GAMMA RAYS AND GRAVITATIONAL WAVES

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NASA MSFC

237th AAS Meeting
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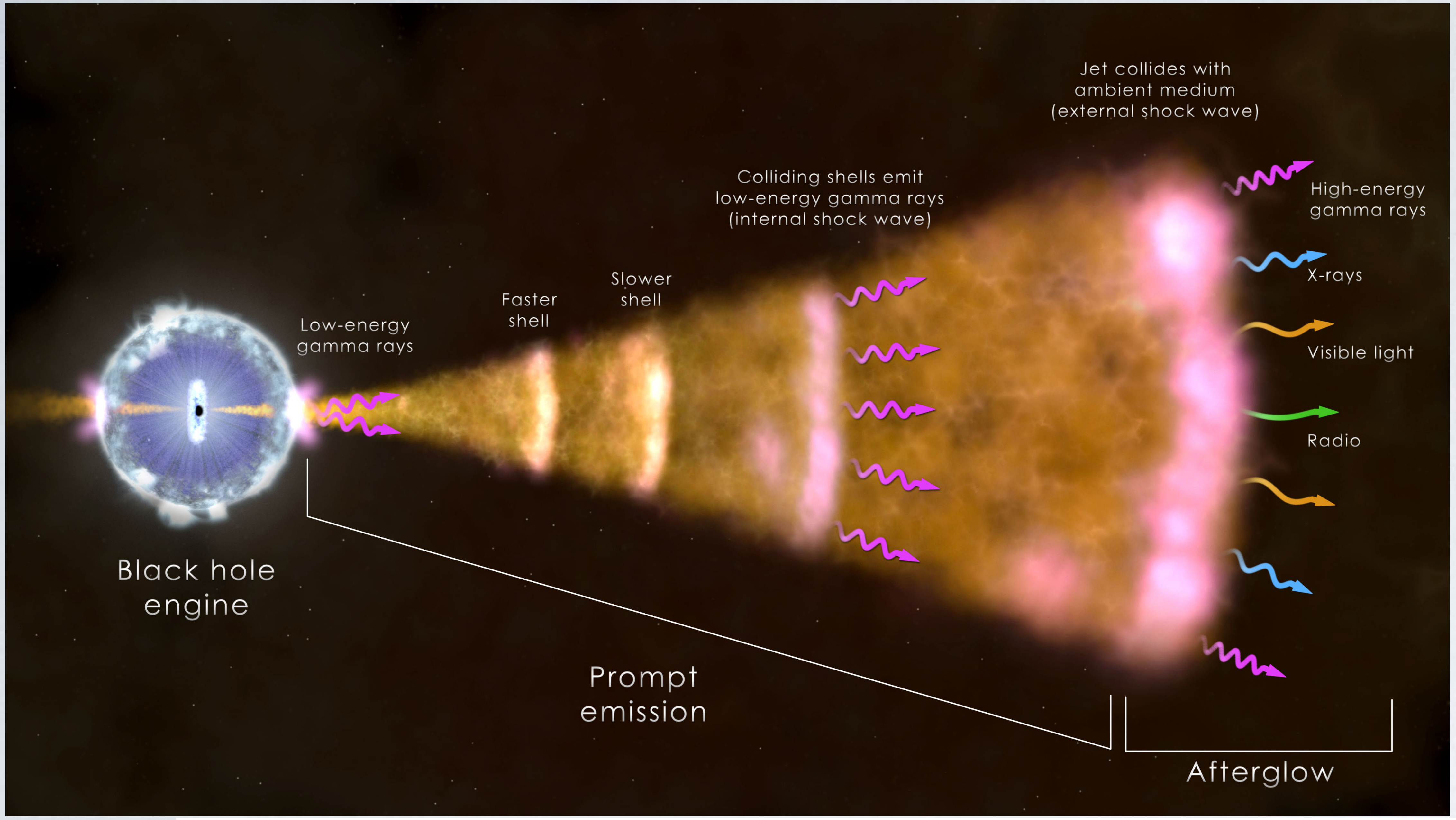
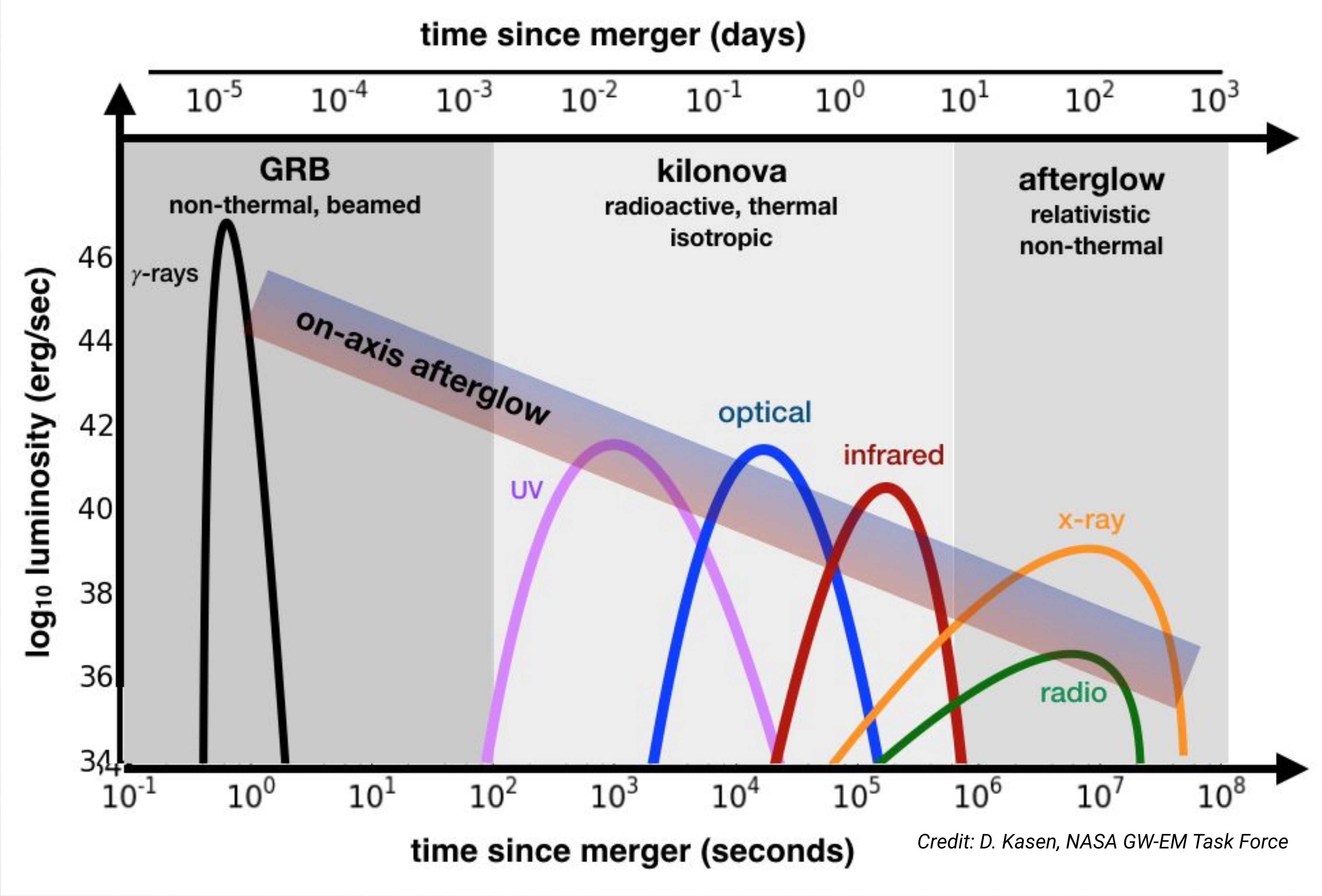
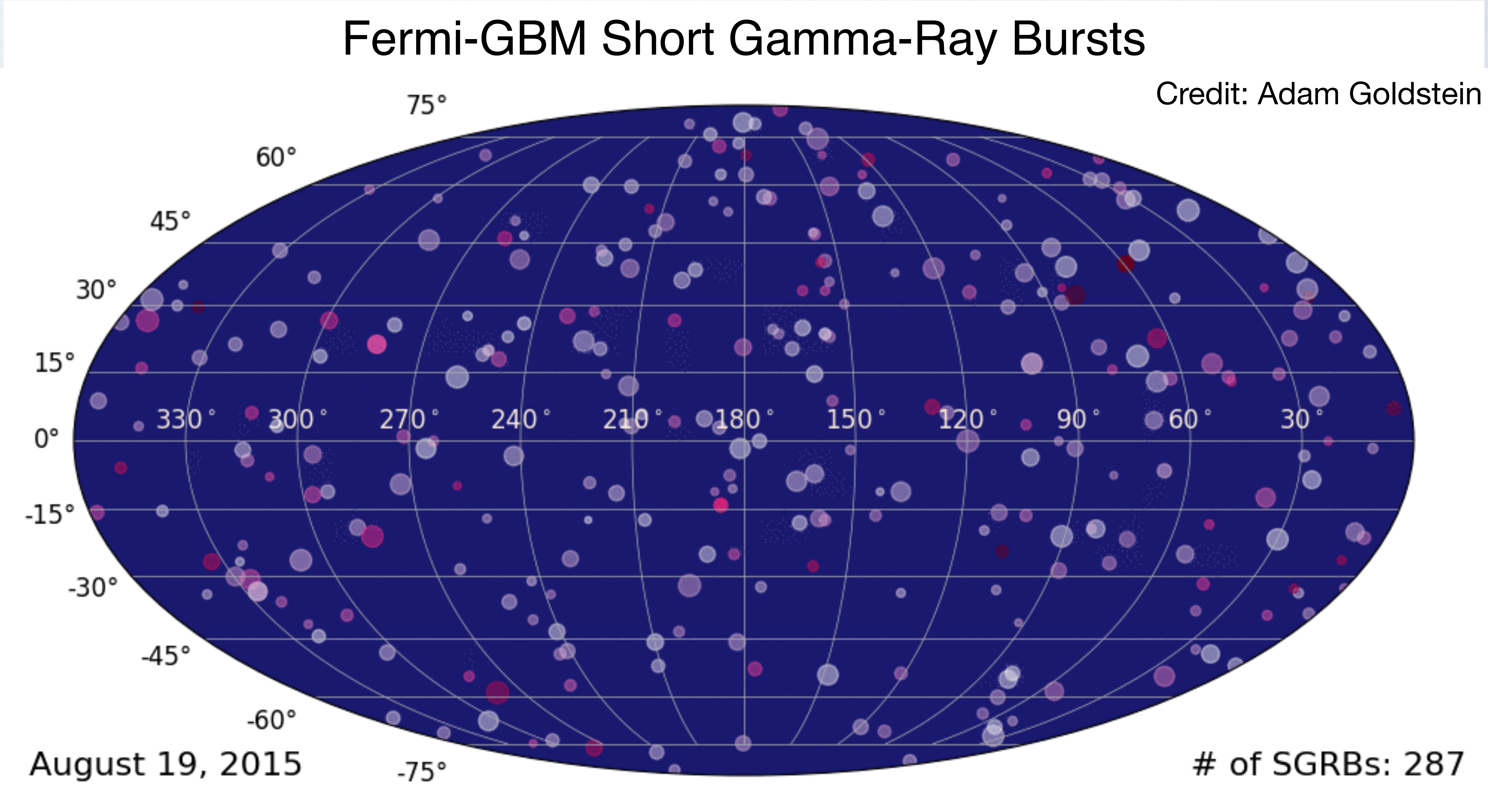
Gamma-Ray Bursts



