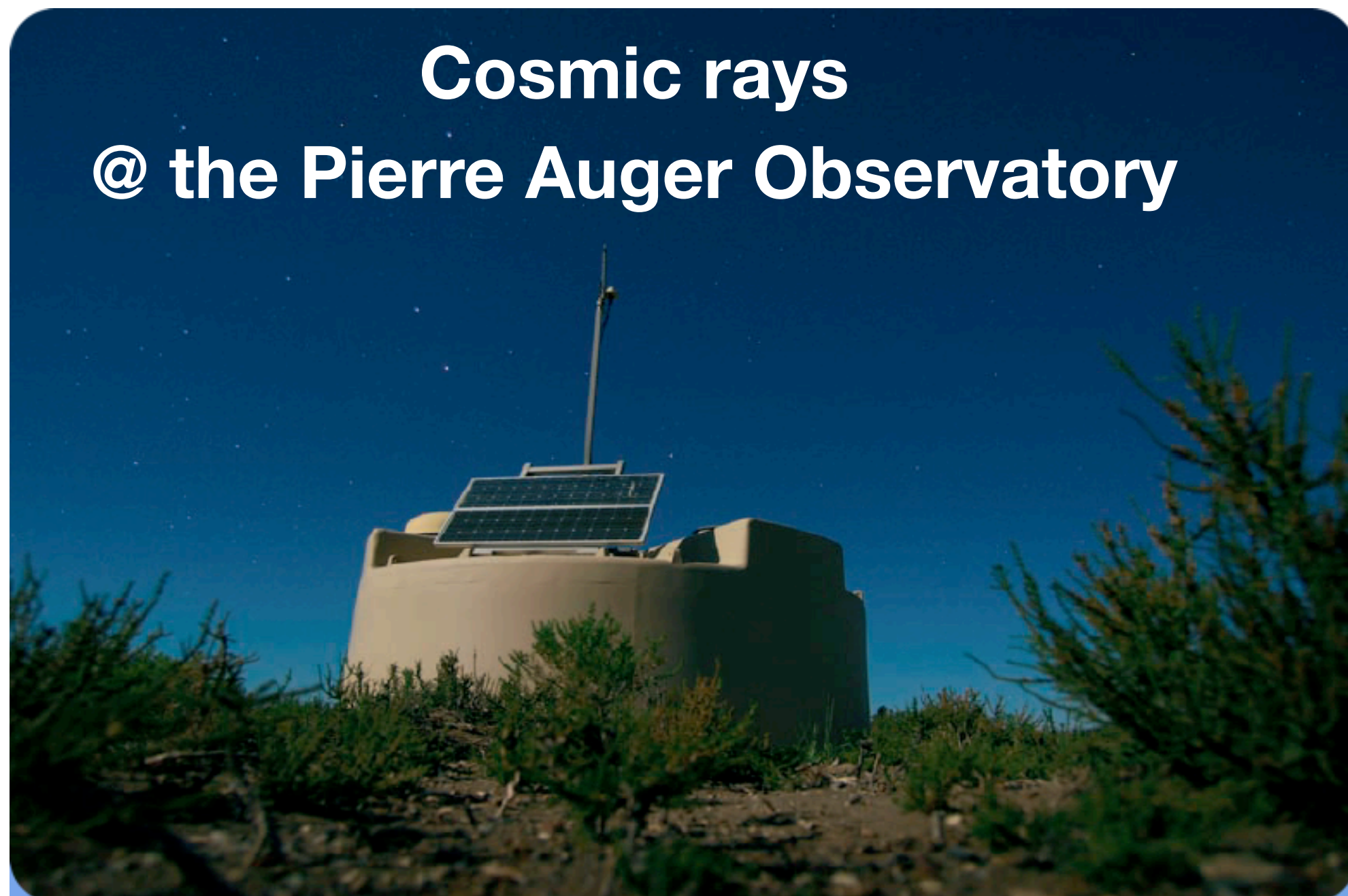


Cosmic Rays & Neutrinos

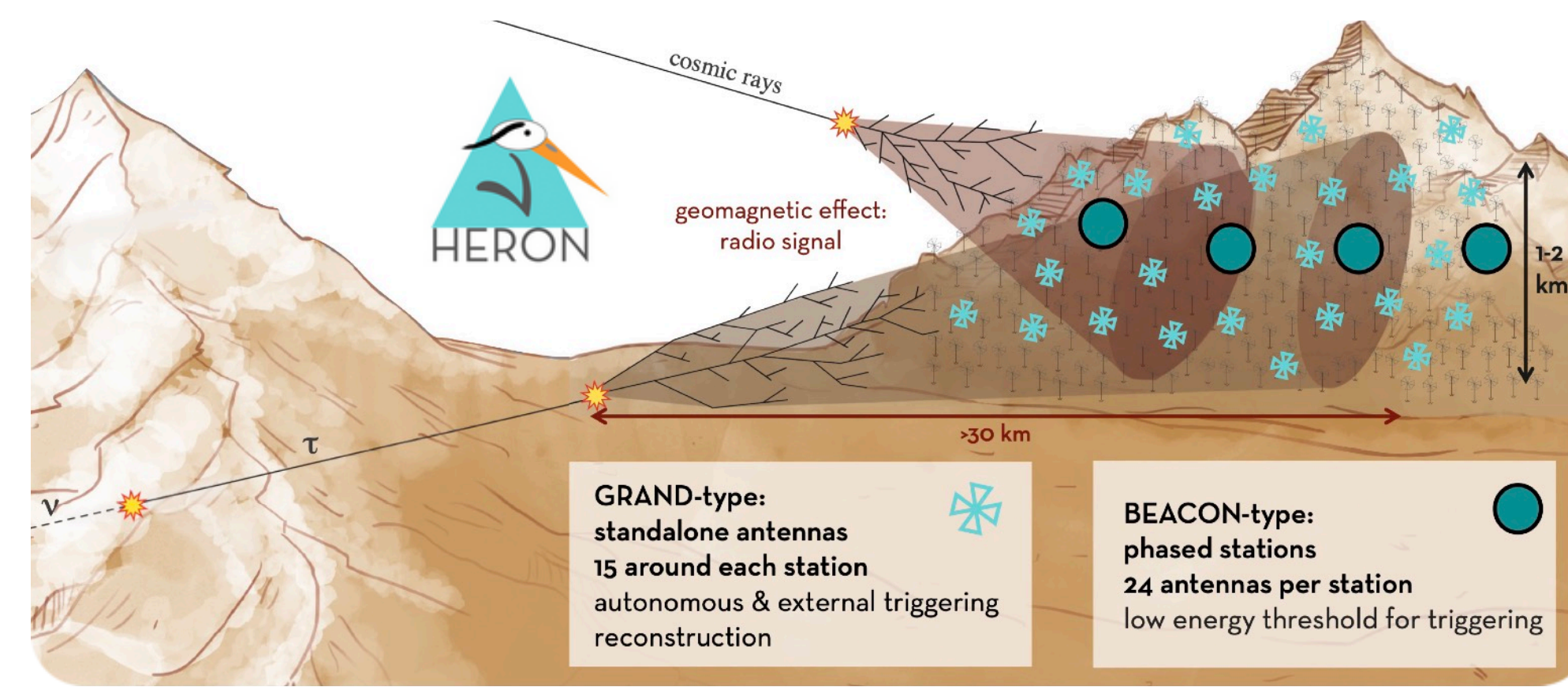
@ CLAF–CNRS Latin-American Astroparticle Physics IRN

Piera L. Ghia & Claire Guépin

Cosmic rays @ the Pierre Auger Observatory



Cosmic rays & Neutrinos @ GRAND & HERON



Cosmic rays @ Auger: long-standing Franco-Latin American collaborations

Collaboration with Argentina and Brazil since the Observatory's inception

Common interests on the surface detectors



Common work on a wide range of aspects

- **Arrival direction studies:** large-scale and intermediate-scale anisotropy
- **Multi-messenger studies:** correlations CR-neutrinos (IceCube; Antares) and Open Data
- Measurement of the **energy spectrum**
- **Detector:** calibration, monitoring, trigger

Involved groups (over a time span of 25 years):

France: College de France/APC; IPNO/IJCLAB; LPNHE, LPSC

Argentina: Centro Atomico Bariloche (CAB); UN La Plata; ITEDA; Observatorio Malargüe

Brazil: CBPF; U. Rio de Janeiro, Centro Federal de Educação Tecnológica (CFET)

NB. Franco-Argentine exchanges enabled within the LIA ALFA-AC (2017–2023)

Arrival direction studies: search for large- and small-scale anisotropy

