TRIGGERING PRESOLAR CLOUD COLLAPSE AND INJECTION OF SHORT-LIVED RADIOISOTOPES BY A SUPERNOVA SHOCK WAVE: ADAPTIVE MESH REFINEMENT CALCULATIONS WITH THE FLASH CODE. S. I. Ipatov[1], A. P. Boss[1] & E. A. Myhill[2], [1]DTM, Carnegie Institution, Washington DC [2]Marymount University, Arlington VA.

The short-lived radioisotope (SLRI) ^{60}Fe must have been synthesized in a supernova [1,2] and then either injected into the presolar cloud [3,4] or onto the surface of the solar nebula [5,6]. A similar nucleosynthetic event is likely to be the source of the bulk of the solar nebula's ^{26}Al [7,8] and of other SLRIs. Here we reconsider the problem of triggering the collapse of the presolar cloud and of simultaneously injecting SLRI with a supernova shock wave. Previous work on this problem [3,4,9,10] used either fixed grid or smoothed particle hydrodynamics (SPH) codes with a limited ability to resolve fine scale structure in the Rayleigh-Taylor fingers that form at the shock/cloud interface and are responsible for SLRI injection into the collapsing presolar cloud [10]. Here we begin studying this same problem with a new hydrodynamics code, FLASH, which promises to able to provide a far superior ability to resolve small scale structure, while providing adequate spatial resolution of the flow in regions without strong gradients.

The FLASH code is based on adaptive mesh refinement (AMR) by the block-structured adaptive grid approach. AMR techniques automatically insert new grid points in regions of strong physical gradients, and remove them in regions without strong gradients, in order to maximize the spatial resolution in the crucial regions while minimizing the computational burden. Advection is handled by the piecewise parabolic method (PPM). PPM includes a Riemann solver at cell boundaries that handles shock fronts exceptionally well. In FLASH, PPM is incorporated in a form that is second-order accurate in space and time. The Poisson equation for the cloud's gravitational potential is solved by either a multipole or multigrid technique. We have tested the FLASH code's ability to reproduce the results of several different test cases that are relevant to the problem of triggering cloud collapse, namely the Sod shock tube problem and the collapse of a pressureless sphere. While the performance of FLASH on the pressureless sphere collapse is not as accurate as with codes designed to study collapse problems (e.g., [11]), FLASH does a superb job of handling the Sod shock tube problem on a Cartesian grid, when the shock flows parallel to one axis or at a 45 degree angle.

While the standard FLASH test cases were run on Cartesian grids, we have also reproduced the correct results for the Sod shock tube and for pressureless cloud collapse on a cylindrical coordinate (R, Z) grid, similar to that used previously [3,4,9,10]. We have also tested the stability of the same target cloud as was used in the previous work, namely the Bonner-Ebert (BE) sphere [12], which is the equilibrium structure for a self-gravitating, isothermal sphere of gas. BE spheres are excellent models for the structure of pre-collapse dense molecular cloud cores seen in star-forming regions [13].

The number of grid blocks used by the FLASH code depends on the initial parameters $Nblockx$, $Nblocky$, and $lrefine_{\max}$. $Nblockx$ and $Nblocky$ regulate the number of large blocks in 'x' (R) and 'y' (Z) directions, respectively, while $lrefine_{\max}$ determines the number of levels of smaller blocks. For example, if $lrefine_{\max}$=3, then besides the 'large' blocks of unit size 1, FLASH generates smaller blocks of sizes 1/2 and 1/4. Each block consists of $16 \cdot 16 = 256$ grid cells and the number of blocks used varies during a run. We considered models with $Nblockx = Nblocky = lrefine_{\max} = l_{lev}$.

The BE sphere starts with a radius $R_s = 1.79 \cdot 10^{17}$ cm, central density $\rho_{so} = 6.2 \cdot 10^{-19}$ g cm^{-3}, and a temperature of 10 K (Figure 1). The BE sphere is stable against collapse for times of order $\sim$ 60,000 yr (Figure 2). Eventually the dynamic oscillations of the BE sphere lead to collapse at the center of the sphere. FLASH followed the collapse to maximum densities of $\sim 10^{-13}$ g cm^{-3} (six orders of magnitude increase) in 100,000 yr with $l_{lev} = 4$, before the central regions began to rebound. With $l_{lev} = 5$, a greater maximum density was reached: $\sim 10^{-12}$ g cm^{-3} in 100,000 yr and $\sim 10^{-11}$ g cm^{-3} in 106,000 yr. For a uniform density sphere with the same ρ_{so}, 10^{-11} g cm^{-3} was reached in 87,000 yr or 330,000 yr for $R_s = 1.79 \cdot 10^{17}$ cm or $R_s = 10^{17}$ cm, respectively.

