

From *EXIST* and *BATSS*, to  
Future HEA-TDA Prospects...

My tribute to Neil...

Josh Grindlay

## Some early remembrances...

- Discussing preparations for our first Harvard coded aperture telescope (EXITE) balloon flight in the 1988 SN87A campaigns in Alice Springs (Neil had been there for GRIS the preceding Fall, as I recall).
- Discussing SIGMA (on Granat) sources in the 90's: we needed more and better coded aperture imaging to better explore the Hard X-ray sky!
- Preparing our first presentations for the 2000 Decadal Survey and its "Black Hole Finder" program for what was to become *EXIST*

## More remembrances...

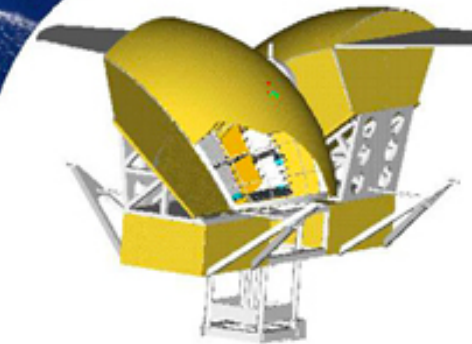
- Initial (2002-3) design of *EXIST* –meetings at GSFC; ISAL and IMDC runs
- Walking on the beach at a conference at UCSB/ITP and discussing how forthcoming *Swift* mission could test scanning imaging sensitivity
- Planning, designing the BAT Slew Survey (BATSS) at the 2006 HEAD mtg.
- Improving the *EXIST* design for 2010 Decadal, with XRT & Opt-IR telescope
- Talking science on hikes/walks at conferences (Bremen, Milan, Lake Como...) and what was needed for post-*Swift* high-z GRBs and general HEA-TDA:
  - *SALSO* & Probe proposals for *TSO*<sup>1</sup>: 1.5m telescope (0.5–5 $\mu$ m) in Geosync over *LSST*
  - *4piXIO*. a proposed future SmallSat SMEX for *simultaneous* 3-200 keV 4pi imaging for GRBs, GWs now under development for a 12U CubeSat (Eng. Model) prototype

1. Time-domain Spectroscopic Observatory (*TSO*) 2. 4pi X-ray Imaging Observatory (*4piXIO*)

## The beginnings of *EXIST*

- GRO/*BATSE* discovered the remarkable (since unexpected) isotropy of GRBs – yet the community was 50-50 split they were Extra-Galactic...
- The WFC coded aperture X-ray telescope on BeppoSAX located the GRB970508 (to  $\sim 10$  arcmin) enabling the prompt detection of its optical afterglow and Keck spectra revealing it was at  $z = 0.83$
- *EXIST* was proposed to the 2000 Decadal Survey for Study as an Intermediate Mission for a large area full-sky Hard X-ray imager for high- $z$  GRBs and Blazars
- Likewise, several MIDEX proposals were submitted (c.1998) for a GRB imaging mission from which Neil's incredibly successful *Swift* was chosen

## Astro 2000: *EXIST* recommended for Study as an ISS Payload



### Decadal Survey Projection AANM, pg 98

Project: Energetic X-ray Imaging Survey Telescope

Description: Hard X-ray Telescope  
International Space Station  
attached payload,  
*Full sky scanning* at ISS local  
zenith

*Primary instrument:* 8m<sup>2</sup> CZT  
High Energy Telescope (HET)  
Energy response = 5 – 600 keV  
FoV = 40 x 120 deg  
Imaging resolution = ~5 arcmin  
Source positions ≤1 arcmin

Status: Preliminary Concept

First Light: 2005 on ISS

US Cost: \$150 million (FY2000 dollars:  
HET instrument only;  
Launch & power/telemetry all  
provided from ISS program)



Post-2000 Decadal Survey

## EXIST Mission Reference Design

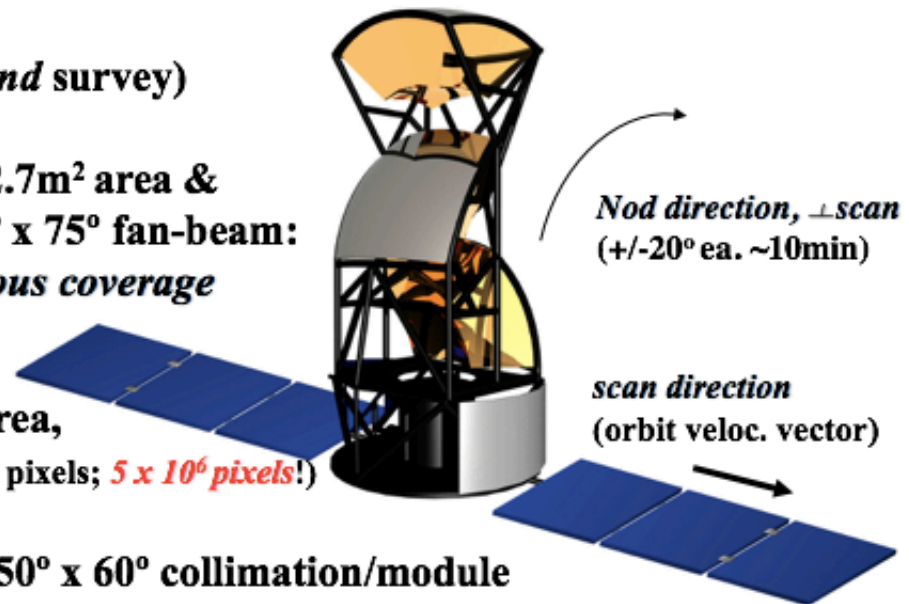
### *Free-Flyer (500km, $i \sim 22^\circ$ ):*

