Proposal E-165

**Fluorescence from Air in Showers (FLASH)**

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Ultra High Energy Cosmic Rays

- Cosmic Rays have been observed with energies beyond $10^{20}$ eV
- The flux (events per unit area per unit time) follows roughly a power law: $\sim E^{-3}$
- Changes of power-law index at “knee” and “ankle”.
  - Onset of different origins/compositions?
  - Where does the spectrum stop?
Cosmic Ray Spectrum Beyond The Ankle

The graph shows the energy spectrum of cosmic rays, with energy on the x-axis (in eV) and the differential flux $E^3 J(E)$ on the y-axis, where $E^3 J(E)$ is given in units of $(eV^2/m^2/sr/s)$. The data is divided into two categories: HiRes-I Monocular and HiRes-II Monocular, as indicated by the symbols on the graph. The graph includes error bars for each data point, showing the uncertainty in the measurements. The data points are plotted on a logarithmic scale, with energy ranging from $10^{17}$ to $10^{20}$ eV.
UHECR: From Source to Detector

CMB \( \gamma @ 2.7 \text{ K} \)

Threshold for \( \Delta \) resonance at \( \sim 6 \times 10^{19} \text{ eV} \)

Acceleration

Propagation

Detection
• Protons above $6 \times 10^{19}$ eV will lose sizable energy through CMB
• Super-GZK events have been found with no identifiable local sources
Akeno Giant Air Shower Array (AGASA)

100 km² ground coverage

AGASA Scintillation Counter
HiRes Observation of Cosmic Rays with Fluorescence Technique

- The two detector sites are located 12 km apart
- Geometry of an air shower is determined by triangulation.
- Energy of primary cosmic ray calculated from amount of light collected.
Discrepancy Between Two UHECR Experiments

![Graph showing the discrepancy between two UHECR experiments, with data points and annotations for HiRes and AGASA.]
FLASH useful for future UHECR Experiments

Ground-Based: The Pierre Auger Observatory

- Hybrid detection
- 1600 Water Cherenkov detectors
  1.5 km grid in 3000 km²
- 4 fluorescence eyes – Comparable to HiRes
Space-Based: EUSO, OWL/AirWatch
Previous Fluorescence Measurements

• A.N. Bunner, PhD thesis, Cornell (1967)
  – Compiled a spectrum from many sources.
  – Unknown systematic errors.
• F. Kakimoto et al., NIM (1996)
  – Measured 3 narrow band lines not a spectrum.
• M. Nagano, FIWAF presentation (2002)
  – Sr\textsuperscript{90} source, measuring all known major lines.

⇒ Systematics \textasciitilde 15\% or more.
⇒ Errors in individual lines larger.
Other Proposed Fluorescence Experiments


- Experiments under preparation
  - C. Escobar (Campinas, Brazil): $^{90}$Sr source and 5-12 MeV electrons
  - A. Santangelo (Palermo, Italy): 22 keV photon excited fluorescence
  - P. Colin (LAPP, France): $e^-$, $\pi$, $p$ beams at CERN PS and SPS (MACFLY)
  - P. Gorodetzky (College de France): $^{90}$Sr source and 50 keV electrons

- Other proposals
  - P. Privitera (Rome, Italy): similar approach to Kakimoto and Nagano
  - H. Klages (Karlsruhe, Germany)

- Most sources at low energies $\rightarrow$ Shower development not possible
- Different systematic errors $\rightarrow$ Efforts complementary
Cosmic Rays versus SLAC Beams: Corresponding $e^-$ and $\gamma$ energy distributions.

$10^{18}$ eV cosmic ray (proton) at shower max using CORSIKA.

28.5 GeV SLAC beam at shower max using GEANT.
• History has shown that symbiosis between *direct observation* and *laboratory investigation* instrumental in the progress of astrophysics.

• Astro-frontiers mostly involve high energy particles interacting with high density, high temperature, high fields environments.

  ➔ Insights into underlying fundamental physical mechanisms and processes require controlled laboratory experiments.

• Complexity of such systems render fully theoretical treatment difficult; Large scale *simulations* indispensable.

  ➔ Validation of simulation codes relies on laboratory experiments.

• SLAC beams ideal for high energy laboratory astrophysics.