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Abstract

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THE SUPERNOVA OF 1054—A BINARY STAR?

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During the last two decades (more precisely, since the works of Baade ([1]) and Minkowski ([2])) it has been assumed that one of the two close 15th-magnitude stars located in the central part of the Crab Nebula may be the former Supernova. True, this assumption was never seriously substantiated, but was made mainly because of the central position of this star. According to ([1]), the color index of the star is 0.14, which corresponds to spectral class F1. The energy distribution in its spectrum then obtained by Minkowski indicated a fairly high spectrophotometric temperature, which served as an additional argument in favor of the assumption that this star was the former Supernova. Recently, however, Kraft found H and K lines in its spectrum and concluded that it is an ordinary class-F star, accidentally projected onto the Crab Nebula and not genetically connected with it ([3]). According to ([3]), there is no star brighter than 18^m at the center of the Crab Nebula.

However, a more careful analysis of the question makes one doubt the validity of this conclusion. It is hardly possible, for example, to regard as accidental the central position of the star with respect to the Crab Nebula. The physical center of the Crab Nebula, understood as the region where the source of the activity continuing to this day and of the powerful energy release is located, is determined fairly well. On the basis of an analysis of Baade' s known observations (see ([4])), as well as of unpublished photographs by Minkowski, one may assert that the source of activity of the Crab Nebula is located in a region that includes the central star and has a radius smaller than $3''$. On the other hand, according to the data of stellar statistics, in the region of the galactic equator the mean density of 15th-magnitude stars is ~ 0.5 star per square minute. It follows directly from this that the probability of the accidental falling of a 15th-magnitude star into a small region of radius $3''$ is less than 10^{-2}. To this it should also be added that the star of interest to us has spectral class F. It is easy to verify that only stars of this spectral class having an apparent photovisual magnitude of 15.5 ([1]) can be at a distance equal to the distance to the Crab Nebula (1.4 kpc). In doing so one must take into account an interstellar

absorption of light of $\sim 1^m$.

The a priori probability that a star of type F is located by chance in the region of the physical center of the Crab Nebula is close to 10^{-3}. This compels us to make the basic assumption that the F star and the Crab Nebula are genetically connected.

On the other hand, the trivial character of this star apparently excludes the supposition that it is the former Supernova. In such a situation it is natural to put forward the hypothesis that the observed star is one of the components of a binary system, while the second component flared up as the Supernova and at present is not observed optically. There is one remarkable circumstance which apparently confirms our hypothesis. Baade ([1]) already drew attention to the comparatively large proper motion of the star that had earlier been assumed to be the former Supernova.

In fact, according to Duncan ([5]), the proper motion of this star is $\mu_\alpha = -0''.019$, $\mu_\delta = 0''.000$, whereas for another nearby star in the central region of the Crab Nebula $\mu_\alpha = 0''.000$, $\mu_\delta = 0''.002$. The old Pulkovo measurements by Deich and Lavdovsky agree well with Duncan' s results, giving for the star of interest to us $\mu_\alpha = -0''.018$, $\mu_\delta = 0''.002$ ([6]). Recently Deich and Chudovicheva repeated the measurements, using a new epoch, and confirmed this result. The probable error of the measurements described above does not exceed $\pm 0''.003$. Let us note that, according to ([1]), on the basis of van Maanen-Baade observations $\mu_\alpha = -0''.010$, i.e., half as large. However, this result is at variance with the three independent measurements described above and carries little weight. It is interesting that the proper motion of the entire system of filaments of the Crab Nebula, according to ([5]), is close in magnitude and has the same sign: $\mu_\alpha = 0''.022 \pm 0''.007$. This result, however, is not confirmed by the recent measurements of Deich and Chudovicheva.

If the distance to the class F star is equal to the distance to the Crab Nebula, then the tangential component of its peculiar velocity is about 130 km/sec, which exceeds by a factor of 5-6 the velocity dispersion for type F stars. Such a large value of the peculiar velocity can be explained in the same way as Blaauw recently explained the nature of rapidly moving type O stars ([7]). Namely, after the explosion of one of the components of a binary system, in which a large part of its mass is ejected, and at enormous speed, the second component will move while retaining an almost unchanged orbital velocity. If, for example, we suppose that the initial masses of both components were equal and were each $1.3\,M_\odot$, then from the condition that the circular velocity was equal to the observed space velocity of the unexploded component ($\sim$ 150 km/sec, taking into account the as yet unknown radial velocity), the separation between the components before the explosion was $\sim 4 \cdot 10^{11}$ cm, or $\sim 6\,R_\odot$ (assuming that the orbit is circular). The star—the remnant of the explosion—will in almost all cases move together with the unexploded star, and its orbit may undergo substantial changes (for example, become strongly elliptical).

We clearly see the difficulties with which our hypothesis is faced. The principal ones are the following: a) the mass of the gases ejected in the explosion must be close to the mass of the Sun, whereas existing estimates of the mass of the gaseous envelope of the Crab Nebula give a value an order of magnitude smaller (see, for example, ([8])); b) the law of conservation of momentum requires that the velocity of motion of the center of gravity of the gaseous envelope ejected in the explosion be opposite to the velocity of the star, which may contradict the available observations (see above).

Difficulty a) can be removed by the assumption that a large part of the mass of the filaments of the Crab Nebula consists of neutral gas. Let us note that the presence of the line λ6300 (OI) in the spectrum of the Crab Nebula supports this assumption. There are several ways of overcoming difficulty b), which we shall not discuss here, especially since the question of the proper motion of the Crab Nebula still remains open.

The supposition that the Supernova of 1054 was a close binary system opens up new possibilities for interpreting phenomena in the Crab Nebula. In particular, if accretion of gases by the contracted star is regarded as the cause of the continuing activity of the nucleus of the Crab Nebula ([9]), then the observed $\sim$ 60-day periodicity of metamorphoses in the central part of the Crab Nebula ([4]) can be explained by the motion of the remnant of the explosion—the collapsed star—in a very elongated ellipse around the observed F star. The orbital period is $\sim$ 60 days, and at periastron the stars come very close together. Such a close approach may lead to the ejection from star F of powerful streams of gas, which will fall onto the collapsed star. The process of such ejection will—

has a duration on the order of several hours, after which a relatively quiet two-month period begins.

It is not excluded that the phenomenon of binarity, or of multiplicity in general, is a fundamental property of all exploding stellar objects. In particular, this may also be the case for supernovae. It may be that the 13-year period of luminosity variations of 3C-273, as well as the emerging 3-5-year period of brightness variations of 3C-48 [(10)], are explained by periodic changes in accretion as collapsed objects move in eccentric orbits. It is also appropriate to recall that ordinary novae are close binary systems [(11)].

As for the hypothesis of binarity of the nucleus of the Crab Nebula, to test it one needs, first of all, careful and long-term spectrophotometric, as well as electrophotometric, observations of the star located at the center of the nebula. Such observations, for example, could provide indications of spectral binarity, the presence of outbursts recurring every $\sim$ 60 days, and certain other possible peculiarities.

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Note: Figure translations are in progress. See original paper for figures.