SALTUS: A NASA Probe Mission Concept

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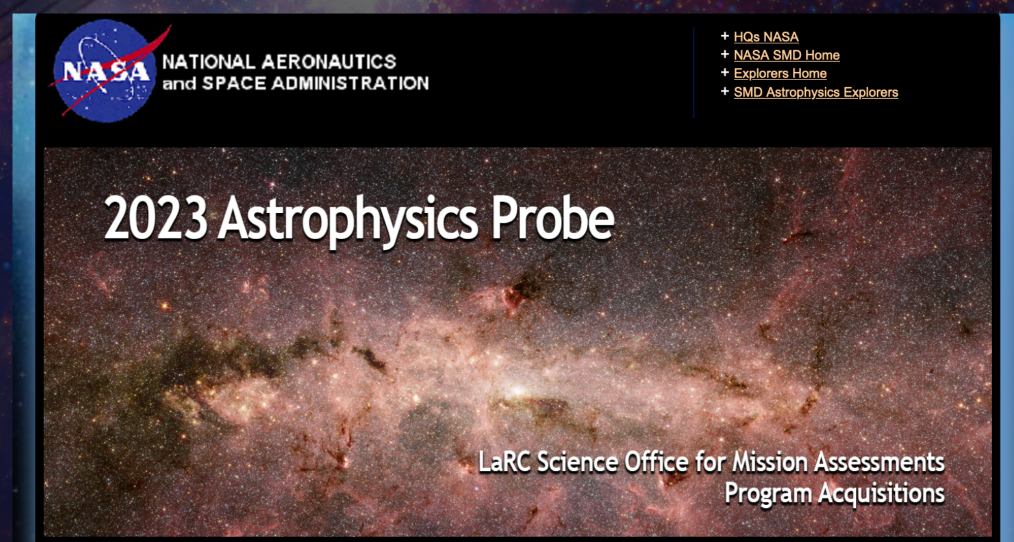
NASA Probe Missions

- NASA's $1B mission class - responding to Astro2020 recommendations
  - Close gap between MIDEX ($300M, once per 4y) and flagship missions (many $B)
  - Specific need for FIR and X-ray missions now
  - One opportunity per decade
- Probe competition schedule
  - Pre-announced in January 2022
  - Draft AO released August 2022
  - Final AO expected: July 2023
  - Proposal deadline (AO + 90days): October 2023
    - Select 2-3 for Phase A study: March 2024
    - Phase A studies due: Early 2025
    - Final selection: Late 2025
  - Launch Readiness: January 2032



FIR Probe - Astro2020

7.5.3.3 A Far Infrared Imaging or Spectroscopy Mission

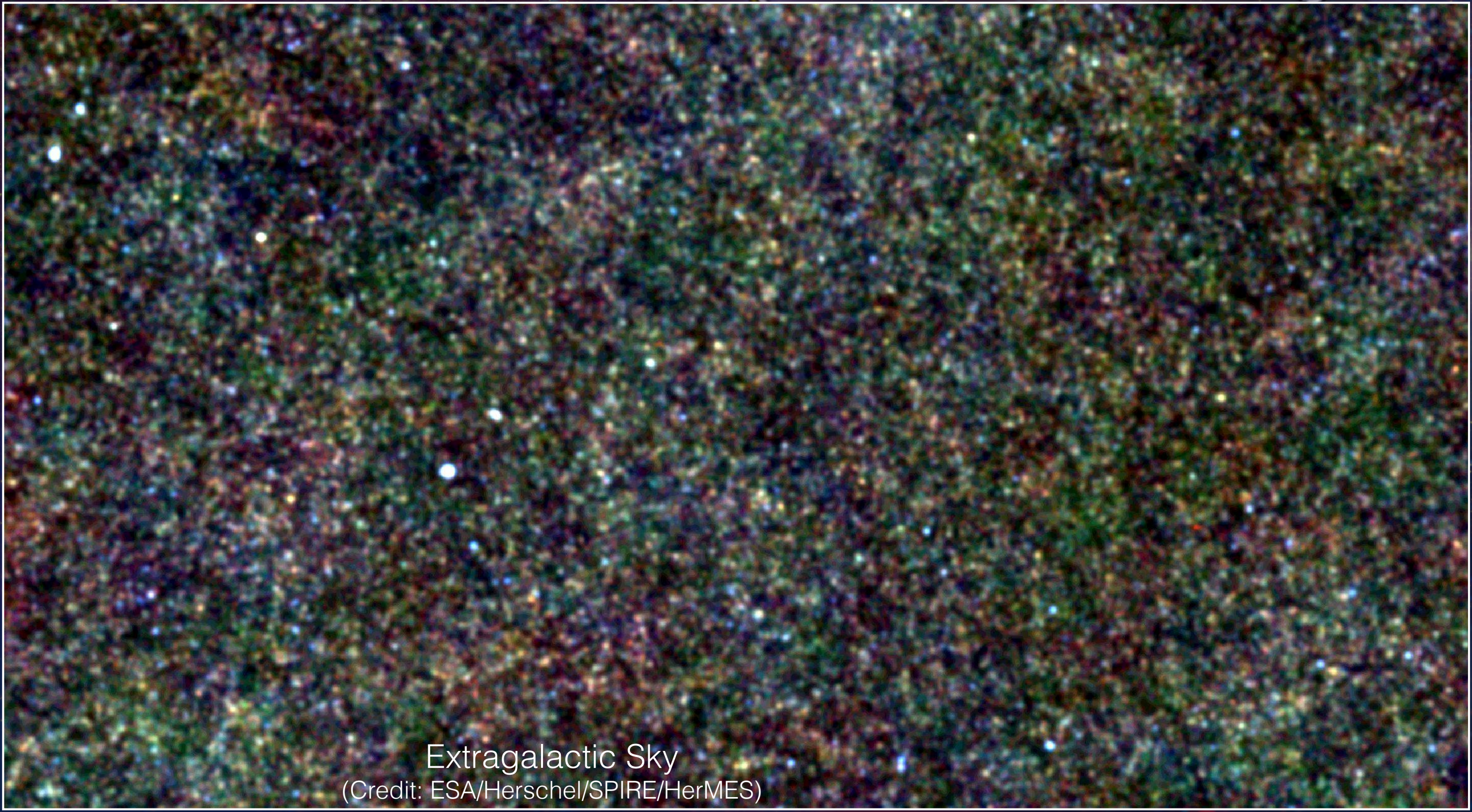
A far-IR imaging or spectroscopy probe mission would address scientific objectives central to Astro2020, and would fill an important gap in world-wide capabilities. Since the EOS-2 report was completed, ESA made the decision to remove the joint ESA/Japan Aerospace Exploration Agency (JAXA) Space Infrared Telescope for Cosmology and Astrophysics (SPICA) far-IR mission from consideration for its M5 slot. SPICA was identified as a priority for NASA participation by Astro2010, would have flown a powerful set of spectrometers covering the 12 – 230 µm range, as well as a mid-infrared imager. SPICA was positioned to make significant progress in a number of the science areas highlighted by this survey. …

The survey committee believes that considering this change in landscape there are many unique opportunities for a properly scoped far-IR probe to advance high priority science, and a probe scale mission is an extremely timely and compelling opportunity to do so. These scientific areas include tracing the astrochemical signatures of planet formation (within and outside of our own Solar System), measuring the formation and buildup of galaxies, heavy elements, and interstellar dust from the first galaxies to today, **and probing the co-evolution of galaxies and their supermassive black holes across cosmic time**. …

- Origins Space Telescope: 4K 5.9m telescope, $10.6B
- Previous state-of-the-art
  - Herschel: 80K 3.5m telescope, 50-500um spectrometers/imagers
  - JWST: 45K 6.5m telescope, <1-28um spectrometers/imagers
- Paths to improved FIR sensitivity:
  - Cold (4K), small telescope
    - Better at surveying, spatially confused
  - Cool (45K), large telescope
    - High spatial resolution, limited blind surveys

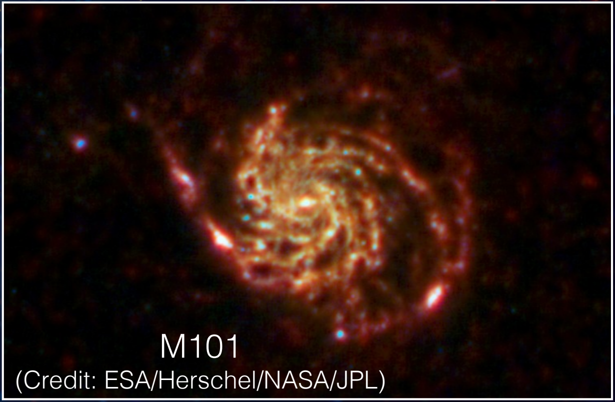
SALTUS: Design Points

- Cool aperture critical for MIR/FIR science
- Large aperture would dramatically improve science opportunities
  - De-confuse sky
  - See faint emission from cool ISM and fine structure lines
  - Provide arcsecond resolution between ALMA and JWST
- Spectroscopy across MIR/FIR with carefully selected observing capabilities



Extragalactic Sky
(Credit: ESA/Herschel/SPIRE/HerMES)

