LUNAR FARSIDE RADIO LAB

A STUDY BY
THE INTERNATIONAL ACADEMY OF ASTRONAUTICS

Coordinated by

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ABSTRACT. In this Study it is proposed that the Farside of the Moon should be protected legally against man-made radio pollution and uncontrolled exploitation. In fact, only by establishing a radiotelescope on the Farside of the Moon it will finally be possible to cope with the Radio Frequency Interference (RFI) that is now increasingly plaguing all of Radioastronomy, Bioastronomy and SETI Searches done from the surface of the Earth.

In this Study, it is suggested to partition the Farside into 3 sectors, each of 60 degrees in longitude, to ensure:

1) The creation of the Lunar Farside Radio Lab inside crater Daedalus (at 180° E) with our planned Radiotelescope (in practise a Phased Array).
2) Complete freedom to exploit the Nearside as well as the four Lagrangian Points (see Figure 1) L1, L3, L4 and L5 of the Earth-Moon system allowing even some International Space Stations be located there. But it is claimed that...
3) The "opposite" Lagrangian Point L2 must be kept free at all times from spacecrafts that would RFI-blind the Farside.

This IAA Study was started in 1994 by the French IAA Member Jean Heidmann, who proposed crater Saha on the Farside as the "best" location for a Farside radiotelescope. When Heidmann passed away on July 3rd, 2000, this author was asked by the IAA to succeed Heidmann as the leader of the "IAA Lunar SETI Cosmic Study" to study all problems involved with setting up a Lunar Farside Radio Lab.

1. Historical Introduction: Jean Heidmann's 1994 Proposal for a SETI Base in the Farside Saha Crater

Bioastronomical signals currentlly searched for by radioastronomers fall into two classes:

1) Radio signatures of molecules important to the development of life, like the 22 GHz water maser.
2) SETI (= Search for Extraterrestrial Intelligence) signals, narrowband signals possibly broadcast by unknown extraterrestrial civilizations located somewhere in the Galaxy.

In order to detect signals of either types it is mandatory to firstly reject all RFI (Radio Frequency Interference). But RFI is produced in ever increasing amounts by the technological growth of civilization on Earth, and has now reached the point where large bands of the spectrum are blinded by legal or illegal transmitters of all kinds.

Since 1994, the late French radioastronomer Jean Heidmann had pointed out (see refs. [1], [2], [3]) that Radioastronomy from the surface of the Earth is doomed to die in a few decades if uncontrolled growth of RFI continues. Heidmann also made it clear, however, that advances in modern space technology could bring Radioastronomy to a new life, was Radioastronomy done from the Farside of the Moon, obviously shielded by the Moon spherical body from all RFI produced on Earth. Heidmann proposed that a radiotelescope should be placed inside the "Saha" Moon Farside crater, a ~ 100 km crater located in between 101° E and 105° E and 2° of latitude South, surrounded by a 3000 m high circular rim. An Earth-pointing antenna sould also have to be located in the Nearside Mare Smythii plain, linked to Saha "conveniently". Since 1994, this and other authors studied with details the link between Saha and Mare Smythii, and suggested it to be made by either optical fibers (plus a "tether" for the descent-on-the-Moon maneuver) or by a few relay stations to be landed on the Moon surface. The relevant space mission, however, is hard to design at a low cost (ref. [4]).

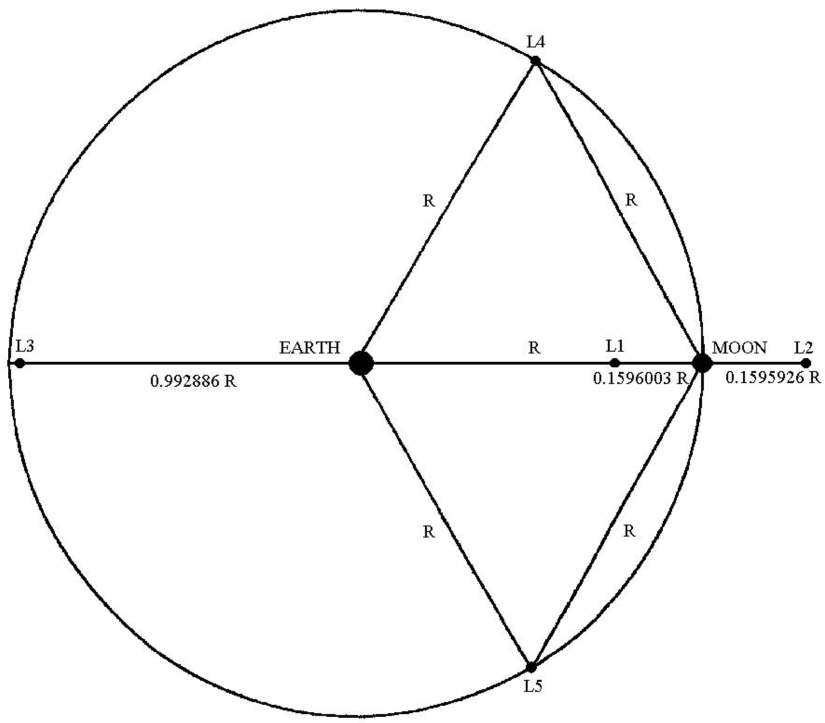

Figure 1: The five Earth-Moon Lagrangian Points (where Earth and Moon pulls cancel out):

1) **Let *R* denote the Earth-Moon distance, that is 384,400 km. Then, the distance between the Moon and the Lagrangian point L1 equals 0.1596003*R, that is 61350 km. Consequently the Earth-to-L1 distance equals 0.8403997*R, that is 323050 km.**
2) **The distance between the Moon and the Lagrangian point L2 equals 0.1595926*R, that is 61347 km.**
3) **The distance between the Earth and the Lagrangian point L3 equals 0.992886*R, that is 381666 km.**
4) **The two "triangular" Lagrangian Points L4 and L5 are just at same distance *R* from Earth and Moon.**

2. Terminal Longitude l on the Moon Farside for Radio Waves emitted by Telecommunication Satellites in orbit around the Earth

In this section we prove an important mathematical formula, vital to select any RFI-free Moon Farside Base.

We want to compute the small angle α beyond the limb (the limb is the meridian having longitude 90° E on the Moon) where the radio waves coming from telecommunications satellites in circular orbit around the Earth still reach, i.e. they become tangent to the Moon's spherical body. The new angle $l = a + 90°$ we shall call "terminal longitude" of these radio waves. In practice, no radio wave from telecom satellites can hit the Moon surface at longitudes higher than this terminal longitude l.

To find a (see Figure 2) we draw the straight line tangent to the Moon's sphere from G, the point tangent to the circular orbit having radius R. This straight line forms a right-angled triangle with the Earth-Moon axis, EM, with right angle at G. Next, consider the straight line parallel to the one above but from the Moon center M, intersecting the EG segment at a point P. Once again, the triangle EPM is right-angled in P, and it is similar to the previous triangle. So, the angle a is now equal to the EMP angle. The latter can be found, since:

1) The Earth-Moon distance $\overline{EM} = D_{Earth-Moon}$ is known and we assume its worst case (Moon at perigee): Earth-Moon distance equal to 356410 km.
2) The $\overline{EP}$ segment equals the $\overline{EG} = R$ segment minus the Moon radius, R_{Moon}.
3) Using Pythagoras' theorem one finds $\overline{PM} = \sqrt{\left(\overline{EM}\right)^2 - \left(\overline{EP}\right)^2}$.
4) The tangent of the requested angle α is then given by $\tan a = \frac{\overline{EP}}{\overline{PM}} = \frac{\overline{EP}}{\sqrt{\left(\overline{EM}\right)^2 - \left(\overline{EP}\right)^2}}$.

