Radio detection of neutrinos with LOFAR & ARIANNA

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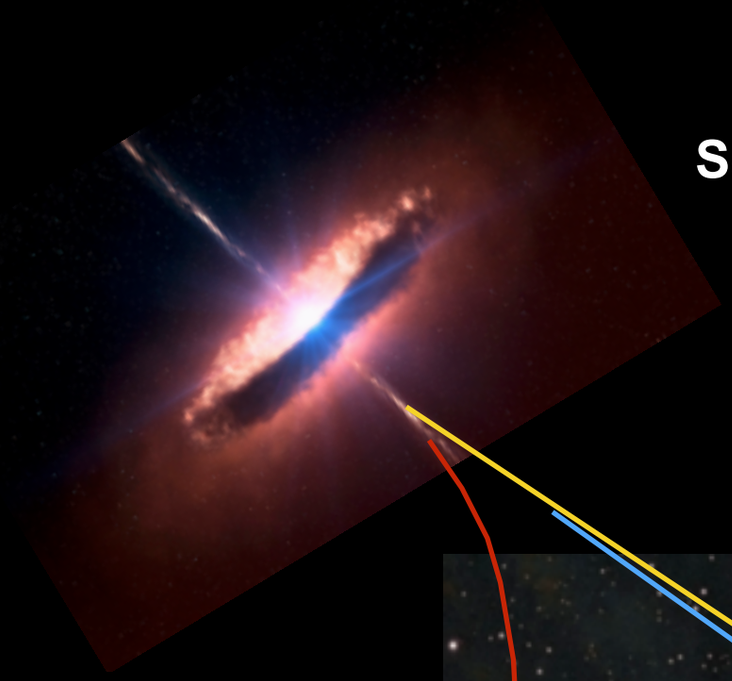
Low Frequency Observing, Bologna, 23-6-2017

Particle Universe



Sources ?

$p + \text{nucleus} \rightarrow \pi + X$

$p + \gamma_{CMB} \rightarrow \Delta^{+} \rightarrow \pi + p/n$

$\pi^{+/-} \rightarrow \nu + \text{lepton}$

$\pi^{0} \rightarrow \gamma\gamma$

Composition?

Cosmic rays

Gamma rays

Neutrinos

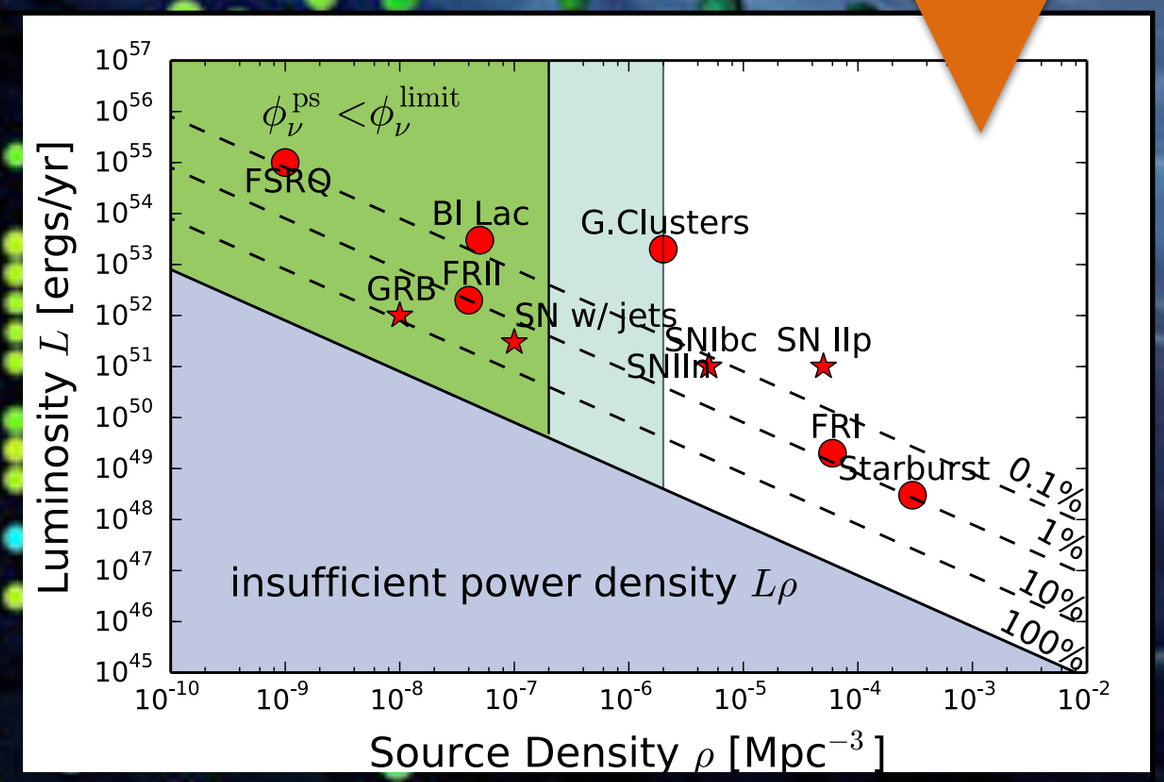
Magnetic fields?

ISM

IceCube: optical Cherenkov from **muon** tracks / **electron** cascades

cosmic neutrinos found ~ 10/y
100 - 1000 TeV

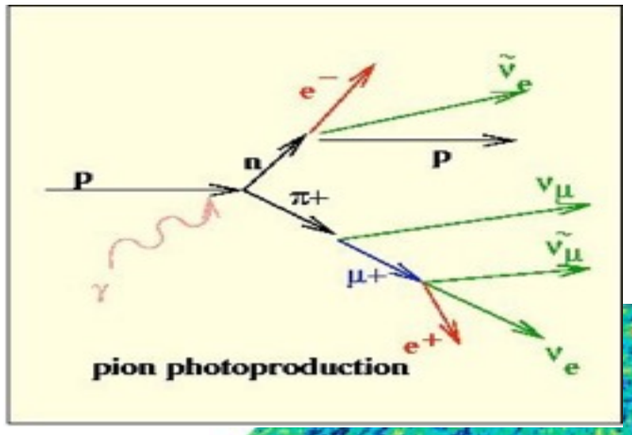
neutrino production **at source**



arXiv:1411.4385

Cosmogenic neutrinos

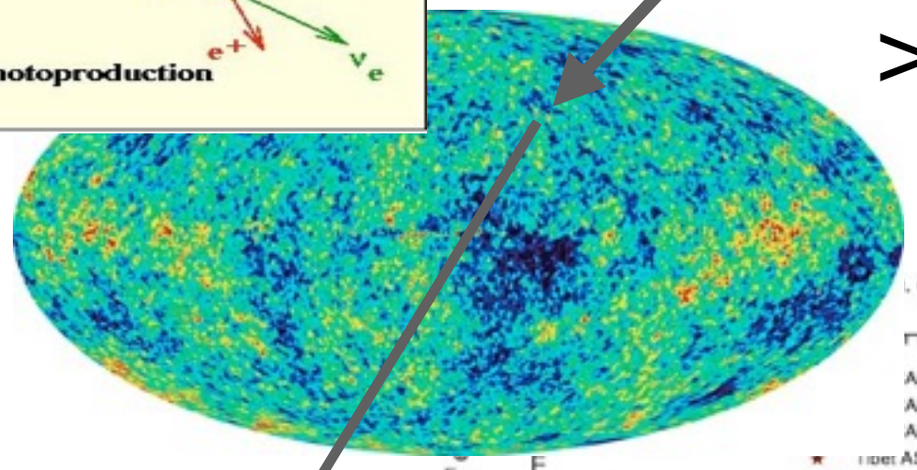
Greisen-Zatsepin-Kuzmin (**GZK**) effect
neutrino production <u>during propagation</u>



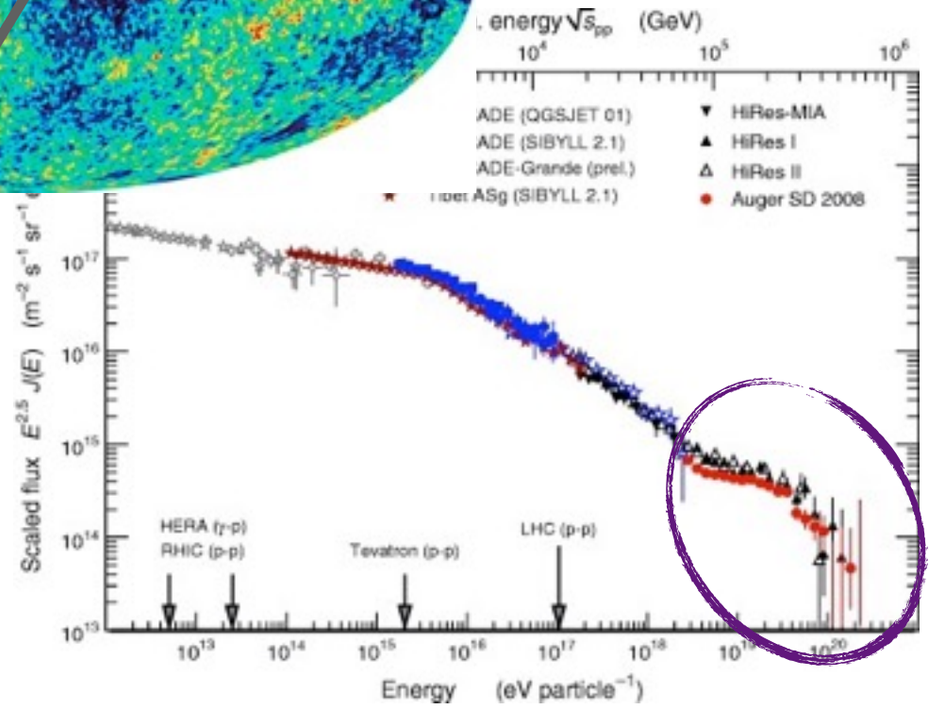
p

~ 50 Mpc

$> 6.10^{19}$ eV



ν



GZK neutrinos (~10^{17} - 10^{19} eV):

