Nova Herculi 2021 as an intermediate polar

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Outline

Nova event

Novae belongs to cataclysmic variable stars

A classical nova occurs when material accreting onto the surface of a white dwarf star's surface begins an unstable thermonuclear fusion reaction.

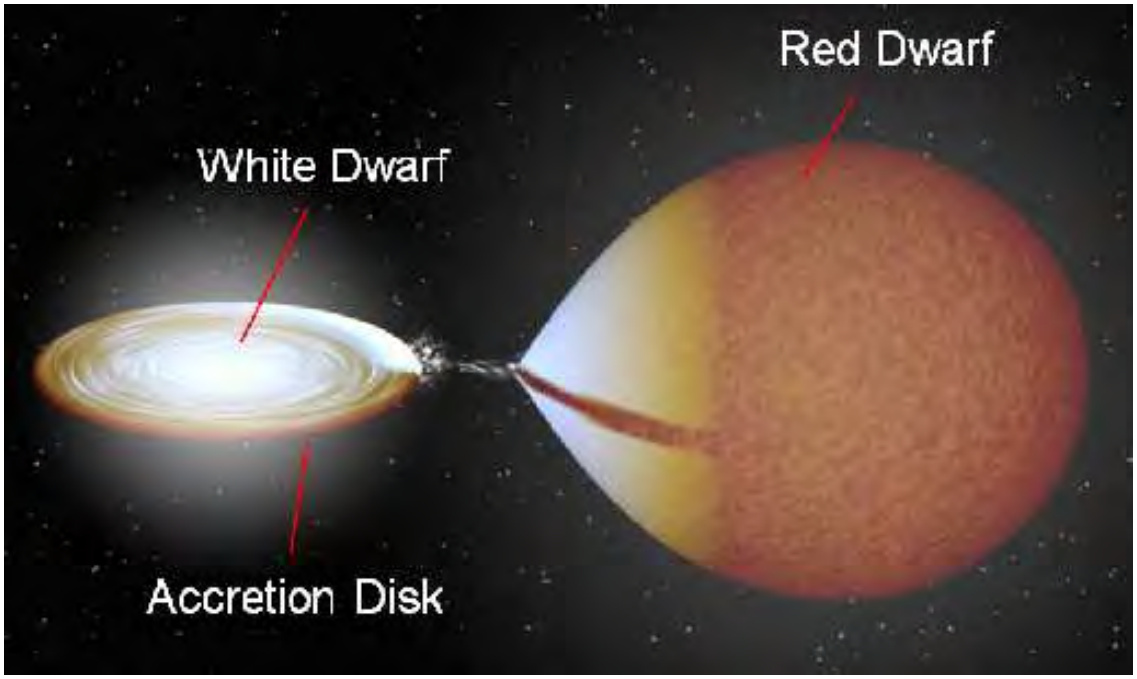


Figure: Model of the dwarf nova

Modern model of nova event

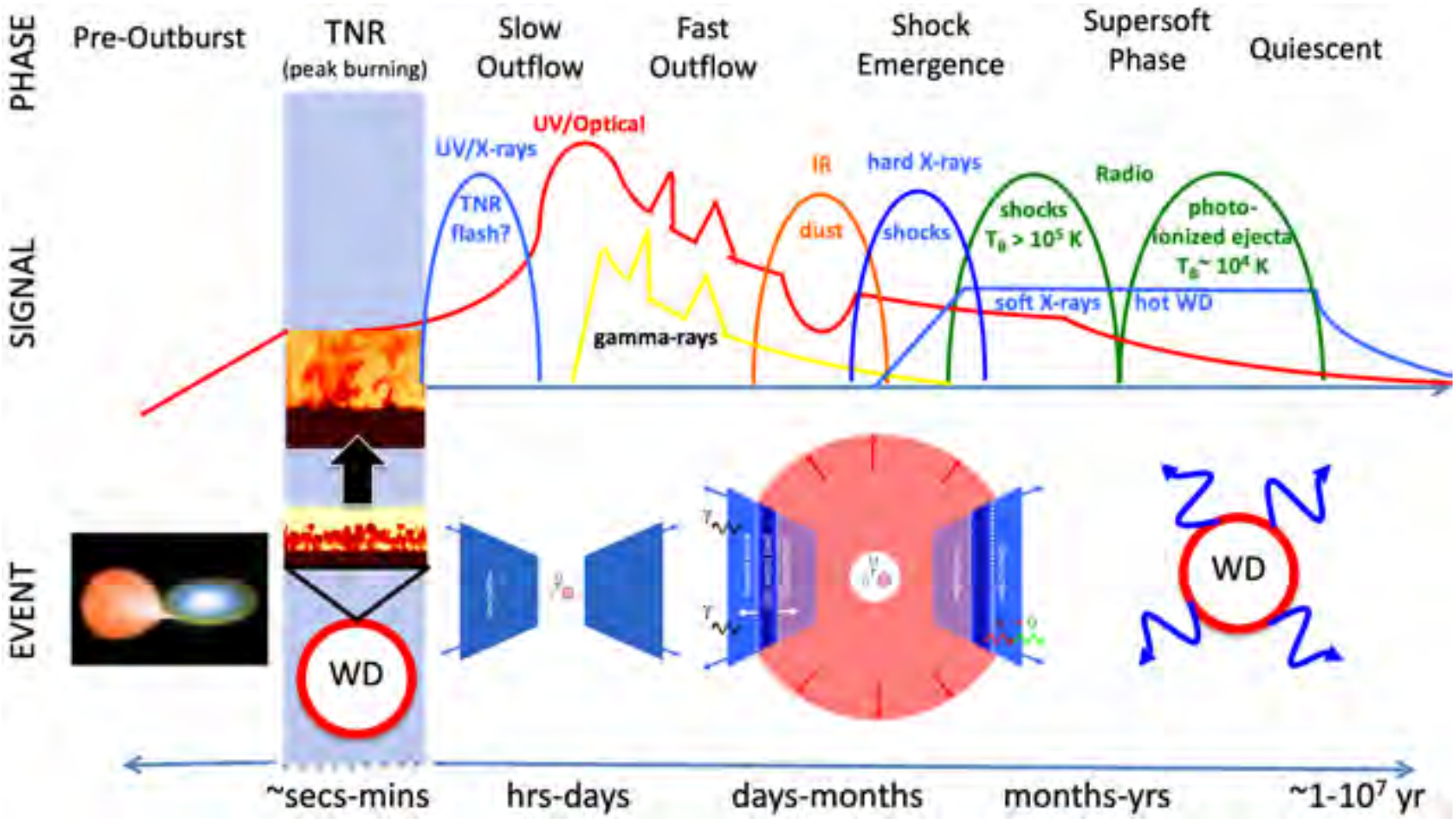


Figure: Schematic timeline of the physical processes and electromagnetic signals from novae. Figure from Chomiuk et al. 2020.

