The Giant Radio Array for Neutrino Detection

The GRAND Collaboration

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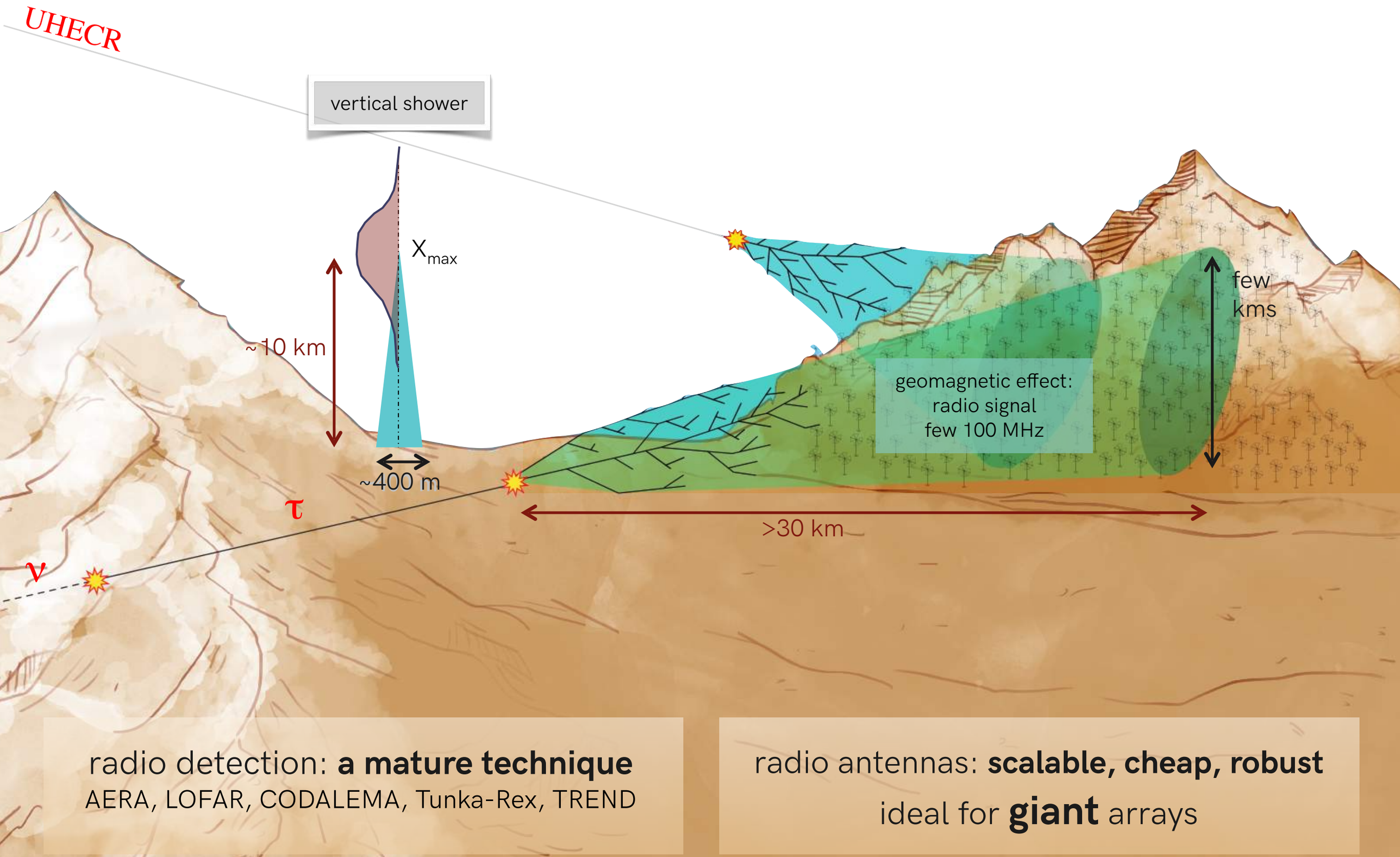
GCOS - 19/05/2021

