# A Revised Prompt Explosion Mechanism For Core Collapsed Supernova

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# Ⅰ. Background

**Two kinds of Explosion mechanism for core collapsed SN**

**1. The prompt explosion mechanism**

**2. The Neutrino delayed explosion mechanism by Wilson**

**The prompt explosion fails.**

**Reason: The rebounded shock wave has disappeared before it failures to arrive at the boundary of the outer core due to its energy is used up by the photon-integrated reaction**

$$^{56}Fe \rightarrow 13\alpha + 4n \rightarrow 26p + 30n$$

**The key parameters for prompt explosion of SNII are :**

**1)The energy of the rebounded shock wave;**

**2)The mass of outer iron core (too small to explode).**

# Neutrino delayed explosion mechanism

**Wilson(Bowers, Wilson, 1985)**

**Two questions:**

**1. How to get a huge flux of neutrino ( $10^{52}$-$10^{53}$ergs$^{-1}$)**

**What is the physical process? (Dai Z. Peng Q. and Lu T. ApJ., 1995,440:815)**

**A strong flux of neutrino is produced in a short timescale( $\Delta t < 1 \mu s$) through phase transition: nucleons -(u,d) quarks -(s,u,d) quarks**

**2. How to revives the outward rebounded shock by the strong neutrino flux ($<E_q> \approx 10$ MeV) ??**

**So far, no successful answer have been reported** for **SN simulations**

**Conclusion: the SN explosion is still the open question up to now in theory!!!**

**Buras et al., 2003, Phys. Rev. Lett., 90 No. 24, 241101**

**"Improved Models of Stellar Core Collapse and Still No Explosions: What is Missing?"**

# Current idea on the core collapse for SNII

After the end of Si-burning, both the electron fraction ( $Y_e$) and the electron degenerate pressure gradually decrease due to EC process. The iron core begins to shrink and it contracts faster and faster. As the EC process proceeds and the electron decreases, $M_{ch}$ decreases with ($M_{ch} \propto Y_e^2$) also.

When $M_{ch}$ is less than $M_{core}$(Fe), the whole iron core will collapse rapidly by the general relativistic effect. At the moment of the beginning of rapid collapse, the inward collapsing velocity at the surface of the iron core has arrived at 1000km/s.

The general relativistic effect is the primary factor to make the whole iron core collapsing rapidly , although the EC process makes the iron core beginning to shrink.

Besides, The SN core is in a homogenous collapse traditionally (Colgate, 1968).

# II. My idea

A) **The key is the electron capture process**

**The primary factor which causes core collapse of massive stars is the electron capture (EC) on the nuclei of iron group.**

**The EC rate, $\bigcirc_{EC}$(ne), is a increasing function of the density.**

**The timescale of the EC process decreases with increasing density.**

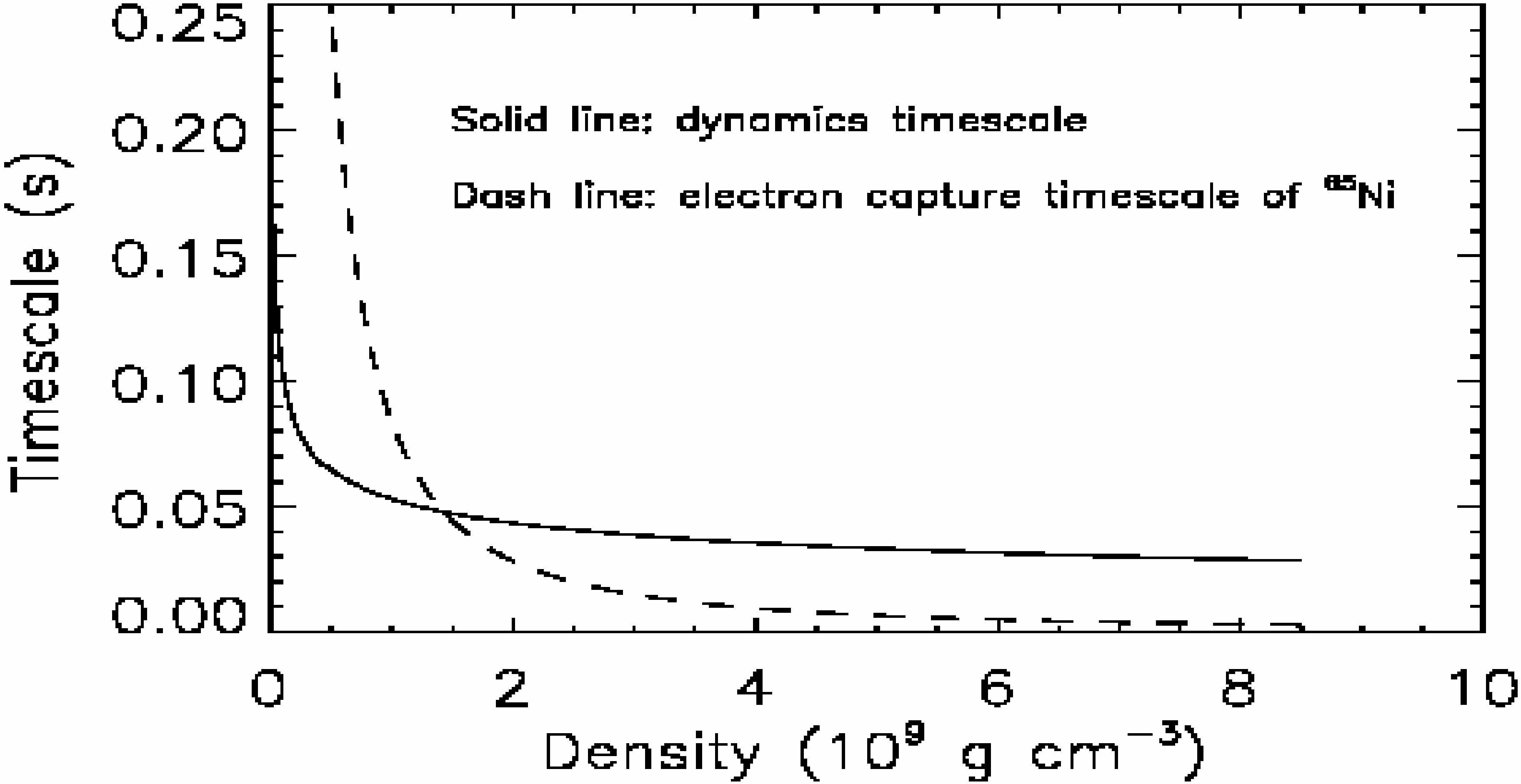
**The decreasing rate of the timescale of the EC process is faster than that for hydrodynamic collapse .**

