Numerical simulation of nucleosynthesis and matter mixing in core-collapse supernova explosions

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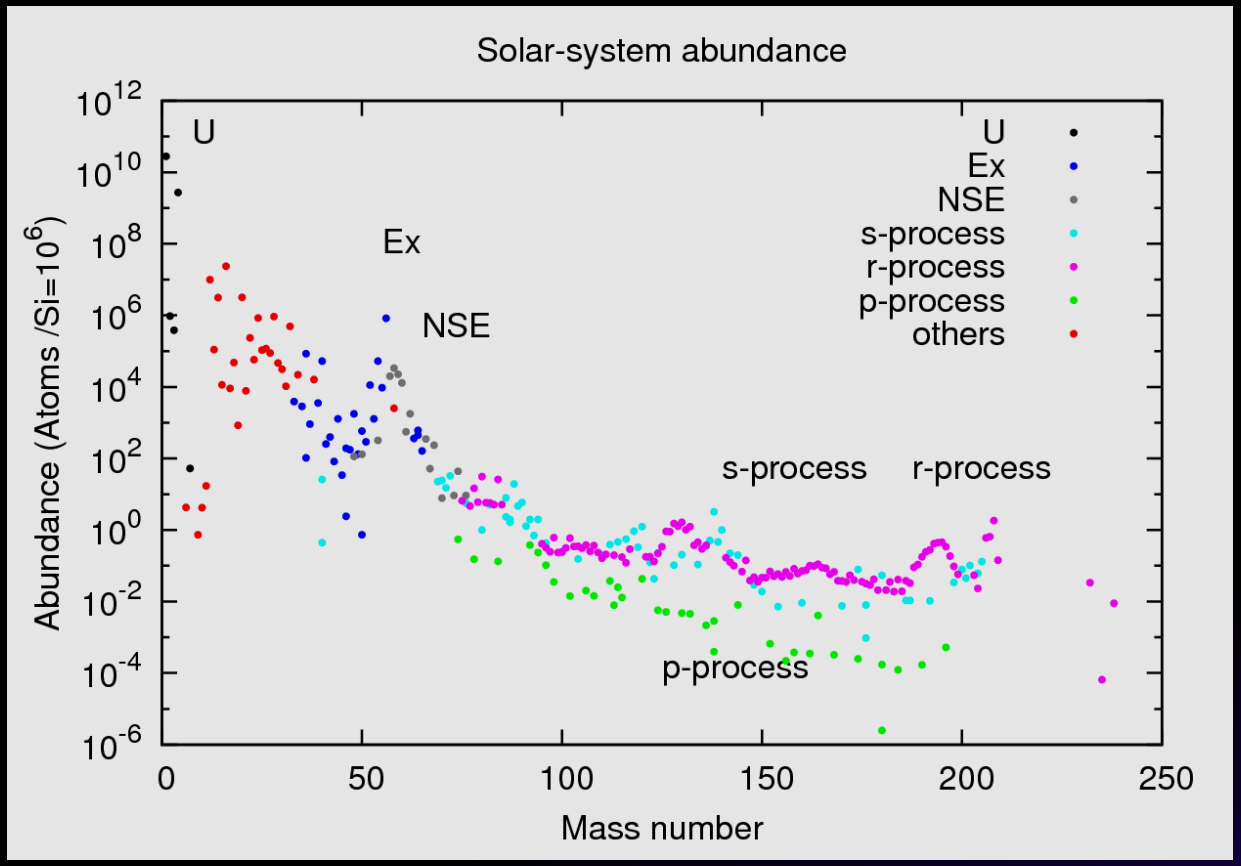
Outlines

- Origin of heavy elements
  - *r*-process
  - Heavy element nucleosynthesis in a magnetorotationally-driven supernova
- Matter mixing in supernova explosions

Origin of elements



Anderse & Grevesse 1986

Up to Iron

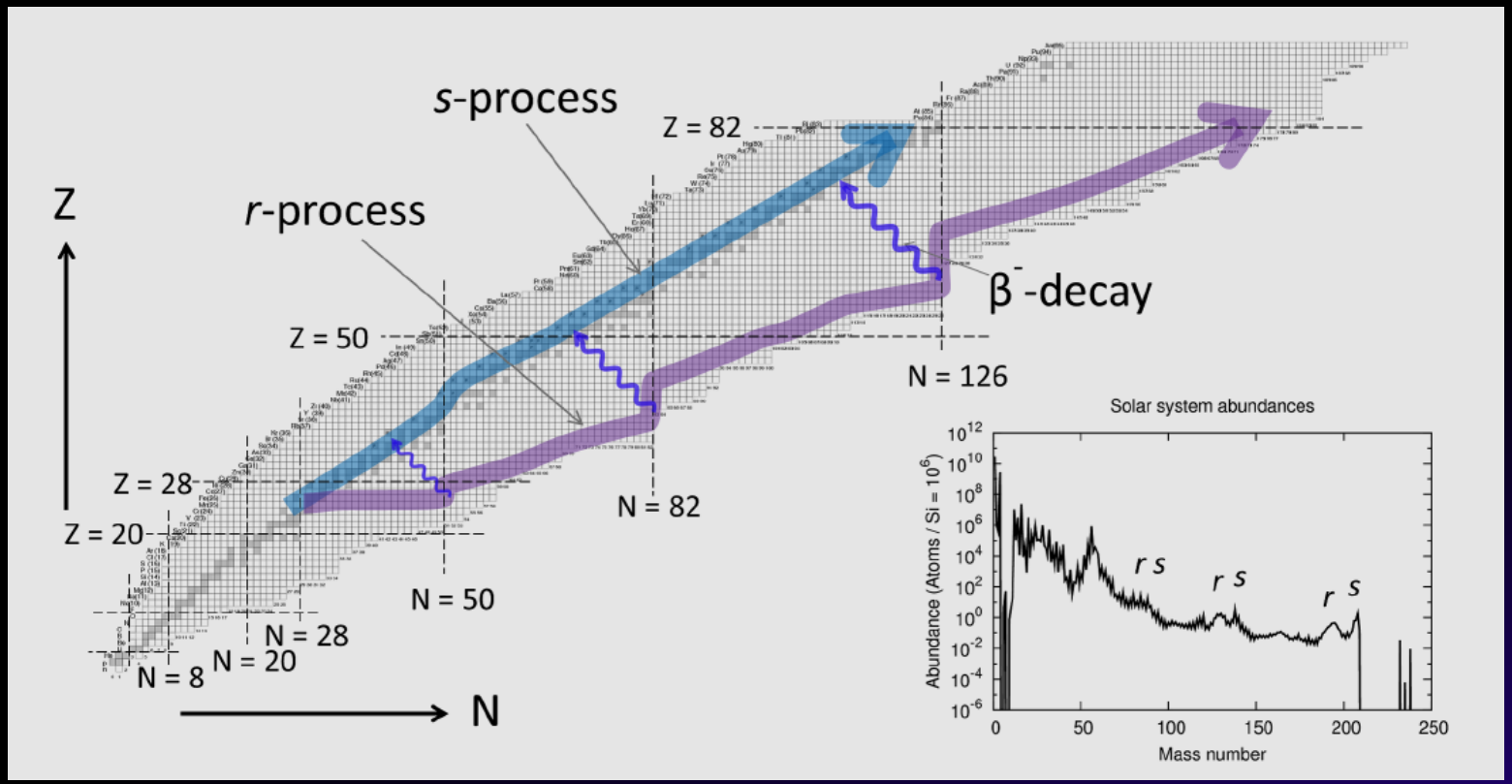
- BBN (light elements)
- Stellar evolution