Radio detection of ultra-high-energy air-showers

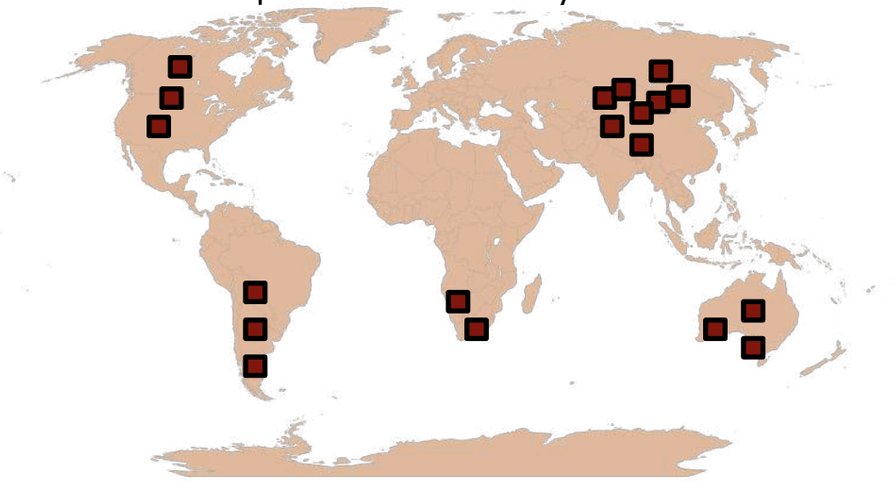


radio detection: **a mature technique**
AERA, LOFAR, CODALEMA, Tunka-Rex, TREND

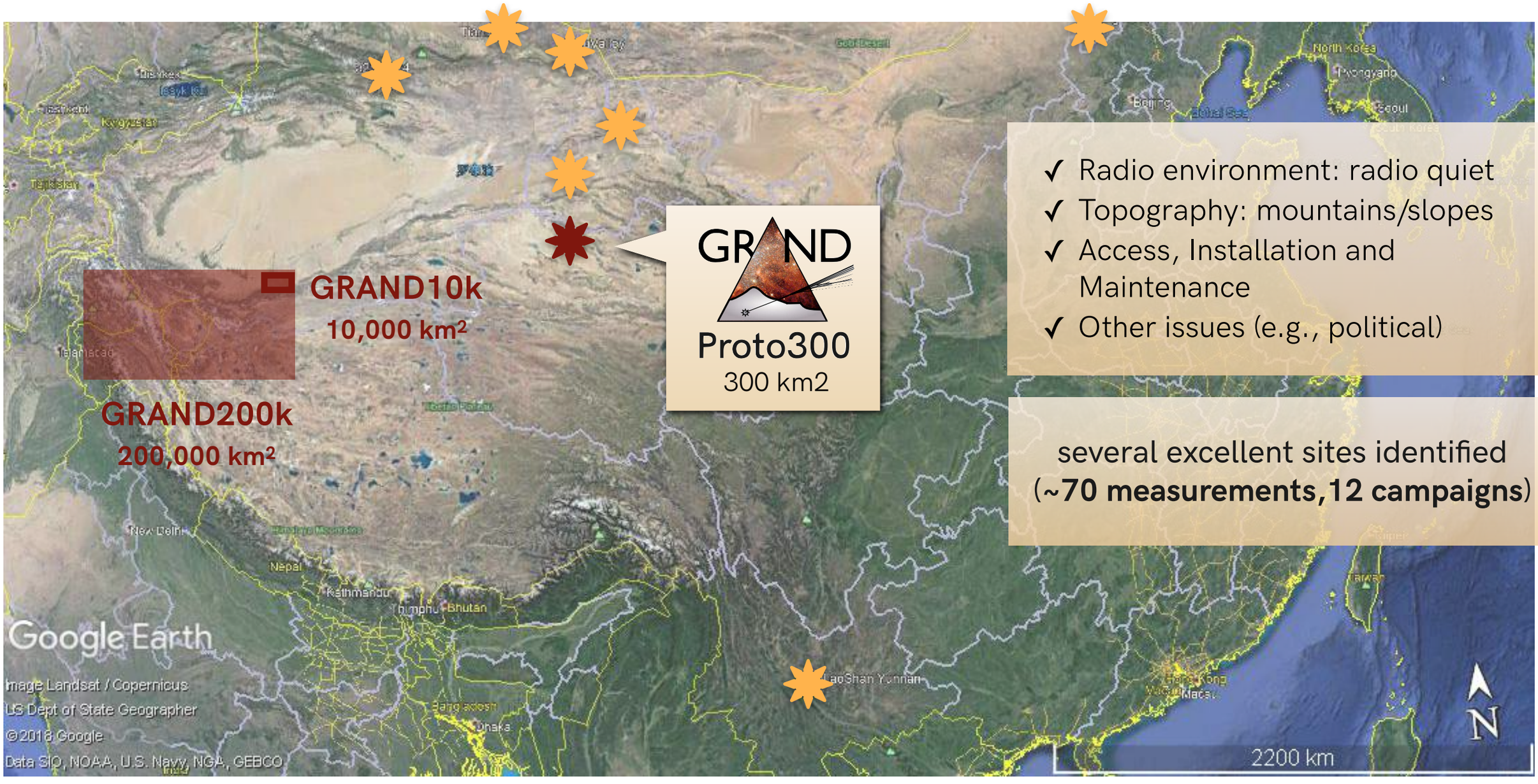
radio antennas: **scalable, cheap, robust**
ideal for **giant** arrays

The GRAND Concept

example of sub-array locations



200'000 radio antennas over 200'000 km²
~20 sub-arrays of 10'000 antennas
over favorable sites in China and worldwide

