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Scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences (26 April 2000)

A scientific session of the Division of General Physics and Astronomy of the Russian Academy of Sciences was held at the P L Kapitza Institute for Physical Problems, Russian Academy of Sciences. The following reports were presented at the session:

(1) **Braginskiĭ V B** (M V Lomonosov Moscow State University, Moscow) "New measuring techniques for gravitational antennas"[1];

(2) **Gurevich A V** (P N Lebedev Physics Institute, Russian Academy of Sciences, Moscow) "Kinetic theory of breakdown induced by runaway electrons";

(3) **Efremov Yu N** (M V Lomonosov Moscow State University, P K Shternberg State Astronomical Institute, Moscow) "Star formation centers in galaxies";

(4) **Maksimov E G** (P N Lebedev Physics Institute, Russian Academy of Sciences, Moscow) "Current status of theoretical HTSC research in cuprate systems"[2];

(5) **Tsebro V I, Omel'yanovskiĭ O E** (P N Lebedev Physics Institute, Russian Academy of Sciences, Moscow) "Persistent currents and magnetic flux trapping in a multiply connected carbon nanotube structure";

(6) **Kulakovskiĭ V D, Tartakovskiĭ A I, Krizhanovskiĭ D N, Armitage A, Roberts J S, Skolnik M S** (Institute of Solid-State Physics, Russian Academy of Sciences, Chernogolovka, Moscow region; University of Sheffield, Sheffield, Great Britain) "Two-dimensional excitonic polaritons and their interaction".

An abridged version of the reports Nos 3, 5, and 6 is given below.

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Star formation centers in galaxies

Yu N Efremov

1. Introduction. Stellar complexes

Stars are the most important subject matter of astronomy, and this is so not merely because they encompass a major part of the visible mass of the Universe. Our Sun, which governs the entire life on the Earth, is just an ordinary star; studying the origin and the evolution of our planet is not feasible without the corresponding knowledge of the stars. They are gathered in giant systems — galaxies. One of them is our Galaxy — the Milky Way system, with the Sun located on its outskirts. The time-varying intensity and localization of star formation in a developing galaxy has given rise to the infinite diversity of presently observable galactic forms, which may be grouped into spiral, irregular, and elliptic only in the first approximation. The latter have virtually exhausted their supply of gas in the initial flare of star formation, and stars are presently formed only in irregular and spiral galaxies whose disks still retain much gas. The distribution of young stars replicates the structure of the parental gas medium; young hot stars and supernova explosions in turn have a profound effect on the surrounding gas. These processes hold considerable interest for gas dynamics and theoretical physics in general. Also indirectly related to star formation are, as shown in the subsequent discussion, the events accompanied by tremendous energy release, which are observed primarily as gamma-ray bursts; the study of these is currently the central problem facing astrophysics.

Since stars are ultimately formed as a result of the gravitational collapse and fragmentation of the most dense gas clouds, young stars always occur in groups — stellar clusters and stellar associations which are less dense but larger in dimensions. These groups in turn unite in giant stellar complexes measuring 0.5 – 1 kpc (recall that the Sun – Galaxy center distance is about 7 kpc). Stellar complexes involving associations and clusters related to gas clouds, in which star formation persists, are the largest structural units in the hierarchy of young stellar groups. As a class in its own right, they were first classified in our papers [1, 2].

In complexes formed spontaneously by the action of different instabilities in the gas medium, a great diversity in star age is observed. They comprise both small and dense domains of continuing star formation and relatively old stars, for instance, cepheids up to a 100 million years old, scattered over the entire complex. However, there exist complexes in which the spread in age does not exceed several million years. They are sometimes arclike or spheroidal in shape and were evidently formed after the action on the gas medium by some local event related to energy ejection into the interstellar medium and its subsequent packing. These star formation triggers may be repeated supernova outbursts in a cluster, the fall of sufficiently massive and fast clouds (or star clusters) onto the gas galactic disk, and, as became apparent recently, phenomena related to gamma-ray bursts.

2. Spontaneous formation of stellar complexes

Spontaneous star formation in gas galactic disks is determined primarily by the combination of the processes of

[1] A review of the presentation-related materials was published in *Usp. Fiz. Nauk* **170** (7) 743 (2000) [*Phys. Usp.* **43** 691 (2000)].
[2] A review of the presentation-related materials was published in *Usp. Fiz. Nauk* **170** (10) 1033 (2000).

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gravitational instability in a gas and its turbulent motion. The resultant higher-density clouds give rise to stellar groups of different scales. It comes as no surprise that the size and mass distributions of gas clouds closely resemble those of the daughter stellar groups. To a series commencing from multiple stars and further through clusters, associations, and association groups to stellar complexes corresponds a sequence of gas clouds — from density enhancements in the nuclei of molecular clouds to superclouds. An ever increasing amount of evidence is accumulating that interstellar clouds are an extended net of turbulent gas having a hierarchical fractal structure (with the exception of those relatively infrequent cases when the gas experiences regular forces, e.g., gravity in spiral density waves).

