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INVISIBLE OBJECTS INSIDE THE SUN AND NEAR THE SOLAR SYSTEM?

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A b s t r a c t

We consider the accretion onto objects consisting of the hypothetical y-matter, suggested by L.B.Okun. It is shown that the presence of such an object in the Solar neighbourhood might resolve some difficulties of the hypothesis of a massive invisible companion to the Sun. A planet-like y-object inside the Sun may explain long period Solar oscillations.

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Intensive development of the particle theory gives numerous interesting astronomical consequences. New types of particles with extraordinary properties and new types of interactions are predicted. L.B.Okun /1/ has recently suggested the possibility (which may be realised within the the frame of developing grand unified theories) of existence of the so-called y-particles interacting with the ordinary matter (o-matter) by means of the gravitation only. (See refs. /2,3/ on some other possible new types of particles.) These y-particles may have their own y-interactions, similar to the weak, strong and electromagnetic interactions of the o-particles. The existence of such y-interactions, not acting on the o-matter, may lead as a result of the cosmological evolution to the formation by the y-matter of compact astronomical objects (y-stars and y-planets), which may be discovered only by their gravitational effect on the o-matter. It was pointed out in ref. /1/, that the presence of y-matter may explain the phenomenon of the "hidden mass" of galaxies and of clusters of galaxies and may give rise to the oscillations of the gravity field on the Earth and to the disturbances in motion of o-planets.

Leaving aside interesting aspects of the cosmological evolution of the y-matter (this will be done elsewhere) we show in the present note that there are some observational indications, which may be interpreted in the framework of the program proposed in ref. /1/ for the search of y-matter within the Solar system. We suggest that the y-matter may help to resolve some difficulties of the hypothesis of a massive companion of the Sun /4/ and of the explanation of the solar oscillations having the period of 160 min./5,6/.

One must, obviously, check such a suggestion both from the point of the reality of the observed phenomena and from the point of the possible consequences of our hypothesis. Our aim is not to build a complete theory of the phenomena which may be refuted by further observations or may have another, less exotic, explanation. We just wish to draw attention to principal possibilities of the appearance of the y-matter. The very absence of observational indications of this matter may put useful restrictions on its properties and hence on the fundamental physical theories. Contrariwise, the presence of such a matter may offer to astronomy new fantastic possibilities for the interpretation of observations.

1. Massive solar companion - the evidence from pulsars

Let us consider first the Harrison's /4/ hypothesis on the invisible companion to the Sun. The acceleration of the barycentre of the Solar system in the direction to this companion of the order of $a = 10^{-6}$ cm s^{-2} may decrease the observed rates of deceleration $\dot{P}$ for the pulsars viewed in the same direction by the quantity $\Delta\dot{P} = -aP/c$ because of the Doppler effect. Here P is the pulsar period and c is the speed of light. For the pulsars with the intrinsic values $\dot{P}_{in} \simeq 10^{-16} \simeq 0.01$ ns/day that decrease may lead to the observed values $\dot{P}_{ob}$ which are several orders of magnitude lower and may even make them negative. Harrison suggested his hypothesis just to explain the clustering of pulsars with anomalously low $\dot{P}_{ob}$ in a definite region of the sky.

This hypothesis may be criticized from two points: 1) the possibility $\dot{P}_{ob} \cong \dot{P}_{in}$ is not excluded, and 2) it is almost improbable that such a companion could have escaped the observation (by disturbances of planet orbits or by its radiation).

It is difficult to refute the first possibility, i.e. the decrease of $\dot{P}$ due to intrinsic properties of the pulsars. Indeed, this possibility would be preferable if the pulsars with low $\dot{P}_{ob}$ were distributed uniformly around us, i.e. the Harrison's argument /4/ is purely statistical . As was pointed in ref. /7/, in order to falsify the hypothesis of a companion it is sufficient to find only one pulsar with a low value of $\dot{P}$ in the opposite region of the sky. In ref./4/ there were selected 5 pulsars (excluding the double PSR 1913 +16) in the region $17^h30^m \leq \alpha \leq 21^h06^m$ with low $\dot{P}$, including two pulsars with $\dot{P} < 0$.

What is the situation in the light of more recent results of observatinns? According to the latest available to us compilation of the pulsar parameters by Y.Terzian (Feb. 21,1979) there is more or less reliable information on $\dot{P}$ for 83 pulsars. The value $\dot{P} < 0$ (of low reliability) is given only for PSR 1813-26. This value may be explained by random errors - the phenomenon well known for measuring small, but essentially positive, quantities (e.g. parallaxes). Nevertheless the fact of the clustering of pulsars with low $\dot{P}_{ob}$ in the same region of the sky is not refuted.