# II. My New Idea (1)

- **The key is the electron capture process.**
- **The primary factor which causes core collapse of massive stars is the electron capture (EC) on the nuclei of iron group.**
- **The EC rate, ○$_{EC}$(ne), is an increasing function of mass density. The timescale of the EC process decreases faster than that of hydrodynamic collapse with increasing density.**

$$t_{EC}(R_{rc}) < t_{HD}(R_{rc}) \approx 4.46\rho_{10}^{-1/2}(R_{rc}) \qquad ms$$

$$t_{EC}(R_{rc}) = [\lambda_{EC}(n_e)]^{-1}, \qquad n_e = N_A Y_e \rho$$




$^{56}Ni:$

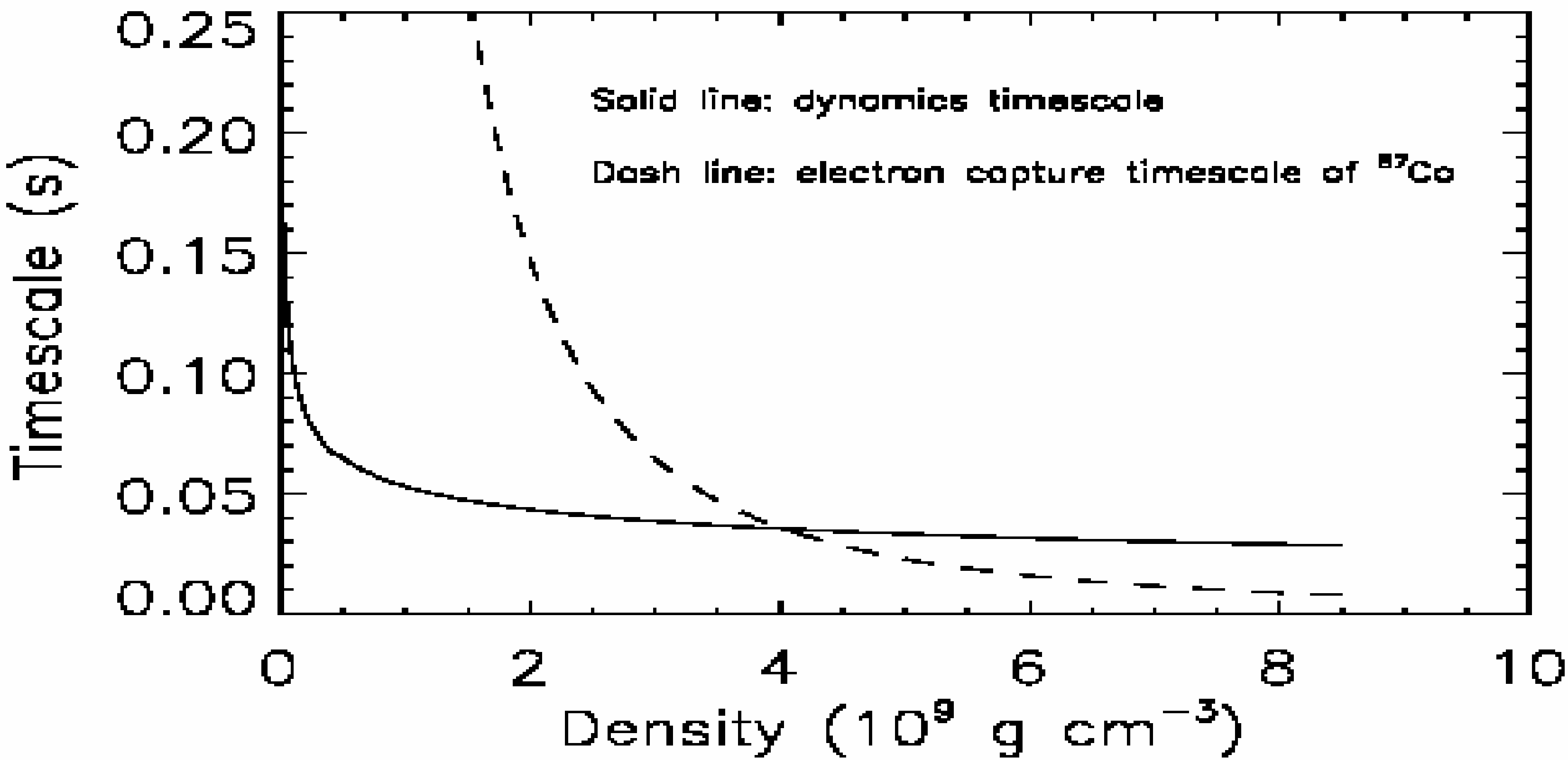
$R_{cr} = 4.645 \times 10^{7}\, cm$

$\tau_{cr} = 0.04787 s$

$\rho_{cr} = 1.43 \times 10^{9}\, g \cdot cm^{-3}$

$M(R < R_{cr}) = 1.31 \times 10^{33}\, g$

$\Delta\phi(R_{cr} \to 4 \times 10^{6}\, cm) = 5.31 \times 10^{52}\, erg$




$^{57}Co:$

$$\rho_{cr} = 4.03\times 10^{9}\, g\cdot cm^{-3}$$

$$R_{cr} = 2.858\times 10^{7}\, cm$$

$$M(R < R_{cr}) = 0.557\times 10^{33}\, g$$

$$\tau_{cr} = 0.03544 s$$

$$\Delta\phi(R_{cr} \rightarrow 4\times 10^{6}\, cm) = 1.27\times 10^{52}\, erg$$

