Astroparticle physics

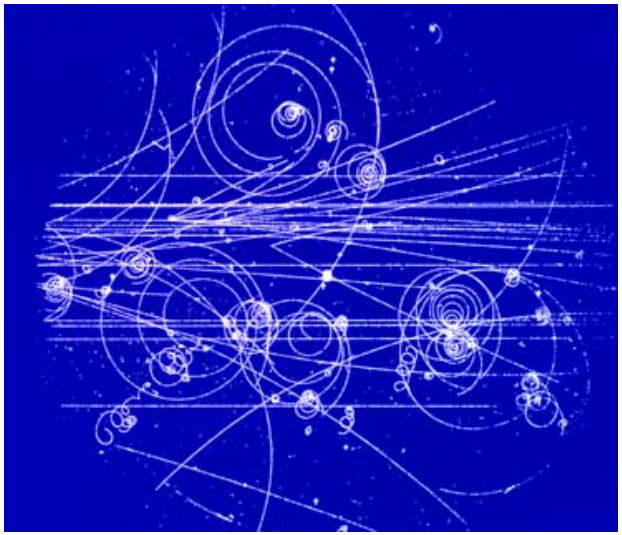
Ruben Conceição

TÉCNICO LISBOA

LIP summer internship workshop, Lisboa, July 18th 2019

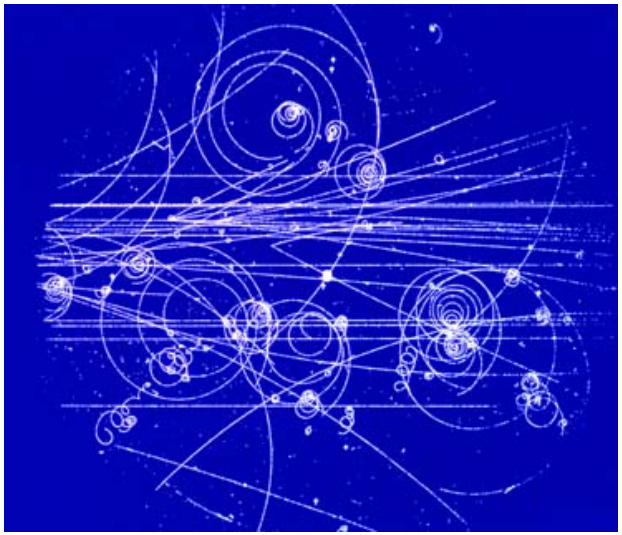
What is Astroparticle physics?

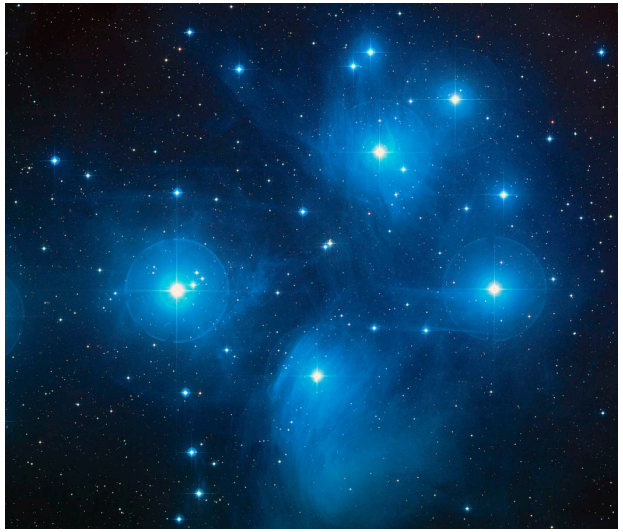
What is Astroparticle physics?



- Particle Physics
  - Study the properties of matter and interactions

What is Astroparticle physics?





- Particle Physics
  - Study the properties of matter and interactions
- Astrophysics / Cosmology
  - Study Universe's evolution and surrounding astrophysical objects

Astroparticle physics

Particle phyiscs

Astrophysics

Cosmology

Understand the dynamics of our Universe through the radiation/particles collected at Earth

Messengers from the Universe

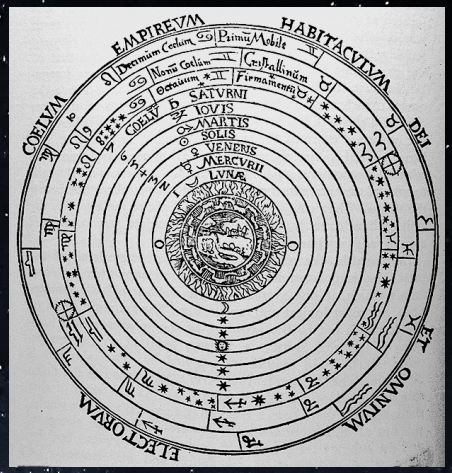
Photons

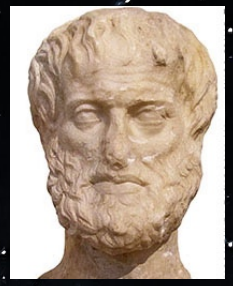
(visible light)

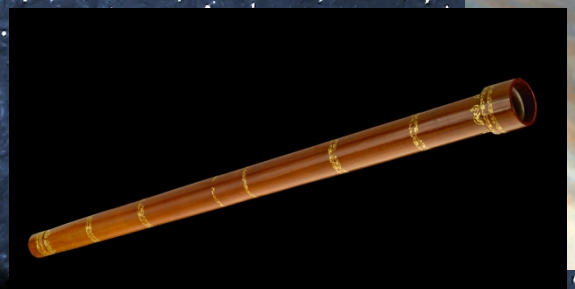
Messengers from the Universe

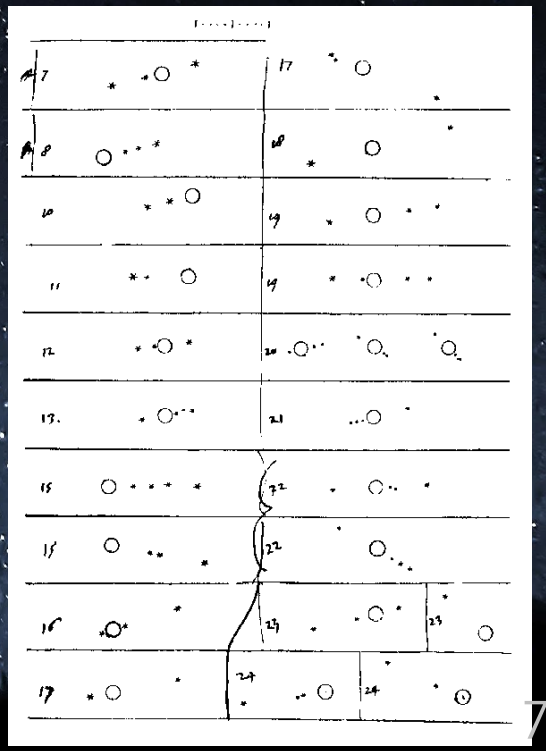
Photons

(visible light)



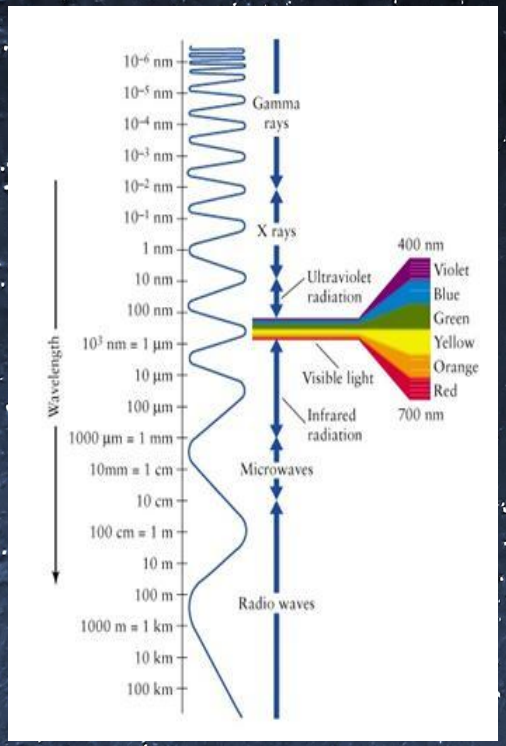


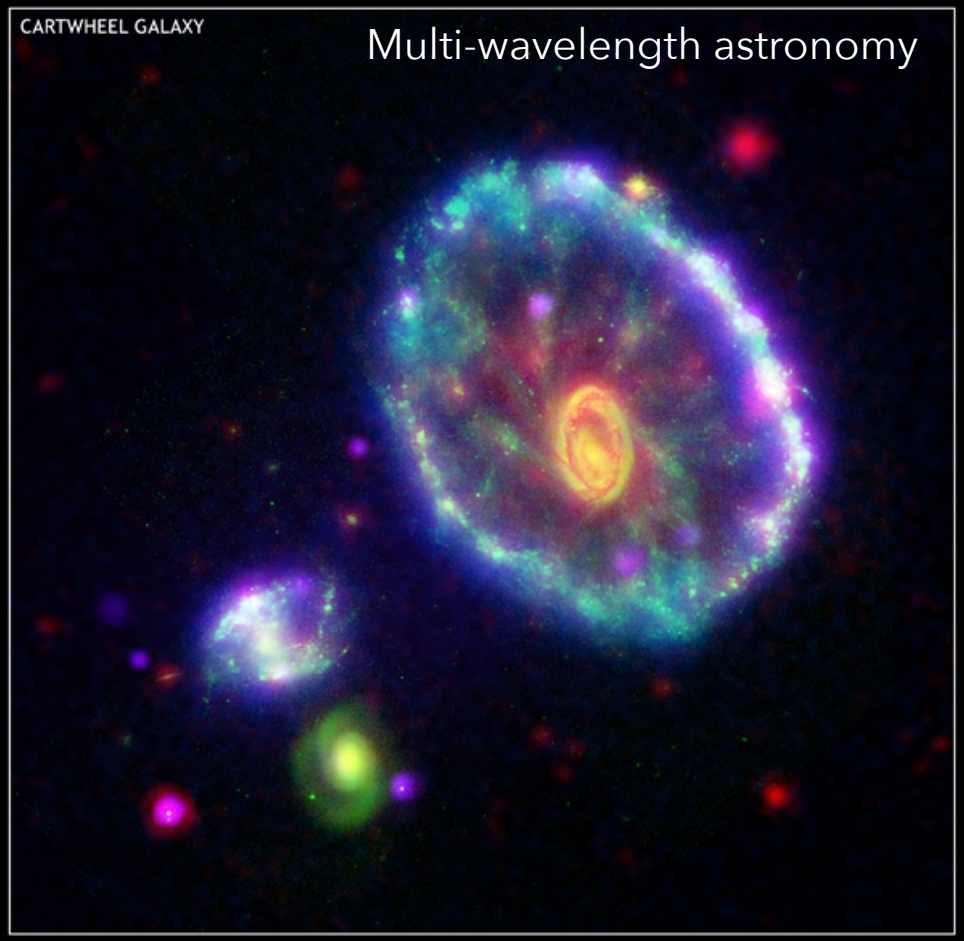




Messengers from the Universe

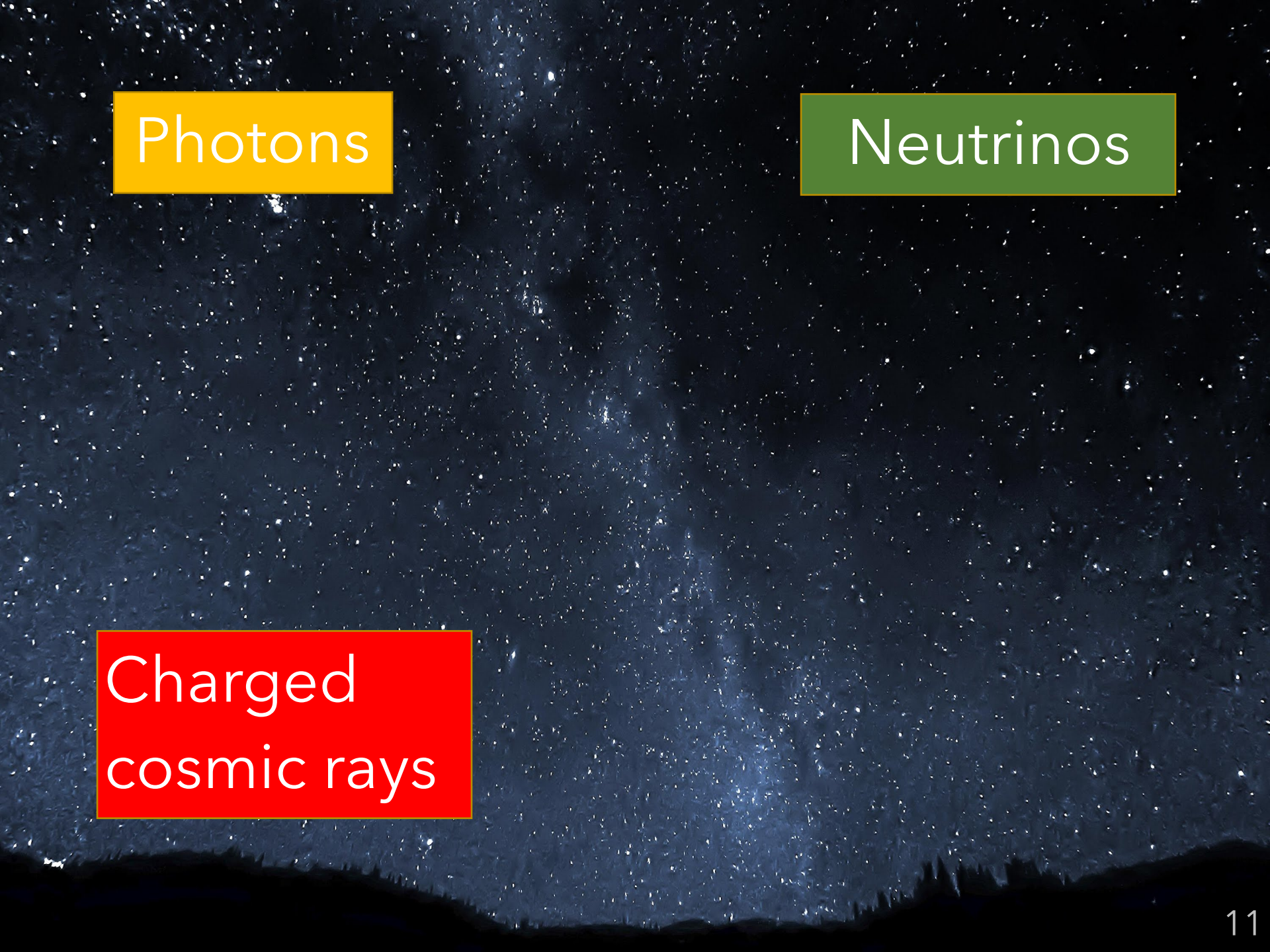
Photons (other wavelengths)

