Roberto Pesce

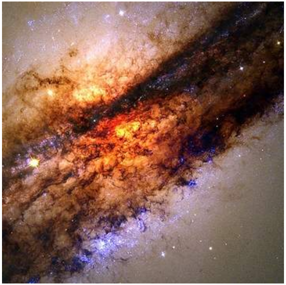
University of Genova, Department of Physics and INFN

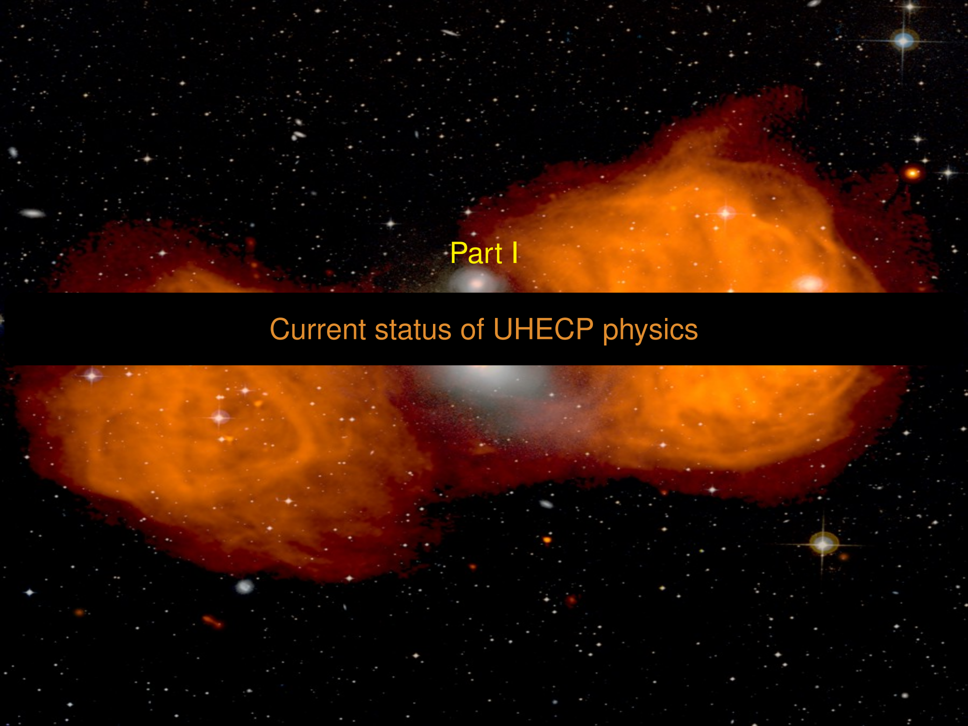
ULTRA-HIGH ENERGY COSMIC PARTICLES ASTRONOMY with a space-based experiment ?

XXVIII PHYSICS IN COLLISION - Perugia, June 25-28, 2008

Summary

1. Current status of UHECP physics
2. UHECP detection from space
3. The Super-EUSO mission





Part I

Current status of UHECP physics

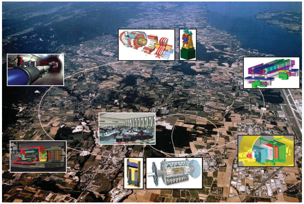
Ultra High Energy Cosmic Particles

- very low flux:
  ($\sim 10^{-3}$ particle$\cdot$km$^{-2}\cdot$sr$^{-1}\cdot$yr^{-1}
  for $E \geq 10^{20}$ eV)
- origin still unknown

If we want to accelerate a proton to such energies using the LHC magnetic field. . .

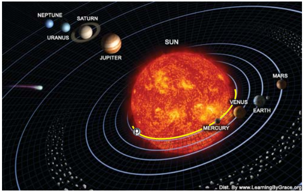
Ultra High Energy Cosmic Particles

- very low flux: ($\sim 10^{-3}$ particle$\cdot$km$^{-2}\cdot$sr$^{-1}\cdot$yr^{-1} for $E \geq 10^{20}$ eV)
- origin still unknown



B = 8.3 T
R ≈ 4.3 km
E = 14 TeV

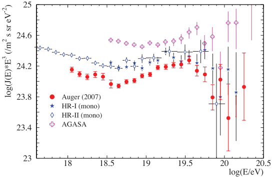
If we want to accelerate a proton to such energies using the LHC magnetic field. . .



