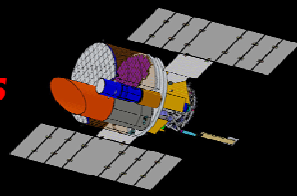

GRB Probes of the Early Universe and First Black Holes to *EXIST*

Josh Grindlay
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and the *EXIST* Team

Talk Outline

- The Key Questions we hope GRBs as Probes of High z might answer

- What's needed to answer these, and *Trace the Epoch of Reioniztion*?

- … the *EXIST* mission, as proposed to the Decadal Survey
  - Overview
  - Science objectives and capabilities
  - Can it be built "now"?

- Summary

GRBs as probes of Early Universe

- Do PopIII stars make luminous LGRBs?
  - Yes, according to Meszaros and Rees (2010), who consider stars above PISN (destruction) range (~150-250 $M_\odot$) up to ~1000 $M_\odot$, and predicted very luminous, long, GRBs
  - And (we hope) yes, if indeed PopIII stars "fission" during formation in their DM + gas haloes to form *binaries* with individual masses below the PISN limit (Stacy et al 2010, Turk et al 2009), or if PopIII binaries form by capture in dense PopIII clusters (Bromm & Loeb06)
- What fraction of "PopII.5" stars (=first-gen. PopII) make LGRBs?
  - Not presently known; prime observation objective for future GRB mission(s)…but it is *possible* that already GRB090423 (at z =8.2) is such an object…

GRBs as probes of Early Universe

- Can PopII.5 BH – WR binaries make *luminous* SGRBs?
  - Physical picture (*Toy Model*…):

    Primordial PopII (or II.5?) binary of WR + WR stars ➡ BH + WR binary ➡ CE evolution (for P ≤10d) ➡ merger of BH + WR star

    ⇨ SGRB, but overly luminous and "long" since hyper-accretion onto ≥15 $M_\odot$ BH.

<u>Prediction(s):</u>

- **Class of "L/SGRBs" at high z (req. for higher density and binary fraction) withOUT SNIc (or any SN) counterpart.**
- **Classify as "LGRB" since typical E_{iso} ~10^{51-52} ergs… OR**
- **Classify as "SGRB" since due to merger, and likely *single* (dominant) pulse, though broader than NS-NS or NS-BH SGRBs**
- **Yet another possible interpretation of the 3 "LGRBs" at z >6 with T90 ~2sec**

GRBs as probes of Early Universe

- **What is *required* to measure (=detect and locate GRB fast enough to obtain z) GRBs at z >6-10?**
  - GRBs up to ~2X fainter than 050904 (at z = 6.3) can be discovered with Swift/BAT and up to ~4mag fainter in J could be detected within ~3h by X-Shooter/VLT. Similar limits for BAT for the other 2 known z >6 GRBs but even more stringent limits for JHK imaging
  - *Possibly* similar GRB detection limits from SVOM given its softer X-ray sensitivity (down to 4 keV); similar X-Shooter limits.
  - NOTE that all 3 Swift GRBs at z >6 have similar spectra and E_{oeak} values as GRBs at typical z ~2 (Sakamoto, Kyoto Conf.), so softer response of SVOM may not help that much…

Predict:

Assuming next 5y of Swift + following 5y of SVOM coverage, and similar JHK detection and spectroscopic followup as in past 5y, we could expect ≥6 new GRBs at z >6 to be discovered with JHK photo-z's (e.g. GROND) and available for deep followup studies with X-Shooter & JWST (for which a high-z "trigger" is needed…)

GRBs as probes of Early Universe

- **What is required to measure EoR at z >9-12?**
  - **Note: MWA, LOFAR, etc. also possible, but less certain…**
  - Need **>30-100 detections** to a) measure DLA red wing with spectra at resolution R ≥3000 and S/N >10 per pixel across J, H, K bands in order to a) measure at ≥5-20 with Host galaxy NH $<10^{20}$ cm^{-2} to measure *shape of DLA* red wing with sufficient accuracy to constrain ionization fraction in host IGM (McQuinn et al 2009).

Predict:

Unlikely to obtain significant constraint(s) on EoR evolution with *Swift*/BAT (+VLT/X-Shooter) although may be lucky and get additional ~2 redshifts "measured". But need >30-100 to begin to "map" patchy structure in EoR, so will require GRB discovery and rapid JHK spectroscopy ~10X more sensitive than available with *Swift*/X-Shooter

→ Need GRB mission like ***EXIST***

Summary: Early Universe GRB Questions…& current/planned prospects

- **When and how did the first (Pop III) stars form & evolve? Did they produce >300 $M_\odot$, "stellar" BHs (e.g. Meszaros & Rees 2010) or ~20 $M_\odot$ BHs from binaries?**
  - As stars, and their galaxies, they are not directly detectable with JWST…

- **How did subsequent generations ("Pop II.5") of star formation evolve?**
  - HST/WFC3 reaches z ~8-9 but (even) JWST at z ~10 is limited (in 10^6 sec exposure!) to $M_{UV} < -16$, or proto-galaxy masses $\geq 10^8$ $M_\odot$
  - What is SFR(z) and Z(z)? Did WR stars in dwarf-irregulars really power the EoR?

- **Did reionization begin at z ~12 (WMAP-5) and reach, say, 50% by z ~10?**
  - GP troughs for QSOs indicate Universe was ~99% ionized by z ~6.4
  - 21cm surveys could map EOR in 3D ***but may be blinded by foregrounds***

- ***When did the first ~10^8 $M_\odot$ SMBHs form? Did they require >100 $M_\odot$ PopIII BH seeds?***
  - QSOs will not be usable probes at z >7-8 given the very limited SMBH formation time

*As this Workshop has made clear, GRBs are excellent Probes to exploit these questions, provided requirements are met for the mission needed to **EXIST**!*

Post-Swift Requirements for the *desired* high-z GRB mission

- GRB sensisitivity ~10X greater than Swift/BAT
- Band width extending to both lower and higher energy than BAT
- Instantaneous FoV at least comparable to BAT, but ***faster*** *sky coverage*
- Rapid on-board image triggers on multi-timescales
- High spatial resolution (~5-100keV) ≤2arcmin allowing <20" positions to avoid source confusion
- Soft X-ray (0.1-10 keV) imaging and spectra ~10X more sens. than XRT
- Optical (0.3-1μm) imaging and spectroscopy ~10-100X more sens. than UVOT
- *n**IR** (1-2.3μm) imaging and spectroscopy >10X more sens. than VLT or Keck!*

Such a mission requires more mass, power than Swift (but only comparable to Fermi) to enable both Discovery <u>and</u> Followup science to EXIST

What is *EXIST?*

(Energetic X-ray Imaging Survey Telescope)

- A *Medium Class Mission* to conduct the most sensitive *full-sky* survey for ***Black Holes*** on all scales (stellar to supermassive) to ***Probe the high-z Universe***

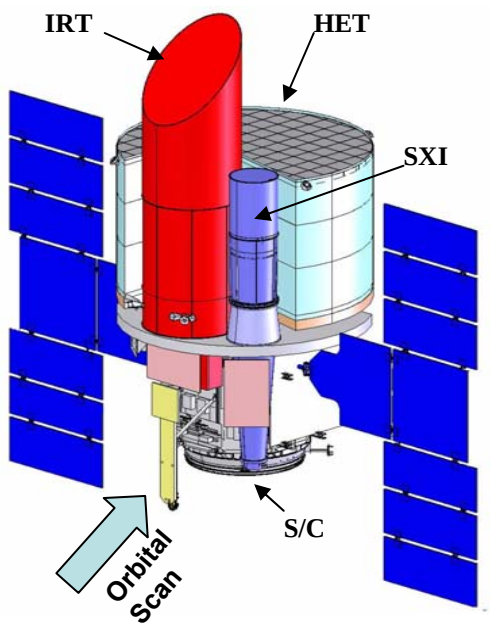
- A wide-field (90°) **hard X-ray (5-600 keV) imaging** (2 arcmin resolution, <20" source positions) telescope surveying/monitoring full sky *every 3h* with 10X higher sensitivity than any previous or planned full-sky HX imaging survey…

- *Plus* a 1.1m **optical -IR telescope** (***IRT)*** 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, JWST, LSST, ALMA, SKA, IXO and LISA(!)**

- A mission studied under NASA's ***Astrophysics Strategic Mission Concept (ASMC)*** *Study* program, in preparation for its current review by the *Astronomy/Astrophysics Decadal Survey (Astro2010)*

- **A mission recommended by the previous (2001) Decadal Survey & now considerably improved in its science, implementation & unique capabilities**

A Hard X-ray, full-sky imaging mission with deep IR/X-ray followup is required for the ultimate GRB & SMBH survey 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)

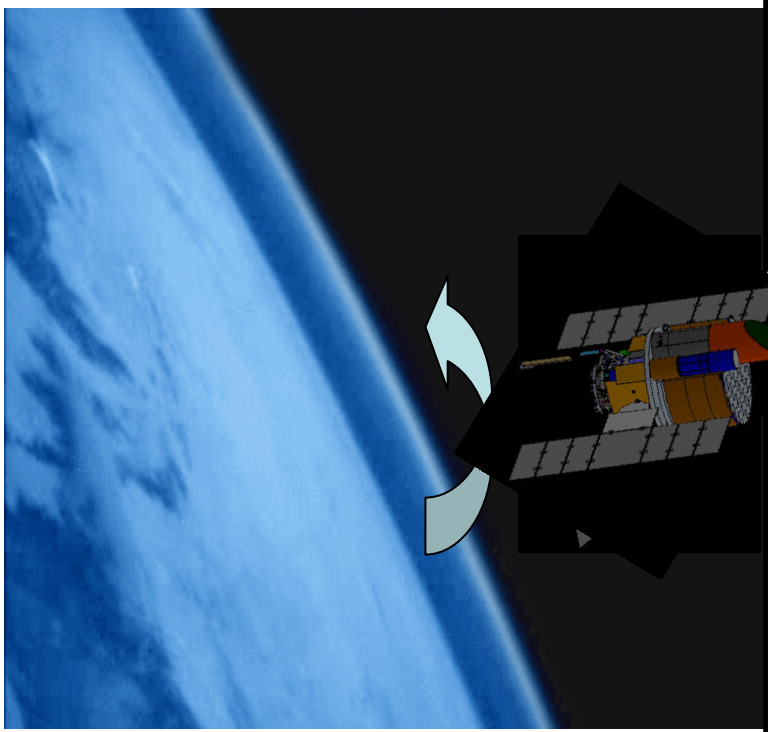
IRT: 1.1m; cooled (-30C) (dichroic: 0.3-0.9μm (HyViSI) and 0.9–2.3 μm (NIRSPEC)

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

The *New EXIST* mission (600km LEO, i ≤15°):

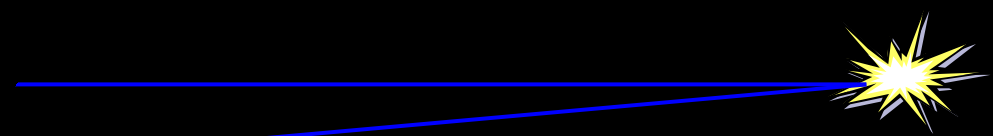
- ***2y full sky survey:*** ±20deg *Zenith-pointed* **scanning**, 2sr FoV, *full-sky ea. 3h*.
- ***3y followup IDs:*** **IRT/XRT/HET** **pointings** for IDs, ***redshifts***, spectra & timing

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

Deepest Hard X-ray *Full-Sky* Survey

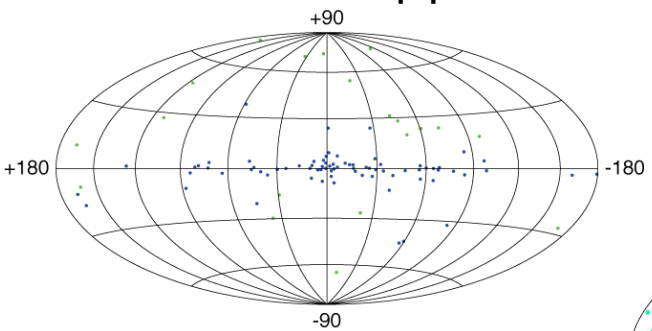
- ***EXIST***/**HET**: **5-600 keV <u>full sky mission</u> survey to Fx <u>~5 x 10^{-13} cgs, or 10X more sensitive than *Swift* or *INTEGRAL*,</u> gives ≥6 x 10^4 sources, <20″ positions**

- ***EXIST***/**SXI**: **0.1-10 keV imaging & spectra to Fx <u>~5 x 10^{-14} cgs,</u> <2" positions**

- ***EXIST***/***IRT***: **0.3-2.3μm imaging & spectra (AB ≤24, 19; R =30, 3000), <0.2" pos.**

