INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

ASTRI

CTAO

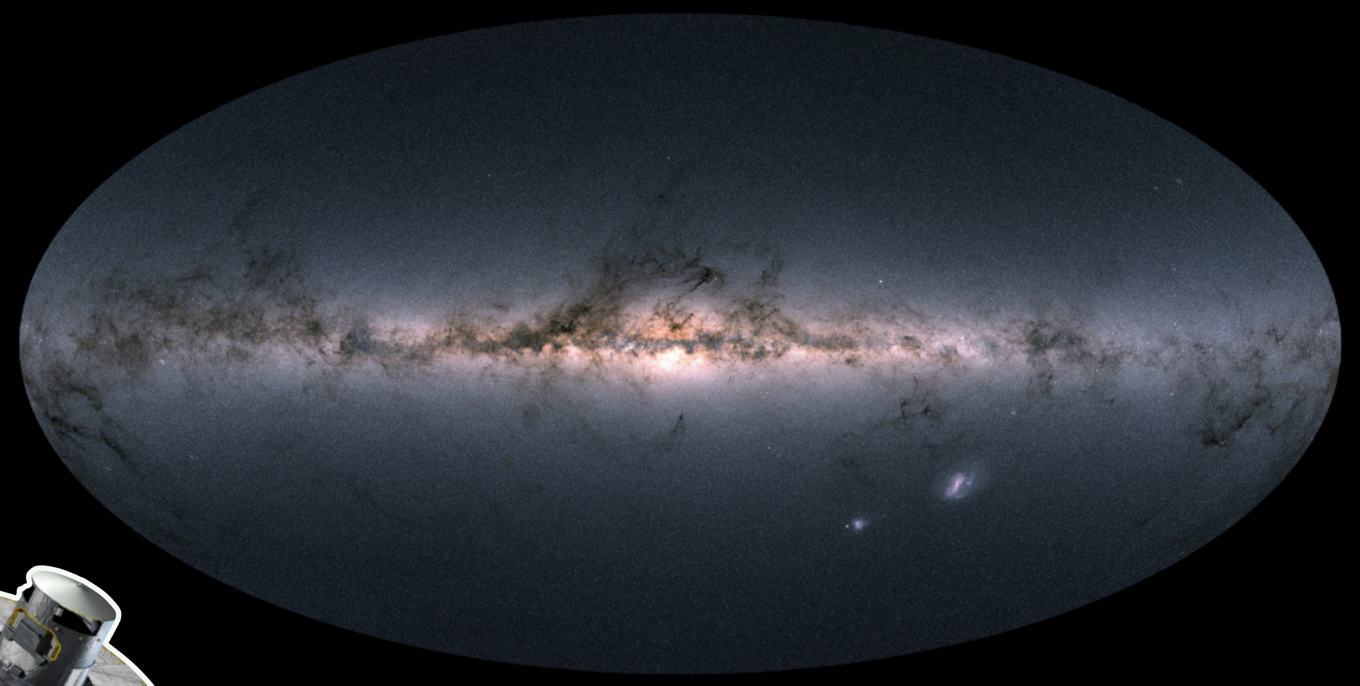
Telescopi gamma di nuova generazione

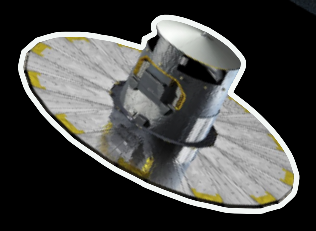
Silvia Crestan
IASF-INAF Milano

Incontri di fisica moderna - Università di Pavia - 5 Novembre 2024

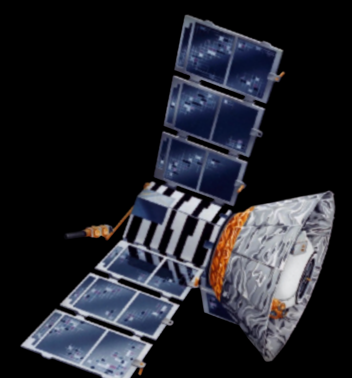
L’universo termico

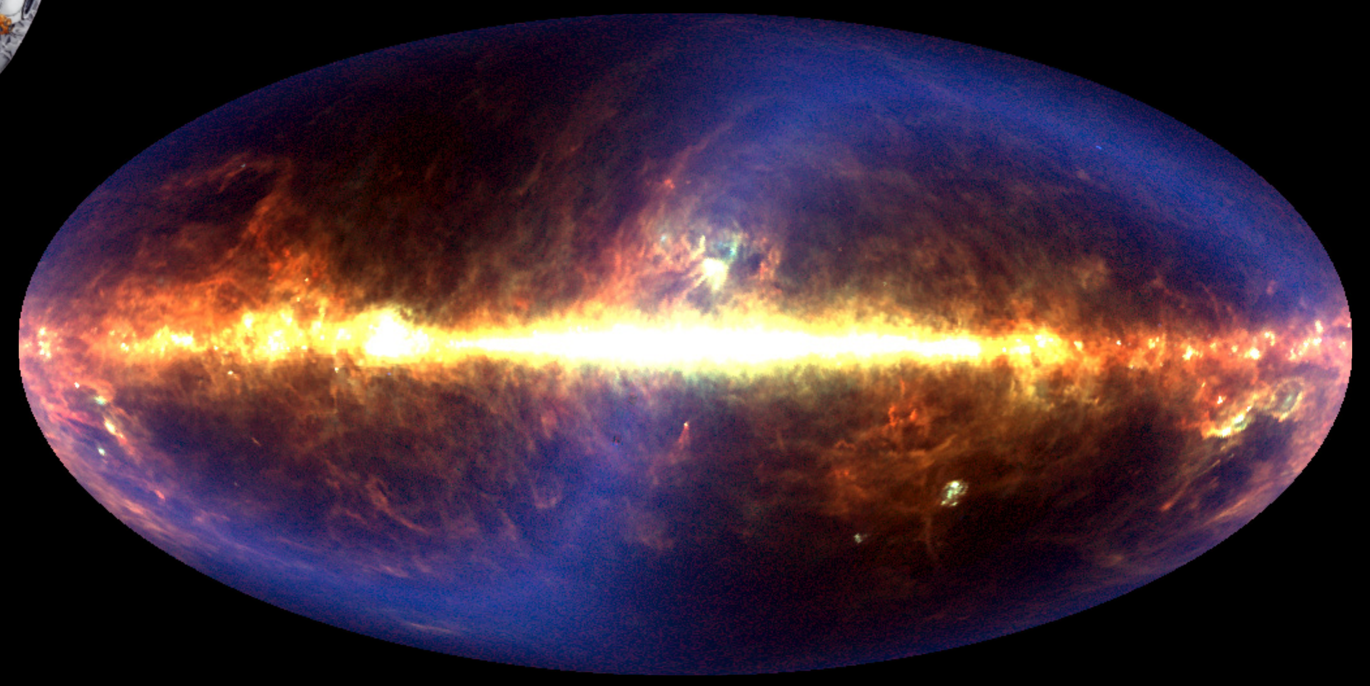
Visibile (GAIA)



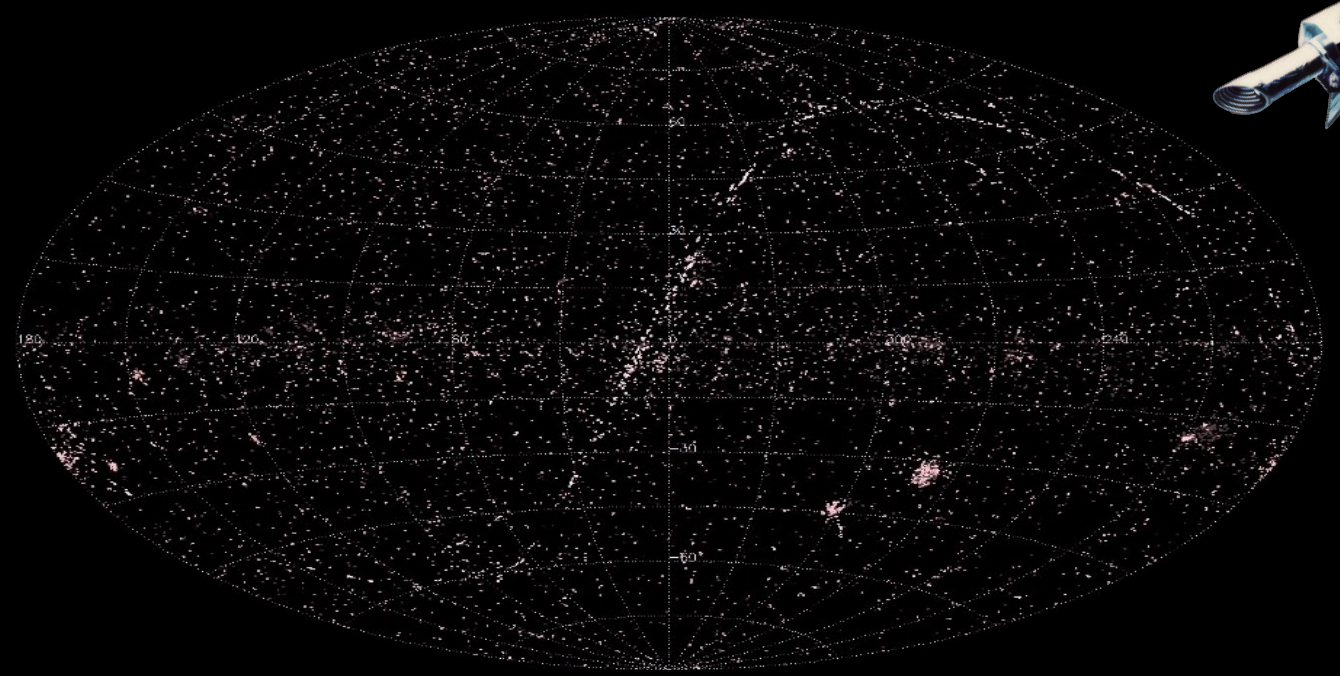


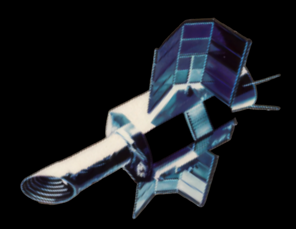
Infrarosso (COBE)



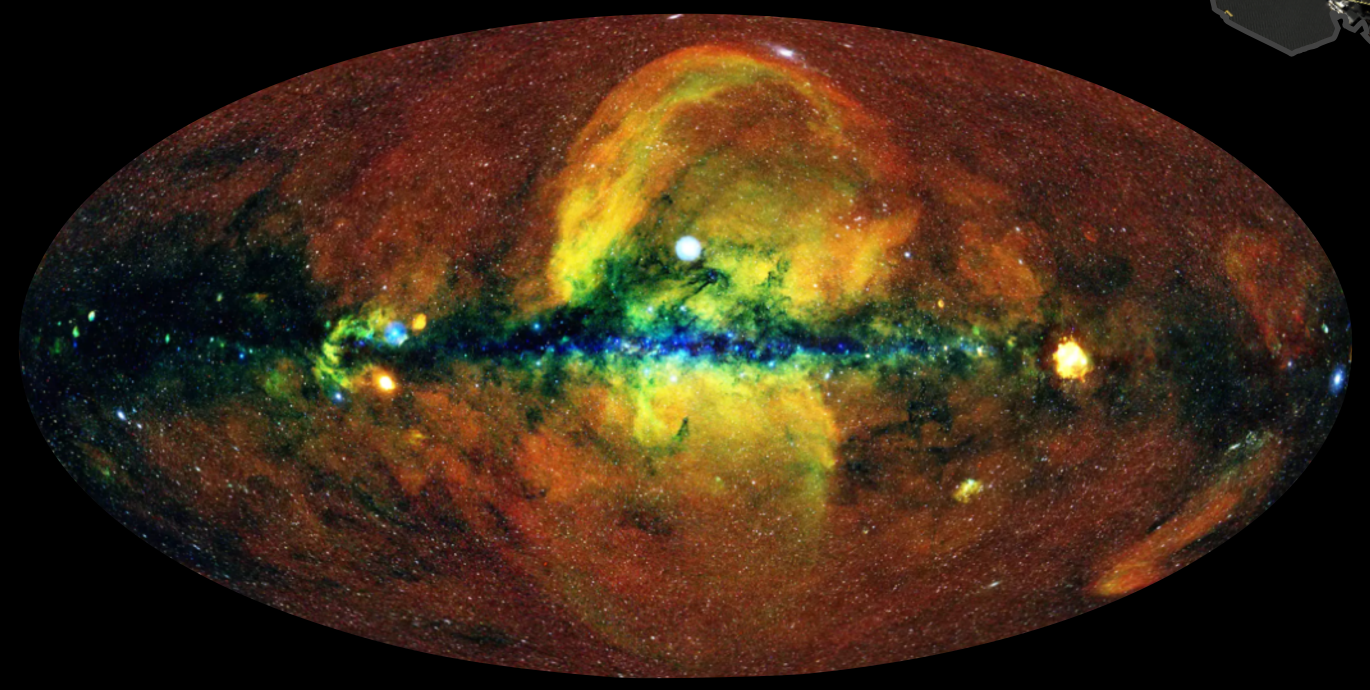


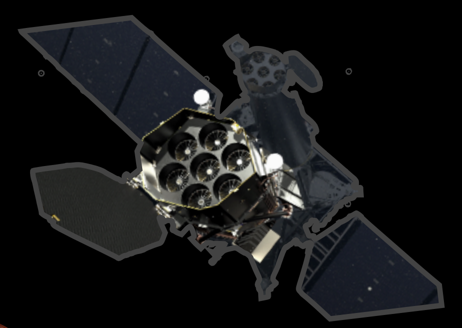
UV (IUE)