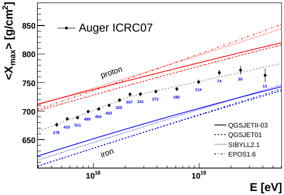
B = 8.3 T
E = 10^{20} eV
R ≈ 4 x 10^{6} km
≈ Mercury orbit !

UHECP: what news from the Pierre Auger Observatory ?

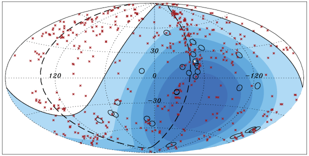
Spectrum



Composition



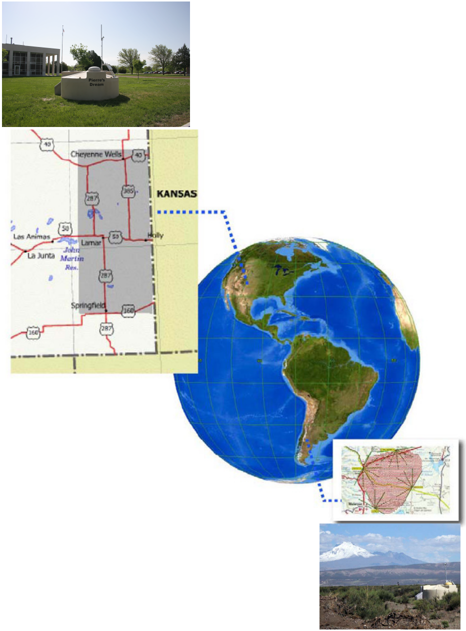
Anisotropies



see Sergio Petrera's talk

If we can have much more statistics is better! ...

UHECP: what future experiments ?



The next step is the PAO North site, that will be built in the near future.
Together with the South site we will have:

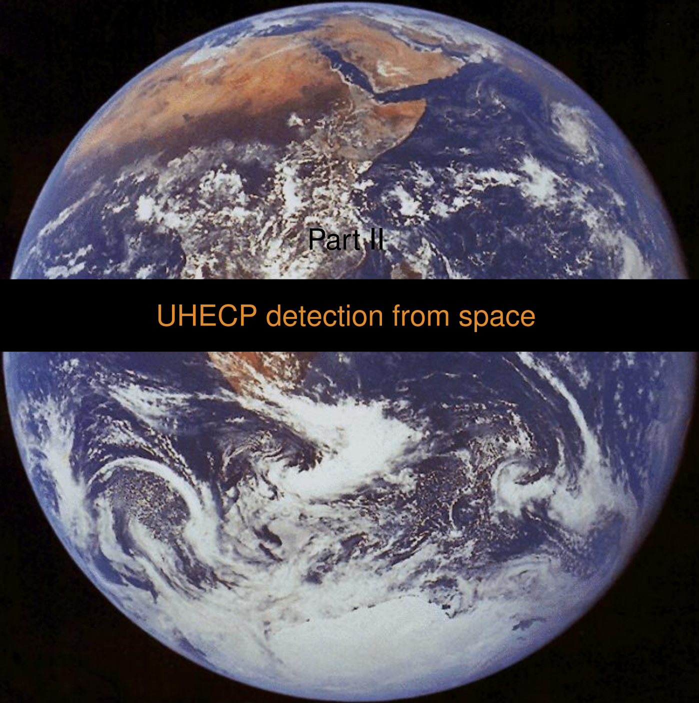
- full sky coverage
- much more event statistics

What if we want to further increase the event statistics ? We need of a large aperture ($\mathcal{A} \sim 10^6\ \mathrm{km}^2 \cdot \mathrm{sr}$).

