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

C. M. Hui[1], M. S. Briggs[2], A. M. Goldstein[3], P. A. Jenke[2],
D. Kocevski[1], C. A. Wilson-Hodge[1], E. Burns[4]

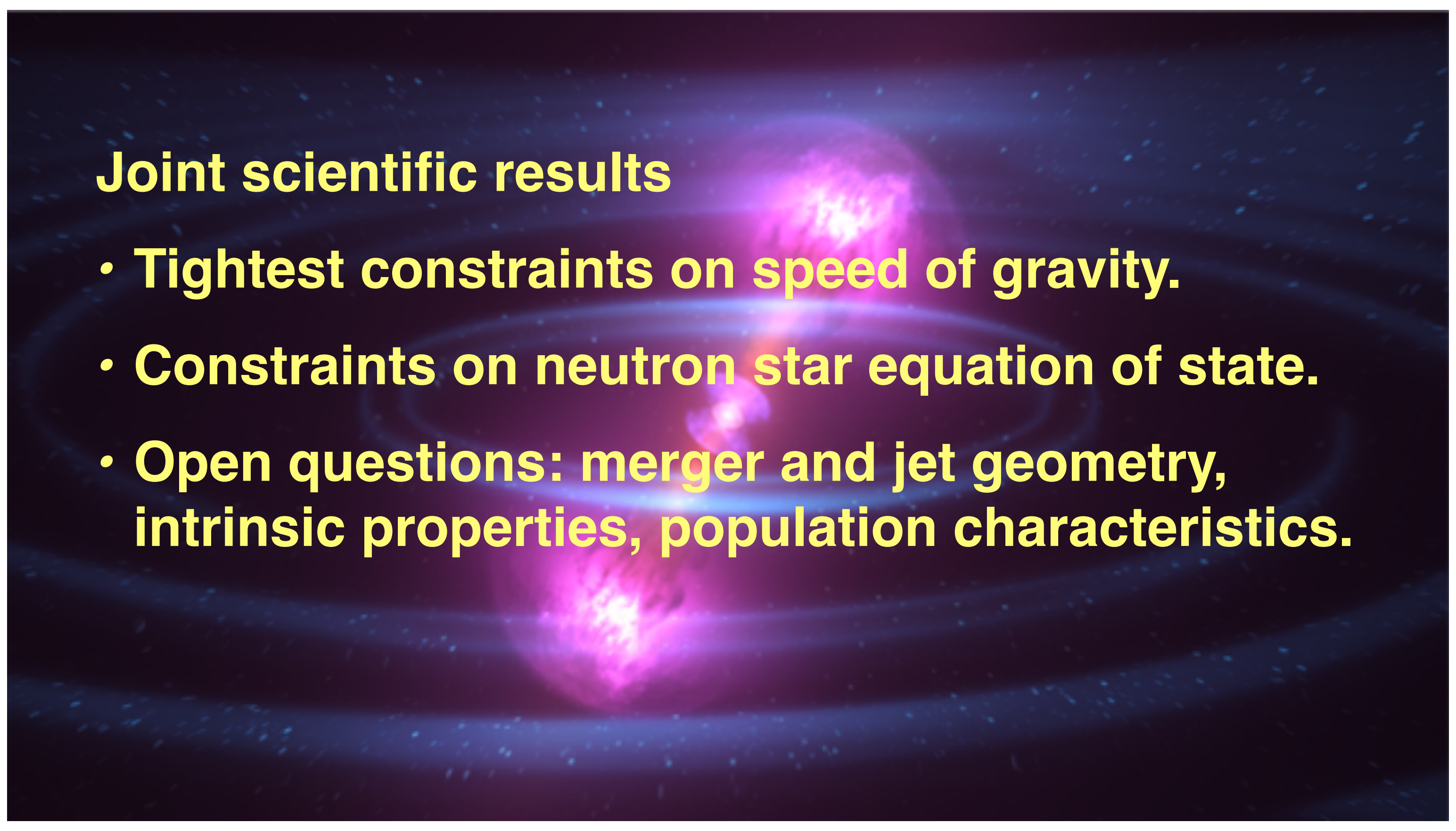
[1]NASA/MSFC, [2]University of Alabama in Huntsville, [3]USRA, [4]NASA/GSFC

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 in 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 other wavelengths.
- ~ once per day, isotropically distributed.

