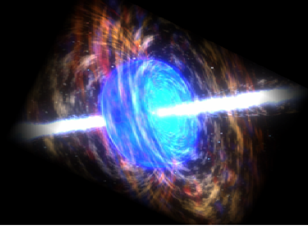
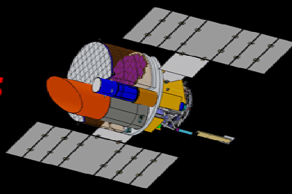




EXIST

Energetic X-ray Imaging Survey Telescope

Josh Grindlay

(Harvard)

and the ***EXIST Team***

Survey and ***Identification*** (with redshifts) of Black Holes on all scales:
High-z GRBs, obscured/dormant AGN & the Transient Universe

To use the earliest (stellar mass) BHs as Cosmic Probes of the Early Universe and study BHs over space & time

Under Study (ASMC) as a possible joint US-Italy mission

What is *EXIST?*

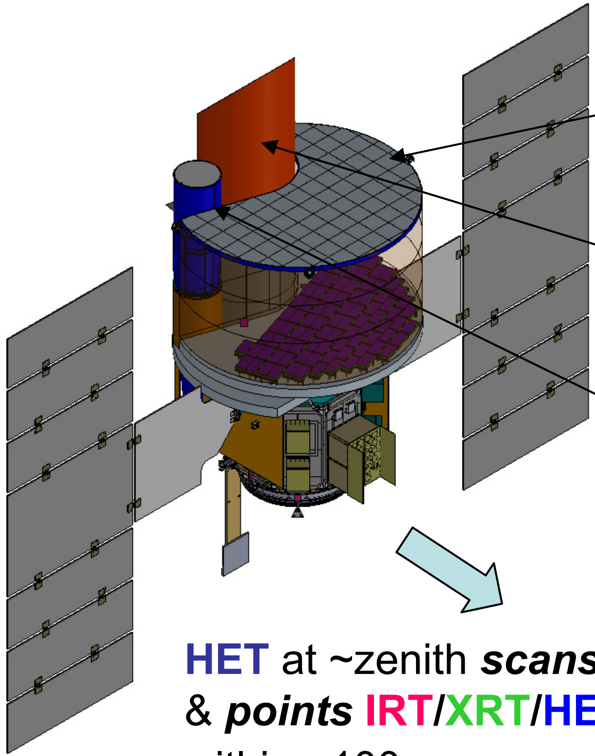
- A *Medium Class Mission* (~$800M) to conduct the most sensitive full-sky survey for ***Black Holes*** on all scales (stellar to supermassive)

- A leading candidate to be the ***Black Hole Finder Probe (BHFP)*** as one of the 3 *Einstein Probe* missions (hopefully in c. 2017, next after JDEM)

- A mission completing a study for the ***Astrophysics Strategic Mission Concept (ASMC)*** *Study* program, in preparation for review by the *Astronomy/Astrophysics Decadal Survey (Astro2010)*

- A wide-field (90^o) **hard X-ray (5-600 keV) imaging** (2 arcmin resolution) telescope surveying/monitoring full sky every 3h *plus* a 1.1m **optical-IR telescope** and contributed (Italy) **soft X-ray imaging (0.1-10keV) telescope** to obtain identifications, redshifts and diagnostics of black holes, transients & extreme objects for followup study by **Fermi, IXO, JWST, LSST and LISA**

A Hard X-ray, full-sky, deep imaging Survey and IR/X-ray followup is required for the Black Hole Finder Probe to *EXIST*



HET: CZT detector arrays + mask:
5-600 keV **4.5m² tiled CZT**,
coded mask images 90° diam.
FoV, 2' resol. & <20" positions;
BGO rear shield (0.2-2MeV)

IRT: 1.1m; cooled (-30C)
(dichroic: 0.3-0.9μm (HyViSI)
and 0.9–2.3 μm (NIRSPEC)

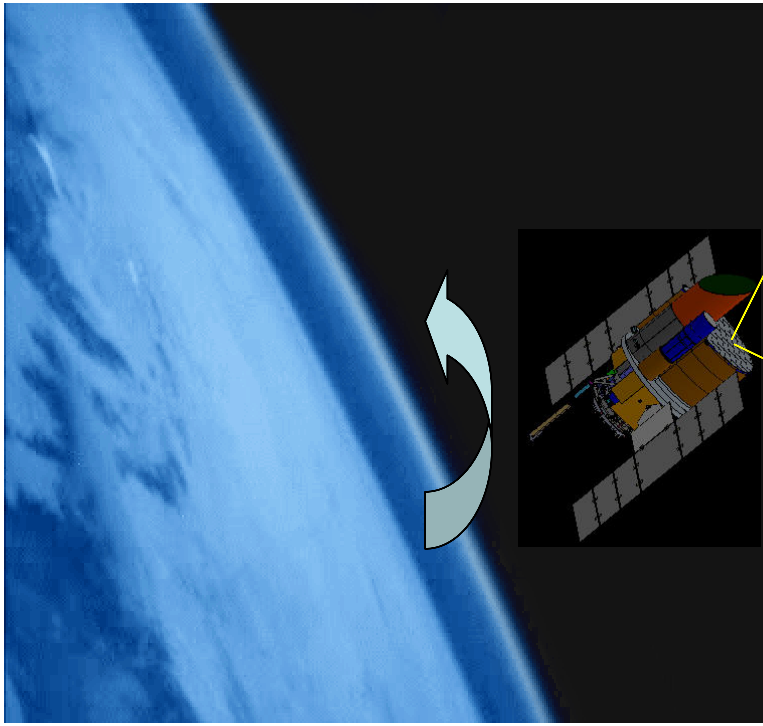
SXI: 0.6m; Italy/ASI contributes(?)
upgrade of *Swift/XRT: **S**oft **X**-ray **I**mager* (0.1-10keV (CCD))

HET at ~zenith ***scans*** at orbital rate
& ***points*** **IRT**/**XRT**/**HET** to GRBs
within ~100s

The *New* *EXIST* mission:

- ***2y full sky survey:*** Zenith-pointed **scanning**, 2sr FoV, *full-sky ea. 3h*.
- ***3y followup IDs:*** **IRT/XRT/HET** **pointings** for IDs, redshifts, spectra & timing

How does ***EXIST*** operate?



1. Zenith (+/-~30°) **scan** of 90° FoV of HET at orbital rate to cover ~half-sky each orbit

2. Imaging in 90° FoV detects Gamma-ray burst (GRB) -- or variable AGN or transient

3. ***EXIST*** slews S/C onto GRB for IRT imaging ID and spectrum (optical + IR) for redshift

4. Pointing for 1-2 orbits to measure structure in distant Universe; HET measures spectrum & variability of target *and* continues Survey

5. Resume scan (years 1 & 2) or new target

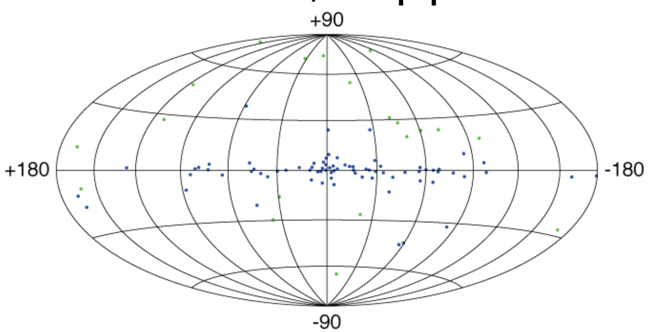
Hard X-ray Sky

- **Hard X-ray (10-600 keV) sky not yet surveyed to ROSAT sensitivity. *EXIST* would be ~10X more sensitive than *Swift* or *INTEGRAL* and cover full sky**

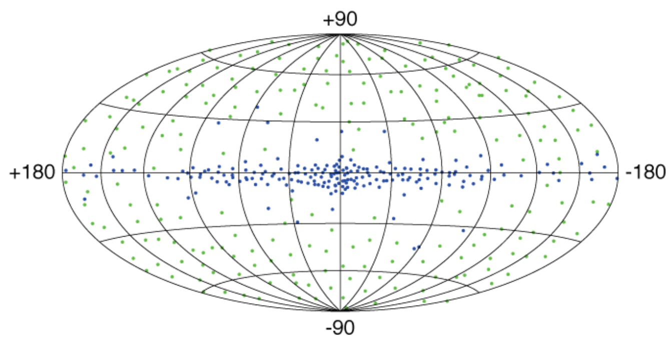
- ***EXIST* will detect ≥3 x 10^4 sources, ≤15″ positions, 5-600 keV spectra**

- ***EXIST* would provide unique temporal survey: *full sky imaging every 2 orbits***

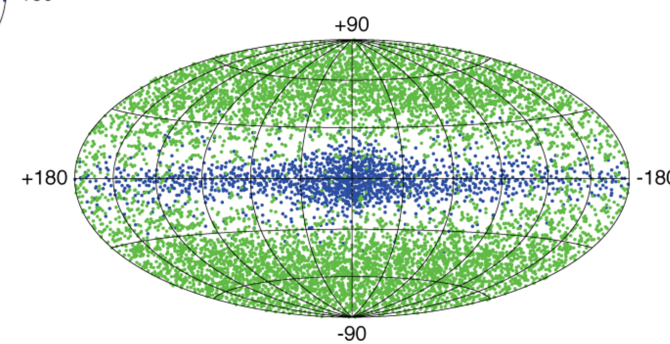
Previous Hard X-ray Sky
HEAO-1, BeppoSAX