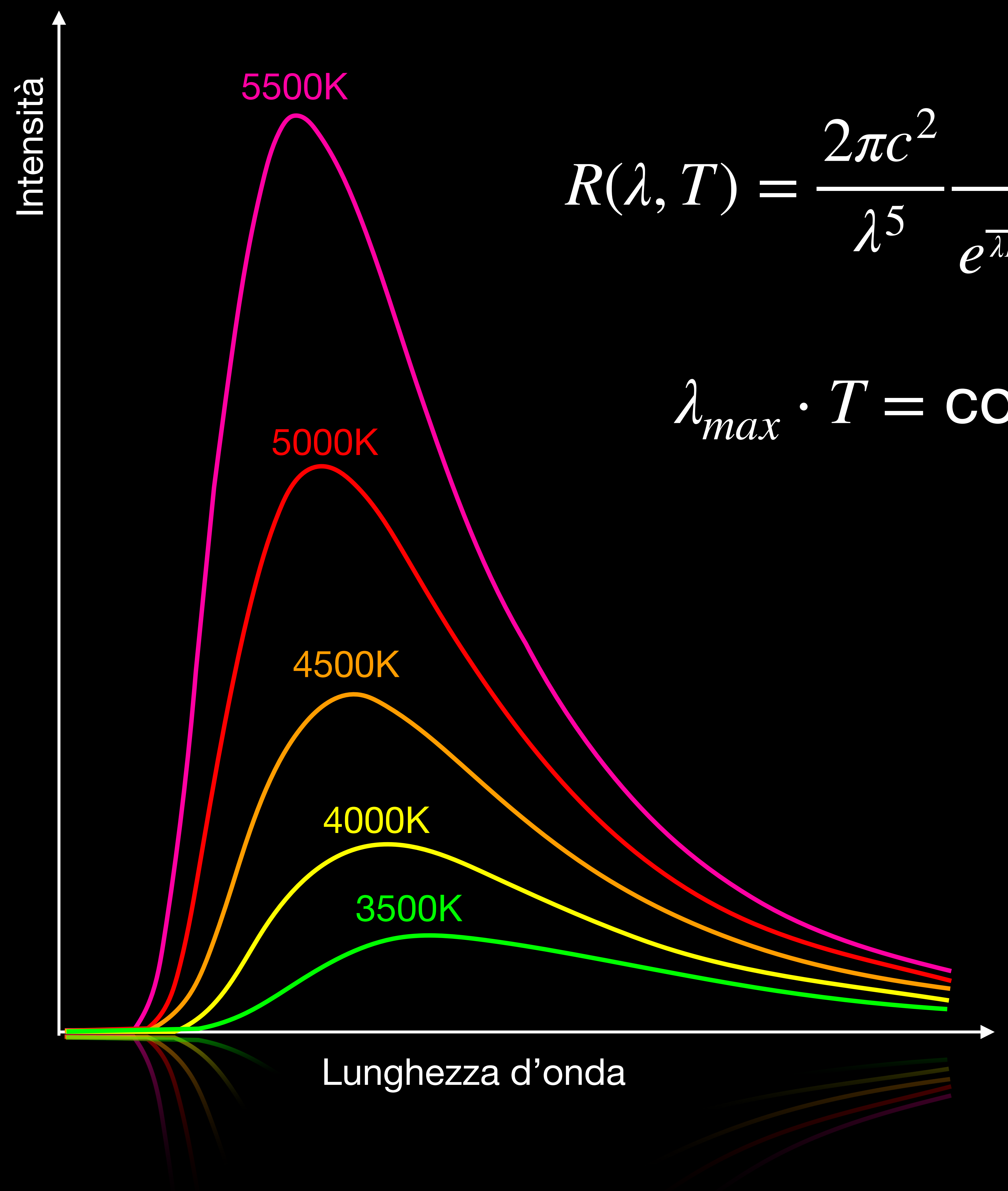


X-ray (eROSITA)



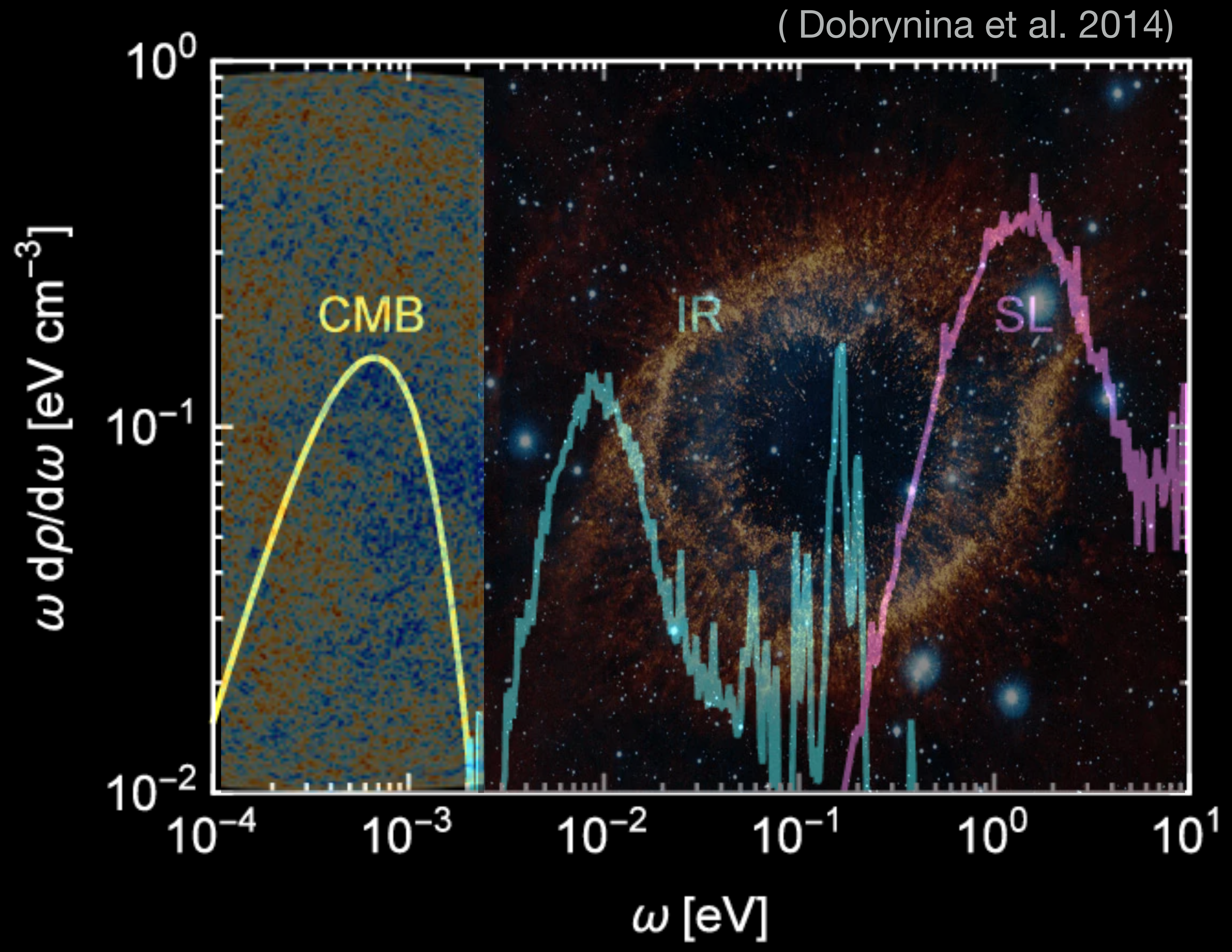


L'universo termico



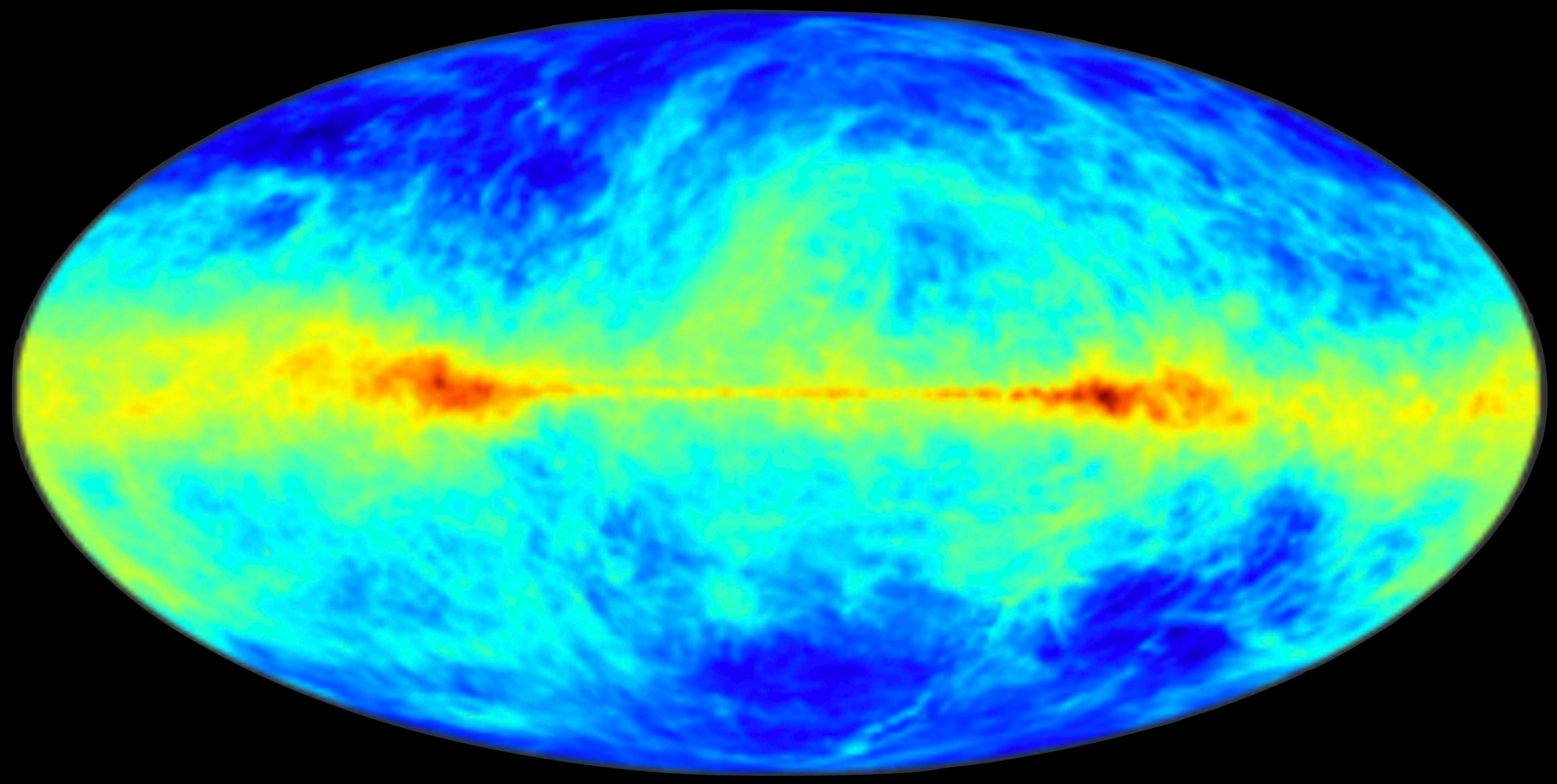
$$R(\lambda, T) = \frac{2\pi c^2}{\lambda^5} \frac{h}{e^{\frac{hc}{\lambda K_B T}} - 1}$$

