Submitted to Space Times, August, 2001

A New Sputnik Suprise?

Paul D. Lowman Jr.
Goddard Space Flight Center (Code 921)
Greenbelt, MD 20771

27 Aug. 01

Popular Summary

This paper suggests that a new "Sputnik surprise" in the form of a joint Chinese-Russian lunar base program may emerge in this decade. The Moon as a whole has been shown to be territory of strategic value, with discovery of large amounts of hydrogen (proably water ice) at the lunar poles and helium 3 everywhere in the soil, in addition to the Moon's scientific value as an object of study and as a platform for astronomy. There is thus good reason for a return to the Moon, robotically or manned. Relations between China and Russia have thawed since the mid-1990s, and the two countries have a formal space cooperation pact. It is argued here that a manned lunar program would be feasible within 5 years, using modern technology and proven spacecraft and launch vehicles. The combination of Russian lunar hardware with Chinese space technology would permit the two countries together to take the lead in solar system exploration in the 21st century.

Introduction

The western world was taken by surprise in 1957 when the Soviet Union launched Sputnik 1, although the USSR had made no secret of its plans. The result of the "sputnik surprise," as it has been termed, was an epic competition between the United States and the Soviet Union, one that rapidly focussed on a race to the Moon. With six successful manned landings, the U.S. won the race decisively. (The term "manned" will be used without apology. Women today fly spacecraft and bombers, and no longer need condescending euphemisms.)

The long-range results of the Apollo Program were far greater than most people realize. For example, Apollo triggered a wide program of remote sensing research,and it has been documented (1) that Landsat is one of the results of the Apollo Program. The direct scientific return from Apollo has been enormous, including new fundamental knowledge of the solar system in general, not just the Moon. It has even been argued (2) that the clear demonstration of American technological superiority provided by Apollo, specifically cited by Andrei Sakharov in 1970, contributed in some degree to the end of the Cold War. A somewat similar suggestion has recently been made (July 2001) by Russian academician Boris Chertok (3), that the Soviet-American space competition helped prevent nuclear war by diverting the military-industrial complexes of both sides to "a peaceful channel."

Much has of course happened since the last Apollo landings in 1972. Major developments of the final decade of the 20th century are shown in Table 1. The period covered is that since completion of the last broad space planning exercise, the Space Exploration Initiative (SEI).

The purpose of this article is to look ahead to the first decade of the new century, and specifically to show that a new "sputnik surprise" may emerge soon, in the form of **a cooperative Chinese-Russian lunar base program**. The basis for this proposition is a broad one, summarized as follows.

Views presented here are those of the author alone, and do not represent those of Goddard Space Flight Center or NASA.

Strategic Value of the Moon

The Moon has now been shown to be not only a body of scientific interest but territory of strategic value. This realization had been emerging since the Apollo landings, and was confirmed by a number of scientific studies and two unmanned lunar missions, Clementine and Lunar Prospector, during the 1990s. There are several specific aspects of the Moon's strategic value for space exploration, technology development, and basic scientific research (4).

First, and most obvious, the Moon is **accessible**, compared, for example, to Mars. The Apollo spacecraft got to the Moon in about 3 days. The lunar launch window is essentially always open, in contrast to that for Mars, which opens only every two years or so. The Moon's closeness to Earth, only 1.3 light-seconds, permits real-time remote control of instruments or vehicles. This has been done on Mars, never closer than 4 light-minutes, but is obviously easier for the Moon.

A more fundamental advantage of the Moon's closeness is that the **continually open launch window**, combined with short transit times, means that any lunar program is inherently faster than any planetary one, other factors equal. Long term plans for the exploration of Mars are necessarily quantized in 2 year units; a lunar program has no such constraint.

Nearly as important as the Moon's accessibility, the environment of the lunar surface is **predictable, stable,** and **survivable**. Surveyor 3,visited by the Apollo 12 crew, was still intact, though not functioning, after two and a half years on the Moon. The Apollo-emplaced geophysical instruments operated for several years, and were only turned off for budgetary reasons (5). One component, the laser retroreflectors, is still functional, in that these unprotected optical surfaces are still being used for earth-based studies. The telerobotic rovers Lunokhods 1 and 2 - one Soviet lunar achievment never matched by the United States - operated successfully for several months. The success of the Apollo geophysical instruments, and the successful operation of the first Moon-based telescope during Apollo 16, have directly demonstrated that properly designed equipment can survive the lunar environment indefinitely.

The Apollo astronauts lived for as long as 3 days on the Moon, finding it an enjoyable and exciting experience despite the cramped living quarters of the Lunar Module. Long-term survival for humans on the Moon is of course a different matter, and factors such as radiation shielding must be taken into account. However, the space environment in general - to which the lunar surface is essentially equivalent except for a gravity field - is now well-understood, as decades of space station operation have now demonstrated. There is no doubt that the Moon is fundamentally habitable.

