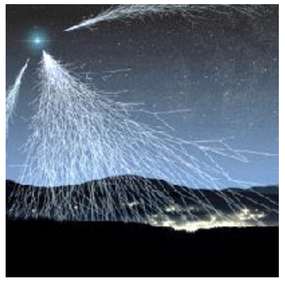
GCOS - The Global Cosmic Ray Observatory

Brainstorming workshop May 2021



We had a successful workshop with many interesting contributions and discussions.

Thanks a lot for all your contributions!

Rafael Alves Batista, Antonella Castellina, Ralph Engel, Toshihiro Fujii, Jörg R. Hörandel, Charles Jui, Lu Lu, Ioana Maris, Shoichi Ogio, Takashi Sako, Fred Sarazin

What's next? How do we proceed?

GCOS next steps

- ICRC contribution (see next topic)

- discussion session at ICRC:

  CRI: Where to go in UHECR observations?

  convenors: A. Olinto, J.R. Hörandel

This will give us the opportunity to widely advertise the GCOS idea

(and in general the topic of UHE multi-messenger astroparticle physics, from the ground as well as in space)

GCOS next steps

Several of us are working to get the GCOS idea into national and international strategic documents (APPEC, Snowmass, national roadmaps, … Japan …)

- **It would be useful to have a written *working document*, in which ideas are compiled for an UHE particle science case and also designs for potential detection concepts.**

- **We could have a follow-up workshop (~fall/winter 2021)**
  People would have time to
  - think more about details of the physic case
  - do more concrete theoretical and simulation studies for the physics case and possible detection concepts

- **Goal of the follow-up workshop:**
  define skeleton of *working document*

GCOS next steps

Several of us are working to get the GCOS idea into national and international strategic documents (APPEC, Snowmass, national roadmaps, … Japan …)

It is probably too early to write a classical *WhitePaper*.

But we can write a *Scientific Roadmap for UHE multi-messenger astroparticle physics beyond 2030.*
It would be desirable to have a draft document ~end of 2021/early 2022

—> will assemble a writing committee, incl. POEMMA, GRAND, …

Of course things (theory and experiment) will change/improve in the next years…

We can always decide to make an update of the document in a few years, this is not static, science will develop as well as our plans/views.

GCOS science case roadmap

Can we identify the sources of UHE particles?

Theoretical requirements

- GMF improvements (prospects good; talks by Marijke, Michael, Glennys)
- EGMF improvements (prospects unknown; talks missing)
- —> after 2030 we should be able to correct for effects of B-fields?
- prospects for photonuclear cross-section measurements (talk by Denise)
- knowledge of source physics to justify assumptions (e.g., cutoff shape, Peters' cycle, etc; talk by Denise)
- hadronic physics (prospects good: LHC p-O run at the end of 2020s; Tanguy's talk)
  new measurements of photo-nuclear cross sections (Japan)

- we need to prepare model scenarios and demonstrate in few examples that we can locate sources
- show in examples that we can correct for the B-field (galactic and beyond)
  e.g. Auger correlation with catalogues use „smearing angle“ ~15°,
  correcting by 10°-20° would improve the situation
- how many sources do we expect?

Comments on anisotropy:

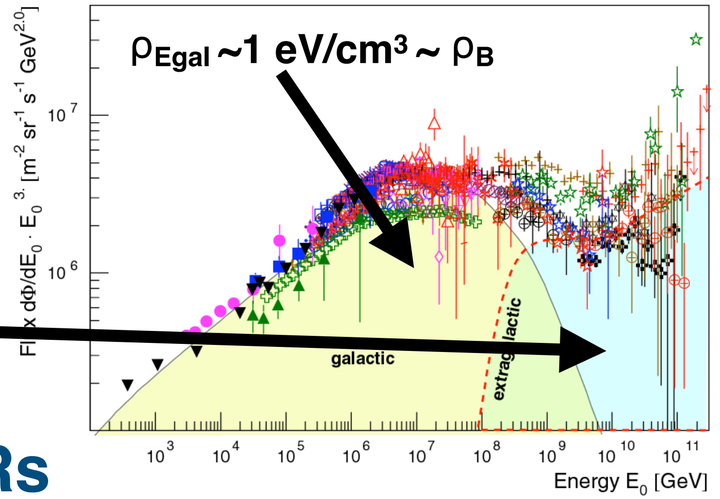
number of sources:

use old Baade & Zwicky argument and apply to AGNs:

$$\rho_E = \frac{4\pi}{c} \int \frac{E}{\beta} \frac{dN}{dE} dE$$

ρ_E=3.7 10^{-7} eV/cm^3 (Poly Gonato)

ρ_E=1.9 10^{-7} eV/cm^3 (T Gaisser, astro-ph/9707283)



GZK sphere r=75 Mpc —> 9.7 10^{43} erg/s in extragal. CRs

typical power in AGN jets ~10^{44} to 10^{46} erg/s* —> a few% E in CRs

*E. Körding et al., Mon.Not.R.Astron.Soc. 383 (2008) 277.

