Optical photometry and preliminary modeling of Type IIb Supernova 2017gpn

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Abstract MASTER OT J033744.97+723159.0 (SN 2017gpn) was discovered in the error box of LIGO/Virgo alert G299232. The spectrum of SN 2017gpn is consistent with a Type IIb supernova. In this work we present the photometry of 20 epochs of observations performed with CCD photometer on the Zeiss-1000 telescope. The light curves in B and R filters were obtained. The multicolor light curves were also modeled numerically using the one-dimensional radiation hydrodynamical code STELLA.

Keywords: Supernovae: General – Supernovae: Individual: Sn 2017gpn – Stars: Evolution

1. Introduction

During follow-up inspection of the error box of the LIGO/Virgo alert G299232 on 2017 August 27.017, MASTER Global Robotic Net [7] discovered an optical transient named MASTER OT J033744.97+723159.0 [9], [10]. On 2017 September 6, M. Caimmi reported the discovery of a supernova with the 0.24-m telescope from Valdicerro Observatory [4]. The supernova received the IAU designation AT 2017gpn and was identified as MASTER OT J033744.97+723159.0.

On 2017 August 29, the spectrum of MASTER OT J033744.97+723159.0 was obtained with the Xinglong 2.16-m telescope of National Astronomical Observatory of China [11]. The object was classified as Type IIb Supernova (SN) by cross-correlating with a library of spectra (SNID, [3]). The spectra of SN IIb display hydrogen features at early phases with no evidence of helium. Helium features appear after about two weeks and they become stronger with time as the hydrogen features weaken rapidly. SN IIb has been proposed as an intermediate step between SN II and SN Ib [5]. The IIb Type supernovae arise from stars that have lost most of their hydrogen envelope because of powerful stellar winds or by interaction with a binary companion.

2. Observation and Data Reduction

We performed 20 epochs of observations (B and R filters) with CCD-photometer on the Zeiss-1000 telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences.

All data were processed using the MIDAS software package of the European Southern Observatory (ESO). It includes standard image processing such as bias subtraction and flat field correction, removing the traces of cosmic particles, and stacking of individual frames into the summary image, but we did not make dark reduction as its influence was negligibly small. The line-of-sight reddening is adopted to be $E(B-V) = 0.017$ mag [12]. SN 2017gpn is located in ~0.039 degrees (> 20 kpc) from the center of the potential host galaxy NGC1343, so the galaxy's contamination is negligible.

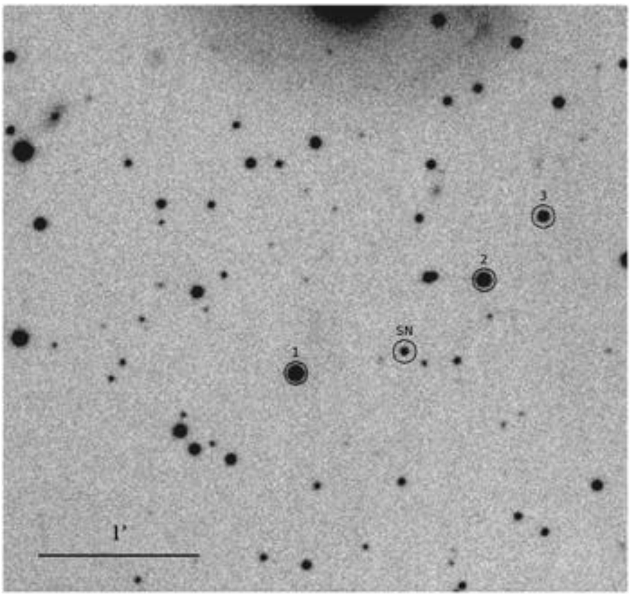

Fig1. *The image of SN 2017gpn and its host galaxy obtained with the Zeiss-1000 telescope of SAO RAS.*

3. Light curves

We performed the aperture photometry using standard procedures of ESO-MIDAS software package with an aperture diameter of four times the full width at half-maximum. The FWHM was measured for point sources at each epoch.

Since no Landolt or any other standard stars were available for this region, we used the Pan-STARRS magnitudes for comparison stars. The magnitudes of comparison stars were re-calculated from g, r, i to B, R with use of Lupton's transformation equations. For better modeling (see Sec. 4) the obtained light curves were also combined with publicly available data in B and R filters from the PIRATE robotic telescope [9]. The final light curves are shown in Fig. 2.

