be a minor one. In *Gloeocapsa montana* there occurs nothing of the nature of complementary chromatic adaptation.

* The glow-tubes were furnished through the courtesy of the Electrical Products Corporation, Los Angeles.

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ON SUPER-NOVAE

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A. Common Novae.—The extensive investigations of extragalactic systems during recent years have brought to light the remarkable fact that there exist two well-defined types of new stars or novae which might be distinguished as *common novae* and *super-novae.* No intermediate objects have so far been observed.

Common novae seem to be a rather frequent phenomenon in certain stellar systems. Thus, according to Bailey,[1] ten to twenty novae flash up every year in our own Milky Way. A similar frequency (30 per year) has been found by Hubble in the well-known Andromeda nebula. A characteristic feature of these common novae is their absolute brightness (M) at maximum, which in the mean is -5.8 with a range of perhaps 3 to 4 mags. The maximum corresponds to 20,000 times the radiation of the sun. During maximum light the common novae therefore belong to the absolutely brightest stars in stellar systems. This is in full agreement with the fact that we have been able to discover this type of novae in other stellar systems near enough for us to reach stars of absolute magnitude -5 with our present optical equipment

B. Super-Novae.—The novae of the second group (super-novae) presented for a while a very curious puzzle because this type of new star was found, not only in the nearer systems, but apparently all over the accessible range of nebular distances. Moreover, these novae presented the new feature that at their maximum brightness they emit nearly as much light as the whole nebula in which they originate. Since the investigations of Hubble and others have revealed that the absolute total luminosities of extragalactic systems scatter with rather small dispersion around the mean value $M_{vis} = -14.7$, there is no doubt that we must attribute to this group of novae an individual maximum brightness of the order of $M_{vis} = -13$.

A typical specimen of these super-novae is the well-known bright nova which appeared near the center of the Andromeda nebula in 1885 and reached a maximum apparent brightness of $m = 7.5$. Since the distance modulus of the Andromeda nebula is

$$m - M = 22.2, \tag{1}$$

the absolute brightness of the nova at maximum was $M = -14.7$. An integration of the light-curve shows that practically the whole visible radiation is emitted during the 25 days of maximum brightness and that the total thus emitted is equivalent to 10^7 years of solar radiation of the present strength.

Finally, there exist good reasons for the assumption that at least one of the novae which have been observed in our Milky Way system belongs to the class of the super-novae. We refer to the abnormally bright nova of 1572 (Tycho Brahe's nova).[2]

About the final state of super-novae practically nothing is known. The bright nova of 1885 in the Andromeda nebula has faded away and must now be fainter than absolute magnitude -2. Repeated attempts to identify the nova of 1572 with one of the faint stars near its former position have so far not been very convincing.

Regarding the initial states of super-novae only the following meager facts are known. First, super-novae occur not only in the blurred central parts of nebulae but also in the spiral arms, which in certain cases are clearly resolved into individual stars. Secondly, the super-nova of 1572 in its initial stage probably was not brighter than apparent magnitude 5 as otherwise it would be registered as such in the old catalogues, which, however, is not the case.

Super-novae are a much less frequent phenomenon than common novae. So far as the present observational evidence goes, their frequency is of the order of one super-nova per stellar system (nebula) per several centuries.

We believe that on the basis of the available observations of super-novae the following assumptions are admissible:

(1) Super-novae represent a general type of phenomenon, and have appeared in all stellar systems (nebulae) at all times as far back as 10^9

years. To be conservative we shall assume for purposes of calculation that in every stellar system only one super-nova appears per thousand years.

(2) Super-novae, initially, are quite ordinary stars whose masses are not greater than 10^{33} gr. to 10^{35} gr.

(3) The super-nova of 1885 in Andromeda is a fair sample. We therefore base our calculations on the characteristics observed for this super-nova, namely:

(α) At maximum the visible radiation L_V emitted per second is equal to that of 6.3×10^7 suns. The radiation from our sun is

$$L_{\odot} = 3.78 \times 10^{33} \text{ ergs/sec.} \tag{2}$$

Therefore

$$L_V = 6.3 \times 10^7 L_{\odot} = 2.38 \times 10^{41} \text{ ergs/sec.} \tag{3}$$

The *total* visible radiation which was emitted by our super-nova represents an energy $E_V = 10^7$ years of $L_{\odot}$, that is

$$E_V = 1.19 \times 10^{48} \text{ ergs.} \tag{4}$$

(β) A common nova reaches maximum brightness in about two to three days. Indications are that a super-nova reaches maximum brightness during about the same interval.