There is now conclusive evidence that the Moon has valuable material resources. The Apollo samples showed that, as expected, the surface composition is grossly similar to that of the Earth in being dominantly silicates of calcium, sodium, iron, and magnesium, and - surprisingly - iron/titanium oxide. Silicates are based on the silicon-oxygen tetrahedron, with each silicon atom surrounded by four oxygen atoms. There are thus abundant oxygen and industrial metal resources on the Moon. The biggest deficiency in sites visited by Apollo was water, returned samples being not only completely without water of crystallization but chemically reduced, implying dry magmas and lavas.

The Clementine bistatic radar experiments (6) indicated microwave polarization properties similar to those of water ice for a south pole area. Earth-based radar studies (7) stimulated by the Clementine results failed to confirm them. However, the Lunar Prospector mission of 1997 (8) carried a neutron spectrometer that demonstrated the existence of large amounts of hydrogen at the north and south poles, equivalent to several billion tons of water. It is possible that this hydrogen is implanted by the solar wind in the soil of the Moon, i.e., elemental hydrogen rather than water. However, since the survival of water ice at the lunar poles had been predicted many years before, it is reasonable to conclude that the Lunar Prospector results imply water ice.

There is another demonstrated lunar resource that will be of value for scientific research and possibly for the long-term energy supply of the Earth: helium 3. Helium 3, a rare (in the Earth) isotope of helium, was found from Apollo samples to be deposited in the lunar soil by the solar wind. The importance of helium 3 is that it can undergo nuclear fusion without producing unwanted neutron flux. Commercial nuclear fusion is at this writing a long way from being achieved. However, at the very least, abundant helium 3 from the Moon should be valuable for fusion research, and may eventually become a major energy source for the Earth.

An important point about the lunar surface should be brought out here. The force of gravity on the Moon is one-sixth that of the Earth, as most people know. However, the energy per unit mass needed to escape from the lunar surface is only 1/22 that for the surface of the Earth, being inversely proportional to the **square** of the escape velocity. This means that bringing material from the Moon to the Earth, or to earth orbit, is in principle much easier than it may seem.

To summarize: the Moon's new status as strategically valuable territory is based on its location, its surface environment, and its material resources. More generally, the Moon is a **useful** body. Mars is unquestionably of enormous scientific interest, but has no apparent applied value comparable to that of the Moon.

Strategic Locations on the Moon

The total surface area of the Moon is roughly that of North and South America combined, and it would seem that that there is plenty of room for everyone. This is of course true, but in fact there are several sites with clearly superior value, comparable to the English Channel, the Straits of Gibraltar, or the Persian Gulf (9).

To discuss these strategically valuable locations, we must first address the question of valuable for what, i.e., to what uses can the Moon be put. This topic has been discussed at great length by many authors, starting with Arthur C. Clarke's (1961) article "The Uses of the Moon."

The first "use" of the lunar surface will probably be as a site for remotely-controlled astronomical instruments, such as optical and radio telescopes, probably used in arrays for interferometry (Table 3). Moon-based astronomy has been endorsed repeatedly for many years, as summarized in Table 2. Its recent omission from future plans by NASA and ESA probably stems from the assumption that Moon-based astronomy requires astronomers on the Moon, i.e., a new and presumably expensive Apollo Program. This assumption is incorrect. Recent developments in light-weight optics and robotics (10) can make emplacement of extensive astronomical complexes controlled from Earth possible quickly and at moderate cost, roughly equivalent to two Discovery-class missions (around $300 million). Considering that new Earth-based telescopes now planned will cost on the order of a billion dollars, it should be clear that Moon-based astronomy is economically quite feasible. Despite the enormous success of space-based instruments such as the Hubble Space Telescope, the Moon remains the best site, from a general perspective, for astronomy in the solar system.

In principle, observatories anywhere on the Moon would be valuable. However, some locations are clearly better than others . If only one site can be occupied, it should be close to the lunar equator, for all-sky visibility and line-of-sight communications/data relay to Earth (Fig.3). Polar sites (11) would provide cold sites for infrared astronomy, quite apart from their inherent interest, to be discussed, as well as continuous visibility of the northern and southern celestial hemispheres. For astronomical purposes alone, then, the most valuable lunar sites are **four**: on the east and west limbs (Mare Smythii and Riccioli), and at the lunar poles.

The north and south poles of the Moon, as discussed previously, are now known to have large deposits of hydrogen, probably in the form of water ice. This ice is of great scientific interest alone, since it probably represents deposits from comets over perhaps a few billion years. This should provide an accumulation of solar system volatiles, whose study may throw light on the origin of the Earth's oceans and atmosphere, perhaps even on the origin of life. A final advantage of the poles is that solar energy is continually available, in contrast to low latitudes where the days and nights are 14 earth days long.

In summary, the Moon is in area equivalent to two large continents, but a finite number of locations are clearly more valuable than the lunar surface in general. The term "choke points" is not quite applicable to the Moon, but we now know that there are some strategically important sites.

Operational Experience

A more general use of the Moon will be as a proving ground, so to speak, for solar system exploration in general. Missions to the Moon themselves are actually short interplanetary flights, involving escape from earth orbit, crossing space, and landing on a solid surface. Operations on the lunar surface are in many ways similar to those on the surface of Mars, which is in several aspects biologically space-equivalent. Emplacement of instruments on Mars will undoubtedly draw on experience with instrument emplacement on the Moon. The Soviet Lunokhod vehicles, duplicated only for short ranges on Mars by the 1997 American Pathfinder rover, showed the practicability of telerobotic lunar rovers with the technology of the 20th century. Similar programs are obviously possible with that of the 21st century.