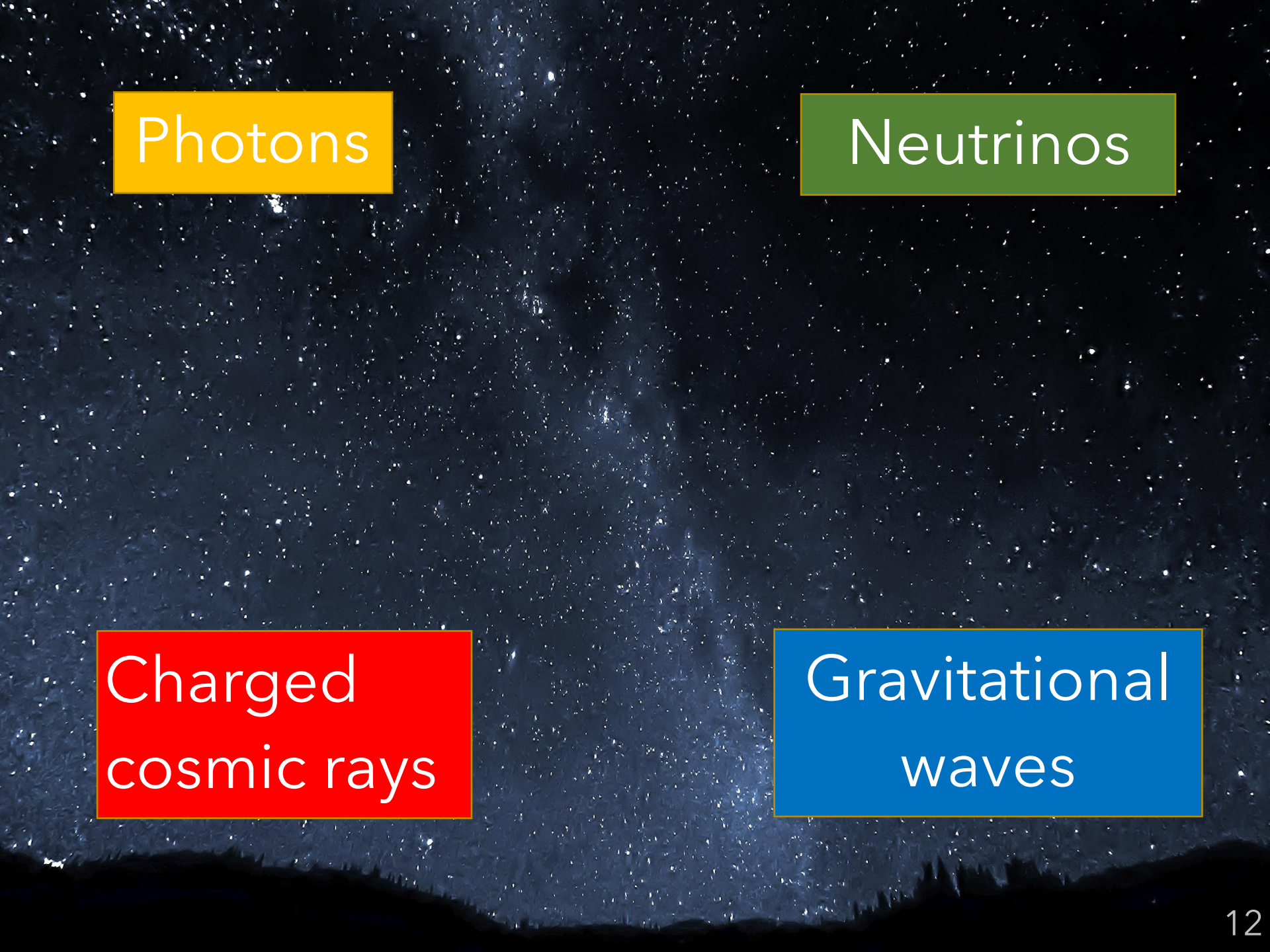


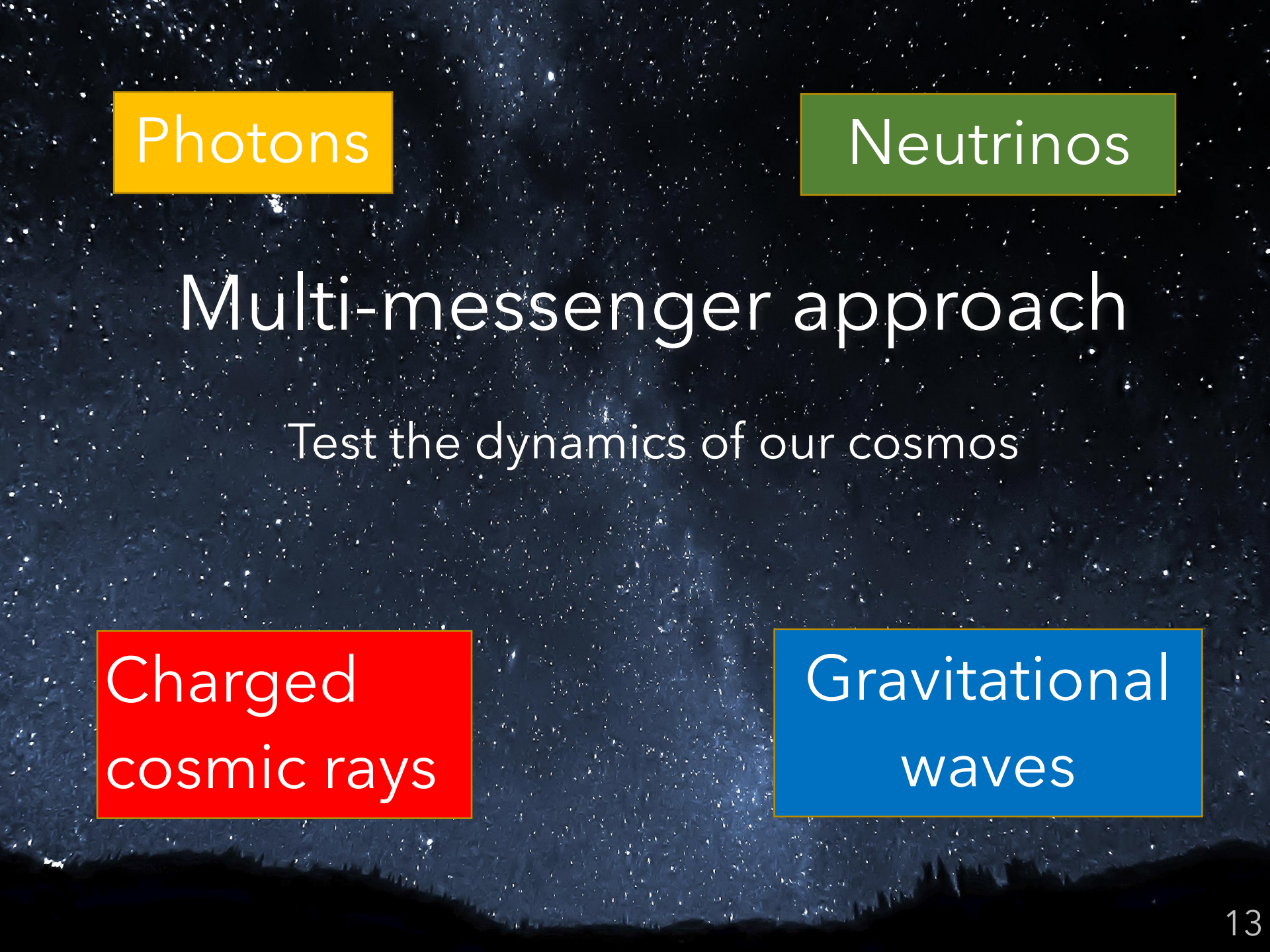



Photons

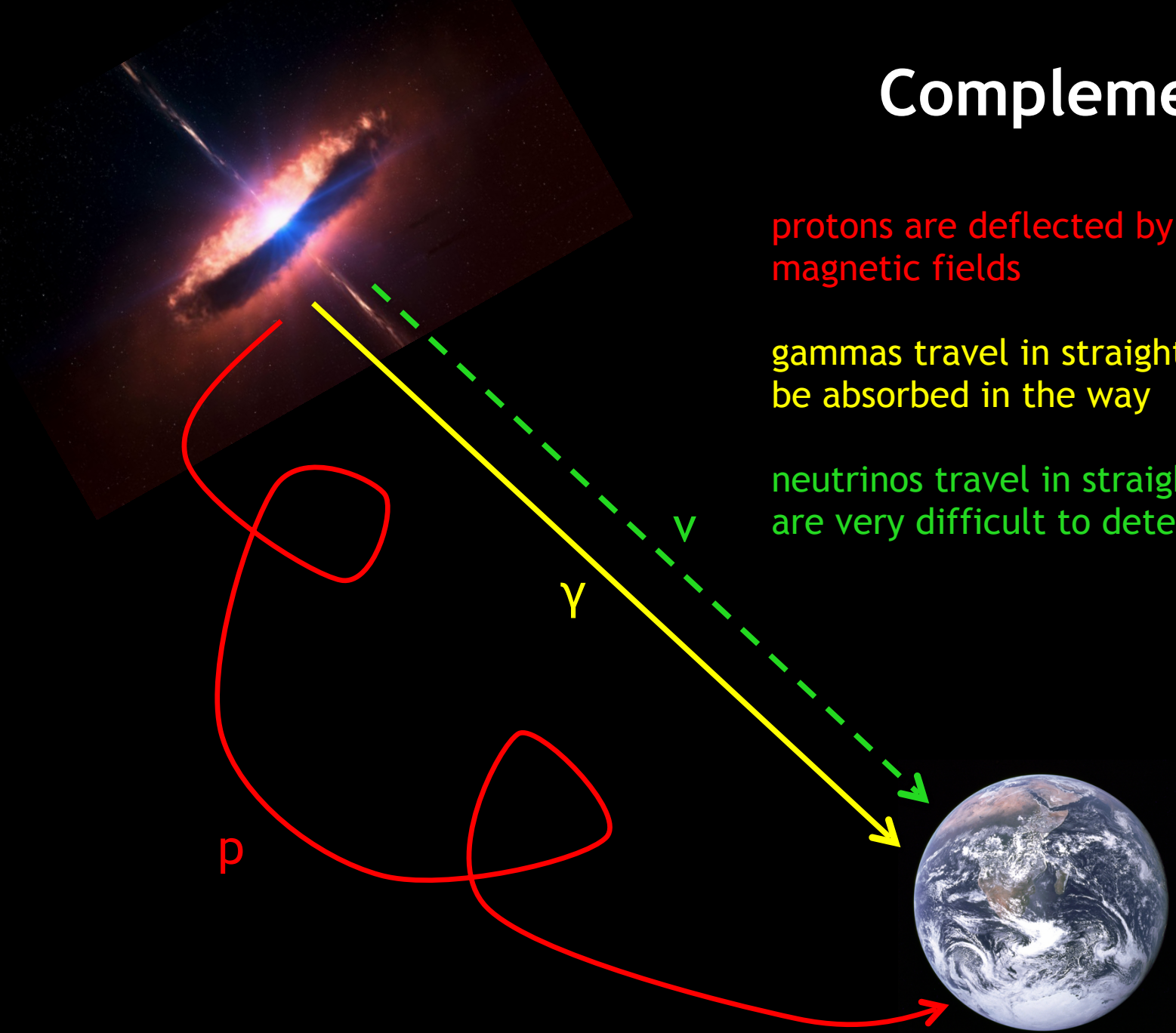

Photons
Charged cosmic rays


Photons
Neutrinos
Charged cosmic rays


Photons
Neutrinos
Charged cosmic rays
Gravitational waves


Photons
Neutrinos
Multi-messenger approach
Test the dynamics of our cosmos
Charged cosmic rays
Gravitational waves

Complementarity



protons are deflected by the galactic magnetic fields

gammas travel in straight lines but can be absorbed in the way

neutrinos travel in straight lines but are very difficult to detect

Photons

Neutrinos

Examples of astroparticle experiments

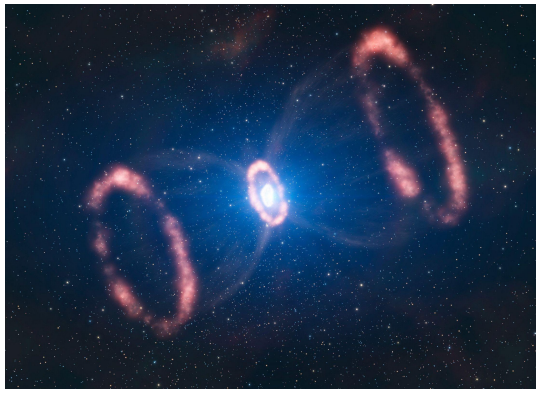
Charged cosmic rays

Gravitational waves

In this lecture…

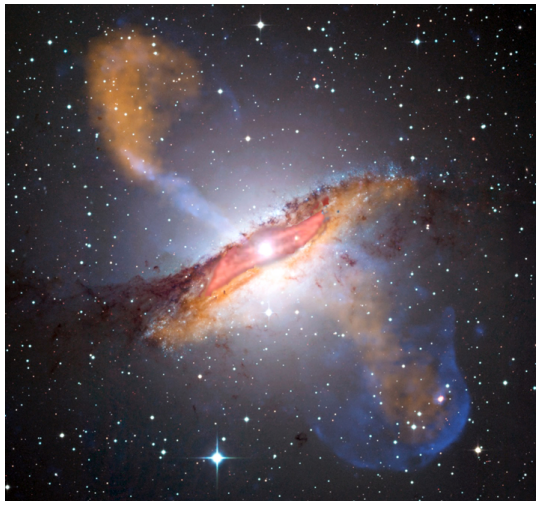
- (Very) high-energy gamma-rays
  - Probe some of the **most violent astrophysical phenomena**
    - SuperNovae (SN) & SuperNovae Remnants (SNR)
    - Gamma-ray bursts (GRB)

SN1987a



- Ultra high-energy cosmic rays
  - Universe **greatest accelerators**
    - Nature and origin still a mystery
  - Opportunity to do particle physics above the human-made accelerator energies

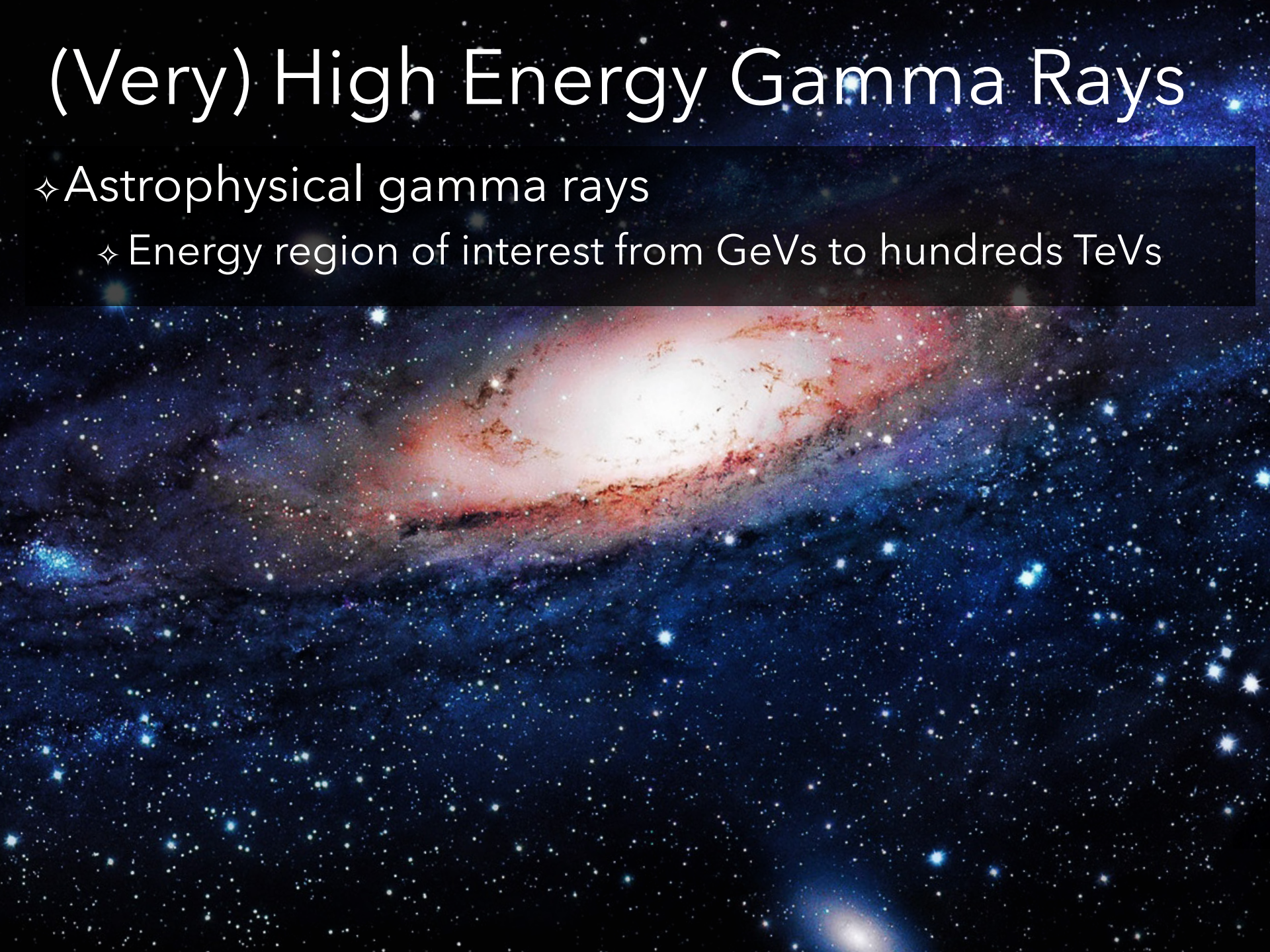
Centaurus A



Very High-Energy Gamma-rays

(Very) High Energy Gamma Rays

- Astrophysical gamma rays
  - Energy region of interest from GeVs to hundreds TeVs



