

Eliza McDonald

THE PHYSICS OF CORE COLLAPSE SUPERNOVAE

REVIEW OF CORE COLLAPSE SUPERNOVA

- ✘ One of two main types of supernova
- ✘ Caused as stars collapse in on themselves as fusion stops
- ✘ Leaves behind neutron star, remnant, photons, neutrinos, and heavy elements

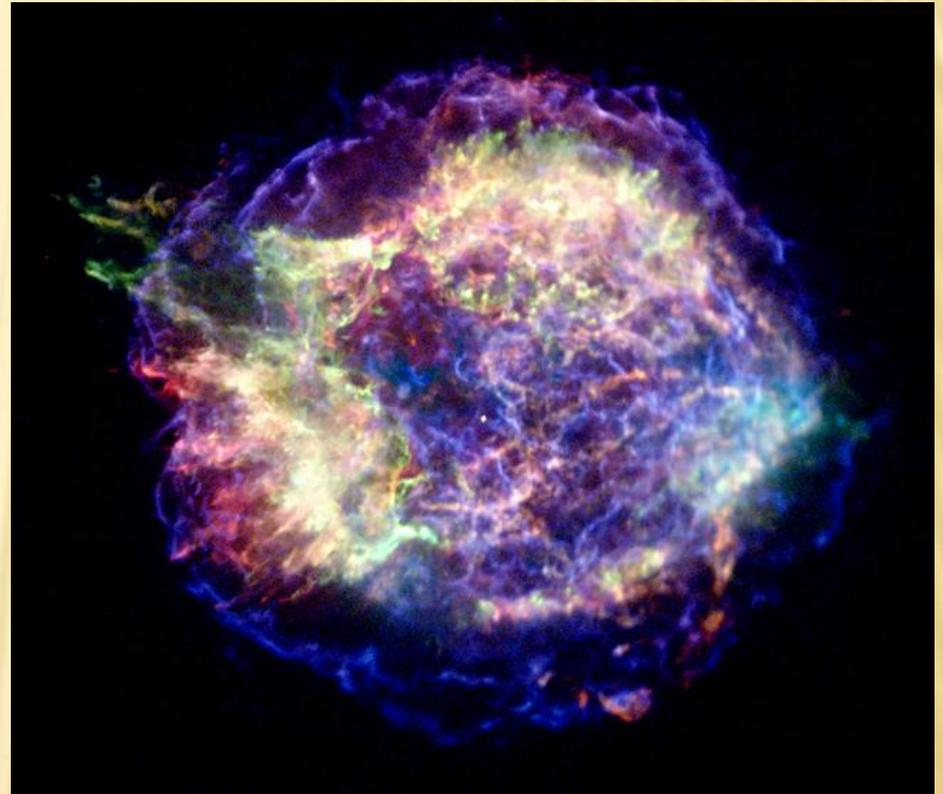


Image Credit: Chandra, NASA

NON-EXPLODING STARS

- ✘ Fuse Hydrogen by $4^1\text{H} \rightarrow ^4\text{He} + 2e^+ + 2\nu_e + 2\gamma$
- ✘ Energy per $4^1\text{H} = 25\text{MeV}$
- ✘ Supports star against gravity
- ✘ Energy Lost to Neutrinos per $4^1\text{H} \sim 0.25\text{ MeV}$
- ✘ Star runs out of Hydrogen, fuses heavier elements

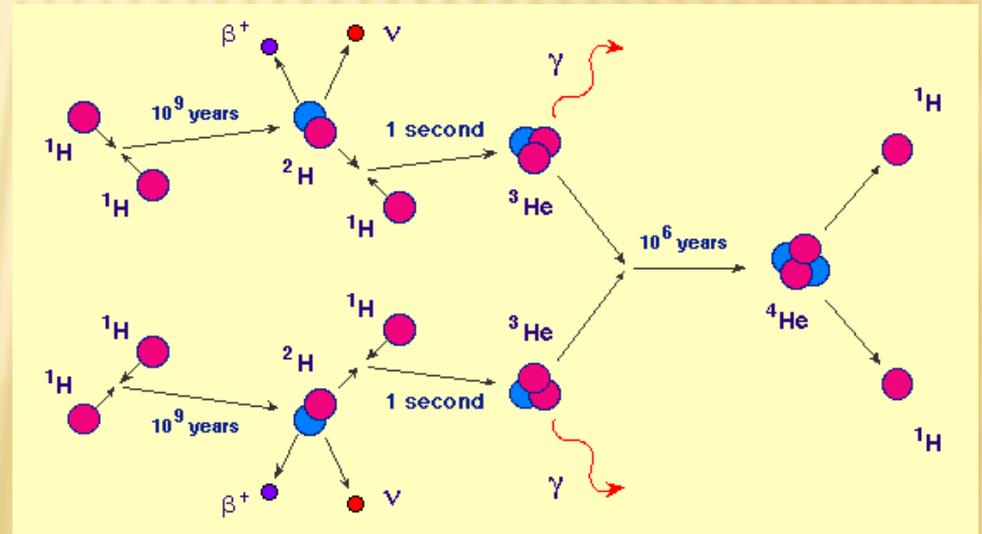


Image Credit: UCSD Center for Astrophysics

NEUTRINO PRODUCTION

✘ Stars over 10^9 K have many e^+ and e^- , which collide and annihilate, sometimes producing neutrinos