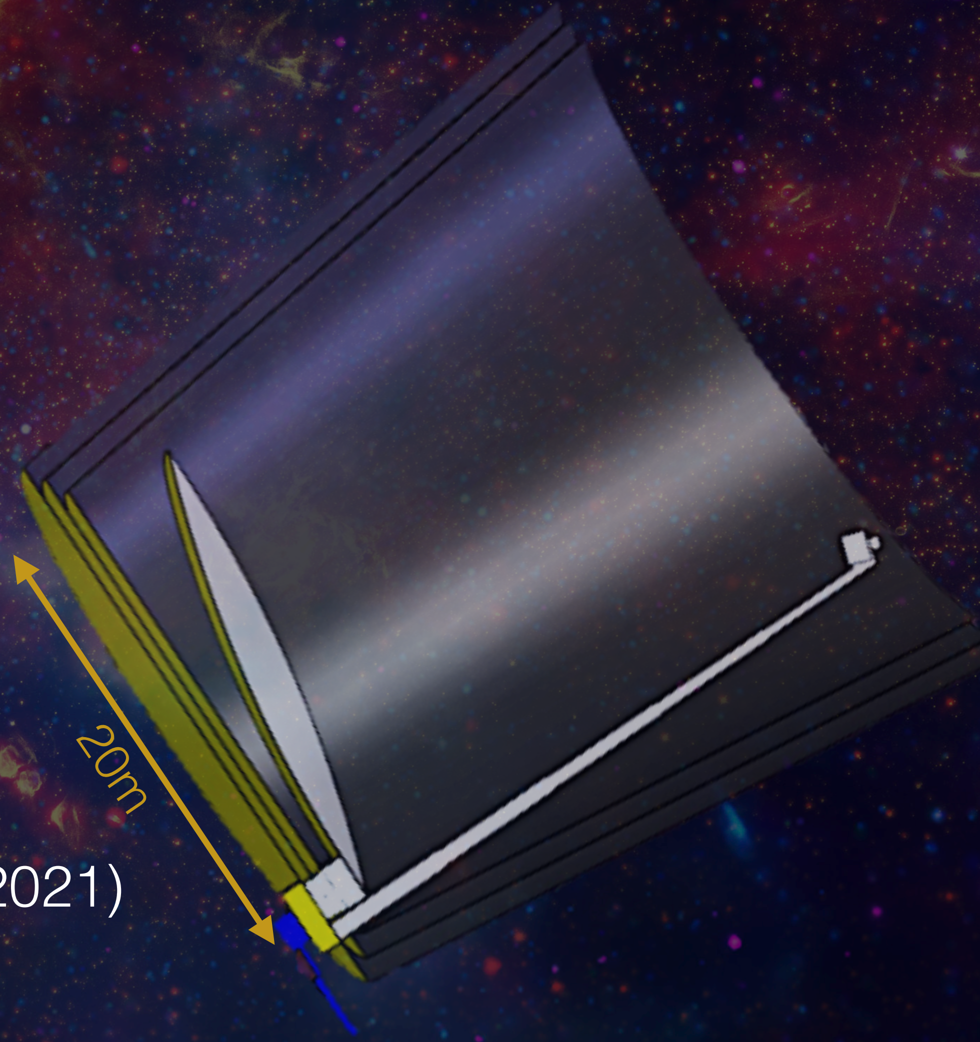
Galactic Center
(Credit: ESA/Herschel/JPL/Hi-GAL)



M101
(Credit: ESA/Herschel/NASA/JPL)

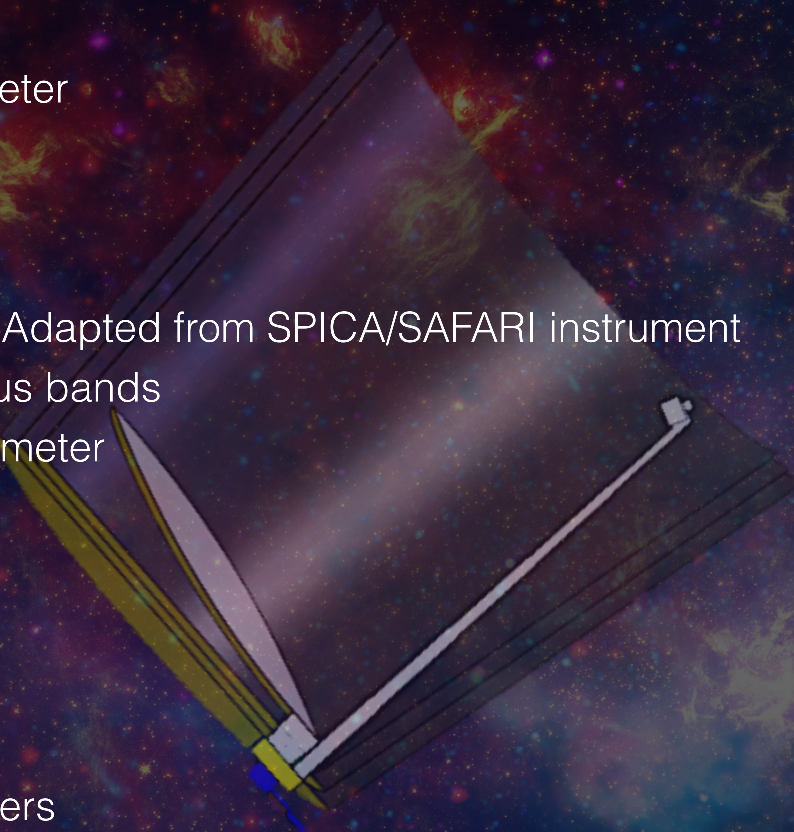
SALTUS

- SALTUS: 20m aperture, passively cooled to ~45K
    - PI: Chris Walker (Arizona)
    - Deputy PI: Dan Marrone (Arizona)
    - Jon Arenberg (Northrop Grumman)
    - Michaela Villareal (Northrop Grumman)
    - Proj Scientist: Gordon Chin (Goddard)
    - Deputy Proj Scientist: Carrie Anderson (Goddard)
    - Science Team Leads
        - Solar System - Carrie Anderson
        - Proto-planetary/ISM - Kamber Schwarz
        - Exoplanets - Carrie Anderson, Jonathan Fortney
        - Extragalactic - Justin Spilker, Suzanne Aalto
        - VLBI - Dan Marrone



- Building on Northrop Grumman + Arizona design/engineering for OASIS MIDEX mission (Submitted Dec 2021)

SALTUS Instruments



Mid-Infrared Spectroscopic Instrument

- 4-15 um
- R~600 grating spectrometer
- HgCdTe detector arrays

SAFARI-Lite

- SRON/Peter Roelfsema, Adapted from SPICA/SAFARI instrument
- 30-240um, 4 simultaneous bands
- R~3-600 grating spectrometer
- MKID detector arrays

HEB Heterodyne Array

- 60-300 um
- R = 10^5-10^6
- 8 x 7 pixel HEB DSB mixers

Multiband VLBI Instrument (MuVI)

- 90/230/345 GHz
- **Simultaneous tri-frequency VLBI**
- SIS mixers and LNAs

FIR = Far Infrared

VFIR = Very Far Infrared?
FrIR = Farther Infrared?
“Far Infrared”
FIR_u

SALTUS MuVI

Multiband VLBI Instrument (MuVI)

Simultaneous three-frequency VLBI

90/230/345 GHz: MMIC / SIS / SIS

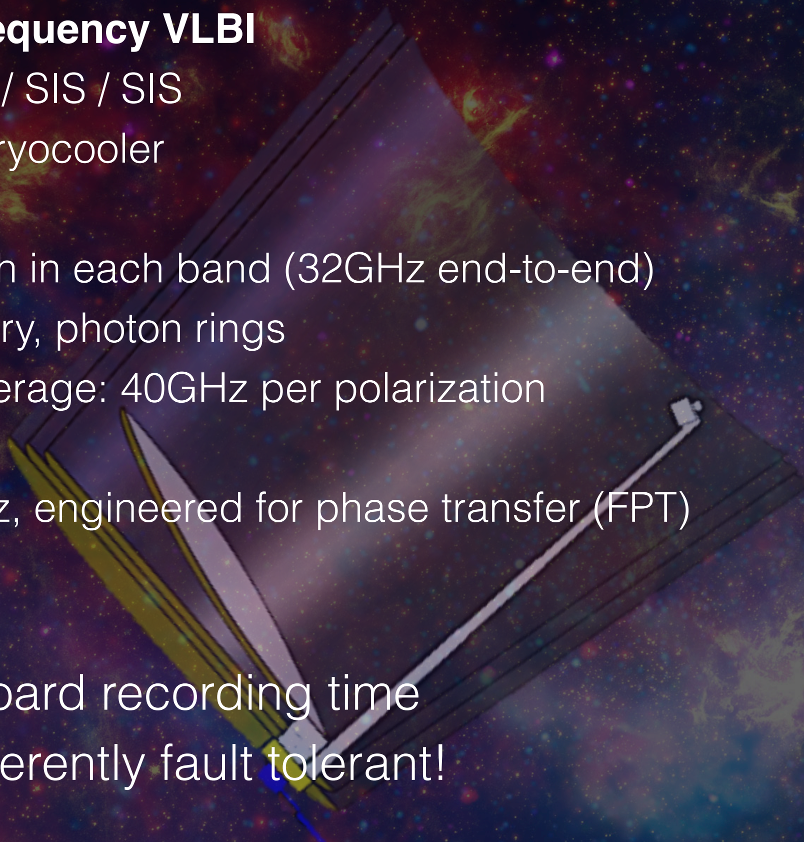
Simplified JWST MIRI Cryocooler

Wide spectral bandwidth in each band (32GHz end-to-end)

Critical for polarimetry, photon rings

Total sky frequency coverage: 40GHz per polarization

Fringe-finding at 90 GHz, engineered for phase transfer (FPT)



Up to 8 hours of on-board recording time

VLBI raw data: inherently fault tolerant!

