DSLWP-B

The Amateur satellite in lunar orbit

Dr. Daniel Estévez
EA4GPZ / M0HXM

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IV Iberradio, Ávila

Outline

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The mission Chang'e 4

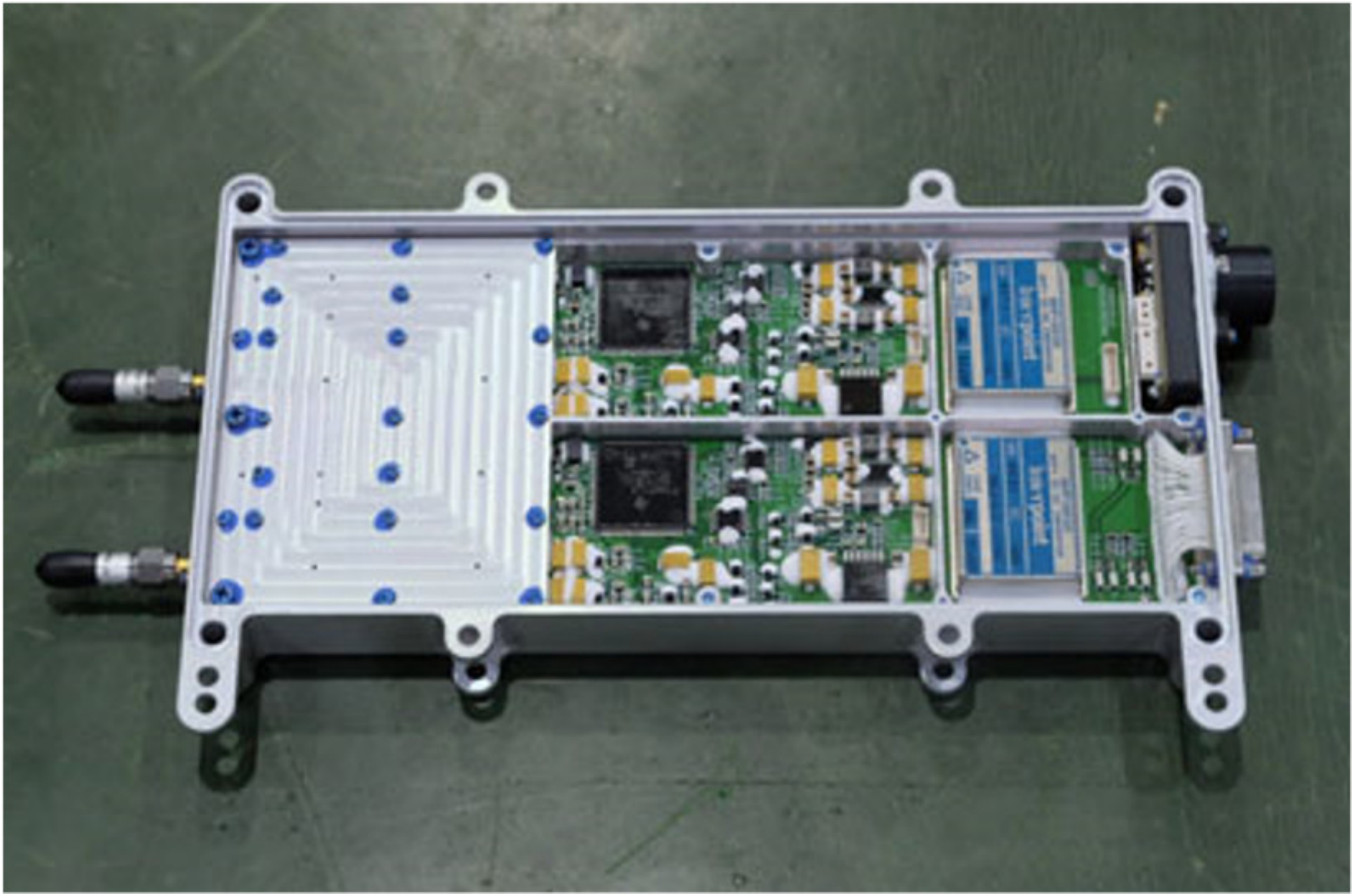
- *Chang'e 4* is a Chinese lunar rover in the dark side of the Moon. Launch estimated December 2018.
- To support the communications of the mission, on 20 May *Queqiao* was launched. It is a comms relay orbiting the L2 point. With its 4.2m antenna it supports up to 2Mbps using X band with the rover and S band with Earth.
- Two microsatellites were launched With Queqiao, known under several names: CE-4 microsatellites, DSLWP-A1 and -A2, DSLWP-A and -B, and Longjiang 1 and 2.

DSLWP microsatellites

- Weight 45kg.
- Size 50x50x40cm.
- Designed and built by the Harbin Institute of Technology (China)
- Scientific mission: radioastronomy with interferometry in 1-30MHz. Formation flight at a distance of 1 to 10km.
- DSLWP-B carrier a camera designed by King Abdulaziz City for Science and Technology (Saudi Arabia)
- Telemetry and telecommand in S band, inter-satellite link in S band, science data in X band (1Mbps).
- Amateur payload designed and built in BY2HIT, the Harbin Institute of Technology radioclub.

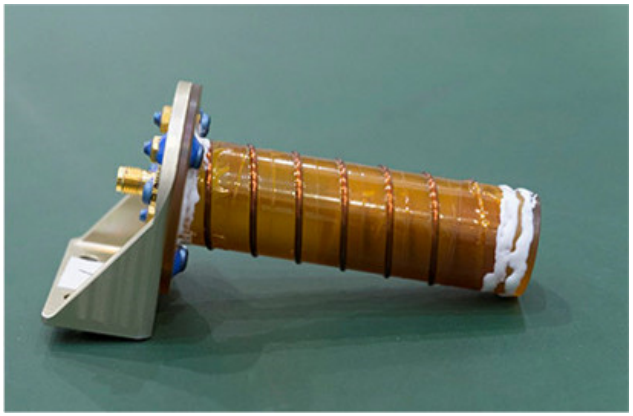
DSLWP Amateur payload

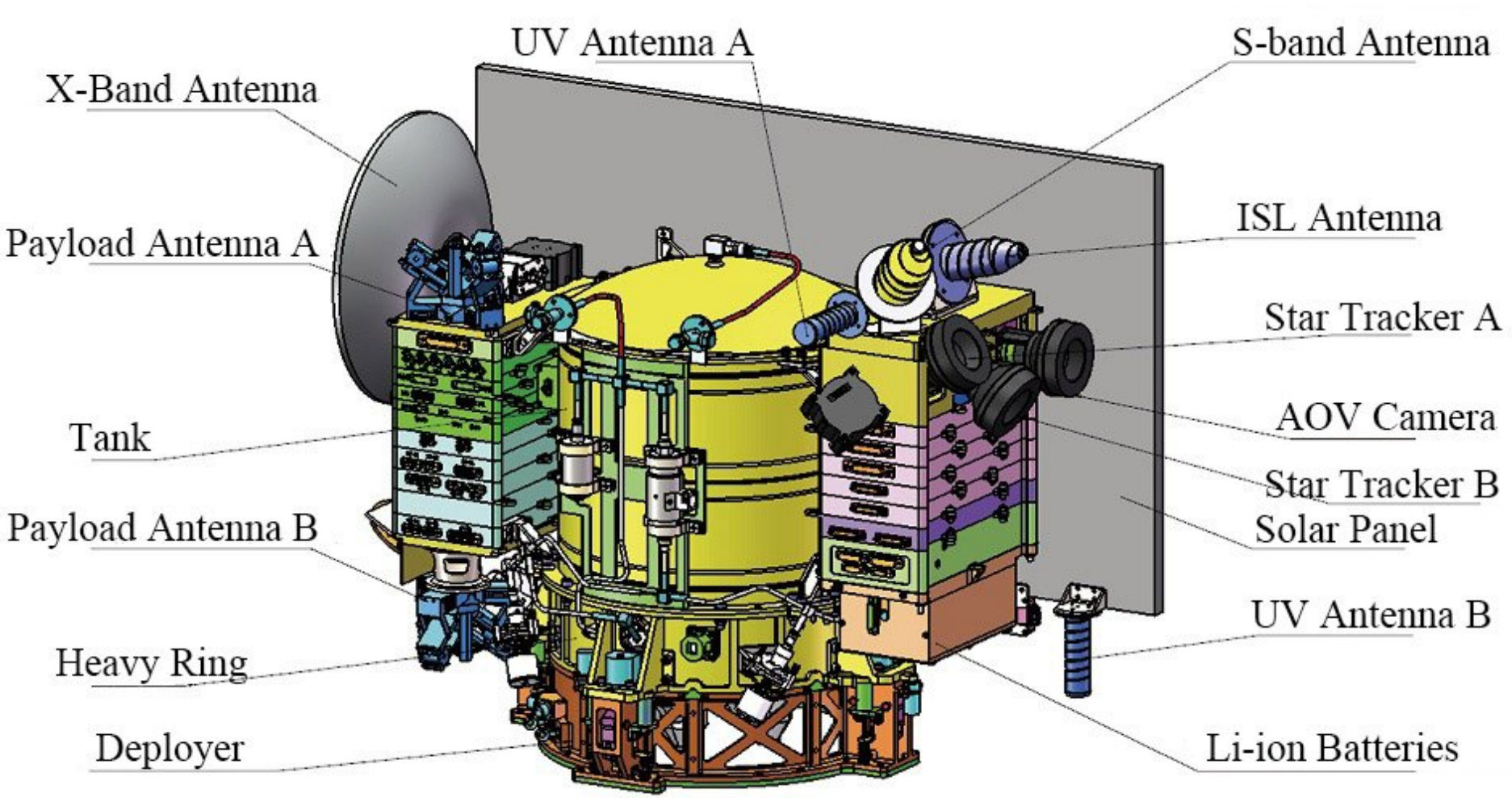
- Project directed by Wei Mingchuan BG2BHC.
- SDR based on the LilacSat 1 and 2 designs.
- Use: Auxiliary telemetry and telecommand. Experiments by Amateur radio operators.
- TX: 70cm, RX: 2m.
- CCD camera (Inory Eye) to transmit SSDV images.
- Main groundstations: PI9CAM, Dwingeloo (The Netherlands), 25m dish. Shahe, Beijing (China), 12m dish.
- VLBI experiment.
- Modulations used:
  - GMSK 250baud with $r = 1/2$ Turbo code. Transmission of telemetry and SSDV.
  - JT4G. Telemetry (abbreviated) and message repeater.
- Possibilities of telecommand by Amateurs:
  - Message transmission through the JT4G repeater.
  - Camera control.

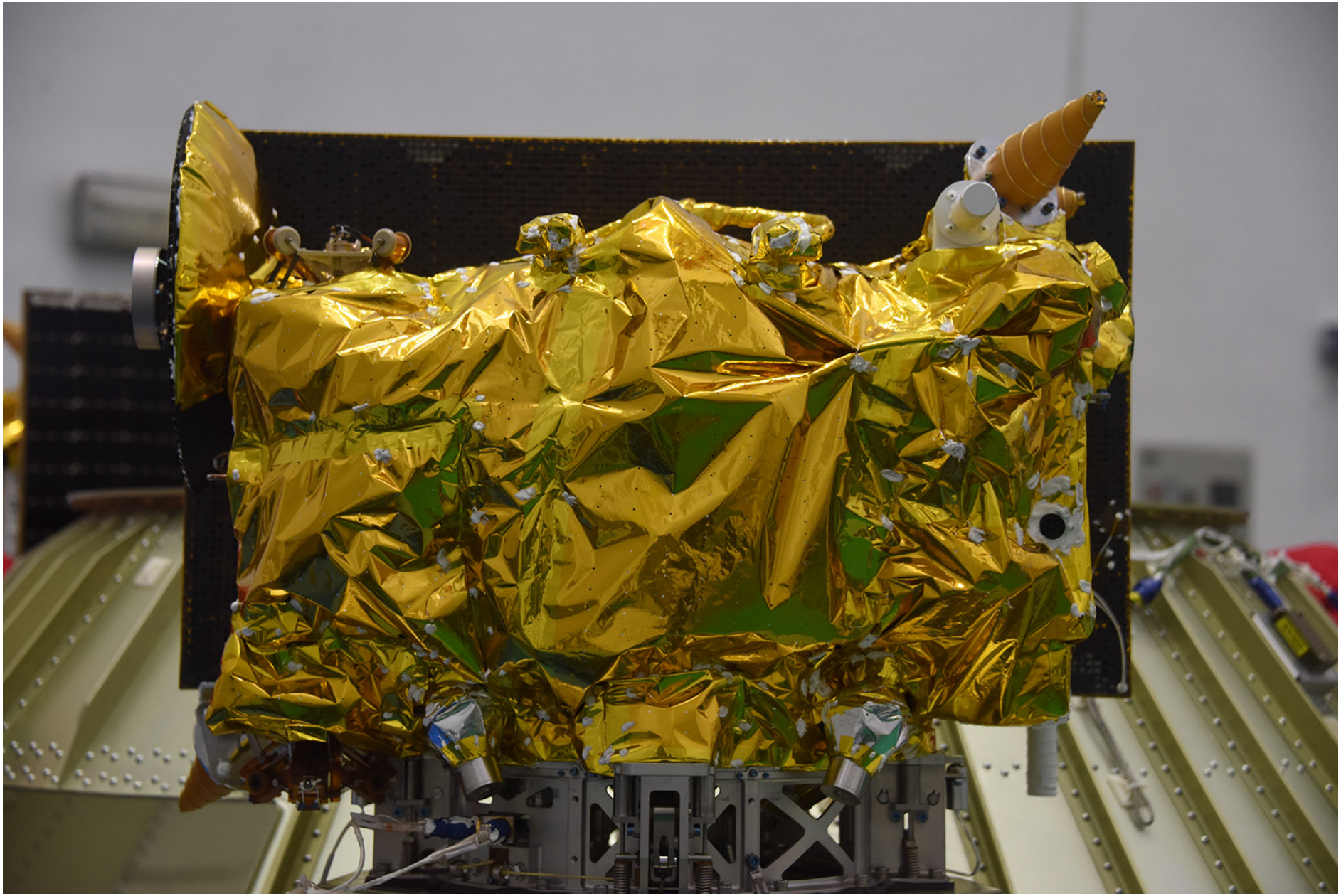


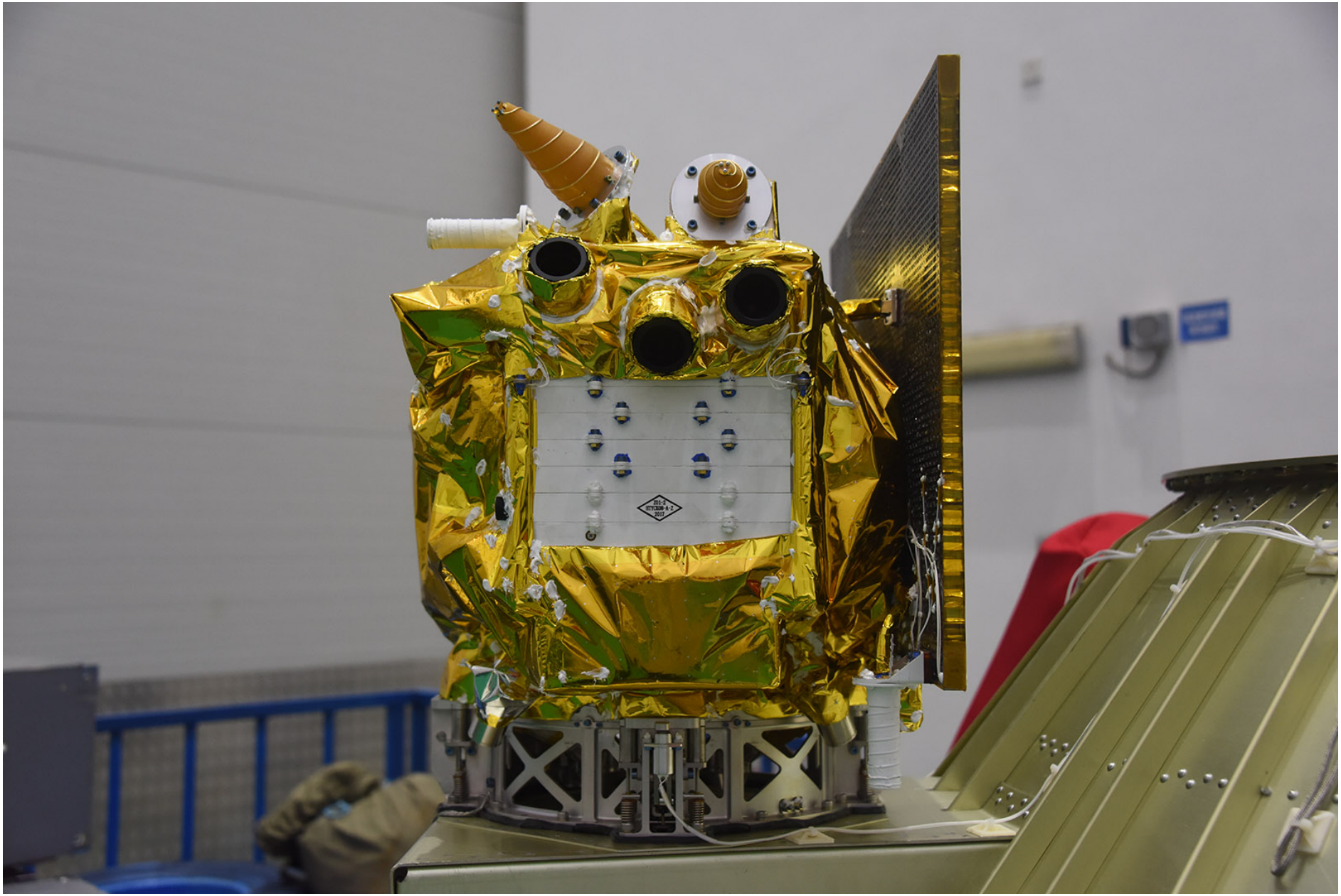
Amateur payload antennas

- Design: shortened biband double helix.
- Linear polarization.
- Peak gain. 0dBi en UHF, -9dBi en VHF.




UV Antenna A
S-band Antenna
X-Band Antenna
ISL Antenna
Payload Antenna A
Star Tracker A
AOV Camera
Tank
Star Tracker B
Payload Antenna B
Solar Panel
UV Antenna B
Heavy Ring
Deployer
Li-ion Batteries





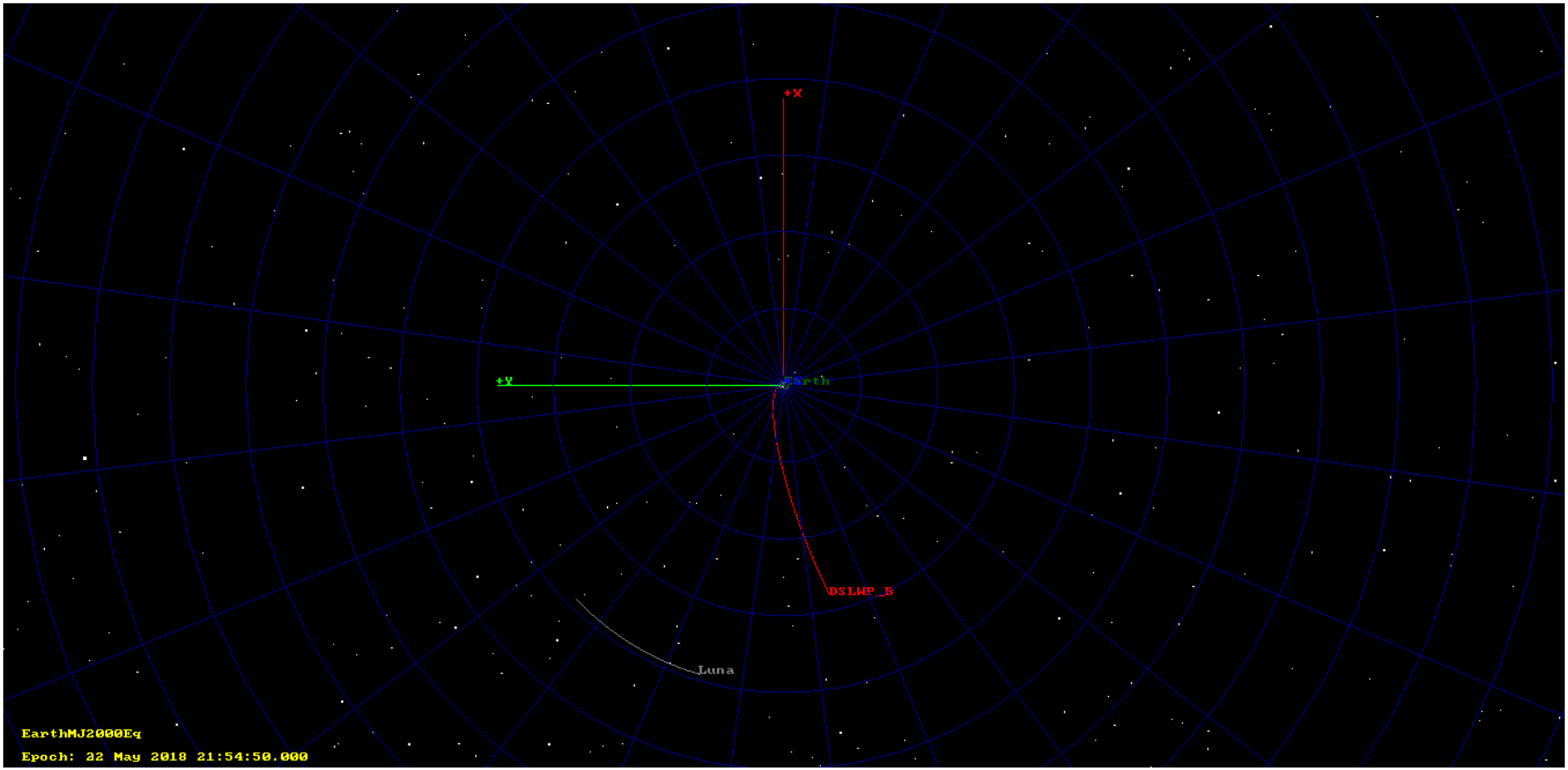
Outline

Launch

- DSLWP-A y -B were launch with Queqiao on 20 May at 21:25 UTC from Xichang (China).
- Trans-lunar injection and separation happened around 21:50 UTC.
- Shortly after, DSLWP-A and -B started transmitting GMSK telemetry over America.
- First signals from DSLWP-A receibed by Edson Pereira PY2SRD with a 4 element LFA yagi.
- Both satellites continued transmitting GMSK until 02:45 on 21 May, when the UHF transmitters where turned off at a distance of 70000km.
- The following stations receibed the GMSK signal: PY2SDR, CD3NDC, PY4ZBZ, N6RFM, PY2ZX.

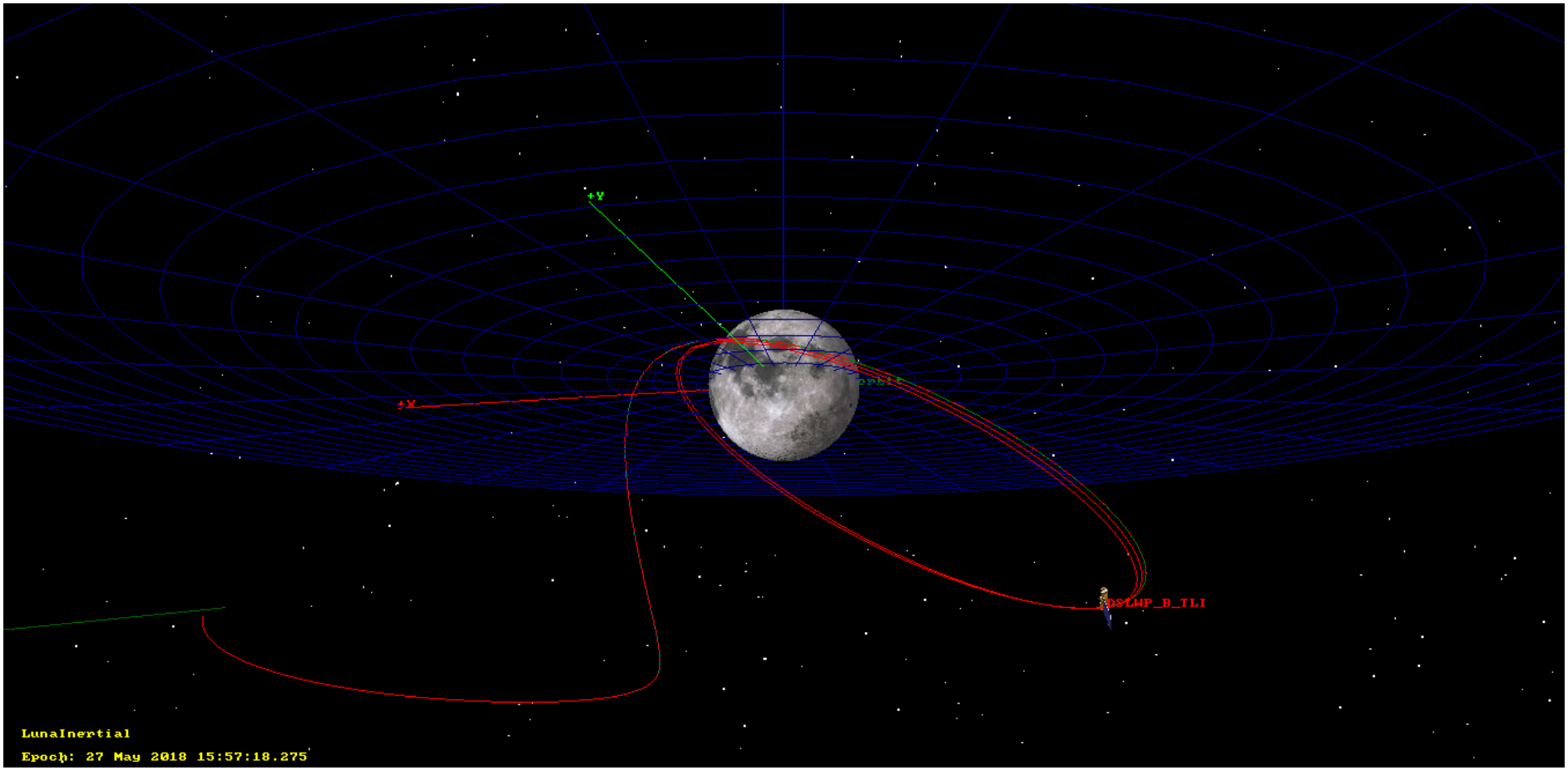
Transfer

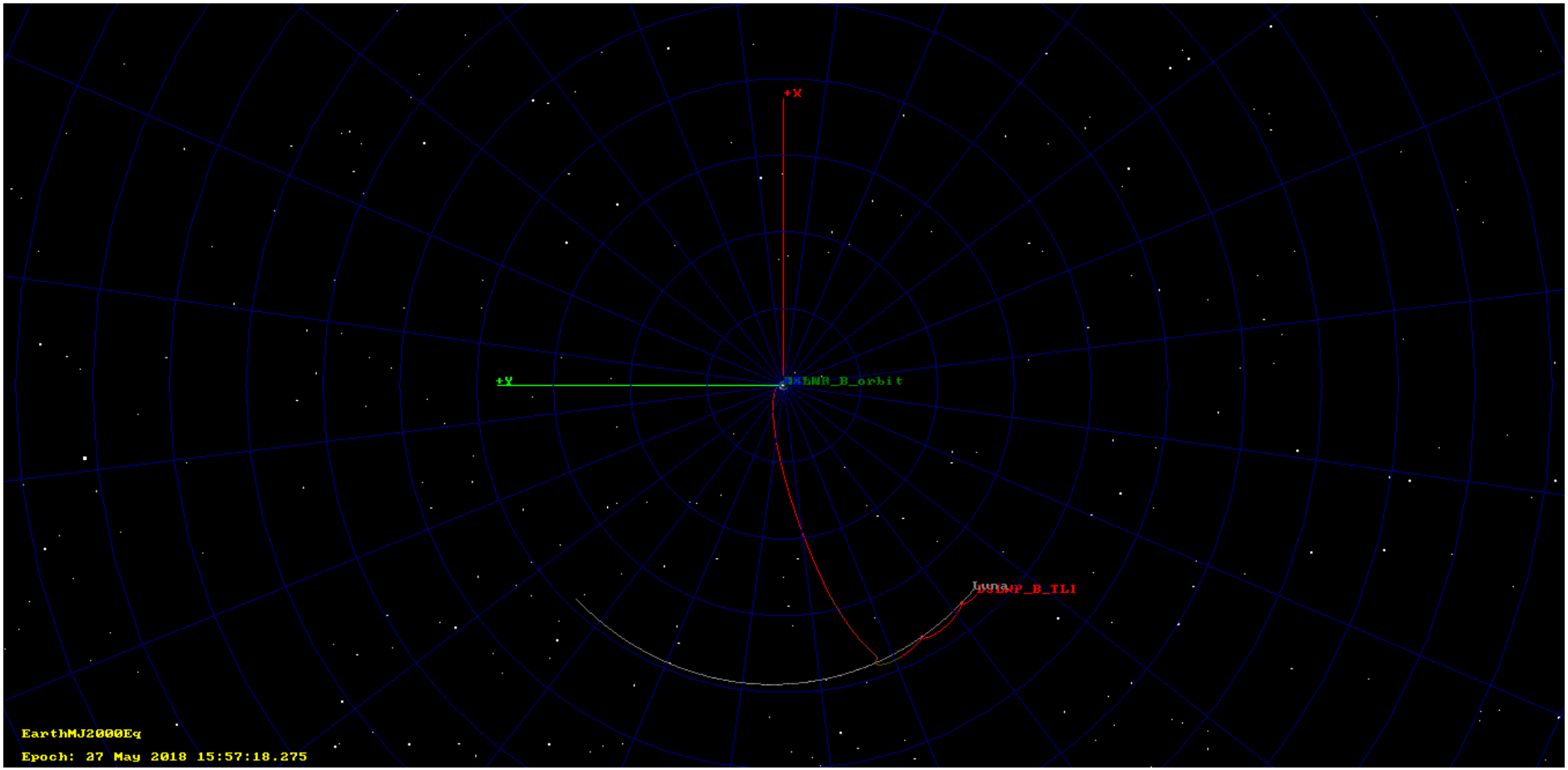
- Spacecraft tracking by Amateurs continued using the S band beacon (2275MHz).
- Several stations received the signal: IW1DTU, M0EYT, VE7TIL, and others.
- On 21 May at 19:54 UTC a trajectory correction manoeuvre was made with DSLWP-A.
- During this manoeuvre the contact with DSLWP-A was lost. The contact has never been recovered and the mission has been deemed a failure.
- On 23 May at 12:00 UTC a correction manoeuvre was made with DLSWP-B.
- Fortunately, the manoeuvre was exectued correctly and DSLWP-B continued without problems its way towards the Moon. Luna.
- On 23 May at 12:20 UTC the UHF transmitter of DSLWP-B was activated again and the telemetry was received correctly in Beijing at a distance of 321500km.


+X
+Y
Earth
DSLWP_B
Luna
EarthMJ2000Eq
Epoch: 22 May 2018 21:54:50.000

Lunar orbit injection

- On 24 may at 13:30 UTC a second correction manoeuvre was made with DSLWP-B.
- On 25 may at 14:18 UTC the lunar orbit injection of DSLWP-B was made.
- Orbital parameters:
  - Semi-major axis: 8750km
  - Excentricity: 0.76
  - Inclination: 21º
  - Apoapsis height: 13660km
  - Periapsis height: 360km
  - Period: 20h 24min


+Y
+X
DSLWP_B_TLI
LunaInertial
Epoch: 27 May 2018 15:57:18.275

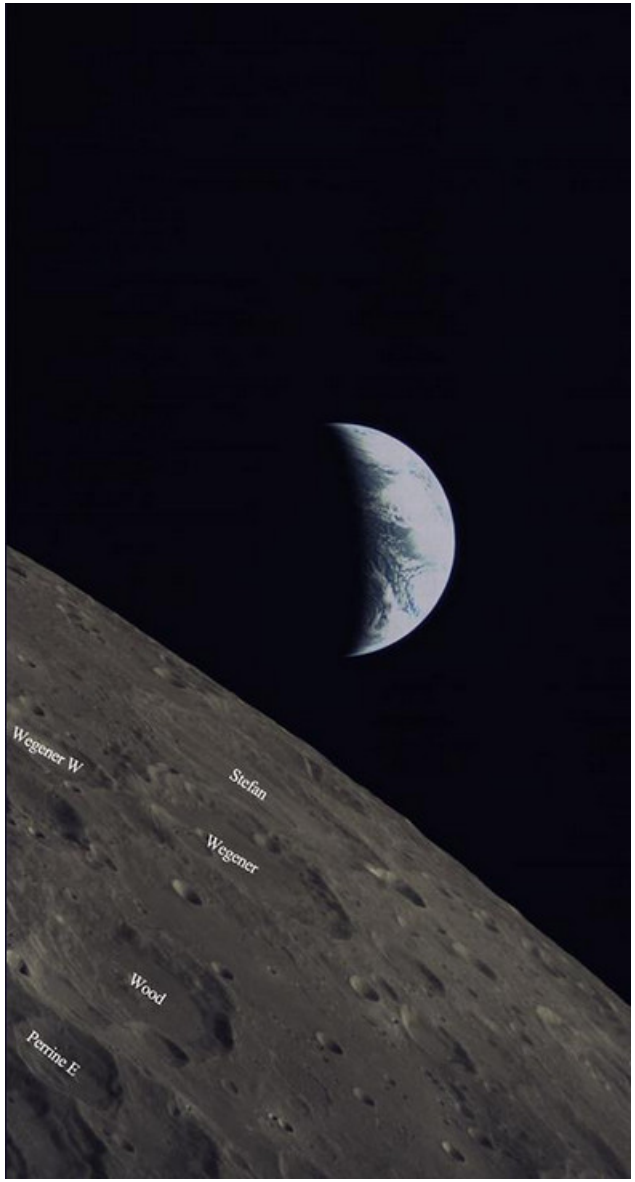

+X
+Y
Luna
EarthMJ2000Eq
Epoch: 27 May 2018 15:57:18.275

Operations in lunar orbit

- On 2 June at 22:00 UTC the first GMSK transmissions from lunar orbit were made. Received correctly in Beijing.
- More transmissions were made on 3 June at 3:00 UTC and were received correctly in Dwingeloo.
- Since then, occasional transmissions have been made during 2 hour periods (usually on the weekend). The periods in which the UHF transmitter
- On 10 June at 4:00 UTC the first (and only to date) VLBI experiment was made. The GMSK signal was recorded in a synchronized way in Dwingeloo and Beijing.
- On 16 June at 9:00 UTC the first JT4G transmissions were made. Since then both GMSK and JT4G are used in the periods when the UHF transmitter is active.

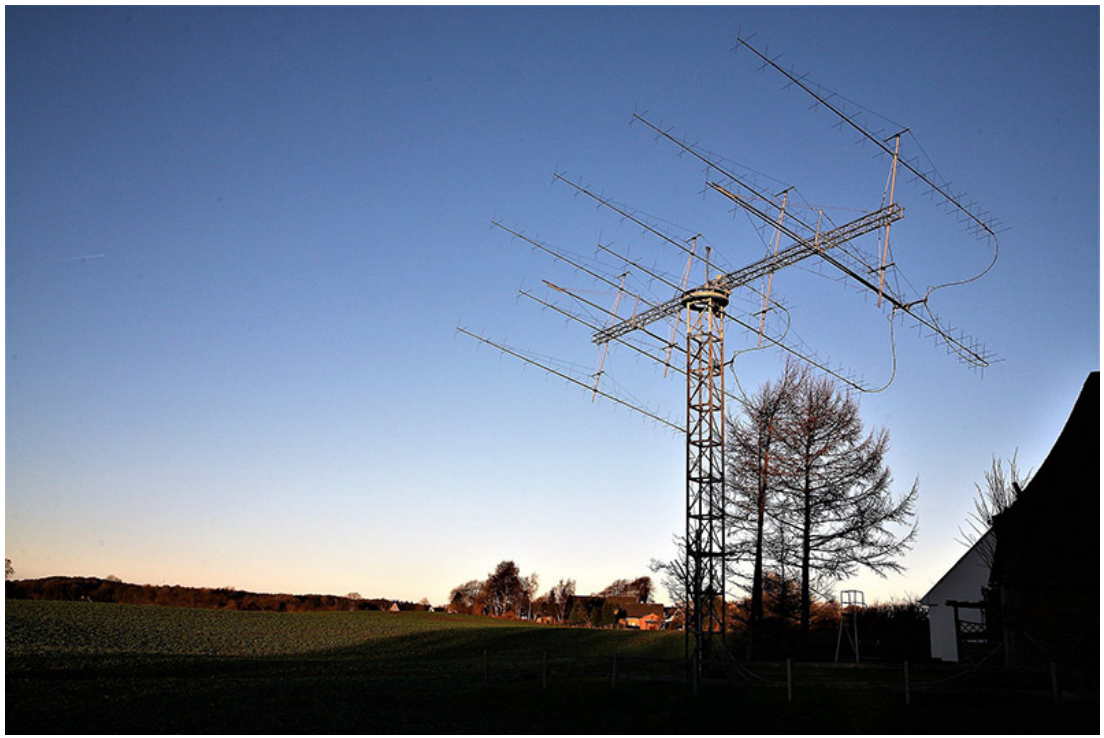
Saudi camera images

- On 14 June some images taken by the Saudi camera were transmitted on X band.



JT4G repeater

- On 15 july the GMSK⇒JT4G was tested successfully. Reinhard Kuehn DK5LA transmitted a message through DSLWP-B. The message was received by HB9OAB, W2RTV, IW1DTU, IU2EFA, PY4ZBZ, PA0DLO y I0LYL.



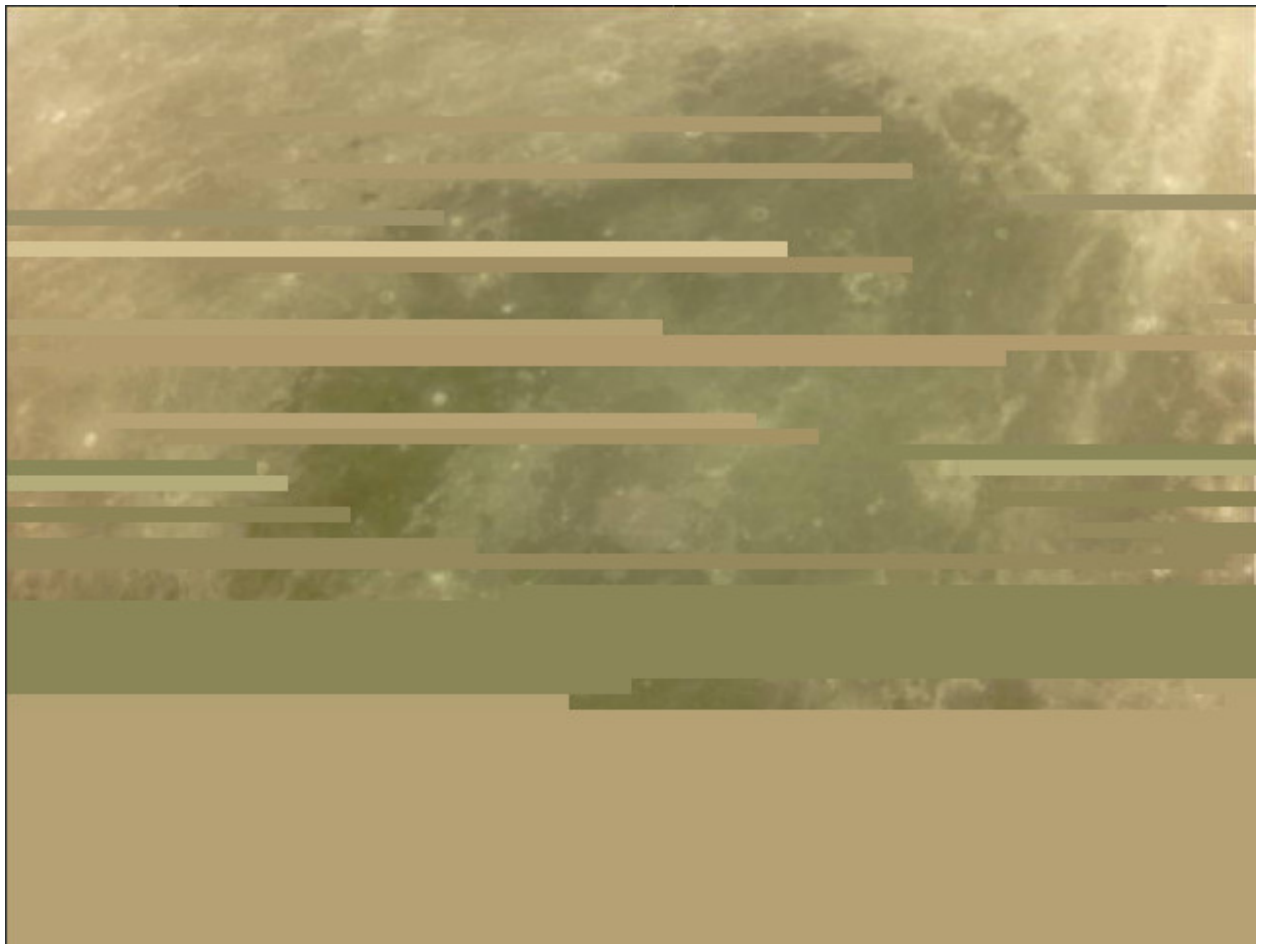
Lunar eclipse

- On 27 de july at 20:21 UTC there was a total lunar eclipse.
- In anticipation, on 20 July at 10:47 UTC a manoeuvre was made to raise the periapsis of DSLWP-B. The periapsis radius was raised by 385km.
- This manoeuvre had two goals: prevent DSLWP-B from passing too much time eclipsed by the Earth and prevent DSLWP-B from hitting the Moon on December 2018.

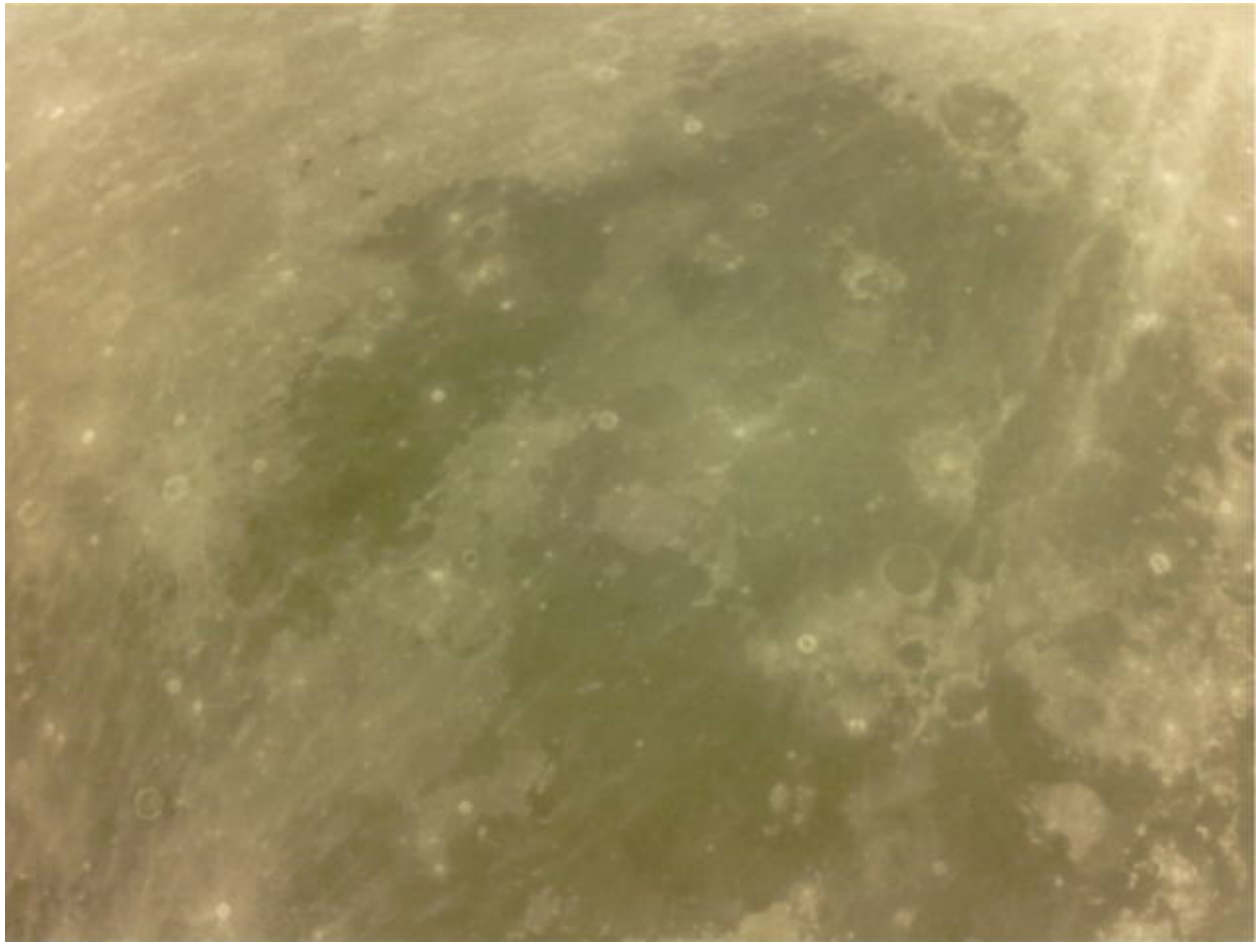
SSDV transmissions

- On 3 August at 01:27 UTC the first SSDV transmission was made. The transmission failed and only 872 bytes could be received in Dwingeloo.
- Only the start of the image was received, but Mars can be seen.

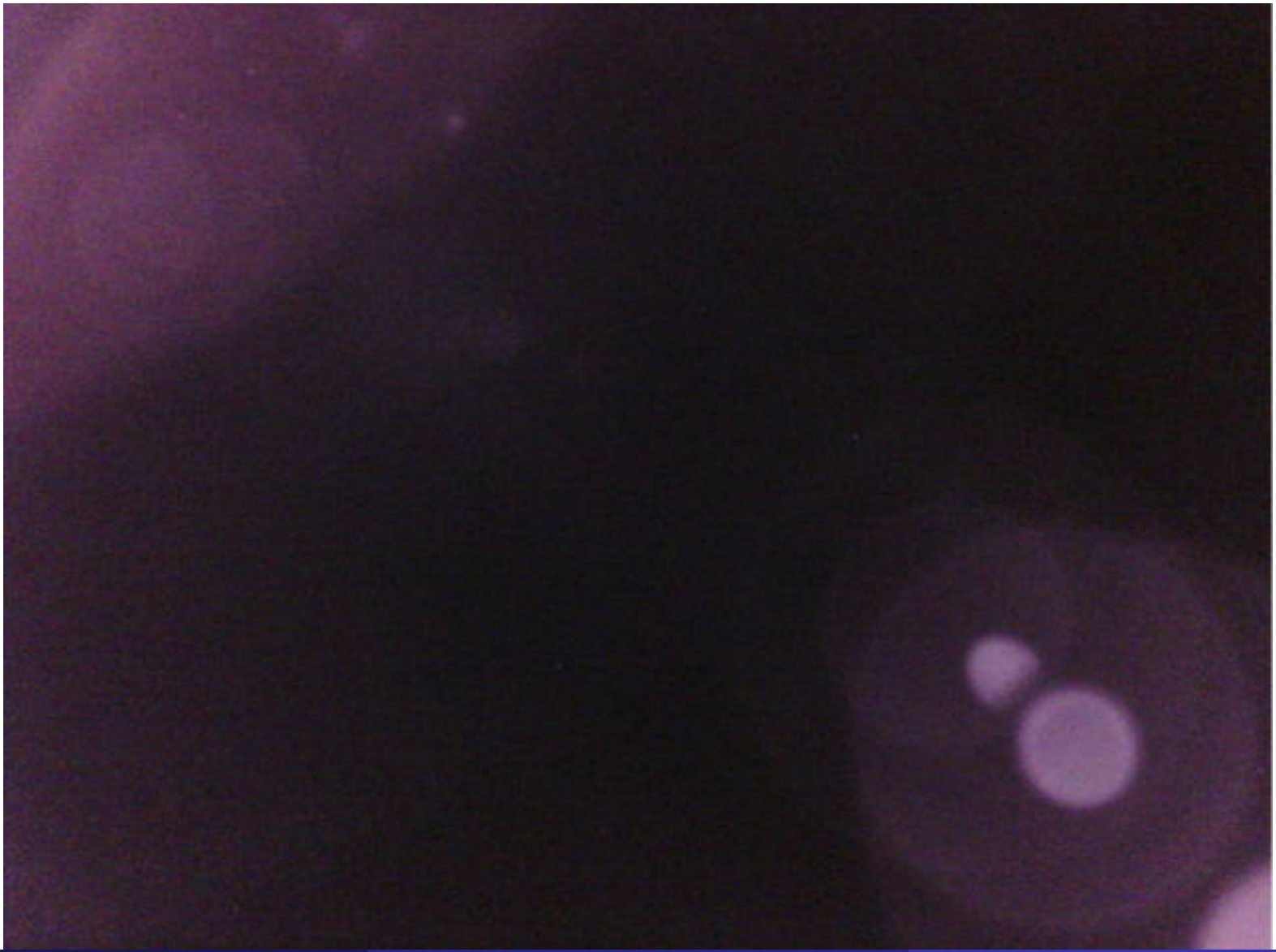
- On 5 August the second SSDV transmission was made.
- Using the groundstations in Beijing and Dwingeloo, the image of Mars and Capricornius was received completely, as well as a partial image of Mare Nubium, on the Moon.

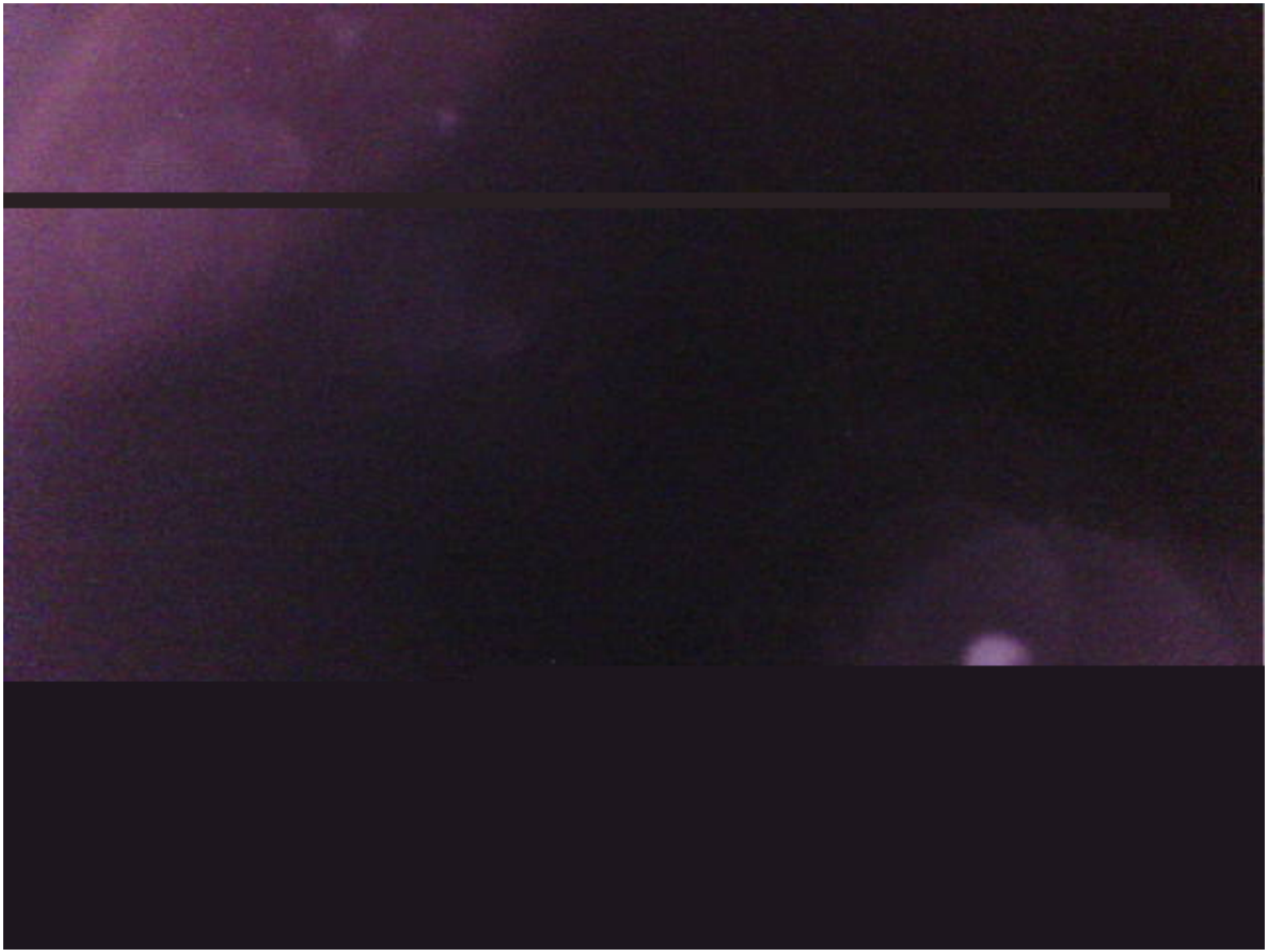


- On 12 August at 7:00 UTC the next SSDV transmission was made.
- The complete Mare Nubium image and an image of the Sun were received.

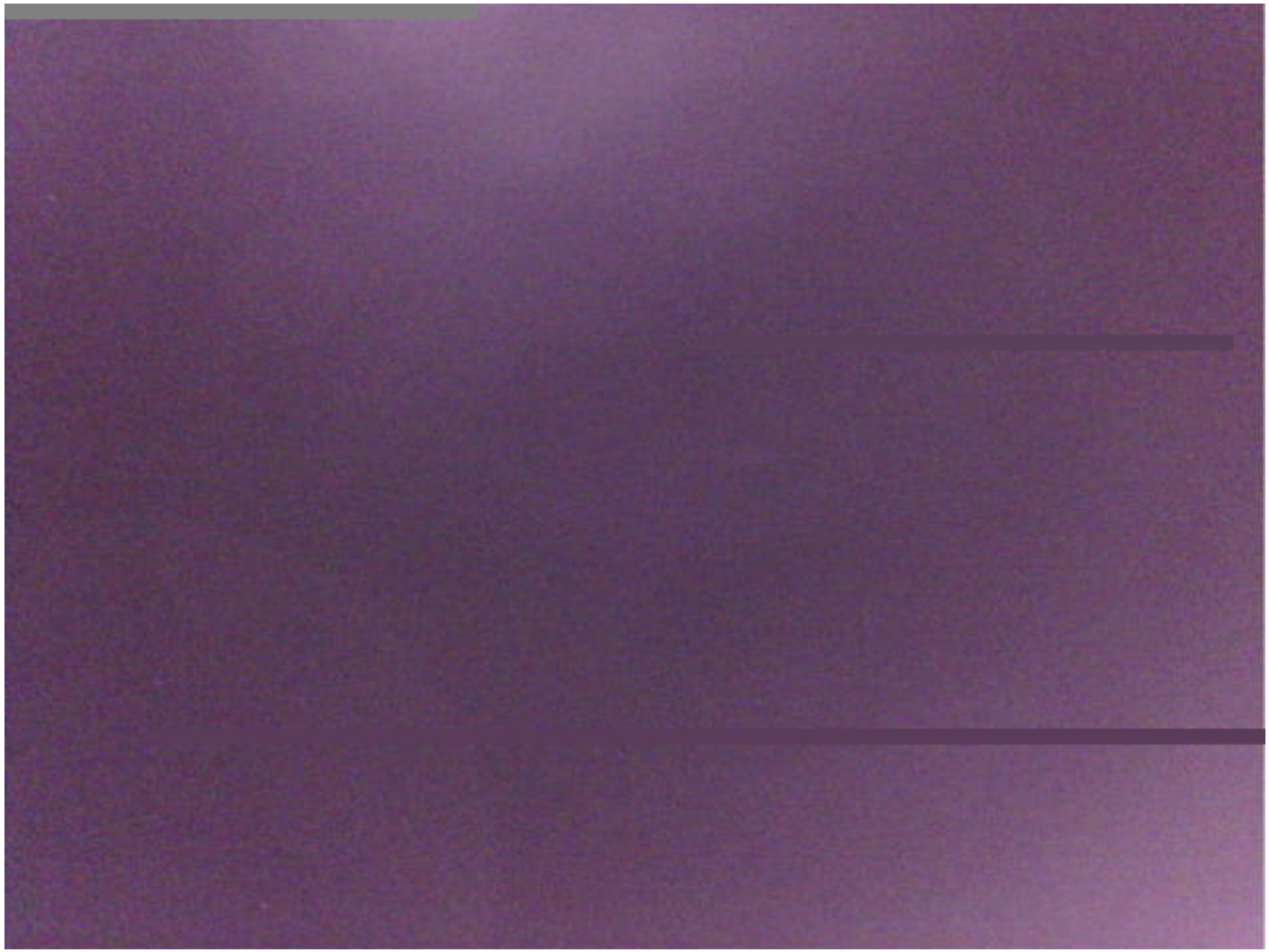


- On 14 August at 9:00 UTC another SSDV transmission was made.
- Two purple images were received, a complete one and a partial one.





- El 14 September at 14:40 UTC an SSDV transmission of two images was made. The transmissions were commanded by Reinhard DK5LA and received in Dwingeloo.



Receptions by Amateurs

- The transmissions by DSLWP-B from lunar orbit have been received by many Amateur stations, using antennas with very different performance.
- Reports listing `http://lilacsat.hit.edu.cn/wp/?page_id=844`
- PY2SDR, N6RFM, SP5ULN, PI9CAM, M0IEB, PA3FXB, DK3WN (incluso SSDV), IW1DTU, BG6LQV, BD9BU, G4RGK, 4Z5CP, IU2EFA, JA0CAW, JA2BLZ, BY2HIT, Wakayama University IFES Lab (disco de 12m), SQ5KTM, M0VKK, IK8XLD, LU5EWR-LU8DQ-LU3DMB, EA4GPZ, W2RTV, BG8IXQ, JA1OGZ, YL3CT, I0LYL, SQ3SWF, PA0DLO, K4KDR, JE1CVL, VK5EI, KO4MA, 3B8DU.

Outline

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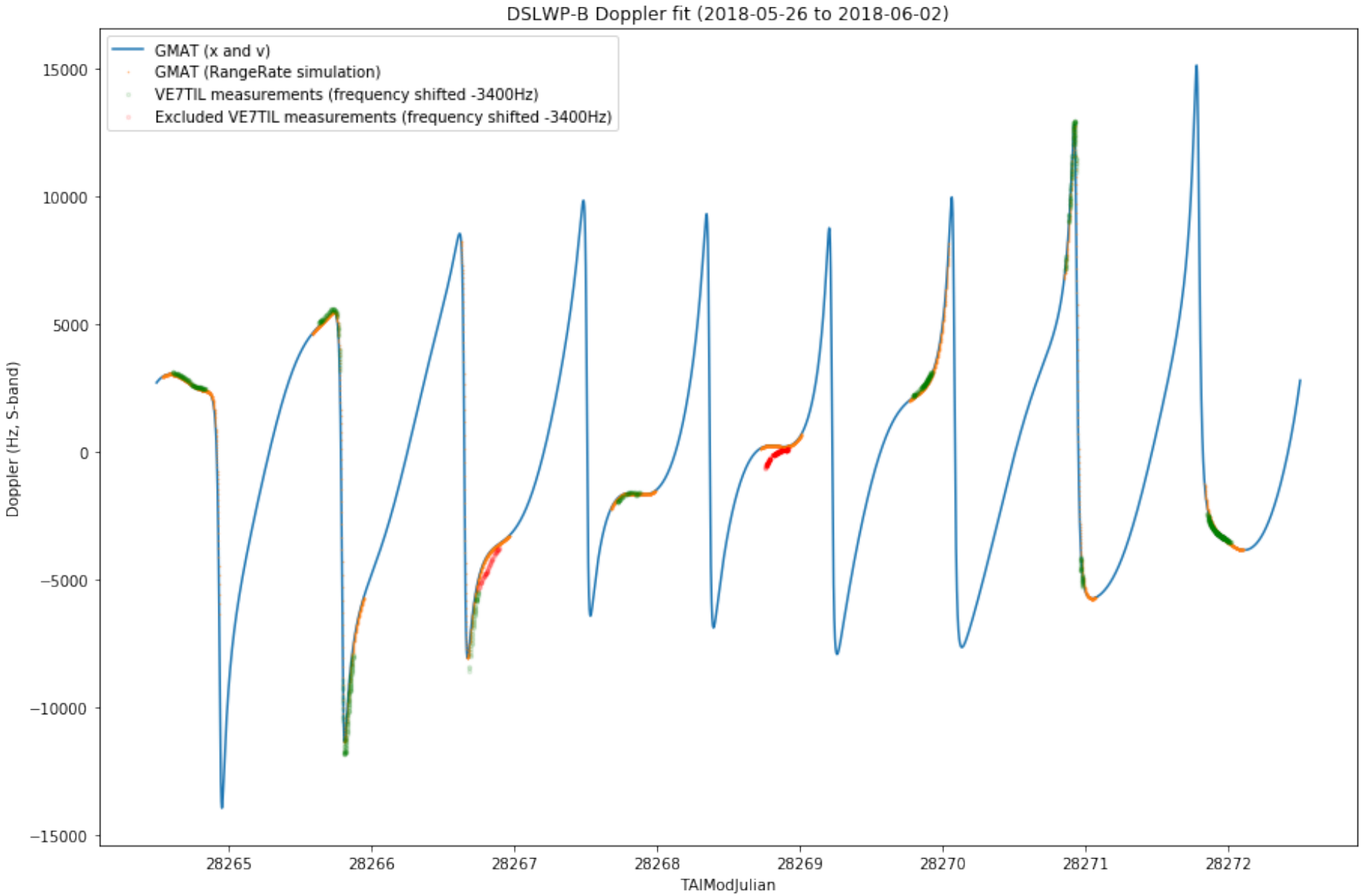
Satellites outside of Earth orbit

- To track satellites on Earth orbit TLEs are often used. These are useless outside of Earth orbit.
- If we know the position and velocity (elements / state vector) of the satellite in a given instant and all the forces acting on them (gravity, solar radiation, etc.), we can calculate its trajectory.
- GMAT is an open source software developed by NASA. We can use it to make orbital computations and calculate DSLWP-B's trajectories.
- We can also use the tracking files published by BG2BHC. These are a listing with the position and velocity of the satellite at each second.
- Mainly, we need to compute DSLWP-B's orbit if we want to correct for Doppler ($\pm$4kHz in 70cm), since its position is always near the Moon (1 or 2 degrees of maximum deviation).

Orbit determination with Doppler measurements

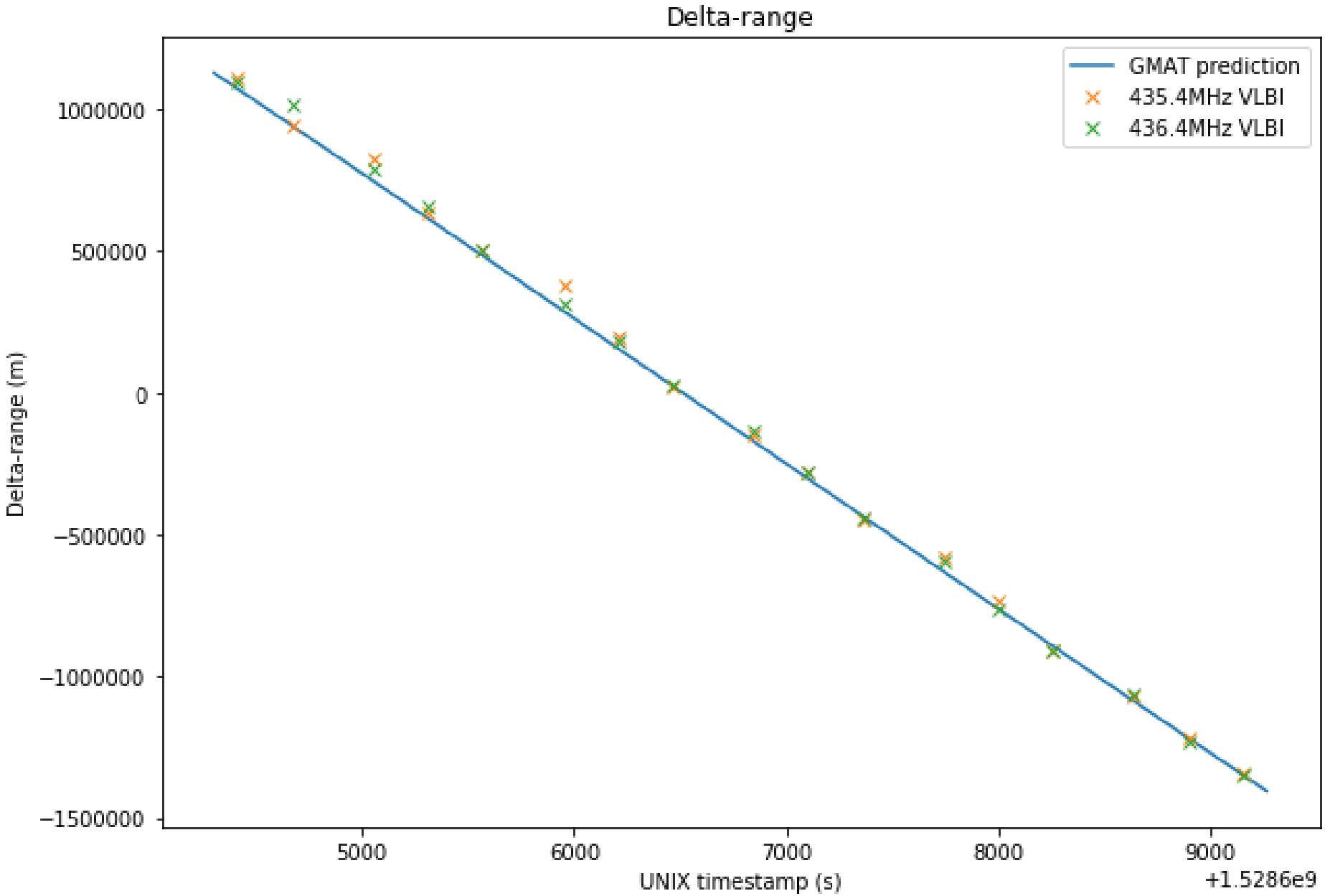
- But, how can we know the satellite position and speed? In the Moon there is no radar as we have in low Earth orbit.
- The satellite beacon Doppler tells us the speed with which it approaches/recedes from our station.
- Using Doppler measurements we can determine the satellite orbit using GMAT.
- I have made orbit determinations of DSLWP-B using the measurements of the S band beacon done by Scott Tilley VE7TIL.
- The official orbit determination comes from the tracking done by the Chinese Deep Space Network.
- My orbit determination, which only uses VE7TIL Amateur data, is very close to the official calculations.

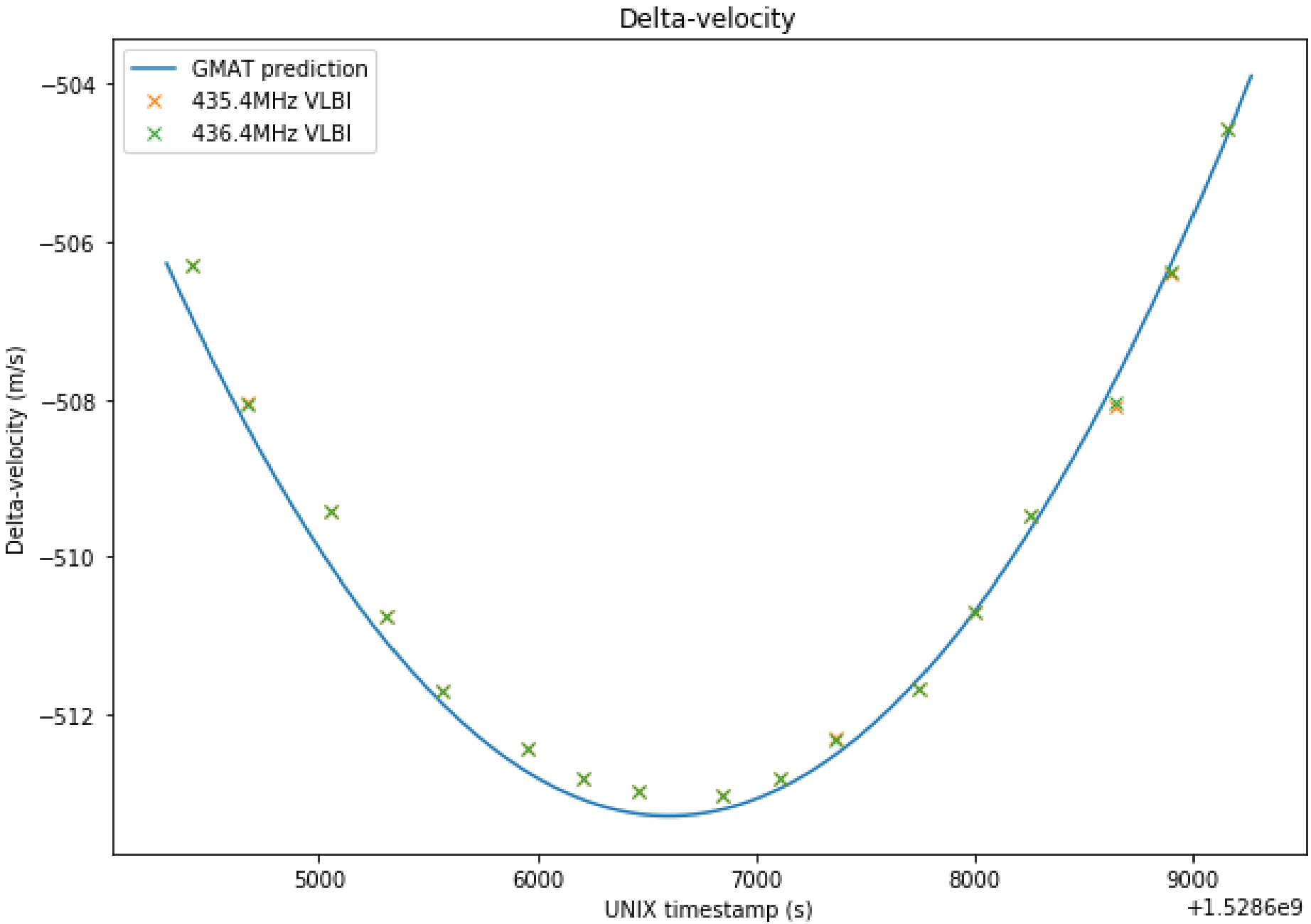

DSLWP-B Doppler fit (2018-05-26 to 2018-06-02)
GMAT (x and v)
GMAT (RangeRate simulation)
VE7TIL measurements (frequency shifted -3400Hz)
Excluded VE7TIL measurements (frequency shifted -3400Hz)
Doppler (Hz, S-band)
15000
10000
5000
0
−5000
−10000
−15000
28265
28266
28267
28268
28269
28270
28271
28272
TAIModJulian

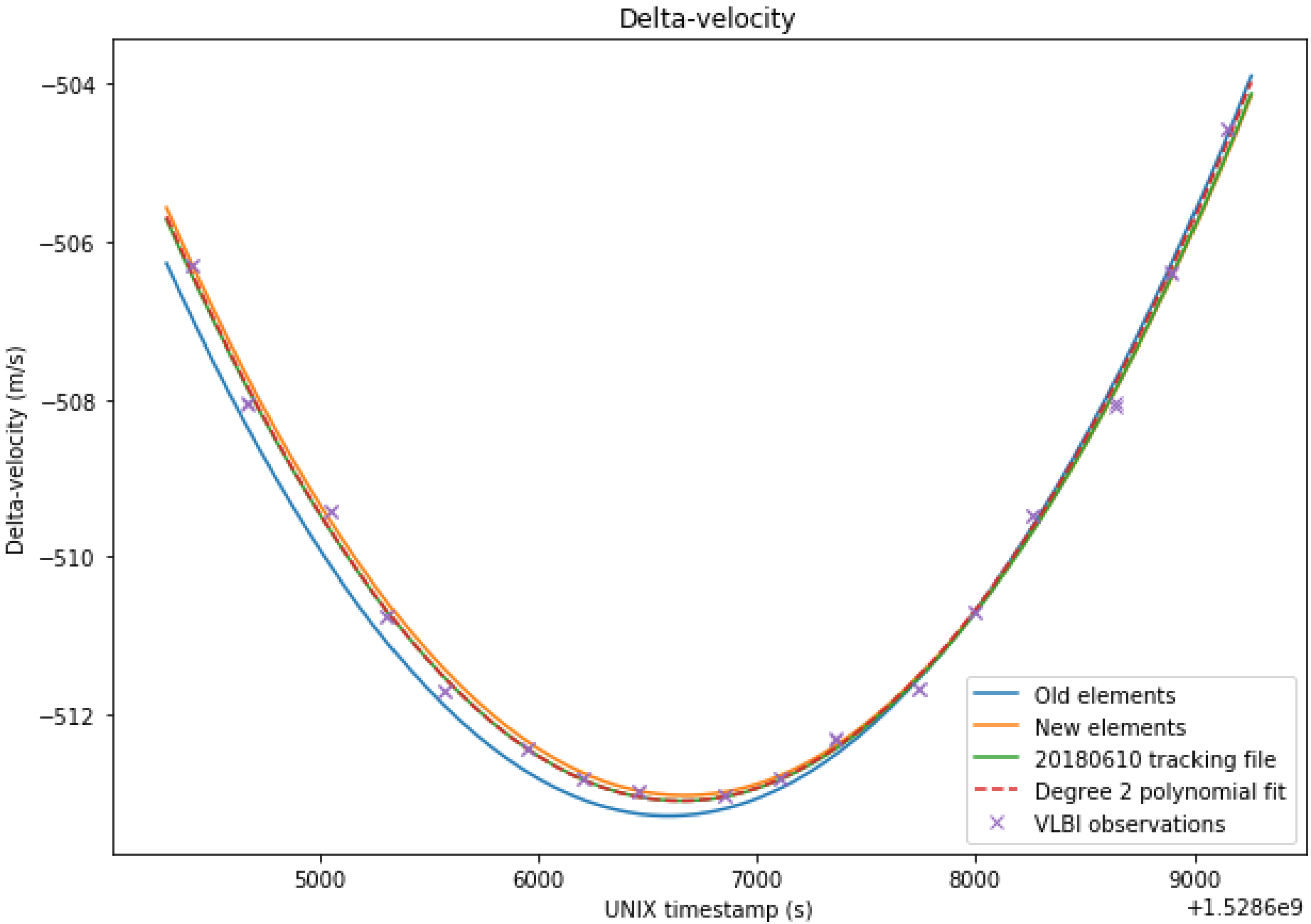
Outline

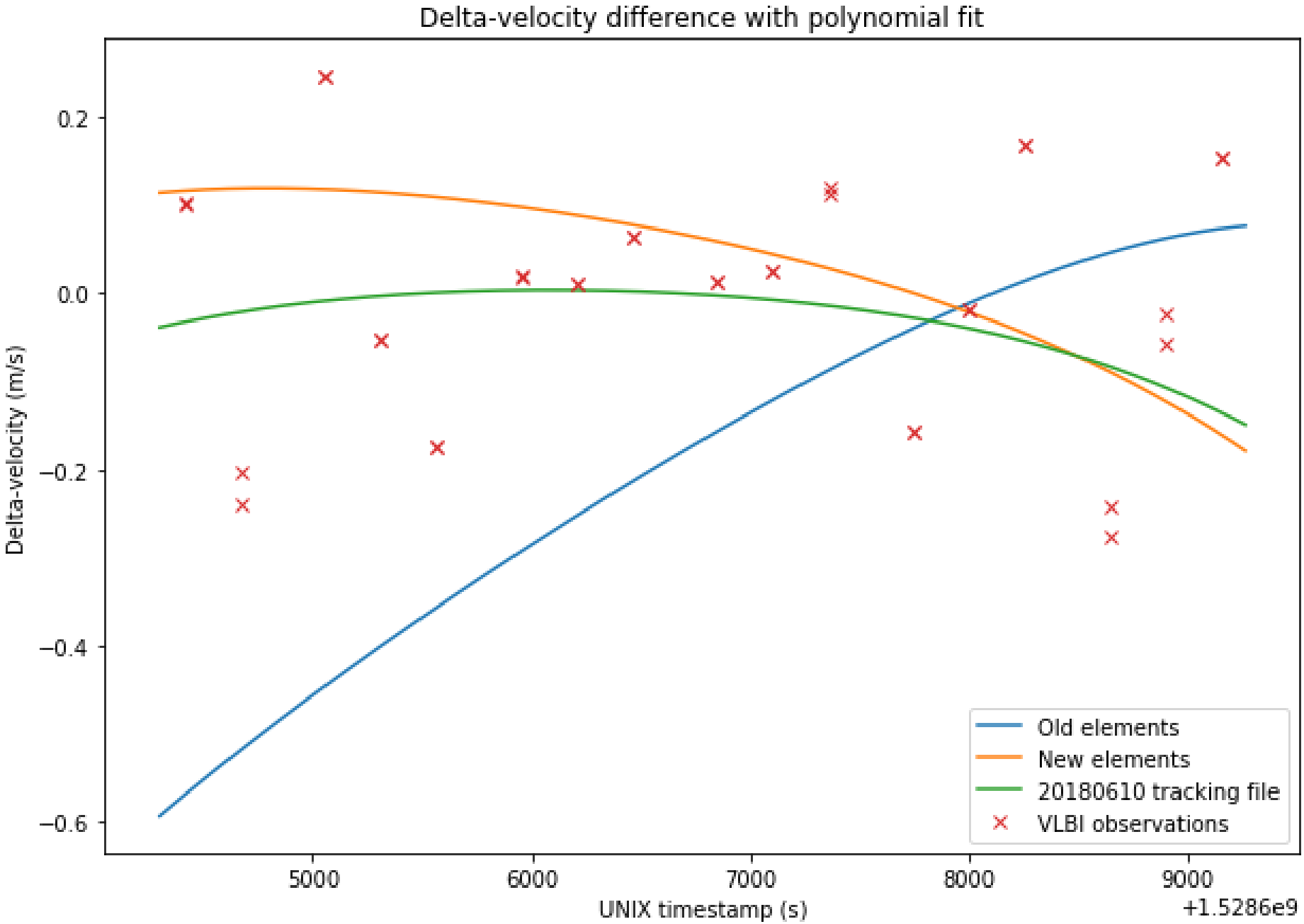
Amateur VLBI

- Making a sinchronized recording of the satellite from two distant stations we can measure the difference in distances and velocities between the satellite and stations.
- This data can be used for orbit determination.
- The only VLBI session was made on 10 june. The GMSK telemetry was recorded with GPS synchronized USRP receivers in Shahe (China) and Dwingeloo (The Netherlands) over one hour.
- I have developed the algorithms to process the VLBI recordings and obtain the measurements.
- I have also contrasted the VLBI measurements with the orbit determination.


Delta-range
GMAT prediction
435.4MHz VLBI
436.4MHz VLBI
1000000
500000
0
−500000
−1000000
−1500000
Delta-range (m)
5000
6000
7000
8000
9000
UNIX timestamp (s)
+1.5286e9


Delta-velocity
GMAT prediction
435.4MHz VLBI
436.4MHz VLBI
−504
−506
−508
−510
−512
Delta-velocity (m/s)
5000
6000
7000
8000
9000
UNIX timestamp (s)
+1.5286e9


Delta-velocity
−504
−506
−508
−510
−512
Delta-velocity (m/s)
5000
6000
7000
8000
9000
UNIX timestamp (s)
+1.5286e9
Old elements
New elements
20180610 tracking file
Degree 2 polynomial fit
VLBI observations


Delta-velocity difference with polynomial fit
Delta-velocity (m/s)
0.2
0.0
−0.2
−0.4
−0.6
5000
6000
7000
8000
9000
UNIX timestamp (s)
+1.5286e9
Old elements
New elements
20180610 tracking file
VLBI observations

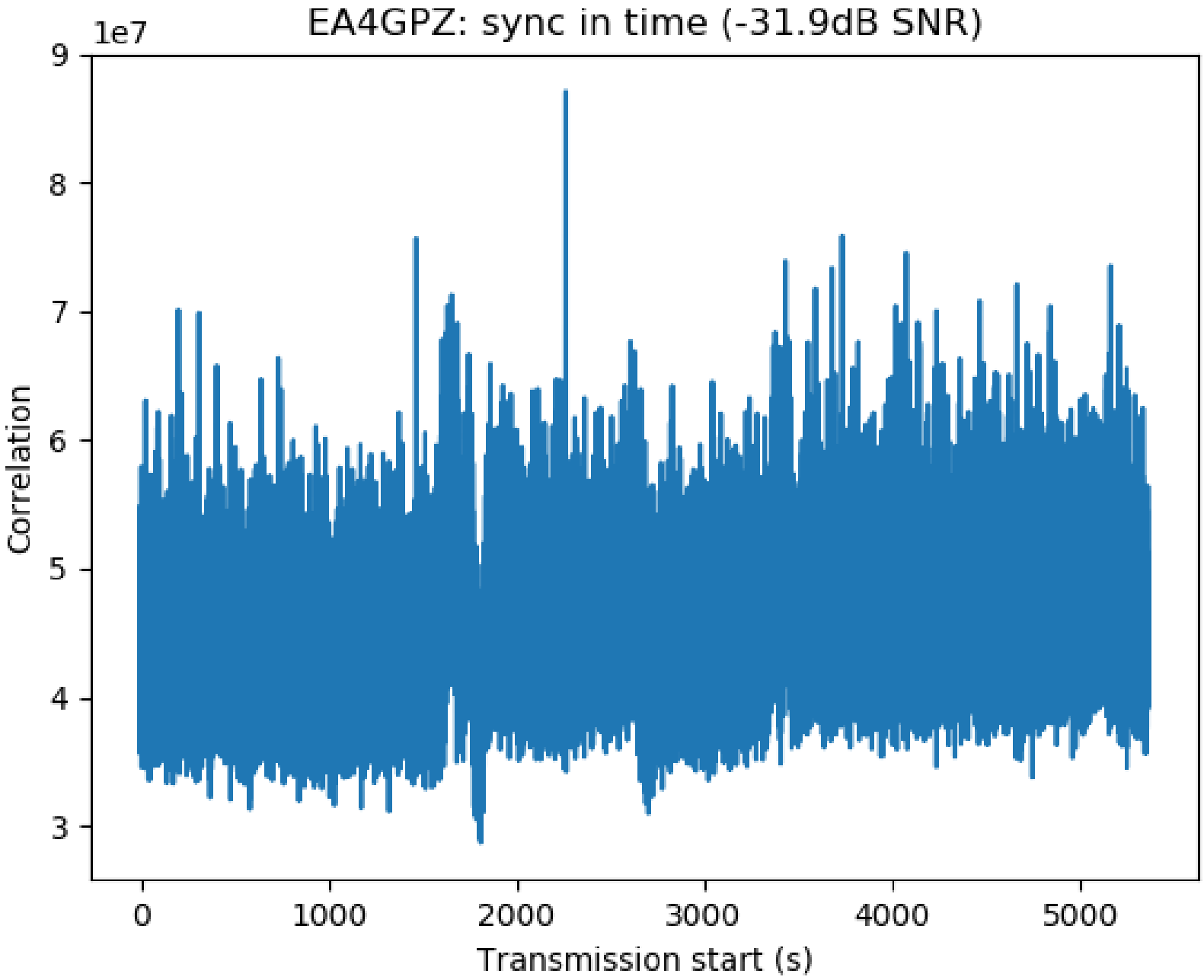
Outline

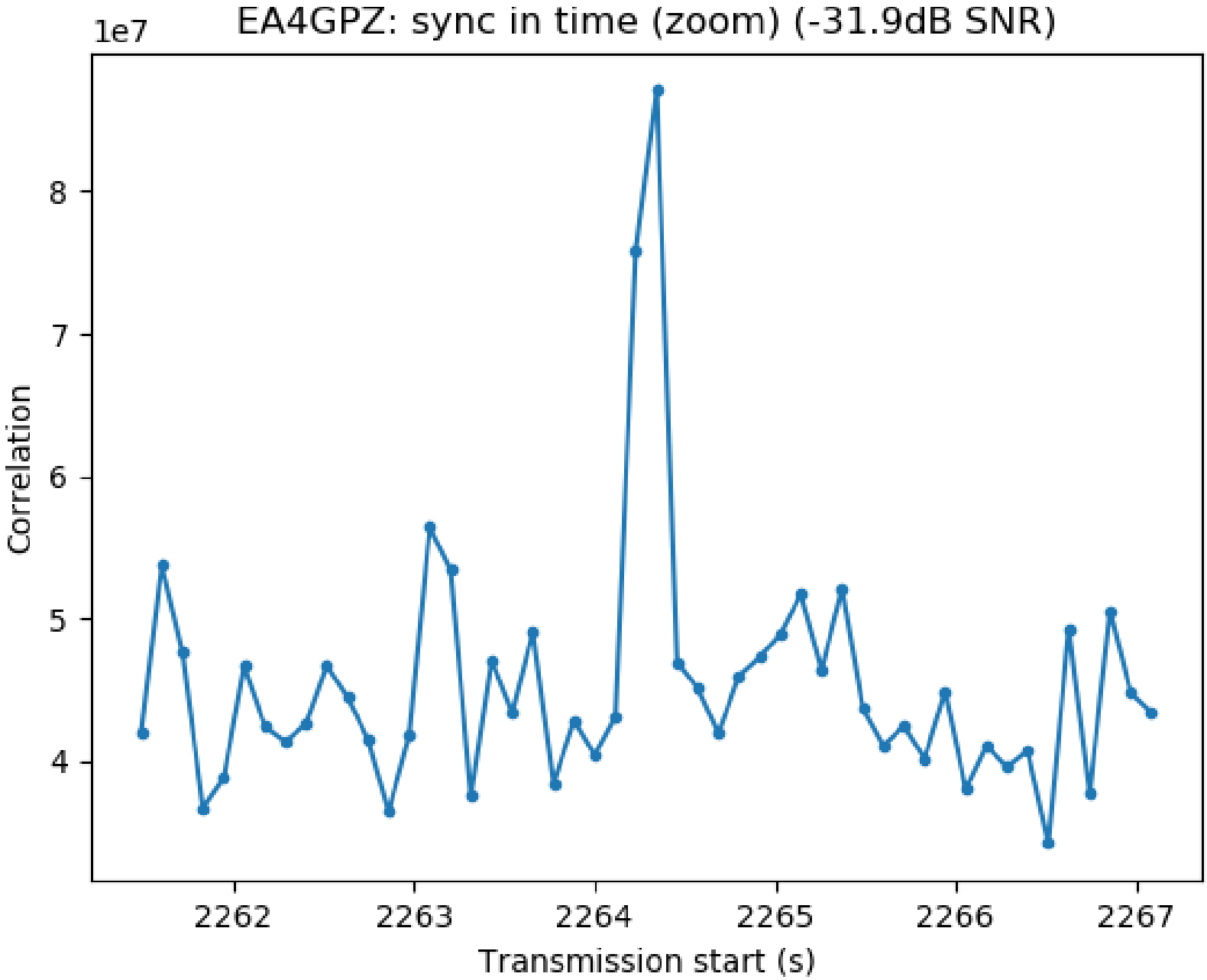
Weak signals

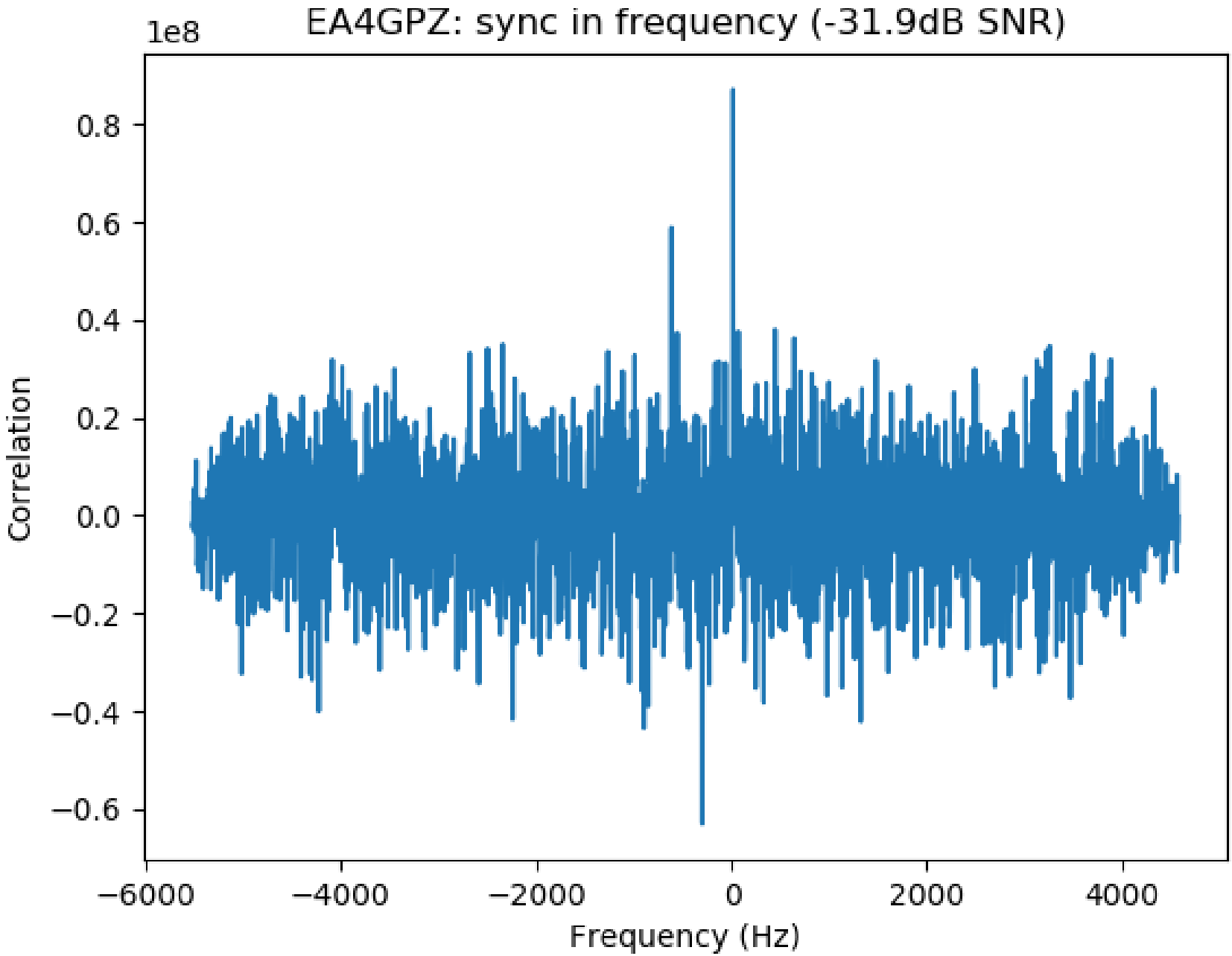
- DSLWP-B transmits with a short antenna and 2W at a distance of 380000km. To decode the signal, a high gain antenna is needed (typically, at least a long yagi).
- JT4G can be decoded down to -23dB SNR in 2500Hz. The GMSK telemetry can be decoded down to -9dB SNR in 2500Hz.
- Nevertheless, it should be possible to do something with small stations.
- I have designed some weak signal detection algorithms using correlation which are able to detect JT4G well below -25dB SNR and GMSK at -22dB SNR.
- These algorithms can produce false positives, so the results always need to be interpreted and filtered.
- With these algorithms, anyone can receive DSLWP-B.

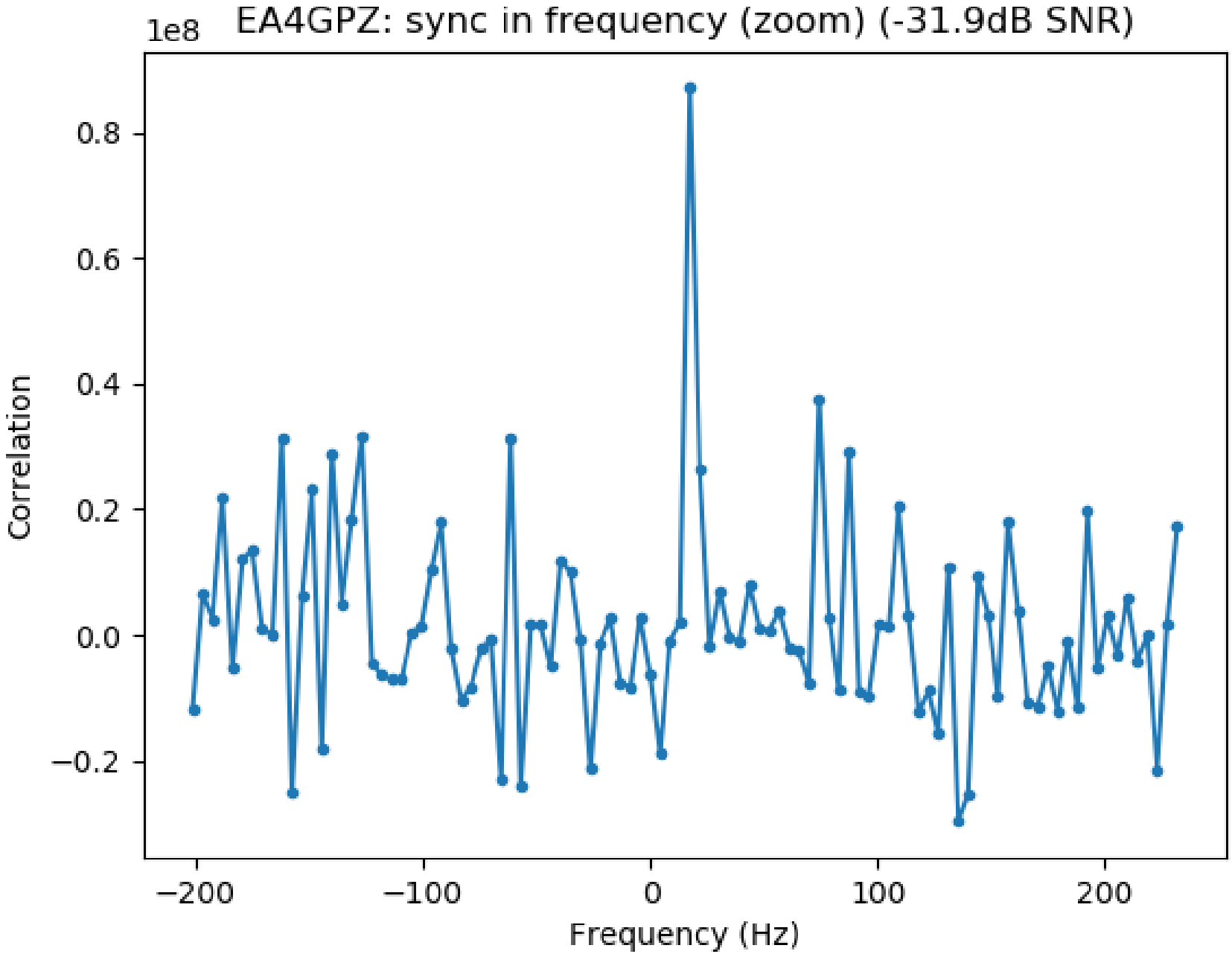
Detection of JT4G with a 7 element yagi

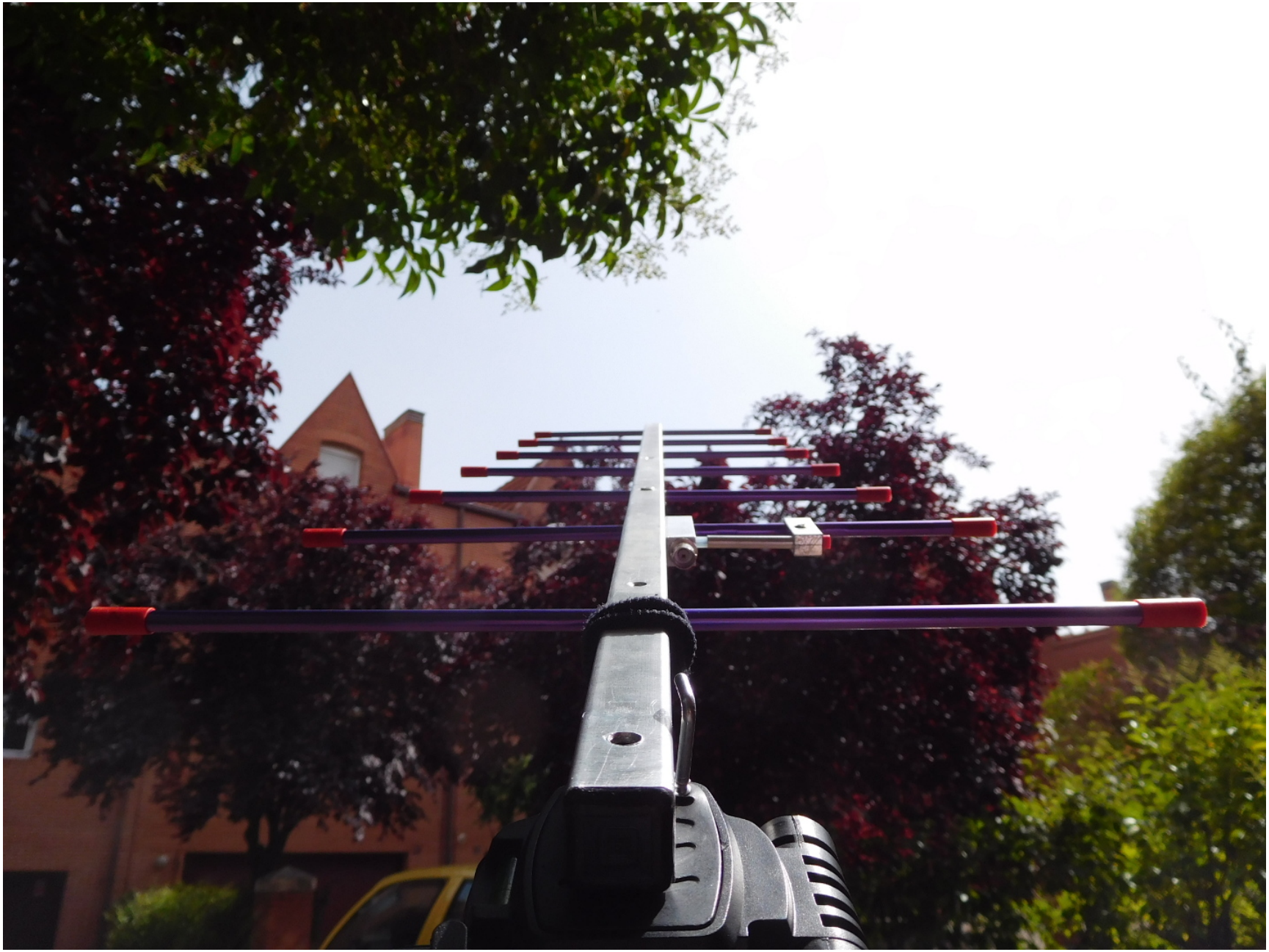
- On 22 June at 21:00 UTC I made a recording of DSLWP-B signals on 435.4MHz.
- The receiver was a 7 element Arrow yagi and a FUNcube Dongle Pro+.
- Using my algorithm, I was able to detect one of the JT4G transmissions with an estimated SNR of -32dB.
- This is the smallest station that has managed to receive DSLWP-B.


EA4GPZ: sync in time (-31.9dB SNR)
1e7
9
8
7
6
5
4
3
Correlation
0
1000
2000
3000
4000
5000
Transmission start (s)


EA4GPZ: sync in time (zoom) (-31.9dB SNR)
1e7
Correlation
8
7
6
5
4
2262
2263
2264
2265
2266
2267
Transmission start (s)


EA4GPZ: sync in frequency (-31.9dB SNR)
1e8
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
Correlation
−6000
−4000
−2000
0
2000
4000
Frequency (Hz)


EA4GPZ: sync in frequency (zoom) (-31.9dB SNR)
1e8
0.8
0.6
0.4
0.2
0.0
−0.2
Correlation
−200
−100
0
100
200
Frequency (Hz)



Outline

SSDV reception

- During the SSDV transmissions, several problems have been detected which cause the lost of some packets, so image chunks are missing.
- The 25m radiotelescope in Dwingeloo has an excellent SNR, so there should be no packet loss.
- I have studied these problems. Two main causes:
  - The TCXO on DSLWP-B occasionally jumps in frequency because it has a digital control. This corrupts the affected packet.
  - The reception algorithm sometimes has problems detecting the beginning of a packet. I have solved most of these problems.
- I have developed an SSDV decoder for the custom format used by DSLWP-B and a script to reorder the received fragments.

Conclusions

- DSLWP-B has been a huge milestone in the history of Amateur Radio. One can say many sentences affirming it hast been “the first...”.
- For me these have been some months of crazy work since Wei told me on 8 May about the upcoming launch (19 blog posts, 9 Jupyter notebooks, 8 GMAT scripts and increasing).
- We who have collaborated in the DSLWP mission have had fun, learned a lot, and taken part in a state of the art mission.
- We need more Spanish Amateurs particpating in this kind of activities.

References

- https://destevez.net/tag/dslwp/
- https://twitter.com/ea4gpz
- Wei Mingchuan BG2BHC https://twitter.com/bg2bhc
- Cees Bassa https://twitter.com/cgbassa
- Scott Tilley VE7TIL https://twitter.com/coastal8049
- LilacSat and DSLWP web http://lilacsat.hit.edu.cn/

Sorry for the advertisment

Next in Spring 2019 (end of April maybe)
In Madrid (probably)
`http://www.radiocluberrante.es/congreso-starcon/`