Quick notes on
Supernova Nucleosynthesis

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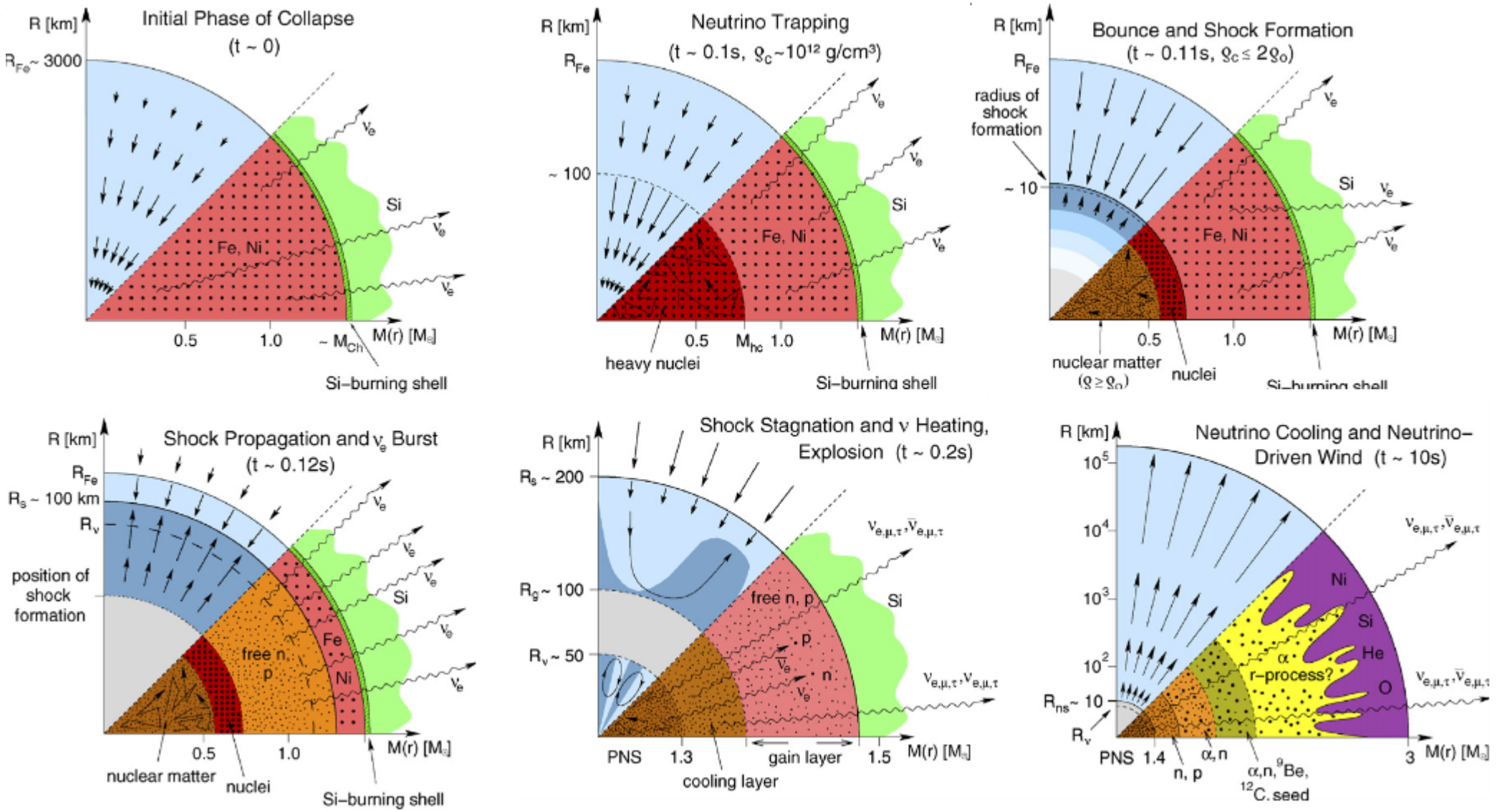
Ohio University - ASTR4201 - Fall 2020