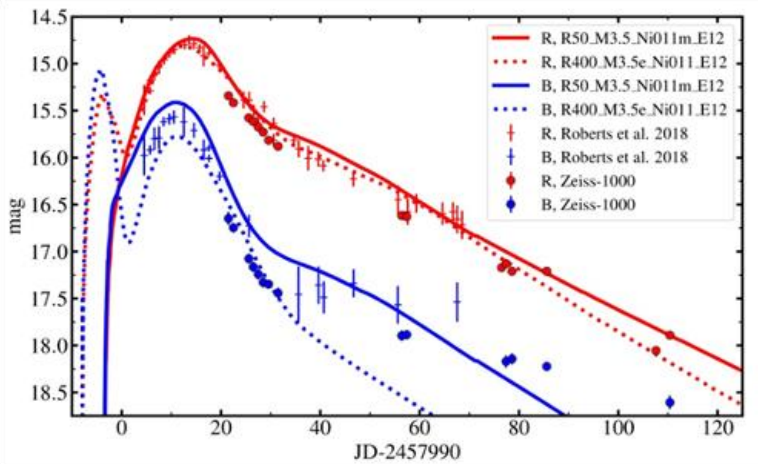

Fig2. *The results of modeling of SN 2017gpn (points are our data and crosses are the data taken from [9]). Our best-fit model is shown by solid lines (M =3.5 M⊙, R = 50 R⊙, E = 1.2 × 10^{51} erg, M_{56Ni} = 0.11 M⊙, mixed). For comparison the model with R = 400 R⊙ (M_{56Ni} = 0.11 M⊙, no mixing) is presented.*

3. Hydrodynamical Modeling

The numerical light curve modeling is performed with the one-dimensional multifrequency radiation hydrodynamical code STELLA. The full description of the code can be found in Blinnikov et al. [1], [2]; a public version of STELLA is also included with the MESA distribution [8].

In the current calculations we adopted 100 zones for the Lagrangian coordinate and 130 frequency bins. The main parameters we varied, were the pre-supernova star mass and radius, the energy of the explosion, the mass of synthesized nickel ^{56}Ni, and the mass of the resulting compact remnant. The compact remnant mass in the central part of the pre-supernova star with a fixed radius is treated as a point-like source of gravity that has a non-negligible influence on the expansion of the innermost layers of supernova ejecta. The ejecta of a supernova has the same chemical composition as a pre-SN star except for ^{56}Ni since STELLA does not calculate nucleosynthesis. The explosion is initiated by putting thermal energy into the innermost layers.

Our best-fit numerical model is shown by solid line in Fig. 2. The parameters of the model are: pre-SN mass M = 3.5 M⊙, pre-SN radius R = 50 R⊙, mass of hydrogen envelope M_{env} = 0.06 M⊙. The explosion energy is E = 1.2 × 10^{51} erg. The 0.11 M⊙ of ^{56}Ni is totally mixed through the ejecta. The compact remnant is a 1.41M⊙ neutron star. The parameters we found to be consistent with the results of hydrodynamical modeling of other typical Type IIb supernovae.

4. Discussion and Conclusions

Varying the model parameters. The parameters we found are consistent with the results of hydrodynamical modeling of other typical Type IIb supernovae. However, in different hydrodynamical models of SN IIb there is some variance in radius of pre-SN star (from 30-50 R⊙ to 700 R⊙, e.g., [1], [6], [13]). To check if it is possible to reproduce the observed light curves of SN 2017gpn with a model of higher radius, we changed the radius in our best-fit model to R = 400 R$_\odot$ and variated the degree of ^{56}Ni mixing. By putting all the ^{56}Ni in the central part of ejecta, we were able to nearly reproduce the observed light curves (Fig. 2). This stresses the importance of ^{56}Ni mixing in such kind of studies.

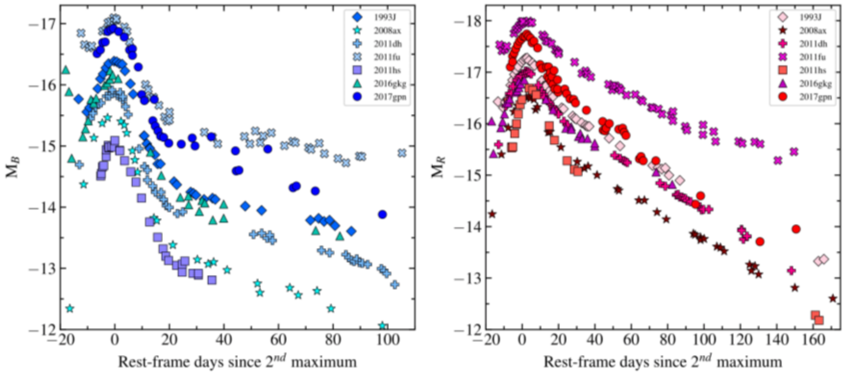

Fig3. *The classical light curves of Type IIb supernovae in B and R filters. The SN 2017gpn light curve is one of the brightest SNe IIb, its light curve behavior is similar to the others.*

