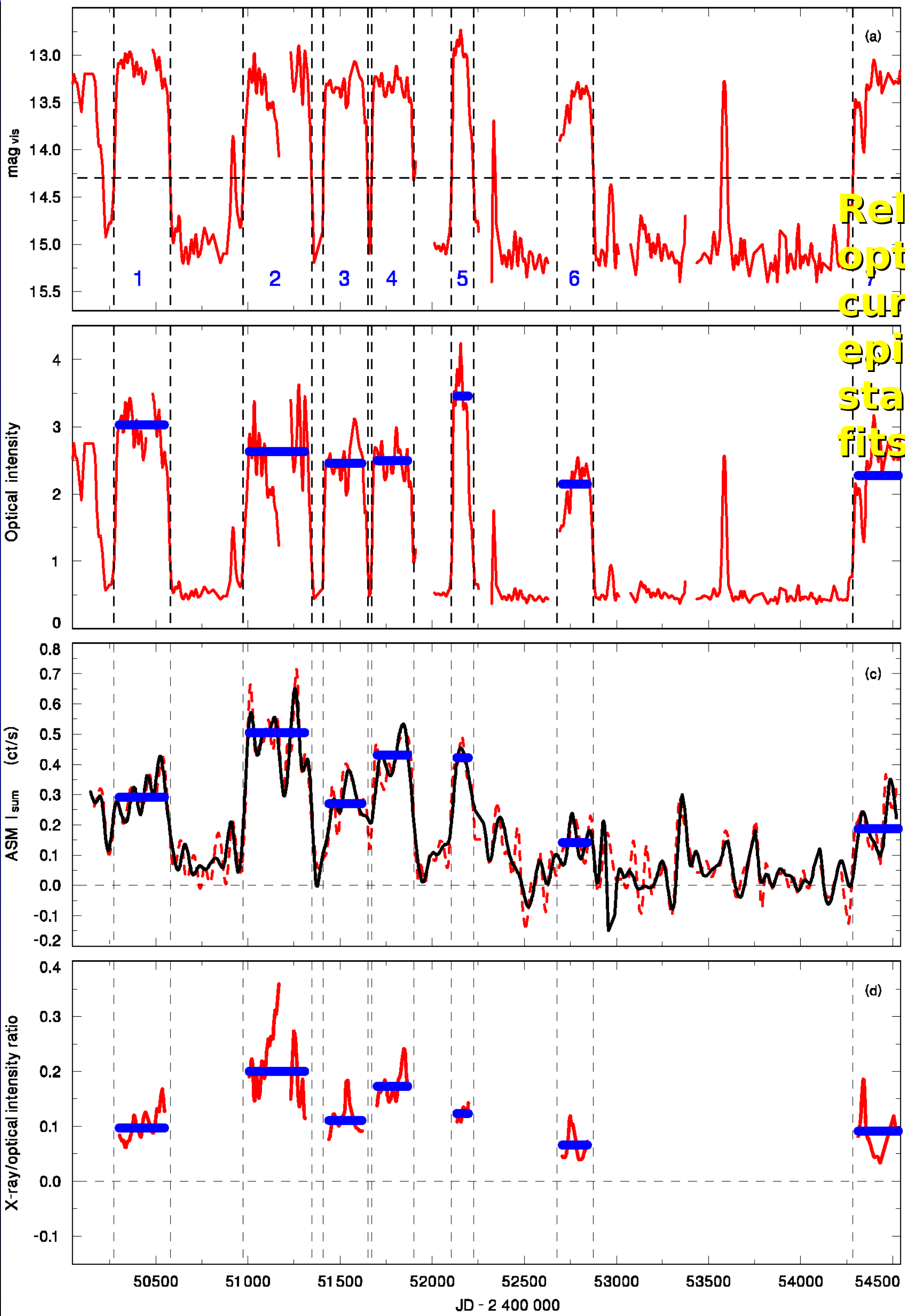



Cowley et al. (2002)

## Optical changes in antiphase with X-rays

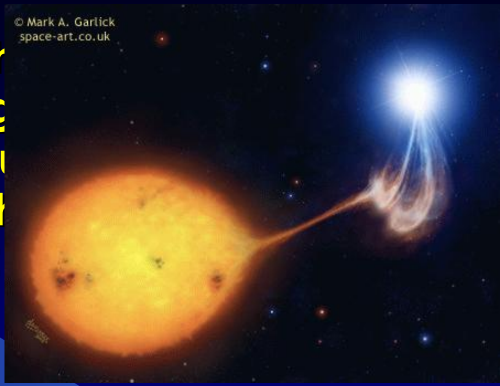
**(Quasi)steady-state thermonuclear burning of accreted hydrogen on the surface of white dwarf**

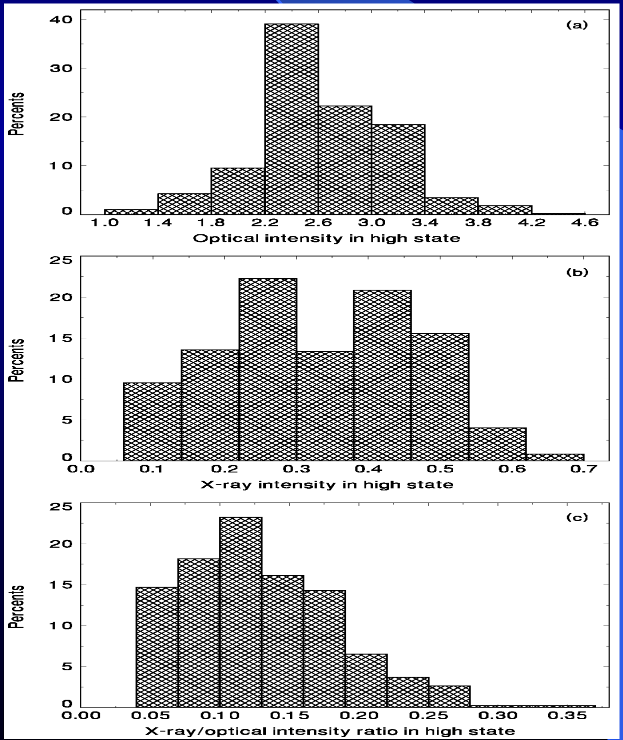
**Intense soft X-ray emission is produced, but its detectability depends on the interstellar extinction, temperature of white dwarf, and metallicity of the source (these are the causes of anticorrelation)**




# Cataclysmic variables – polar AM Her

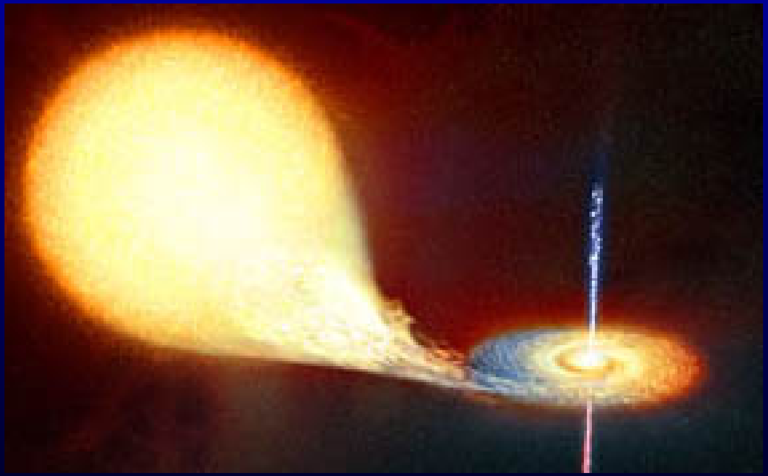
Relation between the optical and X-ray light curve in the individual episodes of the high state. Only the HEC fits are shown.



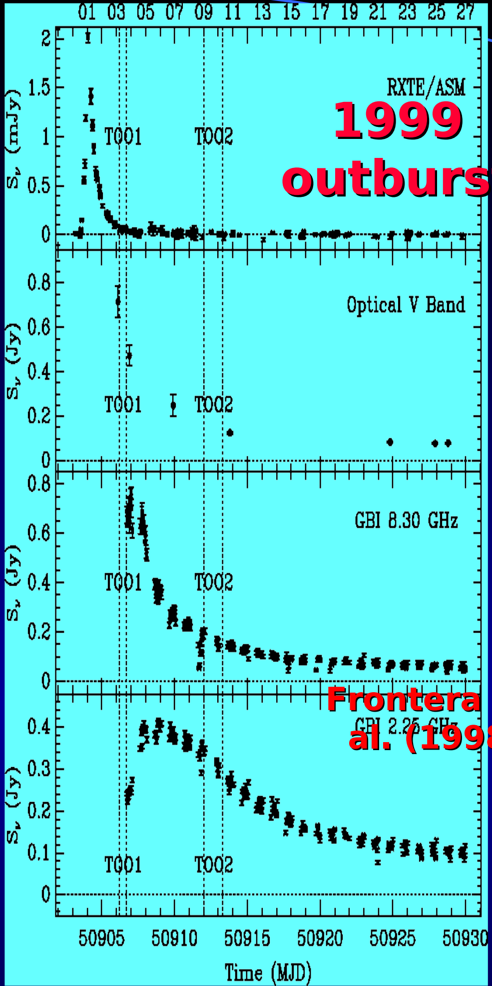




Statistical distributions of the optical and X-ray intensity in the

# Microquasars



# Microquasars




X-ray binaries with relativistic jets

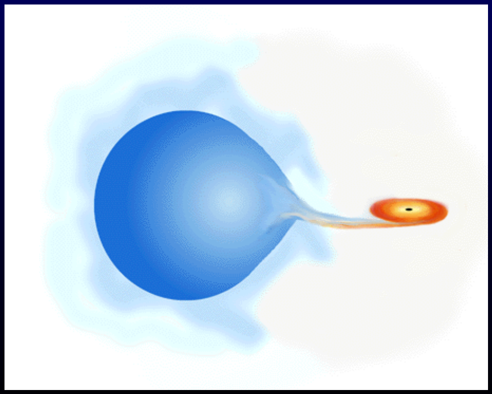
**CI Cam = XTE J0421+560**

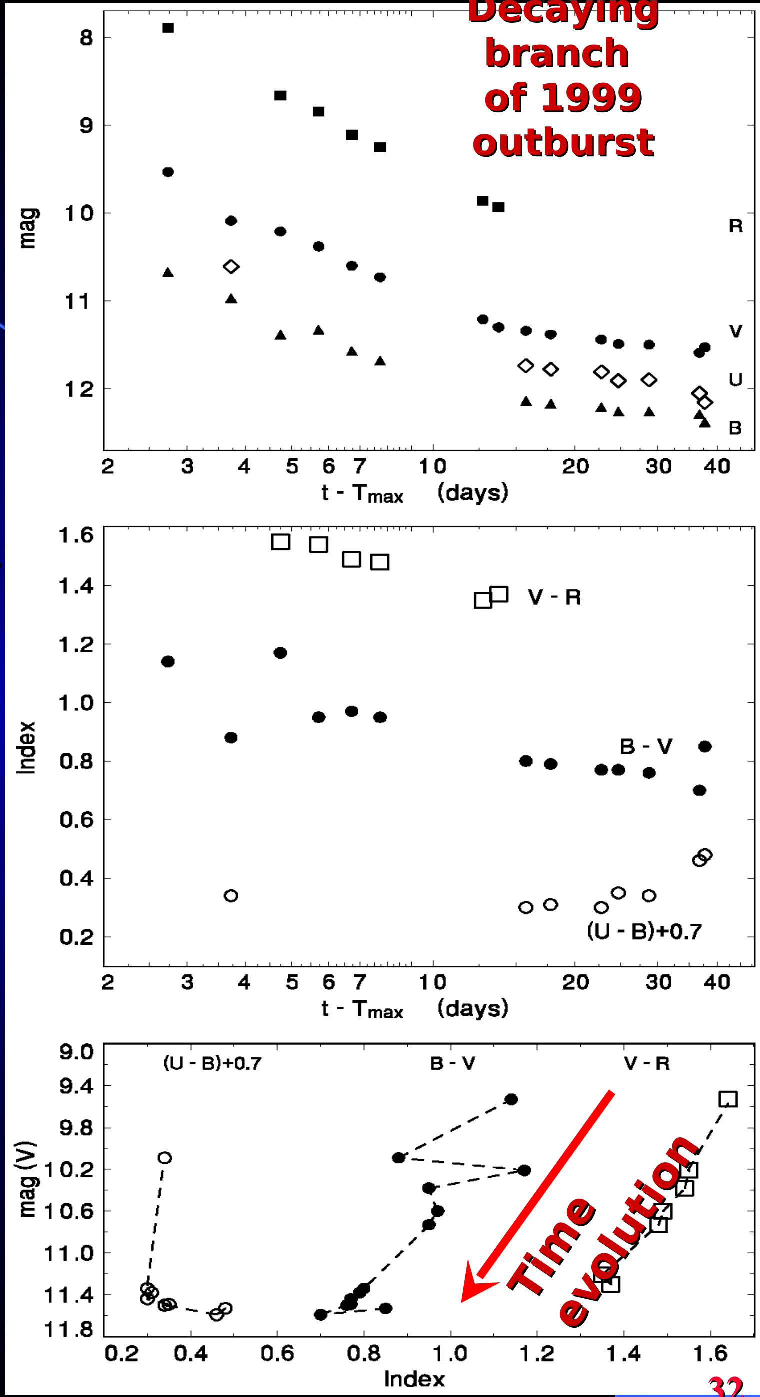
Simon et al. (2007): reanalysis of data of Barsukova et al. (2002) using color indices

The outburst can be explained by the thermal instability of the accretion disk embedding the black hole, analogous to the outbursts of soft X-ray transients (Simon et al. 2006).

