Future Observatories and Techniques

Partial list of projects (UHECR/ν)

IceCube-Gen2: (South Pole, Antarctica)

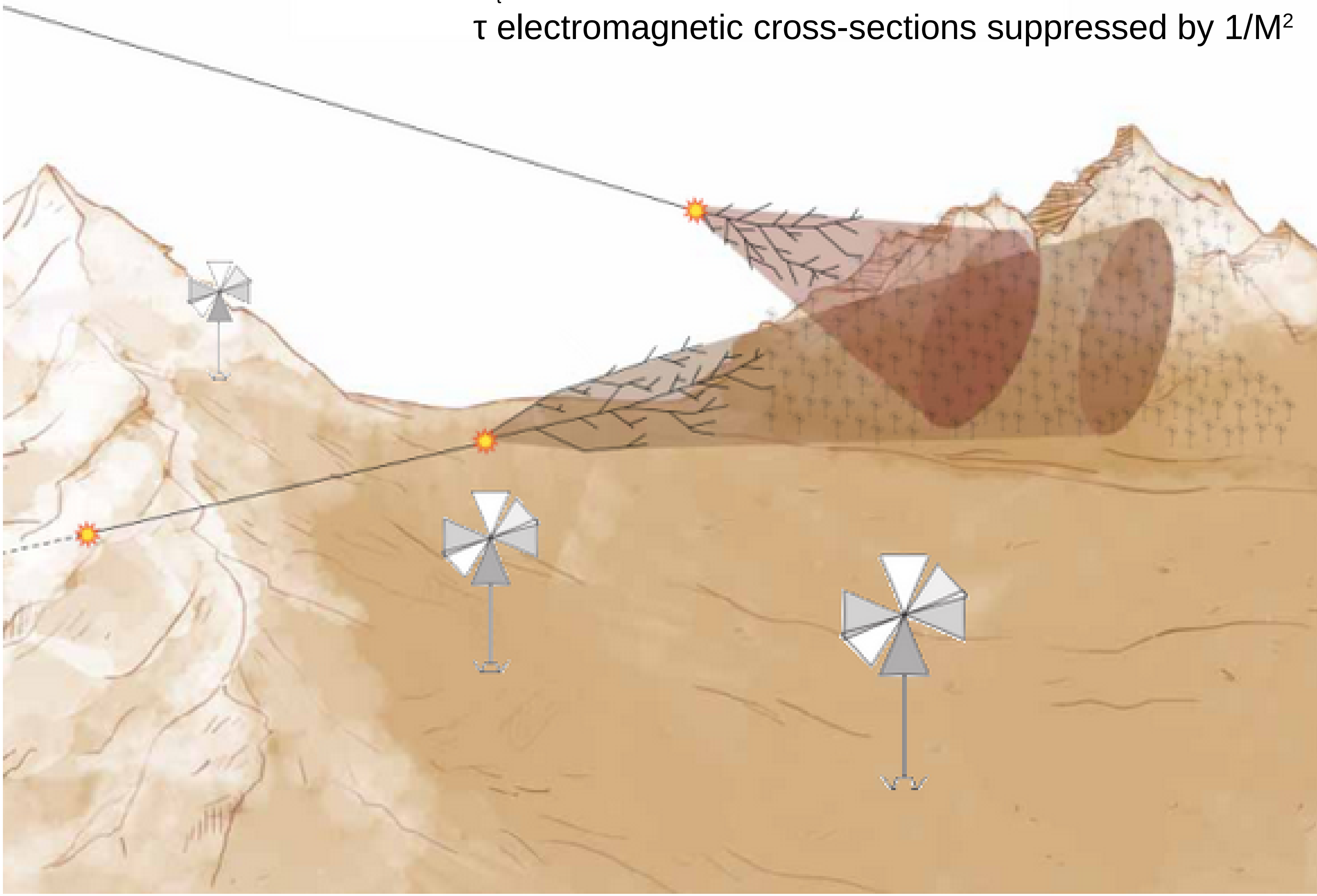
- In-ice photomultipliers + surface radio array (geomagnetic UHECR detection) + in-ice radio array (Askaryan UHE ν detection)

- ARIANNA-200: (Moore's Bay, Antarctica)
  - 200 radio antenna stations; 8 Rx/station
- GNO: (Summit Station, Greenland)
  - 30 in-ice stations (100 m deep); 16 Rx/station
- RET-CR and RET-nu (Taylor Dome, Antarctica)
  - RADAR radio technique, prototyping at Taylor Dome, Antarctica
- GRAND-200K (China)
  - BEACON & Deep Valley (tau neutrinos only)
- POEMMA (Space-based [JEM/EUSO heritage)

Science and Design

$T_\tau = 2.9 \times 10^{-13}$ s;

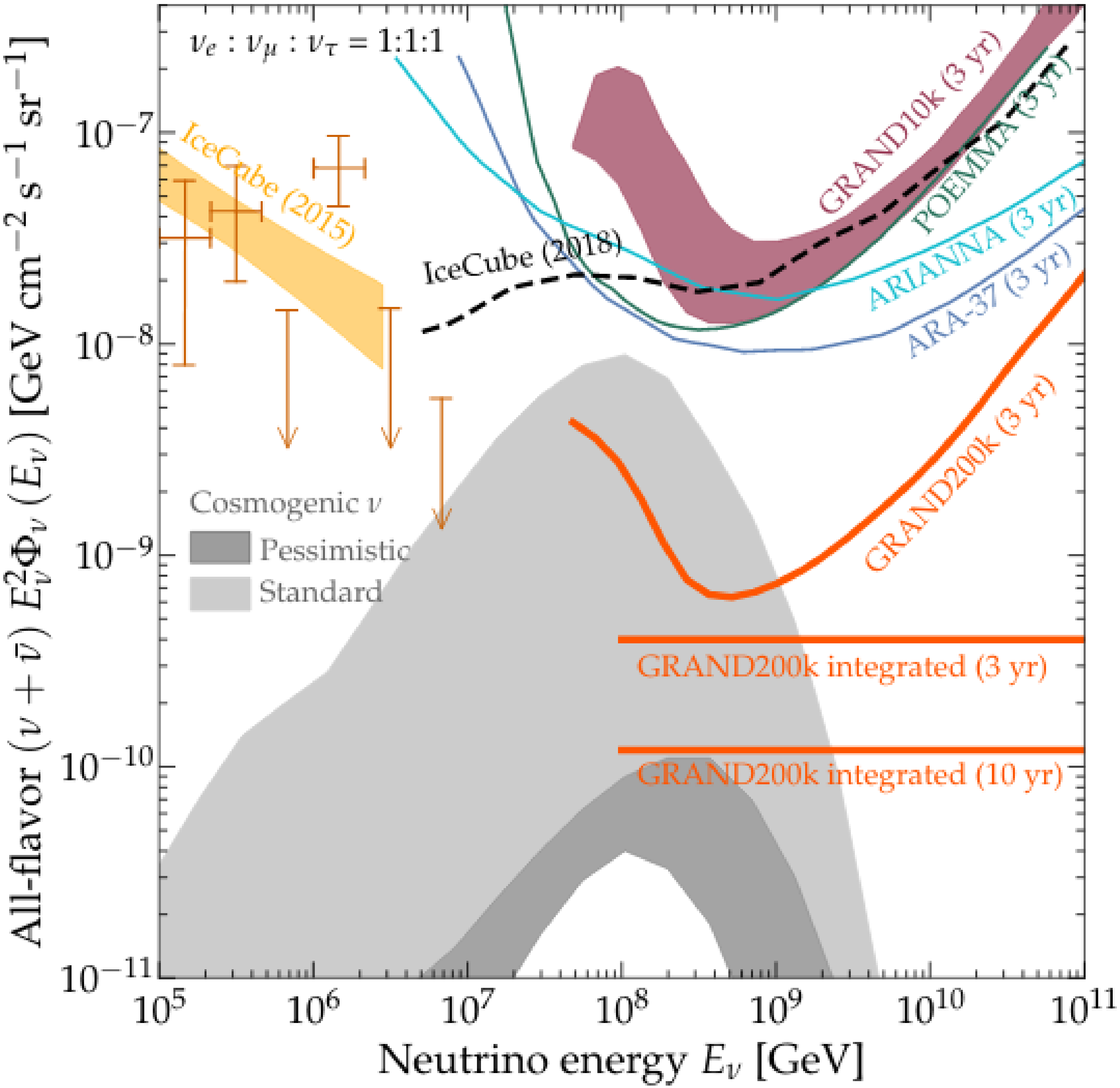
τ electromagnetic cross-sections suppressed by $1/M^2$



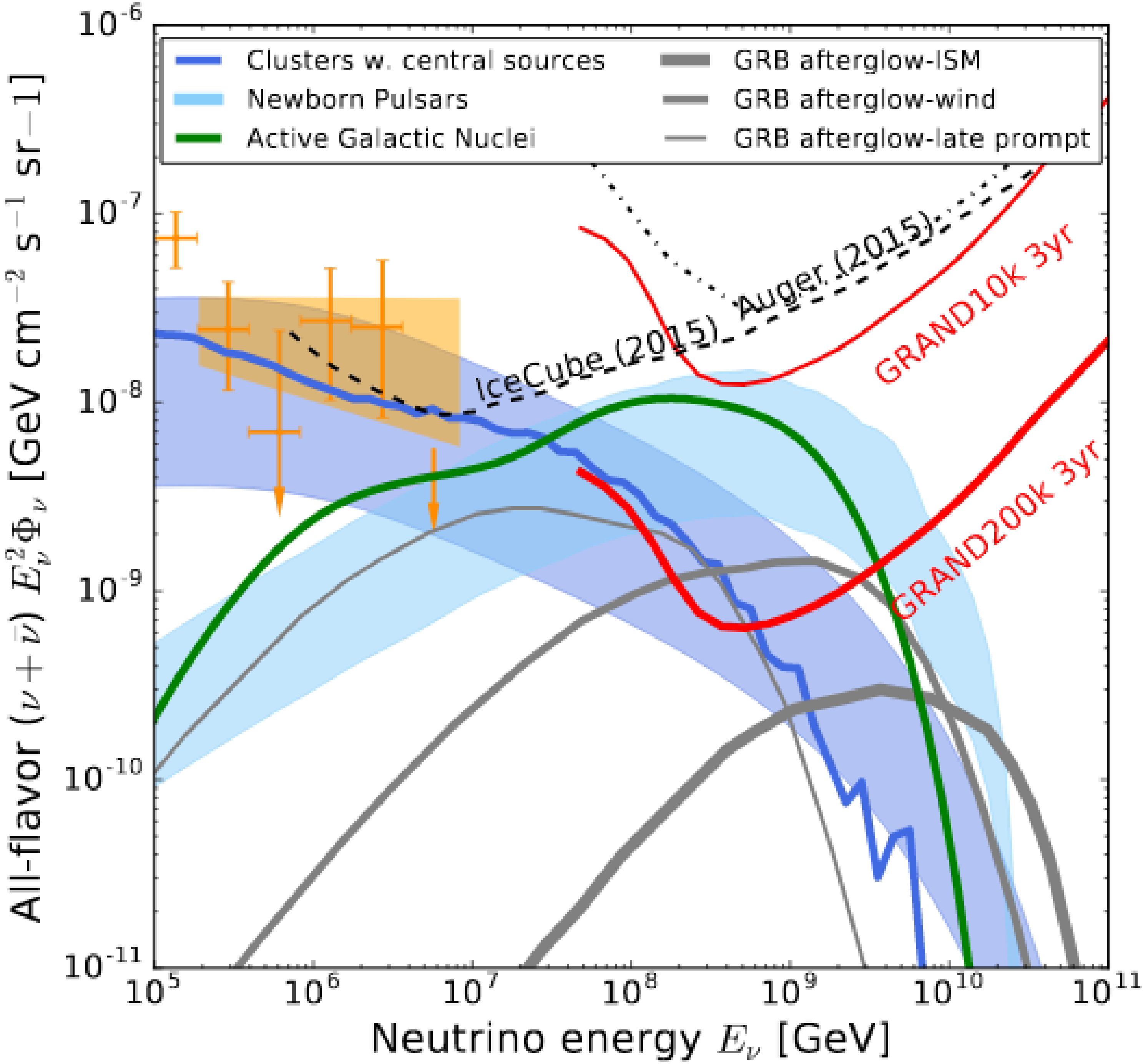
Why would CN consider $1B GRAND?

