IX Draconis – a curious ER UMa-type dwarf nova

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SU UMa stars

One of the types of dwarf novae are SU UMa stars

- short orbital periods ($P_{orb} < 2.5\,\mathrm{h}$)
- white dwarf as a primary
- low mass main sequence star as a secondary
- beside normal outbursts they also show **superoutbursts** (about $1\,\mathrm{mag}$ brighter and about ten times less often)
- additional "tooth-shape" light curve modulations with amplitudes of a fraction of a magnitude – **superhumps**

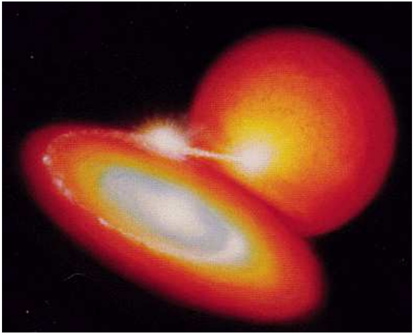


Figure: Artist's Conception: Dana Berry, STScI

ER UMa stars

- most **active** among SU UMa's
- extremely short supercycle lenght of about 20 $-$ 60 days
- seems to be standard SU UMa stars with only a larger activity and luminosity due to their **high mass transfer rates** (Osaki, 1996)
- only **five** stars belonging to the ER UMa-type of dwarf novae, among them IX Draconis (IX Dra)

IX Dra

- detected by Noguchi et al. (1980)
- Ishioka et al. (2001) studied IX Dra in more details: $T_{sc} = 53\ \mathrm{d}$, $T_c = 3 - 4\ \mathrm{d}$, $A = 2.5\ \mathrm{mag}$, $P_{sh} = 0.067\ \mathrm{d}$
- Olech et al. (2004): $T_{sc} = 54 \pm 1$, $T_c = 3.1 \pm 0.1\ \mathrm{d}$, $P_{sh} = 0.066968(17)\ \mathrm{d}$, and another period $0.06646(6)\ \mathrm{days}$ $\Rightarrow$ a very low mass ratio of the system $\Rightarrow$ IX Dra has a brown dwarf as a secondary $\Rightarrow$ the **most evolved dwarf nova**

Observations

Table: Our observations of IX Dra in 2010.

Observatory	Country	Telescope	Observer
Warsaw University Observatory, Ostrowik	Poland	0.6 m	M. Otulakowska-Hypka, A. Olech
TUBITAK Observatory	Turkey	0.4 m, 0.6 m, 1.0 m	A. Rutkowski
Observatorio del CIECEM	Spain	0.25 m	E. de Miguel
Antelope Hills Observatory	USA (CO)	10”	R. Koff
NF/Observatory	USA (NM, AZ)	0.6 m, 24”	A. W. Neely
Tzec Moun Foundation Observatory	USA (NM)	14”, 16”, 18 cm	K. Bąkowska, M. Otulakowska-Hypka

Observations

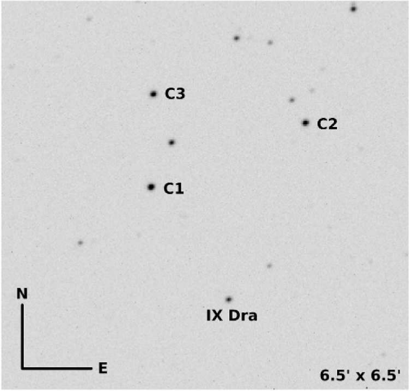


Figure: Position of IX Dra and three comparison stars on a chart.

Global light curve

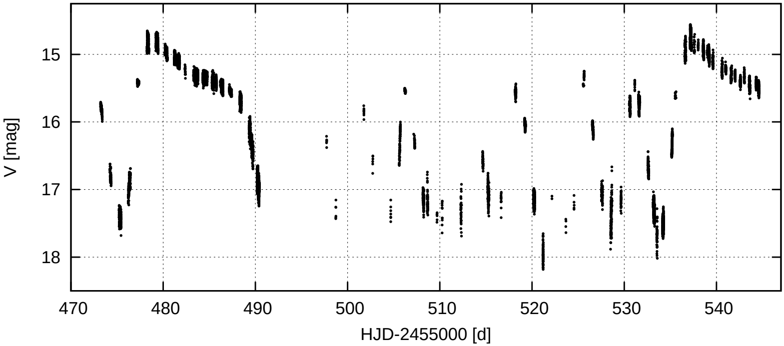


Figure: Global light curve of IX Dra during our observational campaign

Supercycle length

Formerly discovered values of the supercycle lenght (T_{sc}) for IX Dra are:

- 45.7 d (Klose, 1995),
- 53 d (Ishioka et al., 2001),
- and 54 ± 1 d (Olech et al., 2004).

