Gravitational Science with Pulsars and the Square Kilometre Array

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Abstract—Pulsar observations form one of the Key Science Projects for the Square Kilometre Array. These will allow unique tests of General Relativity based on finding and timing pulsars in relativistic binaries and on timing millisecond pulsars distributed across the sky in an effort to detect a background of gravitational radiation.

Stringent tests of strong-field gravity using pulsars and black holes form one of the five “Key Science Projects” (KSPs) for the Square Kilometre Array (SKA; see [1] for a full description of this KSP and [2] for a broader outlook on pulsars with the SKA). General Relativity (GR) may be considered a highly successful theory of gravity, having passed every laboratory and observational test to date. However, GR is not reconciled with quantum mechanics, and there are large sections of the parameter spaces of alternate theories that have not yet been carefully tested.

The SKA will allow key tests of GR and alternate theories of gravity in the strong-field regime, near objects with large gravitational binding energy. Stellar population models (e.g., [3]) suggest that there are likely to be at least a few pulsar-black hole binaries in the Galaxy. With the SKA allowing deep pulsar searches throughout the accessible Galaxy, it becomes very likely that one or more of these systems will be discovered. If a suitable system with a stable pulsar is discovered and tracked over the long term, it will be possible to measure the spin of the black hole and thereby test the Cosmic Censorship Conjecture. Additionally it may be possible to discern the black hole’s quadrupole moment and test its predicted “no-hair” relationship to the spin. The SKA will also dramatically improve existing pulsar-based tests of GR, such as those involving relativistic double-neutron-star systems (e.g., [4], [5]) and setting limits on violations of equivalence principles (e.g., [6]).

The second component of the pulsar KSP involves the study of low-frequency gravitational waves, via the long-term timing observations of an array of the most stable millisecond pulsars found across the sky. A stochastic background of such radiation is thought to result from the inspiral of supermassive black hole systems, which are expected to exist based on the current understanding of galaxy formation as well as the radio imaging of galaxies with double nuclei [7], [8]. It may also be possible to detect individual gravitational-wave sources with the SKA. The long-term timing program should reveal systematic correlations in the timing variations as the waves distort the space-time between the pulsars and the Earth. This project will probe a region of gravitational-wave frequency space inaccessible to current or planned ground- or space-based laser interferometric experiments.

Pulsar planning for the SKA involves ongoing refinement of the science case, extensive simulations and development of instrumental techniques. An example is ongoing long-term timing work on timing-array pulsars and refinement of analysis techniques. The community is also involved in planning pulsar observations with SKA pathfinder telescopes.

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References