Comparison with other SNe IIb. We also compared the resulting light curve with other classical and well-studied supernovae IIb light curves in B and R filters, this comparison is shown in Fig. 3. The shape of the light curve of SN 2017gpn is similar to the other typical SNe IIb light curves. Nevertheless, we noticed an interesting feature: SN 2017gpn is located rather far from its host galaxy, while the others are mainly exploded in spiral arms of their hosts (see Fig. 4).

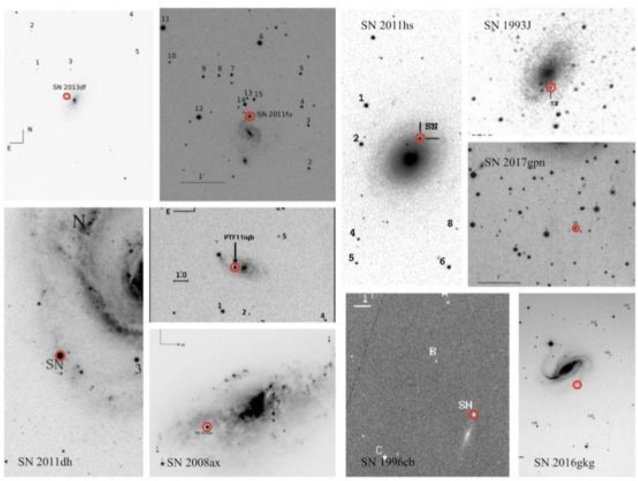

Fig4. *The location of classical Type IIb supernovae in their host galaxies.*

Connection with GW alert. By adopting the date of explosion from the models (Aug 20 for our best-fit model and Aug 16 for the model with R = 400 R$_\odot$), we can conclude that SN 2017gpn is unlikely to be connected to the LIGO/Virgo G299232 alert.

We obtained the multicolor light curve combining photometric data from Zeiss-1000 telescope of SAO RAS and the available data from the PIRATE telescope [9]. The light curves in B and R filters were modeled numerically using the one-dimensional radiation hydrodynamical code STELLA. We determined the values of the main parameters of the pre-supernova star, and these values are consistent with the results of hydrodynamical modeling of other typical Type IIb supernovae.

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References

[1] Blinnikov, S. I., Eastman, R., Bartunov, O. S., Popolitov, V. A., & Woosley, S. E. 1998, ApJ, 496, 454, doi: 10.1086/305375.

[2] Blinnikov, S. I., Röpke, F. K., Sorokina, E. I., et al. 2006, A&A, 453, 229, doi: 10.1051/0004-6361:20054594.

[3] Blondin, S., & Tonry, J. L. 2007, ApJ, 666, 1024, doi: 10.1086/520494.

[4] Caimmi, M. 2017, Transient Name Server Discovery Report, 973.

[5] Filippenko, A. V., Matheson, T., & Ho, L. C., 1993, ApJL, 415:L103.

[6] Folatelli, G., Bersten, M. C., Kuncarayakti, H., et al. 2015, ApJ, 811, 147, doi: 10.1088/0004-637X/811/2/147.

[7] Lipunov, V., Kornilov, V., Gorbovskoy, E., et al. 2010, Advances in Astronomy, 2010, 349171, doi: 10.1155/2010/349171.

[8] Paxton, B., Schwab, J., Bauer, E. B., et al. 2018, ApJS, 234, 34, doi: 10.3847/1538-4365/aaa5a8.

[9] Roberts, D., & Kolb, U. 2018, In: European Week of Astronomy and Space Science: RAS National Astronomy Meeting, 3-6 Apr 2018, Liverpool, UK.

[10] Rui, L., Wang, X., Xiang, D., Lin, H., & Wang, H. 2017a, GRB Coordinates Network, Circular Service, No. 21780, #1 (2017/August-31), 21780.

[11] Rui, L., Wang, X., Xiang, D., et al. 2017b, The Astronomer's Telegram, 10681.

[12] Schlafly, E. F., & Finkbeiner, D. P. 2011, ApJ, 737, 103, doi: 10.1088/0004-637X/737/2/103.

[13] Woosley, S. E., Eastman, R. G., Weaver, T. A., & Pinto, P. A. 1994, ApJ, 429, 300, doi: 10.1086/174319.