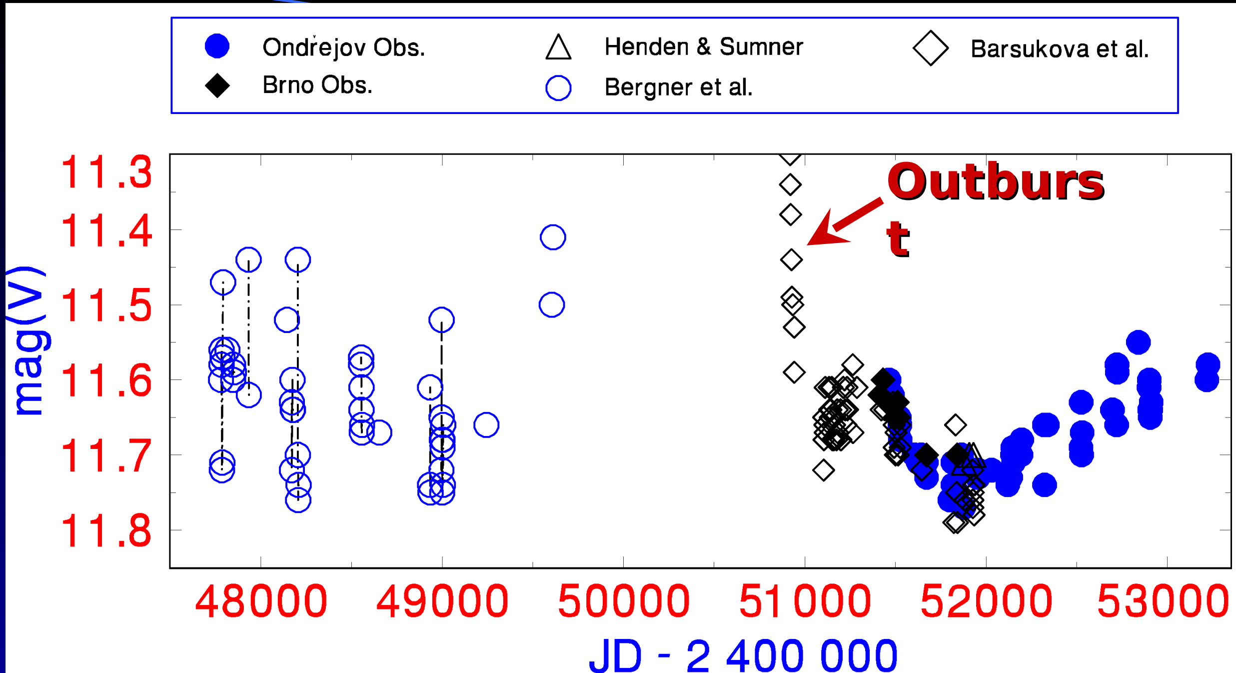
CI Cam reddens in outburst in spectral region longward of Balmer jump – very rare behavior among soft X-ray transients (SXTs) (a kind of X-ray binaries).

On the contrary, color indices of SXTs usually decrease during outburst.



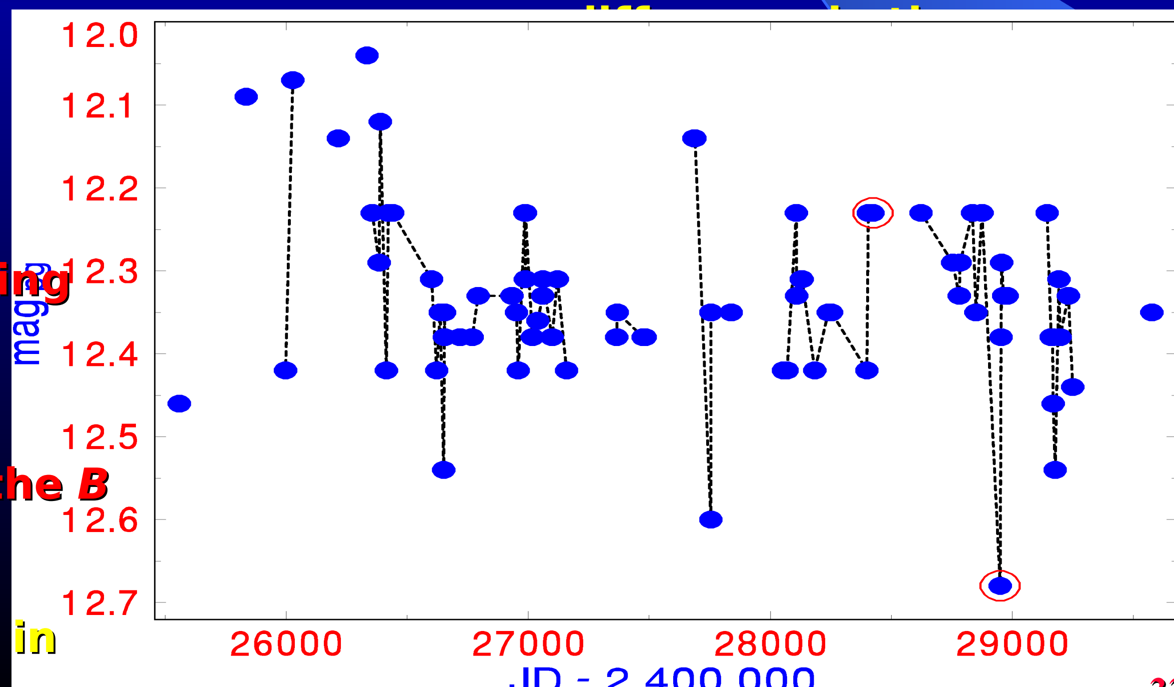


# CI Cam= XTE J0421+560



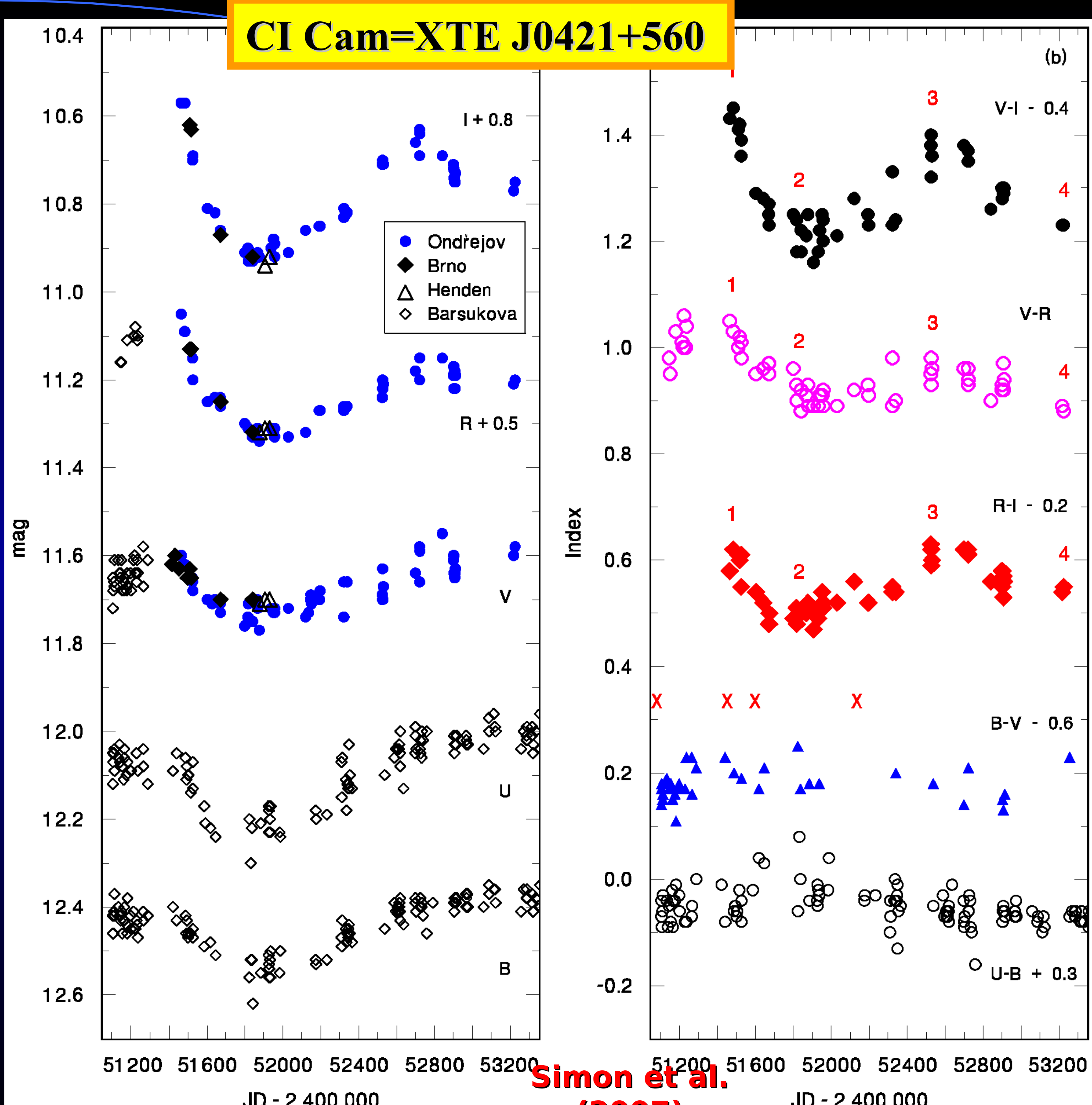

Photometric history according to the photoelectric and CCD observations
(years 1989 – 2004)
Peak of the 1998 outburst is out of scale. Notice the

Simon et al. (2007)




Photometric history according to the Bamberg photographic observations in the blue band (similar to the *B* band)
(years 1928 – 1939)
Points are connected by line in densely

# CI Cam=XTE J0421+560




Simon et al. (2007)

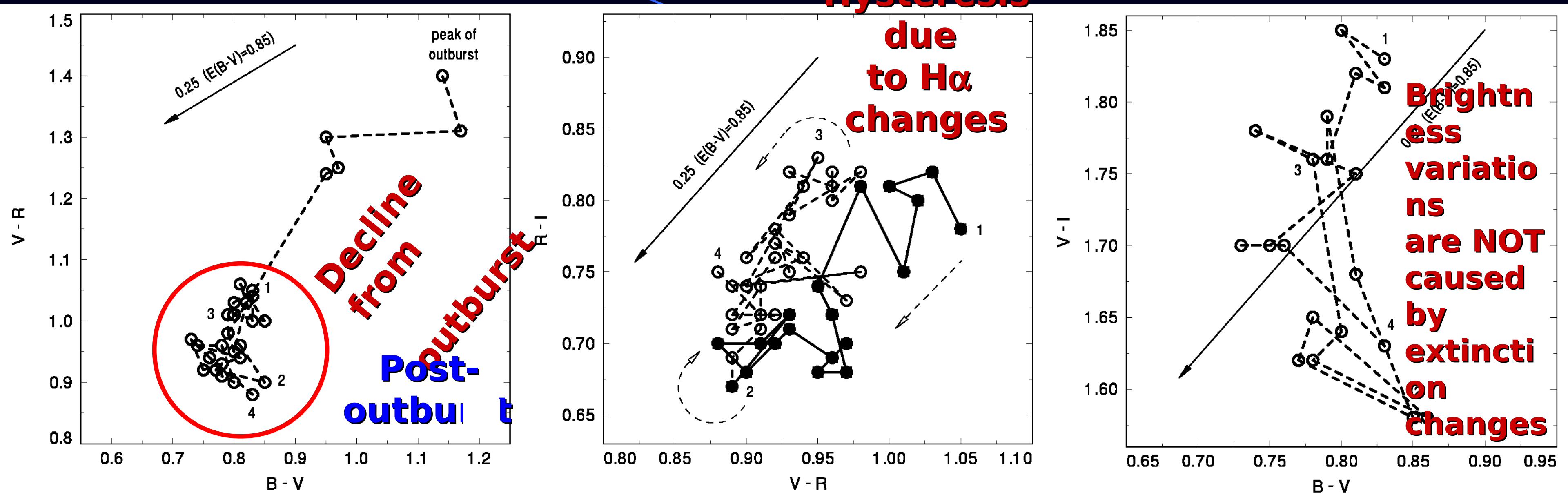
## Post-outburst activity

***UBVRI*** **light curves and color changes in post - outburst interval (daily means) (1999 – 2004)**

**Labels 1, 2, 3, 4 – important moments in curves, used for orientation in color**

# CI Cam=XTE J0421+560

Simon et al. (2007)




