r-process studies at Los Alamos

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- Partial mixing between the high entropy rising plumes and the low entropy sinking down flows that power the convective engine mechanism of core-collapse supernova are a natural site for the r-process in every Type II supernova.

- Material that falls back onto the neutron star surface, re-shocks, and splashes upwards into a neutrino wind is also a natural site for the r-process.

- Both scenarios are elements of asymmetric supernovae.

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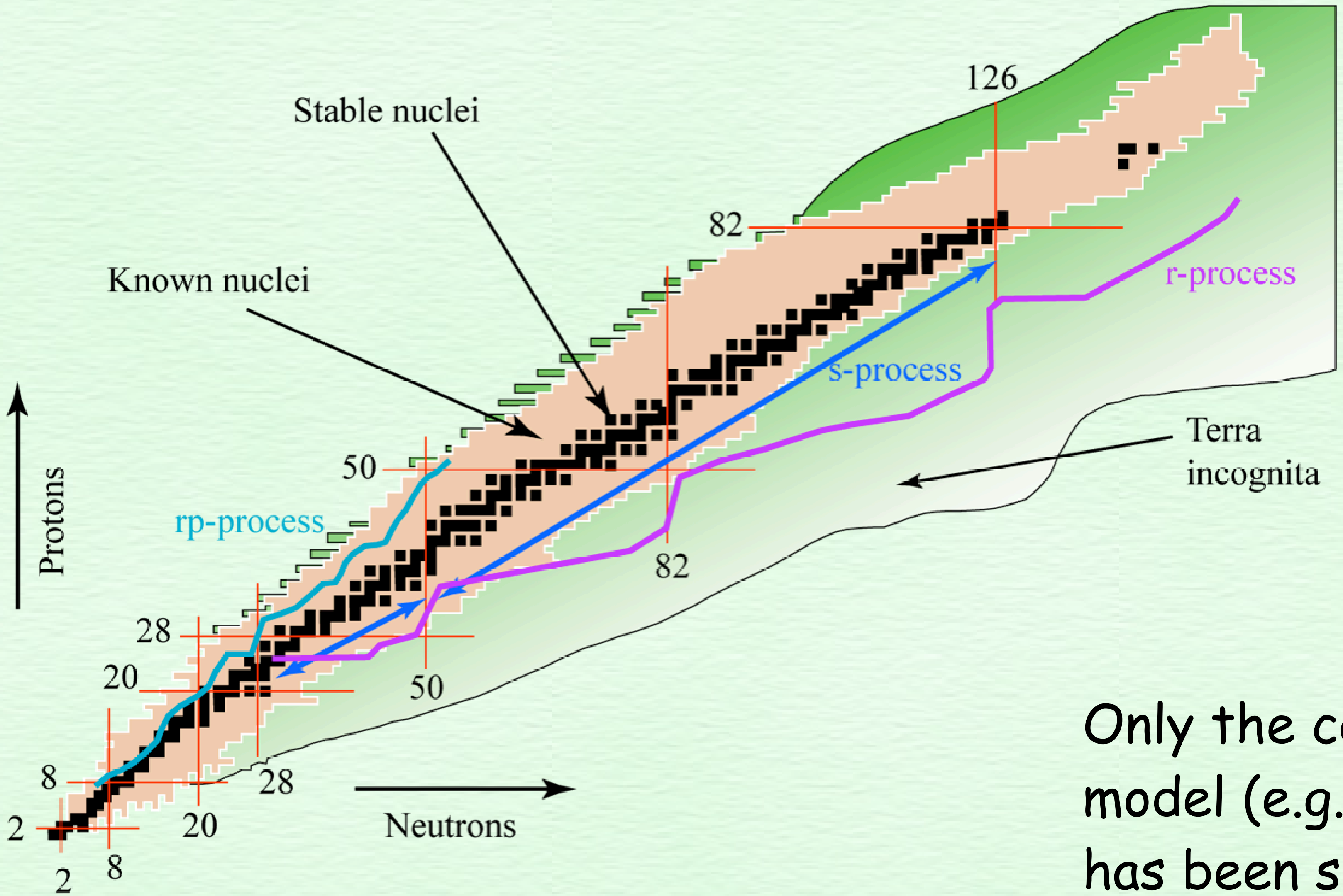
theoretical division

Possible origin sites

- The obvious site is a supernova explosion where, because a neutron star is produced, there are excess neutrons, high temperatures and short times.
- Alas, this alone has proven insufficient to account for an agreed upon r-process site. The problem may be the mechanism of the explosion itself.

