A Lunar Observatory

Chris Williams
Student 1607421
HET 606

14th September 2002

Introduction

From time to time astronomer's put forward proposals for observatories on the surface of the Moon. There are sound technical reasons for placing instruments outside of the Earth's influence but, to the general public, which sees only the "gee whiz" portions of astronomical research (e.g. Hubble Space Telescope (HST) images) through mainstream media, there may seem to be little justification.

So, why are Moon-based observatories desirable, and what are the pros and cons?

The Problems

Looking at the night sky it is clear that stars appear to twinkle. The twinkling effect is caused by turbulent motions in the atmosphere and substantially limits the detail that may be seen. Optical telescopes amplify the twinkling of stars, and other blurring effects, even on relatively rare, clear nights. These effects are less pronounced at colder temperatures (less turbulence) and higher altitudes (less atmosphere), so optical observatories are generally built on peaks in order to minimise the effects.

As astronomers began to use other parts of the spectrum (Figure 1) to probe the heavens they discovered that the atmosphere dims, scatters, or completely blocks radiation in broad ranges (Figure 2). In order to study objects using radiation in these ranges astronomer's have to get above the atmosphere. Telescopes and instrumentation have been launched on balloons or carried to high altitude in aircraft to gain a better view for short periods. With the advent of space-flight, observatories have been placed in Earth orbit and further afield. The most famous space-borne observatory is the HST but there have been observatories for IR, UV, X-ray, and gamma-ray ranges (e.g. IRAS, SOHO, Einstein Observatory, and the Compton observatory respectively). To date, there has been only one astronomical observatory on the lunar surface, the crew of Apollo 16 deployed the Far Ultra Violet Camera to make observations of Earth, the Large Magellanic Cloud and other objects [1].

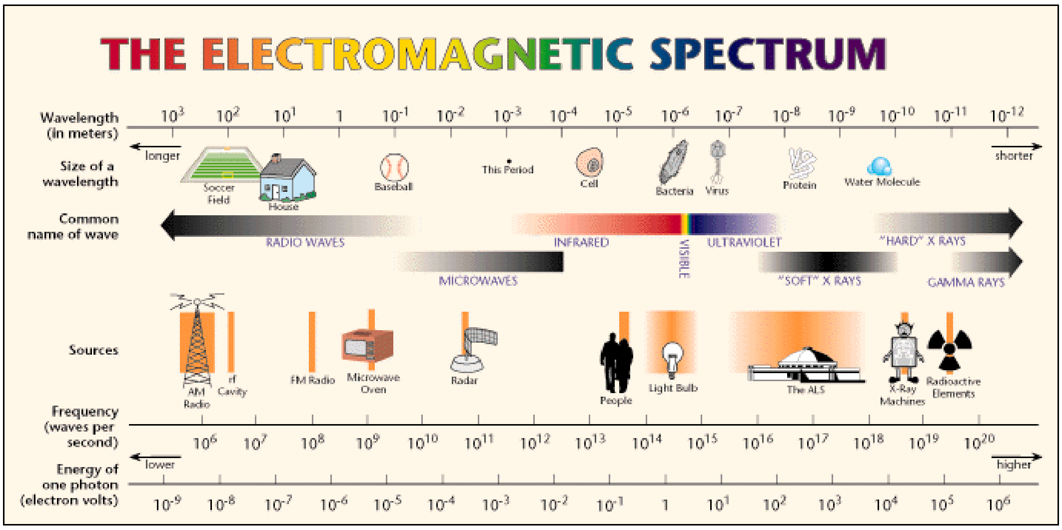

Figure 1: Visible light forms a small portion of the broader electromagnetic spectrum. Radiation from all parts of the spectrum may be used to study astronomical objects. (Reproduced from [2])

In both the optical and radio-astronomy arenas interference from man-made sources is becoming an increasing problem. Stray light from urban lighting reduces contrast and introduces unwanted signals rendering optical telescopes less effective. In radio-astronomy, even very weak Earthly signals swamp signals from space, and the ambient noise level in increasing.

Why the Moon?

Given the effects of the Earth's atmosphere, the most obvious reason for desiring an observatory on the Moon is the absence of an atmosphere. Without an atmosphere there are no blocked observation wavelengths. Consequently, the Moon's surface could be a good place to study IR and long wavelength radio ranges, or the high-energy X and gamma ray ranges. The absence of

