

ON THE SEARCH FOR SUPERNOVAE

BY F. ZWICKY

Several years ago Baade and I discussed the existence of a separate class of temporary stars whose luminosity at maximum surpasses that of ordinary novae by a factor of a thousand. We proposed to designate these stars as *supernovae* and we suggested that they possess the following characteristics.^{1,2}

1. The absolute average photographic magnitude of supernovae at maximum is of the order of $M = -14$, equaling that of the nebulae themselves.

2. The energy radiated from a supernova in the wave-length range from 6500 Å to 3800 Å during one year is of the order of 10^{48} to 10^{49} ergs.

3. The spectrum of a supernova is different from that of any other known stellar object. It consists essentially of very wide bands.

4. The frequency of supernovae is approximately equal to one supernova per average nebula per several centuries.

5. The absolute surface temperature of the central star in a supernova is at least several hundred thousand degrees.

6. Supernovae are an origin of cosmic rays.

7. We suggested tentatively that the cause of the supernova process is to be sought for in the transformation of an ordinary star which is composed mainly of electrically charged particles into a *collapsed neutron star* of enormous density (10^{14} gm/cm³) and exceedingly small stellar radius (10^6 cm).

In order to test these conclusions a systematic search for supernovae has been conducted with the 18-inch Schmidt telescope on Palomar Mountain. As a result of this search three supernovae were found which appeared in the extragalactic nebulae NGC 4157, NGC 1003, and IC 4182, respectively. (Photographs of the supernovae in IC 4182 and NGC 1003 are reproduced in Plate XXII, *a* and *b*.) The supernova in IC 4182 is the brightest stellar object ever observed. Detailed

¹ W. Baade and F. Zwicky, *Phys. Rev.*, **45**, 138, 1934; **46**, 76, 1934; *Proc. N.A.S.*, **20**, 254, 1934; **20**, 259, 1934.

² F. Zwicky, *Sci. Mon.*, **40**, 461, 1935; *Proc. N.A.S.*, **22**, 457, 1936; **22**, 557, 1936; *Publ. A.S.P.*, **48**, 191, 1936; **49**, 204, 1937.

investigations of this supernova as well as of the supernova in NGC 1003 have yielded a large number of data which leave no doubt that conclusions 1, 2, and 3 stated above are correct. From the new material the frequency of occurrence of supernovae has been determined. This frequency corresponds to one supernova per average nebula per six centuries, a value in agreement with conclusion 4. The dependence of the frequency on the absolute magnitude of common novae and of supernovae has furnished new evidence which supports the view that the processes which

DESCRIPTION OF PLATE XXII

a) SUPERNOVA IN IC 4182

1. April 10, 1937:

Shows very faintly the extragalactic nebula IC 4182 before the appearance of the supernova. According to Baade the distance modulus of IC 4182 is $m_N - M_N = 24.8$, corresponding to a distance of about three million light-years. Since the apparent photographic magnitude is $m_N = 13.5$, the absolute magnitude is $M_N = -11.3$, which indicates that IC 4182 is a dwarf system.

2. August 26, 1937:

The same field as 1 with the supernova about four days after maximum. The apparent and the absolute magnitudes of the supernova at this stage were $m_s = 8.4$ and $M_s = -16.4$, respectively.

3. December 31, 1937: $m_s = 13.1$

4. June 8, 1938: $m_s = 15.6$

b) SUPERNOVA IN NGC 1003

1. September 10, 1937:

Shows the extragalactic nebula NGC 1003 with the supernova near maximum brightness. According to Baade the distance modulus of NGC 1003 is $m_N - M_N = 26.8$. The distance of NGC 1003 after corrections for partial obscuration have been applied is about 4.5 million light-years. The absolute magnitude $M_N = -13.7$ indicates that NGC 1003 is a system of average brightness. The apparent and the absolute magnitudes of the supernova at this stage were about $m_s = 13.0$ and $M_s = -13.8$, respectively.

2. October 30, 1937: $m_s = 15.7$

3. December 29, 1937: $m_s = 17.0$

4. February 25, 1937: $m_s = 17.4$

The magnitudes are all photographic. I am indebted to Edison R. Hoge of the Mount Wilson Observatory for the enlargements of the original negatives taken with the 18-inch Schmidt telescope and for their arrangement in Plate XXII.

cause the outburst of common novae and of supernovae, respectively, are essentially different ones.

In regard to the suggestions described under 5, 6, and 7, so far only some indirect arguments can be advanced. Before any definite progress can be made it will be necessary to find the correct interpretation of the spectra of supernovae, a problem which has defied solution.

If our hypothesis of the neutron cores of supernovae is correct, enormous gravitational red shifts should be observable in the light from the central star of a supernova. I am indebted to Dr. R. Minkowski for permission to mention here the following remarkable unpublished fact which he discovered in the spectrum of the recent supernova in IC 4182. All of the permanent characteristic features of this spectrum have been gradually shifted toward the red by about 100 Å. On our hypothesis we may interpret this shift tentatively as a gravitational red shift. If we assume that the central star has a proper mass $\mathcal{M} = 2 \times 10^{33}$ gm, we arrive at a radius $r = 74$ kilometers for this star and an average density $\rho = 1.2 \times 10^{12}$ gm/cm³. Since the supernova at that stage was still about one million times as bright as the Sun, the temperature of the neutron core must have been at least $T = 1.8 \times 10^7$ degrees. If we assume for the central star $\mathcal{M} = 10^{35}$ gm, which must probably be regarded as the largest possible stellar mass, we derive for the radius, the density, and the temperature of the central star the values, $r = 3700$ km, $\rho = 4.7 \times 10^8$ gm/cm³, and $T = 2.5 \times 10^6$ degrees, respectively.

On the neutron star hypothesis a supernova outburst may very rapidly transform a star of average brightness into a body of exceedingly low brightness. It can thus perhaps be understood why the remains of possible supernovae, such as Tycho's star, which flared up in our galaxy only a few centuries ago, have not yet been found.

CALIFORNIA INSTITUTE OF TECHNOLOGY
June 1938