**In the inner core :**

» **The center of the star,** u ı **, EC rate** ı**,** $n_e$ ∅**,** $P_e$ ∅

² **(**$F_g$**-**$P_e$**)** ı**,** ² **the acceleration of collapse** ı**.**

² **the SN core is not in a homogenous collapse.**

**The matter in the inner core is almost in complete free fall collapse. ( it is valid in a region** u < $u_{trap}$ ¬ **3**∘**10**$^{11}$**g/cm**$^{3}$ **where neutrinos escape freely).**

**In the outer core:**

**the EC rate is low, the electron pressure decreases a little, the contracting velocity is much less than the free fall velocity**

# Comparing my new idea with the current idea

**The current idea:**

**The SN core is in a homogenous collapse, the moment of the beginning of rapid collapse of the core is dominated by the general relativistic effect.**

**The criterion of the rapid collapse is $M_{ch} < M_{core}(Fe)$**

**($M_{ch} \propto Y_e^2$, $M_{ch}\downarrow$ with $Y_e\downarrow$ due to the EC process)**

***The key is that the whole iron core rapidly collapses and the result is* the *prompt explosion failures due to the* $M_{core}(Fe)$ *too large.***

# The Key of my idea

**The SN core is dominated by the EC process and it (even for the inner core) is not in homogenous collapse .**

***The key is that only the part of the iron core (rather the whole iron core) rapidly collapses. Another part of the core contracts slowly.***

**i.e. the rapid collapsed core is not the whole iron core of the presupernova, but only the central region where the criterion**

$$t_{EC}(R_{rc}) < t_{HD}(R_{rc}) \approx 4.46\rho_{10}^{-1/2}(R_{rc}) \quad ms \qquad \textbf{(A)}$$

**is valid, i.e. the mass of the rapid collapsed core is only the central region and is obviously smaller than the whole mass of the iron core.**

**Revised prompt explosion mechanism:**

**The rapid collapsed core where (A) is valid collapses in a very short time. It collapses in the same way as that described by the prompt explosion mechanism:**

# Revised prompt explosion mechanism:

**The rapid collapsed core where (A) is valid collapses in a very short time. It collapses in the same way as that described by the prompt explosion mechanism:**

# III. Recent calculations

**Improved simulations of SNII for a Woosley's presupernona model with 15 $M_\odot$ have been done, based on the work by a Chinese group(Wang et al., 1983-2000) and combining with our idea above.**

**1)A prompt explosion for the WS presupernova model with 15$M_\odot$ by adjusting the collapsing velocity properly.**

**2)A prompt explosion for the WS presupernova model with 15$M_\odot$ by adjusting pressure distribution in collapse process.**

# Simulation by adjusting the collapsing velocity

**(The iron core is divided into 96 layers)**

**Working assumption based on our previous idea:**

**setting** $$h = t_{EC} / t_{HD}$$

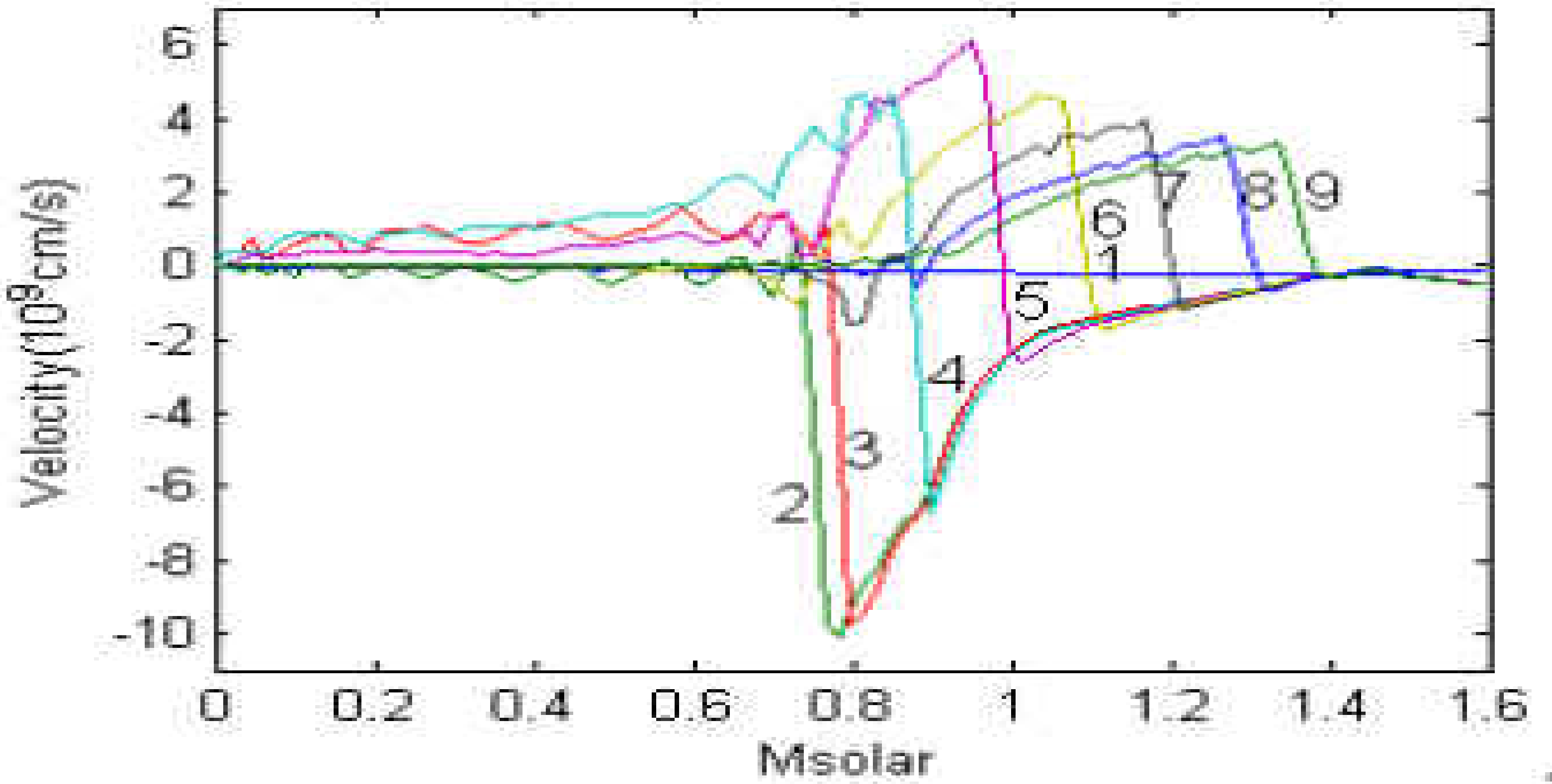
**Taking:** $$V = V_0$$ **When** $h > 1$

