

Key Technology and Capabilities for the 2030s and Beyond

ASTRA

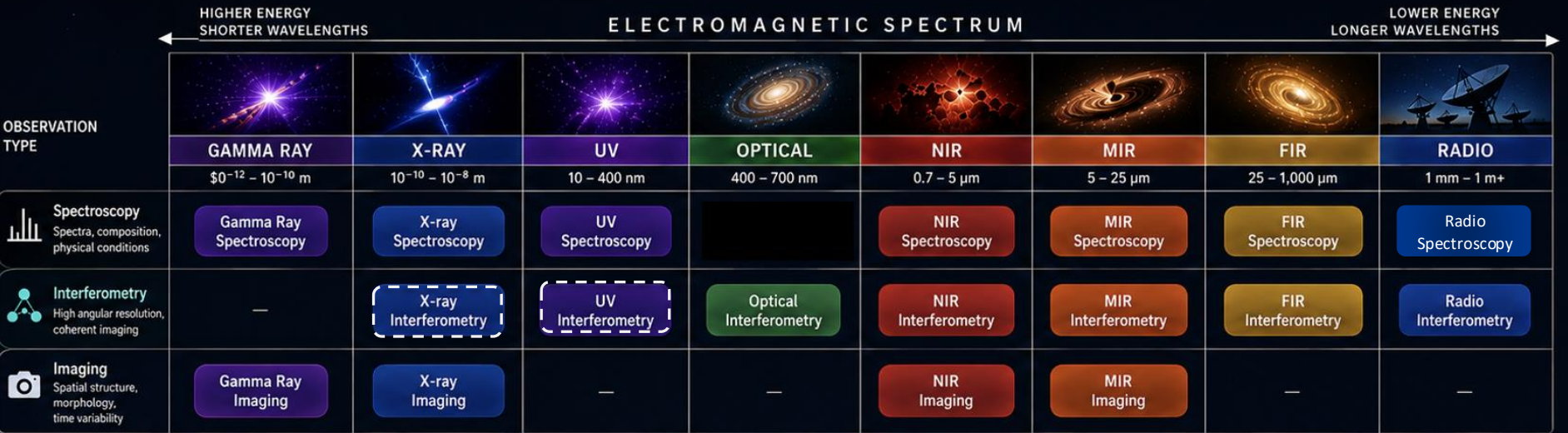
Meredith A. MacGregor

Vera C. Rubin Associate Professor, Johns Hopkins University
Department of Physics and Astronomy



ASTROPHYSICS MISSION ARCHITECTURES ACROSS THE SPECTRUM

EXPLORING THE UNIVERSE WITH COMPLEMENTARY TECHNIQUES AND INNOVATIVE ARCHITECTURES





CMB POLARIZATION
Primordial universe, fundamental physics



GRAVITATIONAL WAVES
Compact objects, extreme physics



COSMIC RAYS
Transients, particle acceleration



NOVEL ARCHITECTURES
Deployable and fluidic apertures, starshade, servicing, etc.

