MoonBEAM: A Beyond Earth-orbit Gamma-ray Burst Detector for Multi-Messenger Astronomy

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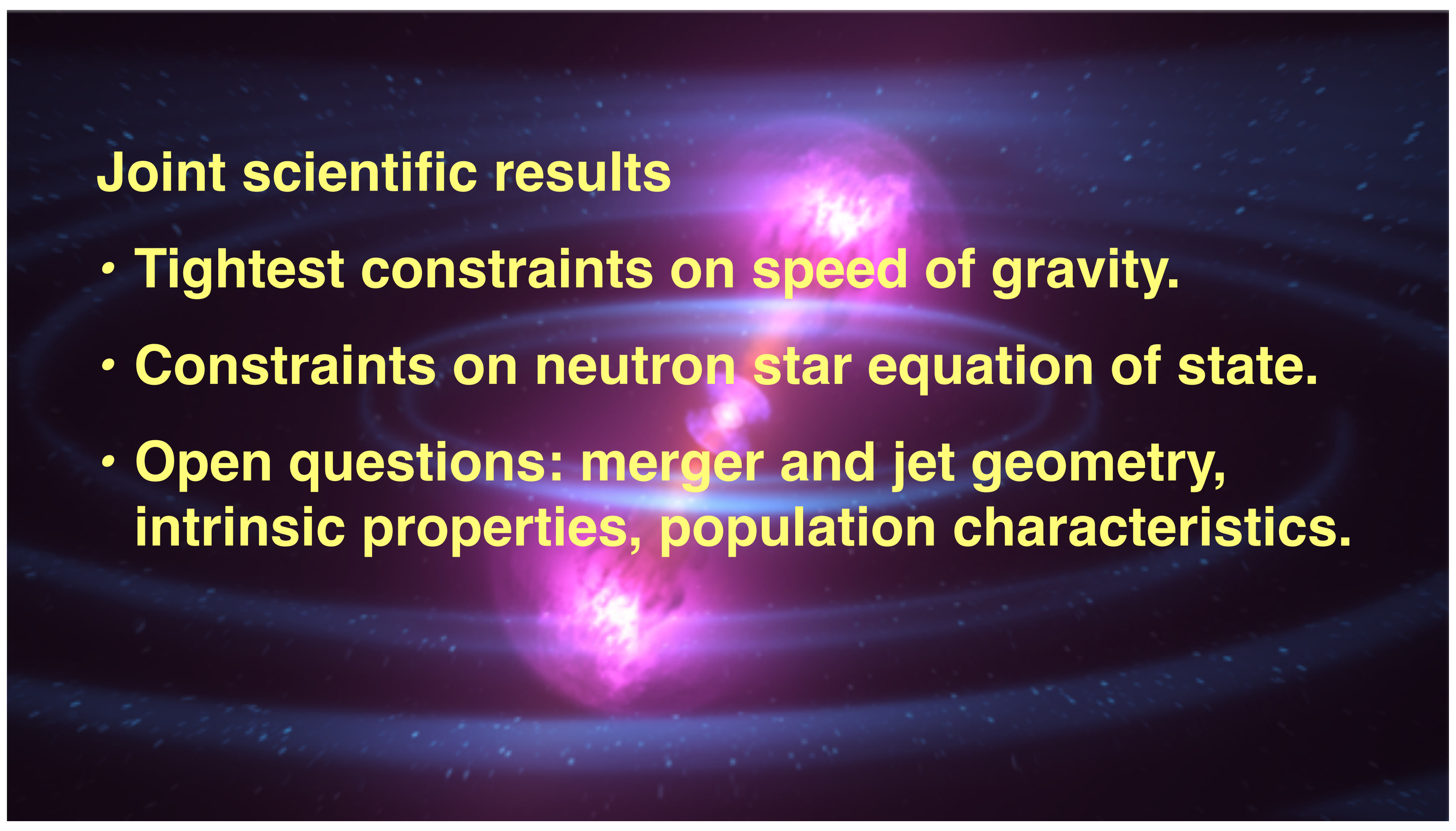
MoonBEAM is a SmallSat concept of deploying gamma-ray detectors in cislunar space to increase gamma-ray burst detections and improve localization precision with the timing triangulation technique. Such an instrument would probe the extreme processes involved in the cosmic collision of compact objects and facilitate multi-messenger time-domain astronomy to explore the end of explore the end of stellar life cycles and black hole formation.

