GRAND :
Giant Radio Array for Neutrino Detection

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Summary

- Introduction to Ultra-High Energy Cosmic Rays (UHECRs)
- Optimizing the layout of a giant hybrid array
- Data analysis of commissioning phase

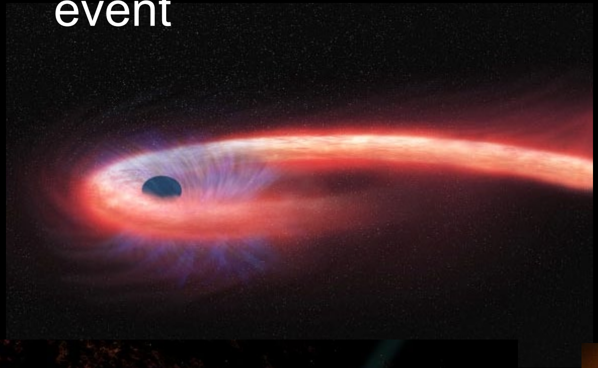
Introduction to UHECRs

UHECR- Emission

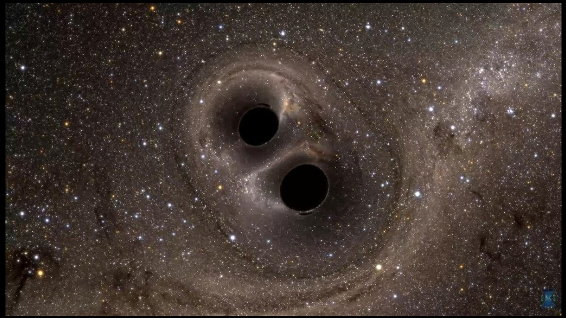
Probing the Violent Universe

Neutron stars merger

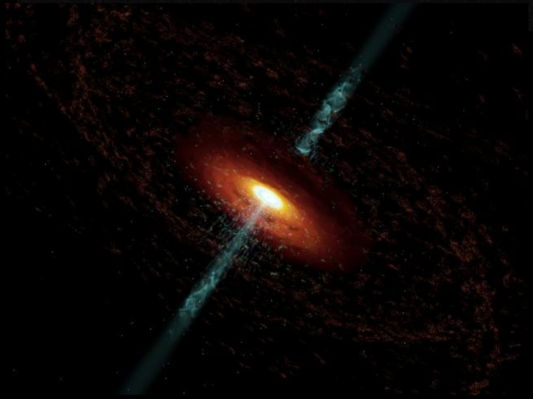
Tidal disruption event



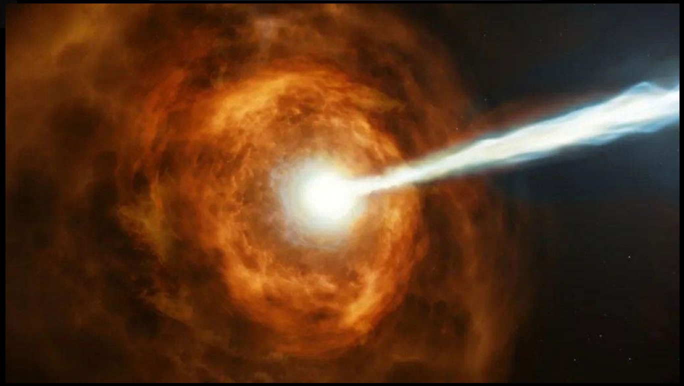
Super luminous supernova



Black holes merger

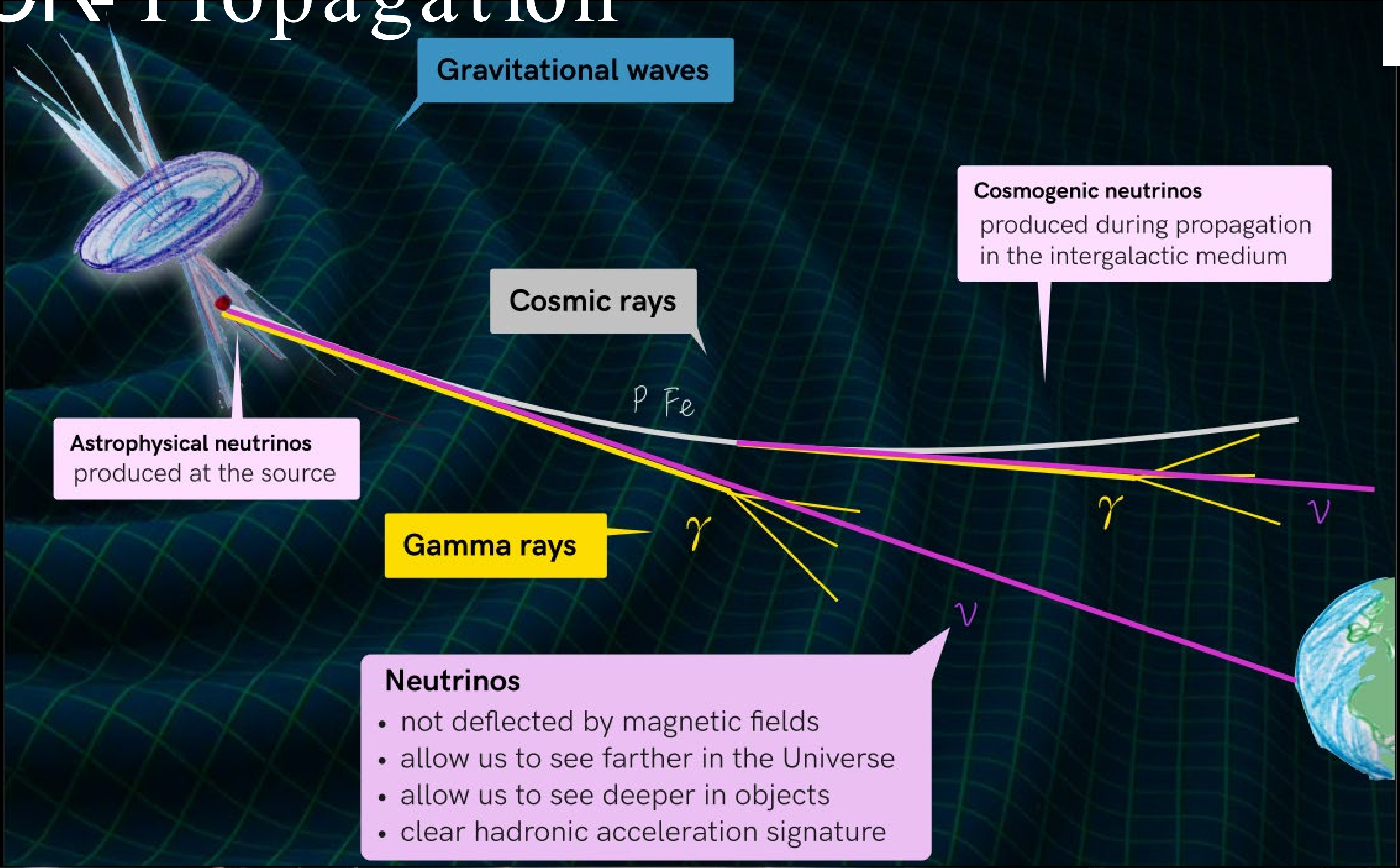


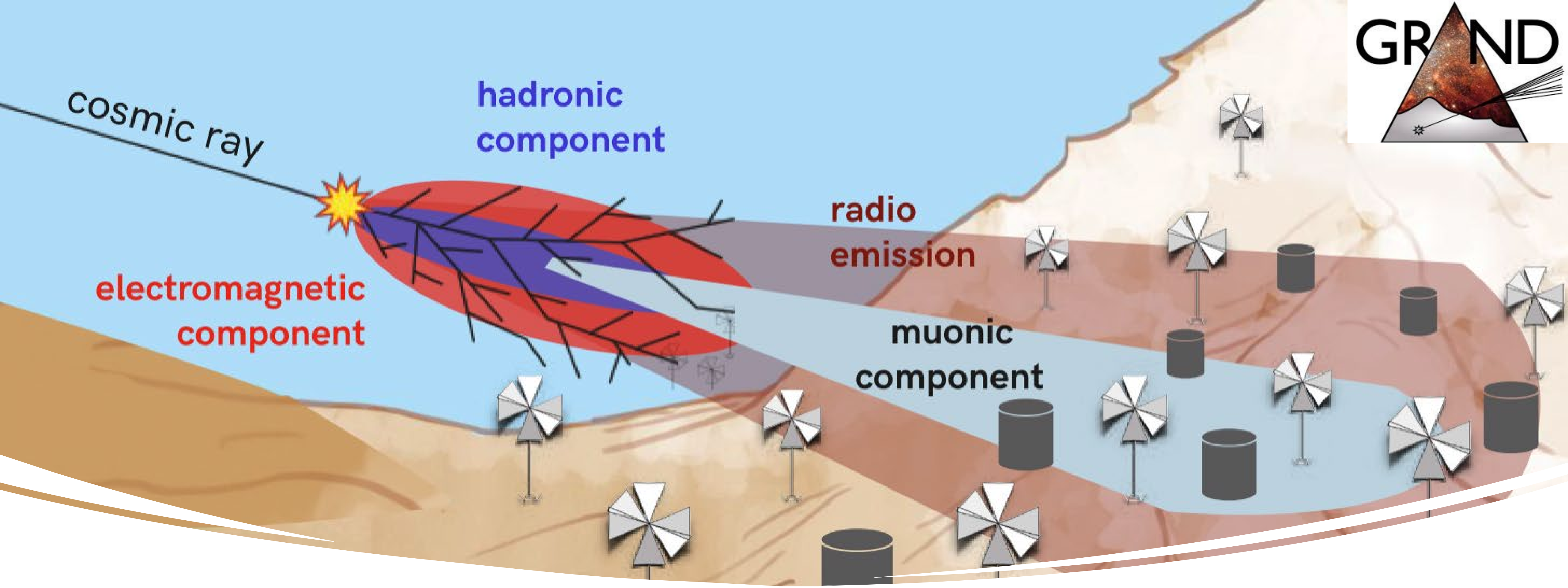
AGN - Blazars



Gamma ray bursts

UHECR- Propagation





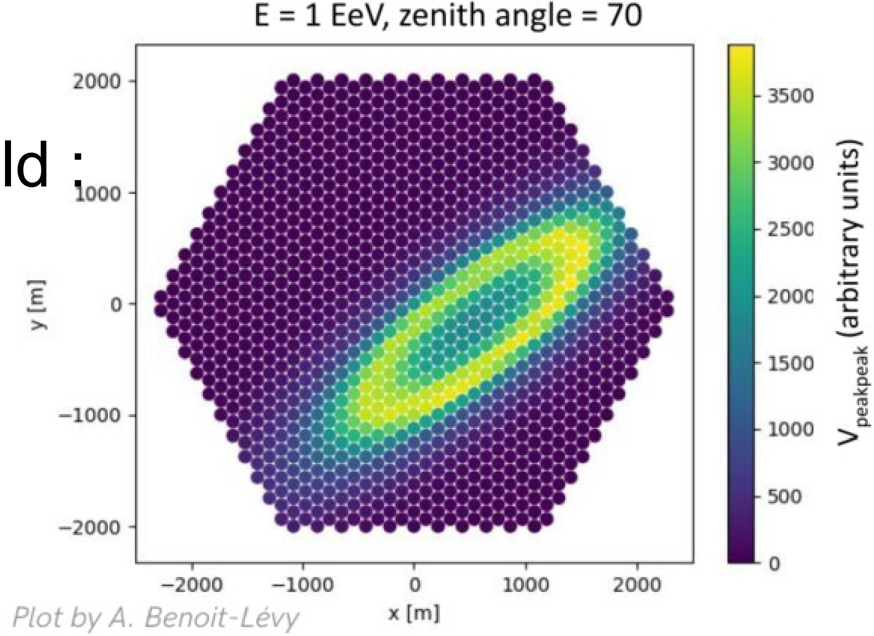
Extensive Air Showers - Development

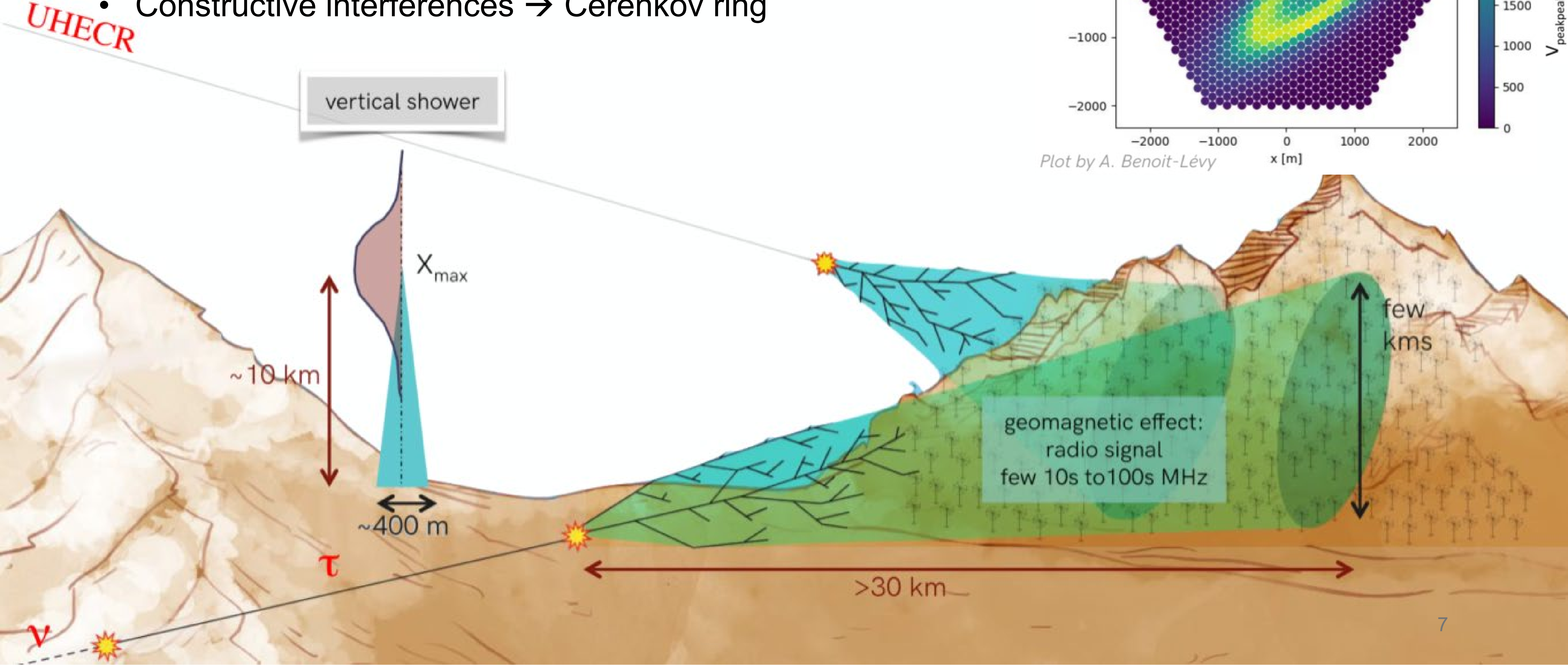
- Interaction of cosmic ray in the atmosphere
- Billions of particles produced
