High Energy Transient Science at MSFC

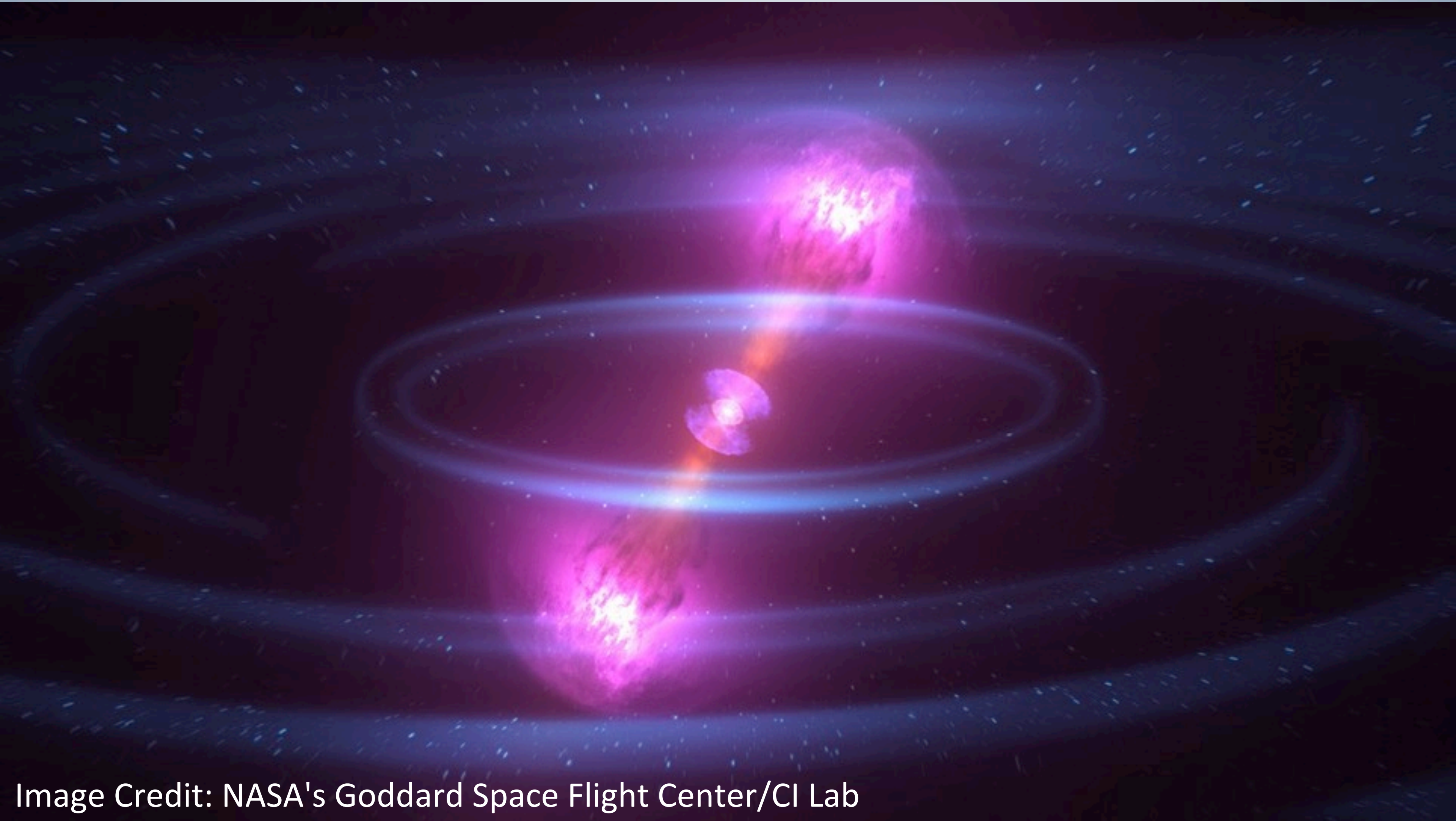
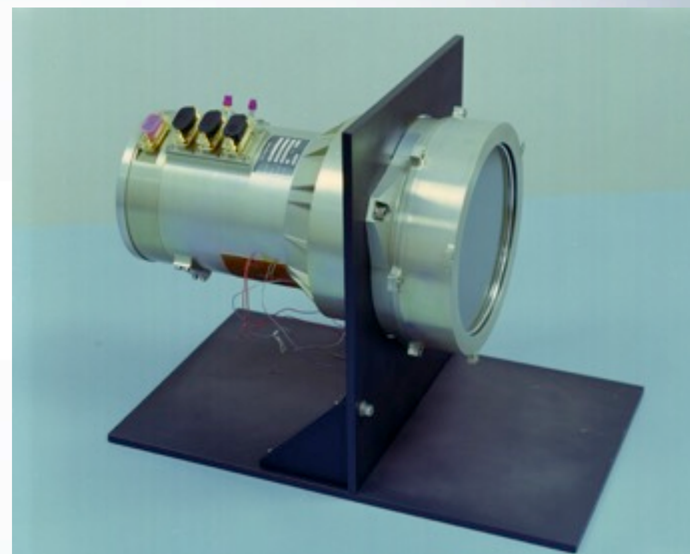


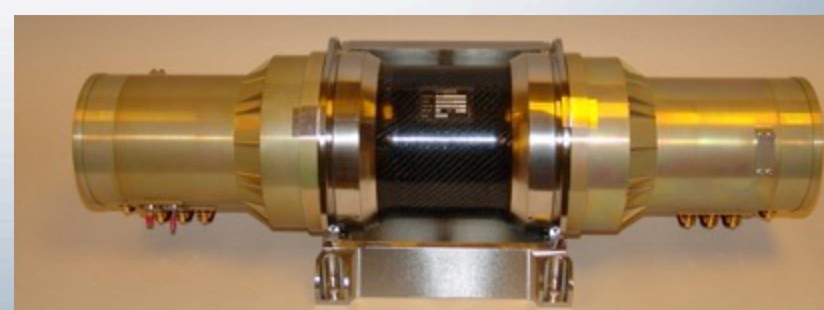
Image Credit: NASA's Goddard Space Flight Center/CI Lab

Colleen A. Wilson-Hodge (NASA/MSFC)

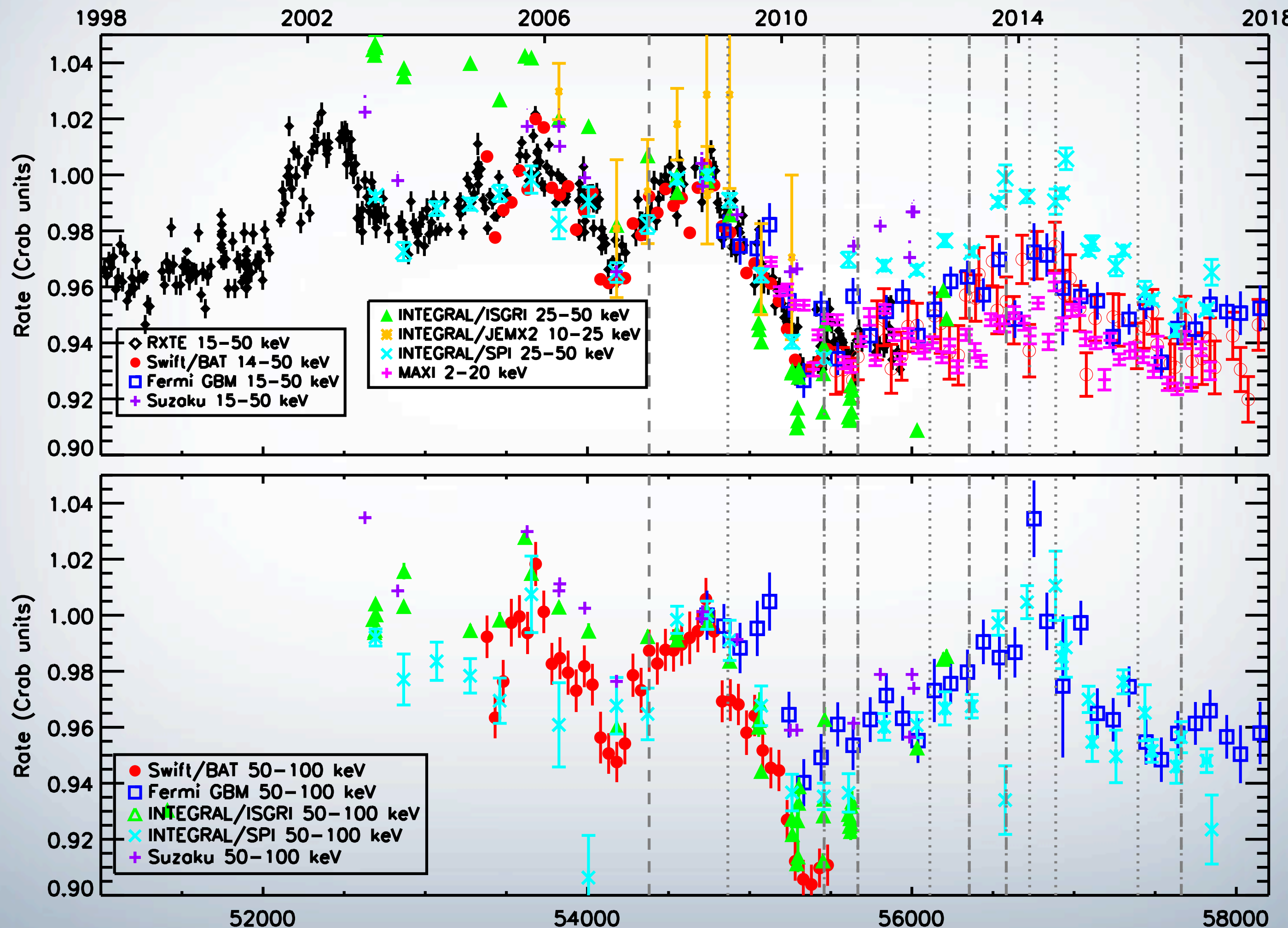
The Fermi Gamma ray Space Telescope

Gamma ray Burst Monitor (GBM)





Hard X-ray Variations in the Crab Nebula



Wilson-Hodge et al. 2011

What is a gamma-ray burst?