The data on $\dot{P}_{ob}$ are given in Fig.1. We subdivided the pulsars into two groups. The first group a is in the area .

of the invisible companion $17^h.5 \leqslant \alpha \leqslant 22^h$ (43 pulsars) and the second group b contains the rest of pulsars with known $\dot{P}$ (40 items). One finds that according to the new data there are six pulsars in the group a and only one pulsar in the group b with $\dot{P} < 0.01$ ns/day (though the groups are approximately equal). The only anomalous pulsar from the group b PSR 2305+55 has an unreliably determined value $\dot{P} = 0.006$ ns/day. This pulsar cannot falsify the hypothesis /4/, since it is situated very close to the group a. As a confirmation of the hypothesis /4/ may be taken a certain deficit of the pulsars with $0.01 < \dot{P} < 0.1$ ns/day in the group a as compared to the group b, since the correction of $\dot{P}_{ob}$ for the acceleration leads to the increase of the number of pulsars from the group a in the bin $0.01 < \dot{P} < 0.1$ ns/day. Unfortunately, the statistics is too poor to make far-reaching conclusions (in particular, the remark /9/ on the small number of measured values of $\dot{P}$ in the region $-90° < l < 0°$, where l is the galactic longitude, remains valid), but it does not contradict the hypothesis /4/.

The second possibility to criticize this hypothesis - i.e. the low probability that such an object remains unnoticed,is considered in refs. /8 - 10/. The acceleration of the centre of mass of the Solar system is $a = GM_c/d_c^2$, where M_c and d_c are the mass and the distance from the companion. For $a \simeq 10^{-6}$ cm s^{-2} and $M_c = 1\ M_\odot$ we obtain /4/: $d_c = 10^3$ a.u. It was pointed out in ref. /8/, that these parameters contradict the data on the disturbances of the Neptune's orbit, determined by the tidal effect, which is proportional to M_c/d_c^3. From the condition of the constancy of M_c/d_c^2 it was obtained in ref. /8/ that $d_c \gtrsim 6 \cdot 10^4$ a.u. and $M_c \geq 6 \cdot 10^3\ M_\odot$. The Harrison's answer /7/ and the remark /9/ that this restriction is unnecessary for noncircular orbits and thus M_c may be of order 1 $M_\odot$ slipped the attention of the experts in celestial mechanics - the final decision is left for them. Note, that from time to time indications arise on unexplained perturbations within the Solar system (see e.g. /11/).

2. The accretion onto the y-objects

It is shown /9,10/ that if the companion were a white dwarf, a neutron star or a black hole it would have been very probably observed by its radiation. These results made the Harrison's hypothesis much less attractive. We would like to emphasize that if the invisible companion were a star made of y-matter, its radiation could be by many orders of the magnitude lower than in the cases considered in refs. /9,10/. Let us give the estimates.

The only source of radiation of o-photons by the y-star is the accretion of the o-matter. The term"accretion" will denote here not only the capture of the matter by the star, but the whole complex of the processes of gravitational interaction of the y-star with the surrounding o-medium (cf. /12/). According to the classical theory of accretion /13/ the gravitating body of mass M effectively captures the matter within the radius

$$R_A = 2GM/v^2, \qquad (1)$$

where v is the velocity of the body's motion through the medium in the supersonic case, or the sound speed in the medium v_s in the subsonic case. The invisible companion may have a velocity of order of the Solar system speed relative to the surrounding medium (if the companion forms the binary together with the Sun) that is 20 km s^{-1}, or higher, if it flies freely by the Sun)- i.e. the motion is supersonic, since the temperature of the medium $T = (0.8 + 1) \times 10^4$ K /14/ corresponds to $v_s \simeq 10$ km s^{-1}. From Eq.(1) we get R_A about few a.u. for $M = 1 M_{\odot}$.

If $\rho \simeq m_p n$ is the density of the surrounding medium then the classical expression /13/ for a rate of accretion is

$$\dot{M} = \pi R_A^2 \rho v \qquad (2)$$

and for $n \lesssim 0.2$ cm^{-3} /14/ it gives $\dot{M} < 10^9$ g s^{-1}. Though Eq.(2) is derived in the hydrodynamical approximation it may be applied in the case of accretion of the interstellar gas even when the mean free path of the particles with respect to collisions is greater than R_A. This is true due to the presence of the magnetic fields /21/.

