5 Month PhD Report

MMS Annual Meeting

04.06.2025

Annanay Jaitly

RNO-G

Radio Neutrino Observatory - Greenland

HELMHOLTZ

Funded by the European Union

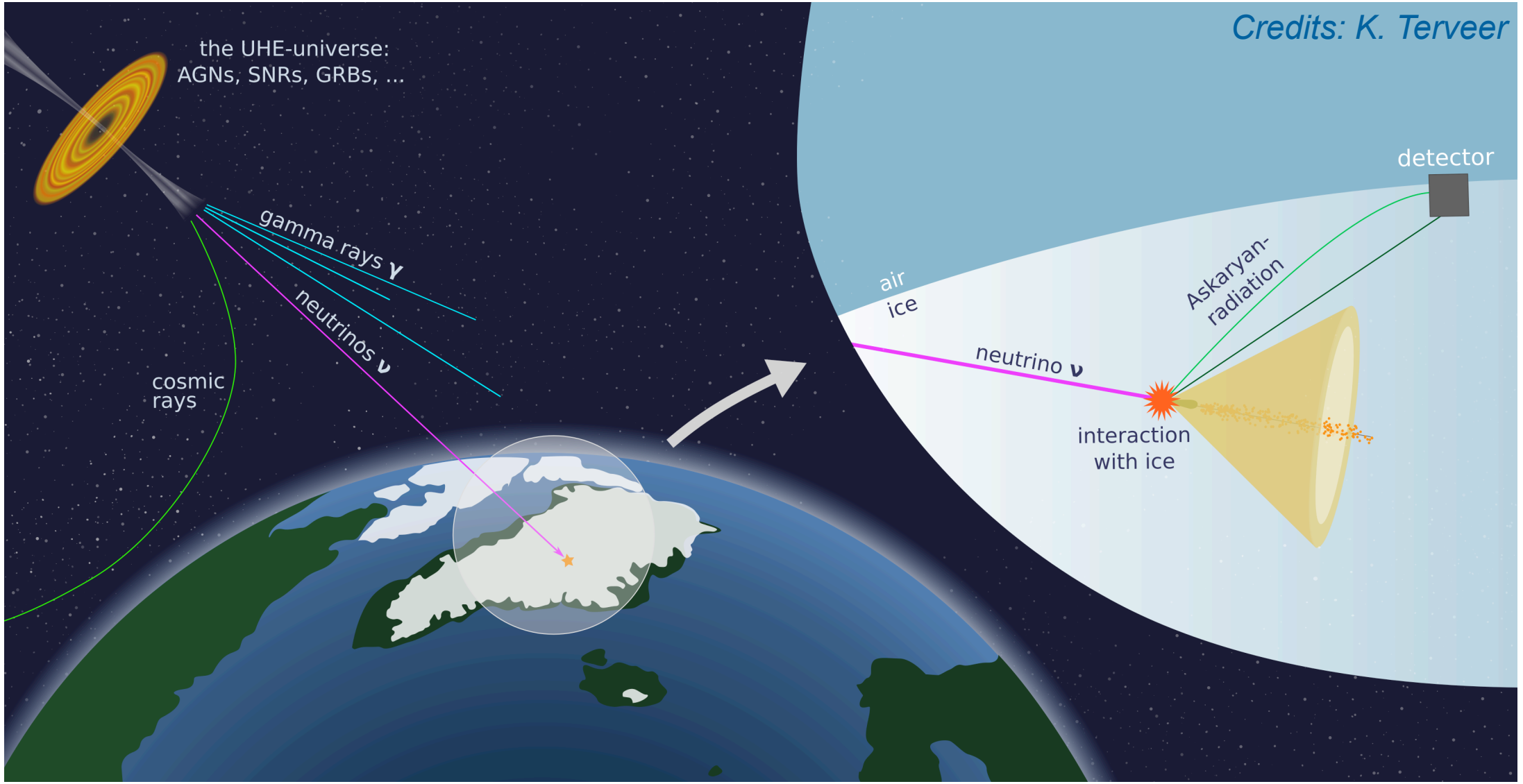
European Research Council

Established by the European Commission

DESY.

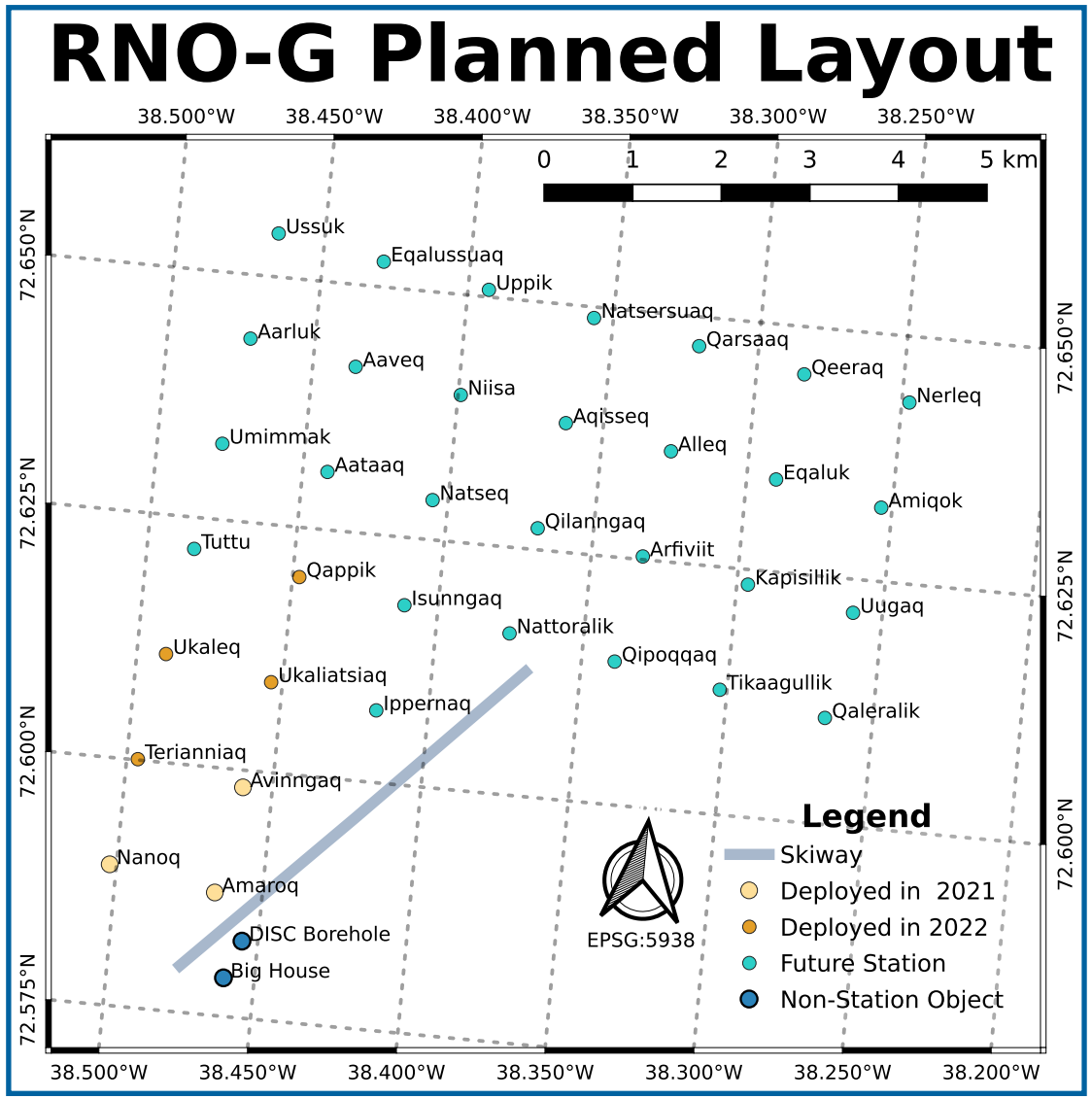
Radio Detection of Neutrinos

Introduction



RNO-G

Introduction



DESY.