Then a challenging space experiment is probably required.

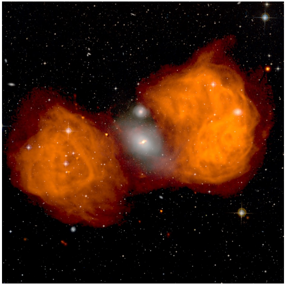
Part II

UHECP detection from space

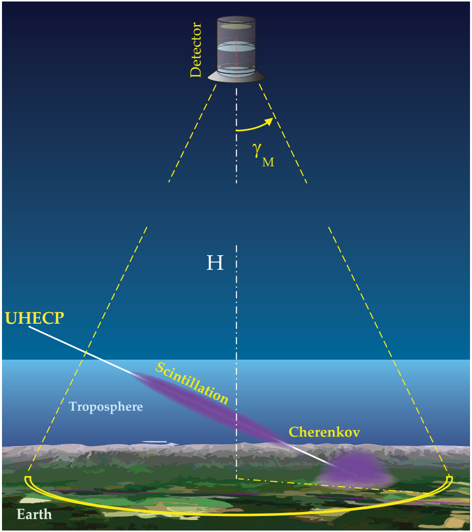


UHECP detection from space: the scientific case

1. Extension of the measurement of UHECP spectrum beyond $\sim 10^{20}$ eV
2. Detailed map of the UHECP arrival direction, extended to the entire sky
3. Identification and localization of compact sources ?
4. Study of the spectra of individual sources ?
5. Study of the UHECP composition ?



UHECP detection from space: the approach



A large aperture and field of view fast and highly pixelized digital camera.

- Orbital height H
- The apparatus looks downward to the Earth observing
  - near-UV scintillation light
  - diffusely reflected Cherenkov light
- Field of view (FoV) $\gamma_{\max}$

The required apparatus is made of:

- main optics (pupil diameter D)
- photo-detector (on the focal surface)
  - photo-sensor (efficiency ε)
  - f/e electronics
  - trigger
- atmospheric monitoring system
- calibration system

Performance parameters

- Instantaneous geometrical aperture Goal: $\mathcal{A} \sim 10^6\ \mathrm{km}^2\cdot\mathrm{sr}$ ($\sim 10\times$PAO)
- Energy threshold Goal: $E_{\mathrm{th}} \sim 10^{19}$ eV
  - superimposition with PAO data
  - high statistics at low energy to study the detector performances
- Energy resolution Goal: $(\Delta E/E)_{\mathrm{stat.}} \sim 10\% + (\Delta E/E)_{\mathrm{sys.}} \sim 10\%$
- Angular resolution Goal: $\sim 1^\circ \div 3^\circ$
- Duty cycle ($\sim 10\% - 20\%$) $\rightarrow$ depends on the background

The above parameters are affected by the photon collection capability of the detector. It mainly depends on

1. photo-detection efficiency [ε]
2. optics aperture [D]
3. other efficiency factors (but already close to 1 !)

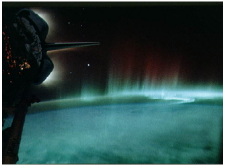
The background from space

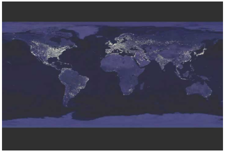
Many sources:

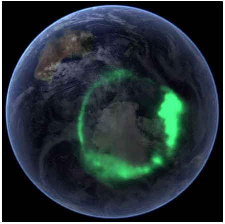
1. Atmospheric Nightglow
2. Man made lights
3. Transient luminous events (lightnings,...)
4. Auroras
5. ...

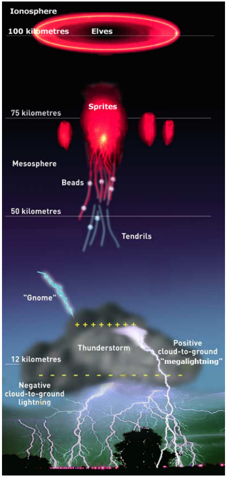
The mean background flux due to nightglow is $300 \div 1500\ \mathrm{ph{\cdot}m^{-2}{\cdot}sr^{-1}{\cdot}ns^{-1}}$ and increases in presence of clouds and/or moonlight.

