Proliferation of Post-Newtonian, Non-Relativistic Theories

Nicolae Sfetcu

29.08.2019

Sfetcu, Nicolae, "Proliferation of Post-Newtonian, Non-Relativistic Theories", SetThings (August 29, 2019), URL = https://www.setthings.com/en/proliferation-of-post-newtonian-non-relativistic-theories/

Email: nicolae@sfetcu.com

A partial translation of
Sfetcu, Nicolae, "Epistemologia gravitației experimentale – Raționalitatea științifică", SetThings (1 august 2019), MultiMedia Publishing (ed.), ISBN: 978-606-033-234-3, DOI: 10.13140/RG.2.2.15421.61925, URL = https://www.setthings.com/ro/e-books/epistemologia-gravitatiei-experimentale-rationalitatea-stiintifica/

Theoreticians have formulated a set of fundamental criteria that any theory of gravity should satisfy, two purely theoretical and two that are based on experimental evidence[1]. Thus, a theory must be:

- *complete* (capable of analyzing from the "first principles" the result of any experiment of interest).
- *self-consistent* (its prediction for the outcome of each experiment must be unique)
- *relativistic* (at the limit when gravity is neglected compared to other physical interactions, non-gravitational laws of physics must be reduced to special relativity laws)
- *with the correct Newtonian limit* (within the limits of weak gravitational fields and slow motions, they must reproduce Newton's laws)

The main theories of gravity from 1686-1900, until the development by Lorentz of his own theory and then the elaboration the theories of relativity by Einstein, are

- *Newton's Law of Universal Gravity* (1686): Newton's theory is considered to be exactly within the limits of low gravity fields and low velocities, and all other theories of gravity must reproduce Newton's theory within the appropriate limits.
- *Mechanistic explanations* (1650-1900): Bifurcated theories having as hard core the mechanistic theory; they failed because most led to an unacceptably high value of aether dragging, which is unconfirmed, violates the law on energy conservation and is incompatible with modern thermodynamics[2].
    - René Descartes (1644) and Christiaan Huygens (1690) used vortexes to explain the mechanistic gravity[3]. Newton opposed the theory arguing with the lack of deviations of the orbits due to the fluid-dynamic resistance, the sometimes-different direction of the natural satellites from the direction of the vortex, and of Huygens's circular explanations.
- *Electrostatic models* (1870-1900): They tried to combine Newton's laws with those of electrodynamics (Weber, Carl Friedrich Gauss, Bernhard Riemann, James Clerk Maxwell), trying to explain the perihelion precession of Mercury. There were partial successes, in 1890 Lévy and in 1898 Paul Gerber, but the models were rejected because were based on assumptions that later proved to be wrong[4].
    - Robert Hooke (1671) and James Challis (1869) assumed that each body emits waves whose effect is the attraction between bodies. Maxwell argued that this theory

[1] Clifford M. Will, *Theory and Experiment in Gravitational Physics, Revised Edition*, Revised edition (Cambridge England ; New York, NY, USA: Cambridge University Press, 1993).

[2] Edward Grant, *The Foundations of Modern Science in the Middle Ages: Their Religious, Institutional and Intellectual Contexts* (Cambridge ; New York: Cambridge University Press, 1996), 60–61.

[3] Christiaan Huygens, *Discours de La Cause de La Pesanteur*, 1885, 443–88.

[4] J. Zenneck, "Gravitation," in *Encyklopädie der Mathematischen Wissenschaften mit Einschluss ihrer Anwendungen: Fünfter Band in Drei Teilen Physik*, ed. A. Sommerfeld (Wiesbaden: Vieweg+Teubner Verlag, 1903), 25–67, https://doi.org/10.1007/978-3-663-16016-8_2.

requires constant production of waves, which must be accompanied by infinite energy consumption. Challis himself acknowledged that he did not reach a precise result due to the complexity of the processes[5].

