



LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Astroparticle Physics

LIP Summer Internships
July 12, 2022

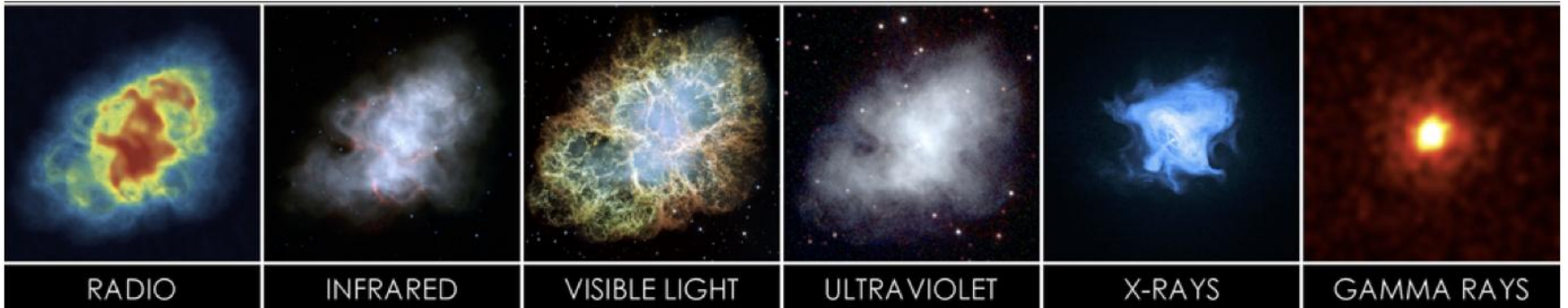
Raul Sarmento
raul@lip.pt

Summary

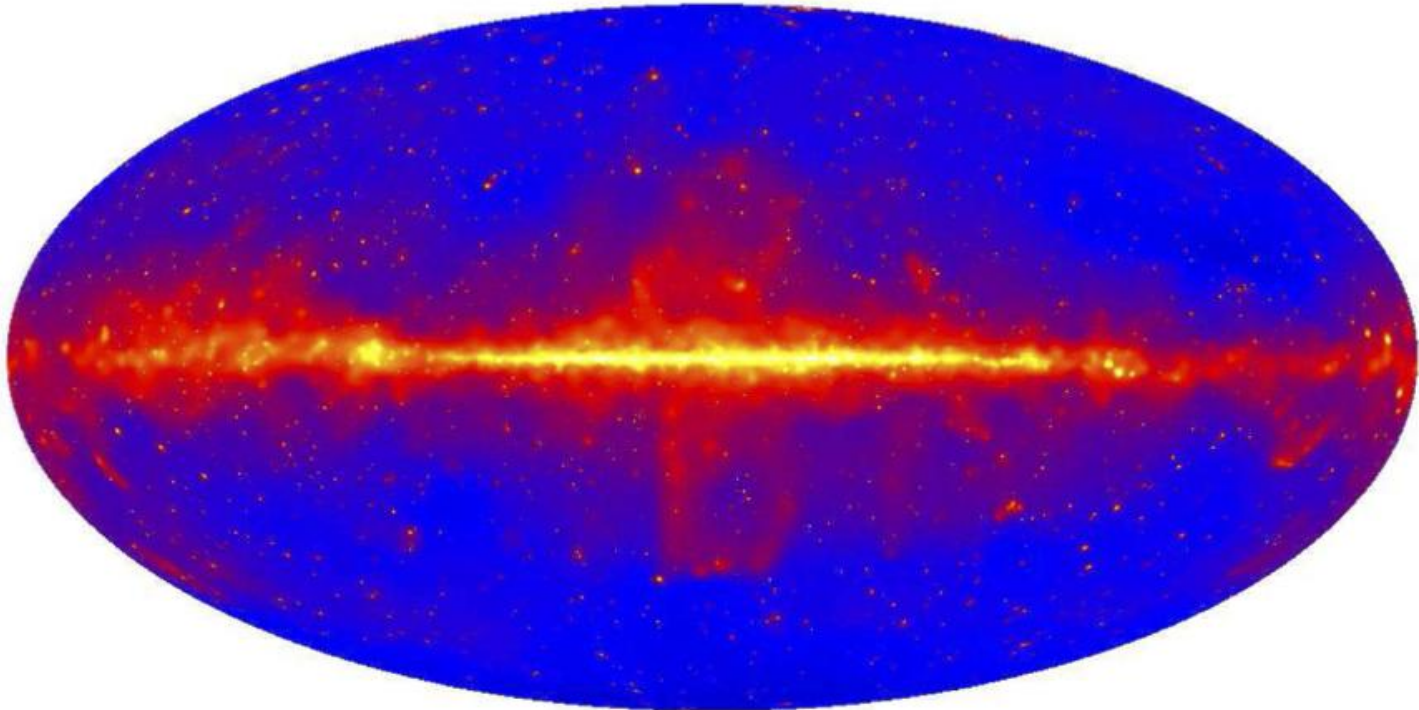
- What is astroparticle physics and why is it important?
- How do we observe astroparticles?
- Hot topic: multi-messenger astrophysical searches