$$\lambda_{max} \cdot T = \text{cost}$$

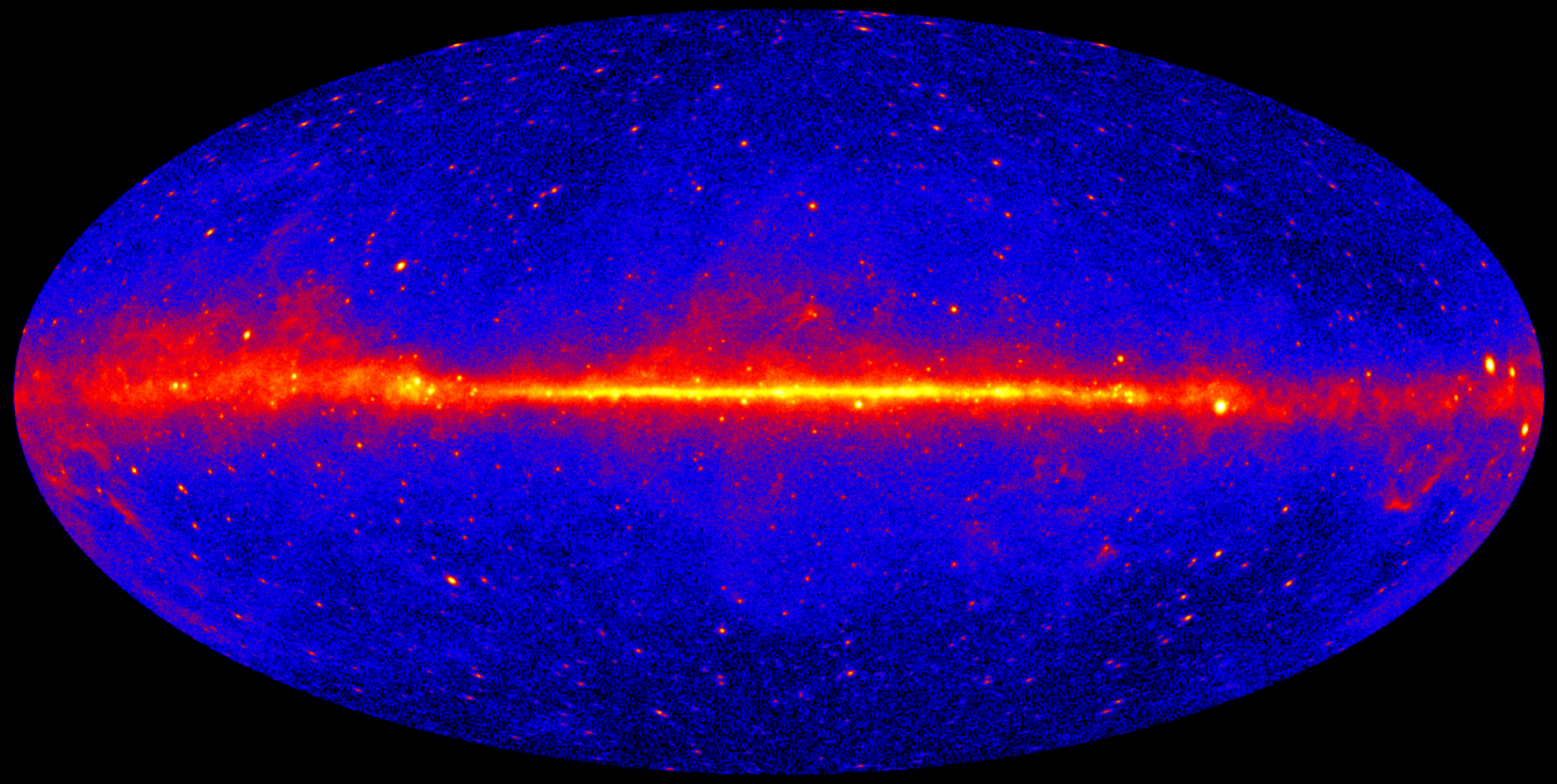


…non tutta la radiazione è termica

Per produrre onde radio serve una sorgente più fredda dell'universo (- 273 °C)



$$T = \frac{3 \cdot 10^{-3}\ [m \cdot K]}{1\ m} = 0.003K$$

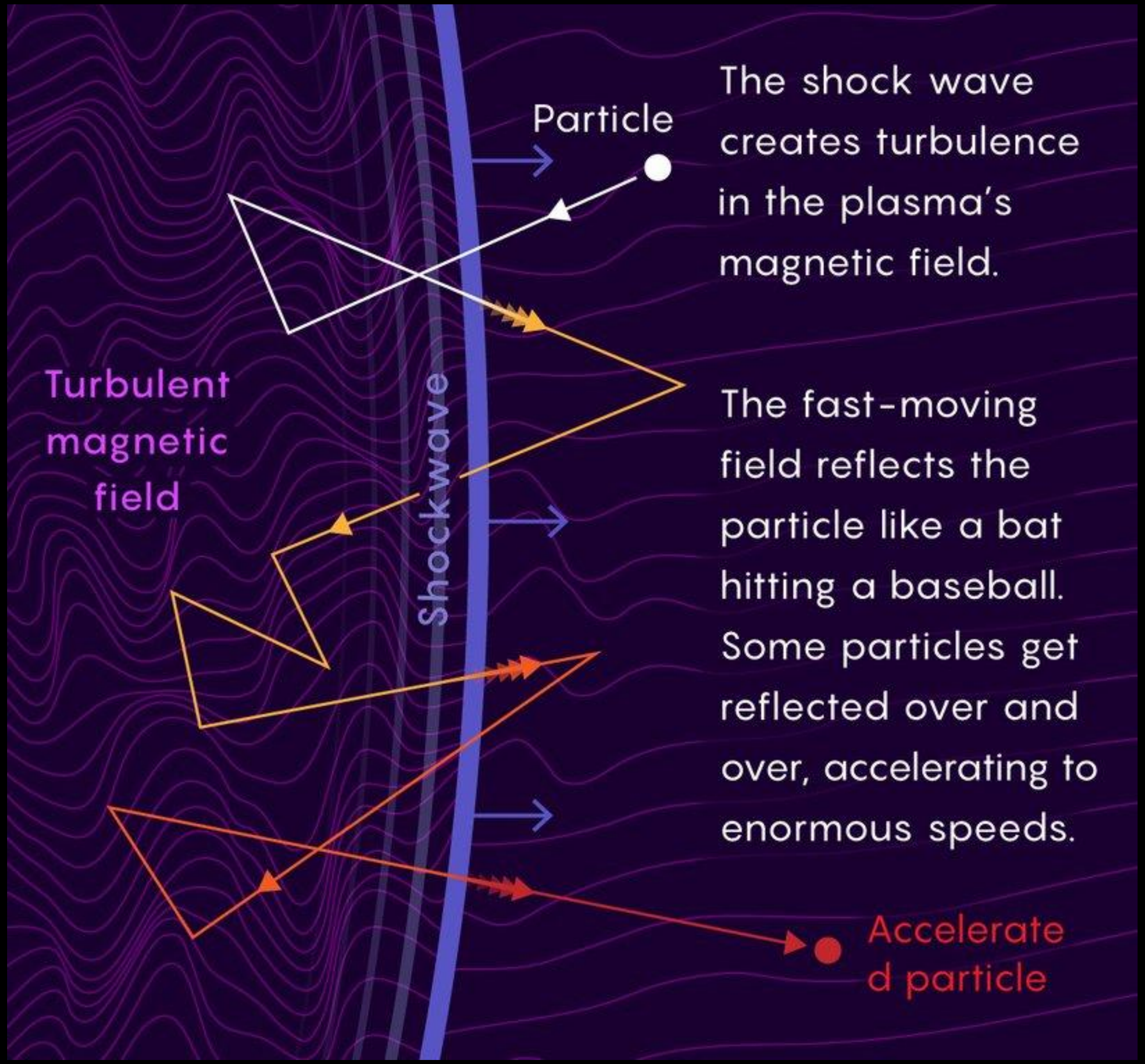


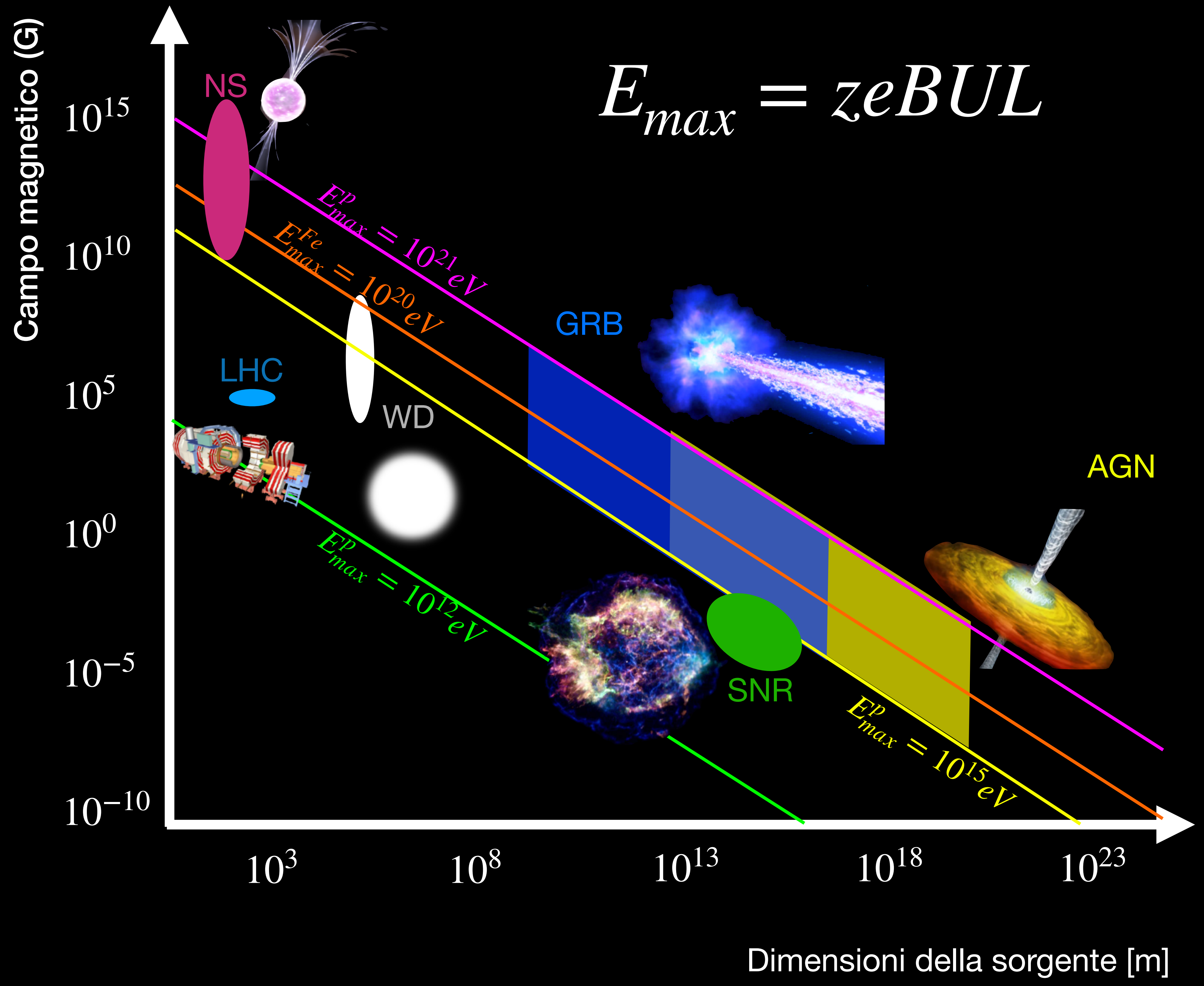
I raggi gamma richiederebbero:

$$T = \frac{3 \cdot 10^{-3}\ [m \cdot K]}{10^{-16}\ m} = 3 \cdot 10^{13}K$$

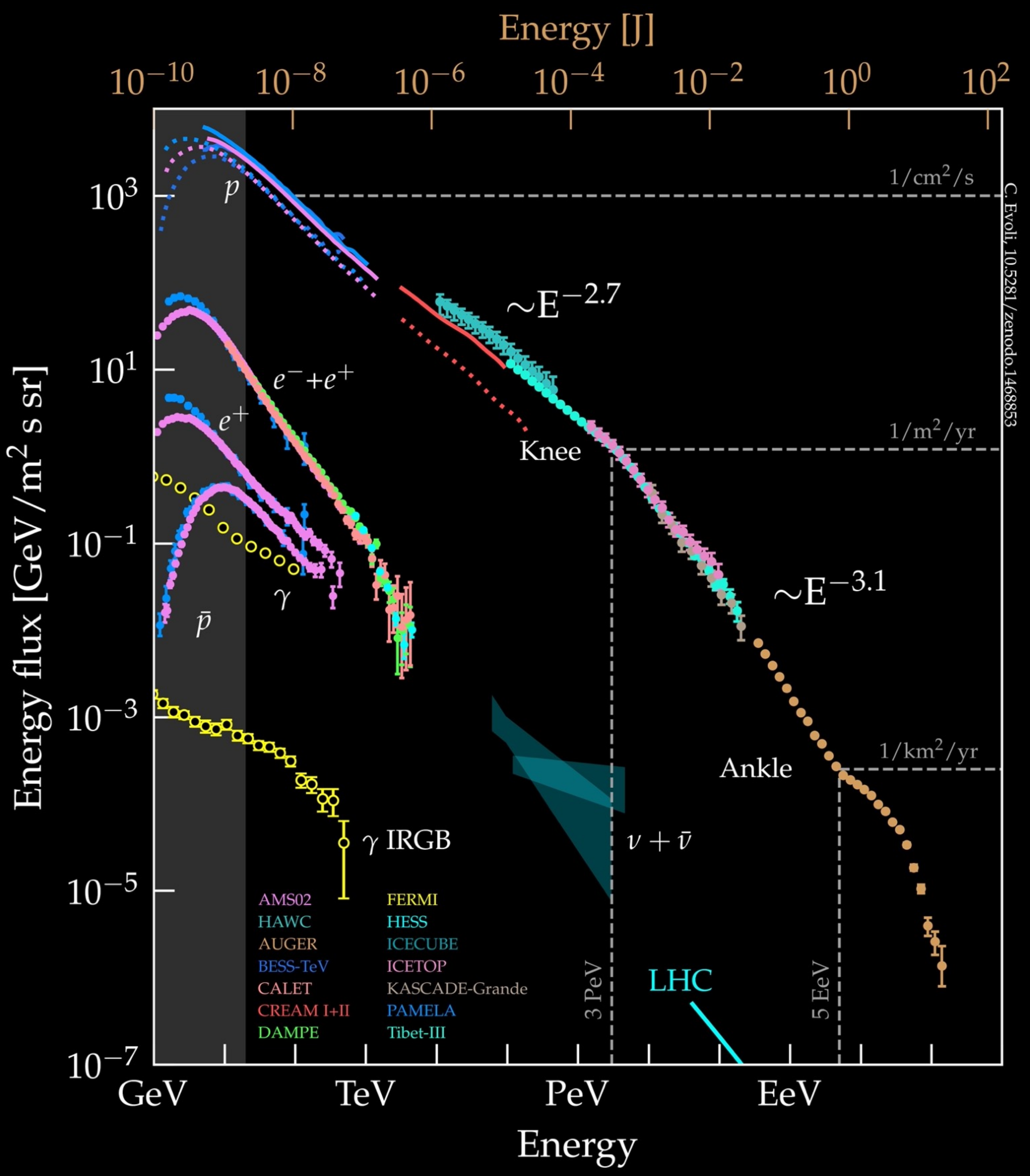
Servono altri processi per produrre questo tipo di radiazione…

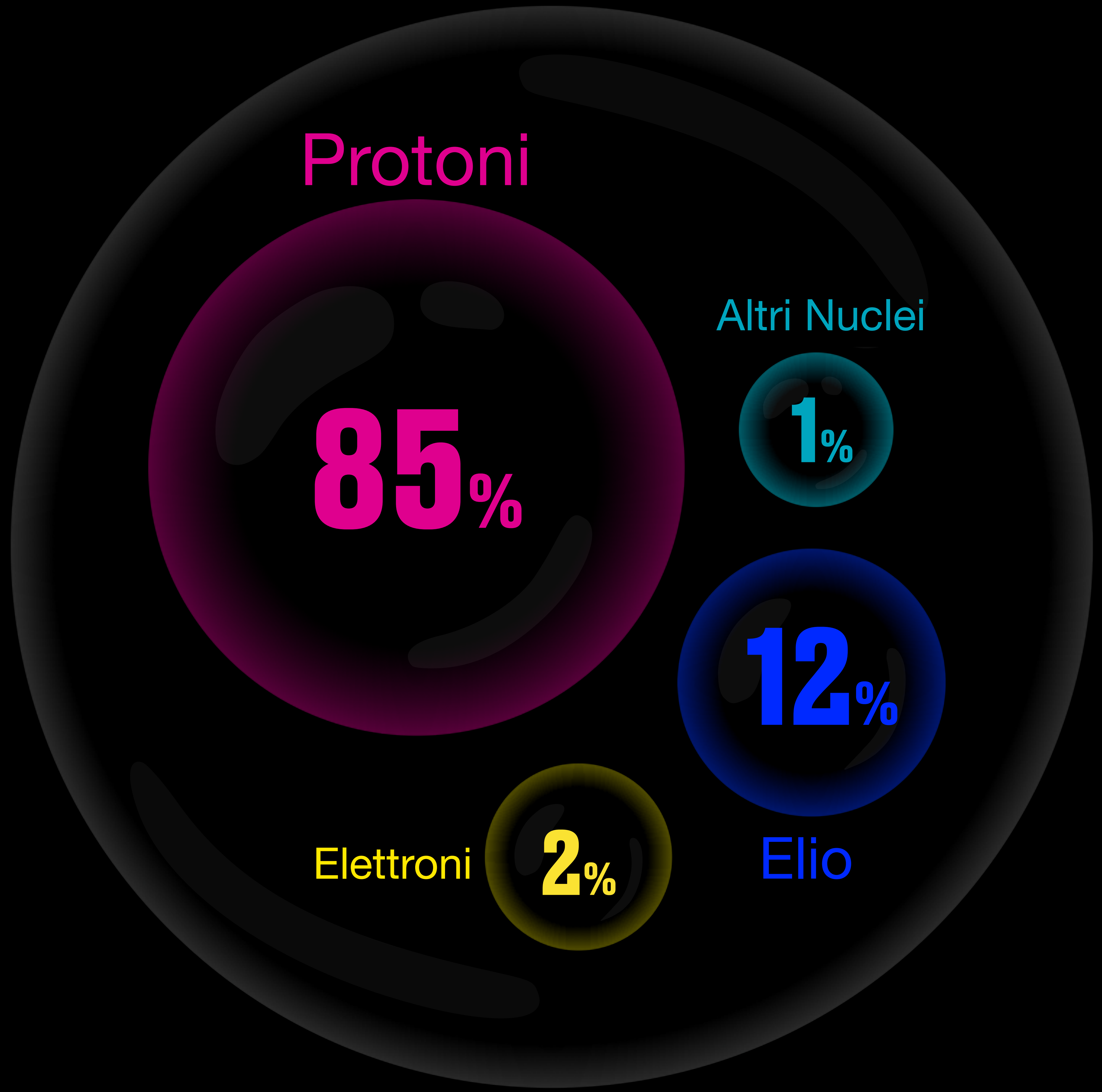
Acceleratori di particelle cosmici





Raggi cosmici





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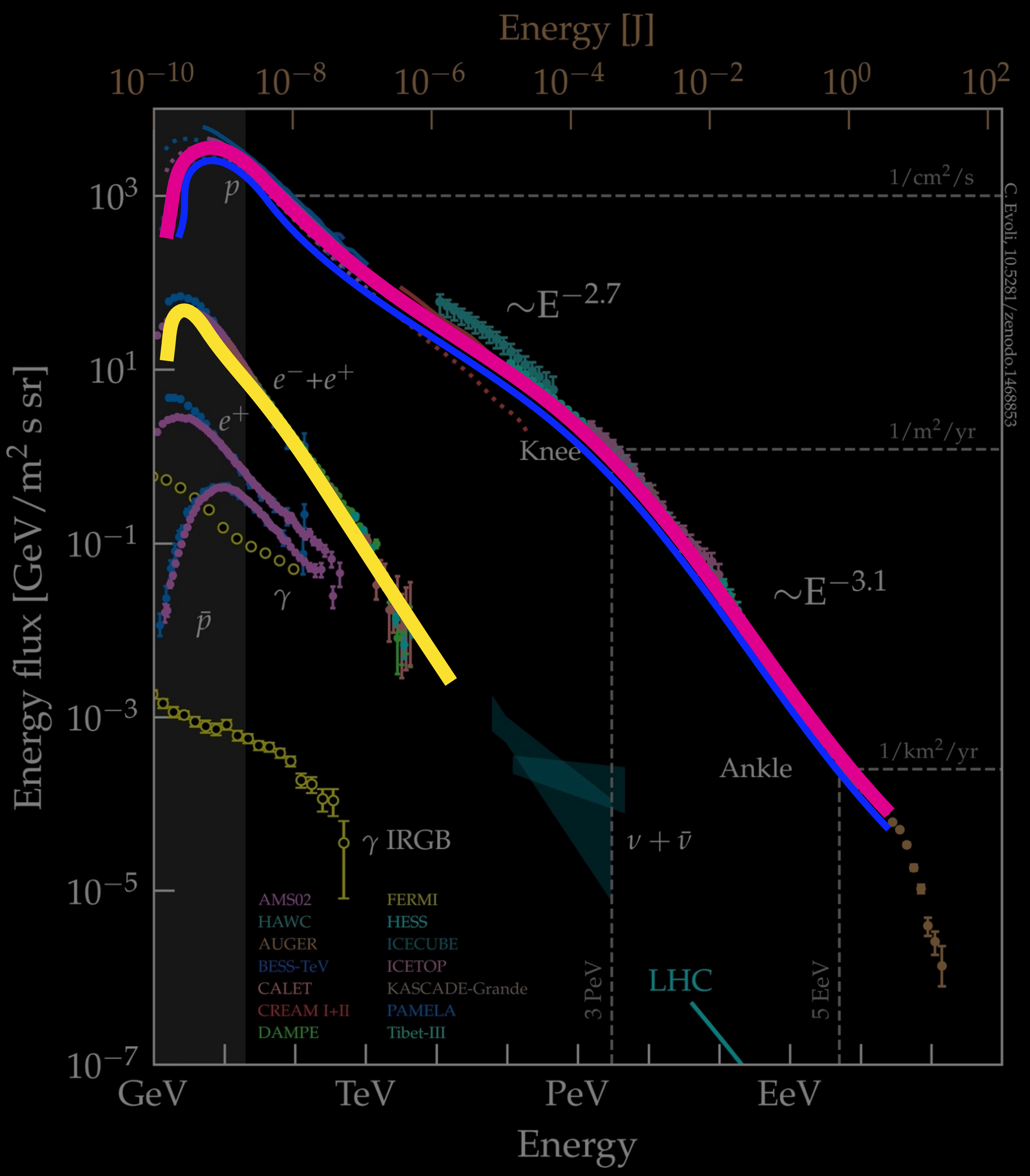