The Moon is in general terms a natural space station providing a stepping-stone to the solar system. As a thought experiment, consider space exploration if the Earth did not have a such a close satellite. The nearest planets are Venus and Mars, depending on orbital configurations. Both have proven to be extremely difficult objectives. NASA has had in the last few years three failed Mars missions. Even now, there has never been a completely successful Russian/Soviet mission to, ironically, the red planet. The Moon is, by comparison, an easy target, as shown by the scores of successful unmanned and manned missions, Soviet and American.

An important conclusion of the 1991 Synthesis Group study, "America at the Threshold,"(12) was that all four of its recommended "architectures," i.e., space exploration/utilization paths, included a new manned lunar program. One specific point brought out by this study was that a manned Mars program without an intermediate lunar program would be analogous to going directly from the Mercury to the Apollo missions without the intervening 10 Gemini flights. This point will be brought up again. The implication of the foregoing discussion is clear; directly and indirectly, the Moon represents a natural and necessary stepping stone for the exploration and eventually the settlement of the solar system.

Chinese-Russian Relations and Capabilities

Relations between the Soviet Union and the People's Republic of China reached a low point in the early 1970s, when the two nations were reportedly on the brink of war . The controversial book by Victor Louis (13) was intended, in Harrison Salisbury's view, as a justification for a Soviet preemptive attack on China. Such an event would have had global consequences, even had such a conflict been restricted to the two countries. Fortunately (!) it did not happen. Relations between the former Soviet Union and the PRC have since thawed completely, as brought out by the 1998 National Defense University (NDU) report "Strategic Trends in China."(14).

The first specific event in this "thaw" was the 1995 formation of "A Strategic Partnership for the 21st Century." Concrete demonstrations of this new "partnership" soon emerged in major purchases of Russian weapons systems by China. Most recently, a broad treaty of friendship and cooperation was signed in July, 2001, but an earlier treaty is perhaps as important. In 1998 the PRC and Russia agreed to cooperate in space research and exploration. This provides a foundation for the thesis of this article, a joint Chinese-Russian lunar base program. However, other aspects of this topic need discussion.

First, it should be stressed that China is by itself a space-faring nation, having launched with its own rockets many research and applications satellites in the last three decades (15). More important, China is on the verge of manned space flight, with successful unmanned orbital tests of its first manned spacecraft, Shenzou, in 1999, and more shortly scheduled. An important point is that Chinese astronauts were trained in Russia's Star City, beginning in 1996 (16). Statements by Chinese officials and journalists include occasional mention of long range space programs such as space stations and lunar exploration.

Another development may have implications for Chinese interest in the Moon: the great expansion of its national astronomy program. As reported in Science, 14 May 1999, the PRC planned to double its budget for astronomy, creating new observatories and consolidating old ones, a "fundamental overhaul" of its national astronomy. Nothing at all was said about space-based astronomy, much less the Moon. However, Chinese astronomers must be well aware of the potential value of the Moon as a base for astronomy, if for no other reason than the paper (11) presented by Steve Durst at the 1999 Xi'an conference in which a program for a small robotic observatory at one of the Moon's poles was proposed. There is of course a large international literature on Moon-based astronomy concepts as well (17).

A general aspect of the subject of this article is the technological capability of the People's Republic of China. Given that even professional level families in rural areas may live in dirt-floored houses, it would be easy to assume that China simply does not have the technology to carry out a lunar base program. This is exactly the attitude that made the launch of Sputnik by the supposedly backward Soviet Union such a surprise to the U.S. The USSR may not have been able to produce a good automobile, but it could produce good rockets. The fact is that China demonstrably has the technology for critical aspects of an ambitious space program (15). Furthermore, it has free access to western literature and technology that can compensate for any deficiencies.

An especially important aspect of Chinese technology is its capability in information technology and remote sensing. The 1999 Bejing "Towards Digital Earth" symposium (18) was dominated by dozens of Chinese papers on various aspects of the subject, including military ones. This symposium reinforces the NDU report of 1998, which highlighted China's emphasis on "information warfare." Recent penetrations of the Internet by allegedly Chinese "hackers" show if nothing else that this is a potential threat. Turning to hardware, Chinese microelectronics have earned a high reputation. The author's best short-wave receiver is a $35 12-band model made in China. Combined with software development, China's microelectronics capability comprises a necessary base for future space efforts.