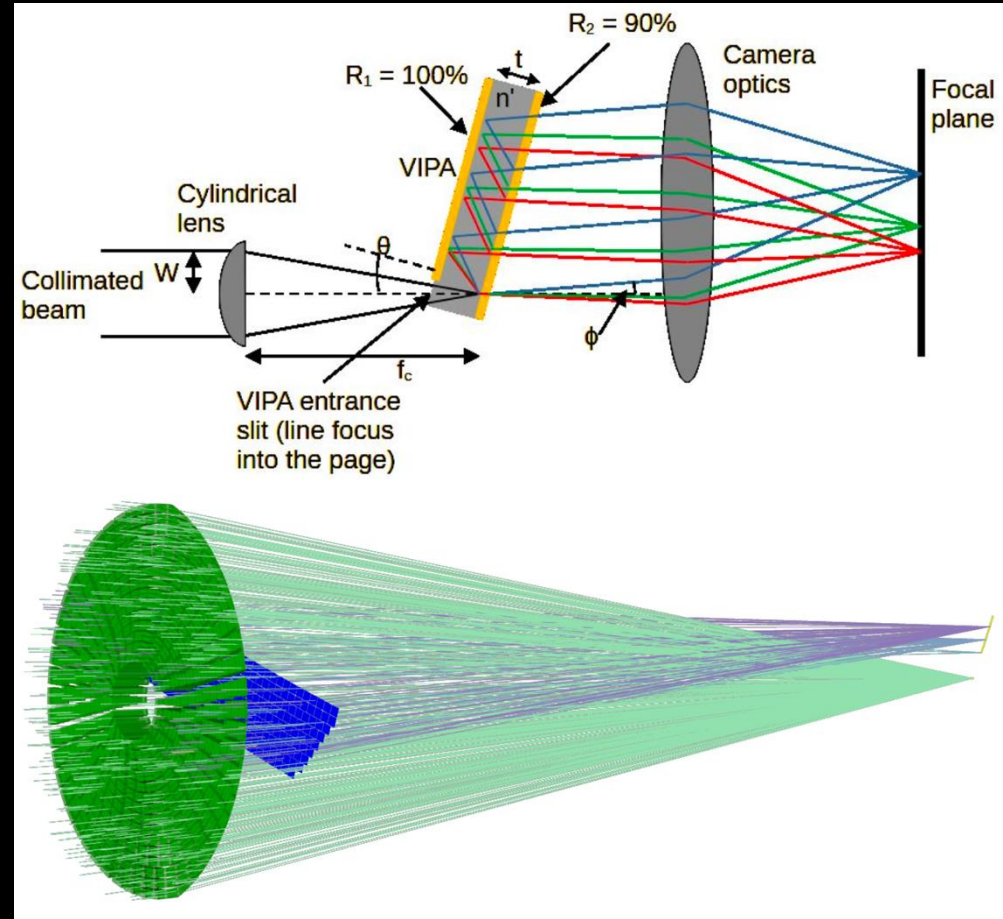


CONSTELLATIONS OF SMALL APERTURES
Formation flying, disaggregated observatories, multi-wavelength or messenger

Spectrometry

Numerous science cases and submitted ASTRA concepts require high spectral resolving power ($R > 10,000$). Novel technologies enable this in smaller packages:

- High-Resolution Dispersers (Etalons, VIPAs, Echelles, LFCs, Photonics)
- Diffraction Gratings / GRISMs / Immersion Gratings

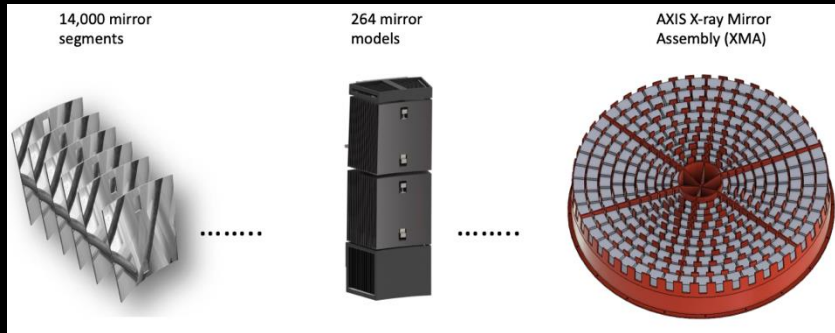


Wide Field Imaging and/or High Spatial Resolution

High Spatial Resolution

High surface-accuracy, deployable primaries, fluidic mirrors, etc.

Super-resolution imaging (Spatial mode demultiplexing)



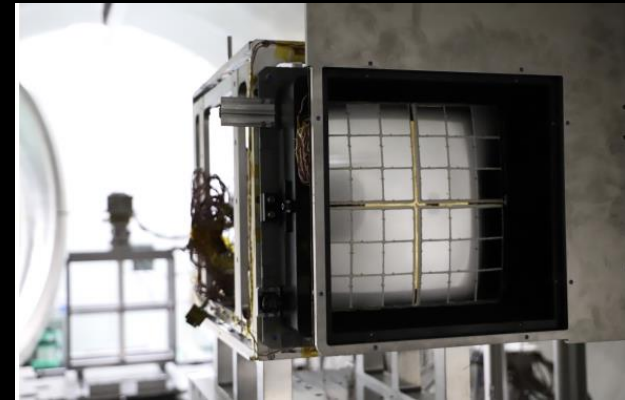
Credit: Reynolds+ (2023)

