Cosmic Rays

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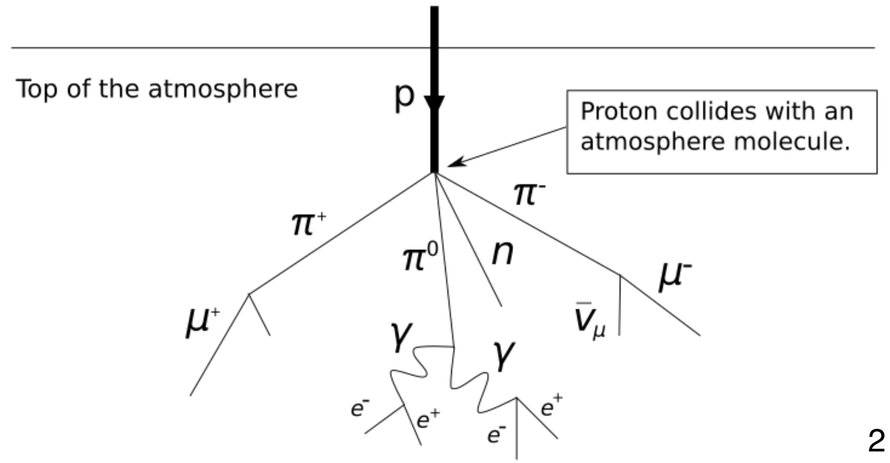
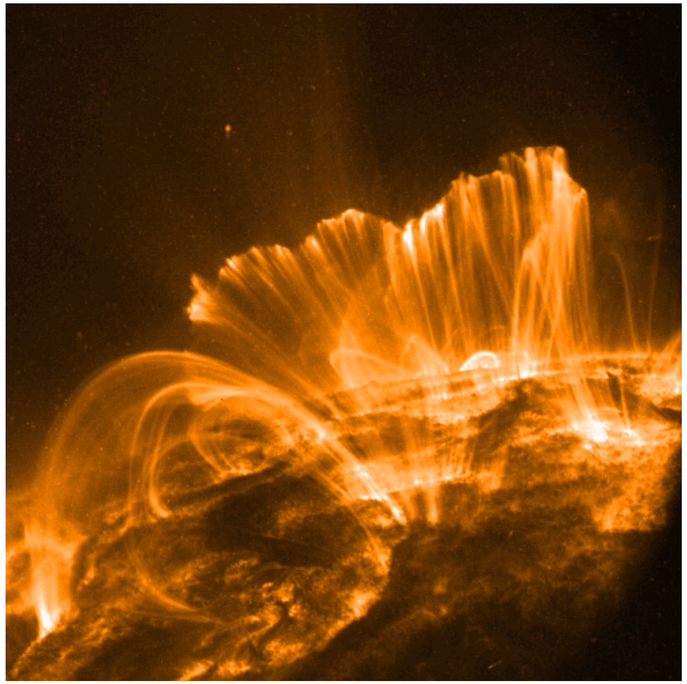
Introduction

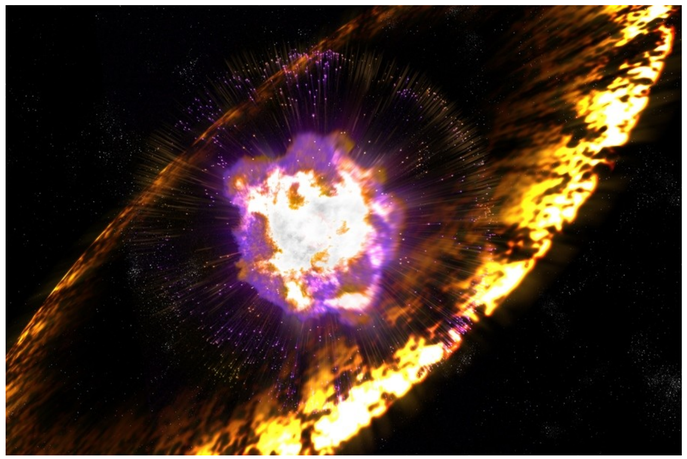
- What is a cosmic ray (CR)?
  - High-energy particles (incident on earth) from outer space
- Two types of CRs:
  - Primary = originate outside the earth's atmosphere
  - Secondary = produced in collision between primary CR and gas molecule (and subsequent decays)
    - How often does a CR muon pass through your head?
      - Answer: ~1 per second