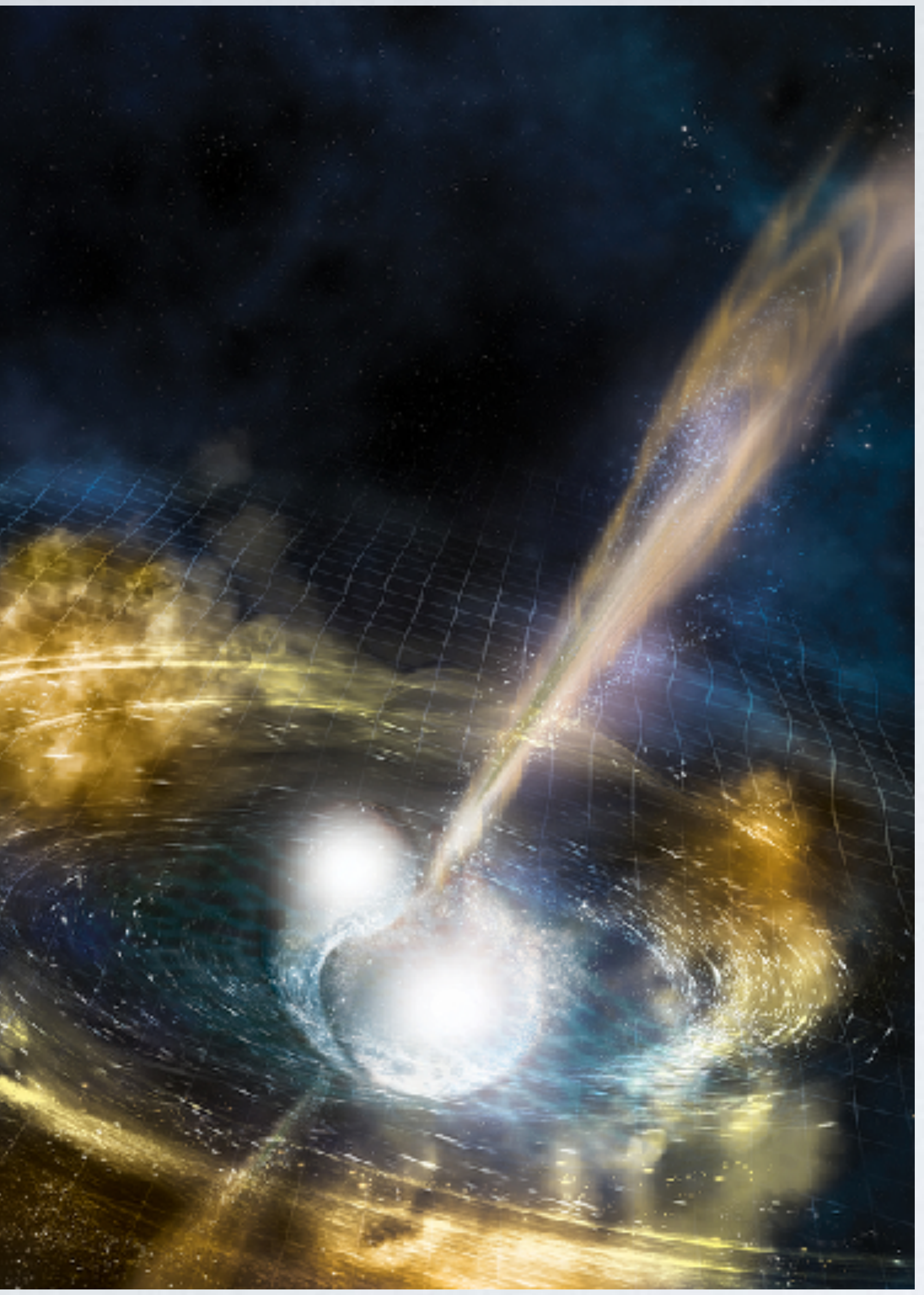
- Collimated relativistic outflow.
- Prompt keV-MeV emission, afterglow in other wavelengths.
- Detected ~ once per day, distributed all over the sky.



NASA GW-EM Task Force Report



Lessons from GW 170817



Predicted

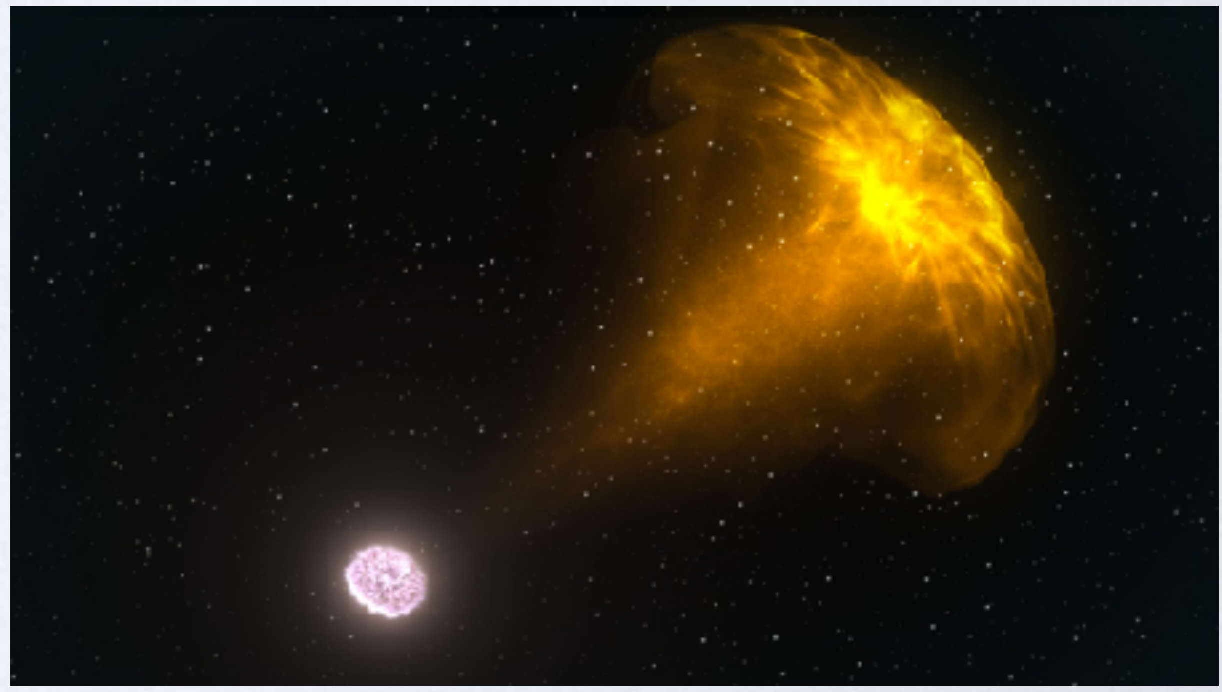
- Merging neutron stars are a progenitor of short Gamma-ray Bursts.
- GW and SGRB are separated by ~SGRB duration.
- Kilonova producing heavy elements.
- Speed of light = speed of gravity.

Observed

- GWs from merging NS followed by a SGRB, 1.7 s later.
- Hours later – kilonova.
- > 1 week, X-ray and radio counterparts.

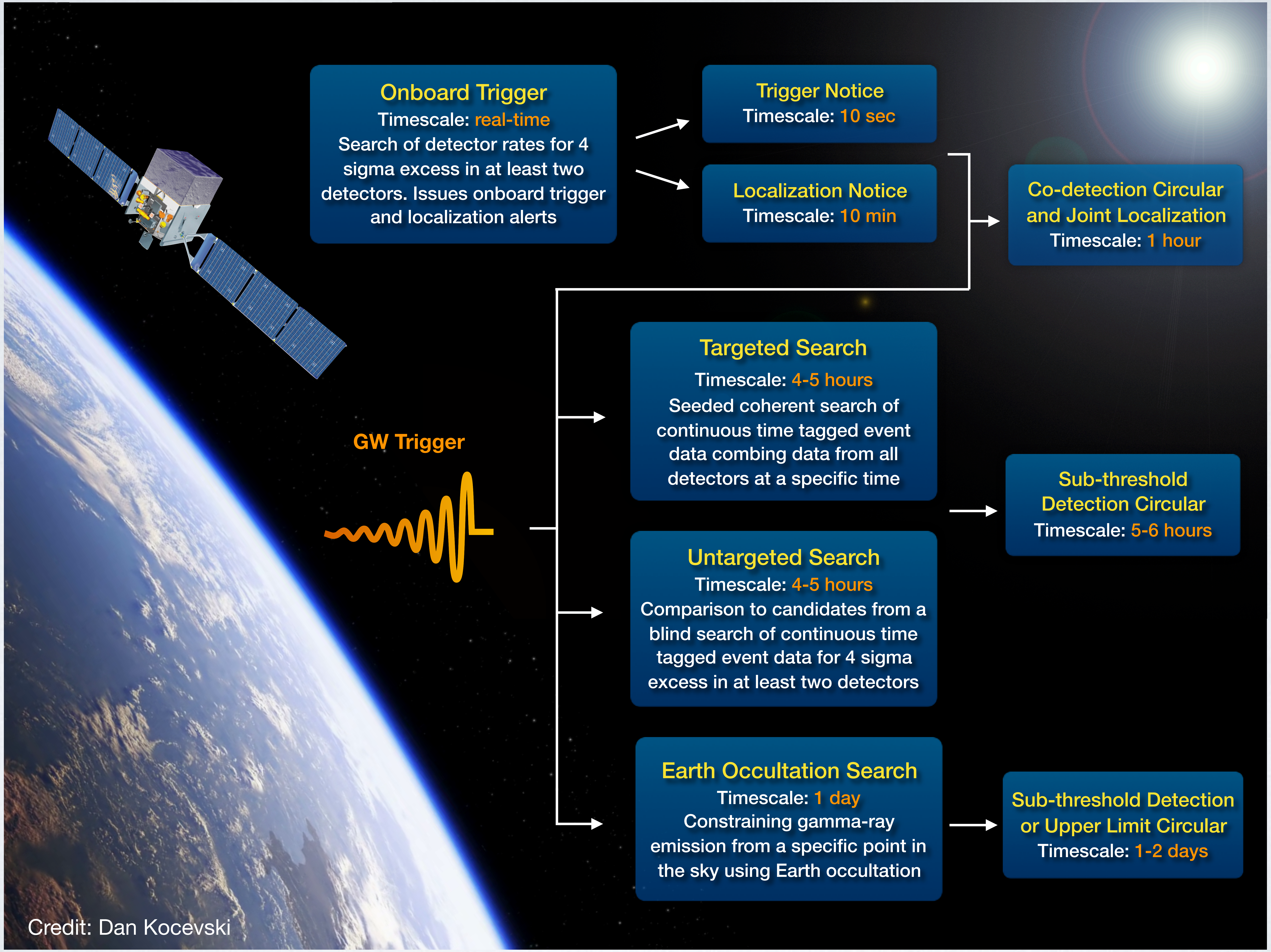
Unexpected

- GW detection from NS merger met optimistic predictions.
- GRB 170817A was dim despite being close.
- Unusual time-history for a SGRB: hard spike followed by a softer tail.
- Optical, X-ray, and radio counterparts brightened instead of fading.
- Bright UV counterpart was not predicted by kilonova models.



Open questions: merger and jet geometry, intrinsic properties, population characteristics.