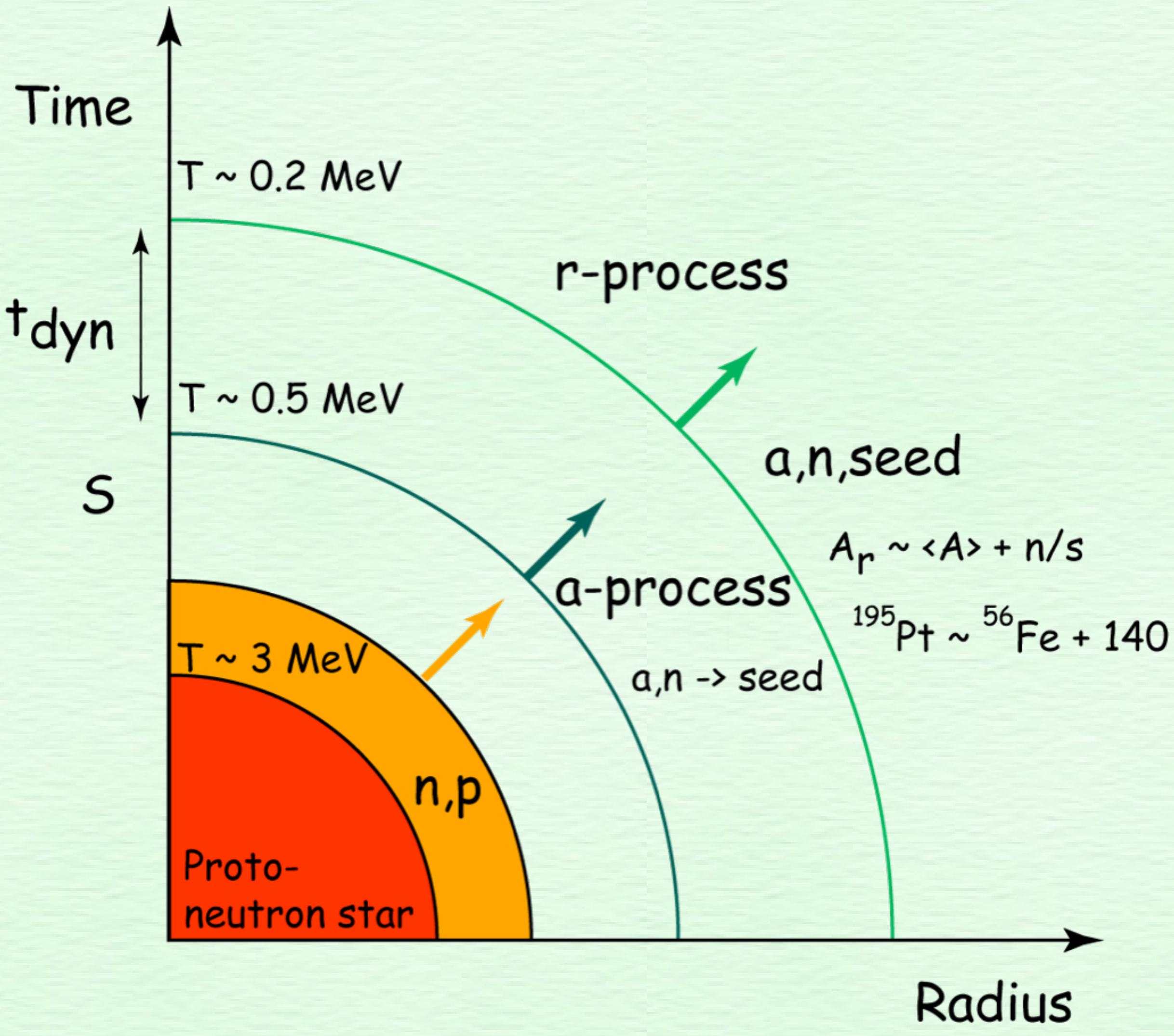


Only the convective engine, large scale plume model (e.g., 3D by Fryer & Warren 2003), has been successful in producing a supernova.

Possible origin sites

- However, a present preferred r-process site is a wind driven from a presumed