2010 Hard X-ray Sky
Swift & INTEGRAL



2017(?) Hard X-ray Sky
EXIST



Primary Science Objectives for *EXIST*

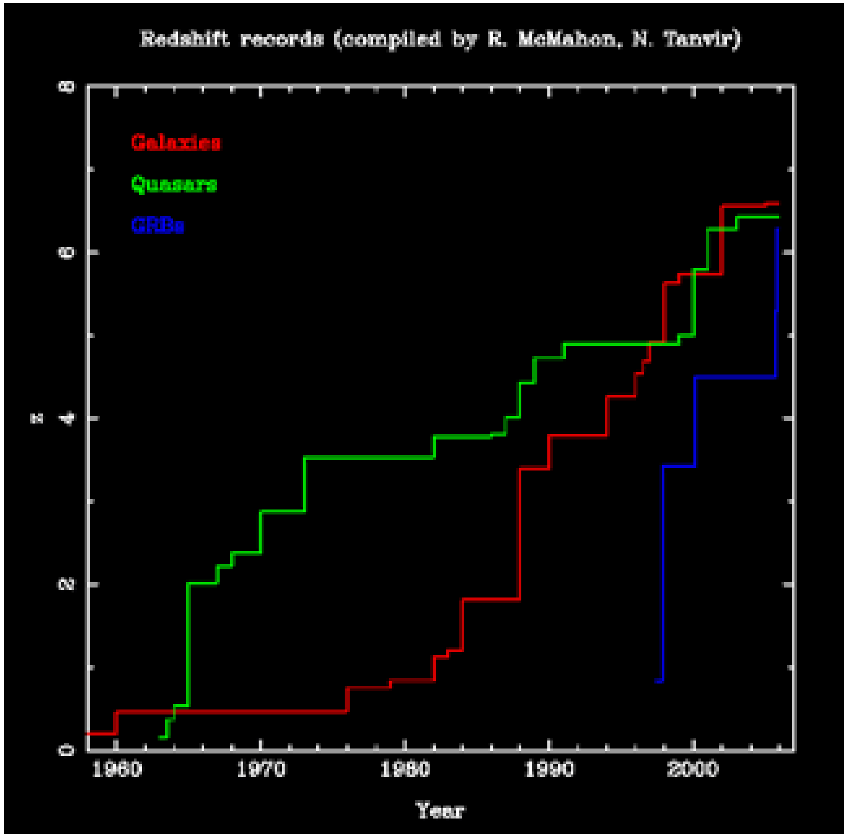
(to survey and study Black Holes on all scales: stellar to supermassive)

- **P1: Measure the birth of stellar black holes** from *cosmic gamma-ray bursts* to measure prompt redshifts, constrain GRB physics **and enable GRBs as probes of** cosmic structure and ***reionization at redshifts z >10***

- **P2: Identify supermassive BHs in galaxies**, whether *obscured* or *dormant*, **to constrain SMBH properties**, their role in galaxy evolution and the origin of the CXB, **and *accretion luminosity of the universe***

- **P3: Measure the stellar and intermediate mass BH populations in the Galaxy and Local Group** by a generalized survey for Transients for which prompt IDs and X-ray/HX/IR spectra distinguish SNe, SGRs & Blazars and complement ***Fermi, JWST, LSST, LISA*** with prompt alerts for unique objects

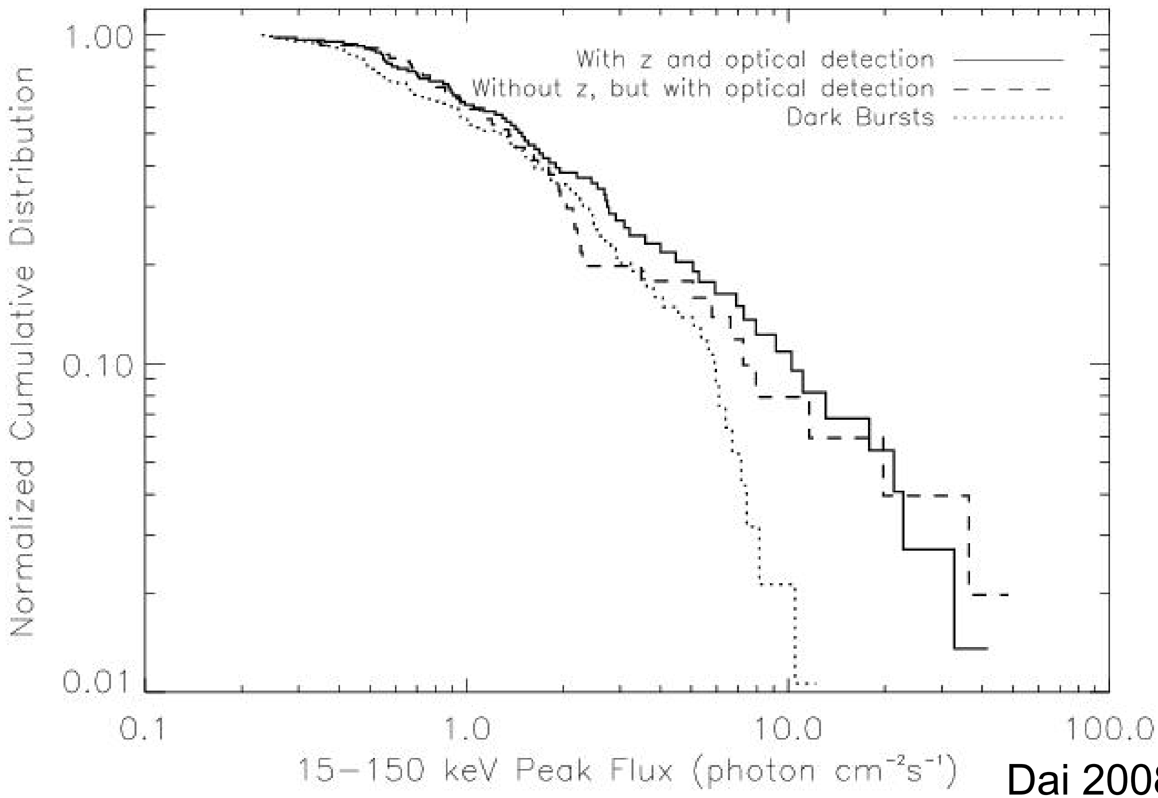
GRBs must preceed QSOs: highest-z stellar Probes



Max. record redshift vs. time: GRBs clearly outpace AGN for most effective high-z probes!

- *Swift* GRBs at z = 6.3, 6.7 & Spitzer galaxies at z ~8 show *GRBs must be detectable out to at least z ~8-10 and early Pop II & possibly even PopIII?*
- *Swift logN-logS* for optically **Dark Bursts** suggests high z? (Dai 2008)
- Broader energy band, higher sensitivity & FoV needed for large sample at z ≥ 8-10
- IR from space needed for z ≥7 since Ly-dropout then in NIR & spectra less sensitive from ground
- GRBs provide "back-light" for IR spectroscopy of IGM, gas, & galactic structure (vs. z) back to epoch of re-ionization (EOR)

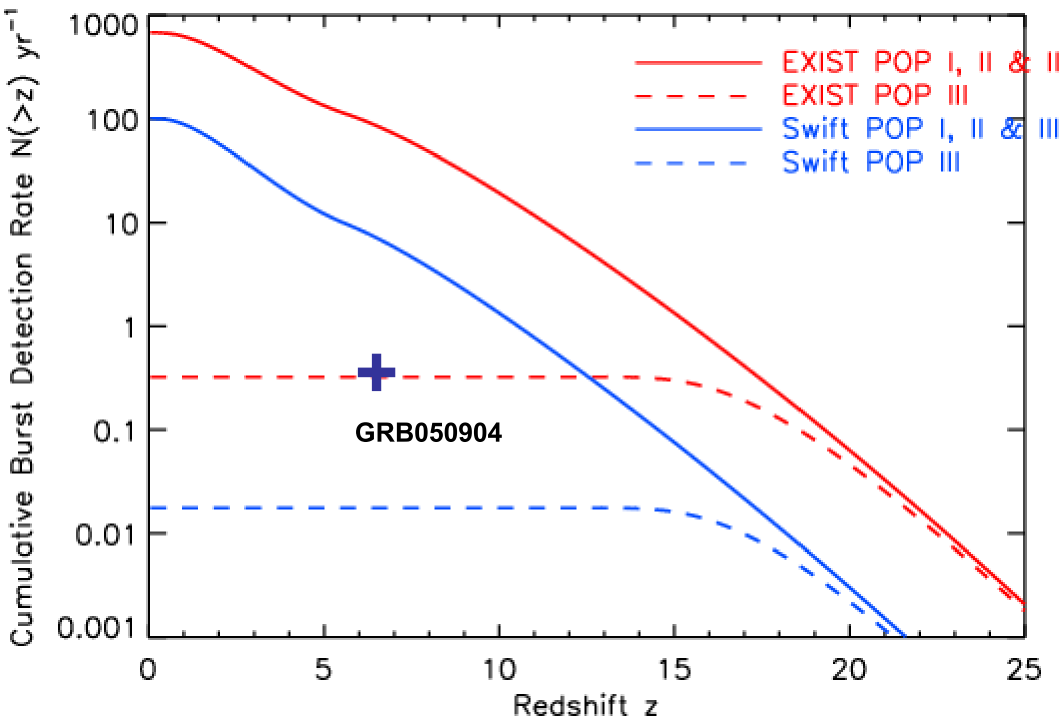
Swift logN-logP for optical vs. "Dark" GRBs: are they *high z*?