The star formation proceeding in gas clouds of different scales should also be hierarchically organized and bring into existence stellar groups of different scales, embedded one into another, which is evident in the structure of stellar complexes. In this case, the star formation in smaller clouds should proceed faster than in the larger ones if it occurs according to the time scale typical for the turbulence development in the gas medium. This picture of spontaneous star formation is confirmed by the recently revealed relationship between the mutual distance and the age difference of relatively young stars and clusters [3]. It is most confidently revealed from the data on the clusters of the Large Magellanic Cloud (LMC).

With increasing distance between LMC clusters, the difference in their ages (which may be considered the duration of star formation in the region of the corresponding size) increases, which answers the theoretical expectations for the star formation in a turbulent gas. Since it goes faster in smaller clouds than in larger ones, the smaller and younger stellar groups (stellar associations and clusters) are embedded in the larger and older ones (stellar complexes). Smaller regions of star formation originate and disappear many times before the process is over in a larger region. The first stars born in smaller active regions within a larger region — a stellar complex — manage to turn into cepheids with a characteristic age of about 50 million years before the star formation in the newly formed associations inside it comes to a close. A similar picture, though on smaller time and spatial scales, is also observed inside OB associations (sparse groups of young stars of the O and B spectral classes): compact subgroups inside them are younger.

The hierarchical fractal structure has no preferred scale. How is it possible to explain the preferred dimension (80 pc) seemingly observed for stellar associations, at least in nearby galaxies [4]? This issue invites further investigation, but it may well be that this dimension is a consequence of the fact that the OB associations are distinguished by the stars of a specific age. These are the brightest stars, and the groups they make up are most conspicuous. It is conceivable that the OB associations are merely a scale in the continuum of dimensions of star groups that corresponds to an age of about 10 million years [3].

The dimensions of stellar complexes correspond approximately to the thickness of the galactic gas disk. If the complexes are defined as the largest rounded stellar groups irrespective of the stellar age, their diameters will prove to be dependent on the characteristics of the galaxies that harbor them. With subsequent increase in dimensions and age, the differential galactic rotation imparts the shape of a piece of a spiral arm to a stellar group [5]. Short fragmentary spiral arms chaotically scattered over the galaxy may be termed large stellar complexes stretched by the galactic rotation. They contain no old stars. The majority of spiral galaxies possess arms of precisely this type, but best known and most beautiful are the galaxies with regular long and symmetric arms. They are explained by the wave theory of spiral structures. According to this interpretation, these arms are waves of enhanced star and gas density, which rotate as a rigid body around the galactic center. The star – gas complexes in wave spiral arms are quite often equally spaced. This is attributable to their formation, which is due to the action of gravitational instability developing along the gas arm.

3. Giant stellar arcs in the Large Magellanic Cloud

Conventional stellar complexes are more or less round in shape, but it was only recently recognized that there exists a sparse class of complexes that have an arclike shape and sometimes a regular circular one. About ten such strange structures are known in different galaxies at present. Sometimes this is an arclike chain of clusters bent round a black domain, which is indicative of a high density of gas and dust inside (Fig. 1). The age of clusters in some of them is known; it is virtually the same within each of the complexes, which testifies to the induced formation of these giant arcs of clusters and stars. Some external event synchronized the star formation in the initial gas cloud after imparting the arclike shape or more likely after forming this cloud from more rarefied gas.

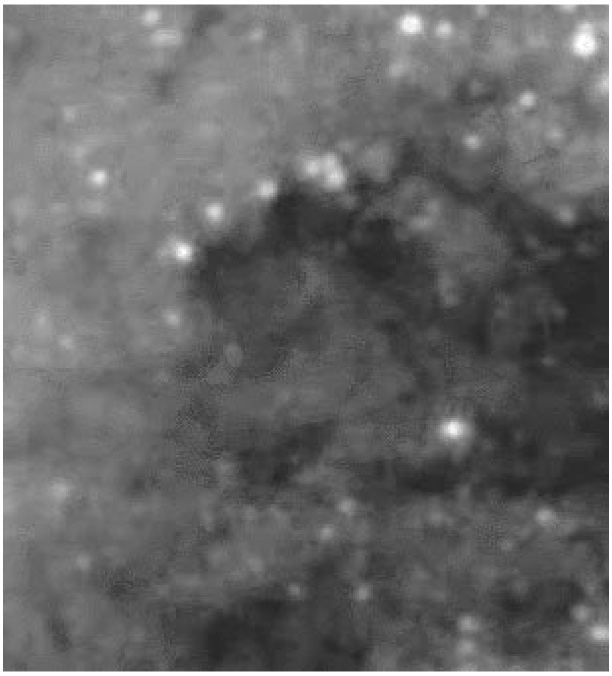

Figure 1. Arc of seven clusters bent round a half circle of dusty matter in the M83 spiral galaxy. The even spacing of five clusters may be an indication that they were formed under the action of a gravitational instability in the gas supershell.