- identify CR sources
- understand cut-off
- CR source evolution

Need detector size **IceCube x 100**

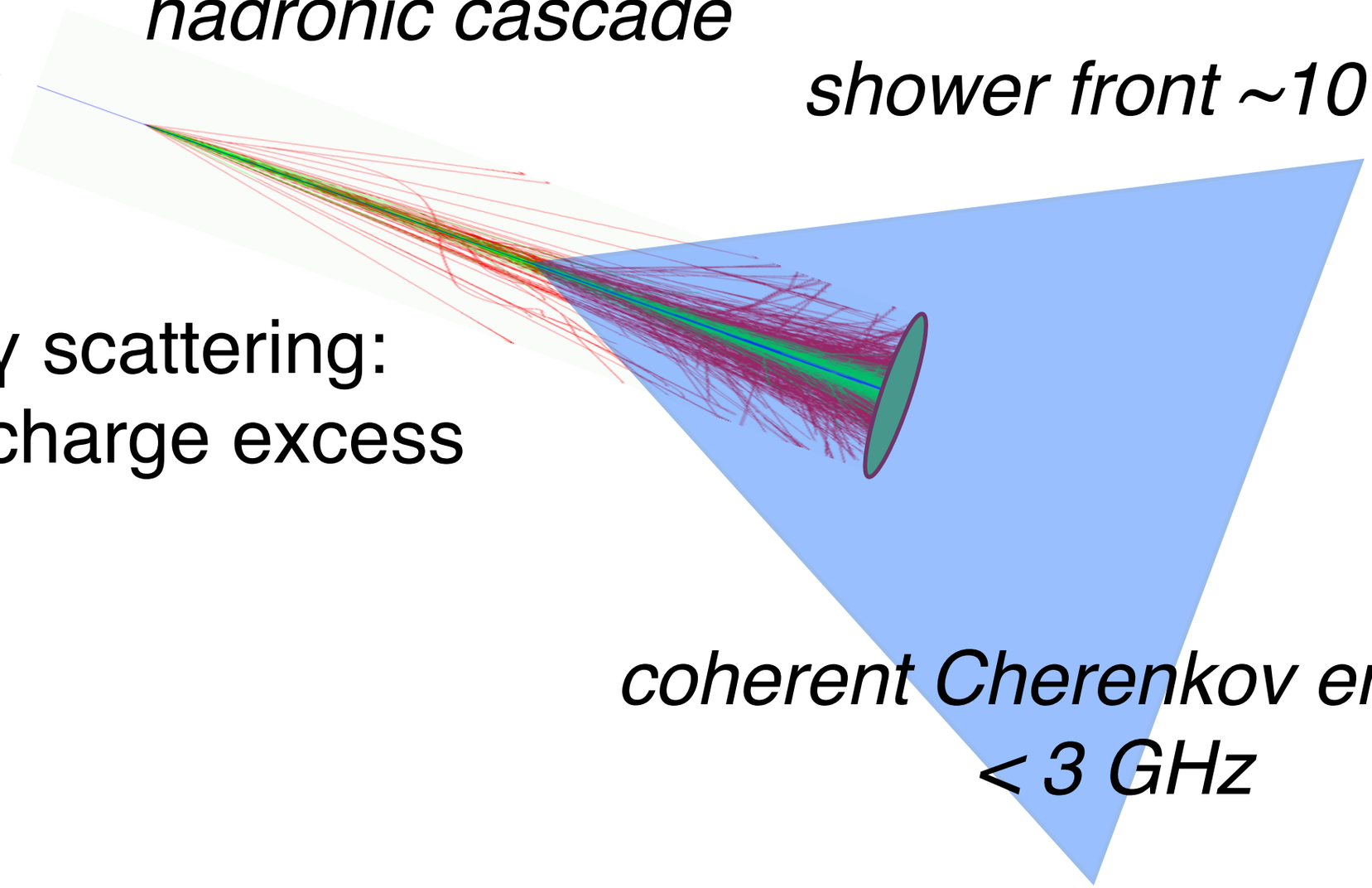
→ **radio emission!**

Askaryan effect

neutrino/CR

hadronic cascade

shower front ~10 cm

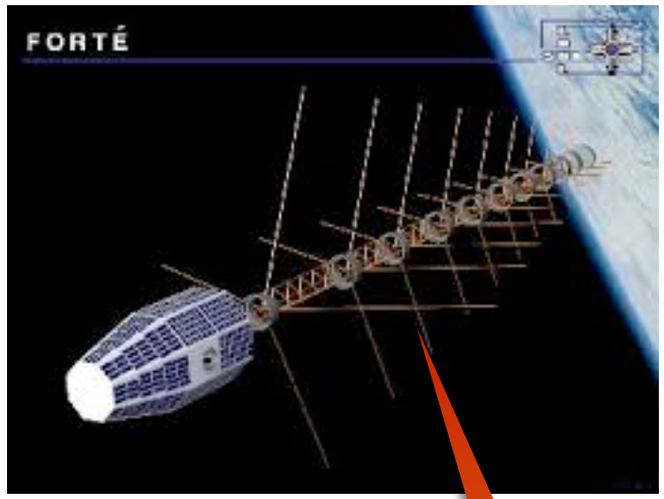


e^- and γ scattering:
negative charge excess

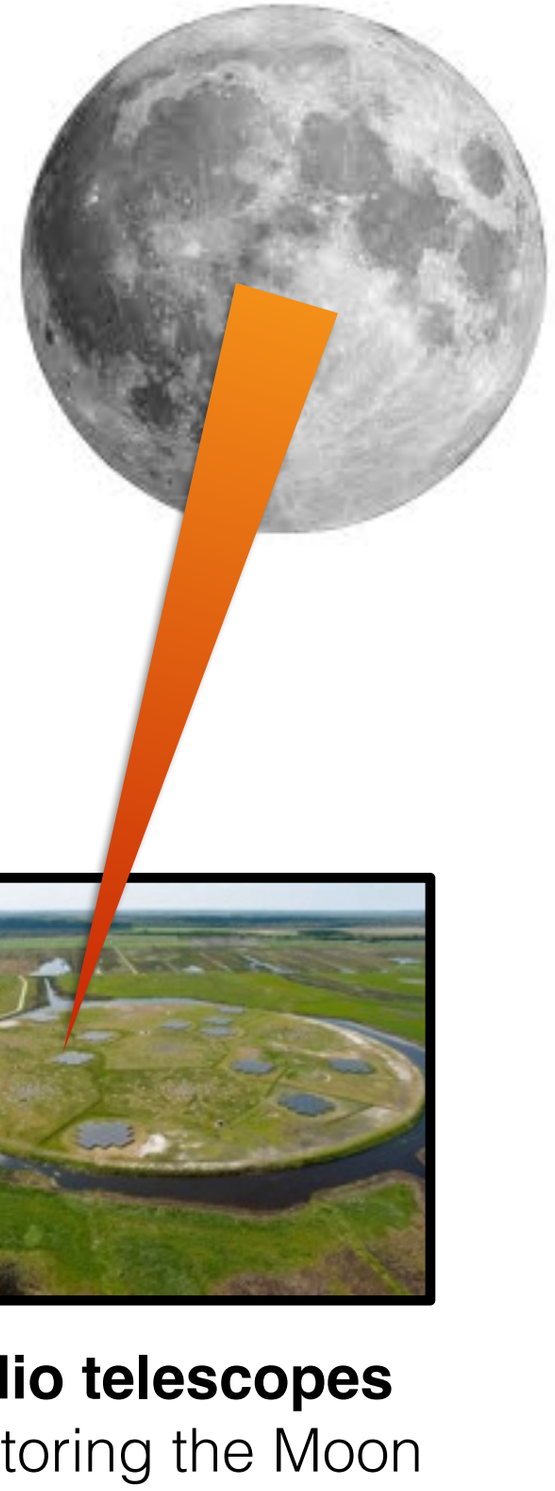
coherent Cherenkov emission
< 3 GHz

Large detector volumes

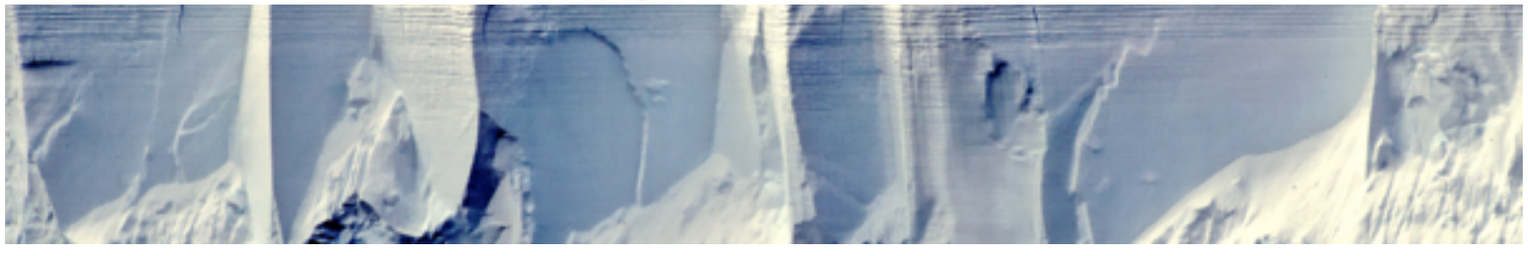
ANITA
monitoring antarctica
from balloon