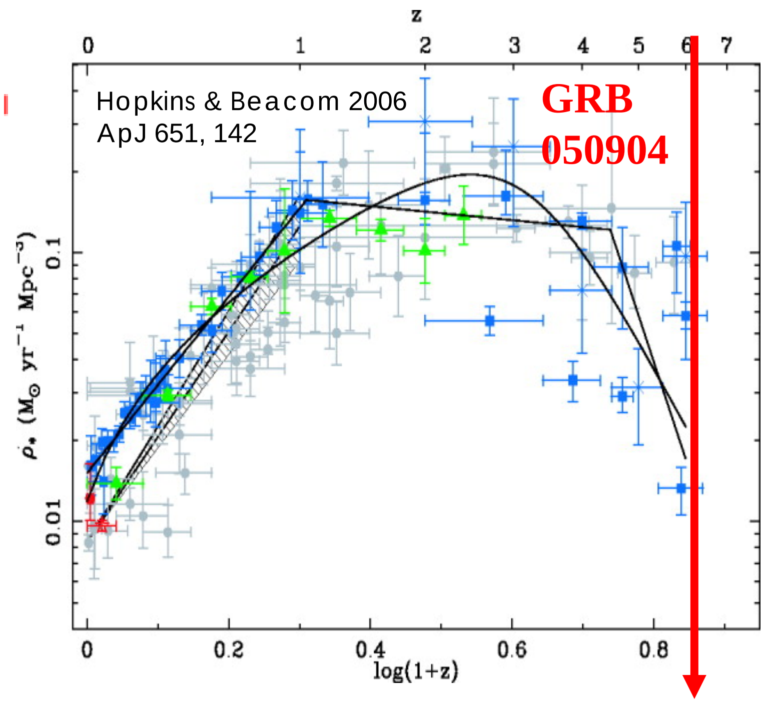
Dai 2008, astroph0812.4466

- Hard X-rays *insensitive to reddening* so optically dark long GRBs should have same logN-logP as Dark GRBs
- >99.8% likely that Dark GRBs are *different* – optical cutoff by Ly-breaks since high-z and logN-logP cutoff by high-z time dilation or GRB luminosity function?

P1: *EXIST* GRBs *probe stellar universe to z ≥ 10*



Predicted *EXIST* GRB rates vs. z based on Bromm and Loeb (2005). *EXIST will detect and measure redshifts for >60 GRBs/yr at z >7 and may detect Pop III GRBs. Lyα spectra will explore EOR at z ~6-15. Salvetera et al (2008) also predict >10-60/yr for EXIST detection rate.*

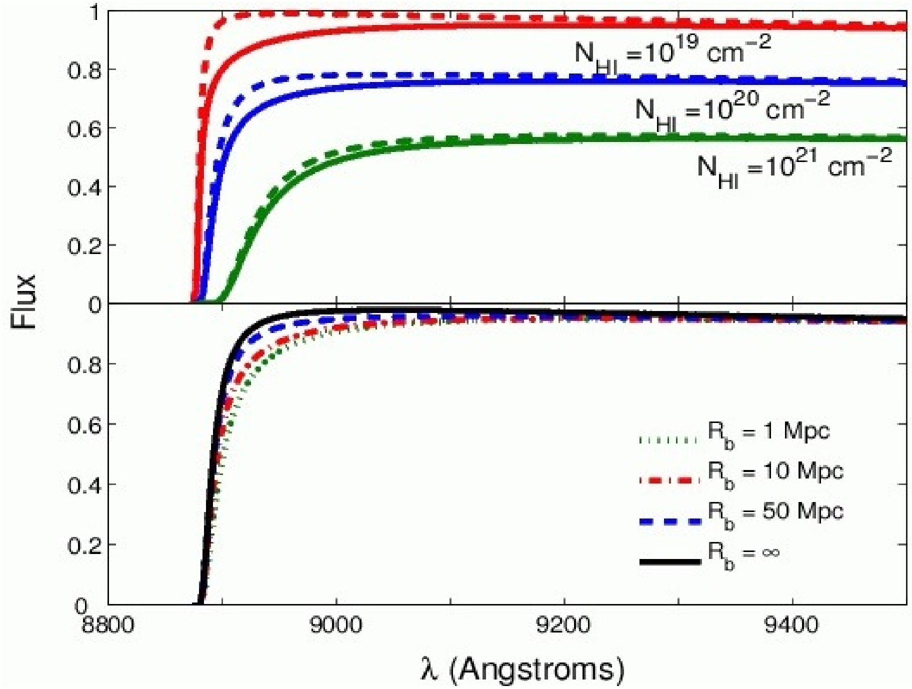


EXIST GRBs vs. z will probe the star formation rate (SFR) vs. z at highest redshifts, and constrain/measure Pop III.

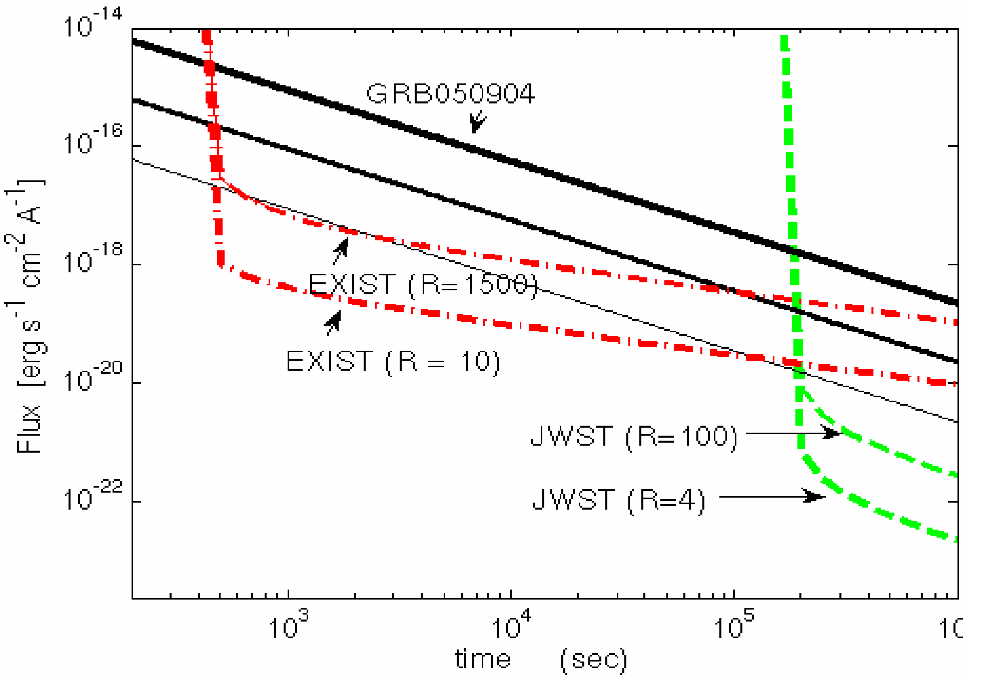
EXIST will probe:

EXIST IRT spectra (R = 30) in 300-1000s: AB(H) ~23-24

2 VIS + 2 IR bands enable GRB redshifts out to z ~20(!)



Sensitivity of Ly-break *shape* to local IGM & EOR



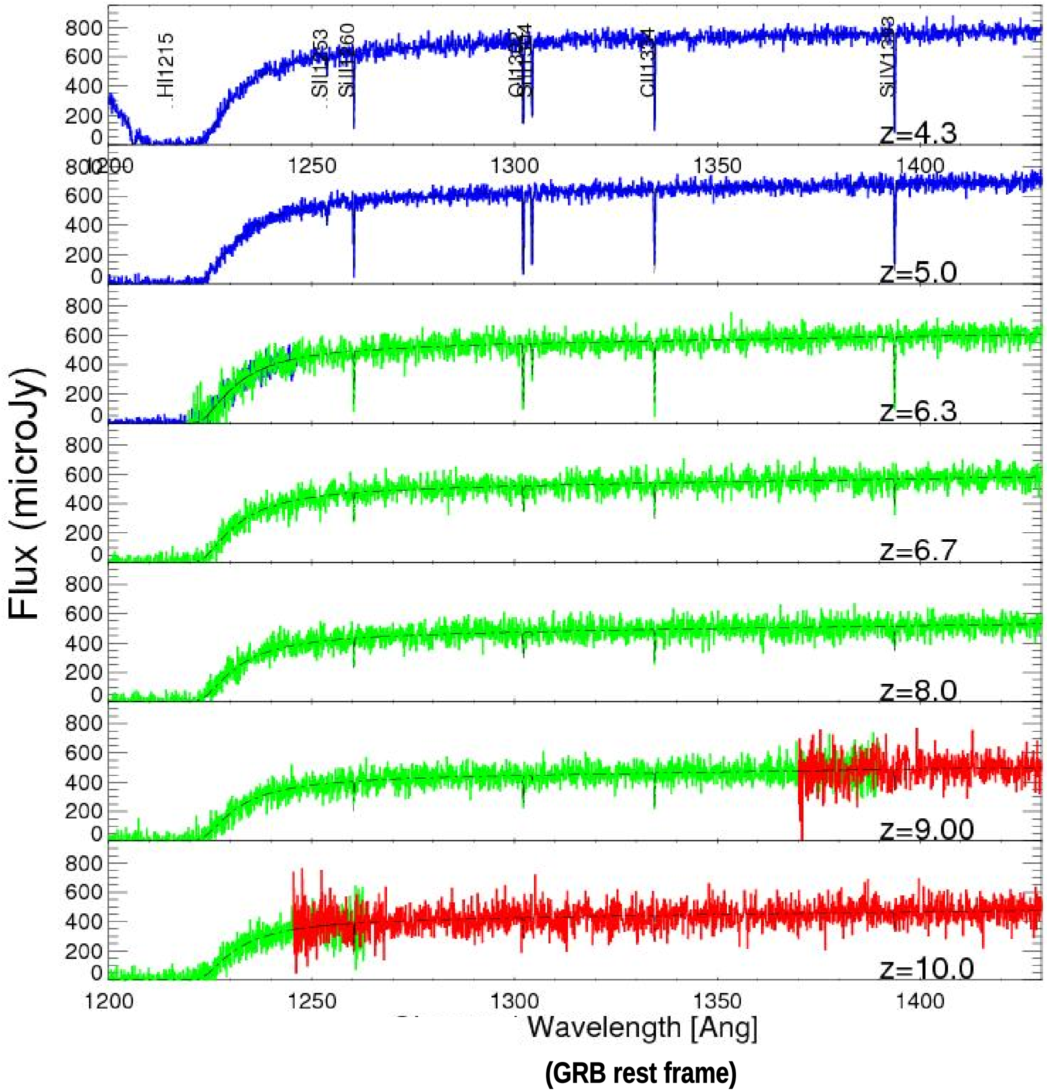
IRT vs. JWST for GRBs 1X, 0.1X and 0.01X flux of GRB050904.