- Different components

Radio detection - Physics

Deflection of charged particles by Earth's magnetic field :

- Separation of electrons and positrons
- Charge current which generates radio emission
- Constructive interferences → Cerenkov ring





Experimental aspects

Different detection methods :

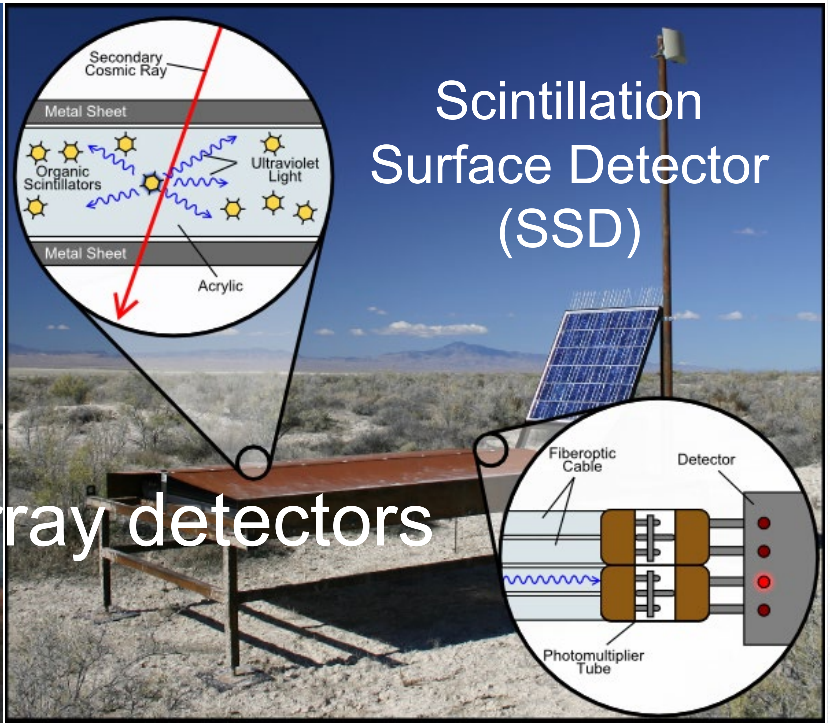
- SSDs and FDs at Telescope Array (North Hemisphere)
- FDs and WCDs at Pierre Auger Observatory (Southern Hemisphere)

Interest of radio detection :

- Antennas are scalable
- Prototypes at Auger and with GRAND

Water Cerenkov Detector (WCD)

Fluorescence Detector (FD)



Scintillation Surface Detector (SSD)

Telescope Array detectors

Radio antennas

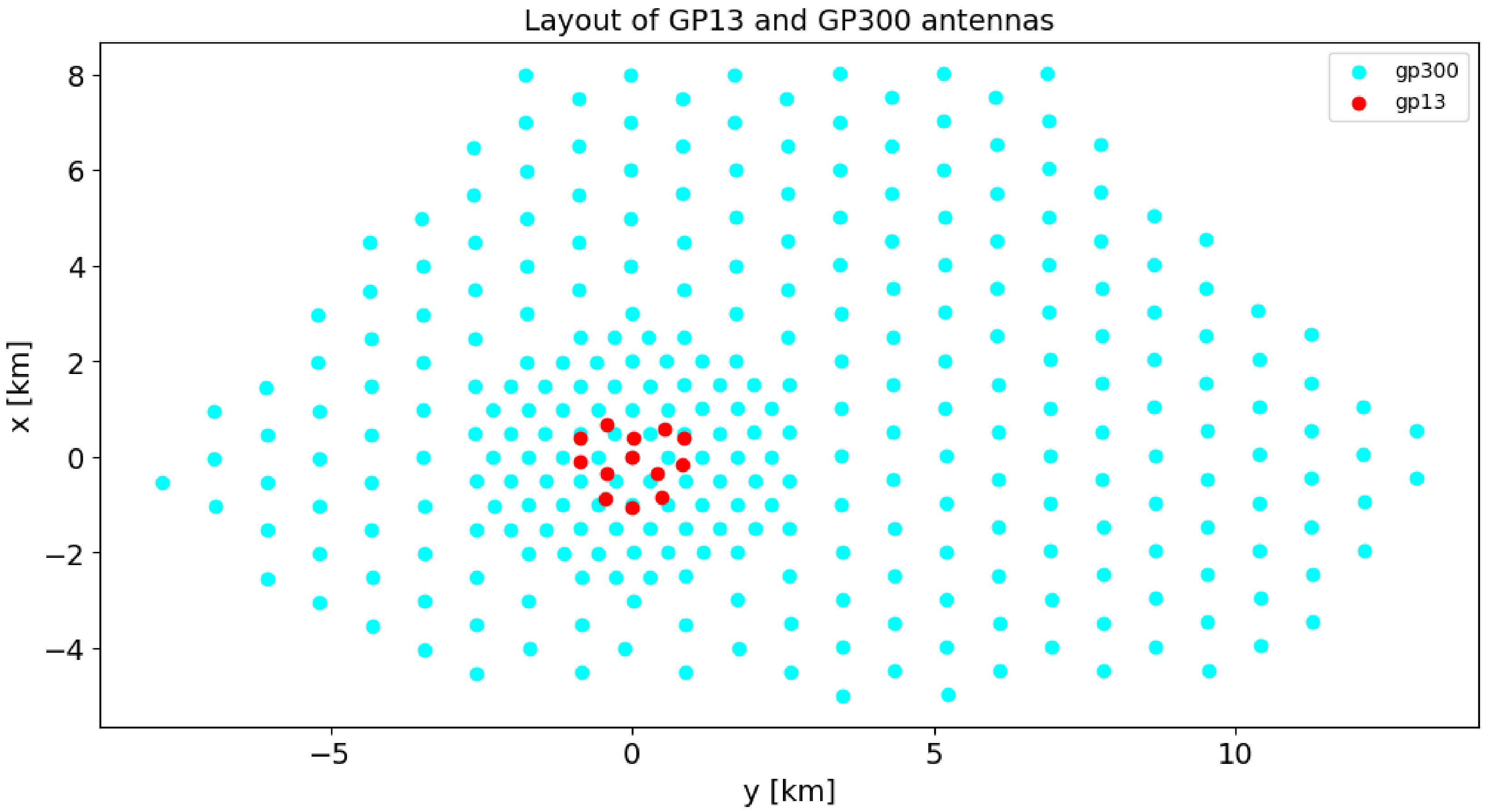
Optimizing the layout of a giant hybrid array

History of GRAND deployment

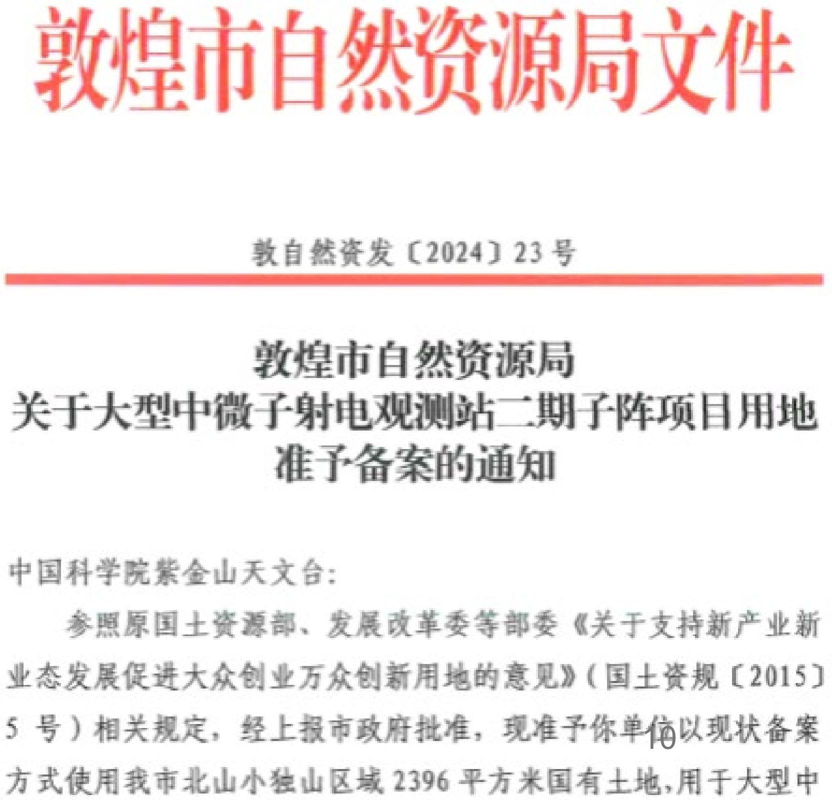
- 13 antennas currently deployed → GP13
- Plan to deploy 300 antennas → GP300