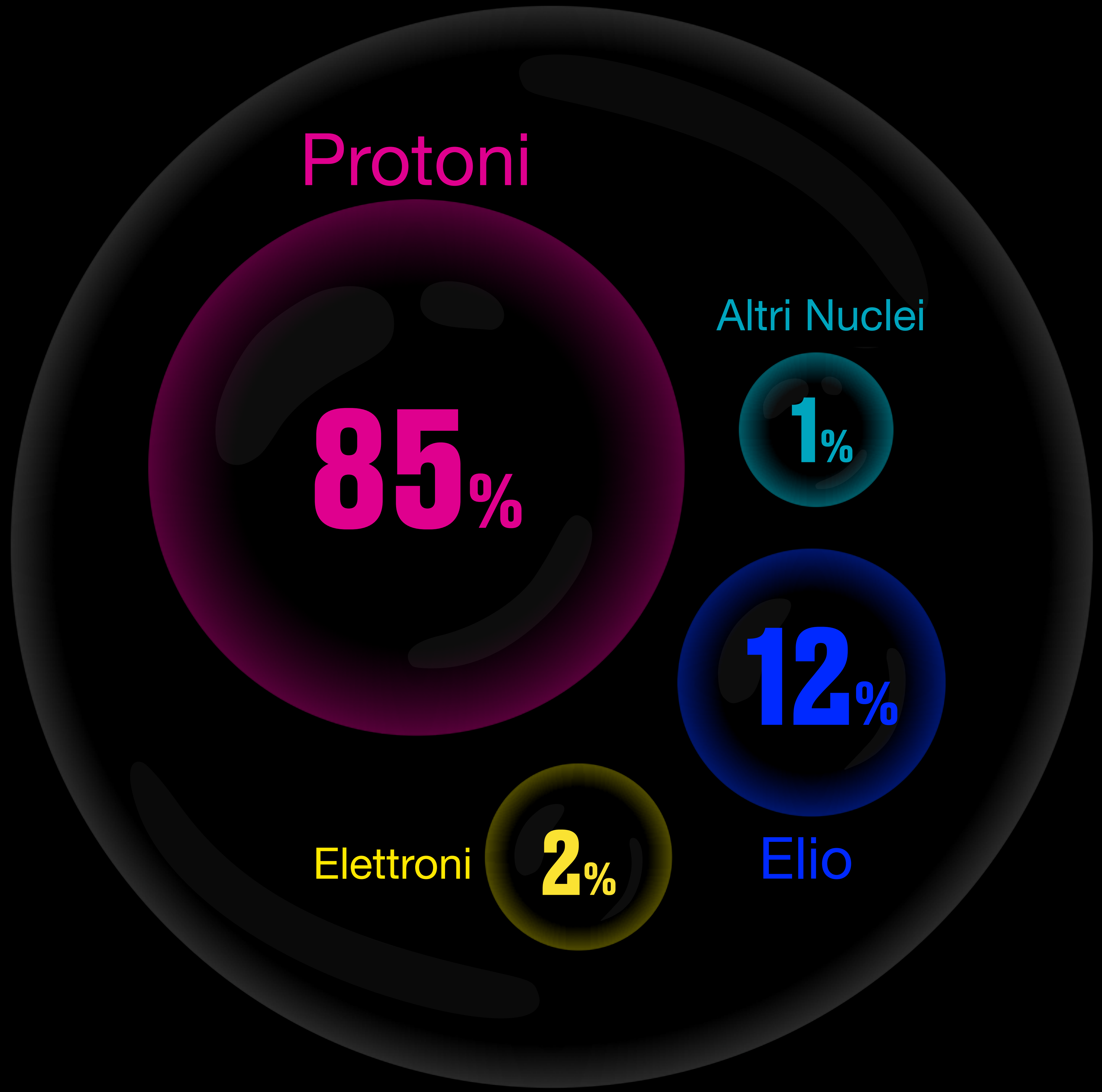

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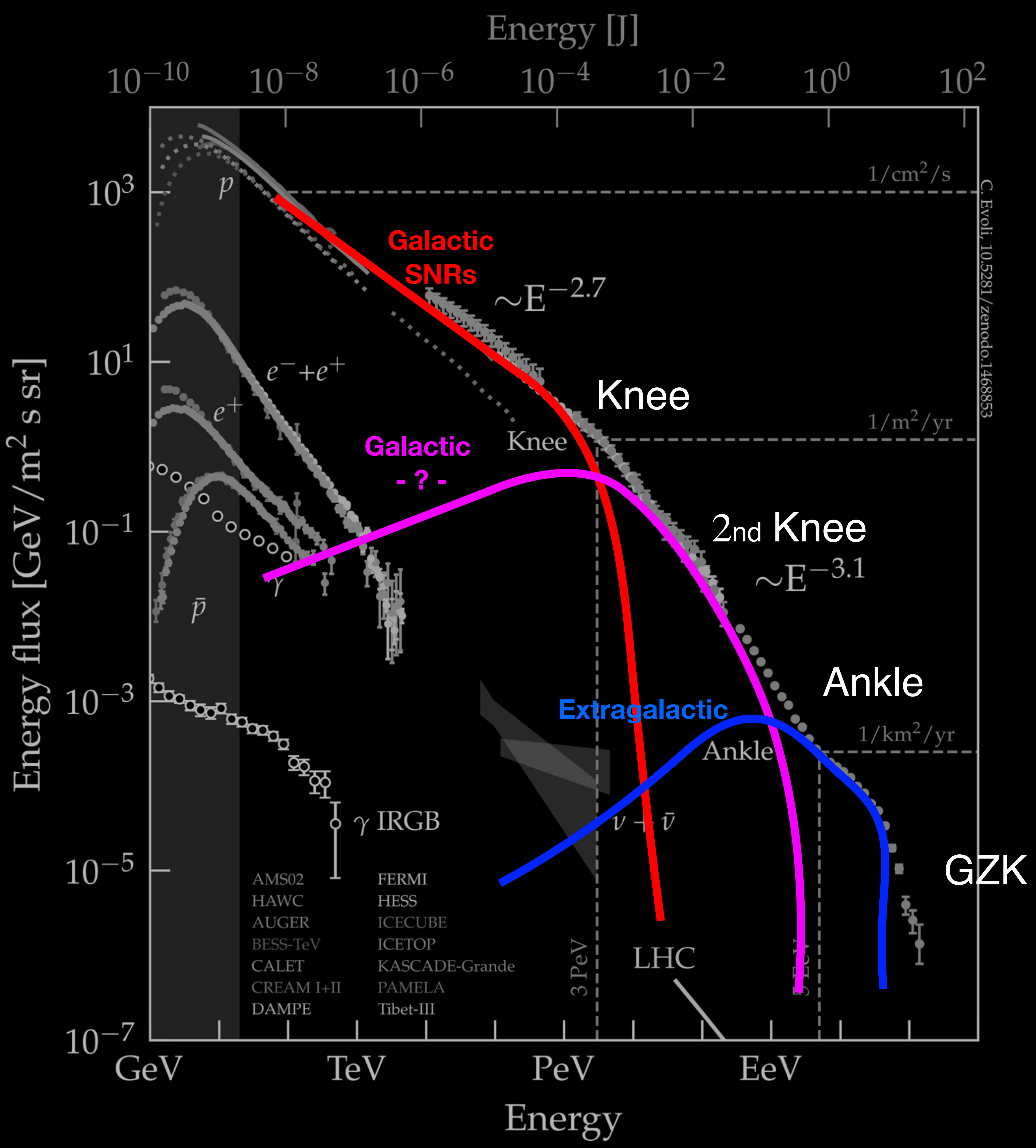


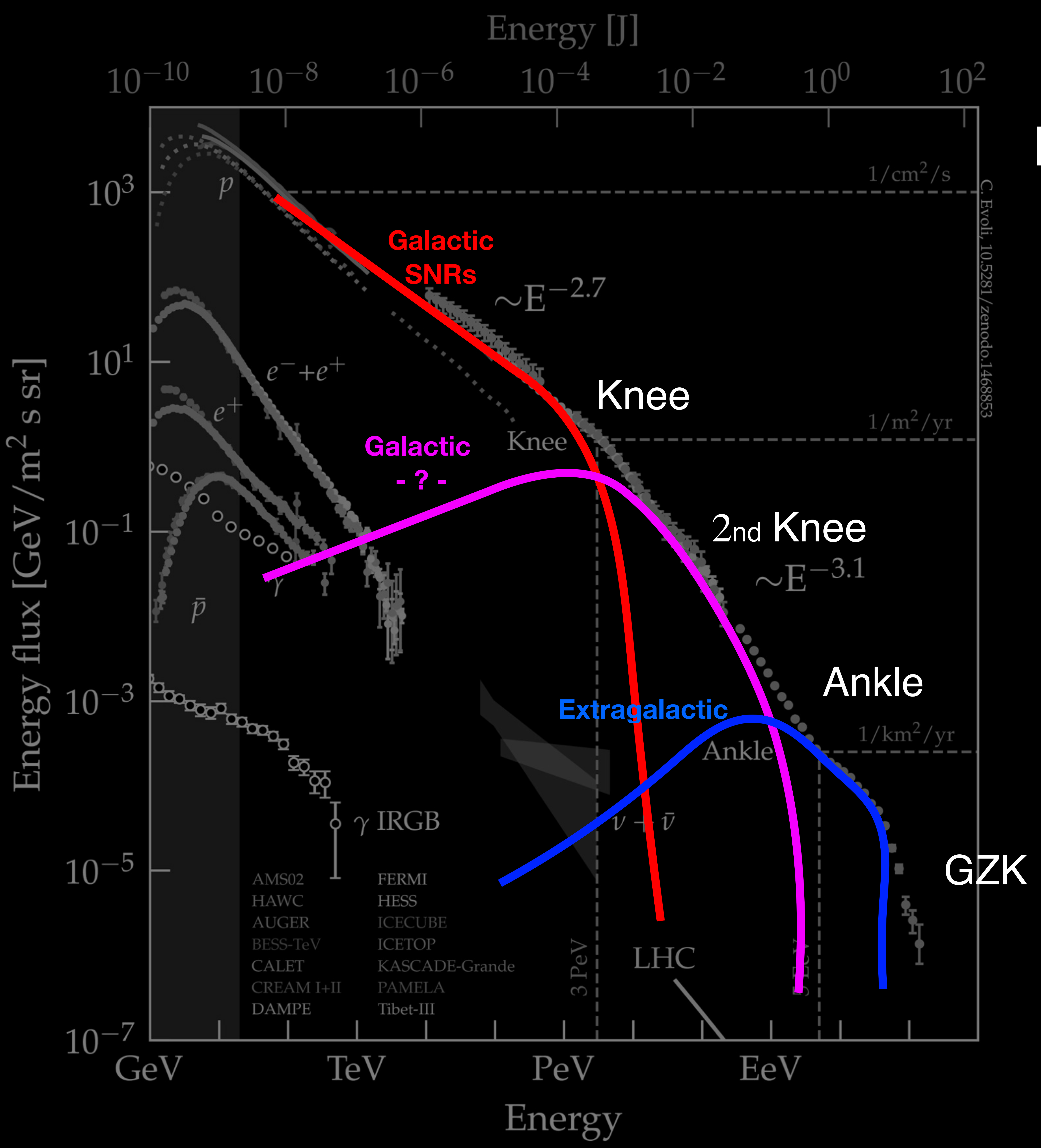
Lo spettro è una legge di potenza + alcune features

$$\frac{dN}{dE} \propto E^{-\gamma} \quad ; \quad \gamma = 2.7$$

	Knee	2nd Knee	Ankle	GZK
Indice	2.7	3.1	3.3	2.7
Energia (eV/nucleone)	$10^{15.5}$	10^{17}	$10^{18.5}$	10^{19}