- Including Isaac Newton (1675), and later Bernhard Riemann (1853) proposed a theory that aetheric flows move all bodies to one another[6]. As with Le Sage's theory, the theory violates the law of energy conservation. There are also problems related to the interaction of bodies with aether.
- Nicolas Fatio de Duillier (1690) and Georges-Louis Le Sage (1748) proposed a corpuscular model, using some sort of screening or shading mechanism - a bifurcation of Newton's law that respects the law of inverse squares. It was re-invented, among others, by Lord Kelvin (1872) and Hendrik Lorentz (1900), and criticized by James Clerk Maxwell (1875) and Henri Poincaré (1908) in particular for thermodynamic anomalies. Le Sage's theory was studied by Radzievskii and Kagalnikova (1960), Shneiderov (1961), Buonomano and Engels (1976), Adamut (1982), Jaakkola (1996), Tom Van Flandern (1999) and Edwards (2007). A variety of Le Sage models and related topics are discussed in Edwards, et al. [7]
- Newton proposed a second theory based on aether (1717) developed later by Leonhard Euler (1760), in which the aether loses its density near mass, leading to a net force directed toward bodies[8]. James Clerk Maxwell pointed out that in this "hydrostatic" model "the state of stress... which we must suppose to exist in the invisible medium, is 3000 times greater than that which the strongest steel could support."
- Later, a similar model was created by Hendrik Lorentz, who used electromagnetic radiation instead of corpuscles.
- Lord Kelvin (1871) and Carl Anton Bjerknes (1871) considered that each body pulsates, which could be an explanation of gravity and electrical charges. This hypothesis was also studied by George Gabriel Stokes and Woldemar Voigt. But the theory forces the assumption that all pulsations in the universe are in phase, which seems highly unlikely. And the aether should be incompressible. Maxwell argued that this process must be accompanied by new production and permanent destruction of aether.

---

[5] James Challis, *Notes on the Principles of Pure and Applied Calculation: And Applications of Mathematical Principles to Theories of the Physical Forces.* (University of Michigan Library, 1869).

[6] B. Riemann, *Neue Mathematische Prinzipien Der Naturphilosophie* (Leipzig: Dedekind, R.; Weber, W., 1876).

[7] Matthew R. Edwards, ed., *Pushing Gravity: New Perspectives on Le Sage's Theory of Gravitation*, y First edition edition (Montreal: Apeiron, 2002).

[8] Leonhard Euler, *Briefe an eine deutsche Prinzessin, aus dem Französischen übersetzt* (Junius, 1773), https://books.google.ro/books?id=FaMAAAAAMAAJ.

Clifford M. Will explains, in *Theory and experiment in gravitational physics*, the motivations of some of these theories, including the elaboration of general relativity and quantum theory[9], which include bifurcations of Newton's initial theory, or do not meet the current criteria of a gravitational theory, with the observation that it is possible that, in the case of the modification of the present forms, some of these theories may subsequently meet these criteria:

- Newtonian theory of gravity: it is not relativistic
- Milne's kinematic relativity[10]: it was initially designed to solve certain cosmological problems. It is incomplete - it does not predict gravitational redshift.
- The various vector theories of Kustaanheimo[11] [12] contain a vector gravitational field in flat space-time. They are incomplete - they cannot be coupled with the other laws of non-gravitational physics (Maxwell's equations), unless we impose a flat space-time. They are inconsistent - they give different results in the propagation of light for the corpuscular and undulatory aspects of light.
- Poincare's theory (generalized by Whitrow and Morduch): the theory of action at a distance in flat space-time. It is incomplete or inconsistent in the same way as Kustaanheimo's theories[13].
- Whitrow-Morduch vector theory (1965): contains a vector gravitational field in flat spacetime. It is incomplete or inconsistent in the same way as Kustaanheimo's theories[14].
- Birkhoff's Theory (1943): contains a tensor gravitational field used to construct a metric. It violates the Newtonian limit by the specific conditions imposed[15].
- Yilmaz's Theory (1971, 1973): contains a tensor gravitational field used to construct a metric. It is mathematically inconsistent - the functional dependence of the metrics on the tensor field is not well defined[16].