Collaboration with Argentina and Brazil since the Observatory's dawn

Common work (over time)

- Characterisation of the **atmosphere "foreground"** in preparation of the search for LS anisotropy (College de France/APC, IPNO, LPNHE, CAB)
- **Large-scale anisotropy:**
 - Harmonic analysis in right ascension (LPNHE, IPNO, CAB);
 - Power-spectrum analysis (LPNHE, IPNO, CBPF, U. Rio de Janeiro);
 - Anisotropy characterisation in terms of mass composition (IJCLab, U. Rio de Janeiro, CFET)
- **Small/intermediate-scale anisotropy:**
 - Blind search and correlation with astrophysical catalogues (IPNO/IJCLab, LPNHE, CAB)
 - Search for multiplets (IPNO, LPNHE, CAB)

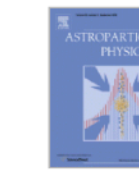
Examples of "success stories"



Atmospheric effects on extensive air showers observed with the surface detector of the Pierre Auger observatory

The Pierre Auger Collaboration, J. Abraham^a, P. Abreu^{bj}, M. Aglietta^{au}, C. Aguirre^k, E.J. Ahn^{by}, D. Allard^{ab bb}, I. Allekotte^a, J. Allen^{cb}, P. Allison^{cd}, J. Alvarez-Muñiz^{bq}, M. Ambrosio^{ar}, L. Anchordoqui^{cn}, S. Andringa^{bj}, A. Anzalone^{av}, C. Aramo^{ar}, E. Arganda^{bn}, S. Argirò^{au}, K. Arisaka^{cg}, F. Arneodo^{ax}, M. Ziolkowski^{am}

