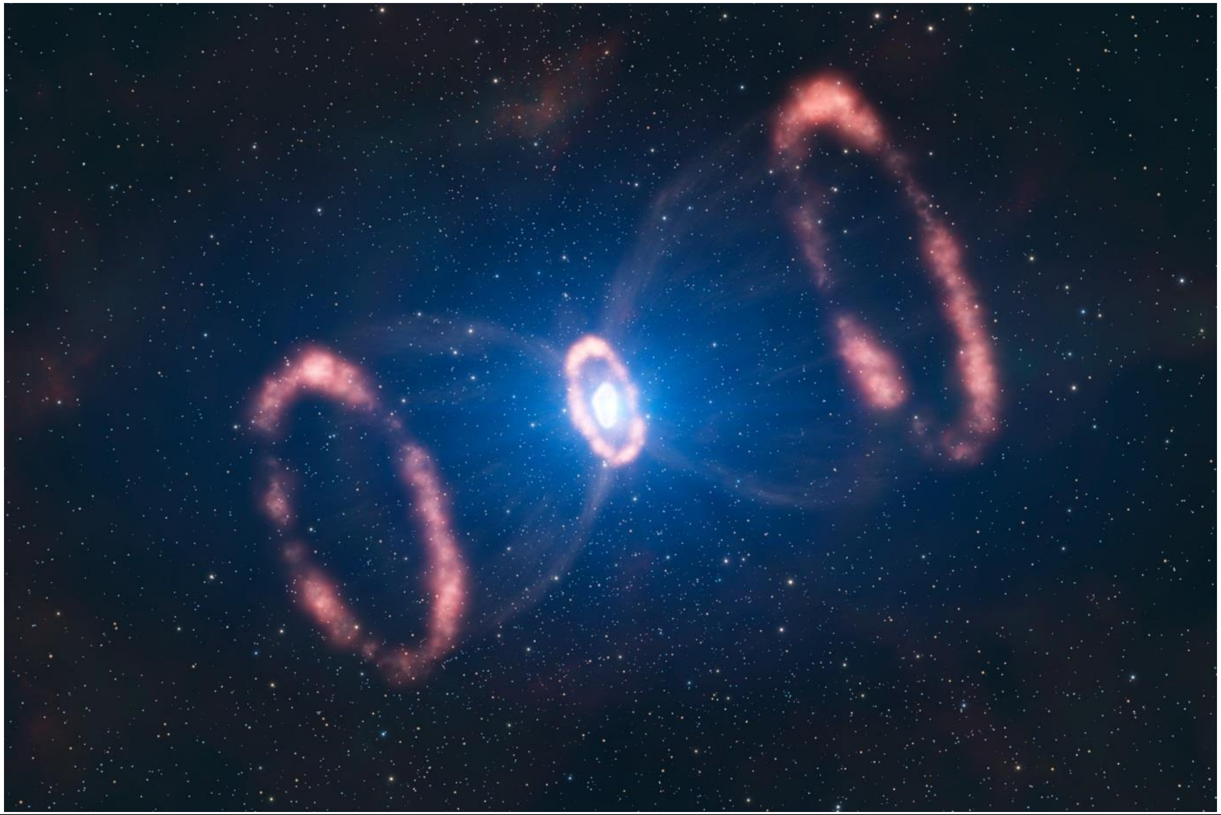
Supernovae

by Lars Köhler



From: scienceblogs.com

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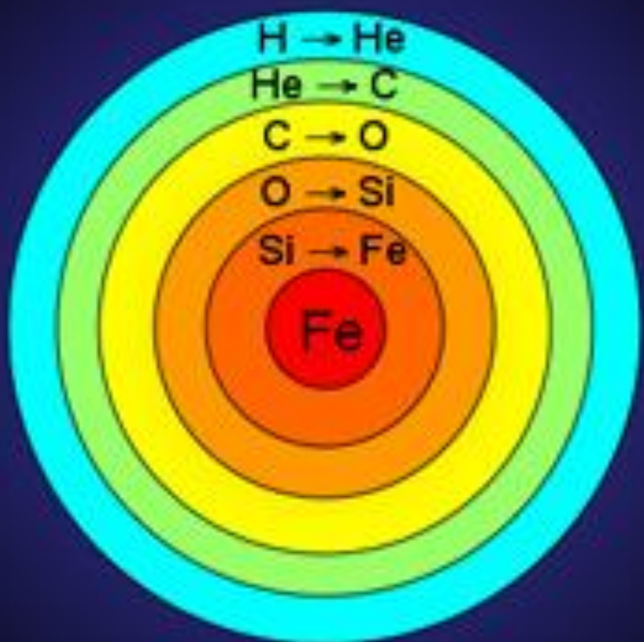
Supernova-types

Type	No H-Balmer-lines		With H-Balmer-lines
thermonuclear	Including Si-lines: **SN Ia**		
Gravitational collapse	No Si-lines: He-lines: **SN Ib**	 no He-lines: **SN Ic**	**SN II**

Core-collapse supernova

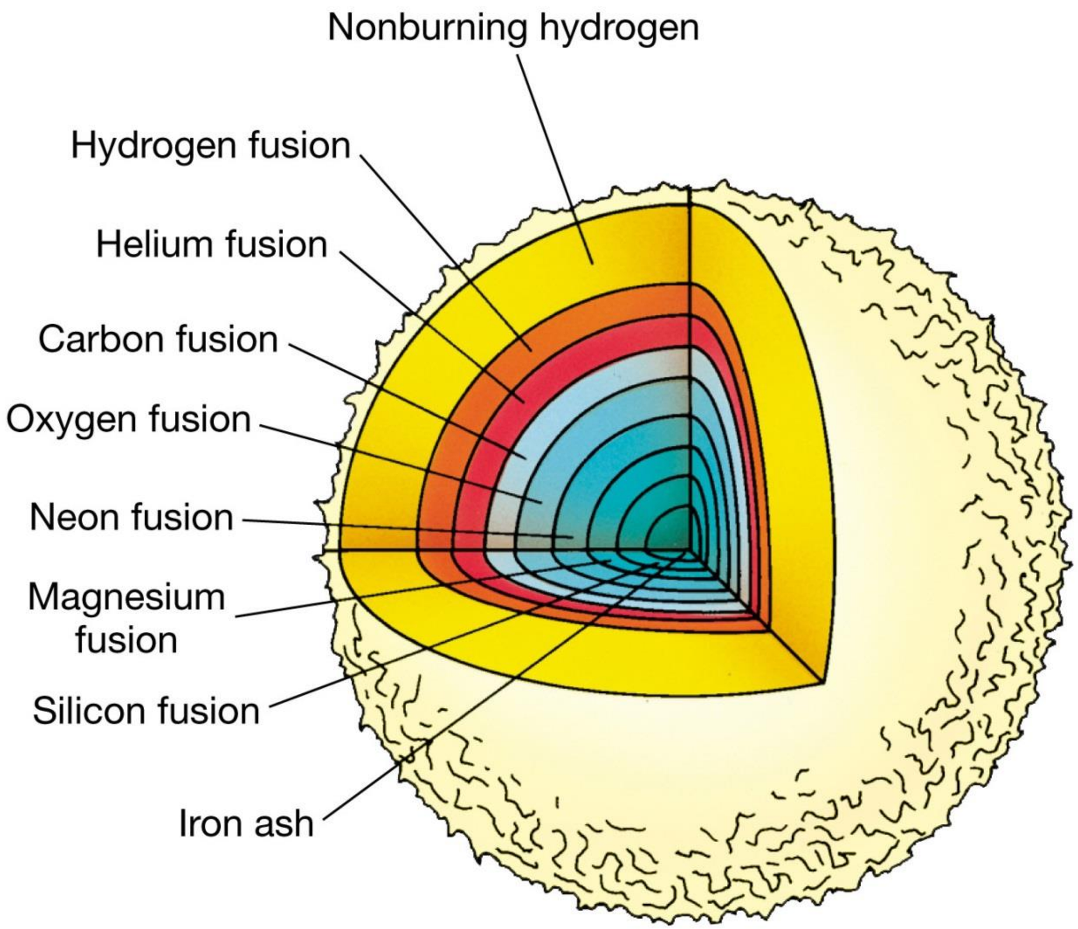


For a 25 solar mass star:

Stage	Duration
H → He	7×10^6 years
He → C	7×10^5 years
C → O	600 years
O → Si	6 months
Si → Fe	1 day
Core Collapse	1/4 second

From: astronomy.swin.edu.au

Stabilizing effects of a star



Initial stabilizer:
Nuclear fusion processes

Graphic taken from: www2.astro.psu.edu

Stabilizing effects of a star

After fuel runs out (end of stars lifetime):

degenerate electron-gas grands pressure to the limit: $P_e/\rho \cong \frac{1}{4} Y_e \mu_e$

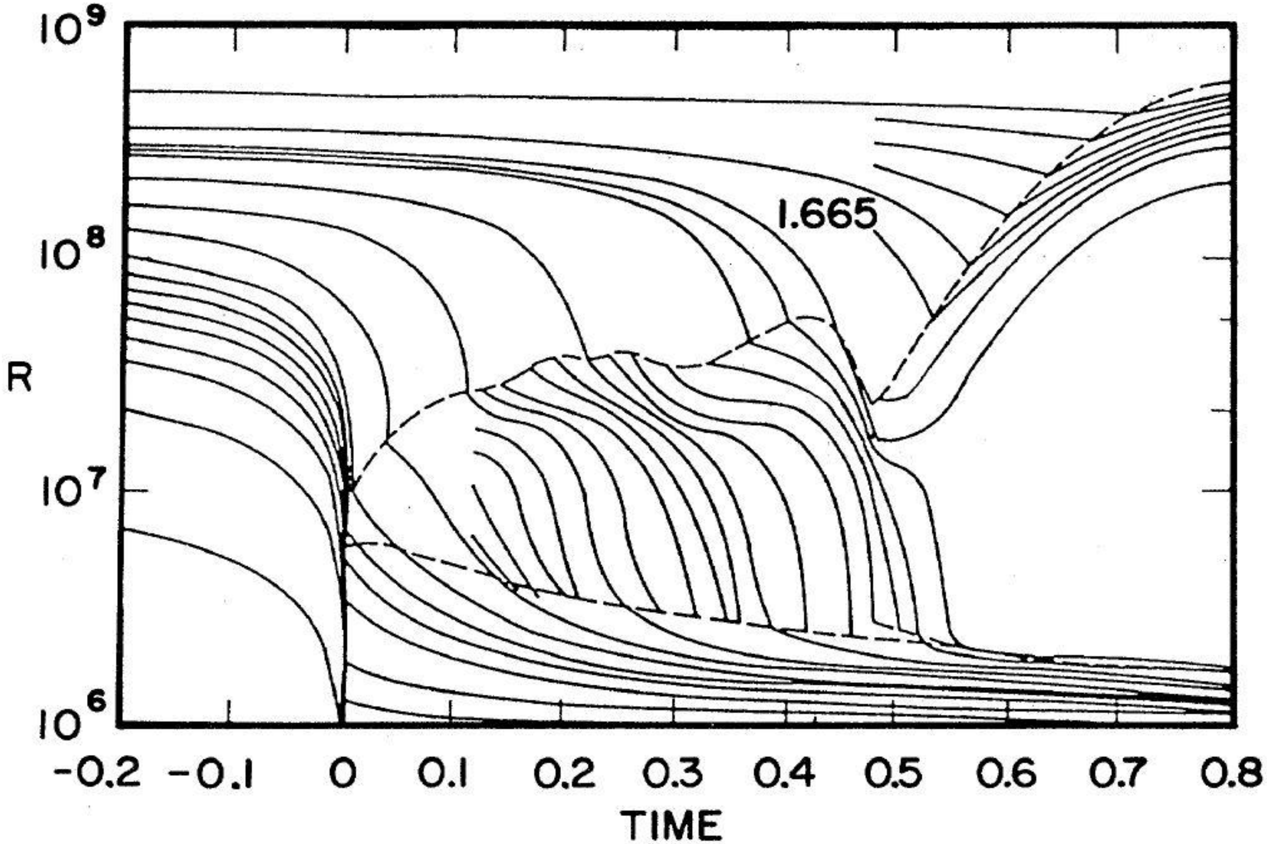
Chandrasekhar-mass: $M_{ch} \cong 5.8\, Y_e^2\, M_\odot$

Core-mass outpaces Chandrasekhar-limit by:

- further burning processes increase core-mass
- electron capture lowers Y_e

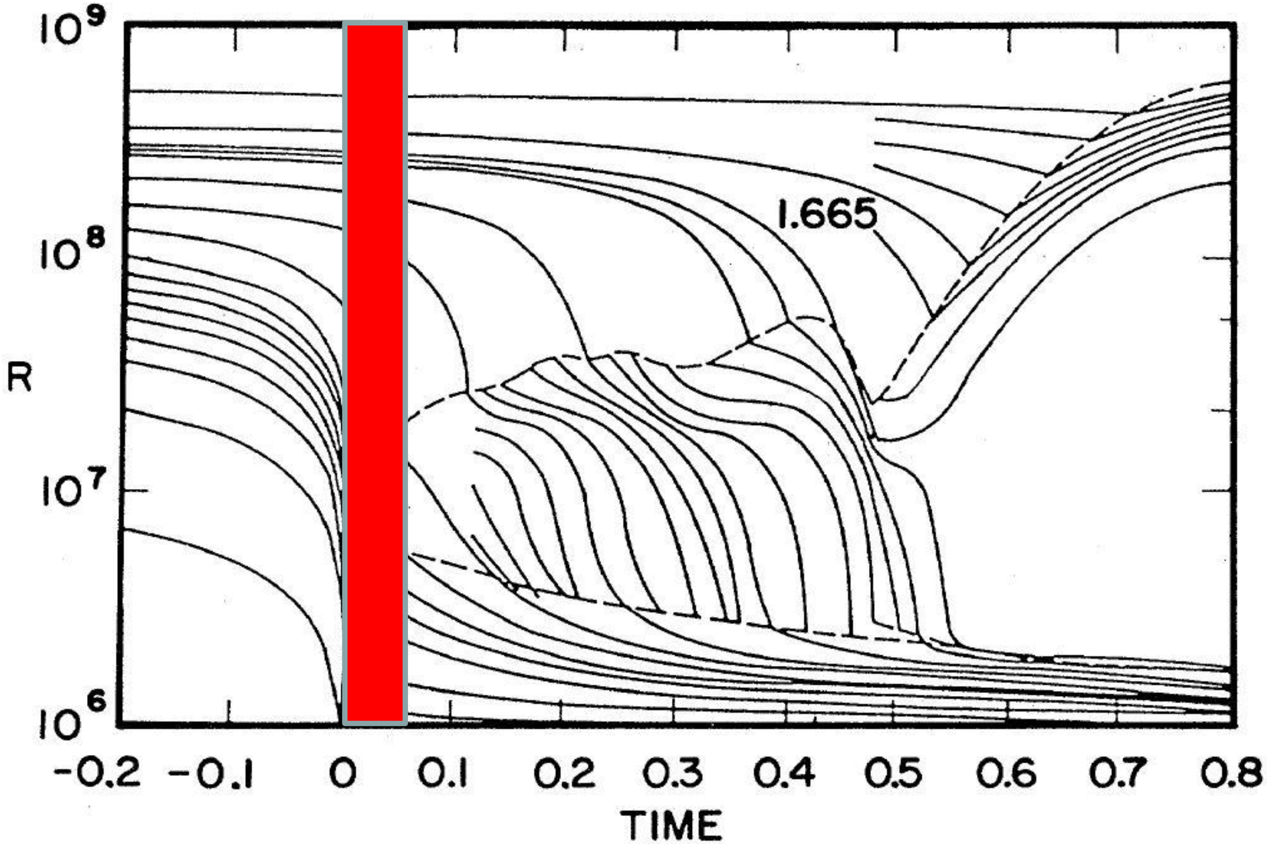
$$e^- + p \rightarrow n + \nu_e$$

The collapse



From: Bethe,1990

The collapse – mass accretion



Matter is falling into center

Density rises:
in core-region $\sim 6 \times 10^{14}\, {}^{\mathrm{g}}/_{\mathrm{cm}^3}$