Observing the Universe

crab nebula

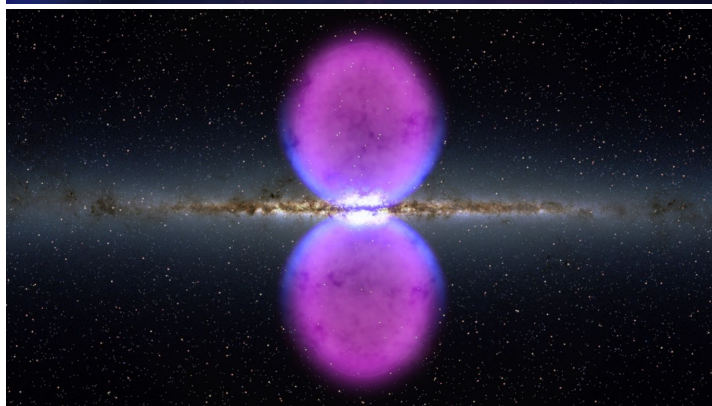


A map of the Universe in gamma rays



The high-energy Universe

AGN, GRB, Fermi bubbles

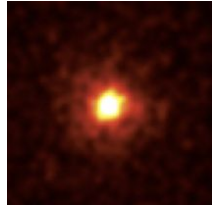


Energy scales photons

3 eV



300 000 000 000 eV

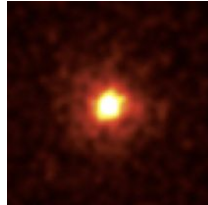


Energy scales charged particles

3 eV



300 000 000 000 eV



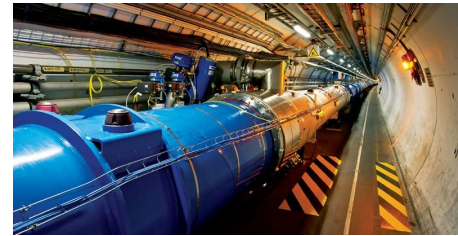
1.5 eV



10 000 eV



7 000 000 000 000 eV

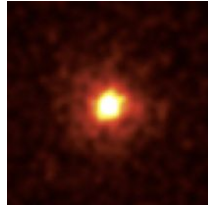


Energy scales cosmic accelerators

3 eV



300 000 000 000 eV



1 000 000 000 000 000 eV

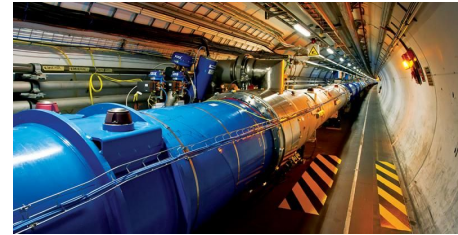
1.5 eV



10 000 eV



7 000 000 000 000 eV



Energy scales cosmic accelerators

1.5 eV



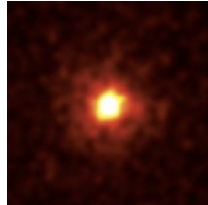
3 eV



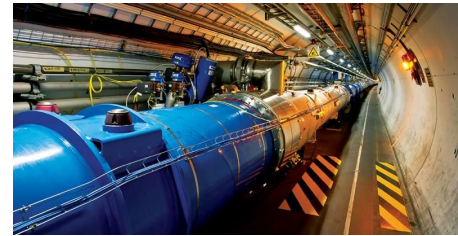
10 000 eV



300 000 000 000 eV

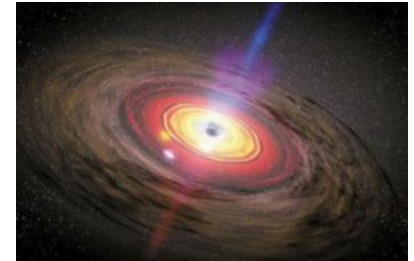


7 000 000 000 000 eV



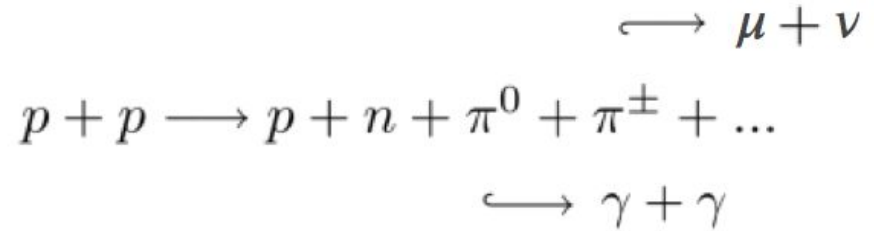
1 000 000 000 000 000 eV

ultra-high energy cosmic rays
100 000 000 000 000 000 000 eV



Astroparticle physics

what it is



Study of particles with cosmic origin:

- charged particles (cosmic rays)
 - gamma rays
 - neutrinos
- + gravitational waves

Astroparticle physics

scientific relevance

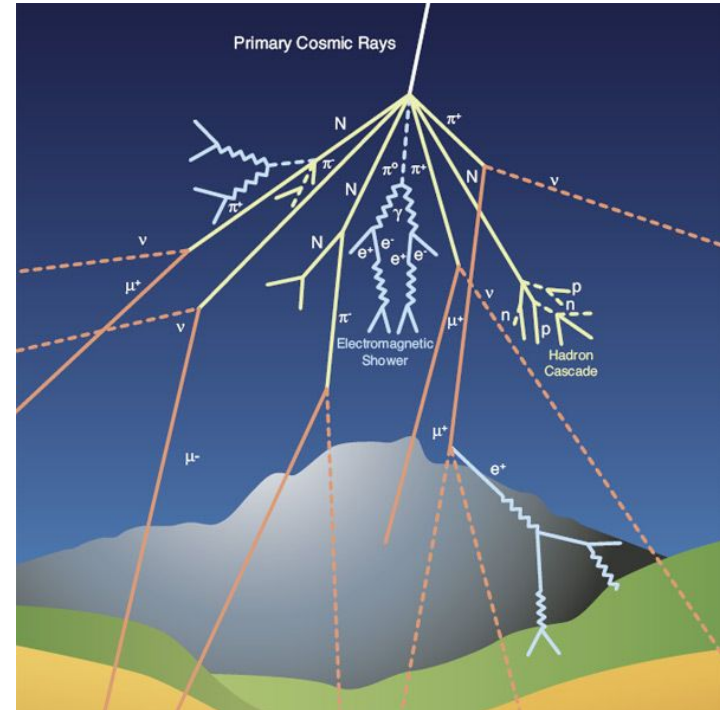
- Production mechanisms of highest energy particles
- Modelling of astrophysical sources
- Searches for new physics phenomena (dark matter, magnetic monopoles)
- Fundamental particle physics (neutrino oscillations)
- ...

