Supernova Explosions

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Outlining

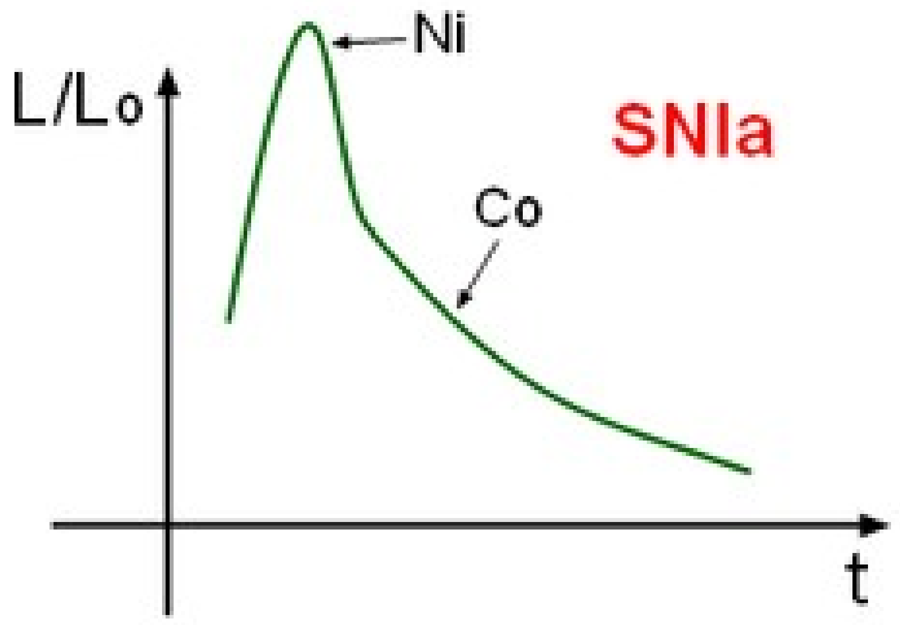
- Types of supernovae
- Their evolution
- Their mechanism

Types of Supernovae

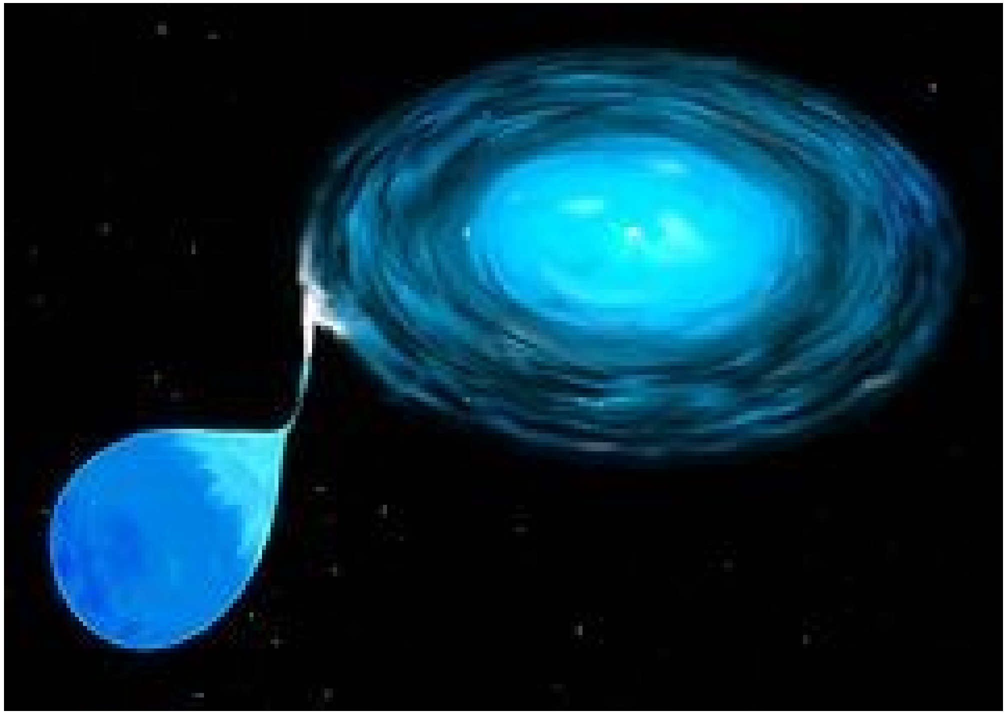
- Two types of supernovae
  - Thermonuclear explosion of accreting white dwarfs
  - Core collapse supernovae
- Classification
  - Type Ia
    - No hydrogen lines in it's spectrum
  - Type II (II, Ib and Ic)
    - Hydrogen lines present in the spectrum

