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IS THE UNIVERSE MATTER-ANTIMATTER SYMMETRIC?

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IS THE UNIVERSE MATTER-ANTIMATTER SYMMETRIC?

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Abstract

According to the symmetric cosmology there should be antimatter regions in space which are equally as large as the matter regions. The regions of different kind are separated by Leidenfrost layers, which may be very thin and not observable from a distance.

This view has met resistance which in part is based on the old view that the dilute interstellar and intergalactic medium is more or less homogeneous. However, through space research in the magnetosphere and interplanetary space we know that thin layers, dividing space into regions of different magnetisation, exist and based on this it is concluded that space in general has a cellular structure. This result may break down the psychological resistance to the symmetric theory.

The possibility that every second star in our galaxy consists of antimatter is discussed, and it is shown that this view is not in conflict with any observations (but of course with many speculative theories!). As most stars are likely to be surrounded by solar systems of a structure like our own, it is concluded that collisions between comets and antistars (or anticomets and stars) would be rather frequent. Such collisions would result in phenomena of the same type as the observed cosmic γ-ray bursts.

Another support for the symmetric cosmology is the continous X-ray background radiation. Also many of the observed large energy releases in cosmos are likely to be due to annihilation.

§ 1 Matter anti-matter symmetry

The discovery of the positron and the antiproton has lead to the recognition that in principle there could be antimatter in the universe. As celestial bodies consisting of antimatter emit the same spectra as bodies of ordinary matter (koino-matter) it is impossible to tell from a distance what kind of matter they consist of. The proof for or against the existence of antimatter has to be indirect.

Oskar Klein has developed a cosmology[1], often referred to as the symmetric cosmology, according to which there should be equal amounts of koino-matter and antimatter in the universe. Although such a symmetry appeals to most scientists there is naturally a reluctance to discuss a theory which necessarily must lead to a revision of quite a few of the present theories in cosmic physics. In fact, the present theoretical frame-work has been inherited from the time when it was generally believed that all matter necessarily must be of the ordinary kind. When it is now evident that in principle the Universe may be symmetric it is necessary to go through all astrophysics in a systematic way in order to see what the consequences of symmetry are.

However, it is naive to believe that a symmetric picture of the universe would gain rapid general acceptance even if there are convincing arguments for symmetry. It is not enough to present arguments in favour of symmetry as one has to overcome an inertia of the same kind as when the Ptolemaean cosmology was replaced by the Copernican one. In reality the situation is more complicated, because the acceptance of the symmetric cosmology is necessarily coupled with a <u>drastic revision of cosmic plasma physics</u>.

Such a revision takes place for other reasons and is based on recent discoveries in space science especially the study of the magnetosphere and interplanetary space.

I have discussed the new plasma physics in a number of papers[2] and shall here only mention what is most important for our consideration, viz that homogeneous models have become obsolete in cosmic physics. In many important cases they have to be replaced by strongly inhomogeneous models.

§ 2 Break-down of homogeneous models in cosmic physics

Up to some ten years ago interplanetary space, interstellar space, and intergalactic space were generally considered to be almost void regions, filled with a very thin almost homogeneous gas or plasma, with scale heights of the same order as the distances between the celestial bodies. Space research has demonstrated that this picture is drastically misleading. Magnetic measurements have shown that in the magnetosphere (at about 10 earth radii) the magnetic field may change its direction by 180° over only one or a few Larmour radii, which is many orders of magnitude less than the distance to the earth (Fig.1). Similar discontinuity surfaces are found in the magnetotail and the solar wind in interplanetary space. Furthermore auroral research has shown that in the magnetosphere (typically at one earth radius) there are thin electrostatic discontinuities with voltage drops of hundreds or thousands of volts over a distance of the order of a Debye length (which is 10^{-7} of the distance to the earth). These and other such considerations force us to abandon simple homogeneous models.

§ 3 Cellular structure of space

The new picture which results from these and other discoveries is that the magnetosphere and interplanetary space is not filled with a fairly homogeneous medium but has a cellular structure in which there are surfaces of discontinuity which divide space into a number of compartments. The magnetisation, the electrical potential, the density and the temperature are often drastically different on the two sides of such a discontinuity surface.

Although there were some early speculations about the existence of such discontinuities there was no possibility to discover them and explore their properties until space research made in situ measurements possible. Even now there is practically no possibility to discover a magnetic discontinuity from a distance, because it does not emit any kind of observable radiation. On the other hand electrostatic discontinuities may be detected at some distance because of the anisotropic particle distribution they produce.

We know that cellular structure characterizes those regions of space which are accessible to space craft, but as such structures cannot be detected at distance we have no certain information about more distant regions. There is no reason to suppose that their existence should be limited to regions of space where space craft have penetrated today and as we now begin to understand how they are formed we can conclude with a high degree of confidence that both interstellar space and intergalactic space should in general exhibit a similar cellular structure.

§ 4 Matter and antimatter cells

It is easily seen how important the discovery of the cellular structure of space is to the discussion of antimatter in the universe. The demand for symmetry is satisfied if the metagalaxy or even our own galaxy is divided into a large number of cells, half of which contain "koinomatter" (ordinary matter) and half antimatter. Cells of different kinds of matter should be separated by "Leidenfrost layers", thin layers of discontinuity containing high energy electrons-positrons produced by annihilation of protons (or other nuclei) at the interphase (Fig.2). A theory of such layers has recently been developed by Lehnert[3] who shows that under cosmic conditions they need only to be 10^{10}cm or about one hundred millionth of a light year thick. The basic reason for this is that annihilation produces a sink of koino- and antimatter, leading to a plasma pressure gradient which is balanced by the force from electric plasma currents and a magnetic field. This force pushes the two opposite plasma regions away from each other, and the rate of annihilation is substantially reduced upon reaching a quasi-steady balance. Similar to the interphases of the magnetosphere and interplanetary space such a layer should be very difficult to discover unless a spacecraft penetrates it. The annihilation radiations emitted from it is many orders of magnitude too small to be detectable with present measuring devices. Thus we can not exclude that matter and antimatter can exist harmoniously in the universe with some system of compartmentalization by "Leidenfrost layers" with no contradictions of observed conditions.

