THE LOW DENSITY SYMMETRIC COSMOLOGY*

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Most cosmological models are based on the 'cosmological principle' according to which the Universe is homogeneous and isotropic on a certain level, chosen such that the present mean density is of the order of $10^{-30\pm1}$ g cm^{-3}.

These (expanding) models show a density singularity (or at least a very high density) at some early time.

Usually when one approaches a singularity in physics this is taken as a sign that one enters a region where the assumed physical laws do not apply.

One could argue that before one takes such extreme situations as mentioned here into consideration one should try less exotic approaches in which only well known natural laws are applied. Work along these lines initiated by Oskar Klein and Hannes Alfvén (Klein, 1953; Alfvén and Klein, 1962) is going on in Stockholm. We are trying to understand e.g. the observed recession of the galaxies as caused by processes governed by known physical laws.

This necessitates an inhomogeneous model like the isolated metagalactic system with much lower density outside than inside. Such a system does not comprise the entire universe but contains all the objects that have been observed.

The metagalaxy is assumed to have started as an extremely thin cloud containing matter and antimatter in equal amounts. This cloud contracts gravitationally until a certain maximum density is reached which is, however, still quite low (less than 10^{-23} g cm^{-3}) because the metagalaxy is not allowed to reach its Schwarzschild limit.

Separation of matter from antimatter must have started long before the cloud reached its maximum density phase in order to allow the metagalaxy to acquire a high enough density. Annihilation of matter and antimatter is assumed to occur at a moderate rate during the contraction phase and reach a very high rate during a short time near maximum density. Thus the original mass of the contracting cloud may have exceeded the present mass of the metagalaxy by several orders of magnitude.

* The original paper has been revised and considerably shortened because of information obtained after the symposium concerning recent calculations on the hydrogen – antihydrogen potential, which invalidate conclusions based on earlier computations.

M. S. Longair (ed.), Confrontation of Cosmological Theories with Observational Data, 341–345.

The observed high rate of recession of the galaxies is interpreted by us as originating from the conditions near maximum density, particularly the sudden annihilation of a considerable part of the mass present at that time.

Dynamical calculations have till now been confined to gas cloud models. The metagalaxy is thought to start as a very thin and wide spread, homogeneous (but limited) gas cloud at rest. This cloud contracts gravitationally and annihilation reactions occur producing radiation.

Equations derived by Alfvén and Klein (1962) were solved by Bonnevier (1964) using Newtonian mechanics. With this model the contraction of the metagalaxy could be converted to an expansion in agreement with observations. However, general relativity should be used as the cloud, when it is at its densest, comes close to the Schwarzschild limit.

In one type of relativistic calculation (Laurent and Söderholm, 1969) an annihilation cross section is assumed, which is inversely proportional to the collision velocity. This gives a life time for the gas particles which is independent of the temperature. In another type of calculation, which is being performed by H. Hellsten at the University of Stockholm, it is assumed that a given part of the gas is suddenly transformed into radiation at a given value of the local density. After the radiation has been formed it is, in both cases, assumed to be governed by a (relativistic) transport equation based on a given scattering cross section.

Numerical treatment of these models shows that they do turn (in a certain parameter range) so that the contraction is followed by expansion. One is not very surprised to learn that there is a limit to the original mass above which a total collapse takes place. This limit increases with the scattering cross section for the radiation and is 2×10^{53} g when the cross section is the Thomson cross section, $\frac{8}{3}\pi r_e^2 = 6.6 \times 10^{-25}\,\mathrm{cm}^2$. The value mentioned seems quite low for the total mass, especially as it seems improbable that the effective cross section could be as high as the Thomson cross section.

Still more significant than this seems, however, the discovery that the first model does not allow a higher outward velocity than $0.4c$ *whatever the values of the parameters* and a very similar behaviour of the second model. In this latter case the limit seems to be reached when an inner part of the metagalaxy collapses.

Hannes Alfvén has put forward a radically different model in which it is assumed that galaxy formation has set in long before the turning point. The thought is that the motion of the galaxies may not be perfectly radial and that at least some of them should be able to pass the turning stage without ever losing much of their kinetic energy. An important role of the annihilation in this type of model could be that it gives rise to radiative mass loss. Thus the galaxies acquire kinetic energy in the fall towards a mass which can be considerably larger than the mass which they later on shall break loose from.

The anisotropy in the velocity distribution of galaxies, indicated in the observations by Rubin *et al.* (1973), as well as the discrepant redshifts observed for some objects in groups of galaxies (Burbidge and Sargent, 1971) are readily explained with this model but seem to be difficult to understand in terms of homogeneous cosmological models. In the model suggested by Alfvén galaxies or groups of galaxies may move along slightly curved orbits at some inclination to the orbits of other galaxies now passing through the same region of space. Due to projection effects the observed radial velocities may then differ considerably, even though the galaxies have approximately the same velocity of recession from the centre of the metagalaxy.

