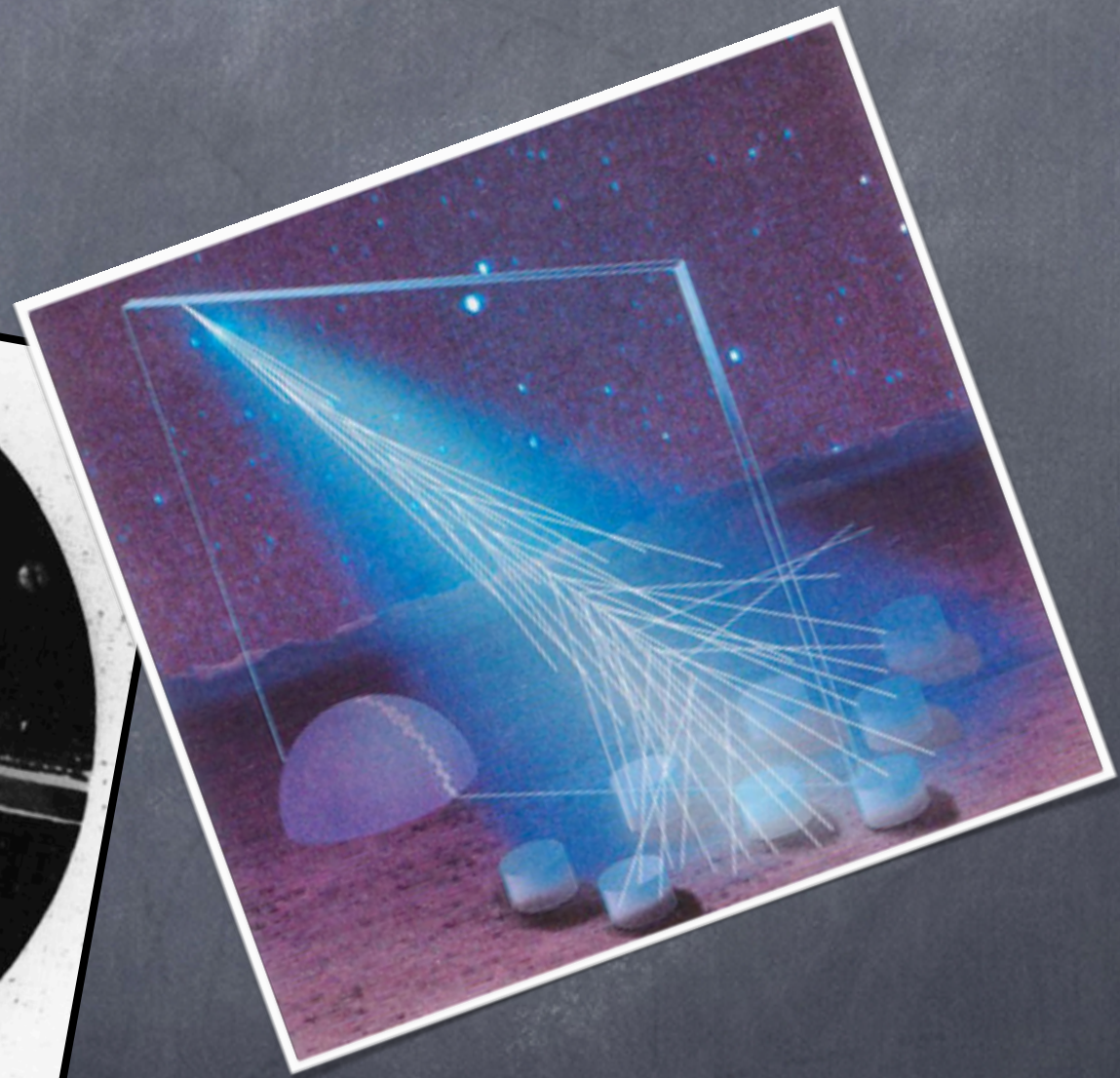
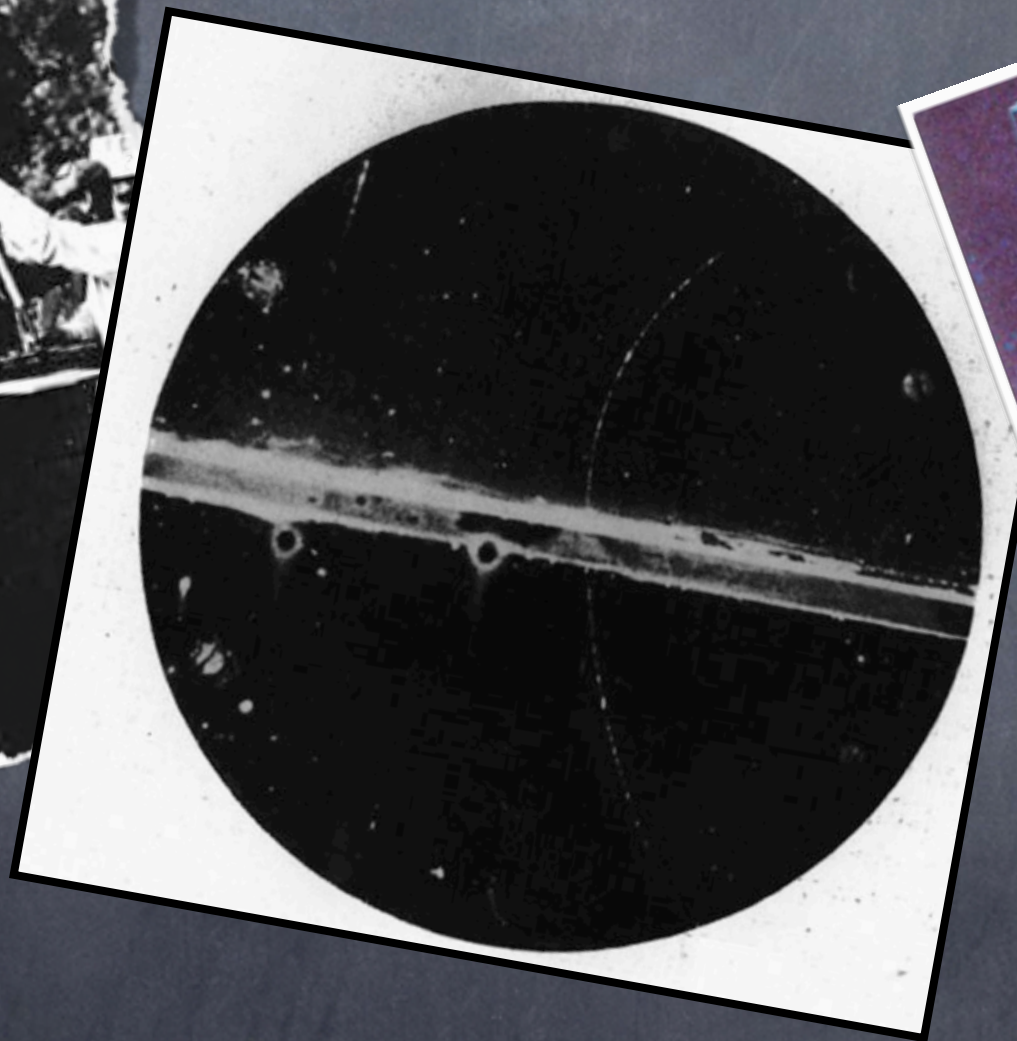


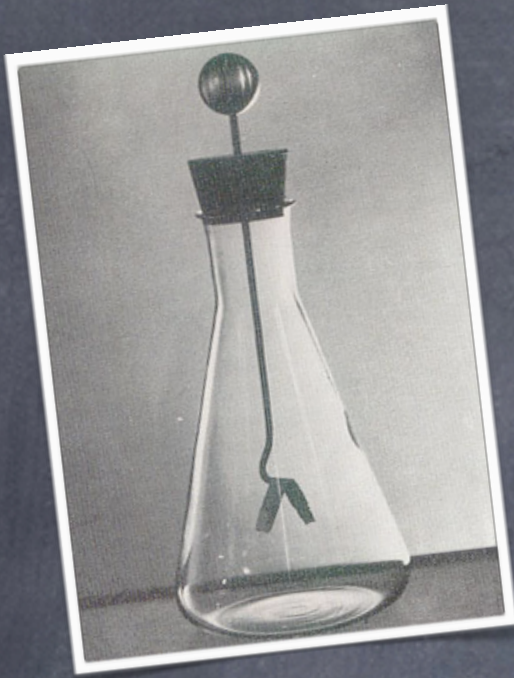
Raggi cosmici: un secolo di sorprese



Oss. Brera
4/12/2013

Un po' di storia...

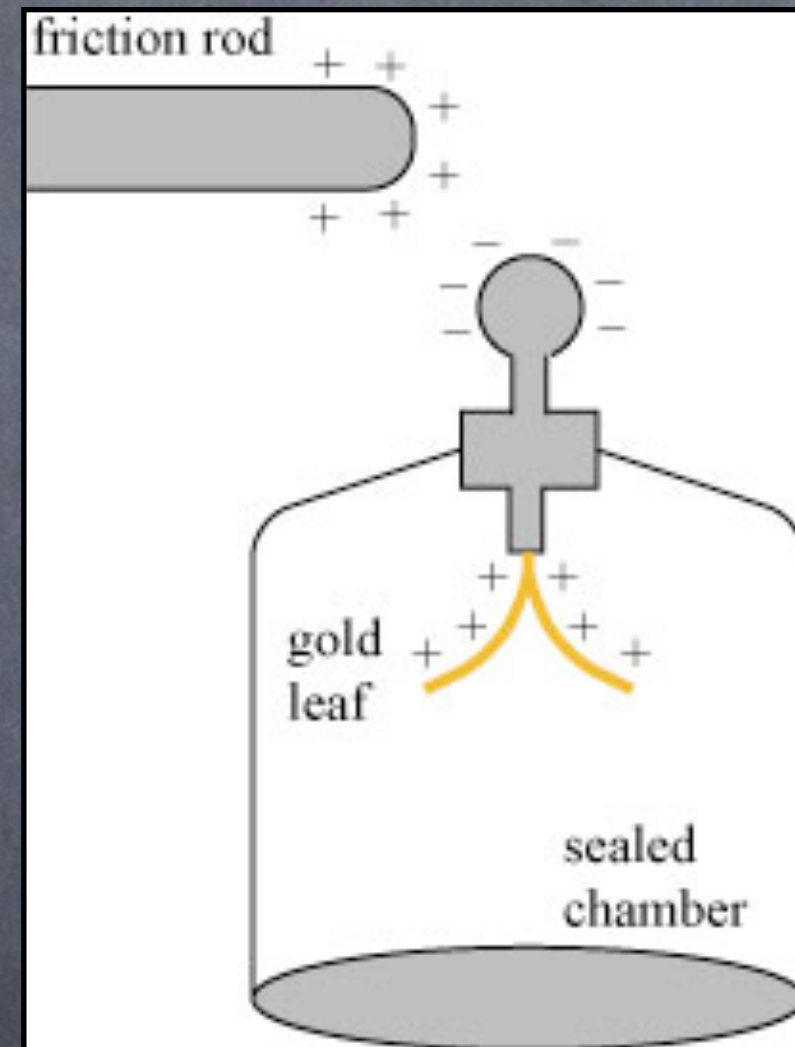
Elettroscopio



Elettroscopio



- < pallina di alluminio
- < barretta metallica
- < tappo isolante
- < striscette di alluminio
- < vasetto di vetro

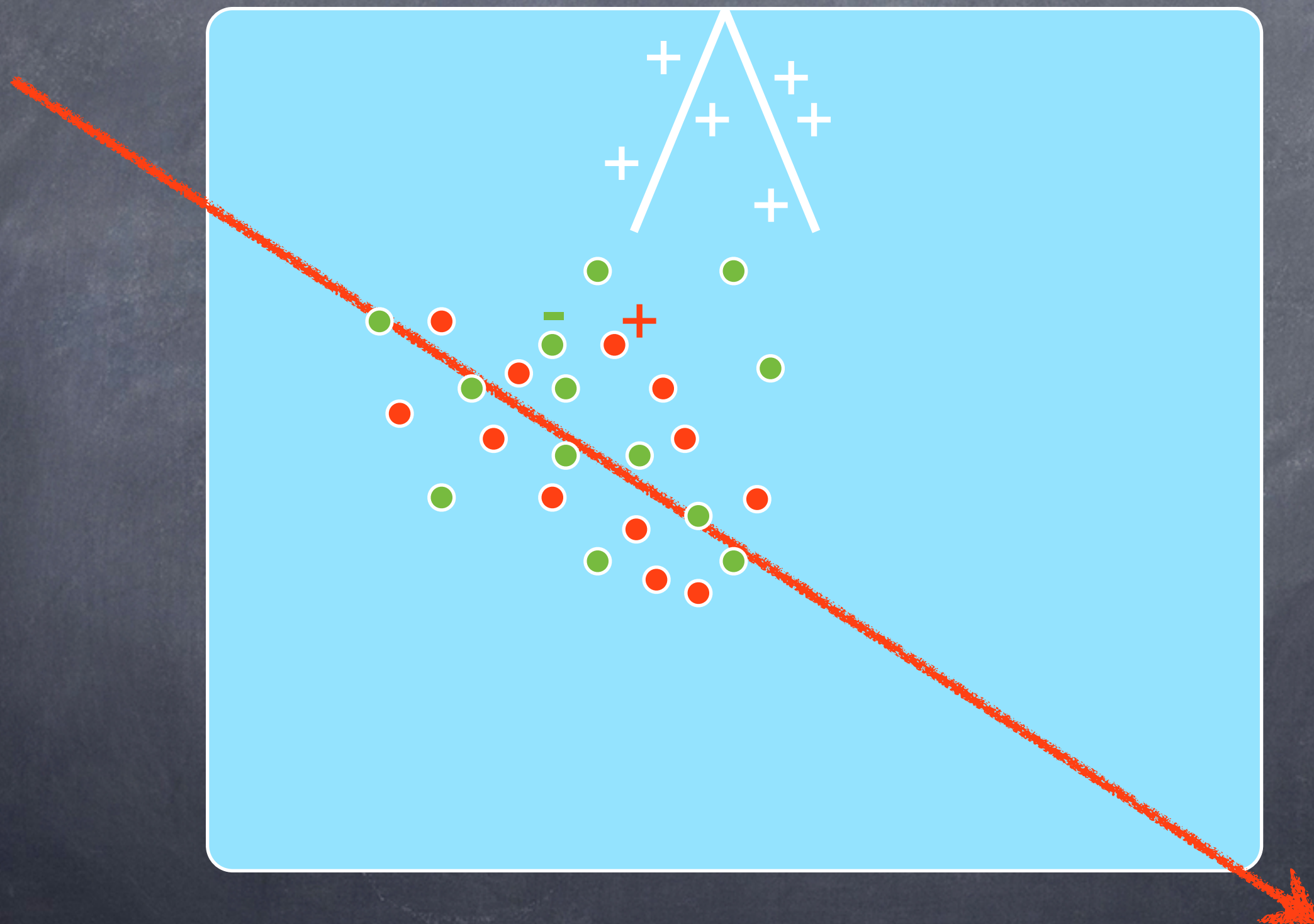


Becquerel: posto vicino a sostanze radioattive
l'elettroscopio si scarica

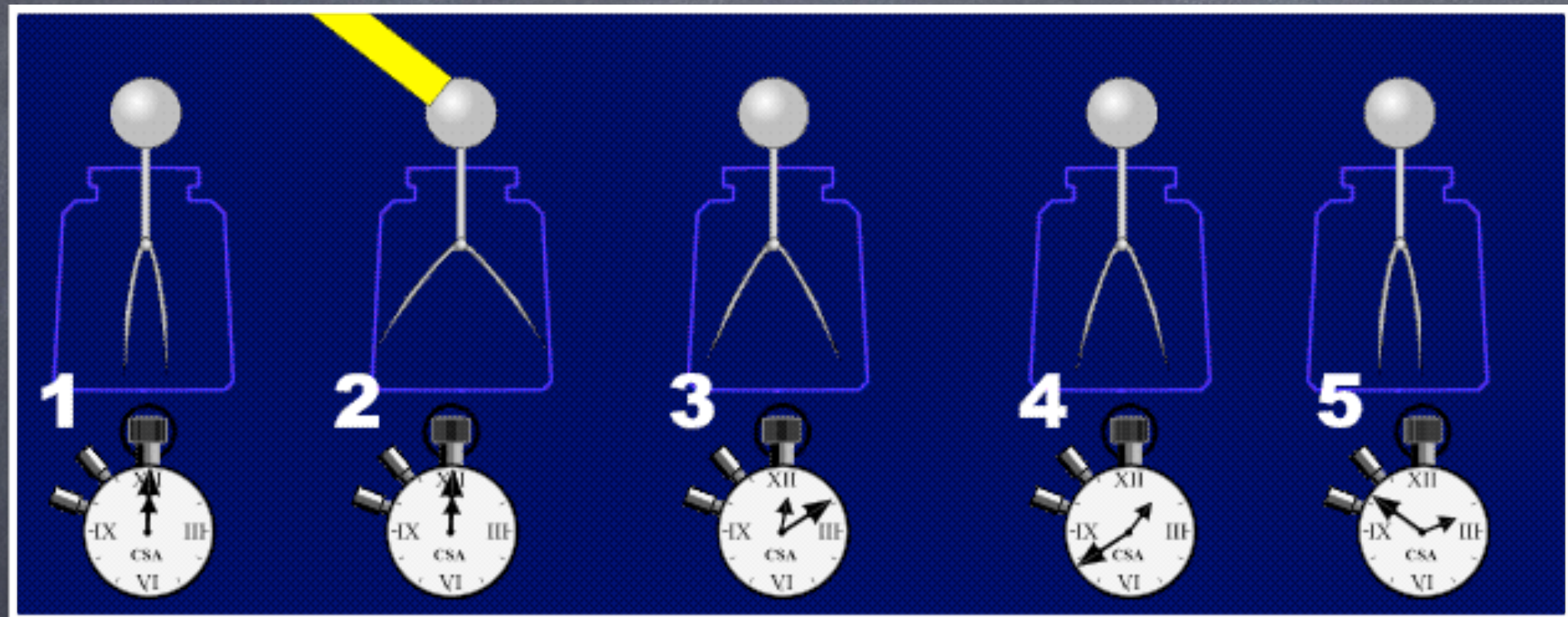


Nel gas all'interno (aria) si formano cariche elettriche
attraverso la “*ionizzazione*” causata dal passaggio della
radiazione carica elettricamente (particelle beta, alfa).
Queste neutralizzano le cariche sulle striscette

**Elettroscopio come
rivelatore di radiazioni
ionizzanti**



Scarica spontanea!



Coulomb (1785)

Perche' l'elettroscopio si scarica?

Ipotesi 1: e' mal isolato, la carica si disperde

Ipotesi 2: esiste una radiazione che ionizza il gas nell'elettroscopio: le cariche cosi' create neutralizzano la carica delle striscette

2a: di origine terrestre (radioatt.)

2b: di origine extraterrestre



Perche' l'elettroscopio si scarica?