Inverting the last equation and making the substitutions described at the points 1), 2) and 4), one gets the terminal longitude l of radio waves on the Moon Farside (between 90° E and 180° E) emitted by a telecom satellite circling around the Earth at a distance R:

$$l = \mathrm{atan}\left(\frac{R - R_{Moon}}{\sqrt{D^2_{Earth-Moon} - \left(R - R_{Moon}\right)^2}}\right) + \frac{p}{2}.$$

Here the independent variable R can range only between 0 and the maximum value that does not make the above radical become negative, that is $0 \le R \le D_{Earth-Moon} + R_{Moon}$. The equation above for l shows that the $l(R)$ curve becomes vertical for $R \to \left(D_{Earth-Moon} + R_{Moon}\right)$ and $l = 180°$. Replacing for R the value of the geostationary radius, $R = 42241.096$ km, one finds for the Moon Farside terminal longitude l the value $l = 96.525°$. *This is how Heidmann came to select and propose crater Saha*: he just used the above (unpublished, but obvious) argument to compute that the longitude of the needed crater had to be higher than the value of 96.525°. Then, allowing a little more tolerance of about 5° in longitude for further shielding by the Moon's body, he finally declared in [1] that Saha was the "best" crater to establish a Lunar SETI base. For six years (1994-2000), no one thought of questioning Saha as "best" crater.

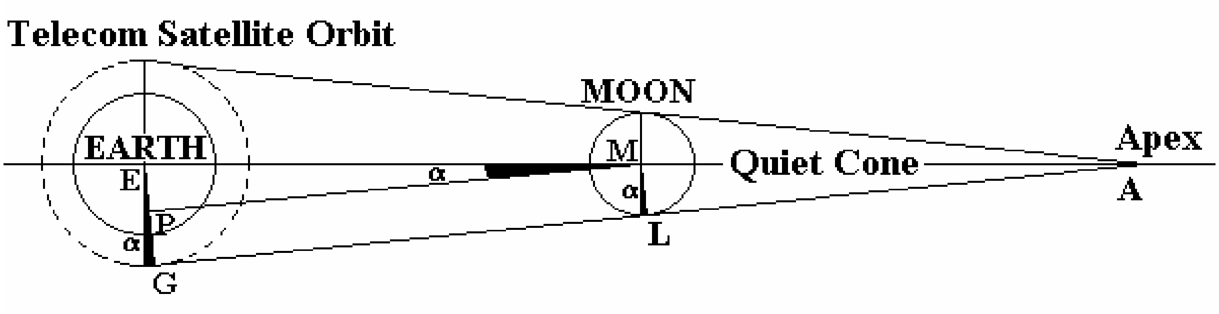

Figure 2. The simple geometry defining the "Terminal Longitude, l" on the Farside of the Moon, where radio waves emitted by telecom sats circling the Earth at a radius R are grazing the Moon surface.

3. Selecting Crater Daedalus at 180° E

The author of this paper claims that Heidmann was too optimistic in excluding that telecommunications satellites will ever be put into orbits around the Earth ***higher than the geostationary orbit of 42241.096 km.***

In other words, this author claims that the time will come when commercial wars among the big industrial trusts running the telecommunications business by satellites will lead them to grab more and more space around the Earth, pushing their satellites into orbits with apogee much higher than the geostationary one, with the result that ***crater Saha will be blinded as soon as a company decides to go higher than the geostationary orbit.*** The last remark is important for Bioastronomers. If we, the supporters of Bioastronomy, bet everything on a SETI and Bioastronomy Base located at Saha, then we may loose everything pretty soon! ***A "safer" crater must be selected further East along the Moon equator. How much further East?*** The answer if given by the diagram in Figure 3, based on the above equation for l.

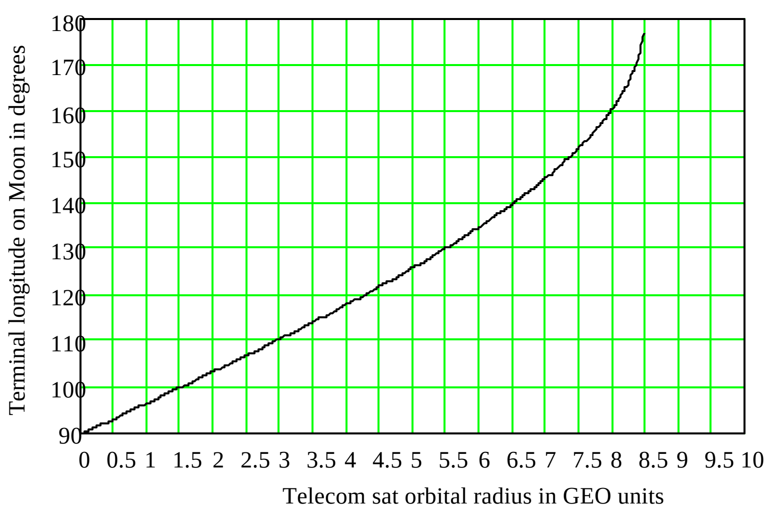

Figure 3.

Terminal longitude l (vertical axis) on the Moon Farside versus the telecom sats orbital radius R around the Earth (horizontal axis), in units of the Earth's geostationary radius (42241.096 km).

The vertical trait predicted by our equation for l shows up in Figure 3 as the "upgoing right branch". This shows that, if we only keep the equation for l into account (as Heidmann did), the maximum distance from the Earth's center for these telecom satellites is about 8.479 times the geostationary radius, corresponding to a circular orbital radius of 358148 km. Was a telecom satellite put in such a circular orbit around the Earth, its radio waves would flood Moon longitudes as high as about ~175° or more. However, here a surprise comes.

We did not consider the Lagrangian points yet!
So, it will never be possible to put a satellite into a circular orbit around the Earth at a distance of 358148 km, simply because this distance already lies beyond the distance of the Lagrangian point L1 nearest to the Earth, that is located at 323050 km (Lagrangian points are, by definition, the points of zero orbital velocity in the two-body problem!).

So we are now led to wonder: what is the Moon Farside terminal longitude corresponding to the distance of the nearest Lagrangian point, L1 ? The answer is given by (1.3) upon replacing R = 323050 km, and the result is $l = 154.359°$. In words, this means the following basic, new result: ***the Moon Farside Sector in between 154.359 E and 154.359 W will never be blinded by RFI coming from satellites orbiting the Earth alone.***

In other words, the ***limit*** of the blinded longitude as a function of the satellite's orbital radius around the Earth is 180° (E and W longitudes just coincide at this meridian, corresponding to the "change-of-date line" on Earth). But this is the ***antipode*** to Earth on the Moon surface, that is the point exactly opposite to the Earth direction on the other side of the Moon. And our theorem simply proves that the antipode is the most shielded point on the Moon surface from radio waves coming from the Earth. An intuitive and obvious result, really.

