Physics

Query paper:
Title: Observation of Gravitational Waves from a Binary Black Hole Merger
Abstract: On September 14, 2015 at 09:50:45 UTC the two detectors of the Laser Interferometer Gravitational-Wave Observatory simultaneously observed a transient gravitational-wave signal. The signal sweeps upwards in frequency from 35 to 250 \text{Hz} with a peak gravitational-wave strain of 1.0 \times 10^{-21}. It matches the waveform predicted by general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole. The signal was observed with a matched-filter signal-to-noise ratio of 24 and a false alarm rate estimated to be less than 1 event per 203 000 years, equivalent to a significance greater than 5.1σ. The source lies at a luminosity distance of 410^{-180+160} \text{Mpc} corresponding to a redshift z=0.09^{-0.04+0.03}. In the source frame, the initial black hole masses are 36^{-4+5}M*{\odot} and 29^{-4+4}M*{\odot}, and the final black hole mass is 62^{-4+4}M*{\odot}, with 3.0^{-0.5+0.5}M*{\odot}c^{2} radiated in gravitational waves. All uncertainties define 90% credible intervals. These observations demonstrate the existence of binary stellar-mass black hole systems. This is the first direct detection of gravitational waves and the first observation of a binary black hole merger.

Candidate papers:

1. **Title:** On gravitational waves
   Abstract: The rigorous solution for cylindrical gravitational waves is given. For the convenience of the reader the theory of gravitational waves and their production, already known in principle, is given in the first part of this paper.After encountering relationships which cast doubt on the existence of rigorous solutions for undulatory gravitational fields, we investigate rigorously the case of cylindrical gravitational waves. It turns out that rigorous solutions exist and that the problem reduces to the usual cylindrical waves in euclidean space.
2. **Title:** Properties of the binary black hole merger GW150914
   Abstract: On September 14, 2015, the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected a gravitational-wave transient (GW150914); we characterize the properties of the source and its parameters. The data around the time of the event were analyzed coherently across the LIGO network using a suite of accurate waveform models that describe gravitational waves from a compact binary system in general relativity. GW150914 was produced by a nearly equal mass binary black hole of masses 3 6− 4+ 5 M⊙ and 2 9− 4+ 4 M⊙; for each parameter we report the median value and the range of the 90% credible interval. The dimensionless spin magnitude of the more massive black hole is bound to be< 0.7 (at 90% probability). The luminosity distance to the source is 41 0− 180+ 160 Mpc, corresponding to a redshift 0.0 9− 0.04+ 0.03 assuming standard cosmology. The source location is constrained to an annulus section of 610 deg 2, primarily in the southern hemisphere. The binary merges into a black hole of mass 6 2− 4+ 4 M⊙ and spin 0.6 7− 0.07+ 0.05. This black hole is significantly more massive than any other inferred from electromagnetic observations in the stellar-mass regime.

3. **Title:** New test of general relativity: Gravitational radiation and the binary pulsar PSR 1913+16
   Abstract: Observations of pulse arrival times from the binary pulsar PSR 1913+16 between 1974 September and 1981 March are now sufficient to yield a solution for the component masses and the absolute size of the orbit. We find the total mass to be almost equally distributed between the pulsar and its unseen companion, with mp = 1.42 +- 0.06 Msun and mc = 1.41 +- 0.06 Msun. These values are used together with the well determined orbital period and eccentricity, to calculate the rate at which the orbital period should decay as energy is lost from the system via gravitational radiation. According to the general relativistic quadrupole formula, one should expect for the PSR 1913+16 system an orbital period derivative Pb = (-2.403 +- 0.005) x 10-12. Our observations yield the measured value Pb(-2.30 +- 0.22) x 10-12. The excellent agreement provides compelling evidence for the existence of gravitational radiation, as well as a new and profound confirmation of the general theory of relativity.
4. **Title:** Scattering of Gravitational Radiation by a Schwarzschild Black-hole
   Abstract: THE discovery of pulsars and the general conviction that they are neutron stars resulting from gravitational collapse have strengthened the belief in the possible presence of Schwarzschild black-holes—or Schwarzschild horizons—in nature, the latter being the ultimate stage in the progressive spherical collapse of a massive star. The stability of these objects, which has been discussed in a recent report1, ensures their continued existence after formation. In what follows, we present a partial summary of some results obtained from an investigation of the scattering of gravitational waves by a Schwarzschild horizon.
5. **Title:** Maximal extension of Schwarzschild metric
   Abstract: There is presented a particularly simple transformation of the Schwarzschild metric into new coordinates, whereby the" spherical singularity" is removed and the maximal singularity-free extension is clearly exhibited.
6. **Title:** A catalog of 174 binary black-hole simulations for gravitational-wave astronomy
   Abstract: This paper presents a publicly available catalog of 174 numerical binary black-hole simulations following up to 35 orbits. The catalog includes 91 precessing binaries, mass ratios up to 8:1, orbital eccentricities from a few percent to 10−5, black-hole spins up to 98% of the theoretical maximum, and radiated energies up to 11.1% of the initial mass. We establish remarkably good agreement with post-Newtonian precession of orbital and spin directions for two new precessing simulations, and we discuss other applications of this catalog. Formidable challenges remain: e.g., precession complicates the connection of numerical and approximate analytical waveforms, and vast regions of the parameter space remain unexplored.