~~Ipotesi 1: e' mal isolato, la carica si disperde~~

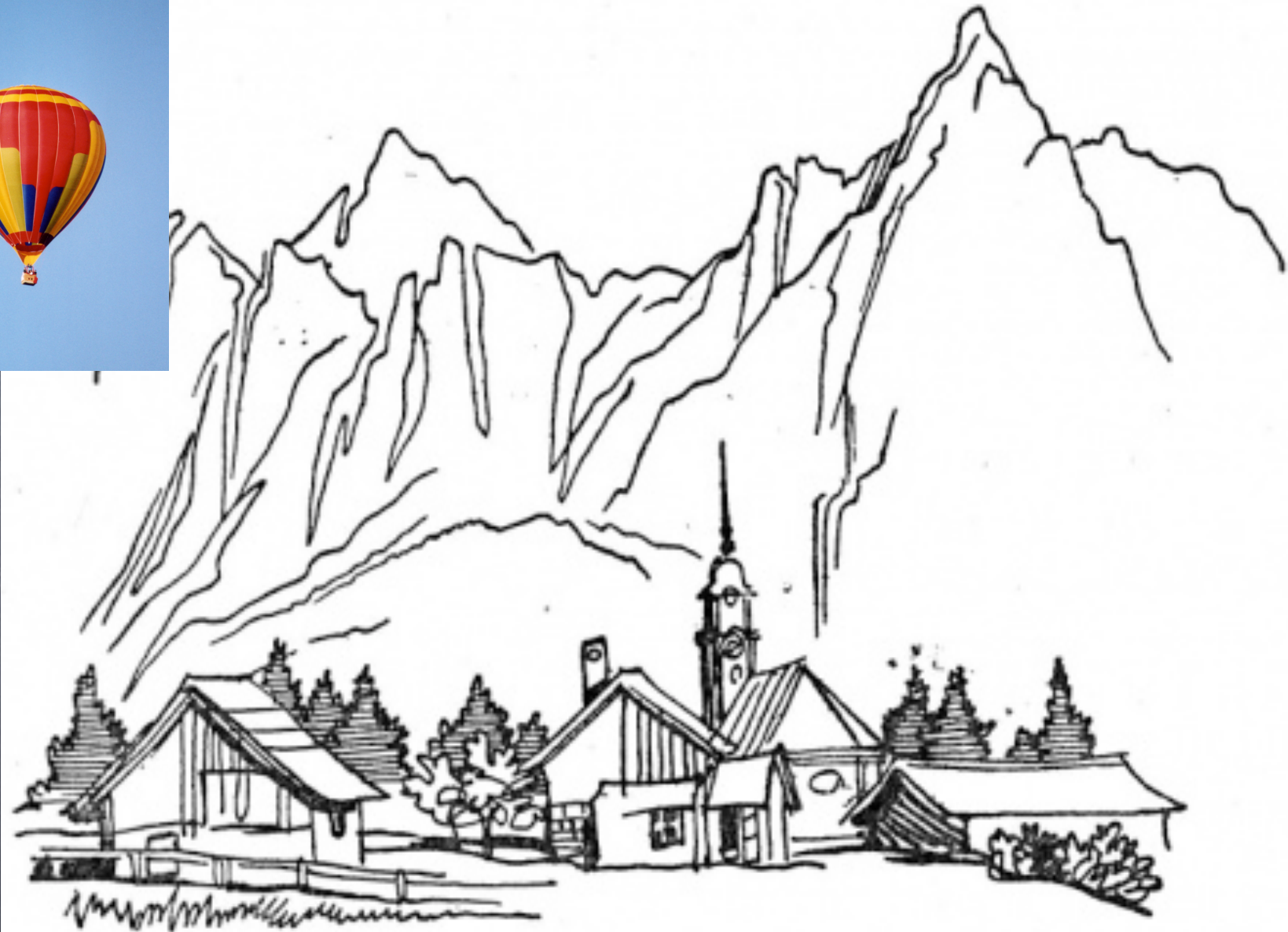
Ipotesi 2: esiste una radiazione che ionizza il gas nell'elettroscopio: le cariche cosi' create neutralizzano la carica delle striscette

2a: di origine terrestre (radioatt.)

2b: di origine extraterrestre



La prova del nove!



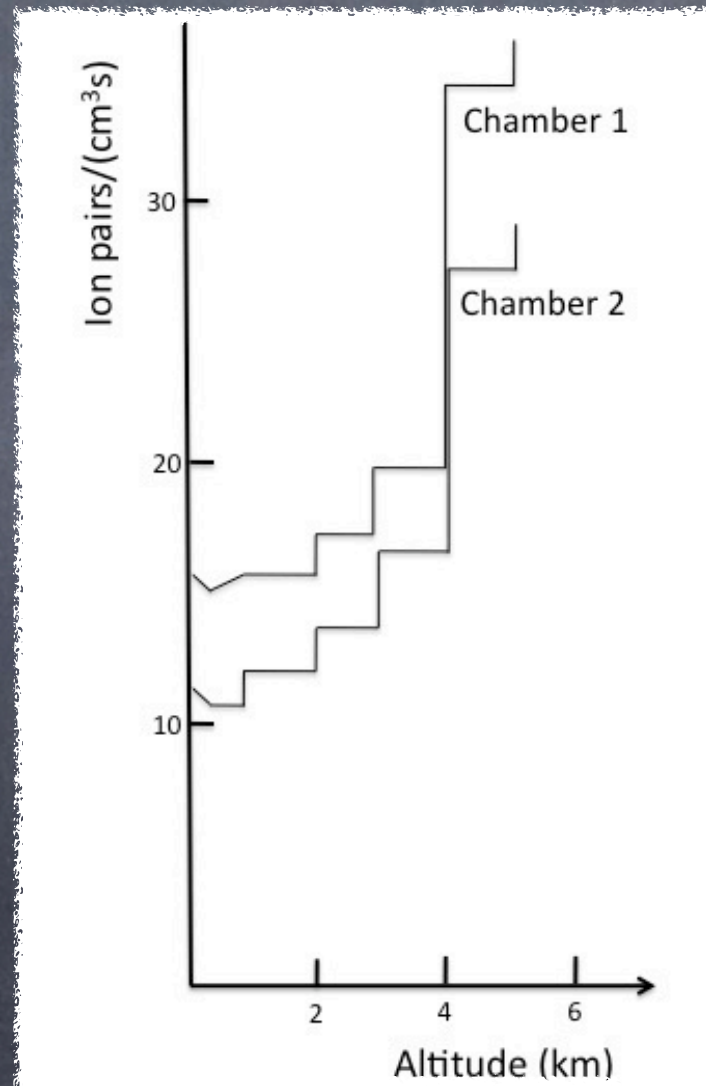
La prova del nove!



Victor Hess (1883–1964)



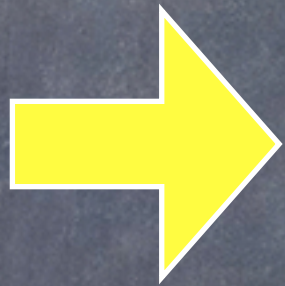
1912:
La prima
misura
risolutiva



La ionizzazione
aumenta con
l'altezza!

La prova del nove!

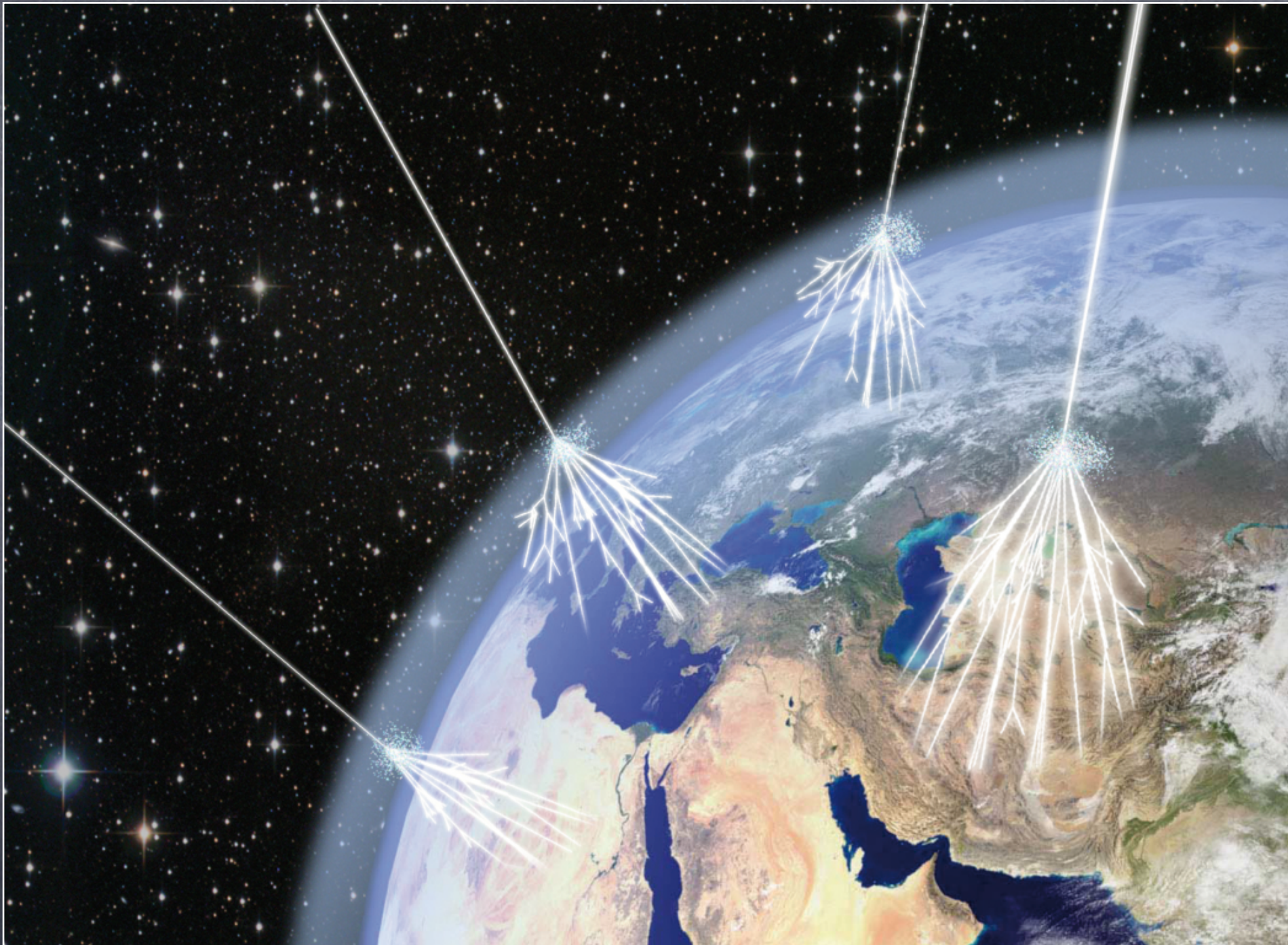




Raggi cosmici

Primari e cascate

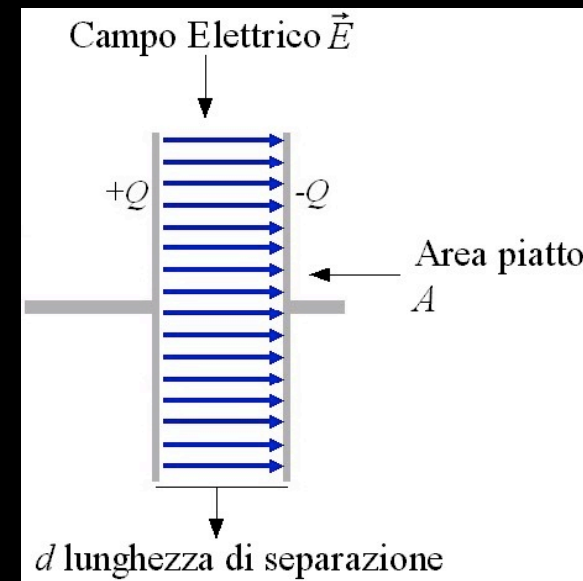
Radiazione primaria e secondaria



Digressione: scale di energia

I fisici usano l'elettronvolt (e i suoi multipli)

