EXIST: All-Sky Hard X-ray Imaging and Spectral-Temporal Survey for Black Holes ⋆

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Abstract

The Energetic X-ray Imaging Survey Telescope (EXIST) is under study for the proposed Black Hole Finder Probe, one of the three *Einstein Probe* missions in NASA's proposed Beyond Einstein Program. EXIST would have unique capabilities: it would survey the full sky at 5-600 keV each 95min orbit with 0.9-5 arcmin, 10μsec - 45min and $\sim$0.5-5 keV resolution to locate sources to 10$''$ and enable black holes to be surveyed and studied on all scales. With 1y/5σ survey sensitivity F_x (40-80 keV) $\sim$5 $\times 10^{-13}$ erg cm^{-2} s^{-1}, or comparable to the ROSAT soft X-ray (0.3-2.5 keV) sky survey, a large sample ($\gtrsim$2-4 $\times 10^4$) of obscured AGN will be identified and a complete sample of accreting stellar mass BHs in the Galaxy will be found. The all-sky/all-time coverage will allow rare events to be measured, such as possible stellar disruption flares from dormant AGN out to $\sim$100 Mpc. A large sample ($\sim$2-3/day) of GRBs will be located ($\lesssim$10$''$) at sensitivities and bandwidths much greater than previously and likely yield the highest redshift events and constraints on Pop III BHs. An outline of the mission design from the ongoing concept study is presented.

1 Introduction

Of the wide-field surveys considered at this meeting, one is likely widest of all: temporally-resolved imaging in hard X-rays ($\sim$5-600 keV) of the full sky every 95min. This is possible with a satellite-borne coded aperture imaging telescope array with very wide "fully-coded" field of view that scans with a photon-counting detector array over the full sky each orbit. Such is the concept for the Energetic X-ray Imaging Survey Telescope (EXIST), originally recommended by the Decadal Survey as a possible ISS mission and then considered as a

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Free Flyer (Grindlay et al 2003), and now under study to be the Black Hole Finder Probe in NASA's *Beyond Einstein* Program. The unique all-sky/all-time imaging capability of EXIST opens the temporal survey window and is highly complementary to LSST (or any Wide-Field OIR surveys) and LISA. The hard X-ray band is particularly well matched for detection and study of accreting black holes, from stellar mass ($\sim$10$M_{\odot}$) in X-ray binaries to supermassive ($\sim$10$^{7-9}$ $M_{\odot}$ in galactic nuclei, which characteristically emit their peak luminosity in a broad band around $\sim$100 keV. At energies above $\sim$7 keV, photoelectric absorption by column densities $N_H \gtrsim 10^{23-24}$ cm^{-2} in galactic nuclei or X-ray binaries in the Galaxy becomes negligible and black holes can be seen until $N_H \gtrsim 10^{25}$ cm^{-2} and they are obscured by Compton scattering.

2 Black Hole Finder Probe Science to EXIST

The Black Hole Finder Probe (BHFP) should enable the most comprehensive survey for black holes, from super massive to stellar, yet undertaken. The EXIST concept for BHFP would emphasize three primary science objectives, described below along with related science goals.

Revealing obscured or dormant super massive BHs: The all-sky hard X-ray imaging survey would reveal Type 2 (obscured) AGN and nearby ($\lesssim$300 Mpc) stellar tidal disruption events in normal galaxies. The Type 2 survey will probe the bulk of the cosmic X-ray background (CXB), which is only $\sim$50-70% resolved by Chandra and XMM at energies 6-8 keV according to Worsley et al (2004), who conclude the missing CXB requires a large population of AGN with $N_H \sim 10^{23-24}$ cm^{-2} and unabsorbed $L_x \sim 10^{43-44}$ erg s^{-1}primarily at z $\sim$0.5 - 1.5. EXIST would provide a full sky sample of these objects out to z $\sim$0.3, and more luminous Type 2 Seyferts and QSOs with $L_x \sim 10^{45}$ and $\sim 10^{46}$erg s^{-1}out to z $\sim$1 and 3, respectively, to constrain the growth and evolution of super massive BHs in the universe. EXIST would provide the first full-sky survey for dormant BHs in galactic nuclei from the expected disruption of stars. If just 1% of this accretion luminosity is released in a hard X-ray component (as found for virtually all Eddington-rate events), some 10-30 events/y should be seen out to $\sim$100 Mpc (Grindlay 2004). The significantly increased sensitivity of EXIST vs. the BAT on Swift, both at $\lesssim$15keV and $\gtrsim$150 keV, should enable detection of the prompt $\sim$5 keV burst predicted by Kobayashi et al (2004), providing a LISA trigger for nearby ($\sim$10Mpc) disruption events.