We have demonstrated the ability of the FLASH code to hold the target BE cloud stable for a suitable time period. Next we will begin to model the interaction of a supernova shock wave with the target cloud. Our first goal will be to reproduce the previous results with comparable spatial resolution, and then to see how the results change as the AMR nature of FLASH is employed. We then plan to remove the isothermal assumption, and to include an energy equation solution that will improve the treatment of this critical part of the shock/cloud interaction. Previous work [14] had found that when nonisothermal thermodynamics was employed in SPH calculations, it was not possible for a shock wave to simultaneously trigger collapse and to also inject SLRIs, a potentially fatal flaw for the triggering and injection scenario. However, subsequent work [15] found that improvements in the dust grain cooling model led to rapid post-shock cooling, closer to the isothermal assumptions used in [3,4,9,10]. Our goal is to use FLASH to determine if the triggering and injection scenario [16] is consistent with post-shock cooling processes.

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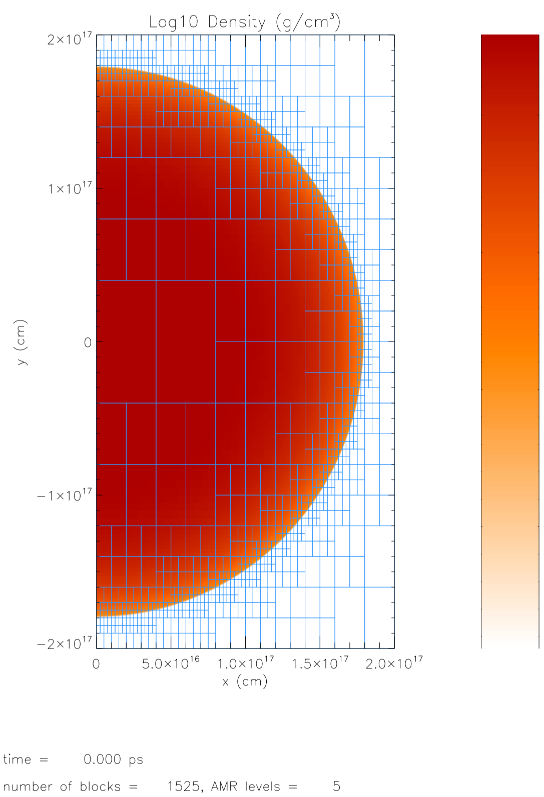

Fig. 1. Density of the target cloud, a Bonnor-Ebert sphere with a radius of 0.058 pc, on the cylindrical coordinate FLASH grid. The $\hat{Z}$ axis is vertical, and the $\hat{R}$ axis is horizontal. The gray scale gives the log of the cloud density in units of g cm^{-3}.

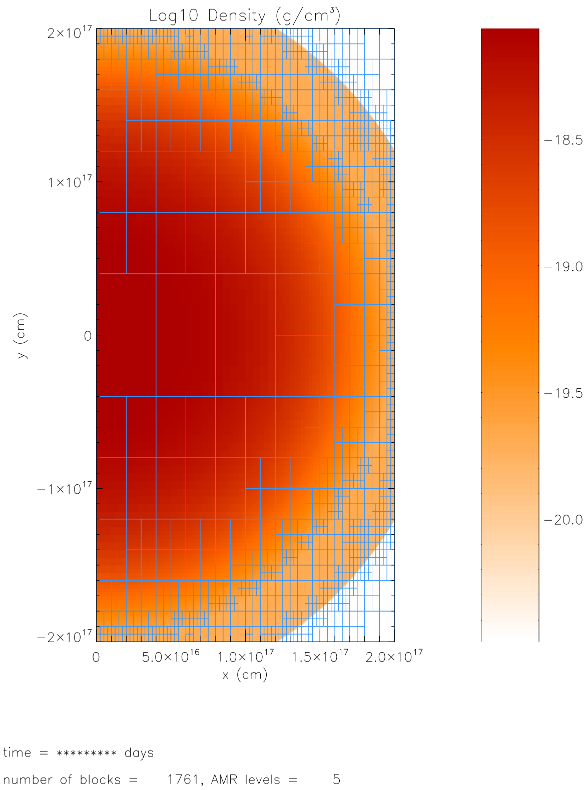

Fig. 2. Same as Fig. 1 but after 58,000 yrs of evolution. The target cloud oscillates but does not collapse over this time period.

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