The surprising thing is that giant stellar arcs were completely forgotten after the three papers [6 – 8] offering examples of the arcs made their appearance in 1964 – 1967. However, both the nature of their parent objects and the opportunity to study the somehow-triggered star formation in its purest form are of great interest. Of special interest are multiple systems of arclike stellar complexes whose very existence is proof that their parent objects had to be of common origin somewhere nearby.

In the LMC, the galaxy nearest to us, there are three or four giant arcs 200 – 300 pc in radius, which are located in the northeast outlying region of the galaxy (Fig. 2). One such arc can be seen on the World Wide Web at the Astronomical Picture of the Day (APOD) site known to many. Its images in the H_α rays of ionized hydrogen were placed there on June 25, 1995 and on August 23, 1997, while in the ultraviolet rays on October 11, 1995 (Fig. 3). The caption to this picture runs as follows: "the reason why this arc has the shape observed is presently unknown".

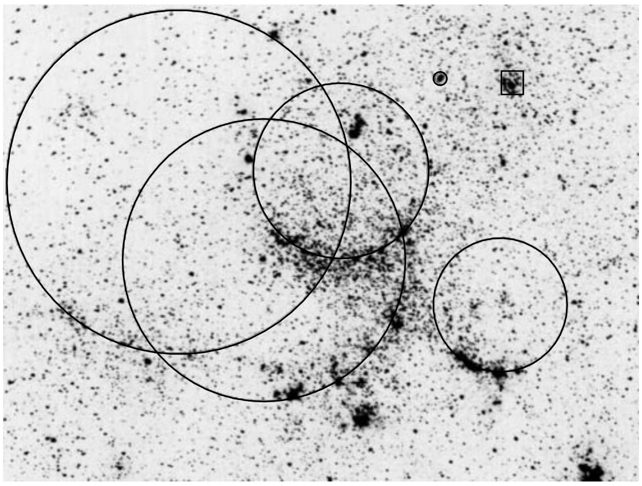

Figure 2. System of three (or four) stellar arcs in the LMC. The Quadrant is at the center, and the Sextant at the bottom right. The cluster NGC 1978 is enclosed in a circle, and SGR0526-66 in a square.

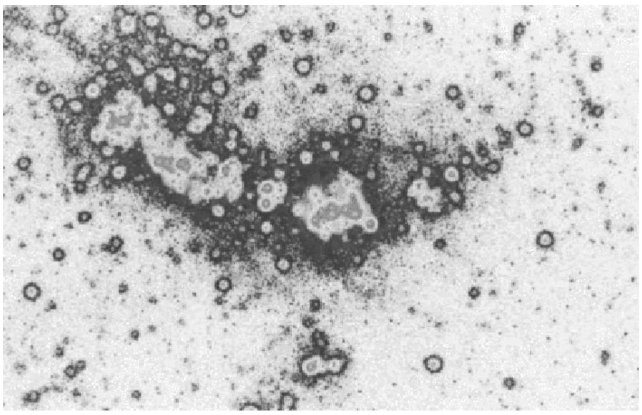

Figure 3. Sextant arc in ultraviolet rays, which owe their existence to only young stars. It is easily verified that the arc is a portion of a regular circle.

In fact, with only two exceptions, the numerous studies of this LMC region did not only leave the stellar arcs unexplained, but made no mention of them at all. The reason may lie in the fact that they are clearly seen only in small-scale photographs in blue rays (see Fig. 2). The arclike shape of these structures stems from the projection effect: they are segments of spherical surfaces viewed from the side (Fig. 4) rather than portions of circumferences in the galactic plane. In the latter case, they would have an elliptic shape instead of a regular circular shape, because the angle between the LMC disc plane and the picture plane is about 30° – 40°. The opening angle of the arc — the projection of a partial spherical shell — corresponds approximately to the apex angle of a conic radiation beam or beamed explosion that densified the ambient gas, in which stellar clusters later came into being.