Forte
monitoring Greenland
from space

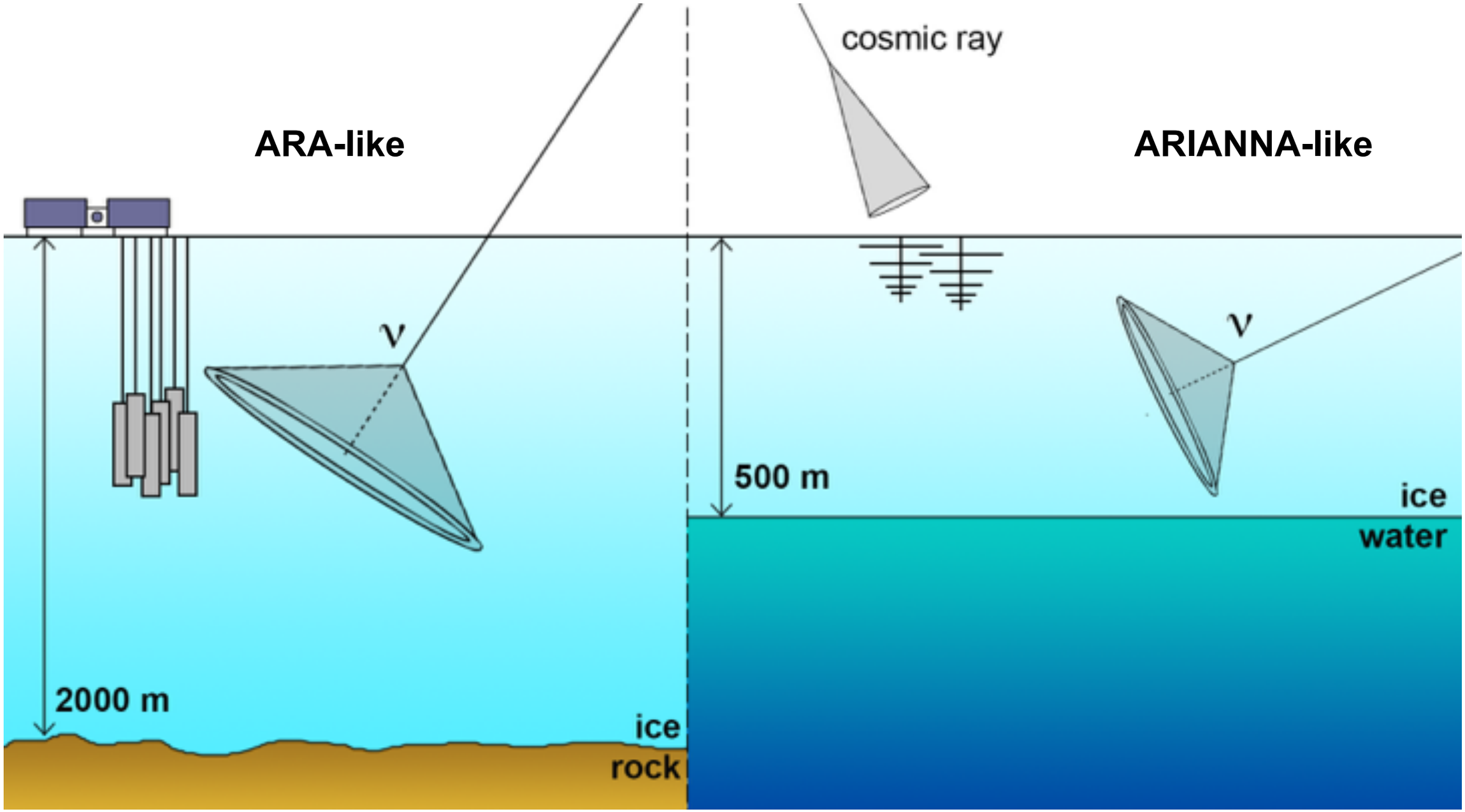


Radio telescopes
monitoring the Moon
from Earth

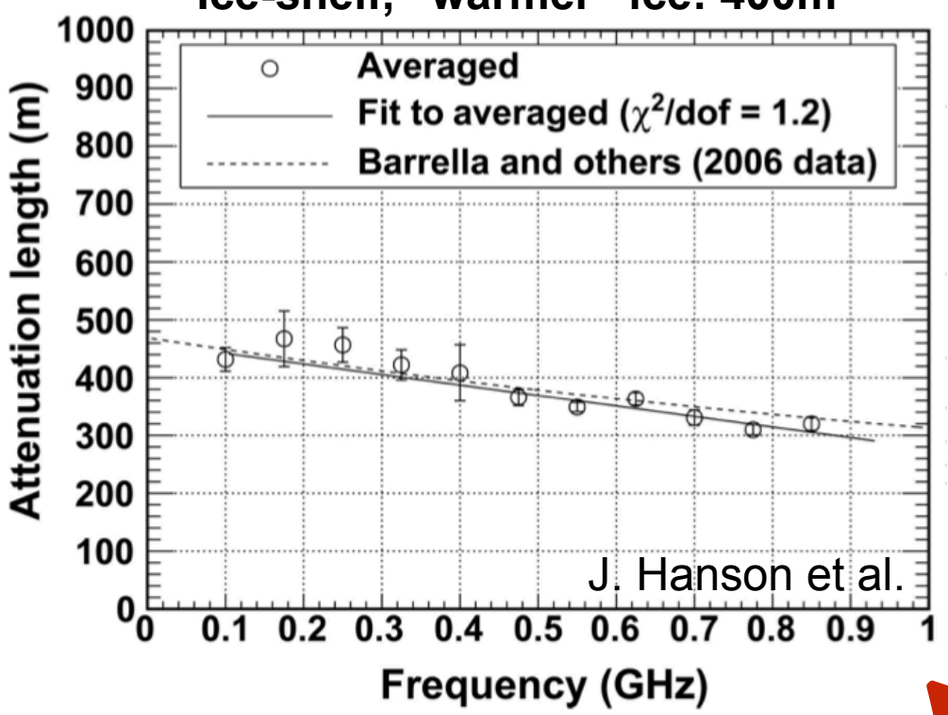


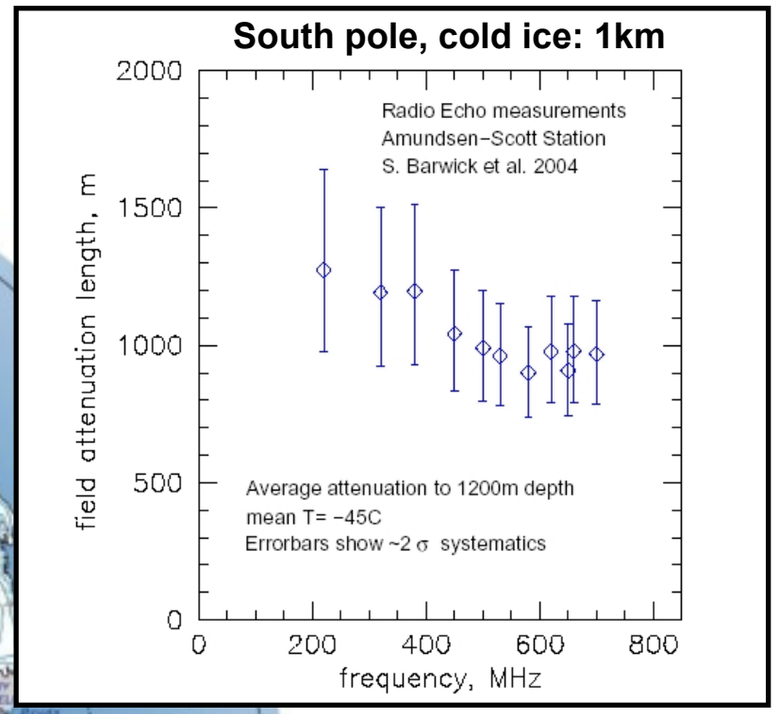
ARA/ARIANNA antenna array in ice

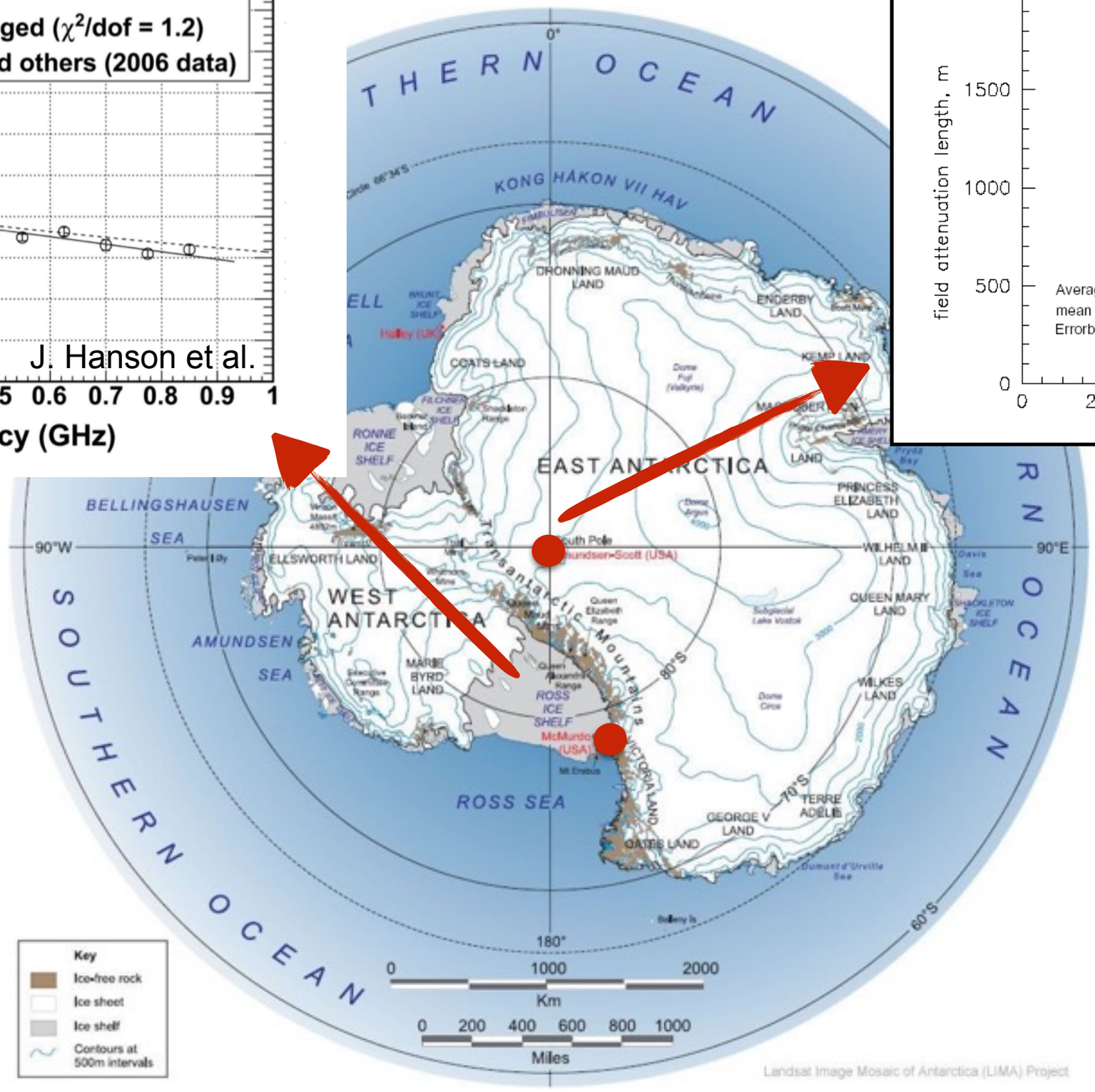
Techniques


ARA-like
ARIANNA-like
cosmic ray
ν
ν
2000 m
500 m
ice
rock
ice
water

Sites



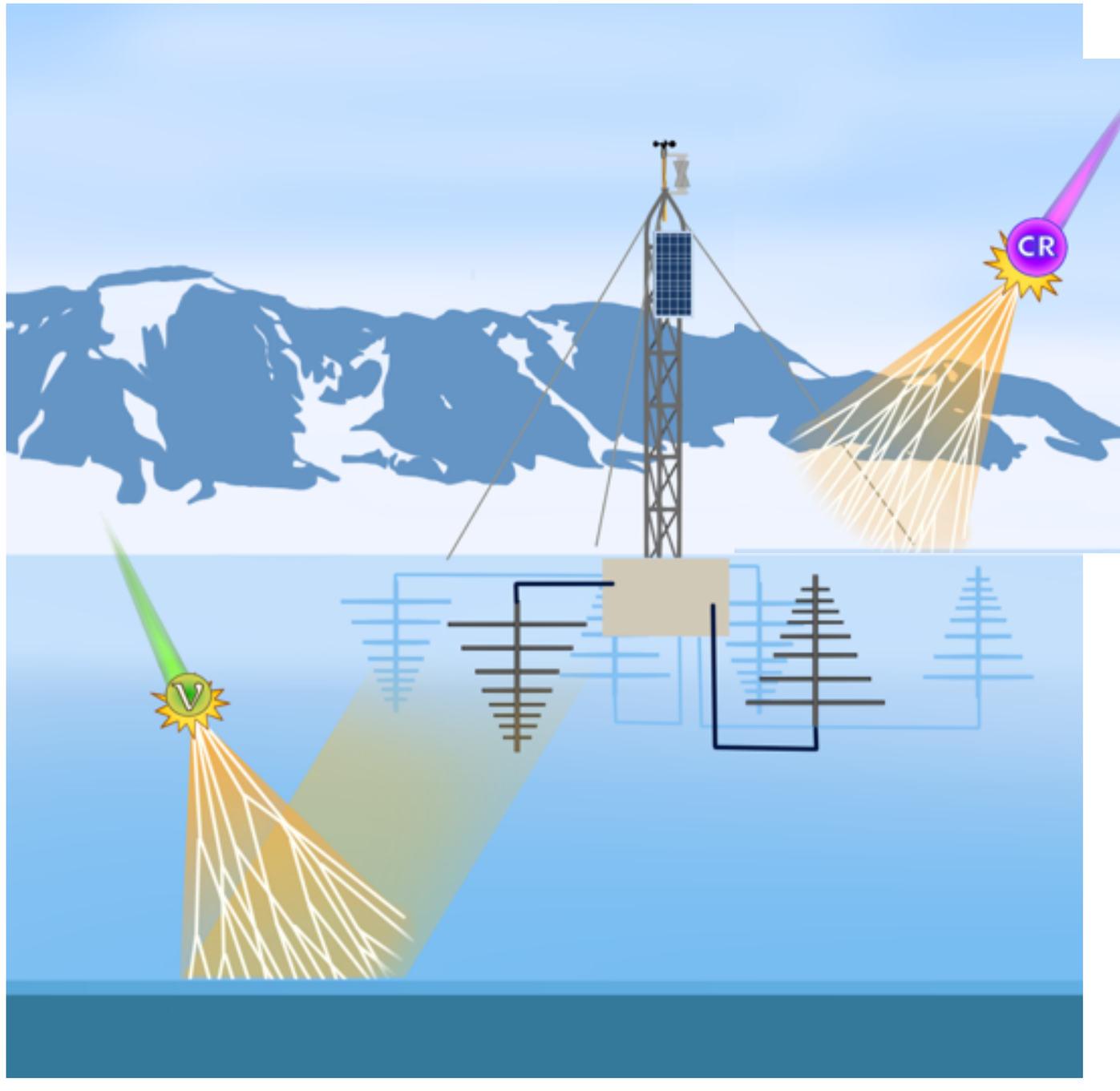




