Quels enjeux scientifiques pour le rayonnement cosmique ?

Devenir du rayonnement cosmique au LPSC ?

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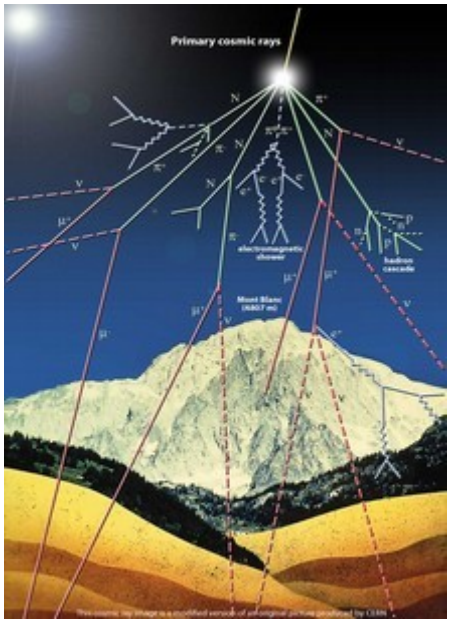
Journées prospectives du LPSC
Autrans - 1er juin 2015

1. Introduction to Cosmic Rays (CR)
2. Astrophysics and new physics with CRs
3. Ongoing and future experiments
4. AMS-02/CREAM and AUGER @ LPSC
5. Conclusions

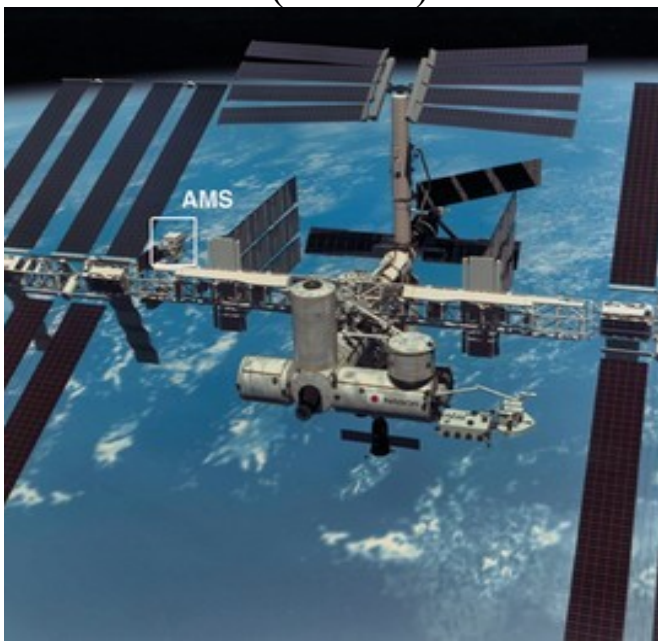
A brief history of cosmic rays

Mountain altitude < 5 km



CREAM balloon ~ 40 km

AMS-02 (on ISS) ~ 300 km



CR discovery

Extensive showers

e^-, e^+

Diffuse γ

$\overline{p}$

TeV astronomy

ν

$\overline{d}$?

1910 — 1930 — 1950 — 1980 — 2000

e^+, μ, π , K, Λ

Elements up to U

^{10}Be - ^{54}Mn

Cosmic rays = Particle physics

Particle physics Astrophysics

+ Astroparticle physics

Multi-messengers: spectra and anisotropies

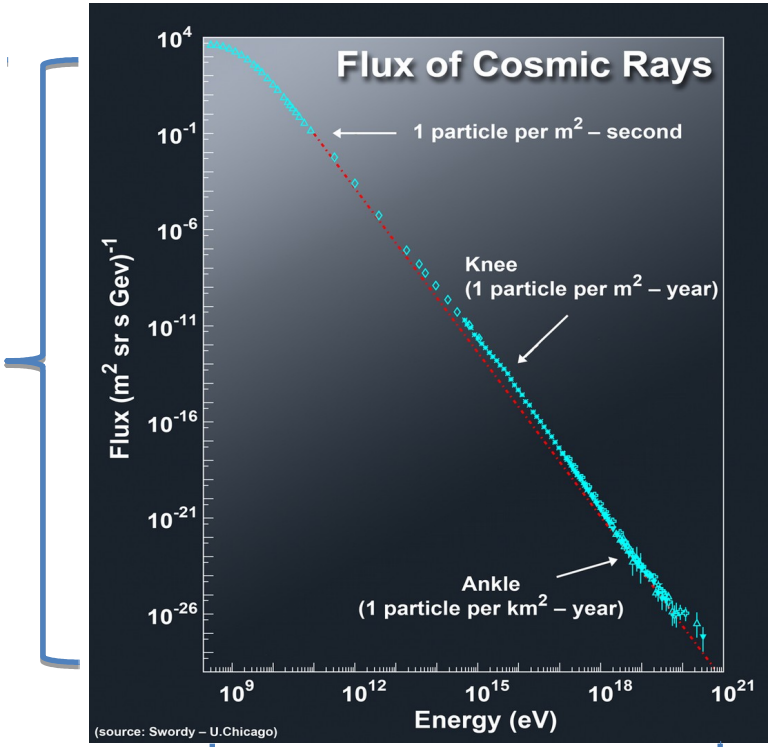
Two categories

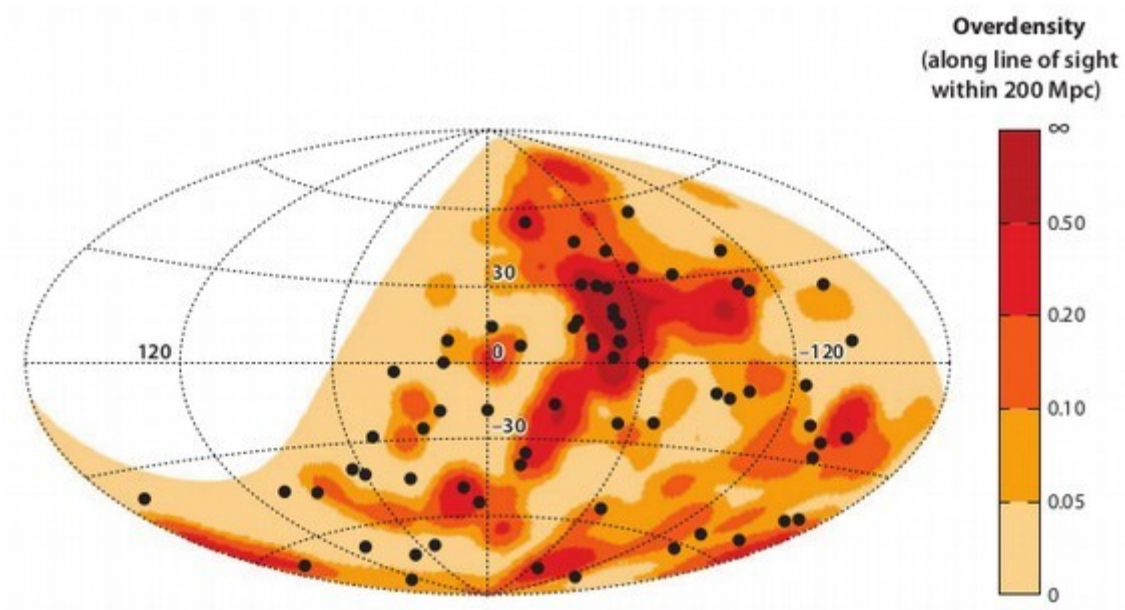
- Neutral species
  - ✓ Gamma-rays
  - ✓ Neutrinos
- Charged cosmic rays
  - ✓ Leptons
  - ✓ Nuclei