$\Rightarrow T_{sc}$ is constant.

Our result: $T_{sc} = 58.5$ d. $\Rightarrow$ the rate of the increase of the period is $\dot{P} = 1.8 \times 10^{-3}$.

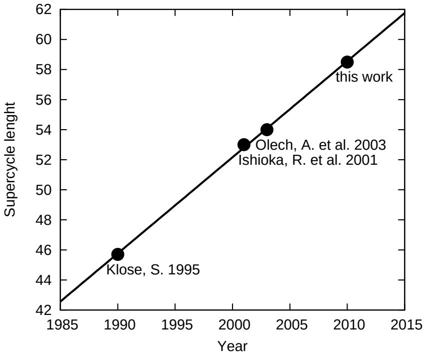


Figure: The upward trend of the T_{sc} for IX Dra.

Folded light curve (with the $T_{sc} = 58.5\ \mathrm{d}$)

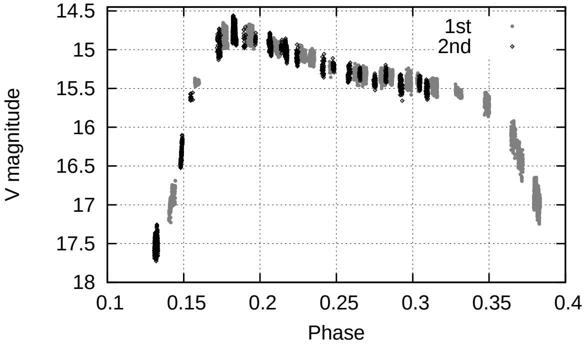


Figure: Light curve of IX Dra during superoutbursts obtained by folding the light curve with $T_{sc} = 58.5\ \mathrm{d}$. Grey circles indicate the data of the first superoutburst, black diamonds represent the data of the second superoutburst.

just to make sure...

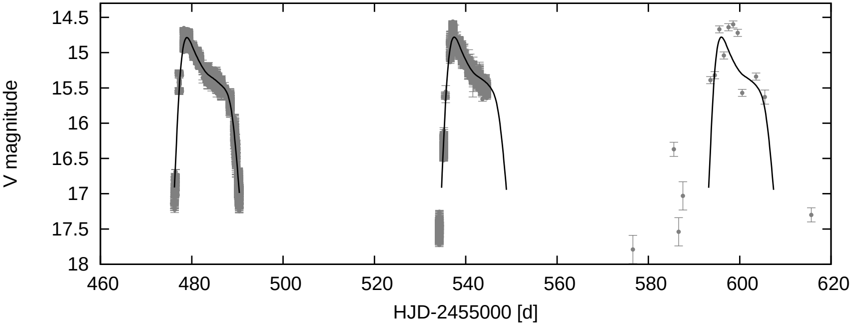


Figure: Observed superouturst of IX Dra (points) from our observational campaign and the succeeding superoutburst from the *AAVSO* archive, confirming our $T_{sc} = 58.5\ \mathrm{d}$. Lines indicate anticipated occurrences of superoutbursts with the supercycle lenght T_{sc}.

Normal cycle length

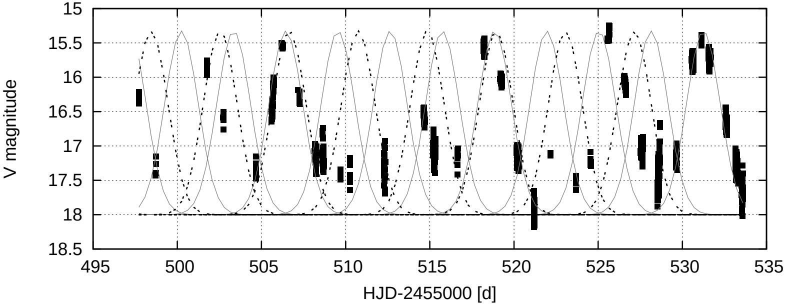
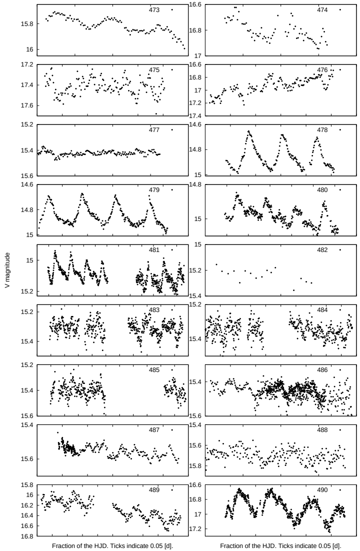