  } Prototyping phase

- Final goal : 200k antennas over 200,000 km^2



Approval of antennas for GP300 by the Chinese Government



敦煌市自然资源局文件

敦自然资发〔2024〕23 号

敦煌市自然资源局
关于大型中微子射电观测站二期子阵项目用地
准予备案的通知

中国科学院紫金山天文台：

参照原国土资源部、发展改革委等部委《关于支持新产业新业态发展促进大众创业万众创新用地的意见》（国土资规〔2015〕5 号）相关规定，经上报市政府批准，现准予你单位以现状备案方式使用我市北山小独山区域 2396 平方米国有土地，用于大型中

Purpose of my internship

2 different questions :

- The development of 80 antennas is planned for Autumn 2024
  - Which antenna layout to deploy
  - Compromise between two criterions :
    - Enough detected events
    - Being able to carry out parameter reconstruction
- Interest of deploying particle detectors: collaboration with TA group
  - Particle content : different depending on primary particle
  - How to add scintillation detectors - TA way
    - Using TA simulations and expertise

Simulations with CORSIKA and CoREAS

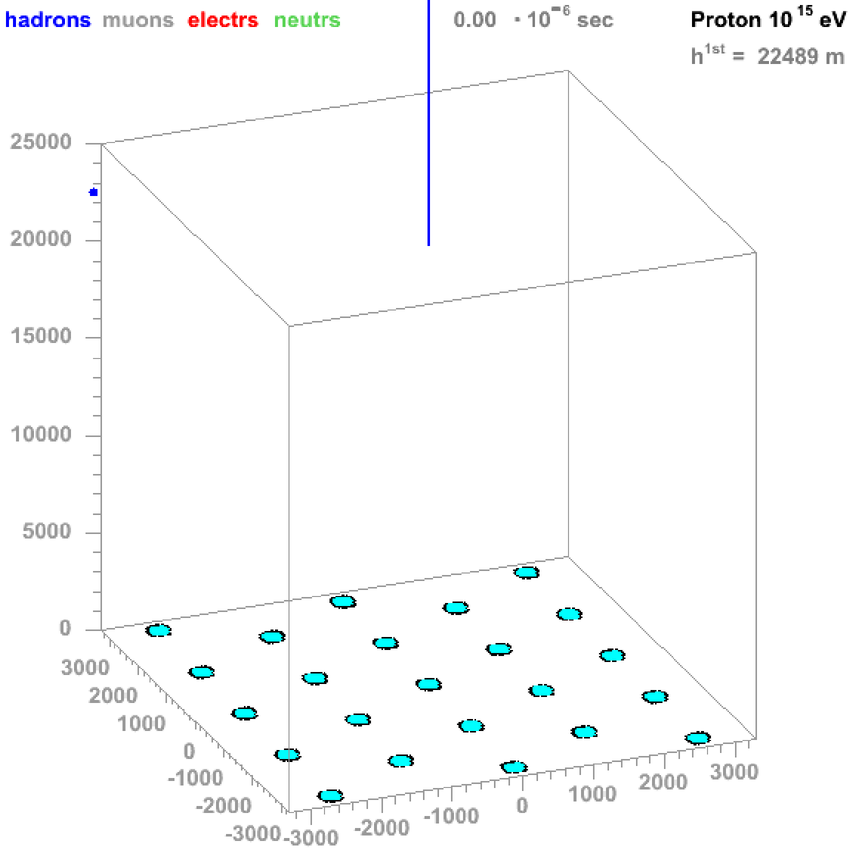
Complete choice of parameters
- Primary particle
- Energy
- Zenith
- Azimuth

CORSIKA

- Simulation tool for the development of air showers
- Calculates interactions between particles very comprehensively
- Extensively tried and tested → very reliable

CoREAS

- Uses CORSIKA particle output
- Calculates electric field generated at antenna level
- All processes considered
- Customizable antenna positions

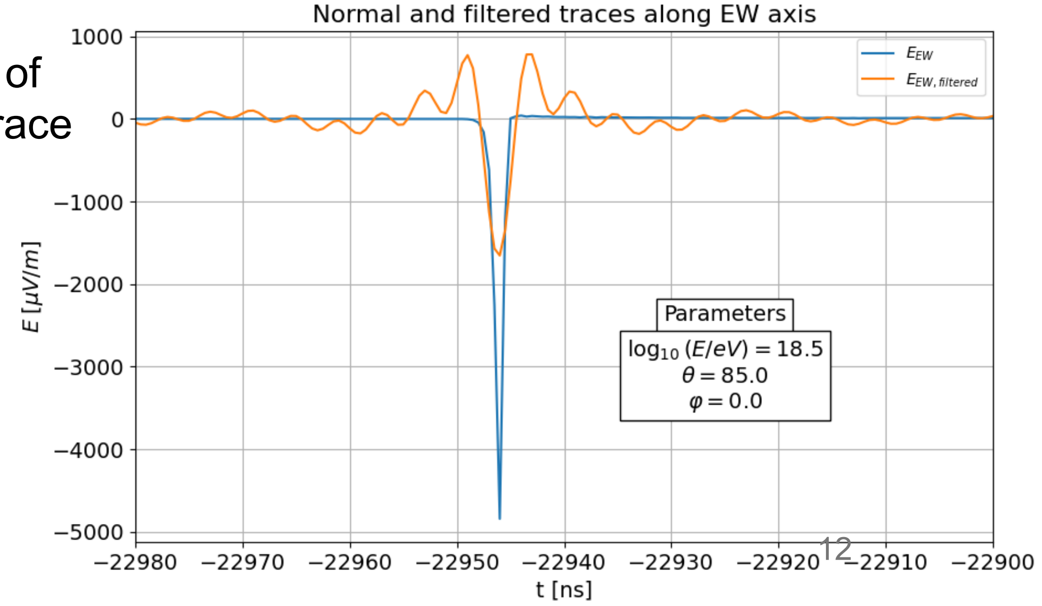


J.Oehlschlaeger,R.Engel,FZKarlsruhe

https://www.iap.kit.edu/corsika/img/trafix15pr05.gif

Particle development calculated with CORSIKA

Example of CoREAS trace output



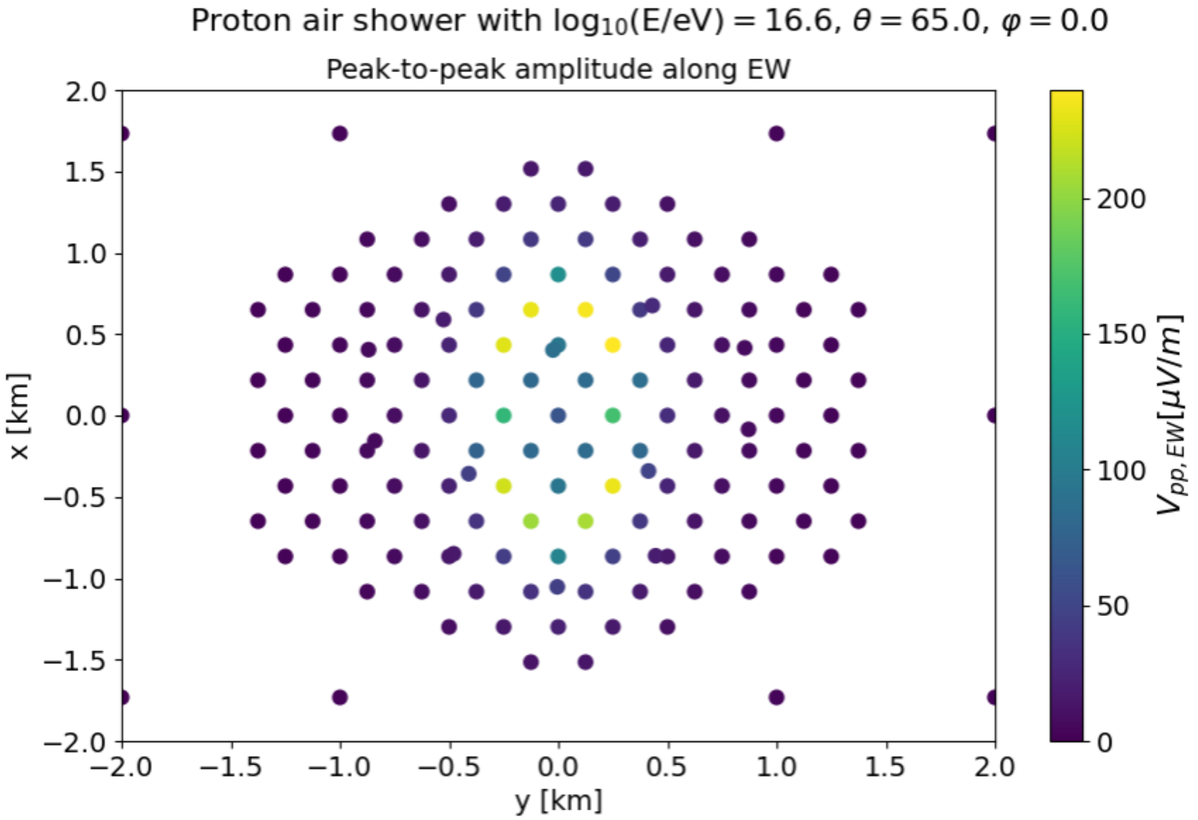
Simulation parameters

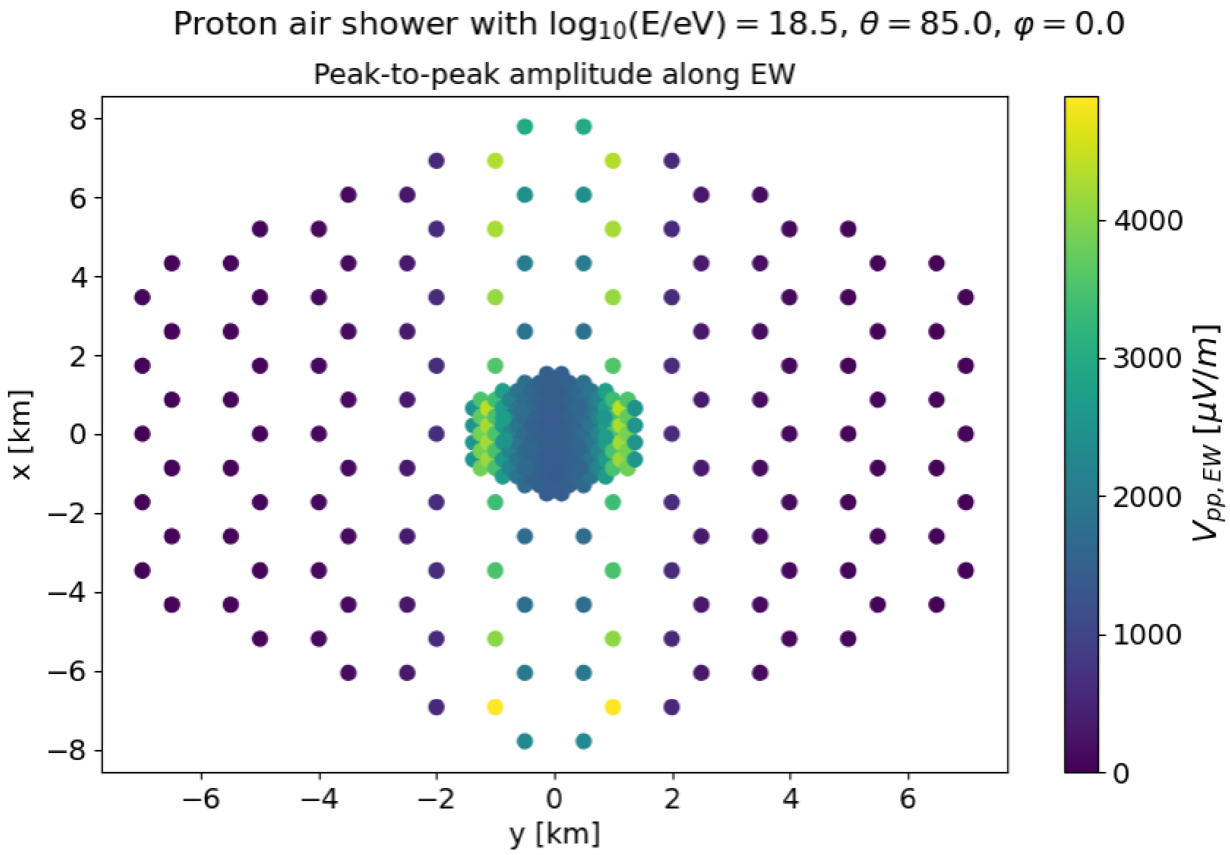
- Create a library of simulated air showers
  - To study different layouts
  - To test reconstruction algorithms and performances