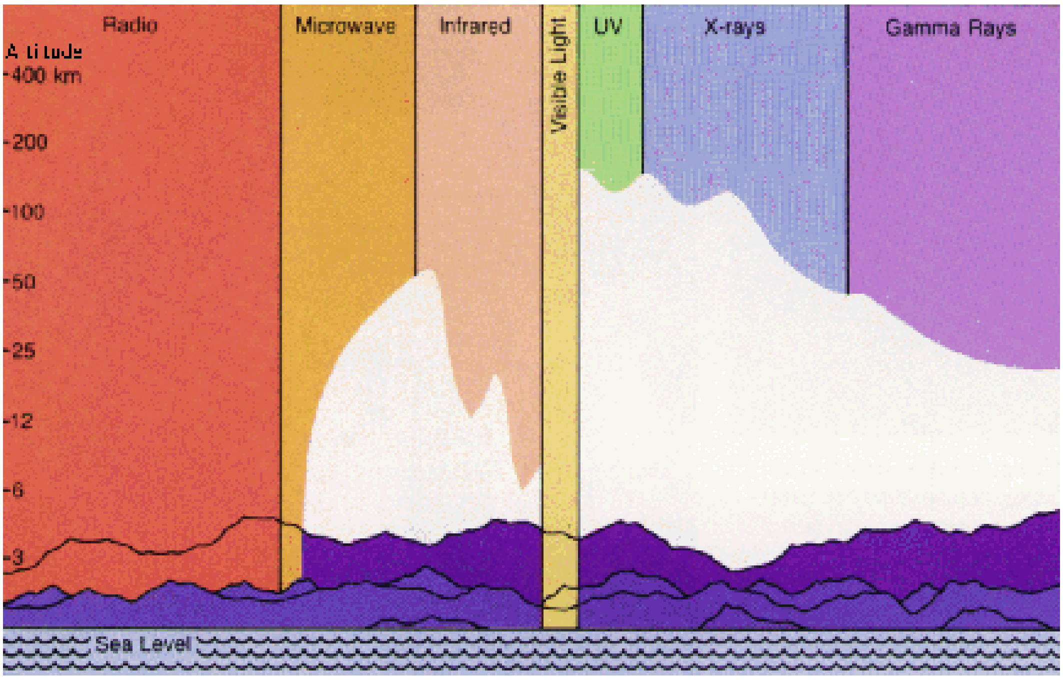

Figure 2: Penetration into the atmosphere of radiation in various bands. Only radiation in the so-called atmospheric windows can be studied from the Earth's surface. This excludes most of the microwave, IR, UV, X-ray and gamma radiation ranges. (Reproduced from [3])

an atmosphere also means the absence of turbulence and weather induced visibility problems.

Radio astronomers have perhaps the best explored and strongest case for an observatory facility on the Moon. The Universe has been observed, to varying degrees, throughout most of the spectrum using ground and space-borne instruments. The largest remaining unexplored region is long-wavelength (> 10m) radio waves, which are badly affected by the Earth's atmosphere and noise. In a lunar far-side location the observatory would be completely isolated from man-made radio frequency interference and partly shielded from our Sun's emissions. Observing this portion of the spectrum generally requires large antennae or arrays of smaller antennae, but the construction of these antennae may be quite simple. The technique of long baseline interferometry, in which signals from many small antennae are mathematically combined to give the resolution of a much larger radio-telescope, could be employed on the Moon. The geologically stable surface would allow very precise location of the antennae, which would not move with tectonic activity as they do on Earth. A free-flying array in deep space would require complex control systems to maintain such positional accuracy. Radio-telescope antennae, which tend to be large and often heavy, would also benefit from reduced gravitational stresses.

Other reasons for placing an observatory on the Moon include:

- The slow rotation rate of the Moon allows for long duration observations. Even large instruments that can only observe a limited range around the zenith could gain longer exposures this way.
- Permanently shaded areas, say in south polar craters, could be used for observations that require instrumentation at very low temperatures or shielding from the direct influence of the Sun.

Unfortunately there are many problems that must be overcome to successfully operate on the Moon:

- The observatory is not protected from impact by dust and larger objects, which would normally burn up in the Earth's atmosphere.
- The observatory is not protected from large doses of radiation that's harmful to electronics, other systems, and materials.
- There is no temperature stability induced by the atmosphere's, or ocean's, thermal mass.

- To operate a far-side facility would require a constellation of communication satellites in lunar orbit, each generating radio frequency signals, potentially interfering with observations.

- At long wavelengths the lunar surface and tenuous lunar ionosphere may have an impact on observational quality, which is also more fundamentally affected by the inter-stellar medium [4]. Site selection would require extensive survey information not currently available.

None of these problems is insurmountable but may require substantial research in many areas.

Clearly, the Moon is not the ideal platform for observation of all objects. The Sun would be out of view for half of each lunar month necessitating multiple lunar observatories to provide constant solar coverage. Similar coverage can be gained from a single observatory, such as SOHO, in solar orbit. The Earth is far easier to observe from Earth orbit or the surface.

Design and Cost

Placement of a small astronomical instrument, of perhaps a few hundred kilogrammes, on the surface of the Moon is well within our current capabilities using delivery systems such as those used in the various Mars landers or even the older Surveyor. However, placing equivalent capabilities in low-Earth orbit is far more cost effective, and less risky in terms of mission failure. Therefore, any observatory proposal for the Moon is likely to be either physically large or not achievable in free-flying form for some other reason.

The design of an observatory for permanent placement on the Moon must overcome some fairly extreme conditions. Temperatures of 130 °C are expected on surfaces exposed to the Sun, and shadow temperatures of -180 °C degrees [5, Ch. 9]. The observatory must cope with a strong temperature gradient from the light to dark side and a monthly cold-soak period. If placed at the poles the equipment must be able to function at constantly low temperature. Internally generated heat must also be dissipated exclusively by radiation. However, most of these problems have already been addressed in the design of satellites, Earth-orbiting observatories, and deep space probes.

