Exercise 2

1. Derive the equation for the binding energy, Eq. (3.1) *

2. Consider a collapsing 1.4 $M_\odot$ core when it reaches the the bounce condition at three times the nuclear density. Assume that there at this point are 0.1 neutrinos and 0.3 electrons per baryon, i.e., $Y_\nu = 0.1$ and $Y_e = 0.3$. The temperature in the core is ~ 5 MeV. **

   (a) Estimate the chemical potentials of the neutrinos and the electrons in the core. What does it mean for the neutrinos?

   (b) Determine the mean free path of the neutrinos at this moment.

   (c) Estimate the diffusion time.

   Motivate your discussion clearly.

3. At what stage and by which processes are the following elements created? Note that there may be several sites and phases contributing. Motivate clearly! *

   (a) Nitrogen

   (b) Oxygen

   (c) Iron

   (d) Uranium

4. Discuss the different phases shown in the two simulations of Fig. 1 and 2. What is the difference? What is the main limitation of the result of Fig. 2? For some extra guidance see Kitaura, F. S., Janka, H.-T., & Hillebrandt, W. 2006, A&Ap, 450, 345 and Rampp, M., & Janka, H.-T. 2000, ApJ, 539, L33 * – **

   Motivate your discussion clearly, and be as quantitative as possible about time scales, masses etc.

5. Describe in your own words the events shown in the different panels of Fig. 3 and the important physics involved. Again, be as quantitative as possible about the different time scales, masses, radii and various processes shown in Fig. 3 as possible. * – ***

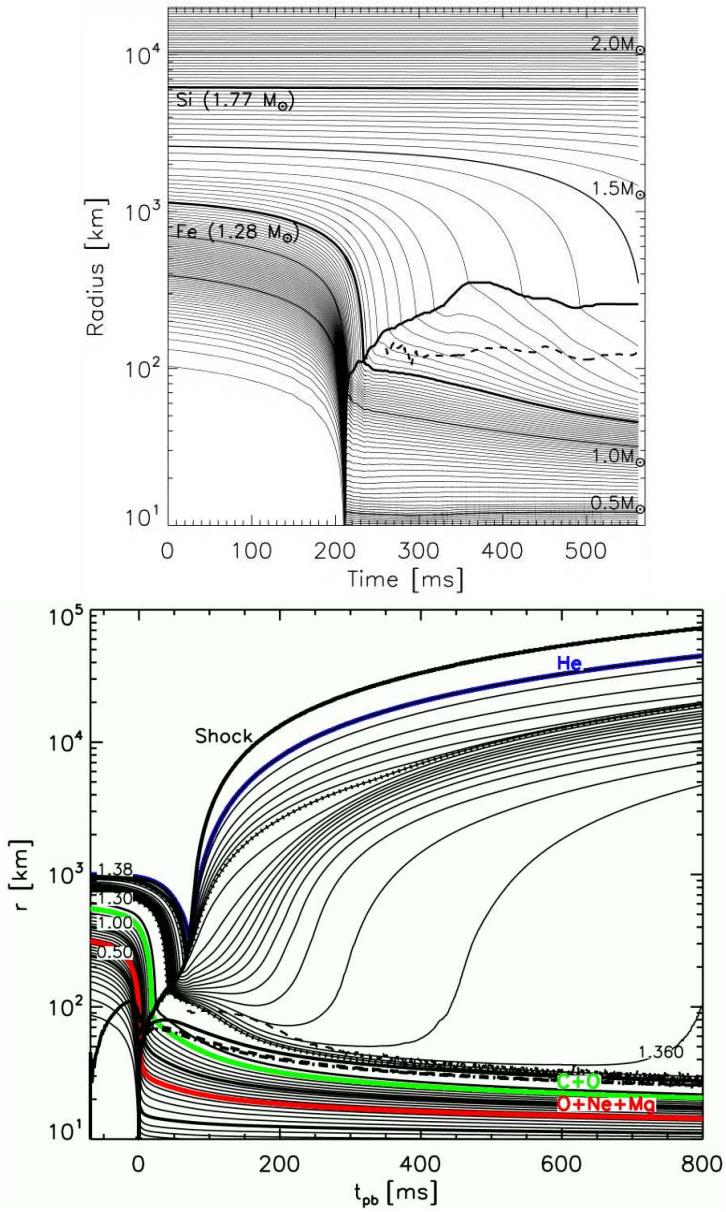
2.0M⊙
Si (1.77 M⊙)
1.5M⊙
Fe (1.28 M⊙)
1.0M⊙
0.5M⊙
Radius [km]
Time [ms]
He
Shock
1.38
1.30
1.00
0.50
1.360
C+O
O+Ne+Mg
r [km]
t_pb [ms]

Figure 1:

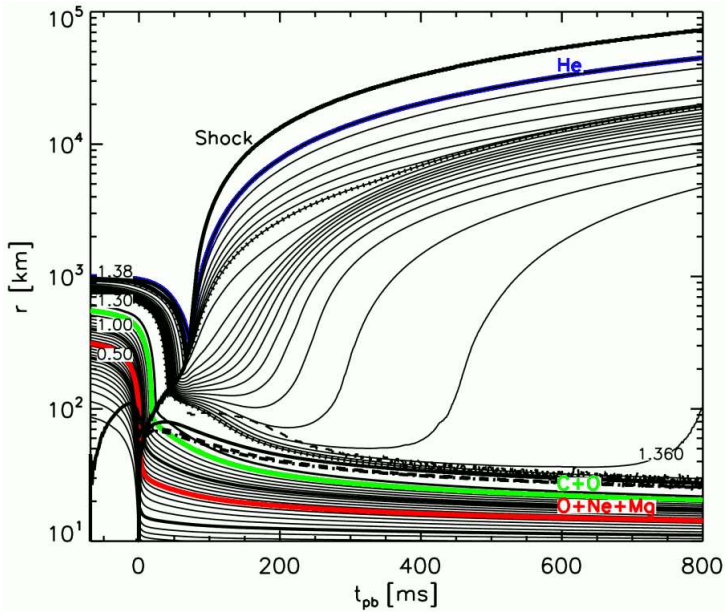
He
Shock
1.38
1.30
1.00
0.50
1.360
C+O
O+Ne+Mg
r [km]
t_pb [ms]
10^5
10^4
10^3
10^2
10^1
0
200
400
600
800

Figure 2:

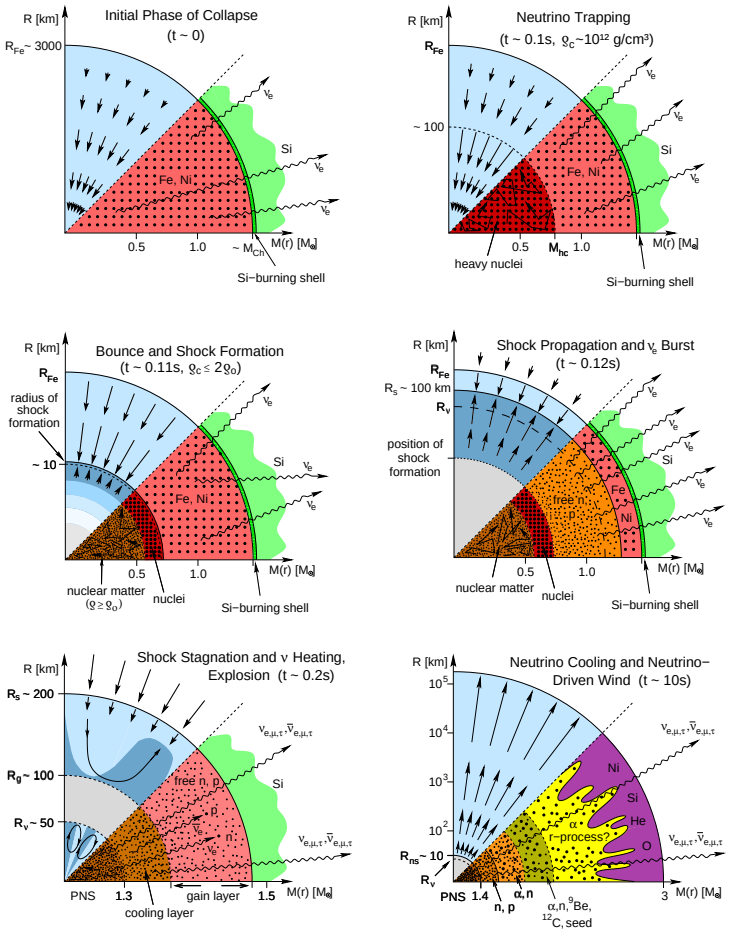
Initial Phase of Collapse
(t ~ 0)
R [km]
R_Fe ~ 3000
Fe, Ni
Si
ν_e
0.5
1.0
~ M_Ch
M(r) [M_⊙]
Si−burning shell
Neutrino Trapping
(t ~ 0.1s, ϱ_c ~ 10^12 g/cm^3)
R_Fe
~ 100
heavy nuclei
M_hc
Bounce and Shock Formation
(t ~ 0.11s, ϱ_c ≤ 2ϱ_0)
radius of shock formation
~ 10
nuclear matter (ϱ ≥ ϱ_0)
nuclei
Shock Propagation and ν_e Burst
(t ~ 0.12s)
R_s ~ 100 km
R_ν
position of shock formation
free n, p
Fe
Ni
Shock Stagnation and ν Heating,
Explosion (t ~ 0.2s)
R_s ~ 200
R_g ~ 100
R_ν ~ 50
ν_e,μ,τ, ν̄_e,μ,τ
PNS
1.3
gain layer
1.5
cooling layer
Neutrino Cooling and Neutrino−
Driven Wind (t ~ 10s)
10^5
10^4
10^3
10^2
R_ns ~ 10
R_ν
Ni
Si
He
O
α
r−process?
PNS 1.4
α, n
n, p
α,n,9Be,
12C, seed
3

Figure 3: