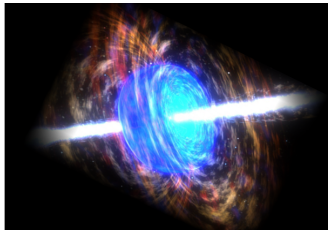
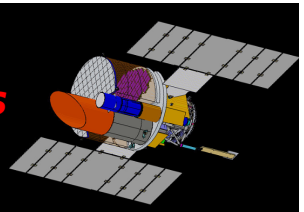


EXIST: Surveying the birth and evolution of Black Holes



Near IR spectra of GRBs and the First Stars to *EXIST*

Surveying Black Holes: from the Early Universe to Local Galaxies

Josh Grindlay

Wide-field Hard X-ray imaging & followup soft X-ray imaging and ***IRT***:

High-z GRBs, obscured/dormant AGN & the Transient Universe

Submitted to ASTRO2010 as a proposed joint US-Italy mission

A personal Tribute to (& lessons from) Giovanni…

- From TeV gamma-rays – to X-rays & Balloons – to IR imaging/spectra

Moving to high redshifts and the Early Universe

- From the lab – with students – to observing in new wavelength regimes…

The promise of new astrophysics compels all

- Through it all, caring and consideration, with conviction…

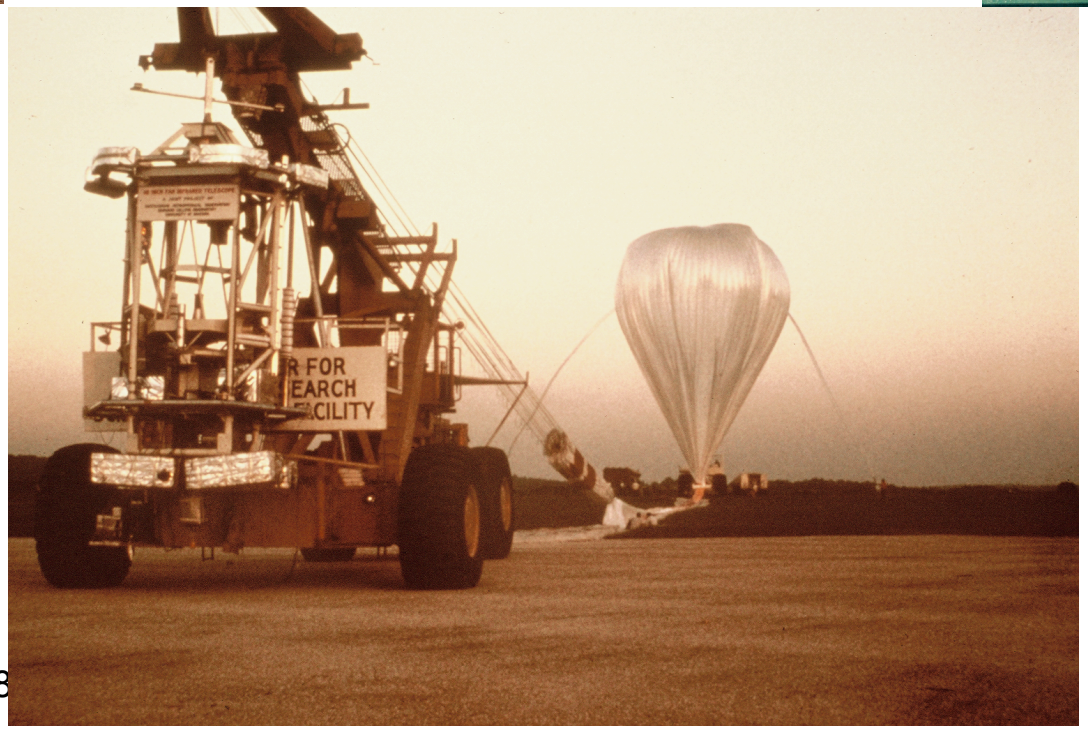
We owe Giovanni our thanks, & congratulations

1970s-90s IRT Balloon launches: Palestine, Ft. Sumner, NM,

G. Fazio's Far IR 1m IR Telescope:

- 19 flights, 1972-1988
- 6 Ph.D. theses, 69papers
- "launched" Giovanni to PI IRT on *Spacelab* and IRAC on *SIRTF*
- "launched" Ned Wright to PI on *WISE*

….and more…



With typical gondola/payload recoveries…

The 1-m IRT waiting for recovery…

Which encouraged future Hard X-ray Balloon Payloads…

Harvard Team (left) & MSFC collaborators with EXITE2 (now ProtoEXIST) Gondola (note similarity to the 1m IRT gondola) in Ft. Sumner, NM, prior to a good 2001 flight…

What is *EXIST?*

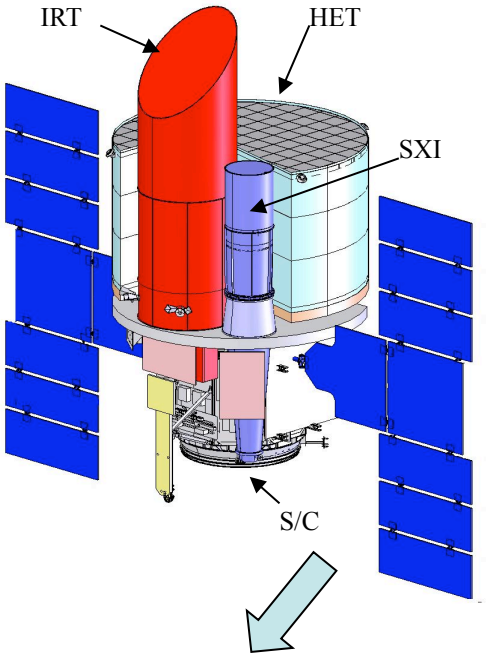
- A *Medium Class Mission* (~$800M) to conduct the most sensitive full-sky survey for ***Black Holes*** on all scales (stellar to supermassive)

- A mission for the ***Astrophysics Strategic Mission Concept (ASMC)*** *Study* program, in preparation for the current 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 with 10X higher sensitivity than any previous or planned HX survey…

- *Plus* a 1.1m **optical-IR telescope** (a new ***IRT) – Fazio-inspired –*** and contributed (Italy) **soft X-ray imaging (0.1-10keV) telescope** (**SXI**) to obtain identifications, redshifts and diagnostics of black holes, transients & extreme objects for followup study by **Fermi, IXO, JWST, LSST &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 at ~zenith ***scans*** at orbital rate & ***points*** **IRT/XRT/HET** to GRBs within ~100s

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)

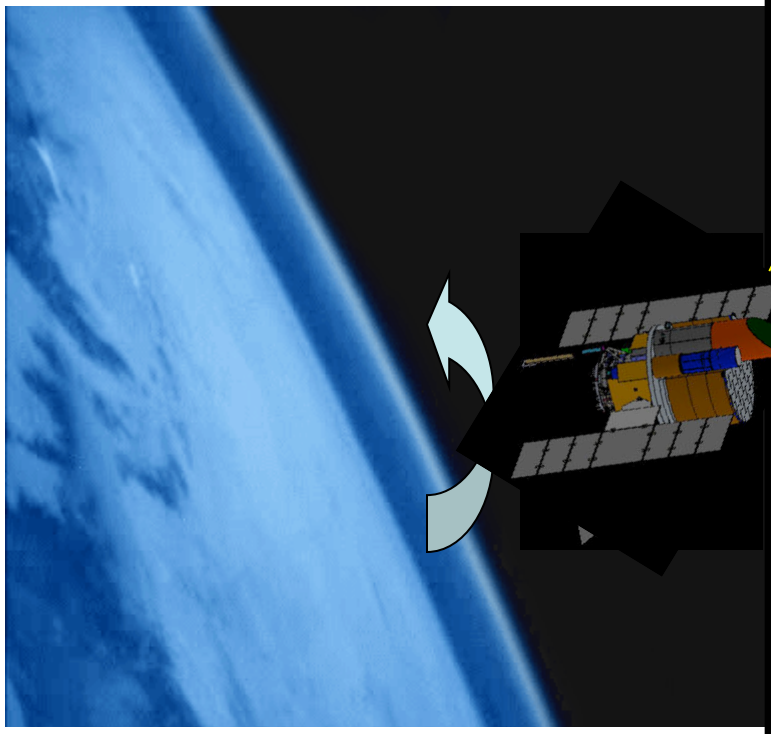
IRT: 1.1m; cooled (-30C) (dichroic: 0.3-0.9μm (HyViSI) and 0.9–2.3 μm (NIRSPEC)

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

The *New EXIST* mission:

- ***2y full sky survey:*** ±20deg *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

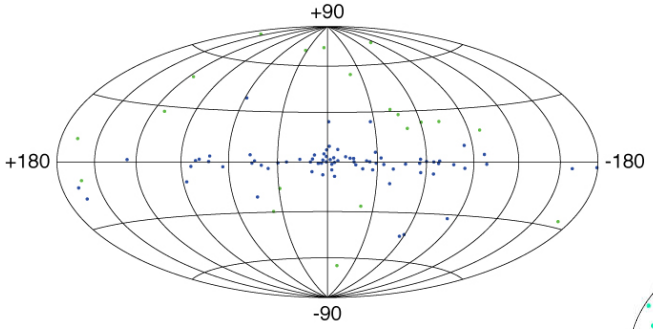
- **Hard X-ray (10-600 keV) sky not yet surveyed to ROSAT sensitivity. *EXIST* would be ~10X more sensitive than *Swift* or *INTEGRAL* and cover full sky**

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

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

2000 Hard X-ray Sky

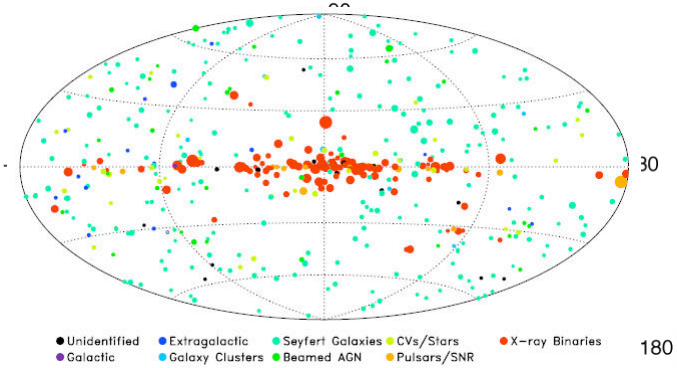
HEAO-1, BeppoSAX



~100 sources

2010 Hard X-ray Sky

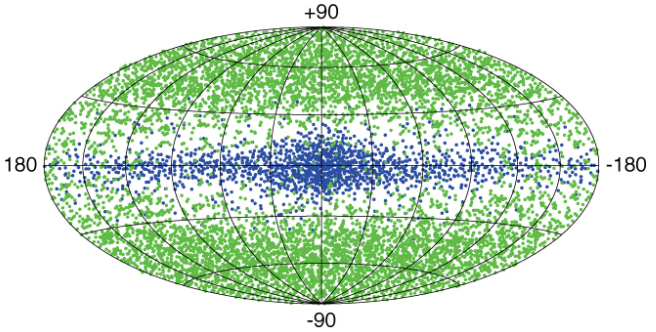
Swift (& INTEGRAL)