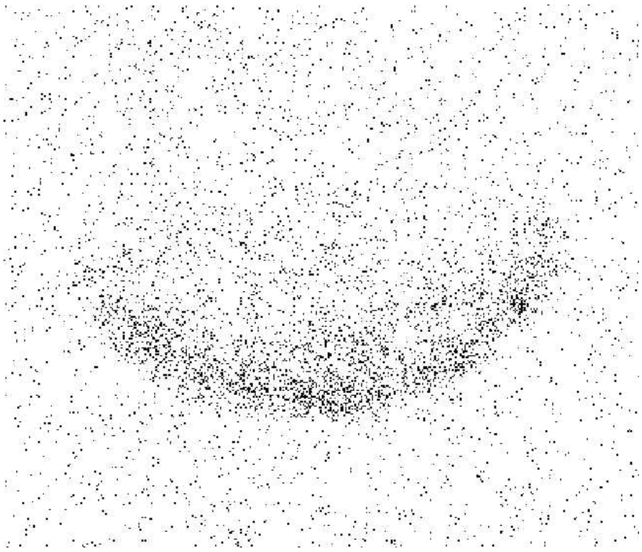

Figure 4. Segment of a spherical layer 0.1 radius in thickness with a central angle of 90° viewed from the side. Compare with Figs 2 and 3.

This system of arcs is located in the region of the HI LMC4 supershell, which encompasses the largest LMC domain of lessened hydrogen density. One of the arcs, the most sharply defined, has long been noted by Westerlund and Mathewson [7] who related the origin of both this arc and the LMC4 hydrogen cavity to a supersupernova explosion. Hodge [8] was the first to call attention to the entire system of arcs. He also proposed that all of them are the remnant of a supersupernova. In the search for similar structures in other galaxies, he found only one such structure, namely, in the spiral galaxy NGC 6946. In just the same way the structure attracted attention only in 1999, when it was accidentally rediscovered (see below).

The origin of the two most clearly perceptible arcs in the LMC4 domain was considered by Efremov and Elmegreen [9]. The regular shape of these arcs, which we termed Quadrant and Sextant (see Figs 2 and 3) as encompassing the corresponding parts of the circumference, was attributed to their formation from the gas swept up by pressure from the center, which formerly harbored O stars and supernovae. For Sextant, an open stellar cluster near its center was pointed out, which was apparently older than the stars of the Sextant itself. Near the Quadrant center, a group of six AI-class supergiants of virtually equal age was found, this age being higher than that of the Quadrant stars. This relatively old association could have once contained O stars and supernovae capable of sweeping up the gas shell, of which the Quadrant stars were produced later. To form this shell, an energy of the order of 10^{52} erg is required, which is equivalent to the energy released in the explosion of ten supernovae. However, Braun et al. [10] found recently that the age of the supergiants near the Quadrant center is only 12 million years, about the same as in the Quadrant itself, while two small clusters there are, on the contrary, too old.

In any event it remains unsolved why the stellar arcs formed around star-poor groups, why they are not found around a multitude of star-richer clusters of appropriate age, and, finally, why all the arcs known in the LMC are clustered in one and the same domain, within 1 kpc from each other. The most likely explanation involves abandoning the idea that the stellar arcs resulted from a sequence of explosions of many supernovae in the cluster. This idea is increasingly questioned also as regards gas supershells unrelated to stellar arcs.

In the spring of 1997, the first evidence appeared in favor of the existence of objects capable of producing ultrahigh-power explosions of the presumed supersupernova type and giving birth to gas supershells and giant stellar arcs. We imply gamma-ray bursts. To date, the red shift has been evaluated for around ten gamma-ray bursts, and the distances evaluated from them imply gigantic outburst energies — up to 10^{53} – 10^{54} erg, the equivalent of hundreds and thousands of supernova stars having burst out simultaneously (see review [11]).

Ultrahigh-power explosions should have a tremendous effect on the interstellar medium. Blinnikov and Postnov [12] were the first to mention it in a paper concerned with the nature of gamma-ray bursts — they should produce gigantic cavities in the interstellar gas measuring several hundred parsecs. In collaboration with Elmegreen and Hodge, we considered this issue in detail [13]. We drew the conclusion that, for the available estimates of the frequency of occurrence of gamma-ray bursts (one burst in ten thousand to a million years) and supershell lifetimes of tens of millions of years, from 10 to 100 thus produced supershells may be observable in every galaxy similar to ours, which is in line with observational data. We provided a number of examples of supershells in several galaxies for which this origin is most probable, for there is no evidence of either central clusters or the fall of clouds onto the galactic gas disk. This signifies that the stellar arcs, too, may be remote relicts of gamma-ray bursts. The old idea that ultrahigh-power explosions give rise to these structures has regained vitality.