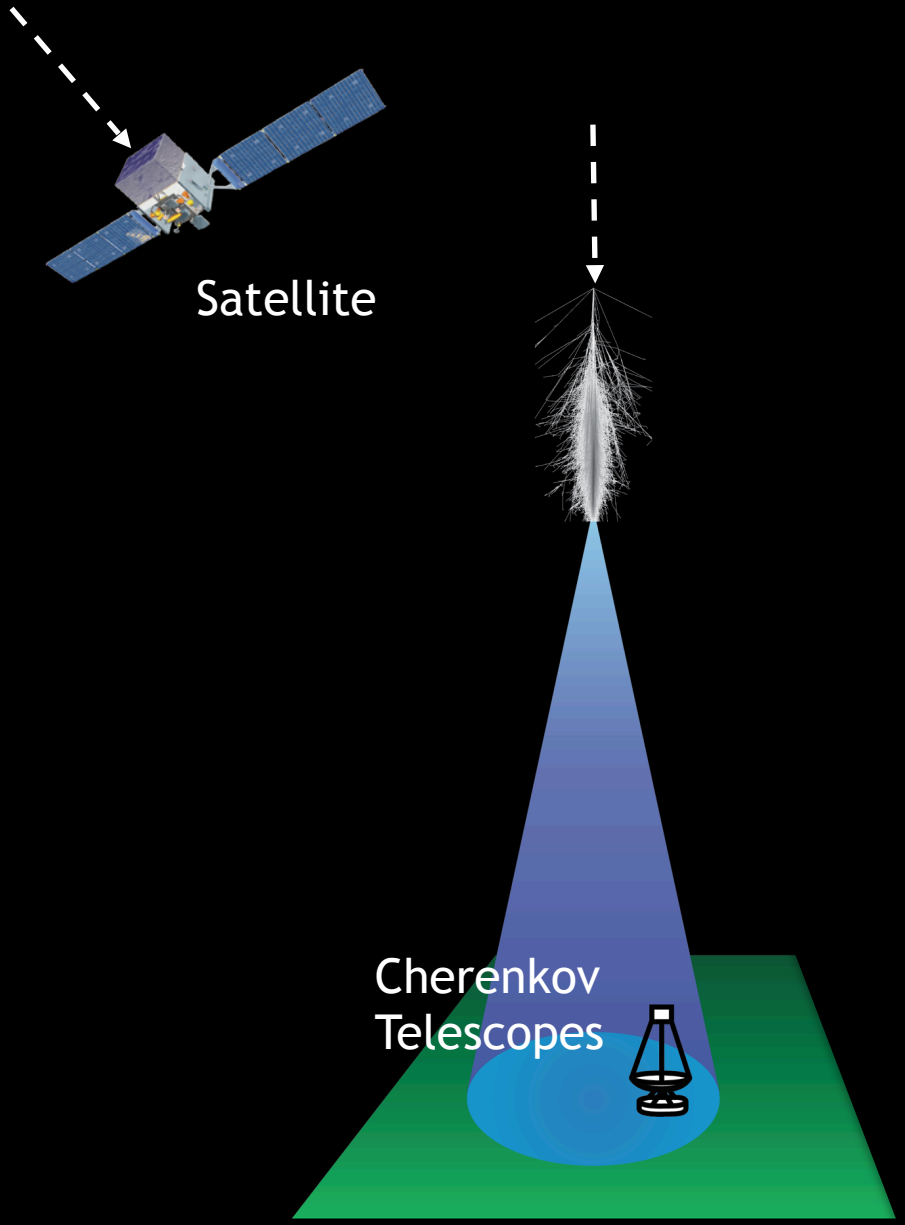
(Very) High Energy Gamma Rays

- Astrophysical gamma rays
  - Energy region of interest from GeVs to hundreds TeVs
- Scientific interest:
  - Key to understand the **acceleration mechanism** of cosmic rays in our galaxy
  - Violent astrophysical phenomena: pulsars and black holes
  - Galactic magnetic fields
  - Photon radiation fields in the Universe
  - Indirect search of **dark matter** (WIMP interactions)
  - Test fundamental properties of quantum gravity
  - …

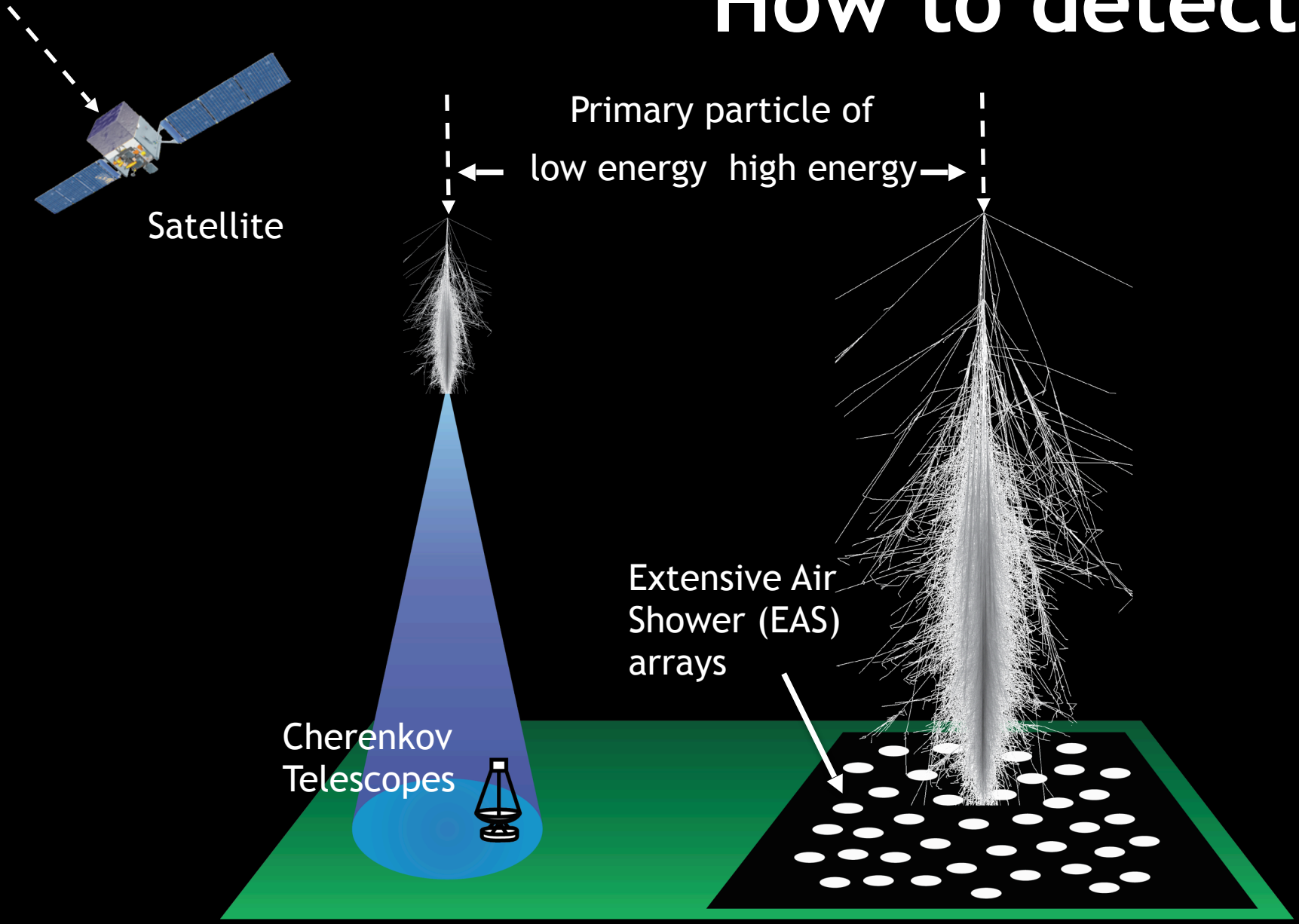
How to detect?

Satellite

How to detect?



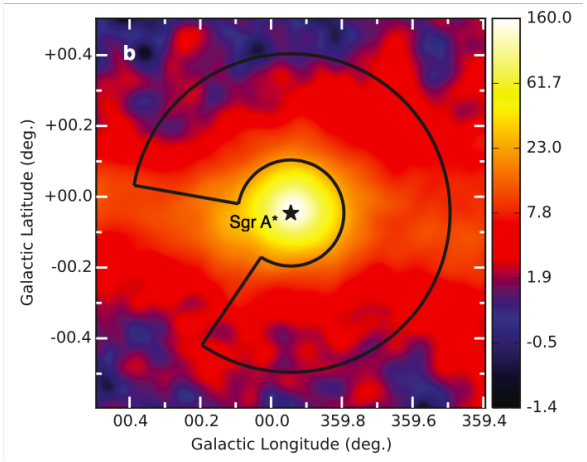
How to detect?

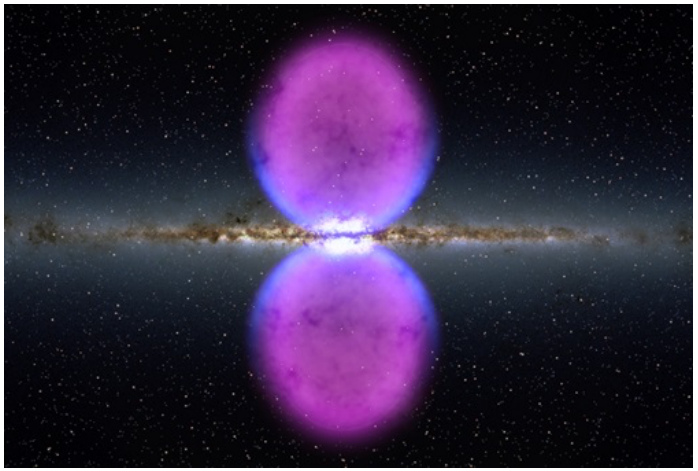


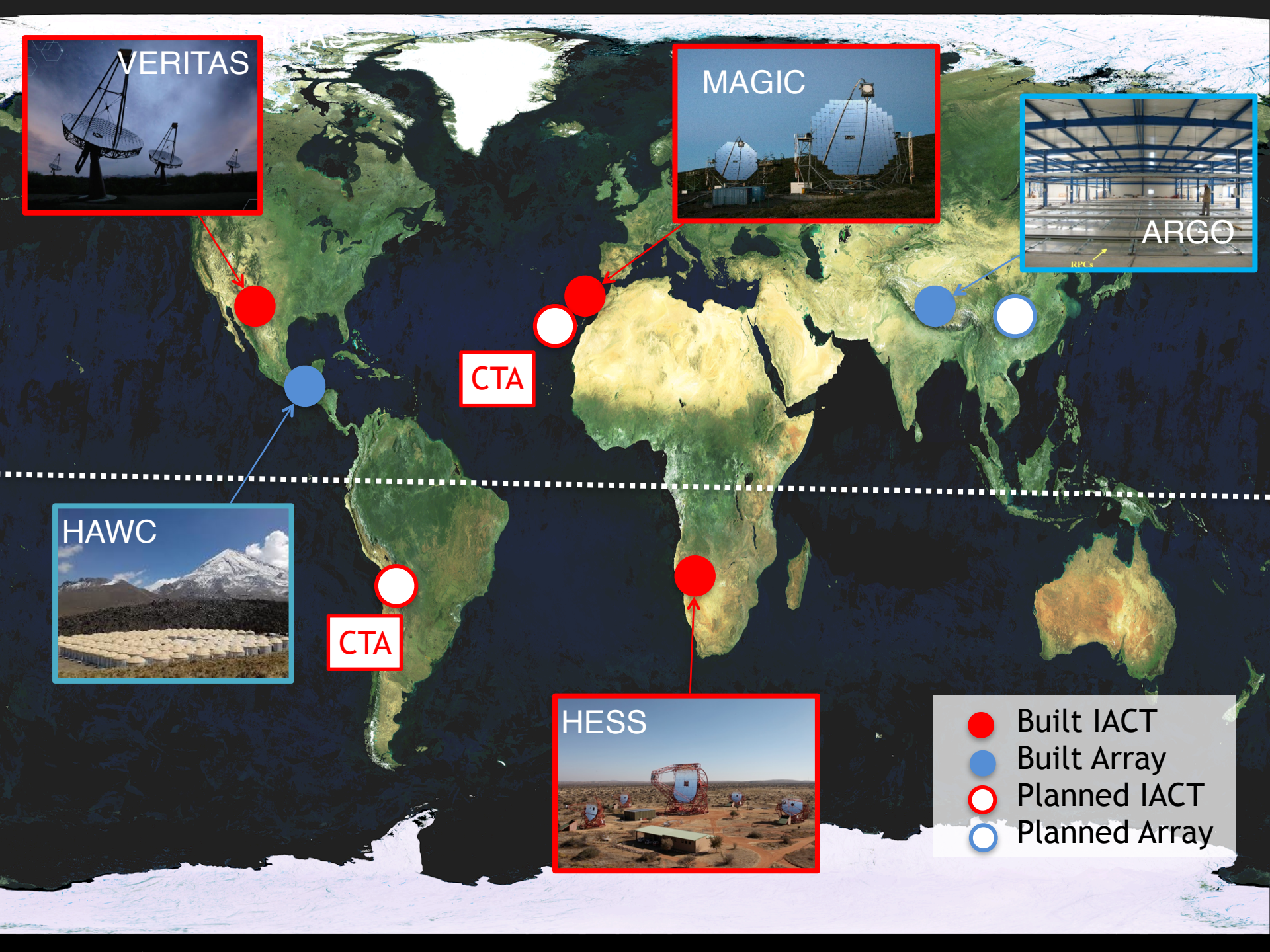
Arrays at high-altitude = large field of view + large duty cycle + low energy

