Observing GRBs with EXIST

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Abstract. We describe the Energetic X-ray Imaging Survey Telescope EXIST, designed to carry out a sensitive all-sky survey in the 10 keV - 600 keV band. The primary goal of EXIST is to find black holes in the local and distant universe. EXIST also traces cosmic star formation via gamma-ray bursts and gamma-ray lines from radioactive elements ejected by supernovae and novae.

EXIST is proposed as a black hole finder probe in NASA's Beyond Einstein Program, and would operate in zenith pointing scanning mode (FoV of 180^ox75^o), to provide all-sky coverage every orbit. Variable sources on the sky would be monitored daily. Each source would be in the FoV for at least 20 min every 95 min orbit, and sampled with ms resolution. EXIST will monitor known variable sources, detect outbursts of known and new sources, and detect Gamma-Ray Bursts (GRBs) with a coverage probability of P = FoV/$4\pi\sim$0.5. Technical details are presented at http://exist.gsfc.nasa.gov/. The "reference design" (Fig. 1) will be refined in a proposed mission concept study. EXIST surveys the sky from a low-inclination (22^o), low-altitude ($\sim$500 km) orbit. With a mission life of five to ten years, EXIST could explore the hard X-ray universe in 2010 to 2020, a century after Albert Einstein developed special and general relativity.

EXIST employs 2.7-m^2 CZT for each of its three telescopes, and images the sky in the 10 keV - 600 keV range with Tungsten coded masks with angular resolution of a few arcmin, and 10-50 arcsec source localization. In the 10 - 200 keV band EXIST will have a continuum sensitivity of 2 mCrab (each orbit), and 0.05 mCrab for a one year survey. Above 200 keV the per-orbit sensitivity would be 20 mCrab, and 0.5 mCrab for a 1 year survey. EXIST would complement observations with GLAST, which will study sources in the 20 MeV - 300 GeV regime [1], and ground-based VHE/UHE instrumentation, such as HESS, MAGIC, and VERITAS. The development of new detector technology is launching gamma-ray astronomy into an exciting new era of breakthroughs in the MeV to TeV regime [2].

GRBs are associated with host galaxies at large redshifts [3, 4]. The red shift record is z = 4.5 for GRB000131 [5]. In at least two cases evidence exists for supernova

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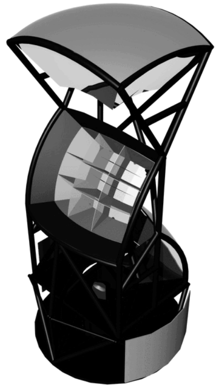

FIGURE 1. The current reference design of EXIST.

associations: GRB 980425 and SN1998bw at z = 0.008 and GRB030329-SN2003dh [6] at z = 0.169. The spectra of these two supernovae are very similar and characteristic of Type Ic hypernovae, such as SN1997ef [7, 8, 9]. The emerging paradigm is a link of massive stars with (long) GRBs, consistent with the predictions of the collapsar model [11]. In this scenario the collapse of a rotating, massive star to a black hole ultimately drives relativistic outflows through a collapsing envelope (e.g., [12] producing a GRB-jet after the breakout, and a subsequent supernova. Under some circumstances the formation of a stellar mass black hole is thus heralded by a burst of gamma-rays, followed by a decaying afterglow from X-rays to radio [3]. GRBs thus provide a unique opportunity to trace the process of star formation to large, cosmological distances. Theoretical studies [13, 14, 15] indicate that the first generation of stars may have formed at z > 10, re-ionizing the universe, perhaps with a bias towards more massive stars due to the low metallicity in the early universe. Observational support for the emergence of the first stars in the red shift range z$\sim$10-30 (100 to 400 Myrs after the bigbang) comes from the polarization of the CMB [16]. Black holes from these population III stars may have played a significant role in seeding AGN cores. Even at such large distances it is easy to detect a red shifted GRB. A sensitivity of 1 mCrab in the hard X-ray band is sufficient to detect GRBs like GRB 990123 at essentially all realistic distances. Based on the assumption that the GRB rate traces the cosmic star formation rate, we estimate that 7% of all GRBs detected by EXIST originate at z > 10 (Fig. 2) To enable ground-based and space-based (e.g., NGST) studies of these bursts, EXIST provides 10”-50” locations in near real time. The total burst rate will be a few per day. EXIST would serve as the primary GRB observatory in the post-Swift era [17], during a time when sensitive neutrino detectors (IceCube) and gravity wave detectors (LISA, LIGO-II) may be able to detect the high-energy (> PeV) neutrino and gravity wave signature of GRBs.

Detection of the first generation of stars may require GRBs as a tracer, as galaxies beginning to form stars are faint. Spectroscopy of host galaxies will require observations with large aperture telescopes [15], and are likely to revolutionize our ability to trace

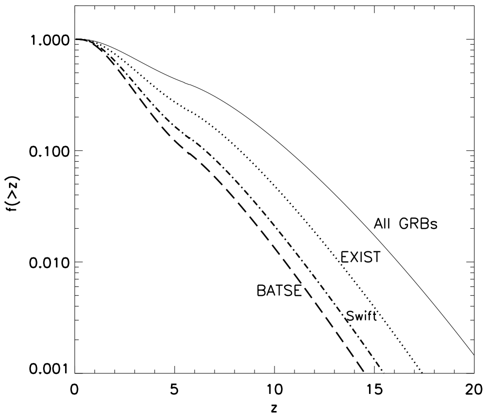

FIGURE 2. The estimated fraction of GRBs with red shift greater than z. Here, “all GRBs” is based on the assumption that GRBs trace the cosmic SFR. Estimates were made for EXIST, BATSE, and Swift.

and probe structure formation and galaxy evolution to the earliest times. GRBs provide signposts along "the road to galaxy formation" [18], and shed light on the crucial question of halo formation via a more or less smooth collapse or successive mergers of independently evolving proto-galactic fragments. The star formation rate during halo collapse is sensitive to stellar feedback (e.g., [19, 20]. Thus high-z GRBs could improve our understanding of a key ingredient in galaxy formation and evolution.

The star formation rate and GRB rate are related, but not one-to-one. As metallicity decreases, the IMF changes due to changes in the cooling function of the gas. After formation, mass loss from stellar winds is a sensitive function of the metal content in the stellar envelope, affecting subsequent evolution and probabilities for creating the right conditions for GRBs [21]. GRBs provide a new tool for studies of early galaxy evolution, and may lead to the elusive Population III stars and their feedback on proto-galaxies [22].

EXIST will also detect many X-ray rich GRBs (the so called X-ray Flashes, [23, 24]. This new burst phenomenon is in many ways similar to classical long duration GRBs, but, as the name indicates, characterized by a lower energy of the bulk of the emission. While the peak in the νF_ν spectrum of GRBs is clustered around 200 keV, the currently small sample of XRFs suggests a peak value of $\sim$50 keV. The nature of XRFs is not yet clear. XRFs could be highly red shifted GRBs, but observations of the host galaxies of XRF 011030 and XRF 020427 [25] argue against that interpretation.

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