IV. RELATIVE MERITS OF VARIOUS OBSERVATORIES

(A) VARIOUS ORBITS AND SITES

Panel: Relative Merits of Various Orbits and Sites in Space

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LUNAR-BASED ASTRONOMY

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Abstract. The Moon offers for astronomy a truly impressive array of advantages, many of which are briefly reviewed in this paper. These advantages include especially the vast inertial platform and the expected availability of human and robotic "hands-on" installation, maintenance, and modification. The Earth-orbiting Great Observatories will advance our knowledge to a new plateau, but some of the most fundamental observational questions which we are already asking will require lunar-based instruments, including very large filled-aperture telescopes, interferometers with baselines of tens and ultimately hundreds of kilometers, and the utilization of the radio-quiet backside. It is already time to begin planning the first such installations.

1. Background

The realization is rapidly growing that the Moon is a uniquely desirable place from which to do astronomy, also that it should become accessible again in the relatively near future.

Ever since Apollo-mission days the possibility of lunar-based astronomy has been discussed, though usually as a relatively minor topic. However within the last few years, four workshops have been devoted entirely to the question. The first attempt to interest a wider community of astronomers in the issue was a one-day session held immediately after the American Astronomical Society meeting in Houston in January, 1986 [*NASA Conference Pub. 2489*, 1988], which developed a general overview of some of the areas of astronomy which might profit from lunar siting. It was followed by two specialized lunar-astronomy workshops at Albuquerque, respectively in 1988 on Very Low Frequency Radio Astronomy [*NASA Conference Pub. 3039*, 1989] and in 1989 on Optical/IR Interferometry [*NASA Conference Pub.*, 1990]. Each of these meetings demonstrated the very great value of the Moon as an astronomical site. The most recent workshop, a large one held in Annapolis in February 1990 [*American Inst. of Physics Conf. Proc.*, **207**, in press, June 1990] asked a related question, but with different emphasis – namely whether there is fundamentally important astronomy which appears to demand the Moon for its achievement. Results from all of these workshops have contributed to this review, but most of the references noted below are to the proceedings from Annapolis, and are given in the text as (author, Annapolis 1990).

2. Space Astronomy Alternatives

We are already able to operate relatively modest Earth-orbiting telescopes with good efficiency, albeit with high costs – typical missions now average hundreds of millions of dollars. Over the coming decade we should have demonstrated the art of operating medium-sized telescopes in orbit, at costs probably averaging well over

Y. Kondo (ed.), Observatories in Earth Orbit and Beyond, 365–375.

a billion dollars each. Wonderful as the space environment is for astronomy, in near-Earth orbit these instruments still suffer from deleterious atmospheric effects, including drag with the attendant possibilities of de-orbiting or the need for reboosting, also damage and/or airglow caused by the 8 km/sec encounter with debris and residual atmospheric ions. The zero-g environment requires complicated machinery for setting and tracking, with increasingly inefficient duty-cycle for larger instruments. The 90-minute revolution period enforces short exposures, limited access-time windows for any given object, and rapid thermal cycling of the system. Large ground-based staffs are needed to build and operate these complex instruments, and human access for maintenance and modification ranges from difficult to impossible. Geosynchronous orbit offers a major improvement from the point of view of astronomical efficiency, but in turn is still less accessible and also lacks the opportunity for efficient magnetic dumping of momentum, thereby presenting serious problems for the very large (perhaps 50- to 100-ton) instruments which we visualize needing in the next generation after HST. Likewise, any orbiting system faces extreme difficulties with the ultra-precise station-keeping needed for long-baseline optical/IR interferometry. In spite of such problems, Earth-orbiting systems should and will continue to be used as long they are they are cost-effective.

The Moon is a thousand times more distant than LEO, and still 11 times farther away than even geosynchronous orbit. But in the more important terms of pure energy needed to access the lunar surface, it is only roughly double the cost to LEO and about 25% beyond geosynchronous. Improvements of space transportation technology will continue to bring the actual cost differentials ever closer to the raw energy differences, thus drawing the Moon effectively closer. And, in any event, lunar development and utilization by the human race will not be denied. Accordingly it is both timely and important to look closely at the challenges and opportunities represented by the lunar surface for astronomy.