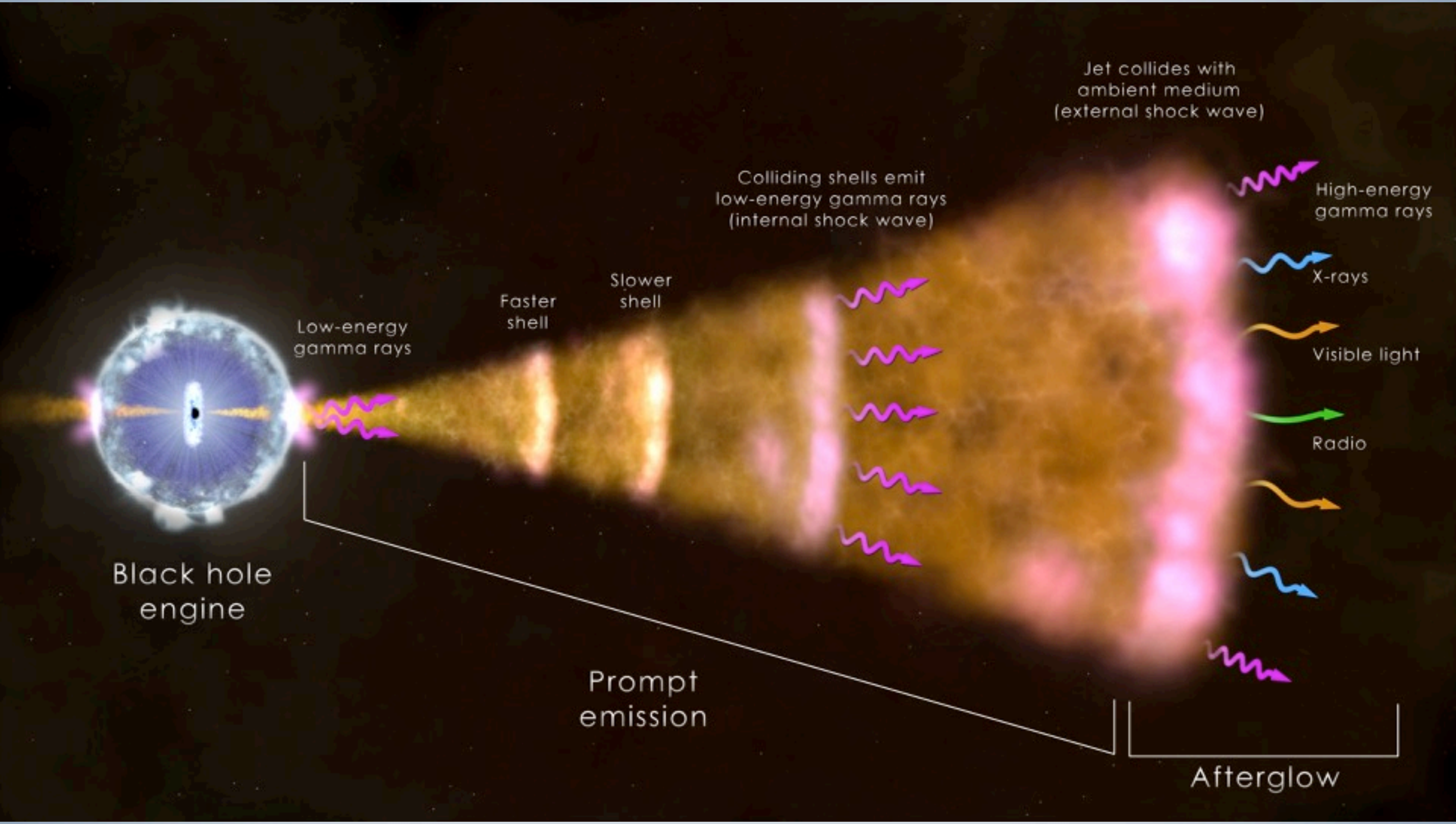
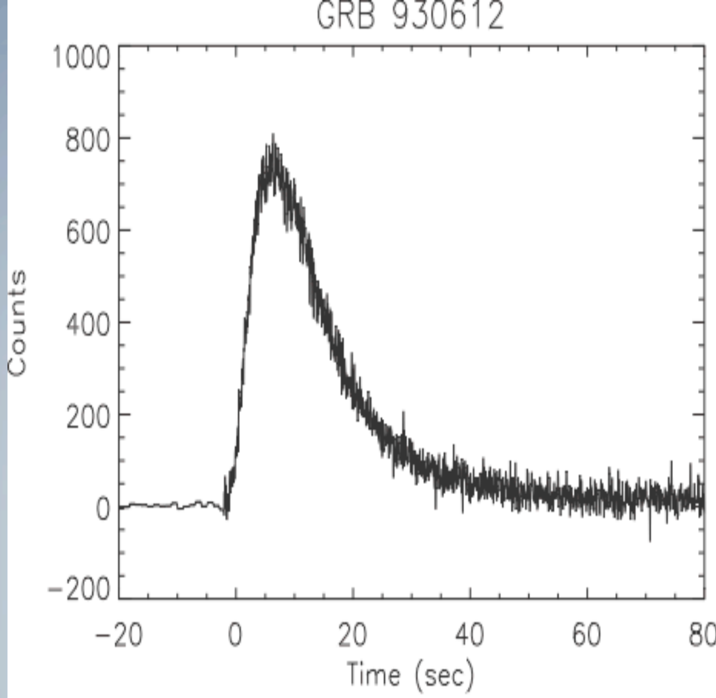


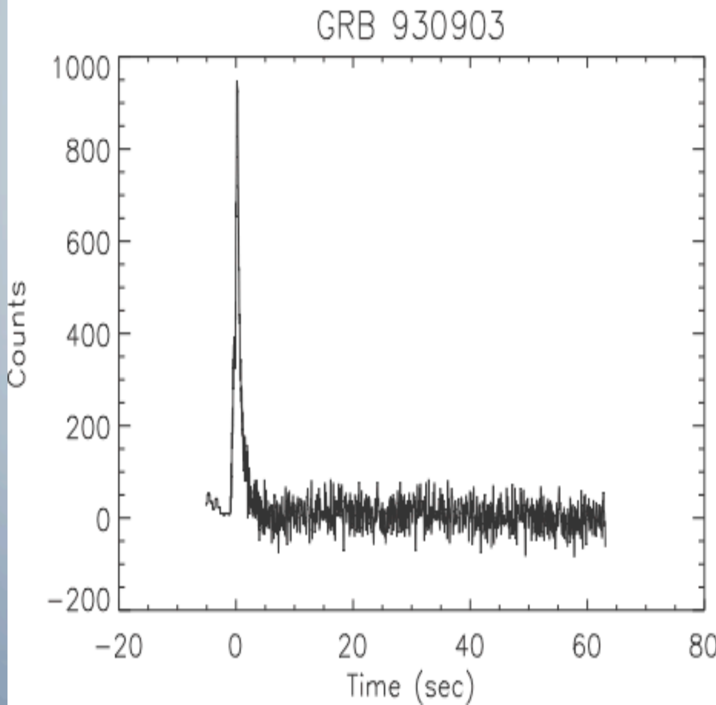
Image credit: NASA/GSFC

Types of GRBs



Long GRBs

- Produced by a massive star exploding
- 200 per year triggered with GBM

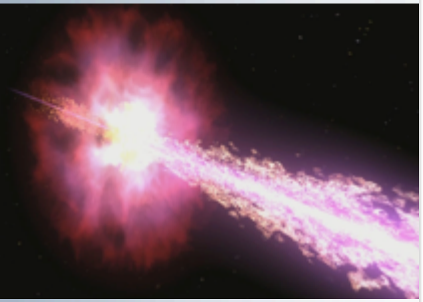


Short GRBs

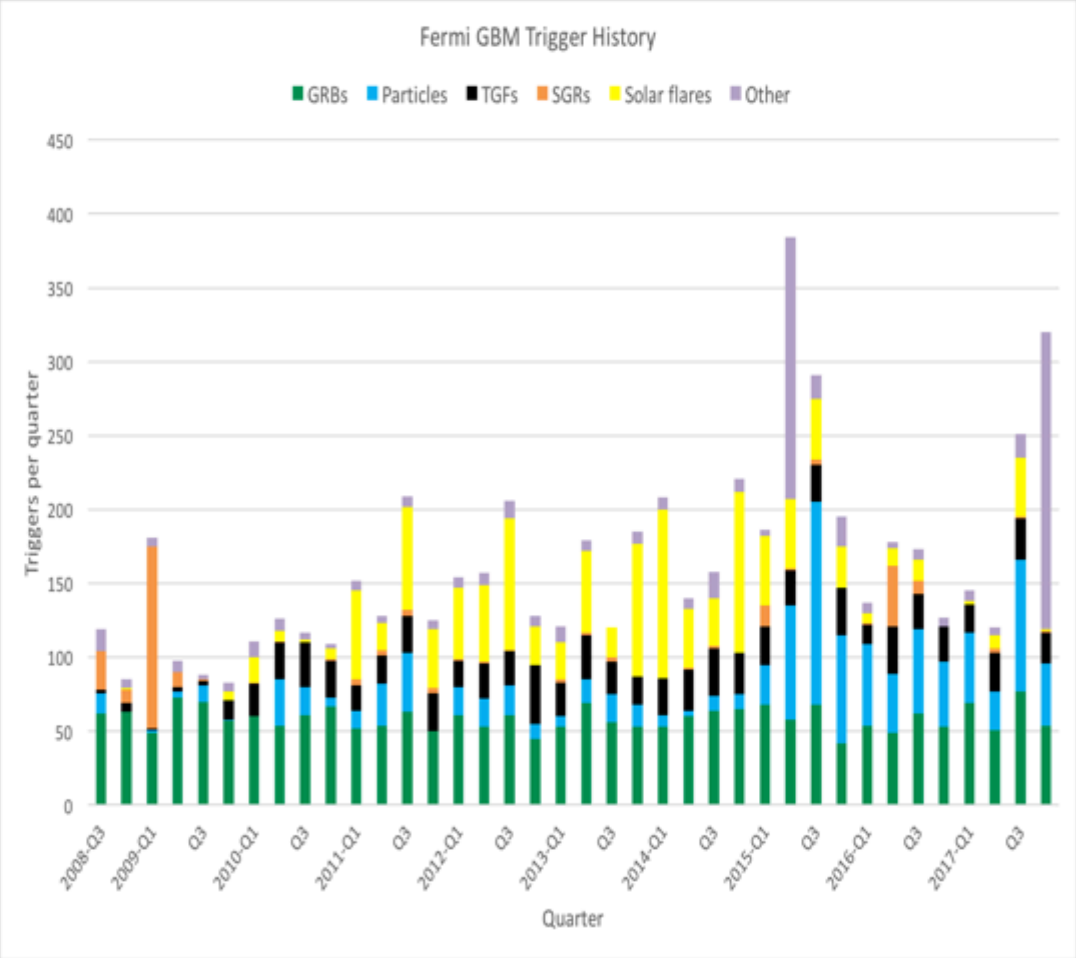
- Produced by merging neutron stars
- 40 per year triggered with GBM
- >80 per year found in searches for weak GRBs