Credits: RNO-G Collaboration

RNO-G

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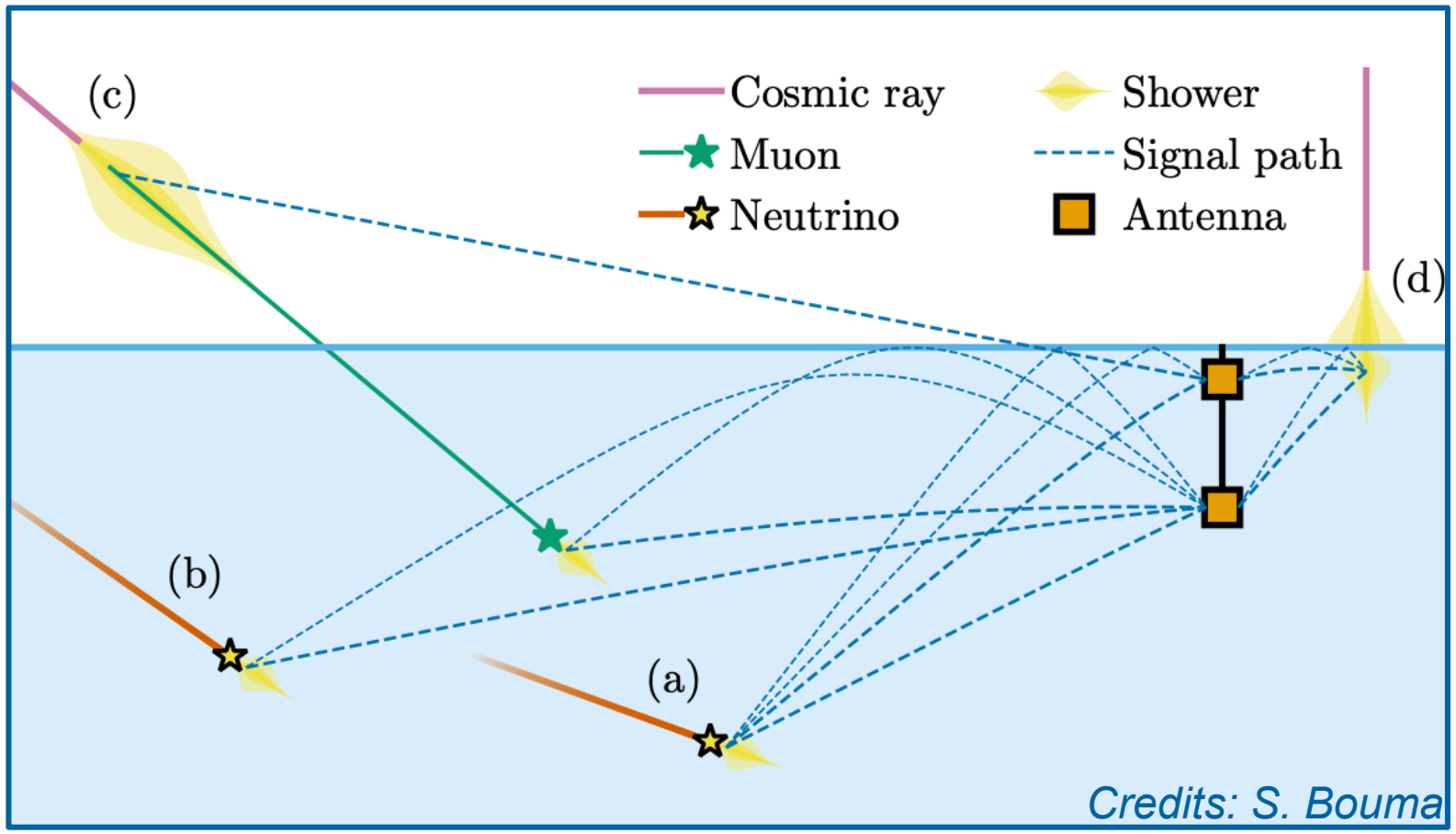
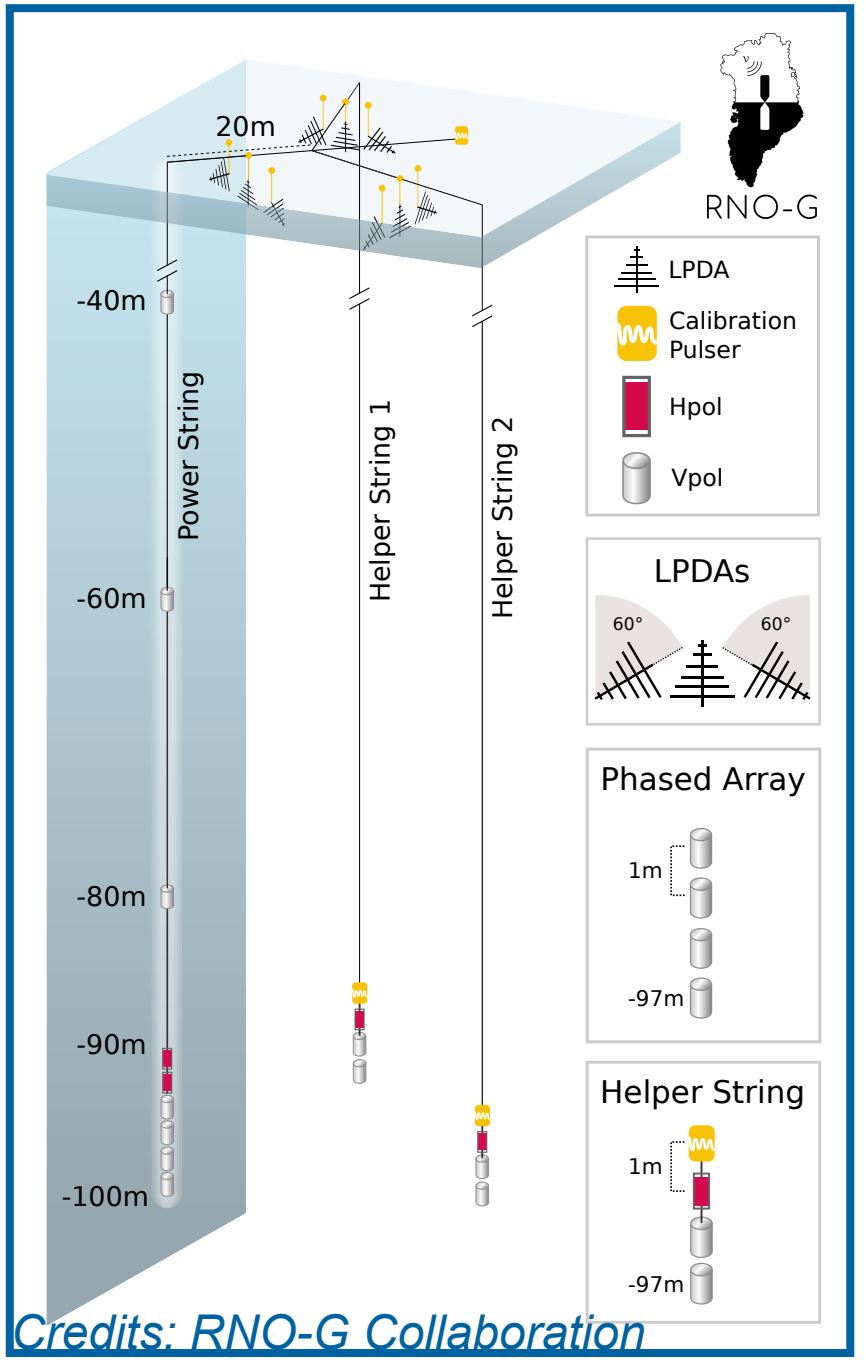
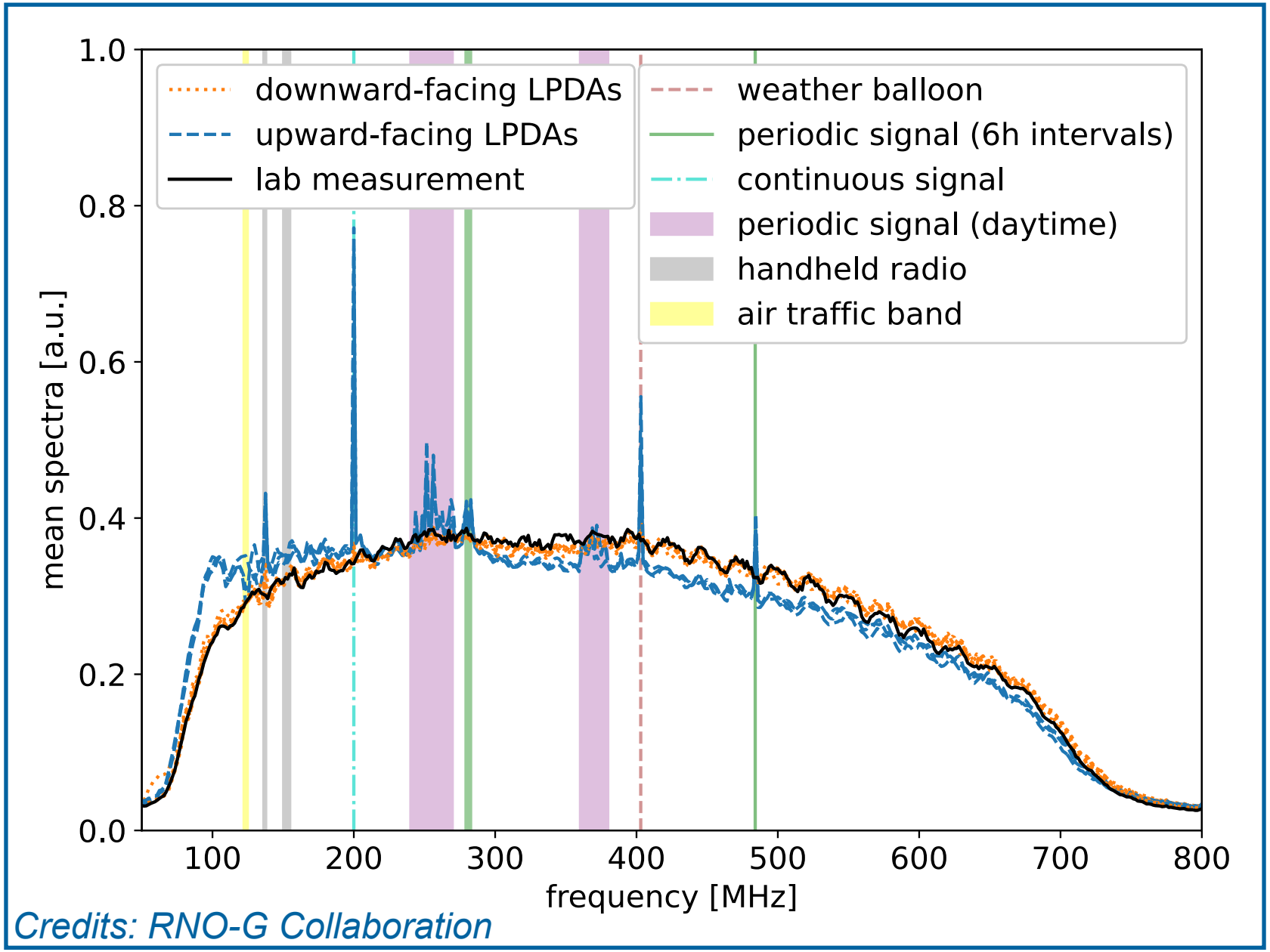




RNO-G: Time Averaged Spectrum



Credits: RNO-G Collaboration

Satellite Search — Motivation

- Satellite numbers are **increasing**
  - ~ **6k** active in 2022 — **~11k** active today
- Other radio/optical experiments see them!

1.

A&A 678, L6 (2023)
https://doi.org/10.1051/0004-6361/202347654

Astronomy & Astrophysics

LETTER TO THE EDITOR

Detection of intended and unintended emissions from Starlink satellites in the SKA-Low frequency range, at the SKA-Low site, with an SKA-Low station analogue

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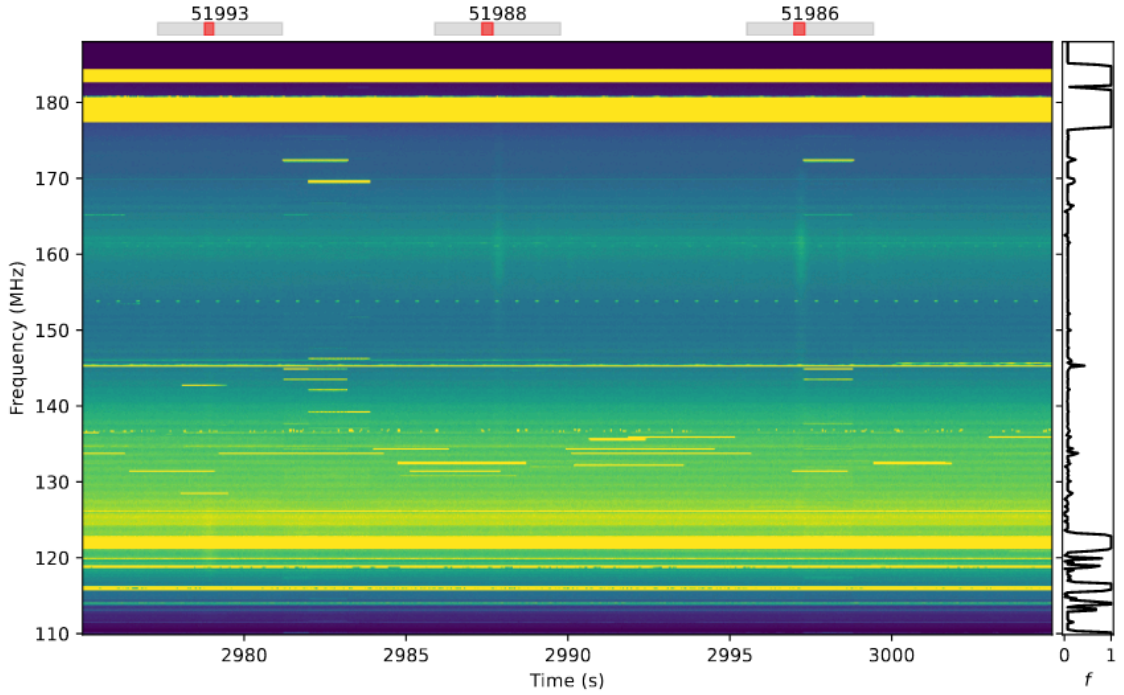
2.