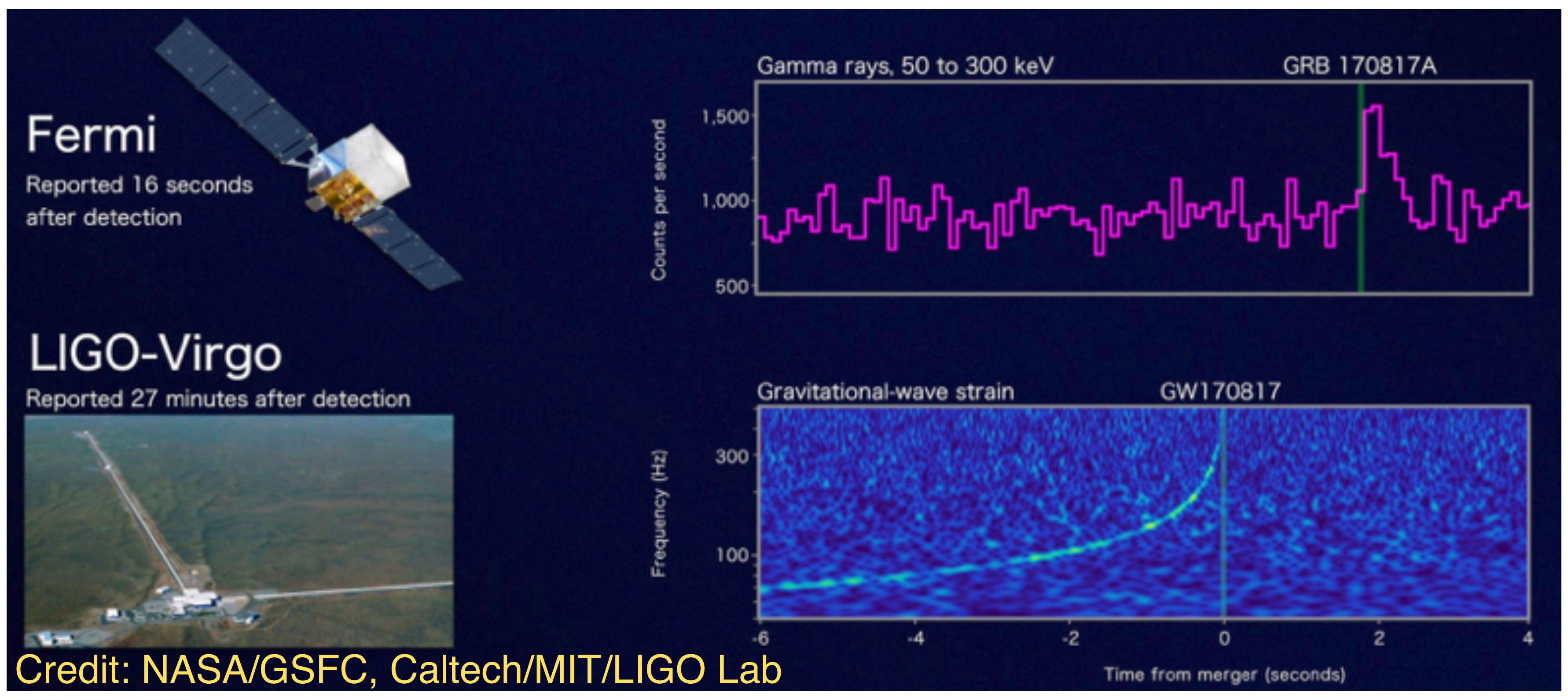


Joint scientific results

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

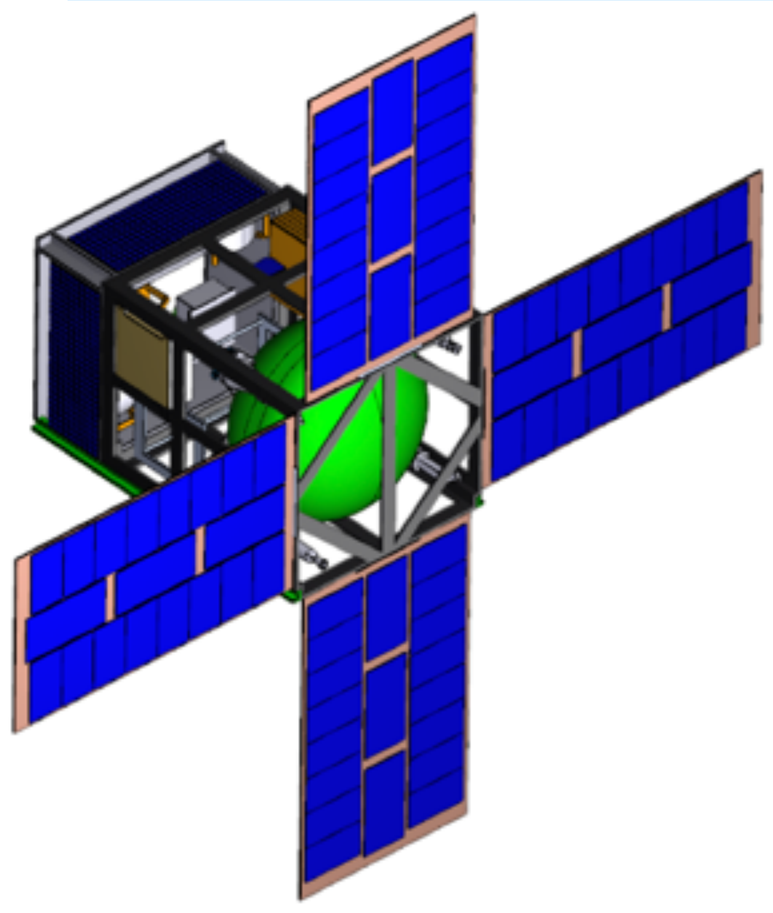
Gravitational Wave (GW)

- 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.

