Traces of Ultra-High–Energy Particles in the Lunar Crust

The Second International Workshop on

Ultra-high-energy cosmic rays and their sources

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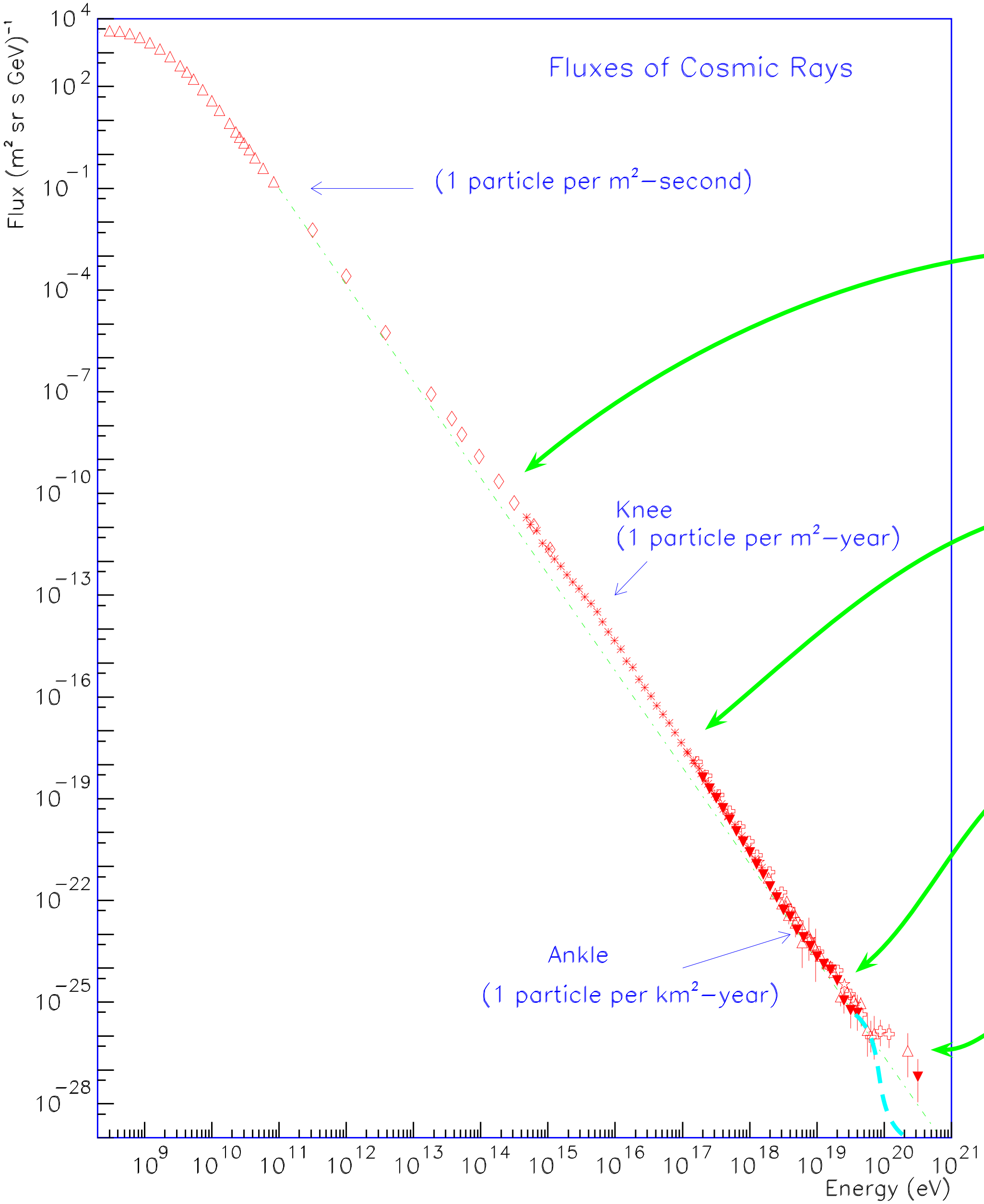
Flux of Charged Cosmic Rays



$$\frac{dN}{dE} \propto E^{-2.65}$$

Knee2:

$$\frac{dN}{dE} \propto E^{-3.05}$$

$$\frac{dN}{dE} \propto E^{-3.20}$$

$$\frac{dN}{dE} \propto E^{-2.7}$$

$$\frac{dN}{dE} \propto E^{-2.7}$$

GZK-cutoff (1966)

