Long-term activity of cataclysmic variables and related objects
(large-amplitude features)

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Talk: Large surveys with small telescopes (Astroplate III)
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Mechanisms for long-term activity of CVs

- **Changes of the mass transfer rate d*m*/d*t* from the donor onto the white dwarf** (timescale: days, weeks, months, years)
  - *transitions between high and low states*

- **Thermal-viscous instability of the accretion disk** (timescale: days, weeks, months)
  - *outbursts of dwarf novae*

- **Hydrogen burning of the accreted matter on the white dwarf:**

  Episodic:

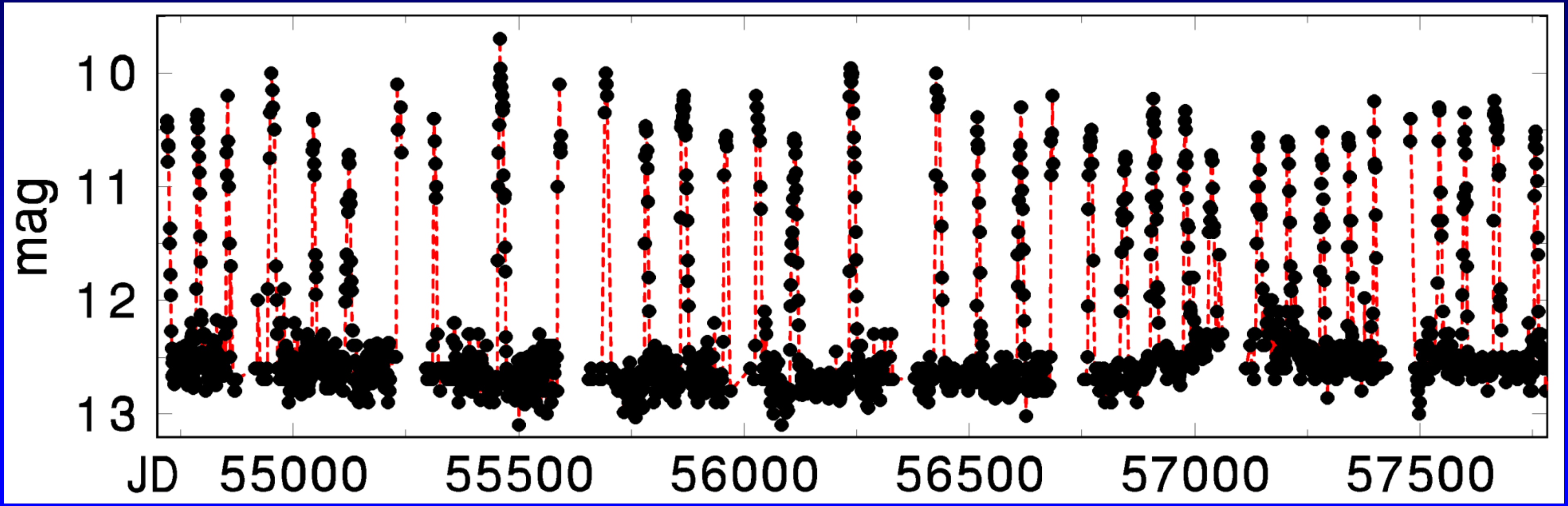
  – *classical nova explosion* (timescale: weeks, months)

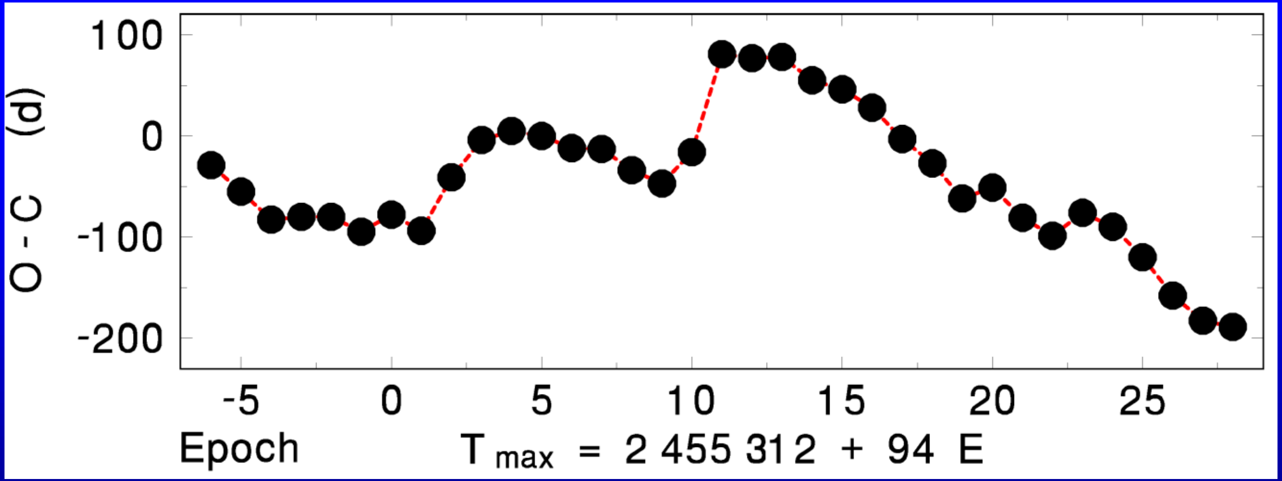
  Steady-state:

  – *supersoft X-ray sources* (timescale: days, weeks, months)

Warner (1995, Cataclysmic Variable Stars, Cambridge Univ. Press, Cambridge)

RU Peg – dwarf nova

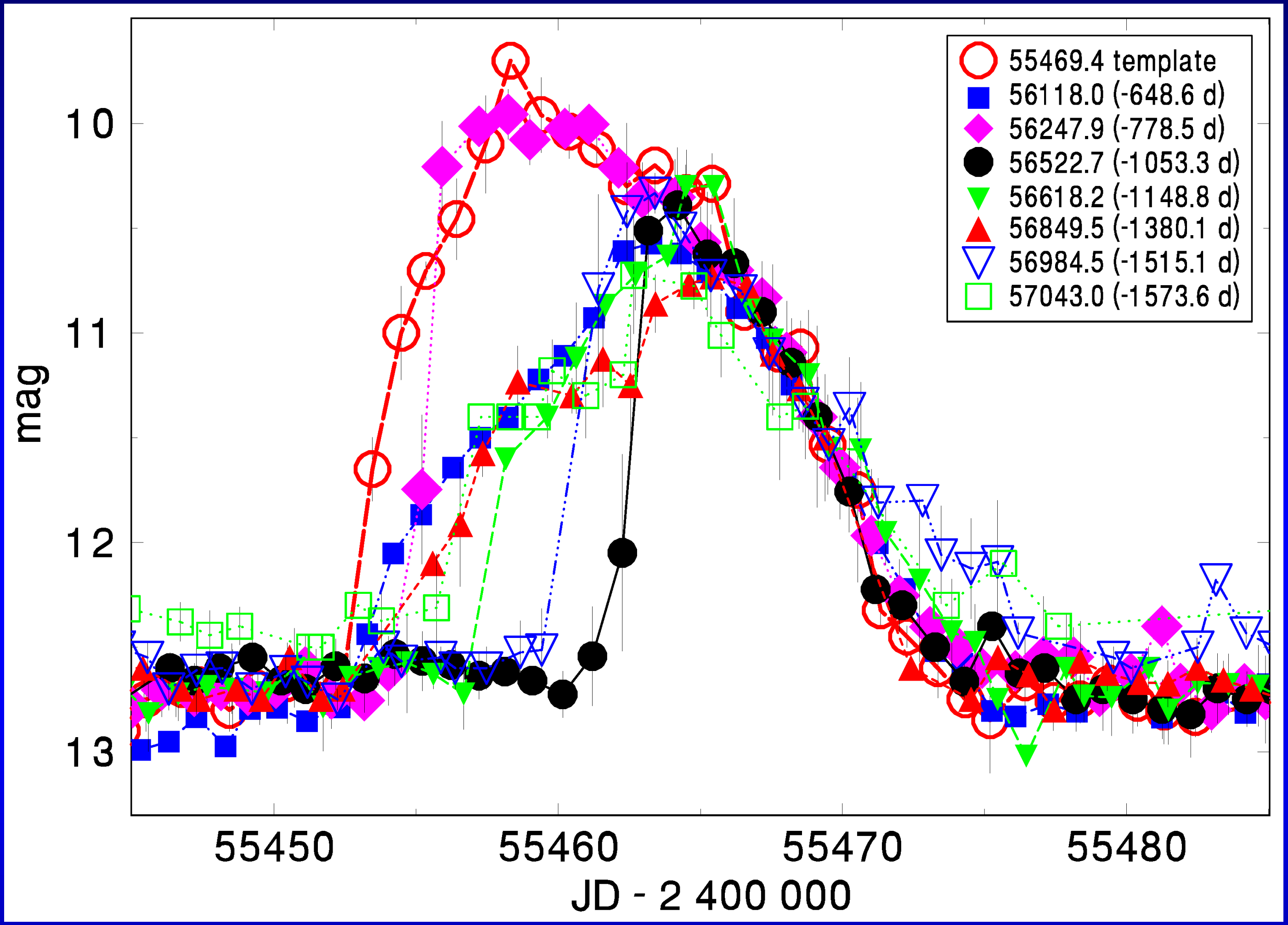


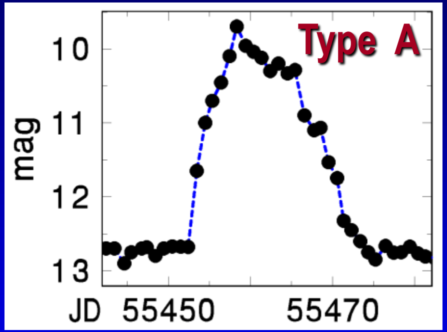


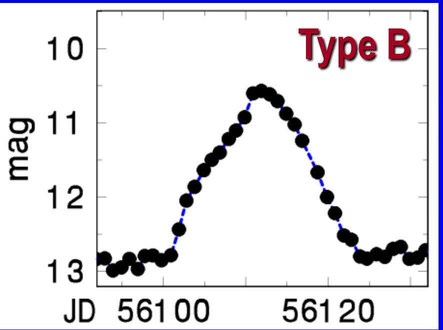
Evolution of the recurrence time T_C of outbursts – the outbursts are dependent on each other.