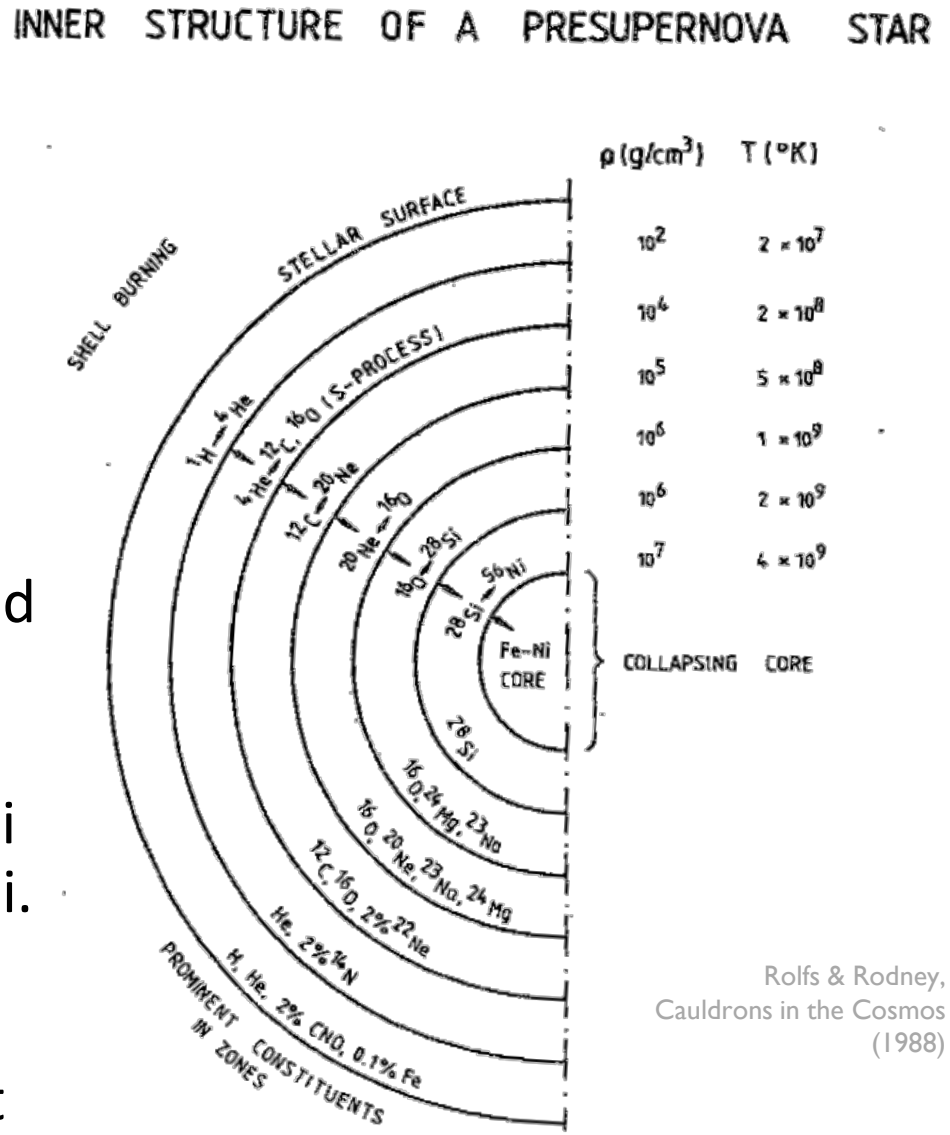
Steps of a Core Collapse Supernova



H. Janka et al. Phys. Rep. 2007

Nucleosynthesis before core collapse

- Following H and He burning we've discussed previously,
  - ***Carbon burning***: $^{12}C+^{12}C$ fusion and captures by the reaction products of produced p & α mostly result in ^{16}O, ^{20}Ne, ^{24}Mg. Stars less than ~ $8M_{\odot}$ end here
  - ***Neon burning***: Photodisintegration of and α captures by ^{20}Ne converts it to mostly ^{16}O and ^{24}Mg
  - ***Oxygen burning***: $^{16}O+^{16}O$ fusion and captures by the reaction products of produce p & α mostly result in ^{28}Si and ^{32}S, but β-decays of some products results in a slightly neutron-rich composition
  - ***Silicon burning***: Photodisintegration and α captures of ^{28}Si and the reaction products, involving a large range of nuclei. This material is nearly in Nuclear Statistical Equilibrium (all forward & reverse rates equal), so the abundance *distribution* (centered around ^{56}Fe, i.e. the "iron" core isn't just iron) mostly just depends on the temperature and the nuclear masses. This is the end-of-the-road and is followed by core collapse.

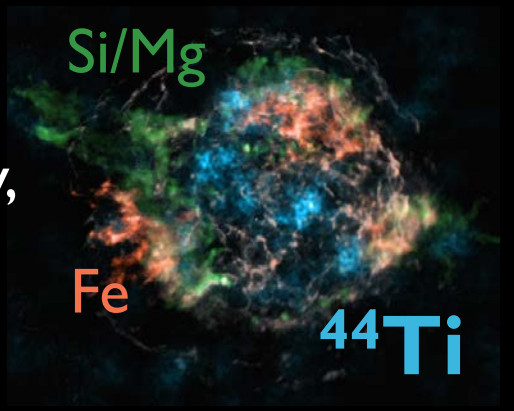


Rolfs & Rodney, Cauldrons in the Cosmos (1988)