3. Why is the Moon So Good for Astronomy?

The Moon offers an extraordinary array of features conducive to astronomy. A brief listing of principal ones includes:

Ultra-high vacuum ($\sim 10^5$ particles/cm^3). The lunar surface is effectively in free space. Telescopes can be used over their full frequency range and with their full spatial resolving power. Radio, infrared, and optical interferometers can be established with baselines of ultimately up to tens or even hundreds of kilometers. Exposed optical surfaces should retain their full efficiency for very long times (limited, if unshielded, only by micrometeorite effects). It should even be possible to use "naked" photoelectric surfaces should this be desirable for detector systems of special configurations and optimum efficiency.

Stable solid surface. The Moon offers a solid platform with effectively infinite inertia, allowing ultra-simple low-cost terrestrial-type mounting, pointing, and tracking systems to be used. Its rigidity and minimal seismic activity (10^{-8} that of Earth) ensure extreme stability for elements of interferometers with even the longest spacings.

Cosmic ray protection for humans. Extra-solar-system cosmic rays include high-energy components very difficult to shield against, which build up significant radiation damage in the bodies of astronauts exposed for long times. Solar storms are much more dangerous still; several times a year during periods of high solar activity they supply, with onset warning times which might be only a few minutes, doses which would be lethal to exposed astronauts. The Moon offers essentially full protection, given the simple precaution of having nearby habitations and shelters under some meters of lunar soil, with selenauts exposed only when it is necessary to work on the surface.

Cosmic ray protection for detectors. Especially outside the Earth's magnetic field, the performance of some of the most sensitive detectors for nearly all types of radiation is degraded by noise caused by solar and galactic cosmic rays. Some types of instruments will be able to avoid most of this problem by being located beneath the lunar surface, looking out through a small aperture. Even with optical telescopes on the surface, it may often be possible to have the detector at a coudé focus deep underground. Finally, in those cases where everything must be on the surface, the stable lunar platform and low lunar gravity encourage the provision of truly massive shielding around the detector package.

Dark sky. The Moon should be virtually free of air glow (a kind of permanent aurora) which sets a limit on the darkness of even the darkest terrestrial nights. Absence of atmospheric scattering means that the deepest observations can be made at night even if the observatory is on the near side with the Earth always in the sky, and with the "full Earth" being a hundred times brighter than our full Moon. With proper shading and thermal control of telescopes, it is even likely that relatively deep observations can be made in the daytime. Terrestrial and near-Earth-orbit telescopes have trouble collecting useful data more than about a quarter of the time. Their lunar counterparts should seldom stop observing.

Cold sky. Since thermal infrared wavelengths are generated by every object not at absolute zero temperature, observing at such wavelengths is like trying to do optical astronomy using a telescope every element of which is emitting light, while looking through a glowing daytime sky. The best current solution is to cool every part of the telescope with liquid helium and to raise the system above as much atmosphere as possible using balloons or spacecraft. This is awkward even with relatively small telescopes, and also either suffers from limited lifetime of the helium cryogen supply or demands costly and difficult re-supply. Because the temperature of the sky as seen from space or the Moon's surface is only a few degrees above absolute zero, a telescope on the Moon – if carefully insulated from the ground and shielded from any direct or reflected radiation not coming from the dark sky – would cool to and remain at an exceedingly low temperature. This would greatly reduce and perhaps in some cases eliminate the need for cryogens, as well as allow the telescope to be quite large.

Low gravity. Experiencing only one sixth of the Earth's gravity, lunar structures of any size will be of much lighter, less expensive construction than their terrestrial counterparts. This modest lunar gravity also serves the useful function of causing debris and contaminants to fall to the surface, rather than tagging along in place as they tend to do in space.

Absence of wind. Much of the strength built into terrestrial systems is simply insurance against the threat of extreme wind forces, no matter how unlikely. Lunar structures need attend only to static and thermal loads. For example, telescope "domes" might be simple systems of movable Sun-, Earth-, and dust-shades probably consisting of multiple layers of virtually weightless aluminized foil, stretched over ultra-lightweight but rigid structures. Mechanical designers of telescopes, which on Earth must be carefully strengthened against low-frequency vibration resulting from wind-buffeting, will be able to concentrate solely on thermal passivity and on static forces at various angles.