The observatory power source must be able to provide power during both light and dark periods, so it cannot be purely solar, and radioactive sources are likely to meet stiff opposition. New technology may be required to provide a power source that does not require replenishment from Earth. Such sources may include hydrogen taken from suspected ice deposits in polar regions or chemical reactions using lunar mineral deposits.

The establishment costs of any lunar observatory are likely to be very large. Estimates range from as low as US$30 billion (Japanese Lunar and Planetary Society) to well into the hundreds of billions (NASA, ESA). Decisions on the construction method will have a major bearing on cost. Should the observatory systems be built in-situ from lunar materials, assembled from parts built on Earth or in Earth orbit, or deployed as a whole from Earth? If built entirely by automated means then the robotic systems must be sufficiently flexible to effect repairs so that rescue missions are not required. Should a manufacturing or design flaw, such as the one that crippled the HST optics, be present in in unmanned facility it will be more difficult to repair on the lunar surface than in Earth orbit. These decisions impact on the required delivery systems and vary the risk involved. Expanded engineering measures to mitigate risks are both possible and expensive.

The major driver in running costs relates to the nature of the observatory operations. A manned observatory has much greater costs, and higher risks, associated with it than an unmanned facility. While cost alone is likely to dictate unmanned operation, manned operations may well provide more flexibility in the event of failure, routine maintenance, and instrumentation calibration or upgrade. Some designs, such as a ground supported dish like Aricebo, are unlikely to be built without human presence.

Funding of fundamental research is problematic at the best of times. The many billions of dollars spent on the Apollo programme, for example, were provided out of a political ideology, not out of some quest for scientific knowledge. Instruments such as the HST, which cost approximately US$1.5 billion to build and nearly the same to maintain, provide some feedback to the tax-paying populace. Gamma and radio observatories provide fewer of these obvious feedbacks than optical observatories and are less likely to attract funding.

It seems the most likely way to get astronomical observing facilities on the Moon is to piggy-back on any future exploitation of the Moon for commercial purposes or as a staging point for Mars manned missions (should they arise). Funding for these activities is not as dependent on the intangible benefits that lunar-based observations may give, and an observatory would make only a small impression on the massive budget required for such undertakings. Much of the support infrastructure, such as delivery systems, communication networks, survey data, manufacturing and power systems, could be shared to reduce cost.

Planning for a lunar observatory is a major undertaking requiring input from many disciplines and much preparatory research. Much of this work can be done prior to any concrete commitment. By doing this, scientists will minimise the lead-time required to actually implement should the opportunity arise. Already a lunar observatory seems to be a common study area for university students and staff.

Alternatives

Alternatives to a lunar observatory for the most part already exist. The use of small (relatively) observatories in orbit about the Earth or Sun is well established.

Techniques such as high-speed adaptive optics and digital processing can be used to squeeze the most from observations made through our atmosphere. Adaptive optics is still a relative newcomer to astronomical instruments, but early results from the Gemini North telescope are extremely promising. Measurement of, and correction for, atmospheric turbulence is likely to improve with time and experience.

Regarding light and radio pollution, further degradation of optical observatory capability can be addressed by enforcing buffer zones around observatories and building new observatories in very remote areas. Radio frequency interference is more insidious but can be countered to some degree with a combination of reducing unwanted emissions, establishing spectrum buffer zones around key observation frequencies, and improved filtering and post-processing to remove unwanted signals.

Conclusion

While the positioning of astronomical observatory facilities on the Moon has obvious benefits to science it may not be perceived as this by the wider populace. The large establishment costs for such facilities, coupled with high risks, mean that they are unlikely to receive public funding in preference to smaller, cheaper orbiting facilities such as the HST and SOHO. Perhaps the best chance of establishing these facilities is by piggy-backing them on private ventures, or more publicly popular ventures like going to Mars. In the meantime though, improvements in technology and technique should be used to extract more from Earth-bound facilities, and improved policy used to reduce the impacts of light and radio pollution. Planning for potential lunar observatories should continue to allow quick response should delivery mechanisms become available.

References

[1] NASA. Astronomy picture of the day: The first lunar observatory. Internet `http://antwrp.gsfc.nasa.gov/apod/ap960608.html`, June 1996.

[2] Electromagnetic spectrum. Internet `http://www.lbl.gov/MicroWorlds/ALSTool/EMSpec/EMSpec2.html`, September 2002.

[3] High Energy Astrophysics Science Archive Research Center. Electromagnetic spectrum. Internet `http://imagine.gsfc.nasa.gov/docs/science/know_l1/emspectrum.html`, September 2002.

[4] G. Woan. Capabilities and limitations of long wavelength observations from space. *Washington DC American Geophysical Union Geophysical Monograph Series*, 119:267–276, 2000.

[5] Roger A. Kaufmann, William J. Freedman. *Universe.* W. H. Freeman and Company, 5th edition, 1999.