==> need $\mathcal{O}$(10) sources to sustain the power observed in extragalactic CRs

==> $\mathcal{O}$(10) sources over 4π (r=100 Mpc —> $\mathcal{O}$(25) sources)

==> with „good“ rigidity-resolution we should be able to find and study them

Of course this is very „back of the envelope“.
But I think the core message remains:
we most likely have only to deal with a limited number of sources.

4π=41252 square degrees
41252/25 = (40°)²

see JRH, Reviews in Modern Astronomy 20 (2008) 203

GCOS science case roadmap

Can we identify the sources of UHE particles?

Experimental requirements

What are the minimum requirements to find and study the sources?

- large area? vs high precision?
- good energy resolution (for transients; new spectral features)
- event-by-event mass discrimination
- full-sky coverage with single apparatus? several sites?
- space *and* ground-based - large aperture *and* high precision

We need good rigidity resolution. R=E/Z
—> good energy resolution (spill over effects) ~10(-15)%
—> good mass resolution, 5 elemental groups, ln A —> ln Z
==> good resolution in R
This is the base to find/study sources, but also to do particle and fundamental physics at extreme energies

GCOS science case roadmap

Complementary science cases

- Dark-matter searches (allowed parameter space; UHE photons and neutrinos)
- UHE particles as probes of quantum gravity (e.g., Lorentz invariance tests in showers and propagation, connections with muon problem; talk by Günter and indirect connections with Dennis for air showers)
- Particle physic (cross sections) and fundamental physic at extreme energies
- Geophysics and atmospheric science (e.g., elves, gamma-ray flashes, etc)

GCOS science case roadmap

Will Auger and TA detect any sources in the next decade?

- if *yes*, what role can a next-generation UHE observatory play?
- if *no*, why is it worth investing in GCOS?

[theoretical requirements and experimental feasibility]

General Issues

- how do we expect Auger/TA anisotropies to evolve over time (extrapolate!)? (talks Eiji, Jihyun)
- how would a large-area detector like GCOS see these anisotropies under a given assumption? *[need simulations …]*
- how long will it take for the CenA signal to reach a higher significance?
- are the sources transient or continuous? *[VERY important for anisotropy interpretation]*
- should we look at the highest energies or first try to solve the galactic-to-extragalactic transition?

GCOS science case roadmap

If we see a correlation, can we make unambiguous claims?

- **Magnetic fields are really complicated!**

- **Why do people neglect extragalactic fields if parameter space is too large?**
  Fermi results suggests voids could be stronger than 0.1 pG

GCOS next steps

possible content of working document:

- **Physic case for UHE particle (charged CRs, neutrinos, gamma rays)**
  multi-messenger astroparticle physics, also including GW
- **GCOS needs to be a multi-messenger instrument: charged CRs, gamma rays, neutrinos**

- **emphasize limited lifetime of present experiments and need for larger detectors**
- **focus on theoretical advances in other fields like GMF and hadronic interactions to justify better prospects**
- **current trendy results (e.g. hotspots) could be easily seen with higher statistics with 10x current area; can they tell us something? [yes, but careful with interpretation]**
- **avoid emphasis on specific source indications (NGC XXXX) but emphasise CenA and starburst, correlations with super galactic structure, …**

- **Suggestion: build up on indications coming from current anisotropy results;**
  If discovery not made in ~10 years, then we have GCOS to take a better look at it;
  If a discovery is made, probably it will require independent confirmation and there will be a lot more to learn (great for GCOS)

GCOS next steps

possible content of working document:

- **Complementarity of approaches**
  space - ground: large aperture - high precision
  What is desirable for GCOS? large aperture or high precision?