§ 5 Structure of solar sysstem

With this as a background let us try to picture our symmetric galaxy. It is easily seen that in our own solar system practically all bodies must consist of koino-matter (sun, planets, satellites and at least most of the comets and meteoroids). We can perhaps not exclude that a few meteoroids might consist of antimatter, but attempts to prove this have so far not been successful. Concerning the comets of which some 10^{10} or 10^{11} are believed to be located in the "cometary reservoir" at 10^{16}- 10^{17}cm from the sun[4], there is not yet any indication that anyone of them consists of antimatter, but we cannot exclude that a few of them do. The solar wind which of course consists of koino-matter is known to penetrate as far as spacecrafts have reached, but whether it also penetrates the cometary reservoir or part of it is subject to speculation (Fig.3).

Even if we accept that all matter in a sphere of 10^{17} cm around our sun consists of koinomatter, we must note that this only is a few per cent of the distance to our closest stars. (See Fig.3). Hence there is ample room for Leidenfrost layers, separating the sun-dominated region from those belonging to other stars. We are in conflict with no observational facts if we claim that one or more of our closest stars consists of antimatter. If we claim that in our galaxy every second star consists of antimatter there is no way of proving or disproving this in a straightforward way. Every star in our galaxy should be surrounded by a region of the same kind as itself. The topology of the separating Leidenfrost layers forms an interesting problem which remains to be investigated.

A number of indirect arguments have been presented in order to prove that there cannot be antimatter in our galaxy. We shall discuss them in § 10.

§ 6 Cometary reservoirs

If half the stars in our galaxy consist of antimatter we have to investigate what happens if a koinostar and an antistar pass close to each other. The probability of a collision between the two stars is very small. If both stars are surrounded by planetary systems, including cometary reservoirs, like our sun, there is a somewhat larger probability for a collision between a star and a planet of opposite kind, but a much more likely collision would involve the comets in the reservoir. As these are believed to contain 10^{10}- 10^{11} comets, there is a considerable chance that a comet will collide with a star of opposite kind.

It should be observed that during the close approach, the Leidenfrost layer separating the two plasma regions of different kind may move in such a way that a large number of comets are situated in a thin plasma of the opposite kind . No very conspicuous phenomena can be expected from this effect.

If two stars pass each other at such a distance that one of them does not penetrate the cometary reservoir of the other, its gravititional perturbation may still be large enough to eject some comets from the reservoir into interstellar space. One estimate of the rate of destruction of the Oort cometary reservoir by close stellar interactions has been made by Nezkinskij[5] in which cumulative dispersion places a lower limit of the order of 10^9 years for the half-life of the cometary system or the same order as the age of the solar system. Hence we should expect that there are a certain number of errant comets such that a star can be hit by a comet (perhaps of opposite kind of matter) even when it does not penetrate the cometary reservoir of another star.

§ 7 Collision between a solid body and a star

We have found that the important case to discuss is when a solid body of cometary size (1-10 km) falls into a star of opposite kind. We shall assume that the star is similar to the sun, and surrounded by a similar structure. When the comet is beyond a distance of about 5-8 solar radii the heating of the body by annihilation is much less than the heating from solar radiation. Inside this limit annihilation becomes the predominant heat source but is still quite weak even down into the corona. It is not until the body reaches the chromosphere and photosphere that dramatic effects should be observed.

The velocity of the body when it reaches the surface of a star like the sun is of the order of 10^8 cm/sec. As the scale-height in the solar atmosphere is of the order of 10^7 cm the time constant of the impact will be of the order of 0.1 sec. The impinging body is likely to be fragmented very rapidly. At the interphase between a fragment and the solar atmosphere, a series of violent explosions are likely to occur because of the annihilation. Probably a number of bubbles are created consisting of an extremely hot magnetized plasma of relativistic electrons--positrons produced by annihilation of nuclei (Fig.4). These bubbles will be ejected from the star, and as they leave the denser region they will emit a spectrum of γ-rays and X-rays. It should be observed, however, that the primary γ-radiation from nuclear annihilation will largely be absorbed and not emitted. The details of the collisonal process are now being investigated by W. Thompson[6].

§ 8 γ-ray bursts

Observations from VELA satellites have lead to the discovery of a most remarkable phenomenon, called γ-ray bursts[7]. During a total period of only a minute or even less, a burst of X-rays and γ-rays in the 2 keV-5MeV range is received which exhibits intensity fluctuations down to 0.01 sec (Fig.5). There are good reasons to believe that the bursts derive from distances of less than 500 light years, hence from our local region in the galaxy. If this is accepted the release of energy at the source must be of the order of 10^{36} - 10^{37} ergs. There is no certain association with any peculiar celestial object (i.e. supernova, pulsar, or X-ray flare star).

A conclusion from these observations is that because of the rapid variations the extension of the source of radiation cannot be more than 0.01 light-second or 3×10^{8} cm which is less than one per cent of the radius of a common star (like the sun) and comparable to or even smaller than the size of an ordinary sunspot. Assuming that 1-10% of the total energy release is emitted as X-rays and γ-rays, we find the energy release to be of the order of 10^{38} erg. This is equivalent to the total annihilation of a body of 10^{17} g, which means a solid body of the size of a few kilometers or about the size of an ordinary comet. The picture we get from the observations is reconcilable with our picture of a comet falling into a star of an opposite kind.

This identification is further supported by the frequency of the events (about half-a-dozen per year) which is reconcilable with the expected frequency of collisions between stars and comets in our vicinity. Of course this calculation is uncertain by one or two orders of magnitude.

The spectrum of some γ-bursts has been measured (Fig.6). The theory of a comet hitting a star is not yet so well developed that a comparison is possible.

The total length of the event is generally half a minute. This should represent the total time it takes for fragmentation and annihilation of a comet when falling into a star. Whether this is reasonable or not is difficult to say.

§ 9 Other celestial objects releasing much energy

Even if a comet-star collision is the most frequent event we expect to observe in our galaxy, they cannot represent more than a small fraction of the total energy release in a symmetric galaxy. Many more bursts of lower energy should be observed and recent balloon-borne instrumentation may support this theory. However the total mass of the cometary reservoir is perhaps only a few earth masses and insignificant when compared to the total mass of planets or that of the sun itself. Hence there may be truly immense bursts of energy associated with planet-star and star--star collisions in galaxies. Indeed there are a great number of celestial objects such as N type systems, Seyfert galaxies, and quasi-stellar objects which exhibit enormous releases of energy,often rapidly varying. It should be explored systematically whether some or all of them may derive their energy from annihilation.