Origine: Galattica → ExtraGalattica

Raggi cosmici



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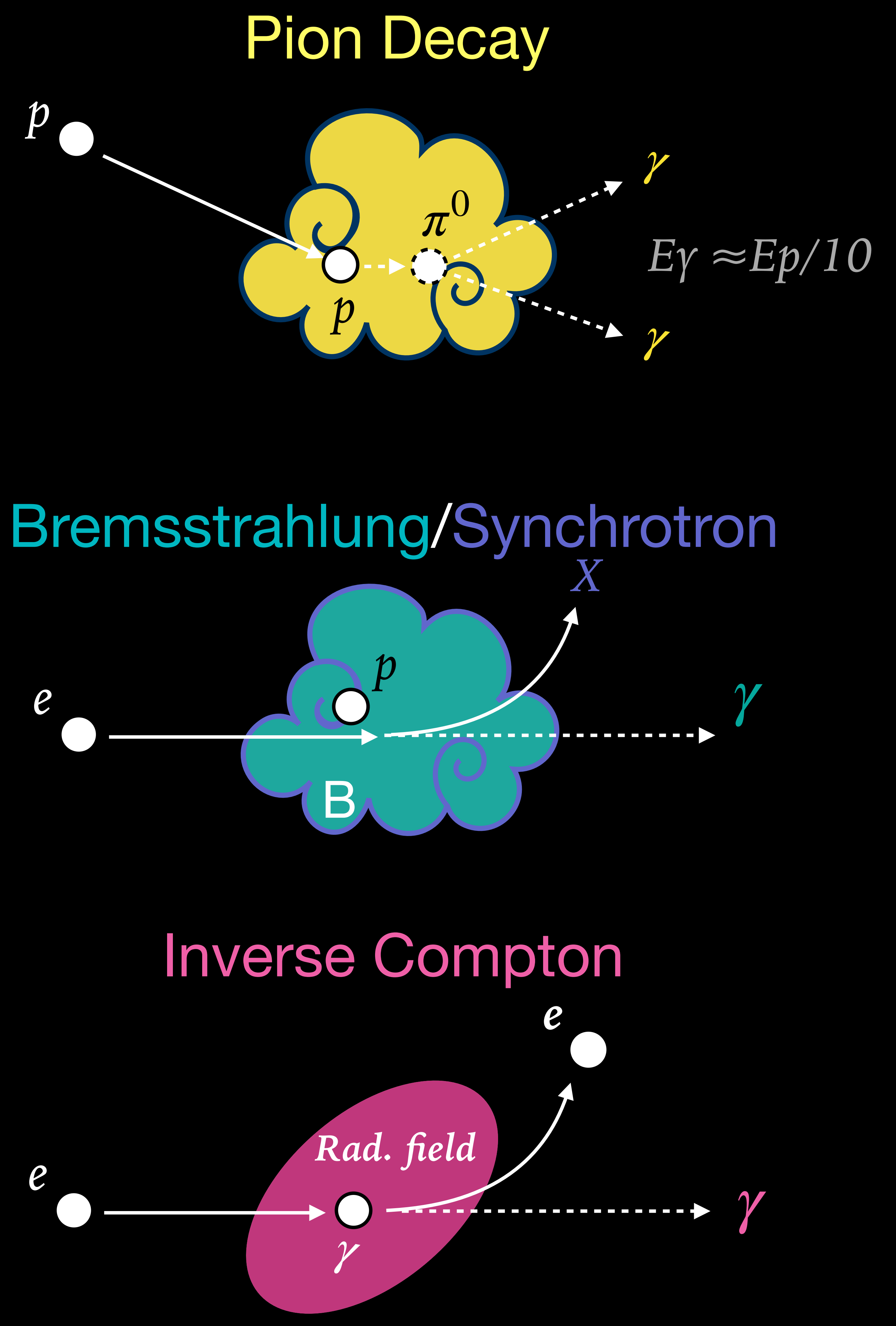
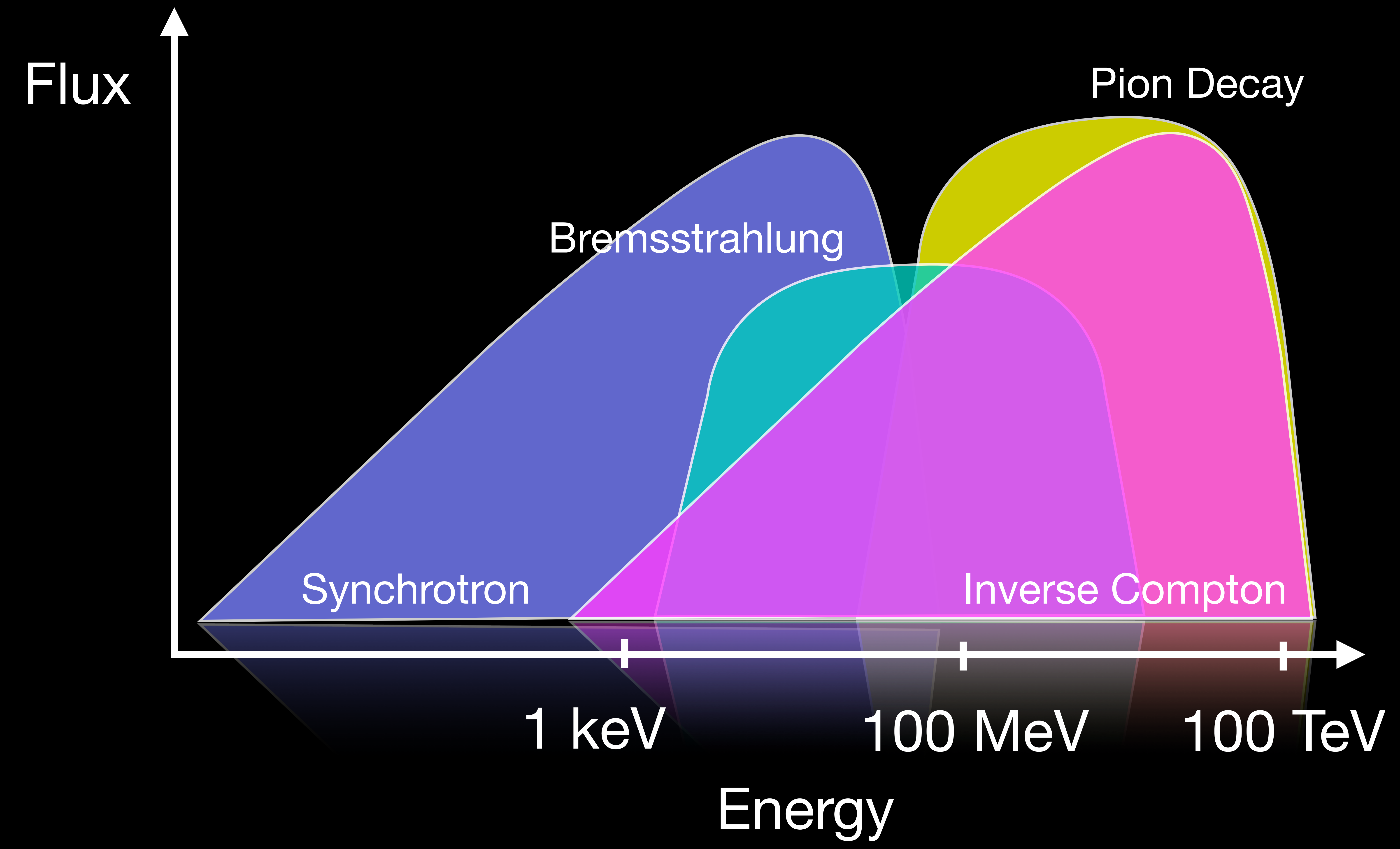
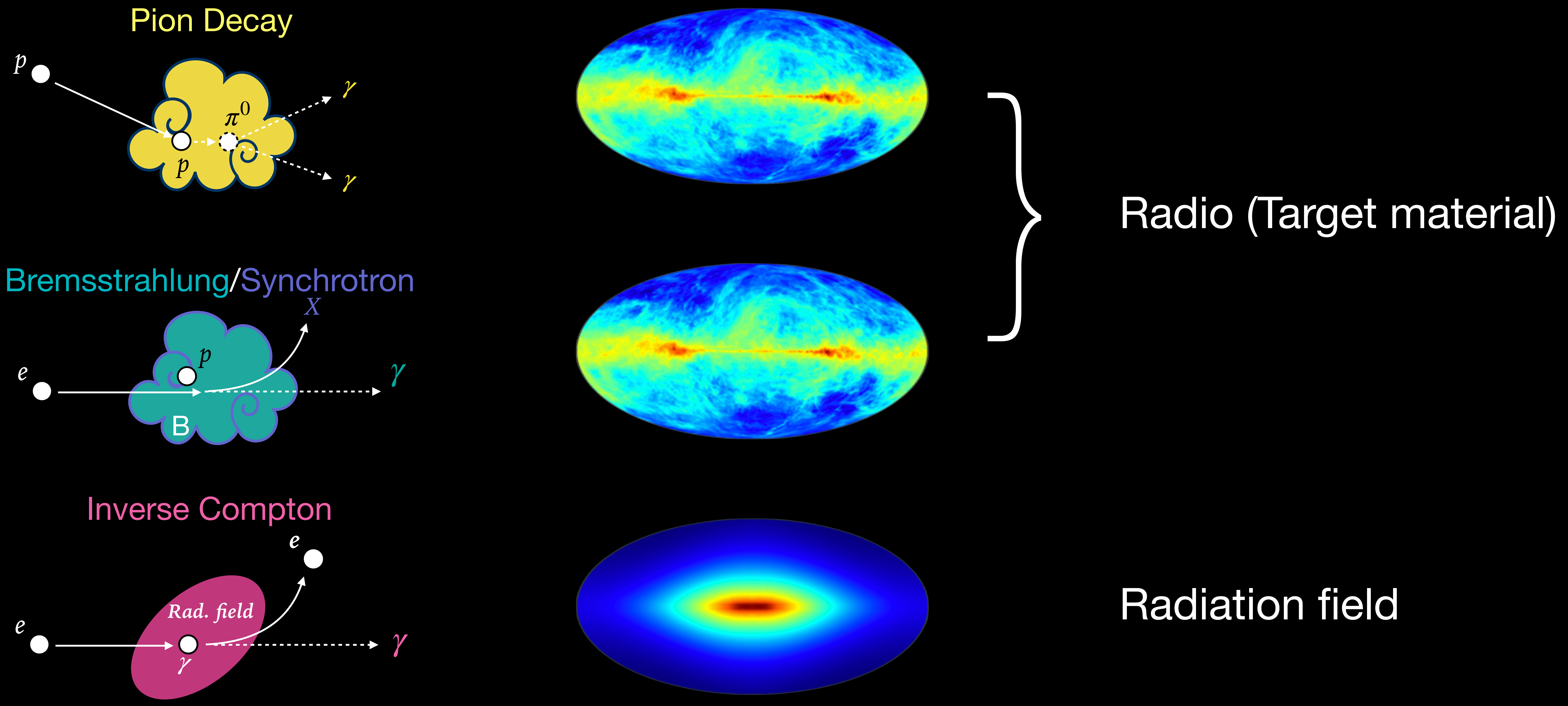
Processi non termici





