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Neutron Star Evolution and Emission

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Abstract

This is the final report of a three-year, Laboratory Directed Research and Development (LDRD) project at the Los Alamos National Laboratory (LANL). We investigated the evolution and radiation characteristics of individual neutron stars and stellar systems. Our work concentrated on phenomena where new techniques and observations are dramatically enlarging our understanding of stellar phenomena. Part of this project was a study of x-ray and gamma-ray emission from neutron stars and other compact objects. This effort included calculating the thermal x-ray emission from young neutron stars, deriving the radio and gamma-ray emission from active pulsars and modeling intense gamma-ray bursts in distant galaxies. We also measured periodic optical and infrared fluctuations from rotating neutron stars and search for high-energy TeV gamma rays from discrete celestial sources.

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Background and Research Objectives

Two exciting focuses of modern astrophysics are the evolution of stellar systems and the generation of observable radiation by stars. Our work is directed toward addressing critical aspects of these important issues. Part of our research program considers the x-ray and gamma-ray emission from neutron stars and other compact objects. With the development of new x-ray and gamma-ray satellite-based observing systems, the astrophysics community has, for the first time, the ability to observe stellar objects over broad spectral bands and with fine time resolution.

In our theoretical work we model and compute the variable spectra from pulsars' magnetospheres, neutron star surfaces, and gamma-ray bursts. Neutron stars are born as rapidly rotating objects that later slow due to interactions with their environment. We are acquiring optical data on neutron stars from ground based facilities and using these data to measure the periodic fluctuations from stellar rotation and to deduce the initial rotation rates and the subsequent deceleration.

One of the most exciting areas in high-energy astrophysics involves gamma rays from compact stars. These emissions have been reported by more than eight groups throughout the world, but their exact nature, and even their existence, is still an open question. We have launched an extensive search for these gamma rays using the most advanced scintillator array and Cherenkov detectors..

Importance to LANL's Science and Technology Base and National R&D Needs

This work is related to technology development at Los Alamos and at other US facilities. Our study of x-ray and gamma-ray emission from neutron stars and other compact objects will allow scientists to interpret data from a host of new x-ray and gamma-ray instruments designed to observe neutron stars. The Los Alamos ALEXIS satellite is continuously monitoring neutron stars over the whole sky in the extreme ultraviolet (EUV) through soft x-ray range.

The NASA-supported ROSAT satellite is observing thermal x-ray emission from the surfaces of several neutron stars. NASA's X-ray Timing Explorer will be launched in about one year to detect irregularities in the spin rates of neutron stars due to their superfluid interiors. The large European x-ray satellite XMM will carry a contingent of instruments, including one from Los Alamos, to study faint and rapidly varying neutron stars. Our measurements of cosmic gamma rays, which will establish the definitive level of

emission from discrete sources, will be the standard for evaluating the detectors of other groups.

Scientific Approach and Accomplishments

We have investigated the structure and evolution of neutron stars and black holes and the radiation emitted from these objects. We explored how the differential rotation between a neutron star crust and the more rapidly rotating interior superfluid leads to frictional heating that increases the star's observable surface emission. The frictional heating may reconcile rapid neutrino cooling from a deconfined quark core or direct-Urca emission with the observed surface temperatures from objects such as the Vela pulsar. We found that rapid neutrino emission produces a sudden plunge of a neutron star's surface temperature after 10 to 100 years, depending on the star's mass and radius. An observation of this phenomenon, coupled with an estimate of the neutron star's mass, yields a tight estimate of the stellar radius and hence the equation of state at supranuclear densities. Using the CYGNUS air shower array at Los Alamos, one of the world's premier detectors of astrophysical gamma-rays above 50 TeV, we searched for ultra-high-energy (UHE) emission from a number of northern pulsars, and other astrophysical objects; no sources were unambiguously detected. We have continued monitoring the putative pulsar in the remnant of supernova 1987A. The low emissivity and rapid period change of this object suggest it is a low-magnetic-field neutron star with a large oblateness.

We have studied the variability and spectra of radiation from neutron stars with the goal of inferring the physics of dynamical processes in the interiors of these dense stars and on their surfaces. We have found a surprising universality in several neutron star phenomena including soft-repeating gamma-ray bursts and pulsar spin irregularities. These phenomena exhibit statistical properties reminiscent of earthquakes, suggesting a seismic origin. We refined our statistical analyses of these phenomena using waiting time distributions and time series correlations. We developed models in which energy is stored and released in the crusts of neutron stars. We have employed variations of the slip-stick models that have proven successful in interpreting terrestrial phenomena. In our models the ultimate source of energy for soft-repeating gamma-ray bursts is the stellar magnetosphere. The magnetic field drives large-scale crustal motions that increase the multipolar components of the magnetosphere, decreasing its overall energy. The gamma radiation could result from magnetic field annihilation and the acceleration of high energy electrons and other particles. For the pulsar timing noise, the seismic activity is driven by

the decreasing rotation rate of the star and its changing equilibrium figure. Fluctuations in the stellar moment of inertia create the observed noise in the pulsar spin rates.

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