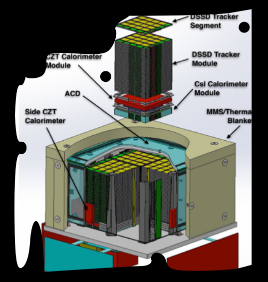
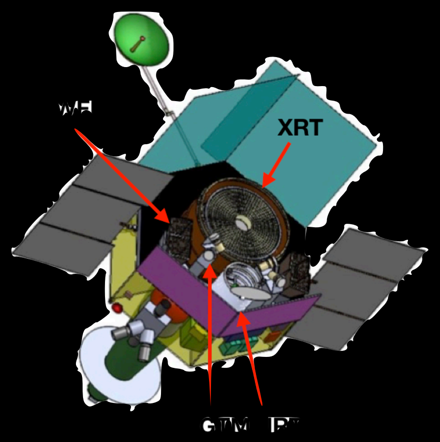
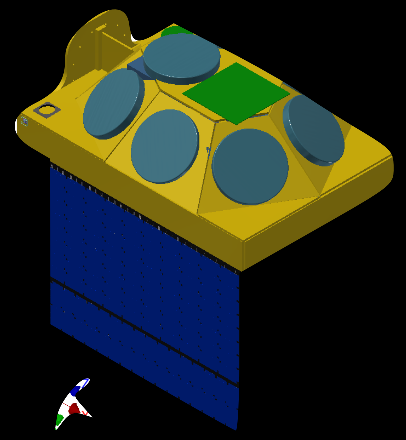
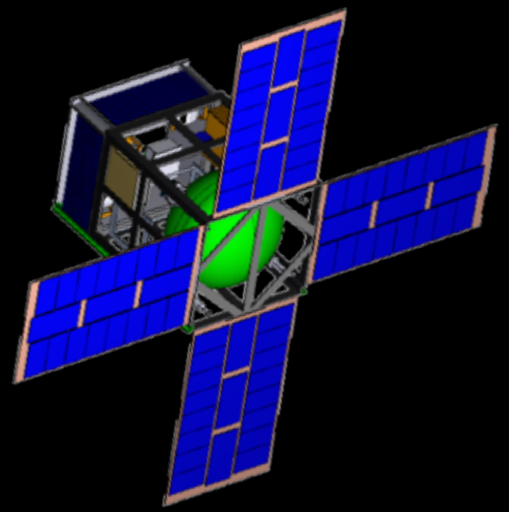
(a selection of planned and proposed) Future NASA Missions for Multi-Messenger Astrophysics

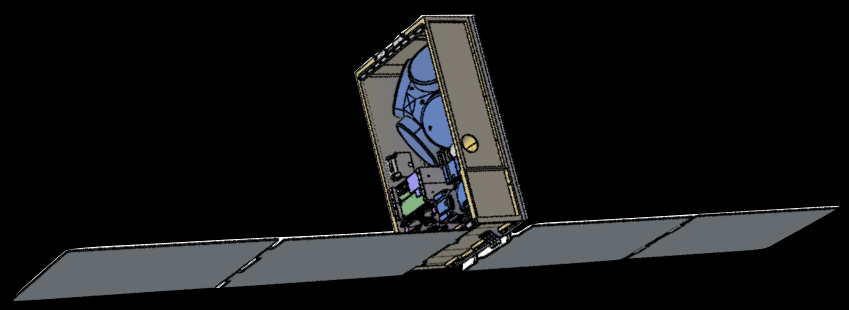


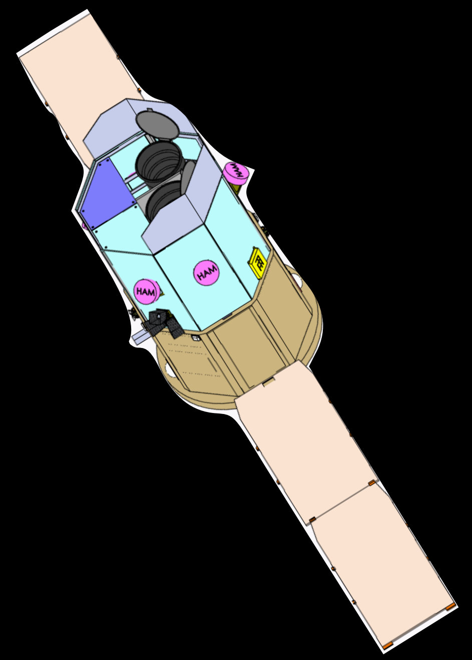


Judy Racusin
NASA Goddard Space Flight Center





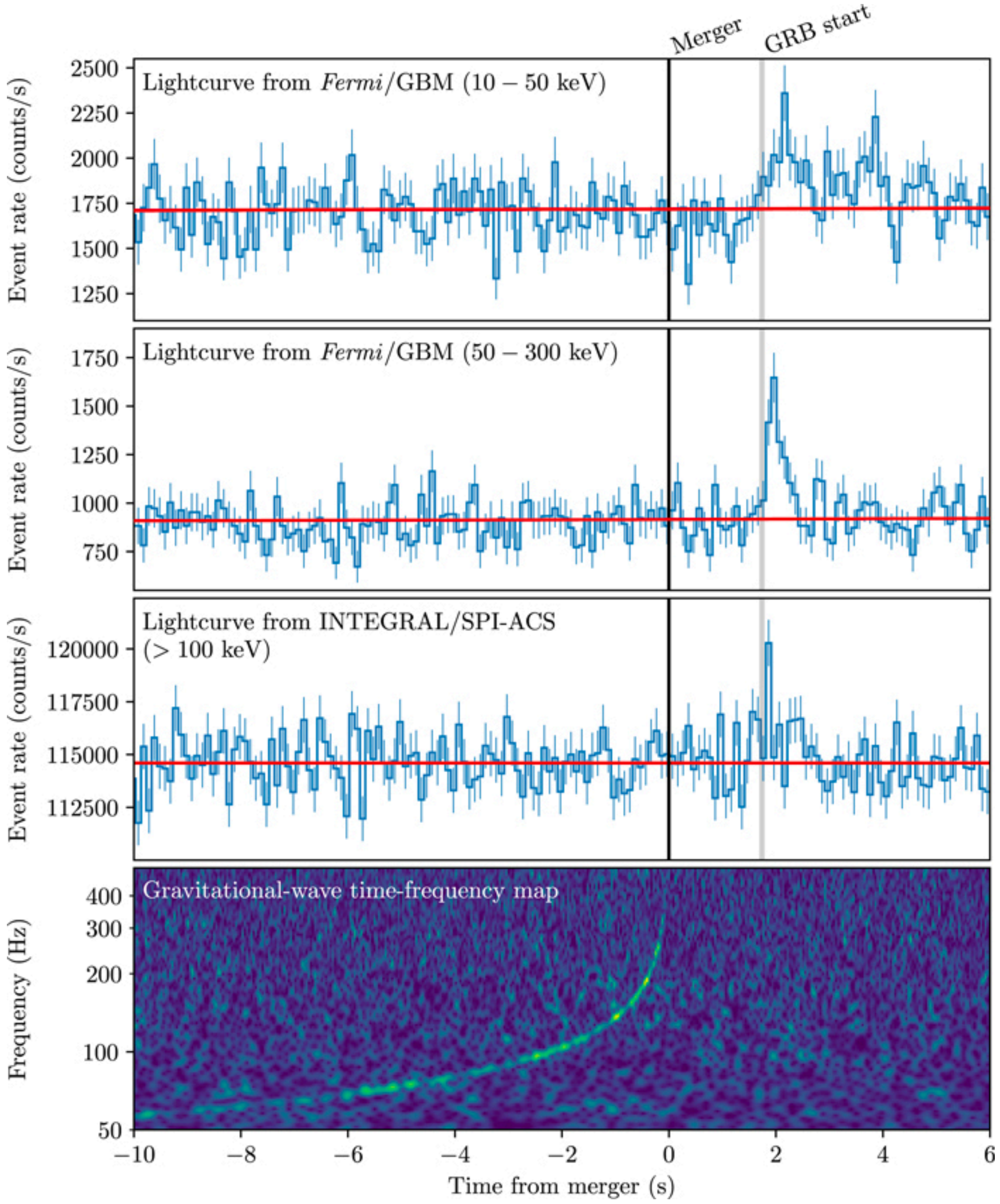




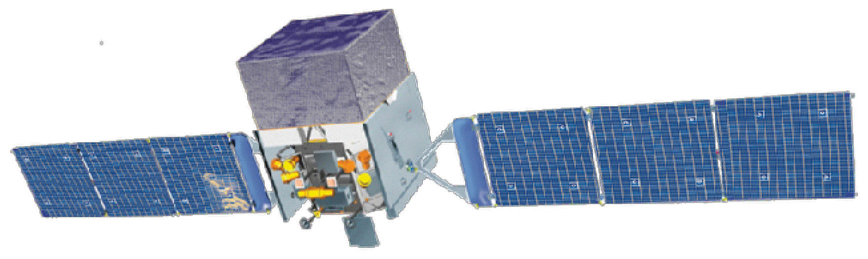
The New Era of Multi-Messenger Astrophysics, Groningen, March 26-30, 2019

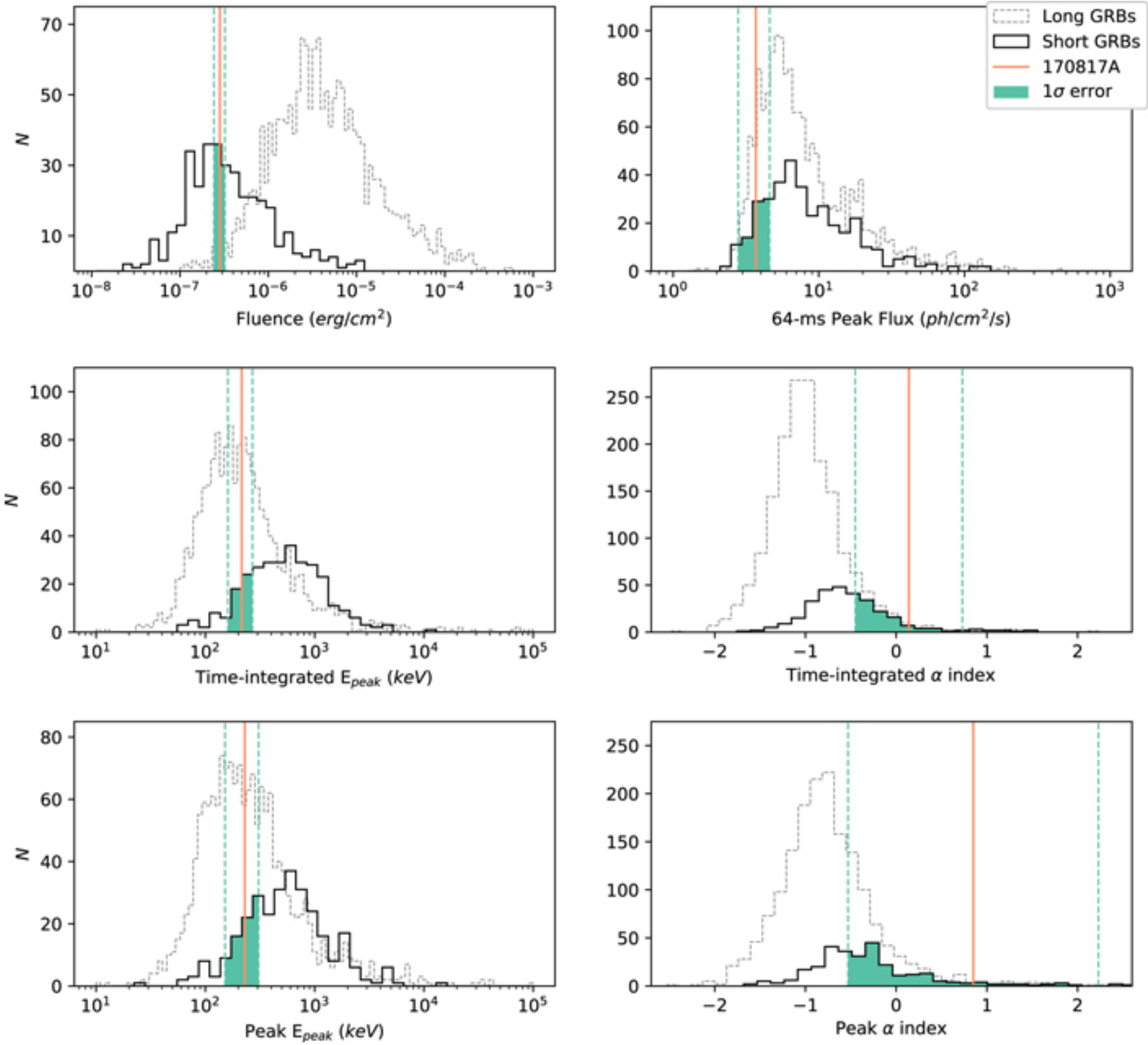
Short GRBs as GW Counterparts

- GRB 170817A
  - Detected by Fermi-GBM and INTEGRAL SPI/ACS
  - GBM triggered onboard regardless of GW detection
- GBM triggers onboard on ~40 sGRBs/year
- Expected low-luminosity sGRB-GW counterparts long before GW170817