§ 10 Objections to the existence of antimatter

Any serious discussion of such a drastic revision of cosmic physics which the acceptance of the antimatter concept would naturally necessitate is bound to meet with strong resistance from advocates of ingrained old theories. A number of more specific objections have been made. Most of them are flat statements, often with homogeneous models as a hazy background, and often connected with thecries the authors strongly believe in.

For example, when Klein first discussed the existence of antimatter, it was claimed then from the measured upper limit of cosmic γ-radiation that only an extremely small fraction of the matter in our galaxy could consist of antimatter. This conclusion was model dependent: the authors assumed that koino-matter and antimatter must necessarily form a homogeneous mixture. As homogeneous models seem to be increasingly obsolete and as space plasmas are likely to be separated by "Leidenfrost layers" this objection is not valid.

Another objection[8] is that the energy source of an abundantly emitting object cannot be annihilation because very little or none of the hard annihilation γ-rays are observed. This conclusion is again model dependent. If the annihilation is produced by a solid (or gaseous) object falling in on a star of opposite kind of matter (See Fig.4), the annihilation takes place at the interphase. The nucleon annihilation may in general be located so deep down in the stellar atmosphere and partially screened by the impinging body that the primary γ-radiation of the annihilation is absorbed instead of being emitted. On the other hand the electrons-positrons which are produced (in the presence of solar magnetic fields) may form extremely hot clouds of magnetized plasma which are ejected from the sun before they radiate their energy into space.

Furthermore the absence of a 0.5 MeV γ-line is cited as an objection[8] to the existence of antimatter. This again is model dependent. The 0.5 MeV line is emitted only when the electron-positron gas is cooled down to non-relativistic energies, which under cosmic conditions may be a rare case.

We are certainly far from a consistent model of what happens during a collision between bodies of different kinds, but it is already now obvious that the flat objections against annihilation as a main source of energy are based on some hazy and not very likely models.

Another model dependent objection concerns the absence of anti-particles in cosmic rays of low and medium energies. This objection depends on assumption about the magnetic field in the transplanetary region which is totally unknown. Furthermore, the magnetic field connected with a Leidenfrost layer may screen cosmic rays of low and medium energies.

As a summary the idea of a symmetric universe is certainly in striking disagreement with several theories in cosmic physics, but so far there is no conflict with any observational facts.

§ 11 The continuous X-ray background radiation

The clouds of magnetized relativistic electron-positron plasma which escape from the region of impact in our model, cannot be retained by the star, and they will also escape from the galaxy. Hence, we expect to find relativistic annihilation products in intergalactic space, where they are likely to have a very long half-life. They will interact with ordinary star light and by inverse Compton effect they will transfer the light quanta into the keV region. According to Carlqvist and Laurent[9] this is a reasonable explanation of the continuous X-ray background which has been discovered and explored during the last few years.

Assuming that the main energy loss of the electrons-positrons is due to synchrotron radiation Carlqvist and Laurent find that the production spectrum (due to nucleon annihilation) is transformed into the steady state spectrum (as seen in Fig.7). The inverse Compton effect between relativistic electrons-positrons with this energy spectrum and ordinary star light gives an X-ray radiation with the spectrum as shown in Fig.8.

The agreement between the calculated and the observed spectrum is remarkable in view of the fact that the theory does not contain any adjustable parameter (except the total intensity). From the measured intensity it is possible to calculate the density of the annihilation electrons in intergalactic space, and the result is 10^{-9} cm^{-3} in the energy interval 10-10^2 MeV. As the average density in the metagalxy ("the universe") is believed to be 10^{-7} nucleons cm^{-3} , this means that the intergalactic electrons-positrons of today should be a result of annihilation during the ages of at least 1% of the total amount of matter. There is nothing obviously wrong with this figure, but how it should be related to a general symmetric cosmology is of course an open question.

§ 12 Antimatter and cosmology

In the preceding sections we have almost exclusively discussed the role of antimatter in the present state of the universe. However, the existence of antimatter is of decisive importance in cosmology, because a symmetric "universe" has necessarily an evolution which is different from a "universe" which contains matter alone.

When Klein started to explore the consequences of a symmetric metagalaxy (which is a more correct term than the "universe ") his main interest was to present an alternative to the big bang theory. Klein's model of the evolution of the metagalaxy is in conflict with the big bang theory, with the result that during this period of cosmological discussion so dominated by the big bang theory, Klein's ideas and the further development of them have not received much attention. However, as now the big bang hypotheses is falling down because of conflicts with observational facts, it is rather a merit that Klein's approach is in conflict with it.

The Klein model of the evolution of the galaxy is essentially homogeneous, starting from a very big sphere with a homogeneous mixture of matter and antimatter. As all homogeneous models it must be replaced by an inhomogeneous model. It would carry us too far to discuss how this could be done, but it seems that based on Klein's general principles a reasonable picture of the evolutionary history of our galaxy could be obtained.

§ 13 Particle physics and cosmic physics

Detailed theories of the matter-antimatter interaction in cosmic physics depend on a collaboration between particle physics and cosmic physics. Such a collaboration seems at present to be virtually non-existant. This seems to be due to the fact that particle physicist focus their interest on phenomena in the GeV region whereas in cosmic physics phenomena in the eV or in rare cases keV region is of main interest. Hence, our fields differ by 5 or 10 orders of magnitude and it is obviously difficult to bridge such a gap.

This lecture has already given you a menu (Fig.9) of cosmically important phenomena in particle and nuclear physics. To these belongs a study of the phenomena occuring when a chunk of antimatter impinges on the atmosphere of a star or planet. Questions concerning matter-antimatter interactions of any type, their frequency, and the resultant radiation should all be studied with the symmetric metagalaxy in mind. It is indeed possible that many of these and other astrophysical phenomena will only be solved through the interest and work of you, the particle phycisist.

