The current active stage of the symbiotic system AG Draconis

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Outline

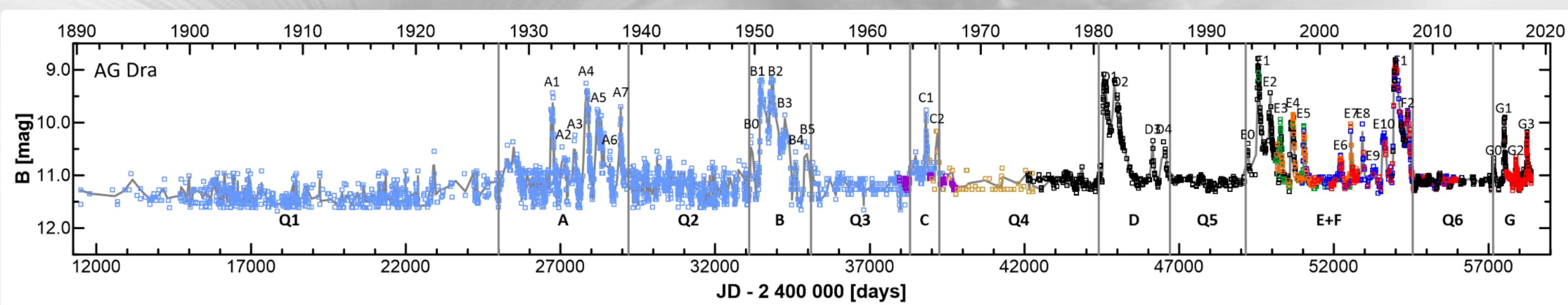
- Symbiotic system AG Draconis
- Recent outburst activity
- Photometric and spectroscopic behaviour
- Conclusions?

Symbiotic system AG Draconis

- AG Dra is a open binary with the orbital period of 551 days (Meinunger et al. 1979; Gális et al. 1999).
- The *cool component* is of a relatively *early spectral type* (K0 - K4), low metallicity (Smith et al. 1996), *higher luminosity* than that of standard class III (*giant*) and is probably pulsated with the period of 350 d (Friedjung et al. 2003).
- The *hot component* is considered to be a *white dwarf* (WD) sustaining a high luminosity ($\sim 10^3\ L_\odot$) and temperature ($\sim 10^5$ K) due to the *TN burning* of accreted matter (Mikolajewska et al. 1995).
- AG Dra is a detached binary and the accretion most likely takes place from the *stellar wind* of the cool giant.
- Both components are in a *circumbinary nebula*, partially ionized by the WD.
- Based on the Gaia DR2 parallax (π = 0.210 ± 0.027 mas), Bailer-Jones et al. (2018) derived for AG Dra the point distance of 3.89 kpc with uncertainty of (3.53 - 4.32) kpc representing ≈ 68% confidence interval.

130 years of the photometric history

- AG Dra regularly undergoes *quiescent* and *active stages* which consist of the series of individual *outbursts* repeating at about 360 d interval (Hric et al. 2014).
- During the period 1890–2018, the AG Dra system underwent 6 (or 7?) phases of activity: A (1932–1939), B (1949–1955), C (1963–1966), D (1980–1986), E+F (1993–2008) and G (2015–). In total, we recognized 36 outbursts in this period.
- The nature of these periodical outbursts has been a matter of long-term debate.
- Using UV and X-ray observations, González-Riestra et al. (1999) showed that there are two types of outbursts: *cool* and *hot* ones.



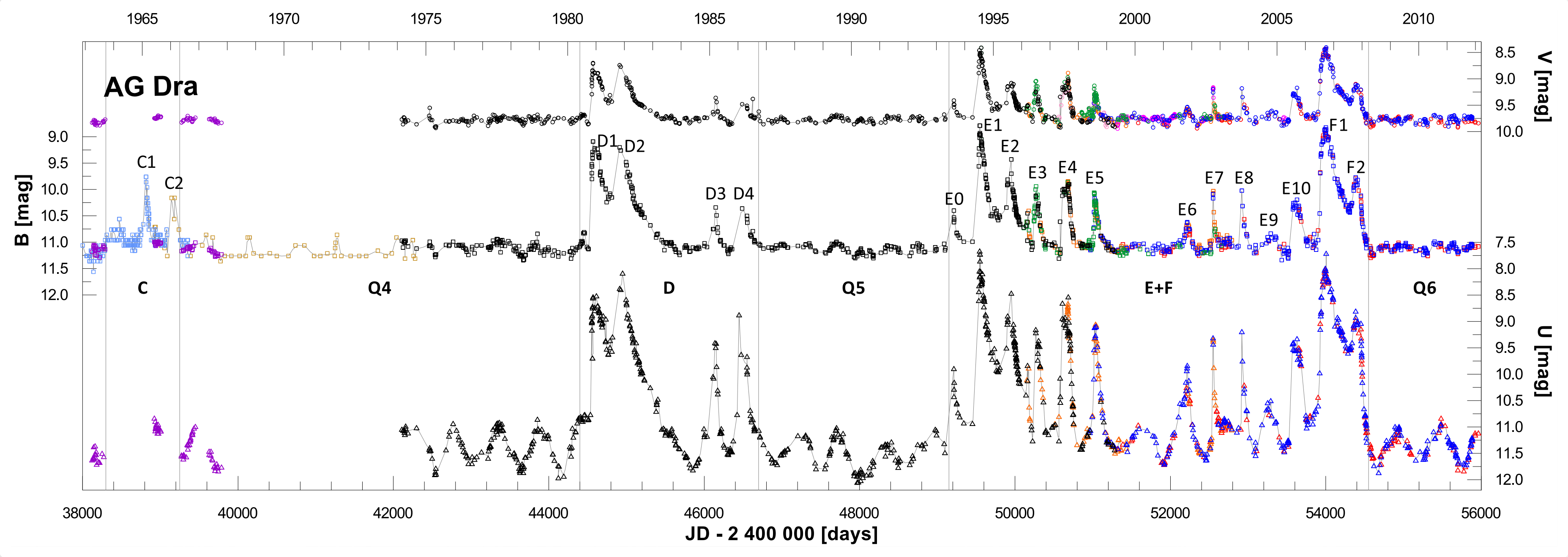
The historical LC of AG Dra over the period 1889 - 2018, constructed on the basis of photographic and *B* photoelectric observations. The LC is divided into active (A - G) and quiescence (Q1 - Q6) stages.