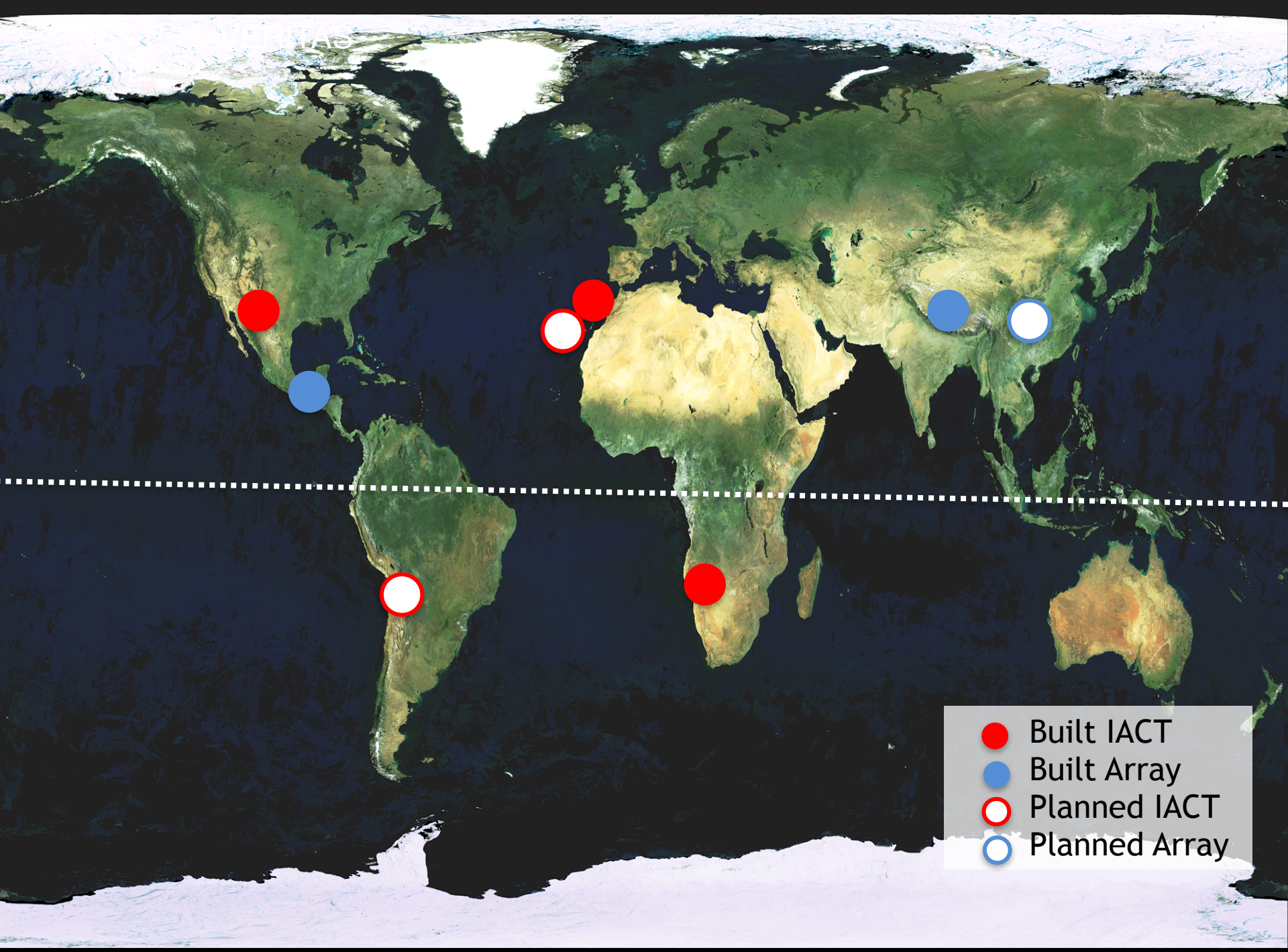
What we know so far…

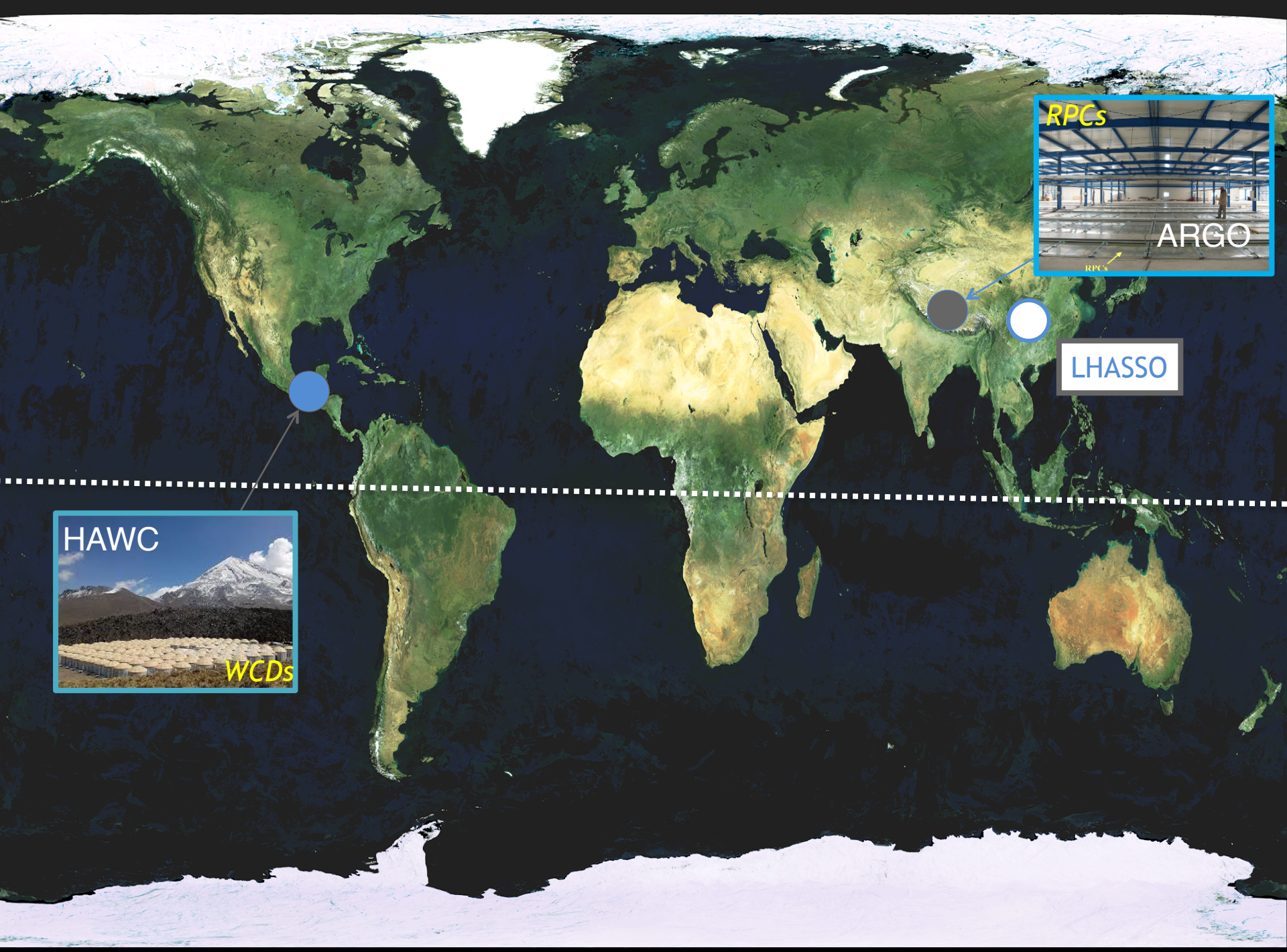
- Protons are known to be accelerated in the galaxy up to PeV energies (E = 10^{15} eV)
- All current acceleration models encounter non-trivial difficulties at these energies
- HESS data suggests that there might be a PeVatron source in the galactic center
- Fermi bubbles - gamma ray emission in outbursts from our galaxy



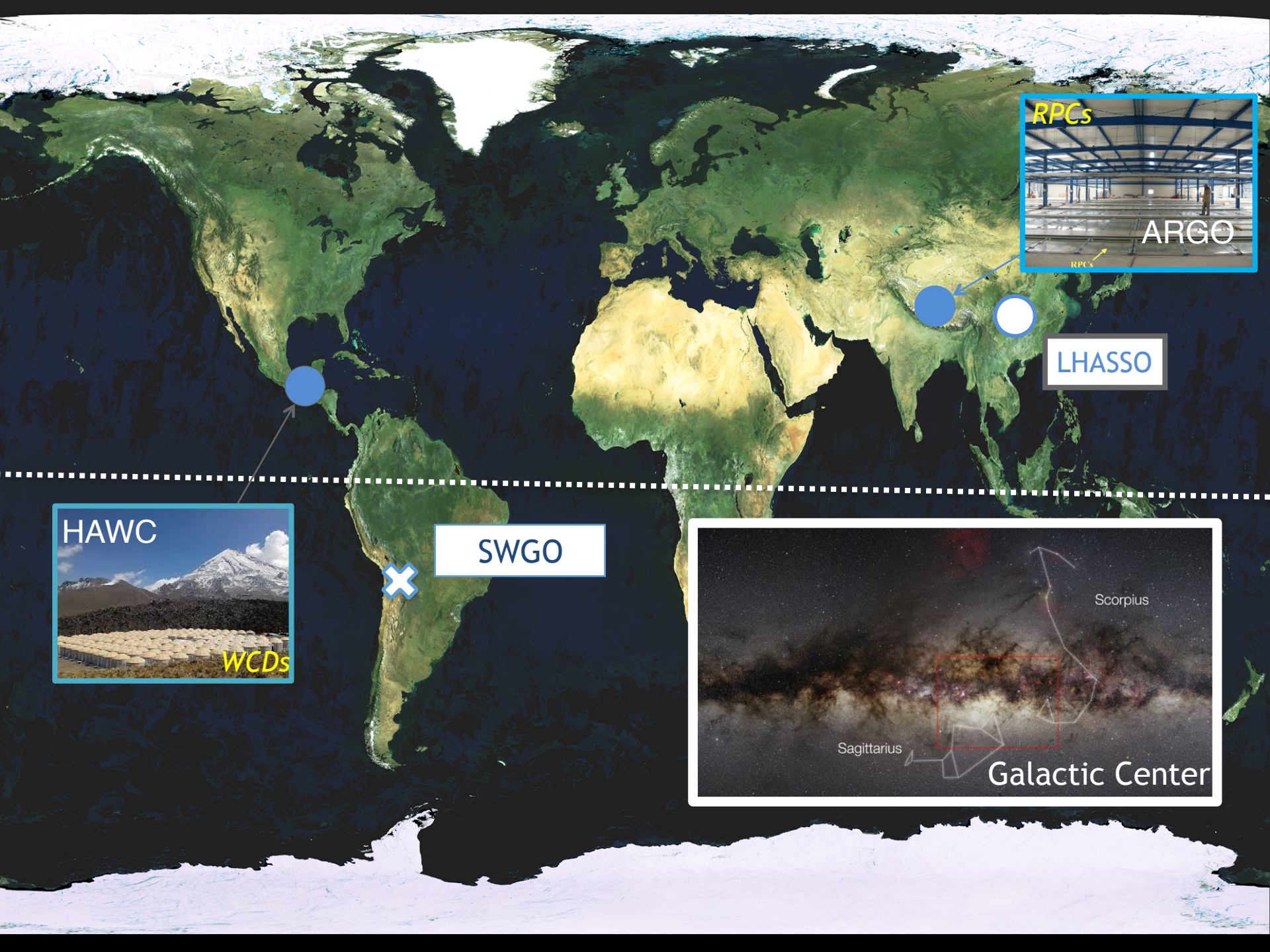



VERITAS
MAGIC
ARGO
RPCs
CTA
CTA
HAWC
HESS
Built IACT
Built Array
Planned IACT
Planned Array


Built IACT
Built Array
Planned IACT
Planned Array


RPCs
ARGO
RPCs
LHASSO
HAWC
WCDs

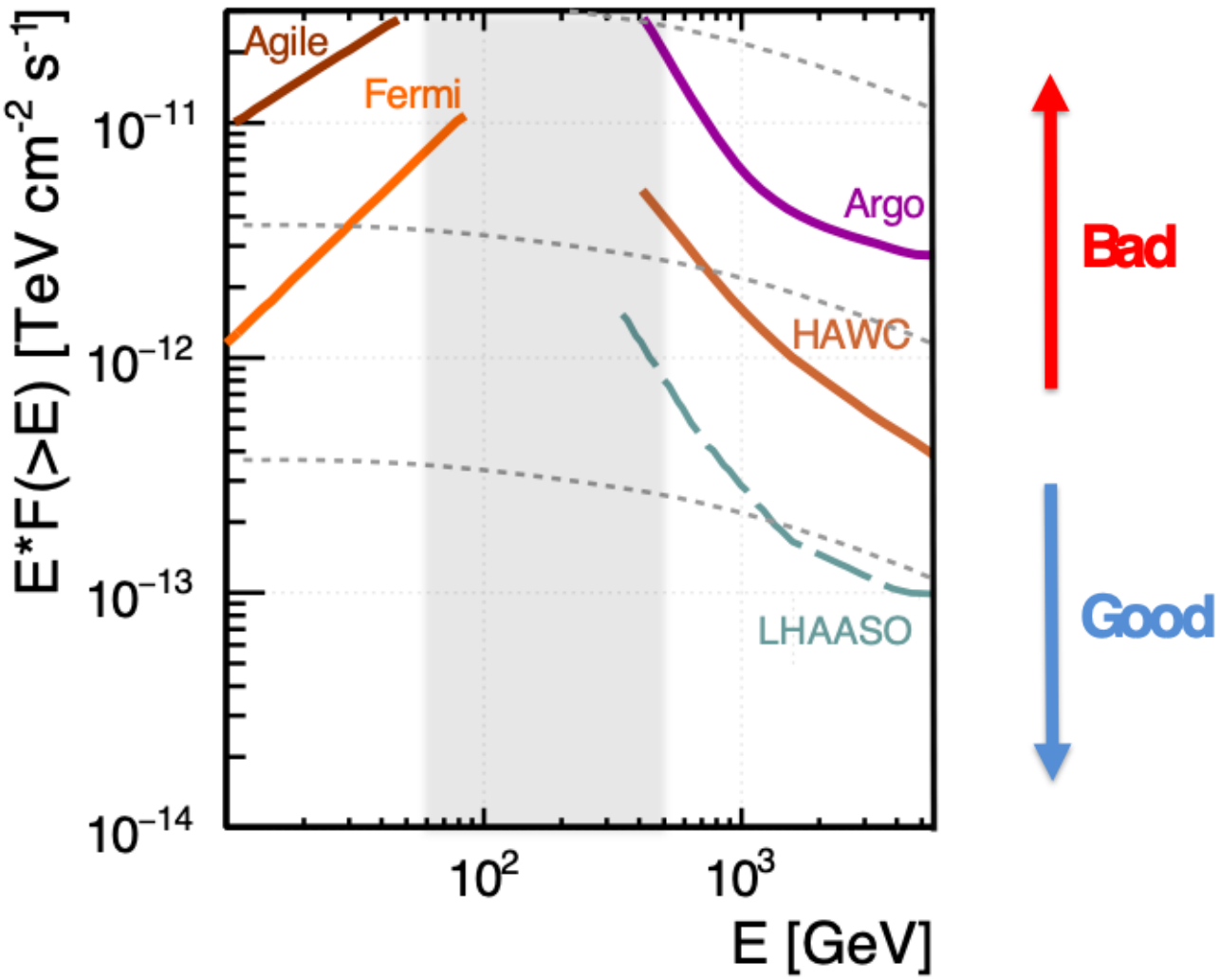

RPCs
ARGO
RPCs
LHASSO
HAWC
WCDs
SWGO


RPCs
ARGO
LHASSO
HAWC
WCDs
SWGO
Scorpius
Sagittarius
Galactic Center

SWGO

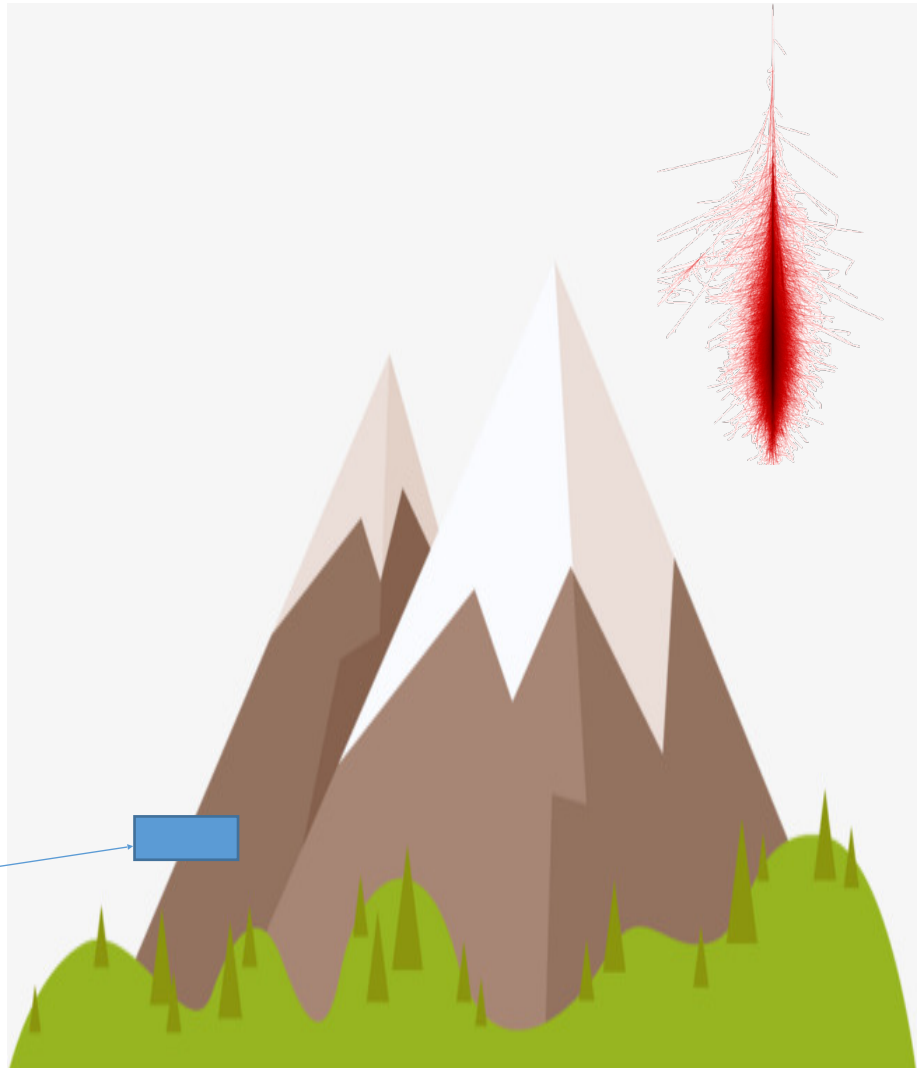
Complementary to the powerful Cherenkov Telescope Array project