nascent neutron star (e.g., Hoffman et al. 1997) S/k ~ 100-400, t_{dyn} ~ 0.1 - 0.3 s, Ye ~ 0.3-0.5

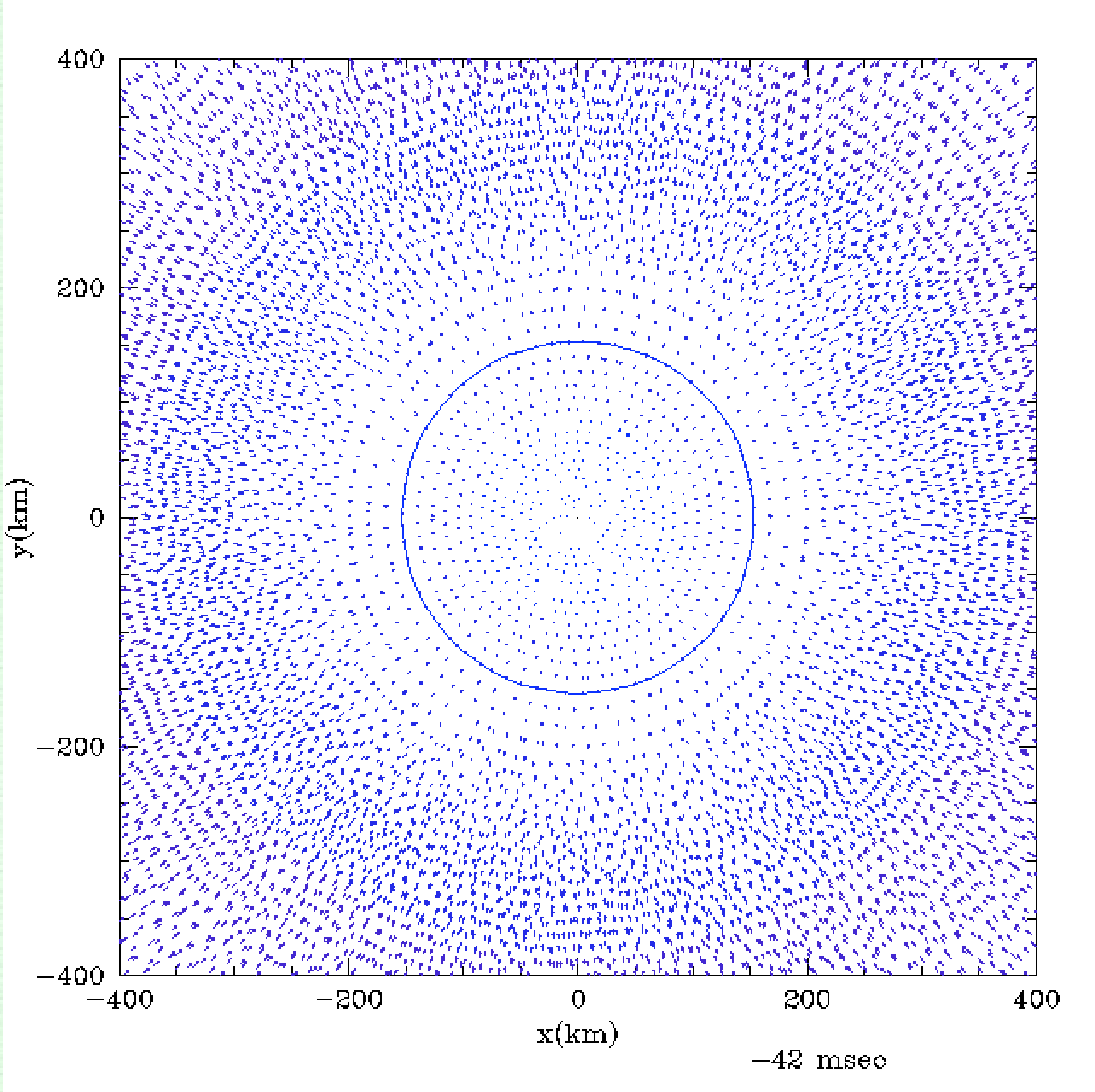
- This assumes that a SN has occurred within the first few seconds of collapse and that a bare, rapidly de-leptonizing neutron star is left.