Therefore, the presence of rich clusters at the centers of stellar arcs is not necessary; these arcs could form as a result of a single gamma-ray burst. Should this be the case, the question arises of why all the four such bursts that took place in the LMC during the past ~ 30 million years (the interval of the cluster ages in arcs) occurred in one and the same domain, not far from each other. The existence of some common source in this domain, in which the progenitors of gamma-ray bursts could originate, seems to be the only plausible explanation. In the view of the majority of authors, these are close binary systems comprising neutron stars or black holes. It would appear reasonable that this source may be a rather rich and dense stellar cluster during whose lifetime the approaches of stars could give rise to many close binary systems. Some of them might leave the cluster and become the progenitors of gamma-ray bursts. A cluster of this kind does exist and, moreover, is quite an extraordinary one. It is only a few hundred parsecs away from the arcs! This is the cluster NGC 1978 whose age is about two billion years, according to the color – magnitude diagram. It is the brightest and, hence, the richest of all the LMC clusters of this age. By its richness, mass (hundreds of thousands of the solar masses $M_\odot$), and density, it deserves to be termed globular, even though classical globular clusters are older by about 10 billion years.

Furthermore, adjacent to this cluster, only 18′ away, is one more extraordinary object — a known relative of gamma-ray bursts! This is SGR 0526-66, the only Soft Gamma Repeater in the LMC, a source of repetitive soft gamma radiation. Its first burst was recorded on March 5, 1979, and after a long debate the object was acknowledged as a member of the LMC. Also concentrated nearby the NGC 1978 cluster are binary stars — sources of X-ray radiation which may likewise be relatives of the objects that give rise to gamma-ray bursts [14]. The accidental location of all these objects so close to each other and to the stellar arcs is incomprehensible; there is bound to be a genetic relation between them [15].

4. System of stellar arcs in the spiral galaxy NGC 6946

It is a striking fact that a very massive cluster was recently found close to the second known system of multiple arcs, too, in the spiral galaxy NGC 6946, which Hodge [8] described in the same paper as the system of arcs in the LMC. It was not until more than thirty years later that it attracted attention! In the summer of 1998, when examining a photographic plate obtained with a 6-meter telescope [15], the author of the present paper suspected the existence of a large cluster inside the structure described by Hodge as a supersupernova remnant. In the spring of 1999, a preprint by Larsen and Richtler [16] made its appearance, which reported the results of the search for young massive clusters in 21 galaxies. Being unaware of Hodge's paper, they rediscovered the system of multiple arcs in NGC 6946 and described it as a spherical cluster of stellar clusters. Inside it, they found a young globular cluster, the brightest of all the young clusters in the galaxies they had studied.

We studied this unique system, which nevertheless remains puzzling, in our joint work [17]. The regular circular shape of this complex of stellar complexes and the existence of several arcs of clusters of about equal age inside it counts in favor of their origin from supershells and of induced star formation; however, the sources of central pressure are not seen. The age of the giant cluster estimated from integral three-color photometry in Ref. [17] is about the same as for other clusters in this system, while the mass is about $10^6 M_\odot$.

As in the case of the LMC, it may be suggested that the progenitors of the stellar arcs left this cluster and produced ultrahigh-power explosions. The diameters of these arcs indicate that they could have originated by the action of explosions equivalent to a few tens of conventional supernova outbursts. The low age of the cluster — if it is indeed responsible for the formation of the entire system — is evidence for the explosions of very massive rotating stars — hypernovae, which may be accompanied by a gamma-ray burst [18]. We note, however, that to the southwest of the supercomplex resides an object that may be either a star in the foreground (of our Galaxy) or a massive and compact cluster in NGC 6946 with an age of approximately 600 million years. This problem will soon be tackled by observations with the Hubble space telescope and the 6-meter telescope of the Special Astrophysical Observatory of the RAS, and time has already been allotted for observations by our team.

Also noteworthy is the striking similarity of the dimensions of the four arcs inside the circular stellar complex and close by. Considering that the age of all the clusters in the complex is about the same, the similarity of dimensions should signify the similarity of the amounts of energy that went into the formation of each of the arcs (Fig. 5). Recently, Postnov et al. [19] made an audacious proposal that the true

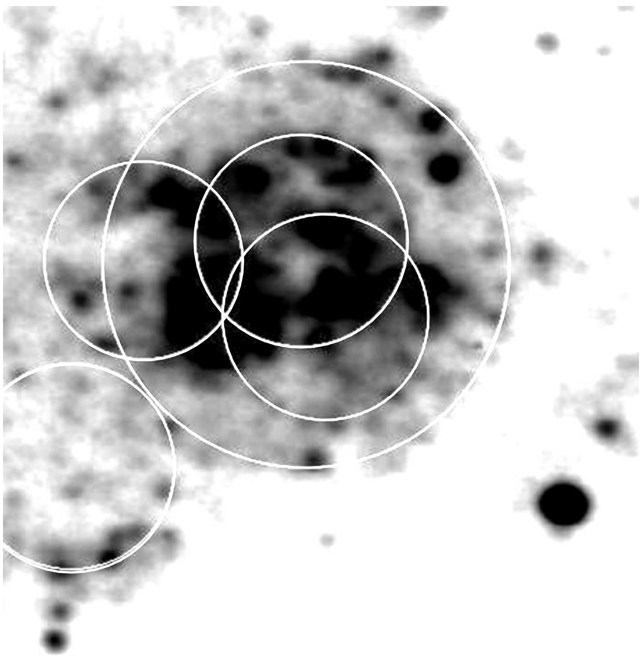

Figure 5. Spherical complex of stellar clusters in the spiral galaxy NGC 6946. A portion of the photograph obtained by S Larsen with the 2.5-meter Nordic Optical Telescope on the island of Las Palmas.