Statistics & Methods

overall low : $\frac{dN}{dE} \propto E^{-3}$ Thus @ $E = 10^{20}$ eV

GZK – false – # particles per 10^2 km^2 per year

GZK – true – # particles per 10^4 km^2 per year

Statistics – Exposure:

- observational area (volume) $S \sim 10^2 - 10^4\ km^2$
- observational time $t \sim 10$ year

Earth & Moon

Track's
recorder

Calorimeter
& Fast Tracker

Let imprints of UHECR be in the Lunar Crust

Advantages:

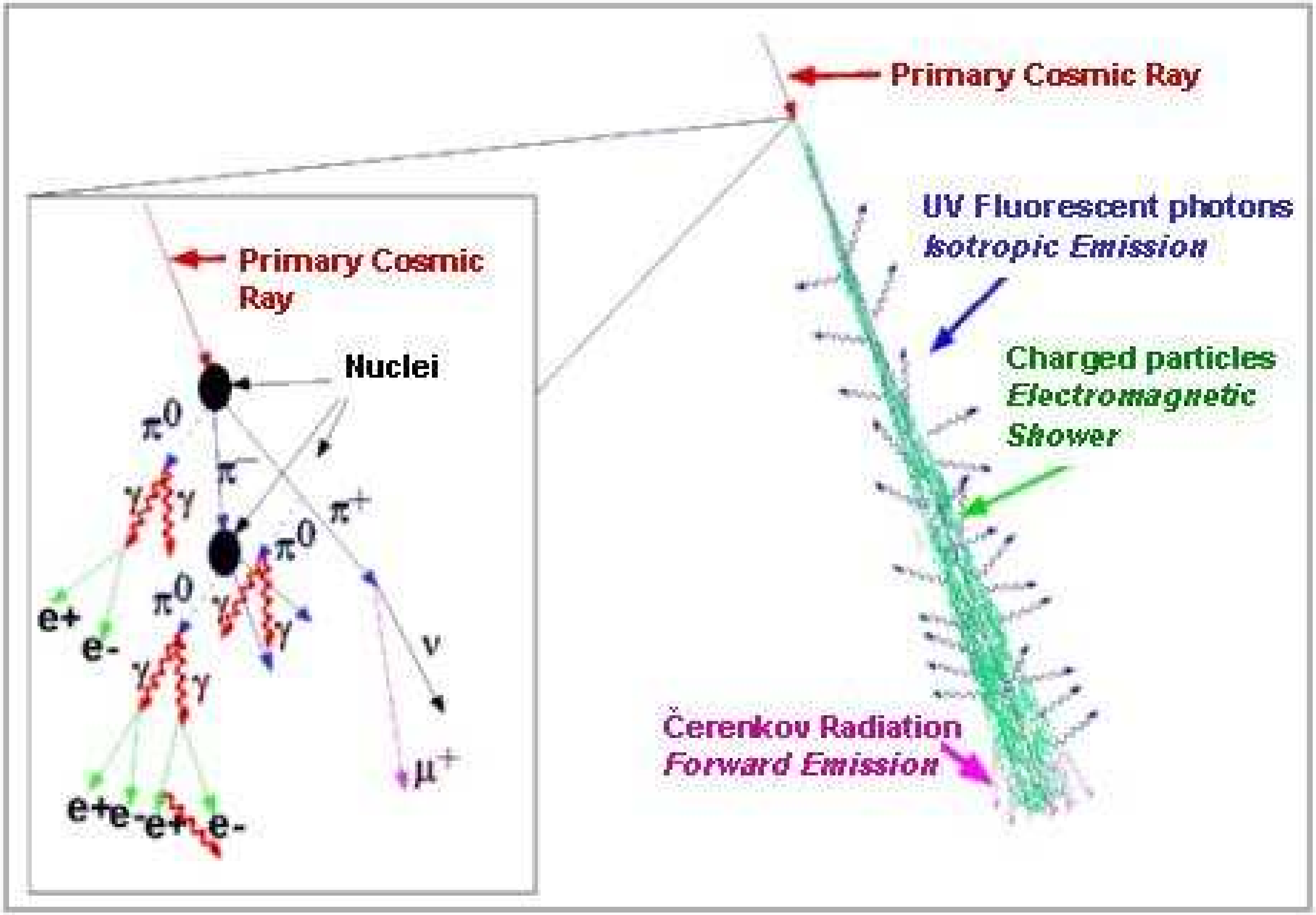
- enormous exposure: $t \sim \tau_{Moon} \simeq 4 \cdot 10^9$ year