Observation type

→ Astronomy: point-like, extended, diffuse emissions

→ Fuzzy (deflection in B fields): spectra and anisotropy maps

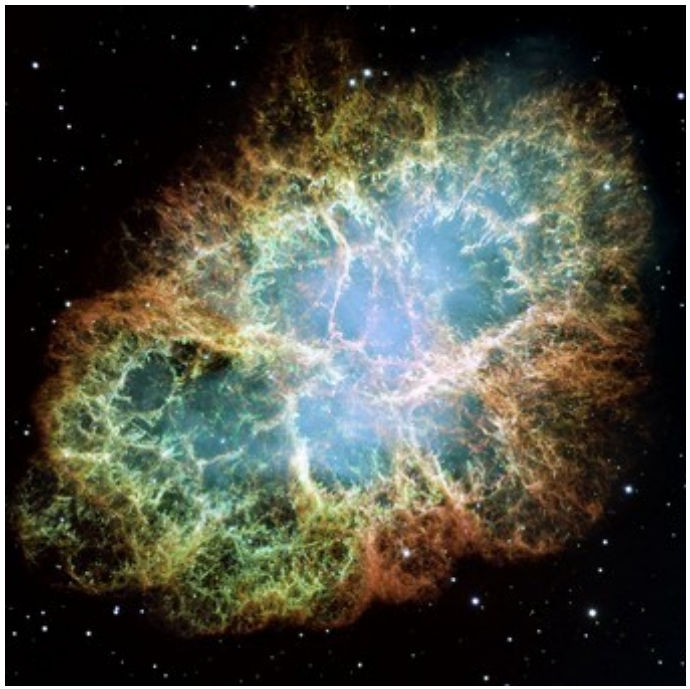




→ Multi-messenger approaches
→ Multi-wavelength observations

Extreme phenomena: sources of (extra-)galactic CRs?

Crab nebula

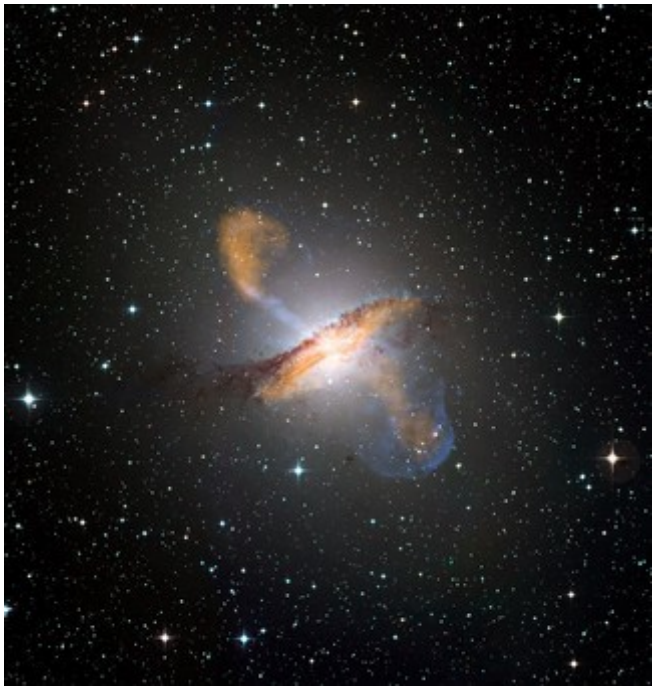


Galactic scale

- Pulsars
- Supernovae
- ...

→ $E_{max} \sim 10^{15}$ eV

Centaurus A



Extra-galactic scale

- Gamma-ray bursts
- Quasars
- Active Galaxy Nuclei (AGN)

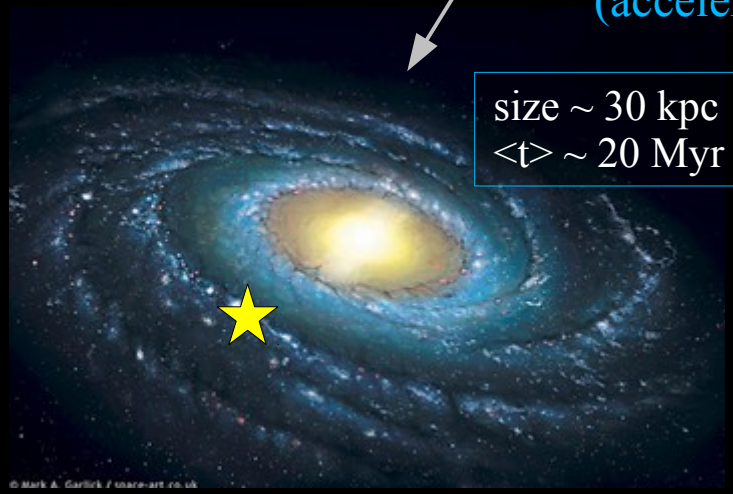
→ $E_{max} \sim 10^{20}$ eV

→ One century after their discovery, we still lack a clear evidence of what are the sources for the observed CR spectrum

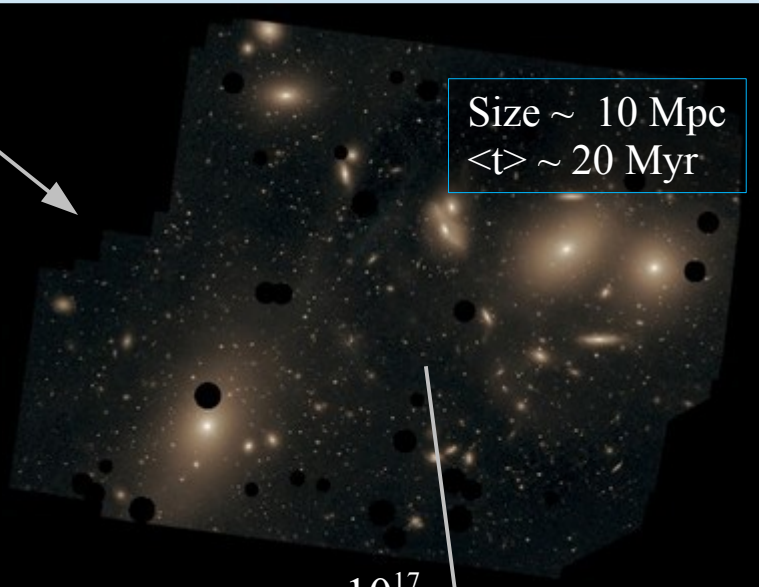
Typical scales and timescales

Galactic cosmic rays or extra-galactic

→ Spectra and abundances
(acceleration and transport)



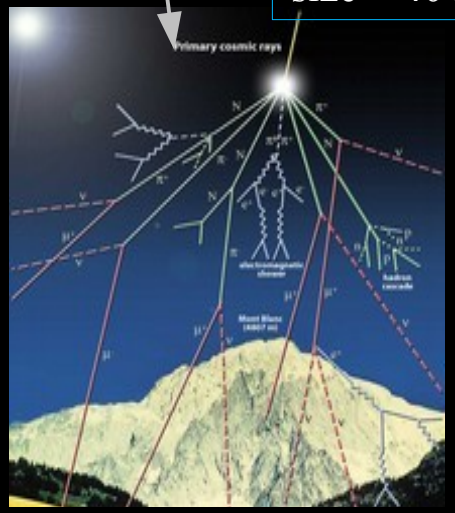
size ~ 30 kpc
<t> ~ 20 Myr



Size ~ 10 Mpc
<t> ~ 20 Myr

x 10^{17}

size ~ 40 km



Atmospheric showers

→ Ground-based detection
→ Solar activity monitoring
[N.B.: Čerenkov flash ~ 10^{-8} s]