2000 Hard X-ray Sky

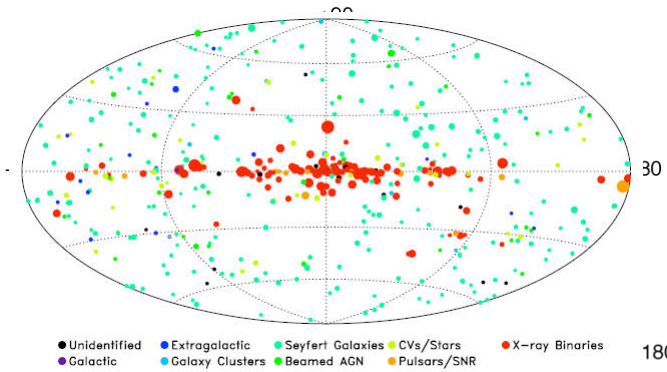
HEAO-1, BeppoSAX



~100 sources

2010 Hard X-ray Sky

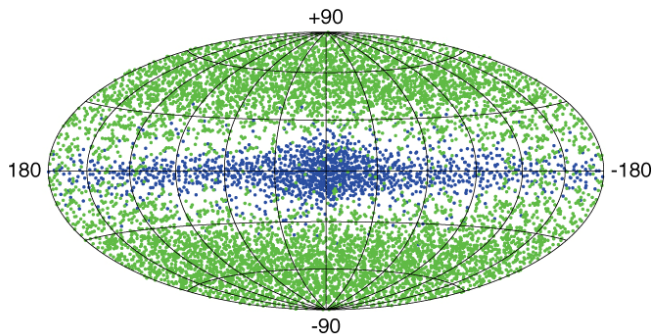
Swift (& INTEGRAL)



~600 sources

2017(?) Hard X-ray Sky

EXIST



~60,000 sources

Primary Science Objectives for *EXIST*

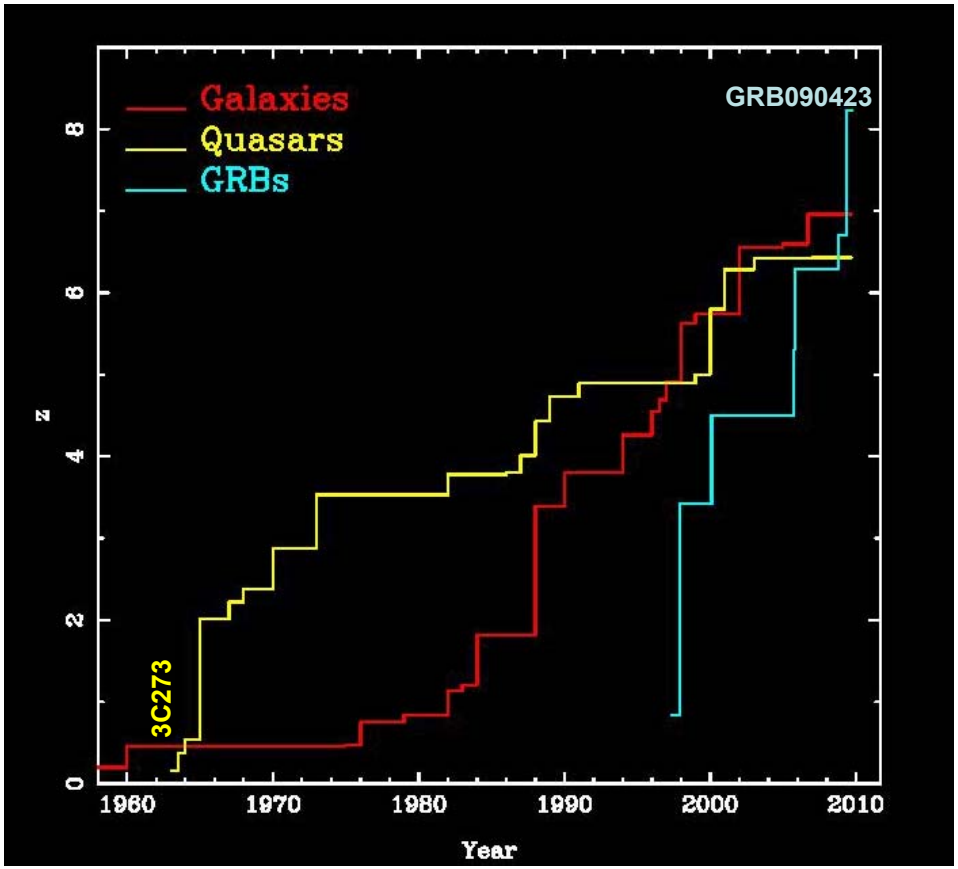
(to survey and study Black Holes on all scales: stellar to supermassive)

- **P1: Measure** cosmic gamma-ray bursts as in-situ probes of the ***Epoch of Reionization at redshifts z >7-12*** from prompt GRB redshifts and spectra

- **P2: Measure supermassive BHs in galaxies**, including *obscured* or *dormant*, to constrain SMBH demographics, growth and evolution, and ***to constrain the accretion luminosity of the universe & SMBH evolution***

- **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, Astro-H, LOFAR/ALMA/GMT-TMT-ELT*** with prompt alerts for unique objects

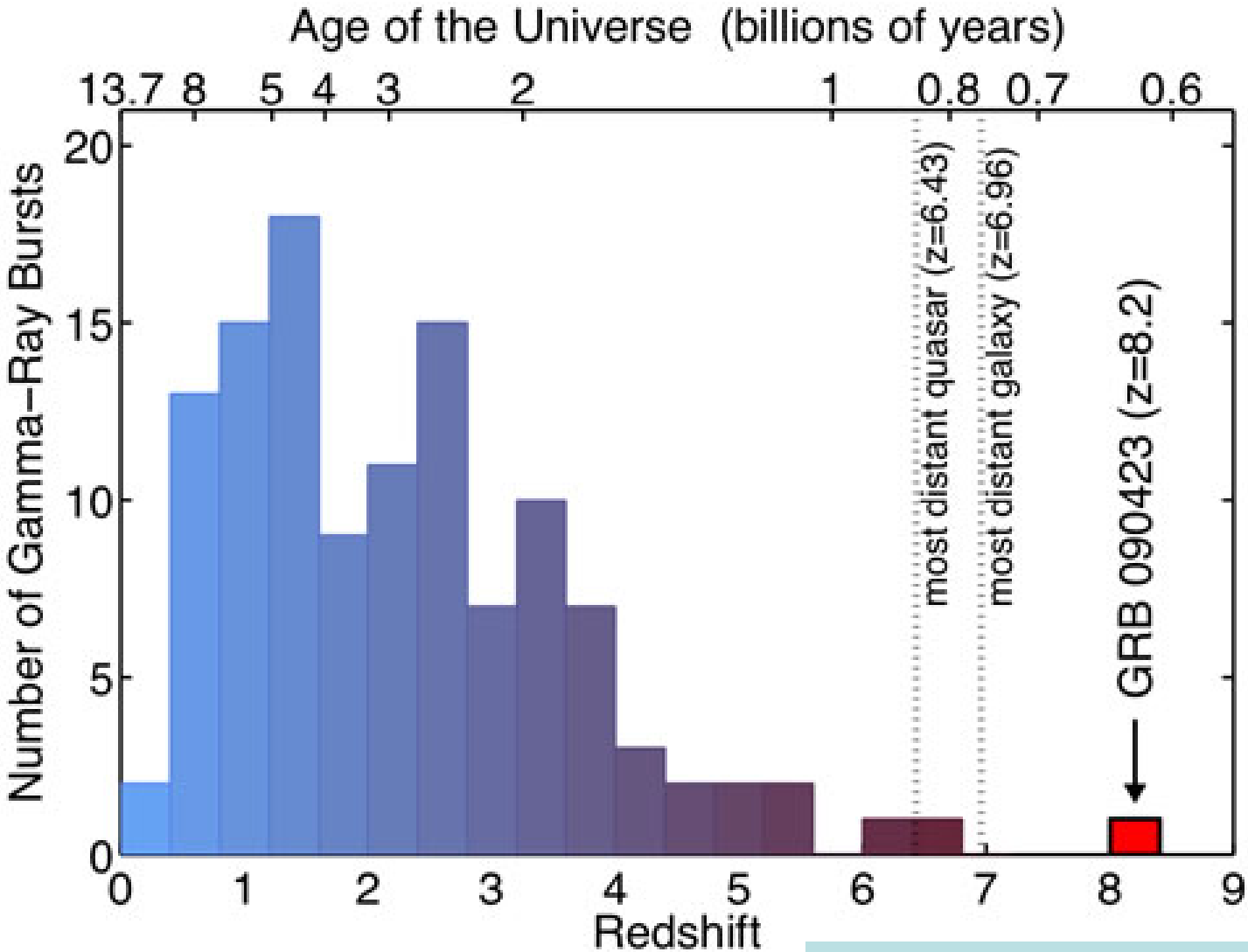
GRBs *must* preceed QSOs: highest-z stellar Probes



GRBs clearly outpace AGN for most effective probes of Early Universe at z >7-8!

- *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?*
- Broader energy band, higher sensitivity & FoV needed for large sample at z ≥ 8-12
- IR from space needed for z ≥7 since Ly-dropout then in NIR & spectra less sensitive from ground (OH bkgd)
- GRBs provide "back-light" for IR spectroscopy of host ISM & IGM gas. *Measure galactic structure (vs. z) back to epoch of re-ionization (EOR)*

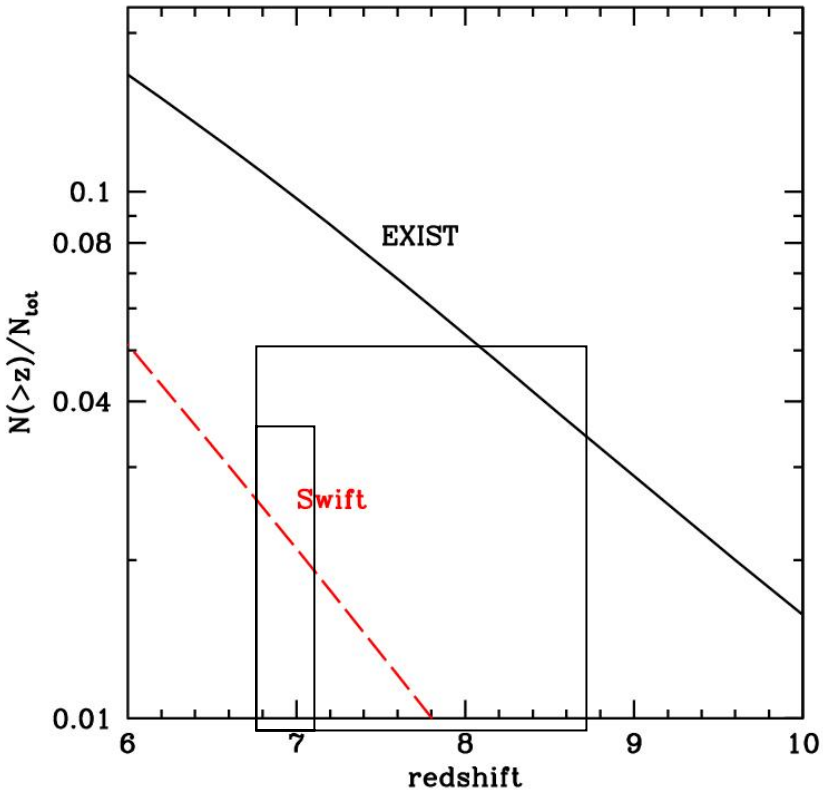
The ***EXIST***ence proof… GRB090423 (and perhaps 090429B?)

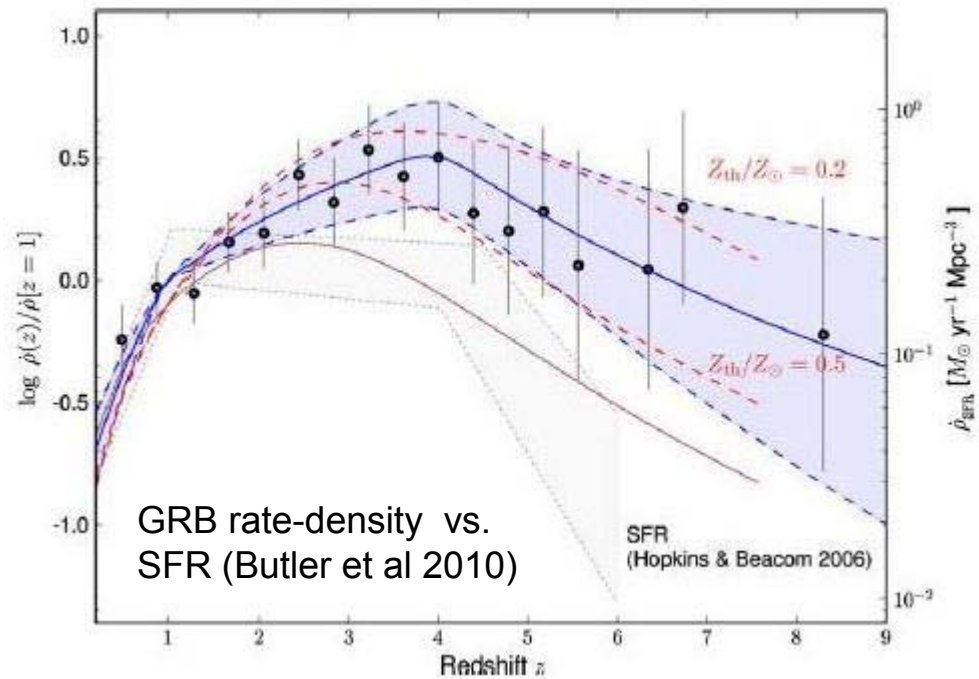


z-distrib. of all ~130 *Swift* GRBs over first **4y**:
EXIST **would match this in ~4mo.**