C. Total Radiation from a Super-Nova.—In order to obtain an estimate of the total radiation, visible and invisible, from a super-nova, we consider two idealized limiting cases.

First Case.—We assume that the observed L_V corresponds to the integrated red end of a black body radiation of the effective temperature T_e, which we proceed to determine. We shall later make use of the further assumption that the total energy emitted from the super-nova is at least as great as that of the black body radiation at the temperature T_e, the red end of which is equal to that of the observed visible radiation from the super-nova. The integration over the red tail will be taken from the frequency $\nu = 0$ to the violet end ν_v of the visible spectrum; that is, to $\nu_v = 7.5 \times 10^{14}$ sec.$^{-1}$. The temperature resulting from our calculations justifies the introduction of the Rayleigh-Jeans law, namely,

$$I_\nu = \frac{2\pi k T_e \nu^2}{c^2}, \tag{5}$$

into the integration mentioned, so that

$$L_V = S \int_0^{\nu_v} I_\nu d\nu = 1.34 \times 10^8 \, S T_e, \tag{6}$$

where S is the surface of the super-nova. If the initial stage (i) of the super-nova is a star similar to our sun, its radius would be

$$R_i = 6.95 \times 10^{10} \text{ cm.} = R_{\odot}. \qquad (7)$$

At maximum brightness our super-novae will be considerably blown up and its radius R must then be considerably greater than $R_{\odot}$. Reasons can be advanced, however, for supposing that probably

$$R < 100\, R_{\odot} = R_1, \qquad (8)$$

and that almost certainly

$$R < 400\, R_{\odot} = R_2. \qquad (9)$$

This estimate of the radius R of a super-nova at maximum brightness is based on a comparison with common novae.[3] Roughly speaking, a common nova radiates like a black body until a radius R_m is reached such that

$$R_1 < R_m < R_2. \qquad (10)$$

For $R = R_m$ the brightness of the common nova is at its maximum. For $R > R_m$ extremely wide (50 to 100 Å) emission lines appear and gaseous shells are expelled from the nova at great speeds. Also the brightness of the nova declines; on the other hand the observed ionization of the gaseous shells indicates that a vast amount of ultra-violet radiation is emitted at this stage of the expansion. Furthermore, there are indications that R_m is the smaller the greater the speed with which the nova initially blows up. As a super-nova blows up faster than a common nova, we feel safe in assuming that R_m for a super-nova cannot be greater, and probably is smaller, than R_m for a common nova. To be conservative, we shall carry out our calculations for the two cases

$$R_m = R_1 = 7 \times 10^{12} \text{ cm. and } R_m = R_2 = 2.8 \times 10^{13} \text{ cm.} \qquad (11)$$

The corresponding surfaces are

$$S_1 = 6.15 \times 10^{26} \text{ cm.}^2 \text{ and } S_2 = 9.84 \times 10^{27} \text{ cm.}^2 \qquad (12)$$

With these figures we obtain from (6), (8) and (9) the effective surface temperature

$$\left.\begin{aligned} T_e &= L_V/1.34 \times 10^8 S = 1.78 \times 10^{33}/S, \\ T_1 &= 2.89 \times 10^6 \text{ degrees}, \ T_2 = 1.81 \times 10^5 \text{ degrees}. \end{aligned}\right\} \quad (13)$$

From T we obtain the total radiation per second from our sample super-nova:

$$\left.\begin{aligned} L_T &= S\frac{ac}{4}T_e^4 = 1.80 \times 10^{-37} L_V^4 S^{-3} = 5.75 \times 10^{128}\, S^{-3} \\ L_{T_1} &= 2.46 \times 10^{48} \text{ ergs/sec.}, \ \ L_{T_2} = 5.98 \times 10^{44} \text{ ergs/sec.}, \end{aligned}\right\} \quad (14)$$

where $a = 7.63 \times 10^{-15}$ ergs is the Stefan-Boltzmann radiation constant, and c the velocity of light. The total energy emitted during the existence of the super-nova therefore is of the order of

$$\left.\begin{aligned} E_T &= L_T E_V/L_V = 5 \times 10^6 L_T \\ E_{T_1} &= 12.3 \times 10^{54} \text{ ergs}, \quad E_{T_2} = 2.99 \times 10^{51} \text{ ergs.} \end{aligned}\right\} \quad (15)$$

