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ON THE NATURE OF THE SOURCES OF HARD PULSE X-RAY RADIATION

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Since December of 1975 the attention of the astronomical community has been drawn to observations of bursts of X-ray radiation by the actively operating X-ray observational satellites "ANS," "SAS-3," and "Ariel-5." [1], [2], [3], [4], [5]. Prior to this there had been a significant number of observations of bursts in the higher-energy spectral range from 40 to 290 keV by the Soviet satellite "Cosmos-428" [6], [7]. And even earlier very strong bursts in the lower range of the gamma-ray spectrum had been received by the "Vela" series of satellites. These "gamma-ray bursts" excited a great deal of attention, with investigations being conducted over a broad range of the electromagnetic spectrum. However, the poor angular resolution of the measuring instruments prevented the identification of the "gamma-ray bursts" with any known astronomic object. /4*

An important first step was accomplished at the end of 1975 by Soviet and Dutch researchers who, working with data from the "Cosmos-428" and "ANS" satellites, definitely identified one of the burst sources as the globular cluster NGC 6624

*Numbers in the margin indicate pagination in the foreign text.

[7],[10]. Shortly after this a second source of bursts was identified as the globular cluster NGC1851, and at the location of the very interesting burst source MXB 1730-335 Liller discovered a new globular cluster, hitherto unknown due to strong interstellar absorption of light.[10] In addition, Melioranskii et al., on the basis of data obtained in 1971 by the satellite "Cosmos-418" identified three more sources of burst radiation as the globular clusters NGC 5904 (M5), NGC 6388, and NGC 6541 [11].

Let us extend these identifications of burst sources as globular clusters using the data provided in the monograph of B. V. Kukarkin [12]. Although the accuracy of the coordinates of the sources of burst radiation is not very great in the majority of cases (it varies from 10 to 170 degrees of solid angle), the process of identifying the sources with globular clusters, which are all widely-spaced objects par- /5
ticularly remote from the central regions of the galaxy, is sufficiently reliable to be persuasive. Thus the source in the constellation Norma observed by "Vela-5" [13] (probable error of location $\approx$10 degrees solid angle) may most probably be attributed to one of two neighboring globular clusters, either NGC 5927 (α = 15h 24.4m, $\delta = -50^{\circ}\ 29'$) or NGC 5946 ($\alpha$ = 15h 31.8m, $\delta = -50^{\circ}\ 3'$). Since the first cluster has a considerably greater luminosity ($m_V = 7.95$) it is the more likely candidate to be identifed as the source of bursts in

Norma. All other globular clusters in this region of the galaxy are located far beyond the limits of location of the source of burst radiation.

The source in the constellation Aquila observed by "SAS-3" ($\alpha = 19h\ 30m$, $\delta = +8^{\circ}$), with a probable error of location of ≈ 150 degrees solid angle, may be identified either with NGC 6838 (M71) ($\alpha = 19h\ 51m$, $\delta = +18^{\circ}\ 41'$) or with the 0.8-magnitude weaker object, NGC 6760 ($\alpha = 19h\ 08.6m$, $\delta = +1^{\circ}$). Finally, the source in Puppis, also observed by "SAS-3", ($\alpha = 7h\ 35m$, $\delta = -50^{\circ}$, probable error of location ≈ 170 degrees solid angle) with NGC 2298 ($\alpha = 6h\ 47m$, $\delta = -36^{\circ}$). Although none of these identifications, of course, can be regarded as definitive, the fact that all three peculiar sources are located in the neighborhood of globular clusters, in addition to the fact that other sources of this type are identified with globular clusters, significantly increases the probability of the proposed identifications. Thus, of the list in [5] of sources of high-energy burst radiation observed by "ANS," "SAS-3," and "Ariel-5," comprising 10 objects, 6 have been identified with globular clusters. In addition, three of the remaining four unidentified sources are in the region of the galactic nucleus (MXB 1743-293, 1742-297, 1728-34) and may be globular clusters concealed by layers of interstellar dust absorbing their light [10] (other possible interpretations are discussed below). /6

To this may be added three identifications performed not long ago by A.S. Melioranskii and his coworkers [11]. Thus it is possible to maintain that a substantial portion, if not the majority, of observed sources of high-energy pulse radiation have been identified as globular clusters.

