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Multi-Dimensional Modeling of Nova with Realistic Nuclear Physics

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Final Report for "**Multi-dimensional Modeling of Nova with Realistic Nuclear Physics**"

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FINAL REPORT
For the period ending 09/30/2010

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Final Report on

LLNL Subcontract B589924
Multi-dimensional Modeling of Nova with Realistic Nuclear Physics

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Summary

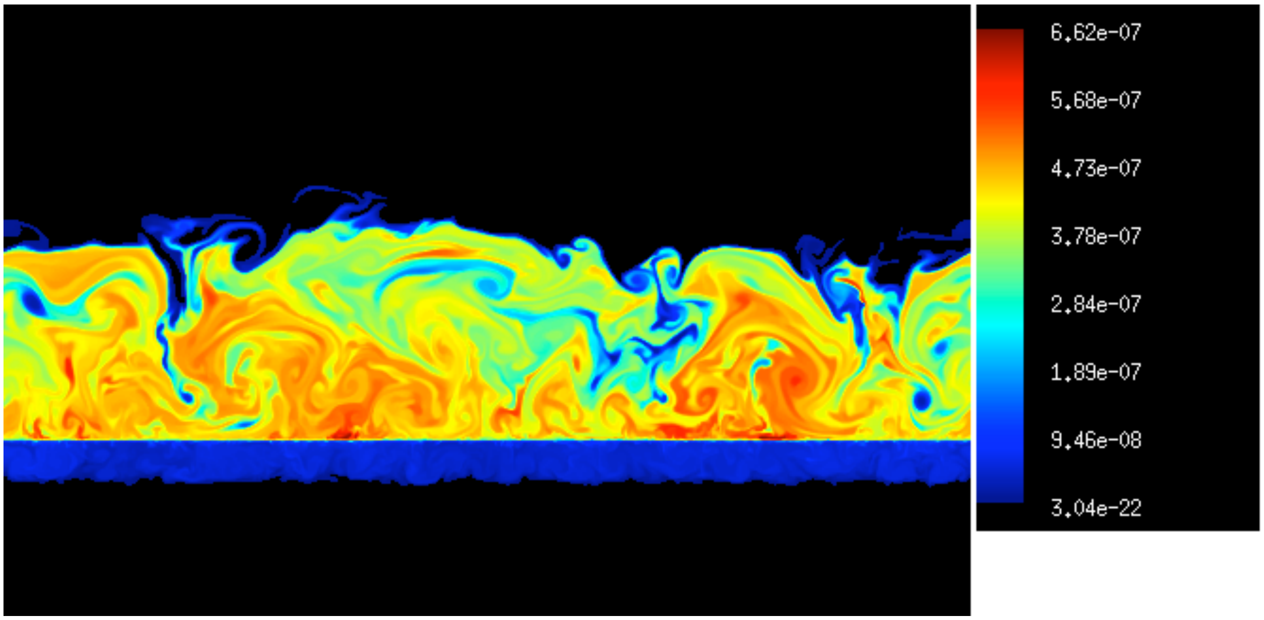
This contract covered the period from 03/09/2010 to 09/30/2010. Over this period, we adapted the low Mach number hydrodynamics code MAESTRO to perform simulations of novae. A nova is the thermonuclear runaway of an accreted hydrogen layer on the surface of a white dwarf. As the accreted layer grows in mass, the temperature and density at the base increase to the point where hydrogen fusion can begin by the CNO cycle—a burning process that uses carbon, nitrogen, and oxygen to complete the fusion of four hydrogen nuclei into one helium-4 nucleus. At this point, we are running initial models of nova, exploring the details of the convection. In the follow-on contract to this one, we will continue this investigation.

Technical Approach

The centerpiece of our modeling effort is the MAESTRO code, developed outside of Livermore for the study of low Mach number astrophysical convection. Traditional hydrodynamics codes have timesteps restricted by the time it takes a soundwave to propagate across a single computational zone. If the flow is highly subsonic, then acoustic waves do not greatly alter the dynamics. MAESTRO exploits this by filtering soundwaves out of the system, allowing for a timestep based on the fluid velocity alone. This provides an enormous efficiency boost for low Mach number flows.

The main ingredient we needed to add to MAESTRO to enable explorations of nova was a reaction network that adequately describes hydrogen burning. Using a simplified analytic expression for CNO burning, and working with Rob Hoffman, we identified the range of temperatures and densities we expect to encounter in our simulations. This led us to collaborate with Frank Timmes (ASU) who pointed us to his publically available pphotcno burner, which incorporates 26 nuclear species and the reactions linking them, fully describing the hydrogen burning we will encounter. This publically-available network was integrated into MAESTRO and tested by graduate student Brendan Krueger, who was supported by the contract.

In addition to the reaction networks, we modified MAESTRO to enable a more realistic treatment of gravity. Ami Glasner (Racah Institute of Physics) provided us with some nova initial models that he had used in previous nova studies. These were mapped onto MAESTRO's Eulerian grid by adapting some initialization routines used by other MAESTRO studies. In our simulations, we just model a small portion of the surface of the white dwarf, using a Cartesian geometry. The 1-d stellar evolution code that generated those models used a realistic treatment of gravity. The plane-parallel approximation employed by MAESTRO assumed that the gravitational acceleration was constant (a valid approximation when the thickness of the accreted layer is small compared to the radius of the underlying star). MAESTRO describes the state of the flow using a 1-d hydrostatic base state and a 2- or 3-d Cartesian full state. As energy is released into a star or atmosphere, the 1-d base state is evolved, by computing an expansion velocity from our velocity constraint equation. We relaxed this assumption of constant gravity in MAESTRO by deriving a new constraint equation that retains the Cartesian geometry, but allows the gravitational acceleration to fall off as $1/r^2$. In this approximation, only the mass of the underlying star is used in computing gravity, the accreted envelope mass is negligible. Our derivation and implementation of this "plane-parallel $1/r^2$" gravity followed closely the previously published spherical, self-gravitating full star implementation in MAESTRO [1].



With these developments, MAESTRO is currently performing realistic nova simulations. The figure above shows the ^{15}O abundance in the accreted layer on the white dwarf. The convective rolls shown are driven by the energy release from the thermonuclear reactions. This is a preliminary calculation that demonstrates that we are able to begin to follow the convection that dominates the dynamics. We are still understanding the behavior of the flow at the top of the accreted layer, where the steep density gradient can cause unwanted acceleration, greatly affecting our timestep. We expect to perform scientifically-interesting calculations in the next project period. Our immediate goal is to understand whether the convective flow can "dredge-up" heavy nuclei from the underlying white dwarf, thereby catalyzing the hydrogen burning.

Papers and Book Chapters Supported in Part by the Subcontract

N/A

References

[1] MAESTRO: An Adaptive Low Mach Number Hydrodynamics Algorithm for Stellar Flows Nonaka, A., Almgren, A. S., Bell, J. B., Lijewski, M. J. Malone, C., & Zingale, M., 2010, ApJS, *188*, 358.