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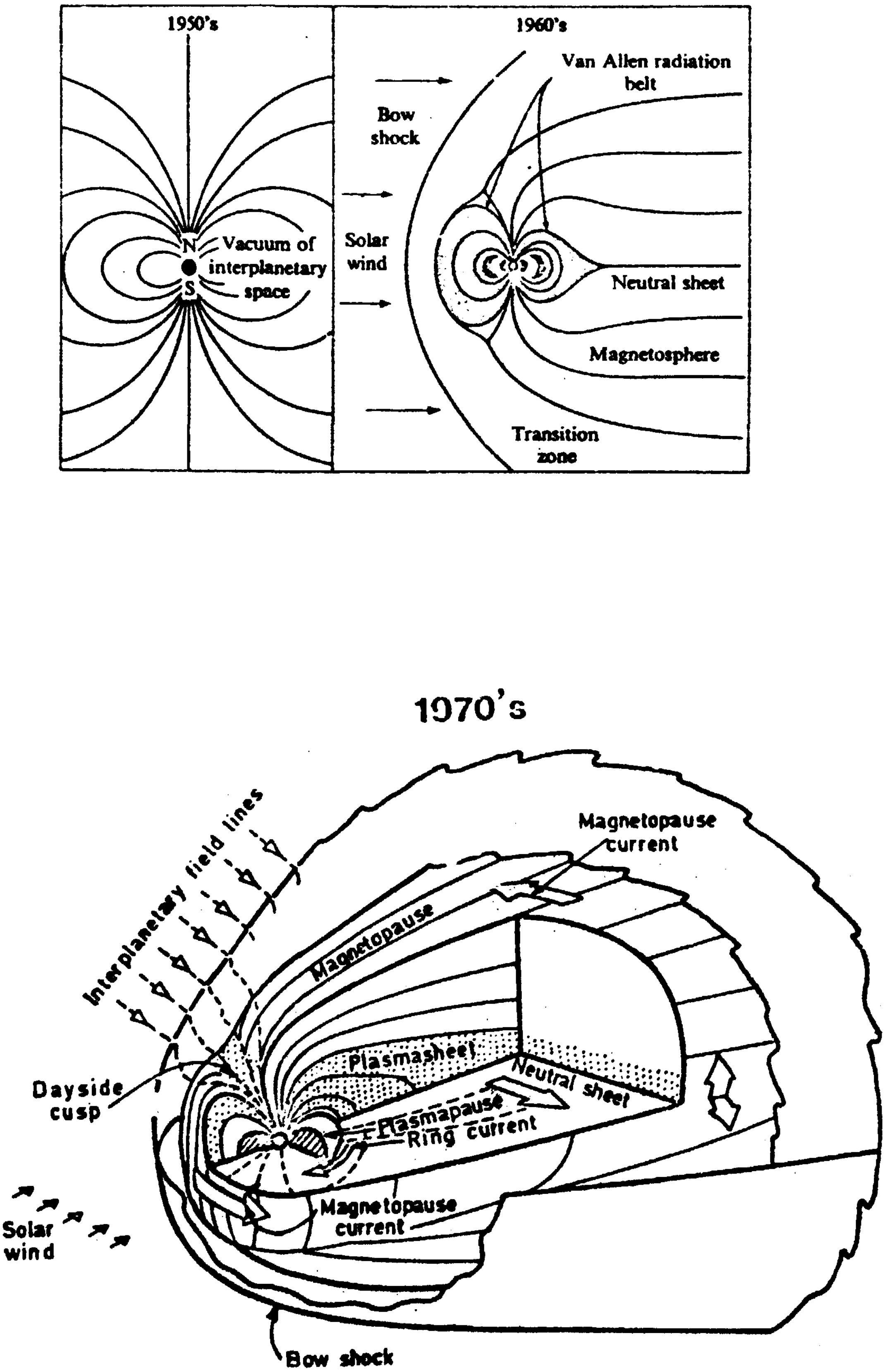

FIG. 1 Contrast between the early theories of space as a dilute homogeneous medium and the modern observations of the "cellular structure" in which space generally consists of a number of magnetic "compartments" containing plasmas of different properties.

