

# Cool and luminous transients from mass-losing binary stars

Ondřej Pejcha<sup>1,2</sup>, Brian D. Metzger<sup>3</sup> and Kengo Tomida<sup>4</sup>

<sup>1</sup> Department of Astrophysical Sciences, Princeton University, 4 Ivy Lane, Princeton, NJ 08540, USA

<sup>2</sup> Hubble and Lyman Spitzer Jr. Fellow

<sup>3</sup> Columbia Astrophysics Laboratory, Columbia University, New York, NY 10027, USA

<sup>4</sup> Department of Earth and Space Science, Graduate School of Science, Osaka University, 1-1 Machikaneyama, Toyonaka, Osaka 560-0043, Japan

E-mail: <sup>1</sup> [pejcha@astro.princeton.edu](mailto:pejcha@astro.princeton.edu)

**Abstract.** Motivated by the recently established link between luminous red novae (LRN) and catastrophic phases of binary star evolution, we perform smoothed particle hydrodynamic calculations of outflows from binary stars with realistic equation of state and opacities. We focus on the case of mass loss from the outer Lagrangian point ( $L_2$ ), where the resulting spiral stream experiences tidal torques from the binary and becomes unbound. As the individual spiral arms merge and collide near the binary, the outflow thermalizes about 5% of its kinetic energy. For reasonable binary parameters, the outflow can produce luminosities up to  $10^6 L_\odot$  with effective temperatures between 500 and 6000 K, depending on the optical depth through the outflow. This is compatible with many examples of the LRN such as V838 Mon and V1309 Sco. The luminosity and the expansion velocity are correlated, as is roughly observed in the known LRN. The outflow readily forms dust, leading to great variations of the appearance of the transient as a function of the viewing angle. Our results are relevant for a more general class of equatorial outflows with asymptotic velocity and heating rate near the binary proportional to its orbital speed.

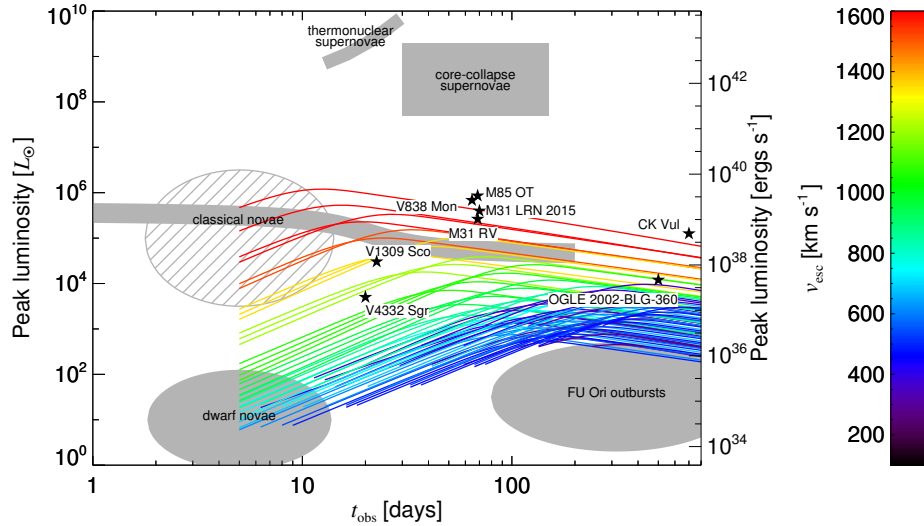
## 1. Introduction

The discovery of a contact binary with rapidly decreasing orbital period followed by an outburst in V1309 Sco [1] established a connection between catastrophic phases of binary star evolution and a group of transients best represented by objects such as V838 Mon, M31 RV, and M85 OT and characterized by their red color and luminosity in the gap separating classical novae and supernovae. However, these objects, often labeled as luminous red novae or intermediate luminosity optical transients, exhibit considerable diversity in their properties [2, 3].

## 2. Hydrodynamic simulations

To better understand the emission mechanism and the underlying physics of LRN, we explored the dynamics of outflows from mass-losing binary stars using smoothed particle hydrodynamic simulations, which employ realistic low-temperature equation of state, radiative diffusion and cooling with realistic opacities including dust, and irradiation by the central binary [3]. We inject the particles at the outer Lagrangian point of the binary and leave the initially corotating gas evolve in the time-changing gravitational field of the central binary. For a set of binary





**Figure 1.** Peak luminosities as a function of transient duration [4]. Coloured lines mark our predictions for mass-losing binaries, where each line corresponds to a single set of binary parameters and a range of time-scales (left as a free parameter). The colour marks the escape velocity of the binary, as denoted in the colour bar on the right. Positions of red transients are shown with black stars. Approximate regions occupied by dwarf and classical novae, FU Ori outburst, and thermonuclear and core-collapse supernovae are shown in grey. More details are provided in [3].

parameters, the resulting equatorial and primarily radial unbound outflow exhibits internal shocks, which thermalize part of the kinetic energy. We track the luminosity and effective temperature of the resulting emission, and construct a semi-analytic model capturing the salient features of the simulations.

### 3. Results

In Figure 1 we show that our results can broadly explain the known transients associated with mass-losing binaries. Brighter transients come from binaries with higher orbital speed, and that fainter or longer transients are cooler, with effective temperatures  $\lesssim 500$  K possible. The group of long and extremely cold transients recently identified with Spitzer [5] might thus share common mechanism with LRN. We predict correlation between the observed expansion velocity and the transient luminosity. Due to copious dust formation in the equatorial outflow, the transient appearance might vary greatly depending on the orientation of the binary orbital plane.

### Acknowledgments

Support for OP was provided by NASA through Hubble Fellowship grant HST-HF-51327.01-A awarded by the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., for NASA, under contract NAS 5-26555.

### References

- [1] Tytenda R *et al* 2011 *Astron. Astrophys.* **528** 114
- [2] Pejcha O 2014, *Astrophys. J.* **788** 22
- [3] Pejcha O, Metzger B D and Tomida K 2016 *Mon. Not. R. Astron. Soc.* **455** 4351
- [4] Kasliwal M M 2011 PhD thesis, California Institute of Technology
- [5] Kasliwal M M *et al* 2014 *Astron. Telegram*, 6644