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SPACE AND LUNAR-BASED OPTICAL TELESCOPES

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The Great Observatory Program

The Great Observatory Program indicates a commitment by NASA and, I hope, by this Nation to support permanent major capabilities in space covering much of the electromagnetic spectrum. The well-known five major observatories are Hubble Space Telescope (HST), Gamma-Ray Observatory (GRO), Advanced X-Ray Astrophysics Facility (AXAF), Space Infrared Telescope Facility (SIRTF), and Solar Optical Telescope (SOT). All are relatively general purpose astronomical facilities, tailored to a given spectral region or, in the case of SOT, to solar observations. The HST, the AXAF, and the SIRTF are intended to be long-lived satellites; therefore, their large development costs can be amortized over 10- to 15-year lifetimes.

In addition to the budgetary benefits, maintenance of these satellites by the Space Shuttle and the Space Station will provide important scientific benefits: the continuity of national and individual science programs, the use of replenishable cryogenics on all three satellites, and maintained excellence through the upgrading of the scientific instruments. These qualities are valuable and should not be dismissed lightly. Just as valuable but more difficult to quantify are the multiplicative benefits provided by the scope of the overall program.

1. The temporal overlap with the other space observatories will provide for rapid followup in multiple bands.

2. The long-term nature of the observatories permits both short-term and long-term programs along a broad front of scientific objectives.

3. Ultimately, these observatories will lead to increased discipline-crossing, coordination, and scientific integration with ground facilities. This progression is extremely valuable for both the scientific spinoffs and the sharing of technological advances.

Thus, although there is an equal need for unique and innovative programs to solve critical scientific problems, the long-term access to general-purpose space observatories holds a great future for astronomy and science in general. Indeed, one of the major attractions of a lunar base for astronomy is the continuation and expansion of the Great Observatory Program. The long-term use of each observatory and continuity within the program are two goals addressed in the timetable and the remarks that follow.

[1]Operated by the Association of Universities for Research in Astronomy, Inc., for the National Aeronautics and Space Administration.

The Next 25 Years

An optimistic timetable for reaching various milestones in the development of astronomical facilities is presented in table I. The approximate years of launch are indicated for the Great Observatories, the Space Station, and an orbital transfer vehicle. Dates are estimated for the launch of optical, infrared, and x-ray observatories. Because each of these observatories is assigned a 15-year lifetime, the launch date given on the timetable for the second generation of these observatories is 15 years later. It is clear from such a schedule that the second-generation space telescope will be needed a decade before the construction of the required far-side base. Indeed, planning for the HST replacement should begin within the next 3 to 4 years.

Possible Successors to the Hubble Space Telescope

The approach Bely (Space Telescope Science Institute) and Roddier (National Optical Astronomy Observatories) have taken in a recent paper is to compare the relative scientific benefits and maturity of designs proposed for the spectral region covered by the HST, with consideration given to effective collecting area and angular resolution. The effective collecting area and the angular resolution for a 4-m-class ground-based telescope, for the HST, and for satellite instruments with a variety of effective filling factors are shown in figure 1. Near the line given by a completely filled single disk is an 8-m disk proposed by Perkin-Elmer (P-E 8-m) in a recent study done for NASA. Plotted nearby is the Space Ten-Meter Telescope (STMT), a 10-m monolith described later. Appearing somewhat farther from this line are the partly filled interferometric arrays, COSMIC 1 and COSMIC 4, proposed by Traub and the nonredundant Golay designs also studied by Perkin-Elmer. At much higher resolution, but with considerably less collecting area, the free-flying, kilometer-baseline spacecraft couples such as TRIO, proposed by Labeyrie, can be found.

The considerably broader angular field, the ability to use conventional spectroscopic and imaging instrumentation, and the considerably enhanced collecting area support the selection of a filled-aperture approach for the next-generation, general observatory in the ultraviolet/near-infrared region. Further, the low-risk simplicity of operation and design of a filled array may well compensate for much or all of the increased costs suggested by typical scaling laws. However, the appropriate scientific weighting of these factors will be much better understood following the analysis of early space telescope data and, in particular, the work on complex stellar fields and distant sources.

