

4M Mission: a Lunar FlyBy experiment

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Introduction

The 4M mission is an opportunity mission, in honor of late Professor Manfred Fuchs, founder of the OHB group.

4M means: Manfred Memorial Moon Mission

The project is conducted by LuxSpace, Grand Duchy of Luxembourg and is a quick, low cost mission aiming at global cooperation whilst presenting challenges opening new ways.

Mission description

The spacecraft will be part of the last stage of a lunar mission, due to be launched end of October 2014. The trajectory will be a lunar flyby and return to Earth, with 90% chances of re-entry in the atmosphere. The 10% remaining chances lead to a very interesting orbit.

The nominal mission duration is 196 hours, 8.17 days. The Lunar flyby will occur 97 hours after injection, 4.04 days.

During flyby, the range to EU stations will be 399636km at most and the distance to the Moon will be between 12000 and 24000 km depending on the final injection vector.

The 4M spacecraft will transmit continuously on 145.980MHz (+/- 2.9kHz) with a 1.5W power input at antenna which is a simple Monopole. This will give S/N comparable to EME signals at Earth's surface.

The transmission is based on a 1 minute sequence and a 5 minutes cycle.

The transmission will start 4670s (77.8 minutes) after launch (-0, +600s)

4M Spacecraft description

The spacecraft is located on the Vehicle Equipment Bay of the launcher (much like the Rubin and IDEFIX mission, BO47&48, in 2002).

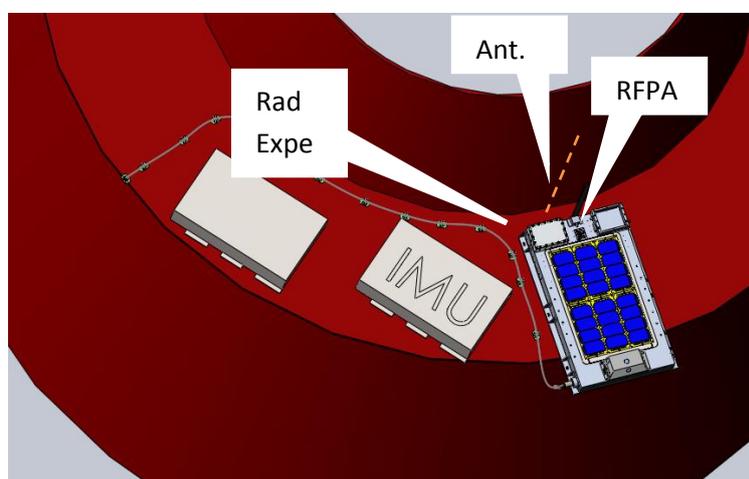


Figure 1 Location of the 4M S/C

The spacecraft is comprised of the following equipment:

- Primary power source: 28 high energy density, non rechargeable cells, guaranteeing the nominal mission whilst providing 6W to the payloads.
- Secondary power source: 2 x 8 Triple layer solar cells and 4 x Li-Ion rechargeable cells.
- An Onboard Computer, FM430 and interface board
- An I/Q modulator
- An RF power amplifier, providing a nominal 1.5W into the antenna
- An L/4 antenna
- RAD experiment for radiation dose determination on the trajectory

The RAD experiment is a special chip from IC-Malagua (Spain), that is able to accurately measure the Radiation dose rate.

Trajectory description

Overall view

The injection will occur over the Pacific Ocean and only Eastern Australia / New Zealand stations will be able to receive the 4M S/C.

The 4M is on a “collision” course with the Moon for the FlyBy.

The Moon will be at its lowest declination, to optimize the launcher capability. The southern hemisphere stations will be favoured during all the nominal mission.

The following view shows the Earth, the Equatorial plane, the Moon and the trajectories (nominal and deviation cases), viewed from -23° latitude (Equatorial plane is ‘above’)

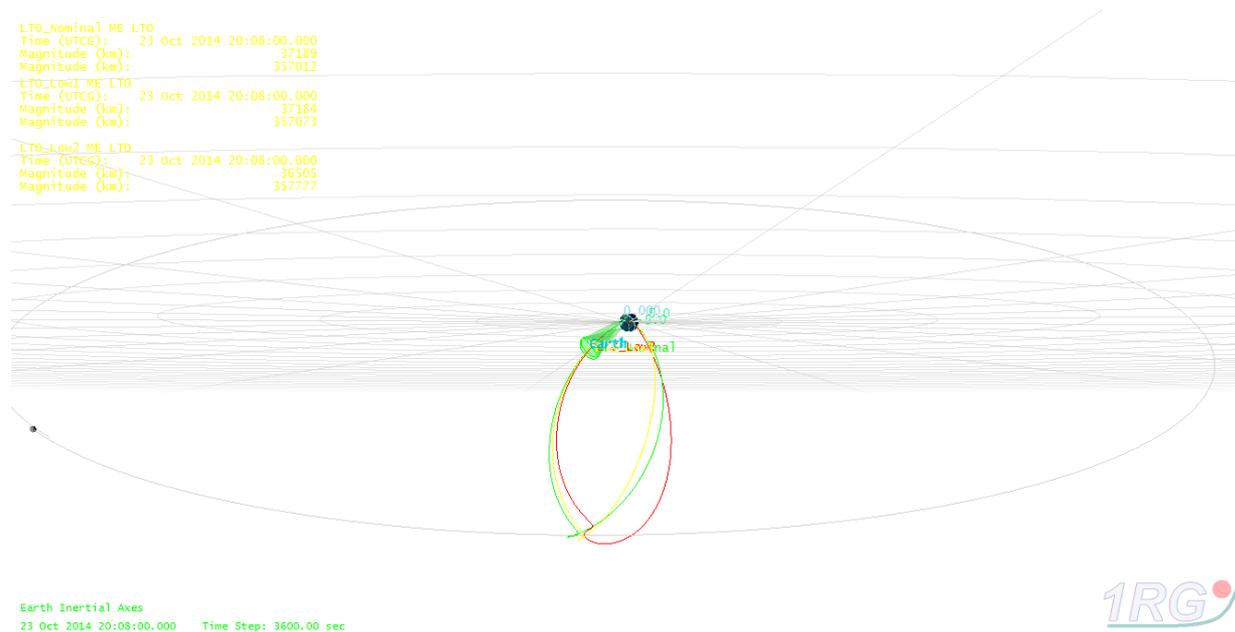


Figure 2 Overall trajectory

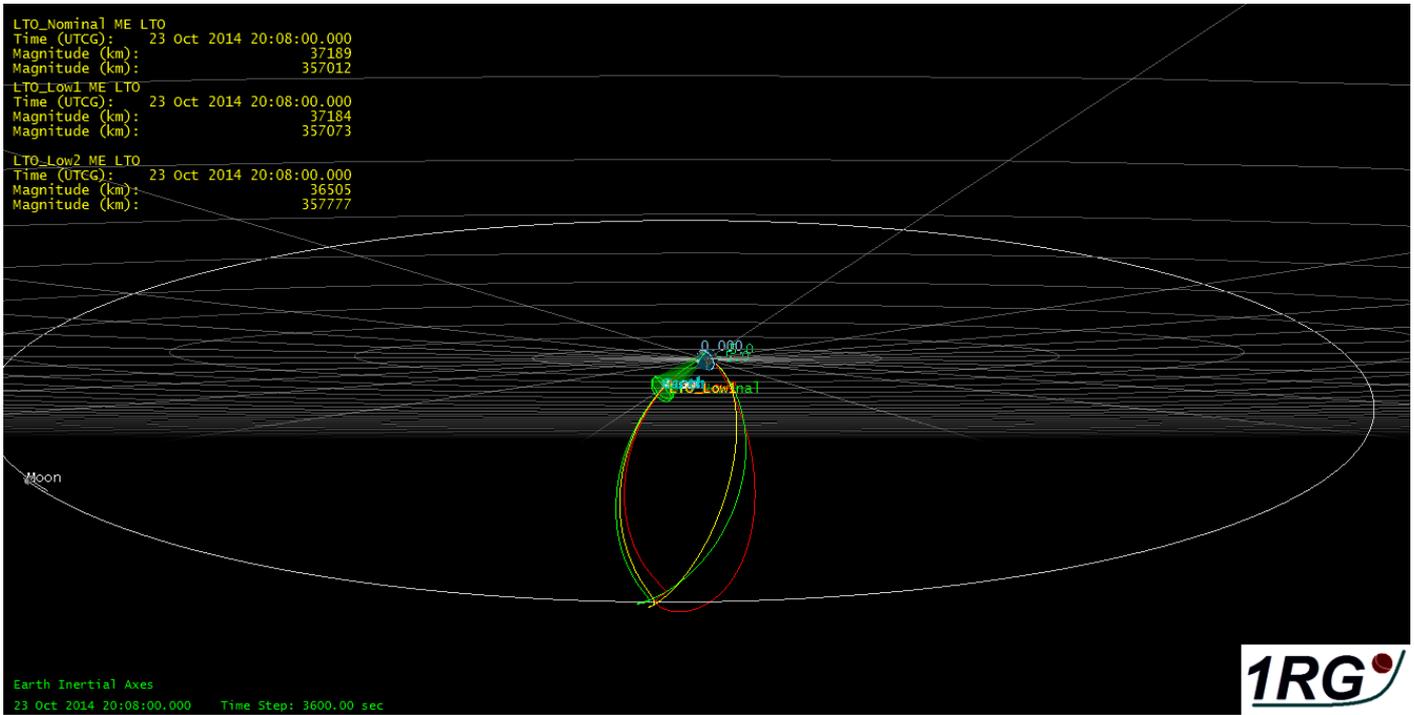


Figure 3 Same view

The Nominal trajectory is in Green, the -3300 km SMA trajectory is in Yellow, the -12200 km SMA trajectory is in Red.

The following screen shots show the circle of visibility at injection and after.