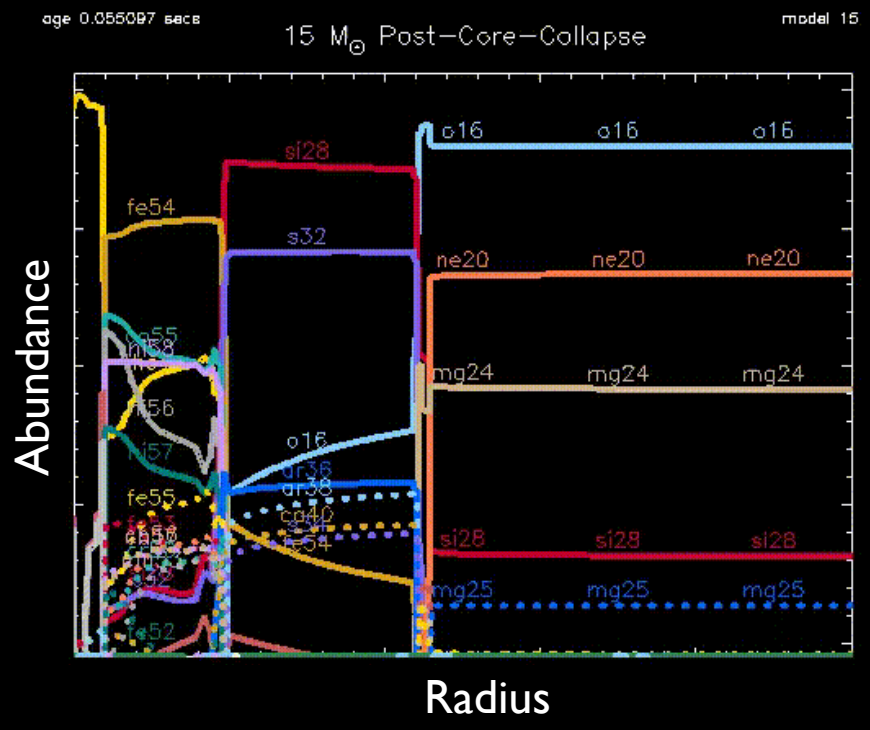
Also release s-process & i-process elements made during late-stage evolution

Nucleosynthesis in the Supernova Shock

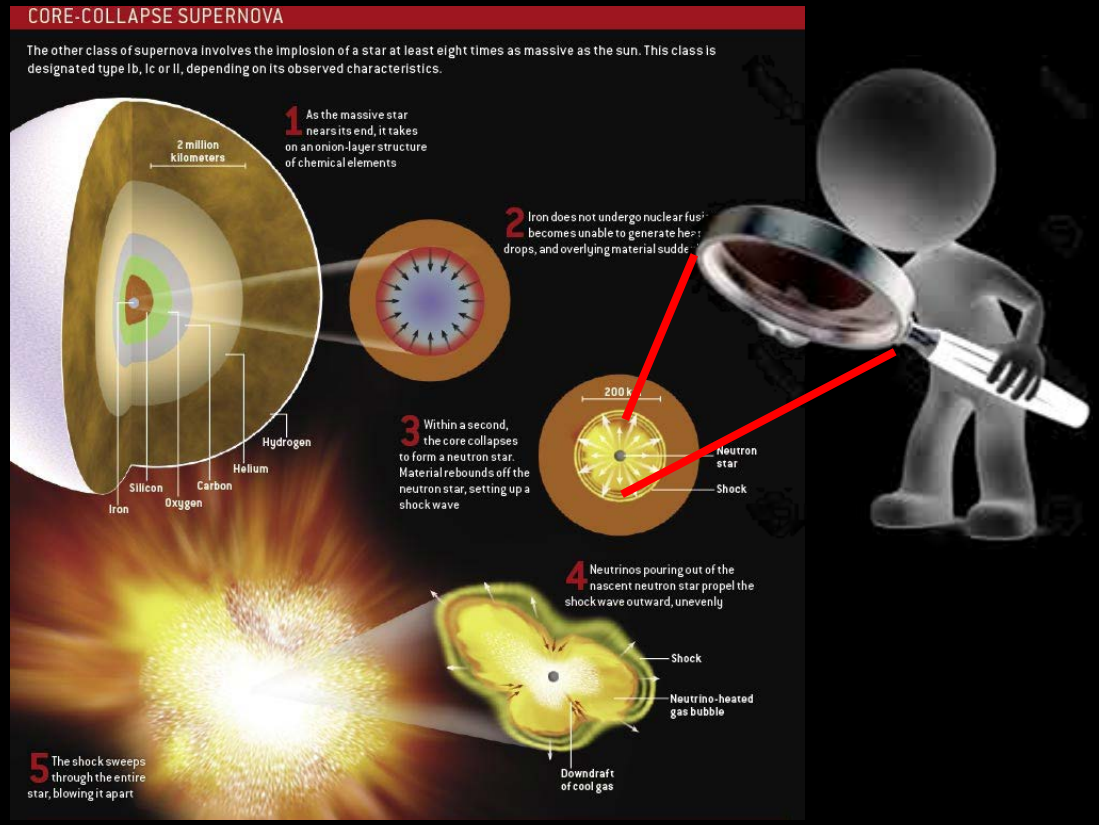
- The outgoing shock following core-bounce raises the temperature & density, where nuclides are mostly made during a freeze-out from equilibrium
- Some radioactive nuclides (e.g. ^{44}Ti) are core collapse supernova diagnostics



