Master "Advanced Physics" Universitat de València

"Advanced Relativity" (Curs 2010–11)

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Bibliography (basic)

- É. Gourgoulhon, *Relativité Reinstreinte* des particules à l'Astrophysique (EDP Sciences, CNRS Éditions, 2010).
- R. M. Wald, *General Relativity* (The University of Chicago Press, Chicago, 1984).
- N. Straumann, *General Relativity and Relativistic Astrophysics* (Springer-Verlag, Berlin, 1984).
- H. Stephani, *General Relativity*, (Cambridge University Press, Cambridge, 1982).
- R. d'Inverno, *Introducing Einstein's Relativity*, (Clarendon Press, Oxford, 1998).
- F. de Felice, C. J. S. Clarke, *Relativity on Curved Manifolds* (Cambridge U.P., Cambridge, 1990).

- L. P. Hughston, K. P. Tod, *An Introduction to General Relativity*, (Cambridge U. P. 1990).
- H. Stephani, D. Kramer, M. Maccallum, C. Hoenselaers and E. Herlt, *Exact Solutions to Einstein's Field Equations*, Second edition (Cambridge Univ. Press, 2003).
- J. Plebański, A. Krasiński, *An Introduction to General Relativity and Cosmology*, (Cambridge U. P. 2006).
- G. S. Hall, *Symmetries and Curvature Structure in General Relativity*, (World Scientific Lecture Notes in Physics, Singapure, 2004).
- L. P. Eisenhart, *Riemannian Geometry* (Princenton U.P., Princenton, 1949).
- M. Nakara, Geometry, Topology and Physics, Graduate Student Series in Physics, (IOP, Bristol and Phyladelphia, 1990).

Bibliography (extra)

- M. Alcubierre, *Introduction to 3+1 Numerical Relativity*, Oxford University Press (2008).
- T. W. Baugarte, S. L. Shapiro, *Numerical Relativity, Solving Einstein's Equations on the Computer*, Cambridge University Press (2010).
- C. Bona, C. Palenzuela-Luque, C. Bona-Casas, *Elements of Numerical Relativity and relativistic Hydrodynamics, From Einstein's equations to Astrophysical Simulations.* Lecture Notes in Physics **783**. Springer (2009). Second edition.
- Y. Choquet–Bruhat, *General Relativity and the Einstein Equations*, Oxford University Press (2008).
- B. Coll, *Isometries et conditions initiales en Relativité General*, Thèse d'Etat (Paris, 1980).
- J. A. Font, *Numerical hydrodynamics and magneto-hydrodynamics in general relativity*, Living Reviews in Relativity, 7 (2008), `http://www.livingreviews.org/lrr-2008-7`
- É. Gourgoulhon, *3+1 Formalism and bases of Numerical Relativity*, gr-qc/0703035.
- É. Gourgoulhon, J. L. Jaramillo, *A* $3+1$ *perspective on null hypersurfaces and isolated horizons*, Physics Reports **423**, 159–294 (2005).
- L. Smarr and J.W. York, Jr., *Kinematical conditions in the construction of spacetime.*, Phys. Rev. D. 17, 2529-2551 (1978).
- J.W. York, Jr. *The initial value problem and dynamics*, en "Sources of Gravitational Radiation" edited by L. Smarr, (Cambridge Univ. Press: Cambridge, 1979) pp. 175-201.
- J. Winicour, *Characteristic evolution and matching*, Living Reviews in Relativity, 3 (2009), `http://www.livingreviews.org/lrr-2009-3`
- *New frontiers in Numerical Relativity*, M. Campanelli and L. Rezzolla Eds., Classical and Quantum Gravity, **24** 12 (2007)