- Air showers with :
  - Proton primary (for now, maybe gamma later)
  - Energies between $\log_{10}\left(\frac{E}{eV}\right) = 16{,}6$ and $\log_{10}\left(\frac{E}{eV}\right) = 18{,}5$
  - Zenith angles between 60° and 87° (probability distribution in $1/\cos(\theta)$)
  - Random azimuth angles between 0° and 360°

Radio footprint

Peak-to-Peak amplitude of the electric field as a function of antenna position



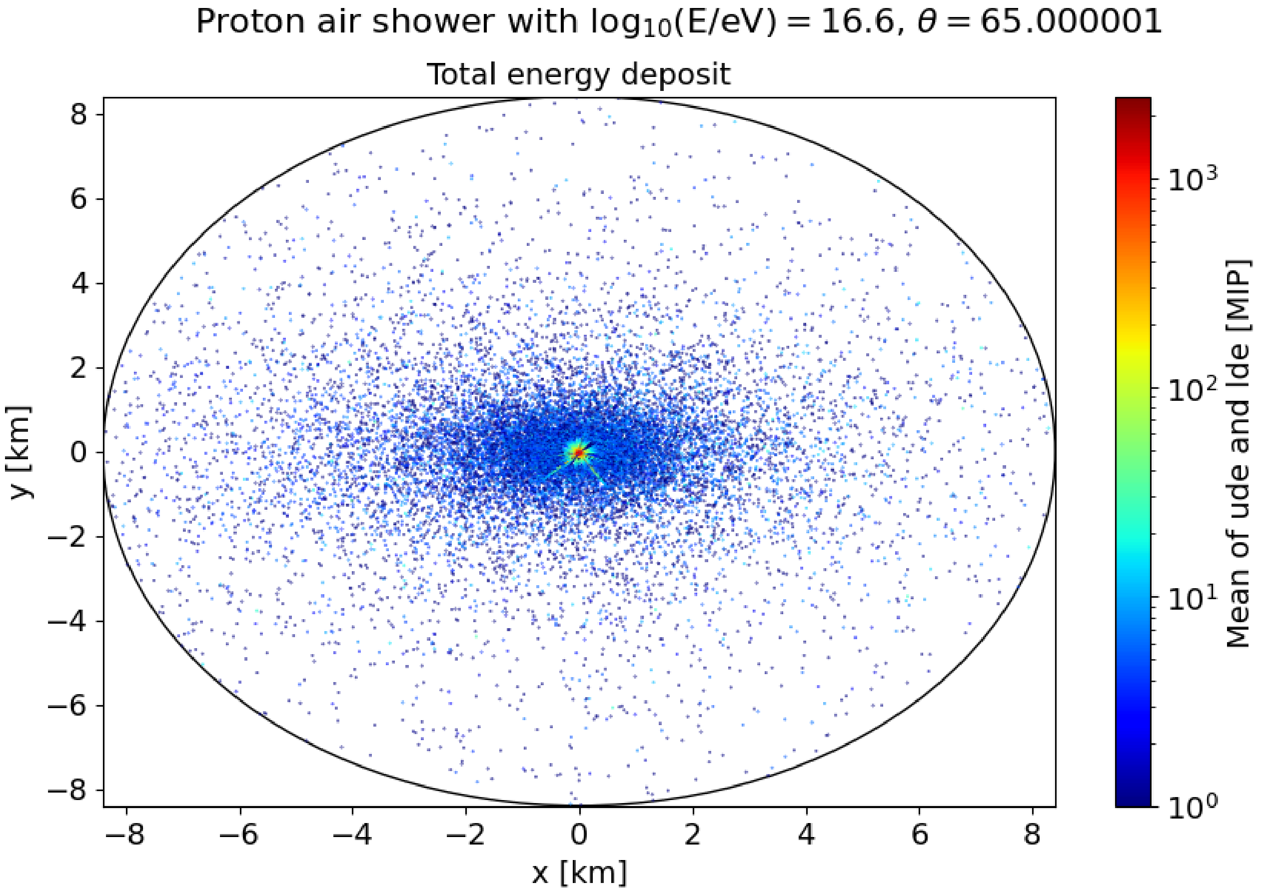


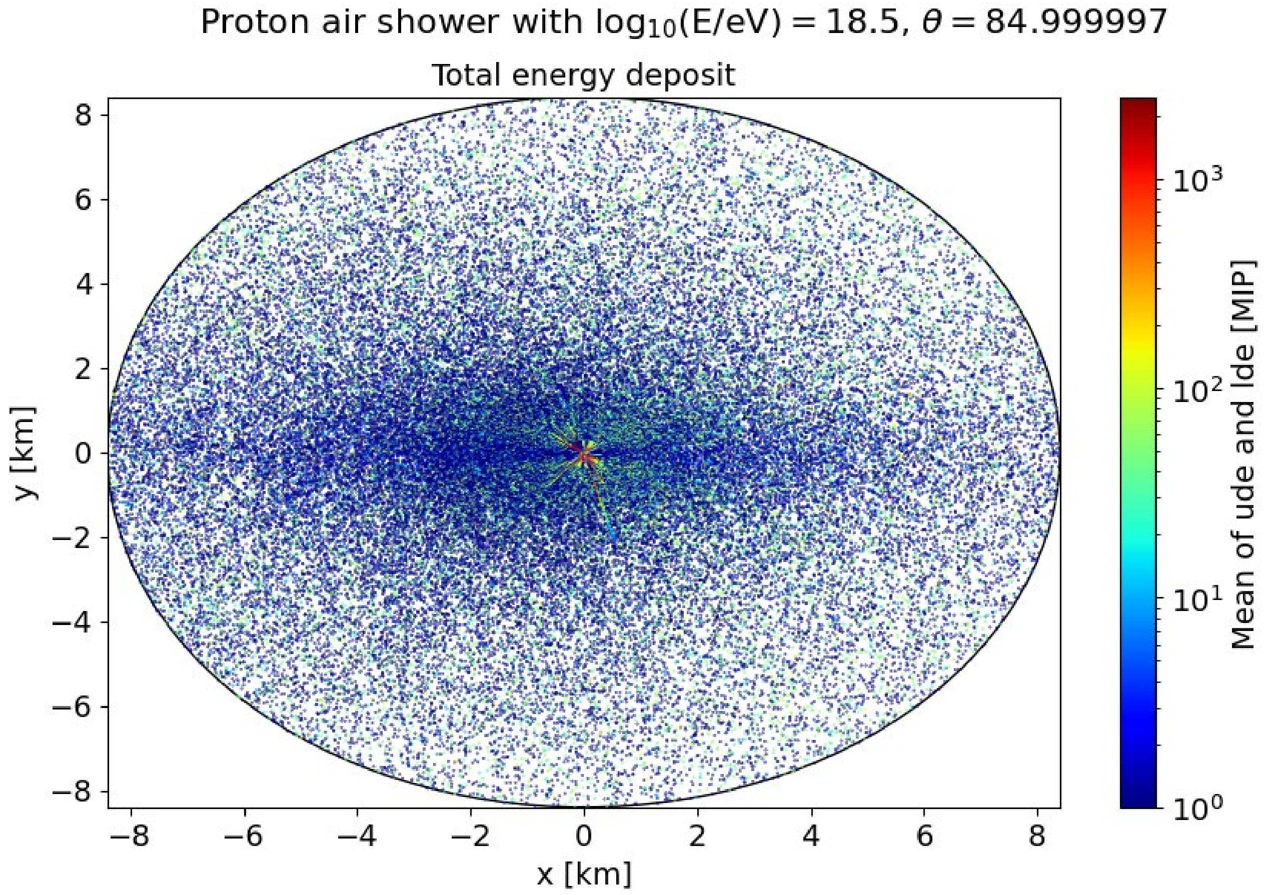
Number of triggered antennas depends on the energy of the primary particle and its zenith angle

An event is triggered if 5 or more antennas have an amplitude above $60\ \mu V/m$ (3 times the Galactic noise) after filtering (keeping only 50-250 MHz band)

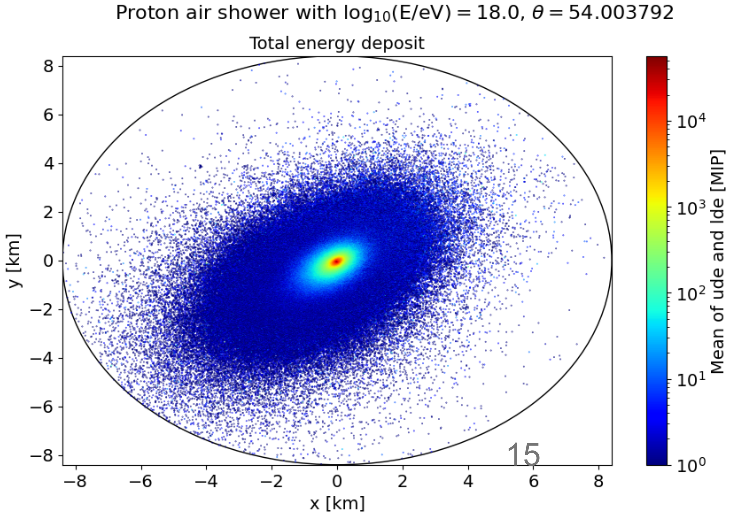
Particle footprint

Energy deposits on scintillation detectors on the ground





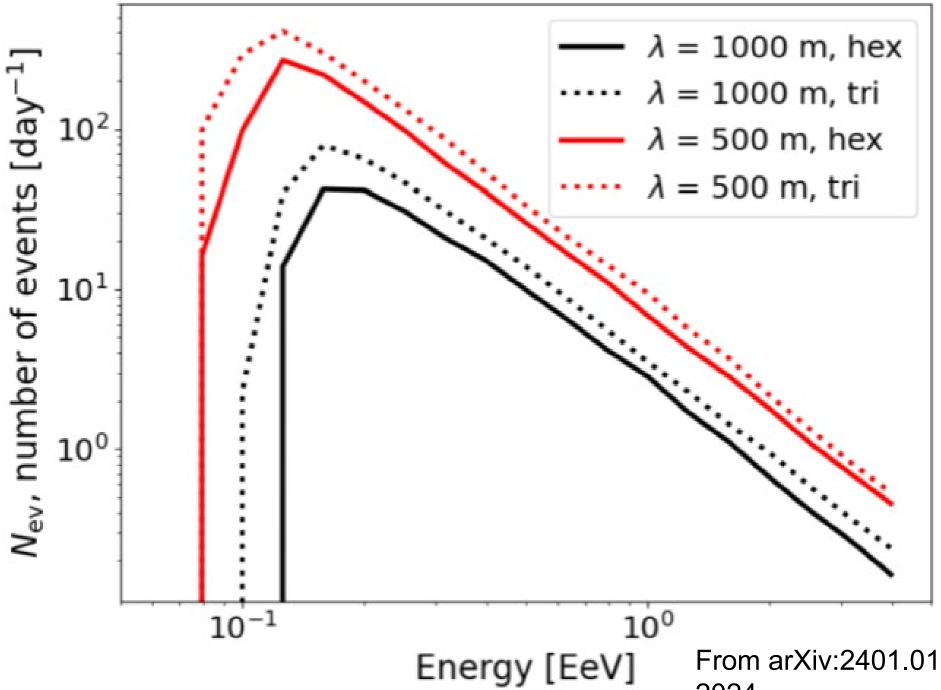
For very inclined air showers, the particle footprint is to spread out to see patterns



