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

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Moon Burst Energetics All-sky Monitor (MoonBEAM) is a CubeSat concept of deploying gamma-ray detectors in cislunar space to improve localization precision for gamma-ray bursts by utilizing the light travel time difference between different orbits. We present here a gamma-ray SmallSat concept in Earth-Moon L3 halo orbit that is capable of rapid response and provide a timing baseline for localization improvement when partnered with an Earth-orbit instrument. Such an instrument would probe the extreme processes in cosmic collision of compact objects and facilitate multi-messenger time-domain astronomy to explore the end of stellar life cycles and black hole formations.

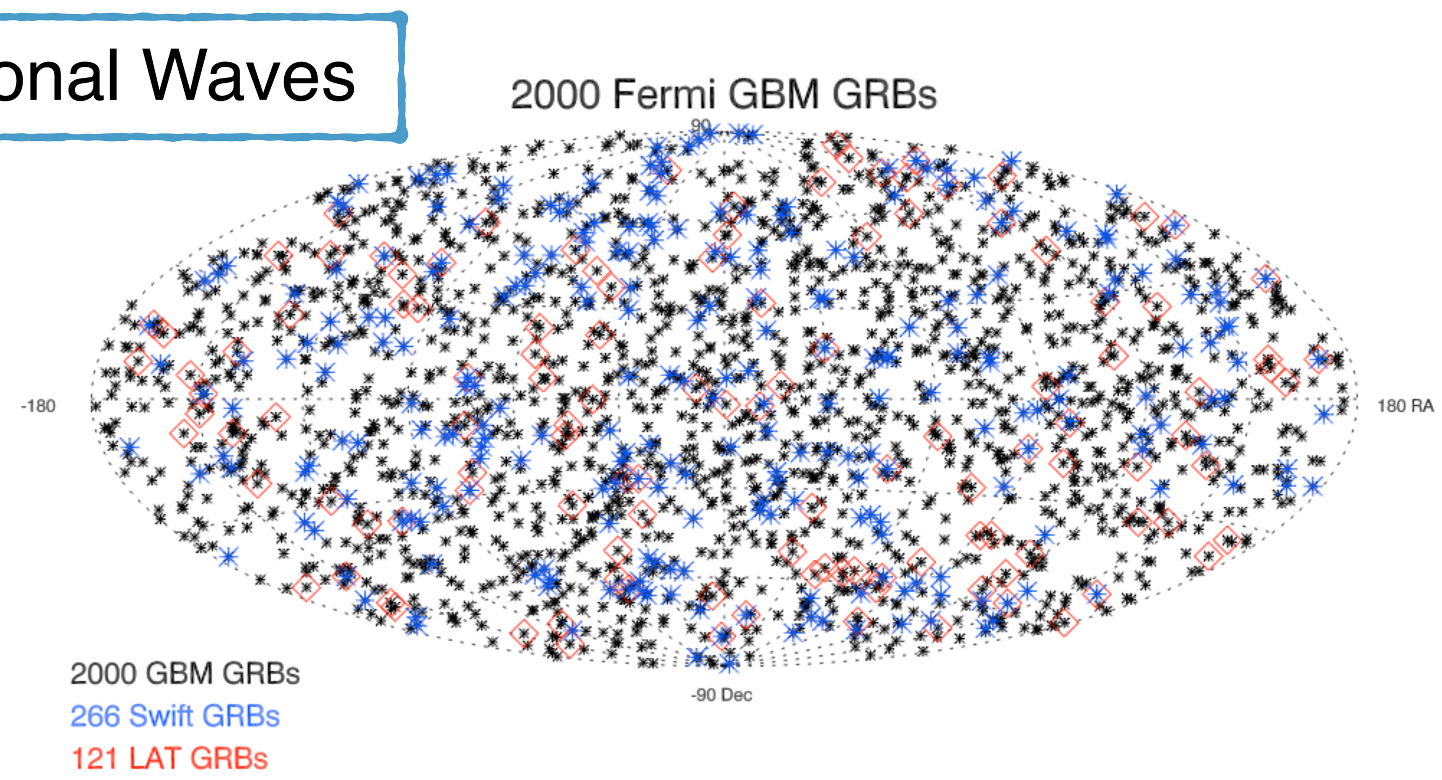
Gamma-ray Bursts and Gravitational Waves

Gamma-ray Burst (GRB)

- Merger of two compact objects or collapse of a massive star.
- Collimated relativistic outflow.
- Prompt keV-MeV emission, afterglow in other wavelengths.
- ~ once per day, isotropically distributed.