Heavier than Iron

- Stellar evolution
  - *s*-process
- Supernova explosion
  - *r*-process
  - *p*-process

The *r*-process

- Rapid neutron capture (*r*-process) : explosive environment
- Slow neutron capture (*s*-process) : AGB stars, massive star



Key physical parameters for the *r*-process

- Electron fraction Y_e
- Entropy $S \propto T^3/\rho$

$$Y_e = \sum_i \frac{X_i}{A_i} Z_i \sim \frac{n_p}{n_n + n_p}$$

neutron-rich environment: $Y_e < 0.5$

low Y_e is essential for the *r*-process

$Y_e \sim 0.1$

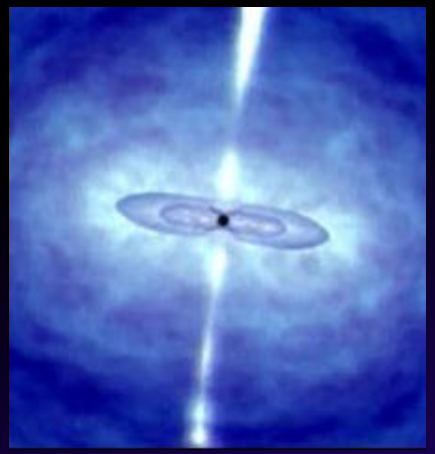
What is the site of the *r*-process ?

Main promising sites

- Neutrino-driven wind (NDW)
- Neutron star mergers (NSM)
- Magnetohydrodynamical (MHD) jets

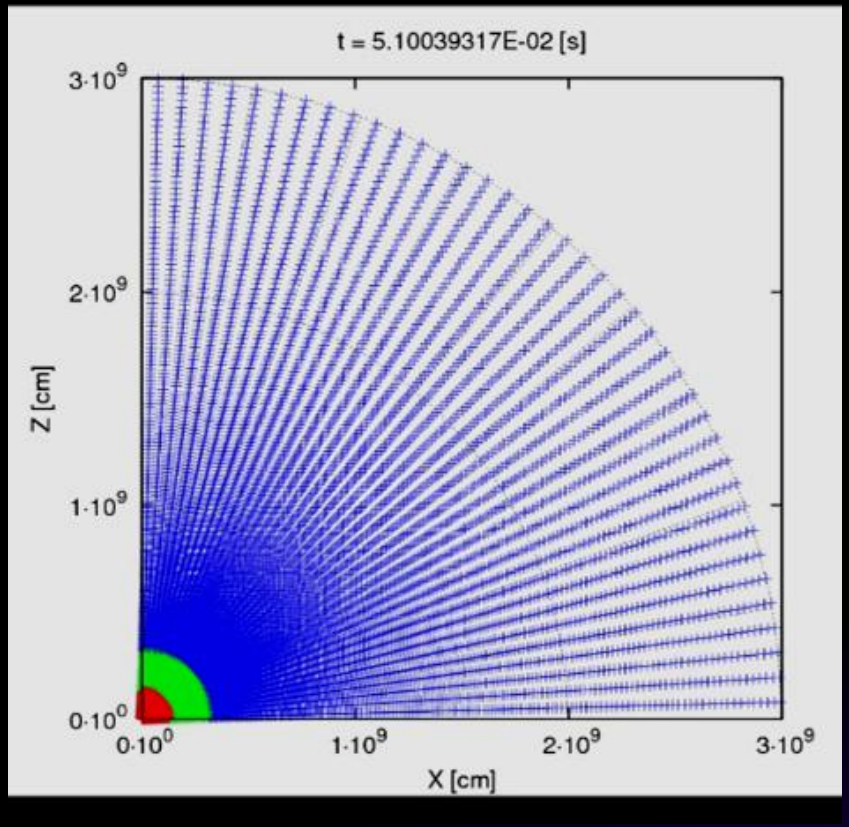
Nucleosynthesis in MHD jets including the *r*-process

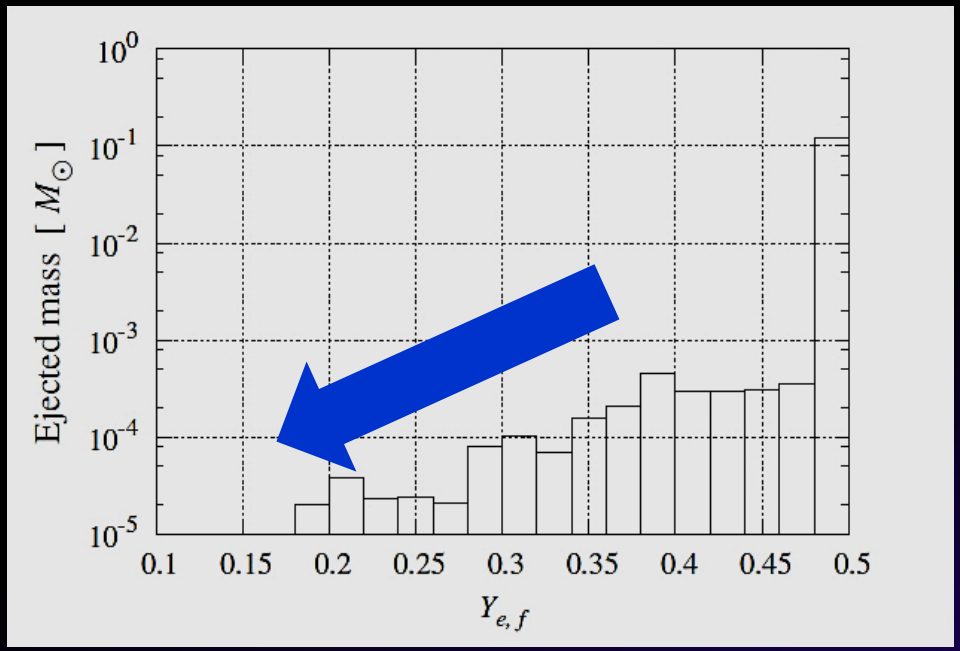
- **Magnetorotationally driven core-collapse supernova** (**MHD-CCSN**)
  - Nishimura +06
  - Winteler +12 (Basel)
- **Collapar model** (**BH + accretion disk**)
  - Fujimoto +07, 08
  - MO+12



Central engine of Gamma-ray bursts ?