- **IRT spectra (R ~3000) for AB(H) ~18-20 in 2000sec exp. *simultaneously* for optical (0.3-0.9µm) and IR (0.9-2.1 µm): Ly profiles for EOR studies of high-z IGM**

- **Simulations: *>95% of Swift GRBs would have z measured* ; ~300-700 GRBs/yr!**

Simulated Ly-breaks for EXIST IRT vs. z (*R = 3000, T = 2000sec*)

for a GRB 3mag brighter than the anomalously faint GRB080913 (z = 6.7)



<u>Assumed model (which IRT tests!):</u>

AB(H) = 15.5 at T =200s, then GRB lightcurve decays: $F \sim T^{-1} \nu^{-1}$

Log(NH) = 20 in GRB host

Metallicity vs. z:
z < 6, [Fe/H] = -2
6 < z < 7, [Fe/H] = -3
Z > 7, [Fe/H] = -4

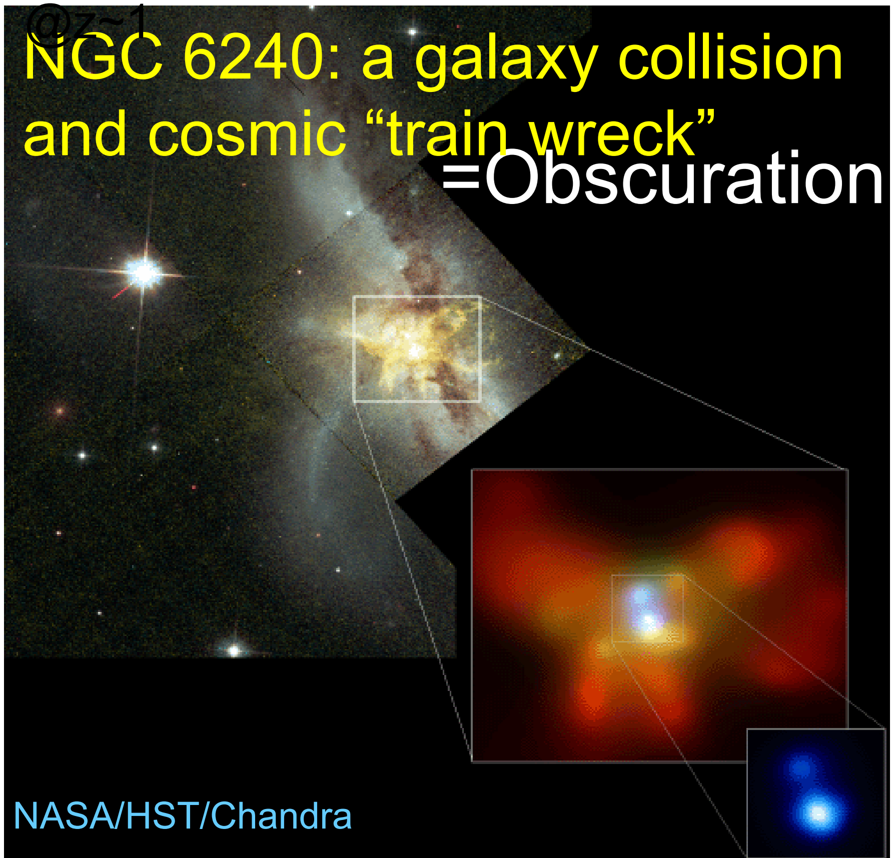
Simulated spectra shown in IRT bands:
0.3 – 0.9μm (not plotted here)
0.52 – 0.9μm
0.9 – 1.38μm
1.38 – 2.1μm

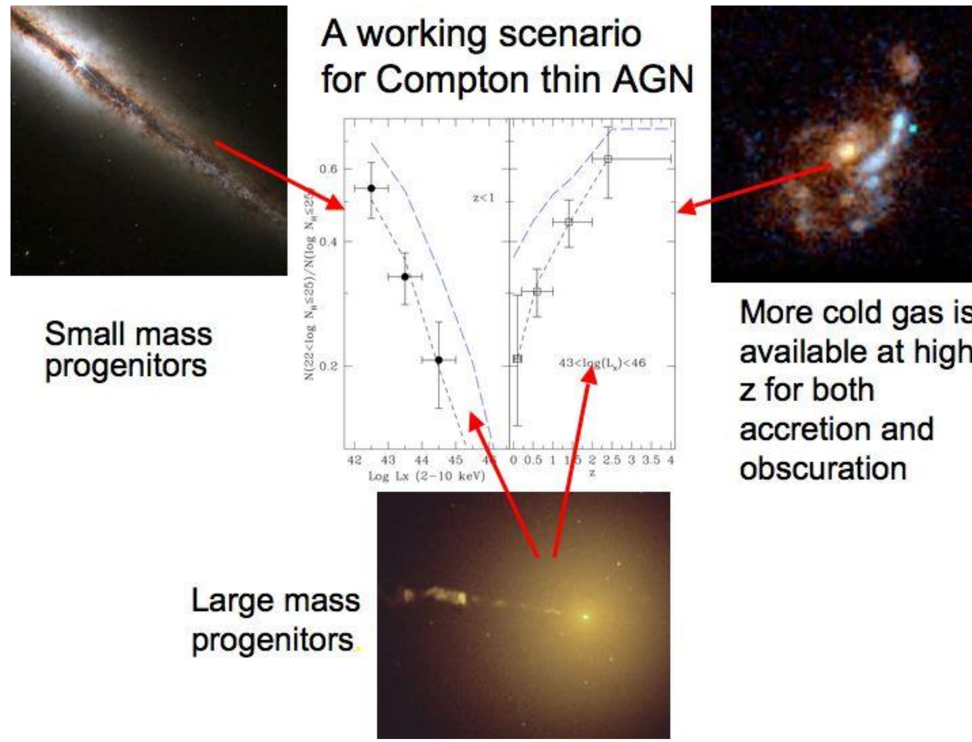
EOR & Fe/H can be measured vs. z!

P2: Obscured or Dormant AGN (all types) & QSOs vs. z?

- ***EXIST*** discovers: 1) ***obscured AGN*** over a broad range of Lx and absorption column NH *to constrain NH vs. z and growth of SMBHs*, and 2) ***Dormant SMBHs*** (like SgrA*) *revealed by HX flares from Tidal Disruption of field stars* → ***LISA triggers***

- ***EXIST*** best suited to discover rare ***Type 2 QSOs*** at z ≤3 and study Type 2s vs. SFGs @z~1