L'universo non termico



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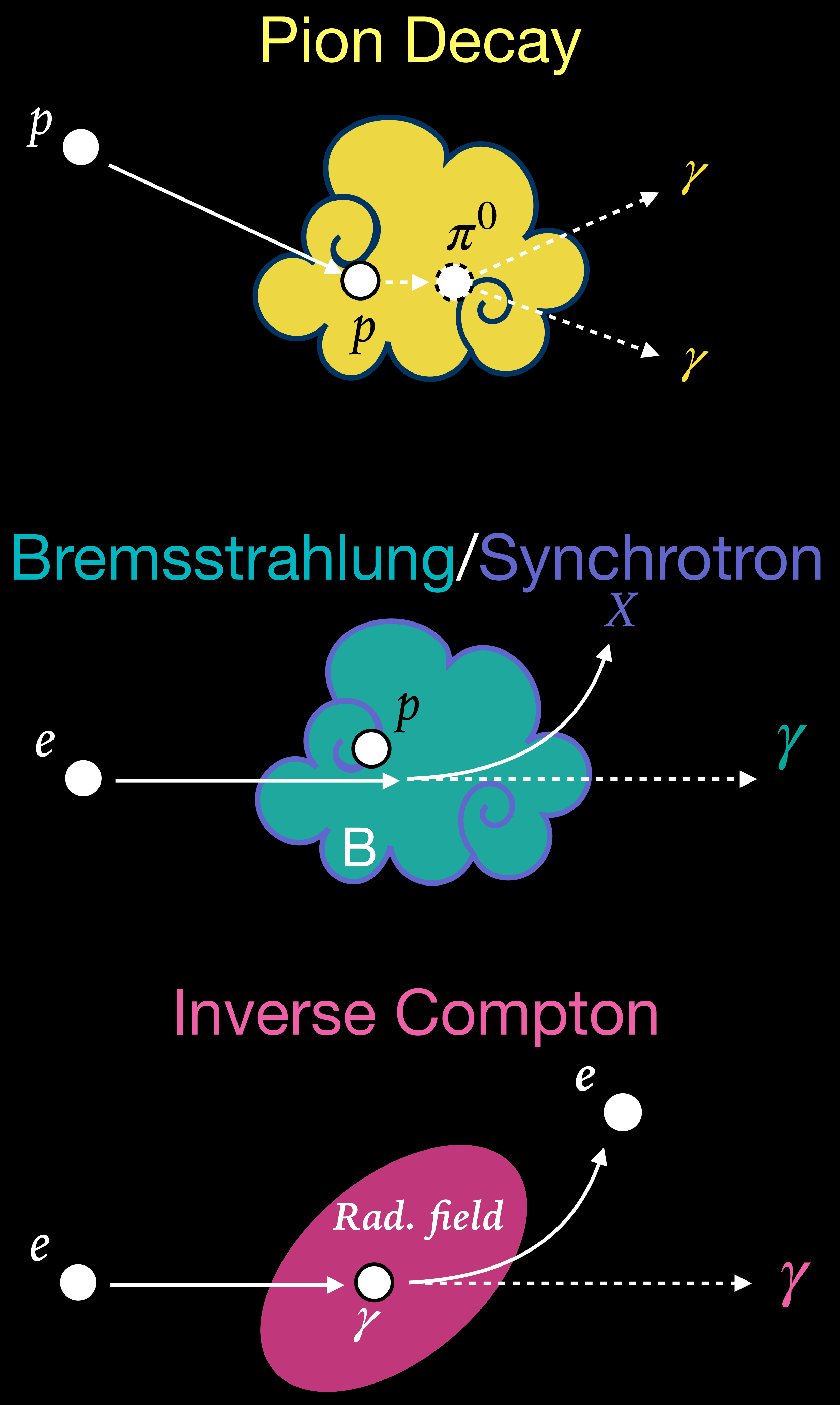
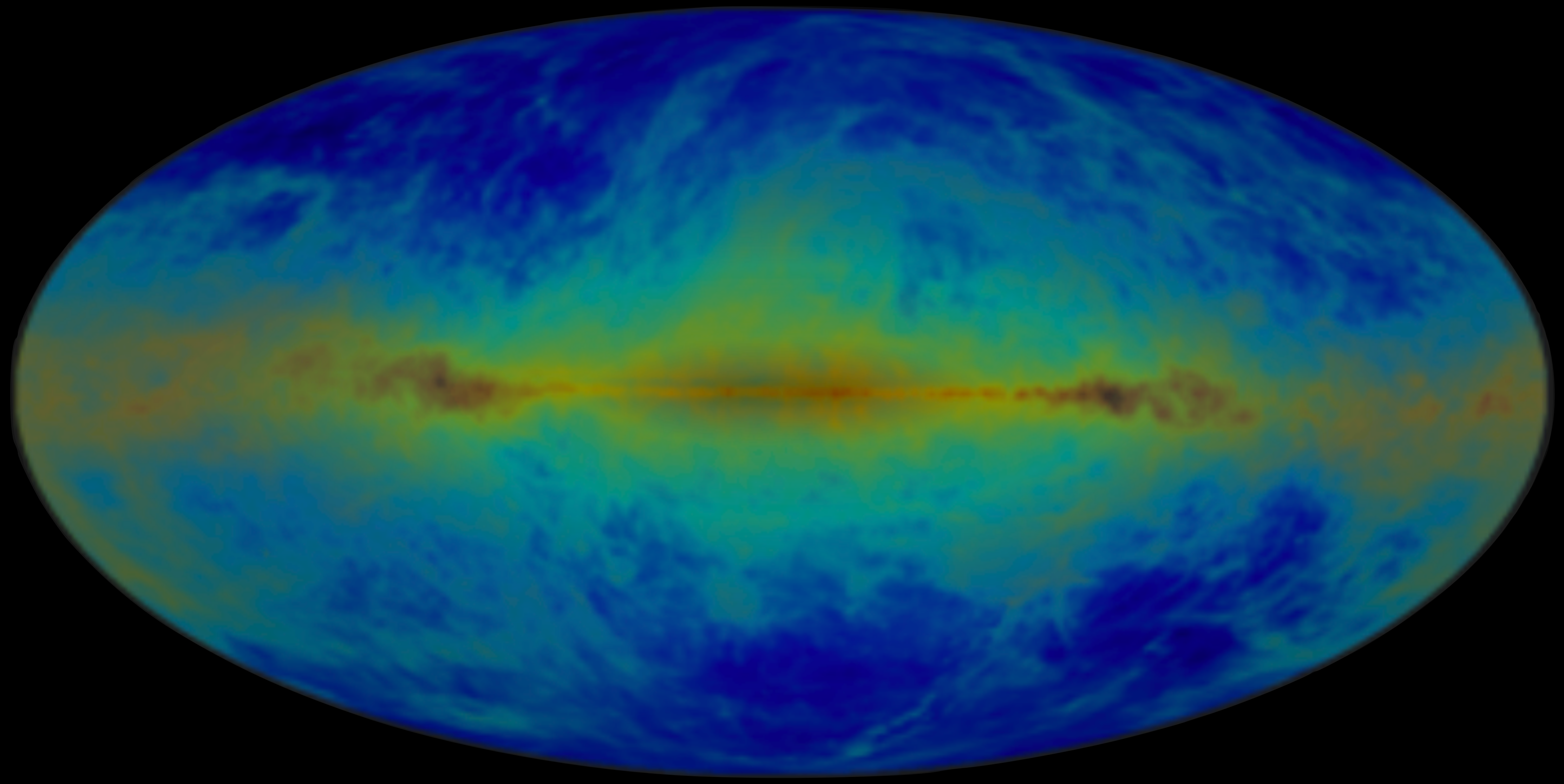
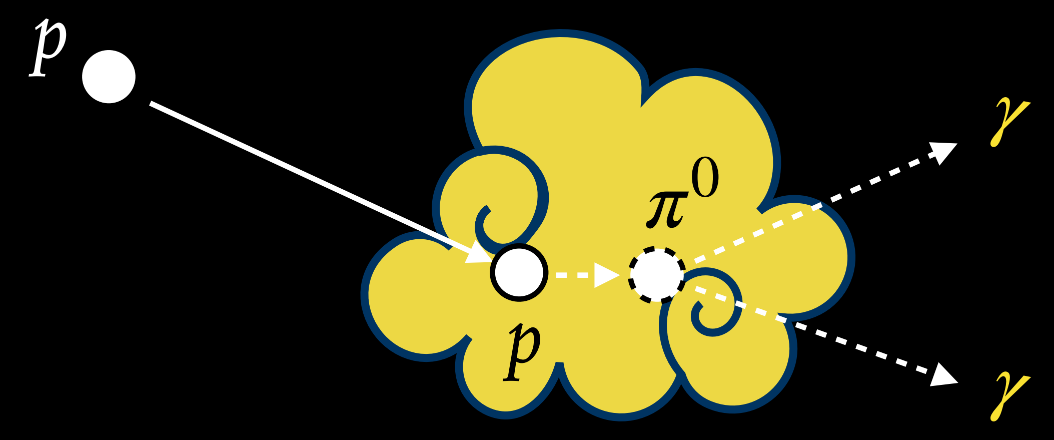


