SIMULTANEOUS TRIGGERED PRESOLAR CLOUD COLLAPSE AND INJECTION OF SHORT-LIVED RADIOISOTOPES BY A SUPERNOVA SHOCK WAVE.

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Introduction: Cosmochemical evidence for the existence of short-lived radioisotopes (SLRI) such as ^{26}Al [1] and ^{60}Fe [2] at the time of the formation of primitive meteorites requires that these isotopes were synthesized in a massive star and then incorporated into chondrites within $\sim 10^6$ yr. A supernova shock wave has long been hypothesized to have transported the SLRI to the presolar dense cloud core, triggered cloud collapse, and injected the isotopes [3,4]. Previous numerical calculations have shown that this scenario is plausible when the shock wave and dense cloud core are assumed to be isothermal at $\sim$ 10 K [4-8], but not when compressional heating to $\sim$ 1000 K is assumed [9]. We show here that when calculated with the FLASH2.5 adaptive mesh refinement (AMR) hydrodynamics code, shock waves with speeds in the range from 5 km/sec to 70 km/sec can indeed trigger the collapse of a solar-mass cloud while simultaneously injecting shock wave isotopes into the collapsing cloud, provided that cooling by molecular species such as H_2O, CO_2, and H_2 is included [10].

Results: Models have been run in 2D (axisymmetry) with shock speeds varied between 5 km/sec and 100 km/sec for target clouds of 2.2 solar masses. Models with speeds between 5 and 70 km/sec led to simultaneous collapse and injection, while speeds above 70 km/sec did not lead to sustained collapse. Here we focus on model C [10], with a 20 km/sec shock, and the nominal level of molecular cooling [11] for a 1 solar-mass target cloud.

Figure 1 shows the density for model C after 0.03 Myr of evolution. Contours show regions with color field densities (initially 1, representing SLRI from the shock front) greater than 0.01. The symmetry axis is along the left hand side of the plot, and the shock travels downward from the top of box. Rayleigh-Taylor fingers and Kelvin-Helmholtz vortices form at the shock-cloud interface. Figure 2 shows the cloud at 0.1 Myr, where the contours now show regions with temperatures greater than 100 K, which only occur at the shock-cloud interface as a result of the molecular cooling. A high-density region has formed along the symmetry axis. Figure 3 is after 0.16 Myr and is limited to a small region around the density maximum of $\sim 2 \times 10^{-12}$ g cm^{-3}. Velocity contours are shown for every other AMR grid cell. Much of the cloud is infalling onto the growing protostar on the symmetry axis. Finally, Figure 4 depicts the color field at 0.16 Myr, showing that while the growing protostar contains some color, the infalling regions contain a higher color density, i.e., a higher density of SLRI from the shock wave. A SLRI dilution factor of $\sim 10^4$ [6,13] is consistent with model C's injection efficiency [10].

Conclusions: When cooling by molecular species is included, shocks with a wide range of speeds are able to trigger the gravitational collapse of an otherwise stable, solar-mass cloud, as well as to inject appropriate amounts of supernova shock wave material into the collapsing cloud core. This injected material consists of shock wave gas as well as dust grains small enough to remain coupled to the gas, i.e., sub-micron-sized grains, which are expected to characterize supernova shock waves [12] and to carry the SLRI whose decay products have been found in refractory inclusions of chondritic meteorites [1,2]. Evidently a radiative-phase supernova shock wave is able to cool sufficiently rapidly to behave in much the same way as a shock wave that is assumed to remain isothermal with the target cloud [4-8]. These models thus lend strong support to the hypothesis first advanced by [3] that a supernova shock wave carrying SLRI may have triggered the formation of the solar system.

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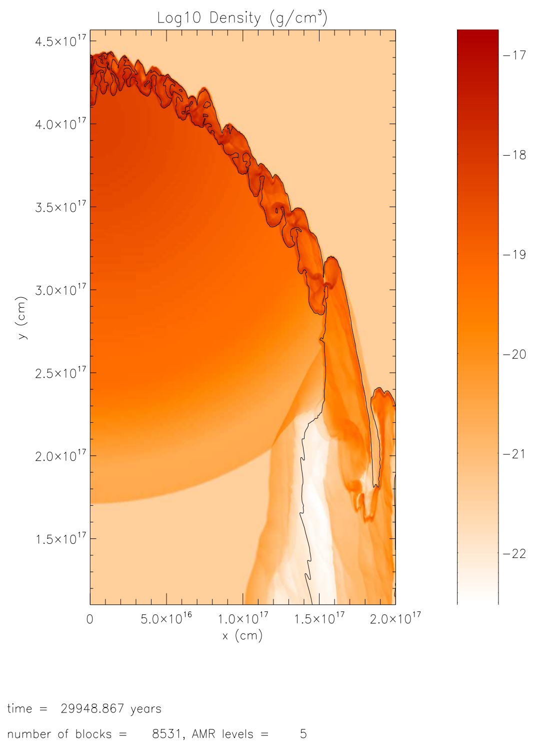

Figure 1. Density at 0.03 Myr.