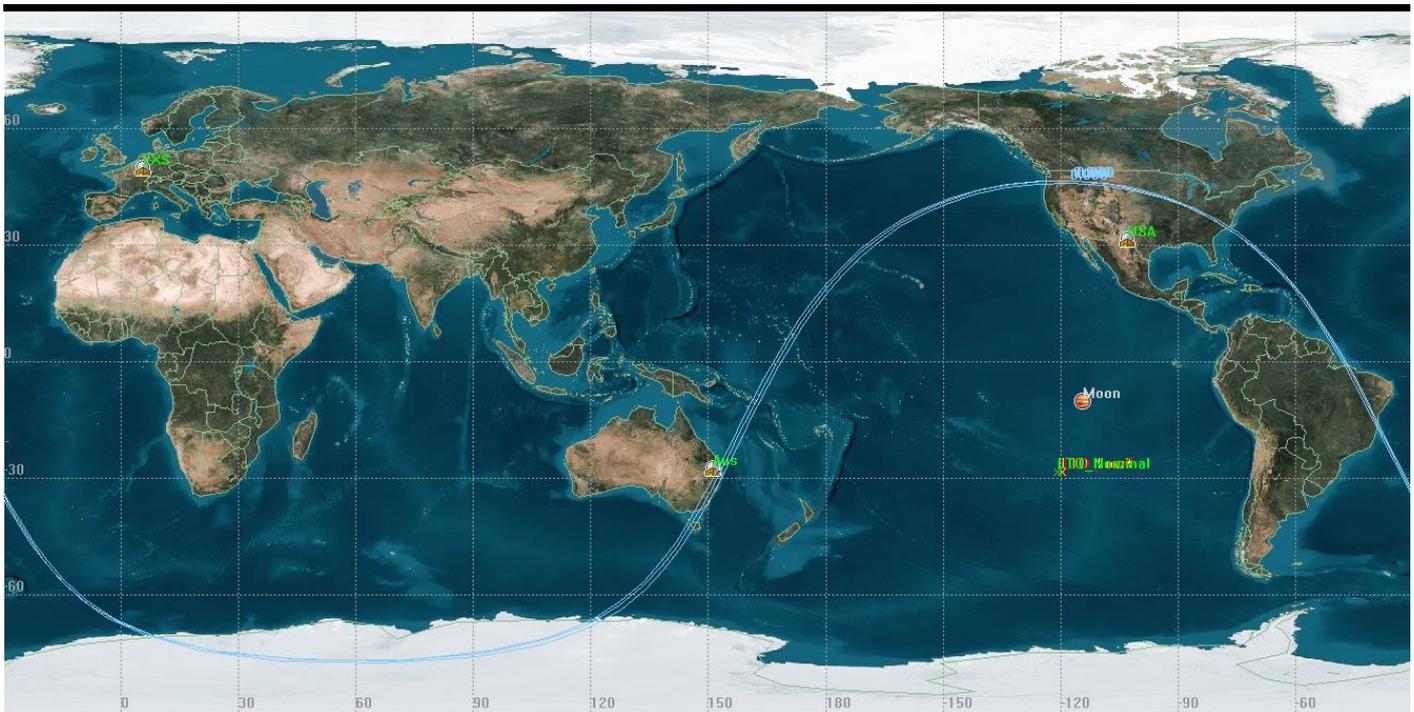


Figure 4 Visibility circle at injection

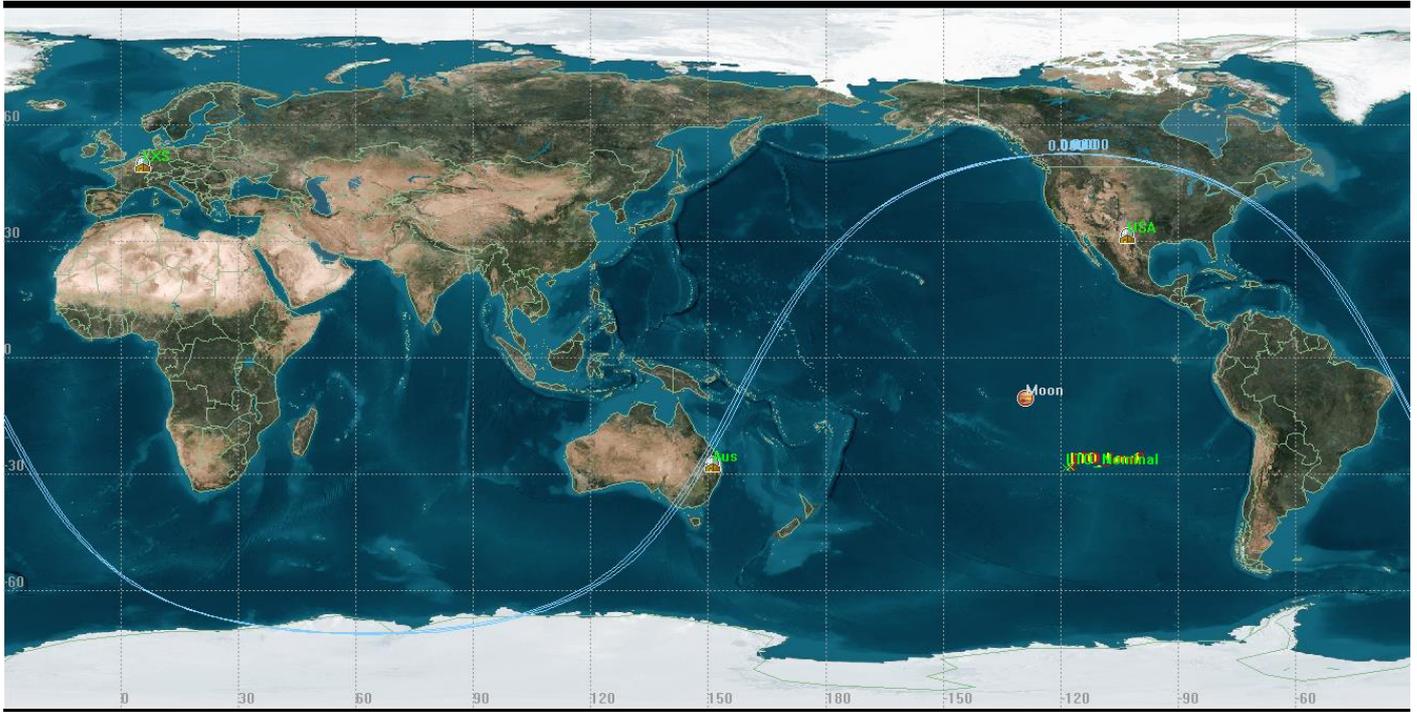


Figure 5 visibility circle 1 hour after injection

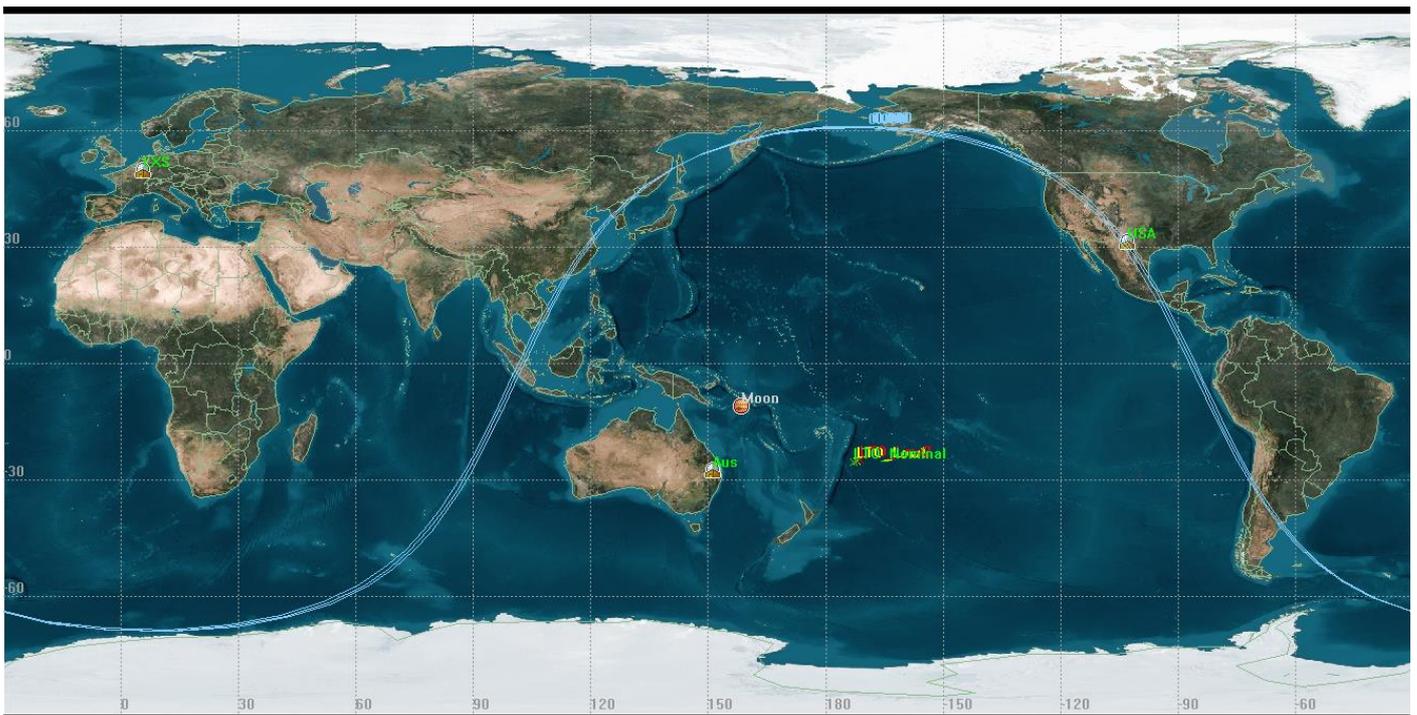


Figure 6 6 hours after injection

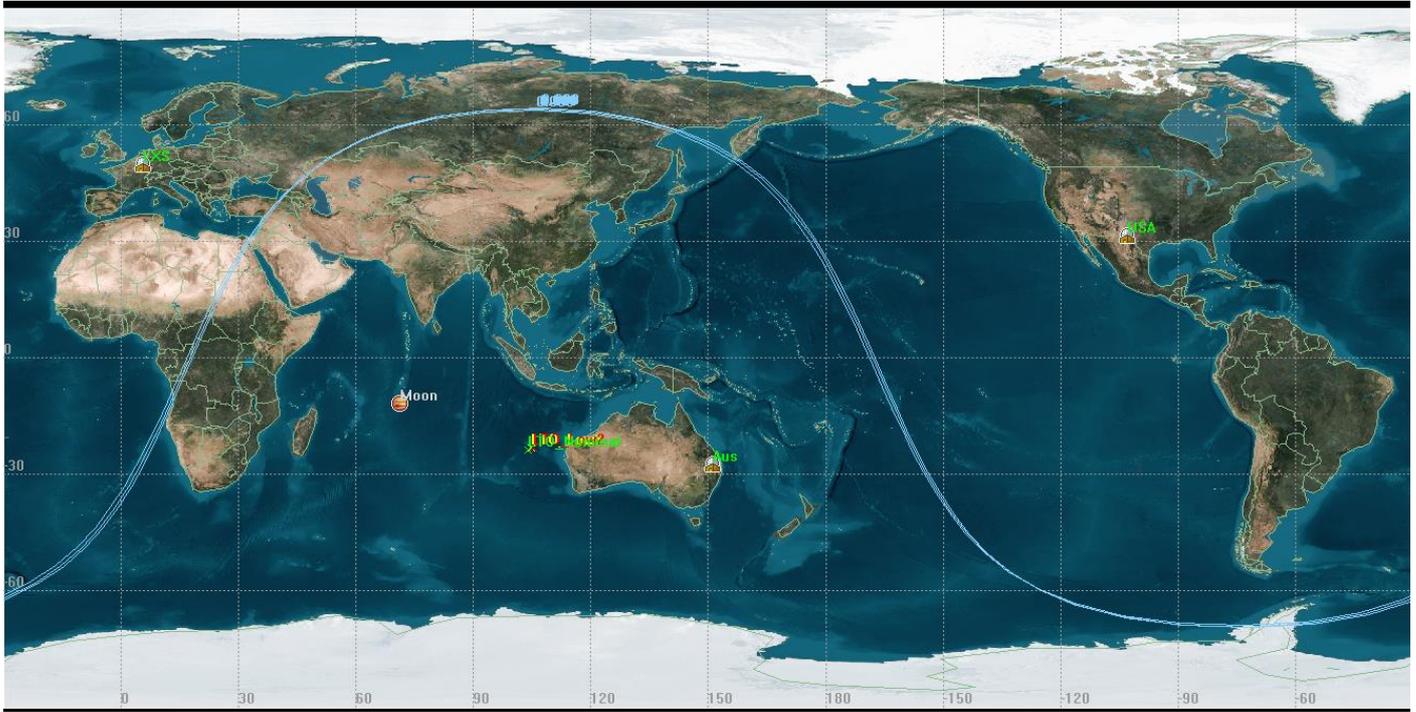


Figure 7 Injection + 12 Hours

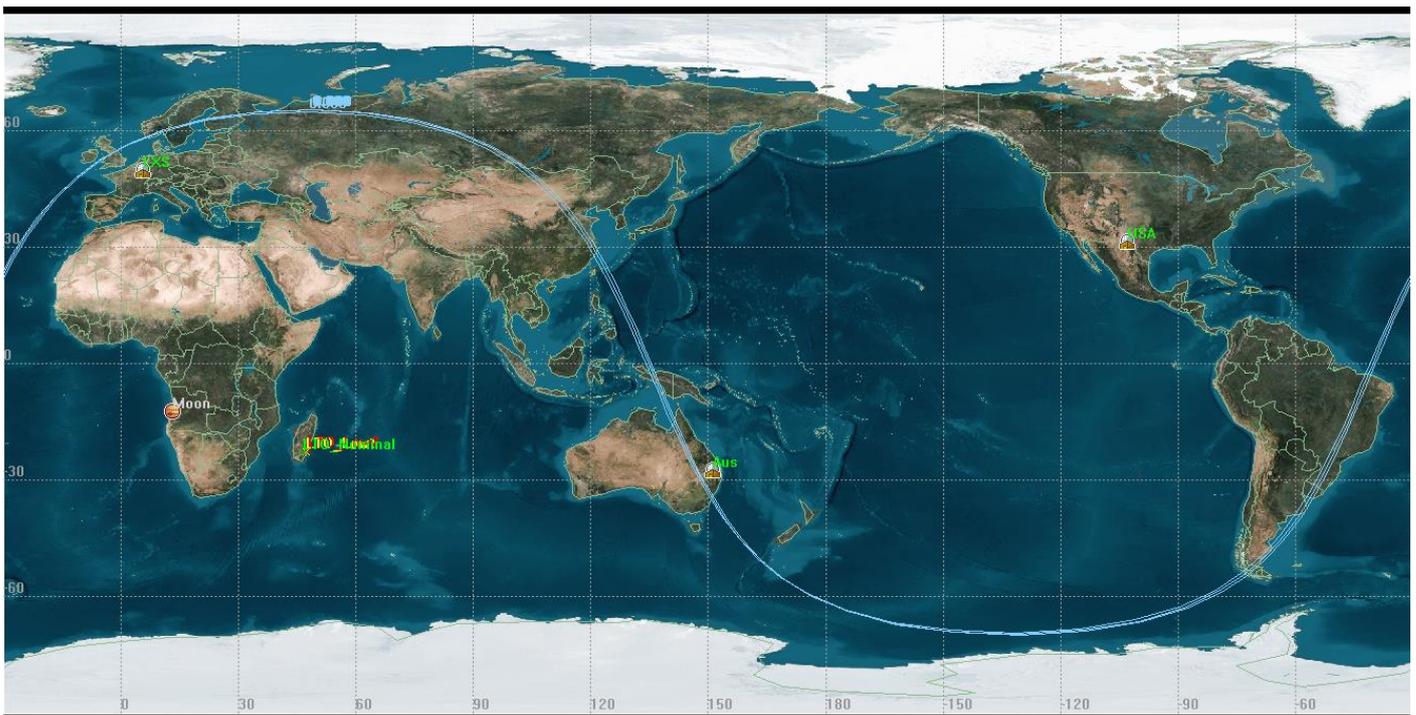


Figure 8 Injection + 16 Hours

It is to be noted that the bearing of the 4M is different from the Moon, but closes as the encounter approaches.

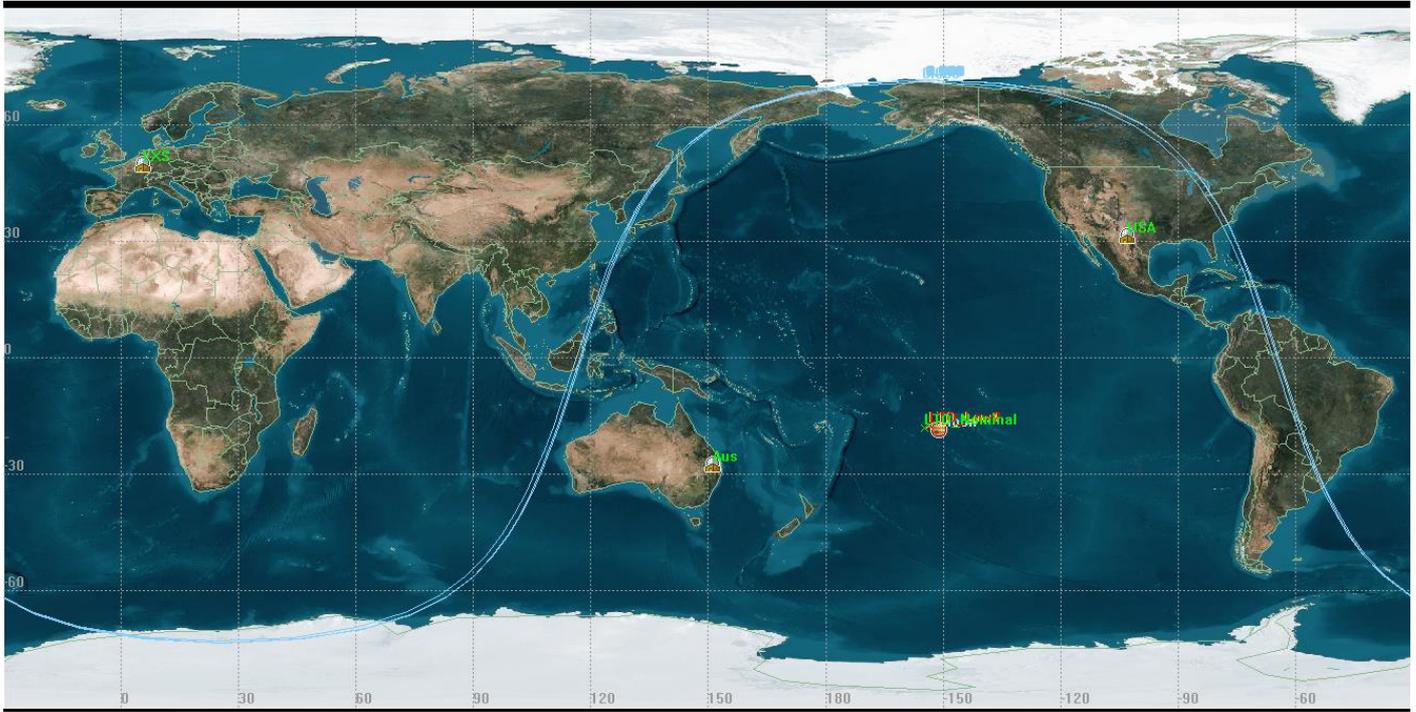