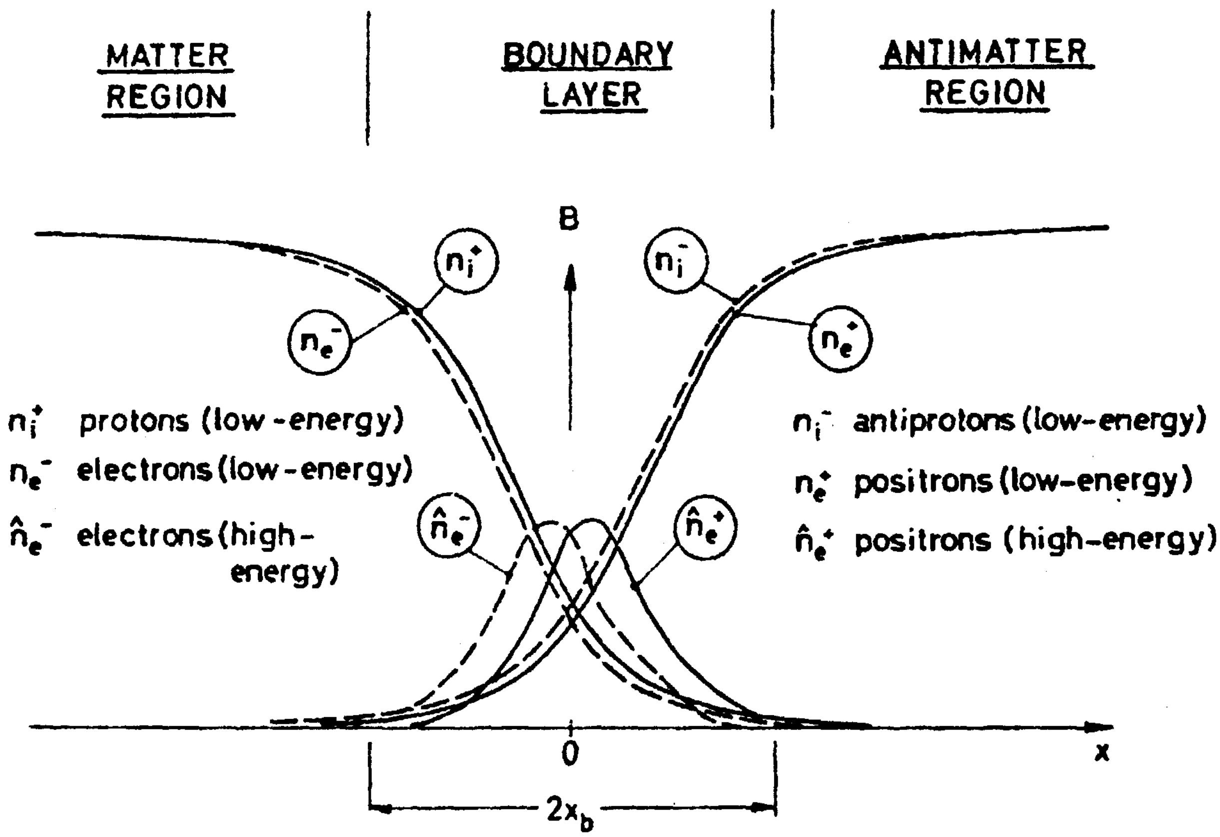

FIG. 2 A Leidenfrost layer, separating a region of antimatter from a region of koinomatter.

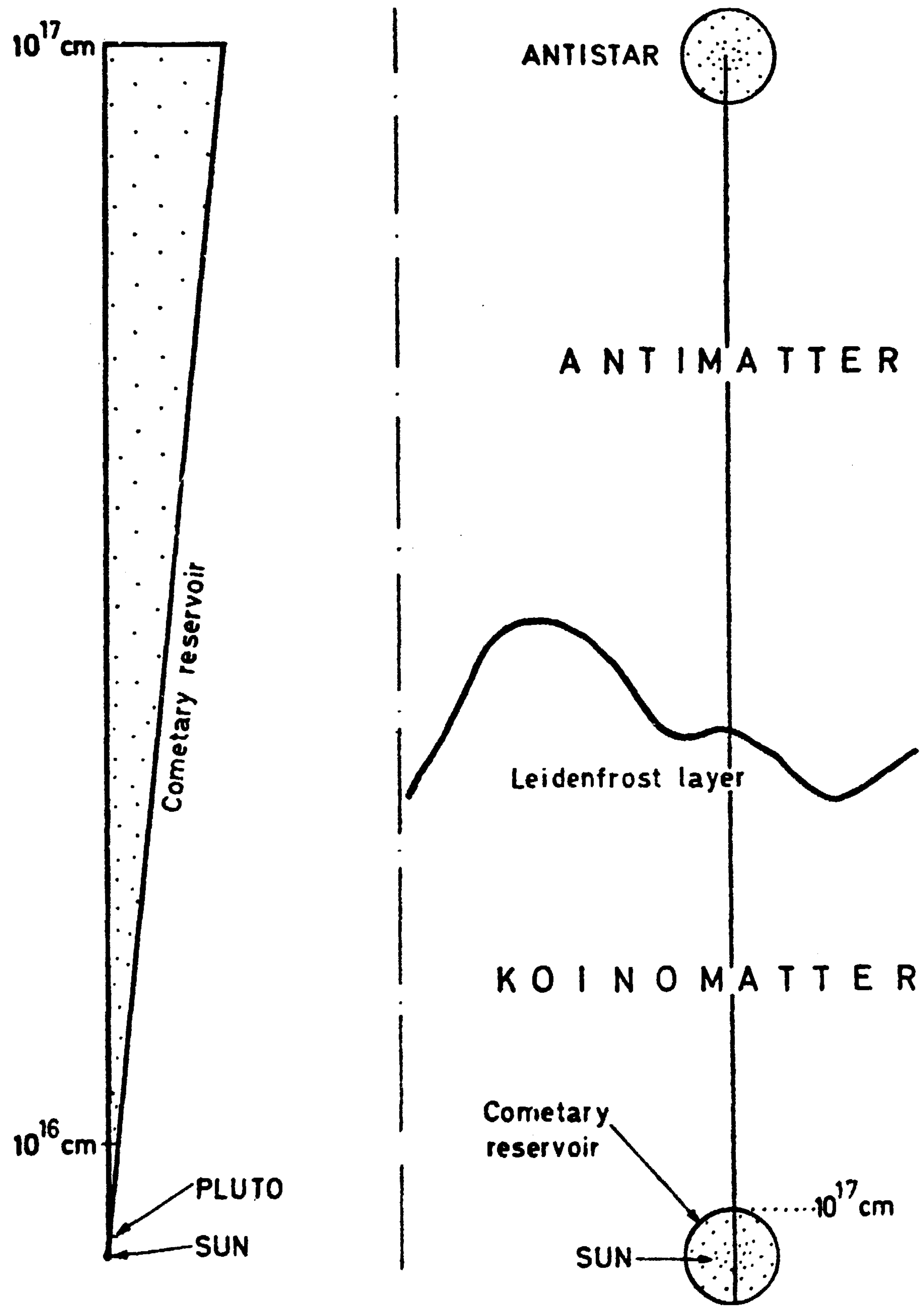

FIG. 3 Scale of Distances

Cometary reservoir surrounding the planetary system

Separation between matter around our sun and antimatter around a neighbouring antistar