2 journal papers crucial for all analyses of surface detector data



Journal of Instrumentation

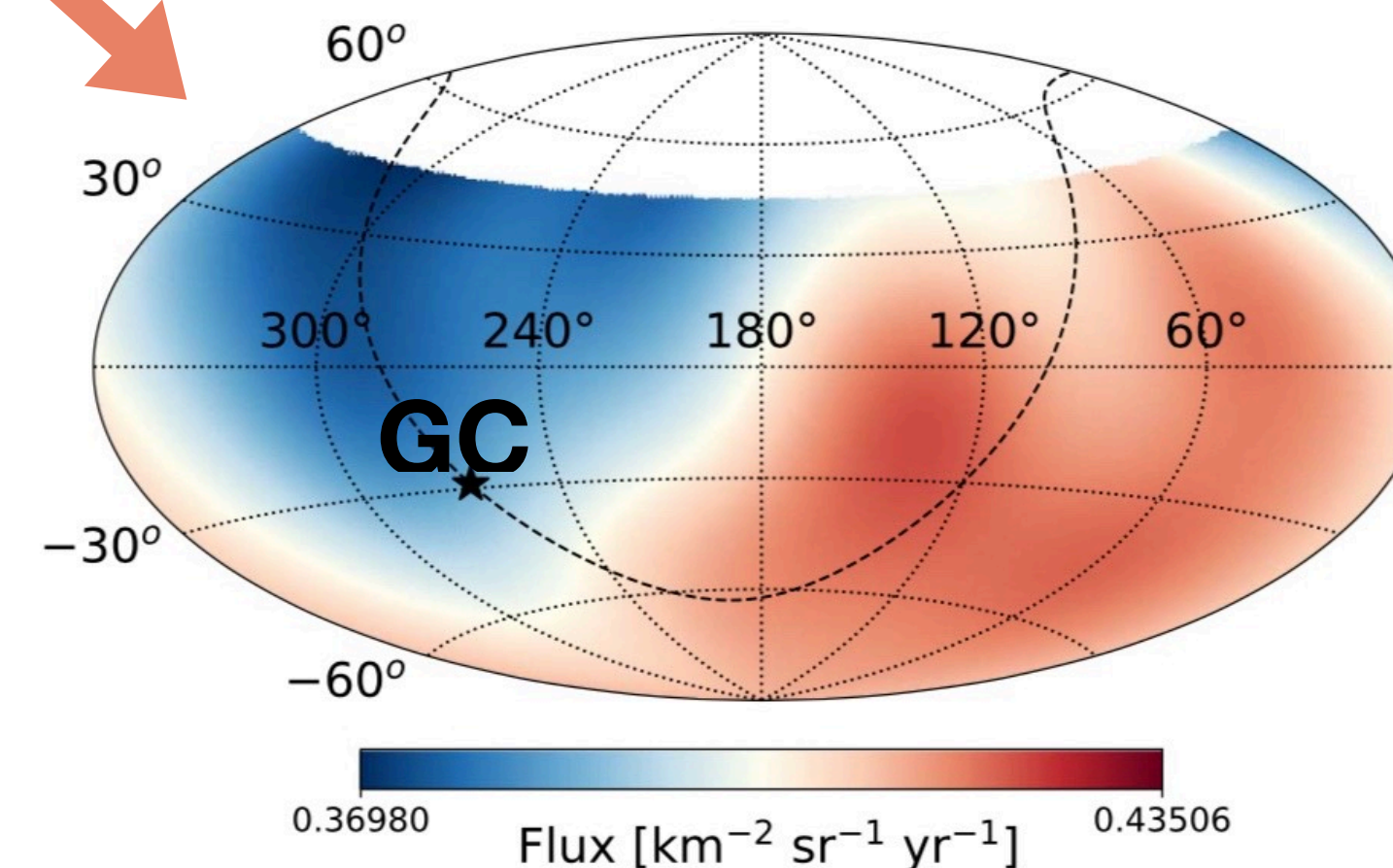
Impact of atmospheric effects on the energy reconstruction of air showers observed by the surface detectors of the Pierre Auger Observatory

A. Aab, P. Abreu, M. Aglietta, I. Al Samarai, I.F.M. Albuquerque, I. Allekotte, A. Almela, J. Alvarez Castillo, J. Alvarez-Muñiz, G.A. Anastasi [Show full author list](#)

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[Journal of Instrumentation](#), Volume 12, February 2017