Current Wide Field-of-View Gamma-Ray Observatories



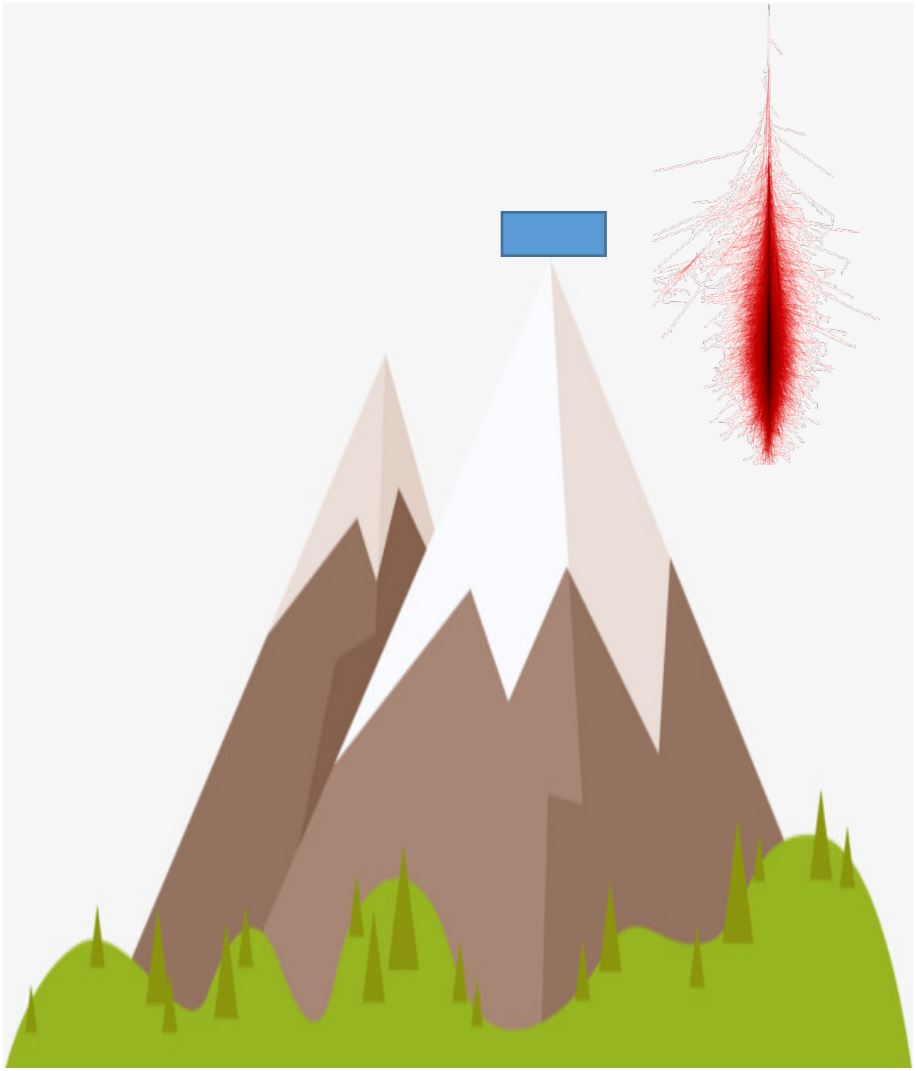
How to lower the energy threshold?

- Put the experiment at higher altitude
- Gamma-ray EAS arrays have typically 20 000 m^2



How to lower the energy threshold?

- Put the experiment at higher altitude
- Gamma-ray EAS arrays have typically 20 000 m^2
- It is possible to find sites with ≈5000 m of altitude
  - Atacama desert, Northern Chile
- *Can the detector concept be improved?*




Next wide FoV gamma-ray experiment
Probable Site ~ 5000 m altitude - North Chile

Newly formed international collaboration to make this experiment possible!


NOTÍCIAS DESPORTO TELEVISÃO RÁDIO RTPPLAY

ÚLTIMA HORA Operação Antídoto. PJ detém médicos em buscas a consultórios

RTP NOTÍCIAS

2 Jul. 2019 | 10:48

DESPORTO PAÍS MUNDO POLÍTICA ECONOMIA

PARTILHE NO FACEBOOK PARTILHE NO TWITTER PARTILHE NO LINKEDIN

Portugal junta-se a oito países para construir observatório de raios gama nos Andes

Lusa
01 Jul, 2019, 07:24 | Mundo


TVI24 TEMPO MAISFUTEBOL TVI SELFIE RÁDIOS BLOGS NIT SITES

Terça-feira, 2 Julho 2019

Funchal 24°

tvi24

INÍCIO NOTÍCIAS VÍDEOS FOTOS DIRETO GUIA TV DOSSIERS EU VI

Últimas Opinião Sociedade Política Economia Internacional Desporto Motores Tecnologia Música

Investigações Alexandra Borges Investigações Ana Leal Deus e o Diabo Gente Que

Portugal junta-se a oito países para construir observatório de raios gama nos Andes

Será o primeiro observatório de raios gama no hemisfério sul. Já existe um do género, mas no hemisfério norte, no México


JN DN TSF Dinheiro Vivo V Digital Plataforma O Jogo Motor 24 Men's Health Women's Health Evasões Volta ao Mundo NM N-TV Delas

MENU 19 Diário de Notícias

INÍCIO / LUSA

Portugal junta-se a oito países para construir observatório de raios gama nos Andes

Lisboa, 01 jul 2019 (Lusa) - Portugal e mais oito países juntam-se a partir de hoje numa colaboração internacional para construir um observatório de raios gama na região dos Andes, para procurar sinais de matéria escura no centro da Via Láctea, foi hoje anunciado.


SIC SIC NOTÍCIAS SIC RADICAL SIC MULHER SIC K SIC CARAS SIC INTERNACIONAL SIC ESPERANCA

MENU SIC NOTÍCIAS

PLÁSTICO NOSSO DE CADA DIA POLÍGRAFO SIC E SE FOSSE CONSIGO?

NOTÍCIAS OPINIÃO PROGRAMAS GUIA TV

MUNDO

Portugal junta-se a oito países para construir observatório de raios gama nos Andes


P2 ÍPSILON CULTO FUGAS P3 CINECARTAZ

CIÊNCIA › ESPAÇO MEDICINA ECOSFERA

UNIVERSO

Portugal junta-se a oito países para construir observatório de raios gama nos Andes

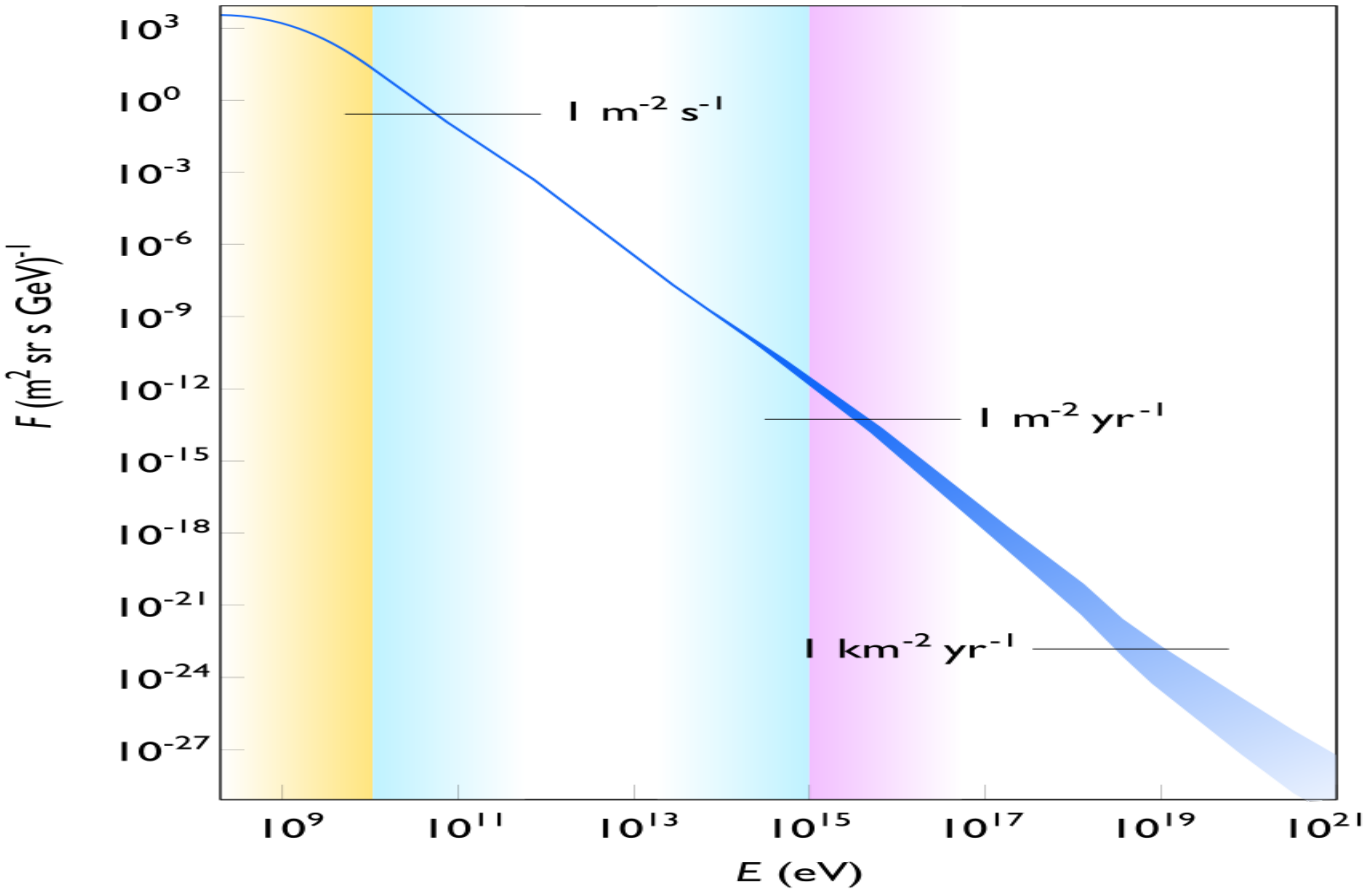
Empreendimento marcará a edificação do primeiro laboratório de observação de raios gama no hemisfério sul. Custo da construção estimado em, pelo menos, 50 milhões de euros.

Lusa · 1 de Julho de 2019, 21:00

57 PARTILHAS

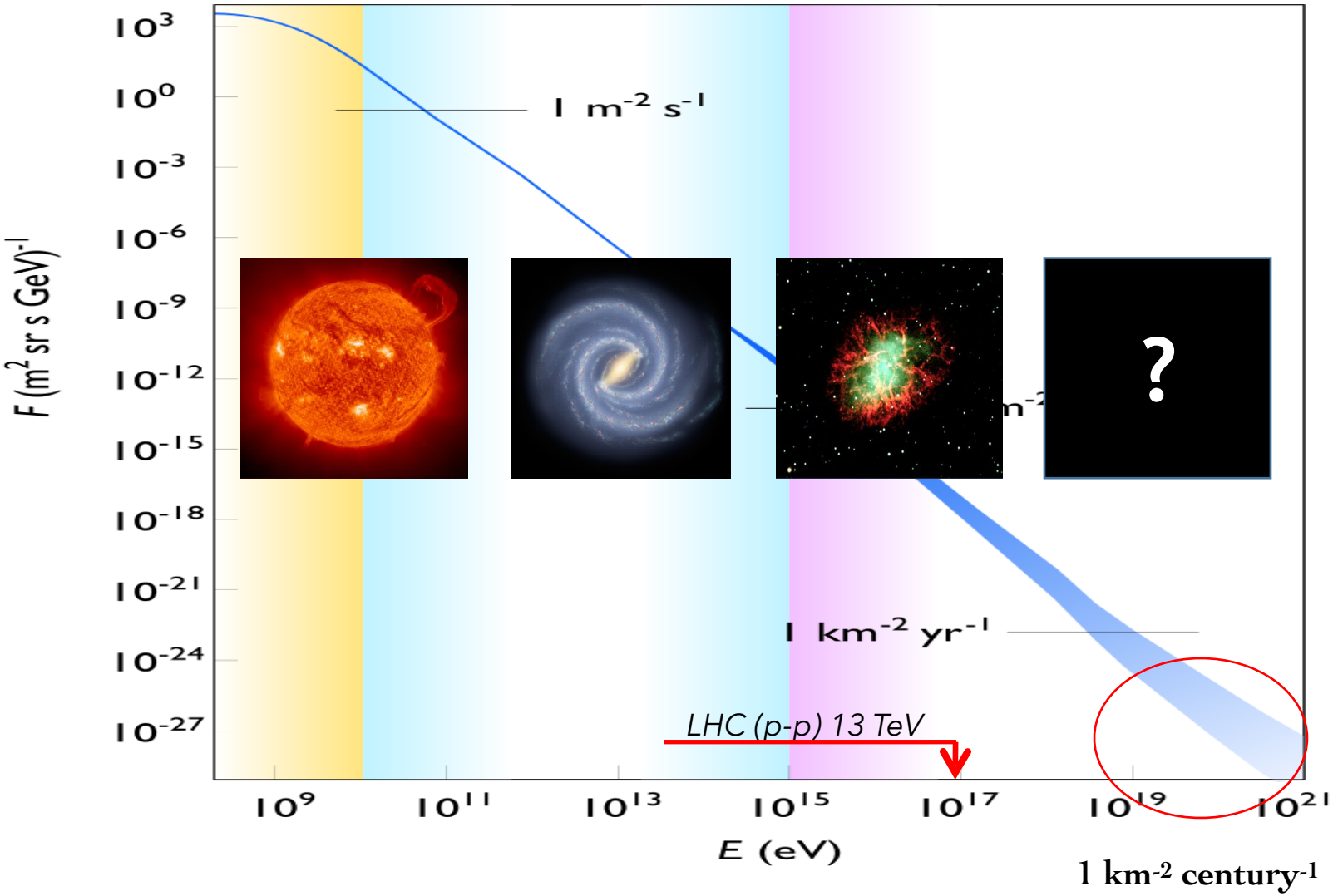
Ultra High-Energy Cosmic Rays

Cosmic ray energy spectrum



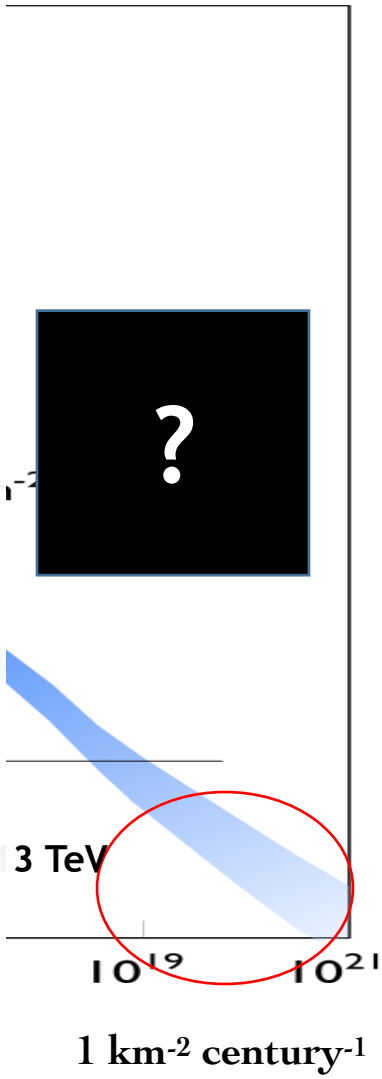
(Charged particles continuously bombarding Earth)