$$V = \left(1 + \frac{\alpha}{h}\right) V_0$$ **When** $0.1 < h < 1$

$$V = (1 + 10\alpha) V_0$$ **When** $h \leq 0.1$

**$V_0$: The collapsing velocity simulated by Wang et al. (fail to explode)**

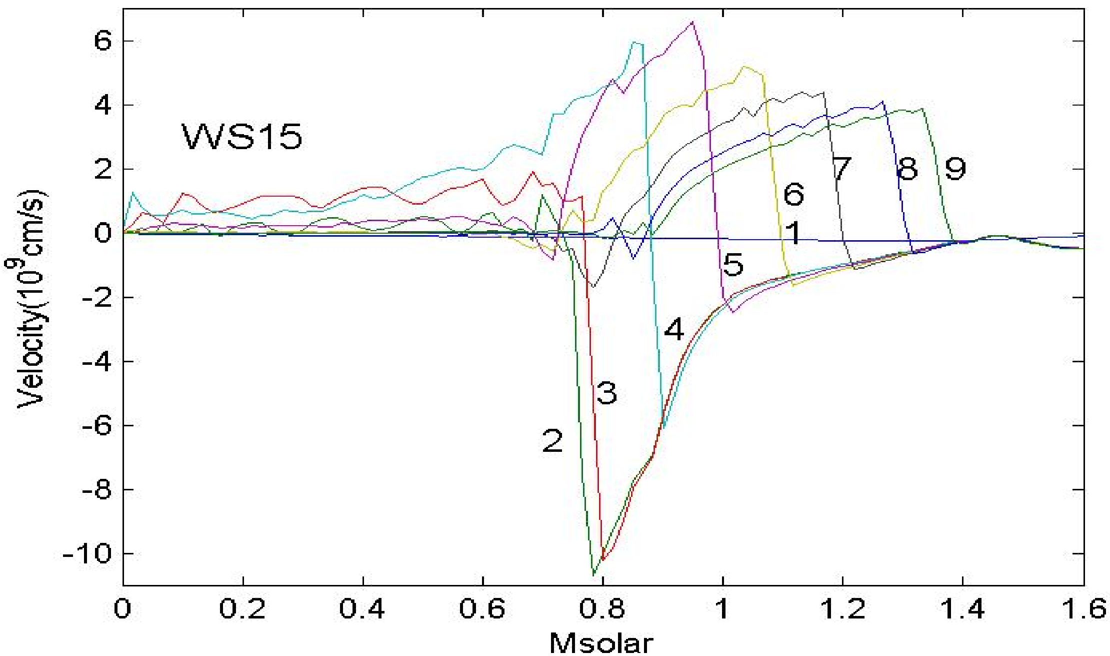
# The radial velocity at various moment (δ = 0.006 )




**1:at 0.1025 s， 2: when the core central density arrives at maximum**

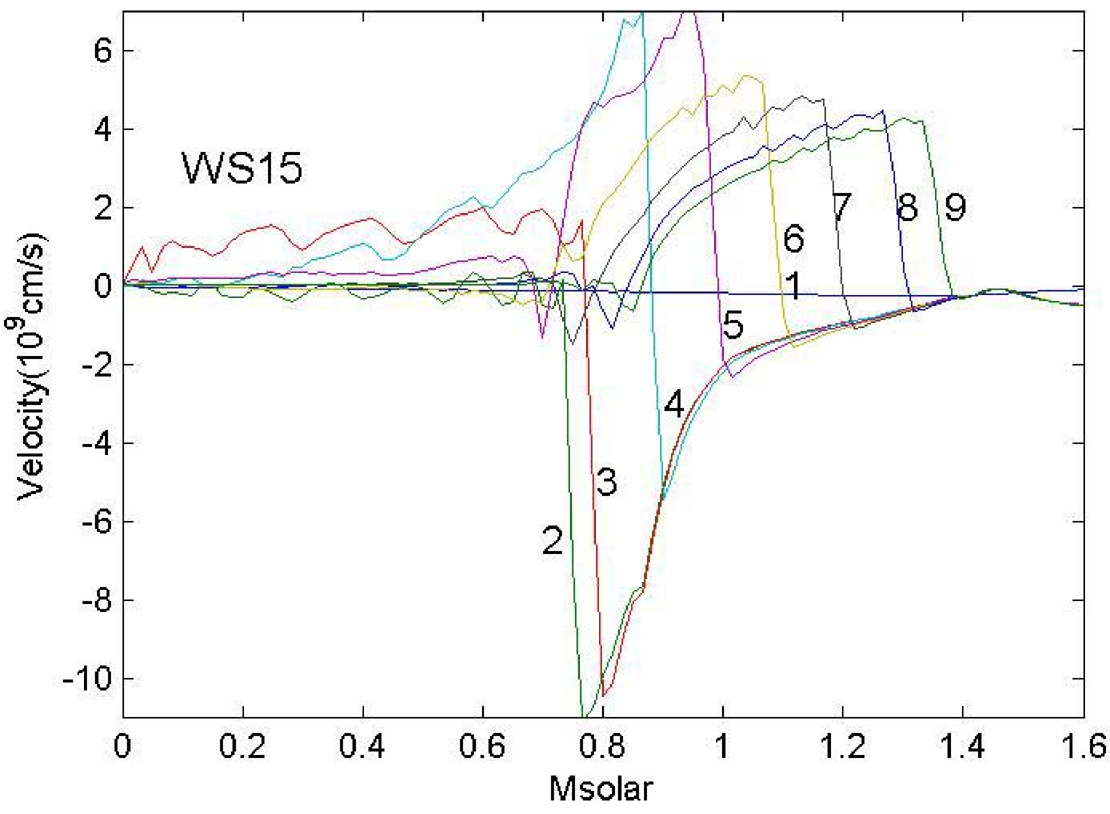
**3 : when the rebounded shock wave(RSW) arrive at 8 $M_\odot$; 4: when RSW wave arrive at 0.9 $M_\odot$, 5: when RSW arrive at1 $M_\odot$;6: when RSW at 1.1 $M_\odot$, 7 : when RSW arrive at 1.2$M_\odot$, 8: when RSW arrive at 1.3 $M_\odot$; 9: when RSW arrive at 1.38 $M_\odot$。**

