Kazan Federal University

A joint SRG/eROSITA + ZTF search: Discovery of two eclipsing cataclysmic variables SRGeJ045359.9+622444 and SRGeJ041130.3+685350

Dr. Ilkham Galiullin

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Overview:

- Accreting White Dwarfs

- A Joint SRG/eROSITA + ZTF Survey

- SRGeJ045359.9+622444 (SRGeJ0453)

- SRGeJ041130.3+685350 (SRGeJ0411)

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Accreting White Dwarfs

- White Dwarfs (WDs) are the final stage of the evolution of low and intermediate-mass stars $M_{star} \lesssim 8 \sim 10\ M_{\odot}$.
- Binary system: WD accretes material from a companion star (Roche-lobe overflow/stellar wind).

Broad classification of accreting WDs

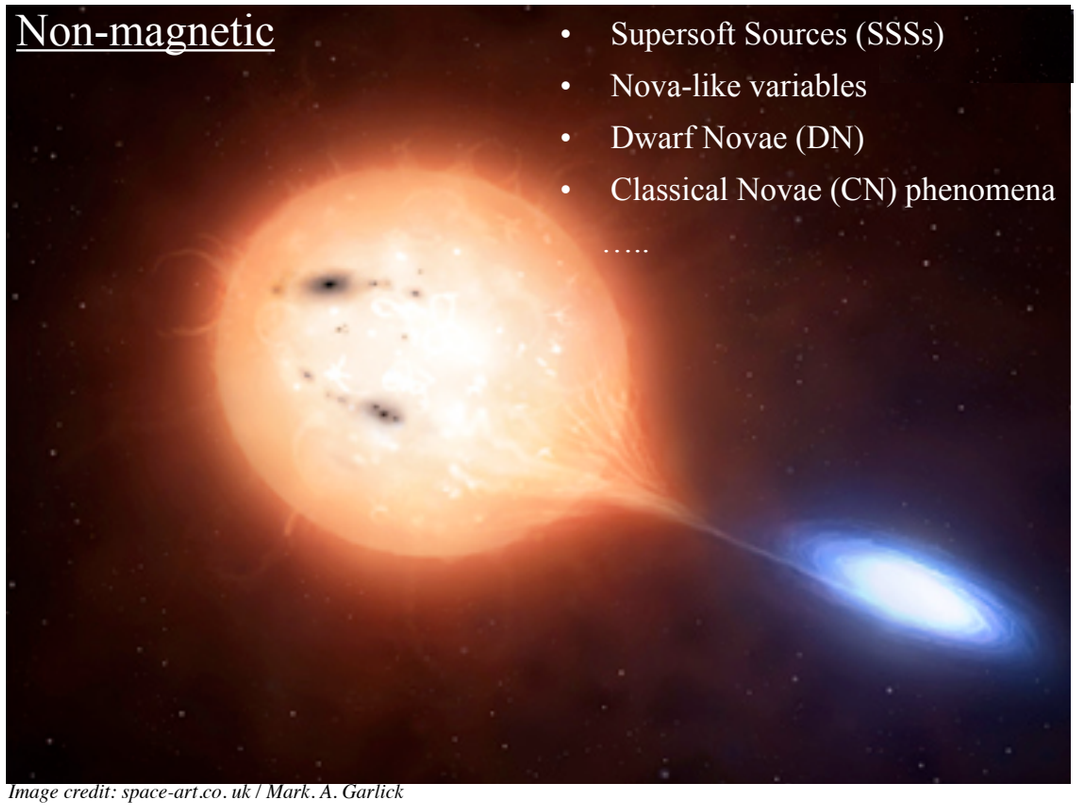


Image credit: space-art.co. uk / Mark. A. Garlick

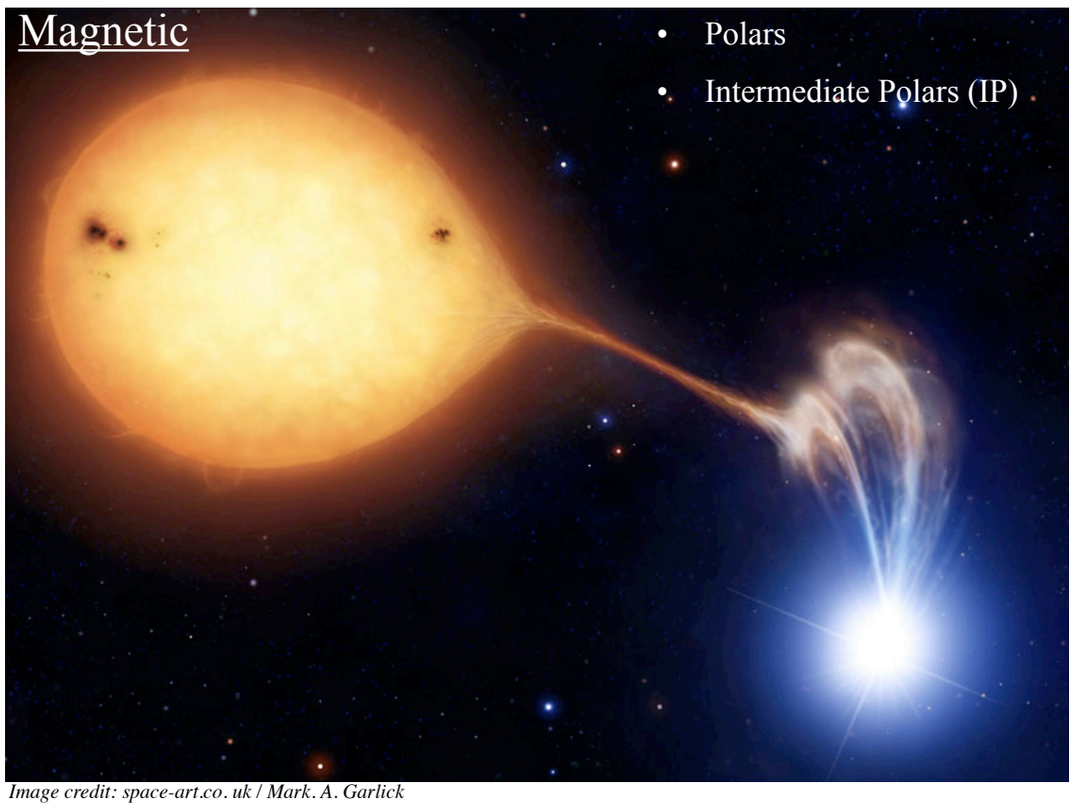
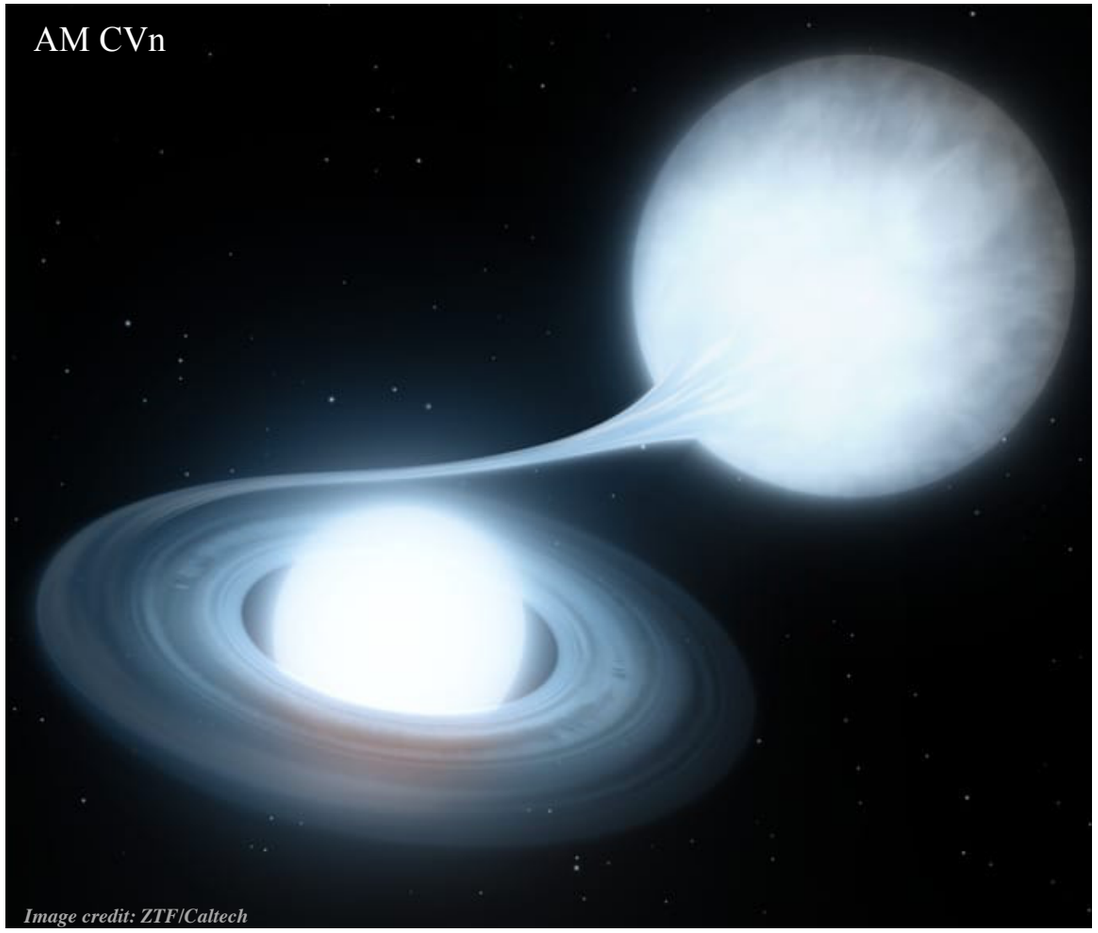


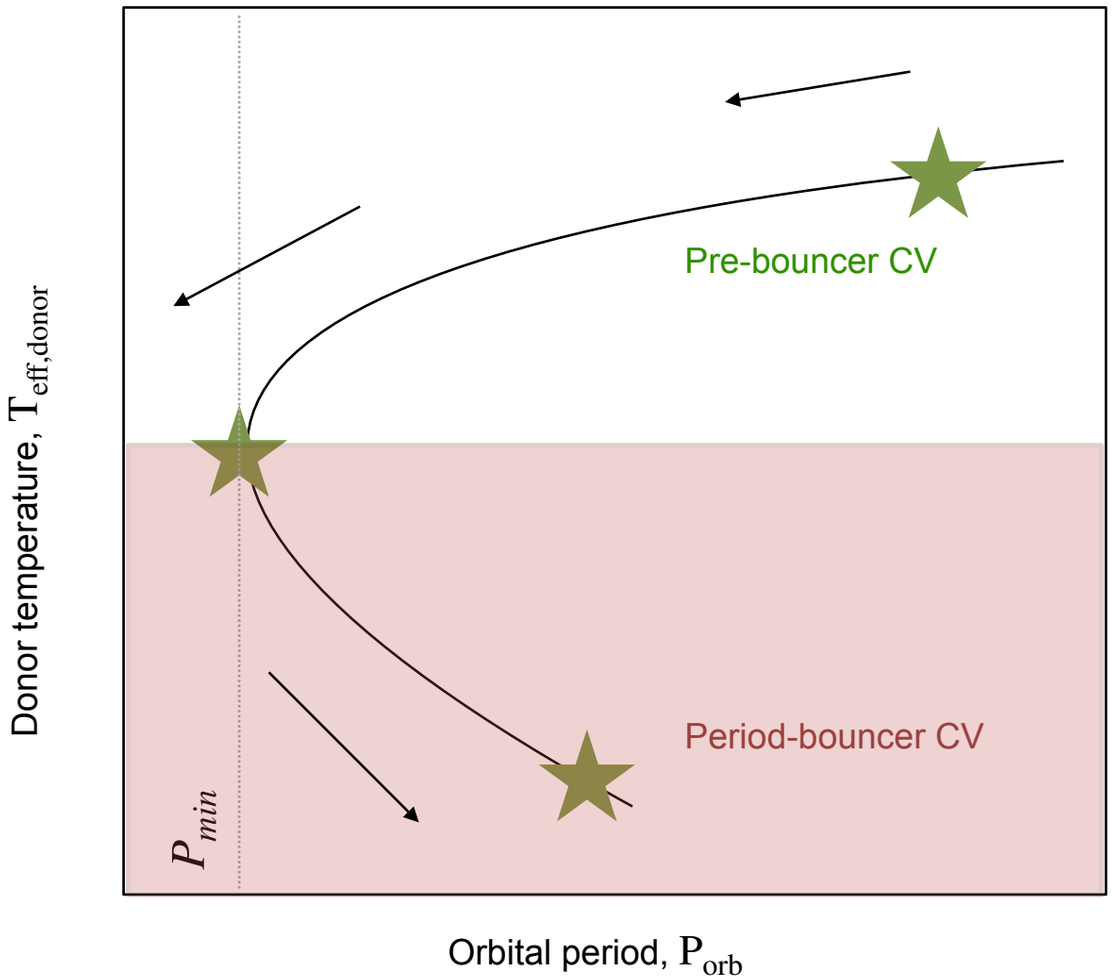
Image credit: space-art.co. uk / Mark. A. Garlick

Two primary energy sources in accreting WDs:

- Accretion disk, boundary layer (BL), corona (DN)
- Nuclear fusion of H/He on WD surface (SSS or post-nova SSS phase)

Rare type of Cataclysmic Variables





- **AM CVn stars** are ultra-compact binaries, where a WD accretes material from a helium-dominated, Roche-lobe-filling donor. The orbital period of these systems lies in the 5.4–67.8 minutes range (for recent reviews, see Solheim 2010; Ramsay et al. 2018).

- CVs that have evolved past the period minimum during their lifetimes are predicted to be systems with a brown dwarf donor. So called **«period-bouncers»** CVs (e.g., Paczynski 1976).

- Less than ~ 20 - 40 objects are reported in the literature.