GRBs preceed AGN…

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 ~ 30 at z >8 per year!*

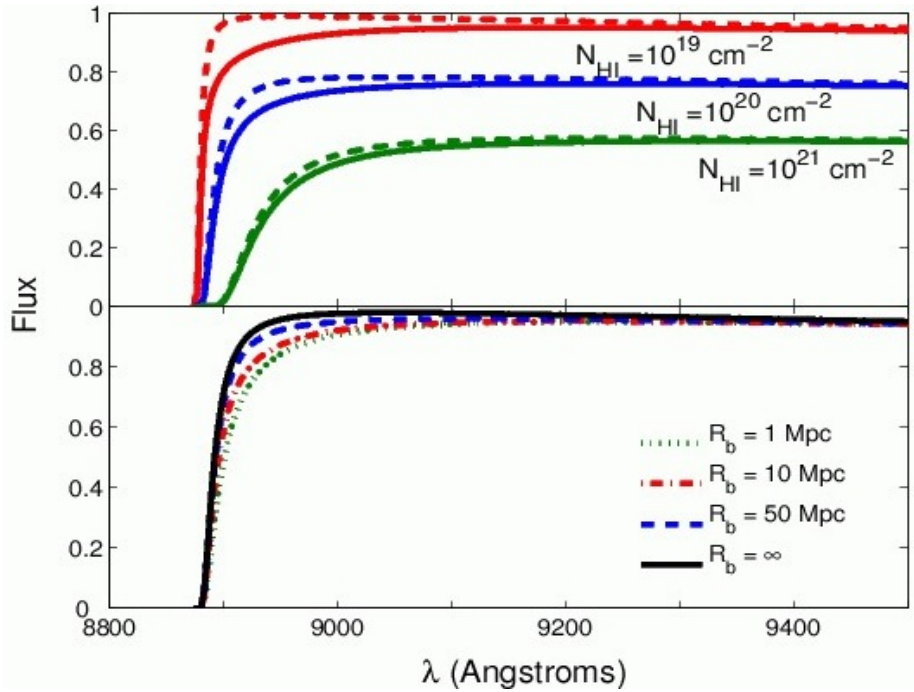
***Swift* detects ~100 GRBs/y and now ~450 GRBs. It should detect ~0.04 x 450 = 18 at z >6 and has now detected 3, likely due to limited JHK coverage and GROND result that ~25% of dark GRBs are high z**

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

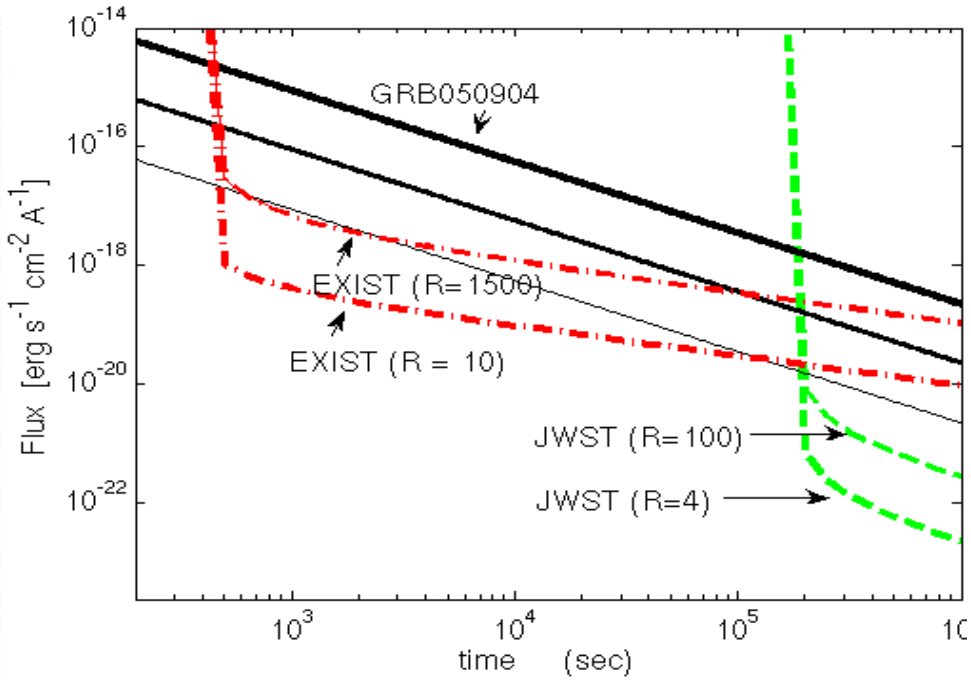
***EXIST will* probe:**

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 red wing Lyα *shape* to local IGM & EOR (McQuinn et al 2008) **but need gal. IGM ≤10^{20}cm^{-2}**



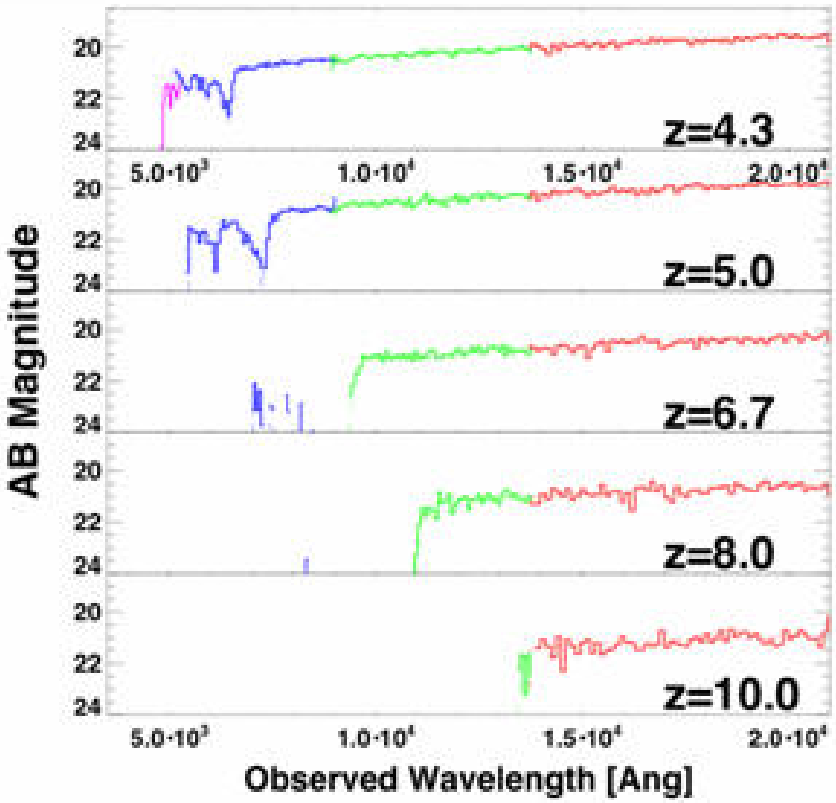
IRT vs. JWST for GRBs 1X, 0.1X and 0.01X flux of GRB050904.

- **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**

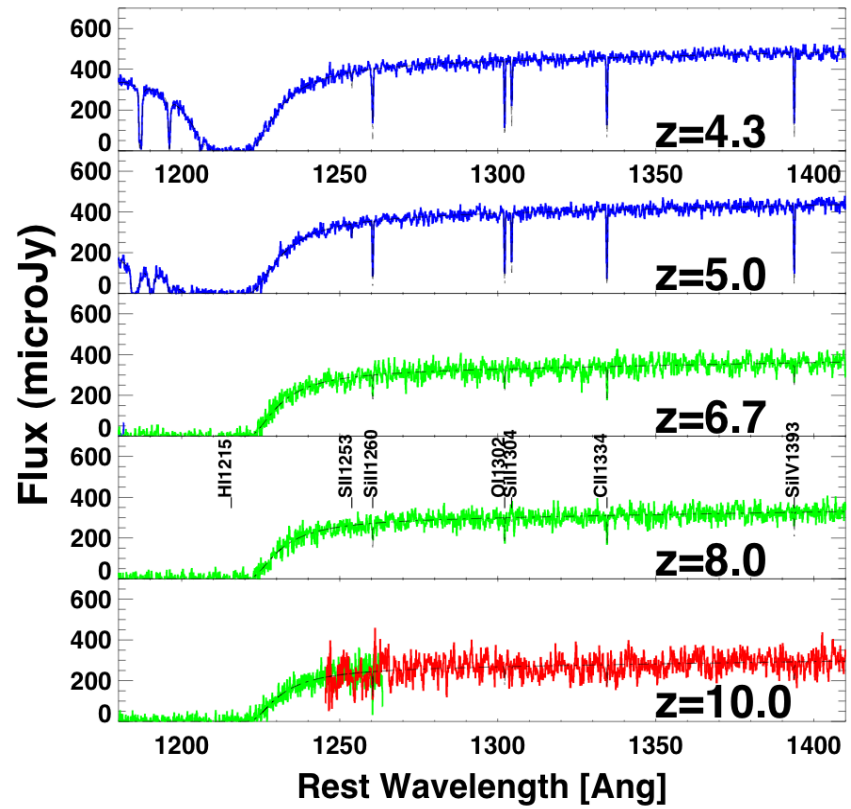
- **Simulations: > 450 GRBs/yr *of EXIST GRBs would have z measured* ; and ~30/yr at z >8. Over 5y mission, expect N(z>8) ≥ 100 EOR sight-lines to be measured.**

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] = -3; Z > 7, [Fe/H] = -4

Simultaneous spectra obtained in 4 IRT bands: **0.3 – 0.9μm, 0.52 – 0.9μm, 0.9 – 1.38μm, 1.38 – 2.2μm**

EOR can be measured and [Fe/H] constrainted vs. z!

EXIST/IRT can measure z for **All** Swift GRBs and high res. spectra for ~3/4 of all Swift sample for spectra extrapolated to J, H, K and redshifted to z ~12!

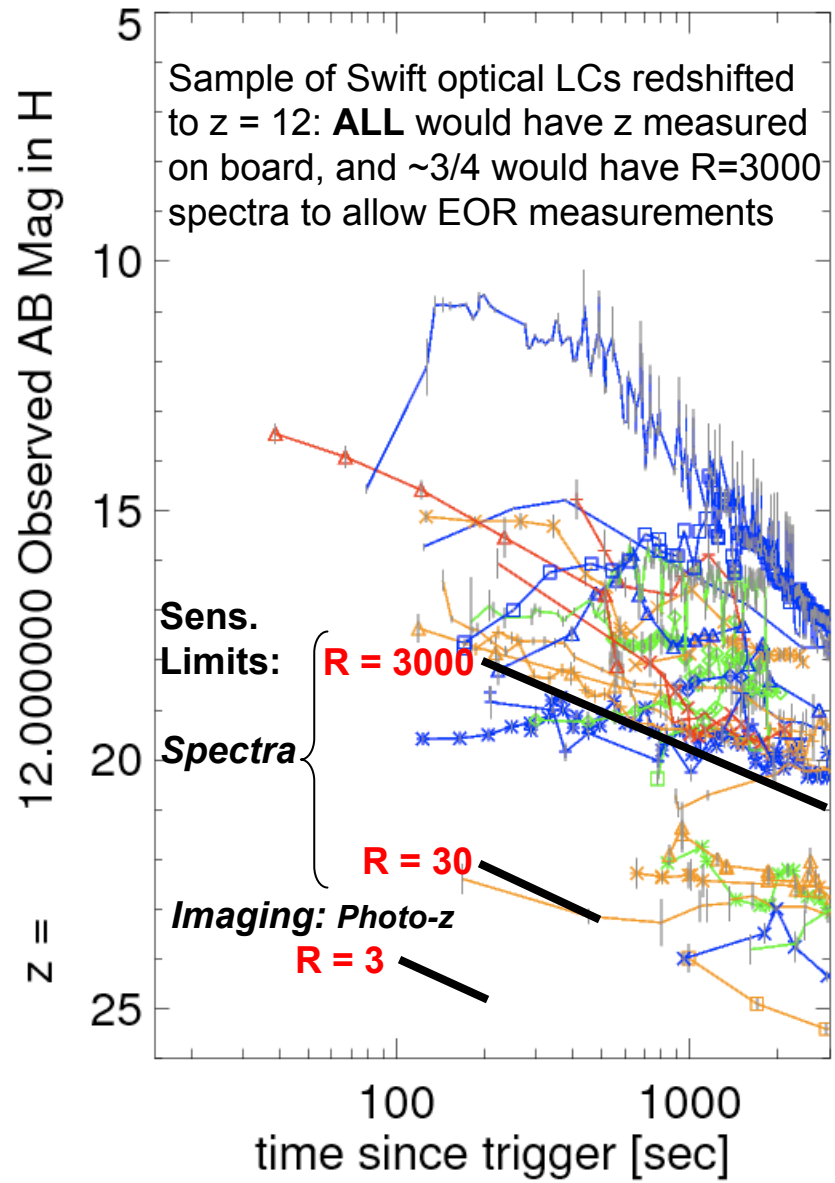
Swift GRB AGs with spectra in/extrap. to H band and redshifted to z = 12.

