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[1] Lewin, W. H. G., Clark, G. W., and Smith, W. B., *Nature*, **219**, 1235 (1968).
[2] Clark, G. W., Lewin, W. H. G., and Smith, W. B., *Ap. J.*, **151**, 21 (1968).
[3] Lewin, W. H. G., Clark, G. W., and Smith, W. B., *Ap. J. Lett.*, **152**, *L*49 (1968).
[4] Peterson, L. E., Jacobson, A. S., Pelling, R. N., and Schwartz, D. A., *Canad. J. Phys.*, **46**, *S*437 (1968).
[5] Lewin, W. H. G., Clark, G. W., and Smith, W. B., *Canad. J. Phys.*, **46**, *S*409 (1968).
[6] Seward, F. D., and Toor, A., *Ap. J.*, **150**, 405 (1967).

Radiation and Matter in an Open Cosmological Model

THE discovery[1] of the cosmic background radiation has stimulated research on the cosmological model with both matter and radiation[2]. As usually used the Friedmann solutions correspond either to pressureless matter alone

$$a_m = A_m(\cosh\eta - 1),\quad c\tau = A_m(\sinh\eta - \eta) \qquad (1)$$

or to radiation alone

$$a_r = A_r \sinh\eta,\quad c\tau = A_r(\cosh\eta - 1) \qquad (2)$$

Here $a(\tau)$ is a scale factor of the line element

$$ds^2 = c^2 d\tau^2 - a^2\ \{\sinh^2\chi(d\nu^2 + \sin^2\nu d\varphi^2) + d\chi^2\}$$

and A_m, A_r are constants. These equations describe an open model with negative curvature. It seems reasonable to consider an open model because of a number of observational and theoretical arguments[3]. Here I consider some properties of the analytical solution for the open cosmological model containing both radiation and matter.

The solution can be written in the following form[4]

$$a = A_m(\cosh\eta - 1) + A_r\sinh\eta,\quad c\tau = A_m(\sinh\eta - \eta) + A_r(\cosh\eta - 1) \qquad (3)$$

This expression gives the correct time dependence for the scale factor and, what seems to be more important, it permits the analysis of the relationships between the characteristics of radiation and matter in terms of an exact solution. Solution (3) has a peculiar property: a (and τ too) is given as a sum of two items, each of which is the solution for matter and radiation taken separately. It is worth recalling at this point the non-linearity of cosmological equations.

The symmetry of solution (3) with respect to radiation and matter might in a sense be still more complete, provided the two constants A_m and A_r are equal. Let us therefore see what can be deduced from the supposition $A_m = A_r$. The supposition gives rise to a connexion between the mass–density of matter

$$\rho_m = \frac{6}{\varkappa}\frac{A_m}{a^3}$$

and the mass–density of radiation

$$\rho_r = \frac{3}{\varkappa}\frac{A^2_r}{a^7}$$

Indeed, A_m and A_r are as follows

$$A_m = \frac{1}{2}\left(\frac{3}{\varkappa}\right)^{1/2}(\rho_c - \rho)^{3/2}\,\rho_m,\quad A_r = \left(\frac{3}{\varkappa}\right)^{1/2}(\rho_c - \rho)\,\rho_r^{1/2}$$

where $\varkappa = 8\pi G c^{-2}$, $\rho = \rho_m + \rho_r$, and ρ_c is the critical density. Given that $A_m = A_r = A$, then

$$a = A(e^\eta - 1),\ c\tau = A(e^\eta - \eta - 1);\quad \rho_m = 2\rho_r^{1/2}(\rho_c - \rho)^{1/2} \qquad (4)$$

These expressions relate ρ_m to ρ_r and ρ_c. The values of ρ_r and ρ_c are known rather precisely: $\rho_r \simeq 6\times10^{-34}$ g cm^{-3}, and $\rho_c \simeq 2\times10^{-29}$ g cm^{-3}. But the values of ρ_m can only be estimated with considerable uncertainty

$$10^{-31} < \rho_m < 10^{-28}\ \text{g cm}^{-3}$$

The lower limit corresponds to the density due to galaxies[5], while the upper limit takes into account the other possible forms of cosmic matter[6].

Using relation (4) and ρ_r and ρ_c, we obtain $\rho_m \simeq 2\times10^{-31}$ g cm^{-3} which does not contradict the empiric data. This result, as well as other arguments[3], is in favour of a special preference for the open cosmological model with matter density close to the average density of the visible matter due to galaxies.

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[1] Penzias, A. A., and Wilson, R. W., *Astrophys. J.*, **142**, 419 (1965).
[2] Jacobs, K. C., *Nature*, **215**, 1156 (1967). Cohen, J. M., *Nature*, **216**, 249 (1967). McIntosh, C. B. G., *Mon. Not. Roy. Astro. Soc.*, **138**, 423 (1968).
[3] Chiu, H. Y., *Ann. Phys.*, **43**, 1 (1967).
[4] Chernin, A. D., *Astro. Zhur.*, **42**, 1124 (1965). English translation in *Sov. Astro., AJ.*, **9**, 871 (1966).
[5] Hubble, E., *Astrophys. J.*, **64**, 321 (1926). Oort, J. H., *Solvay Conf.*, **163** (1958). Sandage, A. R., *Astrophys. J.*, **133**, 355 (1961).
[6] Zeldovich, Y. B., Smorodinsky, Y. A., *Zhur. Exp. Theor. Phys.*, **41**, 907 (1961). English translation in *Sov. Phys., JETP*, **14**, 647 (1962).

New Method of Forecasting Geomagnetic Activity using Features of the Solar Corona

EARLIER studies[1,2] have shown that a geomagnetic disturbance will occur when, and only when, a coronal formation is directed towards the Earth. An idea of the features and the temporal changes of the solar corona which are not currently observable can be acquired through the known relations between coronal formations and prominences. It is also necessary to realize that the coronal structure is formed by local magnetic fields, the extent and temporal stability of which are studied by means of prominences and the chromospheric structure in general. Coronal formations can be divided into four groups: helmets, streams, equatorial helmet of the minimum type and polar rays. Streams are characterized by a relative instability of the local magnetic fields at their base, which is displayed especially by the occurrence of unstable filaments, surges and a changing chromospheric structure. The remaining coronal formations are characterized by relatively stable conditions in the chromosphere and the photosphere.

From the point of view of geomagnetic effects, coronal streams and the minimum type corona are significant. The coronal stream above the centre of the solar disk is followed by a geomagnetic disturbance either with a sudden commencement, provided the stream was formed in the central region, or with a gradual commencement, if a coronal stream which already exists is moved to the centre of the disk by the solar rotation. A similar case occurs if the peak of the minimum type corona passes through the centre of the disk. If a minimum type corona is formed directly over the central meridian, as a result of the decay of perturbing local magnetic fields, a geomagnetic disturbance with a sudden commencement follows. If the minimum corona formation has already been formed