High Energy Astroparticles: Jim’s legacy and Future Directions
A Life in High-Energy Physics: Success Beyond Expectations

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Keywords

hyperons, K mesons, elementary particles, autobiography, experimental physics, CP violation

Abstract

The author describes in some technical detail his career in experimental particle physics. It began in 1955, when he joined Brookhaven National Laboratory, and ended in 1985, when he moved to the field of cosmic-ray physics. The author discusses not only his successes but also his failures and his bad judgments. This period was the golden age of particle physics, when the experimental possibilities were abundant and one could carry out experiments with equal ease of all sorts and kinds.
I was stubborn,

“I have great difficulty in measuring anything better than 10%.”

This period was the golden age of particle physics, when the experimental possibilities were abundant and one could carry out experiments with a small team of colleagues and students.
The Golden Age of Cosmic Rays

Ratio: 4 counters/3 counters

at 2 m, \( R = 0.47 \pm 25\% \)

at 20 m, \( R = 0.50 \)

area of counter added = 0.015 m²

\[ \Delta a = \frac{0.47}{0.015} = 30/m^2 \quad 40/m^2 \]

\[ \Delta 20 = \frac{0.5}{0.015} = 33/m^2 \quad 30/m^2 \]

Wilson chamber

Events with 0 tracks = 48

Total events = 210

\[ \frac{48}{210} = 0.23 \Rightarrow \Delta = 37/m^2 \]

Auger, Maze, Ehrenfest Jr., and Fréon

J. de Phys. 10, 39 1939

Les effets secondaires, très marqués dans le cas des systèmes de petite envergure \((d < 20 \text{ m})\), deviennent faibles pour \( d = 50 \text{ m} \), distance à laquelle la courbe d’absorption par voûtes présente un départ horizontal, et ne jouent plus de rôle important à 75 m où la courbe décroît dès les premiers centimètres d’écran, comme pour les écrans interposés. On peut voir là une indication de l’énergie moindre des électrons géométriquement très écartés des condensations ou les particules les plus énergiques sont présentes (courbe 5).

(1) Ce nombre est un minimum, à cause de l’introduction dans la statistique de clichés sans rayons visibles, dus à un manque de lumière ou à d’autres conditions défavorables.
Cosmic Rays Today

High Energy gamma Rays

- VERITAS
- HAWC
- FERMI

High Energy Cosmic Rays

- AMS
- AUGER

Ultra-High Energy Cosmic Rays

- IceCube

High Energy neutrinos
Historical Prospective

- **HESS, MAGIC, VERITAS**  
- **MILAGRO** first data ≈ 2000, **HAWC** inaugurated 2015
- **FERMI** concept late 90s, launch 2008
- **AMS** proposal 1994, first flight 98, launch 2011
- **IceCube** 1st string 2005, completed 2010 (building on **AMANDA**, late 90’s)
- **AUGER** first SD and FD prototypes 2001, completed 2008
- **HiRes** 1997-2006, **TA** completed 2007

Large, ambitious experiments conceptually developed in the 1990s, built and operated in the last decade, now starting to address century-long open questions

**Jim Cronin’s legacy in Astroparticles:** the dawning of a new Golden Age
Jim speaking of the CASA array

This is the way a high-energy physicist attacks this problem. It’s large; it’s brute force; just make it big and let’s see if there’s anything there.

(Jim speaking of the CASA array)
The Chicago Air Shower Array (CASA)

1089 detectors with 15 m spacing covering an area of ~ 500 m x 500 m

> ten times bigger than previous detectors
The legacy of CASA

Gamma-ray astronomy by the air shower technique: Performance and perspectives (*)

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(*) Invited talk given at the XXIV International Cosmic-Ray Conference, Rome, August 28-September 8, 1996.

The large arrays, built to exploit the tantalizing results from Cygnus X-3, have completed their mission with the disappointing result that this and other similar sources of 100 TeV γ-rays do not exist.

brought Jim Cronin to the Auger adventure, and ultimately to inspire so many of us all around the world.
Design Concept for a 5000 km\(^2\) Air Shower Array

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Abstract

I describe a conceptual design for an air shower array with an area of 5000 km\(^2\) to study cosmic rays with energies \(\geq 10^{18}\)eV. The individual detectors can operate without external connections. Power comes from solar collectors, communications are by microwaves, and relative and absolute timing are provided by the GPS satellite system. It is hoped that this will stimulate others to consider how a giant array should be built.

