An outburst powered by the merging of two stars inside the envelope of a giant

Shlomi Hillel, Ron Schreier & Noam Soker

Department of Physics, Technion, Israel

Accepted for publication by astro-ph (arXiv:1704.08438)

Abstract

- We conduct three-dimensional hydrodynamical simulations of energy deposition into the envelope of a red giant star as a result of the merger of two close main sequence stars, and show that the outcome is a highly non-spherical outflow.
- Such a violent interaction of a triple stellar system can explain the formation of 'messy', i.e., lacking any kind of symmetry, planetary nebulae (PNe).
- The ejection of the fast hot gas and its collision with previously ejected mass are very likely to lead to a transient event, i.e., an intermediate luminosity optical transient (ILOT).

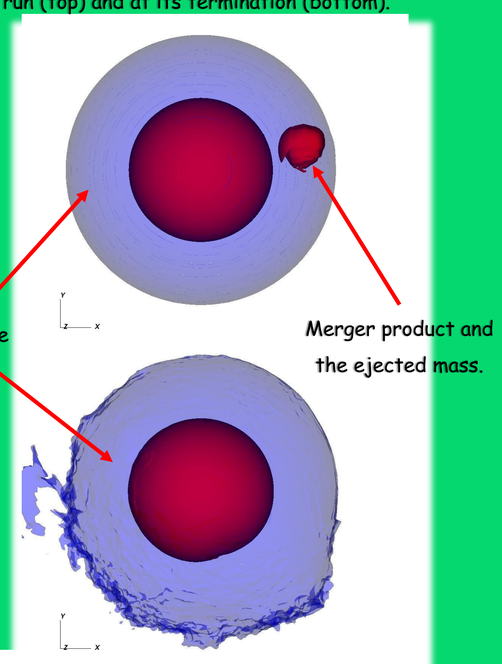
Our model

We run the 3D hydrodynamic code PLUTO. At t=0 we place a $4M_\odot$ AGB with a radius of $100R_\odot$, at the center of the grid.

The simulation starts with the merger of two stars of a tight binary system at $r=70R_\odot$.

We inject a mass of $0.1M_\odot$ into the AGB envelope with an energy of $E = 5 \times 10^{45}$ erg, over a time period of ~9 hours.

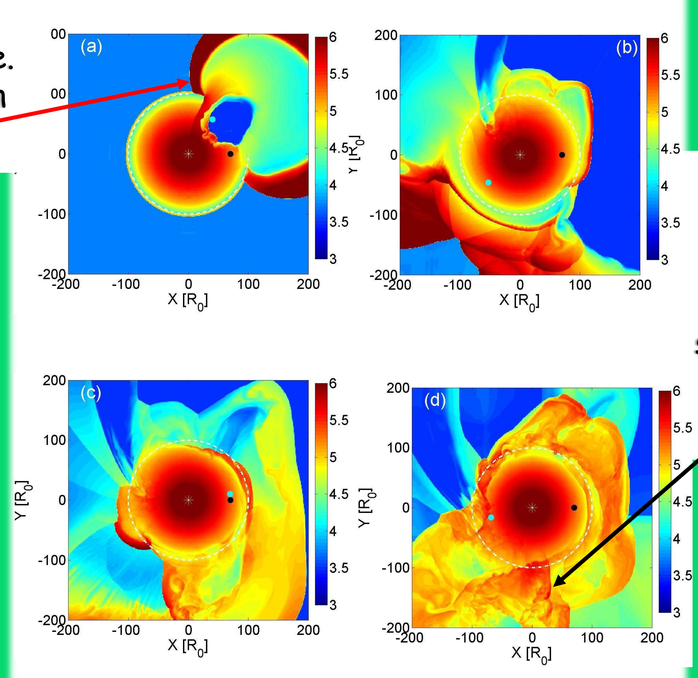
3D density structure of the merger process of the binary system inside the AGB envelope, close to the beginning of the run (top) and at its termination (bottom).



Results

A shock propagates on the outskirts of the giant envelope. This will lead to an outburst in the visible.