Photometric observations and analysis

- We use all available photometry for the study of AG Dra.
- The historical LC of AG Dra over the period 1889 – 1966 was constructed using the compilation of photographic observations by Robinson (1969).
- The historical LC of AG Dra over the period 1966 – 2018 was constructed using our compilation of photoelectric and CCD observations in *U*, *B*, *V* and ΔR_i filters.
- The photometric material (*U*, *B*, *V* and ΔR_i) was obtained at the observatories at Skalnaté Pleso and Stará Lesná (AI SAS), Valašské Meziříčí, Caucasus Mountains (SAO RAS, S. Karpov, 261 nights), Liptovská Štiavnica (M. Vrašťák, 155 nights), and from *AAVSO* database (966 nights).
- Correlation analysis of the observational data was performed using different methods implemented in our code CorrLAB (Merc & Gális, 2018).
- Period analysis was performed using an advanced implementation of the Date-Compensated Discrete Fourier Transform. We used a Fisher Randomization Test for determining the significance of the obtained periods.
- The minimum error of period *P* was determined by calculating a 1σ confidence interval on *P*, using the method described by Schwarzenberg-Czerny (1991).

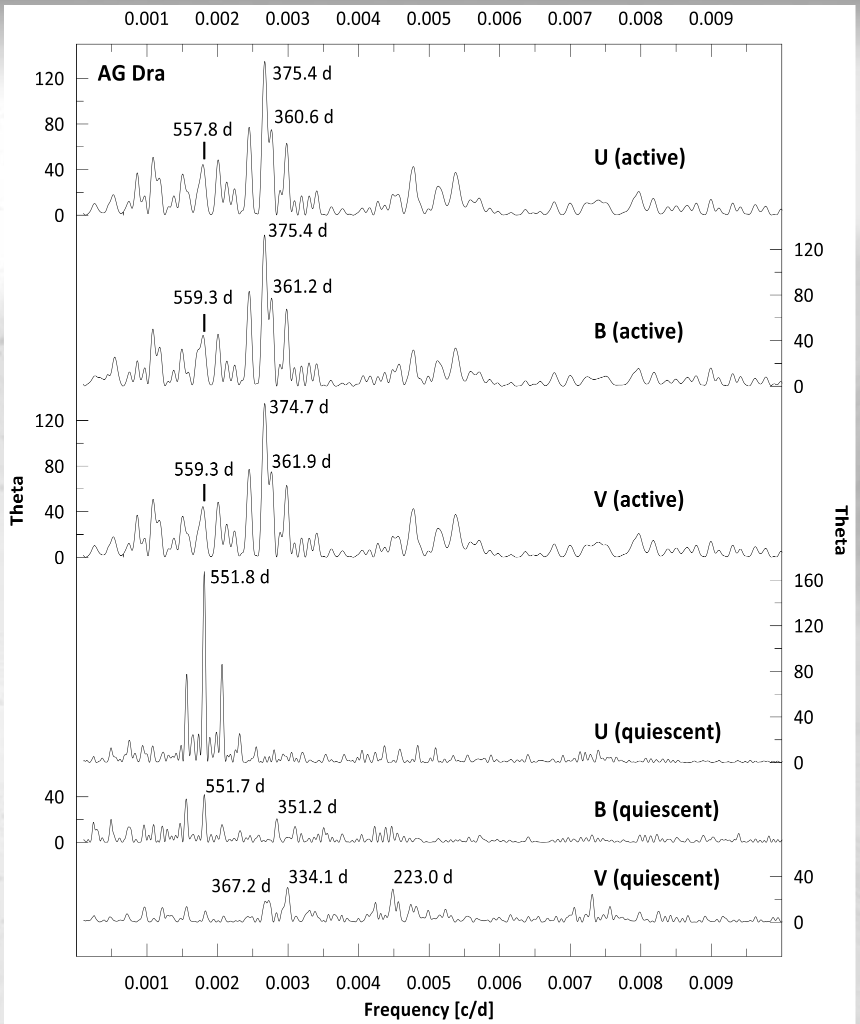
Photometric behaviour of AG Draconis

- Our statistical analysis showed that the LCs in *U*, *B* and *V* filters were very well correlated (correlation coefficients ≈0.9) during the active stages (D, E and F).
- During the quiescent stages (Q4–Q6), the correlation coefficient of the LCs in bands *U* and *B* as well as one of the LCs in bands *U* and *V* are less than 0.5 while, the variations in the *B* and *V* bands are correlated quite well.
- This result showed that brightness variations during the quiescent stages of AG Dra in the various bands were caused by different physical mechanisms.



UBV LCs from the period 1963–2012 with marked active stages (C, D, E and F) and quiescent ones (Q4, Q5 and Q6). Particular outbursts are assigned as C1–C2, D1–D5, E0–E10 and F1, F2.

Photometric behaviour of AG Draconis



- We carried out the complex period analysis of photometric data of AG Dra.
- The LC in the U filter during the quiescent stages is clearly dominated by variations with orbital period ~ 550 d.
- In the B and V bands, we found also a shorter period (~ 350 d); however, its value in each quiescent stage changed slightly.
- The most prominent period in active stages is one around 375 d. The value of this period varies with wavelength and is different for the individual active stages.
- Period analysis of the active stages revealed many longer significant periods (e.g. 1 330, 1 580, 2 350, 5 500 d), too.

Power spectra of AG Dra taken from photoelectric and CCD data in *U*, *B* and *V* filters for active (D, E+F) and quiescent (Q4 - Q6) stages. Power spectra for active stages were obtained after removing long-term periods around 1500 and 5400 d, which are related to the global morphology of these active stages.

Photometric behaviour of AG Draconis

- The results of this analysis are two real periods present in this symbiotic system: 550 and 350 d, related to the orbital motion and postulated pulsation of the cool component, respectively.
- The orbital period is mainly manifested during the quiescent stages at shorter wavelengths (*U* filter), while the pulsation period is present during quiescent as well as active stages at longer wavelengths (*B* and *V* filters).
- The period analysis of active stages confirmed the presence of a period of around 365 d, which is the median of the time interval between outbursts. It is worth noting that these time intervals vary from 300 - 400 d without an apparent long-term trend.
- Our detailed analysis shows that most of the longer periods (e.g. 1 330, 1 580, 2 350, 5 500 d) are more likely related to the complex morphology of the LCs during active stages than to the real variability present in this symbiotic system.