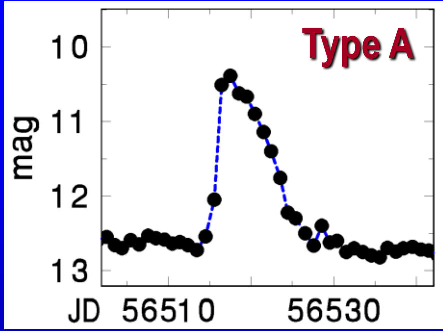
- **Outbursts caused by a thermal-viscous instability of the accretion disk – only a small amount of the disk mass is accreted in outburst**
  (model: Smak 1984,Acta Astron.,34,161)

RU Peg – dwarf nova outbursts



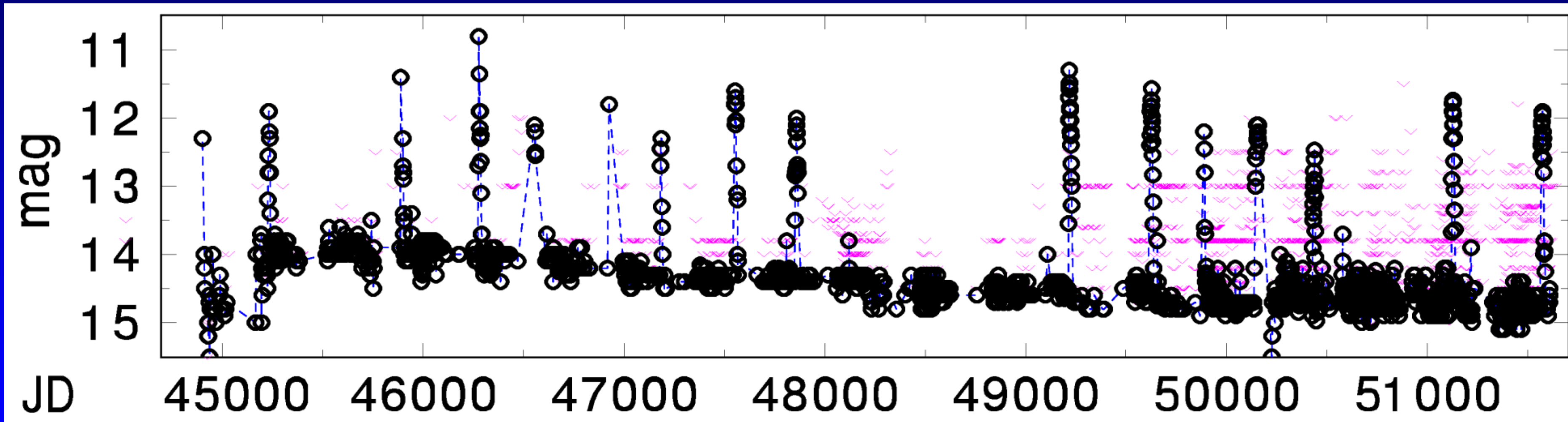


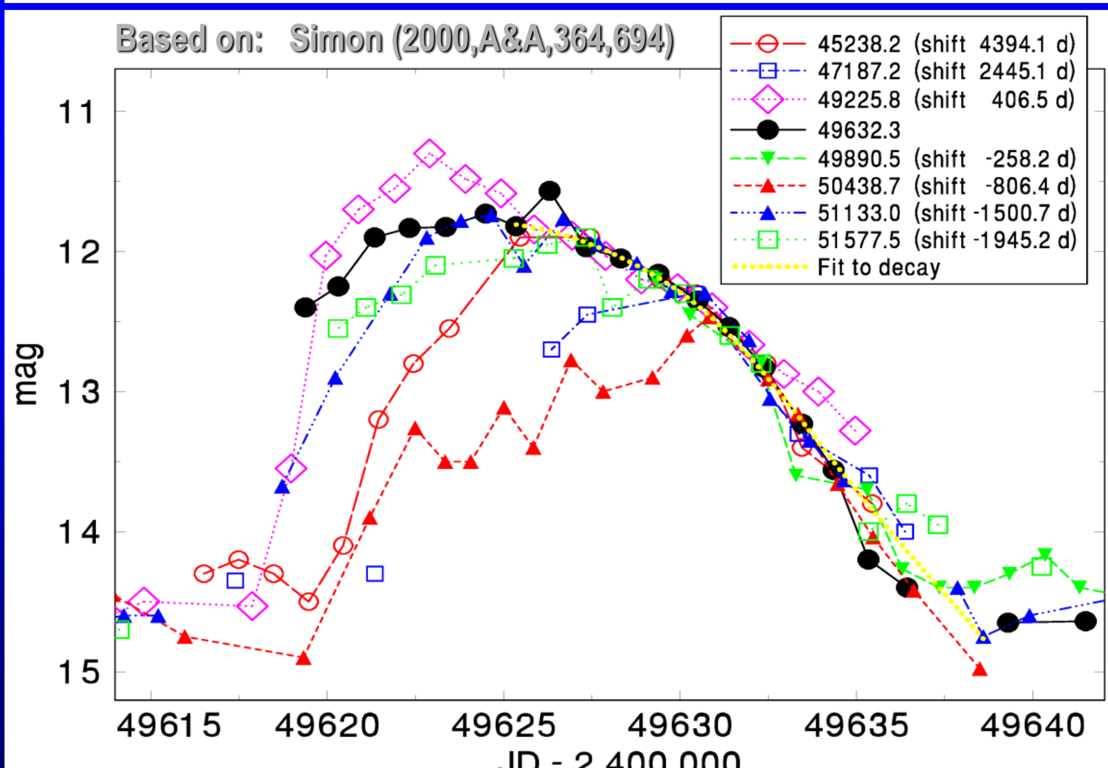




- **Variable positions of the start of heating front (type A versus type B) crossing the disk – variable rising branches of the individual outbursts** (model: Smak 1984,Acta Astron.,34,161)

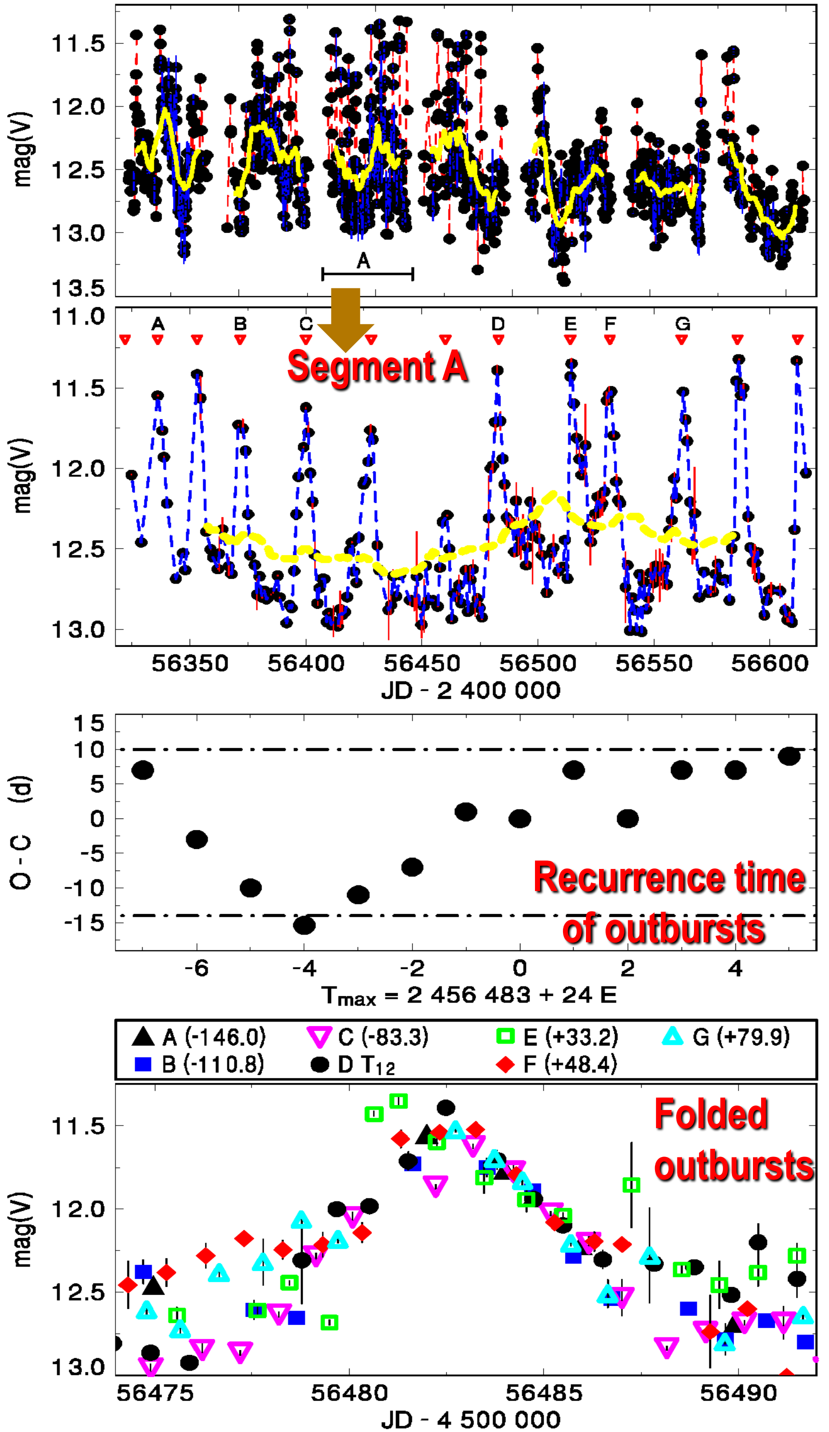
DX And – dwarf nova





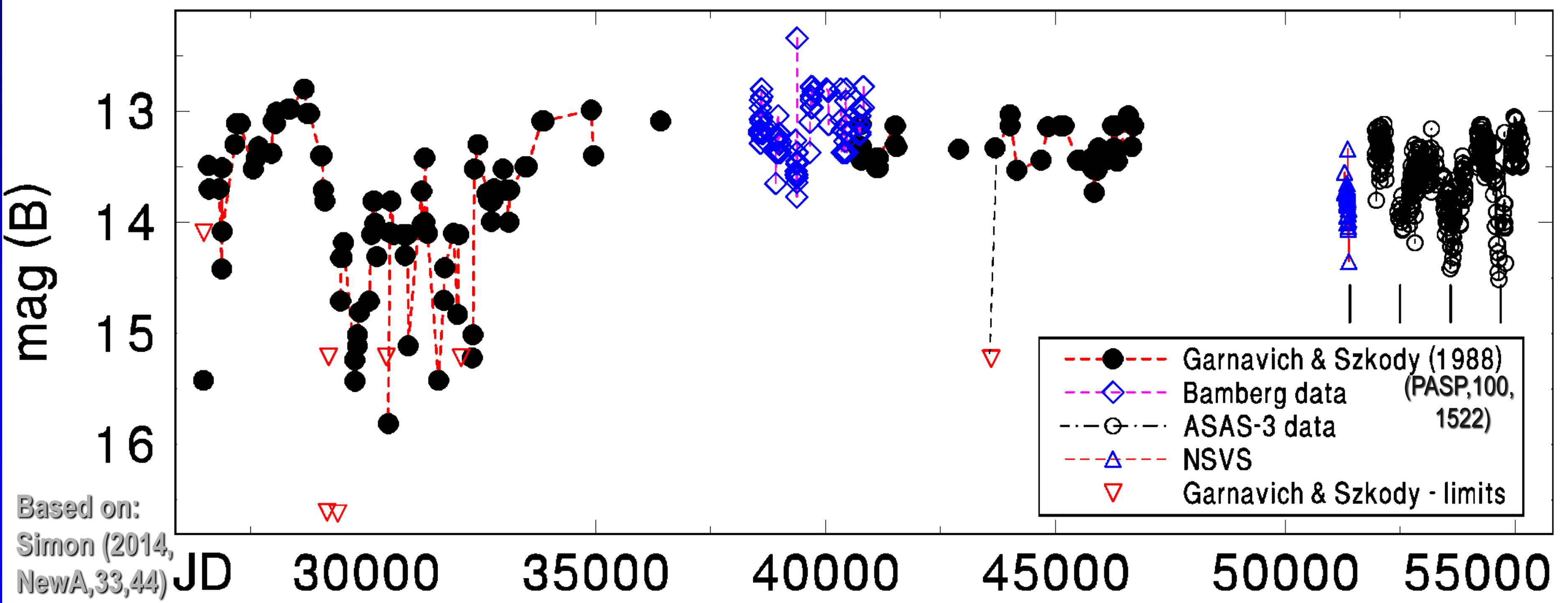
- The rising branches of the outbursts largely variable (heating front in the disk)
- The decaying branches are most stable (cooling front)
- Largely variable disk zone where the outbursts start (no clear separation into outside-in (type A) and inside-out (B) outbursts)

V426 Oph – (dwarf nova? intermedite polar)