Rotation. The Moon's roughly month-long rotation period guarantees access to all the sky accessible from the latitude of the observatory site, yet is slow enough to permit very long integrations on the faintest possible objects. Some important modern observations demand unbroken time series with durations of weeks or longer; these are extremely hard to get from the ground or anywhere else except deep space. Lunar rotation also gives free sky-scanning to fixed telescopes and the capability of aperture synthesis to interferometers with fixed elements.

Proximity to Earth. The three-second Earth/Moon round-trip communication time allows Earth-based control of some robotic systems and offers no hindrance at all to operation of telescopes by astronomers on Earth. Massive data streams can be continuously broadcast to the Earth for analysis. Few if any astronomers will need to be on the Moon, even when a great many telescope systems are functioning.

Distance from Earth. Human activities, plus those of the Earth itself, generate noise and interference in nearly all kinds of observations. At 400,000 km, the Moon is far enough away to be relatively well quarantined from most of this pollution – experiencing a hundred-fold reduction below the levels even at geosynchronous orbit. Except at radio frequencies, observations from the Moon will be virtually unaffected by the presence of the Earth in the sky.

The lunar farside. Terrestrial broadcasting and other sources of interference blanket all but a few small slices of the rf spectrum. Yet radio astronomy is a fundamentally important branch of the science, and also includes the part of the electromagnetic spectrum in which detectable emissions from any extraterrestrial civilizations are most likely to lie. For limiting sensitivity, radio astronomers and SETI programs must ultimately go to the only place in the universe which never sees the Earth in its sky – the back side of the Moon. This unique state of radio-quiet needs to be preserved as lunar development proceeds.

Raw material. The Moon offers an inexhaustible supply of many essential materials. In the beginning the raw lunar regolith will form essential shielding against cosmic rays as well as outstanding insulating material. As processing facilities gradually come into operation, various cements and building blocks, ceramics, glasses, fibers, and metals will become available. These will be increasingly important as very large astronomical instruments are eventually undertaken.

Landforms. Perhaps the most cost-effective radio telescope ever built is also the largest – the 300-meter dish lining a hemispherical crater near Arecibo, Puerto Rico. Comparably symmetric lunar craters come in almost every size. Aided by the low lunar gravity, and the lack of wind and weathering action, similar radio telescopes up to several kilometers in diameter may someday be built on the Moon.

Room. The Moon offers almost unlimited area for laying out systems of instruments, which can be added to at any time yet be conveniently located near one or more common bases for supplies of consumables, replacement parts, electric and computer power, etc.

Access. The last, but perhaps most important, lunar advantage with respect to other kinds of astronomy from space will follow from the development of lunar bases, offering the immediate proximity of people and support facilities. For the first time this will allow construction of very large, highly sophisticated space telescopes and instrumentation in extremely simple low-cost mountings and housings, with virtually all components readily accessible for maintenance or change by skilled people in the immediate vicinity. Though nearly all observing will be done by astronomers on Earth, the continuous availability of real-time, hands-on technical support will constitute a revolution in the way cost-effective space astronomy can be done.

For more than a century astronomers have been struggling to develop ever-better sites for their telescopes. Quite apart from the many other factors taking the human race to the Moon, the continued needs of astronomers should soon lead us there – to the best place in the solar system from which to do many if not even most kinds of astronomy.

4. How in Practice Can Some of These Lunar Opportunities be Realized?

Lunar astronomical development can be anticipated from two contrasting viewpoints:

Along for the ride. There are substantial reasons (*e.g.*, Smith, Annapolis 1990) to expect that permanently manned lunar bases will be constructed in the very early years of the coming century, primarily for reasons unrelated to astronomy. To the extent this is true, astronomy can and should be "along for the ride." The cost of establishing and maintaining human operations on the lunar surface will be very great for the first several decades, until a significant degree of self-sufficiency is achieved and until transportation costs come down substantially. However, the *incremental* costs of astronomy done from otherwise-supported lunar bases should be quite modest since, as noted above, even simplified versions of relatively low-cost terrestrial instruments can be installed by the selenauts and maintained by them as intermittently necessary – with nearly all the astronomical operations being directed from, and data sent by radio directly back to, the Earth.

Part of the engine. As astronomers, we can hope that the costs of human presence on the Moon will be accepted as part of the price the human race should expect to pay for the exploration, development of, and expansion into the solar system. However, one can also ask, as at the Annapolis Workshop, whether there are next-generation astronomical questions *requiring* instruments which in turn appear to *require* lunar siting. The answer at Annapolis was emphatically yes. From this point of view astronomy becomes one of the drivers for lunar development and thereby potentially liable for some of the infrastructure costs in addition to those of the astronomical instruments *per se.* To the extent this type of bookkeeping occurs, it should not prevent but will likely have the effect of slowing the development of lunar-based astronomy.