B. Grefenstette et al. *Nature* 2014



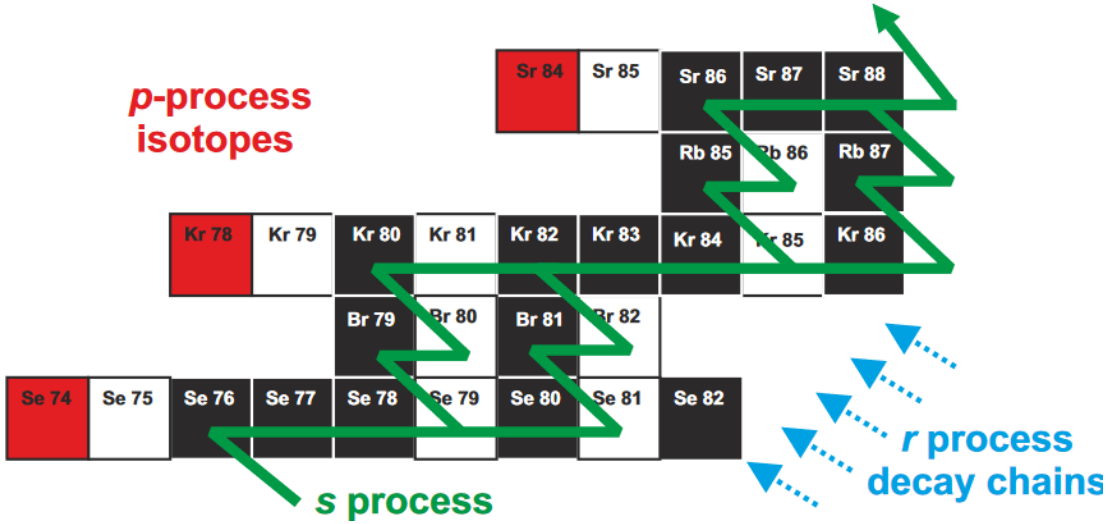
B. Paxton et al. *ApJS 2015*



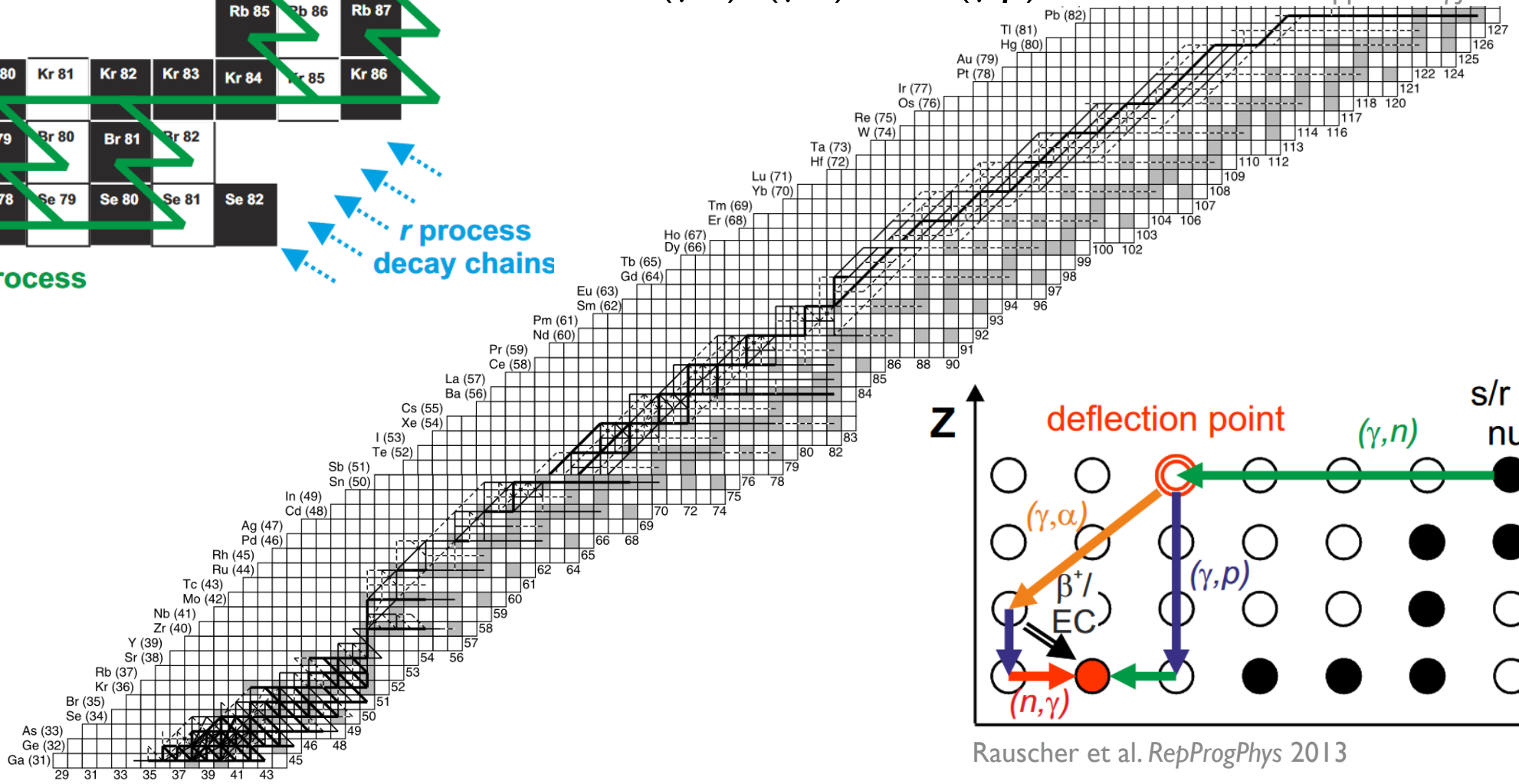
W. Hillebrandt et al. *SciAm* 2006

The origins of p-nuclei, in the wake of the CCSN shock

At slightly larger radii, the γ-process in the O/Ne shell is thought to form (most of) the *p*-nuclei, where seed nuclei are destroyed in a massive chain of (γ,*n*), (γ,α), and (γ,*p*) reactions:



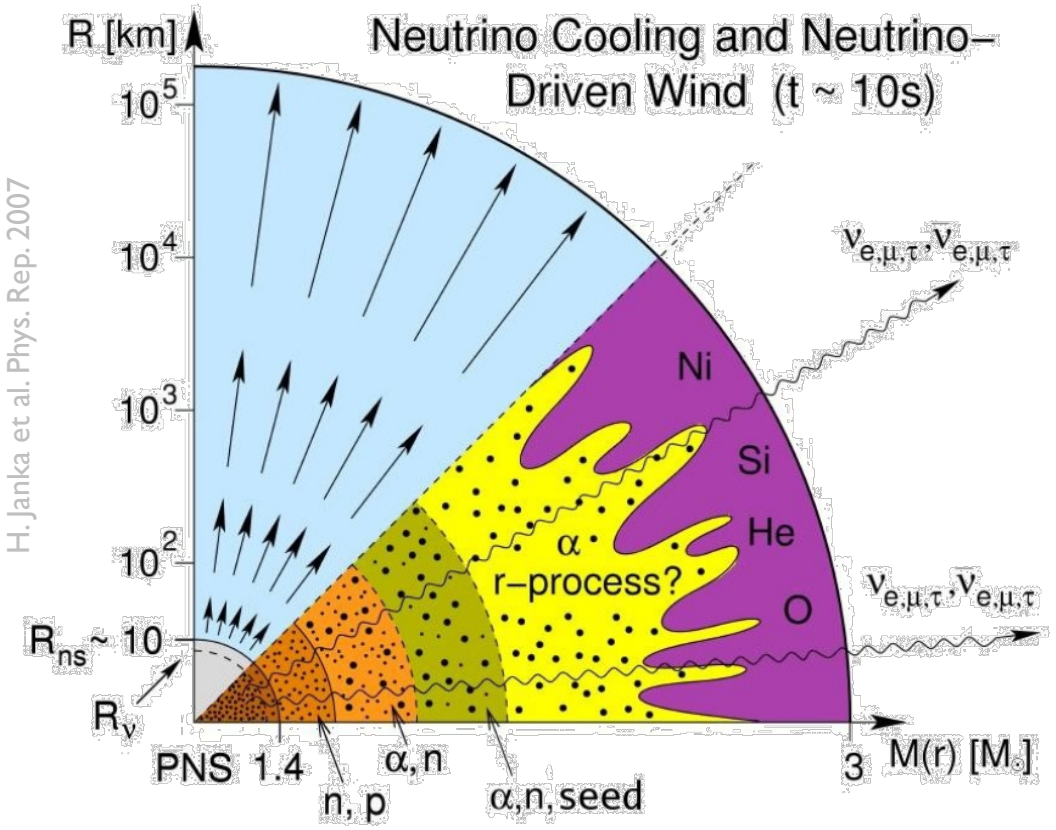
Rapp et al. *ApJ* 2006

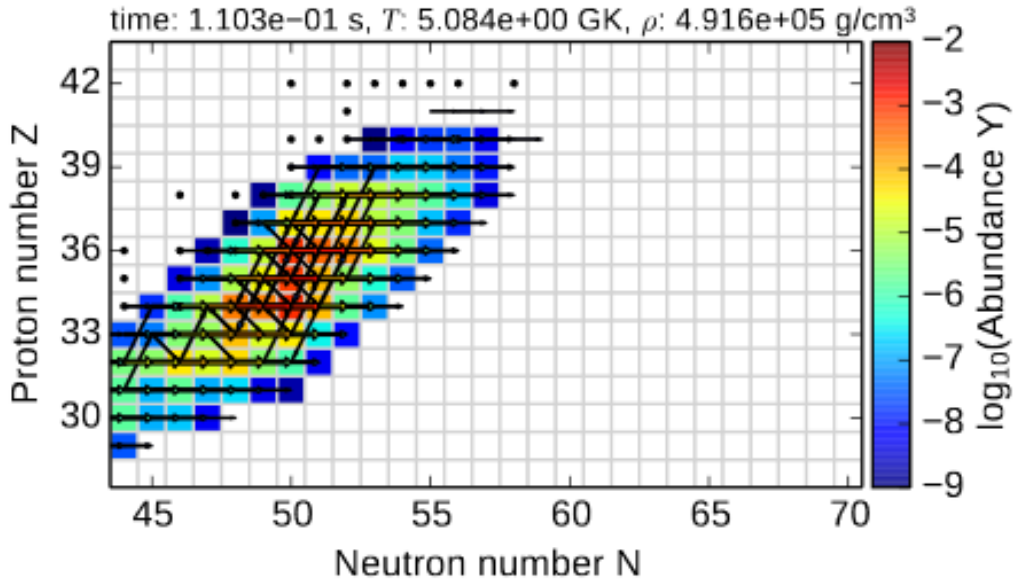


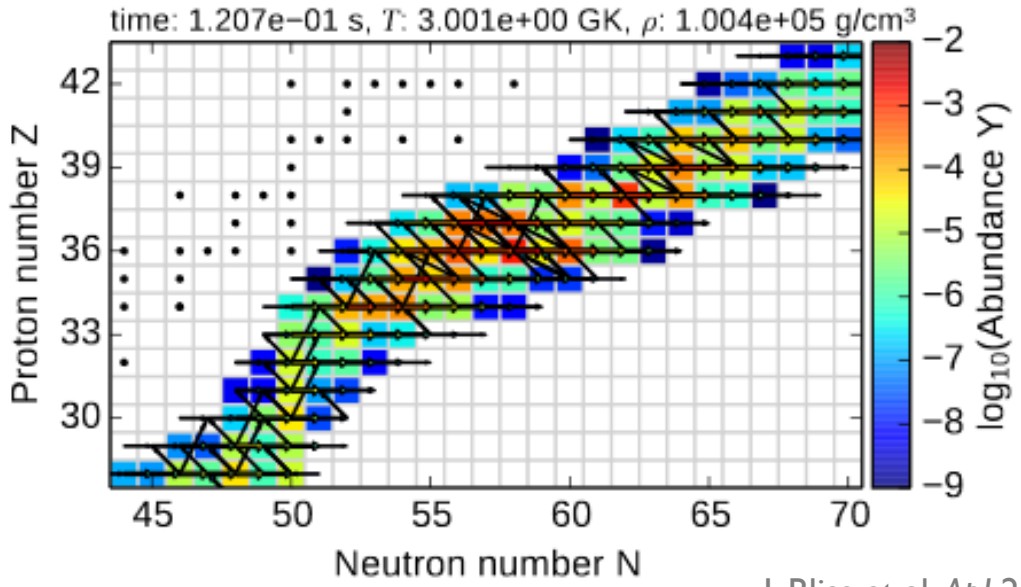
Rauscher et al. *RepProgPhys* 2013

Neutron-rich ν-Driven Wind Nucleosynthesis

For $Y_e < 0.5$, (α,n) reactions drive the flow of nucleosynthesis from seed elements, creating elements from zinc to tin