***Post-outburst activity (1999 – 2004):***

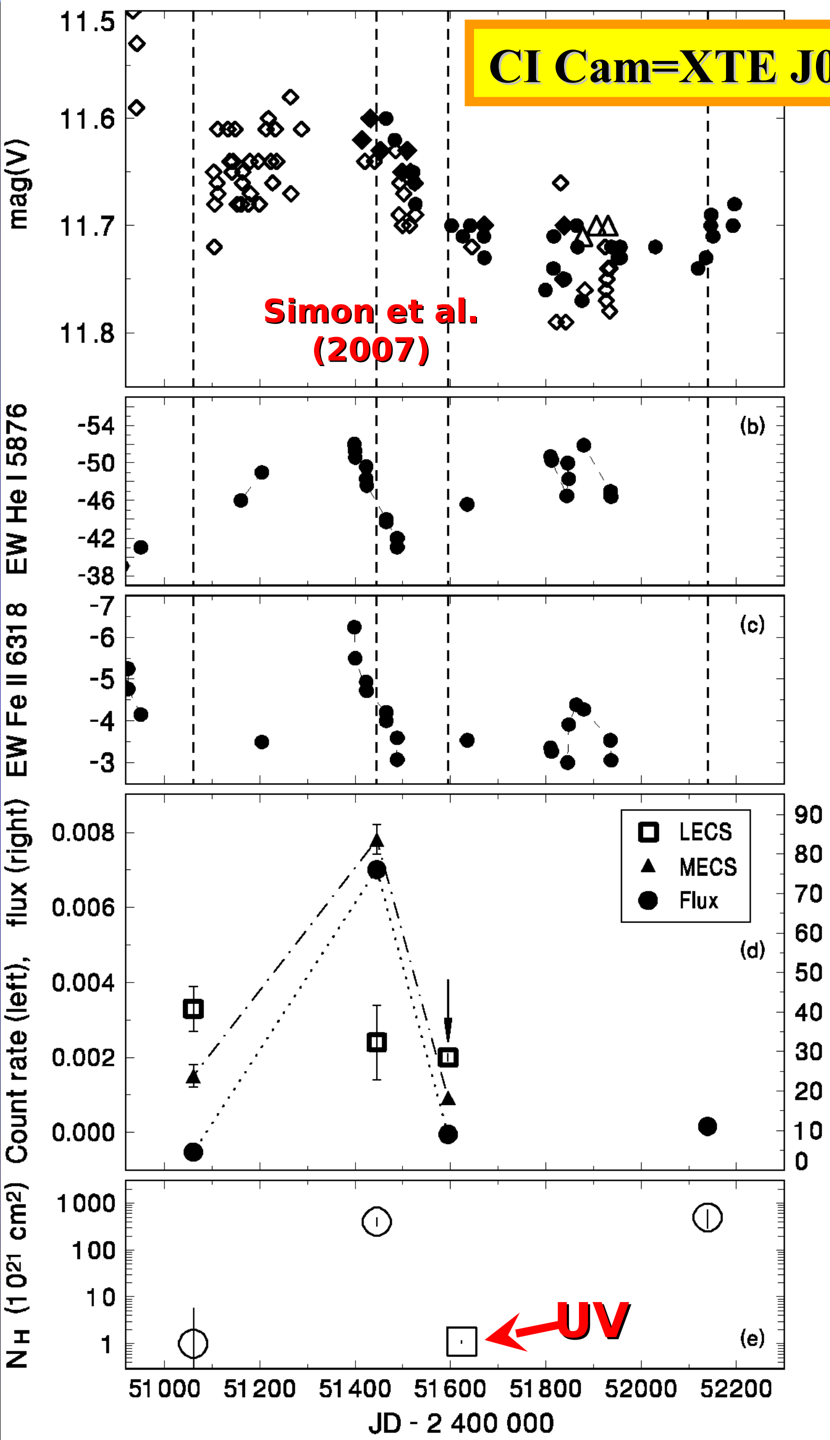
- **Significant variations of continuum;dominant line changes would lead to independent variations of indices. Not explicable by changes of reddening intrinsic to CI Cam.**

  **Interpretation: several superposed spectral components.**

  **Division of dominant contributions of spectral components near λ =550 nm: free-free emission from wind and/or envelope (in red and near-IR;**

# CI Cam=XTE J0421+560

# Optical vs. X-ray activity in quiescence




Dashed vertical lines – moments of X-ray observations.

(a) *V* band data in post-outburst interval

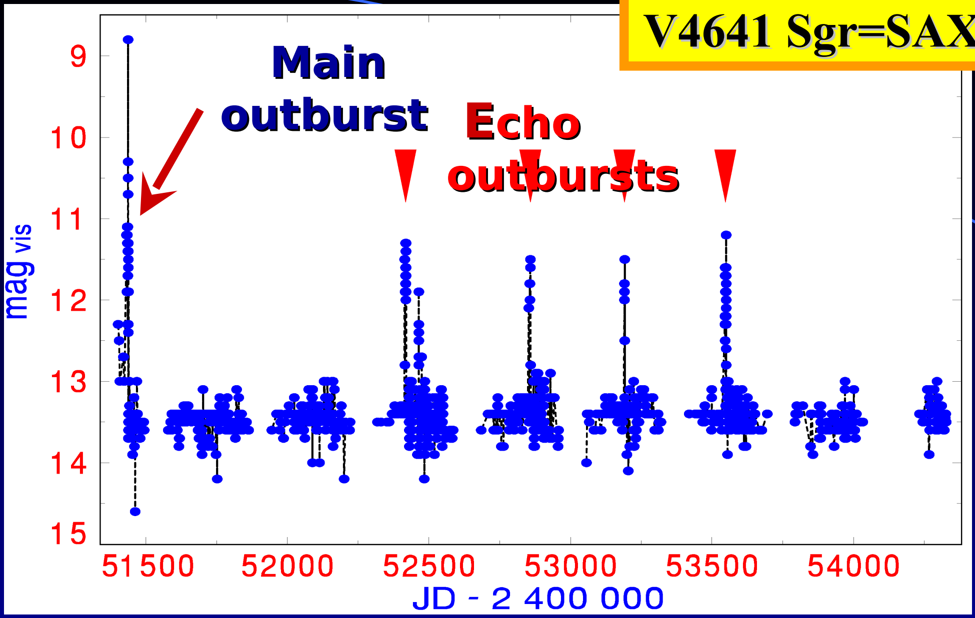
(b,c) Variations of EW of HeI 5876 (in A) and FeII 6318 (data from Barsukova et al. 2002, AZh, 79, 309).

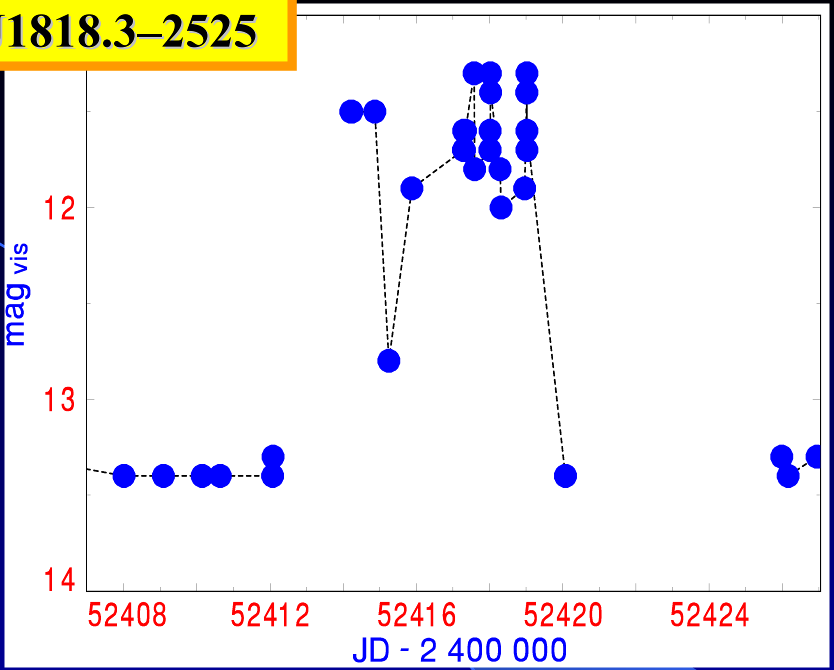
(d) BeppoSAX data (Parmar et al. 2000, A&A, 360, L31) and XMM obs. (Boirin et al. 2002, A&A, 394, 205). Unabsorbed 1-10 keV flux (in $10^{-13}$ erg/cm2/s; right-hand ordinate). Obs. in JD 2451595 – upper limits only

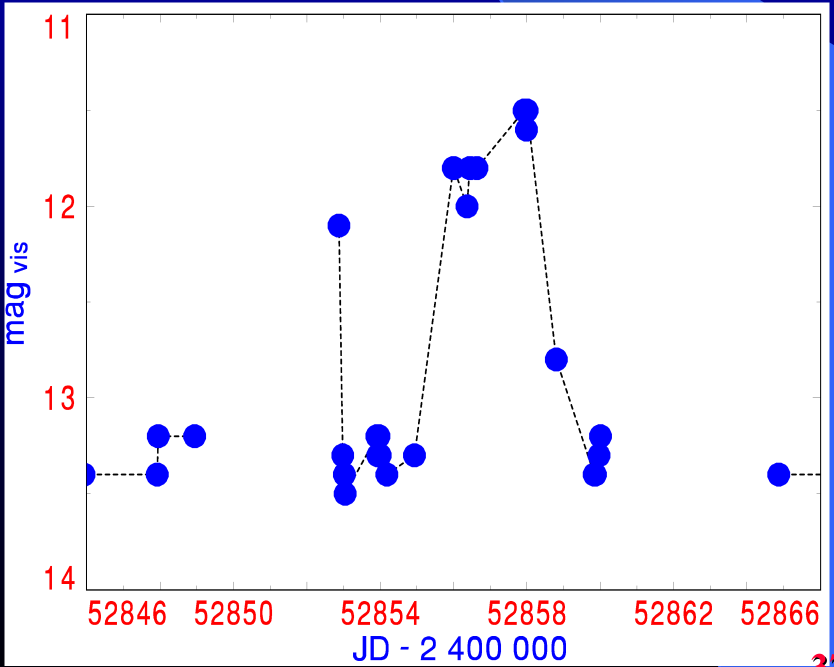
Huge changes of the extinction in X-rays and no extinction variations in the optical suggest that the X-ray emission comes from the close vicinity of the mass-accreting black hole (re-filling of the disk after outburst?), not from the giant donor star.