Variety of novae lightcurves

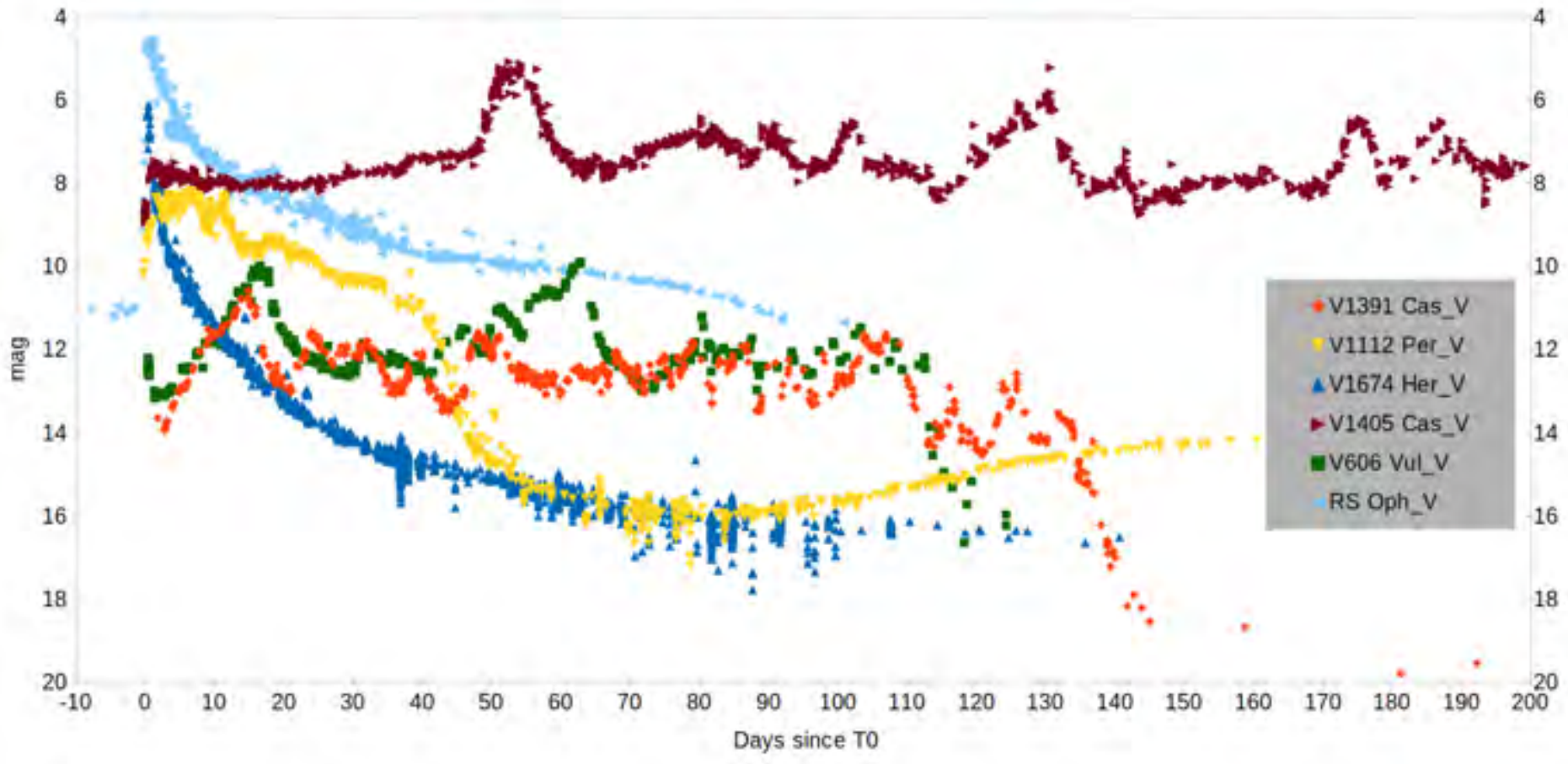


Figure: LC of recent novae. V band from AAVSO database.

Intermediate polars

In general nova eruption can occur on all types of cataclysmic variables including intermediate polars

The general model for intermediate polars is a red dwarf filling its Roche lobe, and a white dwarf, the magnetic field of which is strong enough to disrupt accretion disk completely or at least in its internal parts.

- Strong magnetic field, but weaker than in polars.
- Magnetically channeled accretion to the magnetic poles
- Rapidly rotating WD. $P_{spin} \ll P_{orb}$
- Oscillations around spin equilibrium. Accretion torque = spin up. Magnetic braking = spin down
- Selection effect. Almost in all IPs we see spin up. Because when spin down, the accretion is inhibited and luminosity is low.