- Zenith pointer (Survey mode)
- 3-axis pointer (Observatory *and* survey)
- 3 coded aperture telescopes (2.7m<sup>2</sup> area & 60° x 75° each) for 8m<sup>2</sup> & 180° x 75° fan-beam: full sky/orbit & >20% continuous coverage

### *Mission Parameters:*

- CZT tiled arrays: 8m<sup>2</sup> total area, (20x20x5mm crystals, ea. with 16x16 pixels;  $5 \times 10^6$  pixels!)
- Passive and active shielding; 50° x 60° collimation/module
- Mass, power, telemetry: 8500kg, 1400W, 1.5Mbs (X-band)
- Delta-IV launch

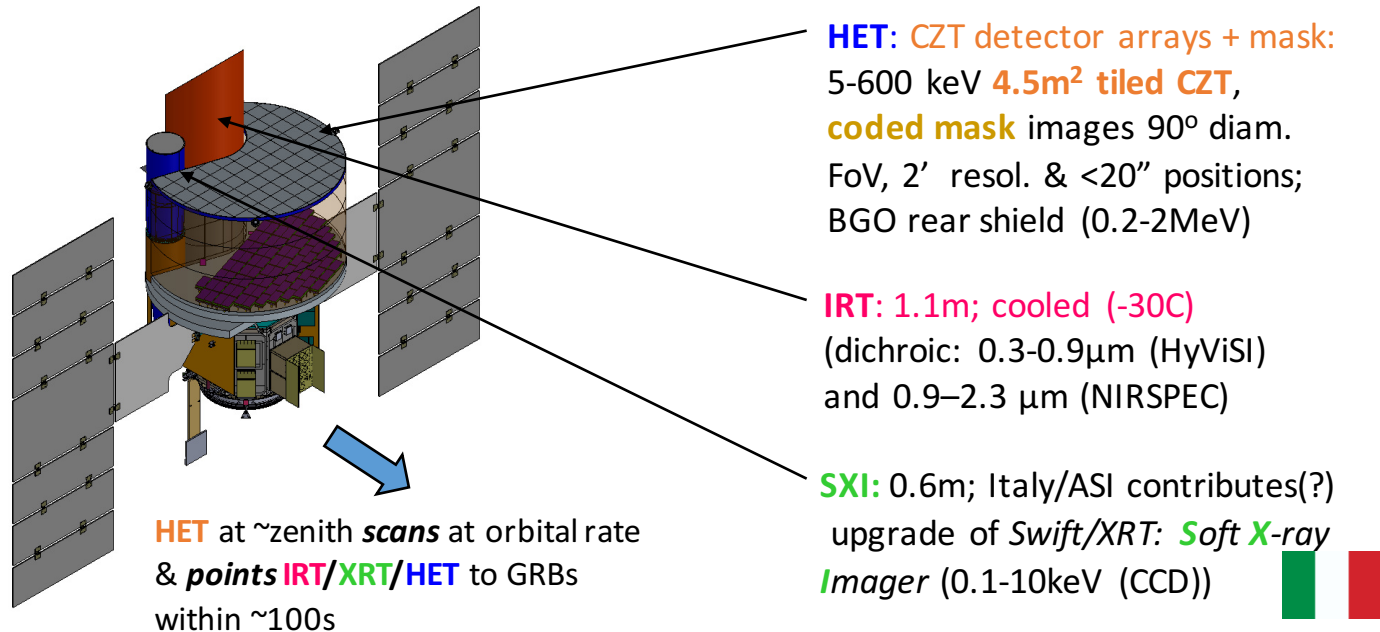
Reference Design: IMDC (Nov. '01) and addtl. work



**EXIST**

## Astro 2010 *EXIST* Concept:

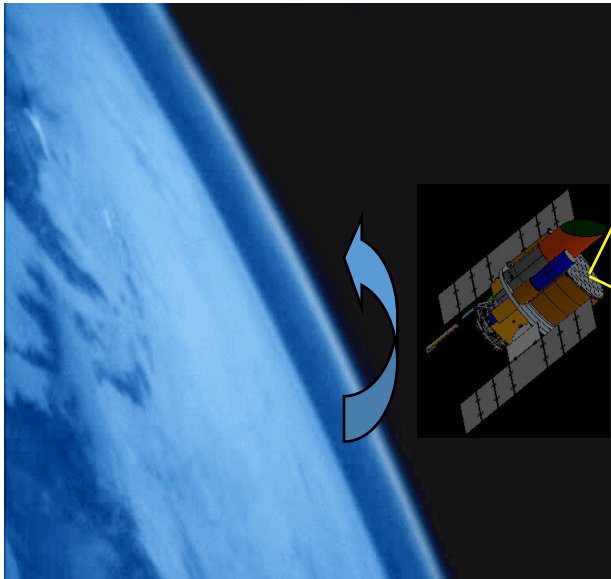
A Hard X-ray, full-sky, deep imaging Survey and IR/X-ray followup is required for the Black Hole Finder Probe to *EXIST*



## 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 would *EXIST* operate?



1. Zenith ( $\pm \sim 30^\circ$ ) **scan** of  $90^\circ$  FoV of HET at orbital rate to cover  $\sim$ half-sky each orbit
2. Imaging in  $90^\circ$  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