(e) H column density $N_H$

# V4641 Sgr=SAX J1818.3–2525



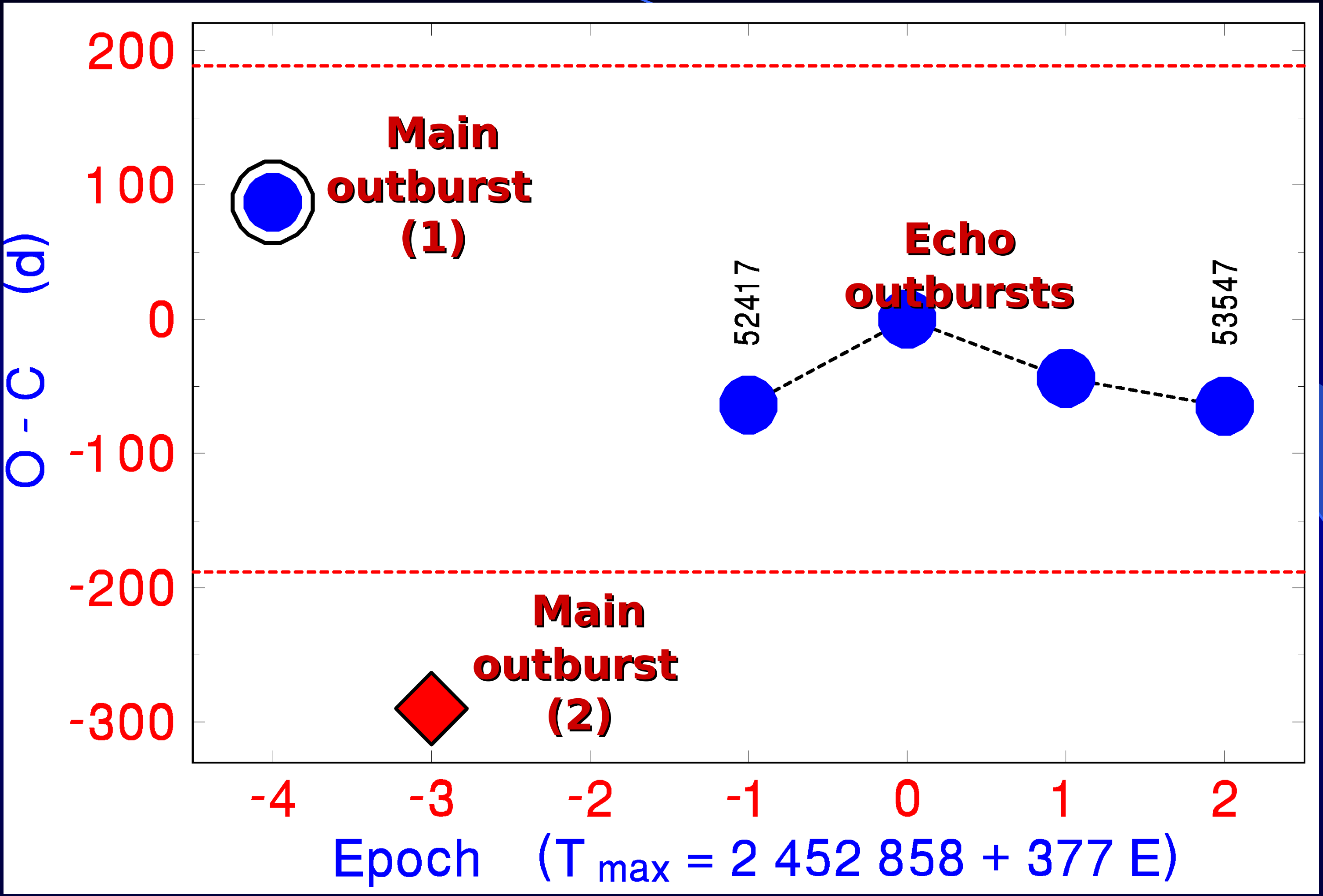

**Recent photometric history of V4641 Sgr. Peak of the 1999 main outburst is near the left hand edge of the plot. Four smaller echo outbursts are marked by arrows. Each of them is defined by multiple observations.**

**Examples of echo outbursts**

**Notice the multi-peak structure of outburst and the accumulation of the points near the peak mag. This implies that the outburst does not consist of a long series of short, narrow peaks starting**

Simon & Henden (2009)

# V4641 Sgr=SAX J1818.3–2525

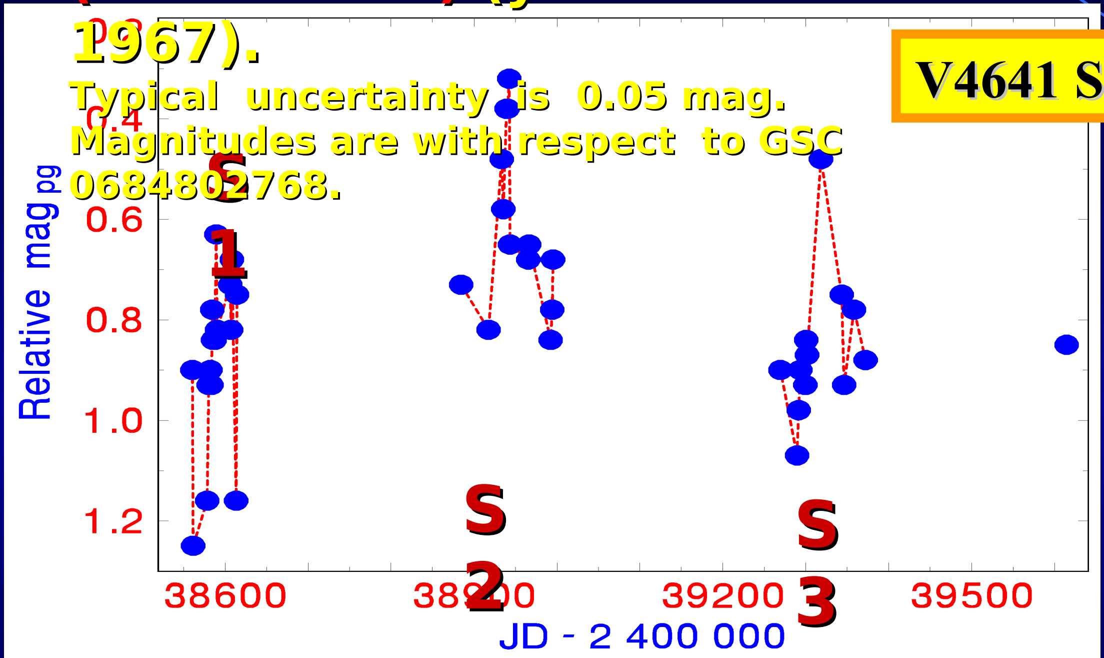



**Recurrence time $T_C$ of outbursts**

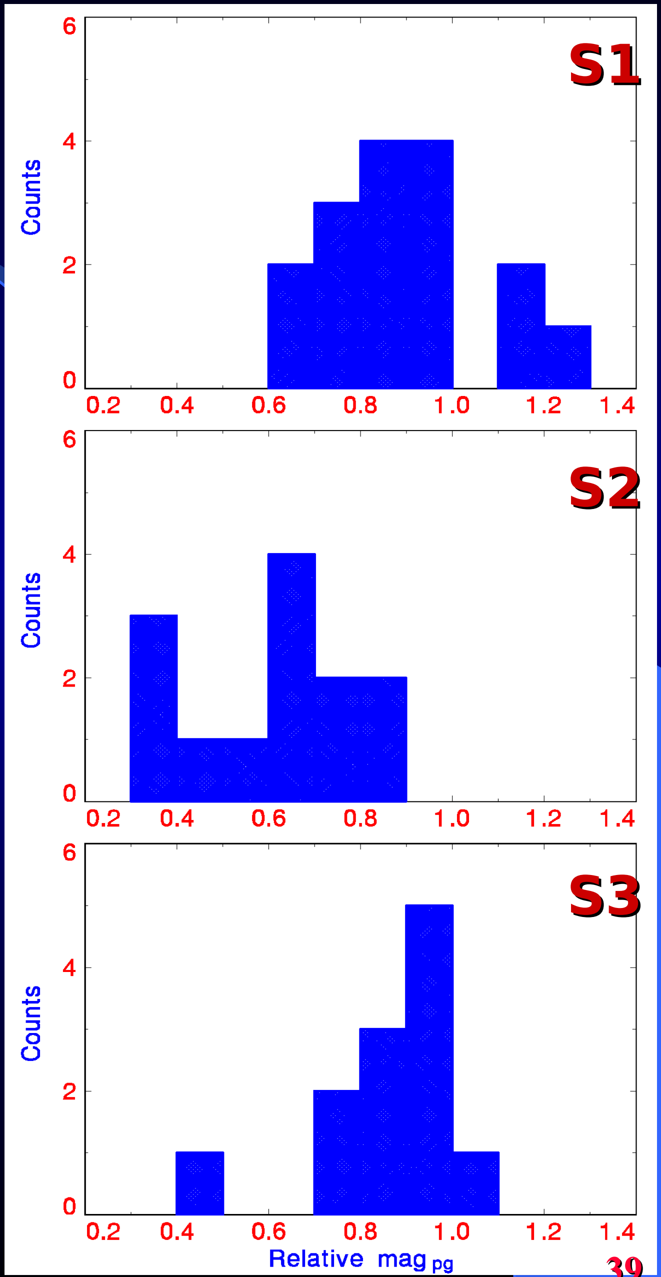
**Evolution of $T_c$. Dashed horizontal lines – length of the reference period of 377 d to show the relatively small scatter of $T_c$ of the echo outbursts. Two positions of the main outburst are shown: (1) – two missing echo**

**Photometric history according to the Bamberg photographic observations in the blue band (similar to *B*) (years 1964 – 1967).**

Typical uncertainty is 0.05 mag.
Magnitudes are with respect to GSC 0684802768.




**Statistical distribution of**




**S1:** Fluctuations in quiescence.

**S2:** The general level of brightness is higher than in S1, a weak outburst occurred from this level.

**S3:** The state similar to that in

Simon & Henden (2009)

# Conclusions – CVs, X-ray binaries, microquasars

- **Dense series of observations covering the intervals of several years are necessary to investigate the properties of the long-term activity:**

  - **resolve the state transitions, like rising and decaying branches of outbursts and high/low states.**
  - **put these events to the context of long-term activity of a given system**
  - **form the representative ensemble of events (e.g. outbursts) in (a) a given system, (b) in a type of systems**

**This is important for our understanding of the physical processes involved.**

- **We emphasize the very important role of X-ray monitors like ASM onboard *RXTE* on our understanding of the processes operating in X-ray sources.**

# Color indices of the early phase of optical afterglows of GRBs ($t - T_0 < 10$ days)

# Role of the color indices in the GRB-supernova connection

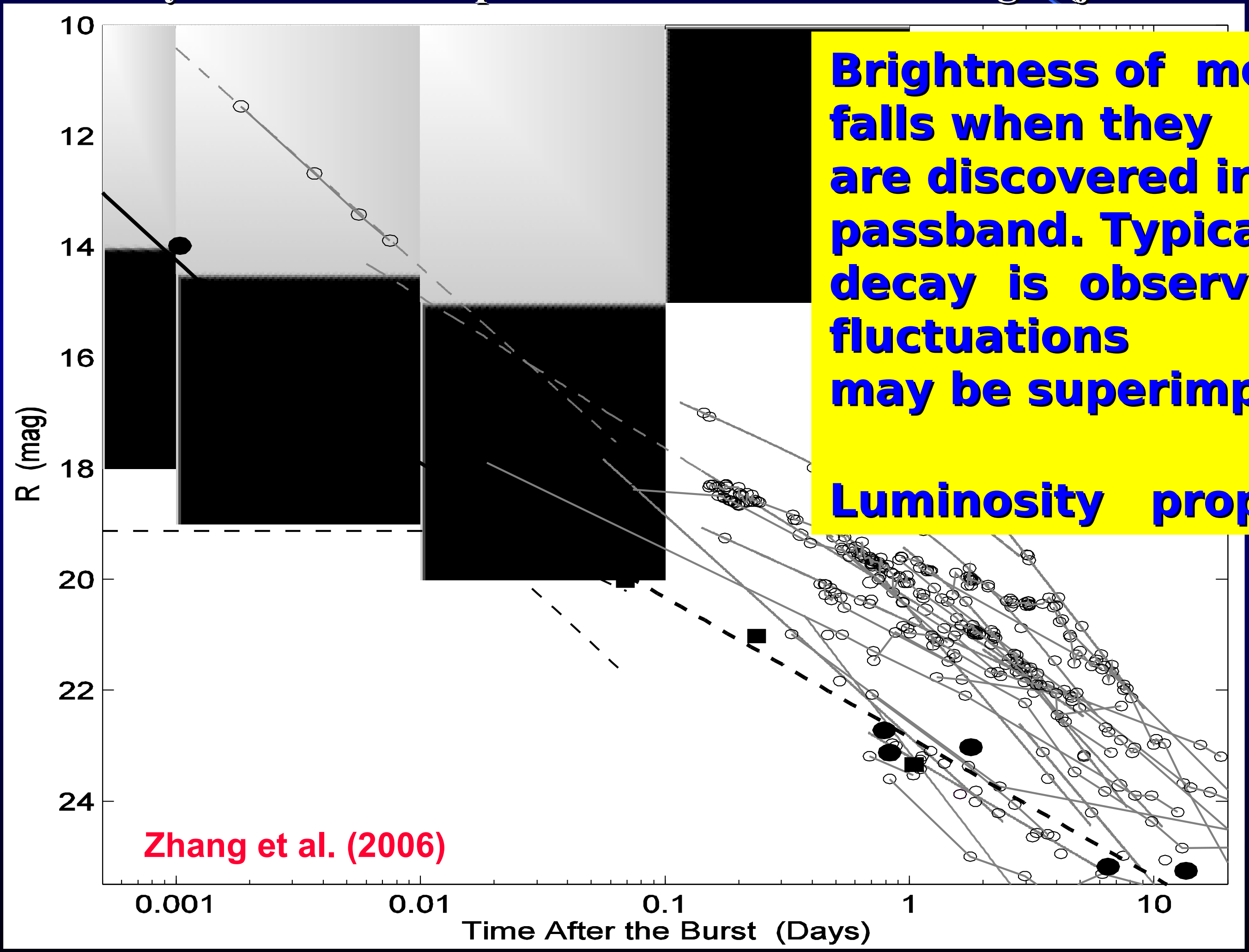
**Currently used methods to resolve the contribution of a supernova (SN ) in optical afterglows (OAs):**