Searching For More



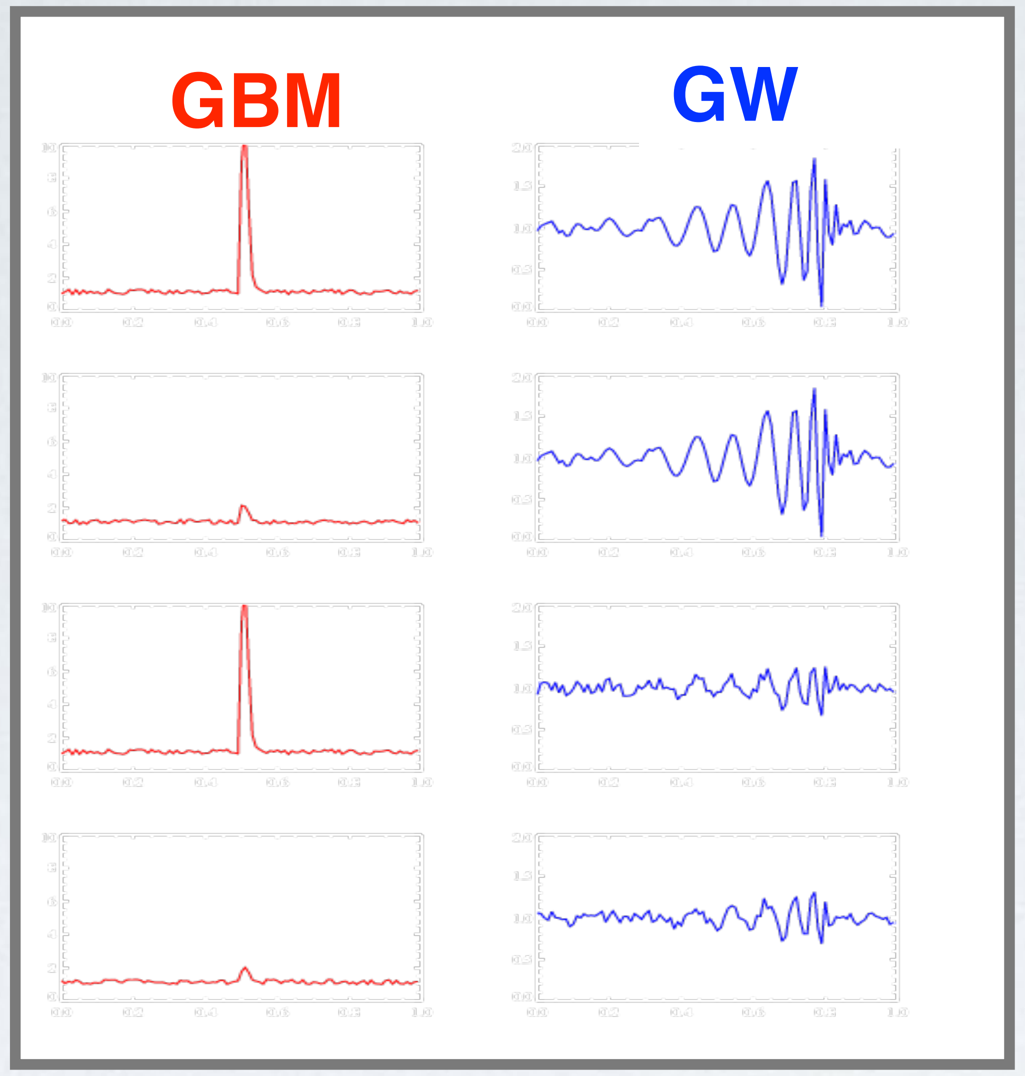
Joint Gamma-Ray and Gravitational Wave Searches

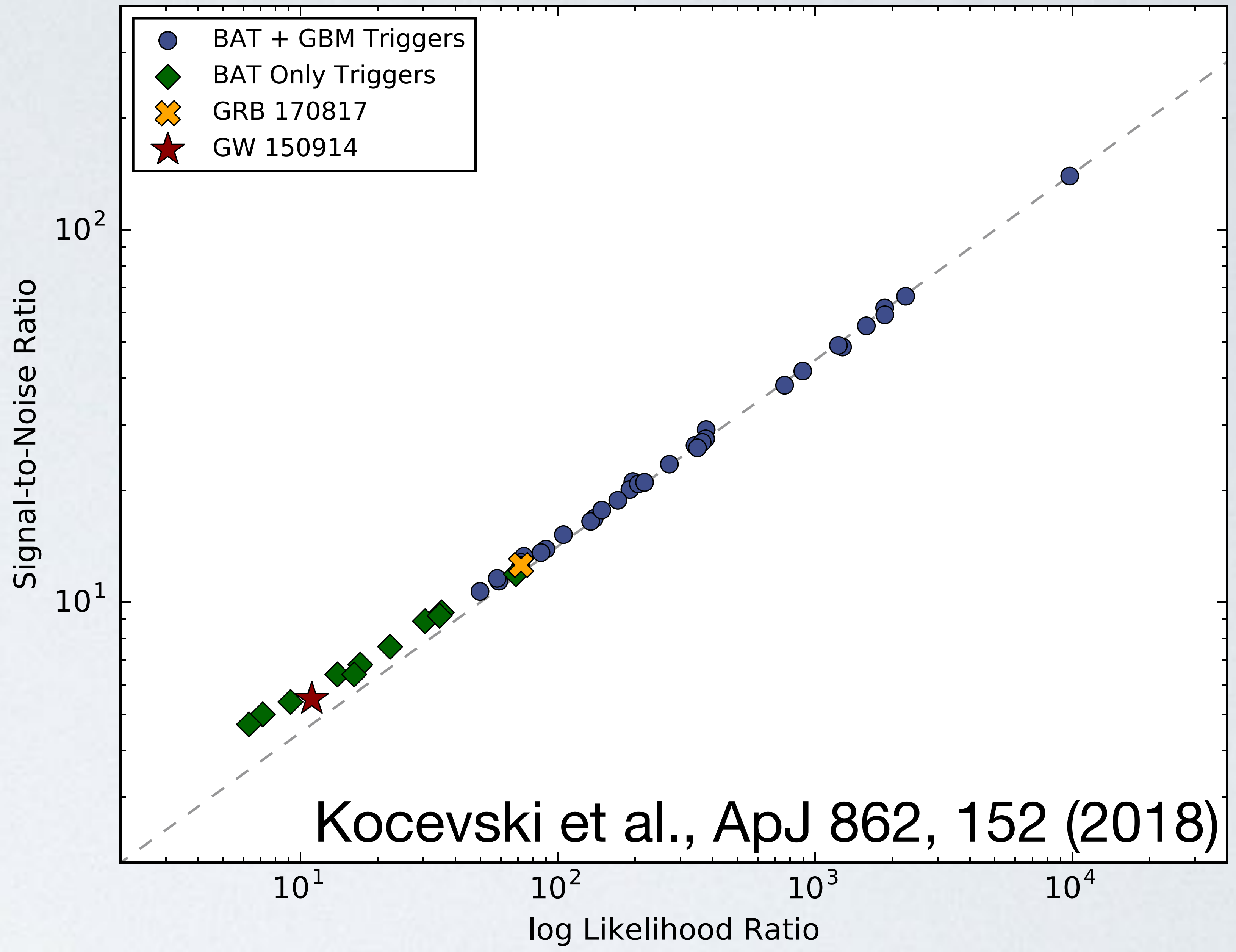
Ideal 170817 Scenario: triggered both GBM and GW detectors