Type Ia

- Start
  - C-O White dwarf in a binary system accreting matter
- End
  - The star explodes completely
- Light curve



Type Ia



- Approaching Chandrasekhar limit
- Increase in pressure and density lead to temperature increase
- Convective carbon burning period follows
- Terminated by small spacial region(s) undergoing thermonuclear runaway
- Thermonuclear flame and onset of explosion

Type Ia – Flame propagation and explosion

- Subsonic deflagration
  - The flame mediated by convection of the degenerate electron gas
- Supersonic detonation
  - The flame driven by shock wave
  - All matter burned at high densities into iron-group elements
  - In conflict with observations
  - intermediate mass elements produced when burning at low densities

Type Ia – Flame propagation and explosion

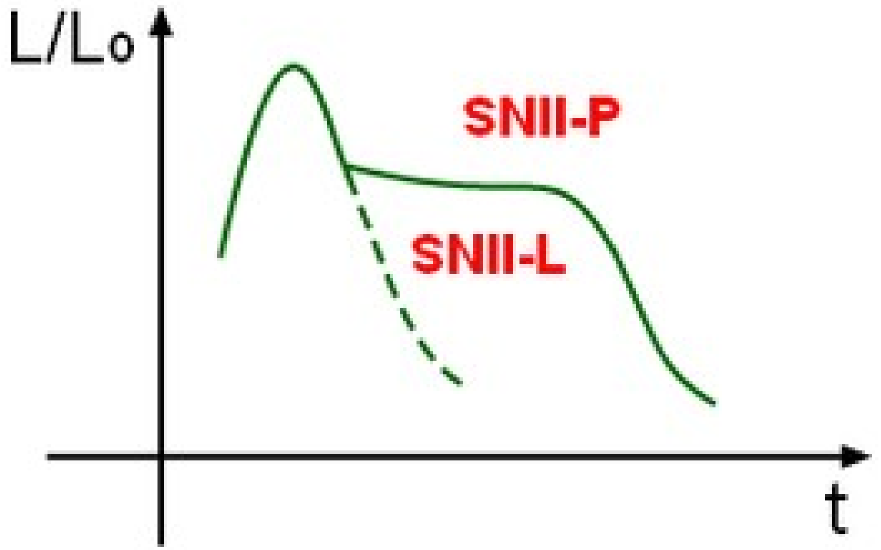
- Flame acceleration
  - Buoyancy unstable
    - Leaves light and hot ashes behind below the dense fuel
  - Rayleigh-Taylor instability
    - Mushroom-shaped burning bubbles
  - Kelvin-Helmholtz instability
    - Turbulent eddies – increase of the effective area of flamelets – rate of fuel consumption