Figure: Normal outbursts of IX Dra during our observational campaign (black dots) with two imposed curves indicating regular anticipated occurrences of normal outbursts with the most likely period estimated from our observations $T_c^1 = 4.1$ d (black dashed line), and with the value of the normal cycle lenght from the literature, $T_c^2 = 3.1$ d (grey solid line).

Superhumps



Superhumps at each day of the first superoutburst. Consecutive nights are denoted by dates given as HJD-2455000 [d]

Period analysis

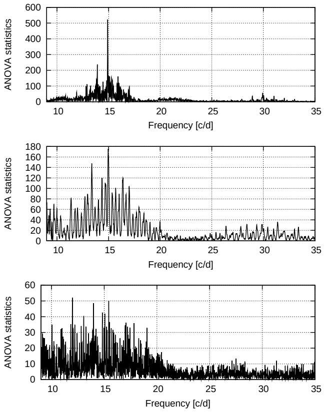


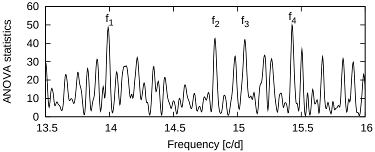
Figure: Power spectra for the light curve (from top to bottom) of the 1st, 2nd superoutburst & normal outbursts

1st superoutburst:

f = 14.910(7), $P^1_{sh} = 0.06707(3)$

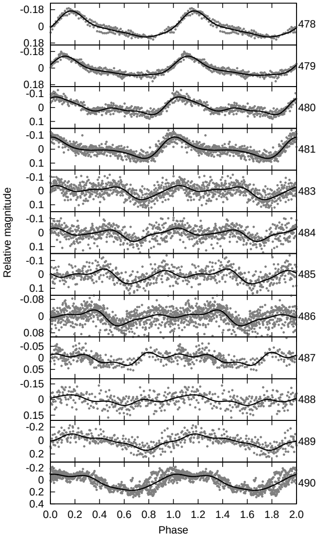
2nd superoutburst:

f = 14.96(2), $P^2_{sh} = 0.06683(9)$



$$
\begin{aligned}
P_{f_1} &= 0.07148(4)\\
P_{f_2} &= 0.06745(3)\\
P_{f_3} &= 0.06641(3)\\
P_{f_4} &= 0.06482(3)
\end{aligned}
$$

Analysis of the stability of the phase of superhumps

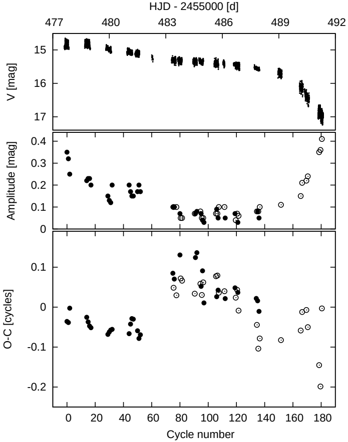


We removed the general decreasing trend from the light curves, and phased them with the P_{sh} for each of the nights separately $\Rightarrow$ evolution of superhumps.

Numbers on the right indicate dates of observations (HJD-2455000 [d]). The black curve represents our fit to the light curve.

$O - C$ analysis: superoutburst

Light curve of the first superoutburst of IX Dra (top panel),
evolution of the amplitude of superhumps (middle panel),
and $O - C$ diagram for corresponding superhumps maxima.