Other alternative historical theories developed over time have been refuted by experimental checks or replaced by better corroborated theories:

---

[9] Will, *Theory and Experiment in Gravitational Physics, Revised Edition.*

[10] E. A. Milne, *Kinematic Relativity* (Facsimile Publisher, 2015), 566–78.

[11] Paul Edwin Kustaanheimo and V. S. Nuotio, *Relativistic Theories of Gravitation* (Helsingin Yliopisto. Department of Applied Mathematics, 1967).

[12] G. J. Whitrow and G. E. Morduch, "Relativistic Theories of Gravitation : A Comparative Analysis with Particular Reference to Astronomical Tests," *Vistas in Astronomy* 6 (1965): 1–67, https://doi.org/10.1016/0083-6656(65)90002-4.

[13] Whitrow and Morduch, "Relativistic Theories of Gravitation."

[14] Whitrow and Morduch.

[15] George D. Birkhoff, "Matter, Electricity and Gravitation in Flat Space-Time," *Proceedings of the National Academy of Sciences* 29, no. 8 (August 1, 1943): 231–39, https://doi.org/10.1073/pnas.29.8.231.

[16] Hüseyin Yilmaz, "New Approach to Relativity and Gravitation," *Annals of Physics* 81, no. 1 (November 1, 1973): 81, https://doi.org/10.1016/0003-4916(73)90485-5.

- In 1690, Pierre Varignon assumed that all bodies are exposed to thrusts of aether particles from all directions, with a limitation to a certain distance from the Earth's surface, under which bodies would experience greater attraction to Earth[17].
- In 1748, Mikhail Lomonosov assumed that the effect of aether is proportional to the complete surface of the elemental components of which matter is composed[18].
- In 1821, John Herapath tried to apply the co-developed model of kinetic gas theory to gravity. He assumed that the aether is heated by bodies and density decreases occur that push the bodies in that direction[19]. Taylor showed that the low density due to thermal expansion is compensated by the increased velocity of the heated particles; therefore, no attractions appear.
- Ritz gravity theory[20], Weber-Gauss electrodynamics applied to gravity. Classical promotion of perihelions[21].
- Nordström's theory of gravity (1912, 1913), an early competitor of general relativity.
- Kaluza Klein's Theory (1921) [22]
- Whitehead's theory of gravity (1922), another early competitor to general relativity.

Lorentz aether theory was developed from Hendrik Lorentz's "electron theory", between 1892 and 1895 considering it as a completely immobile aether[23]. It introduced an ad-hoc hypothesis to cancel the failure of negative first order aether deviation experiments in v/c by introducing an auxiliary variable called "local time". The negative result of the Michelson-Morley experiment resulted in the introduction of another ad-hoc hypothesis, length contraction, in 1892. But neither did the subsequent experiments confirm the theory, which became a degenerate theory according

---

[17] Pierre (1654-1722) Auteur du texte Varignon, *Nouvelles Conjectures Sur La Pesanteur , Par M. Varignon,...*, 1690, https://gallica.bnf.fr/ark:/12148/bpt6k74179x.

[18] Mikhail Vasil'evich Lomonosov, *Mikhail Vasil'evich Lomonosov on the Corpuscular Theory*, First edition. edition (Cambridge, Mass: Harvard University Press, 1970), 224–233.

[19] J Herapath, "On the Causes, Laws and Phenomena of Heat, Gases, Gravitation I, II, III, in Annals of Philosophy, or Magazine of Chemistry, Mineralogy, Mechanics, Natural History, Agriculture and the Arts 1 Pp. 273–293," Atticus Rare Books, 1821, 273–93, https://www.atticusrarebooks.com/pages/books/761/john-herapath/on-the-causes-laws-and-phenomena-of-heat-gases-gravitation-i-ii-iii-in-annals-of-philosophy-or.