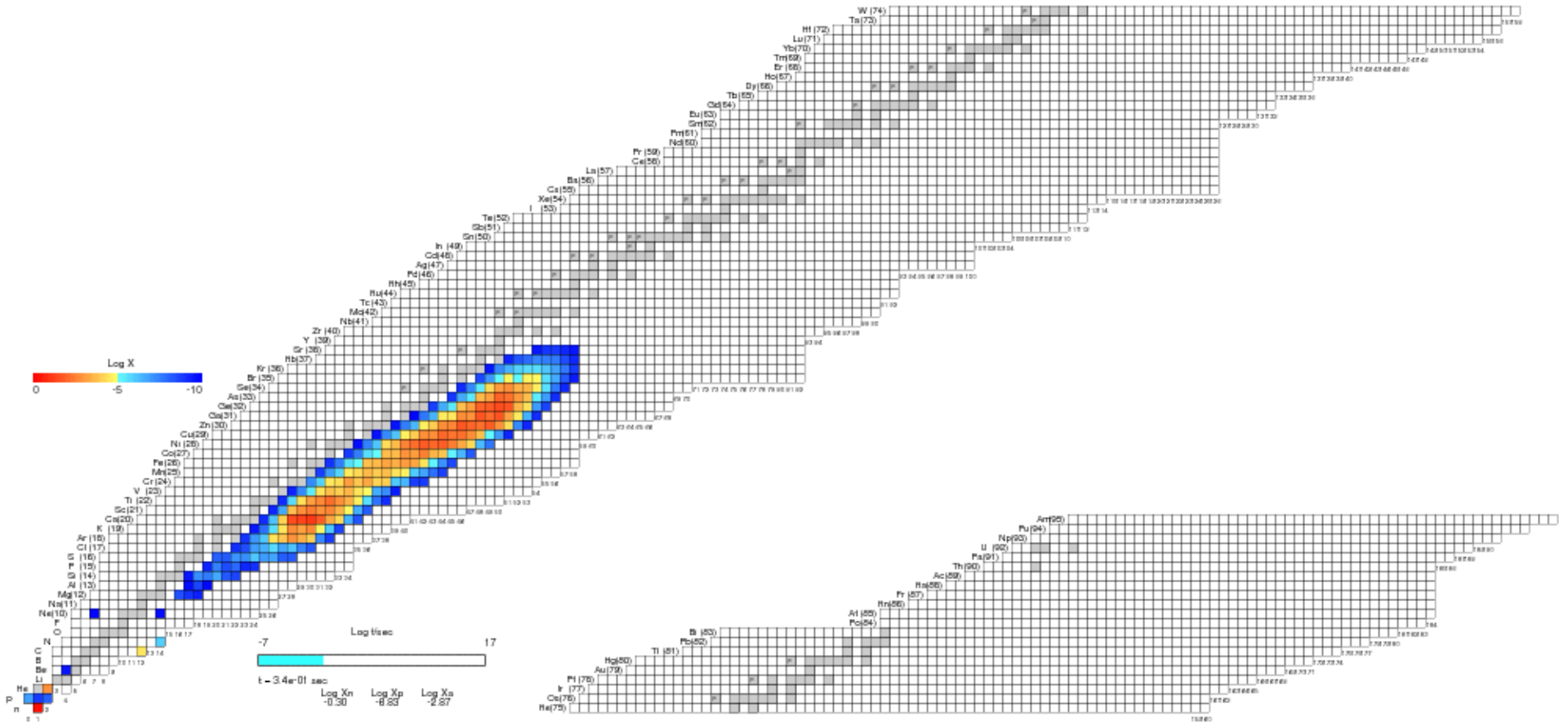
Nucleosynthesis in the MHD jet from a collapsar including weak *s*-, *p*-, and *r*-processes