Neil was key to **EXIST** being ranked by Galaxies across Time Panel of Astro2010 as Highest Science ... But Astro2010 costed it at \$2.2B... too massive to exist



# BAT Slew Survey (BATSS)

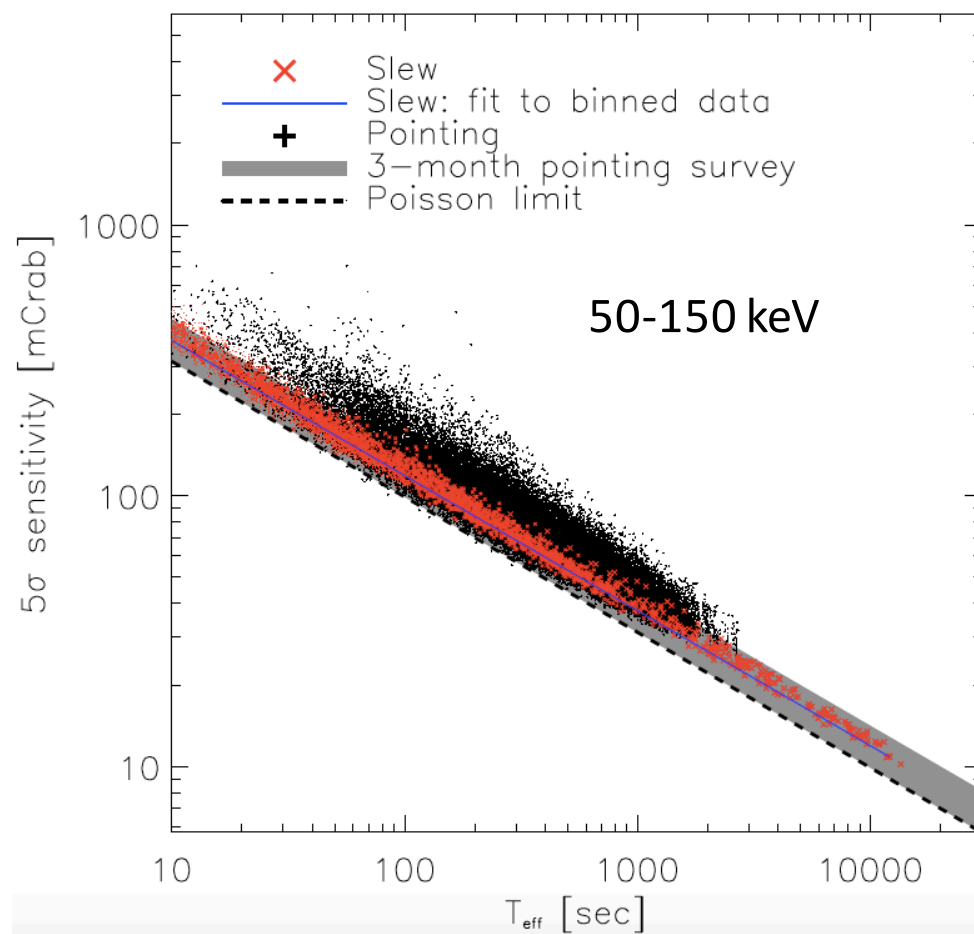
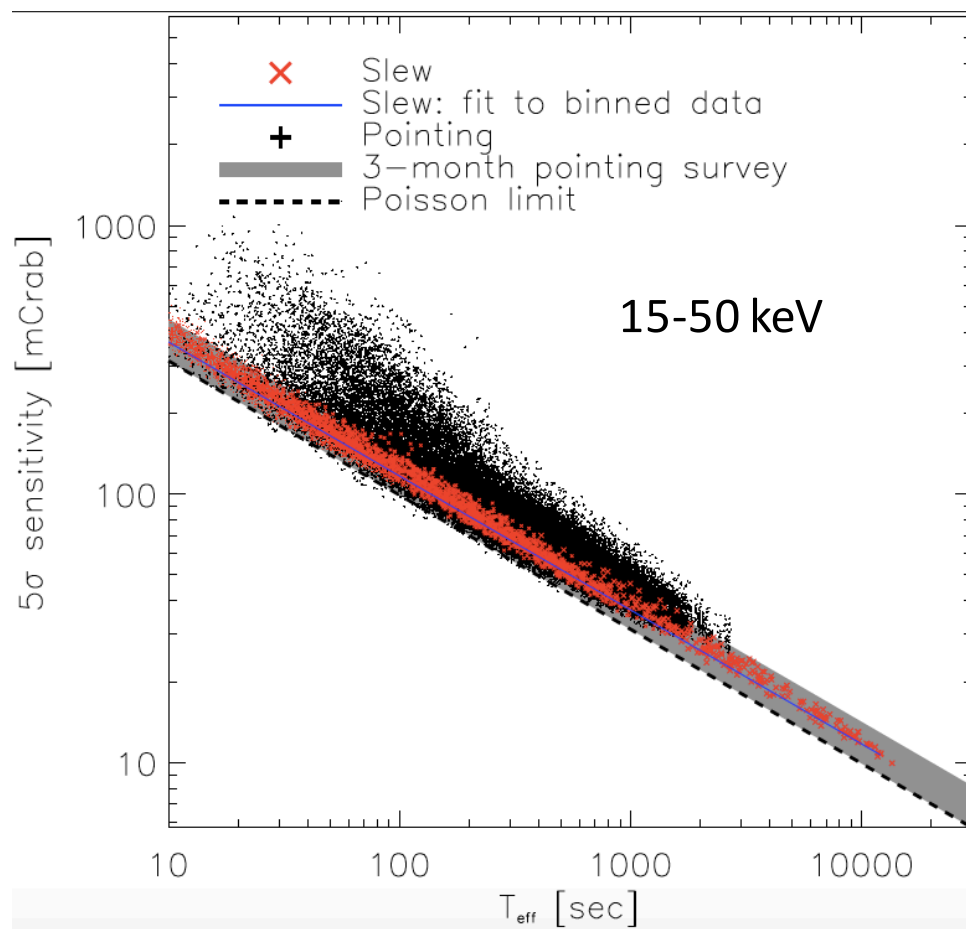
- Neil was a strong supporter (as well as Scott Barthelmy) of BATSS, to explore the sensitivity of scanning coded aperture imaging (i.e. **EXIST**) and to recover more GRBs (and transients) from Event Mode data during Swift slews.
- BATSS operated from Mar 2007 – June 2012, with analysis of 58,557 slews (out of 186,201 total) brought down (5.2Msec total exp.) and processed by the BATSS Pipeline at Harvard.
- 19 GRBs discovered in BATSS slews + 9 GRBs first detected in BATSS and then in Pointing at end of slew. No new transients.
- 4 papers to be submitted to ApJ soon, *dedicated to Neil*.