A&A 676, A75 (2023)
https://doi.org/10.1051/0004-6361/202346374

Astronomy & Astrophysics

Unintended electromagnetic radiation from Starlink satellites detected with LOFAR between 110 and 188 MHz

F. Di Vruno[1,2,⋆], B. Winkel[3,2,⋆], C. G. Bassa[4,⋆], G. I. G. Józsa[3,2,5,⋆], M. A. Brentjens[4], A. Jessner[3], and S. Garrington[6,⋆]

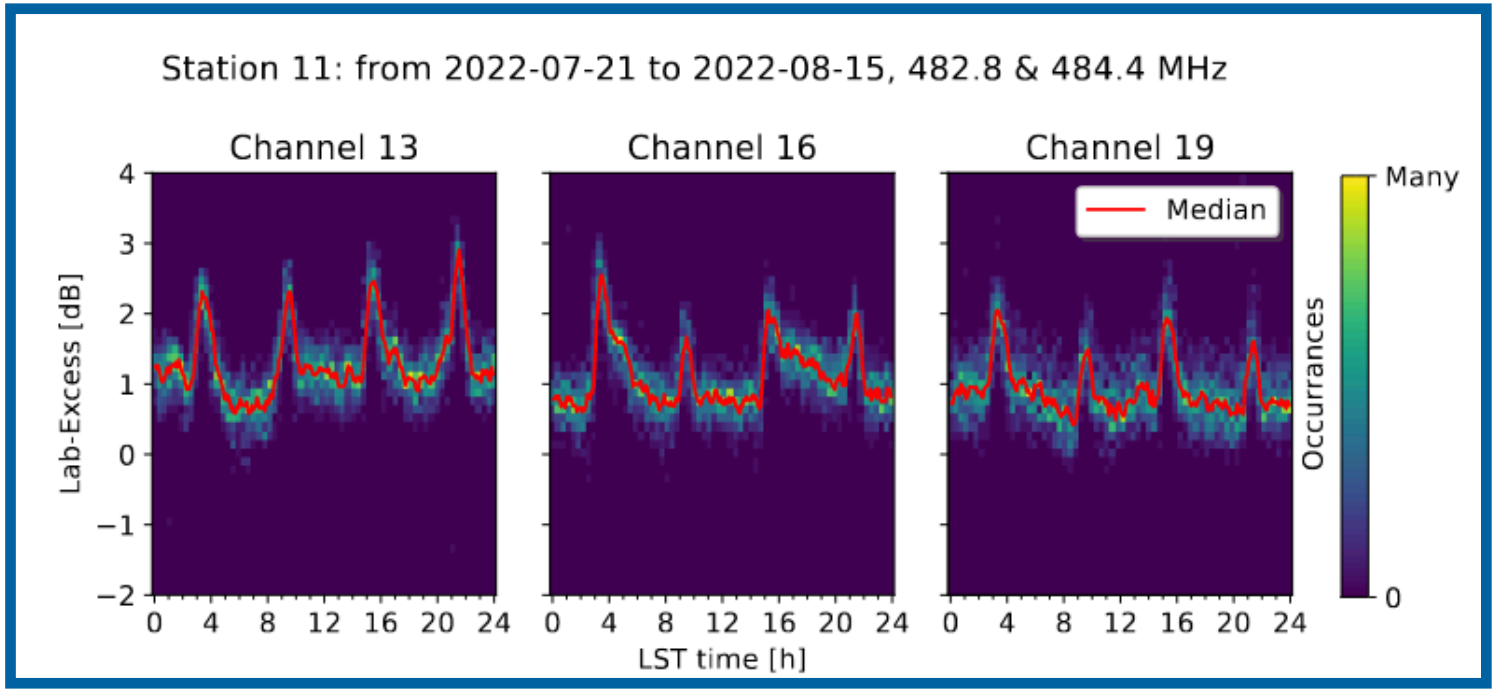


Satellite Search — Motivation

- Satellite numbers are **increasing**
  - ~ **6k** active in 2022 — **~11k** active today
- Other radio/optical experiments see them!
- Indication for them in RNO-G spectrum
  - BSc. Thesis, Reichert:

  Periodic signals

  @ ~280MHz and ~480 MHz?



Satellite Search — Strategy

1. Pipeline for retrieving satellite data, calculating past & future orbits.

2. RF emission from satellites can be split into "intentional" and “unintentional” categories:

Intentional	**Unintentional**
• Data downlink • Radar pulses • Other continuous wave (CW) emission	• Propulsion systems • Power supplies

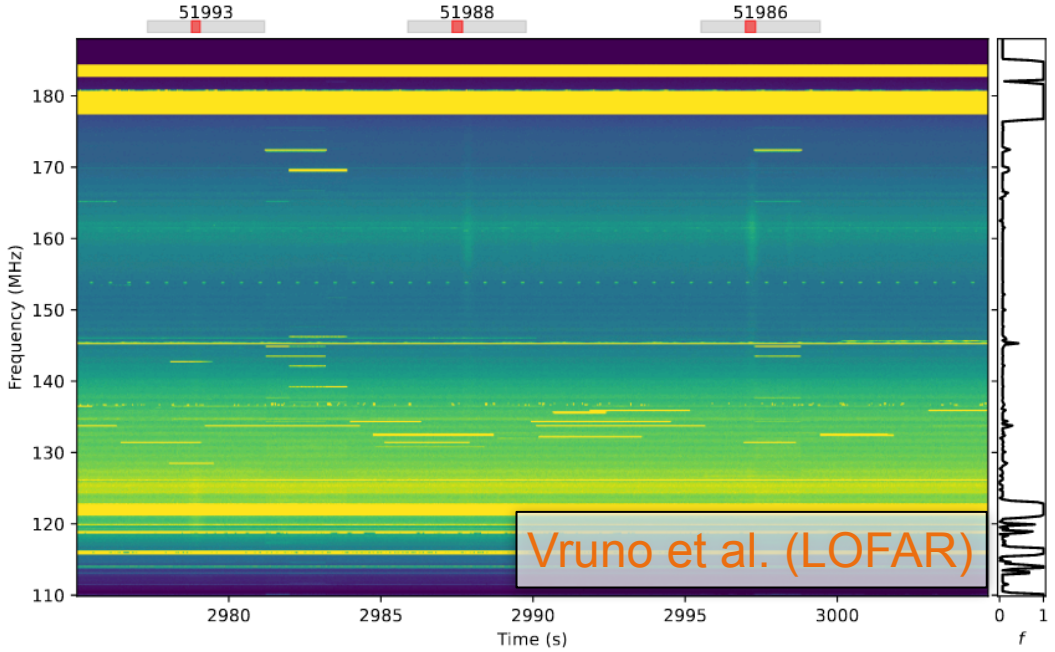
3. Search RNO-G **data** for such signals in:

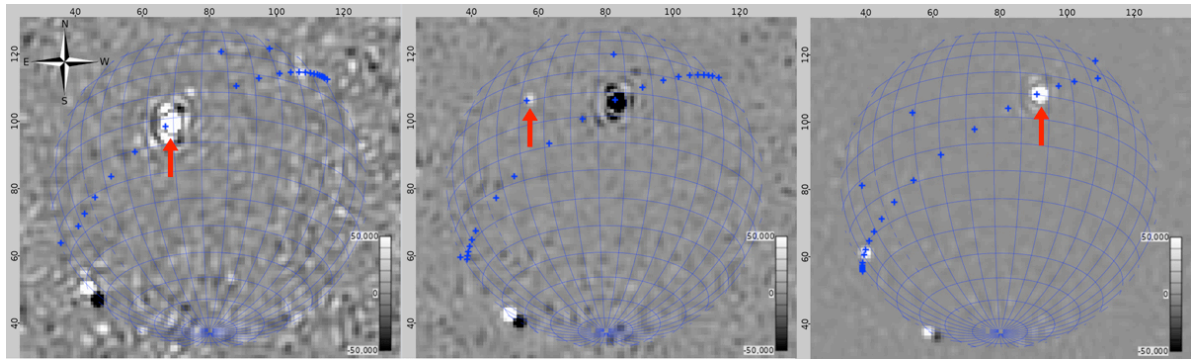
Frequency Spectra	**Time Traces**
• Leverage known emission bands	• Look for impulsive events triggering multiple stations (clusters)

Accounting for “unintended" signals

EMPCART event clusters

- Unintentional: from propulsion system, power supply, etc.
- Airplane analysis code looks for event clusters with multiple stations triggered
- ~ 700 clusters likely not from aircrafts (signal too weak, no flight no. associated, etc.)
  - Will look for any nearby sats within ~1 min of clusters





Grigg et al. (SKA)

Calculating Orbits

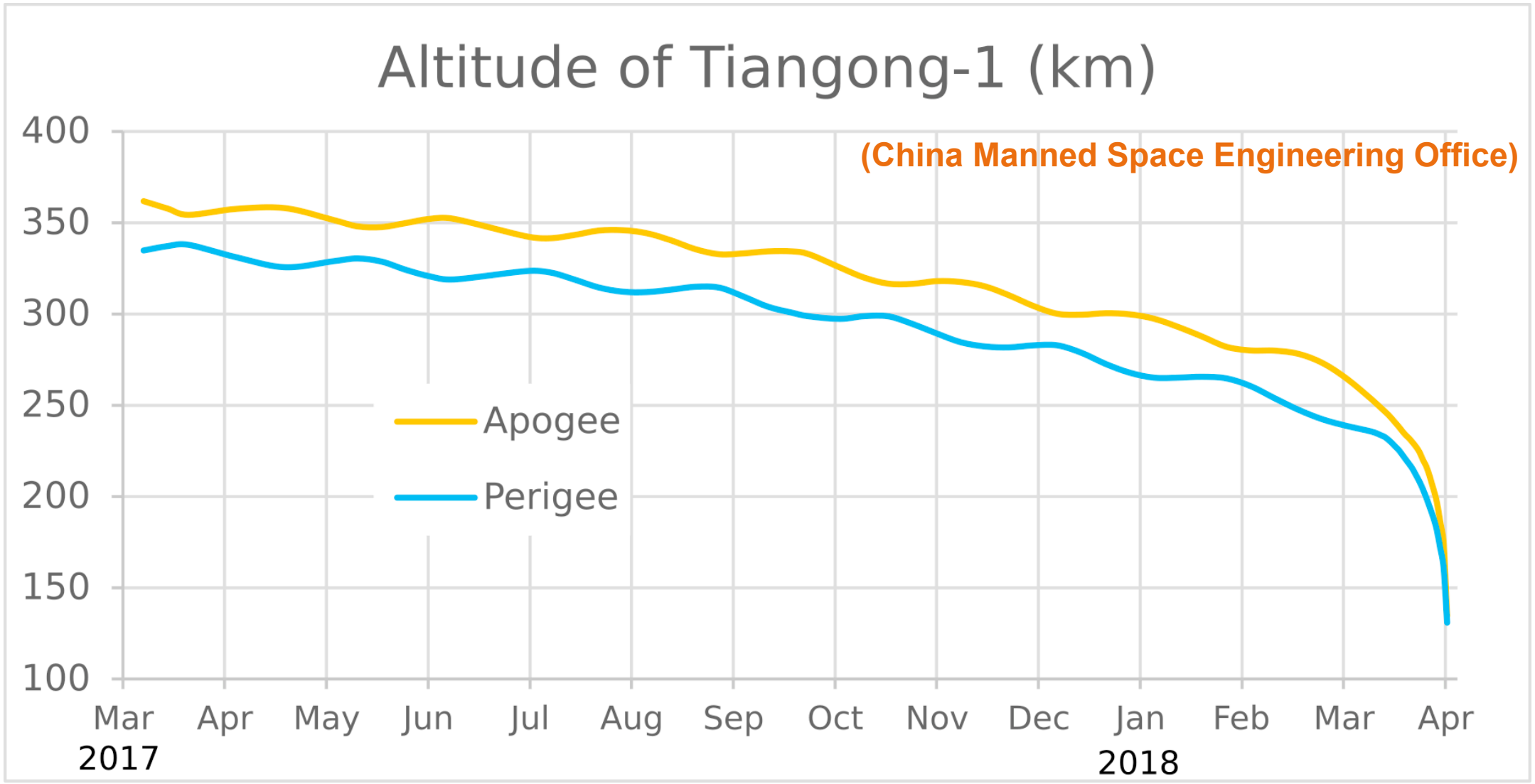
- **Skyfield** python library: solves for orbits of celestial objects
- Satellite datasets get **out of date fast**! (~2 weeks)
    - Orbital adjustments
    - Orbits decay over time — re-entry

State of data:

- Weekly cronjob to pull **celestrack database**
- ETH-Zürich **satdb** — rich data from 2023-03 onwards!
- Internet archive — found one celestrack database from 2022-07

- Can query **Celestrack** for (small!) amounts of historical data for few sats

Orbits Decay!