radio attenuation length 0.5 - 1 km, depending on temperature

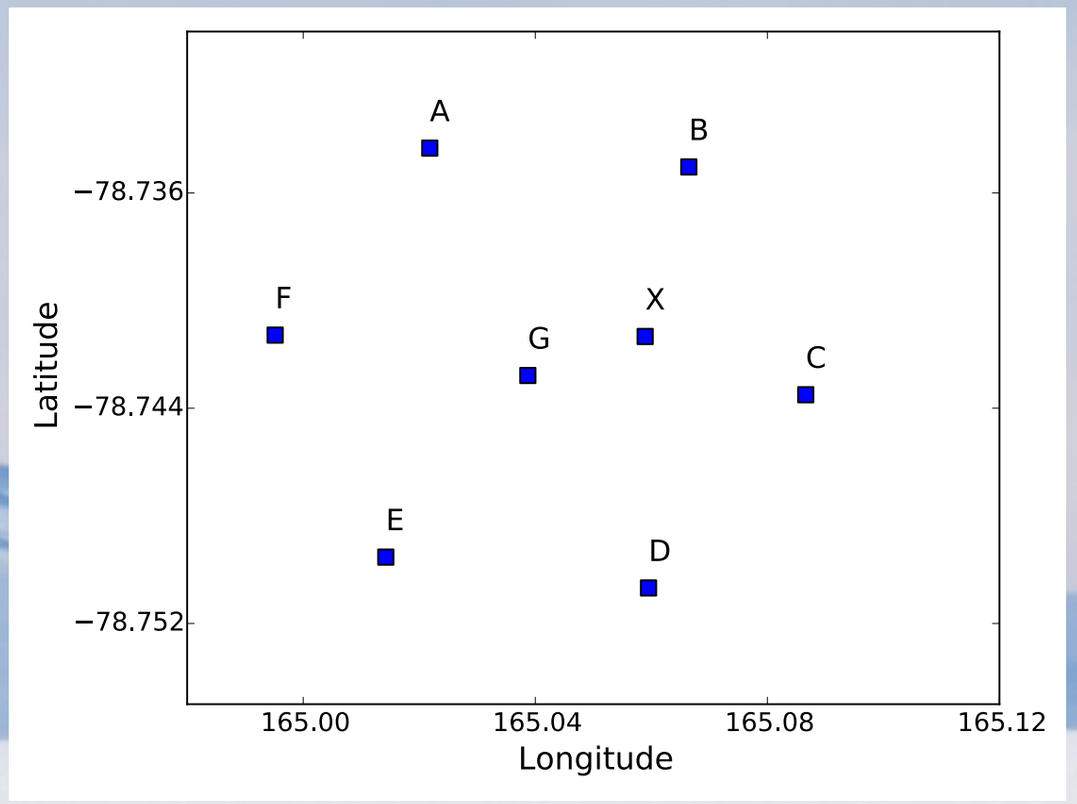
Concept of ARIANNA

- **Independent antenna stations** can be installed at low costs on the surface
- On ice-shelf: **Ice-water boundary** almost perfect reflector for radio emission
- **Real-time data transfer** via satellite
- Solar and wind power possible
- **High gain antennas** (50 - 1000 MHz) can be used to instrument a large volume
- Array of about 1000 antennas needed



