

# REMOTE SENSING SCIENCE AND INSTRUMENT DEVELOPMENT PARADIGMS WILL RADICALLY CHANGE AS DEEP SPACE OPTICAL COMMUNICATIONS INFRASTRUCTURE IS STANDARDIZED



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## INTRODUCTION

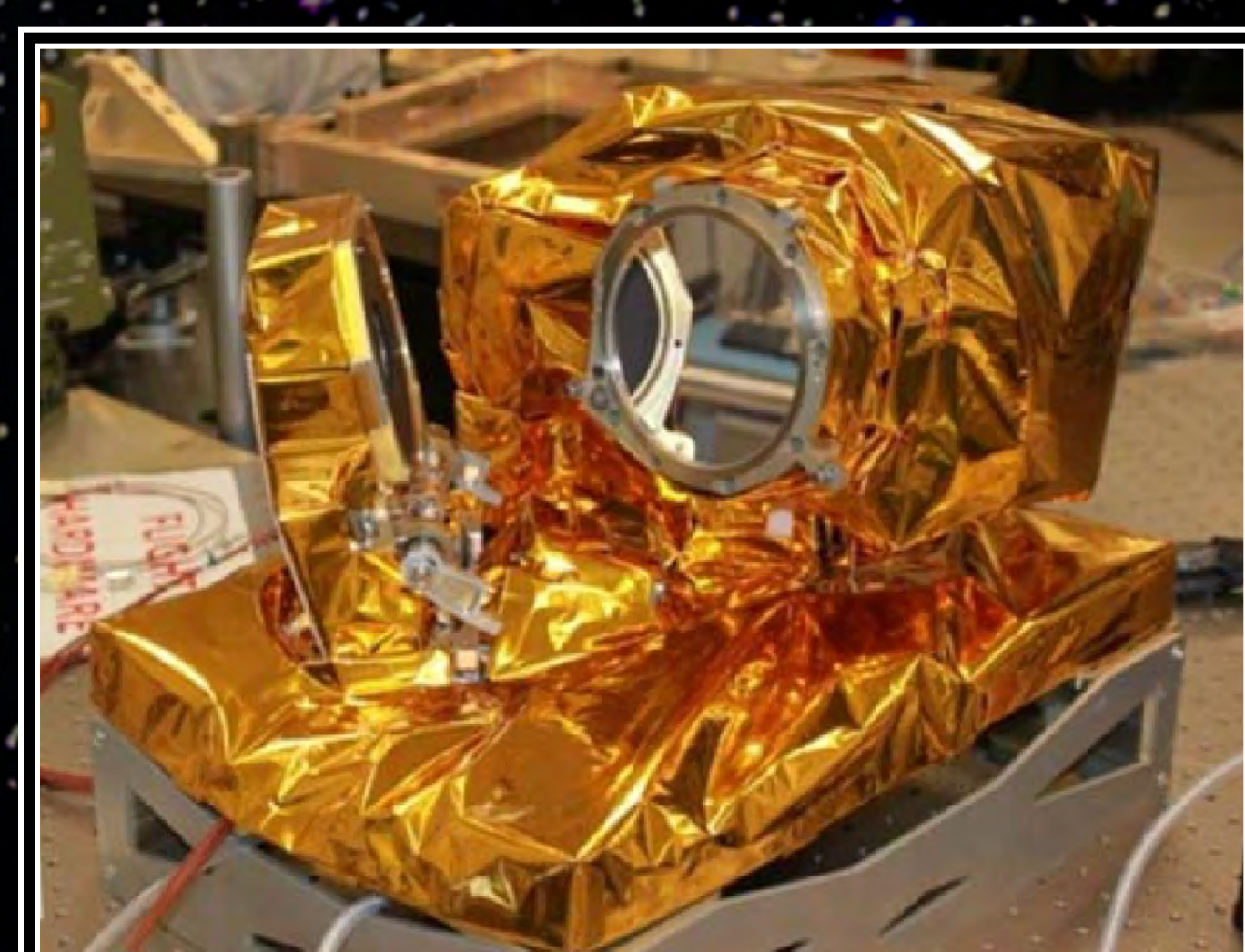
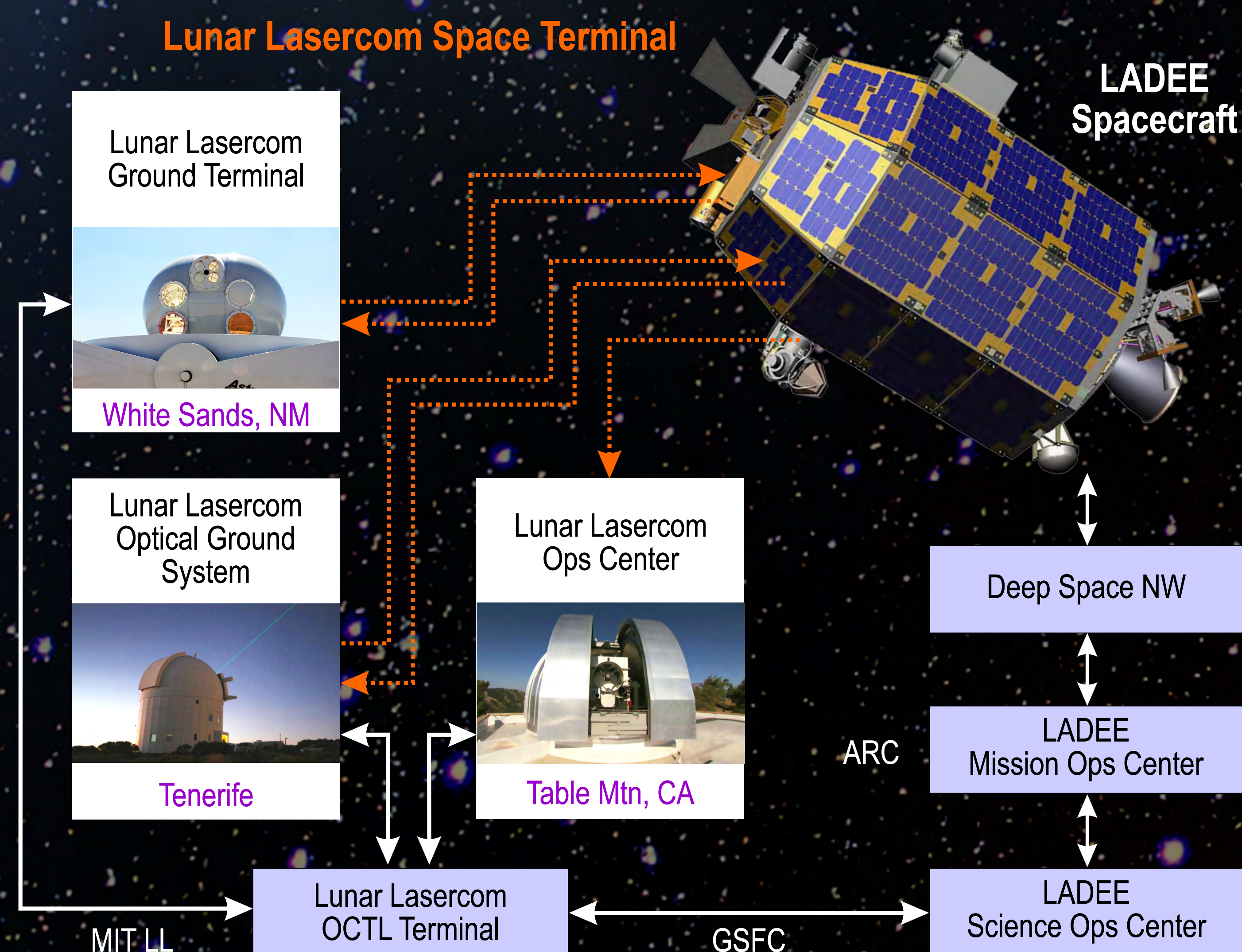
The advent of Deep Space Optical Communications (DSOC) systems in this and the coming decade ensures that this technique will surely become the norm, given the inherent advantages of high data rates and volumes for achieving the science of the future [1]. Present day mission design concept proposals describe the data sufficiency to achieve goals in terms of the constraint/bottleneck in data volume returned, as opposed to the inherent data gathering capabilities of instrumentation and spacecraft operations. Likewise, remote sensing instruments designed for planetary missions could readily include the latest 4k x 4k mega-pixel detector formats or larger, but opt not to owing to the inability to return the full amount of data collected within such capabilities.