Cosmic rays an accidental discovery

*atomic nuclei are
raining on Earth*

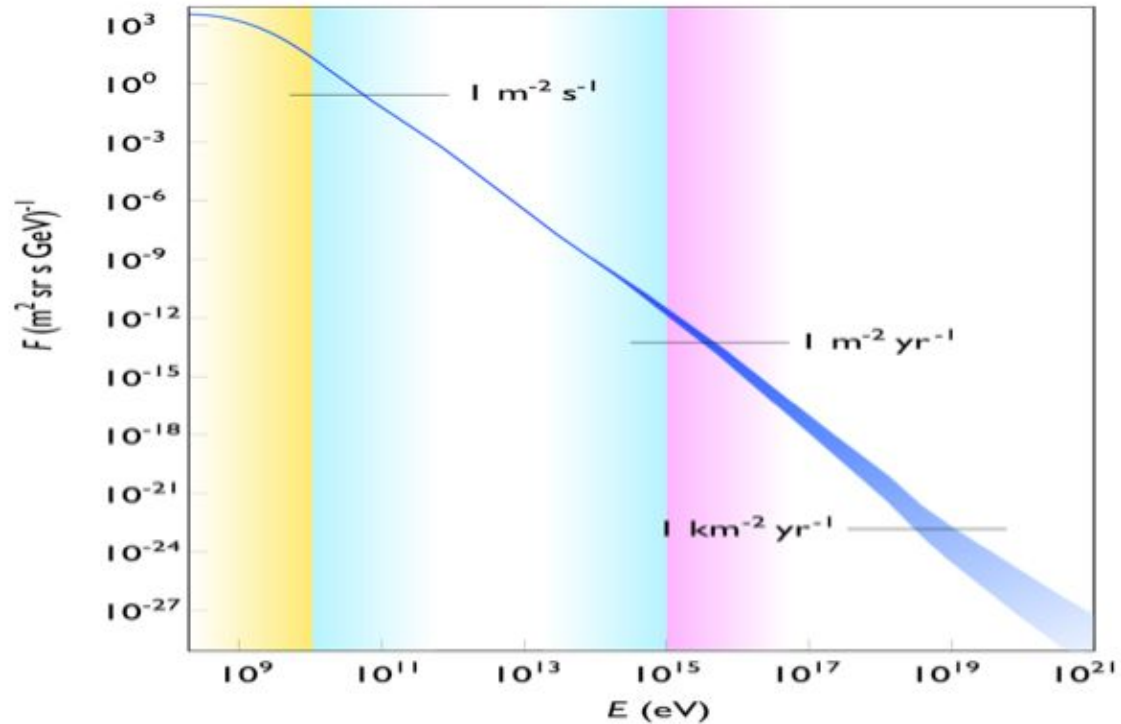


Cosmic rays atmospheric particle showers



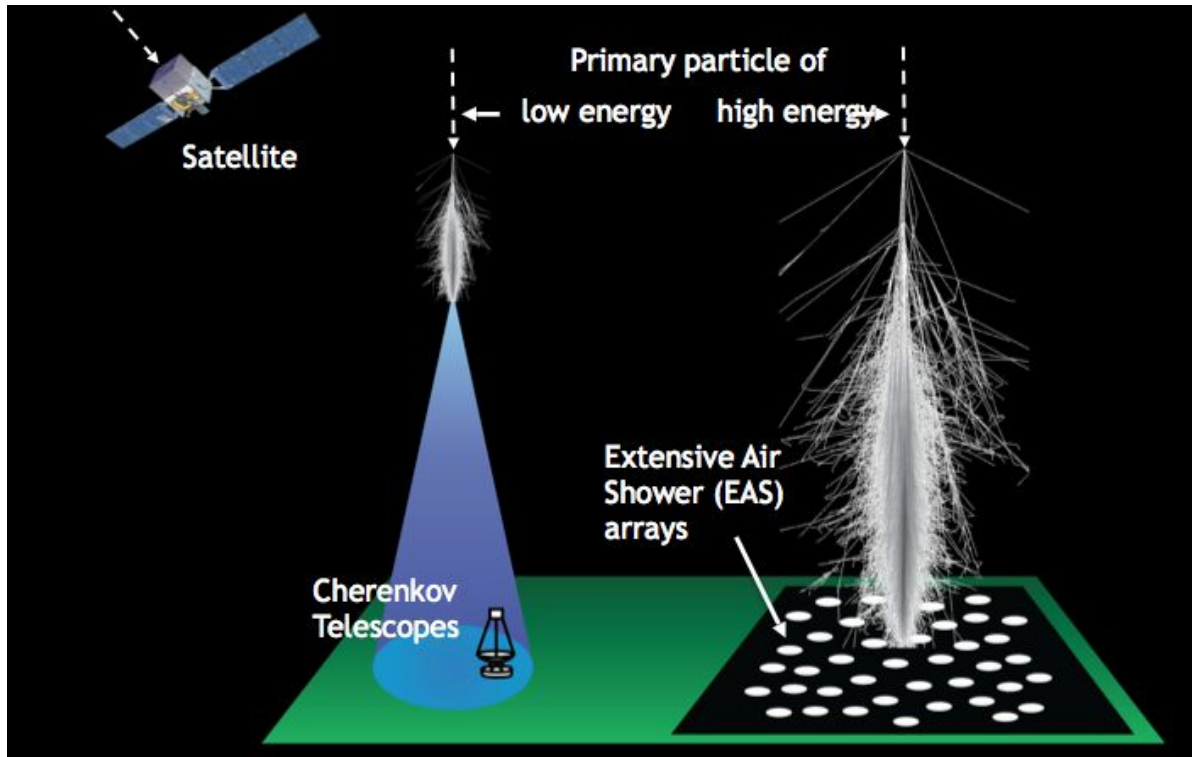
Cosmic rays

more energetic, more rare



Cosmic rays

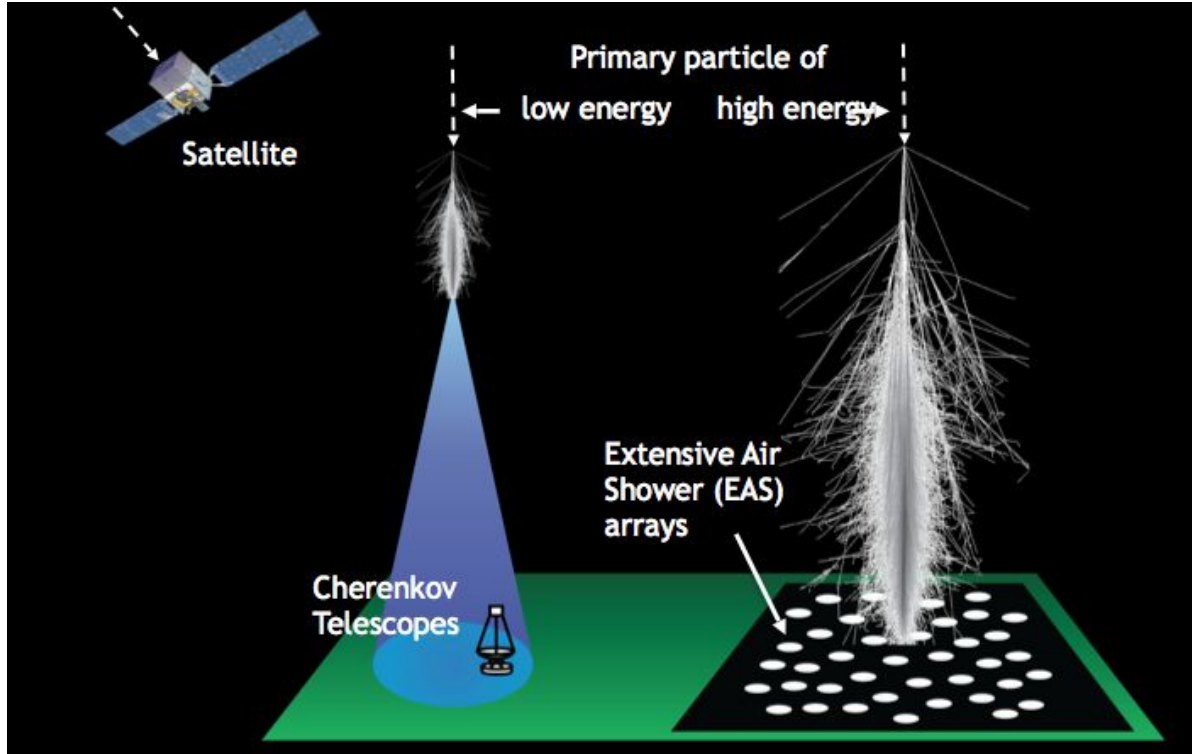
how to observe them?



Cosmic rays

how to observe them?