The luminosity is approximately given by

$$L \simeq \dot{M} \varphi_o , \qquad (3)$$

where φ_o is the characteristic value of the gravitational potential in the place of the stopping the infalling matter. If R is of order of the radius of the neutron star (here R is the radius of an accreting y-star), then $R \ll R_A$ and L will approach the luminosity of the neutron star. This case was considered in refs. /9,10/. Note that, though the surface of the y-star is transparent for the infalling matter (similar to the black hole), this case is much closer to the case of a neutron star. The y-star has no event horizon (unless it has collapsed) and the infalling o-matter may interact with the captured o-matter, generating shock waves etc. (At the rate $\dot{M} \simeq 10^9$ g s^{-1} about 10^{26} g of the o-matter may be captured during the lifetime of the solar system. This is less than the mass of any of the big planets, but at $R \sim 10^6$ cm and $M_c \sim 1\ M_\odot$ the equilibrium conditions imply the contraction of the o-matter down to the same radius 10^6 cm and to the density $\sim 10^9$ g cm^{-3}.) Even the neutron star might have escaped the discovery /10/, though the probability of this is small. The same is true for a compact y-star. But if R is much greater than the radius of the neutron star, then φ_0 and the luminosity (3) fall down as R^{-1} and accordingly decreases the probability of observation of the y-star.

If R is greater than R_A there arises a qualitatively new situation. Now the resultant velocity of particles after the collisions in the wake is everywhere greater than velocity of escape and o-matter is not captured by the y-star, since the latter is transparent for o-matter. Here R should be understood as a characteristic radius of an y-star, containing, say, half of its mass and not its photospheric radius which has nothing to do with the o-matter. For $R > R_A$ we may substitute R instead of R_A in Eq.(2) and thus obtain an estimate of the mass perturbed (but not captured!) by the y-star in unit time:

$$\dot{M} \simeq \pi R^2 \rho\, v, \qquad (2')$$

In this case the main source of the luminosity L is an accretion shock and one can get a reliable estimate for $R \simeq R_A$

$$L \lesssim \dot{M} v^2. \qquad (4)$$

The estimates (3) and (4) are then of the same order, so for $R \simeq R_A$ Eqs. (1) - (4) give $L \lesssim 10^{23}\ (v/1\ \mathrm{km\ s^{-1}})^{-1}\ \mathrm{erg\ s^{-1}}$.

The obtained luminosity of such an order of magnitude may easily explain /10/ why the y-star has not yet been observed. The special search might discover such an object by, e.g., the recombination radiation of the shock wave. The verification of this suggestion needs detailed calculations of the predicted spectra, which now seems to us premature.

If the radius of an y-star is still larger, namely, if

$$R/R_A > v/v_s, \tag{5}$$

the velocity perturbation Δv of the infalling gas turns to be less, than the sound speed v_s. In this case the shock is weak and the heating is of the order $\dot{M}(\Delta v)^3 v_s^{-1}$. If the inequality (5) is strong then it is conceivable that the shock does not form at all. But even in the presence of the weak shock in case (5) the y-star perturbes the medium very slightly, almost adiabatically and its search by the radiation seems to be practically impossible. Various possibilities of accretion are shown qualitatively in Fig.2.

Let us point one possibility to distinguish the y-star as an invisible companion to the Sun from a neutron star, or a black hole. It was noted in ref. /10/ that a compact invisible companion might have given a possibility to observe the effect of a gravitational lens. Such an effect was mentioned in ref. /1/ for the cluster of the y-matter. If an y-star is compact, the gravitational lens effect would not differ from the similar effect of an ordinary compact star. But if $R \simeq R_\odot$ the angular size of the y-star at $d_c \simeq 10^3$ a.u. is about 2". If the alignment of a remote source and of the y-star occurs then it is possible to distinguish the image from the former case, since now we have a transparent gravitational lens /24/. If $R \gg R_\odot$ the gravitational lens effect is unobservable - the deflection of light is too small.

3. An y-planet inside the Sun?

Another example of the appearance of the y-matter is the possibility of oscillations of celestial bodies /1/. In distinction with paper /1/, where the search for the terrestrial oscillations was suggested, we draw attention to the solar pulsations /5,6/ having so far no satisfactory explanation.