**(a) Spectroscopic – only for brighter OAs, large telescopes needed;**

**(b) Late bump in the light curve of OA – not a**

## Typical light curves of optical afterglows (OAs) of long GRBs

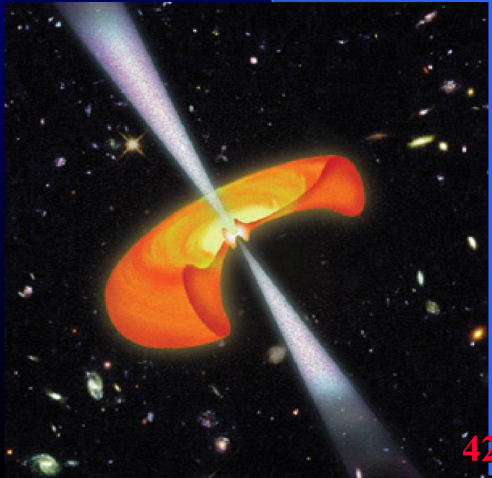
**GRBs occur during core-collapse of a massive star or during a merge of compact objects. Relativistic jet is the dominant source of radiation from gamma-ray to the infrared (and radio) spectral region.**
**Intensity of emission depends on the inclination angle (jet has to point to the observer).**



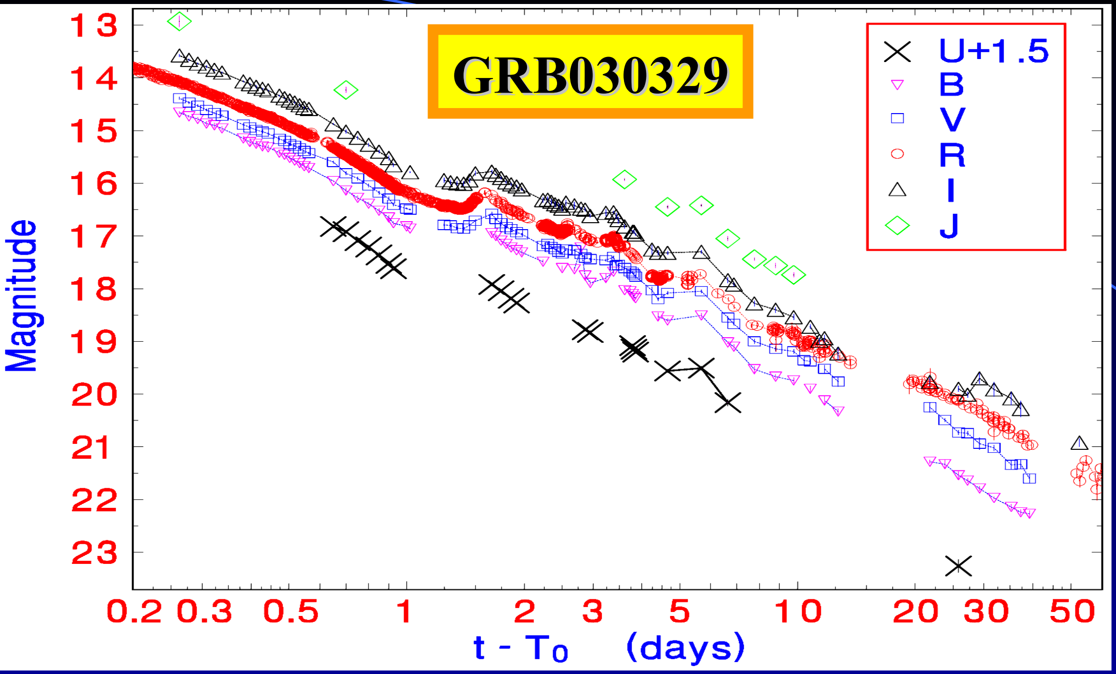

**Brightness of most OAs already falls when they**
**are discovered in the optical passband. Typically, power-law decay is observed, but fluctuations**
**may be superimposed on it**

**Luminosity propo**

**OA lasts much longer than GRB (days versus seconds or minutes)**



**All observations are in the *R* band (red light) and their**

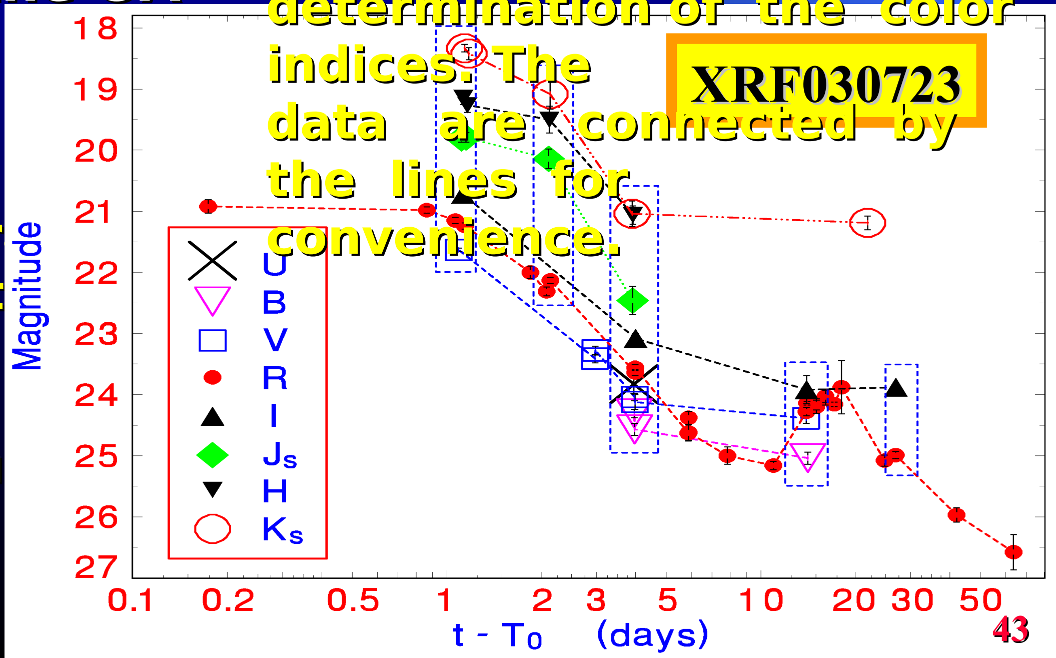



Simon et al. (2004, 2007)

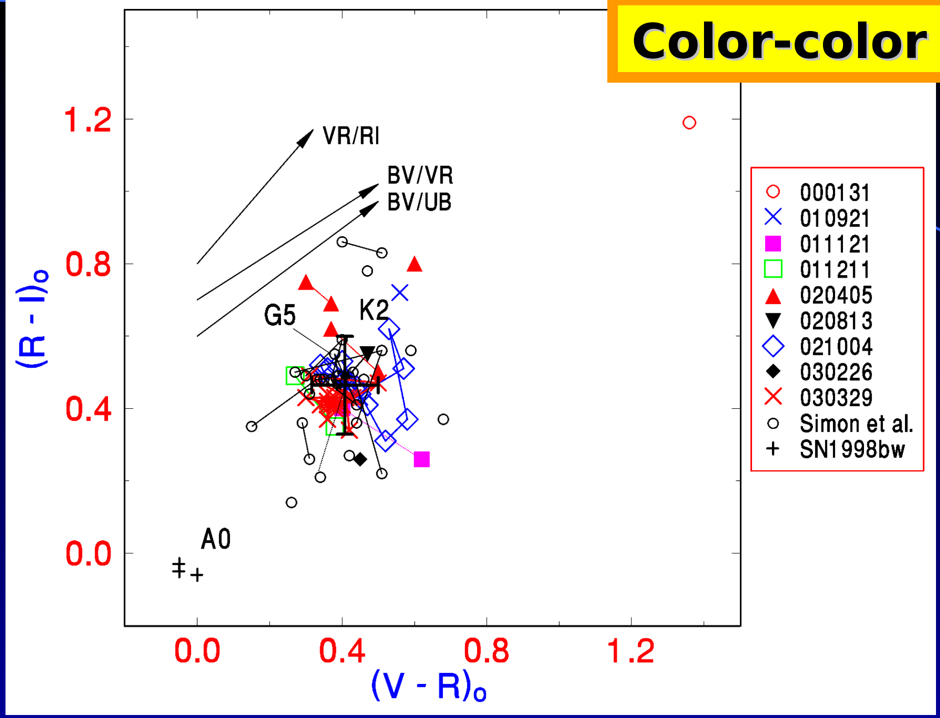
Light curve of the OA according to the data of Fynbo et al. (2004). Data in the dashed boxes are the ones used for the determination of the color indices. The data are connected by the lines for convenience.

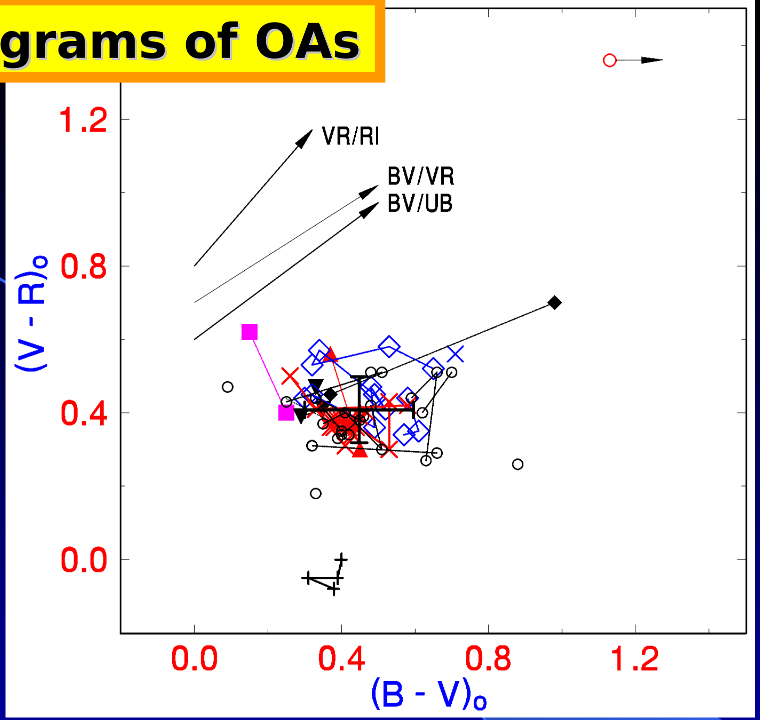
well observed light curve of the OA
B030329
whole *R* band curve to show the
ution of the brightness.
er filters – only those (often aver
nts which were used for calculat
he color indices.

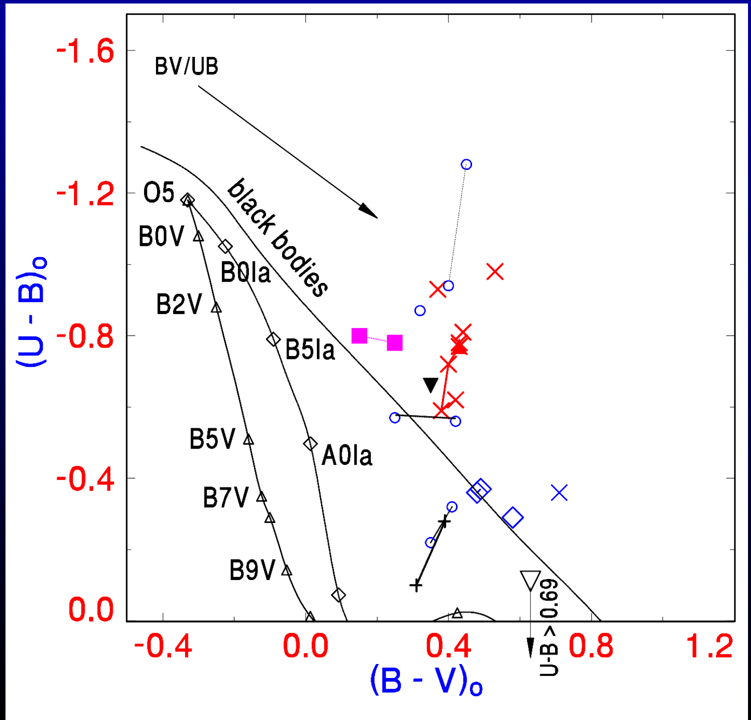
bars are included, but they are u
r than the symbols.