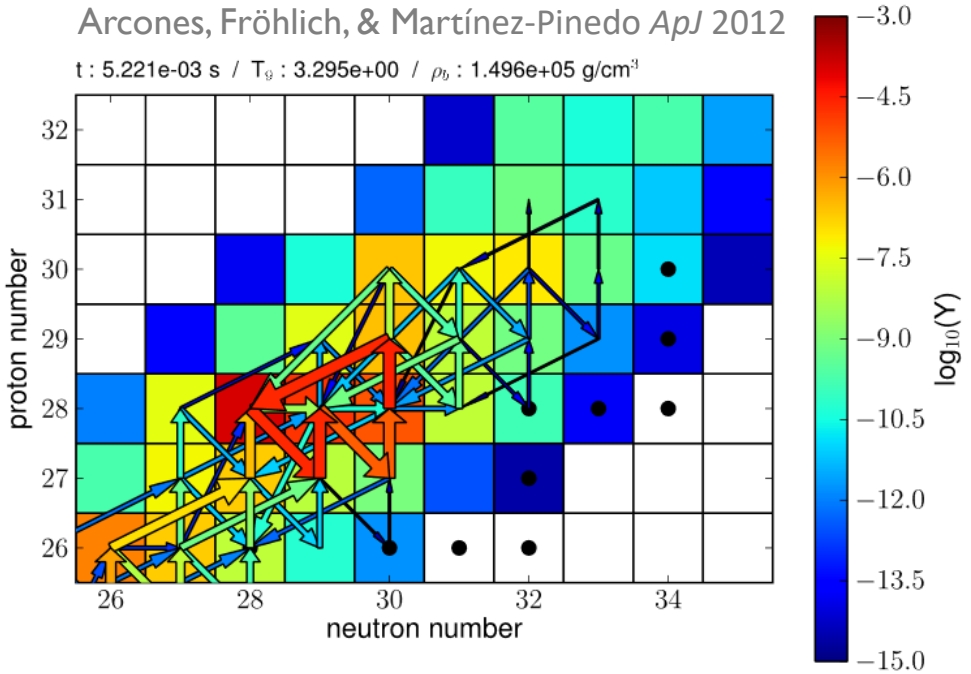


J. Bliss et al. *ApJ* 2018

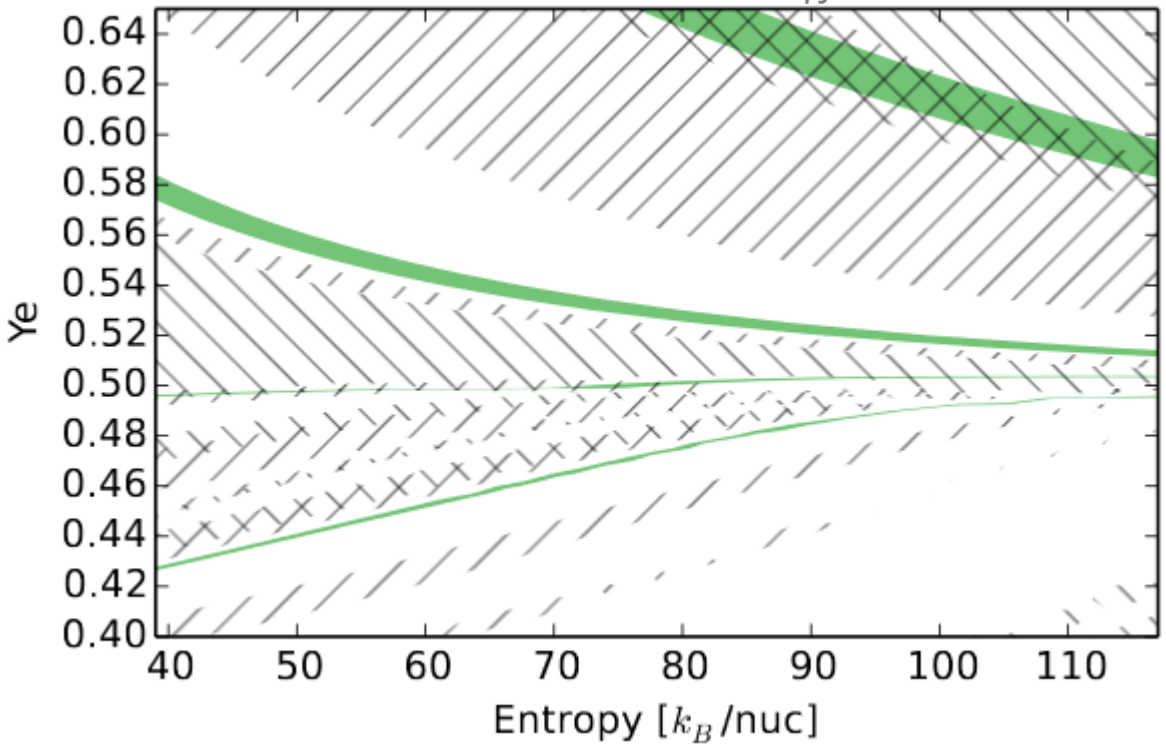
Proton-rich ν-Driven Wind Nucleosynthesis