- Inexpensive
  - construction of a horn antenna ~ $20 in raw material
  - TUNKA-REX (~6 publications) based on $30K hardware budget
- Optimal frequency regime for geomagnetic detection of air showers: 30-200 MHz
  - Can program 200 MHz bandwidth digital scopes @$100/channel
- Physics: dN/dE, composition, lightning discharge
- Simulations are mature!
  - CoREAS / ZHSAireS: Uncertainty in radio signal yield~uncertainty in UHECR simulations (ergo, radio now part of 'standard' hybrid)
- "unique" sky coverage (aside, Ooty `isolated')
- 'multi-disciplinary'
  - Connection to CompSci (fast processing) and EE (radio engineering)
- Physics aside, broader impact (maybe most important!):
  - Training next generation of CR researchers in techniques likely to be essential to future CR efforts

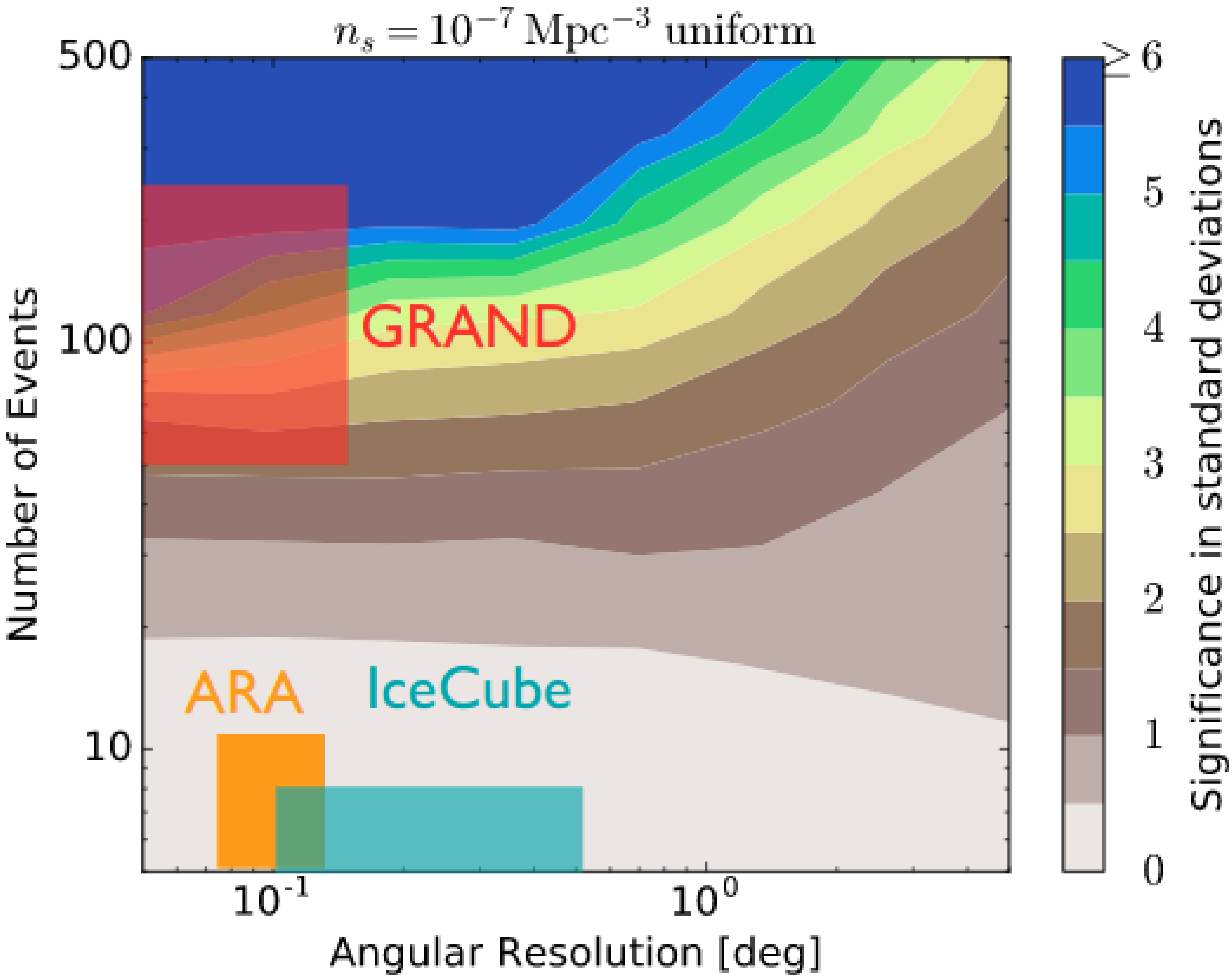
Science comparison



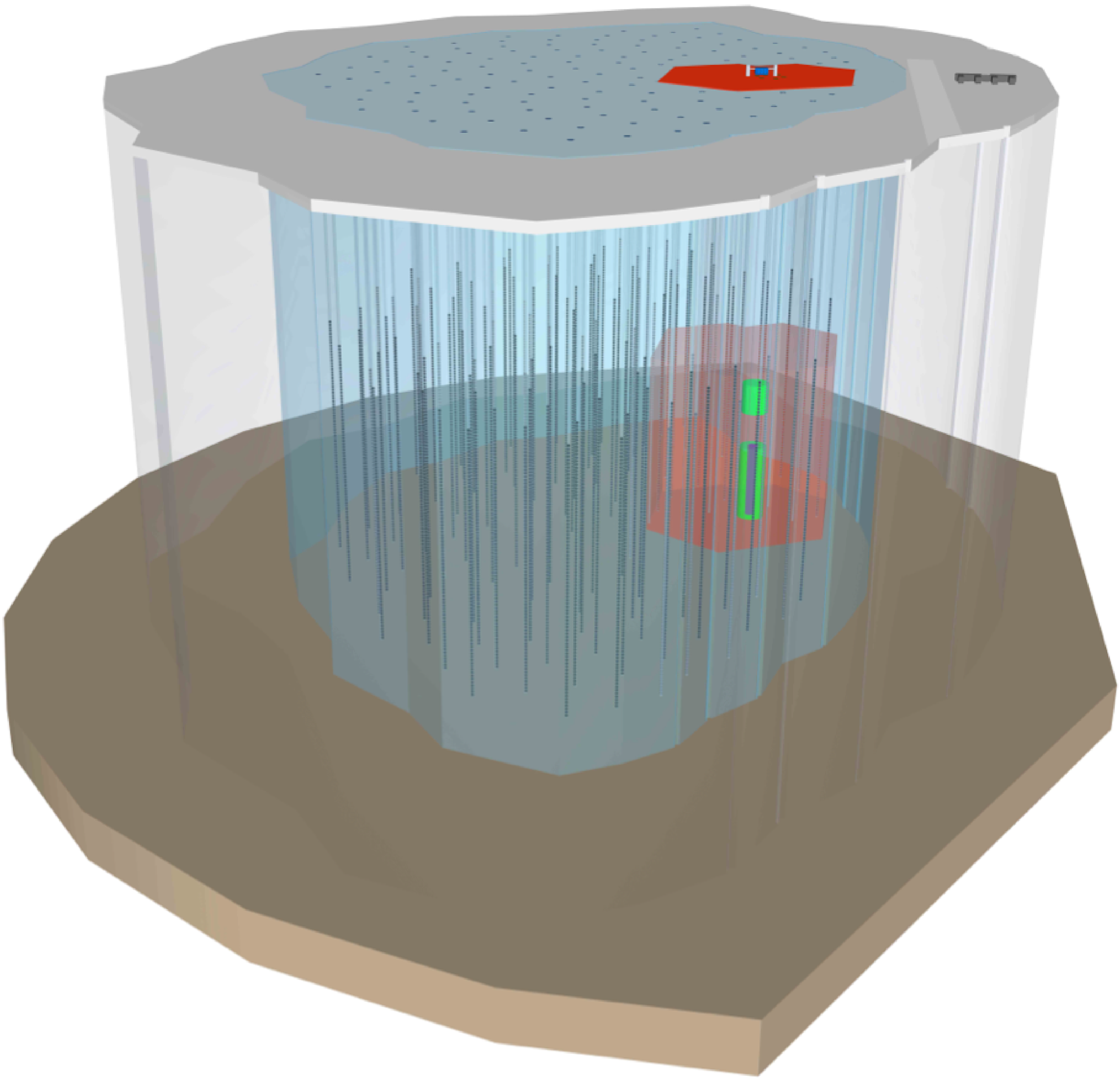
Variety of sources



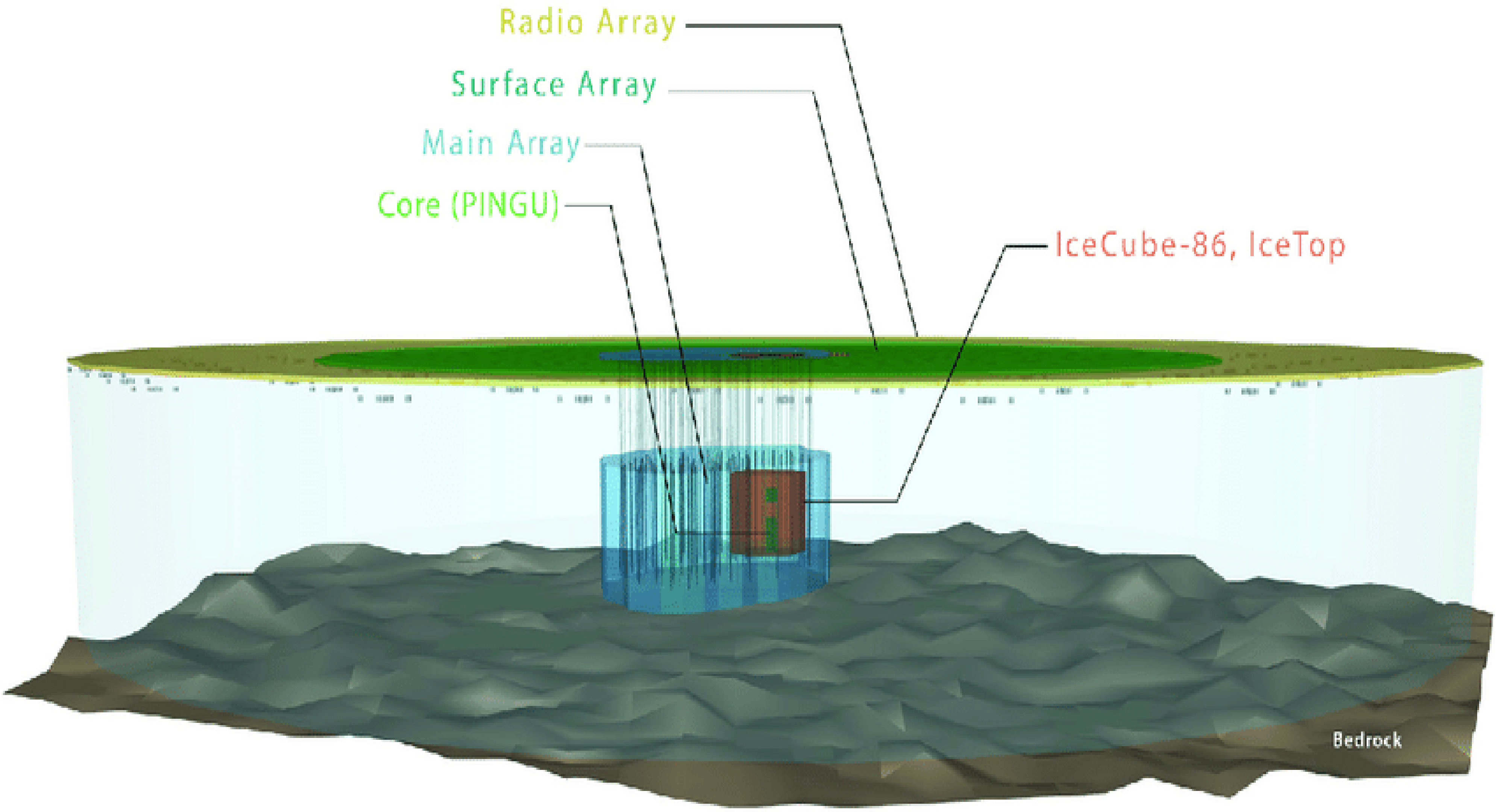
Neutrino pointing



IceCube-Gen2

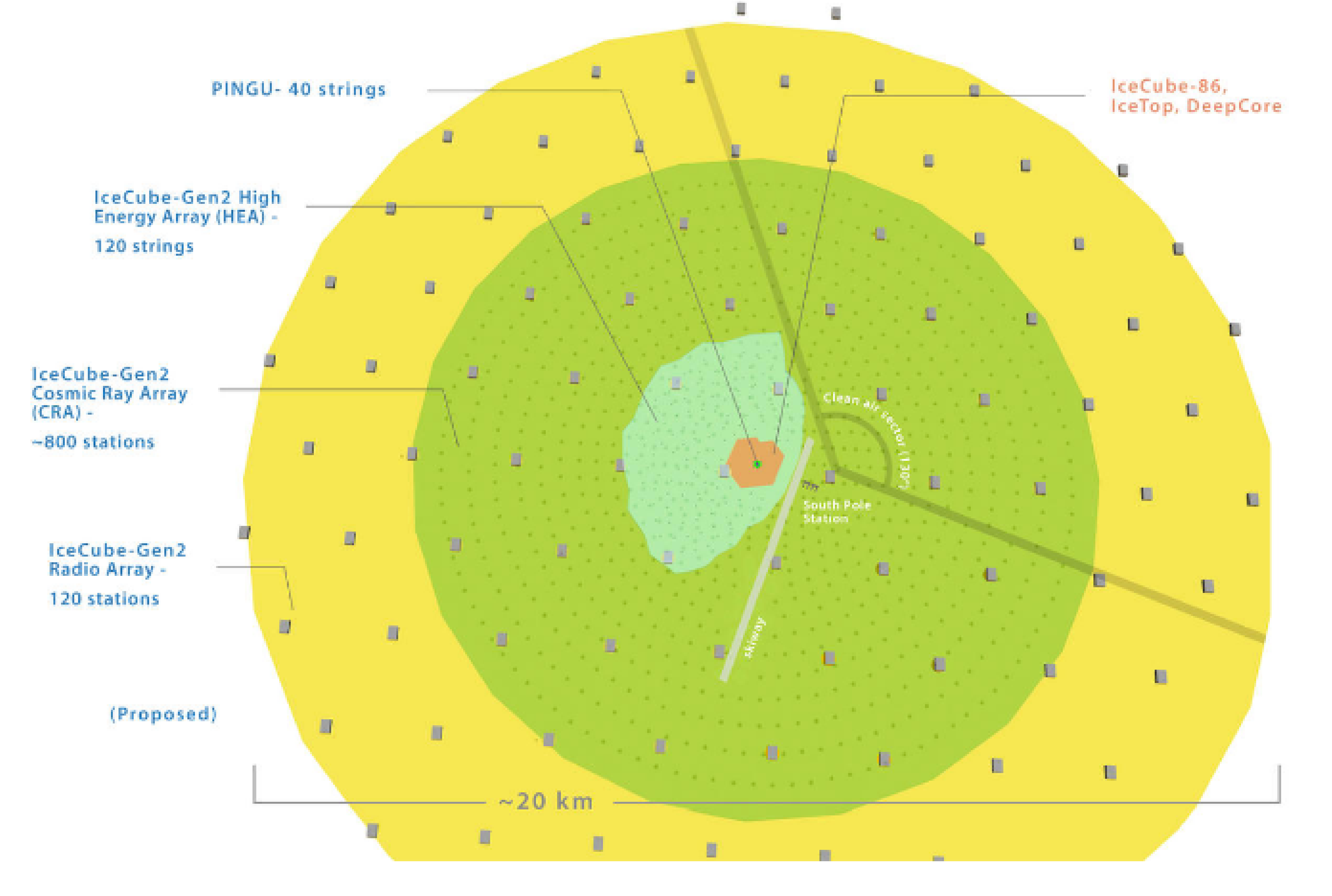


Cutaway



Radio Array
Surface Array
Main Array
Core (PINGU)
IceCube-86, IceTop
Bedrock

IceCube-Gen2 layout

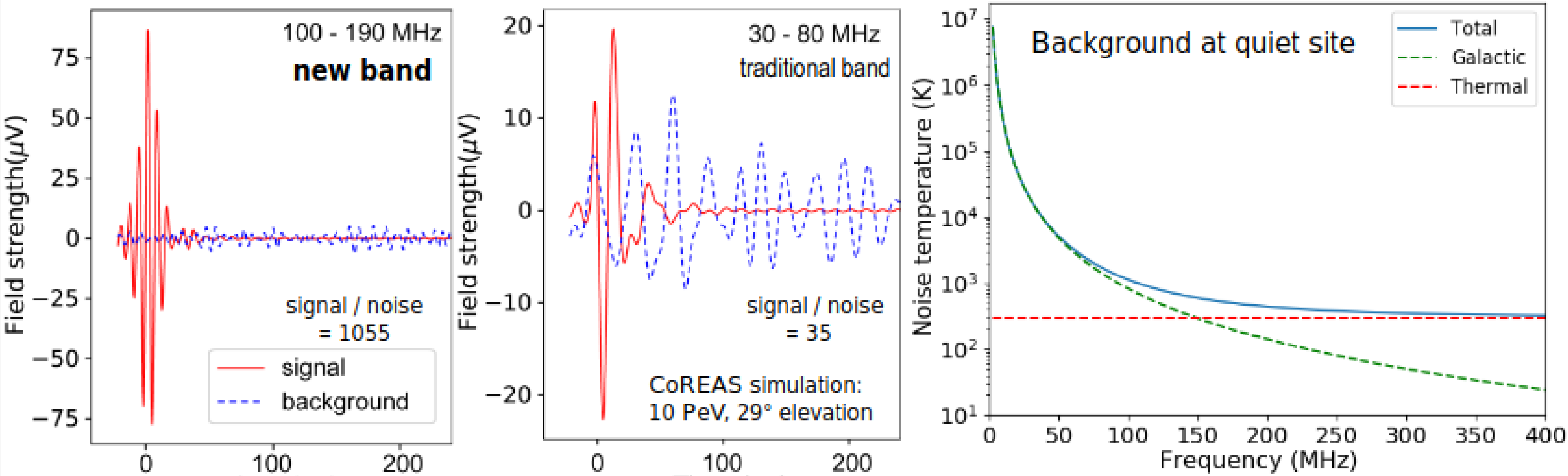


Surface radio array for Gen-2

Lower threshold by higher frequencies

- Background at radio-quiet sites falls rapidly towards higher frequencies
- Signal close to Cherenkov cone extends to several 100 MHz (GHz directly at the cone)

→ PeV detection threshold for antennas close to the Cherenkov cone.



EPJ C 78 (2018) 111

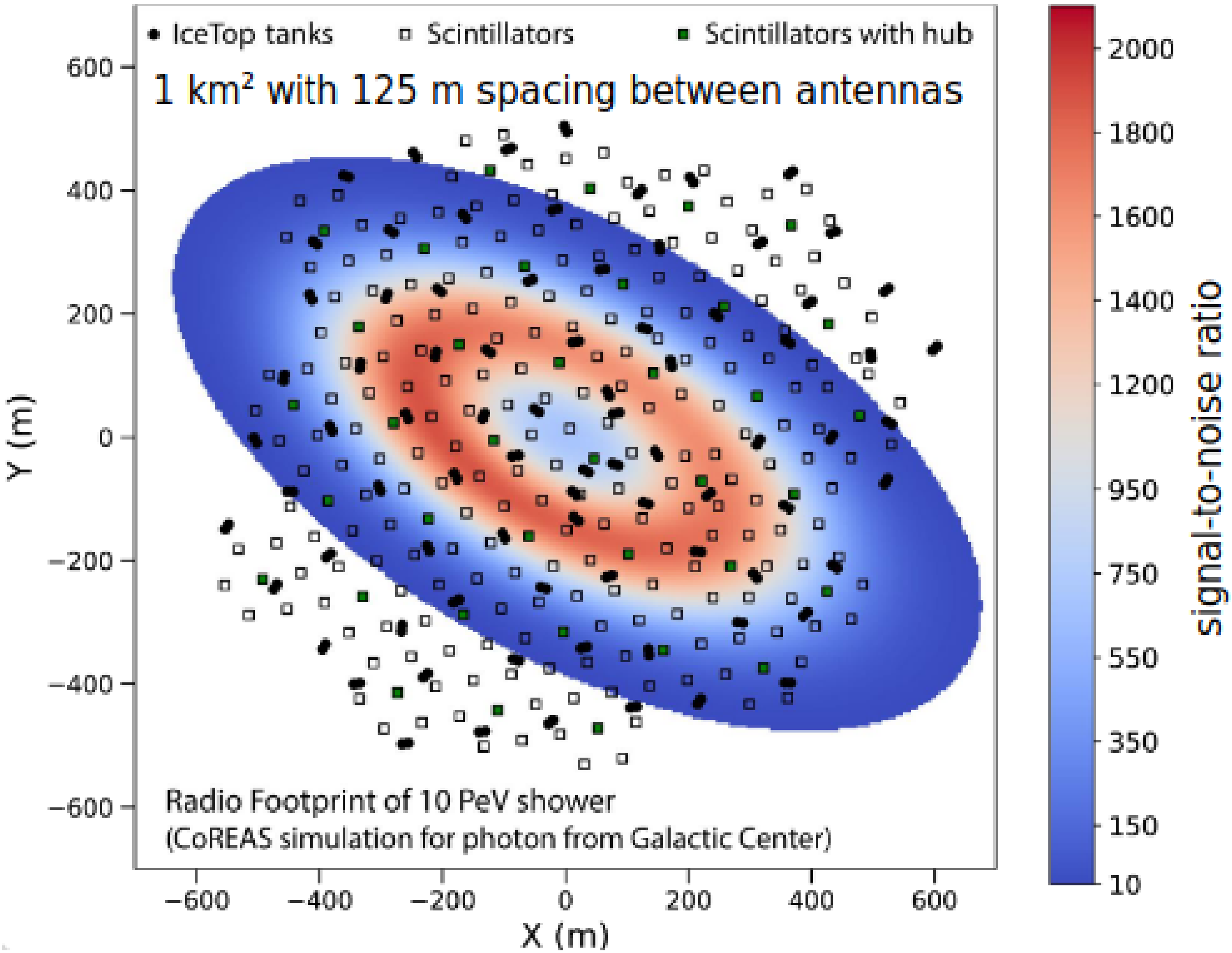
Claim: Can push threshold to 1 PeV by moving to higher frequencies

