The Mechanism of the Two-Stage Explosions of Type I Superluminous Supernovae

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Abstract: Here, applying the Scale-Symmetric Theory (SST), we described the mechanism of the two-stage explosions of the hydrogen-poor Type I superluminal supernovae (SLSNe-I). We calculated their quantized masses: 3.14, 6.28, 12.55 and 25.10 solar masses, maximum absolute magnitudes for the initial and main explosions and we solved the ejecta-velocity problem. The derived light curves are consistent with observational data.

1. Introduction

Here, applying the Scale-Symmetric Theory (SST) [1], we described the mechanism of the two-stage explosions of the hydrogen-poor Type I superluminal supernovae (SLSNe-I).

The SST shows that the succeeding phase transitions of the superluminal non-gravitating Higgs field during its inflation (the initial big bang) lead to the different scales of sizes/energies [1A]. Due to a few new symmetries, there consequently appear the superluminal binary systems of closed strings (entanglons) responsible for the quantum entanglement (it is the quantum-entanglement scale), stable neutrinos and luminal neutrino-antineutrino pairs which are the components of the luminal gravitating Einstein spacetime (it is the Planck scale), cores of baryons (it is the electric-charges scale), and the cosmic-structures/protoworlds (it is the cosmological scale) that evolution leads to the dark matter, dark energy and expanding universes (the "soft" big bangs) [1A], [1B]. The electric-charges scale leads to the atom-like structure of baryons [1A].

Among a thousand of calculated quantities within SST, which are consistent with experimental data, we calculated the quantized mass of the Type Ia supernovae ($m_{SN\text{-}Ia}$ = 1.395 solar masses [2]) and masses of the condensates composed of the confined neutrino-antineutrino pairs in centres of muon (mass of the muon condensate is Y_{Muon} = 52.828 MeV [1A]) and nucleons (mass of the nucleon condensate is $Y_{Nucleon}$ = 424.124 MeV [1A]). In SST, mass of the muon condensate determines mass of the Type Ia supernova [2].

2. The quantized masses of SLSNe-I

Stars with mass higher than $m_{SN\text{-}Ia}$ try to modify their internal structure in such a way the efficiency of transferring energy to their surface was highest i.e. in order that efficiency of cooling a star was highest. Efficiency is highest for the well known dominating Chandrasekhar limit that follows from creation of the muon condensates with a mass of

52.828 MeV [2]. It leads to conclusion that a massive star transforms into a system composed of Type Ia supernovae. Moreover, due to the gravitational compression, in centre of the systems appears a condensate of nuclear matter with a mass of, say, $M_{n,CC}$. But SST shows that not each star can transform in such a system. Due to the four-neutrino symmetry, there are preferred systems containing following numbers, D_n, of the entangled Type Ia supernovae [1B]

$$D_n = 4^d \text{ (for single objects) or } = 2 \cdot 4^d \text{ (for binary systems)}, \tag{1}$$

where $d = 0, 1, 2, 4, 8,\ldots$ The non-trivial lower limit is $D_{n,LL} = 2$ i.e. there are produced the binary systems of the muon condensates (the components in each pair are entangled). The upper limit, $D_{n,UL}$ for D_n follows from the ratio of the masses of the nucleon and muon condensates

$$R = Y_{Nucleon} / Y_{Muon} = 8.0284 \approx 8. \tag{2}$$

It leads to conclusion that $D_{n,UL} = R\, D_{n,LL} = 16$. We obtain $D_n = 2, 4, 8, 16$.

The ratio that follows from formula (2) should as well determine the ratio of masses involved in the main and initial explosions of the SLSNe-I

$$D_n\, m_{SN\text{-}Ia} / M_{n,CC} \approx 8. \tag{3}$$

We can see that the quantized masses of the SLSNe-I are 3.14 solar masses, 6.28 solar masses, 12.55 solar masses and 25.10 solar masses ($3.14 \leq m_{SLSN\text{-}I} \leq 25.10$ solar masses). Notice that the biggest mass is close to the mass of the neutron black hole: 24.81 solar masses [1B] so this mass as well can approximately fix the upper limit for mass of the SLSNe-I. But, of course, there can be simultaneous explosions of systems containing 2, 4, 8, 16, and so on, the neutron black holes. Here we neglect such processes. We can assume that evolution of the neutron black holes started due to the inflows of the dark energy and dark matter [1B].