amount of energy released in gamma-ray bursts is always the same, while the distinctions observed are associated with either an angular difference in the radiation cone or with a difference in its orientation. The authors start from the known examples of equal-energy Ia-type supernova explosions and a very narrow interval of measured masses of neutron stars, about $1.4M_{\odot}$, and believe that the coalescence of neutron stars in a binary system can yield an invariable energy for the gamma-ray burst, $\sim 5 \times 10^{51}$ erg. This amount of energy is close to that required to form the cluster arcs in NGC 6946. It is conceivable that the crossing of three cluster arcs at precisely the center of the massive cluster (see Fig. 5) is not accidental and implies that it was formed in the collision of their parent gas shells. An enhanced external pressure may be one of the prerequisites for the formation of gravitationally connected massive clusters.

5. Nature of the progenitors of gamma-ray bursts

Whatever the progenitors of gamma-ray bursts may be, clearly this type of star is scarce and the likelihood of finding them in a massive rich cluster is higher. Conceivably the features of those two clusters which we suspected of being the source of these objects may tell something of their nature.

But why are neither a supershell nor stellar arcs or rings present immediately around NGC 1978 if their progenitors originated in this cluster? If this hypothesis is true, the objects that gave rise to the arcs should possess a unique combination of properties: they come into being in the cluster but leave it and, prior to exploding, recede to a large distance, up to several hundred parsecs. Amazing as it may seem, such objects do exist. Moreover, these are precisely the objects which have long been proposed as candidates for the progenitors of gamma-ray bursts, this having been done without any connection with the assumption of the capacity of gamma-ray bursts to initiate star formation! This coincidence can hardly by accidental. It lends credence to our view that the stellar arcs in the NGC 1978 region owe their origin to gamma-ray bursts.

The unique objects that come into being precisely in a dense stellar cluster but are bound to leave it with time are close binary systems whose components are compact objects — neutron stars and black holes. The logic of reasoning is as follows. Many binary systems that comprise compact objects are not primary but form in dense central regions of globular clusters as a result of close stellar approaches. It has been known that it is precisely this kind of process that is responsible for the high relative frequency (two orders of magnitude higher than in the field) of occurrence of X-ray binary stars in globular clusters.

On repetitive approaches to a third star, a close binary system becomes progressively closer and the velocity of both participants of the encounter in the cluster increases. In a system of normal stars, a coalescence of the components may occur, resulting in the formation of a peculiar blue star — a blue straggler. We emphasize that it is precisely their abundance that is responsible for the high brightness of the dense central region of NGC 1978 in ultraviolet rays [20]. However, if the system consists of two compact objects (whose dimensions are many orders of magnitude smaller than those of normal stars, about 3 km for black holes and 15 km for neutron stars), the chances that the system gathers, owing to repeated approaches to passing stars, a velocity high enough to escape from the cluster prior to coalescence of the components are good. For a typical globular cluster, this velocity is ~ 40 km s^{-1} [21].

So, it may be suggested that, contrary to the general belief, a close system of compact objects most frequently originates not after supernova-type explosions of both massive stars in the initial binary system (which results in a high velocity, if not a decay, of the system which, however, is not observed for the three pairs of neutron stars known in our Galaxy, see Ref. [22]), but owing to capture in stellar approaches in the dense central region of the stellar cluster. The results of recent simulations of dynamic cluster evolution, which take into account unequal stellar masses, testify to the high efficiency of pair formation in stellar approaches in dense clusters and confirm the long-established analytical solution that the systems consisting of compact objects sooner or later are, on subsequent approaches to other stars, ejected from the cluster [23].

It is clear that the velocities of the ejected systems can vary greatly. However, one would expect them to be primarily close to the minimal velocity required to escape from a massive cluster (~ 40 km s^{-1}), although the data needed to verify this are still missing. A pair of black holes is ejected from a massive cluster already being very close, and therefore the coalescence proceeds rather fast, over millions or tens of millions of years after the escape from the cluster [23]. The aim of Portegies Zwart and McMillan [23] was to estimate the feasibility of observing gravitational radiation bursts, but in the coalescence of black holes a gamma-ray burst also occurs if they are surrounded by accretion disks. A black hole and neutron star pair should have a similar destiny. The above velocity and time estimates give hundreds of parsecs for the distance between the parent cluster and the point of coalescence (a gamma-ray burst), which is what is observed in the LMC.