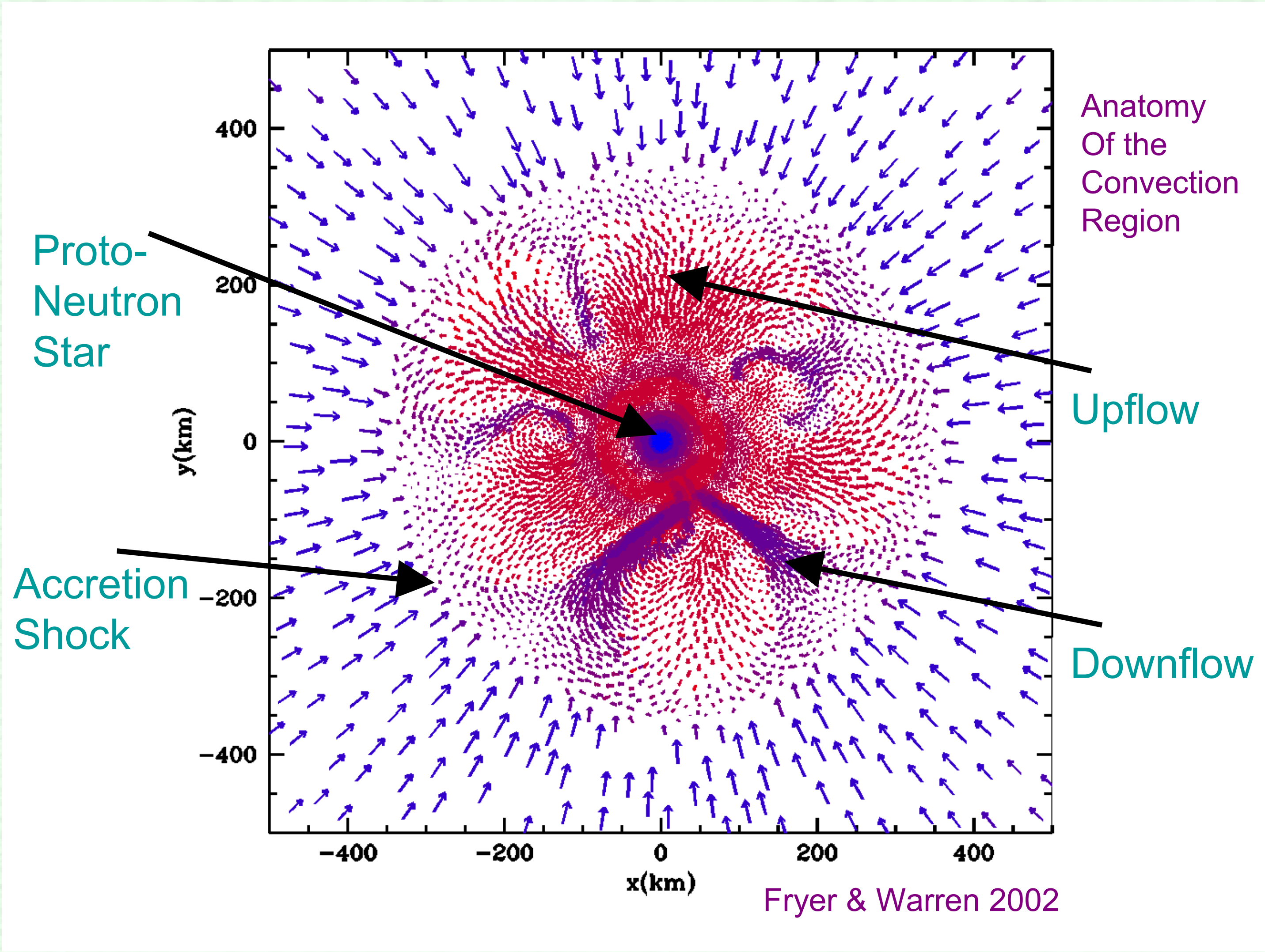


Instead, low entropy matter, S ~ 2, from behind the shock, falls as dense fingers to the surface while plumes of high entropy, S~100, matter rise to drive the shock.