-Less radio noise from galaxy

-Sharper signal on Cherenkov cone

Note: no phasing, and relatively low-gain antennas

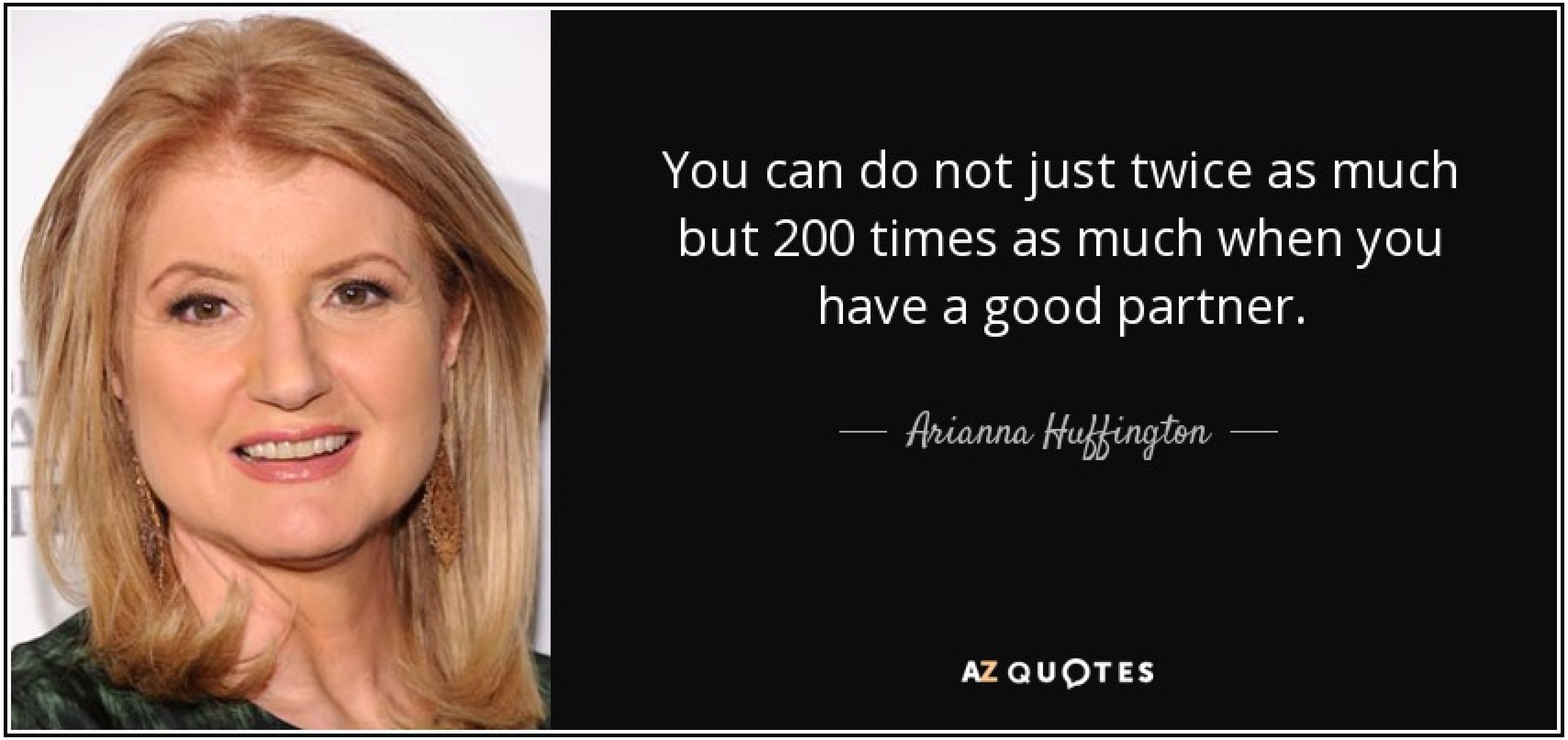
Footprint: Scintillators+radio Rx



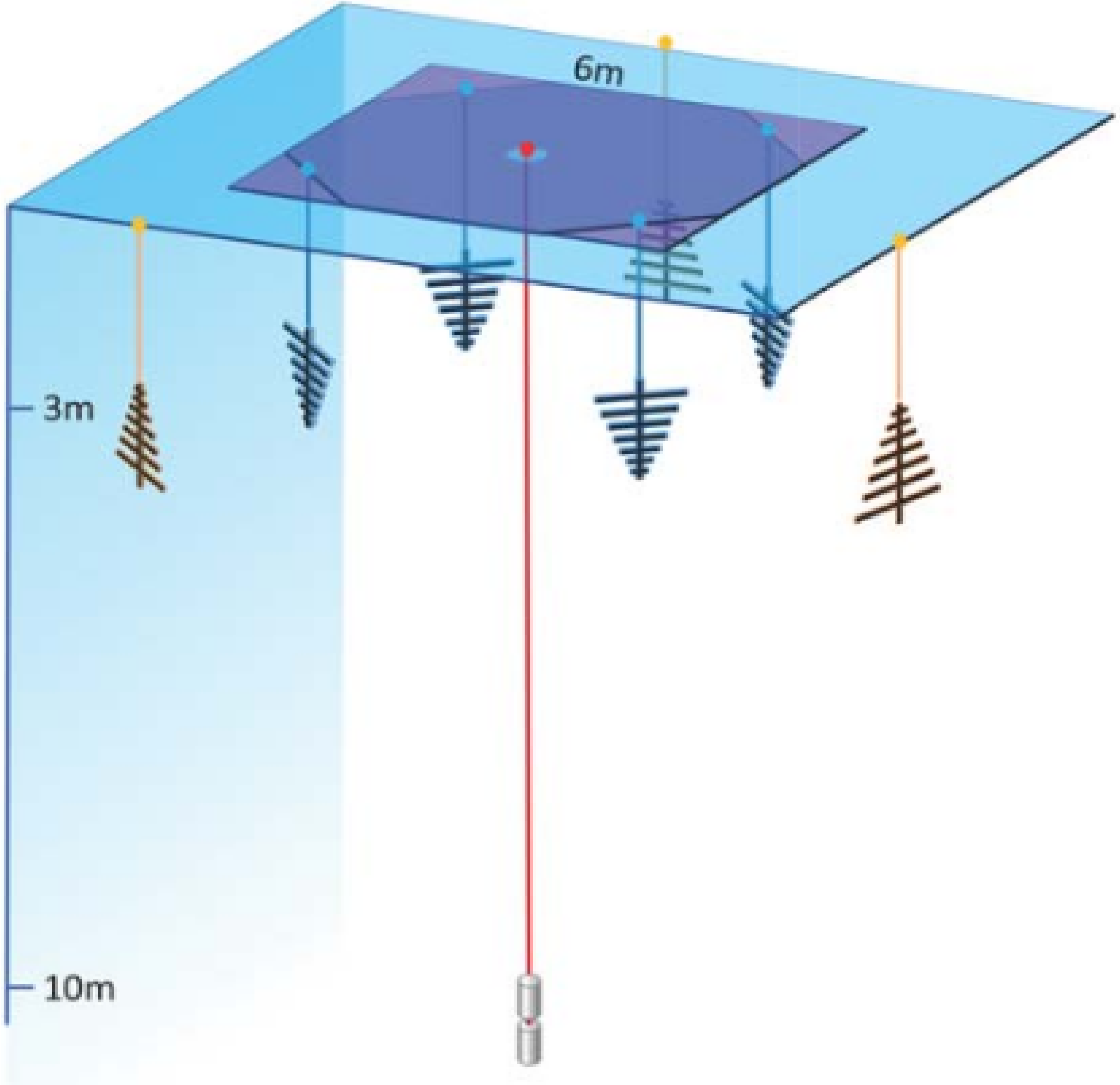
Footprint of radio geomagnetic signal

- Trigger
  - Default = external trigger on station level by scintillators
  - Array trigger by IceTop and scintillator arrays?
  - Self-trigger to lower threshold for PeV photons?

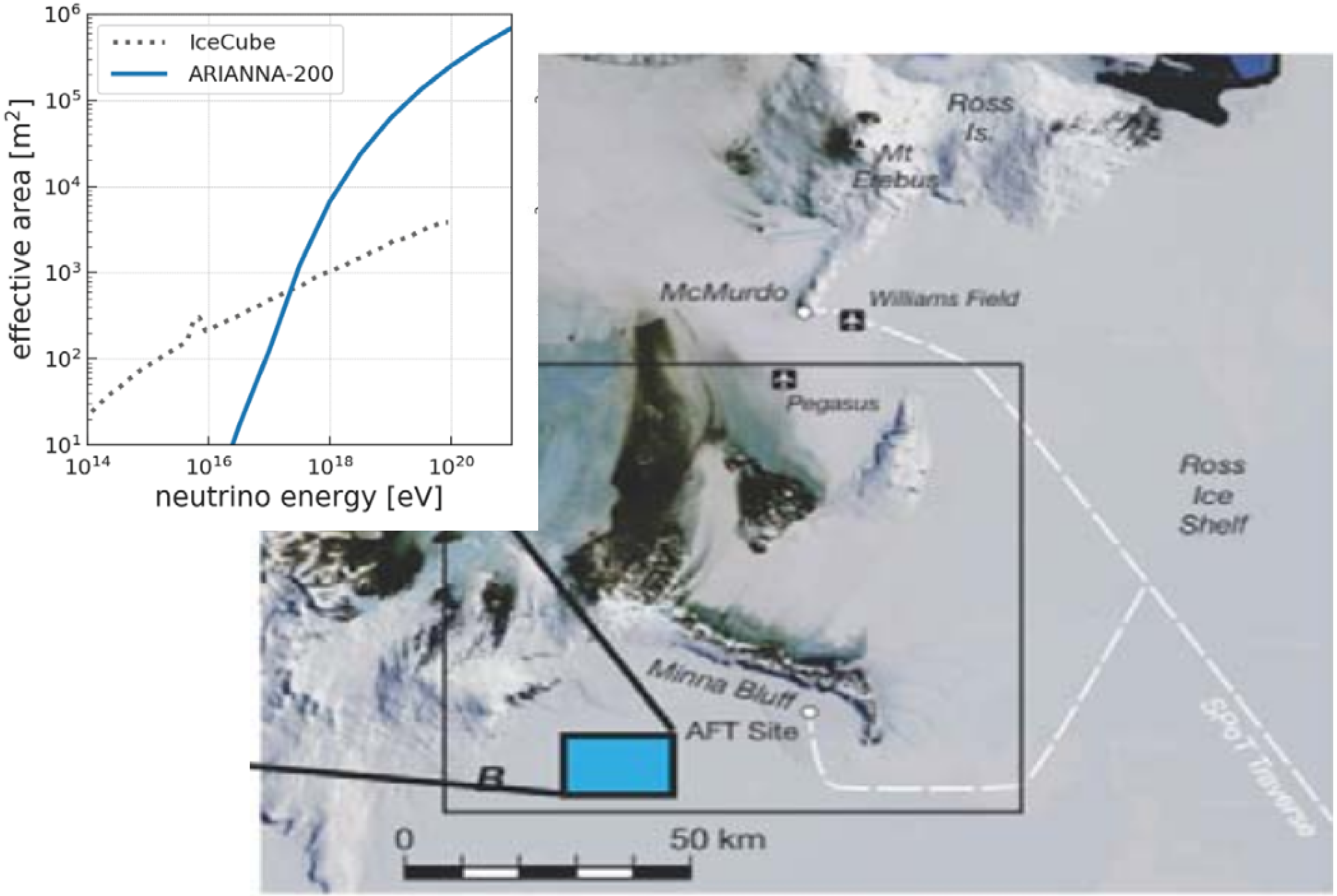
ARIANNA-200


You can do not just twice as much but 200 times as much when you have a good partner.
— Arianna Huffington —
AZ QUOTES

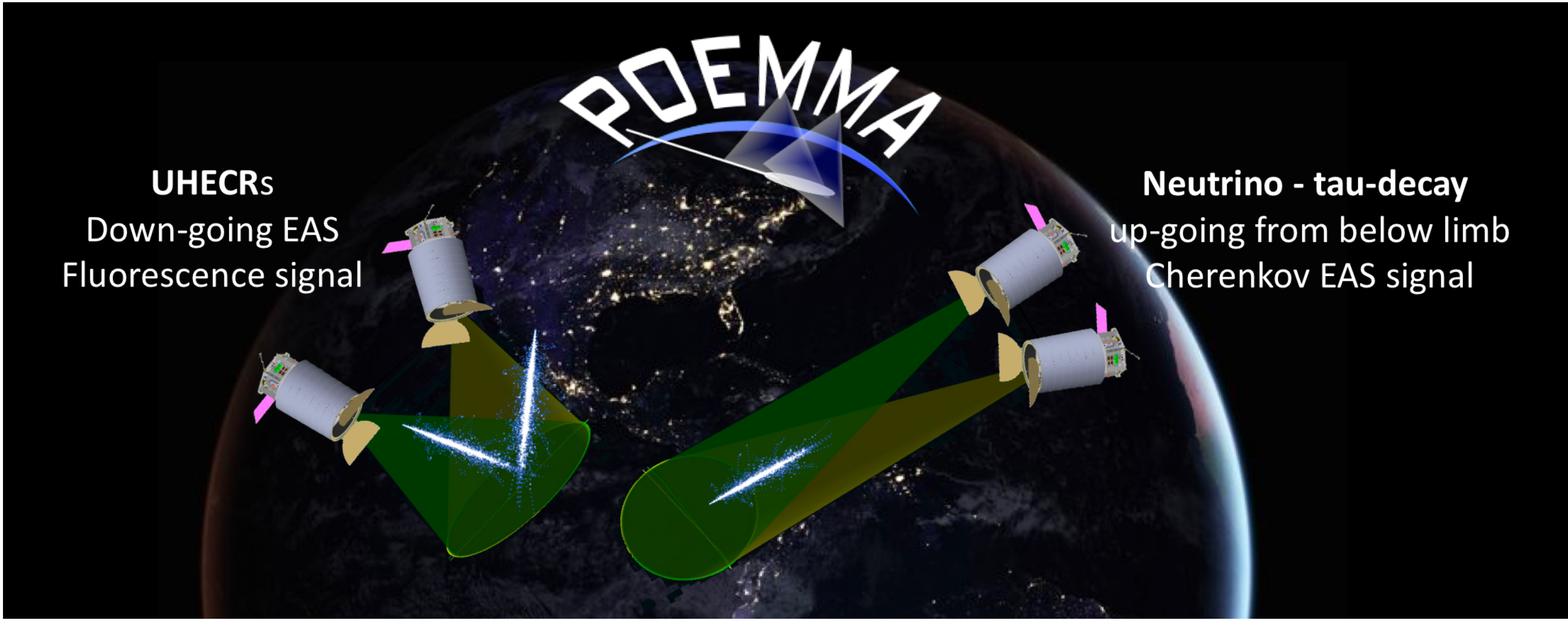
ARIANNA-200



ARIANNA site (shielded from noise)



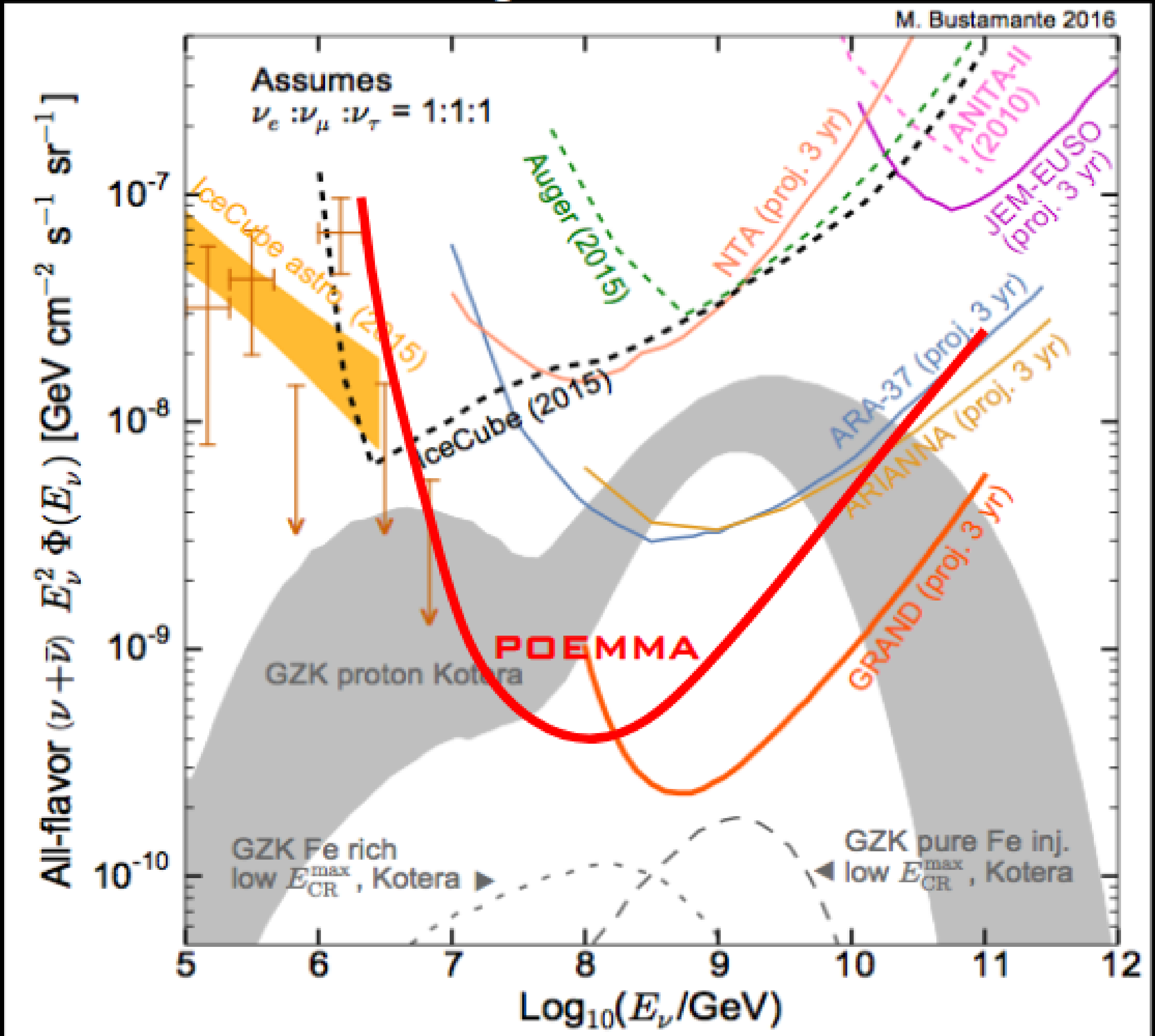
“A billion here, a billion there...”



