LOCAL ELECTROMAGNETIC FIELD PROPAGATION IN THE IMPERFECT FLUID FRIEDMAN COSMOLOGY

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The problem of the electromagnetic and thermodynamic arrow of time is discussed within the framework of the imperfect fluid Friedman cosmology.

According to Hogarth [1], Roe [2], Hoyle and Narlikar [3, 4] the only cosmological model in which the cosmological arrow of time (determined by the expansion of the universe) agrees with the local direction of the electromagnetic radiation is the steady-state world model. Only this steady-state model gives a perfect absorber along the future light cone, and hence only this model is suitable for obtaining empirically observed retarded electromagnetic field propagation.

Heller et al. [5] have shown that the solution for the Friedman universe filled with a viscous fluid (with $k = 0$, $\Lambda = 0$, and a bulk viscosity coefficient ζ = const) imitates Hoyle's solution [6] for a stationary expanding universe with a constant rate of continual creation of matter. The matter creation term introduced a priori by Hoyle, in the "viscous model" has a clear physical meaning as the term describing the bulk viscosity dissipation. Because of this formal affinity it might seem that the viscous model could share with the steady-state universe the advantage of giving the correct electromagnetic field propagation. We shall consider this problem.

Let us consider the following conformally flat metric

$$ds^2 = (\alpha\beta\tau)^{2\alpha\gamma}[d\tau^2 - dr^2 - r^2(d\theta^2 + \sin^2\theta d\phi^2)], \tag{1}$$

where α is an indicator equal to ± 1. The metric discussed by Heller et al. can be derived from (1) by the following transformation

$$\tau \to -(1/\beta)\exp(-\beta\tau) \tag{2}$$

with $\alpha = -1$, $\gamma = 1$, $\tau < 0$. The metric of the steady-state model is exactly the same. For both cosmologies the Friedman equation reads

$$2R\ddot{R} + \dot{R}^2 - \Lambda R^2 - 2\delta R\dot{R} = 0, \tag{3}$$

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where $2\delta R\dot{R}$ may be interpreted either as the dissipative term ($\delta = \frac{2}{3}\zeta$), or as the term describing the matter creation field. The only difference between the steady-state cosmology and the imperfect fluid cosmology appears in the number N of charged particles per unit proper volume. In the imperfect fluid cosmology, as in ordinary Friedman models, $N \sim R^{-3}(t)$, where $R(t)$ is the scale factor, and from (2) and (3): $R(t) = \exp(\beta\tau)$. However, in the steady-state theory $N = \text{const}$. This difference between the imperfect fluid model and the steady-state model appears to be decisive for their absorbing properties since the refractive index n is a function of the density of charged particles [7]:

$$n = 1 - \frac{2\pi N e^2}{m\omega^2}, \tag{4}$$

where ω is the local frequency of the electromagnetic waves.

One of the two absorption mechanisms considered in [1–4] is the collisional damping. This phenomenon is natural for the viscous universe. The fluid viscosity makes the frequency of collisions increase as compared to the perfect fluid. The expression for the refractive index after taking into account the collisional damping assumes the following form [1]:

$$n = 1 - \frac{2\pi N e^2}{m\omega^2}\left(1 - \frac{i\varepsilon\nu}{\omega}\right), \tag{5}$$

where

$$\varepsilon = \begin{cases} +1 & \text{for the future absorber} \\ -1 & \text{for the past absorber.} \end{cases}$$

Based on the hydrodynamic meaning of viscosity, the collision frequency ν in (5) for the viscous fluid is $\nu \sim N$, and it is readily seen, using Hogarth's formalism, that neither future nor past of the universe are perfect absorbers. A geometric similarity between the imperfect fluid model and the steady-state model is not sufficient to provide the correct electromagnetic field propagation in the viscous universe. Note, however, that the introduction of the particle creation process out of "bulk viscosity dissipation"–analogously to the particle creation out of "shear dissipation" [8]–could change the result drastically. This problem will be discussed later.

As stated by Roe [2] and Davies [9], Hogarth overlooked the dependence of the collision frequency ν on temperature in his treatment of the cosmological absorption problem. This overlook leaves our above conclusion unchanged. The improved results are the following: 1) In the steady-state model there is perfect absorption by discrete objects such as planets, stars, black holes, etc., but *not* by intergalactic ionized gas. 2) In particle number conserving models there is also absorption by discrete sources provided that these models expand as $t^{1/3}$ or slower. 3) The oscillating Friedman models act as perfect absorbers if they collapse to the final singularity as $t^{1/3}$ or faster. 4) All other cosmological models are not perfect absorbers. See [9] p. 143.

It should be noted that the absorption process is intrinsically a thermodynamic process and that the viscous world models have this advantage over the ordinary Friedman models (which are isoentropic models) in that they possess a well-defined thermodynamic arrow of time. For the viscous cosmic fluid we have

$$\frac{1}{R^3}\frac{d(R^3 s)}{dt} = \frac{9\zeta s}{\varepsilon + p}\frac{\dot{R}}{R}, \tag{6}$$

where s is the entropy density, and if s, ζ, $p+\varepsilon > 0$, the entropy increases as the universe expands, and the cosmic evolution is irreversible.

In fact, we are able to show, following the original treatment by Wheeler and Feynman [10], that a certain consistency must take place between the thermodynamic and electromagnetic arrow of time. Indeed, the equation for the motion of the typical particle in a perfect absorbing medium is the following

$$m_a \ddot{a}_n = e_a \sum_{k \neq a} F^{(k)}_{n\alpha \, \substack{\mathrm{ret} \\ (\mathrm{adv})}} \dot{a}^\alpha (\pm)(2e_a^2/3)\,(\dot{a}_n \dddot{a}_\alpha - \dddot{a}_n \dot{a}_\alpha)\,\dot{a}^\alpha, \tag{7}$$

where m_a and e_a are the mass and charge of the typical particle of the absorber. $F_{n\alpha}$ is the field describing the reaction of the absorber on the source. If we sum up all contributions in (7), we obtain the following results for the retarded propagation, particles of the absorber are at rest or in random motions *before* the disturbance from the source hits them. *Afterwards* they are accelerated and collide. We have the transition from the state with a lower entropy to a state with a higher entropy. For the advanced propagation, each of the absorber particles receives an impulse precisely at the right time and generates disturbance converging upon the source. The absorber particles are left with less energy, part of which is transferred to the source. This process is evidently anti-entropic. We can conclude that only the retarded propagation is consistent with the thermodynamic arrow of time, determined by increase of entropy. Strictly speaking, this argument has been put forward in the Minkowski space-time, nevertheless, it remains valid, at least locally, also in viscous universes.

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