Origin

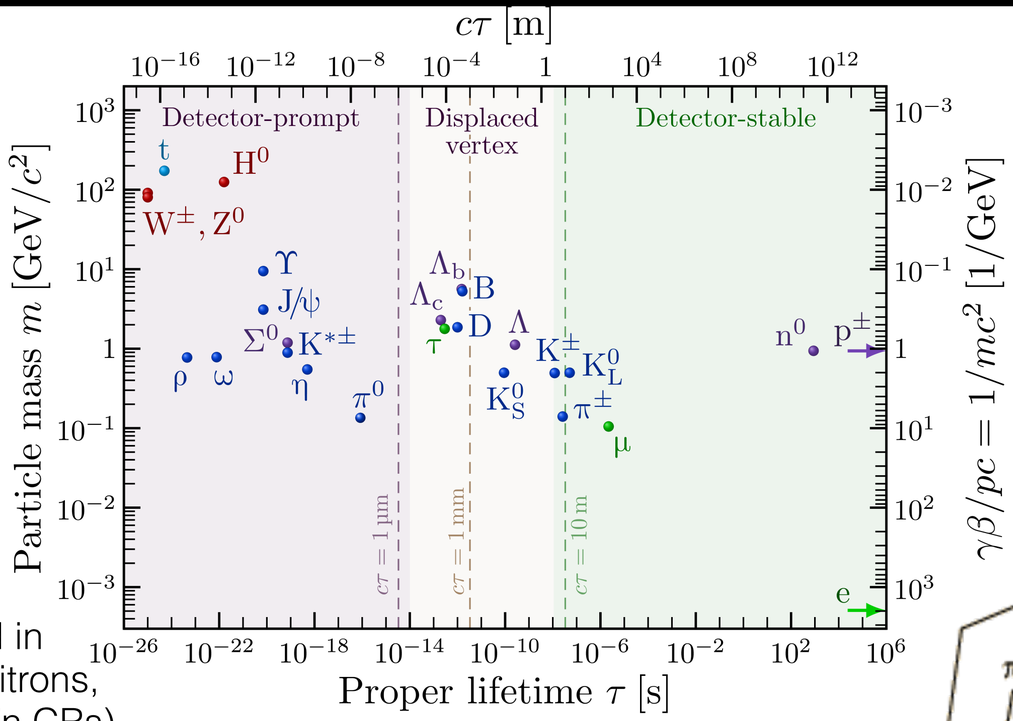
- Where do primary CRs come from?
  - The sun
    - Solar flare, coronal mass ejection (~10^{36} particles per second)
  - Extrasolar/extragalactic
    - Mechanisms not fully understood
      - Supernova, active galactic nuclei, blazars, …
    - Tend to be more energetic than solar CRs