Type Ia – Flame propagation and explosion

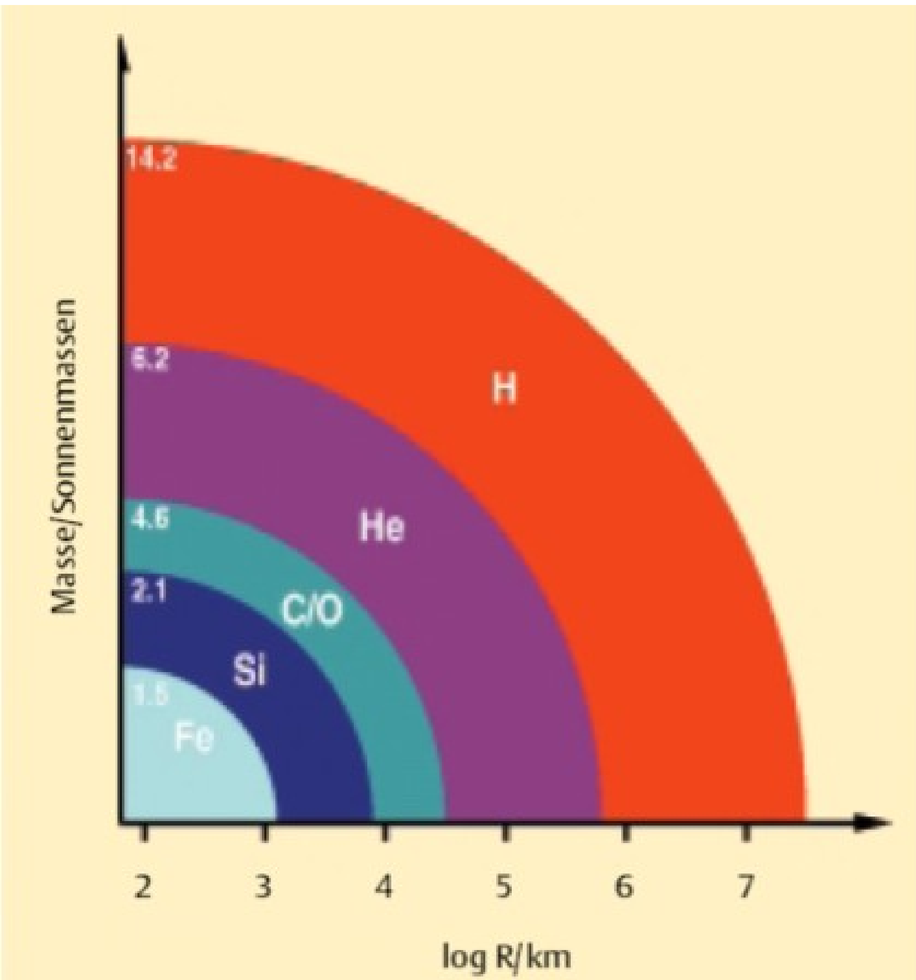
- Flame acceleration
  - Transition from subsonic deflagration to supersonic detonation
  - Mechanism for that kind of transition not found yet

Type II

- Start
  - The mass of the progenitor star > 8 solar masses
- End
  - Neutron star
  - Black hole
- Light curve