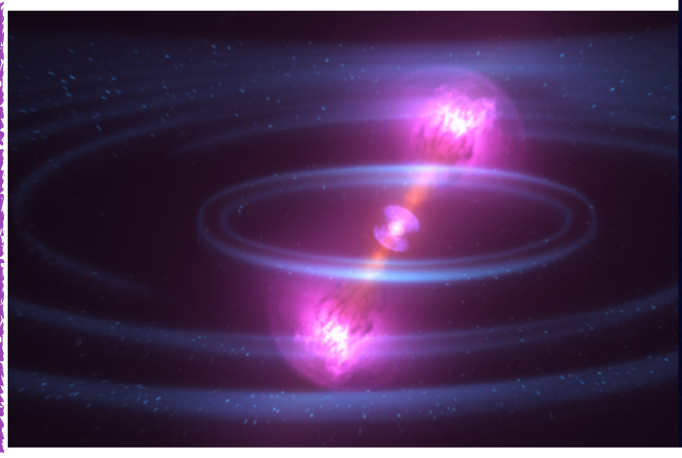
Gravitational Wave (GW)

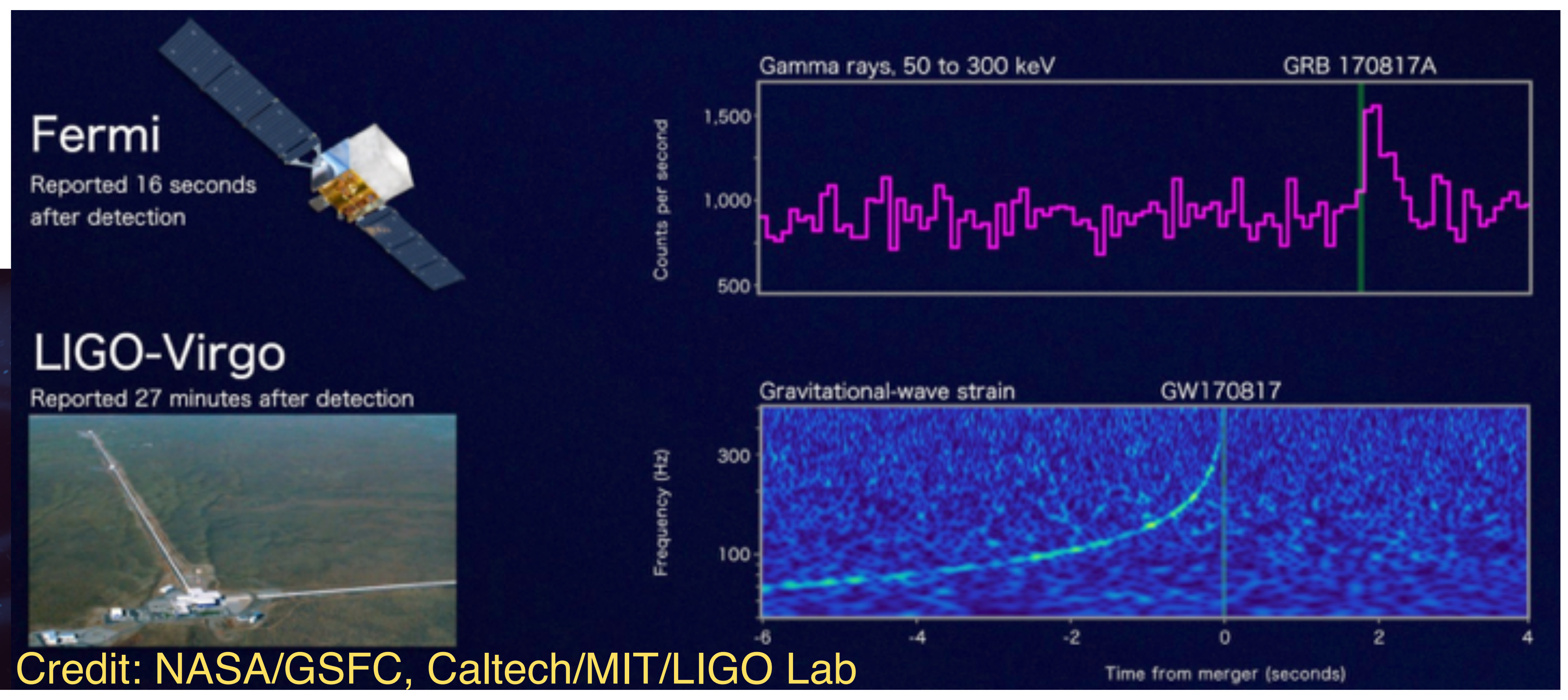
- Merger of two neutron stars observed in 2017 — GW170817:
  - 1.7s after merger, GRB 170817A detected by *Fermi*-GBM and triggered extensive electromagnetic followup resulting in detection of a kilonova.
  - First association between gravitational wave and short gamma-ray burst from a binary neutron star merger.