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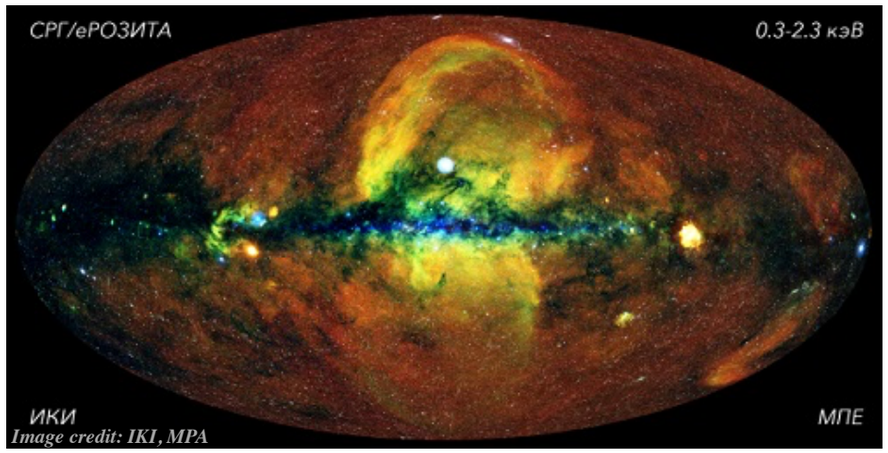
A Joint SRG/eROSITA + ZTF Survey

(a) RU Consortium of SRG/eROSITA (Galactic $0^\circ < l < 180^\circ$; $b > 10^\circ$):

- Field A: 600 deg^2
- Field B: 600 deg^2



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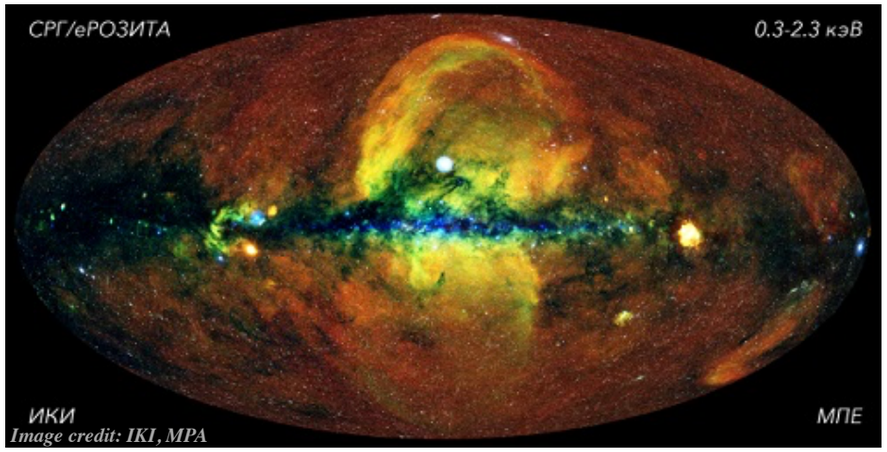
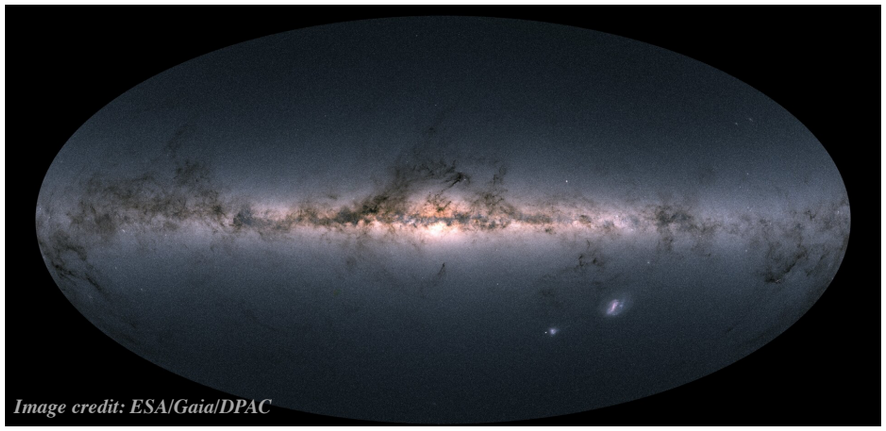


(b) Crossmatch with Gaia DR3

- Only Galactic sources, just above the WD track on the HR diagram
- High X-ray to optical ratio Fx/Fopt



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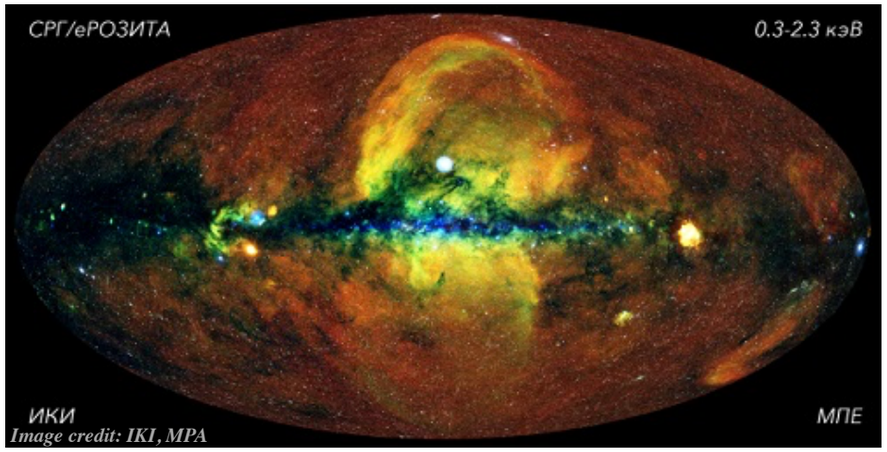

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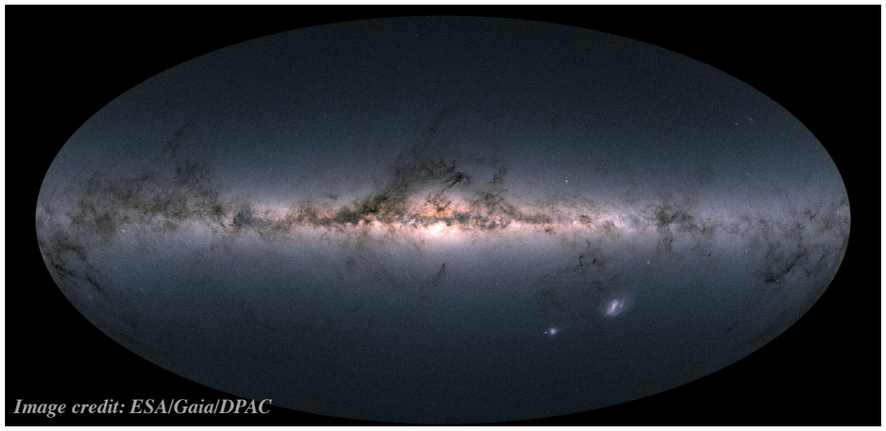
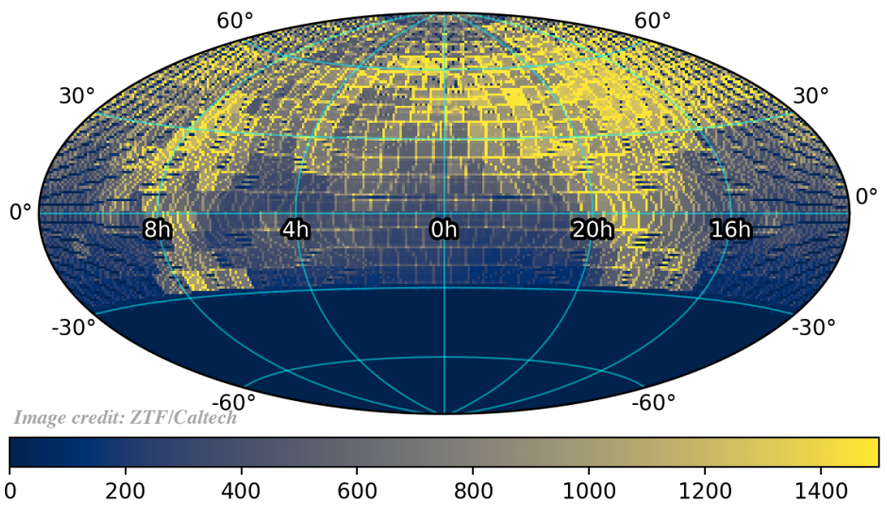


(c) Crossmatch with Zwicky Transient Facility (ZTF):

- Caltech proprietary data included



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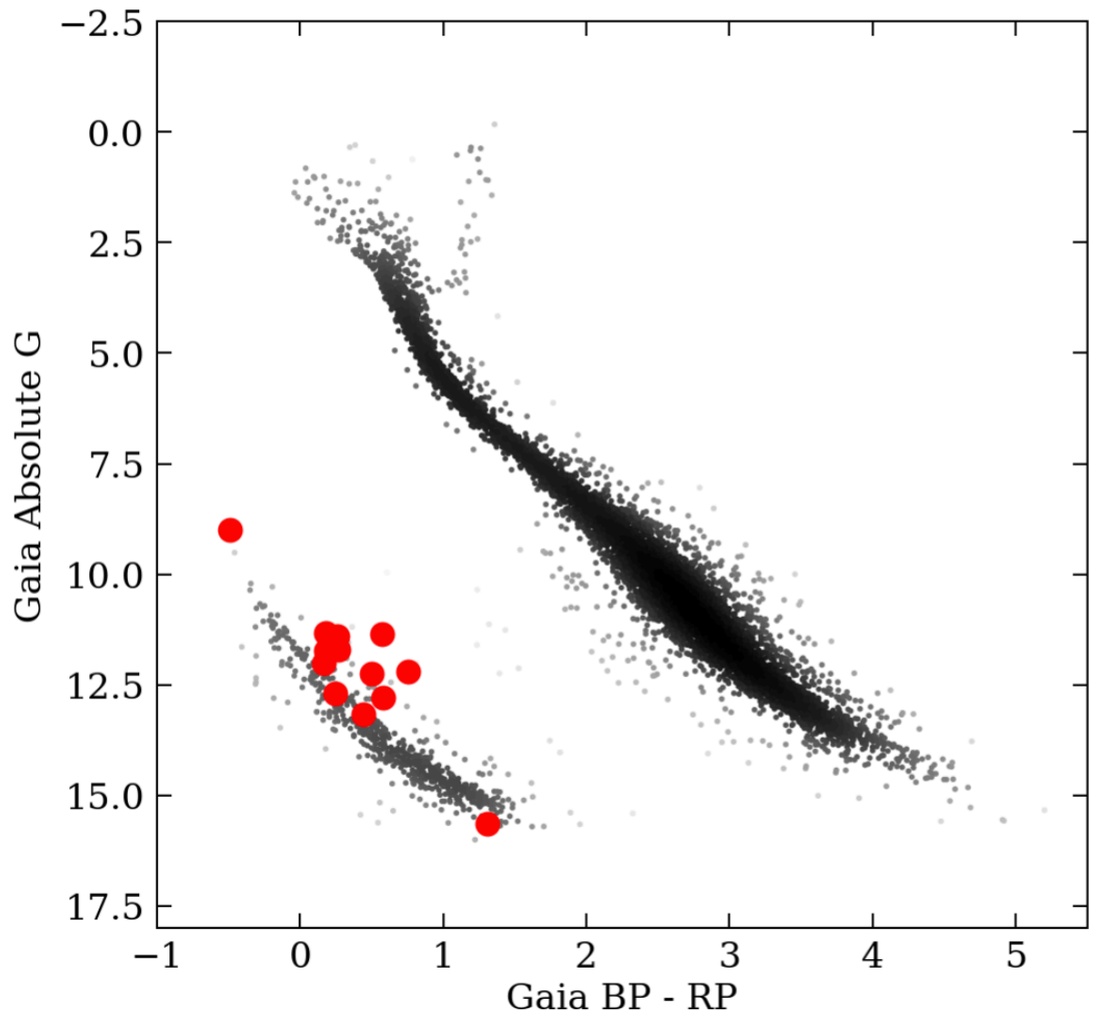
Results on Field A

- Nine CV candidates were selected above the WD region on the HR diagram.

- We undertook optical spectroscopic follow-up observations with the 10m Keck I telescope using the Low-Resolution Imaging Spectrometer and the 5m Hale telescope using the Double Spectrograph (DBSP).

- Additional photometric follow-up was performed with Caltech High-speed Multi-color camERA (CHIMERA) and 1.5m RTT-150 (TUBITAK observatory).

- Five out of nine objects are confirmed to be new CVs.



HR diagram with Gaia sources within 100 pc with significantly measured parallaxes (black color) (parallax_over_error > 3, Gaia Collaboration et al., 2023). Red dots: CV candidates found in Field A.

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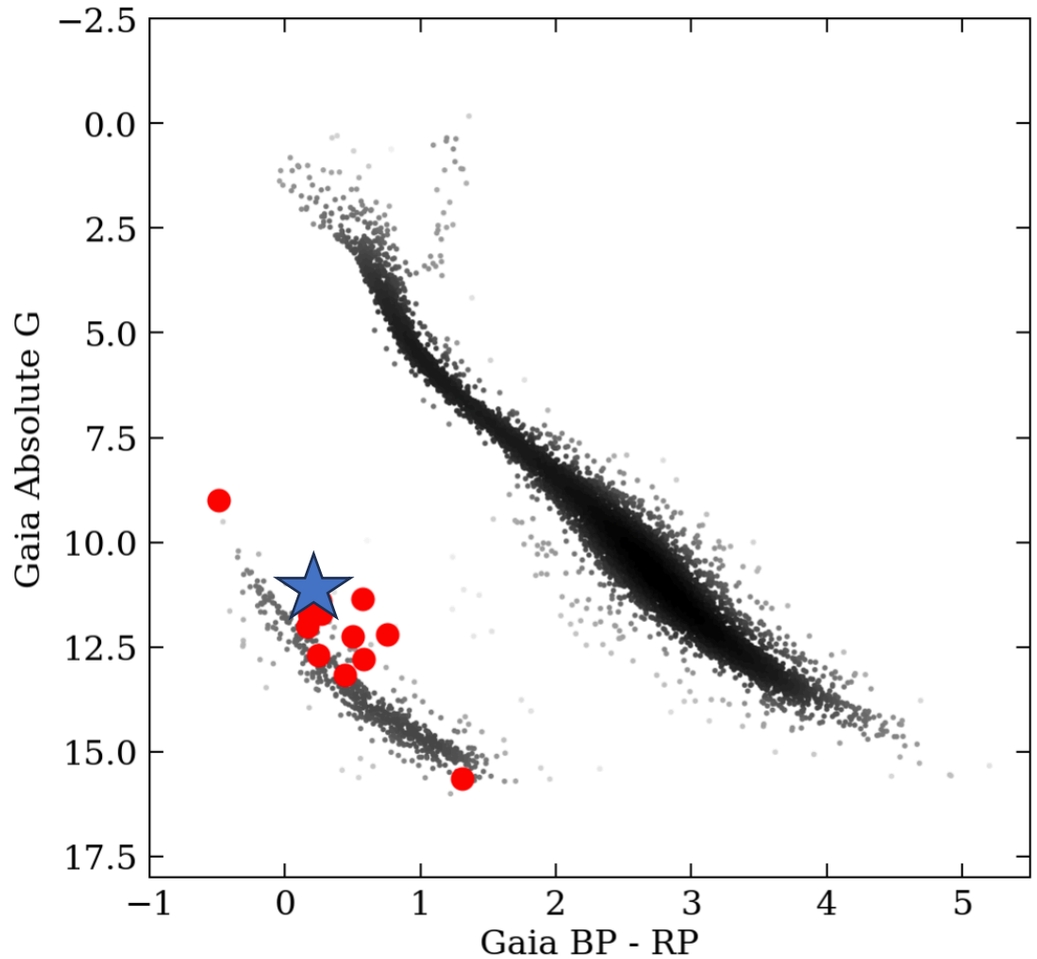
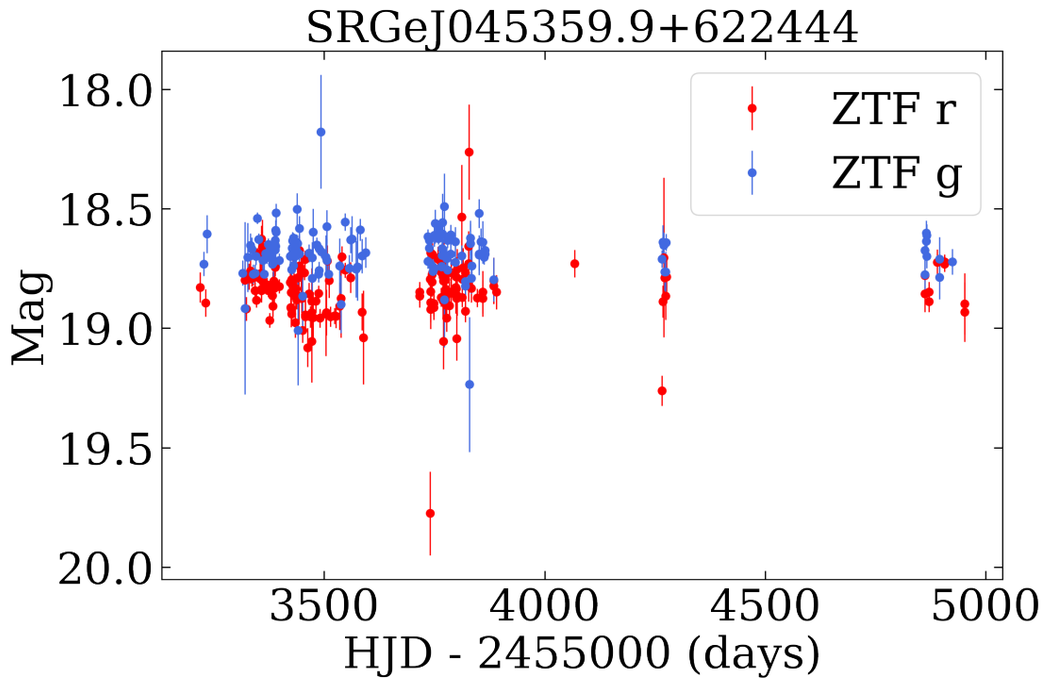
SRGeJ045359.9+622444

- High ratio of X-ray flux to optical flux $F_X/F_{opt} \approx 0.12$.
- Lack of optical outbursts in ZTF light curves.
- Distance to the object ~240 pc.