Typical evolution of spin period in intermediate polars

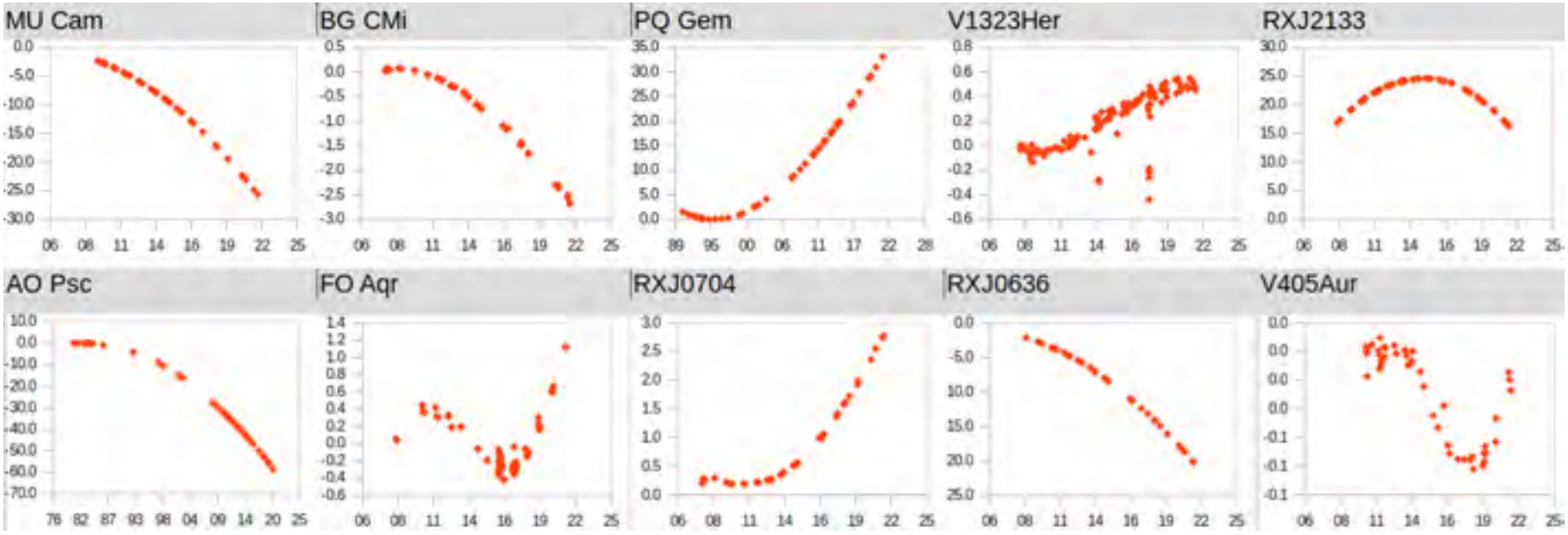


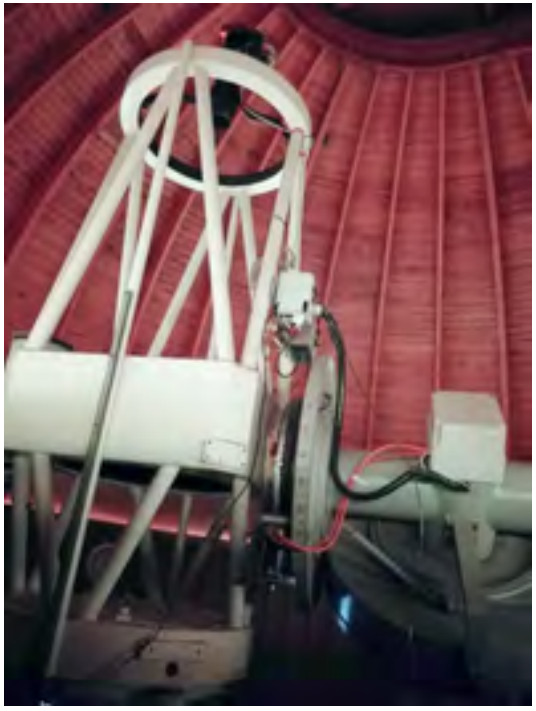
Figure: O-C diagram of spin pulse maxima of selected IPs observed in Kolonica, Hlohovec + older points from literature. Spin-up is observed almost in all systems.