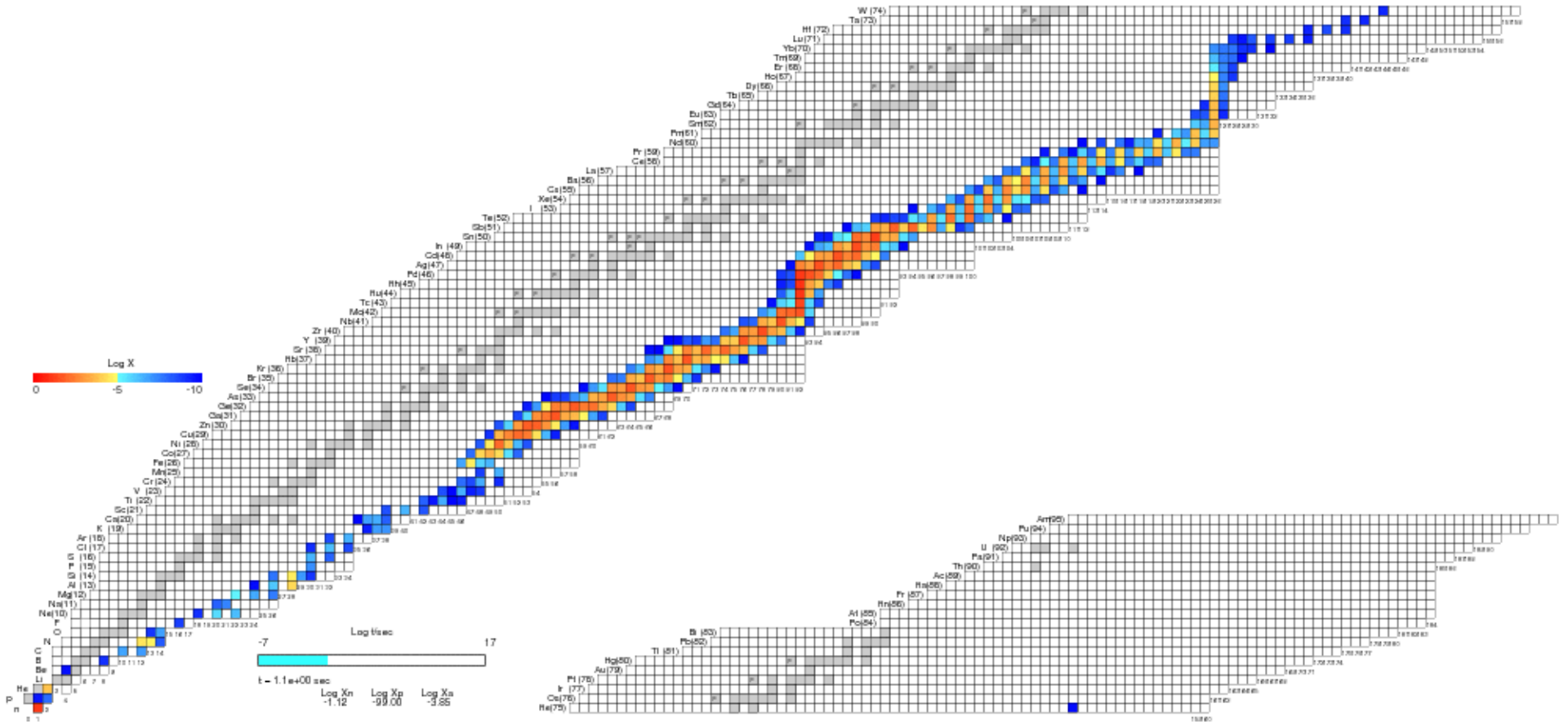


MO+12

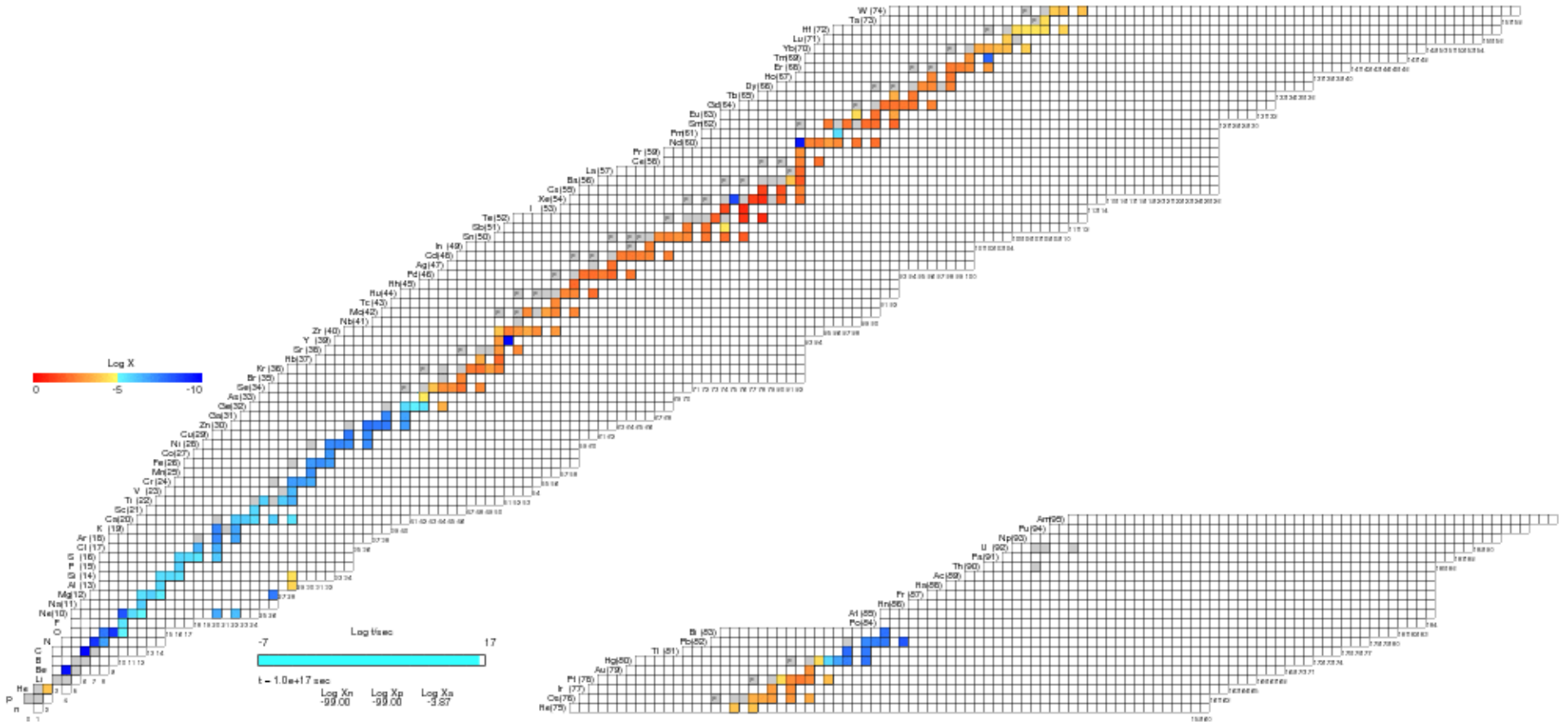
r-process nucleosynthesis



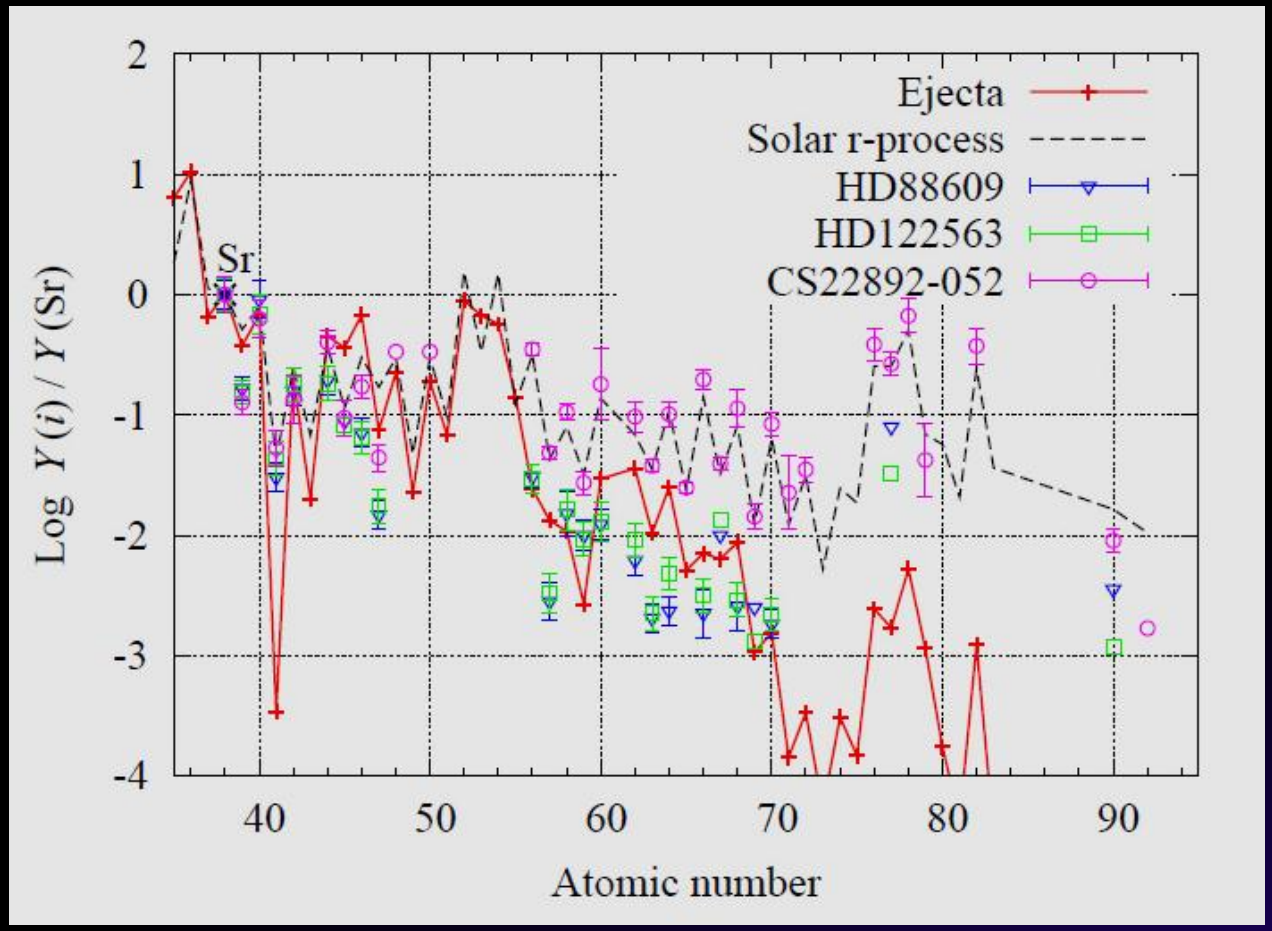
r-process nucleosynthesis



r-process nucleosynthesis