Citation A. Aab et al 2017 *JINST* 12 P02006



Science 2017
Discovery of a dipolar anisotropy
Extragalactic origin

Multi-messenger studies and Open Data

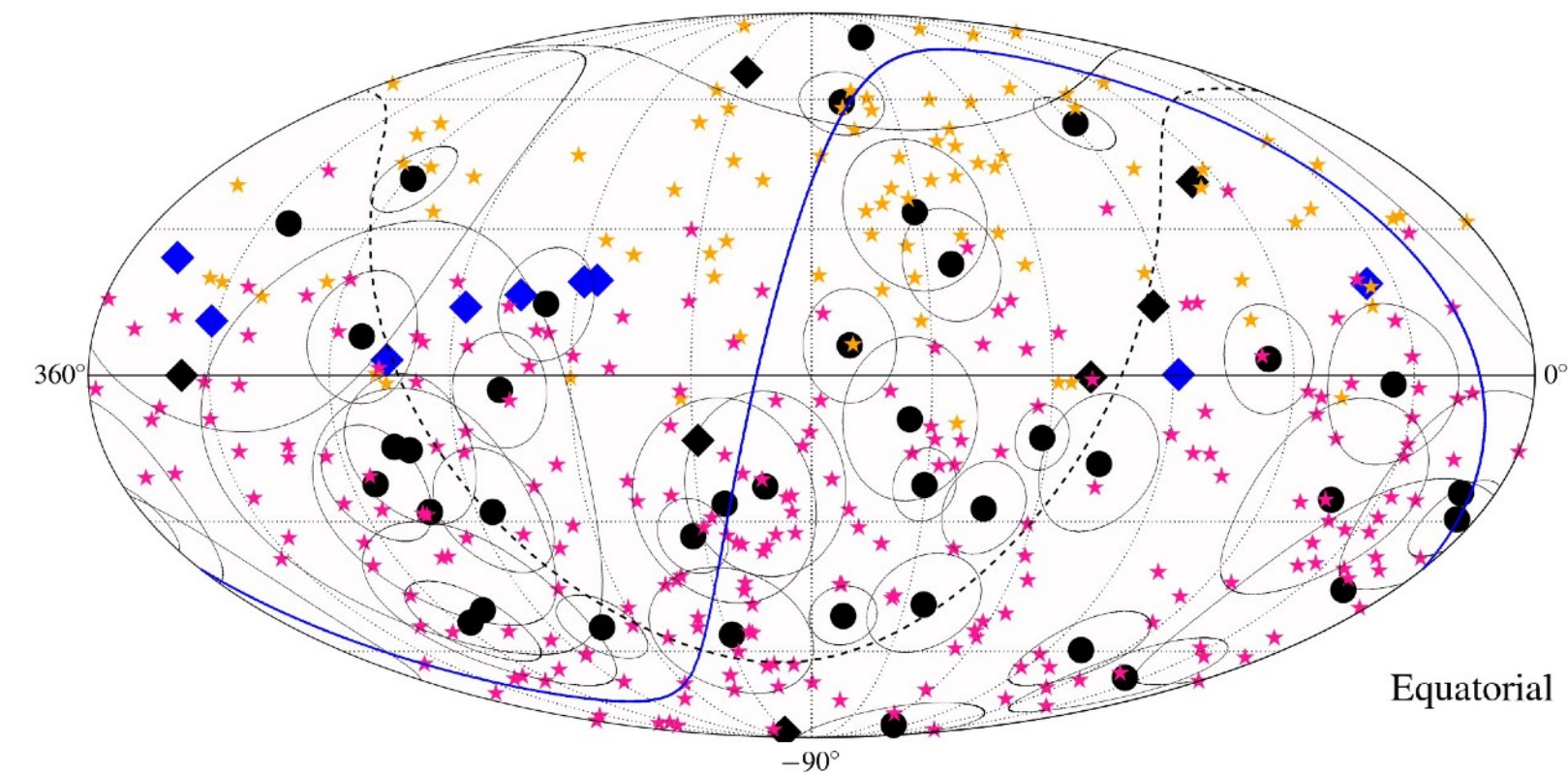
Collaboration with Argentina since mid 2010s

Common work (over time)

- Participation in the inter-experiment working group (Auger, IceCube, Telescope Array: 2014–2016; Antares, Auger, IceCube, Telescope Array: 2017–) to **search for full-sky space-correlations between the highest-energy cosmic rays and astrophysical neutrinos** (LPNHE, IPNO, CAB)
- Realisation of the **public release of Auger data** (10%): creation of a portal, including not only data (raw and processed), but also a visualisation tool, documentation, and analysis codes (IJCLab, CAB)
- Participation in the inter-experiment working-group (Auger and IceCube) to search for ultra-high-energy transients by combining multi-flavour neutrino data from IceCube with photon candidates from Auger (IJCLab, CAB)

Examples of “success-stories”

JCAP 2016



First sky-map of UHECRs (Auger & TA) and neutrinos (IceCube)

auger.org/opendata

Pierre Auger Observatory Open Data

Following the [Auger Collaboration Open Data Policy](#), the Pierre Auger Open Data is the public release of 10% of the Pierre Auger Observatory cosmic-ray data published in recent scientific papers and at international conferences. The release also includes 100% of weather and space-weather data collected until 31 December 2020. This website hosts the datasets for download. Brief overviews of the Pierre Auger Observatory and of the Auger Open Data are set out below. An online event display to explore the released cosmic-ray events and example analysis codes are provided. An outreach section dedicated to the general public is also available.

All Auger Open Data have a DOI that you are required to cite in any applications or publications. These files are part of the main dataset whose DOI is [10.5281/zenodo.4487812](https://doi.org/10.5281/zenodo.4487812) and always points to the current version.

- Datasets**: the released datasets and their complementary data
- Visualize**: an online look at the released pseudo raw cosmic-ray data
- Analyze**: example analysis codes in online python notebooks to run on the datasets
- Catalog**: of the highest-energy cosmic rays
- Outreach**: a page dedicated to the general public

Data accessible for MM studies:
10% of data public since 2021
30% in 2026 !