Magnetic fields play an important part in our model, e.g. for the separation of ordinary matter from antimatter. A process based on ideas presented by Alfvén (1966) has been studied and it can be shown that under certain conditions a small initial separation, perhaps a statistical fluctuation, may lead to the creation of a weak magnetic field which causes an increased separation. In this way it may be understood how magnetic fields have been formed and enhanced and how a considerable degree of separation was accomplished. This separation process first produced small-scale (~ 1 AU) 'cells' of koinoplasma and antiplasma. The 'Leidenfrost phenomenon' (Alfvén, 1965) later led to the formation of larger regions. As remaining unseparated ambiplasma will have been annihilated during the denser phases of the evolution of the metagalaxy the annihilation should later take place mainly in very thin layers on the boundaries of colliding clouds of matter and antimatter. The γ-radiation from such layers should be very small, usually negligible. Recent observations of γ-radiation (Stecker, 1973; Stecker and Puget, 1972; Trombka *et al.*, 1973) may be used as arguments in favour of our model rather than against it.

In the dense nuclei of some galaxies and especially in quasistellar objects annihilation may be a powerful source of energy.

The collision between a star and a moderately dense gas cloud is not very efficient, and the collision between clouds is counteracted by the repulsion due to the hot regions developing at the boundary of the colliding clouds.

Collisions between stars may be expected in very dense nuclei of galaxies as has been discussed in several papers (Spitzer, 1971 and references therein). In a galaxy consisting of 50% antimatter every second collision between stars in the dense nucleus will lead to annihilation of parts of these stars. As the collision rate depends very strongly on the number density of stars in the nucleus, only systems with a very dense nucleus will show appreciable activity. The nuclear density is assumed to decrease systematically from very high values in QSOs to lower values for Seyfert galaxies and still lower for normal galaxies, where stellar collisions become quite rare. This dependence on galaxy type of the star density in the galactic nuclei has been inferred from observations of various kinds, such as photometry, spectral analysis and dynamical considerations based on radial velocity data. In our Galaxy we expect only a small activity from the nuclear region with its moderate density.

The stellar population of a galaxy nucleus probably contains a great number of dwarf stars and a small number of giants of considerably larger dimensions. In nuclei dense enough for frequent stellar collisions a typical case may be the collision between a dwarf and a giant star.

In favourable cases the entire dwarf star will be swallowed by the giant and the annihilation will take place inside the giant star. Head-on collisions like this must be very rare, however, grazing collisions being much more probable. Also in such cases the annihilation will occur in the boundary region between the colliding stars where the gases mix.

Most of the γ-rays from the annihilation are then likely to be absorbed in the stellar gases, causing strong heating and shock waves which in many cases may cause disruption of one or both stars. Several consequences of this violent energy release may be observed, as has been argued in earlier papers (Alfvén and Elvius, 1969; Elvius, 1972). At the same time the γ-radiation may be so effectively absorbed that a very small percentage leaks out to be observed by us. Thus it seems possible to allow the flux of γ-rays to be small although a high enough rate of annihilation is assumed to account for the energy flux from QSOs and more or less active galactic nuclei.

The 100 MeV electrons and positrons released in the annihilation will cause other observed phenomena, mainly the radio radiation which may be quite variable at high frequencies, as is expected in our model.

It has been argued (Steigman, 1972) that observations of Faraday rotation for radiation from galactic and extragalactic sources excludes the possibility that either our Galaxy, other galaxies, or the intergalactic gas can contain equal amounts of matter and antimatter. However, it is not possible to draw such conclusions from the observed Faraday rotation.

In an ambiplasma, the Faraday rotation is proportional to the integral along the line of sight of the product of the magnetic field component parallel to the line of sight ($B_{\|}$) and the difference in density between electrons and positrons $(n_{e^-} - n_{e^+})$:

$$\Delta\Theta \sim \int (n_{e^-} - n_{e^+}) B_{\|} \, \mathrm{d}s$$

In the present stage of the metagalaxy, however, matter and antimatter must be in the form of separated cells. If the magnetic field permeating the cells is unidirectional, contributions from different cells tend to cancel. However, if $B_{\|}$ changes sign, as we pass from one cell to another, the Faraday rotation will be in the same direction in both cells, and no cancellation will occur.

Applying this result to our Galaxy, we see that only if we know that $B_{\|}$ is of the same sign along the whole line of sight, could we draw the conclusion that the electron surplus does not average to zero. Thus the existence of antimatter in our Galaxy can *not* be excluded.

For intergalactic space, we could argue as follows. There is no reason to assume an ordered magnetic field of metagalactic scale. Instead, it seems reasonable that the intergalactic magnetic field should have a random structure. For a pure matter plasma, the Faraday rotation of waves from extragalactic sources would then be given by a probability distribution. For an intergalactic plasma with separated cells of matter and antimatter, a similar probability distribution will result, irrespective of the character of the magnetic field. Thus, it is not possible to draw any conclusions about the existence of antimatter in the intergalactic gas.

The discovery in 1965 of an intense background radiation in cm and mm wavelengths and the high degree of isotropy of this radiation found by several investigators have been used as strong arguments in favour of isotropic cosmological models starting from a state of high density. Although the high intensity and isotropy of the microwave radiation are no obvious consequences of our metagalaxy model, we do not feel that the model should be discarded for this reason.

Acknowledgements

It is a pleasure to thank Hannes Alfvén for stimulating discussions. We further thank Hans Hellsten for his clarifying dynamical calculations. Åke Nordlund and other members of the Stockholm group contributed in various ways for which we are grateful.

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