Photon “energy range”

- Radio waves
- Microwaves
- Infrared
- Ultra Violet
- X-rays
- Gamma

Wavelength (meters):
- $10^2$
- $1^1$
- $1m$
- $10^{-1}$
- $10^{-2}$
- $10^{-3}$
- $10^{-4}$
- $10^{-5}$
- $10^{-6}$
- $10^{-7}$
- $10^{-8}$
- $10^{-9}$
- $10^{-10}$
- $10^{-11}$
- $10^{-12}$

Length of wavelength:
- Football field
- Human
- Bee
- Pin head
- Cell
- Bacteria
- Virus
- Atom
- Nuclei
Energy range of Cosmic Rays

+ 12 orders of magnitude
from 0.1 GeV to 0.3 ZeV or from $10^8$ to $10^{20}$ eV
Cosmic Ray Science

- Cosmic Sessions at APS april 2014
  - **Session C4 Invited Session: Astrophysical and Cosmological Neutrinos** (Apr 5 2014 1:30PM, Saturday)
  - Session E9 Galactic Cosmic Rays
  - Session J8: Ultra-high Energy Cosmic Rays
  - Session K8 Astroparticle Observatories and Techniques
  - Session R8: Gamma-ray and Neutrino Observations
  - Session S8 Radio in Ice: UHECR Cosmic-rays and Neutrino
  - **Session U4 Invited Session: Cosmic Rays** (Apr 7 2014 3:30PM, Monday)
Energies and rates of the cosmic-ray particles

Proton, Helium, heavier nuclei

Protons only

Electrons

Positrons

Antiprotons

Gamma-ray ~ 0.1%

E_{kin} (GeV / particle)
Energies and rates of the cosmic-ray particles

SUPERNOVA REMNANTS

\( E^2 dN/dE \) (GeV cm\(^{-2}\) sr\(^{-1}\) s\(^{-1}\))

Gamma-ray \( \sim 0.1\% \)

\( 10^{-10} \) \( 10^0 \) \( 10^4 \) \( 10^8 \) \( 10^{12} \)

\( 10^6 \) \( 10^{10} \) \( \cdots \)

CAPRICE
AMS
BESS98
Ryan et al.
Grigorov
JACEE
Akeno
Tien Shan
MSU
KASCADE
CASA-BLANCA
DICE
HEGRA
CasaMia
Tibet
Fly Eye
Haverah
Yakutsk
AGASA
HiRes

%
Fluxes of Cosmic Rays

Space Experiments

Solar Influence

Galactic Cosmic Rays

Extragalactic Cosmic Rays

Ground Experiments

Energy (eV)

Flux (m^2 sr s GeV^-1)
Cosmic Ray Science on the Ground

- **Ground Observatories = Giant Arrays of Detectors**
  - Observe air-showers produced by primary cosmic rays

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**Current Observatories of Ultrahigh Energy Cosmic Rays**

- **Telescope Array**
  - Utah, USA
  - (5 country collaboration)
  - 700 km² array
  - 3 fluorescence telescopes

- **Pierre Auger Observatory**
  - Mendoza, Argentina
  - (19 country collaboration)
  - 3,000 km² array
  - 4 fluorescence telescopes

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**3,000 km²**
Anisotropy Hints $> 6 \times 10^{19}$ eV

- $E > 5.7 \times 10^{19}$ eV
- $20^\circ$ smoothing
- $\approx 5 \sigma$ pretrial
- $\approx 3 \sigma$ pretrial

Telescope Array

Auger Observatory
Cosmic Ray Science from Space
Open Questions in CR Science

- **Origin of Galactic Cosmic Rays (GCR):**
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate in the Galaxy?
  - Where is the Transition between Galactic & ExtraGalactic CRs?

- **Origin of ExtraGalactic Cosmic Rays (XGCR):**
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate to Earth?
  - At what Energy COSMIC RAY ASTRONOMY begins?

- How do Cosmic Rays Affect the Earth, the Solar System, the ISM, the Galaxy, other Galaxies, and the formation of Stars and Galaxies?
Open Questions in CR Science

- **Origin of Galactic Cosmic Rays (GCR):**
  - What are the accelerators? (CosmicSIG + GammaSIG)
  - What are they accelerating?
  - How do they propagate in the Galaxy?
  - Where is the Transition between Galactic & ExtraGalactic CRs?

- **Origin of ExtraGalactic Cosmic Rays (XGCR):**
  - What are the accelerators?
  - What are they accelerating?
  - How do they propagate to Earth?
  - At what Energy COSMIC RAY ASTRONOMY begins?

- How do Cosmic Rays Affect the Earth, the Solar System, the ISM, the Galaxy, other Galaxies, and the formation of Stars and Galaxies?
Questions Related to CR Science

- Origin of PeV neutrinos (IceCube detections)
- Indirect Dark Matter Searches
  - WIMP in the Galactic Halo: e+, e-; p, anti-p, γ, ν ...
- Probe of Particle Interactions above LHC energies
  - Ultrahigh Energy Cosmic Rays (UHECR) \( E_{cm} > 100 \text{ TeV} \)
  - Ultrahigh Energy Neutrinos
- Searches for Exotic Components of Matter:
  - Antinuclei
  - Magnetic Monopoles
  - Strangelets
  - Qballs
  - Primordial Black Holes
Recent Highlights
Cosmic Rays Recent Highlights

- Voyager 1 reaches Interstellar Space (Aug/Sep 2012)