So, where are we going to locate our SETI Farside Moon base? Just take a map of the Moon Farside and look. One notices that the antipode's region (at the crossing of the central meridian and of the top parallel in the figure) is too a rugged region to establish a Moon base. Just about 5° South along the 180° meridian, however, one finds a large crater about 80 km in diameter, just like Saha. This crater is called Daedalus. So, ***this author proposes to establish the first RFI-free base on the Moon just inside crater Daedalus, the most shielded crater of all on the Moon from Earth-made radio pollution!***

Figure 4.

AS11-44-6609 (July 1969) - An oblique of the Crater Daedalus on the Lunar Farside as seen from the Apollo 11 spacecraft in lunar orbit. The view looks southwest. Daedalus (formerly referred to as I.A.U. Crater No. 308) is located at 179 degrees east longitude and 5.5 degrees south latitude. Daedalus has a diameter of about 50 statute miles (~ 80 km). This is a typical scene showing the rugged terrain on the Farside of the Moon, downloaded from the web site:
http://spaceflight.nasa.gov/gallery/images/apollo/apollo11/html/as11_44_6609.html

4. This author's vision of the Moon Farside for RFI-free Searches:

Let us replace the simpler value of l =154.359° with the simpler value of l =150°. This matches perfectly with the need for having the borders of the Pristine Sector making angles orthogonal to the directions of L4 and L5. The result is this author's vision of the Farside of the Moon, shown in Figure 4.

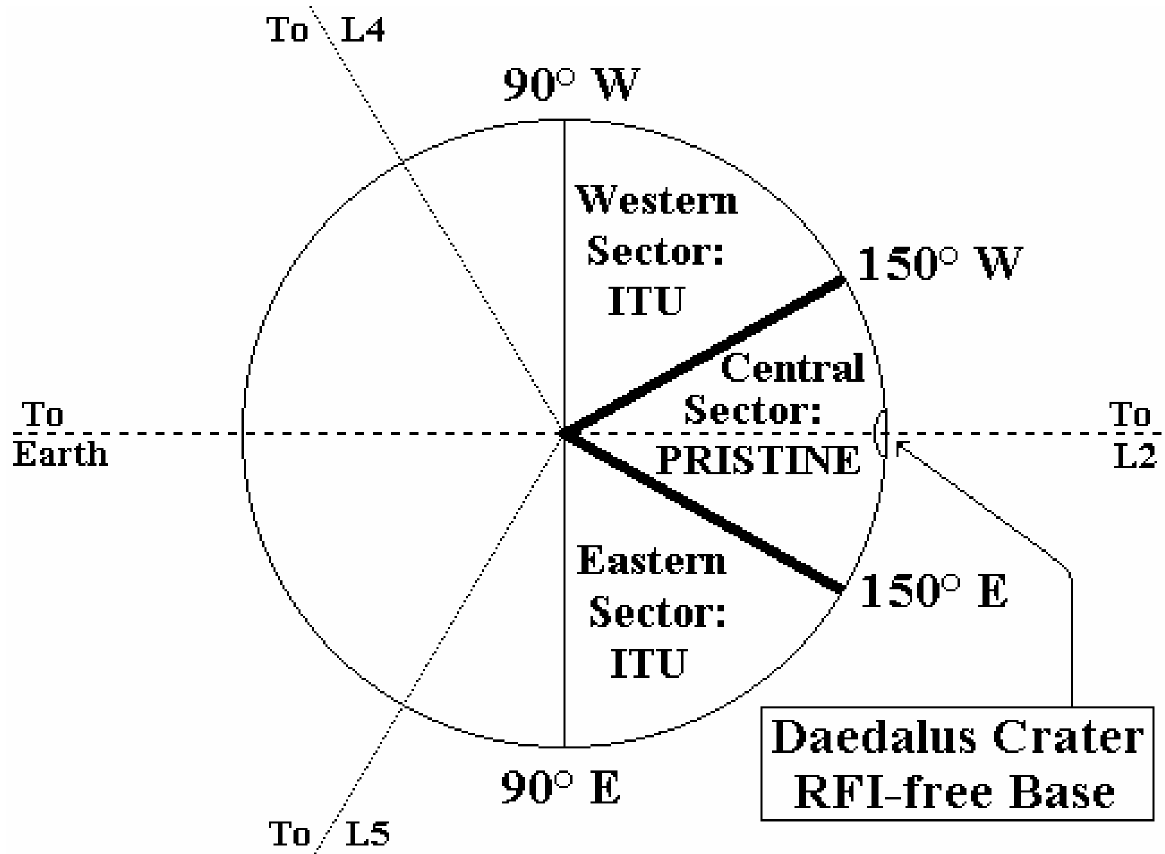

Figure 5.

This author's vision of the Moon Farside with the Daedalus Crater Base for RFI-free Bioastronomy, Radioastronomy, as well as SETI. International Space Stations (ISS) might be located at both the L4 and L5 Earth-Moon Points in the future. Only Point L2 will have to be kept free at all times.

Figure 5 shows a diagram of the Moon as seen from above its North Pole with the different "colonization regimes" proposed by this author. We see that:

1) The near side of the Moon is left totally free to activities of all kinds: scientific, commercial and industrial.
2) The Farside of the Moon is divided into three thirds, namely three sectors covering 60° in longitude each, out of which:
   a) The Eastern Sector, in between 90° E and 150° E, can be used for installation of radio devices, but only under the control of the International Telecommunications Union (ITU-regime).
   b) The Central Sector, in between 150° E and 150° W, must be kept totally free from human exploitation, namely it is kept in its "pristine" radio environment totally free from man-made RFI. This Sector is where crater Daedalus is, a ~ 100 km crater located in between 177° E and 179° W and around 5° of latitude South. At the moment, this author does not know how high is the circular rim surrounding Daedalus.
   c) The Western Sector, in between 90° W and 150° W, can be used for installation of radio devices, but only under the control of the International Telecommunications Union (ITU-regime). Also:

1) The Eastern Sector is exactly opposite to the direction of the Lagrangian point L4, and so the body of the Moon completely shields the Eastern Sector from RFI produced at L4. Thus, L4 is fully "colonizable".
2) The Western Sector is exactly opposite to the direction of the Lagrangian point L5, and so the body of the Moon completely shields the Western Sector from RFI produced at L5. Thus, L5 is fully "colonizable" in

this author's vision, whereas it was not so in Heidmann's vision. In other words, this author's vision achieves the ***full bilateral simmetry*** of the vision itself around the plane passing through the Earth-Moon axis and orthogonal to the Moon's orbital plane.

3) Of course, L2 may not be utilized at all, since it faces crater Daedalus just at the latter's zenith. Any RFI-producing device located at L2 would flood the whole of the Farside, and must be ruled out. L2, however, is the only Lagrangian point to be kept free, out of the five located in the Earth-Moon system. Finally, L2 is not directly visible from the Earth since shielded by the Moon's body, what calls for "leaving L2 alone"!

5. The Further Two Lagrangian Points L1 and L2 of the Sun-Earth System: their "polluting" action on the Farside of the Moon

There still is an unavoidable drawback, though.

This is coming from the ***further two Lagrangian points L1 and L2 of the Sun-Earth system***, located along the Sun-Earth axis and outside the sphere of influence of the Earth, that has a radius of about 924646 km around the Earth. Precisely, the Sun-Earth L1 point is located at a distance of 1496557.035 km from the Earth towards the Sun, and the L2 point at the (virtually identical) distance of 1496557.034 km from the Earth in the direction away from the Sun, that is toward the outer solar system. These two points have the "nice" property of moving around the Sun just with the same angular velocity as the Earth does, while keeping also at the same distance from the Earth at all times. Thus, they are ***ideal places for scientific satellites***.