Energy spectrum and detector

Collaborations with Argentina and Brazil

Energy spectrum

Collaboration with ITEDA since \approx 2010
[started with a Bolivian student @ LPNHE]:

- Measurement of the **energy spectrum** above 10^{17} eV with **SD-750 data** and combination with the spectrum measured with SD-1500 data (IPNO, LPNHE, ITEDA).
- Observation of the “second knee” in the energy spectrum with SD-433 data and combination of the spectra from all three arrays (IJCLab, ITEDA)
- Study of the highest-energy events from Auger and Telescope Array to test the differences between the energy spectra (IJCLab, ITEDA)

Detector

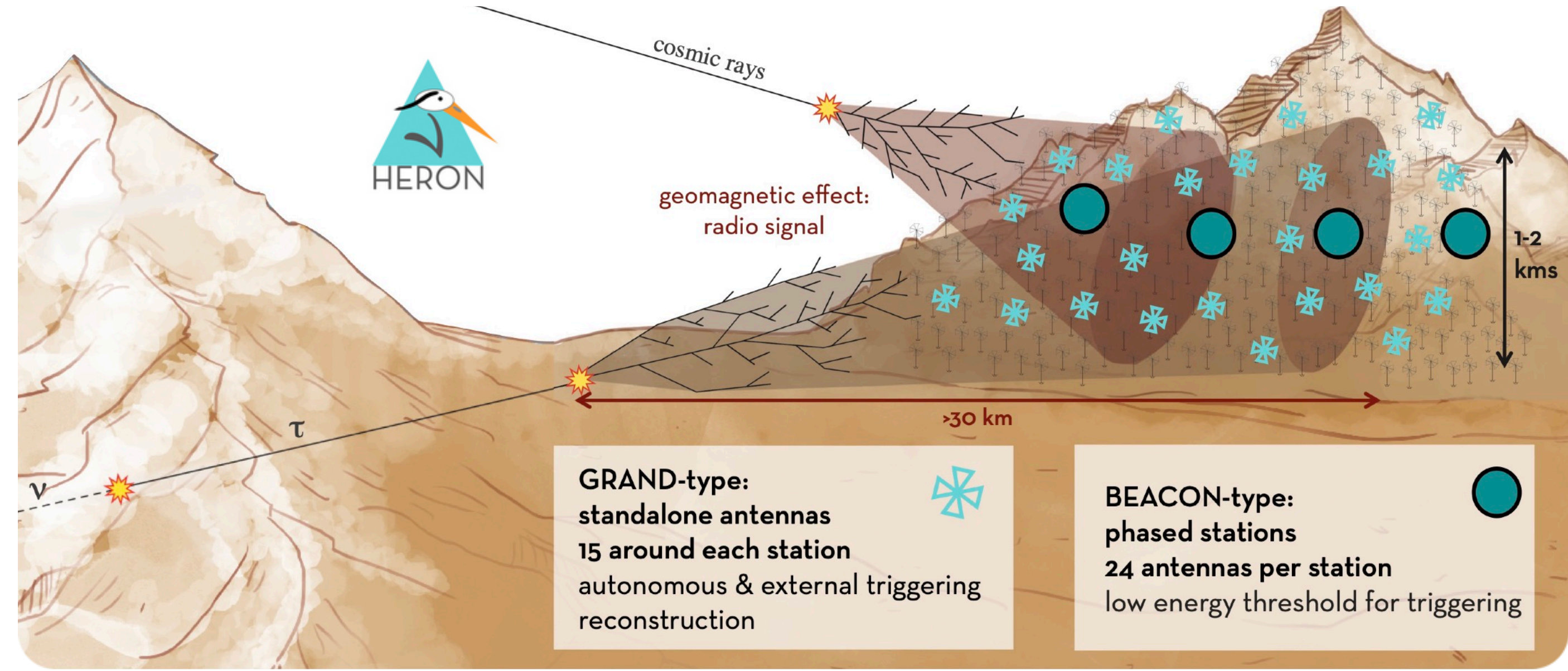
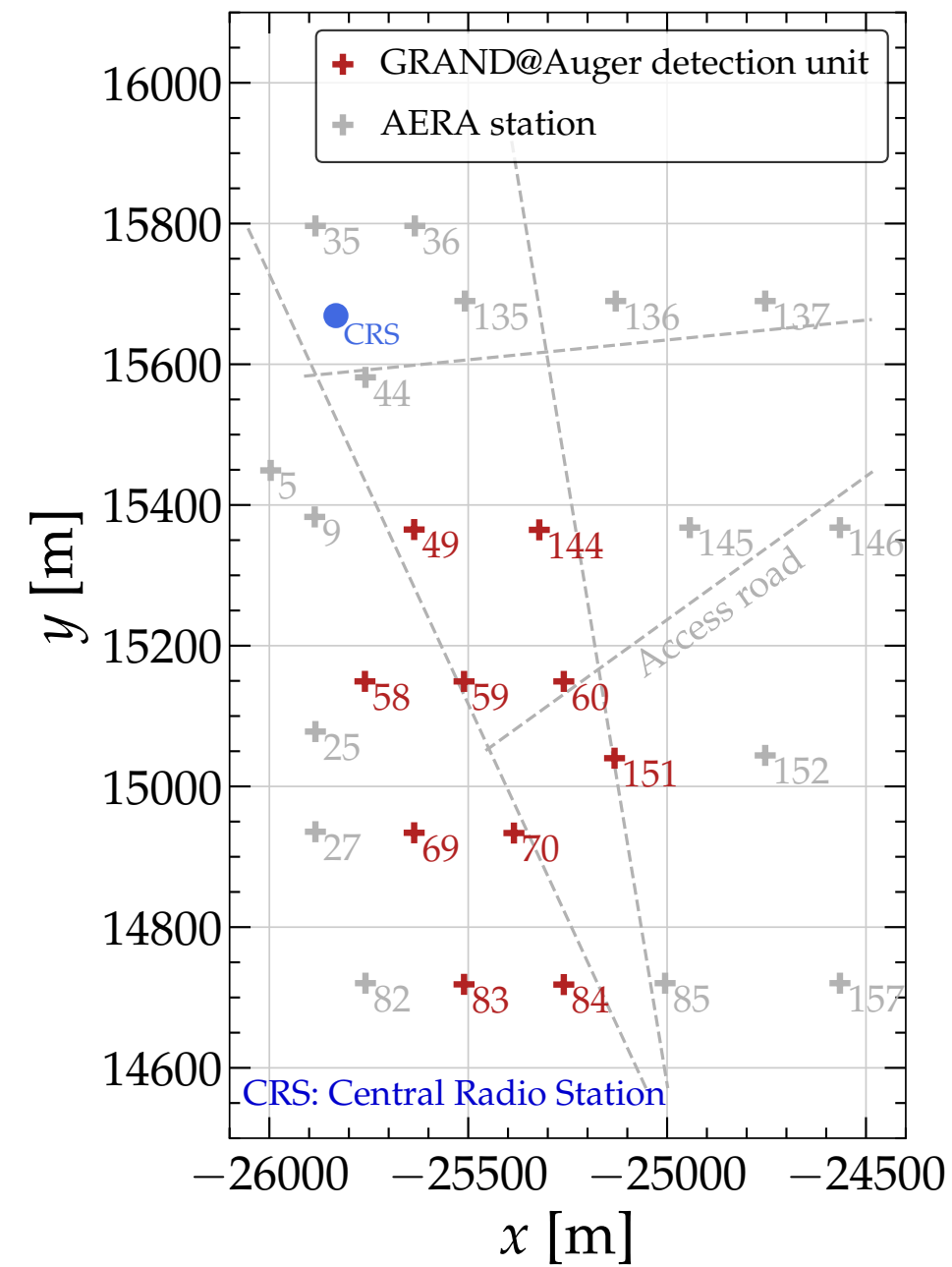
Collaboration with Argentina (from Observatory's dawn) **and Brazil:**