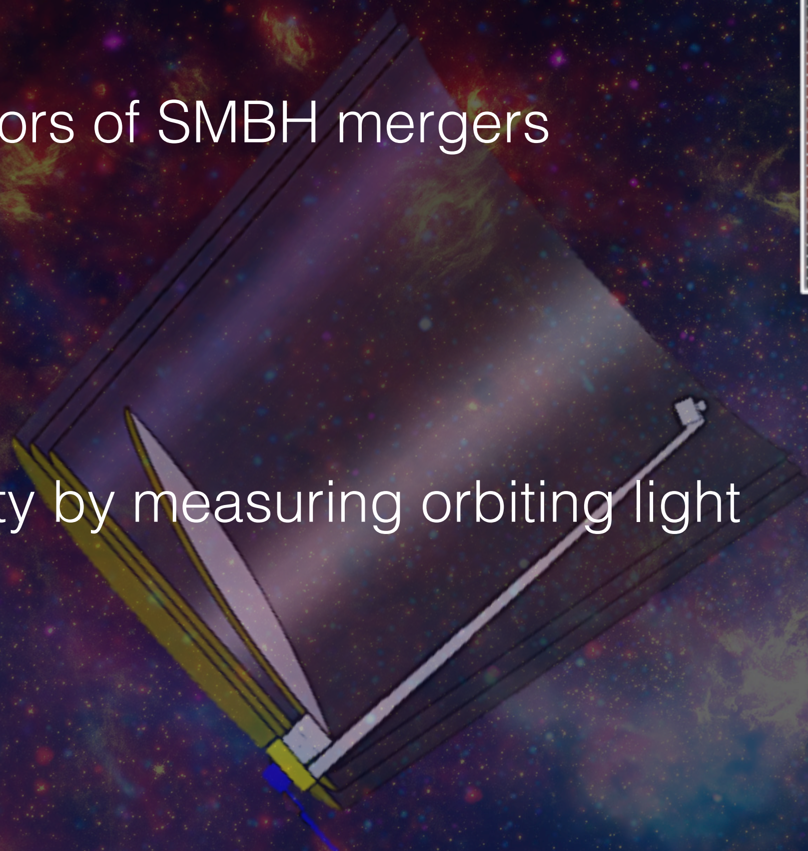
Transmission to ground over days (target rate: 10Gbps = 16h transmission time)

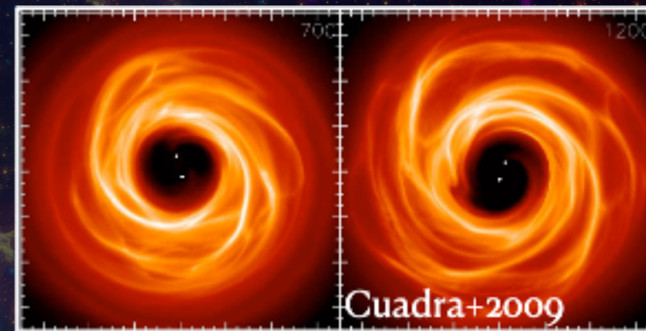
Laser link would be nice, plausibly unnecessary

20m aperture could downlink at this rate to beyond lunar distance in standard K-band link to DSN

SALTUS VLBI Science

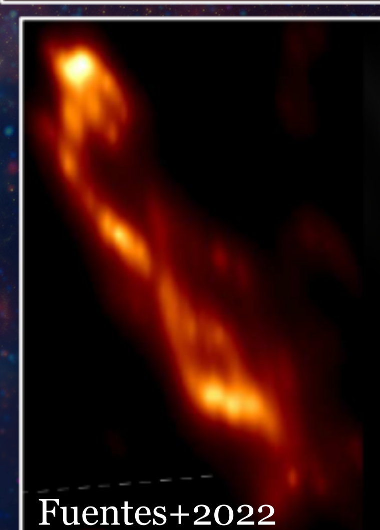
- Observe the precursors of SMBH mergers
- Test General Relativity by measuring orbiting light
- Reveal the acceleration sites of UHE neutrinos and the launching structures of relativistic jets





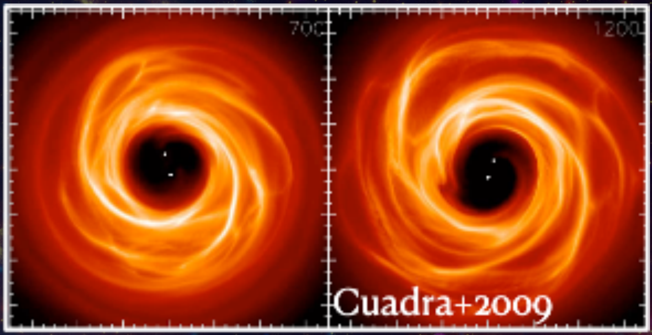
Cuadra+2009

Gralla+2020

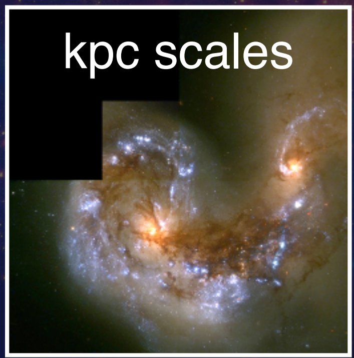


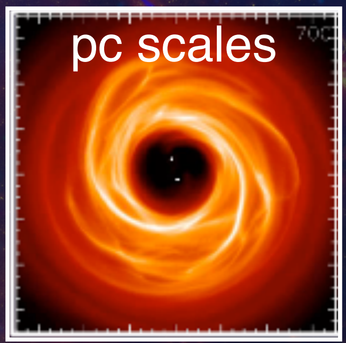
Fuentes+2022

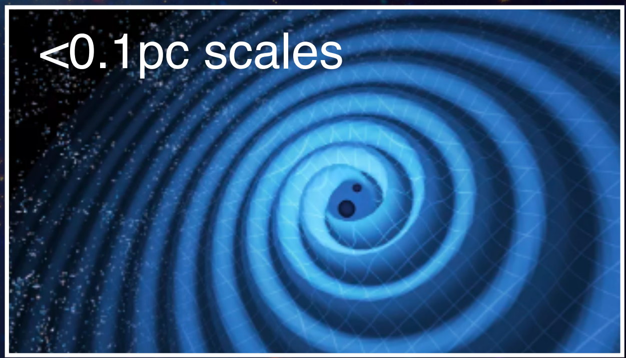
SALTUS VLBI Science



- Observe the precursors of SMBH mergers
  - BH growth identified as a critical research topic in Astro2020
  - Large multi-snapshot BH survey
  - (BH mass census for free)
  - Counting binary black holes (BBHs) at microarcsecond separations
    - GW-driven model estimates 10% of massive galaxies (5-10k) at z<0.05 have BBH







SALTUS VLBI Science

- Test General Relativity by measuring orbiting light
  - See yesterday's photon ring talks
  - n=2 ring particularly powerful: GR-predicted diameter is 3-parameter family of curves independent of spin

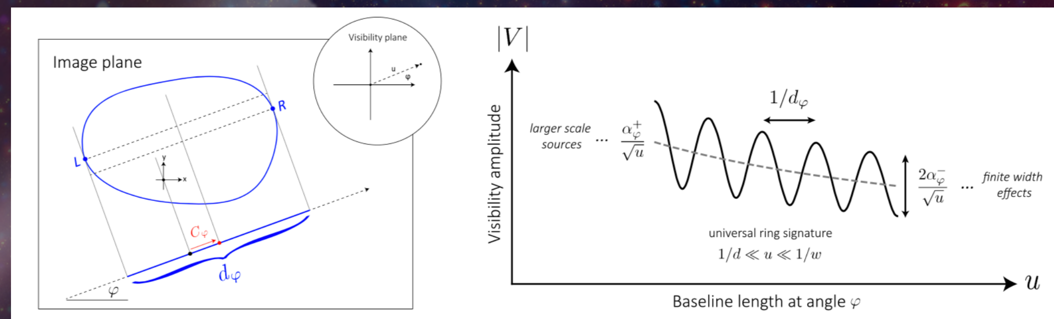
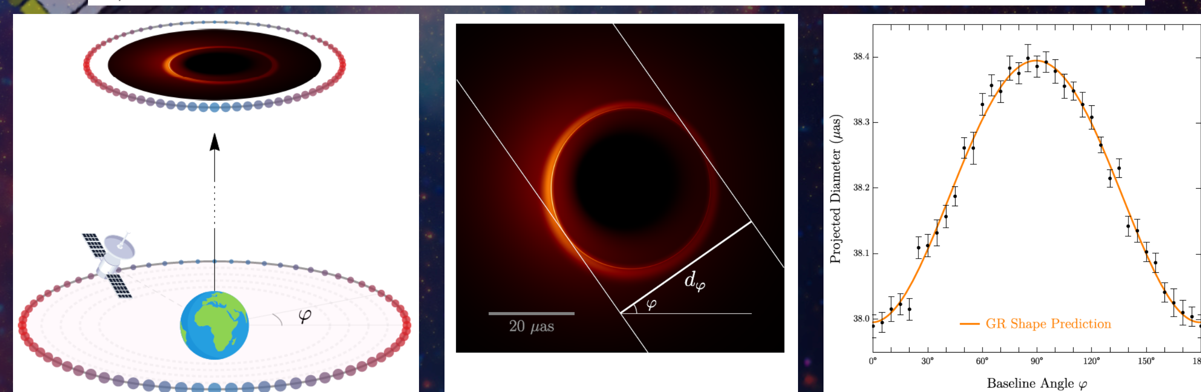