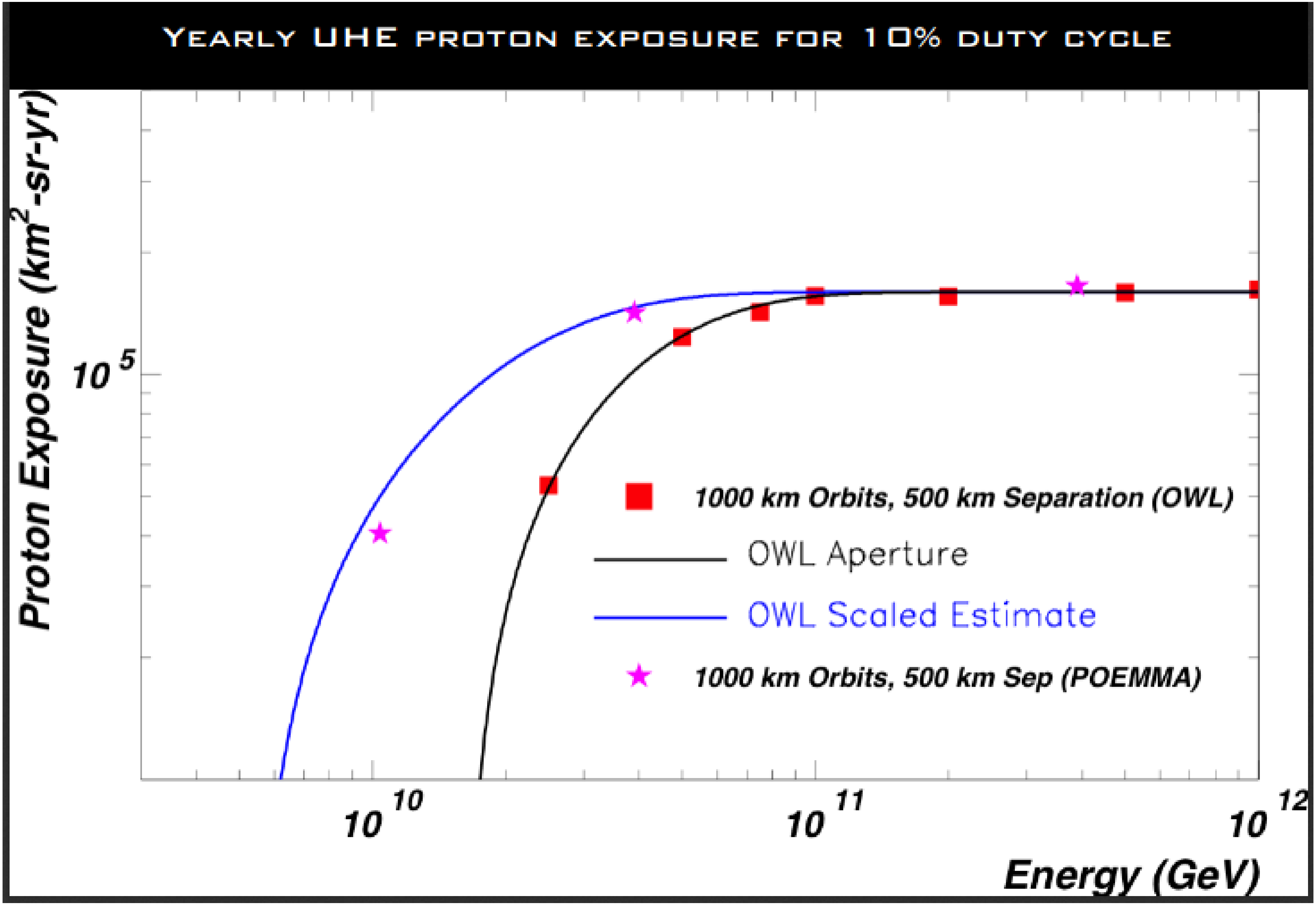
Put multiple nitrogen fluorescence detectors in space orbit