3. The initial explosion of the baryonic condensate in centres of SLSNe-I cools the interior of the SLSNe-I

The initial explosion of the baryonic condensate in centres of SLSNe-I rejects the hot plasma from surroundings of the Type Ia supernovae the progenitors of SLSNe-I consist of. Such shock cooling is a catalyst for the main explosion i.e. for explosions of the Type Ia supernovae the SLSNe-I consist of. Just the lowered temperature near the SNe-Ia causes that transfer of energy (i.e. transfer of the muon condensates) from core of the Type Ia supernovae to their surfaces is more effective – it leads to their gravitational collapse preceding the main explosion of SLSNe-I. It means that in each SLSN-I there are several areas of explosion (2, 4, 8 or 16).

4. Absolute brightness, B, and absolute magnitude, M_V, of SLSNe-I

Some SLSNe-I have double-peaked light curves [3]. The radioactive decay of ^{56}Ni cannot in a simple way explain dynamics of SLSNe-I. Here we show how internal structure of SLSNe-I described within SST leads to maximum absolute magnitudes for the initial and main explosions.

We can convert from absolute-magnitude difference ($M_{V,2} - M_{V,1}$) to absolute brightness ratio (B_1 / B_2) by using the formula

$$log_{10} (B_1 / B_2) = 0.4000 (M_{V,2} - M_{V,1}). \qquad (4)$$

It means that absolute magnitude is defined in such a way that a difference of $0.7526 \approx 0.75$ in absolute magnitude corresponds to a ratio of 2.00 of absolute brightness.

Notice that absolute brightness of a system composed of N Type Ia supernovae without mutual screening is NB_o , where B_o is the absolute brightness of one Type Ia supernova.

The typical absolute magnitude of Type Ia supernovae is $M_{V,o} = -19.30 \pm 0.03$ [4]. Applying formula (4), we obtain that maximum absolute magnitude for main explosion of a SLSN-I composed of two Type Ia supernovae (i.e. for SLSN-I with a mass of 3.14 solar masses) should be $-20.05 = -19.30 - 0.75$, for composed of four (i.e. for SLSN-I with a mass of 6.28 solar masses) should be -20.80, for composed of eight (i.e. for SLSN-I with a mass of 12.55 solar masses) should be -21.55 and for composed of sixteen (i.e. for SLSN-I with a mass of 25.10 solar masses) should be -22.30. We showed that mass involved in the initial explosion is in an approximation $8 = 2^3$ times smaller than the mass involved in the main explosion so maximum absolute magnitude for the initial explosion should always be smaller by about $2.25 = 3 \cdot 0.75$, i.e. respectively we obtain -17.80, -18.55, -19.30 and -20.05 – see the light curves in this paper (Fig. 1) and compare them with observational data [5] – obtained results within SST are consistent with observational data.

5. The ejecta velocities of SLSNe-I

Due to the four-neutrino symmetry, initially there mainly are produced the atomic nuclei containing 256 nucleons, not 56 nucleons (see formula (1): $D_n = 4^4 = 256$).

In very high temperature during the explosions of the SLSNe-I, there take place the symmetrical decays of the nuclei containing 256 nucleons: $256 \rightarrow 128 \rightarrow 64$ (it finally decays to Fe-56) $\rightarrow 32 \rightarrow 16 \rightarrow 8$ (it decays to Li-7) $\rightarrow 4$. The symmetrical decays of the nuclei of helium-4 to nucleons need highest energy per nucleon (~7 MeV) so need highest energy density – it is the reason that the SLSNe-I are the hydrogen-poor objects (in much more energetic explosions, the decays of helium-4 to nucleons are possible so such explosions increase abundance of hydrogen in the Universe).

Since for kinetic energy is $E = mv^2$ (we neglect the relativistic effects because $v << c$) so atomic nuclei containing 256 nucleons have the ejecta velocities $(256 / 56)^{1/2} \approx 2.2$ times lower than the nuclei of iron-56. To describe the dynamics of the SLSNe-I applying the ^{56}Ni-powered models, we need the ejecta velocities close to 22,000 km/s whereas the measured ejecta velocities are close to 10,000 km/s [5]. We can see that the ratio is 2.2 also so presented here mechanism within the SST solves the ejecta-velocity problem.