Sub-threshold GBM

Sub-threshold GW

Sub-threshold GBM and GW

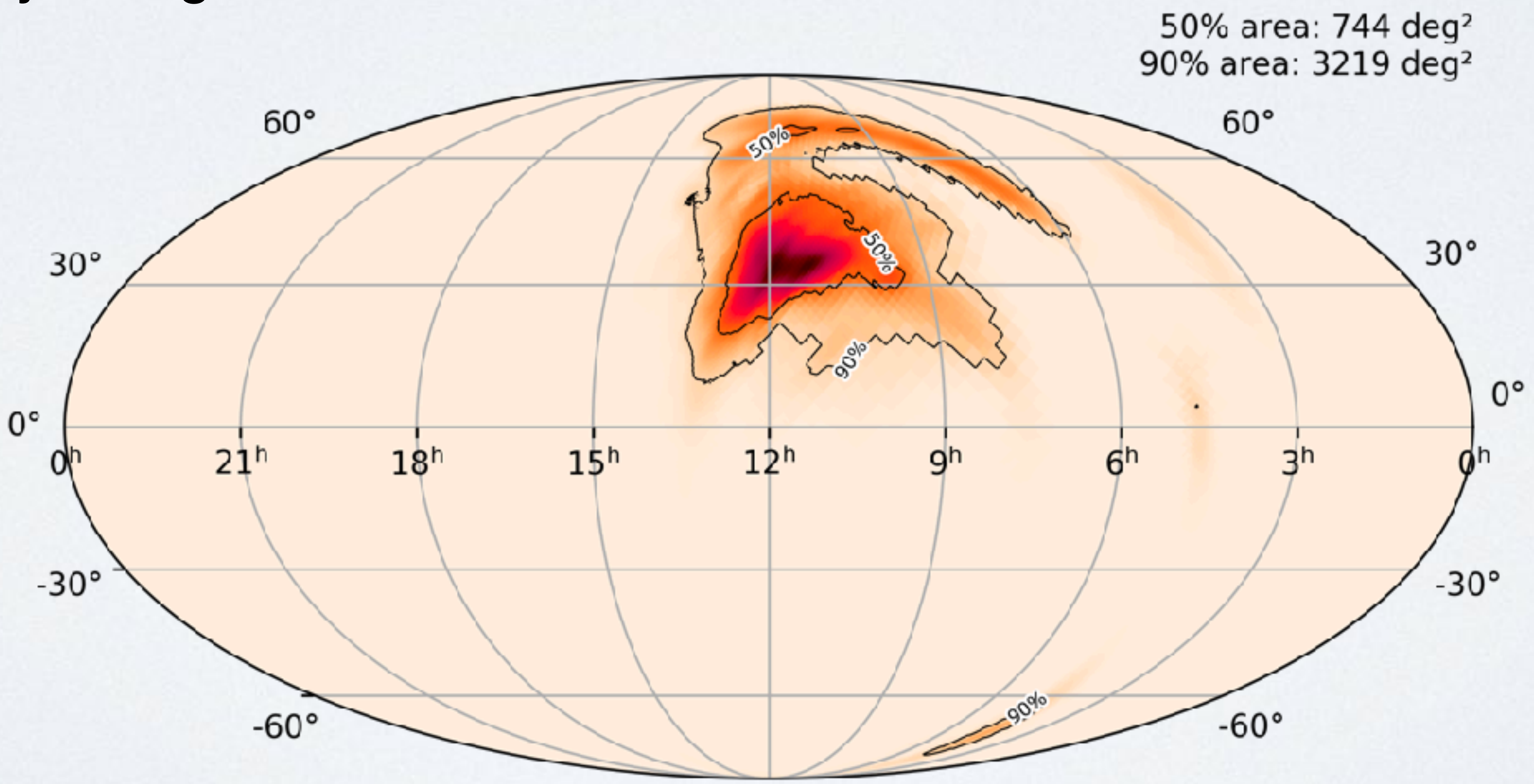




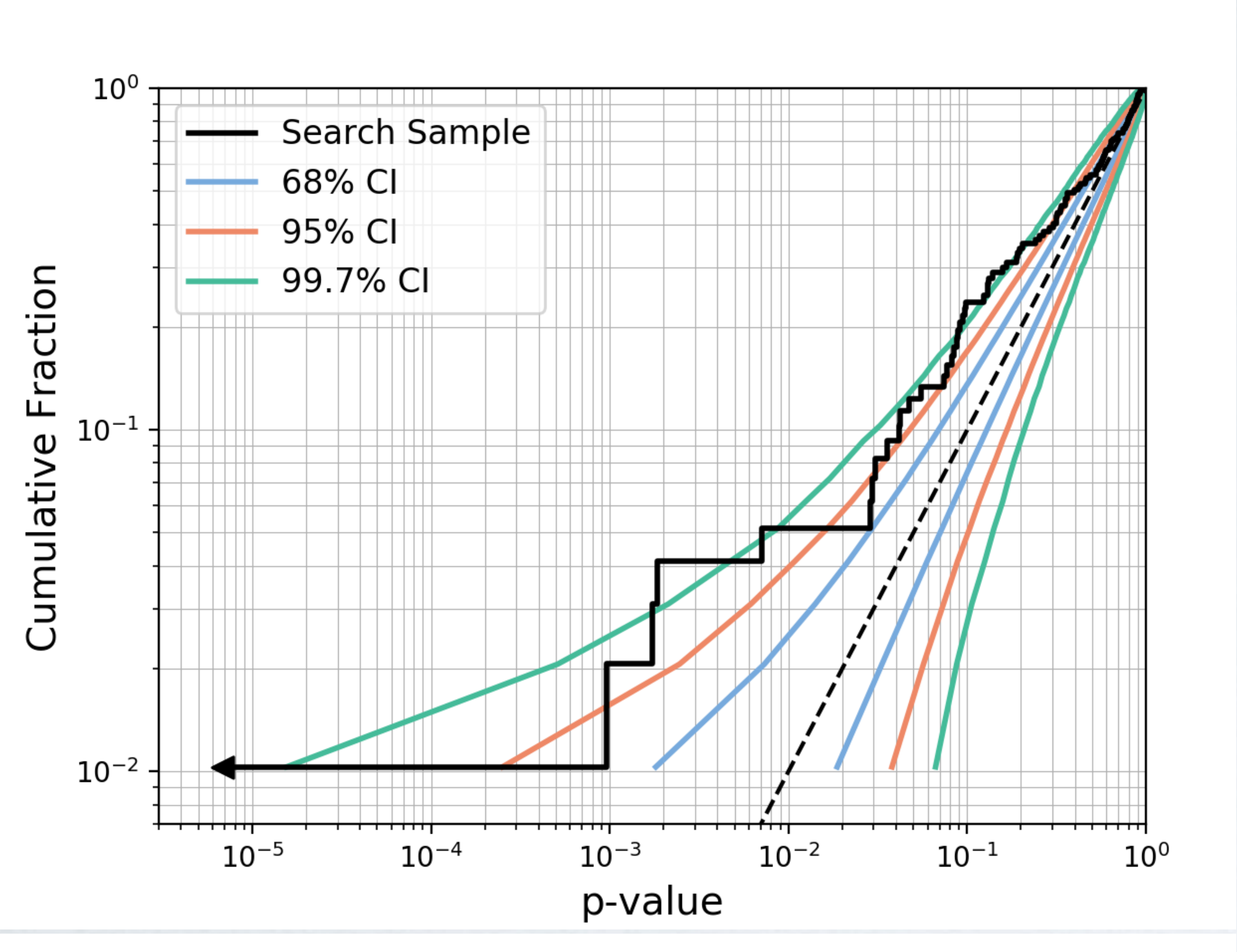
- GBM-LVC partnership for unique data sharing.
- GBM provides sub-threshold GRBs in low-latency for GW follow-up.
- LVC provides GW candidates below EM Follow-up threshold in low-latency for autonomous targeted searches with GBM.
- GBM detections would increase GW detection confidence, effectively increasing the volume of the Universe accessible.
- Similar GBM / Swift-BAT agreement to increase number and confidence of GRB detections.
- GBM targeted search increases gamma-ray horizon, 60% increase in maximum detection distance of GRB 170817A.

Sub-threshold Searches

- First joint sub-threshold alert sent on Aug 20 2019 (GCN 25406 / 25465):
  - Fermi GBM-190816: A sub-threshold GRB candidate potentially associated with a sub-threshold LIGO/Virgo compact binary merger:
    - a candidate gamma-ray signal identified starting 1.5 s after the GW trigger time.
    - GBM-190816 is approximately 0.1 s in duration, consistent with a short GRB-like signal.
  - Followed up observations by several gamma-ray, neutrino, and optical observatories:
  - Some optical candidates found but no firm association.
    Both gamma-ray and gravitational events remain sub-threshold after further analyses.

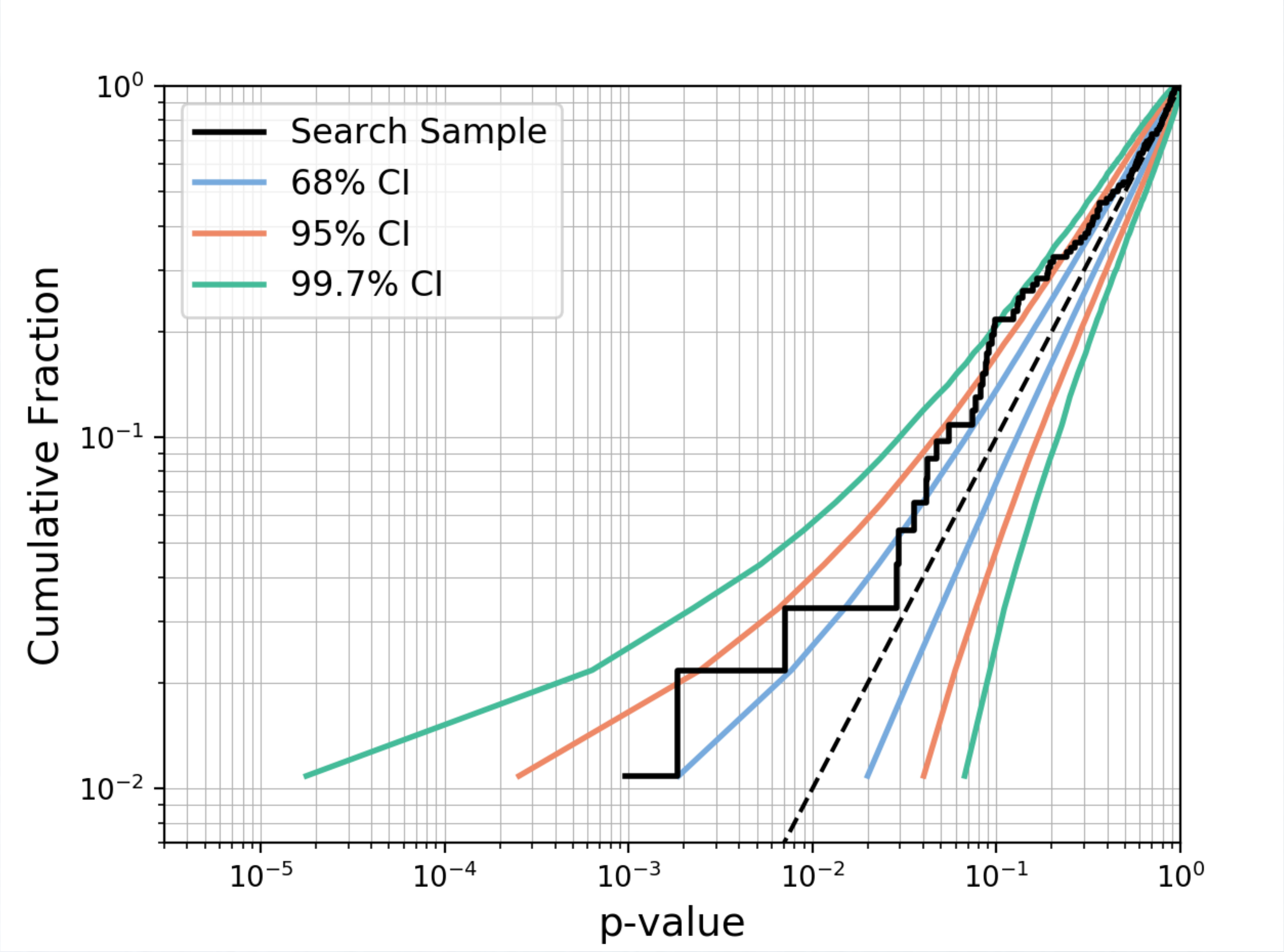


Sub-threshold Searches

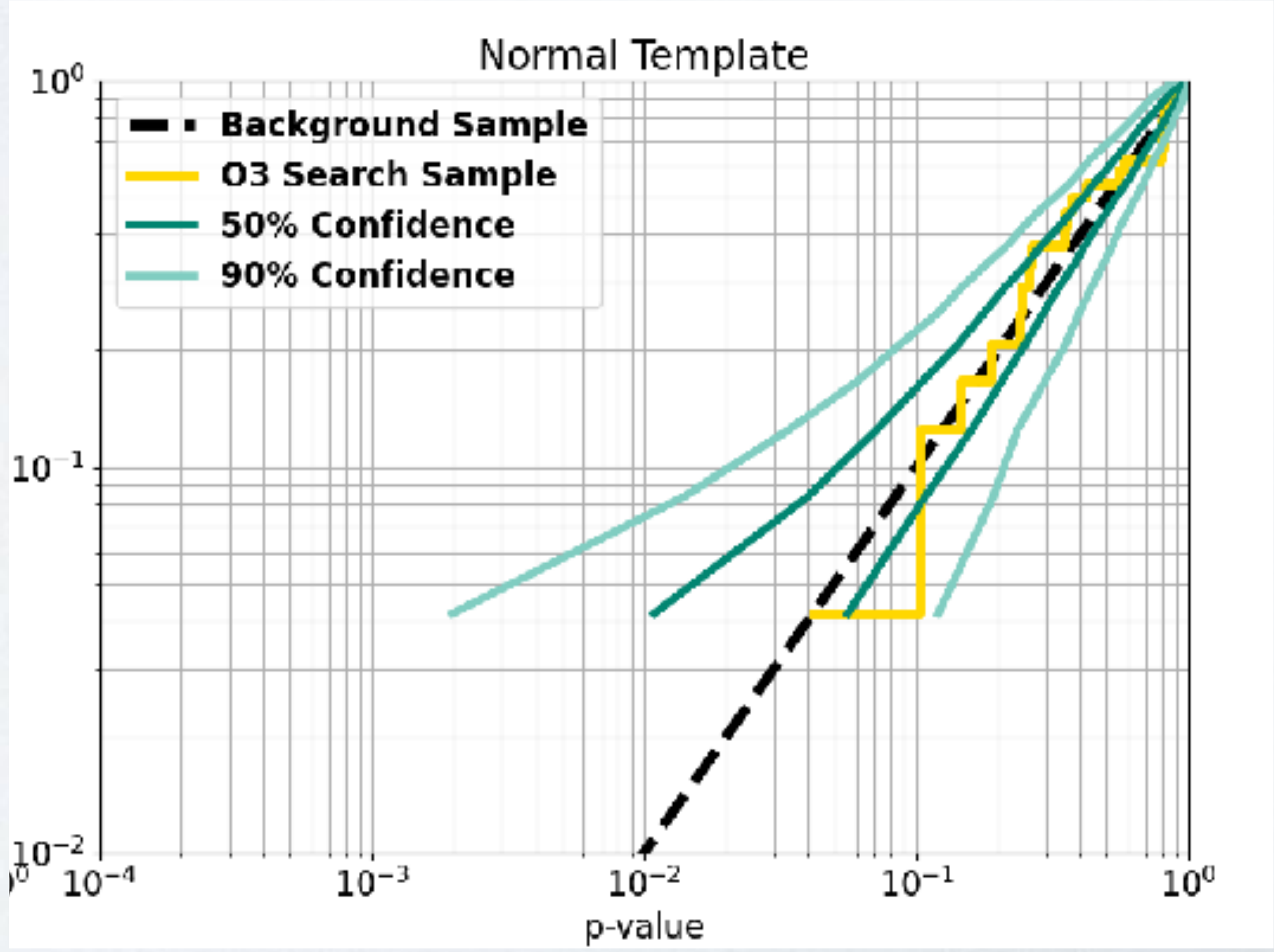


O1/O2 catalogs followup with Fermi-GBM targeted search,
Hamburg et al. ApJ 893,100 (2020).
◀ Cumulative distribution with GW170817