Figure 9 Visibility circles during flyby

Pointing of the antenna

The problem to solve is that only nominal trajectory is known. The trajectory dispersion is also known. The actual trajectory will be comprised inside the limits. The purpose of this chapter is to examine if it is sufficient to point the antenna on the 'nominal' trajectory and verify that the extreme case (± 3 Sigma) trajectories yet allow the 4M to be inside the pattern of the antenna.

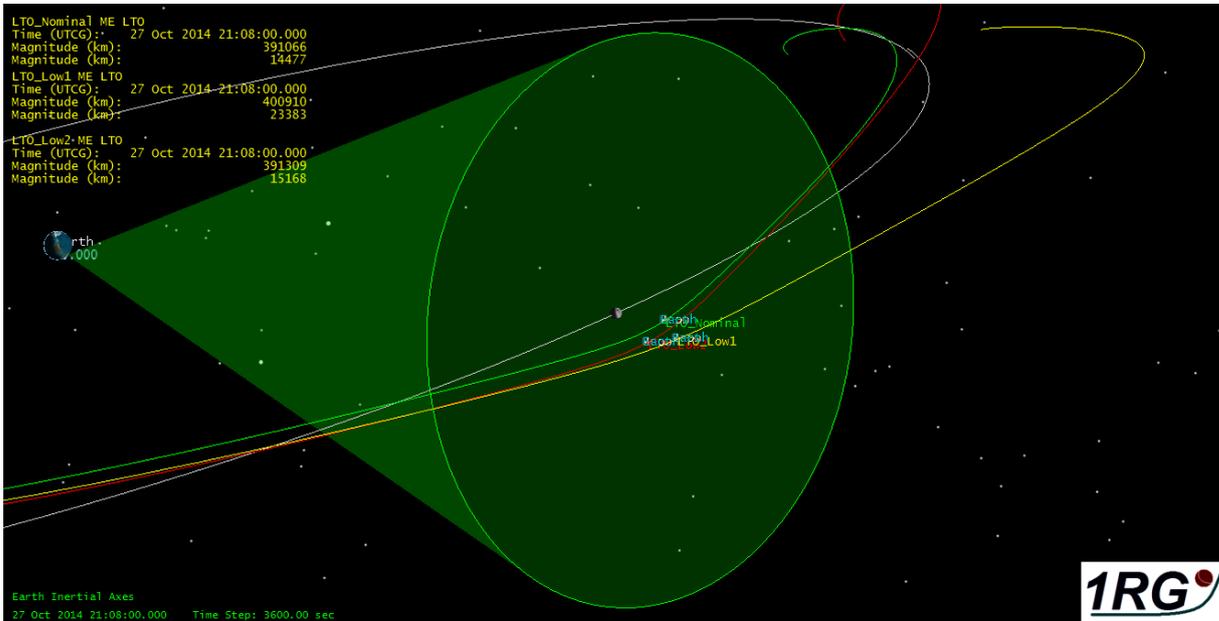
The simulations have been performed with a 25° beamwidth.

