The Highest Energy Phenomena in the Universe Final Report 95-ERI-008

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Final Report
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Abstract

One of the most enduring and frustrating mysteries in astrophysics is the nature of the cosmic gamma-ray burst (GRB). GRB's were first reported in the 1970's, and since then have been observed from over a dozen different satellites. Two recently launched satellites have revolutionized this field. One, the most sensitive, is known as the Compton Gamma-Ray Observatory (CGRO). This orbiting observatory carries an experiment known as the Burst and Transient Source Experiment (BATSE), which was intended to help elucidate the nature and origin of GRB's. The other is the Italian-Dutch satellite Beppo-SAX, which is substantially less sensitive than BATSE, but can provide greatly superior positional accuracy for the GRBs it detects. The purpose of this LDRD project was to maximize the combined return of these satellites and two ground-based programs (MACHO [Massive Compact Halo Objects] and LOTIS [Livermore Optical Transient Imaging System]), which LLNL largely controls. We have been successful in designing and implementing real-time response systems, and have successfully responded to GRBs with the MACHO Telescope System.

Introduction:

The most spectacular surprise to come out of the BATSE experiment has been the apparently isotropic distribution of the GRB's in the universe; what was expected at the time of launch was that the GRB distribution would show a pronounced concentration toward the plane of the Milky Way. This was expected because the most favored models prior to launch involved activity on the surfaces of galactic neutron stars. (These galactic neutron stars should

be distributed across the sky in a manner similar to the visible stars in the Milky Way.)

The BATSE data have eliminated these pre-launch models. As the isotropy started to become evident, radically new models came into favor in which the GRB's are believed to be collisions between neutron stars, which typically occur at cosmological distances! The energy scale involved is revised upwards by 12 orders of magnitude as a result of this change!

The dramatic circumstantial evidence from BATSE was spectacularly confirmed by the Beppo-SAX satellite. Optical identifications have been made possible by its superior positional accuracy, and these are clearly in distant galaxies!

Work performed in this project:

Statistics of GRB locations: A major controversy developed two years after the launch of CGRO between the proponents of the "cosmological" models mentioned above, and the proponents of models in which the GRB's reside in the extended halo of the Milky Way. The controversy heightened when it was claimed that there was evidence in the BATSE data for recurrence among the GRB's which have moderate fluences. Since this went to the heart of the debate, we examined the data for evidence of these correlations, and developed a parameter-free test for evidence of correlation. We developed sensitive new statistical tests that showed there was no evidence for spatial correlations among the GRB's.

The subsequent identifications made possible by the Beppo-SAX satellite have confirmed our conclusion in this regard. The statistical test (Bennett and Rhie, 1996) remains a very powerful test for correlations among cosmic sources of any kind.

Rapid follow-up with ground-based systems: We have looked critically at the prospects for improving what is known about GRB's. In this regard, we examined the potential for using highly automated optical survey instruments to respond to alerts from three high profile missions. The first of

these to be launched was the High Energy Transient Explorer (HETE), which failed upon launch in 1997; NASA approved a new HETE opportunity, which is expected to be launched in 1999. The second mission is the Beppo-SAX mission already mentioned. The third of these is BOLT (Broadband Observatory for Localization of Transients); BOLT will be proposed to NASA later in 1998 as a new MIDEX class mission, and it appears to be very competitive. We (specifically Kem Cook) have been placed in charge of real-time optical follow-up for BOLT.

We have found that the most promising ground-based instrument for this purpose is the Macho Telescope System, which can detect optical counterparts as faint as 19th magnitude. We have designed the software needed to override the routine data taking on the Macho Telescope System and respond to an alert. We are also working closely with LOTIS which is based at LLNL, to improve the probability that LOTIS will detect optical counterparts of GRB's. We are assisting in the development of the data analysis system.

This system has successfully been implemented on the MACHO Telescope System, and has already taken data on several Beppo-SAX alerts. It is ready for use with BOLT, should BOLT be approved by NASA.

Theoretical models: We have explored possible origins for large numbers of black holes in the universe. Large populations of black holes may prove necessary to account for the objects detected in the Macho Project, and interactions between black holes (or between black holes and neutron stars) may be responsible for GRB's. We have shown that the formation of black holes may be greatly facilitated at the epoch of the cosmic quark-hadron phase transition, and further that the most favored mass that forms at this epoch is $\sim 0.5 M_{\odot}$! This simple model calculation is preliminary in nature, but remarkably suggestive, given the coincidence between the theory and the mass inferred in the Macho Project (for Galactic halo dark objects) and from models of GRB's (Bennett and Rhie, 1995; Sigl *et al.*, 1995; Kurki-Suonio *et al.*, 1997; Niemeyer and Jedamzik, 1997).

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