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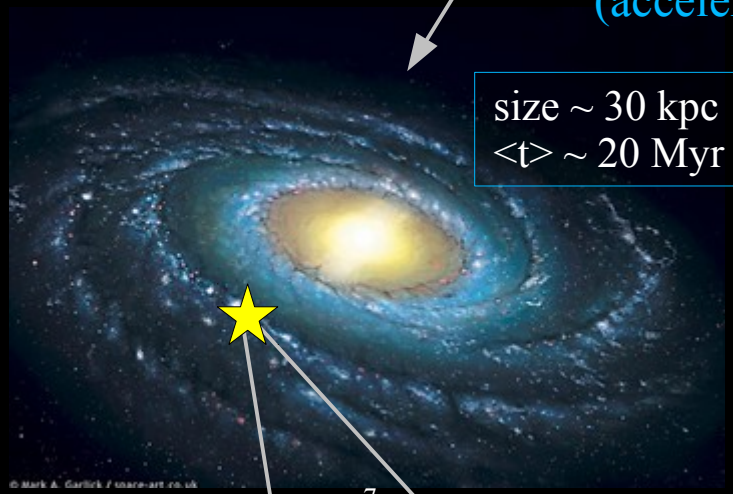
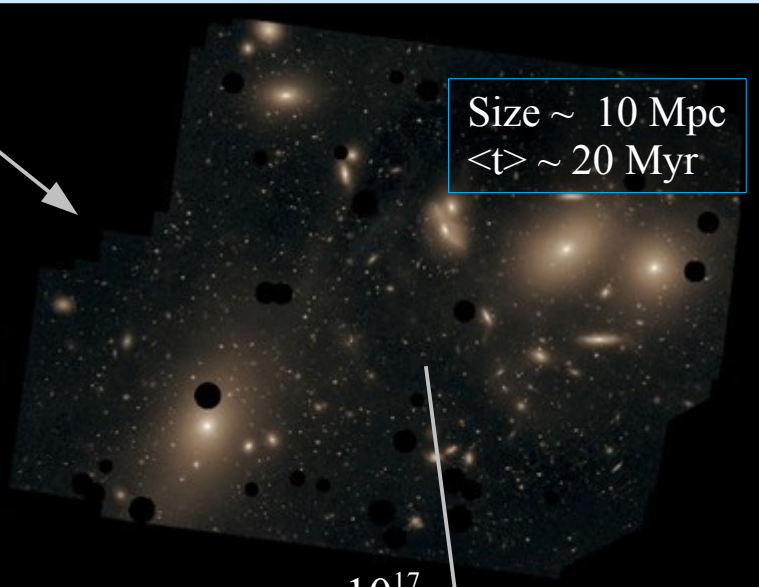


size ~ 30 kpc
<t> ~ 20 Myr



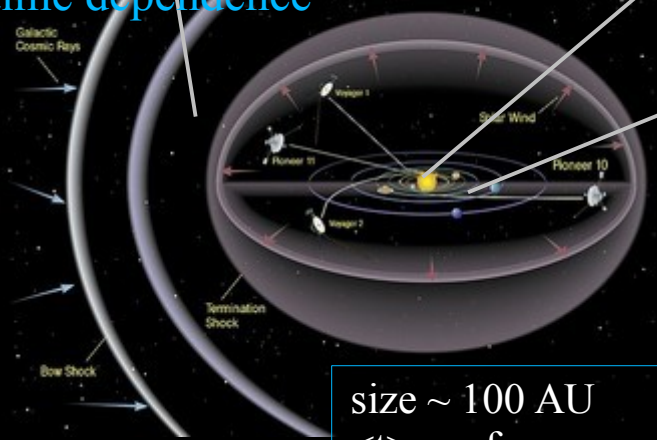
Size ~ 10 Mpc
<t> ~ 20 Myr

x 10^{17}

x 10^{7}

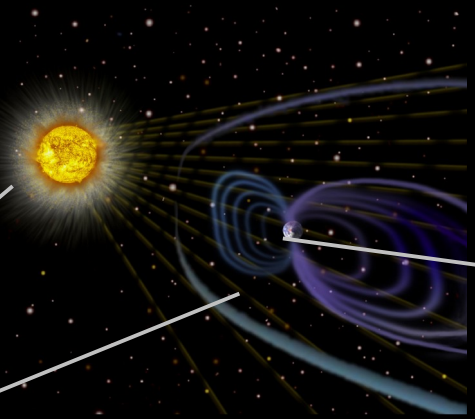
Transport in the Solar cavity

→ flux modulation < 10 GeV/n
→ time dependence



size ~ 100 AU
<t> ~ a few years

x 10^{5}



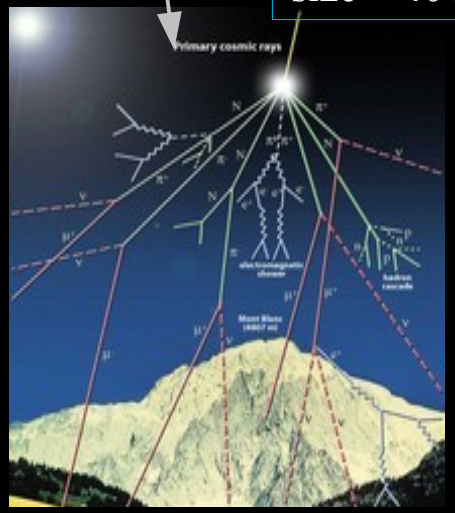
Earth magnetic shield

→ Cut-off rigidity for detectors

size ~ 10^{4} km

x 10^{2}

size ~ 40 km



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   - Galactic Cosmic Rays and γ-rays
   - High Energy Cosmic Rays
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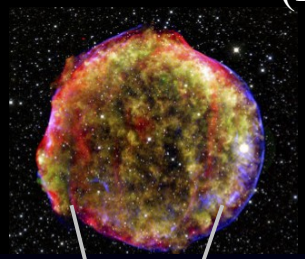
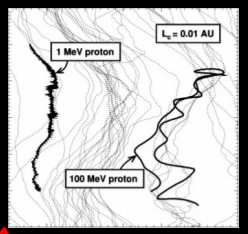
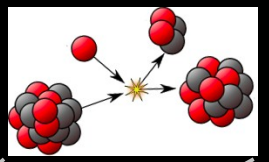
Galactic cosmic rays: astrophysics and dark matter