During the first part of the trajectory up to the Flyby, the nominal and max deviation trajectories are close one to each other, therefore, the nominal trajectory elements may be used.

The dedicated website and Facebook pages will be updated as soon as the injection vector is known.

For ease of use, tables will be published that will also indicate the Offset pointing in Az and El relatively to the Moon.

The following figure shows that all possible trajectories fit well into a pattern of 25° beamwidth.



After the FlyBy, the trajectory is much more difficult to predict due to the sensitivity of the elements, and the pointing may require some 'search'. We shall endeavour to provide correct elements.

The following figure shows the 'de pointing' for all the mission. The Antenna is pointed on the nominal trajectory.

The graph shows the de pointing of the possible trajectories relatively to the pointing axis of the antenna.

The de pointing augments as time passes. LTO-Low1 and LTO-Low2 are extreme trajectories.

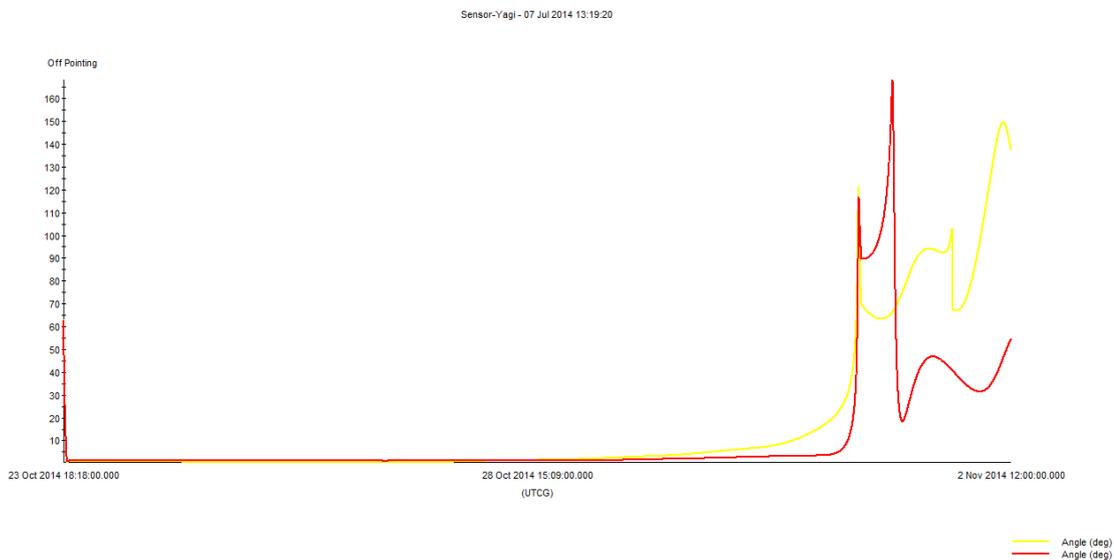


Figure 10 Off pointing from main trajectory

The above graph shows in Red (Low2) and Yellow (Low1) the off pointing with respect to the pointing to the nominal trajectory.

Two days after the Lunar FlyBy, the trajectories are sufficiently different so that manual pointing may be required.

It justifies therefore the need to have a trajectory determination, which is the purpose of the Experiment 2, which is described later in this document. The geometry is shown hereafter:

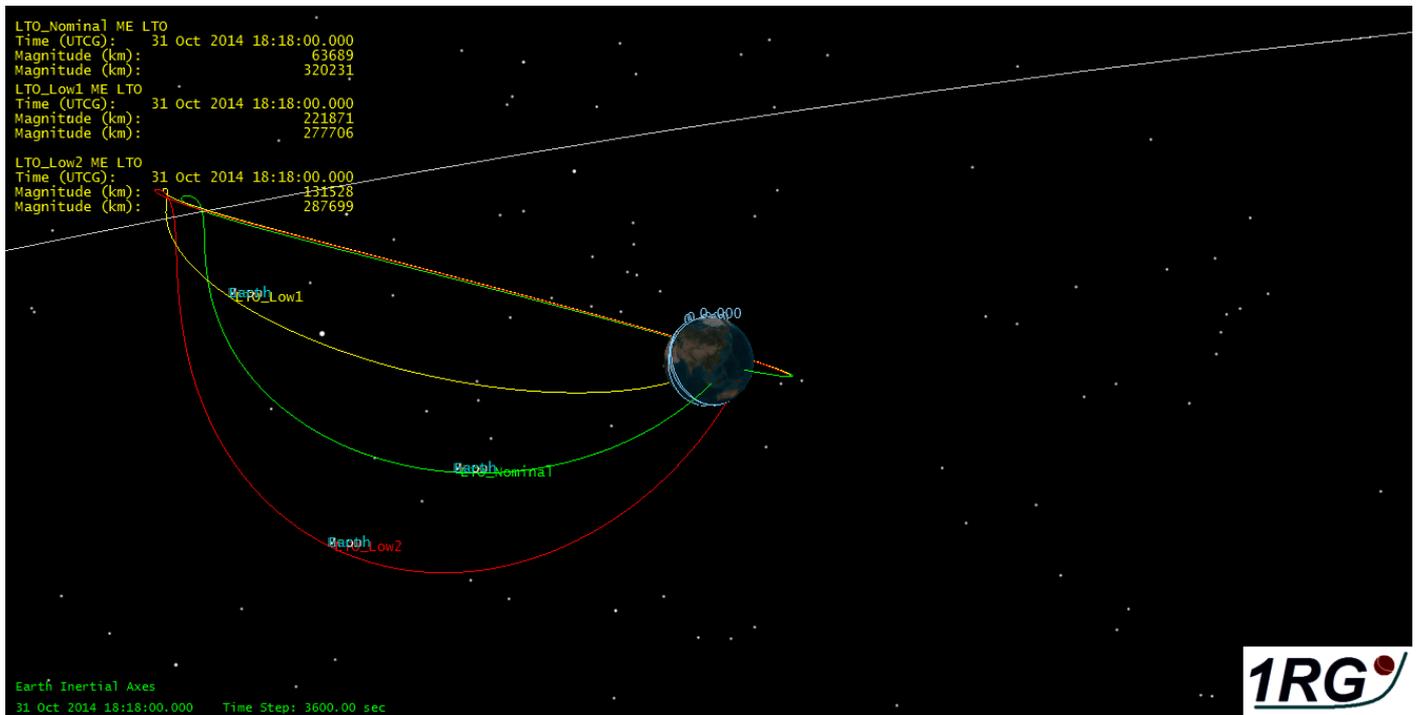


Figure 11 Possible trajectories after FlyBy

Happy fate

In case the injection vector falls within some limits, the 4M S/C may enter an Earth orbit instead of re-entry. This orbit will have an apogee altitude of 400000km and be inclined, allowing the extension of the mission for some days/weeks.