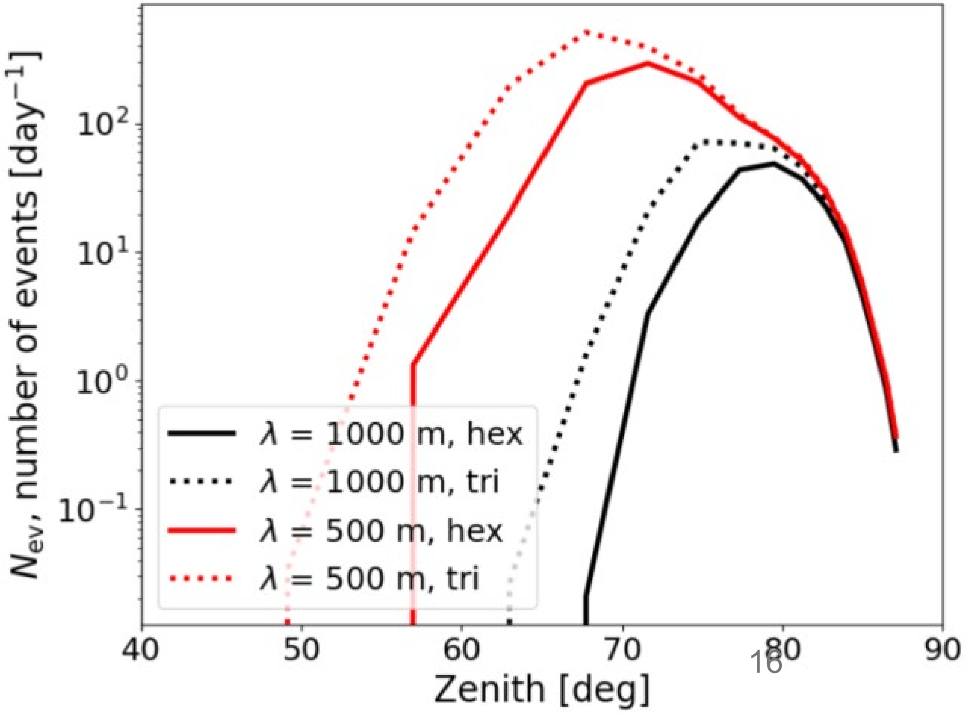
Perspectives

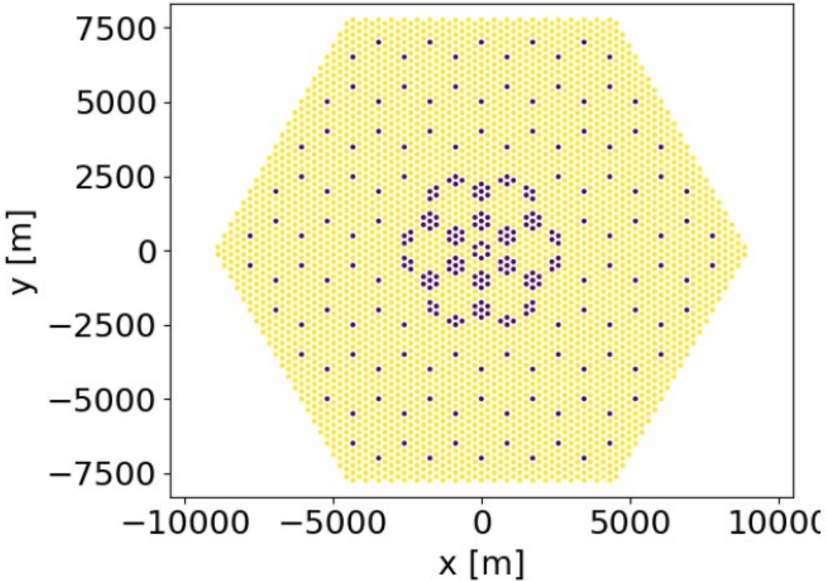
Once the simulation library is complete :

- Compute the **trigger rate** depending on energy and zenith angle, and the **number of detected events per day**
- For different layouts of 80 antennas to prepare next deployment phase



From arXiv:2401.01267v1 [astro-ph.IM] 2 Jan 2024



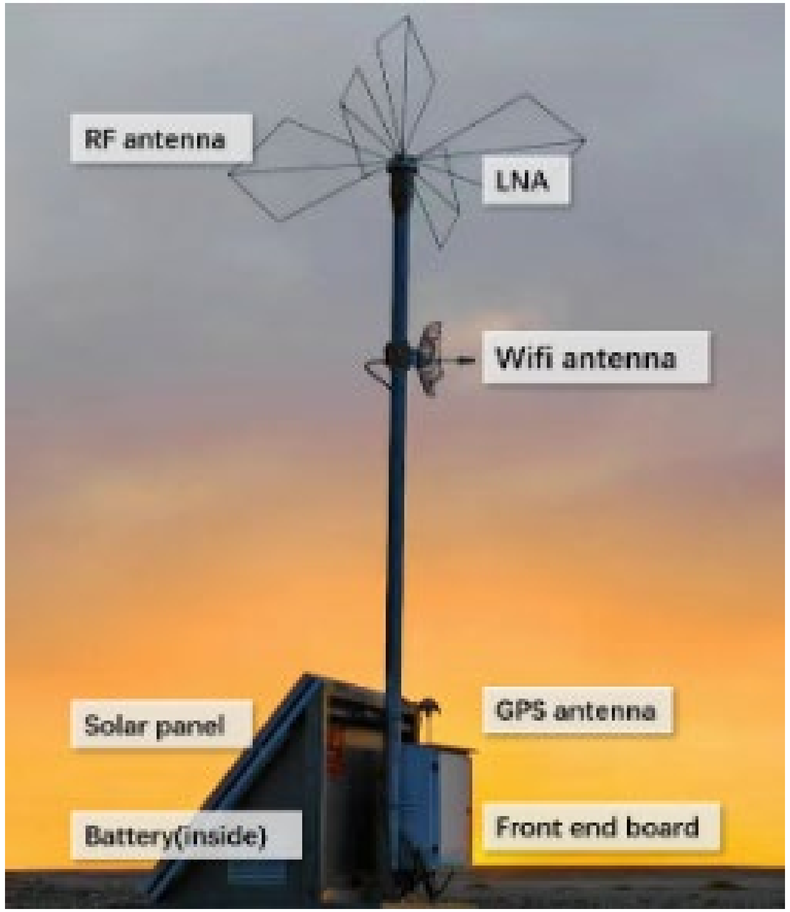


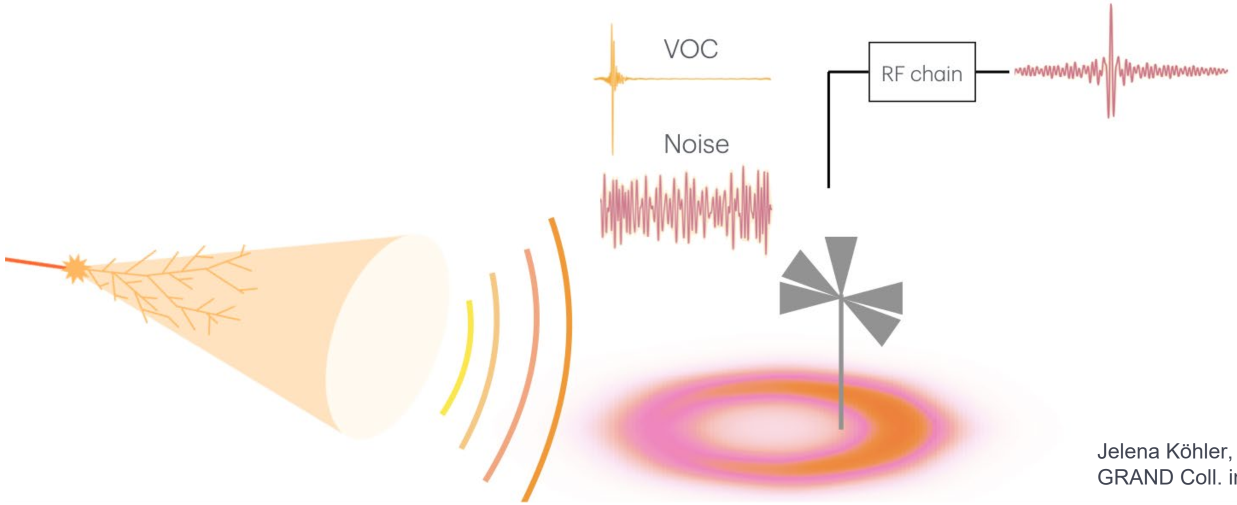
Potential layout to explore

Calibrating the Detector

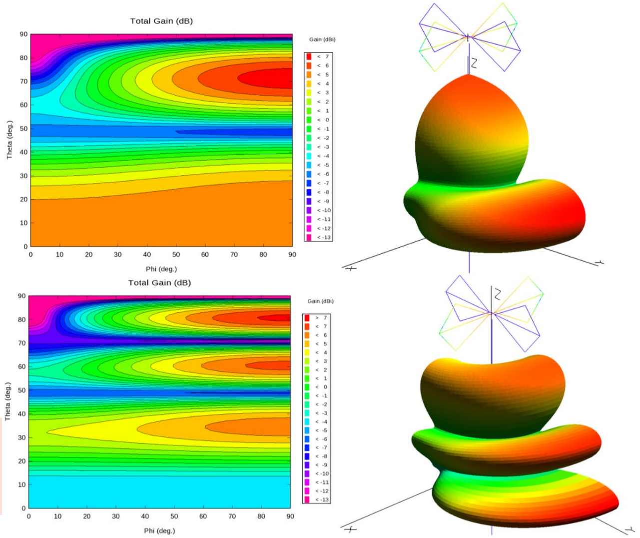
Data Commissioning Analysis

Experimental Aspects Part 2





Jelena Köhler, GRANDlib paper, GRAND Coll. in prep.



Two-dimensional (left column) and three-dimensional (right column) total gain of the X-arm as a function of direction

Needs to be calibrated…

Data Analysis

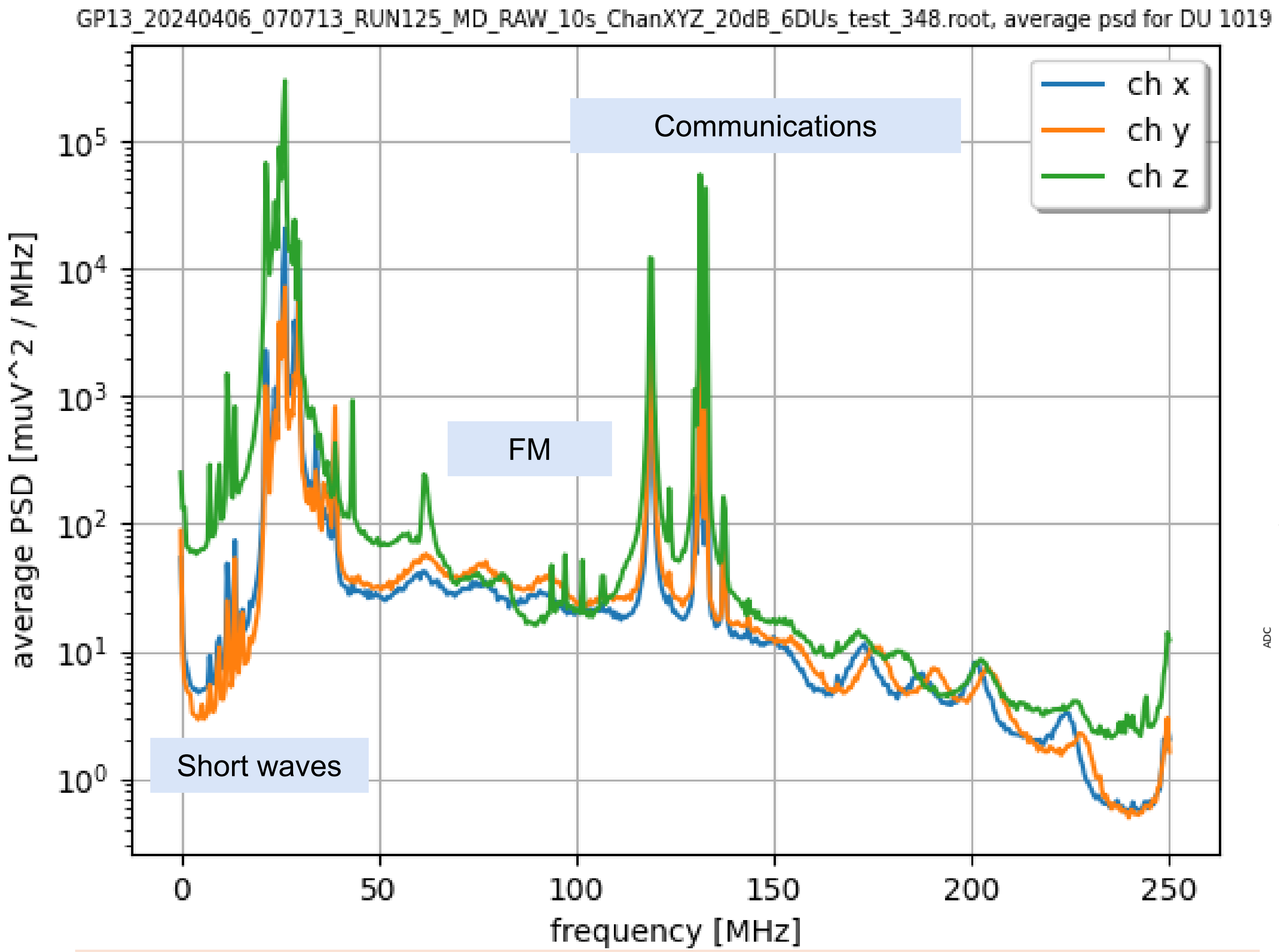
- Root type >> Tree like
- ~1000 Root file per month
- From January 2023 to today
- 2 µs bins, every 10s