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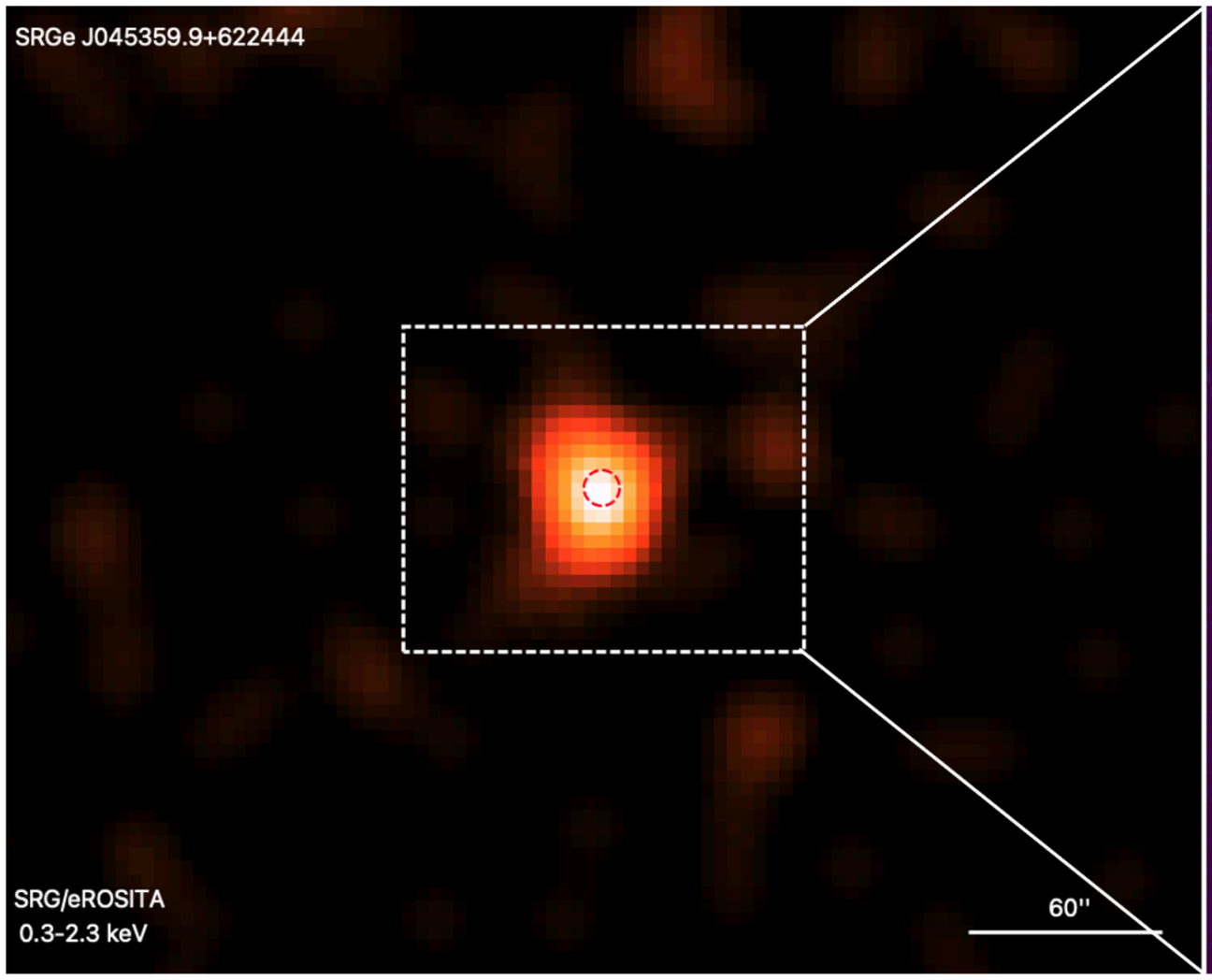
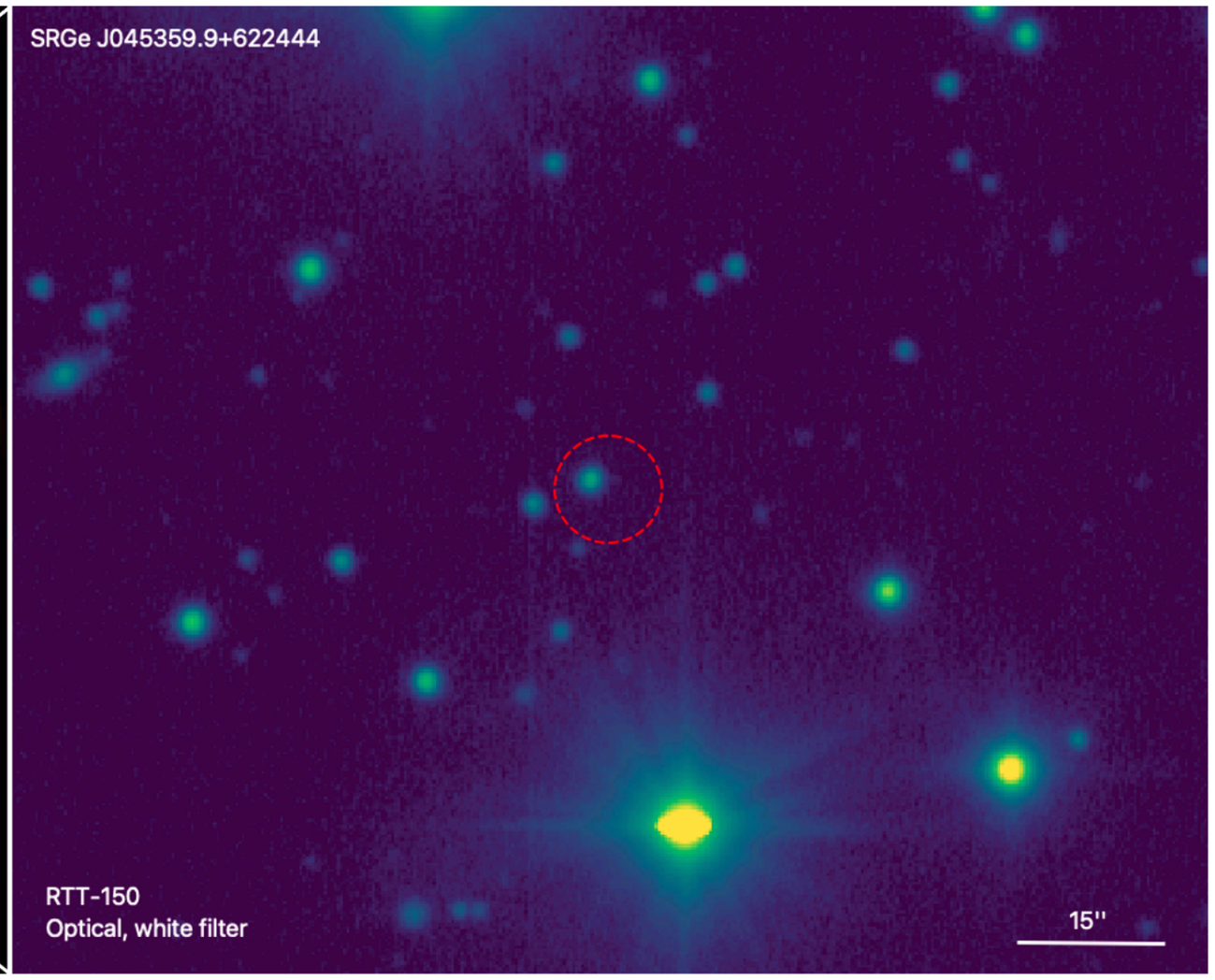
SRGeJ045359.9+622444



False-colour X-ray image of SRGeJ0453 in the 0.3–2.3 keV energy band from combined data of four all-sky surveys of SRG/eROSITA.



Composite optical image around SRGeJ0453 based on RTT-150/ TFOSC data. A pseudo-colour image was composed using gri filters. The magenta circle: R98 = 5.6".

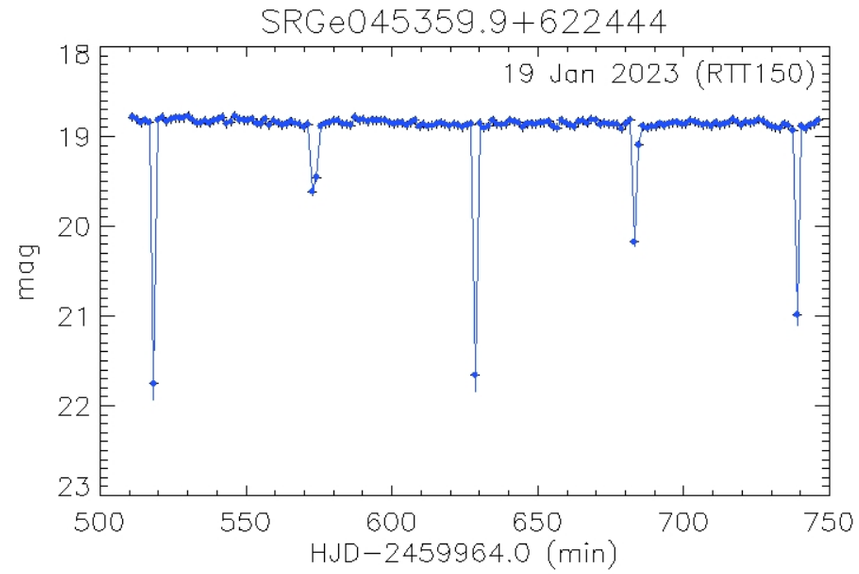
- ~40 optical sources, only 1 X-ray source

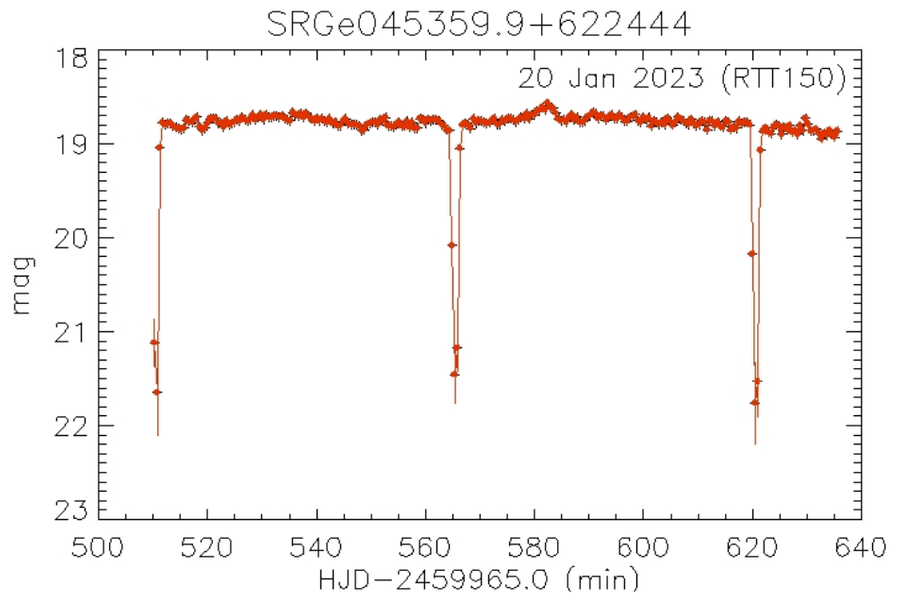
Optical light curves and period determination

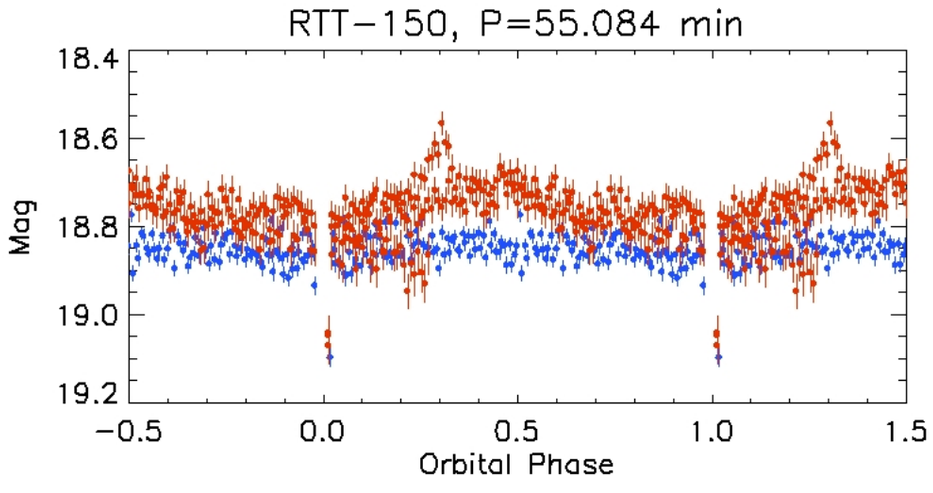
- We observed SRGeJ0453 with the 1.5m RTT-150 (TUBITAK observatory) and high-speed photometry using the Caltech High-speed Multi-color camERA (Palomar Observatory).

- The light curve shows low-amplitude ($\approx 0.1 - 0.3^m$) flickering, possibly caused by an accretion disk. During eclipses, the light curve shows deep dips ($\approx 3^m$).

- The orbital period of SRGeJ0453 is ~55 minutes.