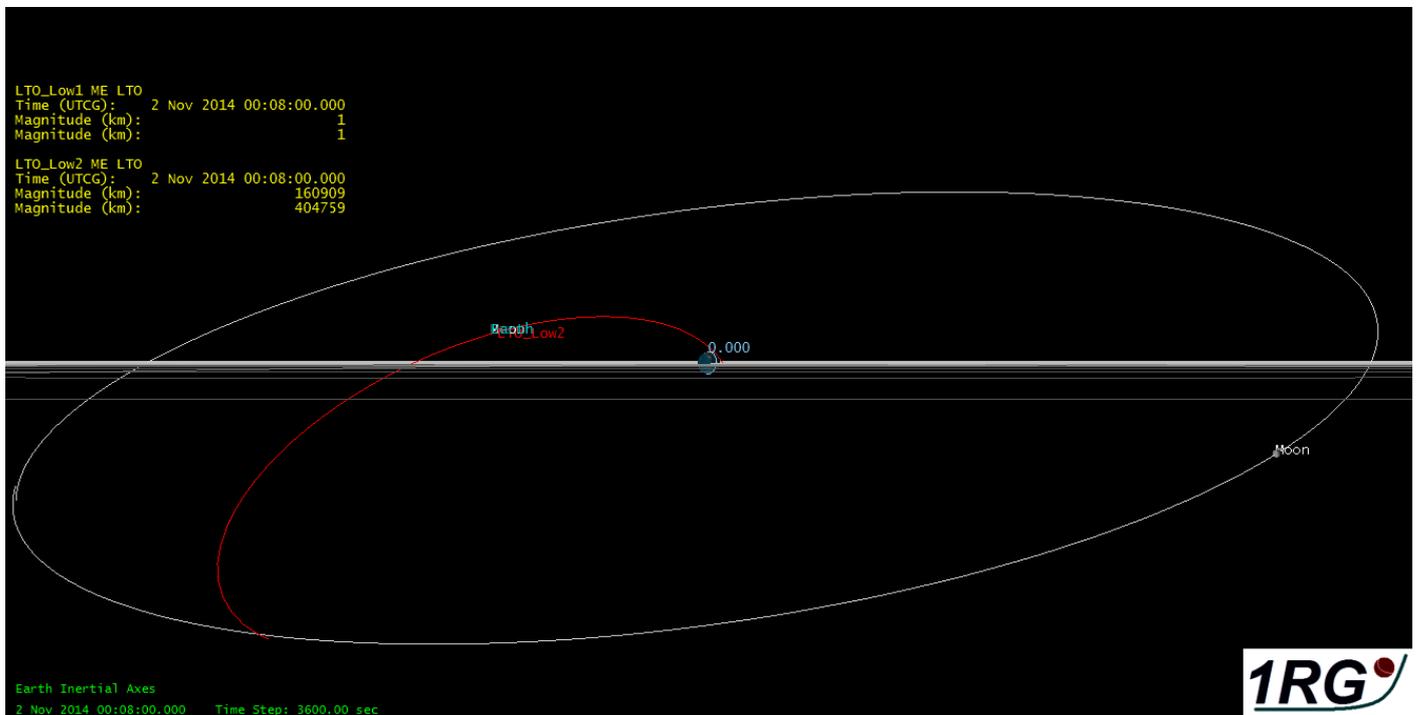


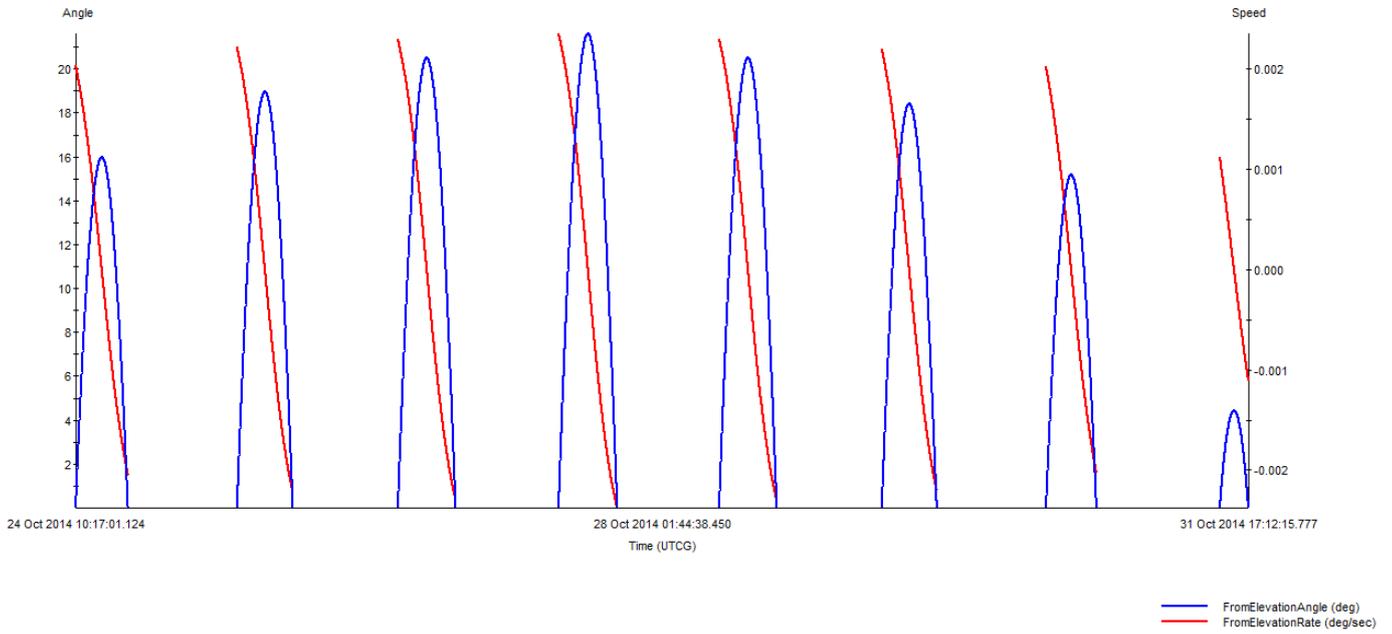
Figure 12 Happy fate orbit

Injection vector

The nominal injection vector will be published roughly 2 weeks before launch, on the dedicated website and the facebook page

Antenna elevation from 50° Latitude North

Facility-LXS-Sensor-Yagi-To-Satellite-LTO_Nominal: Elevation - 17 Aug 2014 00:43:31



Antenna pattern of 4M

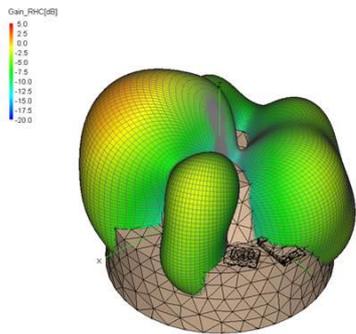
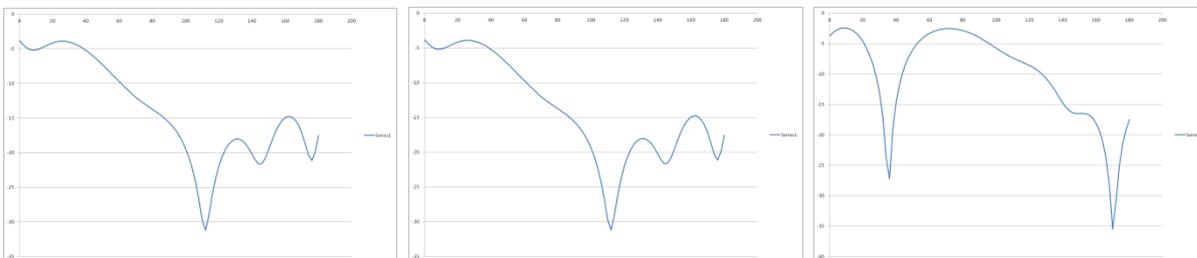


Figure 13 Antenna pattern, -20 to +5 dB RHCP gain



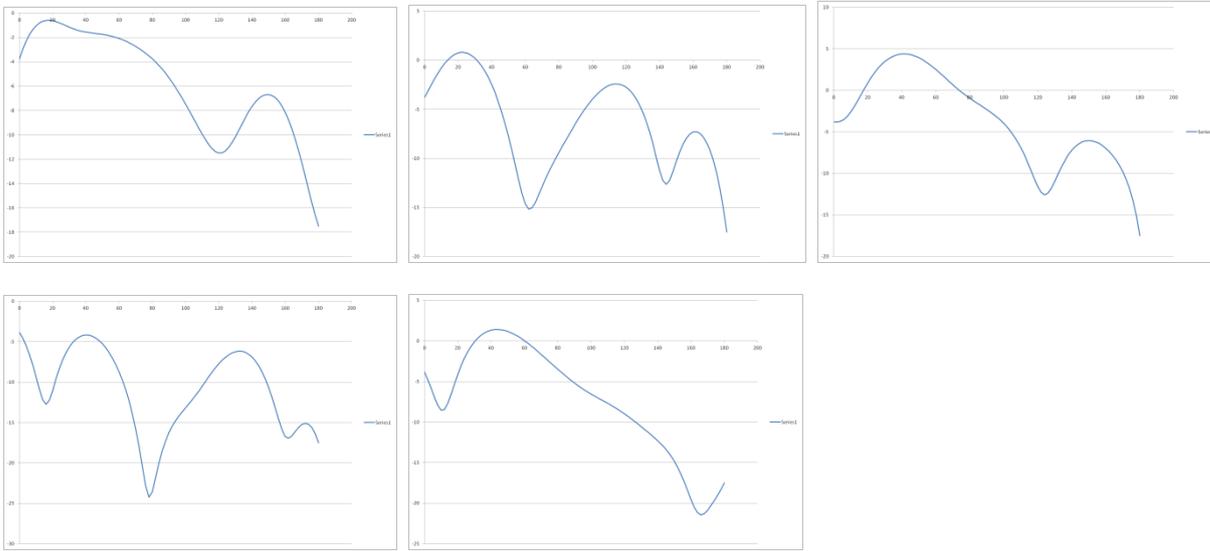


Figure 14 Antenna pattern in Theta for Phi = 0, 45, 90, 135, 180, 225, 270 and 315°

Received signals

Average case

The average EIRP is -6dBW, actually depending on the orientation of the last stage and can vary from -30dBW to +5.5dBW.

The required received signal is -158dBm assuming a system temperature of 641°K. (roughly corresponding to 0.5dB losses and LNA = 1dB NF)

Such conditions can be met with the following setup:

- Antenna: 12dBic, equivalent to a 12elements Yagi CP
- Losses before LNA: 0.5dB
- LNA: NF = 1dB

The link budget is estimated using the above parameters and shown hereafter:

VOIE DESCENDANTE	
Données à entrer	
Satellite	
Fréquence (MHz):	146
Puissance sortie émetteur (W):	1
Pertes câble (dB):	0.5
Gain antenne (dBi):	-6
Espace	
Distance (km):	399000
Bruit ciel (*K):	600
Station sol	
Gain antenne (dBi):	12
Pertes câble (dB):	0.5
Facteur de bruit à 290 *K (dB):	1
Bande passante (kHz):	0.0027
Résultat. SNR (dB):	13.5
Puissance reçue (dBm):	-152.7
Atténuation espace libre (dB):	187.706515
Température rx (K):	75.08836342
Température SYSTEME (K):	641.3761602
Puissance totale de bruit (dBm):	-166.2164434

Figure 15 S/N average gain case, 2.7Hz bandwidth

VOIE DESCENDANTE	
Données à entrer	
Satellite	
Fréquence (MHz):	146
Puissance sortie émetteur (W):	1
Pertes câble (dB):	0.5
Gain antenne (dBi):	-6
Espace	
Distance (km):	399000
Bruit ciel (*K):	600
Station sol	
Gain antenne (dBi):	12
Pertes câble (dB):	0.5
Facteur de bruit à 290 *K (dB):	1
Bande passante (kHz):	2.4
Résultat. SNR (dB):	-16
Puissance reçue (dBm):	-152.7
Atténuation espace libre (dB):	187.706515
Température rx (K):	75.08836942
Température SYSTEME (K):	641.3761602
Puissance totale de bruit (dBm):	-136.7279686

Figure 16 S/N average gain case, 2400Hz bandwidth

Average S/N during trajectory and FlyBy

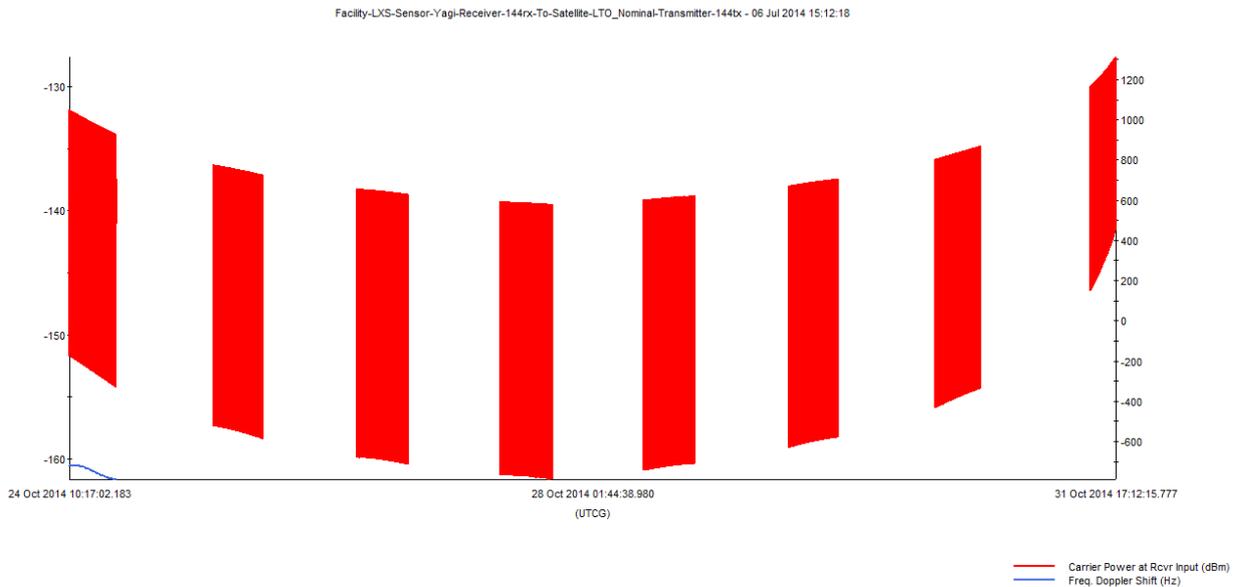


Figure 17 Average S/N during trajectory from injection to Earth flyby (or re-entry) from Luxembourg, left scale in dBm, right scale in Hz. (Actual antenna pattern)

It can be seen that the average is above the requirements. However, some deep fading may be expected due to the radiation pattern (actual pattern used in the simulation). However, assuming the angular rotation speed of the last stage is as expected (0.5 rpm), there is hope that the whole sequence is received properly. Unfortunately this is out of our control and we designed to maximize the probability of reception.