Instruments for photometry

VNT

- Vihorlat National Telescope, modified Cassegrain 1000/9000 mm
- FLI PL1001E + B,V,Rc,Ic, Clear filters, binning 2x2
- Scale 1.10 arcsec/px
- FOV = 9.44 x 9.44 arcmin
- Autoguiding on 300/2400 mm telescope
- Recording software - CCDCiel
- Data reduction - CoLiTecVS and MCV
- Observer - P. A. Dubovský at AO Kolonica Saddle

Instruments for photometry



ZC600 Csere

- Zeiss Cassegrain in primary focus 600/2400 mm
- CCD camera Atik 383L + U B V Rc Ic filters, binning 2x2
- Scale 1.24 arcsec/px
- FOV = 25.9 x 19.5 arcmin
- Autoguiding on 180/1000 mm telescope
- Recording software - CCDCiel
- Data reduction - CoLiTecVS and MCV
- Observer - P. A. Dubovský remotely at M. R. Štefánik Observatory and Planetarium Hlohovec

V1674 Her - Nova erupted on an intermediate polar

- Nova Her 2021 was discovered at 8.4 mag on 2021-06-12.537UT by Seiji Ueda.
- It turned out to be the fastest nova: $t_2 \cong 1.2d$, $t_3 \cong 3d$
- The progenitor is an intermediate polar with spin period 8.357 min. This value is based on ZTF survey data (Mroz et al., 2021).
- X-ray pulsations with spin period were detected in Chandra DDT observation made on July 10, 2021 (Maccarone et al., 2021).
- Shugarov and Afonina, 2021 reported the orbital period detection.
- Patterson et al., 2021 reported the presence of strong double-humped photometric signal at 0.15302(2) days and another strong signal at 8.3586(3) minutes.
- Patterson et al., 2022 analyzed the extended dataset collected by CBA observers. Fast spin period change was presented.