Another conceptual branching arises with the question of whether human attendance is necessary for all lunar-based instruments.

Totally automated systems. This may be the fastest way to get started with lunar-based astronomy. It is surely possible to build softlanders carrying simple astronomical telescopes which could do useful work from the lunar surface. At least initially, these might be relatively small instruments designed in effect primarily for testing the lunar astronomical environment. Also, with some specialized instruments such as elements of radio telescope arrays it may prove cost-effective to design systems to be entirely remotely implanted and operated. However, this approach appears to have problems if adopted as the general rule for lunar telescopes. Compared to free-space operations with their necessarily complicated pointing and tracking systems, it gains the solidity of the lunar surface but pays the price of the extra design and construction cost and complexity associated with totally remote installation and operation, while also giving up continuous accessibility of the entire sky. In addition, it is hard to see how very large and complex systems can be successfully installed and operated without direct human access (or in some cases, perhaps immediately adjacent telerobotic operation).

Human presence. An earlier section has listed a great many opportunities presented by the Moon for astronomy. Many if not most of these come into play when human presence is established. In the long run, and however the bills are paid, significant lunar astronomical developments will, with virtual certainty, involve hands-on human contact. At least in the early stages, this contact might be continual rather than continuous. Telescopes could be installed during relatively short lunar missions, and serviced or modified as necessary by later ones. But the very large systems proposed at the Annapolis workshop will probably require almost constant presence, which fortunately should be available by the time it becomes feasible to build them. It is thus reasonable to expect a variety of kinds and sizes of telescopes to be installed on the Moon. Once the first lunar base is established, its astronomical aspects are likely to develop very much the character of the European Southern Observatory, where groups of nations, individual nations, or even smaller organizations contribute telescopes and equipment while sharing common support and operating facilities. In particular, within the first decade a number of relatively modest instruments are likely to be at the lunar observatory. Each of these – for simplicity, economy, reliability, and stability of calibration – should normally be dedicated to a single function. One such telescope could be a small, even a very small, item in the payload of nearly every lunar re-supply mission. Some candidate instruments are discussed in Sykes *et al.* (Annapolis 1990). We now lump the class of such low-cost but high-yield systems under the acronym DARTs [Dedicated Astronomical Research Telescopes], and visualize that from the beginning of lunar development many of these should be "tossed" at the Moon for unloading, laying out on the lunar surface, plugging in, turning on, and subsequent near-ignoring by the selenauts. A typical list of DARTs might include:

– Fixed transit telescope(s) with clocking CCDs for deep sky studies; – Simple multi-color photometric telescope(s) for studies of stellar variability, stellar seismology, and the possible rare but important detection of planets around other stars; – Simple high-resolution imaging telescope to supplement HST; – Dedicated planetary imaging telescope, especially for detailed studies of the Martian atmosphere in preparation for eventual human landings; – Simple spectroscopic telescope(s) – (sons of IUE); – All-reflecting Schmidt (deep UV and near-IR surveys in many wavelengths); – Passively (later actively) cooled thermal IR telescopes; – Two- (later more-) element optical/IR interferometer.

Similar, non-optical instruments should probably include:

– Prototype very low frequency (VLF) radio interferometer; – Moon-Earth VLBA antenna; – "Suitcase" X-ray telescope; – "Suitcase" gamma-ray telescope.

However, in spite of the great advantages which human-tended lunar operations will offer for the above and similar small to modest instruments, it is unlikely that lunar bases would be established solely for this class of instruments which at least in principle could be operated in Earth orbit.

5. What Astronomical Problems and Instruments Demand the Moon?

The Annapolis workshop did not consider exhaustively all aspects of astronomy – in particular it treated only peripherally a number of challenges in modern physics which impinge on astronomy. Nevertheless, each of the major working groups at the meeting came up with fundamental questions, all of which are sure to challenge astronomy of the 21st century and all of which appear to require lunar basing of the instrumentation needed to tackle them.