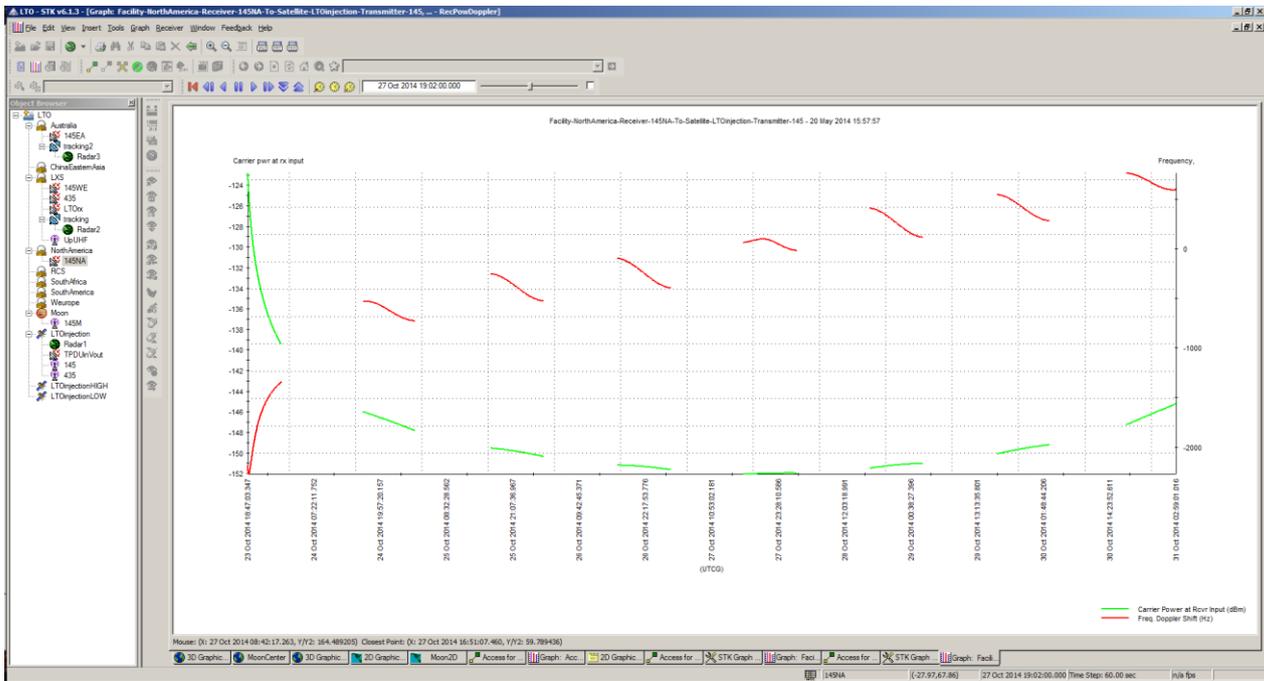


Figure 18 'cleaned' S/N, average case, the change of Doppler is visible during the FlyBy, left scale in dBm (computed with -6dBW EIRP isotropic)

The following figure shows a zoom of the received signal during FlyBy from Luxembourg. This is a typical case.

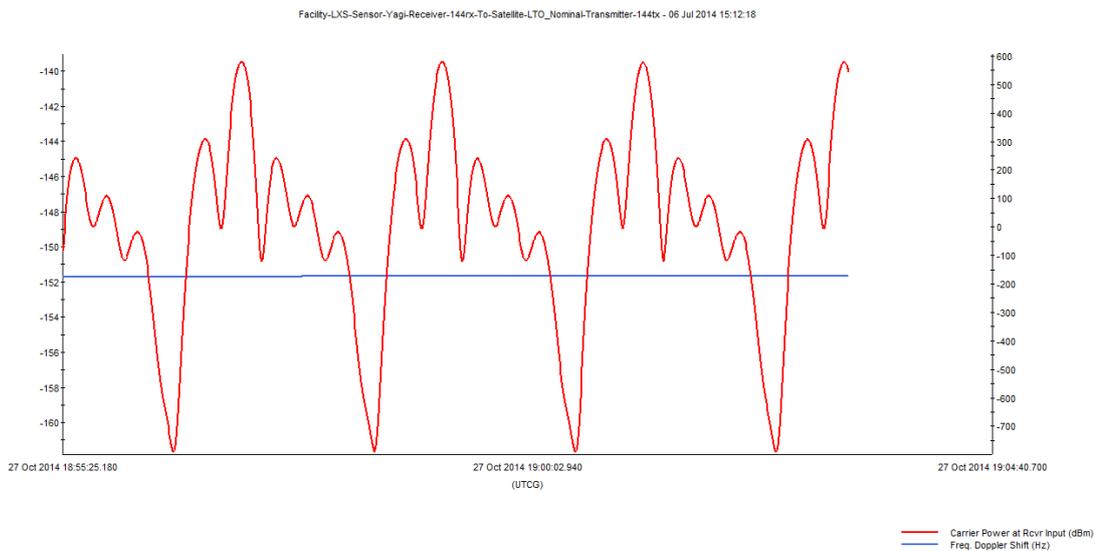


Figure 19 Average S/N during flyby, zoom, left scale in dBm, right scale in Hz, actual antenna pattern

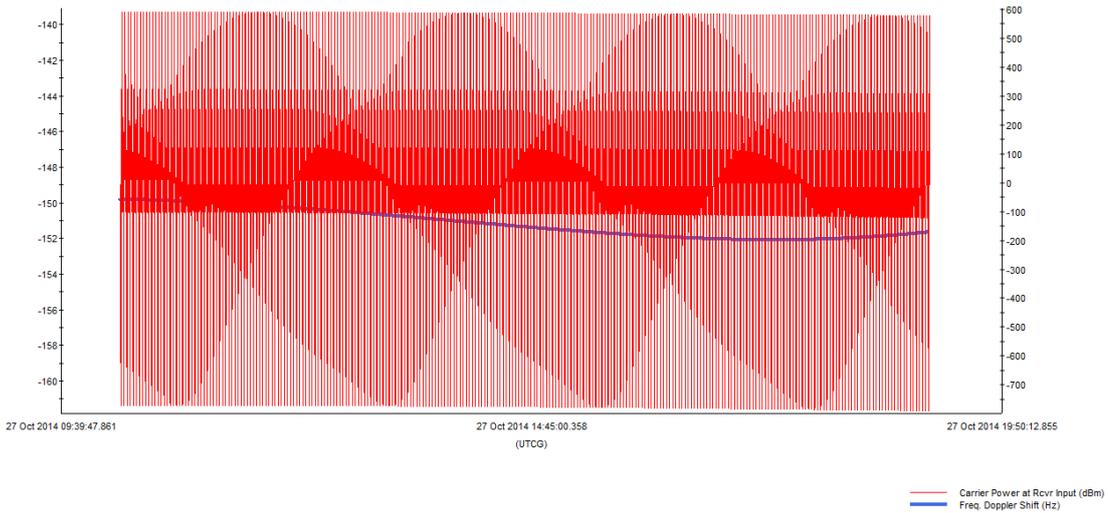


Figure 20 Pass from Luxembourg just before flyby, left scale in dBm, right scale in Hz, actual antenna pattern

All the above can be summarized as:

Equivalent S/N in 2.4kHz bandwidth as displayed in WSJT assuming: 12dBic Antenna, 0.5dB cable loss, 1dB NF LNA, ground and sky noise integrated in the antenna pattern, man made noise not included	
Rec. Power (dBm)	SNR (eqv WSJT / 2400Hz)
-135.00	1.70
-138.00	-1.30
-141.00	-4.30
-144.00	-7.30
-147.00	-10.30
-150.00	-13.30
-153.00	-16.30
-156.00	-19.30
-159.00	-22.30
-162.00	-25.30
-165.00	-28.30

Figure 21 Equivalent S/N as displayed in WSJT

Access for reference radio amateur stations

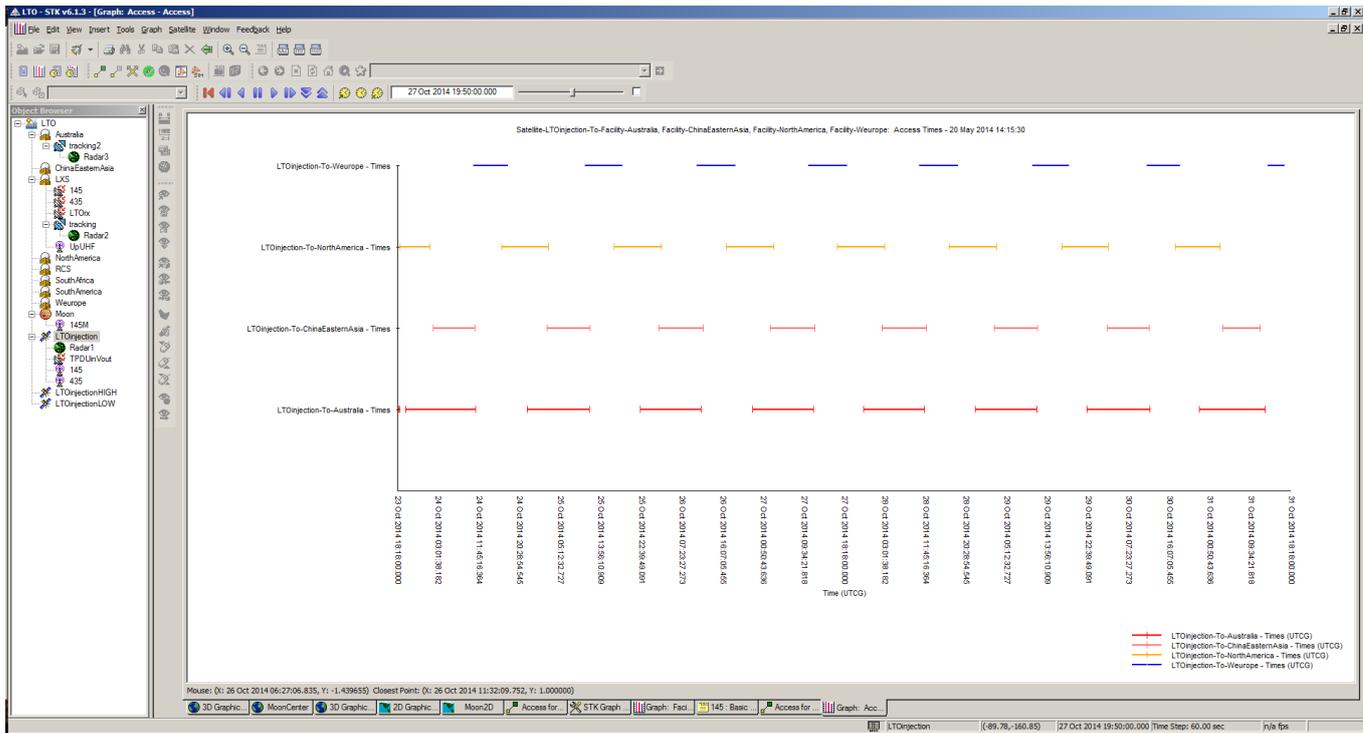


Figure 22 Access for USA, AUS, China and WEur stations

Transmit sequence description

To account for the various constraints, mass, size, power, link budget, available average receiving station, an EME mode was selected as the most appropriate way to transmit the data.