IRT sensitivities for prompt imaging in 4 bands (0.3 – 2.2μm):

4-band **Imaging** (R = 4) :
AB ~24 (10σ) in 100s
photo-z's

R =30 **Spectra** :
AB ~23 (10σ) in 300s
accurate-z's

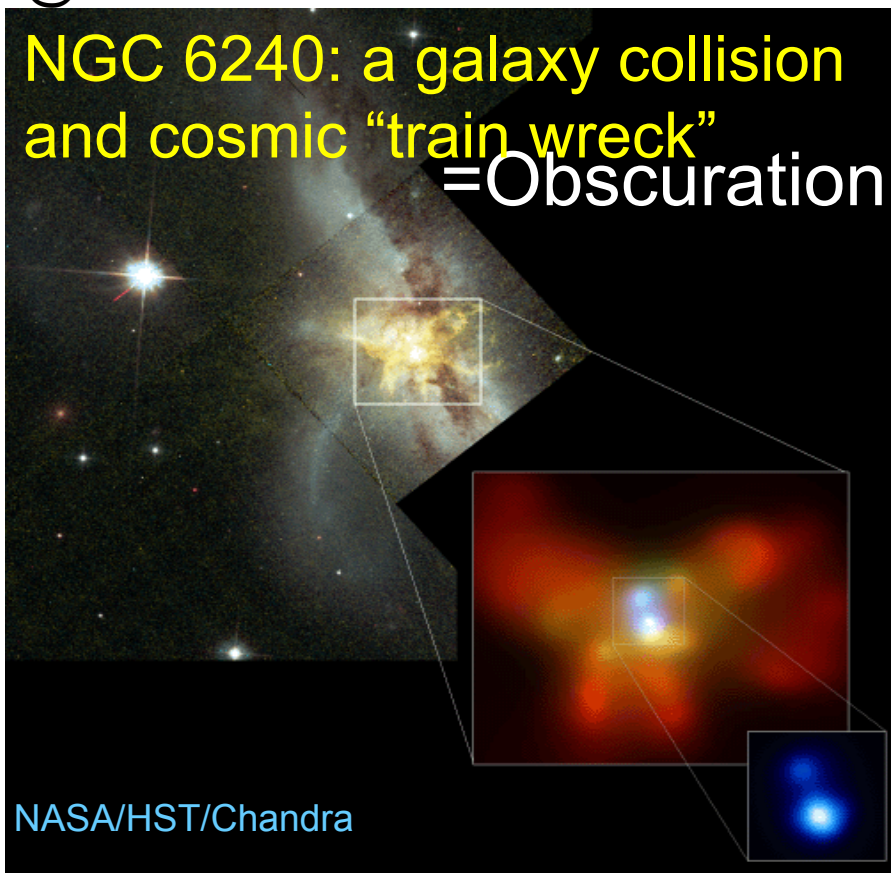
R=3000 **Spectra** :
AB ~19 (10σ) in 2000s
EOR & Fe/H measures!!

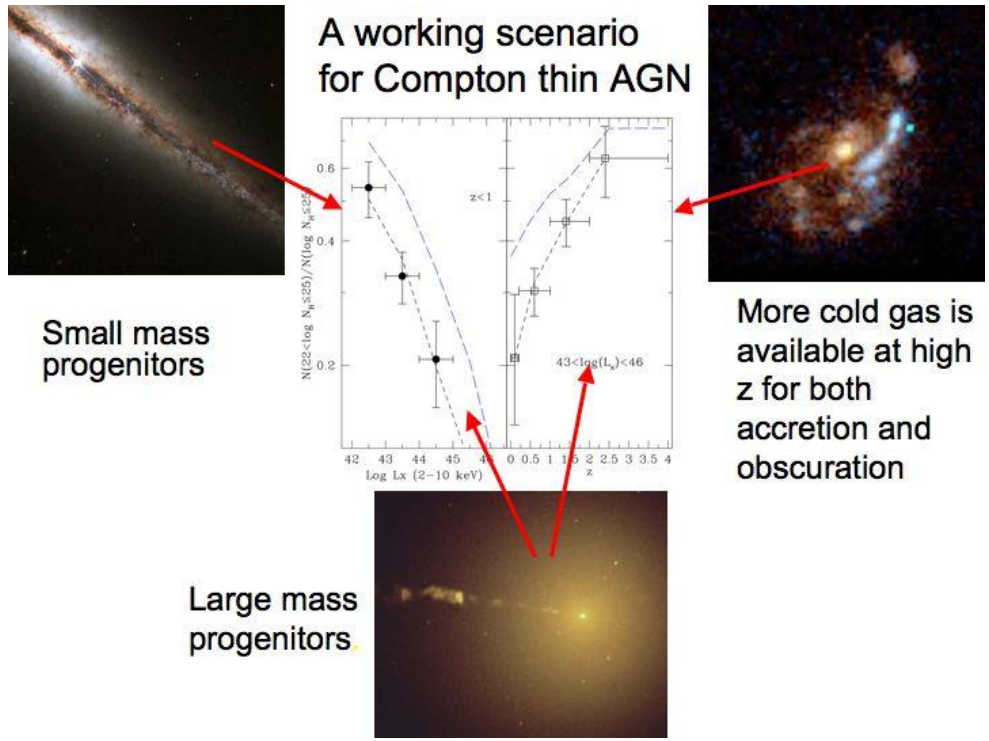


P2: Obscured or Dormant AGN (all types) & Blazars vs. z?

• ***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

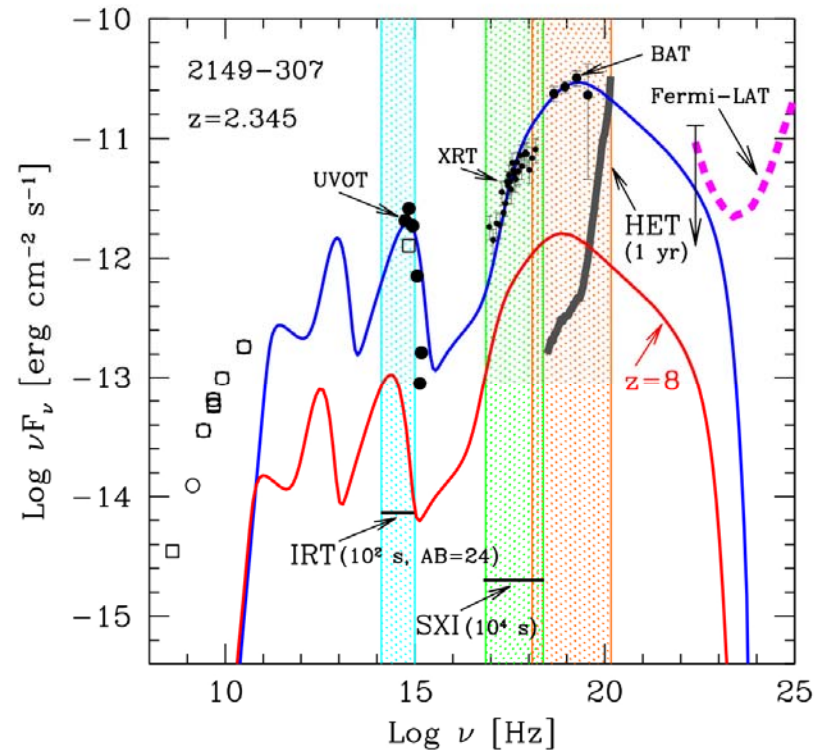




EXIST **survey will explore the evidence (e.g. La Franca et al 2005 and Treister & Urry (2006) that obscured AGN are *increasing as* $(1+z)^{0.4}$**

EXIST could extend Blazar surveys to z ≥8 ! (should they *EXIST*…)

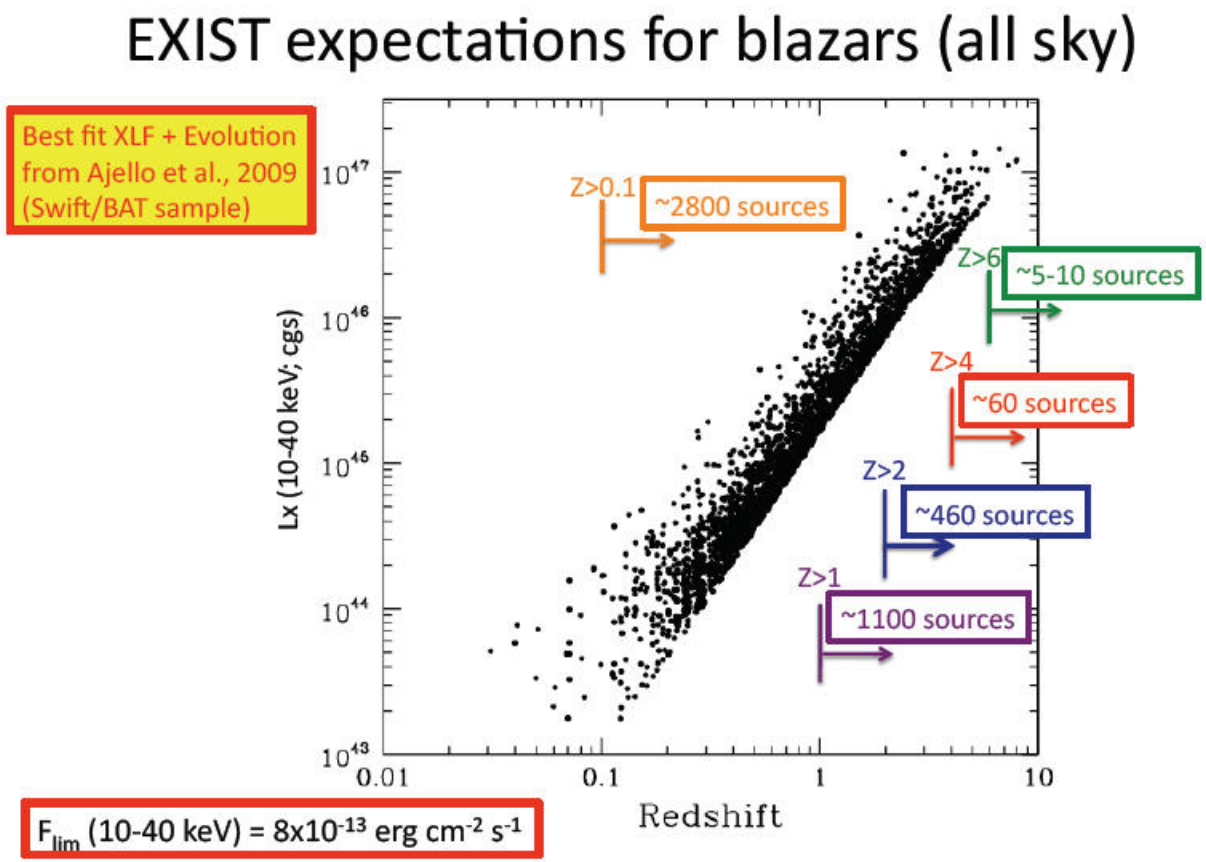
- Blazars are the AGN analog of GRBs: persistent, extreme-beamed and exceptionally luminous and variable
- Understanding their formation and evolutio requires deep full sky samples with sensitivity to rapid variability
- ***EXIST*** could detect the Blazar 2129-307 (detected by Swift/BAT, XRT, UVOT) out t z ~8. Blazars might best probe SMBH growth (Ghisellini et al 2010)
- 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 will detect *large* Blazar samples:
(to "beam in" to the first SMBHs?)

- *Swift*/BAT sample of >20 Blazars out to z ~3 implies very large nos. for ***EXIST***
- Highest m-dot when *SMBHs growing at z>7.* ***Jets*** likely so Blazars may be larger fraction of AGN than in local Universe
- All-sky survey required for rare & variable objects; redshifts from IRT "easy" from Ly-α breaks in cont. spectra (***like GRBs!)***

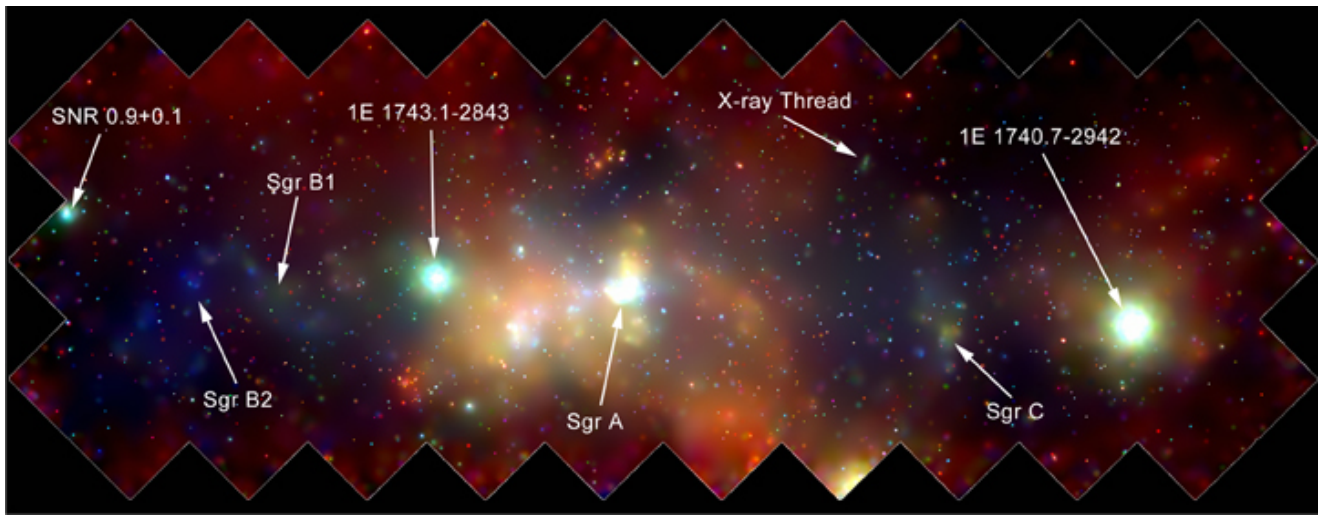


P3: *EXIST measures* stellar BHs & IMBHs as *Transients* in Galaxy, Local Group

- ***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: **SNe, XRFs, SGRs** and… Bursting Blazars (?!)