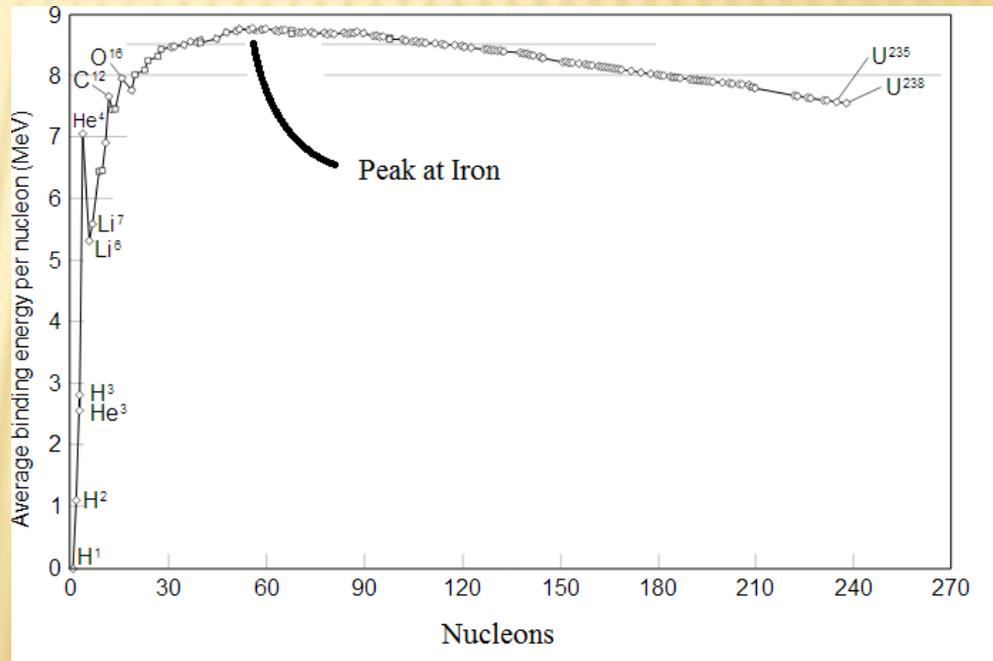
✘ Neutrinos have small interaction cross sections, so they go straight out of stars, without supporting them and only interact weakly

Neutrino production of $15 M_{\odot}$ Star

Stage	Temperature (10^9 K)	Neutrino Losses (solar units)
Hydrogen	0.035	1800
Helium	0.18	1900
Carbon	0.81	3.7×10^5
Neon	1.6	1.4×10^8
Oxygen	1.9	9.1×10^8
Silicon	3.3	1.3×10^{11}
Iron core collapse	> 7.1	$> 3.6 \times 10^{15}$

CORE COLLAPSE

- ✘ Fusion stops after Iron, leaving an inert core
- ✘ After Chandrasekhar mass, it collapses
- ✘ Reverse beta decay: $e + p \rightarrow n + \nu_e$
- ✘ Even more neutrinos
- ✘ Stopped by strong force



HOW DOES THE EXPLOSION HAPPEN?

- The core collapses and then is held up by the strong force. The shockwave isn't enough.
- Expanding bubble of neutrinos pushes away outer layers.
- KABOOM