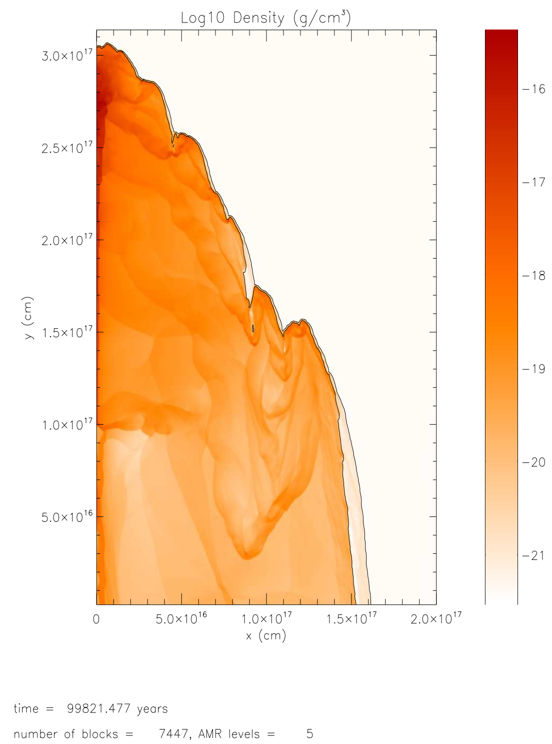

Figure 2. Density at 0.1 Myr.

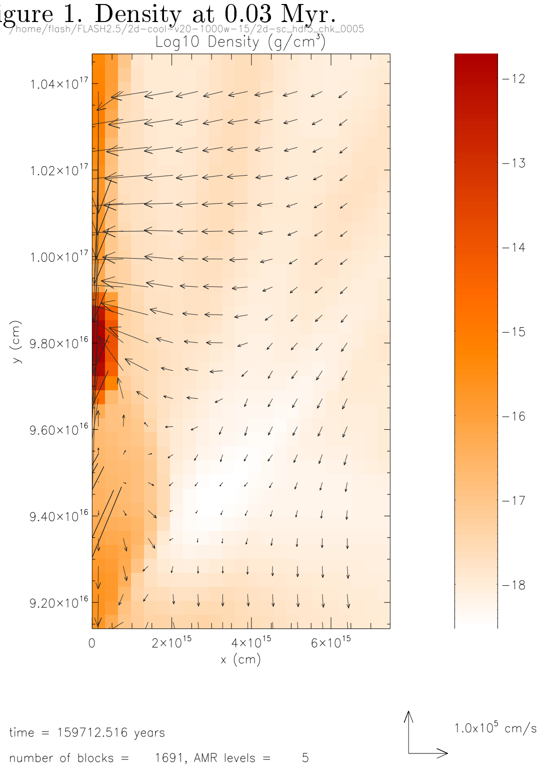

Figure 3. Density at 0.16 Myr.

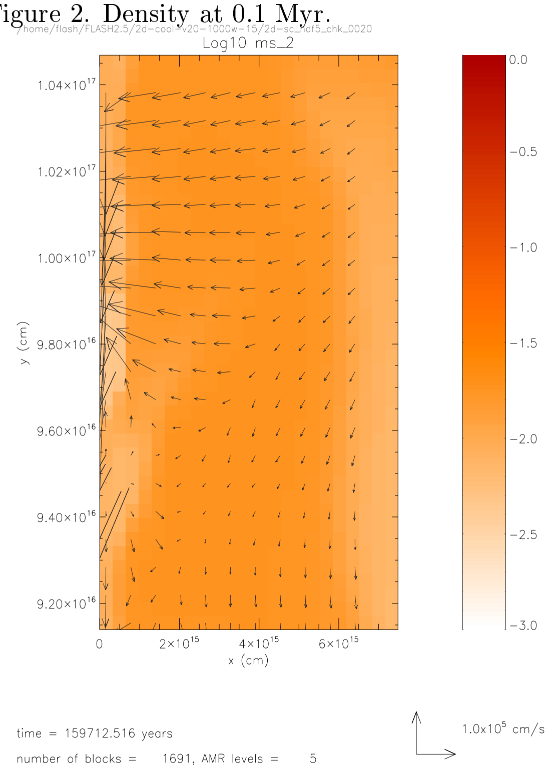

Figure 4. Color (SLRIs) at 0.16 Myr.