- **What is the optimal/target energy range?**
  fall-off region? or slightly lower? (due to steep spectrum big impact on size of array)
  Do we need light (low Z) particles at highest E to do astronomy?
  Or, can we correct the effect of B-fields and can focus on slightly lower energies?

- **Complementarity of techniques, GRAND - GCOS relation**

- **to move onward we should unite and align the world-wide efforts**

GCOS next steps

possible content of document:

- **discussion of potential technical concepts**
  discussion of pros and cons of techniques, duty cycle, resolutions

- **FAST-type fluorescence detectors**

- **water Cherenkov detectors (segmented/nested)**

- **radio detectors**

- **where should we build GCOS? several sites?**

- **if we have several sites:**
  we need same technology/same groups at different sites

- **„green“ experiment/impact on host region**

GCOS next steps

.. after the follow-up workshop this year …

Have a „*workshop on the future*“ at every UHECR symposium
(like we had one after the Paris UHECR symposium in 2018)

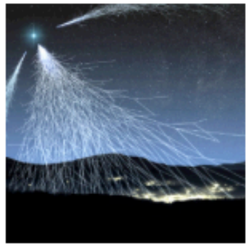
Ultra High Energy Cosmic Rays 2018

8-12 octobre 2018
Ecole Supérieure de Chimie, Paris

14:00	**Introduction** *Institut Henri Poncaré (IHP)*	*Ralph Engel et al.* 14:00 - 14:05
	Status and open problems in ultrahigh-energy cosmic ray and neutrino physics *Institut Henri Poncaré (IHP)*	*Paolo Lipari* 14:05 - 14:40
	Origin of UHECR anisotropies and what we can learn from them *Institut Henri Poncaré (IHP)*	*Prof. Günter Sigl* 14:40 - 14:50
	Mixed composition and the chances of finding UHECR sources *Institut Henri Poncaré (IHP)*	*Michael Unger* 14:50 - 15:00
15:00	**Towards a Global Cosmic Ray Observatory (GCOS) - requirements for a future observatory** *Institut Henri Poncaré (IHP)*	*Ralph Engel et al.* 15:00 - 15:10
	A giant air shower detector *Institut Henri Poncaré (IHP)*	*Dr Jörg Hörandel* 15:10 - 15:20
	Layered surface detector (10 min) *Institut Henri Poncaré (IHP)*	*Ioana Maris* 15:20 - 15:30
	Discussion time *Institut Henri Poncaré (IHP)*	 15:30 - 16:00
16:00	**Coffee break** *Friedel Amphitheater, Ecole Supérieure de Chimie, Paris*	 16:00 - 16:20
	Plans for GRAND 200k *Hermite Amphitheater, IHP*	*Kumiko Kotera* 16:20 - 16:30
	A "snake array" of fluorescence detectors (10 min) *Hermite Amphitheater, IHP*	*Pierre Sokolsky* 16:30 - 16:40
	SKA with muon counters as super-cosmic-ray detector in the transition energy region *Hermite Amphitheater, IHP*	*Tim Huege* 16:40 - 16:50
	Lower energy TALE, down to 10^14 eV *Hermite Amphitheater, IHP*	*Charles Jui* 16:50 - 17:00
17:00	**On the importance of analyzing very-high and ultra-high energy data together, towards a new working group for UHECR symposia** *Andreas Haungs*	
	Discussion *Hermite Amphitheater, IHP*	 17:10 - 17:30

GCOS next steps

We could start to have internal notes. (GCOS notes)
—> small notes, estimates, simple calculations, …



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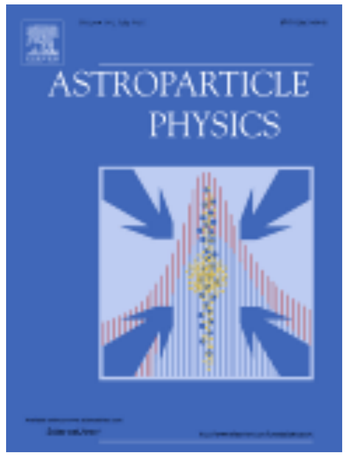
GCOS notes

- GCOS15-1: Helmholtz Roadmap 2015 (in German), see pg. 40
- GCOS18-1: GCOS ideas presented at UHECR 2018
- GCOS20-1: Letter of Interest for Snowmass 2021

http://particle.astro.ru.nl/gcos/gcos-docs.html

Do we want a special issue in Astroparticle Physics?
—> Tim Huege



Maybe after the follow-up workshop?