It follows from the foregoing that the objects inducing the formation of stellar arcs may well be identified with the objects giving rise to gamma-ray bursts. It is evident even from the hypothesis economy principle, although only the energy rejection into the interstellar medium holds significance for the triggering of star formation. There is no question that supernovae with an outburst energy of the order of 10^{52} erg do exist; SN 1998bw associated with a weak gamma-ray burst GRB 980425 [1] is a case in point. There are several arguments in favor of the assumption that gamma-ray bursts are related to beamed explosions of supernovae of certain types (see review [18]). However, the observed manifestations of this relation can also be ascribed to the circumstance that the gamma-ray burst stimulated a supernova-type explosion of the nearest massive star which had matured for it. This is what the known discordance of the coordinates of SN 1998bw and GRB 980425 (more precisely, the GRB-related X-ray source) can be attributed to. The weakness of this gamma-ray burst could result from precisely the fact that the beam pointed away from us. A supernova explosion could undeniably be induced in a component of the multiple system in which a gamma-ray burst had taken place [24].

As already noted, the regular circular shape of stellar arcs in the LMC indicates that they are projections of segments of spherical shells. Their orientation, unrelated to that of the LMC plane, suggests that these segments of stellar spheres viewed from the side are the outcome of a beamed explosion or an outflow rather than an isotropic explosion exterior to the galactic gas disk [25]. In the latter case, the tops of the arcs produced owing to the gas density gradient would point *toward* or *away* from the line of intersection of the picture plane and the LMC plane. Note that the opening arc angle of tens of degrees and the absence of twin arcs symmetric relative to their center of curvature are consistent with the Usov model [26, 27]. According to the latter, the sources of gamma radiation are asymmetric relativistic plasma jets fixed in a magnetic field. The Spruit hypothesis [14] of the relation between the progenitors of gamma-ray bursts and binary X-ray stars is an outgrowth of the Usov model.

6. Star formation initiated by gamma-ray bursts

The hypothesis that gamma-ray bursts can produce HI supershells and eventually initiate star formation is consistent with data on GRB 971214 gamma radiation source inside the supershell, supposedly originated by a previous gamma-ray burst in the same region [28]. The repetition of gamma-ray bursts in the same region of the galaxy is undeniably indicative of the source of their progenitors in this region. A gigantic domain of star formation, which contains several stellar complexes, is formed around this source. The isolated position in the galaxy is inherent in this domain, as with the LMC4 region. Therefore, the evidence that the afterglows of gamma-ray bursts are observed in the regions of star formation is by no means proof that the direct progenitors of the gamma-ray bursts were massive young stars. These regions of star formation could be produced by the preceding gamma-ray bursts in the same region. The age interval of the arcs of clusters in the LMC is about 30 million years.

Nevertheless, the feasibility of hypernova-type explosions (accompanied by gamma-radiation bursts) of massive stars (up to a half of them are ejected from the core of an open cluster in a time no longer than 50 million years [29]) is not ruled out, the more so as the data on the afterglow of gamma-ray bursts are consistent with the existence of two types of progenitors [30]. However, contrary to Paczynski [18], the gamma-ray bursts in the regions of star formation do not run counter to the hypothesis that they originated in a coalescence of compact objects up to several billion years old. These assumptions will become verifiable when the data on the afterglows of gamma-ray bursts are sufficiently statistically numerous.

It is not improbable that phenomena corresponding in energy release to hundreds and thousands of supernovae are not of infrequent occurrence and that they are precisely those also related to the origination of other isolated stellar complexes with a small spread in age known, for instance, in the LMC [2]. It is clear that the jet-initiated complexes appear arclike only for a certain angle of view, and it is possible that they acquire an arclike shape only in a rather homogeneous medium. For a small opening angle of the ejection cone, the resultant region of star formation will be void of any characteristic shape at all.

The phenomenon of initiated synchronous star formation may occur more widely than is generally considered to be the case. There are indications of star formation at the ends of jets from so-called microquasars in our Galaxy [31]. Kindred to these objects is SS433 whose precessional relativistic jet originates in a binary system which comprises a black hole. A gas shell measuring about 100 pc around this object is already observable and ascribed to the action of the precessional jet despite the fact that its parent supernova explosion took place only about 10,000 years ago [32]. It is not inconceivable that star formation will commence in this shell in several hundred thousand years.