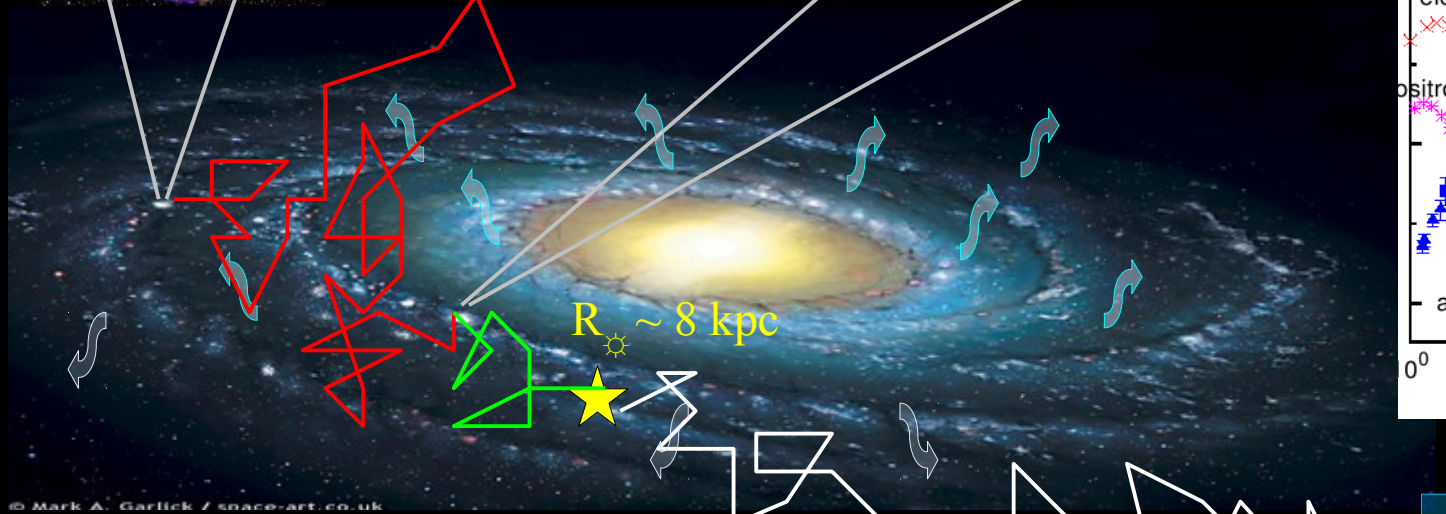
(MHD)



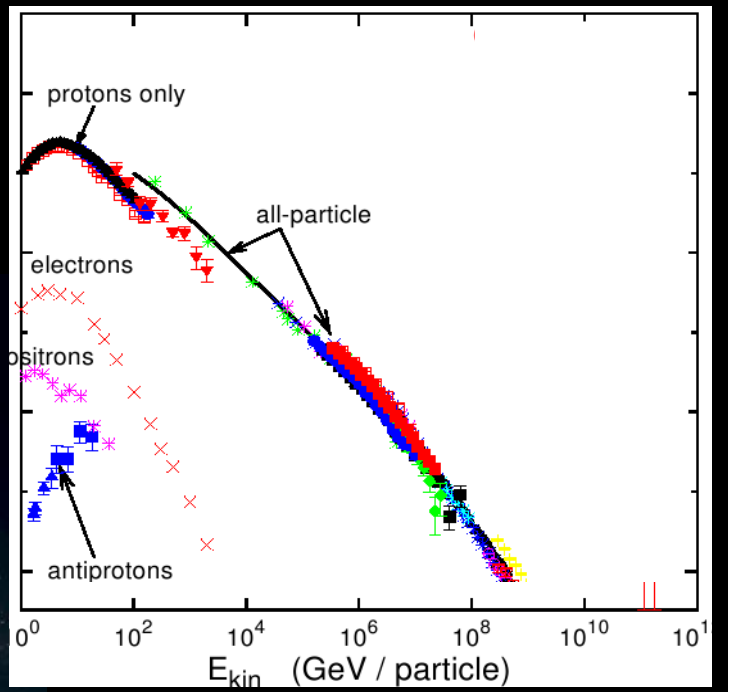


(nuclear physics)





(astrophysics + particle physics)



Dark matter halo
- ~ spherical
- radius ~300 kpc

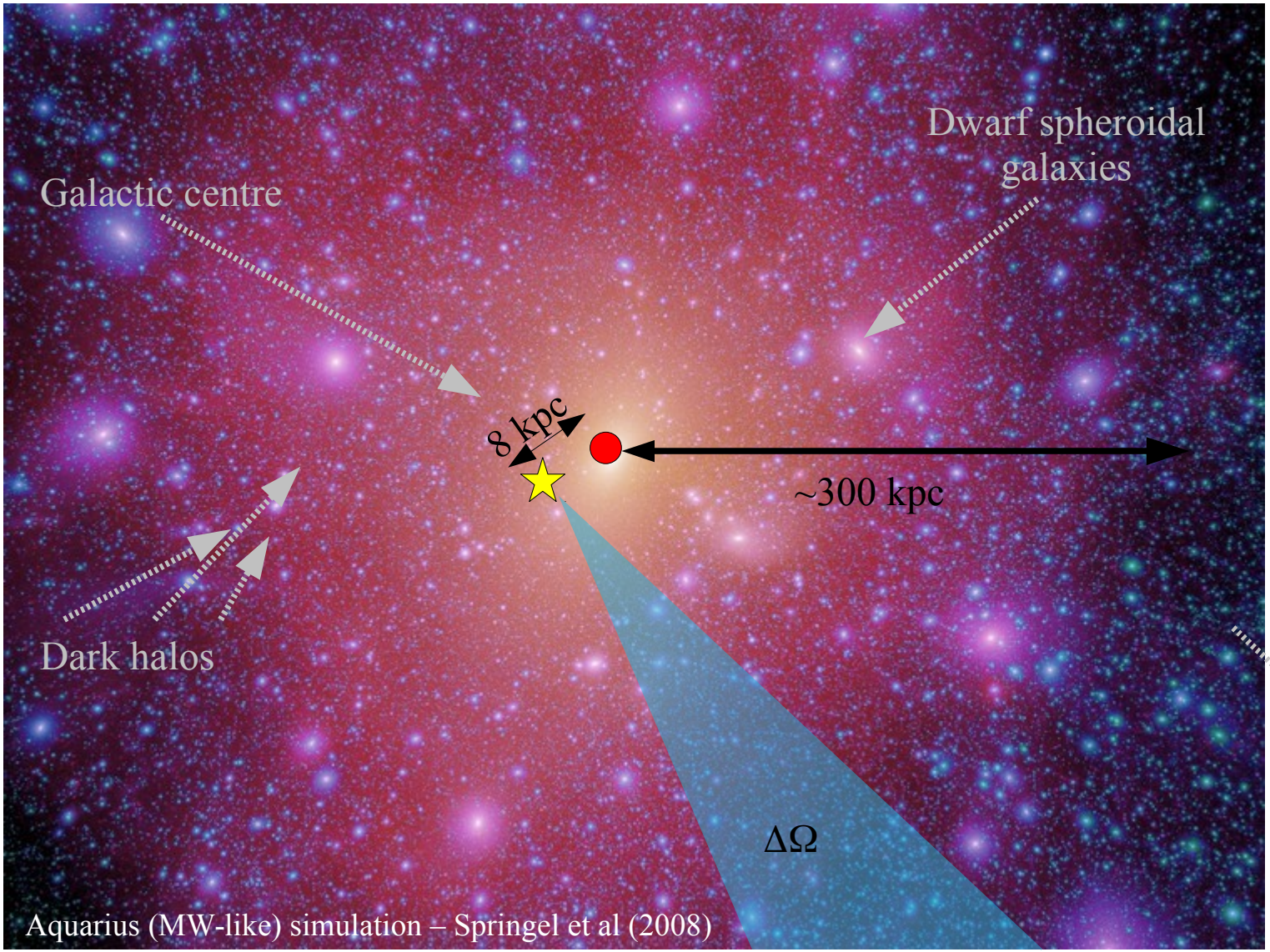
- Spectrum of antiprotons, diffuse γ-rays, e^- and e^+ (and sources)
- CR anisotropy ($\delta<10^{-3}$) for ≠ energies and ≠ species

→ searching for sources, understanding transport, looking for dark matter

→ antiprotons and antideuterons probably the best targets for DM searches

Dark matter targets for γ-ray searches

Strategy: dense ($\sim \int \rho^2$) + close ($1/d^2$) + no astrophysical background



Diffuse Emissions (galactic or extragalactic)