Possible origin sites

- These down flowing fingers drive ("splash") a small mass of neutron rich matter into the rising plumes creating r-process conditions.

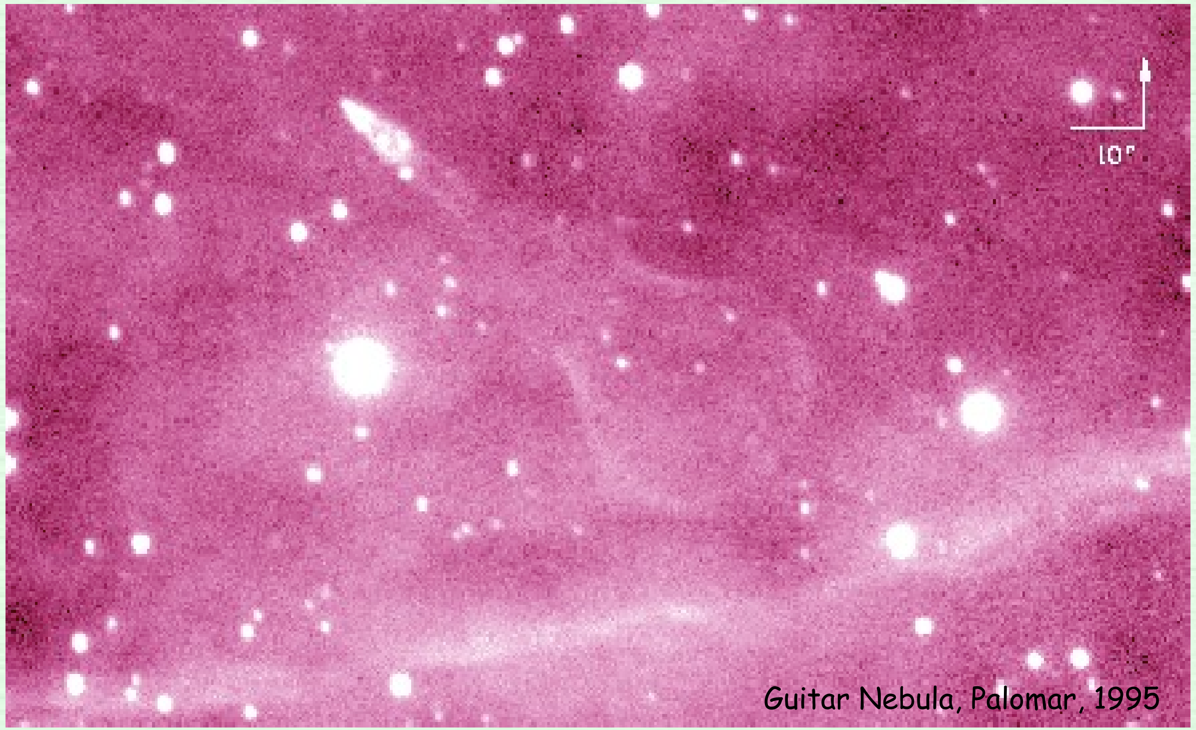




Spherical symmetry won't work

- Supernova are know to be far from symmetric. At the very least, rotation and convective instabilities alter the spherically symmetric picture producing asymmetric explosions. Asymmetries in the core may be critical to the supernova mechanism.

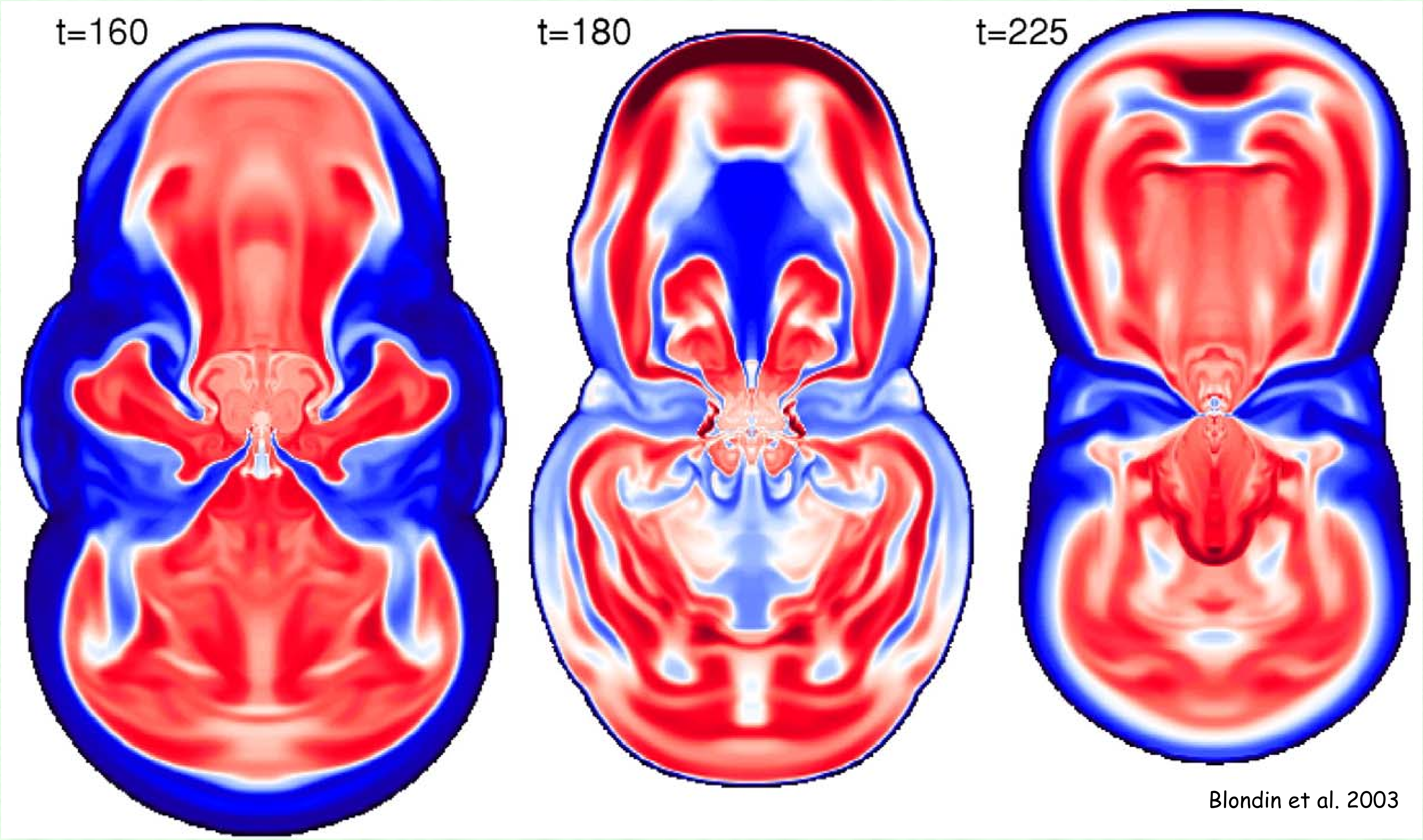
- Similarly, asymmetries in the core just after the launch of the explosion may well change the r-process yields. Rotation and fallback are two major aspherical effects that produce asymmetric winds and can increase the entropies and the time-scale over which the r-process operates.



