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THE OPTICAL VERY LARGE ARRAY AND ITS MOON-BASED VERSION

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Abstract

An Optical Very Large Array (OVLA) is currently in early prototyping stages for ground-based sites, such as Mauna Kea and perhaps the VLT site in Chile. Its concept is also suited for a moon-based interferometer. With a ring of bi-dimensionally mobile telescopes, there is maximal flexibility in the aperture pattern, and no need for delay lines. A circular configuration of many free-flying telescopes, TRIO, is also considered for space interferometers. Finally, the principle of gaseous mirrors may become applicable for moon-based optical arrays.

Fifteen years after the first coherent linkage of two optical telescopes, the design of an ambitious imaging array, the OVLA, is now well advanced. Two 1.5 m telescopes have been built and now provide astronomical results. Elements of the OVLA are under construction. Although primarily conceived for ground-based sites, the OVLA structure appears to meet the essential requirements for operation on the Moon.

Results of the CERGA Interferometers

The small and large interferometers at CERGA have been extensively described (Koechlin 1988, Labeyrie 1988, Bosc 1988, Mourard 1988). After 12 years of prototyping and construction, the large " GI2T" interferometer has begun its observing program. With its full 1.5 m apertures, the GI2T obtained 500,000 exposures, most on the Be star gamma Cassiopea, but some also on Algol. The initial problem of vibrations in the mounts was solved by replacing the hydraulic elements in the drive system with small (20 W) electric motors.

Current developments include:

1. A laser metrology system, following the design of C. Townes for his heterodyne interferometer. It will stabilize the GI2T and serve as a prototype for the OVLA

array (figure 1). As described by Labeyrie et al. 1988, three laser beams are emitted by the central station toward a cat's eye reflector located at the center of each telescope. This gives three-dimensional information on telescope positions.

The initial use will be in the incremental mode to stabilize the baseline geometry during observation with fixed telescopes. Subsequently, fringe counting with several laser wavelengths is foreseen for absolute determination of the system geometry with moving telescopes, in the presence of seeing.

Pointing the laser beams toward the telescopes will have to be automated when the telescopes are moving and observing at the same time.

2. The study of a field-slicer system serving to observe a reference star and the main object at the same time (Bosc, Labeyrie, and Mourard 1988).

3. Based on compact OVLA technology, beginning the construction of a No. 3 telescope. For compactness, a fiberglass/epoxy sphere has been delivered to Haute Provence observatory, where the drive system is to be designed and built by A. Richaud and M. Cazalé. The sphere's diameter is 2.8 m, its thickness 6 mm and its mass 250 kg. It will contain a 1.5 m mirror apertured at f/1.75. Polished aluminum or replicas on new substrates currently studied are both considered for the mirror.

Steps Toward The Optical Very Large Array

The telescope No. 3 just mentioned serves as a prototype for the 27 telescopes of the OVLA (Labeyrie et al, 1988, Mourard, 1988, Bosc 1988). An XY carriage system is also needed to move the telescopes on the base platform. The platform concept makes delay lines unnecessary. It also allows varied options of aperture configurations, as required for observing different kinds of objects.

An XY carriage concept is being studied by D. Plathner at IRAM, and a prototype may be funded by INSU (France). This prototype will perhaps be used to move the OVLA prototype telescope when it is added to the CERGA system for exploiting a three-telescope array.

A somewhat different translation concept, shown in figure 4, involves 6 robotic legs. It appears suitable for smooth locomotion on either bare unprepared soil (including lunar soil) or an array of accurately positioned posts. The 6-legs solution has much similarity with insects: during motion each triplet of "feet" maintains a fixed triangular geometry, the linkage being achieved by neural networks, as is the case in insect brains.

The three-dimensional laser metrology system is essential for real time control of the telescope motion with about 1 micron accuracy. Even better accuracy may be needed for a moon-based OVLA, to benefit from the absence of atmosphere and achieve phased recombination of the beams within the Rayleign tolerance. This may require ultraviolet laser wavelengths.