Actually, the Sun-Earth L1 Point has already been in use for scientific satellite location since the NASA ISEE III spacecraft was launched on 12 August 1978 and reached the Sun-Earth L1 region in about a month.

On December 2, 1995, the ESA-NASA "Soho" spececraft for the exploration of the Solar Corona was launched. On February 14, 1996, Soho was inserted into a halo orbit around the Sun-Earth L1 point, where it is still librating now (June 2001).

As for the Sun-Earth L2 point, there are plans to let the NASA's SIM (Space Interferometry Mission) satellite be placed there, as will probably be ESA's GAIA astrometric satellite as well.

So, all these satellites do "POLLUTE" the otherwise RFI-free Farside of the Moon when the Farside is facing them. Unfortunately, the Moon Farside is facing the Sun-Earth L1 point for half of the Moon's synodic period, about 14.75 days, and it is facing the Sun-Earth L2 point for the next 14.75 days. Really all the time!

This radio pullution of the Moon Farside by scientific satellites located at the Lagrangian Points L1 and L2 of the Sun-Earth system is, unfortunately, UNAVOIDABLE. We can only hope that telecom satellites will never be put there. As for the scientific satellites already there or on the way, the radio frequencies they use are well known and usually narrow-band. This should help the Fourier transform of the future spectrum analyzers to be located on the Moon Farside to get rid of these transmissions completely.

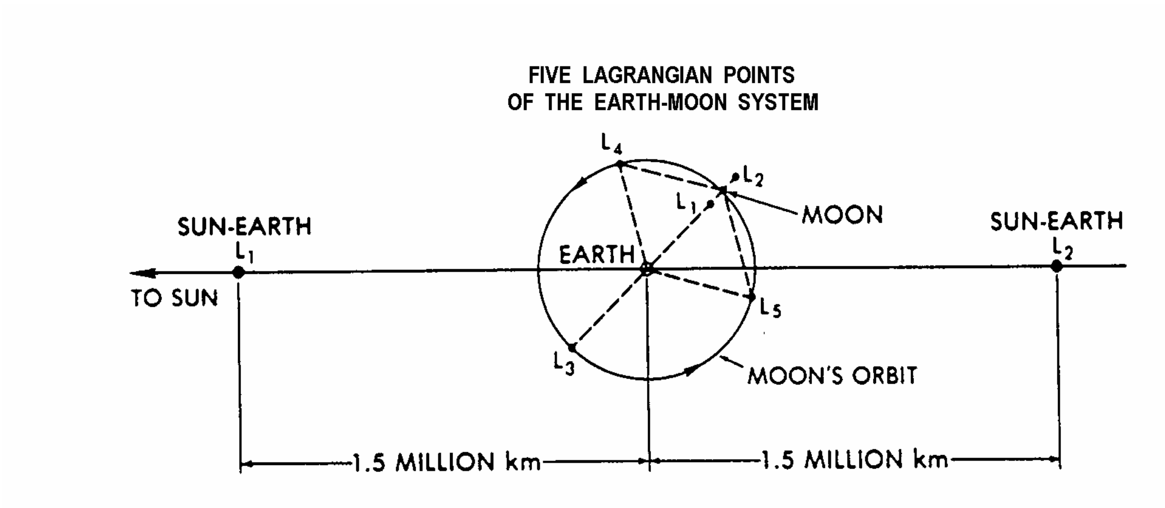

Figure 5.

In addition to the five Lagrangian Points of the Earth-Moon system (already described in Figure 1) the next two closest Lagrangian Points to the Earth are the Lagrangian Points L1 and L2 of the Sun-Earth system. These are located along the Sun-Earth axis at the distances of about 1.5 million kilometers from the Earth toward the Sun (L1) and outward (L2). Unfortunately, spacecrafts located in the neighbourhood of these L1 and L2 Sun-Earth Points do send electromagnetic waves to the Farside of the Moon. Examples are the ISEE-III and Soho spacecrafts, already orbiting around L1, and more spacecrafts will do so in the future around both L1 and L2.

6. The Quiet Cone above the Farside of the Moon

The spherical body of the Moon prevents all terrestrial electromagnetic waves from reaching the central part of the Farside, as described in the previous secions. But it does so also for a certain region of ***space*** above the Farside itself, that we have decided to call the "Quiet Cone". This definition is appropriate inasmuch as clearly the radio waves tangent to the Moon body define a cone, and clearly the apex of such a cone is the closer to the Moon Farside the higher the radius R of the telecom sats around the Earth is. To calculate how far into space the quiet cone extends, consider Figure 2 again. The similarity between the rectangular triangles EGA and MLA (rectangular at G and L, respectively) immediately shows that (EM+MA) : EG = MA : ML, that is $\left(D_{Earth-Moon} + H_{Apex}\right)/ R = H_{Apex} / R_{Moon}$. Solving for H_{Apex} yields the height H_{Apex} of the apex of the quiet cone above the Moon farside with respect to center of the Moon:

$$H_{Apex}(R) = \frac{D_{Earth-Moon} \cdot R_{Moon}}{R - R_{Moon}} .$$

Two numerical cases of this equation are important:

1) ***For geostationary orbits of 42,241.096 km, the corresponding apex of the quiet cone is located at 16,496 km outward from the Moon center. In other words, this is how far the quiet cone extends into space nowadays, but pratically the actual value may be lower in the year 2002 already, for we don't know about military satellites.***
2) The lowest possible value of the apex height corresponds to a satellite circling the Earth at the maximum possible distance, namely at the distance of the Langrangian Point L1. Thus, ***the minimal value of the apex is just 2,079 km.***

7. Proposing "RadioMoon": A New Space Mission to Robotically Set up and Operate an RFI-free Base inside Crater Daedalus (called the "Lunar Farside Radio Lab")

A problem is that it will hardly be possible to link the base at crater Daedalus to other bases on the Moon visible side by virtue of optical fibers or landed data relays, because of the large distance of 2730 km existing between Daedalus and anywhere along the limb.

To solve this problem, the proposal is made for a new space mission dubbed "RadioMoon" and briefly described in this final section. RadioMoon is made up by two spacecrafts: one orbiter and one lander. They fly together from the Earth to the Moon and are initially parked in a Moon circular and equatorial orbit having a radius of, say, 10,000 km. The orbital period of this single spacecraft around the Moon is 31.641 hours (1.3 days). Then, at a time when the spacecraft is just crossing the Earth-Moon axis on the visible side, the lander is released from the orbiter and starts getting down towards the Moon surface along a Hohmann transfer half-elliptical trajectory. By the very definition of this Hohmann transfer, the lander just lands at the longitude of 180° E, namely inside crater Daedalus (slightly different manoeuvers there would slow down the spacecraft, to prevent it from crashing). The Hohmann transfer has these parametrs: semimajor axis 6378 km, eccentricity 0.742, time to get down from 10,000 km along the half-ellipse 6 h 52.86 m. The lander would be protected by airbags against crashing. We know that such airbags worked out well on July 4, 1997, for the Mars Pathfinder landing on Mars. Since the gravity on the Moon is about a half of the gravity on Mars, there is no reason to doubt that such an airbag-protected landing would work equally well on the surface of the Moon. Finally, after touching down, the lander deploys a flat phased array capable of steering its beam electronically for all RFI-free Searches in Radioastronomy, Bioastronomy and SETI. The orbiter's task is to gather data from the Phased Array at crater Daedalus when flying above the Farside, and transmit these data back to the Earth when flying above the near side. And the other way round for giving the Earth's instructions to the Phased Array operating at Daedalus, now dubbed the "Lunar Farside Radio Lab". We contend this is by far the cheaper, easier and safer way to operate a Moon Farside Base.