We consider the so-called "gamma-ray bursts" observed by the "Vela" and other satellites to represent the same phenomenon as the X-ray bursts observed by the "Cosmos-428," "ANS," "SAS-3," and "Ariel-5" satellites. The following facts support this contention:

a.) The duration of appearance (1-100 seconds) is the same in both instances;

b.) In a number of cases both the gamma-ray and X-ray bursts display structure (for example, come in pairs);

c.) Although the bursts observed by "Vela" displayed a higher energy spectrum ($kT \approx 150$ keV) than typical X-rays ($kT \approx 50$ keV), this is a natural result of the observational receptivity. The detectors installed on the "Vela" satellites could only record high-energy ($E > 150$ keV) bursts. It must be emphasized that the spectra of the X-ray bursts were of a relatively high energy. The detectors installed on "Cosmos-428" only recorded high-energy X-ray radiation. Bursts of high-energy spectra were also received by "Ariel-5" from the source identified as the globular cluster MVB

1730-335 [15];

d.) The value of the flux from the brightest X-ray sources ($\approx 10^{-5}$ erg/cm^2/sec [11]) was equivalent to the flux from the intense gamma-ray bursts.

e.) The frequency of bursts of gamma-rays is compatible /7 with the frequency of the X-ray bursts.

If the bursts of both gamma-ray and X-ray radiation represent the same cosmic events, then it is reasonable to expect to associate some of the gamma-ray bursts with globular clusters. Although the accuracy of the determination of the coordinates of the sources of gamma-ray bursts is not very great, in a number of cases, as we shall now see, such an identification can be accomplished.

Of the four gamma-ray bursts for which exact and unambiguous coordinates are available in [16], three (70-2, 67-1, and 69-2) can be identified respectively as originating from the globular clusters NGC 5694, NGC 4147, and NGC 288. Even more certain is the identification of the extremely interesting gamma-ray burst ($I = 2 \times 10^{-4}$ erg/sec, $\Delta t = 27$ sec.), observed 27 April 1972 at the coordinates $\alpha \approx 23$h, $\delta = -68^{\circ}$ [17], as the intense globular cluster 47 Tucan (α = 0h 21m, $\delta = -72^{\circ}21'$). Finally, one cannot deny the possible identification of the gamma-ray burst observed on 1 November 1972 [18] as originating from the rather intense globular cluster NGC 1904 (M79).

On the other hand we must emphasize that the very intense gamma-ray burst observed on 14 May 1972, perhaps the best-investigated of all bursts ($I = 5 \times 10^{-4}$ erg/cm^2, $\Delta t = 80$ sec, $\alpha = 11^h 50^m$, $\delta = 74°5' \pm 4°$) [8], occurred at a point at least 40° distant from the nearest known globular cluster. In addition, the characteristics of this burst are indistinguishable from those observed in other strong bursts. This means that among the observed gamma-ray bursts (and in particular also among those for which we assigned a probable identification above), a significant portion might not be associated with globular clusters. However, we should recall that the investigation of X-ray bursts showed that a substantial portion, if not the majority, of the sources of these bursts /8 are identified as globular clusters. The important consequences resulting from this "dualism" of burst sources will be considered below.

Might the burst sources in globular clusters have something to do with the type of stellar population found there? The question of the nature of the X-ray sources detected by the "Uhuru" satellite in globular clusters had become acute in 1975, before the discovery of their burst-like character. The relatively high, that is, per stellar mass, frequency of sources in globular clusters was striking in comparison to the galaxy as a whole. As explanations for this effect, two hypotheses were proposed: a.) In the

originally densely-packed central regions of globular clusters there were formed a great number of closely-bound double star systems with a neutron star as one component in each pair [19].
b.) In the center of globular clusters are black holes with masses on the order of several hundred solar masses [20,21]. As a foundation for these hypotheses it was pointed out that in the intense globular clusters which were sources of X-ray radiation there were high parabolic velocities and an elevated concentration of matter towards the center. The discovery of the burst-like nature of the X-ray sources located in globular clusters sharply intensified the problem. While earlier attention had been drawn by the fact that ≈3% of all sources were located in clusters while clusters contain only ≈0.1% of the mass of the galaxy, now it became clear that the majority of burst sources were in globular clusters. On the other hand it is typical that in all of the globular clusters there are perhaps 1,000 of the short-period Cepheid variables of the RR Lyrae type, while the sphere of the galaxy contains 500,000 of them. This naturally has implications for all the other stellar populations in globular clusters: their total in clusters must be several hundred times less than in the spherical stellar corona of the galaxy. There- /9
fore from the fact that a substantial portion, if not the majority, of the burst sources are located in globular clusters, it follows that it is impossible to identify the

sources of burst radiation with any class of population of stars, either in the globular clusters or in the galactic "halo." The hypothesis expressed in [19] is refuted by the simple fact that in the neighborhood of the galactic nucleus, where the stellar density is at least twice as high as that in the center of globular clusters and where it would seem conditions would be much more favorable for the formation of closely-bound binary stars by capture, the predicted large number of burst sources is not observed. Such characteristics of the sources of burst radiation as a very high-energy spectrum and a strong energy flux (up to 10^{41} erg/sec [7]), differ completely from the characteristics of X-ray sources such as Hercules X-1, Scorpio X-1, and others, which according to [19] should be formed in globular clusters.