6222 Fermi GBM triggers

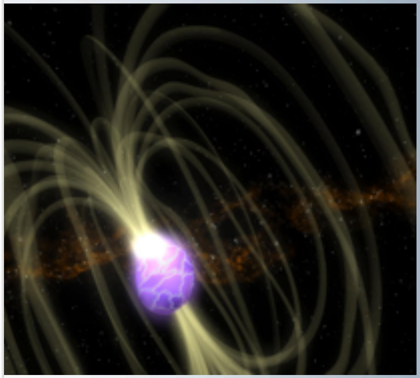
2238 GRBs



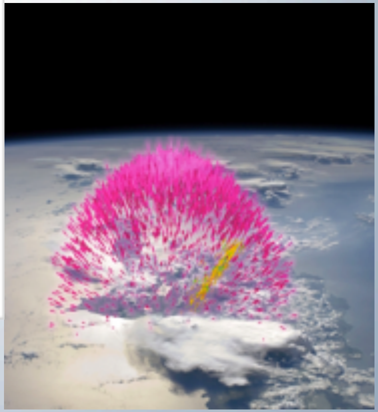
1176 Solar Flares



275 Magnetars

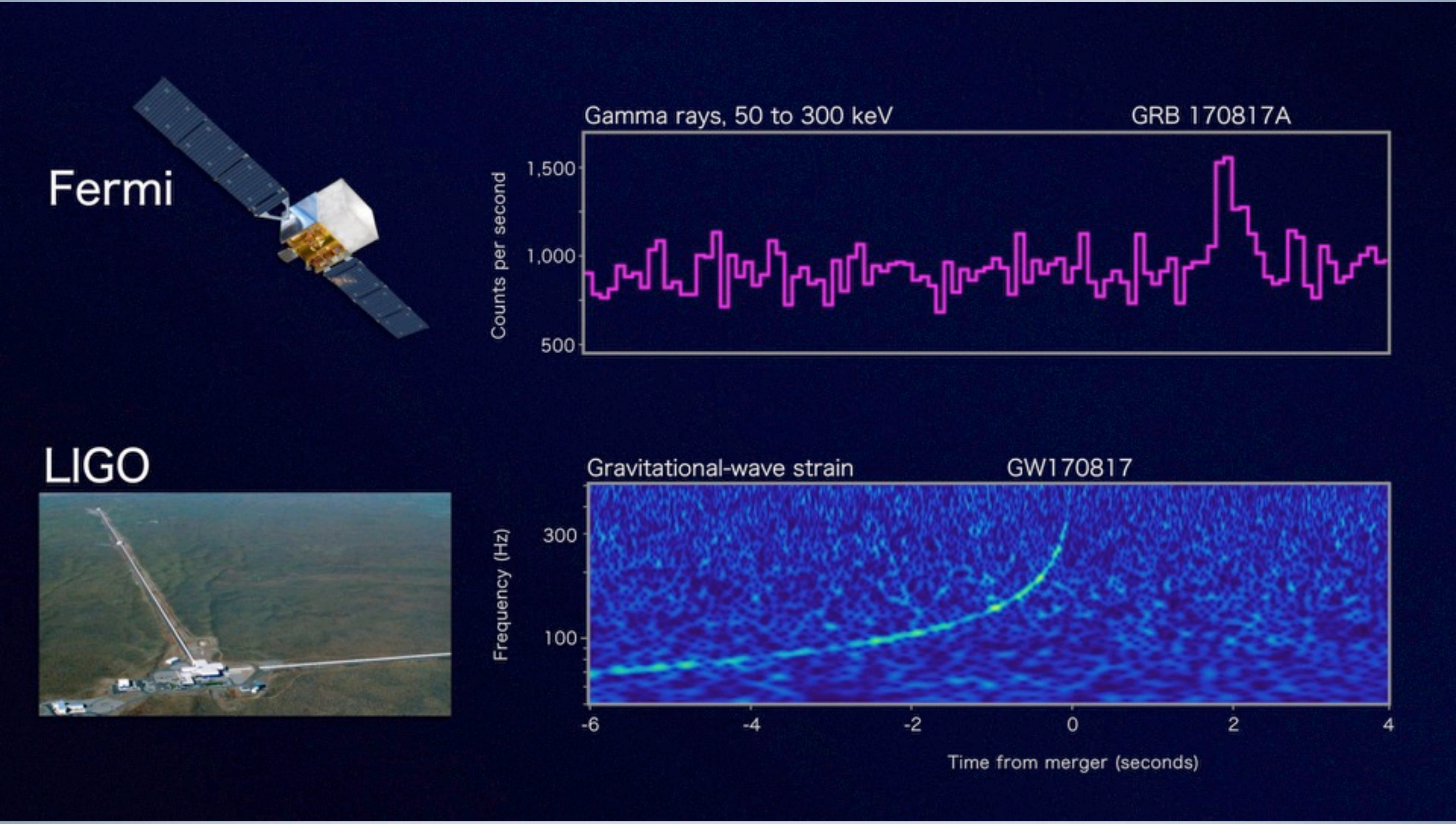


875 TGFs



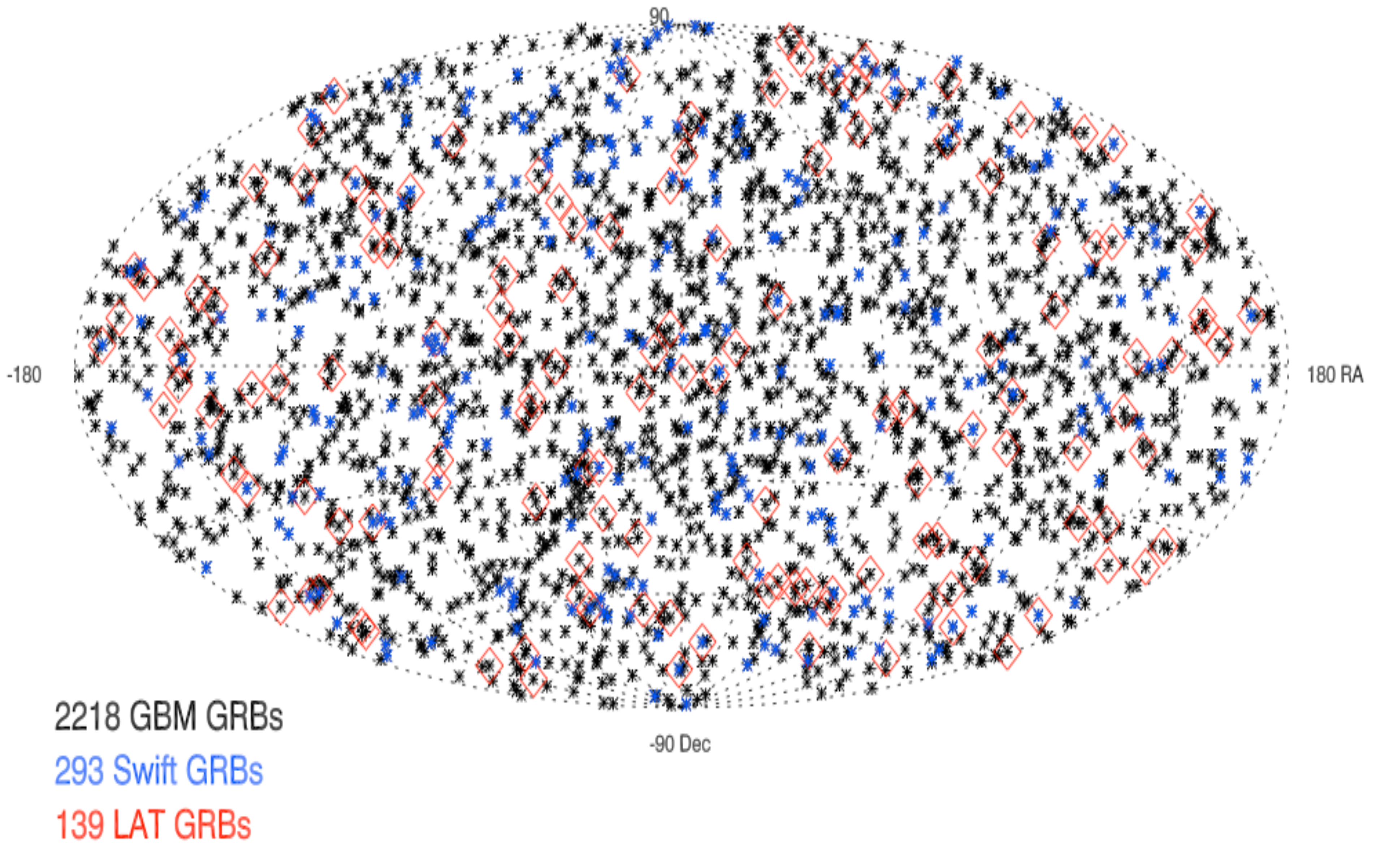
668 Others, including 189 from Swift J0243.6+6124 and 169 from V404 Cyg; 1041 particles