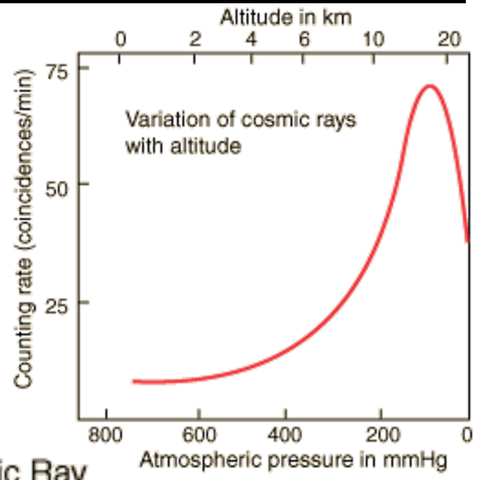


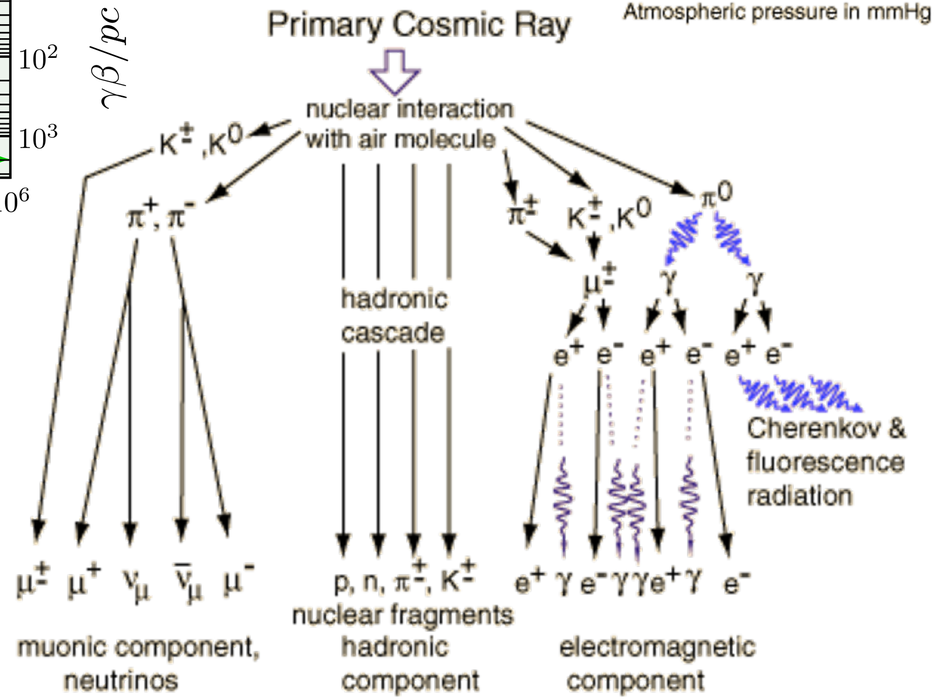


Composition

- Primary
  - 99% atomic nuclei (q>0)
    - 90% protons
    - 9% α particles
    - 1% heavier nuclei
  - 1% electrons (q=-1)
  - Very small fraction of antimatter (antiprotons and positrons)
- Secondary
  - Zoo of unstable particles produced in shower 15-20 km above earth (positrons, muons, and pions first discovered in CRs)
    - Flux and composition varies with altitude
  - At sea level:
    - 70% muons
    - 29% electrons/positrons