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ Joule}$$



eV	keV	MeV
reazioni chimiche	raggi-X	reazioni nucleari
	10^3	10^6

GeV

TeV-PeV

10^9

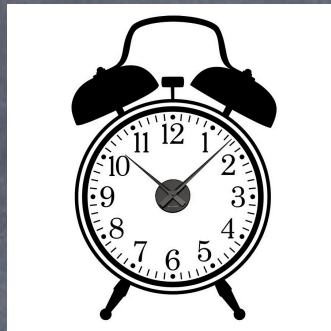
10^{12-15}

$$1 \text{ TeV} = 1.6 \text{ erg}$$

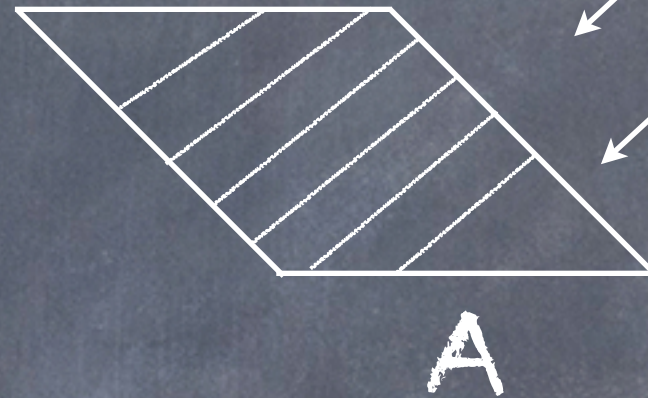
LHC 4 TeV



Digressione: il flusso



T

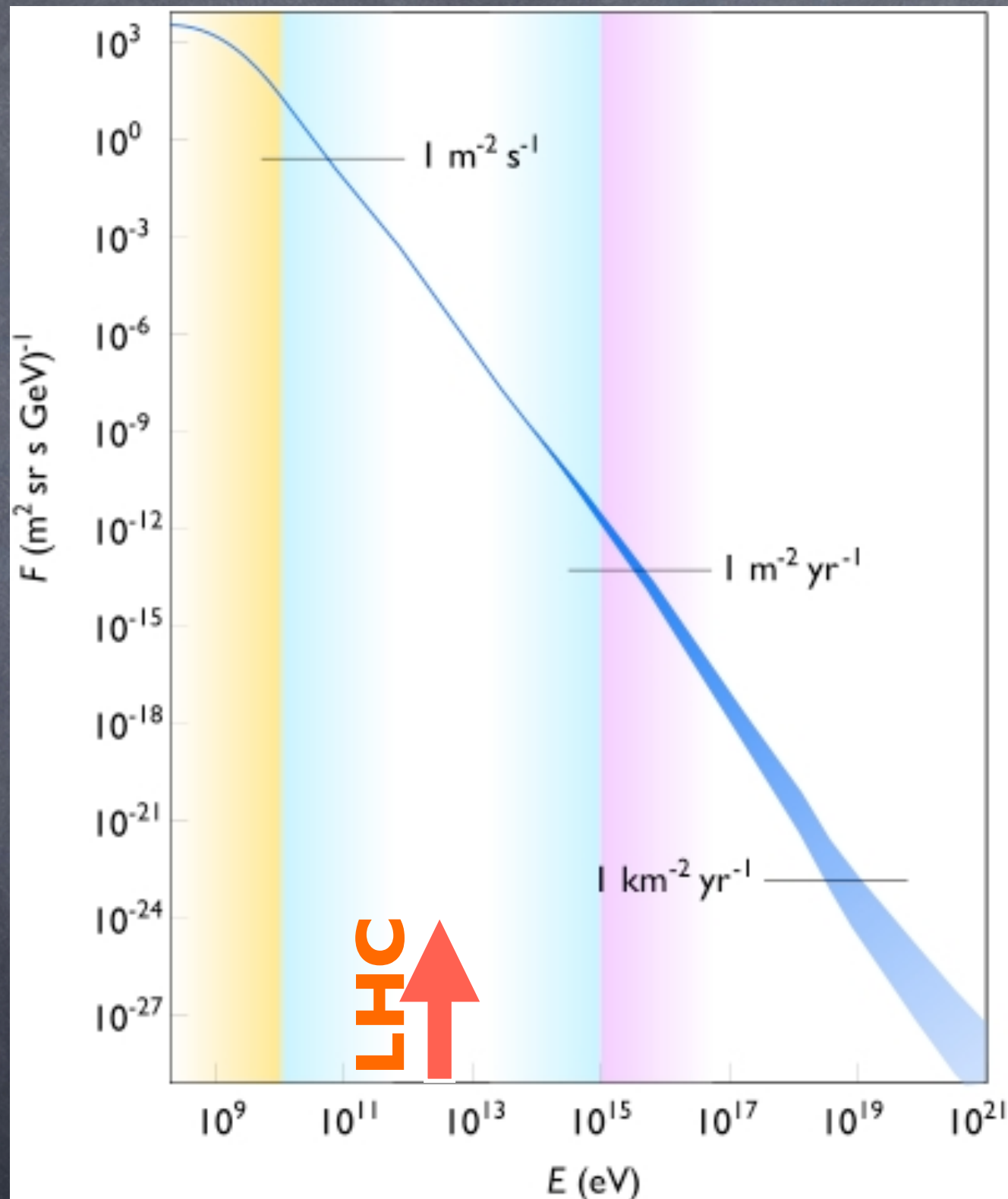


N

$$F = N/A \cdot T$$

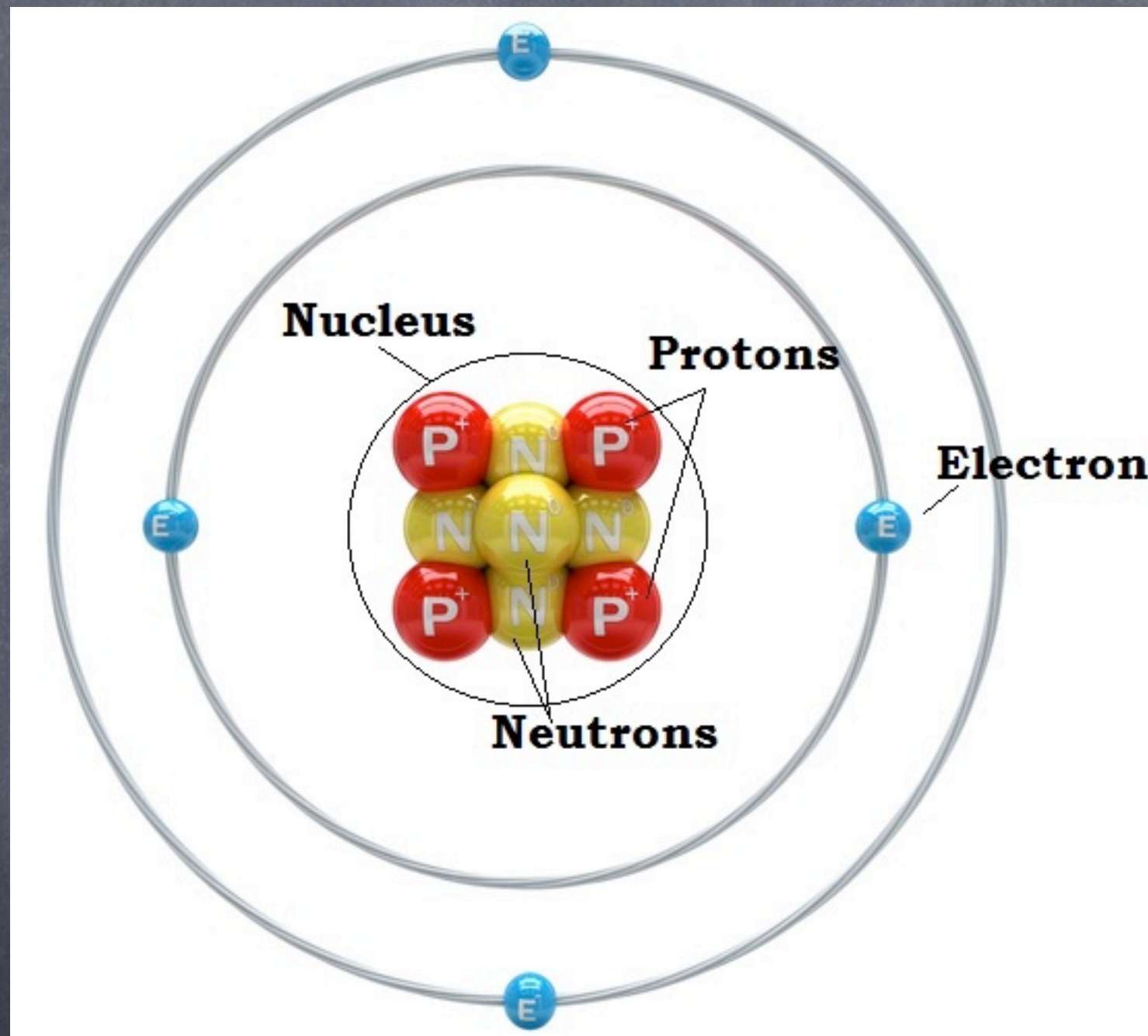
Spettro energetico dei RC primari

↑
Flusso

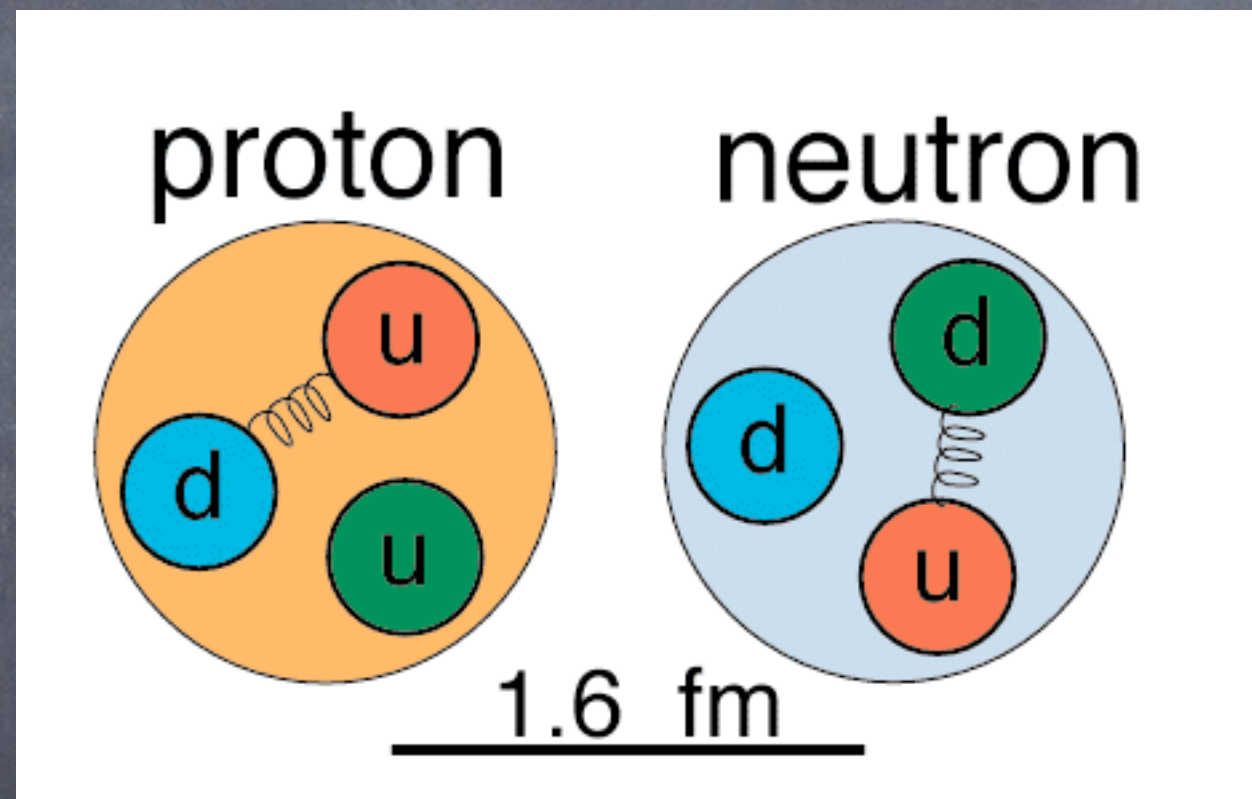


Energia →

Parentesi: il modello standard delle particelle

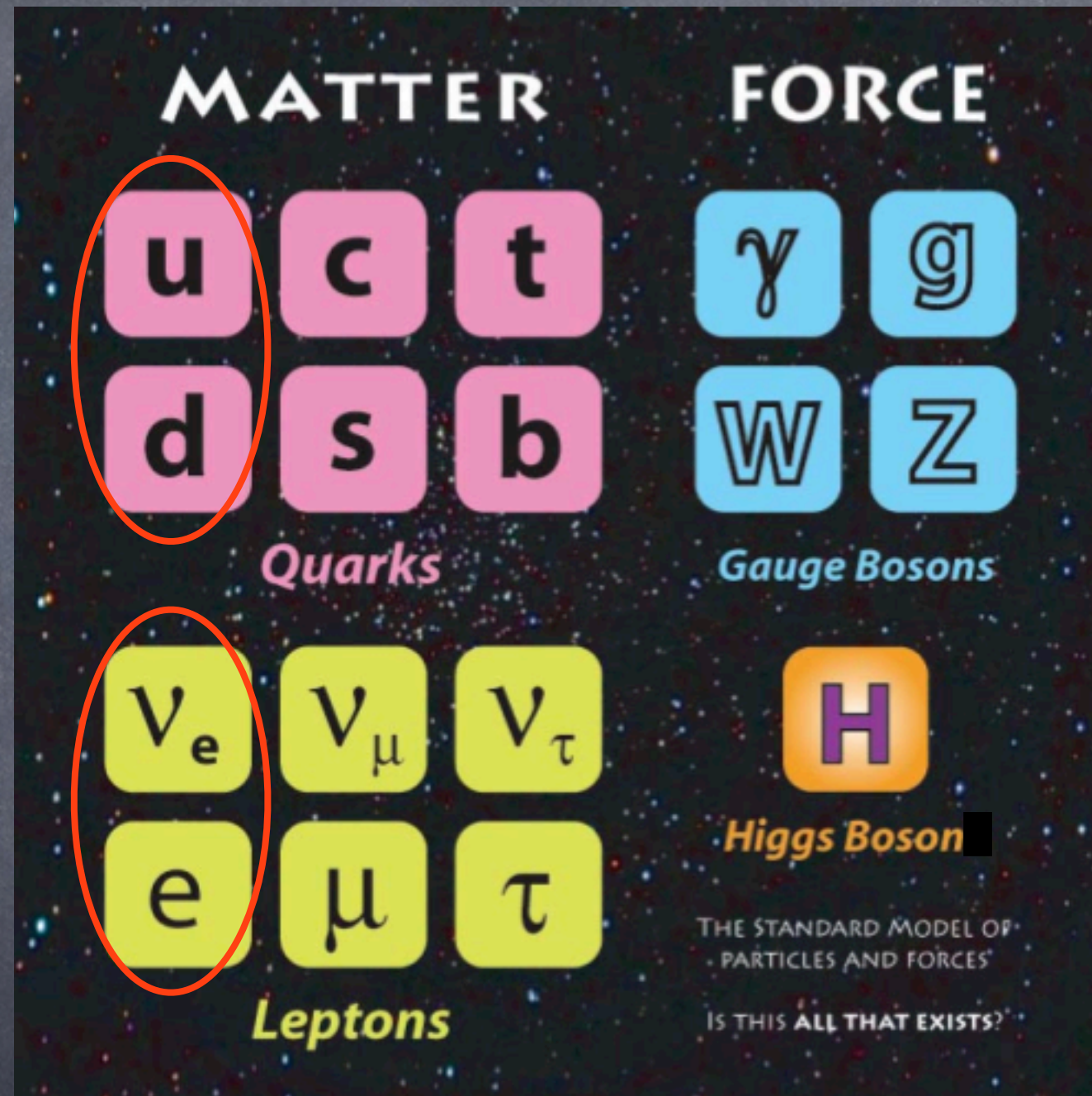


quarks

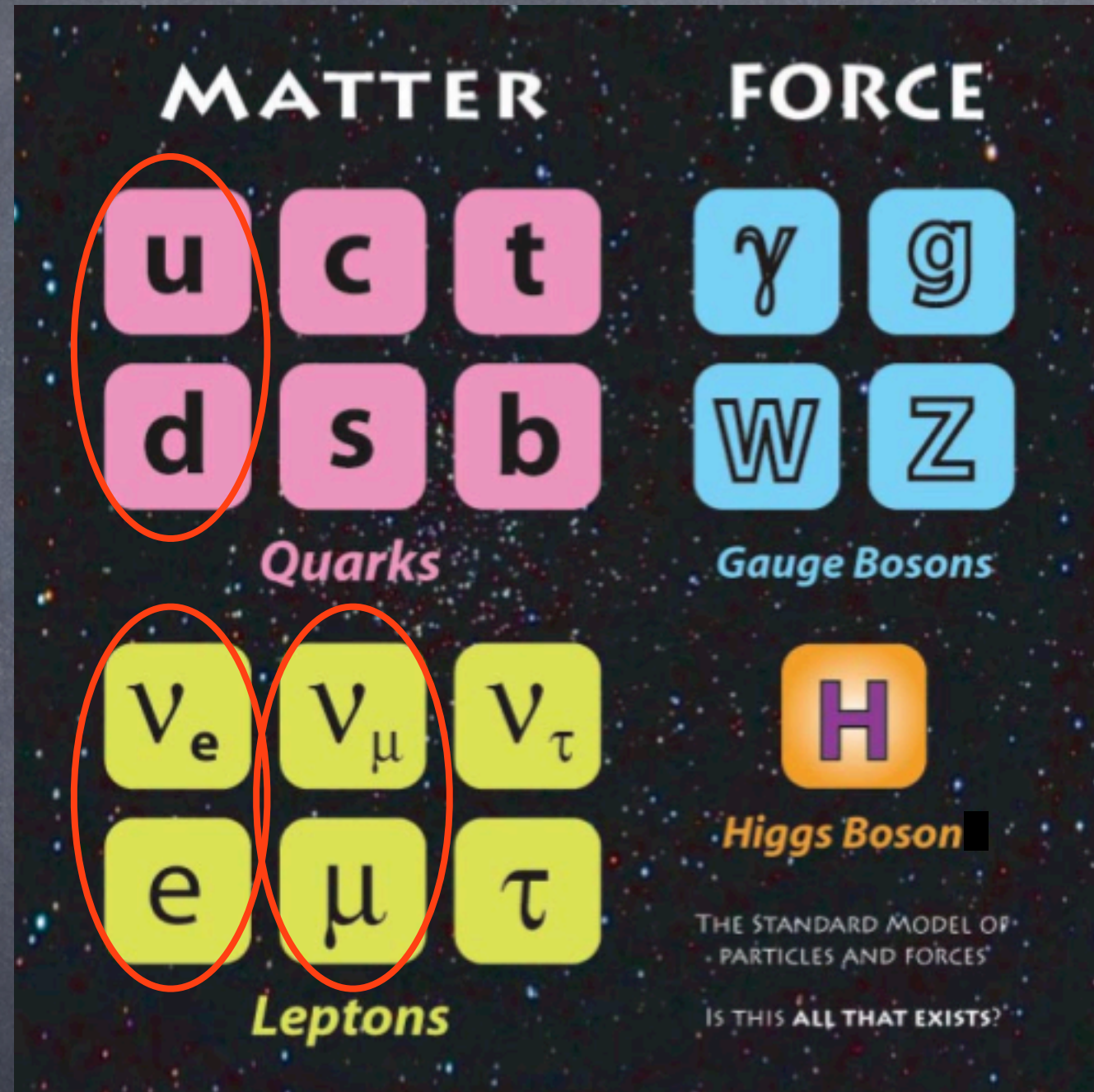


Parentesi: il modello standard delle particelle

p.m

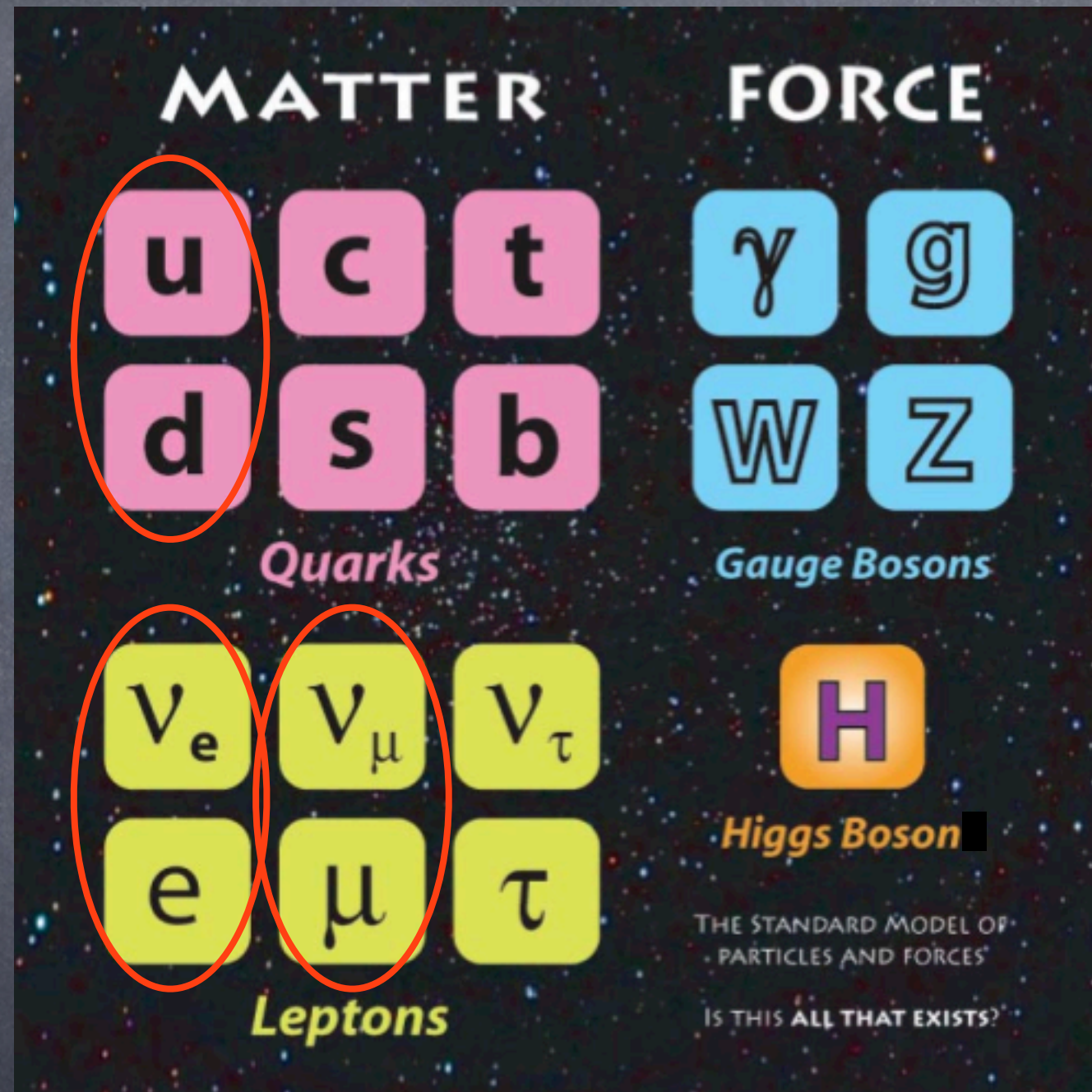


p,n

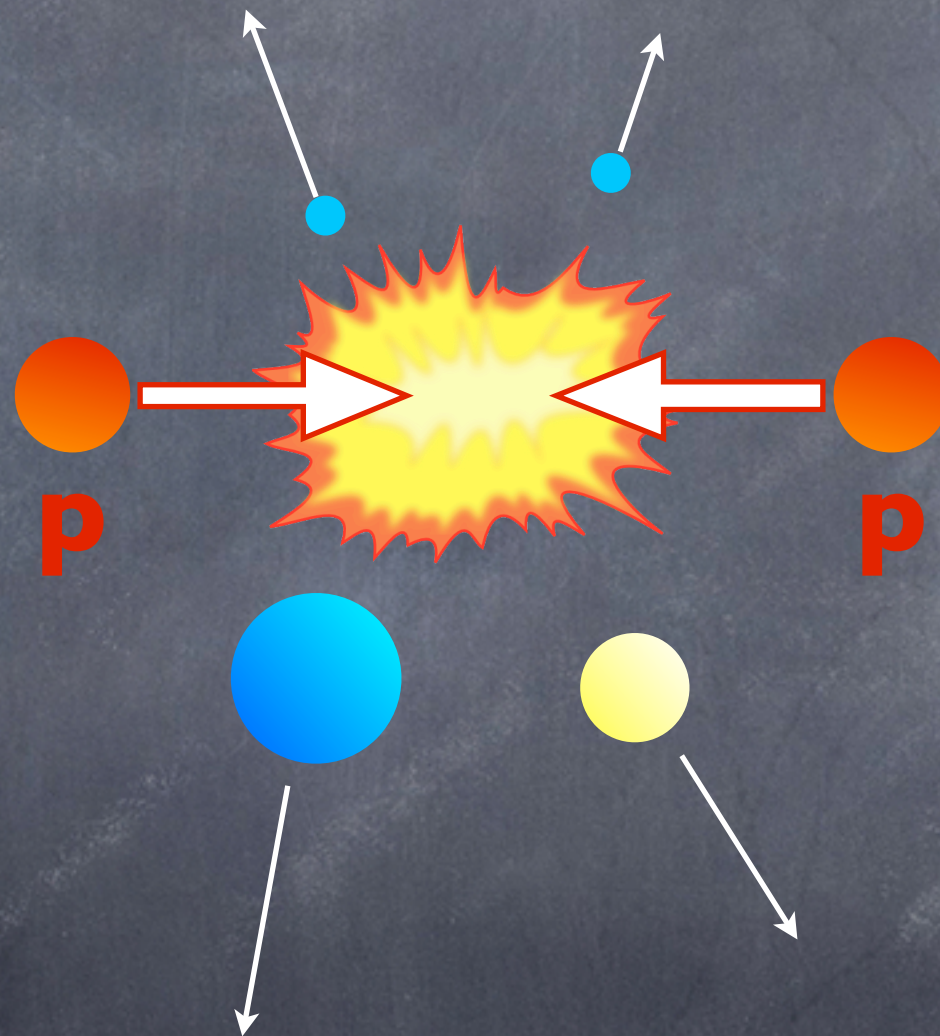


Muone: elettrone "pesante"
(circa ~200 volte)