~600 sources

2017(?) Hard X-ray Sky

EXIST



~40,000 sources

Primary Science Objectives for *EXIST*

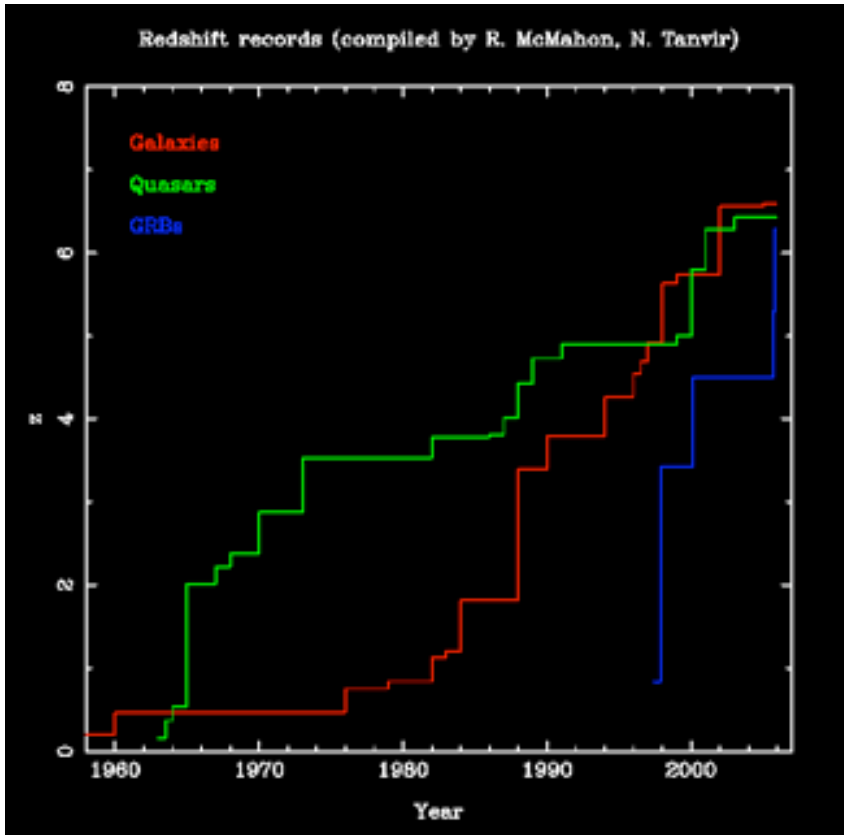
(to survey and study Black Holes on all scales: stellar to supermassive)

• **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 & ***reionization at redshifts z >7-10***

• **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

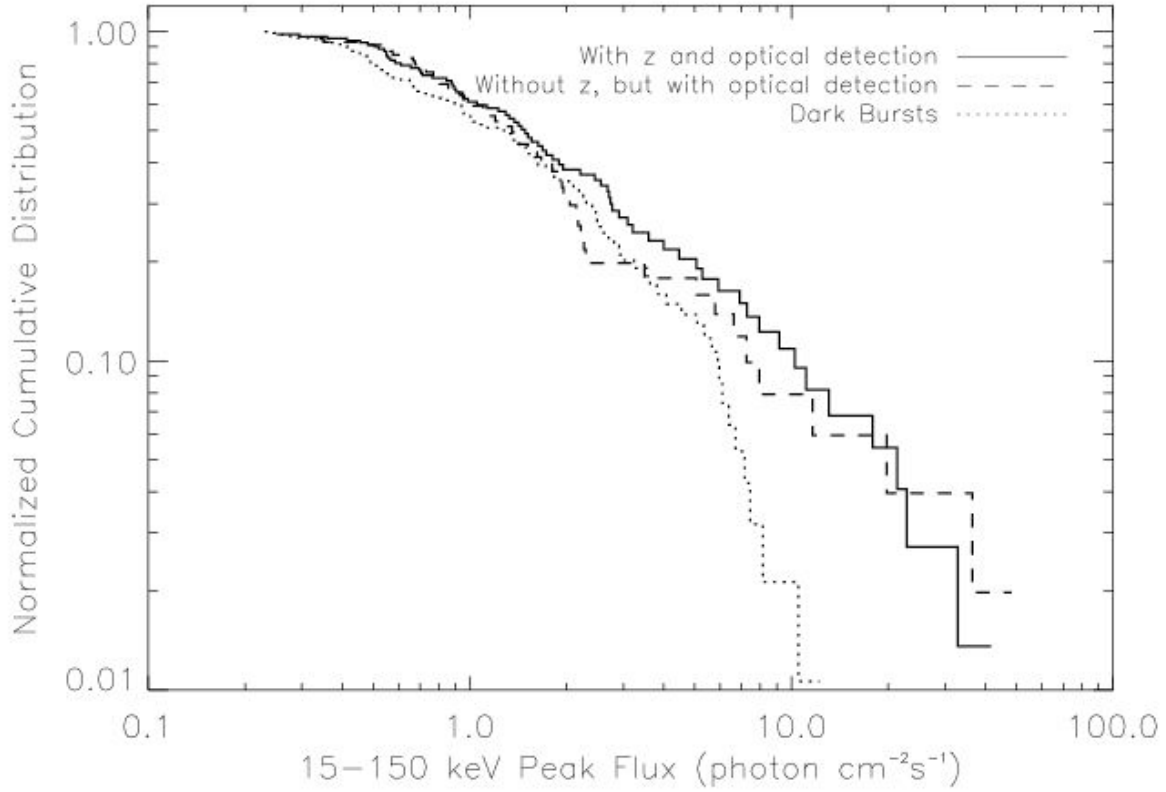
GRBs must preceed QSOs: highest-z stellar Probes



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

- *Swift* GRBs at z = 6.3, 6.7 and recent record GRB090423 at z = 8.2! *GRBs **are 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 host ISM & IGM gas. *Measure galactic structure (vs. z) back to epoch of re-ionization (EOR)*

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



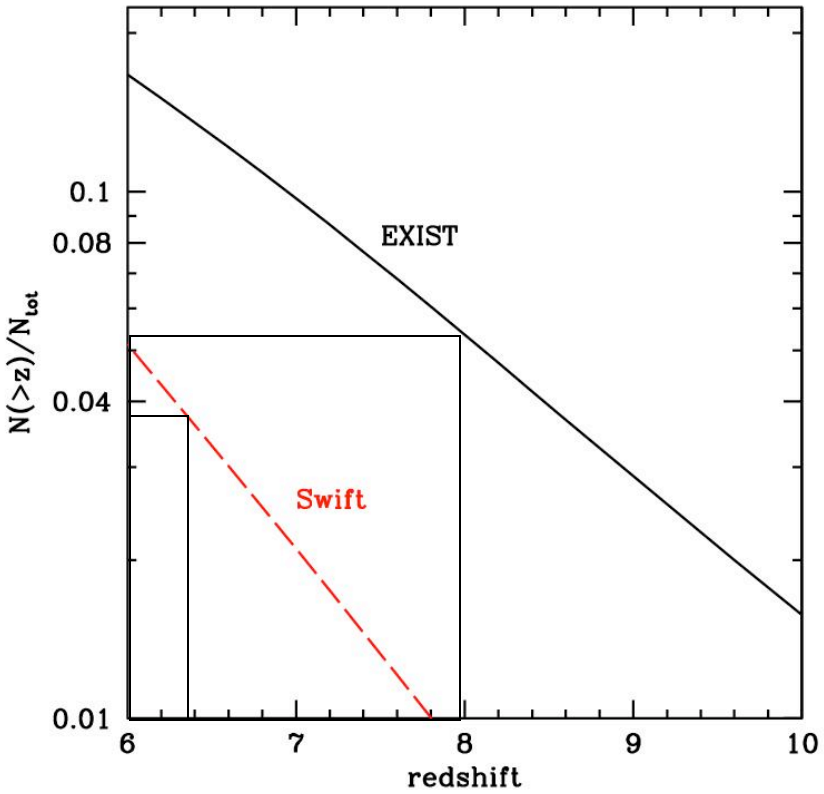
(Dai 2008, arXiv:0812.4466)

GRB090423 suggests *many (but not all) "Dark" GRBs may be at z >7 since sensitive JHK (i.e. J >17.5) generally NOT available in first 20min*

GRB090423 ID found at K~17.5 @ T ~20min (so probably J >18.5)
(Tanvir et al GCN 9202)

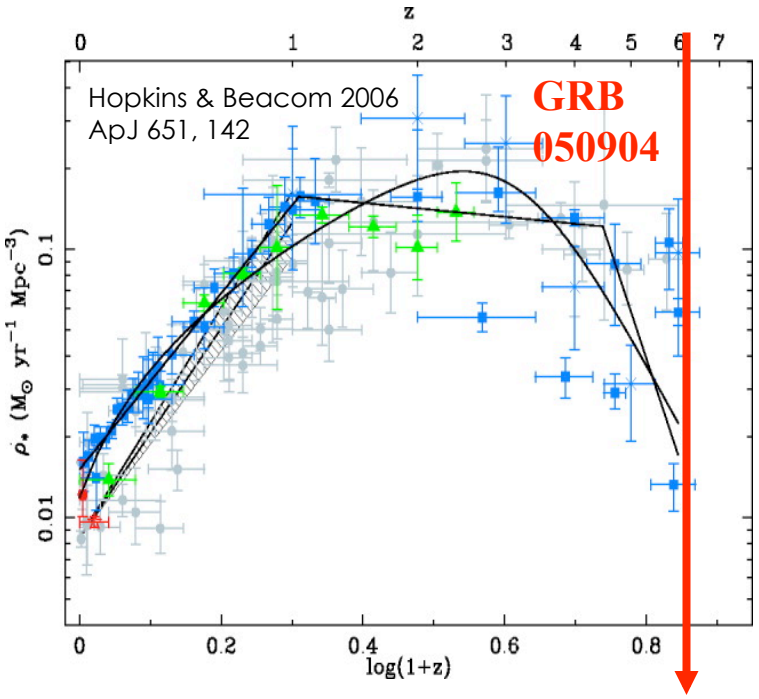
- Hard X-rays *insensitive to reddening* so optically dark long GRBs should have same logN-logP as Dark GRBs
- >99.8% likely that Dark GRBs are *different* – optical cutoff by Ly-breaks since high-z and logN-logP cutoff by high-z time dilation or GRB luminosity function

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



Predicted *fractional* GRB rates *above* z vs. z for *EXIST* vs. Swift/BAT based on Salvaterra (2009). *EXIST will detect ~600 GRBs/y and thus ~90/y at Z > 6 and thus ~0.055 x 600 = 33 at z >8 per year!*

Swift detects ~100 GRBs/y and now ~450 GRBs. It Should detect ~0.04 x 450 = 18 at z >6 and has now detected 3, suggesting most are missed.

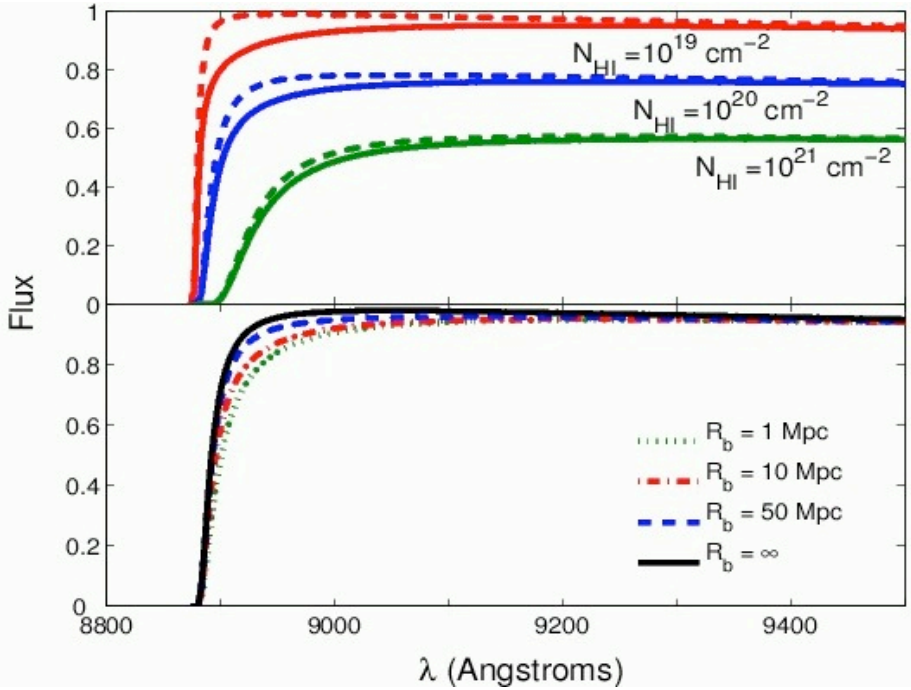


EXIST GRBs vs. z will probe the star formation rate (SFR) vs. z at highest redshifts, and constrain/measure Pop III.