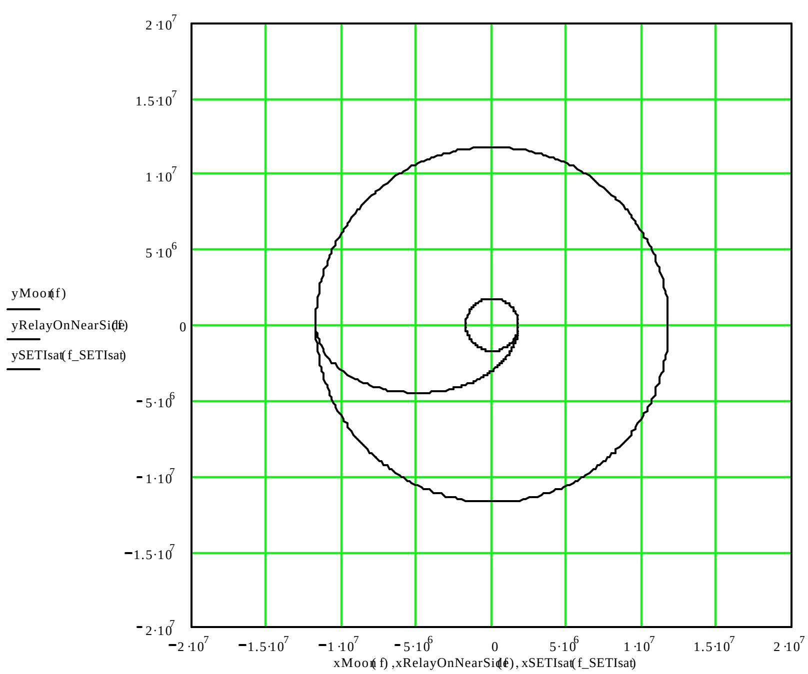

Figure 6.

The “RadioMoon” space mission in the Moon’s equatorial plane: in the example, the orbiter is at 10,000 km and the Hohmann transfer lets a Phased Array be landed inside Crater Daedalus.

Acknowledgments

The author is grateful to Drs. Michael I. Yarymovych, President of the IAA, Gerhard Haerendel, President of COSPAR, and Jean Michel Contant, Secretary General of the IAA, for their encouragement and support. Dr. Mike Davis of the SETI Institute provided the author with vital information about research done in the USA on many of topics related to this IAA Study. The cooperation of the following Jet Propulsion Laboratory current or past employees and leading astronautical experts is gratefully acknowledged: Drs. Macgregor S. Reid, Thomas B. H. Kuiper, Thomas R. McDonough, Dyton Jones, Michael J. Mahoney, Carl Palko. Substantial contributions at the JPL Meeting held on Nevember 2nd, 2001, and described in Annex #1, were also given by Drs. Philip Venturelli of Caltech, Leslie I. Tennen of the Law Offices of Sterns and Tennen in Phoenix, AZ, and Louis D. Friedman, Executive Director of the Planetary Society. Finally, the excellent research work and Lunar web site: http://www.astro.gla.ac.uk/users/yuki/ of young and bright Mr. Yuki Takahashi of Japan is greatefully acknowledged.

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[1] J. Heidmann, "Saha Crater: a candidate for a SETI Lunar base", Academy Transactions Note, *Acta Astronautica*, Vol. 32, (1994), pages 471-472.

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[4] C. Maccone, "Laydown of a Tether from Earth Visible Location to Far Side for Lunar SETI", *Advances in Space Research*, Vol. 26 (2000), pages 359-370.

[5] C. Maccone, "Searching for Bioastronomical Signals from the Farside of the Moon", a paper presented at the First European Workshop on Exo/Astrobiology held at ESRIN, Frascati, Italy, 21-23 May 2001. Later this paper was published by ESA in the relevant Proceedings called ESA SP-496 (published in August 2001), pages 277-280.

[6] C. Maccone, "The Lunar SETI Cosmic Study of IAA: Current Status and Perspectives", paper IAA-01-IAA.9.1.05 presented at the 52nd International Astronautical Congress held in Toulouse, France, 1-5 October 2001.

[7] C. Maccone, "Planetary Defense and RFI-Free Radioastronomy from the Farside of the Moon: A Unified Vision", *Acta Astronautica*, Vol. 50 (2002), pages 185-199.

ANNEX #1

MINUTES OF THE MEETING

ABOUT THE "LUNAR FARSIDE RADIO LAB"

HELD AT NASA's JET PROPULSION LABORATORY

IN PASADENA, CALIFORNIA,

ON FRIDAY, NOVEMBER 2nd, 2001.

International Academy of Astronautics

Meeting about the "Lunar Farside Radio Lab" Cosmic Study

Held at the Jet Propulsion Laboratory on Friday, November 2nd , 2001,
Building 180, Room 501, 9:00 am – 13:00.

ATTENDEES:
Davis, Michael. SETI Inst., meeting chair.
Friedman, Louis D. The Planetary Society
Jones, Dayton. JPL.
Kuiper, Thomas B.H. JPL. Meeting coordinator.
Maccone, Claudio. Alenia, Italy; meeting originator.
Mahoney, Michael J. JPL
McDonough, Thomas R. The Planetary Society
Palko, Carl. The Aerospace Corporation
Reid, Macgregor. JPL (retired)
Tennen, Leslie I. Law Offices of Sterns and Tennen, Phoenix
Venturelli, Philip. Caltech

People who attended a part of the meeting:
Klein, Michael. JPL
Weinreb, Sander. JPL

People on email list who didn't attend:
Betts, Bruce. The Planetary Society
Easter, Robert. JPL
Preston, Robert. JPL
Resch, George M. JPL
Slade, Martin A, III. JPL
Stone, Edward C. Caltech

MINUTES OF THE MEETING, DRAFT 8
by Thomas R. McDonough and Louis D. Friedman

9:00 am **Opening by Meeting Chair and Introduction of Attendees** (15 min).

Reid: If a farside station is established, the UN will be involved. The Academy is the most independent agency to advise them. All the technical work has to be done by committees like this one.

Friedman: The Planetary Society is also a Non-Governmental Organization (NGO) at the UN.

9:15 am **New Status of the IAA "Lunar Farside Radio Lab" Cosmic Study after the International Astronautical Congress (IAC) held in Toulouse, October 1-5, 2001** (**Claudio Maccone**, 15 min).

Maccone: The study started with Jean Heidmann under the IAA aegis.

Reid: The UN should be relevant for advancing this study when it becomes time.

Maccone: The goal is to complete the study in time for presentation at the World Space Congress (IAF/COSPAR meeting in Houston October 10-19, 2002); implying March 20-21 meeting of IAA in Paris.