Spectroscopic observations

- We use all available radial velocities and EWs for the study of AG Dra.
- High-resolution spectra were obtained at:
  - *Canada–France–Hawaii Telescope* (3.58 m) @ Mauna Kea, Hawaii; Echelle Spectro-Polarimetric Device for the Observation of Stars (ESPaDOnS); *R* = 68 000; JD 2 456 906.72 (September 6th, 2014); 3700 – 10480 Å
  - *Nordic Optical Telescope* (2.56 m) @La Palma; FIbre-fed Echelle Spectrograph (FIES); *R* = 46 000; JD 2 457 176.51 (June 3rd, 2015); 3635 – 7270 Å
- The spectra we obtained at:
  - the *Tartu Observatory* in Estonia (1.5 m telescope, 515 spectra with *R* ≈ 6 000, 7 000 and 109 spectra with R = 12 000);
  - the *Astronomical Institute of ASCR* in Ondřejov (2.0 m telescope, 76 spectra, *R* ≈ 13 000).
- New spectra were obtained from ***A**stronomical **R**ing for **A**mateur **S**pectroscopy* (25 – 35 cm telescopes, R ≈1 800 – 11 000, 274/477 spectra).

Period analysis of spectroscopic data

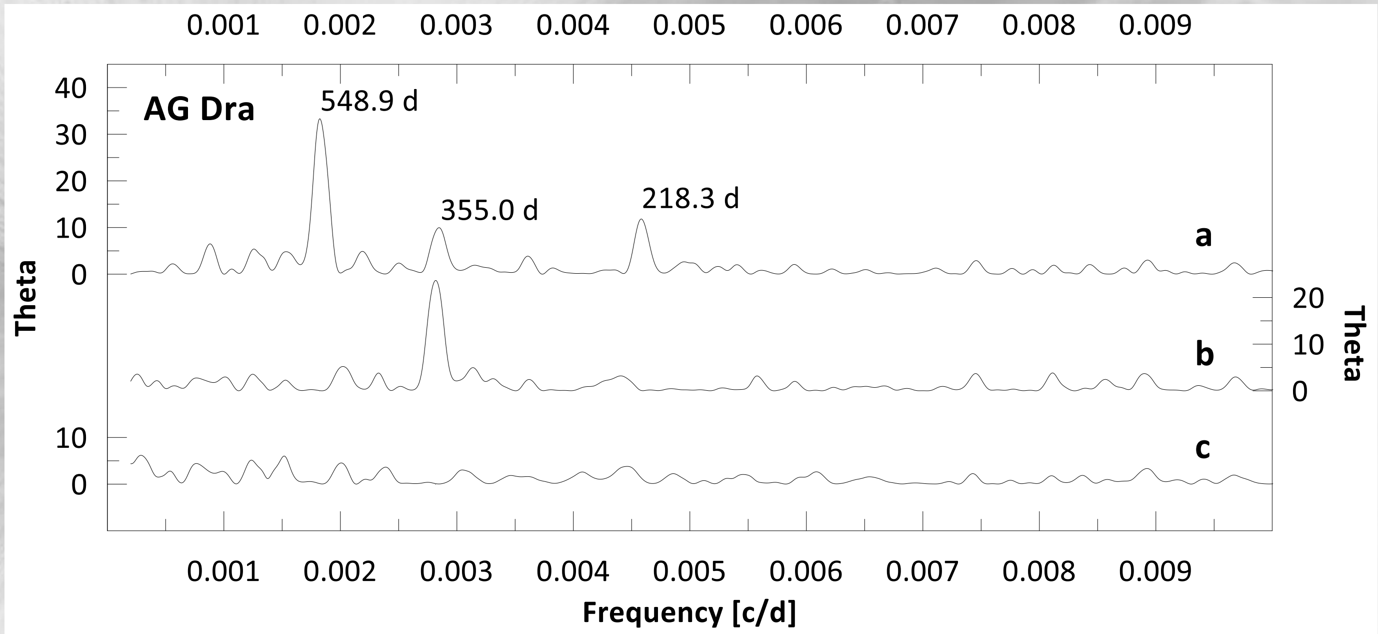
- The detailed period analysis of 135 radial velocities based on absorption-line measurements confirms the presence of only two significant periods:

  $P_{orb} = 551.^{d}0 \pm 1.^{d}5$ (the orbital motion)

  $\gamma = (-147.6 \pm 0.1)$ km s^{-1}, $K = (4.9 \pm 0.4)$ km s^{-1}, $JD_{min} = 2\,448\,996.^{d}4 \pm 2.^{d}8$

  $P_{pul} = 355.^{d}7 \pm 1.^{d}9$ (the cool-component pulsations)