From: Bethe,1990

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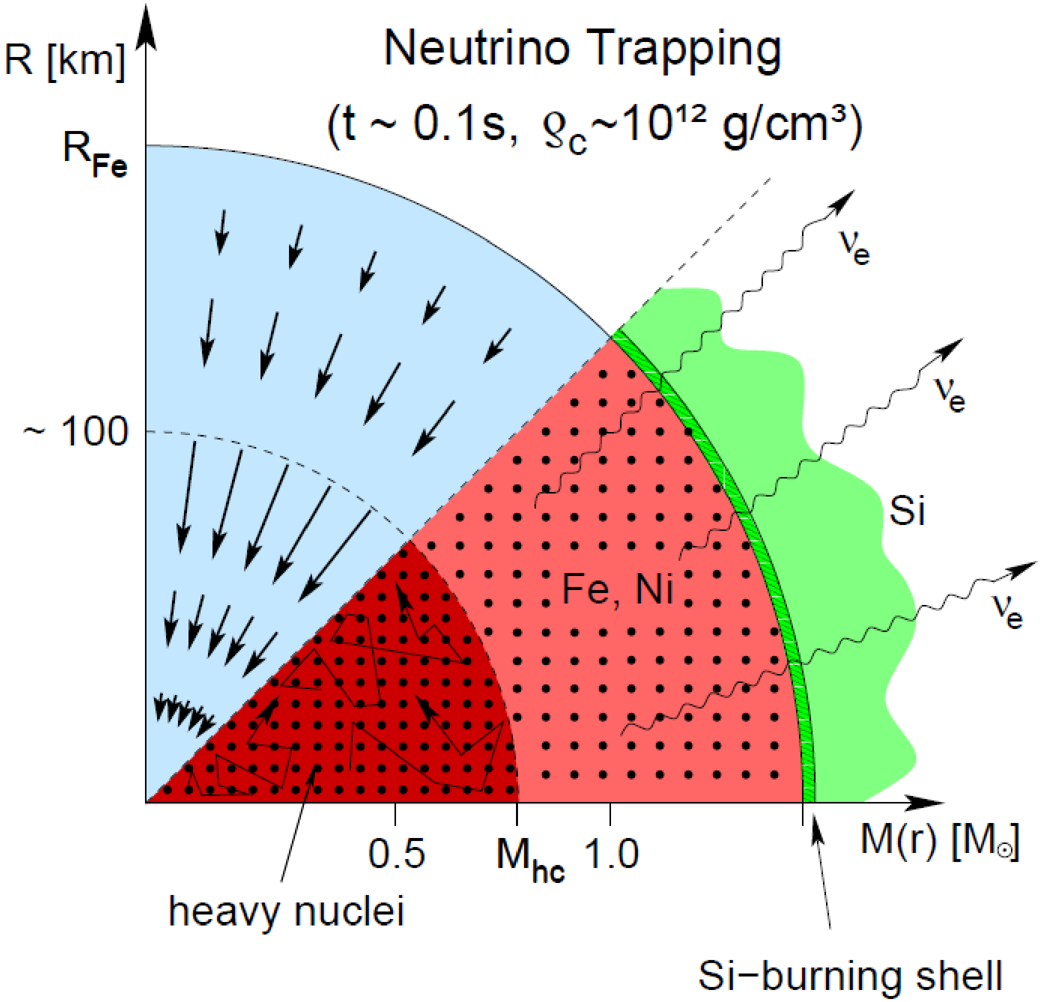
Neutrino trapping



At densities $\sim 10^{12}\ {}^{g}/_{cm^3}$ neutrinos getting trapped due to scattering:

$$\nu_e + N \leftrightarrow \nu_e + N$$

Mean free pass:

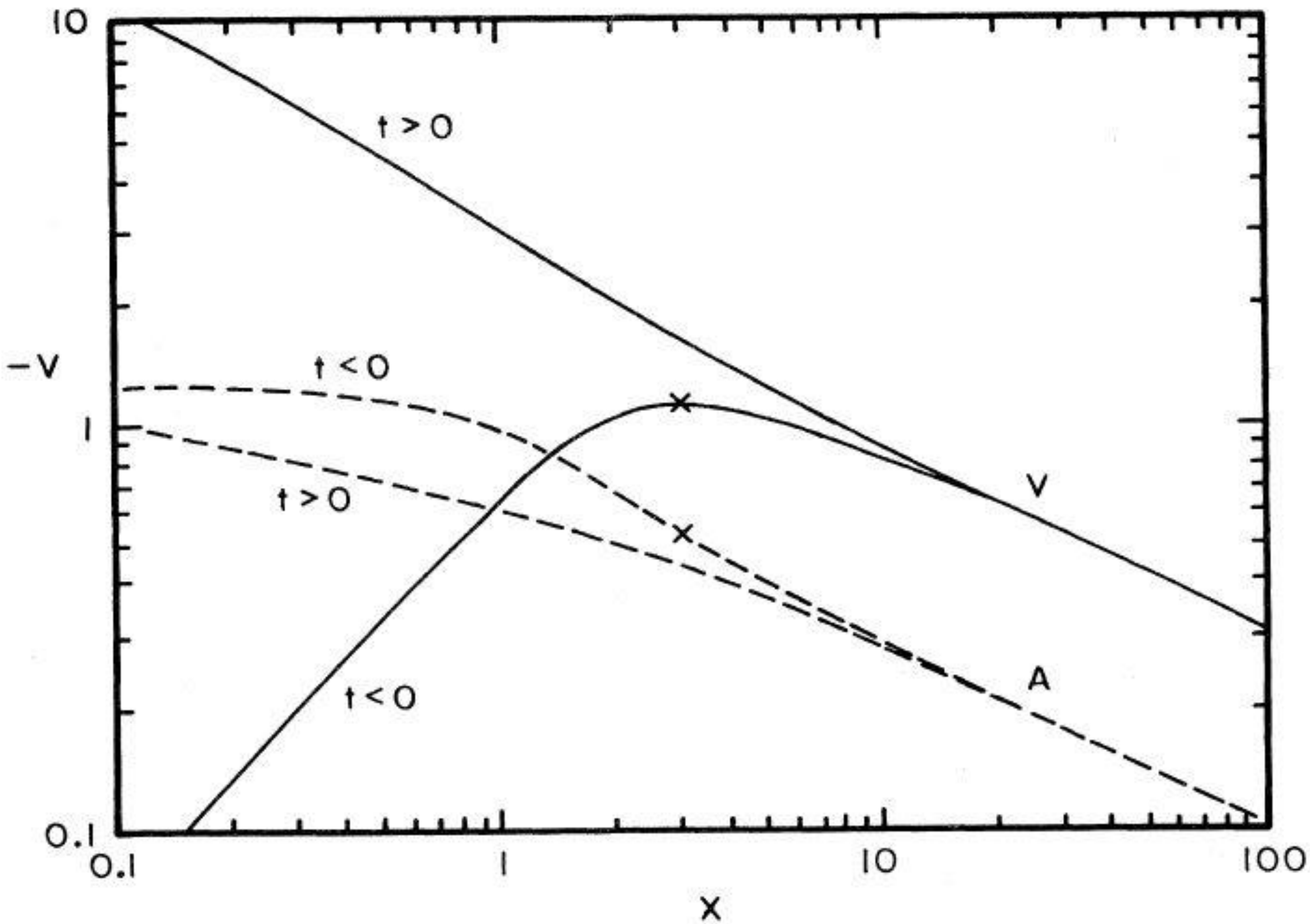
$$\lambda_\nu = 10^8 \rho_{12}^{-1} \left[\left(\frac{N^2}{6A} \right) X_H + X_N \right]^{-1} E_\nu^{-2} \mathrm{cm}$$

Stabilizes Y_e (to about 0.25-0.27):

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

From: Janka

Homologous core



Homologous core

(inside −v = A)