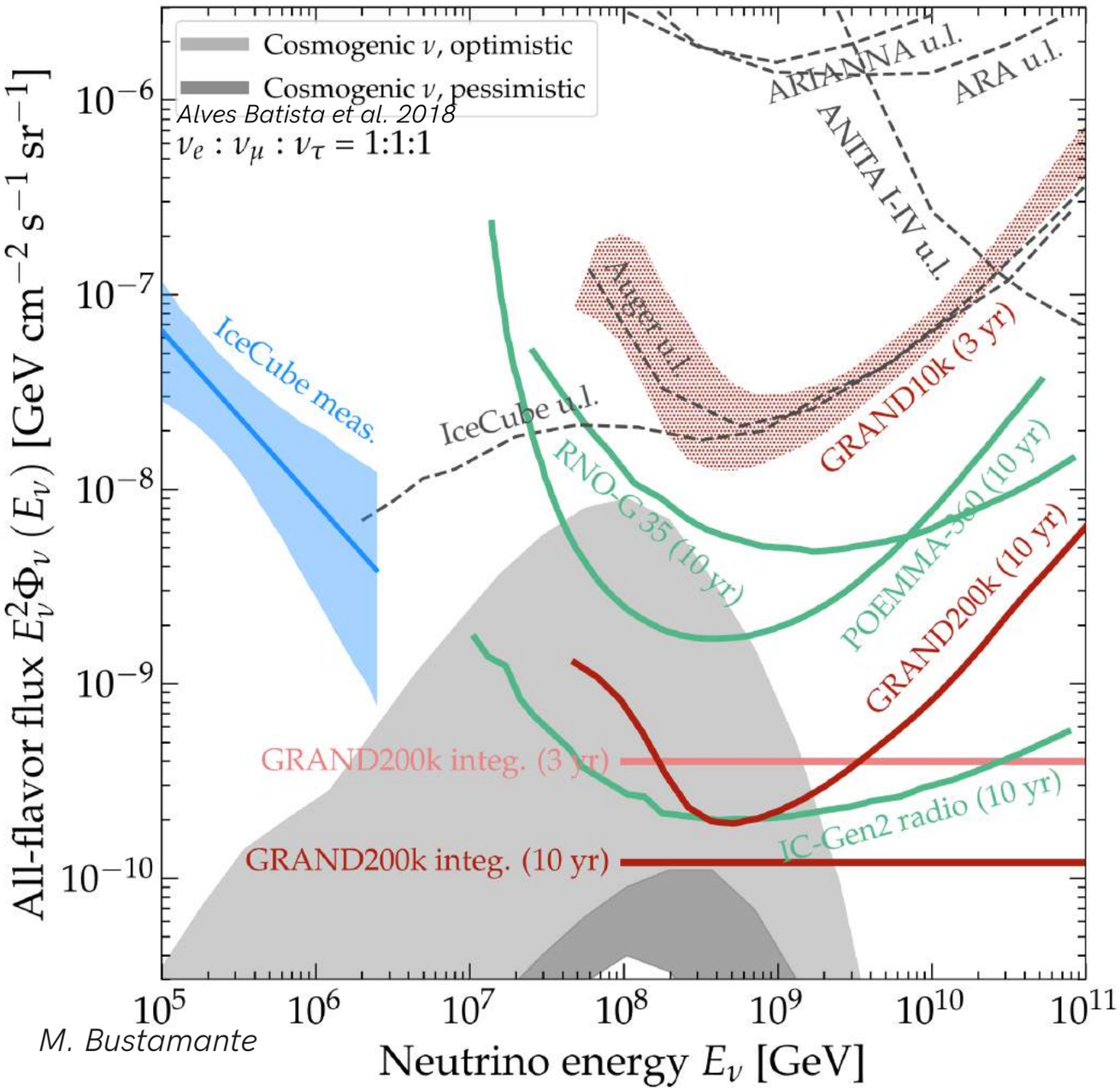


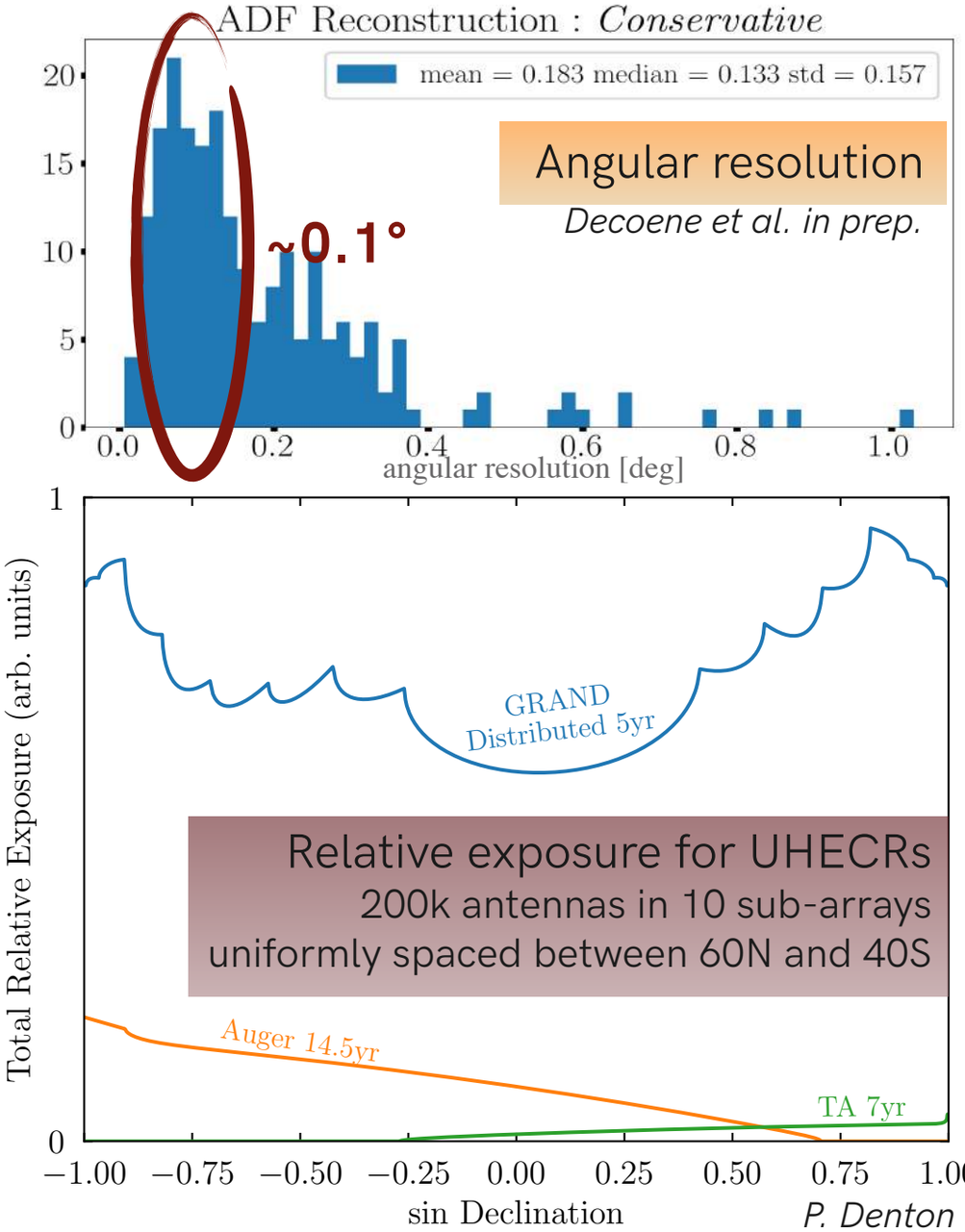
- ✓ Radio environment: radio quiet
- ✓ Topography: mountains/slopes
- ✓ Access, Installation and Maintenance
- ✓ Other issues (e.g., political)

several excellent sites identified
(**~70 measurements, 12 campaigns**)

Simulated performances

GRAND Science & Design, GRAND Coll. Science China, arXiv:1810.09994





- **GRAND full sensitivity to neutrinos** (E>10^{17} eV) ~4 x 10^{-10} GeV cm^{-2} s^{-1} sr^{-1}
- **Angular resolution** ~0.1° for GP300 & GRAND — *V. Decoene PhD 2020*
- **Energy resolution** < 10% for GP300 & GRAND — *B. Lago & Rio GRAND team*
- **X_{max} resolution** < 40 g/cm^2 achievable for E>10^{19} eV for GRAND — *C. Guépin PhD 2019*