Galaxy clusters

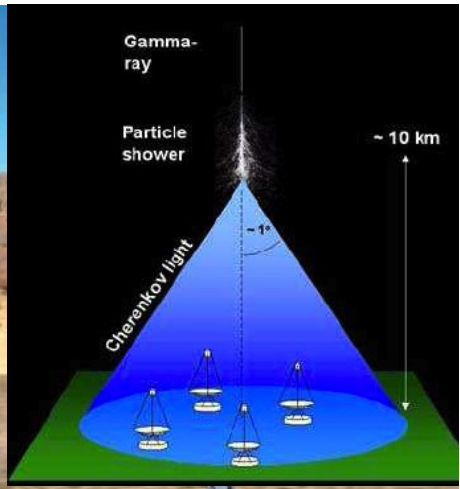
→ dSph galaxies and offset from Galaxy centre seem the best targets

Direct vs indirect CR detection

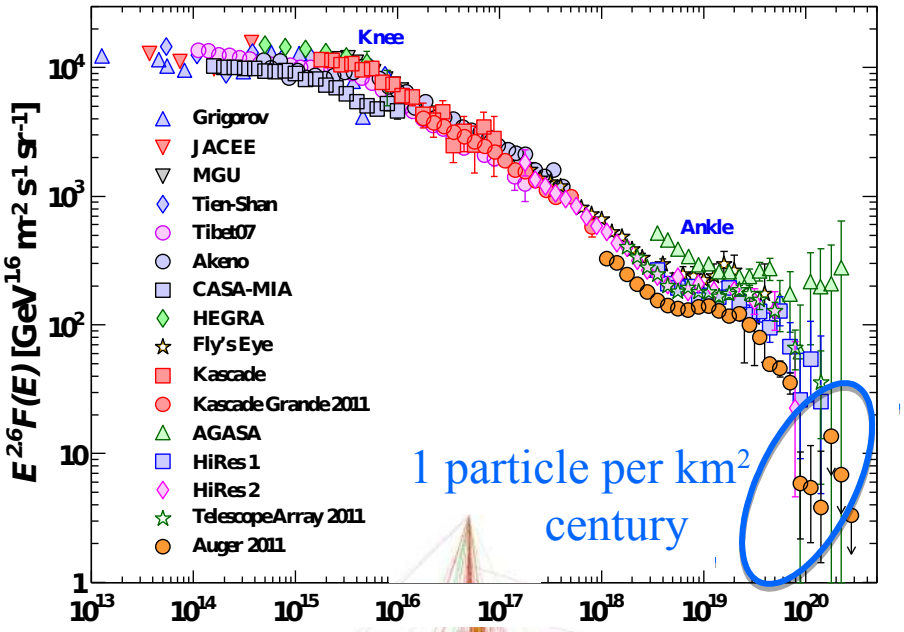
Fermi-LAT: space-borne
- Energy range: **30 MeV – 300 GeV**
- Resolution: 1° – 0.1°
- Fullsky

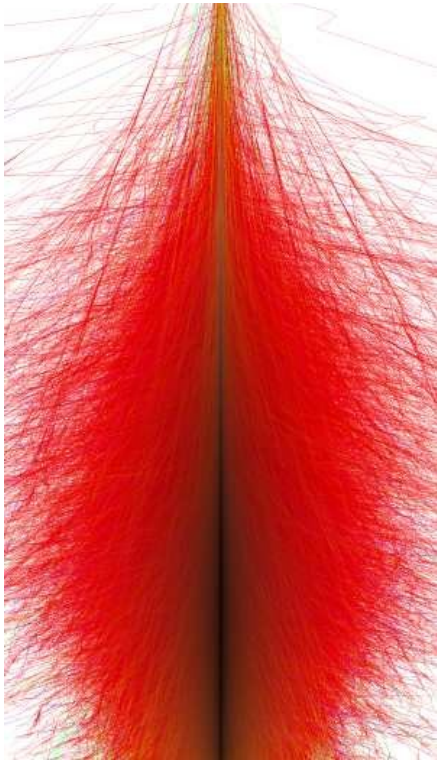
DM mass constrained: $\langle E_\gamma \rangle \sim m_\chi / 10$

Current: H.E.S.S. (4 telescopes) and H.E.S.S.II (5th telescope)
Future: CTA (Cherenkov Telescope Array)
- Energy range: **100 GeV → 100 TeV**
- Resolution: 0.2° – 0.02°
- CR contamination → background limited



Ultra-High Energy Cosmic Rays





UHECR

- Messengers of the high energy universe
- Energies beyond those accessible at man-made accelerators

Detection

- Extremely weak flux at the top of atmosphere
  → large detection surfaces are mandatory
- Interaction with the atmosphere
  → extensive air showers
  (~10^9 charged particles on a few km^2)

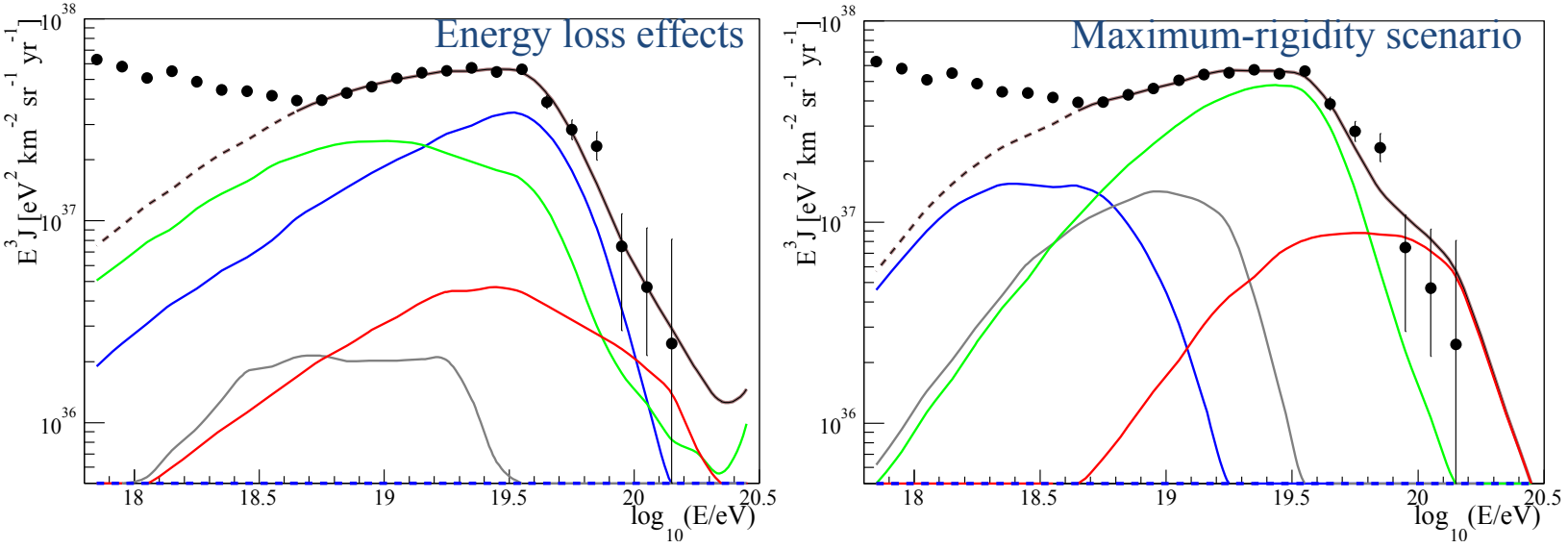
Ultra-high energy cosmic ray observatories
→ Air shower detection and measurement
→ Large array of detectors

UHECR: open questions and future goals

Origin of the flux suppression at the highest energies

- Energy loss effects due to the propagation (GZK effect) ?
- Maximum energy of particles injected by astrophysical sources ?