The Space Ten-Meter Telescope

The Bely and Roddier design has as its goal a general-purpose observatory, supporting both imaging and spectroscopy, with a significant gain in collecting power and resolution compared to the HST. Like the HST, it will cover the ultraviolet portion of the spectrum to the midinfrared. It will be limited by mirror coatings and polish to a low wavelength near 120 nm and by thermal mirror emissivity to the 4- to 5-μm range, with good collecting power for bright sources to 10 to 20 μm. One crucial feature is the use of geosynchronous orbit, which yields very high operational efficiency and simplicity as demonstrated by the successful International Ultraviolet Explorer.

A cross section of the satellite displayed in figure 2 shows its most salient features.

- The fast f/1 primary mirror made from glass or ceramic is diffraction-limited in the 0.6- to 1.0-μm wavelength range.

- Because of "g" release concerns and the potential for large temperature differentials across the primary, the secondary mirror will be actively controlled on time scales of hours.

- The ultimate in resolution for the ultraviolet can be achieved by using interferometric techniques over a narrow field as suggested by Roddier.

- Because of the fast primary mirror and the distance to the Earth, the baffle can be kept very short yet still achieve negligible scattered light background.

- The baffle and the primary and secondary mirrors are passively cooled to 170 K in the same fashion as the large deployable reflector (LDR).

Given optimum enabling technologies, the telescope's performance would be spectacular. The STMT would have

1. Four times the resolution of the HST: 20-marcsec images in the visible

2. Sixteen times the light gathering power of the HST

3. A limiting magnitude in the visible wavelength for a 3-hour exposure of a 33rd magnitude star (an A star in Virgo)

4. Excellent performance out to 4 μm, where the collecting power and angular resolution will complement SIRTF and the next-generation cryogenically cooled telescope in the same way that LDR complements SIRTF on the long-wavelength side

The Advantages of Earth Orbit and Lunar Sites

Some of the key advantages of the Space Ten-Meter Telescope are provided or enabled by a high Earth orbit. A review of the various qualities of low Earth orbit (LEO), geosynchronous orbit (GEO), and lunar siting (table II) reveals some of the major issues which will determine the manner in which a lunar base will continue the development and maintenance of permanent ultraviolet-optical astronomical facilities.

Launch and Building Costs

Launch and building costs for lunar-based facilities certainly will determine the nature of the first optical telescopes. If site preparation and construction costs are very high, then the first astronomical facilities are likely to be largely preassembled and capable of standalone operation. These could be small-diameter, Explorer-class telescopes mounted in support stations similar to the lunar or Mars landers. Examples of these could be astrometric telescopes, all-sky ultraviolet-optical survey telescopes, and solar stellar monitors. An exciting prospect is that the initial restriction to small sizes would still permit the construction of unique very-large-array optical facilities in the early years of a lunar base. To ensure that the cost of site preparation and construction of the prefabricated observatory will be small relative to ongoing expansion and utilization of the lunar base, large, 10-m-class telescopes probably will be constructed after the lunar base population has increased significantly.

Low Light Backgrounds

For both small and large telescopes, the lunar basing offers extremely low light backgrounds for the majority of the orbit. To avoid scattered light from earthshine, the optical site should be placed on the equatorial limb or preferably on the far side. To avoid manmade light pollution, the site should be placed approximately a kilometer from any lighted manned base.

Maintenance and Refurbishment

A major drawback of a geosynchronous orbit is the cost and difficulty of maintenance and refurbishment from the Space Station. Once a lunar base is self-sufficient in propellant manufacture, one of the early benefits of a lunar base may be servicing of geosynchronous satellites such as the STMT.

STMT Designs for a Lunar Base

The single monolith telescope which is suitable for geosynchronous orbit would need major changes for a lunar site. First, the finite gravity would deform even the 10-ton single dish. Instead, the lunar analog would probably be a segmented mirror, constructed on the Moon , with a significantly larger diameter, say 25 m. Control of each segment in the fashion of the Keck telescope would be possible and would yield the largest optimum field of view. Given the slow rotation of the Moon, the tracking might be done by secondary control, interspersed with motions of the entire dish.