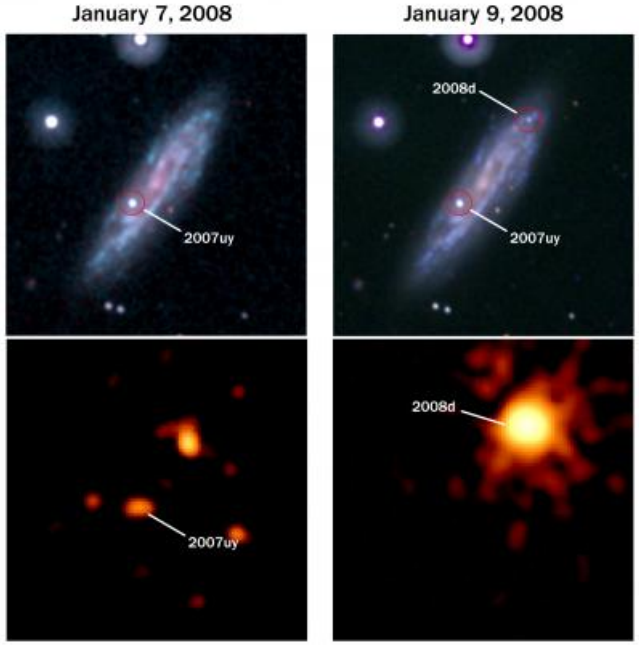
- **Supernovae *breakout shocks*** like NGC 2770/SN2008d discovered with Swift/BAT: ***EXIST*** HET sensitive down to ~5keV can **trigger Neutrino and GW telescopes**

- **Off-axis GRBs (& XRFs?)** *many more* like GRB980425/SN1998bw?!

- **Soft Gamma-ray Repeaters** (SGRs): *Magnetar survey out to ~300Mpc*

- **Short GRBs** (~150/y expected), and those within ~300Mpc (z <0.07) will **provide triggers for Advanced-LIGOII**

- **Blazar flares**: evidence for significant flaring hard X-ray Blazars and obscured radio-loud AGN from Swift/BATSS (Grindlay et al 2010, in prep.)



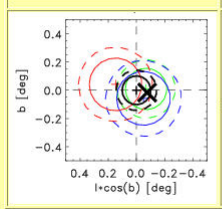
Scientists had planned on studying Supernova 2007uy in the galaxy NGC2770, which was already several weeks old when seen in this visual, ultraviolet image (upper left) taken on Jan. 7, 2008, by NASA's Swift satellite. A close-up, X-ray image of that supernova is beneath.

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 scanning demonstrated with BAT Slew Survey (***BATSS***)

- Swift conducts ~4 slews per orbit (to/from targets and Earth limb avoidance) at ~45arcmin/sec, moving BAT FoV by ~2-3 diameters. Aspect file gives S/C pointing direction each 0.2sec (~9' ~BAT resolution/2 for Nyquist sampling of scan image)

- By turning "event mode" data on during a slew, and sending it down on next TM pass, BAT imaging tools can be run on each 0.2sec data segment to make 500 images in given band for a 100sec slew and then co-add for sky image (not trivial…). *BATSS provides the only high-time res. imaging from Swift/BAT; all other data (except GRBs) comes down as **5min** integrations!*

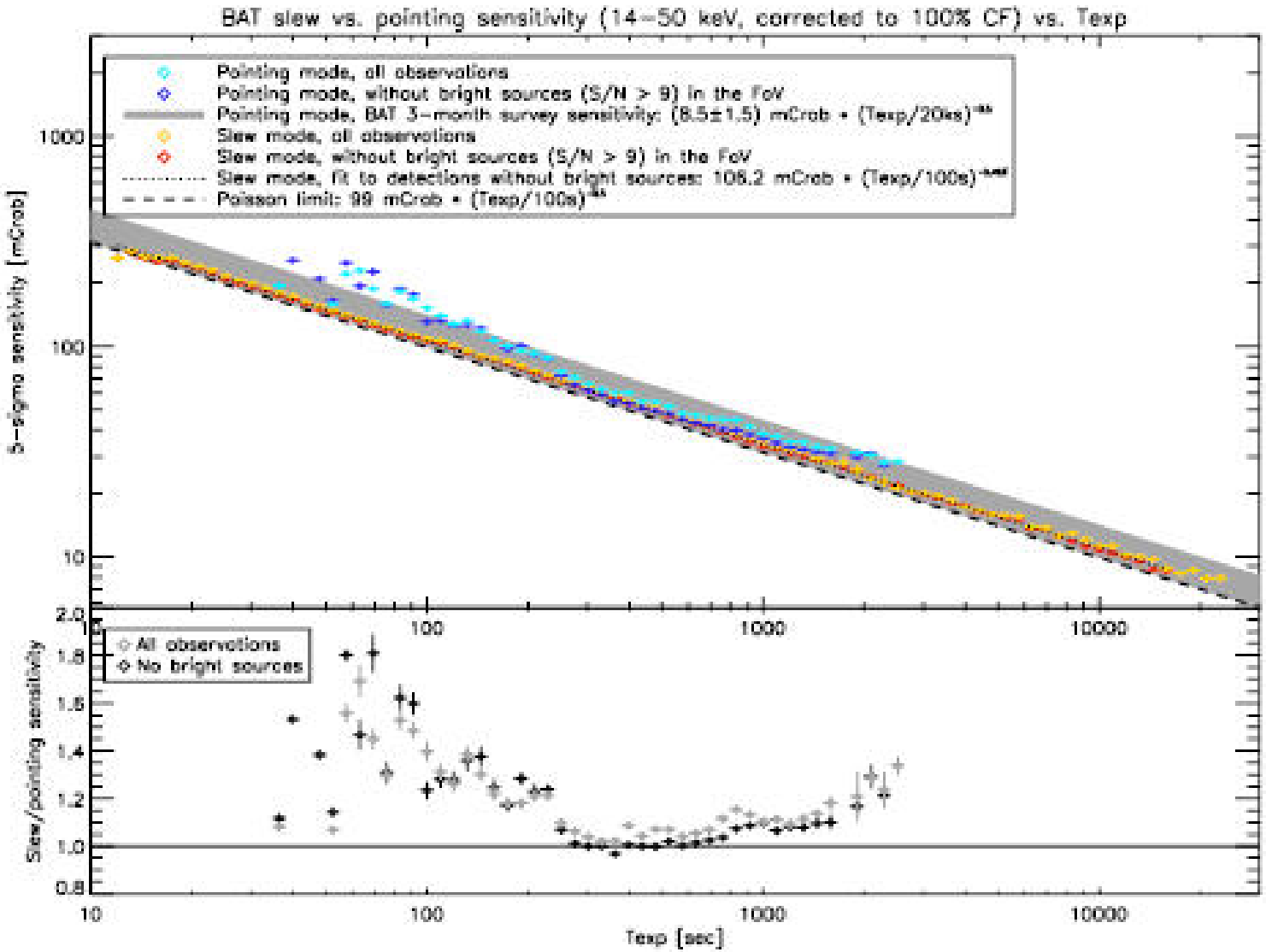
- BATSS images formed in 2 bands (S= 15-50keV and H= 50-150keV) and BAT detect run on each separately as well as on co-added broad band image (B = 15-150keV)

- **~90% sky coverage/day optimizes GRBs and search for PopIII GRBs(?), possibly ~0.5d duration (!) events (Meszaros and Rees 2010)**

- **Re-processing of all BATSS catalogs (single slews, orbits, day, week, month, year slew sums) coming *SOON* on CfA website**

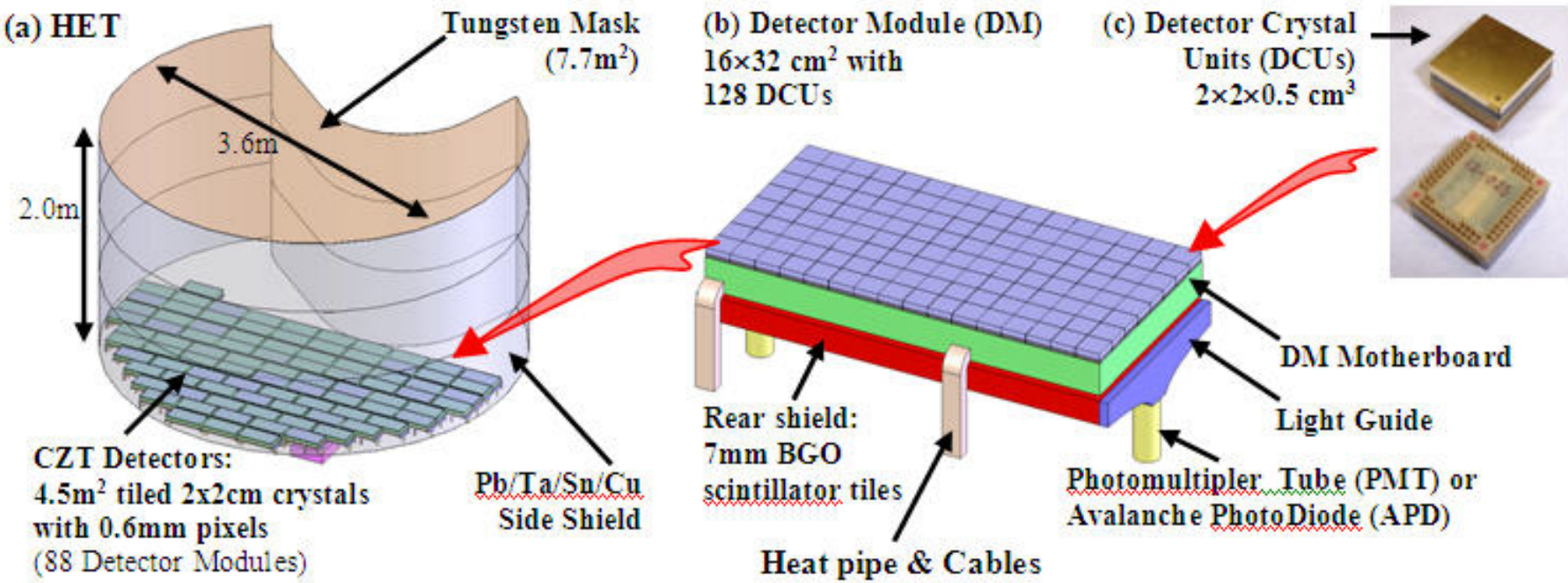
See Copete et al (2010a,b) for description of BATSS processing; Copete et al (2010c,d) for GRB results and new transients, and Grindlay et al (2010) for Blazars

BATSS has demonstrated **enhanced** coded aperture imaging sensitivity vs. Normal BAT (or INTEGRAL) pointings



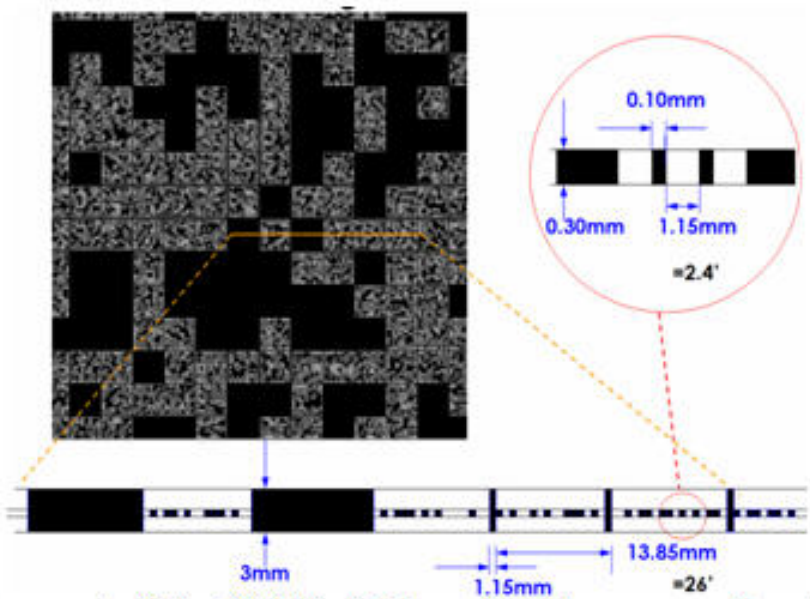
Factor of ~1.2-1.6 enhanced sens. For T_{exp} <200sec; factor ~1.3 for T_{exp} >2ksec

Design of the Mission…
High Energy Telescope (HET) imaging CZT detectors



(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 Summary



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.