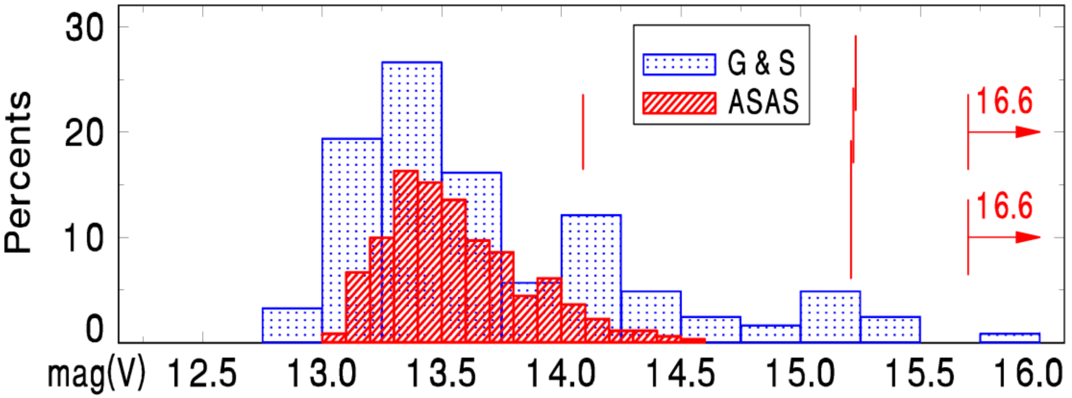


- Clusters of outbursts
- The recurrence time of outbursts usually evolves gradually – outbursts in the cluster depend on each other
- Very similar decaying branches of the outbursts
- Abs. magnitudes permit a thermal-viscous instability of the disk (dwarf nova outbursts?)
- Episodic shallow low states

V1223 Sgr (novalike CV, intermediate polar)

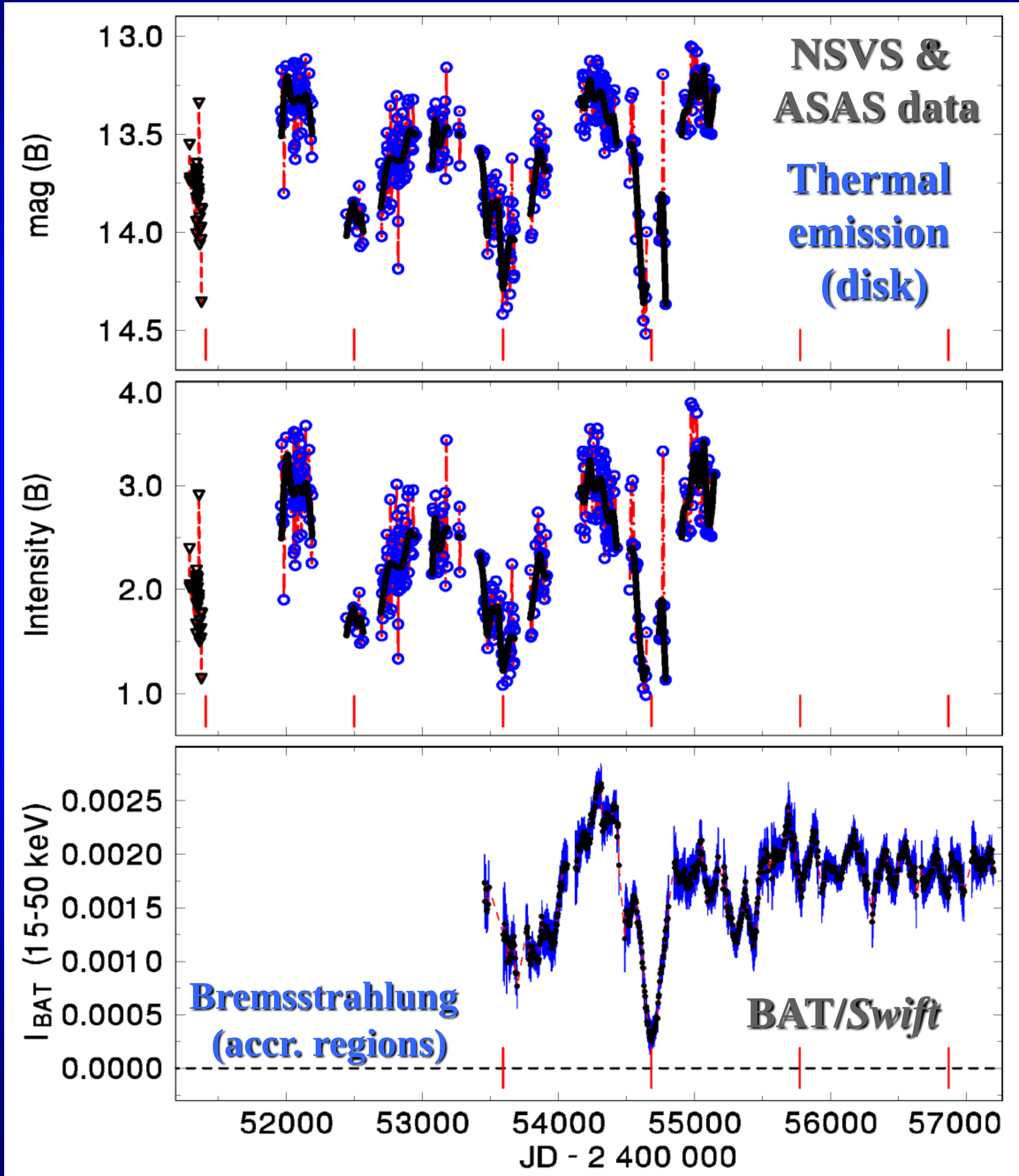


Based on: Simon (2014, NewA,33,44)



- Most low states (decreases of mass transfer rate) occur in clusters.
- Largely variable depths of the low states (decreases of the mass accretion onto the WD)
- The low-state transitions make a long tail in the histogram.

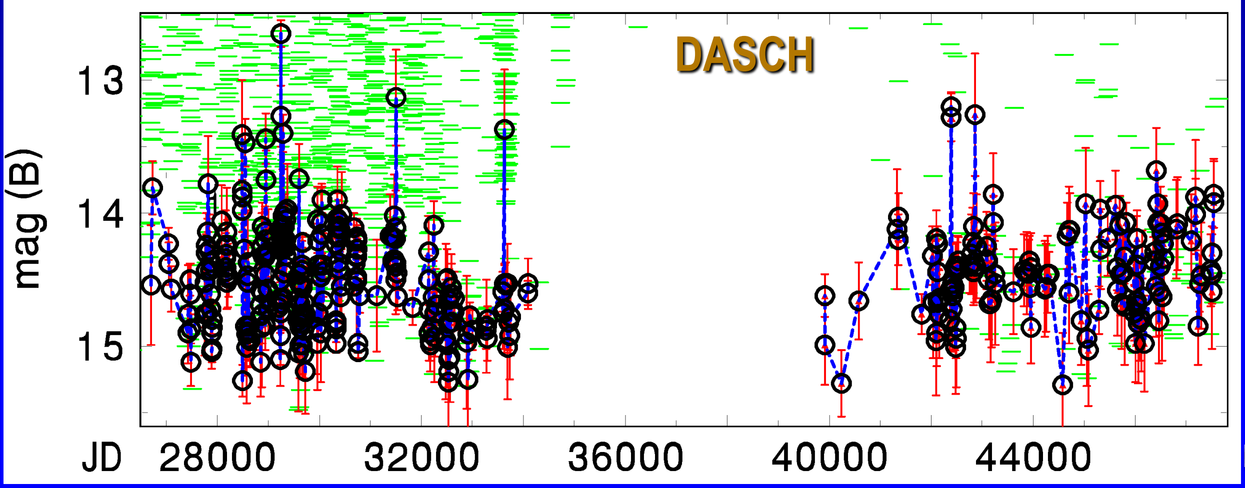
V1223 Sgr – relation of optical and X-ray activity

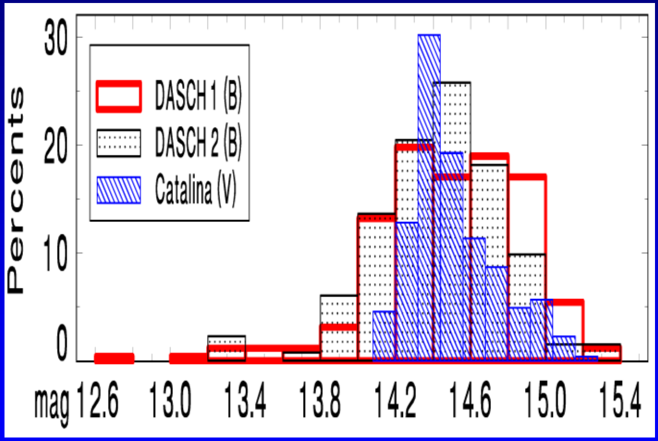


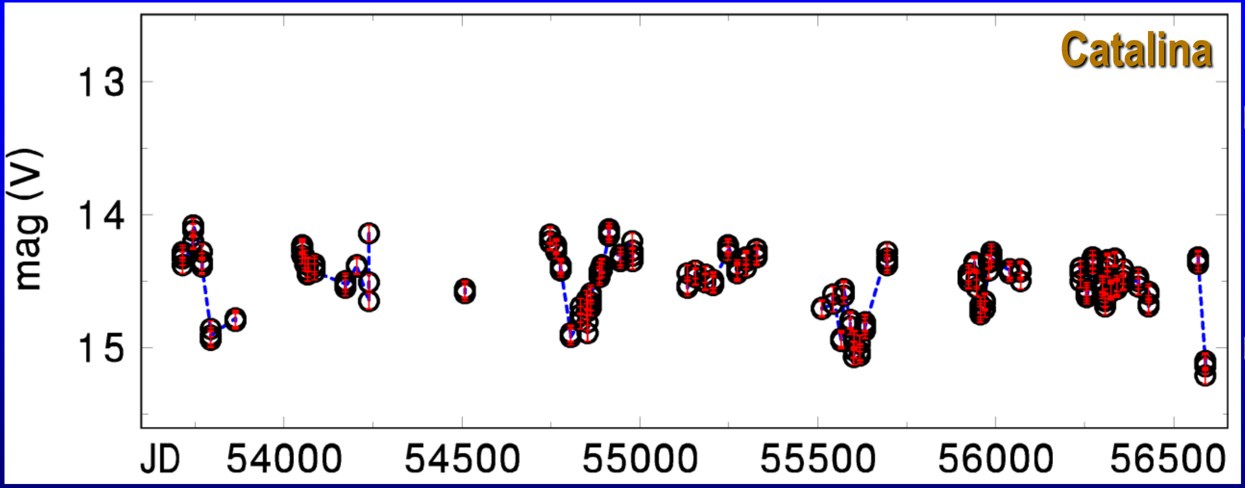
- Accreting regions at the polar caps of the WD:
  – sources of very hard X-ray emission (bremsstrahlung)

- The cause of the shallow low state – decrease of the mass inflow to the disk from the donor (not only changes of the disk structure) – this places the constraints on the model of Beuermann et al. (2004,A&A,419,291)

EI UMa (intermediate polar (novalike?))