Comparison with abundances of the solar and metal-poor stars



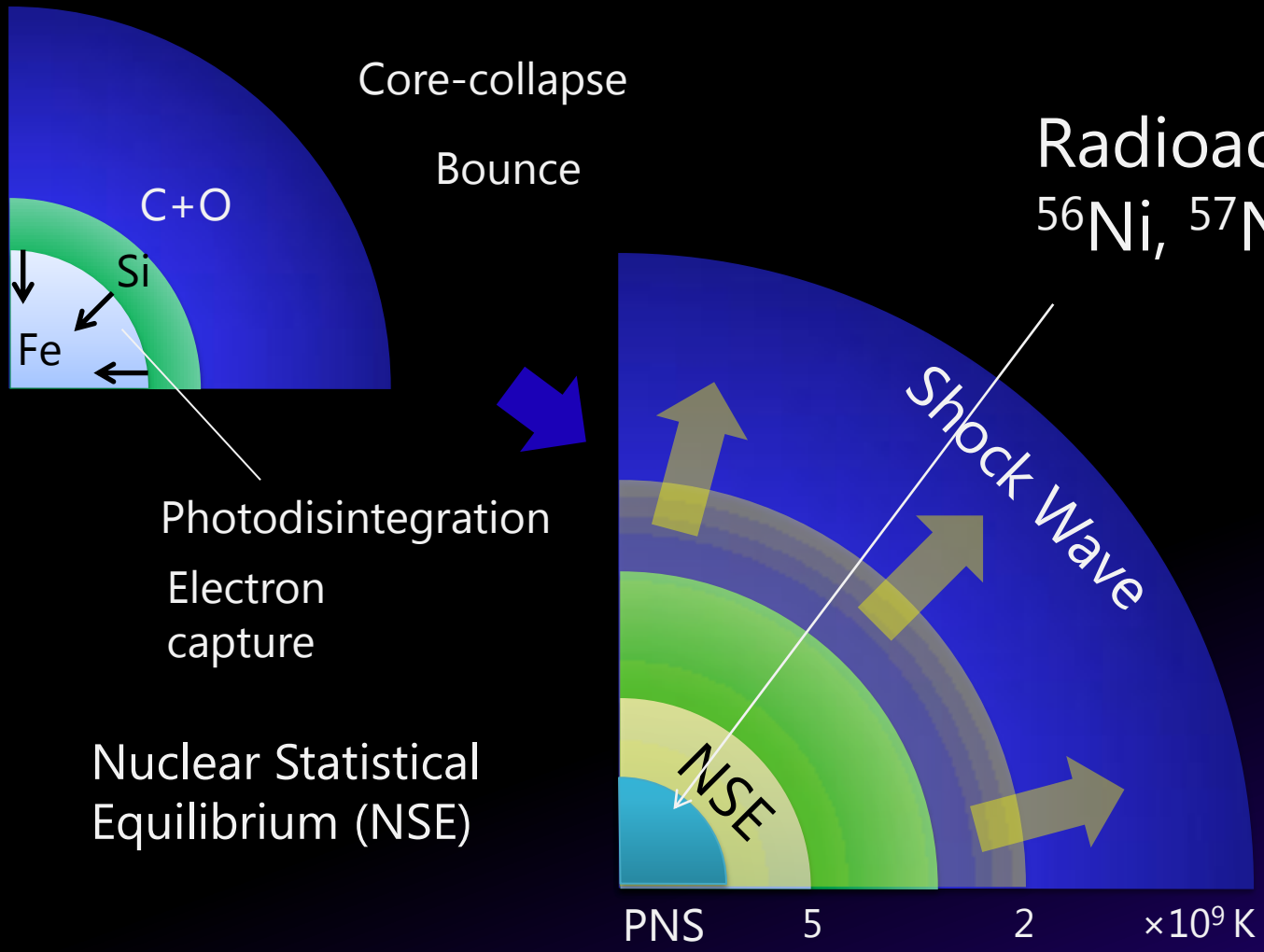
- Weak *r*-process ?

  MO+12

How synthesized elements are ejected ?

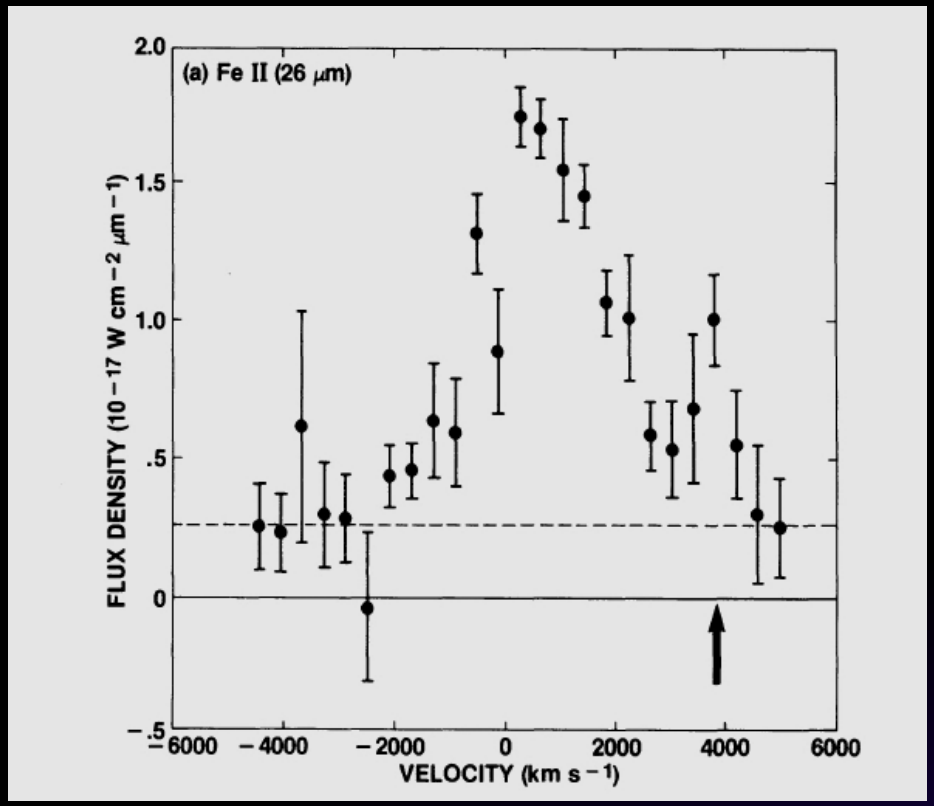
Matter mixing in core-collapse supernovae