BROOT /home/jcolley/projet/grand_wk/grand/grand/data/test_efield.root

tefield;1 | trun;1 | tshower;1

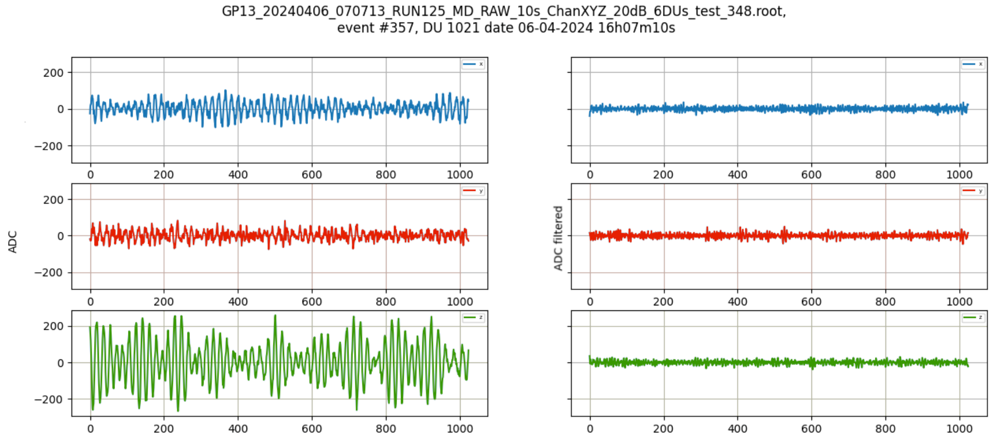
ID	Branch	Value	Type	Shape	Size [Byte]	Action
001	run_number	0	uint32	(1,)	4	Print Plot 1D Plot point Image
002	event_number	1	uint32	(1,)	4	Print Plot 1D Plot point Image
003	time_seconds	0	uint32	(1,)	4	Print Plot 1D Plot point Image
004	time_nanoseconds	0	uint32	(1,)	4	Print Plot 1D Plot point Image
005	event_type	0	uint32	(1,)	4	Print Plot 1D Plot point Image
006	du_count	96	uint32	(1,)	4	Print Plot 1D Plot point Image
007	du_id	Array! Try Action	uint16	(1, 96)	192	Print Plot 1D Plot point Image
008	du_seconds	Array! Try Action	uint32	(1, 96)	384	Print Plot 1D Plot point Image
009	du_nanoseconds	Array! Try Action	uint32	(1, 96)	384	Print Plot 1D Plot point Image
010	trace	Array! Try Action	float32	(1, 96, 3, 999)	1,150,848	Print Plot 1D Plot point Image
011	fft_mag	Empty !?	float32	(1, 0, 0, 0)	0	Print Plot 1D Plot point Image
012	fft_phase	Empty !?	float32	(1, 0, 0, 0)	0	Print Plot 1D Plot point Image
013	p2p	Empty !?	float32	(1, 0, 0)	0	Print Plot 1D Plot point Image
014	pol	Empty !?	float32	(1, 0, 0)	0	Print Plot 1D Plot point Image

Raw Data and Filtering



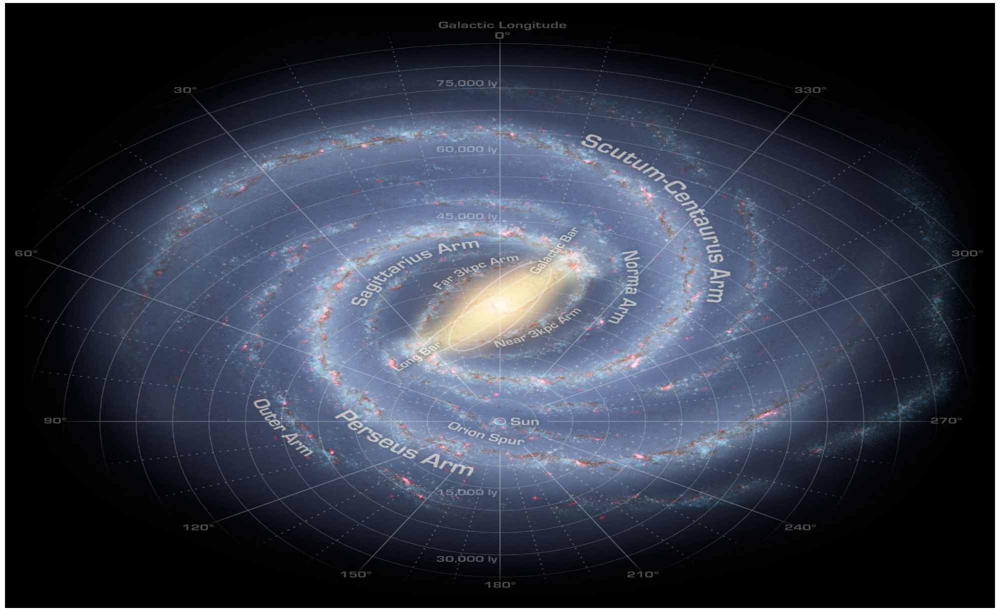
Average Power Spectral Density (PSD) for all 3 channels

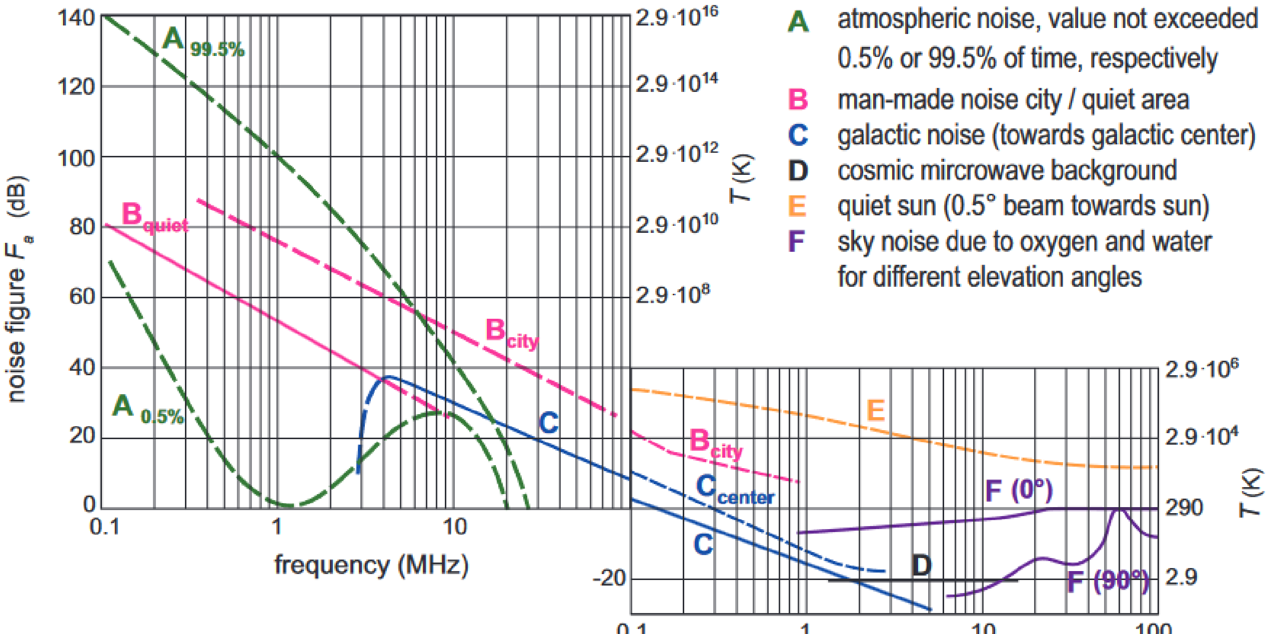
- Polluted signals
- Different noise sources (human-made noise (transient or continuous): car traffic, planes, FM emission, - instrumental noise (charge controller, component heating...), - Galactic noise (continuous))



Unfiltered (right) and filtered (left) traces

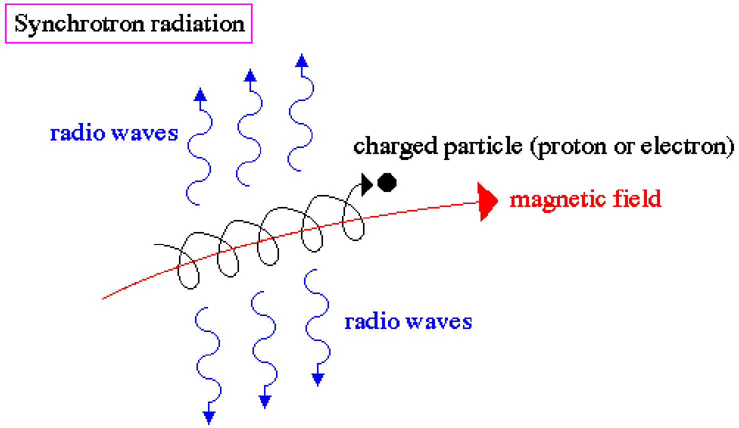
Galactic Noise





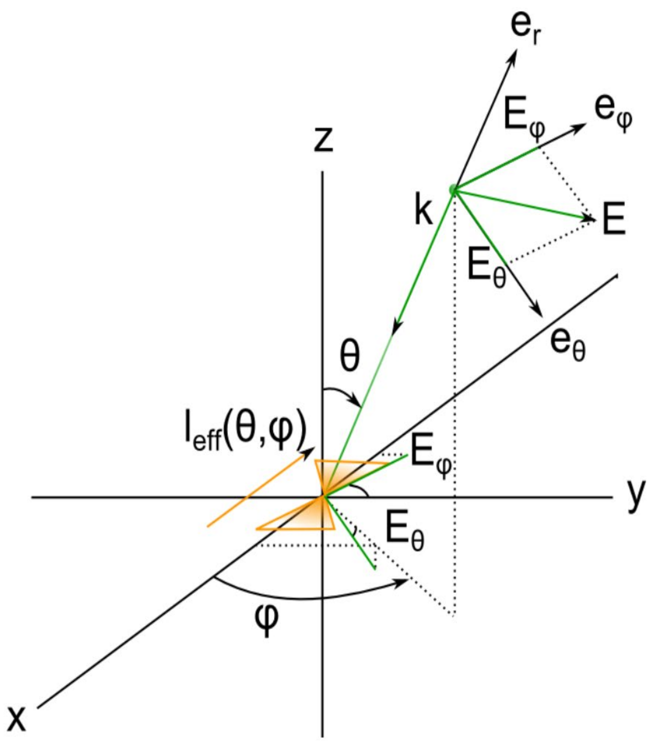
Reproduced from figures 2 and 3 of recommendation *ITU-R P.372-12* by International Telecommunication Union

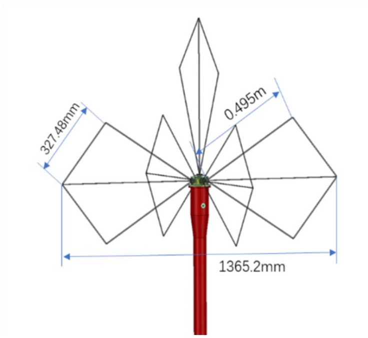
Sources of external radio noise as a function of frequency, expressed as temperature or noise figure F = 10 log10(1+T /Tamb). The blackbody radiation emitted by the ground corresponds to a straight line at T = Tamb = 290 K.



synchrontron radiation occurs when a charged particle encounters a strong magnetic field – the particle is accelerated along a spiral path following the magnetic field and emitting radio waves in the process – the result is a distinct radio signature that reveals the strength of the magnetic field

The Antenna





Electromagnetic wave comobile frame within antenna frame. **k** is the wave vector and in orange is the antenna. The components of the electric field in the comobile frame (Eθ , Eϕ) are translated to the origin of the antenna frame and projected on the antenna effective length l_{eff} with dotted lines.