▶ Cumulative distribution without GW170817

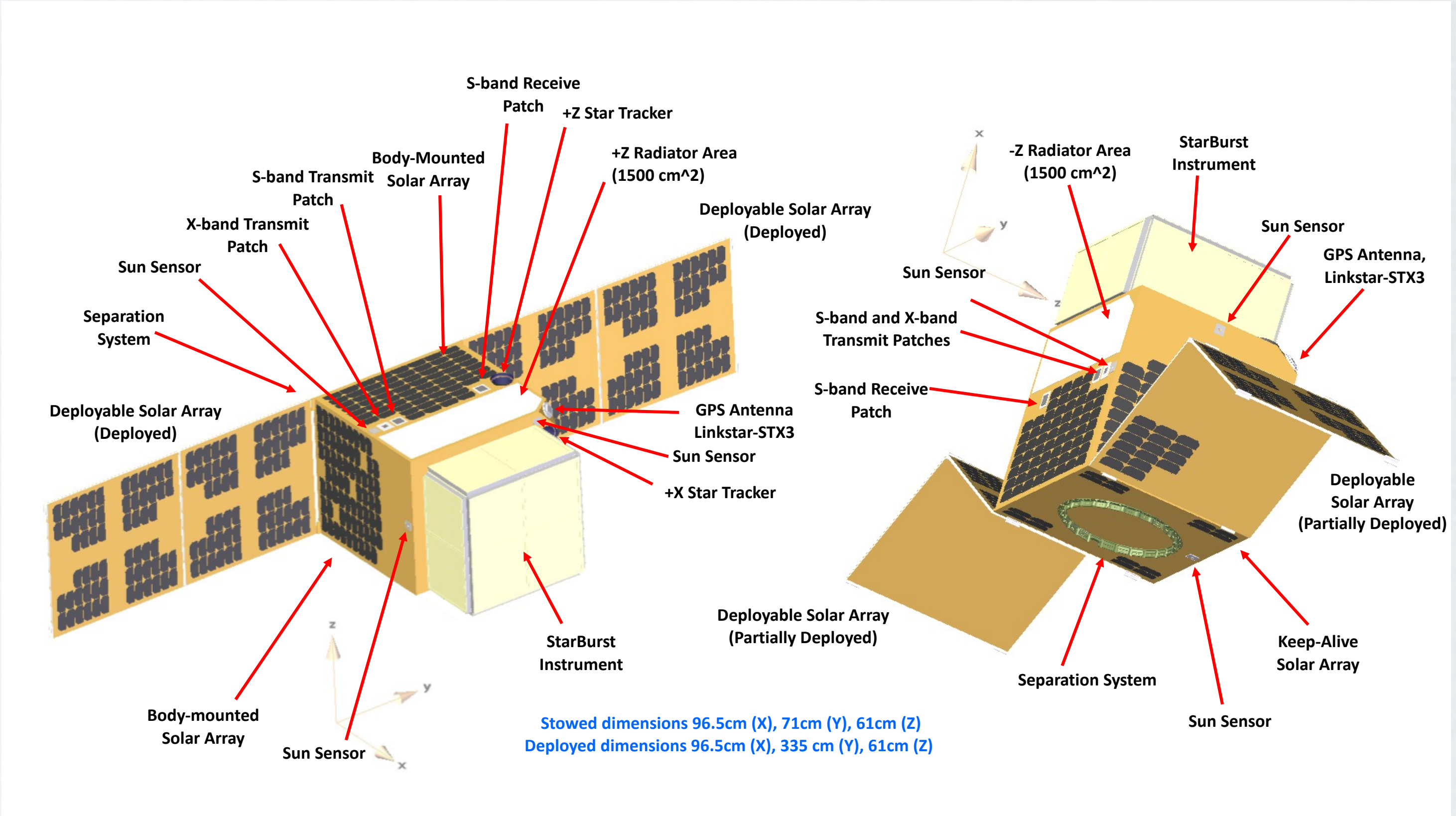


O3 catalogs followup with Fermi-GBM targeted search is underway.
More details in iposter by Corinne Fletcher:
Session 125
[125.07. Gamma-ray Follow-up of the LIGO/Virgo Third Observational Run (O3) with Fermi-GBM]



StarBurst

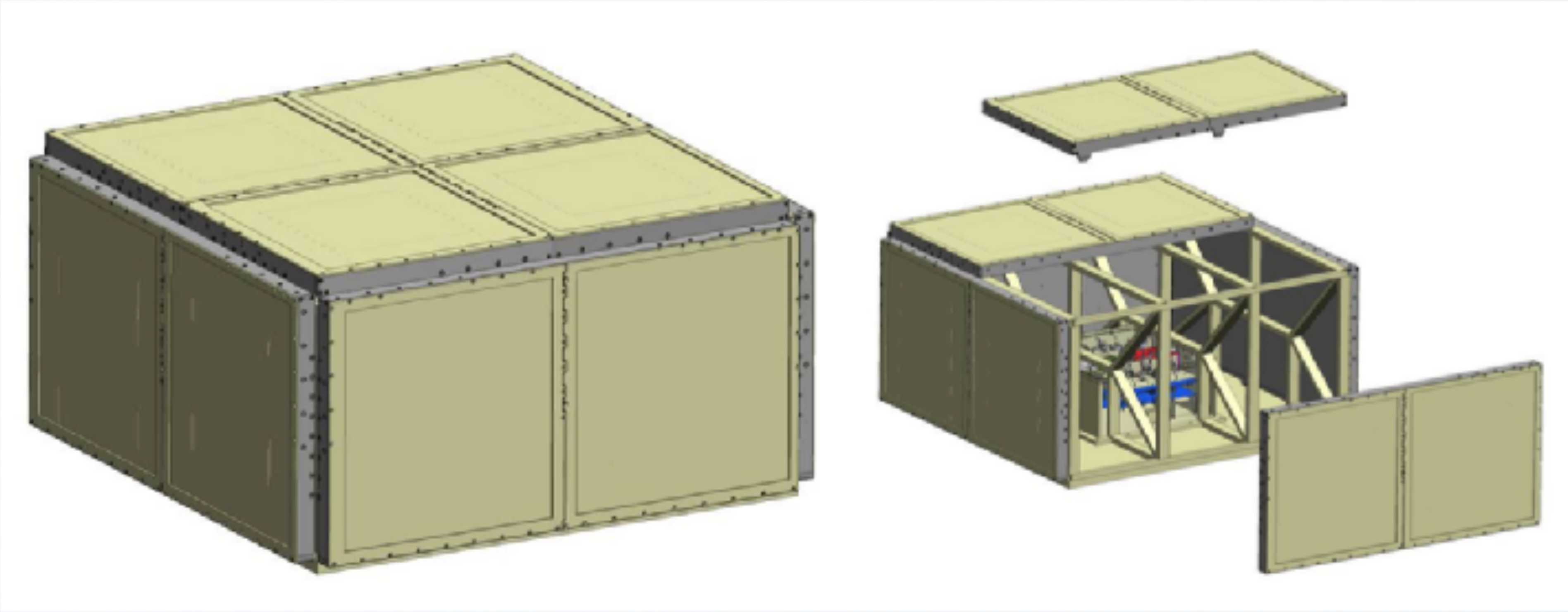
- ESPA-Grande SmallSat to detect SGRBs coincident with GW detections.
- Selected for NASA's new Astrophysics Pioneers Program.
  - **PI: Dan Kocevski**
  - 50% Science, 25% tech dev, and 25% advancing early career researchers.
  - Cost cap of $20M.
- Partnership between NASA Marshall Space Flight Center, Naval Research Lab, and the University of Toronto's Space Flight Laboratory.
- Nominal launch in 2025 for a 1-2 year mission to coincide with LIGO A+.

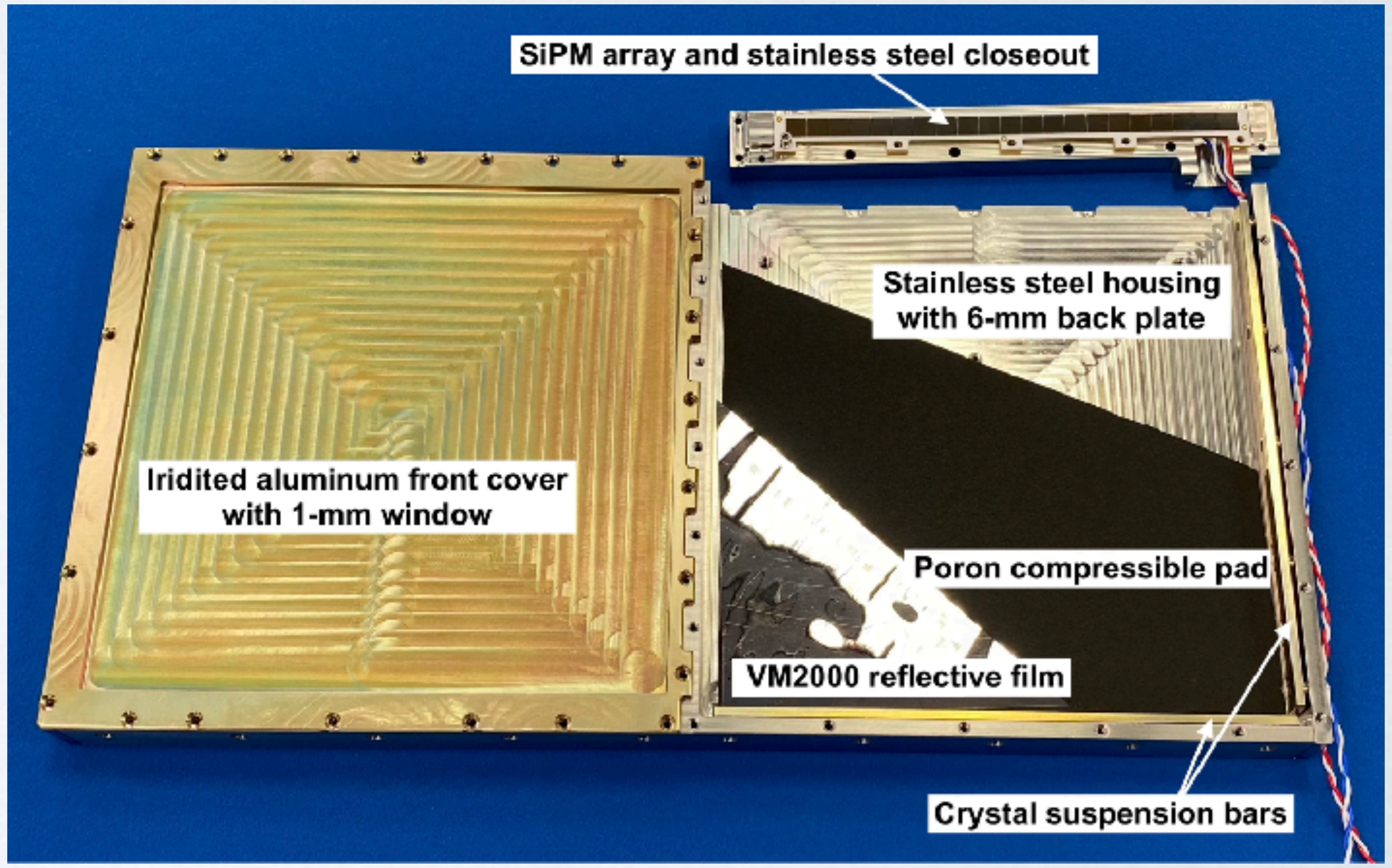


- Science Objectives:
  1) Constrain the progenitors of SGRBs.
  2) Probe the remnants of BNS mergers.
  3) Constrain the neutron star equation of state.
  4) Probe the structure of relativistic outflows produced in neutron star mergers.