Joint scientific results

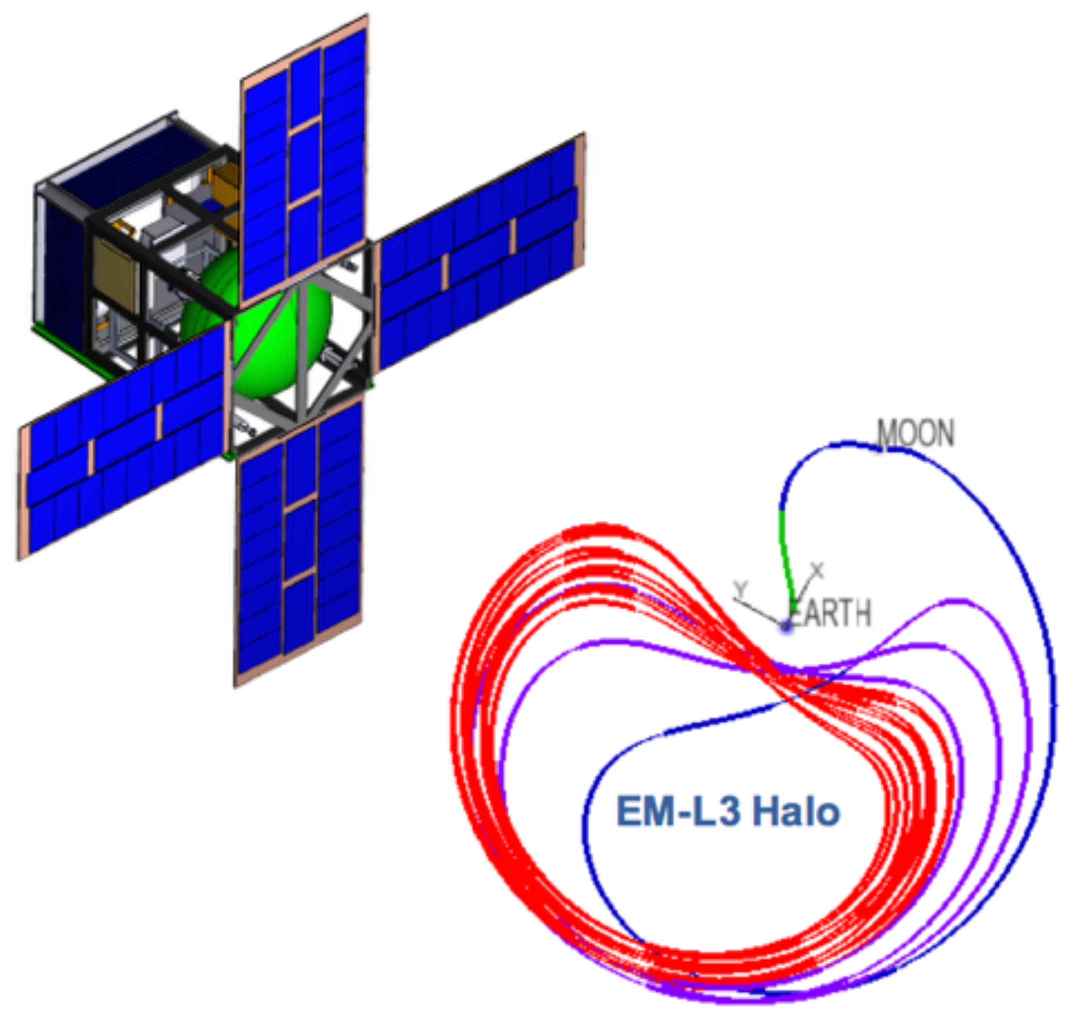
- Tightest constraints on speed of gravity.
- Constraints on neutron star equation of state.
- Open questions: merger and jet geometry, intrinsic properties, population characteristics.