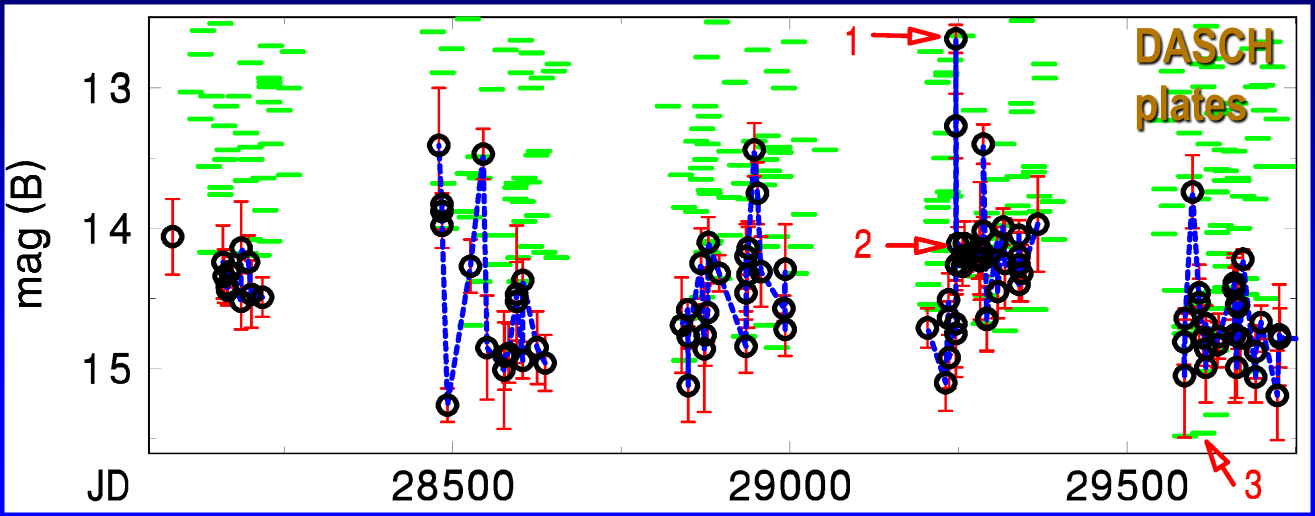


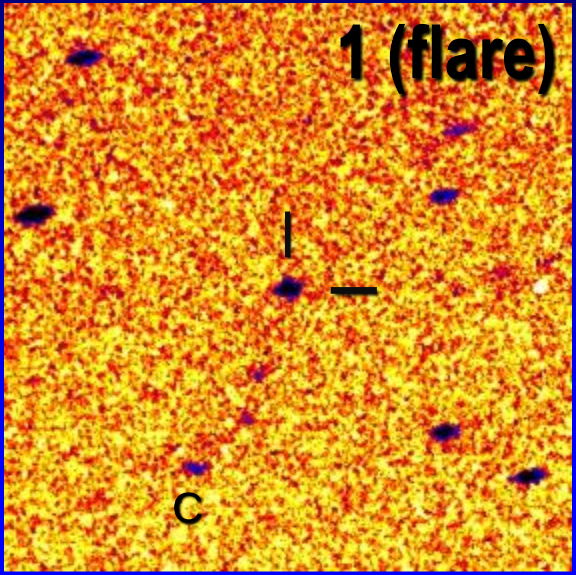




- Roughly constant mean brightness (months)
- Brightness fluctuations and short flares (days)
- Shallow low states in the Catalina data (but flares are missing)

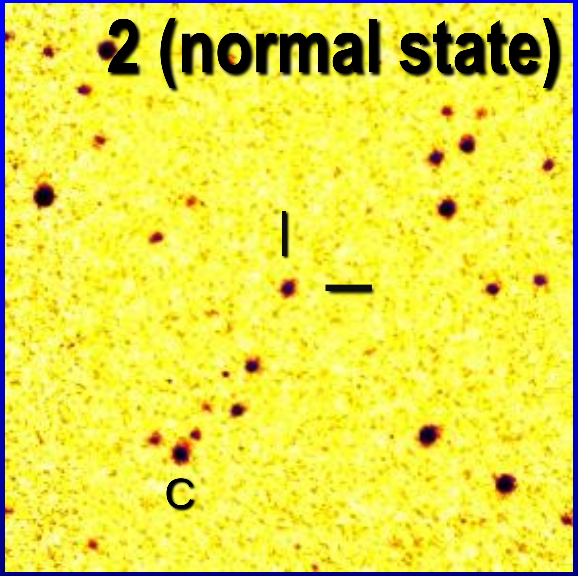
EI UMa – flares (outbursts)

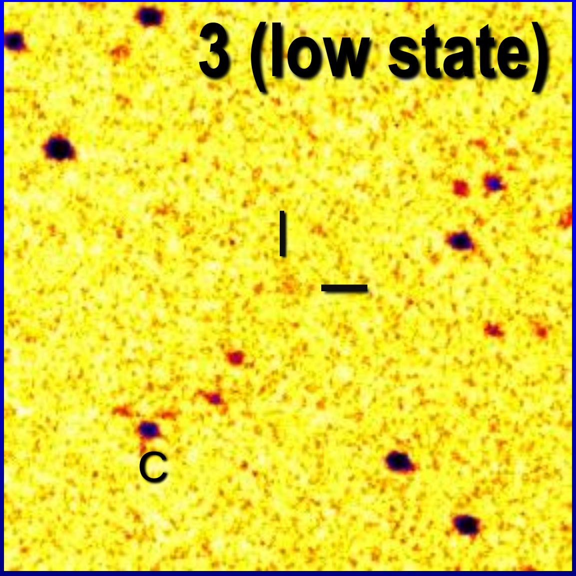




- The flare is a short rare event (at most a few days)

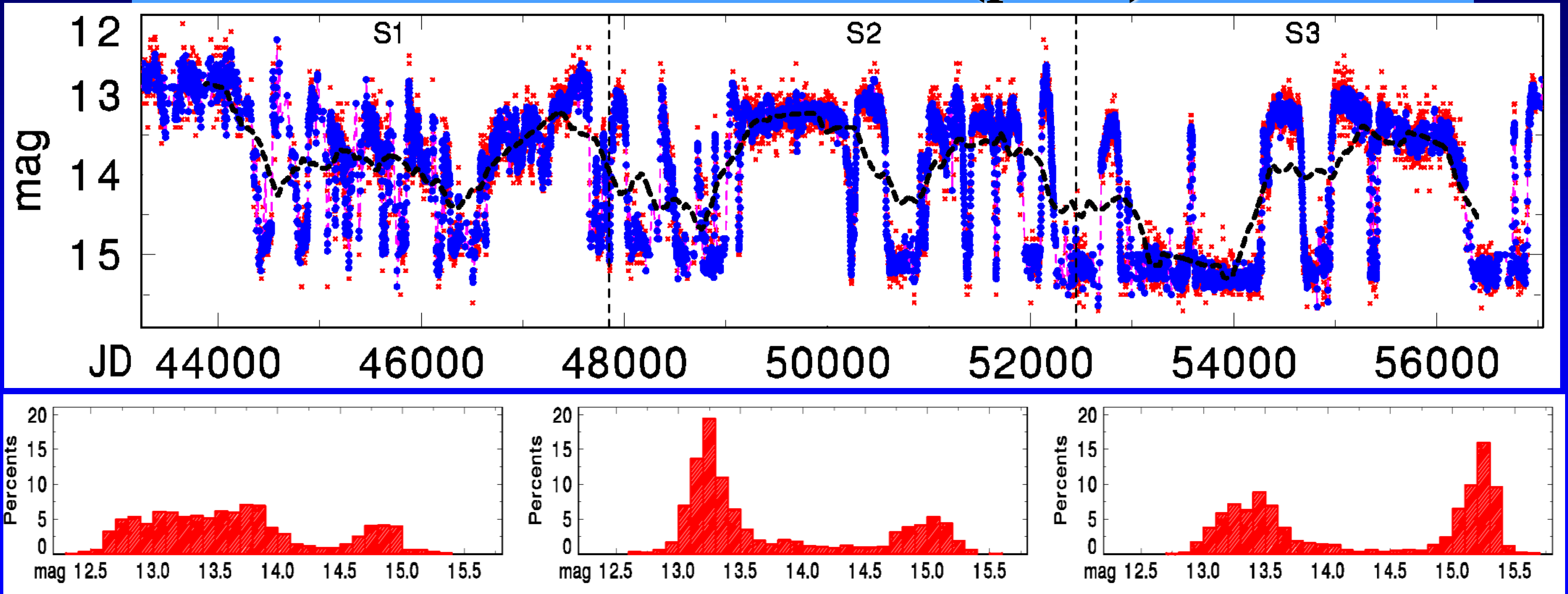
- The flares start from a too high luminosity (between outburst and quiescence of dwarf novae) – a thermal-viscous instability is thus unlikely.





20 x 20 arcmin. North is up, East to the left.

AM Her (polar)

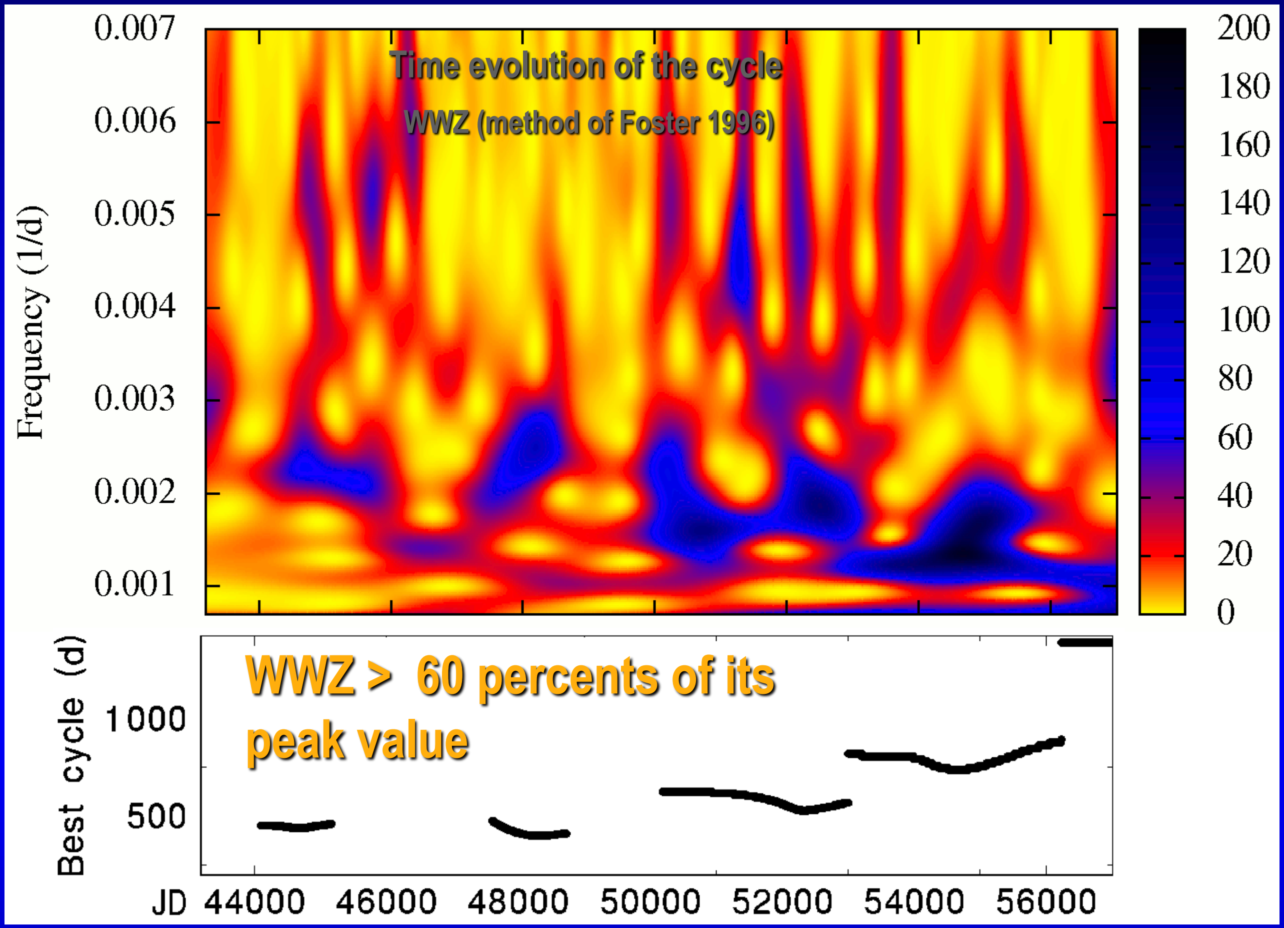


Blue points: HEC13 fit running through the strong orbital modulation to emphasize the long-term light curve (~33 years)

Based on: Simon (2016,MNRAS,463,1342)

- Most low states (decreases of the mass accretion rate onto the WD) occur in clusters.
- Moving averages (black line) running through the clusters of the high and low states produce a very long cycle (several years).
- The high states are NOT the well-defined levels of brightness.