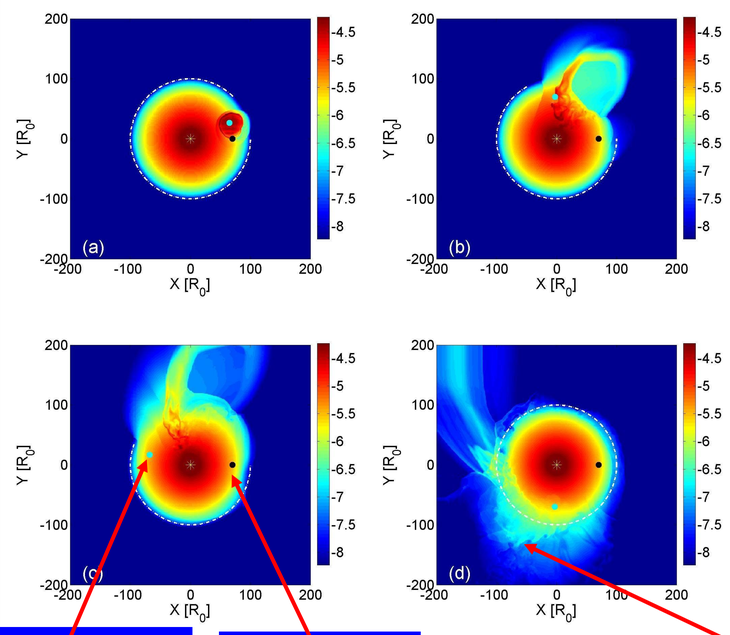
Evolution of the temperature



Temperature colormap in the orbital plane (z=0) at (a) t=6, (b) t=22, (c) t=36, and (d) t=55 days.
The high temperature regions in the outer envelope are post-shock regions. When it closes on itself on the other side of the star it forms a gas prominence and high pressure region.

The shock that propagates through the giant envelope causes prominences and ejection of mass for about several weeks. By the end of this run, about $0.03M_\odot$ escapes the AGB.

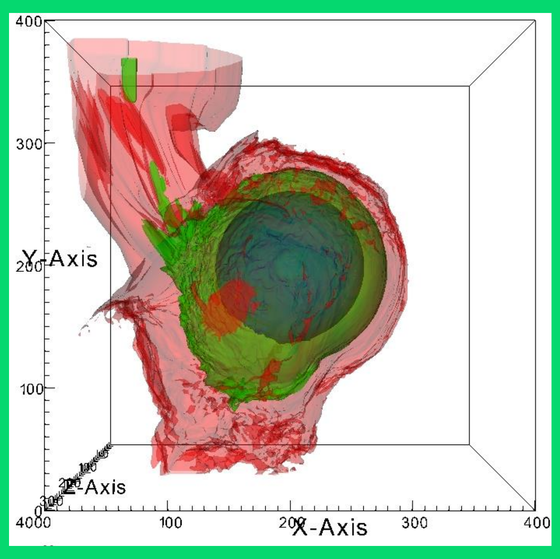
Evolution of the density



Density colormap in the orbital plane (z=0) at (a) t=2, (b) t=9, (c) t=16, and (d) t=62 days. The color contours are in logarithmic scale in units of g cm^{-3}. A yellow asterisk marks the center of the AGB star that is also the center of the grid. The dashed-dotted white line marks the initial surface of the AGB star, the black dot is the location of the merger process, and the cyan circle marks the location of the merger product as it orbits inside the envelope (counterclockwise). The orbital period of the merger is ~36 days.
The low density gas from near the merger site pushes onto the denser gas toward the center and accelerates it inward, leading to the development of Rayleigh-Taylor instabilities.

The flow that results from the merger process is asymmetric, which lead to the formation of a messy nebula.

3D density structure



Density iso-surfaces in 3D, with color-coding of red 6×10^{-9} g cm^{-3}, green 1.2×10^{-7} g cm^{-3}, blue 2.8×10^{-6} g cm^{-3}, and pale blue 6×10^{-5} g cm^{-3} close to the end of the simulation, at t=55 day.