# Color-color diagrams of OAs



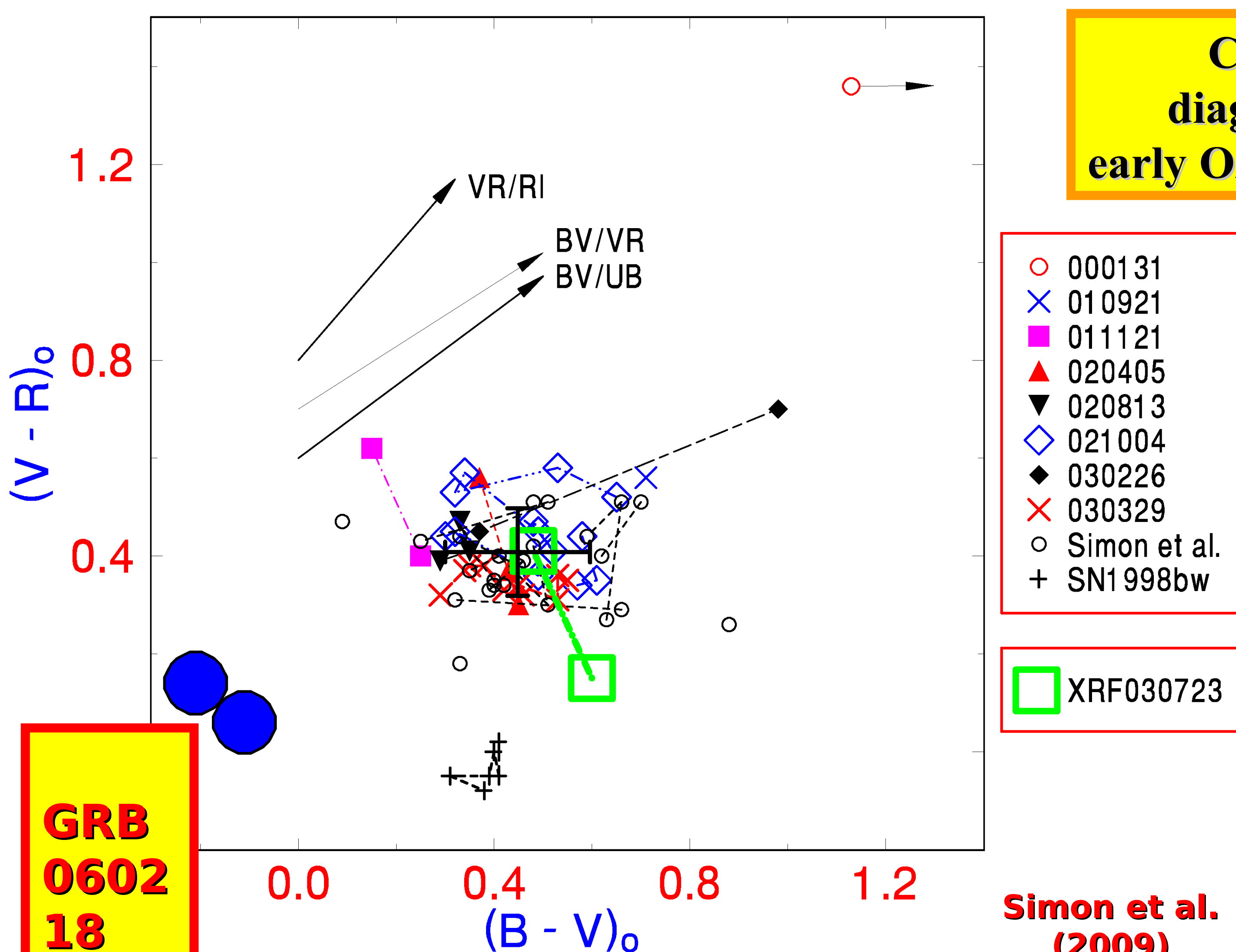




**Ensemble of OAs of long GRBs (0.17< *z* < 3.5; *t-T*$_0$ <10 d) in The observer frame, corrected for the Galactic reddening. Multiple indices of the same OA are connected by lines for convenience. The mean colors (centroid) of the whole ensemble of OAs (except for GRB000131 and SN 1998bw) are marked by the large cross.**

**Simon et al. (2001, 2004)**

**Color-color diagram for the early OA of GRB060218**

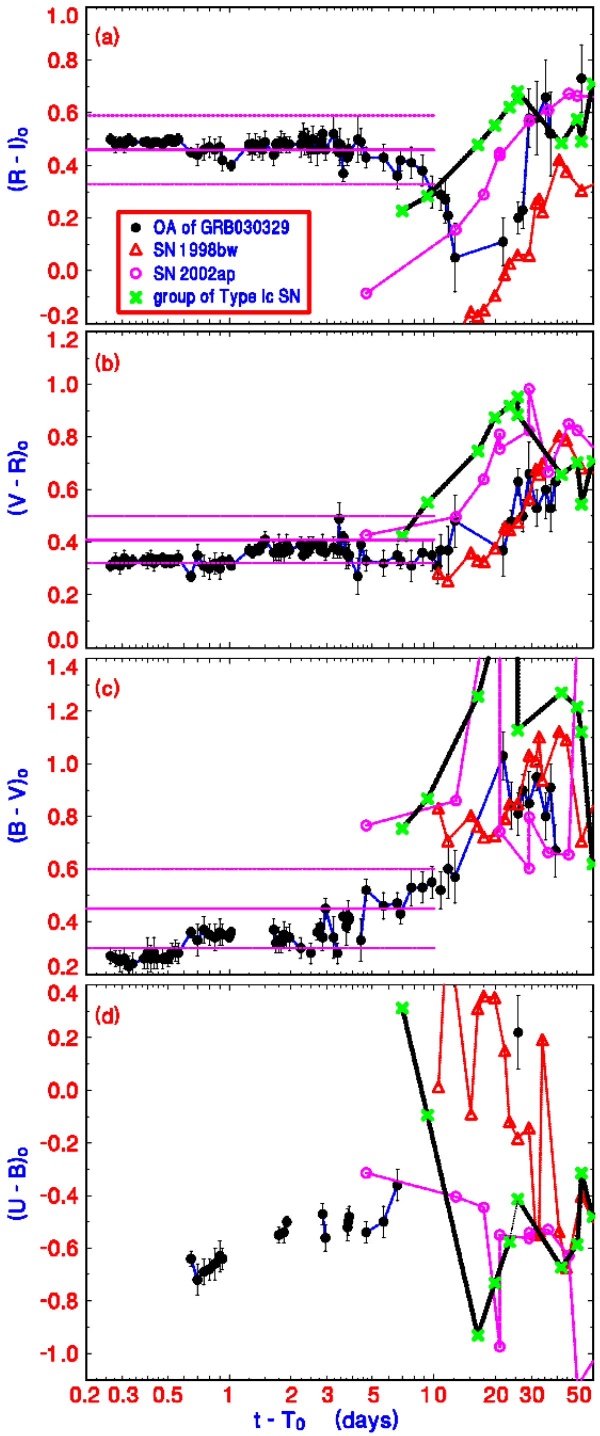



***BV*** **data: UVOT**

***R*** **band data: Mirabal et al. 2006, ApJ,643,L99**

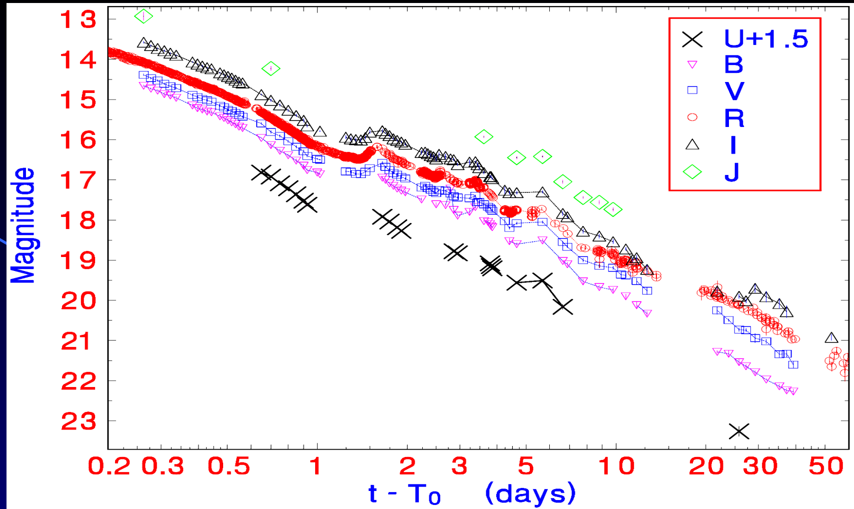
**Representative reddening paths are for $E_{B-V}$=0.5 mag.**

***B–V*** **vs.** ***V–R*** **diagram of OAs ($t$-$T_0$<10.2 d). The colors are corrected for the Galactic reddening. Multiple indices of the same OA are connected by lines for convenience. The mean colors of the whole ensemble (except for GRB000131) are marked by the large cross. The colors of**




# GRB030329

Simon et al. (2004)



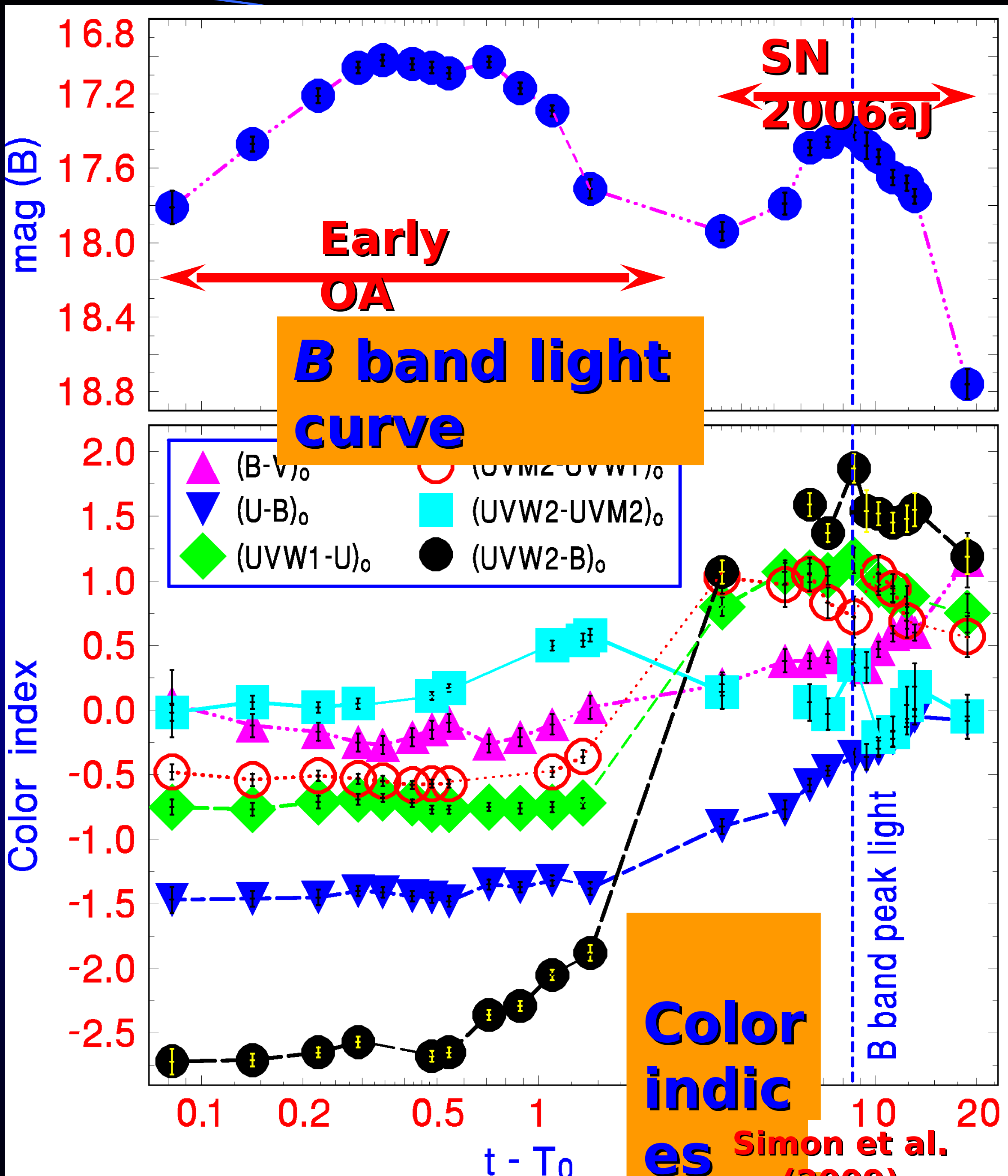

**Time evolution of the color indices of the OA of GRB030329 (solid circles):**

- **Horizontal solid line with error bars – mean color indices of ensemble of 25 OAs (Šimon et al. 2004).**