Black dots : CR spectrum measured by the Auger collaboration



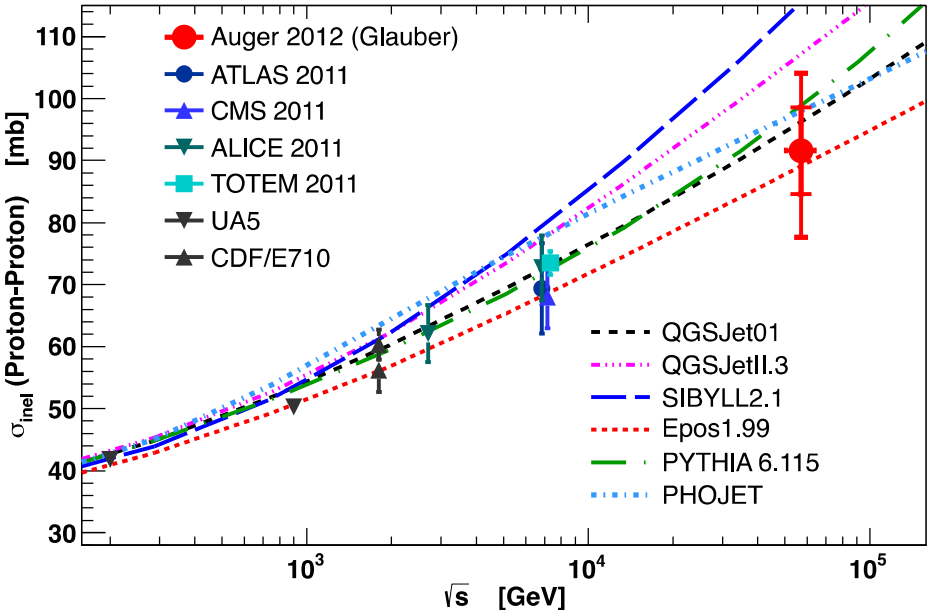
Search for proton contribution up to the highest energies

- Useful to search for sources, anisotropies
- Ingredient for estimating the physics potential of existing and future observatories

New physics with UHECR?

Exploration of fundamental particle physics at energies beyond those accessible at man-made accelerators

- hadronic multiparticle production in air showers
- test of different exotic interaction model scenarios (pion production or pion decay suppression?)



Derivation of constraints on Lorentz invariance violation

- Change in the interaction energy threshold
- Increase of the energy threshold of the GZK effect, pair production suppression (UHR photon search: constraints on LIV models)

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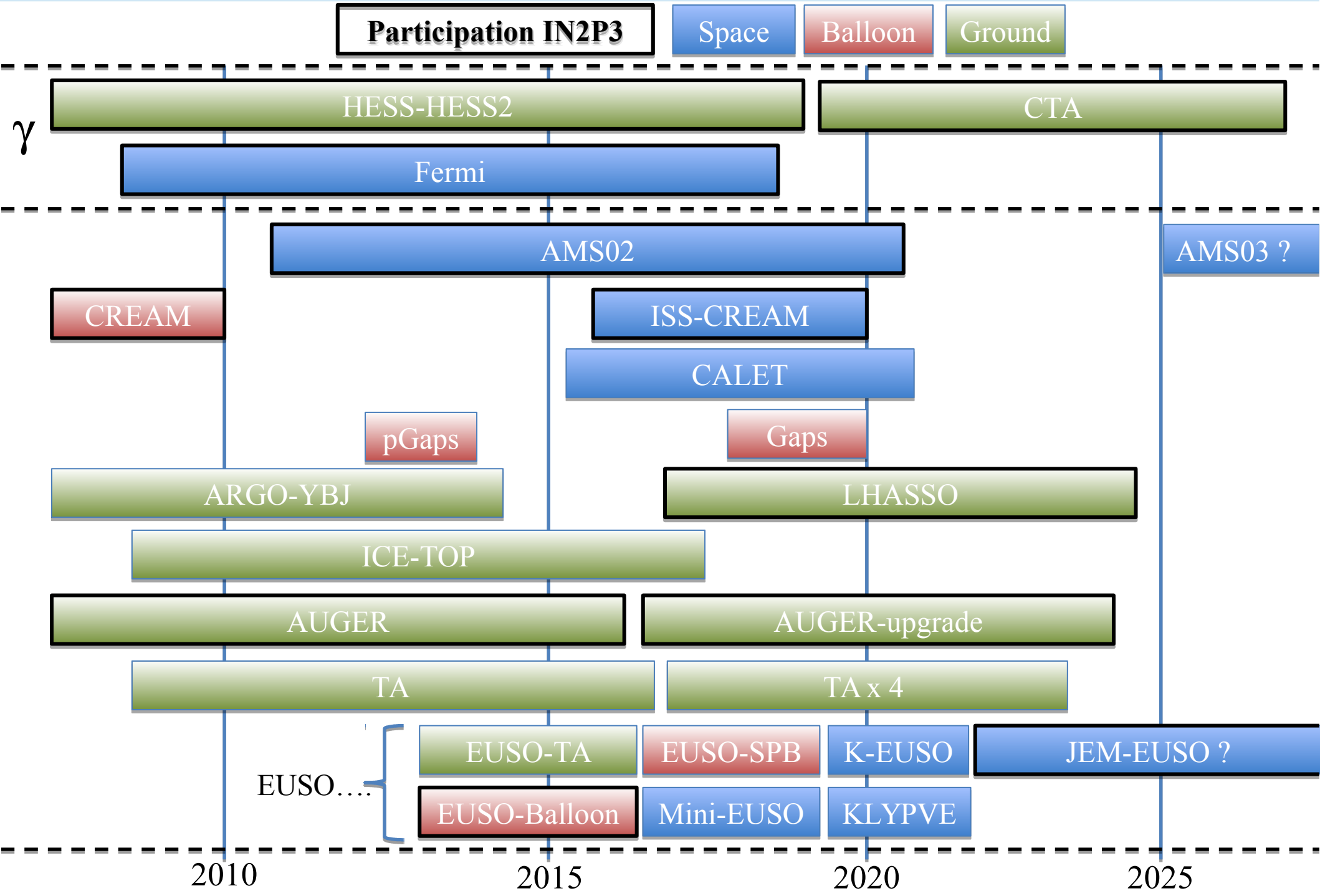
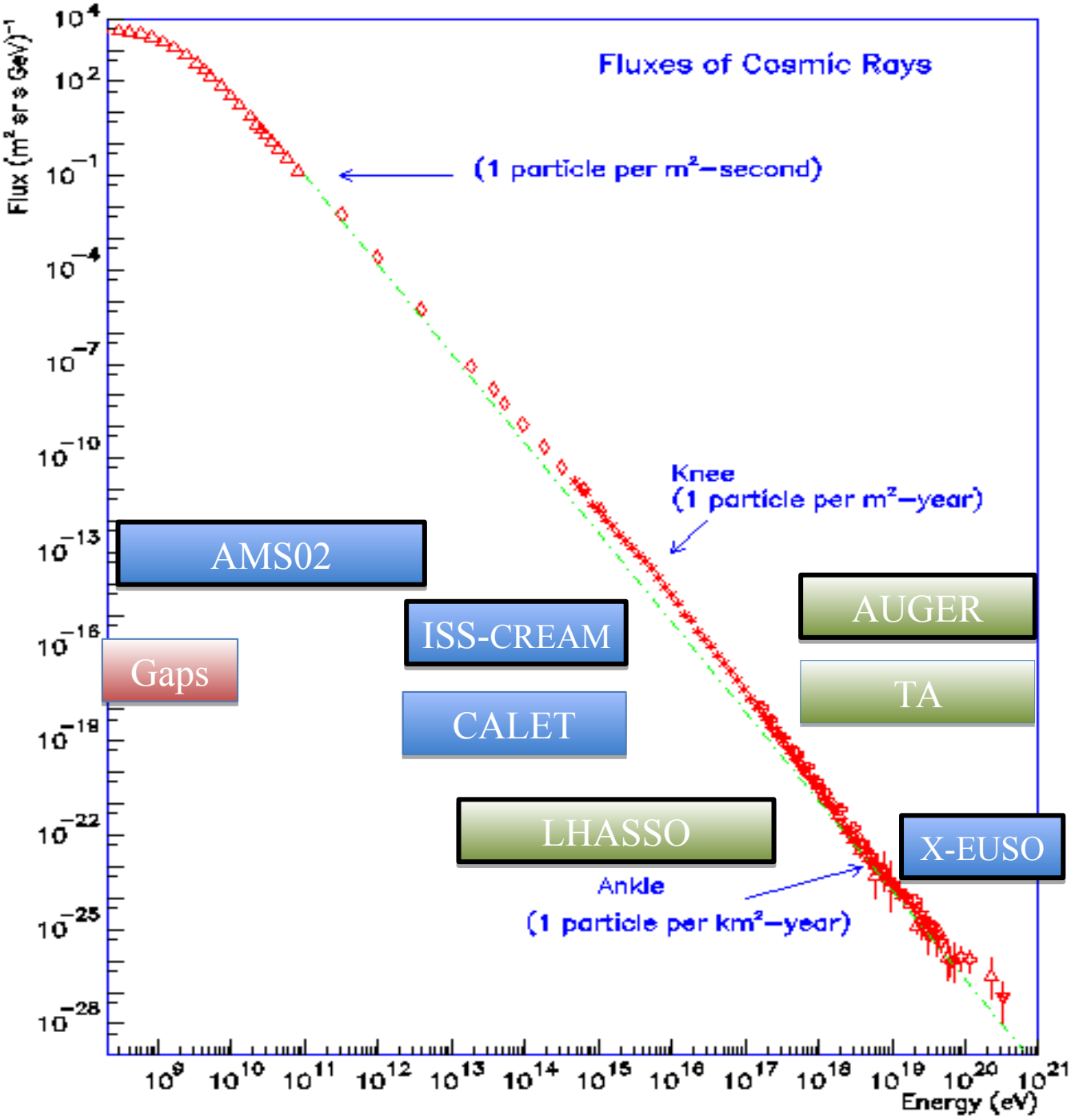
Present and future experiments (γ and charged CRs)