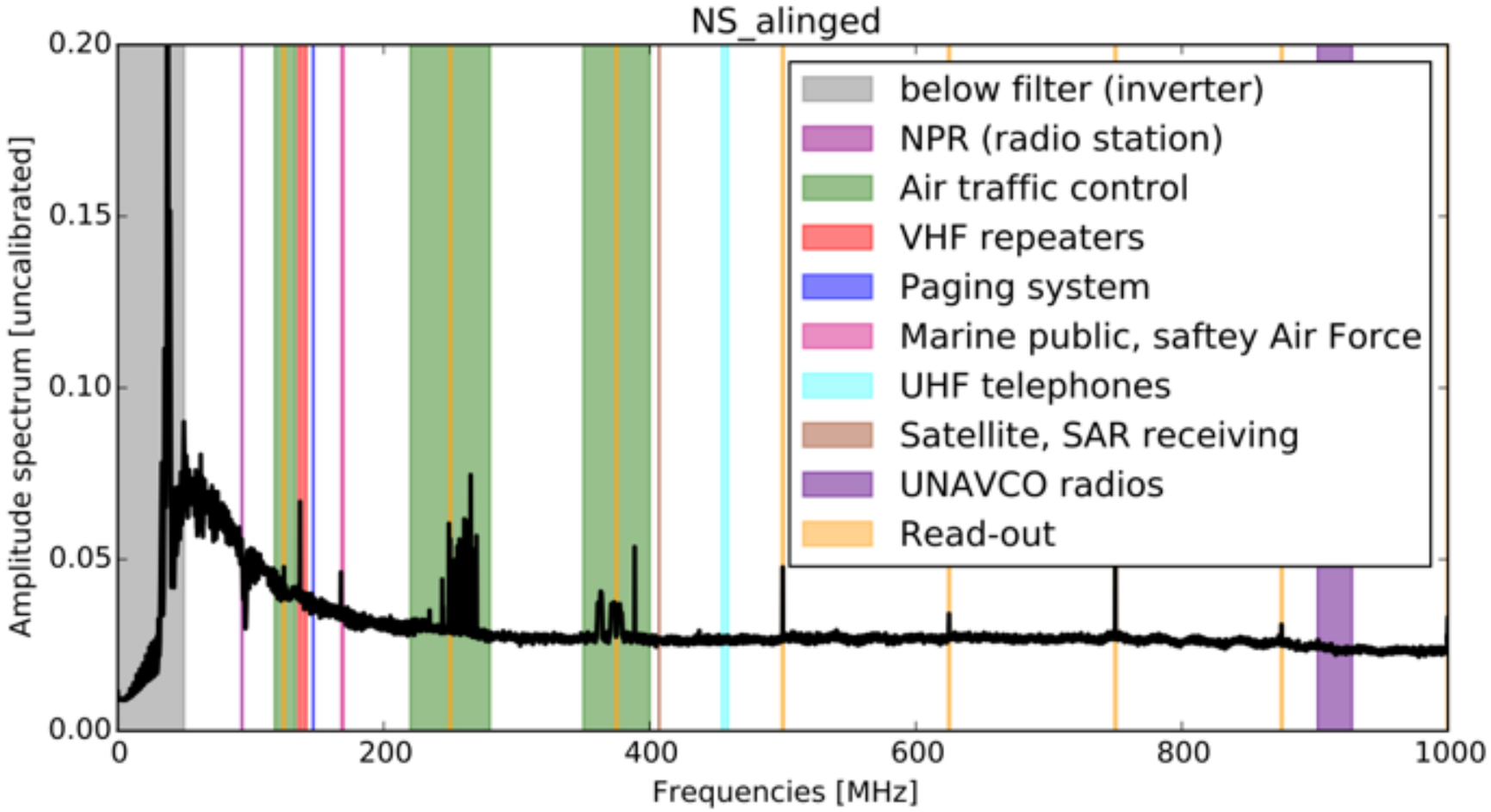
Current status of ARIANNA - HRA

First hexagonal array in operation since 2015



Radio noise background

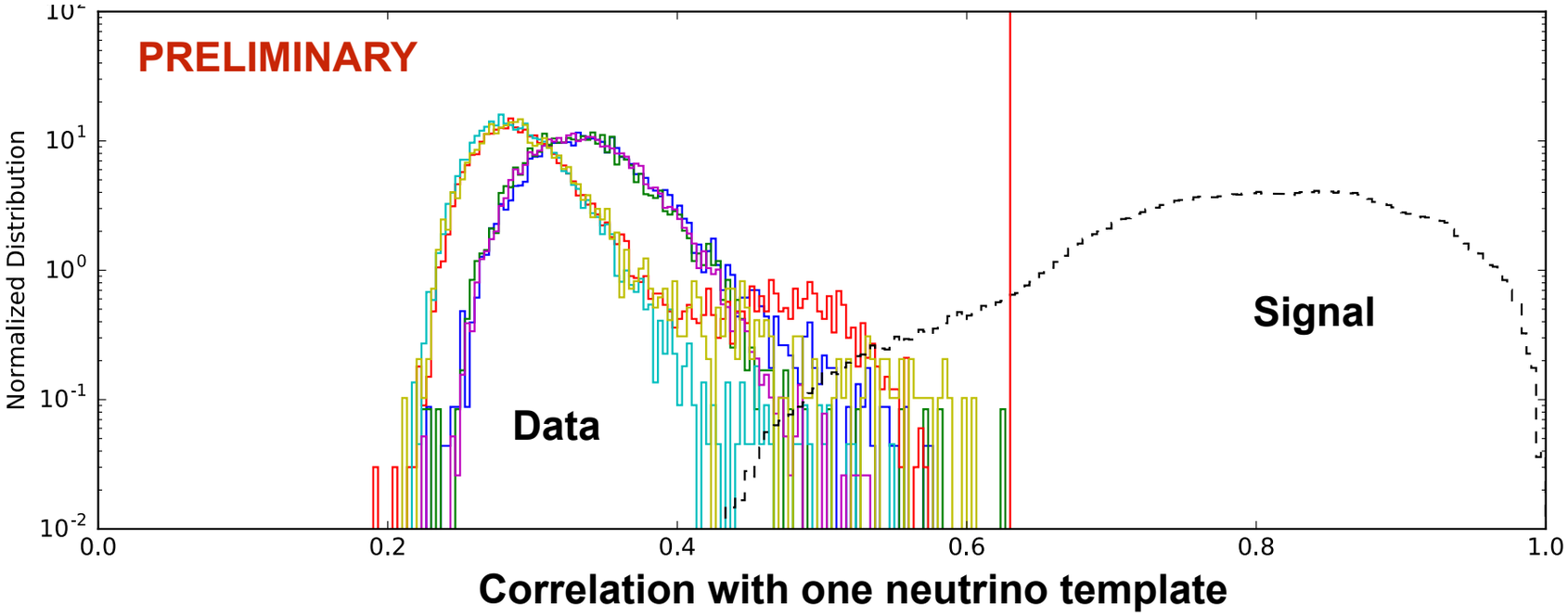
- Dedicated studies with at ARIANNA site
  - **extremely quiet radio environment**
  - small, time-varying contribution of **narrowband emitters**
  - spectrum clearly dominated by Galactic noise



- As opposed to earlier efforts one needs to study broad- and narrowband noise

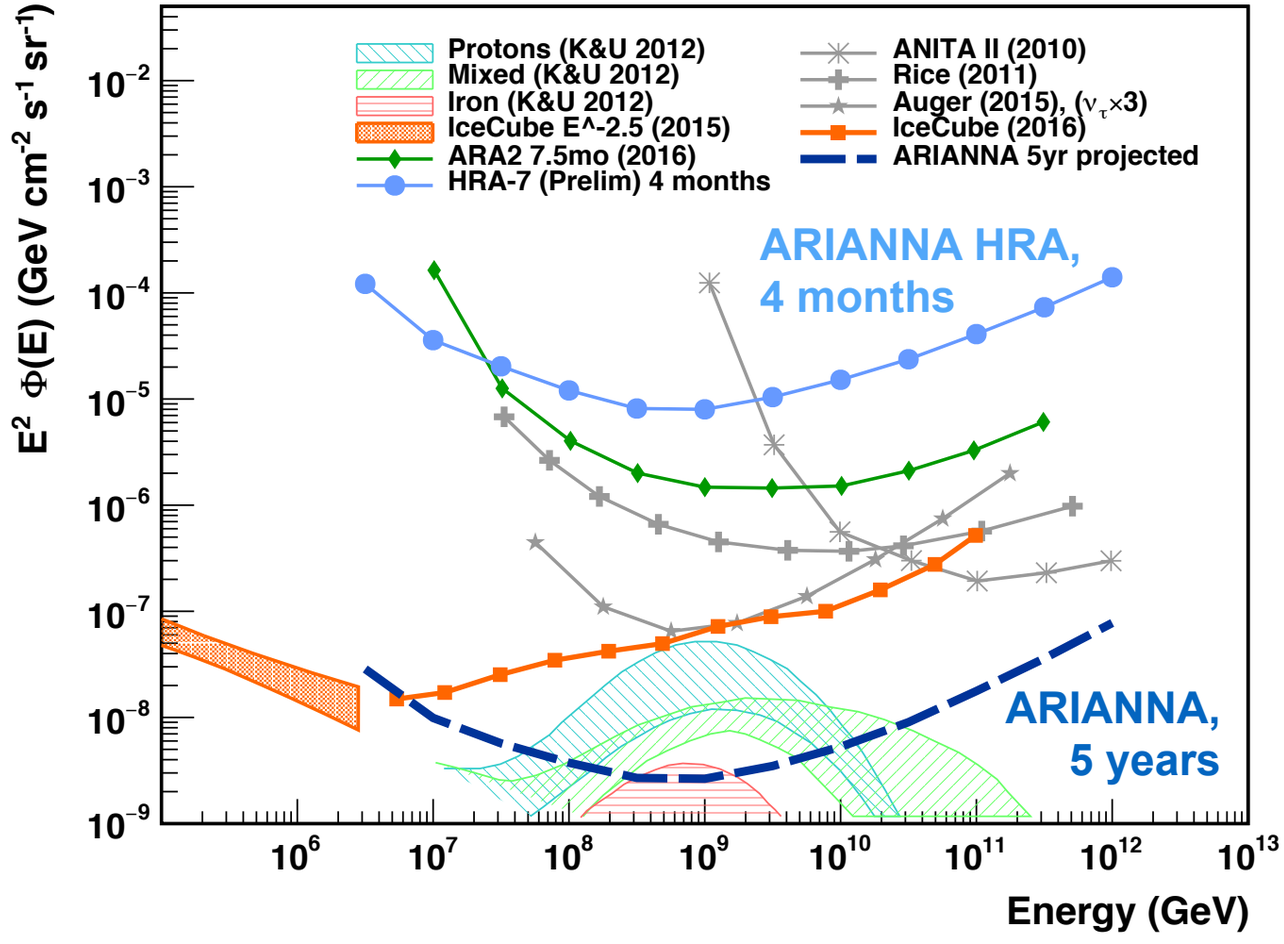
- To be repeated at South Pole in season 2017/18

Neutrino searches



- Very little background holds also for neutrino searches

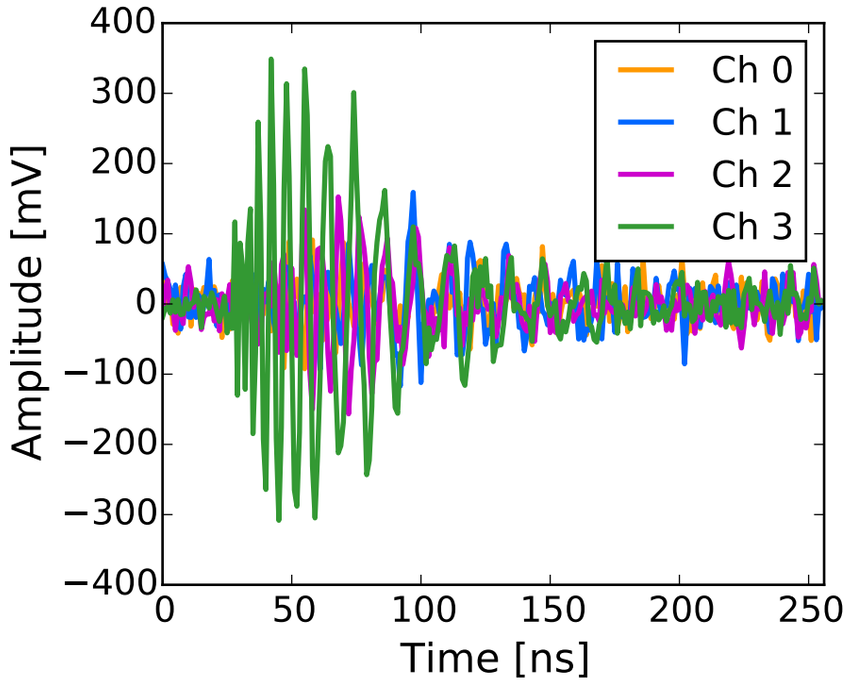
- Cooperation with ARA to share neutrino Monte Carlo
- Predictions now converge
- Preliminary work is well underway