The present complexity of such DSOC systems and the relative lack of ground-based infrastructure compared to traditional radio communication systems have perhaps slowed the pace of this sea change compared to earlier predictions. The next Decadal Survey is likely to discuss a telecommunications orbiter relay system for Mars, currently under study by MEPAG and others. Such a Mars orbiter would have a science focus but would also resemble elements of the Mars Telecom Orbiter concept briefly studied back in the mid-2000's, which included a Mars Laser Communications Demonstration [2]. Notably the Discovery mission Phase A competition had 3 of 5 mission concepts that chose to include a DSOC technology demonstration component (i.e., Psyche, VERITAS, and NEOCam) with the Psyche mission (and its DSOC) being selected.

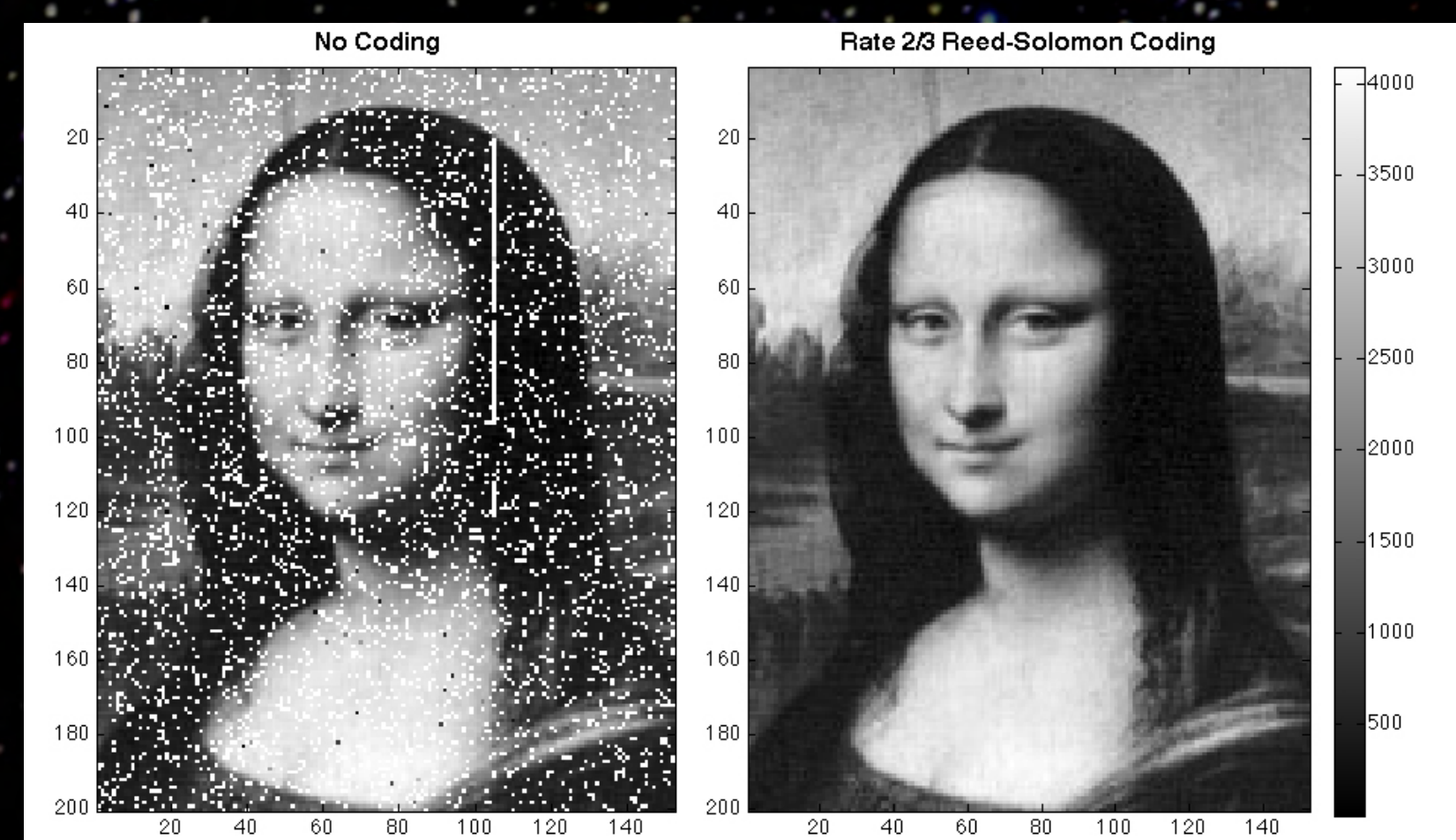
## PLANETARY MISSION PAYLOAD & CONOPS ARCHITECTURE IN 2050

Our primary argument is that once 0.5 m class telescopes and larger are contemplated for DSOC systems on interplanetary missions it is inconceivable to not attempt to add remote sensing science instruments at the focal plane to take advantage of the mass, complexity, and cost invested in this spacecraft capability. Furthermore, the DSOC system drives requirements on spacecraft attitude control systems for exquisite pointing knowledge, control, and stability that, in addition to the telescope structure, adds even more mass, complexity, cost, and power resources.