Turning to the present capability of Russia, it must first be pointed out that the Soviet Union was in fact racing the United States to the Moon, and hoped to be first to land man. A concise history of Soviet efforts has been put on the Web by Lindroos (**http://www.fas.org/spp/eprint/lindroos_moon1.htm**). Repeated catastrophic failures of the N-1 booster, a Saturn V class rocket, eventually stopped the Soviet manned lunar program. However, the entire infrastructure for manned landings, including an equivalent to the American lunar module (the LK lander), was developed, elements of which are on display now in Russian museums. Furthermore, a new Saturn V class launch vehicle, the Energia, has flown successfully. However, even smaller launch vehicles, notably the well-proven Proton, could be used for manned lunar missions with EOR or combination EOR/LOR modes, as considered at one time for Soviet programs. Soviet and now Russian capability for manned space flight in general has long been demonstrated by decades of space station operation, most recently the Mir and of course participation in the International Space Station. In summary, the outcome of the Moon race was something like the Tour de France; even coming in second is a tremendous achievment.

For the first few years after its collapse , the former Soviet Union was in poor economic health for several well-known reasons. Russia was barely able to meet its commitment to the ISS, one reason the still-functional Mir was de-orbited. However, the Russian economy is recovering. As reported by Aslund (2001) (19), the GDP grew by 5.4% in 1999 and by 8.3% in 2000. The post-Soviet economy is difficult to understand, but is apparently much healthier than it looks. A recent article by Claire Bowles (New Scientist, 30 June 2001) said that Russia was planning to resume launches of its Shuttle equivalent, the Buran, to take advantage of its large (100 ton) heavy lift capability. As quoted by the London Times (21 April 2001), Anatoli Grigoriev said that Russia could send a manned mission to Mars by 2016. Most recently, Yuriy Karash, in Moscow Nezavisimaya Gazeta (13 July 01) criticized the ISS as dooming Russian cosmonautics to "stagnation." He went on to suggest that the "manned opening up of Mars" would stimulate Russian-American competition, analogous to the race to the Moon, and would divert American resources away from missile defense.

Given the nearly unbroken record of failed Soviet/Russian Mars missions, such statements may sound visionary, but if nothing else they demonstrate that Russian national interest in space flight is still strong. It should be remembered that Tsiolkovsky was a Soviet hero in the 1930s, when Robert Goddard was generally considered a crank in the United States. More to the point, Russia has decades of experience with long duration manned space flight, and in particular with space stations culminating in the late Mir. Space station modules can in principle become interplanetary orbital transfer vehicles, or "Space Cruisers," (20) with addition of propulsion and sufficient life-support expendables. Such modules can also be used as initial shelters on the Moon or on Mars (21).

It has been painfully demonstrated that Mars is a far more difficult objective than the Moon. The medical problems alone of manned Mars missions are enormous: radiation, long-term weightlessness, psychological conflicts. The operational problems are still significant; oxygen or fuel leakage rates, for example, tolerable for a 4 day flight to the Moon would be fatal to a 9 month Mars flight. Furthermore, a manned mission to Mars involves atmospheric entry and controlled landing, and thus a new generation of spacecaft. However, recent Russian statements such as that by Anatoli Grigoriev (22) indicate confidence that "there are no big hurdles left," predicting a Russian landing on Mars by 2016. Similar statements, such as that by cosmonaut Valery Polyakov (23),show comparable confidence, and include "settlements" on the Moon.

These recent Russian views may reflect a realization that there has been enormous technological progress since the Apollo days. The development of, for example, the American Lunar Module (LM), well-described by Pellegrino and Stoff (1999), was a pioneering effort in which everthing was being done for the first time. This lunar lander, successful in every mission, was built with the technology of the mid-1960s. A new lunar program could use the original LM design without fundamental changes but with greatly improved performance brought about by the use of modern microelectronics and light-weight composite materials. The same situation presumably applies to the Russian LM. Missions possible or nearly so with 1965 technology should be relatively straightforward with that of the 21st century.

Even without major new development programs, the combination of **existing** Russian hardware with that of China should permit achievment of manned missions to the Moon within perhaps five years. Furthermore, as pointed out previously, the lunar environment is now well-known; the series of reconnaissance missions flown by the U.S. before Apollo - Ranger, Surveyor, Lunar Orbiter - would be unnecessary.

Turning now to China, a brief look at Chinese history, specifically events of the Ming Dynasty in the 14th century, will be relevant to the thesis of this article. China was at that time a major maritime power and sent ocean-going ships as far as Africa under Admiral Zhen Ho. However, the Chinese government stopped these exploration trips and construction of large ships, primarily to concentrate on domestic problems such as the Mongol incursions. The immediate result was that the lead in global exploration passed to western Europe: Portugal, Spain, and England. President Jiang Zemin has been quoted by Liu (Newsweek, Summer Special Issue, 2001, p. 13) as saying that China "missed its historic opportunity" as a result of the Ming Dynasty actions. It had turned in on itself, and its power faded over the next centuries, aggravated by the well-known actions of various European powers. In recent decades, this trend has obviously been reversed. With regard to exploration, the solar system represents the new frontier, in the familiar phrase, and the existing Chinese space program suggests that the lesson of medieval China's policies has been well learned. The Moon offers unclaimed and still largely unexplored territory of continental size, an obvious goal for Chinese manned space flight in the 21st century.