Gamma-ray Bursts and Gravitational Waves

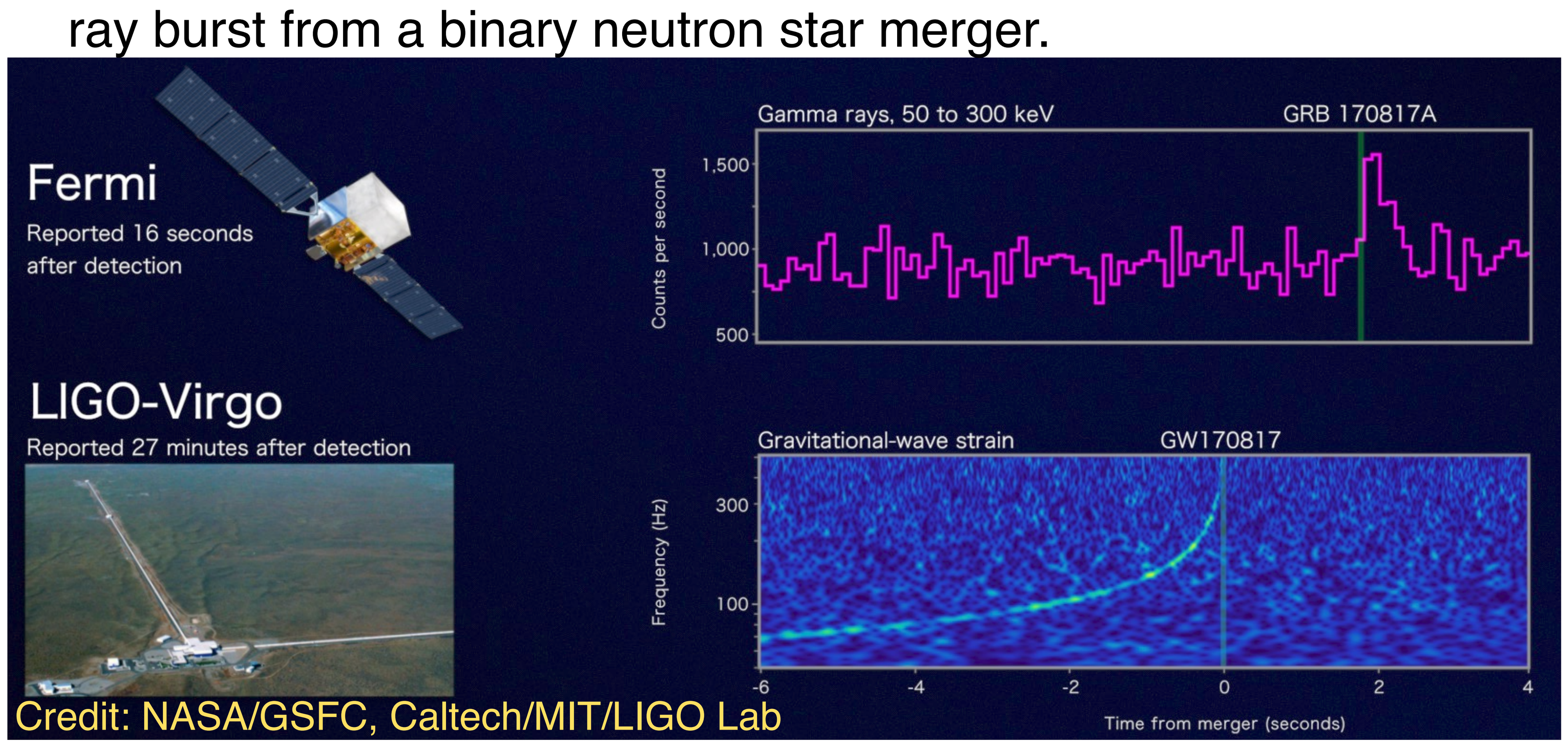
Gamma-ray Burst (GRB)

