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ON THE PRINCIPLE OF RELATIVITY

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In a recent article [1] M.A. Oliver argues there is a conflict between Einstein's Special Theory of Relativity (STR) and Cosmology. In ascertaining this conflict (see below), Oliver finds allies in Bergmann [2] and Bondi [3]. To resolve this conflict, he proposes to restore "the classical (mechanical) concepts of space and time" [1, p.666] and an absolute rest-frame. I shall devote a few words (**1**) to the Principle of Relativity and (**2**) to the notion of cosmic time in cosmology; this enables me (**3**) to argue that the alleged conflict between STR and Cosmology is based on a misunderstanding of the Principle of Relativity. (4) Finally I take a critical look at Oliver's allies.

Key words: principle of relativity, cosmic time, special relativity, Einstein, backround radiation.

1. ITS SUBJECT MATTER

In the local inertial frame F attached to Earth, it is a fact that the Earth is at rest and that the Sun is orbiting around the Earth; and in the local intertial frame F' attached to the Sun, it is a fact that the Sun is at rest and that the Earth is orbiting around the Sun. Are the inertial frames F and F' then not equivalent? Does this count as a violation of the Principle of Relativity (PR)?

Not so. Because according to PR all inertial frames are equivalent *with regard to physical law, not with regard to physical facts* (∗).

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By a *physical fact* in this context I mean properties of existing objects — in the example above the properties 'moving' and 'resting' of the Earth and the Sun in the different inertial frames. By a *physical law* I mean a universal, mathematical relation between physical quantities which is part & parcel of an empirically adequate physical theory — in the example above the usual relations from STR between position, time, velocity, momentum, angular momentum and kinetic energy (of the Earth and the Sun). Not only in Einstein's writings [4, p.41,111], but in every textbook on STR statement (*) can be found; Weinberg [5, p.19] formulates PR as follows: *the laws of physics are the same in all inertial frames.* Oliver refers to Weinberg's *classic* twice. By 'the same' is meant *form-invariance*: the mathematical relations between the physical quantities remain identical after a coordinate transformation has been performed on these quantities. In STR the transformations between inertial frames are Lorentz-transformations. It should be stressed that PR only applies *in the absence of gravity*; in the presence of gravity (inertial frames lost) one enters the General Theory of Relativity and PR is not required to hold, save in the case of a vanishing Riemann curvature tensor (the true marker of the absence of gravity) and reduction of the metric tensor to the Lorentz-Minkowski tensor (inertial frames regained [5, p.92]). This motivates speak about the Principle of *Special* Relativity.

What would count as *a violation of* PR? If, *in the absence of gravity*, the same experiment were performed in different inertial frames, say a collision experiment with billiard balls on land and on a ship moving with constant velocity in quiet waters (so that we have two inertial frames), yielding *different* mathematical relations between the measured values of *the same* physical quantities (like position, time, momentum), then the two inertial frames are not equivalent and PR is violated. (To anticipate, such violations are not what Oliver, Bergmann and Bondi discuss.)

2. COSMIC STANDARD TIME

Let us follow Weinberg to see how the notion of *cosmic standard time* comes about [5, p.409]: "To define a time coordinate, it is convenient to use the evolving universe itself as a clock. It is believed that several cosmic scalar fields, such as the proper energy density, or the black body radiation temperature, are everywhere decreasing monotonically; choose any one of these, say a scalar S, and let the time of any event be any definite decreasing function $t(S)$ of the chosen scalar S, when *and where* the event occurs. (...) The coordinates $\mathbf{x}$,t so defined will be called the *cosmic standard coordinate system.*" So the definition of *cosmic standard time* is a matter of convenience. At this point Weinberg introduces a notion of equivalence between frames. "A dif-

ferent [from x^μ] set of space-time coordinates x'^μ may be considered *equivalent* to the cosmic standard coordinates, if the whole universe appears the same in the x'^μ coordinate system as in the cosmic standard coordinate system." The latter is codified by Weinberg [*ibidem*] as follows: the coordinate transformation $x \rightarrow x'$ must be an *isometry* (form-invariance under general coordinate transformations of the metric), and the other cosmic fields, like the energy-momentum tensor, must be *form-invariant* under this transformation. Combining the definition of cosmic standard time and the form-invariance requirement yields that all coordinate systems which are equivalent to the cosmic standard coordinate system necessarily use cosmic standard time [5, p.410].