A rich science case

UHE neutrinos

- UHE neutrino astronomy
- UHE neutrino cosmogenic flux

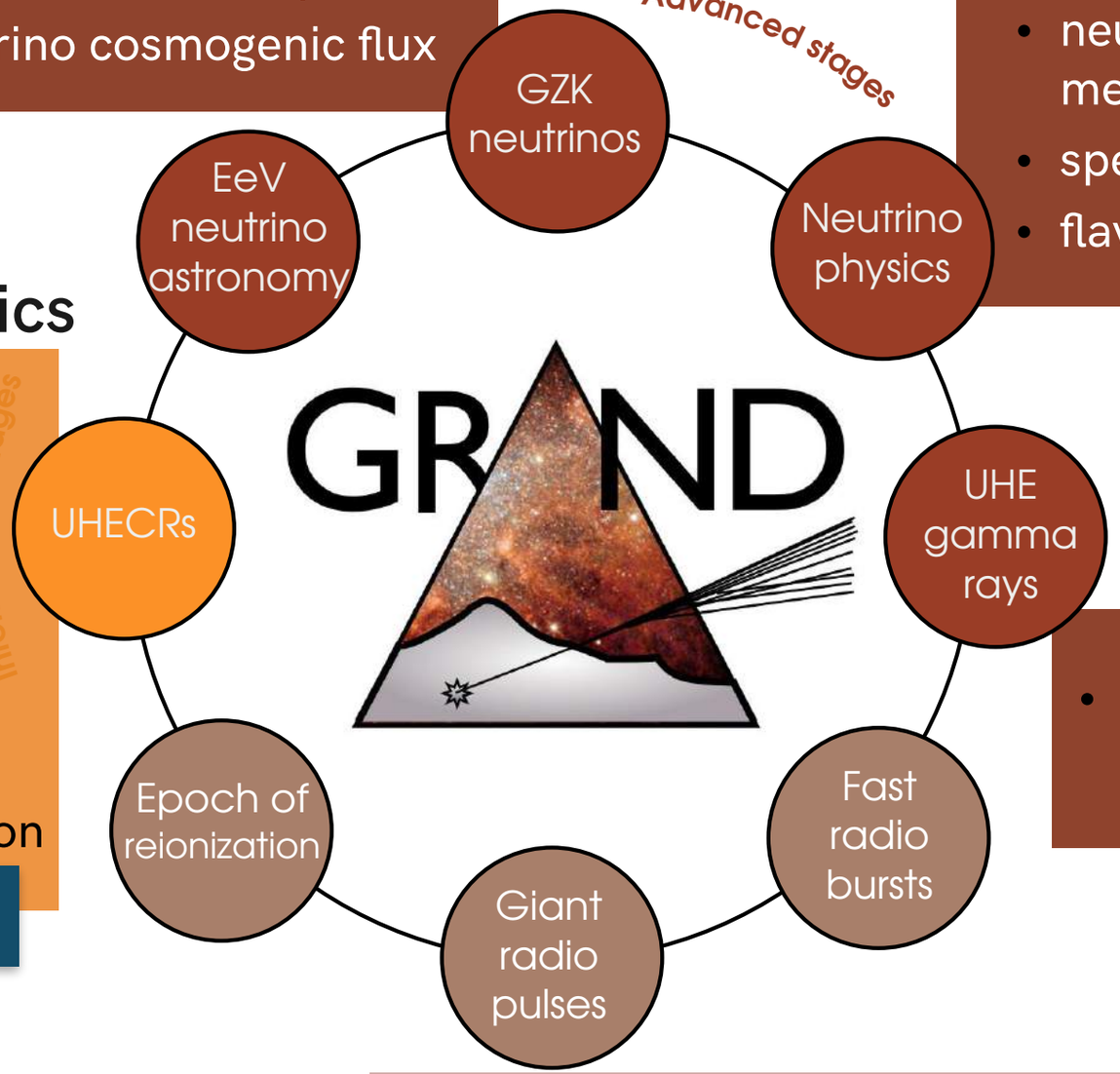
neutrino physics

- neutrino cross-section measurements
- spectral, angular distortions
- flavor ratios

UHECR, hadronic physics

- 20-80 times the exposure of Auger!
- GRANDProto300: transition from Galactic/ extragalactic
- hadronic physics: muon discrepancy, UHECR mass composition, p-air cross-section

GCOS connection!



UHE gamma rays

- competitive with Auger at GRANDProto300 stage

radio-astronomy in a novel way

Early stages

- unphased integration of signals: an almost full-sky survey of radio signals
- can detect FRBs and Giant Radio pulses of the Crab already at the GRANDProto300 stage

GRAND Technical Challenges

Autonomous trigger on radio signals

- TREND: ~32% offline identification efficiency
- Noise = ultra-dominant: rejection $1/10^8$
- Identification of signals at various trigger levels, methods to be developed *e.g., Chiche et al. submitted*
- Optimization of data collection

Reconstruction of primary particle parameters

- good performances for vertical air-showers
- no-man's land for inclined air-showers

Develop new "conventional" and machine learning methods

How to deploy/run 200k units over 200k km^2?
How much will it cost? Who will pay for it?