Wide Field Imaging

Ultra-wide field imaging

Fast mapping

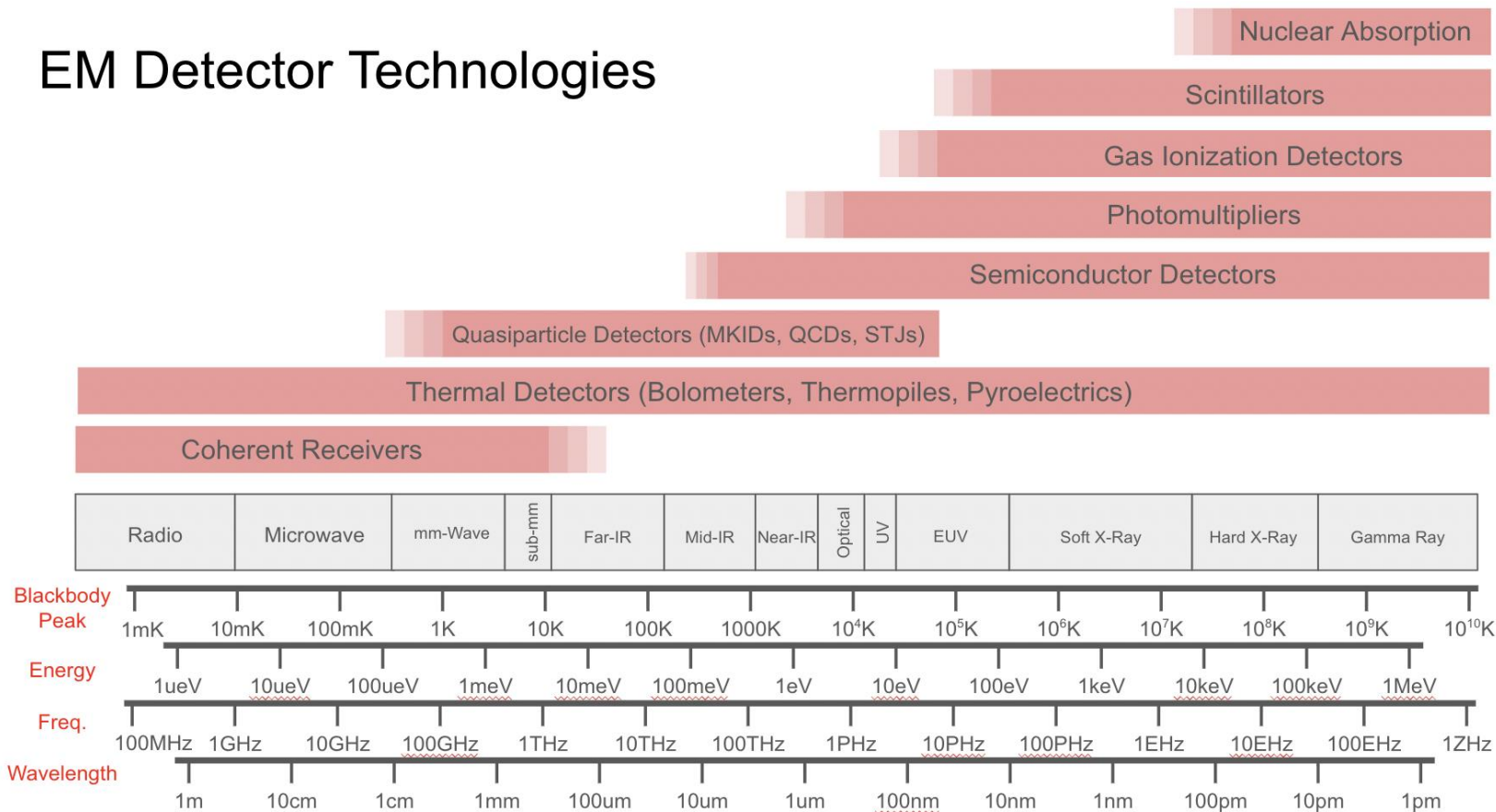
Integral field / multi-object spectroscopy



Credit: Zhang+ (2022)