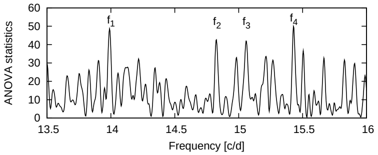


A linear fit to the data brought the following ephemeris:

$$\mathrm{HJD_{max}} = 2455478.2865(5) + 0.066894(6) \times \mathrm{E}$$

$O - C$ analysis: normal outbursts

- very weak modulations of the LC
- only a subtle flickering, like in the case of typical SU UMa stars
- clear humps were identified only below the mean magnitude of outbursts, very close to the minimum brightness
- from a linear fit to the points we got the ephemeris:
  $\mathrm{HJD_{max}} = 2455508.176(3) + 0.06646(2) \times \mathrm{E}$
- the obtained period $0.06646(2)$ is in agreement with the P_{f_3}, which is in our opinion the orbital period of the system



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P_{f_4} &= 0.06482(3)
\end{aligned}
$$

Periods' interpretation

- periods obtained during superoutbursts are consistent between both methods of analysis
- the obtained P_{sh} indicates that the value of the superhump period remains constant for this object over the last decade
- in contrast to the previous publications, we did not detect any orbital period modulation of the light curve throughout superoutbursts

Evolutionary status of IX Dra

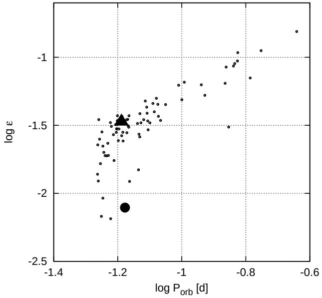

Figure: The dot corresponds to the position of IX Dra obtained from P_{orb} and P_{sh}. The triangle indicate the position of IX Dra calculated from P_{f_4} and P_{sh}

The period excess, ε, is defined as:
$\varepsilon = \frac{\Delta P}{P_{orb}} = \frac{P_{sh} - P_{orb}}{P_{orb}}$

It can be expressed as a scaled mass ratio of the system, $q = M_2/M_1$:
$\varepsilon \approx \frac{0.23q}{1+0.27q}$

Thus, the P_{orb} vs. ε relation provides us an excellent plane to examine the evolution of the stars.

Evolutionary analysis of the whole ER UMa class

- after 17 years since the distinction from typical SU UMa stars (Kato and Kunjaya, 1995; Robertson et al., 1995), ER UMa-type of dwarf novae is still very poorly understood
- we present a new set of basic statistics
- this class is not uniform
- ER UMa and V1159 Ori
- DI UMa and IX Dra
- RZ LMi

Evolutionary analysis of the whole ER UMa class

Table 6. Properties of known ER UMa-type stars. P_{orb} and P_{sh} are the orbital and superhump periods. P_{sc} and P_c are the supercycle and cycle lengths, D_s and A_s are the duration and amplitude of superoutbursts, and D_n with A_n are the same for normal outbursts. ϵ is the period excess, and ϵ_- is the period deficit in the case of a presence of negative superhumps. *Reg.* stands for *region* in the P_{orb} vs. ϵ diagram (see Fig. 15): the black triangle symbol indicates a position in the region of typical SU UMa stars before they reach the minimum period during their evolution, and the dot corresponds to a position of an object in the area of *period bouncers*. The last two rows show both possible sets of parameters of IX Dra, depending on the choice of the orbital period (see Sec. 4.3 for details).

Object	P_{orb} [d]	P_{sh} [d]	P_{sc} [d]	P_c [d]	D_s [d]	A_s [mag]	D_n [d]	A_n [mag]	ϵ %	ϵ_- %	*Reg.*	Ref.
ER UMa	0.06366(3)	0.066862798	43-45	4-6	20	3	3-4	2-2.5	2.1	−7.5	▲	a, b, c, d
V1159 Ori	0.06217801(13)	0.064167(40)	44.6-53.3	4	20	2.5	3-5	2	3.2	−7.6	▲	a, b, e, f
RZ LMi	—	0.059396(4)	19.07(4)	4.027(3)	10	2.6	4-5	2.1	—	—	?	g
DI UMa	0.054579(6)	0.055318(11)	31.45(30)	?	12	3.3	?	2.4	1.4	—	•	h
IX Dra (1)	0.06646(2)	0.066982(36)	58.5	3.1-4.1	15	3.0	4	2.5	0.8	—	•	this work
IX Dra (2)	0.06481(5)	0.066982(36)	58.5	3.1-4.1	15	3.0	4	2.5	3.4	—	▲	this work

[a] Wood et al. (2009)
[b] Thorstensen et al. (1997)
[c] Gao et al. (1999)
[d] Zhao et al. (2006)
[e] Patterson et al. (1995)
[f] Kato (2001)
[g] Olech et al. (2008)
[h] Rutkowski et al. (2009)

Thank you