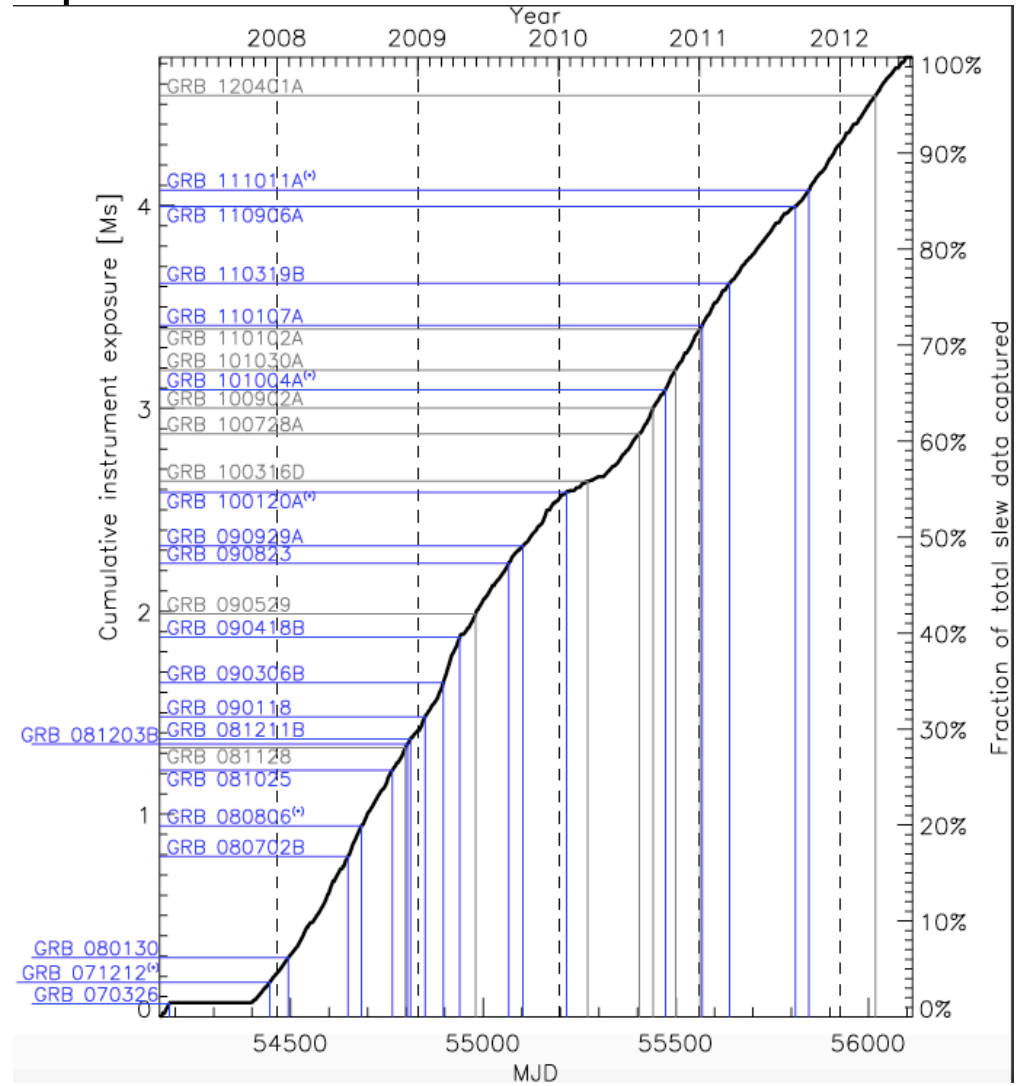
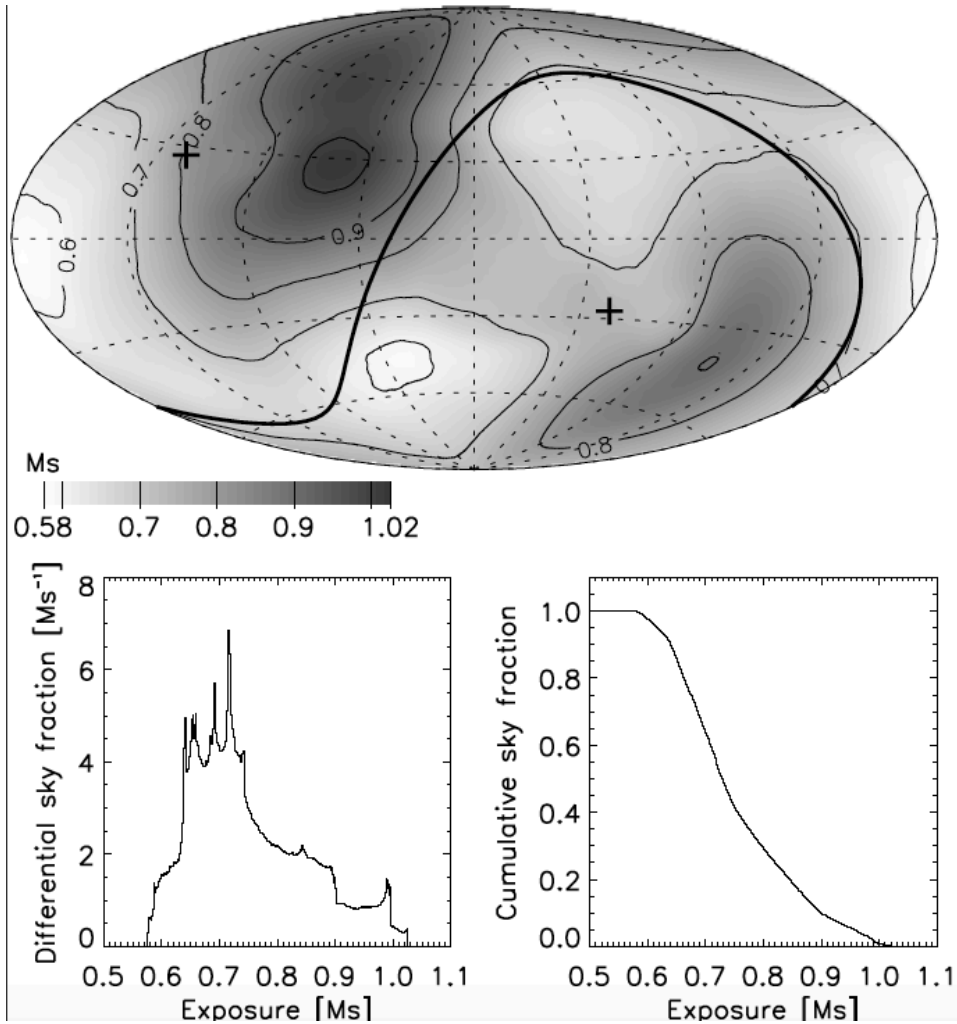
Antonio Copete did his Harvard Ph.D. Thesis on development of BATSS.

