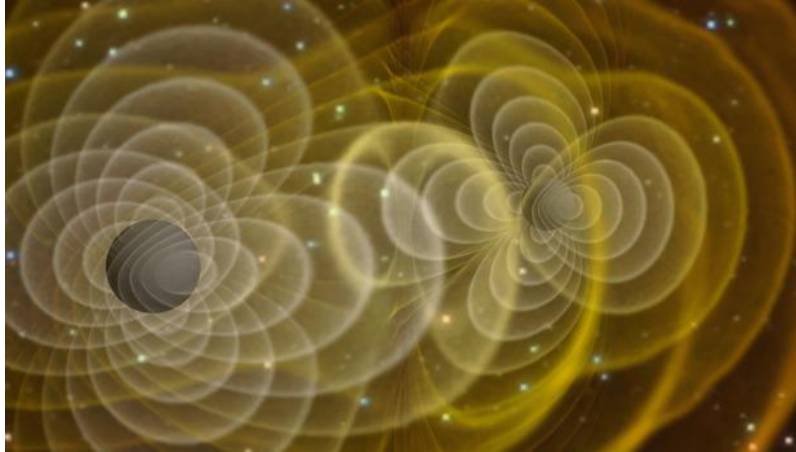


## The Challenge of Gravitational Waves<sup>§</sup>

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**Fig. 1. Illustration of gravitational waves produced by two orbiting black holes [Credit: Henze/NASA]**

Gravitational waves are undulations in space-time produced by processes, which are most violent and energetic. They are invisible in nature. Existence of gravitational waves was predicted by Albert Einstein, when he presented his general theory of relativity in 1916. According to the mathematical formulation of this theory massive accelerating objects, which include black holes or neutron stars orbiting each other, should disrupt space-time in such a manner that waves of undulating space-time propagate in all directions away from the source, traveling with speed of light and carry with them information regarding their origin. Their study should help scientists understand the nature of gravity. The strongest gravitational waves are generated by colliding black holes (Fig. 1) and neutron stars as well as supernovae. Other causes include neutron-star rotation as well as remnants of gravitational radiation produced by Big Bang. Their existence was predicted in 1916 by Einstein, the first of their existence was given in 1974, when two astronomers in Arecibo Radio Observatory in Puerto Rico discovered a binary pulsar, exactly of the type that should radiate gravitational waves according to general theory of relativity. After eight years of observations, the astronomers concluded that the stars were approaching each other at exactly the same rate predicted by general relativity, in the event that they are emitting gravitational waves. The observations have been repeated by different astronomers confirming the hypothesis. However, these confirmations were not from direct contact but were derived mathematically. On September 14, 2015, LIGO (Laser Interferometer Gravitational-Wave Observatory), supported by National Science Foundation and Operated by Caltech and MIT (the speaker had the honor to visit Caltech in 1980 and give a talk at MIT in 1990), physically observed ripples in space-time produced by gravitational waves, generated by two colliding black holes 1.3 billion light-years away. By the time gravitational waves from LIGO's first sensing reached the earth, the amount of space-time wobbling, generated by these waves, was one thousand times smaller than the nucleus of an atom. This discovery may become one of the candidates to be considered for a future **Nobel Prize in Physics**.

**Keywords:** Black holes • Curvature of space-time • General relativity • Geometrodynamics • LIGO experiment

**Web address of this document:** <https://www.ngds-ku.org/Presentations/Gravitational.pdf>

<sup>§</sup>Main ideas of this abstract are taken from <https://www.ligo.caltech.edu/page/what-are-gw> — related work of speaker:

- Ali, L., S. A. Husain, S. A. Kamal and Z. D. M. Al-Kurdi (1979, October 17-19).  $4 \times 4$  representation of REMO (Relativistic-Effective-Mass Operator) for bradyons. *The Nineteenth Annual Science Conference*, the Quaid-é-Azam University, Islamabad, Pakistan, p. 8, full text: <https://www.ngds-ku.org/Papers/C06.pdf>
- Kamal, S. A. (1980). Physical significance and properties of REMO (Relativistic Effective mass Operator). *Journal of Natural Sciences and Mathematics*, **20** (1): 15-22, full text: <https://www.ngds-ku.org/Papers/J01.pdf>
- Kamal, S. A. (1981). Extended symmetries in special theory of relativity. *Chinese Journal of Physics*, **19** (4): 87-91, full text: <https://www.ngds-ku.org/Papers/J02.pdf>
- Kamal, S. A. (2009, May 11, 12). Avoiding infinities from the Lorentz and the Poincaré transformations. *The Fourth Symposium on Computational Complexities, Innovations and Solutions (CCIS 2009)*, COMSATS Institute of Information Technology, Abbottabad, KP, Pakistan, p.16 (invited lecture), abstract: <https://www.ngds-ku.org/Presentations/CIIT.pdf>
- Kamal, S. A. (2010a, February 11-13). A Minkowski-type metric for curved spacetime. *Conference on General Relativity and Gravitation*, Department of Mathematics, University of the Punjab, Lahore, Pakistan (Prof. Dr. Khurshid Alam Khan memorial lecture), abstract: <https://www.ngds-ku.org/Presentations/GenRelGrav.pdf>
- Kamal, S. A. (2010b, May 10, 11). Generalization of principle of equivalence. *The Fifth Symposium on Computational Complexities, Innovations and Solutions (CCIS 2010)*, COMSATS Institute of Information Technology, Abbottabad, KP, Pakistan, p.11 (Prof. Dr. Q. K. Ghorri memorial lecture delivered as nominee of Vice Chancellor, University of Karachi), abstract#2: <https://www.ngds-ku.org/Presentations/Ghorri.pdf>
- Kamal, S. A. (2015, October 17). General relativity: past, present and future. *Celebration of 100 Years of General Theory of Relativity*, Department of Physics, University of Karachi, Karachi, Pakistan (chief guest's address), abstract: <https://www.ngds-ku.org/Presentations/General-Relativity.pdf>
- Kamal, S. A. and S. A. Husain (1979, October 17-19). Luxon-bradyon transformation. *The Nineteenth Annual Science Conference*, the Quaid-é-Azam University, Islamabad, Pakistan, p. 9, full text: <https://www.ngds-ku.org/Papers/C07.pdf>
- Kamal, S. A. and S. A. Husain (1989). Behavior of massive particles near the velocity of light. *Karachi University Journal of Science*, **17** (1&2): 111-120, full text: <https://www.ngds-ku.org/Papers/J10.pdf>
- Husain, S. A., Z. D. M. Al-Kurdi, S. A. Kamal and L. Ali (1979, October 17-19).  $2 \times 2$  representation of REMO (Relativistic-Effective-Mass Operator) for bradyons. *The Nineteenth Annual Science Conference*, the Quaid-é-Azam University, Islamabad, Pakistan, p. 8, full text: <https://www.ngds-ku.org/Papers/C05.pdf>

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