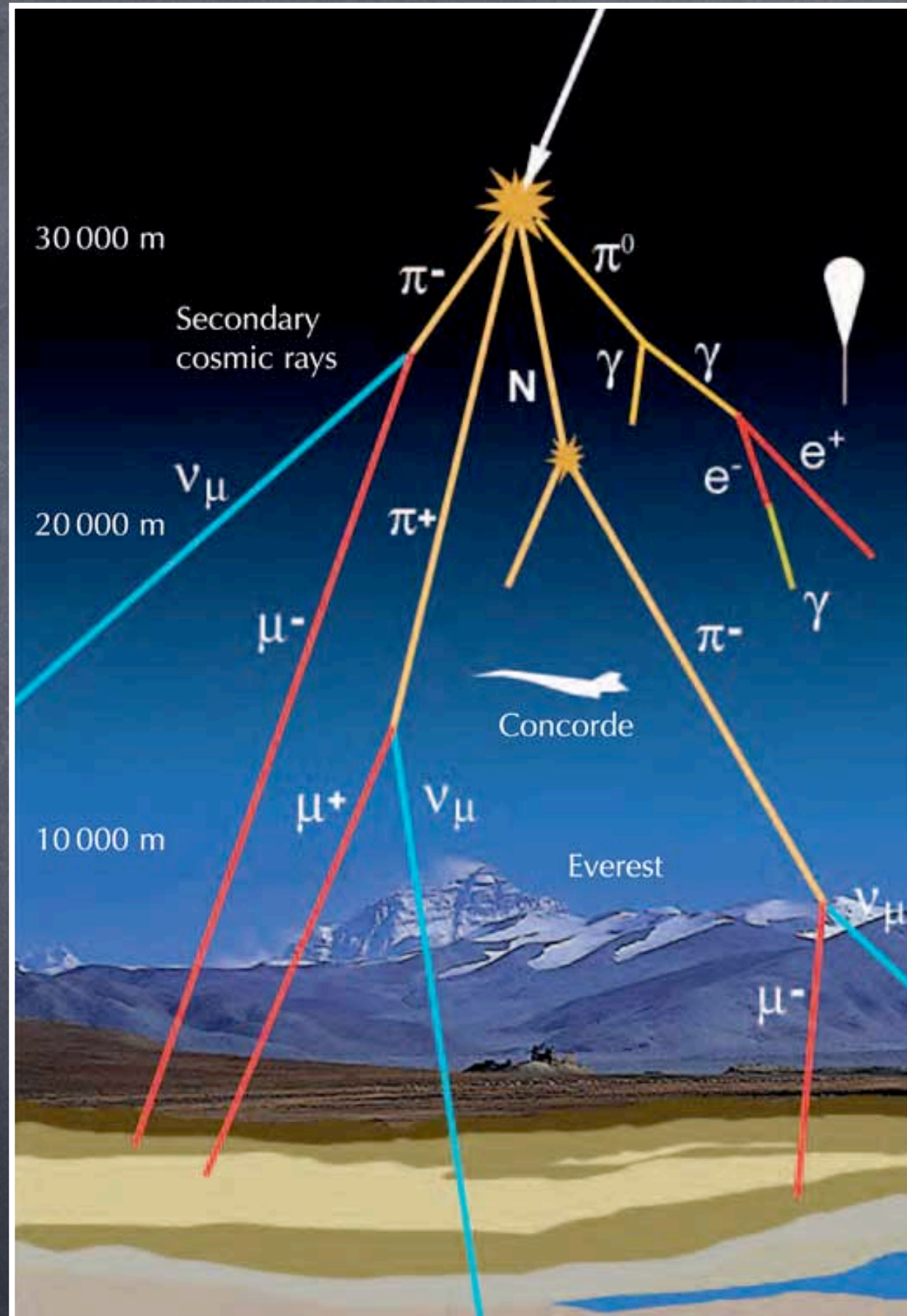
Pioni: due
quarks



Parentesi: produzione/distruzione di particelle



Cascade



Primario

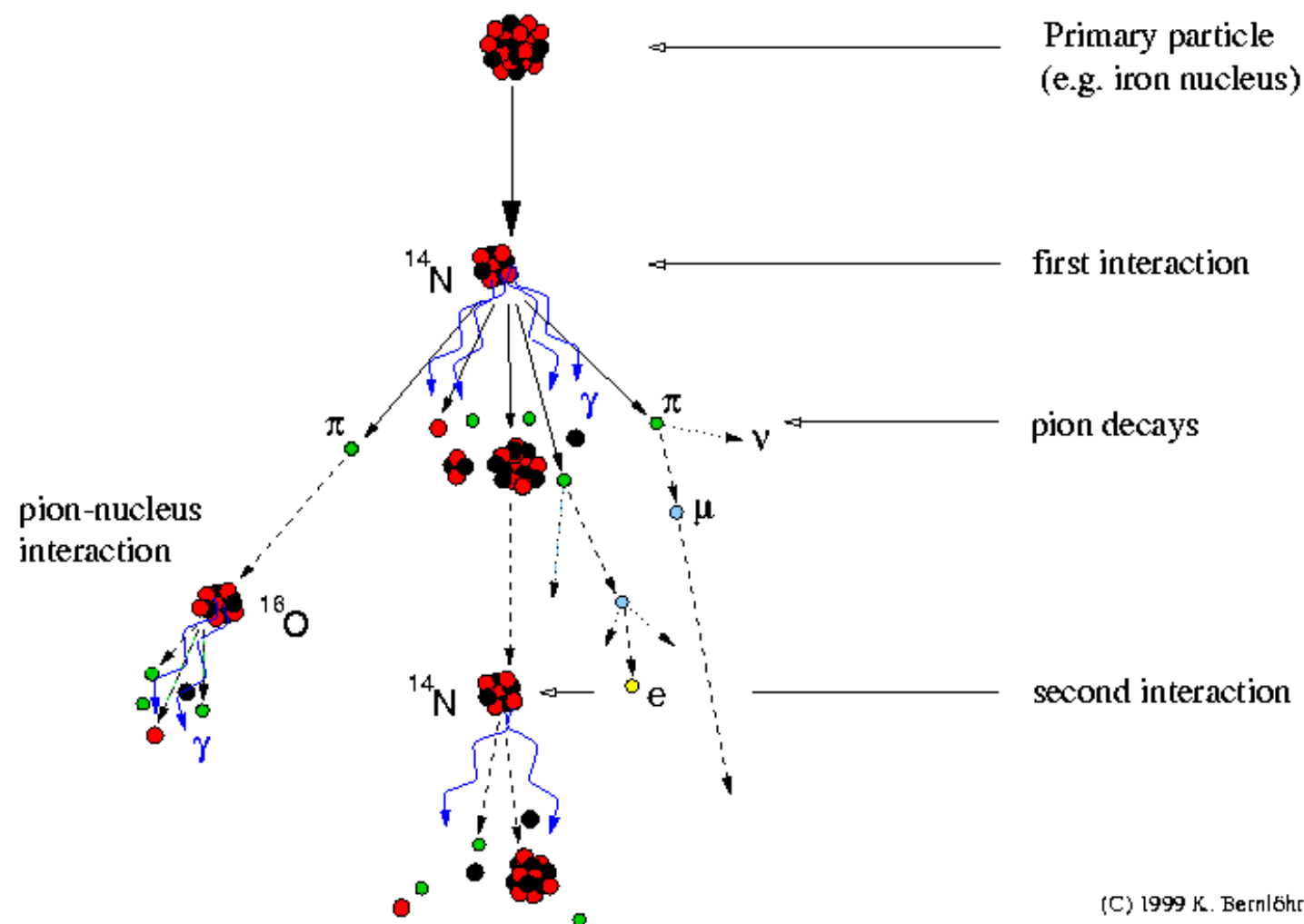
Secondari

$$p + N(\gamma) \rightarrow \pi^0 + \pi^\pm + \dots$$

$$\searrow \gamma + \gamma \searrow \mu^\pm + \nu_\mu(\bar{\nu}_\mu)$$

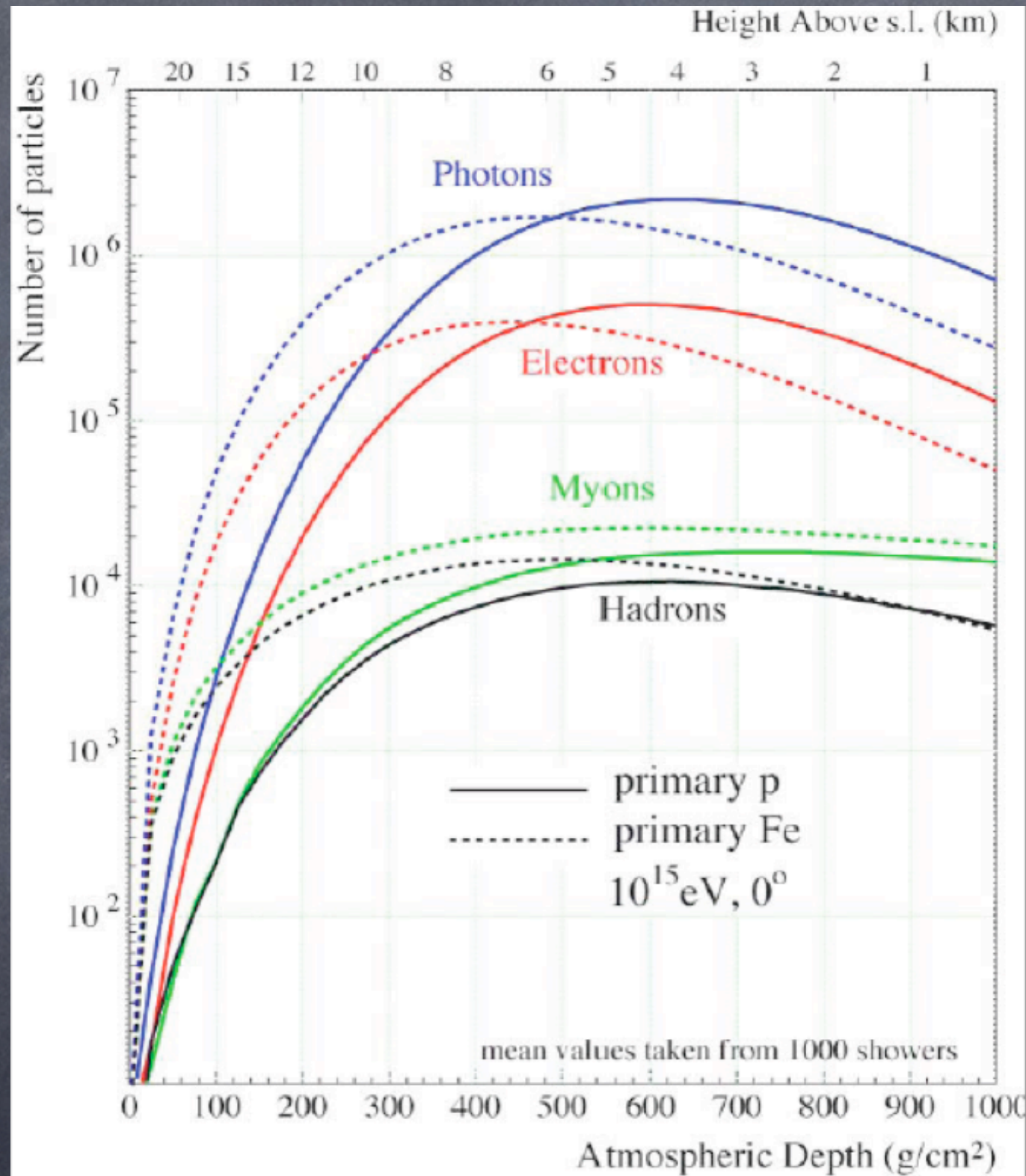
$$\searrow e^+ + \nu_e + \bar{\nu}_\mu (e^- + \bar{\nu}_e + \nu_\mu) . \quad (1)$$

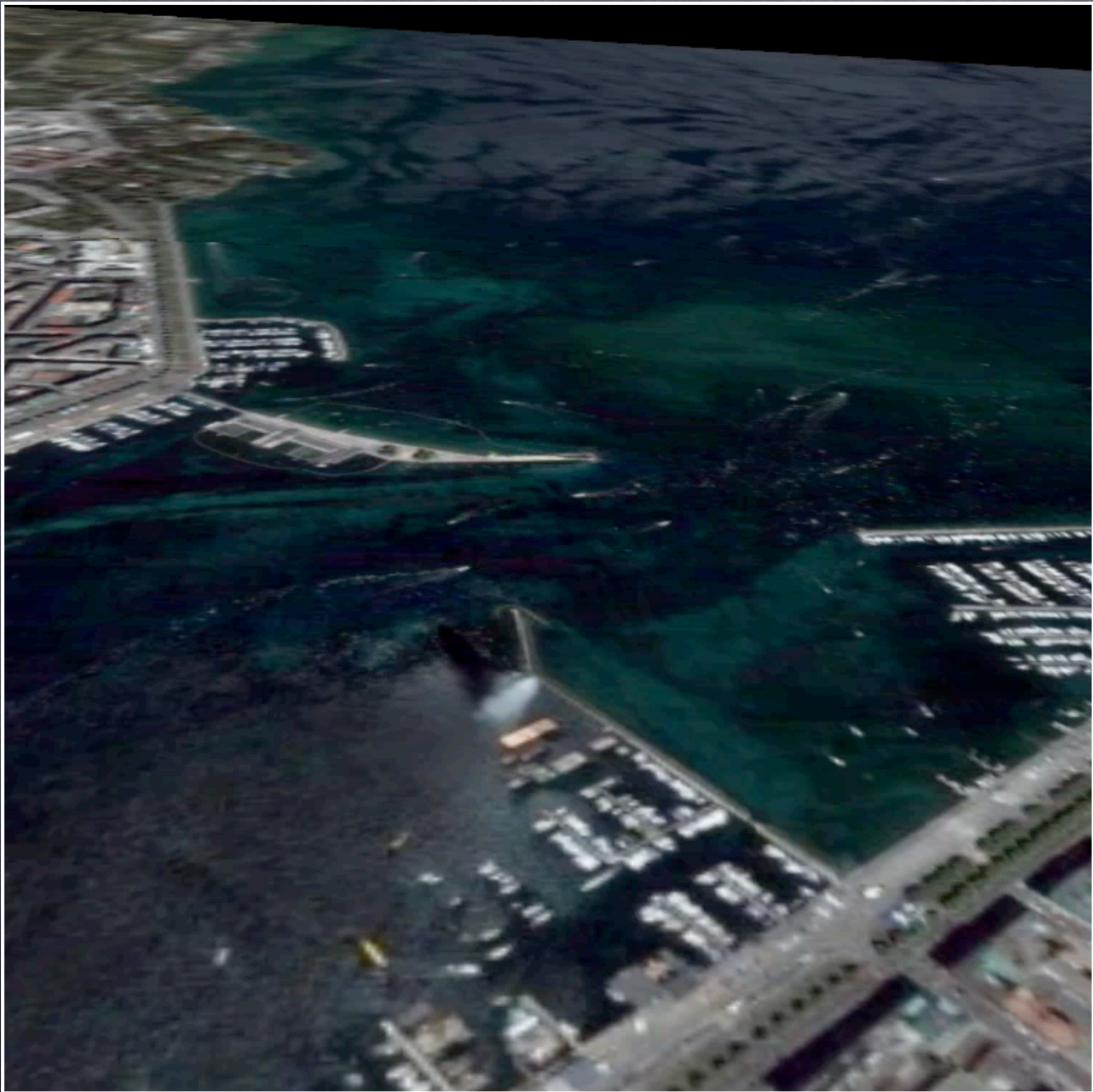
Development of cosmic-ray air showers



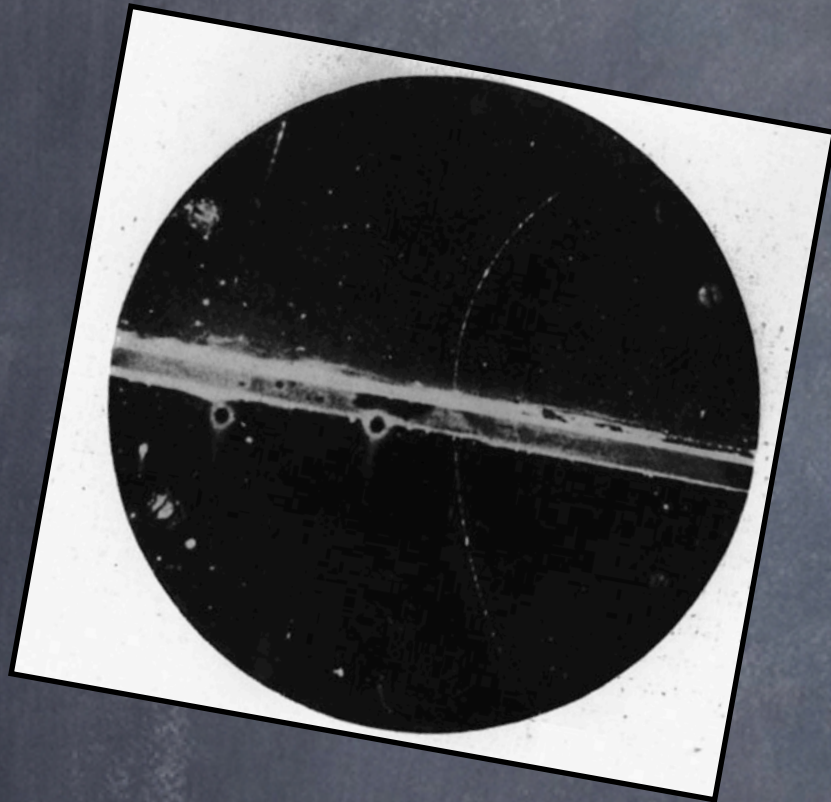
← Altezza

↑
Numero di
particelle

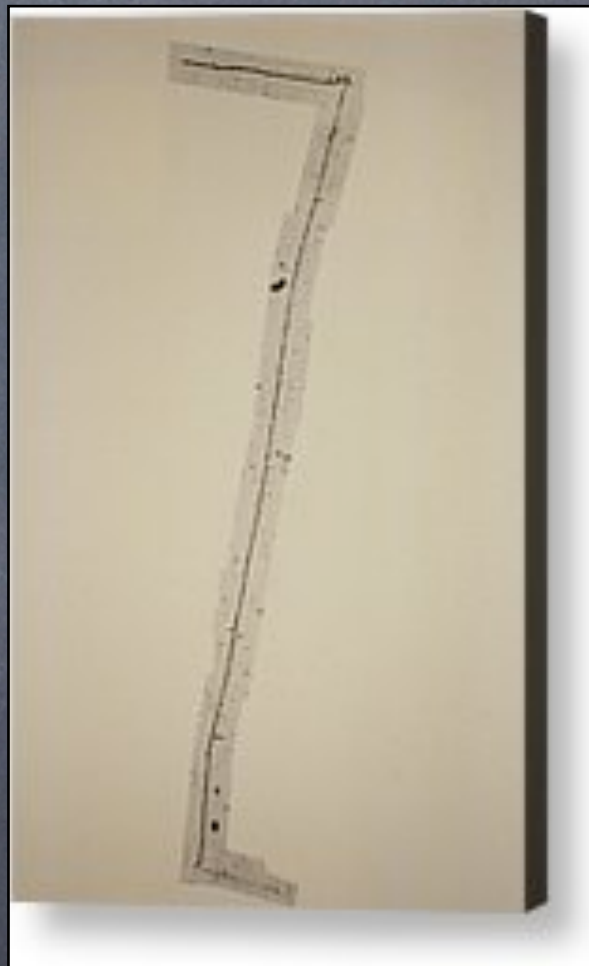




Raggi cosmici secondari: la nascita della fisica delle particelle



Elettone positivo
(positrone)
1932



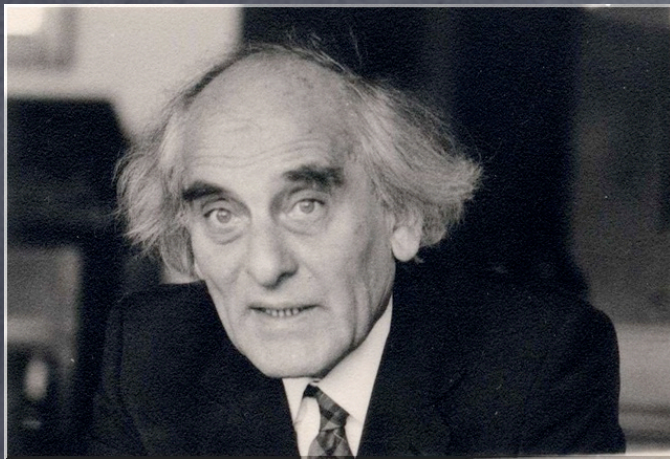
Muone
1937

Pione
1947



“Materializzazione”
di un fotone in
elettrone e positrone

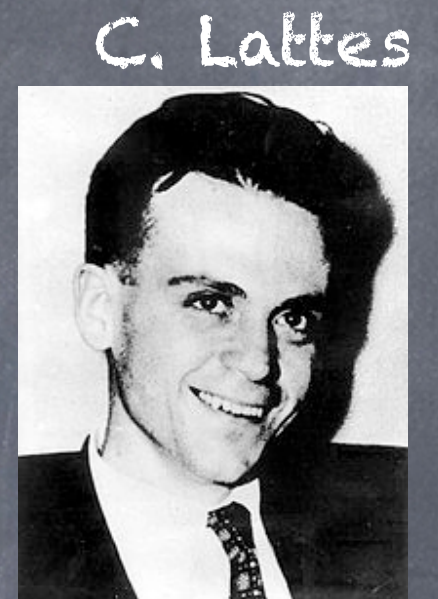
Alcuni protagonisti



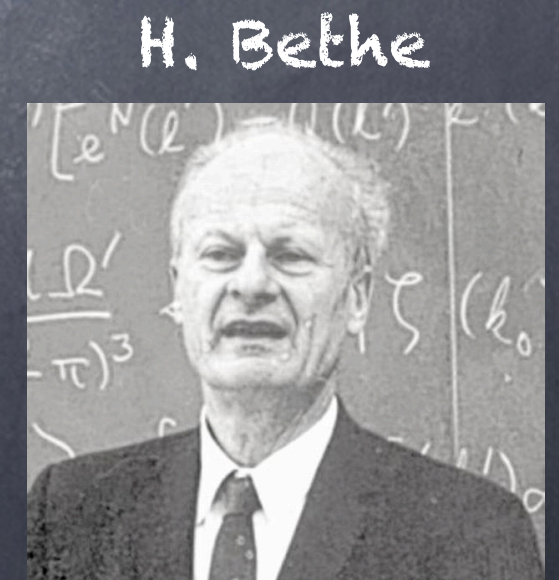
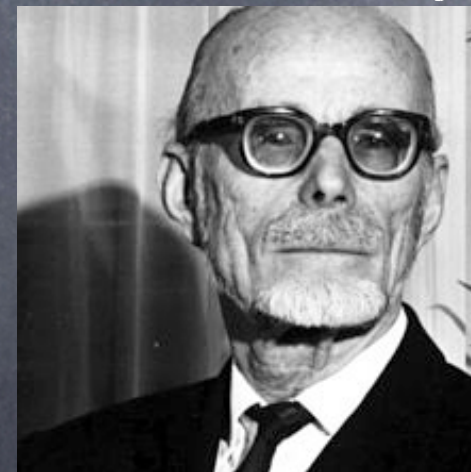
G. Occhialini