[20] Walther Ritz, "Recherches critiques sur l'électrodynamique générale," *Annales de chimie et de physique*, 1908, 267–71.

[21] Ritz, 267–271.

[22] Theodor Kaluza, "Zum Unitätsproblem in Der Physik | BibSonomy," 1921, 966–972, https://www.bibsonomy.org/bibtex/19218e3a965ffaefa3af2d4c14bb5ae52/zhaozhh02.

[23] Hendrik A. Lorentz, "Considerations on Gravitation," in *The Genesis of General Relativity*, ed. Michel Janssen et al., Boston Studies in the Philosophy of Science (Dordrecht: Springer Netherlands, 2007), 559–574, https://doi.org/10.1007/978-1-4020-4000-9_13.

to Lakatos. Lorentz tried to revitalize it in 1899 and 1904 by introducing the Lorentz transformation. But neither the new theoretical models solved the problem of aether. Henri Poincaré corrected the errors in 1905 and incorporated the non-electromagnetic effects into the theory, calling it "New mechanics" and using for the first time the expression "the principle of relativity." [24] He also criticized Lorentz for introducing too many helpful assumptions into his theory. Later, Minkowski (1908) and Arnold Sommerfeld (1910) also tried to develop a Lorentz invariant gravity law[25]. Poincaré's theory resisted a period due to his greater heuristic power, but he was defeated by the special relativity of Albert Einstein, who also took over some of the ideas of this theory. Lorentz acknowledged in 1914 that his theory was incompatible with the principle of relativity and rejected it[26]. At present some physicists consider the Lorentz theory developed later by Poincaré as a special, "Lorentzian" or "neo-Lorenzian" interpretation of special relativity[27]. Since both use Lorentz transformations and the same mathematical formalism, it is not possible to distinguish between the two theories by experiment. The difference between them is that Lorentz assumes the existence of an undetectable aether.

Modified Newtonian Dynamics (**MOND**) is a theory that proposes to modify Newton's law of universal gravity with the intention of taking into account the observed properties of galaxies. MOND is trying to eliminate the controversial theory of dark matter. It was developed in 1982 and published in 1983 by Israeli physicist Mordehai Milgrom[28]. Milgrom introduced the hypothesis that the gravitational force experienced by a star in the outer regions of a galaxy is proportional to the square of centripetal acceleration (as opposed to simple proportionality, from

[24] Henri Poincaré, "Les Relations Entre La Physique Expérimentale et La Physique Mathématique, in Revue Générale Des Sciences Pures et Appliquées," issue, Gallica, 1900, 1163–1175, https://gallica.bnf.fr/ark:/12148/bpt6k17075r.

[25] Scott Walter, "Breaking in the 4-Vectors: The Four-Dimensional Movement in Gravitation, 1905–1910," in *The Genesis of General Relativity*, ed. Michel Janssen et al., Boston Studies in the Philosophy of Science (Dordrecht: Springer Netherlands, 2007), 193–252, https://doi.org/10.1007/978-1-4020-4000-9_18.

[26] Eduard Prugovecki, "Historical and Epistemological Perspectives on Developments in Relativity and Quantum Theory," ResearchGate, 1992, https://www.researchgate.net/publication/300434048_Historical_and_Epistemological_Perspectives_on_Developments_in_Relativity_and_Quantum_Theory.

[27] Quentin Smith, *Einstein, Relativity and Absolute Simultaneity*, ed. William Lane Craig, 1 edition (London: Routledge, 2007).

[28] M. Milgrom, "A Modification of the Newtonian Dynamics as a Possible Alternative to the Hidden Mass Hypothesis," *The Astrophysical Journal* 270 (July 1983): 371–389, https://doi.org/10.1086/161130.