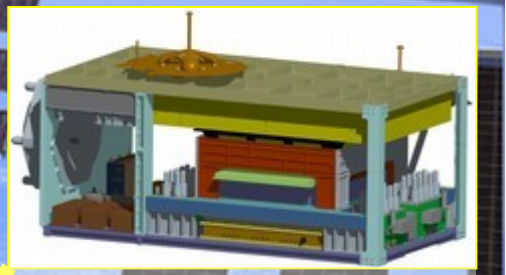


Experiments vs energy (~ in 2019)

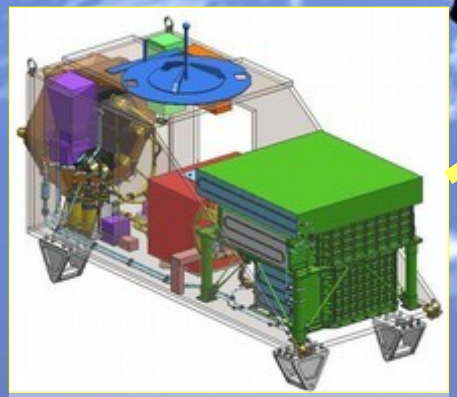


Cosmic Ray Observatory on the ISS (from NASA)

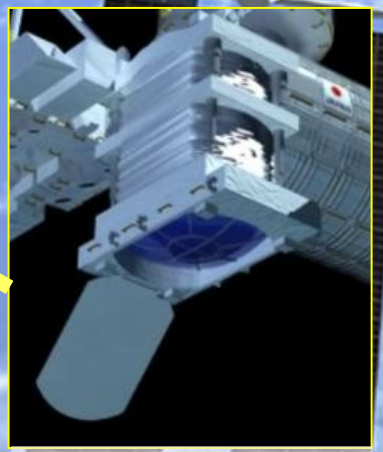
AMS-02
May 16, 2011



ISS-CREAM
Launch 2016 (Sp-X)

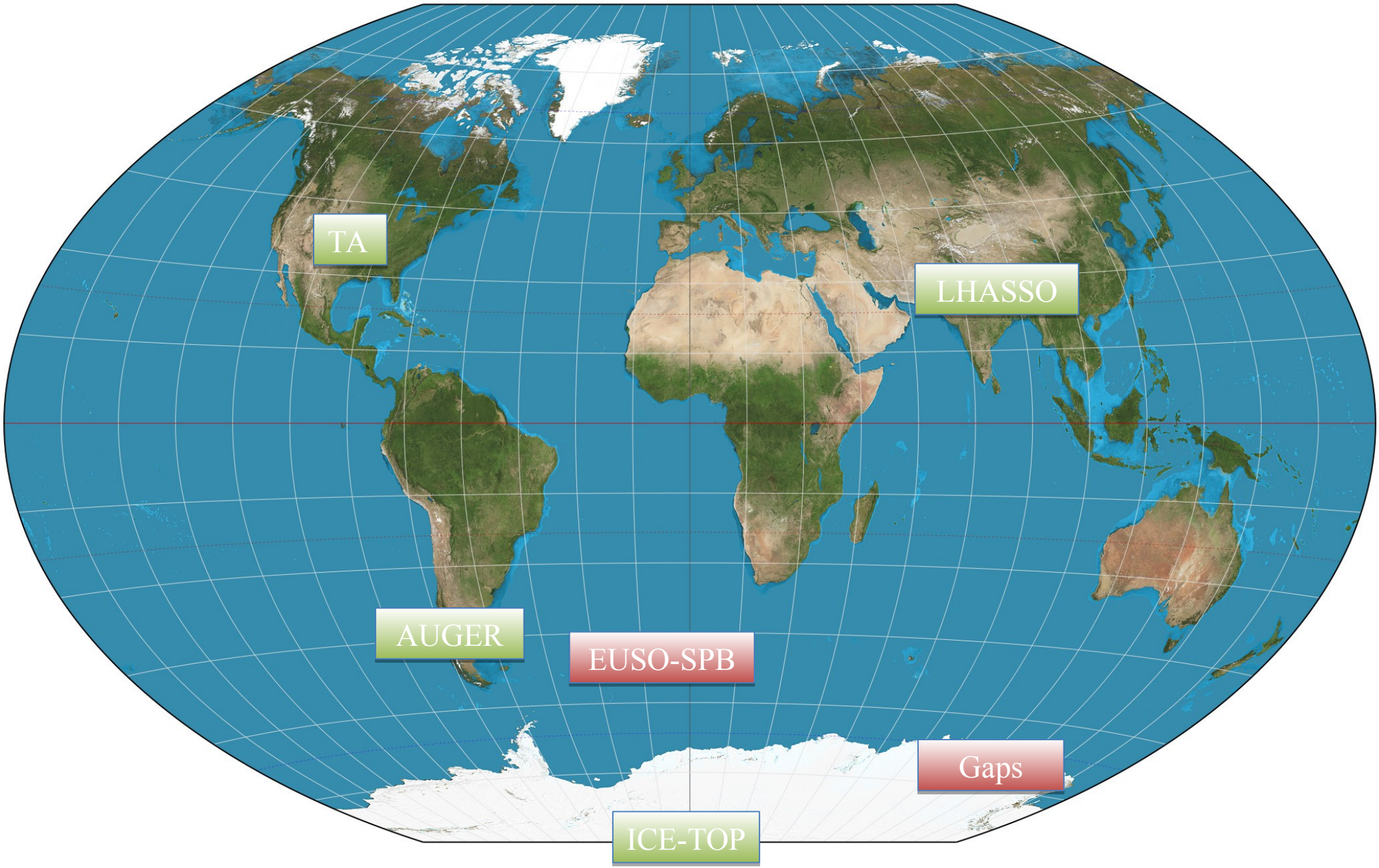


CALET on JEM
Launch 2016 (HTV)