[The World Space Congress is at http://www.aiaa.org/wsc2002/; the IAA is at http://www.iaanet.org/; the IAC is at http://www.iaanet.org/c_papers/iac52.html].

Jill Tarter is the chair of the SETI committee. A Cosmic Study, she says, must merge the various papers into a single technical document. The document will be published as supplement to Acta Astronautica. There will be a meeting between the UN and space bodies.

Maccone handed out his AIAA paper from Toulouse, "Lunar SETI Cosmic Study of IAA: Current Status and Perspectives."

He discussed:

- Crater and site selection of protected area on the Moon for a radio laboratory
- Proposed site centered at the anti-Earth direction, 180 deg longitude

- Proposed circular lunar orbit, getting data from the phased array on the surface site on the far side of the Moon, and then transmitting to Earth when on the near side

Heidmann may not have realized the importance of the Lagrangian points. Heidmann had recommended that the crater Saha be used for a lunar farside observatory. It is just a little beyond the lunar limb. But the Lagrangian point L5 would be visible from Saha. L1 might be used for planetary defense against asteroids.

Maccone concluded that the safest place is 180 deg longitude on the far side, i.e., the antipode. He suggests that the crater Daedalus, near this antipode, is the best place for a farside observatory. [There's a nice Apollo photo of this crater at http://spaceflight.nasa.gov/gallery/images/apollo/apollo11/html/as11_44_6609.html]

Lagrange point L2, directly above the center of lunar farside, should be kept free of spacecraft.

The cheapest and safest farside mission would be a lunar orbiter that observes when it is on the farside of the Moon.

DAVIS: this is very important.

9:30 **Tech Topic #1: ITU & Frequency Management** (**Michael Davis**, 15 min).

SUMMARY: Davis spoke about spectrum allocation, and gave a handout, "Recommendation ITU-R RA.479-4. Protection of Frequencies for Radioastronomical Measurements in the Shielded Zone of the Moon."

Definition: SZM = shielded zone of the Moon

Davis: The ITU [International Telecommunication Union, http://www.itu.int/home/] started in 1868, concerned with how to coordinate Morse code voltages between France and Germany, before Hertzian waves were discovered. It's now a UN function. They recommend how governments should behave. It is advisory. Then the governments sign on via an international treaty. Almost all governments in the world usually sign on. Working party 7 is for the scientific use of the spectrum; 7D deals with radioastronomy. They produce a proposed draft new recommendation (PDNR).

The Microwave Anisotropy Mapper (MAP) spacecraft is at L2, blasting away at the lunar farside. Deep space spacecraft are also visible from farside.

IAU recommends radio communication be limited to 2 to 3 GHz.

Friedman: Who opposes this?

Davis: The recommendations carry no weight till brought to someone's attention. The IAU recommendation is a necessary but not a sufficient document. Recommendations die if not energized; there's a very effective sunset provision. They must be touched every 3 to 5 yrs.

Kuiper: Nothing is binding till a government or set of governments request it. Then Australia, US, Canada, Russia and Netherlands typically work together. Tom Gergely is chair of US working party 7D, which consists of volunteers.

Reid: Are we just going to talk about it, or is something going to happen?

Davis: In the past a very few key people such as Bill Erickson, Dick Thompson and Tom Gergely carried a large fraction of the work load. Now there is a growing group of astronomers involved actively in ITU work.

9:45 **Tech Topic #2: Low Frequency Array Concepts** (**Thomas B.H. Kuiper**, 15 min).

SUMMARY: Kuiper summarized low frequency array concepts on the lunar surface. This gives advantages of far-side lunar location for science and for combating interference.

Kuiper: My paper from 3 years ago, "Lunar Surface Arrays," was published by the American Geophysical Union (AGU) in RADIO ASTRONOMY AT LONG WAVELENGTHS, edited by RG Stone *et al*. [http://www.agu.org/cgi-bin/agubookstore]

Interplanetary scattering causes a limit beyond which increasing array size does not give you improved resolution. E.g., 100 km is the maximum size at 1 MHz. For higher frequencies, up to 30 MHz, we might want to populate almost all the back of Moon for low-frequency observations.

Crater Tsiolkovsky has the advantage that it has a high point where you can locate an antenna for communication. [Apollo photo: http://grin.hq.nasa.gov/ABSTRACTS/GPN-2000-001128.html]

All the concepts involve processing some data on the Moon, to reduce the data rate sent to Earth.

Every month on the Moon, you go thru a solar "day," when you could charge up your batteries.

Officially, ITU ends at 300 GHz.

10:00 **Tech Topic #3: Radio Astronomy with Microspacecraft in Lunar Orbit** (**Dayton Jones**, 15 min).

SUMMARY: Jones summarized a JPL study using microspacecraft orbiter for low-frequency radioastronomy. A lunar orbit was the result – five orbiters fitting within a Taurus. Data processing and transmission is a big deal and big concern in any such proposal. Maccone wants to publish and promote the results of the study. Jones agreed to prepare something.

Jones: We have done a study with 5 satellites in lunar equatorial orbit. The data is stored onboard while on farside. It uses several meter-long dipoles. You can launch it on a Taurus, avoiding an expensive launch vehicle.

All the satellites are single string, with a wet mass of 14 kg for each spacecraft. Total wet mass: 128 kg with carrier. 204 kg total launch mass.

Differential Doppler gives spacecraft heights very accurately.

A 4-tone UHF system is used to monitor inter-satellite ranges. It is separate from the ground-based differential Doppler measurements. Both are needed to maintain the array configuration.

Davis: Transmissions mean we cannot have a totally pristine radio environment on farside.

Jones: They decided to live with a low duty cycle. But this is an unexplored part of spectrum, 30 kHz to 30 MHz. Station-keeping fuel limits the lifetime of mission. it is designed to last for 2 to 3 years.

Kuiper: Some scientists would like to observe phenomena that most astronomers would try to avoid. For example, the magnetotail would be observed from the lunar nearside; solar phenomena when the sun is above the horizon.

Jones: Eventually the spacecraft will hit the Moon and raise a small amount of dust.

Maccone: There will be a lunar conference in Berlin, January 14-16, 2002, described at the web site: http://solarsystem.estec.esa.nl/~dheather/nveurope.htm

10:15 Tech Topic #4: SALSA, a mm-Wave Array **(**M.J. Mahoney **15 min).**

Mahoney: This is a study of a submillimeter array from ~1990. The objective was to observe from 60 to 300 microns (i.e., 5 to 1 THz), a wavelength regime that can't be seen from Earth, but which is important for many high priority astrophysics problems, such as imaging dusty disks around newly forming stars.

To image these complex regions at least 12 antennas are required. Given the sensitivity requirements and the state-of-the-art in THz receiver technology, this implied that 3.5 meter diameter antennas would be needed. Both minimum redundancy circular and Wye-shaped arrays were considered, with the Wye being adopted as the baseline since it provided better imaging (i.e. UV coverage) at low spatial frequencies. The array uses 0.5 km arms, which provides 10 mas angular resolution at 5 THz, or 0.16 AU at the distance of beta Pictoris and 1.4 AU at the Taurus-Aurigae star formation region.

To simplify the array, all 12 receivers were located at a centrally located cryostat, and the antennas used a Gaussian optics beam waveguide to relay signals to the cryostat from each antenna. Different-sized relay optics, ranging from 0.5 to 1.6 meters, are needed to control diffraction. The total mass was 6700 kg, and power, 3 kW. Most of power was for the digital correlator.