Measuring the birth of the first BHs: EXIST would conduct the highest sensitivity and bandwidth survey for GRBs out to limiting z $\sim$15 for most burst fluences detected at z $\lesssim$5 by BATSE (Band 2003). The broad spectral coverage and very large FoV of EXIST would maximize the detection of the extremes of GRBs: those at the highest z or low luminosity events and X-ray flashes at lower z. EXIST will allow the determination of GRB spectra and the peak energy flux, E_{peak}, in a νF_ν broad band spectrum, which may allow GRBs to be calibrated as standard candles (Ghirlanda et al 2004) and thus allow cosmological redshifts directly from GRB spectra. The active anti-coincidence side-shields (over 8m^2 of CsI) also would allow the upper energy range for GRBs detected with EXIST to be extended to $\sim$10MeV, or significantly beyond the $\sim$600 keV limit of the primary imaging detectors (see below), thus enabling GRBs from Pop III BHs to be compared directly with those at lower redshifts detected at $\sim$10-1000 MeV by GLAST.

Studying BHs in the Galaxy and AGN as Probes: By continually measuring spectra and time variability of accreting BHs in brighter AGN and galactic X-ray binaries, EXIST will constrain their physics and evolution. The population of galactic BHs accreting from both high and low mass companion stars will be measured from both persistent and transient sources. EXIST would study the full population of obscured accreting BHs suggested by the INTEGRAL survey of the galactic bulge (Revnivtsev et al 2004). BH populations would be probed in high mass binaries such as the intrinsically absorbed possible sgBe system IGR J16318-4848 discovered with INTEGRAL and identified (Filliatre and Chaty 2004) with an IR counterpart that resembles the peculiar transient CI Cam. BHs in low mass binaries would be seen as X-ray "novae", with characteristic hard spectra and L_x (20-100 keV) $\sim 10^{38}$ erg s^{-1}and $\tau \sim$10d decay time (cf. McClintock and Remillard 2005; MR05), could be studied in detail in the Galaxy and LMC/SMC and detected as "new" sources out to the Andromeda galaxy (super-flares from soft gamma-ray repeaters, magnetars, are detected out to Virgo). For brighter stellar mass BHs and transients and AGN, the continuous and long-duration monitoring will allow measures of QPOs that appear to correlate with BH mass (MR05) and (for AGN vs. Cyg X-1) accretion luminosity (Leighly 2004). For non-thermal and jet-dominated BHs such as microquasars and Blazars, EXIST spectra and variability coordinated with IR-TeV observations will constrain the BH-jet interface. Notably, for Blazars, simultaneous EXIST spectra and GeV-TeV spectra from GLAST and VERITAS will anchor the underlying SSC model (e.g., Katarzynski et al 2004) to enable measurement of the cosmic diffuse IR background flux from the observed vs. predicted cutoff in the GeV-TeV spectrum.

3 Telescope and Detector Concept

The EXIST Concept Study mission design (Fig. 1) would include two large area and FoV coded aperture telescope arrays: a High Energy Telescope (HET; 10-600 keV) and a Low Energy Telescope (LET; 5-30 keV). The HET is an array of 6 x 3 coded aperture telescopes covering a a $131^\circ \times 65^\circ$ fully-coded/flat-response FoV (and $153^\circ \times 87^\circ$ FWHM FoV) with total detector area of 5.6m^2 of imaging (1.25mm pixels) CZT. The LET is 4 arrays of 7 $\times$1 coded aperture telescopes covering a similar FoV with total detector area of 1.1m^2 of imaging (0.158mm strips or pixels) Si. The angular resolution of the HET and LET are

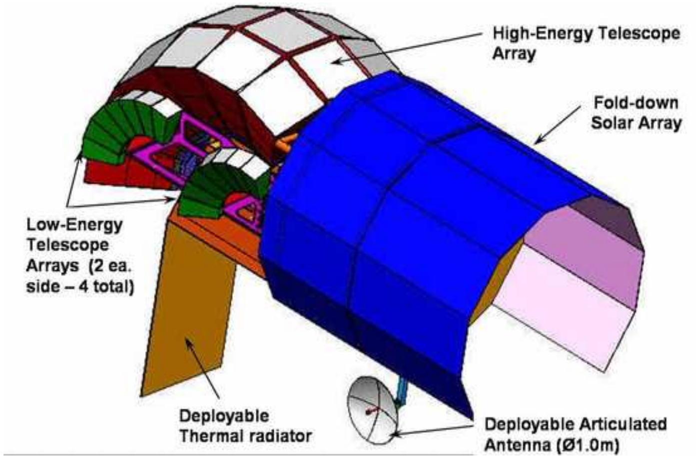

Fig. 1. EXIST on orbit. The 131° ×65° FoV of the HET array is zenith-oriented with the long direction perpendicular to the orbit velocity vector and "nodded" by ±20° every ∼20min so that the full sky is scanned each orbit.

5′ and 0.9′ , respectively, or well below source confusion limits for the AGN surface density at F_x (20-40keV) $\gtrsim 5 \times 10^{-13}$ cgs as well as faint hard X-ray sources in the Galaxy, and sufficient to allow $\gtrsim 5\sigma$ threshold detections to be centroided to $\lesssim 10''$ to enable correct optical/IR identifications.

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