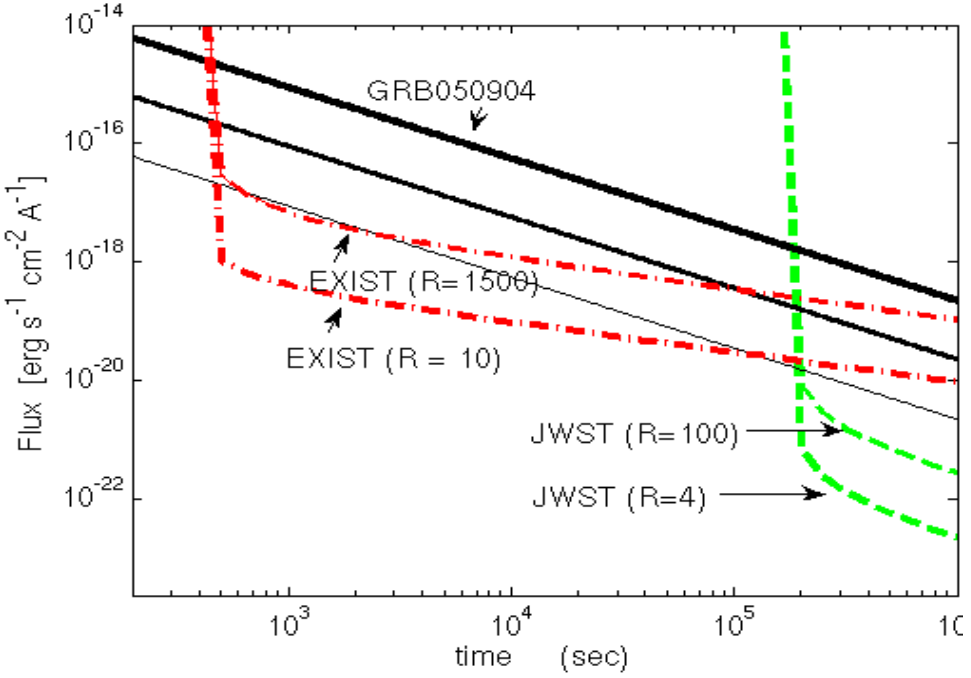
EXIST will probe:

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 (McQuinn et al 2008)



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

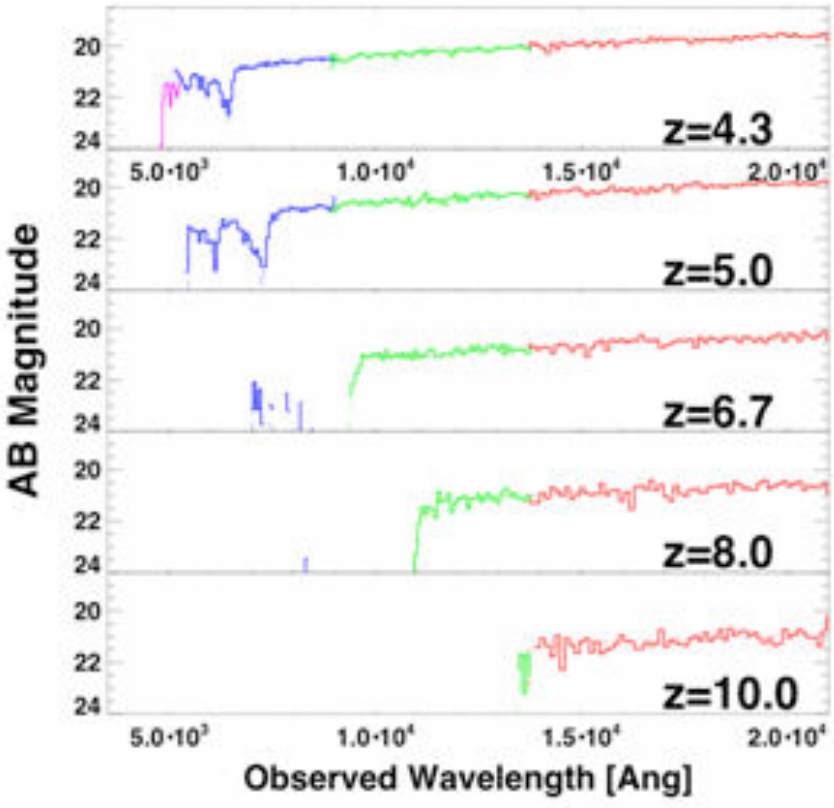
- **IRT spectra (R ~3000) for AB(H) ~18-20 in 2000sec exp. *simultaneously* for optical (0.3-0.9μm) and IR (0.9-2.1 μm): Ly profiles for EOR studies of high-z IGM**

- **Simulations: > 450 GRBs/yr *of EXIST GRBs would have z measured* ; and ~40/yr at z >7. Over 5y mission, expect N(z>8) ~ 50-100 EOR sight-lines measured.**

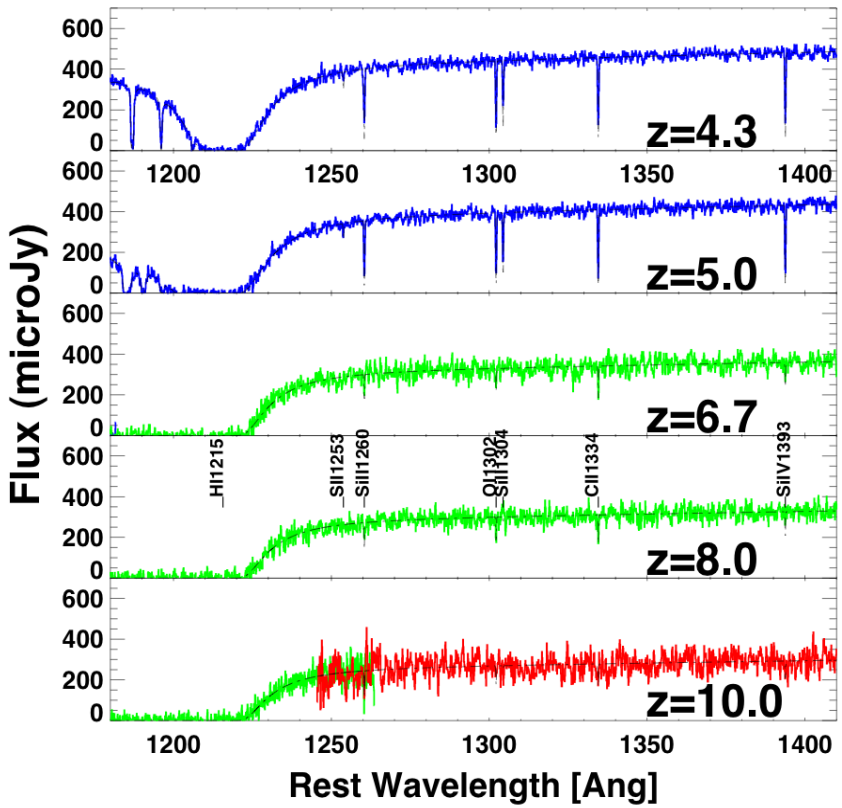
Simulated Ly-breaks for EXIST ***IRT*** vs. z (*R = 3000, T = 2000sec*)

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

R = 30 Grism, imaging or slit, for AB(H) > 20



R = 3000 long slit (4"), for AB(H) <20



Assumed model (which *IRT* tests!):

AB(H) = 15.5 at T =200s, then GRB lightcurve decays: F ~ T^{-1} ν^{-1} Log(NH) = 20 in GRB host

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

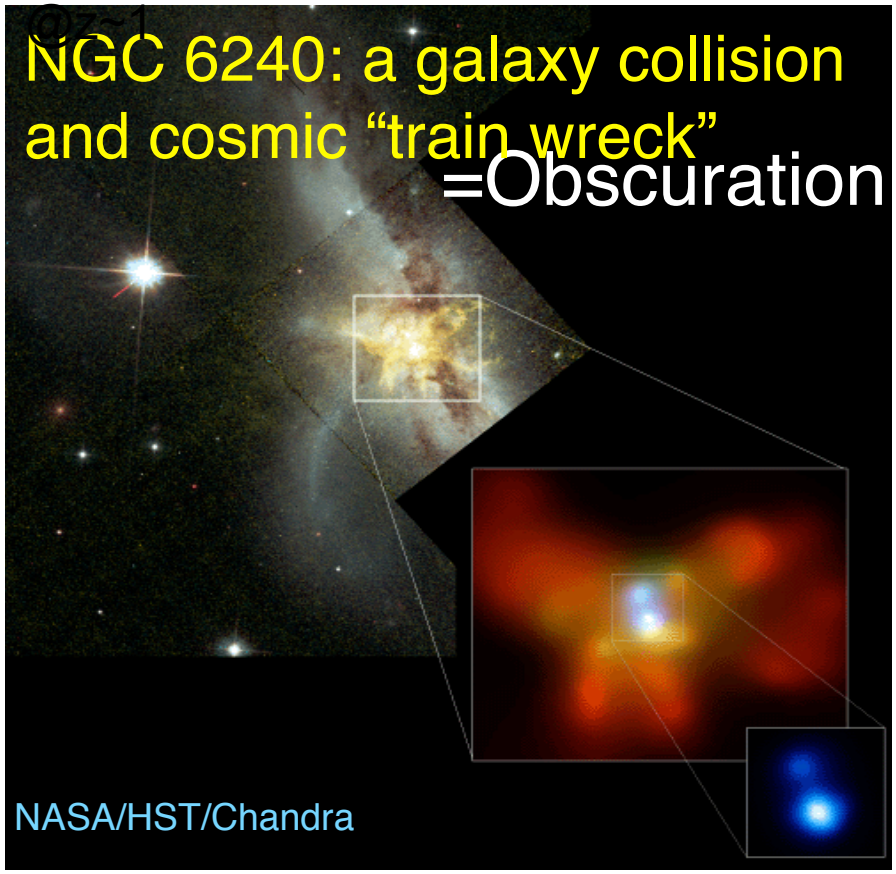
Simulated spectra shown in IRT bands: 0.3 – 0.9μm, 0.52 – 0.9μm, **0.9 – 1.38μm,** **1.38 – 2.1μm**

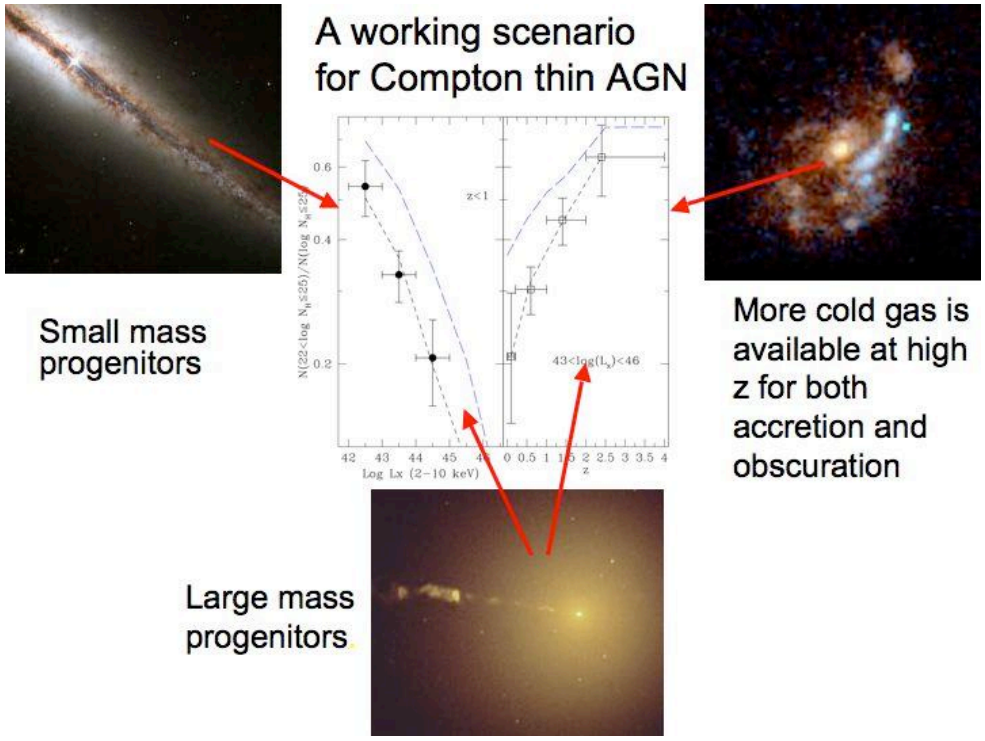
EOR & Fe/H can be measured vs. z!