Ultra High Energy Cosmic Rays

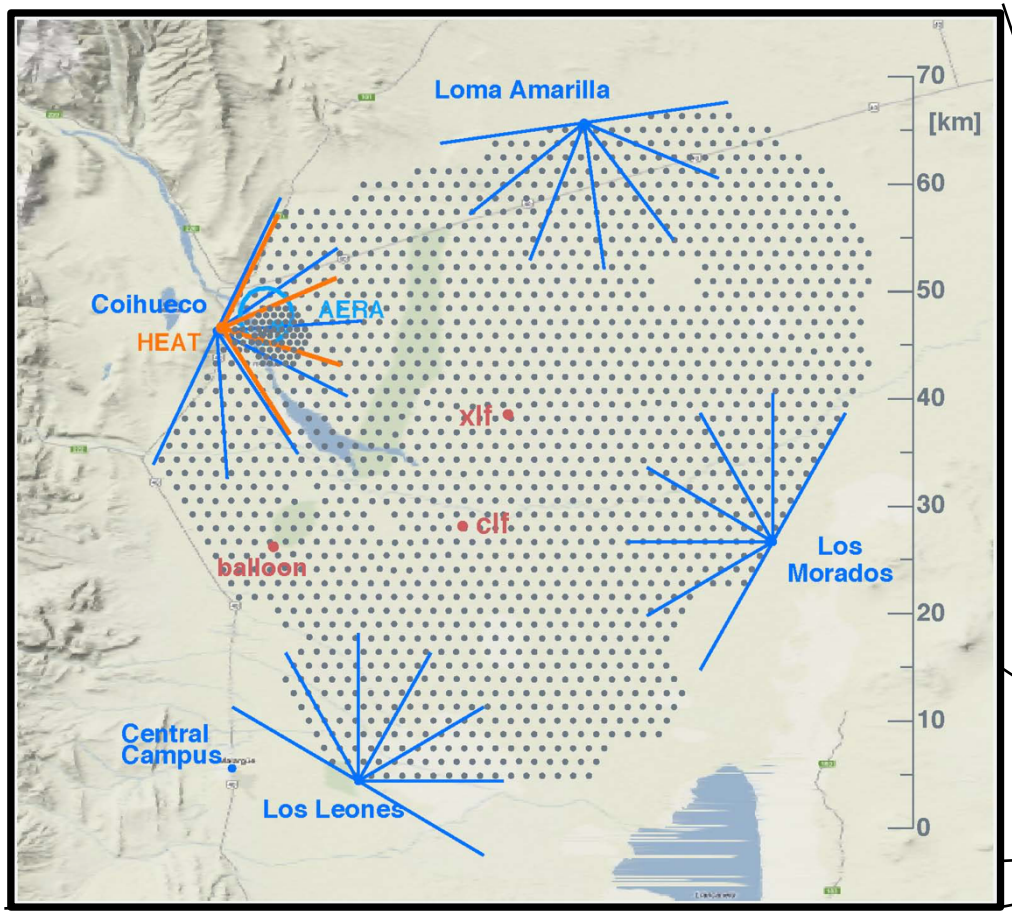


Ultra High Energy Cosmic Rays

- Opportunity to understand high-energy Universe
  - Production (sources; acceleration mechanisms…)
- Opportunity to test particle physics at energies above the LHC
  - High-energy interactions
    - E = 10^{19} eV => sqrt(s) ~ 130 TeV



Pierre Auger Observatory

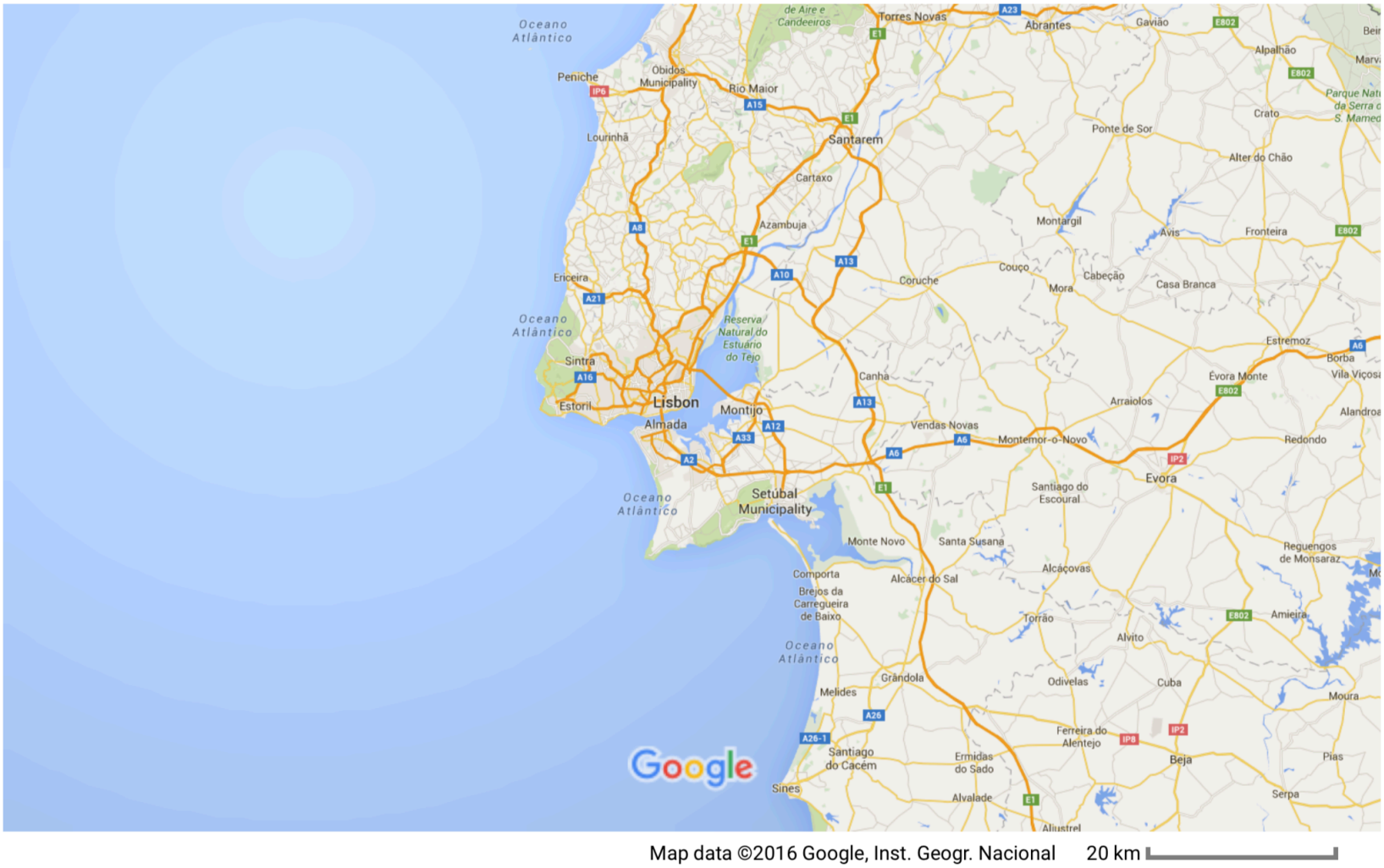


Area: 3000 km^2

Located in the Pampa Amarilla, Mendoza, Argentina

Altitude: 1400 m a.s.l.

How big is it?


Oceano Atlântico
Peniche
Obidos Municipality
Rio Maior
Lourinhã
Santarem
Cartaxo
Azambuja
Ericeira
Sintra
Estoril
Lisbon
Almada
Montijo
Setúbal Municipality
Reserva Natural do Estuário do Tejo
Torres Novas
Abrantes
Gavião
Alpalhão
Ponte de Sor
Alter do Chão
Crato
Montargil
Avis
Fronteira
Coruche
Couço
Cabeção
Mora
Casa Branca
Canha
Vendas Novas
Montemor-o-Novo
Arraiolos
Évora Monte
Estremoz
Borba
Redondo
Evora
Santiago do Escoural
Monte Novo
Santa Susana
Alcáçovas
Alcacer do Sal
Comporta
Brejos da Carregueira de Baixo
Torrão
Amieira
Alvito
Grândola
Melides
Odivelas
Cuba
Moura
Ferreira do Alentejo
Santiago do Cacém
Ermidas do Sado
Beja
Pias
Sines
Alvalade
Serpa
Google
Map data ©2016 Google, Inst. Geogr. Nacional
20 km

Really big!!

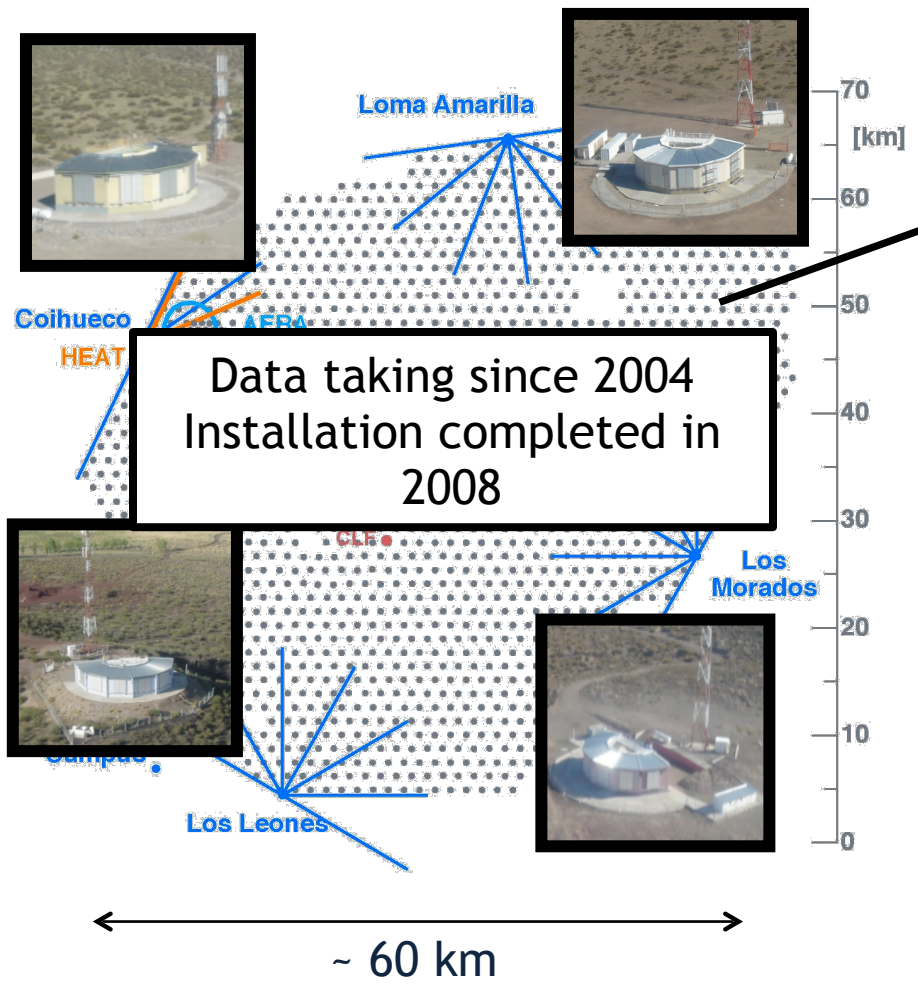

Loma Amarilla
Coihueco
HEAT
AERA
XLF
CLF
Lisbon
Los Morados
Central Campus
Los Leones
Google
Map data ©2016 Google, Inst. Geogr. Nacional
20 km
[km]
70
60
50
40
30
20
10
0

Pierre Auger Observatory

Pierre Auger Collaboration

Auger Portuguese group at LIP

Pierre Auger Observatory



- ~ 1600 Surface Detector (SD) Stations
- 1.5 km spacing
- 3000 km^2

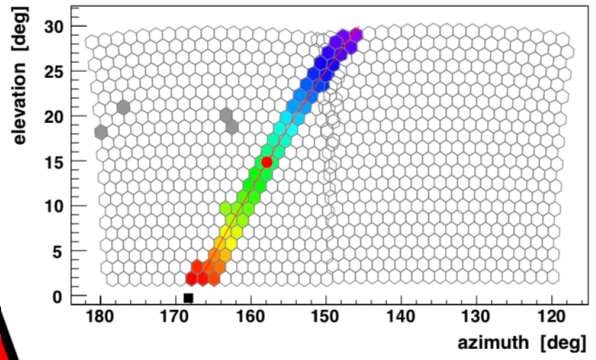
- 4 Fluorescence Detectors (FD)
- 6 x 4 Fluorescence Telescopes

Low energy extension

- Aim to E ≈ 10^{17} eV
- AMIGA
  - Denser array plus muon detectors
- HEAT
  - 3 additional FD telescopes with a high elevation FoV