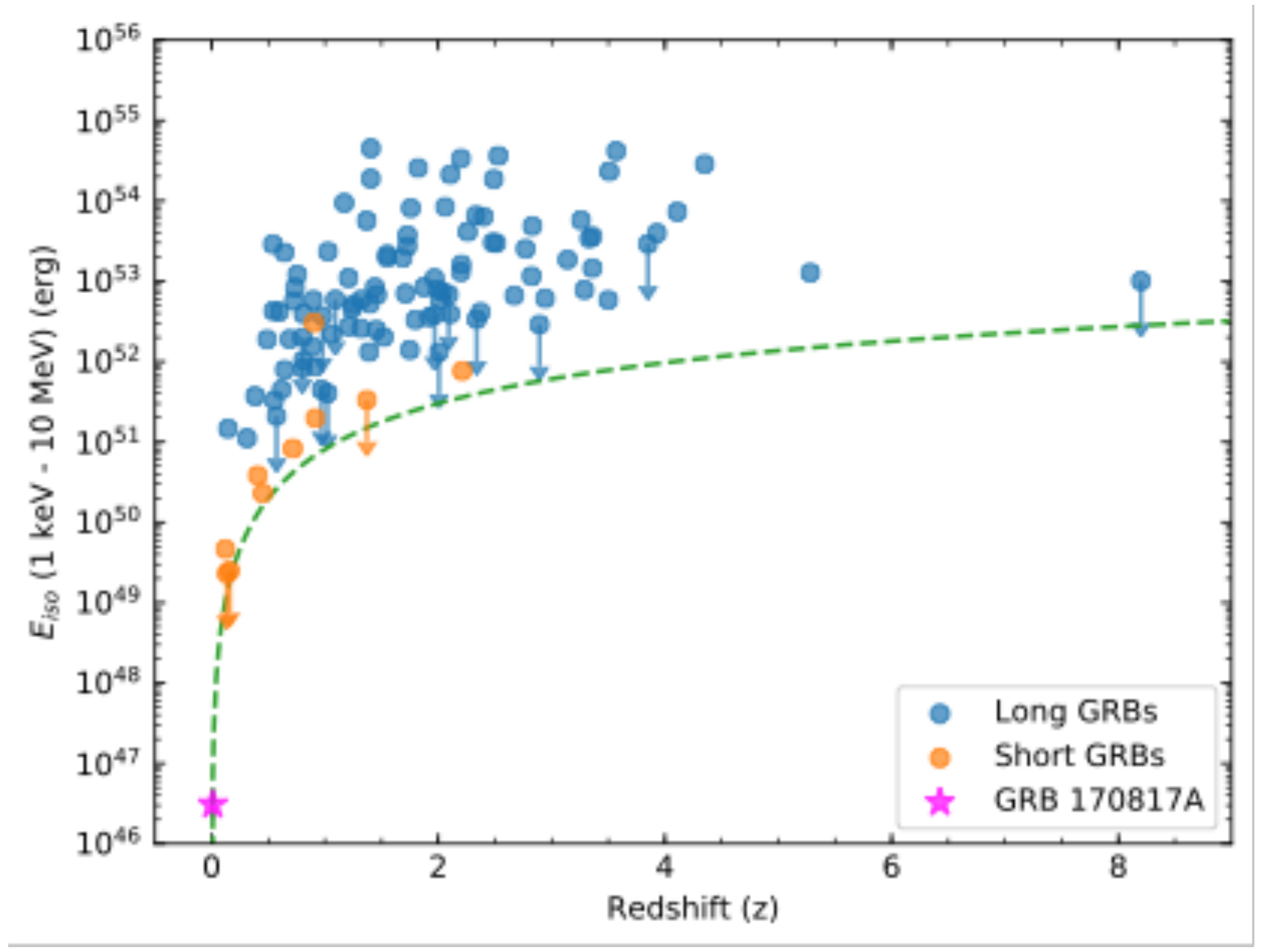


GRB 170817A Properties

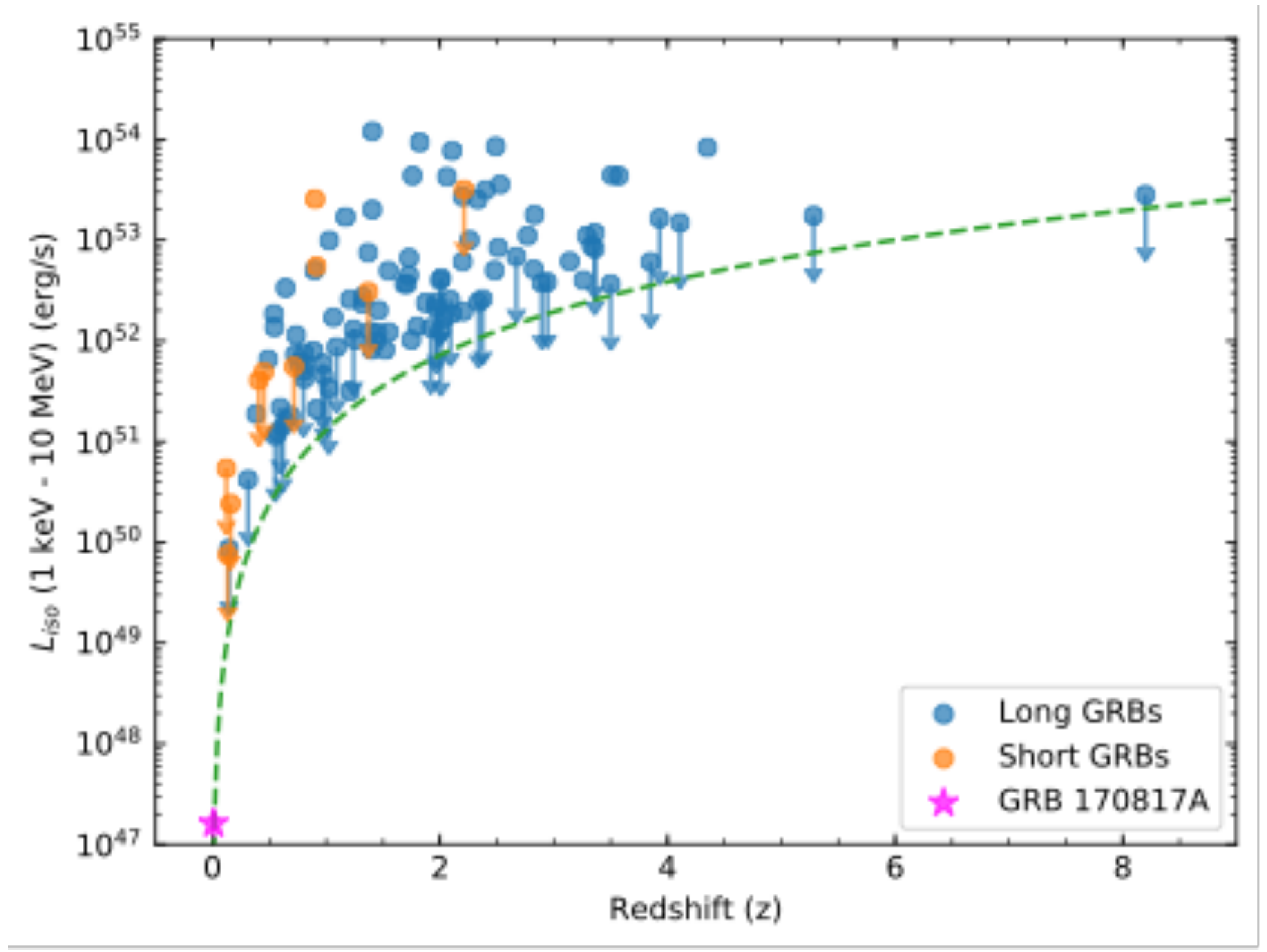




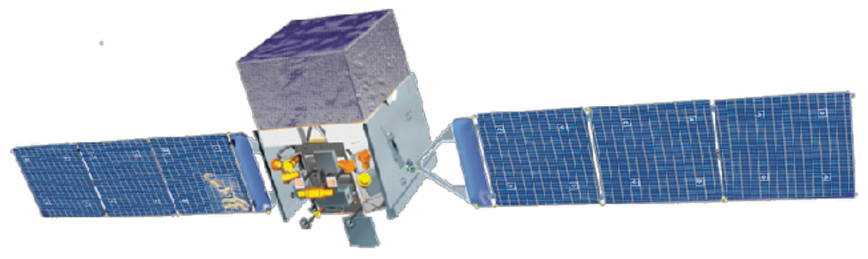
Goldstein et al. 2017

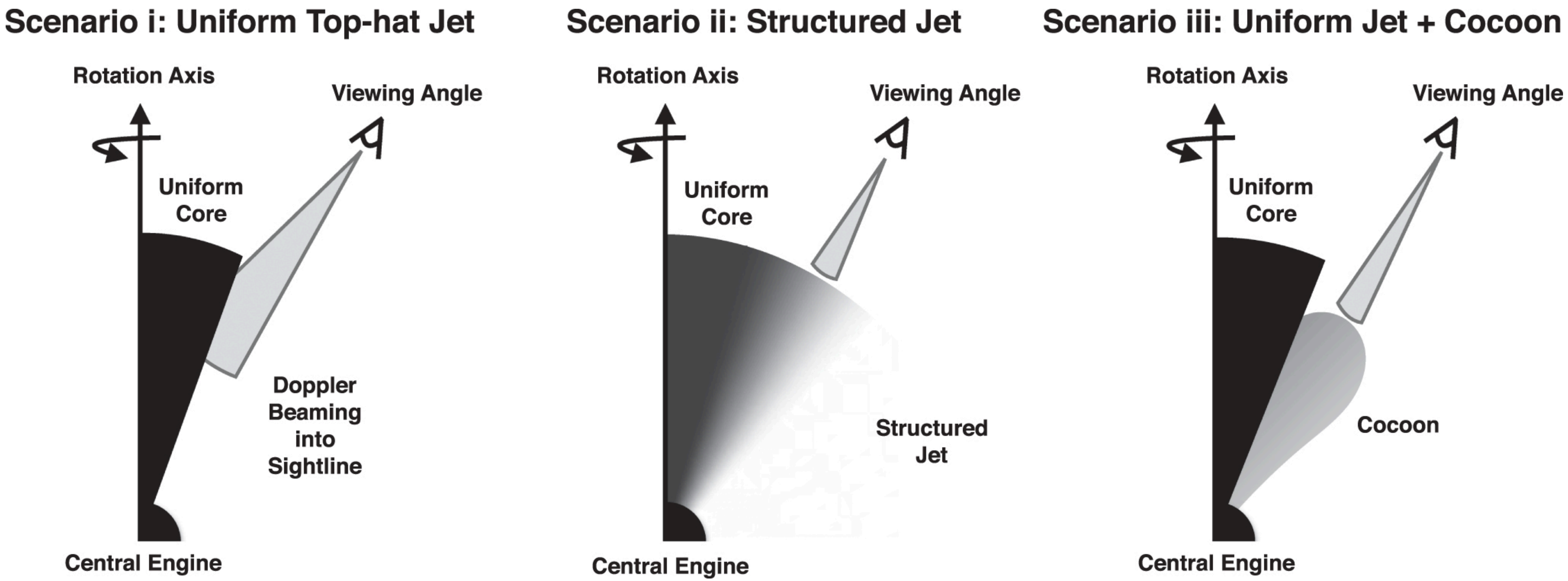


Abbott et al. 2017



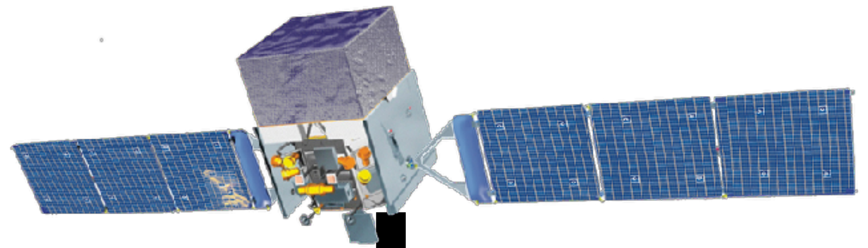
GRB 170817A Geometry

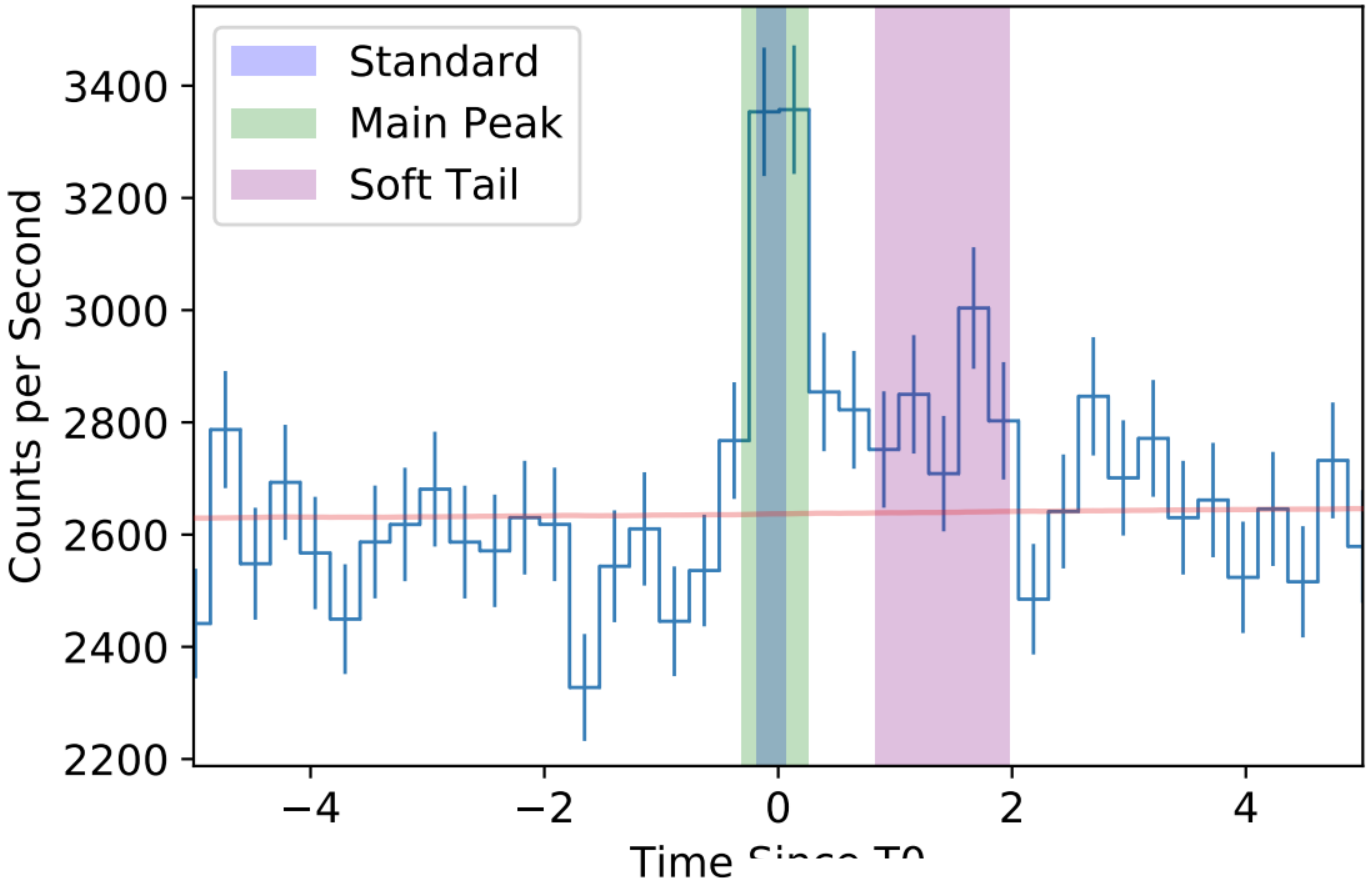




Abbott et al. 2017

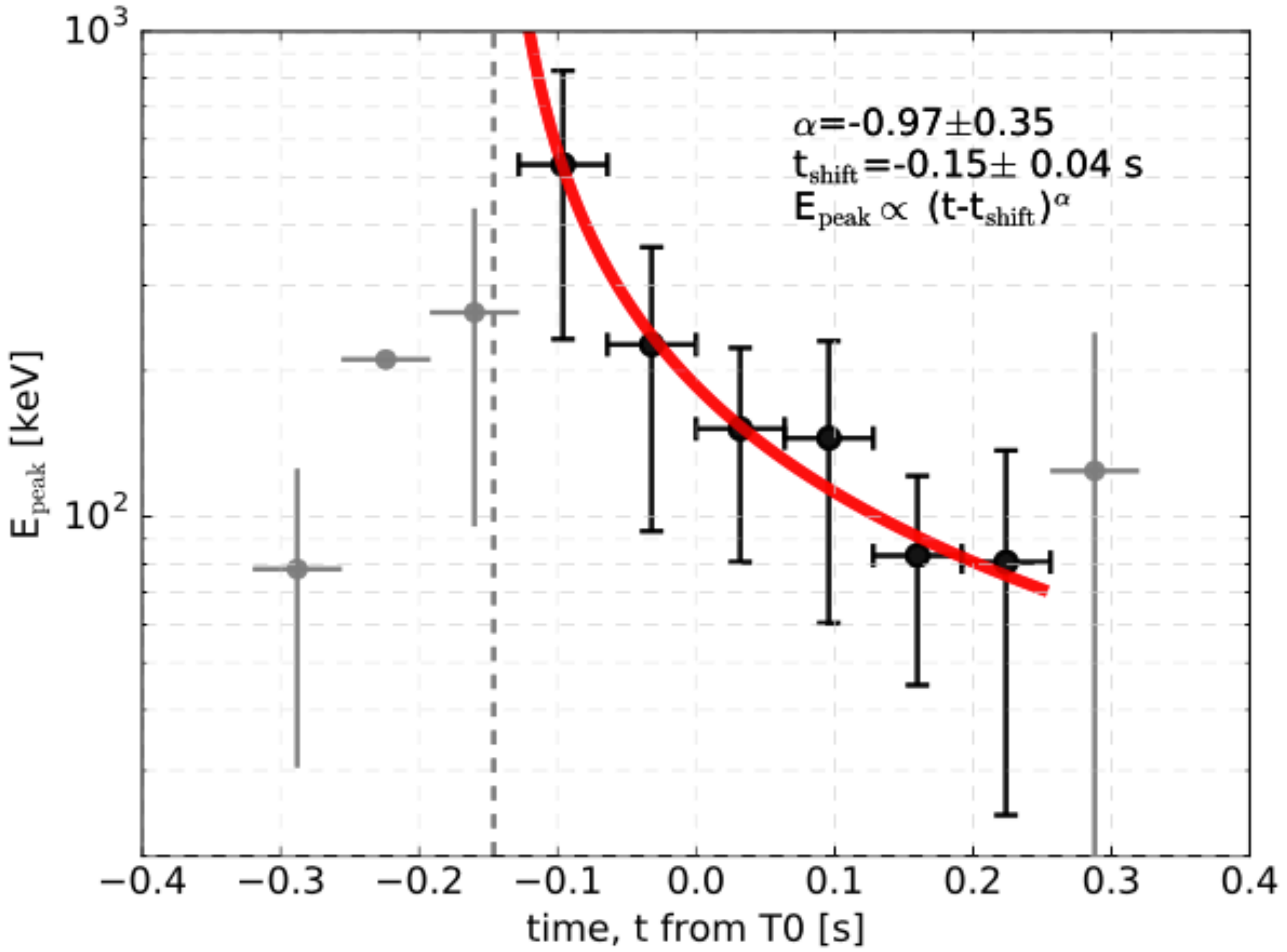
GRB 170817A Spectral Components



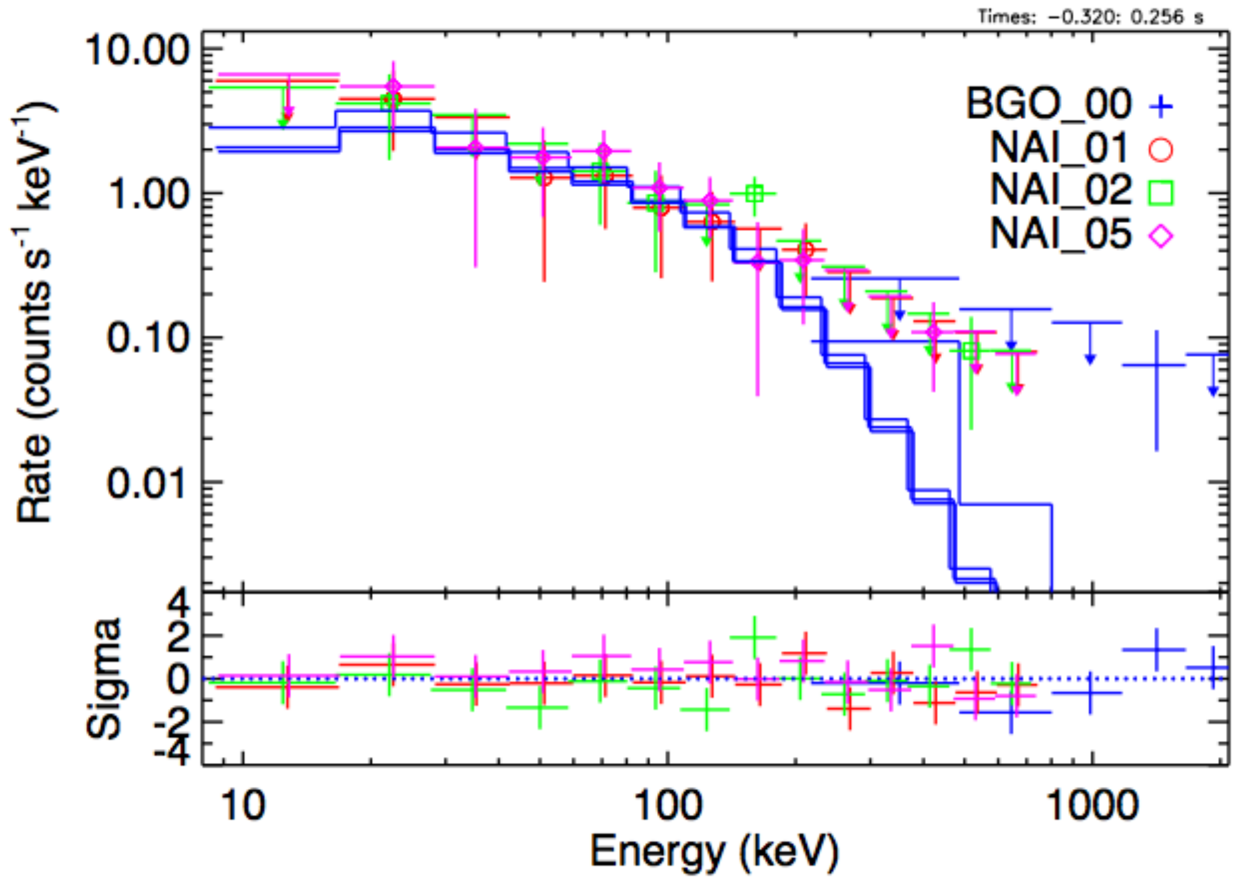


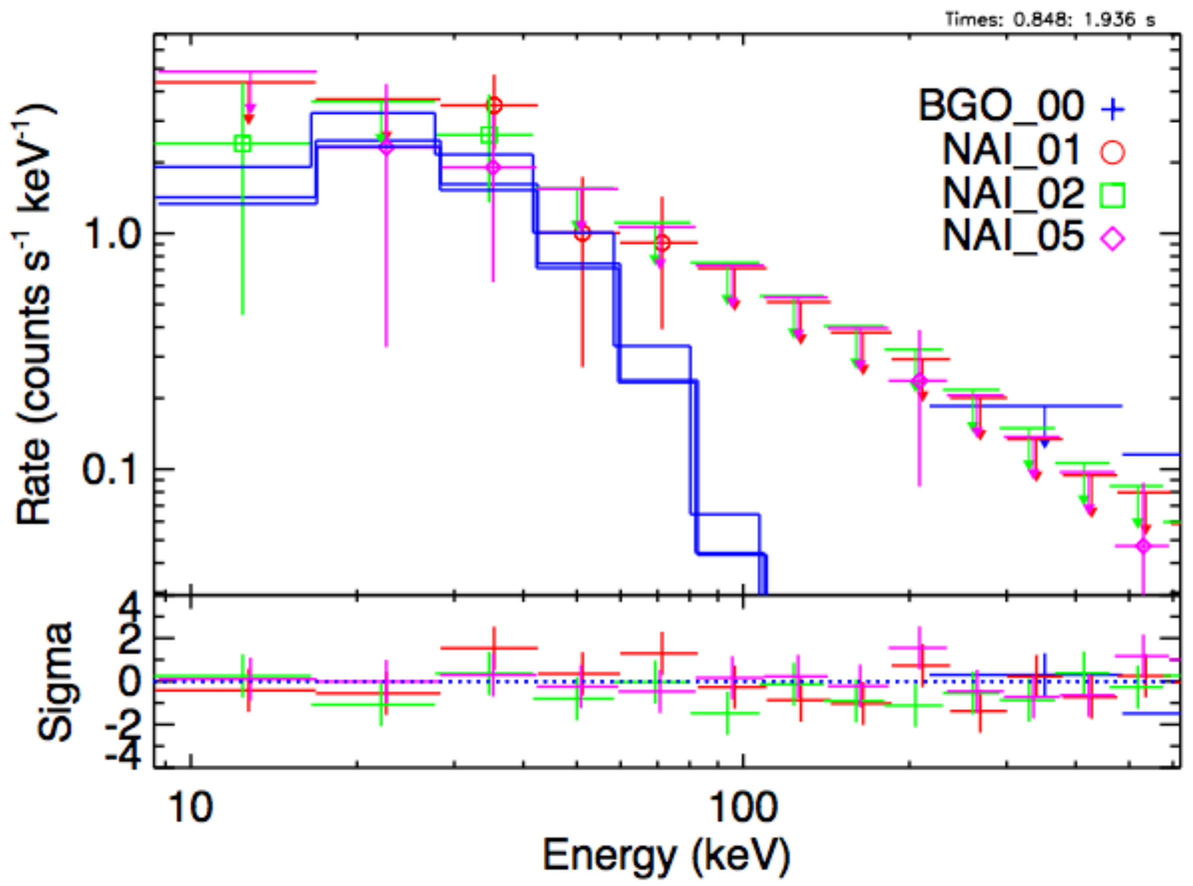
Goldstein et al. 2017

- Typical short (~0.5 s) hard spike
  - $\alpha = -0.62 \pm 0.40$
  - $E_{peak} = 185 \pm 62$ keV
- Longer (~1 s) soft thermal tail
  - $kT = 10.3 \pm 1.5$ keV

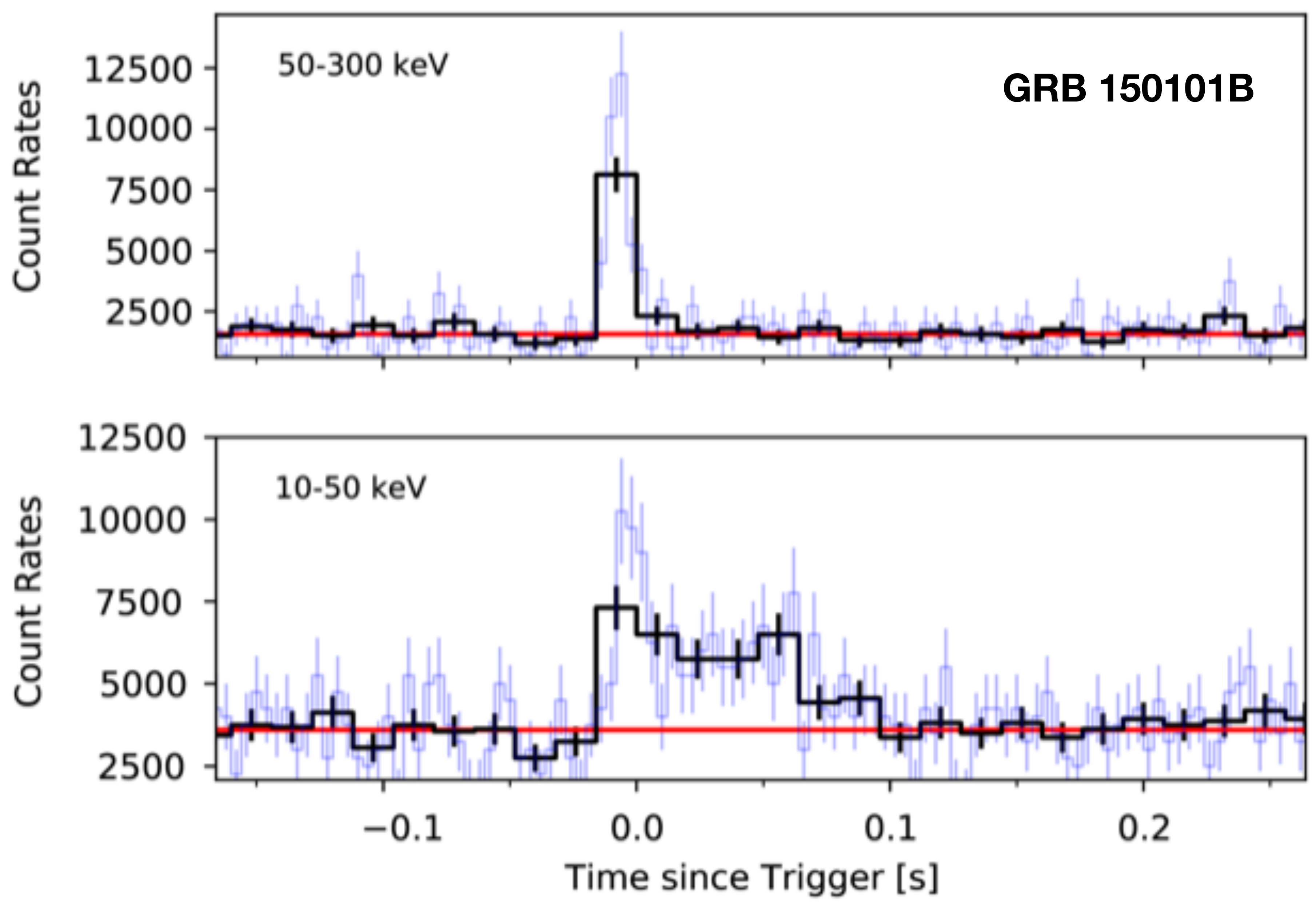


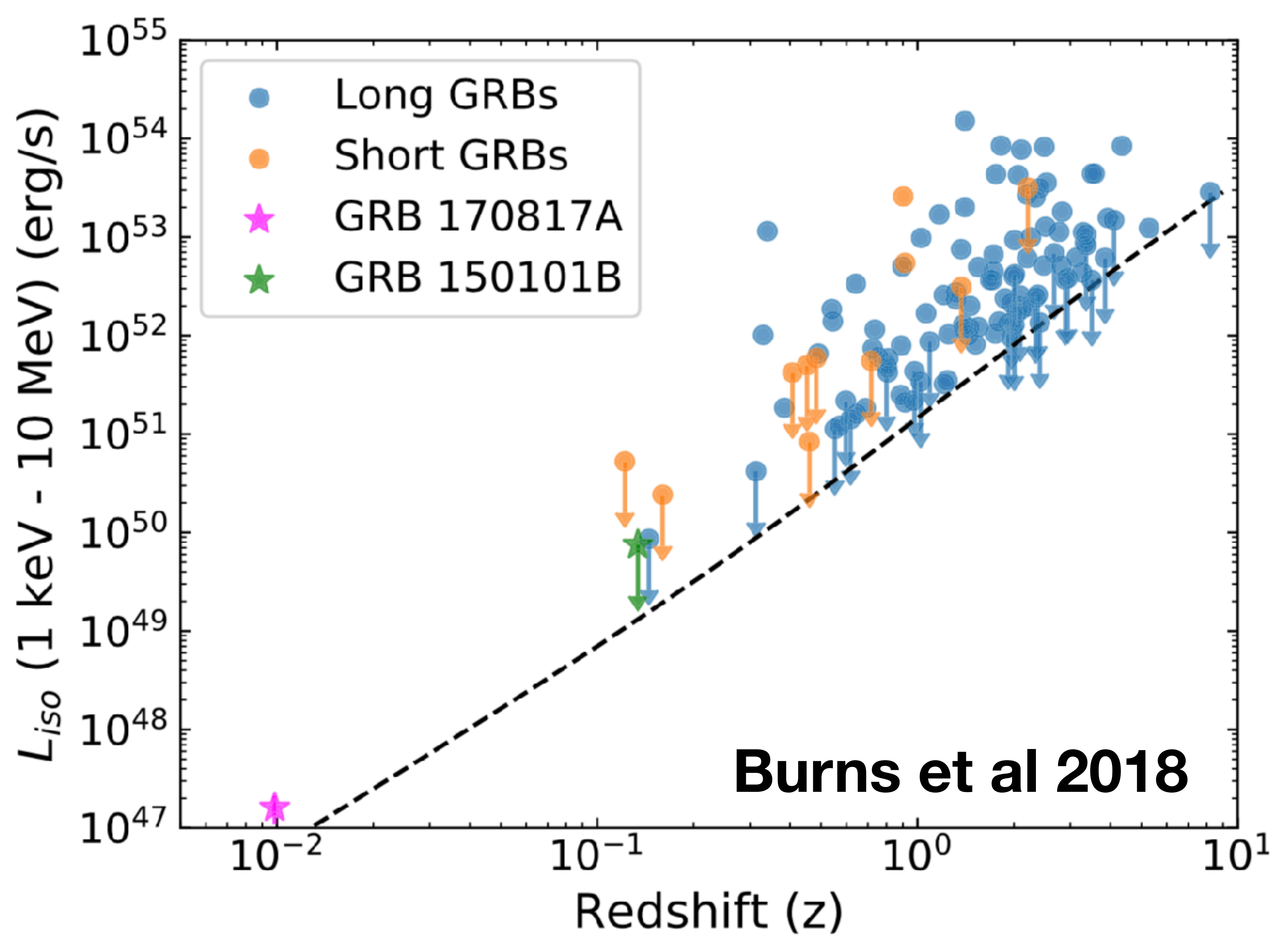
Veres et al. 2018





GRB 150101B





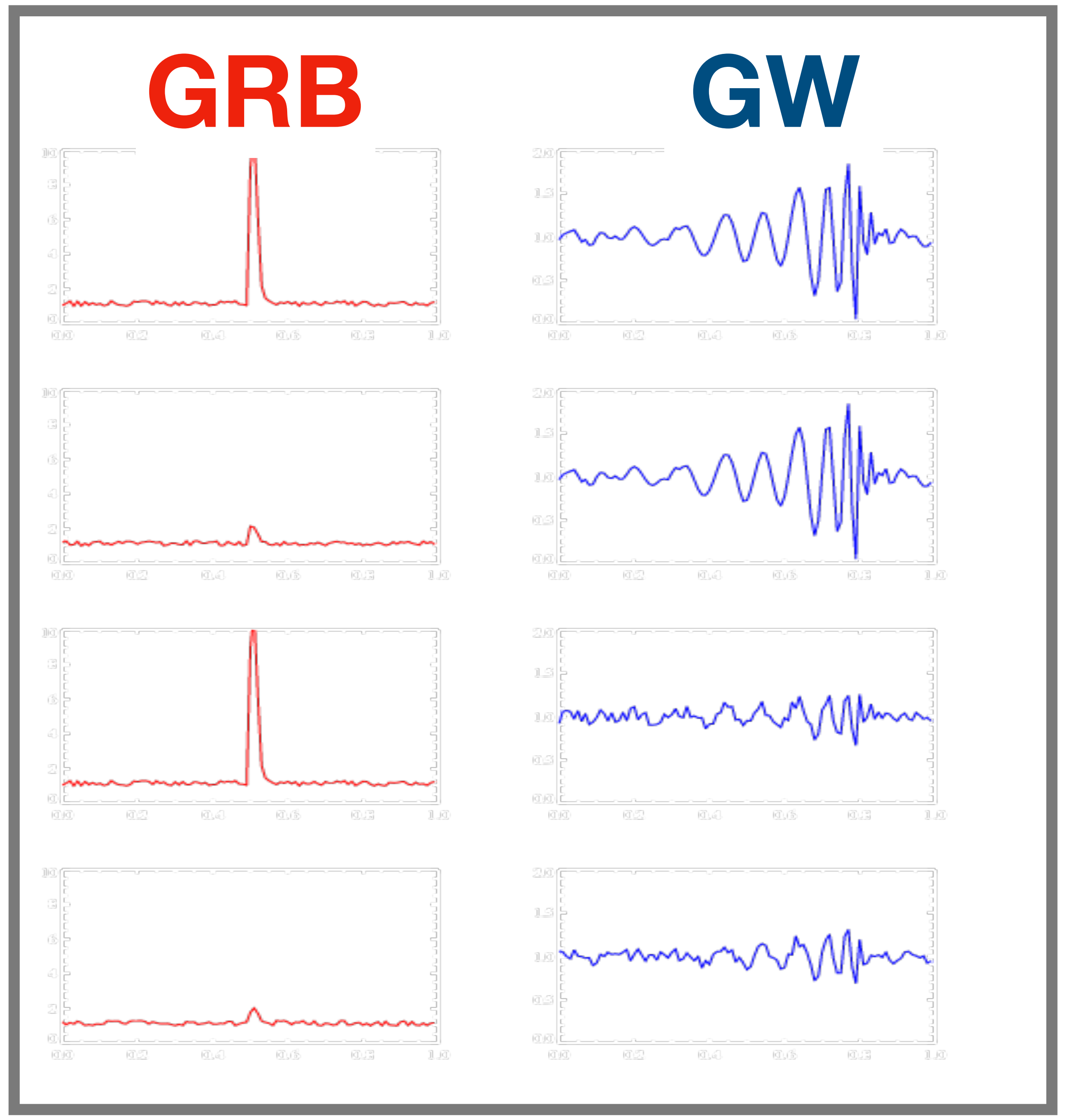
- The third closest SGRB with known redshift - GRB 150101B
- Very hard initial pulse with E_{peak} =1280±590 keV followed by a soft thermal tail with kT~10 keV
- Unlike GRB 170817, 150101B was not under luminous and can be modeled as an on-axis burst
- Suggests that the soft tail is common, but generally undetectable in more distant events
- Thermal tail can be explained as GRB photosphere, but degeneracy with the cocoon model still exists
- See also Troja et al. 2018 on GRB 150101B
- See also von Kienlin et al. 2019 for additional candidate events

Sub-Threshold GBM-GW Searches

1. Untargeted search - blind search for sub-threshold GRB candidate events (~80/yr; for more details see Kocevski et al. 2018, ApJ, 862, 152)

2. Targeted search - coherent search of all detectors using input event time and optional skymap (for more details see Goldstein et al., arXiv:1612.02395)