- **Calibration** (IPNO, ITEDA, CAB, Observatorio)
- **Monitoring:**
 - Long-term monitoring (IPNO, LPSC, La Plata)
 - Monitoring and SD shifts (APC, CBPF, ITEDA)
- **Trigger and new electronics:**
 - Development of triggers for electromagnetic signals (LPNHE, Observatorio)
 - New electronics development (IJCLab, LPSC, CAB)
 - Development of a trigger for Terrestrial Gamma-ray Flashes (IJCLab, Observatorio)
 - Trigger revision to make room for new ones in the new electronics (IJCLab, Observatorio)

Benefits of the LIA ALFA-AC. An ITEDA researcher visited IJCLab: transfer of expertise from SD-750 to SD-433 data analysis. An Observatorio researcher visited IJCLab: onset of the idea to revise triggers

Cosmic rays and Neutrinos: collaborations Auger, GRAND and HERON

Collaboration with Argentina and Brazil



Involved groups:

France: IAP; LPNHE; Subatech; Lagrange; LUPM

Argentina: Centro Atomico Bariloche (CAB); ITEDA; UN San Juan; UN La Plata

Brazil: U Federal do Rio de Janeiro (UFRJ); Centro Federal de Educação Tecnológica (CEFET)

Agreements and projects:

GRAND: International Agreement between several institutes for GRAND@Auger (since 2022)