The morning of August 17, 2017

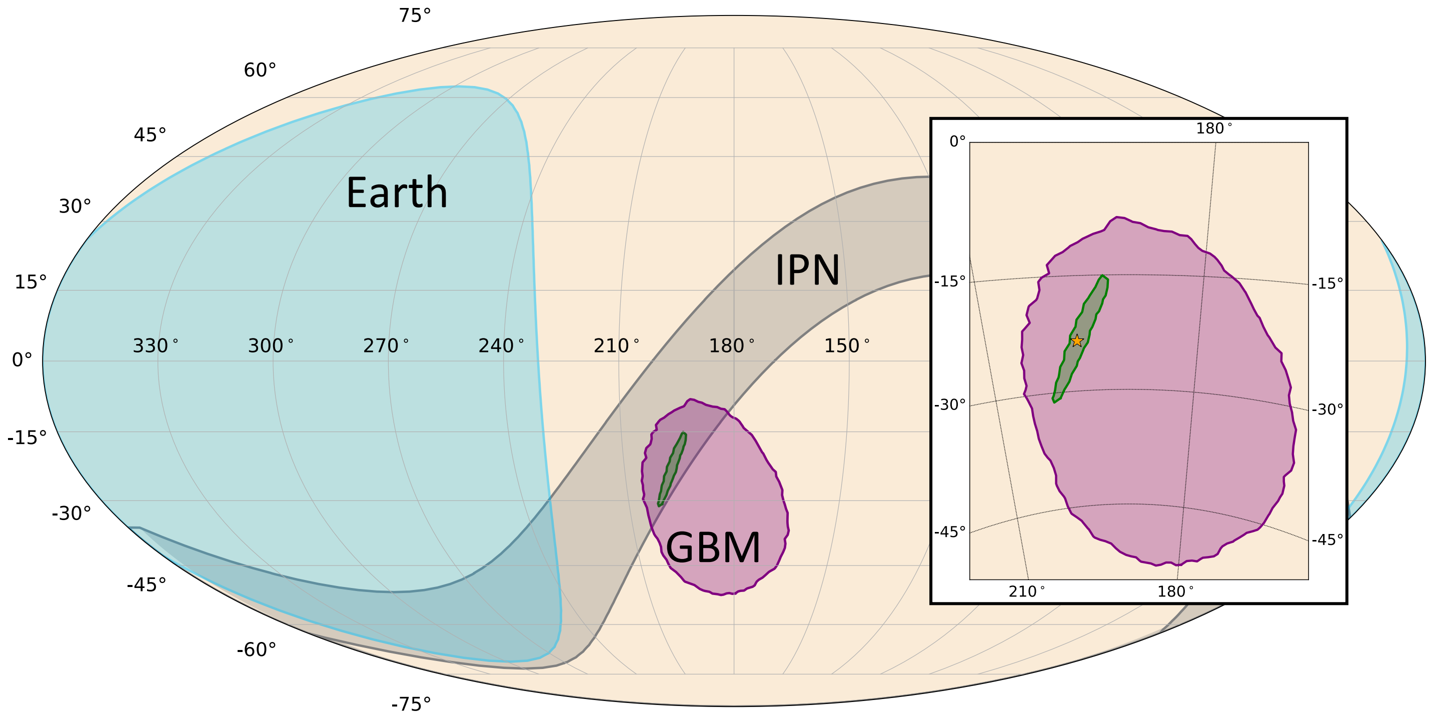


Video and image Credit: NASA GSFC, Caltech/MIT/LIGO Lab and ESA

GBM Triggered GRBs



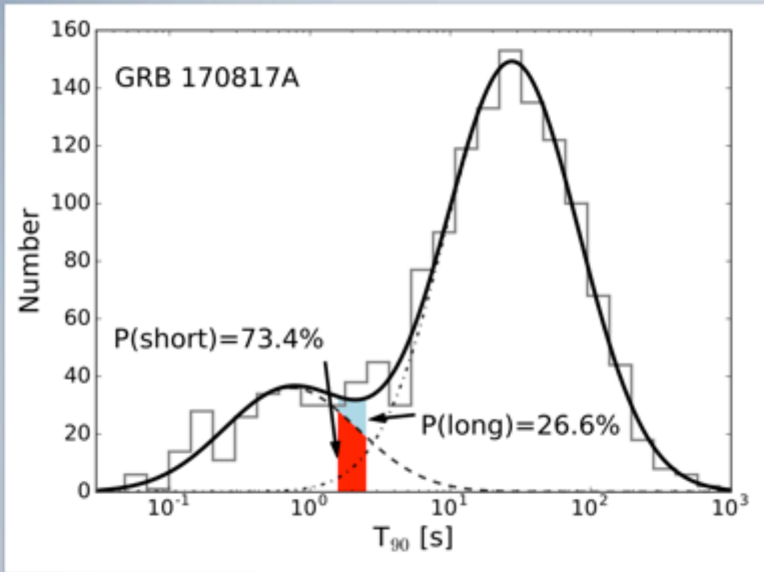
Locating the events on the sky

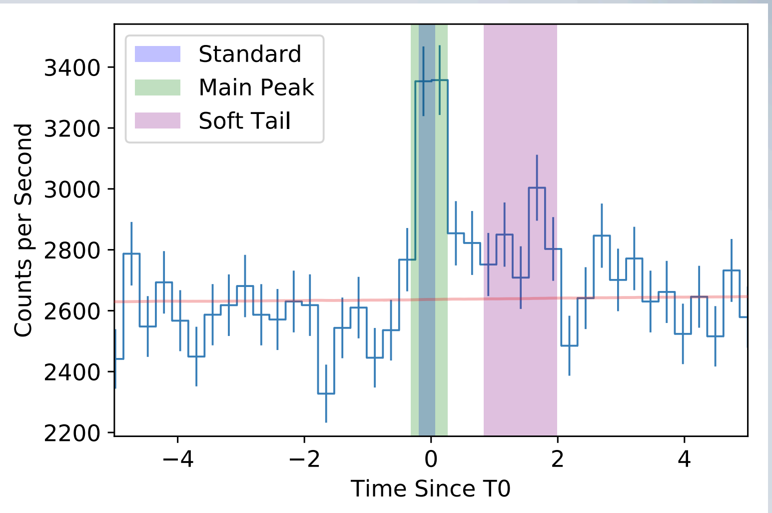


Abbot et al. 2017, ApJ, 848, L13

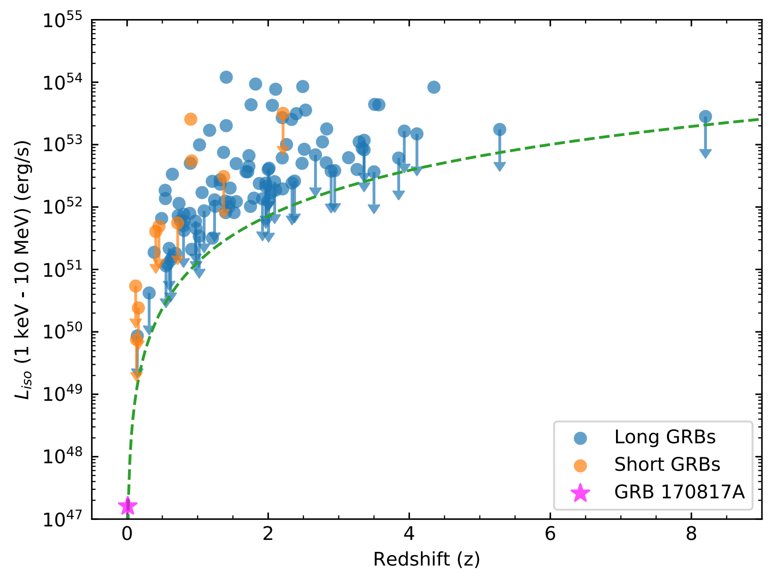
Probability of chance coincidence: 1 in 20,000,000

A weak short GRB with a low-energy tail



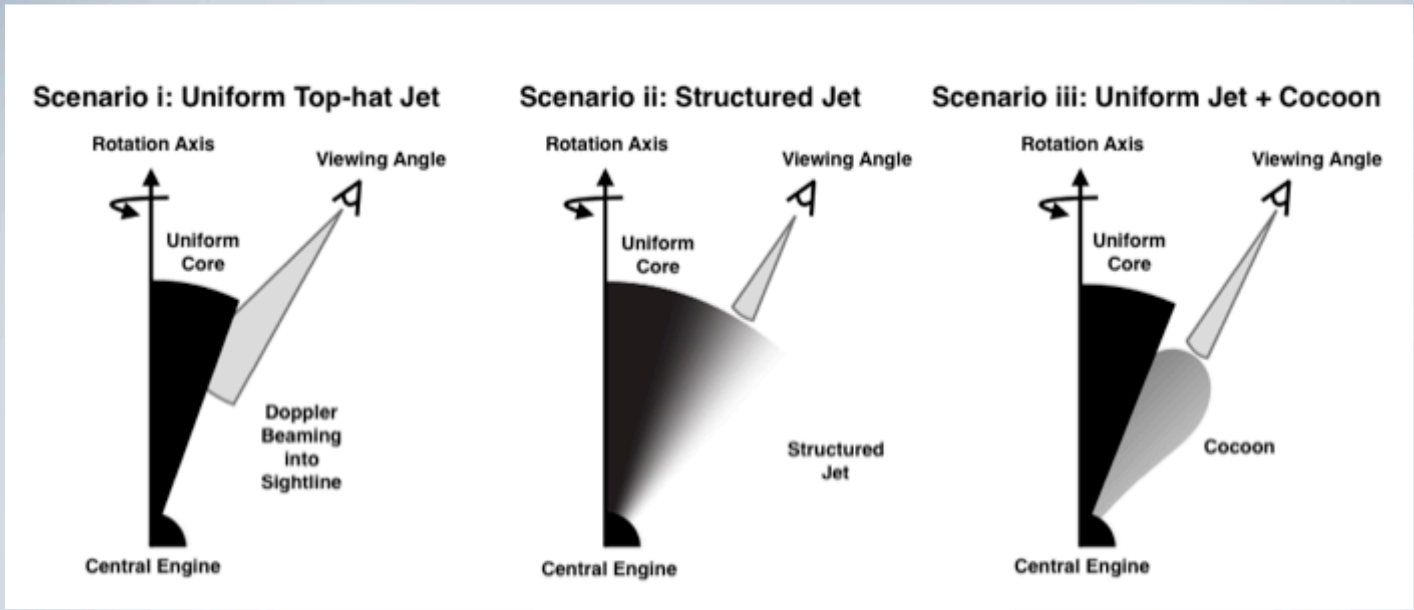


- GRB 170817A is a short GRB—predicted to originate from mergers
- It appears to have the traditional "spike" but also a weak lower-energy tail
- It appears intrinsically less luminous than any other GRB with measured distance