An architectural approach that uses one common telescope to conduct science investigations across multiple spectral ranges is the logical driving direction that planetary mission payload concepts will be increasingly pushed into in the next three decades. A clear precedent for this observatory approach is the Hubble Space Telescope (HST) example of using one as-large-as-possible telescope to conduct experiments from far-UV (~105 nm on the Cosmic Origins Spectrograph) to the near-IR (~2.5  $\mu$ m on NICMOS). Certainly the James Webb Space Telescope (JWST) and other astrophysics missions have followed this successfully demonstrated strategy. This approach typically uses a Cassegrain type telescope with different alignments of detectors and fields of view within the focal plane, and often include the implementation of pick-off mirrors, beam-splitters, and grating/filter wheels to achieve multi-wavelength capabilities.



**Figure 1:** The LADEE Lunar Laser Communication Demonstration (LLCD) [3] achieved long-range uplinks at 10 and 20 Mbps, with downlinks in the 39 Mbps to 622 Mbps (top). A 0.10 m reflective telescope is coupled by optical fibers to a modern transmitter (bottom left). Its primary ground station terminal, located at White Sands, NM, was composed of four 40-cm telescopes for downlink and four 15-cm telescopes for uplink (bottom right). Alternate sites were located at NASA/JPL and ESA's OGS telescope in Tenerife, Spain. The successful demonstration of key technologies such as pointing, acquisition, and tracking from lunar orbit enables the progression of demonstrations at further distances on upcoming missions throughout the solar system in the next decades.