A Week's Sky over Summit Station

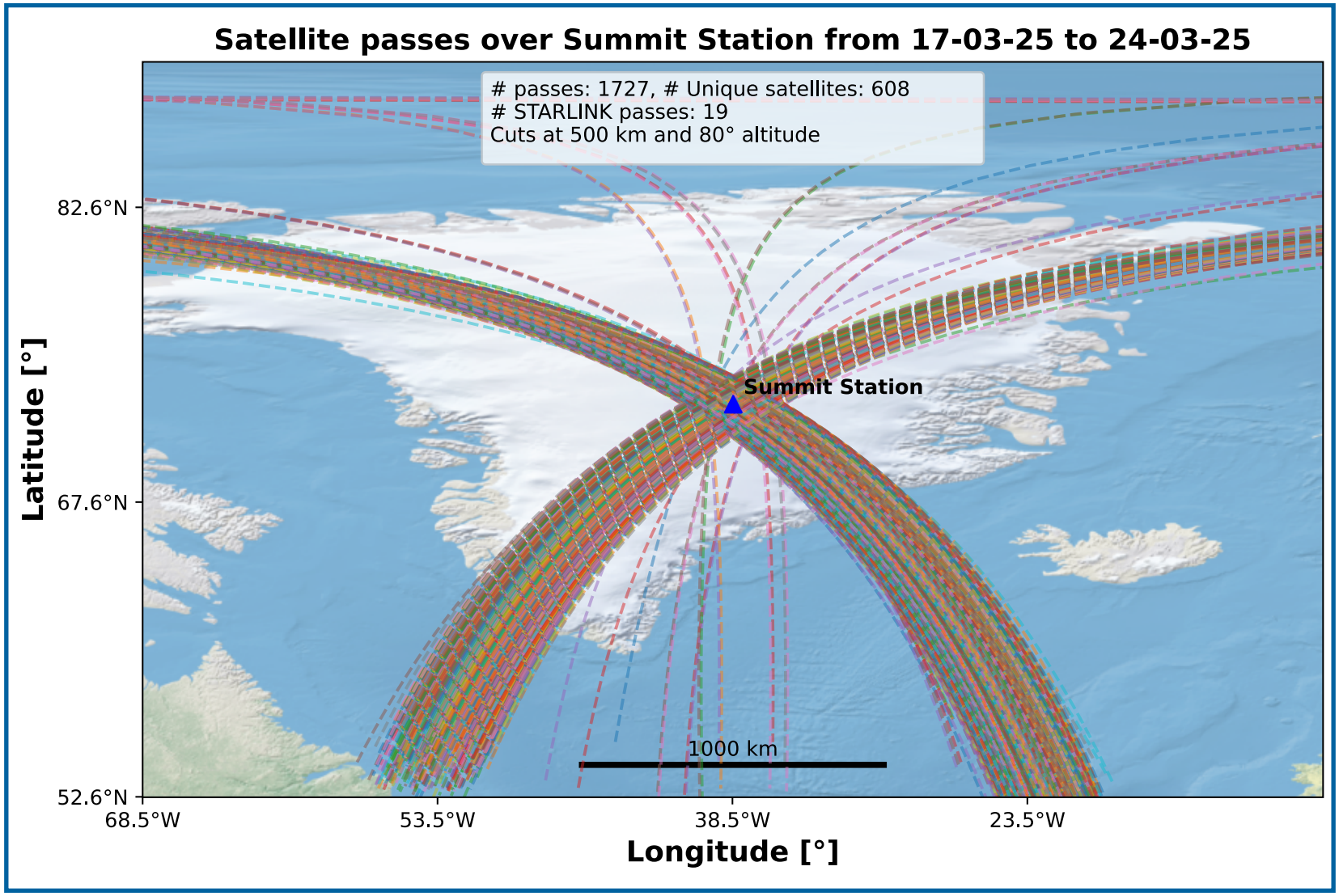
Celestrak Catalogue

Consider sats rising above the horizon (Altitude > 0 degrees)

From **17.03 - 24.03**:

- **4913** fly-bys with dmin < **500 km**
- **662** unique satellites

- **535** fly-bys with dmin < **400 km**
- **87** unique sats



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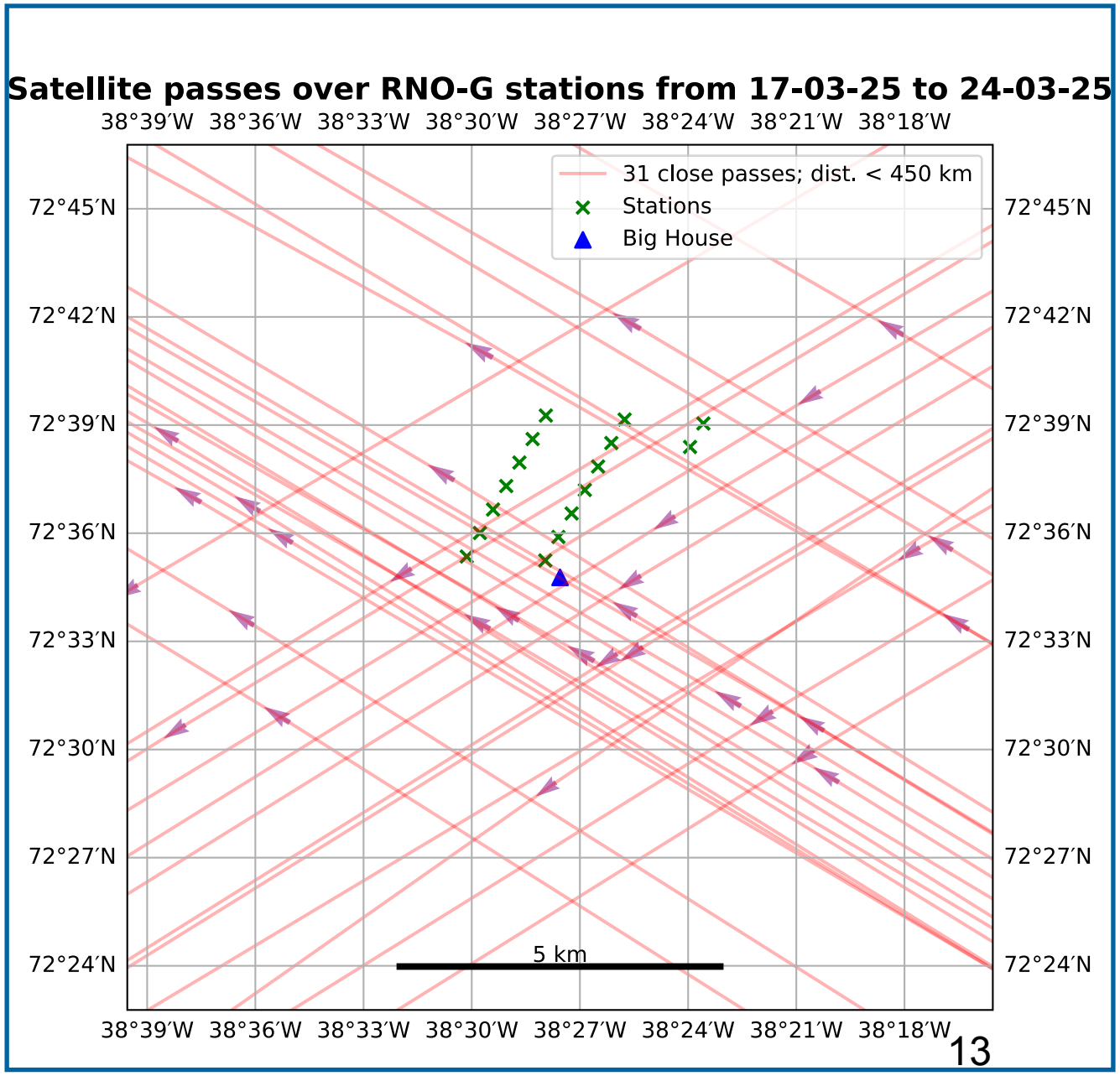

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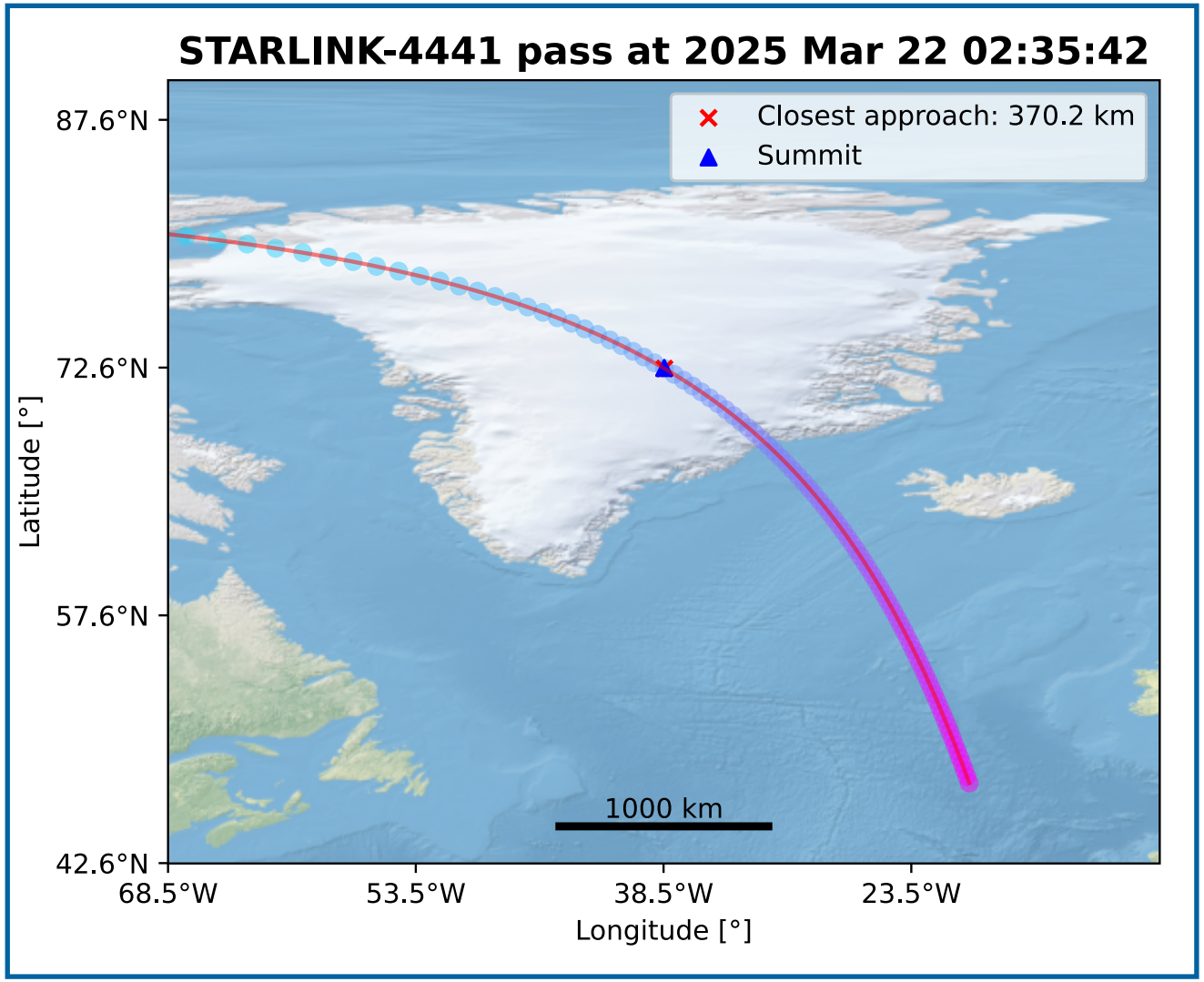