The transmit cycle is organized in 5 consecutive, one minute sequences starting at 0s of the UTC minute.

In addition, to fill in the 1 minute sequence, an additional “analog” sequence is added, that allows the detection of the transmission by longer integration, and provides for the basic data of the S/C.

NOTE: the internal real time clock of the OBC may drift by several seconds, even minutes in the course of the mission, due to severe temperature variations.

The Transmitter of the payload performs a 1 minute sequence on a 5 minutes cycle starting on UTC hour, based on JT65B mode and ‘human readable’ tone transmissions according to the following sequence:

Tableau 1 transmission sequence

Time /s	Description	Frequency / data rate	Duration / s	Purpose	Notes
0	OFF	-	1	First UTC second for JT65 is off	
1	Data area(*)	m-FSK – JT65B mode	46.8s	Digital data	Call sign + data
47.8	Unique tone 4	400, 420, 440, 460, 480Hz (depending on which)	1.2s	Start of digital sequence	

		sequence is transmitted)			
50	Unique tone 1	250 Hz	2 s	Start of sequence 1	
	Variable tone 1	500 – 2500 Hz	2s	Battery voltage	1Hz/10mV – 0-20V max
	Unique tone 2	300 Hz	2s	Start of sequence 2	
	Variable tone 2	500 - 2500 Hz	2s	OBC temperature	13.33Hz/°C – range: -50, +100°C
58	OFF	-	2s		

There are 5 successive sequences that are transmitted in a 5 minutes cycle.

The content of the analog sequence is the same in all sequences.

JT65B data sequence

The data content of the JT65B sequence is described in the following table:

Tableau 2 JT65B sequence content

Sequence number / start	Description	Experiment
1 / UTC + 0 m 00s	Callsign	RAD experiment is turned ON
1 / UTC + 0 m 02s	(at the latest)	RAD experiment sends Boot message
2 / UTC + 1 m 00s	Telemetry of 4M: V, I, T	
3 / UTC + 2 m 00s	Global MSG transmission	
3 / UTC + 2 m 58s	(at the latest)	RAD experiment sends its data and is turned OFF
4/ UTC + 3m 00s	RAD experiment data transmission	
4 / UTC + 3m 02s	(at the latest)	
4 / UTC + 3m 58s	(at the latest)	
5/ UTC + 4m 00s	Global MSG transmission	

The content of the JT65B sequences is described here after. Note that the CAM and RAD data are 'random' character in the allowable set of JT65B. (copy of the Text window of WSJT9)

```
A00001 5 -22 -0.5 3 3 * LX0OHB-4M 1 0 // Callsign
A00003 8 -23 -1.0 3 3 * 125V500A120C 1 0 // Voltage in 100mV, current in mA, Temp in°C
A00009 4 -24 -0.9 -3 3 * HELLO WORLD P 1 0 // clear text messages, 4000 different ones, sent 1 time each
A00013 5 -24 -0.9 -5 4 * 3? 2AF6DDC9- / 1 0 // RAD experiment data
A00019 9 -22 -0.8 5 3 * Ni Hao XinHua 1 0 // CAM experiment data
A00020 5 -24 -0.8 3 2 * LX0OHB-4M 1 0 // new cycle begins
```

The 'unique tone 4' may take 5 different values indicating which JT65B sequence follows.

- 400Hz: Seq 1
- 420Hz: Seq 2
- 440Hz: Seq 3
- 460Hz: Seq 4
- 480Hz: Seq 5

Analog sequence

The analog sequence consist of three times two tones as per the following table:

Description	Frequency / datarate	Duration	Purpose	
Unique tone 1	250 Hz	1.666s	Start of analog sequence 1	
Variable tone 1	500 – 2500 Hz	1.666s	Battery voltage	1Hz/10mV – 0-20V max
Unique tone 2	300 Hz	1.666s	Start of analog sequence 2	
Variable tone 2	500 - 3000 Hz	1.666s	Battery temperature	15Hz/°C – range: -50, +117°C
Unique tone 3	350 Hz	1.666s	Start of analog sequence 3	
Variable tone 3	500 - 3000 Hz	1.666s	Reserved	Current
Unique tone 4	400, 420, 440, 460, 480Hz (depending on which sequence is transmitted)	1.2s	Start of digital JT65 sequence	
Data area (*)	m-FSK – JT65B mode	46.8s	Digital data JT65B	See description above
Loop		1 minute cycle		

Analog sequence demodulation

The analog sequence is modulated in DSB, SC, allowing for stations with non accurate receiver to determine the value of the telemetry by measuring the spacing between the peaks of the FFT.

However, even in SSB, recording the signal for several minutes allows a rapid identification of the sequences.

This will allow also to identify the Unique Tone 4 that indicates the start of the JT65B sequence.

Assuming a sample rate of 11025s/s, the duration of each tone allows a 16k (0.673Hz BW) or 32k FFT (0.336Hz BW) which gives an 'eye' decoding increased performance of up to 9dB compared to JT65B. Average should be rather on 3 to 6 dB improvement, mainly depending on the angular speed of the 4M S/C. (Doppler 'jitter') and its relative orientation.

Required minimum station and softwares

The minimum required station setup is the following:

Antenna: 12dBic , 12elements Yagi CP, possibly with fixed pointing and reoriented every 15 minutes.

Harness and cable to LNA: loss < 0.5dB

LNA : NF<1dB

Receiver: SSB, 2.5kHz bandwidth or more, the FunDongle is suitable http://www.funcubedongle.com/?page_id=1225

PC: Clock Sync'ed on Internet, sound card.

WSTJ10 decoding software (and associated requirements) <http://physics.princeton.edu/pulsar/K1JT/index.html>

Use latest release that includes special feature for 4M.

Spectrum Lab recording and time stamping software: <http://www.qsl.net/dl4yhf/spectra1.html>

Spectrum Lab is a widely used and highly practical software that allows recording and time stamping signals. More over, it allows to 'chunk' the recordings into predetrmined lengths, and automatically naming the recordings with the time stamp.

NOTE: be careful with the time zone settings of your computer in programming Spectrum Lab file naming.

The next figure is a screen capture of a complete sequence with SpectrumLab:

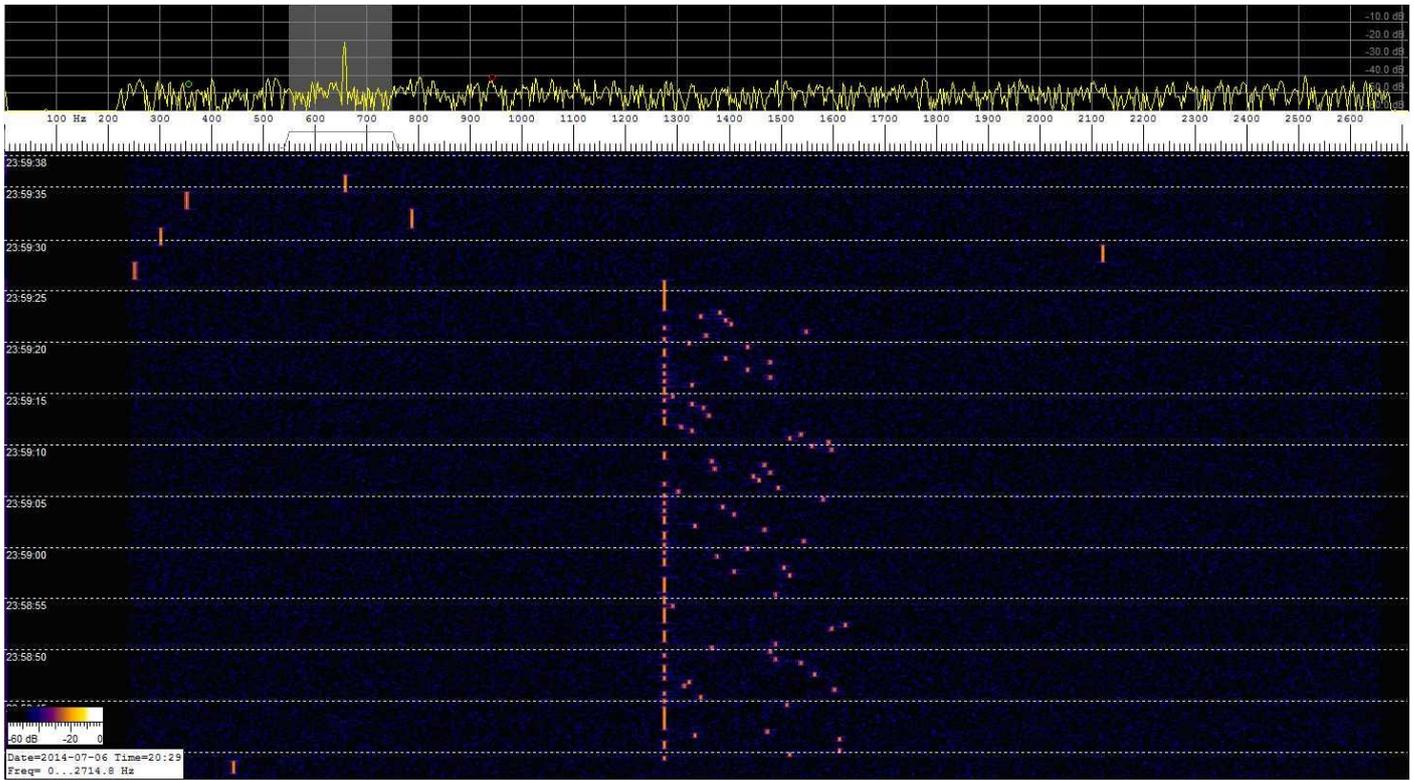


Figure 23 Spectrum Lab capture

In the bottom, on can see the 440Hz Unique tone 4, followed by the JT65B transmission, and the 'analog ' sequence on top of the screen.