Goldstein et al. 2017, ApJ, 848, L14; Abbot et al. 2017, ApJ, 848, L13

GRB Observing Scenarios

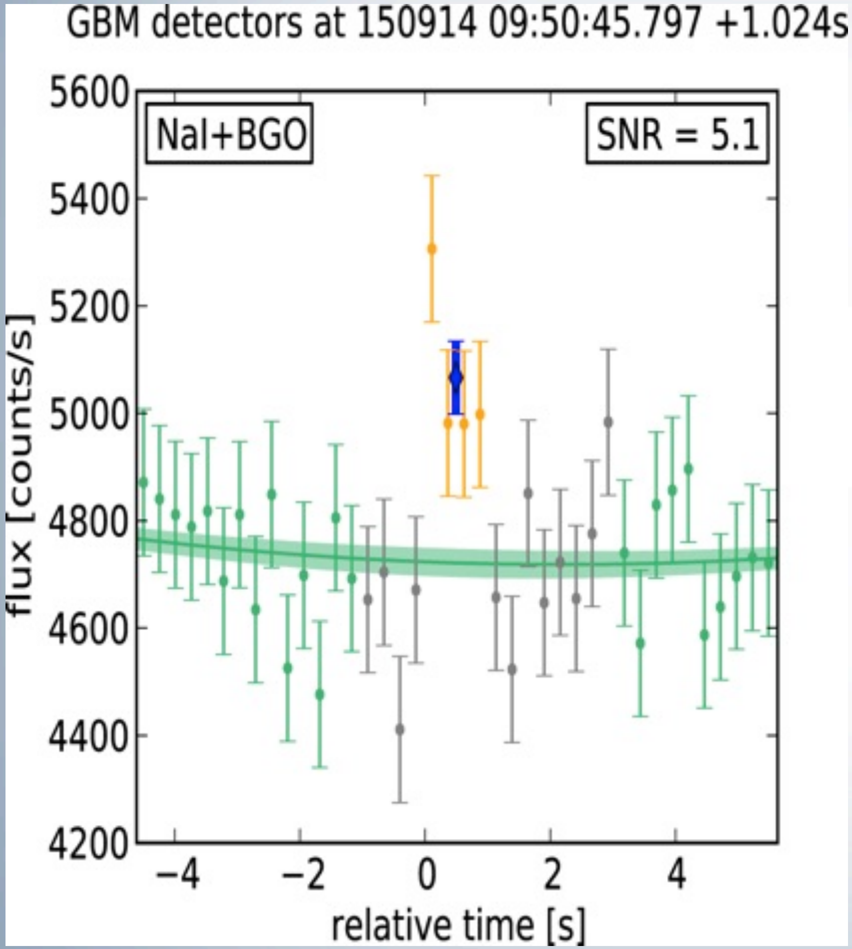


- Simplest model is just a uniform density jet with sharp edges
- Possible that we are looking off the center of the jet, which does not have a uniform density
- For the low-energy emission after the initial GRB spike, there may be a “cocoon” of surrounding material that is pulled along by the interior jet

Science from GW170817 and GRB 170817A

- Directly measure the speed of gravity
  - It is the same as the speed of light within one part in one quadrillion!
- Probe the neutron star equation of state: the densest matter in the universe!
- Understand the emission physics of relativistic jets and the engine that produces the short GRB
- Estimate the rate of events like these throughout the universe

Counterpart to a Black hole merger?



Connaughton et al. 2016

GW150914

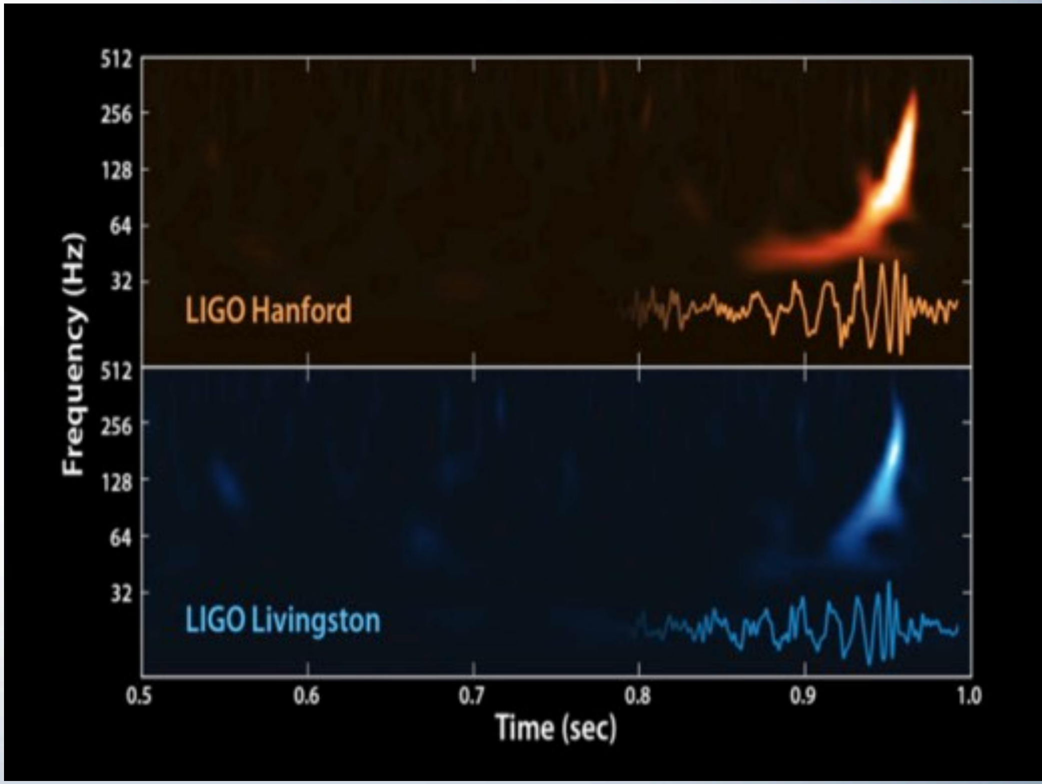
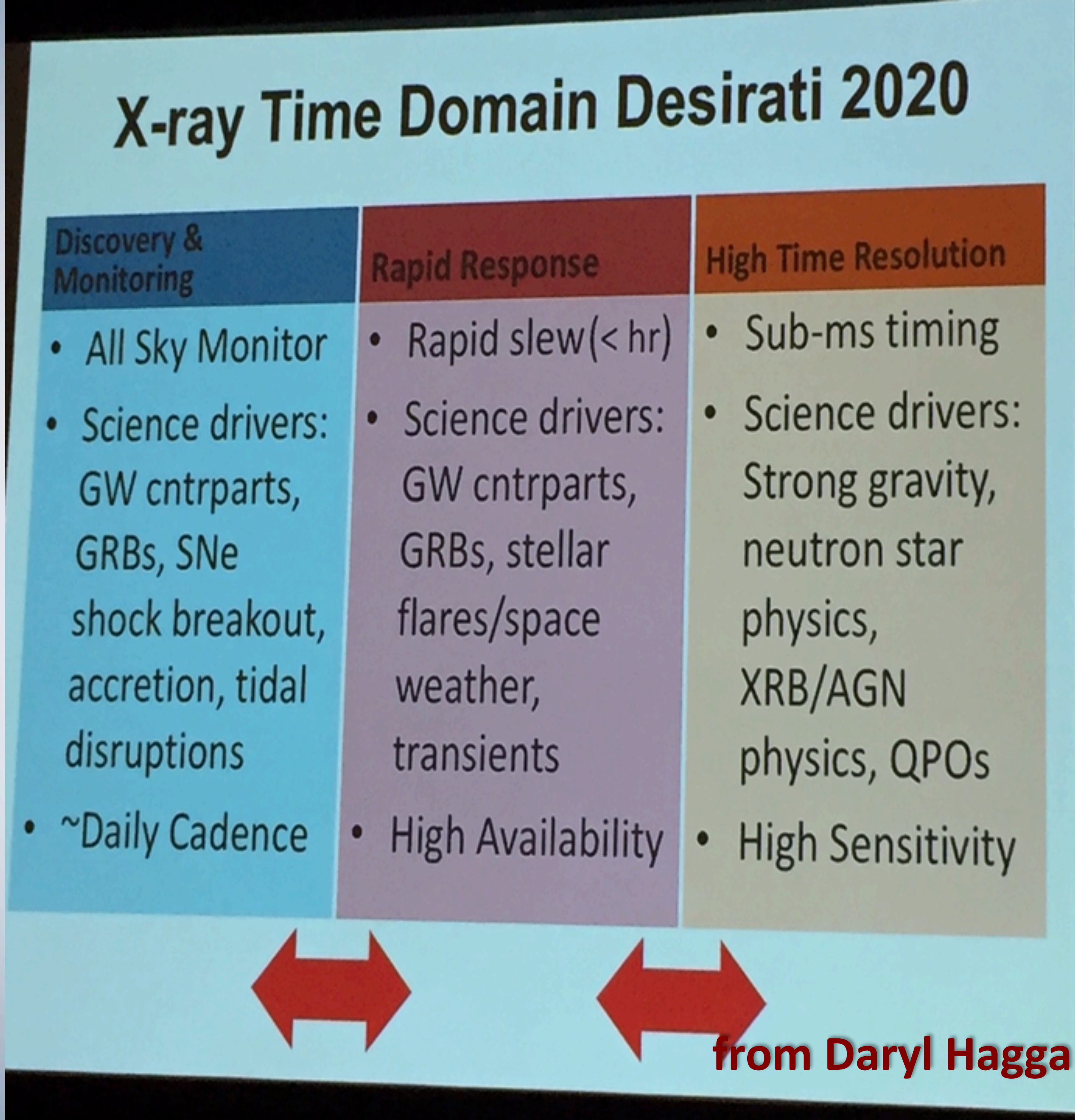