He has been involved with other projects since his Thesis but is now finishing 4 papers on BATSS

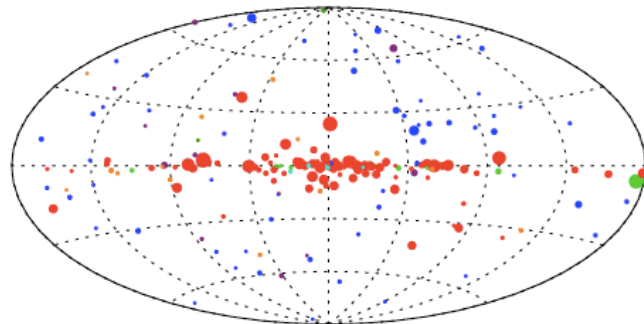
# Slews (scanning) average over noise for $\sim 10\%$ increased image sensitivity



# BATSS Galactic coverage, exp. time & new GRBs

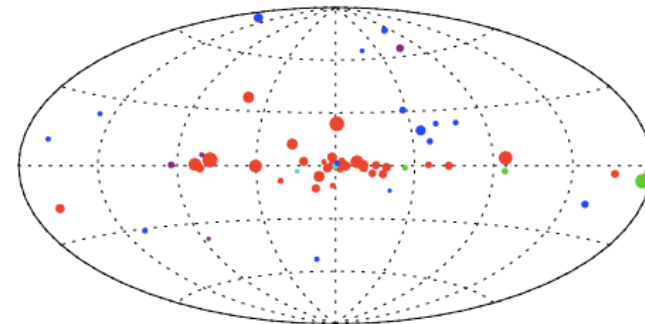


# BATSS Sources detected (from Slews) over full 5y survey



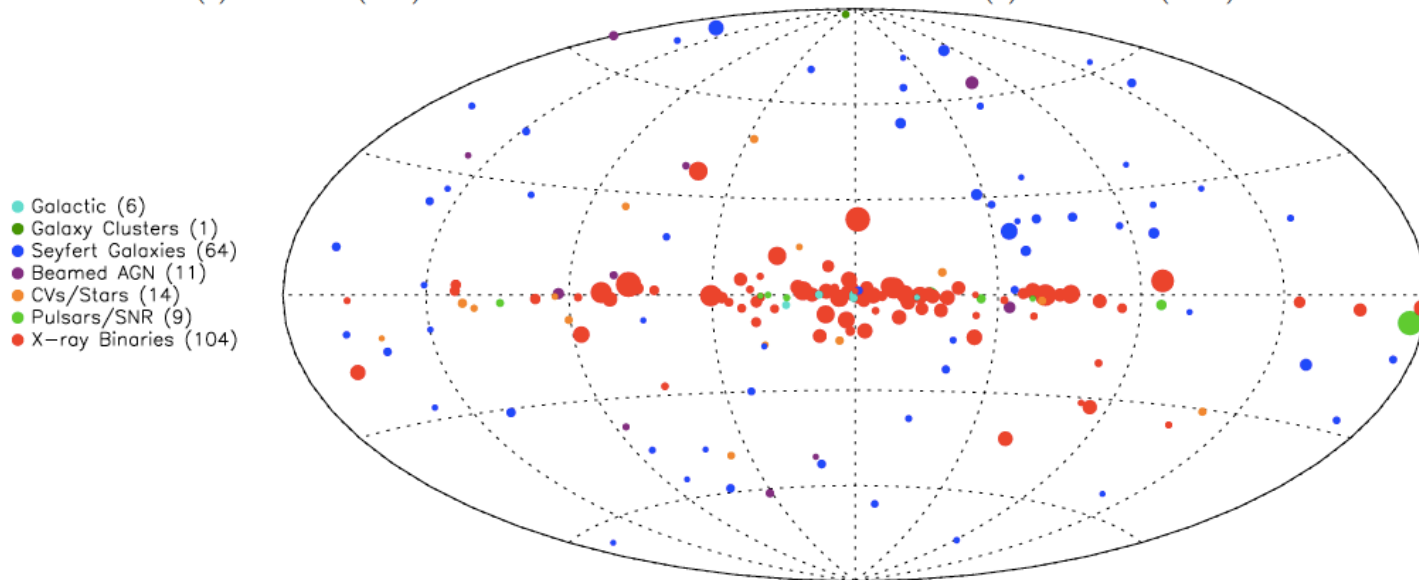
● (6) ● (2) ● (59) ● (11) ● (15) ● (9) ● (104)

(a) 15-50 keV (Soft)



● (2) ● (0) ● (16) ● (4) ● (0) ● (3) ● (36)

(b) 50-150 keV (Hard)



- Galactic (6)
- Galaxy Clusters (1)
- Seyfert Galaxies (64)
- Beamed AGN (11)
- CVs/Stars (14)
- Pulsars/SNR (9)
- X-ray Binaries (104)

(c) 15-150 keV (Broad)

## Current HEA-TDA science goals (shared by Neil...)

- GRBs as cosmological probes of SFR(z), EoR(z) and PopIII BHs
- ALIGO/VIRGO (ALV) NS/BH mergers – are they “Type 2 SGRBs” ?
- Do *some* ALV BH-BH mergers produce GRBs ?
- What fraction of TDE’s produce Non-thermal Jets and why ?
- How can SMBH mass vs. z be traced by AGN flaring ?

## These could be answered by 2 Mission Concepts...

- GRBs at  $z > 9$  are rare ( $< \sim 1/350$ ) so  $4\pi$  GRB imaging needed *and prompt/deep IR imaging and spectroscopy from space is needed*
- Upcoming ALV BH-NS, NS-NS mergers are also rare so  $4\pi$  GRB imaging *and prompt/deep IR imaging and spectroscopy from space is needed*
- *And a long list of other HEA-TDA “Hot” goals: AGN, TDEs, BH-transients, ...*
- **4piXIO** as a **SMEX** and **TSO** as a **Probe class** mission are needed...