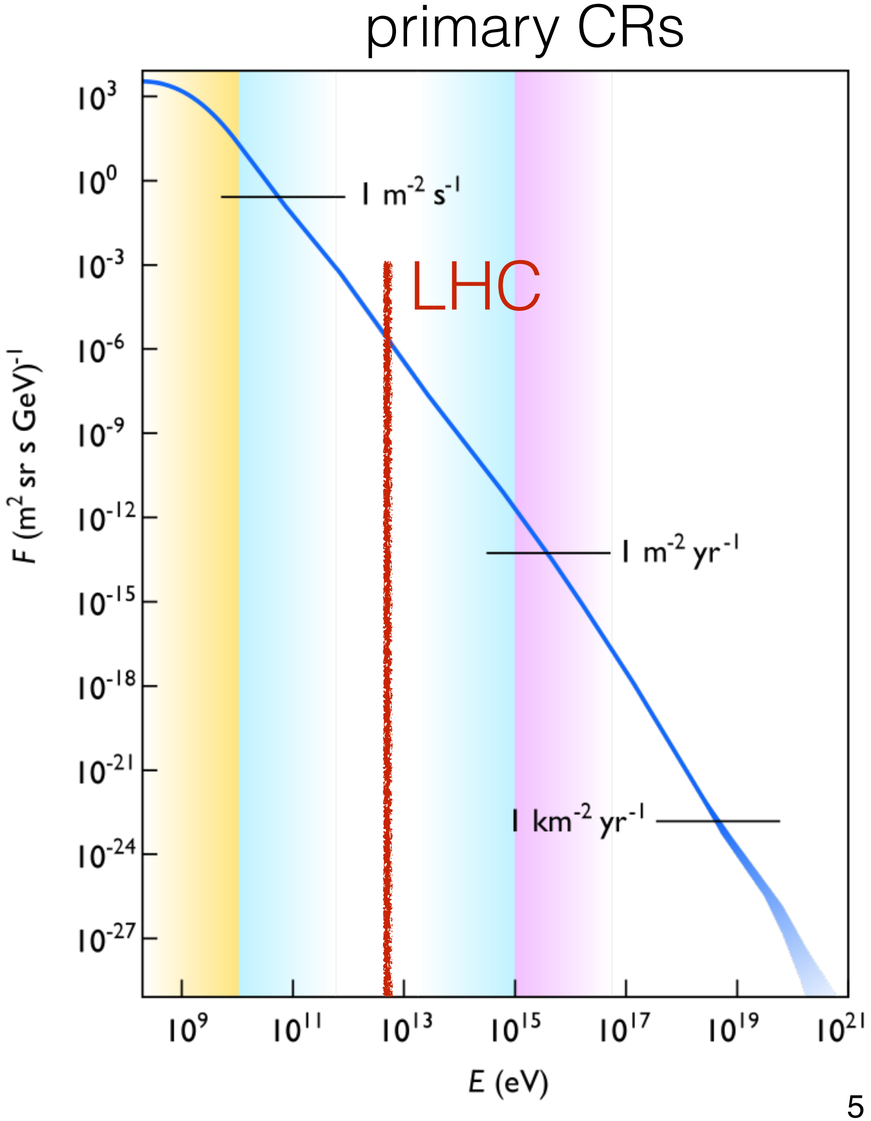






Energy

- What is the highest energy primary CR ever detected?
  - For reference, LHC beam energy is 7 TeV (*KE* of a mosquito)
  - Answer: 3×10^7 TeV (*KE* of a baseball w/ $v = 25$ m/s)
- Most probable energy ≈ 0.3 GeV
  - 3 orders of magnitude less than LHC beams
- Can cause damage to life and electronics
  - Fortunately, earth's magnetic field protects us



reminder: 1 TeV = 1.6×10^{-7} J

Muons

- Produced ~20 km above earth with $v \approx 0.995c$ and a lifetime of τ = 2.2 x 10^{-6} s
  - What fraction reach us?

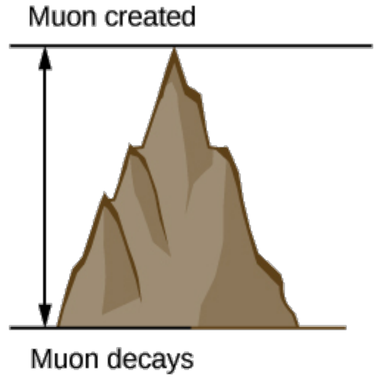
$$t = \frac{\ell}{v} = \frac{20000\text{m}}{0.995c} = 7 \times 10^{-5}\text{s}$$