A detailed characterization of background in space-time through a microsatellite mission is mandatory to extract the tiny signal from the huge background.







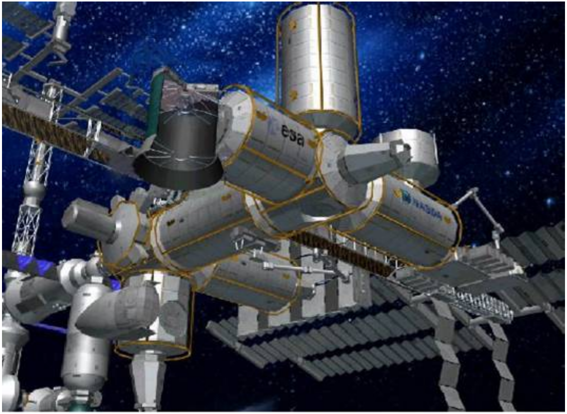


Part III

The Super-EUSO mission

The EUSO experiment

- 1999: proposal as free-flyer satellite
- 2000: proposal for an accomodation on the International Space Station
- 2001: start of Phase A
- 2004: end of Phase A. EUSO is “frozen” due to financial and programmatical issues



From EUSO to S-EUSO

The EUSO heritage

- small optics diameter $D_{\mathrm{EUSO}} \sim 2.5$ m
- accommodation on the ISS
- fixed orbit
- strong constraints on mass, volume, power, telemetry
- overall photo-detection efficiency $\varepsilon_{\mathrm{EUSO}} \sim 0.1$
- limited threshold ($E_{\mathrm{th}} \gtrsim 10^{20}$ eV)

The S-EUSO improvement

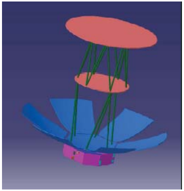
- big optics diameter $D_{\mathrm{S-EUSO}} \sim 7$ m
- free-flyer satellite
- less constraints on the orbit
- less constraints on mass, volume, power, telemetry
- overall photo-detection efficiency $\varepsilon_{\mathrm{S-EUSO}} \gtrsim 0.25$
- better threshold ($E_{\mathrm{th}} \sim 10^{19}$ eV)

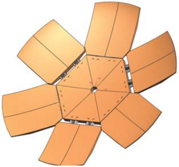
EUSO was a preliminary exercise. We have to regard it as a beautiful lesson to build a second-generation UHECP space experiment.

The S-EUSO apparatus (preliminary design)

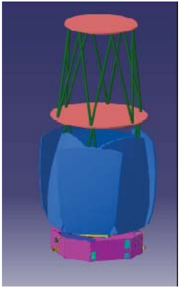
- catadioptric system (Schmidt telescope)
- lightweight and deployable

mirror diameter	$11\ \mathrm{m}$
pupil diameter	$7\ \mathrm{m}$
f/#	0.7
granularity at ground	$\sim 700\ \mathrm{m}$
field of view	$\gamma_{\mathrm{max}} \sim 25^{\circ}$

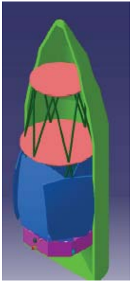




in-flight



closed



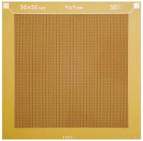
in stowed

The S-EUSO apparatus (preliminary design)

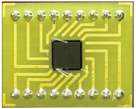
Focal surface

- Array of photo-sensor with high photo-detection efficiency
- For example Geiger-Mode Avalanche Photodiodes (GAPD)

foc. surface diameter	4 m
number of channels	$\sim 10^6$
pixel size	~ 4 mm
photo-detection efficiency	0.25
power per channel	2 mW