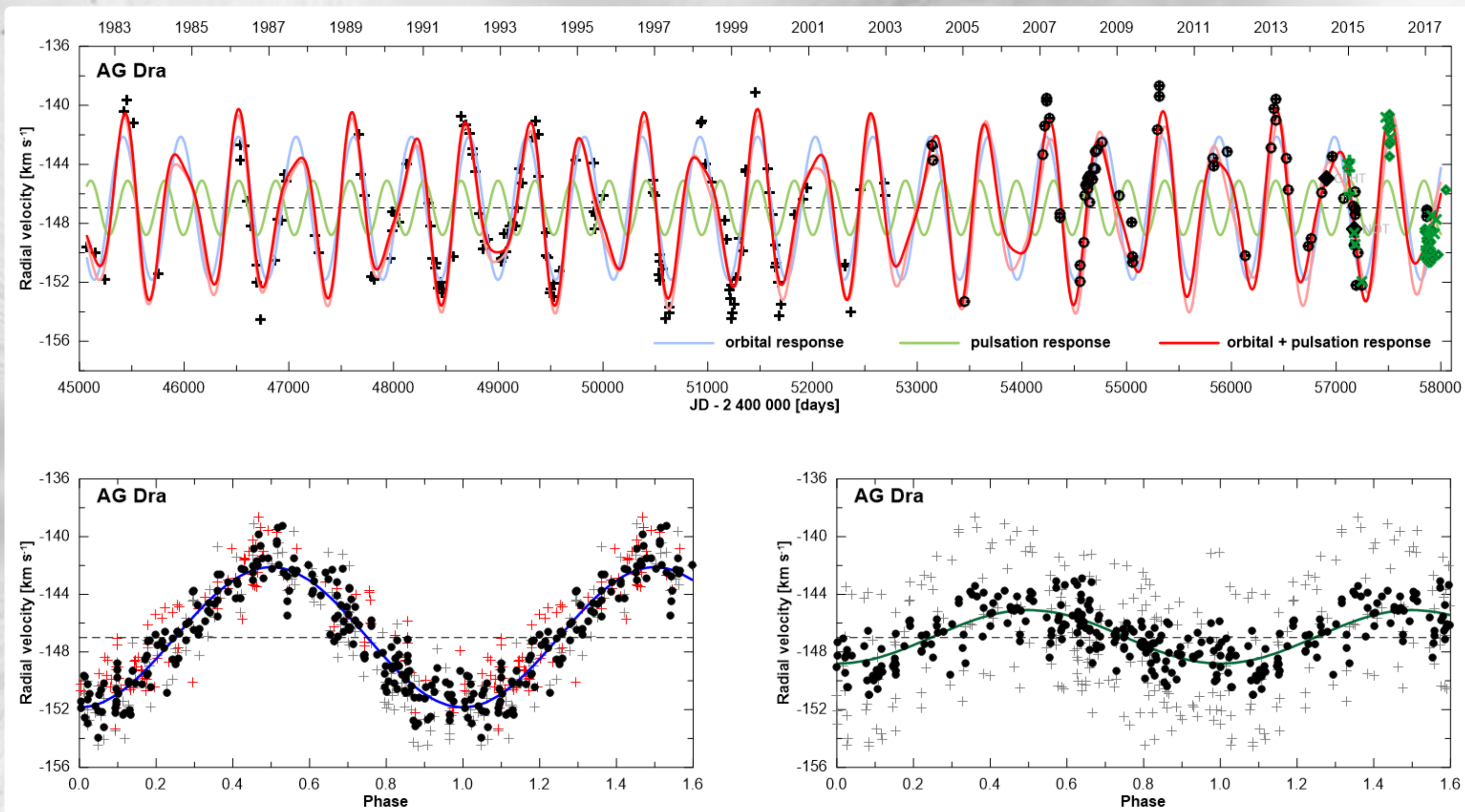
  $\gamma = (-147.4 \pm 0.1)$ km s^{-1}, $K = (1.7 \pm 0.4)$ km s^{-1}, $JD_{min} = 2\,449\,181.^{d}0 \pm 5.^{d}8$



Power spectra of AG Dra taken from combined radial velocities based on absorption-line measurements: (a) original data and (b) data with orbital response removed, as well as (c) data with both orbital and probable pulsation response removed.

Radial velocities of the cool giant

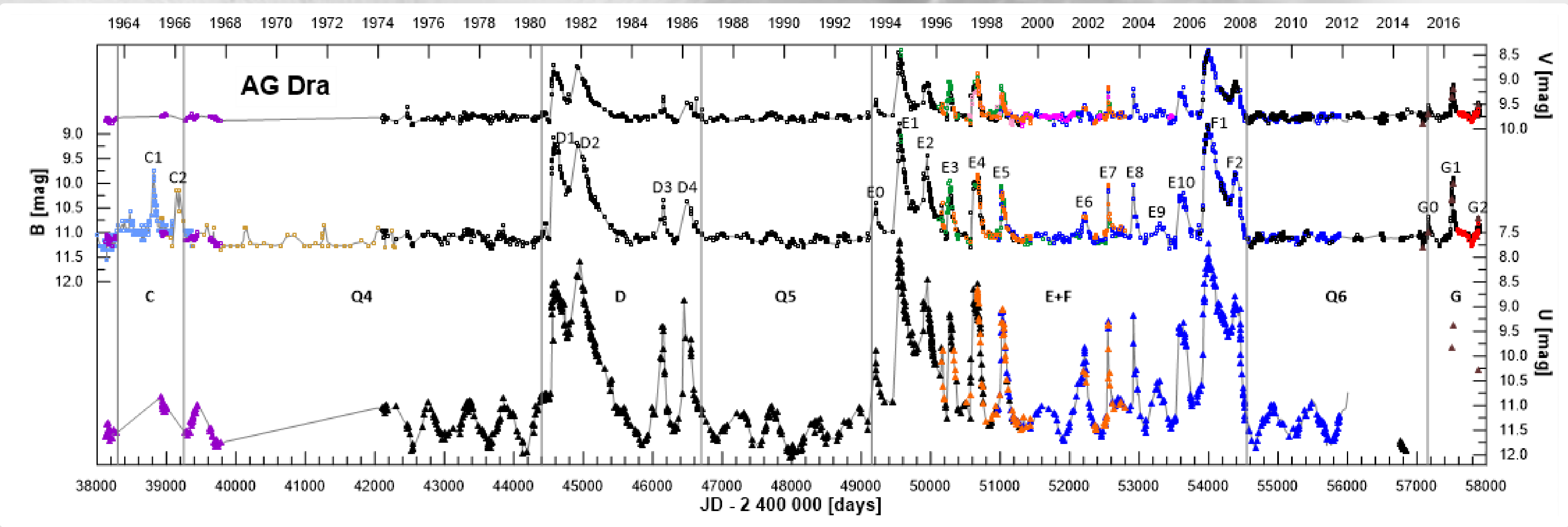
- We have added 110 radial velocity measurements based on spectra obtained at Astronomical observatory AI ASCR in Ondřejov, CFHT, NOT and from *ARAS*.
- The orbital period of the symbiotic binary AG Dra as well as proposed pulsation period of the cool giant in this system are stable over 35 years!



Radial velocities of the cool component in AG Dra together with the synthetic curves for corresponding responses (top) and their diagram phased using orbital (left) and pulsation (right) period.

Recent activity of AG Draconis

- After seven years of flat quiescence following the 2006-08 major outbursts, in the late spring of 2015, AG Dra begun rising again in brightness toward what appeared to be a new minor outburst (May 23, 2017; G0).
- New outburst activity of AG Dra was definitely confirmed by the outbursts in May 8, 2016 (G1) and May 16, 2017 (G2).
- We have initialised two observational campaigns to study photometric and spectroscopic behaviour of the recent active stage of AG Dra.