AM Her – cycles in the HS/LS transitions



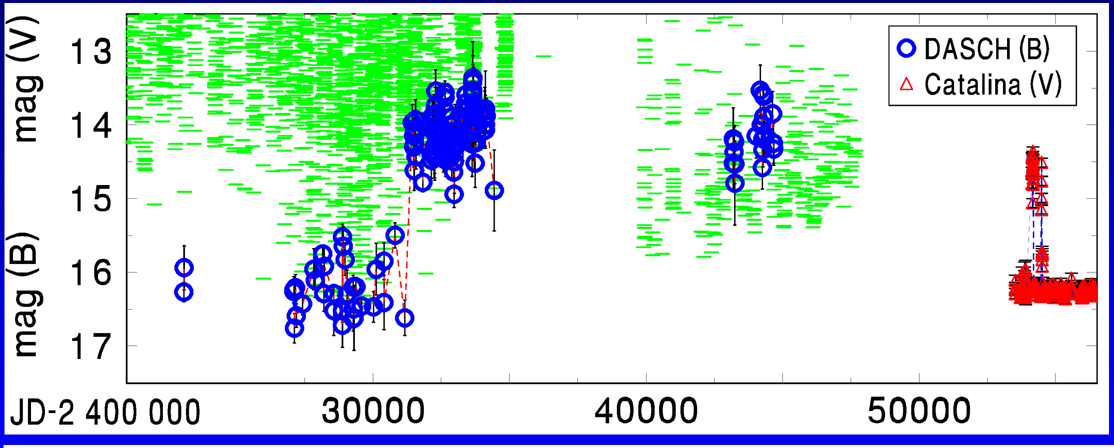
- Accumulation of the episodes of the high and low states in clusters – this produces the cycle

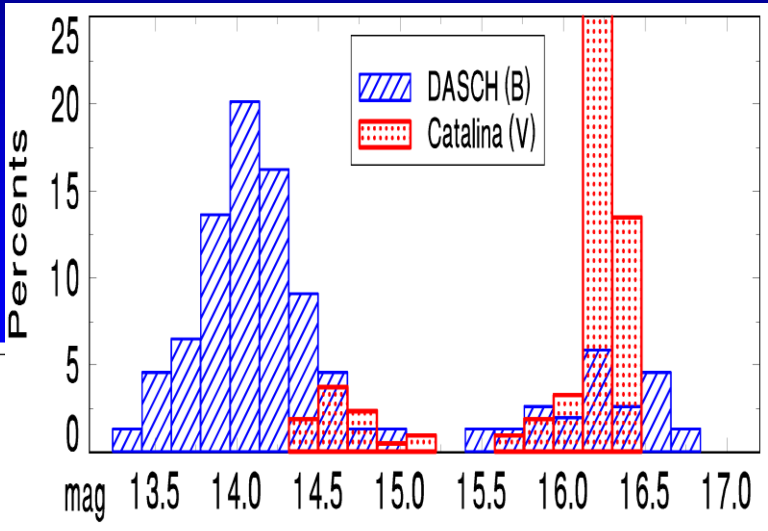
– a single isolated short low-state episode does not imply a break of this cycle

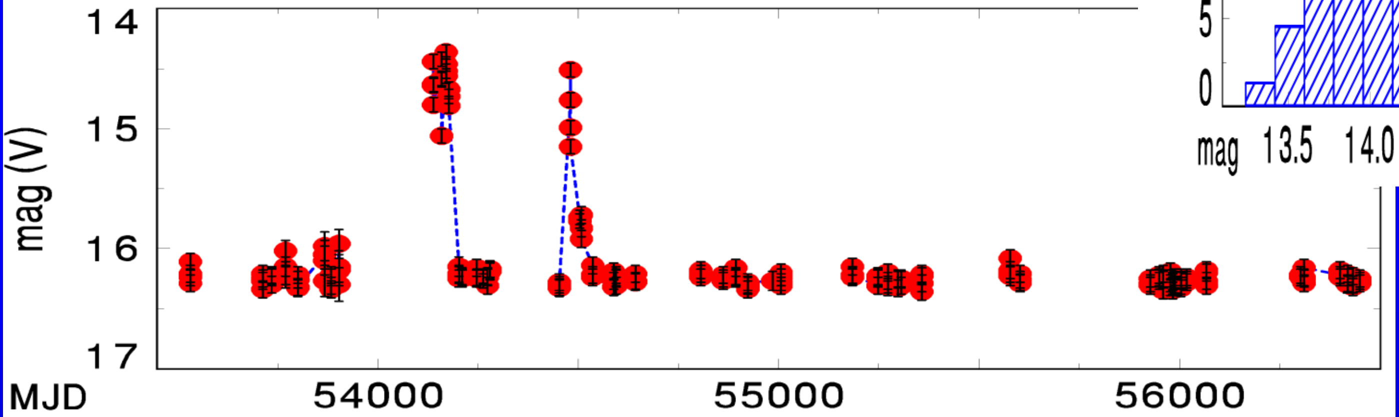
- The series of the transitions between high and low states can be controlled by the lifetime of the active regions on the donor with the differential rotation, modulating the mass transfer rate.

Based on: Simon (2016,MNRAS,463,1342)

AR UMa (polar)

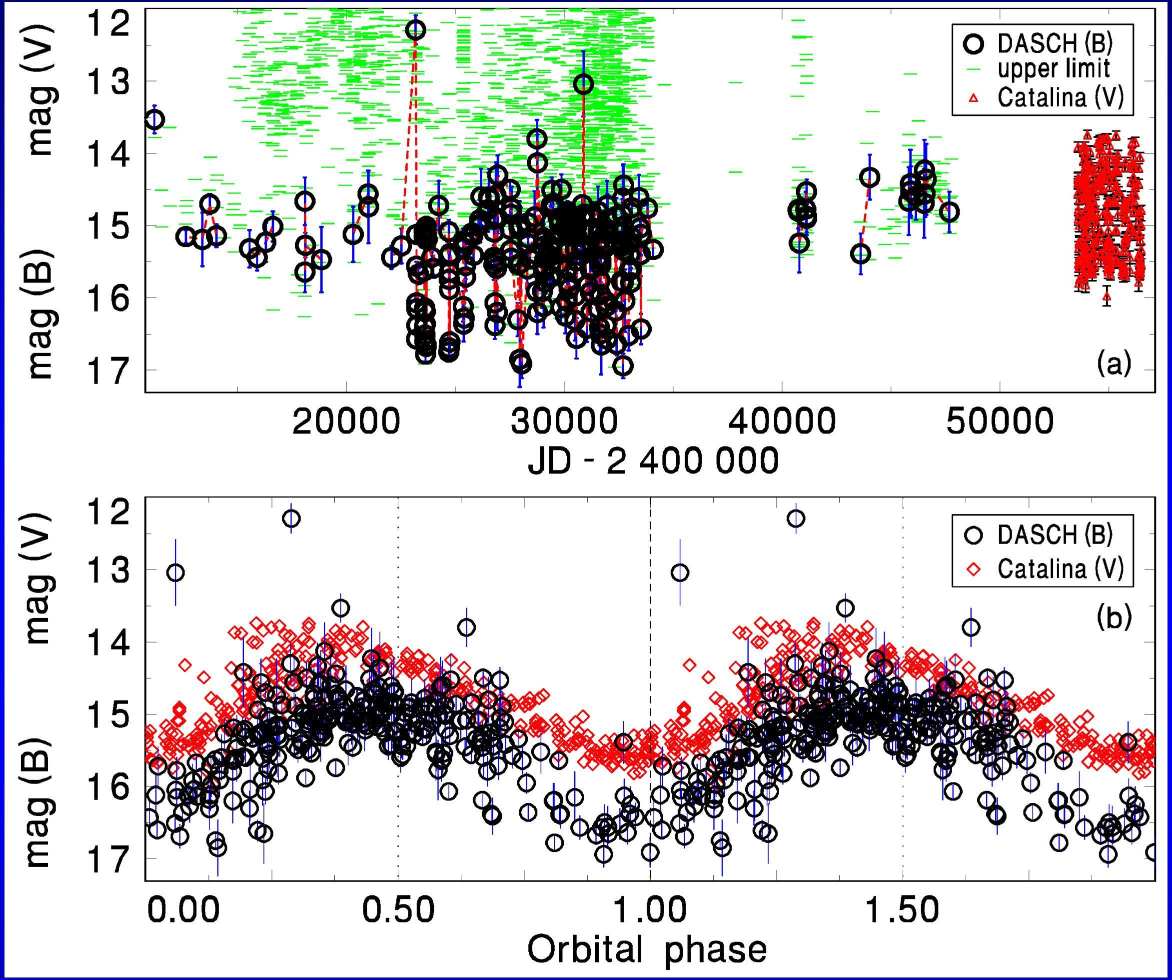


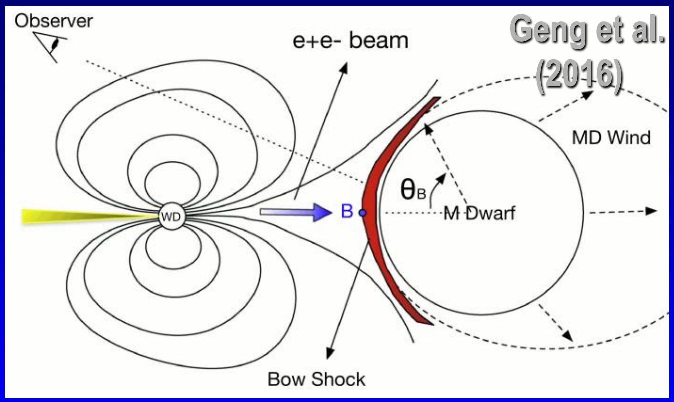




- **The high-state episodes occur from a stable low-state level**
  - ***the low-state mass transfer rate and the structure of the accretion regions thus attain similar values for each episode***
- **Catalina obs. suggest isolated bursts of mass transfer from the donor (very short high states).**

AR Sco (WD pulsar)