Kuiper: Moore's law [implies great reduction in power and mass today].

Mahoney: Yes, this work was done more than a decade ago and a lot has changed, especially the receiver and back end technology. The array would experience 85-385 K temperatures. Radomes might be needed to protect the mirrors from dust, which could cause localized thermal problems because of the high absorption of dust compared to the mirror surfaces. Today, the radomes would be made of Teflon or Gore-Tex, but these are opaque shortward of 300 microns. The needed material doesn't exist yet. But a lot of progress has been made in reducing power, mass requirements.

Davis: There's no reason this couldn't go on the front face of the Moon.

Mahoney: That's right; it's very difficult to generate much power at THz frequencies, so our original plan was for a front face equatorial array. (Reference: MJ Mahoney and KA Marsh, SALSA: A Synthesis Array for Lunar Submillimeter Astronomy, SPIE Vol. 1494, p182-193, 1991.)

10:30 **Tech Topic #5: Moon and Sun-Earth L1 and L2** (**Claudio Maccone**, 5 min).

Maccone: There are already a number of spacecraft missions in place or coming, that will produce signals detectable from lunar farside. We need to take into account missions at the L1 and L2 Lagrange points and keep track of all the frequencies being used.

Kuiper: Spacecraft need to use really clean modulation schemes. Sloppy modulation schemes are used because they're cheap, but they spread signals all over the spectrum, causing electromagnetic pollution.

Davis: There is a proposed ITU draft resolution of recommendations from 7D on Lagrangian points.

Kuiper: Missions are being designed and built. This is important.

Davis: There really is something to protect, not just that there might be.

10:35 **Tech Topic #6: Mars Opportunities** (**Carl Palko**, Aerospace Corp., 15 min).

SUMMARY: Palko is the chief architect of a Mars base study for JPL. He discussed Mars robotic base radioastronomy opportunities. The name of the study is "Mars North Polar Base." They are doing it for JPL (Bob Easter – Program Lead for Mars Bases at JPL). Some of the characteristics of the proposed Mars Robotic Bases are:

- sustained continuous presence
- multiple cooperating assets
- flexible, adaptable, robust, large mass and power
- supplemental but not dependent on Mars Sample Return

Palko: It is an ongoing study. They are looking at options – engineering and science studies. Test site: 65 deg west, 75 deg north. JSC is involved too and claims a connection with human exploration. Being driven by huge data requirements (virtual presence, HDTV or at least DVD). Radioastronomy becomes a low-cost add-on.

The overall architecture is estimated to cost $10 to 15B over 10 to 20 yrs. This is just a study of the best strategies, and types of scientific investigations possible.

Currently, we're studying a Mars North Polar Base, with a first launch in 2016. It would have multiple rovers, communication and weather satellites. Each lander carries 1,000 kg or 4 cubic meters of cargo to the Mars surface. The payload typically is four 250 kg, 1 cubic meter cargo modules. Two such landers are planned for each launch opportunity.

The goal of the current architecture study is a balance of robotic and human precursor investigations.

Why do radioastronomy on Mars? Mars is a central part of NASA's future exploration plans. Nothing in the next 10 to 15 years is planned for a Moon landing.

The plan for Mars robotic bases include a multi-megabit comm link back to Earth, using Ka band.

They want to deliver high quality video, at a DVD level. People want virtual reality. With such a high data rate, radio astronomy data could easily be accommodated.

The long winter period is blocked from solar emissions, and much of the time also blocked from Earth emissions.

There would be sensor packages distributed over several hundred km by the provided rovers. Also the rovers could reposition sensor packages (including radio telescope elements) as needed.

Friedman: Mars landers are planned for 2005 to 2012. Has anyone planned radioastronomy experiments on them?

Palko: No.

Davis: The square-kilometer array needs a quiet site on Earth.

10:50 **Tech Topic #7: Legal Protection of the Farside** (**Leslie Tennen and Patricia Sterns**, 15 min).

SUMMARY: Tennen provided a review of legal statutes and considerations. He also cited links with UN, COPUOS, IISL, etc. He noted also that self-regulating by science has been a stronger factor than legal regulations.

Tennen: The 1967 treaty on the peaceful uses of outer space is the main relevant treaty. All states are guaranteed access to all parts of celestial bodies. It is not necessarily first come first served.

If a mission is privately funded, private entities must be licensed. Private companies have no right to conduct space activities. Private US projects must go through the Office of Commercial Space Transportation, Dept. of Transportation.

The 1979 Moon Treaty has only been ratified by a handful of states. The only spacefaring nations that have signed are European. France has signed but hasn't ratified the treaty. The US hasn't signed or ratified. It has a provision for the designation of "international scientific preserves." Environmental protections are rather vague.

One problem area is the Lagrange points. The Moon Treaty doesn't cover these. At the moment, there is no legal protection for L2.

The UN Committee on the Peaceful Uses of Outer Space (COPUOS) created these treaties. Kopal is very open to these areas. [http://www.oosa.unvienna.org/COPUOS/copuos.html]

A good contact: the International Institute of Space Law [http://www.iafastro.com/iisl/iisl_gar.htm#in].

Davis: ITU operates on the principle of "quiet unless you have permission"; the space treaty is the opposite.

Tennen: The scientific community's protection is often more important than laws.

Kuiper: We should be able to solve these problems until commercial interests become important.

Tennen: If a spacecraft lands, other than to search for life, it doesn't need to be sterilized.

Palko: MPL was only cleaned on the surface; but it crashed on Mars.

Maccone: Tennen should get in touch with Kopal about legal points.

11:05 **Tech Topic #8: Public Outreach "Keep Farside Noiseless"** (by **Louis D. Friedman**, The Planetary Society, 15 min).

SUMMARY: Friedman said The Planetary Society was mostly listening, and not doing much on this question. Except that its widespread SETI involvement is broadening even more, so that it was willing to consider more. Kuiper brought up this as a pollution issue, and there is a strong need for public education. Friedman said the Society would stay involved and is willing to publish and promote more as these issues become part of space exploration issues.

Friedman: Is optical SETI (OSETI) not being discussed?

Maccone: It wasn't envisaged originally.

Davis: OSETI has zero interference reported currently.

Kuiper: One must worry about future possibility that there may be bright spots [for Earth-based OSETI] from geostationary objects.

Kuiper: People designing telecomm systems are not aware of radioastronomical problems. The Iridium [communication-satellite system] was unaware, and could have made slight changes to avoid the terrible problems to radioastronomy. If only we could get the public to understand that this is a type of pollution.

Davis: We must continually educate the public.

Kuiper & Davis: Commercial pressures are huge and growing.

Friedman: Thomas McDonough will be the liaison [between this group and The Planetary Society]. Perhaps we could do an article in our magazine, The Planetary Report.

Davis: Lunar farside is the only place in the solar system guaranteed free of terrestrial interference.

Davis: The UN OECD [Organization for Economic Cooperation and Development] megascience board said a key issue in international law is protection of radioastronomy.

Reid, to Maccone: Give credit to both JPL and NASA if quoting JPL reports, because otherwise NASA gets out of sorts.

Palko: The move is to Ka band for Mars missions, rather than X band. Reid said he thinks this would help; Davis is not sure.