According to the recent publication /15/ the parameters of these pulsations are: the period $P = 160^{m}.010 \pm 0^{m}.004$, the velocity amplitude is $0.5 \div 1$ m s^{-1} and the mode seems to be quadrupole. Sometimes the oscillations are not observed. This is interpreted /15/ as an effect of supergranulation, which explains some negative results (e.g. /16/). But if the oscillations are noticeable they are always in phase with the preceding cycle of observations - this is true for about 5 years /15/. The confirmation of those oscillations was reported on the base of the observations in Stanford /17/.

The difficulties of explanation of long period pulsations on the base of standard solar models are discussed in ref./18/. The possibility of generation of these oscillations by the motion of a small black hole orbiting the Sun at the depth of 2×10^{4} km below the photosphere is mentioned in paper /15/ as a curiosity. If taken seriously this hypothesis seems to be improbable due to the following reason.

In the approximation of hydrostatic adiabatic tide /19/ the body of mass m at the depth h under the surface of the star of mass M and of radius R displaces the surface for the distance of order

$$\Delta R \simeq \frac{R}{h}\frac{m}{M}R . \qquad (6)$$

The estimate (6) is valid if $h/R \ll 1$, but $h^2/R^2 > m/M$. The velocity amplitude 1 m s^{-1} corresponds to the full displacement of the surface ΔR (the double amplitude) of about 3 km. Substituting $h = 2\times10^4$ km, $R = R_\odot$, $M = M_\odot$ into (6) we obtain $m = 10^{-7}M_\odot$. This estimate is not very reliable. If we take into account that the observed ΔR may be underestimated owing to the averaging over the large area of the solar disk $\pi R_\odot^2/2$ (and in (6) ΔR corresponds to the area of order πh^2), m may increase substantially. On the other hand, the estimate of m may strongly decrease due to the resonance with the eigenfrequency of a solar g-mode, so we prefer to use the value $m = 10^{-7}M_\odot = 2\times10^{26}$ g (the exact value is necessary for the model with a black hole, and for the model of the y-planet the crude estimate is sufficient).

According to the standard solar model /20/ at the depth $h = 2\times10^4$ km the density $\rho = 2\times10^{-4}$ g cm^{-3}, and the temperature $T = 10^5$ K, so the sound speed is $v_s = 3\times10^6$ cm s^{-1}. The velocity of the body is $v = 4.4\times10^7$ cm s^{-1}, i.e. the accretion is supersonic. Substituting the value $m = 10^{-7}M_\odot$ in Eq.(1) we obtain $R_A = 10^4$ cm. The Eq.(2) gives $\dot{m} = 10^{12}$ g s^{-1}. Such a rate of accretion onto a black hole with account for the magnetic field results in the energy release /21,22/ of order $0.1\dot{m}c^2 \simeq 10^{32}$ erg s^{-1}. This is comparable with the solar luminosity and so absolutely unacceptable. The account for the radiation pressure decreases the luminosity of the hole down to the Eddington limit $\sim 10^{31}$ erg s^{-1} - being unacceptable either.

For the y-planet the condition (5) is realized for $R > 10^5$ cm = 1 km and is surely fulfilled if y-planets have the radii of order of those for the o-planets. Thus the case of Fig.2c is realised for the accretion and the y-planet induces inside the Sun only gravitational and weak acoustic effects. The same is true, even if our evaluation of m is underestimated by orders of magnitude (it is surely true if m is overestimated). The mass m must not be too large. "Spreading" m along the ring of radius $R_\odot - h \simeq R_\odot$ (which is reasonable since $P = 160^m = 1/9$ day $\ll$ 88 days $= P_☿$ - the period of Mercurian revolution) we obtain the perturbation of the perihelion precession of the Mercury /23/ for one revolution around the Sun:

$$\delta\varphi = \frac{6\pi m R_\odot^2}{4M_\odot d_☿^2} \qquad (7)$$

where $d_☿$ is the mean distance of the Mercury from the Sun. For $m = 10^{-7} M_\odot$ Eq.(7) gives the precession of the Mercurian perihelion 0".02 per century. However, if m is higher by 2 ÷ 3 orders then the magnitude of $\delta\varphi$ will contradict the predictions of general relativity. Besides that, the oscillations of the whole figure of the Sun will be large, since the centre of mass of the system is to be at rest.

Leaving aside the question of origin of the y-planet inside the Sun, we note that the value $m \simeq 10^{26}$ g is suprisingly close to the amount of y-matter accreted by the Sun during its lifetime if the parameters of the interstellar y-matter in the Galaxy are the same as for o-matter (cf. Section 1).

The presence of a body inside the Sun may be in principle discovered by its gravitational effect on the solar probe, approaching the Sun for a distance of few $R_\odot$. For the test of this opportunity the detailed analysis is needed of possible noncircular (and non-elliptic!) orbits inside the Sun.