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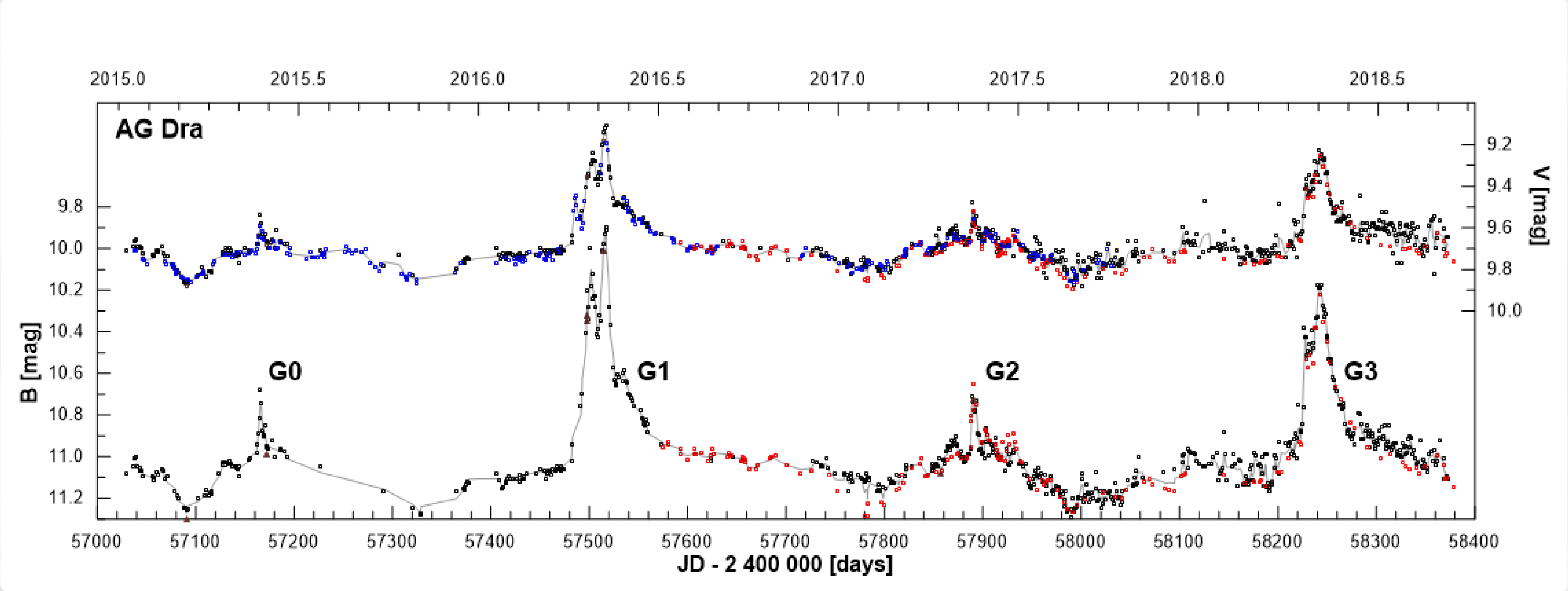
Recent activity of AG Draconis

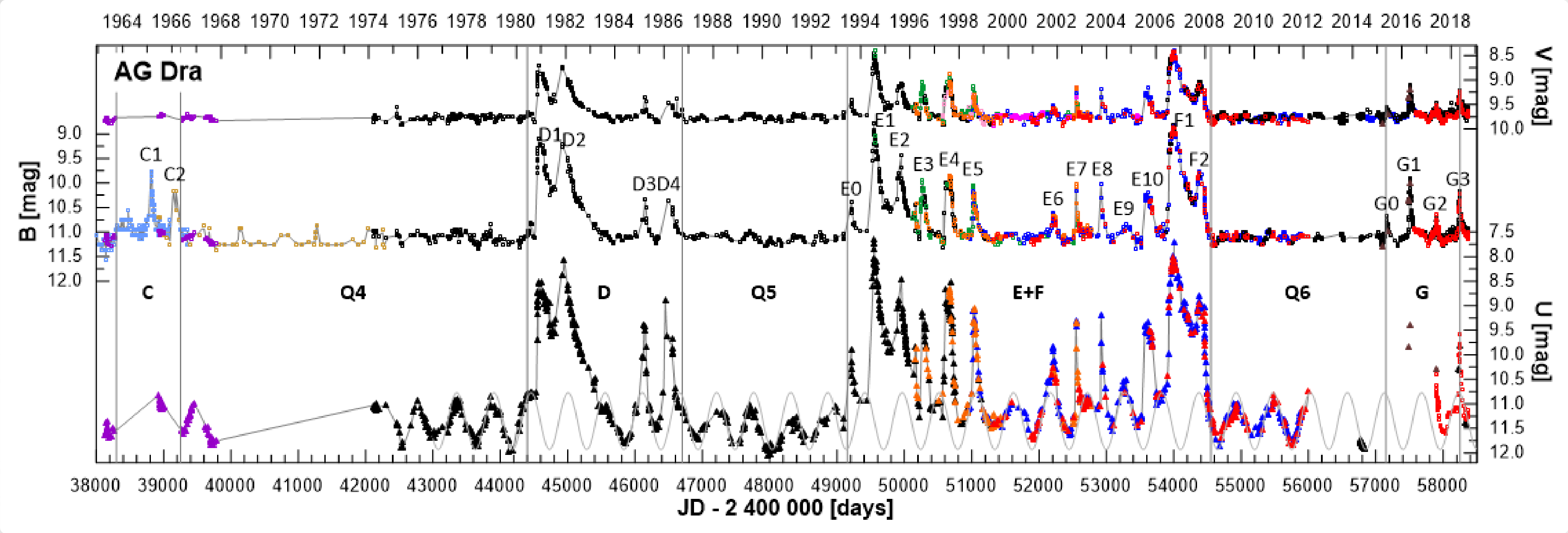
- According to our statistical analysis of photometric observations, we know that the time interval between outbursts of AG Dra vary from 300–400 d (without an apparent long-term trend), with median around 360 d.
- We expected the next outburst in the interval from JD 2 458 230 (April 21, 2018) to JD 2 458 270 (May 31, 2018).
- Actually, AG Dra manifested the fourth outburst of the recent activity stage in JD 2 458 243 (May 4, 2018; 353 days after previous one).



The recent active stage (G) of AG Dra in *B* and *V* filters. Particular outbursts are assigned as G0–G3.