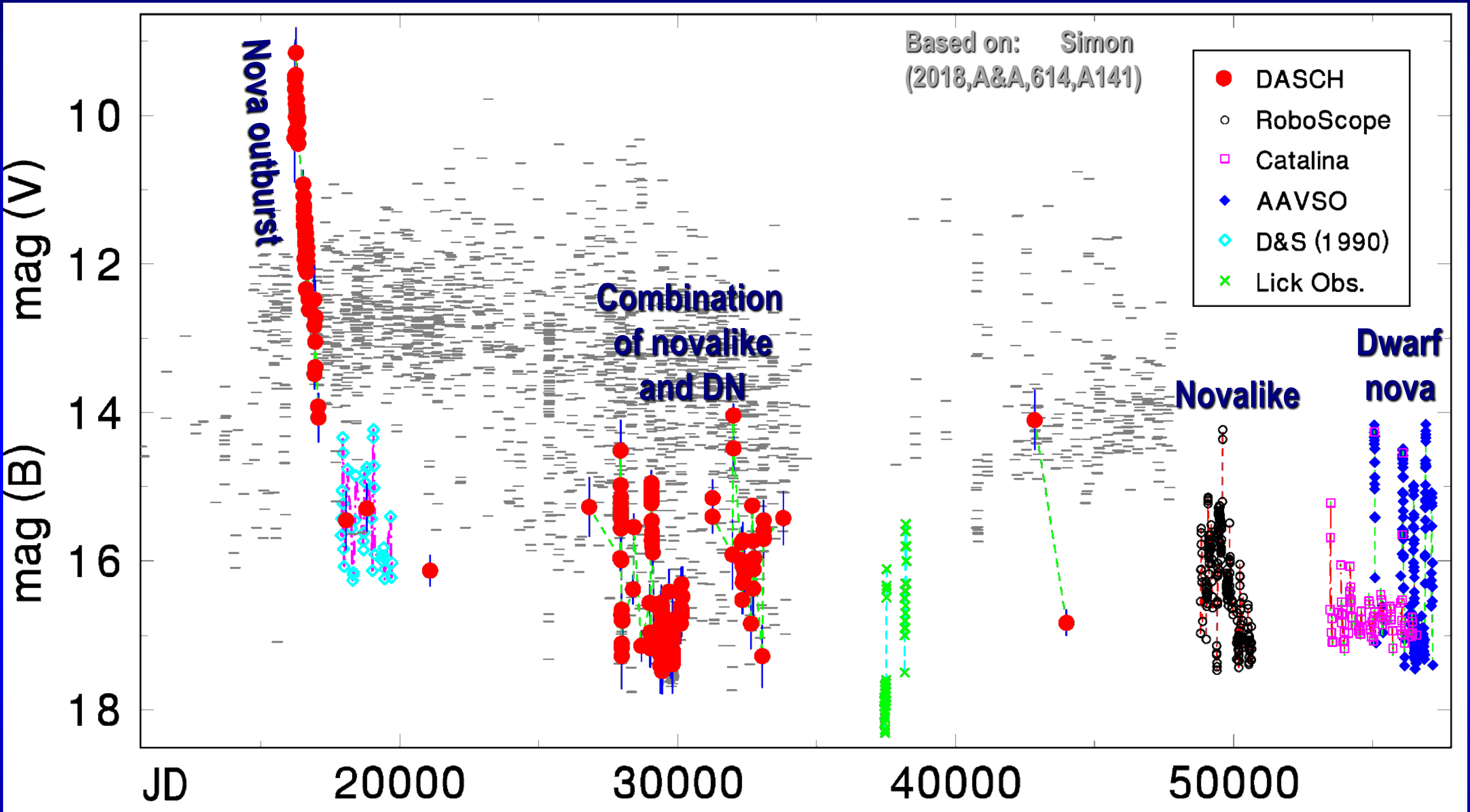




- Persistent asymmetry of the modulation – stable strength of the outflow from the donor

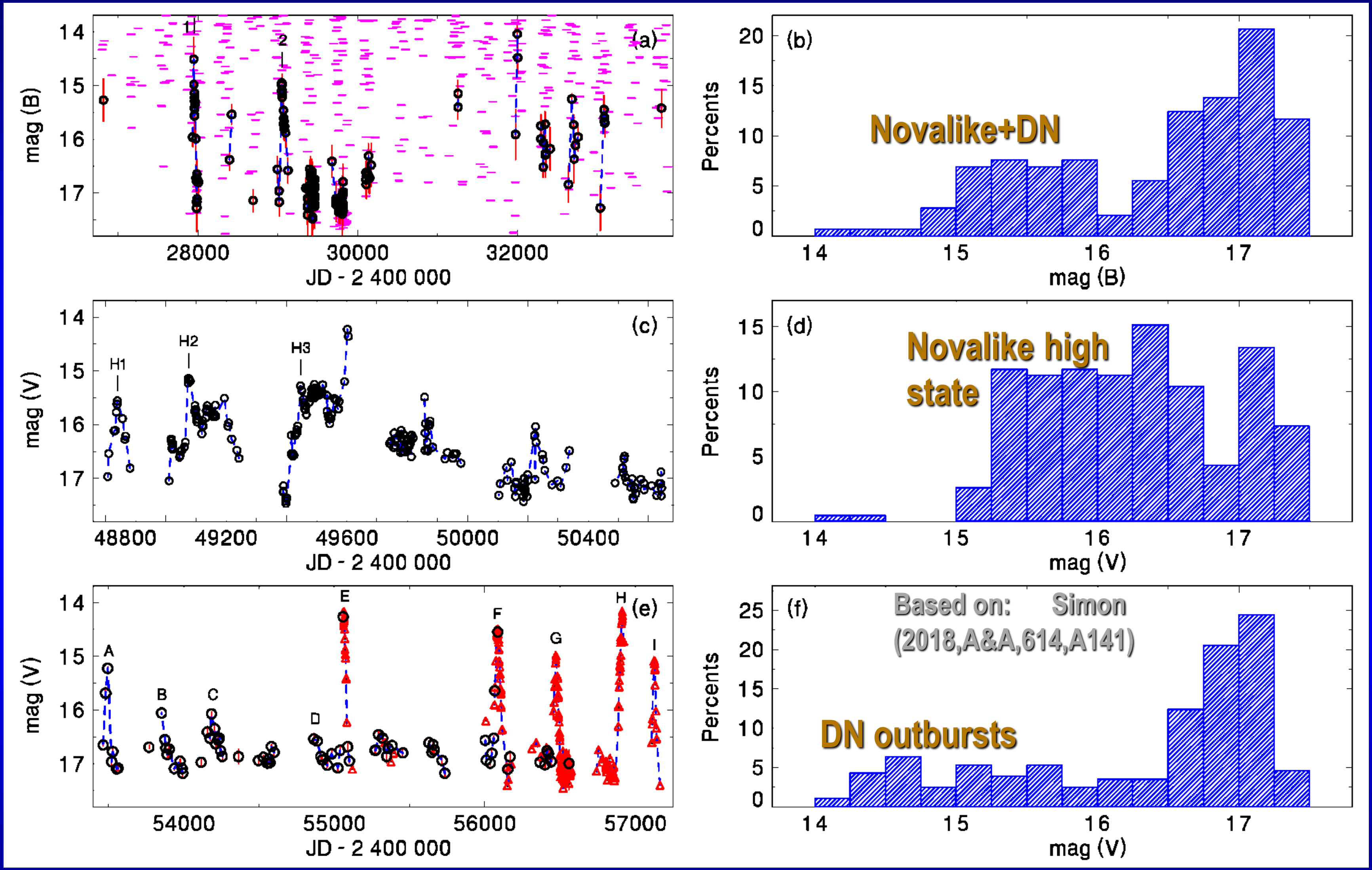
- Activity caused by a very strong orbital modulation (P_{orb} = 3.56 hr) – interaction of synchrotron jet from the magnet. WD with the wind of the late-type donor star (Marsh et al. 2016,Natur,537,374; Geng et al. 2016,ApJ,831,L10)
- A very low luminosity of AR Sco (similar to a very long low state in novalikes) and a very rapid spin of the WD ⟹ CV after a phase of a very high mass transfer rate

Role of classical nova outbursts – X Ser



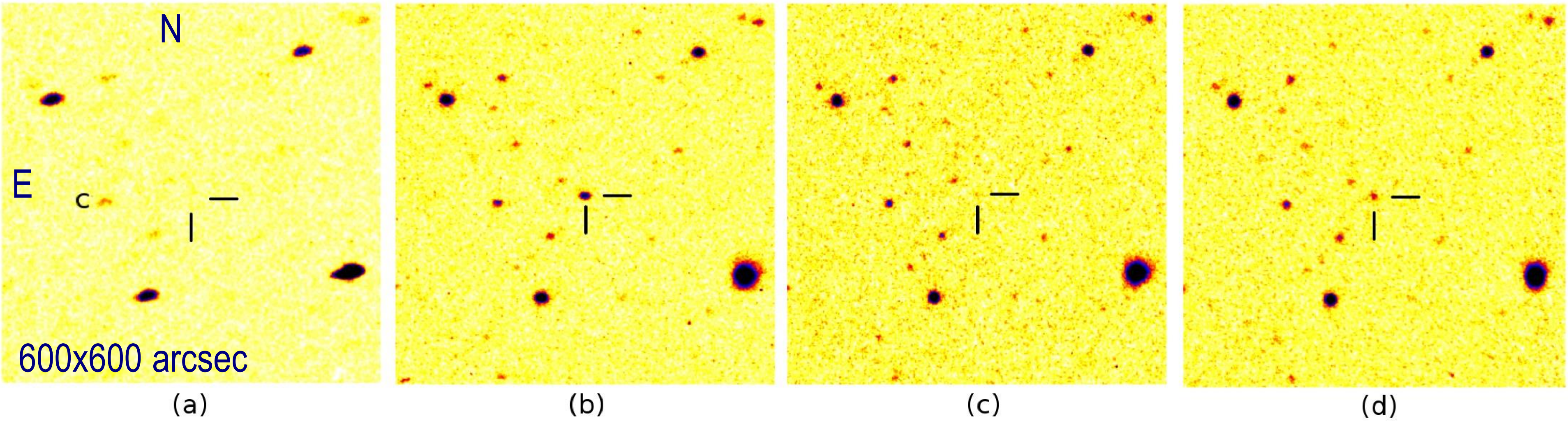
- Complex time evolution of activity of a post-nova (CV recovering from its classical nova outburst)
- The characteristics of various CV types in this post-nova (transient increases of mass outflow from the donor toward the WD?)

Role of classical nova outbursts – X Ser



- **Evolution of this post-nova – rapid transition to a thermal-viscous instability regime of the disk, initially only intermittently.**

X-Ser: appearance on the DASCH plates



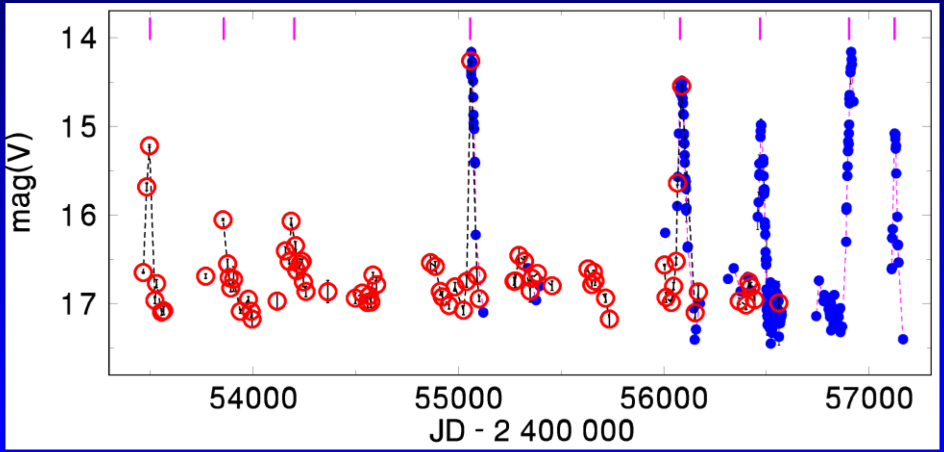
(a) The deepest image of X Ser in its pre-nova stadium (the year 1901.586388) (fainter than the check star C with 16.1mag(*B*)