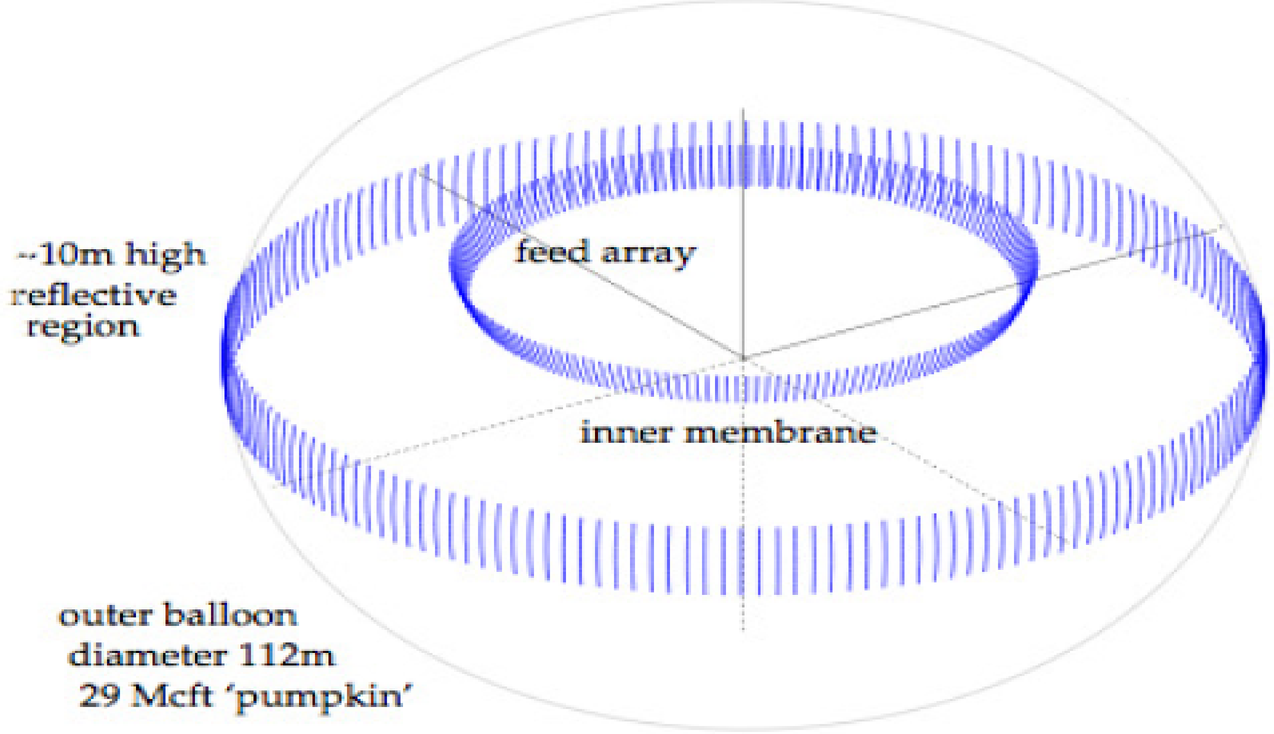
POEMMA sensitivity

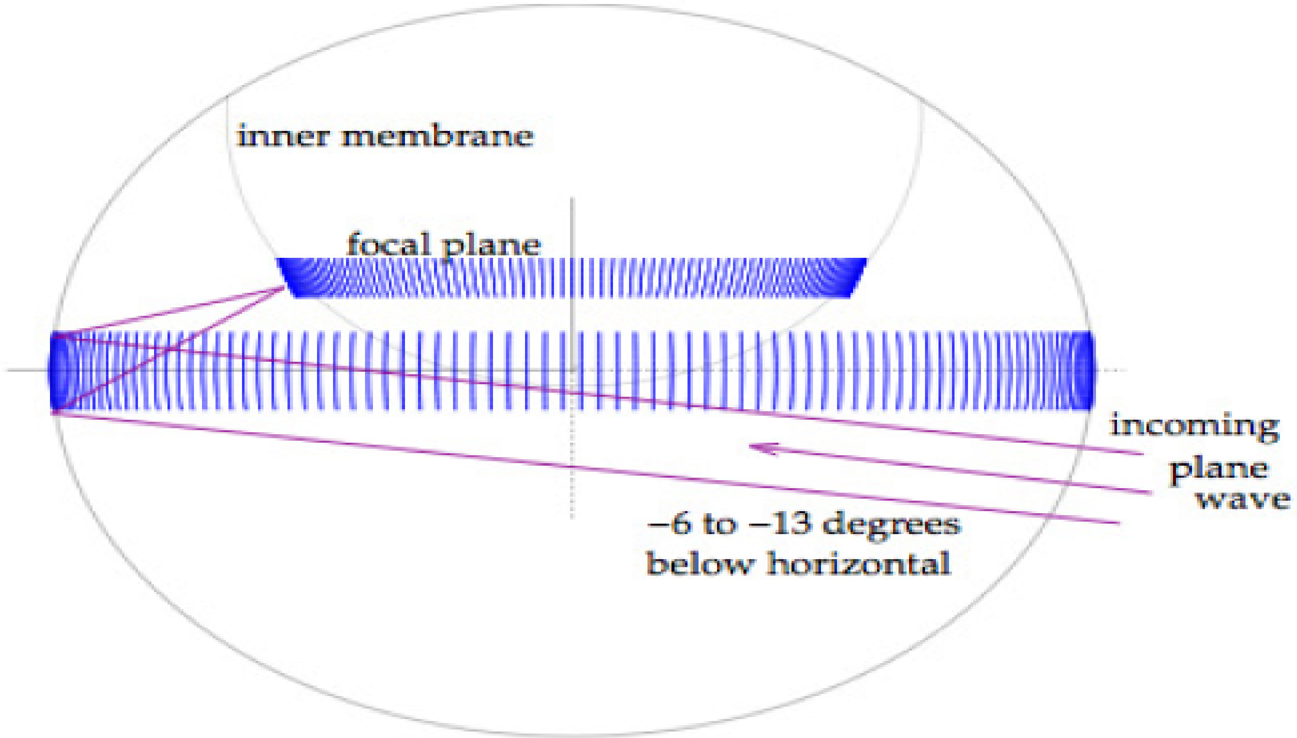
Cosmogenic Neutrinos



POEMMA exposure vis-a-vis GZK

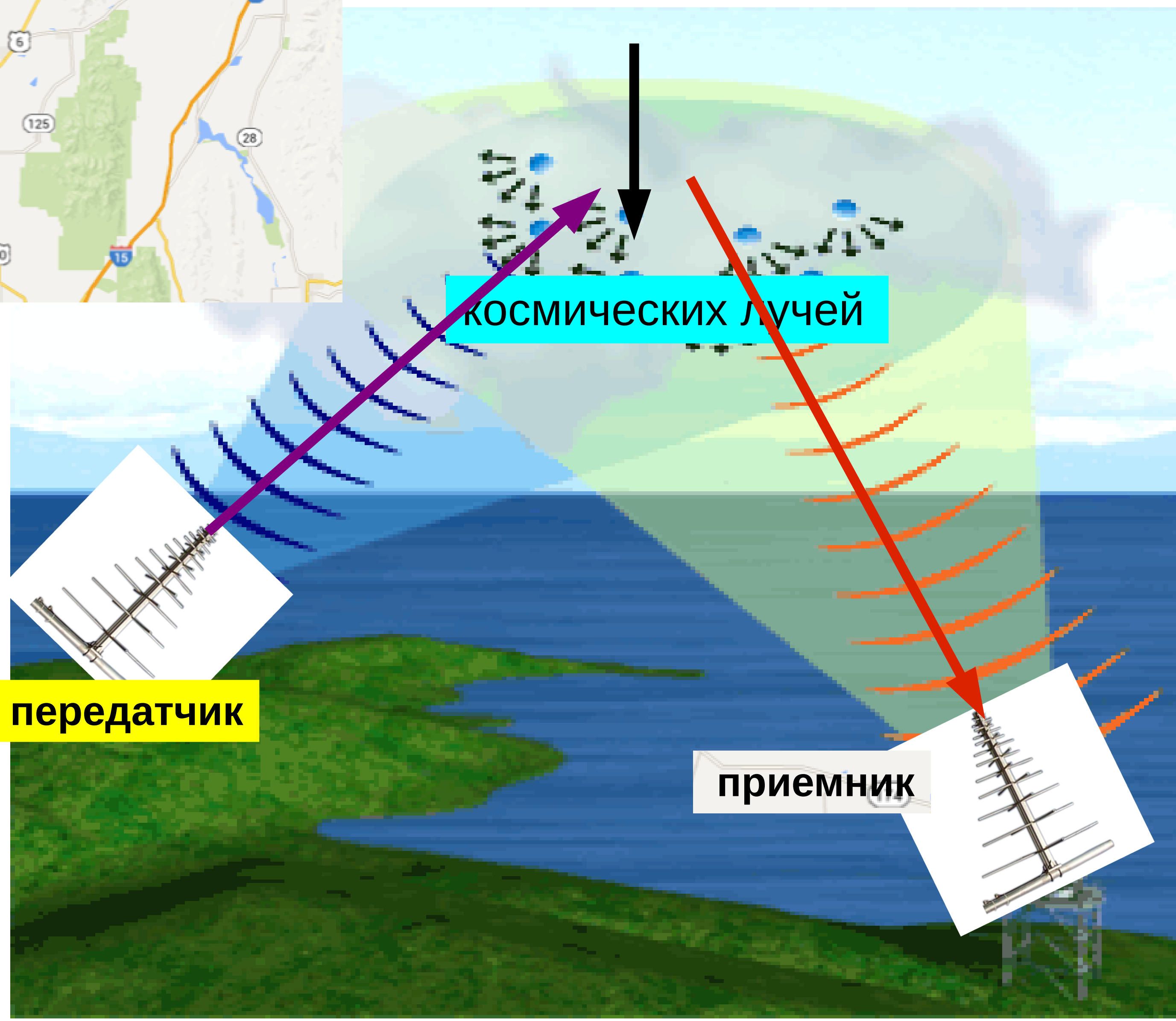






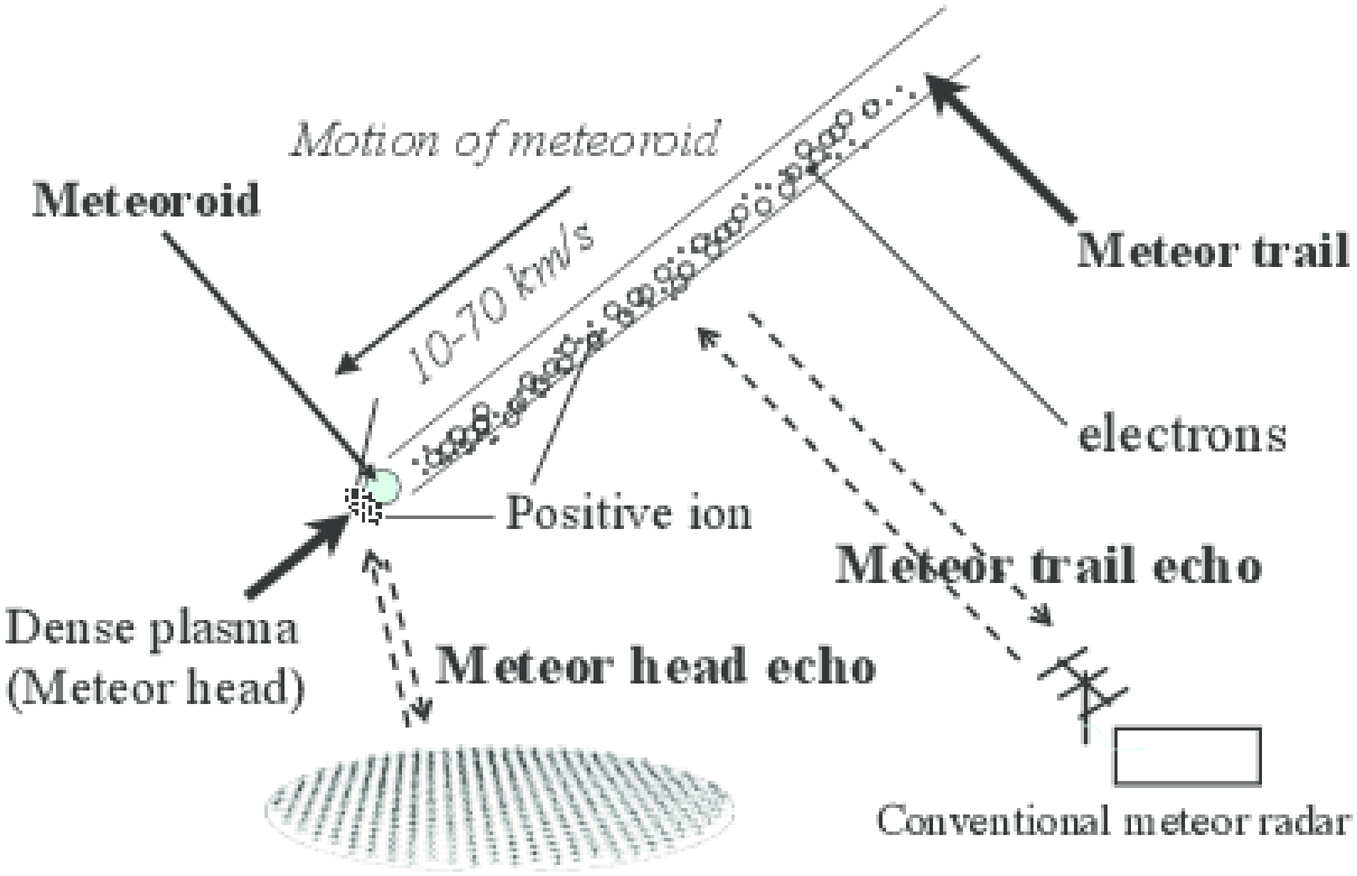
EVA – the future: the medium is the message

Radar approaches (RET)



Q: Chirp up or down?

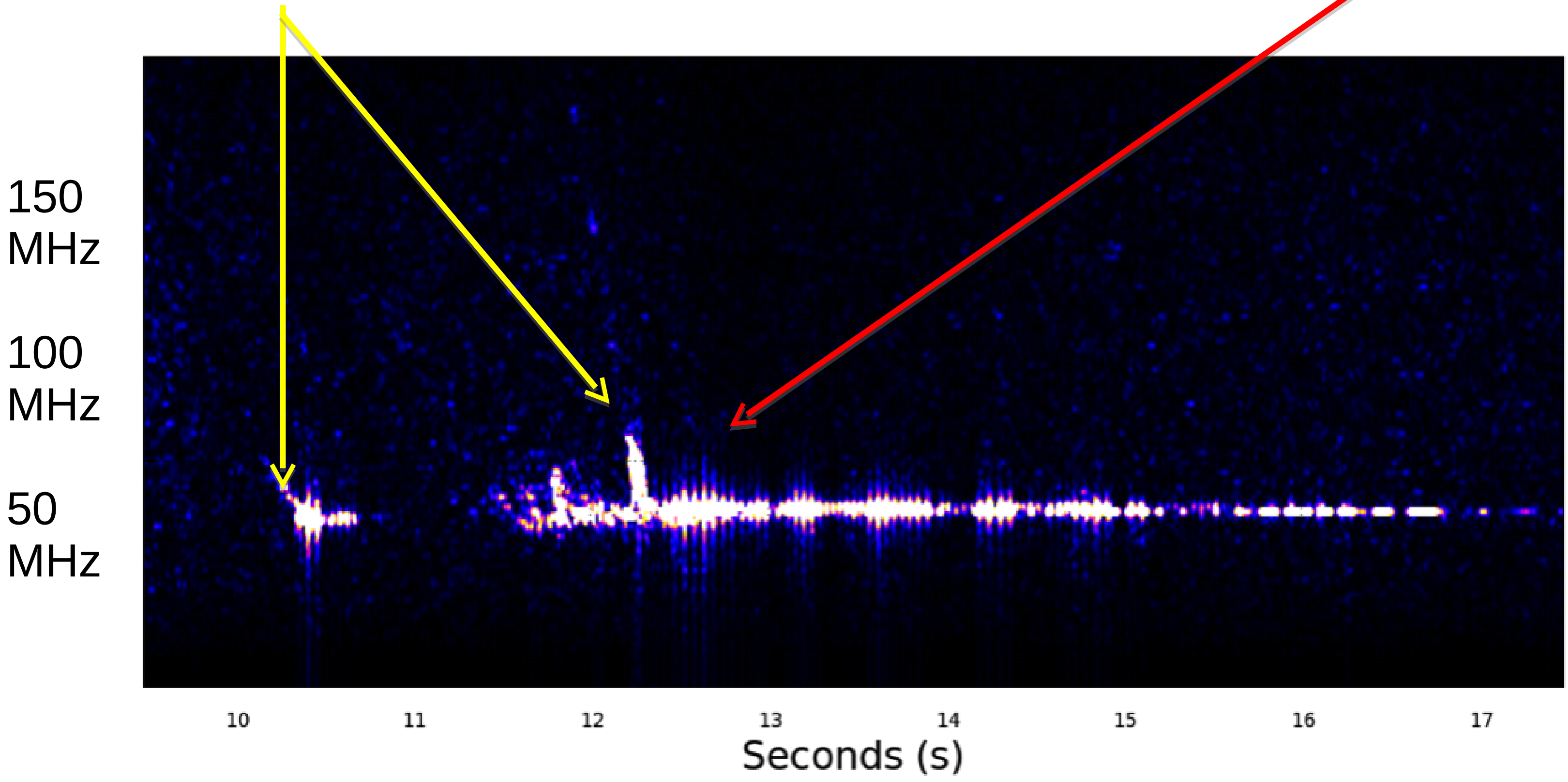
Anatomy of a reflector



TARA Meteorite (80 km elevation; no LOS)

Head Echo (~ Shower Front)

Trail Echo (~ Ionization Trail)



Tx : TARA Utah Back lobe

1600 km

Rx : Lawrence, KS

Plasmas and critical frequencies

Free ionization trail ~ coupled harmonic oscillators
F=ma=qE(ω,t) + damping-term (dissipative collisions)

$d^2x/dt^2=q\omega E(\omega,t)/(\omega+i*f_{collisions})$

Resonant (plasma frequency): $\omega_P \sim (q^2/m)^{1/2}$ (cf: ω=sqrt(k/m))

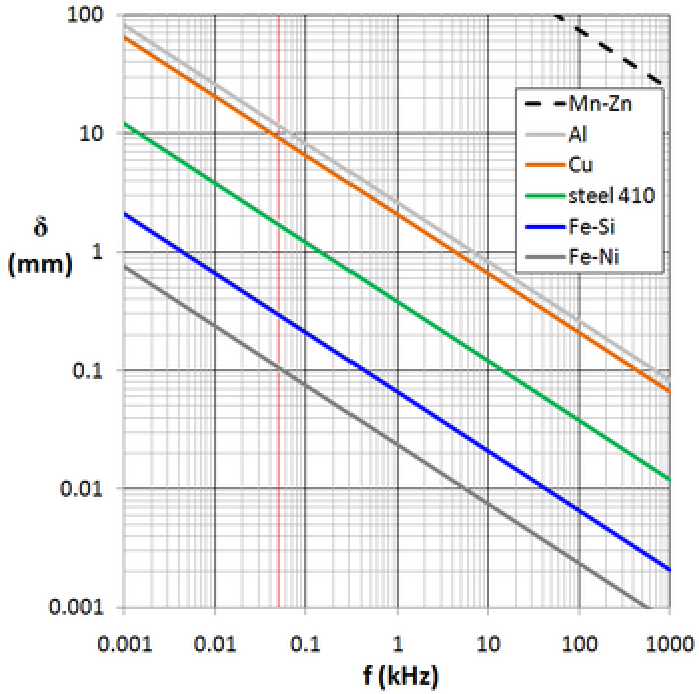
Derive equivalent of complex refractive index
imaginary component: attenuation (→in absence of damping)
real component: c→c/n

Qualitatively, in coupled harmonic oscillator model, expect maximum absorption at high or low frequencies?

Quick primer on plasma frequencies!

Recall Prof. Pravata's slide on particle number vs. radial distance from core. For small particle number density, scattering is at individual-particle level; for large particle number density, can have coherent response

Q: To get coherent return signal, want ω_{radar} > or < ω_{plasma}?