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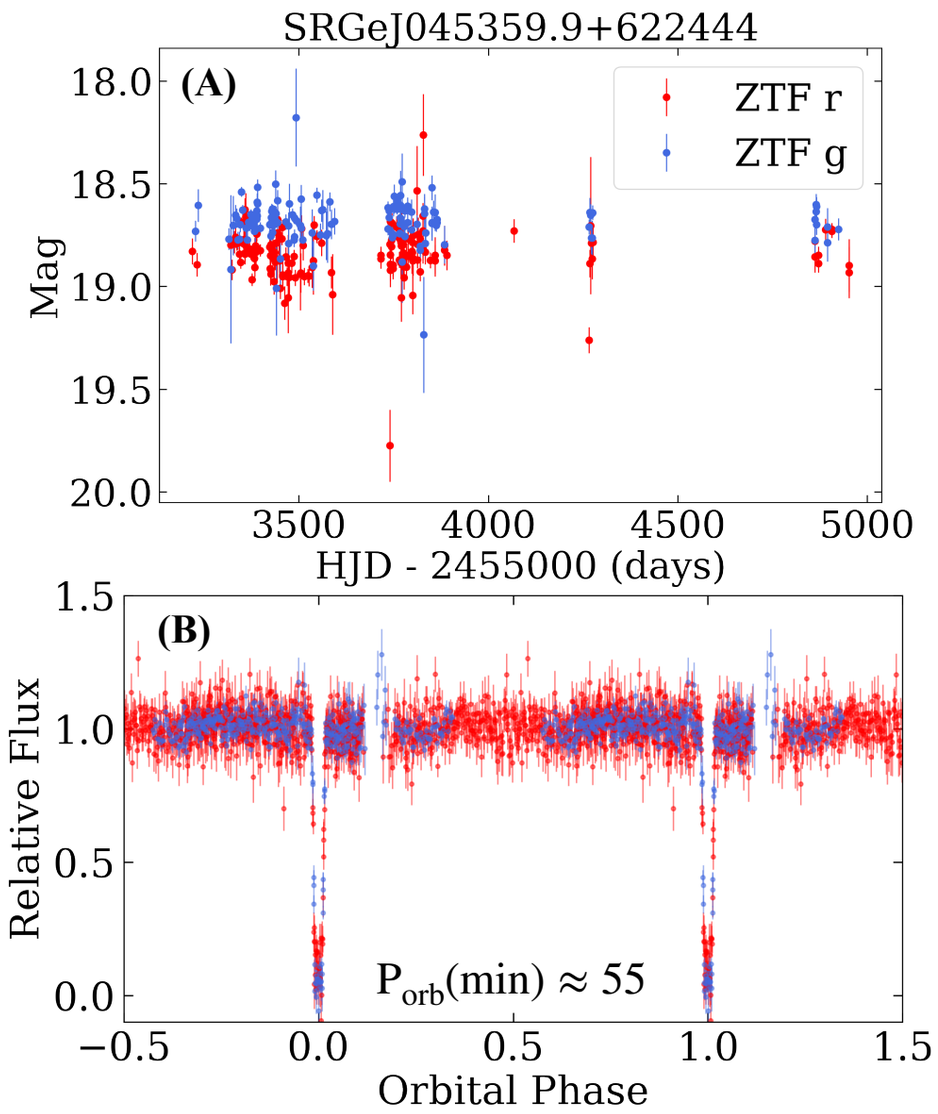
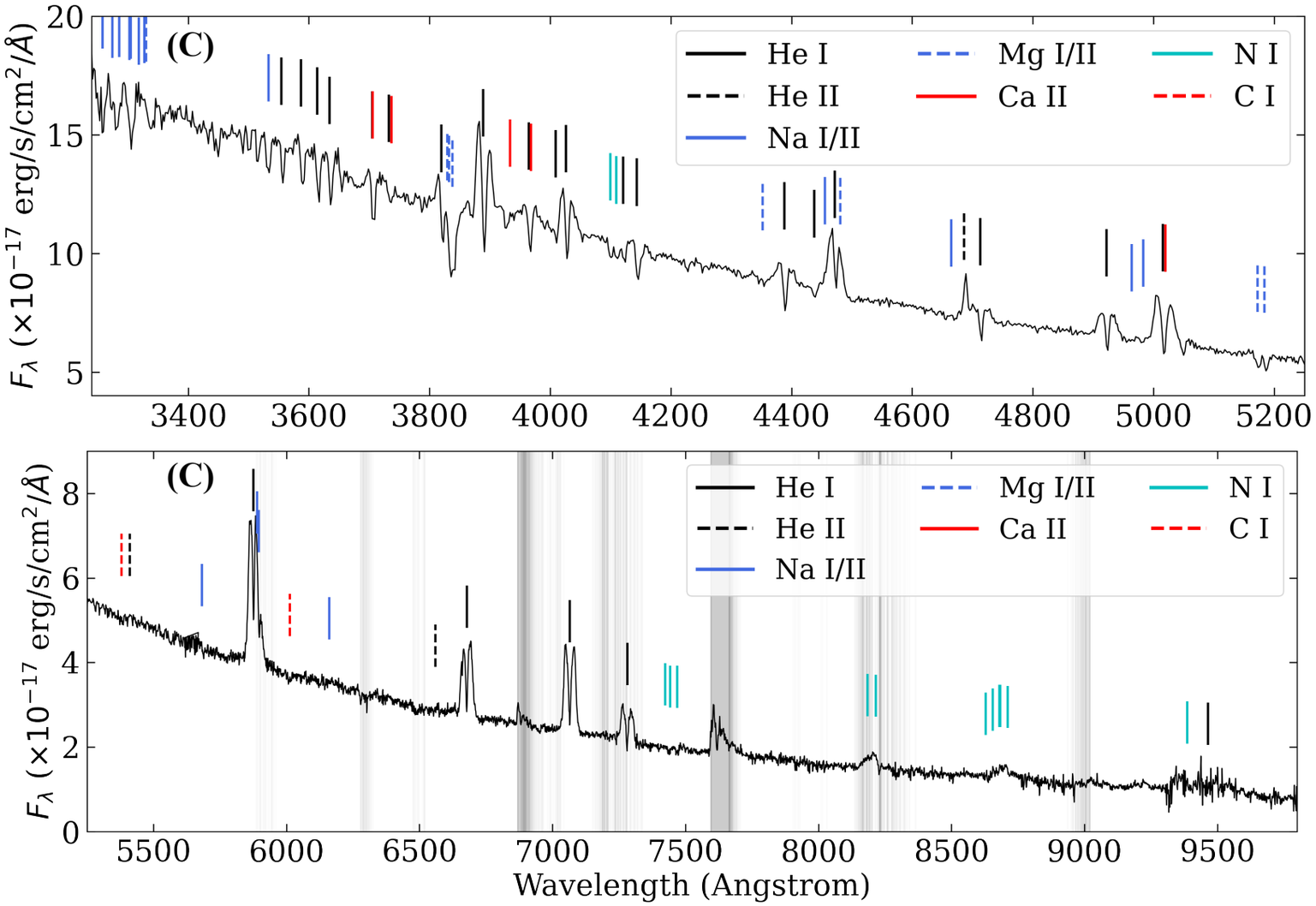
First SRG/eROSITA-discovered AM CVn: SRGeJ045359.9+622444





(A) ZTF light curves on g, r filters. (B) The phase-folded CHIMERA r and g filter data. (C) Keck I /LRIS phase-averaged optical spectrum.

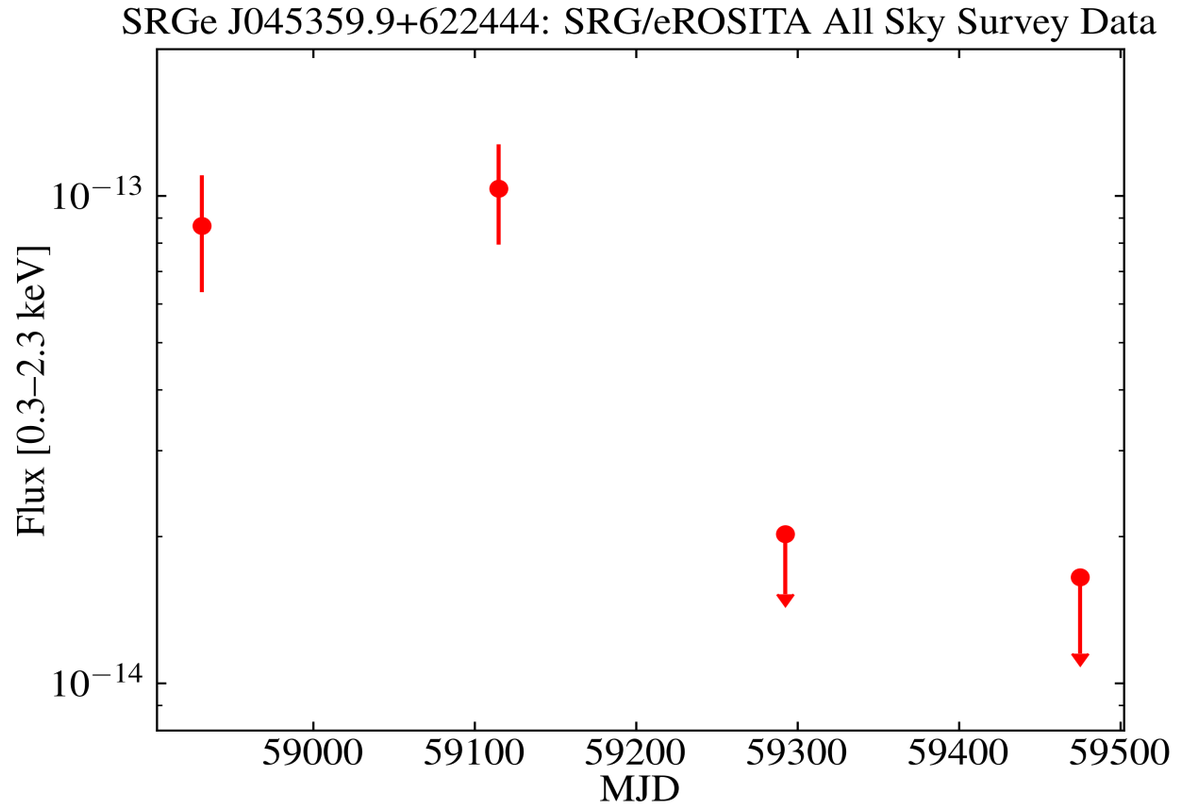
- The optical spectrum of SRGeJ0453 shows common features of AM CVn systems: a blue continuum with prominent He lines and an absence of H lines.
- Optical spectroscopy suggests that the donor star of SRGeJ0453 could have initially been a He star or a He white dwarf.
- SRGeJ0453 is the ninth eclipsing AM CVn system published to date.

X-ray spectrum of SRGeJ045359.9+622444

- The X-ray light curve shows the variability within four sky surveys of SRG/eROSITA.

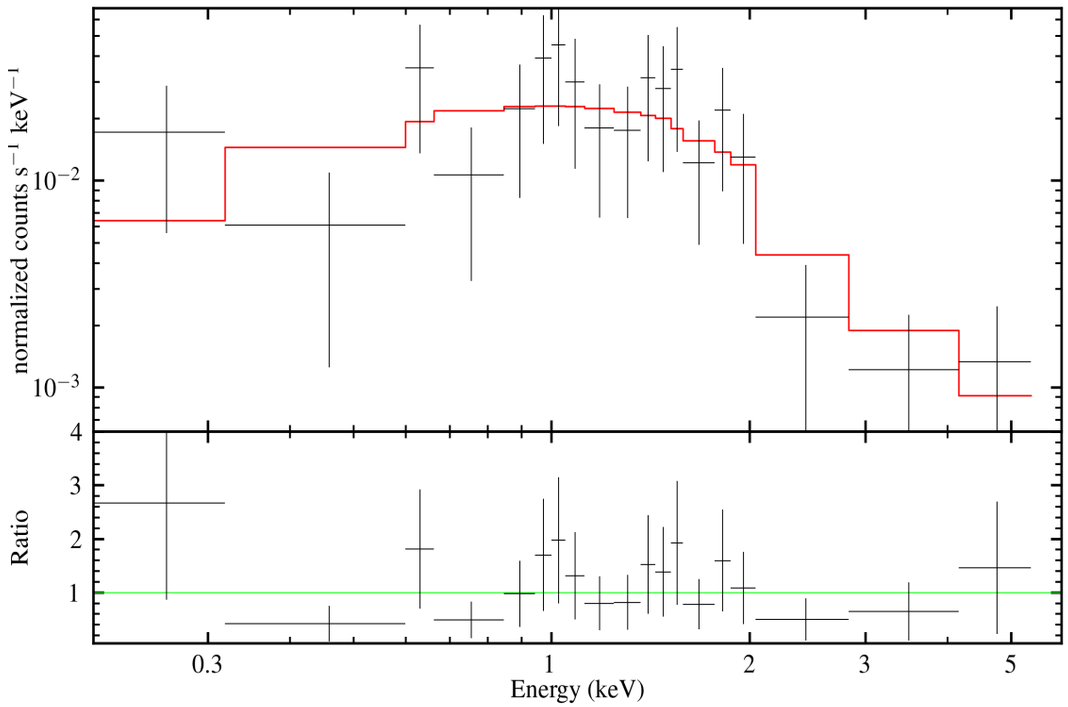
- X-ray luminosity (0.3-2.3 keV): $\approx 6 \times 10^{29}$ erg/s.

- Accretion rate: $\approx (2 - 10) \times 10^{-12}$ $M_\odot$/yr.



- The approximation of the X-ray spectrum of SRGeJ0453 by the power-law model gives a photon index of $\Gamma \sim 1$.

- The X-ray spectra of several IPs and polars are approximated by a photon index $\Gamma \sim 1$, and nonmagnetic systems by $\Gamma \sim 2$ (e.g., Galiullin & Gilfanov 2021).



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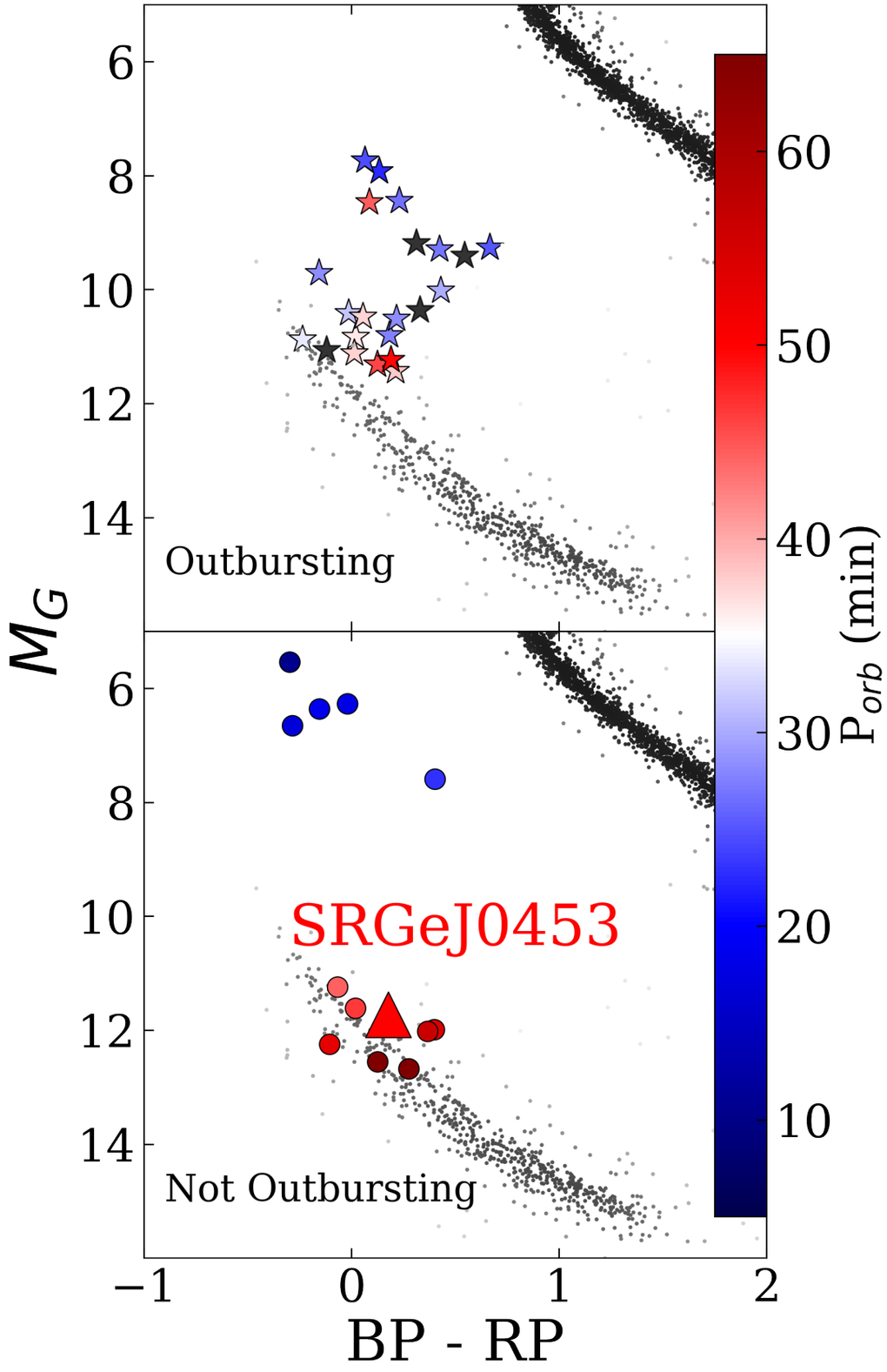
Position of SRGeJ0453 in the Gaia HR diagram

- Position of SRGeJ0453 in the 100 pc Gaia HR diagram alongside previously known AM CVn systems with a significant Gaia parallax (parallax_over_error > 3). The nonoutbursting population occupies distinct portions of the phase space.