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



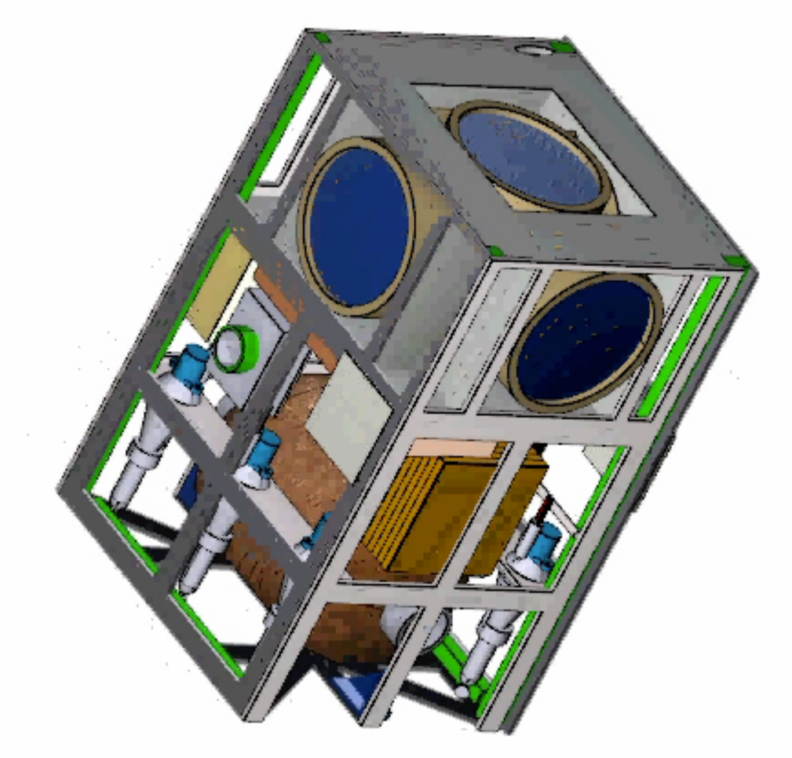
Gravitational Wave (GW)

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

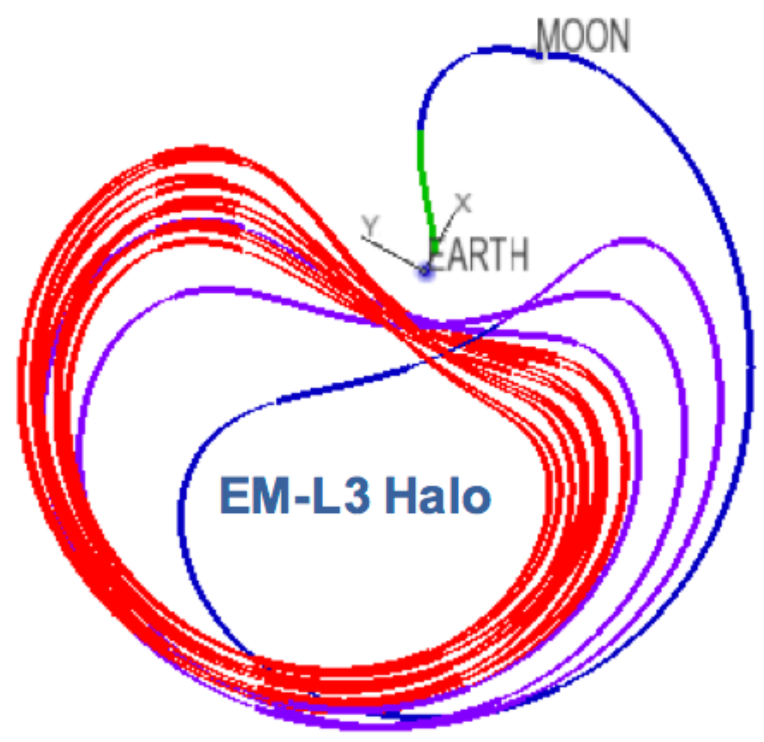


Credit: NASA/GSFC, Caltech/MIT/LIGO Lab

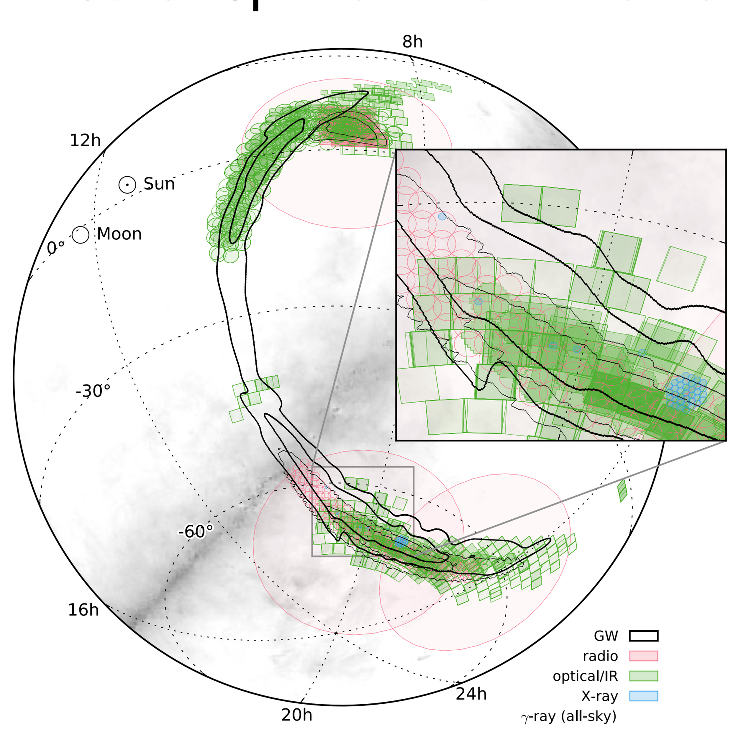
Moon Burst Energetics All-Sky Monitor (MoonBEAM)