**Figure 2:** The Lunar Reconnaissance Orbiter (LRO) Lunar Orbiter Laser Altimeter (LOLA) instrument performed a novel proof-of-concept one-way reception of laser pulses coded with the image information of the Mona Lisa painting shown here. Earth atmosphere effects on transmission are shown at left, while simple error correction by Reed-Solomon algorithm (e.g., commonly used in DVD players) helped fill in missing (white) or false (black) signals.



**Figure 3:** MRO/HIRISE's 0.5 m diameter mirror (shown here) and the 0.30 m diameter telescope on Deep Impact/EPOXI's High Resolution Imager (HRI) are two of the largest telescopes flown on planetary missions, for examples. In 2013 McEwen presented a "Mars Orbiting Space Telescope (MOST): Advancing Planetary Science (+Astrophysics, Heliophysics), Space Technology, and Human Spaceflight" concept for using the Hubble-class 2.4 m diameter telescopes provided to NASA by NRO [4]; McEwen similarly identified the ideal use of this telescope at Mars for optical communications technology demonstration.

Future work in the coming decades should identify the particular complications and unique challenges that incorporating both DSOC and science remote sensing instrumentation on the same telescope will entail. Obvious complications arise from needing to slew from planetary target to the Earth, but many spacecraft with fixed pointing arrays already solve these operational complexities satisfactorily. Bigger challenges reside in finding mirror materials, coatings, and temperature control properties, but many enabling advances in such areas are already underway. Adding mechanisms to block off potentially intense laser light from Earth from entering and damaging highly sensitive spectrographs and cameras seems unavoidable in at least some cases.

## INSTRUMENT DESIGN CHALLENGES FOR THE NEXT 3 DECADES

New instrument technologies will need to be implemented within the framework of a DSOC optimized telescope plus spacecraft system (i.e., an observatory approach rather than a "probe" approach). The continued imperative to reduce mass and power resources in technology developments should proceed in parallel in any event, but perhaps with an even more enhanced focus. Power supplies, C&DH electronics, and interfaces are likely to become even more standardized within a given observatory framework in order to be accommodated more harmoniously within individual mission designs. Hence the development of these subsystem technologies is likely to even more rigorously push industry wide and NASA-wide standardization of requirements and specifications.

A notable drawback for planetary measurements from Hubble and JWST type observatories where one instrument field of view cannot overlap another by design is that they preclude simultaneous time and/or spatial coverage of interesting features or time-variable phenomena. Individual back-end instruments are more likely in this case to implement beam-splitters or other innovative optical designs to shunt light of different wavelengths onto different detectors simultaneously. This multi-purpose approach to multi-wavelength instrument design would be a radical deviation from present designs that focus on optimizing all aspects of instrument performance to their specified bandpasses.

An interesting area for study and further thought exists when contemplating the inclusion of both in situ and remote sensing experiments within one observatory-probe mission. In situ (mass spec, fields, particles, active radar, etc.) experiments will no doubt want to take advantage of the higher data rates afforded by a DSOC subsystem. Whether or not a dedicated DSOC telescope system provides a cost savings in this type of investigation will answer the question on whether individual planetary missions will face segregation by measurement techniques. For remote-sensing only type observatory missions another potential exists to optimize the telescopes for the band-pass of interest, from x-ray to far-IR and all combinations in between.

## SUMMARY

The future advancement of DSOC will greatly impact the paradigms we invoke for conducting planetary missions and combining different payload instrument elements. Will there be a heightened specialization of measurement types per mission? Or will technologies converge to better enable multi-wavelength remote sensing platforms? What complications are included when in situ measurements are also needed by a particular mission? These practicalities will both constrain and enable opportunities for defining the hypotheses able to be address by future planetary missions.

## REFERENCES

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- [2] Boroson D. M. et al. (2004) *Proc. of SPIE*, doi: 10.1117/12.543014.
- [3] Boroson D. M. (2015) *Proc. of SPIE*, doi: 10.1117/12.2045503.
- [4] McEwen A. J. (2013) *SALSO Meeting* (online Quad-Chart).