Recent activity of AG Draconis

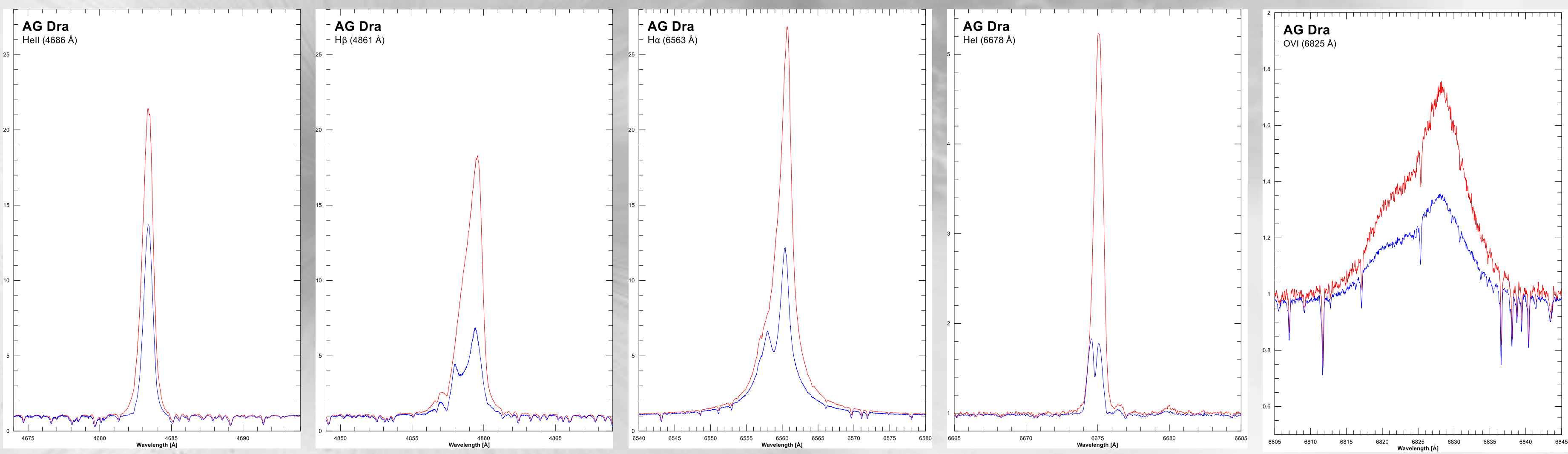
- The maximal magnitudes (10.7, 9.9, 10.7 and 10.2 in *B* filter) rank all recent (4 up to now) brightenings to the minor outbursts of symbiotic binary AG Dra.
- Such photometric behaviour of the active stage is very unusual. More often, the activity of AG Dra starts with major outburst, during which the brightness can reach the 8.8 and 8.4 mag in *B* and *V* band, respectively.
- Recent outburst activity resemble the weak activity stage 1963–66 (C).



UBV LCs from the period 1963–2018 with marked active stages (C, D, E, F and G) and quiescent ones (Q4, Q5 and Q6). Particular outbursts are assigned as C1–C2, D1–D5, E0–E10, F1, F2 and G0–G3.

Recent activity of AG Draconis

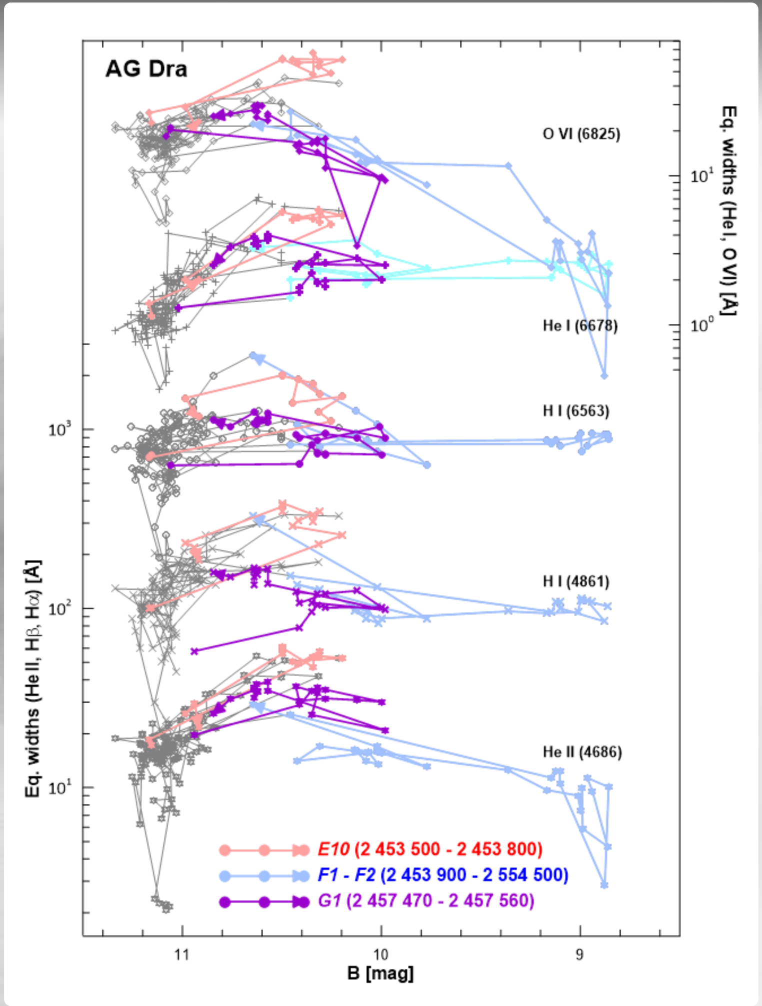
- In our paper (Leedjärv et al. 2016) we demonstrated that the outbursts of AG Dra can be clearly distinguished also according to behavior of the prominent emission lines in optical spectra.
- High-dispersion spectroscopy confirmed dramatic changes (significant increase of EWs) of the studied emission lines during recent active stage of AG Dra.
- The blue-wing absorption component observed in the profiles of the emission lines He I (λ6678), Hα and Hβ completely disappeared during this outburst.
- Such spectroscopic behaviour is typical for the *hot* outbursts of AG Dra.



The profiles of the emission lines of He II 4686 Å, Hβ 4861 Å, Hα λ6563 Å, He I 6678 Å (left panel) and Raman-scattered O VI 6825 Å for quiescent (Q6; JD 2 456 906.72 – Sept. 6th, 2014; blue line) and recent active stage (G; JD 2 457 176.51 - June 3rd, 2015, red line) of AG Dra, respectively.