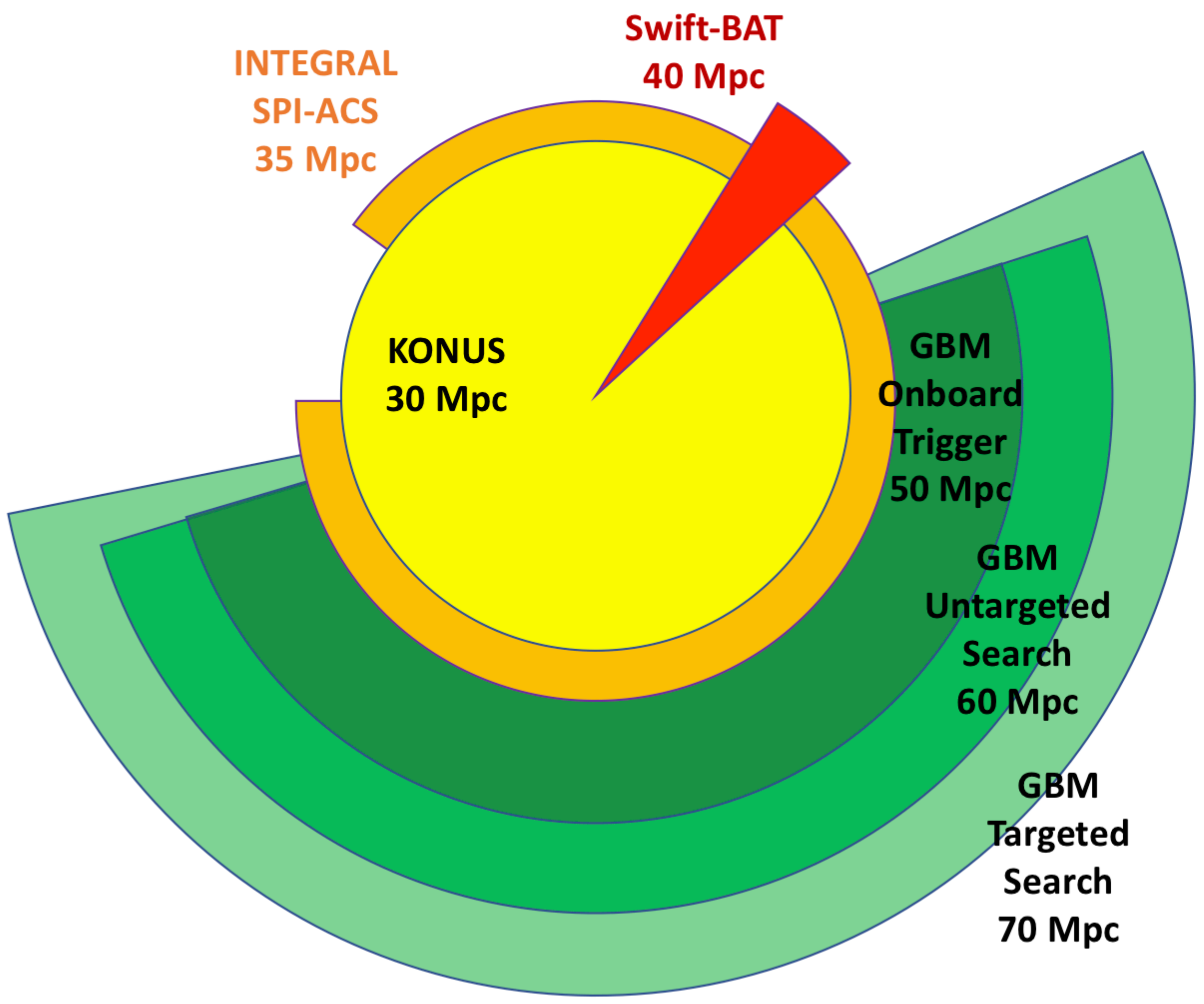
Ideal Scenario	Bright GRB	Loud GW
Weak GRB	Sub-threshold GRB	Loud GW
Typical distant short GRB	Bright GRB	Sub-threshold GW
Both Sources Faint	Sub-threshold GRB	Sub-threshold GW



GRB-GW Prospects

- Was GRB 170817A lucky?
- Is there a huge population of faint nearby sGRBs?
- How well can the current fleet of GRB instruments do?
- How can we do better?

GRB 170817A Detectability

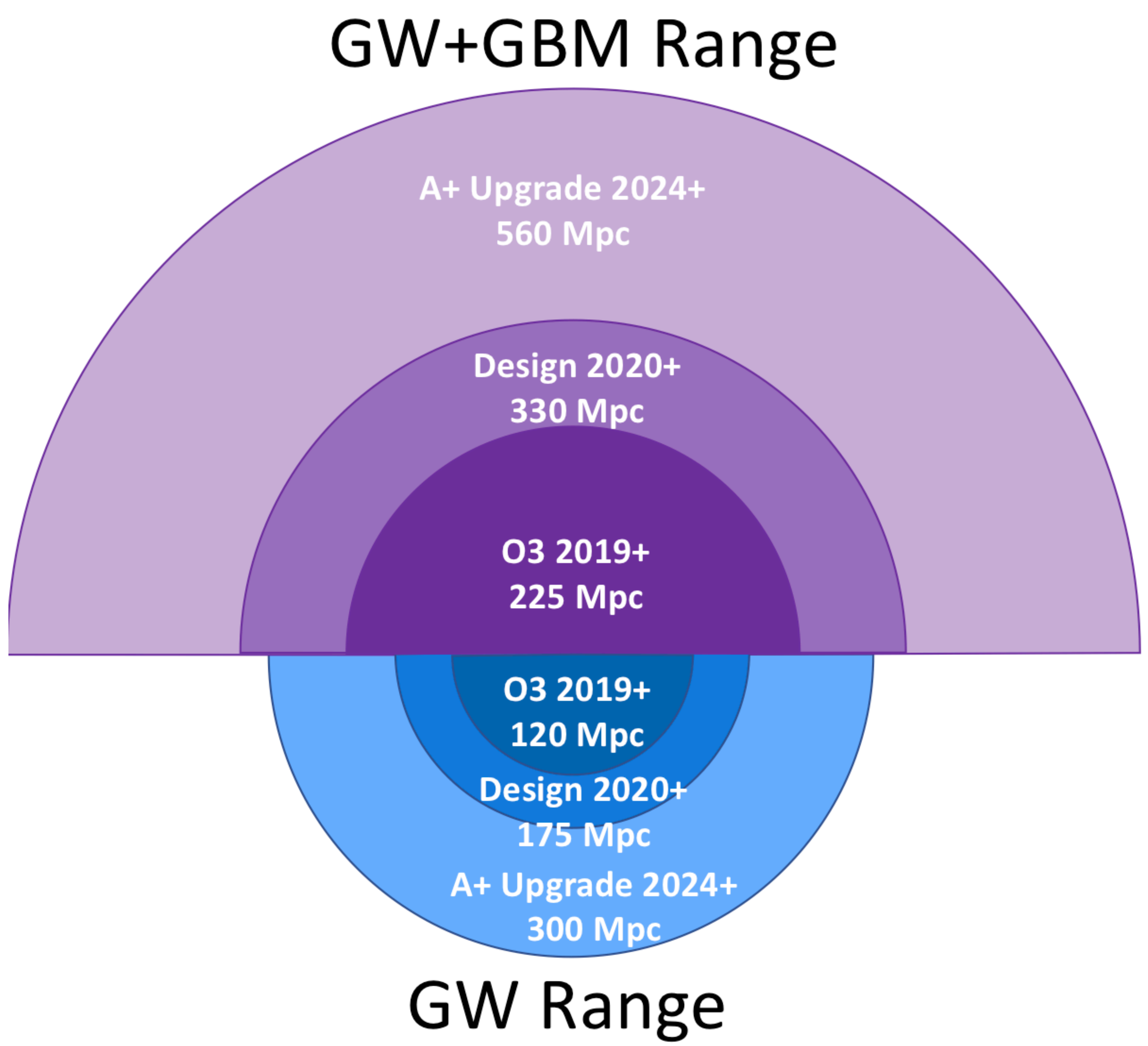


GRB-GW Prospects

- Coincident GRB provides more than astrophysics, but also joint localization and detection, increasing capability
- On-axis events have stronger GW signals
- GRB provides trigger time and rough sky localization, allows GW search window to be smaller, and therefore more sensitive given trials

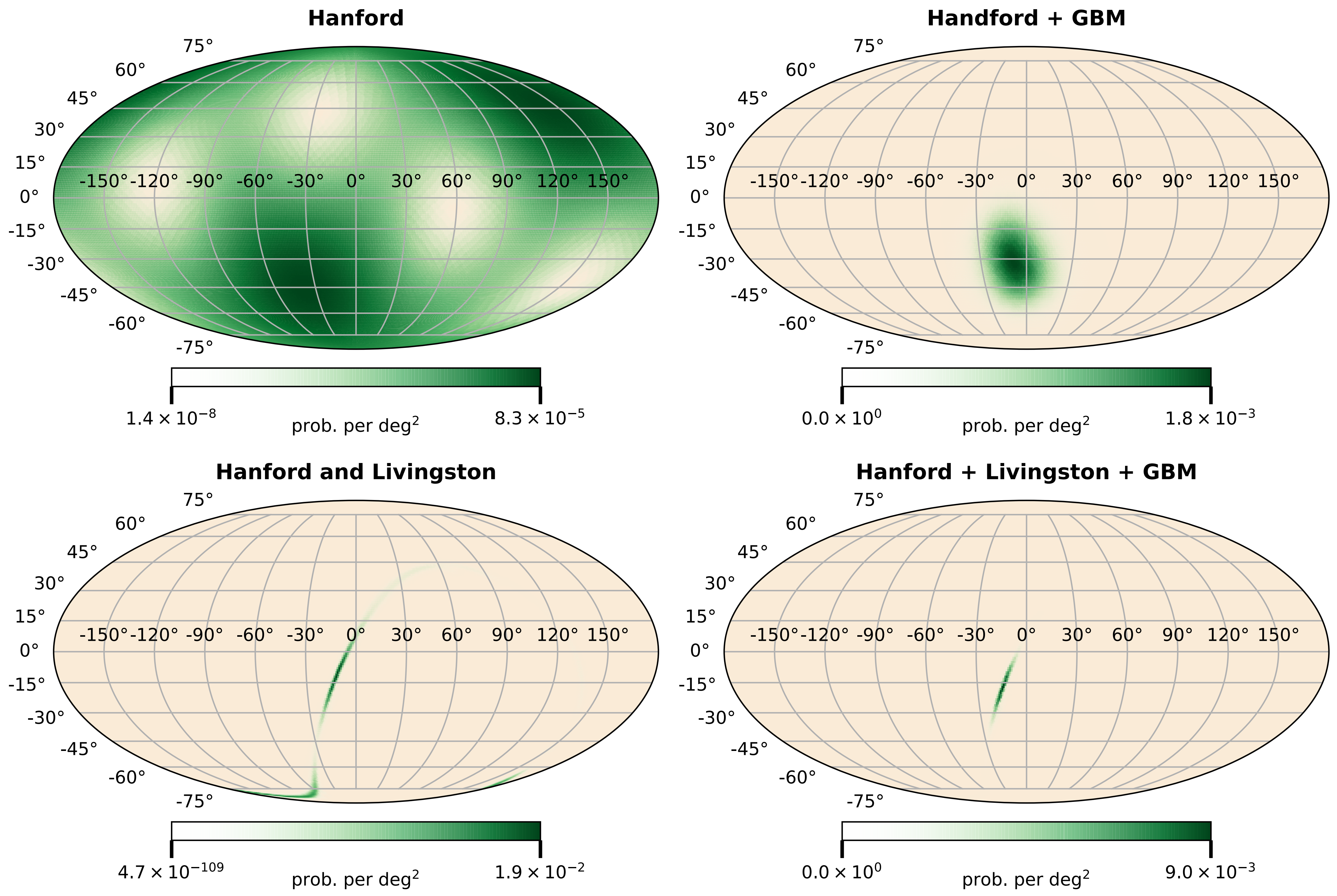
Instrument	Year	Frequency Range	BNS Range	BNS Rates (1/year)
GEO600	1995-	~150-3000 Hz		
Advanced LIGO	2015-	~20-1000 Hz	173 Mpc	0 (O1; 2015-2016)
Advanced Virgo	2016-	~20-1000 Hz	125 Mpc	1 (O2; 2017-2018)
KAGRA	2019+	~20-700 Hz	140 Mpc	4-80 (2020+)
LIGO-India	2024+	~20-1000 Hz	173 Mpc	11-180 (2024+)
Advanced LIGO+	2025+	~20-1000 Hz	325 Mpc	>100
Advanced Virgo+	2025+	~20-1000 Hz	215 Mpc	
LIGO Voyager	2028+	~10-5,000 Hz	~1 Gpc	>1,000

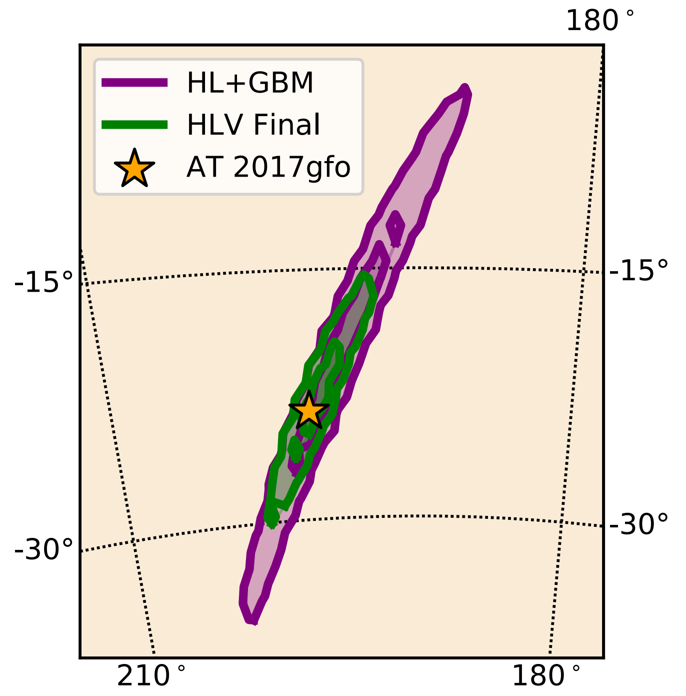
Burns et al. 2019 (arXiv:1903.04472)



Gravitational Wave Counterparts

- GRB localization acts as an additional interferometer in GW network for localization
  - Especially important for 1 or 2 interferometer localizations
  - GBM localization provided within seconds of detection
- Joint localizations with LIGO are going to be provided automatically in O3





Status of the Current GRB-detecting Fleet

	Year Launched	Energy Coverage	Field of View x Duty Cycle (% of sky)	sGRB Rate (yr^{-1})
KONUS-Wind	1994	20 keV - 15 MeV	95%	18
INTEGRAL SPI/ACS	2002	80 kev - 10 MeV	100%	~30
Swift-BAT	2004	15-150 keV	15%	10
Fermi-LAT	2008	30 MeV - >300 GeV	20%	~1
Fermi-GBM	2008	8 keV - 40 MeV	60%	40-80
CALET-CGBM	2014	7 keV - 20 MeV	25%	~3-6
AstroSat-CZTI	2015	10-150 keV	1%	~3
Insight-HXMT	2017	0.2-3 MeV	60%	~5-10
Other gamma-ray monitors that are part of IPN: Odyssey, Messenger				

Lots of other instruments/observatories to follow-up afterglows (both on/off axis) and kilonova

Next Generation GRB Detectors

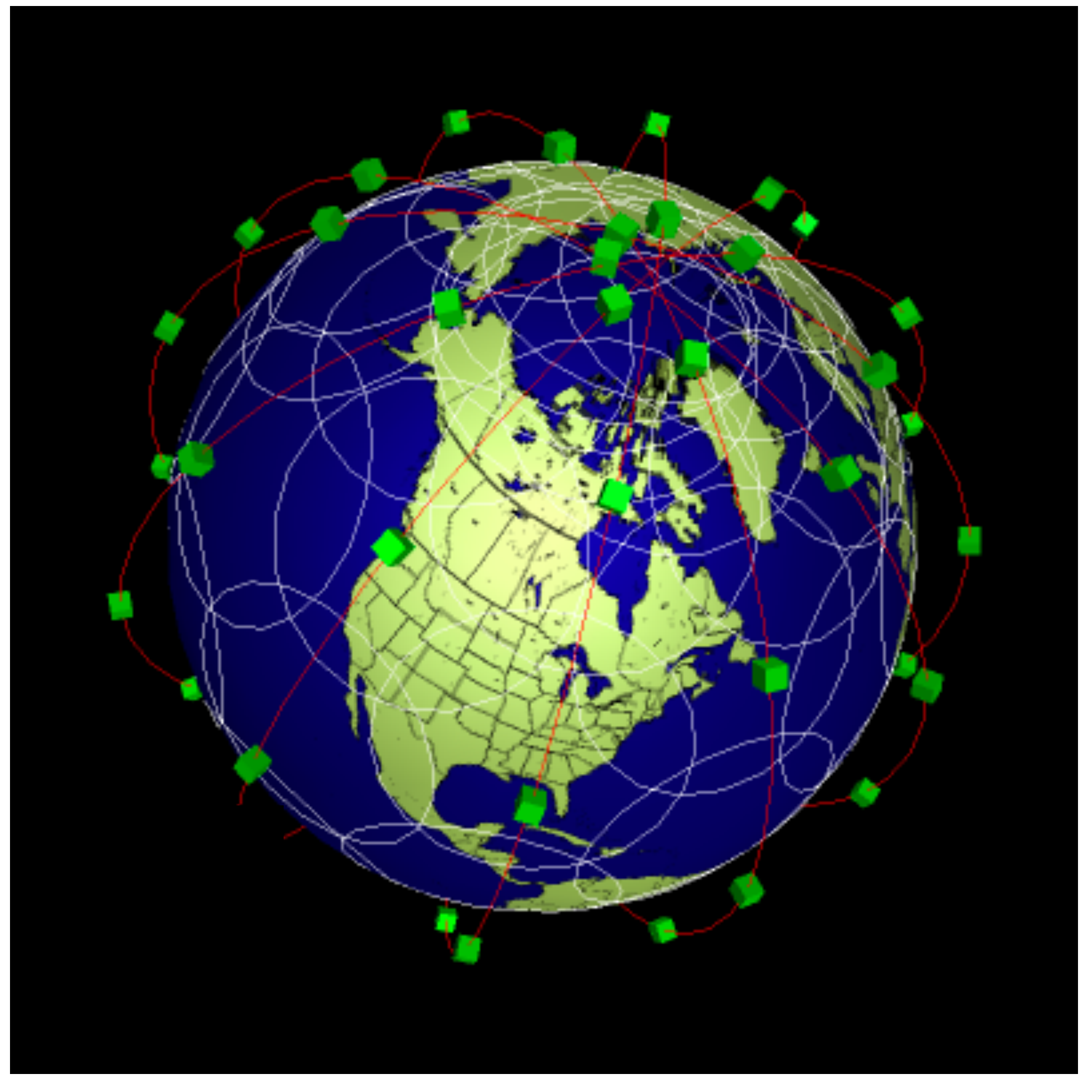
- Capabilities needed for GW-GRB science in the next decade?
  - All-sky coverage
  - Sensitivity to weak GRBs
  - Rapid notification
  - degree-scale (or better) localizations
  - Wide gamma-ray energy band
  - Rapid multi-wavelength follow-up observations
- Considerations
  - all on one platform or distributed
  - dedicated GRB mission or broadly capable
  - $€£¥₩