Alternately, reference stars can contribute to the fine level of geometry stabilization in space. A "field-slicer" optical system can allow the transmission of stellar and reference beams together in the coudé train (Bosc, Labeyrie, and Mourard, 1989). Fiber optics may also be considered, but "wireless" operations are of interest for moving telescopes.

Following the development of telescopes, carriages, and metrology components, OVLA development should proceed on a suitable site, possibly a plateau below the Mauna Kea summit. A few telescopes will be initially installed and more will be added to reach 27, or more if needed. A scaled-up version may also be implemented at some stage, with larger subapertures. A system combining, for example, 27 telescopes of 3.08 m, equivalent in aperture to ESO's Very Large Telescope (VLT), can potentially produce much more science than the VLT and other systems using a few fixed telescopes. The technical risks are also reduced, and probably the cost as well.

The Trio Concept of Space Interferometer

As described at conferences in Cargese (Labeyrie et al. 1984) and Granada (Labeyrie 1987), free-flying interferometer elements in high orbit can be stabilized, relative to each other and inertial space, by small solar sails. Interferometric baselines of 100 m can apparently be achieved in this way at geostationary altitudes, and they can reach several kilometers at 300,000 km from the Earth, at a site such as the L5 Lagrange point of the Earth-Moon system. It is yet difficult to judge the amount of technical developments required. Studies are currently being pursued by ESA. Prototype free-flyers may be launched together with commercial communications satellites for qualifying small "sailing telescopes at geostationary altitudes. In spite of the lack of experience with solar sails and laser metrology in space, workable technical solutions may emerge at affordable costs.

The software aspects are seen as the major development effort required. A neural network approach appears of interest for reliability and optimal control.

A Lunar Version of the Optical Very Large Array

Adapting OVLA to a lunar site appears possible, at least conceptually (figure 1). Telescopes can be arranged along a ring. To avoid delay lines and achieve flexible aperture geometries, the ring has to be a deformable ellipse. Telescopes capable of walking on the bare soil or on an array of posts can meet this condition. Residual positioning errors can be compensated by small movable mirrors in the central optical system.

If very long baselines are desired, the central station could be located on a natural hill to avoid problems with the curvature of the Moon.

A shaded site is desirable for simplifying the baffling of the coudé beams, but also for thermal stability and low temperatures. Some energy must, however, be fed into the telescopes, preferably without wires. If the site is dark, a few watts of near infrared energy can be beamed toward photovoltaic panels on each telescope from a solar power station located on some illuminated ridge overlooking the array. This assumes a polar site.

The OVLA structure is suitable for progressively increasing the baseline spans; walking telescopes can initially remain within 1 km from the central station and later progressively venture farther away, as operating experience is gained.

In the central station, the beam recombining system must be interchangeable to accommodate changing requirements, different object types, and improving detectors. Thus, different kinds of pair-wise, triplet-wise or many-beam recombinators will be usable in the same way as focal instruments are interchanged on conventional large telescopes.

A metrology system similar to that currently developed at CERGA for the OVLA also appears desirable unless better configurations are found. In addition, it may be of interest to have an optional field slicer, which allows the simultaneous observation of the object and a reference star located up to a few arc-minutes away from it.

Detection of Circumstellar Planets

Detecting bodies a billion time fainter, within an arc-second from a bright star, is probably feasible with a lunar optical interferometer. A procedure was proposed for the Hubble Space Telescope (Bonneau, Josse, and Labeyrie 1975) and photon-noise estimates did show that a few hours of observing time should suffice. Dust contamination on the large mirror of the Hubble Space Telescope, and its guiding jitter, are now considered to make things more difficult.

Individual telescopes belonging to a lunar array would themselves be in a better position than the low-orbiting space telescope for detecting planets. This would be achieved with long exposures in the photon-counting mode, coronal masks, and digital image subtractions while the telescope is rotated about its optical axis. The planet would appear at various position angles on the camera while the speckled pattern of stray light would remain fixed, and would thus disappear in the image subtraction process. Repeated rotations allow lock-in detection.