6. Absolute magnitude as a function of the rest-frame phase expressed in days (i.e. the rest-frame *g*-band light curves for SLSNe-I)

We can assume that due to the rotation of the progenitors of the SLSNe-I, the Type Ia supernovae (in a SLSN-I) are arranged in a disc with constant surface number density of them. We can assume as well that in SLSNe-I containing 2 or 4 the Type Ia supernovae, all supernovae are on a ring with the same radius – it is possible when there dominates interaction between SNe-Ia arranged symmetrically with respect to the centre of the SLSN-I. These remarks lead to following relations

$$T_{4,8,16} = F\, D_n^{\;1/2}\,, \tag{5a}$$

$$T_2 = T_4\,, \tag{5b}$$

where T_n is the time distance expressed in days between the initial and main explosions whereas $F \approx 14$ days is a constant that can be calculated from observational data presented in paper [5]. For SLSN-I containing 16 Type Ia supernovae we obtain ~56 days, for containing 8 supernovae we obtain ~40 days, whereas for containing 4 or 2 supernovae is ~28 days – it is consistent with observational data [5].

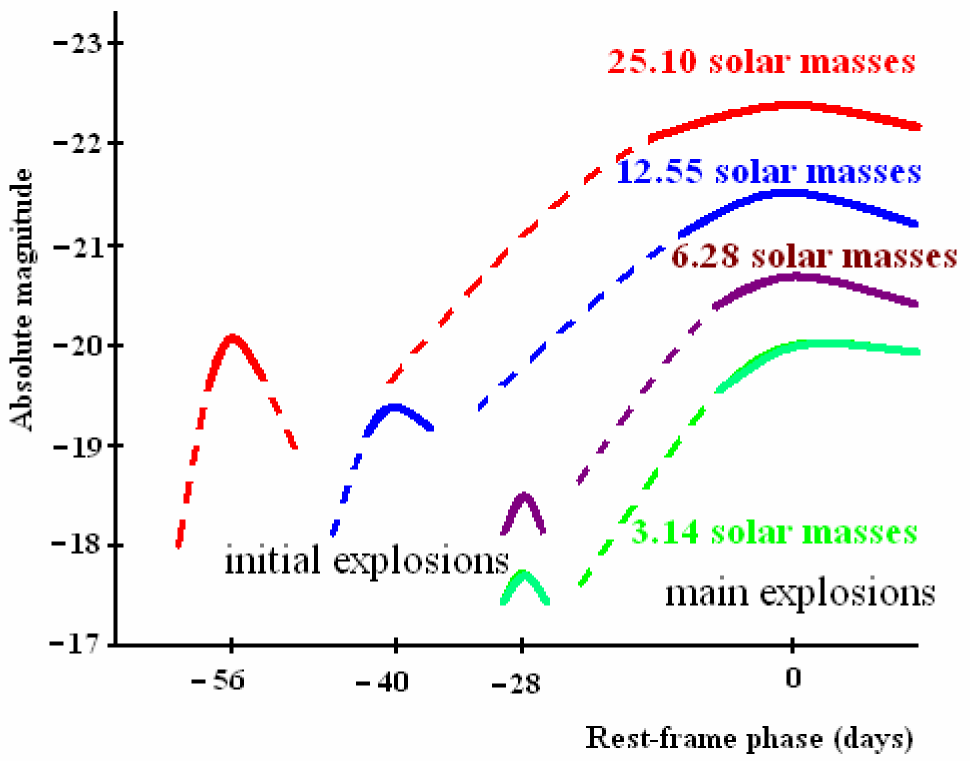

Fig. 1
Light curves for SLSNe-I derived within the Scale-Symmetric Theory (absolute magnitude as a function of the rest-frame phase)

7. Summary

Here, applying the Scale-Symmetric Theory (SST), we described the mechanism of the two-stage explosions of the hydrogen-poor Type I superluminal supernovae.

We calculated their quantized masses: 3.14, 6.28, 12.55 and 25.10 solar masses and maximum absolute magnitudes for the initial and main explosions.

Presented here mechanism within the SST solves the ejecta-velocity problem for SLSNe-I. We obtain 10,000 km/s – it is consistent with observational data.

The derived within SST light curves are consistent with observational data.

References

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