General Relativity and Quantum Cosmology

Noether Symmetries and Covariant Conservation Laws in Classical, Relativistic and Quantum Physics

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(Submitted on 17 Jan 2010)

We review the Lagrangian formulation of Noether symmetries (as well as "generalized Noether symmetries") in the framework of Calculus of Variations in Jet Bundles, with a special attention to so-called "Natural Theories" and "Gauge-Natural Theories", that include all relevant Field Theories and physical applications (from Mechanics to General Relativity, to Gauge Theories, Supersymmetric Theories, Spinors and so on). It is discussed how the use of Poincare'-Cartan forms and decompositions of natural (or gauge-natural) variational operators give rise to notions such as "generators of Noether symmetries", energy and reduced energy flow, Bianchi identities, weak and strong conservation laws, covariant conservation laws, Hamiltonian-like conservation laws (such as, e.g., so-called ADM laws in General Relativity) with emphasis on the physical interpretation of the quantities calculated in specific cases (energy, angular momentum, entropy, etc.). A few substantially new and very recent applications/examples are presented to better show the power of the methods introduced: one in Classical Mechanics (definition of strong conservation laws in a frame-independent setting and a discussion on the way in which conserved quantities depend on the choice of an observer); one in Classical Field Theories (energy and entropy in General Relativity, in its standard formulation, in its spin-frame formulation, in its first order formulation "`a la Palatini" and in its extensions to Non-Linear Gravity Theories); one in Quantum Field Theories (applications to conservation laws in Loop Quantum Gravity via spin connections and Barbero-Immirzi connections).

Comments:	27 pages
Subjects:	**General Relativity and Quantum Cosmology (gr-qc)**
Cite as:	**arXiv:1001.2886v1 [gr-qc]**

Submission history

From: Lorenzo Fatibene [view email]
[v1] Sun, 17 Jan 2010 10:54:45 GMT (47kb)

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