FIG. 1. A sky intensity narrowly peaked around a closed convex curve of typical diameter d and width w has a universal interferometric signature on baselines $1/d \ll u \ll 1/w$. At each angle φ, the periodicity $1/d_\varphi$ in the visibility amplitude encodes the projected diameter d_φ, while the maximum and minimum values encode the intensity at the edge points L and R. The projected centroid C_φ is contained in the full complex visibility.



Gralla, Lupsasca, Marrone 2020

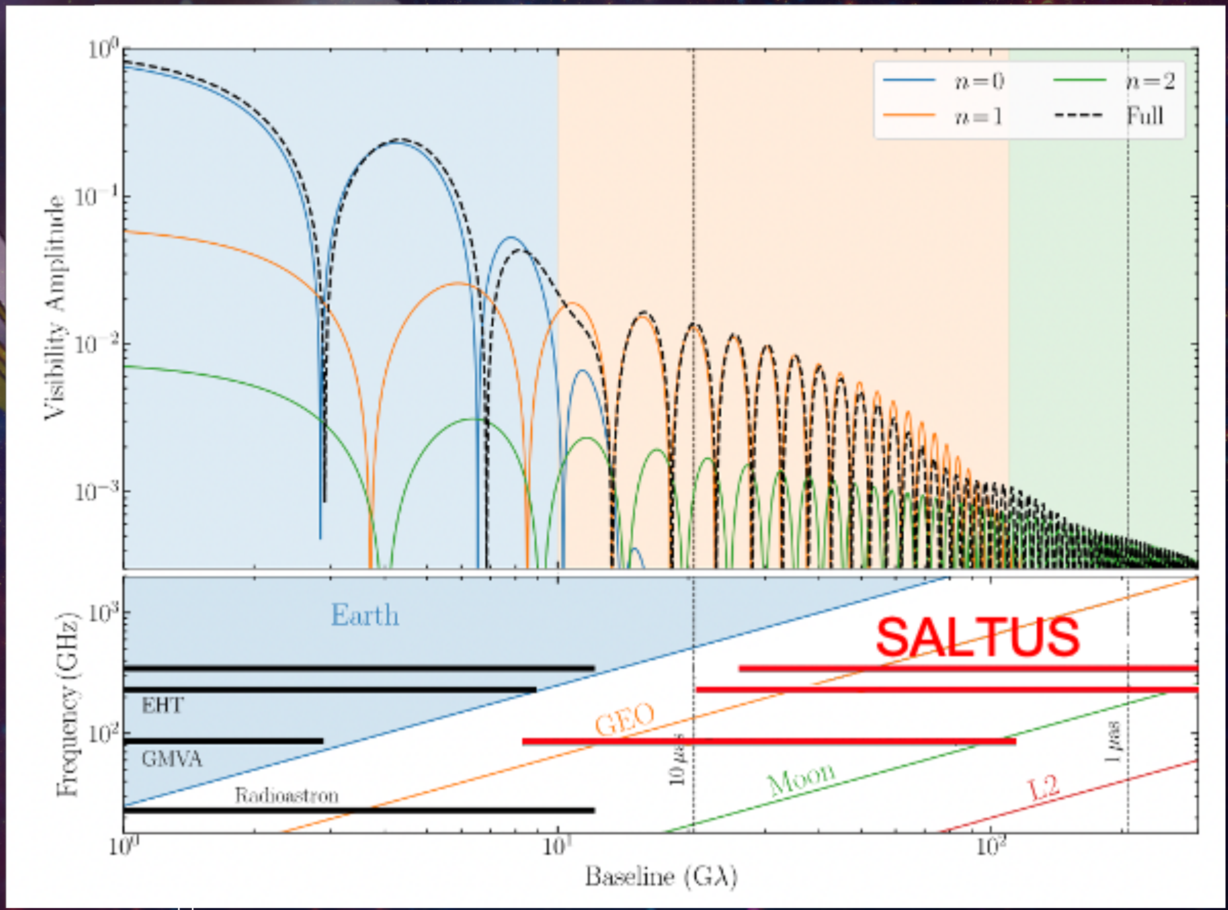
SALTUS VLBI Science

- Test General Relativity by measuring orbiting light
  - See yesterday's photon ring talks

Gralla+2020

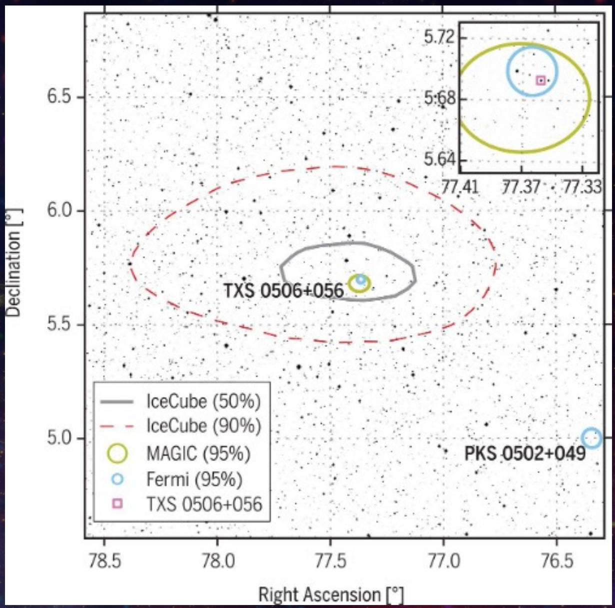
  - n=2 ring particularly powerful: GR-predicted diameter is 3-parameter family of curves independent of spin