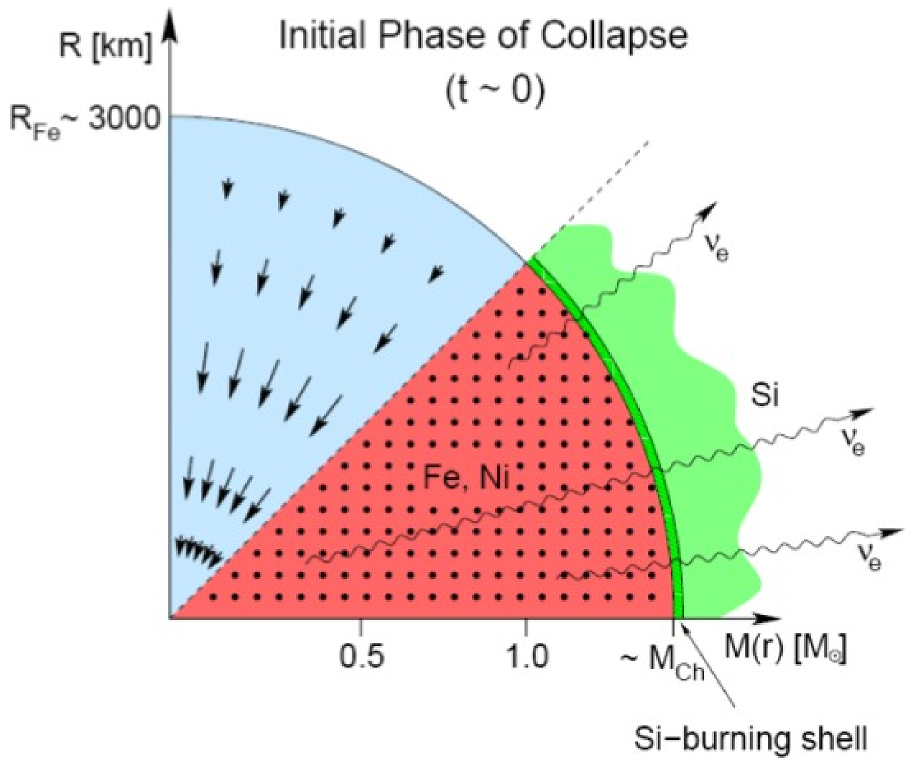


Type II – before the collapse



- Onion shell structure
- Iron-group elements in the inner-core
- Nuclear fusion no longer possible in the core
- Electron degeneracy pressure stabilizes the star

Type II – beginning of the collapse



- The core reaches Chandrasekhar limit
- Photodisintegration:

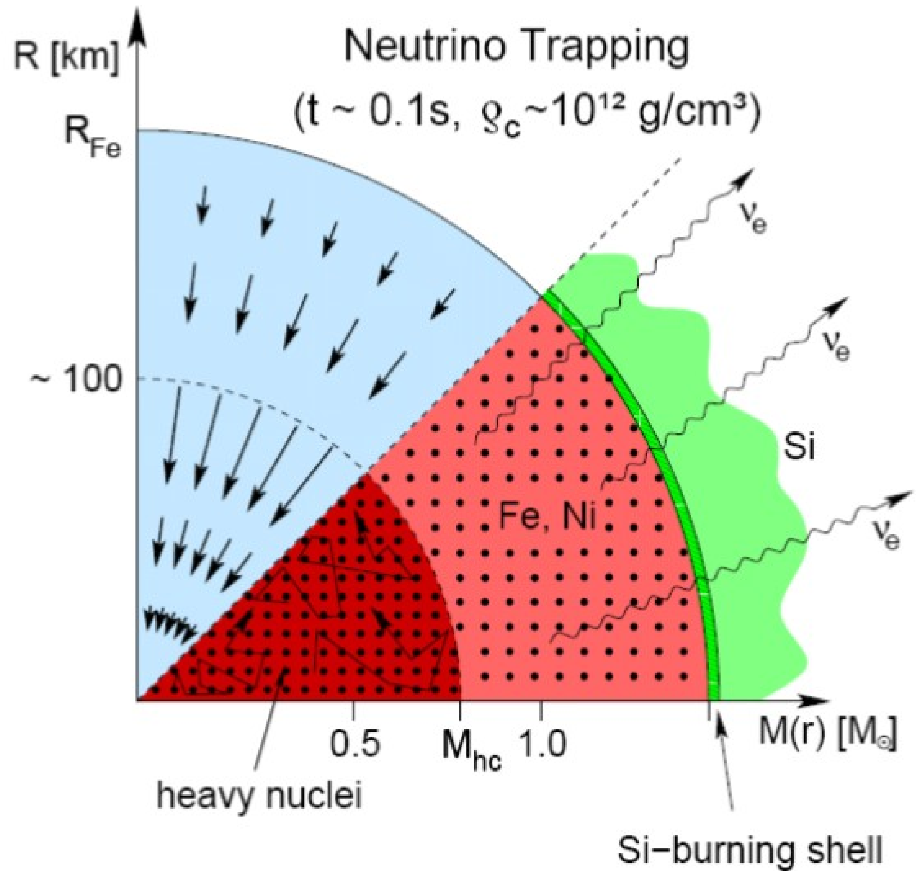
$$^{56}Fe \longrightarrow 13\alpha + 4n$$