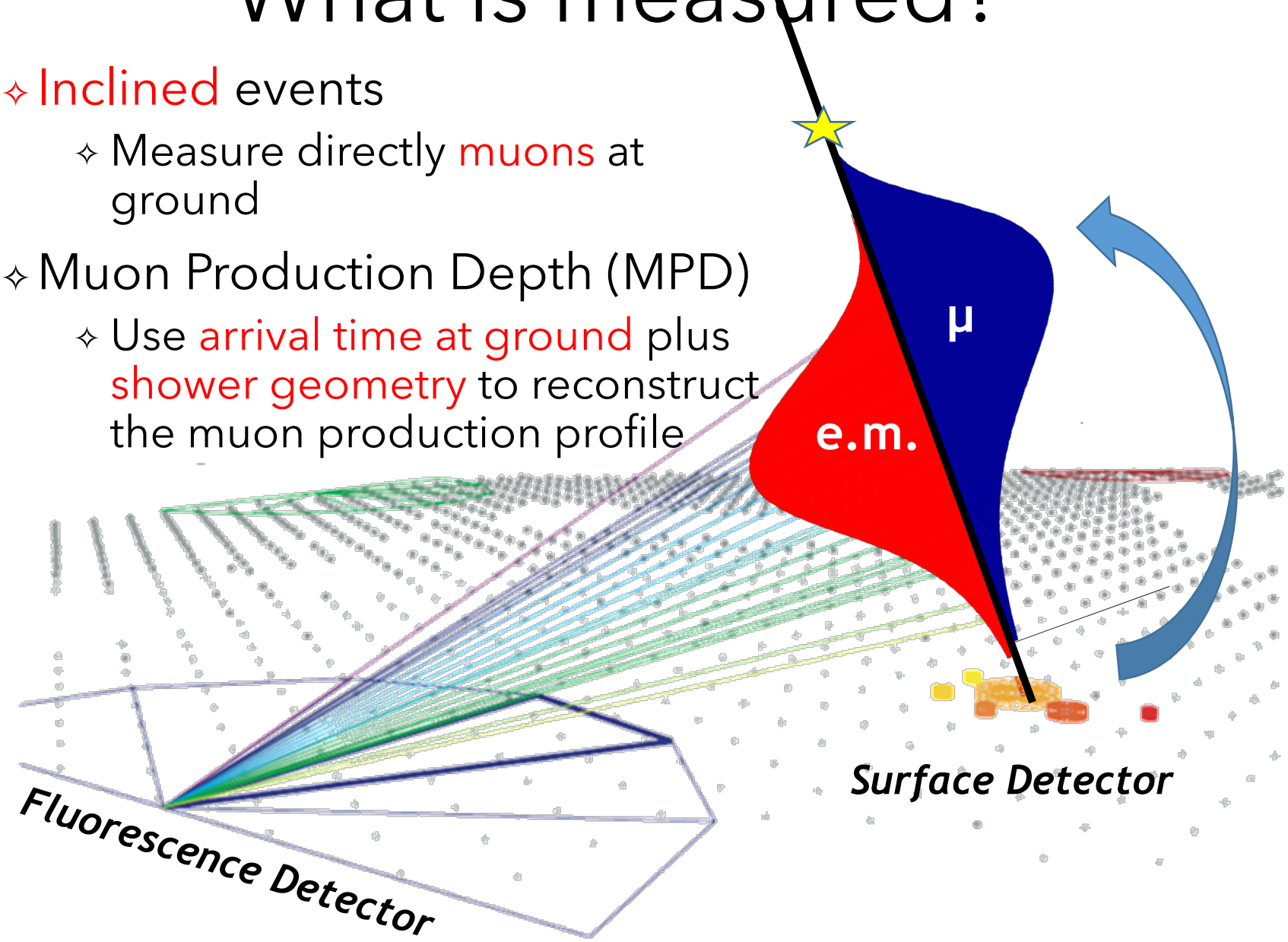
What is measured?

- FD: Collects the fluorescence light produced by the e.m. shower component in moonless nights
  - ~15% duty cycle
  - Energy from integral
    - Quasi-calorimetric measurement
  - Depth of shower maximum (X_{max})
    - Composition sensitive



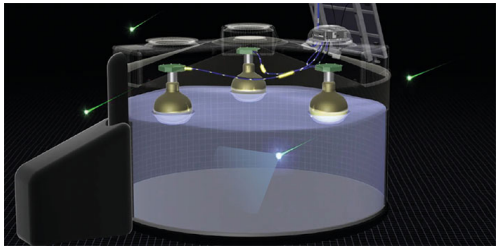
What is measured?

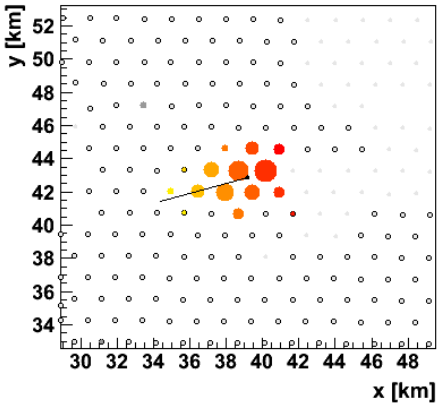
- Inclined events
  - Measure directly muons at ground
- Muon Production Depth (MPD)
  - Use arrival time at ground plus shower geometry to reconstruct the muon production profile

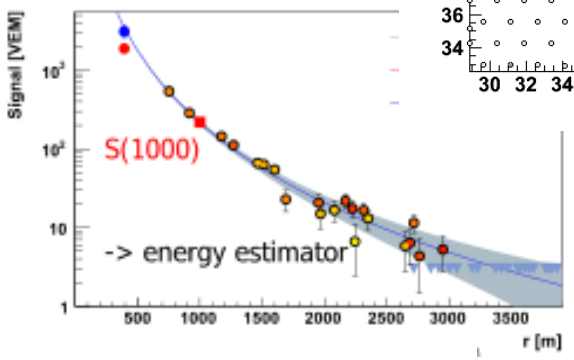


What is measured?

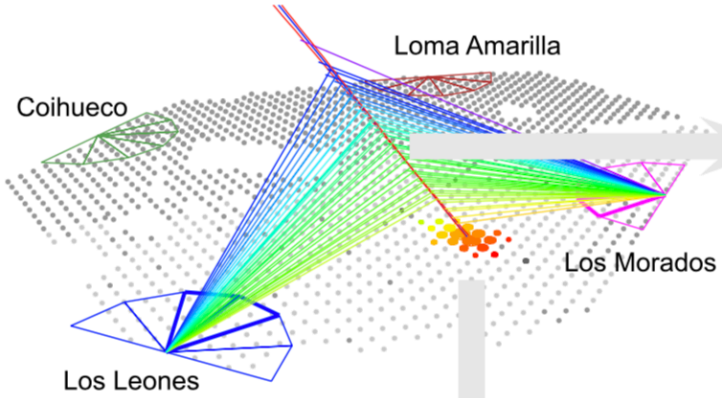
- SD: Sample the charged secondary particles that arrive at ground
  - 100% duty cycle
  - Shower direction: from arrival time
  - Energy estimator: signal at 1000 m from the core

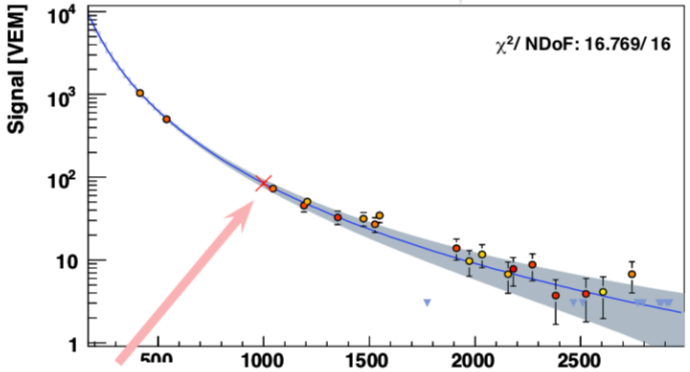






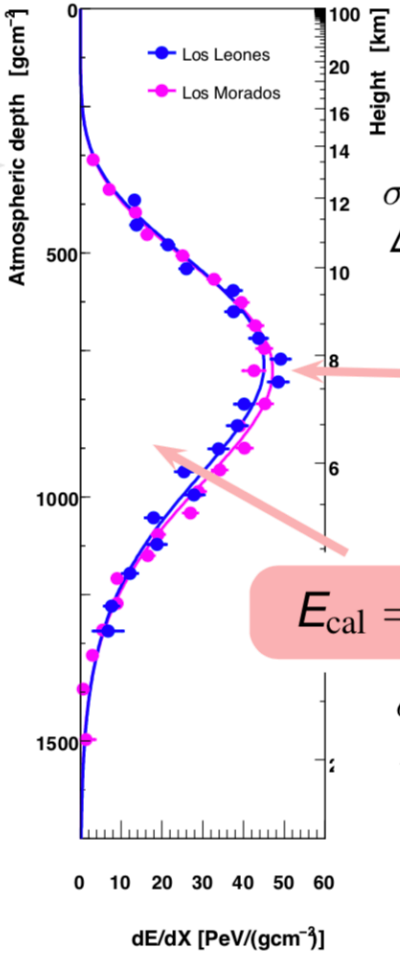
Hybrid Technique





S_{1000}

$E_{\text{surface}} = f(S_{1000}, \theta)$



$\sigma_{X_{\max}} \leq 20\ \text{g/cm}^2$
$\Delta_{\text{sys}} \leq 10\ \text{g/cm}^2$

$X_{\max}$

$E_{\text{cal}} = \int \frac{dE}{dX}\, dX$

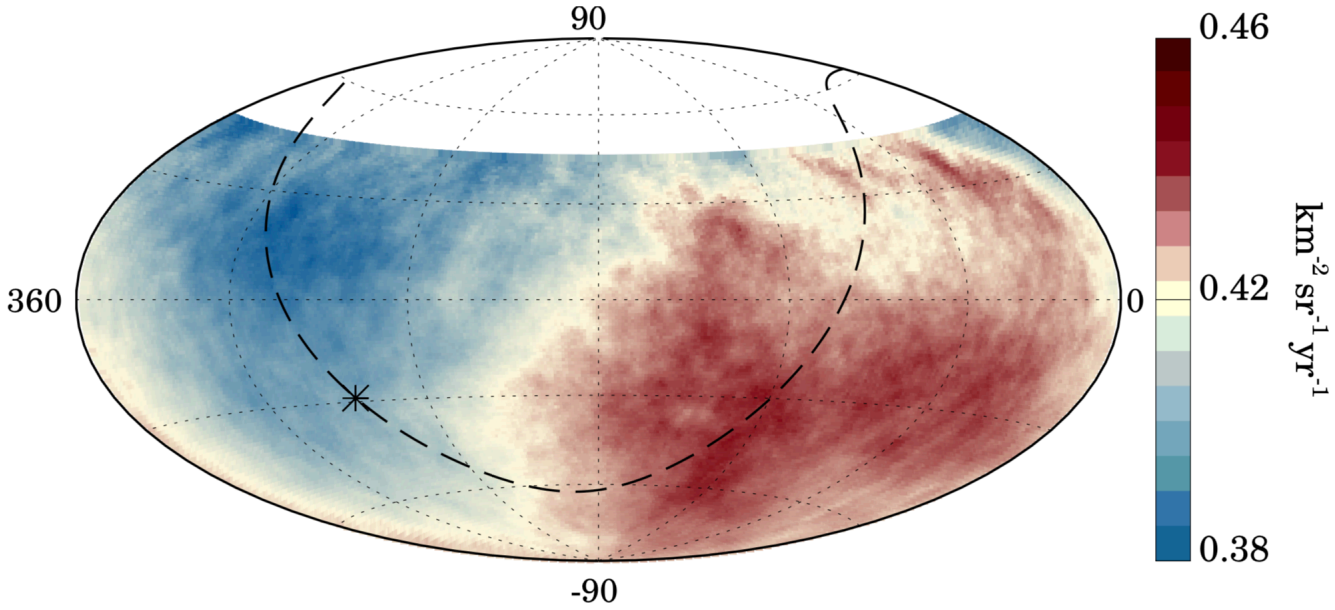
$\sigma_E/E \sim 8\,\%$
$\Delta_{\text{sys}} \approx 15\,\%$

What have we learned so far…

What have we learned so far…

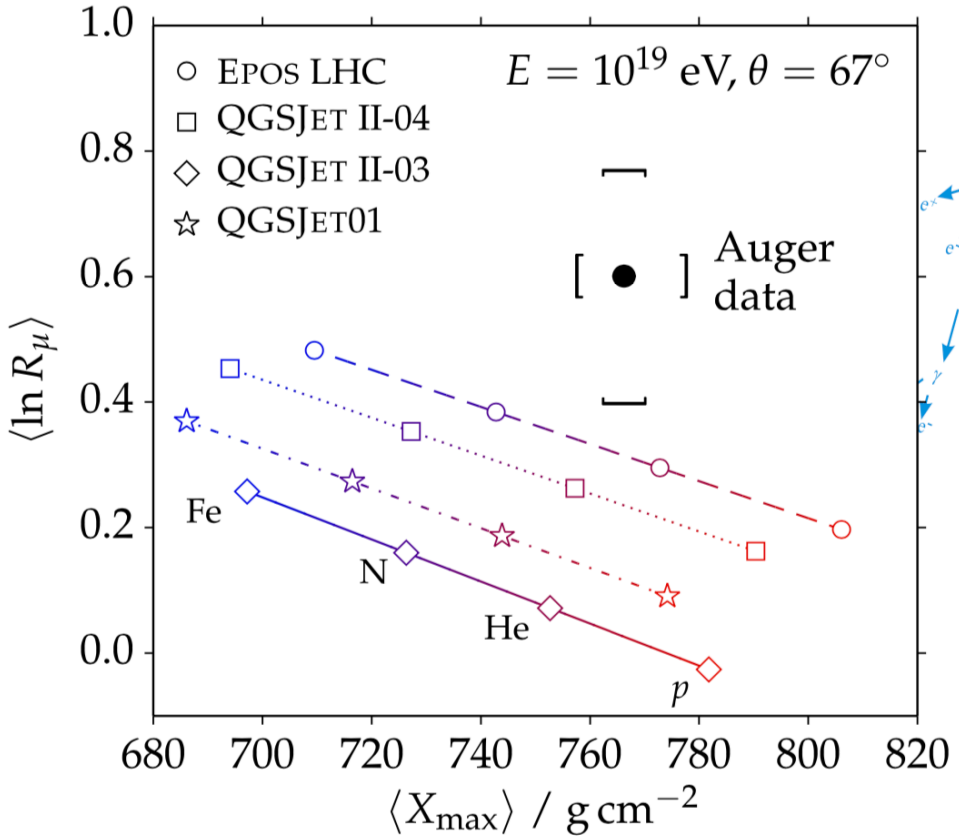
- UHECRs are accelerated:
  - somewhere in our Universe
    - from the photon and neutrino limits
  - Outside the galaxy

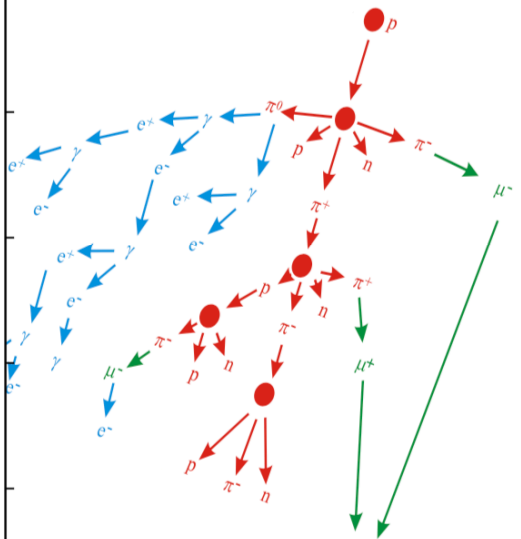
Science 357 (2017) no.6537, 1266-1270



Composition vs Hadronic interactions

Surface Detector



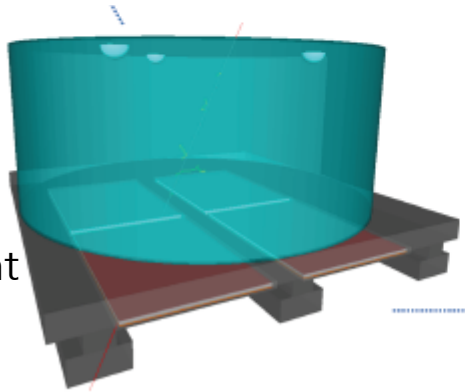


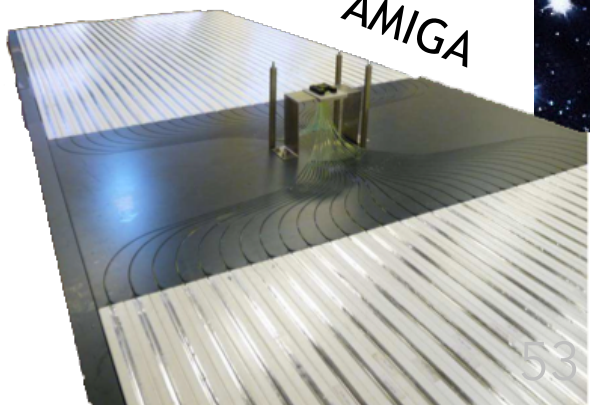
Fluorescence Detector

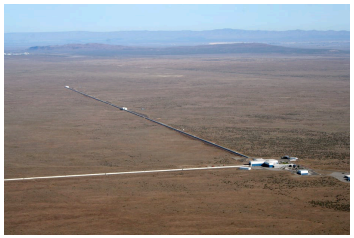
Combination of the number of muons R_μ with X_{max} reveals tension between data and all hadronic interaction models