Newton's second law) or, alternatively, that the gravitational force in these cases vary inversely proportional to radius (as opposed to the inverse square of radius in Newton's law of gravity). In the MOND, the modification of Newton's laws takes place only for the movement of galaxies, at extremely small accelerations.

MOND successfully predicted galactic phenomena unexplained by the theory of dark matter[29], but fails to confirm the properties of galaxy clusters, nor to develop a cosmological model that competes with the current ΛCDM model[30]. Accurate measurement of the speed of gravitational waves in comparison to the speed of light in 2017 did not exclude MOND theories.

A large variety of astrophysical phenomena are corroborated by the MOND,[31] [32] such as:

- Concrete relationship between the total baryonic mass of the galaxy and the asymptotic rotation speed according to the MOND prediction.
- MOND predicts a much better correlation between characteristics in the distribution of the nonbarionic mass and the rotation curve than the dark matter hypothesis, observed in several spiral galaxies.
- MOND predicts a specific relationship between the acceleration of stars at any distance from the center of a galaxy and the amount of dark matter in this radius that would be deduced in a Newtonian analysis, an observationally verified prediction.
- Confirms the stability of disk galaxies for galaxy regions within the deep MOND regime.
- For particularly massive galaxies, MOND predicts that the rotation curve should decrease by 1/r, according to Kepler's law, confirmed by observations of elliptical galaxies with large masses.

From the initial MOND theory, several competing theories have been branched off that are based on the same hard core (negative heuristics) but with different development strategies (positive heuristics):

- AQUAL was developed in 1984 by Milgrom and Jacob Bekenstein, generating MOND behavior by modifying the gravitational term in the classical Lagrangian[33].

[29] Stacy S. McGaugh, "A Tale of Two Paradigms: The Mutual Incommensurability of ΛCDM and MOND," *Canadian Journal of Physics* 93, no. 2 (April 21, 2014): 250–259, https://doi.org/10.1139/cjp-2014-0203.

[30] Pavel Kroupa, *The Vast Polar Structures around the Milky Way and Andromeda*, 2013, https://www.youtube.com/watch?v=UPVGDXNSBZM.

[31] Benoit Famaey and Stacy McGaugh, "Modified Newtonian Dynamics (MOND): Observational Phenomenology and Relativistic Extensions," *Living Reviews in Relativity* 15, no. 1 (December 2012): 10, https://doi.org/10.12942/lrr-2012-10.

[32] Mordehai Milgrom, "MOND Laws of Galactic Dynamics," *Monthly Notices of the Royal Astronomical Society* 437, no. 3 (January 21, 2014): 2531–41, https://doi.org/10.1093/mnras/stt2066.

[33] J. Bekenstein and M. Milgrom, "Does the Missing Mass Problem Signal the Breakdown of Newtonian Gravity?," *The Astrophysical Journal* 286 (November 1984): 7–14, https://doi.org/10.1086/162570.

- QUMOND introduces a distinction between the MOND acceleration field and the Newtonian acceleration field[34].
- TeVeS starts from the behavior of the MOND but considers a relativistic framework. TeVeS has been successful in gravitational lens observations and structure formation but fails to explain other cosmological aspects[35].

There are other alternative relativistic generalizations of the MOND, such as BIMOND and the generalized Einstein-Aeter theories[36].

The external field effect implies a fundamental break of MOND by the principle of strong equivalence (but not necessarily by the principle of weak equivalence), this being recognized as a crucial element of the MOND paradigm.

Supporters of MOND theory have proposed several observational and experimental tests to help establish the best-corrected theory[37] between MOND models and dark matter, such as: the existence of abnormal accelerations on Earth that could be detected in a precision experiment[38]; testing in the solar system using the LISA Pathfinder mission by observing the tides predicted by the MOND and a Sun-Earth saddle point of Newtonian gravitational potential[39]; measuring the MOND corrections to the precession of the perihelion of the planets in the Solar System[40]; an astrophysical test to investigate the behavior of isolated galaxies, and non-Newtonian behavior in binary star systems; testing using the redshift dependence of radial acceleration[41].