Next Generation GRB Detectors

- Missions you'll hear about at this meeting:
  - Network of SmallSats
  - BurstCube
  - Glowbug - see Matthew Kerr's talk Thursday
  - Moonbeam
  - Bia
  - Nimble
  - TAP
  - AMEGO
- Other missions
  - SVOM
  - THESEUS
  - Einstein Probe
  - Athena
  - + others

A Global Network of GRB SmallSats

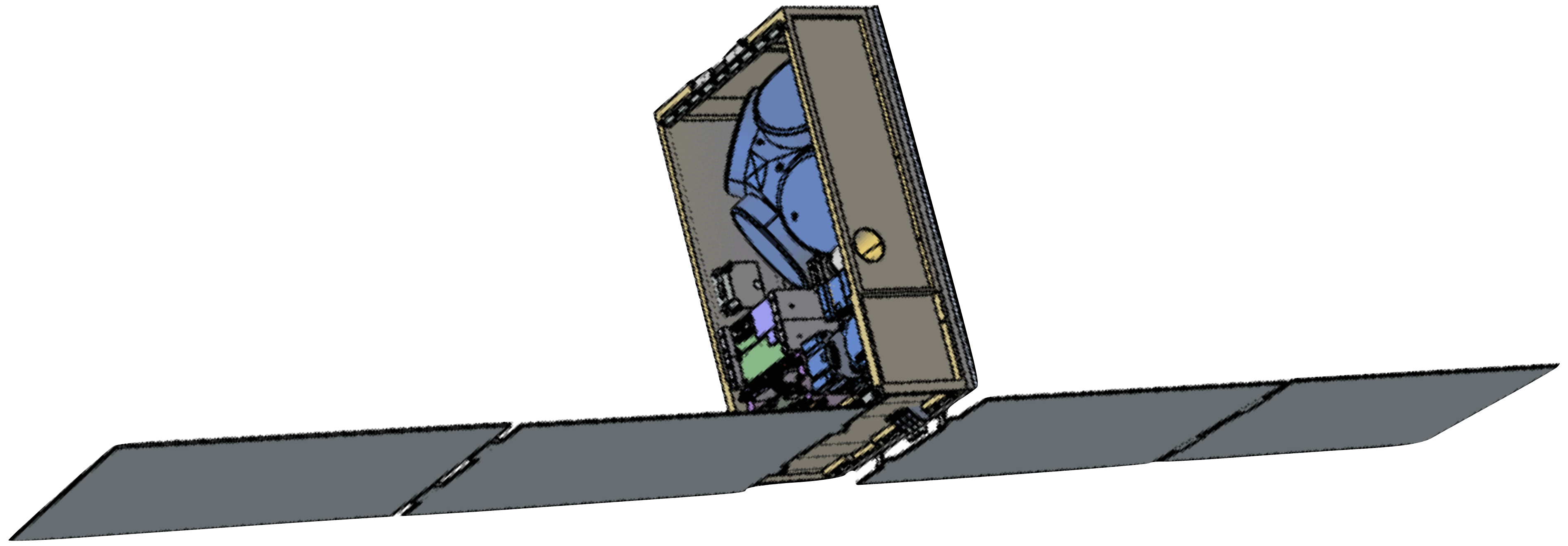
- Build many small detectors distributed in different orbits to observe the whole sky for rare events
- Potential for joint localization?
- Lots of interest in distributed GRB SmallSat network
  - “Towards a Network of GRB Detecting Nanosatellites” Conference in September 2018 - https://asd.gsfc.nasa.gov/conferences/grb_nanosats/index.html
  - Projects in development all over world
  - Low cost access to space via Ride Shares
- Potential downsides - short missions, typically lacks rapid communications, different types of detectors, small detectors

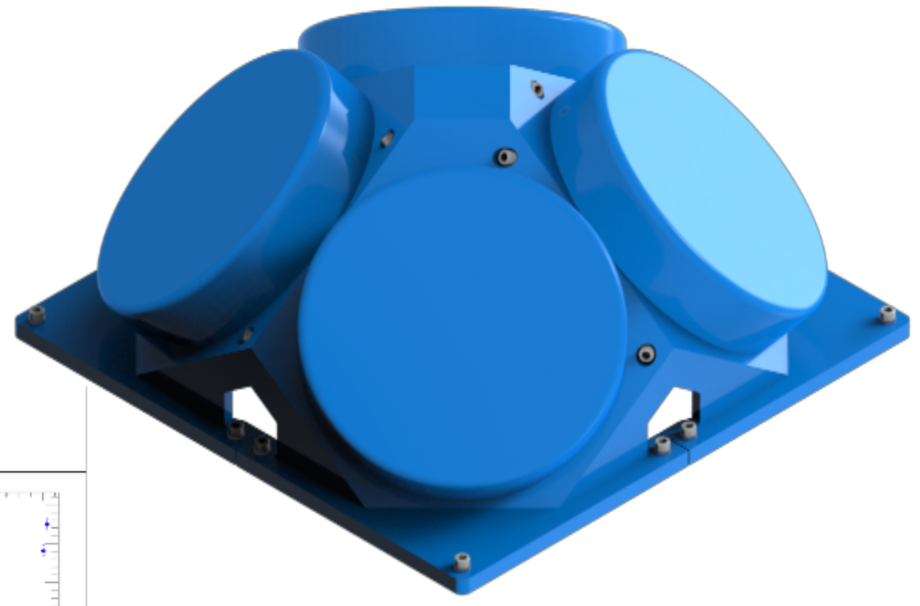


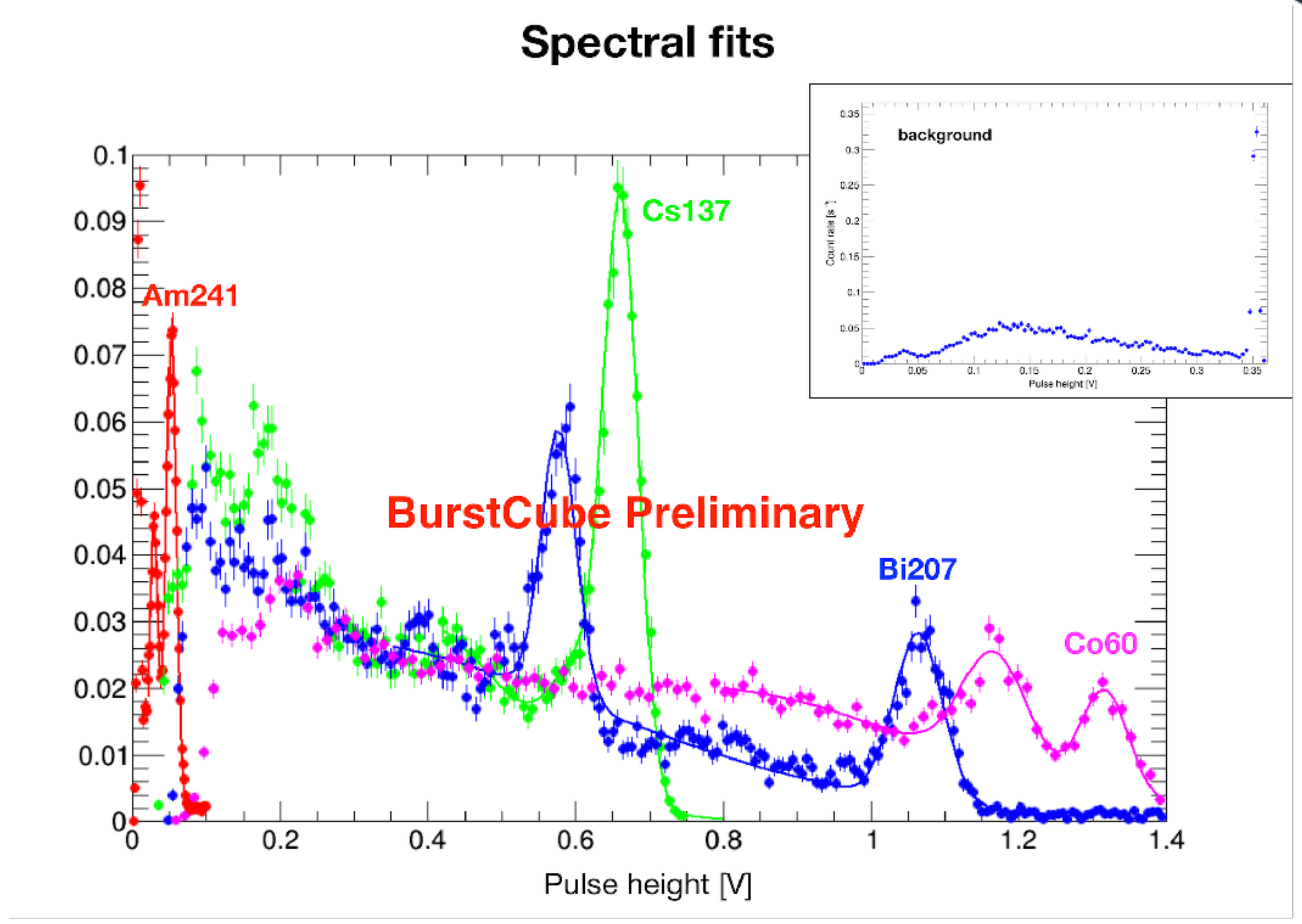
BurstCube

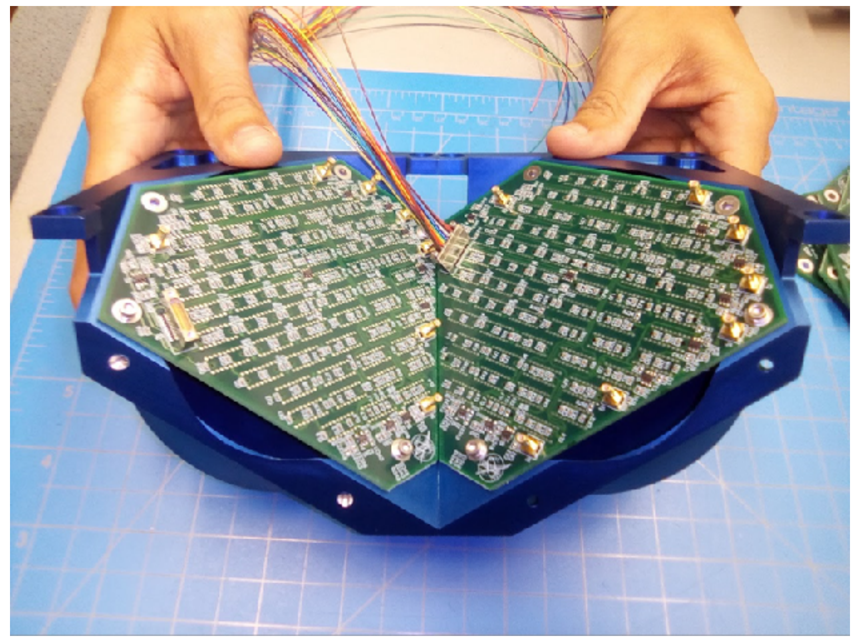
PI: Jeremy Perkins (NASA/GSFC)

- 6U CubeSat currently in design and prototyping phase
- Instrument:
  - Four 9 cm diameter CsI scintillating crystals read out by low-power SiPM arrays
  - Energy band 30-1000 keV
- Rapid Communications - will send GRB alerts and localization to community within minutes
- Complement existing GRB-detecting instruments
- Launch ready in late-2021
- 6 month mission, 1 year goal





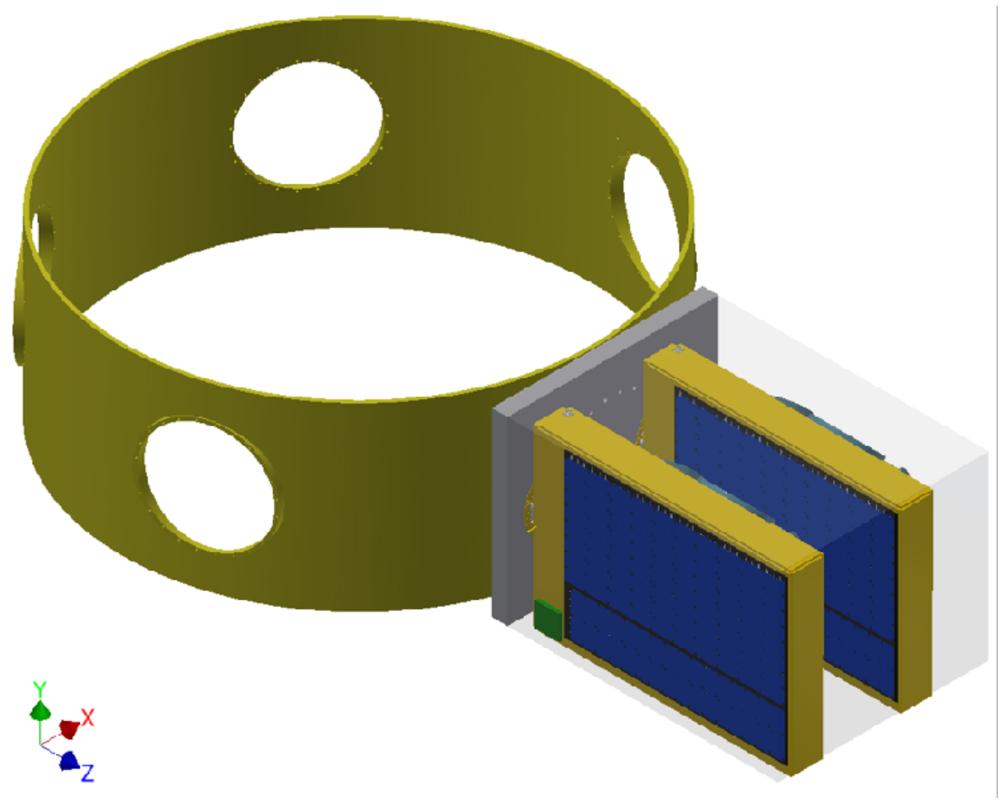


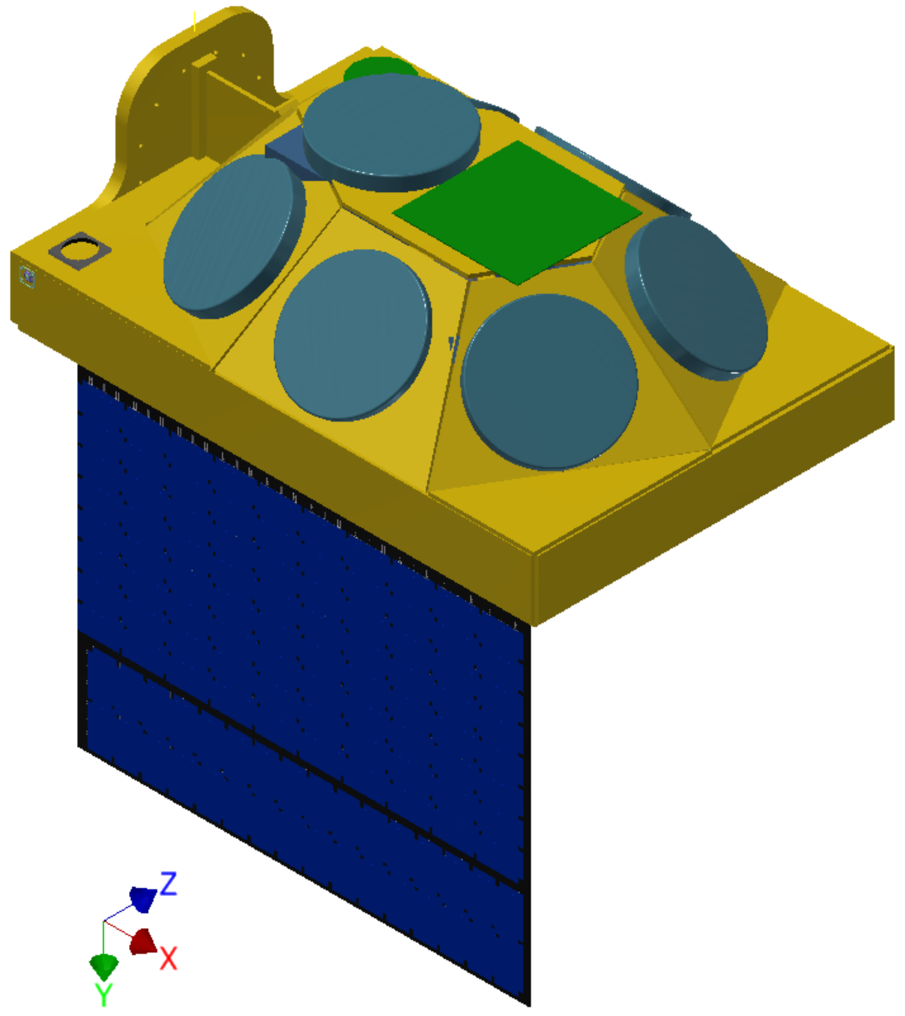


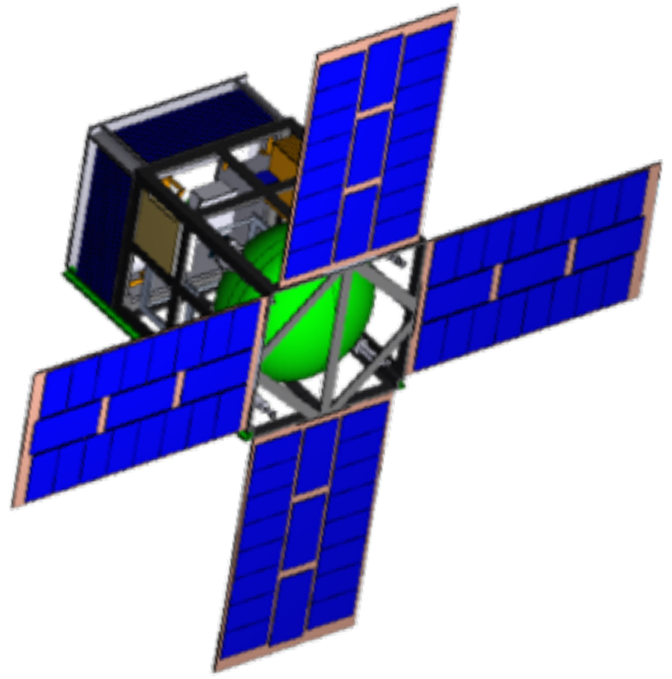
Bia

PI: Judy Racusin (NASA/GSFC)