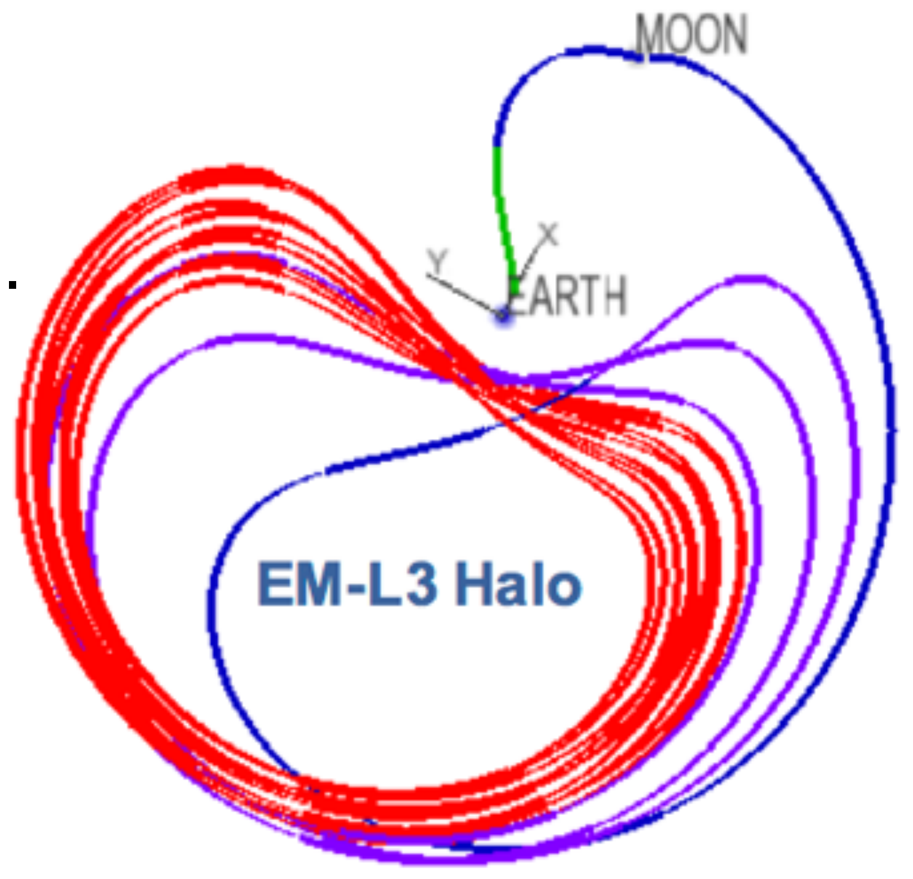


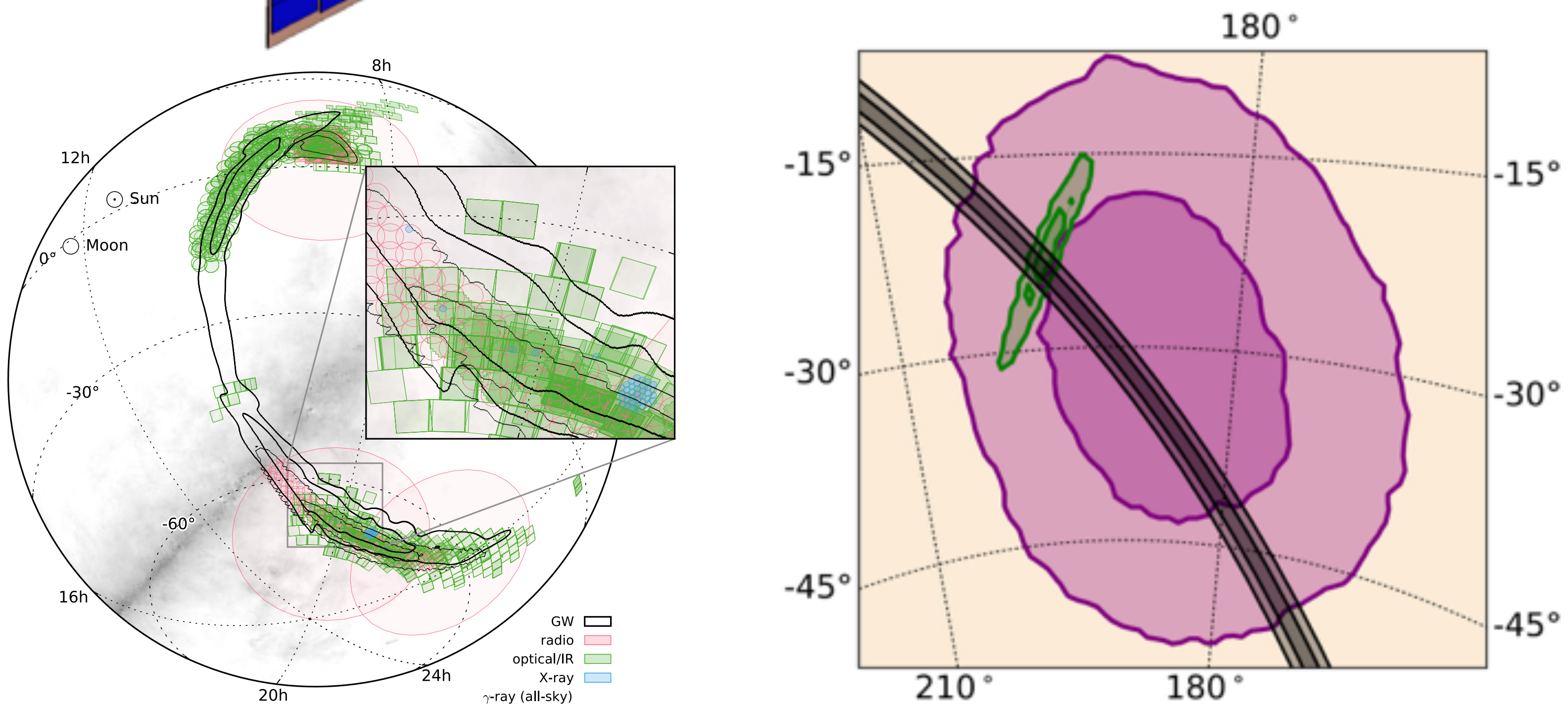
Credit: NASA/GSFC, Caltech/MIT/LIGO Lab

MoonBEAM

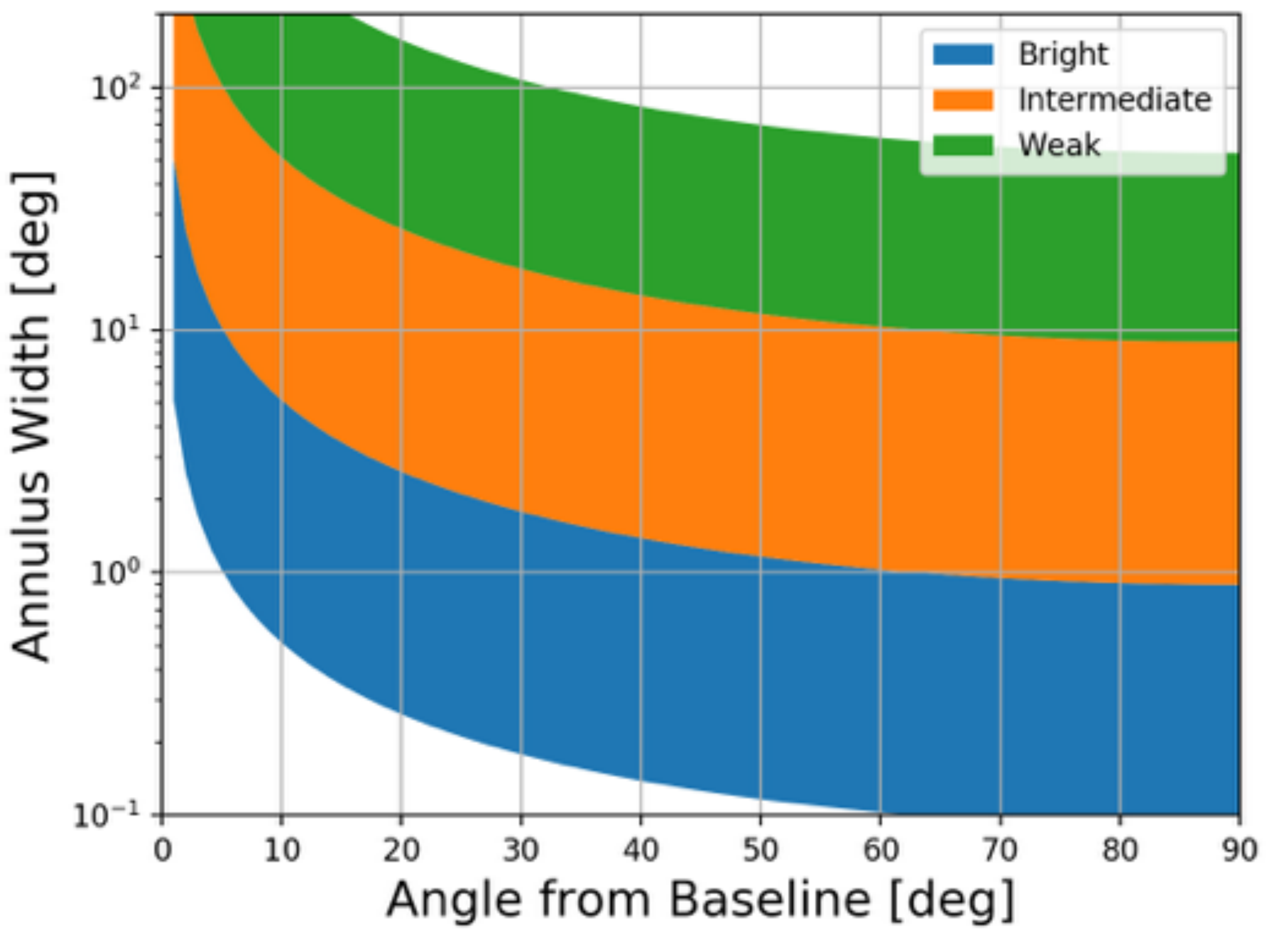


- 12U CubeSAT designed with high TRL components, most are already flight tested.
- 2-year mission duration, 1-year minimum.
- Earth-Moon L3 halo orbit provides a baseline of 0.3-2.1s when paired with an Earth-orbit instrument.
- Science instrument consists of detector modules (NaI scintillation crystal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





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.



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.

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.
- Based on the increased sky coverage at Earth-Moon L3 orbit, detector area and similar onboard detection algorithms as *Fermi*-GBM, **MoonBEAM will detect ~37 short GRBs/year**.
- 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.