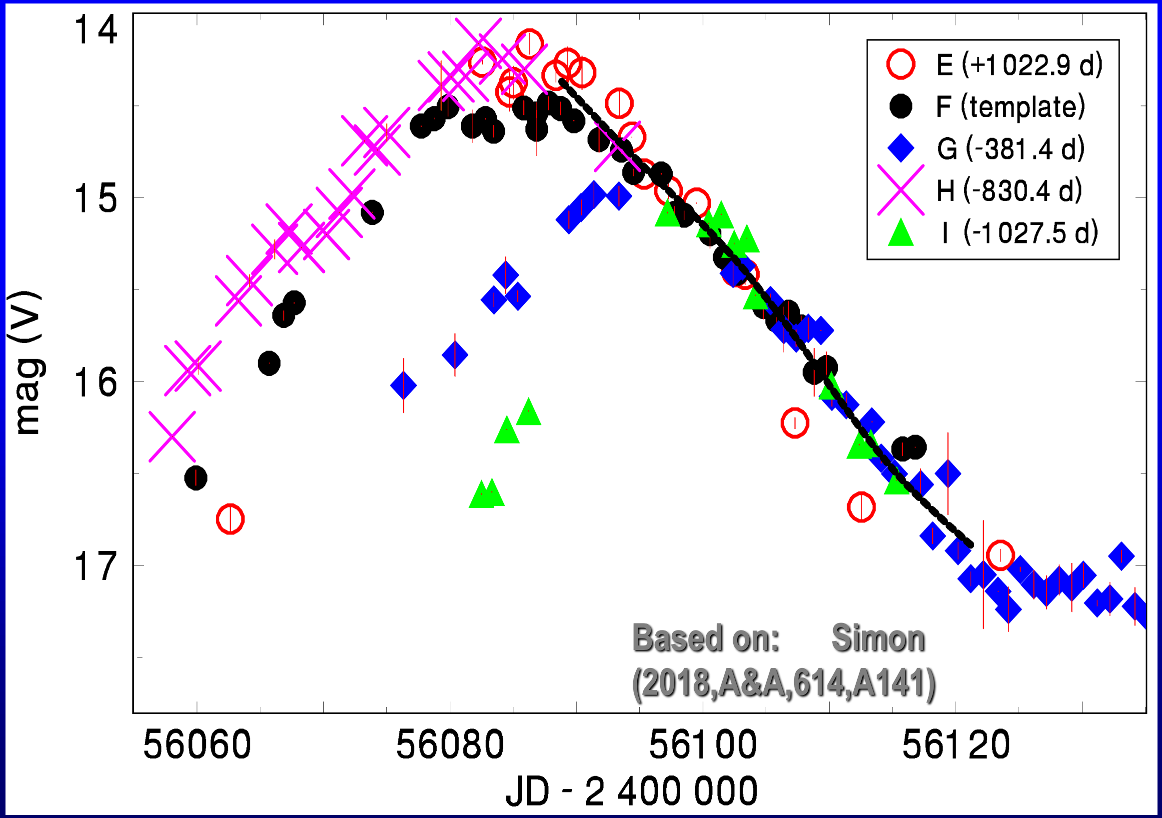
(b) The peak of an episodic brightening in the post-nova stadium (the year 1938.418667).

(c) Faint state (at the limit of the detection) in the post-nova stadium (the year 1940.202419).

(d) The phase of the gradual brightness variations (the year 1948.488371)

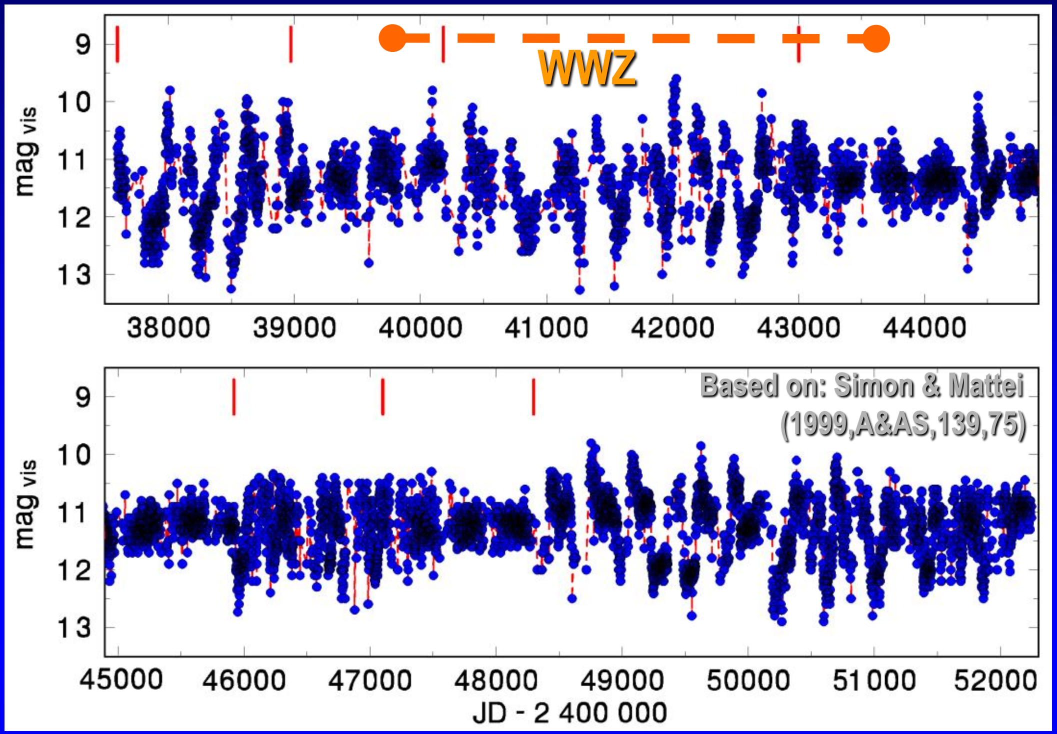
X Ser – DN outbursts

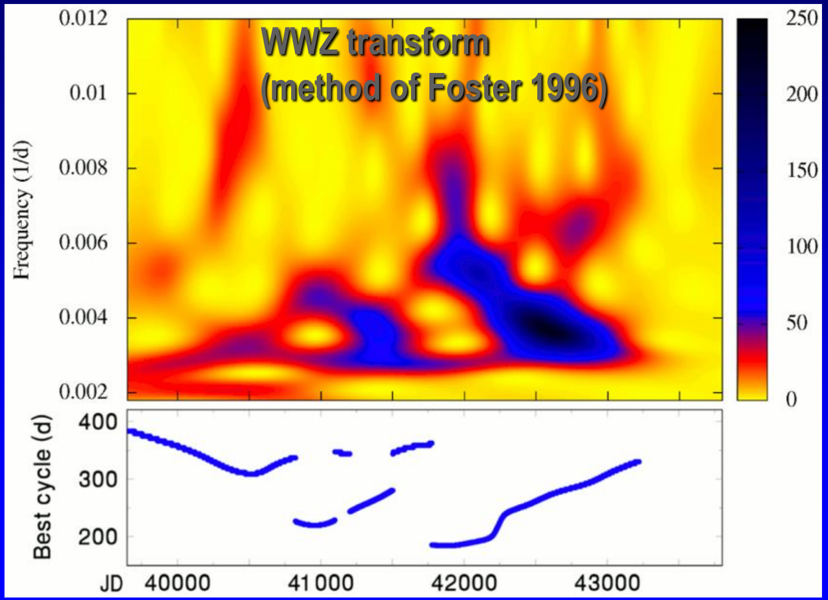


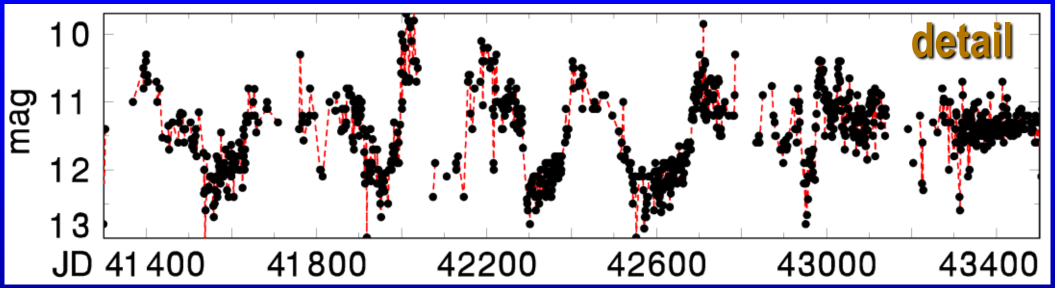


- A series of outbursts from a well defined level
  - Decay rate reproduces itself for the ensemble of outbursts.
- Slow rise – inside-out outbursts (heating front propagates from the inner disk region (it may not reach the outer disk rim).
- The decay rate of outburst corresponds to a CV with a very long P_{orb} = 1.498 d of Thorstensen & Taylor (2000,MNRAS,312,629)

V Sge (transient supersoft X-ray source)





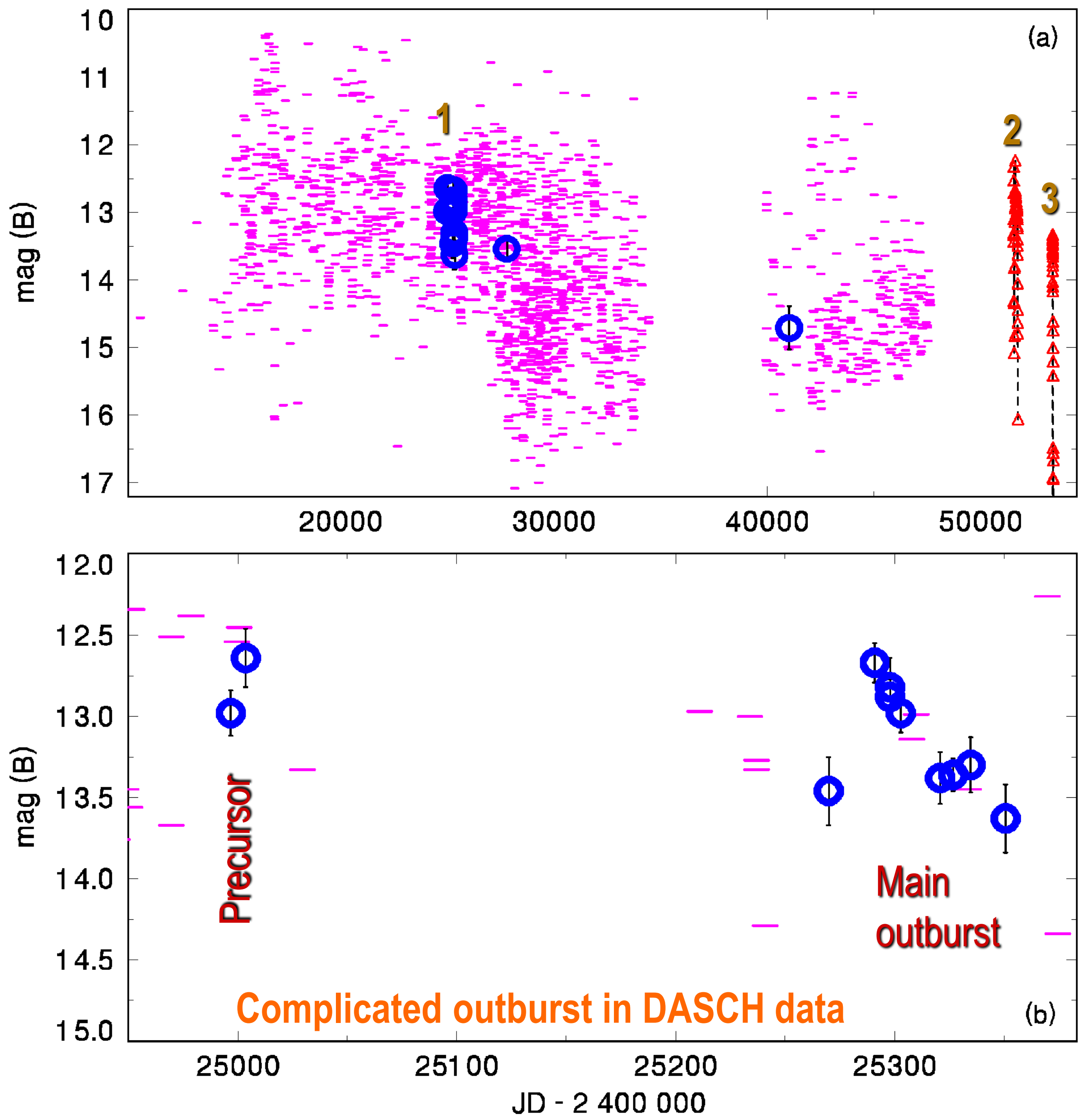


- **Intermittent cycles of transitions between the high and low states (cycles of changes of stripping of the donor by the wind from the WD (model of Hachisu & Kato 2003,ApJ,598,527))**