JEM-EUSO

Ground and balloon-borne experiments



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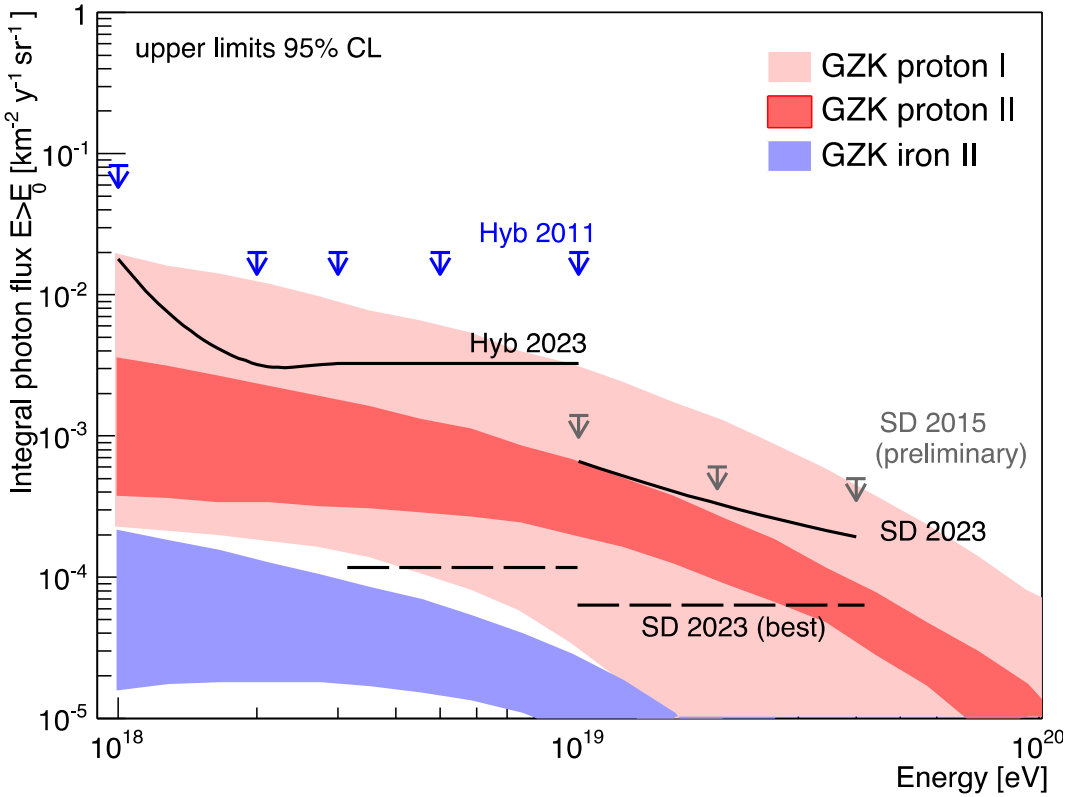
Ultra High Energy Cosmic Rays @ LPSC

Auger group activities

- New electronics development (including on-line monitoring, trigger simulations)
- Commissioning of the engineering array
- Search for UHE photons
  - ✔ address origin of flux suppression
  - ✔ constraints on LIV



→ Waiting for green light and support from IN2P3
→ Need more collaborators @ LPSC

[if one of the two above points not ensured, UHECR@LPSC will be a threatened species]

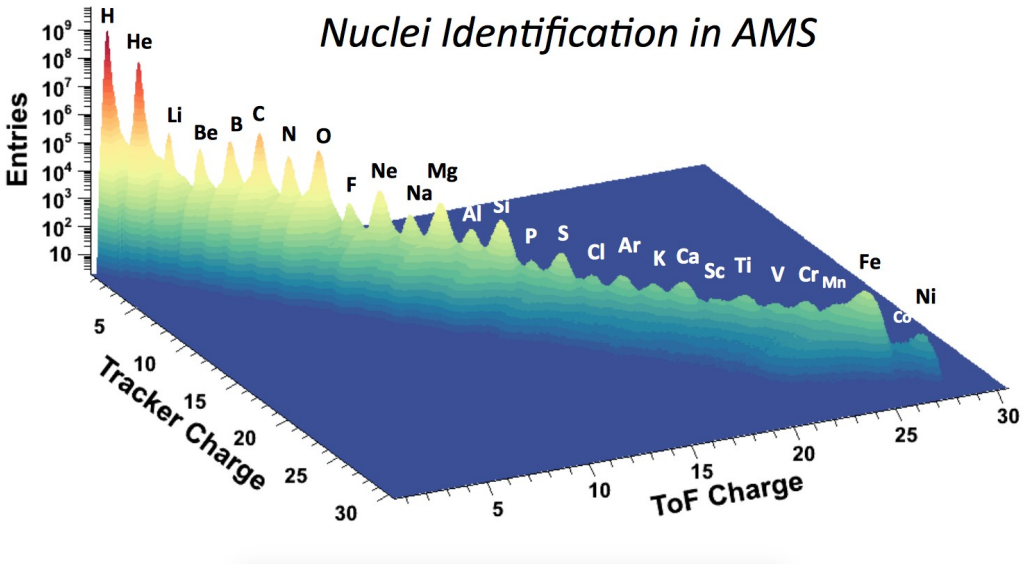
Galactic Cosmic Rays @ LPSC

AMS-02 group activities

- Li, Be, B, C, N, O fluxes
- Isotopic fluxes
  → Propagation in the Galaxy

- Time-dependent fluxes
  → Propagation in the Solar cavity

- Phenomenology
  → interpretation + tools development (support from Service informatique)



Involvement up to ~ 2018

ISS-CREAM opportunity?

- Extend energy domain above that of AMS-02 for nuclei
- Already in the collaboration (service électronique)
  → Participate to analysis?
  Yes, if scientific return possible and interesting

Priority is LSST

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Conclusions and perspectives

Galactic cosmic rays

- exciting new data now (AMS-02)
- possible target of opportunity for higher energy (ISS-CREAM)

→ AMS data exploitation now, but less interesting after → move to LSST

Ultra-high energy cosmic rays

- Auger upgrade status still under discussion
- EUSO (and its avatars) status still unclear

→ Ongoing reflection

γ-rays

- CTA is the future instrument, post-Fermi experiments more uncertain
- Possible local synergies (IPAG and LAPP)

→ Not considered at LPSC so far, but synergy between LSST/CTA could exist (new objects discovered with LSST could be CTA targets)

Neutrinos

- A new interesting window is opening (ICECUBE)

→ *KM3 a tardé à démontrer une stratégie optimale et commune au niveau européen. La détermination de la hiérarchie de masse des neutrinos [...] pourrait constituer une réorientation et une convergence renforcée du projet*
[From prospectives IN2P3/Irfu 2013-2022]