The Equivalence Principles and the Nature of Gravitation

M. Holman – Western University

Abstract

I review three distinct challenges to the standard notions of dark matter/energy and modified gravity as belonging to two entirely different conceptual categories. First, I recall the well-known dynamical equivalence of certain modified gravity models - such as a generic scalar-tensor model or $f(R)$ models - to standard Einstein gravity coupled to additional "matter" fields and stress that the issue of which frame is "physical" cannot, in general, be given an unambiguous answer. I also comment on recent results generalizing some of these equivalences, e.g., to densities with an arbitrary dependence on full Riemann curvature. A more general reason for questioning the usual dichotomy between dark matter/energy models and modified gravity models emerges from reflecting upon the nature of gravitation. Briefly put, within the class of so-called *metric theories* - i.e., theories that conform to Einstein's version of the Equivalence Principle (EEP) - and as far as gravity is concerned, "matter" couples universally to, and *only* to, the metric and the role of any additional gravitational fields, if present, can only be to potentially act as sources, together with matter fields, to help generate the metric. In other words, any additional gravitational fields would effectively behave like dark matter/energy fields (in view of the mentioned equivalences, the pragmatic response to speak of gravity if a field appears in the "gravitational part" of the action does not in general work). Finally, I discuss models that have recently gained some popularity as candidates to explain both the observed mass discrepancies for galaxies and the cosmic accelerated expansion. In these models, based on the notion of so-called "superfluid dark matter", the distinction between dark matter/energy and modified gravity also becomes ambiguous according to (almost) any reasonable criterion.

All three above cases (tacitly) involve the assumption of metricity. It is often held that, in view of the experimental status of EEP, the only alternatives to general relativity that have a hope of being viable are metric theories. What is then taken to empirically distinguish different metric theories in general, is how they respond to the so-called Strong Equivalence Principle (SEP). I will review this line of reasoning, as well as a recent proposal to take SEP as a fundamental distinguishing criterion (i.e., to the extent that any model violating it would be classified as modified gravity). The upshot of these arguments is that a genuine modification of gravity would presumably require something more drastic, that is, beyond metricity. Two concrete examples in support of this conjecture (based on respectively torsion and local conformal invariance) are also discussed.