Unlike equatorial or alt-azimuthal mounts, spherical telescope mounts such as adopted for the OVLA do allow rotations around the optical axis (but not in the coudé mode). Conceivably, a specialized telescope could serve as a planet finder; and the array should be able to provide images of the detected planets. The images should show some resolved detail of planetary features in favorable cases.

Extracting a planet from the synthetic-aperture image obviously requires an excellent signal-to-noise ratio in the CLEAN algorithm. Calculations of photon noise are desirable to estimate the chances of success.

Gaseous Mirrors On The Moon

The above description of a lunar OVLA assumes conventional optical elements. The prospect of utilization gaseous mirrors may also be worth considering.

Since the concept of holographic telescopes with gaseous or pellicle mirrors was proposed (Labeyrie 1979), considerable progress has been made in the art of trapping atoms in laser radiation fields. Recent results by Balykin et al. (1988) confirm that sodium atoms can be channeled in a standing spherical light wave.

Also, the cooling of atoms has been achieved at temperatures below 0.01K. This implies low residual velocities for the atoms, suggesting that the laser field could be turned off intermittently so as to minimize its contribution to focal plane straylight. At such low temperatures, if the density of atoms is high, the gas can condensate into a crystalline film. The narrow spectroscopic lines are affected in the process so that continuous trapping in the standing wave may also require some changes of the laser spectrum.

It is unclear yet whether such condensation into a crystalline film is advisable, and whether molecules such as organic dyes or even larger aggregates should be preferred to separate atoms. Theoretical investigations would be of interest. Using a vacuum tank, some laboratory testing of these techniques could also be initiated in the coming years (see figure 2).

It may thus become possible to install gaseous mirrors on the Moon, but it is difficult to guess what their size will be. Meters, hectometers, or kilometers? Depending on the sizes achieved, the large lunar instrument could consist of many small gaseous mirrors or a single large one.

Conclusion

A Moon-based interferometer is likely to achieve a major breakthrough in the optical penetration of the Universe. Advantages and drawbacks of free-flying versus lunar systems will have to be compared when more detailed design information is available for both kinds.

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Panel Discussion

If a lunar base is to be established, it is certainly worthwhile for the terrestrial civilization to build an optical array at the same site. This is bound to be a prolific discovery machine that will clarify our picture of the stars, and probably their planets in the solar neighborhood; the many mysterious objects located elsewhere in our galaxy; the organization of neighboring galaxies; and the intimate behavior of strange bodies located at the largest observed distances. A lunar interferometer is likely to dwarf all the achievements of optical astronomy since its beginnings.

The comparative advantages and drawbacks of optical arrays in high orbit or on the moon will have to be clarified, as design efforts are pursued. The apparent cost advantage of free-flying systems loses its appeal if a multipurpose lunar base is to be installed. Although solar sails provide a simple way of translating array elements in space, it may turn out that walking telescopes can also be effective on the Moon and allow very long baselies of the order of 10 k. A basic advantage of the Moon is that the detecting camera can be buried fairly deeply in the lunar soil to protect it from cosmic rays and the spurious dark count caused by them.

Dr. Pilcher, from NASA's Office of Exploration, told us that NASA foresees international cooperation to implement lunar interferometry. A dedicated international institute with advanced engineering capabilities could be the most efficient way of tracking a project of such importance, that is, under contract with the national space agencies.

The ground-based OVLA project has been pushed and partially funded by the Association of Laboratories for Optical High-resolution Astronomy (ALOHA), which may soon change its name to WALOHA (W for worldwide) to stress its international scope. The history of previous collaborative projects such as the NASA/ESA collaboration on the Hubble Space Telescope, the European Southern Observatories, and CERN suggests that lunar interferometry could be handled more efficiently by an international astronomical organization than by the agencies directly. In Europe, an Institute for Astronomical Optical Interferometry is currently proposed for building the OVLA and VLT's auxiliary interferometer. Two international conferences were previously organized on space interferometry, at Cargèse in 1984 and at Granada in 1987. The next one should probably include sessions on the lunar concepts discussed at this meeting.