AMS



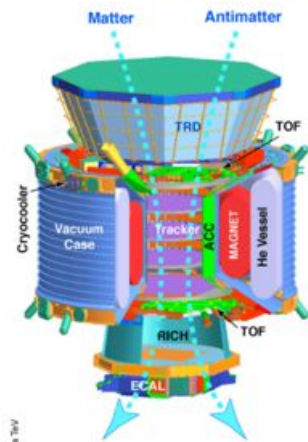
SWGO
Auger

Low-energy cosmic rays

AMS



Alpha Magnetic Spectrometer

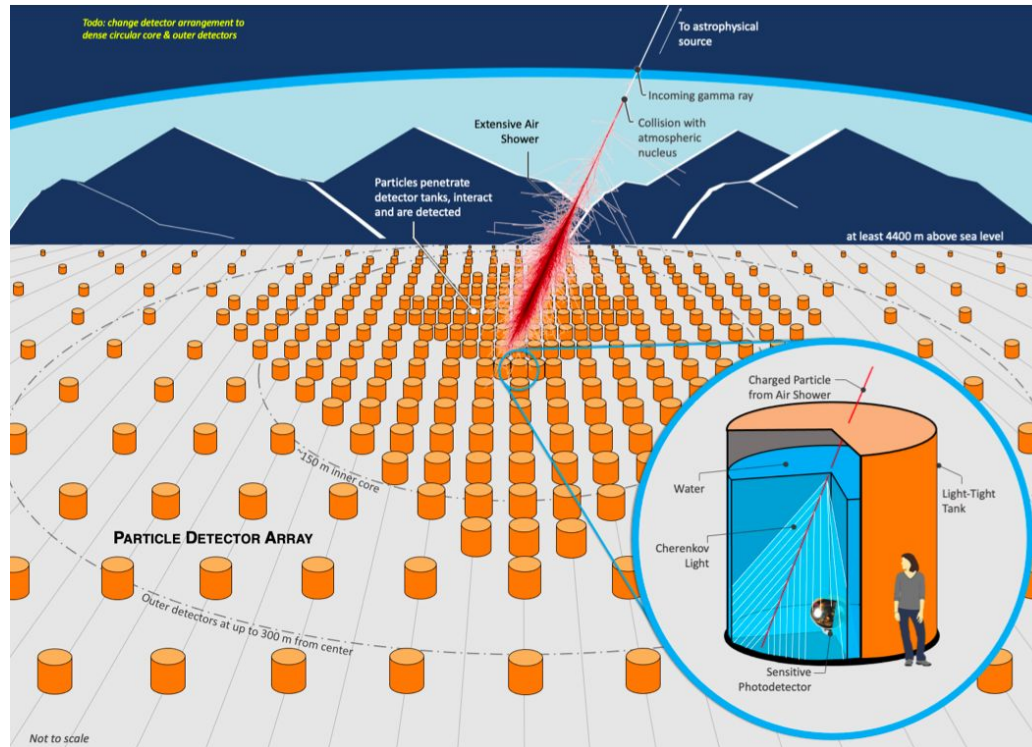


300,000 channels of electronics $\Delta t = 100 \text{ ps}$, $\Delta x = 10 \mu$

0.3 TeV	e^-	e^+	P	$\bar{\text{He}}$	γ
TRD					
TOF					
Tracker					
RICH					
Calorimeter					

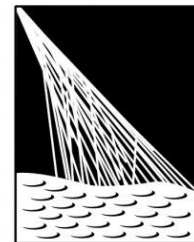
Very-high energy gamma rays SWGGO

*in the phase
of design*



Ultra-high energy cosmic rays

Pierre Auger Observatory



PIERRE
AUGER
OBSERVATORY

More than 500 members from 16 countries

Argentina
Australia
Brasil
Colombia*
Czech Republic
France
Germany
Italy
Mexico
Netherlands
Poland
Portugal
Romania
Slovenia
Spain
USA