Enter the Cosmological Principle, which states (a) that the hypersurfaces with constant cosmic standard time (suppose that a cosmic standard coordinate system has been chosen) are homogeneous and isotropic subspaces of the whole of space-time; and (b) that all the cosmic fields are form-invariant with respect to the isometries of these subspaces [5, p.412]. The Cosmological Principle leads us to the coordinate system wherein the cosmic backround radiation is isotropic and the distribution of red-shifts is homogeneous.

Weinberg does not notice any conflict between the Cosmological Principle and PR, nor between defining a cosmic standard coordinate system and PR.

3. CONFLICT RESOLVED

Let us now turn to Oliver's conflict: "Observation shows that there is a rest-frame defined by the astronomical red-shifts and the cosmic backround radiation: since such a frame is denied by the fundamental structure of STR this should be sufficient to eliminate the theory from physics." [1, p.683]

This assertion is false on three accounts. First, from what is said in part **1** it should be clear that PR *does not require* the isotropy and homogeneity of the mentioned phenomena in all inertial frames, only a misunderstood PR does so. PR applies to physical laws, not to physical facts. Secondly, what PR surely does not forbid (nor requires) is the existence of monotonically decreasing scalar fields in the universe, which form the basis of *the definition of* standard cosmic time. Therefore this definition cannot be in conflict with PR. Thirdly, if the chosen cosmic standard coordinate system is one on a metrical space-time of non-zero curvature, like if one defines cosmic standard time by means of the Robertson-Walker metric, then the very presence of gravity renders PR inapplicable.

Suppose the chosen cosmic standard coordinate system *is* (ap-

proximately) an inertial frame. Then what? PR *only* forbids the laws of physics to be different in different inertial frames, in the sense explicated in part **1**; exactly *because of* PR one is *licensed to choose* any inertial frame for the description of the universe — based on any kind of considerations, factual, pragmatical, or what have you.

Oliver also writes [1, p.668]: "In cosmology the Cosmological Principle implies the existence of cosmic time, which implies the existence of a local rest frame of reference." This assertion is false too. Given the Cosmological Principle, it *is possible to define* a cosmic standard coordinate system [5, p.412]. This is a matter of definition, not of "implication", motivated by our wish for descriptive simplicity. Weinberg [5, p.408]: "The real reason, though, for our adherence here to the Cosmological Principle is not that it is surely correct, but rather, that it allows us to make use of the extremely limited data provided to cosmology by observational astronomy." Apparently we prefer isotropy and homogeneity over and above anisotropy and inhomogeneity; and it is this preference which carries over to the chosen coordinate system. The existence of an absolute rest-frame is not "implied" by such a preference and the resurrection of the concomitant absolute simultaneity is therefore totally uncalled for.

To conclude, there is no conflict between "the fundamental structure of STR" or PR (which applies to physical laws) on the one hand, and choosing a cosmic standard coordinate system or the isotropy and homogeneity of the cosmological phenomena (which are physical facts) on the other hand. Hence the main justification for Oliver's reconciliation program collapses.

4. BONDI AND BERGMANN

Bondi writes (my italics): "In ordinary physics we are taught to take PR, the principle *of the irrelevancy of velocity*, as sometimes so absolutely valid, so essential, so fundamental, that we deduce many things from it and do not ordinarily dare to question that there is no preferred velocity as far as laboratory physics goes." [3, p.136] And Bergmann writes (my italics): "The foundation of STR is the so-called principle of relativity: among the inertial frames of reference (which are, relative to each other, in states of irrotational uniform linear motion) there is no privileged frame representing absolute rest; no conceivable experiment will reveal *any difference in quality* between any two inertial frames of reference." [2, p.20] Both Bondi and Bergmann see a conflict between the isotropy of the cosmic backround radiation and PR.

All the arguments of part **3** apply. Both Bondi and Bergmann ascertain this conflict because of an incorrect formulation of PR. Concerning Bondi: PR is 'irrelevancy of velocity' *with regard to physical law*, not with regard to *anything*. Concerning Bergmann: PR forbids 'any difference in quality' *in physical law*, not *any* conceivable differ-

ence, like for instance factual differences.

In 1905 the founding father of STR expressed PR as follows [4, p.41, my italics]: "*The laws* by which the states of physical systems undergo change *are not affected*, whether these changes of state be referred to the one or the other of two systems of coordinates in uniform translatory motion." *Dixit.*

References

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