Our observations

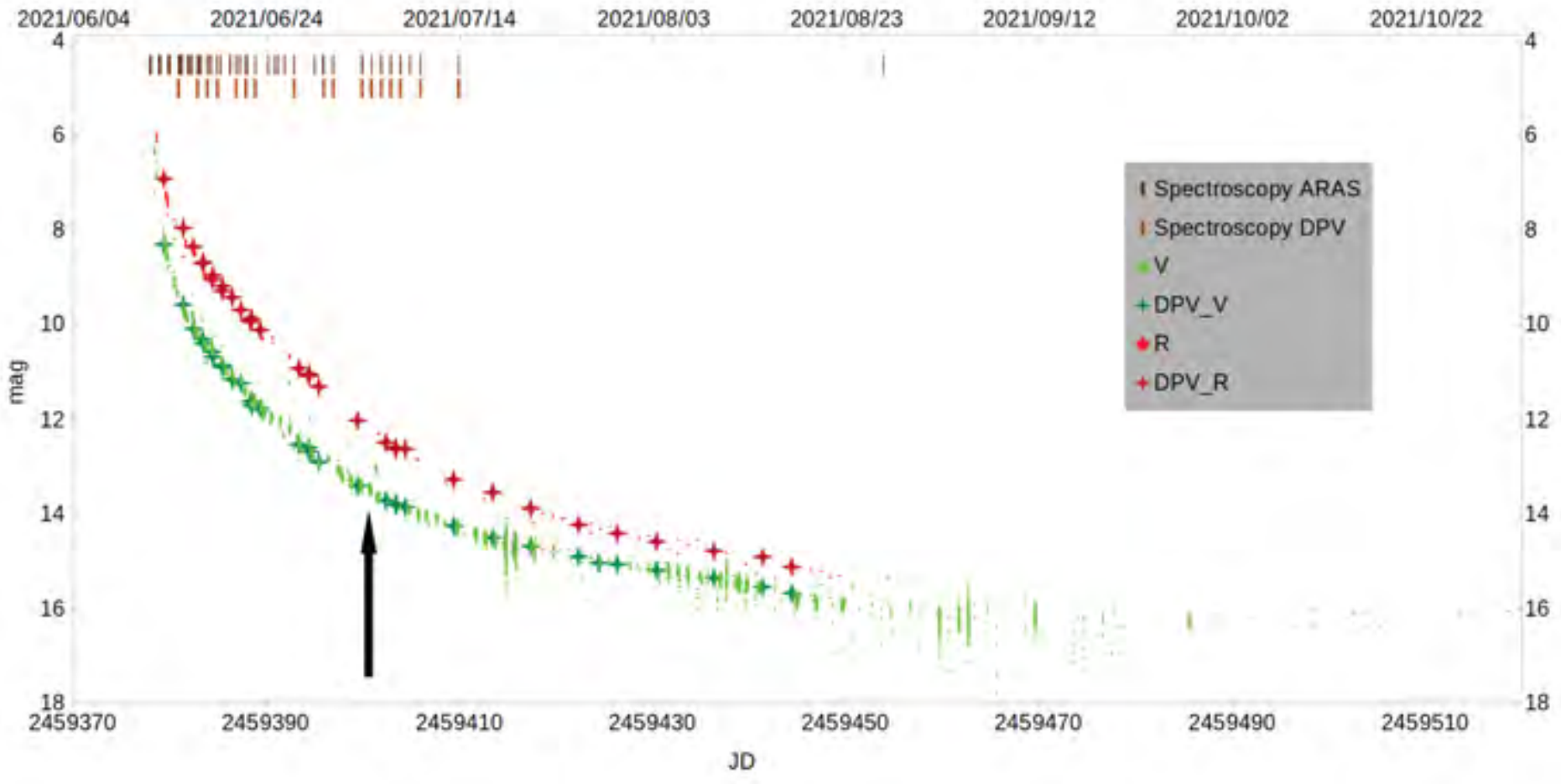


Figure: Photometry and spectroscopy of V1674 Her. The time of first appearance of orbital and spin signal is marked with black arrow.

