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

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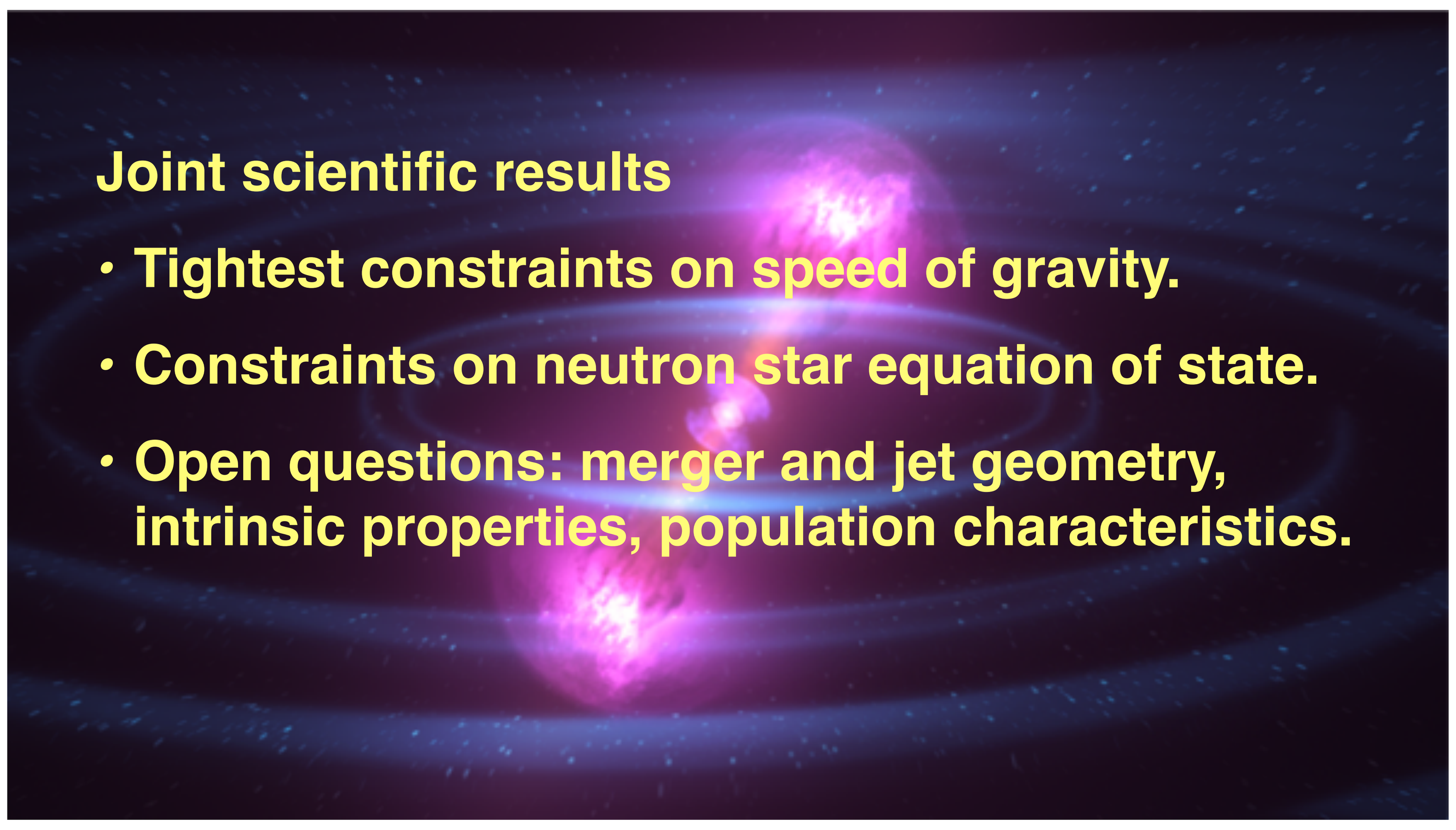
MoonBEAM is a 12U CubeSat concept of deploying gamma-ray detectors in cislunar space to increase gamma-ray burst detections and improve localization precision with the timing triangulation technique. Such an instrument would probe the extreme processes involved in the cosmic collision of compact objects 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