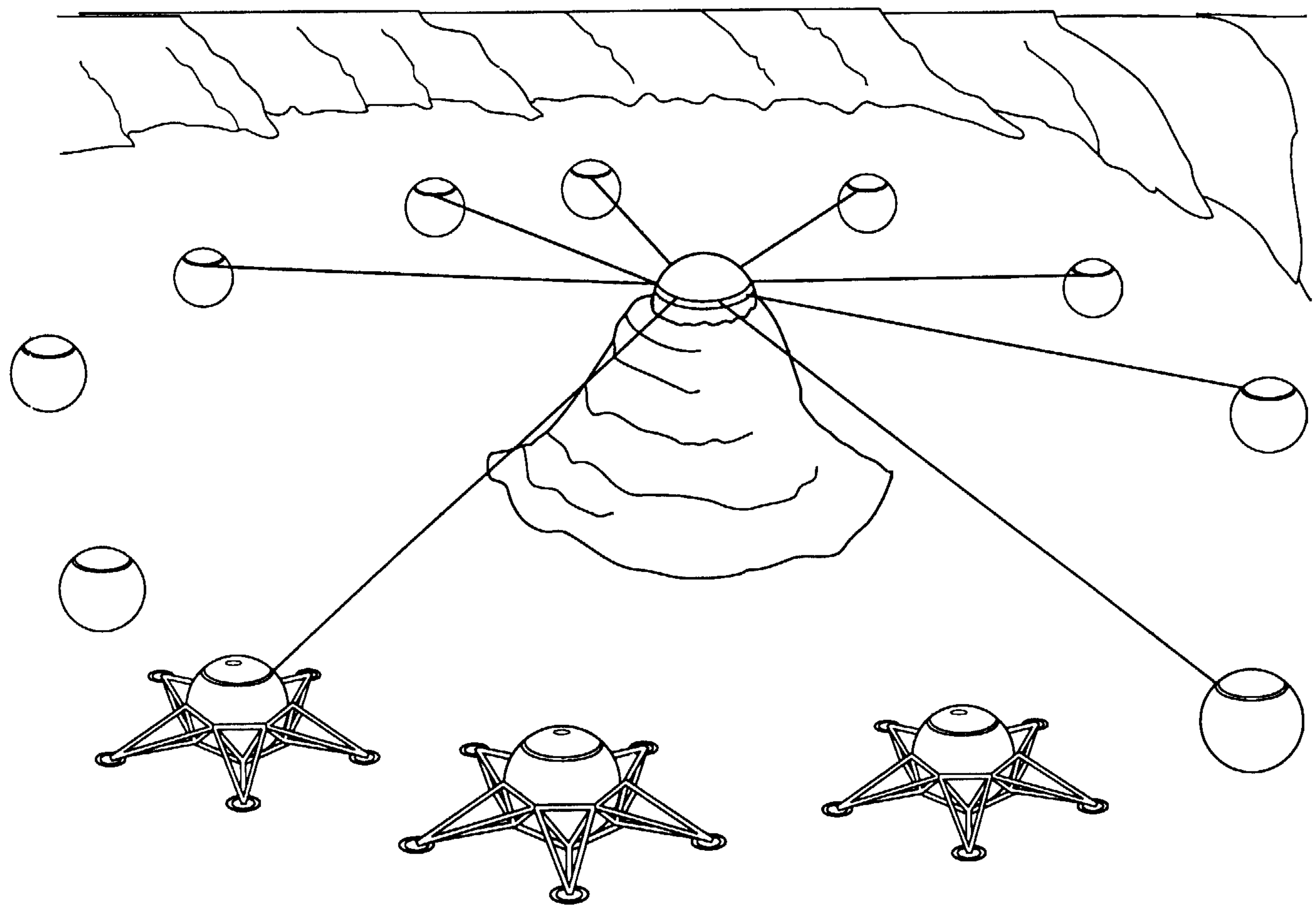

Figure 1: Lunar version of the Optical Very Large Array, which is studied for ground-based implementation in the coming years. The telescopes move in two dimensions during the observation to maintain the equality of optical paths without the need for delay lines. Shown here are telescopes equipped with six robotic legs, like insects, and similarly able to move smoothly under control of a laser metrology system.