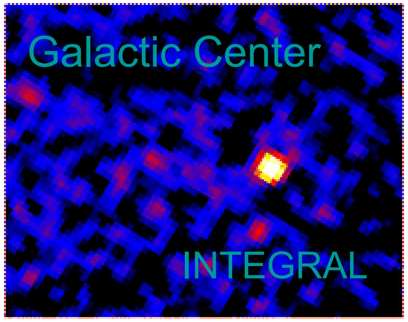


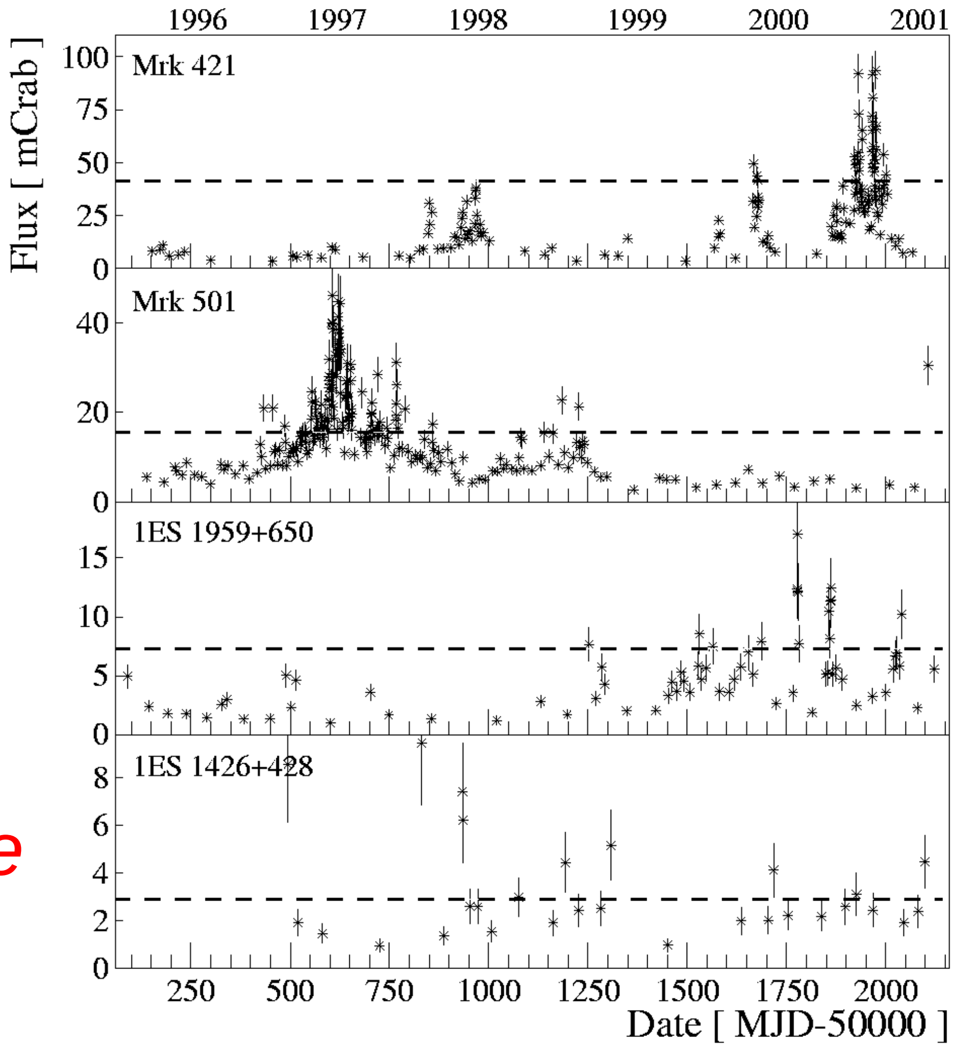
EXIST **survey will explore the recent evidence (La Franca et al 2005 and Treister & Urry (2006) that obscured AGN are *increasing as* $(1+z)^{0.4}$**

Black Hole Variability is the norm…

Continuous sky coverage by *EXIST* constrains BH mass vs. z

E.g., **Blazars** – with very low duty cycle:





And even ***dormant*** **SMBHs** (our galactic Center) flare…

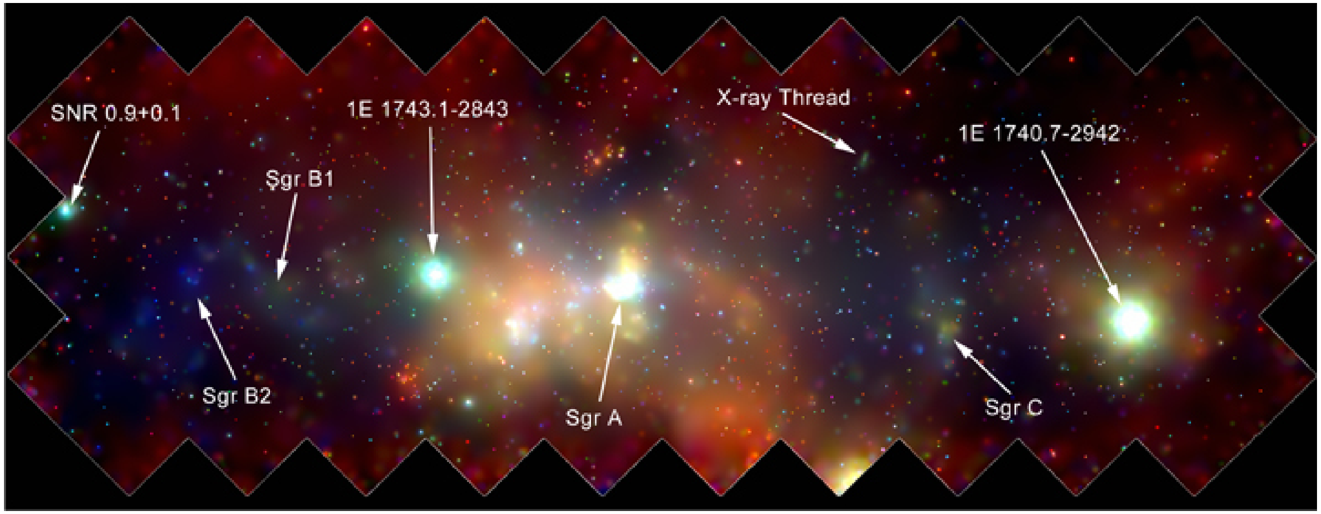
BHs Need *all-sky monitoring … all the Time!*

P3: *EXIST measures* stellar BHs & IMBHs as *Transients* in Galaxy, Local Group

- *EXIST* detects ***all*** bright stellar BHs in transients (Lx(>10 keV) ~10^{36-38} erg/s) throughout Galaxy, LMC/SMC and M31. ***Reveal population of obscured HX sources. QPO monitoring of bright BH-LMXBs; ULX's in Local Group***

- ***Isolated* stellar BHs in Galaxy and IMBHs** in Local Group accreting via Bondi-Hoyle (with ~10^{-4} efficiency) from GMCs nearly Compton thick

- **Faint BH transients in *Central Galactic Bulge*?**: BHs in nuclear cusp (Alexander & Livio 2004) detected (~10d) as VFXTs if Lx(>10 keV) ~$10^{34.5}$ erg/s BH vs. NS or WD binaries around *SgrA** distinguished by Type I bursts & novae



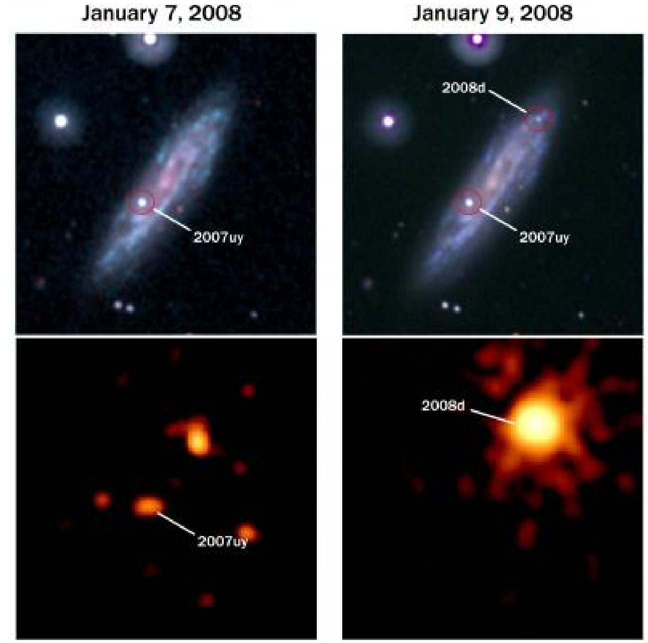
Chandra view of central Bulge (~ 2° x 1°)

And more High Energy Transients…

- **Supernovae *breakout shocks*** like NGC 2770/SN2008d discovered with Swift/BAT: ***EXIST*** HET sensitive down to ~5keV can image these on the fly and **trigger Neutrino and Gravitational Wave telescopes**

- **Soft Gamma-ray Repeaters** (SGRs): Magnetar survey out to ~300Mpc can **provide triggers for LIGOII**

- **Blazar flares**: "contamination" of high-l modes of CMB by flaring flat-spectrum radio sources; evidence for significant flaring hard X-ray Blazars from Swift BATSS (Grindlay et al 2009, in prep.)



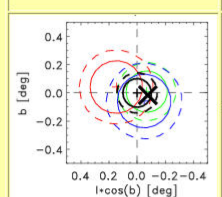
Scientists had planned on studying Supernova 2007uy in the galaxy NGC2770, which was already several weeks old when seen in this visual, ultraviolet image (upper left) taken on Jan. 7, 2008, by NASA's Swift satellite. A close-up, X-ray image of that supernova is beneath.

Seemingly out of nowhere, Supernova 2008D burst onto the scene on Jan. 9, 2008, as seen in ultraviolet images (upper right) and X-ray images (beneath) taken by NASA's Swift satellite, giving scientists the unique opportunity to witness the birth of a supernova.