4. Conclusion

Summarizing, we conclude that the presence of the y-matter near and inside the Sun seems now not excluded. If with the growth of the pulsar statistics or in the result of celestial mechanical analysis the hypothesis /4/ is not falsified, then the special search of the dark solar companion by its radiation will be needed, and the discovery of the y-star will probably be the most difficult task. The possibility of discrimination of the y-star by the effect of gravitational lens is not excluded. The discovery of only one low $\dot{P}$ pulsar in the region of the sky opposite to the "invisible companion" would give strong constraints on the quantity M_c/d_c^2 for star-like y-bodies, but it would not exclude large amounts of the gaseous y-matter spread in the form of spherical shells around the Solar system /1/.

More serious consideration of the y-planet inside the Sun would be necessary if the existence of pulsations with $P = 160^m$ becomes generally accepted, if the phase of the oscillations and their period are stable, and if alternative possibilities of the theoretical explanation of this phenomenon are exhausted.

The cosmological evolution of the y-matter, the evolution of y-stars and their relationship to o-stars, the constraints on the y-matter from the electromagnetic background etc. - all these problems are of great interest and they deserve special investigation.

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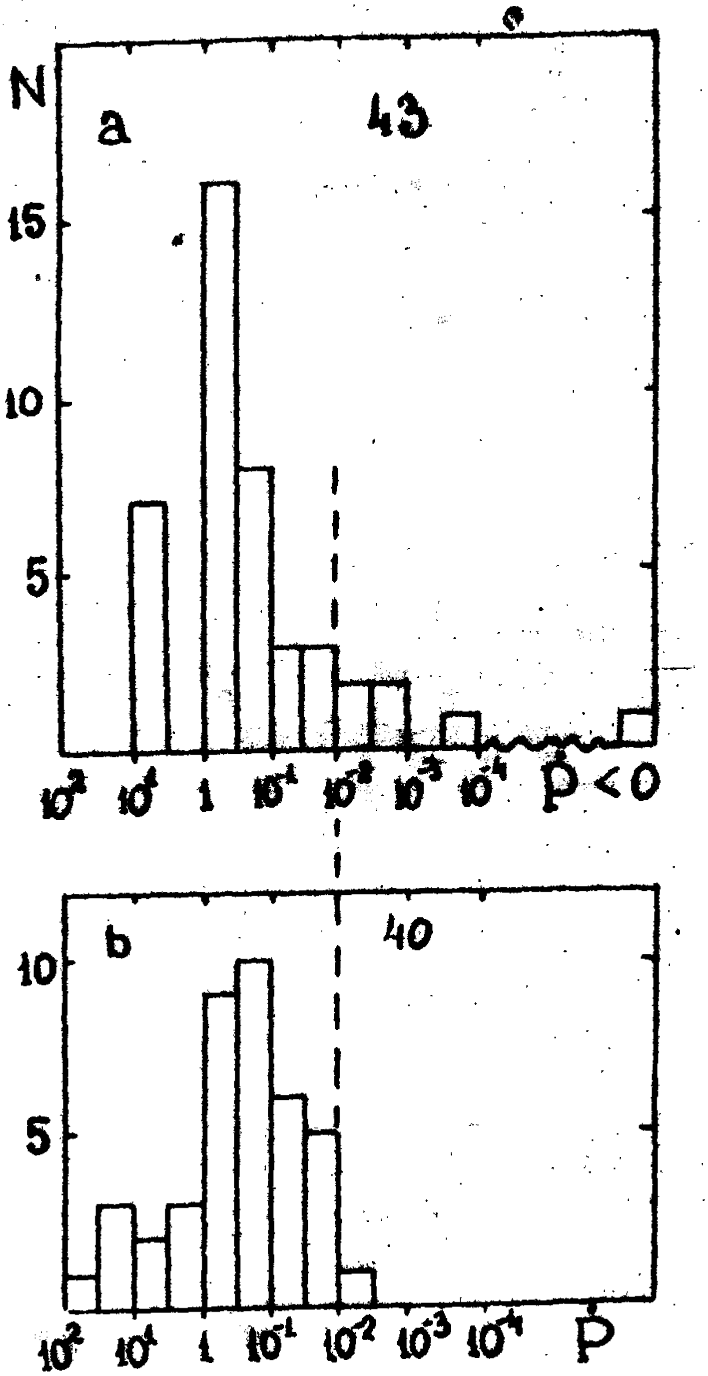

Fig.1. Hystograms for pulsars with known $\dot{P}$:

a) in the region of the "invisible companion" $17^h.5 \leqslant \alpha \leqslant 22^h$;

b) the remaining pulsars.