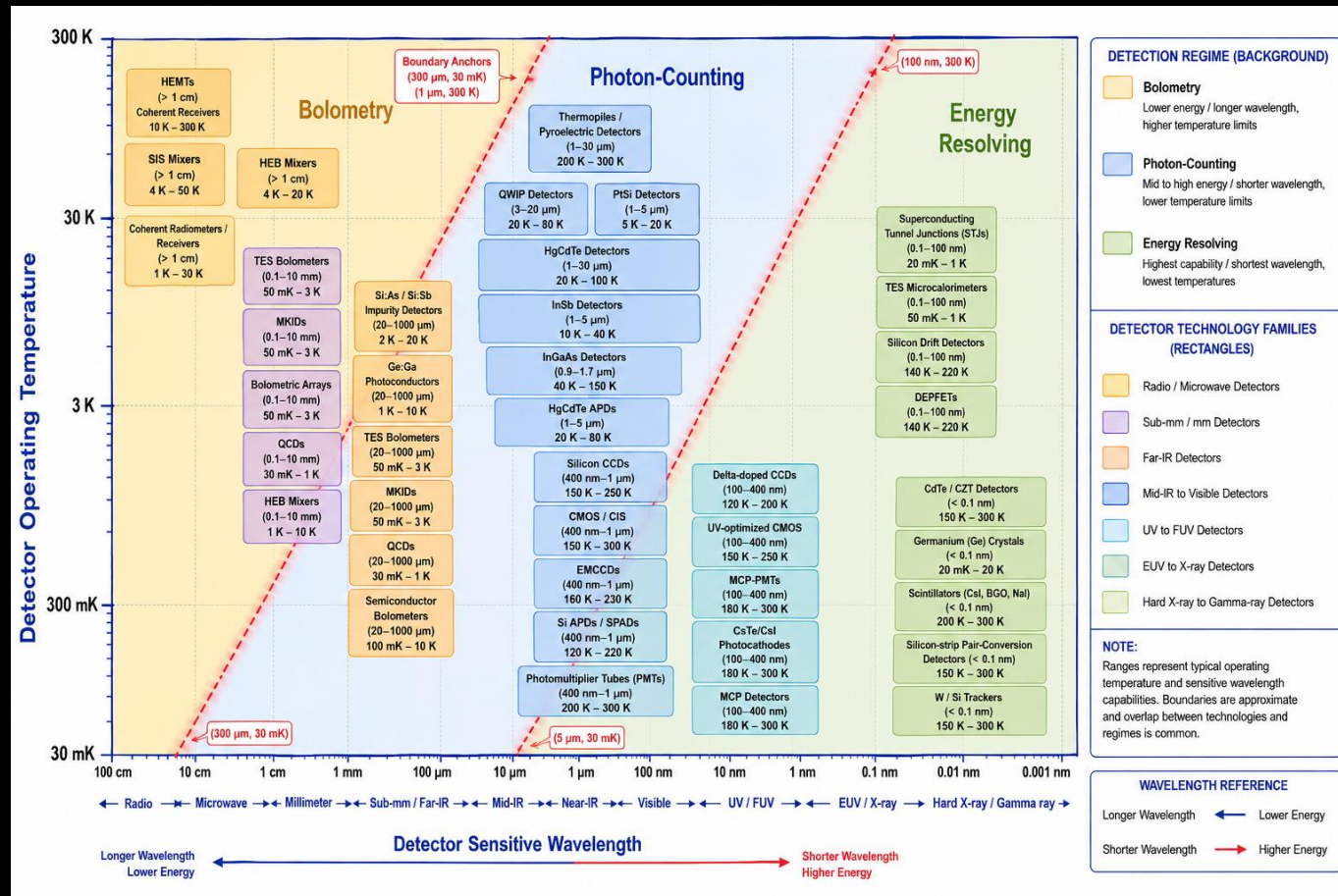
Novel Detectors

EM Detector Technologies



Novel Detectors

Work ongoing to push lines separating regimes to higher temperatures and longer wavelengths



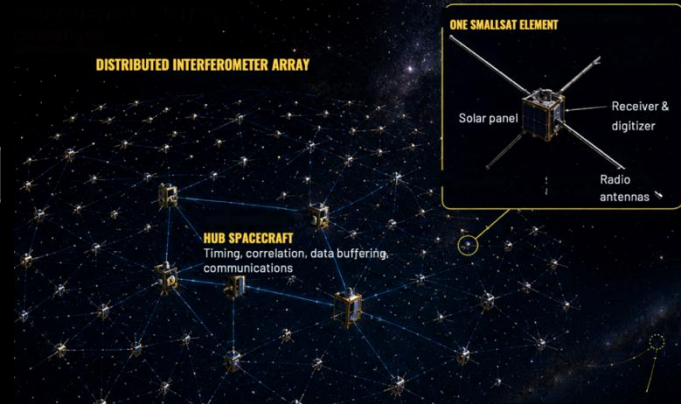
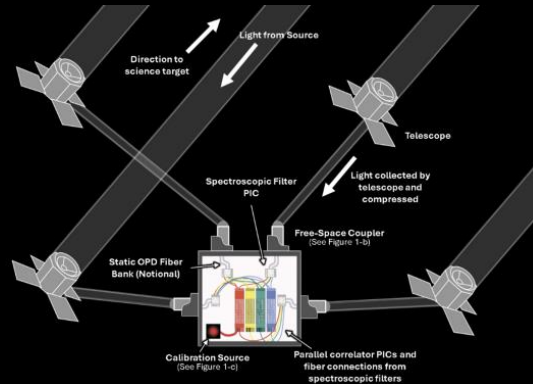
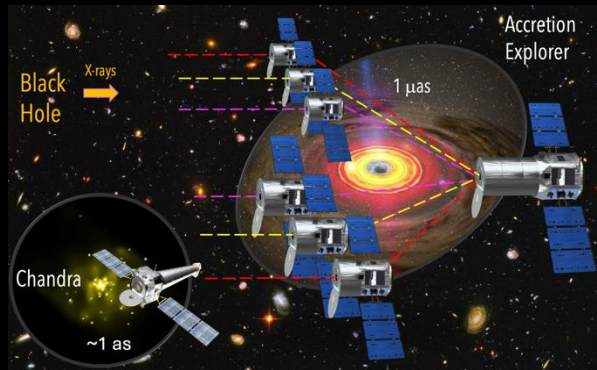
Interferometry

There are multiple potential approaches to interferometry in space:

- Boom-Connected / Deployable Apertures
 - Free-Flying Apertures
 - Lunar Surface
- Nulling, Mach Zehnder, Hanbury Brown and Twiss, etc.