re-radiation happens within the skin depth,

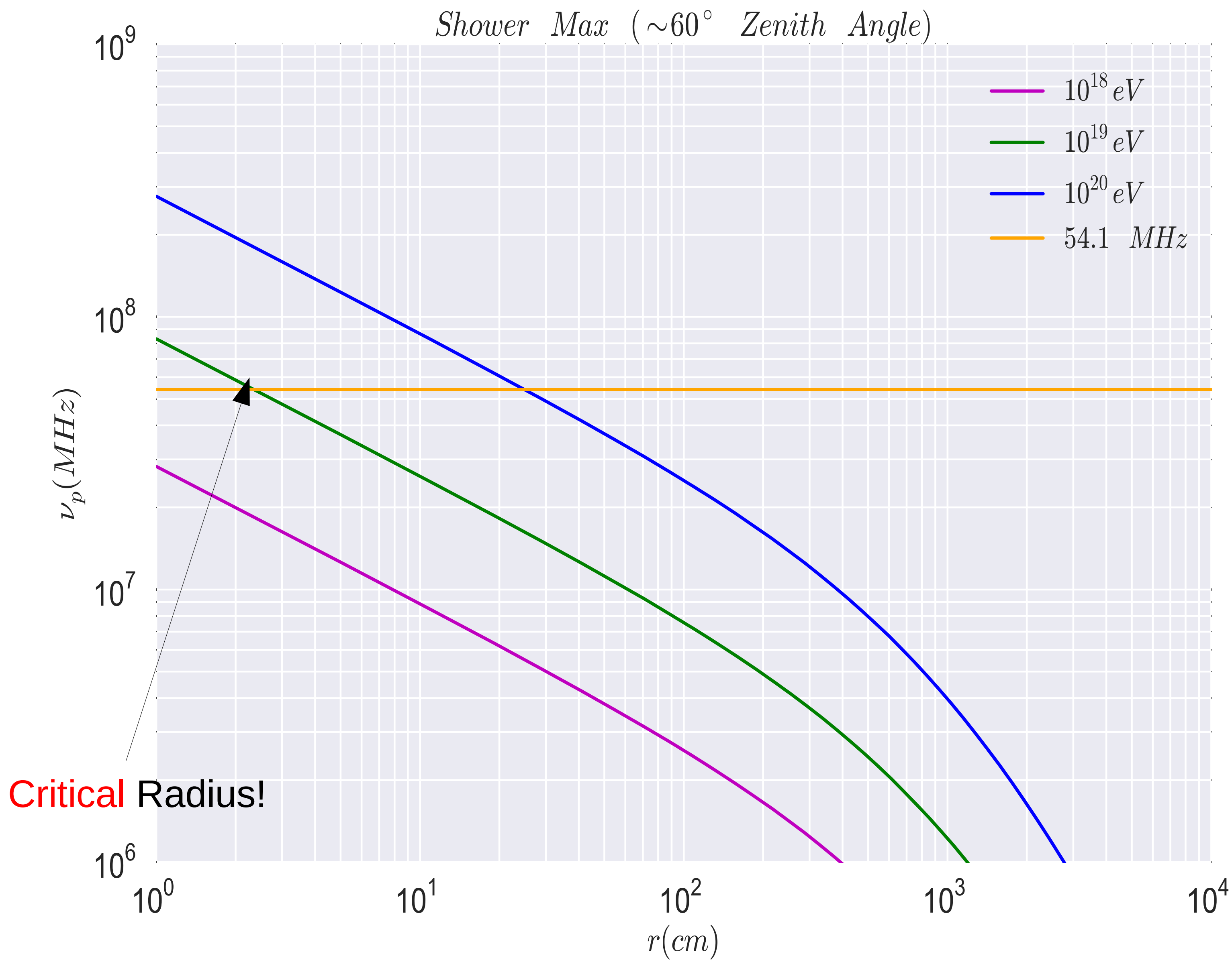
beyond the skin depth the external field cannot penetrate, so that is where there is energy transfer to the free electrons

beyond that the field is damped so the electrons are there but they don't see any external field

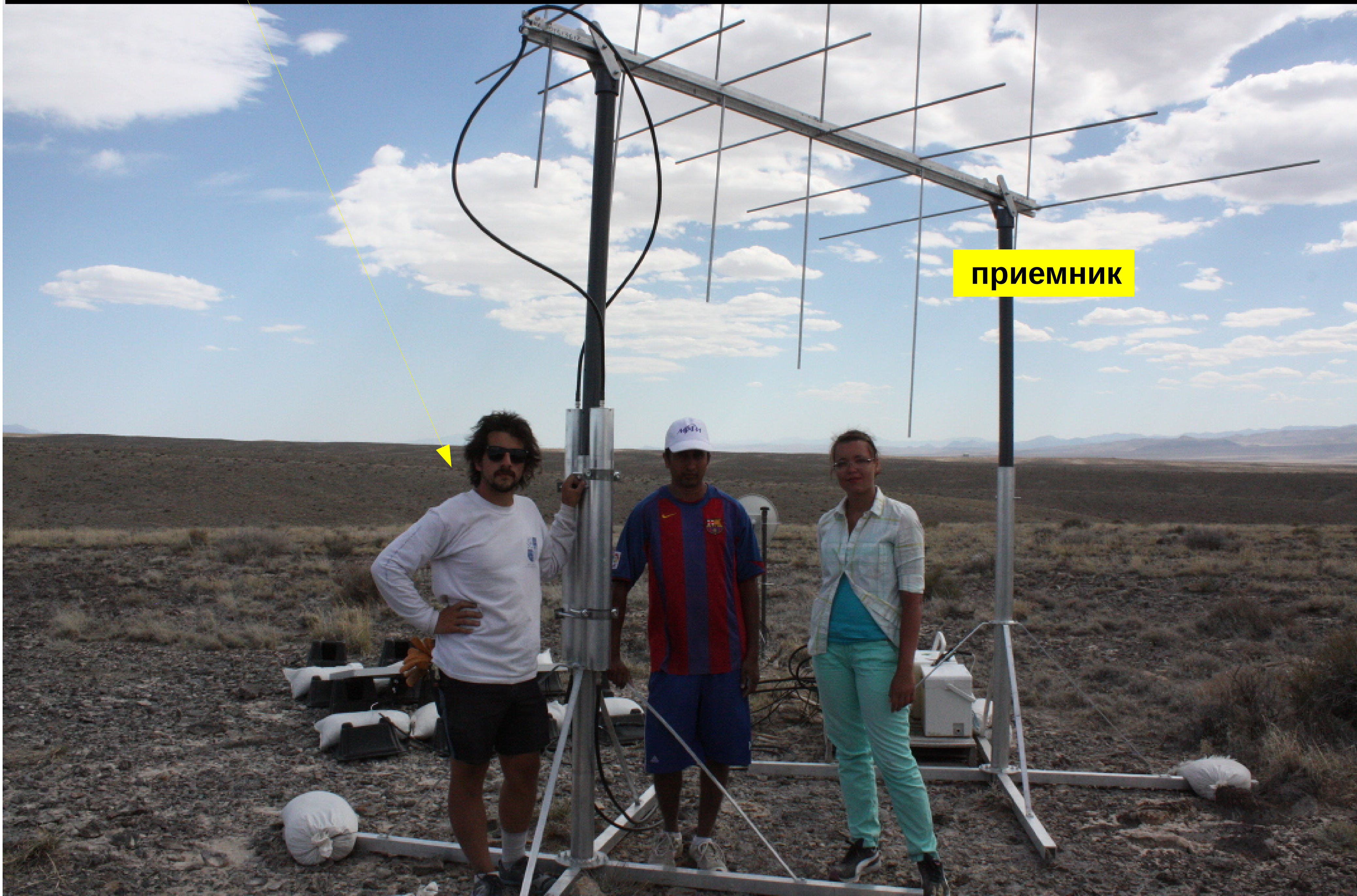
For TARA, e.g., need plasma frequency above 54.1 MHz carrier

~~Under – dense($\nu > \nu_e$)~~
Fatal!

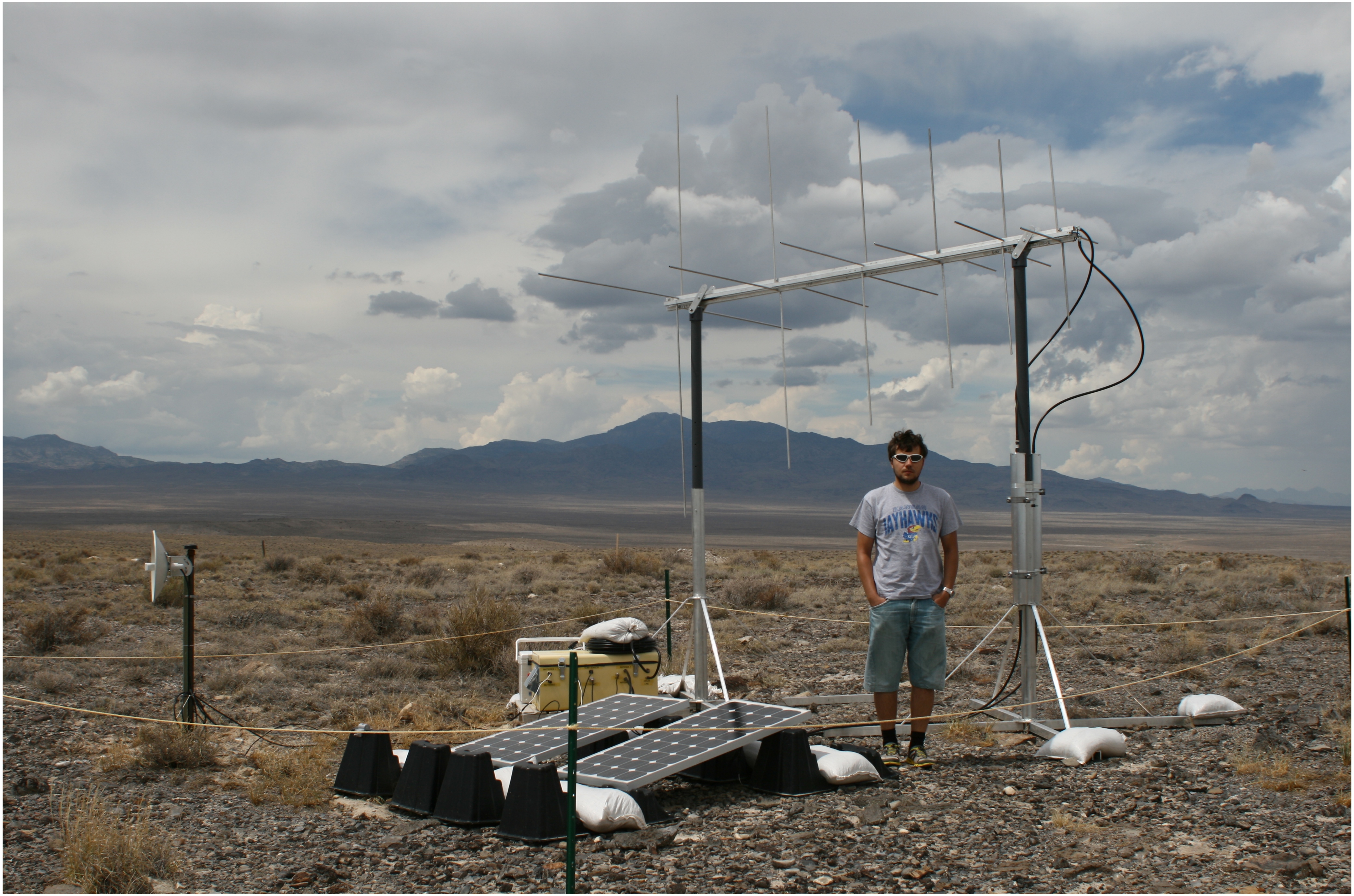
Over - dense ($\nu < \nu_e$)
Thin Wire approximation!



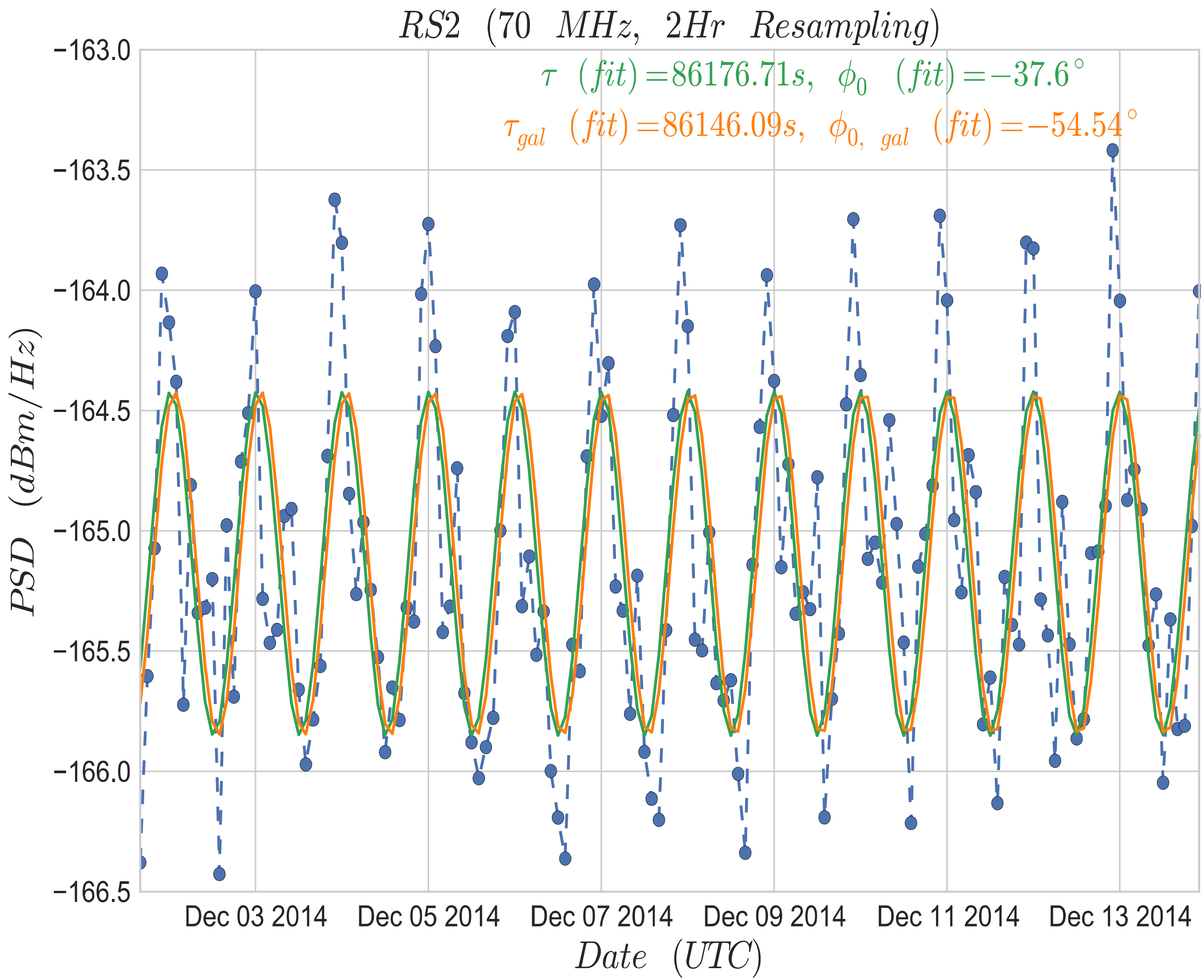
Steven, Sam and Марина (28.06.14)