B. Rossi

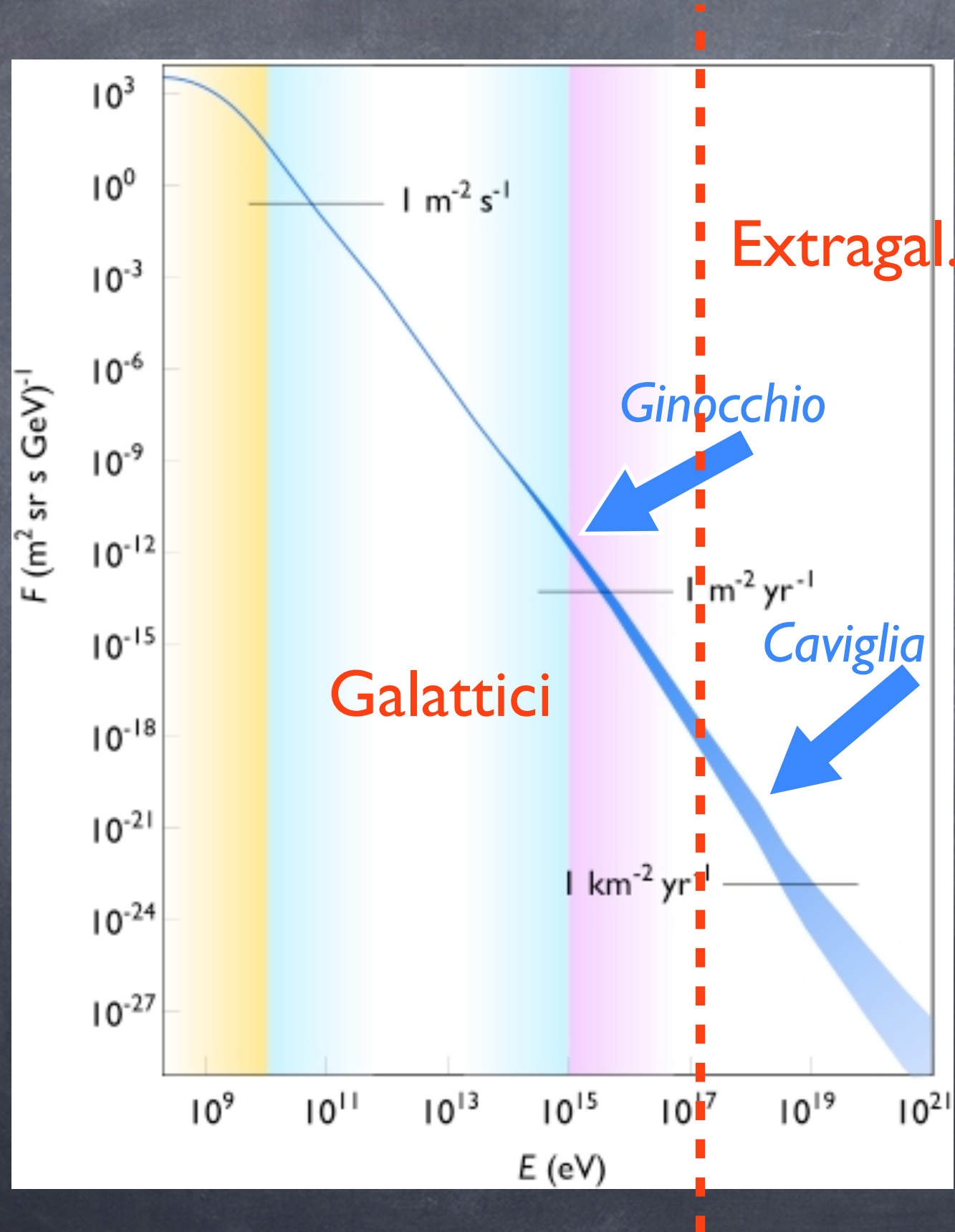


P. Blackett



Da dove provengono?

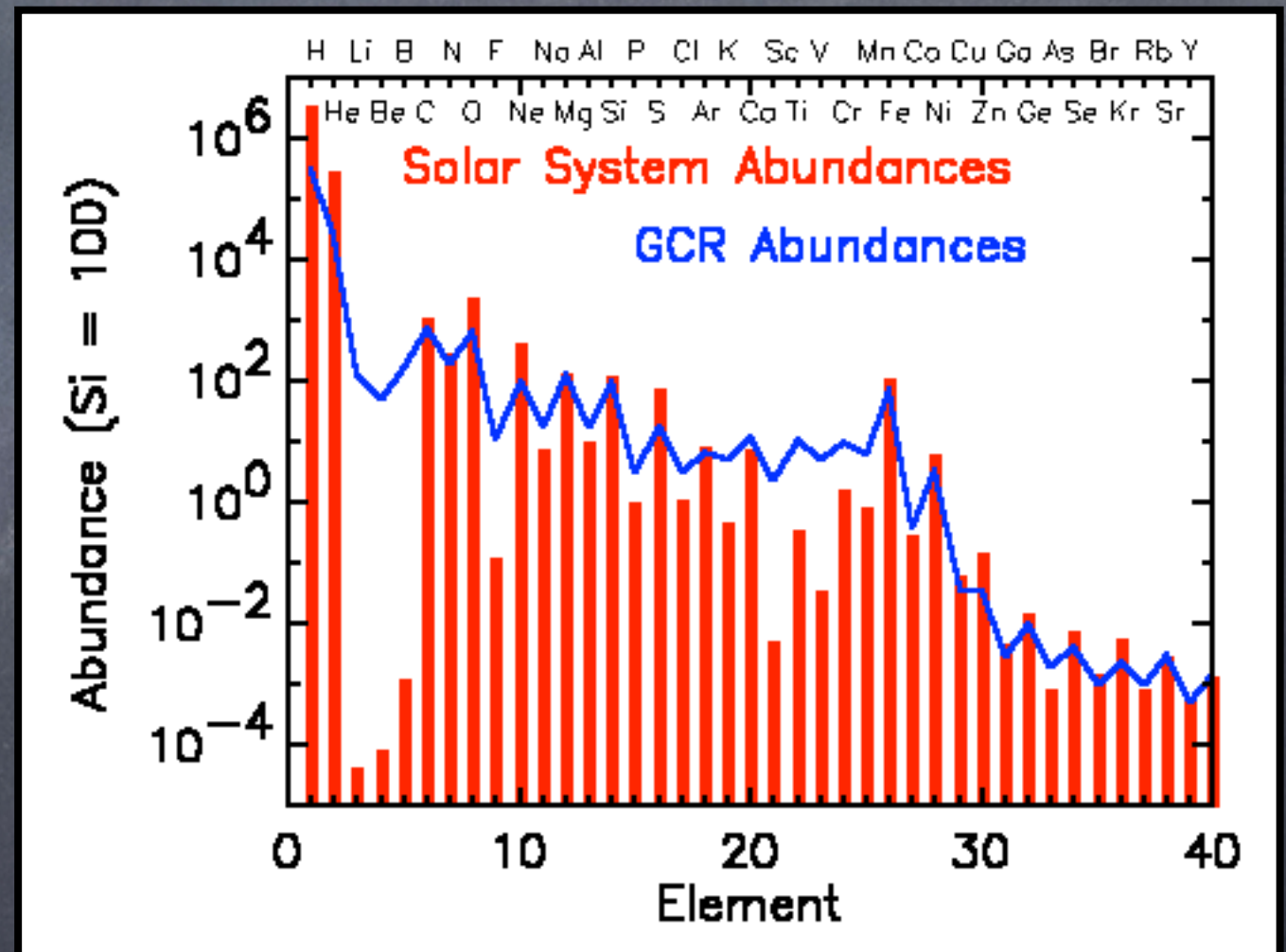
Spettro energetico dei RC primari



Composizione

2% elettroni
98% nuclei

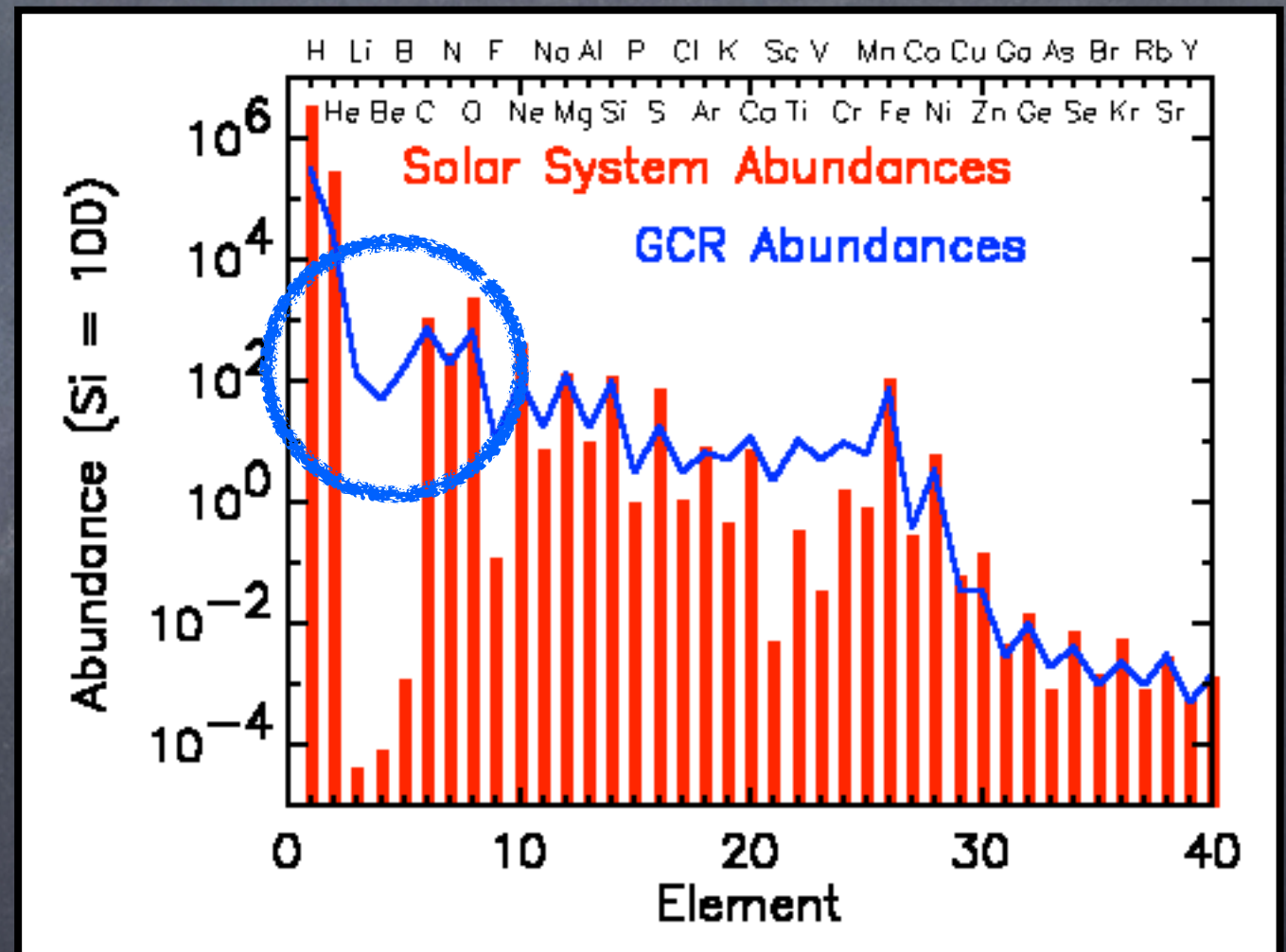
87% H
12% He
1% nuclei
pesanti



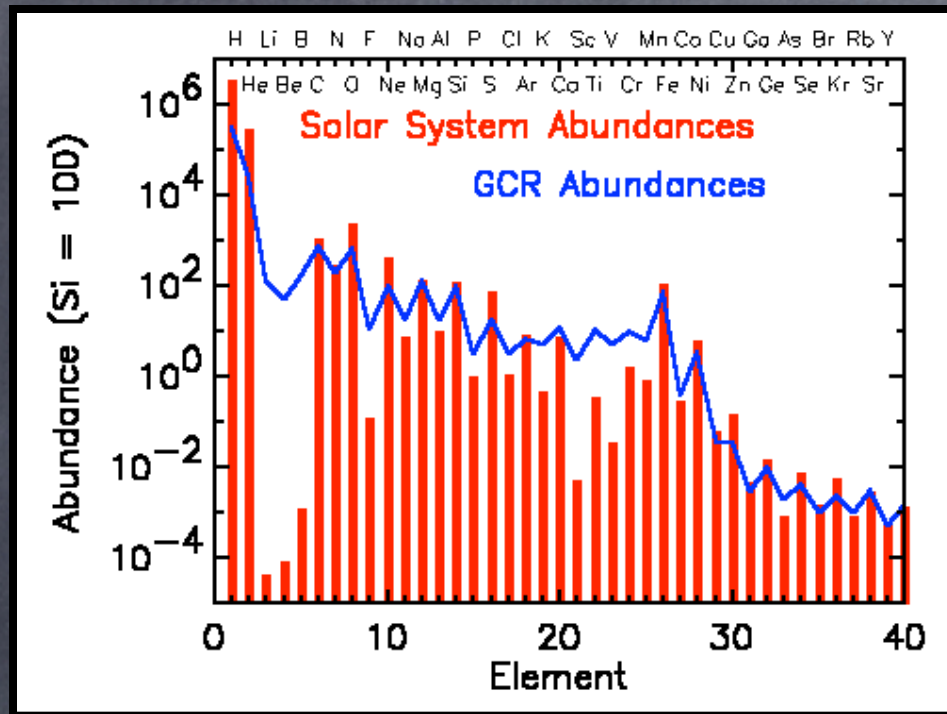
Composizione

2% elettroni
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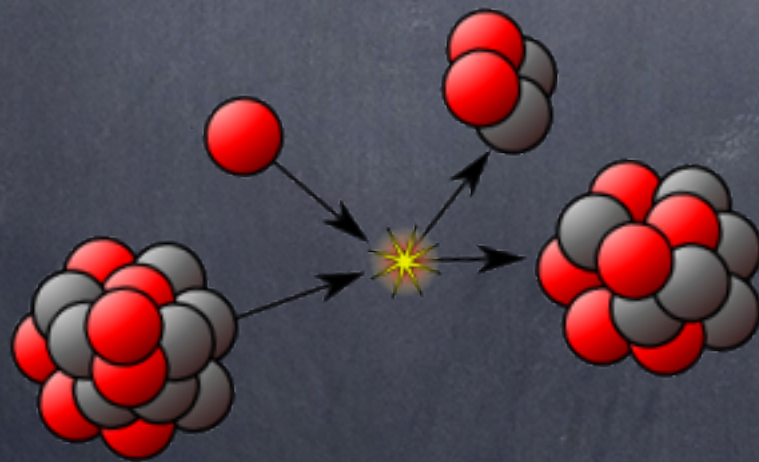


Composizione



Frammentazione di
nuclei pesanti
durante la
propagazione nella
Galassia

"spallazione"