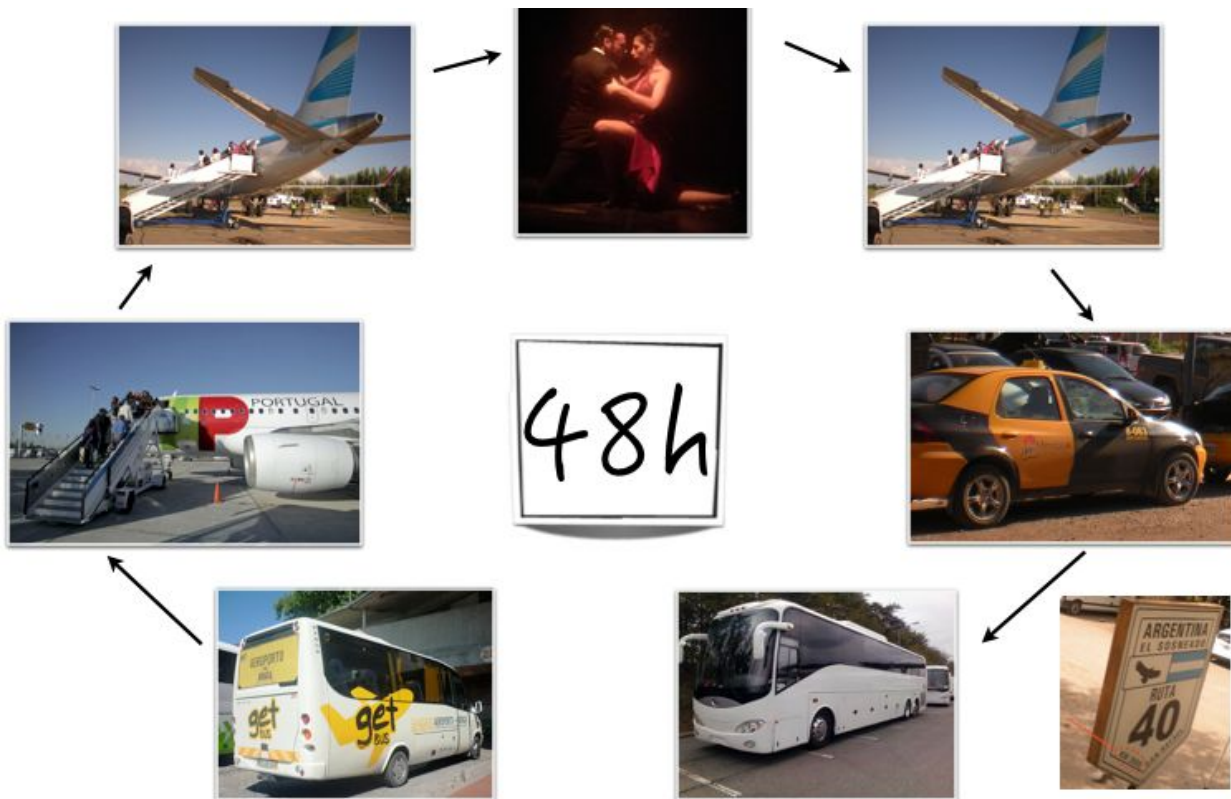
*associated



■ Full members
■ Associate members



Pierre Auger Observatory



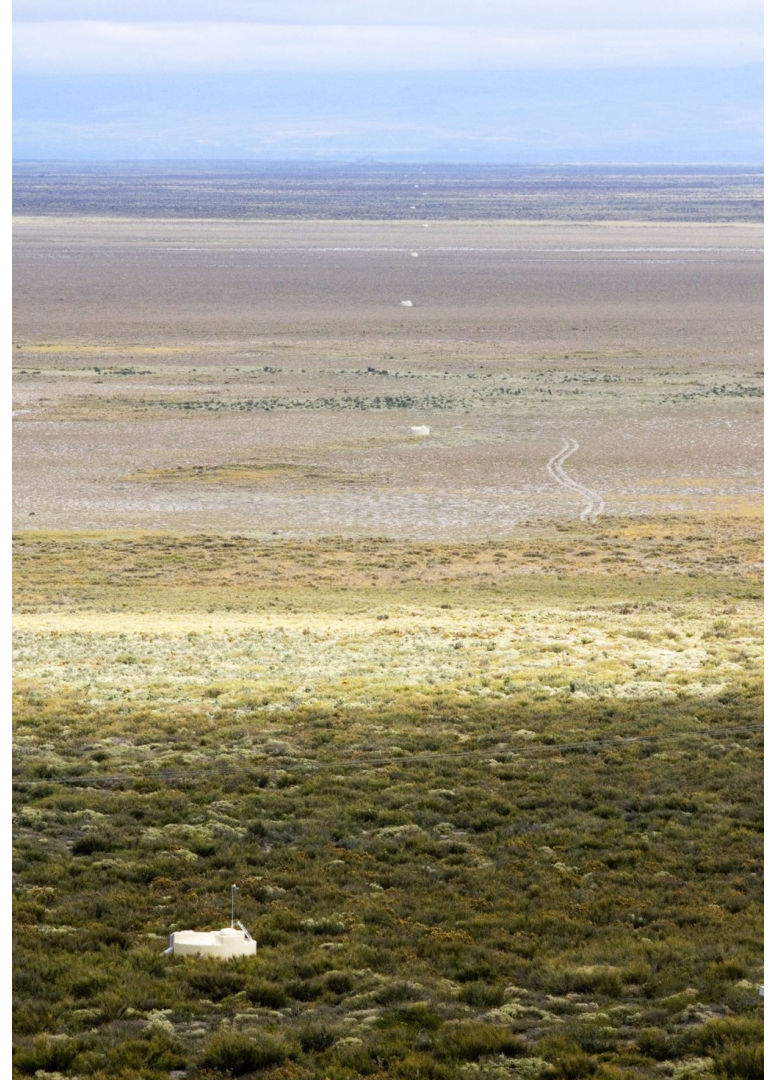
Braga, Portugal

Malargue, Argentina

Pierre Auger Observatory with the size of Minho



1661 tanks
3000 km²



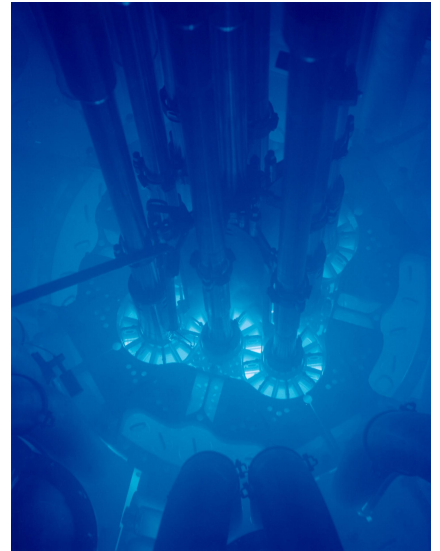
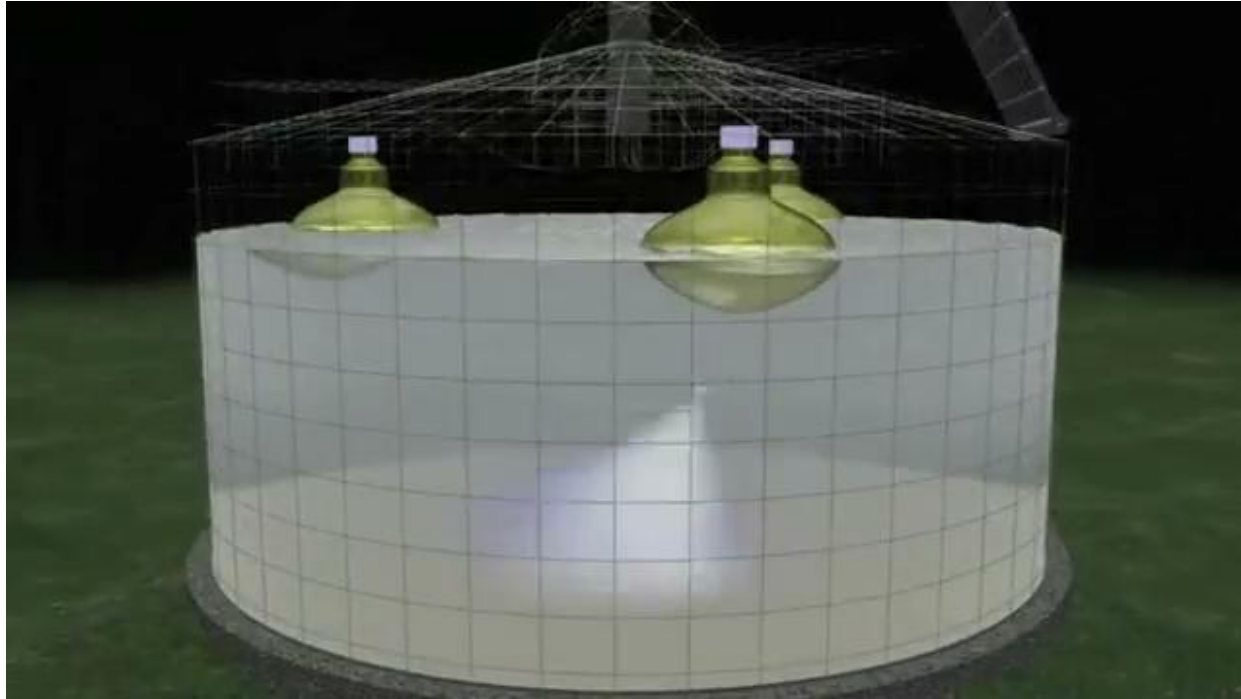
Pierre Auger Observatory
phdcomics.com