Image Credit: LIGO

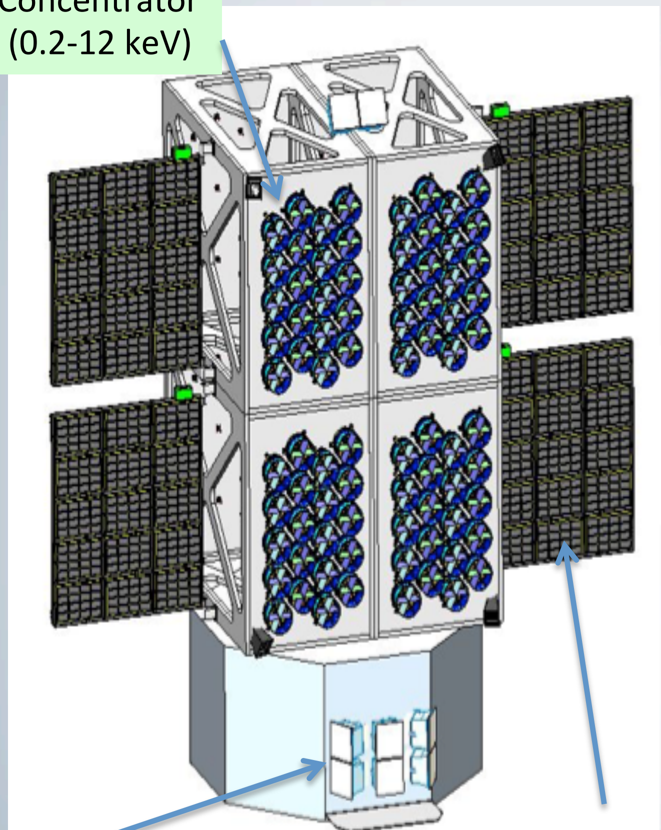
Future Mission Work at MSFC



from Daryl Haggard

STROBE-X Instrument Concept

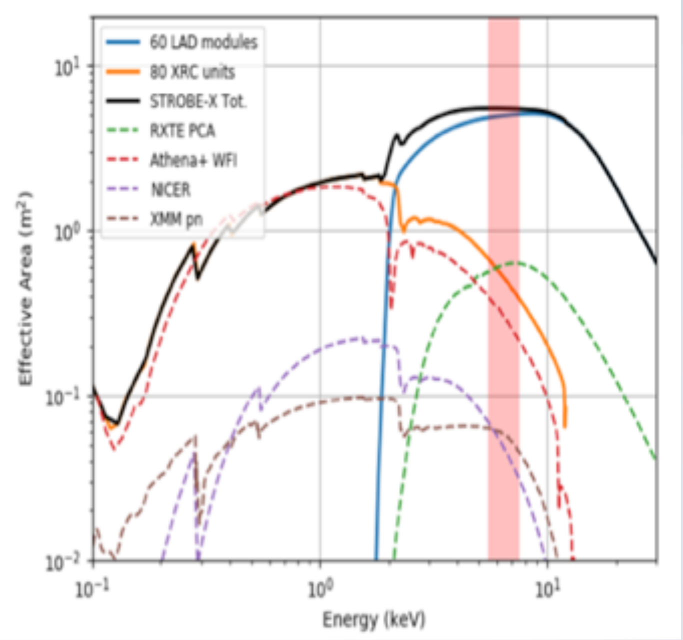
X-ray Concentrator Array (0.2-12 keV)



Wide Field Monitor (2-50 keV)

Large Area Detector (2-30 keV)

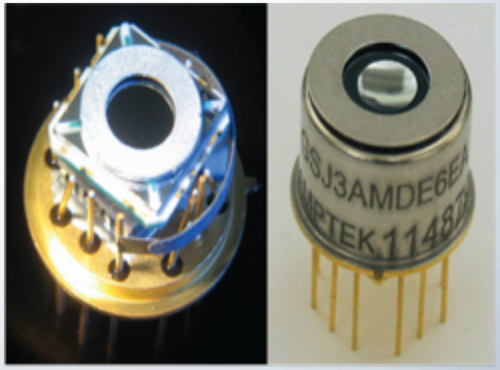
Large effective area >5 m^2 @ 6 keV



- STROBE-X combines the strengths of NICER and LOFT: High throughput X-ray timing with good spectroscopy
- All components are already high TRL
- Highly modular design improves reliability at reduced cost and allows easy scaling.

X-ray Concentrator Array

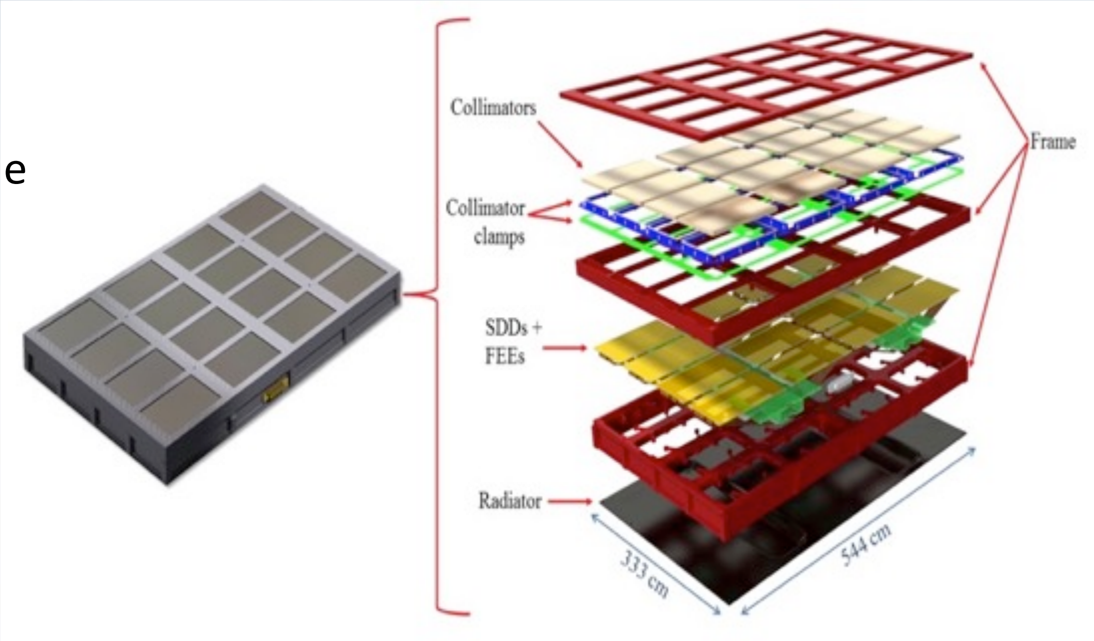
- Low background, high throughput
- Enables high time resolution observations of the faintest sources, both extragalactic and galactic
- Sensitive timing and spectroscopy to thermal emission and iron lines
- Scaled up version of NICER concentrators with NICER SDDs
  - Focal length of 3 m and 2' focal spots for enhanced throughput >2.5 keV
  - Inexpensive Foil optics: large areas w/ low background
  - Energy resolution: 85-175 eV FWHM
  - Effective area @ 1.5 keV: >2.0 m^2



Baseline is 80 XRCA units

Large Area Detector

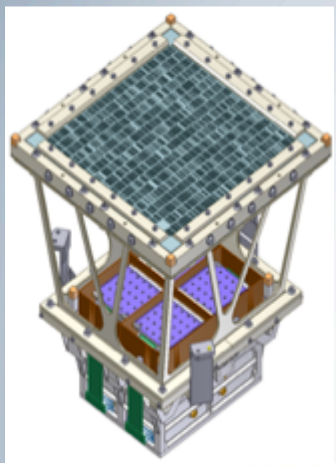
1 LAD Module

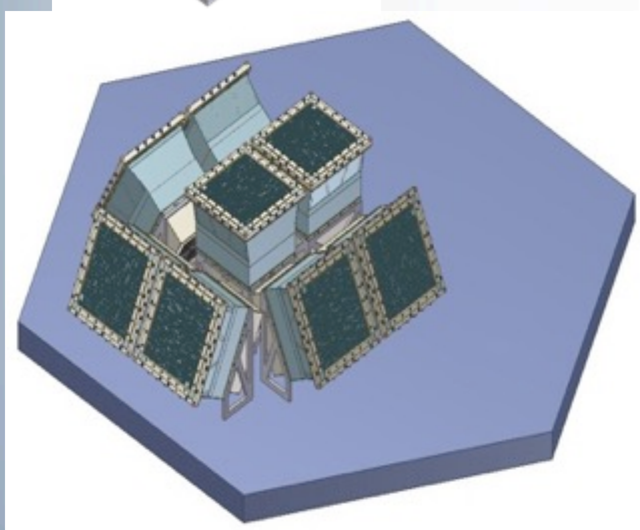


- High time resolution and good energy resolution over the 2-30 keV range
  - Best sensitivity to QPOs; most prominent in harder X-rays
  - Sensitive to non-thermal emission and Compton hump
- SDDs and lightweight microcapillary plate collimators developed for ESA's LOFT M3 & M4.
  - Energy resolution: 200–500 eV FWHM
  - Effective Area @ 10 keV >5 m^2