This work was begun during a visit to the University of Leeds from September to December 1991. I wish to thank Alan Watson for providing a tranquil setting with abundant intellectual stimulation. There were extensive discussions about the design of a giant array. Many people have contributed their ideas to this study. In fact some of the individuals will see that their ideas have been adopted in this paper after first being rejected by me. I apologise for being slow to recognize their wisdom. From Leeds I thank Alan Watson, Michael Hillas, Jeremy Lloyd-Evans, John McMillan, Peter Daly and Kevin de Souza for their ideas and contributions. At the University of Chicago where this paper was completed Ken Gibbs and Leslie Rosenberg have made valuable comments and suggestions. But in the end this document is my own rendition of all of the ideas I have absorbed. If it serves as a stimulus for further thinking and ultimately a real array then we all benefit!
The real Hybrid Array

\[ E_{\text{cal}} = \int dX \frac{dE}{dX} \]

\[ \sigma_{X_{\text{max}}} < 20 \text{ g/cm}^2 \]

\[ \Delta_{\text{sys}} \approx 15 \text{ g/cm}^2 \]

\[ X_{\text{max}} \]

\[ \sigma_E/E \sim 8\% \]

\[ \Delta_{\text{sys}} \approx 14\% \]

\[ S_{1000} \]

\[ E_{\text{surface}} = f(S_{1000}, \theta) \]
For measured S1000 > 10.
Now experimentally established (origin still unclear)
The UHECR Energy Spectrum

Cosmic Ray Flux: Auger spectrum (red)
Anisotropy of UHECRs

Indications of large scale anisotropy for $E > 8 \times 10^{18}$ eV
Dipole amplitude chance probability $6.4 \times 10^{-5}$

No clear source found at the highest energy $> 6 \times 10^{19}$ eV
Energy dependent composition – likely only a small fraction of protons at the highest energies
UHE Neutrinos

On the detection of ultra high energy neutrinos with the Auger observatory

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Abstract

We show that the Auger Air Shower Array has the potential to detect neutrinos of energies in the $10^{19}$ eV range through horizontal air showers. Assuming some simple conservative trigger requirements, we obtain the acceptance for horizontal air showers as induced by high energy neutrinos by two alternative methods and we then give the expected event rates for a variety of neutrino fluxes as predicted in different models which are used for reference. © 1998 Elsevier Science B.V.

MCS: 95.85.Ry; 96.40.Tv; 96.40.Pq; 98.70.Sa

Horizonal shower

$\theta \approx 79^\circ$
Physics beyond the Standard Model

No UHE photon found – beyond the SM physics unlikely to be the explanation of the origin of UHECRs
Still open questions for the highest energy astroparticles

- Is there an end to the cosmic rays spectrum?
  Yes, but origin still unclear (GZK? Energy cutoff at the source?)

- What is the nature of the UHECR particles?
  Likely a mixed composition, but unclear at the highest energy due to lack of data

- How are UHECRs produced?
  non-SM physics unlikely
  acceleration at sources must be, large scale anisotropy appearing, but no clear astrophysical source yet found

“Nature has not been as kind as it could have been”

Auger Observatory September 2016

AugerPrime upgrade: scintillators on top of each tank to disentangle the muonic/e.m. component of the shower
Composition information for all the events
A new Golden Age is dawning
Future ahead

Old problems remain and new mysteries have appeared and there are new researchers armed with enthusiasm and new technology to solve the old problems and unravel the new mysteries.
I dedicate this article to the memory of John Linsley (b. March 12, 1925; d. September 15, 2002). He discovered the first cosmic ray with an energy of $10^{20}$ eV [2] 42 years ago. John Linsley has contributed so much to our understanding of cosmic ray showers.

He considered me an upstart when I began with colleagues to argue for a really large surface detector’ one which ultimately became the Auger Observatory. However with the passage of time I believe I gained his respect. I only wish that he could witness the progress that is going to be made. I cannot avoid the fantasy that he is now in a position to know all the answers!

Jim Cronin was a Magister of science and life, of a disarming modesty that pertains only to the greatest souls. His profound intellect, his humanity and his tender affection will always stay with me and, I know, with many others.
A Celebration of the Life and Work of James W. Cronin
Nobel laureate and pioneering physicist