Exemplary analysis:

1. **Relevance:** The mention of rigorous solutions for cylindrical gravitational waves could be relevant for the theoretical framework that supports the detection of gravitational waves from a binary black hole merger.
   Reason for Citation: This paper likely provides foundational knowledge on gravitational waves, including theoretical underpinnings and mathematical formulations that are essential for understanding the phenomena observed in the query paper.

2. **Relevance:** It offers in-depth analysis of the source characteristics, which complements and supports the observations reported in the query paper. Citing this work helps to corroborate the findings and situates the query paper's observations within the broader scientific discourse on this specific gravitational wave event.

   Reason for Citation: This paper directly relates to the event observed in the query paper, detailing the properties and parameters of the GW150914 event.
3. **Relevance:** The authors of the query paper align their findings with a well-established precedent of gravitational wave detection, reinforcing the validity of their observations and the theoretical framework (general relativity) that predicts such phenomena.

   Reason for Citation: This paper provides empirical evidence supporting the theory of general relativity through observations of gravitational radiation from a binary pulsar.
4. **Relevance:** The findings and theoretical insights from this paper could provide a basis for interpreting the signal patterns observed in the query paper.

   Reason for Citation: This paper discusses the interaction between gravitational waves and the curvature of spacetime around a black hole, which is relevant for understanding how gravitational waves propagate and can be detected by observatories like LIGO.
5. **Relevance:** The Schwarzschild metric is crucial for describing the spacetime geometry around non-rotating black holes.

   Reason for Citation: This paper's discussion on extending the Schwarzschild metric could offer theoretical tools or insights for analyzing the gravitational wave signals detected from the merger of two black holes, as described in the query paper.
6. **Relevance:** This catalog of binary black-hole simulations would be an invaluable resource for comparing the observed gravitational wave signal with theoretical models and simulations.

   Reason for Citation: By citing this work, the authors can demonstrate how their observations of the binary black hole merger align with or differ from existing simulations, providing a context for their findings within the broader field of gravitational wave astronomy.

Exemplary ranking: Ranked order: paper 2, paper 6, paper 3, paper 1, paper 4, paper 5

1. **Explanation:** Offering foundational knowledge on gravitational waves, this paper is essential for understanding the theoretical underpinnings of the phenomena observed. It's likely to be cited for background information and to support the theoretical framework of new research in the field.
2. **Explanation:** This paper is directly related to the event observed and discussed in the query paper, making it the most relevant for immediate follow-up research. It provides detailed analysis and parameters of the GW150914 event, which are crucial for any further studies aiming to deepen the understanding of this specific merger or to compare it with other events.
3. **Explanation:** This paper is foundational in establishing the empirical evidence for gravitational waves as predicted by general relativity. It's crucial for any research that aims to further validate or explore the implications of general relativity in the context of gravitational wave astronomy.
4. **Explanation:** This paper provides insights into how gravitational waves interact with the spacetime around black holes, which is relevant for interpreting signals from mergers. It would be particularly useful for research focused on the propagation and detection of gravitational waves.

5. **Explanation:** While this paper offers important theoretical tools for describing spacetime geometry around black holes, it might be considered more specialized or tangential for immediate follow-up research unless the research specifically aims to delve into the mathematical descriptions of black hole spacetimes and their role in gravitational wave generation.
6. **Explanation:** For follow-up research, this catalog would be invaluable for comparing new observations with existing simulations, helping to refine models of binary black hole mergers and gravitational wave generation. It's a practical resource for extending the research initiated by the query paper.