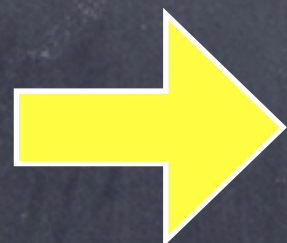
Composizione

Conoscendo

- 1) la densita' del gas (bersagli)
- 2) la probabilita' di interazione

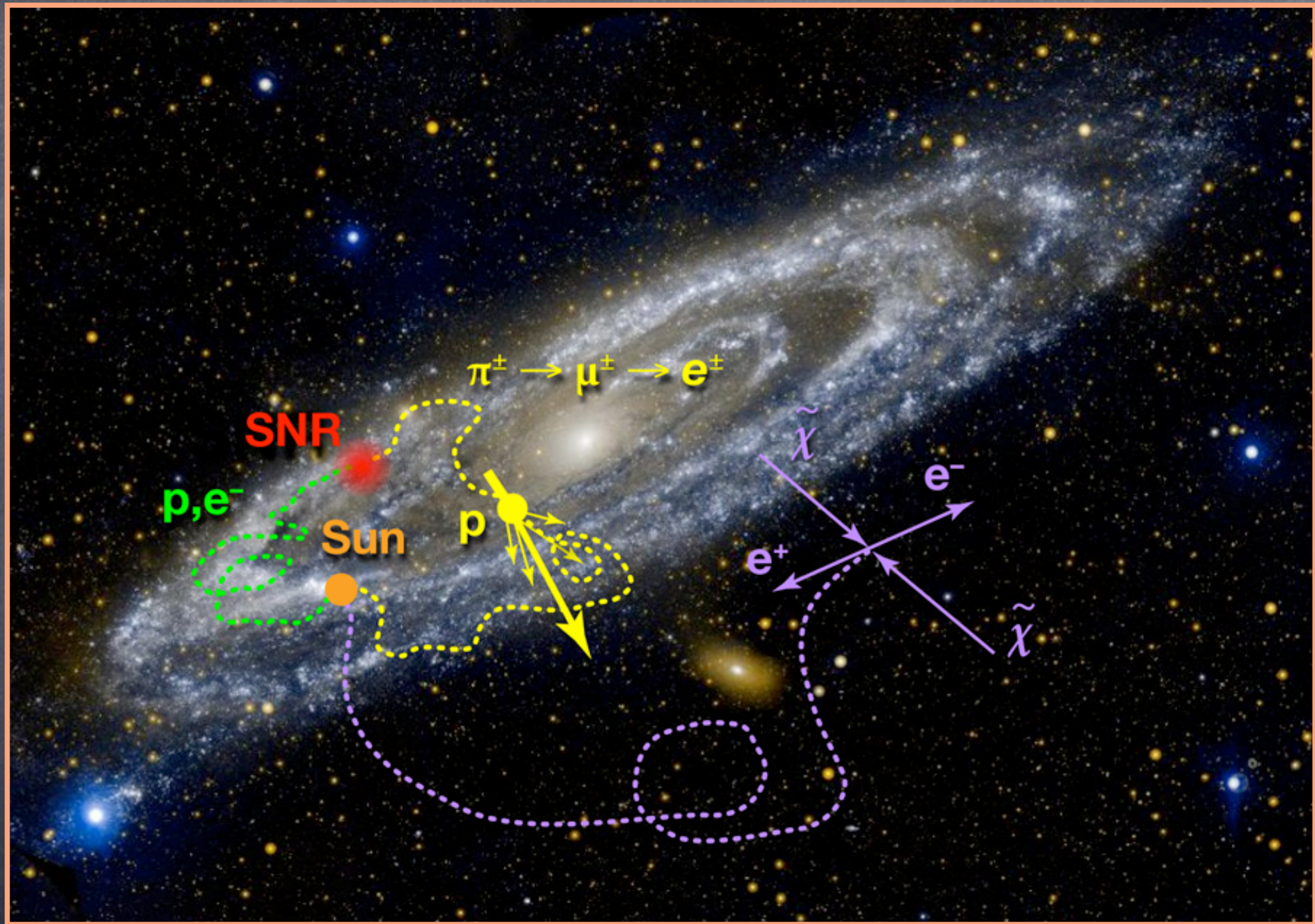
si stima il percorso totale

$d \sim 1 \text{ Mpc}$

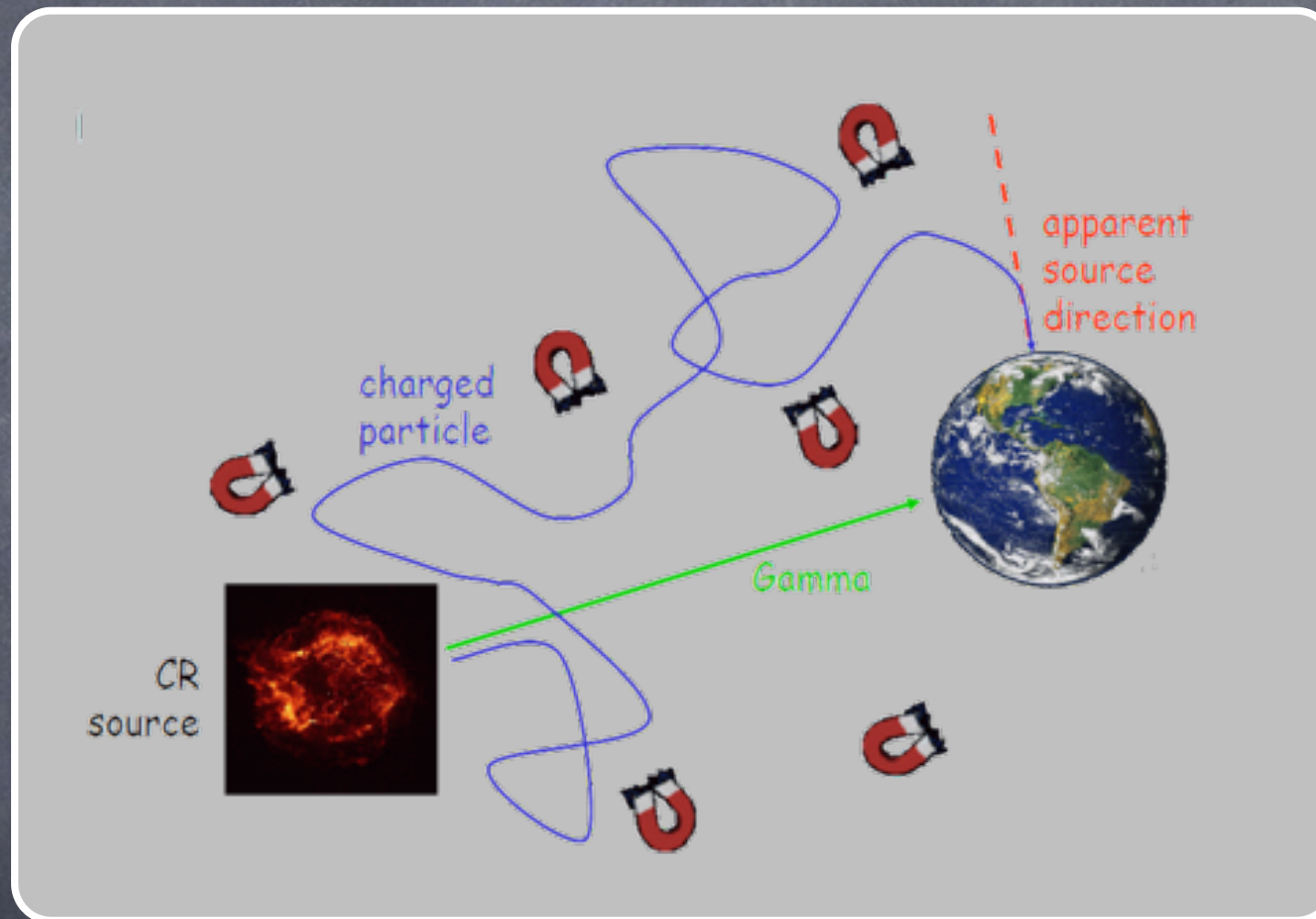


Diffusione

Raggi cosmici galattici



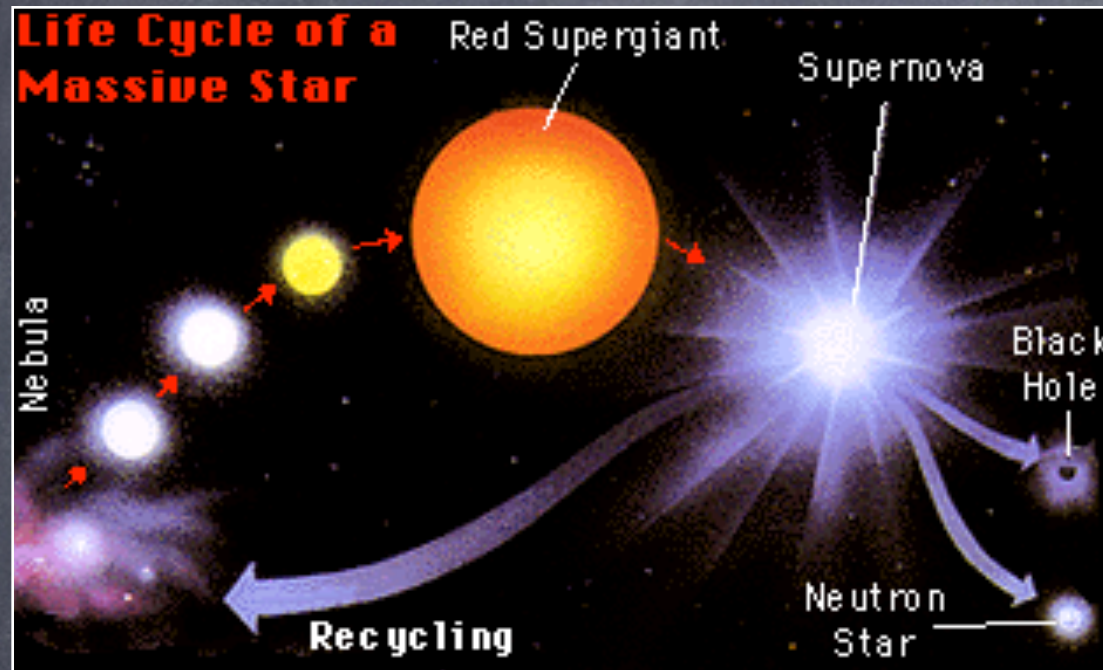
Raggi cosmici galattici: il ruolo del campo magnetico

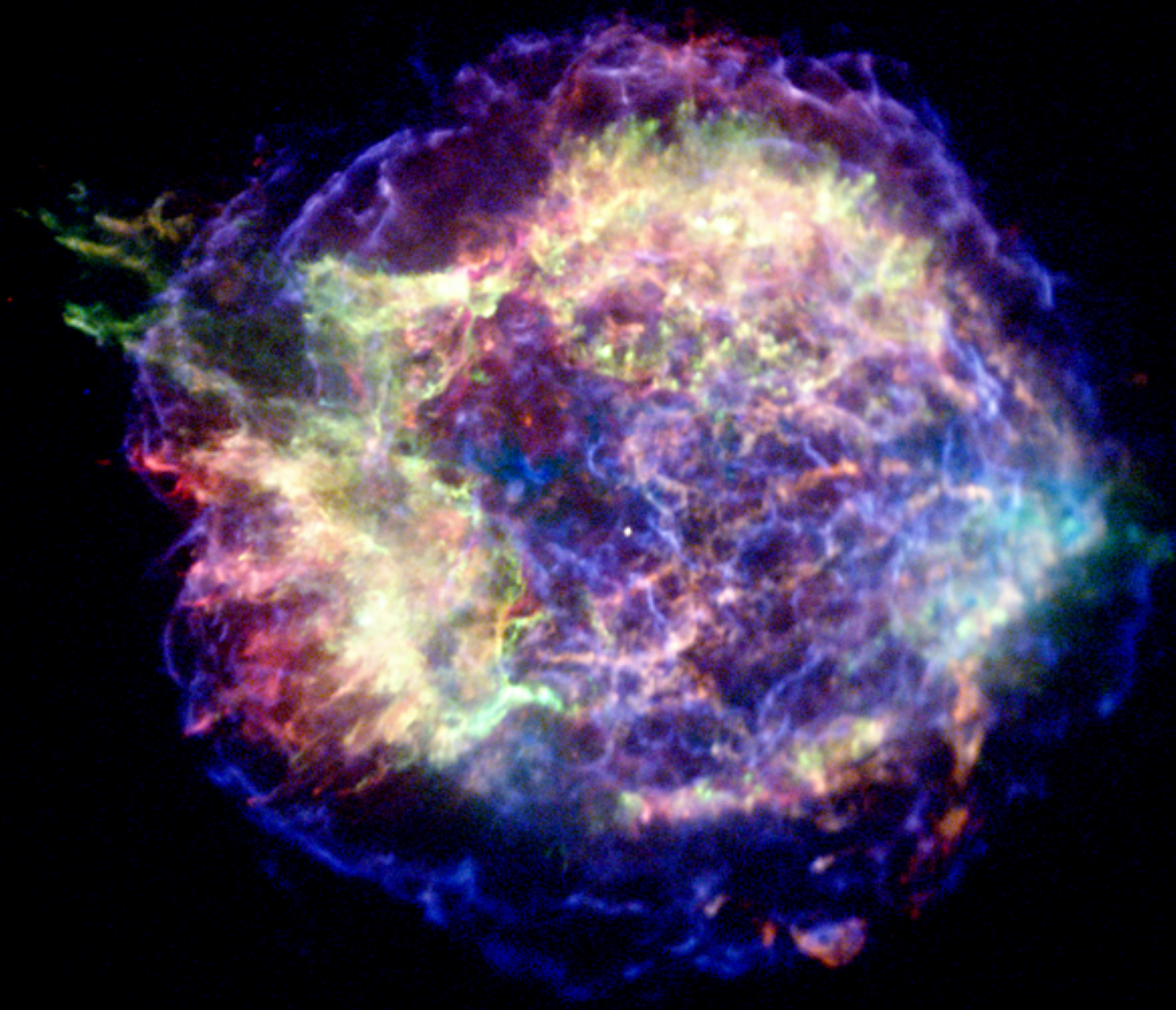


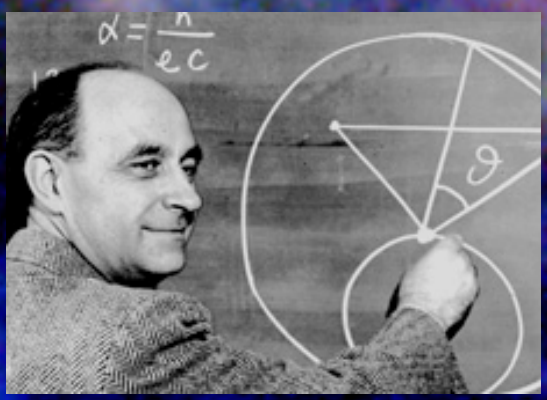
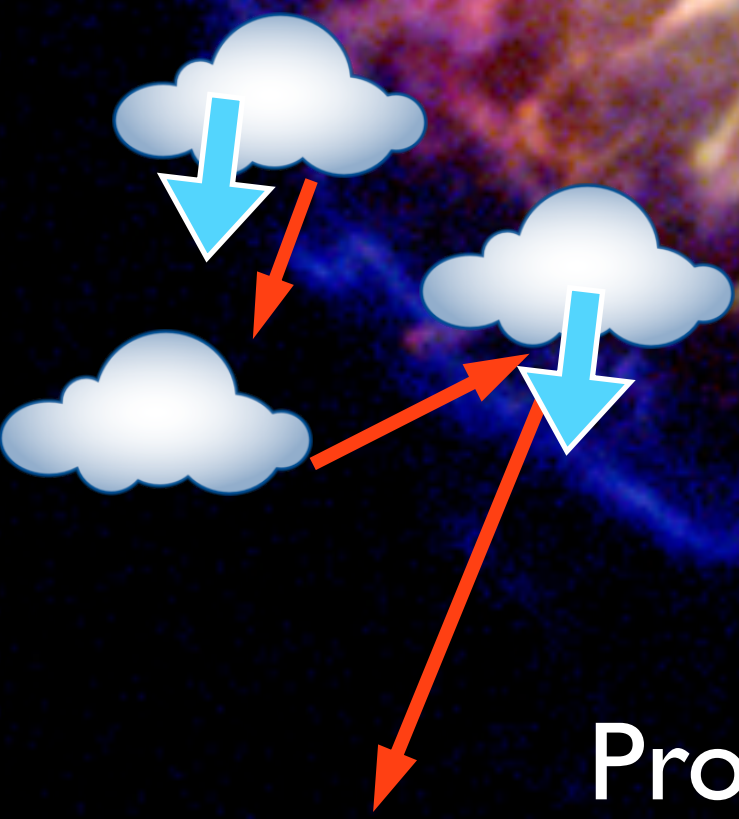
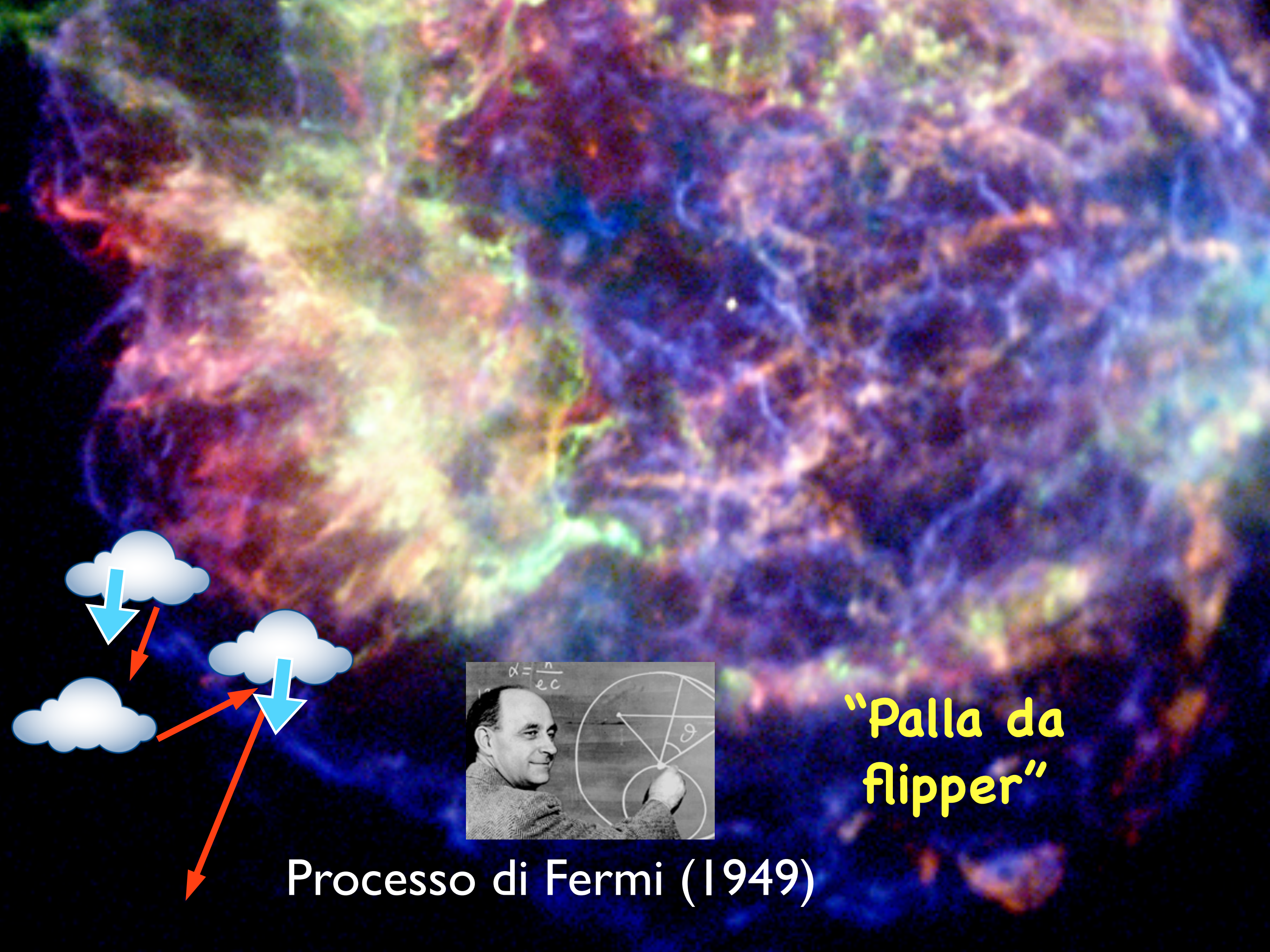
Sospetti: resti di supernovae



Prodotte nelle fasi finali dell'evoluzione stellare



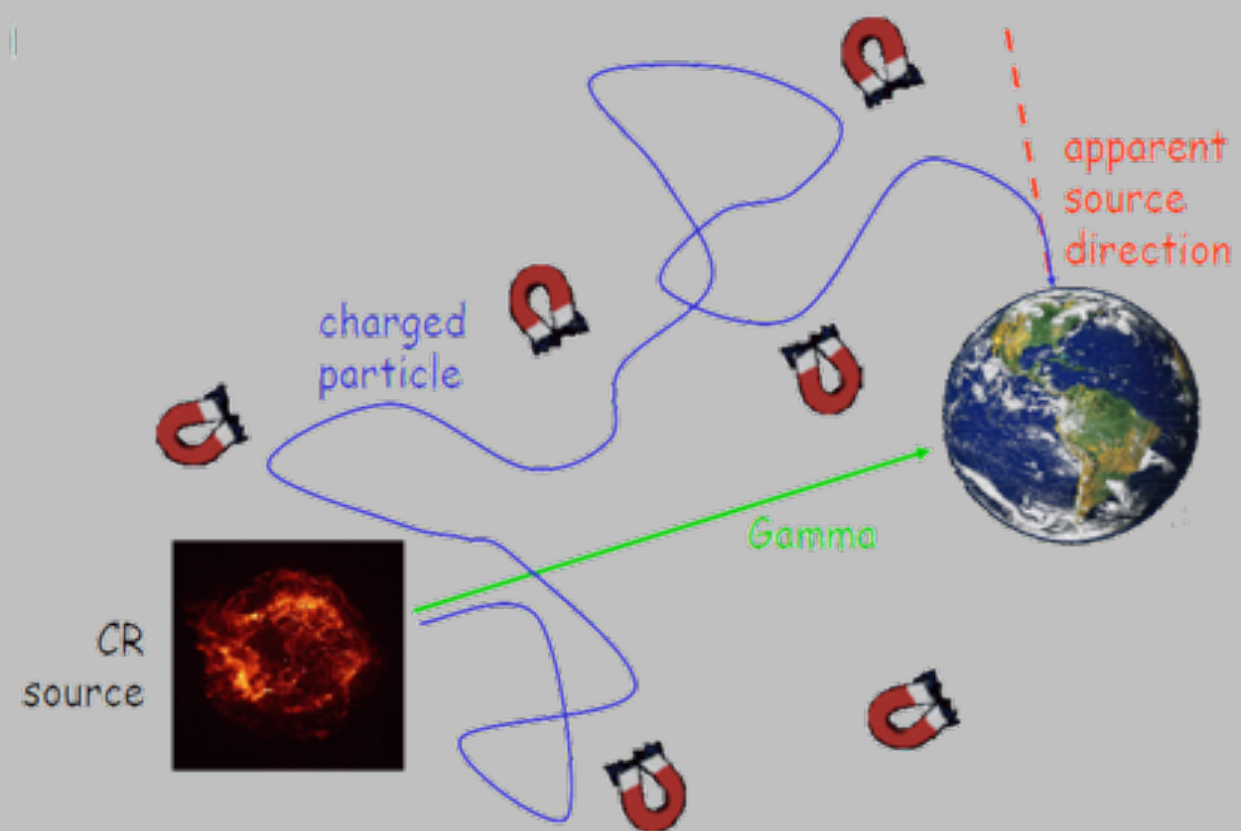


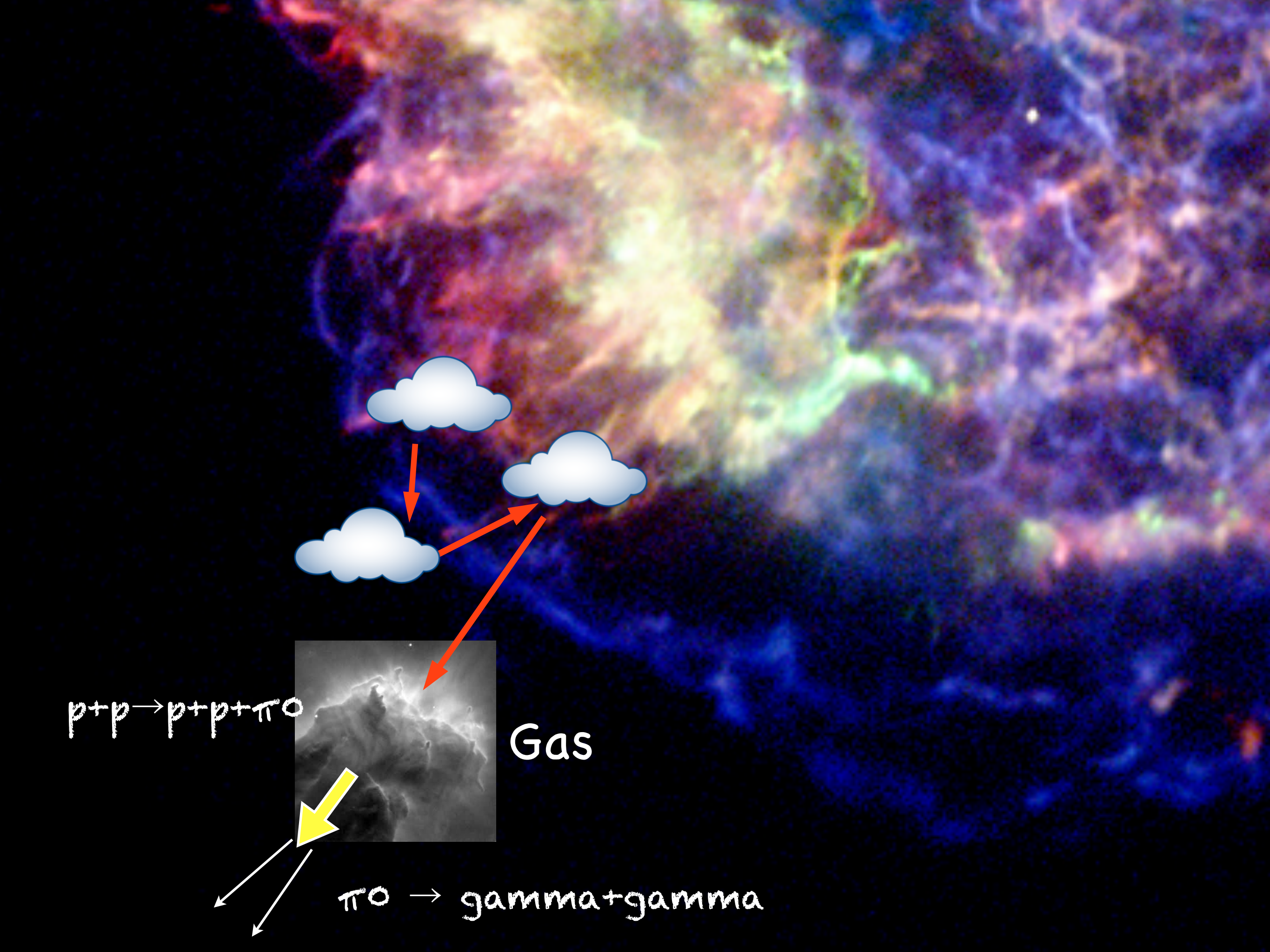


“Palla da flipper”