- How many AM CVns do we expect in the Milky Way?



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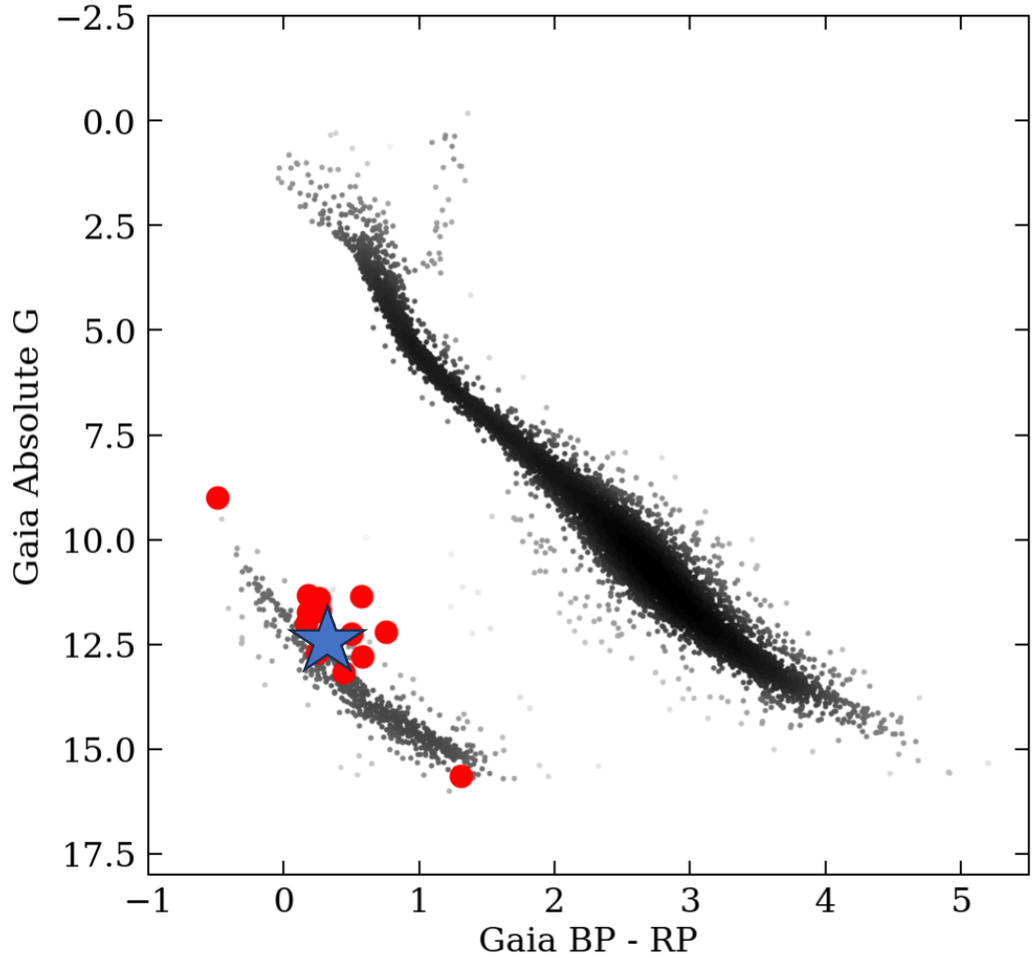
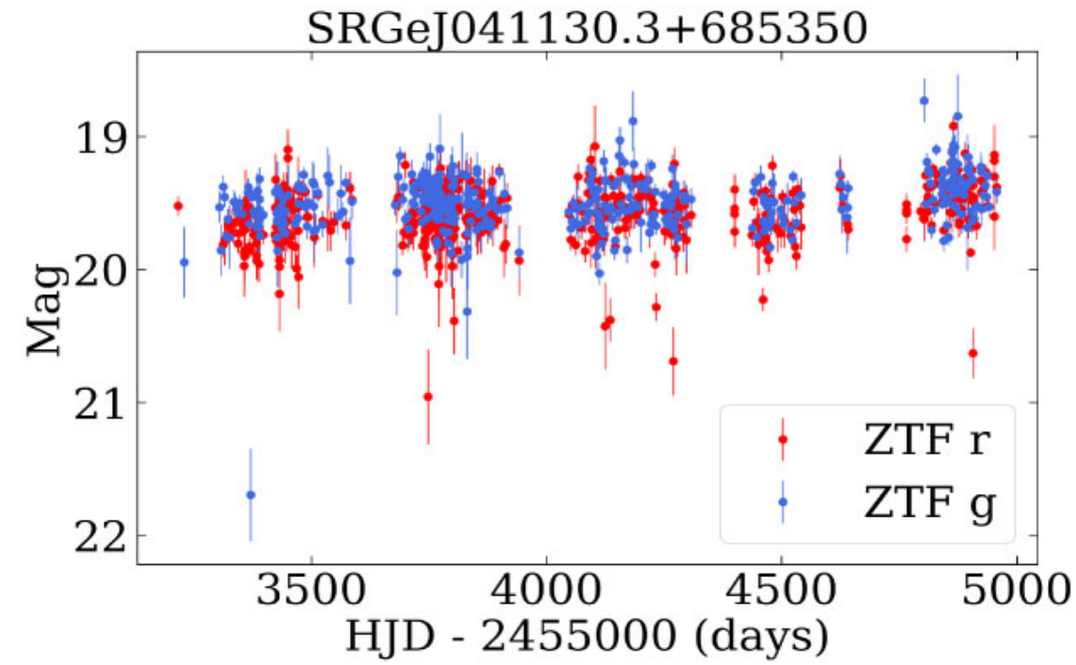
SRGeJ041130.3+685350

- High ratio of X-ray flux to optical flux $F_X/F_{opt} \approx 0.60$.
- Lack of optical outbursts in ZTF light curves.
- Distance to the object ~324 pc.





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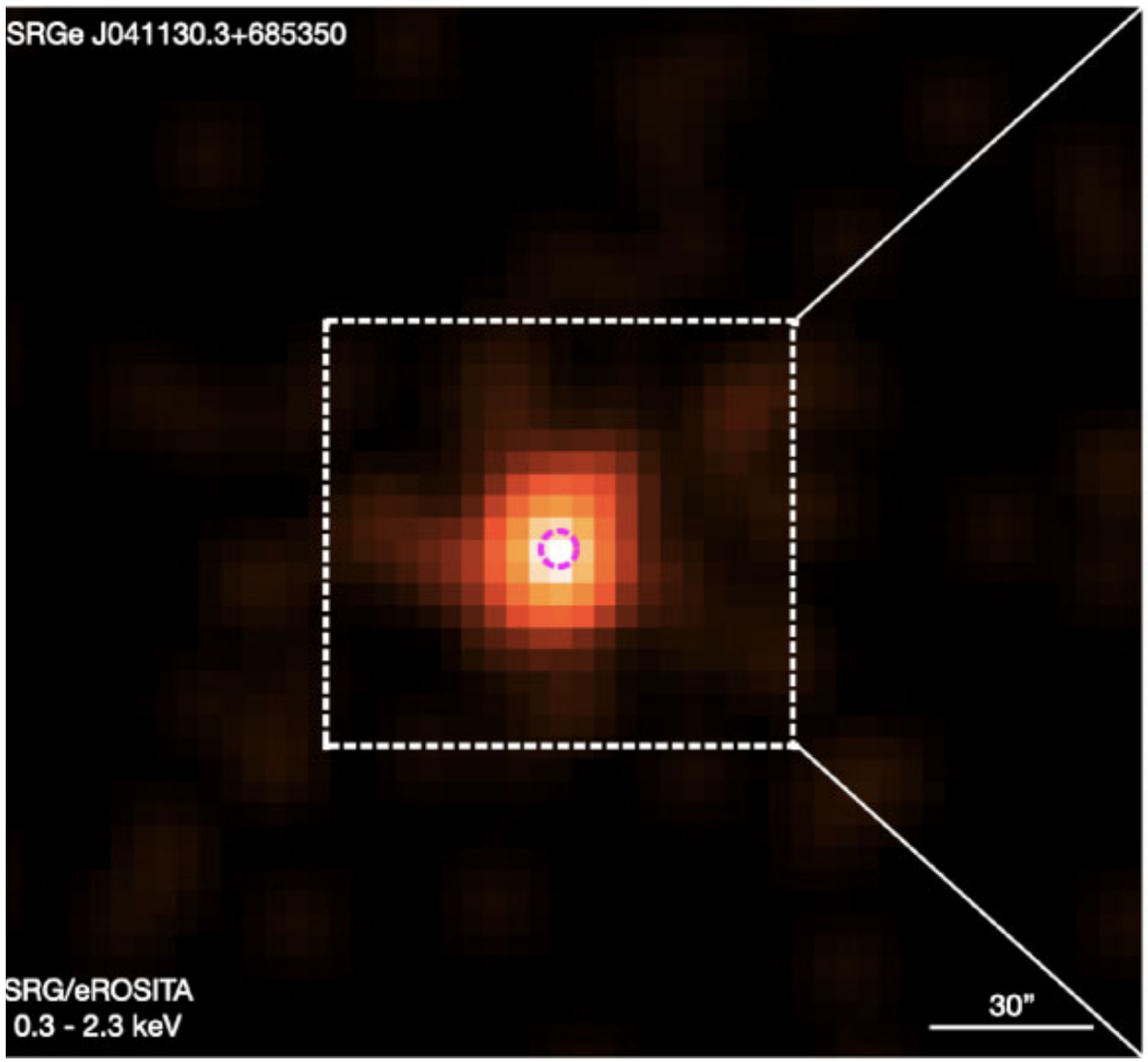

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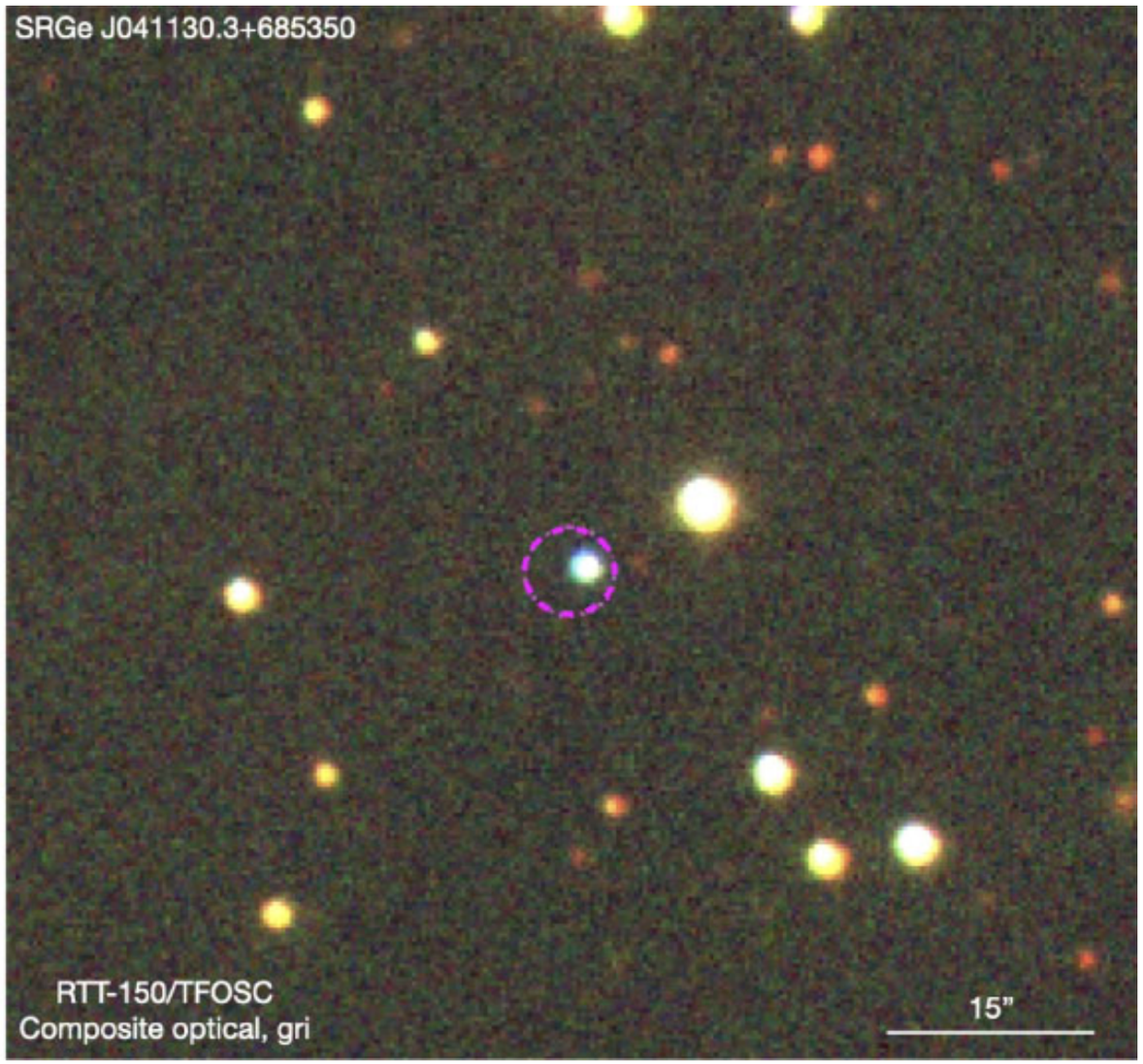
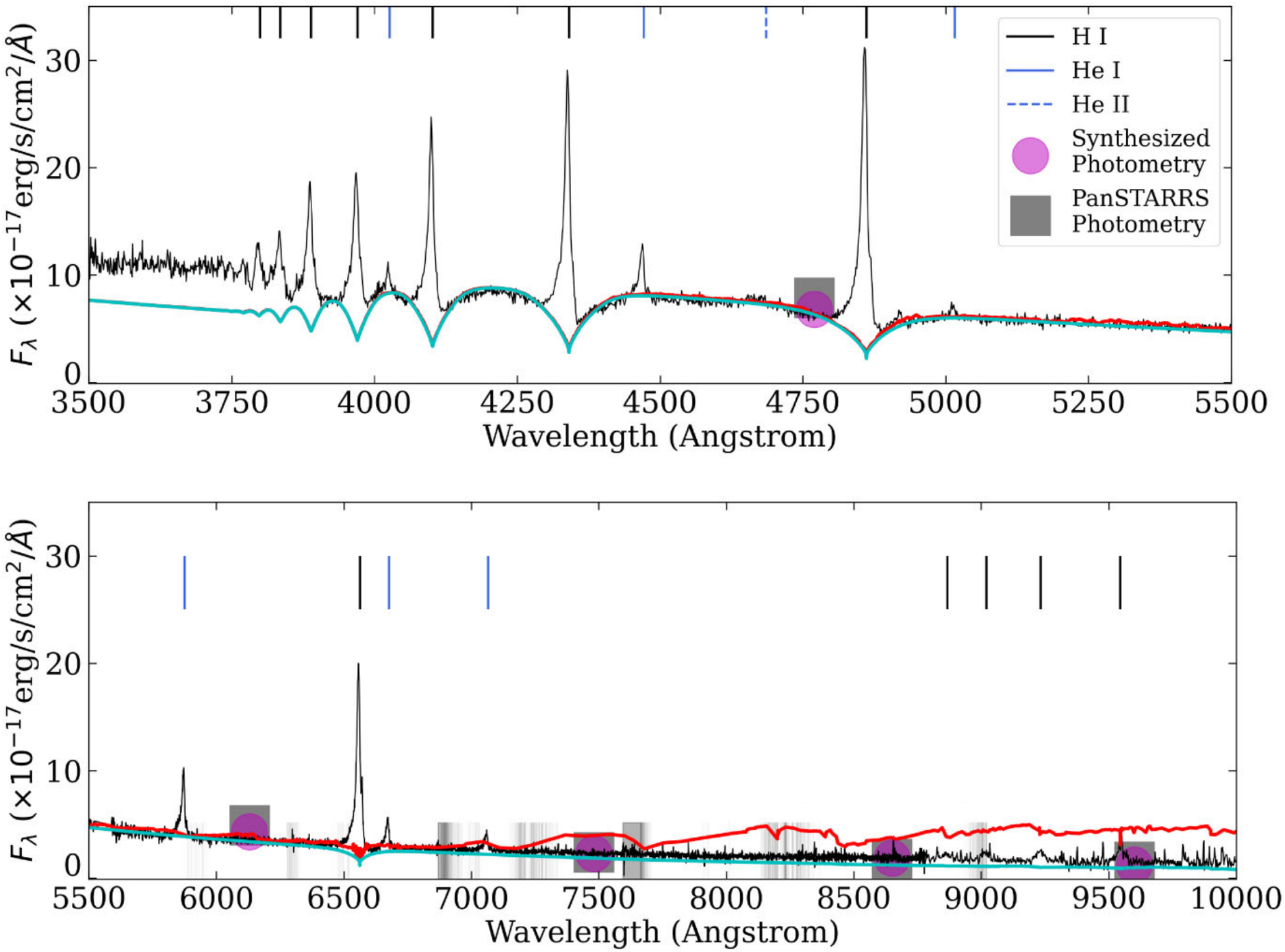


Composite optical image around SRGeJ0453 based on RTT-150/ TFOSC data. A pseudo-colour image was composed using gri filters. The magenta circle: R98 = 3.3”.