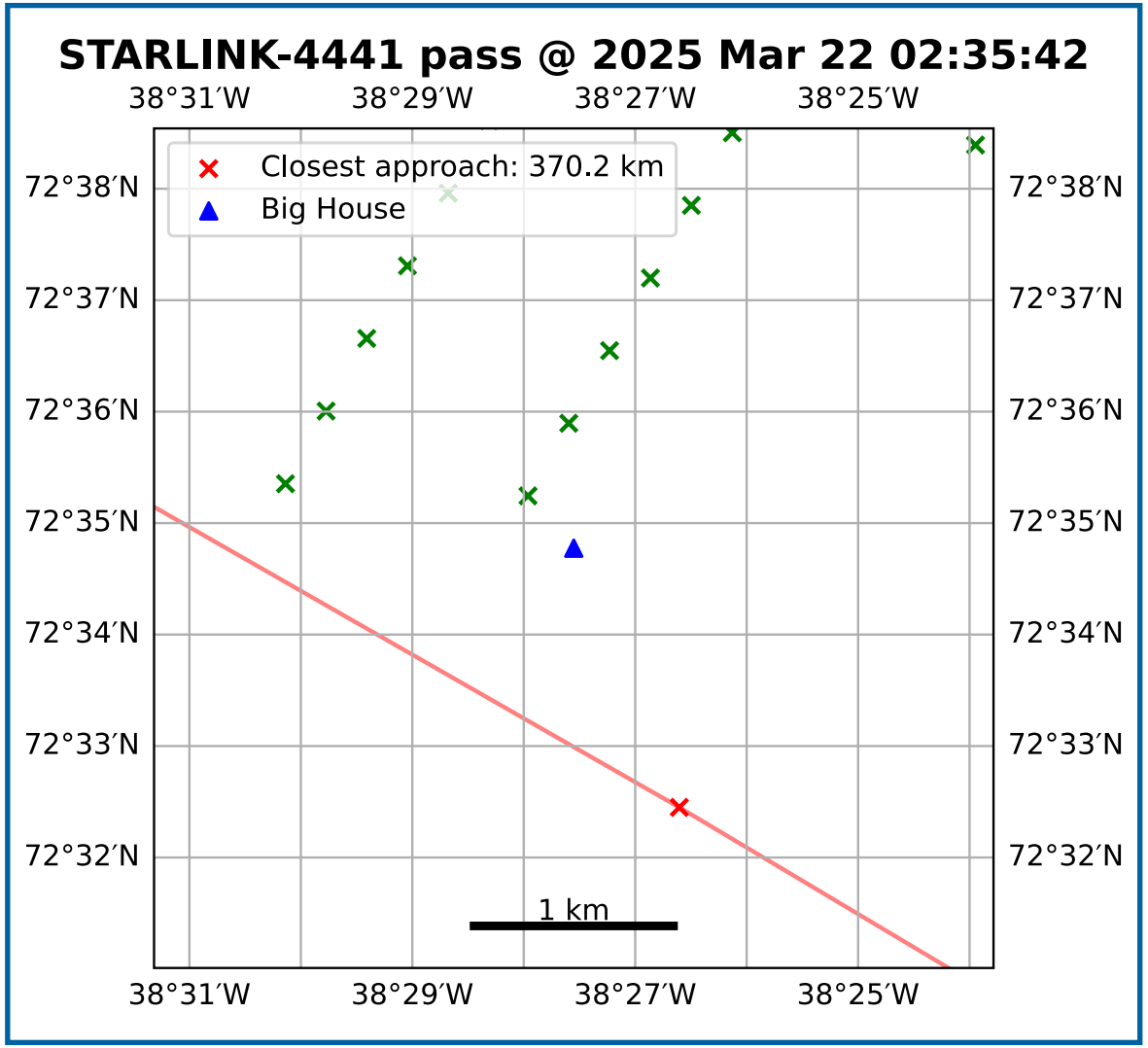

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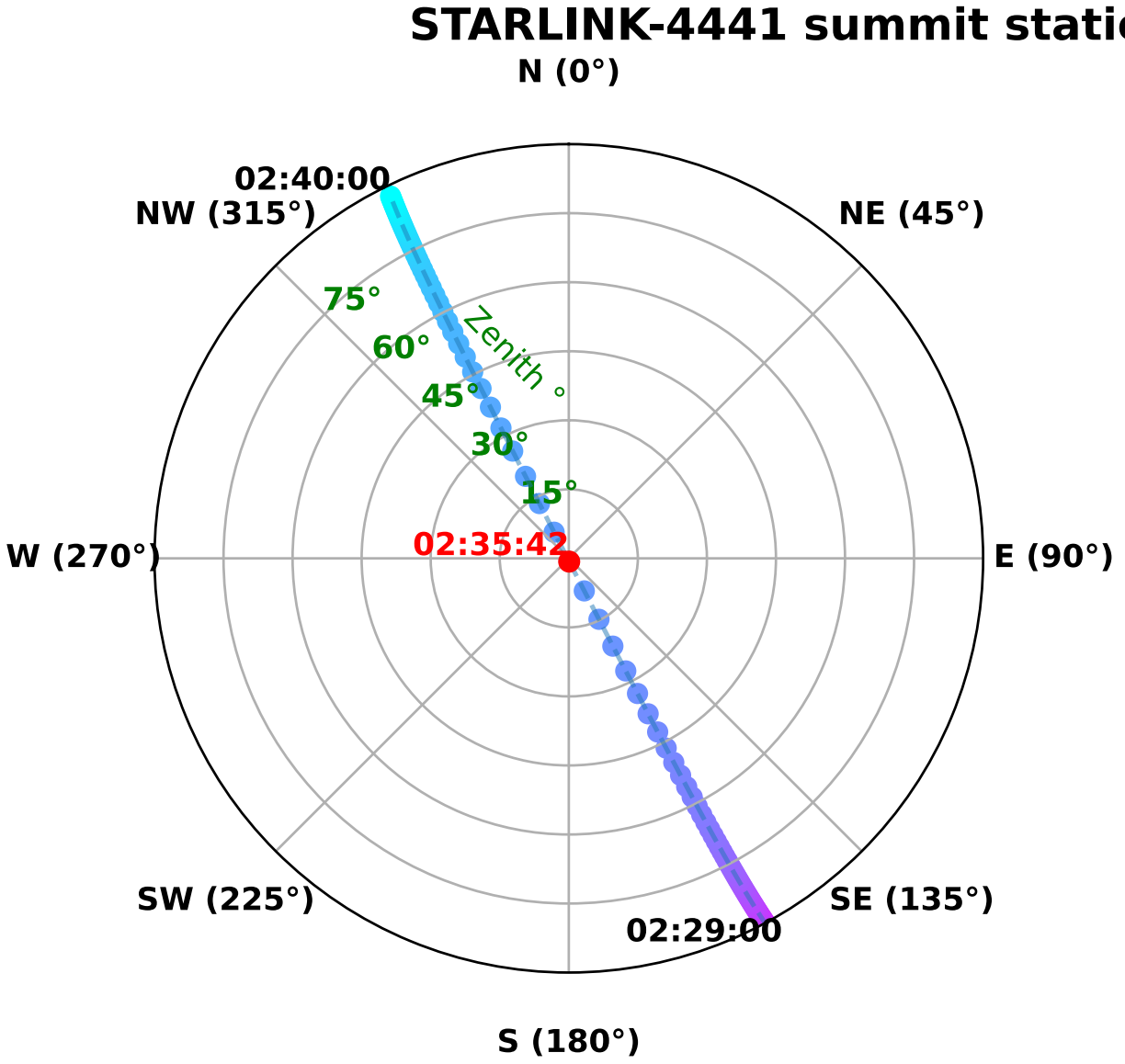
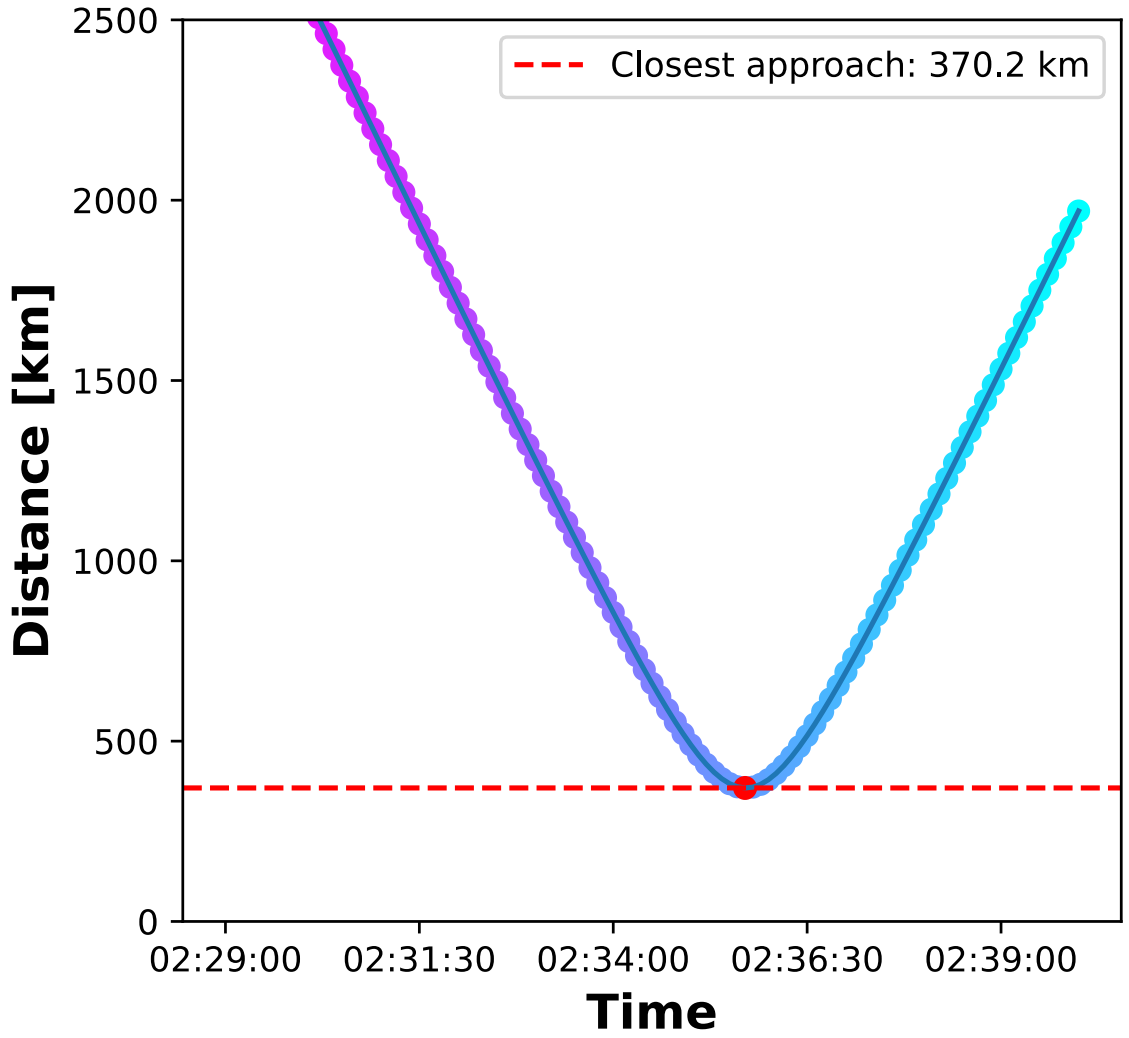
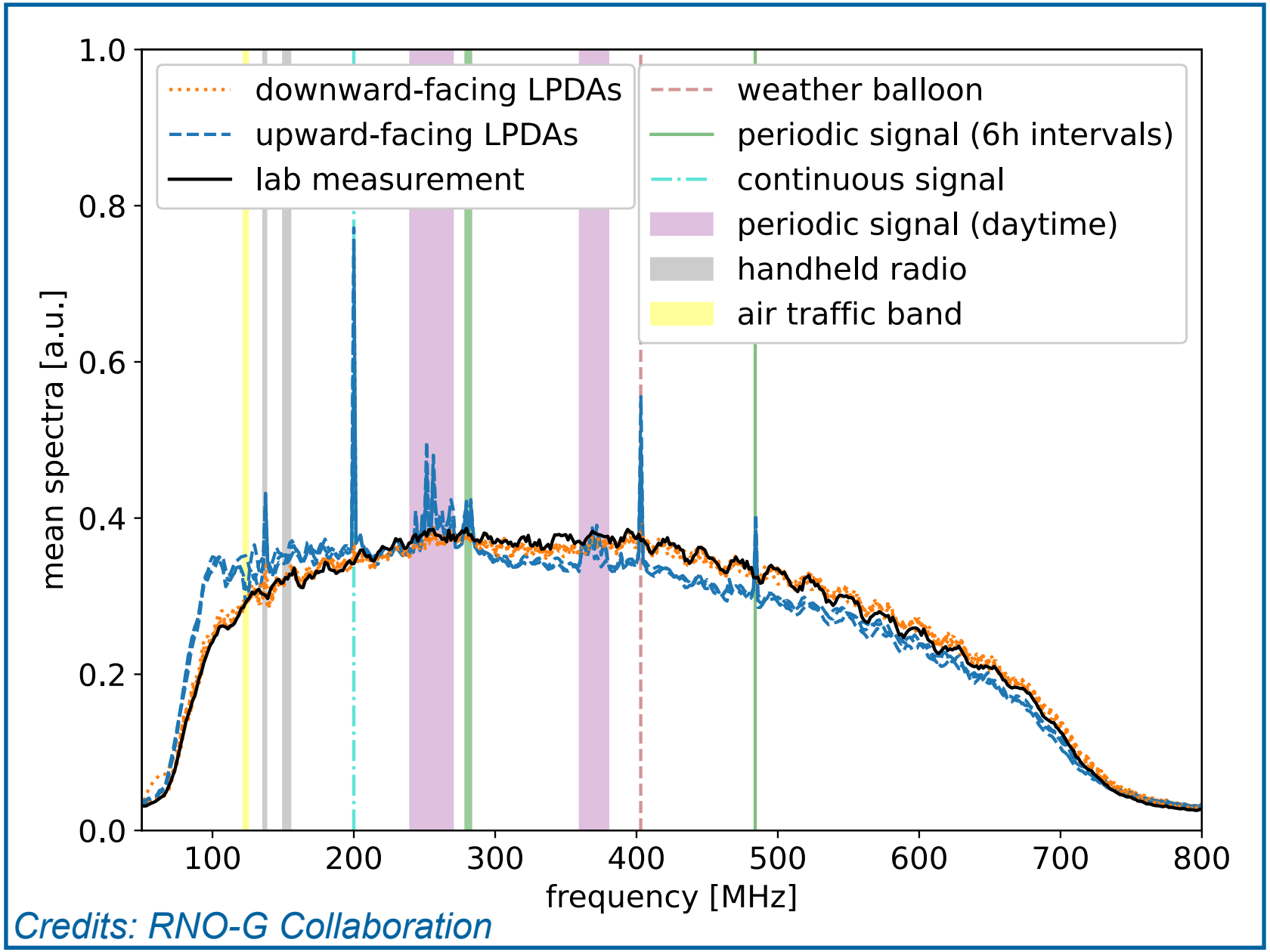