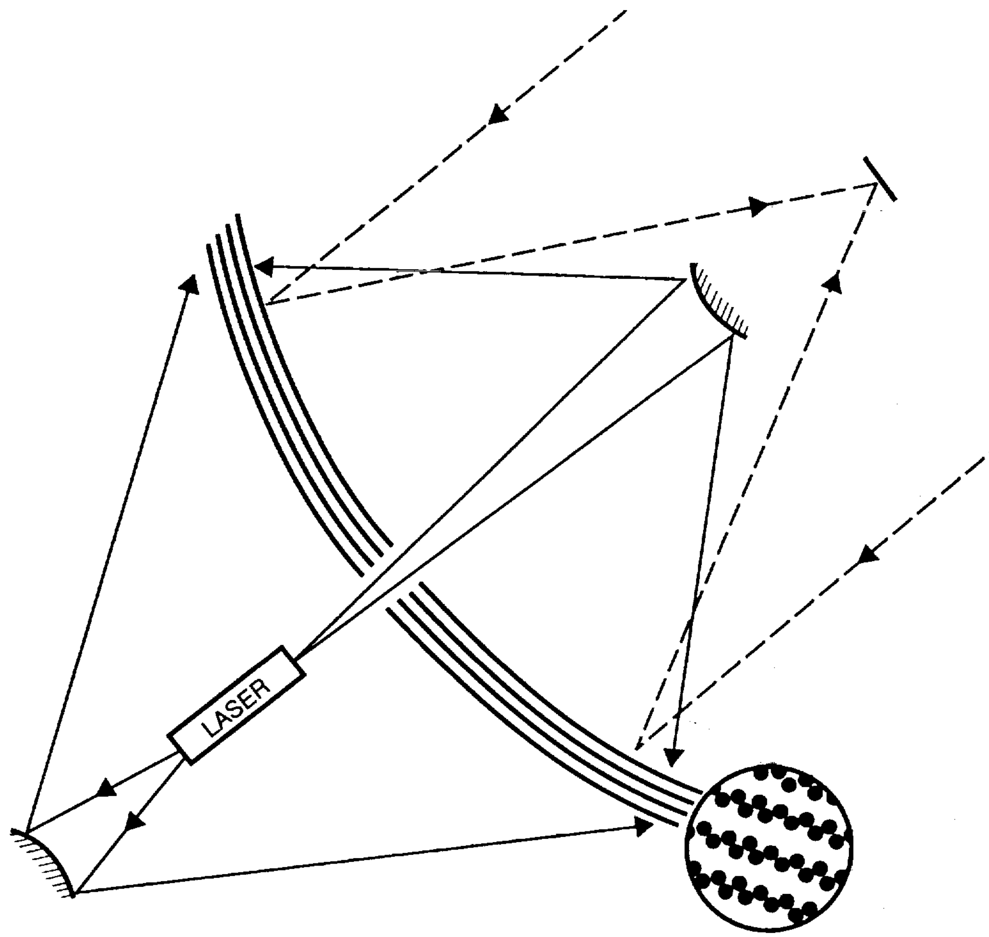

Figure 2: Principle of gaseous mirrors: a standing wave of laser light, having a paraboloidal shape, can trap atoms or molecules and cool them to low temperatures. This can reflect light from a star on axis toward the focus of the parabola. If many nodal surfaces, spaced half-wavelengths apart, are used, the mirror tends to be wavelength-selective. For broadband reflectivity, it appears possible to use a single nodal surface selected by adjusting the corresponding path difference to zero. Atoms are pushed toward this particular nodal surface if a saw-tooth modulation is applied to the laser wavelength. When the wavelength is shortened, the standing wave pattern shrinks toward the zero-order node, and pumps the atoms toward it.

Once the atoms are positioned and cooled, the laser can be turned off intermittently to avoid contaminating the faint stellar beam.