# d=0.007



WS15
Velocity($10^9$cm/s)
Msolar
1
2
3
4
5
6
7
8
9
6
4
2
0
-2
-4
-6
-8
-10
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

# d = 0.008



WS15
Velocity($10^9$cm/s)
Msolar
1
2
3
4
5
6
7
8
9
6
4
2
0
-2
-4
-6
-8
-10
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6

# The Exploded energy when the rebounded shock wave At various layers ( in 0.1foe )

| α | 0.8 $M_\odot$ | 0.9 $M_\odot$ | 1.0 $M_\odot$ | 1.1 $M_\odot$ | 1.2 $M_\odot$ | 1.28 $M_\odot$ | 1.30 $M_\odot$ | 1.38 $M_\odot$ |
|---|---|---|---|---|---|---|---|---|
| 0.005 | 0.00 | 29.63 | 56.36 | 41.42 | 20.00 | 7.38 | 2.16 | 0.00 |
| 0.006 | 0.00 | 18.37 | 72.63 | 58.31 | 36.45 | 21.96 | 16.04 | 6.62 |
| 0.007 | 0.00 | 20.00 | 96.01 | 79.55 | 59.65 | 47.21 | 40.14 | 28.72 |

- The rebounded shock wave appears from 0.8 $M_\odot$

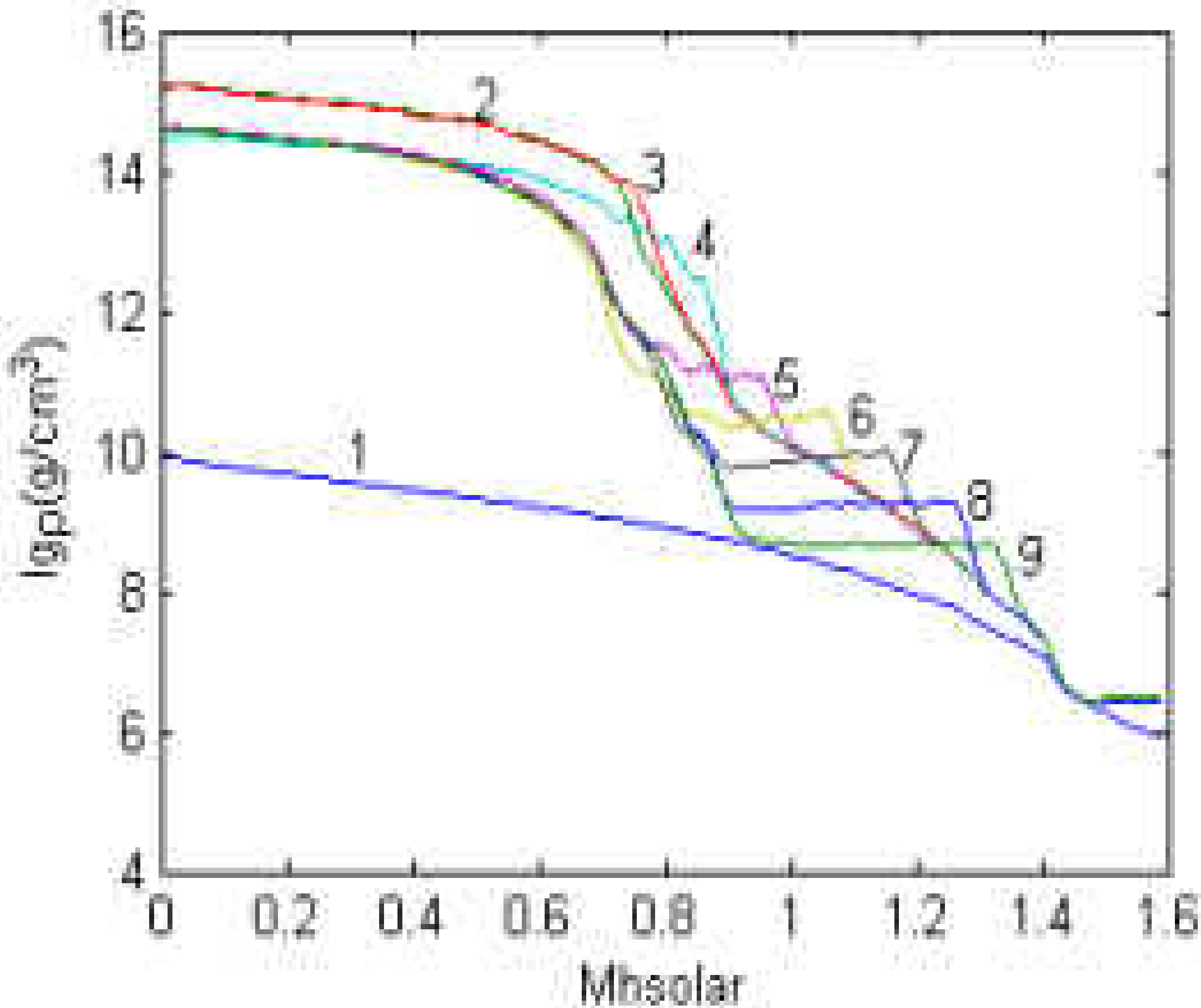
# Calculated results

**No explosion** **if** $\alpha = 0.005$

**Weak explosion** **if** $\alpha = 0.006$

**Strong explosion** **if** $\alpha = 0.007$

# Mass density distribution at various time($\alpha$=0.006)




**1: at 0.1025 s**

**2: when the core central density arrives at maximum**

**3 : when RSW arrive at 8** $M_\odot$

**4: when RSW wave arrive at 0.9** $M_\odot$

**5: when RSW arrive at 1** $M_\odot$

**6: when RSW at 1.1** $M_\odot$

**7 : when RSW arrive at** $1.2M_\odot$

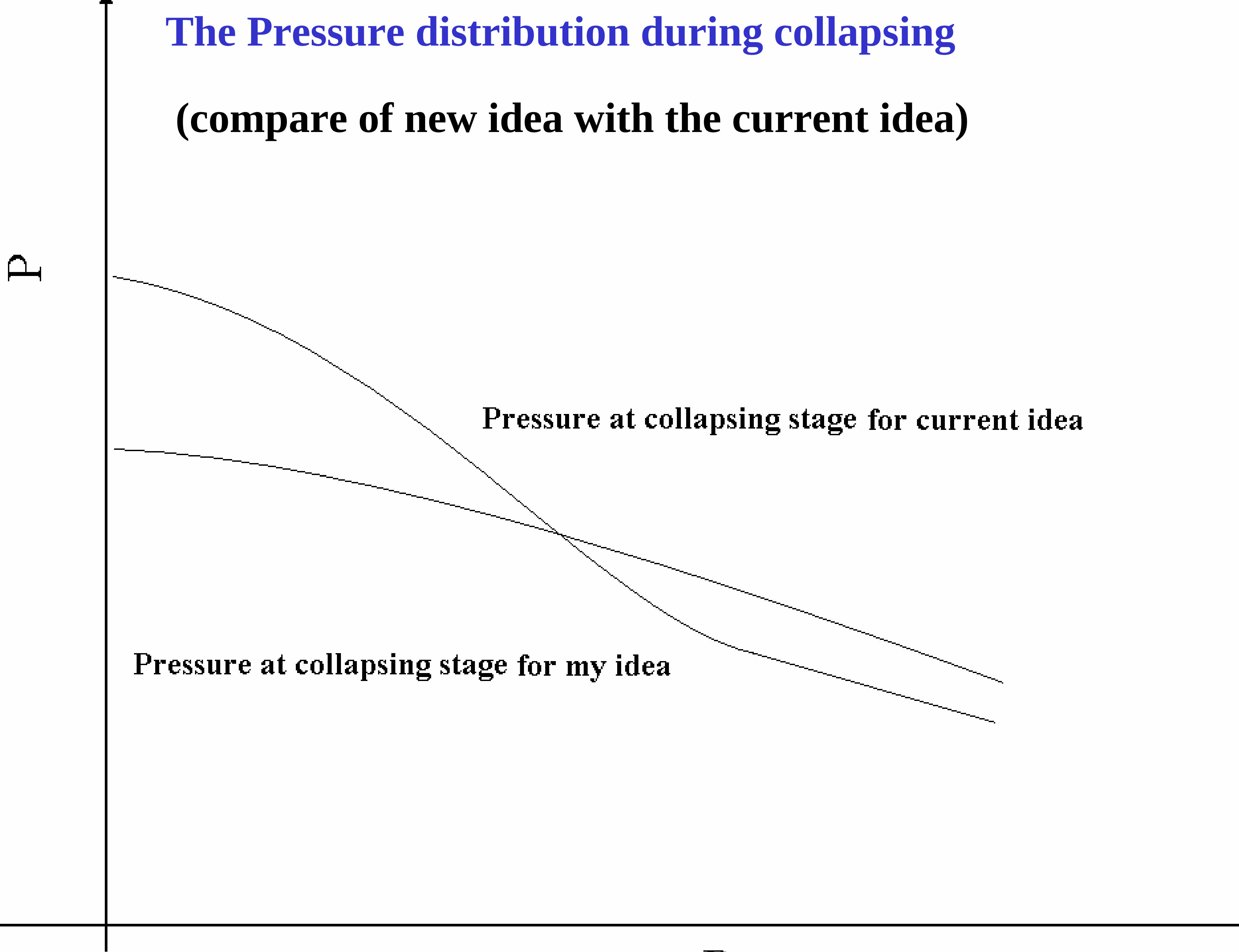