Processo di Fermi (1949)

11



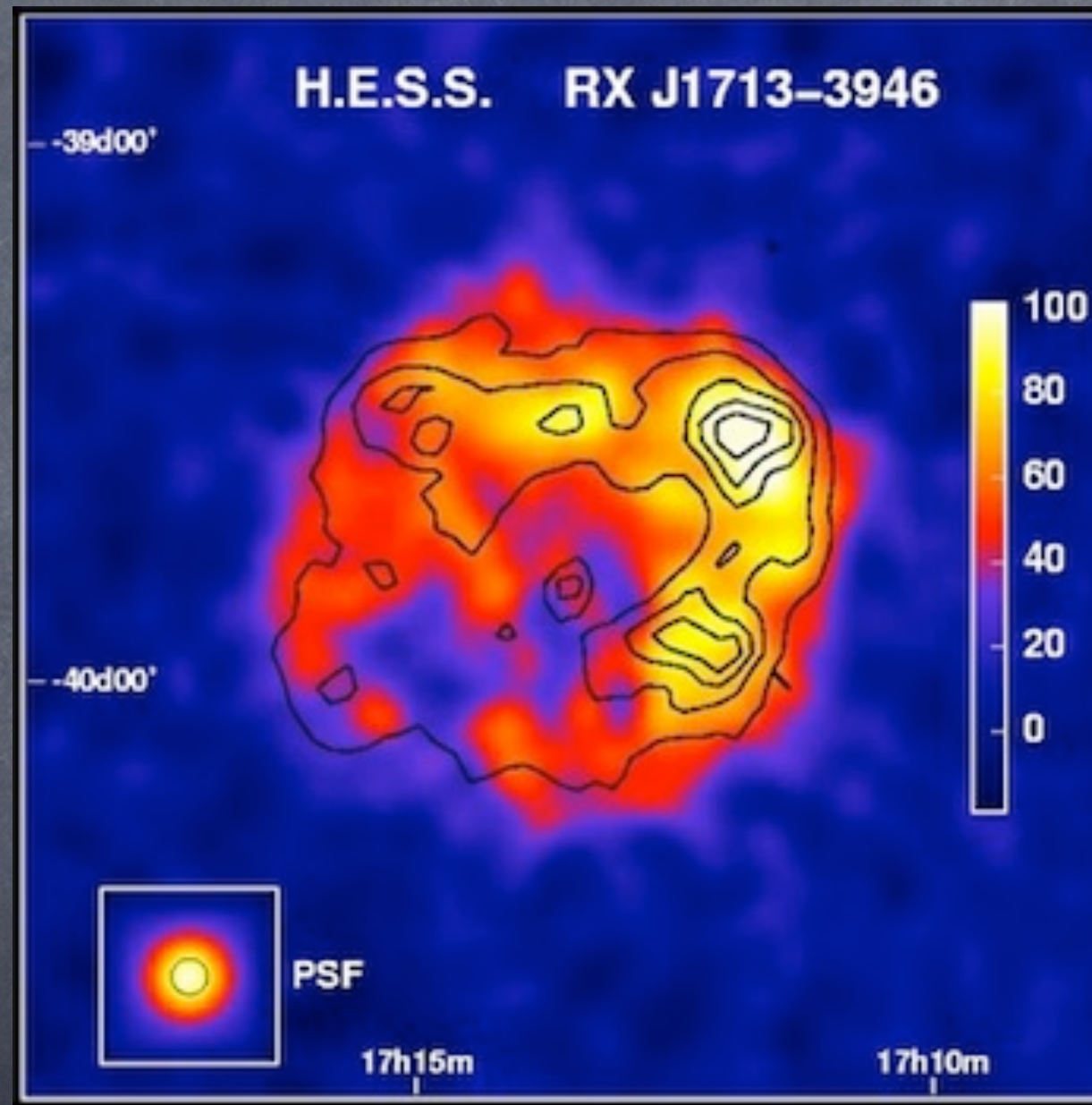


$$p+p \rightarrow p+p+\pi^0$$

Gas

$$\pi^0 \rightarrow \text{gamma}+\text{gamma}$$

Resto di SN nei raggi gamma



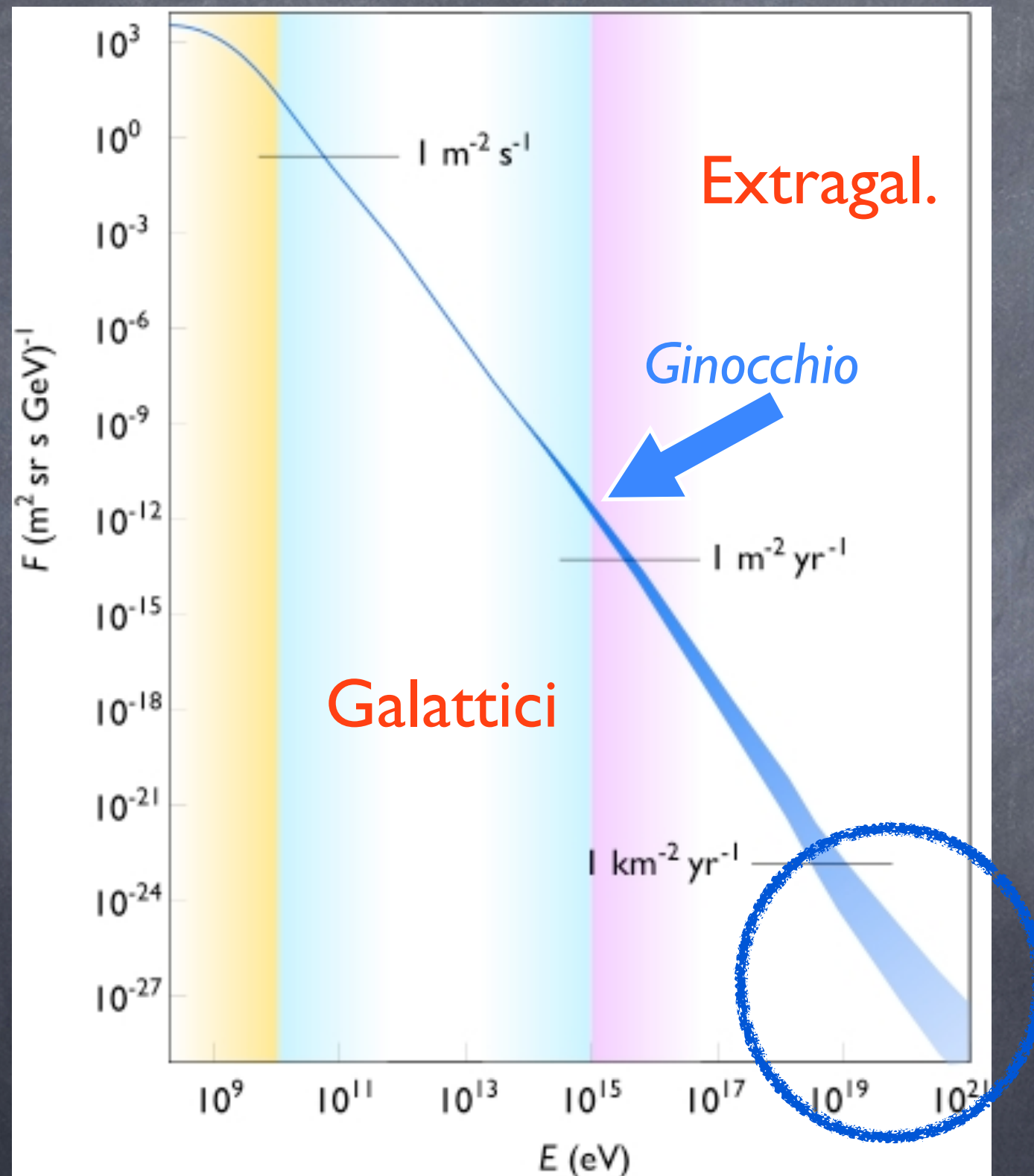
Mistero svelato?

Non ancora la prova
sicura al 100%

Altri processi fisici
concomitanti possono
contribuire

UHECR: ancora un mistero

Spettro energetico dei RC primari



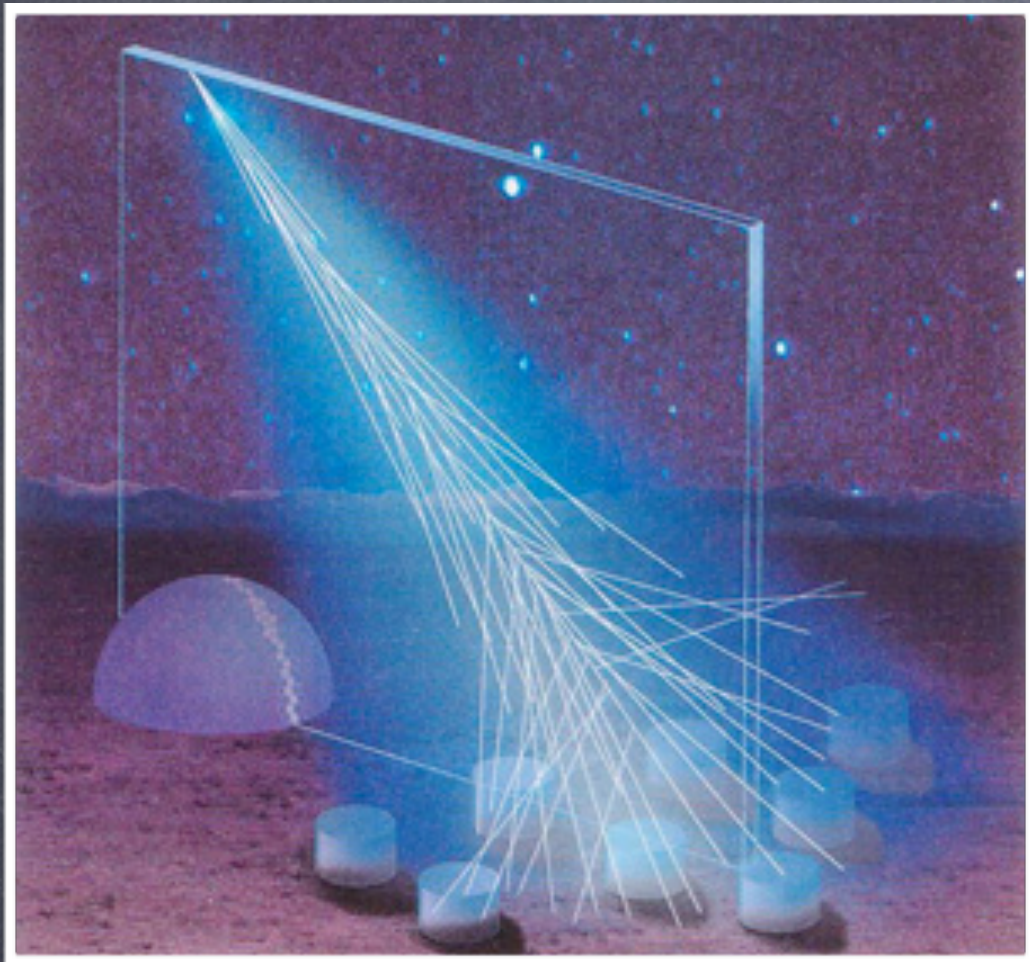
Pierre AUGER Observatory

3000 km²!

500 fisici
15 nazioni

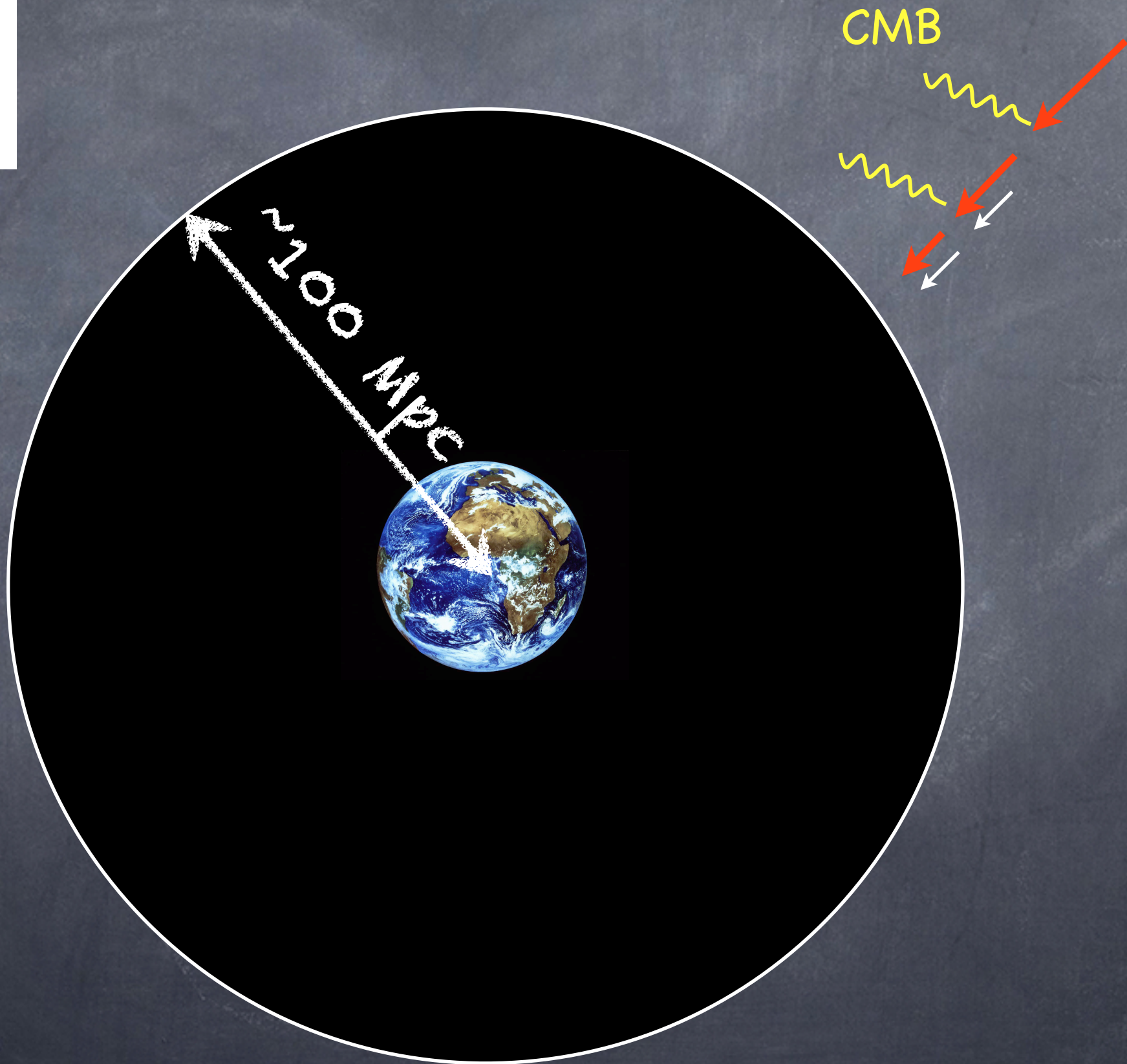


Pierre AUGER Observatory

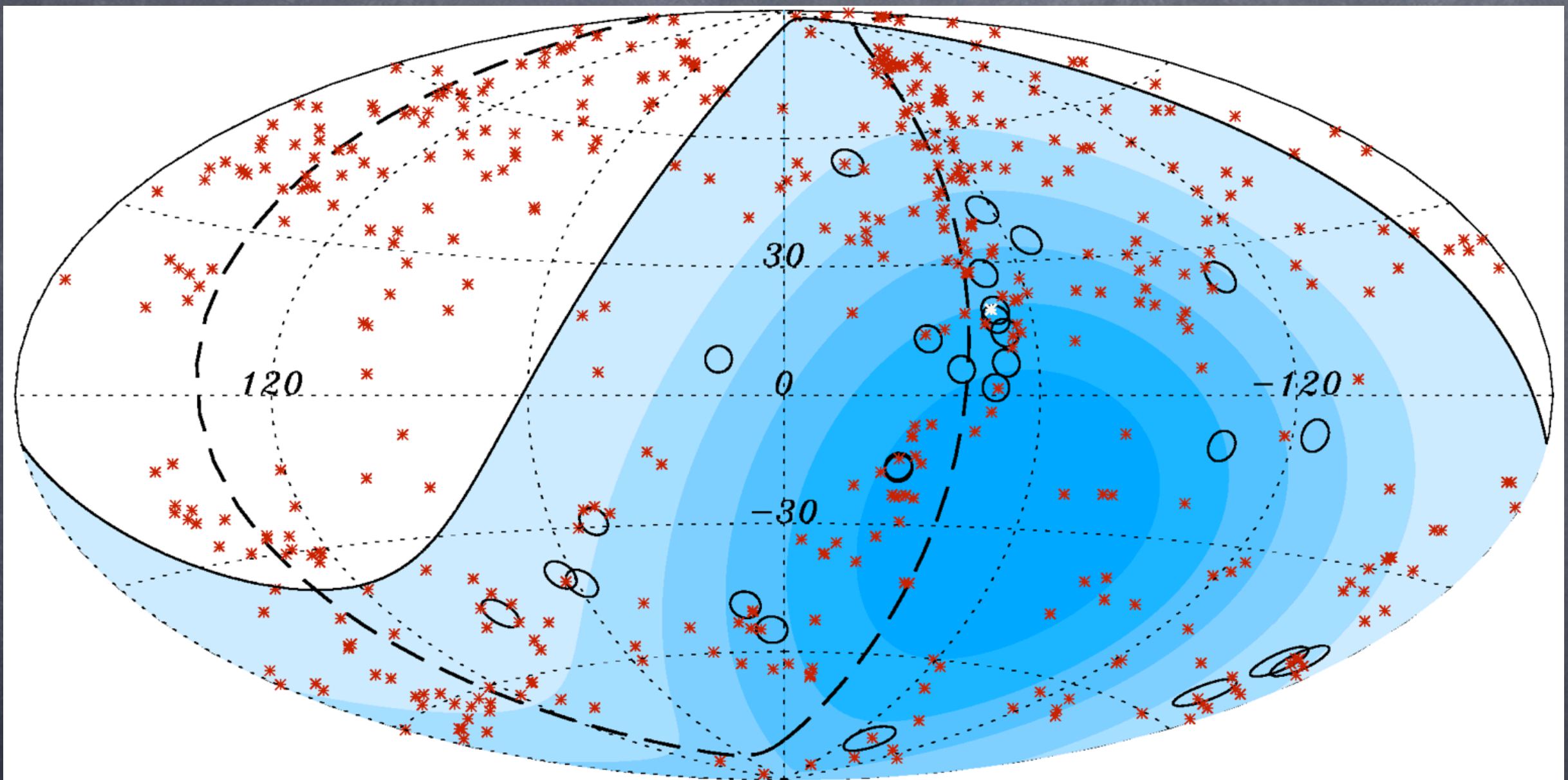


"Orizzonte degli UHECR"