# 4piXIO: 4 $\pi$ X-ray Imaging Observatory, 32 SmallSat SMEX?

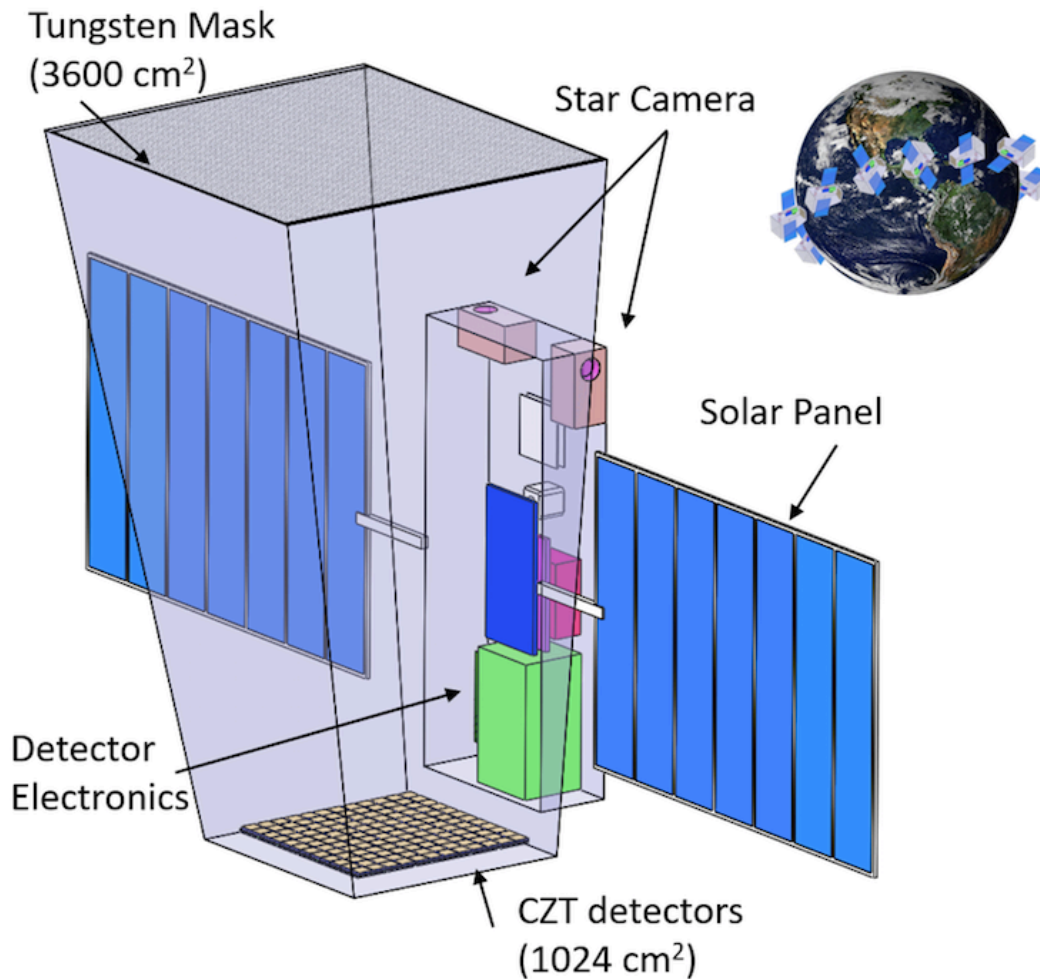


Table 1: Single <u>SmallSat</u> and Mission Parameters	Values
Total Mass	120 kg
Payload Mass	90 kg
Volume	Taper (45–60) <sup>2</sup> ×95 cm
Power Draw	40 W
Solar Panel (max supply)	110 W
Energy Range	3 – 200 keV
Active Detector Area	1024 cm <sup>2</sup>