The future of UHECRs…

- Gain better understanding over the shower physical mechanisms
  - Use LHC data to better tune the hadronic interaction models at low energy
  - Auger upgrade
    - Auger PRIME (operates until 2025)
    - Put a scintillator on top of the SD
    - Complementary information to separate the muon from the e.m. shower component
  - Several R&D projects
    - EAS radio detection
    - MARTA engineering array
      - RPCs below the tank
    - AMIGA
      - Scintillators below the ground





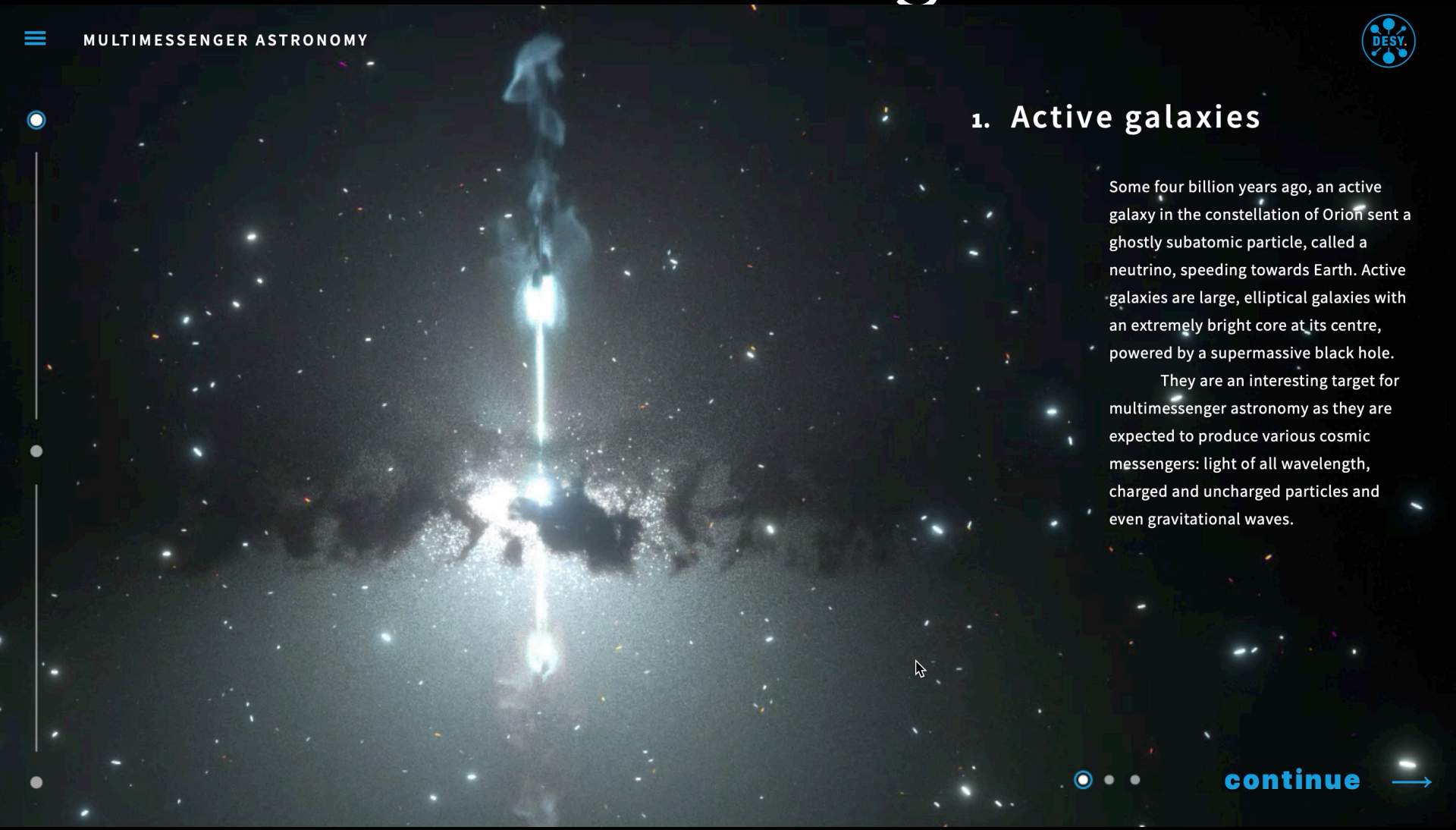




Multi-messengers

The opening of a new era…

Multi-messengers

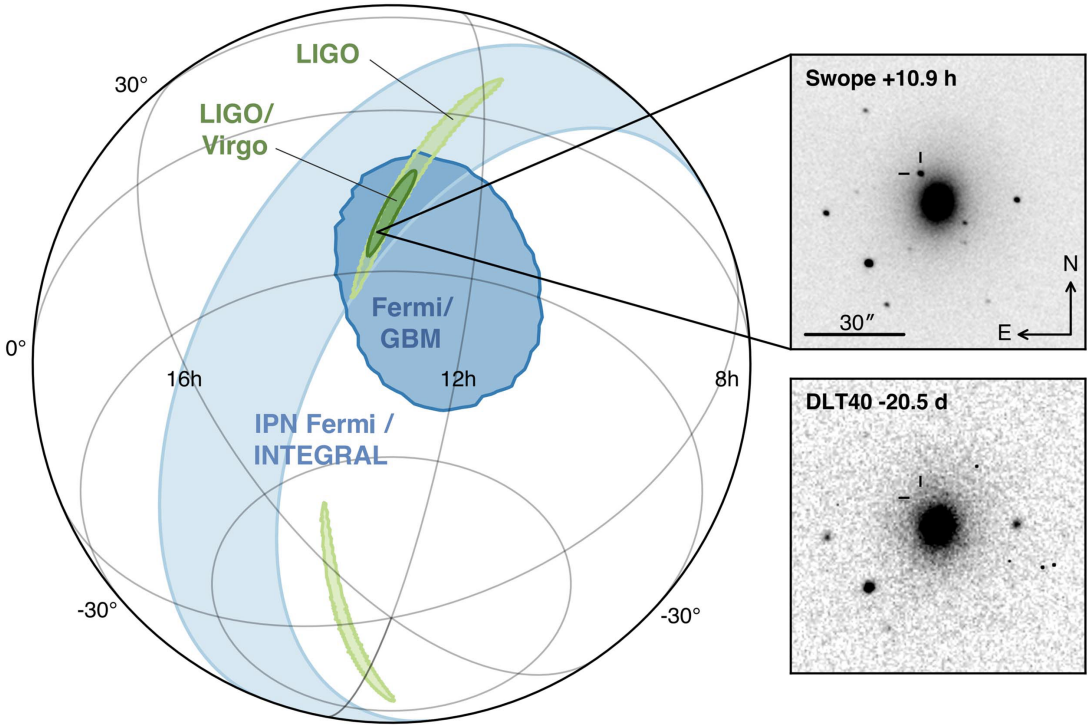


https://multimessenger.desy.de

Multi-messenger observation of a Binary Neutron Star Merger

physicsworld BREAKTHROUGH OF THE YEAR 2017

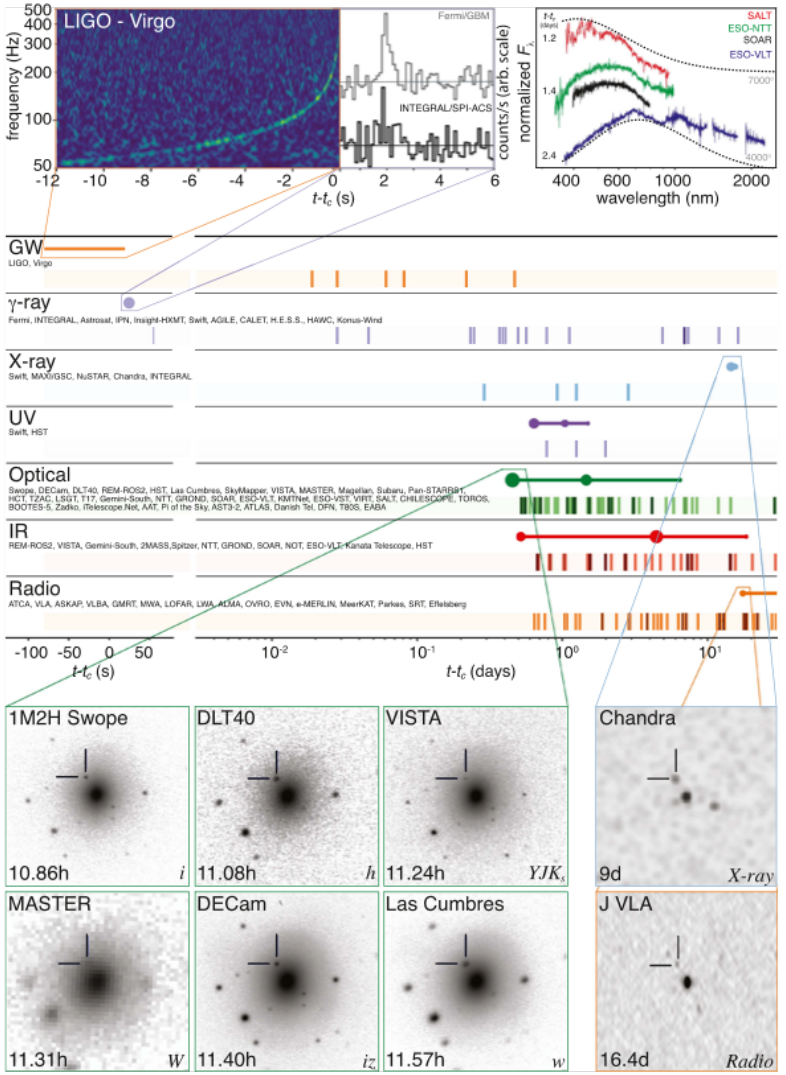
Joint publication of LIGO, VIRGO, INTEGRAL, Fermi, IceCube, Pierre Auger …



- Simultaneous observation of a Gravitational Wave + electromagnetic counter parts
- Allows to test the dynamics of our surrounding Universe
- Study of transient phenomena in all energy regions is one of the main ingredients

Multi-messenger observation of a Binary Neutron Star Merger

- Observe the same phenomenon with different instruments
- Follow the evolution in time
- Different wavelengths ⇒ different kind of interactions ⇒ different phenomena

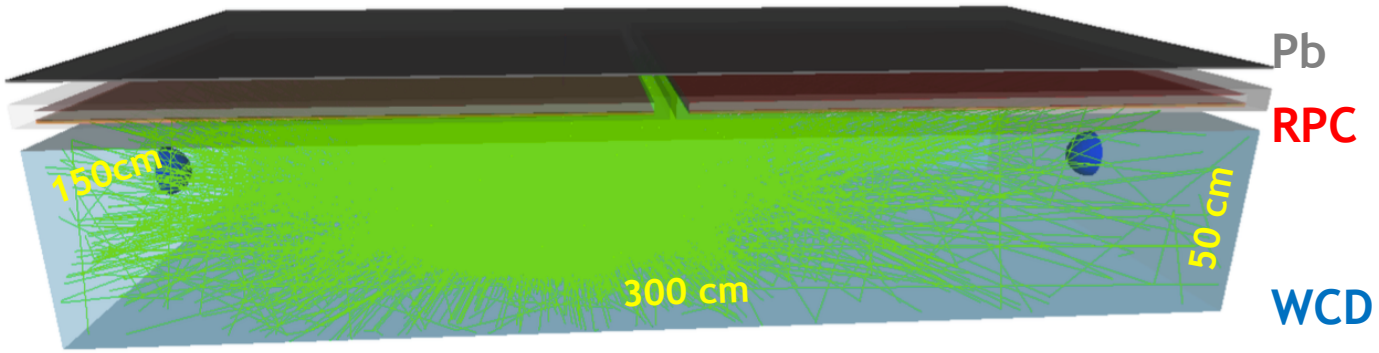


Summary

- Astroparticle physics (Multi-Messengers)
  - Use astrophysical messengers and known particle physics to gain a deeper understanding of the dynamics of our Universe
  - Rapidly evolving field
  - Lots of ambitious projects
  - Will soon provide important tests to our knowledge over fundamental physics

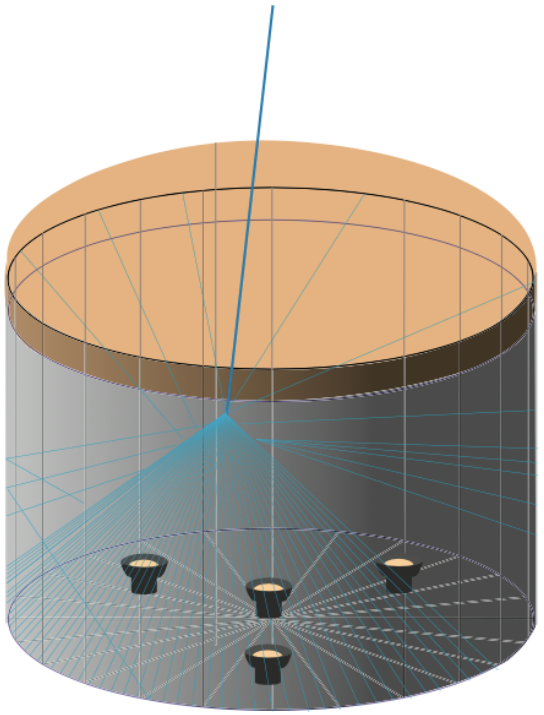
Backup slides

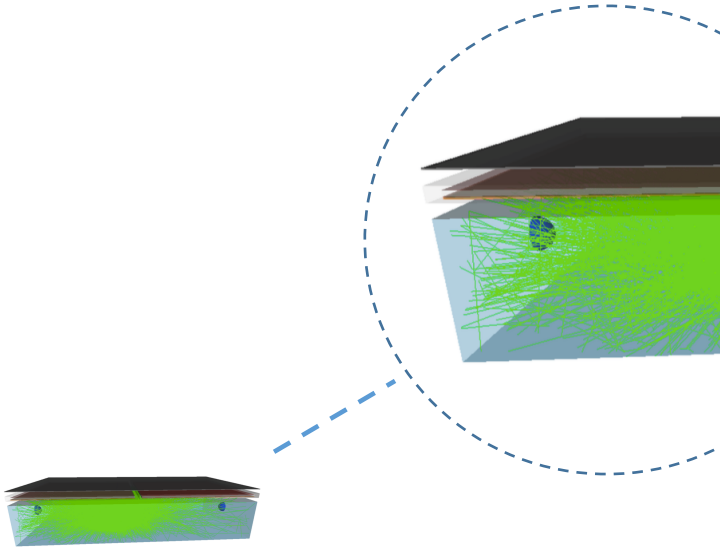
Improve detector concept!



- Thin lead converter plate **(Pb)**
  - Improve shower geometry reconstruction
- Resistive Plate Chamber **(RPC)**
  - Measure charged particles with high spatial and time resolution
- Water Cherenkov Detector **(WCD)**
  - Collect shower secondary photons/electrons to improve trigger at low energy

The station





HAWC
(present detector)

…
(next generation)

**caveat: R&D phase, which means that the detector concept continues to evolve…*