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***

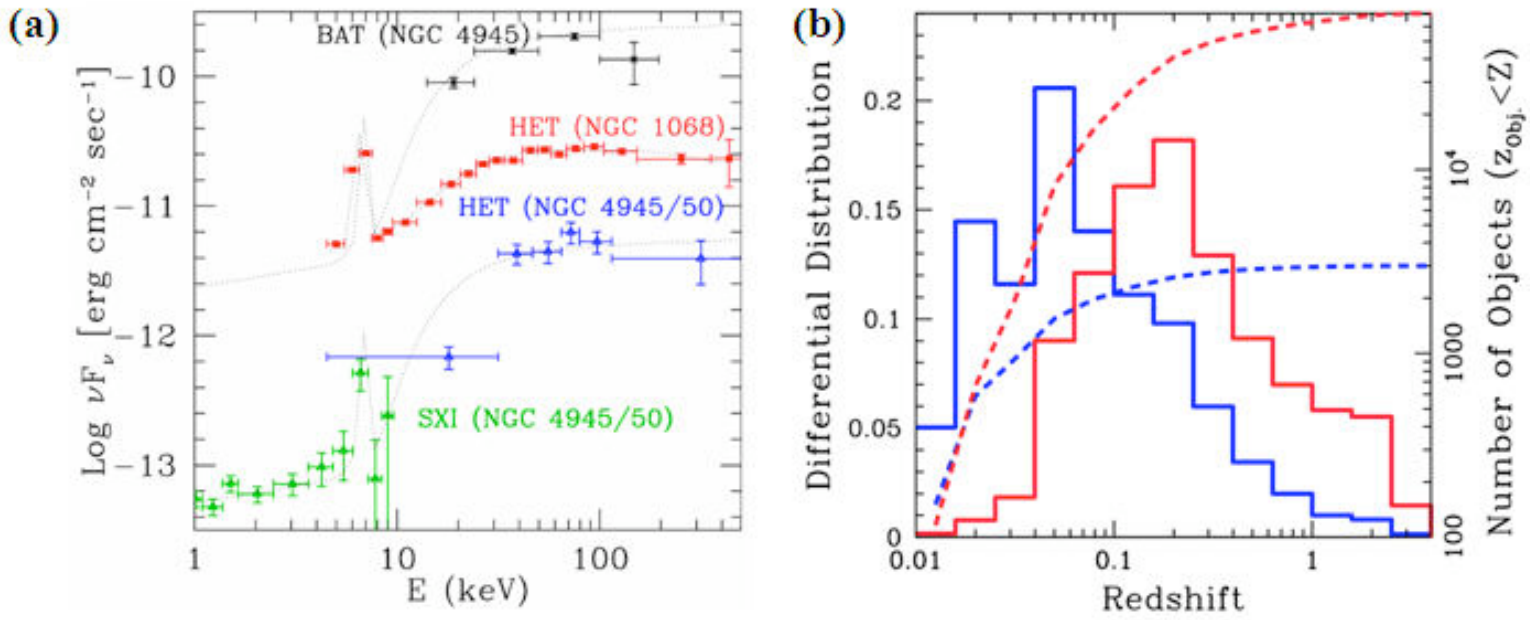
• ***EXIST*** best suited to discover rare ***Type 2 QSOs*** at z ≤3 and study Type 2s vs. SFGs





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

EXIST detects the missing *Compton Thick AGN*

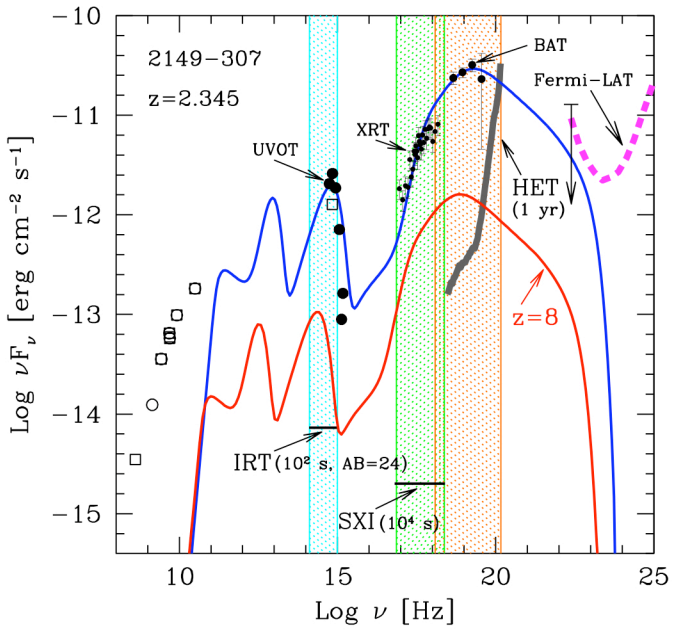


- Less than 20 Compton-thick AGN measured at >10 keV (e.g. NGC4945 & NGC1068). ***EXIST*** would detect objects 50X fainter (Fig. (a))

- Large sample of Compton **THICK** (~10,000?) vs. **THIN** **AGN** (~30,000) in Fig. (b) will also be *only method to find RARE Type 2 QSOs out z ~3*

EXIST could extend Blazar surveys to z >4-8

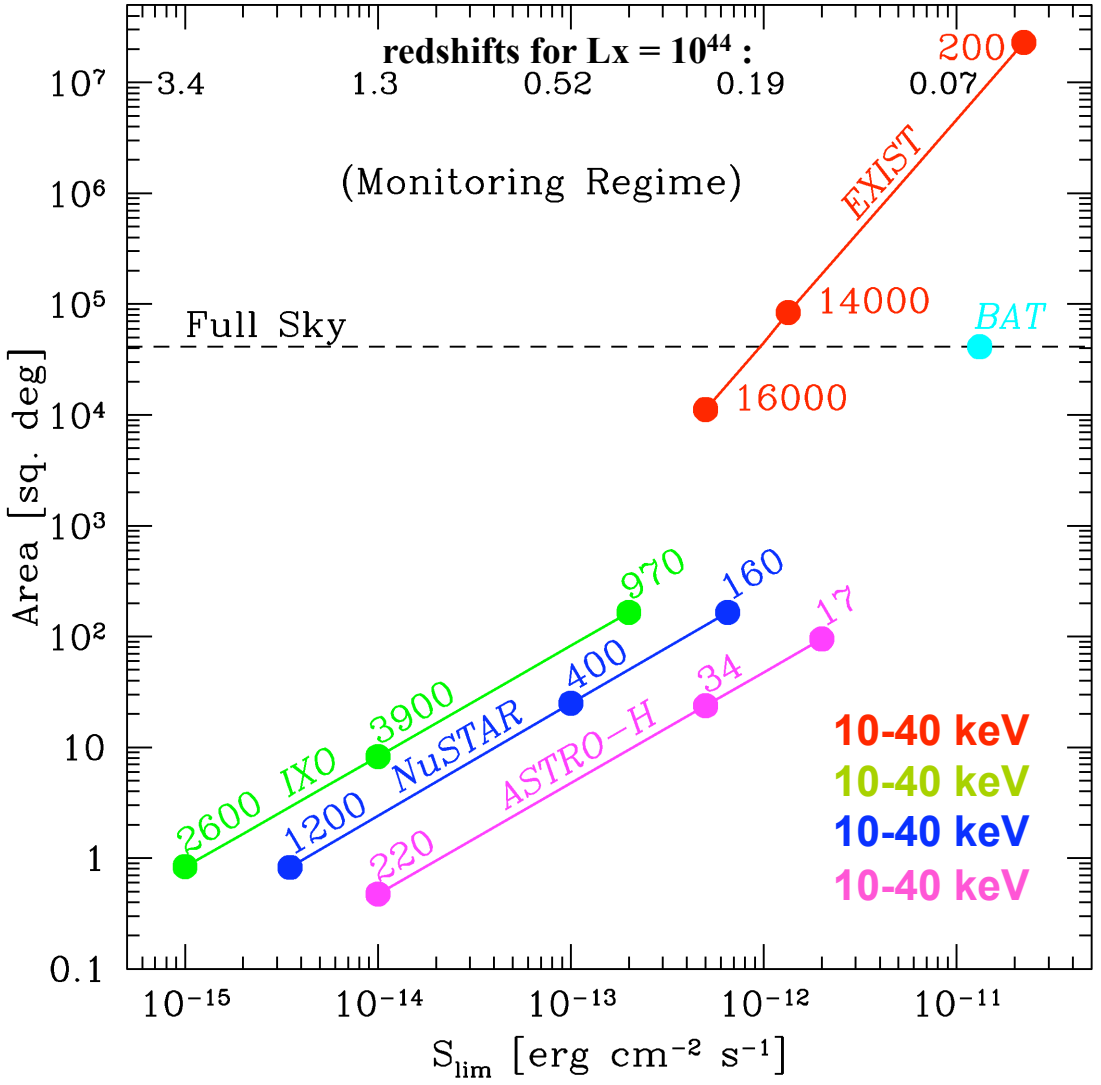
- Blazars are the AGN analog of GRBs: persistent, extreme-beamed and exceptionally luminous and variable
- Understanding their formation and evolution requires deep full sky samples with sensitivity to rapid variability
- ***EXIST*** could detect the Blazar 2129-307 detected by Swift/BAT, XRT, UVOT (see Fig.) out to z ~8.
- Sensitivity for detection and variability study with ***EXIST***/HET exceeds Fermi/LAT



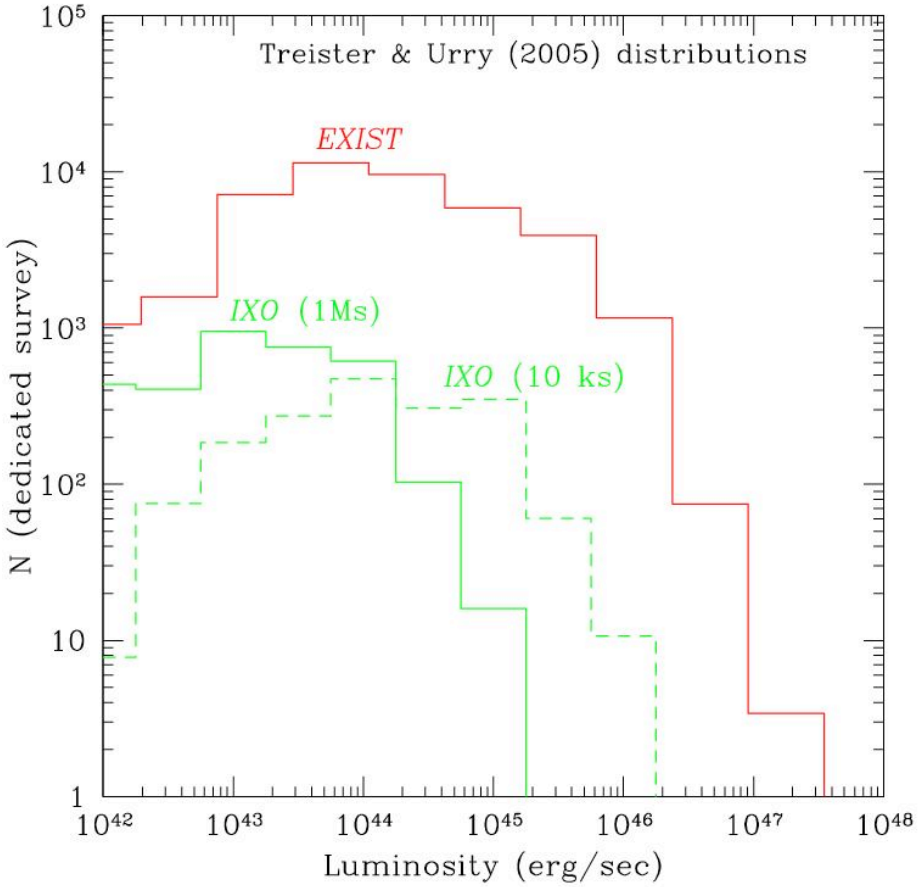
IRT and **SXI** sensitivities allow short observations during **HET** survey or pointings. ***IRT*** measures redshifts directly for Blazar survey