Source localization (10 $\sigma$ )	10 arcsec
Angular Resolution	1.5 arcmin
ACDS	<5 arcsec pointing knowledge
FOV (FWHM)	0.40 sr
Data Rate	5.9 GB/day
Comm. (X-band)	70 min contact/day
Mission Lifetime	5 years
Orbit	Insertion to LEO (~98 min period),

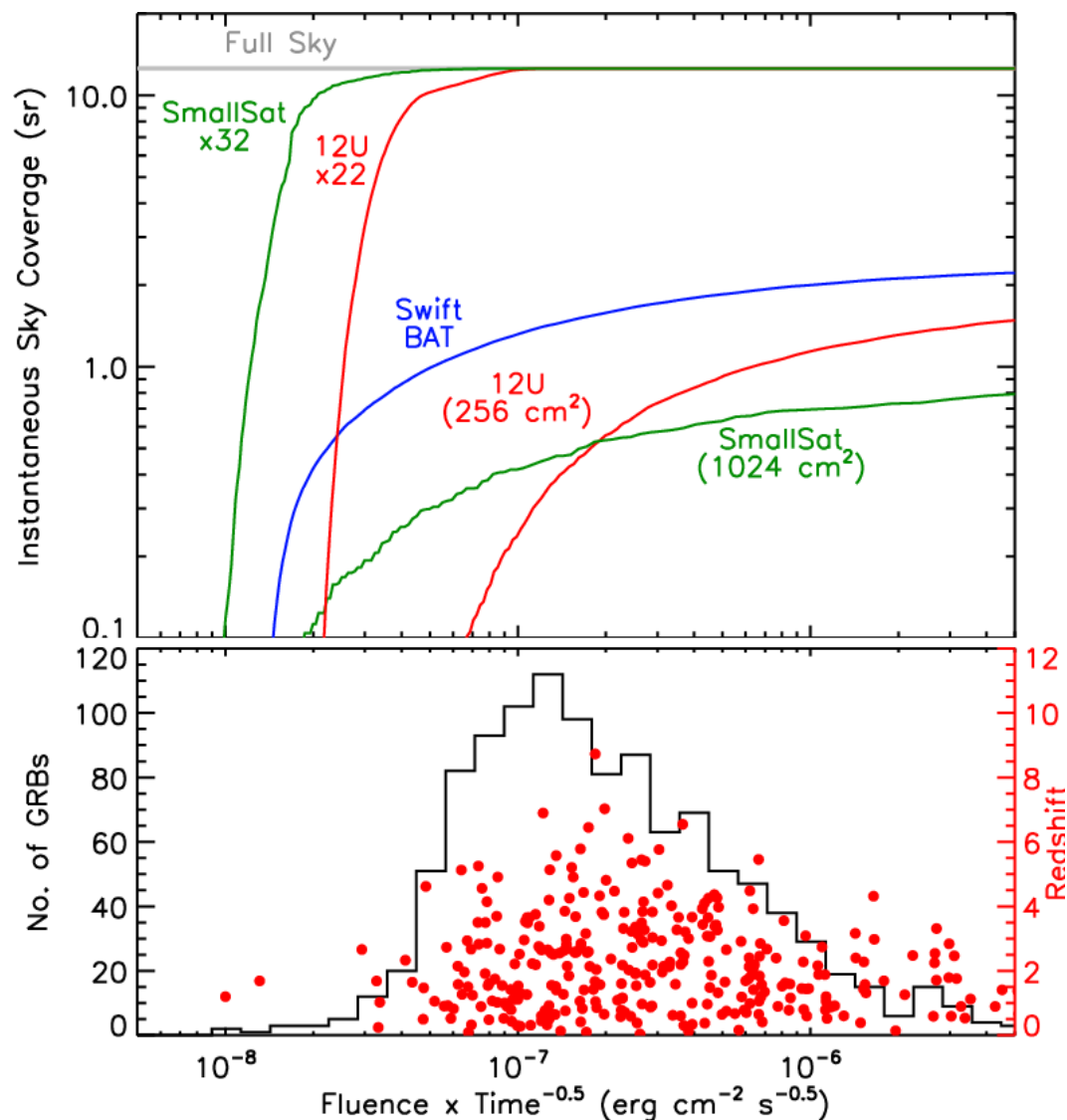
## *4piXIO* implementation as

32 x SmallSats  
9.2" positions; >2 X BAT sens.