Need for an experimental setup to test and optimize

GRAND Proto300

Industrial approach!
low failure rates
deployment ~ electric poles

A staged approach with self-standing pathfinders

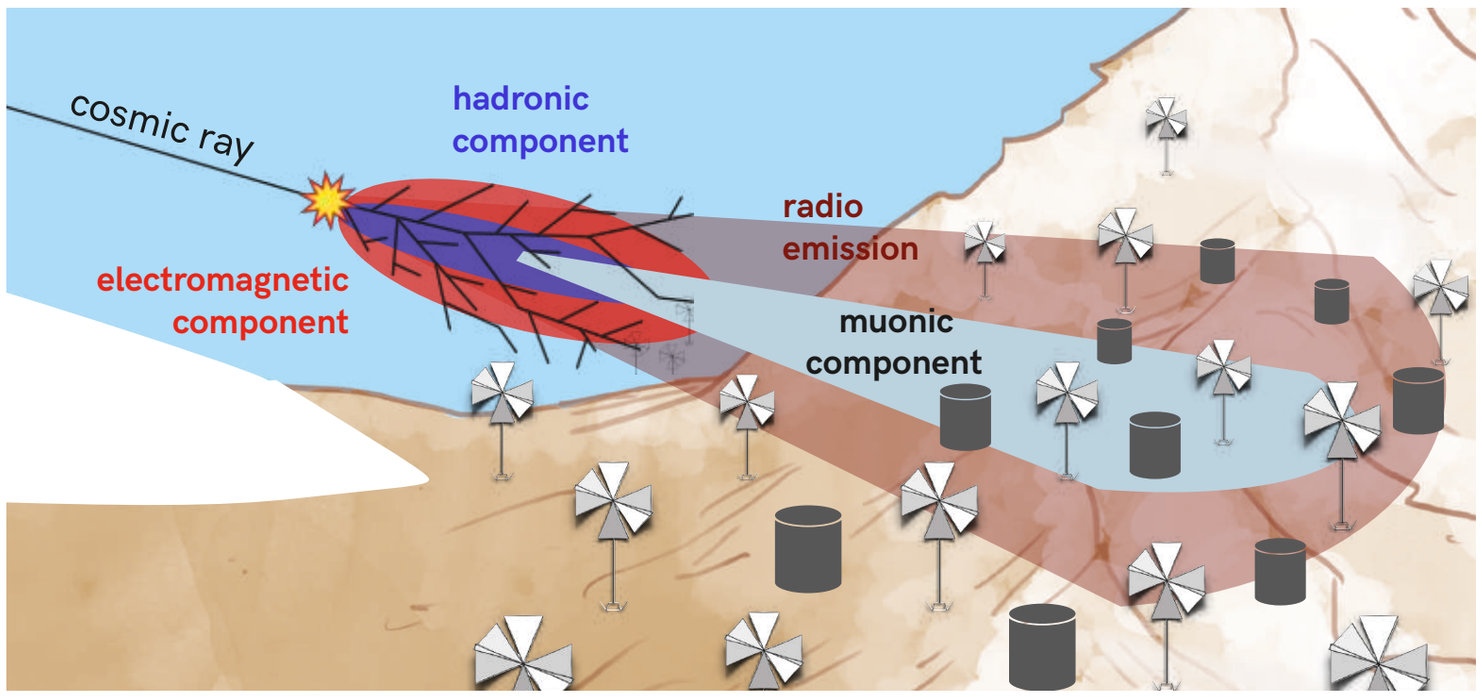
	GRANDProto300	GRAND10k	GRAND200k
	2021	2025	203X
Goals	**autonomous** radio detection of **very inclined** air-showers **cosmic rays $10^{16.5\text{-}18}$ eV** • Galactic/extragalactic transition • muon problem • radio transients	**1st GRAND sub-array** • **discovery of EeV neutrinos** for optimistic fluxes • radio transients (FRBs!)	sensitive **all-sky** detector **1st EeV neutrino detection and/or neutrino astronomy!**
Setup	• 300 HorizonAntennas over 200 km^2 • Particle detectors (a la HAWC/Auger) • Qinhai Province, China	• 10,000 radio antennas over 10,000 km^2 • in China	• 200,000 antennas over 200,000 km^2 • 20 sub-arrays of 10k antennas • on different continents
Budget	**2 M€** 100 antennas already paid (China)	**13 M€** 1500€/unit confident for large contribution from China	**300M€** in total 500€/unit to be divided between participating countries

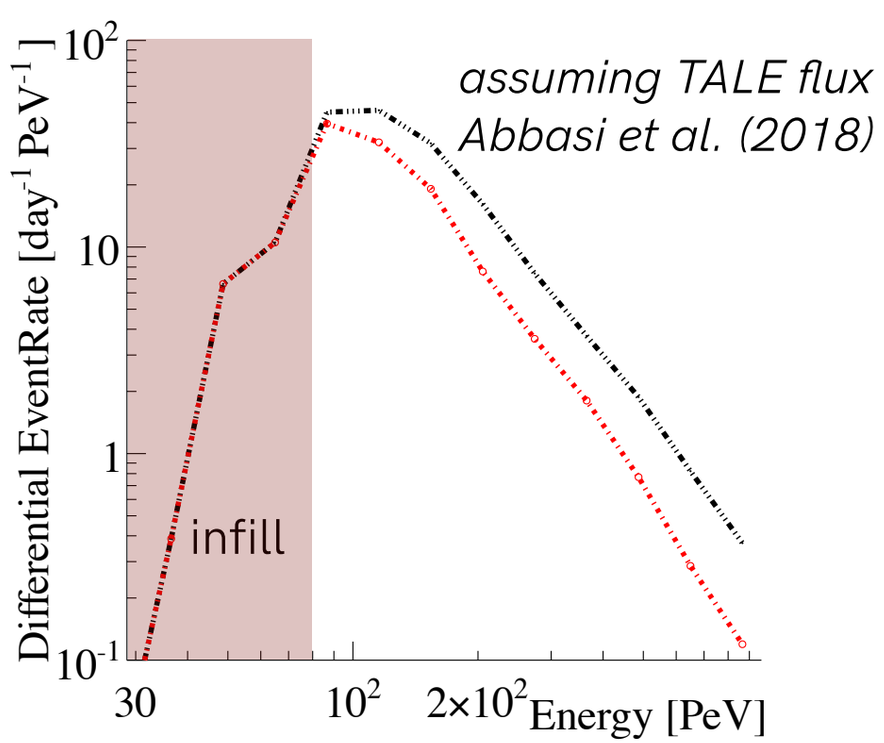
GRANDProto300: a self-standing pathfinder

Autonomous detection of **very inclined cosmic rays** $E = 10^{16.5}$-10^{18} eV
reconstructing spectrum, arrival direction & composition
validation via comparison to known results
test bench for further GRAND stages

Proficient physics instrument if complemented by **particle detector array**
Galactic/extragalactic transition
hadronic physics (muon content in EAS)
UHE gamma-rays
Fast Radio Bursts

+ to check radio calibration at 30-200 MHz, pulse-shape analyses, Cherenkov-cone analyses



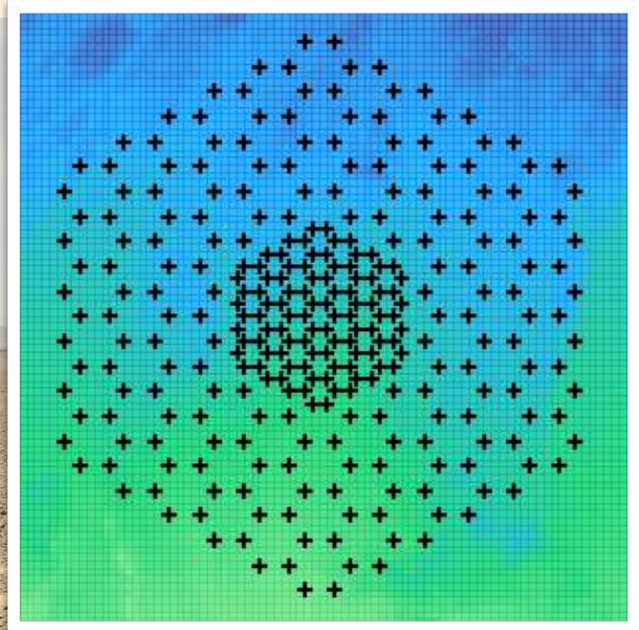


GRANDProto300: experimental setup

HorizonAntenna, successfully tested in the field (Aug., Dec. 2018)

Antenna set-up: antenna simulations, nut design, unit design. Production phase.