Key deciding factors on modality are wavelength regime and required baseline length

Depending on approach, must also consider beam combining and/or precision timing/metrology



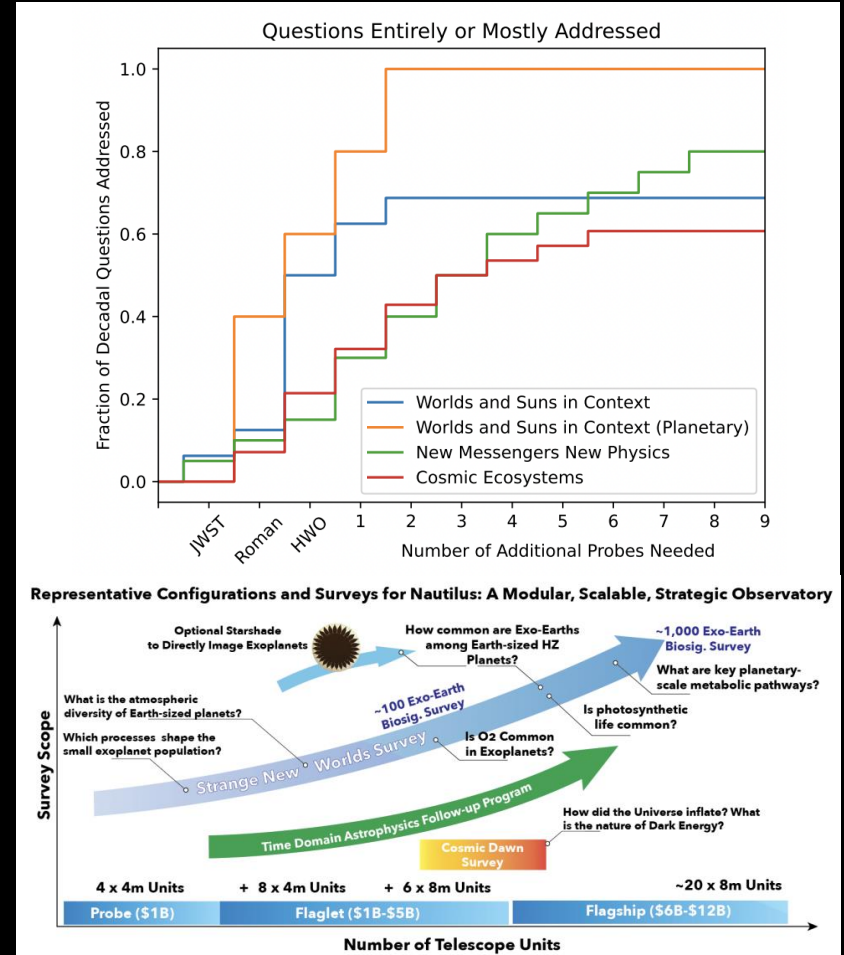
Novel Architectures and Approaches

Multi-Mission Capabilities

- Constellations of small satellites
 - Fleet of flaglets
- Disaggregated observatories
- Servicing, starshade, common platforms, etc.

Multi-Wavelength and Multi-Messenger

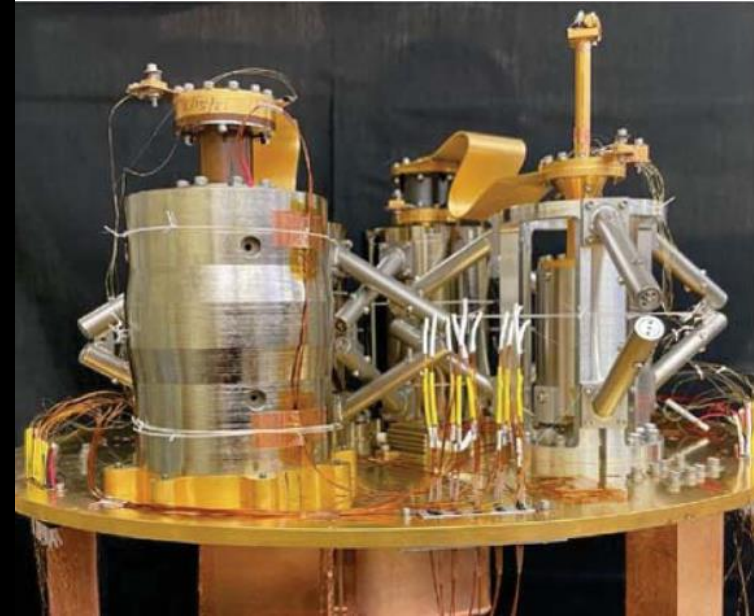
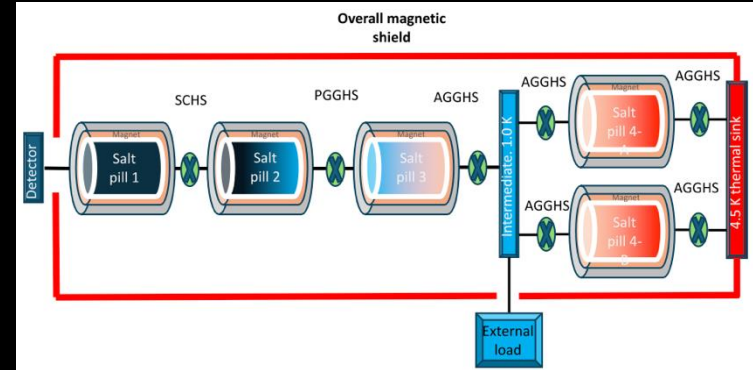
- Many of the exciting science questions we identified on Day 1 require observations at more than one wavelength or messenger