Spectral characteristics of AG Dra

- We found more or less linear correlation between the *U* magnitude and logarithms of the EWs during quiescence and *hot* outbursts.
- This relationship breaks down during major *cool* outbursts (U > 9.4 mag, B > 10.2 mag).
- The recent brightening G1 manifest the behaviour of *cool* outbursts (all emission lines except He II 4686 Å) or some kind of transition between *hot* and *cool* outbursts (emission line of He II 4686 Å).
- Is it a new type of outburst (or transition/combination of) the *hot* and *cool* outbursts?



Logarithms of the EWs of the strongest emission lines (He II 4686 Å, Hβ, Hα, He I 6678 Å, and Raman-scattered O VI 6825 Å) vs. *B* magnitude. Data points are connected chronologically. The red line connects the points corresponding to the outburst episode E10, and the blue line those from the major outbursts F1 and F2. Evolution of the recent outburst G1 is depicted by purple line.

Temperature of the white dwarf

- The He II 4686 Å /Hβ ratio can be considered as a proxy to the temperature of the white dwarf in symbiotic systems (Iijima 1981):

$$T_{\rm hot} \approx 19.38\sqrt{\frac{2.22F_{4686}}{(4.16F_{\rm H\beta}+9.94F_{4471})}} + 5.13\ [10^4{\rm K}]$$

- Sokoloski et al. (2006) have neglected the flux of the He I 4471 Å line in the case of Z And, because $F_{4471} \leq 0.1F_{\rm H\beta}$. The same relation is valid for AG Dra (Leedjärv et al., 2016; Merc et al., 2018). Making this simplification allows to use ratio of the EWs instead of the flux ratio:

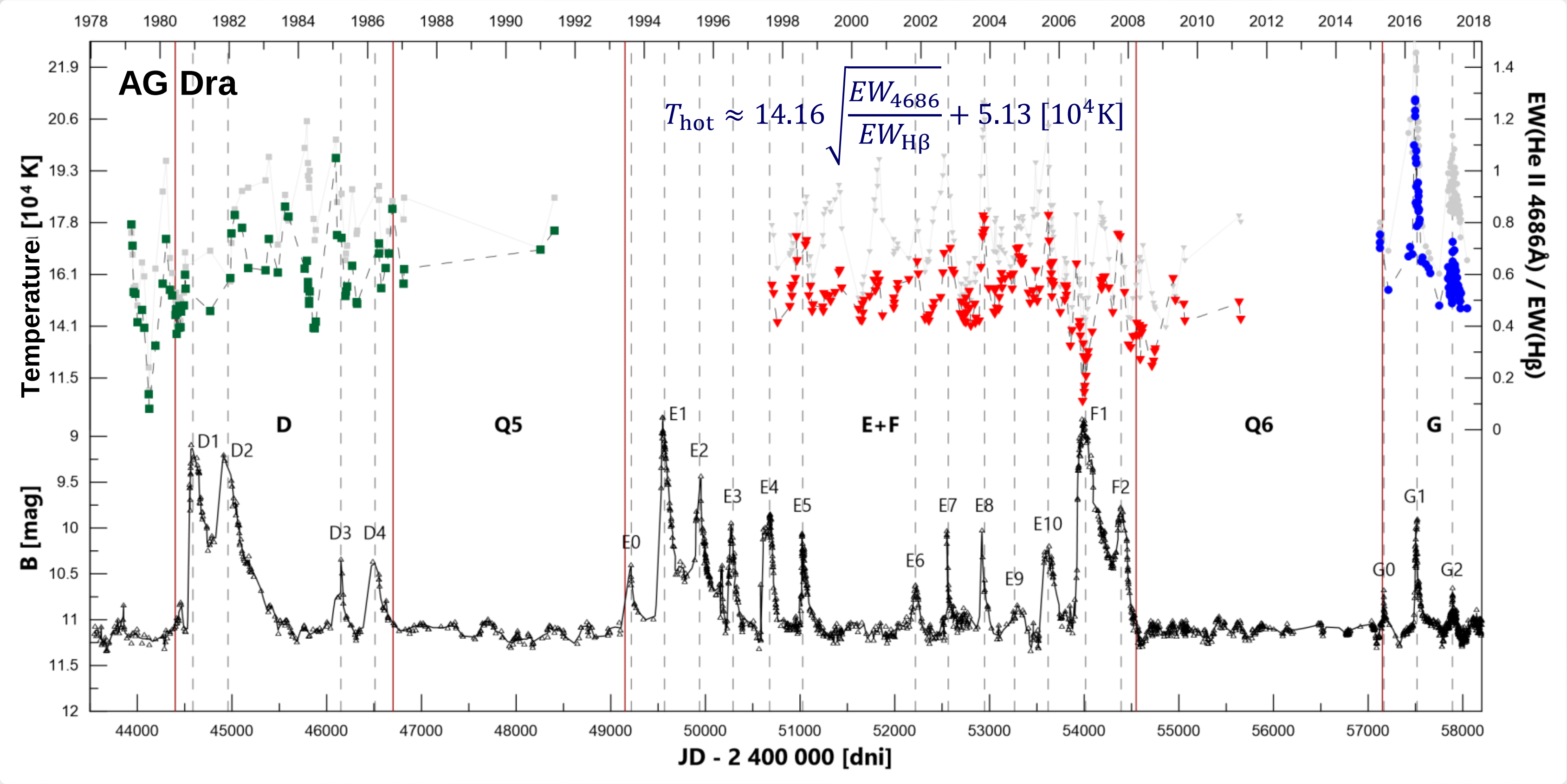
$$T_{\rm hot} \approx 14.16\sqrt{\frac{EW_{4686}}{EW_{\rm H\beta}}} + 5.13\ [10^4{\rm K}]$$

Temperature of the white dwarf

- We have studied the influence of that simplification in detail using ARAS spectra of AG Dra in our recent paper (Merc et al., 2018):
  - The increase in the temperature estimate (5 - 10%) is result of neglecting the flux of He I line and neglecting the difference in interstellar absorption on different wavelengths.
  - Moreover, the nebula is only partly ionisation-bounded and also other physical mechanisms than photoionisation of cool star wind are contributing to the emission strengths (e.g. collision shocks, disk coronae).
  - The EWs (and fluxes) of low excitation lines (e.g. He I and HI) depend on the orbital phase; consequently the derived WD temperature is affected by the orbital motion.
  - The profile of the Hβ line is affected by the absorption component which exists due to giant's wind.
- In total, the WD temperature may be overestimated by 15-20% using this simplification.
- The long-term average of the He II 4686 Å /Hβ ratio over the period 1979 – 2018 was 0.57 ± 0.18 which correspond the temperature of the hot component about 158 000 K.