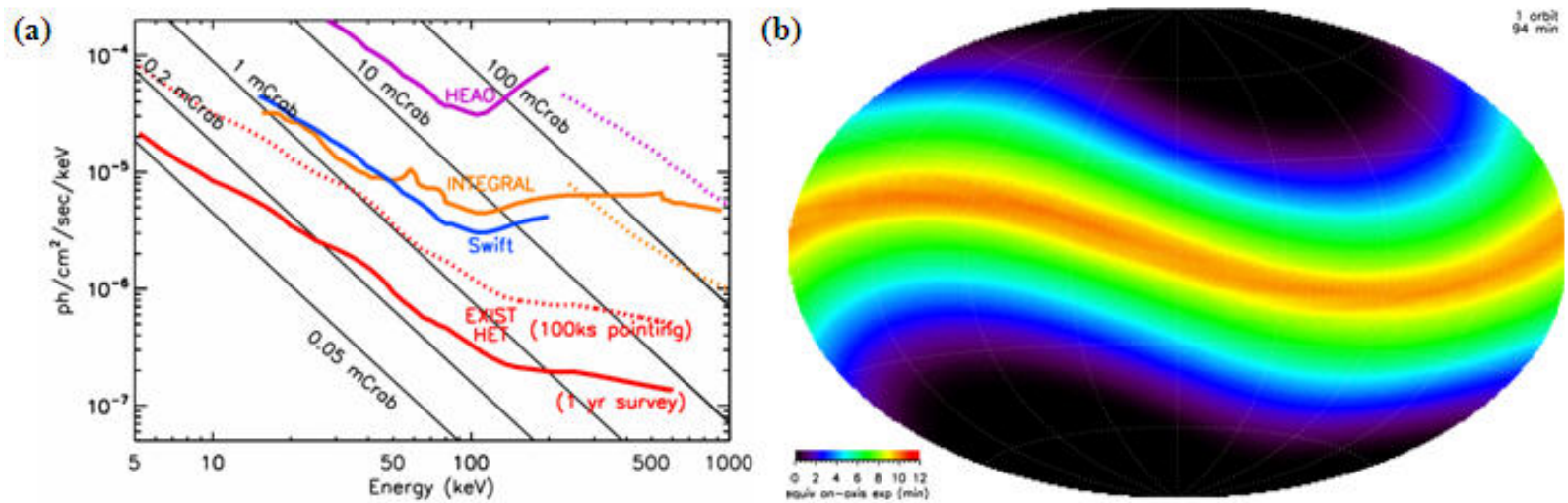
Parameters	Values
Telescope (coded-aperture)	4.5m^2 CZT (0.6mm pix, 11.5Mpix) 7.7m^2 Tungsten mask
Energy Range	5 – 600 keV (imaging CZT) 200 – 2000 keV (BGO for GRBs)
Sensitivity (5σ) (~1y survey)	0.08– 0.4mCrab (<150keV) 0.5–1.5mCrab (>200keV)
(10s on-axis)	~24mCrab (<150keV)
Field of View	90° × 70° (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

Additional *new GRB science from* HET:

- Image triggers and *fast FFTs from 2-scale mask*: well-defined triggers
- E_{peak} from 5-600keV imaging CZT & 0.1 – 3MeV BGO: *Amati reln. with z's*!
- Polarization in GRBs: ≤10% for Fluence ≥10^{-6} erg/cm^2 : **test for *EM jets?!***

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"

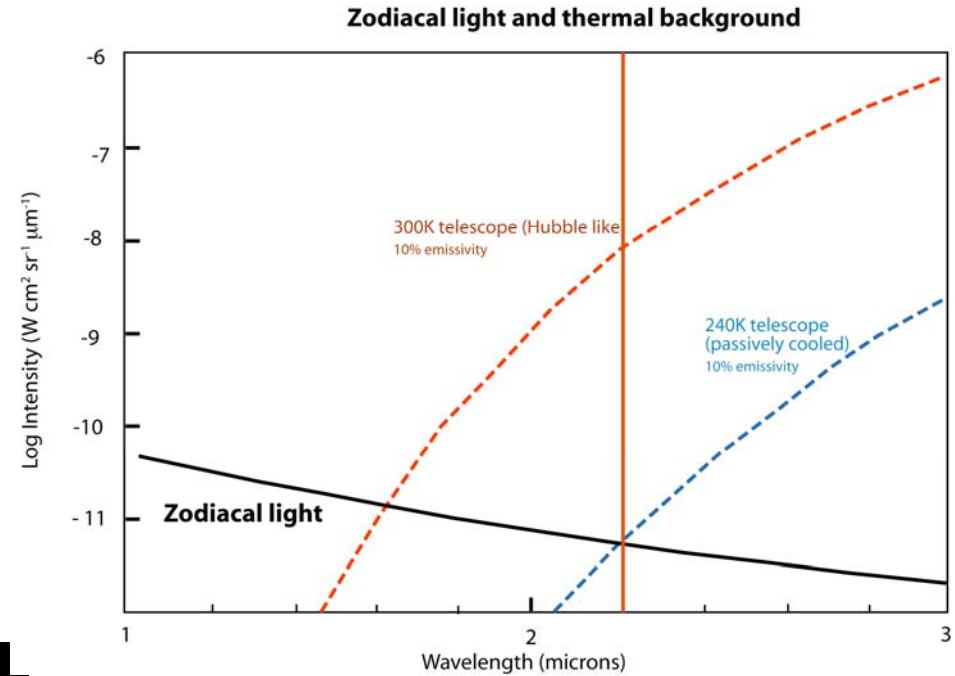
- **0.07mCrab = 7 x 10^{-13} cgs, *(~5-10X below Swift/BAT)* for HET (5-100 keV)**
- **~0.5mCrab = 1 x 10^{-11} cgs (*~20X below INTEGRAL/IBIS)* for HET (100-600 keV)**
- ***~600 GRBs/yr (~6X Swift/BAT rate) and ~30,000 AGN: IRT redshifts for most!***
- ***unique* ~10% duty cycle coverage on any source,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

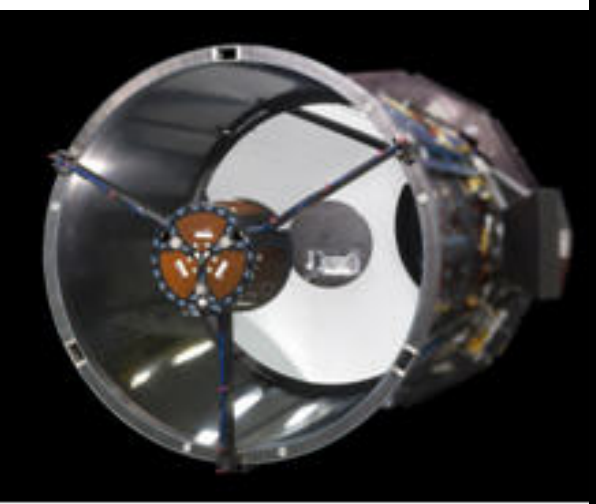
EXIST IRT: *1.1m cold telescope for* 0.3-2.3μm imaging & spectra

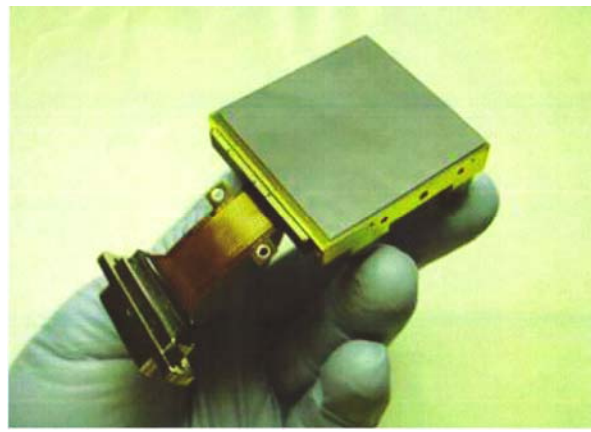
- IRT mirrors (primary and secondary) **passively cooled to -30C** (radiator) give zodiacal light limited backgrounds: *IRT is* ***~10X faster than Keck*** *at 2μm and has sens. limits only 2mag brighter than JWST!*

  ***EXIST*-IRT imaging: AB(JHK) = 24 in 100s**
  = 29 in 1Ms

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



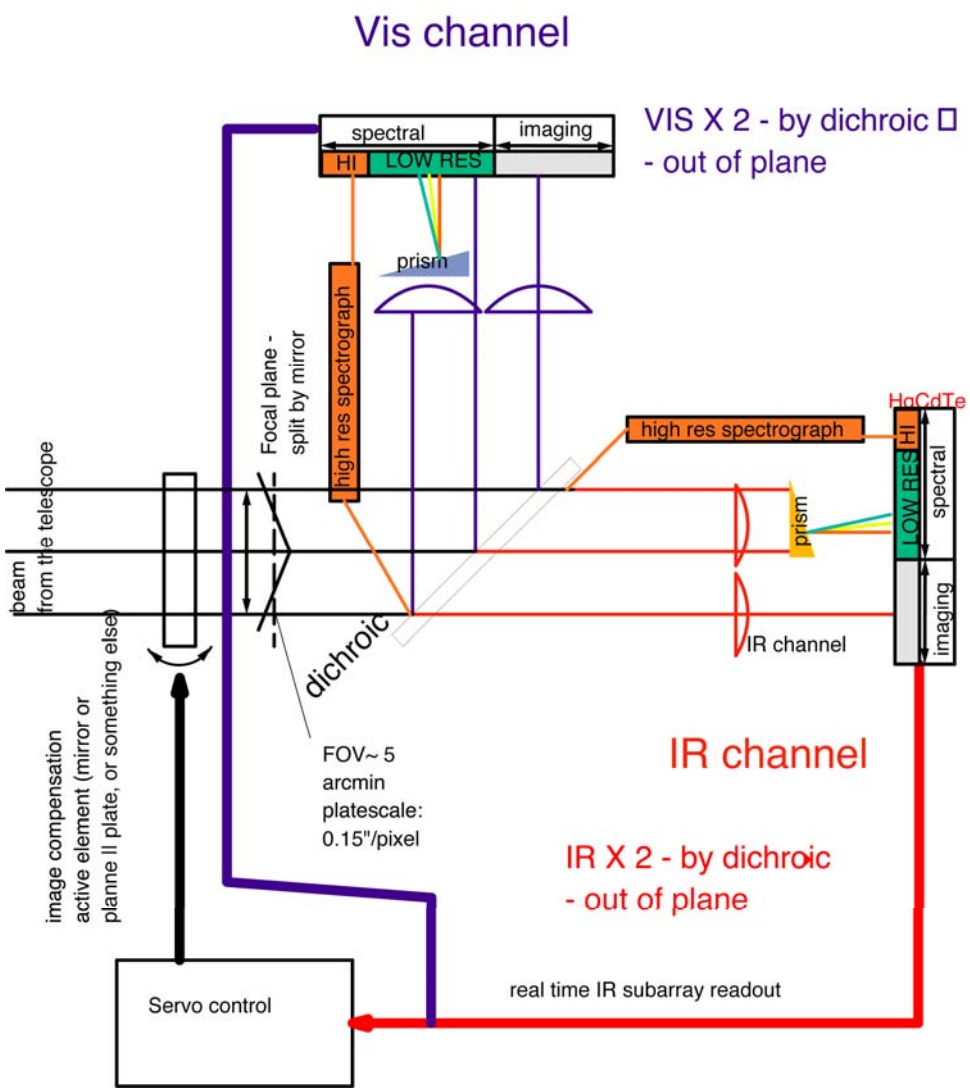




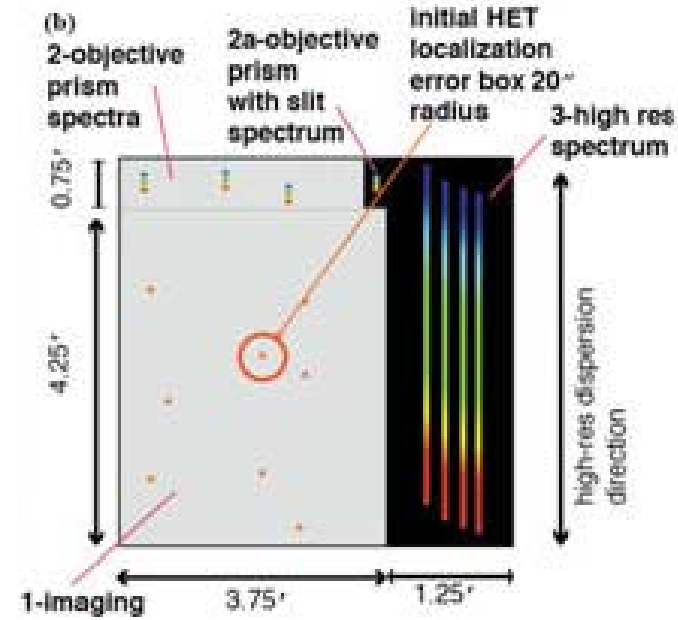
IR: HgCdTe +H2RG detectors (2K x 2K)
Vis: CMOS+H2RG (2K x 2K); pix size 0.15”

IRT telescope and instrument **layout**

(H. Moseley & A. Kutyrev,GSFC)