- **Transitions between the high and low states are the dominant features of the optical activity.**

- **Even in the low state, the luminosity is still much higher than what is possible for operation of a thermal-viscous instability of the disk.**

Soft X-ray transient XTE J1118+480 (KV UMa)



- **Soft X-ray transient (black hole accretor)** (McClintock et al. 2001, ApJ, 551, L147; Khargharia et al. 2013, AJ, 145,21)
- **Big optical outbursts**
  - complex features in the light curves of some outbursts
  - X-ray outbursts
- **The recurrence time: years – decades**

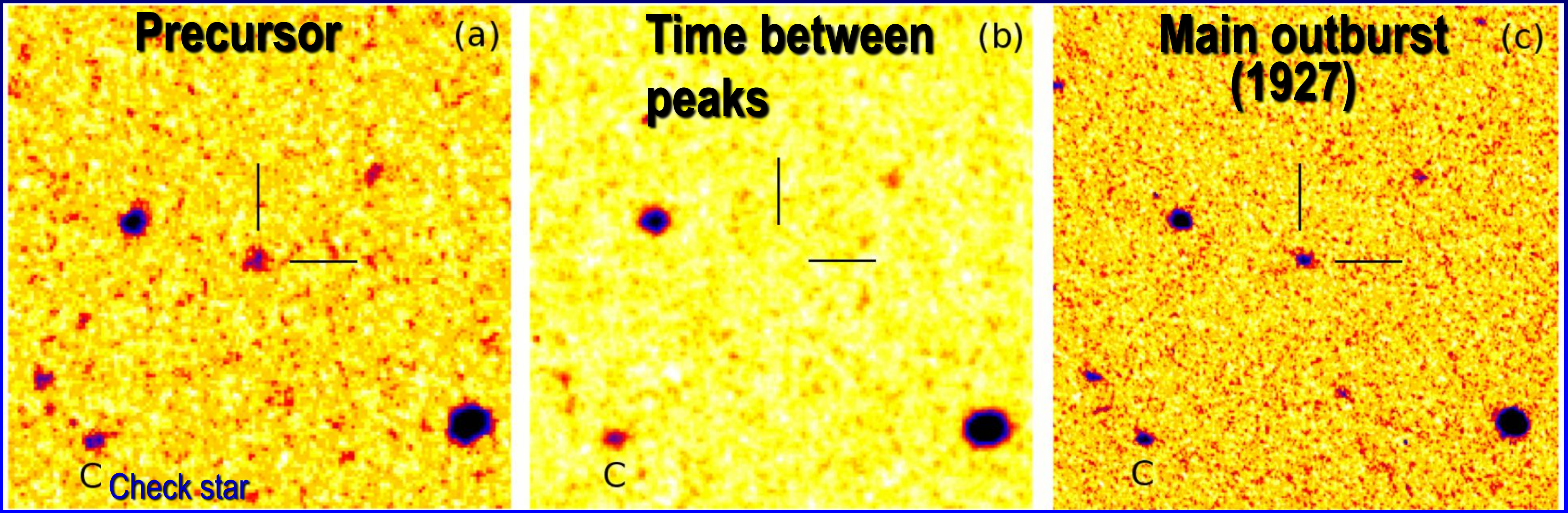
Detected outbursts:

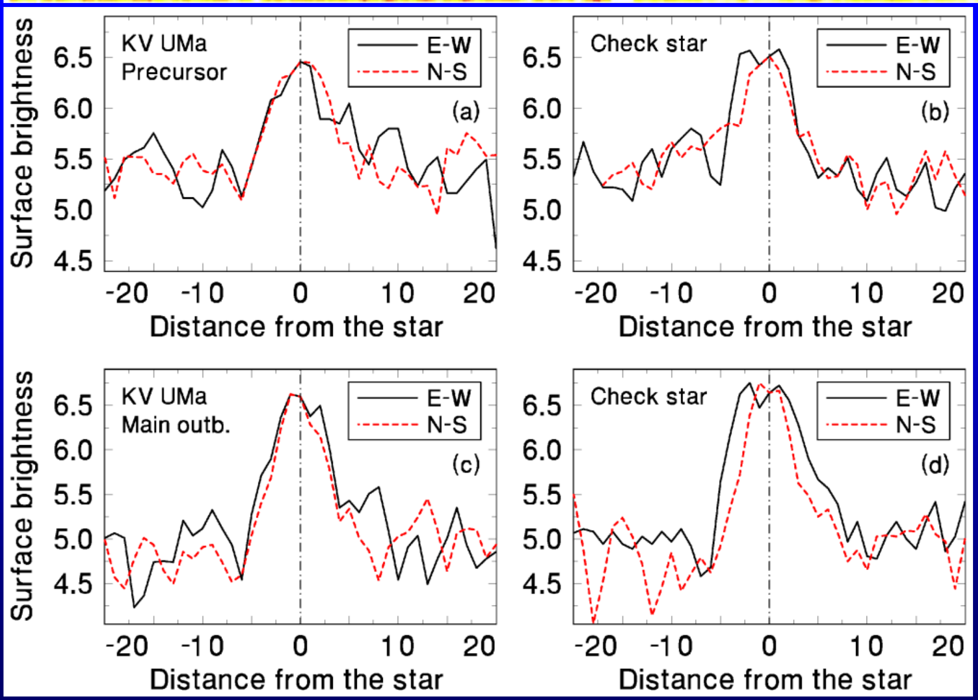
1… DASCH data - 1927

2… Uemura et al. (2002, PASJ, 54,285)

3… Zurita et al. (2006,ApJ,644, 432)

Soft X-ray transient XTE J1118+480 (KV UMa)



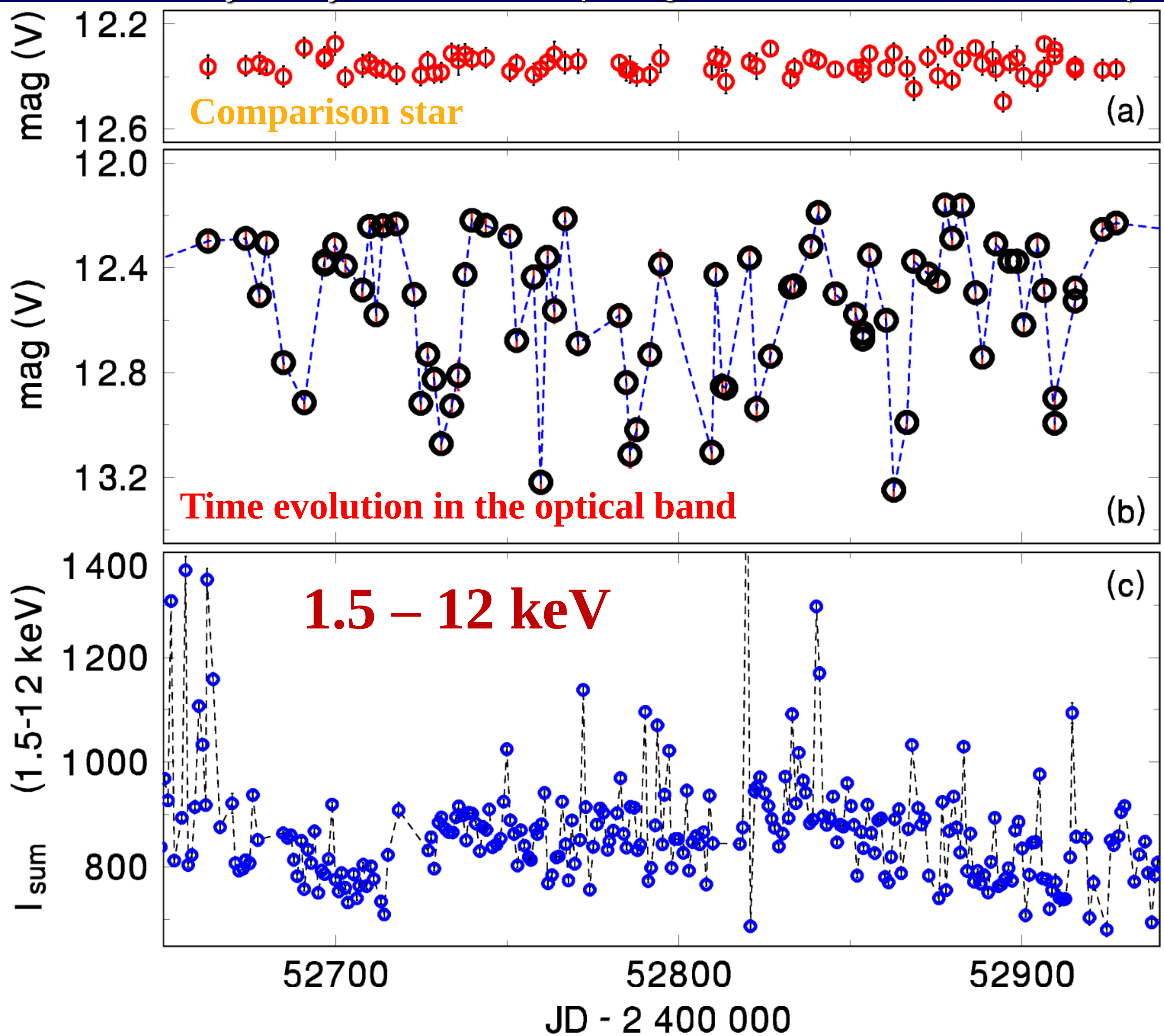


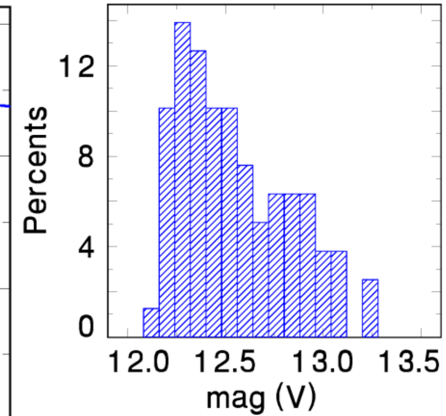
- DASCH digitized plates
- North is up, East to the left.
- Field size: 20 arcmin.

Slices of KV UMa and the check star C in outburst – confirmation of reality

Low-mass X-ray binary, neutron star (Hasinger & van der Klis 1989,A&A,225,79)

Sco X-1 / V818 Sco





- Fluctuations (shallow low states?) in the optical band
- Persistent (very bright) X-ray binary
- X-ray and optic. fluctuations are not correlated.

Conclusions

- Discrete features (outbursts, state transitions) dominate the long-term light curves of most CV types and low-mass X-ray binaries.

- Outbursts of dwarf novae (and possible extension to soft X-ray transients) :
  – the largest differences between outbursts are caused by propagation of heating front across the disk (rising branch of outburst)
  – the individual outbursts depend on each other, only a small fraction of the disk matter is accreted in a given outburst.

- High and low state episodes – often in clusters
  – changes of the position of the active regions on the donor (loops (Kafka et al. 2008, ApJ,688,1302), starspots (Livio & Pringle 1994,ApJ,427,956)) with respect to the L1 point by a differential rotation of the donor (Scharlemann 1982,ApJ,253,298)
  – bursts of mass outflow from the mass-donating component
  – variable stripping of the donor by a very strong wind from the WD in very luminous CVs (V Sge) (Hachisu & Kato 2003,ApJ,598,527))

- Large changes of the type of activity in the decades after the classical nova outburst

- A big role of the magnetic field of the white dwarf in the activity of the propellers

Acknowledgements:

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