Explosive nucleosynthesis in core-collapse supernovae

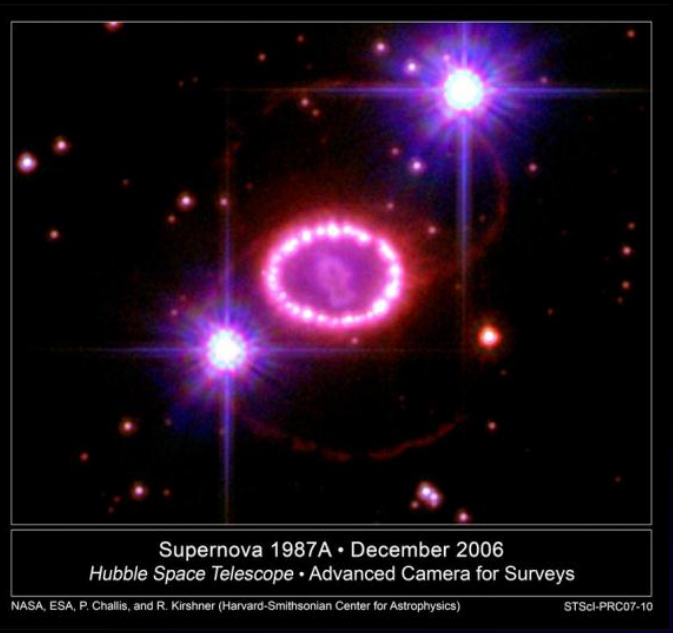


Broadened line profiles of SN1987A

[Fe II] line profiles (Spyromilo+90; Haas+90)



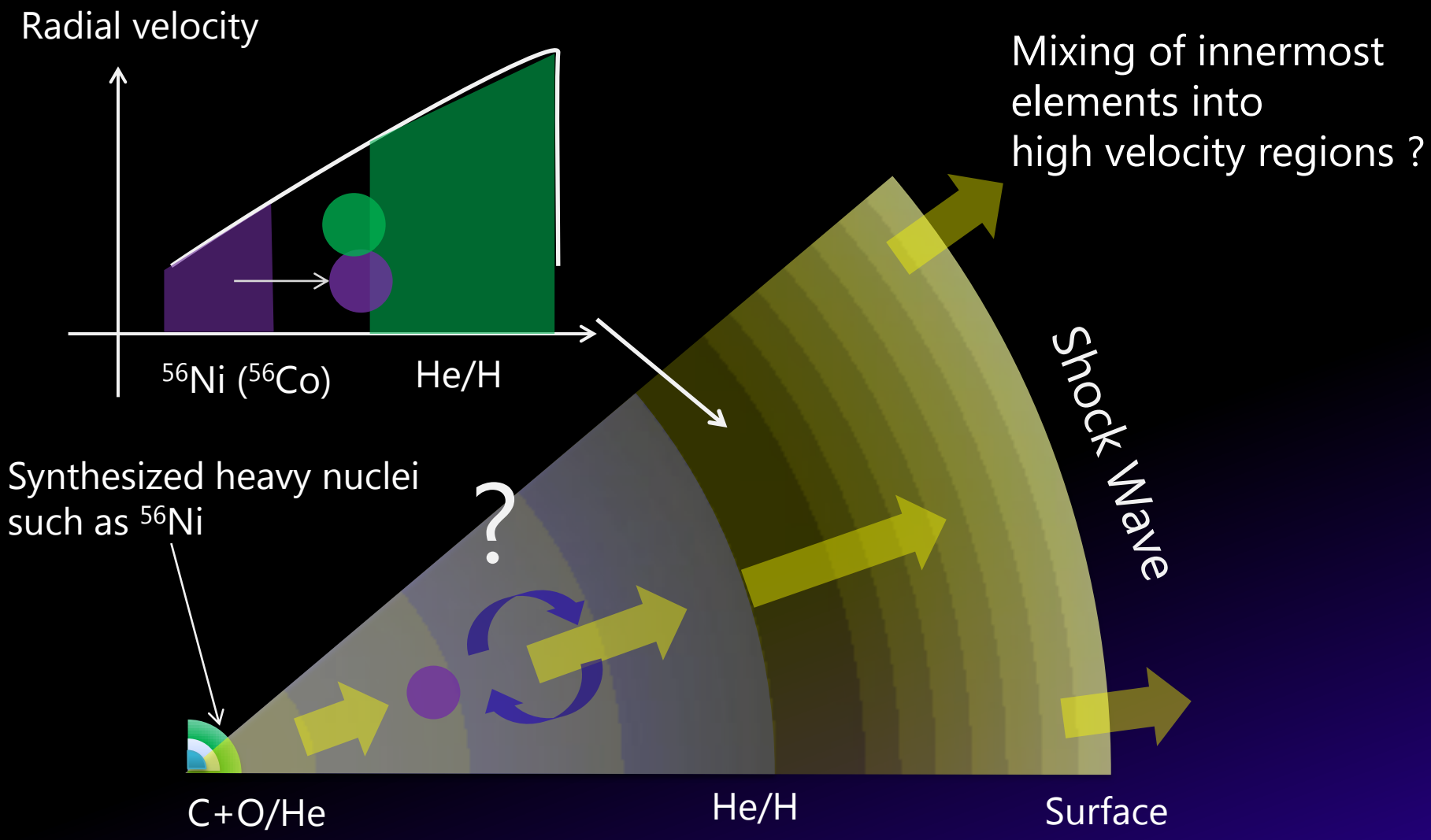
Haas et al. 1990



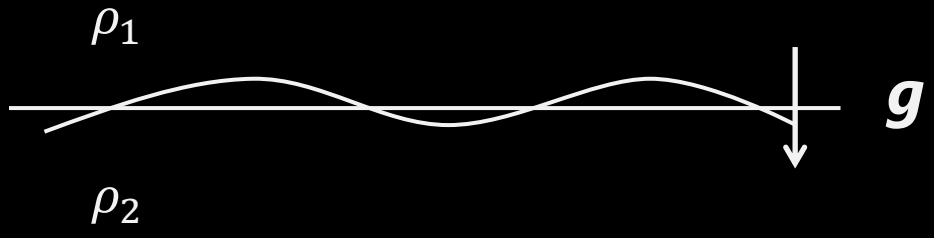
Fe is mixed into high velocity regions ?