$(\sim 0.7 M_{\odot})$:

$$-\mathrm{v} \propto \mathrm{r}$$

Outside the core:

$$-\mathrm{v} \propto \mathrm{r}^{-1/2}$$

Consider: t<0

From: Bethe, 1990

Bounce

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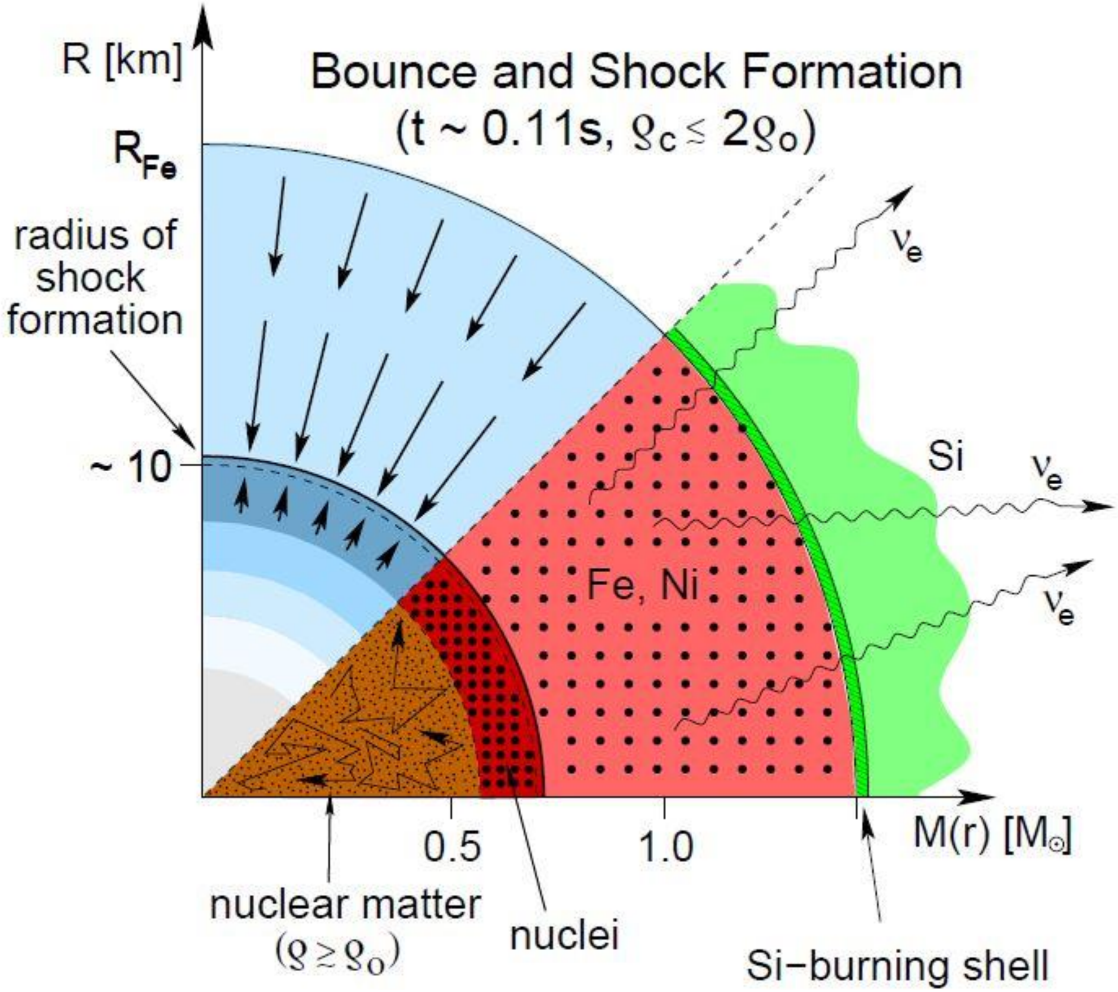


Core density rises up to:

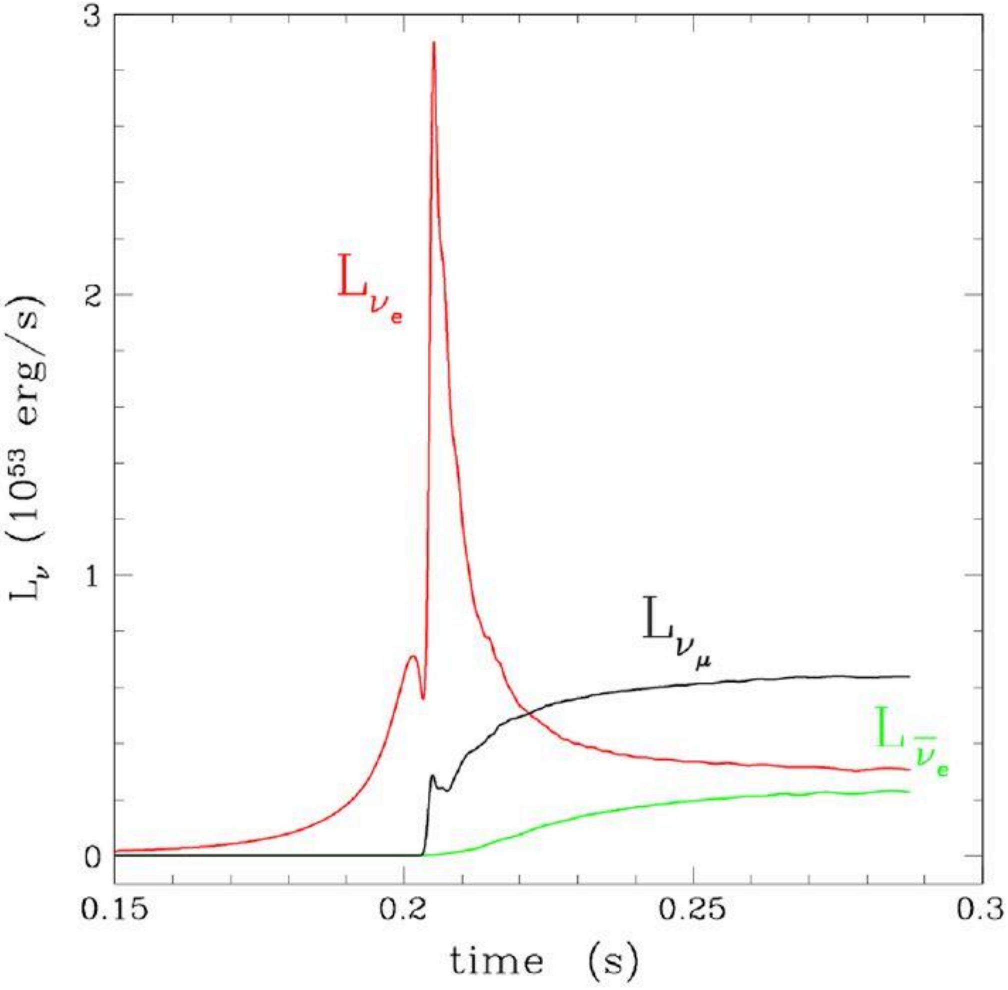
$$\sim 6 \times 10^{14}\, {}^{g}/_{cm^3}$$

⇢Strong nucleon repulsion

⇢ Shockwave starts at homologous core

From: inspirehep.net; Janka

Neutrino burst



First signature of shockwave:

Shock dissociates nuclei into free

p + n

Matter becomes transparent for ν

⇢Burst of the former trapped ν_e

From: Bethe, 1990

shock

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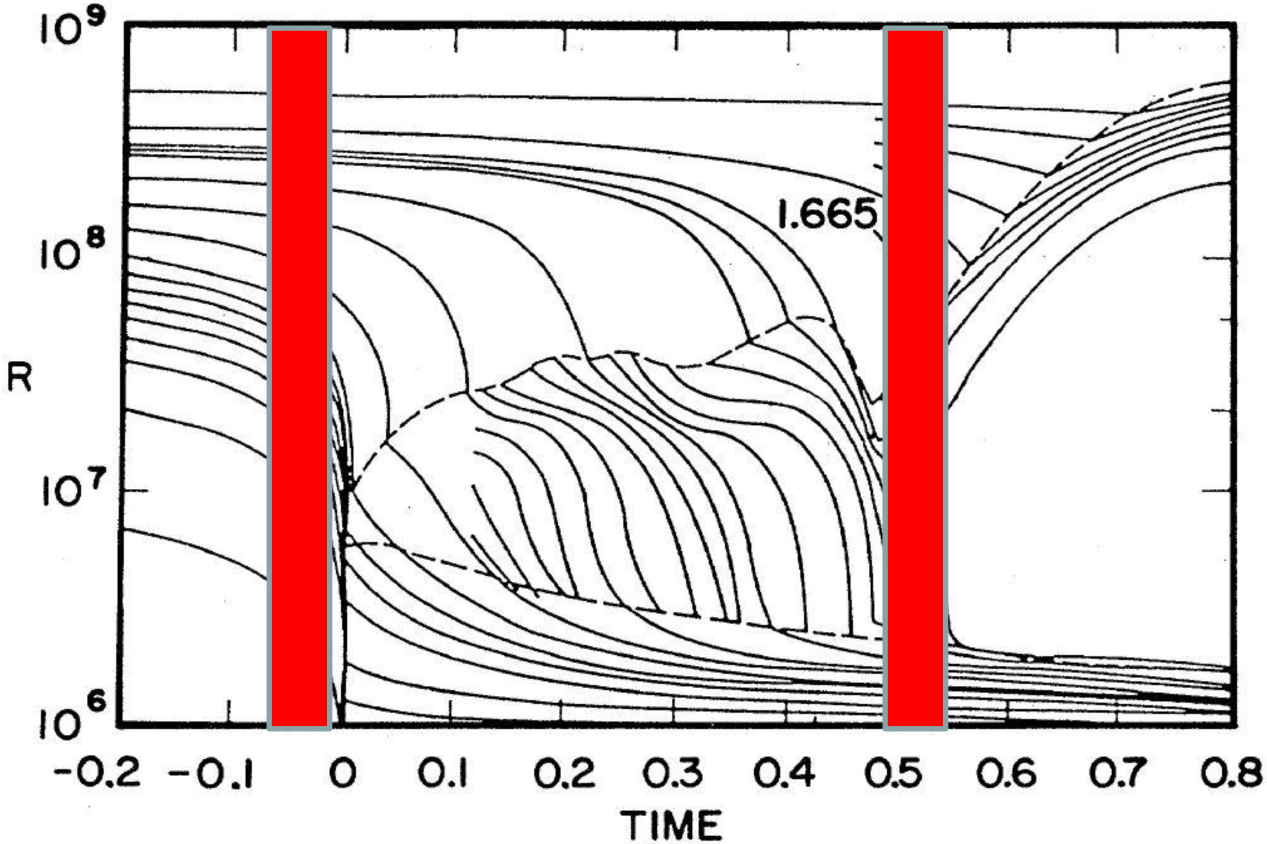

Shockwave is running from outside the homologues core

energy-loss by:
-dissociating nuclei into nucleons (p + n)
-neutrino-emission
($\sim 1.7 \times 10^{51}\mathrm{ergs}/0.1\mathrm{M}_\odot$
$\sim 8\mathrm{MeV/nucleon}$)

⇢ Shock stalls at ~150 km

From: Bethe,1990

Neutrino-sphere

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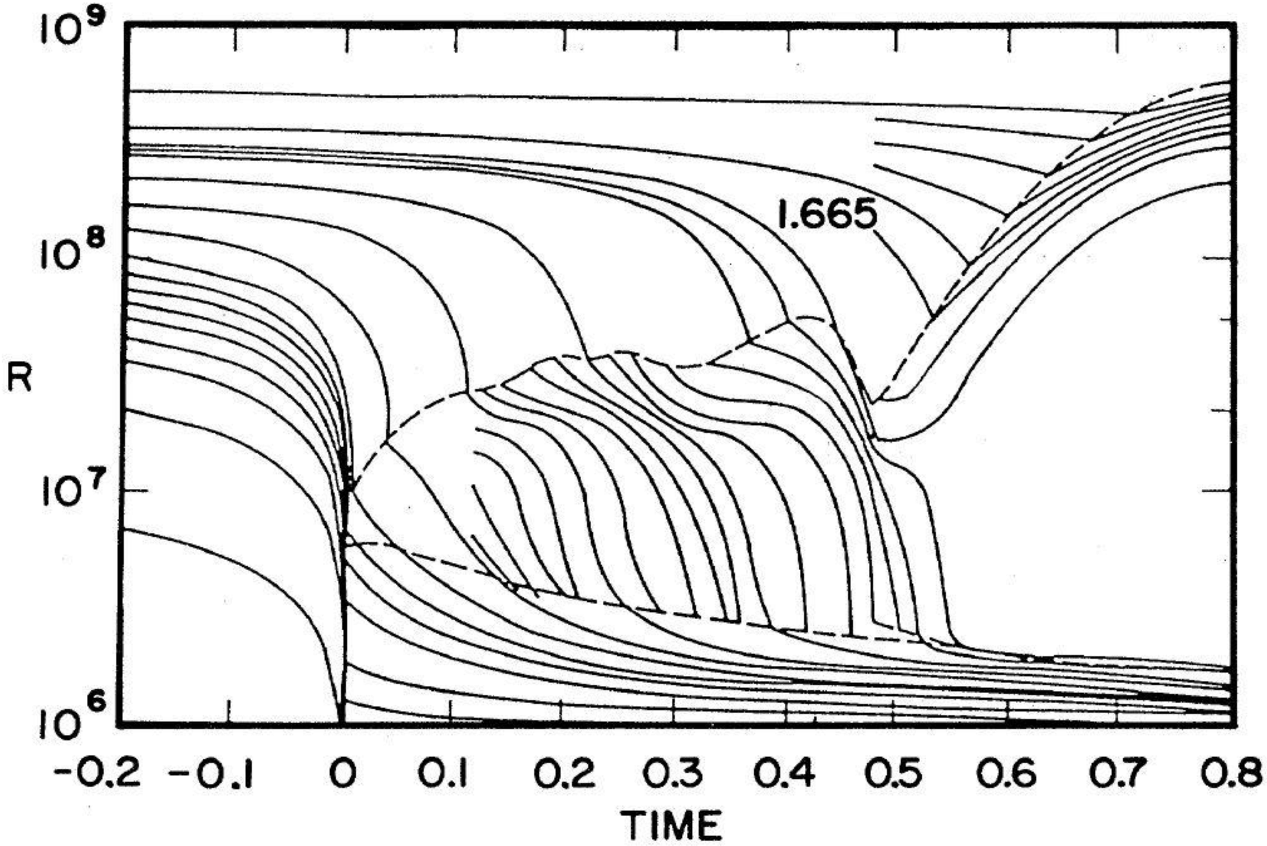


Defined via optical depth:

$$\tau = \int_{R_\nu}^{\infty} dr/\lambda_\nu = 2/3$$

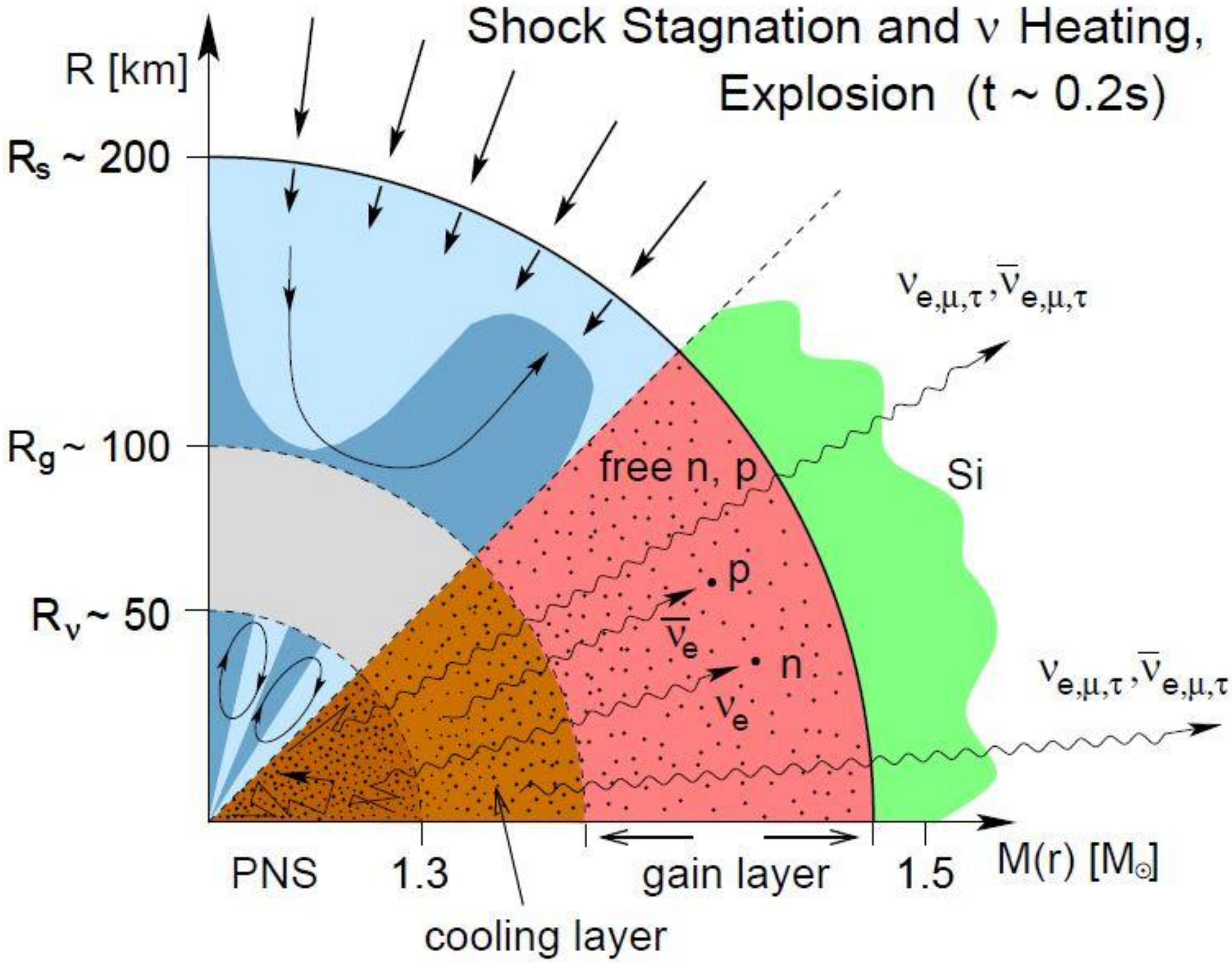
$$1/\lambda_\nu \propto \rho \times {E_\nu}^2$$