5.1. Are there Earth-like Planets Among the Nearby Stars?

Within the next few years any of several techniques should succeed in allowing us to infer the presence of Jupiter-sized planets, assuming they exist, around some of the nearer stars. However, Earth-mass planets approximately an astronomical unit from their primaries will be two to three orders of magnitude harder than Jupiters to discover, and far more difficult still to study in any detail. The problem becomes tractable in principle by going to long wavelengths, where the contrast ratio between such a planet and its central star improves from 10^{-10} (visible light) to 10^{-5} (thermal infrared). To study thoroughly at 10 micrometers wavelength the space as close as 0.2 AU to stars within about ten parsecs of the sun will require an ultra-stable IR interferometer of more than 100-meter baseline. For adequate photon statistics, the total collecting area should be at least several hundred square meters, and the telescopes in the array must be at cryogenic temperatures. To construct and successfully operate such a system in orbit would be a forbidding task, if possible at all, whereas in principle it should be relatively straightforward given human access to the stable lunar surface.

5.2. Do Life and Intelligence Exist Elsewhere?

Life processes drive the Earth's atmosphere far from chemical equilibrium. Detection of both free oxygen and methane in the atmosphere of another planet would be *prima facie* evidence of life at least somewhat as we know it. All candidate planets discovered by techniques such as in the paragraph above, or by any other means, need to be studied by low-resolution spectroscopy, searching especially for O_3, CH_4, NH_3, H_2O, and CO_2 over the wavelength region from about 6 to 15 micrometers. This work requires a preferably single-aperture cryogenic telescope of several hundred square meters aperture with exceptionally precise and stable pointing characteristics. Again it seems necessary to locate such a telescope on the Moon.

Evidence of other intelligence in the universe may be much harder yet to discover. In recommending a modest long-term SETI program, the 1980 Astronomy Survey noted (*Challenges to Astronomy and Astrophysics: Working Documents of the Astronomy Survey Committee*, National Academy Press 1983, pp. 267–272) the probability that, quite apart from the remote possibility of their choosing to establish "beacons," even highly advanced technologies may still use extremely powerful microwave radars and perhaps power beams the spillage from which would be detectable at very great distances. The microwave spectral region is also the quietest in terms of background noise, thus (following the impeccable logic of the drunkard searching for his lost key under the streetlight) we need to study this region minutely, and in effect to search much of the galaxy over an enormous range of microwave wavelengths for evidence of such transmissions. In turn, the back side of the Moon is the only place which is sufficiently radio-quiet for this program to be carried out. Very large antennas – perhaps of the Arecibo type – are needed for the work.

5.3. What's Happening in Our Sun and Other Stars?

Our experience of solar physics and processes is based on a single temporal snapshot in the 4.5-billion-year life of this garden-variety star. We know that the terrestrial climate has changed radically on very long timescales, perhaps in part because of solar changes, and that the sunspot cycle which may affect climate on short (decades to centuries) timescales virtually disappeared during the Maunder Minimum nearly 400 years ago. Even the solar neutrino flux remains an unsolved problem. A fundamentally important way of gaining insight into our sun is to investigate processes occurring in other stars.

Comparative solar-stellar physics requires observing the surfaces of other stars on spatial scales similar to those which appear most relevant for our understanding of the sun (Woolf, Annapolis 1990). Much of the action on the solar surface appears to occur at size scales of 100 km or even smaller, corresponding at nearby stellar distances to micro- or even sub-microarcsecond resolution at optical wavelengths. In turn this mandates optical/near IR interferometers of at least 100-km baselines. The necessary pointing and tracking precision seems unattainable in space but again in principle to be achievable on the lunar surface. So powerful an interferometer will surely require many decades to achieve, but should be an objective toward which initial and intermediate systems can grow – a start can be made with 2-meter class telescopes and 100-meter baselines.

As an important side issue in solar astronomy, very large flares emit particle fluxes which are potentially lethal to unprotected astronauts who are outside the Earth's Van Allen belts. Quite apart from the useful science to be done with a modest several-meter-class diffraction-limited solar telescope on the Moon, its continuous monitoring of the sun should help to warn selenauts of impending danger in time to seek shelter. Full coverage of solar activity will of course require antipodal lunar observatories.