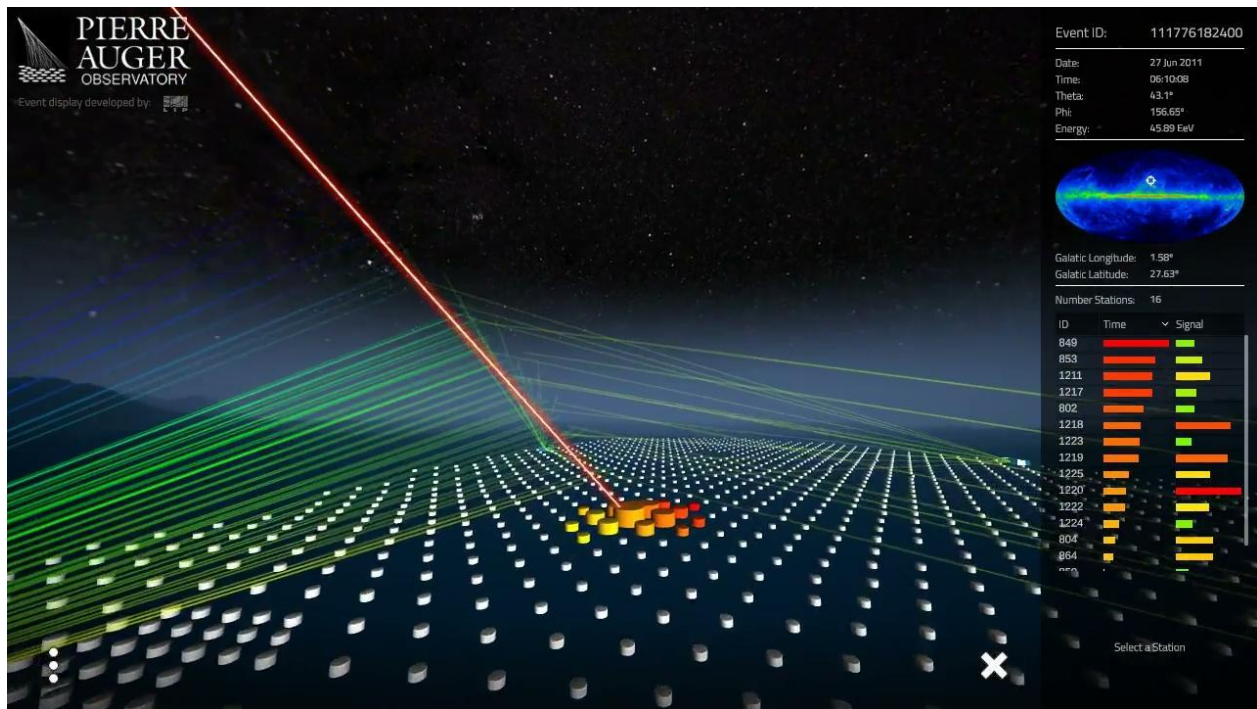
Particle Physics with Cows



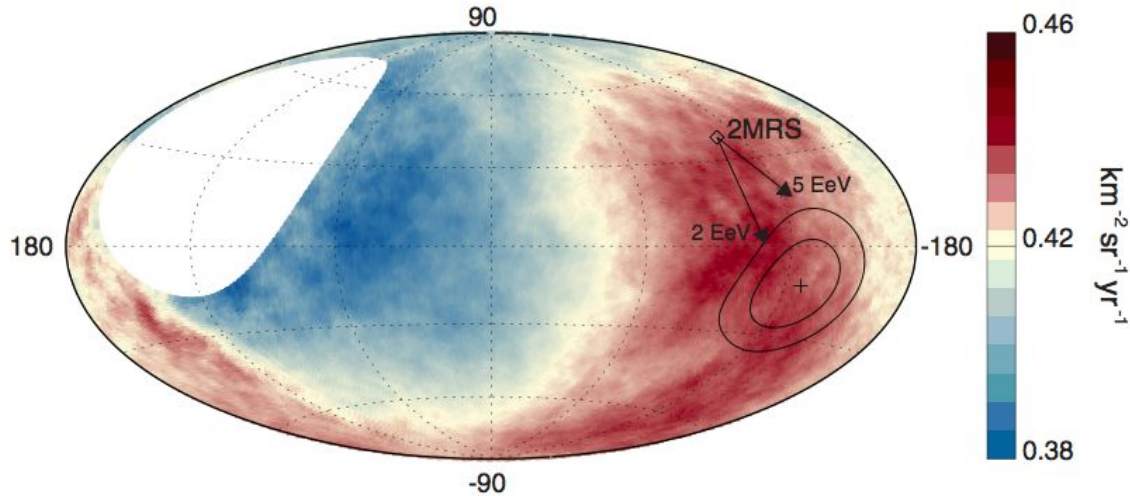
Pierre Auger Observatory water-Cherenkov tanks



Pierre Auger Observatory visualizing events



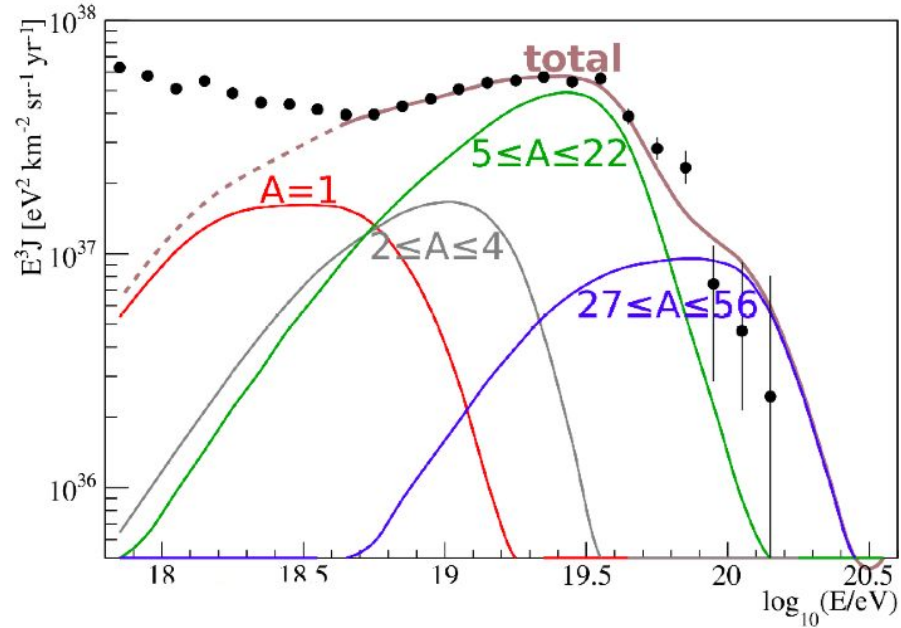
Pierre Auger Observatory new discoveries