What are Chinese intentions for space exploration in the new century? One possibility is late participation in the ISS program, or possibly development of a small Chinese space station analogous to Skylab. At this writing, the Shenzou's module has been operating for several months after detachment of the re-entry module, serving in essence as a small experimental space station. However, Chinese participation in the ISS, or its own space station, would be a conservative and unimaginative program. President Kennedy proposed what became the Apollo Program in the belief - amply justified - that a Moon landing represented the first achievment in which the United States had a real chance of overtaking the Soviet Union . A Chinese space station program would at best be a stern chase, so to speak. Landing on the Moon, and more important settling the Moon, would be a technological end-run, permitting the PRC and Russia to outflank western manned space programs.

A final aspect of the situation is that the United States, and indirectly the world, reaped enormous benefits from the Apollo Program, as previously discussed. Those administering Chinese space efforts must be well aware of how any nation can benefit from an ambitious program, another reason for suggesting that China and Russia may be considering a joint lunar base program.

Summary and Conclusions

At the beginning of the 21st century, the solar system is open for exploration, settlement, and exploitation. The nearest planet, so to speak, the Moon, clearly represents a stepping-stone to the solar system. Russia has the capability, with technology in hand or nearly so, to begin manned exploration of the Moon, for itself or as a precursor to the exploration of Mars. China has awakened in every sense of the word, and is on the verge of manned space flight by its own efforts. These two countries have once again established friendly relations, and are specifically cooperating in space exploration. Collectively, these events imply that a joint Chinese-Russian lunar base program is a logical next step.

This conclusion can of course be dismissed as a transparent attempt to re-ignite the Space Race, and the phrase is hereby offered to critics for their use. However, it is documented speculation from an active participant in American manned flight programs from 1960 on.

A new Space Race - to the Moon or conceivably to Mars - might benefit the entire planet. East-West competition has over the millennia had a stimulating effect, though unfortunately too often boiling over into war. But the first Space Race, to the Moon, eventually benefited all sides. A return to the Moon, "this time to stay," in the (1989) words of President Bush, may do the same.

Acknowledgements

This paper has benefited greatly from discussions with Brian Montgomery, Steve Durst, Peter Chen, and Jacob Yates. James Oberg's Internet news items have been invaluable in providing up to the minute coverage of Russian and Chinese space efforts.

Tables

Figures

References

1. Lowman, P.D., Jr., Landsat and Apollo: The Forgotten Legacy, Photogrammetric Engineering and Remote Sensing, 65, 1143-1147, 1999.
2. Lowman, P.D.,Jr., The Apollo Program: Was It Worth It?, Forensic Quarterly, 1975.
3. Boris Chertok, cited in "Russian Space Strategy," Moscow Nezavisimaya, 13 July 01 translation distributed on Internet by James Oberg, 19 Jul 2001.
4. Lowman, P.D.,Jr., Return to the Moon: A New Strategic Evaluation, presented at the Space Resources Ulitization Roundtable, Colorado School of Mines, Golden, Colorado, October 27-29, 1999.
5. Beattie, D.A., Taking Science to the Moon, Johns Hopkins University Press, 2001.
6. Nozette, S., et al., The Clementine mission to the Moon, Science, 266, 2835-239, 1994.
7. Margot, J.L., et al., Topography of the lunar poles from radar intereferometry: A Survey of Cold Trap Locations, Science,284,1658-1660,1999.
8. Binder, A., Lunar Prospector: Overview, Science, 281, 1475-1476, 1999.
9. Lowman, P.D.,Jr., Candidate site for a robotic lunar observatory: The central peak of Riccioli Crater, Journal of the British Interplanetary Society, 48, 83-86, 1995.
10. Lowman, P.D.,Jr., Astronomy from the Moon: A Second Look, Mercury. Journal of the Astronomical Society of the Pacific, March, 2000.
11. Lowman, P.D.,Jr., Durst, S., and Chen, P., Lunar observatories: Why, where, and when? presented to the Eight Internatioal Space Conference of Pacific Basin Societies, Xi'an, China, June, 1999.
12. Synthesis Group, America at the Threshold: Report of the Synthesis Group, on America's Space Exploration, U.S. Government Printing Office, 1991.
13. Louis, V., The Coming Decline of the Chinese Empire, Times Books, 198 p., 1979 (with dissenting introduction by Harrison Salisbury).
14. National Defense University, Strategic Trends in China (H. Binnendijk and R.Montaperto, Editors), U.S. Government Printing Office, 1998.
15. Oberg, J., Another superpower in space, Popular Science, 257, 4, 66-69, October, 2000.
16. Washington Post, Chinese test craft for manned orbits, M. Lariss 22 Nov. 1999.
17. Astrophysics from the Moon, M.J. Mumma and H.J. Smith, Editors, American Institute of Physics Conference Proceedings 207, 1990.

18. Towards Digital Earth, Symposium Proceedings, G. Xu and Y. Chen (Editors) Science Press, Beijing, 1999.
19. Think Again, A. Aslund, Foreign Policy, July/August, 2001.
20. Lowman, P.D.,Jr., Space Cruiser and Moonbase: USAF Uses for Space Station Modules, Paper submitted to SPACECAST 2020, Air Force Institute of Technology, October, 1993.
21. Lowman, P.D. Jr., Lunar bases: A post-Apollo evaluation, in Lunar Bases and Space Activities of the 21st Century, W.W. Mendell, Editor, Lunar and Planetary Institute, Houston, 1985.
22. London Times, G. Whitell, Russia to put man on Mars by 2020, 21 April 2001.
23. Tass, People to fly regularly to Mars and moon next century, 1 Jan. 2001.