Guitar Nebula, Palomar, 1995

Spherical symmetry won't work

• Instabilities in shocks may also produce asymmetric explosions.



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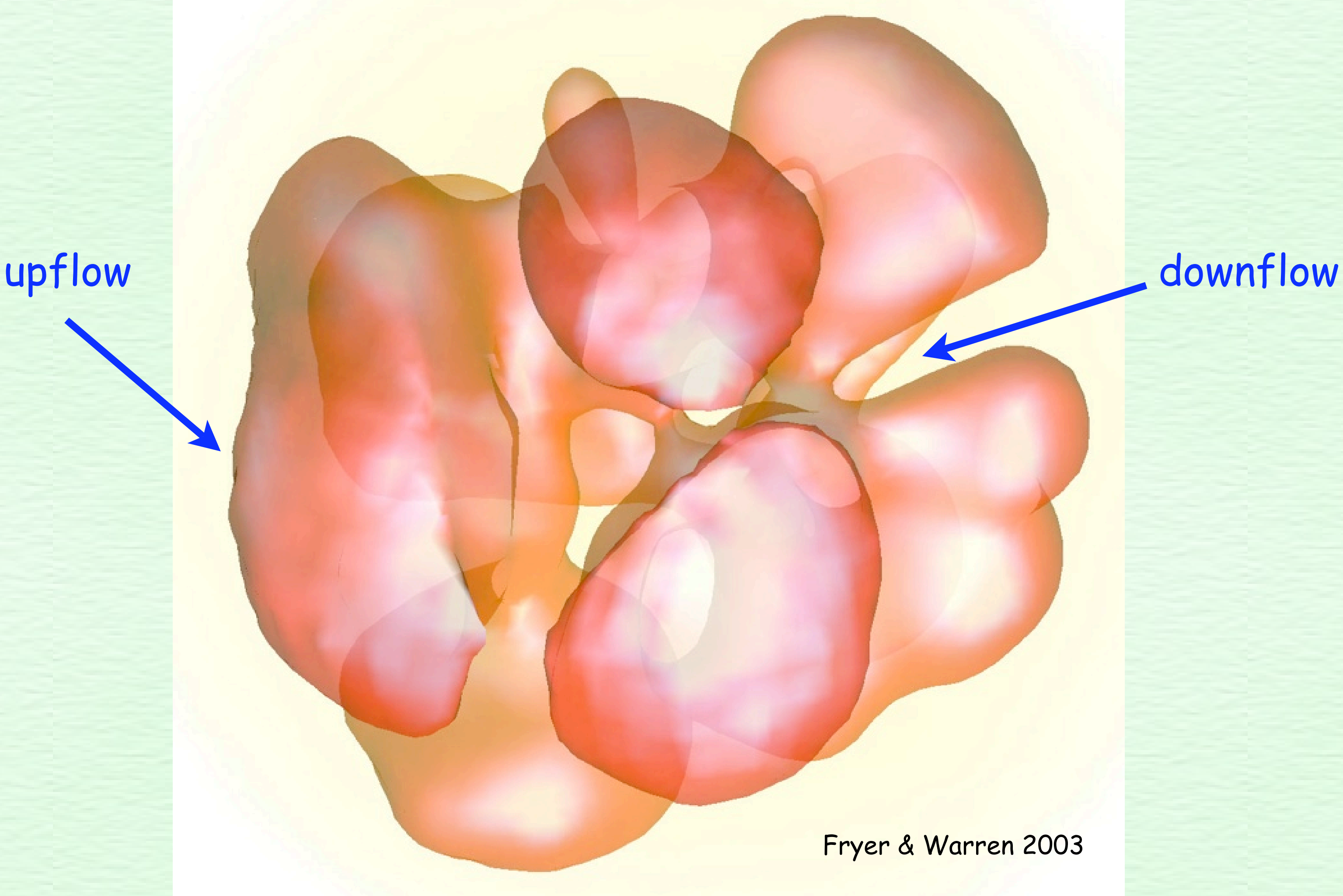
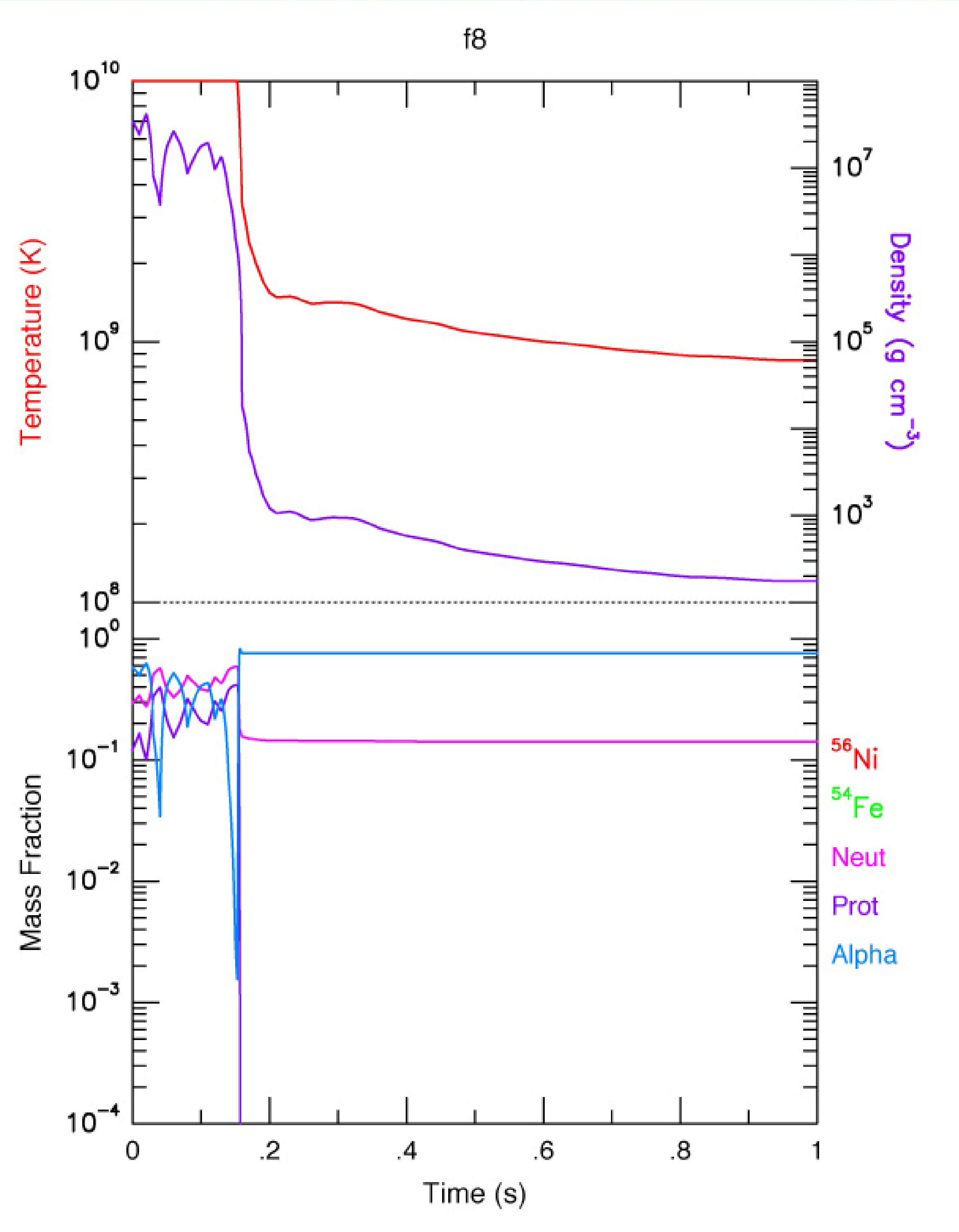
- After the initial shock is launched, material at the base of the shock ultimately decelerates and falls back onto the neutron star and re-shock.