Candidate source: BATSS_J1425+363

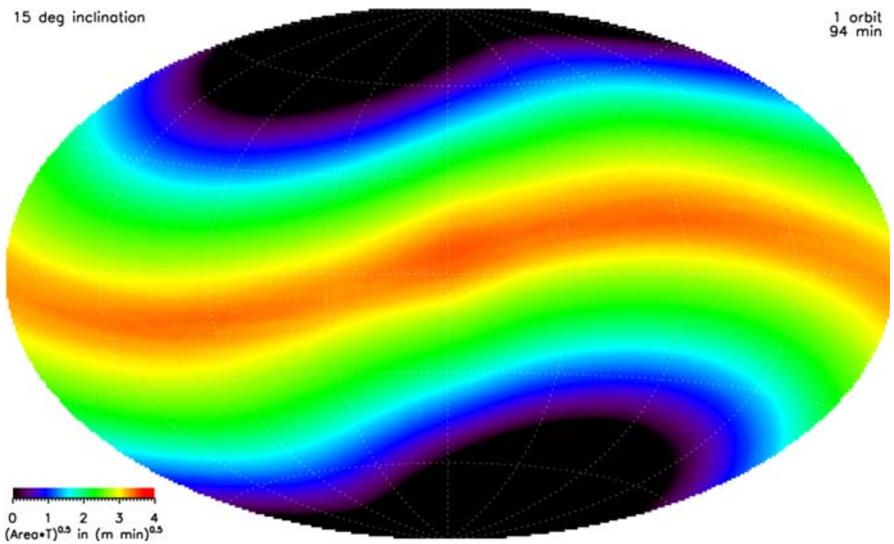
Coordinates:
RA, Dec (J2000) = 14h 24m 44s, +36d 19' 38"
l,b = 63d 41' 50", +68d 12' 37"
Radius (90.0%) = 6.1 arcmin

Candidate criteria satisfied:
Index 6: Non-simultaneous coincidence (S/N>4.0) over more than 2 spacecraft orbits

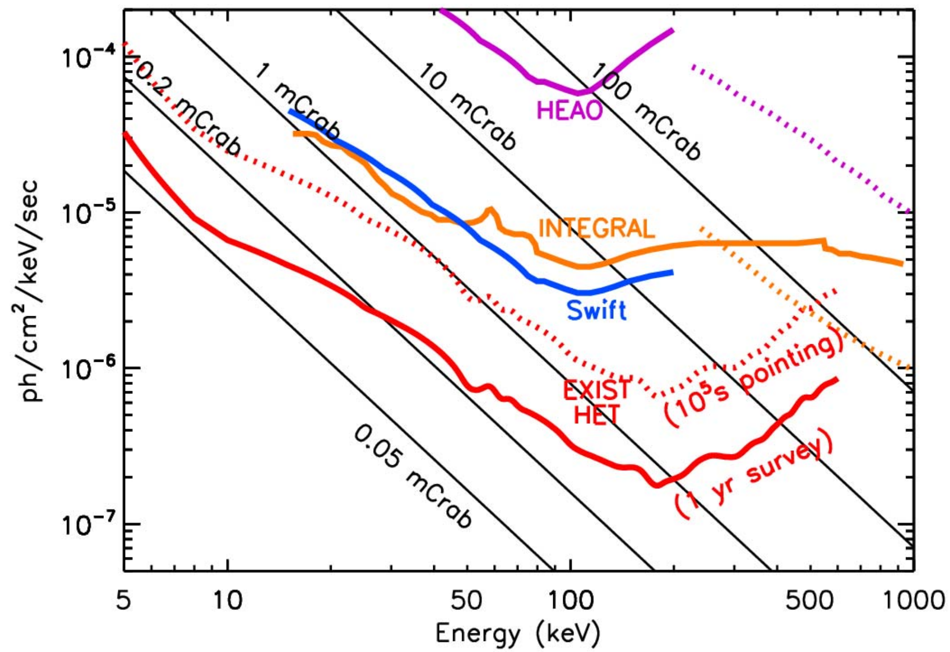
Local plot	Transient Catalog Matches	Blazar Catalog Matches			
		Avg. position (90%rad)		Ind. slews (99%rad)	
		real	random	real	random
	None	Multi-freq BZBJ1424+3615	0.008±0.089	Multi-freq BZBJ1424+3615	0.048±0.214

EXIST sky survey coverage and sensitivity

(5σ survey threshold, 1year of mission ops., **full-sky**; 15º orbit incl.)



EXIST-HET sky coverage over 1 orbit



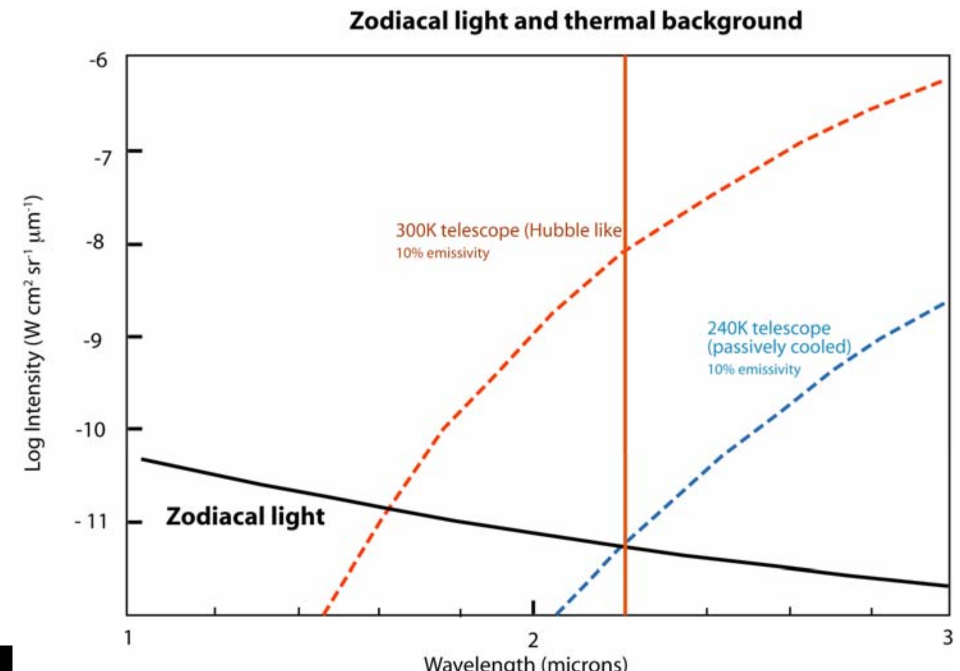
5σ in 1 yr sky survey flux sens. over band ΔE=E , with image psf 2' & pos. <20"

- **0.07mCrab = 7 x 10^{-13} cgs, *(~5-10X below Swift/BAT*) for HET (5-100 keV)**
- **~0.5mCrab = 1 x 10^{-11} cgs (*~20X below INTEGRAL/IBIS)* for HET (100-600 keV)**
- ***300-700 GRBs/yr (~6X Swift/BAT rate) and ~30,000 AGN: IRT redshifts for most!***
- ***unique* ~15% duty cycle coverage on any source, ~90% *full-sky every 3 hours!***

EXIST IRT: 0.3-2.2μm imaging & spectroscopy

- IRT mirror (primary and secondary) passively cooled to -30C (radiator) give zodiacal light limited backgrounds: *IRT could be ~3X faster than Keck at 2μm!*

- IRT based on space-qualified 1.1m telescope (ITT-*NextView*) and H2RG IR arrays with readout ASIC (developed for JWST-NIRSPEC)