Davis: The US astronomy community does a superb job of decadal reviews.

Palko: DSN is being upgraded to Ka band. The military will probably be using it more, too.

11:40 **Round Table Discussion** (by all, 40 min).

Davis: We have a conundrum, due to the difficulty of getting legal changes.

Kuiper: Not really. The ITU mechanismis perfectly workable. We know how to go to the ITU.

Tennen: We could get governments to modify existing outer space treaties.

Davis: Unless someone objected to the ITU system, the issue would be moot. Let sleeping dogs lie. Don't allocate frequencies at L2 that would cause damage.

Tennen: There is freedom unless it is specifically prohibited.

Kuiper: Unlike interference from Earth, which comes from all parts of the spectrum, this problem is much simpler. So maybe we don't have to worry.

Reid: We do. [Maccone agreed strongly.]

Tennen: It will be much easier to prevent something from happening than to stop it once it gets started.

Davis: It can be too late or too early. Apparently there's no money in the NASA budget to go to the Moon. You could argue let it sit for 15 years. On the other side: there are national parks and forests needing preservation for their own use.

Kuiper: The practical goal is to raise the visibility to the national groups. Government is very responsive to commercial interests. The other thing is public outreach; we're fortunate to have The Planetary Society present.

Maccone: This is an ecological endeavor, wishing to keep the world as clean as possible. We are preventing pollution. The European perspective is that the US is concentrating on Mars; ESA is left with the Moon.

Reid: And the Japanese, too [have Moon missions].

Maccone: There will be the [Berlin] meeting January 14 to 16.

Reid: We must do what we can to make agencies involved.

[At this point, Michael Klein joined us.]

Kuiper: Maybe Europeans can take the initiative. We as astronomers can work to be coordinated. Then the US might approve, on seeing what the Europeans have done, and there's nothing objectionable from the US point of view.

Davis: We do have to do our homework. This arose in a SETI context, and passed on to radioastronomy. Because SETI is not restricted to astronomical bands, it was, from the beginning, a long term goal. They knew that by 2100 or 2200, it wouldn't be possible to undo.

Davis: The REAL resource is the SHADOW VOLUME [behind the Moon], which I realized from today's presentation on microsatellites.

Maccone: Gorgolewski of Torun, Poland, has been working with Hewish. Gorgolewski has written some nice papers about satellites going into the shadow of the Moon.
[http://www.astro.uni.torun.pl/personal/sgo_personal.html]

Maccone: You could do a Hohmann transfer directly to the far side of the Moon.

Maccone: You can have VLBI between radiotelescopes on Earth and an antenna at the Moon. The Japanese VSOP mission, the only VLBI Earth satellite to date, isn't working at 22 GHz because of antenna surface inaccuracy; but could certainly work with a fixed antenna located on the farside of the Moon.

Davis: There is a Russian long-proposed mission.

Kuiper: RADIOASTRON is not dead; the Russians are still working on it.

Kuiper: We should be thinking about telescopes based on technology of 20 years from now.

Maccone: How to make a proposal for spacecraft to NASA?

Kuiper: You need to get the mission down into the most affordable category. Small missions can be funded every year; large ones, every decade.

12:20 **Guidelines for further developments** (**Claudio Maccone**, 15 min).

Maccone: the International Academy of Astronautics (IAA) has the website http://www.iaanet.org/.

Within this site, the website for the lunar project is:

www.iaanet.org/lunarfarside/index.html
There is a login and a password that will be communicated by me to interested contributors.
Anyone wishing to contribute to it should send me emails with attachments in Word format; they'll get a reply from me. I WOULD LIKE PICTURES [that can be used on the website].

Mahoney: I have copies of artwork. I'll send any useful material.

Maccone: I'd like copies of recent images of craters such as Saha.

Kuiper: My paper lists a website. [see appendix below]

Venturelli: Yuki Takahashi, a recent graduate of Caltech, has a website about an observatory on the farside of the Moon. He's in Glasgow pursuing a masters degree on this topic.
[http://www.astro.gla.ac.uk/users/yuki/]

Venturelli: I did work at Carnegie Mellon on robots for on-orbit construction of structures. Claudio, did you do any thought of mechanisms for deploying these missions?

Maccone: No. The Hohmann mission requires AI for the final stage to land on Moon.

I used MATHCAD for the graphs.

It will be 10 more years until the next major World Space Congress [after the October 10-19, 2002 one in Houston: http://www.aiaa.org/wsc2002/].

[**OUTLINE OF THE REPORT**] We should have a first chapter showing that RFI is increasing on Earth, a problem for radioastronomy as well as SETI. The 2nd chapter: Why use the farside of Moon? Chapter 3: Technical, with pros and cons of orbiting vs. landing. Chapter 4: Legal, which is very important. Kopal and Fasan are willing do contributions. I've appointed Bess Reijnen as secretary.

Tennen: A good contact is the president of the International Institute of Space Law, N. Jasentuliyana, who is the retired director of the UN Office of Outer Space Affairs.

Tennen: Saha has 3 km walls. Heidmann wanted to restrict the proposal [protecting the lunar farside from electromagnetic radiation] to a bare minimum. Now Maccone would like protection of the entire farside. But if we could concentrate on a particular crater, or sector, it would increase the chances of it being designated an international scientific preserve. The less we ask for, the more we are likely to get it.

Reid: That's a very good suggestion.

Kuiper: There's already a recommendation to protect part of the farside. The concept of radio-quiet sites already exists.

Davis: This is fundamentally an observatory site we're trying to protect within several hundred km.

Tennen: If we go to COPUOS and say we want to protect 1/6 of the Moon, we'll have a much harder time than if we say we want to protect a few hundred sq km.

Kuiper: At long wavelengths, you may want to have elements thousands of km apart.

Davis: Maybe we should ask for a radio-quiet volume, not a zone. There's a radio quiet zone in Greenbank. It goes down Main St. There were TV applicants on either side of Main St. in Charlottesville; the one inside the zone was ruled out.

McDonough: Any rule must allow for some data transmission from the observatory.
Kuiper: The transmissions must be managed with the consideration of the observatory.
Davis: In Arecibo, it's called a coordination zone.
Maccone: A satellite could be put in an orbit around Earth, farther than the Moon, which goes out to the sphere of influence, which is farther than the Moon, ~900,000 km.
Davis: Someone on Pluto could be violating the zone, so luminosity must also be taken into account.
Davis: We are considering a range of 100 kHz to 300 GHz. The low end is due to practical physical limits; the upper limit is due to ITU.
Davis: Backlobes of antennas are caused by radiation creeping around them. I wonder whether the antipode might be the worst place, where terrestrial radiation might concentrate.
[Sandy Weinreb arrived at the end of the meeting; Davis asked him about the latter question. Weinreb thinks there'd be tremendous attenuation.]
Davis: I'll withdraw that concern.

APPENDIX: USEFUL URLs FROM THOMAS KUIPER

Committee on Radio Frequencies [CORF], National Academy of Sciences.
http://www.nas.edu/bpa/corf/

You may also find
http://DSNra.jpl.nasa.gov/Services/Freq_man/
informative.

The Moon images archive appears to have moved. Start searching from
http://nssdc.gsfc.nasa.gov/imgcat/

The Moon archive is at
http://nssdc.gsfc.nasa.gov/imgcat/html/group_page/EM.html