- **Synthetic colors of SN 1998bw, SN 2002ap and the group of Type Ic supernovae (database and code of Poznanski et al. 2002), with the passbands and**

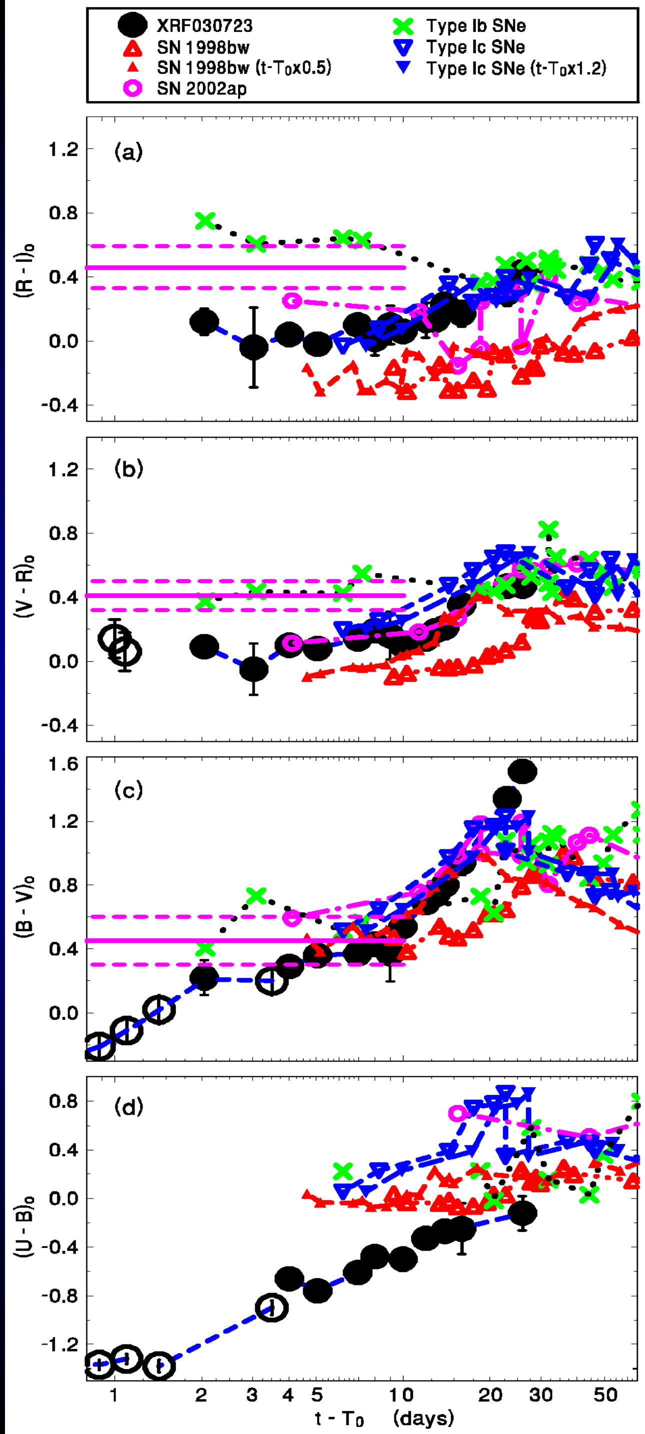
# GRB060218/SN 2006aj

## UVOT data




**Data were corrected for the reddening and light contribution of the host galaxy.**

**Data were interpolated to determine the color indices. Separation of the colors appropriate to the early OA and SN 2006aj is clear for *UVW2-B*, *UVW1-U*, *UVM2 - UVW1*.**




# GRB060218/SN 2006aj

## Time evolution of color indices

**orizontal lines – mean color indices f ensemble of 25 OAs of long GRBs Simon et al. 2004, AIPC, 727, 487). hey are independent on redshift.**

**ynthetic colors of several types of upernovae (Poznanski et al. 2002, ASP, 114, 833) are calculated for edshift *z*=0.03 of GRB060218.**

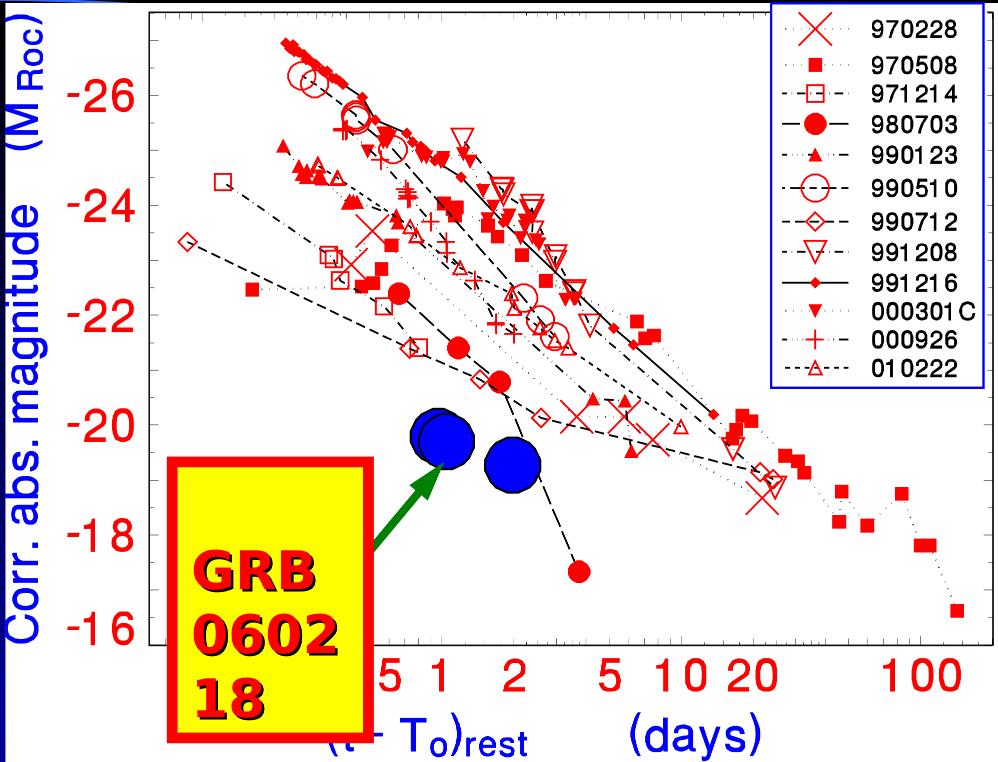
**arge open circles – UVOT data of SN 2006aj**

**arge closed circles – ground-based data of SN 2006aj**

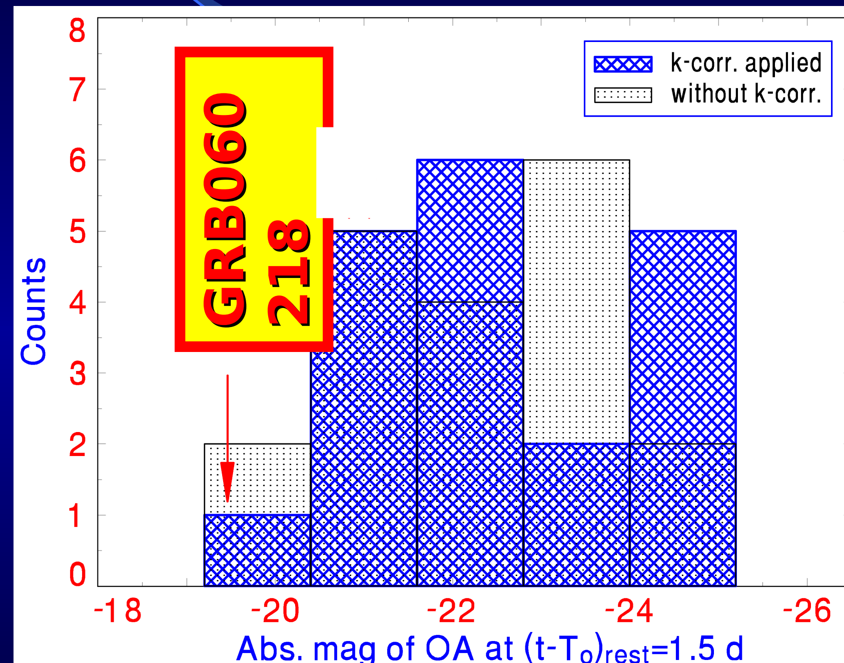
Simon et al. (2007, 2009)

# Histogram of absolute magnitudes of OAs:

# the early OA of GRB060218

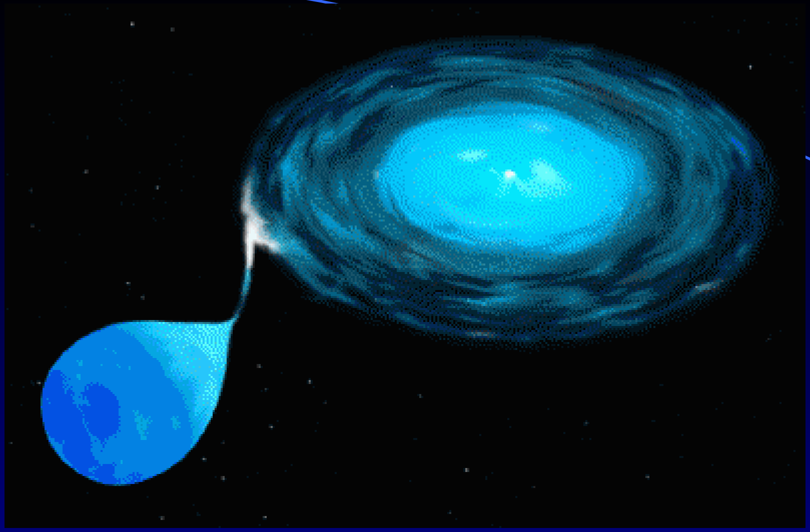



Simon et al. (2009)

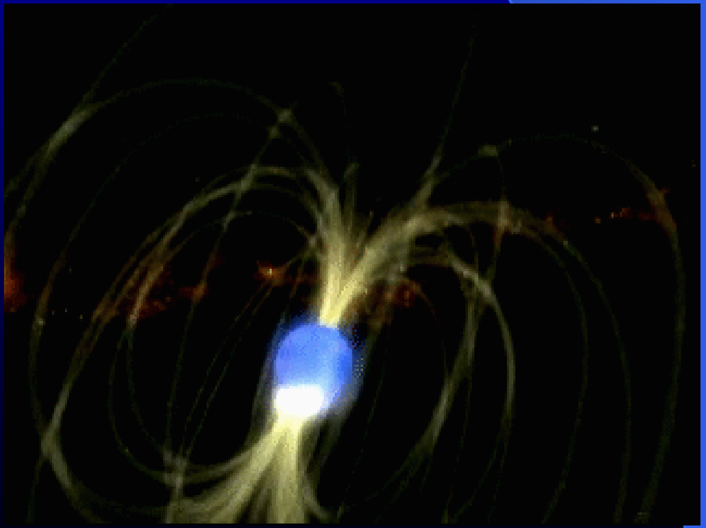



Skewness of the histogram -0.17 suggests asymmetric distribution with a tail toward fainter mag – many supernovae can have the initial optical flare similar to the optical afterglow of GRB – observations in various filters in the early phase of the supernova are needed. The observing angle (with respect to the jet axis) may play a role in the observability of the early emission.