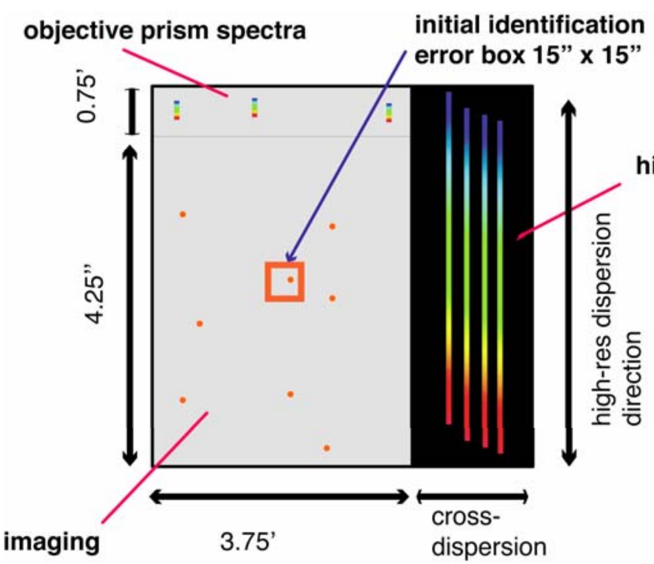


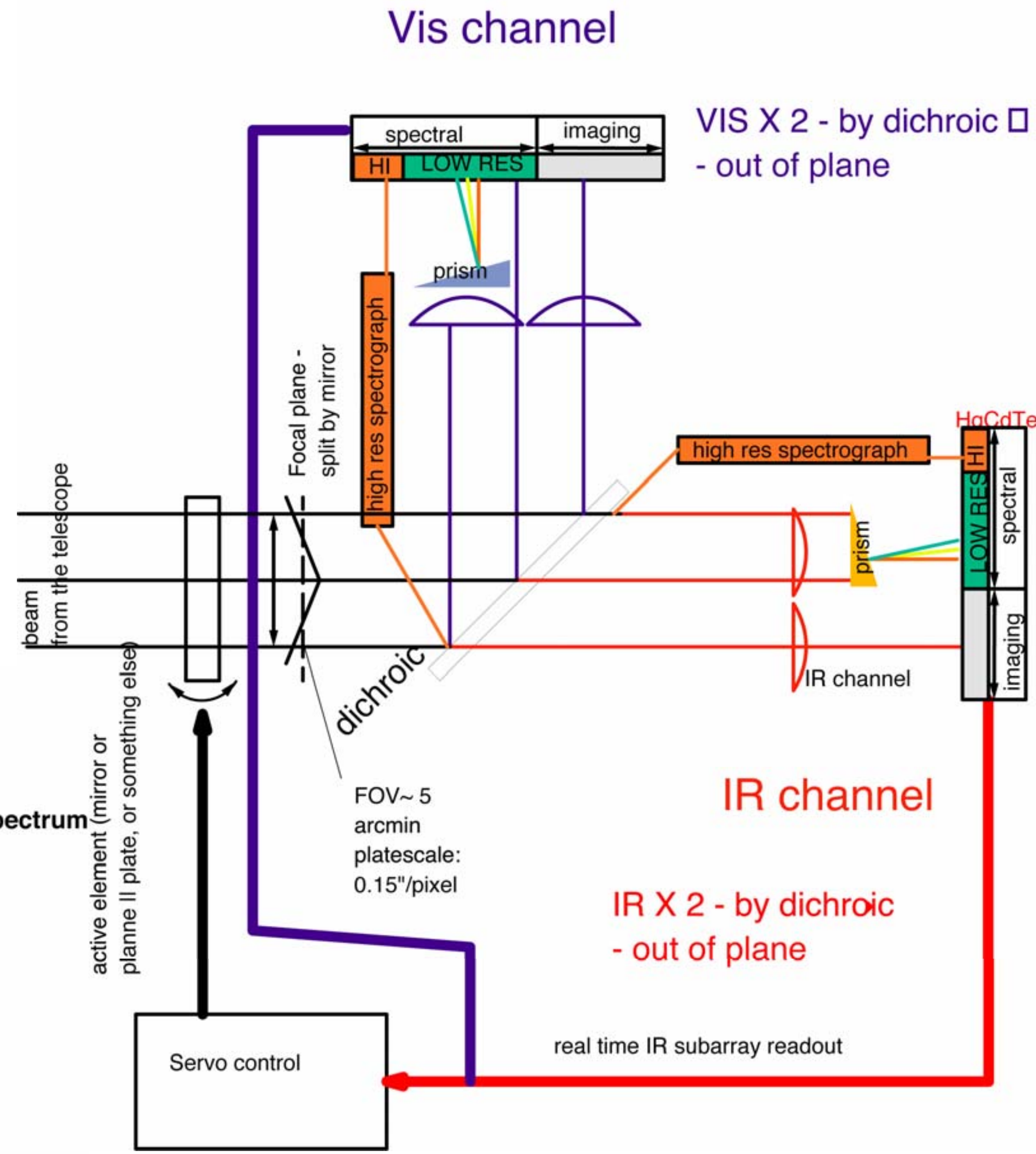
IR: HgCdTe +H2RG detectors (2K x 2K)
Vis: CMOS+H2RG (2K x 2K); pix size 0.15”

IRT instrument layout concept

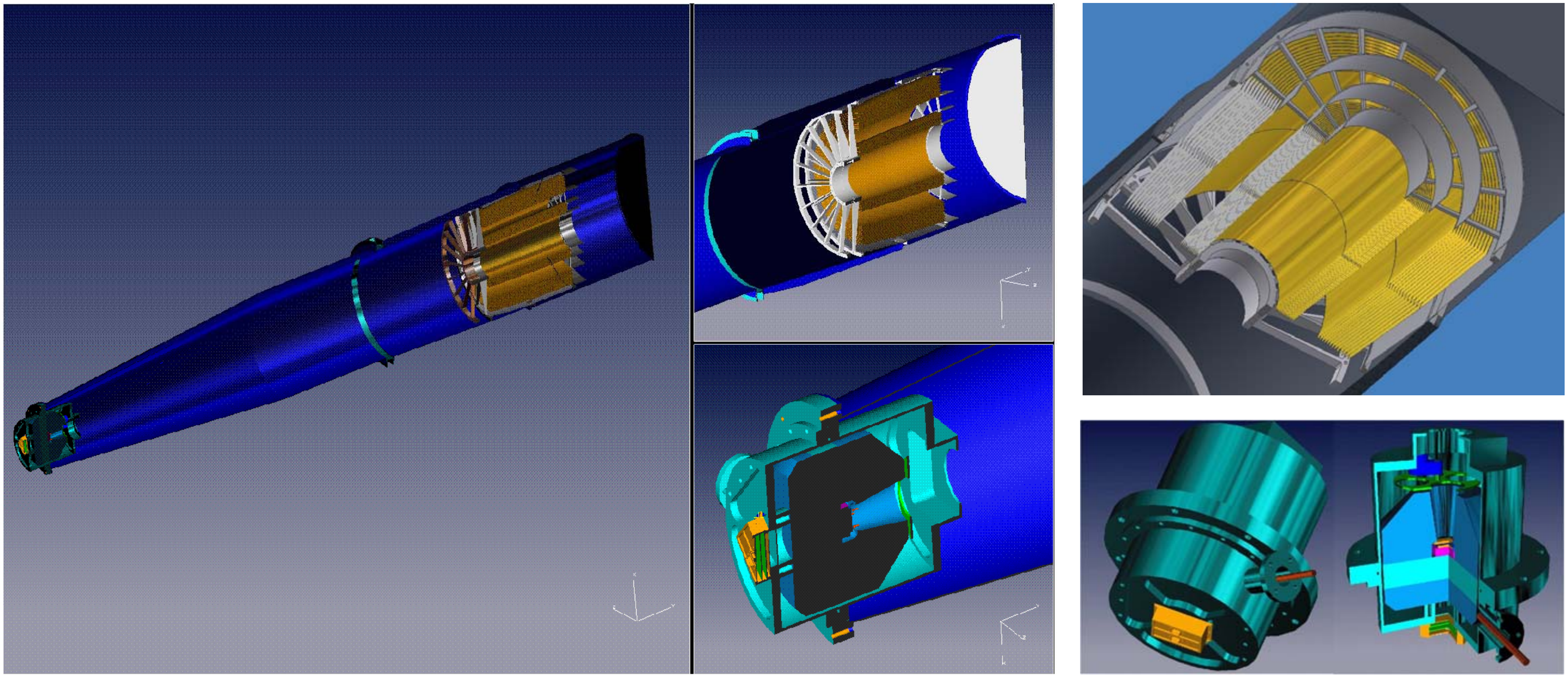
5’ x 5’ FOV on *both VIS & IR*:
- imaging: *2 bands in both VIS & IR*
- low res R~30 obj. prism
- high res R~3000 narrow slit

FOV layout



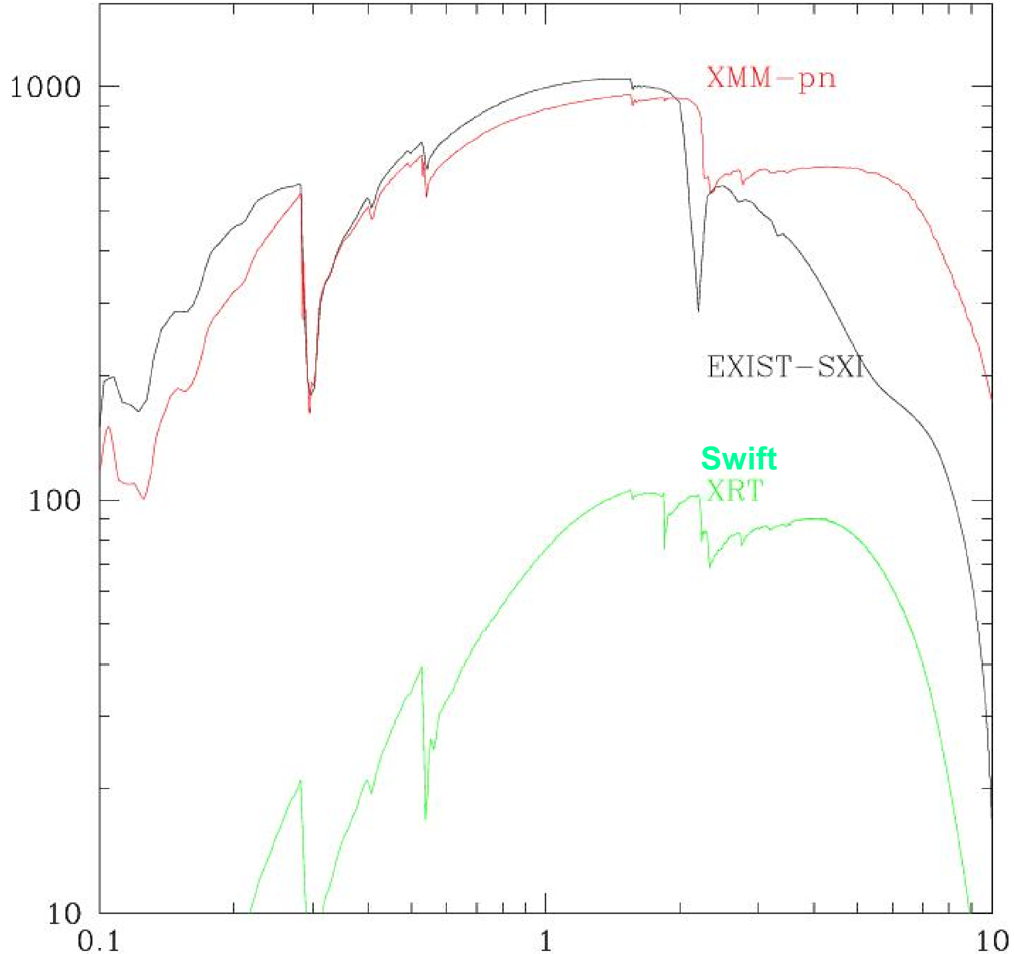


SXI: proposed from Italy/ASI (Rome, Milan, Brera Obs)



- Wolter I telescope: 26 Ni shells, 3.5m focal length, 60cm max. diam. shell
- 950 cm^2 at 2 keV & 120 cm^2 at 8 keV; 20' FoV; ≤15" PSF (HEW, on axis)
- 4 x 4 cm^2 CCD (1K x 1K; 2.3" pixels); *Sens.: 8 x 10^{-15} erg /(cm^2 s) in 10 ks*
- 40 kbs telemetry; 1msec temporal resol. (timing mode); -110C op. temp.