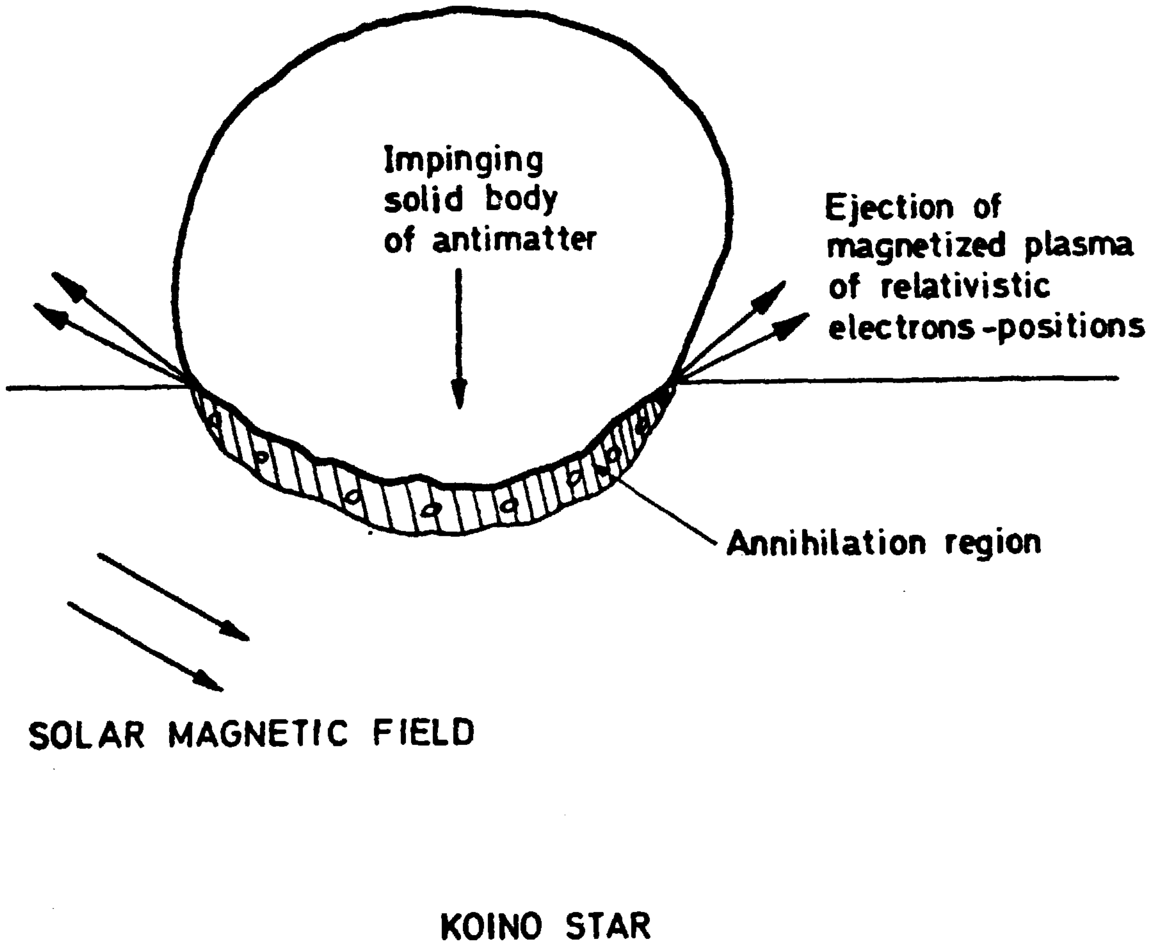

FIG. 4 Antimatter body falling into a koinomatter star. Formation of an annihilation region and ejection of relativistic plasma.

COSMIC GAMMA-RAY BURST

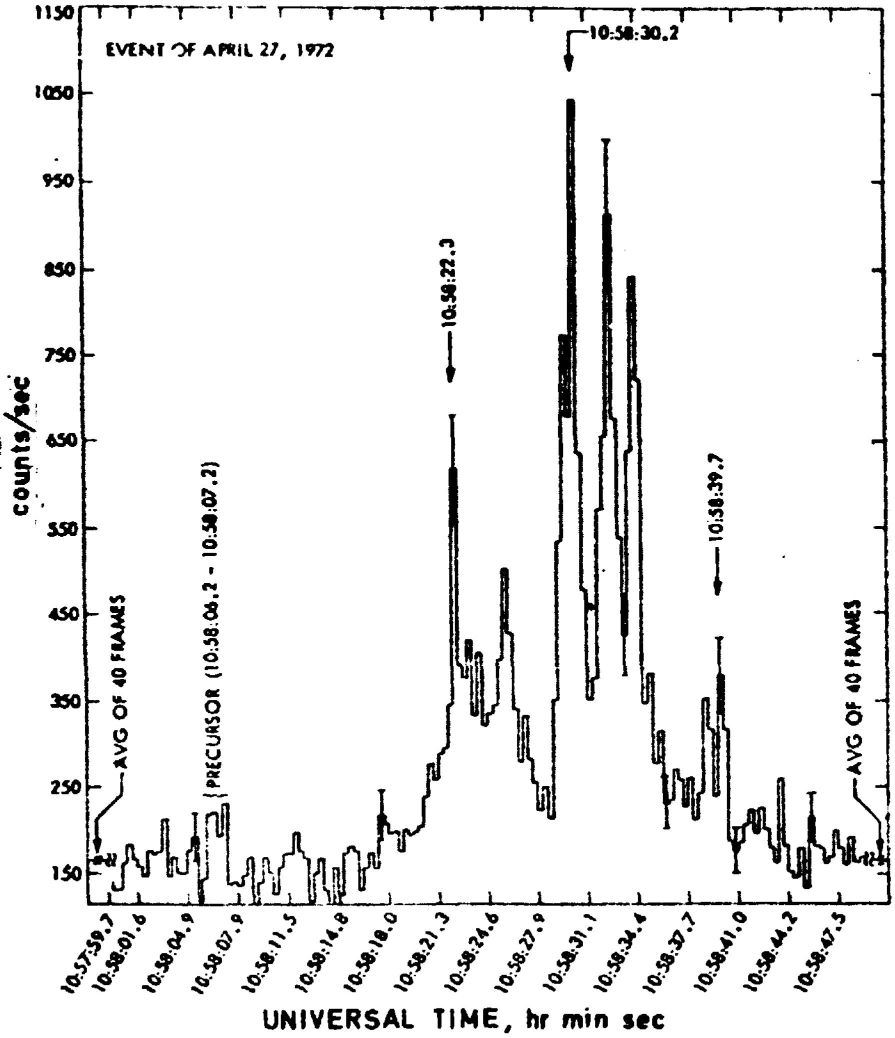

FIG. 5 Cosmic gamma-ray burst with main feature duration of 25 sec. (Apollo 16, Metzger et al)