---

[34] Mordehai Milgrom, "Quasi-Linear Formulation of MOND," *Monthly Notices of the Royal Astronomical Society* 403, no. 2 (February 4, 2010): 886–95, https://doi.org/10.1111/j.1365-2966.2009.16184.x.

[35] Jacob D. Bekenstein, "Relativistic Gravitation Theory for the MOND Paradigm," *Physical Review D* 71, no. 6 (March 14, 2005): 069901, https://doi.org/10.1103/PhysRevD.71.069901.

[36] Famaey and McGaugh, "Modified Newtonian Dynamics (MOND)."

[37] John F. Wallin, David S. Dixon, and Gary L. Page, "Testing Gravity in the Outer Solar System: Results from Trans-Neptunian Objects," *The Astrophysical Journal* 666, no. 2 (September 10, 2007): 1296–1302, https://doi.org/10.1086/520528.

[38] V. A. De Lorenci, M. Faundez-Abans, and J. P. Pereira, "Testing the Newton Second Law in the Regime of Small Accelerations," *Astronomy & Astrophysics* 503, no. 1 (August 2009): L1–4, https://doi.org/10.1051/0004-6361/200811520.

[39] Christian Trenkel et al., "Testing MOND/TEVES with LISA Pathfinder," *ArXiv:1001.1303 [Astro-Ph]*, January 8, 2010, http://arxiv.org/abs/1001.1303.

[40] Luc Blanchet and Jerome Novak, "Testing MOND in the Solar System," *ArXiv:1105.5815 [Astro-Ph, Physics:Gr-Qc]*, May 29, 2011, http://arxiv.org/abs/1105.5815.

[41] Sabine Hossenfelder and Tobias Mistele, "The Redshift-Dependence of Radial Acceleration: Modified Gravity versus Particle Dark Matter," *International Journal of Modern Physics D* 27, no. 14 (October 2018): 1847010, https://doi.org/10.1142/S0218271818470107.

The "**Fifth Force**" is a theory that changes Newton's law of universal gravity. The initial experiments gave contradictory results: one claimed the existence of the fifth force, while the other contradicted this theory. After numerous repetitions of the experiment, the discord was resolved, and the consensus was reached that the Fifth Force does not exist[42].

[42] Michele Cicoli, Francisco G. Pedro, and Gianmassimo Tasinato, "Natural Quintessence in String Theory," *Journal of Cosmology and Astroparticle Physics* 2012, no. 07 (July 23, 2012): 044–044, https://doi.org/10.1088/1475-7516/2012/07/044.

Bibliography

Bekenstein, J., and M. Milgrom. "Does the Missing Mass Problem Signal the Breakdown of Newtonian Gravity?" *The Astrophysical Journal* 286 (November 1984): 7–14. https://doi.org/10.1086/162570.

Bekenstein, Jacob D. "Relativistic Gravitation Theory for the MOND Paradigm." *Physical Review D* 71, no. 6 (March 14, 2005): 069901. https://doi.org/10.1103/PhysRevD.71.069901.

Birkhoff, George D. "Matter, Electricity and Gravitation in Flat Space-Time." *Proceedings of the National Academy of Sciences* 29, no. 8 (August 1, 1943): 231–39. https://doi.org/10.1073/pnas.29.8.231.

Blanchet, Luc, and Jerome Novak. "Testing MOND in the Solar System." *ArXiv:1105.5815 [Astro-Ph, Physics:Gr-Qc]*, May 29, 2011. http://arxiv.org/abs/1105.5815.

Challis, James. *Notes on the Principles of Pure and Applied Calculation: And Applications of Mathematical Principles to Theories of the Physical Forces*. University of Michigan Library, 1869.