POST- SEI (1991) DEVELOPMENTS

1. International Space Station: assembly started

2. Soviet Union collapse; space program crippled

3. Orbital astronomy: Hubble, Compton, COBE,
   Hipparcos, IRAS, SOHO, others

4. New ground-based telescopes: Keck, ESO, others;
   used in optical inteferometry arrays

5. New lunar missions: Galileo, Clementine, Prospector

   Polar ice (?) deposits
   Crustal stucture

6. New Mars missions: Pathfinder, Global Surveyor

   Mars andesites
   Magnetic anomalies
   Crustal structure
   Impact basins
   Water inventory

7. Extra-solar planets (ca 2 dozen by 1999)

8. Danger of impacts on Earth recognized

   Near Earth Objects found, catalogued
   New terrestrial impact craters found
   K-T mass extinctions impact-related

9. No ETI detected on radio or optical frequencies

10. New emphasis on exobiology

    Life-forms (??) in Mars meteorites
    Extreme environment life in Earth recognized

PDL July 99

ASTRONOMY FROM THE MOON– WHO NEEDS IT?

1984 – Lunar Bases and Space Activities of the 21st Century (Washington)

1986 – Future Astronomical Observatories on the Moon (Houston)

1988 – A Lunar Far-side Very Low Frequency Array (Albuquerque)

1988 – Second Conference on Lunar Bases, etc. (Houston)

1989 – Physics from a Lunar Base (Stanford)

1990 – Astrophysics from the Moon (Annapolis)

1991 – Decade of Discovery in Astronomy and Astrophysics ("Bahcall report")

1991 – Robotic Telescopes in the 1990s (Laramie)

1993 – Optical Astronomy from the Earth and Moon (San Diego)

PDL GSFC 11/94

Table 2

ADVANTAGES OF ASTRONOMY FROM THE MOON

1. **No weather**; continual perfect visibility
2. **No atmosphere**; all radiation (EM and particulate) reaches the lunar surface directly; no background radiation from atmosphere; no radiation belts; unlimited spectral window
3. **Ground emplacement**; distributed instrument network and wide separation essentially eliminate experiment integration problems; simple telescope drives possible (vs. orbital instruments); high reliability from independent instruments; single point failure reduced. Large interferometer arrays practical.
4. **No orbital debris** problem; micrometeorite flux similar to earth orbit; **no glow effects** from collisions with residual atmosphere (vs. LEO)
5. **Slow rotation time** permits up to 14 days continuous exposure (vs. LEO, frequent eclipse by Earth) from low latitude sites; polar sites permit exposures of indefinite length for corresponding hemisphere
6. **Distance from Earth** greatly reduces terrestrial source interference (RFI, gamma ray, radar) by inverse square of distance
7. **Far side offers complete radio silence** at all frequencies (assuming regulation of radio use); ideal site for SETI, VLF investigations
8. Near side observatory permits use of **Earth as calibration/comparison target** for reflectance spectroscopy and other observations
9. **Astronomical study of Earth** possible; almost entire hemisphere visible at once including one pole, possibly two
10. **Ultra-long baseline Moon-Earth interferometry** possible; extremely high resolution and sensitivity