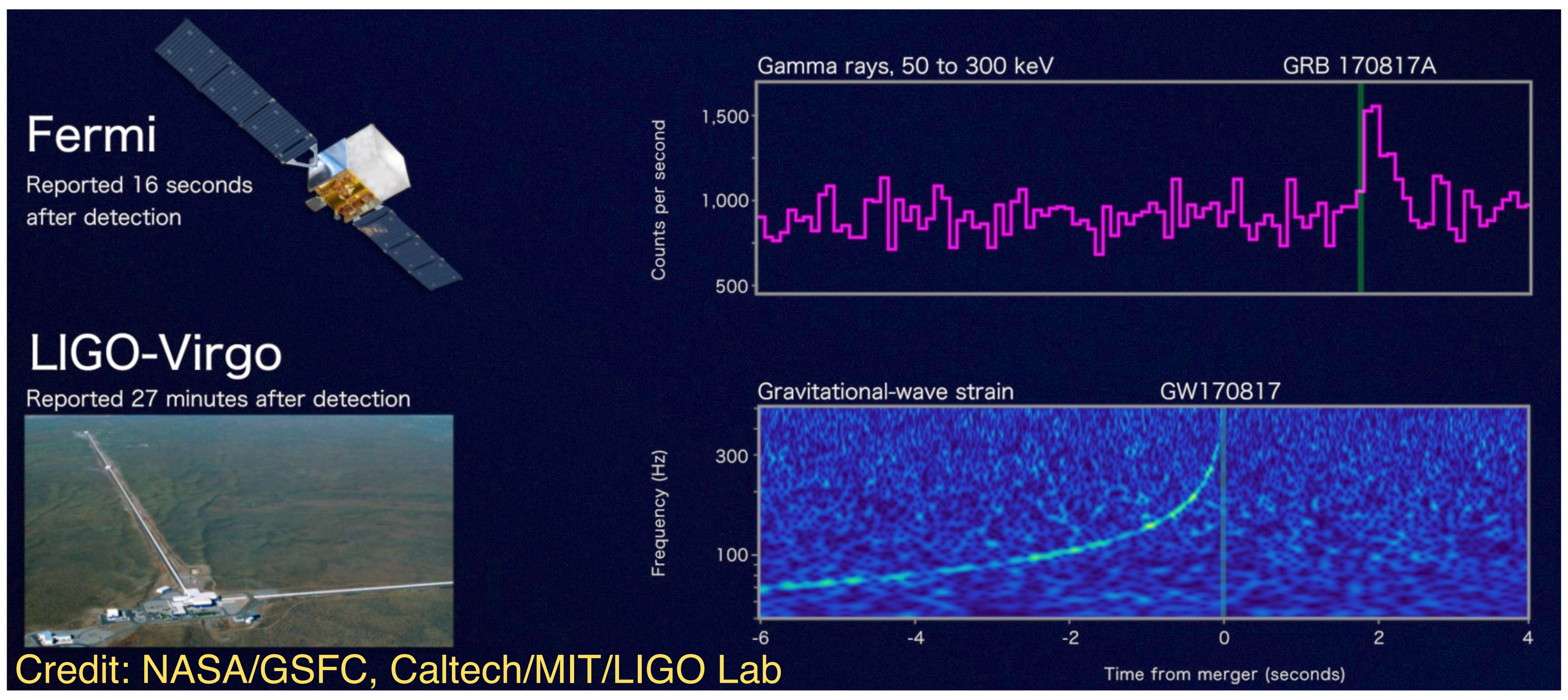
Gamma-ray Burst (GRB)

- 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.