Infrastructure

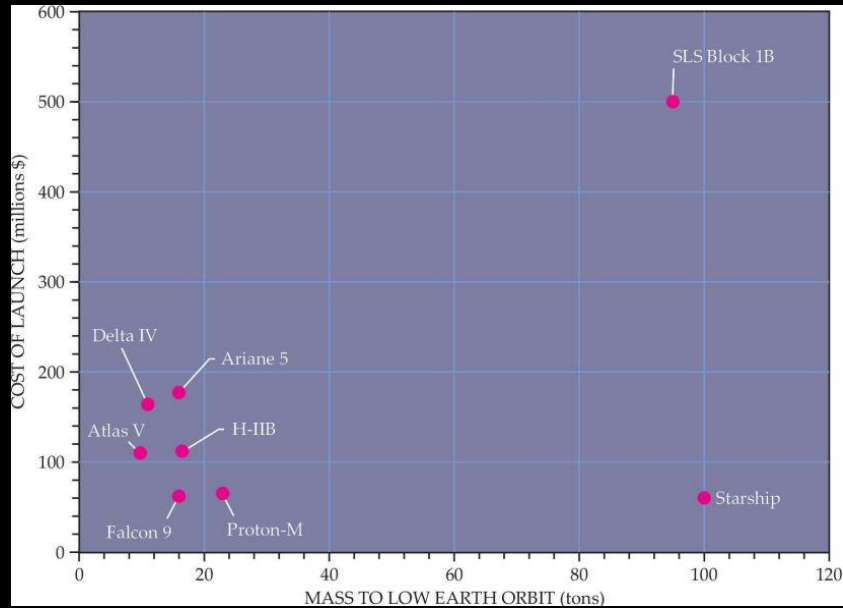
Strategic infrastructure advancements cross wavelength regimes and enable a wide variety of different approaches:

- Cryocoolers (Radio, IR, Optical, X-ray)
 - Optical Communication (radio interferometry, ultra wide field IR, TDAMM)
 - Precision Pointing (optical interferometry, coronagraph, X-ray)
 - Inter-aperture Metrology (interferometry, constellations)



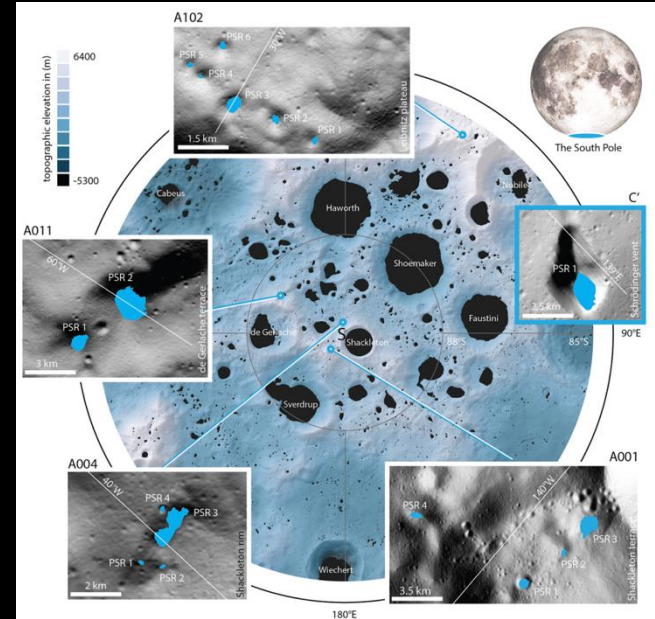
Infrastructure

Larger, cheaper launch vehicles enable different architectures and simplify designs



Credit: Elvis+ (2023)

Artemis infrastructure offers new opportunities for astronomy on the Moon



Credit: van Belle+ (2024)

Time Domain Responsivity

TDAMM science requires unique capabilities that are often overlooked:

- Fast response times
- Fast downlink / alert notifications (to coordinate with other wavebands)
 - Large field of regard / sky coverage
- Fast tracking (for solar system objects and ISOs)

Incorporating these ideas into any new observatory enables more TDAMM science

Or is a dedicated TDAMM observatory platform required?