Cicoli, Michele, Francisco G. Pedro, and Gianmassimo Tasinato. "Natural Quintessence in String Theory." *Journal of Cosmology and Astroparticle Physics* 2012, no. 07 (July 23, 2012): 044–044. https://doi.org/10.1088/1475-7516/2012/07/044.

De Lorenci, V. A., M. Faundez-Abans, and J. P. Pereira. "Testing the Newton Second Law in the Regime of Small Accelerations." *Astronomy & Astrophysics* 503, no. 1 (August 2009): L1–4. https://doi.org/10.1051/0004-6361/200811520.

Edwards, Matthew R., ed. *Pushing Gravity: New Perspectives on Le Sage's Theory of Gravitation*. Y First edition edition. Montreal: Apeiron, 2002.

Euler, Leonhard. *Briefe an eine deutsche Prinzessin, aus dem Französischen übersetzt*. Junius, 1773. https://books.google.ro/books?id=FaMAAAAAMAAJ.

Famaey, Benoit, and Stacy McGaugh. "Modified Newtonian Dynamics (MOND): Observational Phenomenology and Relativistic Extensions." *Living Reviews in Relativity* 15, no. 1 (December 2012): 10. https://doi.org/10.12942/lrr-2012-10.

Grant, Edward. *The Foundations of Modern Science in the Middle Ages: Their Religious, Institutional and Intellectual Contexts*. Cambridge ; New York: Cambridge University Press, 1996.

Herapath, J. "On the Causes, Laws and Phenomena of Heat, Gases, Gravitation I, II, III, in Annals of Philosophy, or Magazine of Chemistry, Mineralogy, Mechanics, Natural History, Agriculture and the Arts 1 Pp. 273–293,." Atticus Rare Books, 1821. https://www.atticusrarebooks.com/pages/books/761/john-herapath/on-the-causes-laws-and-phenomena-of-heat-gases-gravitation-i-ii-iii-in-annals-of-philosophy-or.

Hossenfelder, Sabine, and Tobias Mistele. "The Redshift-Dependence of Radial Acceleration: Modified Gravity versus Particle Dark Matter." *International Journal of Modern Physics D* 27, no. 14 (October 2018): 1847010. https://doi.org/10.1142/S0218271818470107.

Huygens, Christiaan. *Discours de La Cause de La Pesanteur*, 1885.

Kaluza, Theodor. "Zum Unitätsproblem in Der Physik | BibSonomy," 1921. https://www.bibsonomy.org/bibtex/19218e3a965ffaefa3af2d4c14bb5ae52/zhaozhh02.

Kroupa, Pavel. *The Vast Polar Structures around the Milky Way and Andromeda*, 2013. https://www.youtube.com/watch?v=UPVGDXNSBZM.

Kustaanheimo, Paul Edwin, and V. S. Nuotio. *Relativistic Theories of Gravitation*. Helsingin Yliopisto. Department of Applied Mathematics, 1967.

Lomonosov, Mikhail Vasil'evich. *Mikhail Vasil'evich Lomonosov on the Corpuscular Theory*. First edition. edition. Cambridge, Mass: Harvard University Press, 1970.

Lorentz, Hendrik A. "Considerations on Gravitation." In *The Genesis of General Relativity*, edited by Michel Janssen, John D. Norton, Jürgen Renn, Tilman Sauer, and John Stachel, 1038–52. Boston Studies in the Philosophy of Science. Dordrecht: Springer Netherlands, 2007. https://doi.org/10.1007/978-1-4020-4000-9_13.

McGaugh, Stacy S. "A Tale of Two Paradigms: The Mutual Incommensurability of ΛCDM and MOND." *Canadian Journal of Physics* 93, no. 2 (April 21, 2014): 250–59. https://doi.org/10.1139/cjp-2014-0203.

Milgrom, M. "A Modification of the Newtonian Dynamics as a Possible Alternative to the Hidden Mass Hypothesis." *The Astrophysical Journal* 270 (July 1983): 365. https://doi.org/10.1086/161130.