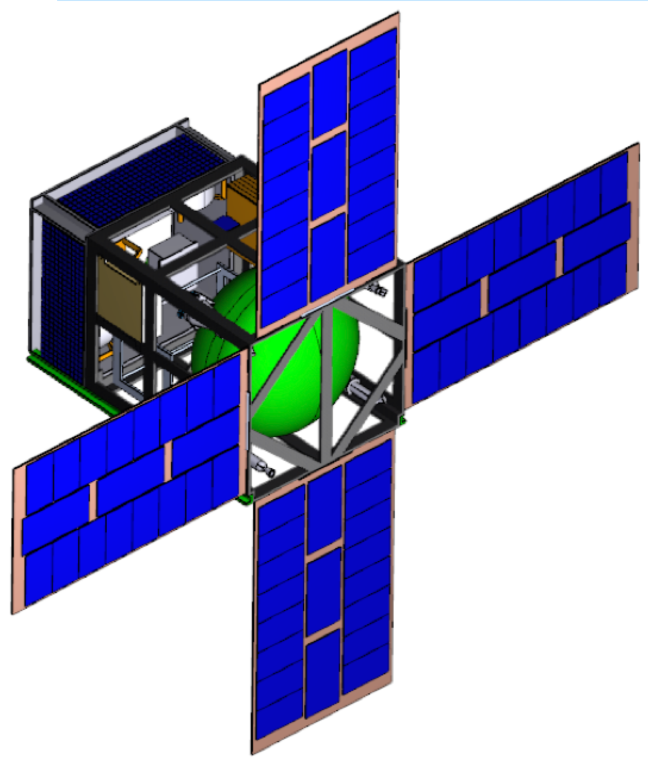


Gravitational Wave (GW)

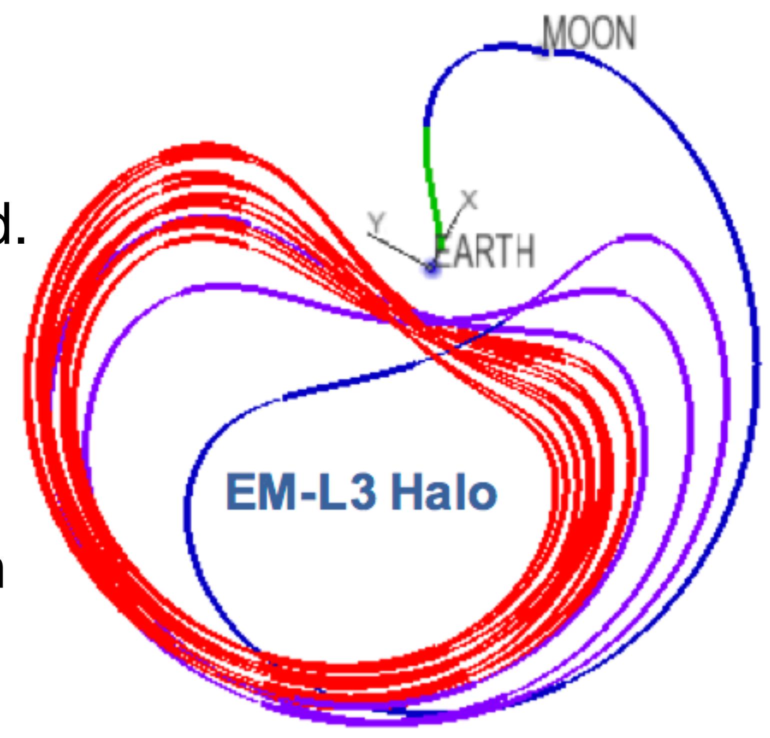
- Merger of two neutron stars observed in 2017 — GW170817:
  - GRB 170817A was independently detected by *Fermi*-GBM at 1.7s after the merger. This triggered an extensive electromagnetic followup resulting in detection of a kilonova.
  - First association between a gravitational wave and a short gamma-ray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