  Then per 1 m^2:

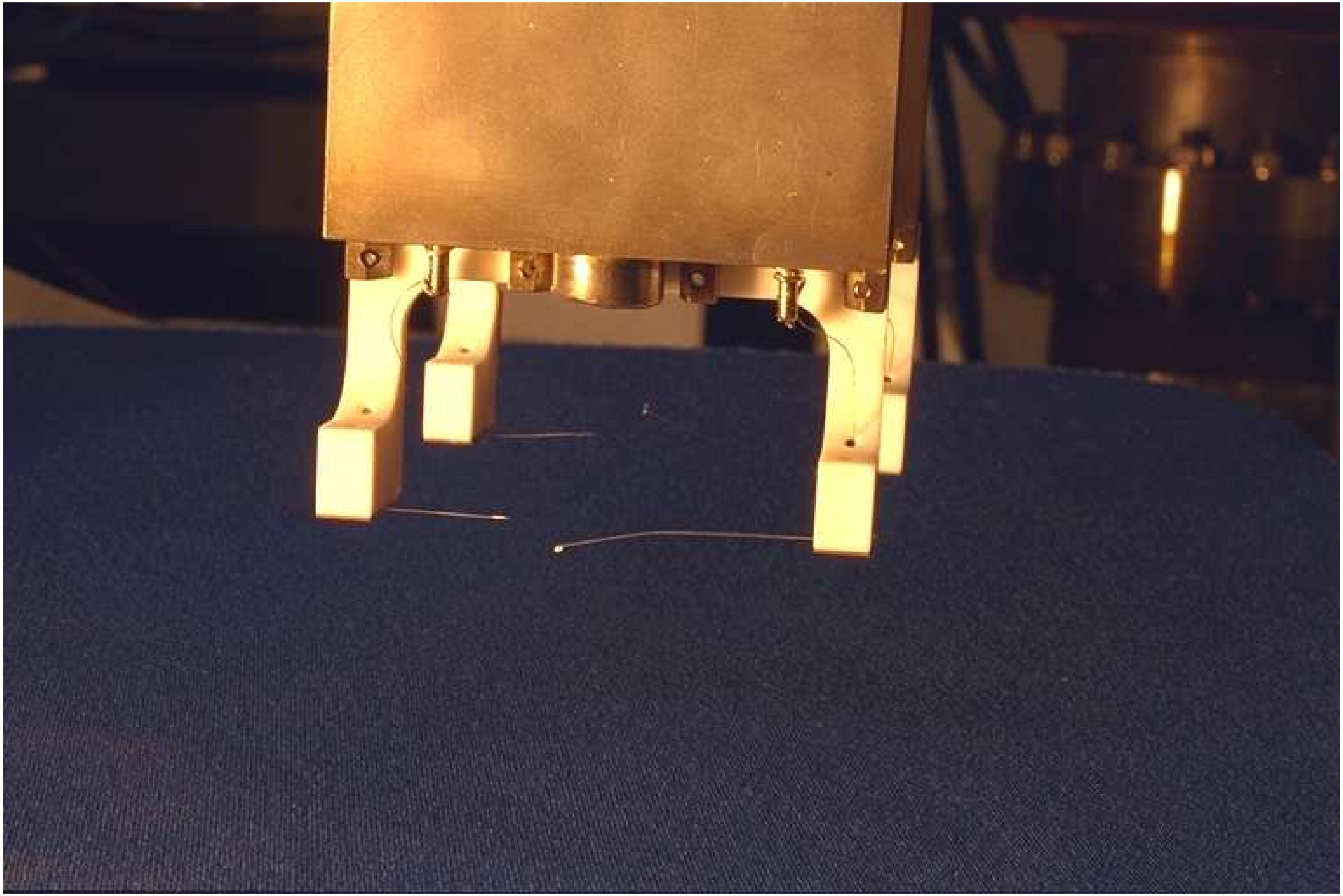
  - GZK — false — ~ 100 imprints
  - GZK — true — ~ 1 imprint

- search for the ultimate cutoff in UHECR spectrum — the highest energy events for the last $1/4$ of the Universe's life

Earth's Atmosphere: Extensive Air Showers



Moon’s Crust: a beam & a target



Shower in a rock

Evolution

- First collision:
  - one partilcle of E_0: ~ 500 secondaries of $E \sim E_0/500$
  - angular beam spread $\delta\alpha \sim \langle P_T \rangle / E_0 \lesssim 10^{-11}$
  - $l_{||} = 10$ m, then $l_{\perp} \simeq 10^{-8}$ cm=1 A
- Next collisions
- ...