These values correspond to a loss of mass

$$\Delta M = E_T/c^2, \quad \Delta M_1 = 1.37 \times 10^{34} \text{ gr.}, \quad \Delta M_2 = 3.32 \times 10^{30} \text{ gr.} \quad (16)$$

In reality the mass radiated away may be several times this amount, and it therefore becomes evident that *the phenomenon of a super-nova represents the transition of an ordinary star into a body of considerably smaller mass.*

Second Case.—It might be objected that we have far over-estimated the effective temperature T_e of the super-nova, inasmuch as the surface, for some reason or other, may be so large that approximately $L_T = L_V$, in which case T_e would be approximately equal to the effective temperature of the sun. As the maximum of L_V corresponds to about 7×10^7 times the radiation from the sun, the radius R of the super-nova at maximum brightness would be

$$R = 8.36 \times 10^3 R_\odot = 5.81 \times 10^{14} \text{ cm.} \quad (17)$$

If the super-nova is initially an ordinary star which in about one day blows up to the radius R, the velocity of expansion of the surface will be of the order of

$$v = 6.72 \times 10^9 \text{ cm./sec.}, \quad (18)$$

which, per *proton*, gives the kinetic energy

$$E_K = m_p v^2/2 = 0.05\, m_p c^2. \quad (19)$$

It appears, therefore, that the kinetic energies E_K of the individual particles would be quite comparable with the energy of annihilation mc^2 of these particles.

Furthermore, in order to produce such energies, the radiation trapped inside the opaque surface must correspond to average temperatures T_i which are considerably higher than T_e. From this it would follow that the energy of the trapped radiation $\left(\frac{4\pi}{3} R^3 a T_i^4\right)$ alone is comparable with energy of total annihilation of the star (10^{54} ergs).

The above considerations seem to indicate that in any case the total energy emitted in the super-nova process represents a considerable fraction of the star's mass. We also think that our case (1) corresponds more nearly to the reality than does case (2). A more detailed discussion of the super-nova process must be postponed until accurate light-curves and high-dispersion spectra are available.

Unfortunately, at the present time only a few underexposed spectra of super-novae are available, and it has not thus far been possible to interpret them.

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[1] S. I. Bailey, *Pop. Astr.*, **29,** 554 (1921).

[2] K. Lundmark, *Kungl. Svenska Vetensk. Handlingar,* **60,** No. 8 (1919).

[3] *Handbuch d. Astrophysik,* Vol. VI (Novae).

COSMIC RAYS FROM SUPER-NOVAE

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A. Introduction.—Two important facts support the view that cosmic rays are of extragalactic origin, if, for the moment, we disregard the possibility that the earth may possess a very high and self-renewing electrostatic potential with respect to interstellar space.

(1) The intensity of cosmic rays is practically independent of time. This fact indicates that the origin of these rays can be sought neither in the sun nor in any of the objects of our own Milky Way.

(2) The decrease in intensity of cosmic rays in equatorial regions has successfully been explained by assuming that at least a part of the rays consists of very energetic, positively or negatively charged particles. These particles must be of extra-terrestrial origin, as otherwise the distance traversed by them would not be long enough for the earth's magnetic field to produce the observed dip in intensity at the equator.

From the fact that in the cloud-chamber experiments no protons or charged particles heavier than electrons have been observed in any considerable number, one might conclude that the corpuscular component of cosmic rays consists of positive or negative electrons, or both. The characteristics of the east-west effect indicate that the positively charged particles far outnumber the negatives. However, whether or not these particles are electrons cannot as yet be said with certainty, since the electrons which are observed in cloud chambers may all be secondary particles formed in the earth's atmosphere by different primaries.

With the facts mentioned as a beginning it has become customary to reason approximately as follows. Since none of the objects of our Milky Way seem to produce any cosmic rays, these rays probably are not emitted from any of the extragalactic nebulae either, as the spirals among these