Baseline is 60 LAD modules

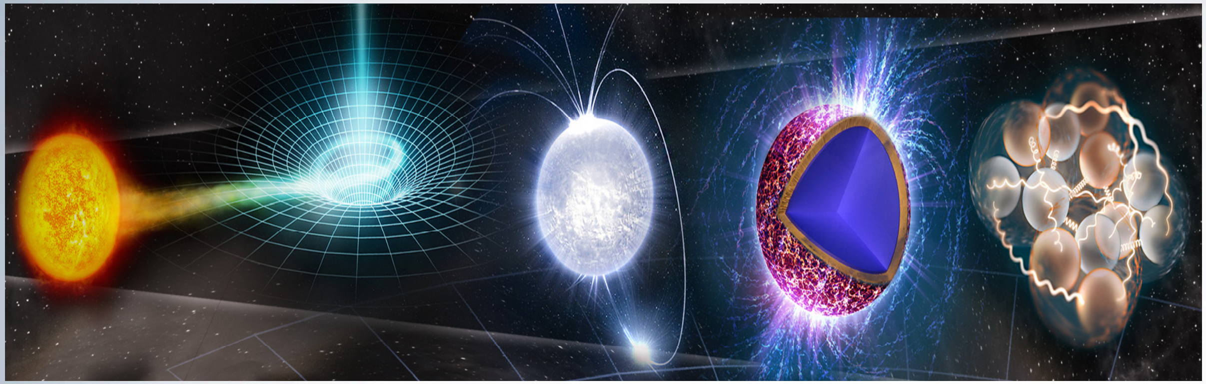
Wide Field Monitor

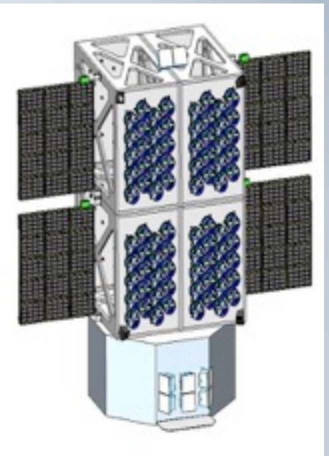




- Wide-field coded-mask imager
- Instantaneous FoV: >1/3 of sky; 50% of sky accessible to LAD
- Sensitive to transients from milliseconds to years
- LOFT SDDs and mask
- Energy resolution: 300 eV FWHM
- Identifies new transients and source states for main instruments, while monitoring long-term source behavior for a large fraction of the sky.

STROBE-X

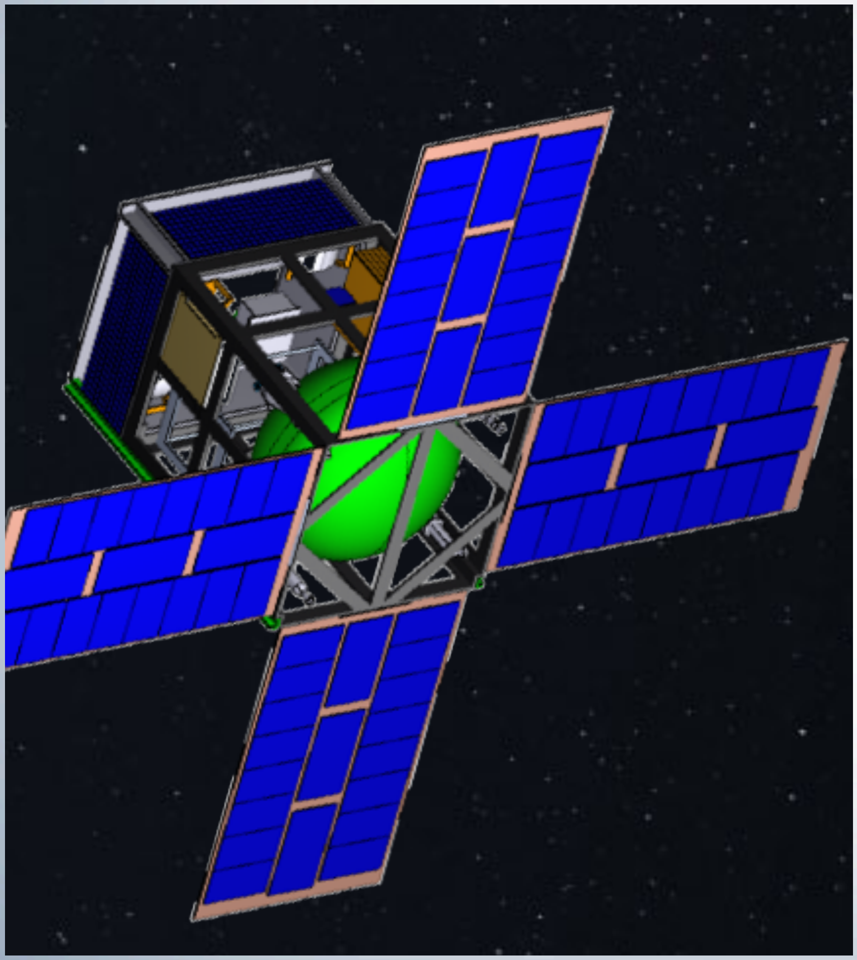




- Huge collecting area, fast timing, and good spectral resolution, addressing fundamental questions in accretion, dense matter, black hole formation and evolution
- Based on existing technology and builds on experience with NICER and LOFT, enabling confidence in cost estimates at this early stage. Highly modular design allows easy scaling.
- Will serve a large community in a decade of time-domain astronomy with complementary capabilities to the large high spectral and spatial resolution missions

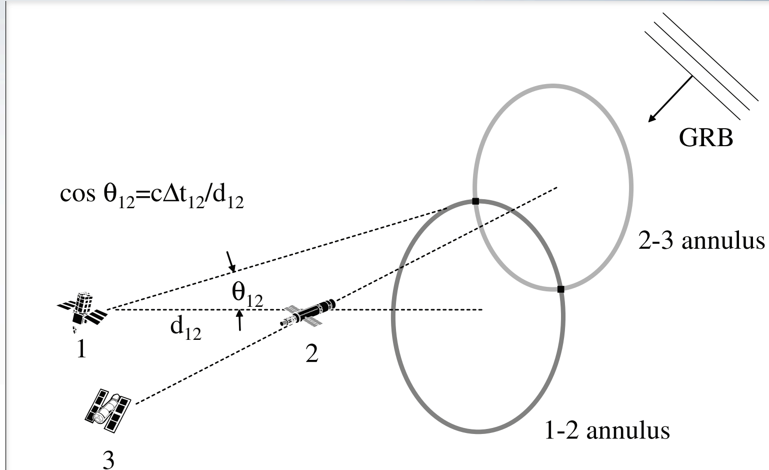
Follow us on Twitter (@STROBEXastro) and Facebook!

MoonBEAM: A Beyond LEO Gamma-ray Burst Detector for Gravitational Wave Astronomy



- Science Goals:
  - Improve localizations for short gamma-ray bursts (GRBs)
  - Increase sky coverage and the number of detected GRBs
  - Probe the extreme processes in cosmic collisions of compact objects
  - Facilitate multi-messenger time domain astronomy

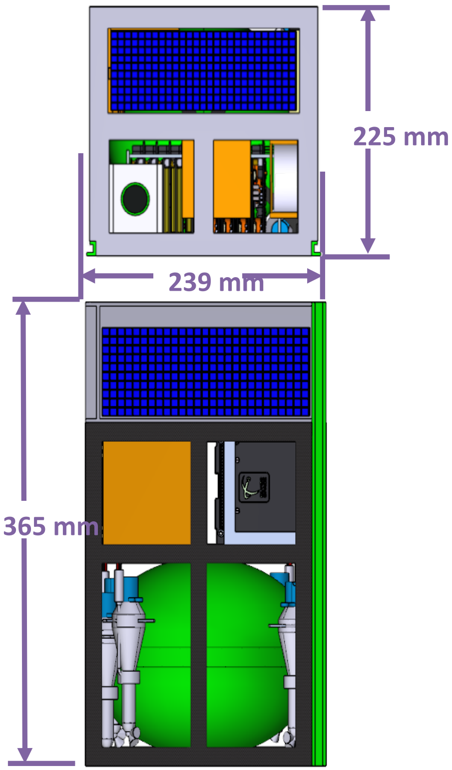
MoonBEAM

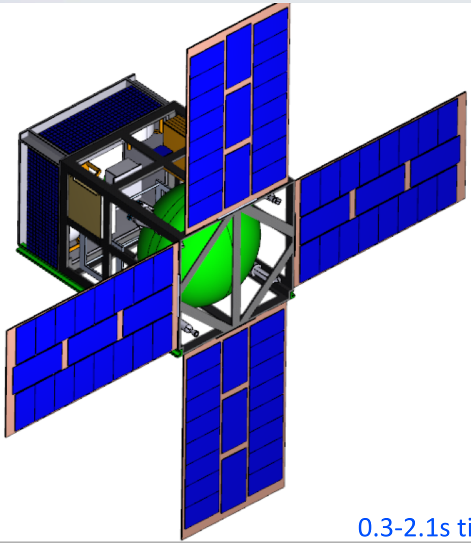


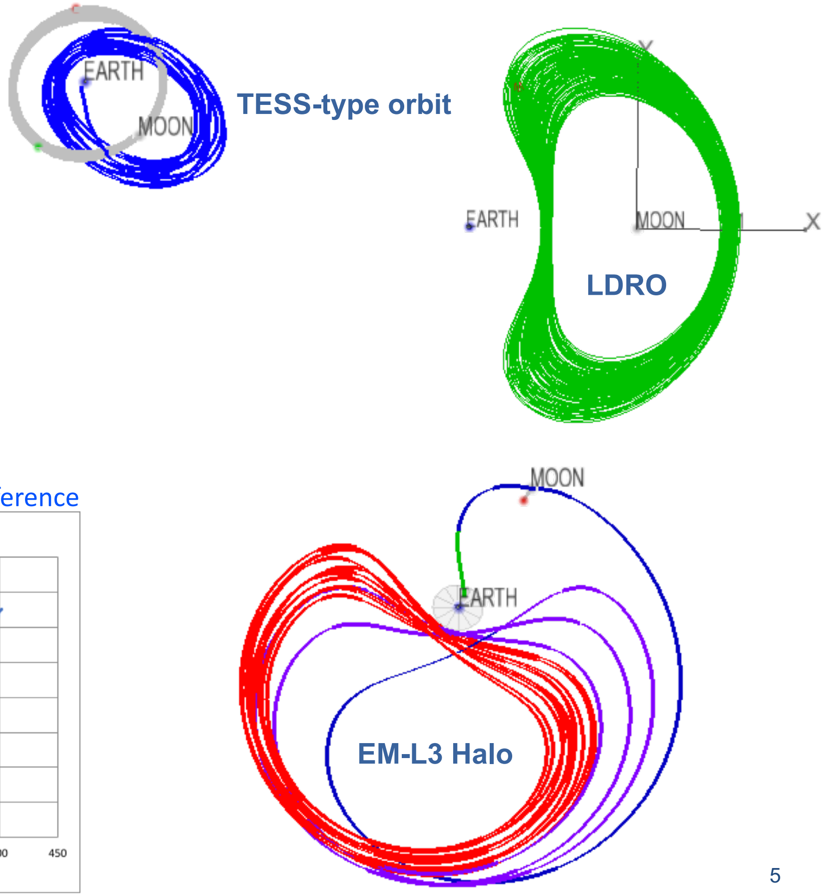
Each spacecraft pair localizes the GRB to an annulus [Hurley et al. ApJS 207, 39 (2013)]

