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# REPORT OF THE WORKING GROUP ON SPACE/LUNAR TRADEOFFS

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The group discussed the advantages and disadvantages of five locations for an optical/infrared array: low-Earth orbit (LEO), Sun-synchronous Earth-orbit, geosynchronous orbit (GEO), Lagrangian points (L4 and L5), and the lunar surface. The factors affecting an array and our assessments of them are given in table 1 and discussed briefly below. In our discussions, we assumed two axioms:

1) Human expansion into space and to the Moon will occur.
2) The Space Station will be constructed and operational.

The major conclusion we reached is that baselines of moderate size (>300m) are best done on the Moon and that large baselines (>10 km) can be done only on the Moon.

Three areas needing additional research were identified as follows:

1) Studies are needed on methods to steer long-baseline systems in orbit. This involves learning how to control free-flyers. It is in not clear how the difficulty of control varies with orbital evelvation.

2) More work is needed on the internal metrology of array systems, both orbital and lunar-surface systems.

3) We need to understand the radiation effects on detectors and electronics and learn how to mitigate them.

Baseline orientation and stability. Baseline stability has two components, internal stability and stability of the orientation of the baseline. The stability of the baseline depends not only on the location of the array (LEO, GEO, etc.) but also on its size. We have also made several assumptions as to the construction of the interferometer array.

For orbiting interferometers, we have assumed that baselines of 300 m or less are single structures and longer baselines in orbit are achieved with multiple spacecraft.

With current technology, distances between optical elements on a large space structure or between spacecraft can be measured with very high precision. The major technical problem is the orientation of the array in inertial space. For short baselines in orbit with the array on one structure, the problem is attitude control. For a multiple-spacecraft array, orientation of the array requires very precise station keeping.

With regard to baseline orientation, two components of the problem are measurement of the orientation and changing the orientatin. For changing the orientation, the problem is relatively simple for both the Moon and for single structure interferometric arrays. The problem of measuring the orientation is more fundamental.

As the baseline and, hence , the angular resolution gets higher, the orientation problem becomes more difficult. The basic approach is to use nearby bright stars as guide stars. In this approach, stellar aberration plays a major role. In LEO, orbital motion of the spacecraft can change the apparent position of a star by 5 arcsec. This orbital aberration must be known to very high precision, one tenth to one twentieth of the resolution of this array. Orientation of the optical array is most difficult in LEO and simplest on the Moon.

For short baselines, <30 meters, the angular resolution (3 mas) is sufficiently modest that even LEO placement does not present insurmountable problems. With 300-m arrays, the largest feasible single spacecraft arrays, operation at higher altitude is a necessity. For very long baseline arrays to 10 km, the committee considers station keeping of separate spacecraft to be extremely difficult, except possibly at L5/L4. The technical problems of very long baseline arrays using free-flyers should be studied further to determine feasibility.

The Moon is an excellent platform for any large arrays for two reasons. One is the high degree of seismic stability. The second is the fact that the orbital motion of the Moon is very precisely known.

Thermal stability. Thermal stability will be achieved most easily in an environment with constant or slowly varying solar illumination and constant or slowly varying telescope pointing. In addition, complete protection from the Sun (ambient darkness) will minimize thermal gradients, thus simplifying achievement of stability. LEO is a poor environment owing to rapid transition between day and night. Higher orbits have constant illumination; Sun synchronous, with an implied preferred viewing angle, may be somewhat better than GEO or the lunar surface. The lunar surface provides a long day and night. The night provides an excellent thermal environment with a surface temperature of about 100°K. A permanently shadowed location (for example, in a polar crater) might offer an ideal, constant environment with low ground-sky differential.

Thermal background. The thermal background disturbs IR measurements when ambient thermal radiation is scattered into the beam. High oribts have the advantage that the background is primarily from the Sun and is most easily baffled. LEO, Sun-synchronous, and the lunar surface have large solid angles of thermal emission, hence pose difficult baffling problems. All free-space configurations have a potential problem with scattering and emission from co-orbiting particles or contamination. The lunar gravity clears such materials from the thin lunar atmosphere. Even during the night the lunar surface has substantial thermal emission at 10 microns and beyond.

Optical background. The optical background disturbs observations by scattering ambient radiation into the beam. Direct sunlight can be baffled well, but extended sources, such as the Earth or the lunar surface in daylight, will be difficult to baffle completely. With adequate baffling, all space-based instruments should be limited by zodiacal and galactic backgrounds.

Radiation environment. Only LEO is relatively free of particle radiation problems. Sun-synchronous orbit )about 1000 km) is getting into the lower (encounters substantial) Van Allen belt, and GEO is in the outer Van Allen belt. GEO and L-5 each experience essentially the full solar wind, solar storm, and cosmic ray flux. The lunar surface is shielded from half of these solar cosmic ray particles.

Duration of darkness. Full dark conditions will almost certainly be required for work on the very faintest sources. This condition is available only for brief intervals (typically half an hour) in LEO, but for intervals of typically 2 weeks on the lunar surfaces.