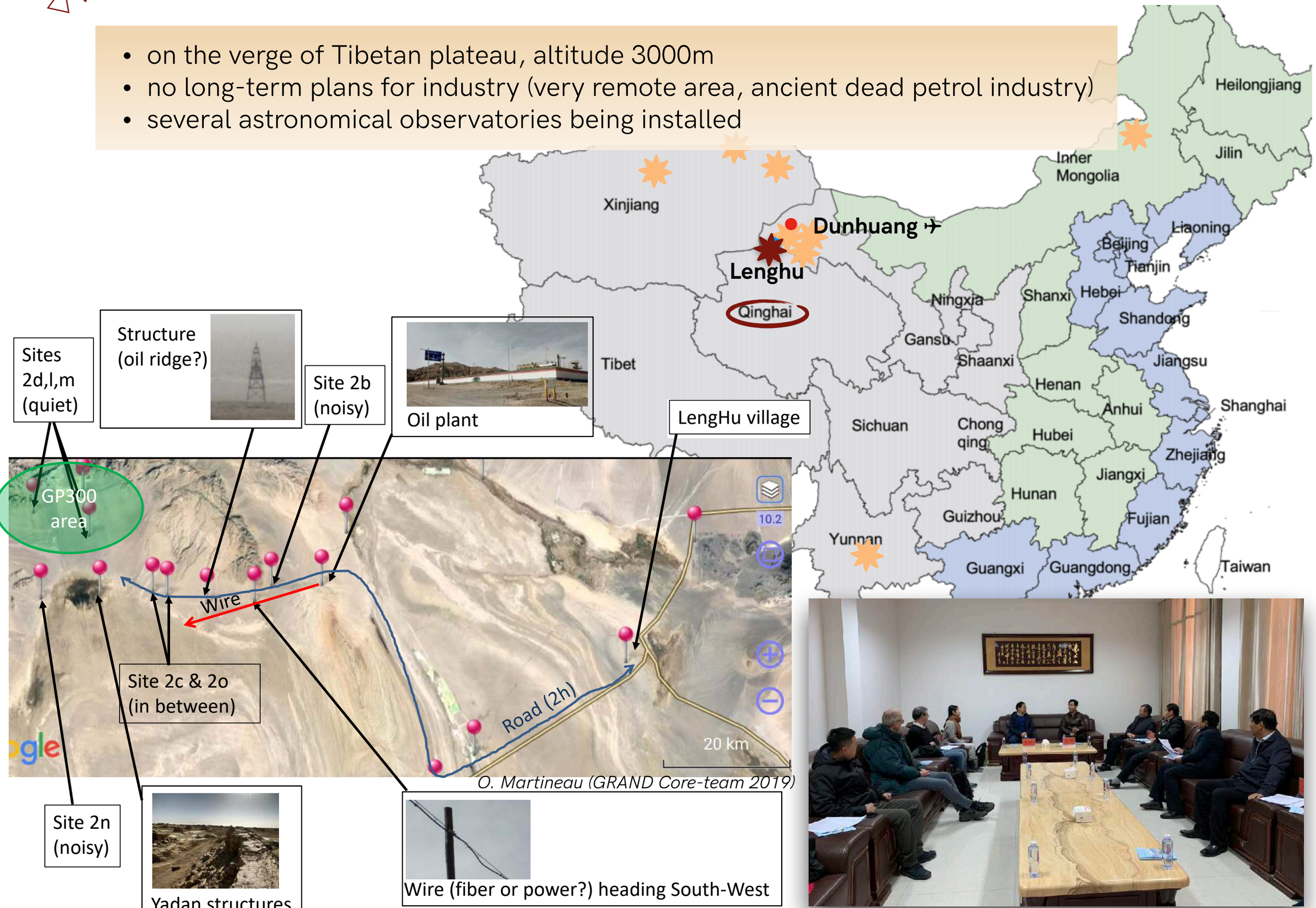
Layout: 300 antennas, 200km^2, 1km step size with denser infill
Erange = $10^{16.5}$-10^{18}eV



Electronics: 50-200MHz analog filtering, 500MSPS sampling FPGA+CPU Bullet WiFi data transfert

GRANDProto300 site

- on the verge of Tibetan plateau, altitude 3000m
- no long-term plans for industry (very remote area, ancient dead petrol industry)
- several astronomical observatories being installed