  - n=1 and n=2 ring within reach



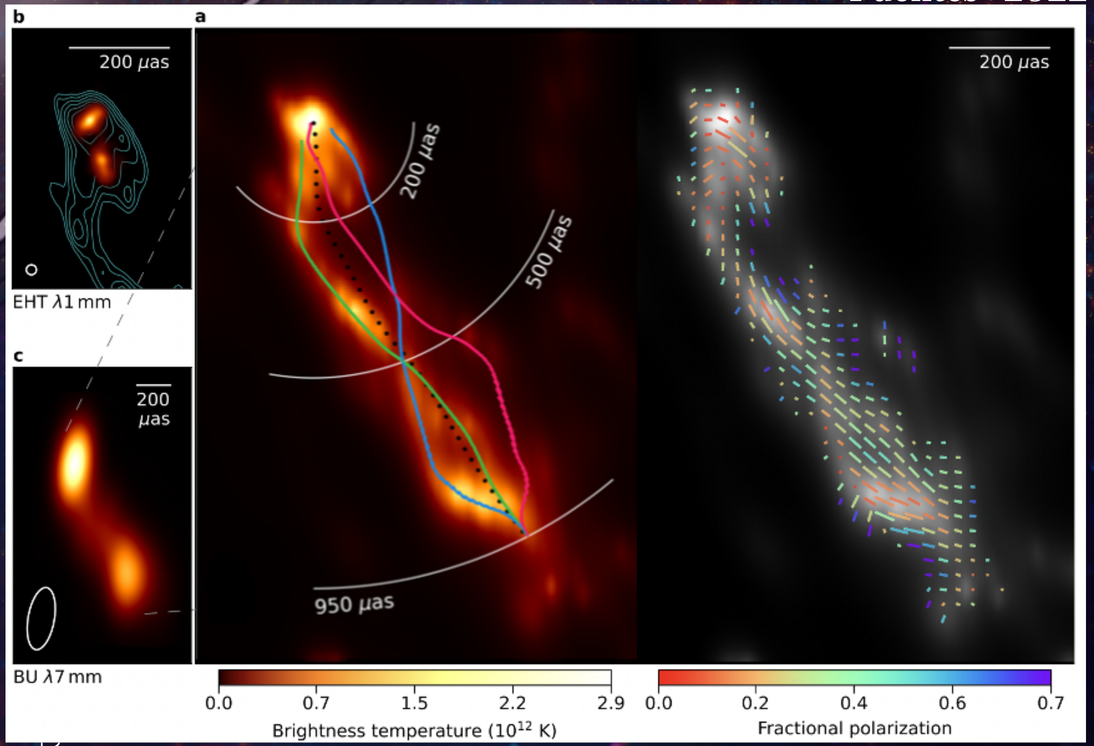
SALTUS VLBI Science

IceCube Collab+ 2018, *Science*



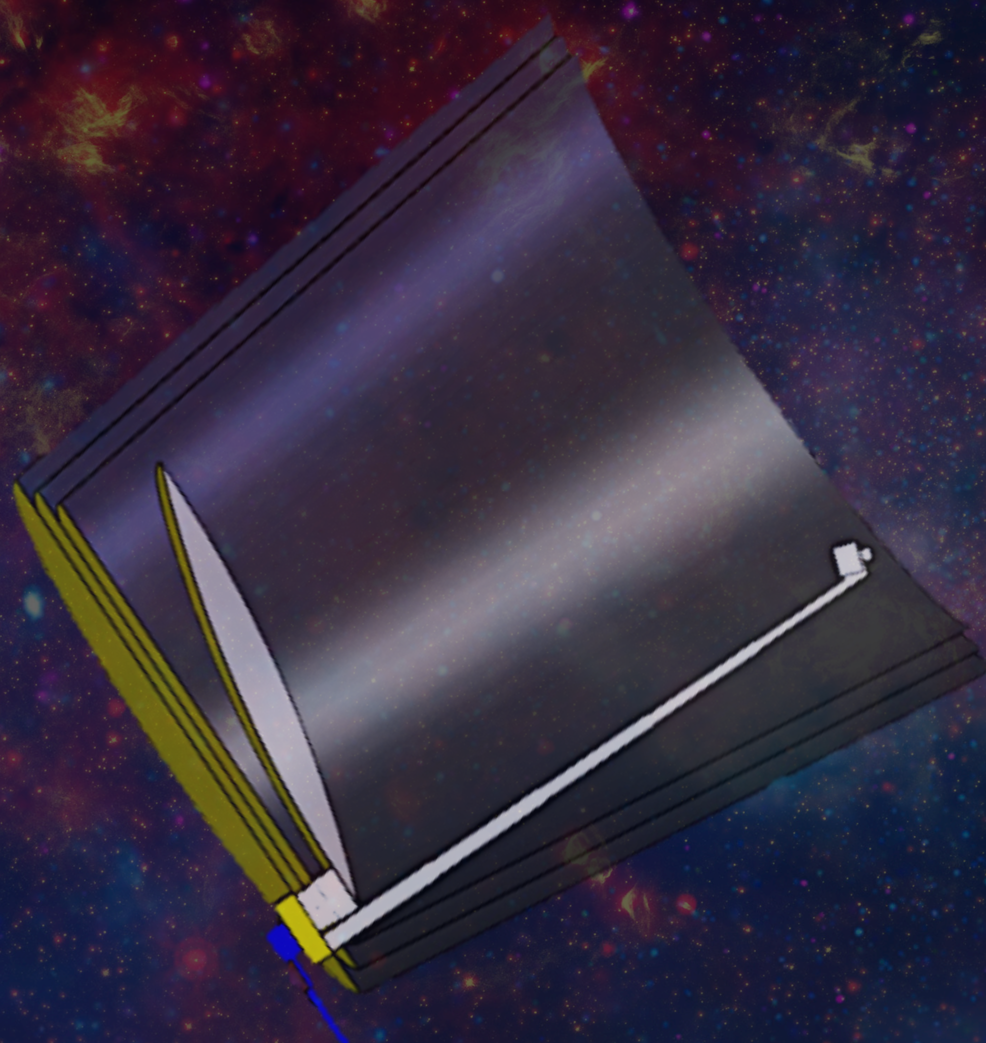
- Reveal the acceleration sites of UHE neutrinos and the launching structures of relativistic jets
  - Astro2020: The formation, collimation, and acceleration of relativistic BH jets remains incompletely understood
  - Multimessenger astrophysics is "discovery area" for decade
  - Resolving jet structures
  - Identifying particle accelerating knots
  - Mapping magnetic structure through and along jets with wideband pol/FR

Fuentes+2022



SALTUS Telescope

- SALTUS: 20m aperture, passively cooled to ~45K



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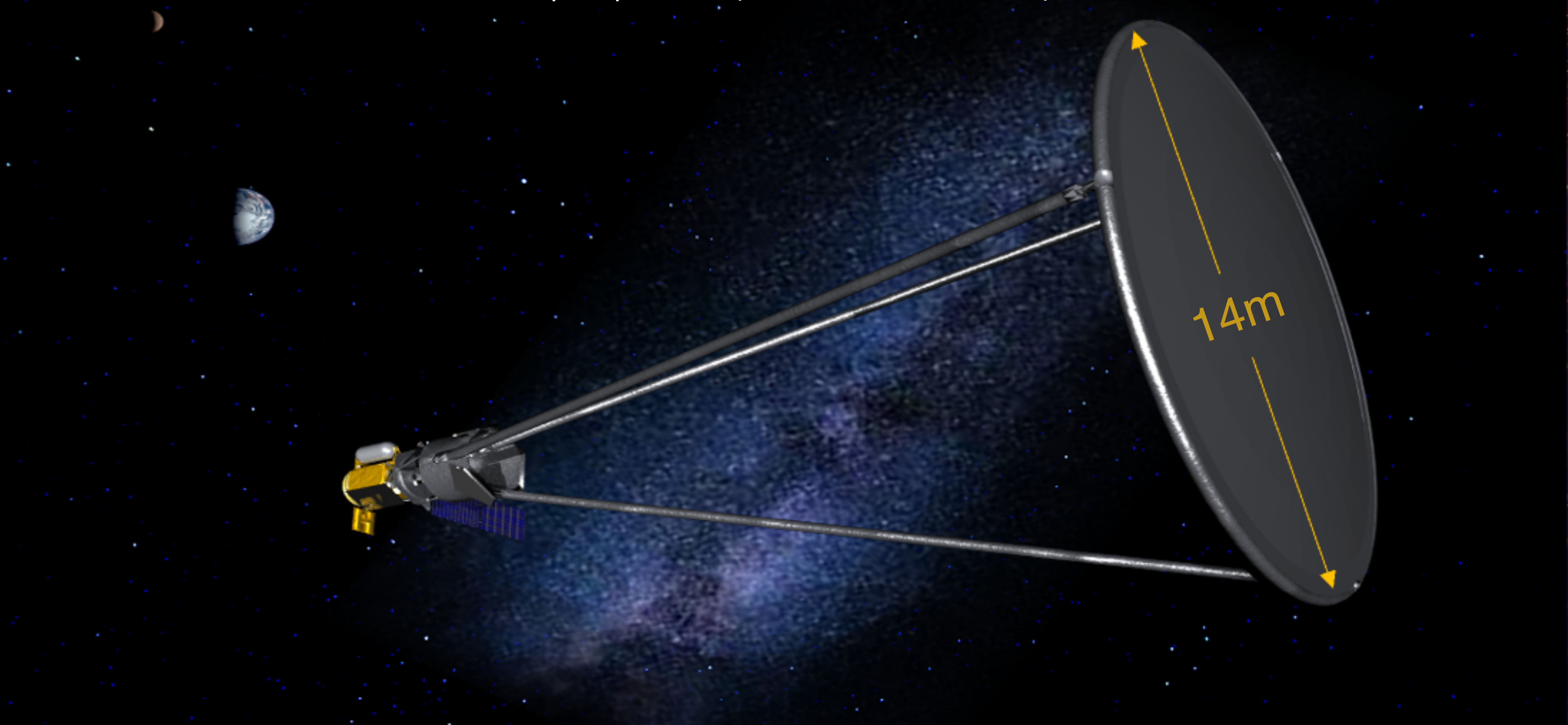