$4\ \mathrm{mm} \times 4\ \mathrm{mm}$
GAPD



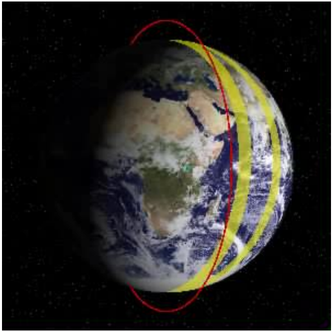
$5\ \mathrm{mm} \times 5\ \mathrm{mm}$
GAPD

Atmospheric monitoring

- infrared camera (horizontal cloud coverage)
- backscatter LIDAR ??? (cloud-top altitude)

Some remarks about the orbit

- The tuning of the orbit is essential
- A free-flyer satellite has many degrees of freedom
- Possibility to change the orbit during the mission
- E.g. using an elliptic orbit or changing the altitude
  - higher orbit ⇒ higher aperture but higher threshold
  - lower orbit ⇒ lower threshold but lower aperture
- No tilting with respect to the nadir is required:
  - A small tilting can improve the geometrical aperture
  - But a large tilting has many disadvantages (atmospheric attenuation,. . .)

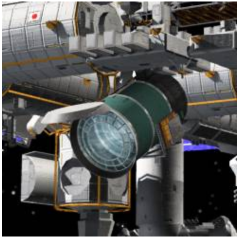


S-EUSO Orbit (preliminary design)

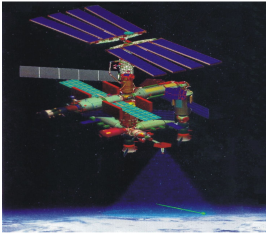
perigee radius	800 km
apogee radius	1100 km
inclination	50° - 60°
period	$\sim$ 100 min
ground velocity	$\sim$ 7.5 km/s

The long road toward S-EUSO

1. A microsatellite mission
   - background characterization in space and time
   - validation of the space approach/apparatus using also ground sources
2. Pathfinder missions:



JEM-EUSO (Japan)



TUS (Russia)

3. Super-EUSO

see also Piero Spillantini's talk

Conclusions

- A space-based detector for UHECP is very challenging
- It is very important to precisely identify the scientific case on the light of the Pierre Auger Observatory results
- The parameters of the apparatus have to be accurately tuned
- The R&D should start as soon as possible
- It is necessary a large effort from the whole UHECP physicist community
- Necessary some preliminary steps (validation, pathfinders,...)
- Possible framework: ESA Cosmic vision 2015-2025 ???

Thank you !

References

- T. Yamamoto et al. Proc. 30th ICRC., 2007. arXiv:0707.2638 [astro-ph].
- M. Unger et al. Proc. 30th ICRC, 2007. arXiv:0706.1495 [astro-ph].
- J. Abraham et al. Astropart. Phys. 29 (2008) 243-256. arXiv:0712.1147 [astro-ph].
- PAO Collaboration. Science 318:938-94 (2007). arXiv:0711.2256 [astro-ph].
- R. Pesce, The detection of UHECP on the Earth and from space, PhD thesis, 2008. www.ge.infn.it/~pesce/phd/PhDThesis.pdf
- A. Santangelo, A. Petrolini, et al. S-EUSO: a proposal for a space-based observatory for UHECP, 2007. http://astro.uni-tuebingen.de/groups/uhe/cv-proposal/
- ESA. Cosmic Vision: Space Science for Europe 2015-2025, 2005.
- J. Adams. Nucl. Phys. Proc. Suppl., 134:15-22, 2004
- P. Mazzinghi et al. Proc. 6th Internat. Conf. on Space Optics, 2006.
- P. Buzhan et al. Nucl. Instrum. Meth., A504:48-52, 2003.
- N. Dinu et al. Nucl. Instrum. Meth., A572:422-426, 2007.
- J. Ninkovic et al. Nucl. Instrum.Meth., A572:454-455, 2007.
- A. Thea et al. Nuc.Phys. B Proc. Suppl. 166 (2007) 223.