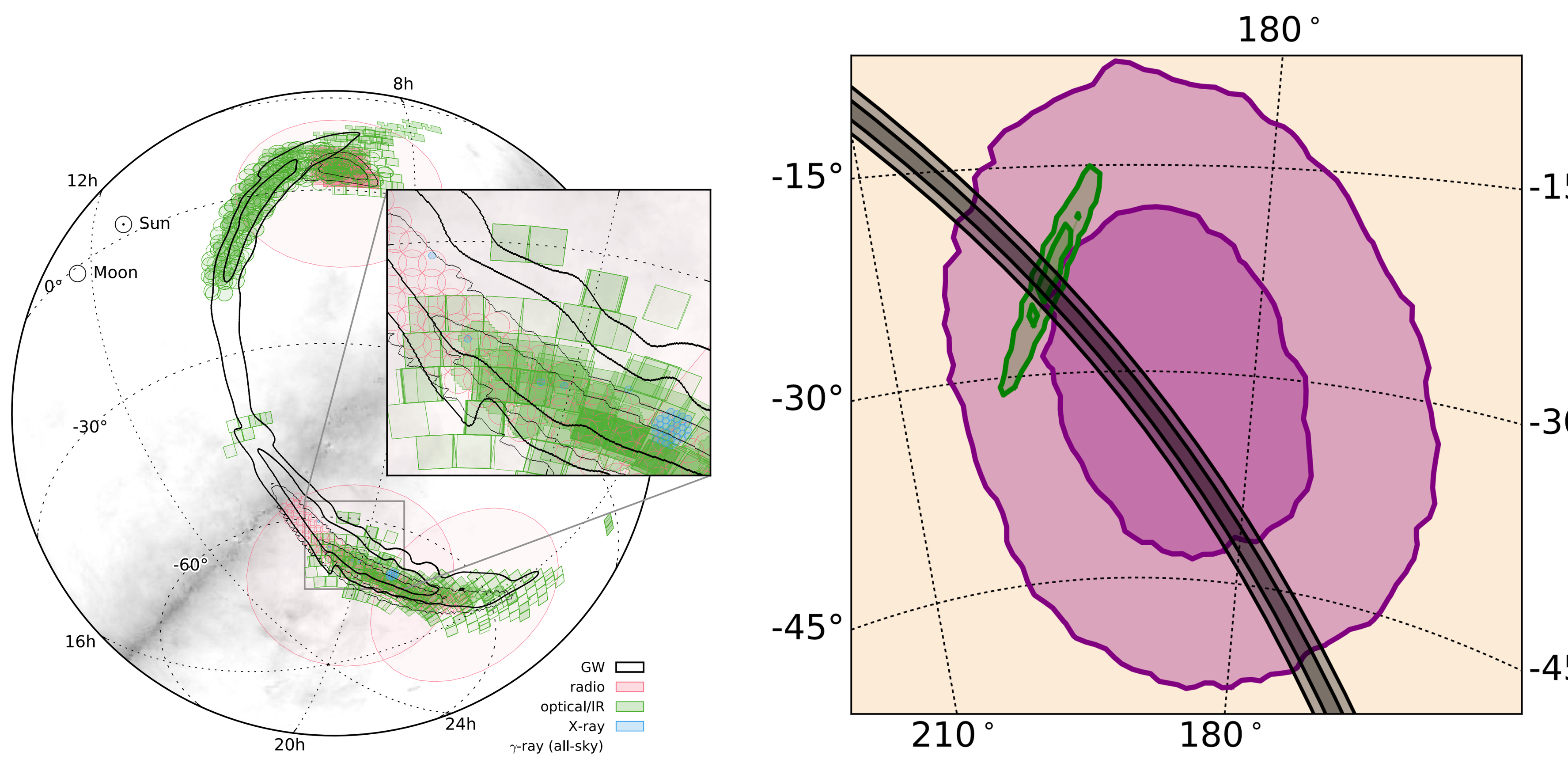
MoonBEAM



- 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 detector modules (NaI scintillation crystal + Silicon photomultipliers) positioned on 5 of the 6 sides of the instrument.