Photometry - Early detection of spin period signal

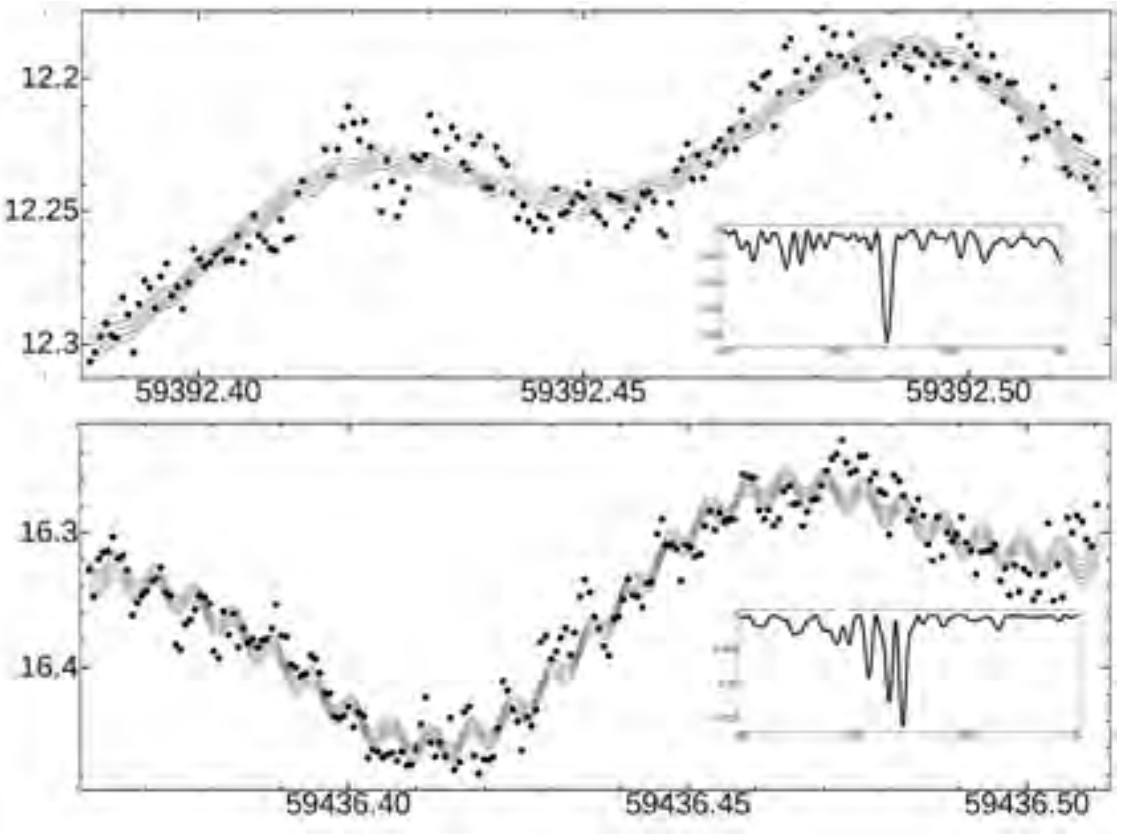


Figure: Top: multi sinusoidal fit of the data from July 5, 2021 in V band with periodogram (small panel) showing the peak at the spin frequency. Bottom: data from August 7, 2021. Sideband frequencies $\omega - \Omega$ and $\omega - 2\Omega$ appeared.

Period analysis

Spin period signal was unambiguously detected only 23 days after the outburst when the brightness of the nova was still 7 mag above the quiescent. Basic parameters of the intermediate polar were determined separately for each observing season.

	Period	**Frequency**
WD spin before nova event	$P_{spin} = 0.00580356d$	$\omega = 172.308c/d$
WD spin in 2021	$P_{spin} = 0.00580417d$	$\omega = 172.290c/d$
WD spin in 2022	$P_{spin} = 0.00580315d$	$\omega = 172.320c/d$
WD spin in 2023	$P_{spin} = 0.00580260d$	$\omega = 172.336c/d$
Orbital motion	$P_{orb} = 0.152921d$	$\Omega = 6.5393c/d$