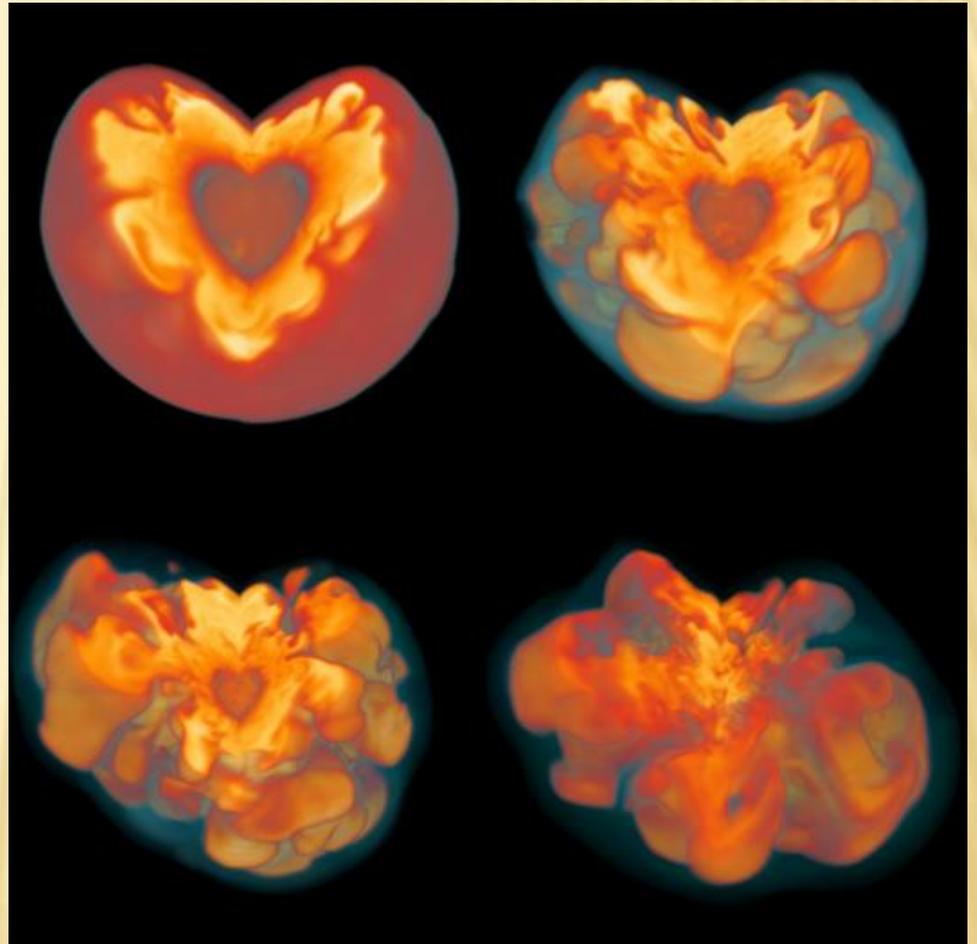


Image Credit: Woosley and Janka 2005

HEAVY ELEMENT SYNTHESIS

- ✘ Neutron wind comes off the core.
- ✘ Lots of neutrons collide with lighter nuclei to make them heavy (rapid capture).

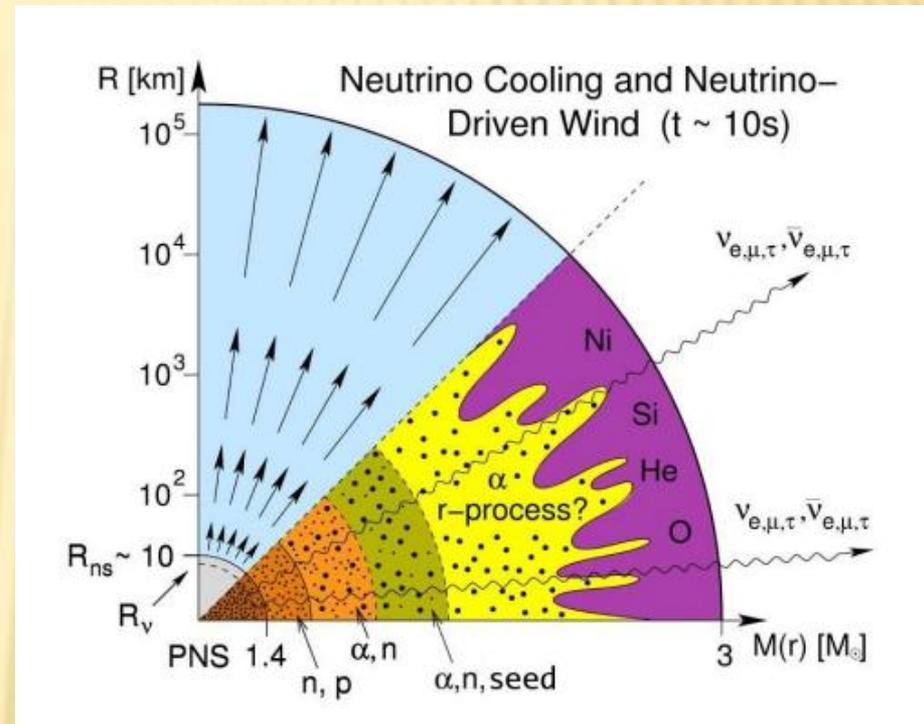


Image Credit: Woosley and Janka 2005

CONCLUSIONS

- ✘ Stars are held up by pressure from nuclear fusion, and fall in when that fusion stops
- ✘ This fall in causes an explosion out
- ✘ Supernovae are different from normal explosions of sound and light and shrapnel, in that the majority of energy (95%) is actually carried by neutrinos, and they leave behind a dense core

REFERENCES

Woosley, Stan and Janka, Thomas, “Physics of Core Collapse Supernovae” *Nature*, 2005

LeBlanc, Francis, *An Introduction to Stellar Astrophysics*, 2010