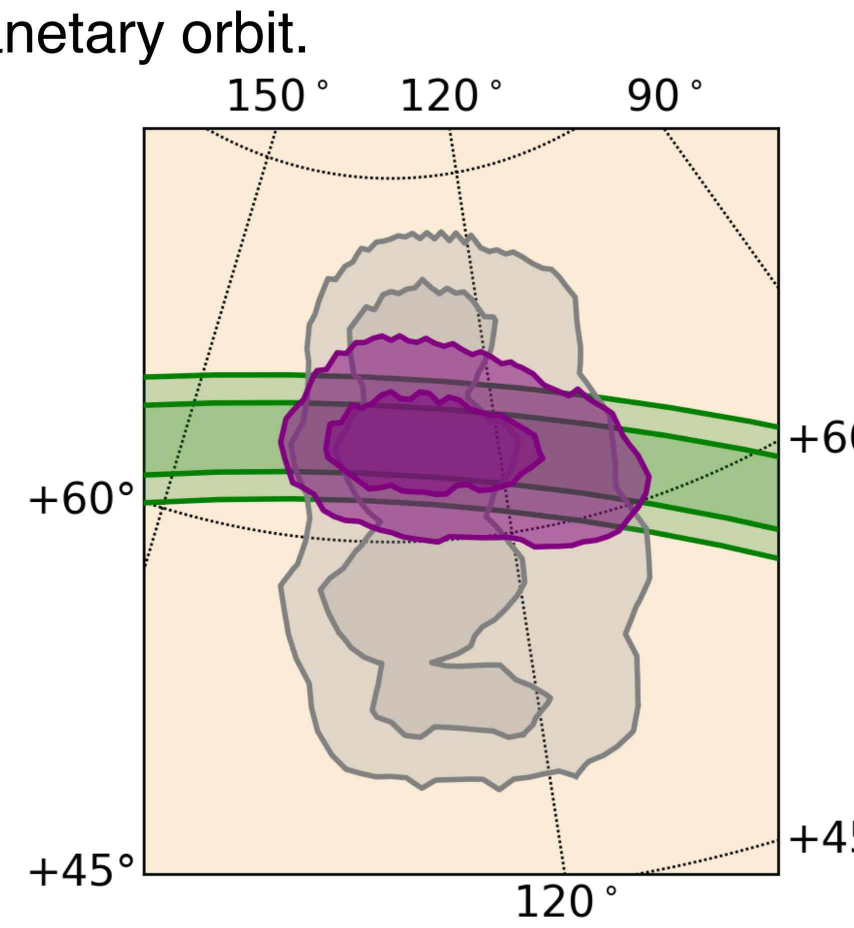
- SmallSat mission concept designed with high TRL components, most are already flight tested.
- 2-year mission duration, 1-year minimum.
- Cislunar L3 halo orbit of Earth-Moon system (95,000—665,000km from Earth, 0.3–2.1 light-seconds difference).
- Science instrument consists of 5 detector modules, each equipped with NaI(TI)/CsI(Na) phoswiches + Silicon photomultipliers positioned on 5 of the 6 sides of the instrument to maximize sky coverage.



- Based on the sky coverage and duty cycle at Earth-Moon L3 orbit and detector area, **MoonBEAM will detect 30-70 short GRBs/ year** with onboard detection algorithms, competitive with current missions in operation.
- 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.



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



MoonBEAM localization of an average GRB; MoonBEAM + LEO instrument timing annulus; and Combined posterior, localization area reduced by factor of 3.

- **Why near the Moon**:
  - Earth occults < 0.1% of the sky at maximum, cislunar provides better sky coverage.
  - High duty cycle, no passage through South Atlantic Anomaly (SAA) affecting detector rates.
  - More stable background compared to Low Earth Orbit.
  - 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.
  - Low Earth Orbit can provide <0.1s baseline, improvement to only top 5% brightest short GRBs when using timing triangulation method with multiple spacecraft detections.

Sky coverage for *Fermi*-GBM, Swift, Swift+*Fermi*-GBM, and MoonBEAM. Full sky coverage is challenging even when combining instruments in LEO.