COSMIC RAY FRONTIERS

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Questions

• What are cosmic rays and how do we detect them?

• Why are they interesting?

• What are we doing to understand things better?
What are Cosmic Rays?

According to Merriam-Webster:

Main entry: cosmic ray
Function: noun
Date: 1925
: a stream of atomic nuclei of extremely penetrating character that enters the earth’s atmosphere from outer space at speeds approaching the speed of light.

Cosmic rays = “energetic particles from outer space”
Energy Scales

1 electron-Volt (eV) = 1.6 x 10^{-19} Joules

1 eV ~ visible light
10^3 eV ~ X-ray
>10^6 eV ~ γ-ray

10^6 – 10^{21} eV ~ cosmic rays

Enormous range!
Coming from outer space

Discovery (1912):
Victor Hess
Balloon flights in Bohemia

Apparatus:
simple electroscope

Found radiation increased as he went higher up.
Cosmic Ray Properties

- **Particles**: nuclei, p, e → not “rays”
- **Charged**: nuclei usually stripped
- **Energetic**: produced in violent processes “non-thermal” or “acceleration”
- **Isotropic**: no preferred direction on sky (mostly)
Energy Spectrum

- Rapid decrease in flux with energy.
- Different regions, different sources?
- Composition info is important.
Energy Spectrum - Flattened

log(Flux * E^3) in eV^2 m^-2 s^-1 sr^-1

- Galactic
  - Akeno 1km²
  - Tibet
  - Runjob
  - Proton Saterite
  - JACEE

- Extra-Galactic
  - E-2.7
  - E-3.1
  - E-2.7

- Ankle
  - AGASA
  - Haverah Park
  - Yakutsk
  - Stereo Flys Eye

Knee

log(ENERGY in eV)
So…. How do we detect them?

Pierre Auger

Satellite

Detector in space

Air Showers

Shower
Extensive Air Showers

Atmosphere

Fluorescence

Ground Array
Giant Air Showers ( $> 10^{20}$ eV)

Figure of Giant Showers hitting the Earth. (removed because of size).
Why are cosmic rays interesting?

- Major source of extra-terrestrial material
- Important in dynamics of solar system
- Abundant – fill galaxy with energy
- Remarkable energies reached $> 10^{21}$ eV

There must be powerful and renewable sources, but ... we still do not know what they are!
General possibilities for origin

Cosmic accelerators

- LE: Sun, interplanetary space
- HE: Supernova remnants
- EHE: Active galaxies – massive black hole systems.
  Gamma-ray bursts
Cosmic Accelerators

Viewed in $\gamma$-rays
Supernova Remnants

- Collapse of massive star
- Expansion powers shock wave
- Particle acceleration via Fermi mechanism

Energy $\sim 10^{51}$ erg
Rate $\sim 1/30$ yr (galaxy)
$L \sim 10^{42}$ erg/s
General possibilities for origin

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**New particle physics**
- Defects in universe – e.g. cosmic strings.
  – not favored cosmologically
- Heavy relic particles
- Other?
Cosmic Strings
Mysteries - Frontiers

1. **Nature of low-energy component**
   - Solar modulation, anomalous CR - F. McDonald

2. **“Knee” – bend near $10^{15}$**
   - New composition? - R. Engel, S. Swordy

3. **Extremely energetic events $>10^{20}$ eV**
   - Should these events even be there? - A. Olinto
Spectrum at Highest Energies

Should these be there?
Sky Map at Highest Energies

Are there point sources?
What are we doing to understand things better?

**Experiments**
- Cosmic ray detectors – in space and on ground
- Gamma-ray and neutrino telescopes

**Theory & Simulations**
- Models of acceleration & propagation
- Simulations of air shower interactions
- Beyond standard particle physics & cosmology
World-wide experiments, c2003

CR experiments
γ-ray, neutrino telescopes

HiRes, VERITAS, HESS, ANTARES, AGASA, IceCube, Auger
VERITAS – $\gamma$-ray Telescope

Arizona, USA
Pierre Auger Project

Northern Auger in Utah

Southern Auger in Argentina

50km
Pierre Auger Project

Fluorescence detector

Surface detector
Air Showers From Space

EUSO or OWL
Air Showers From Space

General concept

Owl-AirWatch Detector

$H \approx 500 \text{ km}$

Ground

EUSO on ISS

General concept
Summary

• Cosmic Rays are remarkable objects.
  ~ 90 years of forefront science.

• There are deep mysteries of origin
  – at least three!

• Probing the most energetic processes in the universe.

• World-wide network of instruments to tackle these mysteries – please stay tuned!
… At present, however, we do not know nearly enough about these rays to come to any decision as to their nature; it is evident, however, that they raise questions of the greatest interest and importance. It would be one of the romances of science if these obscure and prosaic minute leakages of electricity from well-insulated bodies should be the means by which the most fundamental problems in the evolution of the cosmos had to be investigated.

J.J. Thomson, 1928
“Conduction of Electricity Through Gases”