Or

22 x 12U CubeSats:  
34.4" positions; 0.44 X BAT sens.

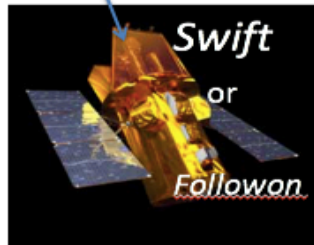
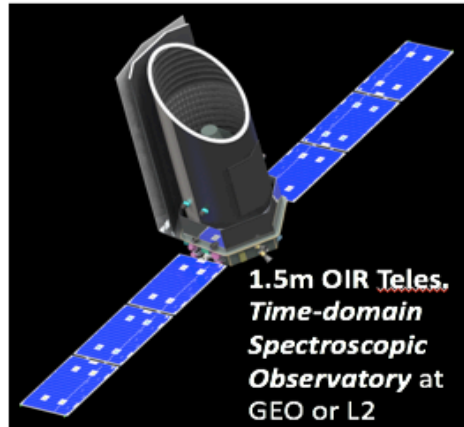
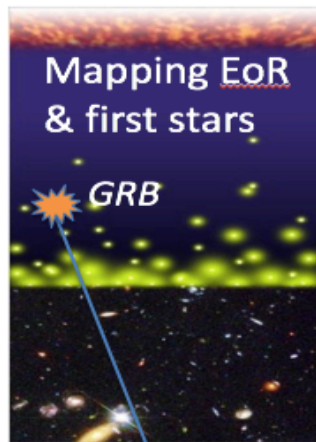
*4piXIO* extends faintest BAT GRBs  
full-sky, all-time...with <10" source  
positions to enable prompt IR  
spectra with *TSO*



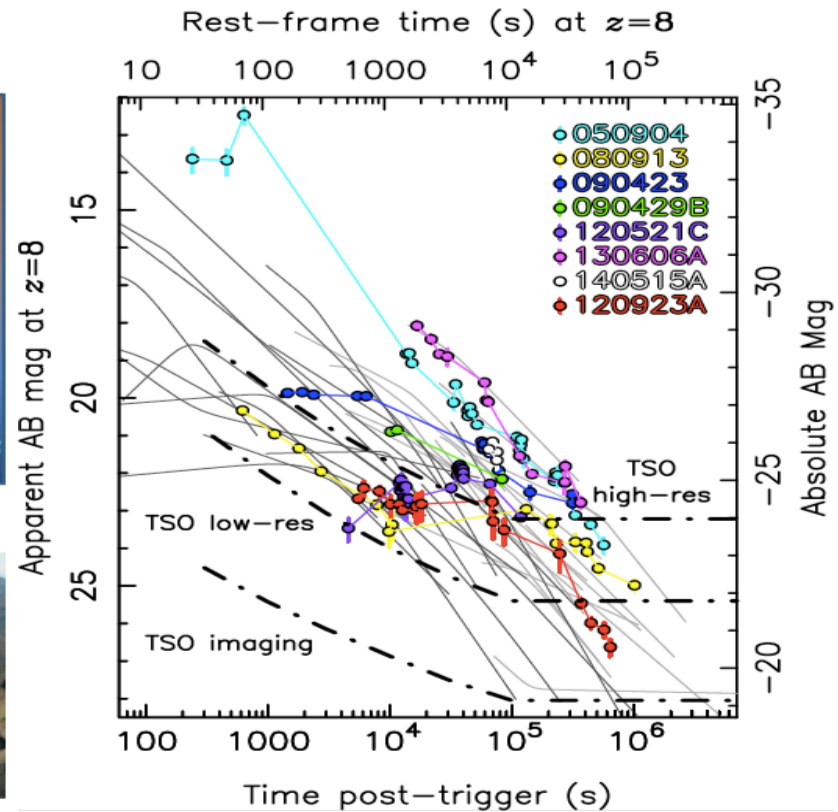
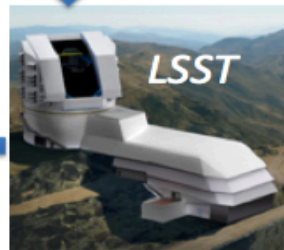


# How to do *high-z GRB Science*? With a 1.5m 0.5 – 5 $\mu$ m 100° K Telescope in Geosync orbit over LSST: *TSO (Time-domain Spectroscopic Observatory)*

## *TSO Science Operations*



TSO Science  
Operations  
Center



# Summary

- Neil's Legacy was *Swift*, now, most appropriately, the *Neil Gehrels Swift Observatory*
- *Neil was also key to so much more: Integral, Fermi, WFIRST, ...*
- *The coming Decade is the time to **extend** the incredible TDA science initiated so effectively by **Swift***
- ***Neil was enthusiastic about the 2 concepts presented here; and of course there are many others... Lets push the Frontier forward***

*Thank you Neil !!*