At the antenna, for given time and f

$$P_{sky}(t,\nu) = \frac{2k_B}{c^2}\int_\nu \nu^2 \int_\Omega T_{sky}(t,\nu,\theta,\phi)A_e(\nu,\theta,\phi)d\nu d\Omega$$

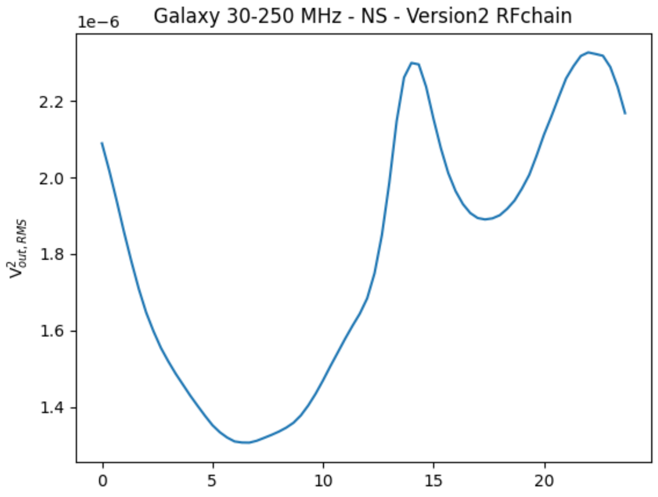
With: the temperature at a given frequency ν, right ascension α, and declination δ, is given as:

$$T_{sky}(\nu,\alpha,\delta) = T_{CMB} + T_{Iso}(\nu) + T_{Gal}(\nu,\alpha,\delta).$$

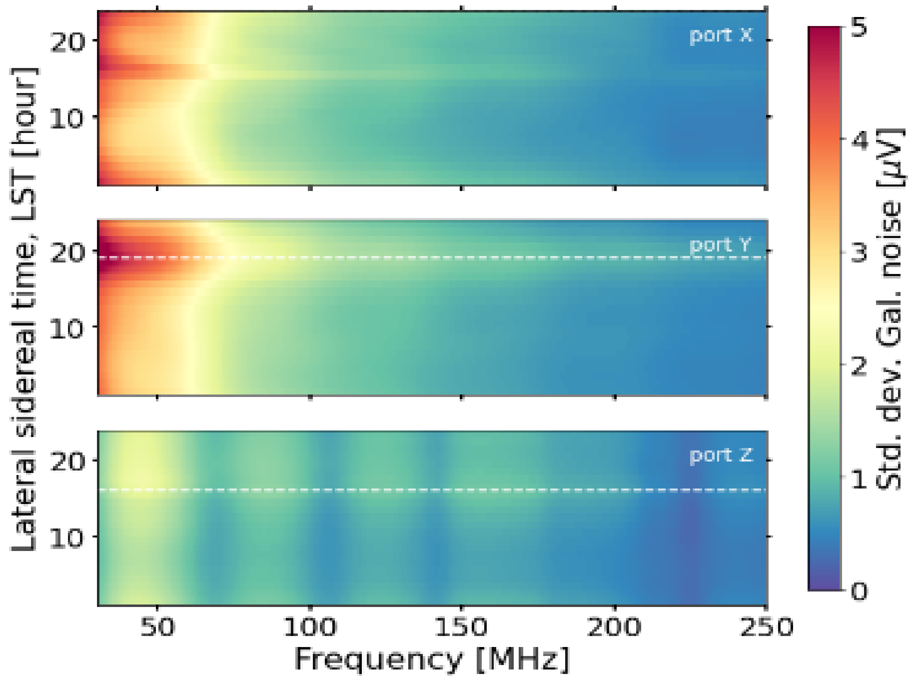
And A_e the antenna effective area.

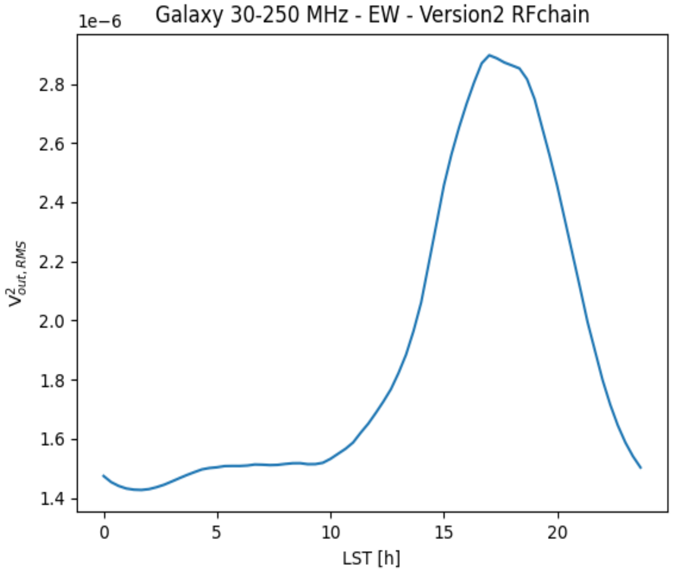
T_{CMB} contribution from the cosmic microwave background (2.73 K)
Isotropic contribution, T_{Iso} (ν): mainly attributed to unresolved emission from extragalactic sources

Simulation Results



NorthSouth = x channel
EastWest = y channel

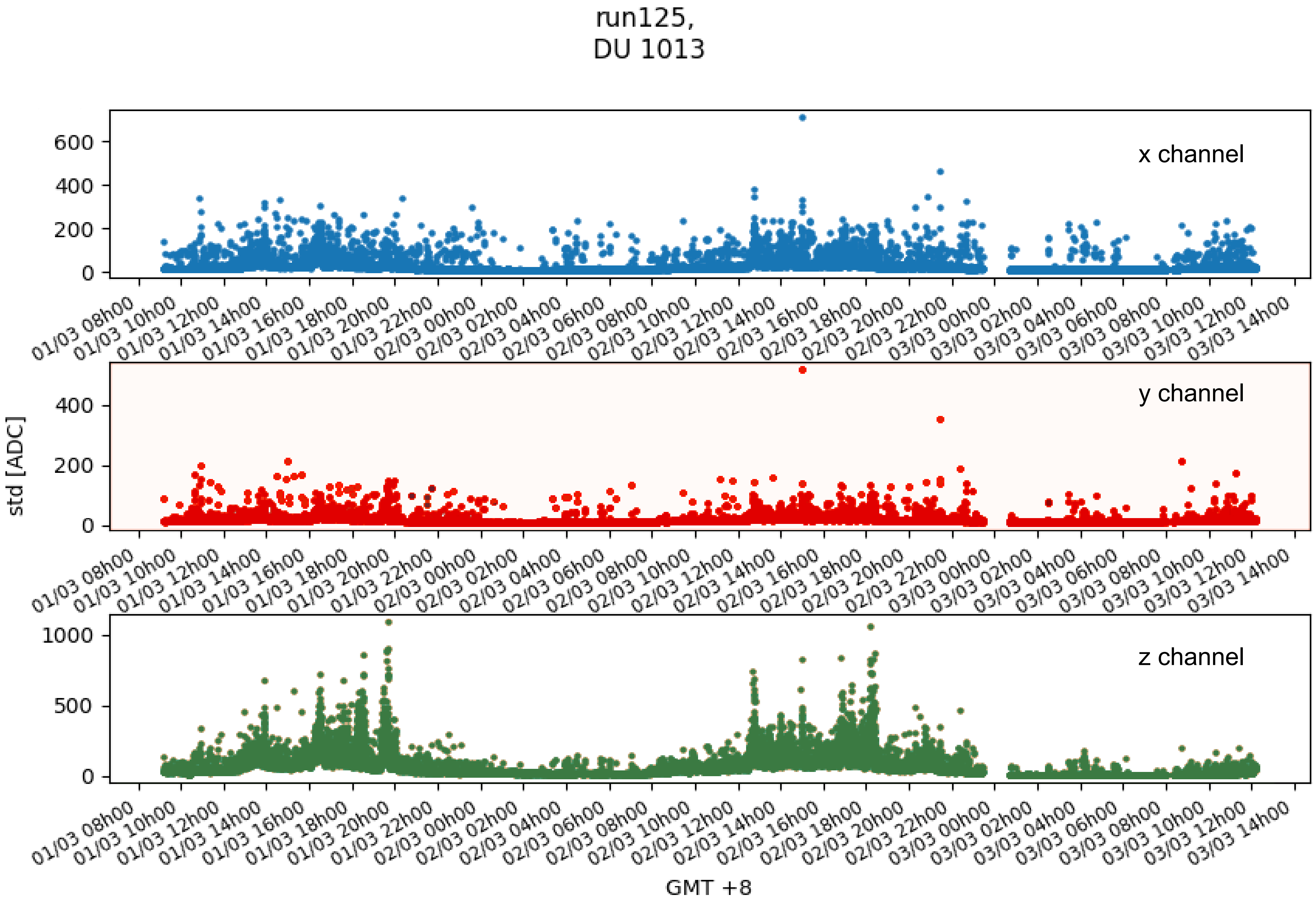




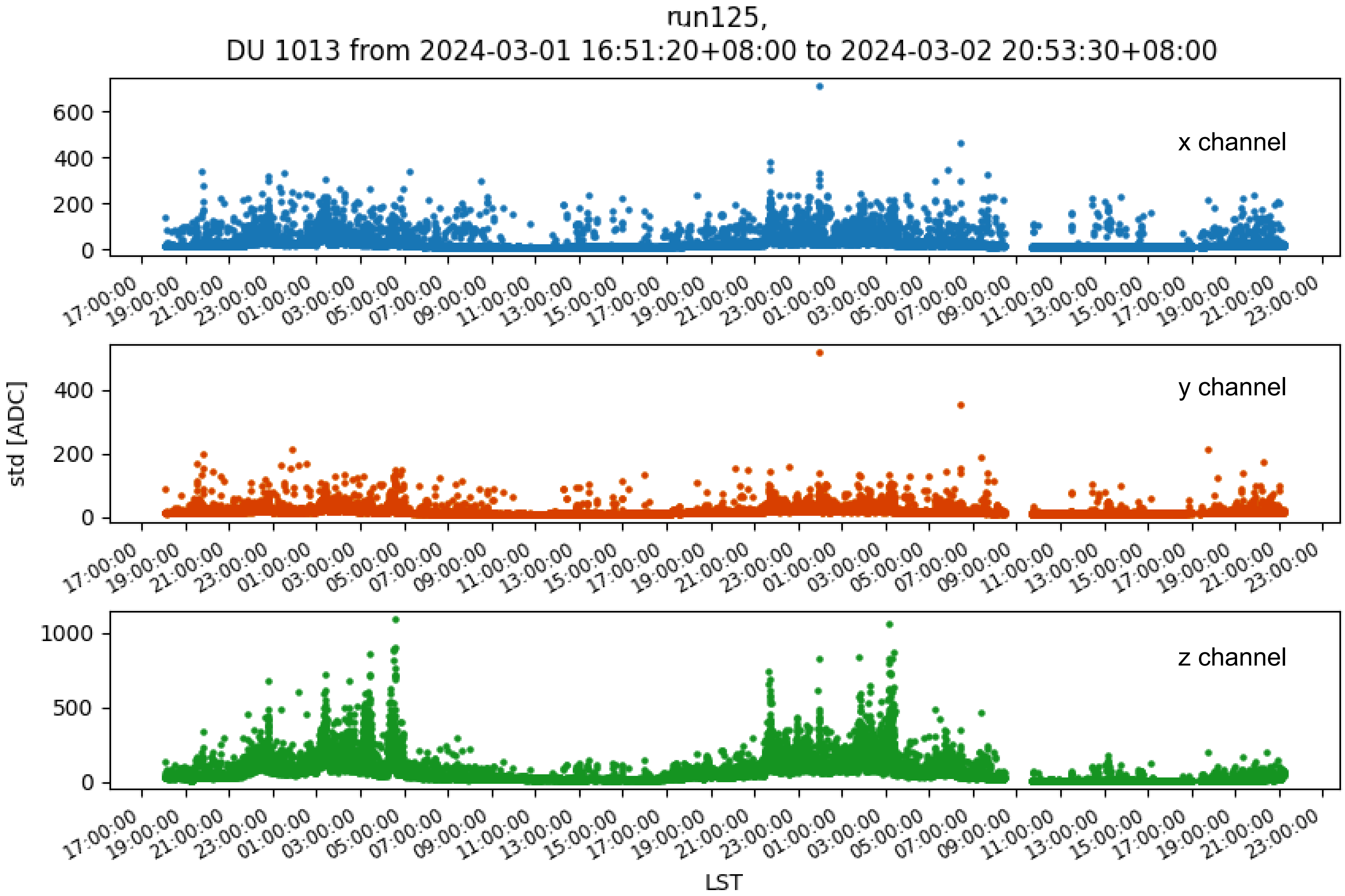
Standard deviation of galactic noise from LFMap package detected by GRAND antennas. Maximum standard deviation of Galactic noise from the model used is for LST=24 for X port, LST=19 for Y port, and LST=16 for Z port and is shown by horizontal dashed lines.