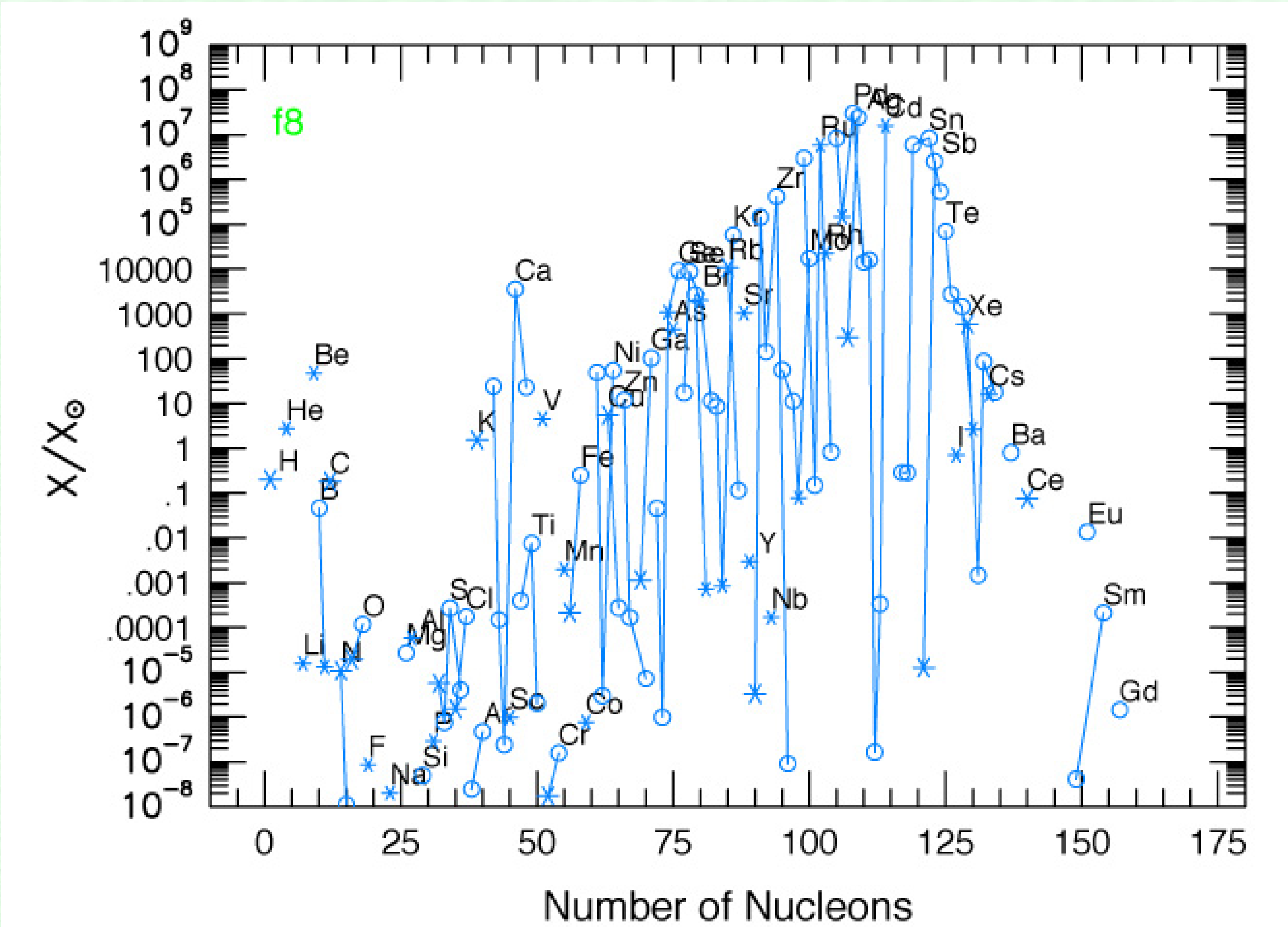
- Much of it will eventually cool off through neutrino emission and accrete onto the neutron star. But some will splash upwards and blow off in “wind”. This phase is far from spherical and not a “wind” per se.



A few particle trajectories

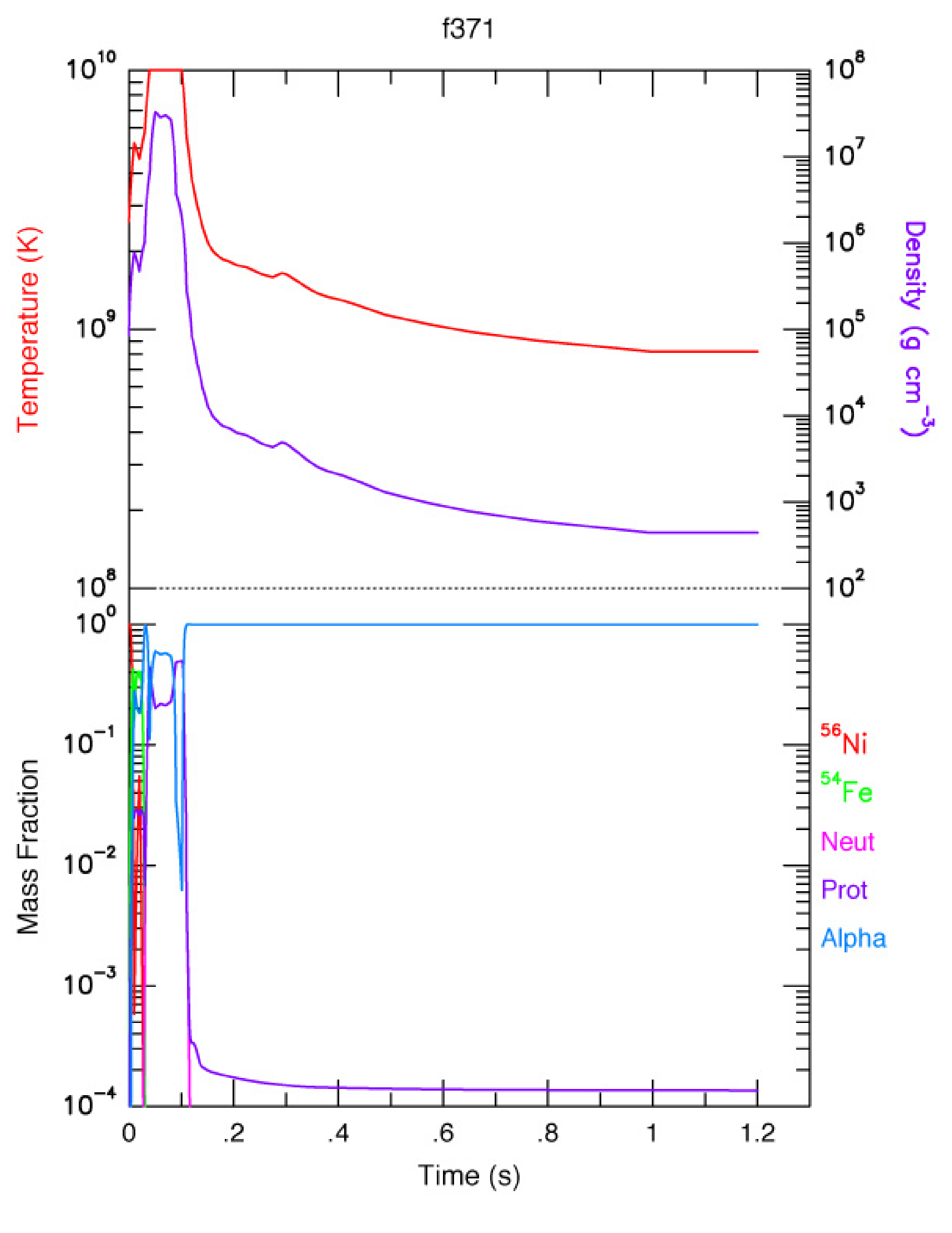
- The abundance pattern of one of the high entropy particles, S/k~ 450 Ye ~ 0.4, escaping the neutron star surface at 7000 km/s.