Cross-observatory coordination infrastructure will be essential not only for maximizing the scientific return of existing facilities, but also for shaping the design of future TDAMM missions. As TDAMM science becomes increasingly dependent on rapid discovery, classification, localization, follow-up, and interpretation across multiple facilities, future missions should not be designed solely as isolated observatories. Instead, they should be conceived as components of a broader, coordinated observing ecosystem, with interfaces and operational concepts designed from the outset to enable fleet-level science. This approach could enable new distributed mission architectures that collectively provide the capability of a larger TDAMM facility.

Opportunities
for community
observing plans

Artificial Intelligence

For better or for worse, we are in the era of AI

How can we leverage it to make mission design better and more efficient?

- Design iteration
- Simulations
- Data analysis
- Autonomy (servicing at L2?)

Human creativity and vetting of final designs remains critical



Technology Crossover

MacGregor

VOYAGER 1

VOYAGER 2

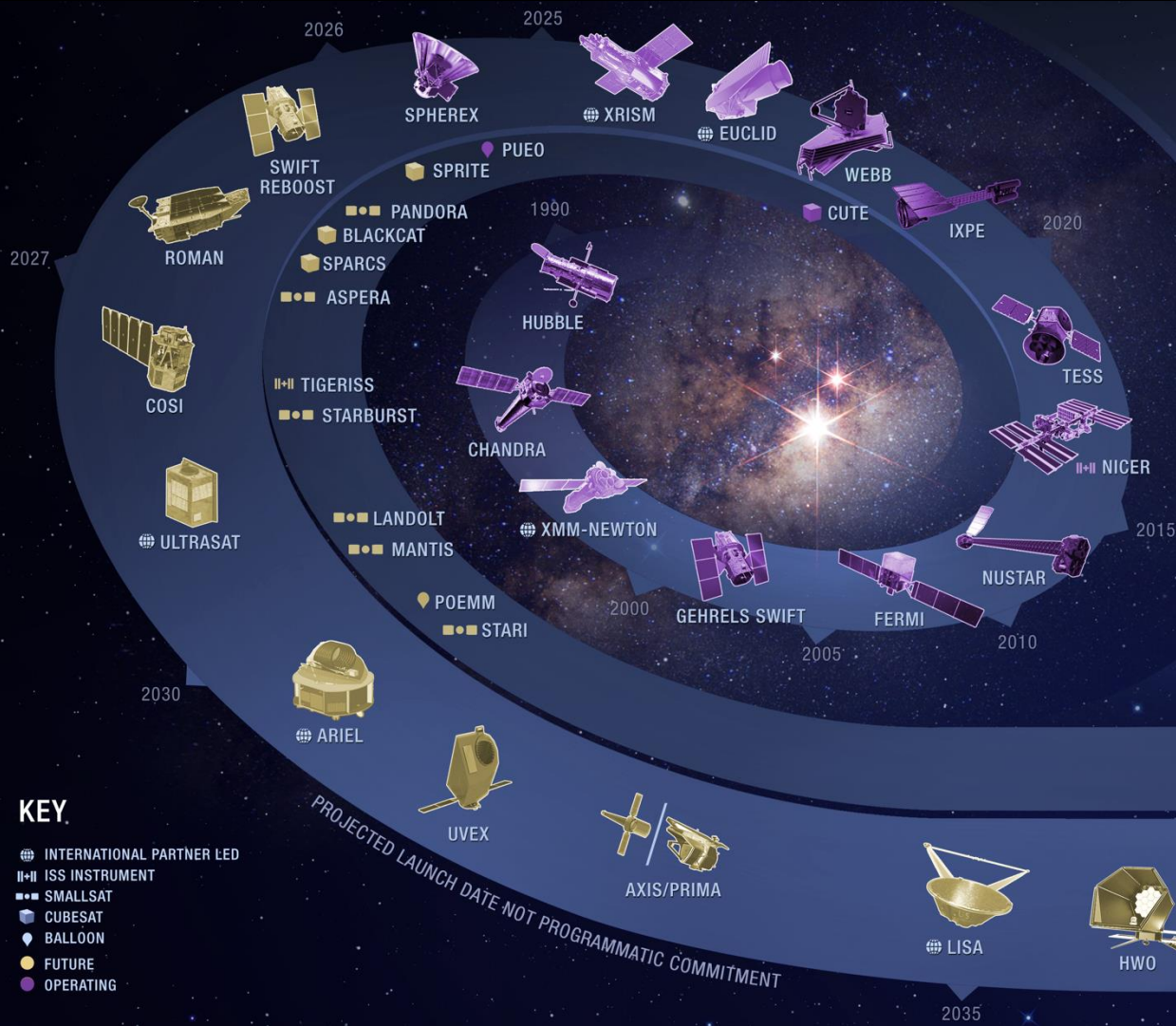
We should leverage technology development from other communities:

- Planetary (laser communications, dust mitigation)
- Helio (solar blind UV detectors, space-based radio interferometry)
- Earth Science (satellite swarms, spectroscopy, long-term NASA support model of upgradable space projects)

OPERATING & FUTURE
SCIENCE FLEET

Planning an Astrophysics Fleet for the Future

We are launching exciting
new missions (Go Roman
Go!), but we are also
losing capabilities



KEY

- INTERNATIONAL PARTNER LED
- ISS INSTRUMENT
- SMALLSAT
- CUBESAT
- BALLOON
- FUTURE
- OPERATING

PIONEERS & CUBESATS

TRADITIONAL MISSIONS

Possibly Controversial Ideas

Flagships are amazing but they take decades to build and cost billions of dollars. If we continue to focus our energy here, we could lose our multi-wavelength view of the Universe. Multiple smaller missions designed for specific science cases could get A LOT of exciting science done and still offer GO opportunities. We need to consider both options.

We should reevaluate how we support technology development. Funding this work early (before architecture trades) can derisk future missions.

We should reuse technology – not everything has to be bespoke for every mission. A common astrophysics platform(s) could enable a modular approach to building observatories at the probe and below scale. Learn from industry partners!

We need to drive technology from the exciting science questions. All wavelengths contribute something interesting. Pitting wavelength communities against each other is not the best way to move our field forward.

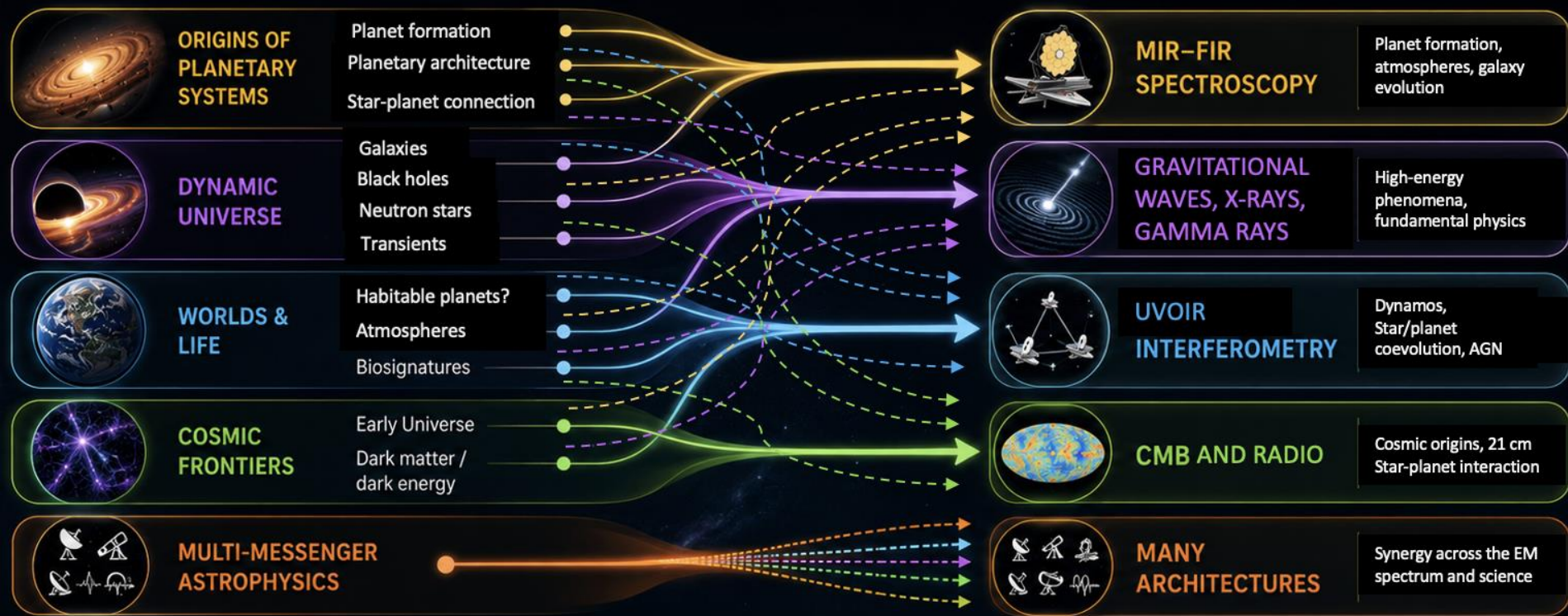
Note: This graphic attempts to trace the 'most frequently' discussed technology to address specific science questions. In fact, many of these science questions can be addressed by observatories operating at multiple wavelengths!

Complementary Architectures. Transformative Discoveries.

Multiple paths to answer humanity's most profound questions

SCIENCE QUESTIONS

OBSERVATIONAL ARCHITECTURES



Note: These categories are large and there are multiple architectures and science cases in each bin!