$$Tmax[HJD] = 59392.447(2) + 0.00580349(5)E - 4.4(3) \times 10^{-12}E^2$$

Spin evolution of V1674 Her

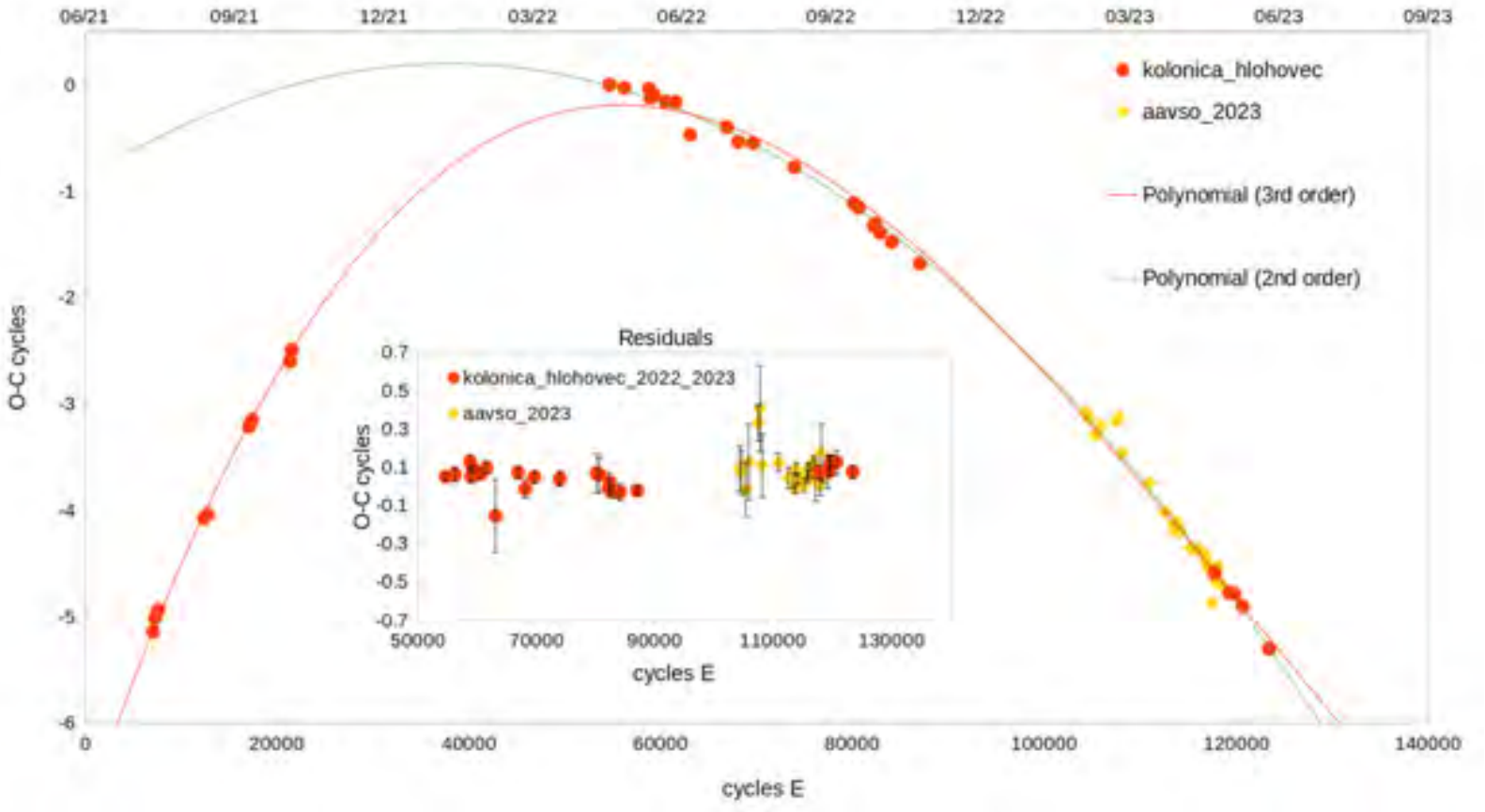


Figure: O-C diagram of spin pulse maxima. All data can be approximately fitted with 3^{rd} order polynomial which has no reliable physical interpretation. So we use a 2^{nd} order polynomial to evaluate the acceleration of the spin.

Discussion - Extremely fast spin-up after the nova eruption

- Pulse-period changes in IPs are generally around 1-2 ms/year.
- In the case of V1674 Her it is $dP/dt \sim -160 ms/year$.
- The anomalously high $\dot{P}$ can be a natural result of the very high accretion rate (and therefore high accretion torque) in the immediate aftermath of a nova eruption.
- The initial spin period increase by $71 ms$ can be due to the angular momentum loss in the ejecta.
- Quick appearance of orbital and spin signal means that the ejecta became transparent soon after the eruption and/or our observing position has favorable geometry. This is in agreement with recent concepts of nova eruption (Chomiuk et al., 2021).

Conclusions

1. Based on the recent spin maxima measurements we can conclude that after the turbulent period connected with the nova eruption, the system is now in a stable spin-up phase and in the near future will evolve according to the proposed ephemeris.
2. The brightness is also stable, still 3 mag above the pre-eruption level. This might be due to the fact that the intermediate polar was in low accretion, spin-down phase just before the eruption.
3. The present observations are also in agreement with the proposition of Patterson et al., 2020 that the observed strong preference of IPs to show spin-up (rather than spin-down) might be also due to the after-effects of an ancient nova eruption.
4. We provide the working ephemeris of spin pulse maxima for the future monitoring.

Outlook

- The spin-up rate should decline slowly, probably on a timescale of centuries or longer.
- Evolution of the orbital period. Increase? (Common in binaries with SSS component)
- Evolution Intermediate polars $\Rightarrow$ Polars. Perhaps V1674 Her will help to understand this possibility.

SLOVAK RESEARCH
AND DEVELOPMENT
AGENCY

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Thank you for your attention