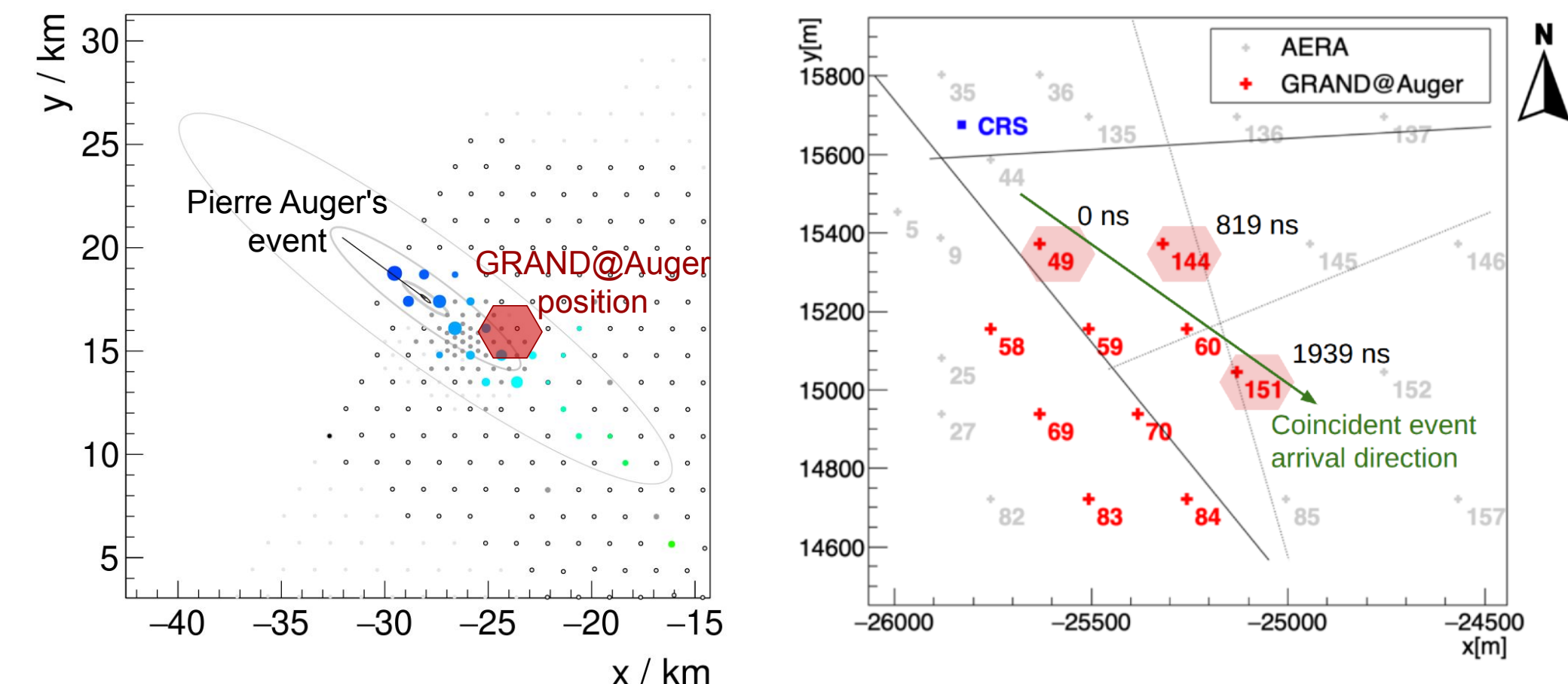
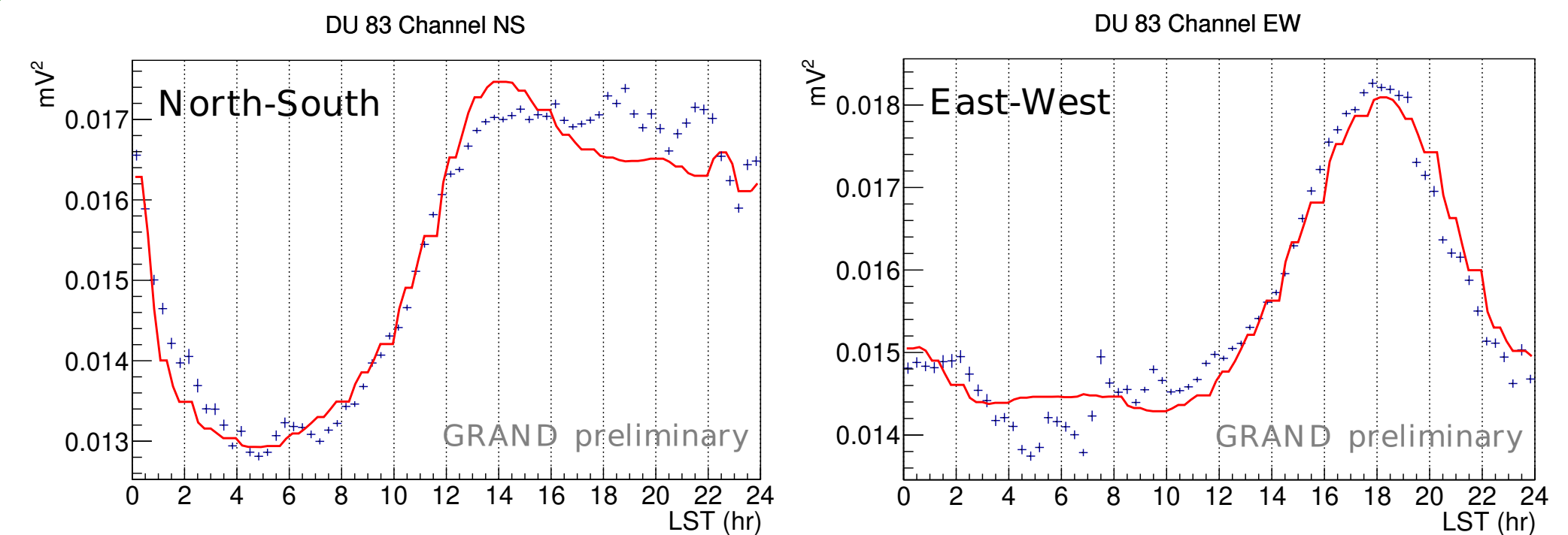
HERON: prototype funded by an ERC synergy (starting soon, 6 years)

J. Alvarez Muñiz (USC, Spain), K. Kotera (IAP, France), O. Martineau (LPNHE, France), S. Wissel (PSU, USA) + I. Allekotte (CAB, Argentine), F. Sanchez (ITEDA, Argentine)