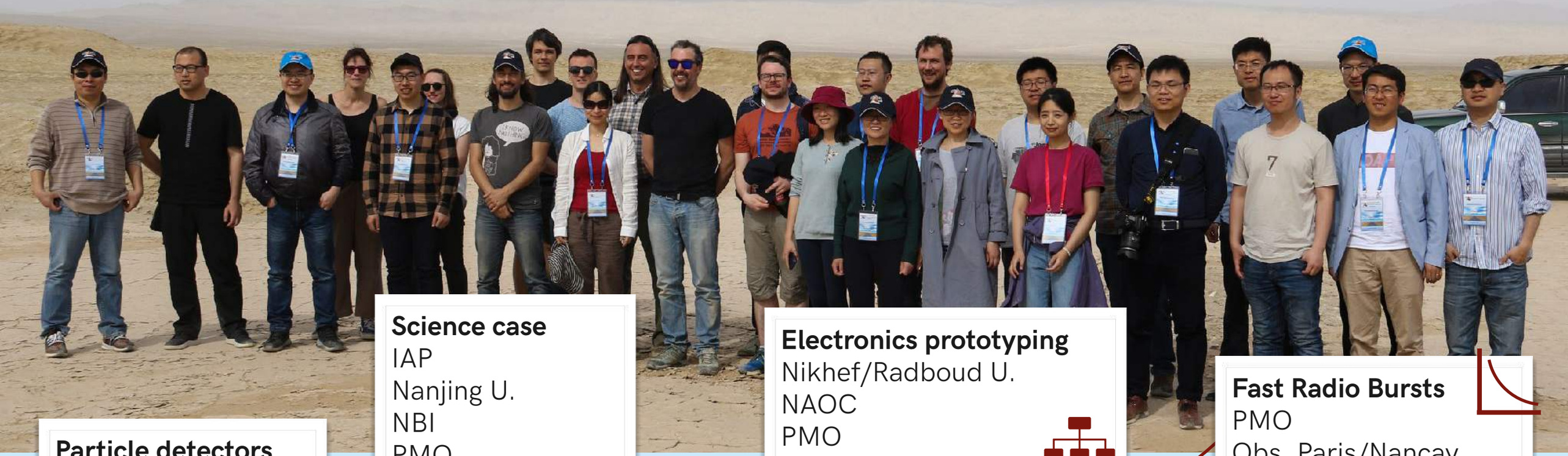


O. Martineau (GRAND Core-team 2019)

GRAND Today

~80 collaborators from 11 countries

GRAND Workshop, Dunhuang, April 2019



Science case
IAP
Nanjing U.
NBI
PMO
Penn State U

Particle detectors
Penn State U.

Electronics prototyping
Nikhef/Radboud U.
NAOC
PMO

Fast Radio Bursts
PMO
Obs. Paris/Nançay

Site management
PMO
NAOC

Simulations/data analysis
IAP
KIT
LPNHE
Nanjing U.
PMO
UF Rio de Janeiro
VU Brussels

Software
Warsaw U.
IAP/LPNHE
LPC Clermont
UF Rio Janeiro

Antenna prototyping
Nikhef/Radboud U.
Xidian U.

Unit production
NAOC
PMO
Xidian U.

GRAND in the international community

APPEC strategy book (2017-2026):

"APPEC strongly supports the Auger collaboration's instalment of AugerPrime by 2019. At the same time APPEC ***urges the community to continue R&D on alternative technologies that are cost-effective and provide a 100% (day and night) duty cycle*** *so that, ultimately, the full sky can be observed using very large observatories."*

Valid for GRAND & GCOS

GRAND appears in several roadmaps

- Mid-term review of the **APPEC** strategy
- Physics briefing book: Input for the **European Strategy for Particle Physics** Update 2020, section 7.3
  http://cds.cern.ch/record/2691414
- **Nikhef** strategic plan 2017-2022 and beyond, p. 43
  https://www.nikhef.nl/strategisch-plan/
- **CNRS** Prospective INSU Astronomie & Astrophysique 2020-2025, p. 34
  https://www.insu.cnrs.fr/sites/institut_insu/files/news/2021-04/Prospective_INSU_AA_2019.pdf
- **Latin American** Strategy for Research Infrastructures for High Energy, Cosmology, Astroparticle Physics LASF4RI for HECAP https://arxiv.org/pdf/2104.06852.pdf
- White Paper in the **Decadal Survey** 2020

Environmental responsibility

GRAND evaluates its environmental impact

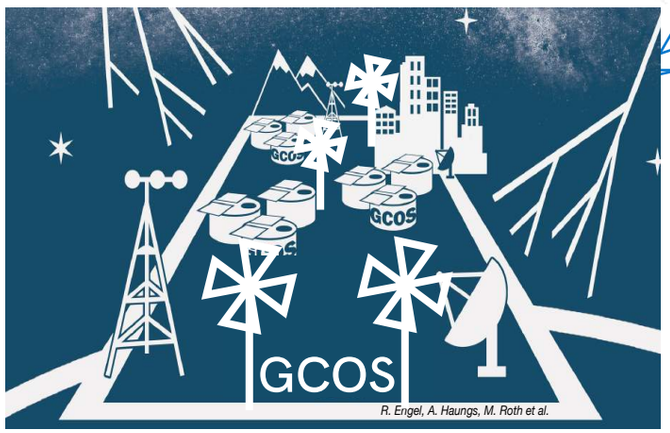
One R&D goal: reduce the environmental impact of the detector

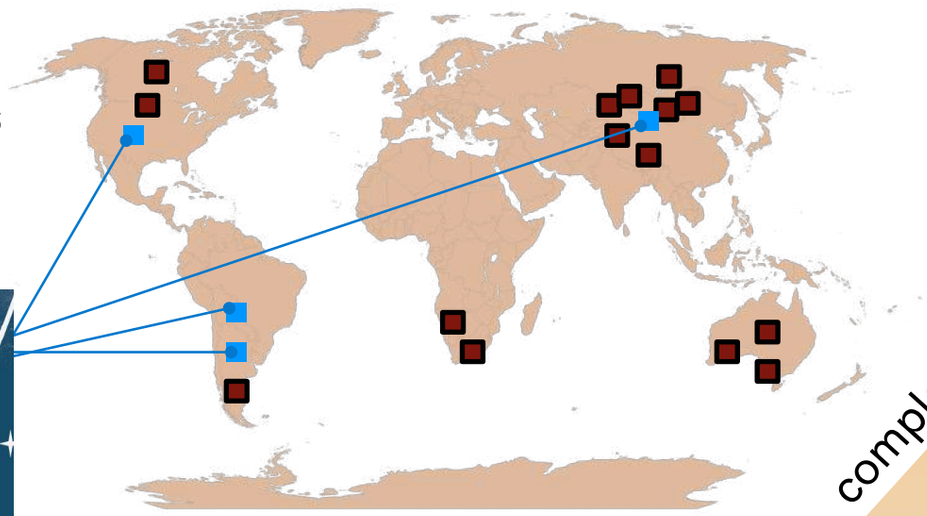
GRAND Carbon Footprint Study
arXiv:2101.02049

GCOS & GRAND: synergies

	GCOS	GRAND
size	> 40,000 km²	20 x 10,000 km²
UHECR sensitivity	> 10 x Auger, TA	(20-80) x Auger
composition	better than Auger	<40 g/cm² (goal: at least 20 g/cm²)
FOV	all-sky coverage	all-sky coverage
science case	**UHECR composition** multi-messengers	**UHE neutrino astronomy** multi-messengers radio-transients

GCOS-GRAND arrays
combining several technologies
for UHECR composition
+ multi-messengers





complementary test benches

TA/TAx4

Auger Prime
hybrid array
(radio + scintillators
+ tanks)

GRANDProto300:
a **hybrid prototype**
(**autonom. radio + particles**)
to be deployed from 2021

Why move forward together?