Thermal Effects

The use of passive cooling would be desirable in order to push as far as possible into the near-infrared. However, temperatures much less than 170 K may be difficult to achieve. Although mirror deformations caused by thermal effects would be removed by the segment actuators, it is clear that thermal effects will probably be the equivalent of Earth "seeing" at the highest angular resolutions, whereas tracking irregularities will replace the wind buffeting as the cause of pointing instability. To better stabilize the thermal environment, the telescope should be housed in a large, insulated enclosure for the daylight period. With the use of a movable sunshade outside the "dome" and a radiation screen in the "slit," a portion of the daylight period could be used for continued observation and work in the solar-blind portion of the spectrum (120 to 200 nm).

Instrument Selection

Another advantage of a permanent, lunar-based optical facility compared to a free-flying satellite would be the ability to upgrade scientific instrumentation and provide for more flexible configurations such as optics customized for particular wavelength regions and more special-purpose instrumentation. One of the serious drawbacks of current space astronomy has been called the "Tyranny of the Masses," which means that special-purpose or complex instrumentation such as polarimeters, multiobject spectrographs, narrow-band imagers, and astrometric devices are at a disadvantage in competition for limited focal plane and satellite resources. With the possibility of weekly or monthly configuration changes, these unique instruments can be used to full advantage. Therefore, it is highly desirable for a filled-dish observatory to have the capability for monthly configuration changes, which are usually accomplished during the daylight period.

Data Handling

Optical astronomy is being inundated with high-volume, digital data. The Space Telescope Data Capture Facility was designed to accommodate 2×10^9 bits per day and will no doubt be saturated, particularly with the second-generation spectrograph. The STMT described earlier and a lunar version would have a usable focal plane of 2×10^8 pixels, and detector arrays of this size should be available. For read periods of 10^3 seconds, the data flow would be 3×10^{11} bits per day, or greater than the capacity of a 3-MHz dedicated link. Although operation of the telescope would probably be handled at a remote base with data telemetered to Earth for reduction, lunar-based operators must have a quick-look capability and limited data reduction tools to enable verifying proper operation. On the basis of HST experience, it is clear that computational capabilities comparable to a current supercomputer will be required (10 to 20 megaflops).

Conclusion

These observations have been limited to an extrapolation of HST capabilities in terms of a large, passively cooled, single-disk telescope, which will be required to continue the progress of ultraviolet to near-infrared astronomy well beyond the lifetime of the HST. On the Moon, many of the operational advantages of ground-based astronomy will permit novel instrumentation and new advances in the region of the spectrum best suited for the studies of stars and stellar systems. However, the Moon holds even greater advantages for spectacular improvements over the traditional observatory, particularly in the areas of long-baseline optical interferometry and large, cryogenically cooled telescopes.

TABLE I.- CURRENT TIMETABLE FOR THE GREAT OBSERVATORIES

Date	Event
1986*	Hubble Space Telescope launch
	Gamma-Ray Observatory launch
1990	Hubble Space Telescope refurbishment
	Space Station started
	Advanced X-Ray Astrophysics Facility launch
	First Hubble Space Telescope advanced scientific instruments (ASI)
	Space Station completed
	Space Infrared Telescope Facility launch
1995	Second Hubble Space Telescope ASI
	Geosynchronous orbit transfer vehicle available
2000	
	First lunar base established
	Space Ten-Meter Telescope launch/large deployable reflector launch
	Gamma-Ray Observatory II launch
2005	
	Advanced X-Ray Astrophysics Facility II launch
2010	Space Infrared Telescope Facility II launch
	Far-side lunar base established
2015	First large lunar telescopes

*Editor's note: These dates represent pre-*Challenger* schedules. As of this writing, the HST is manifested for a 1989 launch. Uncertainties in the Space Shuttle schedule, in Space Station deployment, and in further development of the Great Observatory concept will change this qualitative plan further. (W. W. M.)