The same sequence with Adobe Audition:

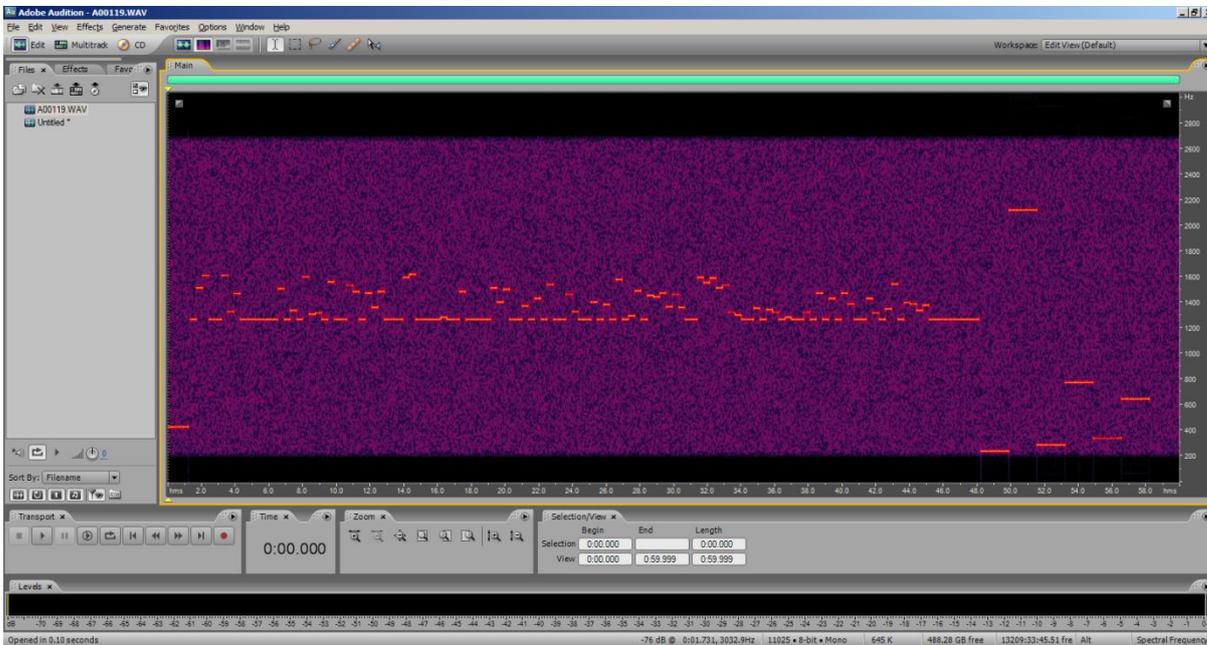


Figure 24 Adobe Audition screen capture

Experiments and mission

Given the trajectory and visibility, it is clear that all around the world OM stations are needed in order to have data continuity.

Several 'experiments' are ran in parallel in this mission and need the collaboration of as many stations as possible.

One contest is organized for each experiment in multiple categories, single station, cooperative group.

For experiment 1 and from the visibility patterns, one significant group may consist of at least a station in Australia/New Zealand/New Caledonia area, one in the American continent, and one in the Western Europe/ Africa area.

For the experiment 2, one significant group may consist of at least 4, better five stations, in common visibility of the 4M spacecraft.

For contest 3, individual stations may compete, although, as for experiment 1, groups are also welcome.

Experiment One

Experiment One consists in retrieving a continuous set of data of telemetry for the RAD experiment.

The data of the RAD experiment do not absolutely need to be contiguous. The RAD experiment transmits the dose rate at the time of measurement. The 4M spacecraft will be subject to a total dose of 74 to 100 kRads during the mission and a dose rate of 13 to 16 Rads / hour.

Further information will be published on how to send the collected data. It will be based either on the copy of the relevant line or text zone of WSJT9 and sending it to a dedicated eMail address along with the timestamp of reception (to within a minute). Either by installing a small java client that will automate the process. The amount of data is quite small.

Experiment Two

Experiment Two is a more challenging one as it will use TDOA (aka 'MultiLateralation', <http://en.wikipedia.org/wiki/Multilateration>) method to determine the position of the spacecraft.

At least 4 simultaneous measurements are needed. The principle relies on the time stamping of the recordings on the Call sign sequence using Spectrum Lab software. As the CallSign sequence is known, a correlation will be made between the 4 (at least) recordings to determine the Time Difference Of Arrival of the call sign sequence.

Using the measured TDOA, the position of the S/C can be determined.

The PC's clock should be sync'ed to within 1ms of the Internet time. 1ms represents 300km transit time or error in this case. The stations shall be clearly identified by accurate Altitude (WGS84) Latitude and Longitude to within 1km or better.

We do not expect a high accuracy of the position, somewhere around 5000km, depending on the accurate setting of the various PC's clocks and the geometry between the 4 stations and the 4M S/C.

It is to be noted that this technique also allows to compute the position of the Moon in casual EME operation !

Contest 3

The 4M S/C shall transmit approximately 2500+ different messages, that are pre recorded in its memory.

The OM's, or constituted group that collects the biggest number of messages will be declared the winner of the contest.

Contest 4

We need the telemetry of the 4M S/C to assess its success.

The OM, or constituted group that collects the biggest number of telemetry points will be declared the winner of the contest.

It is to be noted that the use of the “analog” sequences is encouraged, and allows even ‘small’ stations to participate.

Prizes

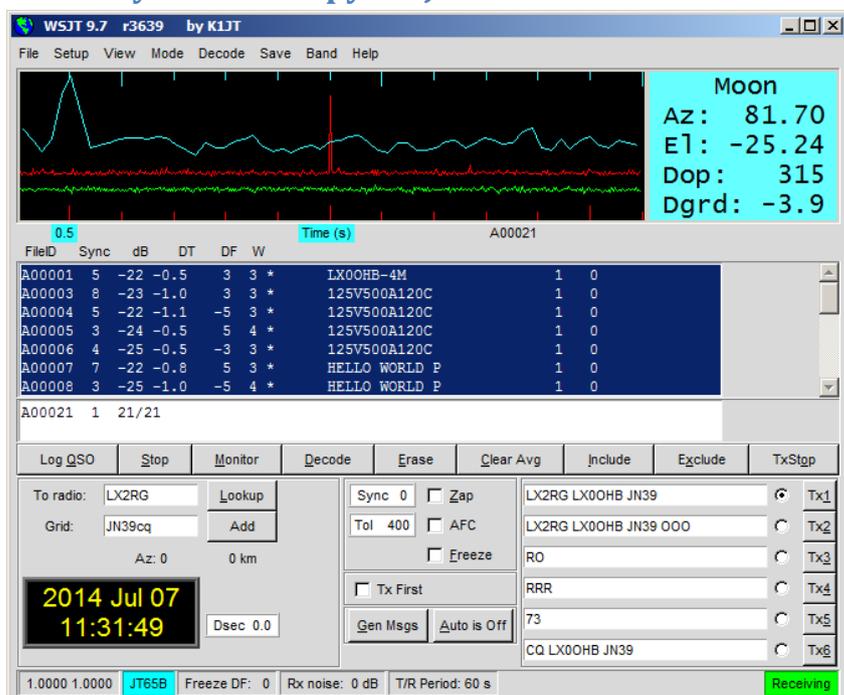
LuxSpace will offer attractive prizes to the winners in each experiment and category.

The prizes will be attributed in the following categories:

- Experiment 1 Individual
- Experiment 1 constituted group
- Experiment 2 constituted group
- Contest 3 individual
- Contest 3 constituted group
- Contest 4 individual
- Contest 4 constituted group

Annex: How to send your decoded messages to LuxSpace ?

Manually :How to copy WSJT9 Text data zone



Select all the text in the ‘Decoded’ window, Ctrl-C and paste in a .txt file. This should give a result like the one shown hereafter:

```
A00001 5 -22 -0.5 3 3 * LX00HB-4Mxxxx 1 0
A00003 8 -23 -1.0 3 3 * 125V500A120Cy 1 0
A00009 4 -24 -0.9 -3 3 * HELLO WORLD P 1 0
A00013 5 -24 -0.9 -5 4 * 3? 2AF6DDC9-/ 1 0
A00019 9 -22 -0.8 5 3 * Ni Hao XinHua 1 0
A00020 5 -24 -0.8 3 2 * LX00HB-4M 1 0
```

Please note that xxxx and y are mission related parameters, the value of which will be published later.

Simpler Alternative

Send daily the ALL.TXT by mail to the eMail address that will be provided on our facebook page.

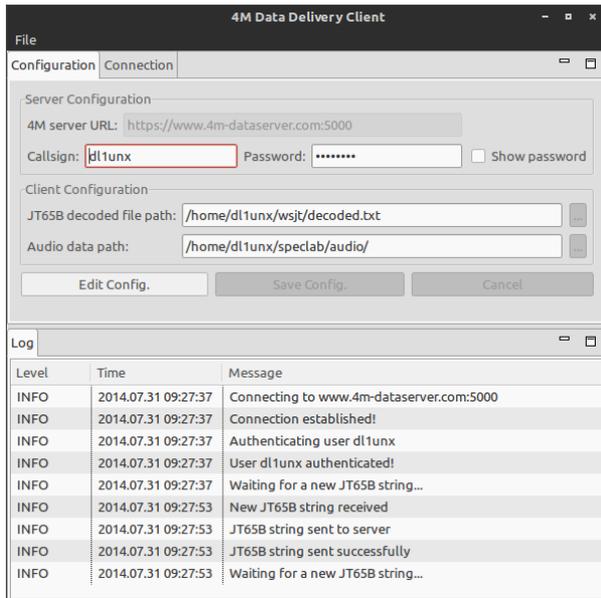
Automated client

The OM's at LSE Space application are developing a small Java client that you can download and install. It will connect to our database, and after your authorization will automatically send the ALL.TXT and the decoded.txt to our database.

In addition, should you wish to do so, you can also allow sending of the .wav files that are recorded by WSJT (only decoded ones).

Everything is under your control.

Client (prototype snapshot - 1)



Client (prototype snapshot - 2)