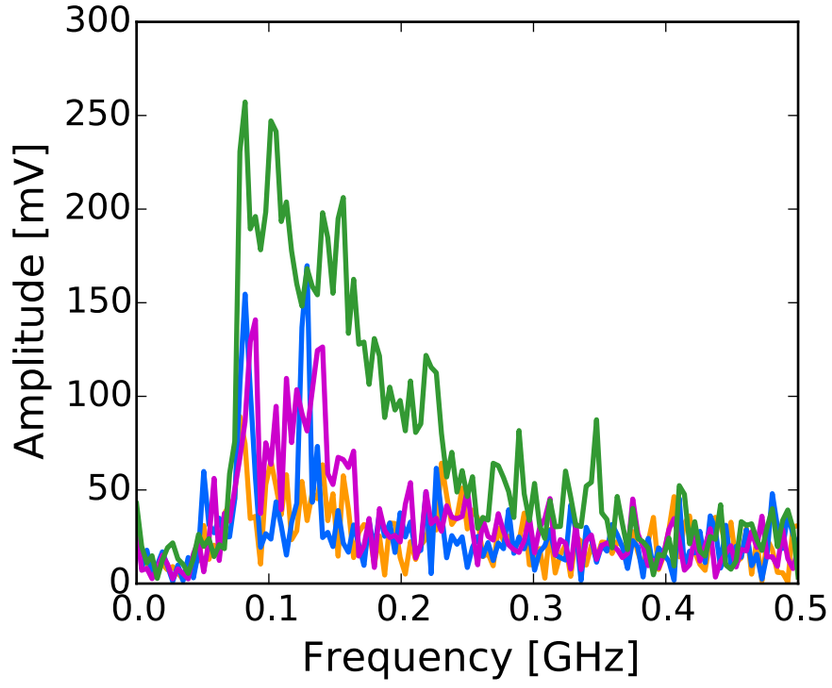


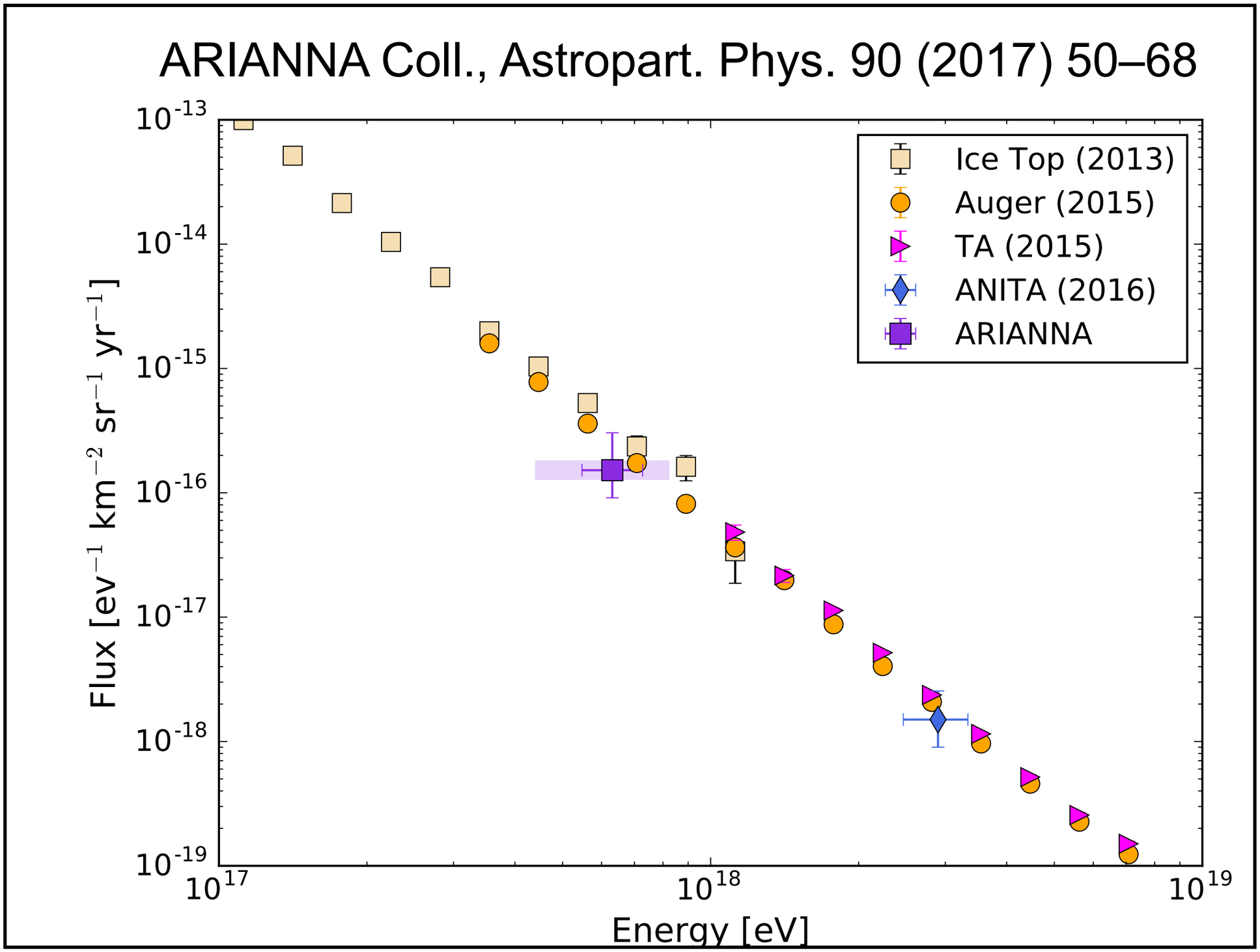
Cosmic Rays

- The most “important” background
- Since emission mechanisms is the same, signals are expected to be very similar

- **Risk**:
  - confusion
- **Opportunities**:
  - cross-check reconstruction
  - train neutrino algorithms
  - detector calibration
  - study cosmic rays







measured flux in agreement with existing data

10^{20} - $10^{??}$ eV: Moon = 10^{7} km^2 detector area

Goldstone

VLA

Kalyazin

LOFAR

Westerbork

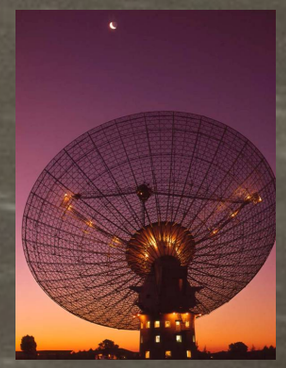
best sensitivity NuMoon
Scholten et al. PRL 103 (2009)
S.B. et al. A&A 521, 47(2010)

radio flash
ns scale!