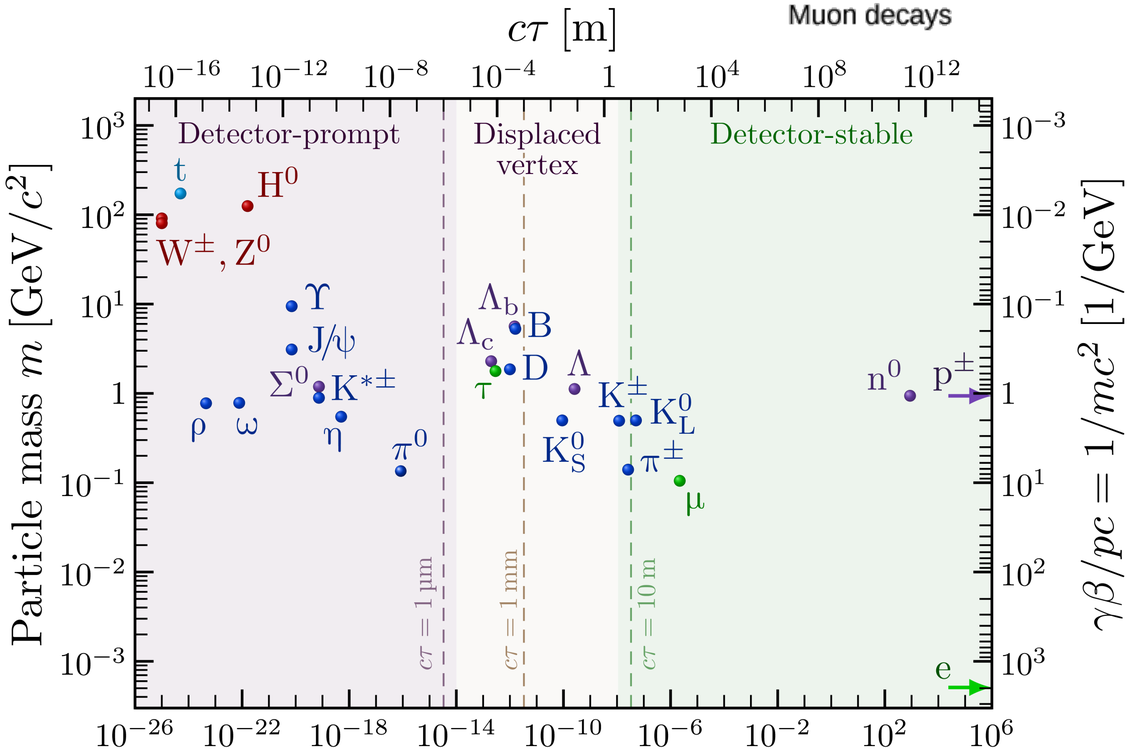
$$\frac{N(t)}{N(0)} = e^{-t/\tau} = e^{-7\times10^{-5}\text{s}/2.2\times10^{-6}\text{s}} = 6 \times 10^{-14}$$

  - That is negligible - where have I gone wrong?
    - Answer: relativity
  - To earth-based observer, muons are produced and decay at different positions → observe dilated lifetime

$$\tau' = \gamma\tau = \frac{\tau}{\sqrt{1 - v^2/c^2}} = \frac{\tau}{\sqrt{1 - 0.995^2}} = 10\tau$$

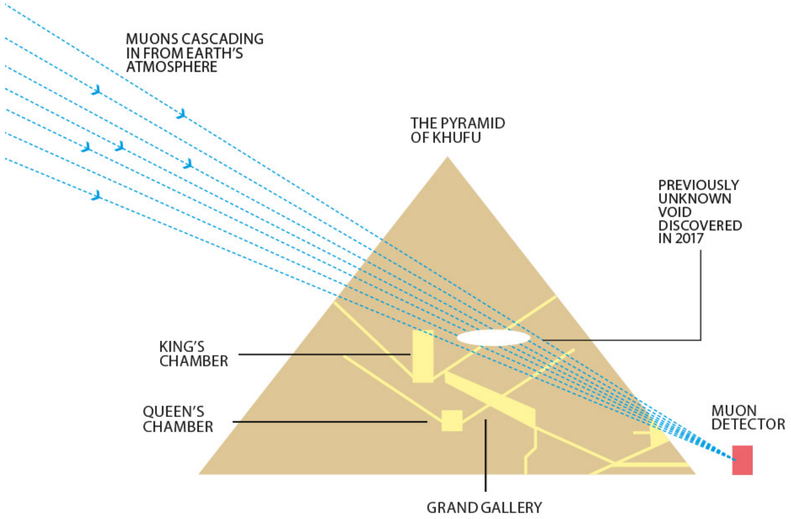
$$\frac{N(t)}{N(0)} = e^{-t/\tau'} = 0.05$$