SRGeJ041130.3+685350



Keck I/LRIS optical spectrum of SRGeJ0411. Grey lines are locations where there are telluric features from the Keck Telluric Line List.

- The optical spectrum of SRGeJ0411 shows prominent hydrogen and helium emission lines, typical for CVs.

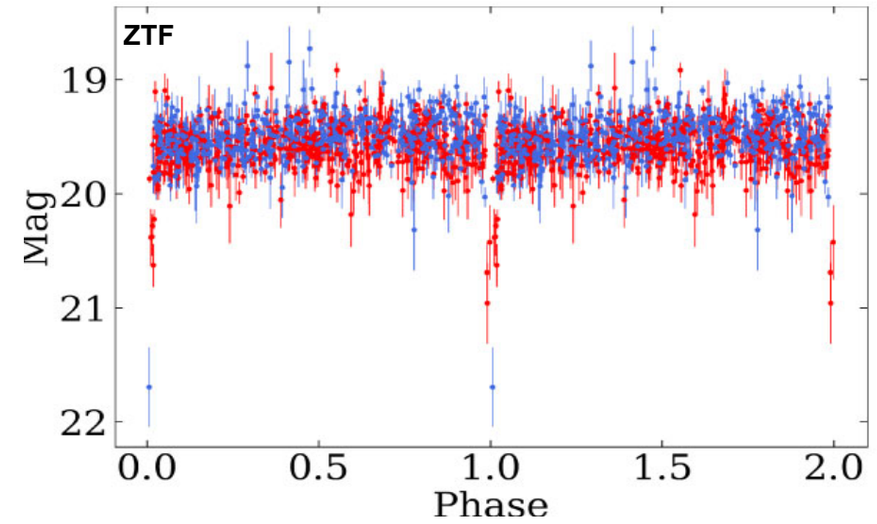
Optical light curves and period determination

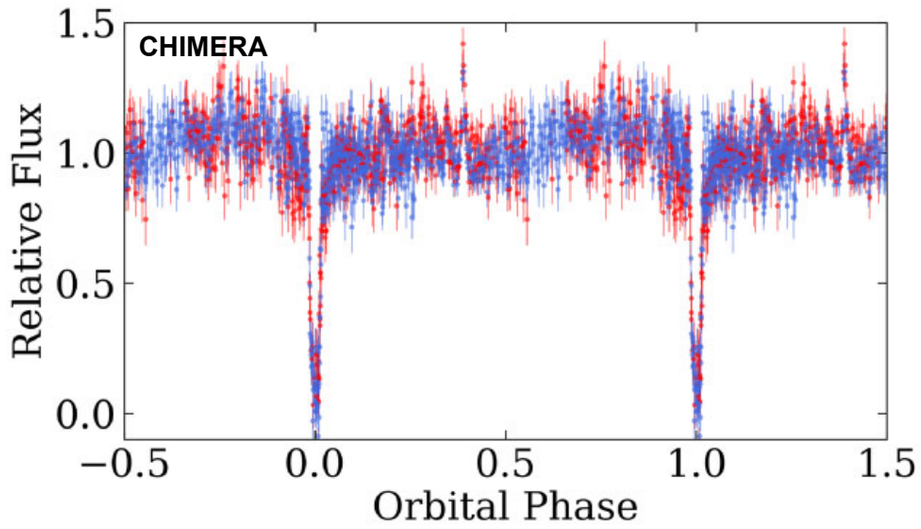
- We observed SRGeJ0411 with the 1.5m RTT-150 (TUBITAK observatory) and high-speed photometry using the Caltech High-speed Multi-color camERA (Palomar Observatory).

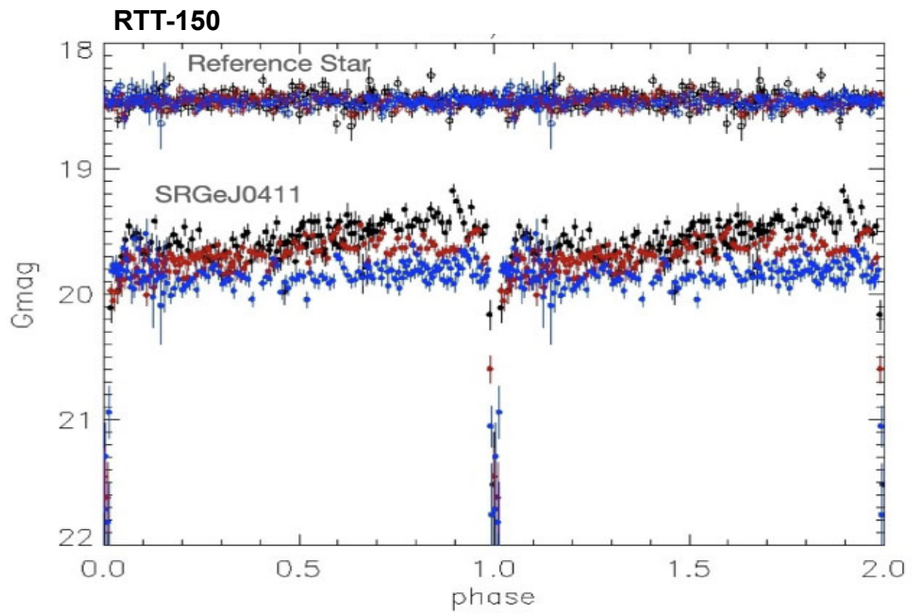
- The light curve shows low-amplitude ($\approx 0.2 - 0.5^m$) flickering, possibly caused by an accretion disk. During eclipses, the light curve shows deep dips ($\approx 2^m$).

- The orbital period of SRGeJ0411 is ~97.5 minutes.

- The orbital period minimum for CVs is ~80 minutes (Knigge 2006, Gansicke et al. 2009).







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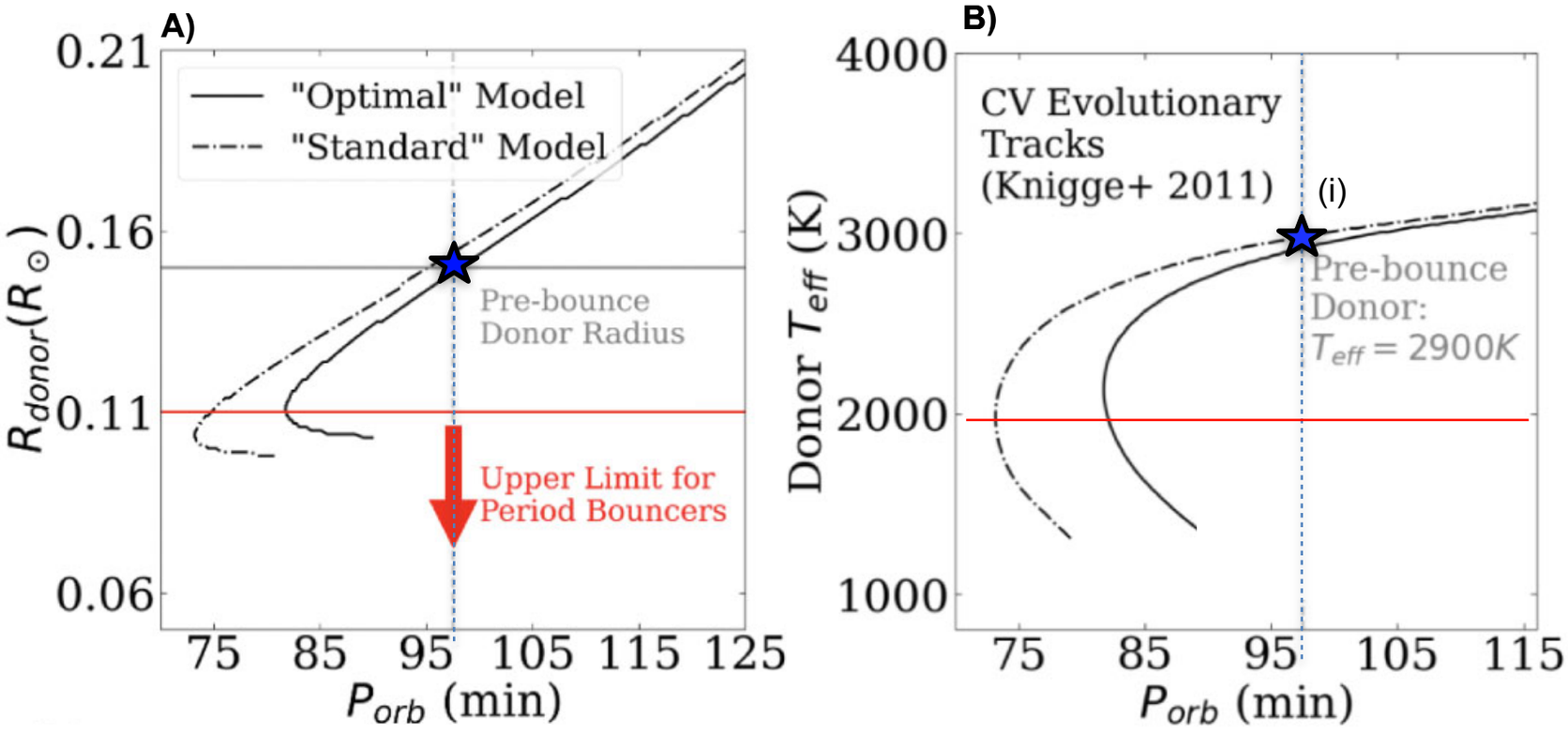
I. Estimation of binary parameters of SRGeJ041130.3+685350

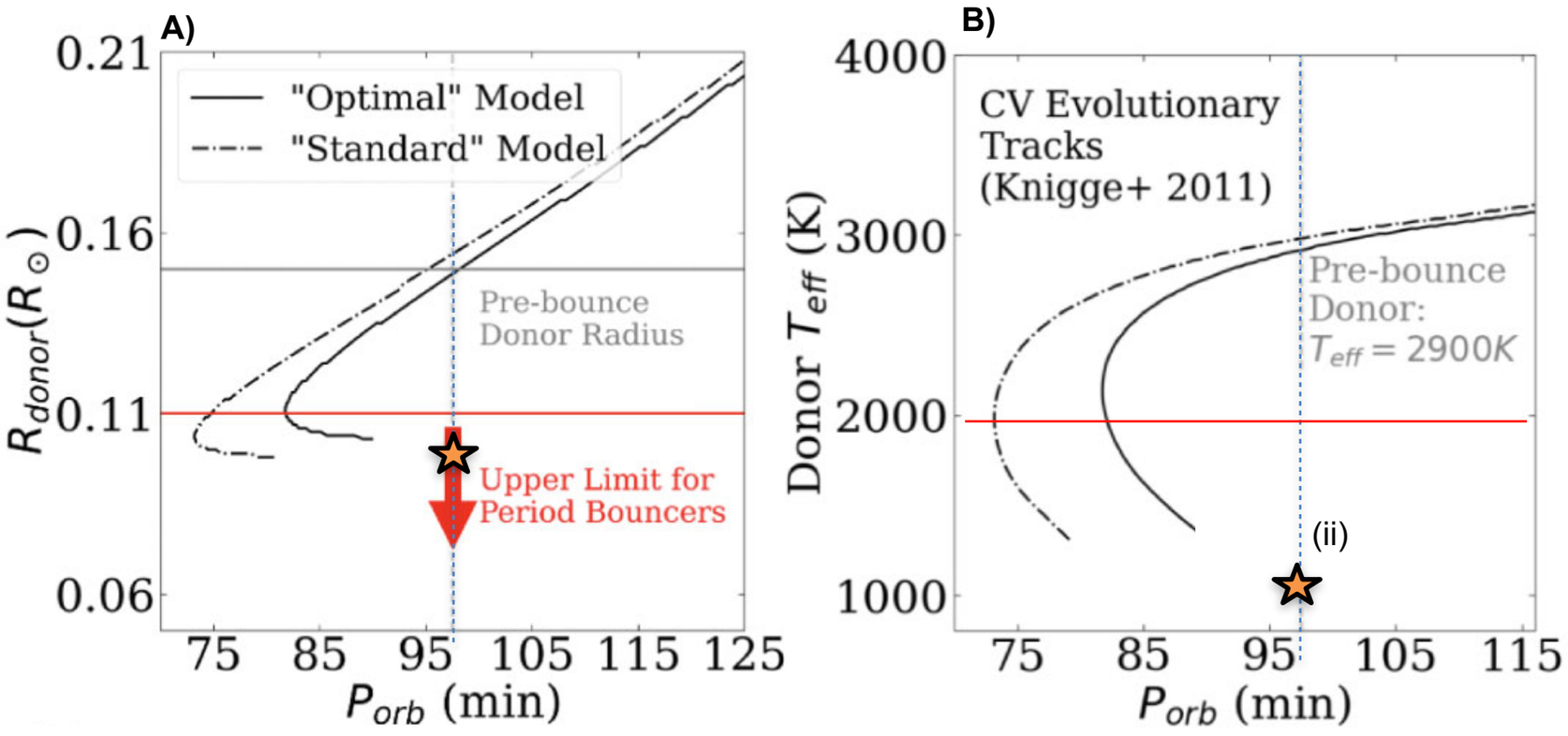


The CV evolutionary tracks from Knigge et al. (2011): A) and B) Donor radius and donor effective temperature as a function of orbital period.

