Visualizing Outbursts of Massive Stars

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Abstract

Massive stars play an important role in many astrophysical environments such as star formation and the structure of the interstellar medium in galaxies. However, the structures and mass loss of massive stars, which are crucial to understand the evolution and fate of massive stars, are still mysteries. Global radiation hydrodynamic simulations of 80 and 40 solar mass star envelopes were performed on the Argonne Leadership Computing Facility's supercomputer, Mira, to find the answers. In this work we present visualizations of the data produced in one of these simulations, which show the important role that helium opacity plays in outbursts from massive stars.

Keywords:
scientific visualization, high performance computing

1. Introduction

To better understand outbursts and variability on evolved massive stars, three dimensional simulations of radiation-dominated massive stars were calculated on Argonne National Laboratory's Mira IBM Blue Gene/Q supercomputer. Each of the calculations used 2048 compute nodes, with 64 MPI ranks per node. One simulation consumed a total of 30 Million CPU hours, producing a total of 30TB of data for analysis.

This simulation, along with related calculations, revealed that the presence of the helium opacity peak is responsible for the outburst of Luminous Blue Variables. The stronger the helium opacity peak is, the larger amplitude envelope oscillation and the larger mass loss rate the star will have [1].

The transparent purple surfaces in Figure 1 show low density regions, which are the outflow of the massive star. This gas, rising due to convection, experiences a much smaller temperature change, compared to a star of similar initial mass, but lower effective temperature. The orange surface shown in Figure 2 is near the outer layer of convection of the outflow, and indicates the location of the helium opacity peak. When the helium opacity peak is weak, the star will not undergo an outburst and move to the constant temperature strip.

2. Visualization

The the visualization was rendered using ParaView[2], enabled with OSPRay[3], a ray tracing-based rendering engine for high-performance, high-fidelity visualization optimized for Intel Architecture CPUs. Approximately 3,700 time steps from the simulation were rendered for the visualization. Because of the number and complexity of contours being rendered, which include transparency and shadows, and a relatively high 10 samples per pixel, rendering times per frame were often exceeding three minutes. Coupled with the contour generation and a number of other transformations the overall time per step could exceed 10 minutes for more complex frames. At this rate, over 600 hours of rendering time would be required for a single pass over all of the ~3,700 time steps using a single CPU. To improve the throughput of the rendering, we leveraged Theta, Argonne's Knights Landing (KNL) Xeon Phi-based supercomputer. In addition, to take better advantage of the 64 cores per KNL node, we used VTK-m[4] based filters, a toolkit of scientific visualization algorithms optimized for many-core architectures, for generating the contours. Utilizing 256 KNL nodes of Theta to load and render different time steps in parallel, the time was reduced to just under two hours for one pass over all of the frames.

A combination of post-processing tools, including ImageMagick, ffmpeg, and the Adobe Creative Suite of tools, was used to combine the frames and add annotations, to produce the final animation. In it we highlight the outbursts of gas, which result in loss of mass, along with the helium opacity peak, which plays an important role in these outbursts.

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Figure 1: The transparent purple surfaces show low density regions, which are the outflow of the massive star.

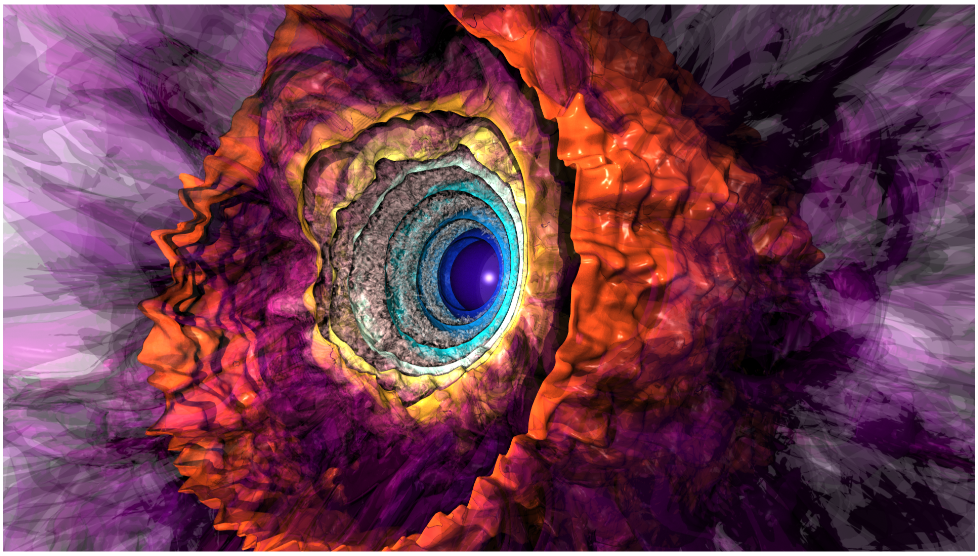

Figure 2: The orange surface, which is near the outer layer of convection of the outflow, shows where the helium opacity peak is located.

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