All this suggests that the sources of burst radiation are very peculiar objects whose nature is completely distinct from the tightly-bound double "X-ray" systems discovered by "Uhuru." The burst sources must be intimately connected to globular clusters, each one of which must be regarded as a single unit. Along these lines, it is proposed that these sources of burst radiation must be black holes, located in the centers of globular clusters, of $\approx 10^2$-10^4 solar masses [20], [21]. This value for the mass is implied by the fact that, for an average power output by the source of $\approx 10^{39}$ erg/sec (see [11]), the stream of accretion causing the high-energy radiation must be $\approx 10^{19}$ gr/sec, and if the age of the source is $\approx 3 \times 10^{9}$ years (probably less), then the total captured gas will be $\approx 10^{36}$ gr $\approx$ 500 solar masses. It is advisable to note, with respect to the "black-hole" nature of the burst sources in the nuclei of globular clusters, that the manned space station "Salyut-4" observed a burst of high-energy radiation from the well-known source Cygnus X-1, which the majority of researchers consider to be a black hole of $\approx$ 10 solar masses [22]. /10

The fact of undoubted observations of bursts of high-energy radiation independent of any known globular clusters (see above) prompts us to the conclusion that the galaxy contains a special group of "invisible globular clusters." Since the sources in globular clusters are black holes located in the nucleus of the cluster, it is natural to propose an "invisible" globular cluster, without its stellar corona. Such a nucleus would have an extremely compact form, composed of a massive black hole surrounded by thousands of stars of relatively low luminosity and a heated interstellar medium. Such an object may have been formed either in the process of evolution of a more or less "normal" globular cluster, or, more probably, from the demolished "corona" of a cluster by the tidal force of its passage at a distance of several hundreds of parsecs from the galactic nucleus. Thus it is possible that

the sources of burst radiation located near the center of the galaxy are "invisible clusters." The predicted intrinsic luminosity of an "invisible cluster" is $\approx$ 0m, so they might be point objects of visual magnitude $\approx$ 12-15m, without being distinguishable from the stellar background. For direct confirmation of our hypothesis we have to obtain excellent coordinate localization of the source of gamma-ray bursts at $\alpha \approx 12h$, $\delta = 73°$, which we understand is a recurrent source, after which optical identification can be obtained. We should also note that it is logical to propose that there exist "completely invisible" globular clusters,that is, black holes of $\approx 10^2$-10^5 solar masses without any collection of stars around them at all. It is not completely clear how many of these objects might be in /11
our galaxy nor to what degree thay may contain the presently-discussed "hidden mass" of our galactic group. See [23].

Obviously, the present proposals concerning the nature of globular clusters, their evolution, and especially their origin may be radically changed. In particular, the role of the nucleus in these clusters must be very important. For example, during the observation by [7] of a burst in NGC 6624 the bolometric luminosity of the cluster increased by a factor of one hundred! Also important is the extended constant observation in the high-energy X-ray spectrum (E > 50 keV) of the central region of the nebula in Andromeda, which, as might be expected, has a variable output of bursts. If rather massive black holes are formed in the central regions of globular clusters in the process of evolution, then it is natural to expect that they must also be formed in the nuclei of galaxies, especially elliptical galaxies, as well. It is possible that the observation of bursts of high-energy X-ray radiation in [24] is related to a black hole located in the nucleus of our galaxy. How much more urgent, then, does the task become of observing bursts from the nuclei of other galaxies, such as M31, M87, and the well-known dwarf galaxies in the constellation Sculptor, for example. N.S. Kardashev has informed us on the latter topic.

In conclusion we note that we have not at all been concerned with the specifics of the bursts of high-energy radiation, in particular, with the interesting problem of quasiperiodic bursts. Our problem was the purely astronomical analysis of the known facts with the goal of outlining as clearly as possible the speculations on the mechanism of the radiation, extending them in the direction of observational and theoretical research.