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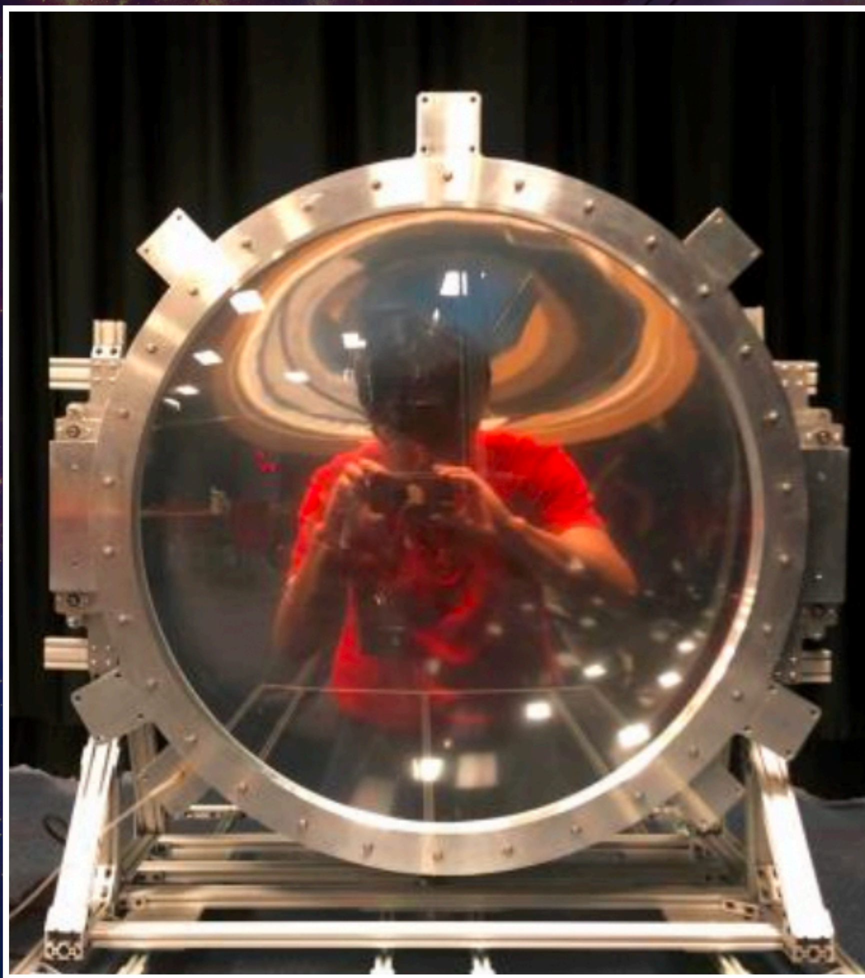
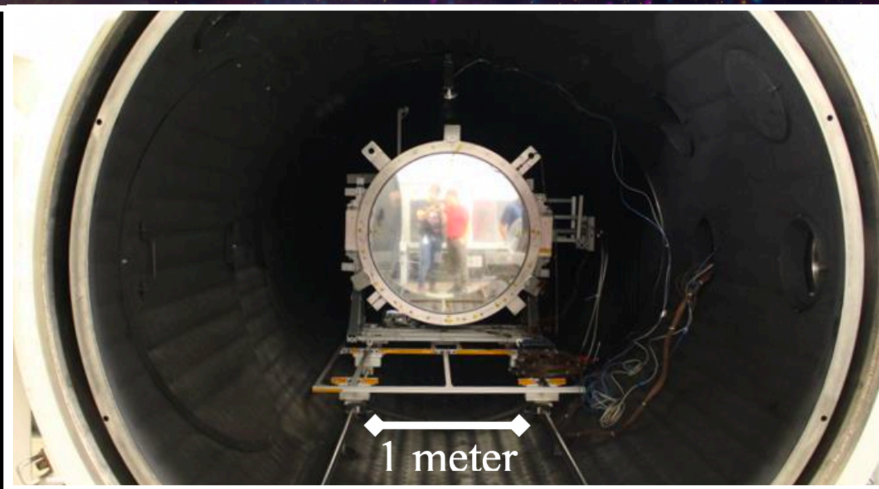
SALTUS Telescope

- SALTUS: 20m aperture, passively cooled to ~45K
- Based on OASIS MIDEX proposal (submitted 2021)
- Based on 1996 Inflatable Aperture Experiment
  - Advanced through 25 years of technology development (e.g., Quach+21, SPIE)





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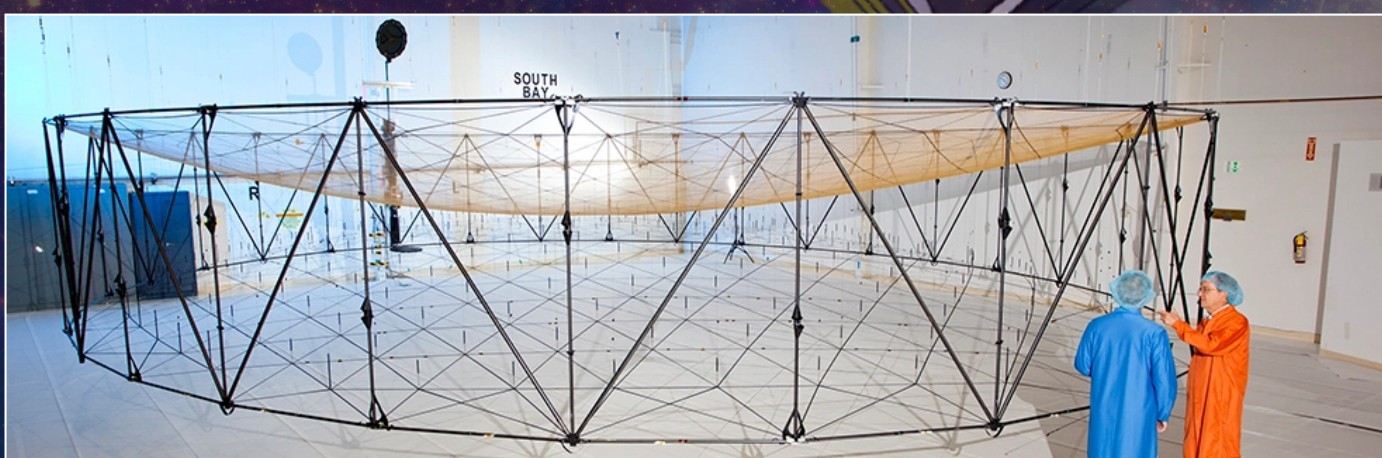
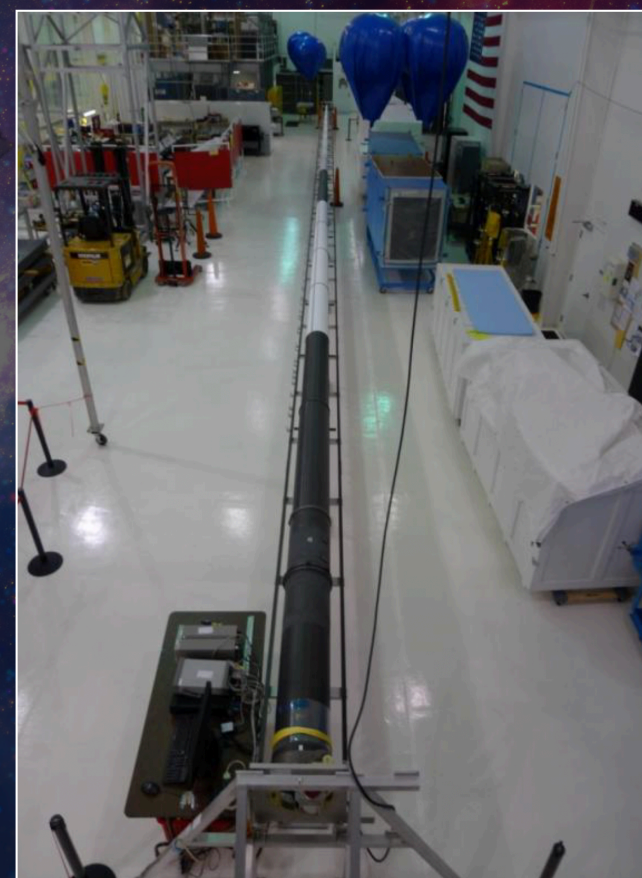
- Further development via NASA Strategic Astrophysics Technology program (see Kurczynski talk)
  - Must reach TRL 6 by Mission PDR (Phase B)
    Conveniently at end of proposed 3y grant