- From the CV evolutionary tracks, the donor parameters for CV with an orbital period of ≈ 97.5 should be:

(i) $R_{donor} \approx 0.15\ R_\odot$ и $T_{eff,donor} \approx 2{,}900$ K (Pre-bounce donor; before passing the P_{min} during the evolution);

II. Estimation of binary parameters of SRGeJ041130.3+685350



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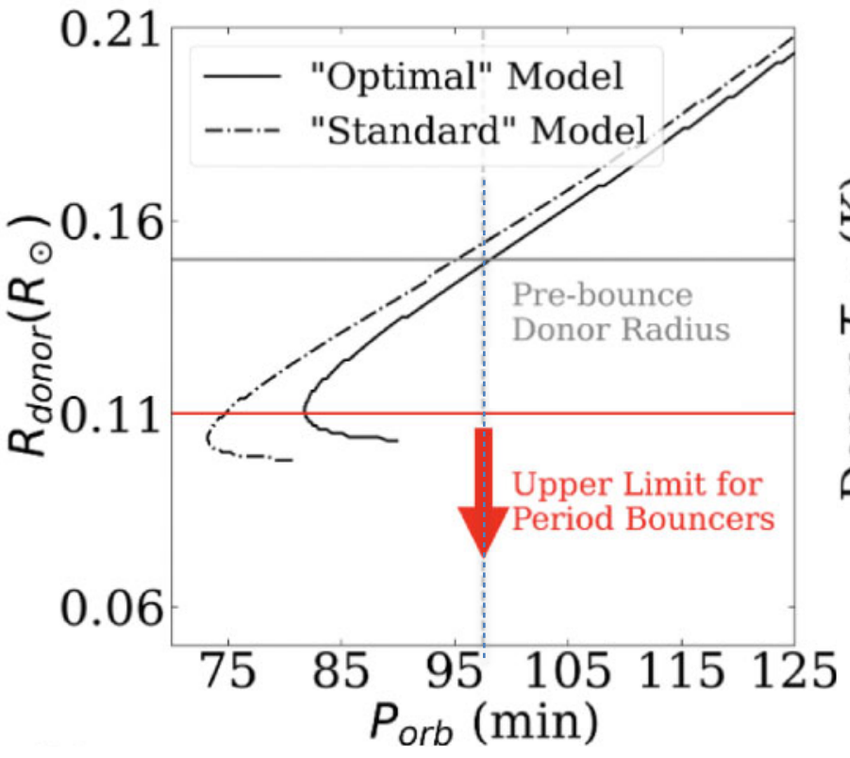
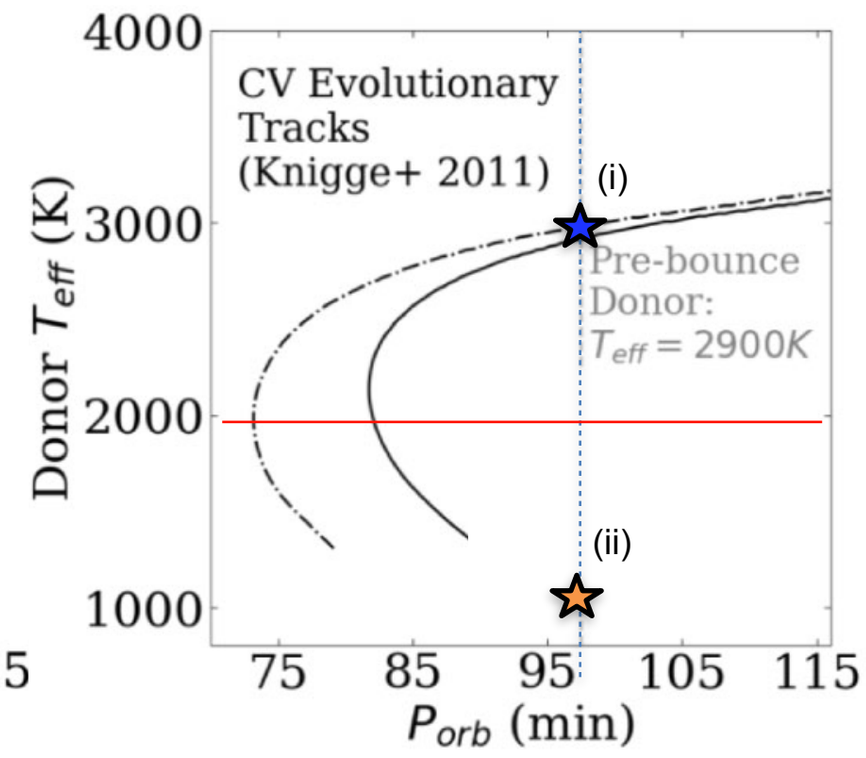
(ii) $R_{donor} \lesssim 0.11\ R_\odot$ и $T_{eff,donor} \lesssim 2{,}000$ K (Donor of period bouncer CV; after passing the P_{min} during the evolution).

III. Estimation of binary parameters of SRGeJ041130.3+685350





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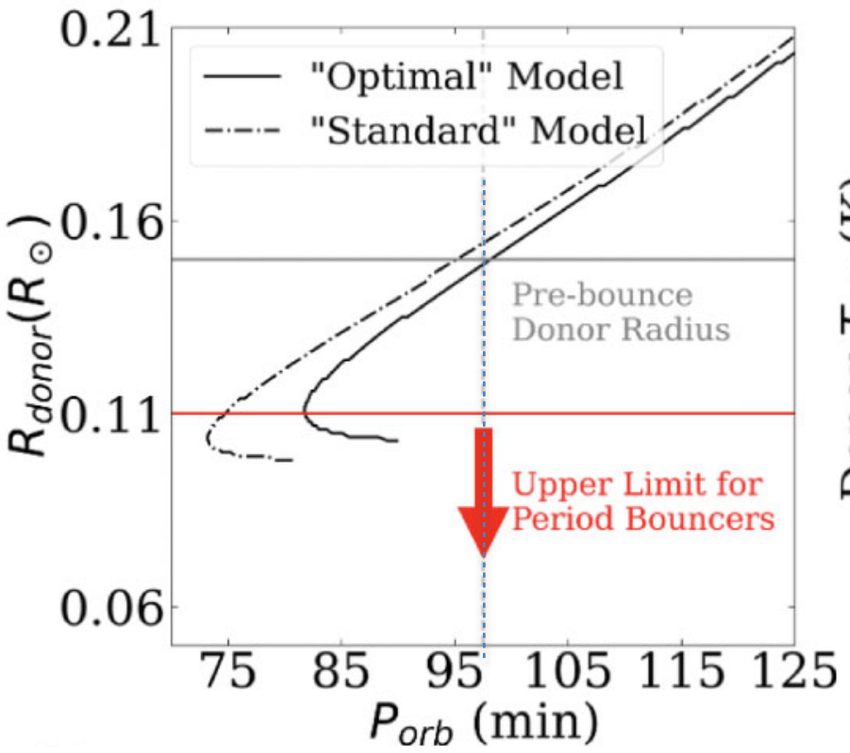
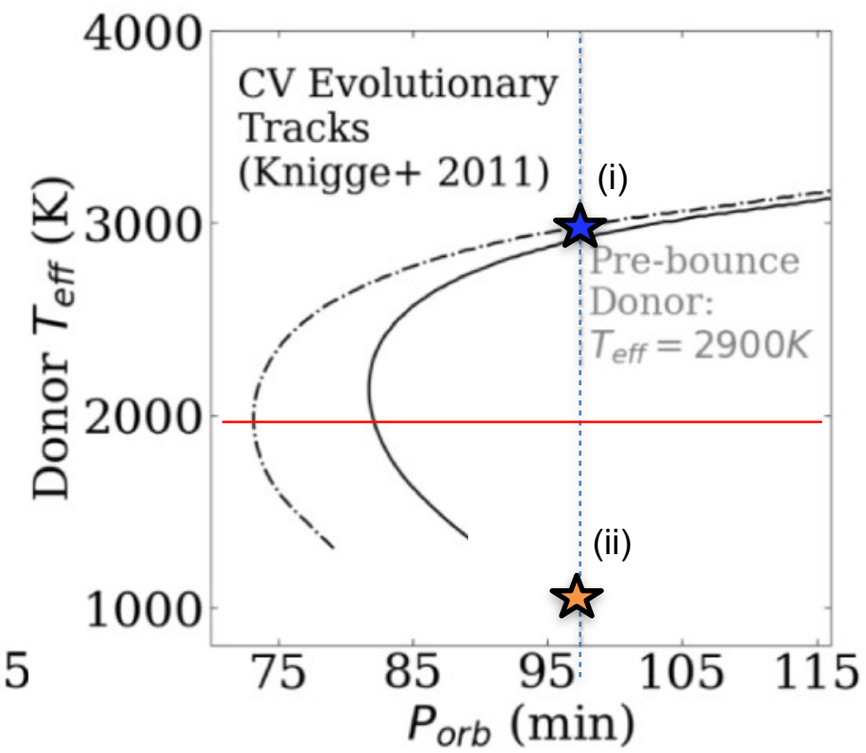
(ii) $R_{donor} \lesssim 0.11\ R_\odot$ и $T_{eff,donor} \lesssim 2{,}000$ K (Donor of period bouncer CV; after passing the P_{min} during the evolution).

IV. Estimation of binary parameters of SRGeJ041130.3+685350





The CV evolutionary tracks from Knigge et al. (2011): A) and B) Donor radius and donor effective temperature as a function of orbital period.

- From the CV evolutionary tracks, the donor parameters for CV with an orbital period of ≈ 97.5 should be:

(i) $R_{donor} \approx 0.15\ R_\odot$ и $T_{eff,donor} \approx 2{,}900$ K (Pre-bounce donor; before passing the P_{min} during the evolution);

(ii) $R_{donor} \lesssim 0.11\ R_\odot$ и $T_{eff,donor} \lesssim 2{,}000$ K (Donor of period bouncer CV; after passing the P_{min} during the evolution).

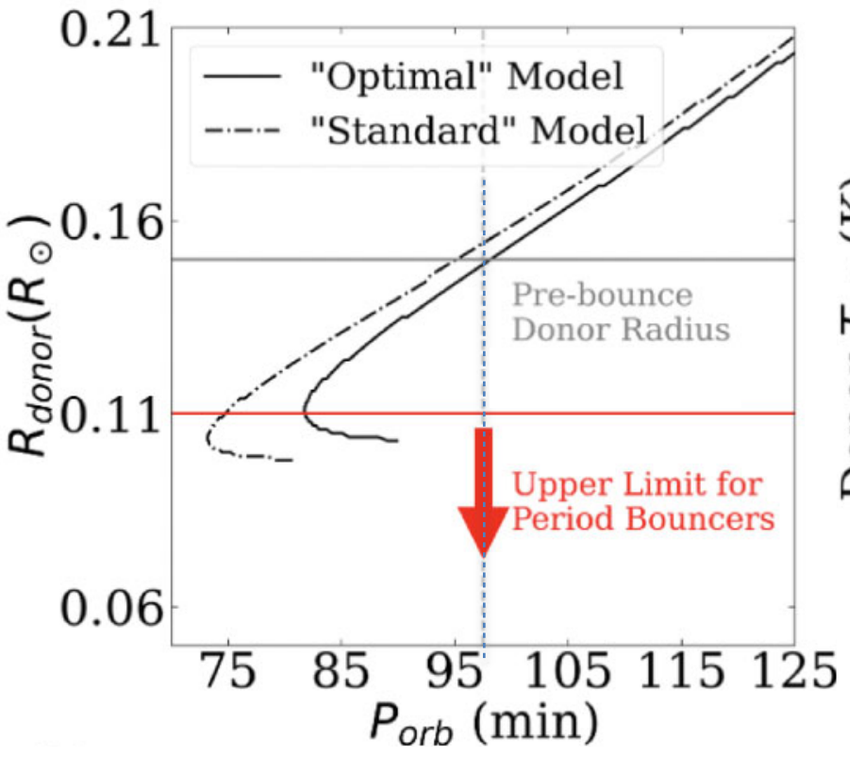
- The model with donor parameters from the case (ii) better approximates the observed SED of SRGeJ0411.

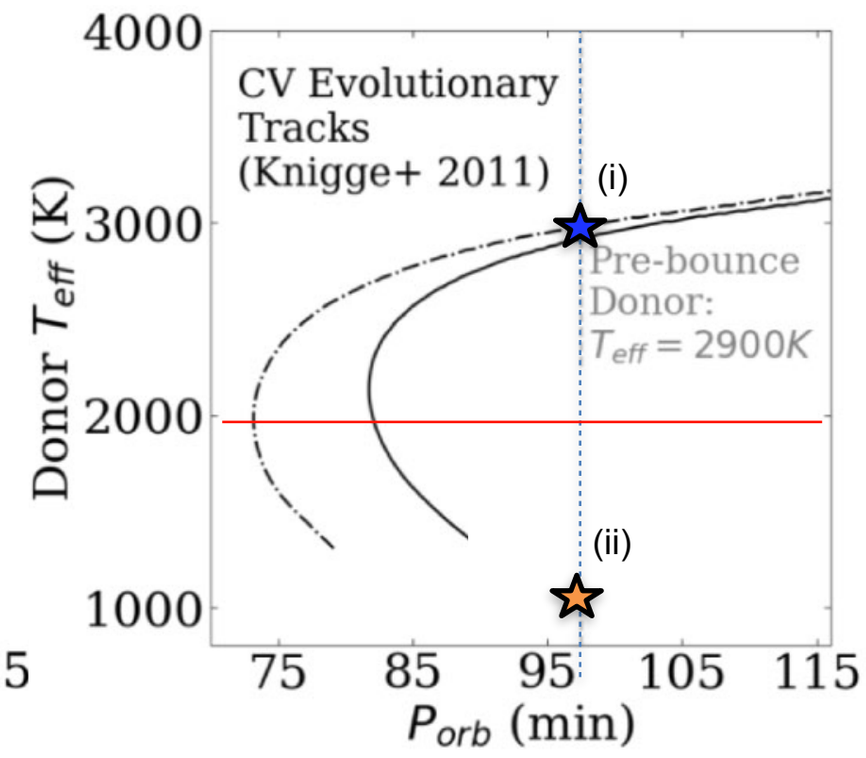
WD: $T_{eff} \approx 13{,}790\ K$; $M_{WD} \approx 0.84\ M_\odot$; $R_{WD} \approx 0.01\ R_\odot$; log(g) = 8 (fixed).

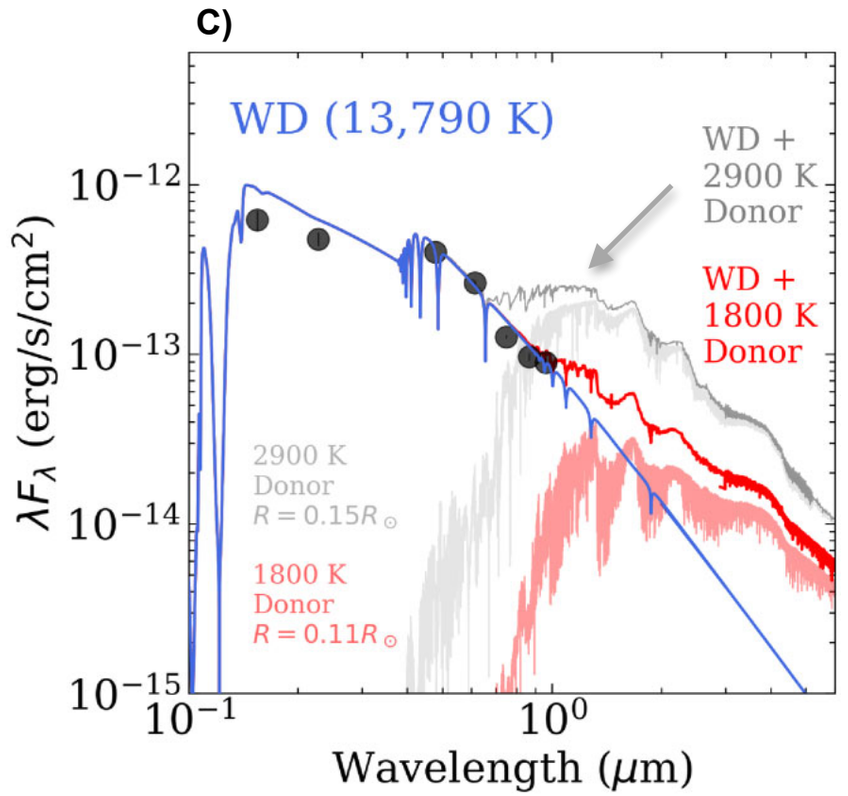
Donor: a) for $R_{donor} = 0.11\ R_\odot$ ($T_{eff,donor} \lesssim 1{,}800\ K$),
b) for $R_{donor} = 0.15\ R_\odot$ ($T_{eff,donor} \lesssim 1{,}600\ K$).

SED modeling without considering the contribution of the accretion disk, boundary layer, and hot spot!

IV. Estimation of binary parameters of SRGeJ041130.3+685350







The CV evolutionary tracks from Knigge et al. (2011): A) and B) Donor radius and donor effective temperature as a function of orbital period; C) The observed UV + optical SED of SRGeJ0411.