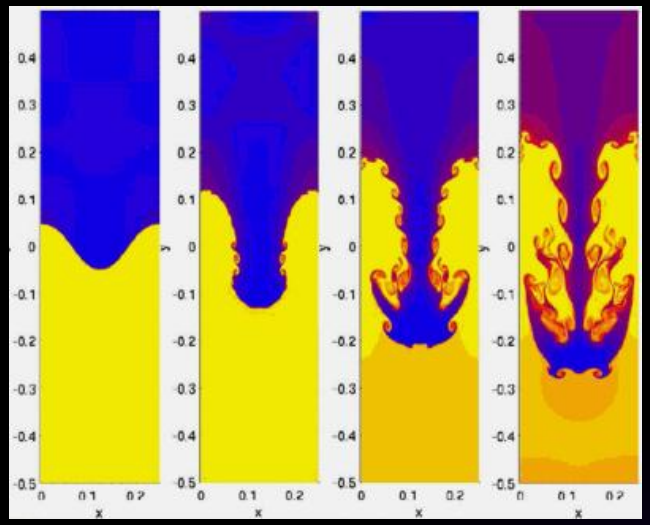
$^{56}Ni \rightarrow {}^{56}Co \rightarrow {}^{56}Fe$

Propagation of supernova shock wave



Rayleigh-Taylor (RT) instability





Shengtai Li & Hui Li 2006

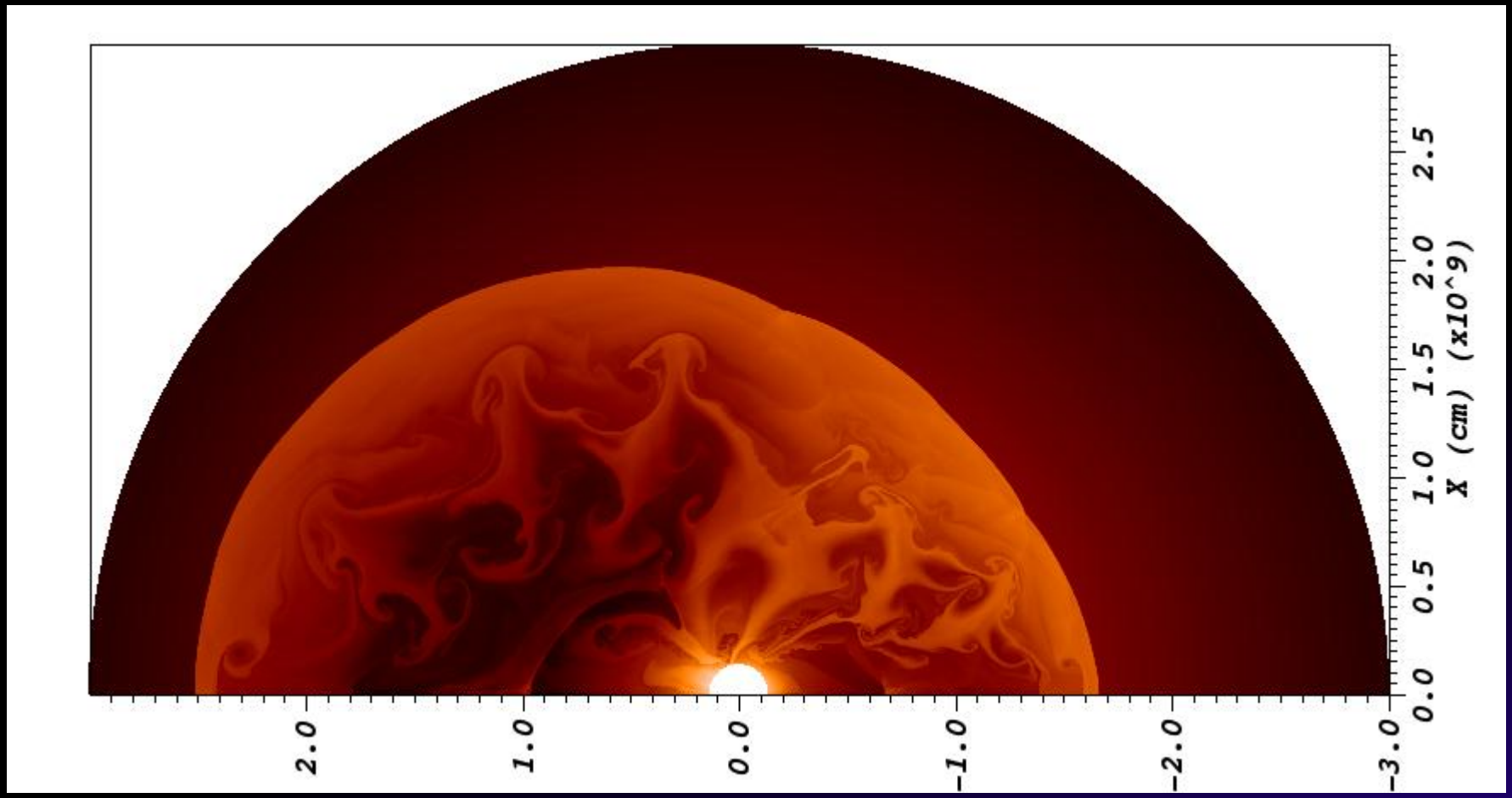
Gravity ⇔ inertial force

RT unstable condition

$\nabla\rho \cdot \nabla p < 0$

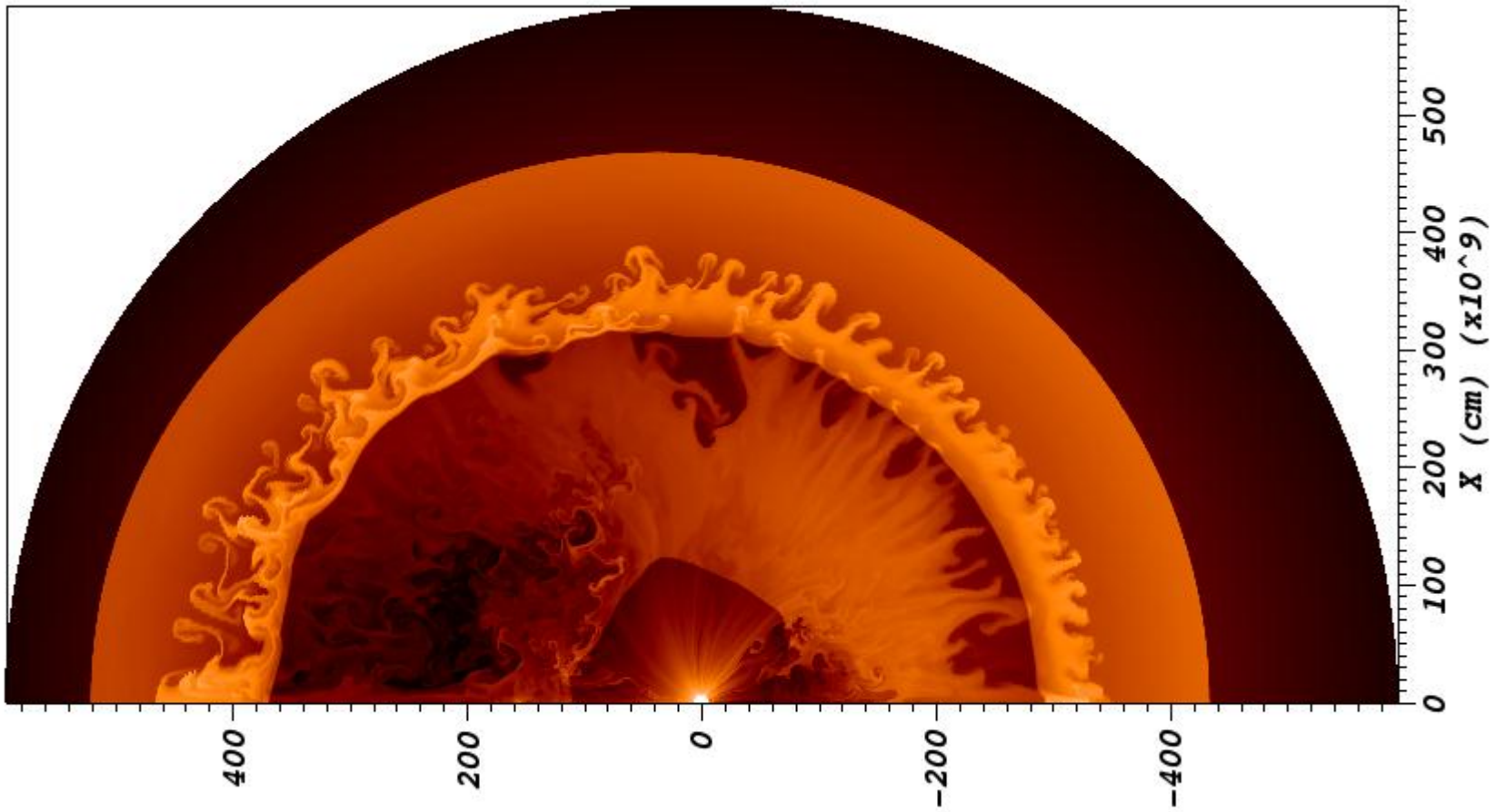
Spherical explosions + RT instabilities have not explained the high velocity ^{56}Ni

Matter mixing in non-spherical core-collapse supernova explosion



M.O. et al. (2013 in prep.)