**Statistical distribution of abs. *R* magnitudes of OAs of long GRBs at $(t-T_0)_{rest}$=1.5 d. Both the *k*-corrected and uncorrected values are displayed. Mag of all the OAs was already decreasing**

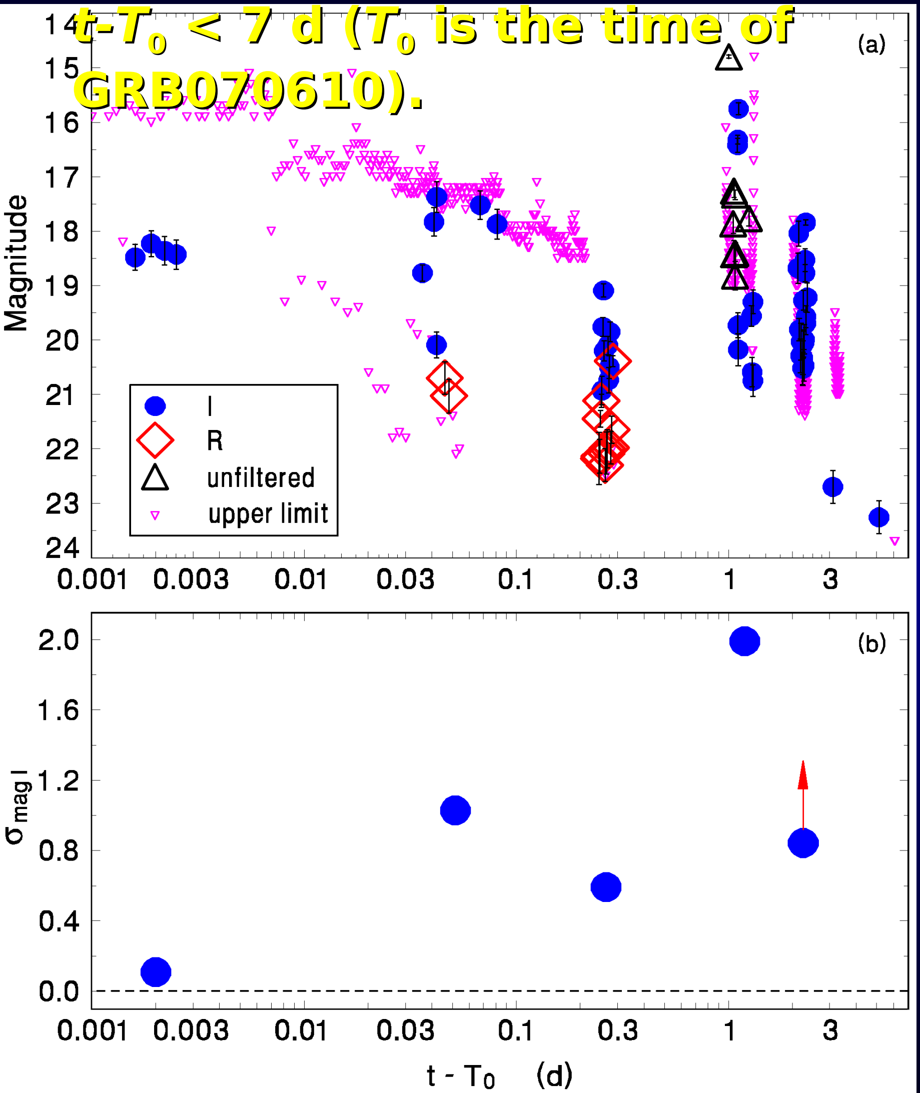


# Magnetars

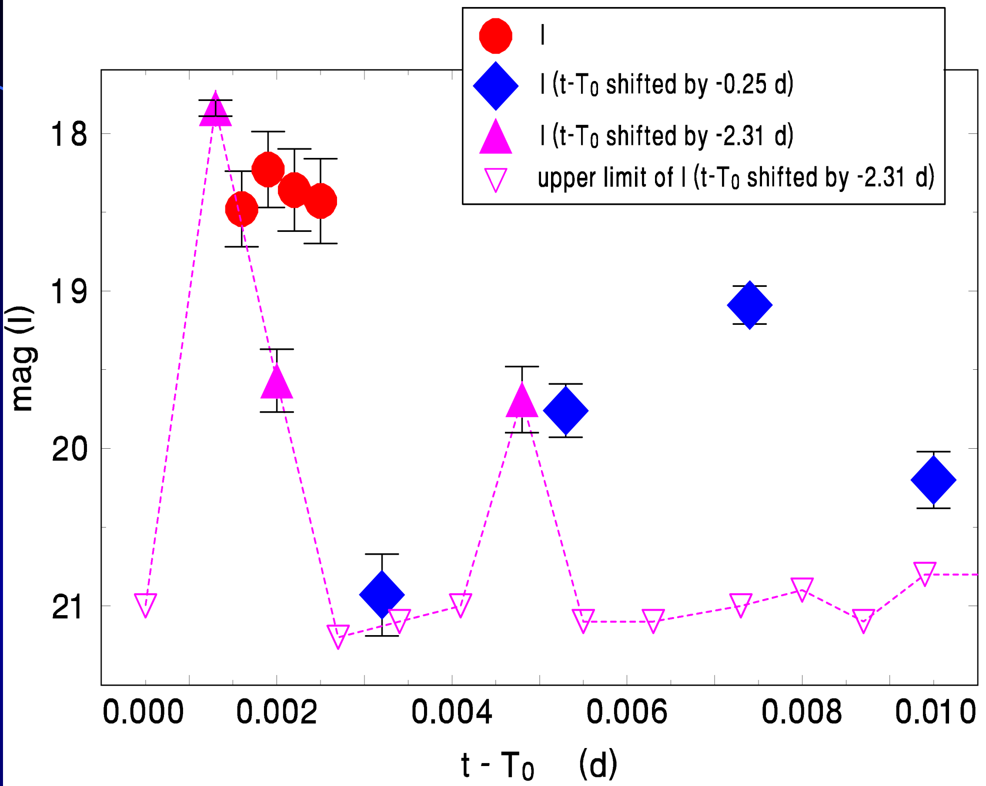


# GRB070610 / SWIFT J195509+261406

**Light curve in the individual passbands for $t$-$T_0$ < 7 d ($T_0$ is the time of GRB070610).**




**Time evolution of the scatter of the points in the**

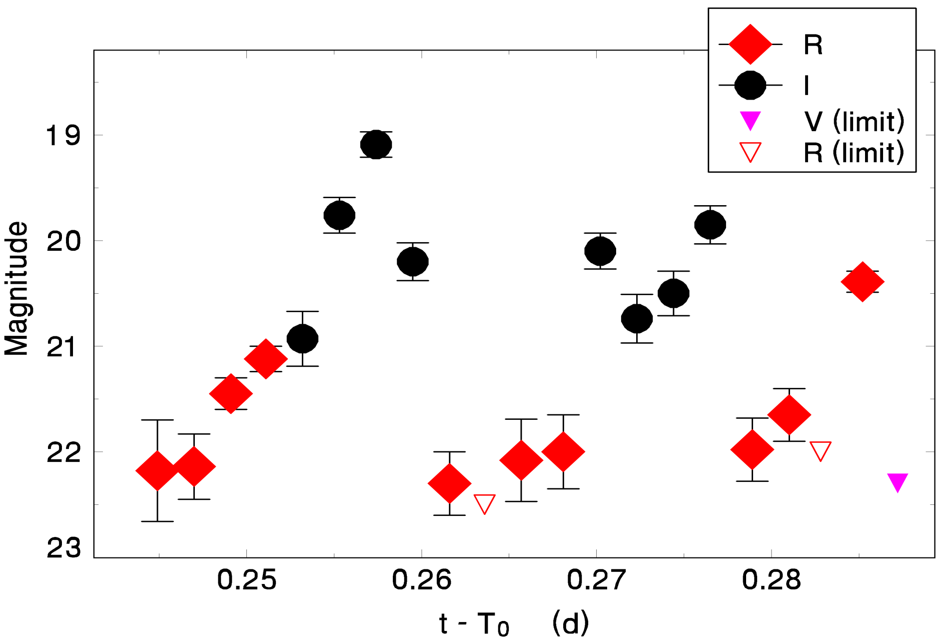



**Comparison of the profile of the *I* band light curve in three epochs after $T_0$.**

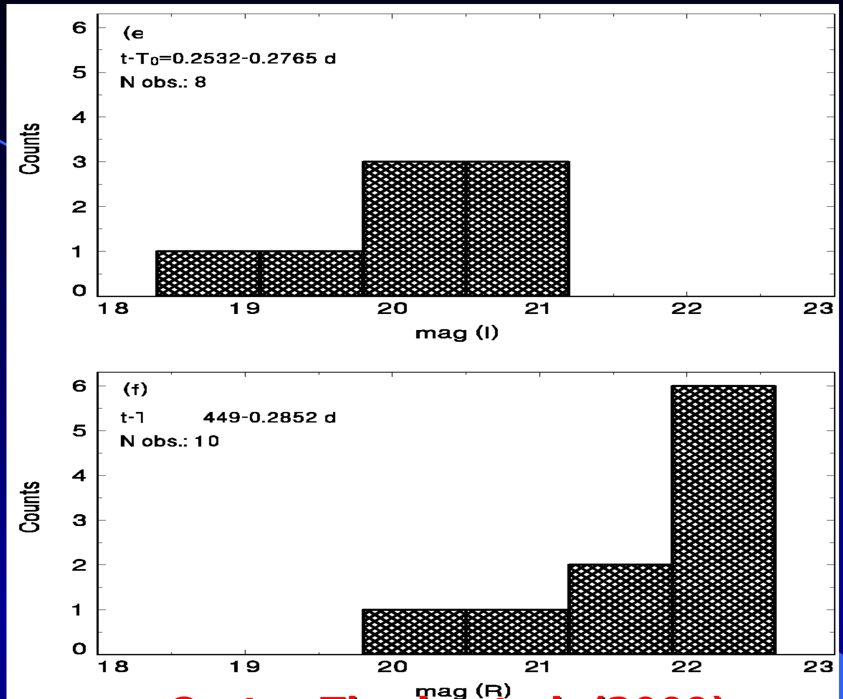
**Flares become more narrow with the progress of the outburst.**

**Castro-Tirado et al. (2008, 2009)**
**Simon et al. (2009)**

# B070610 / SWIFT J195509+2614

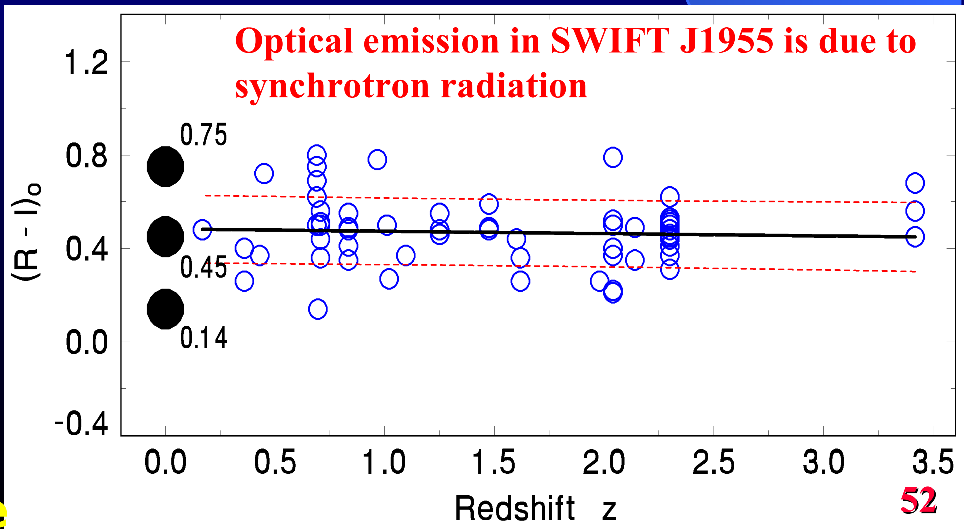



Dense series of the *VRI* observations (dur. ~65 min) (June 11, 2007). The *I* and *R* data are not quite simultaneous. Significant fluctuations of the brightness are apparent (~1 mag, timescale ~15 min).




Castro-Tirado et al. (2009);
Simon et al. (2009)

Comparison of $(R-I)_0$ of J1955 with the ensemble of OAs of long GBs from Simon et al. (2004), plotted as a function of redshift *z* (only OAs with $z < 3.5$, $t-T_0 < 10.2$ d). Color index of each OA is dereddened for the



# General conclusions

- Dense series of observations are necessary to investigate the properties of the long-term activity:

  - resolve the state transitions, like rising and decaying branches of outbursts and high/low states.

  - place these events in the context of long-term activity of a given system

  - form a representative ensemble of events (e.g. outbursts) in (a) a given system, (b) in a type of systems

This is important for our understanding of the physical processes involved.

- Search for the unexpected and unique phenomena

- Wide-field optical monitoring is important for a search for and investigation of

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