Milgrom, Mordehai. "MOND Laws of Galactic Dynamics." *Monthly Notices of the Royal Astronomical Society* 437, no. 3 (January 21, 2014): 2531–41. https://doi.org/10.1093/mnras/stt2066.

———. "Quasi-Linear Formulation of MOND." *Monthly Notices of the Royal Astronomical Society* 403, no. 2 (February 4, 2010): 886–95. https://doi.org/10.1111/j.1365-2966.2009.16184.x.

Milne, E. A. *Kinematic Relativity*. Facsimile Publisher, 2015.

Poincaré, Henri. "Les Relations Entre La Physique Expérimentale et La Physique Mathématique, in Revue Générale Des Sciences Pures et Appliquées." Issue. Gallica, 1900. https://gallica.bnf.fr/ark:/12148/bpt6k17075r.

Prugovecki, Eduard. "Historical and Epistemological Perspectives on Developments in Relativity and Quantum Theory." ResearchGate, 1992. https://www.researchgate.net/publication/300434048_Historical_and_Epistemological_Perspectives_on_Developments_in_Relativity_and_Quantum_Theory.

Riemann, B. *Neue Mathematische Prinzipien Der Naturphilosophie*. Leipzig: Dedekind, R.; Weber, W., 1876.

Ritz, Walther. "Recherches critiques sur l'électrodynamique générale." *Annales de chimie et de physique*, 1908.

Smith, Quentin. *Einstein, Relativity and Absolute Simultaneity*. Edited by William Lane Craig. 1 edition. London: Routledge, 2007.

Trenkel, Christian, Steve Kemble, Neil Bevis, and Joao Magueijo. "Testing MOND/TEVES with LISA Pathfinder." *ArXiv:1001.1303 [Astro-Ph]*, January 8, 2010. http://arxiv.org/abs/1001.1303.

Varignon, Pierre (1654-1722) Auteur du texte. *Nouvelles Conjectures Sur La Pesanteur , Par M. Varignon,...*, 1690. https://gallica.bnf.fr/ark:/12148/bpt6k74179x.

Wallin, John F., David S. Dixon, and Gary L. Page. "Testing Gravity in the Outer Solar System: Results from Trans-Neptunian Objects." *The Astrophysical Journal* 666, no. 2 (September 10, 2007): 1296–1302. https://doi.org/10.1086/520528.

Walter, Scott. "Breaking in the 4-Vectors: The Four-Dimensional Movement in Gravitation, 1905–1910." In *The Genesis of General Relativity*, edited by Michel Janssen, John D. Norton, Jürgen Renn, Tilman Sauer, and John Stachel, 1118–78. Boston Studies in the Philosophy of Science. Dordrecht: Springer Netherlands, 2007. https://doi.org/10.1007/978-1-4020-4000-9_18.

Whitrow, G. J., and G. E. Morduch. "Relativistic Theories of Gravitation : A Comparative Analysis with Particular Reference to Astronomical Tests." *Vistas in Astronomy* 6 (1965): 1–67. https://doi.org/10.1016/0083-6656(65)90002-4.

Will, Clifford M. *Theory and Experiment in Gravitational Physics, Revised Edition*. Revised edition. Cambridge England ; New York, NY, USA: Cambridge University Press, 1993.

Yilmaz, Hüseyin. "New Approach to Relativity and Gravitation." *Annals of Physics* 81, no. 1 (November 1, 1973): 179–200. https://doi.org/10.1016/0003-4916(73)90485-5.

Zenneck, J. "Gravitation." In *Encyklopädie der Mathematischen Wissenschaften mit Einschluss ihrer Anwendungen: Fünfter Band in Drei Teilen Physik*, edited by A. Sommerfeld, 25–67. Wiesbaden: Vieweg+Teubner Verlag, 1903. https://doi.org/10.1007/978-3-663-16016-8_2.