StarBurst Instrument and Bus

- Instrument will be designed and built by Naval Research Lab.
  - Based on the Glowbug ISS payload.
  - 12 CsI scintillation detectors.
  - Sensitive to 30-2000 keV energy range.
  - Crystal size: 27 cm x 27 cm.
  - Instrument payload: 58 cm x 58 cm x 29 cm.
  - Instrument mass: 164.6 kg.
- Spacecraft bus provided by Space Flight Laboratory.
  - ESPA-Grande DAUNTLESS platform.
  - Spacecraft mass: ~63 kg.
- Combined Mass: 228.6 kg.

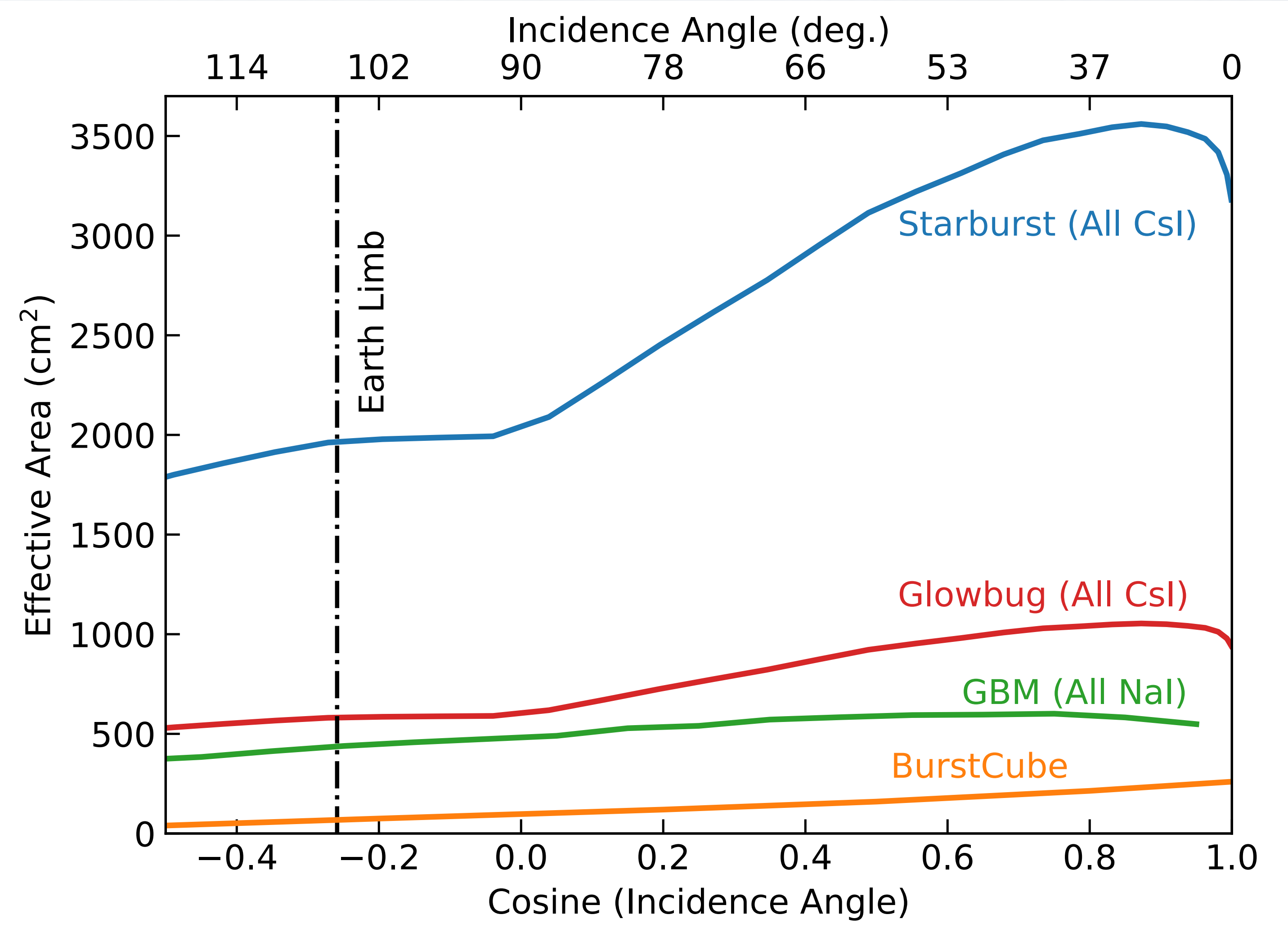


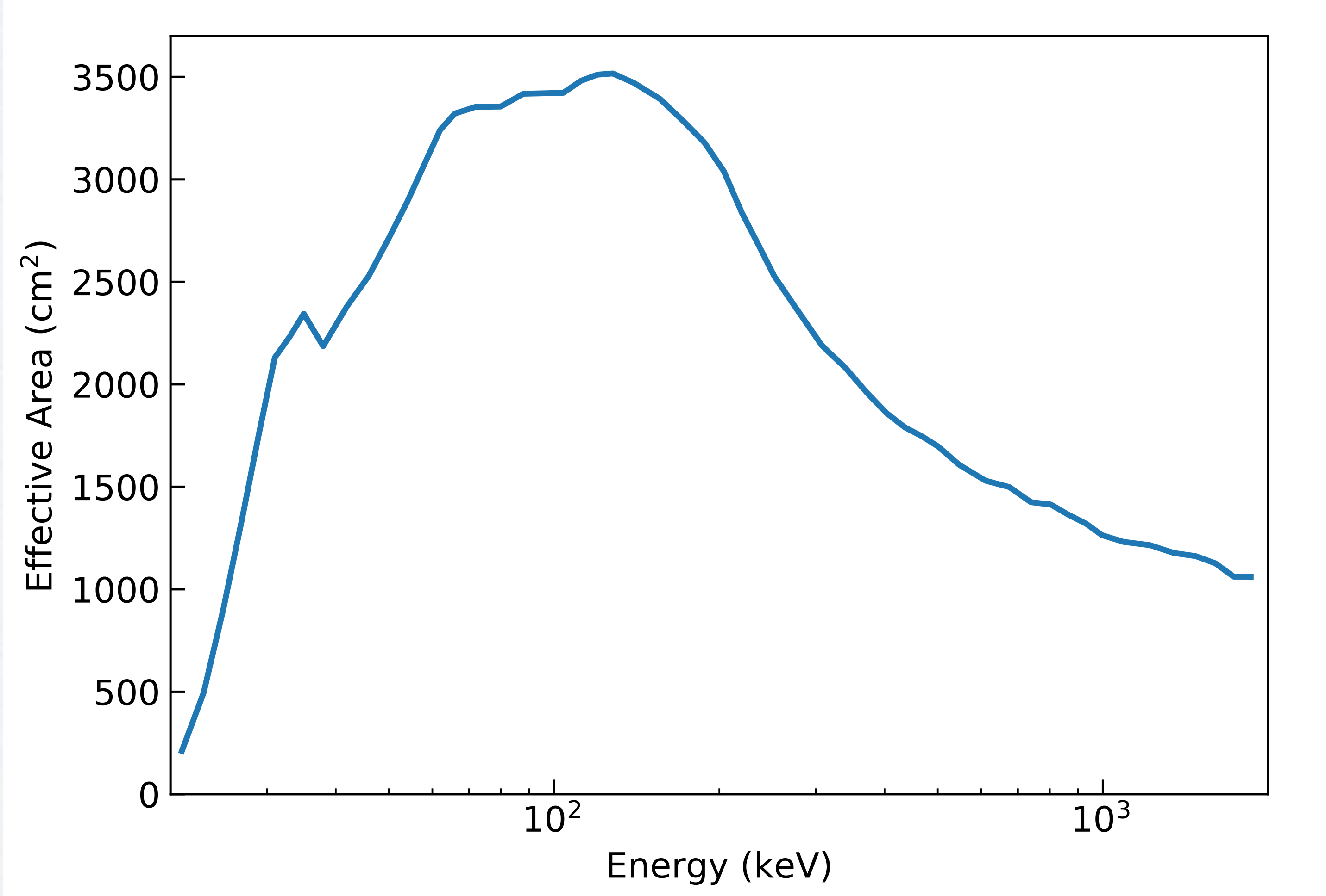


Glowbug flight unit detector assembly and SiPM array

StarBurst Performance

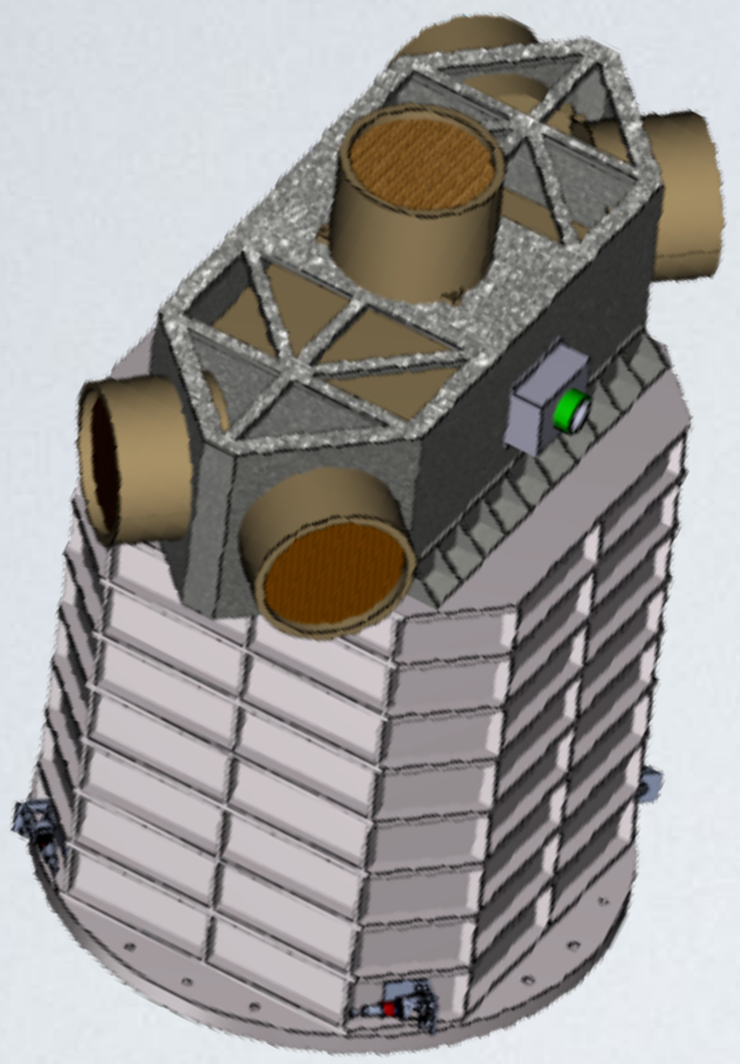
- Instrument Performance:
  - Azimuth average effective area peak of ~3500 cm2
  - Compared to GBM @ ~600 cm2 and Glowbug @ ~1100 cm2
- Detection Rate:
  - StarBurst: 200 SGRBs/yr
  - Swift: 10 SGRBs/yr, GBM: 40 SGRBs/yr
- Joint Detection Rate:
  - Based on model developed by E. Howell et al (2018)
  - Estimated rate of 3.7% of the A+ BNS detection rate
  - Estimated median rate of 9.8 GW-SGRBs/yr (2.6—25.2 @ 90% CL)





MoonBEAM

Moon Burst Energetics All-sky Monitor



- 2-year SmallSat mission concept to detect gamma-ray bursts, currently undergoing concept study funded by the 2019 Astrophysics Science SmallSat Studies.
- Mission goals and objectives:
  - Understanding the physics of neutron star mergers and using them as tools to probe fundamental physics and the behavior of astrophysical jets.
    1. Characterize short gamma-ray bursts to better understand jet structure and evolution in the multi-messenger era.
    2. Associate short gamma-ray bursts with compact binary merger events that also produce kilonovae.
    3. Enable earlier afterglow detection and localization to understand kilonova source evolution and the heavy element enrichment history.