**8: when RSW arrive at 1.3** $M_\odot$

**9: when RSW arrive at 1.38** $M_\odot$。

**Simulation by adjusting pressure distribution in collapse process.**

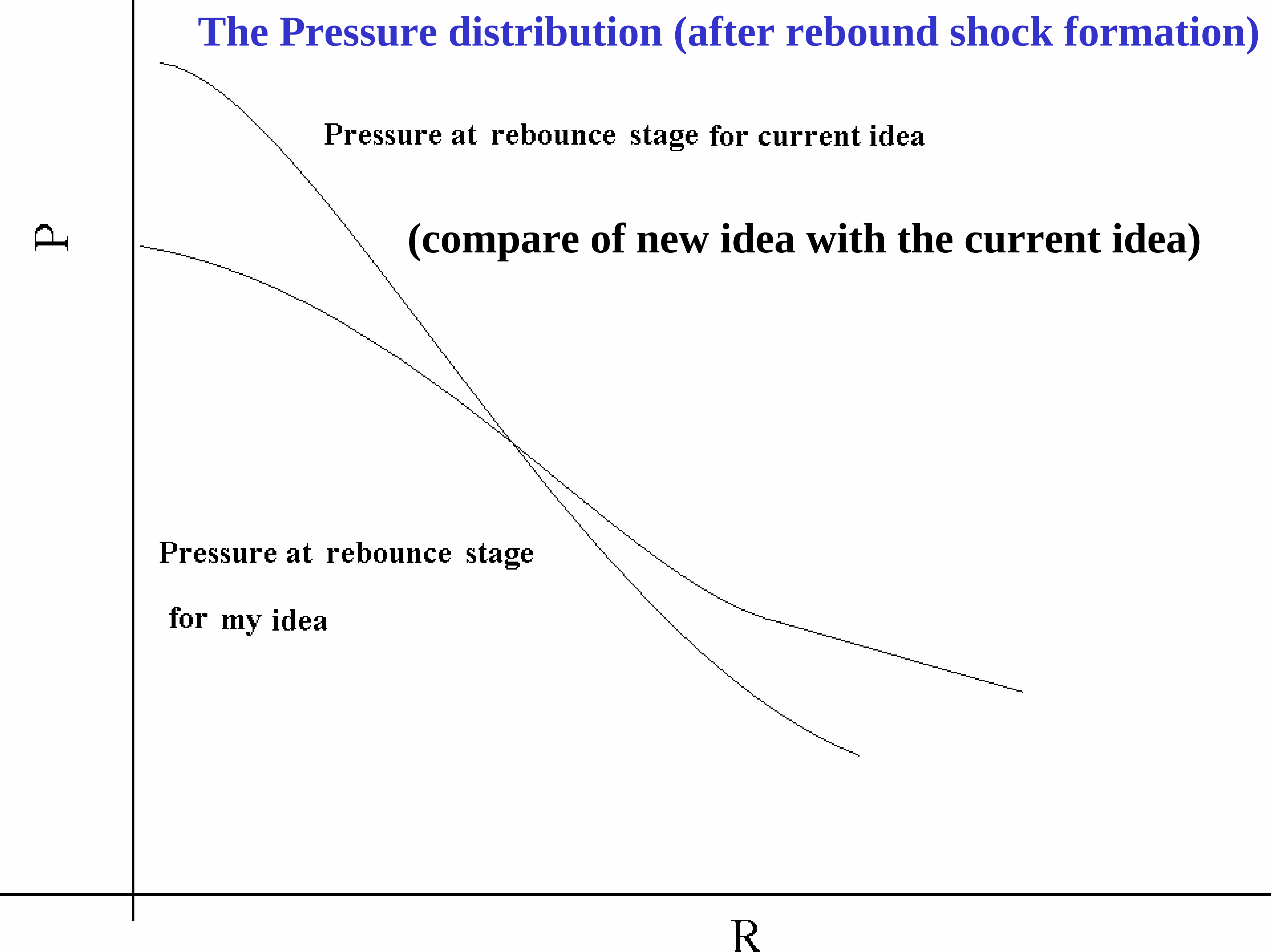
# The Pressure distribution during collapsing

**(compare of new idea with the current idea)**



# The Pressure distribution (after rebound shock formation)

(compare of new idea with the current idea)



# Working assumption

$$-\frac{dP}{dr} = \frac{GM}{r^2}\rho(r) + \rho(r)\frac{d^2 r_\rho}{dt^2}$$

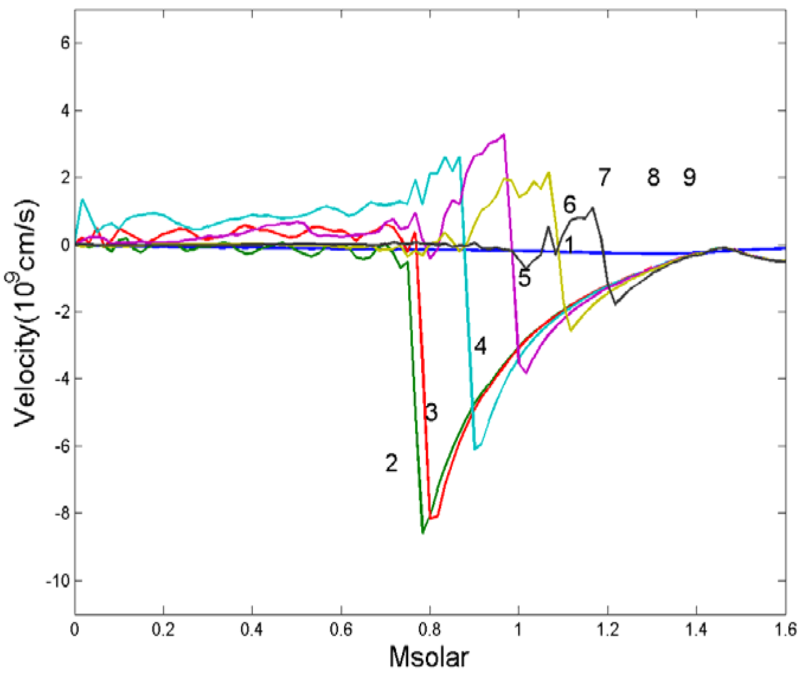
$$P_j = P_{j+1} + \beta \Delta P_{j+1/2}$$