CR/neutrino

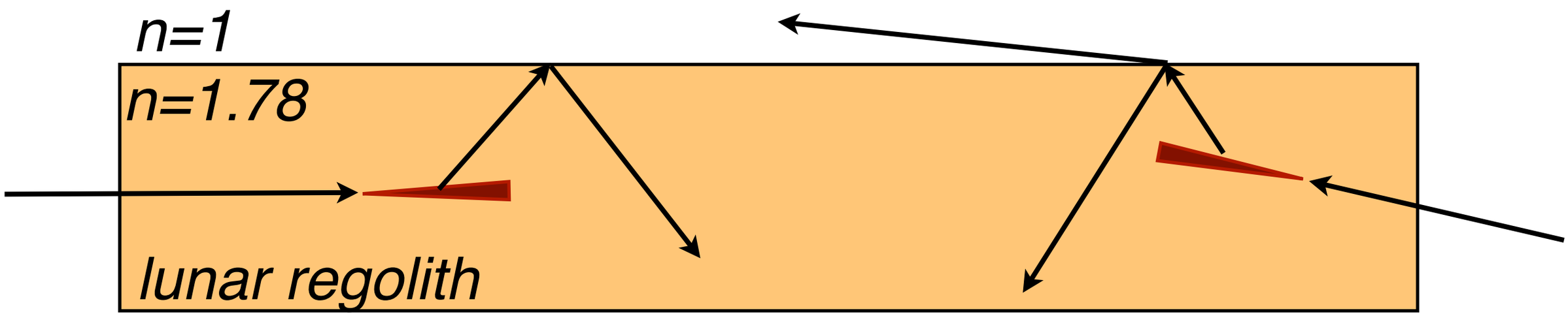
Lovell

ATCA

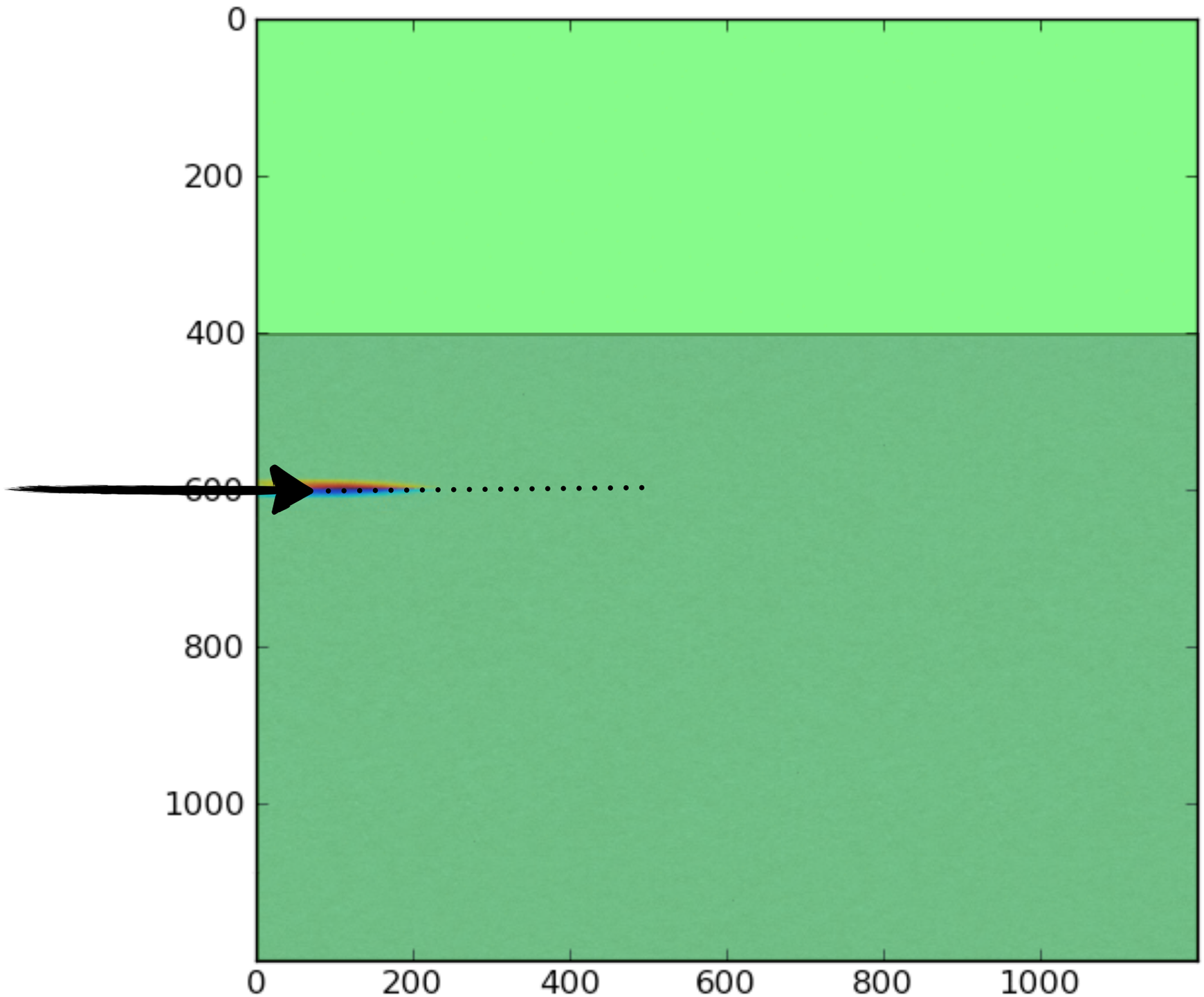


Parkes

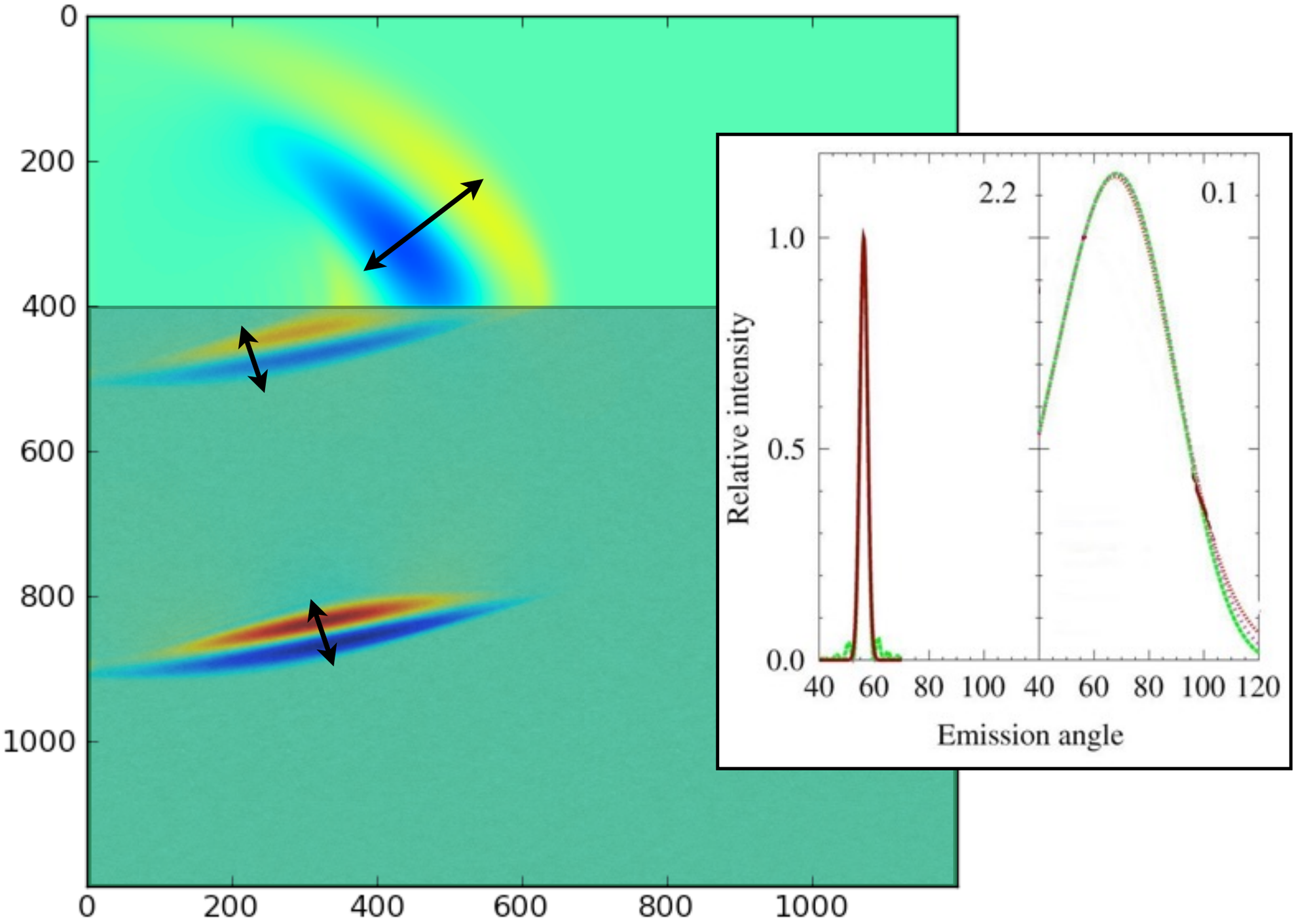
Escape from the Moon?



- Askaryan radiation from cascade charge excess
- Cherenkov angle = angle of total internal reflection (for cascade parallel to surface)
- Up-going showers: only at rim of Moon
- Surface roughness helps!



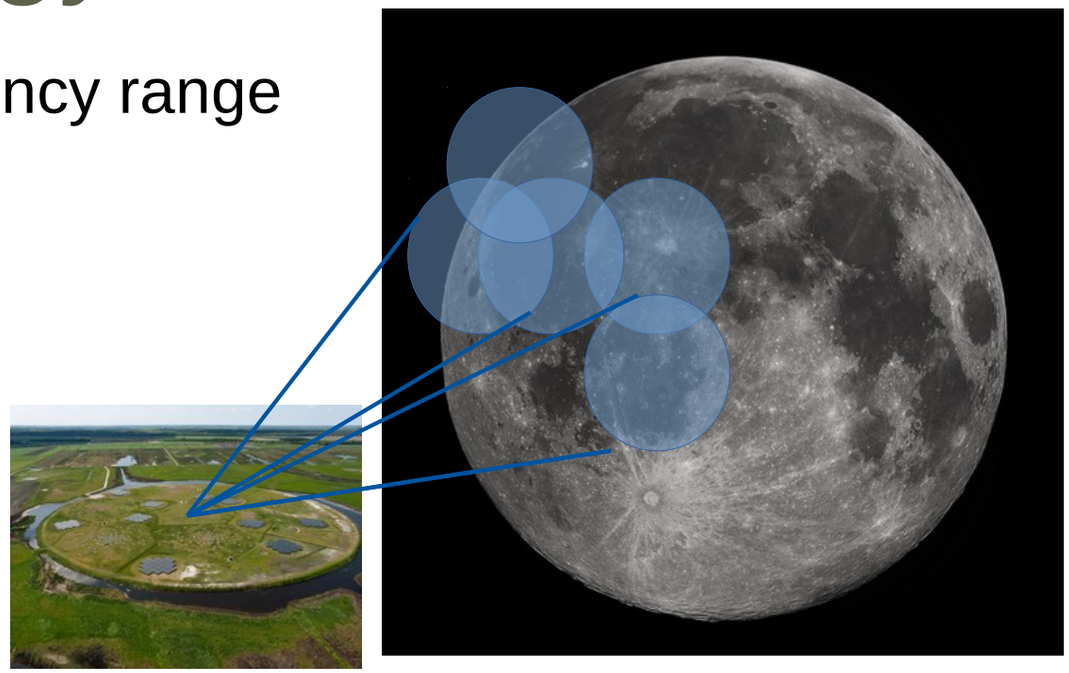
Radio propagation simulation

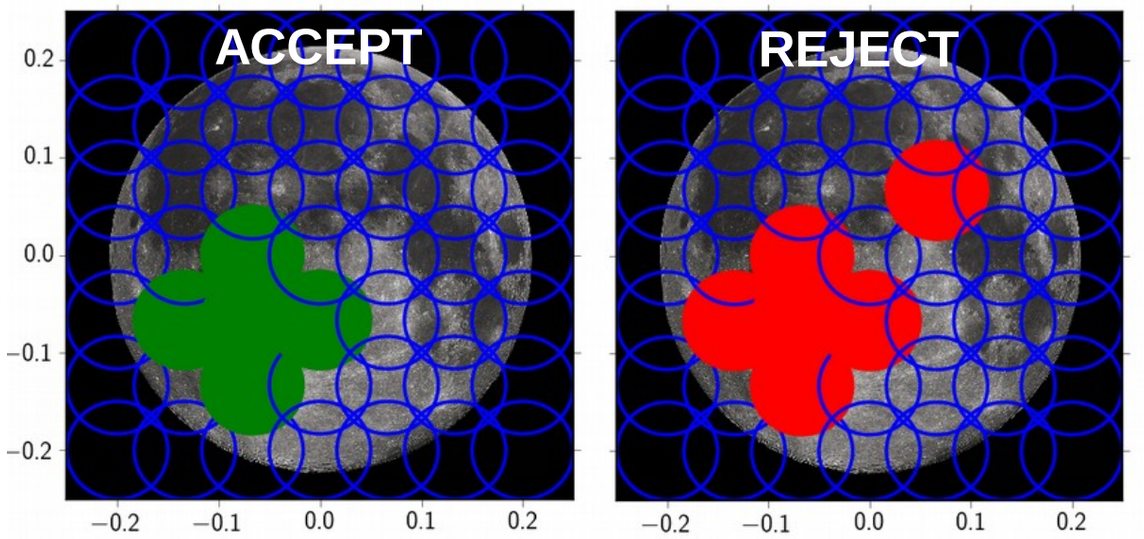


low frequencies can escape! HBA optimal window

Observation Strategy

- HBA Antennas have optimal frequency range
- Form multiple beams on the Moon
- Search for ns pulses in time-series
- Anti coincidence to suppress RFI
- Analyze Faraday rotation and dispersion to check lunar origin