Imaging/Spectroscopy Focal Plane:
Simultaneous 4-band imaging & spectra



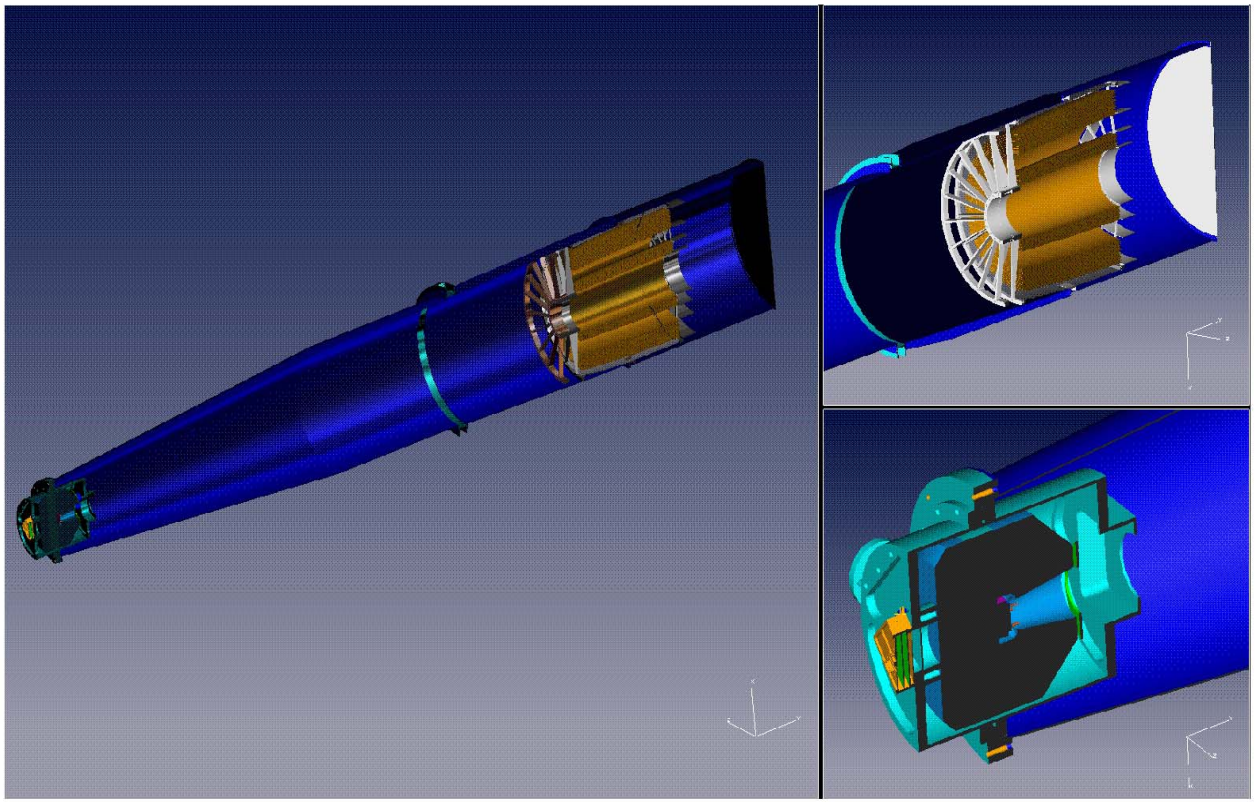
EXIST-IRT Parameters

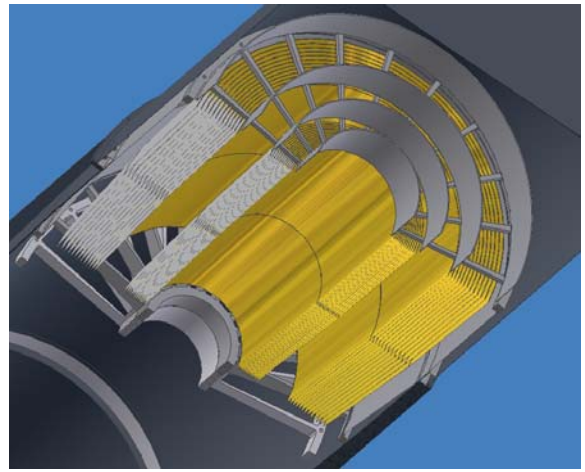
Telescope	1.1m aperture Cassegrain		
Ang. Res.	≤0.3" PSF (0.15"/pixel pl. scale)		
Spectral Bands (4)	0.3 – 0.52, 0.52 – 0.9μm (*HyViSi*) 0.9 – 1.38, 1.38 – 2.2μm (*H2RG*)		
Mode	**Field of view**	**Spec. Res.**	**AB @ S/N≥10σ (int. time sec)**
Imaging (4 bands)	3.75'x4.25' (16arcmin^2)	~3	Vis: 24 (100 sec) IR: 24 (200 sec)
Low Res. Obj. Prism	3.75'x0.75' (1.8arcmin^2)	~30	Vis: 22 (200 sec) IR: 22 (700sec)
Low Res. Single Slit	20" long slit	~30	Vis: 22 (150 sec) IR: 22 (300sec)
High Res. Single Slit	4" long slit	3000	Vis: 19 (1500sec) IR: 19 (3000 sec)

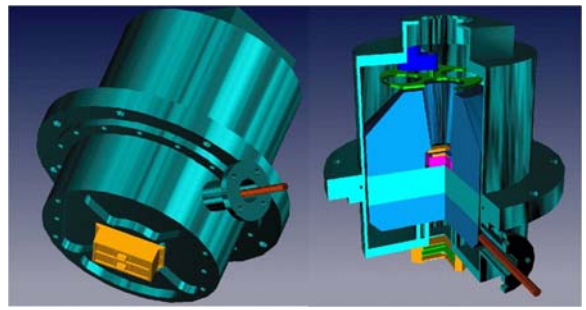
***EXIST-IRT* competitive with JWST! Unique for surveys!**

At same S/N, fainter AB ~ $T_{exp}^{1/2}$ (ZL bkgd.)

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







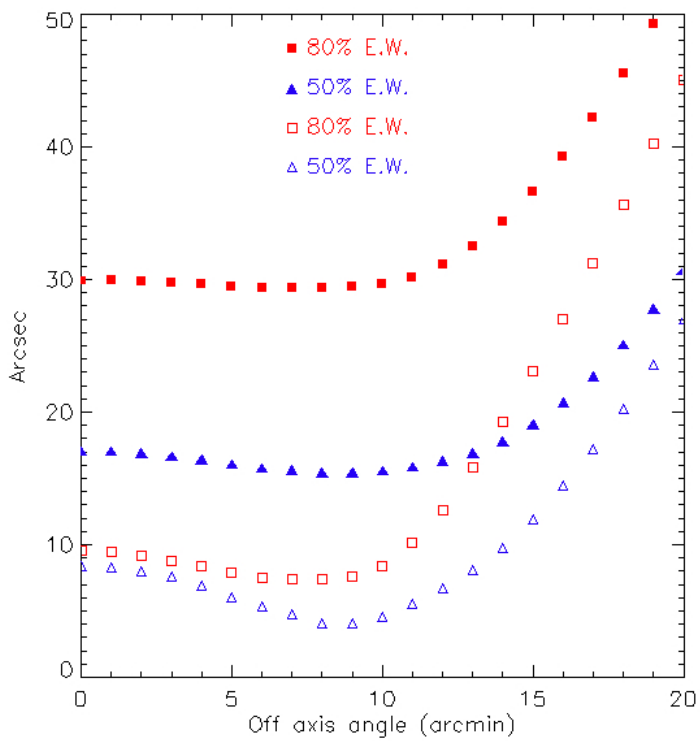
- Wolter I telescope: 26 Ni shells, 3.5m focal length, 60cm max. diam. shell
- 950 cm^2 at 2 keV & 120 cm^2 at 8 keV; 20' FoV; ≤15" PSF (HEW, on axis)
- 4 x 4 cm^2 CCD (1K x 1K; 2.3" pixels); *Sens.: 2 x 10^{-15} erg /(cm^2 s) in 10 ks*
- 40 kbs telemetry; 1msec temporal resol. (timing mode); -110C op.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

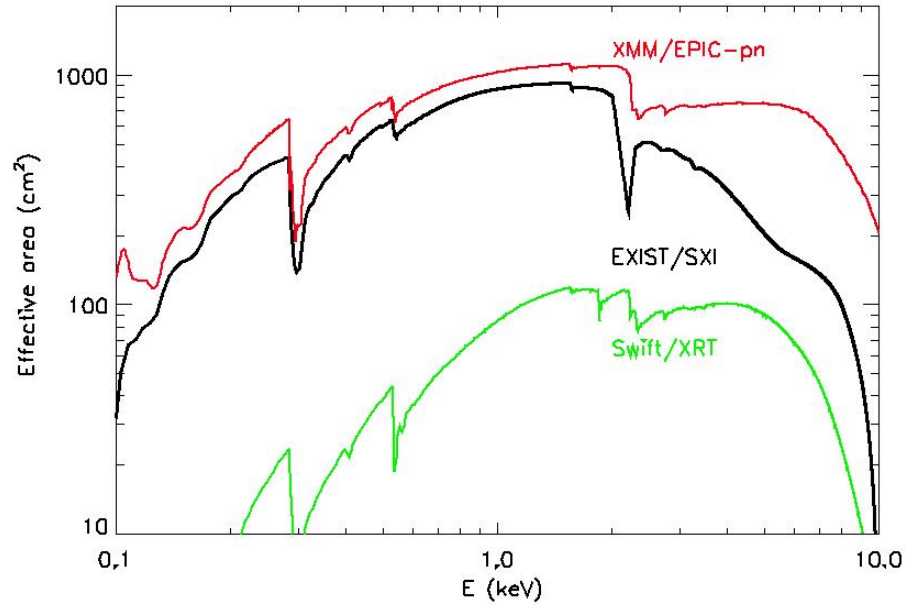
SXI effective area & Resolution and Parameters

- EXIST-SXI comparable to XMM-pn (single telescope). Can match 5-10 keV sens. with addtl. low-mass shells.

- 30arcmin FoV; ~15" HEW resolution

- **SXI** ***scanning survey (2y):*** ***Half-sky, 5 x 10^{-14} cgs, or comparable to eROSITA***





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 arcmin², 3×3 cm²
Energy Res.	E/ΔE = 47 at 6 keV
Readout speed	5 – 10 ms (1 ms)
Instrument effective area	950 cm² (1200 cm²) at 1.5 keV, >100 cm² at 8 keV
Sensitivity (10^4s)	2×10^{-15} (1.5×10^{-15}) erg cm^{-2} s^{-1}

.

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 ~1200 GRB redshifts; then 3y HET/IRT **pointings** on ~40,000 survey AGN for redshifts and timing while continuing GRB survey and followup IRT spectra on additional ~1900 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)*

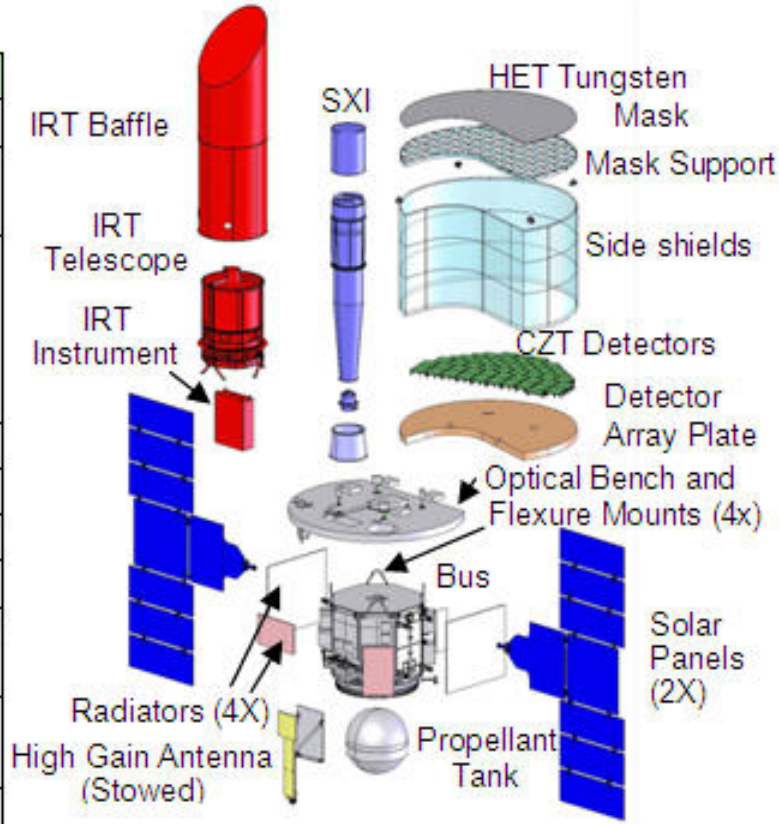
- *GI program similar to Fermi and Swift (Survey) & Chandra (pointings)*

EXIST mission concept: Summary after ASMC Eng. Study (carried out at GSFC's IDL and MDL in Oct. – Dec. 2008)

EXIST Observatory Mission Parameters

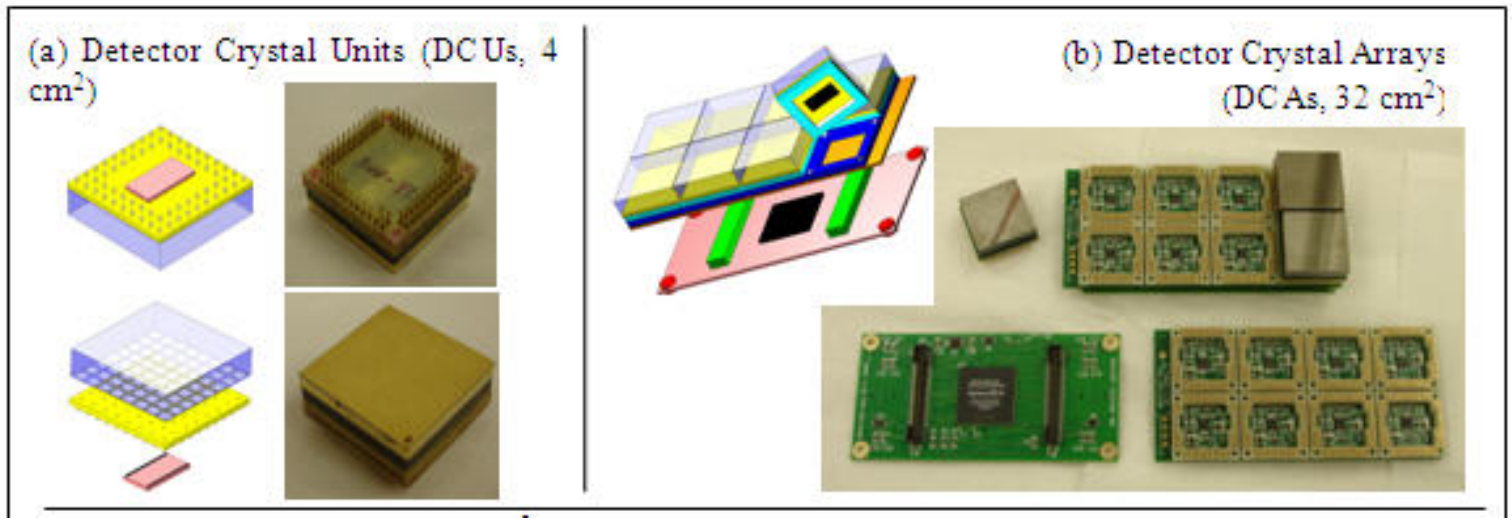
Parameter	Requirement	Capability	Margin
Orbit	600 km, ≤ 22°	Comply	N/A
Launch Mass Atlas V-401	5932kg. CBE+ Contingency	8000 kg @ 22°	35%
Pointing Control Knowledge Stability	 10″ 5″ (3σ) <2″	 5″ < 3″ (3σ) < 1″	 100% 67% >100%
Slew Time	45° in 180 s	Comply	N/A
Avg. Power	2803 W	3645 W	30%
Data Storage	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