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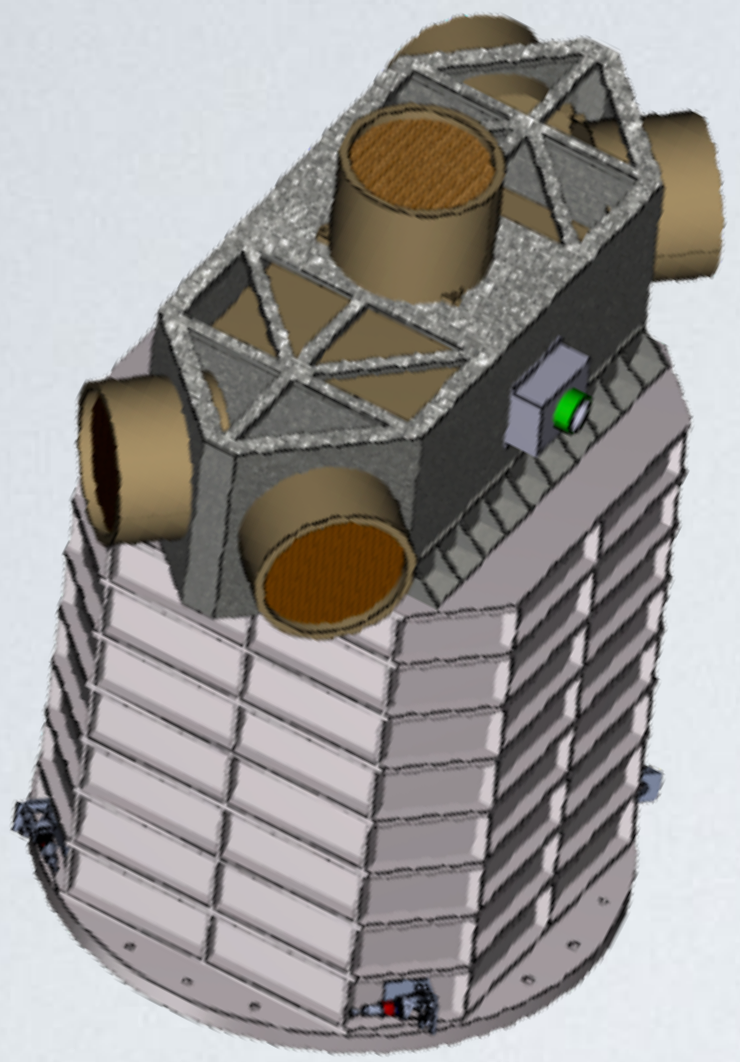
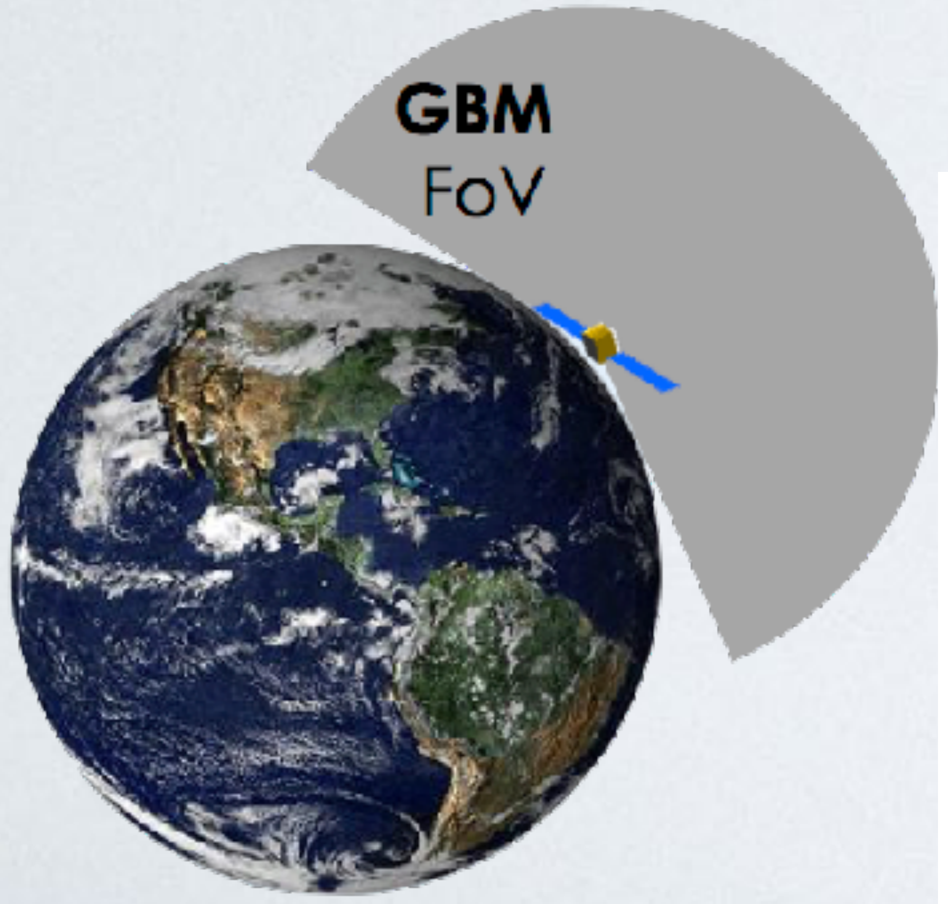
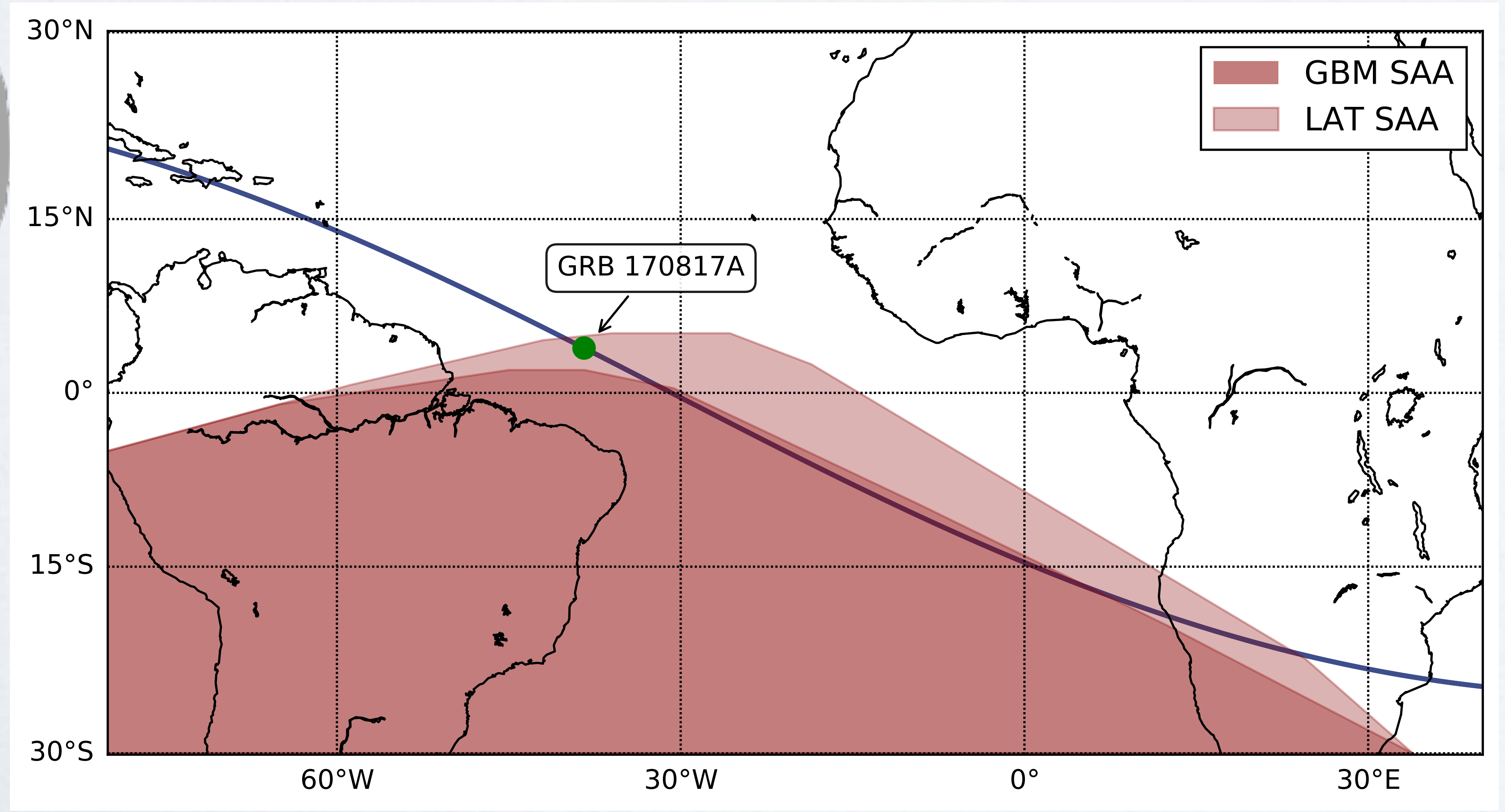
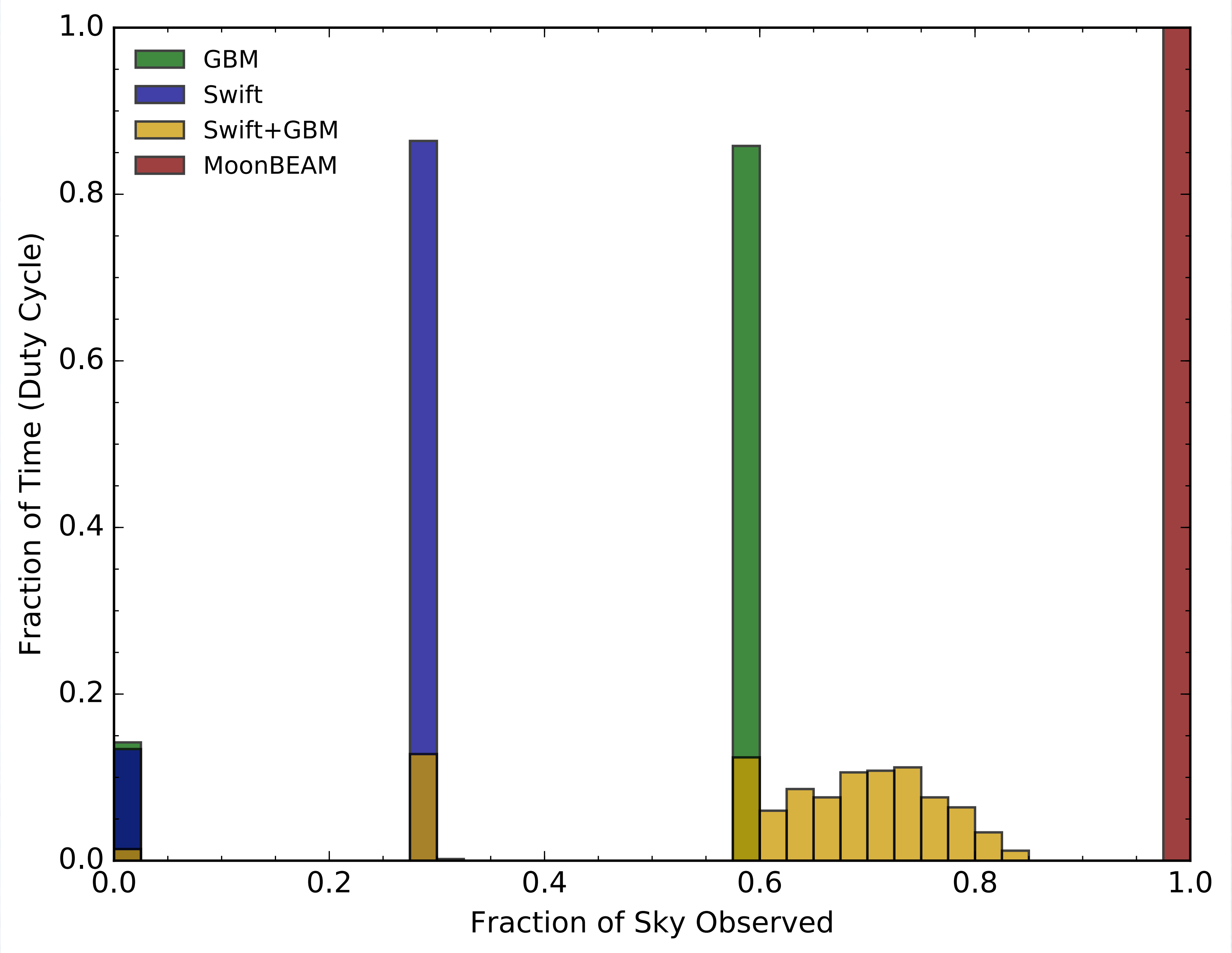