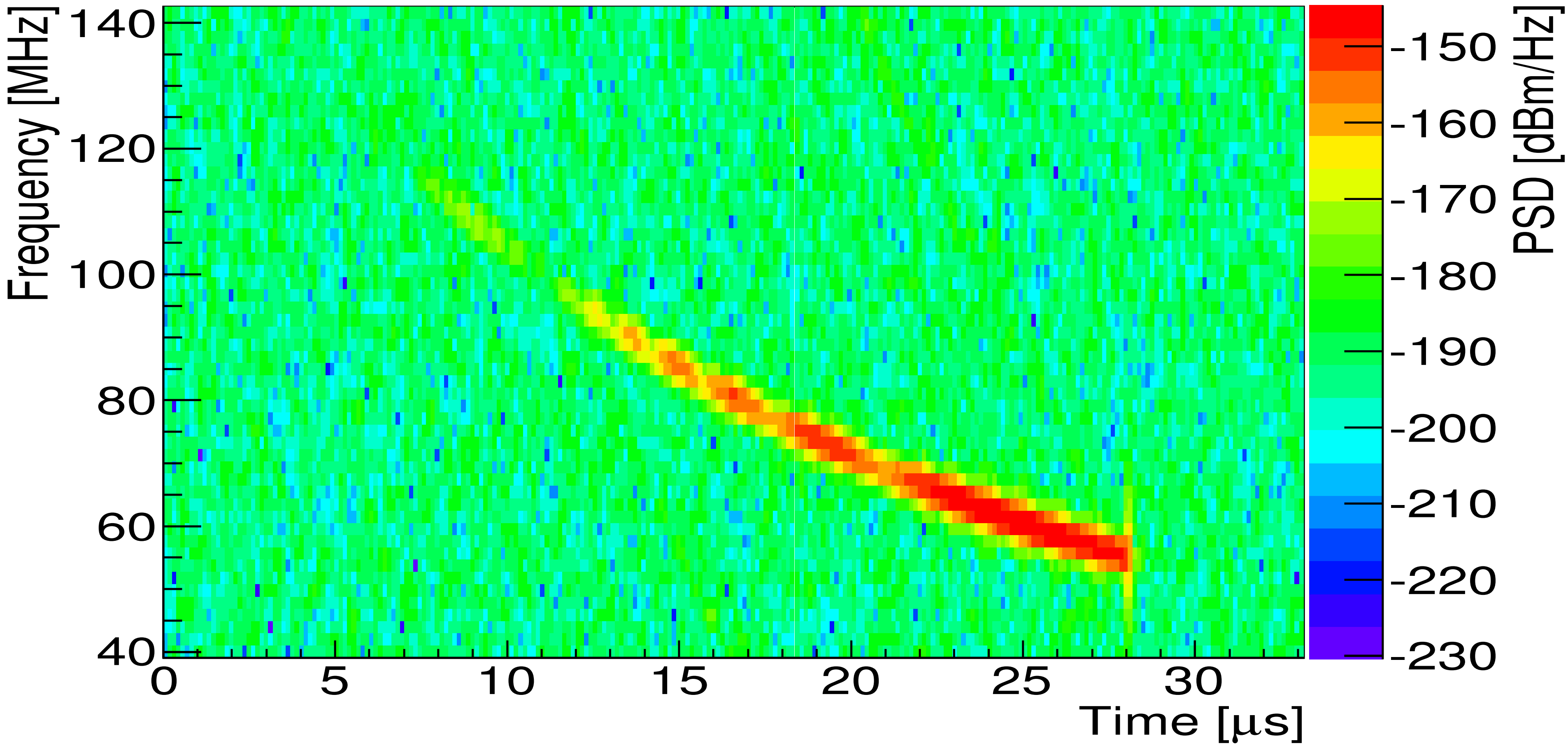
Саша (18.08.14) (ремонт)



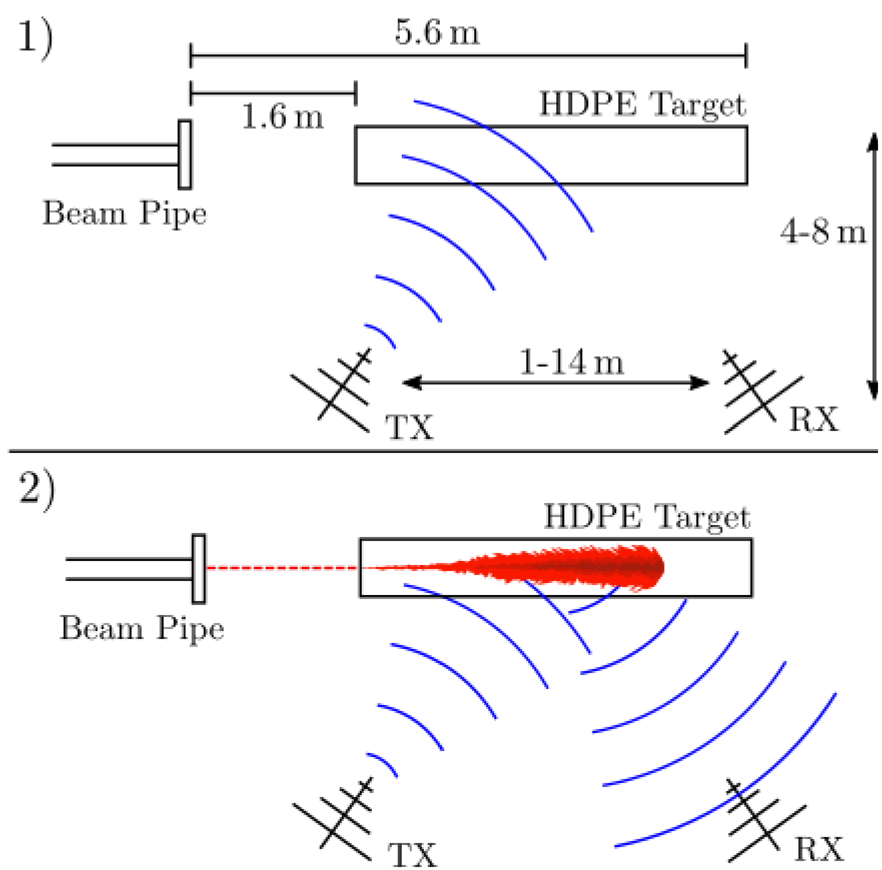
Sidereal Variation (wrt Sagittarius A*)

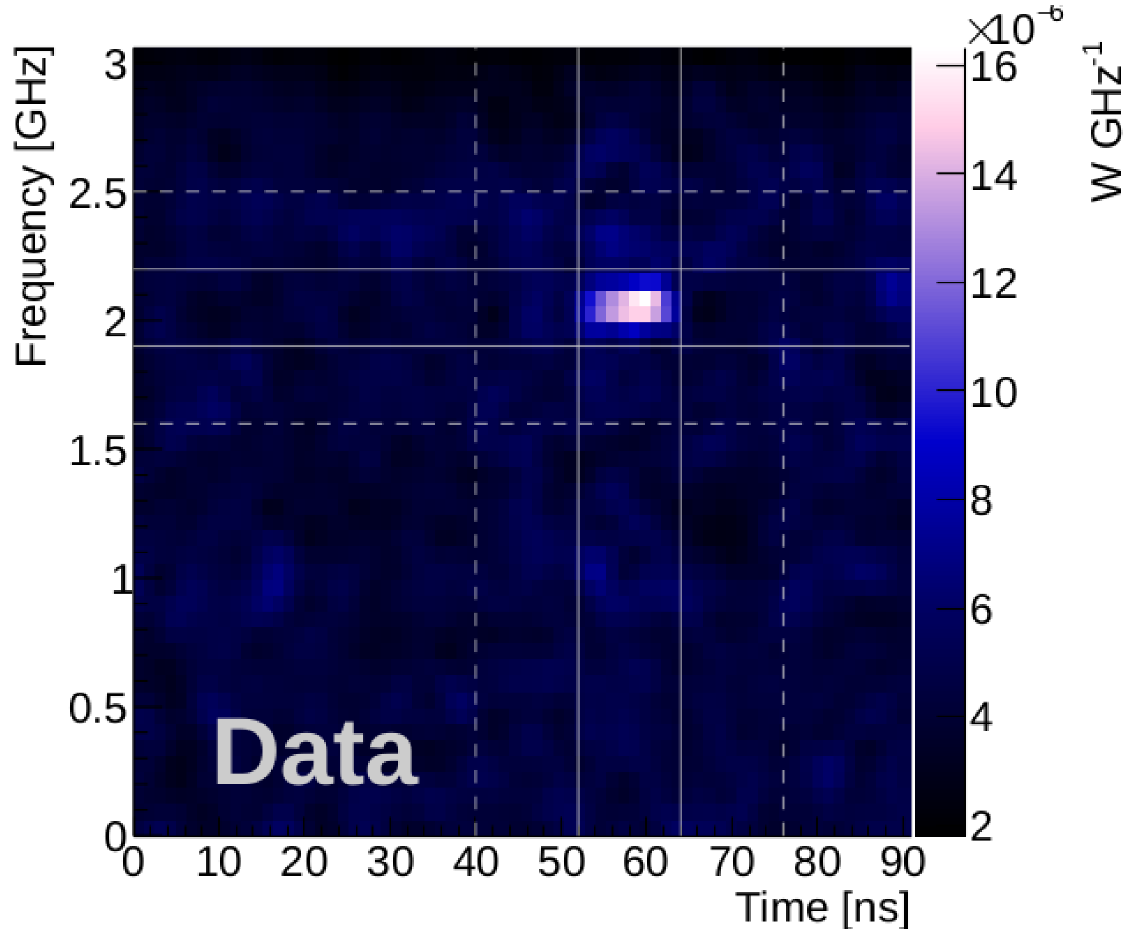


Simulated Chirps!



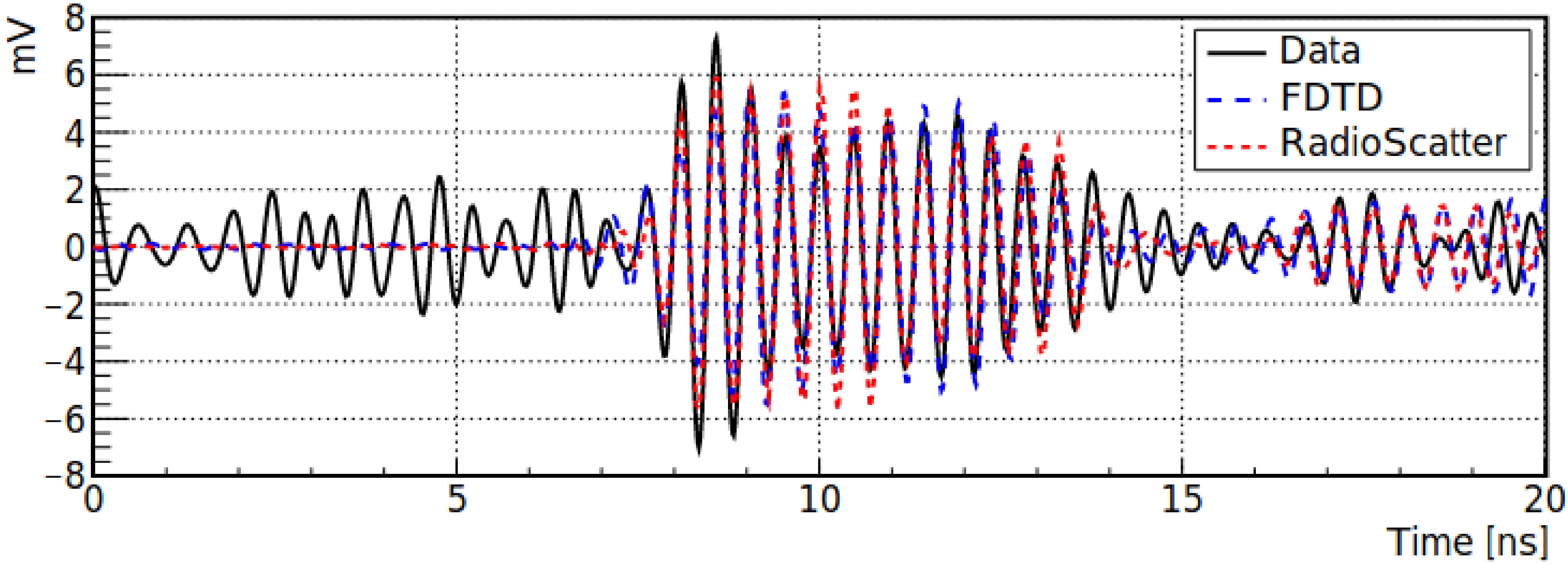
T-576 → RET-CR and RET-NU





Comparison to Askaryan:
2pi coverage rather than limited C-cone;
distinctive chirp-pattern recognition;
Arbitrarily high transmitter strength

Comparison with prediction



Current Status: Proposal submitted to install transmitter and receiver at Taylor Dome, Antarctica for proto-typing...

The only certainty is uncertainty!