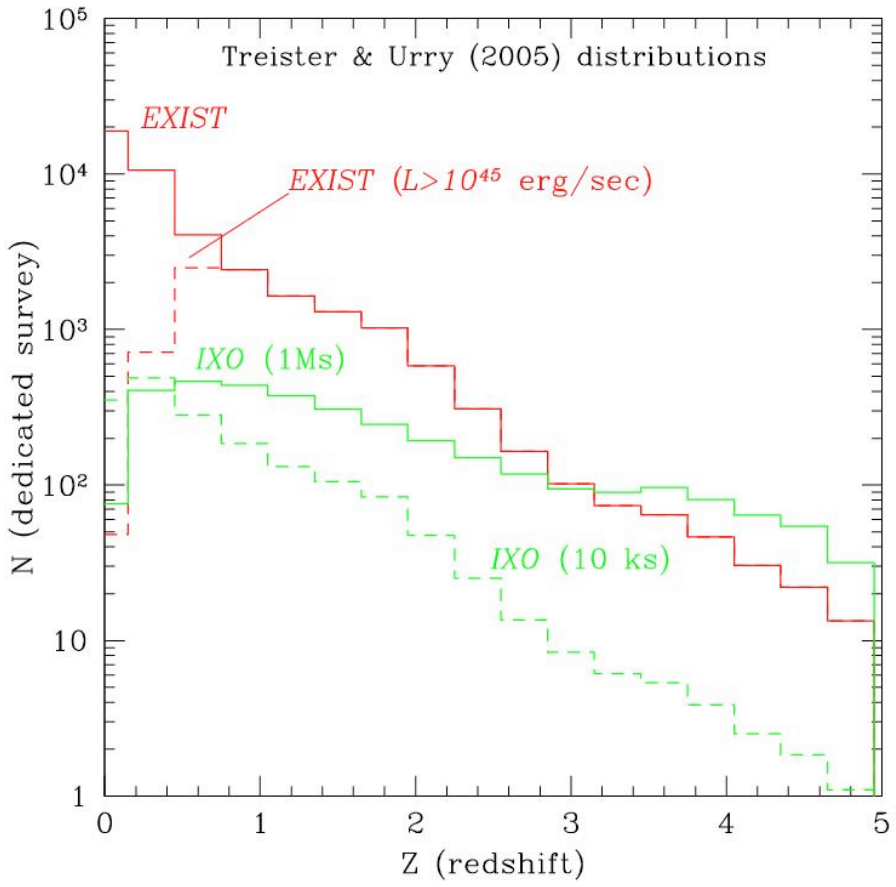
EXIST AGN surveys vs. IXO, Astro-H and NuSTAR

- Compare *hypothetical* pure 2yr pointing survey (2/3 of time) for IXO, NuSTAR, & Astro-H for T_{exp} ≥10ksec vs. ***EXIST*** scanning survey
- ***EXIST*** complements HX focusing (deeper) missions with *much larger samples*
- ***EXIST*** alone detects rare classes of objects (Type 2 QSOs; extreme Blazars
- ***EXIST*** 5y mission survey reaches S_{lim} ~4 x 10^{-13} cgs ***full sky*** for ~60,000 sources



EXIST survey probes unique Lx, z distributions





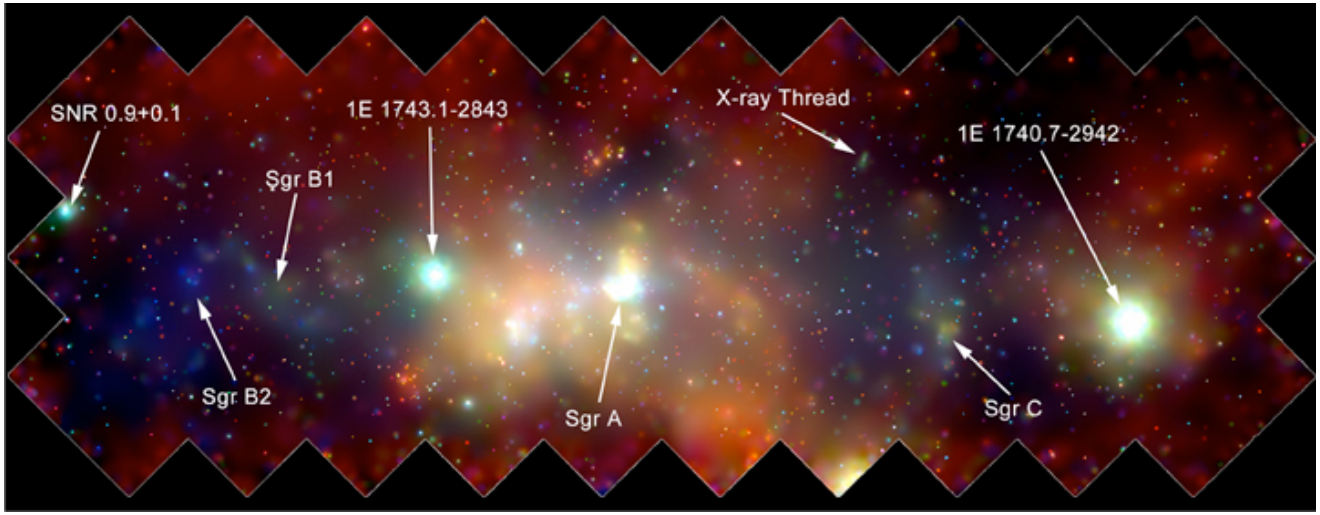
For Lx ≥10^{43} and z ≤3, the 2y scanning survey at 10-40 keV with ***EXIST*** achieves better ***AGN statistics*** in the Lx, z distribution than any proposed focusing mission

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

- ***EXIST*** detects ***all*** bright stellar BHs in transients (Lx(>10 keV) ~$10^{36\text{-}38}$ 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



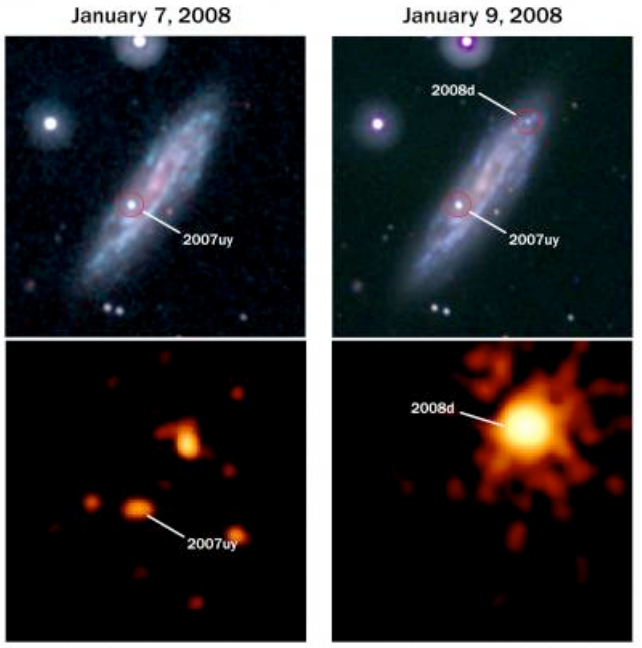
Chandra view of central Bulge (~ 2° x 1°)

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.)



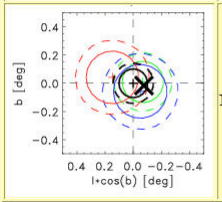
Scientists had planned on studying Supernova 2007uy in the galaxy NGC2770, which was already several weeks old when seen in this visual, ultraviolet image (upper left) taken on Jan. 7, 2008, by NASA's Swift satellite. A close-up, X-ray image of that supernova is beneath.

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.

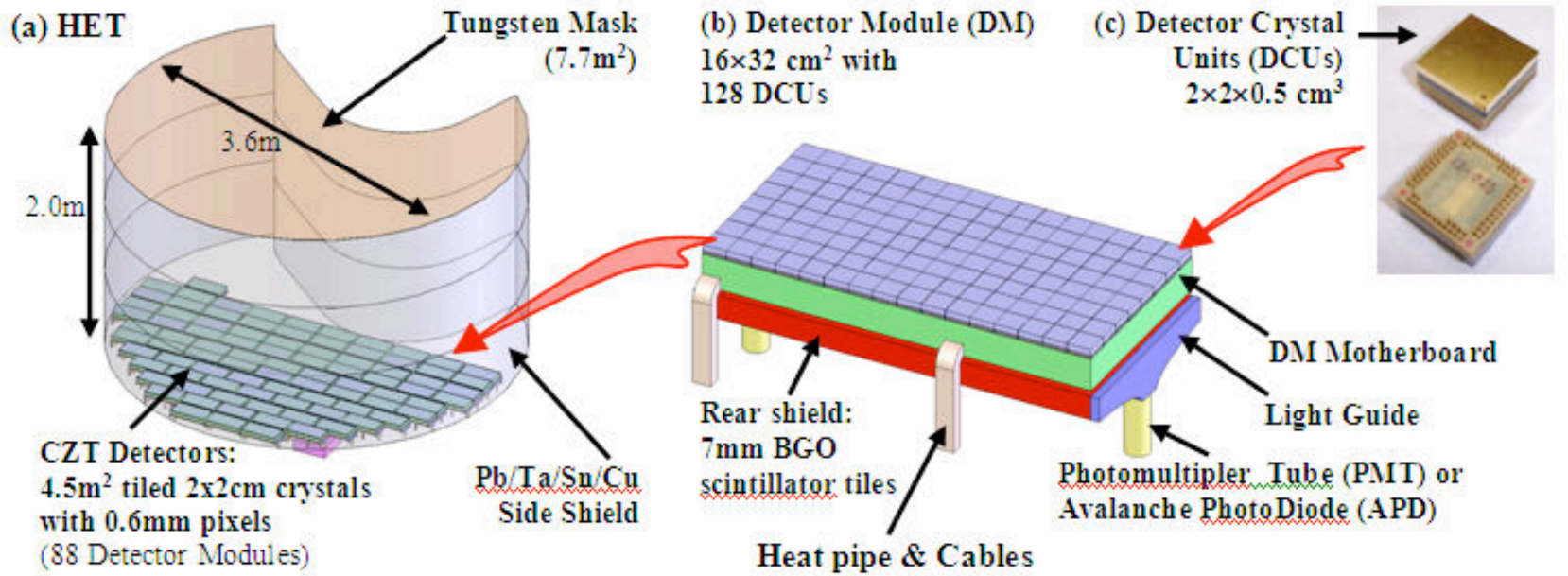
Candidate source: BATSS_J1425+363

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

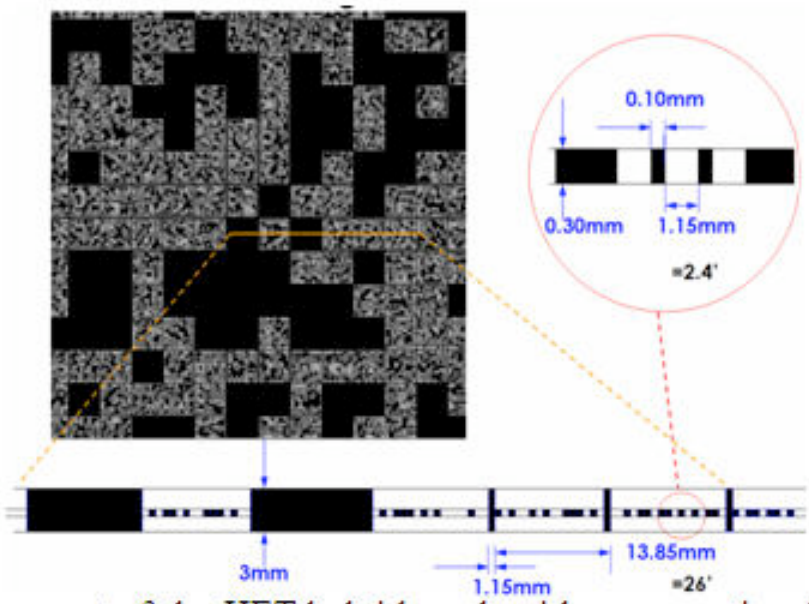
Local plot	Transient Catalog Matches	Blazar Catalog Matches			
		Avg. position (90%rad)		Ind. slews (99%rad)	
		real	random	real	random
	None	Multi-freq BZBJ1424+3615	0.008±0.089	Multi-freq BZBJ1424+3615	0.048±0.214

High Energy Telescope (HET) Detector Design



(a) The HET design overview and the CZT detector plane consisting of (b) Detector Modules (DMs), which in turn consist of (c) Detector Crystal Units (DCUs).