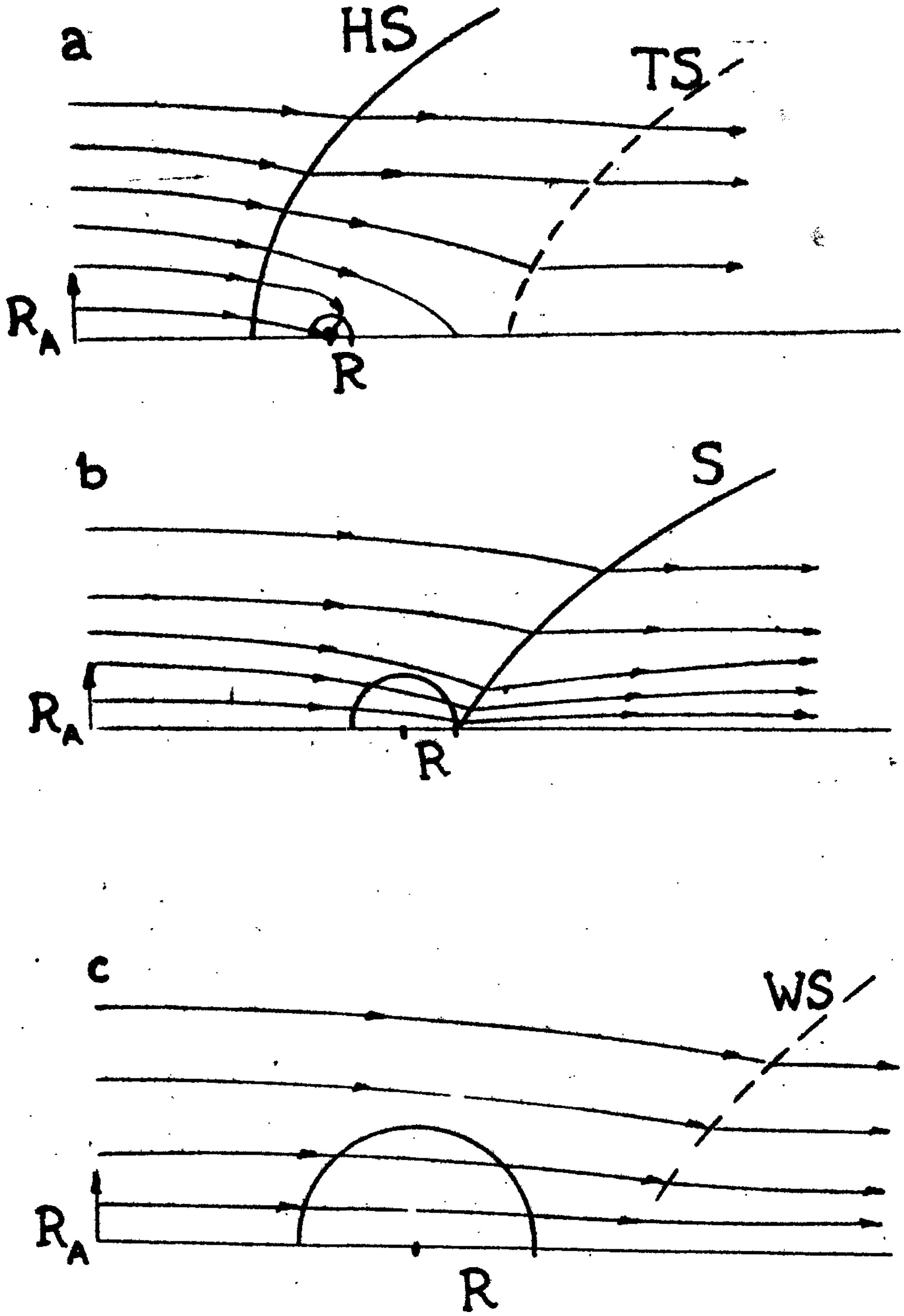

Fig.2. Possible regimes of accretion onto an y-object moving supersonically through o-matter:

a) $R \ll R_A$; HS denotes a head shock, TS - possible trailing shock;

b) $R \simeq R_A$; S is a shock front (the matter is not captured);

c) $R > (v/v_s)R_A$; WS denotes a weak shock (in general, presumably, may not form at all).

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