TABLE II.- ADVANTAGES OF VARIOUS SPACE LOCATIONS FOR ASTRONOMICAL FACILITIES

Characteristic	LEO	GEO	Lunar base
Launch costs	Low	High	High
Maintenance platform	STS/SS[a]	SS/LB[b]	LB
Maintainability	Very good	Poor	Very good
Science operations	Complex	Simple	Simple
Scientific efficiency, %	35	90	45
Optical background	Earth/zodiacal	Zodiacal	Zodiacal
Thermal stability	Poor	Very good	Very good
Maximum exposure, hr	0.75	17	336
Large apertures	Limited	Limited	Good potential
Upgrading	Good	Poor	Excellent
Configuration	Rigid	Rigid	Flexible

[a]STS = Space Transportation System; SS = Space Station.
[b]LB = Lunar base.

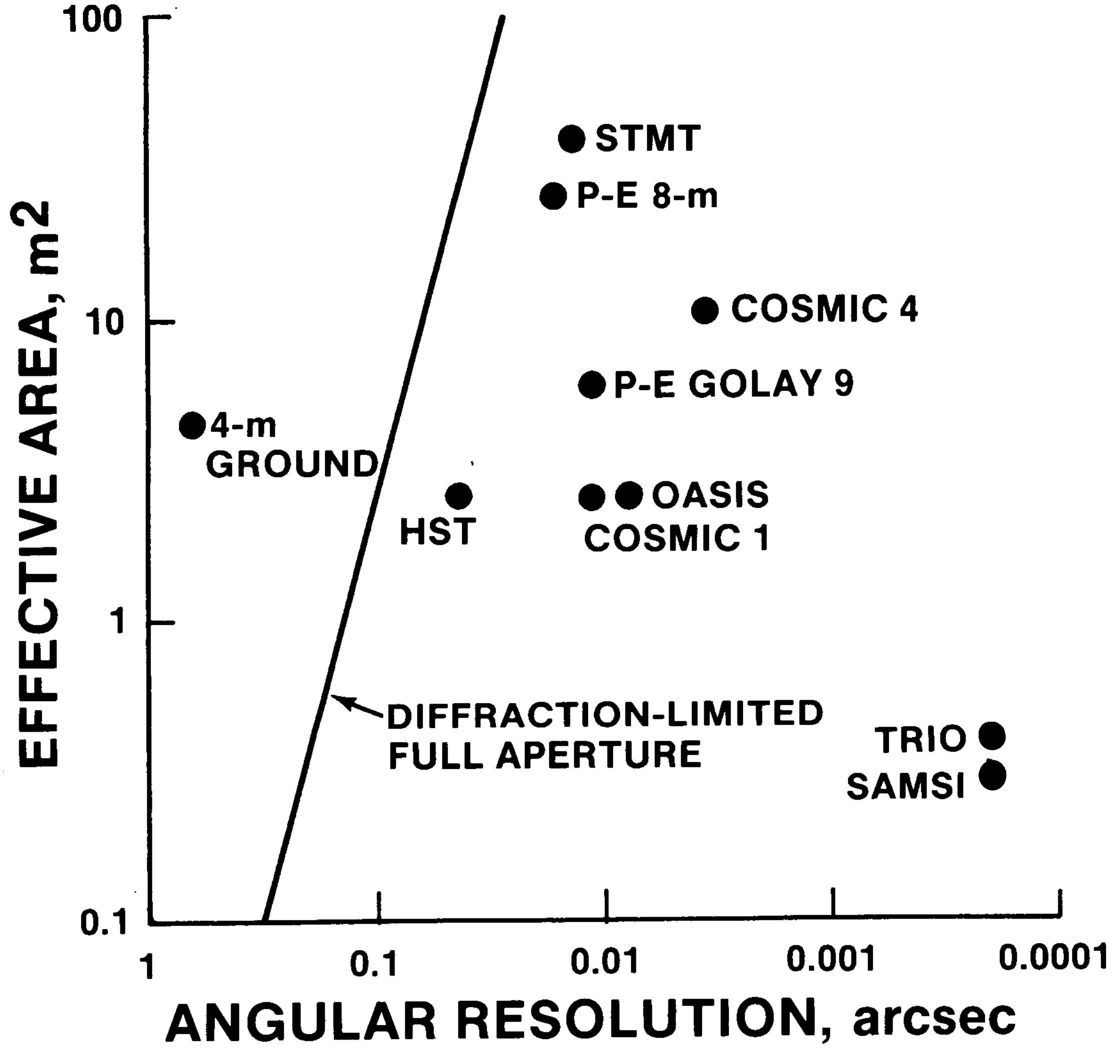
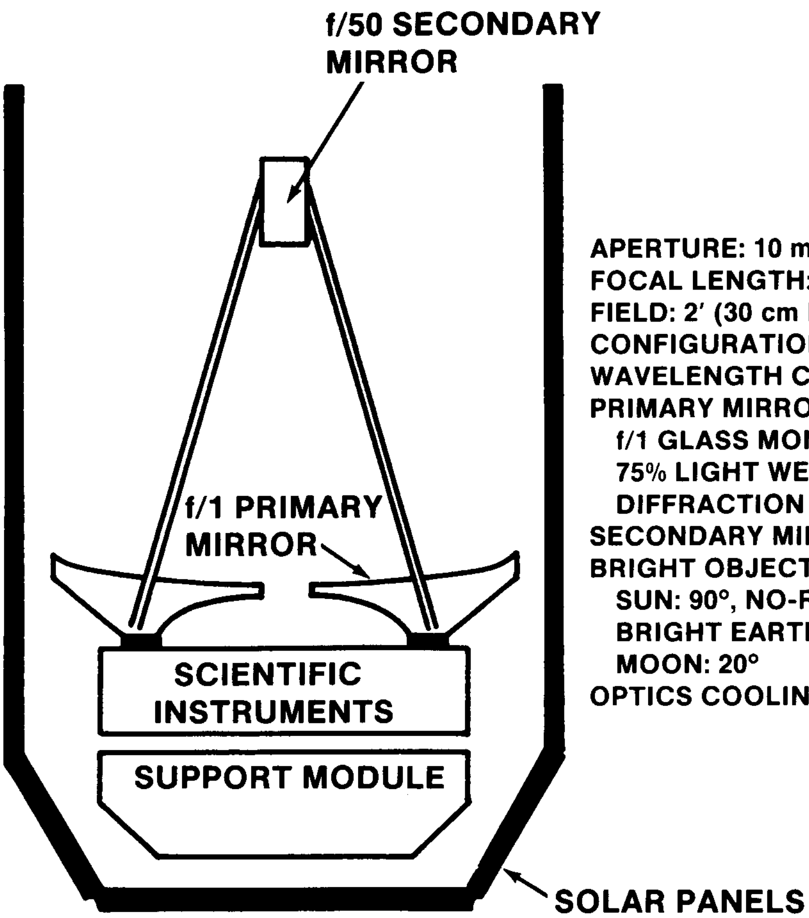


Figure 1.- Effective collecting area as a function of angular resolution for a 4-m-class ground-based telescope, for the Hubble Space Telescope, and for satellite instruments having a variety of effective filling factors. The line represents a completely filled single disk.



APERTURE: 10 m
FOCAL LENGTH: 500 m
FIELD: 2′ (30 cm DIAMETER)
CONFIGURATION: CLASSICAL CASSEGRAIN
WAVELENGTH COVERAGE: 1200 nm TO 30 μm
PRIMARY MIRROR:
  f/1 GLASS MONOLITH
  75% LIGHT WEIGHT
  DIFFRACTION - LIMITED AT 1 μm
SECONDARY MIRROR: ACTIVE
BRIGHT OBJECTS VIEWING LIMITS:
  SUN: 90°, NO-ROLL CONSTRAINT
  BRIGHT EARTH: 60°
  MOON: 20°
OPTICS COOLING: PASSIVE 170 K

Figure 2.- Cross section of Space Ten-Meter Telescope.