Moves from ~60km

to ~22km

From: Bethe, 1990

Neutrino-sphere



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Moves from ~60km

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PNS emits all ν-types

From: inspirehep.net; Janka

shock-revival

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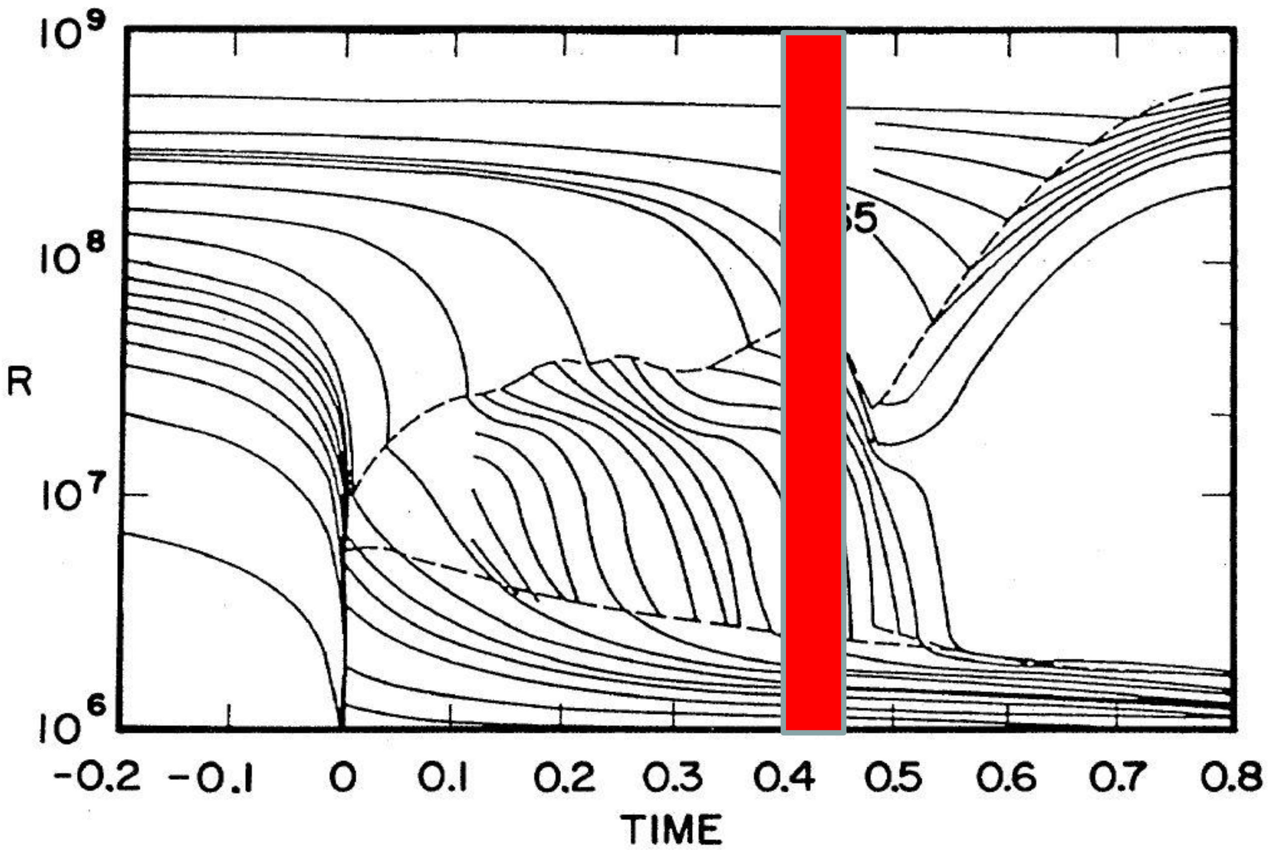


Neutrino driven winds revive the shock-wave:

ν -cooling at cooling-layer:

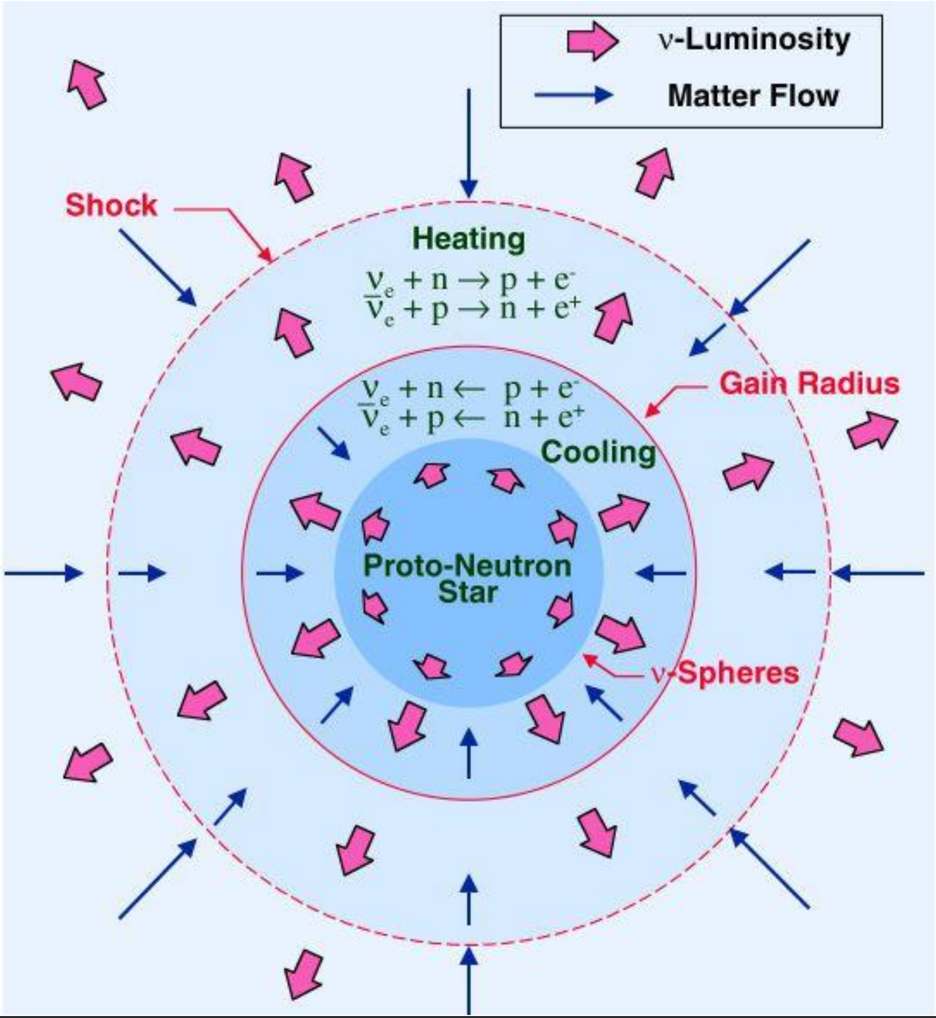
$$e^- + p \rightarrow n + \nu_e$$
$$e^+ + n \rightarrow p + \bar{\nu}_e$$