HET coded mask design and Instrument Summaruy



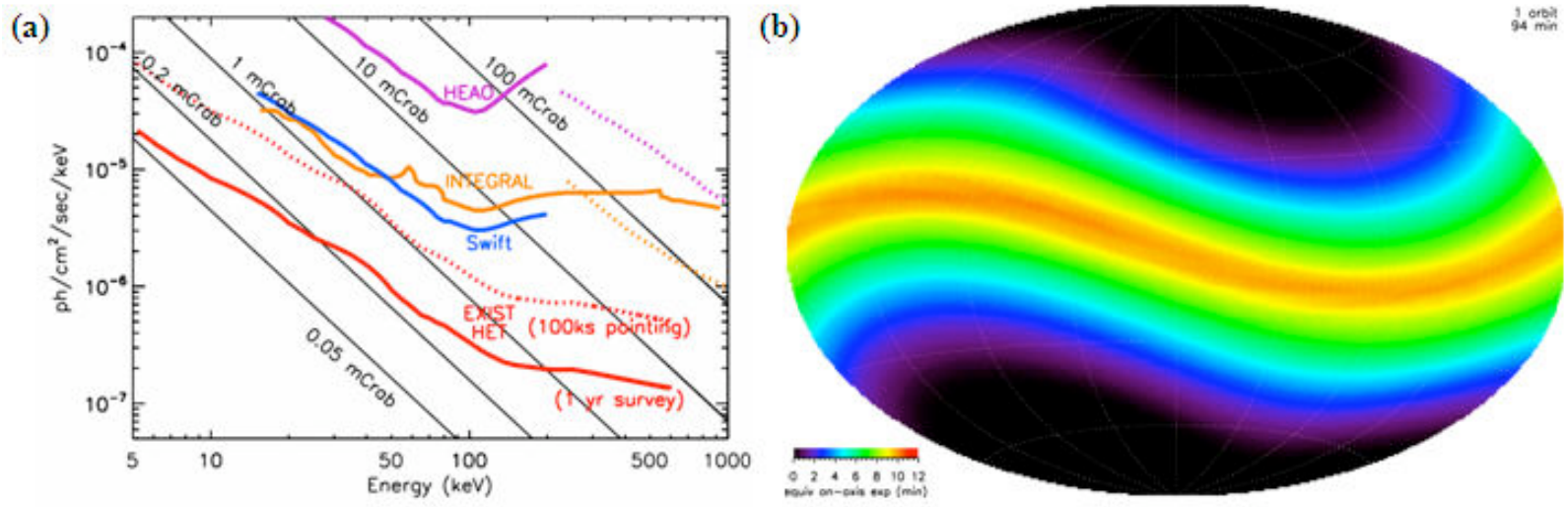
Segment of the HET hybrid mask with cross sectional view: coarse (15mm pitch, 3mm thick) and fine (1.25mm pitch, 0.3mm thick).

EXIST/HET parameters.

Parameters	Values
Telescope (coded-aperture)	4.5m^2 CZT (0.6mm pix, 11.5Mpix) 7.7m^2 Tungsten mask
Energy Range	5 – 600 keV (imaging CZT) 200 – 2000 keV (BGO for GRBs)
Sensitivity (5σ) (~1y survey)	0.08– 0.4mCrab (<150keV) 0.5–1.5mCrab (>200keV)
(10s on-axis)	~24mCrab (<150keV)
Field of View	90° × 70° (out to 10% coding)
Angular Res. Centroiding	2.4′ resolution <20″ for >5σ source (90% conf. rad.)
Sky Coverage	Full sky every two orbits
Spectral Res.	2–4 keV (3% at 60 keV, 0.5% at 511 keV)
Time Res.	10 μsec
Heritage	*Swift*/BAT, *INTEGRAL*/IBIS, *Fermi*/LAT

EXIST sky survey coverage and sensitivity

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



EXIST*-*HET survey vs. pointing sensitivity **(a)** and sky coverage over 1 orbit **(b)**

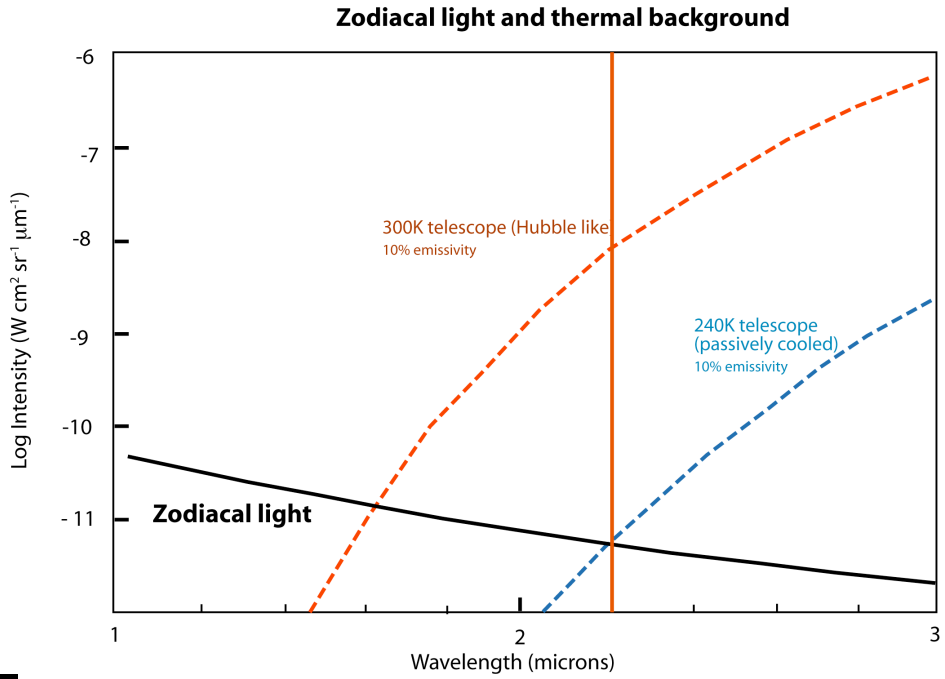
5σ in 1 yr sky survey flux sens. over band ΔE=E , with image psf 2' & pos. <20"

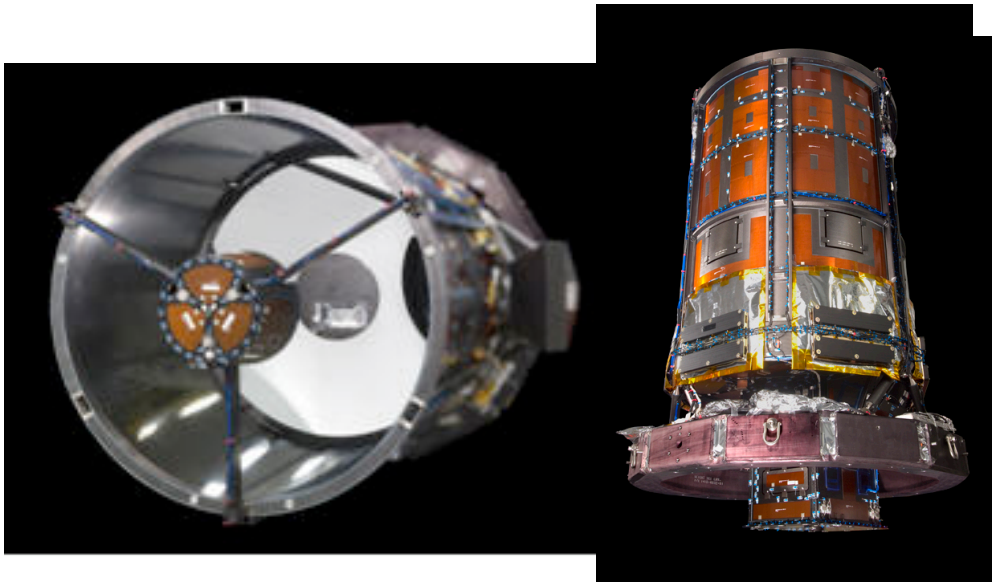
- **0.08mCrab = 7 x 10^{-13} cgs, *(~5-10X below Swift/BAT)* for HET (5-100 keV)**
- **~0.5mCrab = 1 x 10^{-11} cgs (*~20X below INTEGRAL/IBIS)* for HET (100-600 keV)**
- ***~600 GRBs/yr (~6X Swift/BAT rate) and ~30,000 AGN: IRT redshifts for most!***
- ***unique* ~15% duty cycle coverage on any source, ~90% *full-sky every 3 hours!***

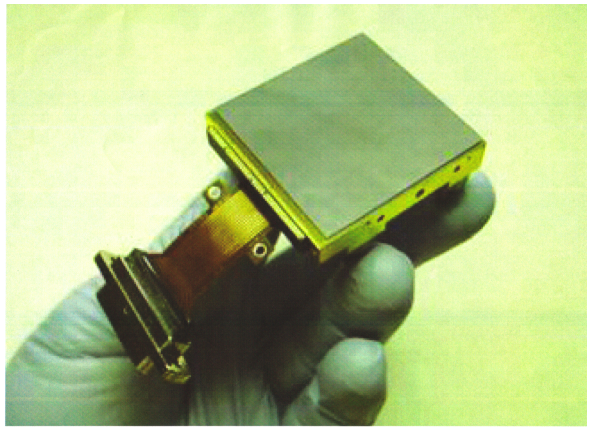
EXIST IRT: 0.3-2.2μm imaging & spectroscopy

- IRT mirror (primary and secondary) passively cooled to -30C (radiator) give zodiacal light limited backgrounds: *IRT could be* ***~10X 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/NIRCAM)