Plausibly these were precisely the gamma-ray bursts, which commenced after a large fraction of binary black holes or neutron stars escaped from the massive parent clusters, that initiated the star formation in galactic gas disks. This may be the reason why the star formation in the disks of spiral galaxies commenced approximately two billion years later than in their halos (the globular clusters in galactic halos originated nearly simultaneously). It may be that the proximity of this delay time to the age of NGC 1978 is not accidental. Once massive stars have emerged in galactic disks, they can foster further star formation themselves. The formation of massive stars is as yet imperfectly understood. It may be that it proceeds only under external pressure on the gas cloud, so that other sources were needed for the first O stars and supernovae to emerge.

7. Conclusions

Therefore, the process closes a cycle. Neutron stars and black holes, the final stages of stellar evolution, give rise to gamma-ray bursts and thereby initiate new regions of star formation. The characteristics of these regions suggest that they were produced by wide-angle (tens of degrees) one-sided jets, which is consistent with the model of gamma-ray bursts [26, 27]. If the beams were narrow, they had to be multiprecessional, long-acting [33], and fill a wide cone to be responsible for the characteristics of stellar arcs [34].

One way or the other, there seems no escaping the conclusion that arclike stellar complexes originated due to gamma-ray bursts whose progenitors were binary systems of compact objects. While the system of multiple arcs in NGC 6946 can be somehow explained by the fall of a swarm of clouds onto the galactic plane, this hypothesis fails for the stellar arcs in the LMC, which diverge significantly in age.

[1] It was recently discovered (GCN 704) that this GRB flared at the cluster periphery.

The existence of multiple systems of stellar arcs implies that their progenitors originate in dense stellar clusters owing to stellar encounters and are ejected from them on subsequent approaches. Most likely, the progenitors of gamma-ray bursts escape from the cluster during the short and possibly repetitive stage of a maximum density of its core.

The specific mechanism of star formation induced by the jets of gamma-ray bursts is not understood. One can concede that the moving surface of the interaction between the jet and the ambient gas rakes the gas together, and the density of the resultant segment of the spherical surface eventually becomes high enough for star formation. Be it as it may, it is well known that active star formation is observed in a number of galaxies, being induced by relativistic jets emanating from the galactic nuclei.

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Persistent currents and magnetic flux trapping in a multiply connected carbon nanotube structure

V I Tsebro, O E Omel'yanovskiĭ

1. Carbon — this wonderful element that forms the basis for a multitude of natural and synthetic materials — amazed the world once again in the last years of the past century. In addition to its well-known solid crystallographic forms like diamond and graphite, it appeared before the world in the form of fullerenes and nanotubes. Ten years have not yet elapsed since the first report [1] of the discovery of multilayer carbon nanotubes in the cathode deposit of electric arc synthesis of fullerenes. It comes as no surprise that their properties have been the object of much concentrated attention and the subject of intensive research (see, e.g., reviews [2–6]. Among recent papers concerned with the electronic properties of carbon nanotubes, we would like to point out the experimental and theoretical papers on coherent electron transport in single-layer nanotubes [7–11] and the theoretical papers [12–14] that consider the related issue of persistent circulation currents in closed toroidal nanotubes. In particular, the data obtained by the method of transport spectroscopy [7, 8] suggest that coherent electron transport occurs in single-layer nanotubes at low temperatures. This transport occurs over very long distances — according to the estimates made by Tans et al. [7], up to the full length of a nanotube several micrometers long.

The subject of our report is the experimental discovery [15] of the effect of magnetic flux trapping in a multiply connected structure of multilayer carbon nanotubes that is formed in cathode deposits during the electric arc process for their synthesis. This flux trapping occurs just as it does in a multiply connected filamentary superconductor similar to the so-called 'Mendelssohn sponge' [16] — a multiply connected system of thin superconducting filaments in a normal matrix. Therefore, it sounds as if it were a statement of the superconductivity of this structure, this being so for a very high temperature (as will be seen from the following, at temperatures well above room temperature). However, superconductivity in the usual sense of the word (the formation of a Bose condensate of Cooper pairs below the transition point) is not the only explanation of the effect discovered. It is possible that we are dealing with the first experimental observation of so-called persistent currents which circulate through the closed mesoscopic paths of a multiply connected structure of this type. The problem of persistent currents and of the construction of the ground state that allows for their existence in mesoscopic closed objects [17] and also results in the trapping of magnetic flux was considered theoretically in several recent papers [18–20] (also see Refs [12–14]). One way or the other, the case in point is not some weak (hardly detectable) or controversial (as regards interpretation) phenomenon, but a quite noticeable macroscopic effect. It is as if we were really dealing with a conventional filamentary superconductor or, say, a type II superconductor with an ultimately weak first critical field.

2. Briefly what led us to discover the effect. It is well known (see, e.g., Ref. [21]) that the anomalous high value of