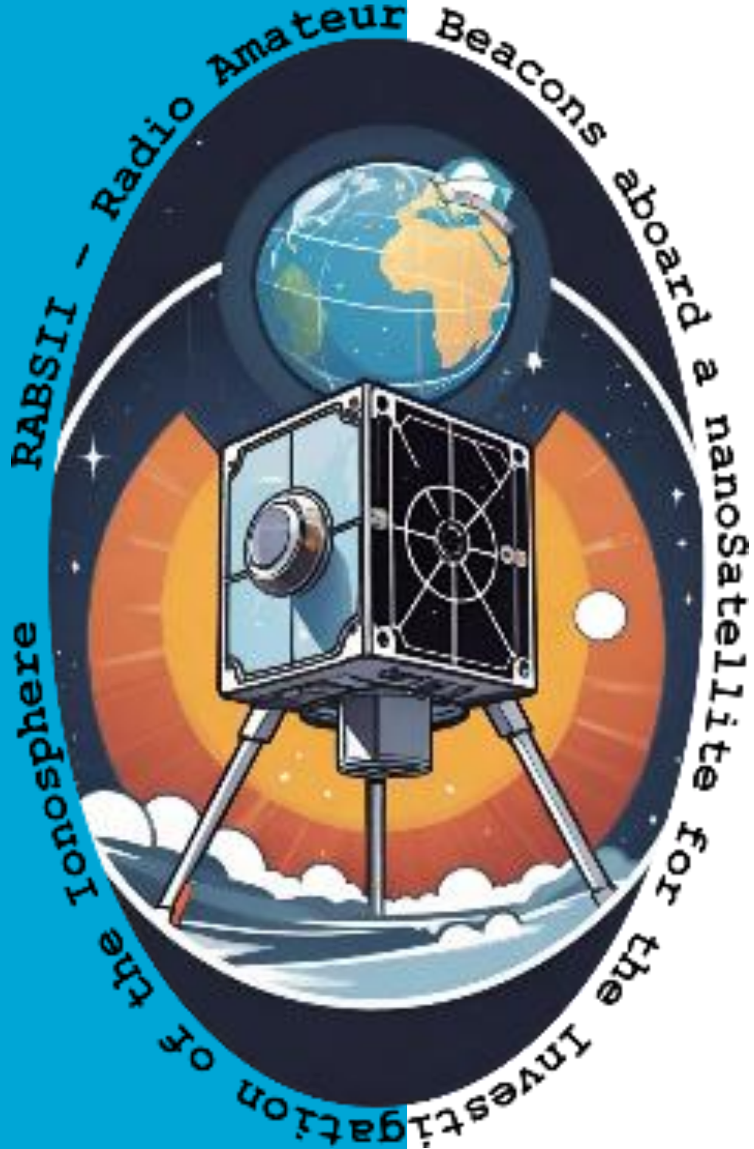
RABSII: Radio Amateur Bakens aan boord van een nanoSatelliet voor onderzoek van de Ionosfeer

JURGEN VANHAMEL — ON5ADL



RF Seminar

RABSII

Radio Amateur Beacons aboard a nanoSatellite for the Investigation of the Ionosphere

Jurgen Vanhamel – ON5ADL
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TU Delft

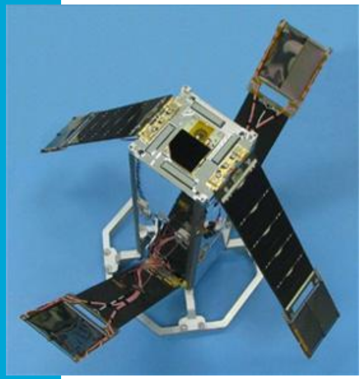
KU LEUVEN

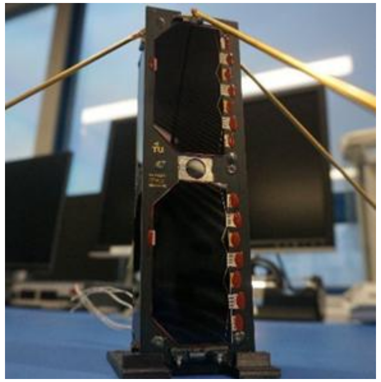
UBA

RF Seminar

The Delfi Space Program

The Delfi Space program realizes education and research by the end-to-end engineering of space missions of high relevance and impact using very small satellites.





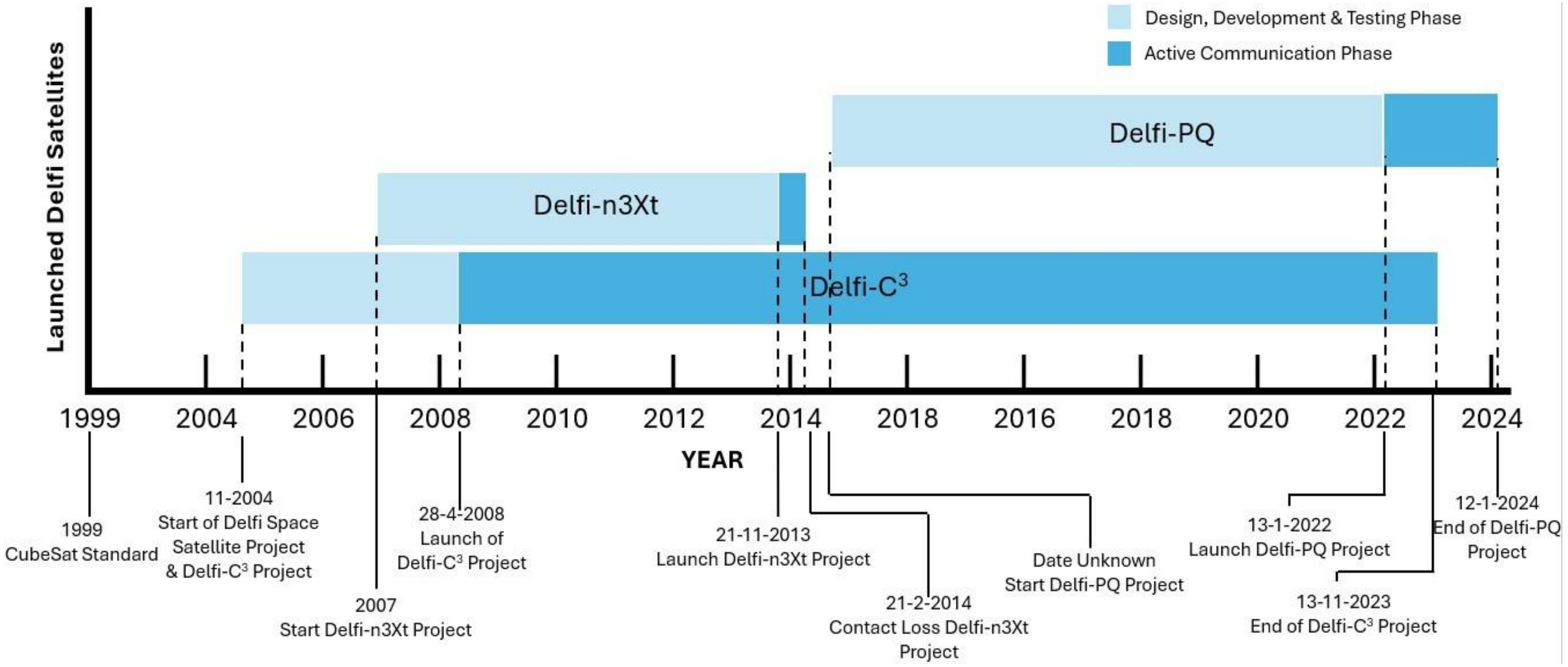
Delfi-C3
2008

Delfi-N3xt
2013

Delfi-PQ
2022

TU Delft

The Delfi Space Program



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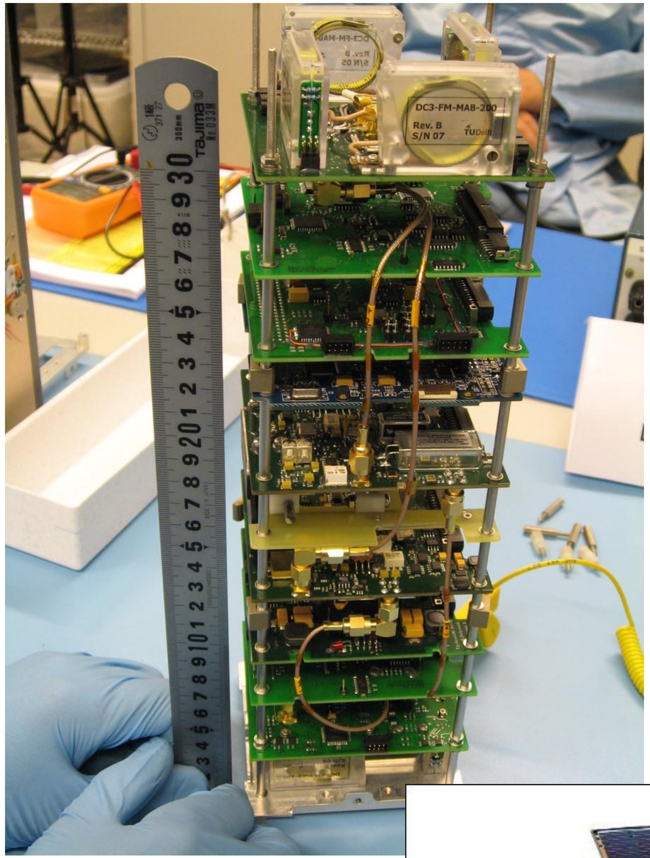
Delfi-C3

- 3U CubeSat
- Power subsystem w/o batteries
- AOCS using magnetic-damping
- Passive thermal subsystem
- Decentralized CDHS
- Decentralized Electrical Power System
- Uplink UHF @ 435 MHz
- Downlink VHF @ 145 MHz, 1200 bps



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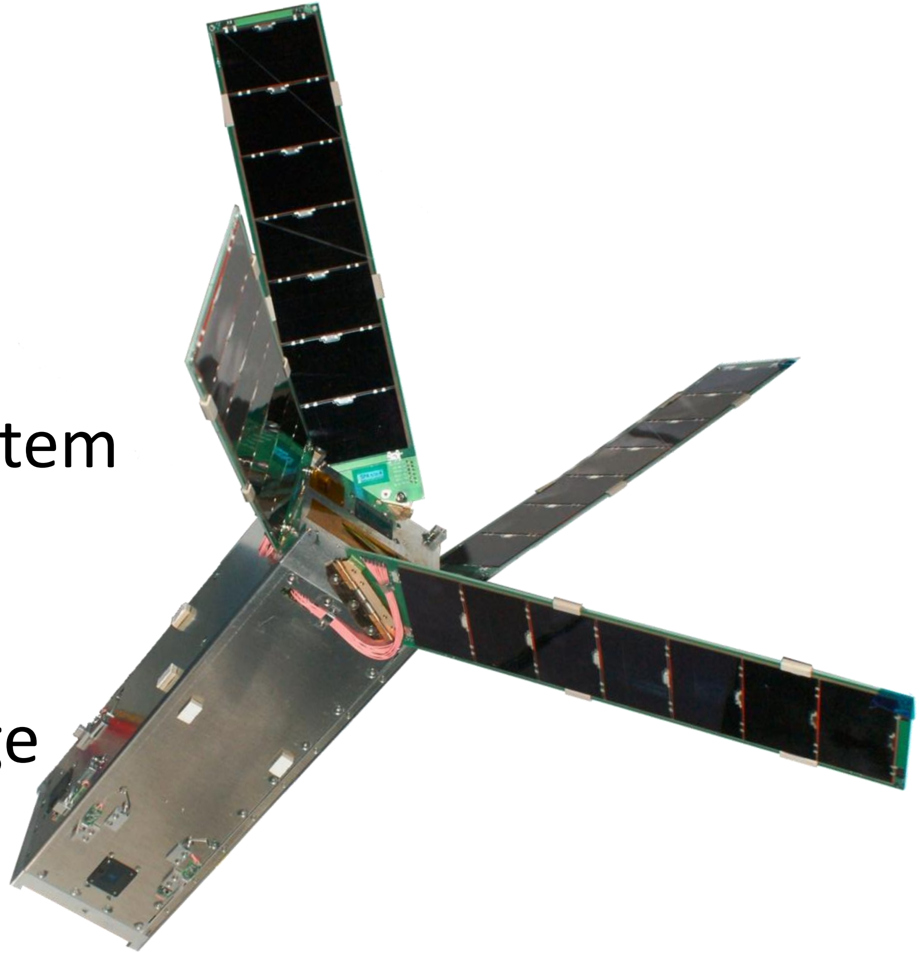
Delfi-n3Xt

- 3U CubeSat
- Fully redundant OBC
- Single Point of Failure free power system
- 30 Wh battery system
- 3-axis attitude control
- Failure tolerant on-board data storage
- Uplink UHF @ 435 MHz
- Downlink VHF @ 145 MHz, 1200 bps
- Downlink S-band @ 2.4 GHz > 10 – 250 kbps



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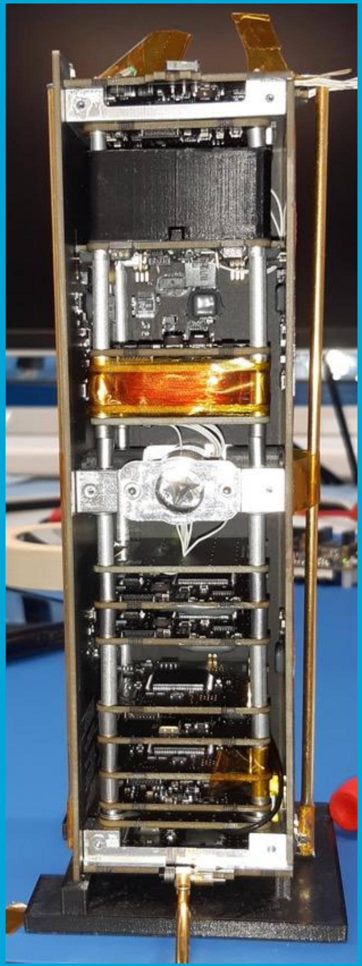
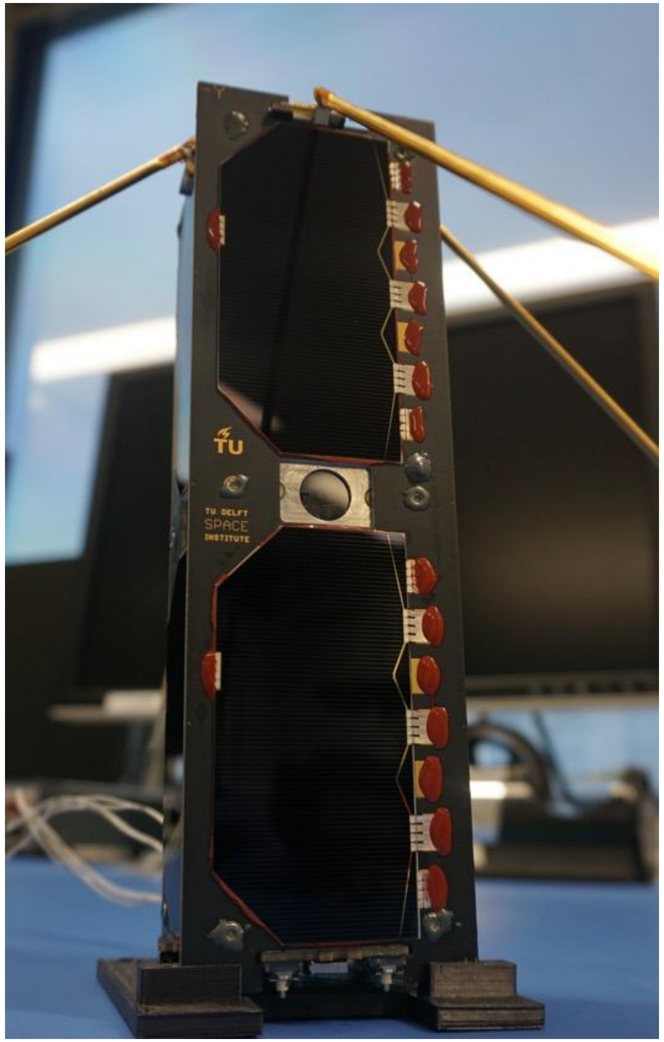


Delfi-PQ

- 3P PocketQube (178x50x50 mm)
- Single string modular bus design
- Passive temperature control
- Similar Performances to Delfi-C3/N3xt
- Magnetic attitude control
- Full sw update capabilities (lab in space)
- Uplink UHF @ 145 MHz
- Downlink VHF @ 435 MHz, 9600 bps



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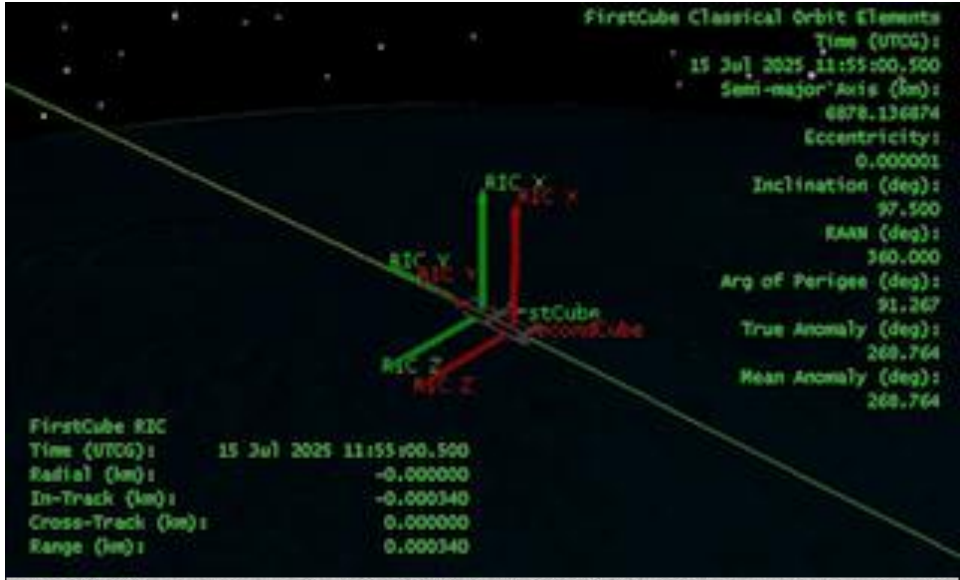
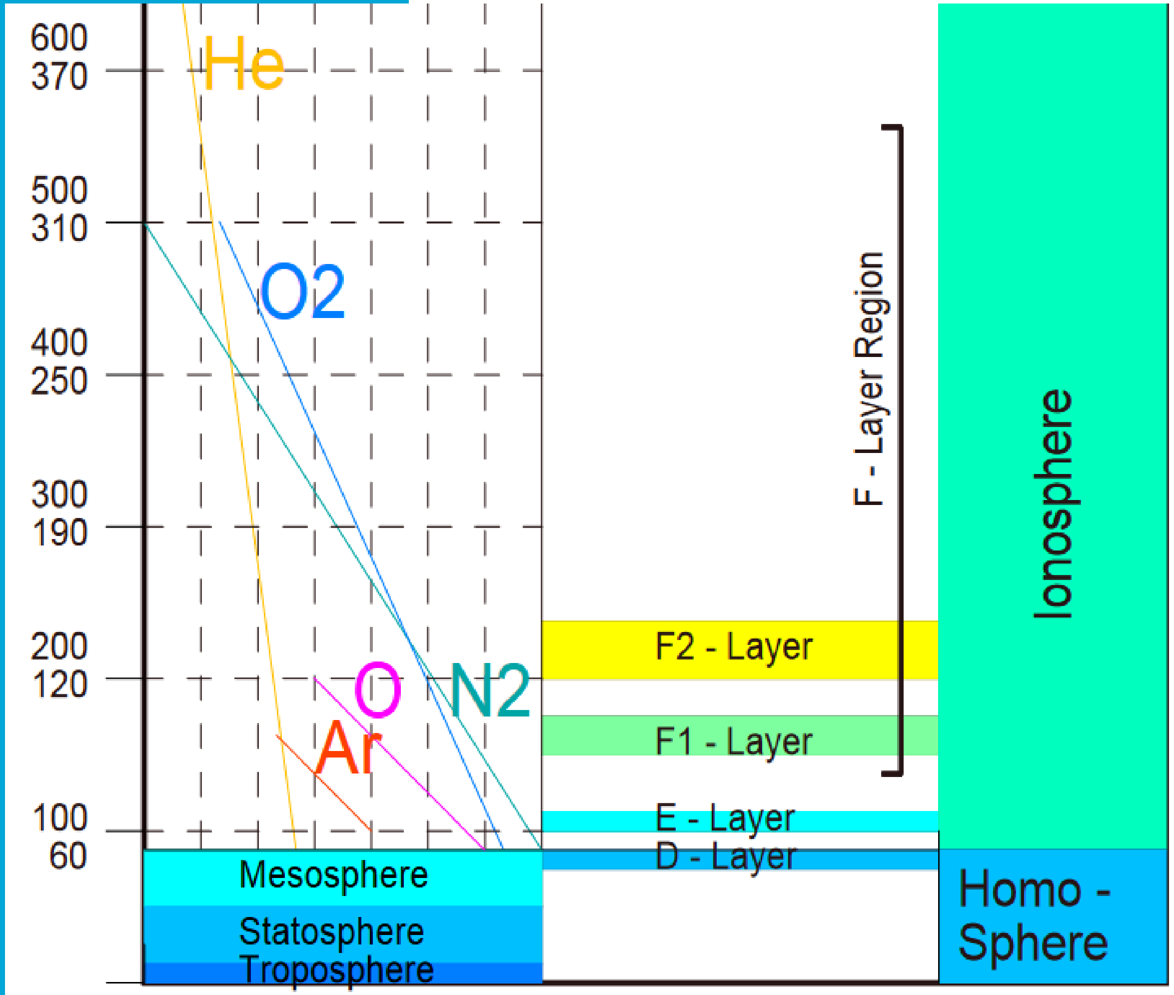
New mission!

- Satellite formation
  - Two (or more?) satellites
- Educational purpose
  - Lab in space
  - Direct involvement in educational activities
  - STEM activities (local and worldwide)
- Scientific purpose
  - Precise orbit determination
  - GNSS + radiometric + laser tracking
  - Space Situational Awareness demonstration
  - Multi (ground) sensor detection
  - **Sporadic E detection**



The Ionosphere



Ionosphere ➔ Composition

He: Helium

O: oxygen

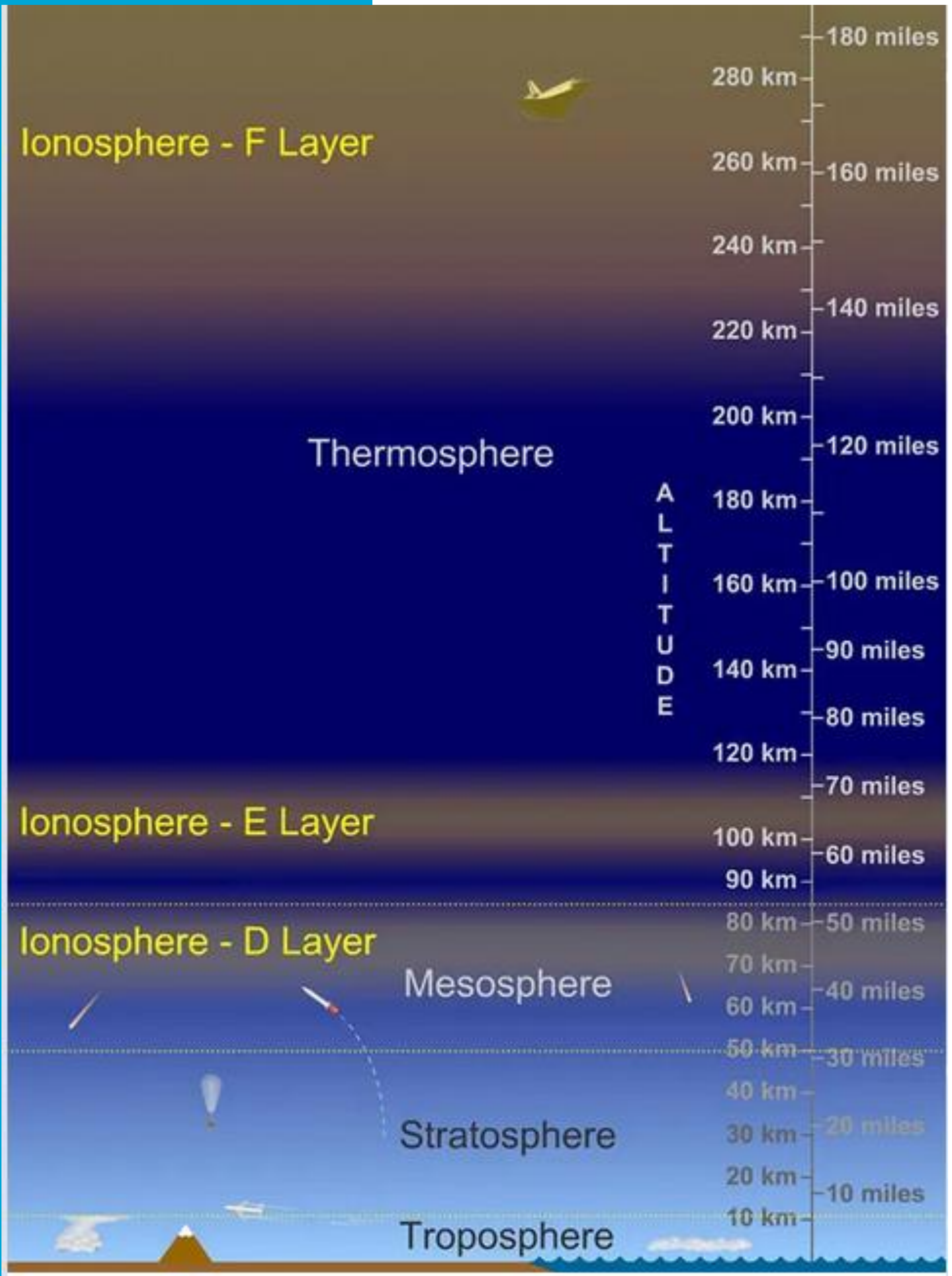
O_2: chemically bound oxygen (oxygen molecule)

Ar: Argon

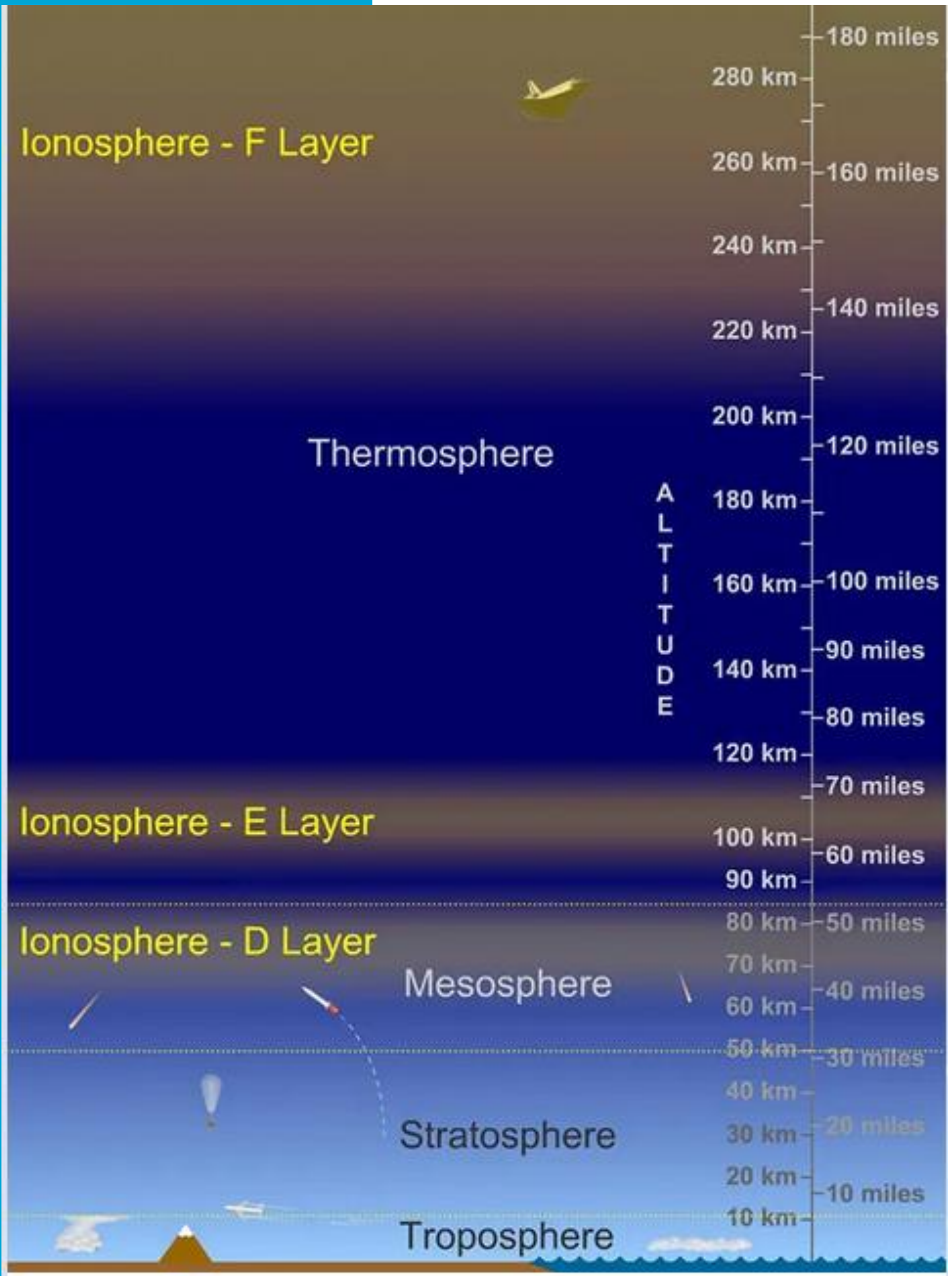
N_2: Nitrogen

The Ionosphere

Ionosphere ➔ setup



Regions of the ionosphere, showing the D, E, and F layers.
UCAR/Randy Russell



Regions of the ionosphere, showing the D, E, and F layers.
UCAR/Randy Russell

The Ionosphere

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Ionosphere ➔ setup

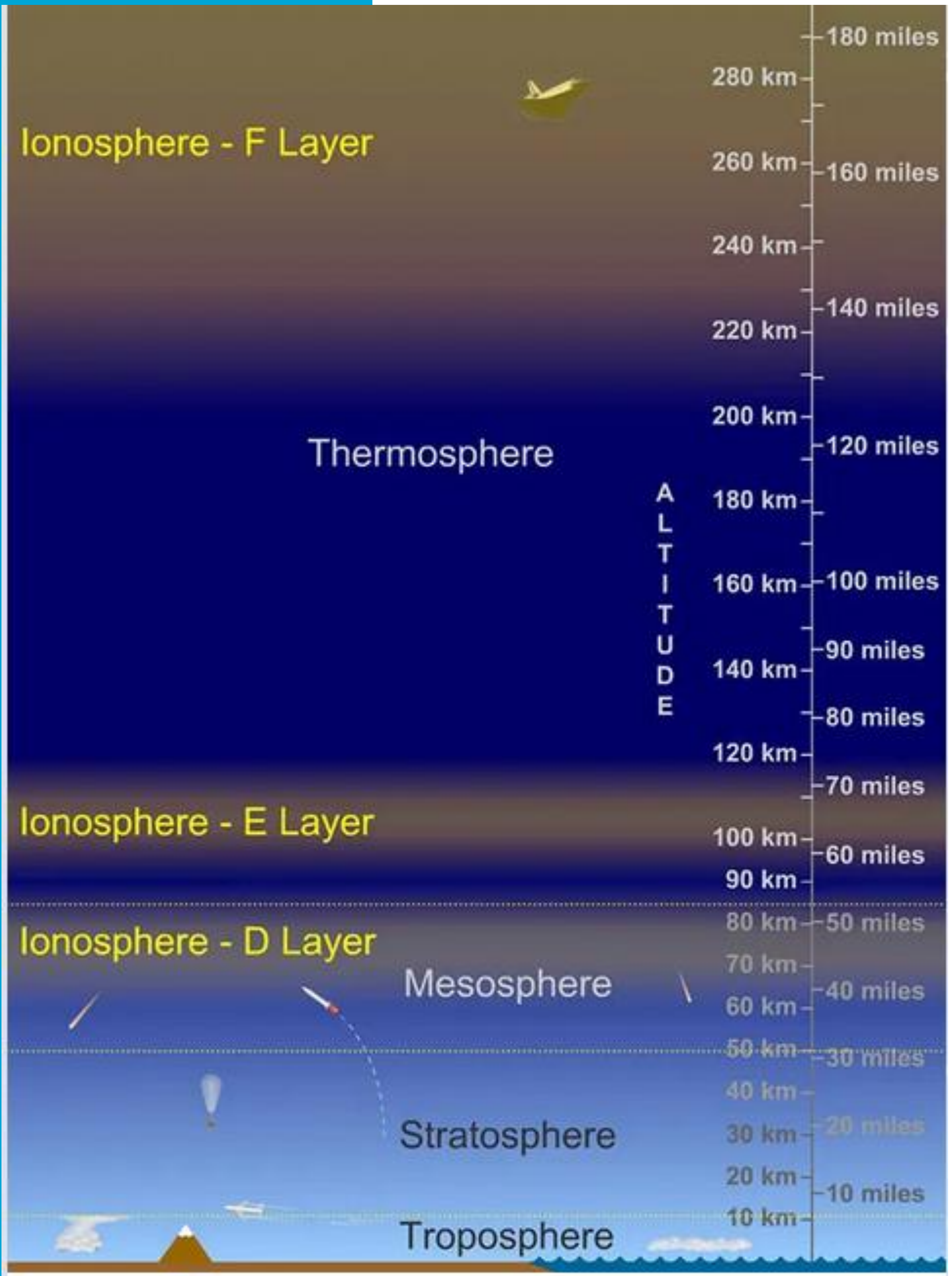
Ionisation process:

- **Sun's ultraviolet light ➔** ionizes atoms and molecules in the Earth's upper atmosphere (50-1000 km)

- **X-ray and gamma-rays ➔** produced when solar events (solar flares) occur
➔ increase the density of the ionosphere on the dayside

- **Protons and electrons ➔** produced by solar events
➔ precipitate into the ionosphere in the polar regions
➔ produce increases in the ionosphere density at low altitudes

- **Particles from the solar wind and cosmic radiation**



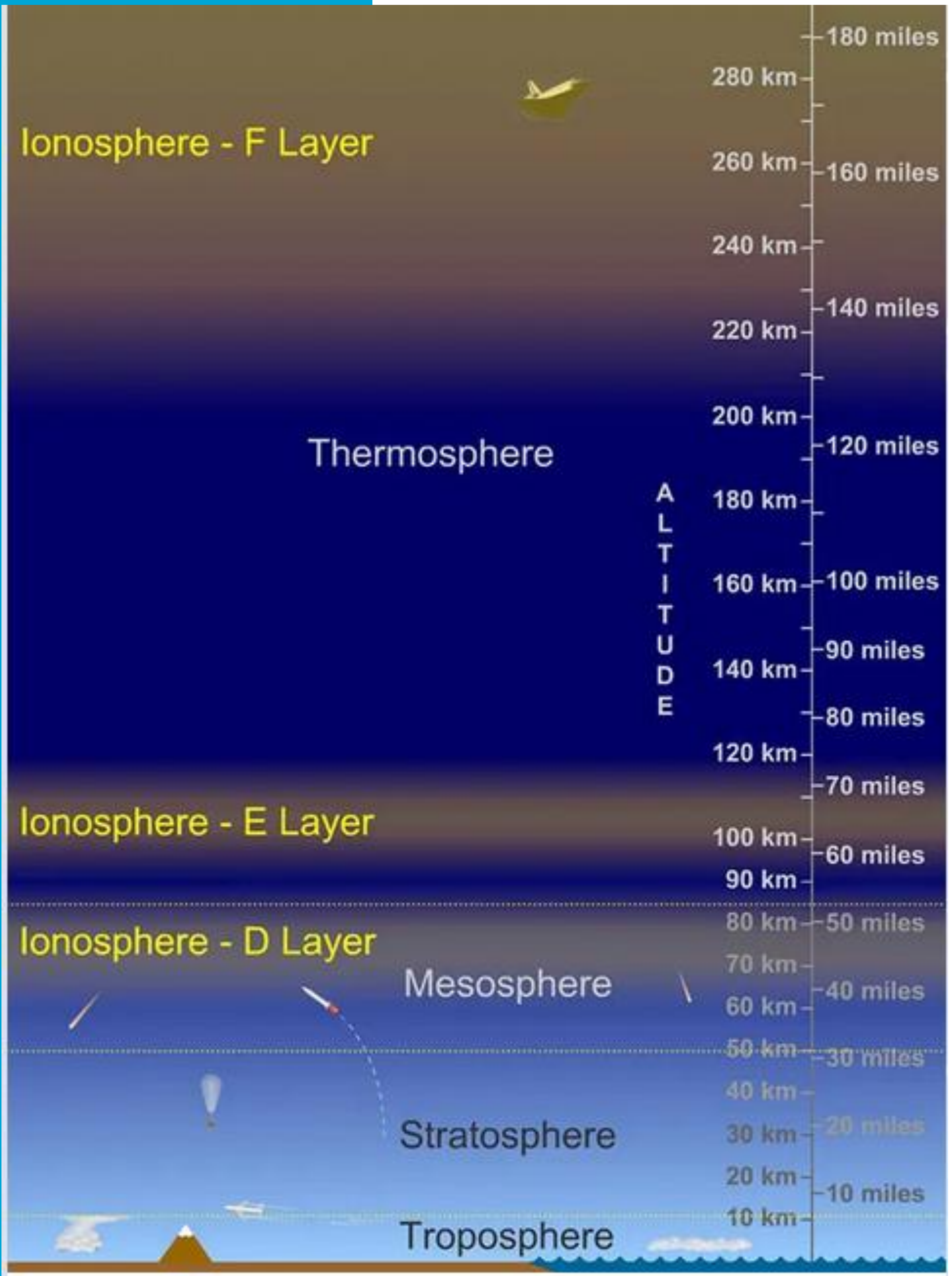
Regions of the ionosphere, showing the D, E, and F layers.
UCAR/Randy Russell

The Ionosphere

Ionosphere ➔ setup

Ionisation process:

REGION	PRIMARY IONISING RADIATION FORMS
D	Lyman alpha, Hard X-Rays
E	Soft X-Rays and some Extreme Ultra-Violet
F1	Extreme Ultra-violet, and some Ultra-Violet
F2	Ultra-Violet



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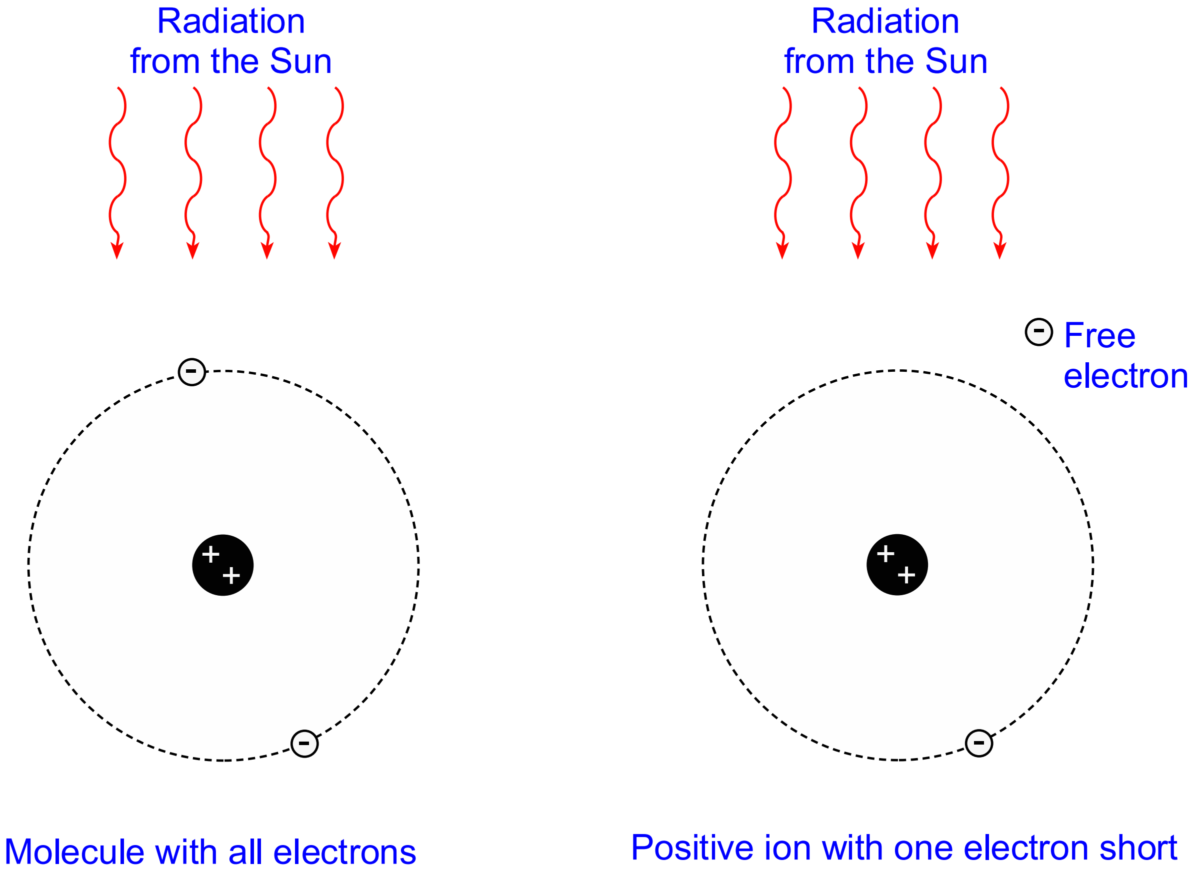
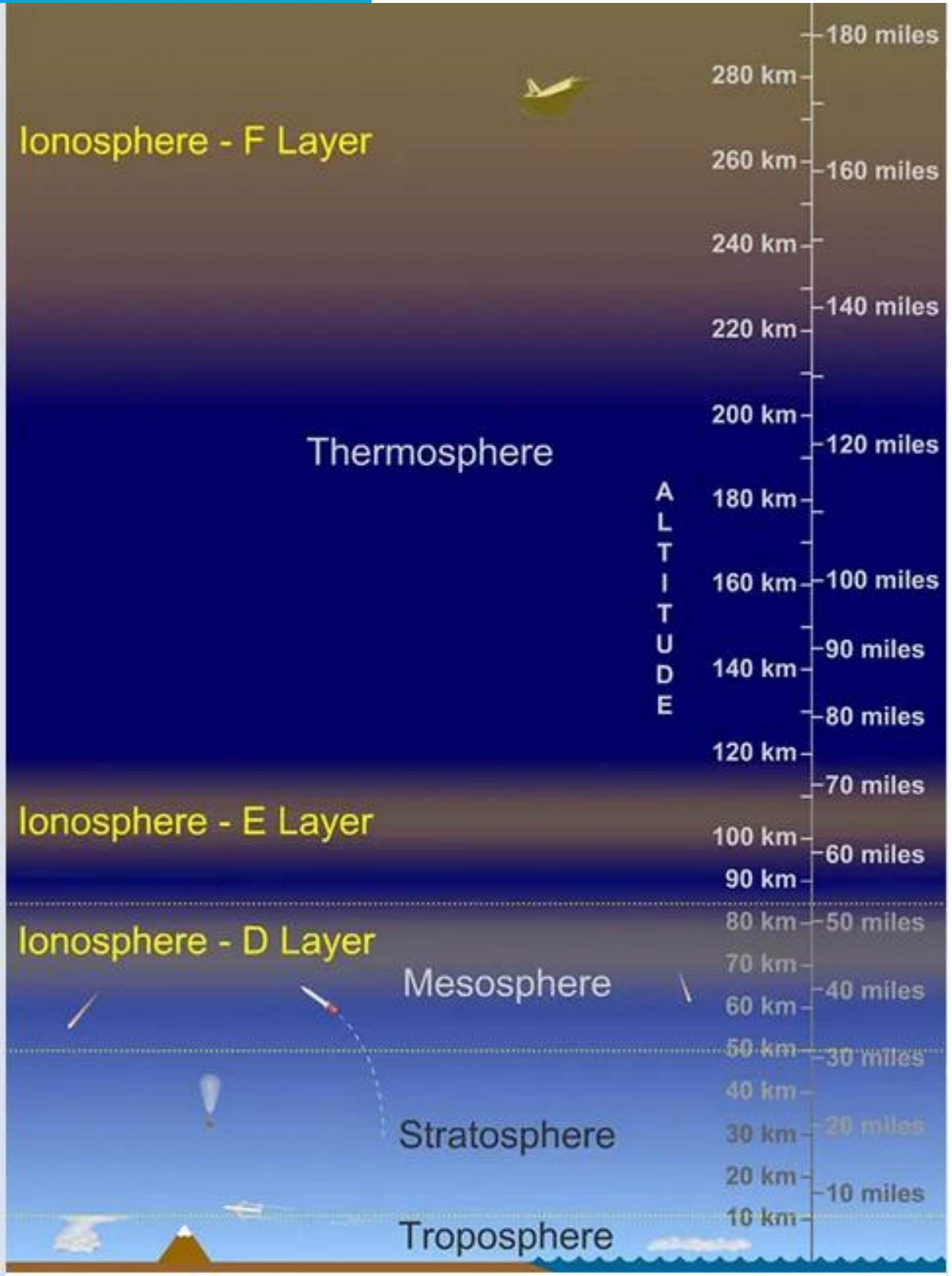
The Ionosphere

Ionosphere ➔ setup

Ionisation process:





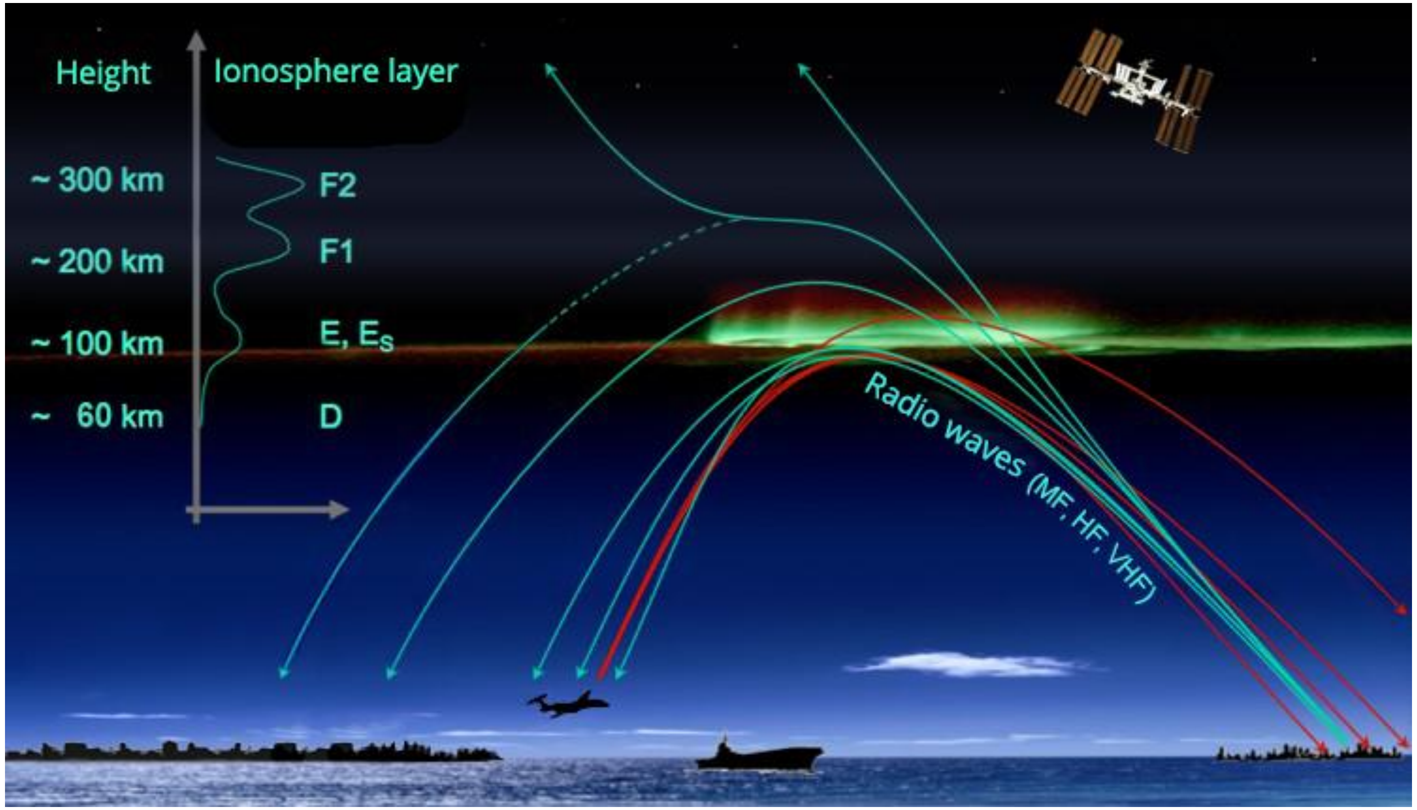
Regions of the ionosphere, showing the D, E, and F layers.

UCAR/Randy Russell

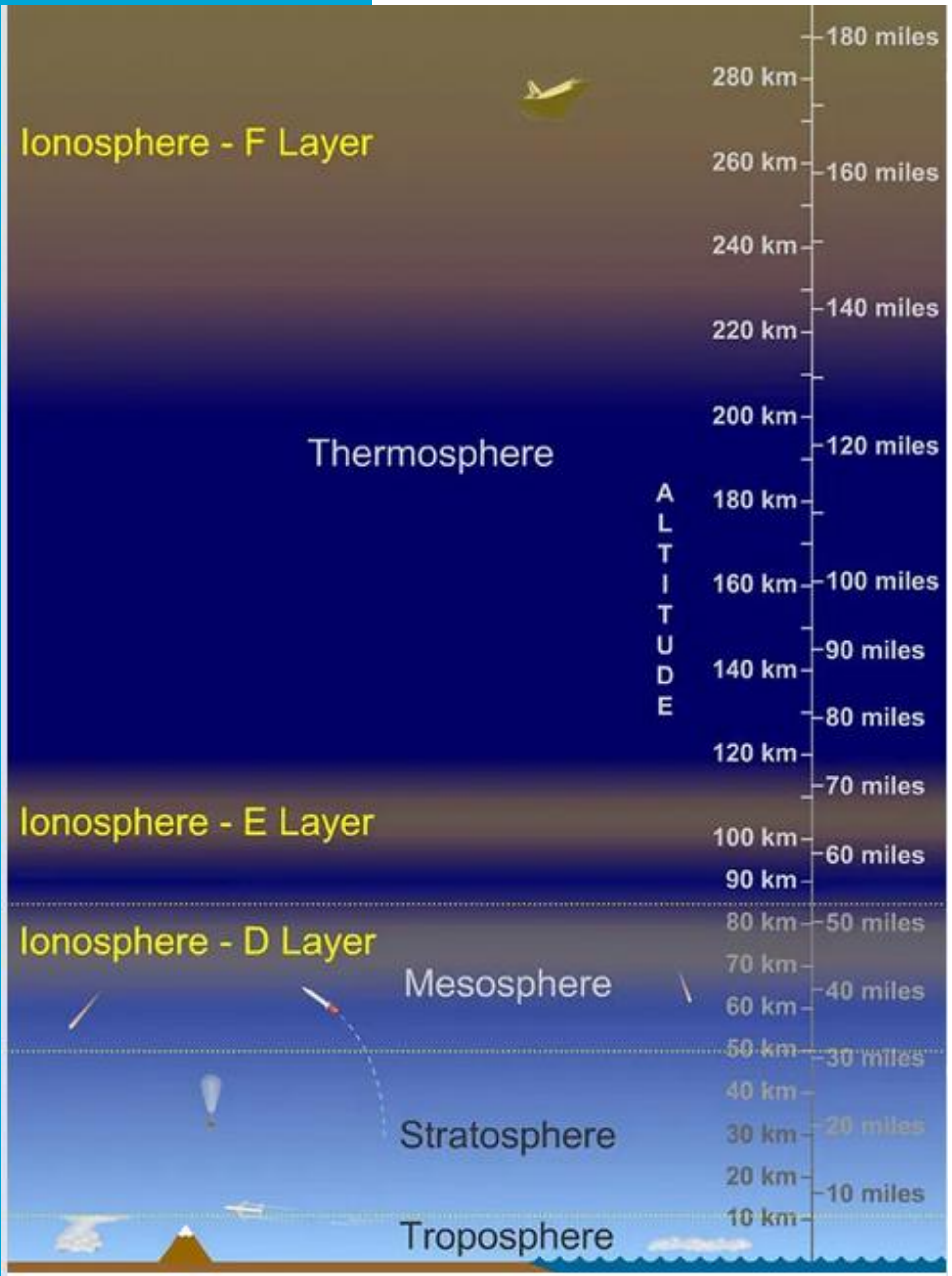
The Ionosphere

Ionosphere ➔ setup

Radio wave reflection



© Image credits: Navy



Regions of the ionosphere, showing the D, E, and F layers.
UCAR/Randy Russell

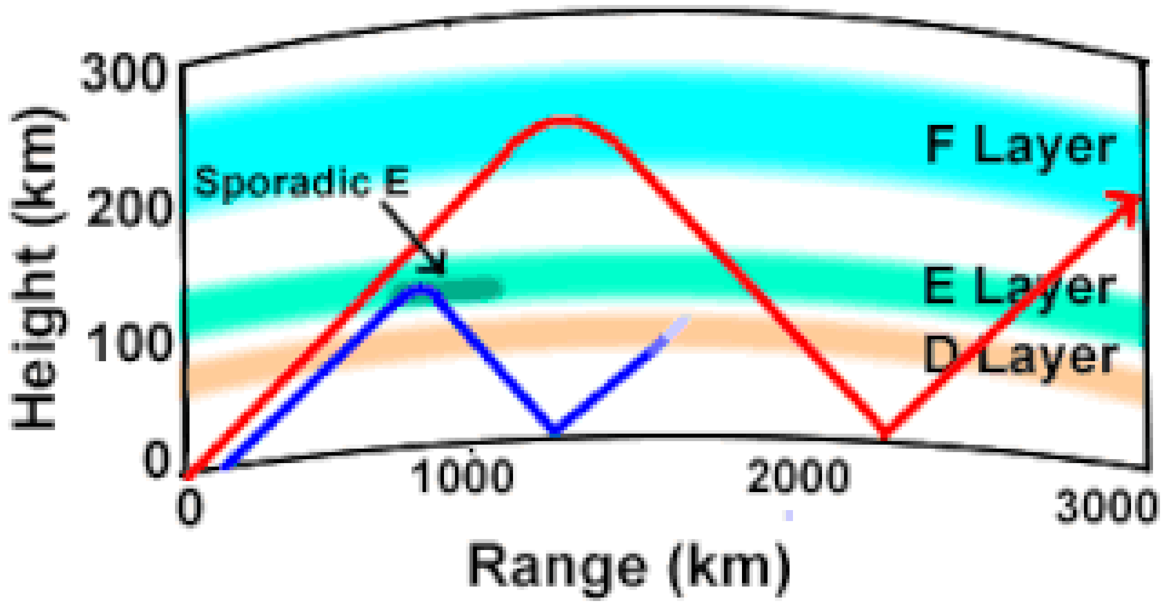
The Ionosphere

Ionosphere ➔ setup

Interest in the E layer region ➔ **sporadic E**

The Ionosphere

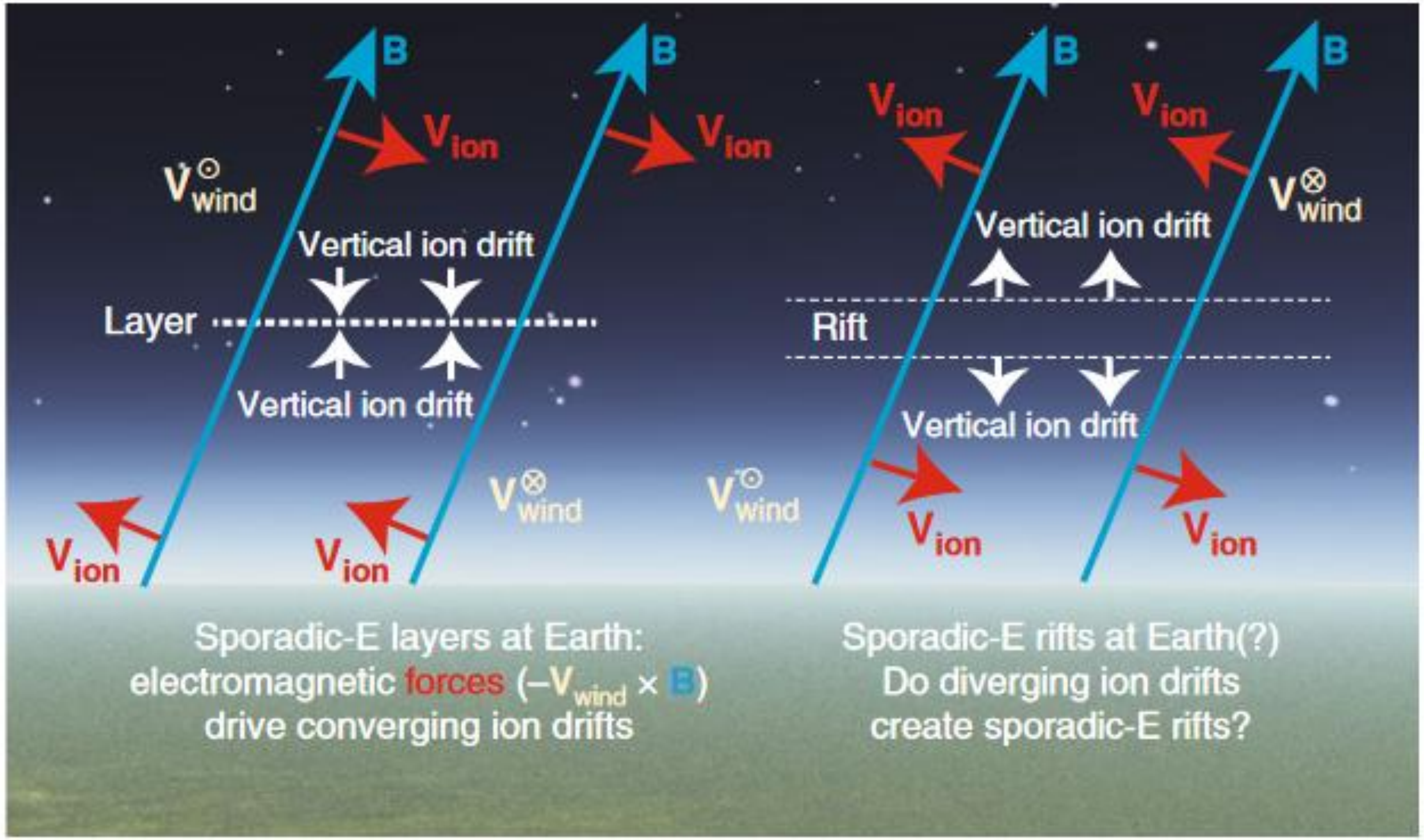
Sporadic E?



- Variability in size
- Variability in location
- Variability in timing
- Clear model is still lacking

The Ionosphere

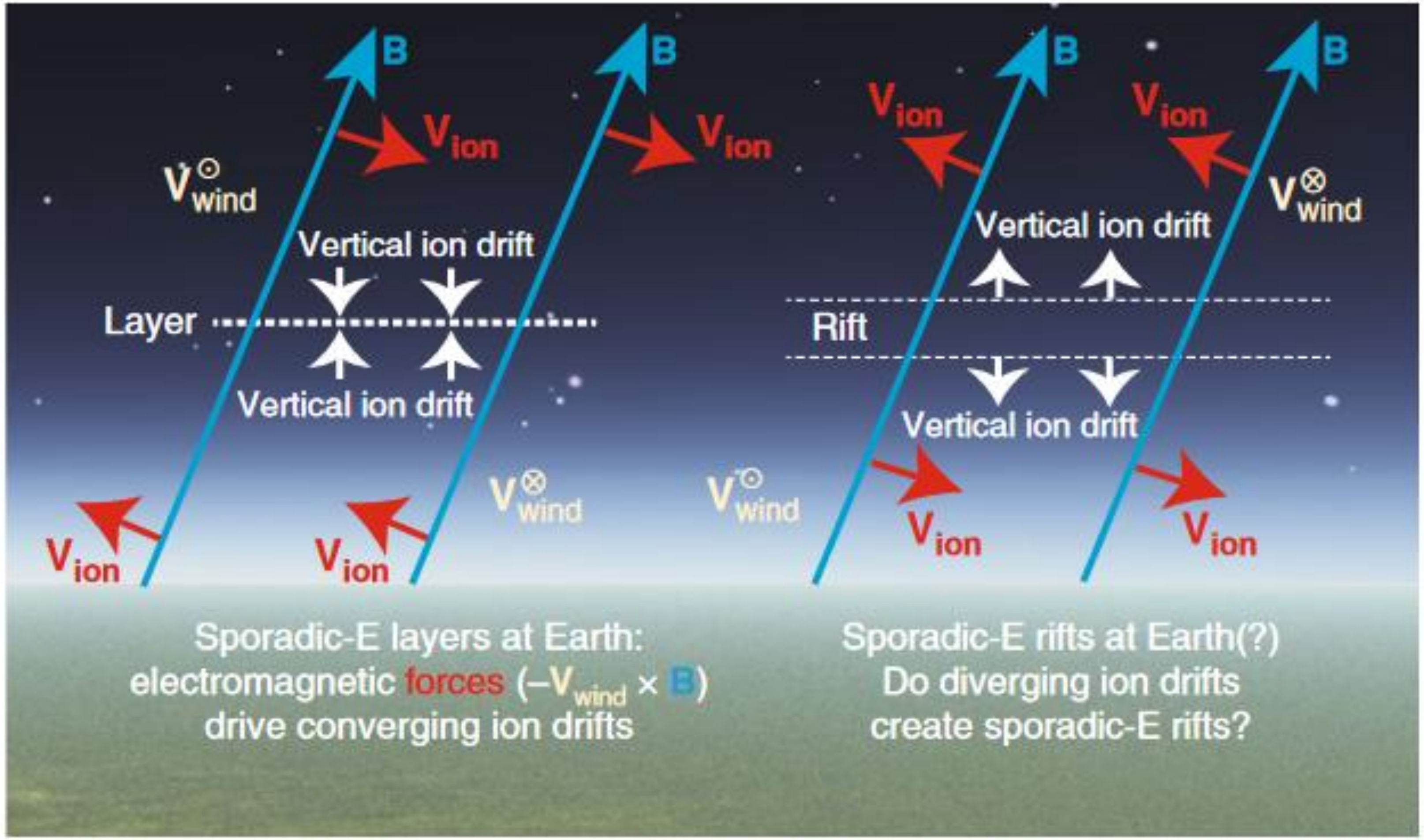
Sporadic E?



Collinson, G.A., McFadden, J., Grebowsky, J. et al. Constantly forming sporadic E-like layers and rifts in the Martian ionosphere and their implications for Earth. Nat Astron 4, 486–491 (2020)

The Ionosphere

Sporadic E?



Unclarities remain

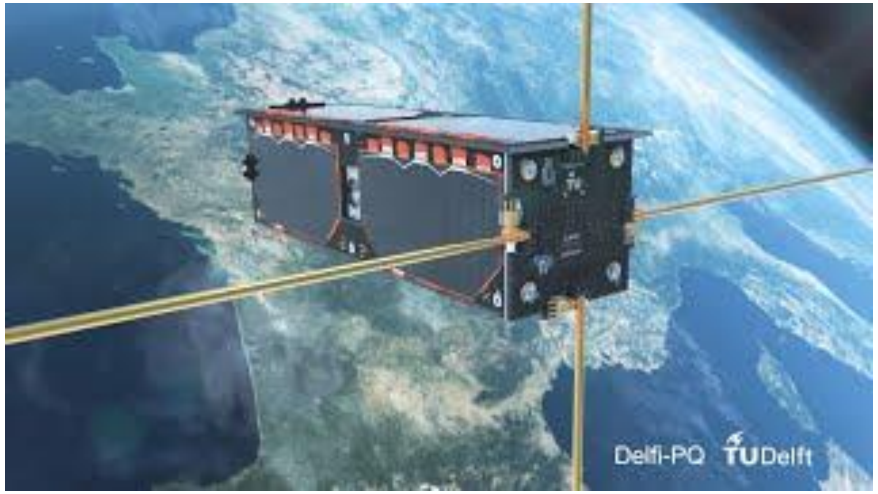
Collinson, G.A., McFadden, J., Grebowsky, J. et al. Constantly forming sporadic E-like layers and rifts in the Martian ionosphere and their implications for Earth. Nat Astron 4, 486–491 (2020)

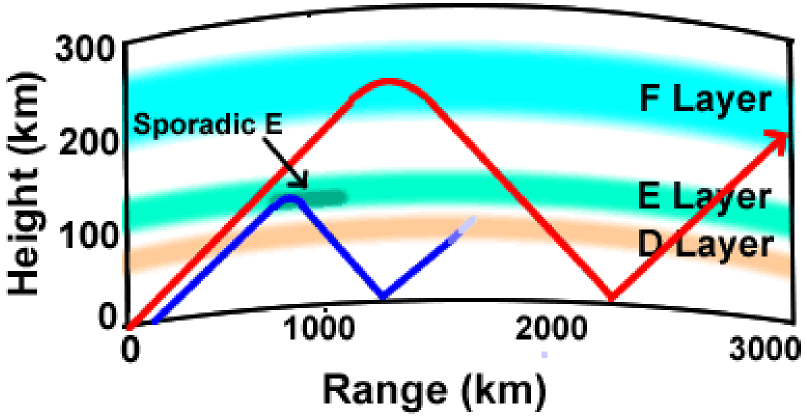
RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

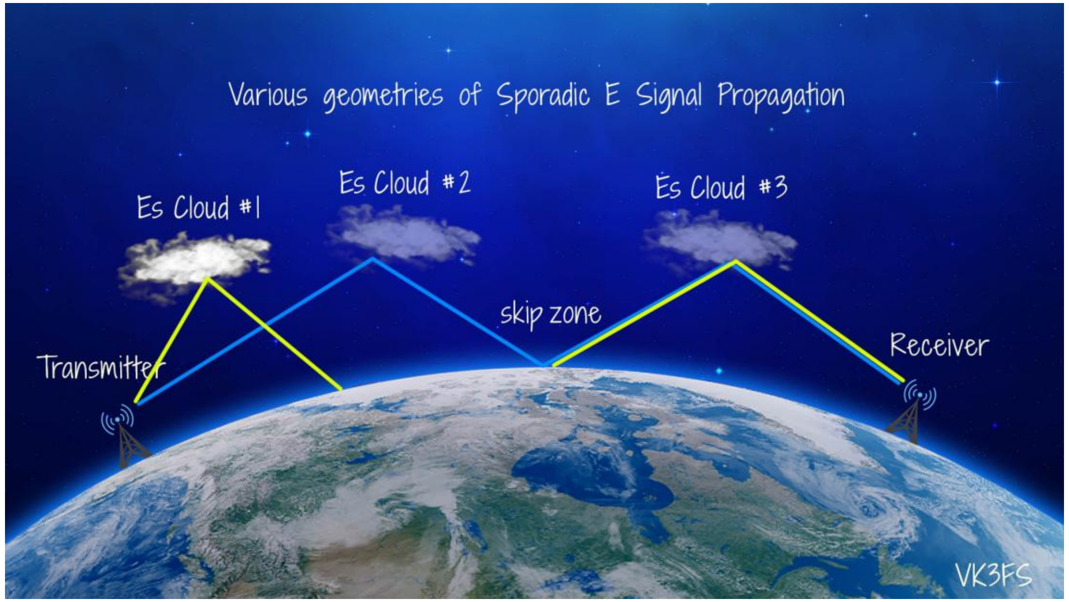
What is a beacon system?

Scientific purpose of RABSII ??

Detect sporadic E in the ionosphere







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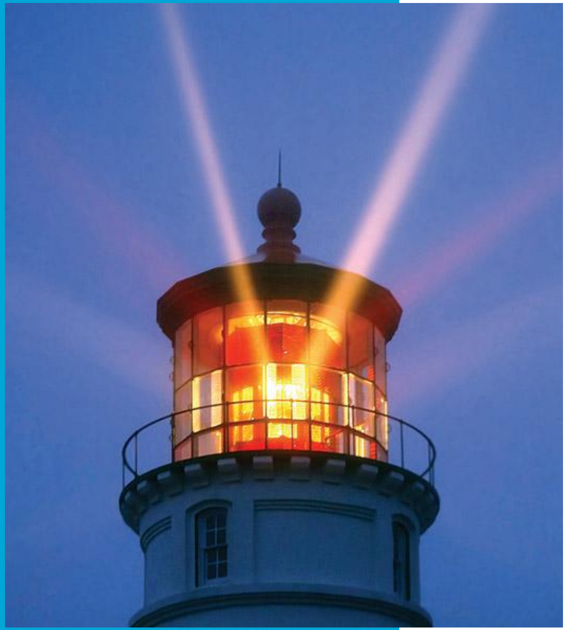
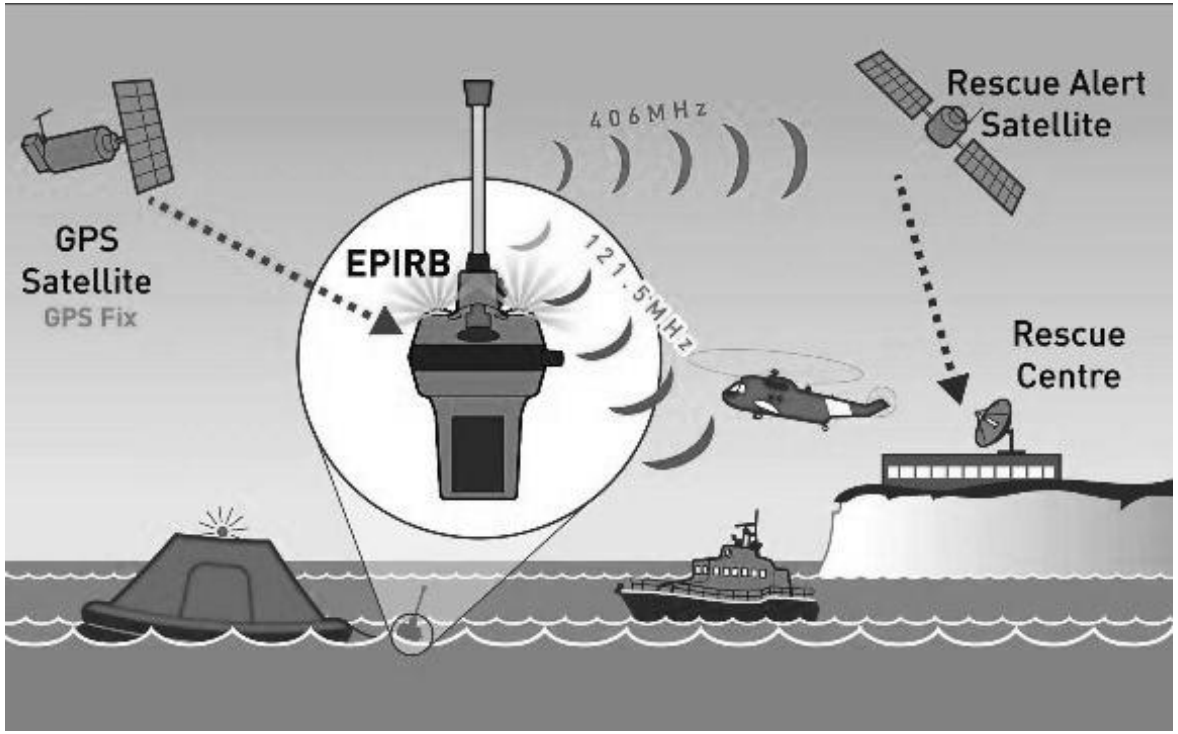
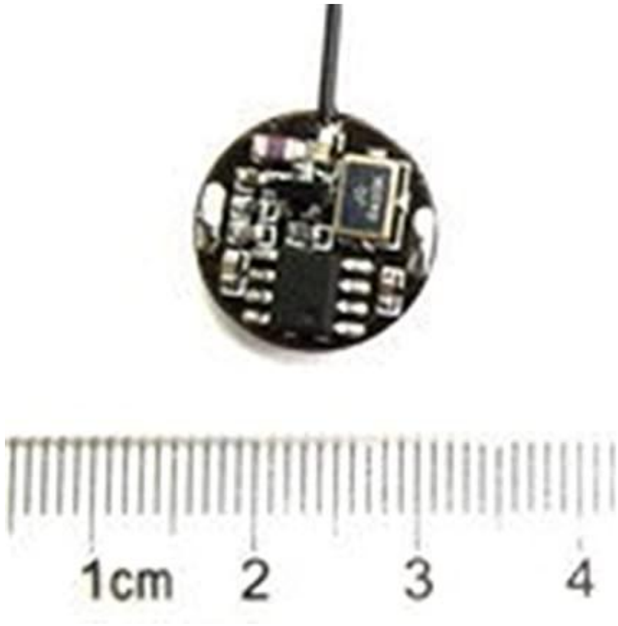


What is a beacon system?

Send info using a transmitter and antenna system





RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard a small satellite

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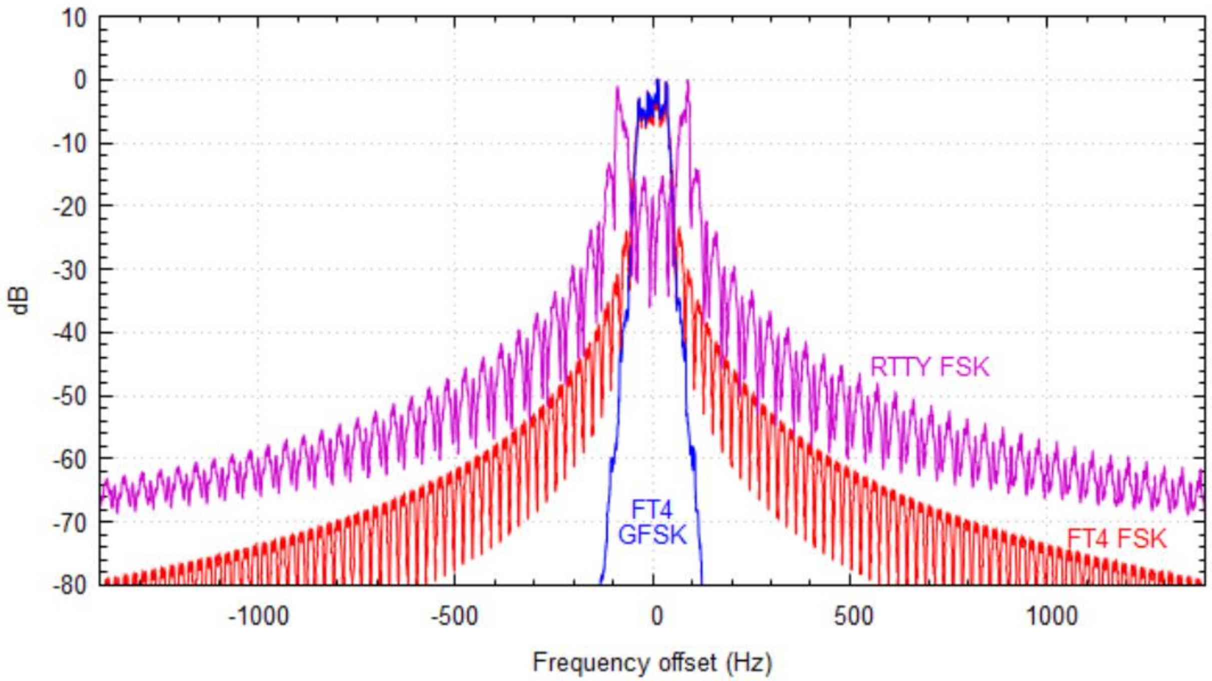
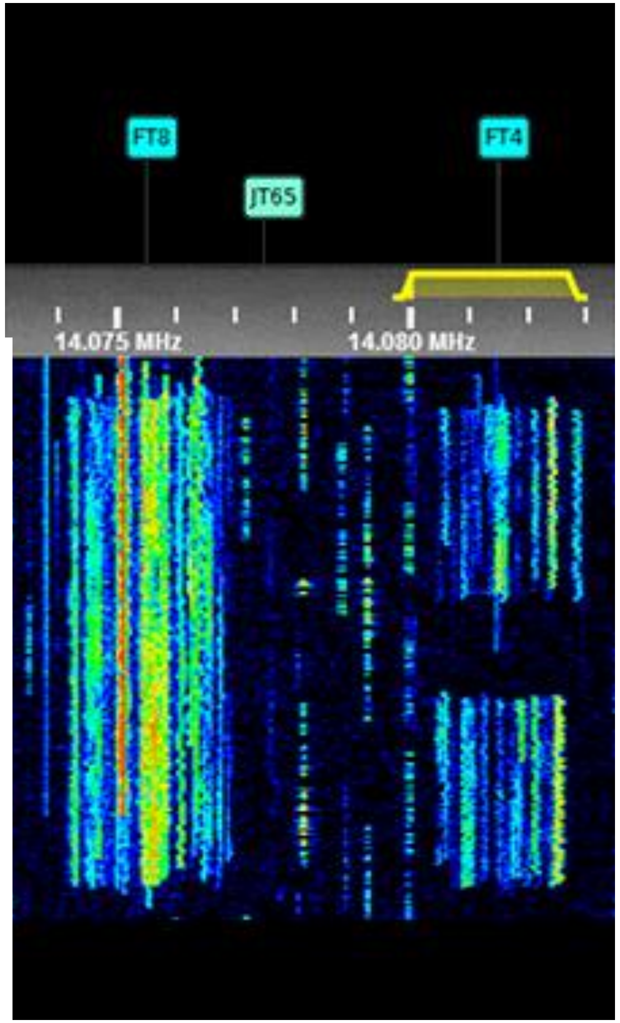
RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard a small satellite

Working principle of FT4:

- 4-tone GFSK modulation;



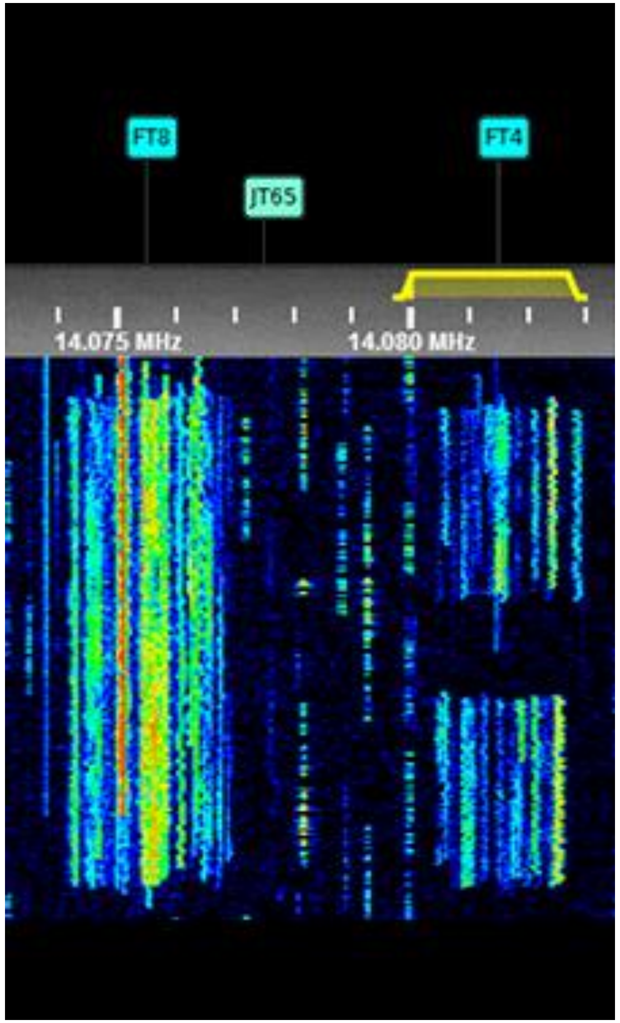


RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard a small satellite

Working principle of FT4:

- 4-tone GFSK modulation;
- 6 seconds sequence: 4.48 s transmit, 1.52 s decode
- Tone separation 20,833 Hz;
- Bandwidth of 90 Hz;
- 50% decoding probability is S/N = –16.4 dB



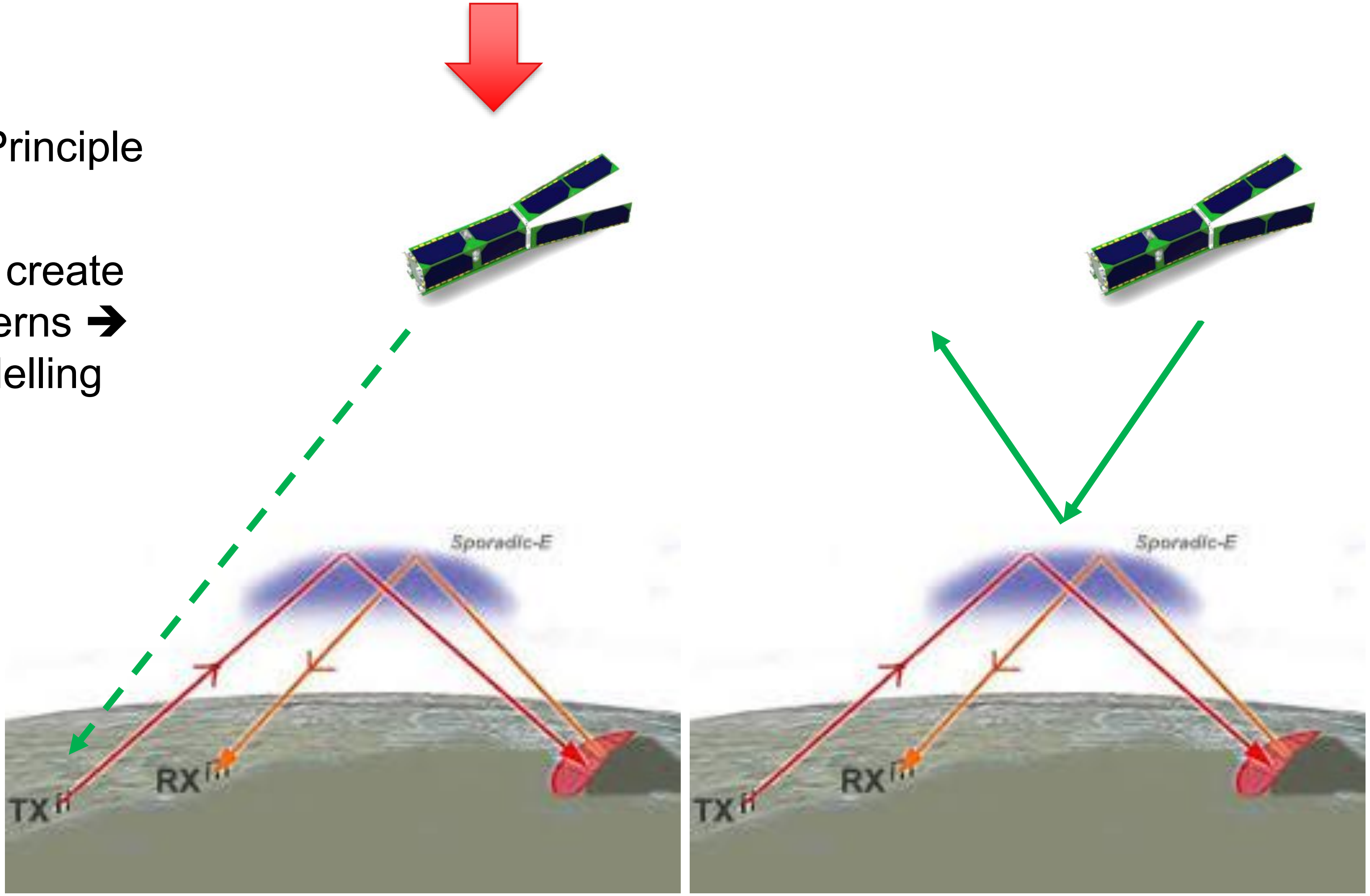
RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard a small satellite

Why FT4 and CW? – Principle

- Different SNR values create different receiving patterns ➔ allows Sporadic E modelling

- Comparison possible



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Implementing a CW and FT4 beacon aboard a small satellite

Implementation aboard the satellite:

160m	
80m	3.575
60m	
40m	7.0475
30m	10.140
20m	14.080
17m	18.104
15m	21.140
12m	24.919
10m	28.180
6m	50.318

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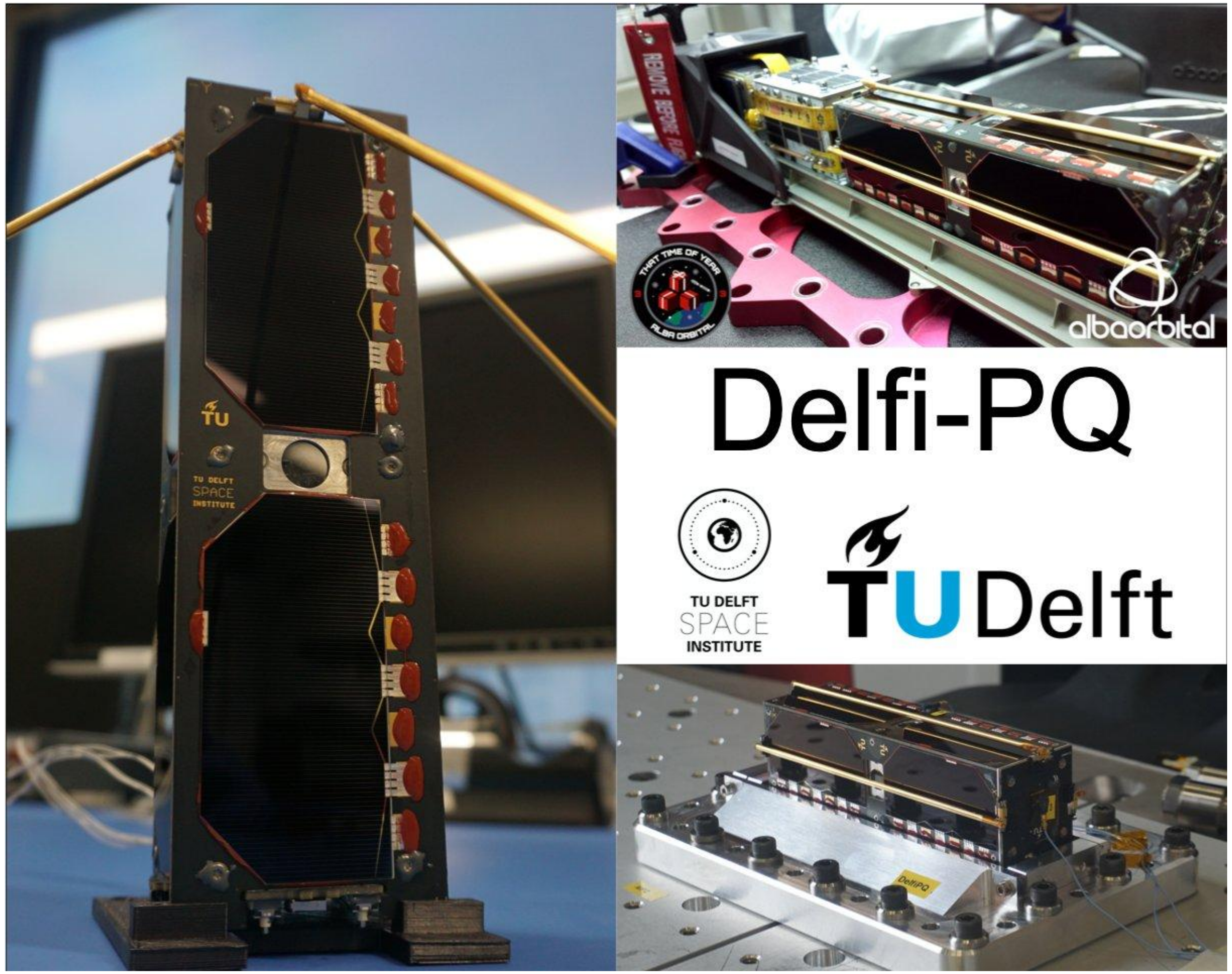

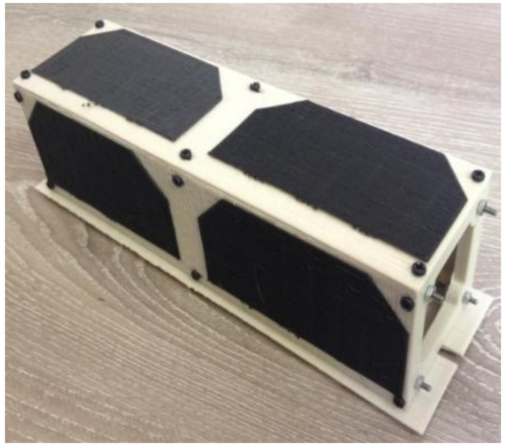

Launch of Delfi-PQ

↓

(Very) small satellites in space are hot !

↓

Many things still to discover

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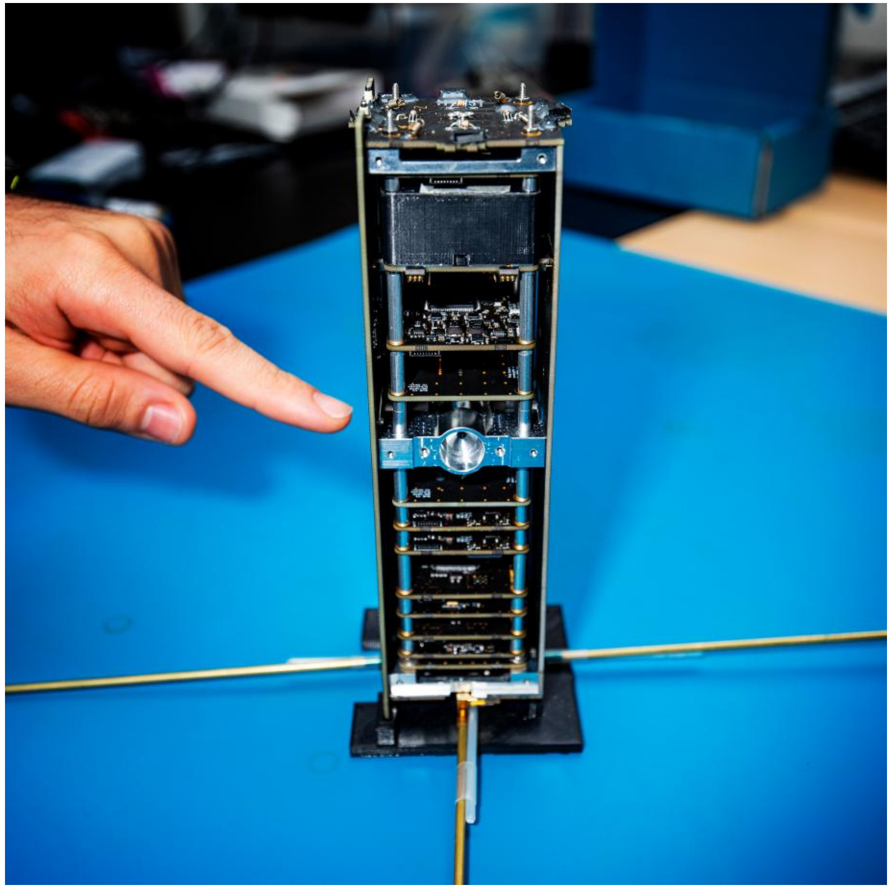
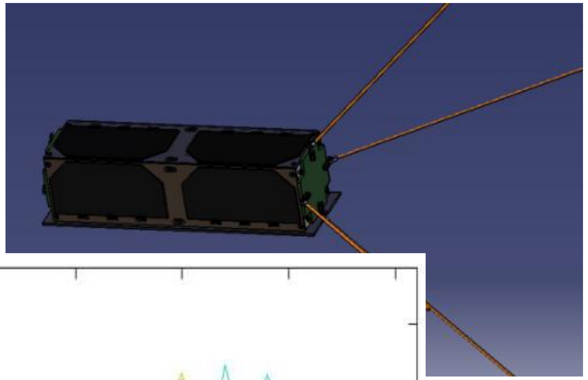
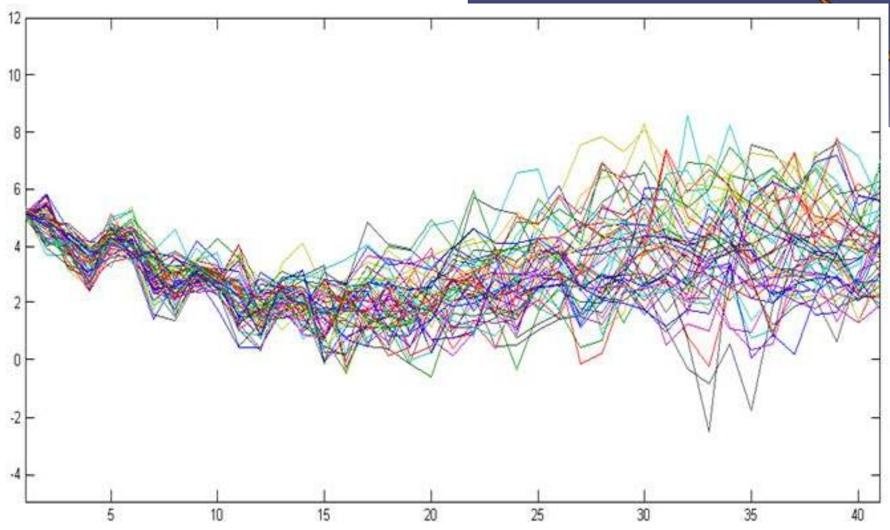
Implementing a CW and FT4 beacon aboard this small satellite



A transmitter & antenna are needed aboard the S/C

Problems??

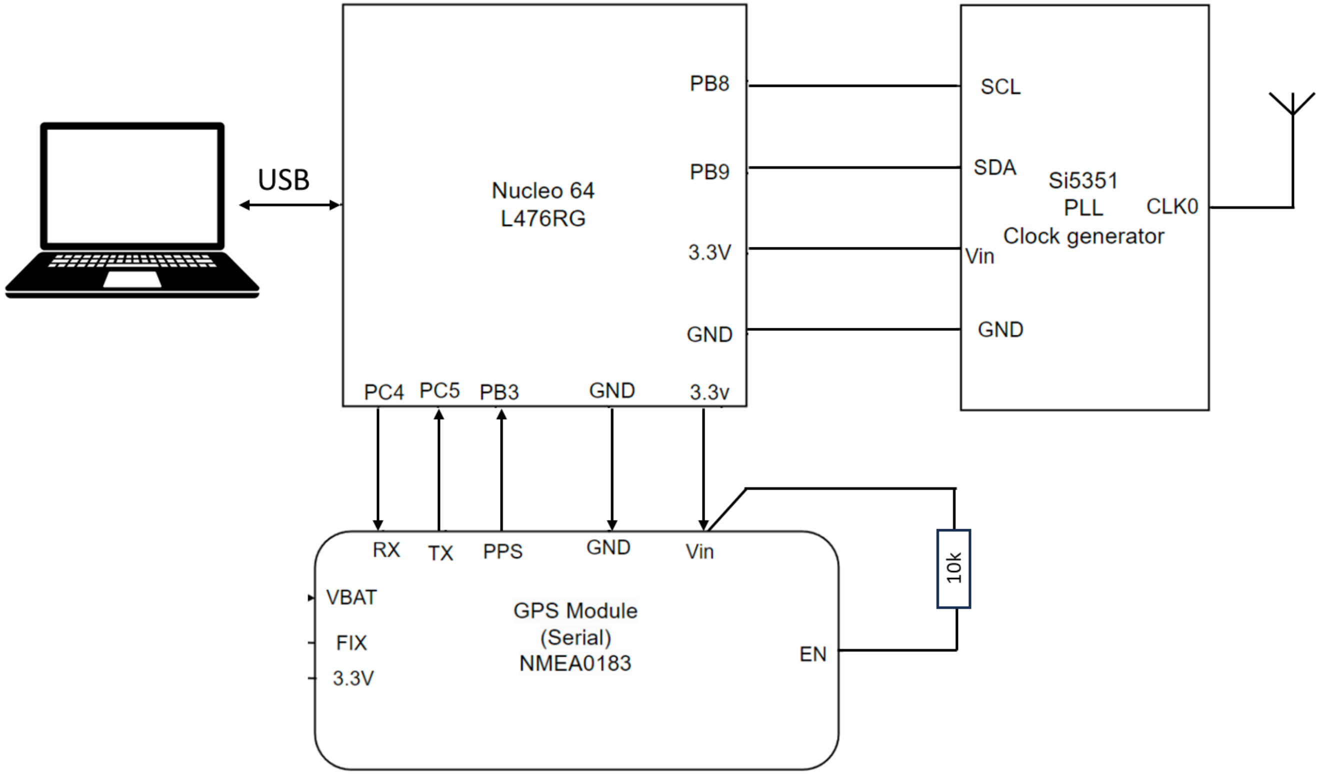




RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard this small satellite

Design based on:



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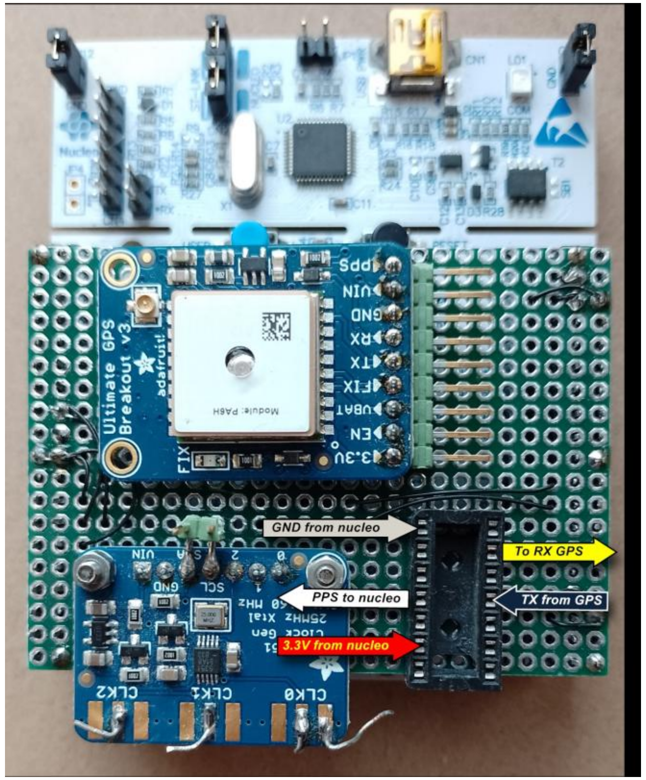
RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard this small satellite

In-house designed instrument by RST-UBA / TU Delft



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RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard this small satellite

Testing:

Doppler shift LEO satellite:

$$f = f_0\left(1 + \frac{v}{c}\right)$$

v = speed of the approaching satellite 7823 m/s

c = velocity of the speed of light $3 \cdot 10^8$ m/s

$f_0 = 28 \cdot 10^6$ Hz

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→ frequency on ground f = 28,000,730.17 Hz

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➔ frequency on ground f = 28,000,730.17 Hz
➔ difference of 730.17 Hz x 2 = 1460.34 Hz

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➔ frequency on ground f = 28,000,730.17 Hz
➔ difference of 730.17 Hz x 2 = 1460.34 Hz
➔ divided by 10 minutes pass = 2.435 Hz/s

RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

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Doppler shift LEO satellite:

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→ frequency on ground f = 28,000,730.17 Hz
→ difference of 730.17 Hz x 2 = 1460.34 Hz
→ divided by 10 minutes pass = 2.435 Hz/s
→ FT4 TX = 0.048s => 20.83 Hz

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Implementing a CW and FT4 beacon aboard this small satellite

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Doppler shift LEO satellite:

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➔ frequency on ground f = 28,000,730.17 Hz
➔ difference of 730.17 Hz x 2 = 1460.34 Hz
➔ divided by 10 minutes pass = 2.435 Hz/s
➔ FT4 TX = 0.048s => 20.83 Hz
➔ shift of 2.435 Hz/s / 20.83 Hz = **117 mHz**

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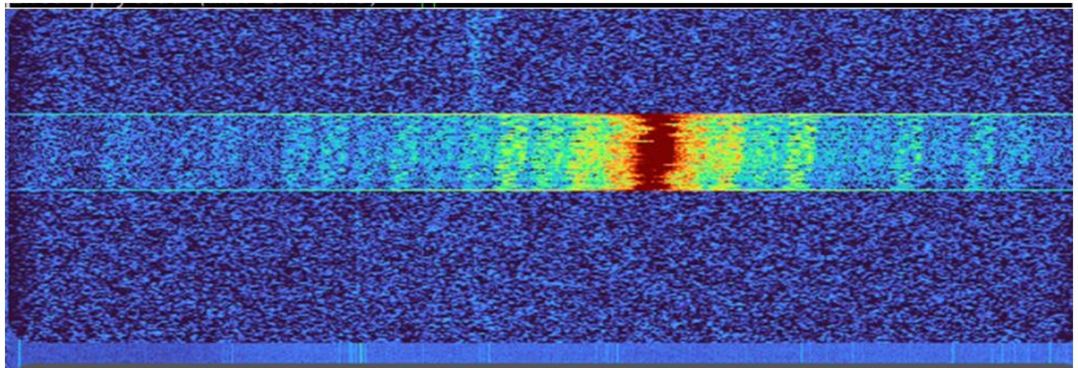
RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard this small satellite

Testing:

```
Used payload='ON5ADL JO20PX'
FT4 sequence started. Doppler delta=120 mHz
Enter payload (max 13 chars) >>200
Delta changed to 200 mHz !!
Enter payload (max 13 chars) >>on5adl jo20px
Used payload='ON5ADL JO20PX'
FT4 sequence started. Doppler delta=200 mHz
Enter payload (max 13 chars) >>250
Delta changed to 250 mHz !!
Enter payload (max 13 chars) >>on5adl jo20px
Used payload='ON5ADL JO20PX'
FT4 sequence started. Doppler delta=250 mHz
Enter payload (max 13 chars) >>
Used payload='ON5ADL JO20PX'
FT4 sequence started. Doppler delta=250 mHz
Enter payload (max 13 chars) >>240
Delta changed to 240 mHz !!
Enter payload (max 13 chars) >>on5adl jo20px
Used payload='ON5ADL JO20PX'
FT4 sequence started. Doppler delta=240 mHz
Enter payload (max 13 chars) >>
```



UTC	dB	DT	Freq	Message
191652	25	0.1	28181762	ON5ADL JO20PX
191737	25	0.3	28181761	ON5ADL JO20PX
191815	25	0.1	28181760	ON5ADL JO20PX
191945	25	0.1	28181762	ON5ADL JO20PX

Clear

RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

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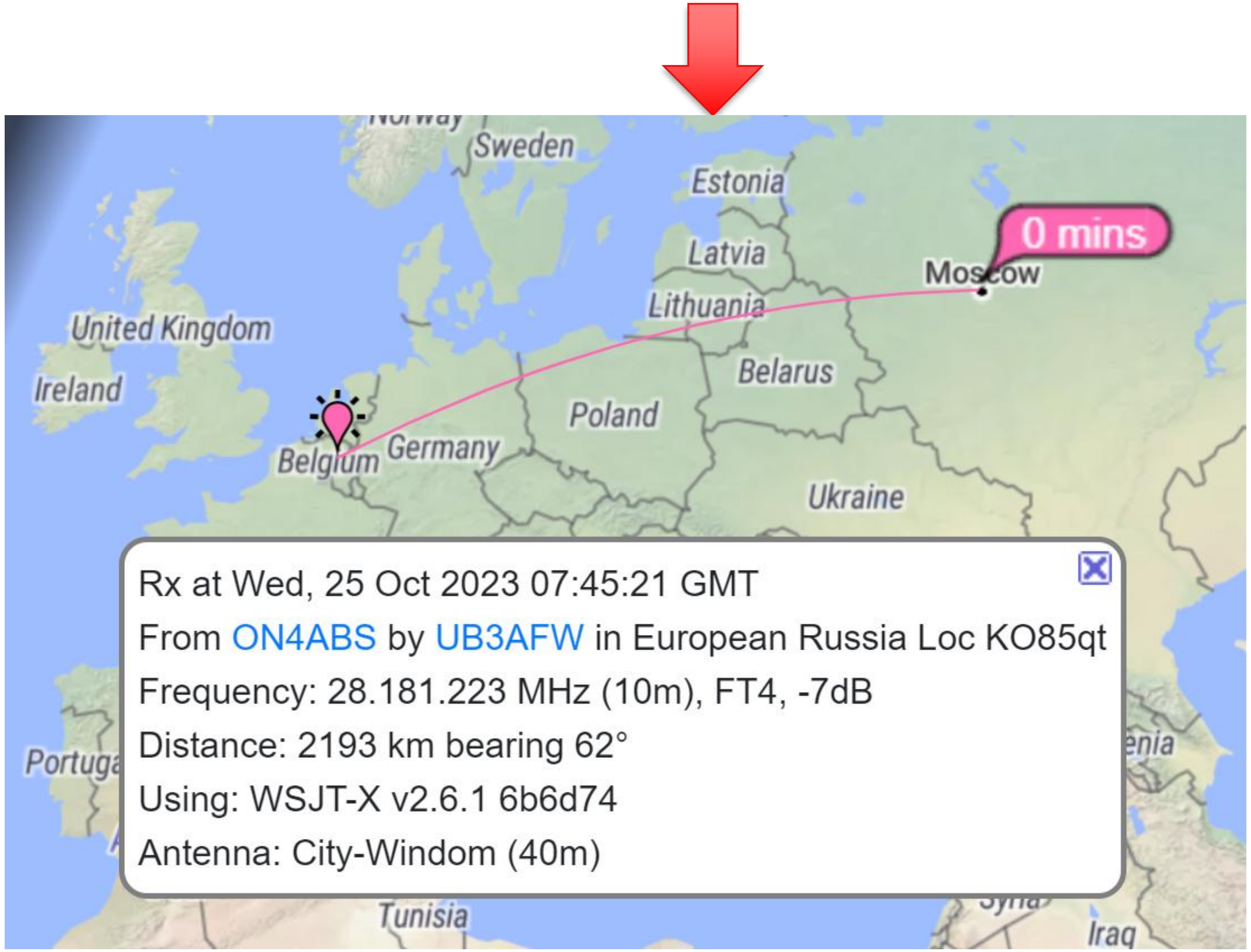

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RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

630m 160m 80m 60m 40m 30m 20m 17m 15m 12m 10m 6m 4m 2m

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☑ ☐ ☐ ☐

cw rtty psk31 psk63

☑ ☐ ☐ ☐

☐ CQ ☐ DX ☐ BCN ☐ /B ☐ NCDXF

Unfreeze Zoom

Max rows: 20 Max age: 10 Hours

New spots: 0

☑ Show Spotters Advanced Mode

CW Speed: Min all Max all

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- ☐ distance km
- ☑ freq
- ☑ mode
- ☑ type
- ☑ snr
- ☑ speed
- ☑ time
- ☑ seen

	● Spotter (de)	● Spotted (dx)
callsign	spotter-callsign	on4abs

● spotter	● spotted	distance mi	freq	mode	type	snr	speed	time	seen
WZ7I	ON4ABS	3750 mi	28020.3	CW	CQ	4 dB	25 wpm	1314z 26 Oct	79 seconds ago
ES5PC	ON4ABS	1003 mi	28020.3	CW	CQ	22 dB	25 wpm	1314z 26 Oct	103 seconds ago
W3UA	ON4ABS	3496 mi	28020.3	CW	CQ	6 dB	26 wpm	1311z 26 Oct	4 minutes ago
UY2RA	ON4ABS	1076 mi	28020.3	CW	CQ	8 dB	25 wpm	1311z 26 Oct	4 minutes ago
RU9CZD	ON4ABS	2255 mi	28020.2	CW	CQ	4 dB	25 wpm	1310z 26 Oct	5 minutes ago

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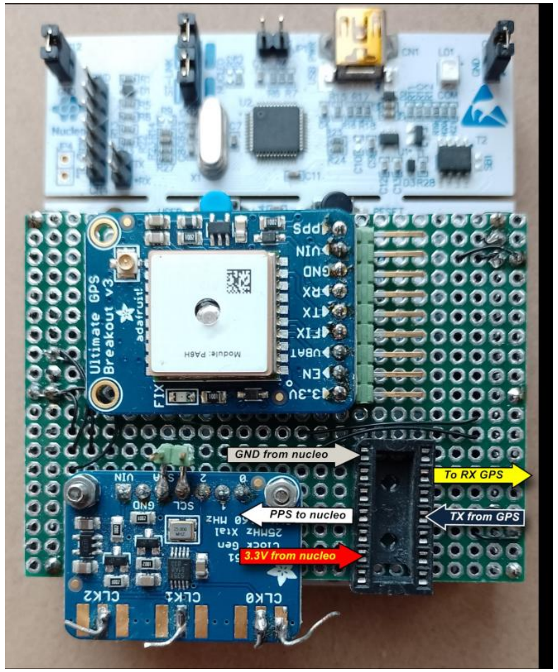
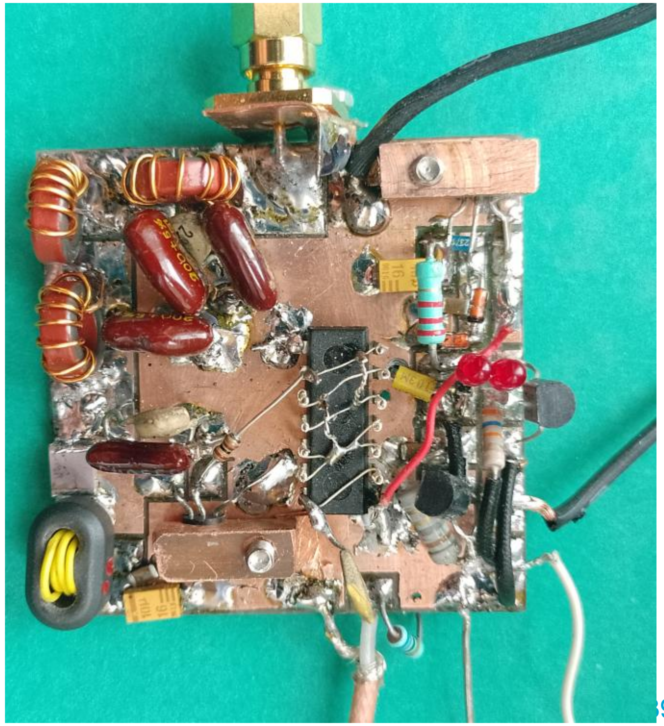
RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard this small satellite



Prototype on one PCB layout :



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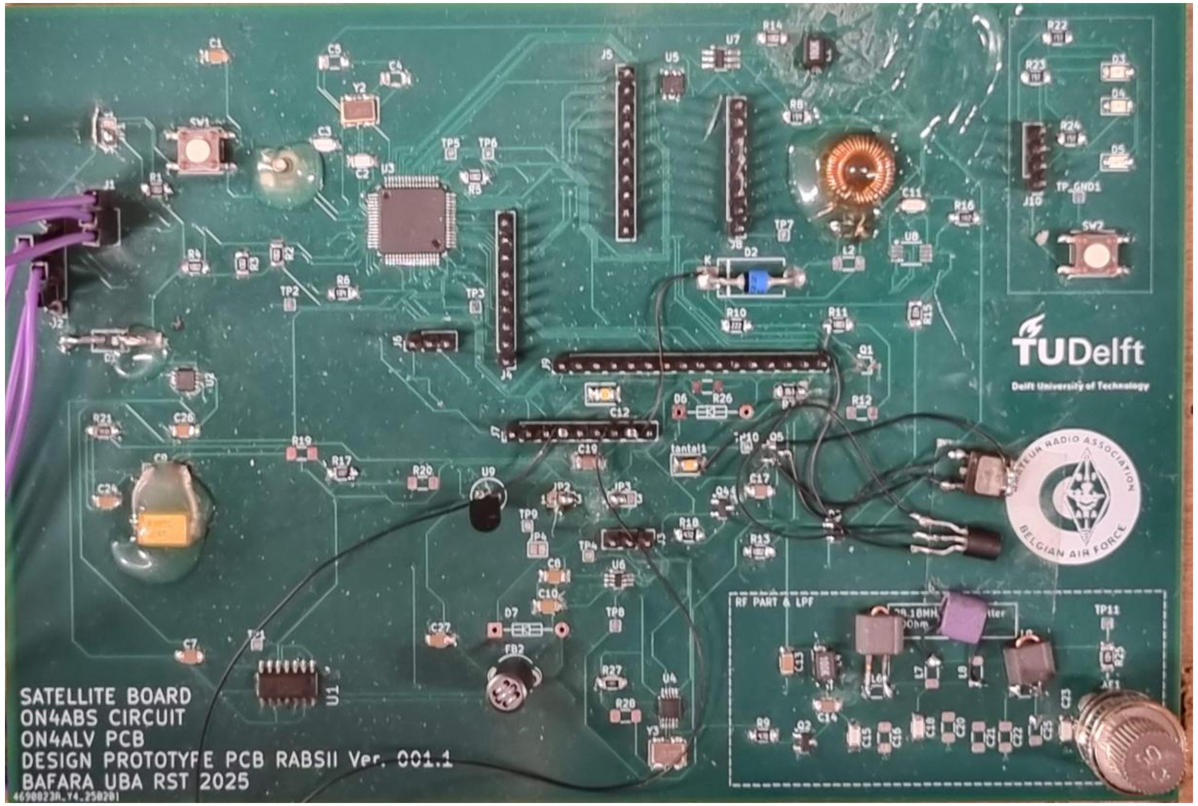
Implementing a CW and FT4 beacon aboard this small satellite

Prototype development (4 layers)



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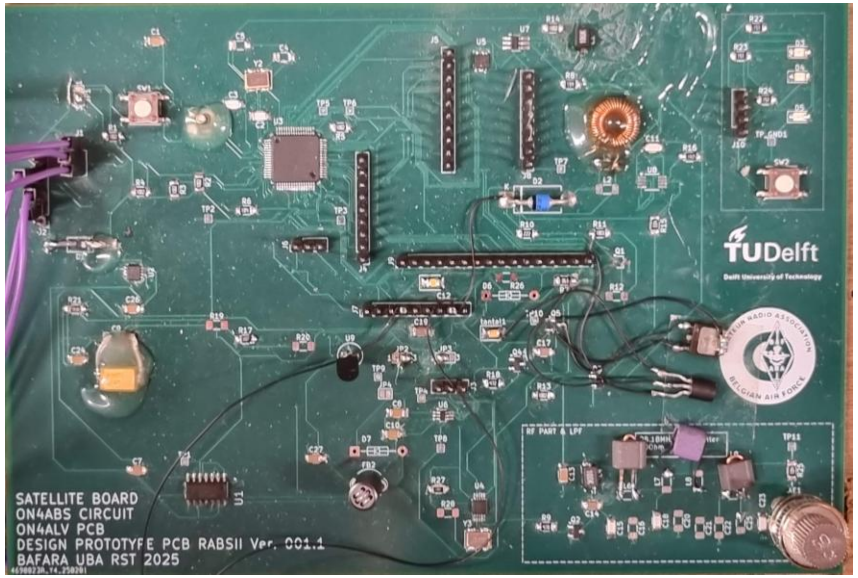
RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Implementing a CW and FT4 beacon aboard this small satellite

Prototype development (4 layers)

- Design a SMD protoype
- Functional testing
- Performance testing



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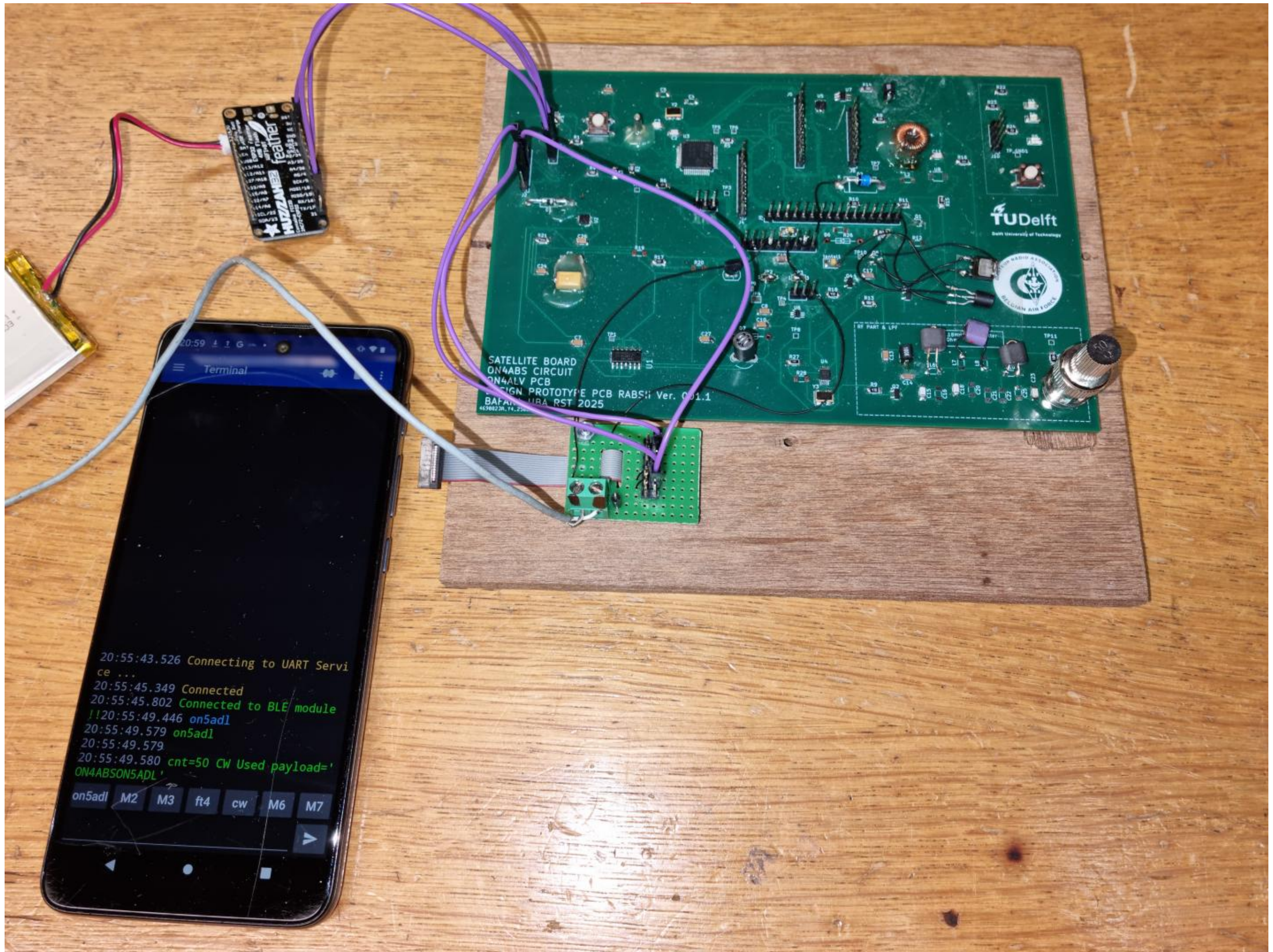

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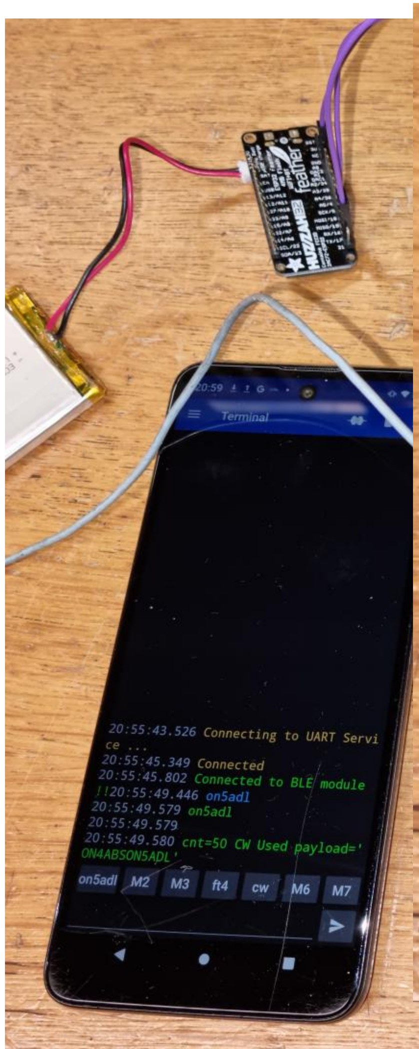

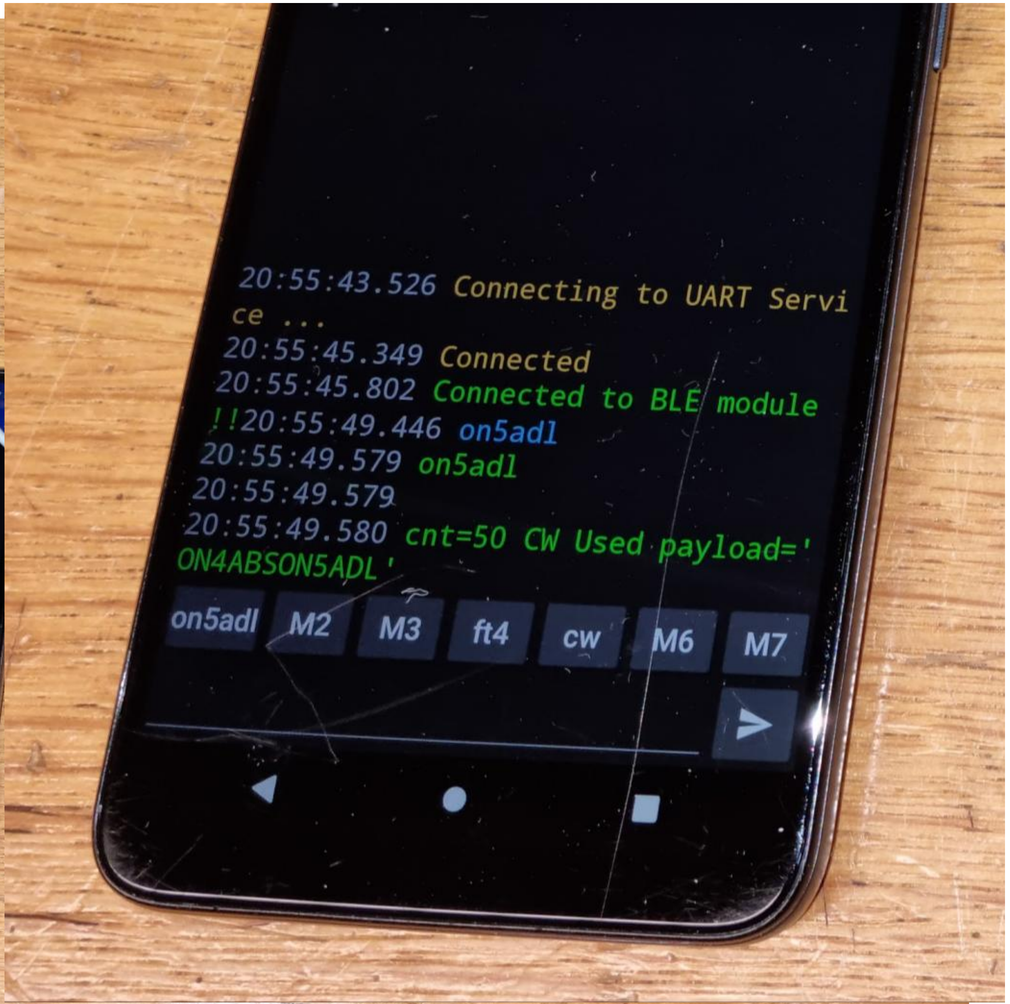

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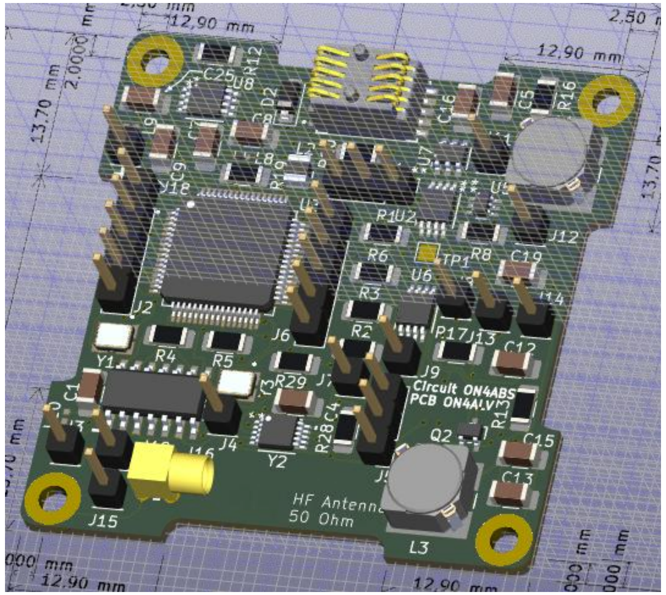
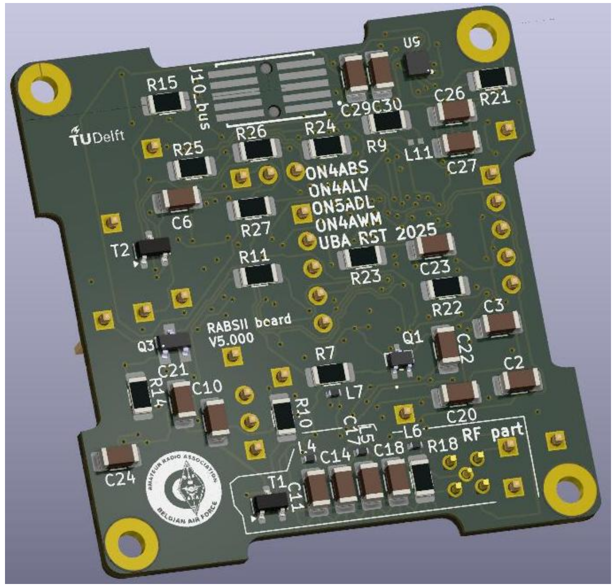
Implementing a CW and FT4 beacon aboard this small satellite

Multiple versions of 4,8 x 4,8 cm PCB (multilayer)





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Implementing a CW and FT4 beacon aboard this small satellite

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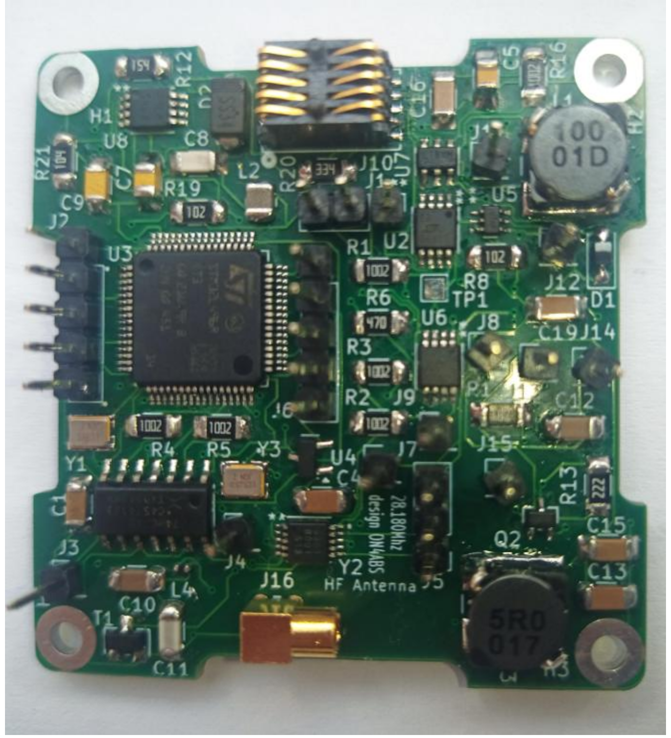

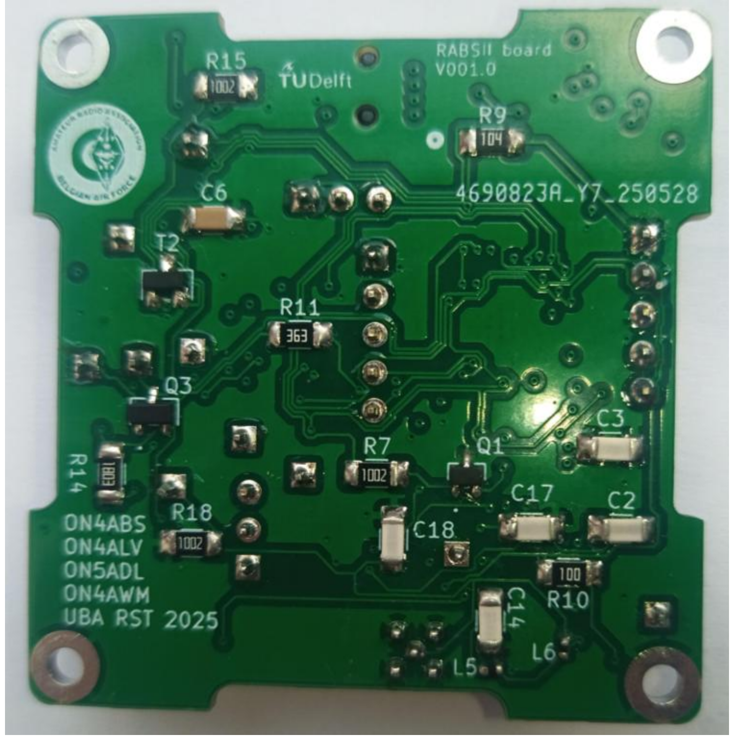

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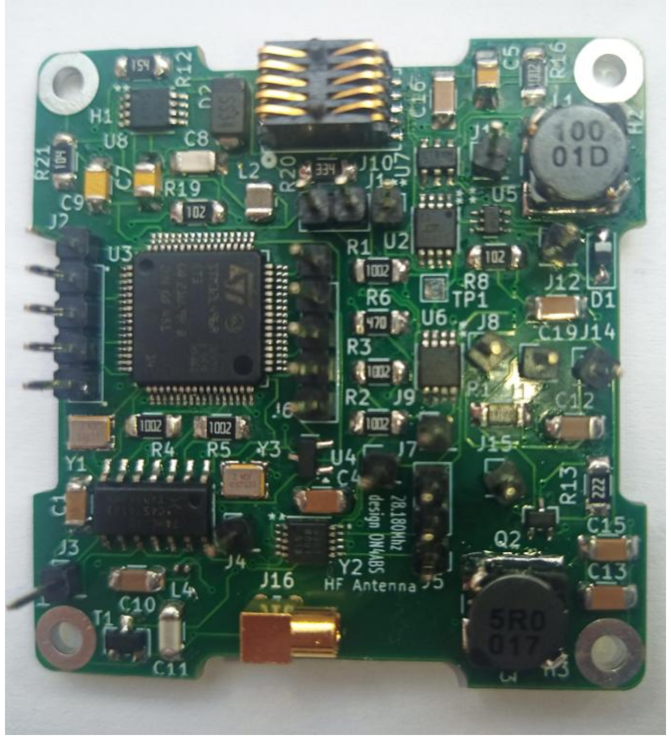
Implementing a CW and FT4 beacon aboard this small satellite

Next steps: testing

- Life cycle
- Vacuum testing
- Thermal cycling
- Radiation testing



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Implementing a CW and FT4 beacon aboard this small satellite

Delfi-Twin setup

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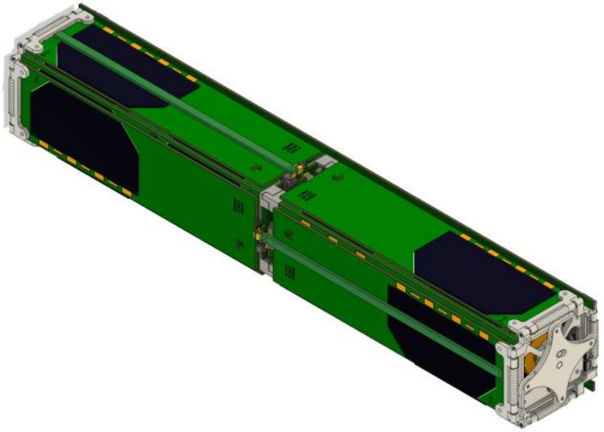
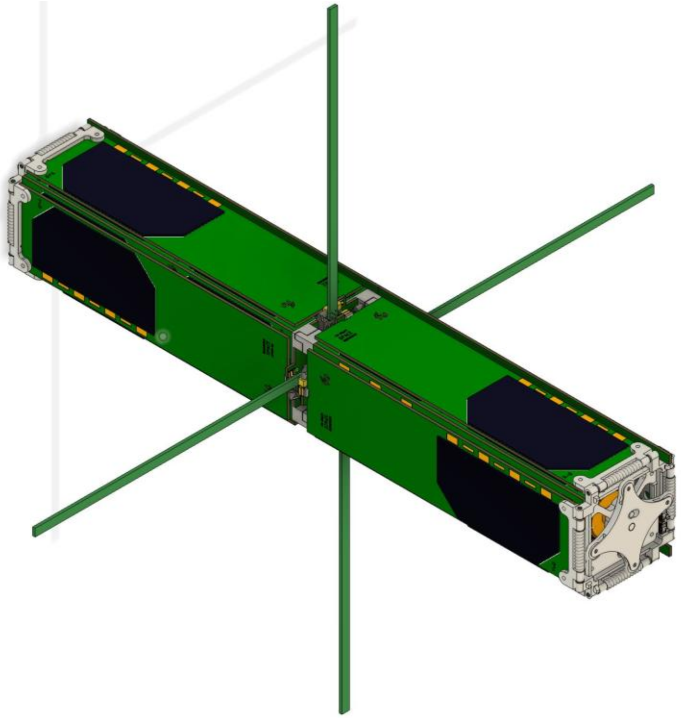
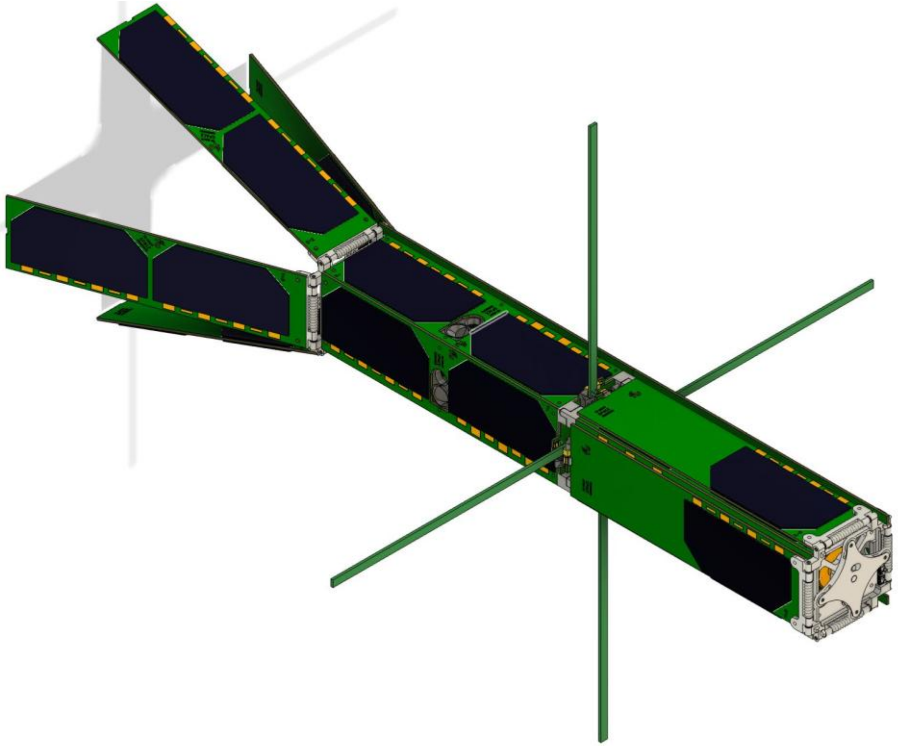
Implementing a CW and FT4 beacon aboard this small satellite







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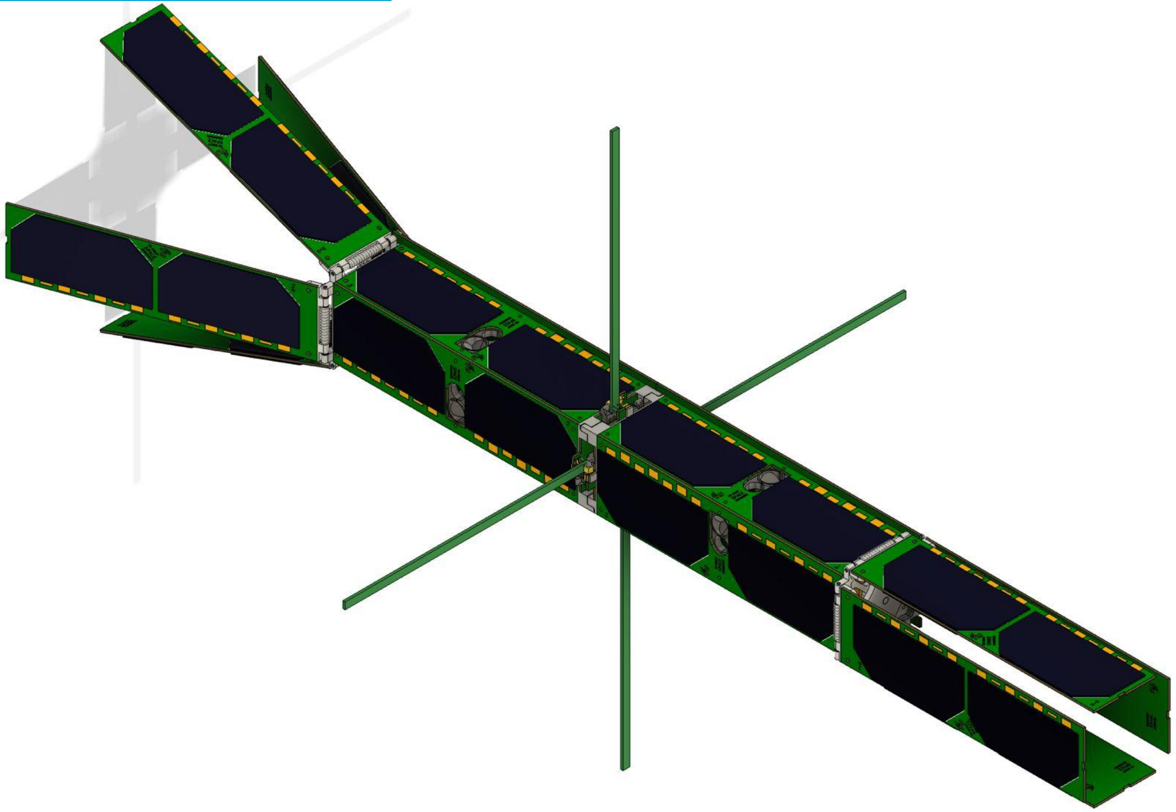
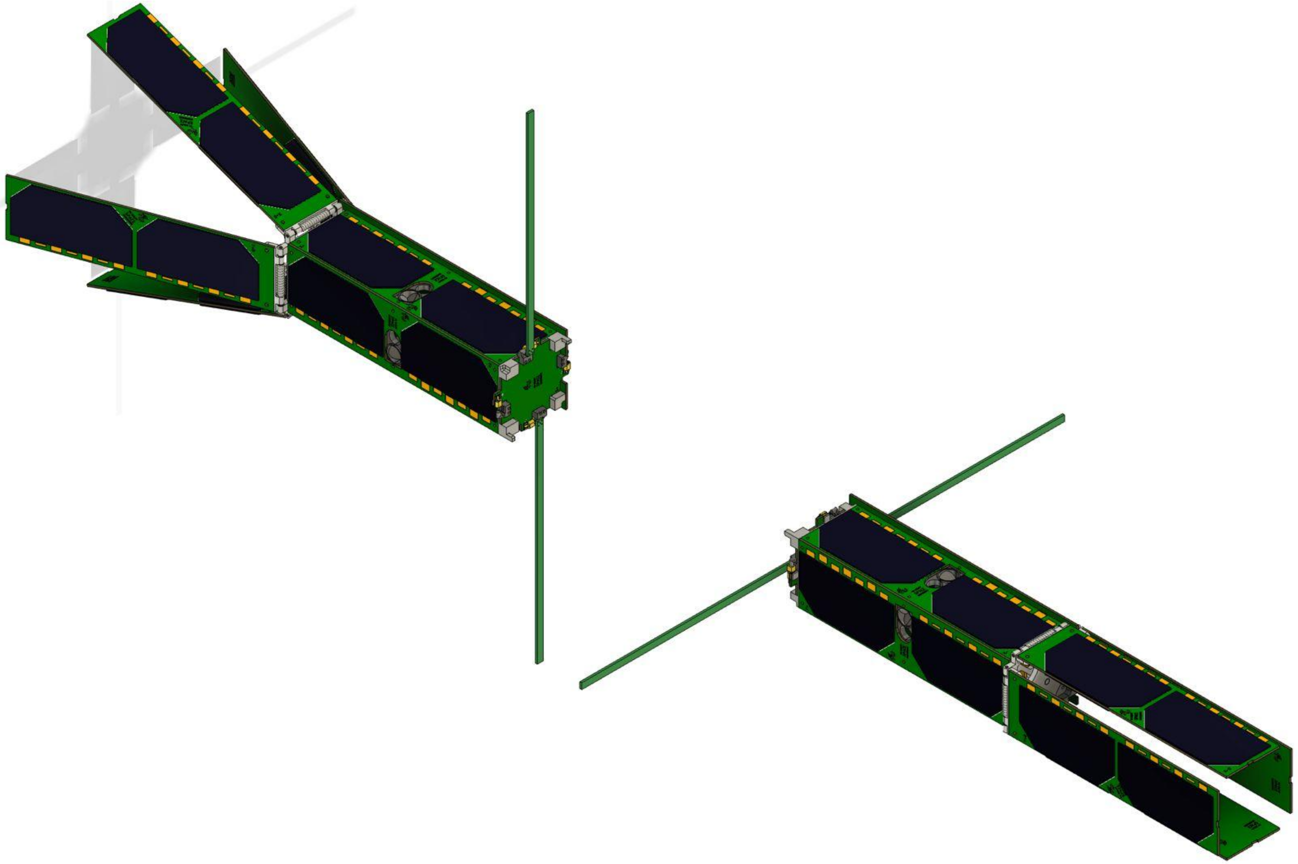
Implementing a CW and FT4 beacon aboard this small satellite





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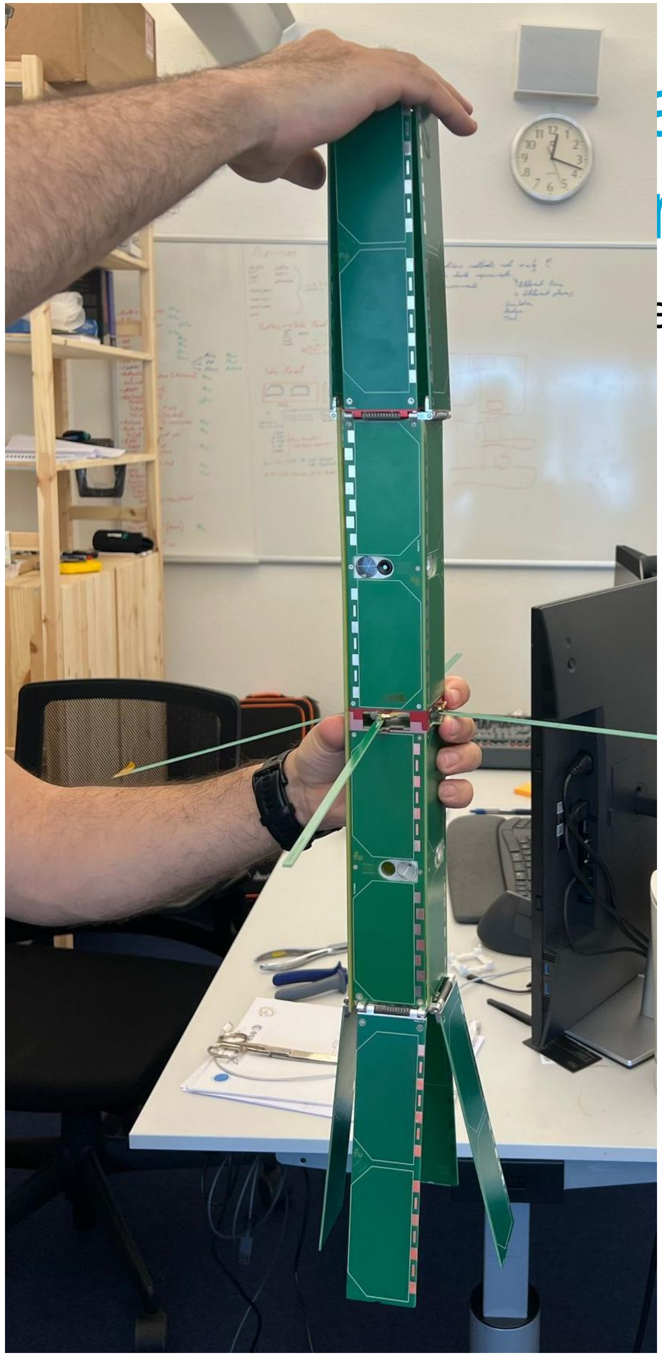

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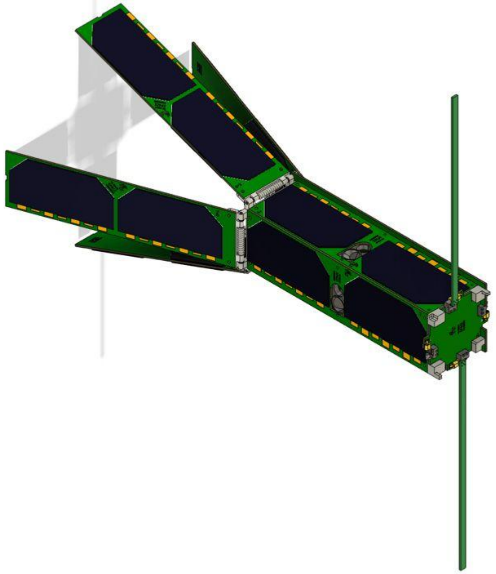

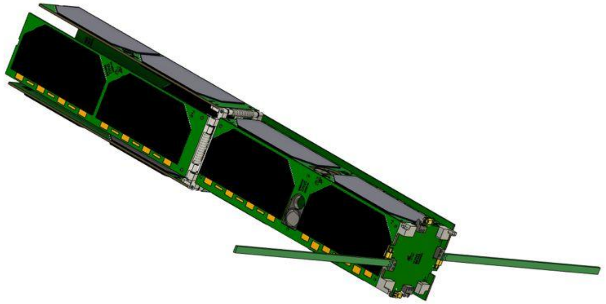

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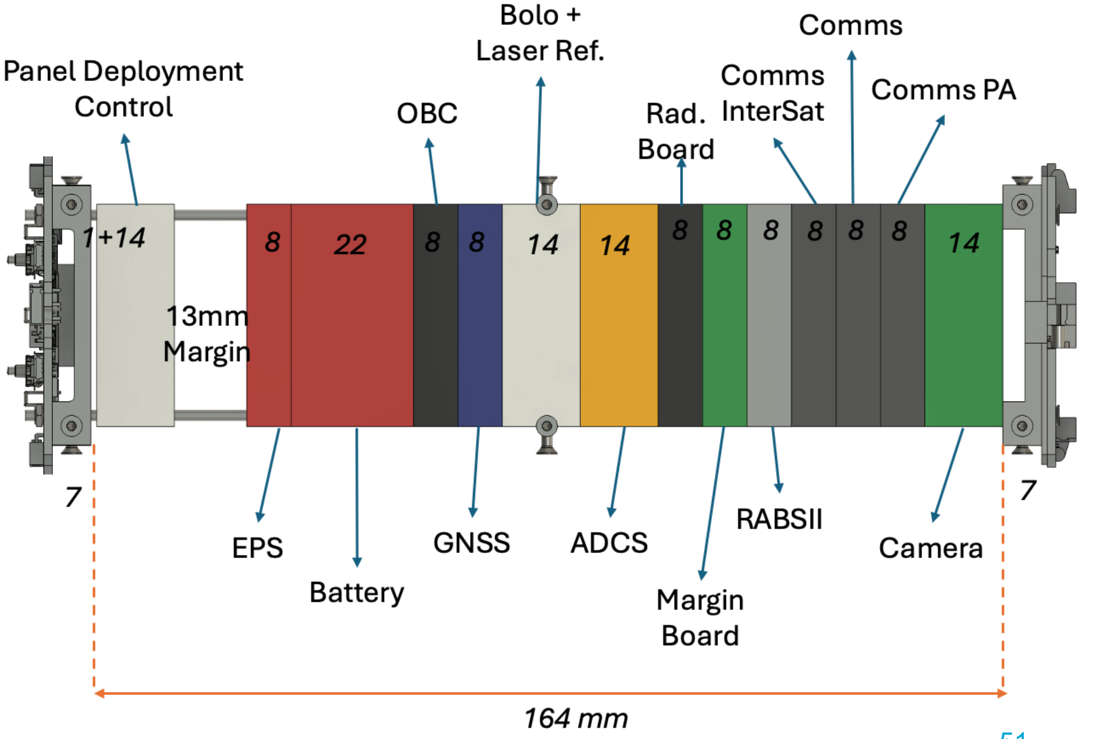
Implementing a CW and FT4 beacon aboard this small satellite

Integration



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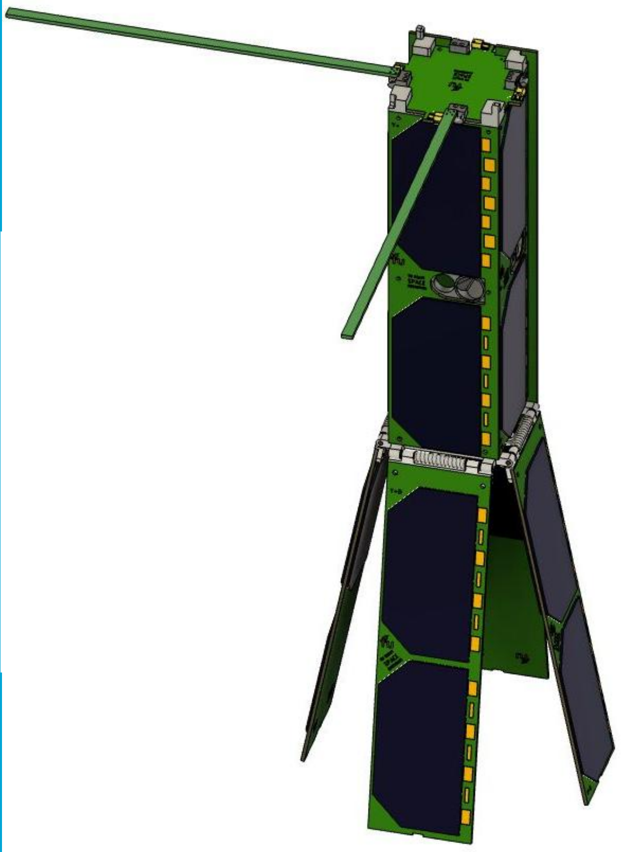
Integrating the antenna aboard this small satellite



Challenges:

- Antenna design
- Deployment system

10m band: dipole ➔ 5 m long ➔ each leg: 2.5 m long

6m band: dipole ➔ 3 m long ➔ each leg: 1.5 m long

RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Integrating the antenna aboard this small satellite

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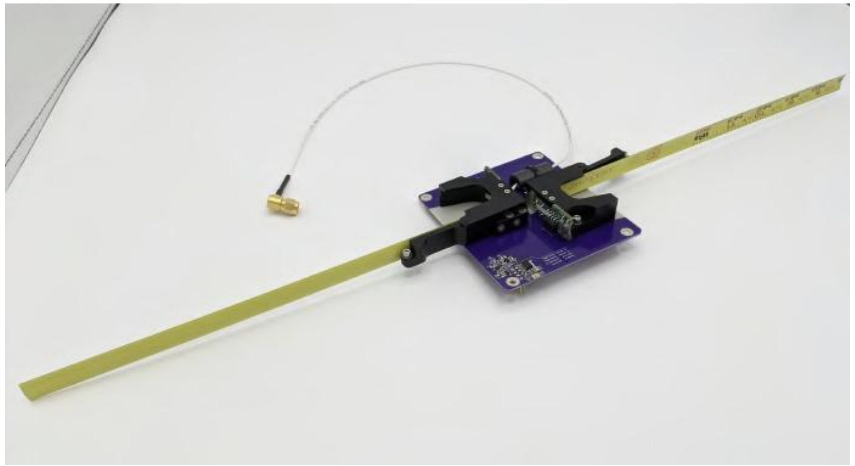

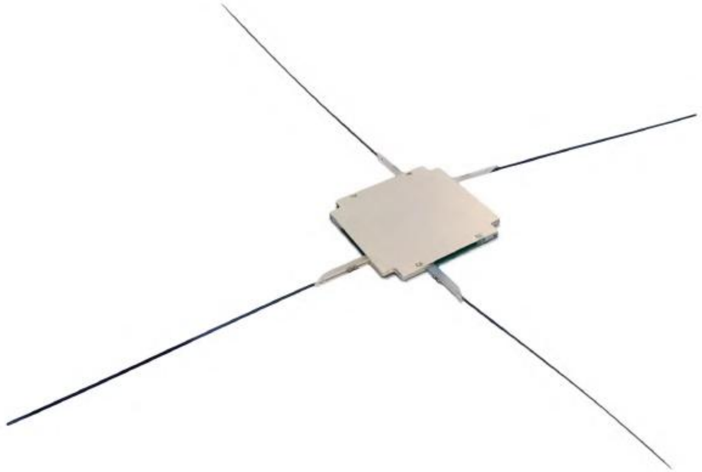

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Integrating the antenna aboard this small satellite

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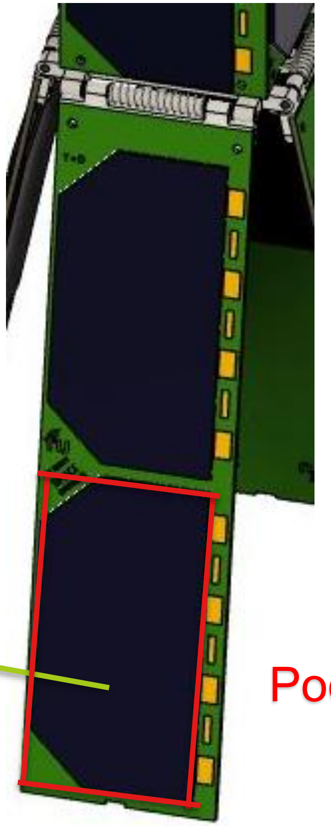


Size: 2 x 2.5 m (28 MHz)

2 x 1.5 m (50 MHz)

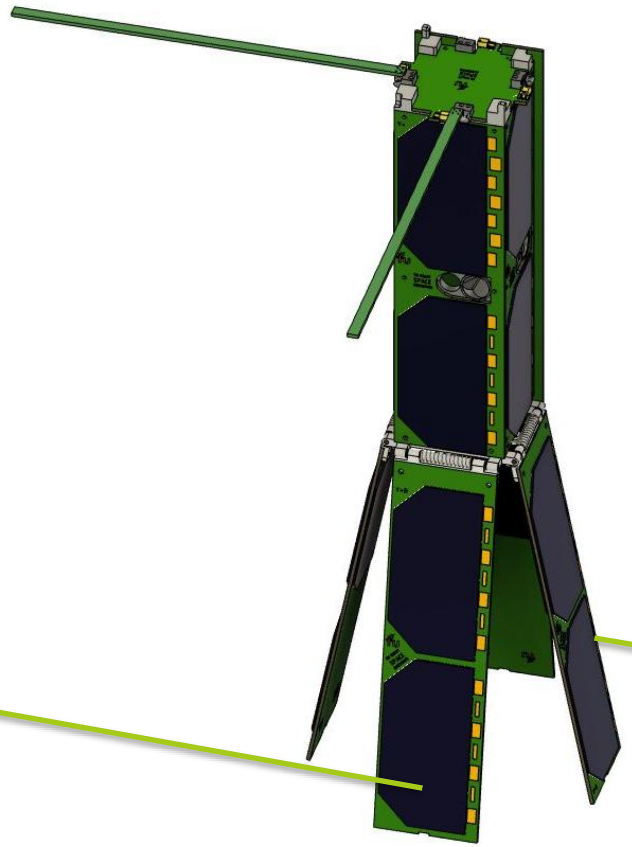
Pocket size available: 8 cm x 4 cm x 2 mm

RABSII - Radio Amateur Beacons aboard a nanosatellite for the Investigation of the Ionosphere

Integrating the antenna aboard this small satellite

10m band: dipole → 5 m long → each leg: 2.5 m long

6m band: dipole → 3 m long → each leg: 1.5 m long



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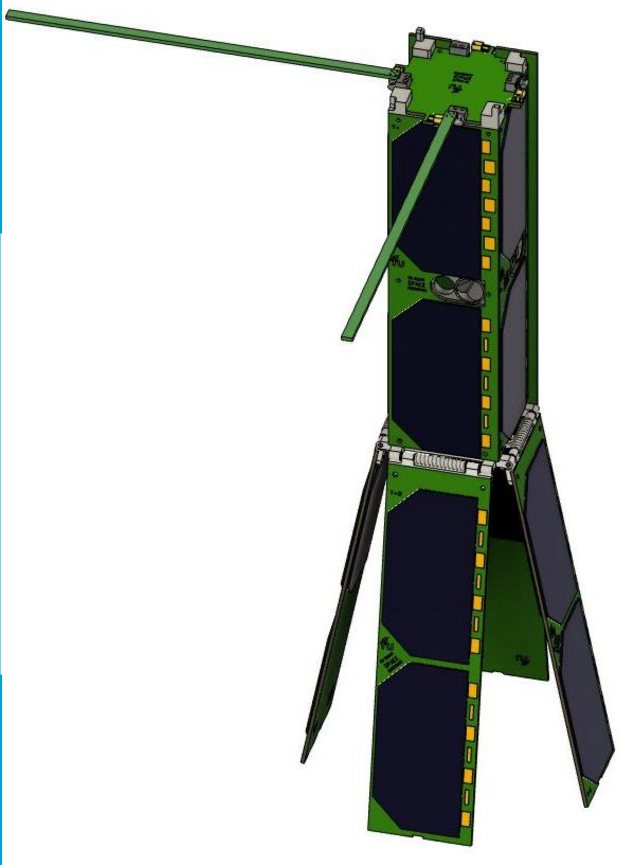
Integrating the antenna aboard this small satellite



Nitinol: shape-memory alloy (SMA)

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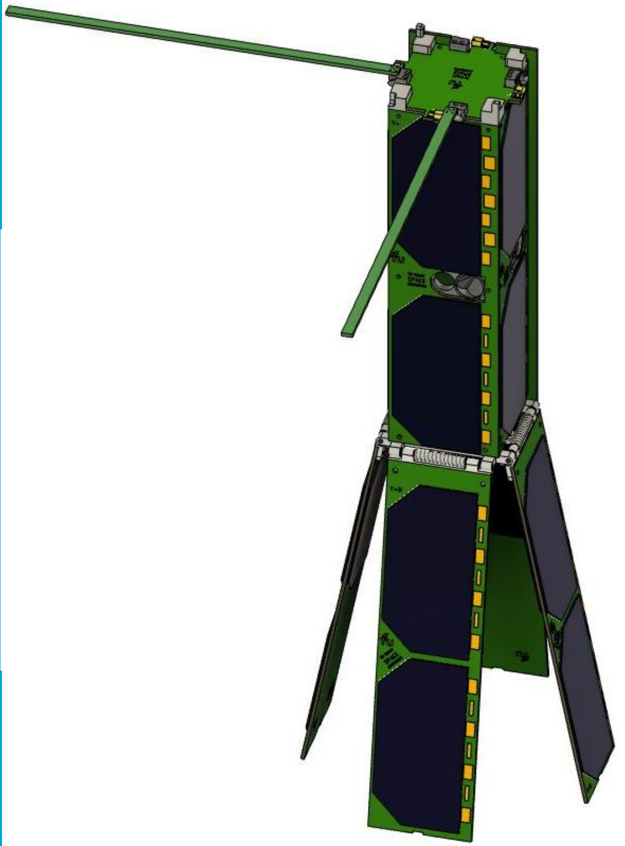
Integrating the antenna aboard this small satellite



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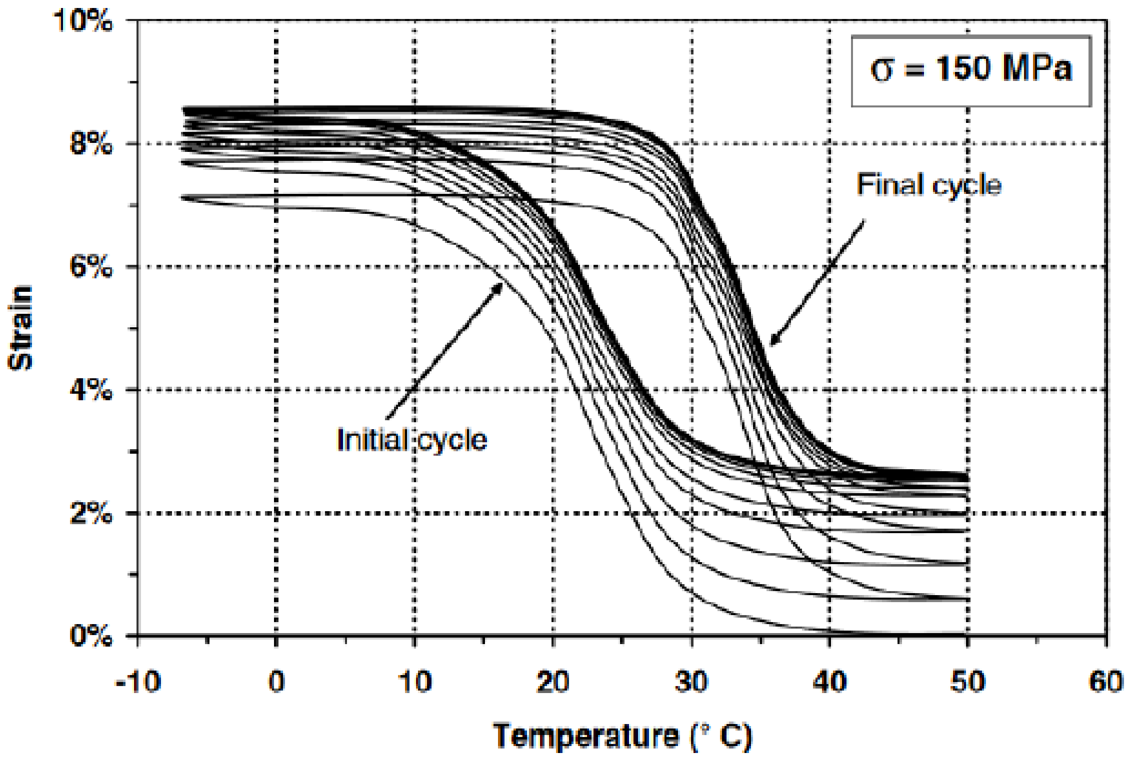

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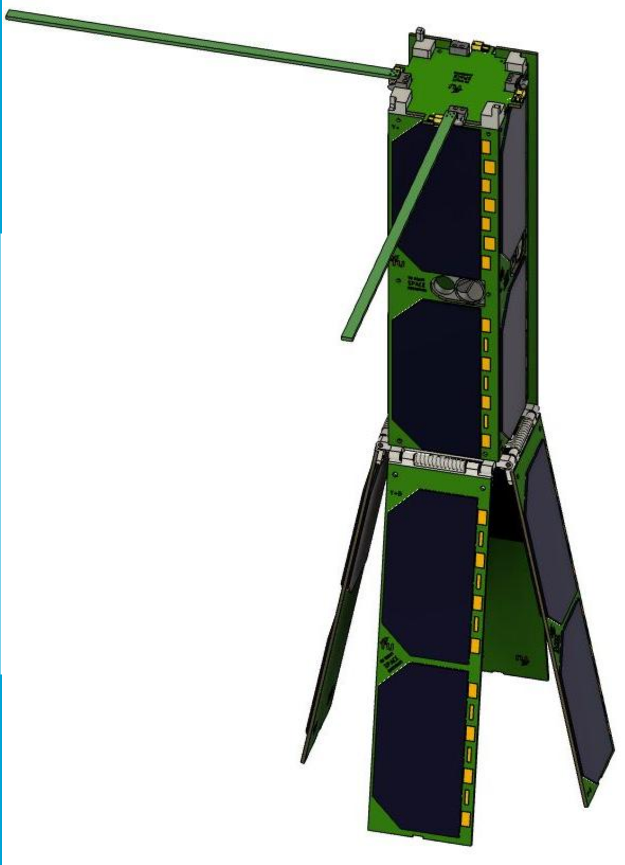
Integrating the antenna aboard this small satellite



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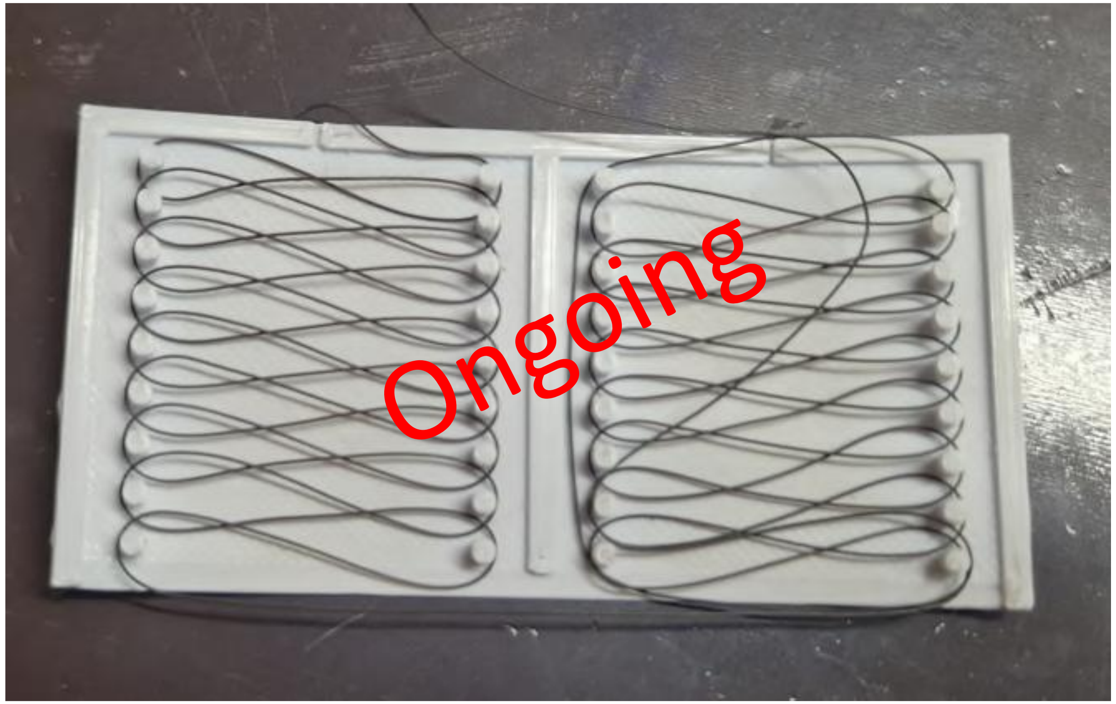

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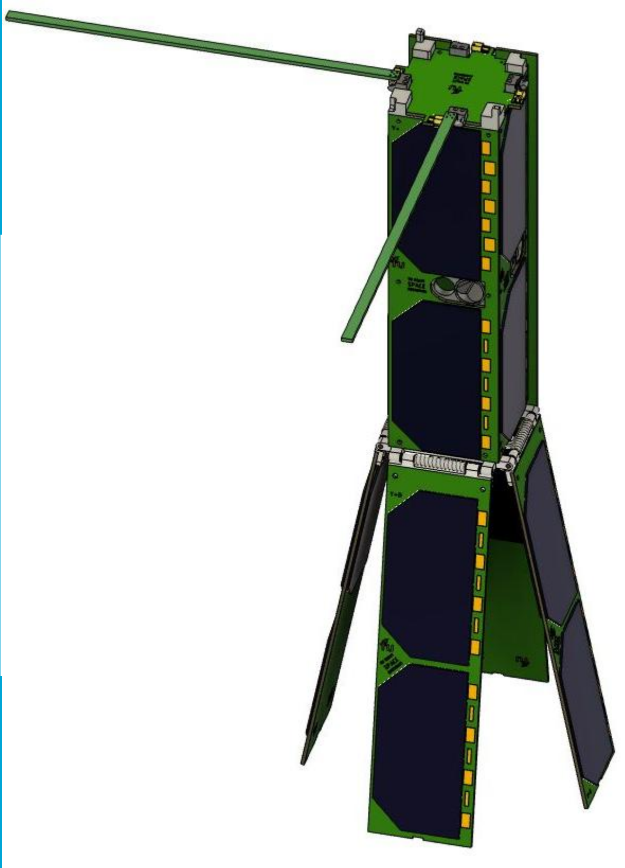
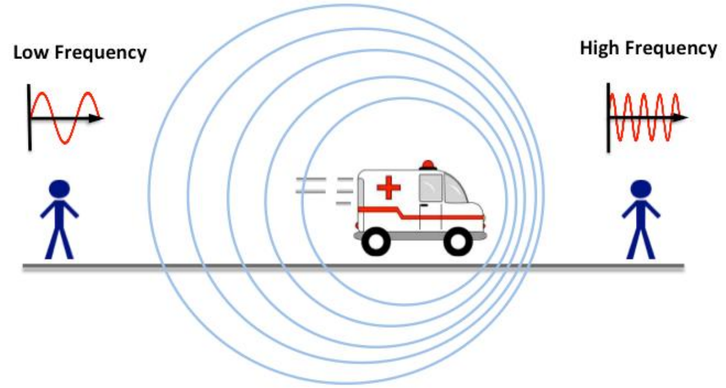
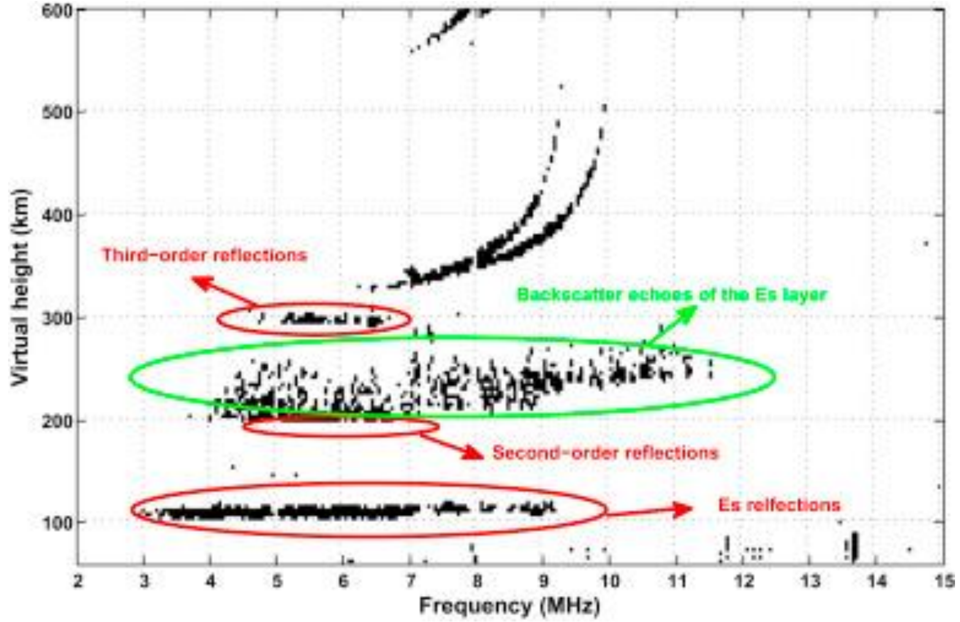


Other challenges

- Antenna design
- Deployment system
- Signal behavior
- Data analyses





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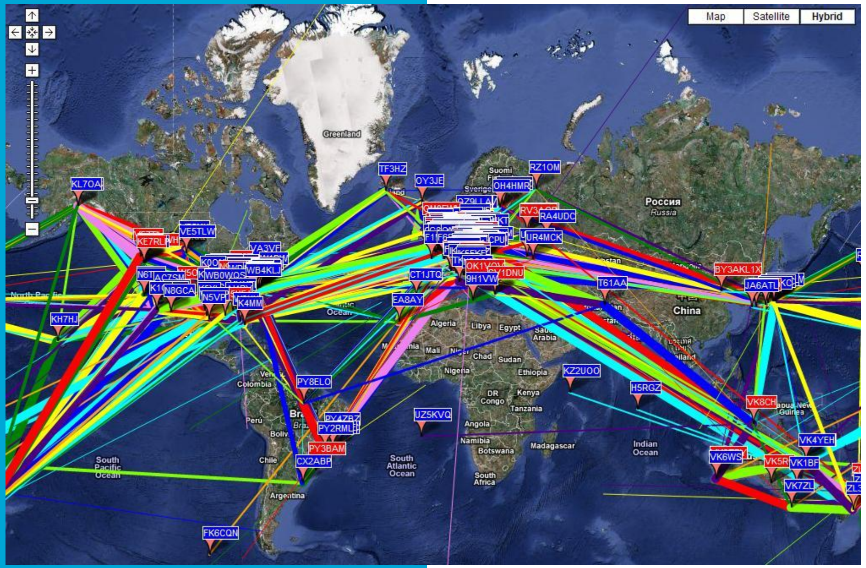

Other challenges

Challenges:

- Data analyses

Signal reception ➔ database

Receiving principle:

- Comparable with WSPR reception:
  - * use of Reversed Beacon Network (CW)
  - * use of WSJT-X – OpenWebRX

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Project timeline 2023

- Mission definition
  - Define payload mission requirements
  - Define satellite architecture
  - Payload listing
- Bus design iteration
  - Take lesson learned from Delfi-PQ
  - Improve bus design
    (SW, HW and operations)

Project timeline 2024-2027

- Mission definition
  - Select most promising payload options (2024)
  - Iterate on payload design (2025)
  - Flight model to be built (2025-2026)
- Bus design iteration
  - Design final bus concept

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Project timeline 2024-2027

- 2025-2026
  - Satellite integration
  - Environmental tests
- 2026
  - Delivery for launch → TBC
- 2027
  - Launch → TBC

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Further reading

atmosphere

MDPI

Article

Concept of Sporadic E Monitoring Using Space-Based Low Power Multiple Beacon-Systems

Jurgen Vanhamel [1,2,*], Marc Berwaerts [3], Stefano Speretta [1] and Sevket Uludag [1]

[1] TU Delft-Faculty of Aerospace Engineering, Kluyverweg 1, 2629 HS Delft, The Netherlands; s.speretta@tudelft.nl (S.S.); m.s.uludag@tudelft.nl (S.U.)
[2] Electronic Circuits and Systems, KU Leuven, Kleinhoefstraat 4, 2440 Geel, Belgium
[3] Union of Belgian Radio-Amateurs, RST-VZW, 3800 Sint-Truiden, Belgium; on4abs@myuba.be
* Correspondence: j.a.m.vanhamel@tudelft.nl

Abstract: Current monitoring systems to detect sporadic E use ground-based setups, ionosondes, and the network of GNSS satellites in order to assess the phenomenon of sporadic E. This paper aims to monitor sporadic E using a miniature space-based platform in an atypical way. The setup consists of multiple radio-amateur beacon systems aboard satellites, each having a specific modulation and transmission scheme. This Radio Amateur Beacon System for the Investigation of the Ionosphere (RABSII) is coupled to a GNSS receiver, revealing the location of the platform. Multiple beacon data streams are sequentially sent from a satellite platform towards the Earth. By receiving and comparing the Signal-to-Noise ratios of these streams using a dedicated ground-based radio-amateur network of receiving stations, the presence of sporadic E can be determined, and a location-based model can be built. The advantage of this miniaturized, low-power, low-cost instrument is its ability to be put on any satellite platform in the future in order to map sporadic E.

Link for free reading: https://www.mdpi.com/2073-4433/15/11/1306

Questions?