- MoonBEAM combined with a GRB detector in LEO can improve localizations for 20+ short GRBs per year
- Improved localizations are needed to enable rapid follow-up with small field of view instruments
- Fast, timely communication is still possible compared to other planetary orbits.

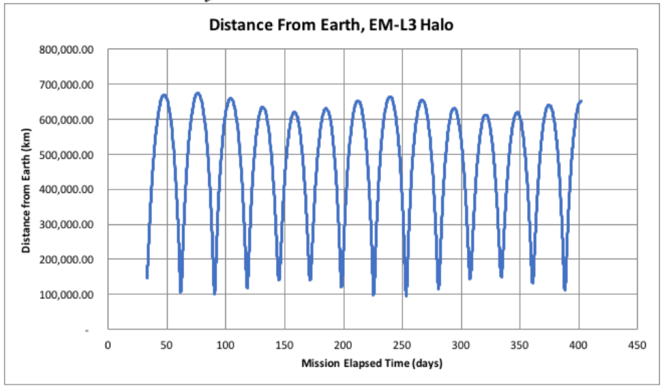
MoonBEAM Possible Orbits







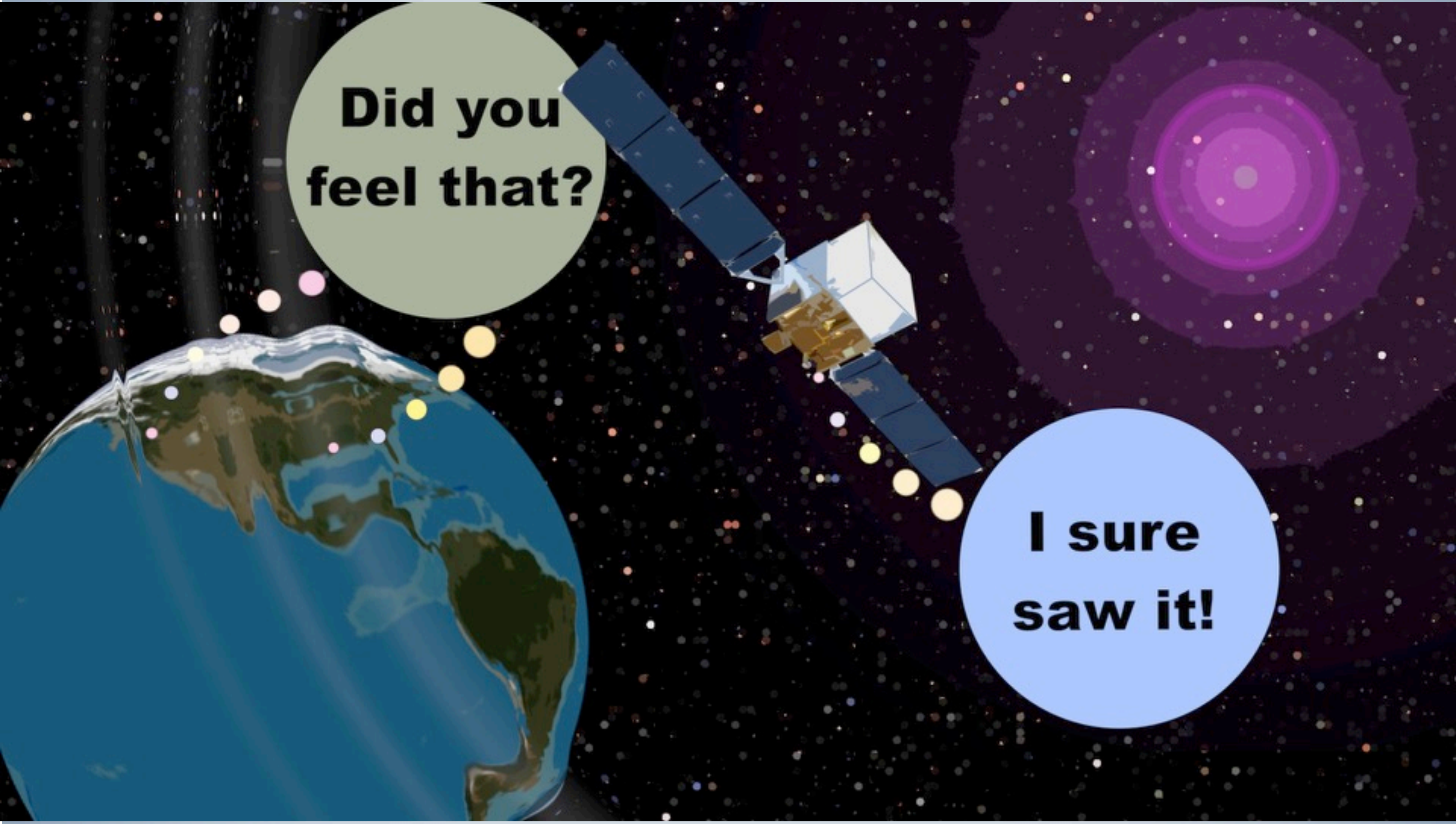
0.3-2.1s time difference



MSFC Relativistic Astrophysics Team

- Currently leading the Fermi Gamma-ray Burst Monitor
  - Recipient of the 2018 Bruno Rossi Prize in High Energy Astrophyiscs
  - Ongoing efforts to search for GRBs associated with graviatational waves
- Future Mission Concepts
  - STROBE-X – Probe-class mission: time domain astronomy; burst and intermediate duration gravitational wave counterparts
  - MoonBEAM – SmallSAT GRB detector in cis-lunar space to improve localizations and increase the number of detected GRBs

Thank you!

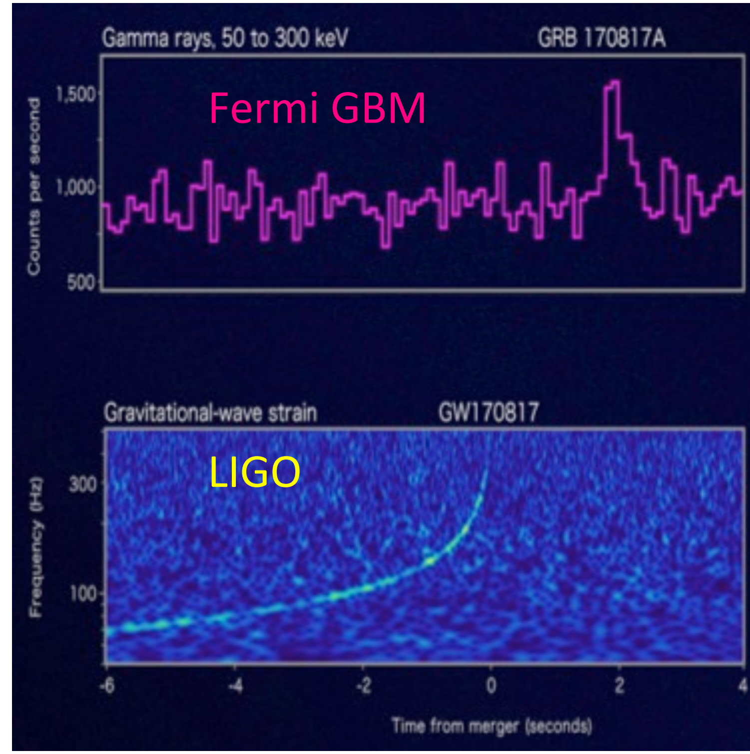


Video and image credit: NASA/GSFC

Backup

GW170817/GRB 170817A:predicted vs observed

- **Predicted**
  - Short-duration GRBs are caused by merging neutron stars and could be observed simultaneously by GBM and LIGO.
  - The aftermath of the merger produces many of the heavy elements in the universe, including gold and platinum
  - According to Einstein's theory of gravity, the speed of gravitational waves and the speed of light should be the same.
- **Observed**
  - GWs from merging neutron stars followed 1.7 s later by a GRB. This confirms neutron star mergers as the source of some GRBs, and that light and gravity travel at the same speed to within 1 part in a quadrillion.
  - Hours after the merger, a "kilonova" was observed, consistent with theory for the production of heavy elements.
  - >1 week later X-ray and radio emission was detected, and have continued to get brighter to this day.



- **Unexpected**
  - The GW+GRB detection was made so soon, before the LIGO/Virgo detectors have reached full sensitivity, suggesting these events may be more common than previously thought.
  - GRB 170817A was dim despite it being the closest on record, and the X-ray source is brightening instead of rapidly fading. Both raise provocative questions about the underlying physics that produces gamma-ray bursts.
  - A bright ultraviolet counterpart was detected 12 hours after the merger – not previously predicted by kilonova models.