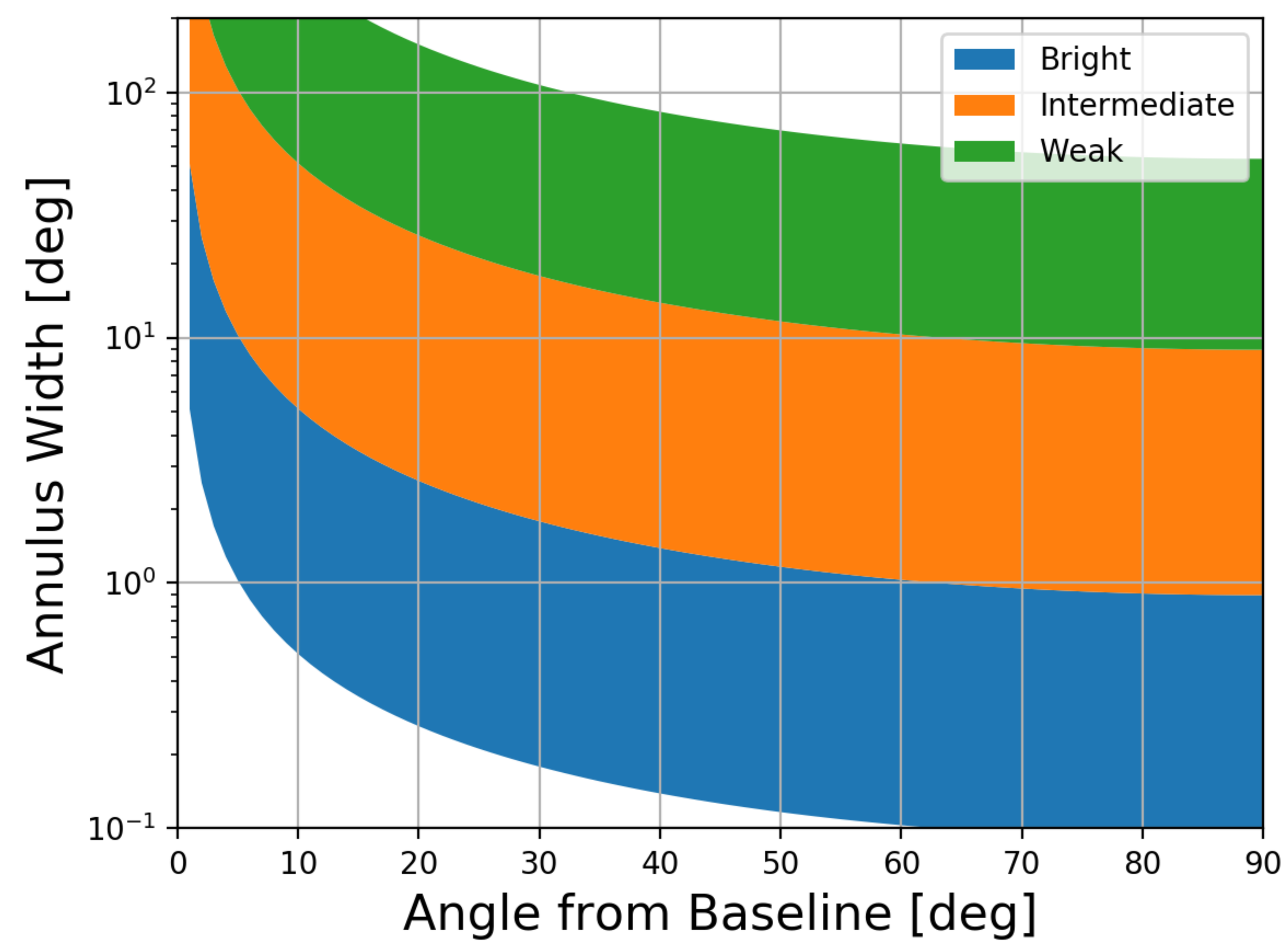


- Based on the sky coverage at Earth-Moon L3 orbit and detector area, **MoonBEAM will detect ~37 short GRBs/year** with onboard detection algorithms.
- Adding another instrument in a different orbit will increase the number of GRB detections and improve localization via arrival time difference.
  - The 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. *Left:* Tiling observations done by different instruments for the first GW detection sky contours [ApJL 826, L13, 2016]. Right: GW170817 and GRB 170817A localization contours, an example annulus for an intermediate bright burst at 45° baseline angle.

- Why near the Moon:
  - Low Earth Orbit can provide <0.1s baseline, 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.



1σ annulus width for a 385,000 km baseline for short GRBs with different intensities. Most bright GRBs will be localized to sub-degree width.