extragalactic origin



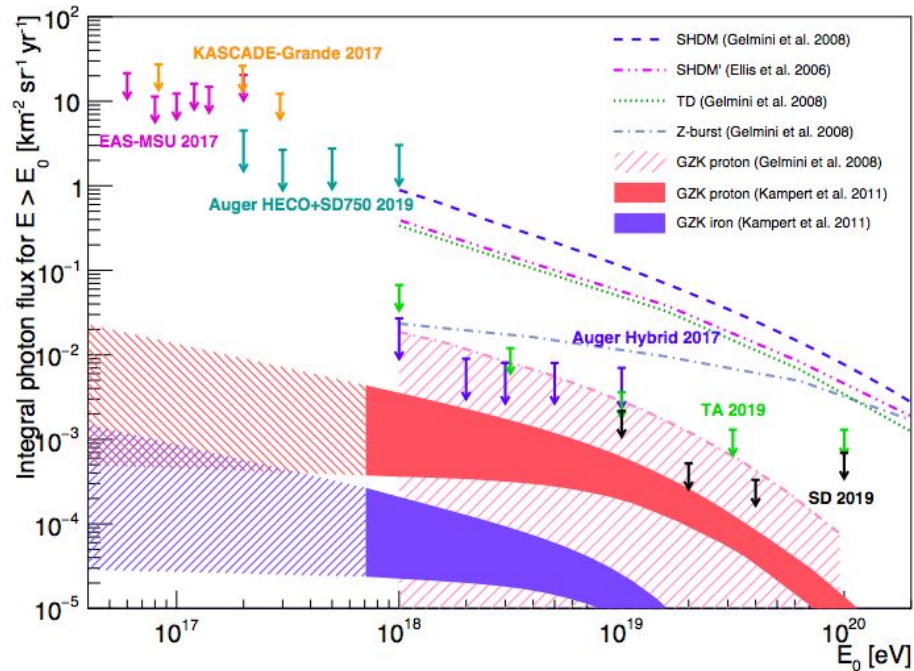
Pierre Auger Observatory new questions



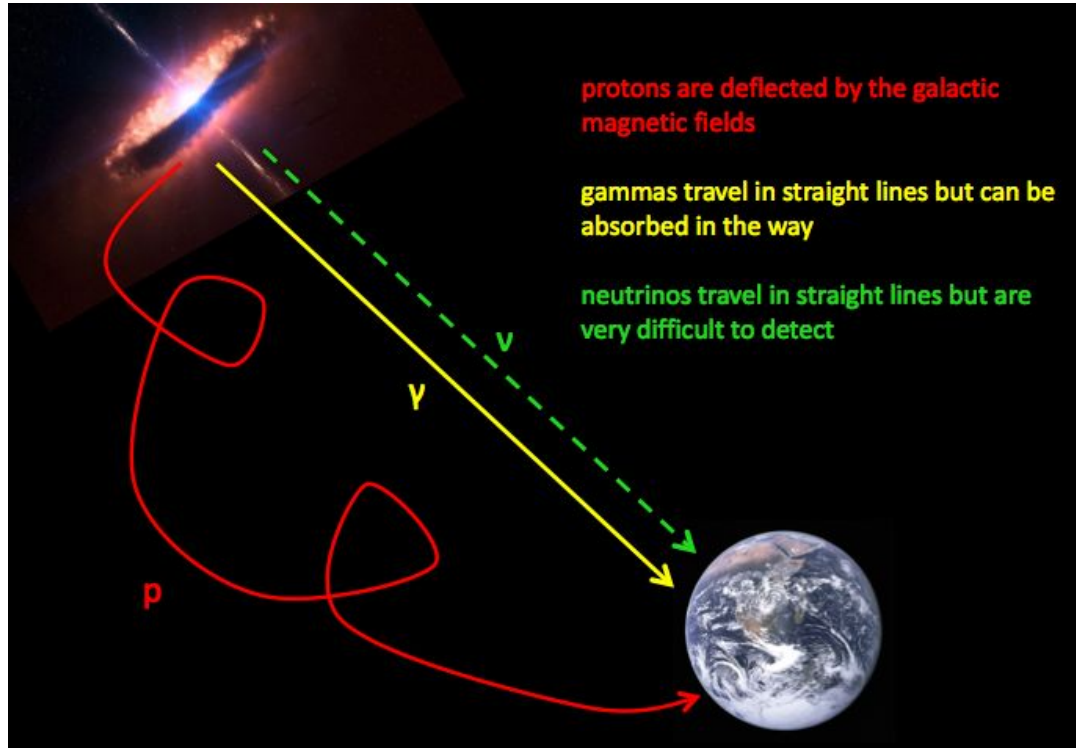
higher energy, heavier nuclei

Pierre Auger Observatory fundamental physics in the sky

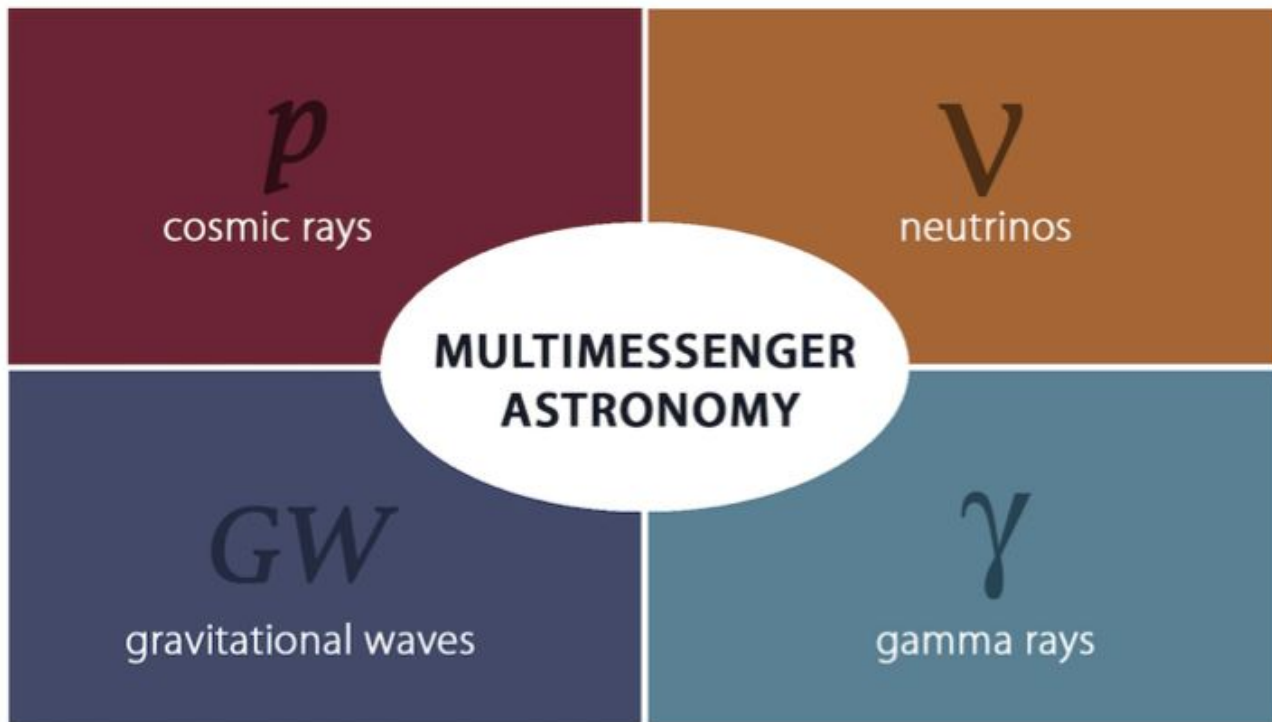
super heavy
dark matter?



Astroparticles no ideal messengers



Astroparticles welcoming gravitational waves



Multi-messenger astrophysics

historical observations

- Observing the same source emitting different particles for complementary information on their origin
1. **Sun:** photons + cosmic rays
 2. **Sun:** photons + neutrinos
 3. **Supernova 1987A:** neutrinos + photons
 4. **Binary neutron star merger GW170817:** gravitational waves + photons

Multi-messenger astrophysics binary neutron star merger

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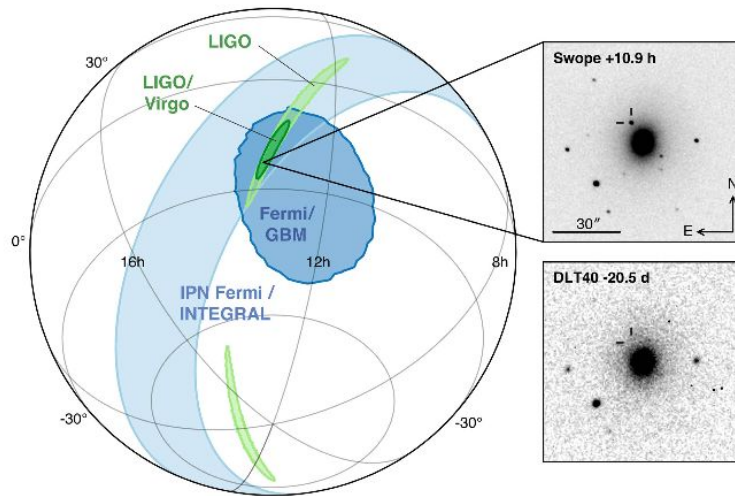


Multi-messenger Observations of a Binary Neutron Star Merger

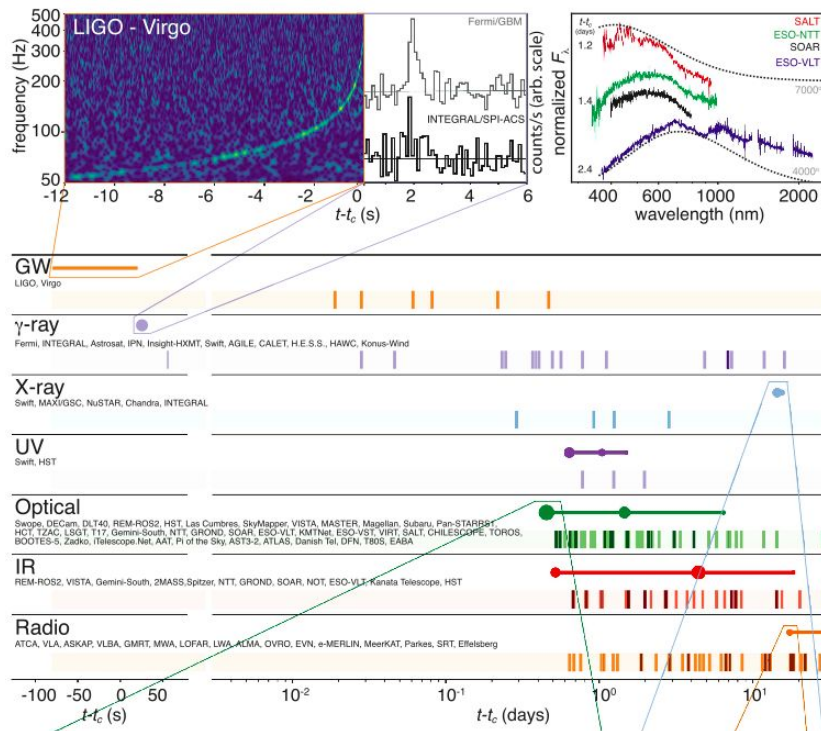
LIGO Scientific Collaboration and Virgo Collaboration, Fermi GBM, INTEGRAL, IceCube Collaboration, AstroSat Cadmium Zinc Telluride Imager Team, IPN Collaboration, The Insight-Hxmt Collaboration, ANTARES Collaboration, The Swift Collaboration, AGILE Team, The 1M2H Team, The Dark Energy Camera GW-EM Collaboration and the DES Collaboration, The DLT40 Collaboration, GRAWITA: GRAvitational Wave Inaf TeAm, The Fermi Large Area Telescope Collaboration, ATCA: Australia Telescope Compact Array, ASKAP: Australian SKA Pathfinder, Las Cumbres Observatory Group, OzGrav, DWF (Deeper, Wider, Faster Program), AST3, and CAASTRO Collaborations, The VINROUGE Collaboration, MASTER Collaboration, J-GEM, GROWTH, JAGWAR, Caltech-NRAO, TTU-NRAO, and NuSTAR Collaborations, Pan-STARRS, The MAXI Team, TZAC Consortium, KU Collaboration, Nordic Optical Telescope, ePESSTO, GROND, Texas Tech University, SALT Group, TOROS: Transient Robotic Observatory of the South Collaboration, The BOOTES Collaboration, MWA: Murchison Widefield Array, The CALET Collaboration, IKI-GW Follow-up Collaboration, H.E.S.S. Collaboration, LOFAR Collaboration, LWA: Long Wavelength Array, HAWC Collaboration, The Pierre Auger Collaboration, ALMA Collaboration, Euro VLBI Team, Pi of the Sky Collaboration, The Chandra Team at McGill University, DFN: Desert Fireball Network, ATLAS, High Time Resolution Universe Survey, RIMAS and RATIR, and SKA South Africa/MeerKAT
(See the end matter for the full list of authors.)