Debris and micrometeorite risk. The risk to telescopes in space from micrometeorites is roughly the same at all potential locations. However, spacecraft debris is concentrated in LEO, so telescope facilities in LEO are at the greatest risk overall, and relatively simple shielding domes can provide almost complete protection to telescope elements on the Moon.

Maintenance , upgrading, and service. Optical arrays will need maintenance (repair and replacements of damaged parts), service (recharge of cryogenics,) and upgrading (changing detectors to different wavelengths or for greater sensitivity). The ease with which these services can be rendered depends on whether humans or robots have access to the facility. This will be relatively simple for the Moon if there is a lunar base. Telescope arrays in LEO will be accessible from the Space Station, though not all orbits will be reached readily. Access to GEO, Sun-synchronous, and L5 points are not likely to be available in the time frame of at least initaial lunar bases.

Complexity of Science Operations. Science operations refer to plannig and scheduling the observations that constitute the science program. It involves optimizing the sequence of required pointings based on predicted conditions such as Earth occultations, bright object interference, and engineering factors, such as constraints on spacecraft orientation with respect to the Sun.

Operations in LEO are more complex than for any other space setting. Earth occultations will interrupt most observations one in each 90-min orbit. The radiation environment, particularly encountering the South Atlantic Anomaly, will disrupt observations sporadically. The requirement to communicate through the TDRRS system is also a major operational hurdle for high data rates or if real-time contract with the spacecraft is frequently required.

A factor that applies to all free-flying observatories, but not to the lunar base, is the celestial sphere reference system. This factor makes lunar observatories, which can use the solid surface as a primary reference, fundamentally simpler. Target acquisition and stabilization are trivial once the system is calibrated.

Reconfigurability. Mirrors can be moved along a single structure to improve UV-plane coverage; the maximum baseline is set by the size of the structure. Free flyers can be arbitrarily reconfigured, as with only moderately greater difficulty can elements on the lunar surface.

Number of reflections. The number of optical reflections, an important factor in the overall throughput of the instrument, depends on the optical configuration selected. Fizeau-type interferometers afford the lowest number of reflections (2), but require that the common secondary mirror be some distance away from the primary apertures. This interferometer configuration is feasible only for the shorter baselines or for free-flyer systems. Other optical configurations make use of separate telescopes and delay lines, resulting in five or more optical reflections.

Table 1. Comparison of Locations For Optical/Infrared Array Observatories

| Array Characteristic | | LEO | Sun Synchr. | GEO | L5 Points | Lunar Surface |
|---|---|---|---|---|---|---|
| | | | | | Array Location | |
| Baseline Stability | 0-30m | Mod. Diff. | Mod. Easy | Easy | Easy | Intriniscally Very Good |
| | 30-300m | Very Diff. | Difficult | Mod. Diff. | Easy | |
| | 0.3-10km | Impossible | Impossible | Very Diff. | Easy to Diff. | |
| | >10km | Impossible | Impossible | Impossible | Diff. | |
| Thermal Stability | | Poor | Very Good | Very Good | Very Good | Polar: Good; Equatorial: Good |
| Thermal Back-ground | | Poor | Very Good | Very Good | Very Good | Lg. Array Poor; Sm. Array Good |
| Radiation Environ-ment (Cosmic, Solar, Van Allen) | | Good | Poor | Very Poor | Very Poor | Poor |
| Duration of Total Darkness | | 0.5 Hr. | 0 | 0 | 0 | 336 Hr. |
| Optical Back-ground | | Day: Earth Night: Zodiacal | Zodiacal | Zodiacal | Zodiacal | Day: Moon; Night: Zodiacal |
| Debris And Micro-meteorite Risk | | Moderate | Low | Low | Low | Lowest |
| Mainten-ance, Service And Upgrading | | Good | Poor | Poor | Poor | Very Good |

Table 1. Comparison of Locations For Optical/Infrared Array Observatories (continued)

| Array Characteristic | | LEO | Sun Synchr. | GEO | L5 Points | Lunar Surface |
|---|---|---|---|---|---|---|
| | | | | | Array Location | |
| Complexity of Science Operations | | Very | Moderate | Moderate | Moderate | Simple |
| Re-Configurability | | Limited | Limited | Limited | Flexible | Flexible |
| Expandability | | Poor | Very Poor | Poor | Good | Excellent |
| # of Reflections | | 2 to 5 | 2 to 5 | 2 to 5 | >2 | >5 |
| Science Potential (Angular Resolution) | 3 mas | x | x | x | x | x |
| | 0.3 mas | | x | x | x | x |
| | 10 $\mu$as | | | x | x | x |
| | 1 $\mu$as | | | | x | x |
| Recommendation (resolution) | 3 mas | √ | | | | √ |
| | 0.3 mas | | √ | | | √ |
| | 10 $\mu$as | | | | ? | √ |
| | <1 $\mu$as | | | | | √ |