Result from simulations using LFmap software (NASA)

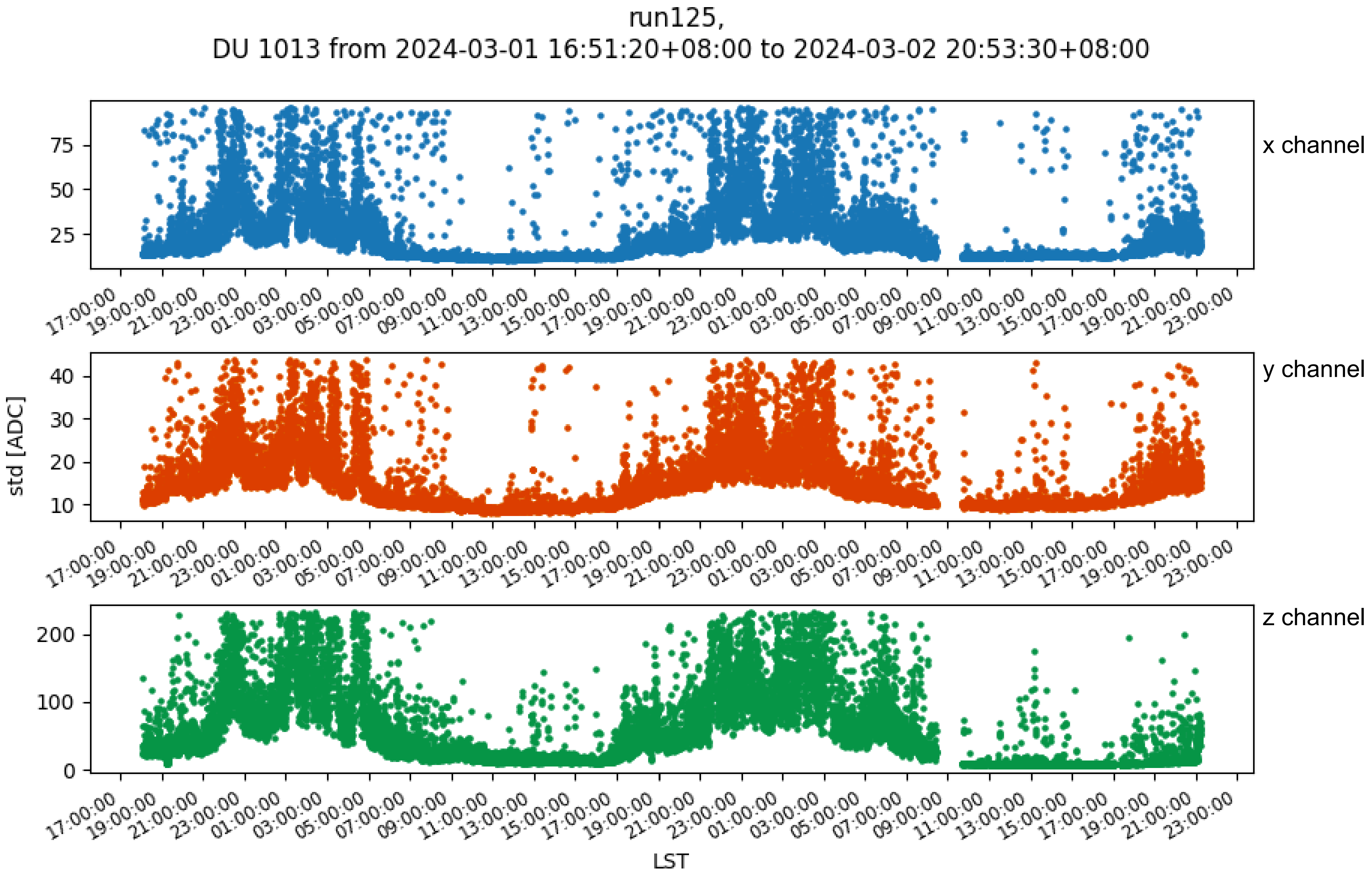
Real Data: Trace Analysis



Real Data: Trace Analysis

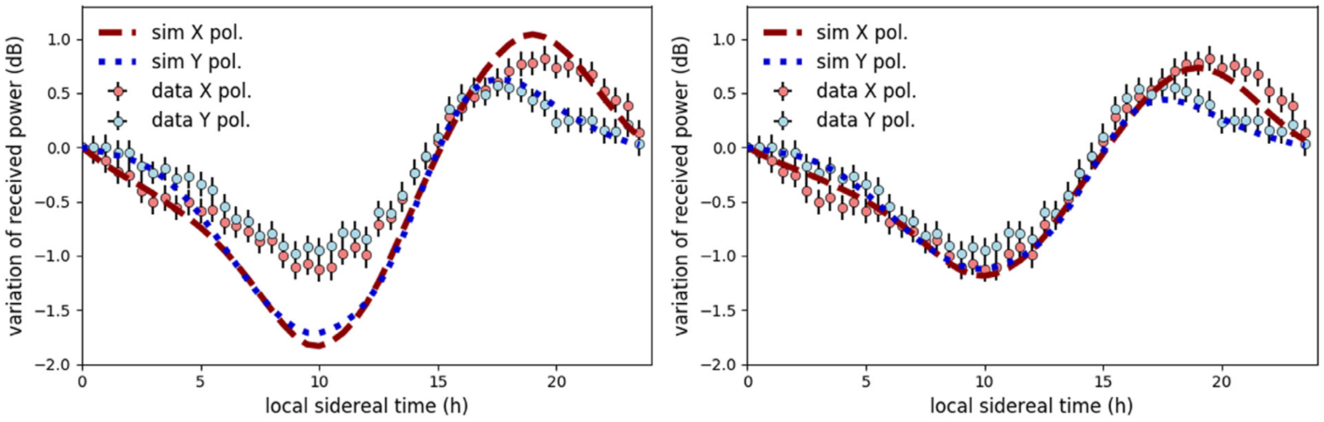


Real Data: Trace Analysis



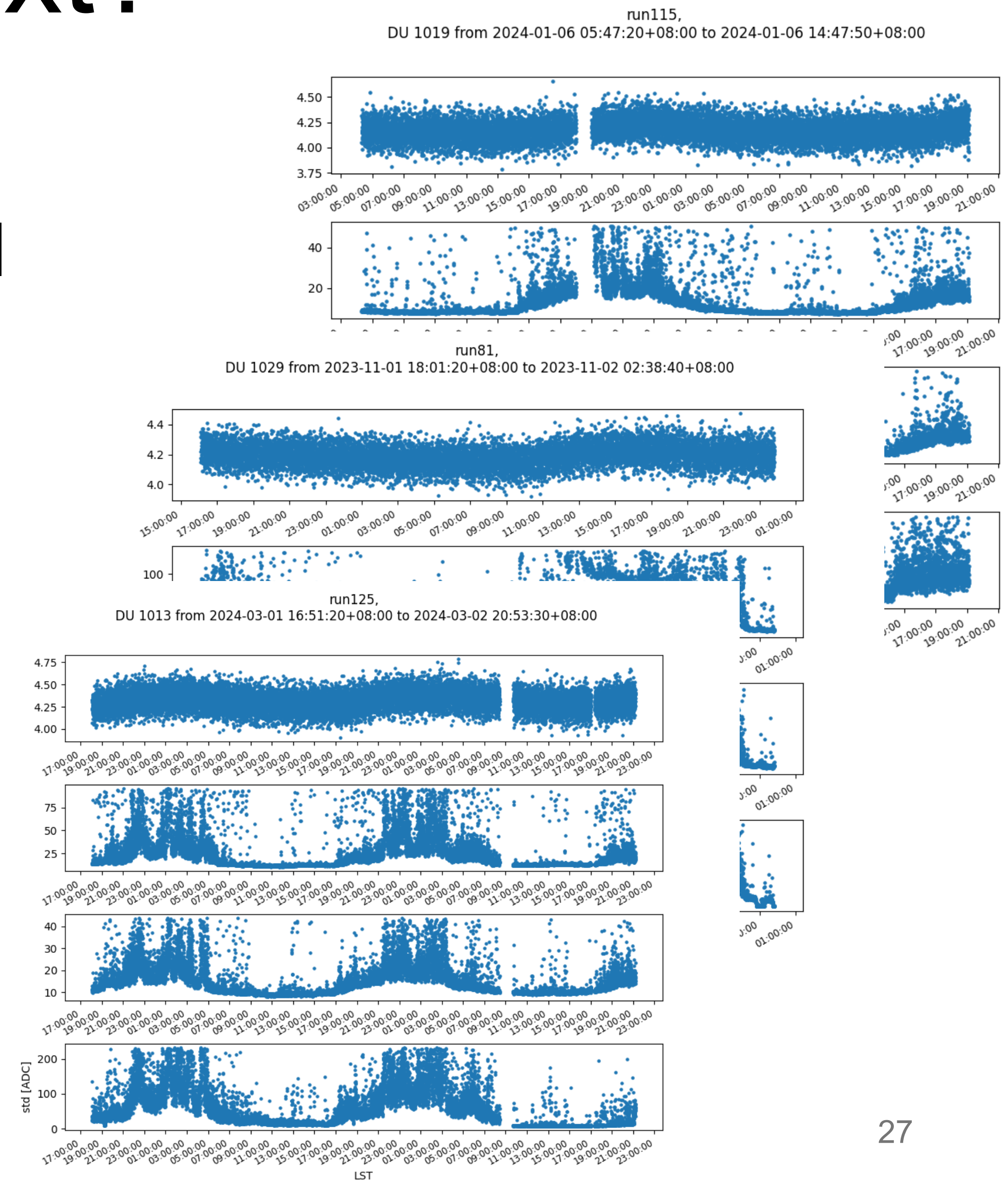
What’s next?

- Stacking several months
- Determine whether we detect GC at all



Left: Variation of received power as a function of local sidereal time.
Right: Simulations including thermal noise contributions and propagated through the signal chain.

Can we obtain similar plots?



References

- Calibration of the LOFAR low-band antennas using the Galaxy and a model of the signal chain: https://doi.org/10.1016/j.astropartphys.2019.03.004.
- GRAND White Paper: https://arxiv.org/abs/1810.09994
- Website: http://grand-observatory.org
- Github: https://github.com/grand-mother/