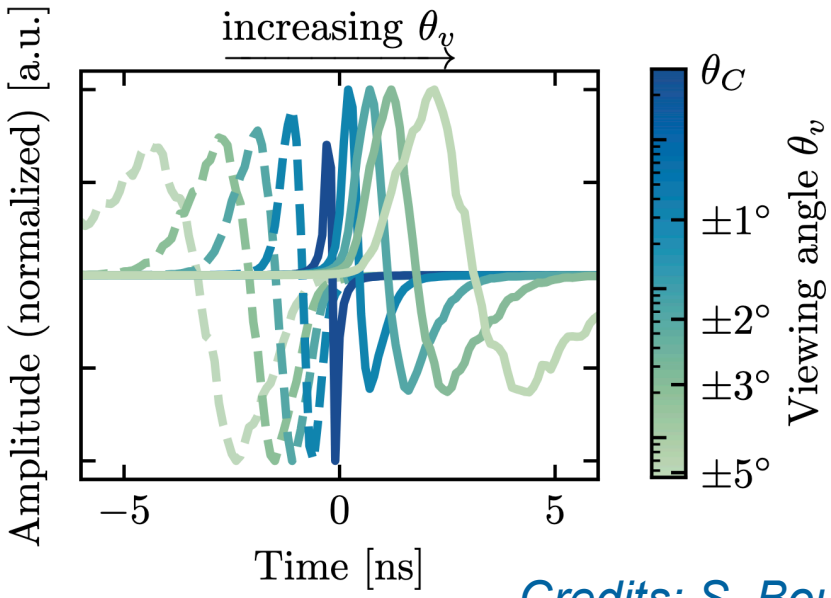
RNO-G: Time Averaged Spectrum



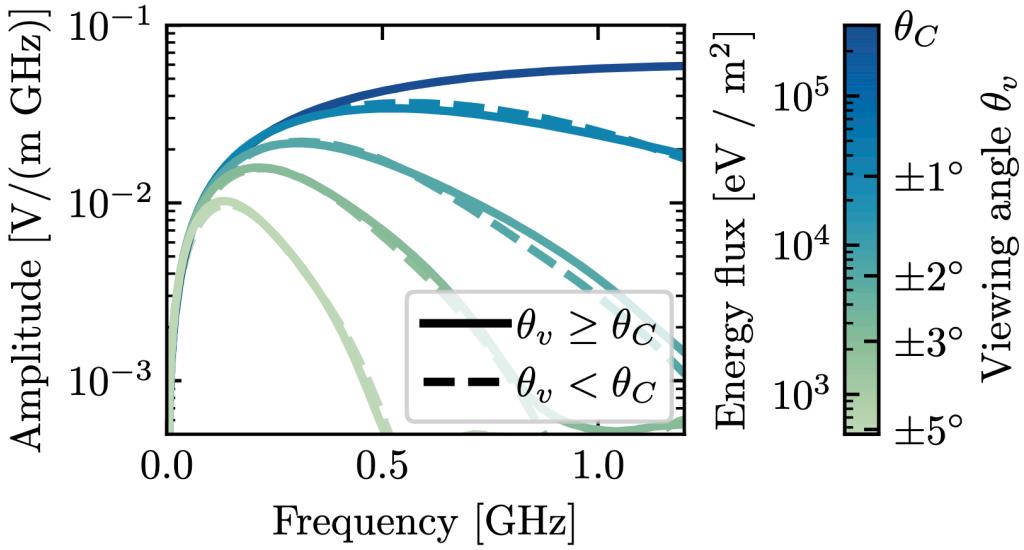
Credits: RNO-G Collaboration

RNO-G Trigger Scheme

- Need ~**GHz sampling rate** to resolve radio-ν signals.
- Continuously recording data unfeasible.
- Requires a trigger scheme (e.g threshold based).
- Forced trigger every 10s (0.1Hz rate).

