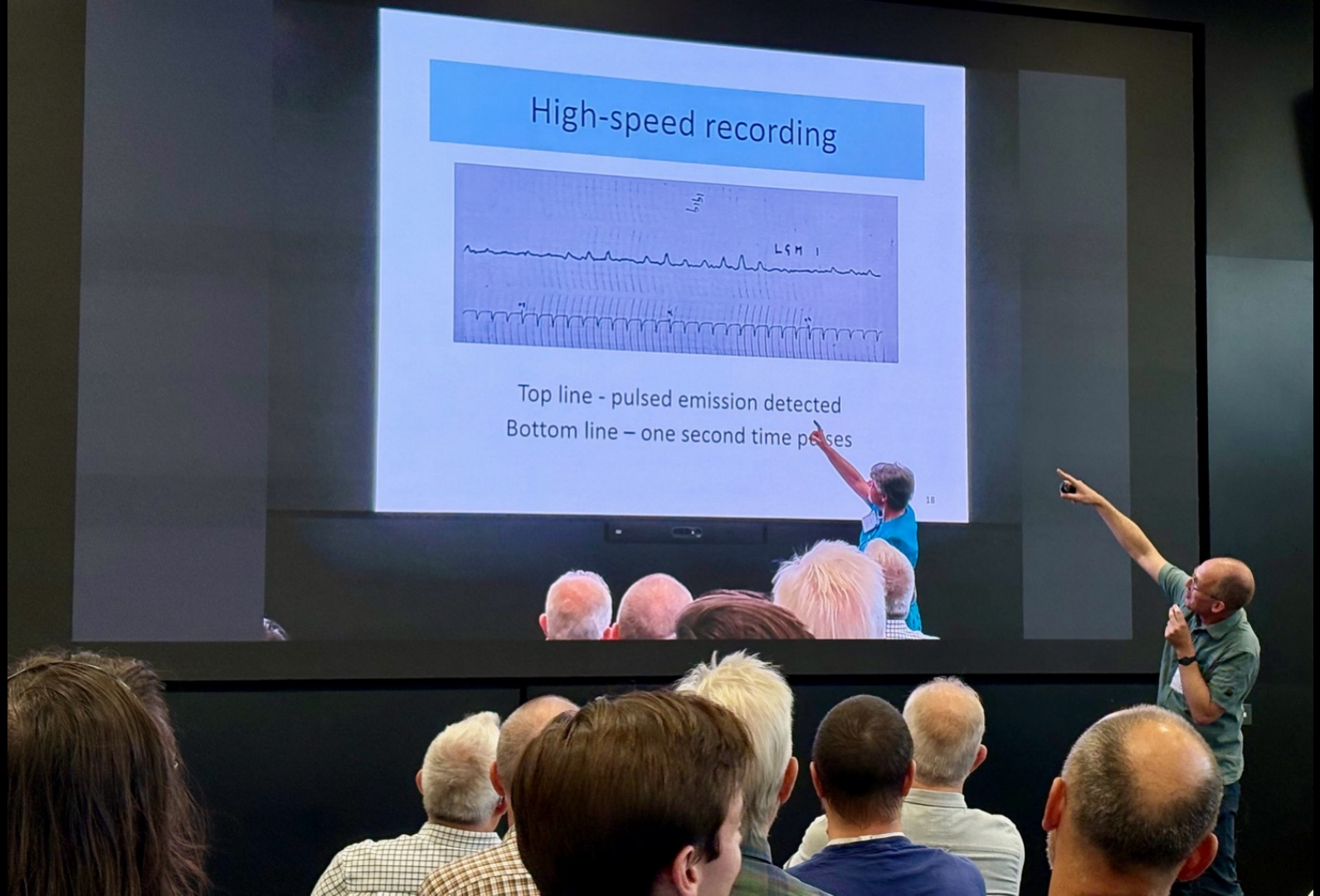
Radar Astronomy

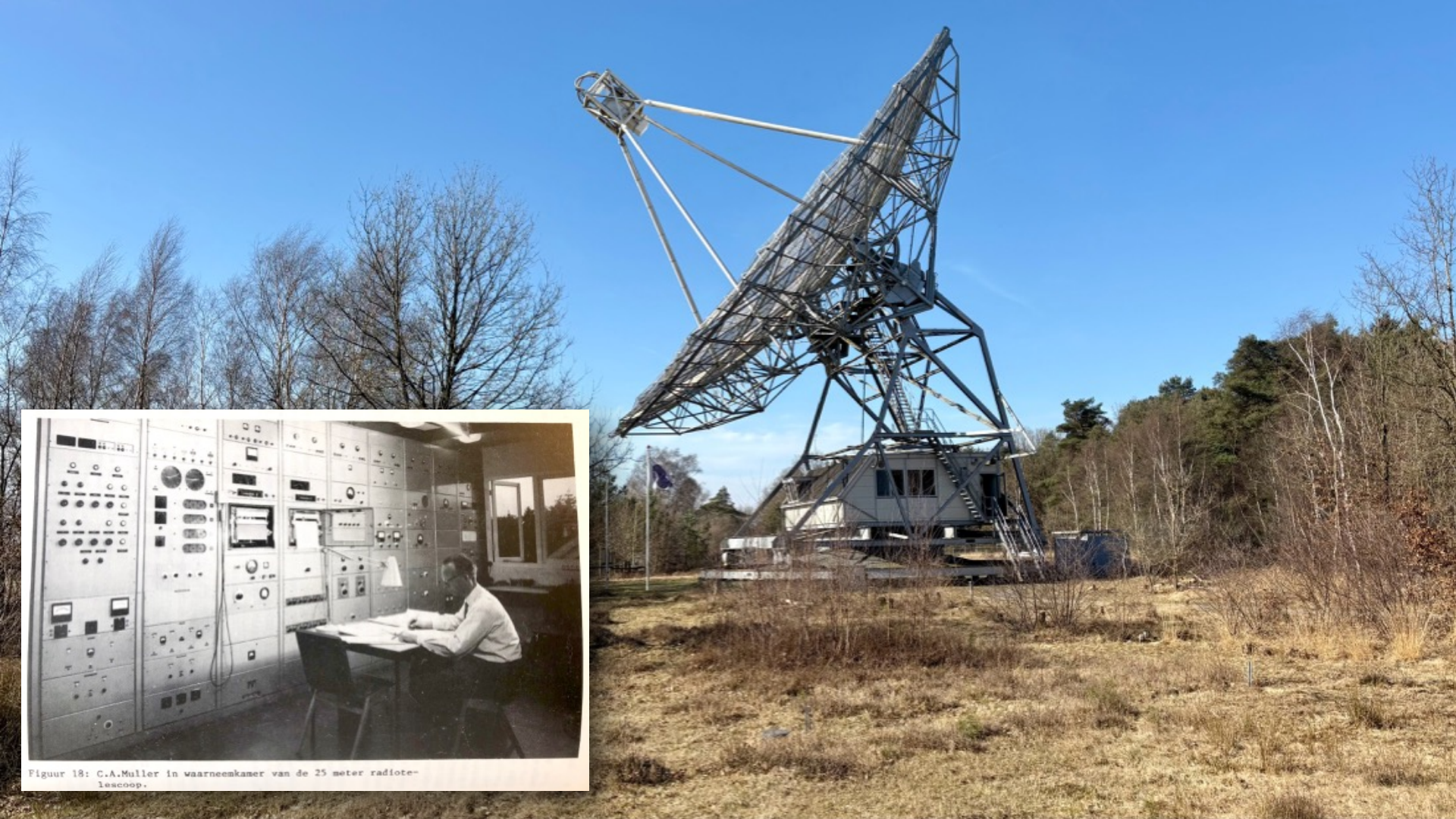
Thomas Telkamp, Cees Bassa, Tammo Jan Dijkema, Wolfgang Herrmann, et al.



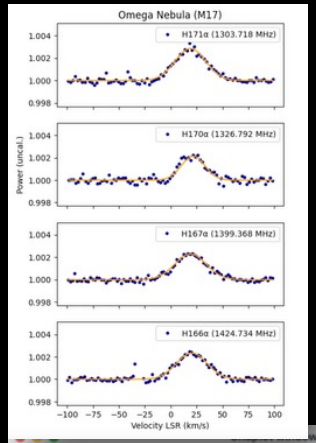


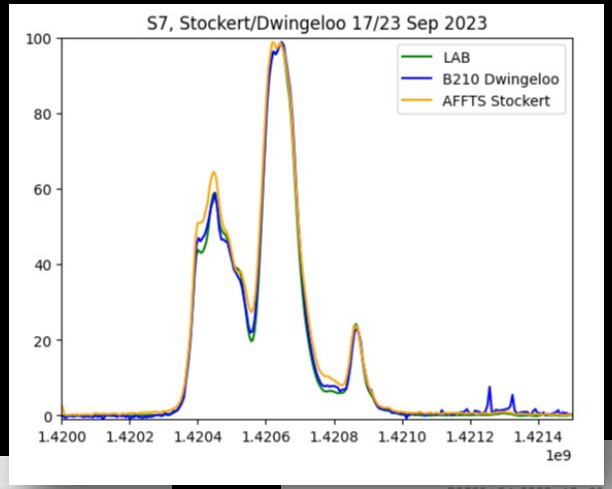
© 2025 by Stichting Radiotelescoop Dwingeloo and Astropeiler Stockert e.V., licensed under CC BY 4.0.
To view a copy of this license, visit https://creativecommons.org/licenses/by/4.0/

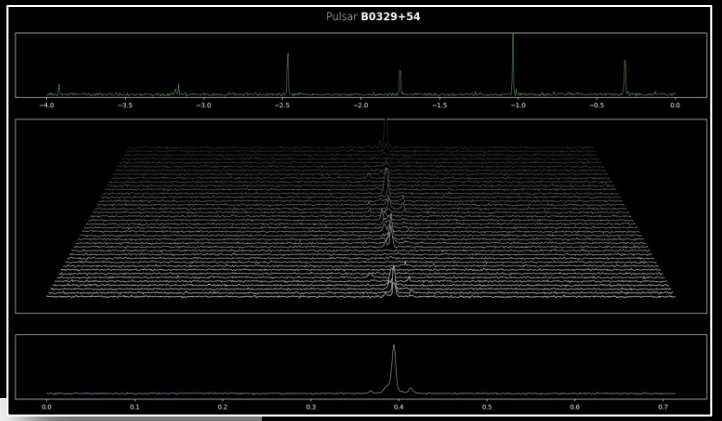

High-speed recording
Top line - pulsed emission detected
Bottom line – one second time pe ses
18

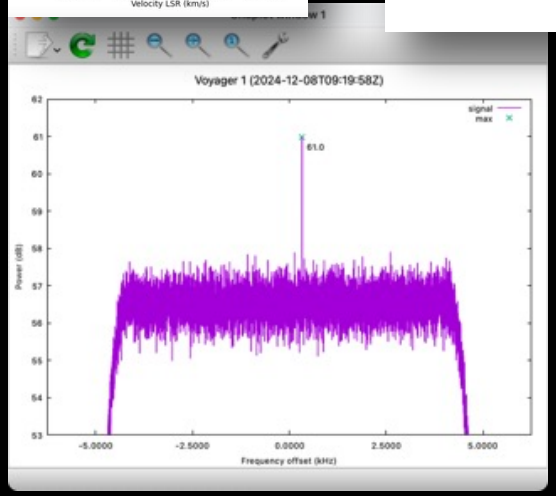


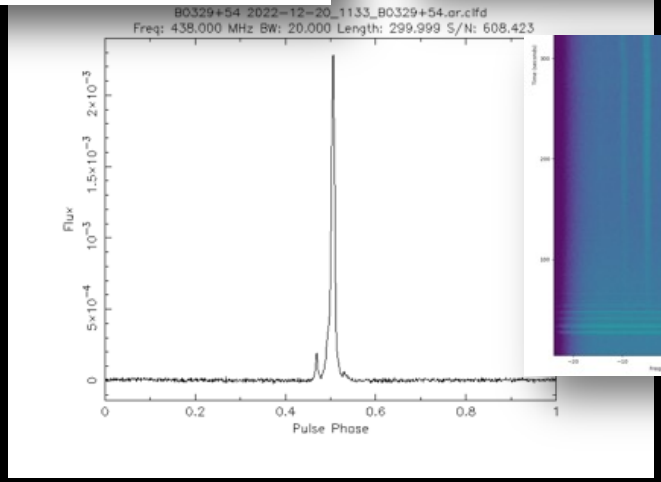
Figuur 18: C.A.Muller in waarneemkamer van de 25 meter radiotelescoop.

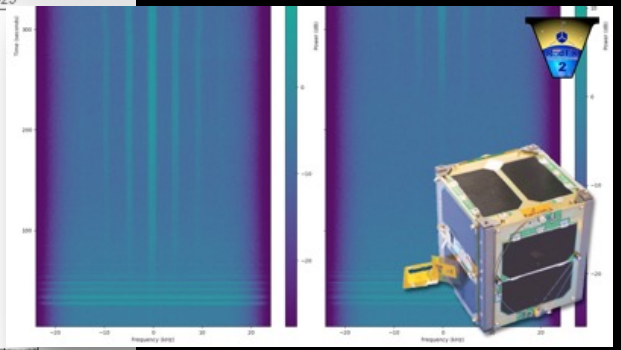

Omega Nebula (M17)
H171α (1303.718 MHz)
H170α (1326.792 MHz)
H167α (1399.368 MHz)
H166α (1424.734 MHz)
Power (uncal.)
Velocity LSR (km/s)

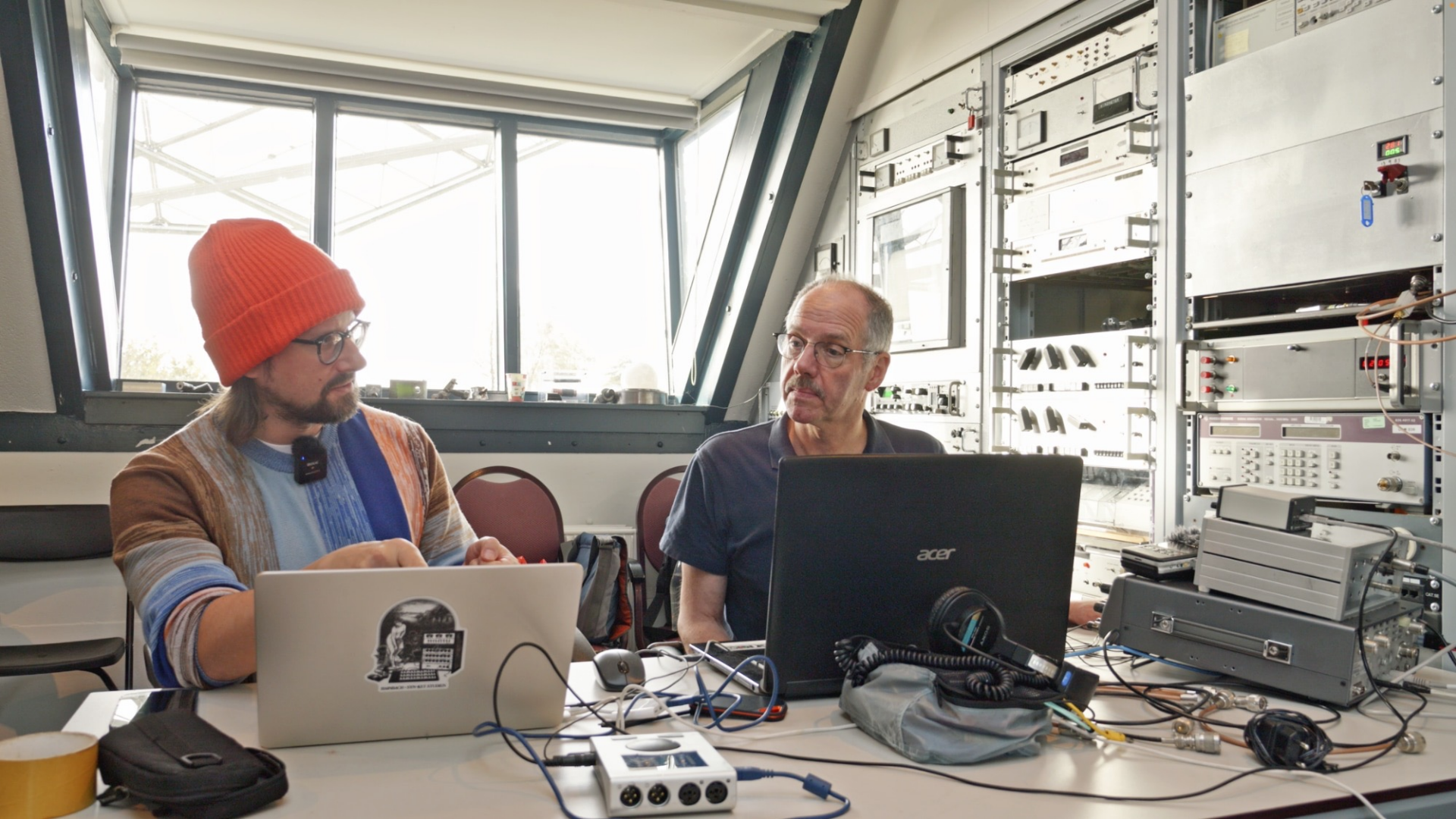

S7, Stockert/Dwingeloo 17/23 Sep 2023
LAB
B210 Dwingeloo
AFFTS Stockert
1e9


Pulsar B0329+54


Voyager 1 (2024-12-08T09:19:58Z)
signal
max
61.0
Power (dB)
Frequency offset (kHz)


B0329+54 2022-12-20_1133_B0329+54.ar.clfd
Freq: 438.000 MHz BW: 20.000 Length: 299.999 S/N: 608.423
Flux
Pulse Phase




acer

THE ASTRONOMICAL JOURNAL VOLUME 72, NUMBER 3 APRIL 1967

Radar Determination of the Rotations of Venus and Mercury

R. B. Dyce and G. H. Pettengill*
Cornell–Sydney University Astronomy Center, Arecibo Ionospheric Observatory,† Arecibo, Puerto Rico

AND

I. I. Shapiro
Lincoln Laboratory,‡ Massachusetts Institute of Technology, Lexington, Massachusetts

(Received 16 September 1966)

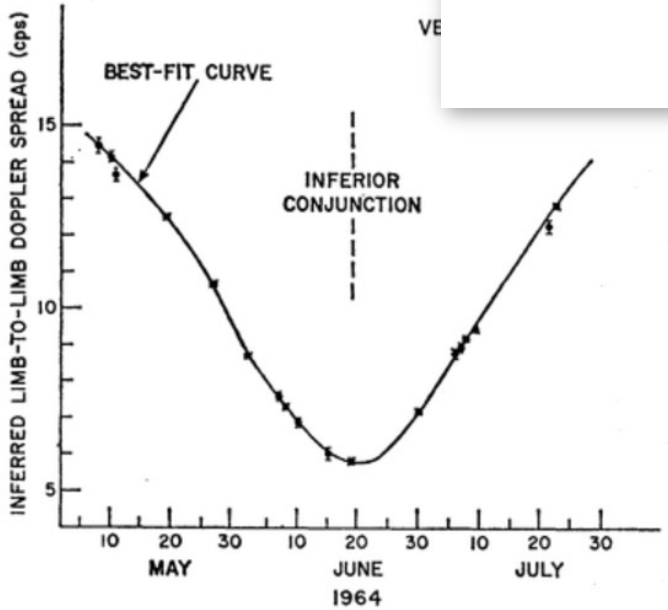
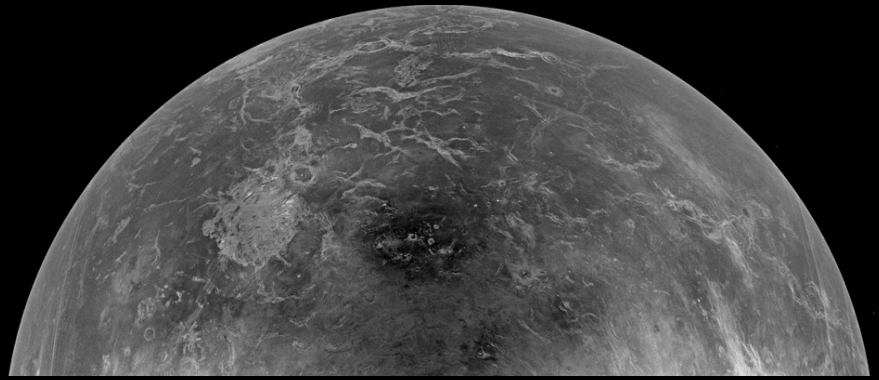
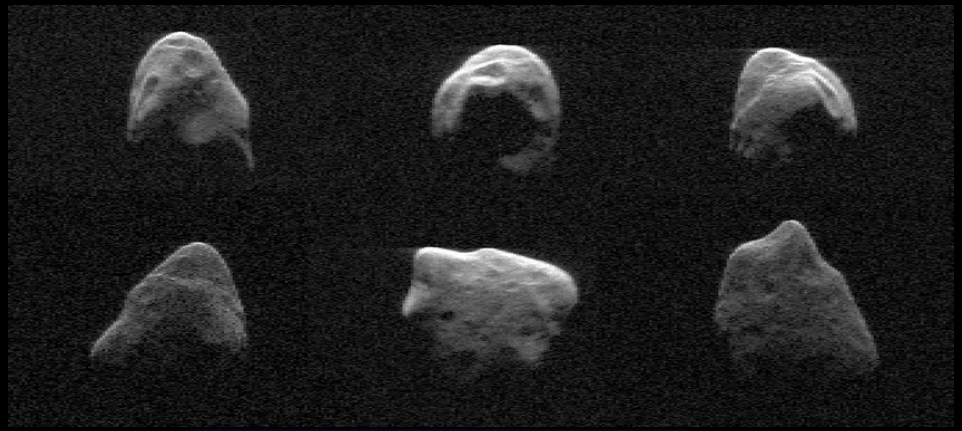


FIG. 2. Inferred limb-to-limb Doppler spread vs date for observations of Venus taken at the Arecibo Ionospheric Observatory during 1964. The solid curve represents the least-mean-square fit to the data and corresponds to a rotation period of 245.1±2 days and a rotation axis inclined by −89.8±1 deg to the ecliptic.

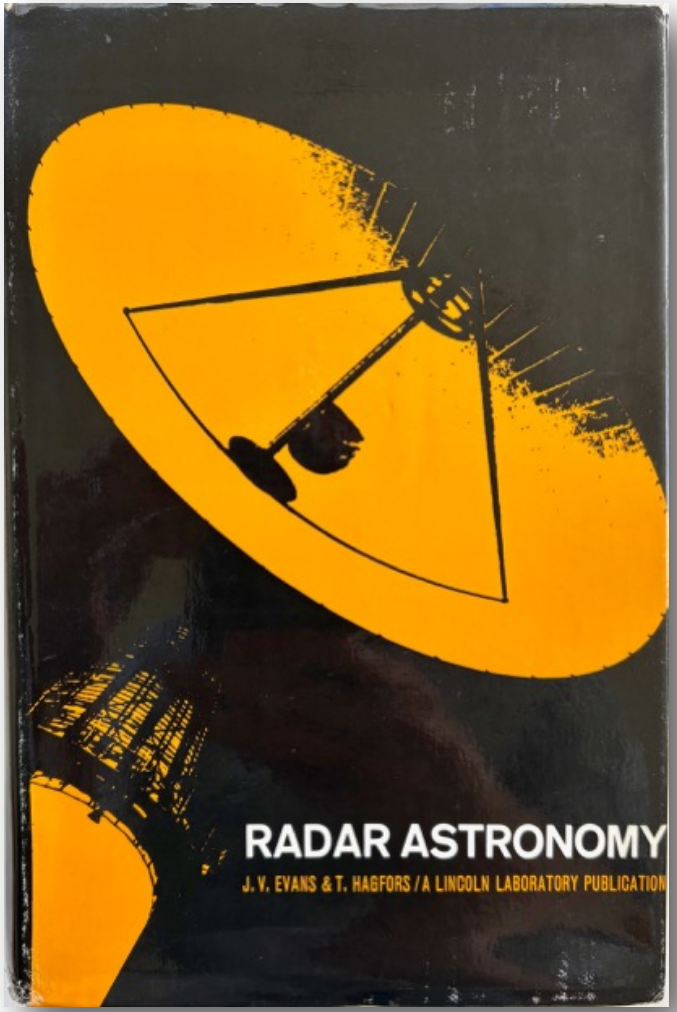


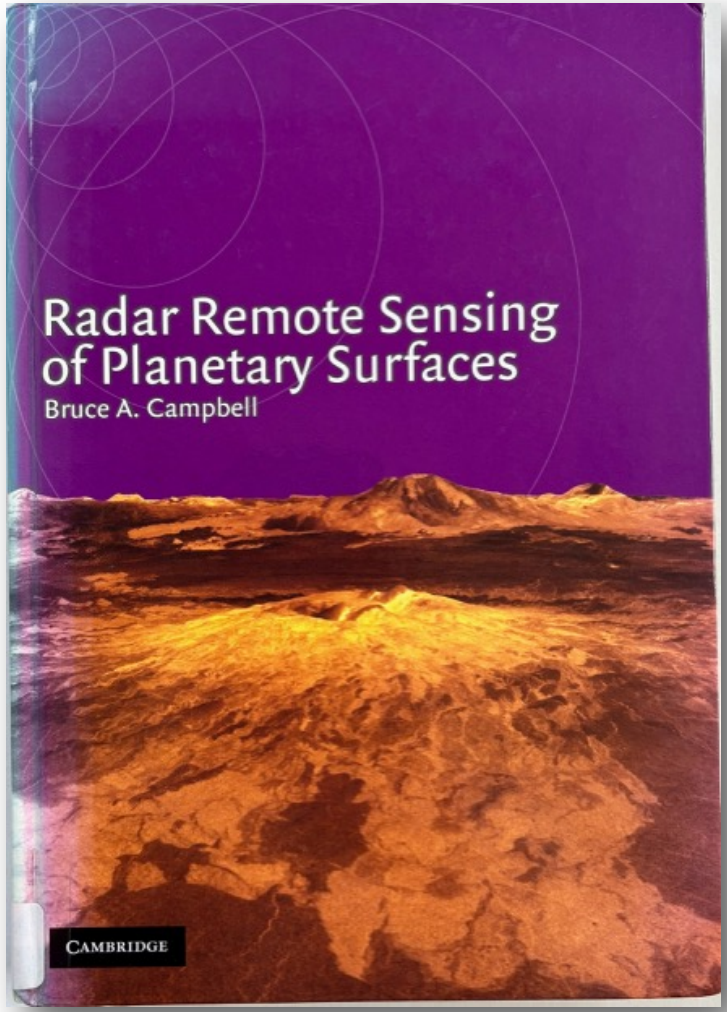




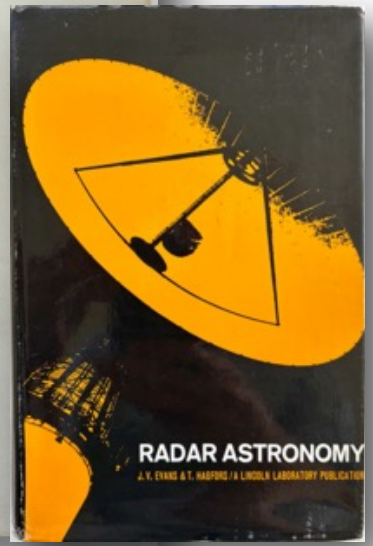


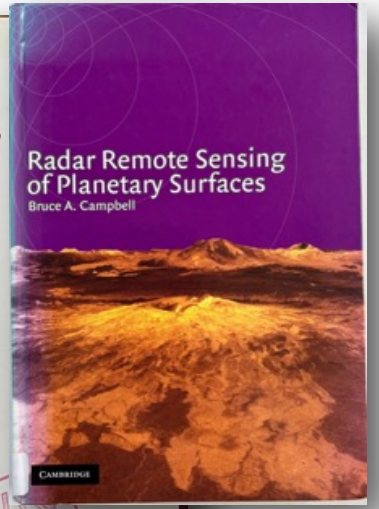



RADAR ASTRONOMY
J. V. EVANS & T. HAGFORS / A LINCOLN LABORATORY PUBLICATION


Radar Remote Sensing
of Planetary Surfaces
Bruce A. Campbell
CAMBRIDGE







RADAR REMOTE SENSING OF PLANETARY SURFACES

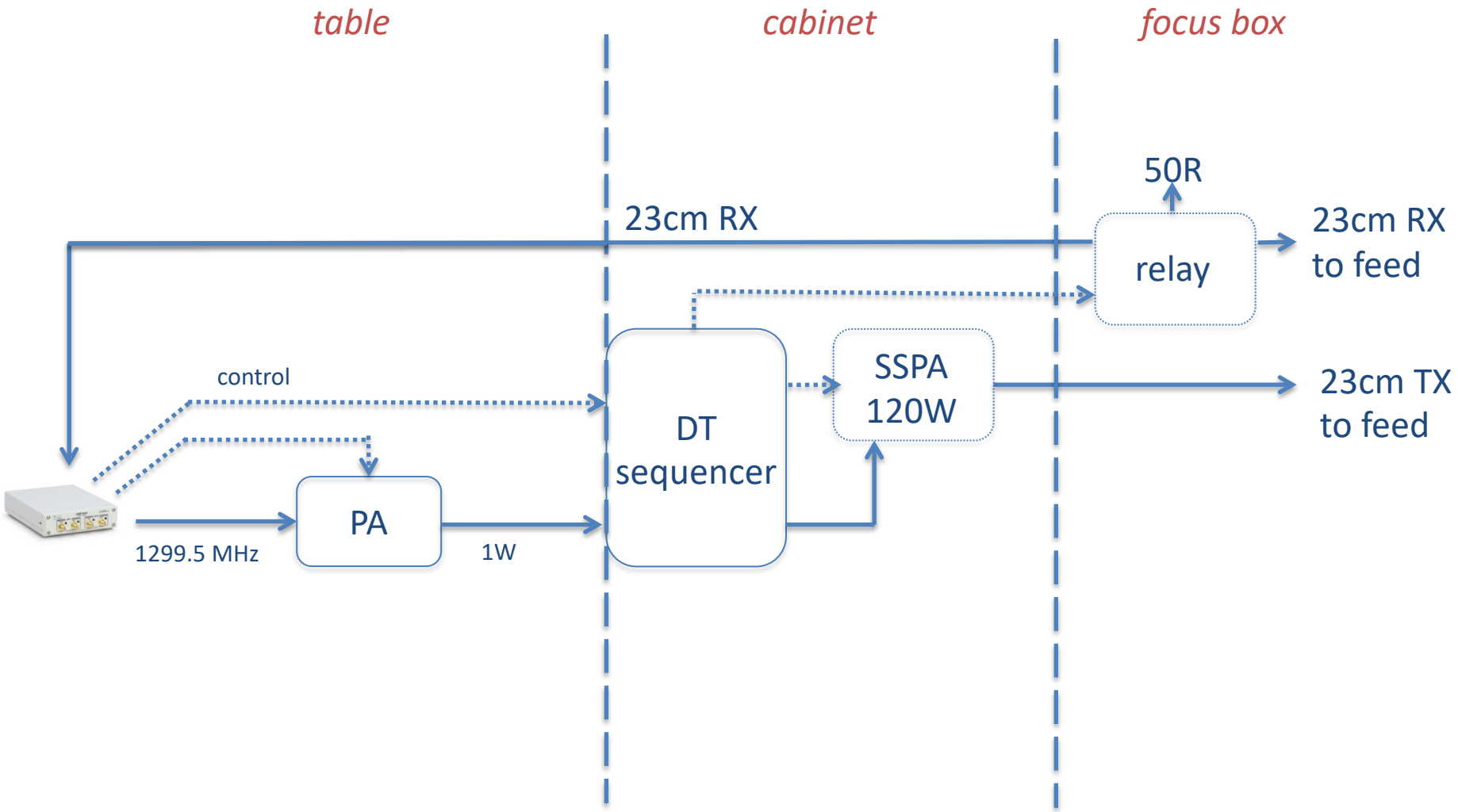
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Radar equation

$$P_{rx} = \frac{P_{tr} G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$


table
cabinet
focus box
50R
23cm RX
relay
23cm RX
to feed
control
DT
sequencer
SSPA
120W
23cm TX
to feed
PA
1299.5 MHz
1W

Dwingeloo







Stockert



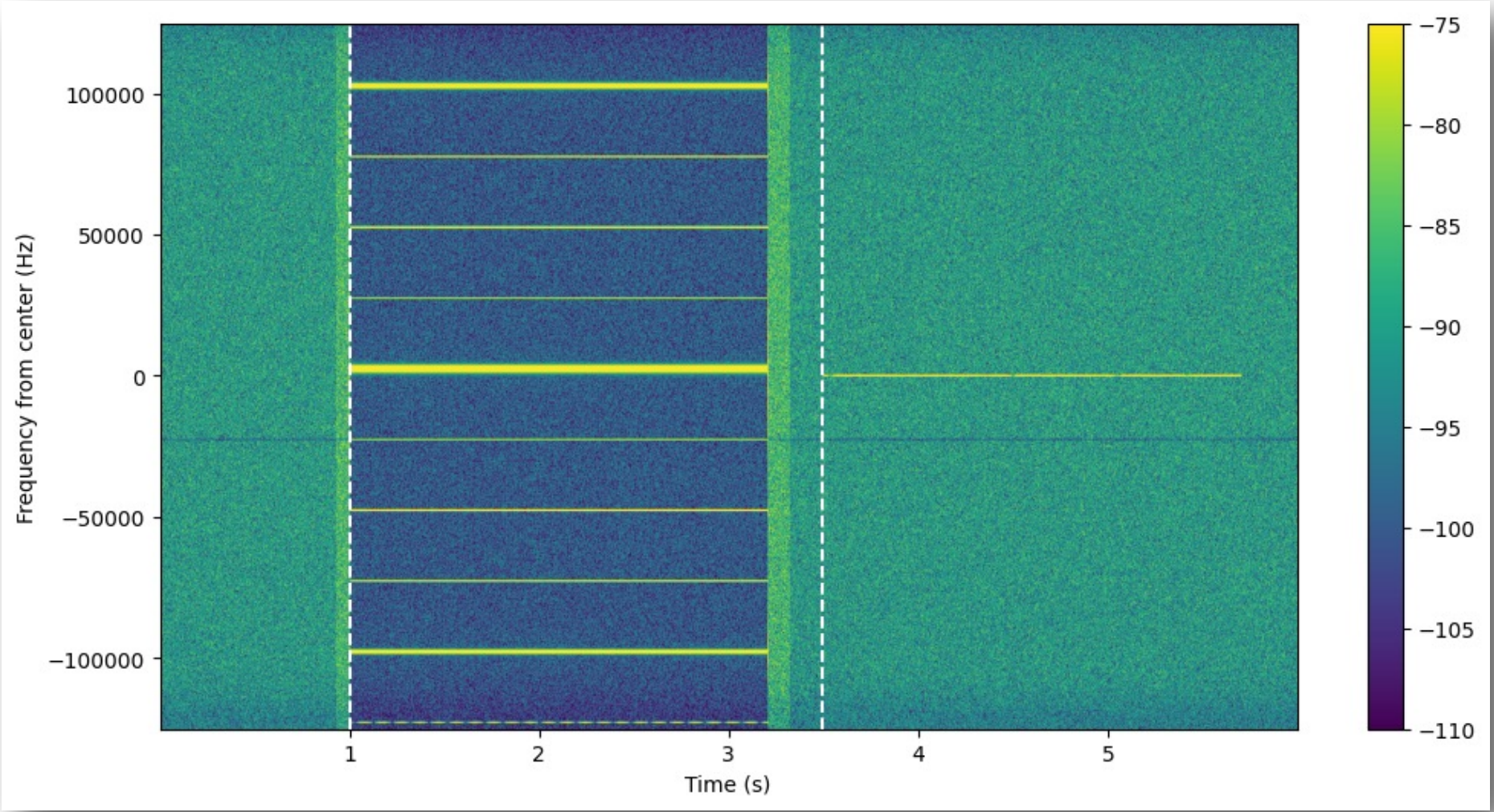


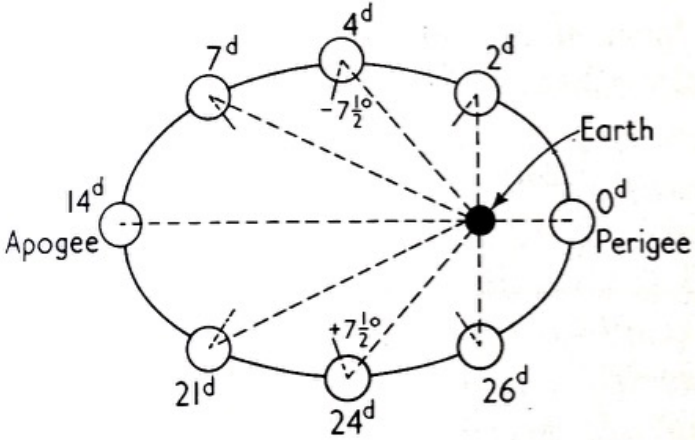
zadoff-chu-2000-556007-10301-0-278-1.sigmf-data

play_sigmf → usrp_to_vrt → vrt_to_sigmf

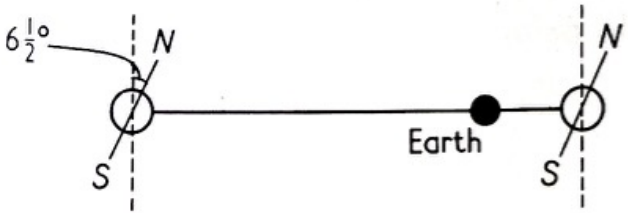
usrp_to_vrt → vrt_to_sigmf

dwingeloo_eve_2025_03_22_11_51_00_1299.500MHz_1.00Msps_ci16_le.sigmf-data
stockert_eve_2025_03_22_11_56_00_1299.500MHz_1.00Msps_ci16_le.chan0.sigmf-data
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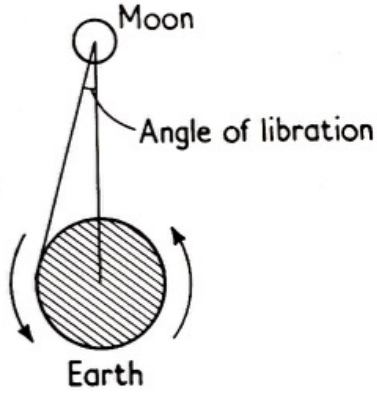

Frequency from center (Hz)
100000
50000
0
−50000
−100000
1
2
3
4
5
Time (s)
−75
−80
−85
−90
−95
−100
−105
−110



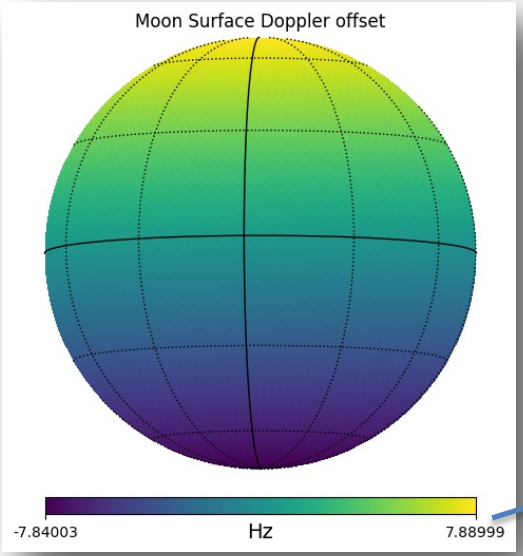
(a) Libration in longitude (plan)

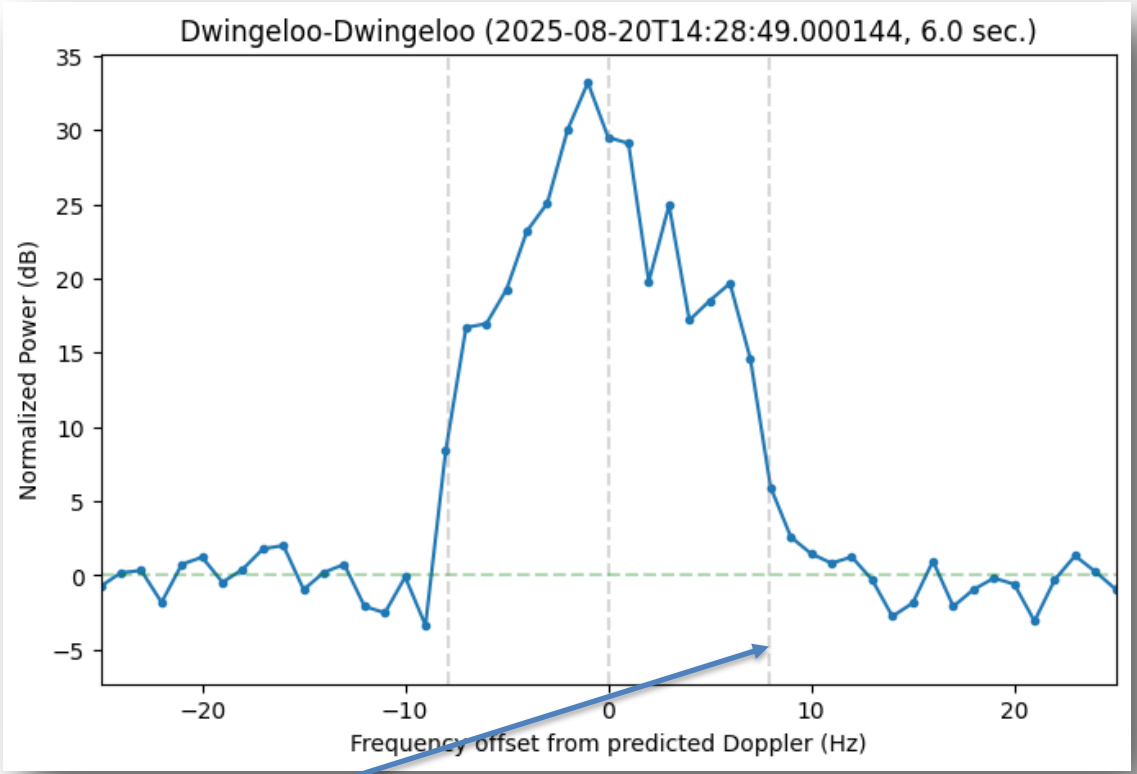


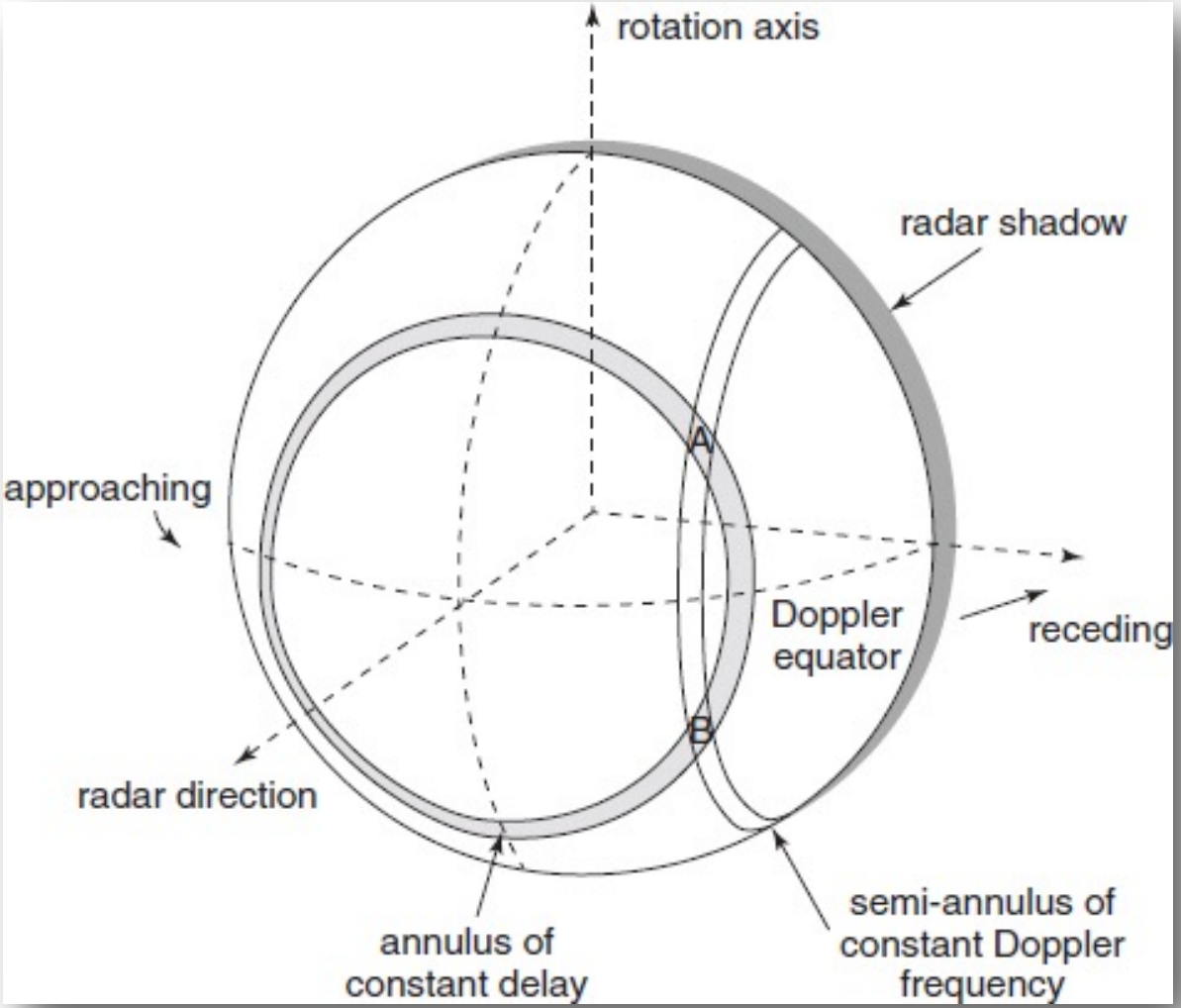
(b) Libration in latitude (elevation)



(c) Diurnal libration


Moon Surface Doppler offset
-7.84003
Hz
7.88999


Dwingeloo-Dwingeloo (2025-08-20T14:28:49.000144, 6.0 sec.)
Normalized Power (dB)
35
30
25
20
15
10
5
0
−5
−20
−10
0
10
20
Frequency offset from predicted Doppler (Hz)


rotation axis
radar shadow
approaching
A
B
Doppler
equator
receding
radar direction
annulus of
constant delay
semi-annulus of
constant Doppler
frequency

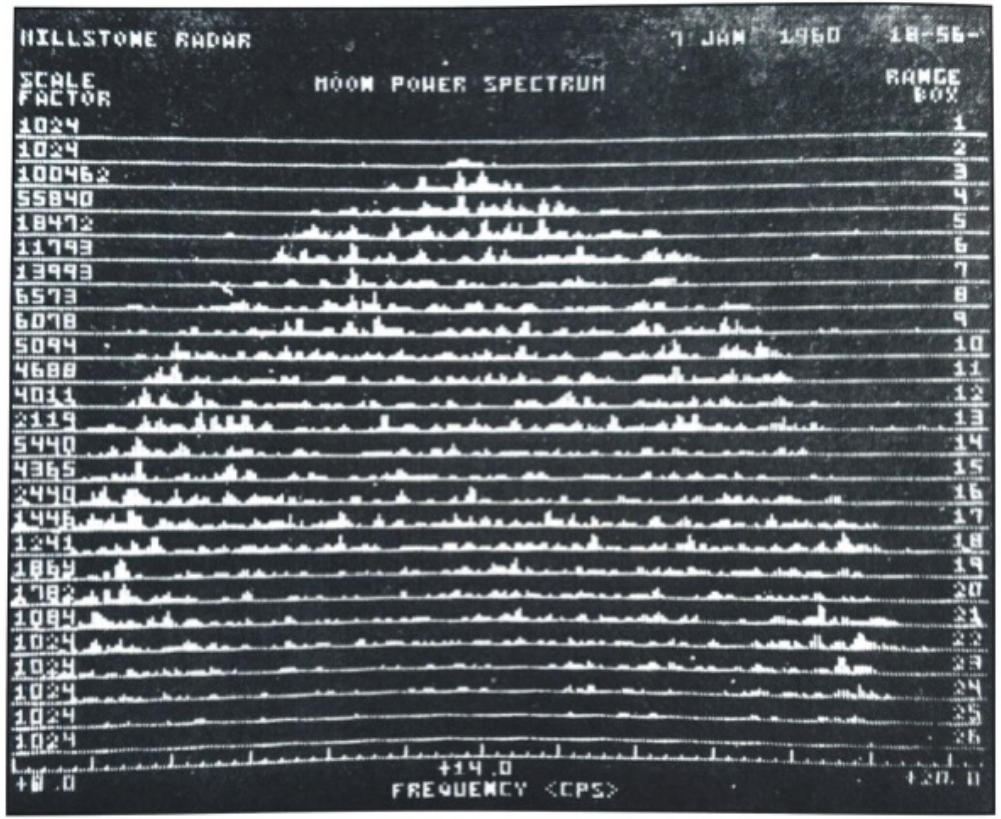
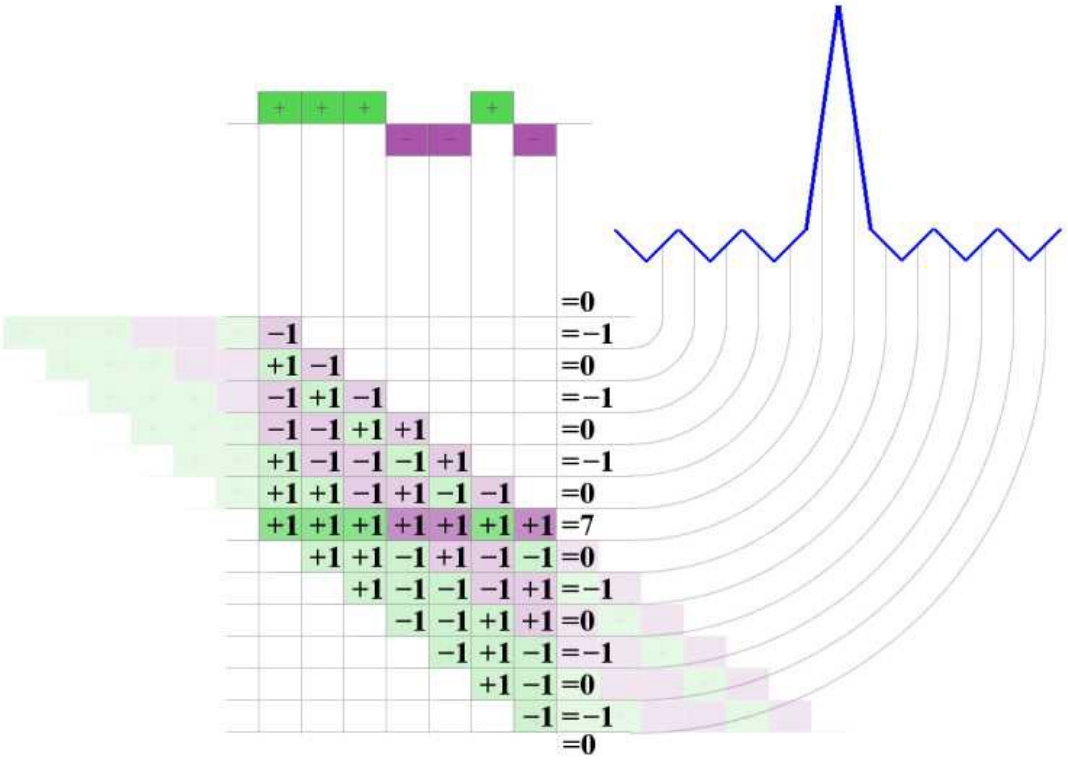
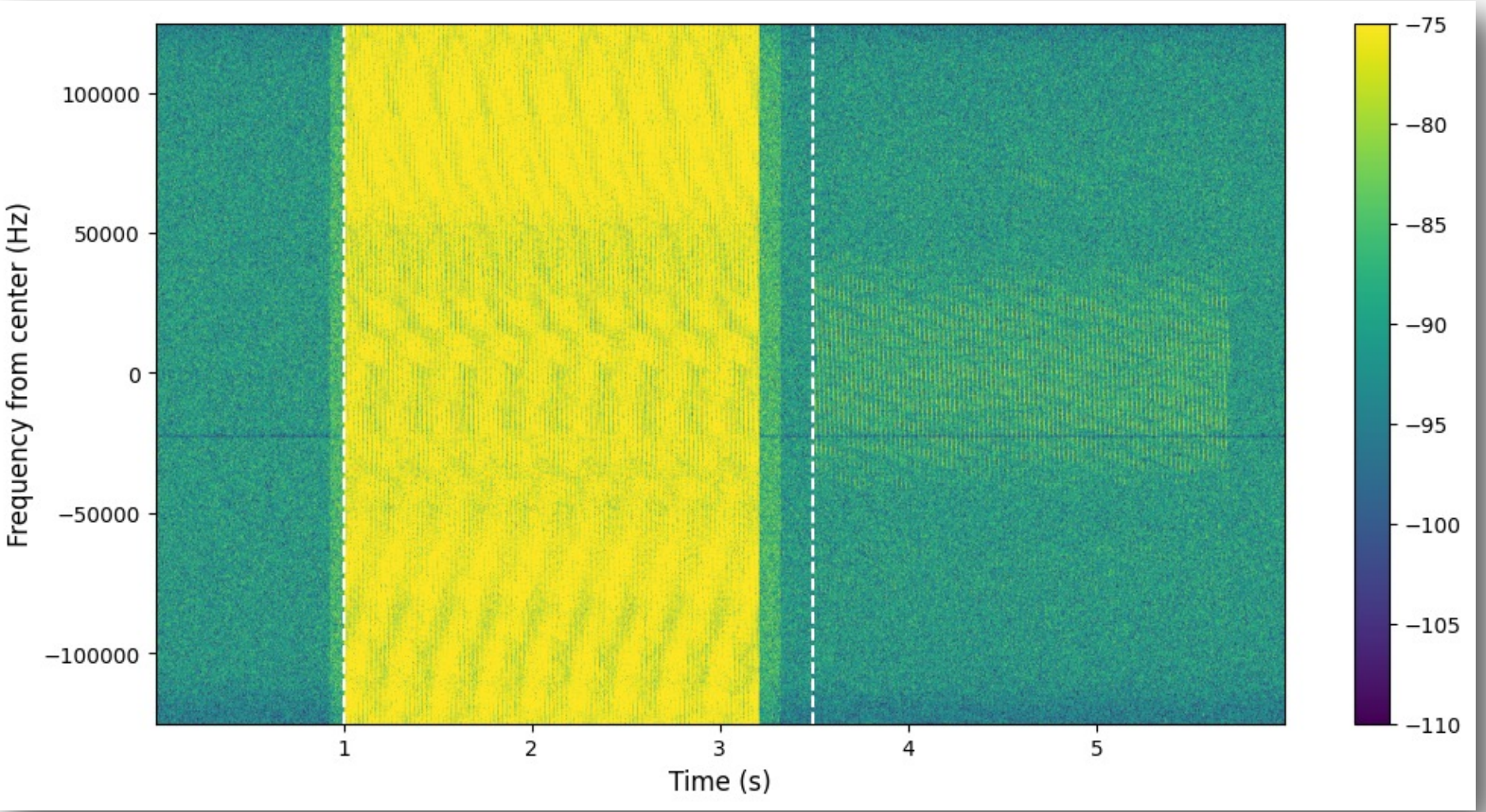


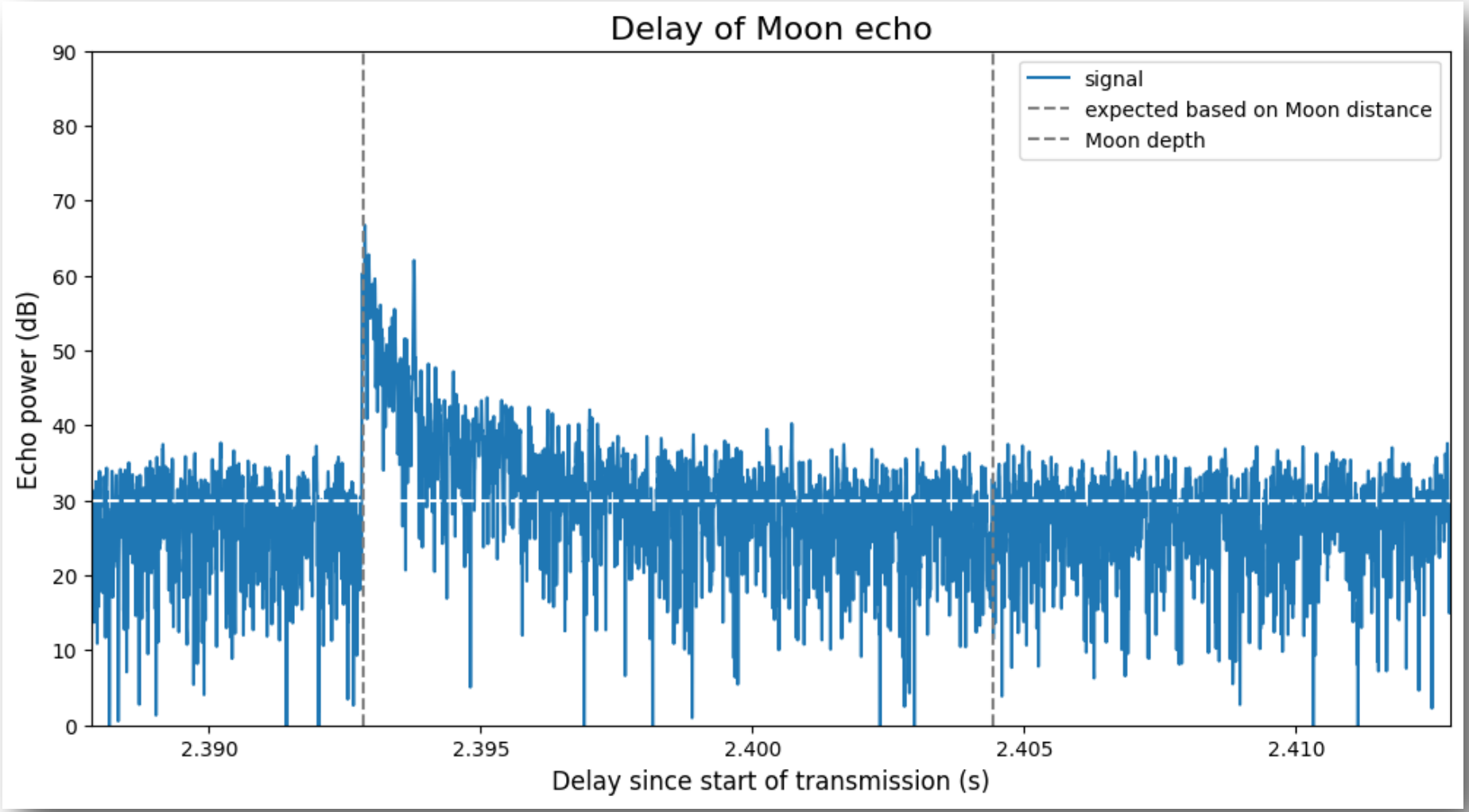
Figure 16

The first range-Doppler image of the Moon, 7 January 1960, made by Gordon Pettengill, using techniques developed by his Lincoln Laboratory colleague Paul Green. The top of the image (shown in range box 2) represents the point on the lunar surface closest to the radar. Pettengill, as the first associate director of the Arecibo Ionospheric Observatory, as it was then called, later guided range-Doppler imaging of the Moon and planets at Arecibo as well as at the Haystack Observatory. (Courtesy of MIT Lincoln Laboratory, Lexington, Massachusetts, photo no. 261209-1D.)

Pulse compression




Frequency from center (Hz)
100000
50000
0
−50000
−100000
1
2
3
4
5
Time (s)
−75
−80
−85
−90
−95
−100
−105
−110


Delay of Moon echo
signal
expected based on Moon distance
Moon depth
Echo power (dB)
0
10
20
30
40
50
60
70
80
90
2.390
2.395
2.400
2.405
2.410
Delay since start of transmission (s)

Zadoff-Chu sequence

frequency shift
of complex signal

$$f'(t) = f(t)e^{i\pi f_\Delta t}$$

ambiguity

The complex value at each position *n* of each root Zadoff–Chu sequence parametrised by *u* is given by

$$x_u(n) = \exp\left(-j\frac{\pi un(n + c_\mathrm{f} + 2q)}{N_\mathrm{ZC}}\right),$$

where

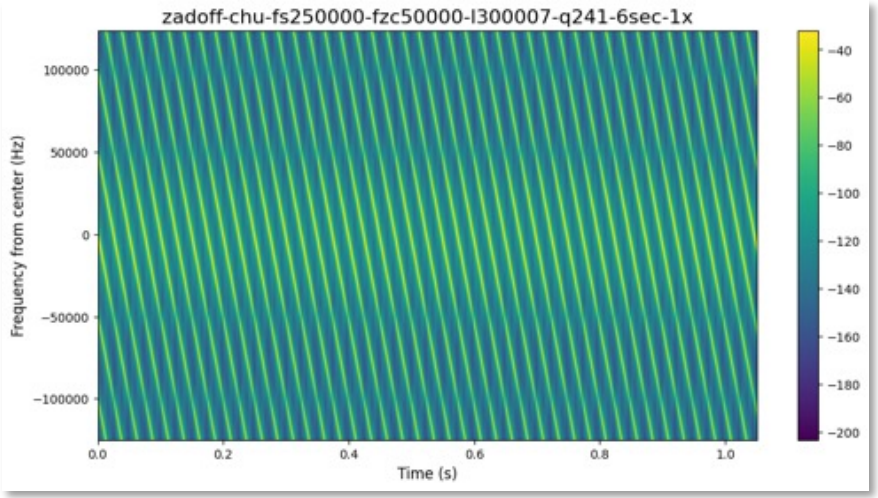
$$0 \leq n < N_\mathrm{ZC}\,,$$

$$0 < u < N_\mathrm{ZC} \text{ and } \gcd(N_\mathrm{ZC}, u) = 1,$$

$$c_\mathrm{f} = N_\mathrm{ZC} \mod 2\,,$$

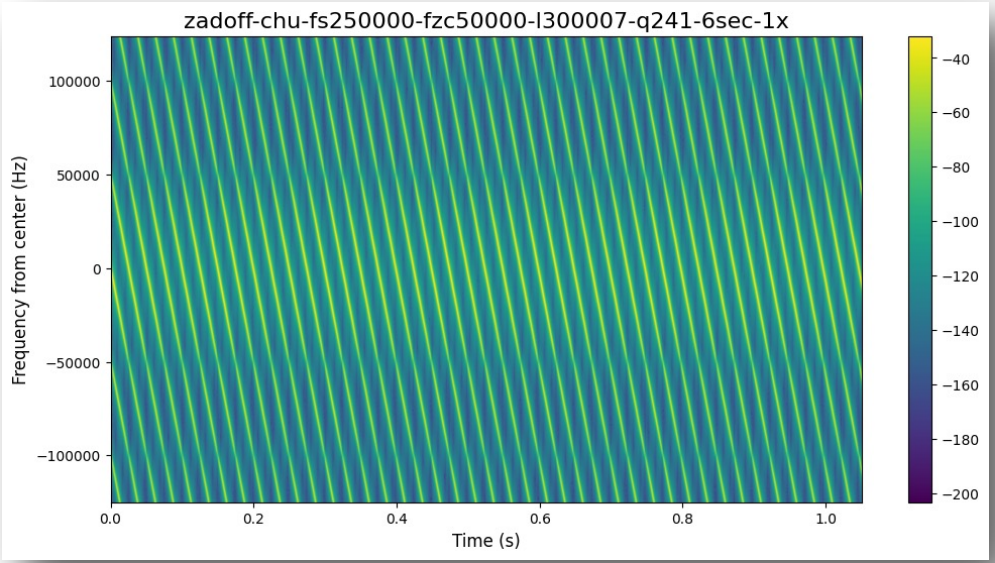
$$q \in \mathbb{Z},$$

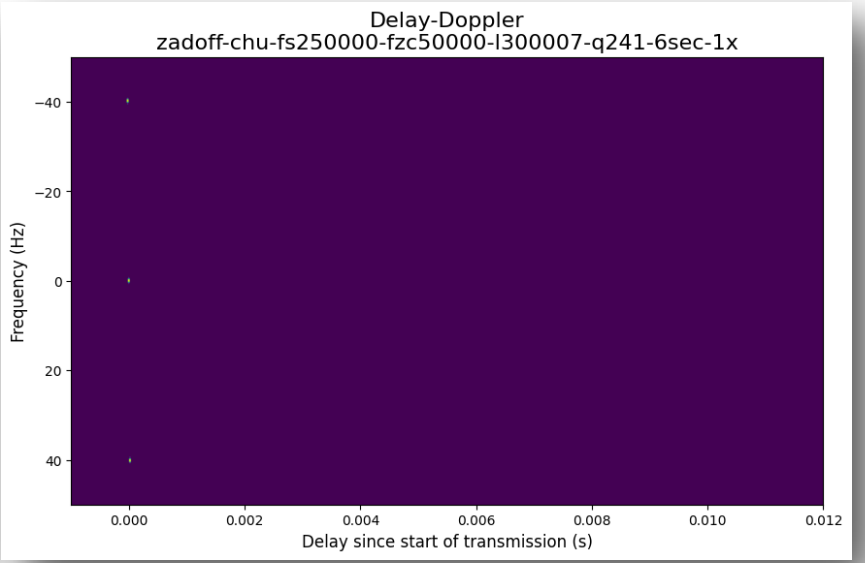
$$N_\mathrm{ZC} = \text{length of sequence}\,.$$

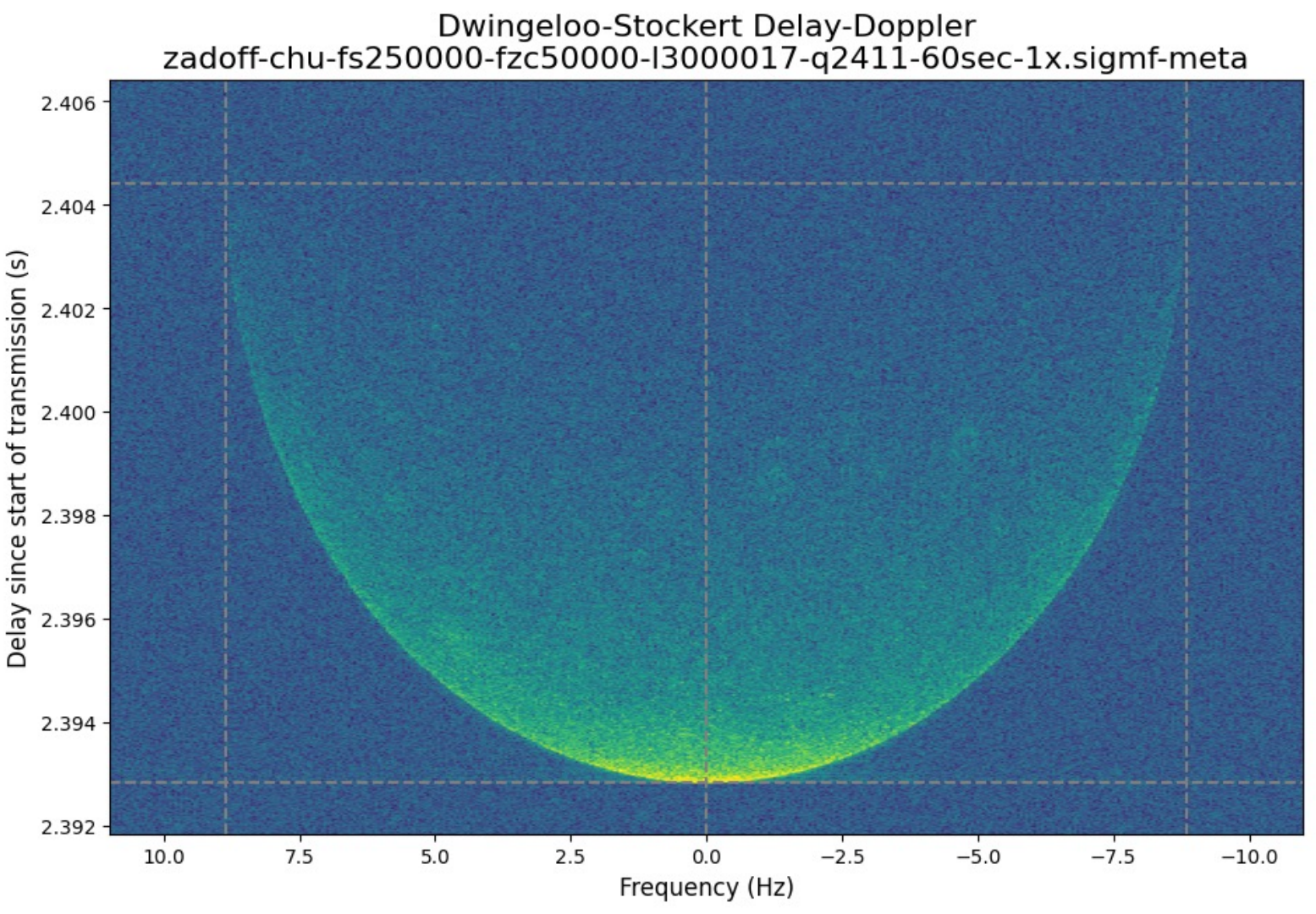


The auto correlation of a Zadoff–Chu sequence with a cyclically shifted version of itself is zero, i.e., it is non-zero only at one instant which corresponds to the cyclic shift.

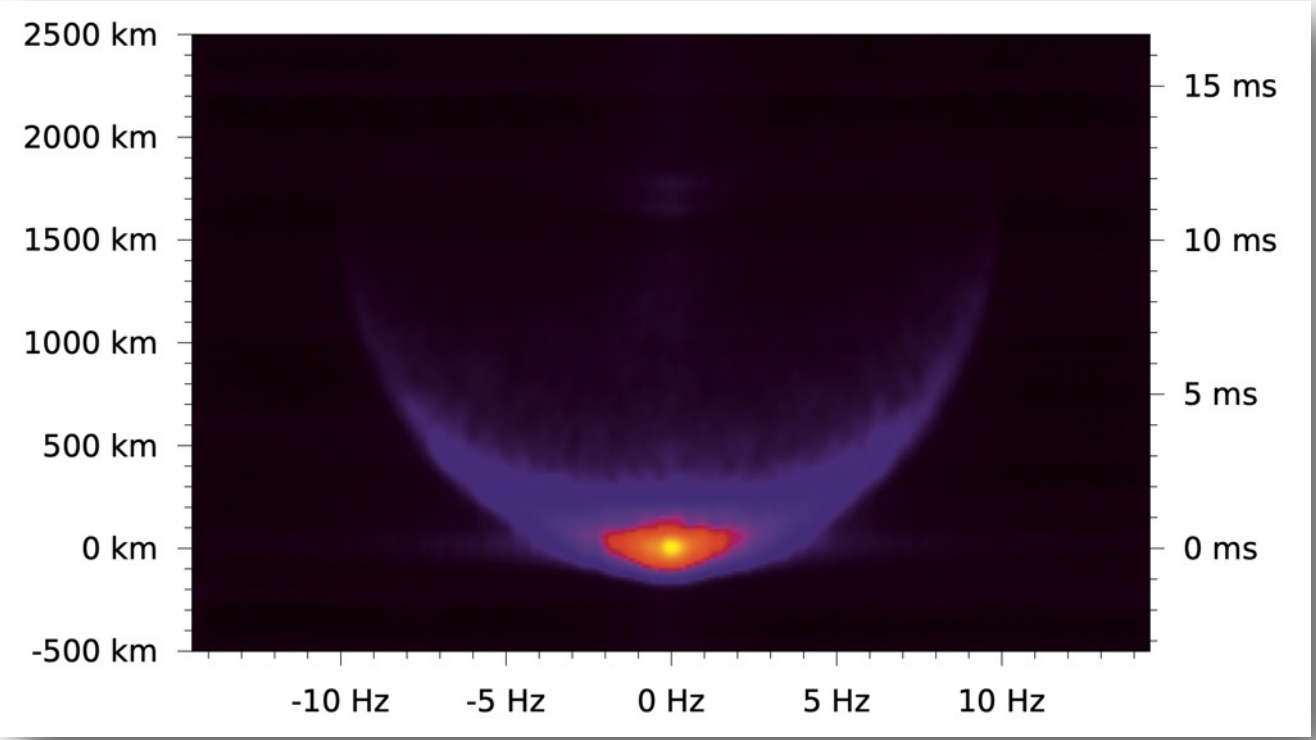
Zadoff-Chu sequence





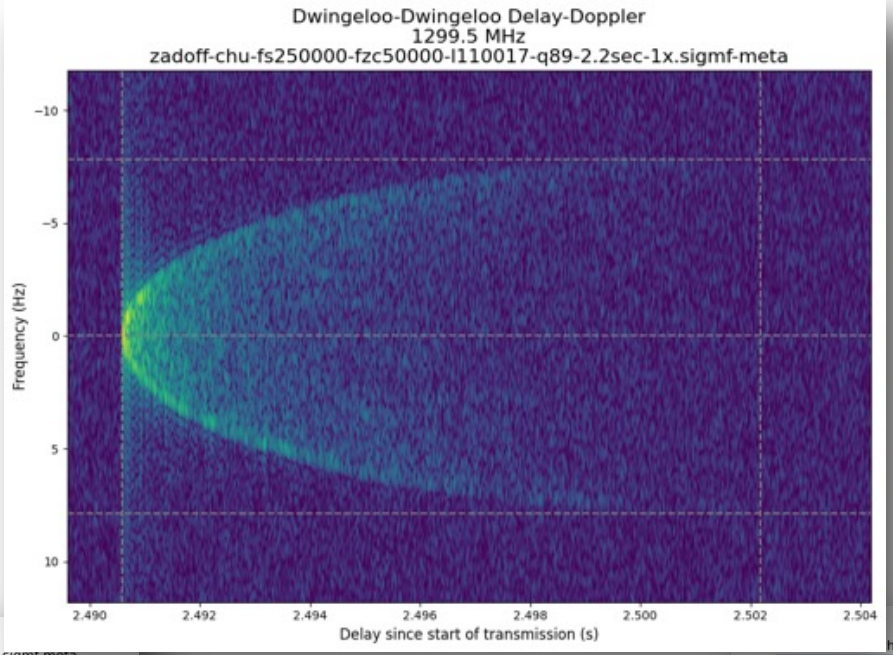

Dwingeloo-Stockert Delay-Doppler
zadoff-chu-fs250000-fzc50000-l3000017-q2411-60sec-1x.sigmf-meta
Delay since start of transmission (s)
2.406
2.404
2.402
2.400
2.398
2.396
2.394
2.392
10.0
7.5
5.0
2.5
0.0
−2.5
−5.0
−7.5
−10.0
Frequency (Hz)

Dwingeloo Delay-Doppler

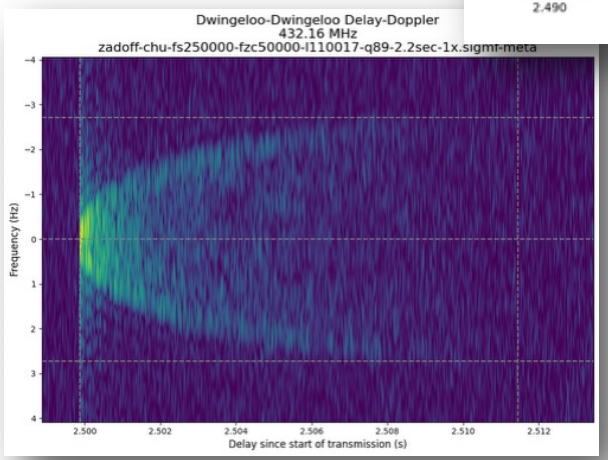


Pieter-Tjerk de Boer, 2011

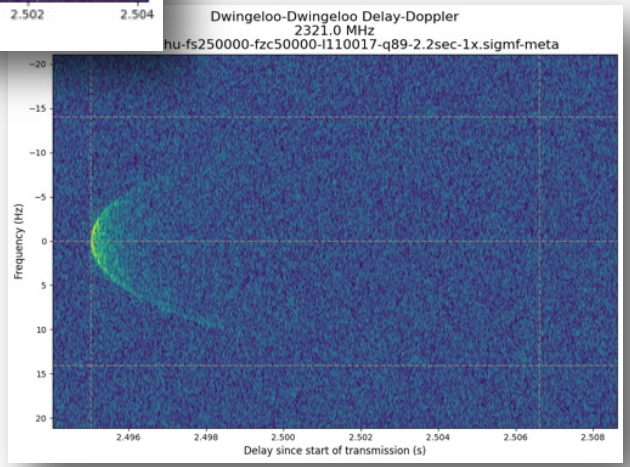
23cm



70cm

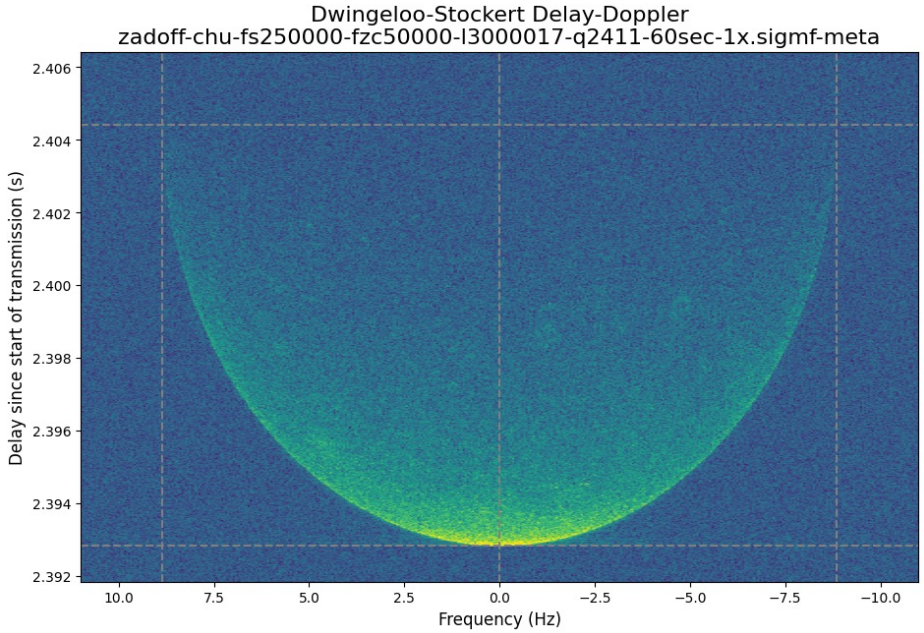


13cm

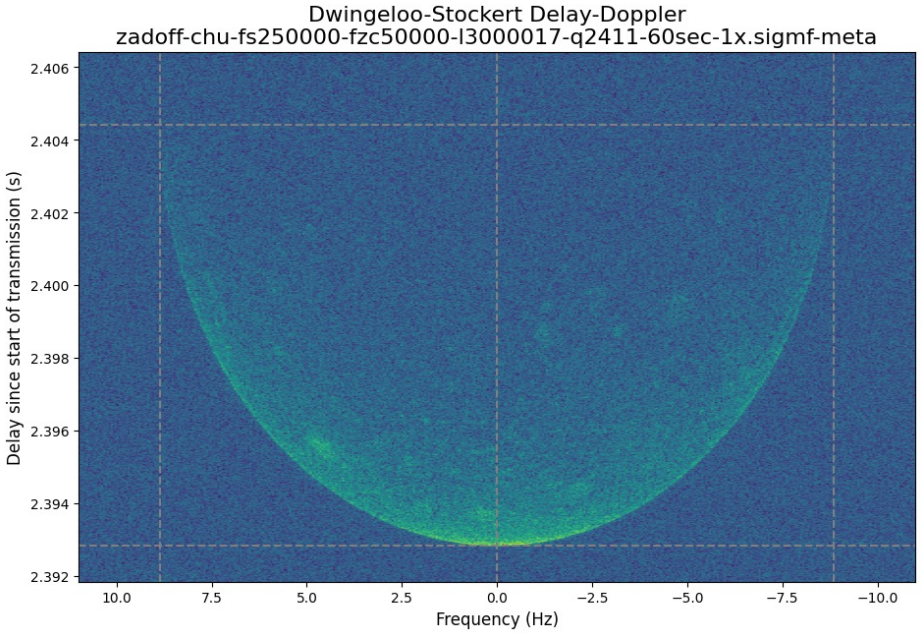


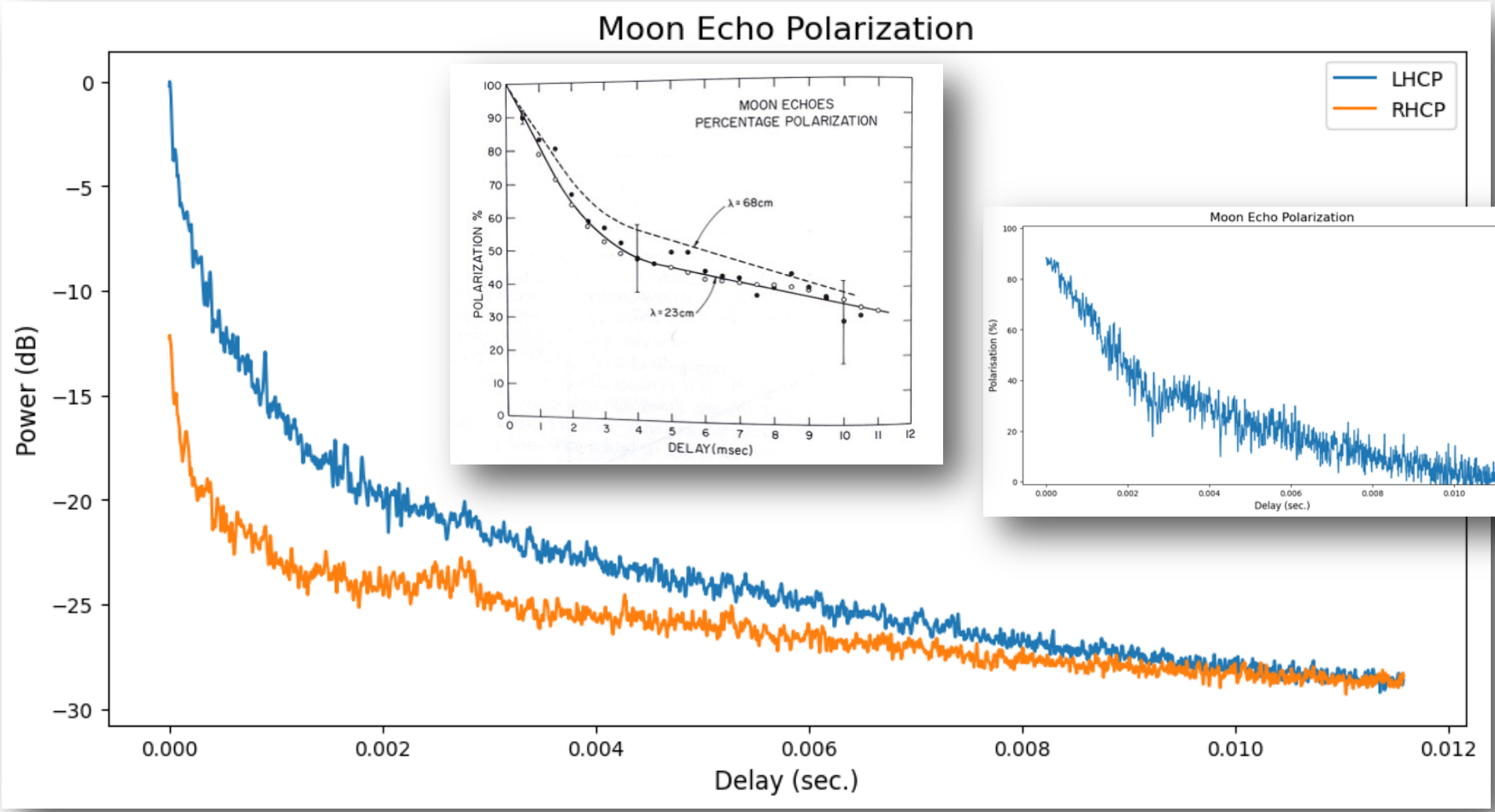
RHCP transmission

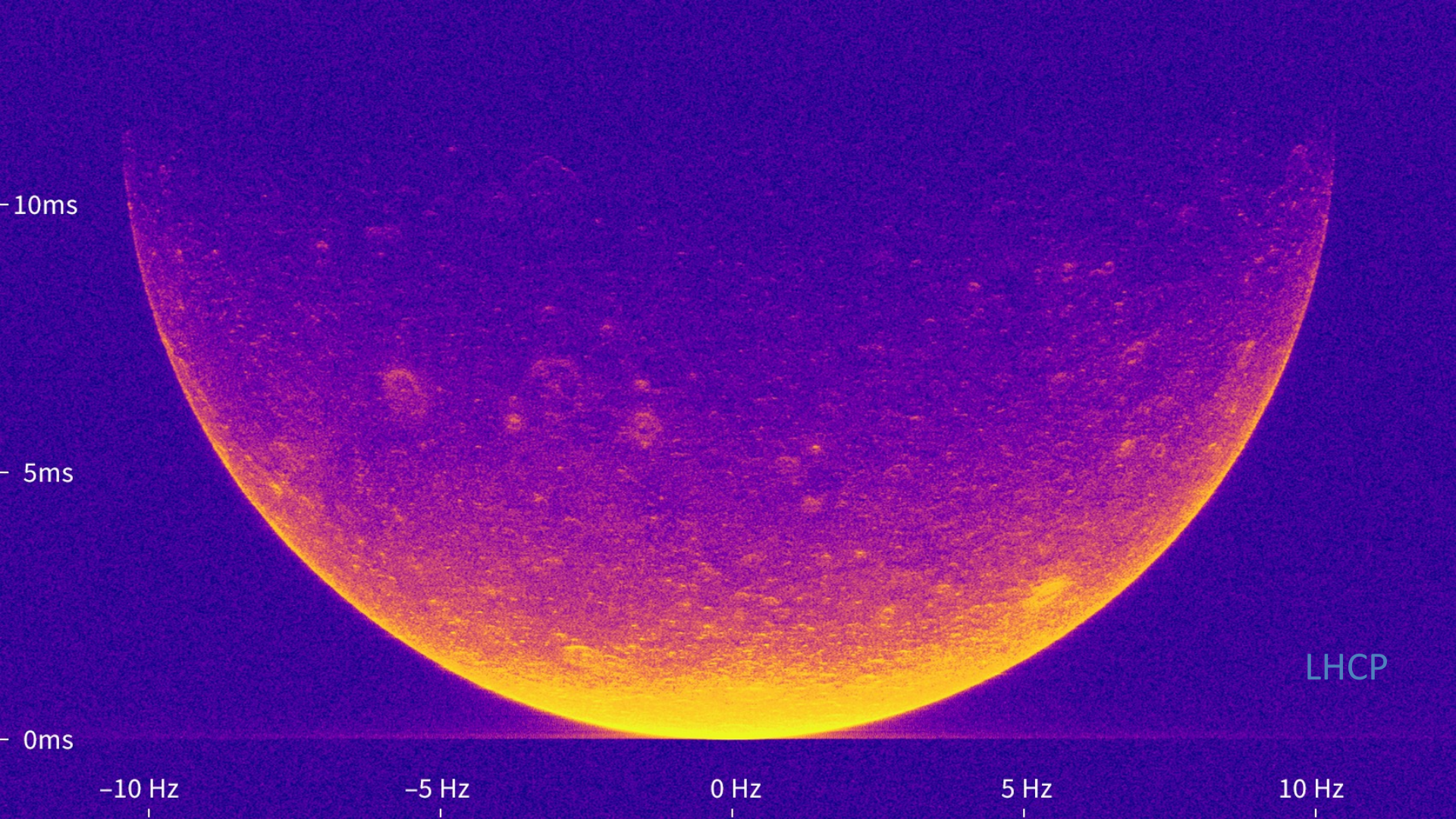
LHCP reception

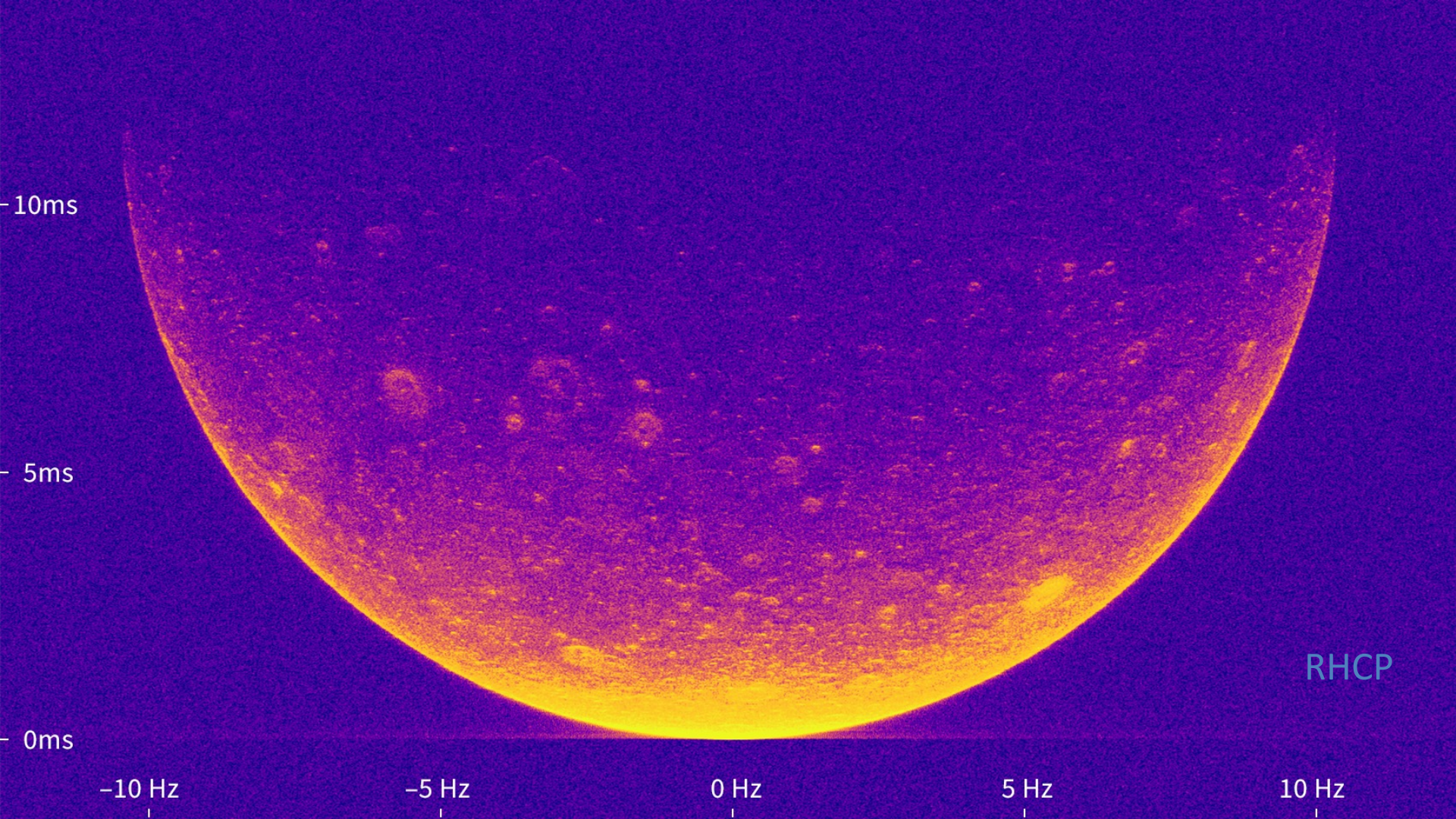


RHCP reception

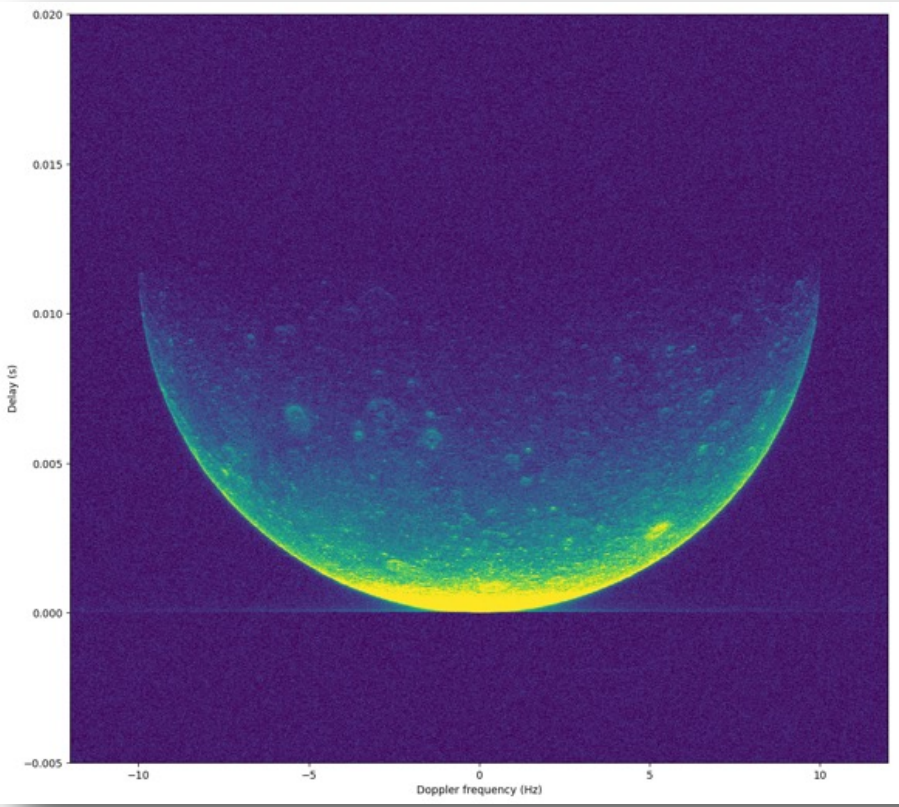


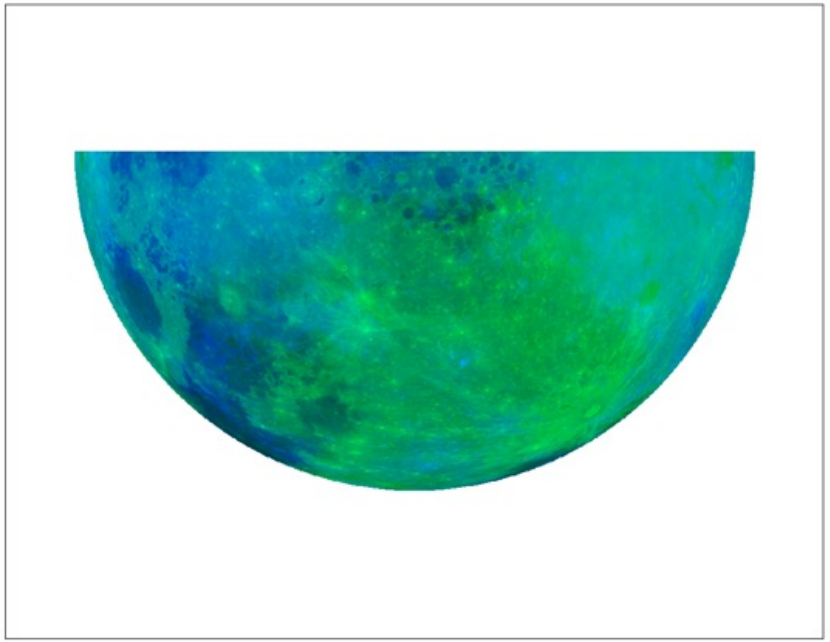

Moon Echo Polarization
LHCP
RHCP
Power (dB)
0
−5
−10
−15
−20
−25
−30
0.000
0.002
0.004
0.006
0.008
0.010
0.012
Delay (sec.)
MOON ECHOES
PERCENTAGE POLARIZATION
POLARIZATION %
DELAY(msec)
λ=68cm
λ=23cm
Moon Echo Polarization
Polarisation (%)
Delay (sec.)

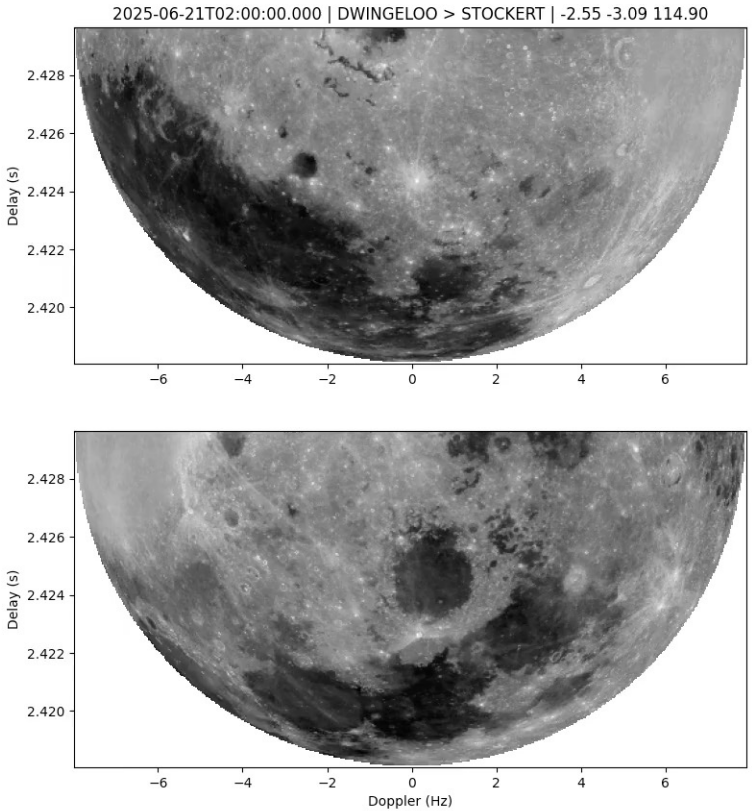

10ms
5ms
0ms
LHCP
−10 Hz
−5 Hz
0 Hz
5 Hz
10 Hz


10ms
5ms
0ms
RHCP
−10 Hz
−5 Hz
0 Hz
5 Hz
10 Hz

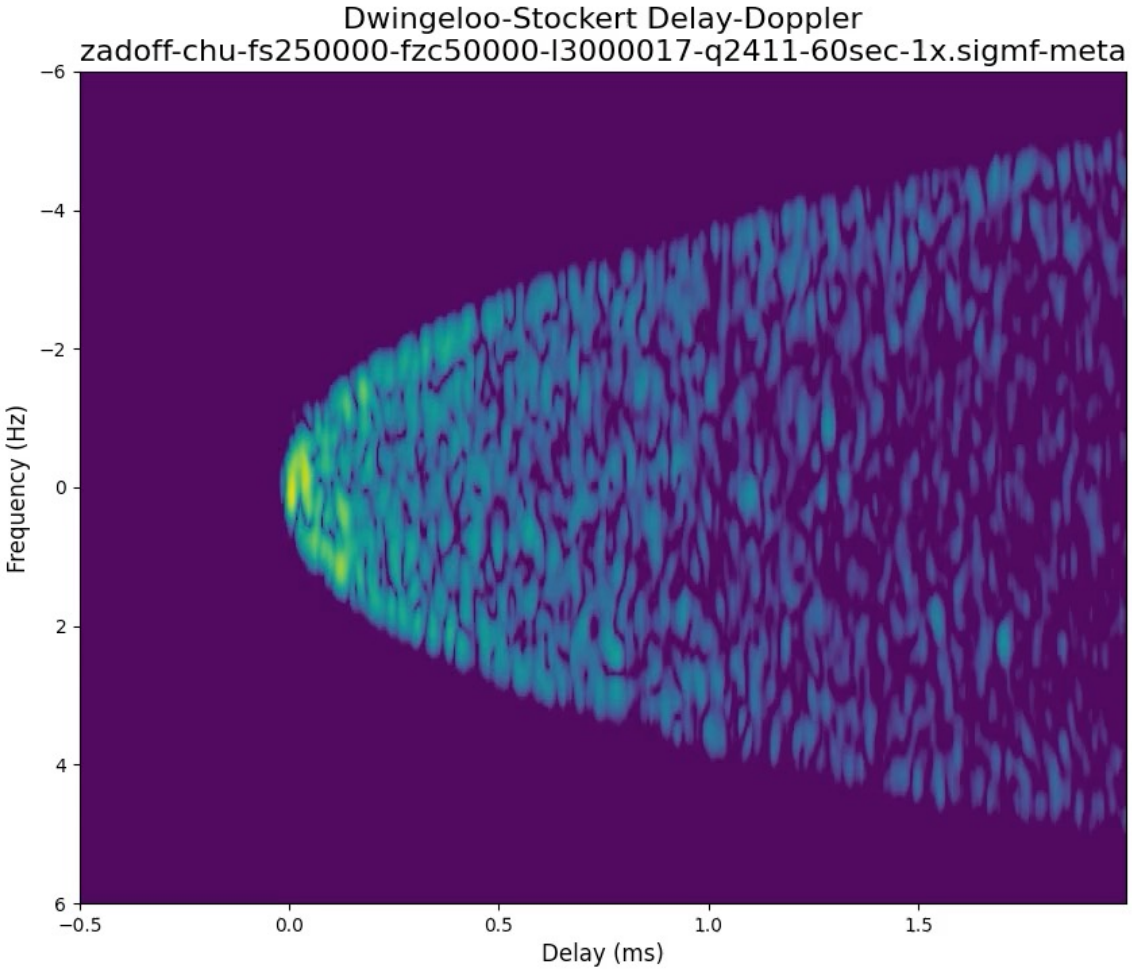
11x 30 sec. Dwingeloo-Stockert



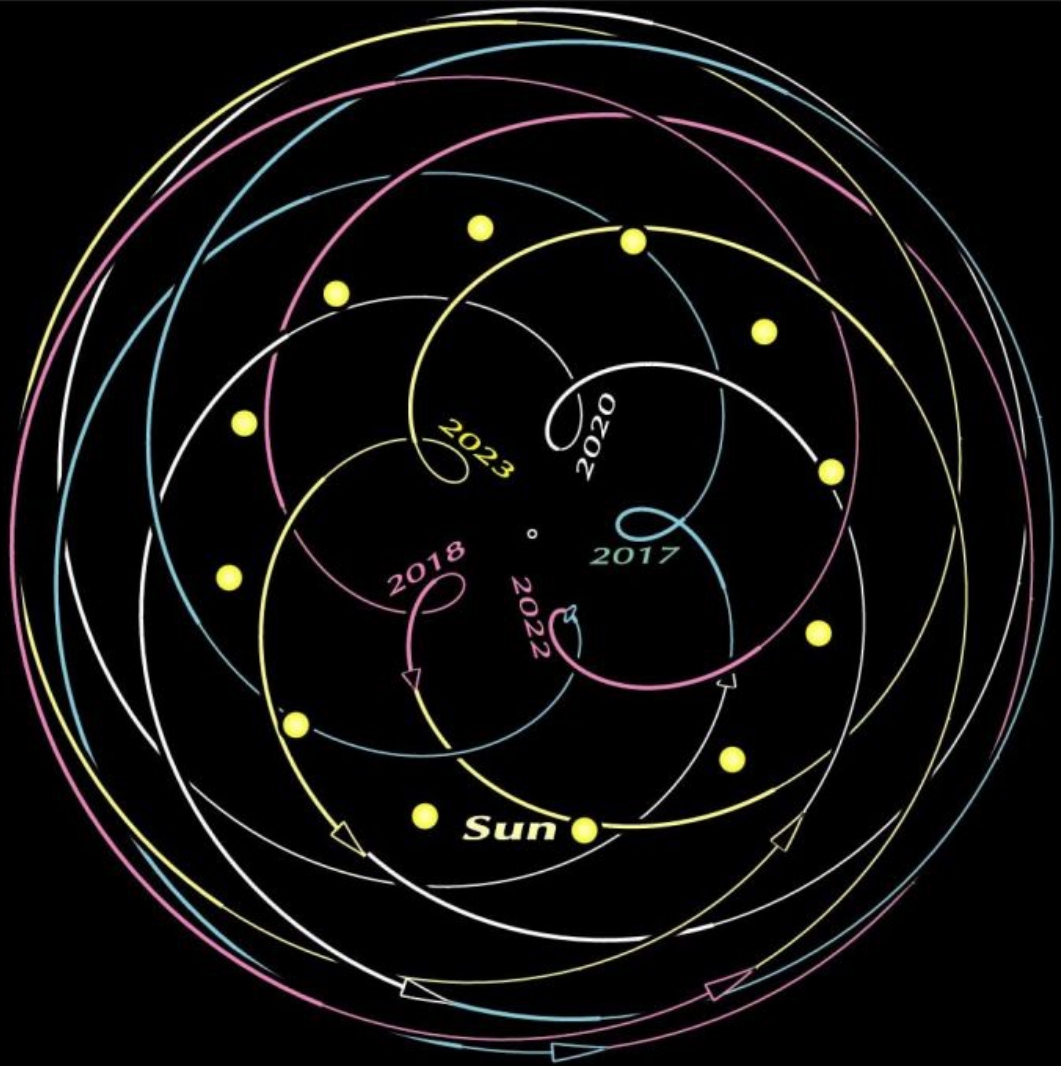



2025-06-21T02:00:00.000 | DWINGELOO > STOCKERT | -2.55 -3.09 114.90
Delay (s)
2.428
2.426
2.424
2.422
2.420
−6
−4
−2
0
2
4
6
Delay (s)
2.428
2.426
2.424
2.422
2.420
−6
−4
−2
0
2
4
6
Doppler (Hz)

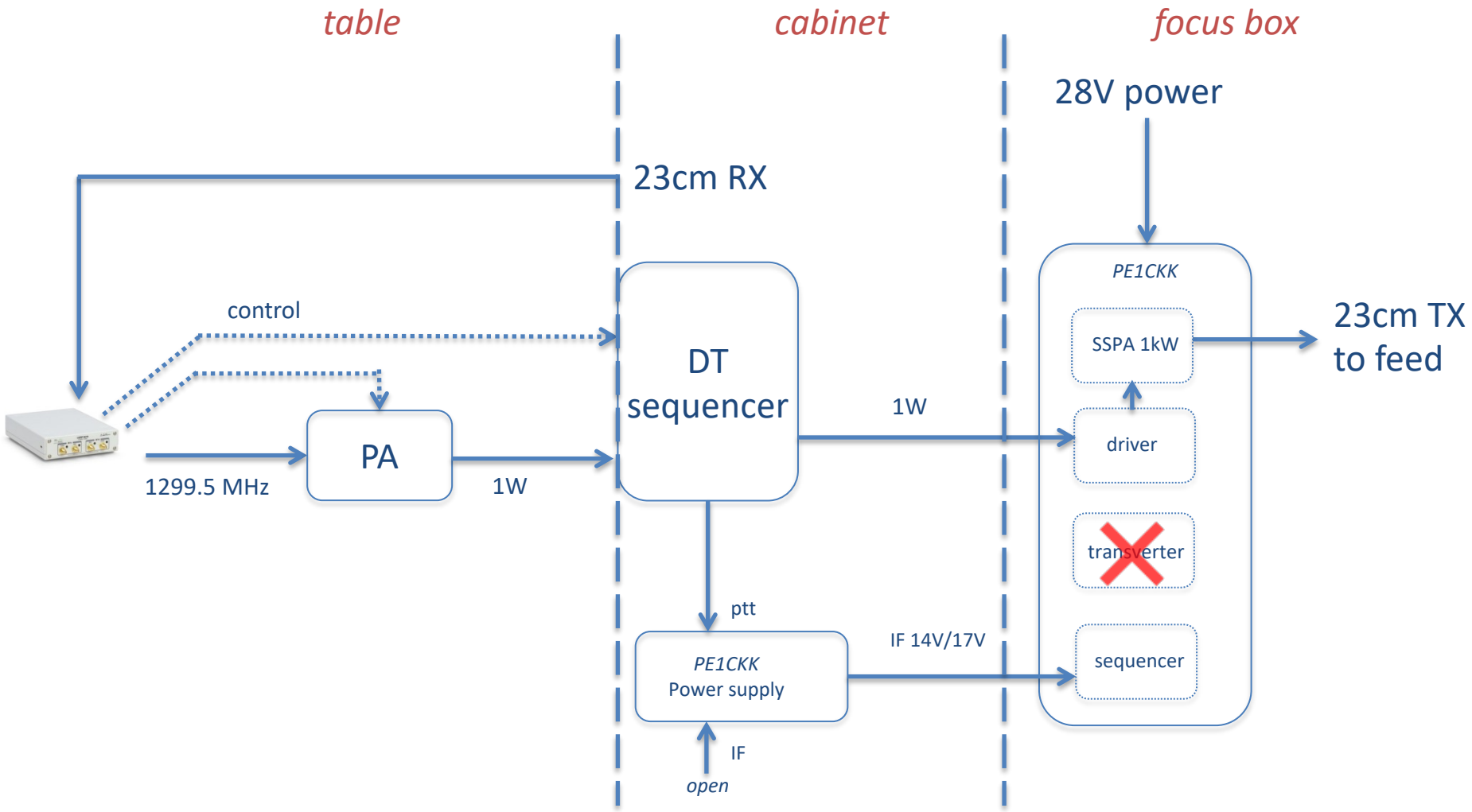



Dwingeloo-Stockert Delay-Doppler
zadoff-chu-fs250000-fzc50000-l3000017-q2411-60sec-1x.sigmf-meta
Frequency (Hz)
−6
−4
−2
0
2
4
6
−0.5
0.0
0.5
1.0
1.5
Delay (ms)

Venus

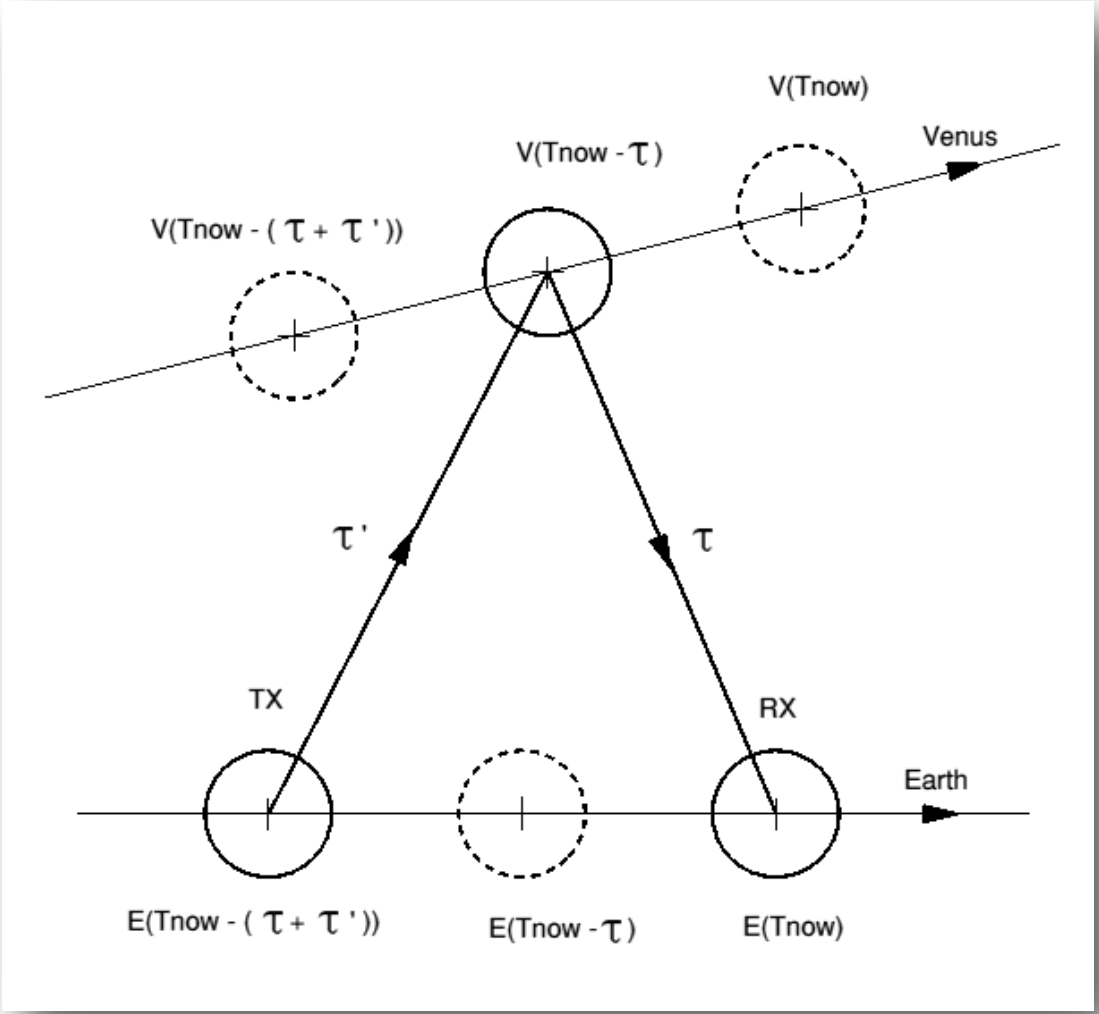





table
cabinet
focus box
28V power
23cm RX
control
DT
sequencer
PE1CKK
SSPA 1kW
23cm TX
to feed
1W
driver
PA
1299.5 MHz
1W
transverter
ptt
IF 14V/17V
PE1CKK
Power supply
sequencer
IF
open

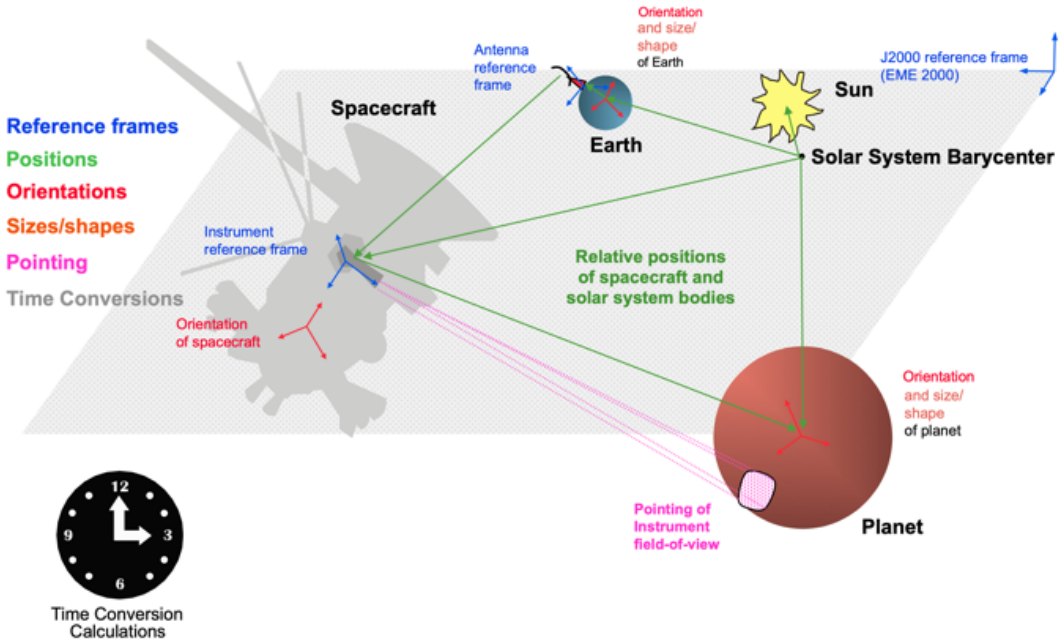


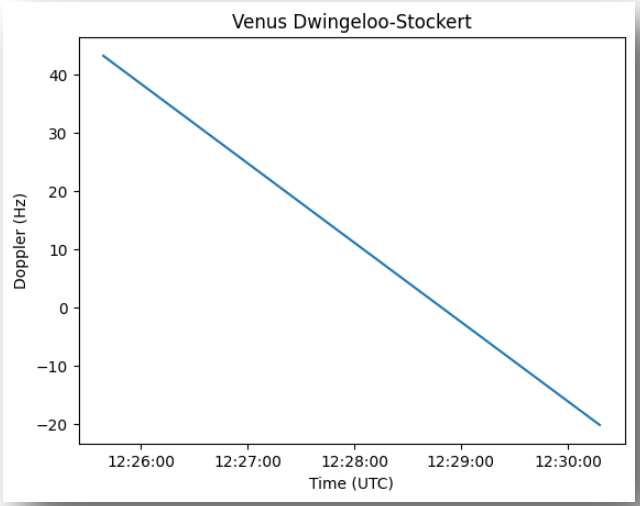


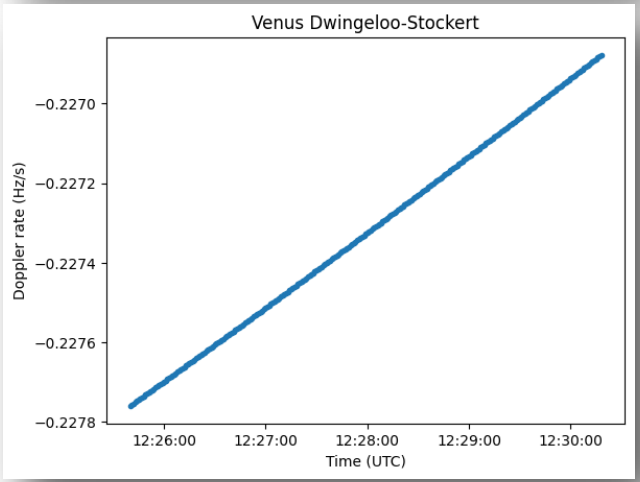


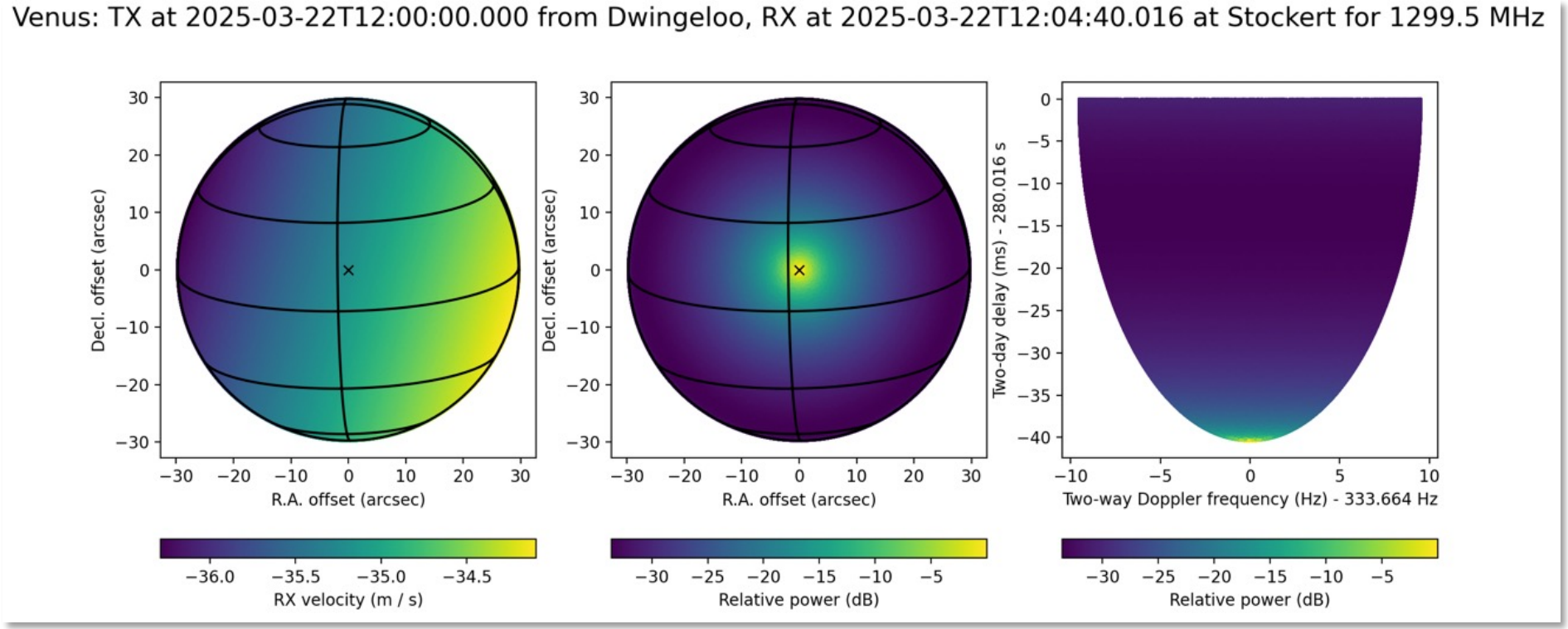
James Miller G3RUH

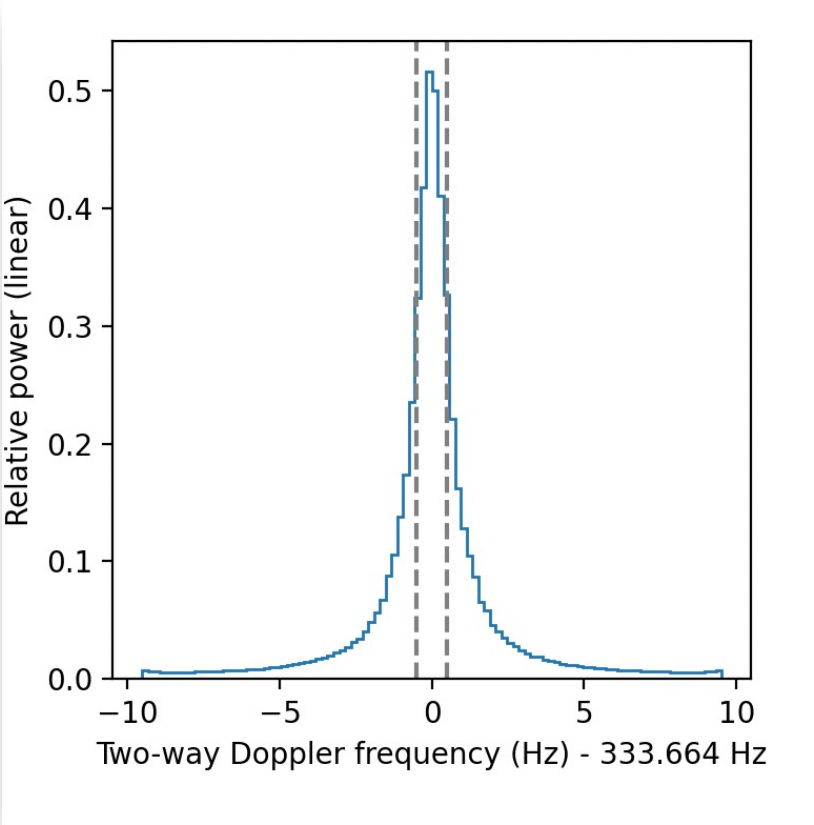
SPICE

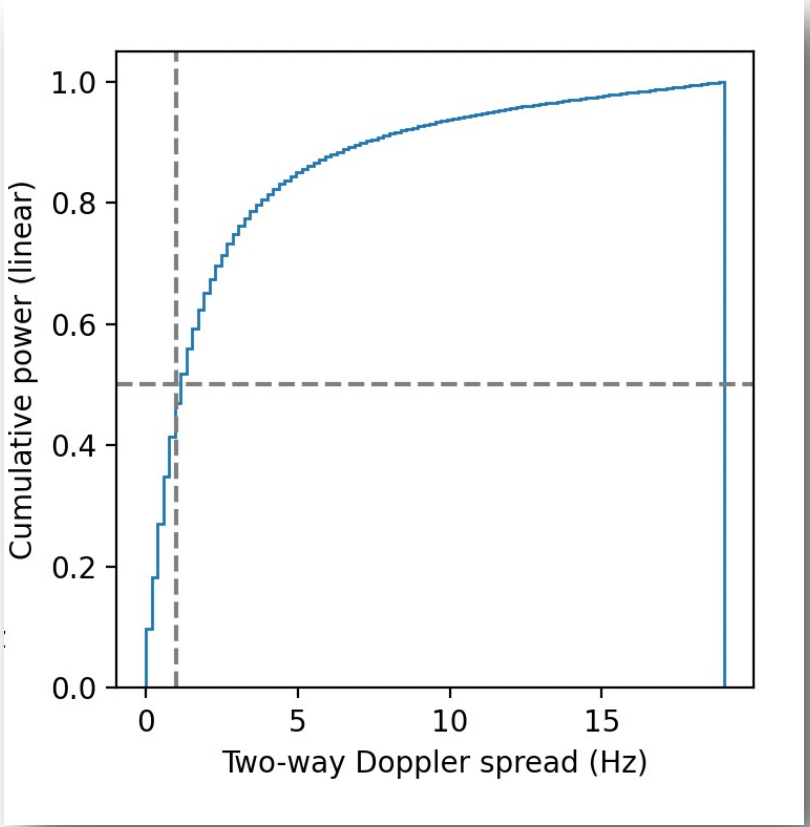

Reference frames
Positions
Orientations
Sizes/shapes
Pointing
Time Conversions
Spacecraft
Antenna reference frame
Orientation and size/ shape of Earth
Earth
Sun
J2000 reference frame (EME 2000)
Solar System Barycenter
Instrument reference frame
Orientation of spacecraft
Relative positions of spacecraft and solar system bodies
Orientation and size/ shape of planet
Pointing of Instrument field-of-view
Planet
Time Conversion Calculations


Venus Dwingeloo-Stockert
Doppler (Hz)
40
30
20
10
0
−10
−20
12:26:00
12:27:00
12:28:00
12:29:00
12:30:00
Time (UTC)


Venus Dwingeloo-Stockert
Doppler rate (Hz/s)
−0.2270
−0.2272
−0.2274
−0.2276
−0.2278
12:26:00
12:27:00
12:28:00
12:29:00
12:30:00
Time (UTC)


Venus: TX at 2025-03-22T12:00:00.000 from Dwingeloo, RX at 2025-03-22T12:04:40.016 at Stockert for 1299.5 MHz
Decl. offset (arcsec)
R.A. offset (arcsec)
RX velocity (m / s)
Relative power (dB)
Two-day delay (ms) - 280.016 s
Two-way Doppler frequency (Hz) - 333.664 Hz


Relative power (linear)
0.0
0.1
0.2
0.3
0.4
0.5
−10
−5
0
5
10
Two-way Doppler frequency (Hz) - 333.664 Hz

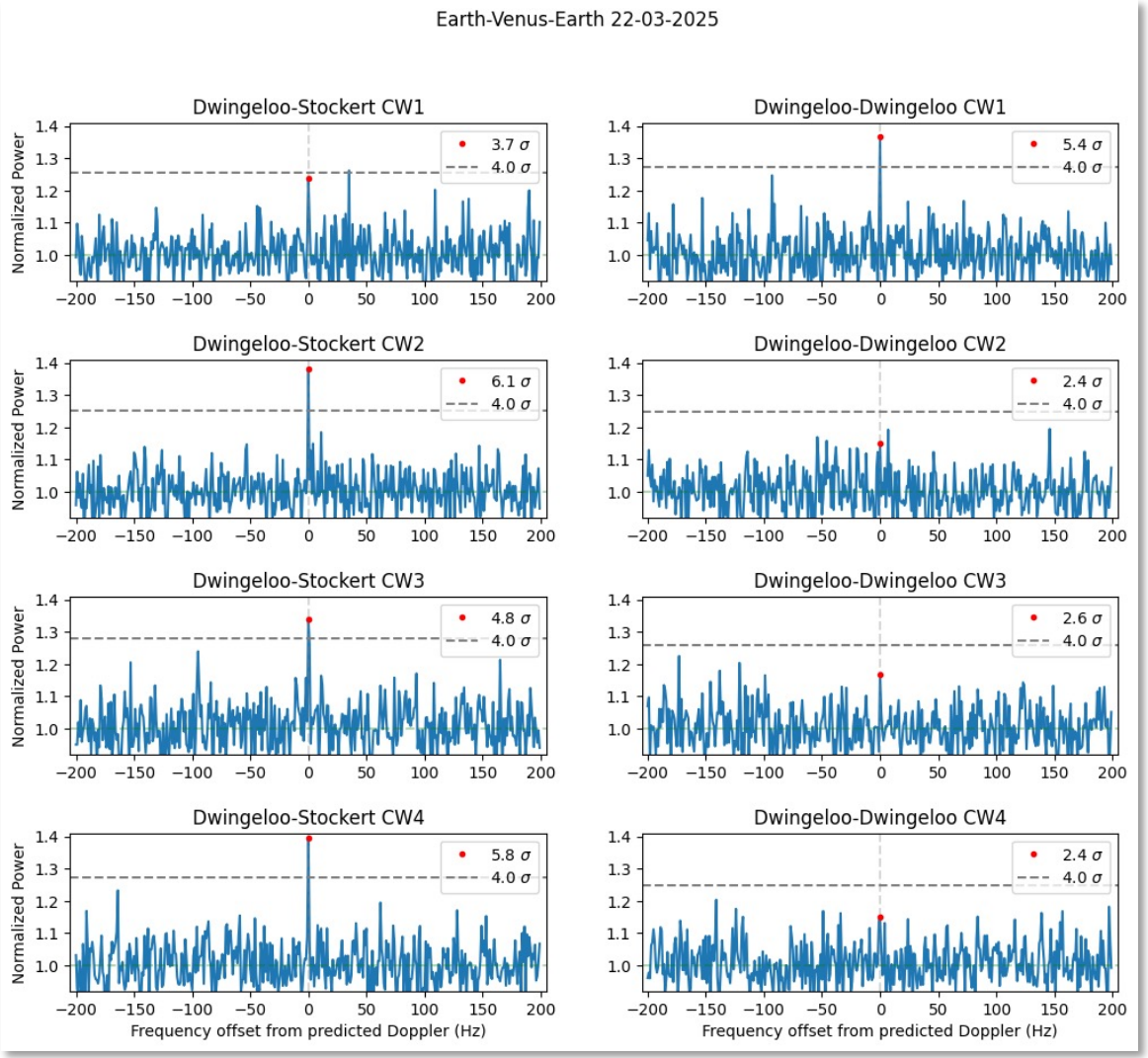

Cumulative power (linear)
0.0
0.2
0.4
0.6
0.8
1.0
0
5
10
15
Two-way Doppler spread (Hz)

Transmission schedule

```
# 120 minutes
files = ([
    "cw-0-278.sigmf-meta",
    "cw-0-278.sigmf-meta",
    "cw-0-278.sigmf-meta",
    "cw-0-278.sigmf-meta",
    "zadoff-chu-2000-556007-10301-0-278-1.sigmf-meta",
    "zadoff-chu-2000-556007-10301-0-278-1.sigmf-meta",
    "zadoff-chu-2000-556007-10301-0-278-1.sigmf-meta",
    "bpsk-2000-278-1.sigmf-meta",
    "bpsk-2000-278-1.sigmf-meta",
    "cw-0-278.sigmf-meta",
    "morse-DT-0.1wpm.sigmf-meta",
    "cw-0-278.sigmf-meta"
])
```

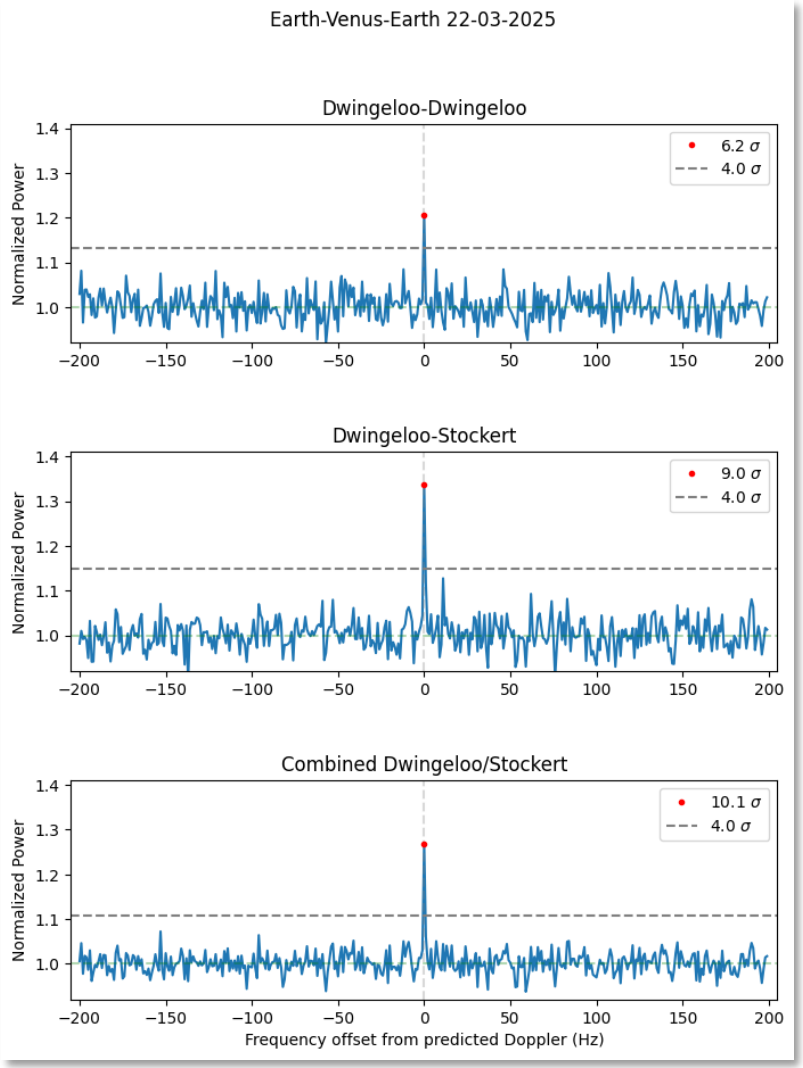






4x 278 seconds CW

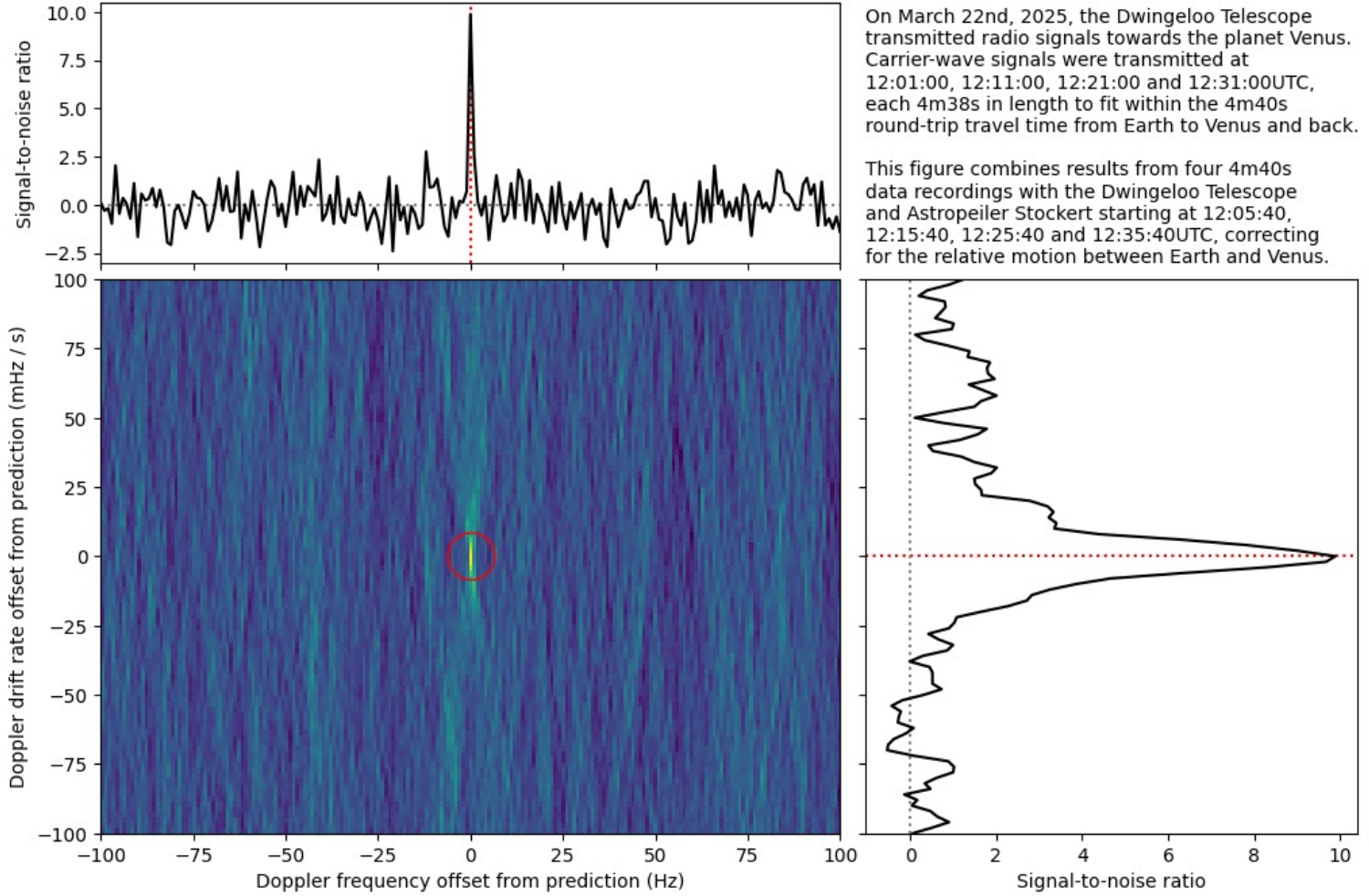
Received at Dwingeloo and Stockert



4x 278 seconds CW Averaged

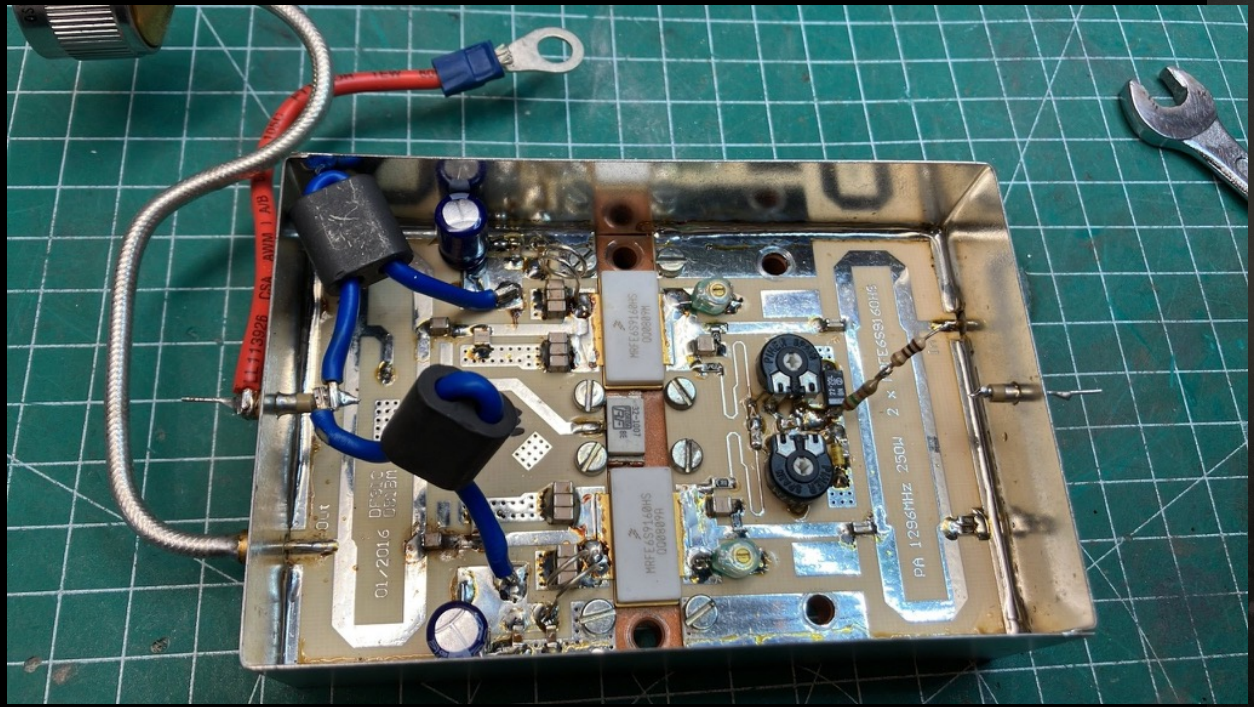
Received at Dwingeloo and Stockert

Dwingeloo-Stockert combined Earth-Venus-Earth detection

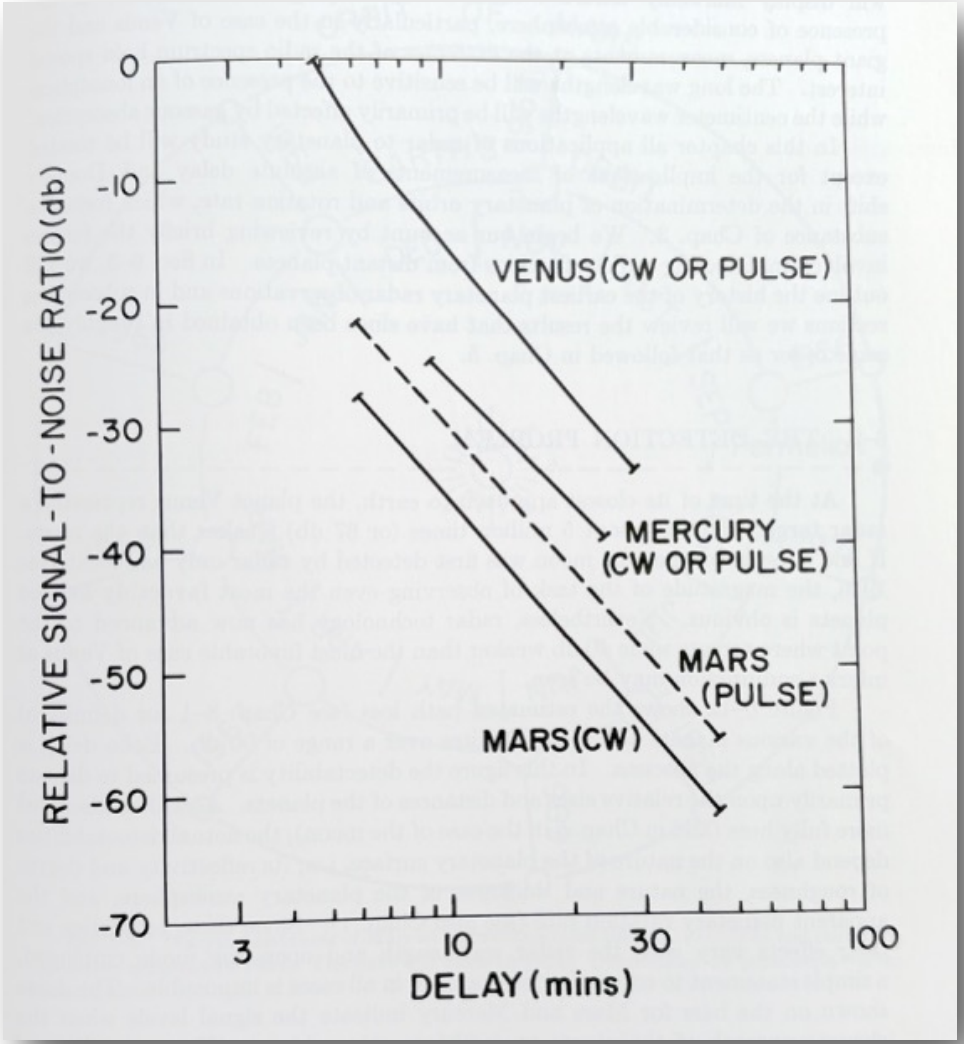


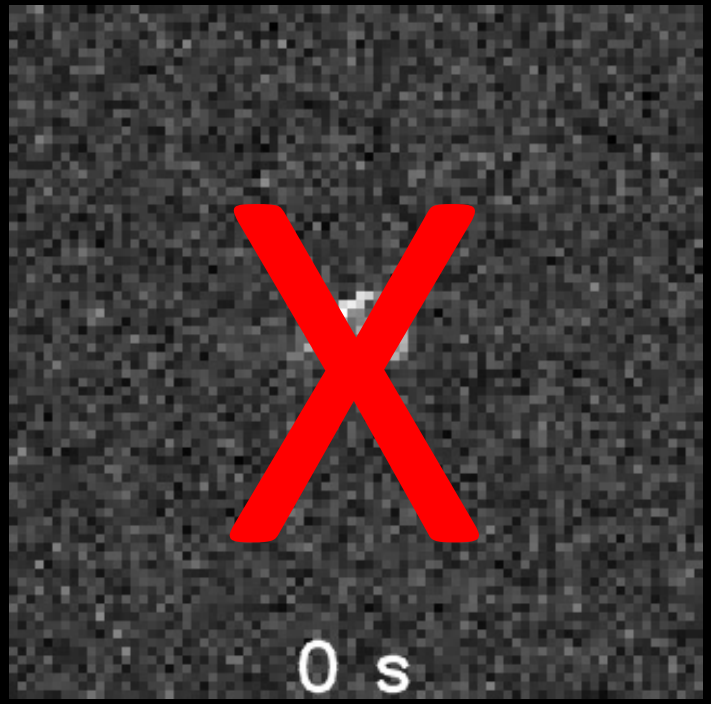
On March 22nd, 2025, the Dwingeloo Telescope transmitted radio signals towards the planet Venus. Carrier-wave signals were transmitted at 12:01:00, 12:11:00, 12:21:00 and 12:31:00UTC, each 4m38s in length to fit within the 4m40s round-trip travel time from Earth to Venus and back.

This figure combines results from four 4m40s data recordings with the Dwingeloo Telescope and Astropeiler Stockert starting at 12:05:40, 12:15:40, 12:25:40 and 12:35:40UTC, correcting for the relative motion between Earth and Venus.


01/2016
PA 1296MHz 250W
2 x MRFE6S9160HS



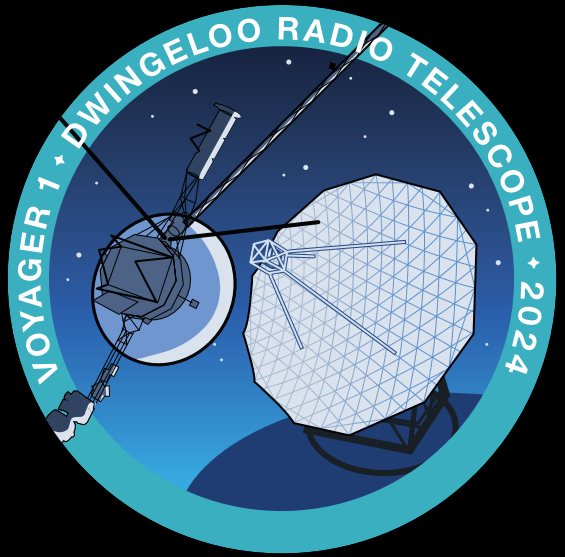

0
-10
-20
-30
-40
-50
-60
-70
RELATIVE SIGNAL-TO-NOISE RATIO(db)
VENUS(CW OR PULSE)
MERCURY
(CW OR PULSE)
MARS
(PULSE)
MARS(CW)
3
10
30
100
DELAY (mins)


0 s

Acknowledgements

- Teams at Dwingeloo and Stockert!
- Jan van Muijlwijk
- Daniel Estévez
- Pete Wyckoff
- Nathaniel Fairfield


CAMRAS
DWINGELOO TELESCOOP


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