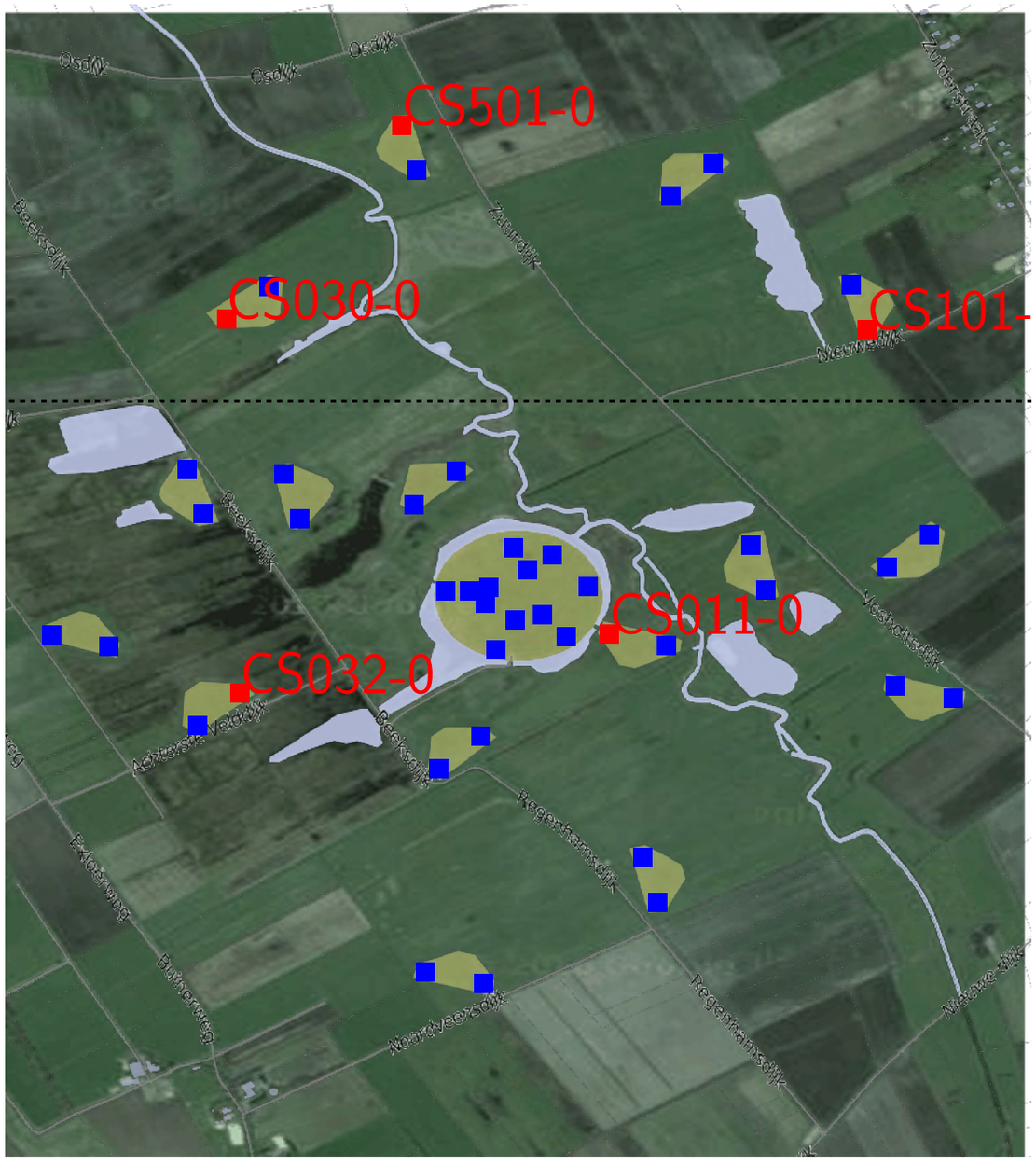
Challenges

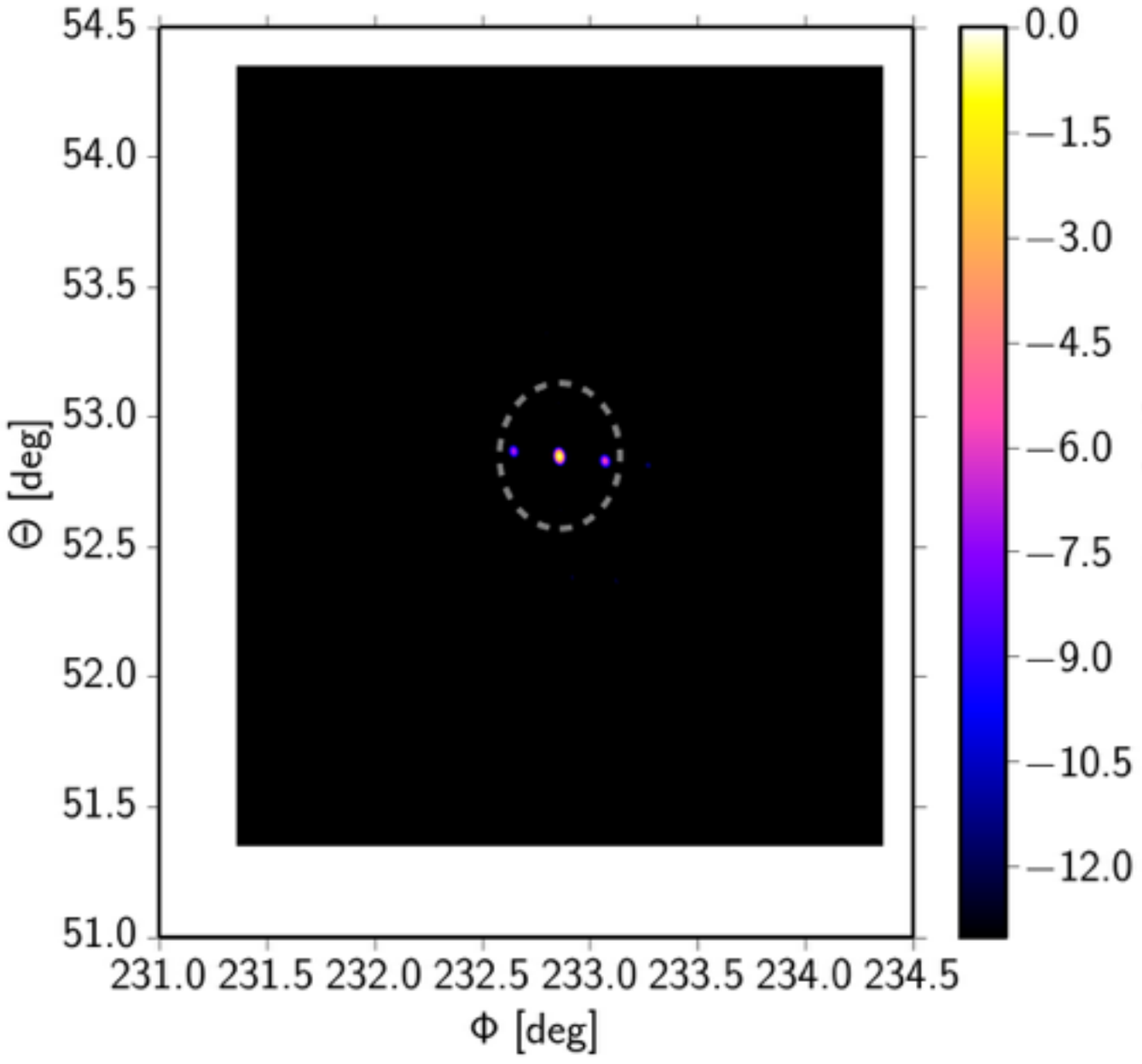
- Data rate 0.8 GiB/s per station/beam

  → Trigger required

- LOFAR designed to integrate flux
  - Reconstruct time series from filtered signal for trigger
  - Use buffered traces for analysis

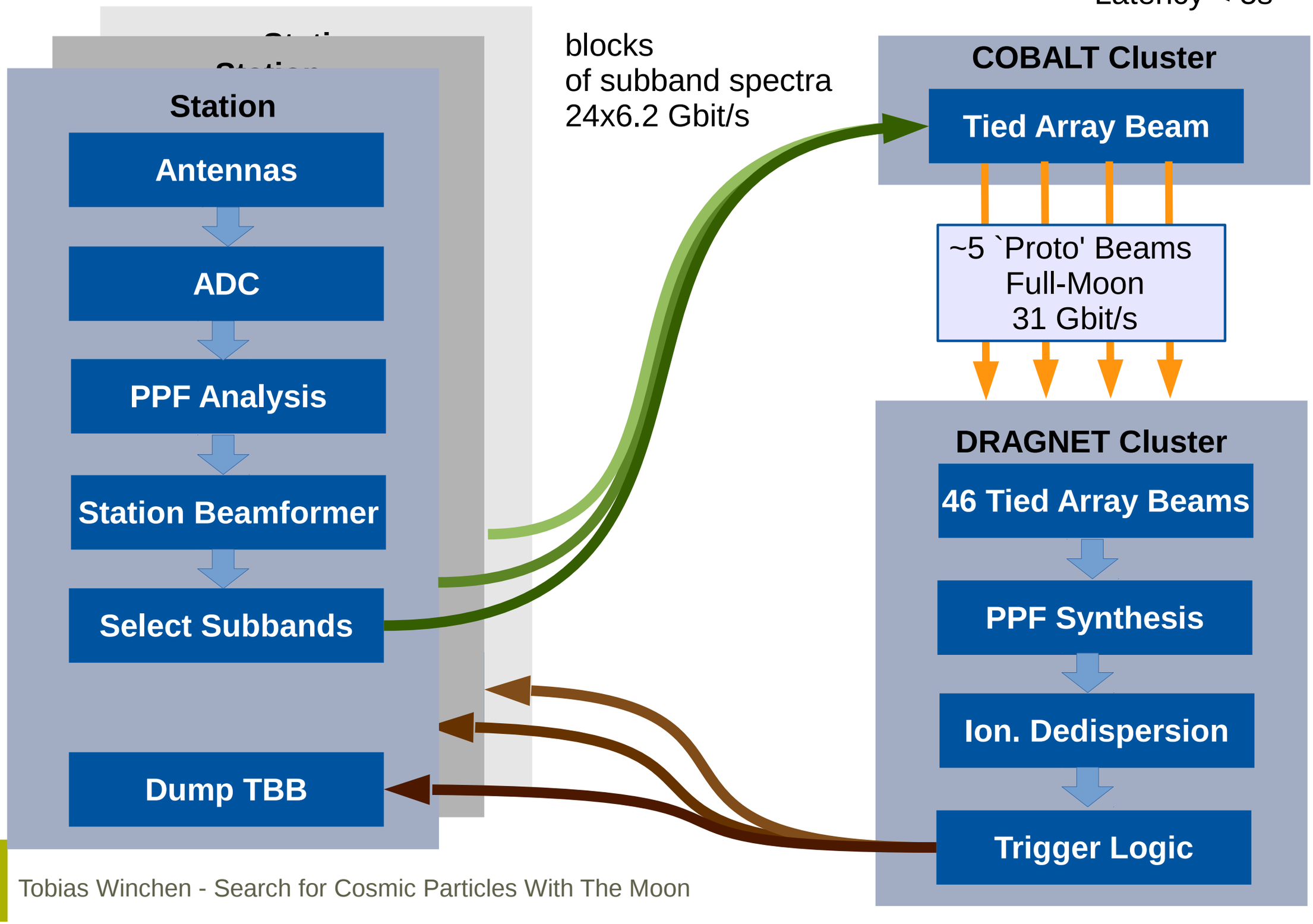
Lunar beams


CS501-0
CS030-0
CS101-
CS011-0
CS032-0


54.5
54.0
53.5
53.0
52.5
52.0
51.5
51.0
Θ [deg]
231.0 231.5 232.0 232.5 233.0 233.5 234.0 234.5
Φ [deg]
0.0
−1.5
−3.0
−4.5
−6.0
−7.5
−9.0
−10.5
−12.0
Gain [dB]

2 Step Online Processing

Requirements:
- Real time
- Latency < 5s



NuMoon Current status:

detection pipeline complete

testing on offline commissioning data

Next: online commissioning on Dragnet

Goal: ~100 hours HBA observations