Table 3

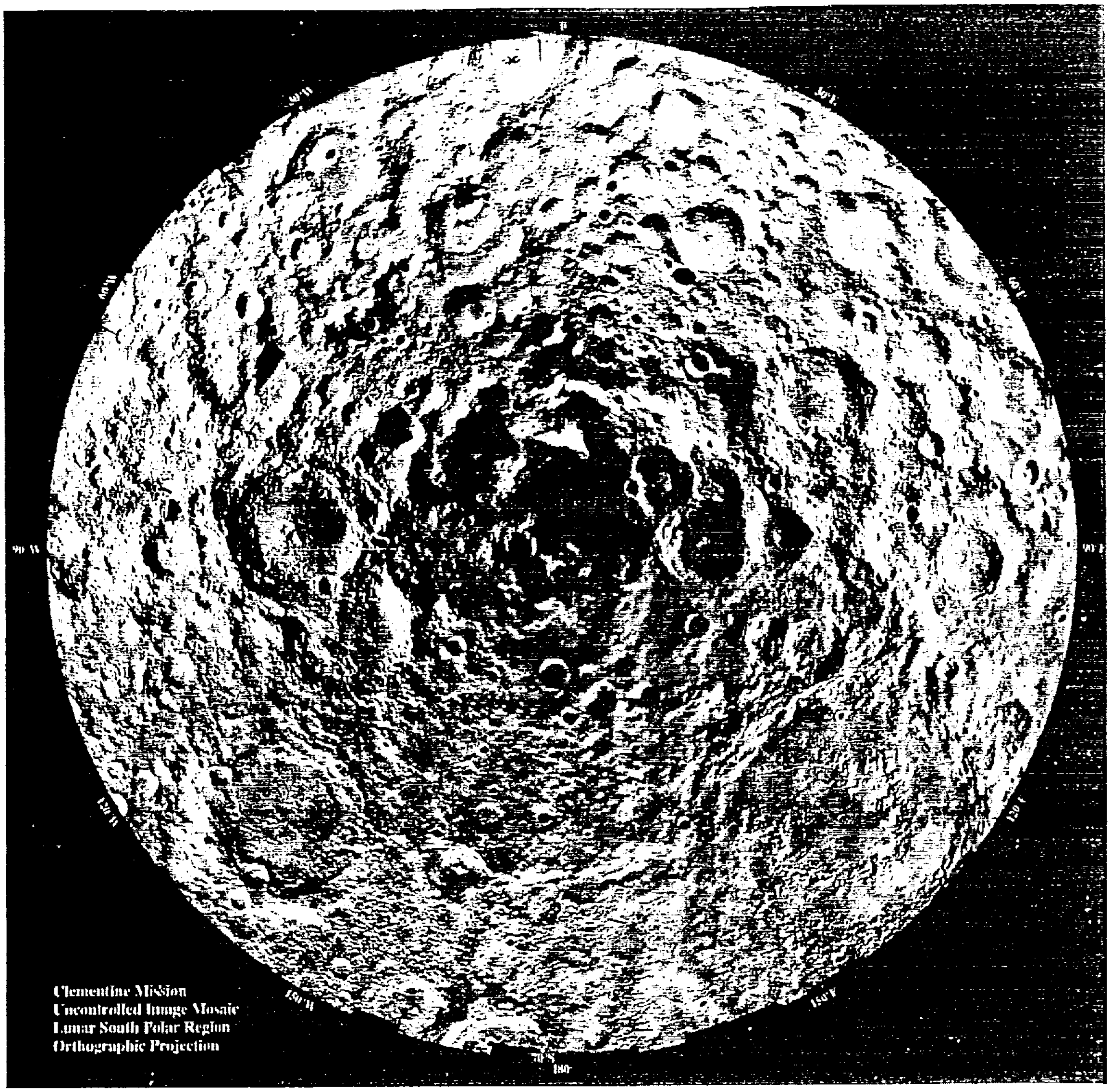


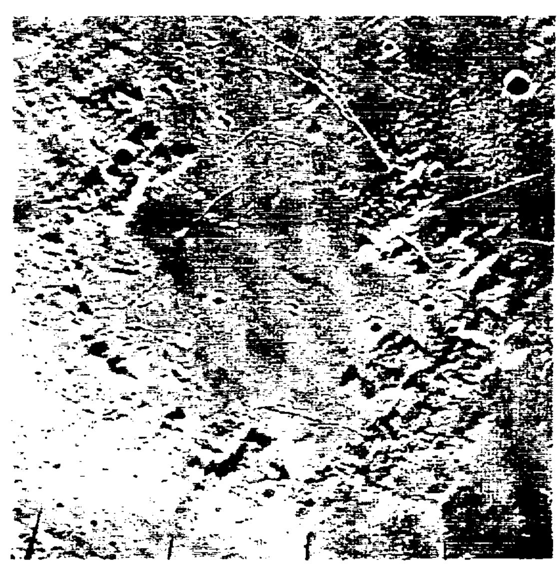
Fig. 1. Mosaic of ~1500 Clementine UVVIS images (750-nm band) of the south polar region of the moon. The projection is orthographic, centered on the south pole. The Schrödinger Basin (320 km in diameter) is located in the lower right of the mosaic. Amundsen-Ganswindt is the more subdued circular basin between Schrödinger and the pole.

above

Clementine Mosaic, Lunar South Polar Region up to 70 deg, S

right

Schrodinger Basin (320 km diameter) (lower right in mosaic above)