- SmallSat ESPA ring Ride Share
- In development for proposing to upcoming NASA Mission of Opportunity call in Summer 2019
- Larger version of BurstCube CsI + SIPM detectors with 7 on each of 2 spacecrafts
- Energy range - 30 keV - 2 MeV
- Potential to detect 80-150 short GRBs per year
- Rapid communications and localizations to enable follow-up observations
- More sensitive than Fermi-GBM, with all-sky coverage
- Launch in 2024/2025
- 2 year mission (5 year goal)







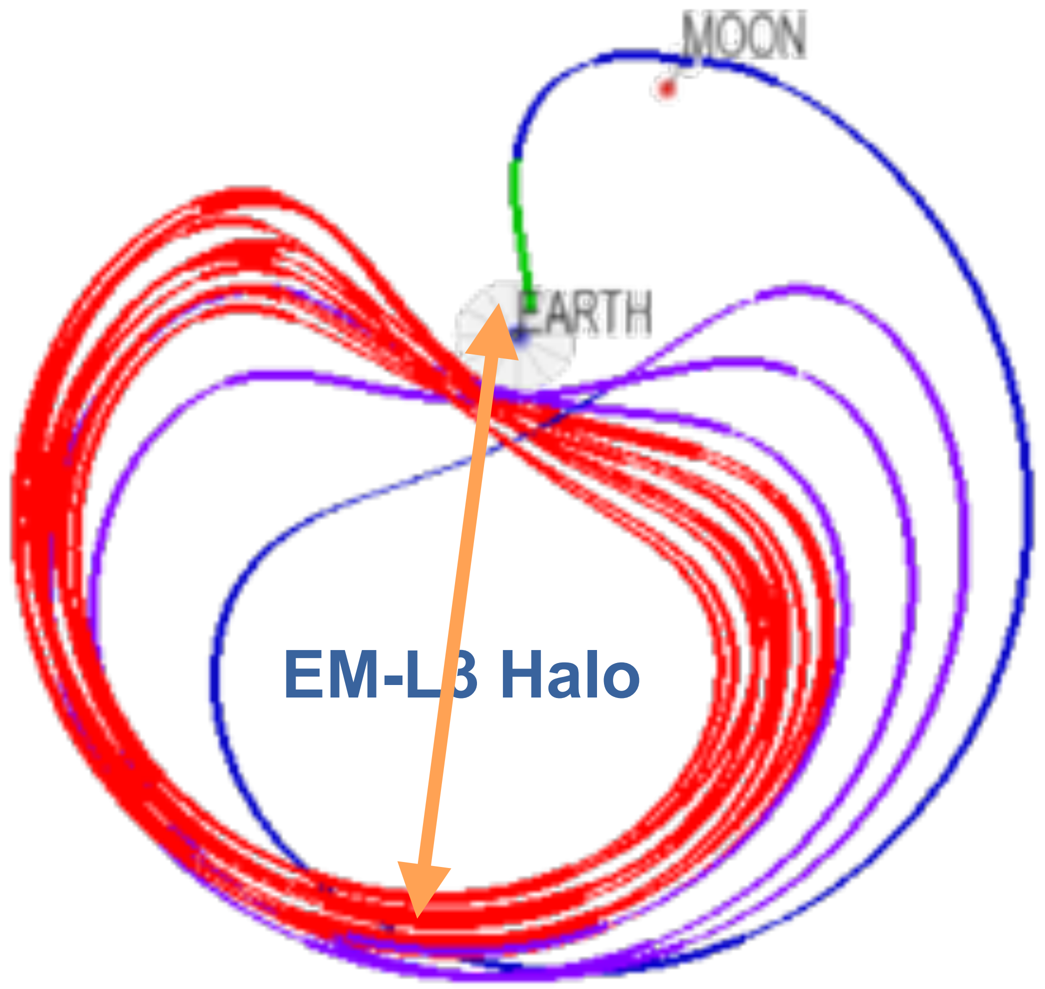
MoonBEAM
Moon Burst Energetic All-sky Monitor

PI: Michelle Hui (NASA/MSFC)

12U CubeSat concept of deploying gamma-ray detectors in cislunar orbit.

Mission Goals

- Detect short gamma-ray bursts associated with gravitational wave events to study astrophysical jets and probe fundamental physics from neutron star merger events.
- Improve localization to enable faster afterglow detection to study kilonova evolution and the origin of heavy elements.



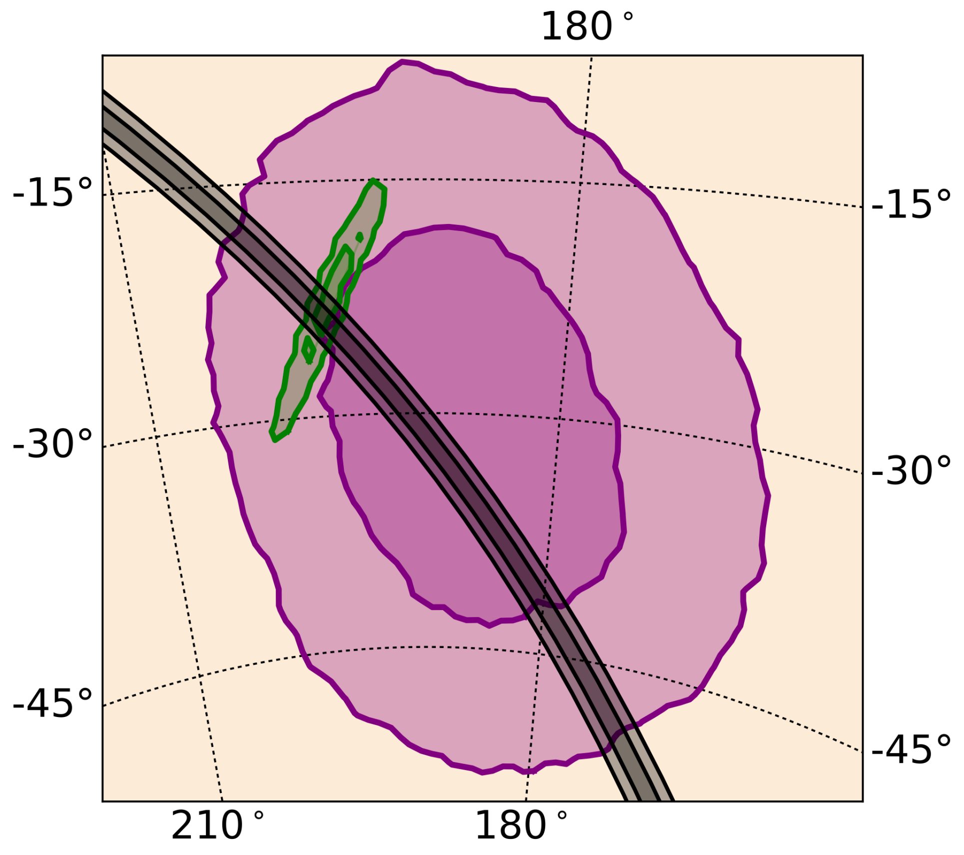
0.3-2.1 light seconds from Earth

All-sky Coverage

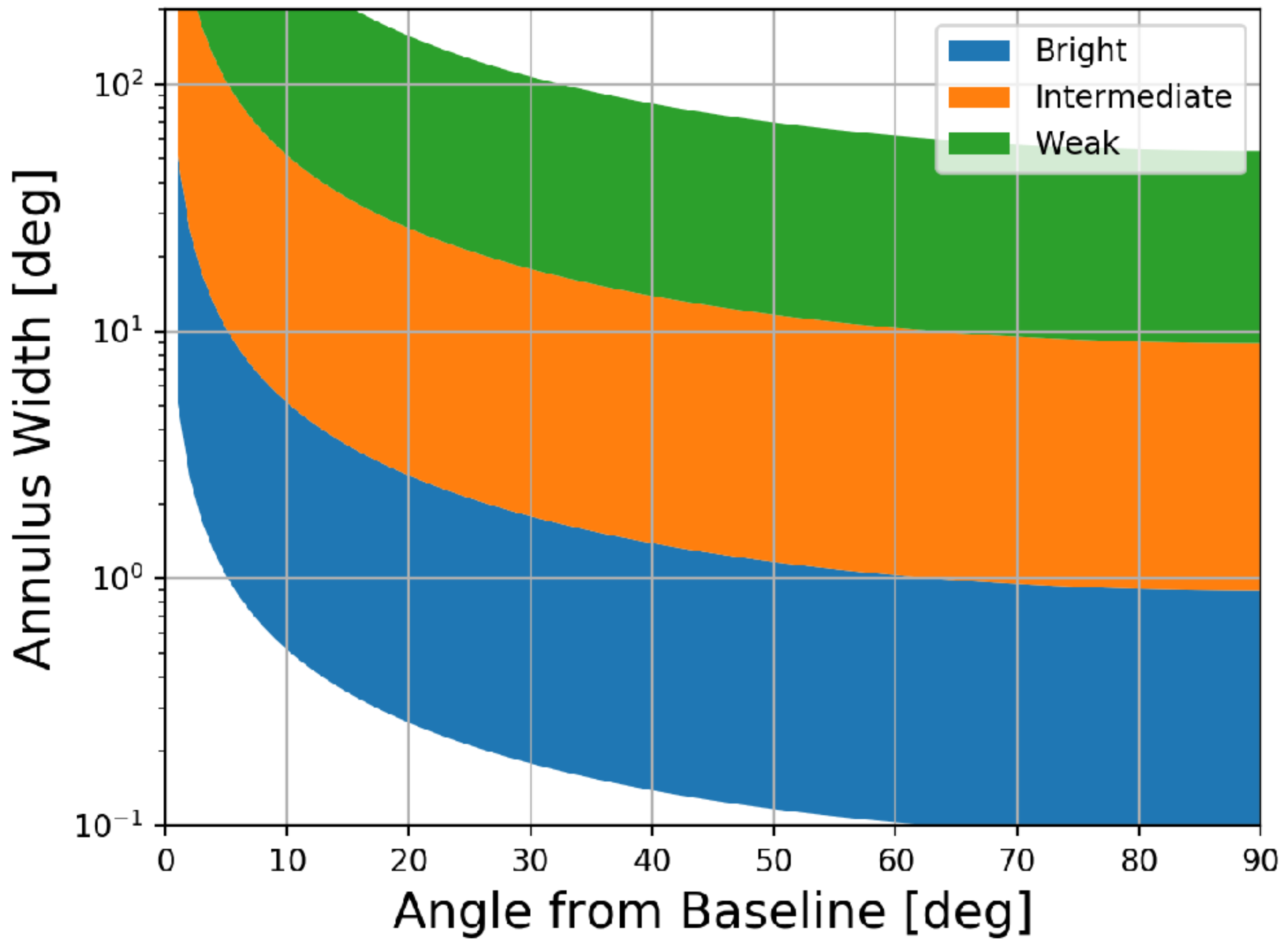
- By deploying MoonBEAM in cislunar orbit, there will be minimal Earth blockage and no downtime due to the South Atlantic Anomaly.
- Based on detector area and sky coverage, expected detection rate of 30-40 short GRBs/year.

Improved Localization

- Up to 2.1s time difference when paired with a detection from Low Earth Orbit.
- Capable of reducing localization area by >50% for an average short GRB with a 45deg baseline using time-of-flight method.



GW170817 and GRB 170817A localization contours, an example annulus for an intermediate bright burst at 45° baseline angle.

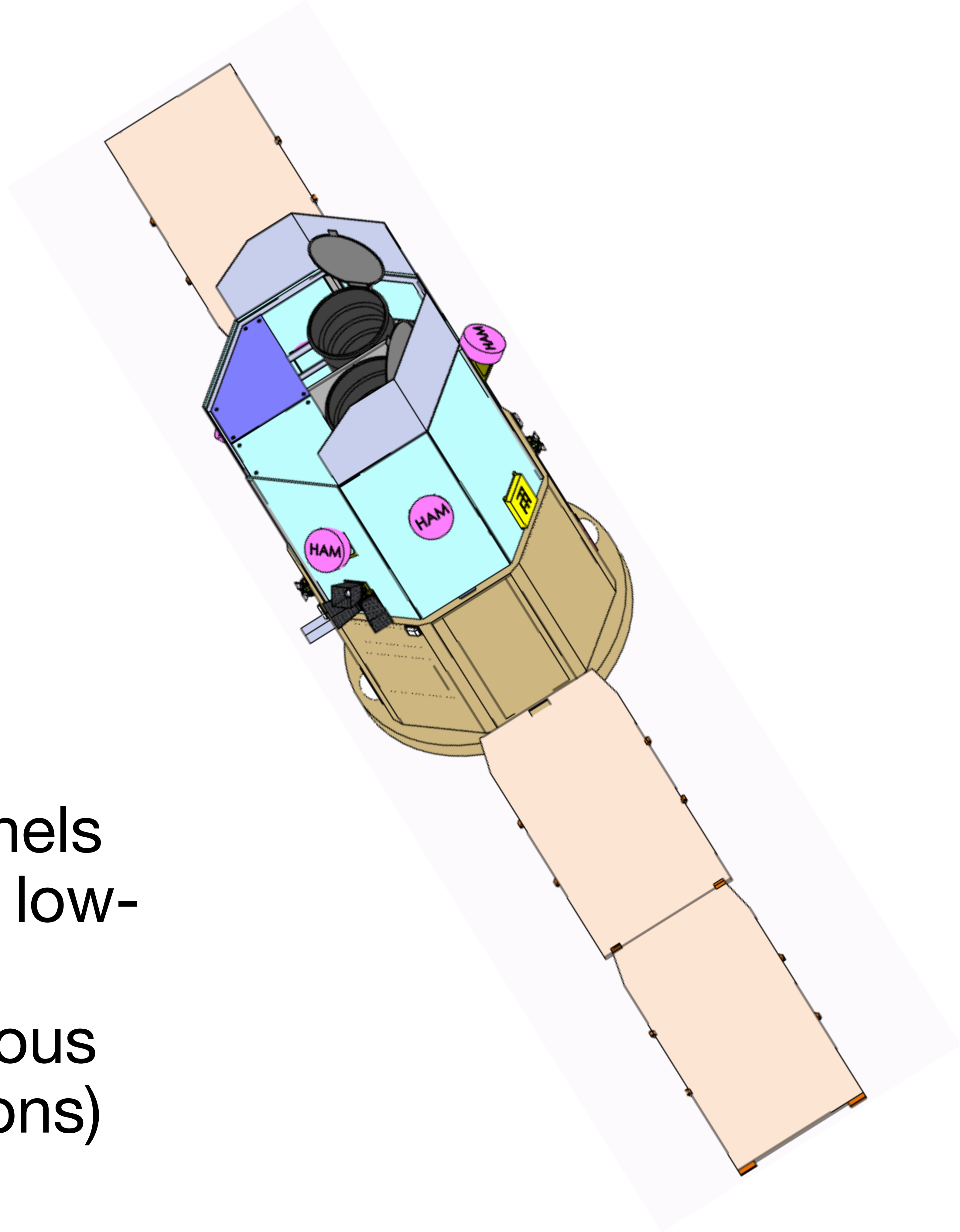


Left: 1σ annulus width for short GRBs with different intensities. Most bright GRBs will be localized to sub-degree width.