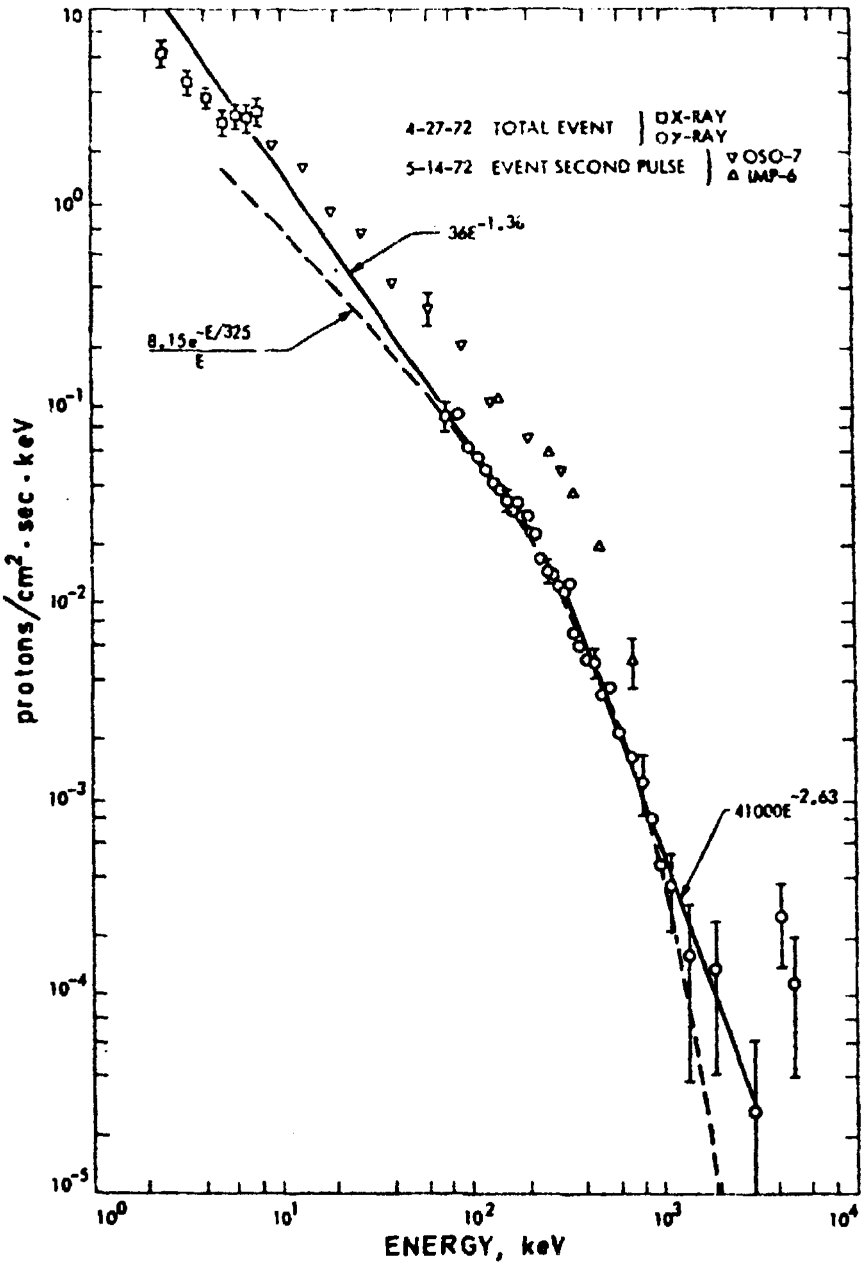

FIG. 6 Energy spectrum of the gamma-ray burst in fig. 5 (Apollo 16, Metzger et al).