- 2-year SmallSat mission concept to detect gamma-ray bursts, currently undergoing concept study funded by the 2019 Astrophysics Science SmallSat Studies.
- Science instrument is 5 detector modules (NaI/CsI phoswich + SiPM) positioned to maximize sky coverage.
- Cislunar orbit at L3 point of Earth-Moon system (95,500 — 665,000 km from Earth).
  - ▶ Earth occults < 0.1% of sky at maximum.
  - ▶ High duty cycle, no SAA passage.
  - ▶ More stable background compared to Low Earth Orbit.
  - ▶ Additional localization improvement with IPN-like timing triangulation.







SGRB rate up to **70/year**
*assuming single-crystal detector

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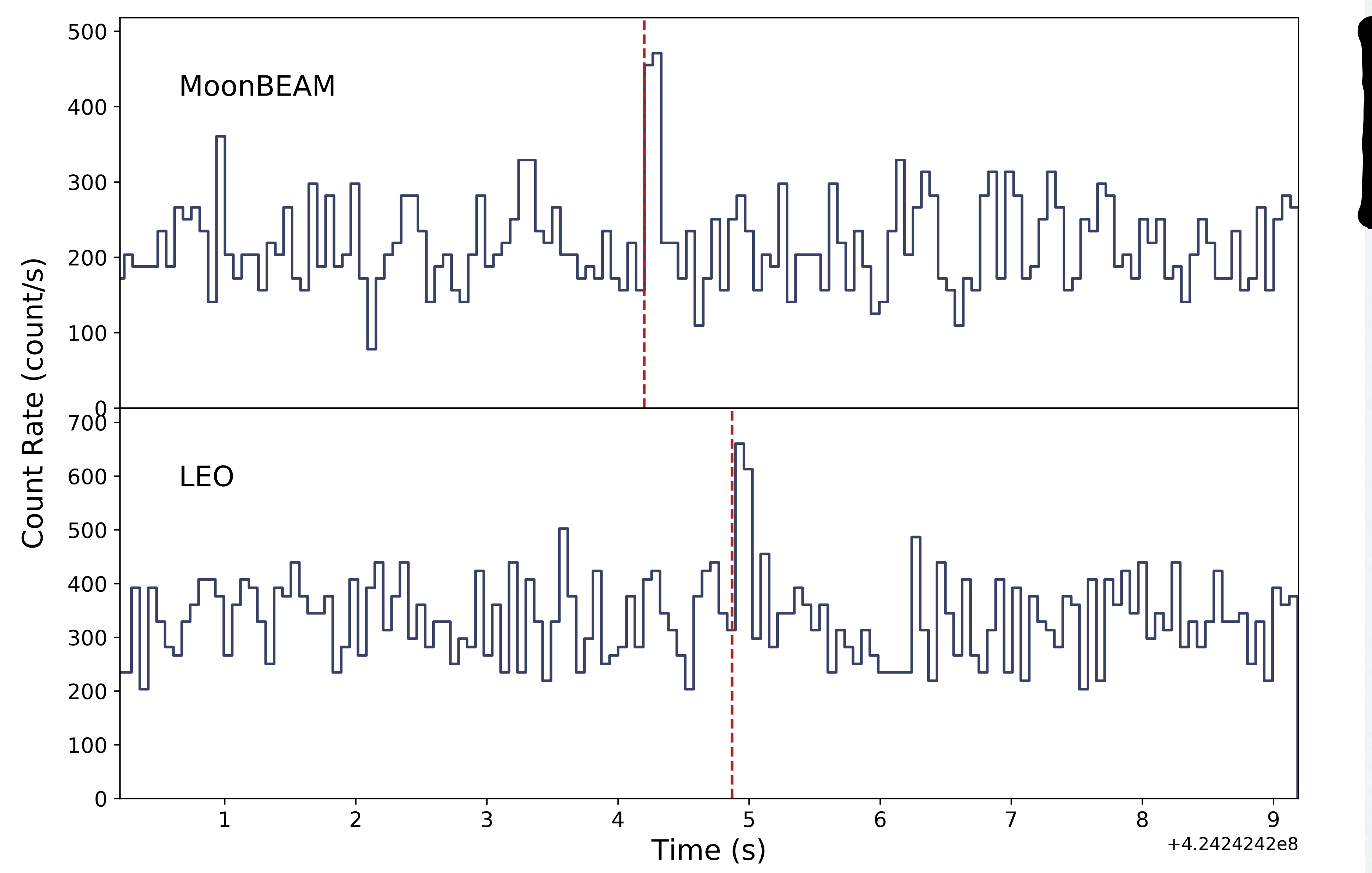
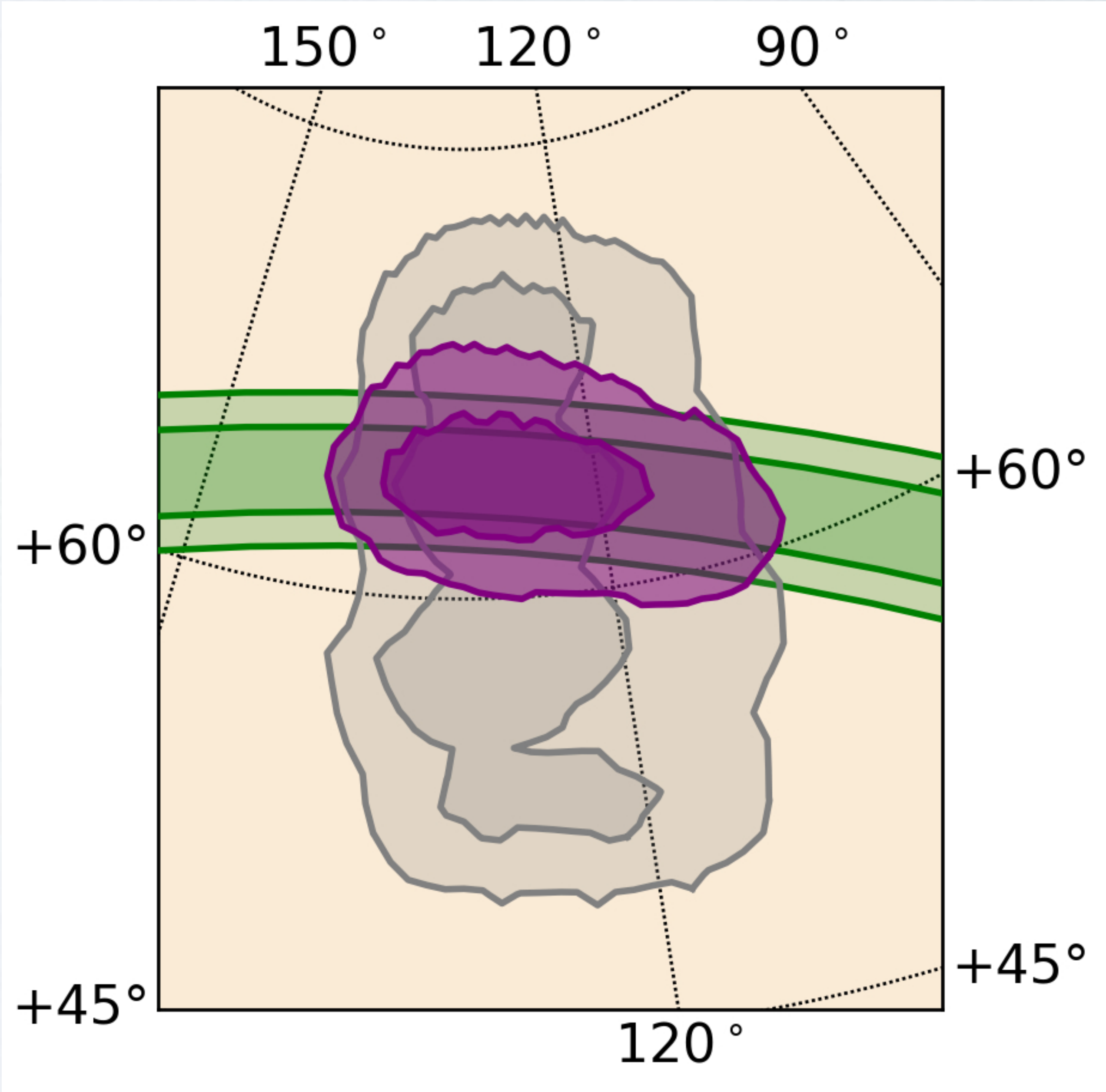
Currently evaluating additional potential orbits



Median-bright GRB at 45deg baseline
MoonBEAM average distance from Earth

MoonBEAM localization of an average GRB
MoonBEAM + LEO instrument timing annulus
Combined posterior (loc area reduced by factor of 3)



SUMMARY

- GW170817 / GRB 170817A is one of the best observed transient and highlights the science impact of multimessenger observations.
- Many open questions remain, with increased GW interferometer sensitivity, looking forward to more joint detections with gamma-ray instruments, enabling deeper population studies of SGRBs.
- Subthreshold searches are crucial to increasing GRB sensitivity and the detection horizon to weak events like GRB 170817A
- Several future gamma-ray missions in different phases of development.
  - Session 135.02 LEAP - A Large Area Gamma-Ray Burst Polarimeter for the ISS by Colleen Wilson-Hodge
  - BurstCube and AMEGO later in this session by Judy Racusin
- Looking forward to future multimessenger discoveries:
  - Neutron star — Blackhole merger, Fast Radio Bursts, giant magnetar flares, neutrinos
    - session 233 on recent giant magentar flares observations
    - Bursting Magnetars press conference on Wednesday