GRAND (Giant Radio Array for Neutrino Detection): prototypes

Commissioning for GRAND

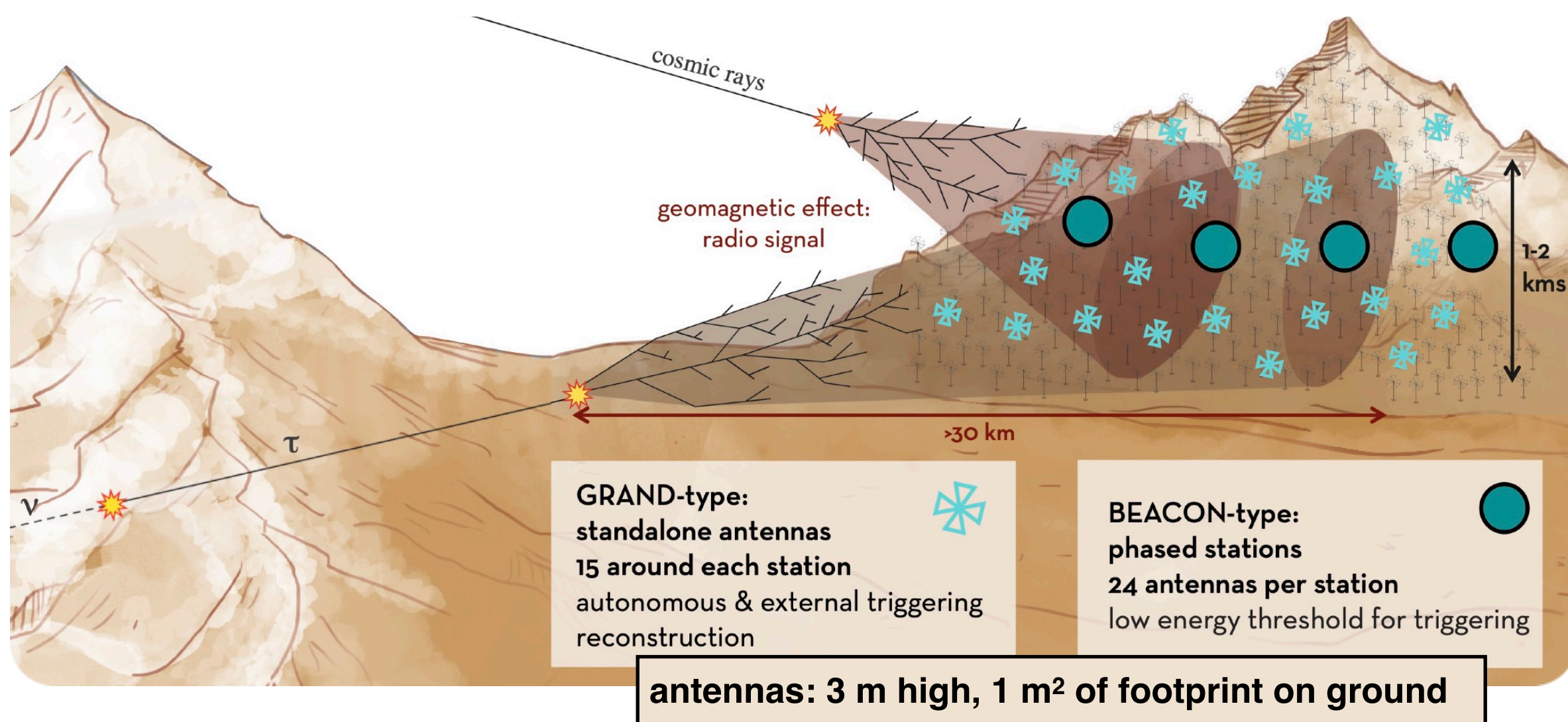
- GRAND@Auger and GRANDProto300 prototypes: testing GRAND setup for cosmic-ray detection
- Software: simulations banks with ZHAireS, dev GRANDlib (UN La Plata, IAP, LPNHE, LUPM)
- Analysis: methods for reconstruction of electric field, arrival directions, energy & composition (CEFET, UFRJ, UN La Plata, IAP, LPNHE, Subatech, Lagrange, LUPM)
- GRAND@Auger: deployment using AERA existing infrastructures; testing stability and **background measurements** (UFRJ, UN La Plata, LPNHE, IAP)
- On-going: identification of cosmic-ray candidates, **coincidence events**, reconstruction, cosmic-ray spectrum (10 PeV - 1 EeV) (IAP, LPNHE, UFRJ)
- Future goals (30's): GRAND10k deployment, refinement analysis methods for neutrino detection



HERON (Hybrid Elevated Radio Observatory for Neutrinos)

Hybrid detection principle

- The future of radio detection of UHE astroparticles, with innovative detection techniques
- Combining BEACON & GRAND detection techniques, R&D for external trigger plugged on GRAND systems
- Configuration envisioned:
 - **24 phased stations**, 70km linear along mountain, altitude 1000m, 3km between stations
 - **360 standalone antennas**, altitudes between 500m and 1500m



Work plan

- Expected: ~ 100 people involved short term
- deployment, commissioning & calibration (ITEDA, CAB, UN La Plata, UN San Juan, IAP, LPNHE), electronics & mechanics (LPNHE, ITEDA)
- trigger algorithms (LPNHE), reconstruction methods (UN La Plata, IAP, LPNHE, Subatech, Lagrange), alert systems & multi-messenger pipelines (IAP, LUPM)