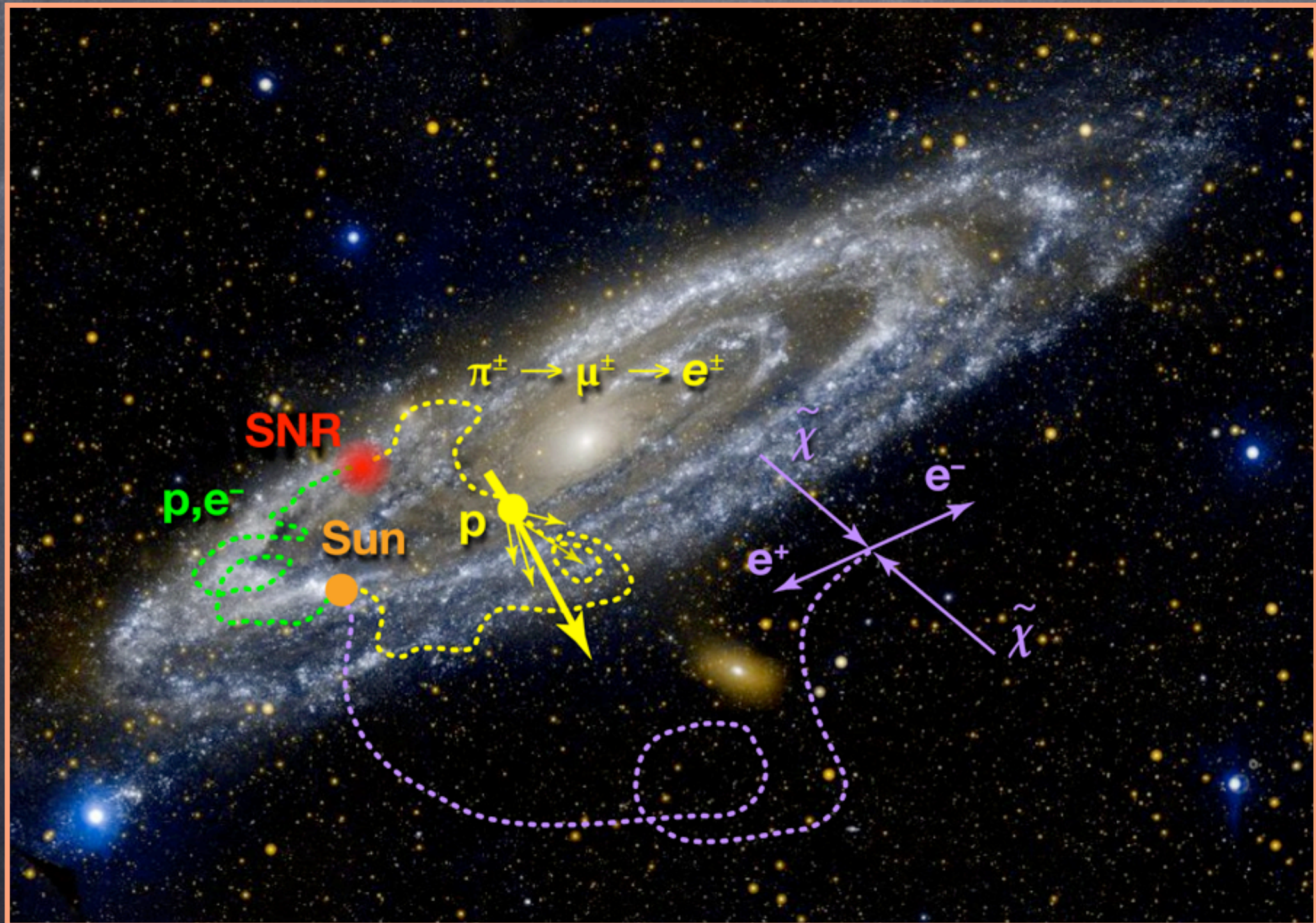
$$p + \gamma \rightarrow \Delta^+ \rightarrow \begin{cases} n + \pi^+ \\ p + \pi^0 \end{cases}$$



IL "cielo" di Auger



Altri tipi di radiazione



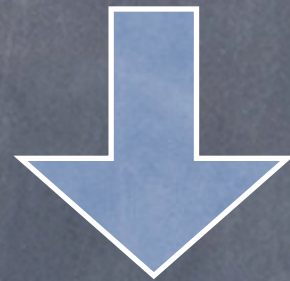
Neutrini

“Sottoprodotto” di reazioni dei raggi cosmici

- Atmosfera
- Galassia
- Spazio extragalattico
- Sorgente

Neutrini

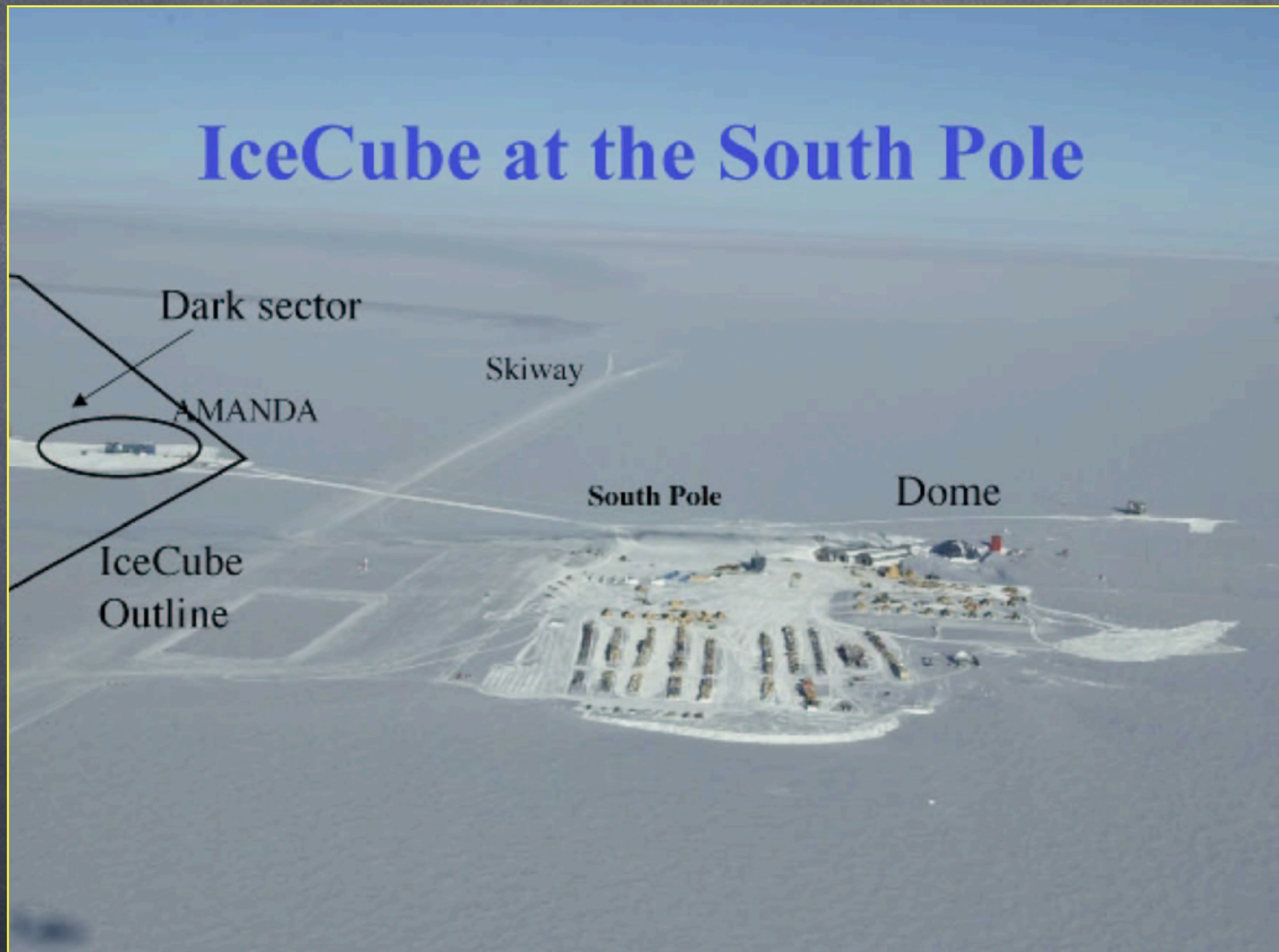
Pochissimo propensi ad interagire (forza "debole")

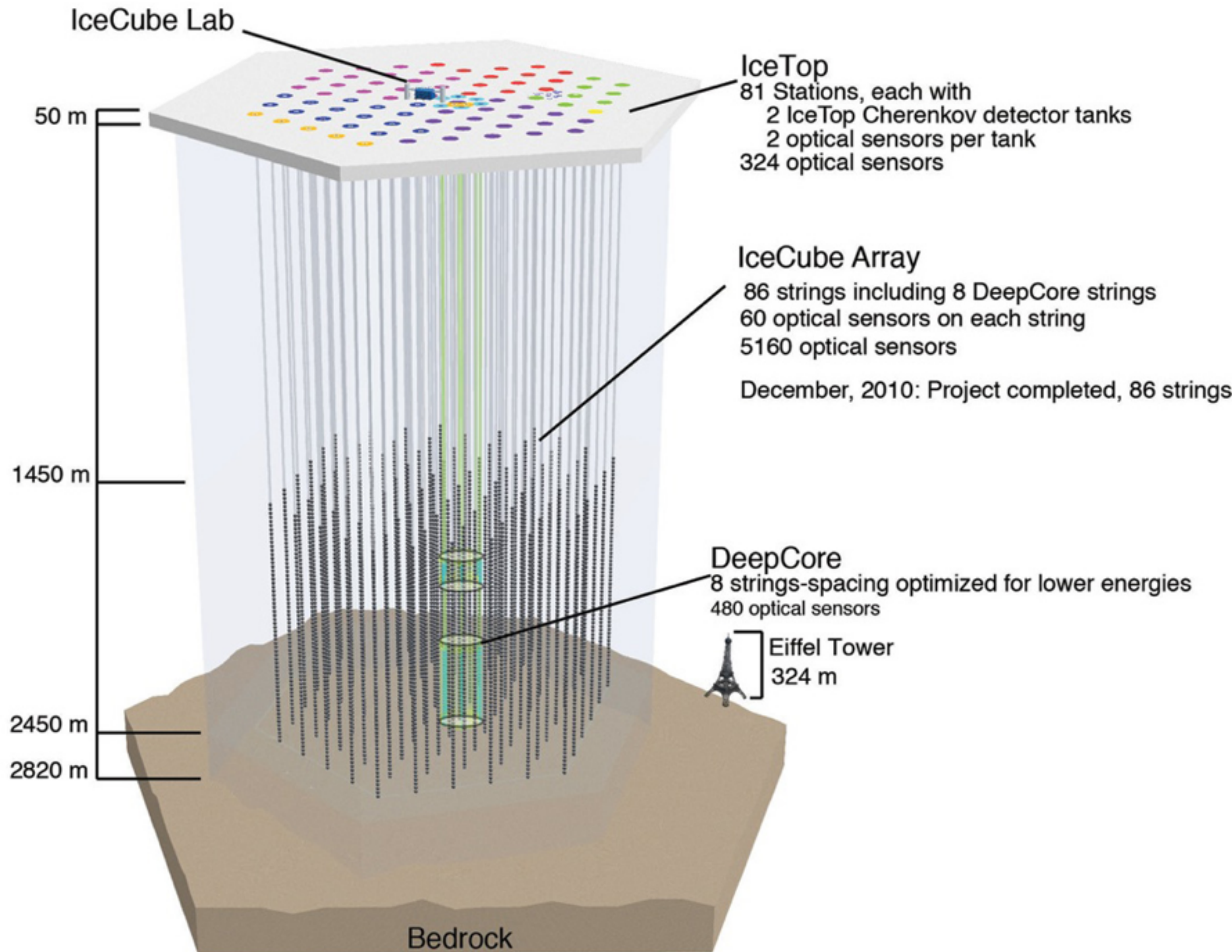


Rivelatori di grandi volumi

Neutrini

IceCube at the South Pole





Raggi gamma

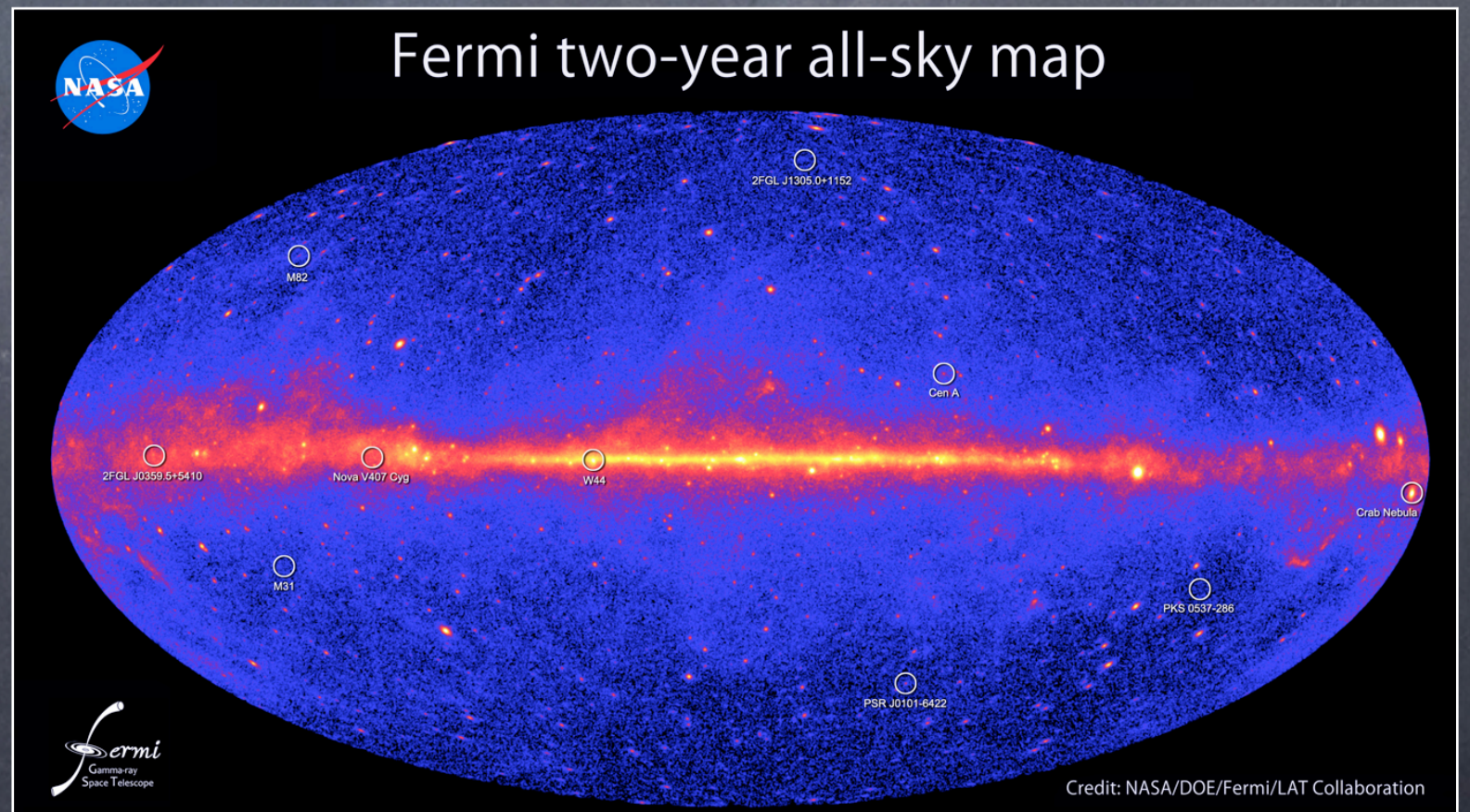
“Sottoprodotto” di reazioni dei raggi cosmici

- Atmosfera
- Galassia
- Spazio extragalattico
- Sorgente

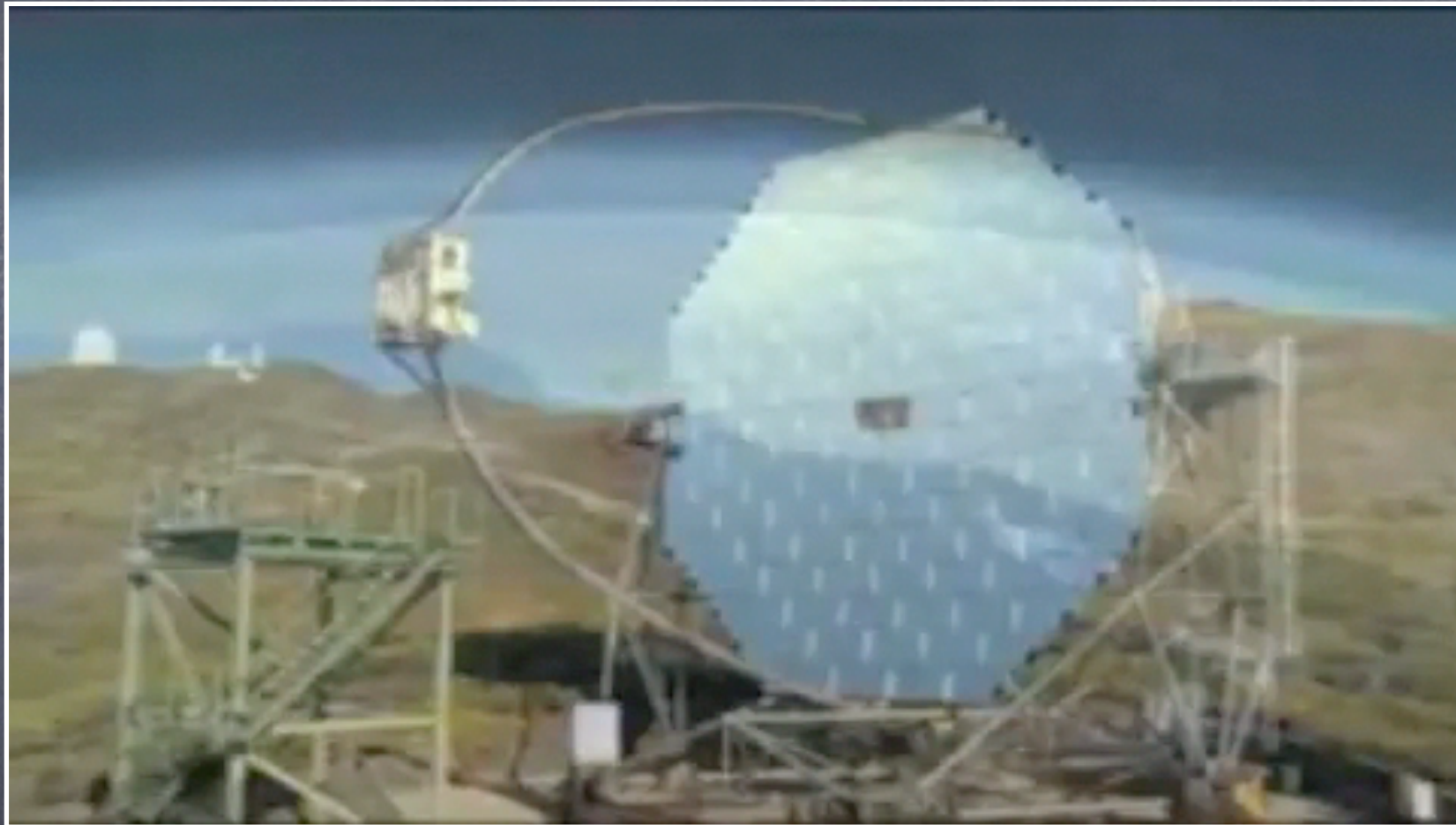
Raggi gamma



Telescopi su satellite:
Fermi/LAT



Raggi gamma



Telescopi a terra:
Cherenkov

Domande!?