- Electron capture:

$$e^- + p \longrightarrow n + \nu_e$$

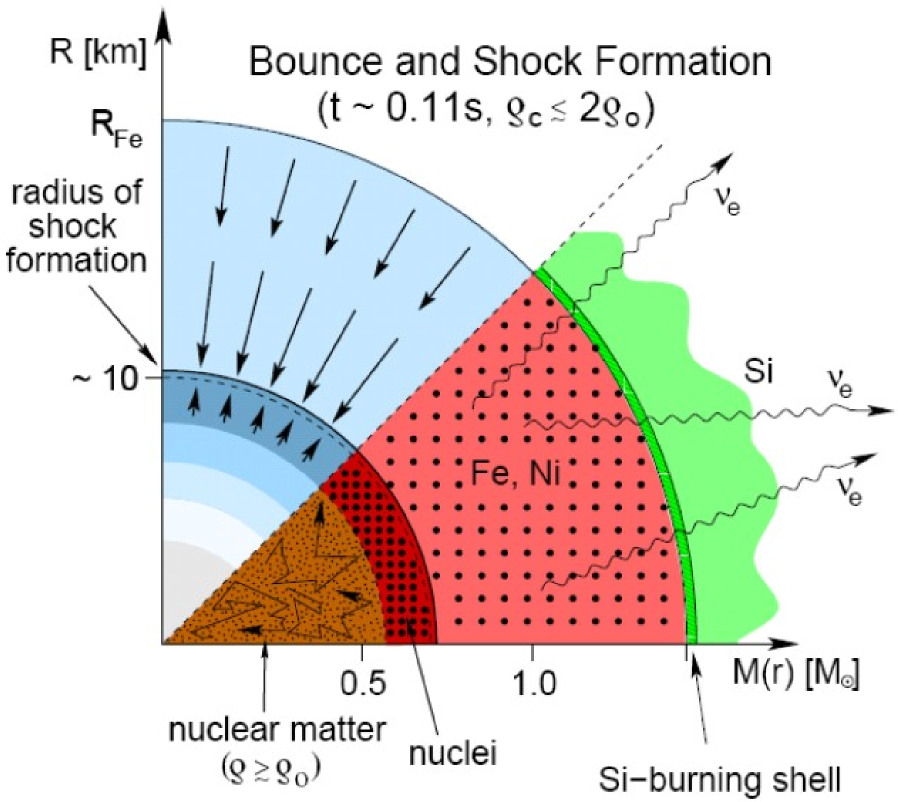
- Neutrino cooling

Type II – Core Collapse Mechanism



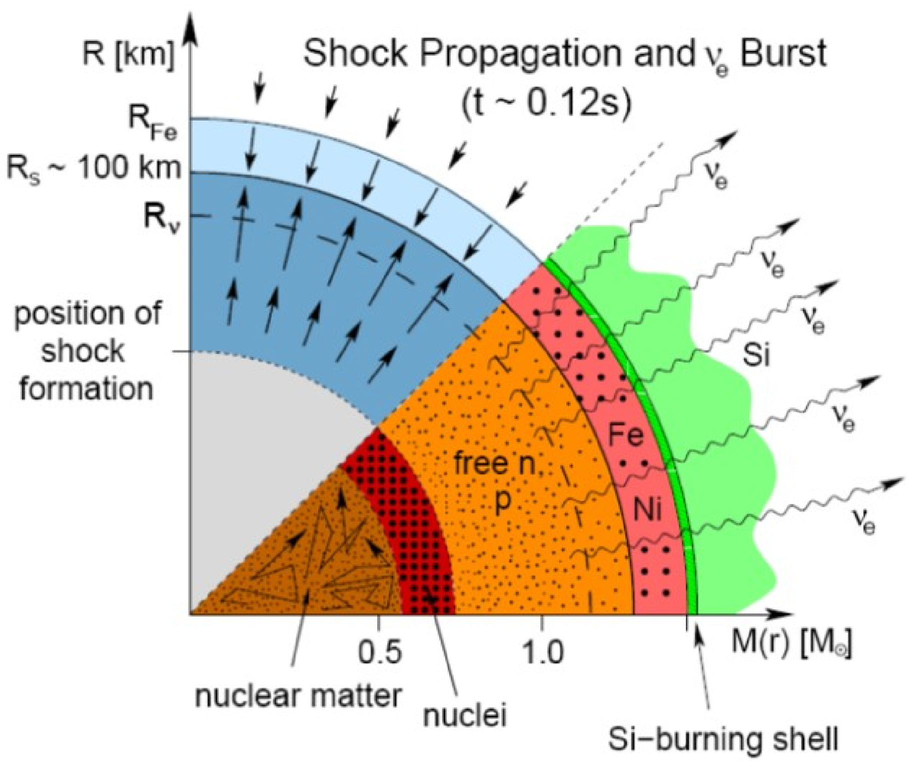
- Core starts to collapse
- Neutrino trapping
  - diffusion time larger than collapse time