Reference: Shoemaker et al., Science, 266, 1851-1854, 1994

Fig. 21 TOP

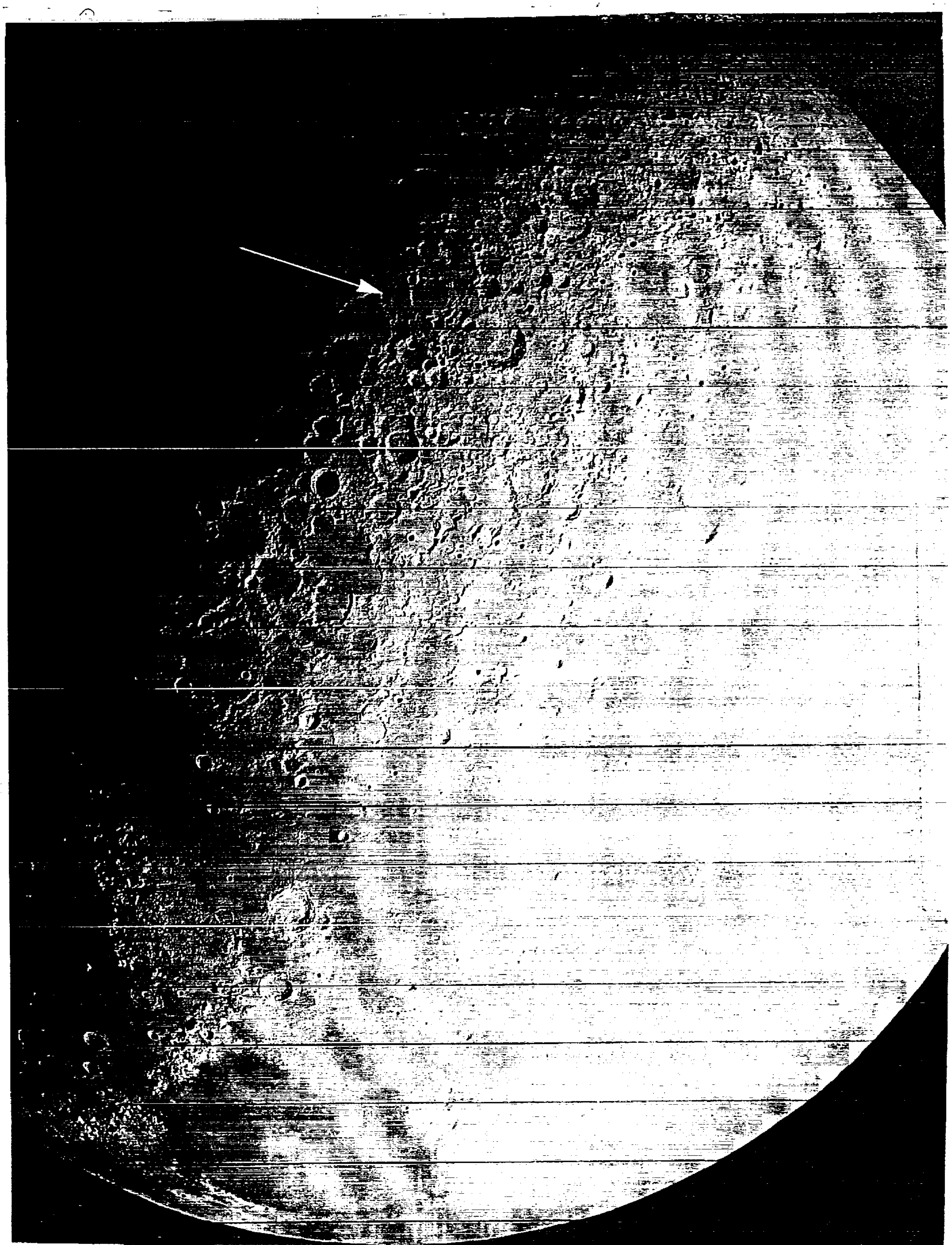
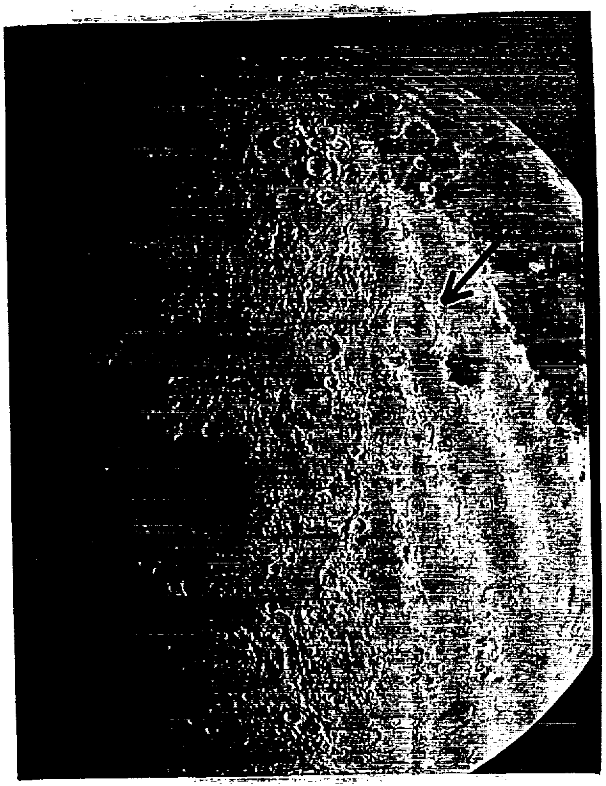


Fig
2



RECOMMENDED SITE FOR A LUNAR OBSERVATORY: RICCIOLI CRATER

Equatorial location: entire celestial sphere visible (in one month), good launch windows for lunar orbital rendezvous

Uninterrupted line of sight to Earth: easy communications, data relay, telerobotics

Close to far side: convenient access to far side VLF and SETI radio astronomy instruments

Varied local geology in crater: mare basalt, rilles, dark halo craters, Orientale ejecta,etc

Varied regional geology: Orientale Basin, Grimaldi (mascon basin), Reiner Gamma, Marius Hills, Aristarchus, Surveyor 1, etc.

Trafficable and workable terrain: analogous to Imbrium ejecta (Fra Mauro, Apollo 14); moderate slopes, mature regolith

Fig. 3