ν -heating at gain-layer:

$$n + \nu_e \rightarrow e^- + p$$
$$p + \bar{\nu}_e \rightarrow e^+ + n$$

From: Bethe,1990

Neutrino-driven shock-revival



ν-cooling (behind shock: $\mathrm{T} \propto r^{-1}$) :
e^{-}-/e^{+}- capture rates:

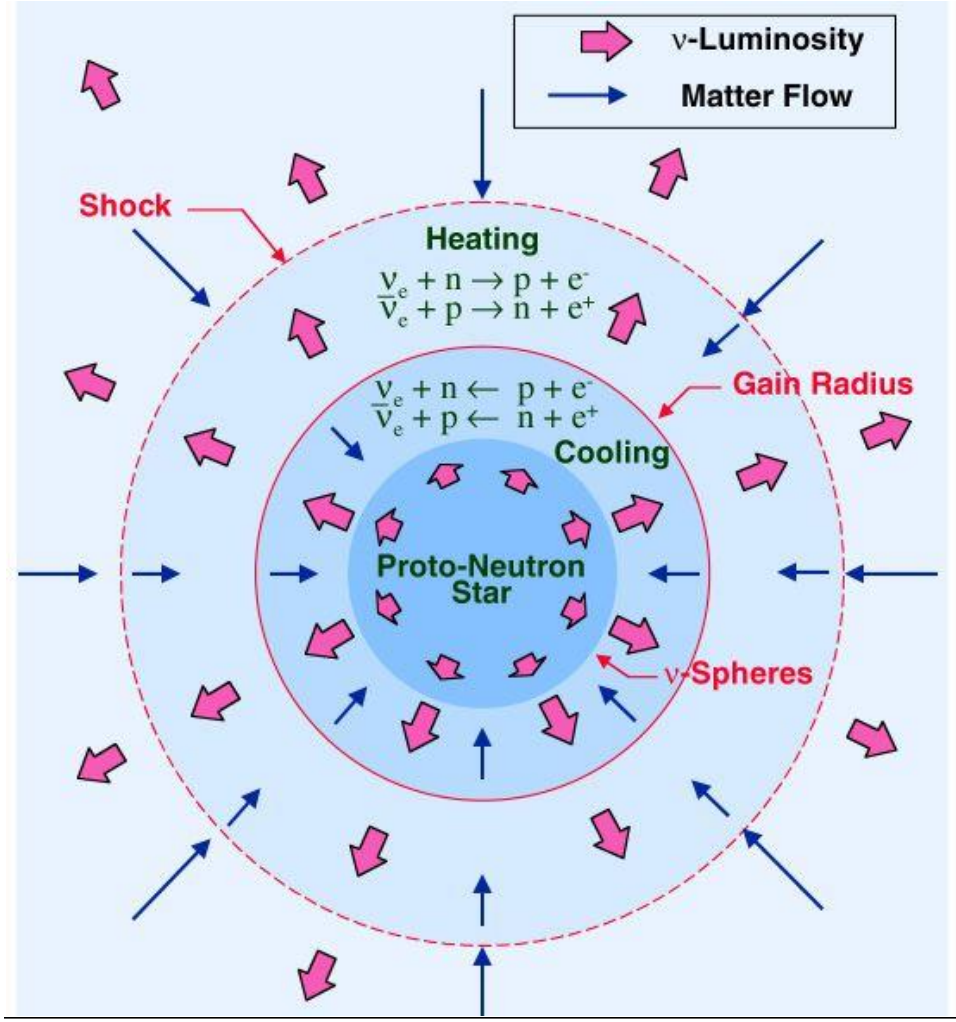
$$q_{\nu}{}^{-} \propto T^{6} \propto r^{-6}$$

ν-heating:
ν_{e}-/$\bar{\nu}_{\mathrm{e}}$- capture rates:

$$q_{\nu}{}^{+} \propto \mathrm{L_e} \langle E_{\nu}{}^{2} \rangle r^{-2}$$

From: http://pics-about-space.com

Neutrino-driven shock-revival



$$q_\nu^- \propto T^6 \propto r^{-6}$$

⇩

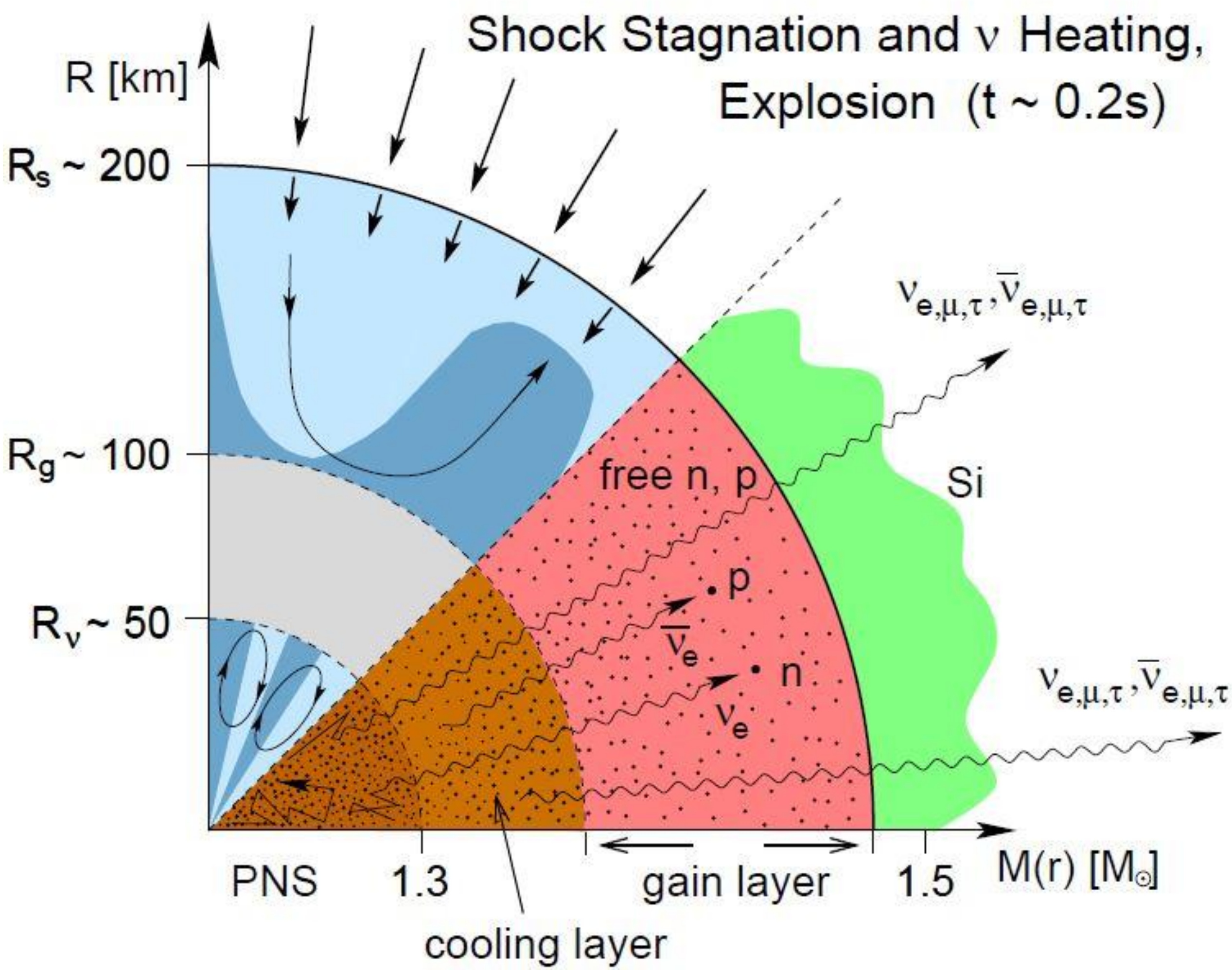
Gain radius at: $q_\nu^- = q_\nu^+$

⇧

$$q_\nu^+ \propto \mathrm{L_e} \langle E_\nu^2 \rangle r^{-2}$$

From: http://pics-about-space.com

Neutrino-driven shock-revival



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

$$e^+ + n \rightarrow p + \bar{\nu}_e$$

$$\Downarrow$$

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

$$e^+ + n \leftrightarrow p + \bar{\nu}_e$$

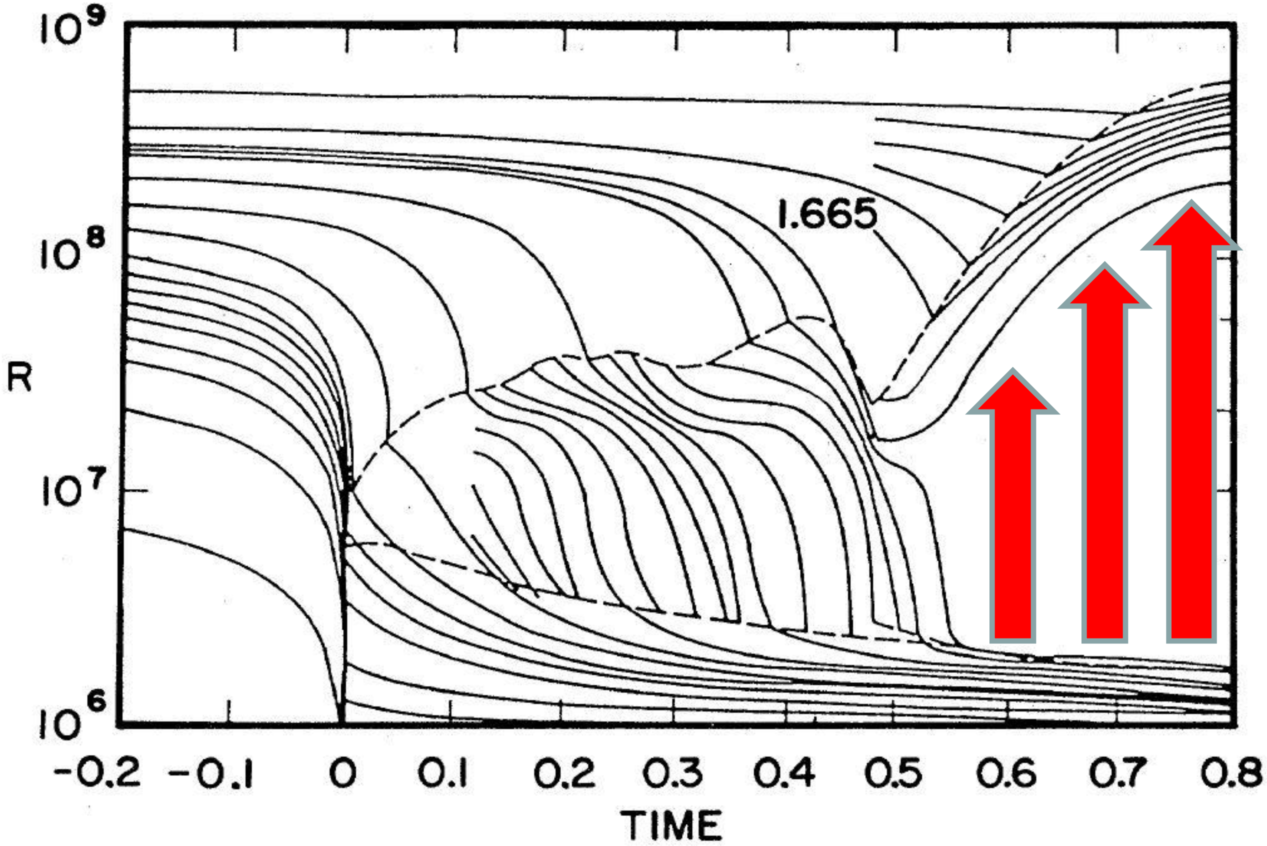
$$\Uparrow$$

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

$$p + \bar{\nu}_e \rightarrow e^+ + n$$

From: inspirehep.net; Janka

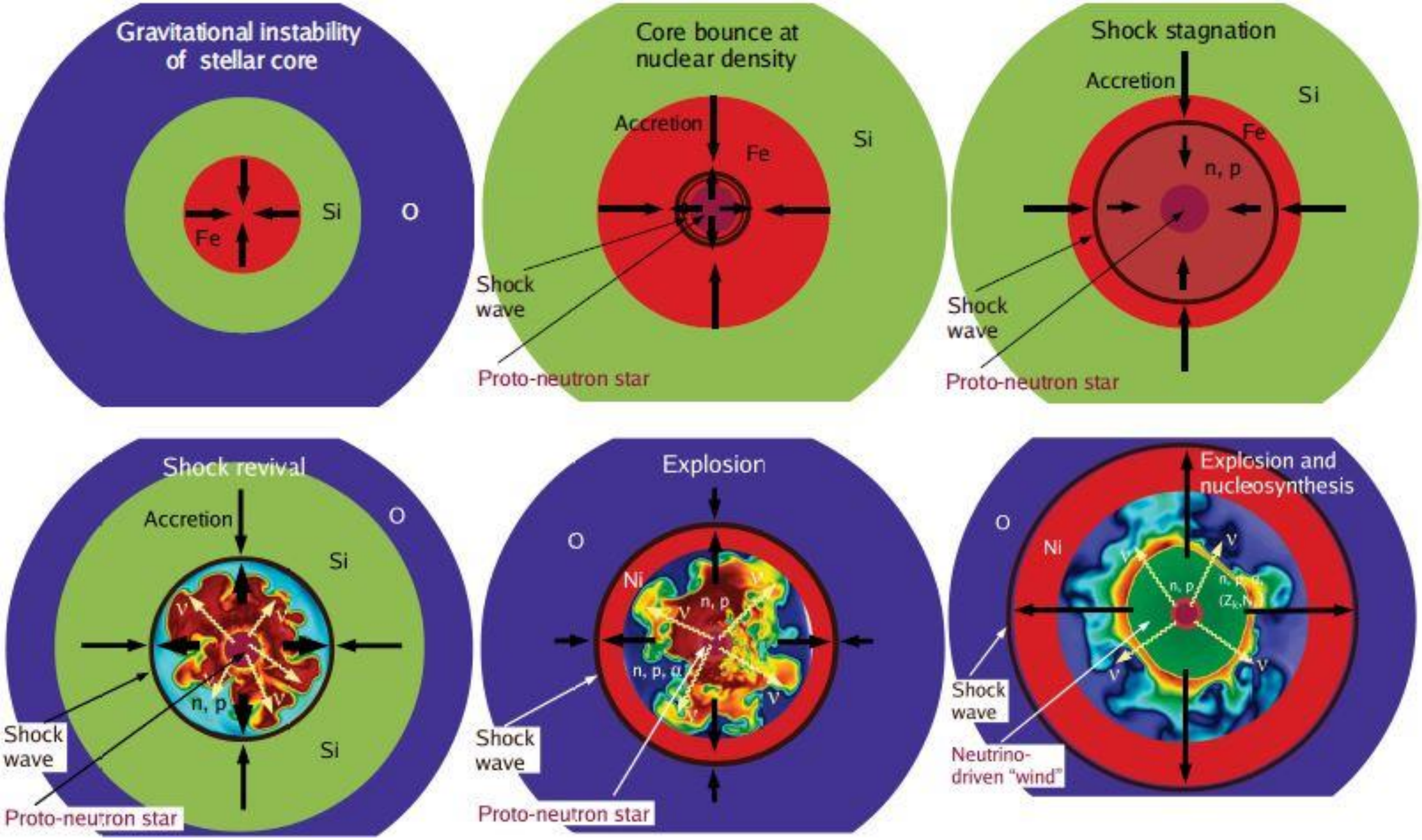
Neutrino-driven wind



Neutrino-driven wind
Pushes away the mantle

From: Bethe,1990

summary



From: Janka, 2012

References

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- “colloquium: perspective on core-collapse supernova theory”, A. Burrows, 2013
- “explosion mechanisms of core-collapse supernova”, Hans-Thomas Janka, 2012
- Pictures from google-search: http://pics-about-space.com; inspirehep.net; dingercatadventures.blogspot.com

Questions welcome

From: dingercatadventures.blogspot.com