SXI effective area (proposed)



- EXIST-SXI comparable to XMM-pn (single telescope) in sensitivity

EXIST mission operations

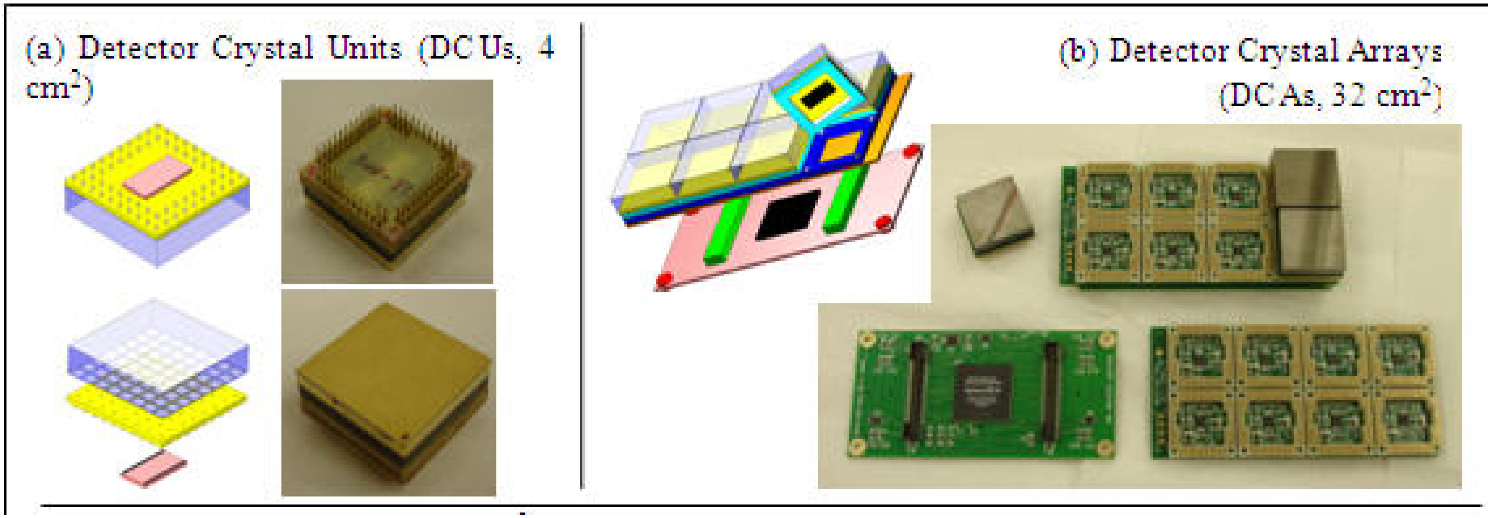
- *Very simple operations*: nominal continuous scan+IRT sun angle constraints → *~90% full-sky coverage every 2 orbits*
- ~100 sec slew to GRB positions (~2-3/day) for IRT spectra and *redshifts on board*
- Full-sky **scanning** survey for 2y and ~1500 GRB redshifts; then 3y HET/IRT **pointings** on ~20,000 survey AGN for redshifts and timing while continuing GRB survey and followup IRT spectra on additional ~2000 GRBs/hosts and continuing survey for transients (LSST)
- 5y mission life required to accumulate large samples of *high-z GRBs, rare survey objects (e.g. Type 2 QSOs) and rare transients (e.g. TDEs)*

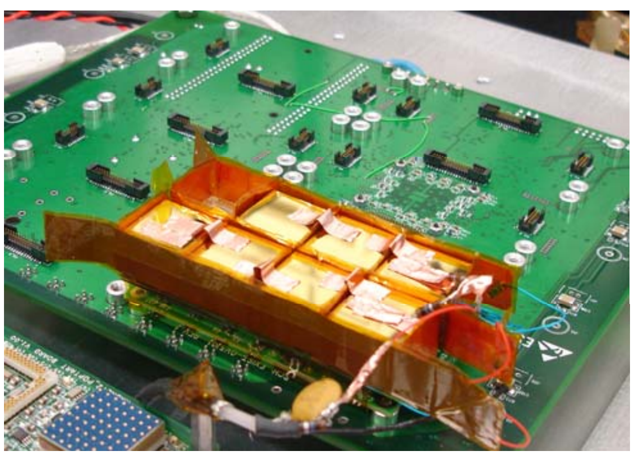
EXIST mission concept: Summary after GSFC IDL and MDL

x	Mass (kg, with contingency)	Power (W, with contingency)	Data (Mbs)
HET	2171	726	5
IRT	704	249	1
SXI	240	150	0.05
S/C	2052	1027	0.01
Other	Instr. mounting struct. 380	.	
	Fuel (de-orbit) 547		
Total	6094	2152	6

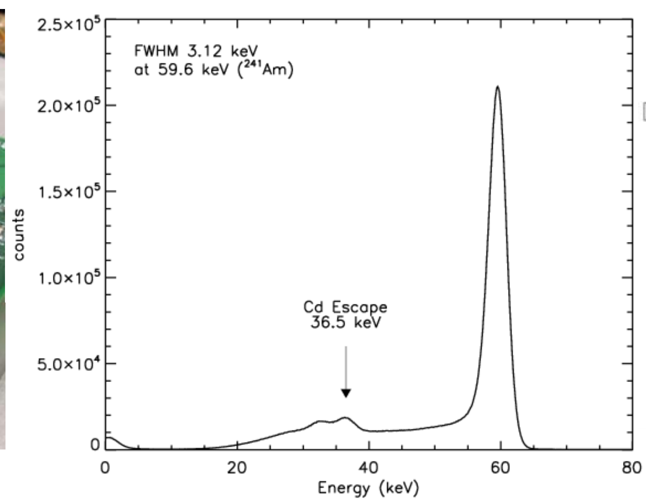
Data rate: 6Mbs ; TDRSS 6 dumps /day + TDRSS prompt for GRBs
S/C Pointing stability: ~1” (but <0.05” onboard w/ IRT tilt mirror Vis/IR tracking)
Aspect (star cameras/IRT): 3” (for HET); 0.03” for IRT (Vis/IR) from IRT images

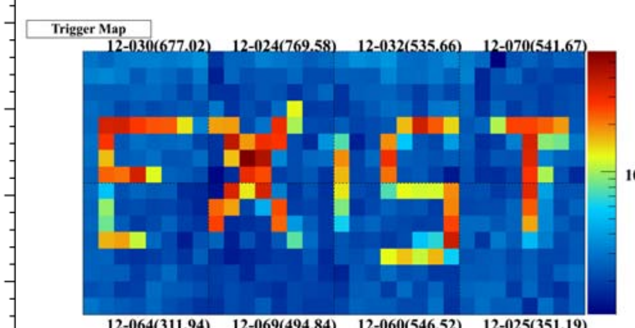
HET Detector develoment: Building a large area CZT detector/telescope prototype for balloon-borne *ProtoEXIST1*





Test flight DCA board (1 of 8)





60keV spectrum & DCA image (2.5mm pixels) through Pb mask

EXIST Team for ASMC study

- *Lead Institutions:* **CfA** (Grindlay, PI) and **GSFC** (Gehrels, co-PI)
- *Co-I Institutions for SWG/TWG leads:* Berkeley (Bloom, *GRBs*), GSFC (Mosely, *IRT*; Skinner, *HETimaging*), CfA (Hong, *HET;* Soderberg, *Transients*; Fabbiano, *MODA*), MSFC (Fishman, *SC-Mission*), Yale (Coppi, Urry, *AGN*)
- *Industry Collaborators:* General Dynamics (*S/C*), ITT (*IRT*)
- *Co-I Institutions for Study (many members):* Caltech, Clemson, GSFC, MSFC, SAO, Washington U., more
- *International partner Institutions:* **Italy** (Rome, Milan, Bologna, Brera Obs.); also, Greece, Israel, Japan, Netherlands, UK

See *EXIST* webpages at ***http://exist.gsfc.nasa.gov/***

EXIST Summary and Prospects

- *Highest z stellar universe only measured via GRBs*: >6X *Swift* rate; **redshifts on board** for ~3000 GRBs can constrain cosmic structure before Quasars turn on
- Both obscured and dormant SMBHs best studied with HX imager: *complete BH census/evolution & accretion luminosity of universe*
- Broad band (~5 – 600 keV), large area & FoV are unique for ***EXIST***: image half-sky each orbit. ALL sources observed with ≥15% continuous coverage; ***EXIST*** *opens the extreme temporal universe; complements LSST as multi-wavelength Observatory*
- *ProtoEXIST1* balloon flight in 2009, *ProtoEXIST2* in 2010 to establish readiness
- ***EXIST*** Technology & costs under study; TRL-6 for HET but TRL-7 for IRT. Reduced mass & cost mission design study underway for ASMC & Decadal Survey!
- ***EXIST*** ***could*** **launch** in ~2017-18 window (after JDEM?) *if* 2012-13 start

  See *EXIST* website (***http://EXIST.gsfc.nasa.gov)*** for Study & **Team**