5.4. How Do Stars and Planetary Systems Form?

There are many uncertainties in our understanding of how stars, and in particular solar systems, form. The spatial scales of greatest interest are the zones where protoplanets are presumably forming in the protostellar nebulae – that is, features about 0.1 AU in size. The available tracers are the spectral lines of many gaseous species, particularly CO and H_2O. Preplanetary disks have enormous optical depths in the visible and infrared regions, but become optically thin around 600 micrometers wavelength. In particular the 557 GHz line of water is the best probe of outer low-temperature regions of the disks. Unfortunately, the nearest star-forming regions are about 140 parsecs distant. Even to reach 600-micrometer resolution of 1 AU at this distance requires an interferometer baseline of at least 24 km; ultimately a submillimeter interferometer system will probably utilize a substantial fraction of the lunar diameter. Here again the necessary unhampered space observing conditions along with the required dimensional stability and pointing precision can be achieved on the Moon (Burke, Annapolis 1990).

5.5. What Happened in the Early Universe?

Cosmology appears to be approaching an impasse, wherein the microwave background insists that the early universe was extraordinarily uniform, whereas observations of the most distant quasars imply that the universe had already crystallized out into stars and presumably galaxies by almost comparably early times. Galaxy clumpings and voids are already seen to extend to at least 3.3 billion light-years, but even more provocatively they appear to be periodic at least in some directions (Szalay, Annapolis 1990). The nature of the voids is not understood, nor has "hidden mass" adequate to close the universe been found, though several lines of evidence suggest its presence.

Investigation of the formation and evolution of stars and galaxies in the early epoch $5 < z < 15$ requires photometric and spectroscopic observations of quasars, early galaxies, and perhaps especially the intergalactic medium in the 0.75–10.4 micrometer wavelength range (Weedman, Annapolis 1990). A 16-meter-class cryogenic filled-aperture telescope would meet these needs, but it must be in space to achieve diffraction-limited imagery and full wavelength coverage. Here again the cooling and extreme pointing stability required of this immense and massive telescope speak for its presence on the Moon.

Along with photometry and spectroscopy, ultra-high spatial resolution will be needed for many key investigations. Imaging the structure and kinematics of active galactic nuclei and quasars is basic to understanding their physics and evolution. This core activity is most significant on spatial scales below 0.1 parsec. Microarcsecond resolution is needed to map these structures at distances of several thousand megaparsecs. Fifty-km baseline lunar-based interferometric arrays working at 2 micrometers would satisfy this condition. Large X-ray and gamma-ray telescopes will also be needed to study these questions.

Common themes running through the fundamental problems outlined above are the need for great, usually cryogenic, apertures to collect sufficient photons from the extremely faint and/or distant target objects, the need to see these in great spatial detail reaching ultimately as far as sub-microarcsecond resolution, and the fact that the Moon is almost certainly the only place where these goals can be achieved. Any of the lunar telescopes will doubtless serve many other astronomical objectives in addition to the specific goal or goals justifying its construction – but this has been the history of astronomy.

6. Are We Ready to Return to the Moon?

Thanks to the Apollo missions a great deal is already known about the lunar surface. Nevertheless, it is not clear that we yet know how best to carry out major astronomical developments on the lunar surface. Extensive moving around and actually working on the lunar surface present problems at which the Apollo experience only hints – in particular, how humans can work efficiently in the environment of vacuum and dust, and cope with the threats of micrometeorites, cosmic rays, and especially solar-flare particles. Teleoperated robots probably hold the key to large areas of this problem. Also, there are important practical details such as how to deal with the possibility of major electrostatic effects on sensitive equipment, with extreme temperature changes from day to night, with the influence of cosmic rays on detectors, and with the effects of micrometeorites on optical surfaces. Some experience with operating telescopes of several kinds on the Moon would be very valuable before committing to the final designs of initial large and expensive instruments. A strong case can be made for planning several test instruments – probably first a transit telescope placed remotely by a softlander or at least installed by the very first lunar return party. Likewise, a small fully-steerable telescope could give invaluable experience in the way complex machinery should be built, operated, and shielded from various environmental influences on the Moon.

Political as well as scientific and technical factors will decide how the lunar observatories finally come into existence, and some degree of international cooperation is almost certain to be involved. Most of us are probably tolerant of a rather wide variety of approaches to these questions, but nevertheless hope and expect to see the effort – so important to the future of human understanding of the universe – begun in the very near future. NASA is planning human return to the Moon around the beginning of the new century. In view of the long lead times required for even relatively simple space projects, it is urgent for detailed study and development of lunar telescopes to be undertaken now.