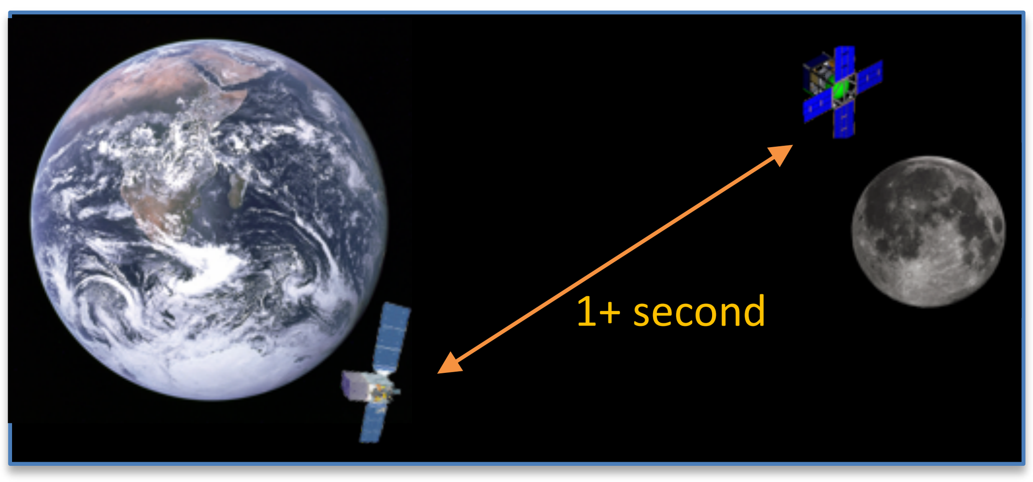


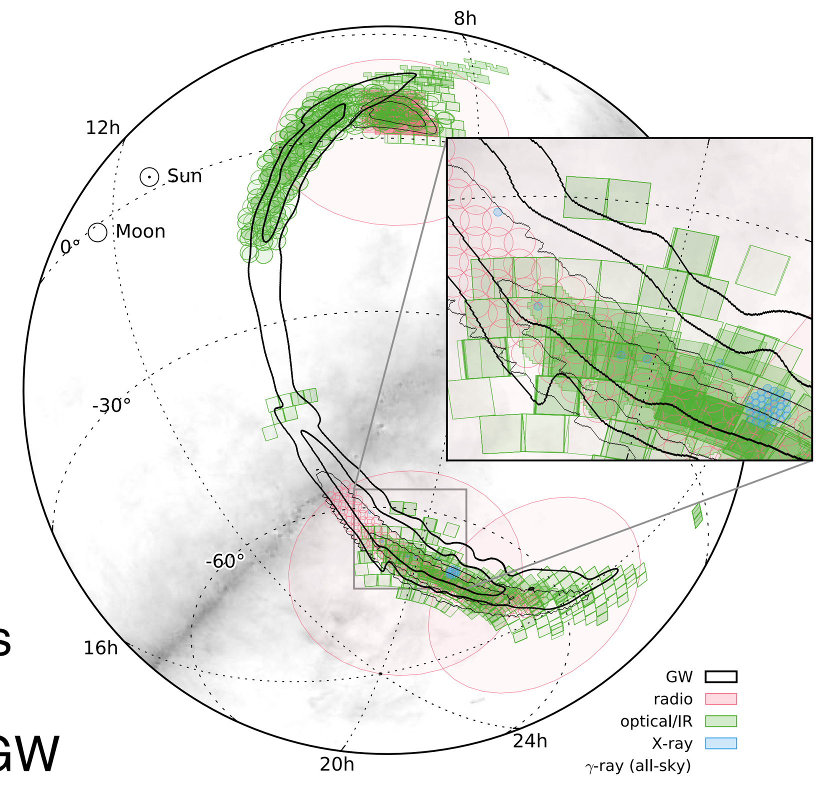
Credit: NASA/GSFC, Caltech/MIT/LIGO Lab

MoonBEAM



- 12U CubeSAT designed with high TRL components, most are already flight tested.
- 2-year mission duration, 1-year minimum.
- Earth-Moon L3 halo orbit provides a baseline of 0.3-2.1s when paired with an Earth-orbit instrument.
- Science instrument consists of 5 detector modules positioned in 5 of the 6 sides of the instrument.
  - Each module will contain a 12.7cm x 12.7cm NaI scintillation crystal coupled to an array of Silicon photomultipliers.