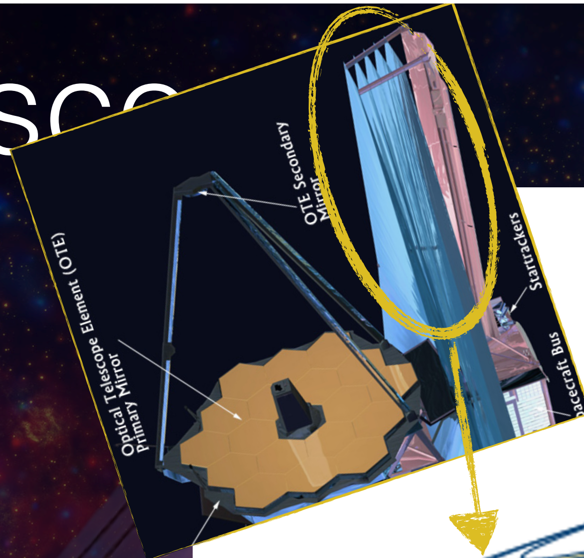


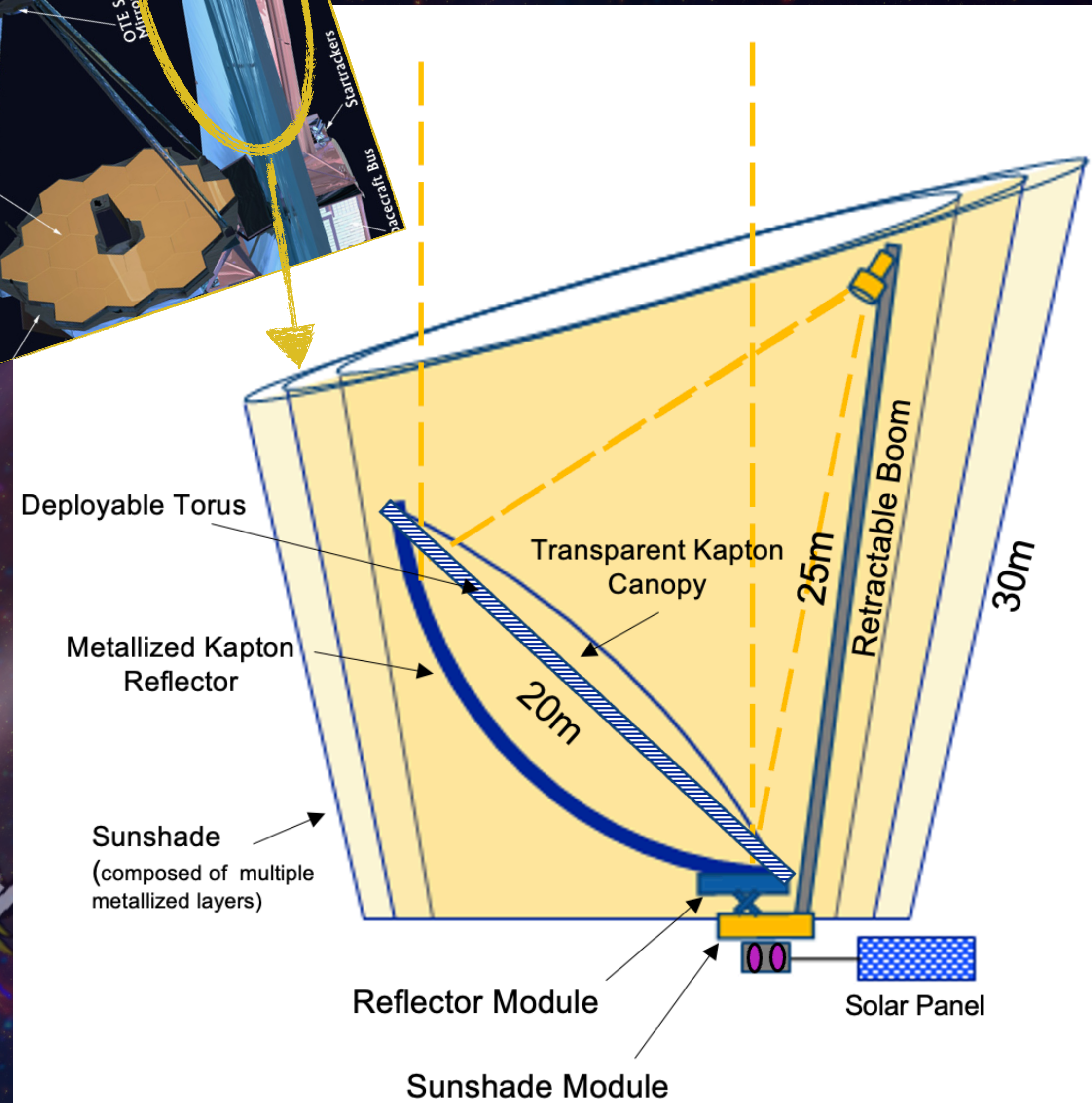


Northrop-Grumman

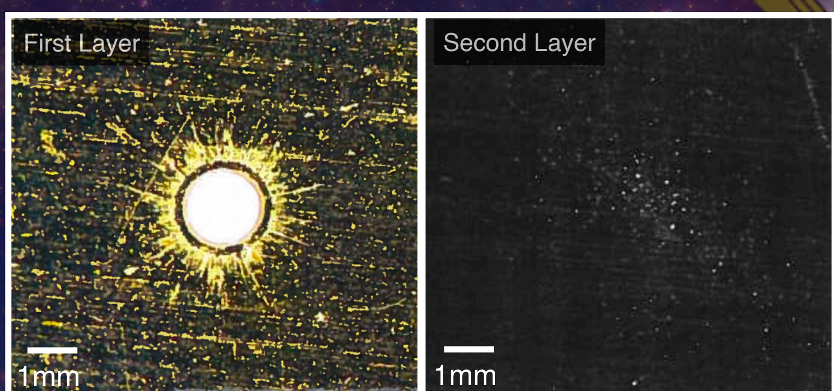
SALTUS Telesco

- Sunshade
  - 5-7 thin layers of thin film
  - Micrometeoroid ablation and thermal insulation
  - Extends life and enables FIR science





Micrometeoroid ablation testing



500x decrease in puncture area in 1 layer

Villarreal, Arenberg, Harris 2022

SALTUS Telescope

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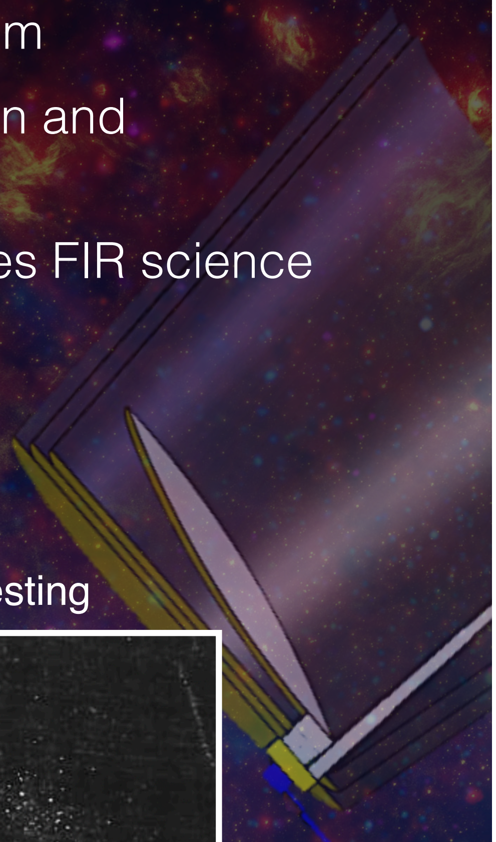

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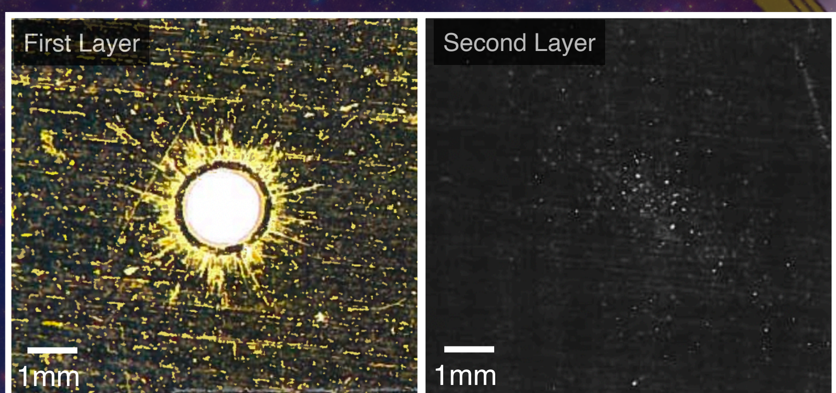