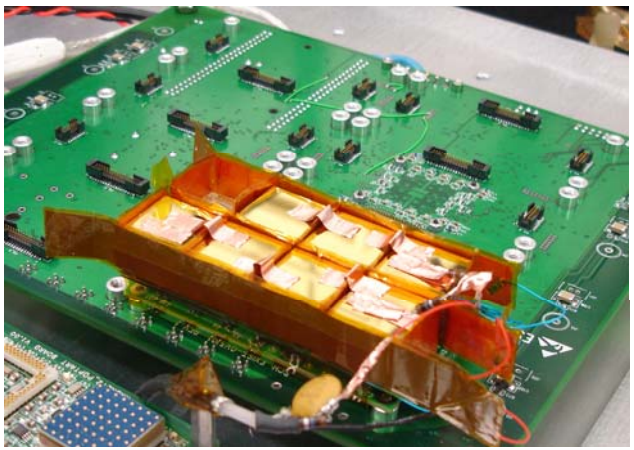
*TDRS only requires 0dB margin due to large system margins.



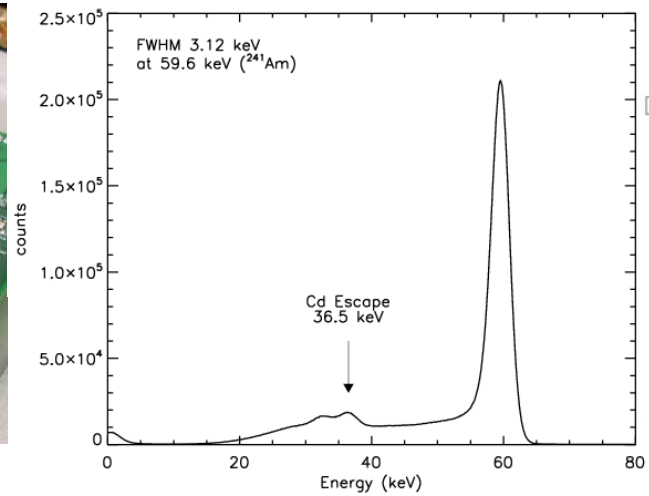
EXIST exploded view; the Observatory uses a modular instrument/bus design.

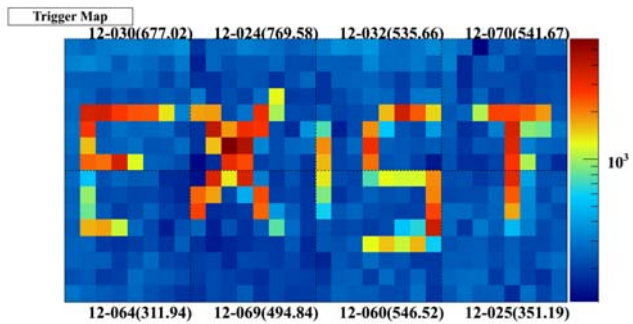
HET Detector develoment: building a large area CZT detector/telescope prototype *ProtoEXIST1, successfully tested on first balloon flight*





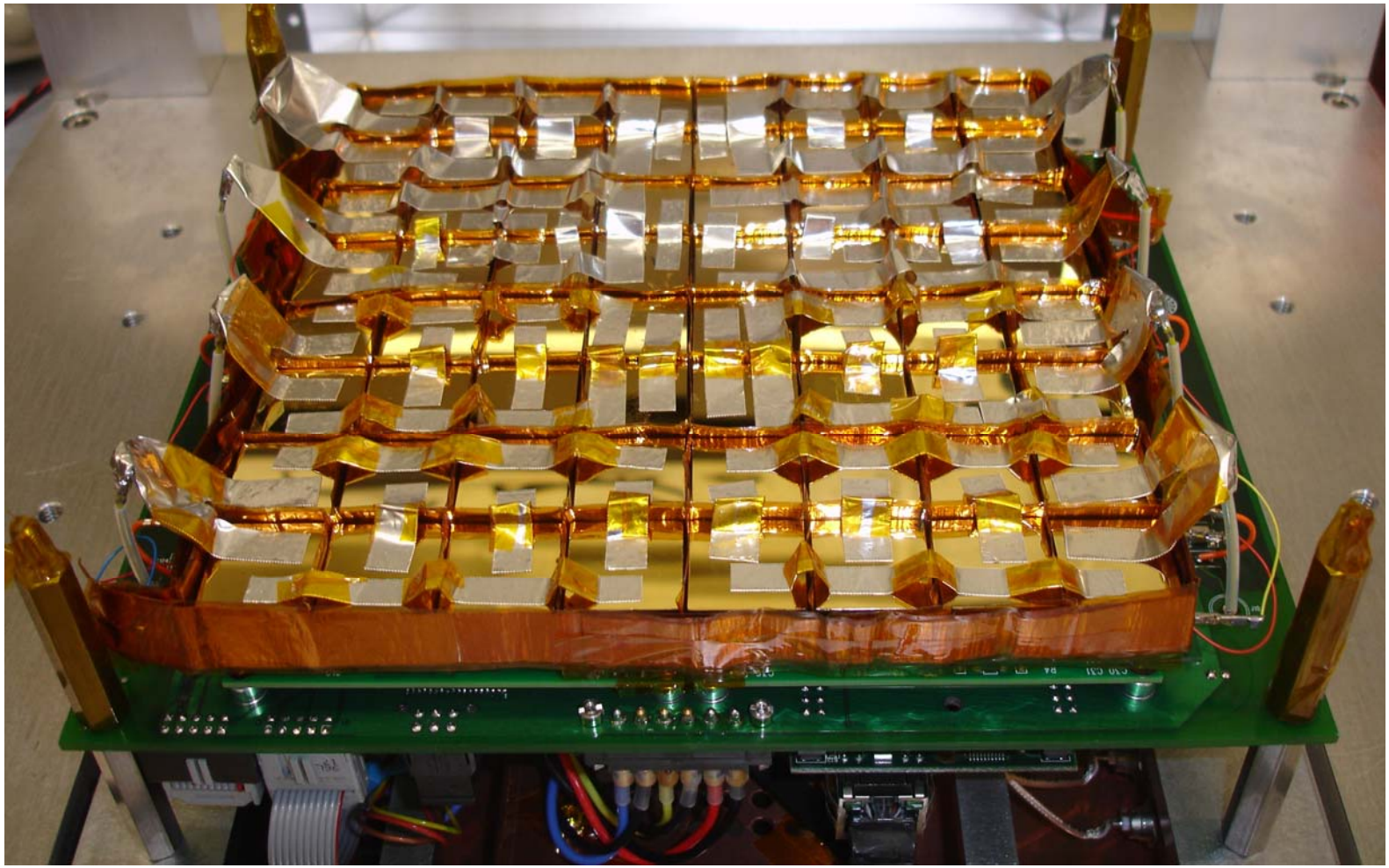
Test flight DCA board (1 of 8)





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

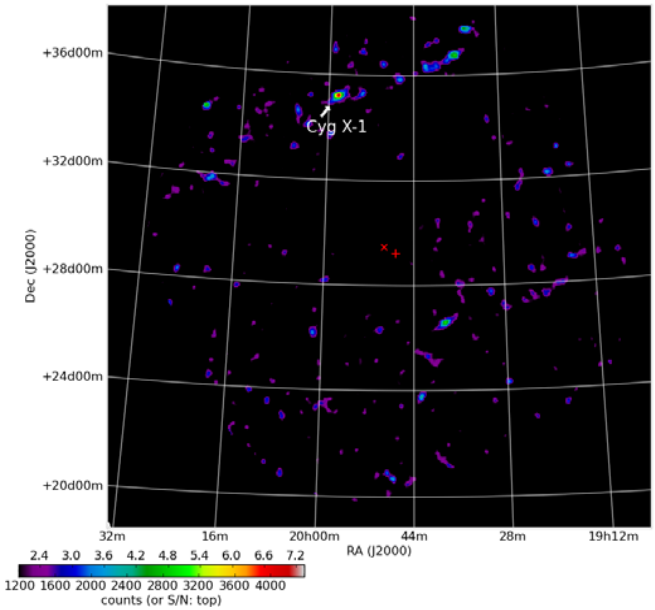
Fully integrated first ***ProtoEXIST1*** detector array



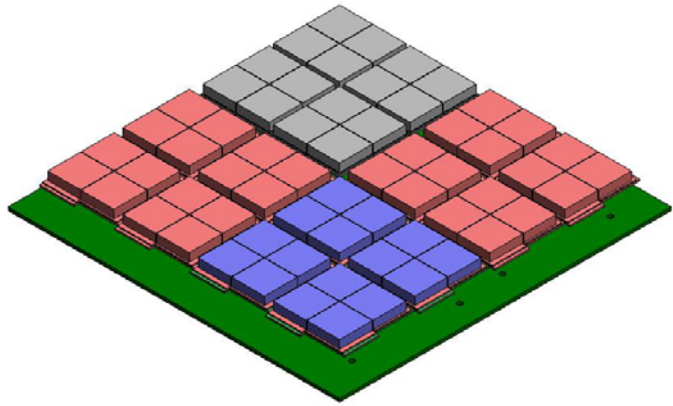
8 x 8 array of close-tiled (0.4mm gaps) CZT crystals (20 x 20 x 5mm), each with 8 x 8 pixels (2.5mm) for 256cm^2 imaging through coded mask

ProtoEXIST1 in Gondola & First Light CygX-1 image, and on to ***ProtoEXIST2-3*** full HET imager (2.4' resol.) prototype:

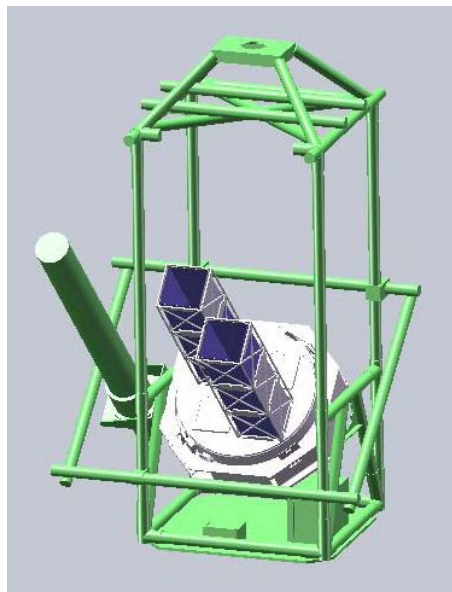
ProtoEXIST1 payload for first Ft. Sumner flight, Oct. 2009



20 x 20deg image, 20' resol., from short exp. on CygX-1on First flight of *ProtoEXIST1*



ProtoEXIST2-3 detector with 0.6mm pixels (2.4' resol.). **P2** vs. initial **P3** vs. final (closer tiled) **P3** Quadrants.



P2-3 & *P1* (UL) for 2012 flight

EXIST Team for *ASMC Study* & Astro2010 submission

- *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/GD (Fishman/Conte, *SC-Mission*), Yale (Coppi, *AGN*)

- *Industry Collaborators:* General Dynamics (*S/C*), ITT (*IRT*)

- *Co-I Institutions for Study (many members):* Caltech, Clemson, GSFC, MSFC, SAO, Santa Cruz, Washington U., more …

- *International partner Institutions:* **Italy** (Milan/Brera, Rome, Bologna); also, *France*, Germany, Greece, Israel, **Japan**, Netherlands, and UK. If recommended by Astro2010, will explore ***ESA-Soyuz launch***

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

EXIST Summary and Prospects

- *Highest z stellar universe only measured via GRBs*: >4-6X *Swift* rate; ***SXI*** essential for rapid ***IRT* IDs & redshifts** for ~2500 GRBs and opt-IR (0.3-2.2μm) **high-res (R=3000) spectra** to constrain cosmic structure (EoR, Z, dust, etc.) back to PopII.5 or Pop III (!)

- Obscured, dormant & *First (?) SMBHs* best studied with ***HET*** imager and ***SXI*/*IRT***: conduct *BH census/evolution & accretion vs. stellar 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-SXI-HET telescope*** enables wide range of Science (stellar flares to early Universe) for GI prog.

- ***EXIST*** **needs no new technology and *could* launch** in ~2017 *if recommended by Astro2010 (Decision in Aug. 2010).* Collaboration with Italy+(& ESO-Soyuz launch?)

International collaboration and participation encouraged!

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