Nimble

PI: Josh Schlieder (NASA/GSFC)

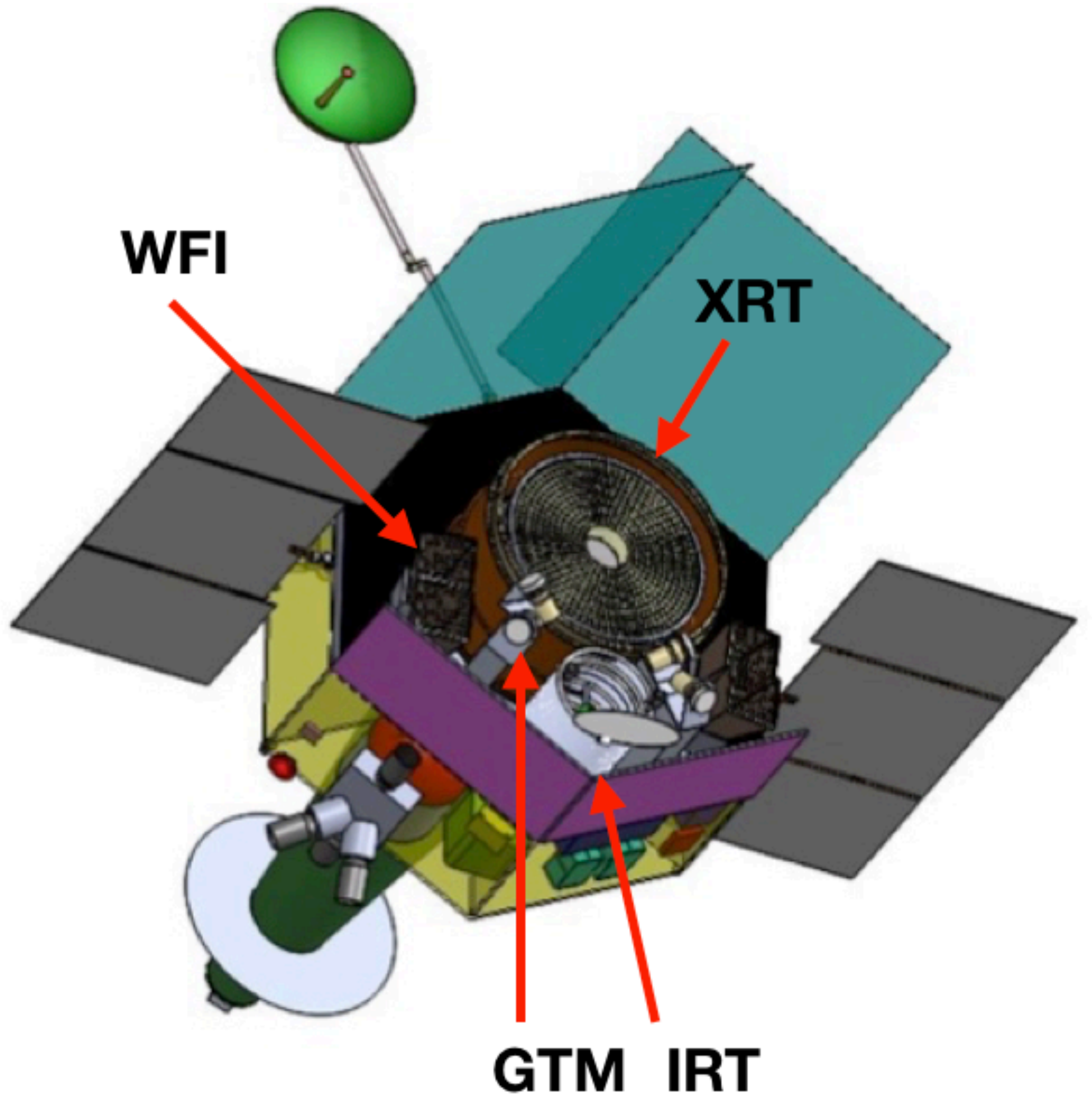
- In development for proposing to upcoming NASA SMEX call in Summer 2019
- Science goals:
  - Detect gamma-ray and UV/optical/IR GW counterparts
  - Characterize exoplanet atmospheres
- Instruments
  - High-energy All-Sky Monitor (HAM)
    - Gamma-ray scintillator (GBM/BurstCube-like)
  - Small UV Optical IR telescope (SUVOIR)
    - Wide-field blue optical telescope for finding transients
    - Narrow field telescope with UV/Optical and Optical/IR channels with filters and grism to provide broadband photometry and low-resolution spectroscopy
- Sun-synchrotronous low-Earth orbit - rapid slewing and autonomous follow-up of HAM triggers or uploaded targets (e.g. GW localizations)
- Launch 2025
- 2 year mission (5 year goal)

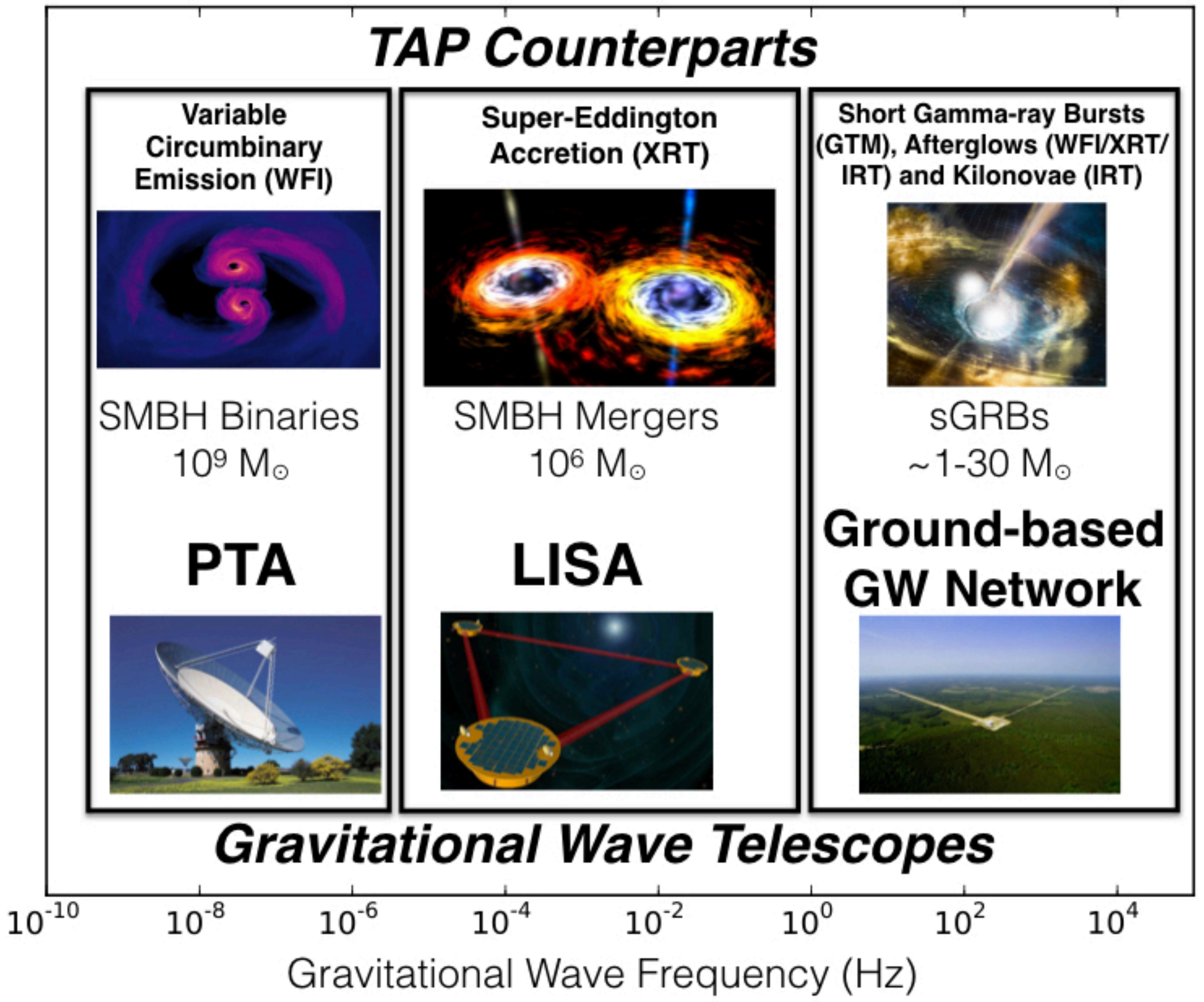


Transient Astrophysics Probe (TAP)

PI: Jordan Camp (NASA/GSFC)

- Awarded one of the 2017 NASA Probe Concept Studies
  - To be submitted to 2020 Decadal Survey
- 4 Instruments
  - Wide Field Imager (WFI)
  - X-ray Telescope (XRT)
  - optical/Infrared Telescope (IRT)
  - Gamma-ray Transient Monitor (GTM)
- Rapidly slewing spacecraft will autonomously detect and follow-up transients and variable sources, and conduct all-sky survey
- L2 orbit with 85% of sky viewable at any time
- Launch in late-2020's
- 5 year mission (10 year goal)
- For more information: https://asd.gsfc.nasa.gov/tap/

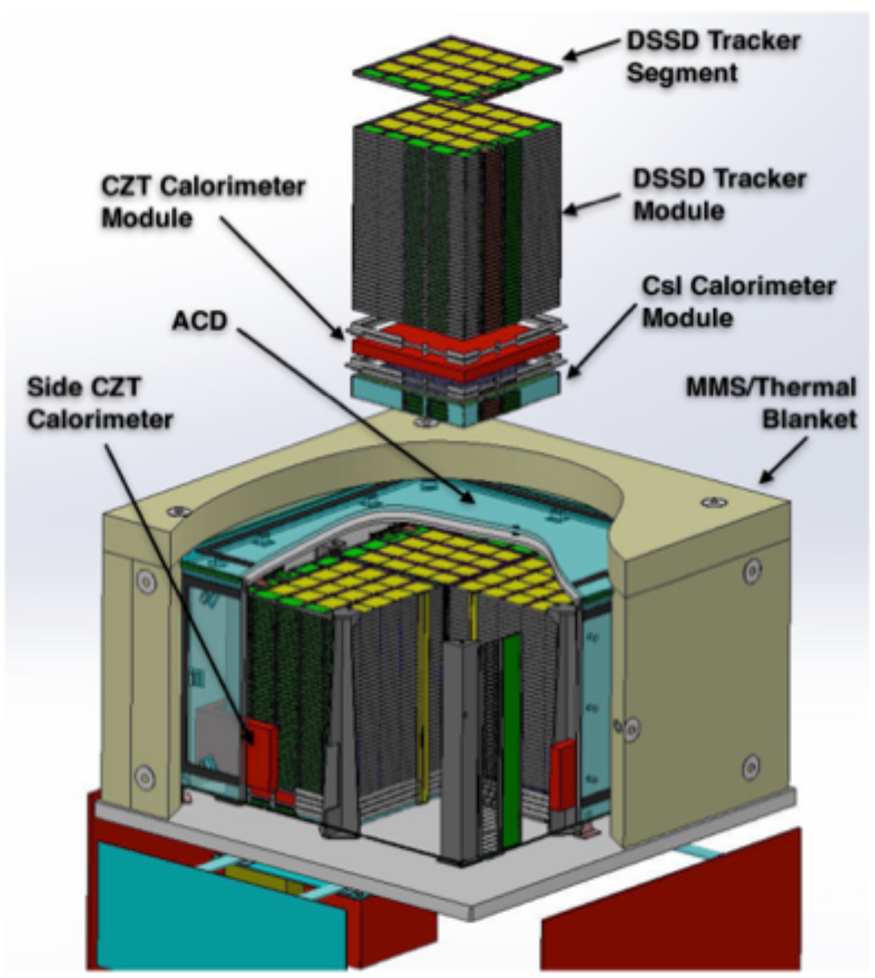




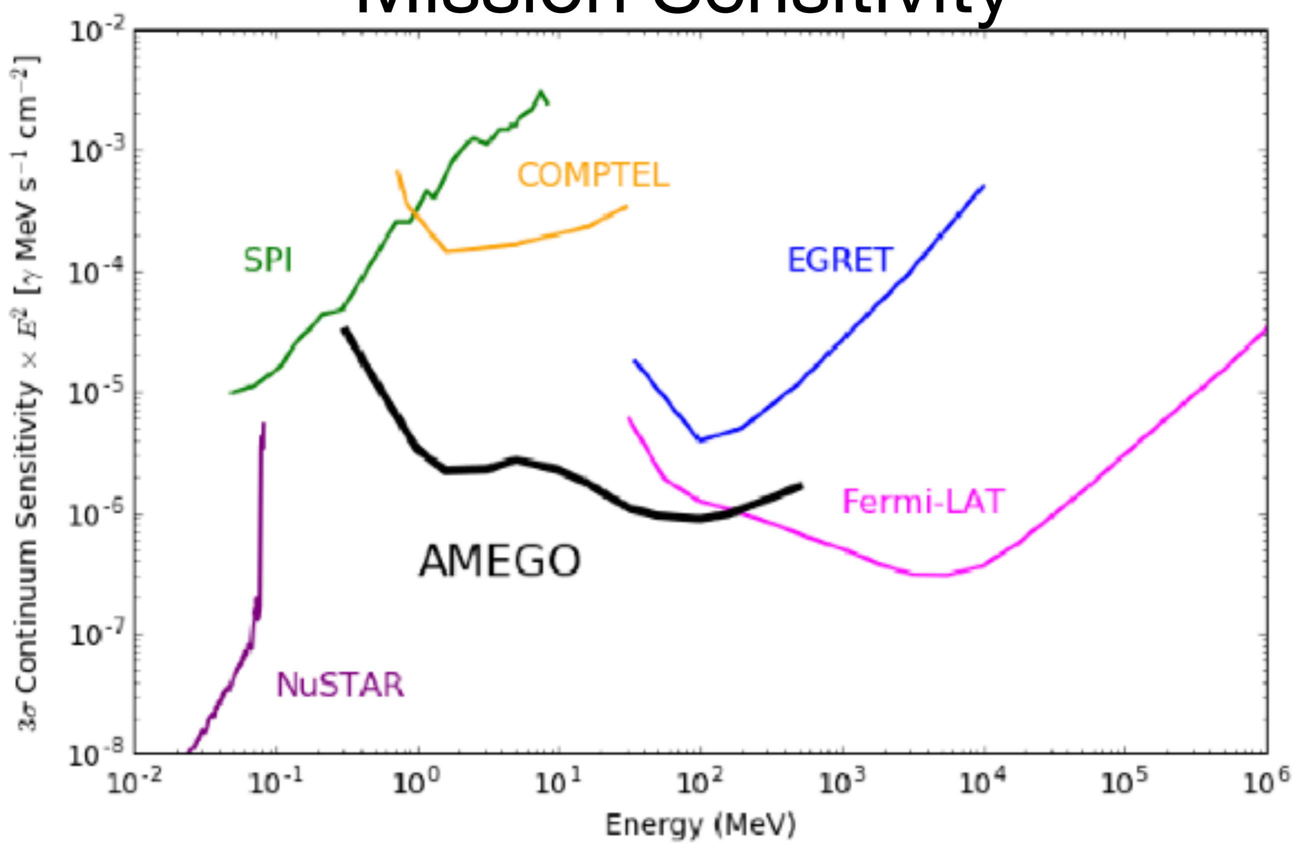
All-sky Medium Energy Gamma-ray Telescope (AMEGO)

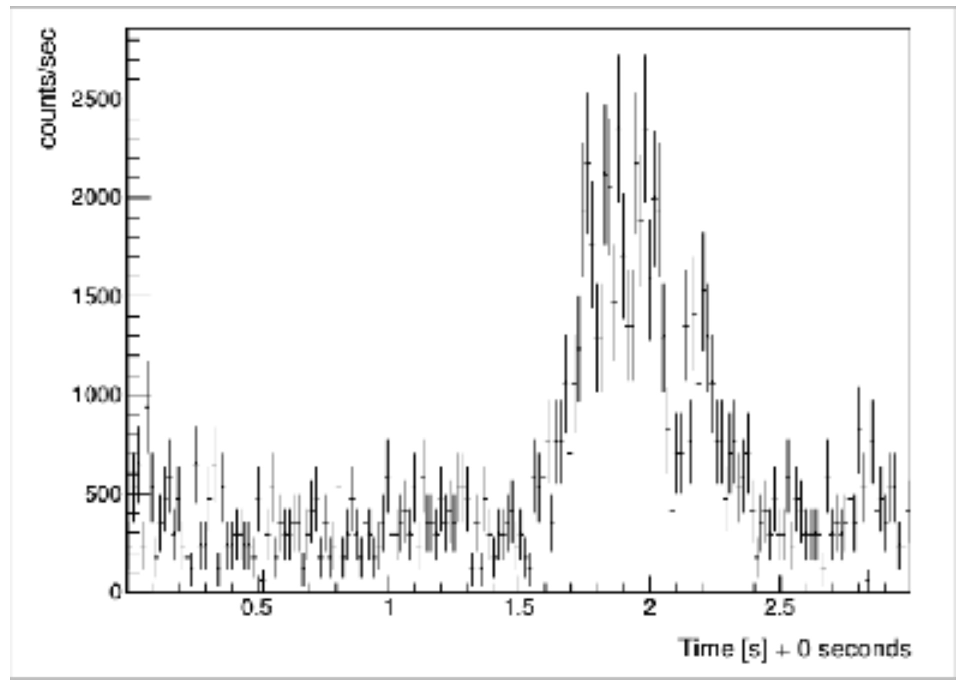
PI: Julie McEnery (NASA/GSFC)