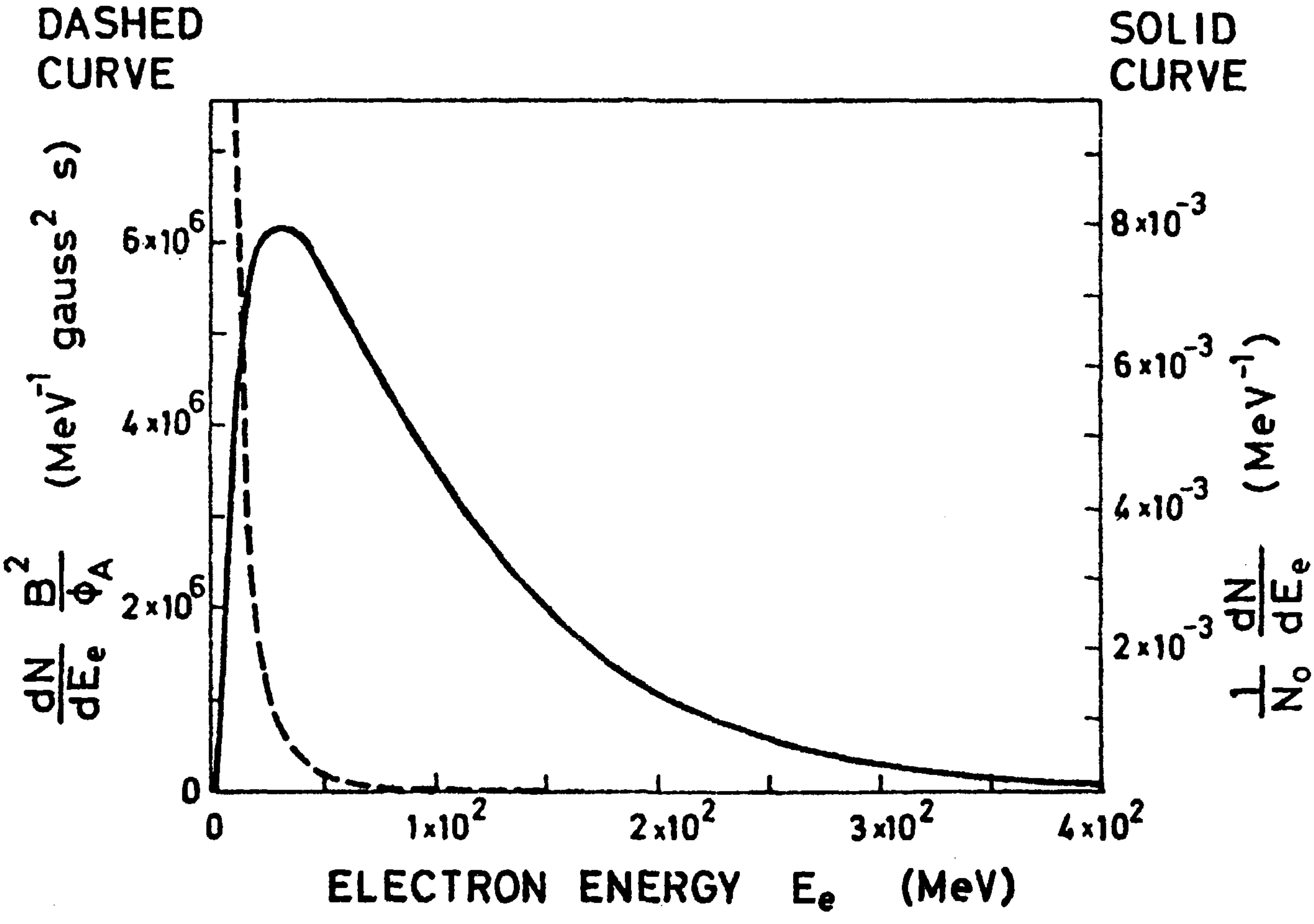

FIG. 7 Theoretical energy spectrum of electrons-positrons from protron-antiproton annihilation.

——————— production spectrum
--------- steady state spectrum

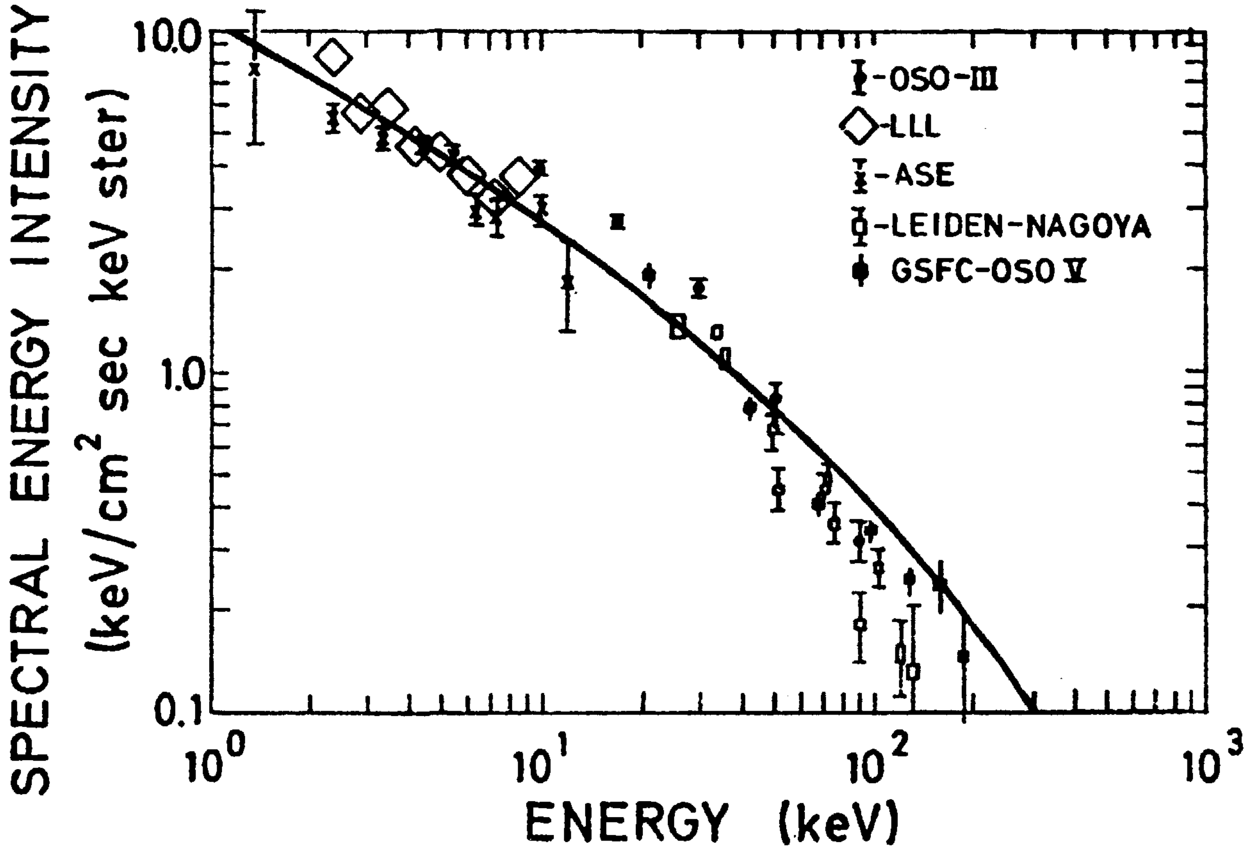

FIG. 8 Comparison between observed background X-ray spectrum and that calculated for inverse Compton effect between ordinary star light and annihilation products.

Some important antimatter problems

Nuclear and particle physics

1. Lifetime of thermal ambiplasma
   Cross section of annihilation for particles <1 eV

2. Reactions between heavy nuclei of opposite kind
   Example: Anti-iron and koinonitrogen

Solid state

1. How rapidly will a solid body of given size be fragmented by annihilation reactions at its surface?
   Example: How far can an antimeteoroid move in interstellar koinomatter?

Plasma physics

1. Evolution of a magnetized homogeneous ambiplasma
   Spectrum of emitted radiations as functions of magnetic fields and plasma densities

2. Interface between koinoplasma and antiplasma
   Structure of "Leidenfrost layer", radiations, stability

3. Separation of an ambiplasma
   Under what conditions does it "coagulate" into regions of partially separated koinoplasma and antiplasma?

4. Shock waves in ambiplasma
   Under what conditions is it "explosive"?

Complex problems (involving several different fields of physics)

1. What happens if an antimeteoroid hits the Earth's atmosphere?

2. What happens if two stars of different kind collide? If their size is very different, how deep can the smaller body penetrate into the larger one?

Fig. 9

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Another support for the symmetric cosmology is the continuous X-ray background radiation. Also many of the observed large energy releases in cosmos are likely to be due to annihilation.

Key words: Antimatter, Annihilation, Cosmology, Plasma physics, γ-ray bursts, X-ray background radiation, Particle physics, Leidenfrost layers, Magnetosphere, Comets.