For $Y_e > 0.5$, (p,γ) and (n,p) reactions drive the flow of nucleosynthesis from seed elements, creating elements from zinc to tin

Arcones, Fröhlich, & Martínez-Pinedo *ApJ* 2012

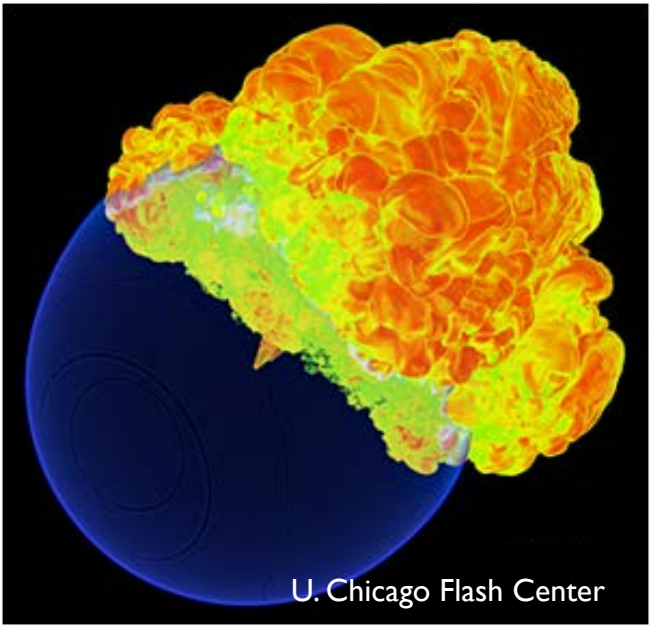


Hansen, Arcones, & Montes *ApJ* 2014

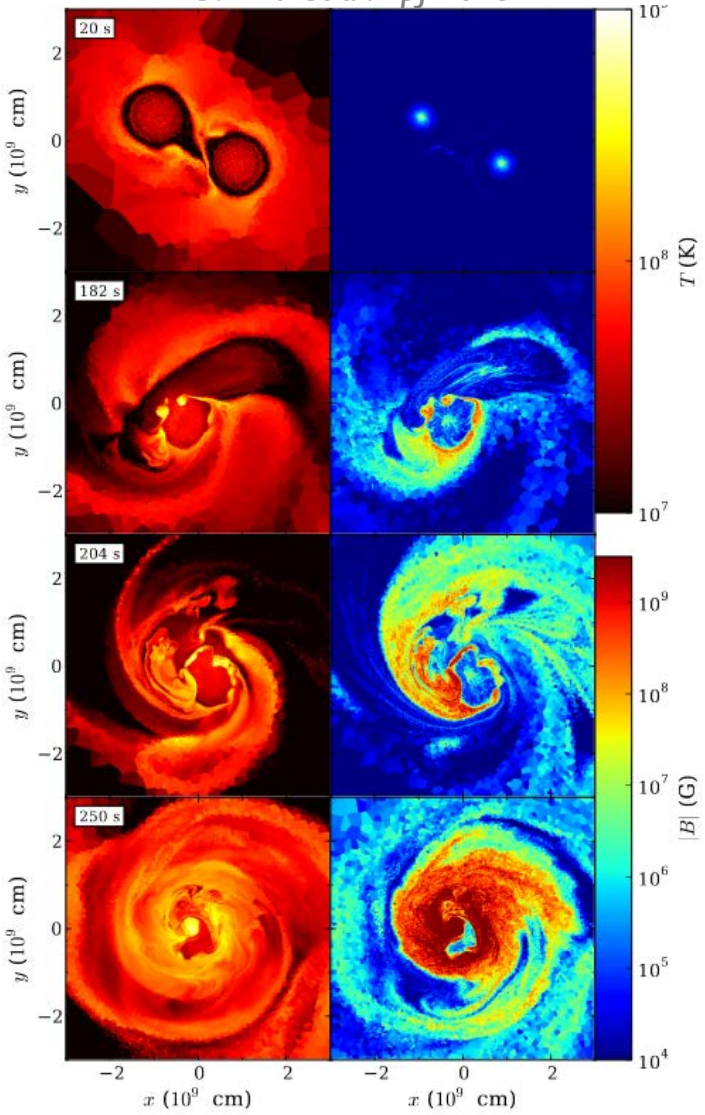


- ν-interactions are poorly constrained, so one or both sets of conditions could be possible
- Nuclear physics uncertainties are currently too large to distinguish between the two processes

Thermonuclear Supernovae (a.k.a. Type-Ia)



C. Zhu et al. *ApJ* 2015



A. Parikh et al. *A&A* 2013