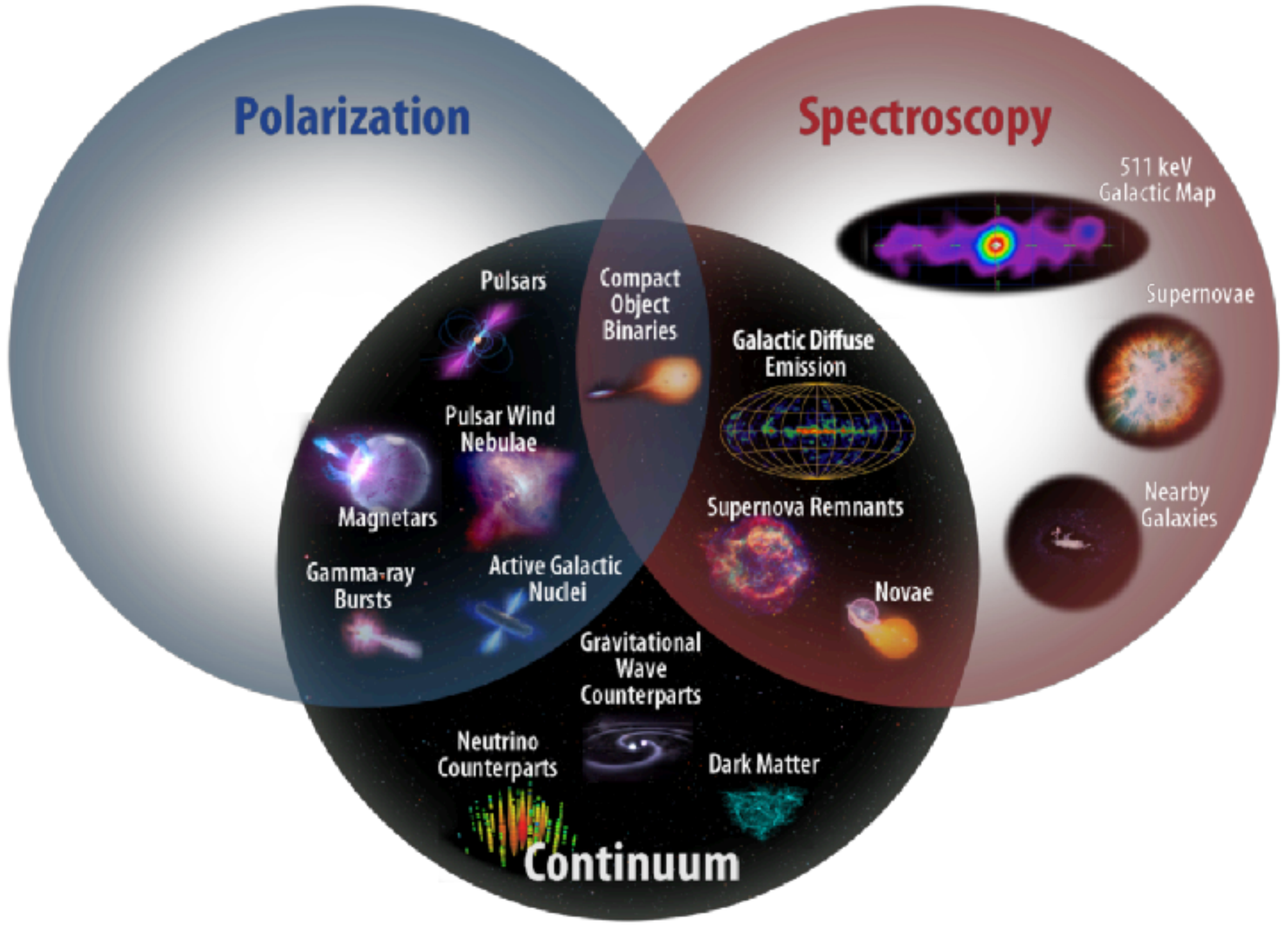
- NASA Probe mission concept to be submitted to US Decadal Survey
- Double-sided silicon strip tracker, CZT & CsI calorimeters, ACD
- 200 keV – 10 GeV
- Compton & Pair Telescope viewing ~20% of sky surveying entire sky over 2 orbits (like Fermi-LAT)
- Many sources have peak spectra in MeV band (AGN, pulsars, GRBs) – sensitive instrument needed to understand emission processes
- If GW-GRBs are under-luminous, AMEGO will be far more sensitive than scintillator instruments
- Launch in late 2020's
- 5 year mission (10 year goal)
- https://asd.gsfc.nasa.gov/amego/



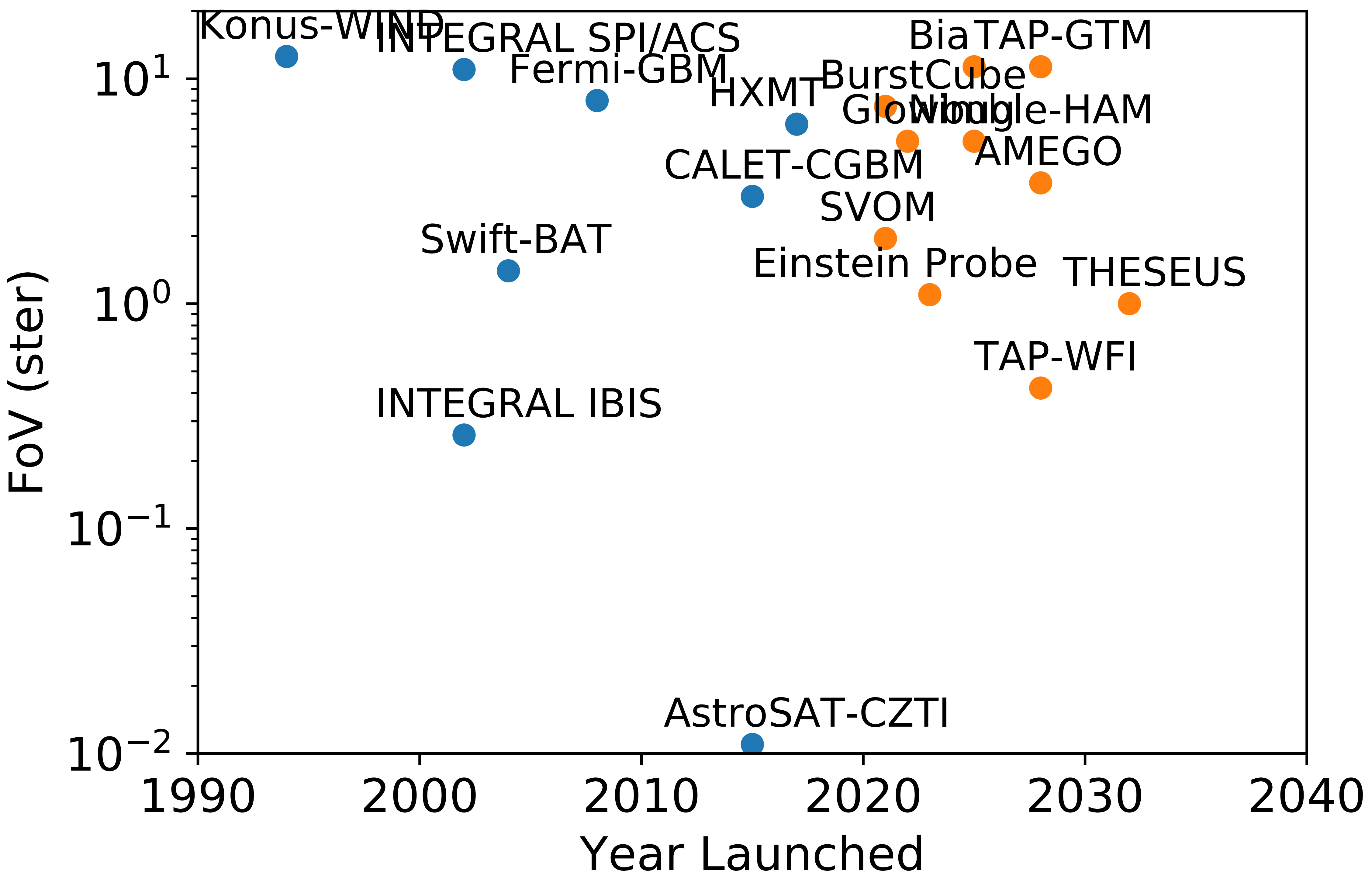
Mission Sensitivity

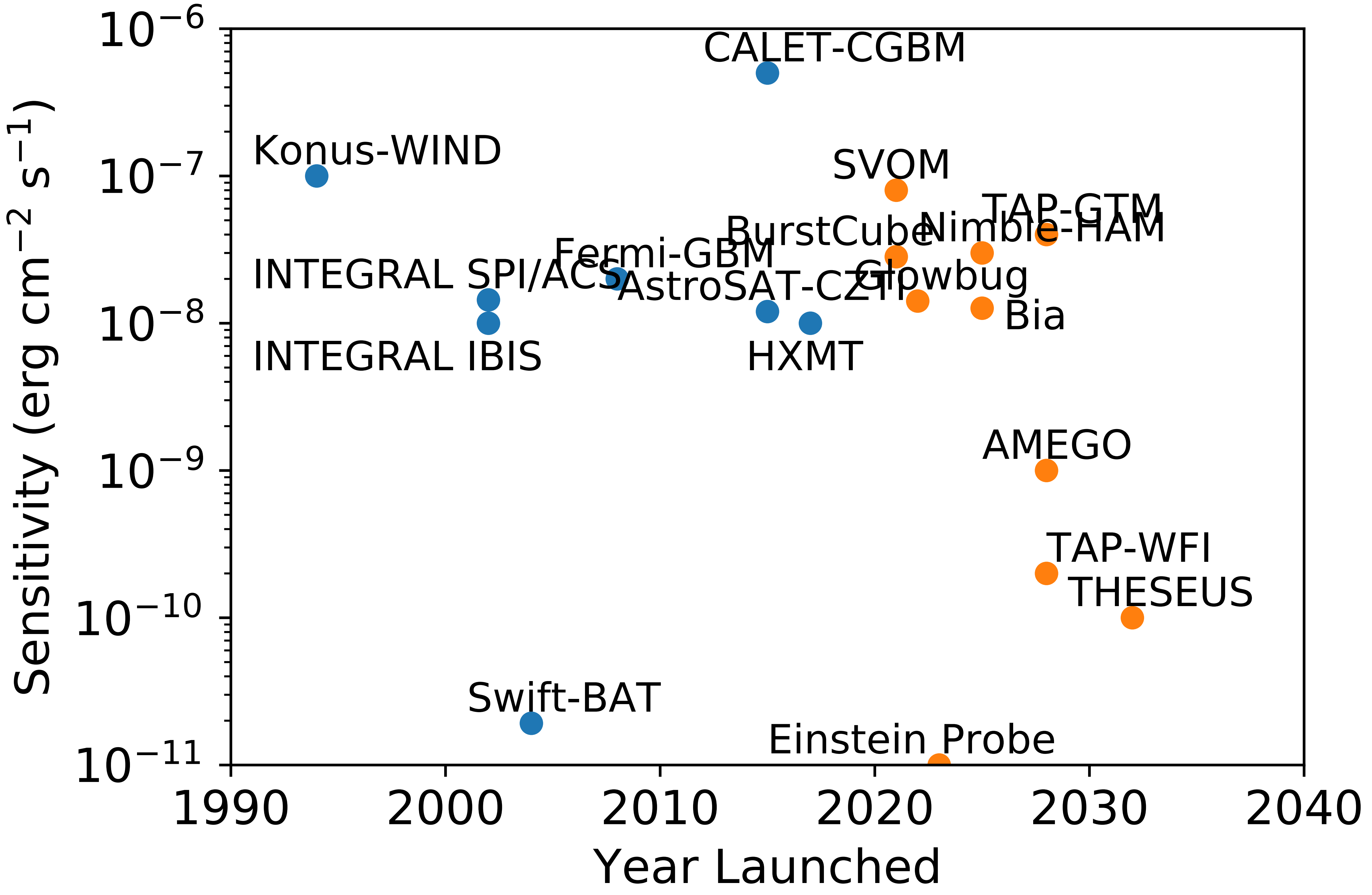






Current & Future Missions





Instruments energy band vary from soft X-ray to medium energy gamma-ray

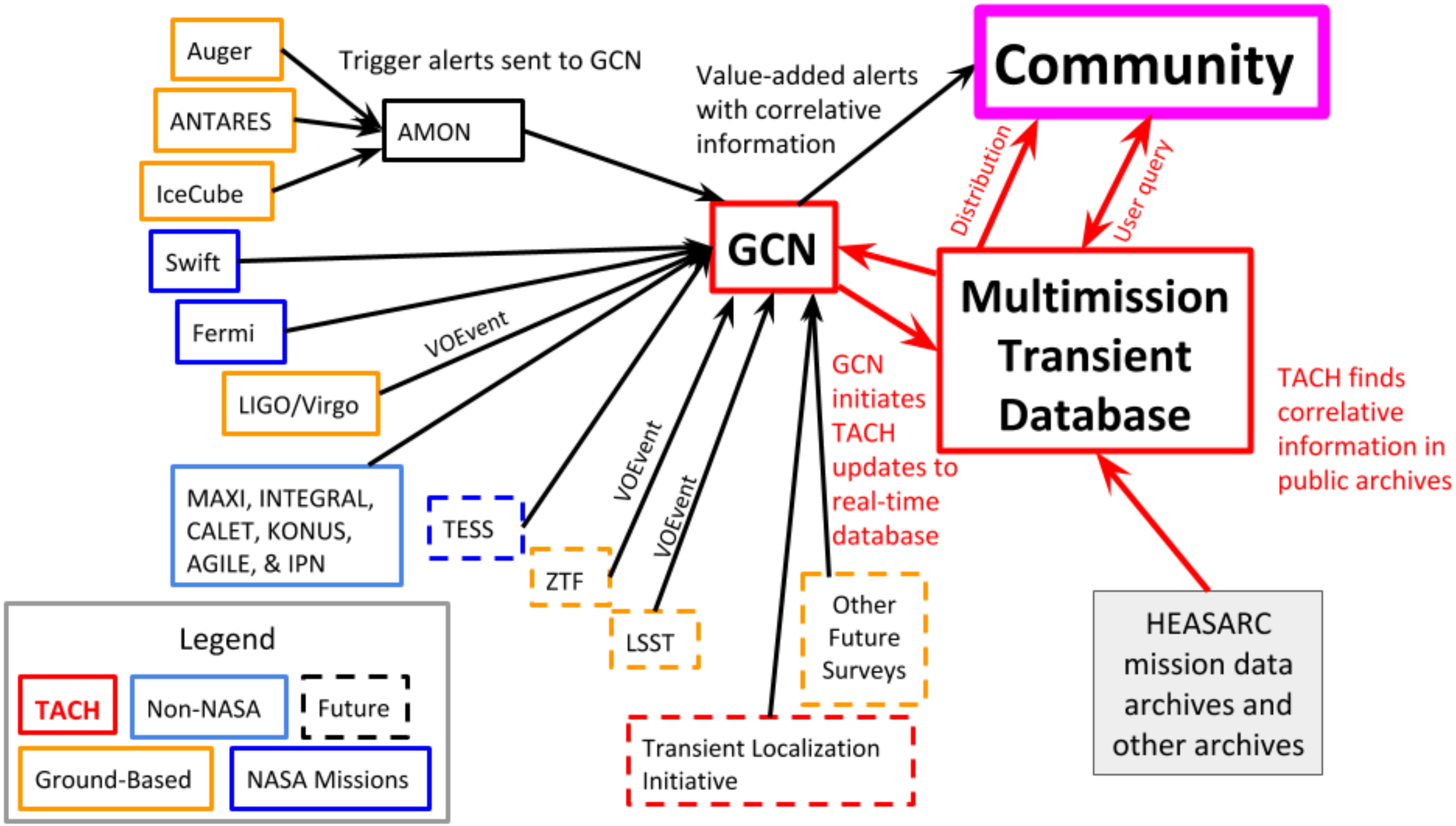
Coordinating Multi-Messenger Observations

- As more instruments/missions/datasets need to be correlated, need more automated methods and systems
  - Advanced computational techniques
  - Dedicated cross-correlation platforms

Time Domain Astronomy Coordination Hub (TACH)

- New initiative at NASA Goddard to build upon existing community resources to address the needs of the multi-messenger/multi-wavelength transient deluge coming in the next decade
  - Improvements to GCN (add reliability with mirror sites, improved coincident source searches)
  - New realtime HEASARC database that ingests GCN & other public data streams to easily cross-correlate and be queryable by community
  - Provide infrastructure to do joint localizations with multiple GRB-detecting satellites
- How can TACH help serve our community?
- How can TACH complement efforts like VO?

TACH



Auger
ANTARES
IceCube
Trigger alerts sent to GCN
AMON
Value-added alerts with correlative information
Community
Swift
Fermi
VOEvent
LIGO/Virgo
GCN
Distribution
User query
Multimission Transient Database
GCN initiates TACH updates to real-time database
TACH finds correlative information in public archives
MAXI, INTEGRAL, CALET, KONUS, AGILE, & IPN
TESS
VOEvent
VOEvent
ZTF
LSST
Other Future Surveys
HEASARC mission data archives and other archives
Transient Localization Initiative
Legend
TACH
Non-NASA
Future
Ground-Based
NASA Missions