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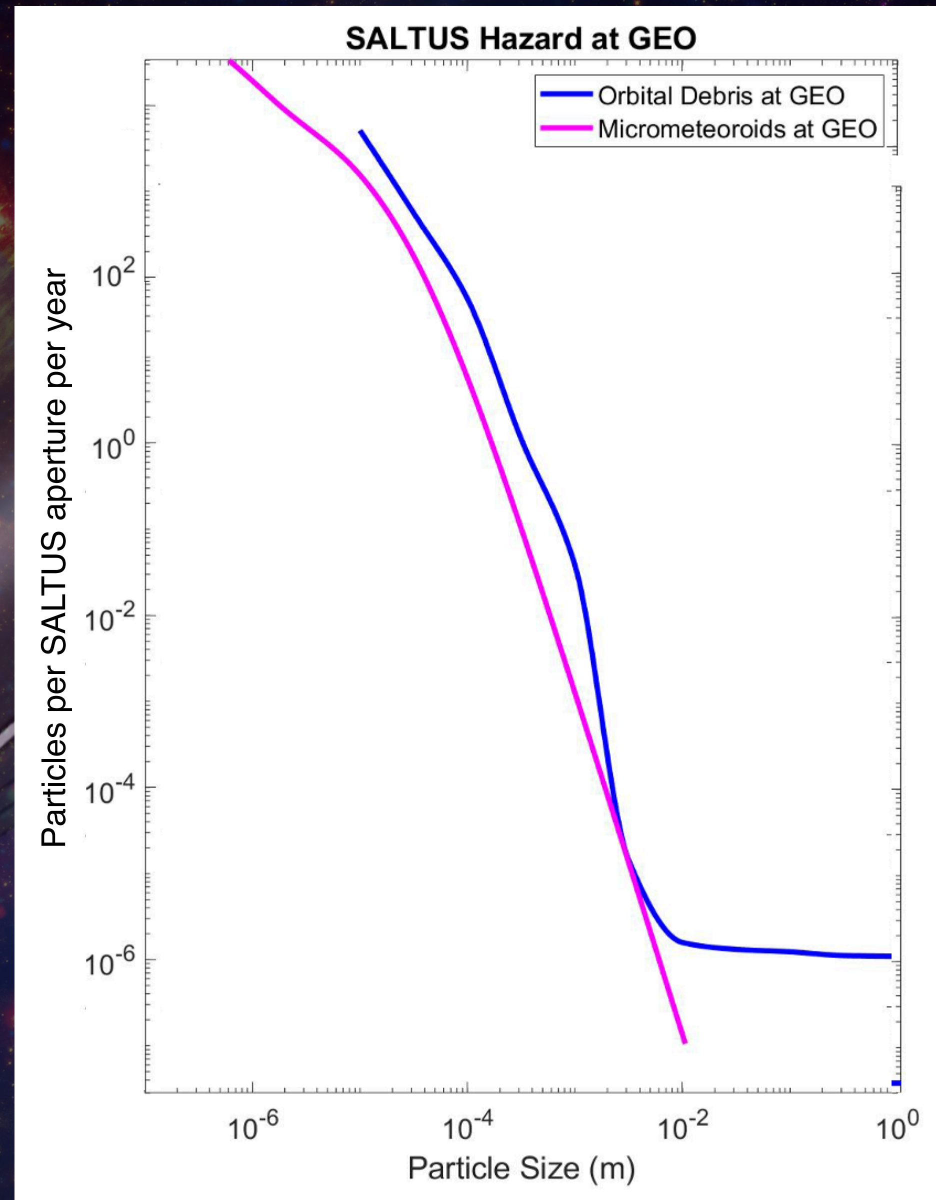
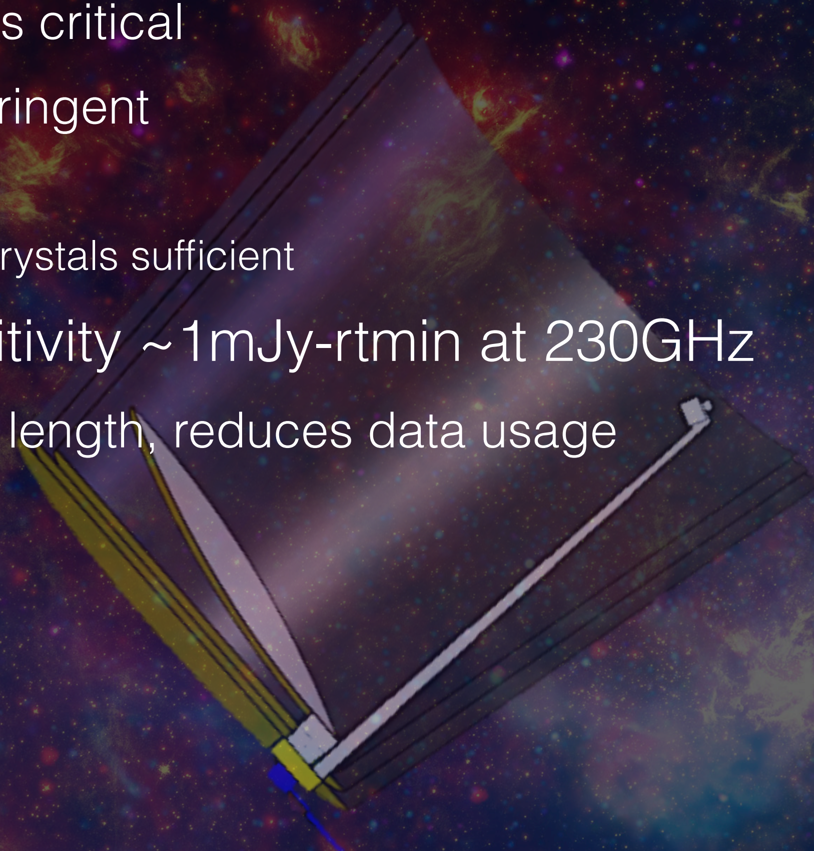


Preliminary micrometeoroid flux estimate

Life is better with 20m!

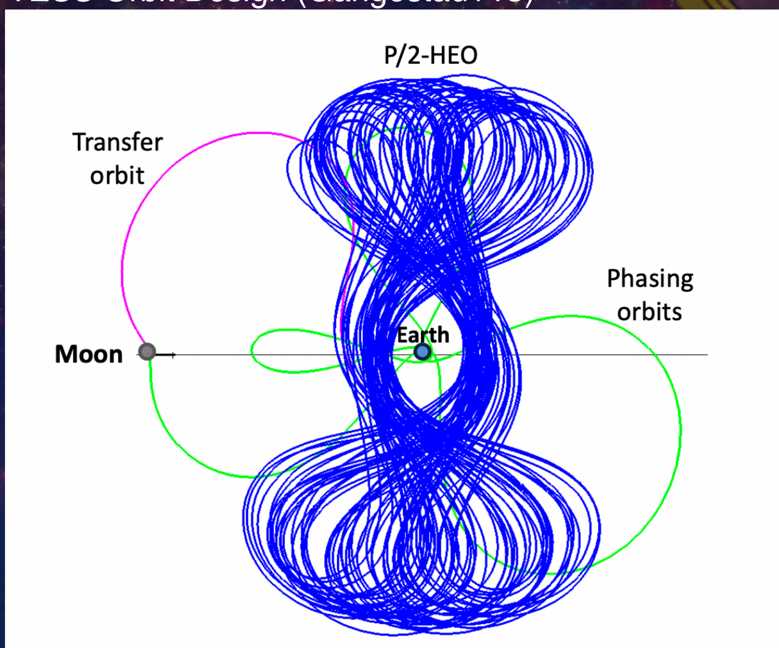
- Coherent integrations can be shorter
  - Orbital metrology less critical
  - Timing needs less stringent
    - Also aided by FPT
    - Commercial quartz crystals sufficient
- ALMA-SALTUS sensitivity ~1mJy-rtmin at 230GHz
  - Shortens “snapshot” length, reduces data usage



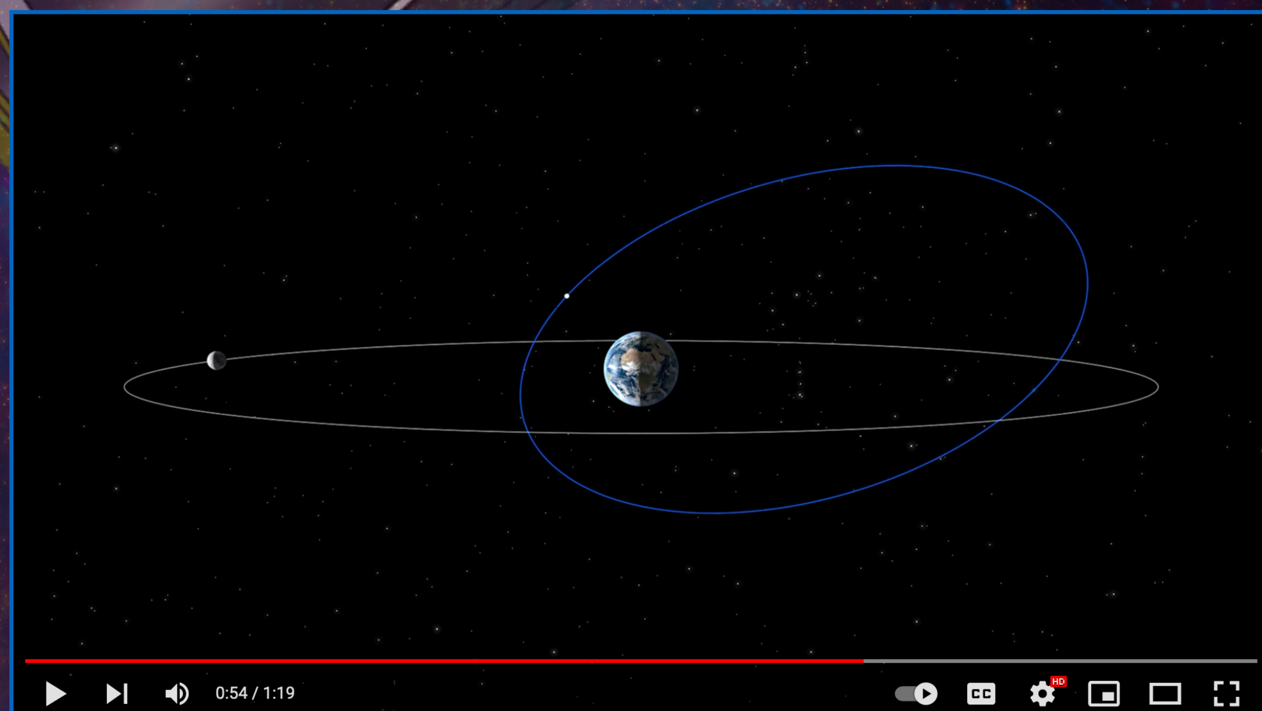
SALTUS Orbit

- 2:1 Lunar resonant orbit (13.7d period)
  - TESS orbit: perigee/apogee:17/59 R_E (Perigee range 7-20R_E), Inclined ~40deg
- SALTUS: 45-440k km
  - **VLBI Zoom lens!**
  - 4-40x EHT resolution
  - Short projected baselines at track-length perigee passage

TESS Orbit Design (Gangestad+13)



(a) P/2-HEO in Earth-Moon rotating frame.



SALTUS Team

- A possible express route to millimeter space VLBI

- Science/technology help useful! Join us!