Matter mixing in non-spherical core-collapse supernova explosion



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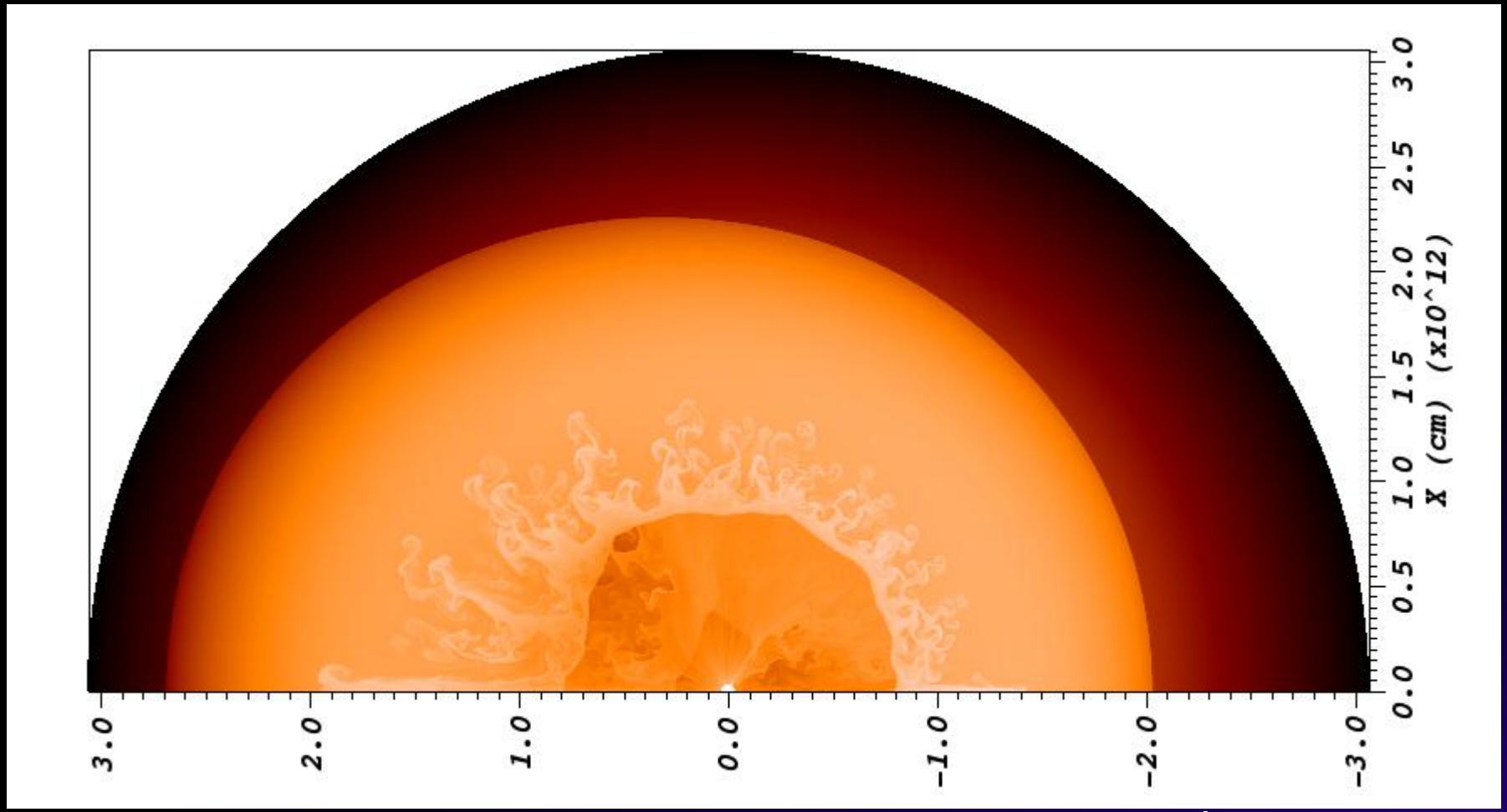

M.O. et al. (2013 in prep.)

Summary

- Origin of heavy elements has still been uncertain
  - What is the site of the *r*-process ?
- It is very unobvious how synthesized elements are ejected in supernova explosions
  - Matter mixing in core-collapse supernovae
  - Diagnostic to speculate the mechanism of core-collapse supernovae

Thank you for your attention