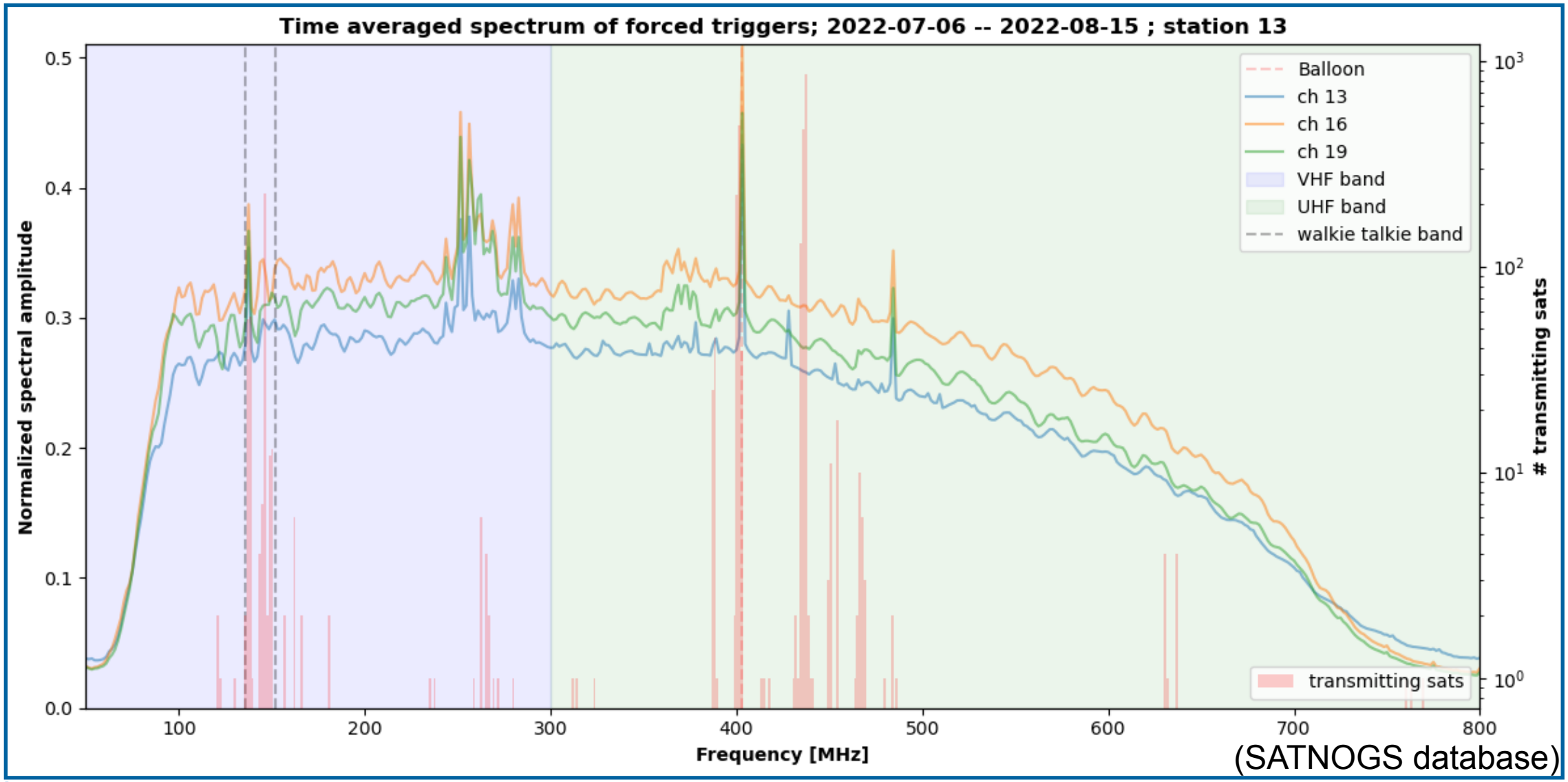


Credits: S. Bouma



Transmitter Band

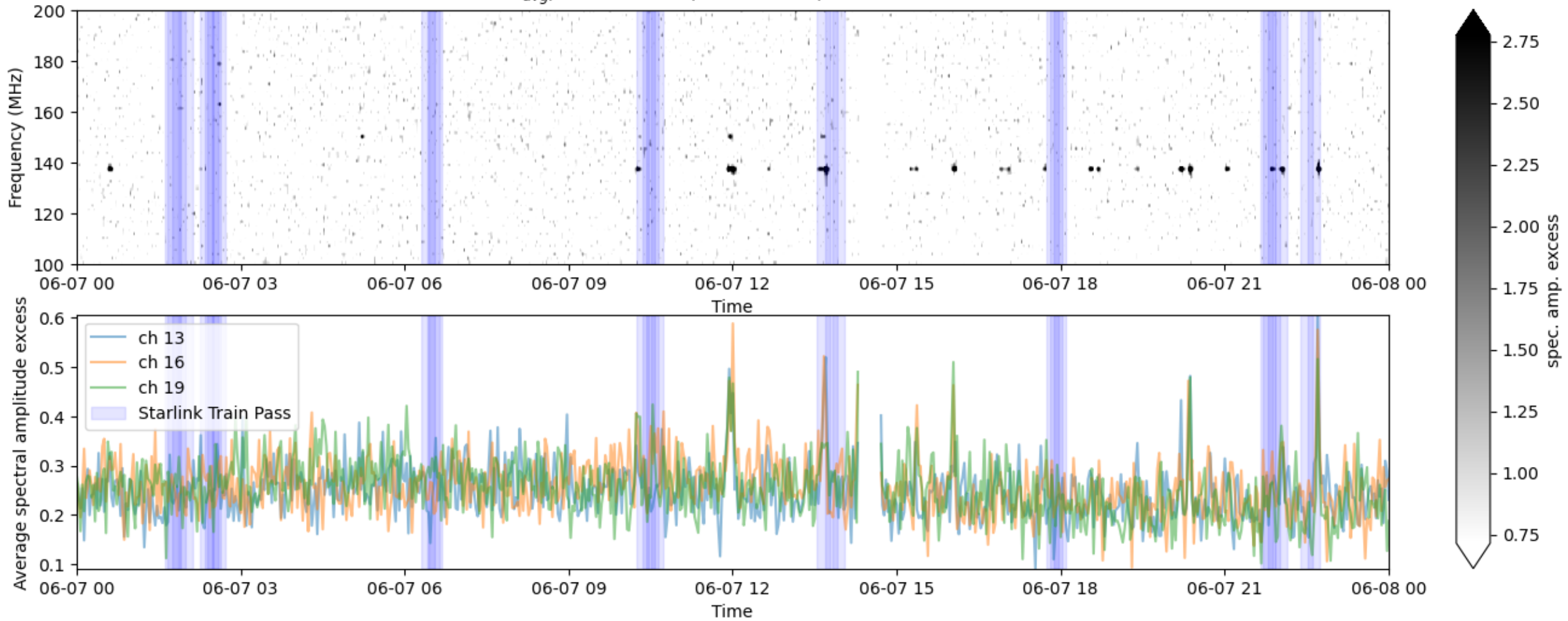
Stated communication bands == “Intentional signals”



(SATNOGS database)

