

Astrophysics Roadmap: Physical Processes in Extreme Conditions

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Astrophysics has traditionally provided “laboratories” to study physics in extreme conditions not attainable on the ground. An early example was the discovery of dark matter by Zwicky (1937); later examples include several Nobel-Prize-winning discoveries such as Hulse & Taylor’s binary pulsar. Over the next 30 years, NASA has the opportunity to progress far along this exciting path, searching for new physics by studying the most extreme astrophysical systems in the Universe, which feature the highest densities and magnetic fields, the most relativistic velocities, and the strongest gravitational fields. Merging and accreting black holes realize all of these conditions. Significant questions that remain insufficiently answered are listed below. These questions would be addressed by a suite of observatories and theoretical studies over the next 30 years, starting in the next decade with IXO- and LISA- like missions, with future measurement programs to be based on the results of these initial investigations.

1) What happens close to a black hole? More sensitive X-ray observatories, with higher spatial and spectral resolution, and an enhanced energy range, could probe the temperature and geometry of black hole coronas, the role of winds and feedback in black-hole formation and evolution, as well as black-hole spin and the role it may play in jet formation. A milli-Hertz gravitational-wave observatory could provide accurate black-hole parameters and precise maps of the geometry around them, verifying if they are Kerr objects as predicted by general relativity.

2) When and how did the first black holes form? Did they form from remnants of the first stars, or from the direct collapse of primordial gas clouds? If the former, how massive were those stars, what were their supernovae like, and what sort of remnants did they leave behind? Understanding the origin of the first black holes will require sensitive, broadband campaigns, including X-ray observations of the first quasars and gravitational-wave observations of the very high-redshift black-hole mergers that follow the first galaxy mergers.

3) How are black hole growth and galaxy formation tied together? Do episodes of black-hole activity play a dominant role in shutting off star formation in the most massive galaxies? The growth of black holes in galactic nuclei can be illuminated by accurate measurements of their masses and spins, across a population of quiescent and active systems. Such measurements are possible by observing the X-ray emission from the central few gravitational radii around the black hole, and by detecting gravitational waves from the merger of massive black-hole binaries and from the inspirals of stellar remnants into massive black holes.

4) What is the end result of black-hole encounters? What fraction of massive black-hole pairs in merged galaxies form gravitationally bound, coalescing binaries? What fraction of mergers leads to the gravitational ejection of the final holes? High-resolution, broadband X-ray observations could address this question. Accurate pulsar-timing observations, possible with radiotelescopes including NASA’s Deep Space Network, also carry fingerprints from the most massive black-hole binaries in the local universe. As an added benefit, they illuminate the extreme physics of pulsar emission mechanisms.