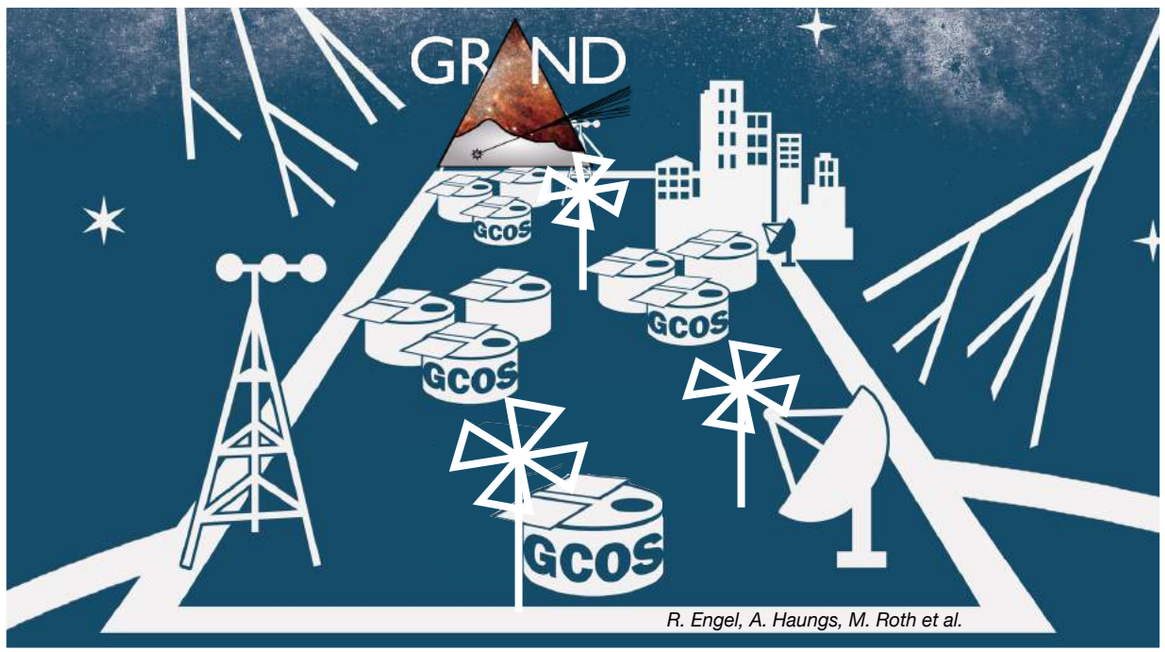
Similarities

- interested in the same particles at the same energies
- both are giant ground arrays
- same community

Practical advantages

by working together, we can put in common:

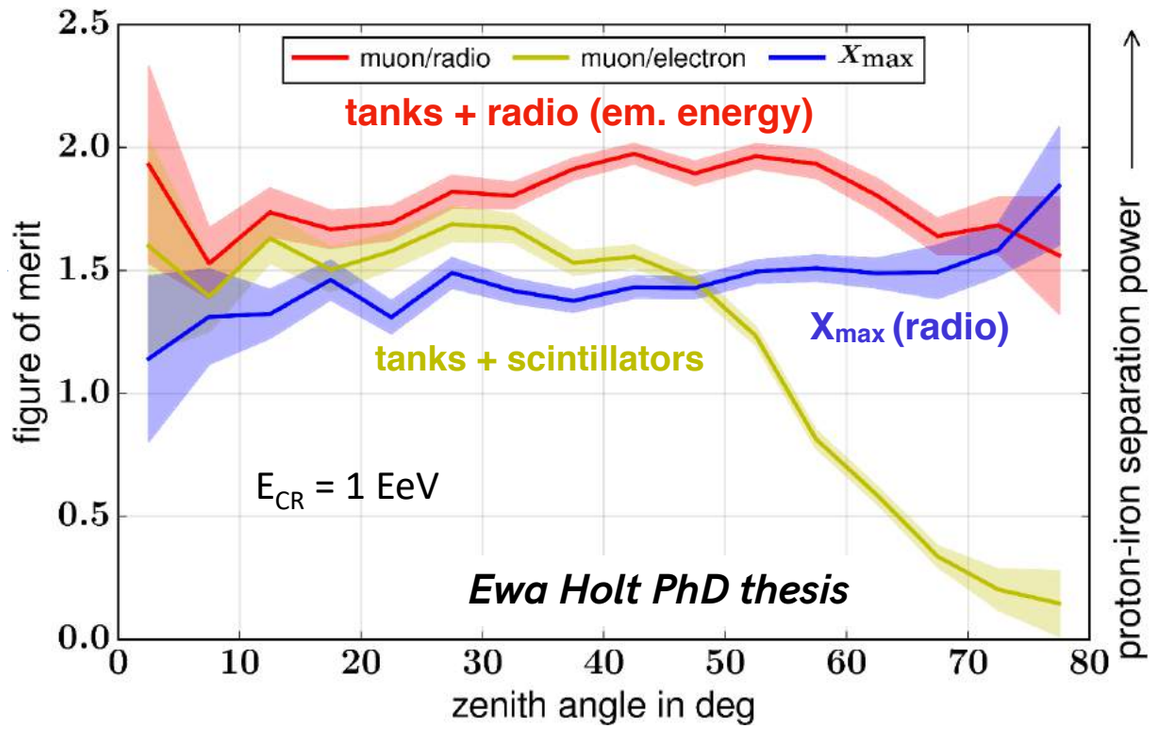
- funding
- infrastructure
- people
- if we compete, high risk of having none of the experiments funded



Enhanced Science Case for all!

Self-triggering radio + **particles**
for **inclined air-showers** offer:

- UHECR mass composition
- gamma-ray veto
- multi-messenger astronomy:
  electromagnetic measurements (radio)
  enable clean energy reconstruction
  + angular resolution
- cross-calibration



References:

Website:
http://grand.cnrs.fr

GRAND White Paper
https://arxiv.org/abs/1810.09994

Github
https://github.com/grand-mother/

GRAND Carbon Footprint Study
https://arxiv.org/abs/2101.02049

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