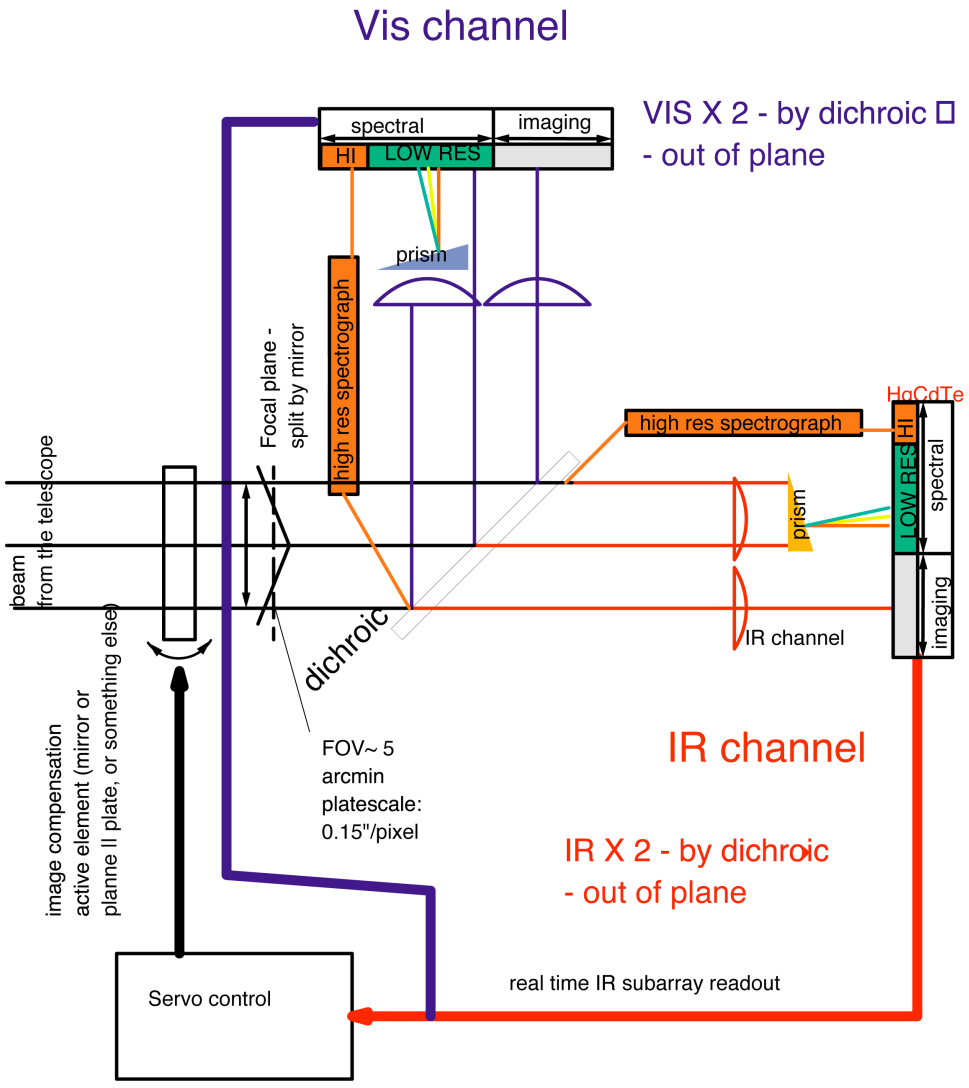


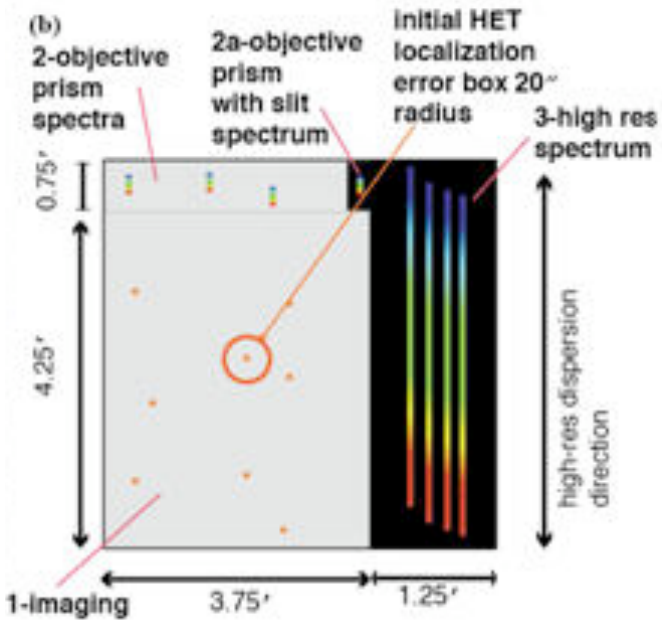


IR: HgCdTe +H2RG detectors (2K x 2K)
Vis: CMOS+H2RG (2K x 2K); pix size 0.15”

IRT telescope and instrument **layout**

(H. Moseley & A. Kutyrev design)

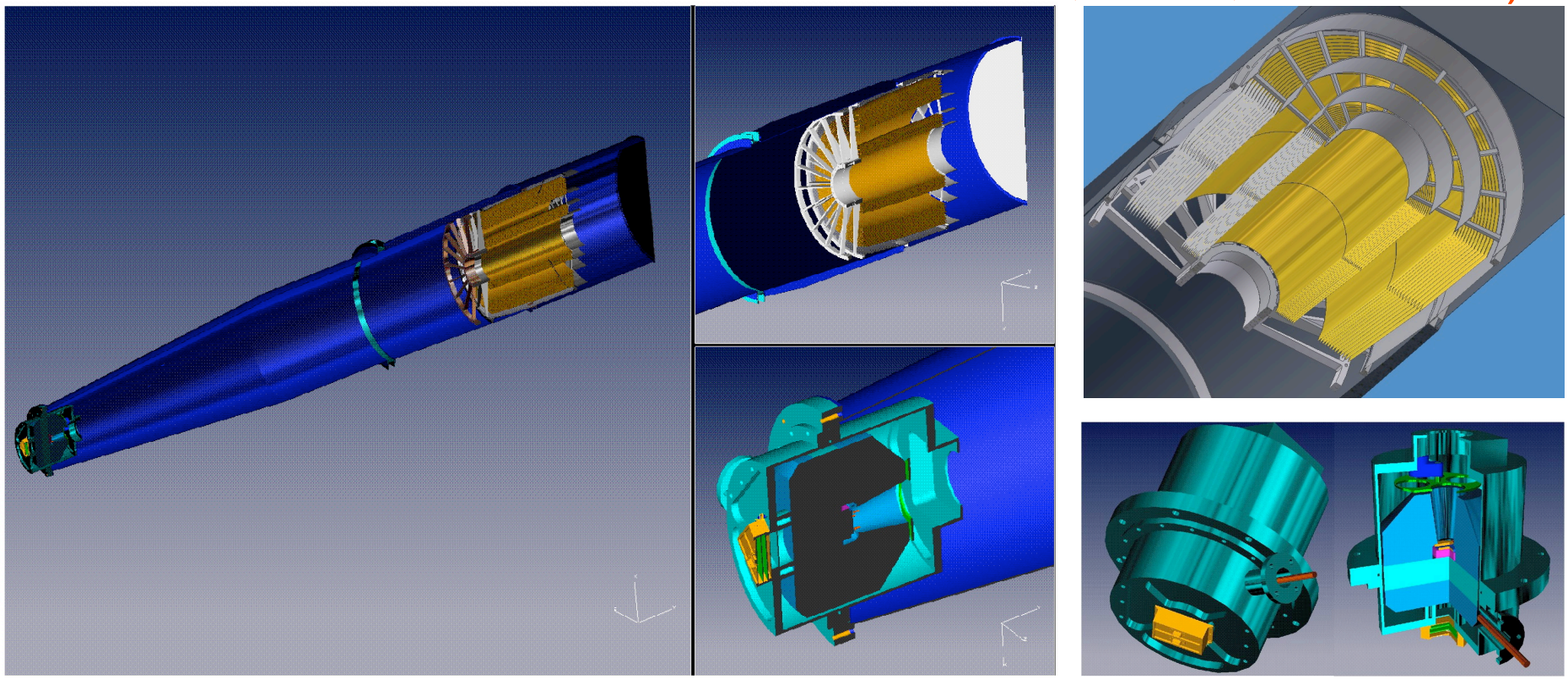




EXIST IRT parameters.

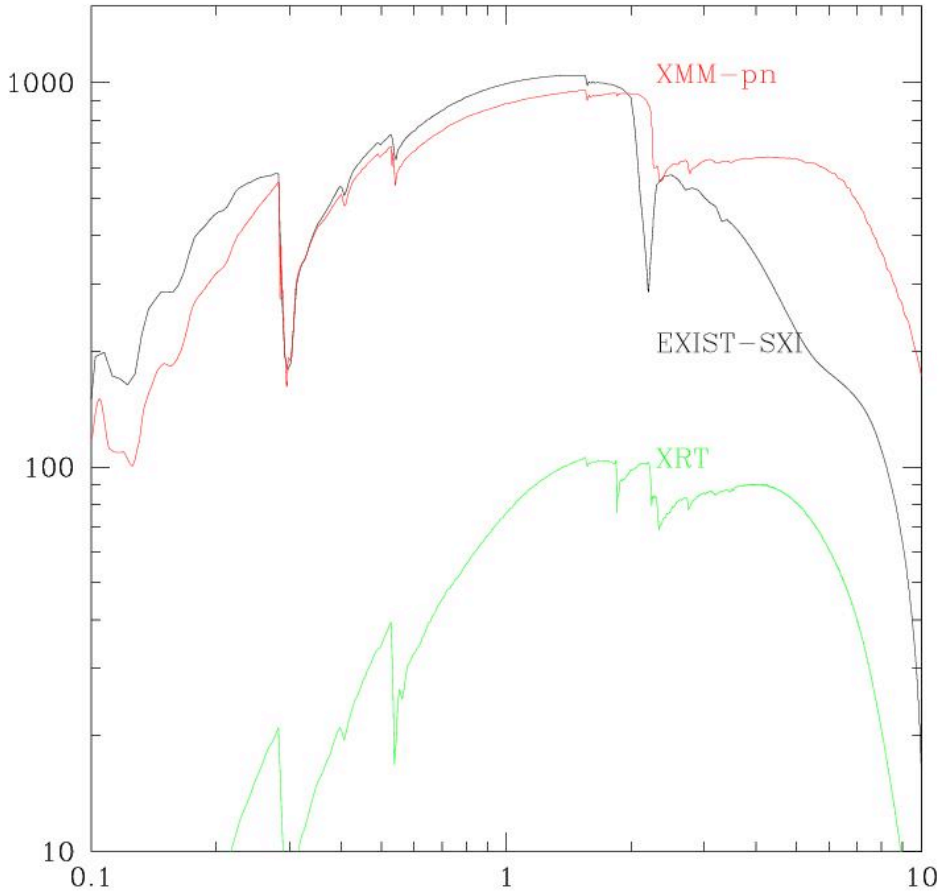
Telescope	1.1m aperture Cassegrain		
Ang. Res.	≤0.3″ PSF (0.15″/pixel pl. scale)		
Spectral Bands (4)	0.3 – 0.52, 0.52 – 0.9μm (*HyViSi*) 0.9 – 1.38, 1.38 – 2.2μm (*H2RG*)		
Mode	**Field of view**	**Spec. Res.**	**AB (S/N≥5σ) @ int. time t_{int}**
Imaging	3.75′×4.25′ (16arcmin²)	~3	24 (100 sec)
Low Res. Obj. Prism	3.75′×0.75′ (1.8arcmin²)	~30	22 (300 sec)
Low Res. Single Slit	20″ long slit	~30	23 (300 sec)
High Res. Single Slit	4″ long slit	3000	18 (1 ksec)

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.: 2 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) and Parameters



EXIST/SXI parameters

Parameter	Baseline (Goal)
Mirror	26 (38) shells
Angular Res.	20″ (15″) @ 1 keV
Energy range	0.1 – 10 keV
Dia. of mirrors	60 cm
Focal length .	3.5m
Detector type	PN-type CCD (APS DEPFET)
FOV, Detector	20×20 arcmin^2, 3×3 cm^2
Energy Res.	E/ΔE = 47 at 6 keV
Readout speed	5 – 10 ms (1 ms)
Instrument effective area	950 cm^2 (1200 cm^2) at 1.5 keV, >100 cm^2 at 8 keV
Sensitivity (10^4s)	2×10^{-15} (1.5×10^{-15}) erg cm^{-2} s^{-1}

- EXIST-SXI comparable to XMM-pn (single telescope) in sensitivity and can mach 5-10 keV sens. with addition of low-mass 3rd mirror system

