Convection from Burning Preceding a Type I X-ray Burst

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In the current model of a Type I X-ray Burst, accretion builds a layer of H/He on the surface of a neutron star. Once the layer is deep enough, the energy generation rate from reactions exceeds the local cooling rate and a thermonuclear runaway ensues. We present results of plane-parallel 2d simulations of the convection preceding the outburst for a pure He accretor using the low Mach number hydrodynamics code, MAESTRO. Furthermore, we present results that show that the resolution requirement to properly resolve the burning layer in multiple dimensions is much higher than that used in the literature.

A Type I X-ray Burst (XRB) is a thermonuclear explosion at the base of a thin accreted layer on the surface of a neutron star in a low mass x-ray binary system. The accreted matter smolders as it is compressed to deeper layers until the conditions are such that the energy generation rate exceeds the local cooling rate and a thermal instability forms which triggers the outburst. An understanding of the state of the atmosphere prior to the outburst may help with interpreting observational features such as oscillations in XRB lightcurves.

**Numerical Method**

- The fluid flows we are concerned with are of very low Mach number (~0.05). Long-term, stable evolution of such flows would be prohibitively computationally expensive using traditional fully compressible hydro codes.

\[
\Delta t \lesssim \frac{\Delta x}{u_{sh} + c_s} = \frac{\Delta x}{\left( \frac{M}{1 + M} \right)} \approx M \frac{\Delta x}{u}
\]

- Instead we use MAESTRO, a low Mach number approximation code which essentially filters out sound waves. Effectively, this removes $M$ from the stability condition above and allows for a much larger timestep.

- See Andy Nonaka’s poster for more details about MAESTRO.

**Resolution Requirements**

- Previous multidimensional XRB simulations (e.g. [LBT06, M.etal.09]) were run at ~10cm resolution.
- This gives beautiful convective features but does not accurately capture the details of the thin burning layer.
- Under-resolved burning tends to overproduce energy (see figure below), over-drive convection and produce a runaway on much shorter timescales than a properly resolved model.
- We find a spatial resolution no coarser than 0.5cm to be sufficient to properly model the burning layer.

**Convection Results**

- Shown below is the carbon mass fraction, X(C12), overlayed with velocity vectors for the region highlighted in the initial model plot above.

- Shown below is the evolution of the peak energy generation rate (EGR). The system is initially static and the convectively unstable region needs to adjust which causes cooling and a decrease in EGR until things have stabilized.

- Above is a plot showing the evolution of the lateral average Mach number during the simulation. This is indeed a low Mach number problem!

**Future Plans**

- Continue evolution until runaway then port to compressible code (e.g. CASTRO; See Ann Almgren’s poster)
- Compare effects of different opacity methods
- Apply initial random velocity field and study it’s effects
- Make the push to 3d utilizing AMR (already implemented; see Andy Nonaka’s poster)