Temperature of the white dwarf

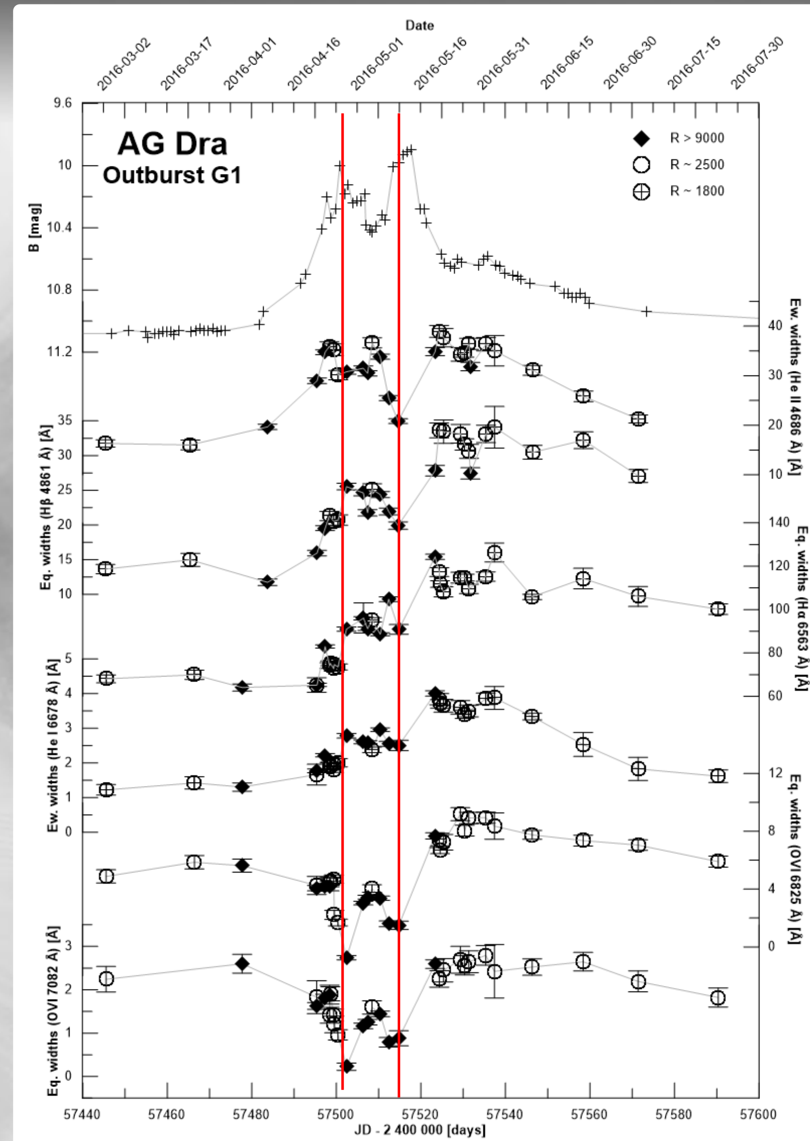
- The ratio reached the long-term minima (0.16) during the period just before the outburst D1 and during F1, which correspond the temperature about 108 000 K.
- The ratio reached the historical maximum (1.82) during the outburst G1, which correspond the temperature of the hot component about 242 000 K.



The ratio of the EWs of the two strong emission lines, He II 4686Å and H β, in time.

Raman-scattered O VI 6825 Å line

- In our paper (Leedjärv et al. 2016) we demonstrated that the Raman scattered[1] O VI line 6825 Å almost disappeared during the *cool* outburst of AG Dra in 2006, confirming a drop in the hot component's temperature.
- The outburst G1 manifest the same vanishing of the Raman scattered O VI line 6825 Å which suggest that is of the *cool* type, too. This decrease of EWs has different physical reason (more in J. Merc's talk).

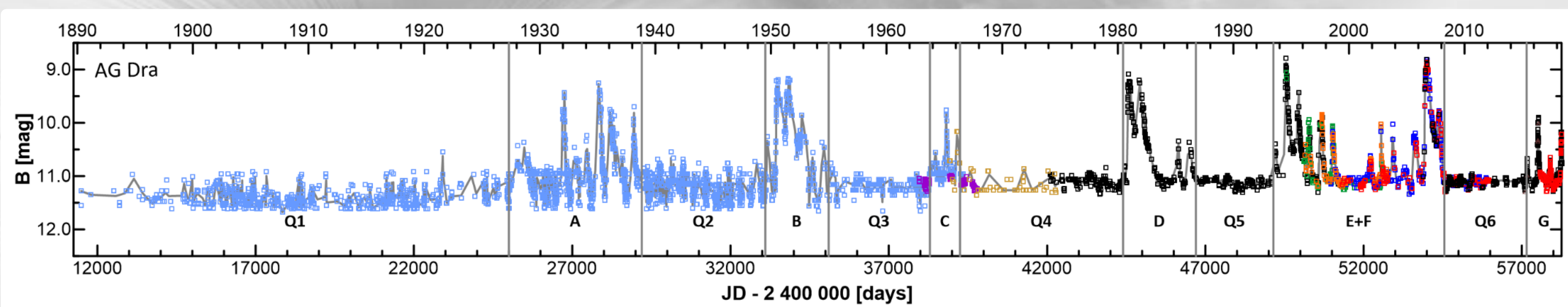


LC of AG Dra in *B* together with the curves of the EWs for studied spectral lines.

[1] The formation of the Raman scattered O VI (λ6825line requires specific physical conditions – the simultaneous presence of a hot radiation source, capable of ionizing oxygen atoms five times, and enough neutral hydrogen atoms that scatter the photons of the O VI resonance line.

Call for observation

- The photometric and spectroscopic observations suggest that recent outburst activity of AG Dra has behaviour of both *hot* and *cool* outburst.
- Is it a new type of activity? Or we have already seen it (activity stage C)?
- AG Dra is still in active stage according of its present spectroscopic behaviour.
- What can we expect in the next year? Other minor outburst? Return to quiescence? A major outburst is still in the game, too.
- AG Dra clearly demonstrates the importance of long-term monitoring and pro/am collaboration of symbiotic stars in order to disentangle the nature and mechanisms of their active stages and outbursts.



Thank you for your attention.