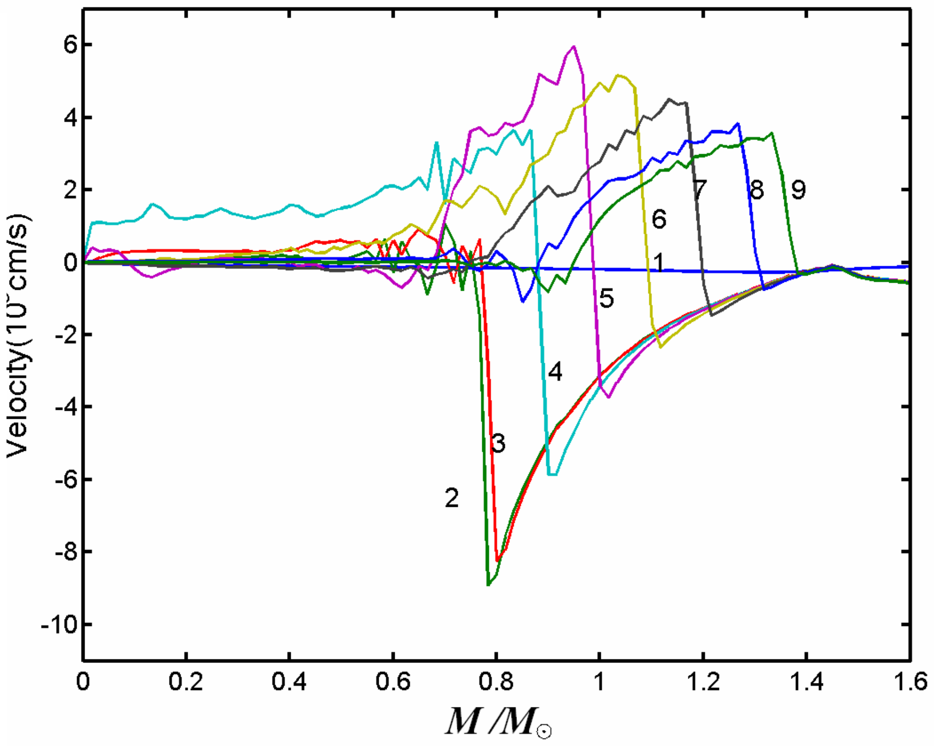
$$\Delta P_{j+1/2} = P_j - P_{j+1}$$

$$\beta = \begin{cases} 1 & t = 0 \\ 0.95 & 0 < t < 285.755\,ms \\ 0.93 & 285.755\,ms < t < 291.953\,ms \\ 1.45 & 291.953\,ms < t < 292.256\,ms \\ 1 & t > 292.256\,ms \end{cases}$$

# 1. The rebounded velocity (Ws15 $M_\odot$)

**Left: former simulation by Wang et al.**
**Right: improved simulation with the adjusted pressure gradient**

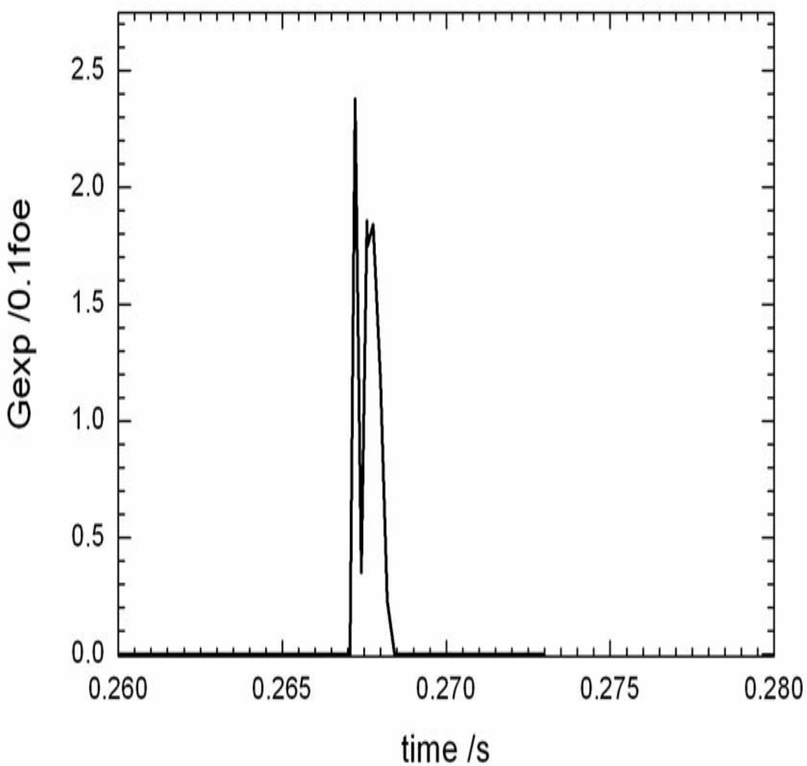


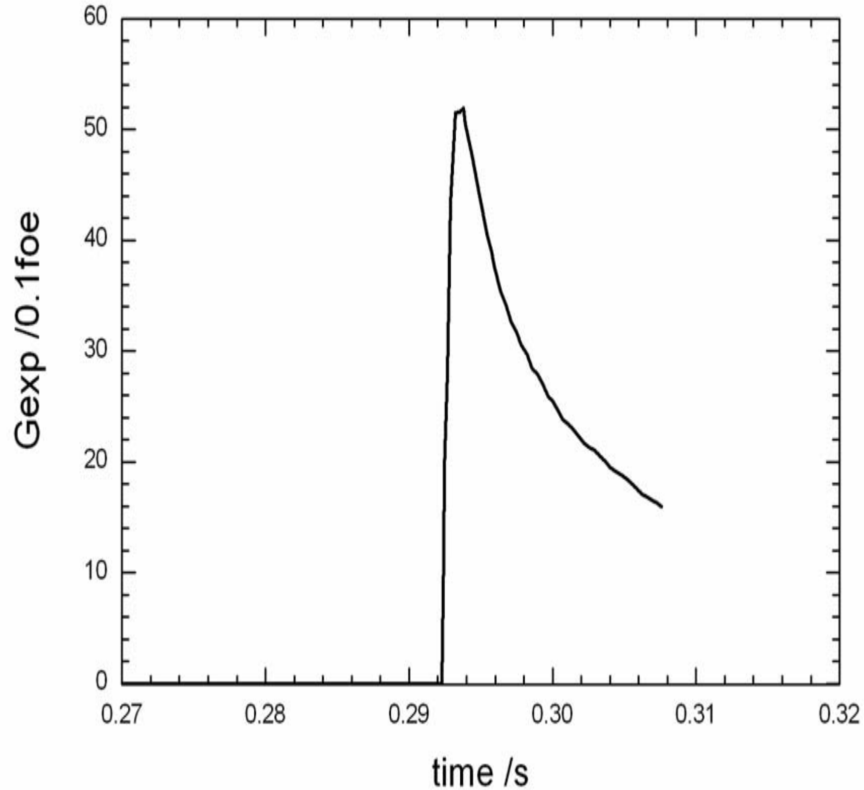



# 2. Compare of the exploding energy

**Left: former simulation by Wang et al.**

**Right: improved simulation with the adjusted pressure gradient**



Hopes: to cooperate with some group to investigate further

- Thanks !