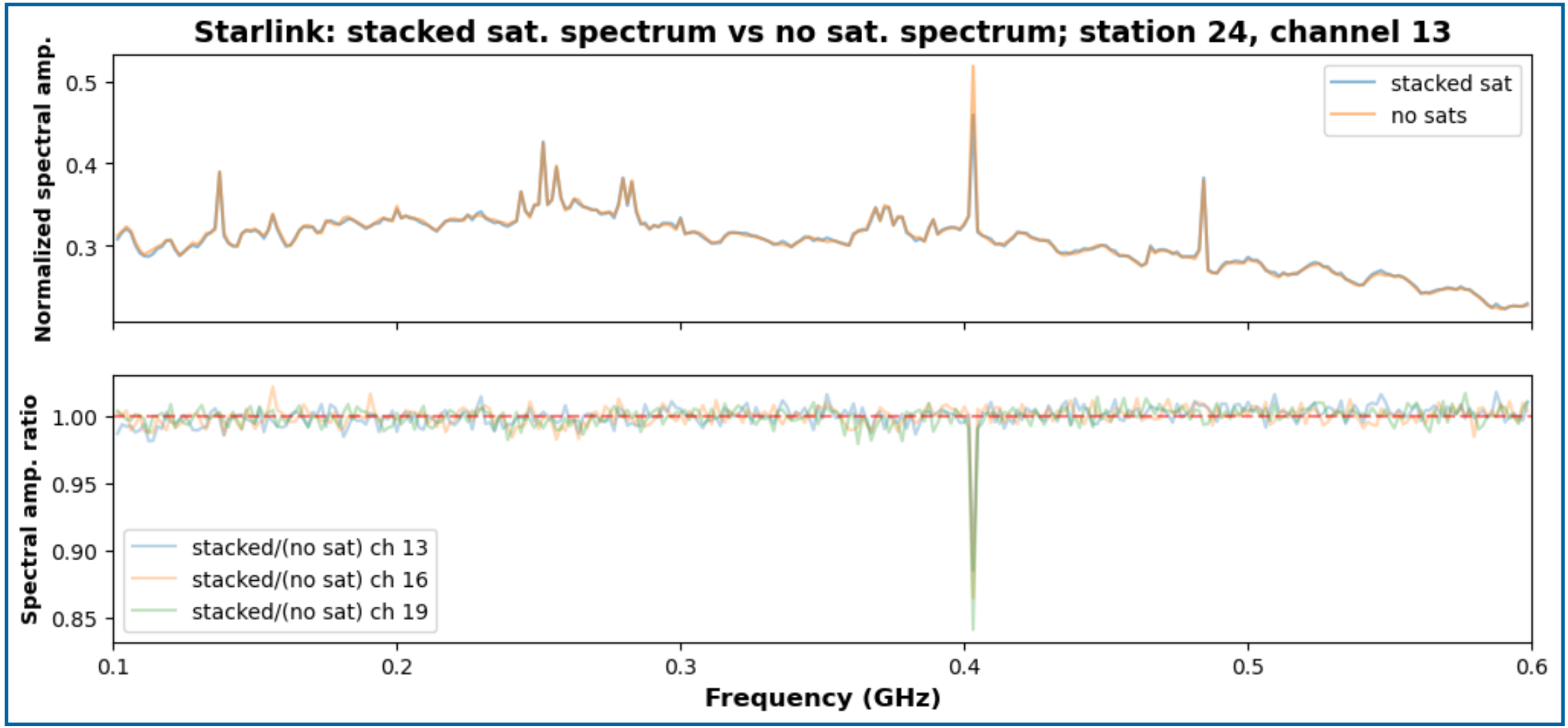
Investigating LOFAR Starlink band

2023 Forced Trigger Data



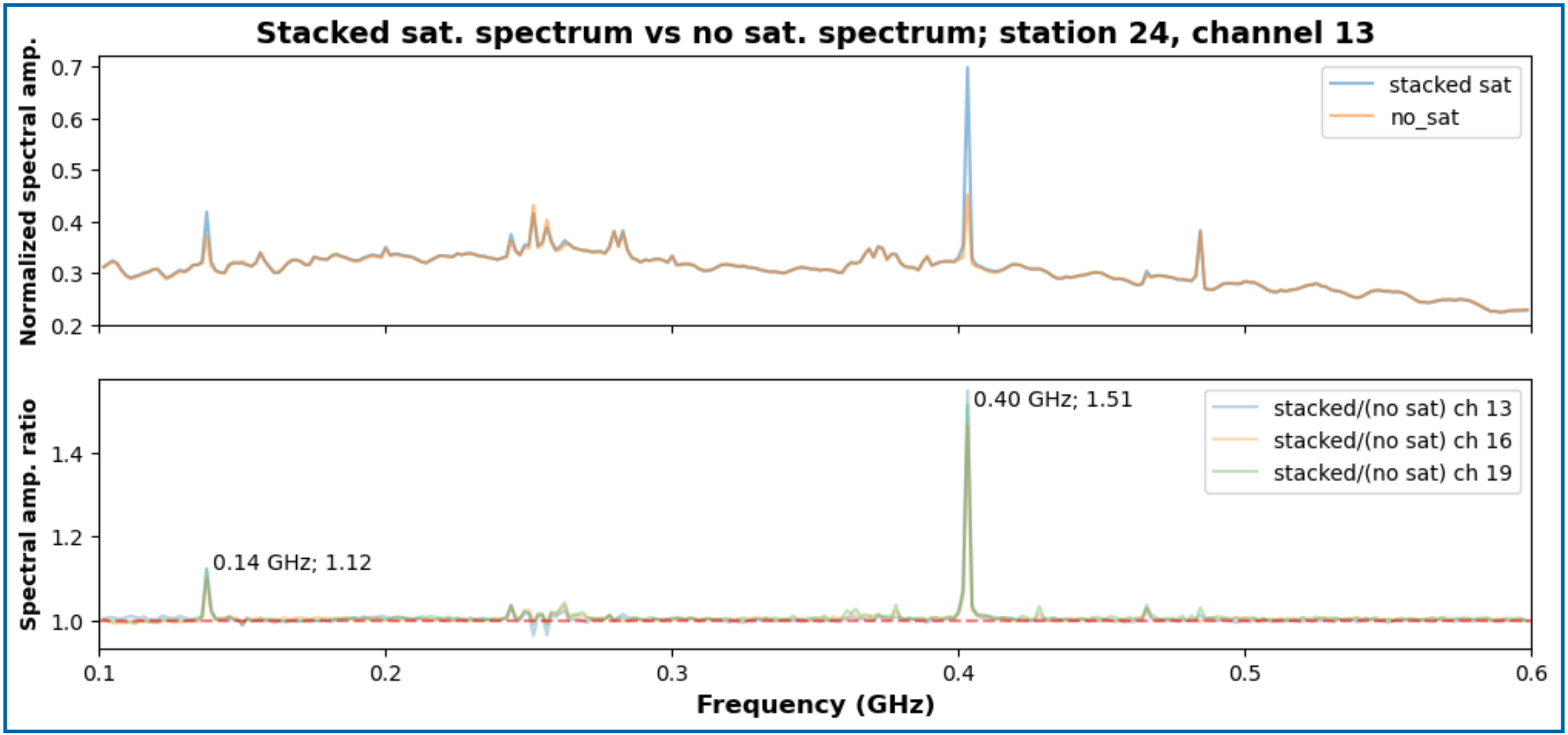
Starlink - Stacking Fly-by Spectra

2023 Forced Trigger Data (June and July)



LEO Sats - Stacking Fly-by Spectra

2023 Forced Trigger Data (June and July); $d_{min} < 450$ km



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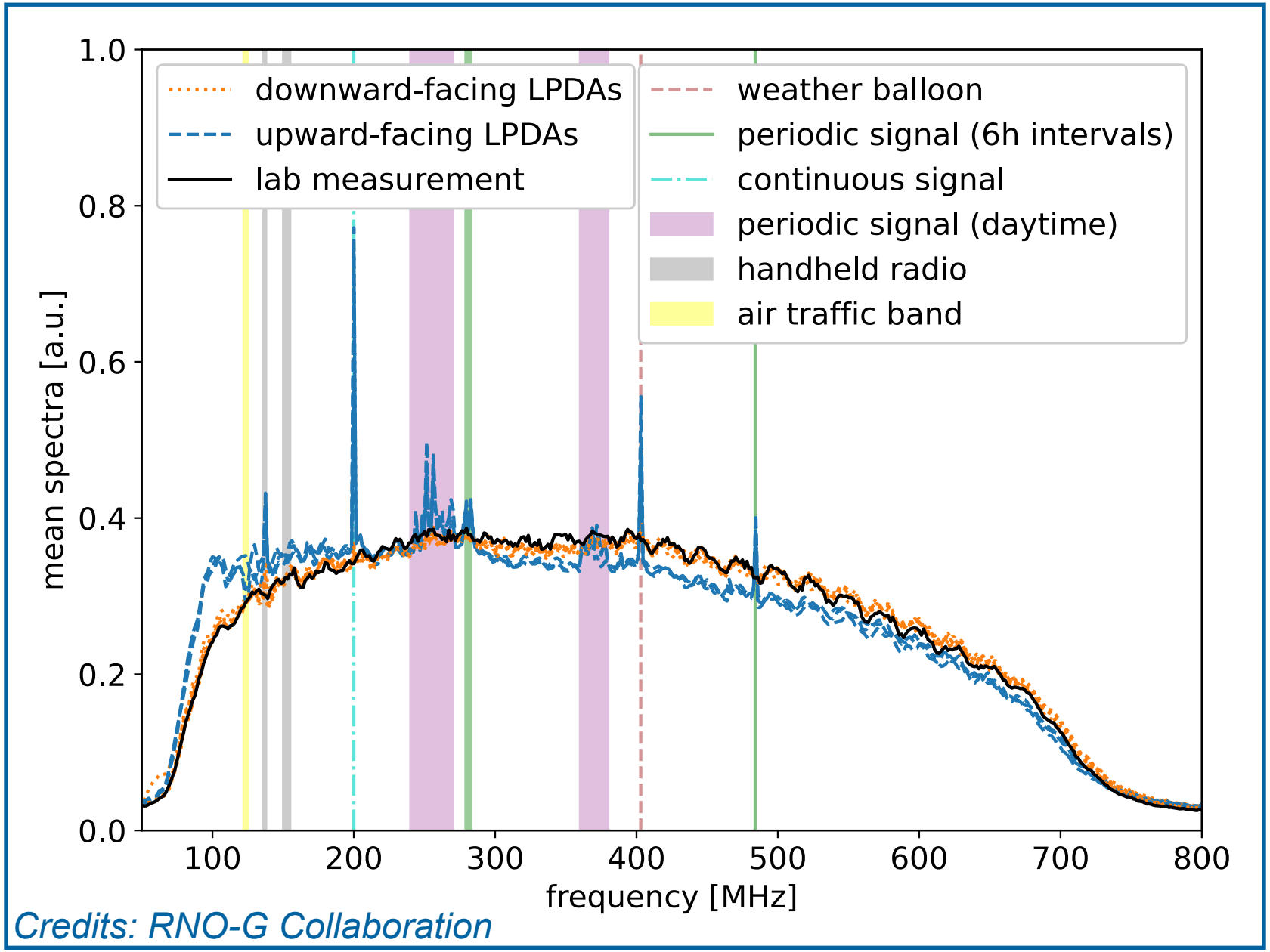


Credits: RNO-G Collaboration

Summary of Plan

Satellite data acquisition and orbit-calculation pipeline is in place.

“Intentional" signals	**ALL signals (incl. “Unintentional")**
• Exploit known transmitter bands (radar bands?) • Investigate band-averaged spectra in forced triggers • Look for coincidence/periodicity of signals • Stack spectra from satellite passes	• Look in empcart clusters that likely aren’t airplanes • Compare w/ satellite fly-bys • Later: Proposal to increase forced trigger rate for predicted Starlink pass?

Conclusion & Future Plans

- Satellites have been seen by other radio experiments.
- Certain anomalies in RNO-G spectrum could be explained this way.
- Analysis of RNO-G Data underway: serendipitous detection in forced triggers

If we see satellites:

- Do we see them in downward and/or deep channels?
- Do we trigger on satellites?
- Dream scenario:
  - Amplitude calibration of stations
  - Broadband emission from de-orbiting sats

If we don't see any satellites:

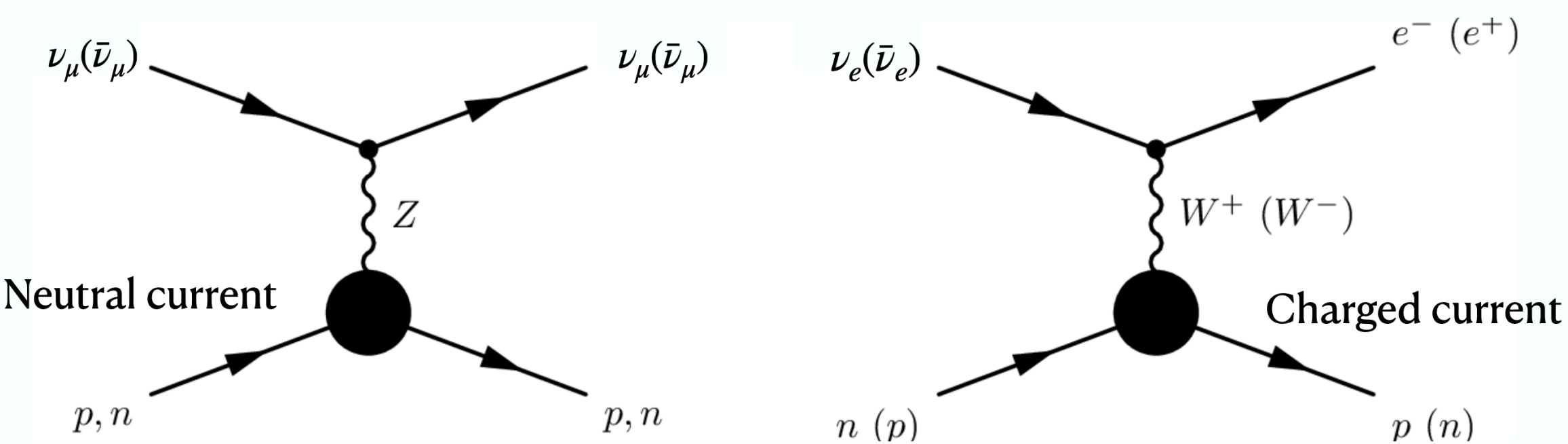
- Move on to neutrino search
- Air/ice shower simulations

Backup

Neutrinos in Ice

Detect (> 10 GeV) neutrinos through deep inelastic neutrino-nucleon interactions

Deep Inelastic Neutrino-Nucleon Interactions

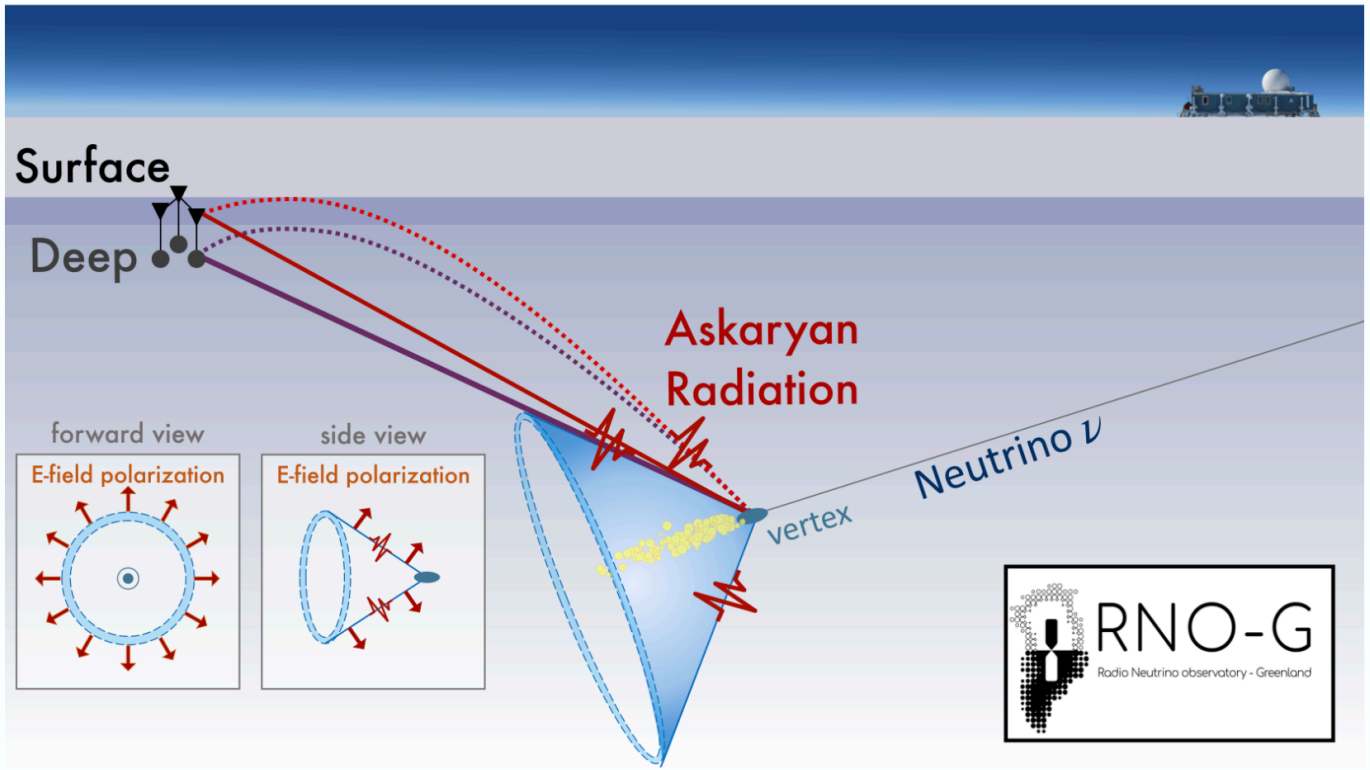


Nucleon Decay

$n \rightarrow p^+ + e^- + \nu_e^-$ (neutron decay)

$p^+ \rightarrow n + e^+ + \nu_e$ (beta plus decay)

Askaryan Emission



- $e^+ + e^- -> 2\gamma$
- Photons ionize atoms to release free e^- or knock out loosely bound electrons
- Excess negative charge radiates
- Radiation at ~10 cm constructively interferes (coherent amplification in radio)
- Constructive interference at lengths > cascade size (~ 10 cm)

	Radio	Optical
Detection Mechanism	Askaryan Emission	Cherenkov Emission
Detection Instrument	Radio Antennas	PMTs (Photomultiplier Tubes)
What is detected?	0.1 - 1 GHz radio pulse	Blue light (“optical”)
Suitable Energy Range	> 1 PeV	< 1 PeV
Scattering and Absorption Length	15-60 m (scattering) 60-200 m (absorption)	10-20 m (scattering) 50-100 m (absorption)
Instrumentation Density	Lower for same effective volume	Higher for same effective volume

Simulated Neutrino Event