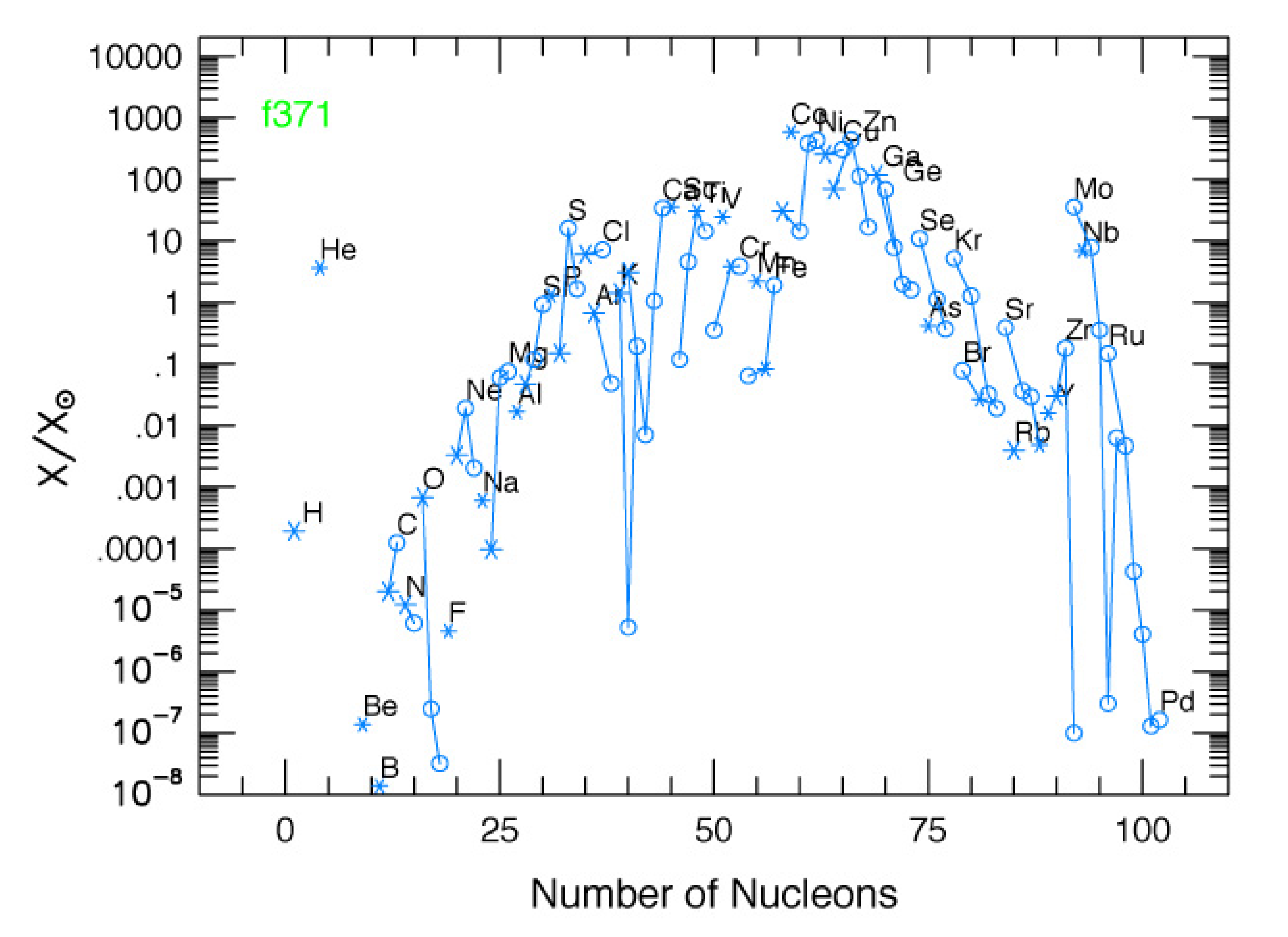




A few particle trajectories

- The abundance pattern of another particle, S/k~ 150 Ye ~ 0.48, escaping the neutron star surface at 3000 km/s.





Questions and Discussion

- We have a lot of work to do.
  - Physics for core-collapse supernovae.
  - Physics to produce r-process conditions.
  - Consistent set of beta-decay rates, nuclear masses, fissions, neutron capture cross sections.

The Medical Alchemist
Franz Christoph Janneck,
(1703 - 1761)
Oil on copper - 13" x 9"