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## Abstract

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# GRAVITATIONAL WAVES AND "SUPER-STARS"

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Recently there has been great interest in newly discovered star-like objects identified with radio sources of very small angular dimensions ($^1$-$^3$). The idea has gained wide acceptance that these objects are star-like cosmic bodies with masses of $10^6$–$10^8 M_\odot$ (see, for example, ($^4$, $^5$)). Calculations of the structure and evolution of objects of such mass and with linear dimensions $< 10^{16}$ cm ($^6$) must from the outset be carried out with allowance for the effects of the general theory of relativity.

In this note we shall consider certain important effects of the general theory of relativity which, as far as we know, have not yet been discussed in application to the problems of superstars and gravitational collapse. Above all it should be emphasized that powerful emission of gravitational waves must play an essential role in the balance of energy and matter of a collapsing supermassive body.

At least two mechanisms of emission of gravitational waves by a supermassive collapsing object are conceivable:

1. If before collapse a superstar was rotating, then, owing to conservation of angular momentum, its rotational velocity will increase rapidly during contraction. It is quite possible that even before the Schwarzschild radius $r_g = 2GM/c^2$ is reached, the collapsing star will take the form of a rotating triaxial ellipsoid, or even a pear-shaped figure. Such a rotating configuration must be a powerful generator of gravitational waves. If, for example, this configuration is modeled by a rotating solid homogeneous rod, then the power of gravitational-wave emission will be equal to ($^7$)

$$P = \frac{GI^2\omega^6}{15c^5}, \tag{1}$$

where $I = \frac{1}{12}Ml^2$ is the moment of inertia of the rod ($M$ is the mass, $l$ the length), and $\omega$ is the angular velocity. Substituting $M = 10^{41}$ g, $l = 10^{14}$ cm ($\sim 5r_g$), $\omega = 3 \cdot 10^{-4}$ (which corresponds to a rotational velocity of the ends of the rod $\sim 0.5c$), we find that $P = 10^{54}$ erg/sec.

The concrete example given has illustrative significance. We note also that formula (1) (like all analogous formulae of the theory of gravitational radiation) is valid only for weak gravitational waves.

It is interesting to note that the emission of gravitational waves, being quadrupole in nature, must be highly asymmetric. In particular, in the case of axial symmetry, the emission of gravitational waves will be concentrated predominantly in two cones.

Let us consider another conceivable generator of gravitational waves, in the form of two equal masses rotating about one another. In this connection we note that a substantial fraction of cosmic bodies (stars, galaxies), as follows from observations, form dynamically bound binary systems with comparable masses, located at distances of the order of their dimensions. Naturally—

···naturally assume that superstars also are no exception to this regularity.

According to (8), the power of the gravitational radiation of such a system can be written in the form

$$P = \frac{0.4c^5}{G}\, x^5 = 1.46 \cdot 10^{59} x^5 \text{ erg/sec}, \tag{2}$$

where $x = r_g/r$ ($r_g$ is the Schwarzschild radius for one of the masses, $r$ is the distance between their centers). If, for example, $x = 0.3$, $P = 3.5 \cdot 10^{56}$ erg/sec, the mass equivalent of such radiation is $2 \cdot 10^2\ M_\odot$/sec. At this level the system can radiate for no less than $r/c \sim 300$ sec (in its proper frame). As $x \to 0.5$, the radiation can no longer be described on the basis of the theory of weak gravitational waves, while a more general theory has not yet been developed. In this connection let us note that in general relativity the two-body problem has not yet been solved.

2. Gravitational waves may be generated in the anisotropic compression of a massive body (for example, the compression of a biaxial ellipsoid along the axis of rotation). In this case, according to (7),

$$P = \frac{Gp^2\lambda^4\pi^2}{120c^3}, \tag{3}$$

where $p$ is the pressure in the direction of compression, $\lambda$ is the wavelength. For superstars, radiation pressure plays the determining role (9). In this case $p = \sigma T^4/c$. Taking $\lambda$ of order $r \sim r_g/x$, $T \sim 10^9$, we find that for $\lambda = 10^{14}$ cm, $P \simeq 7.5 \cdot 10^{57}$ erg/sec.

Of course, the example given is also illustrative in character, but it shows that the power of gravitational-wave radiation in collapsing superstars may be exceptionally large.

From the analysis carried out one can draw two conclusions.

A. Because of the powerful emission of gravitational waves, one should expect a noticeable decrease in the mass and angular momentum of a collapsing superstar. The mechanism proposed in (10) for mass loss by neutrino radiation, as was shown in (9), is insufficient. It is possible that the new mechanism is more effective. In particular, one may try in this way to explain the separation of the outer envelopes of collapsing superstars. It is not excluded that powerful gravitational radiation, at least in some cases, may prevent collapse. In principle it may be that practically the entire mass of the collapsing star is converted into radiation. These questions require careful mathematical analysis.

B. The energy density of gravitational waves in the neighborhoods of collapsing superstars must be very large. Therefore one cannot exclude the possibility that some part of this energy is transformed into other forms, for example into electromagnetic or kinetic energy (gravitational transmutations).

Let us note that the total energy radiated in gravitational waves during the evolution of a collapsed star must be proportional to its initial mass. The proportionality of the energy contained in synchrotron-radiation sources to the masses of collapsed stars also follows from an analysis of the observational results (11).

Until recently, all the few observable consequences of relativity theory played the role of negligibly small effects, having no practical significance for astrophysics. The only domain in which general relativity played a determining role was cosmology. In the latter case, the extreme scarcity of observational data made the conclusions of the theory highly uncertain and, most importantly, ambiguous. Now, however, we are witnessing an entirely new situation. One cannot exclude the possibility that the primary cause of such···

phenomena as cosmic rays, the formation of heavy elements, and the powerful synchrotron radiation of galactic and metagalactic sources are effects of the general theory of relativity.

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