EXIST mission operations: Simple; autonomous

- *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*. On board photometry and acquisition with tip/tilt mirror in focal plane (maintain 0.1" pointing with only ~2" S/C pointing)

- 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 ~2500 GRBs/hosts and continuing survey for transients (LSST)

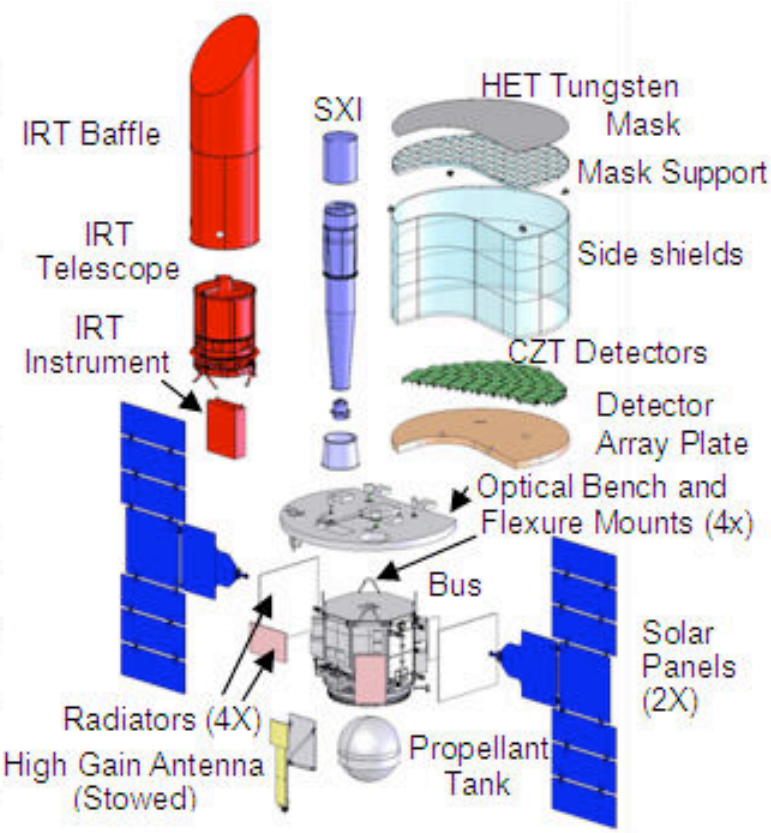
- 5y mission life required to accumulate large samples of *high-z GRBs, rare survey objects (e.g. Type 2 QSOs) and rare transients (e.g. TDEs)*

EXIST mission concept: Summary after ASMC Study GSFC IDL and MDL

EXIST Observatory Mission Parameters

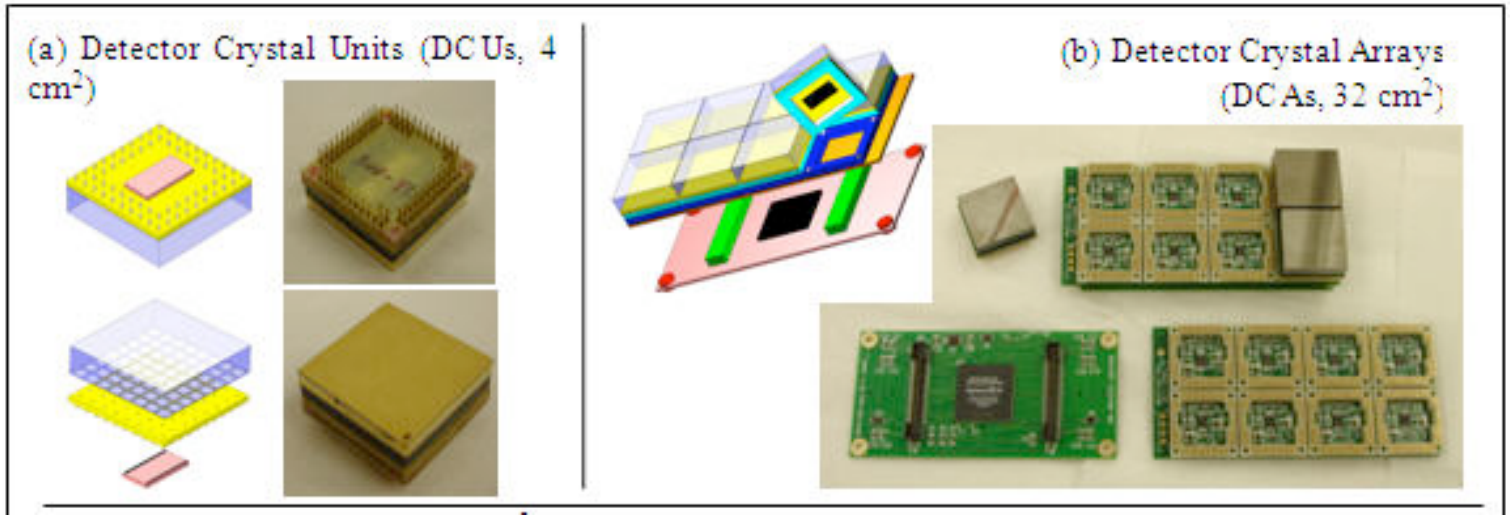
Parameter	Requirement	Capability	Margin
Orbit	600 km, ≤ 22°	Comply	N/A
Launch Mass Atlas V-401	5932kg. CBE+ Contingency	8000 kg @ 22°	35%
Pointing Control Knowledge Stability	 10″ 5″ (3σ) <2″	 5″ < 3″ (3σ) < 1″	 100% 67% >100%
Slew Time	45° in 180 s	Comply	N/A
Avg. Power	2803 W	3645 W	30%
Data Storage	180 Gbits	300 Gbits	67%
Downlink	200 Mbps	Comply, TDRS Ku	3.2 dB*
Commanding Uplink	Not defined	2kbps TDRS SSA, GN; TDRS MA	3.0, 32.0, 3.7 dB*
Propulsion	Controlled de-orbit, 160 m/s	202 m/s with full tank	26%
Lifetime	5-yr	Comply, full redundancy	N/A

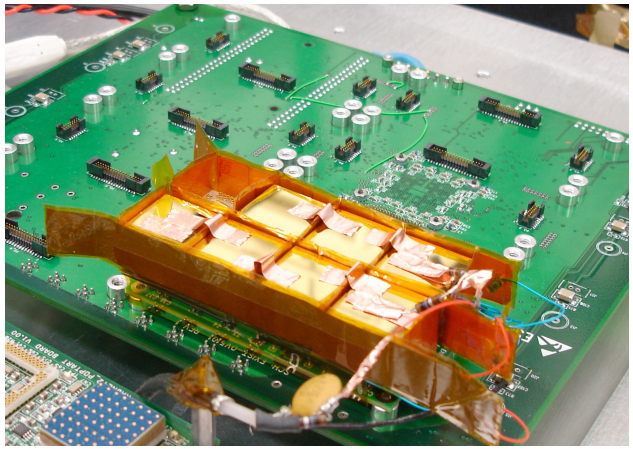
*TDRS only requires 0dB margin due to large system margins.



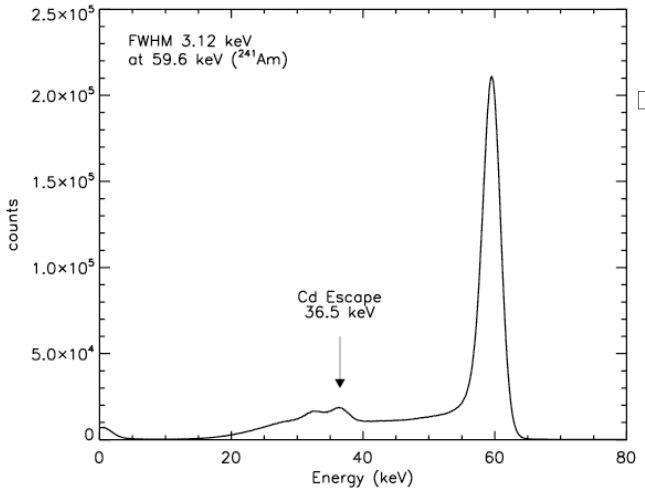
EXIST exploded view; the Observatory uses a modular instrument/bus design.

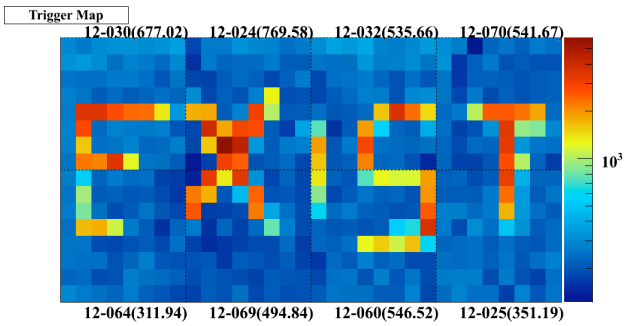
HET Detector develoment: Building a large area CZT detector/ telescope prototype for balloon-borne *ProtoEXIST1*





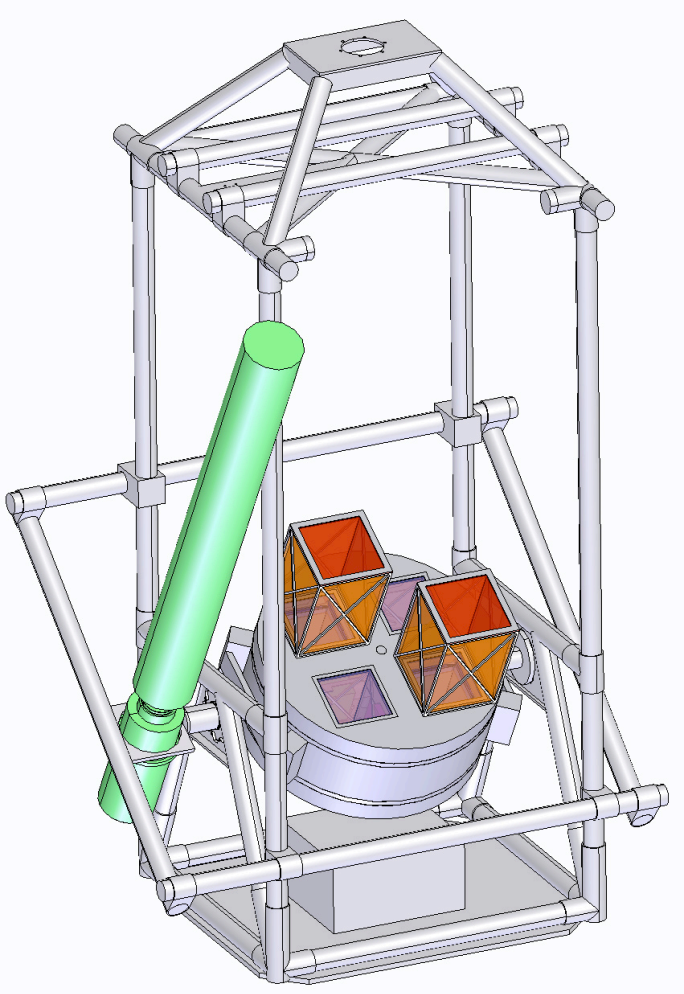
Test flight DCA board (1 of 8)





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

ProtoEXIST Gondola with 2 of 4 Telescopes



ProtoEXIST1 payload (2 telescopes: with/without active rear shield)
(planned for Ft. Sumner flight, Fall 2009)

EXIST Team for ASMC Study & Astro2010

- *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 for *IRT*

- *Highest z stellar universe only measured via GRBs*: >6X *Swift* rate; ***IRT* redshifts & high-res spectra** for ~2500 & >1000 GRBs can constrain cosmic structure back to Pop III (!)

- Both obscured and dormant SMBHs best studied with HX imager and ***IRT***: *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*** is a multi-wavelength Observatory*;* ***Unique IRT general telescope***
  (a tribute to and followup for Giovanni…)

- ***EXIST*** **needs no new technology and *could* launch** in ~2017-18 window (after JDEM?) *if* given a start in ~2012-13

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