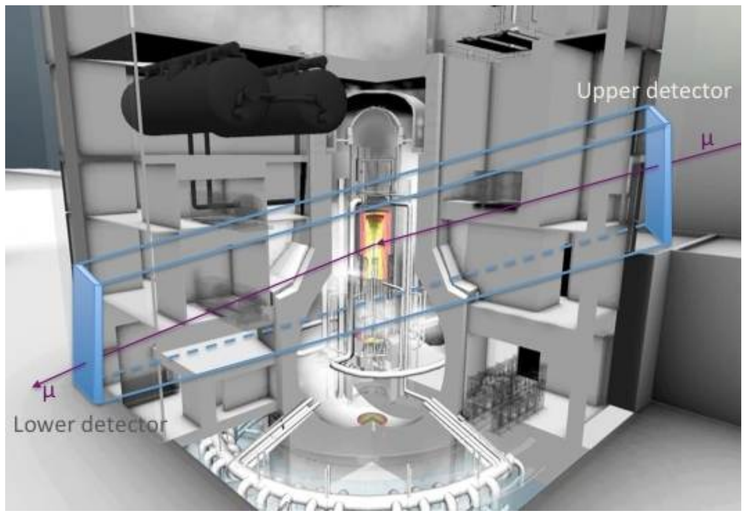


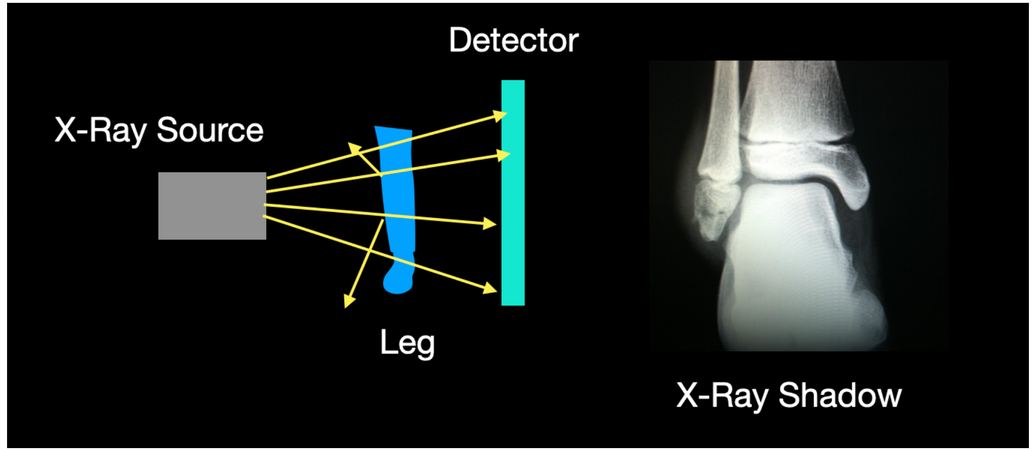


Applications

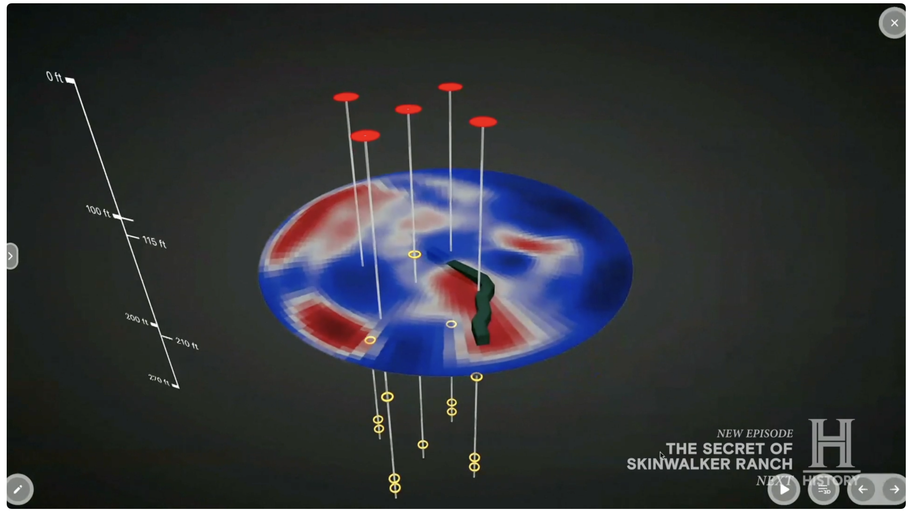
Can use CR muons for imaging







and for treasure hunting!



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