Graphs showing the increase in Cosmic Rays >70 MeV and Heliospheric ions 0.5-30 MeV.
Cosmic Rays Recent Highlights

- Super-TIGER (Trans-Iron Galactic Element Recorder) breaks flight duration record: 55 days at 127,000 feet
- Increase on UltraHeavy Nuclei data by 1 o.o.m. to study composition and origin of Galactic Cosmic Rays
Cosmic Rays Recent Highlights

- AMS (Alpha Magnetic Spectrometer) on the ISS announces first results
“Cosmic Ray Observatory on the ISS”

AMS Launch
May 16, 2011

ISS-CREAM
Sp-X Launch 2014

CALET on JEM
HTV Launch 2014

JEM-EUSO
Launch Tentatively planned for 2017
The balloon-borne CREAM was flown 6 times over Antarctica with ~161 days of total flight time, the longest exposure to date for a single balloon project.

ROSES 2010 proposal: Building on the success of the balloon flights, the payload is being transformed for accommodation on the ISS (NASA’s share of JEM-EF).

CREAM measures the energy spectra from $10^{12}$ to $>10^{15}$ eV over the elemental range from protons to iron.

It extends the energy reach of direct measurements of cosmic rays to the highest energy possible to probe their origin, acceleration and propagation.
ISS-CREAM Instrument

Ahn et al., NIM A, 579, 1034, 2007; Anderson et al., Hyun et al., Seo et al. 33rd ICRC, 2013

**Silicon Charge Detector**
- Precise charge measurements

**Carbon Targets**
- Induce hadronic interactions

**Calorimeter (20 layers W + scintillating fibers)**
- Determine Energy
- Provide Trigger

**Top & Bottom Counting Detectors**
- Each with 20 x 20 photodiodes and a plastic scintillator for e/p separation

**Boronated Scintillator Detector**
- Additional e/p separation
The CALET payload will be launched by the Japanese carrier, H-II Transfer Vehicle 5 (HTV), and robotically attached to the port #9 of the Japanese Experiment Module - Exposed Facility (JEM-EF) on the International Space Station.

**Weight:** 650 kg  
**Mission Life:** 5 years  
**Launch:** by fiscal year 2014 (from April 2014 to March 2015)
JEM-EUSO update

Extreme Universe Space Observatory (EUSO) in the Japanese Experiment Module (JEM) of the International Space Station (ISS)

JEM-EUSO goals (EECR = Extreme Energy Cosmic Rays):
- pioneer the study of EECR from Space
- increase exposure to EECR by 1 order of magnitude
- discover the nearby sources of UHECRs
JEM-EUSO update

- Redesigned for SpaceX Dragon Delivery
- Pathfinders:
  - EUSO-Balloon first launch in 2014
  - EUSO-TA commissioning Spring 2014
  - Mini-EUSO launch 2015-16
Opportunities in Space for CR Science

- **In Situ Measurements of Solar System**
  - Voyager I & II

- **Ultra Heavy Nuclei**
  - ACE/CRIS
  - Super-TIGER

- **Precise Measurements from GeV to TeV**
  - PAMELA
  - AMS
  - CALET

- **Galactic Cosmic Rays up to the knee**
  - CREAM, TRACER
  - ISS-CREAM

- **Extragalactic Cosmic Rays**
  - JEM-EUSO
  - OWL/PATEL
Space Opportunities for Cosmic Ray Science
CosmicSIG Activities

- Committee formed April 2013
  - John Mitchel (GSFC), Igor Moskalenko (Stanford U), Angela Olinto (U Chicago) Chair, Eun-Suk Seo (U Maryland)

- Goals of CosmicSIG
  - Provide an assessment to NASA HQ and the PCOS program office of the status and the current and future needs of the cosmic-ray astrophysics community.
  - Act as a focal point and forum for the cosmic ray community.

- White Paper with Cosmic Ray vision for the next decade(s)
  - Gather input from Community
  - Survey current and future projects and missions and their science goals and coverage
  - Survey technology development needs for future progress in the field
The goals of the Cosmic Ray Science Interest Group (CosmicSIG) are to provide quantitative metrics and assessments to NASA in regard to current and future needs of the cosmic-ray astrophysics community and to act as a focal point and forum for the cosmic ray community.

The CosmicSIG is composed of John Mitchel (GSFC), Igor Moskalenko (Stanford U), Angela V. Olinto (U Chicago) Chair, Eun-Suk Seo (U Maryland). CosmicSIG will work towards producing a white paper covering:

- the major open science questions
- a brief survey of the current and planned, US and International, space and ground-based projects â€“ their energy coverage (from about $10^{18}$ eV to $10^{20}$ eV), sky coverage, and particle type coverage (electrons, positrons, nucleons, anti-nucleons, nuclei, anti-nuclei, neutrinos, and new particles)
- a survey of the state-of-the-art capabilities, the next generation technology needs, and potential science return from new technologies and capabilities
- a vision for the future of cosmic ray science in space

The CosmicSIG is open to all members of the community.

If you are interested in contributing to the work of the CosmicSIG, please subscribe using the link below. For other inquiries, e-mail Angela Olinto, chair of the CosmicSIG, at olinto@uchicago.edu

**CosmicSIG Mailing List**

Subscribe to the CosmicSIG mailing list.
Figure 1.2 Chart of the missions currently planned for launch during the Near-Term Era and of the notional missions of this roadmap for the Formative and Visionary Eras.