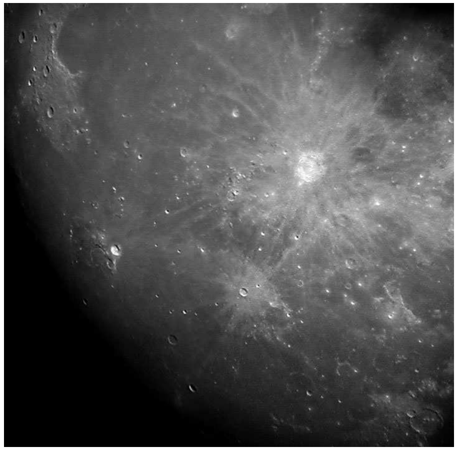
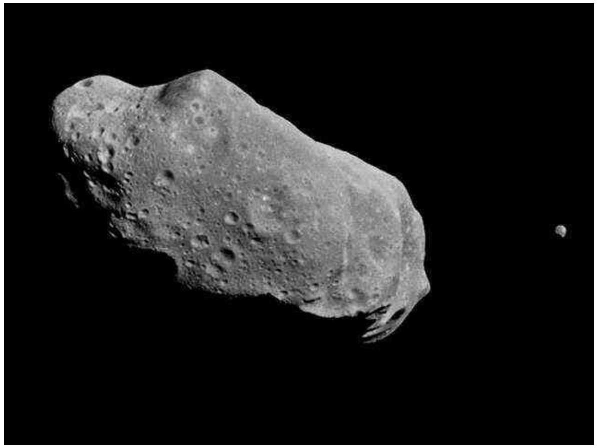
Interaction

- washing out the atoms from the shower core
- high-energy secondaries: radiative energy loss
- low-energy secondaries: ionization
- ...

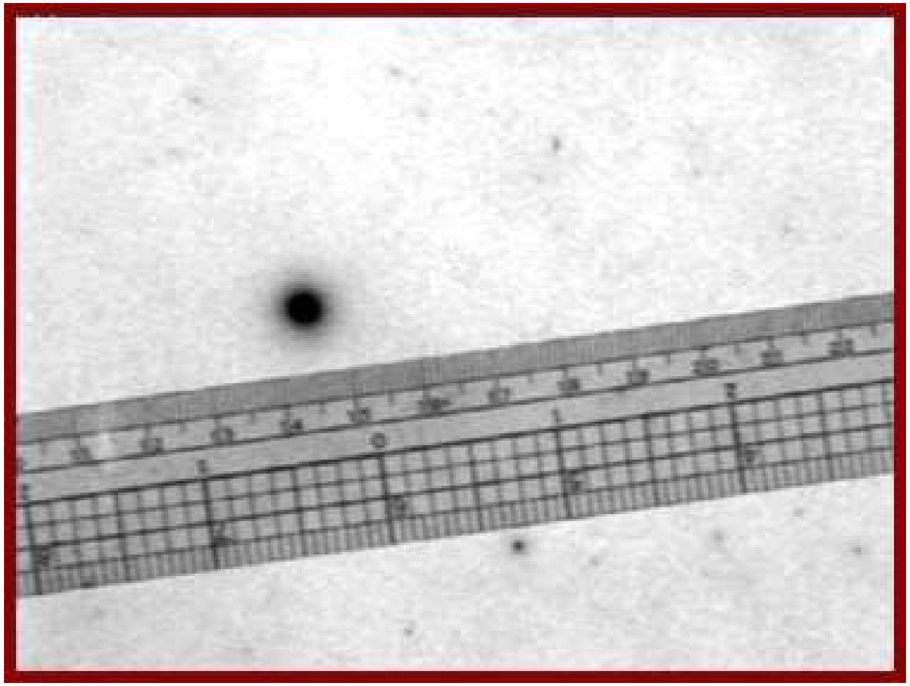
Very naive estimate

One of the candidates: stright long tracks in lunar crust
unrealistic but warming up example:

- iron
- only radiative energy loss ($dE/dx \propto E$)
- lost energy is promptly dissipated — heating
- then the primary of $E_0 \simeq 10^{20}$ eV smelts $\sim 1\ \mathrm{m} \times (10\mu)^2$ cylinder
- measurement of the primary energy: radius $r \propto \sqrt{E_0}$


Reality: tracks of CR in micrometeorites



Study of both intensity & composition of galactic CR in the past

Lunar Robotic Missions