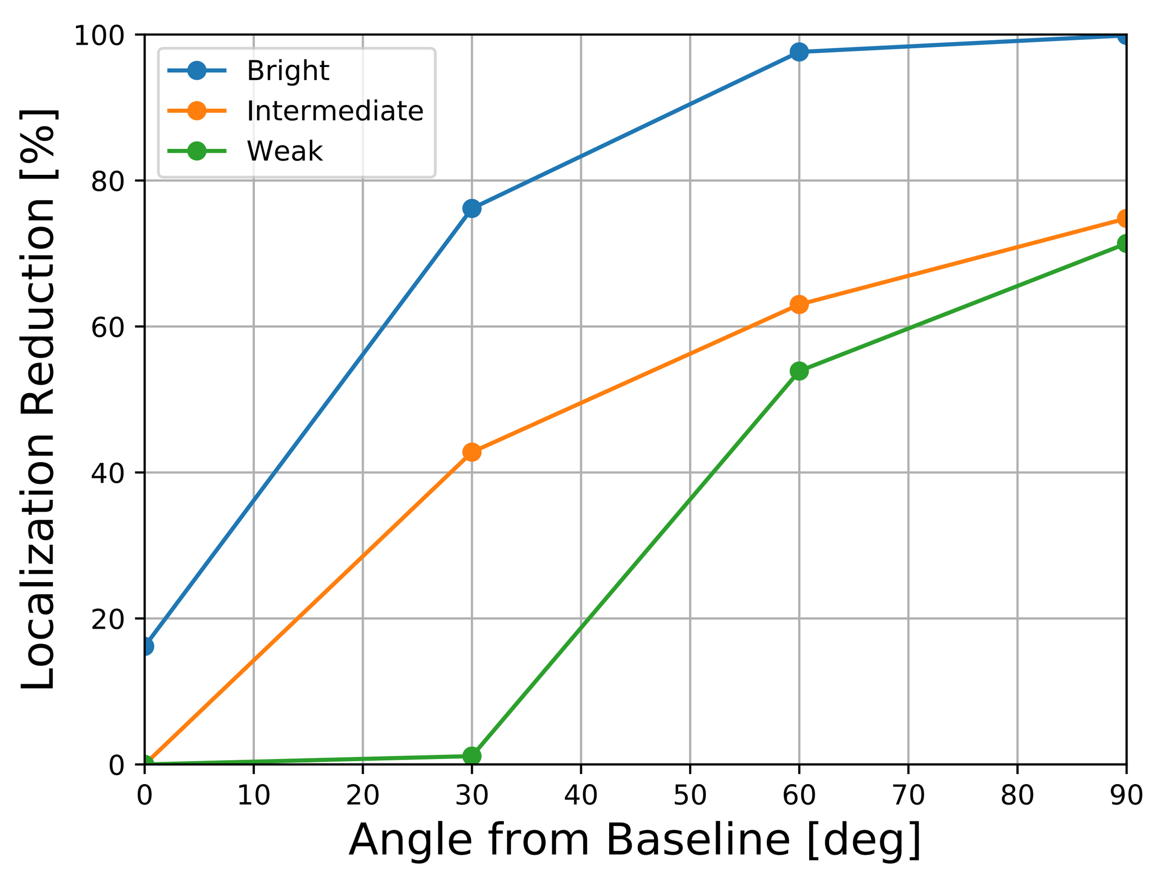




Most instruments have small viewing and rapid followup is difficult when localization area is large. *Right:* Tiling observations done by different instruments for the first GW detection sky contours [ApJL 826, L13, 2016].

Increasing Sky Coverage and Localization Improvement

- Current *Fermi*-GBM is the most prolific GRB detector, it has a sky coverage of ~70% and location precision no better than a few degrees.
- Adding another instrument in a different orbit will increase the number of GRB detections and improve localization via arrival time difference.
- The Interplanetary Gamma-Ray Burst Timing Network demonstrated an average improvement by a factor of 180 relative to *Fermi*-GBM when combining with additional detection from another spacecraft in a different planetary orbit.
- Why near the Moon:
  - Low Earth Orbit is <0.1s, improvement to only top 5% brightest short GRBs.
  - **Cislunar space can improve localization for 20+ short GRBs per year**, more if searching below trigger threshold events in continuous data coincident with triggers from another instrument.
  - **A reduction of >50% in localization area** is achievable for short GRBs with average brightness at a baseline angle of 45deg.
  - Outside of the Tracking and Data Relay Satellite (TDRS) network, data downlinks delay prevents rapid followup. In cislunar space, fast communication is still possible with current technology and limitations.



Localization area reduction relative to *Fermi*-GBM assuming 385,000 km baseline for short GRBs with different intensities.