- From the CV evolutionary tracks, the donor parameters for CV with an orbital period of ≈ 97.5 should be:

(i) $R_{donor} \approx 0.15\ R_\odot$ и $T_{eff,donor} \approx 2{,}900$ K (Pre-bounce donor; before passing the P_{min} during the evolution);

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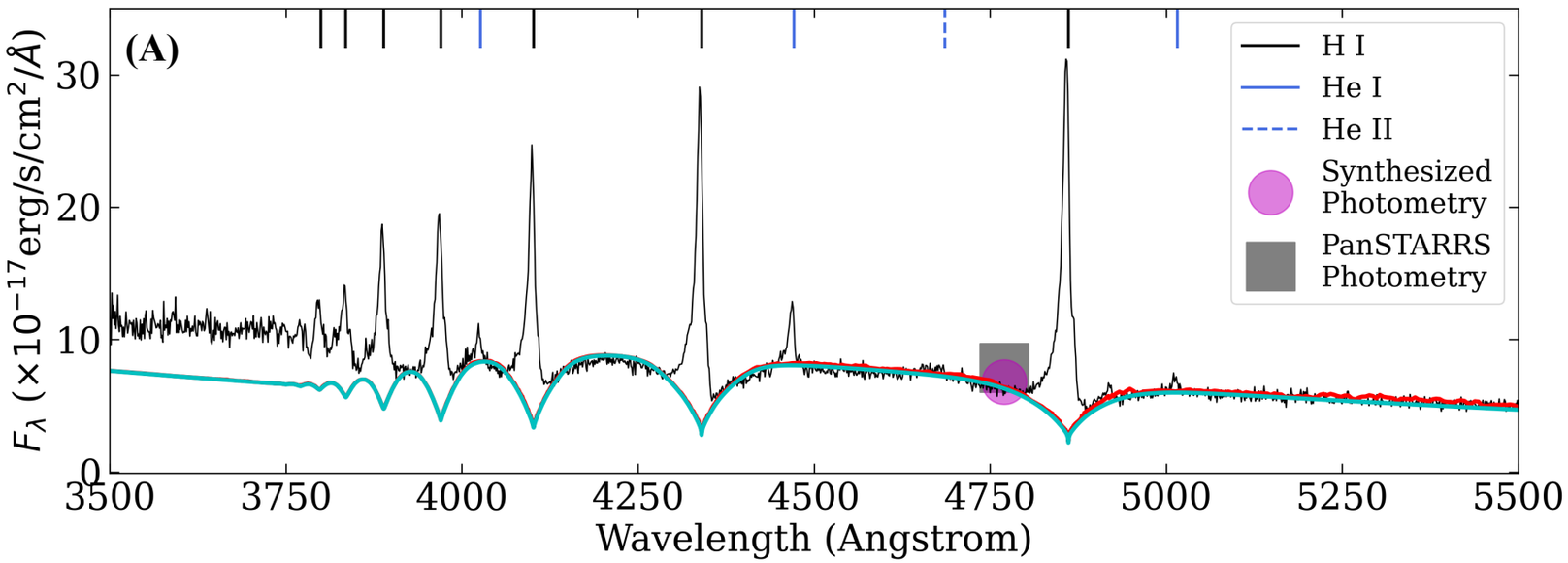
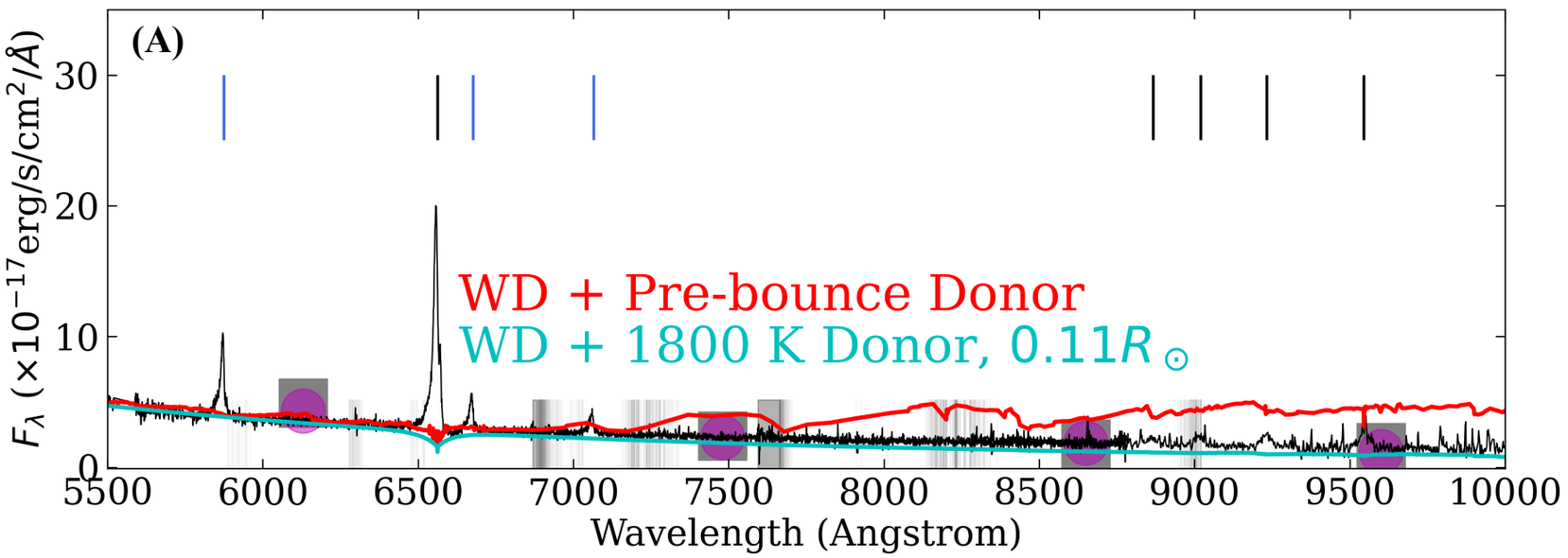
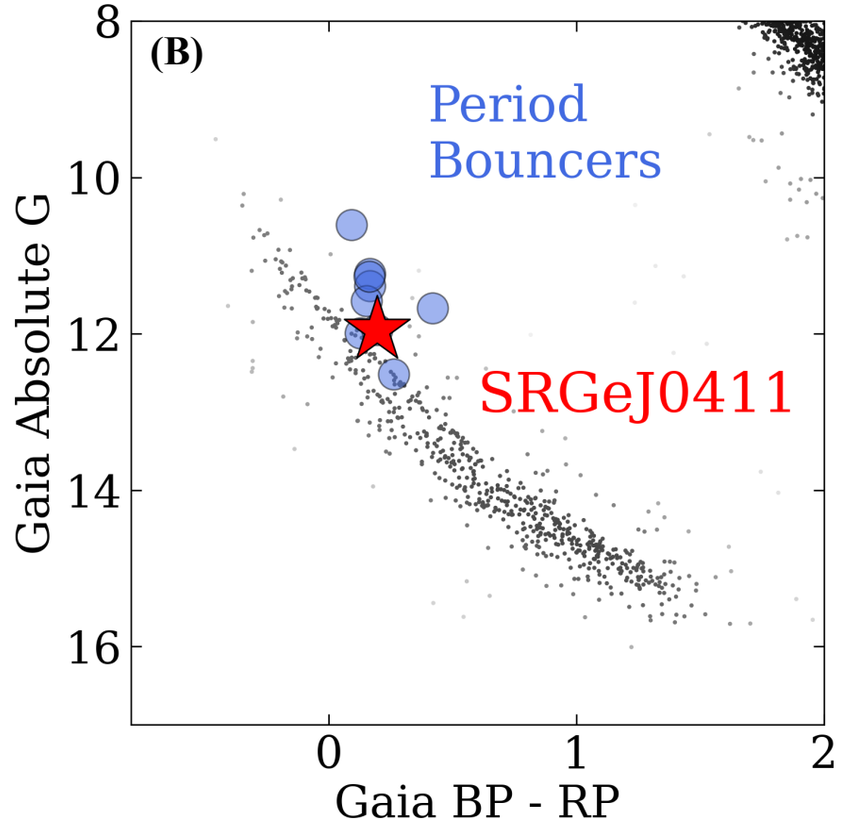
SED modeling without considering the contribution of the accretion disk, boundary layer, and hot spot!

SRG/eROSITA-discovered period-bouncer CV: SRGeJ041130.3+685350





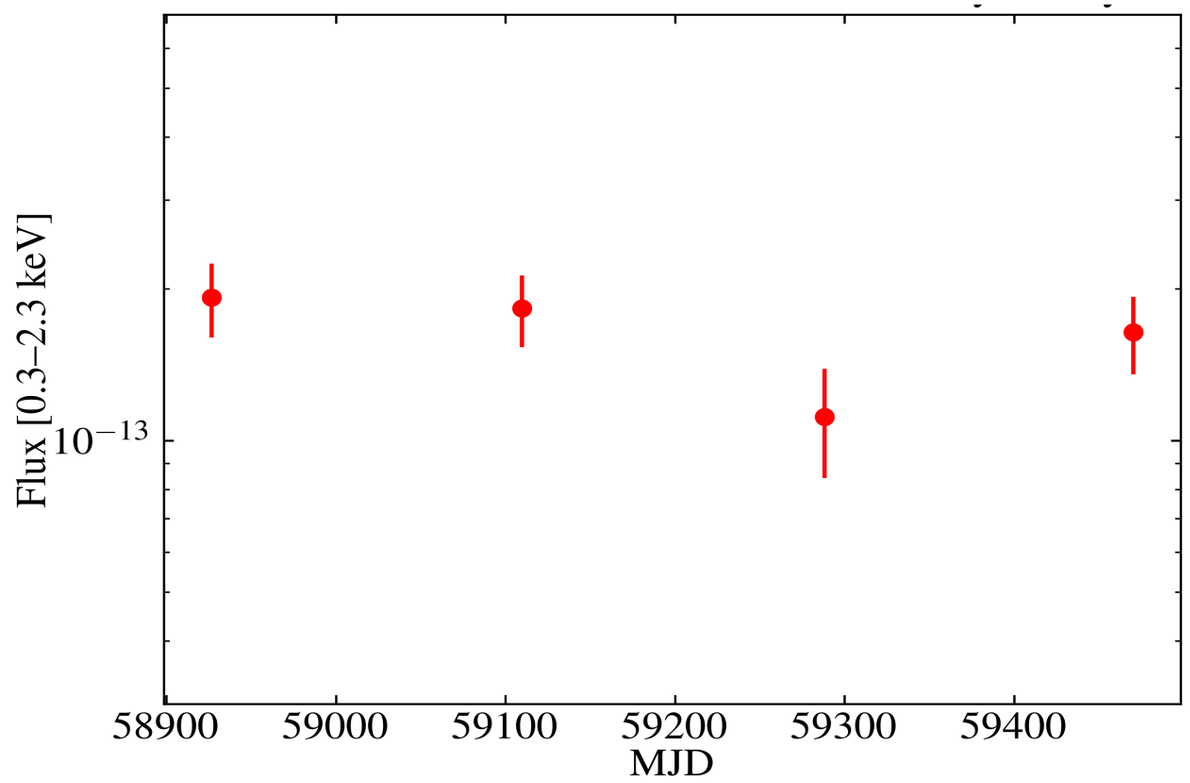


(A) Keck I/LRIS optical spectrum of SRGeJ0411. (B) Position of SRGeJ0411 in the 100 pc Gaia HR diagram.

- The binary parameters ($T_{eff,donor} \lesssim 1{,}800\ K$, $M_{donor} \lesssim 0.04\ M_\odot$) are consistent with evolutionary models for post-period minimum CVs, suggesting that SRGeJ0411 is a new period bouncer.

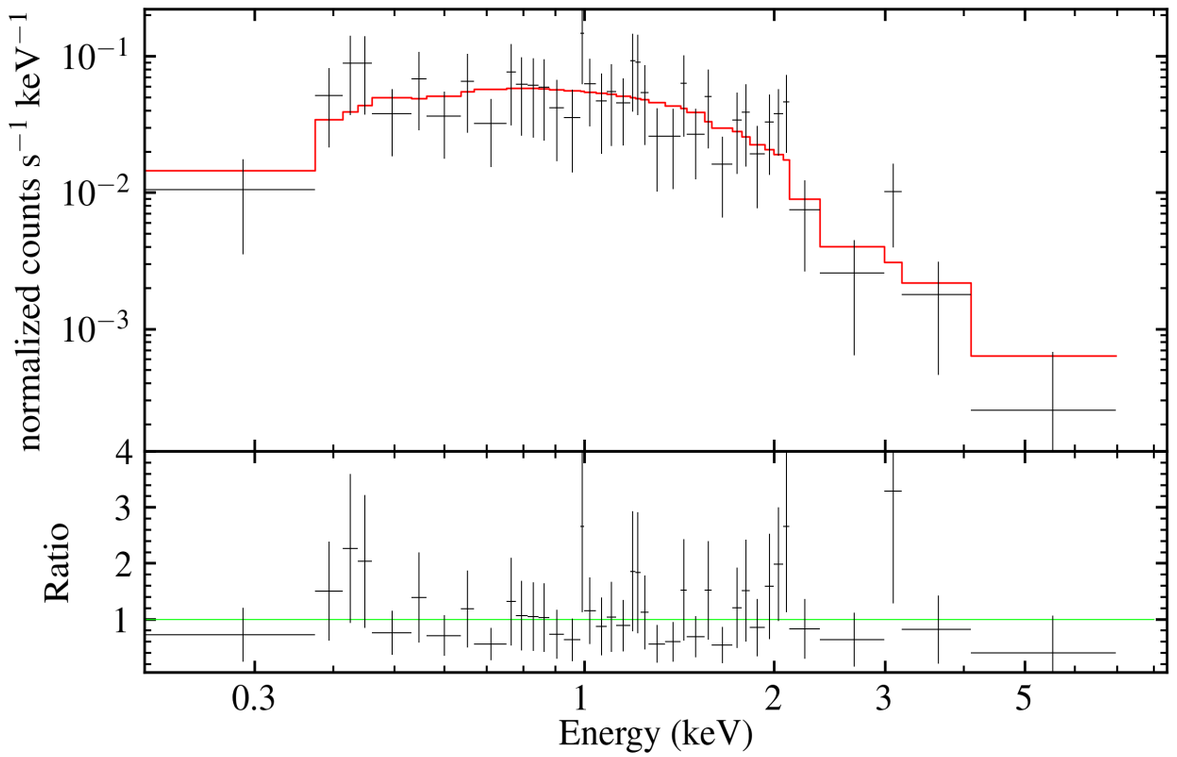
X-ray spectrum of SRGeJ041130.3+685350

- The X-ray light curve shows the variability within four sky surveys of SRG/eROSITA.



- X-ray luminosity (0.3-2.3 keV): $\approx 3 \times 10^{30}$ erg/s.

- The approximation of the X-ray spectrum of SRGeJ0411 by the power-law model gives a photon index of $\Gamma \sim 1$.



Arxiv: 2401.04178

Conclusion

- *Discoveries:*

  - SRGeJ0453 is the first SRG/eROSITA-discovered AM CVn. Also, the 9th published eclipsing AM CVn.

  - SRGeJ0411 is a new period-bouncer CV discovered in the SRG/eROSITA all-sky survey.

- The multiwavelength approach allows for detecting and investigating more CVs missed in one-band surveys alone.

- Future transient optical sky surveys, such as using the Rubin Observatory's Legacy Survey of Space and Time (LSST), with a combination of X-ray data (SRG/eROSITA, Chandra, XMM-Newton etc), would likely have improved success in detecting the accreting binary systems in the near future.

Acknowledgements

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SRGeJ045359.9+622444: A 55 Minute Period Eclipsing AM Canum Venaticorum Star Discovered from a Joint SRG/eROSITA + ZTF Search

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A joint SRG/eROSITA + ZTF search: Discovery of a 97-min period eclipsing cataclysmic variable with evidence of a brown dwarf secondary

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Thank you!