Binary neutron star merger GW170817 in LIGO/Virgo

*no neutrino
counterpart*



Binary neutron star merger photon counterparts

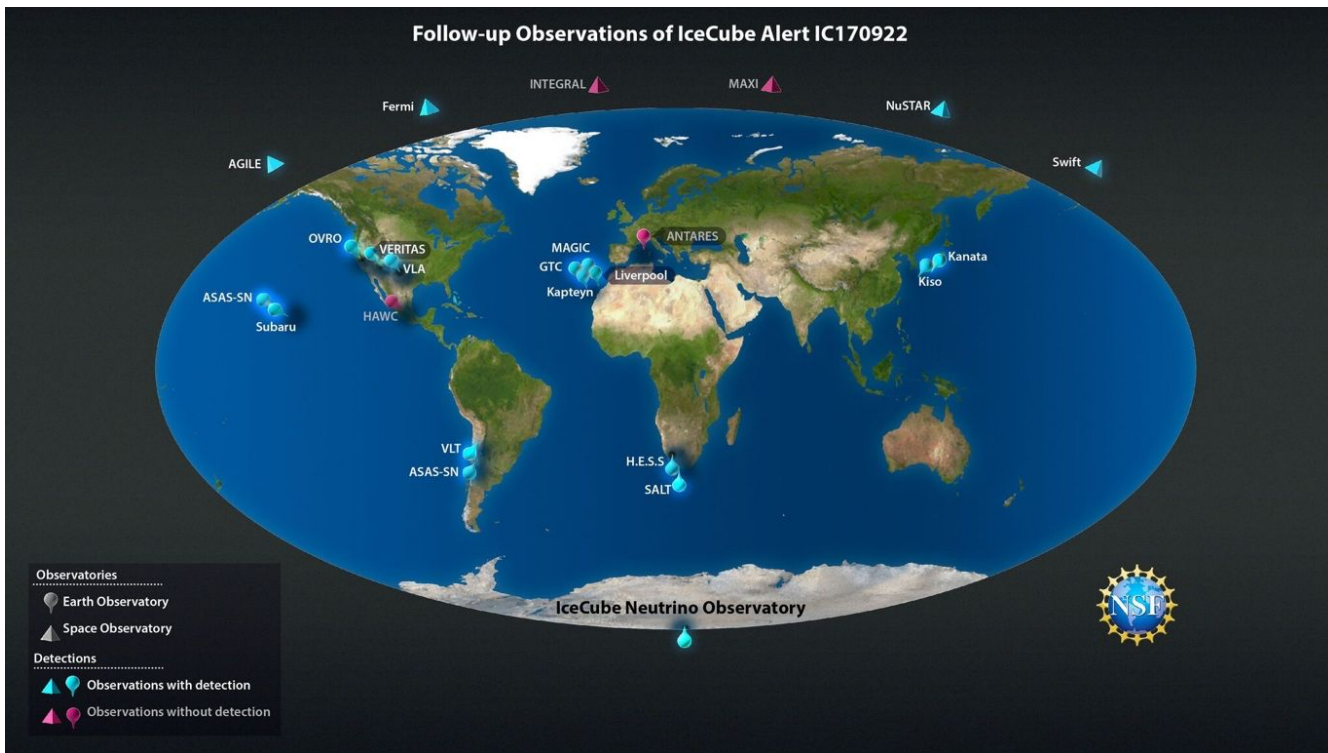


Binary neutron star merger

multiple discoveries

- sources of gravitational waves; constraints on their velocity
- linked to short Gamma Ray Bursts (sGRB)
- linked to kilonovas: origin of heavy elements in the Universe
- constraints on the state equation of neutron stars

Multi-messenger astrophysics a planetary observatory



Thanks for the attention!

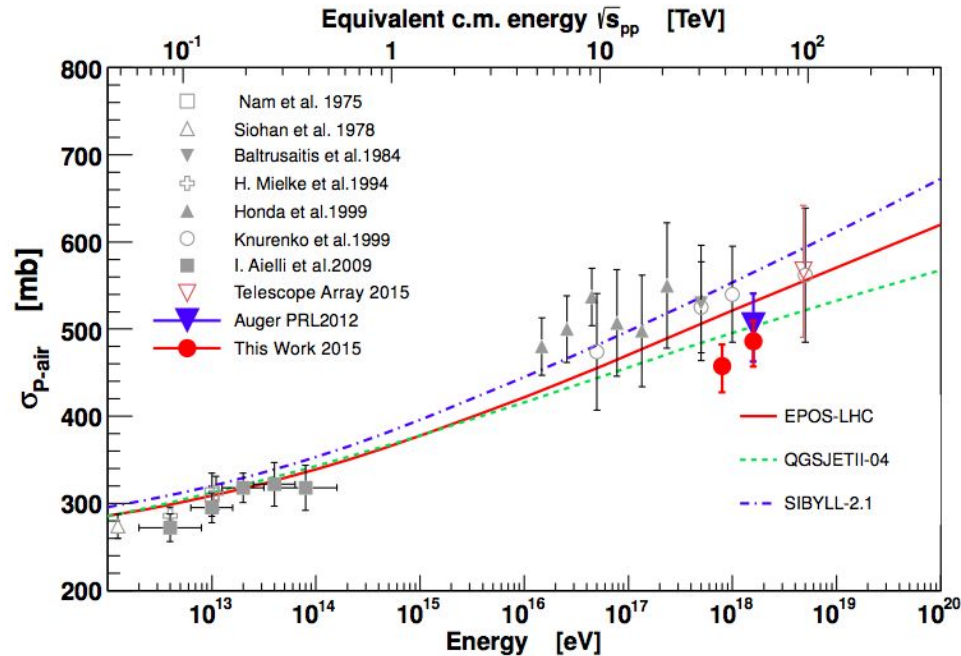
Questions?

You may contact me at:

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Pierre Auger Observatory fundamental physics in the sky

collisions
above
100 TeV



IceCube Observatory

no neutrino counterparts found