Type II – Core Collapse Mechanism



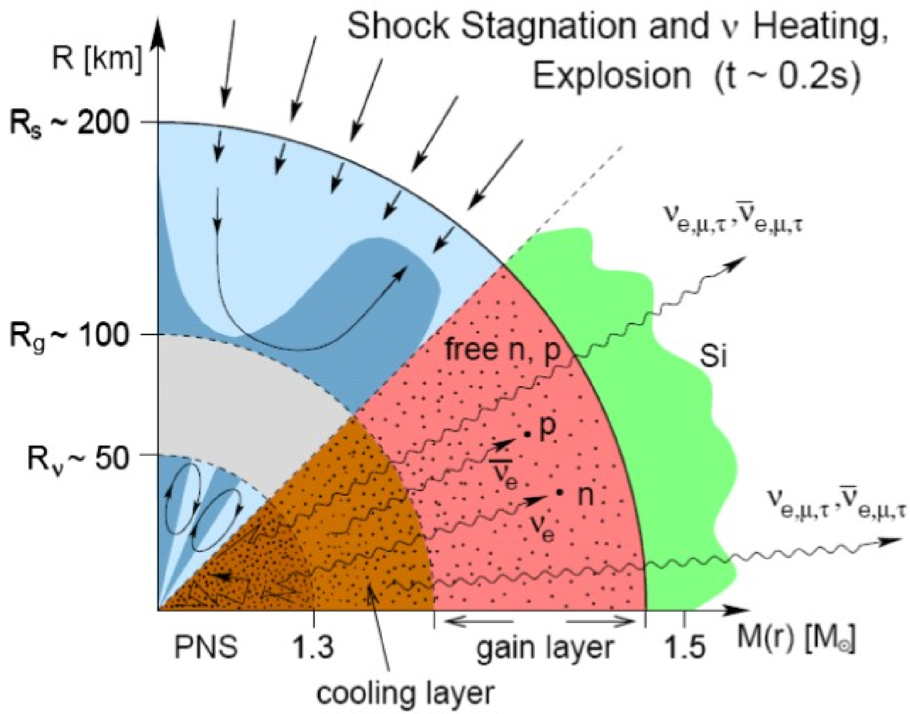
- Matter cannot be compressed any further
- The collapse halts
- Bounce and shock formation

Type II – Core Collapse Mechanism



- The shock decomposes iron – energy loss
- Neutrino heating in the postshock medium
- The shock stalls before reaching the outer layers
- No explosion due to the prompt shock

Type II – Core Collapse Mechanism



- Competition between neutrino heating and cooling
- Neutrino heating causes convective overturn and increases the pressure behind the shock
- The shock gets revived by the delayed neutrino heating mechanism

Type II – progenitor mass larger than 10 solar masses

- Neutrino heating not powerful enough
  - Convective overturn will not become sufficiently strong to push the shock further
- SASI – standing accretion shock instability
  - Can grow efficiently driving the shock front to larger radii – reduce the accretion velocities
  - Causes secondary convection
  - The mechanism is not completely clear at the moment.

Conclusion

- Two types of Supernovae
- Type Ia
  - Subsonic deflagration
  - Flame accelerated – instabilities
- Type II
  - Prompt shock cannot trigger the explosion
  - Delayed neutrino heating
  - SASI