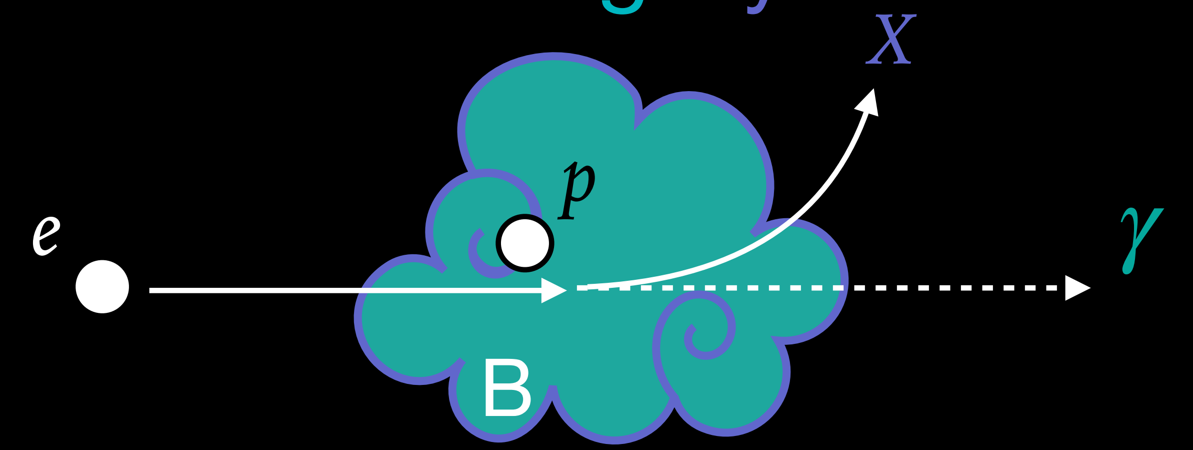


L’universo non termico

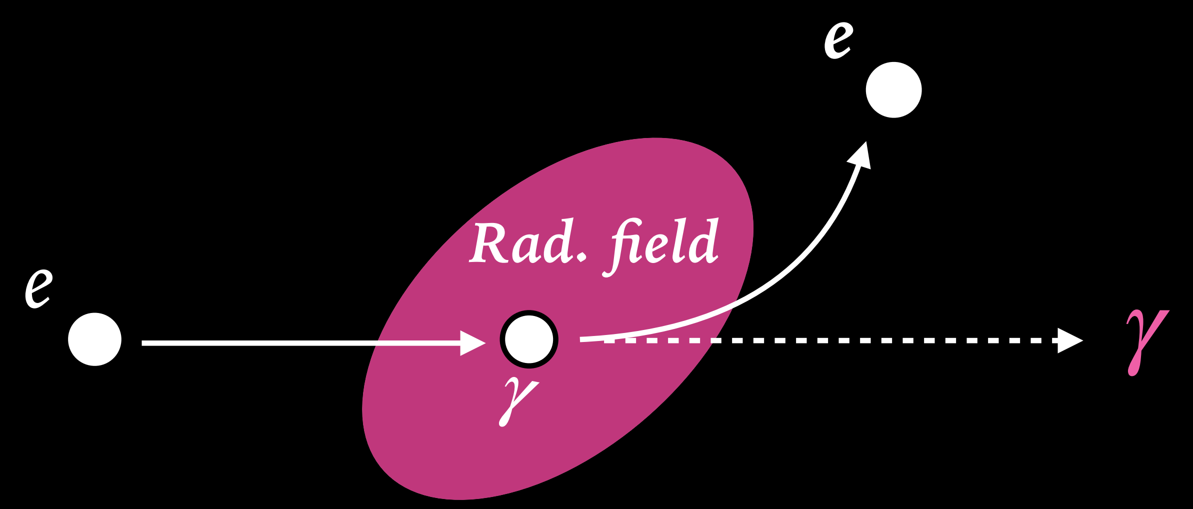
Pion Decay

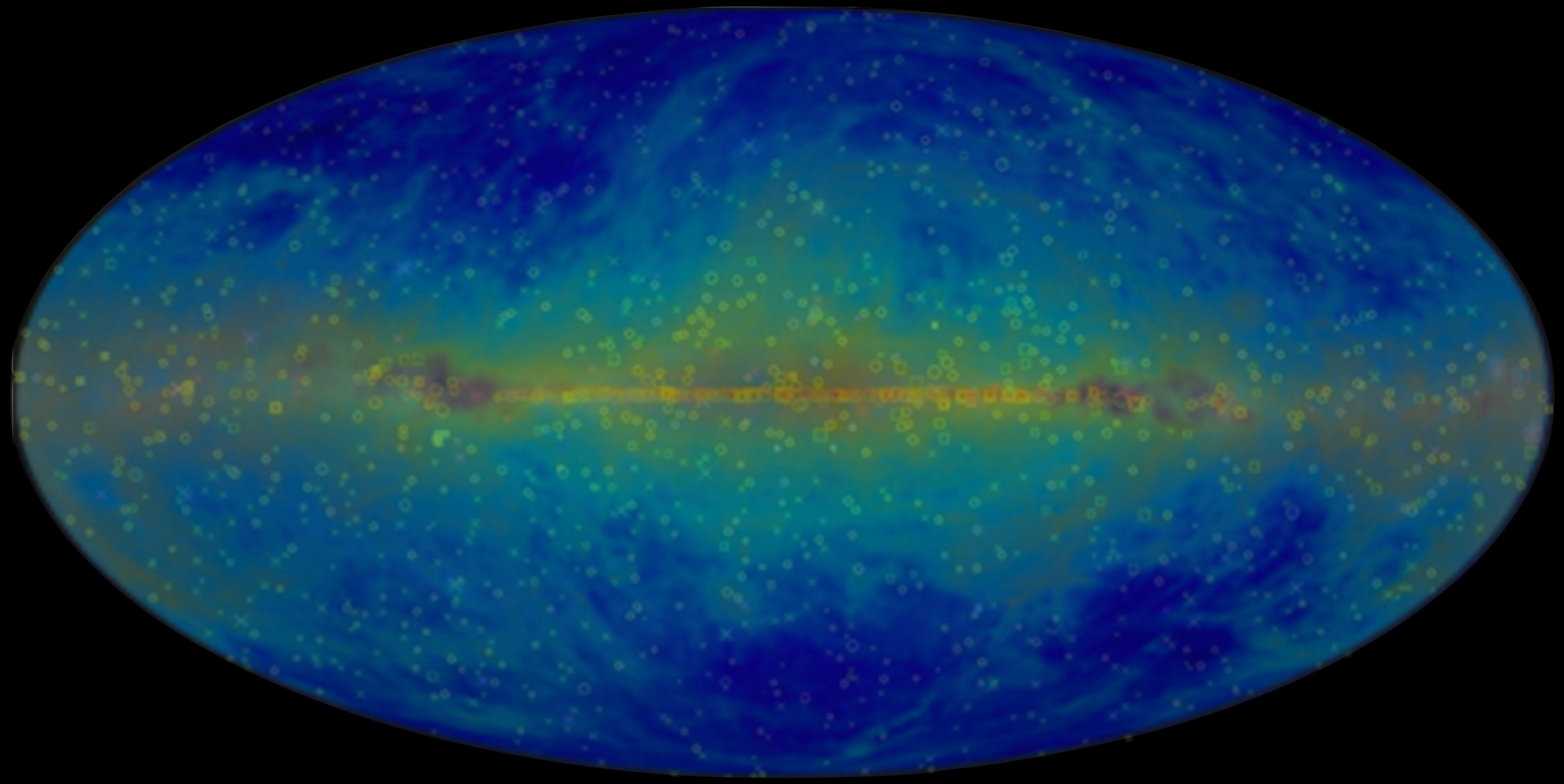


Bremsstrahlung/Synchrotron



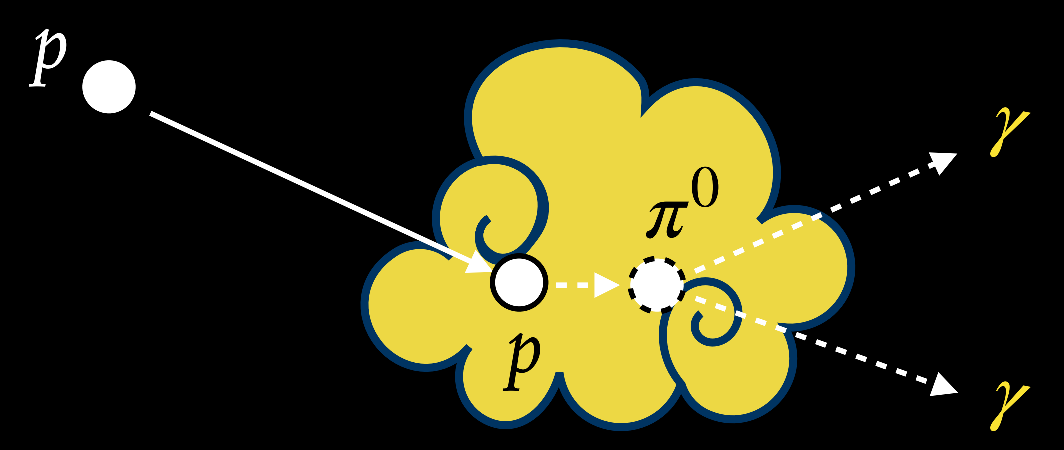
Inverse Compton



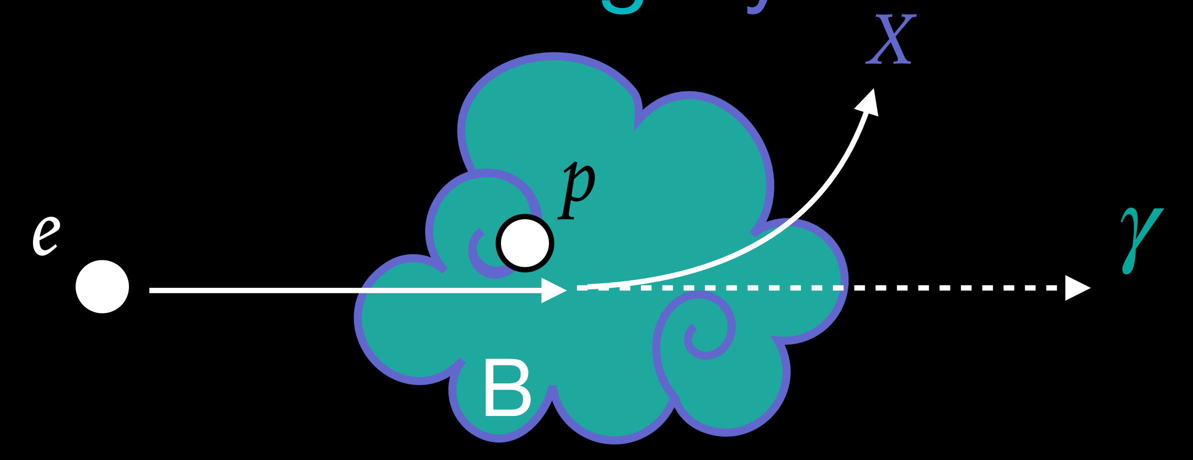


L’universo non termico

Pion Decay



Bremsstrahlung/Synchrotron



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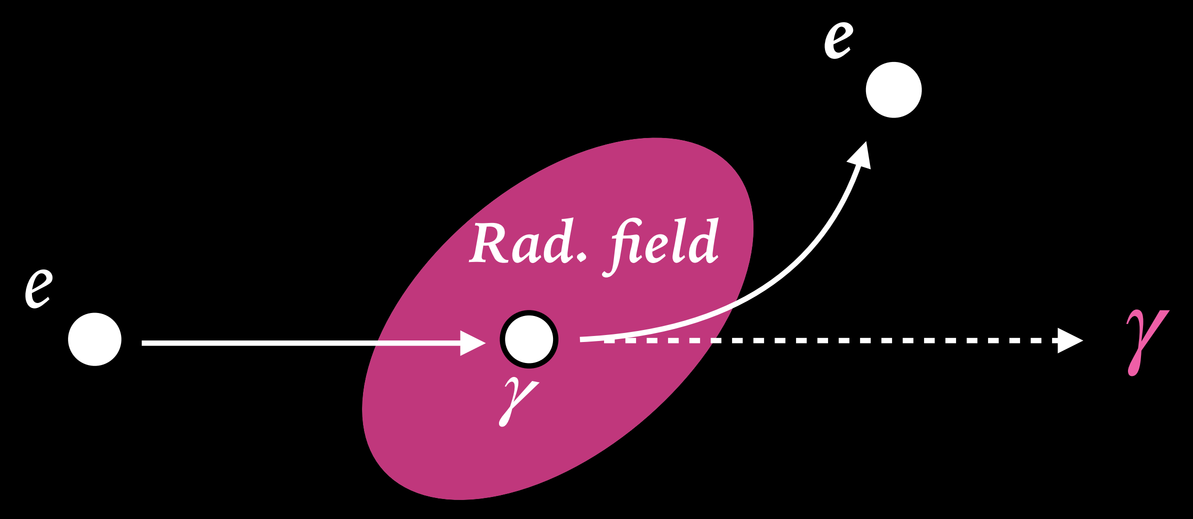
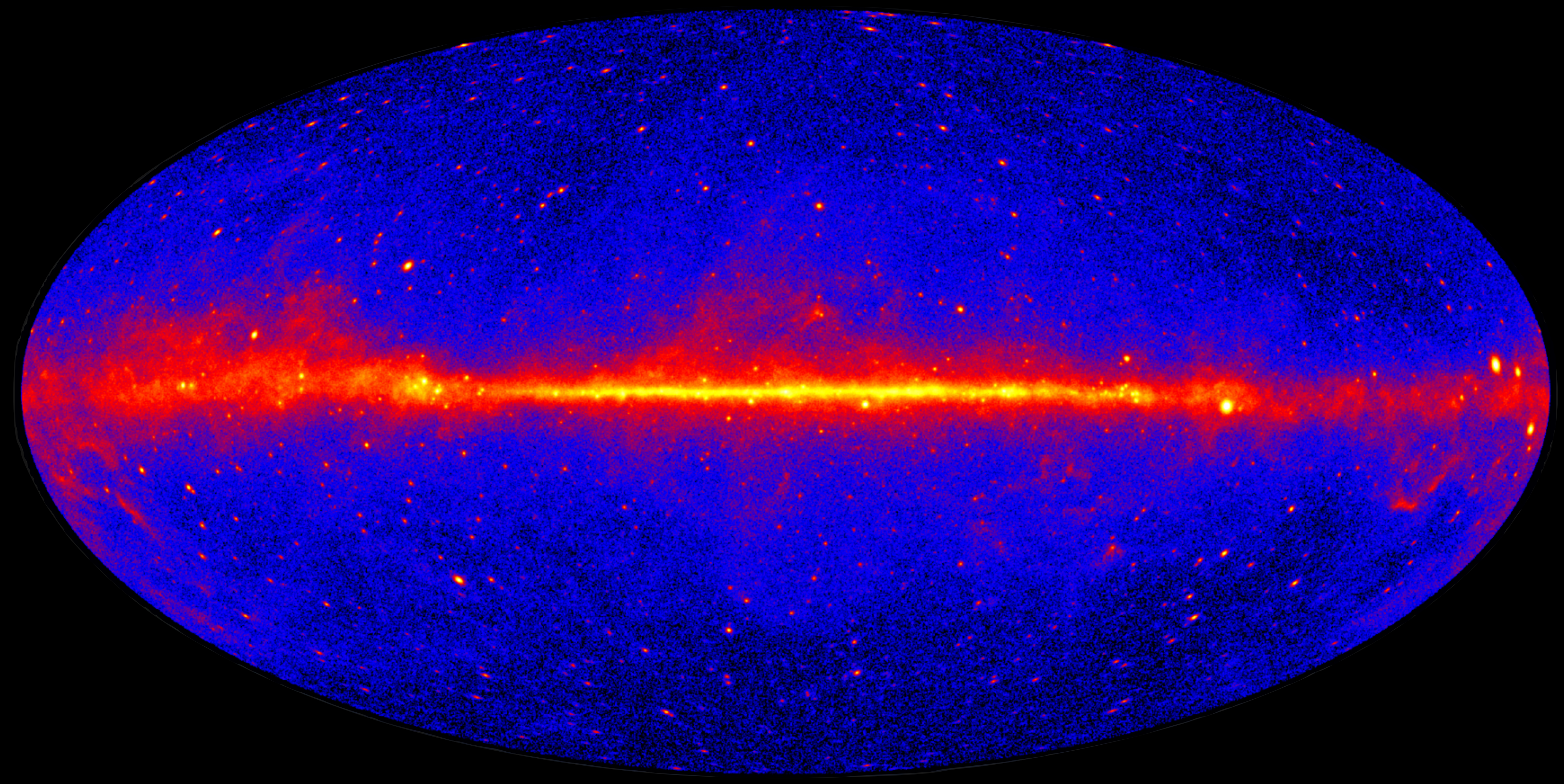
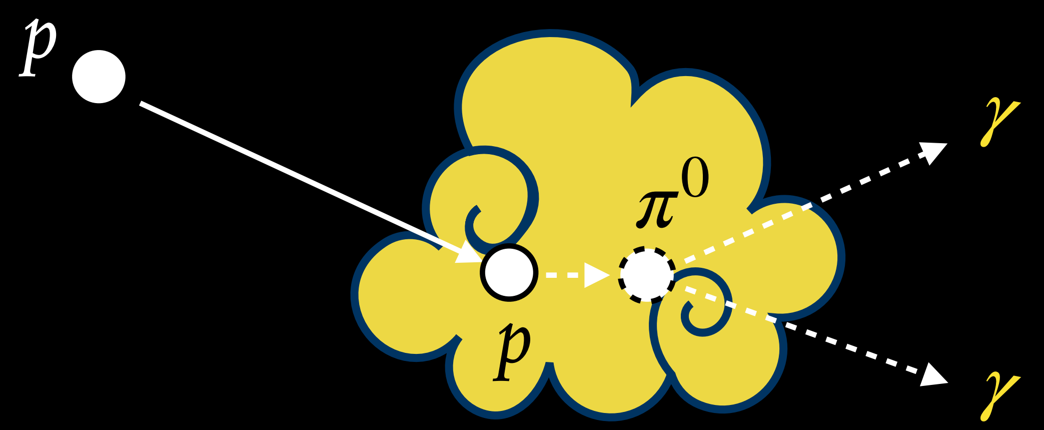


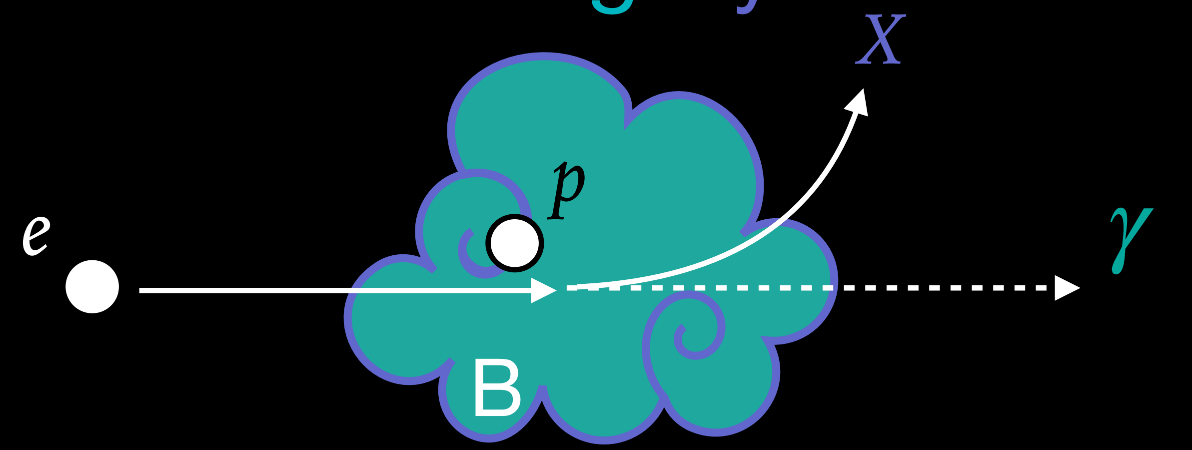


L'universo non termico

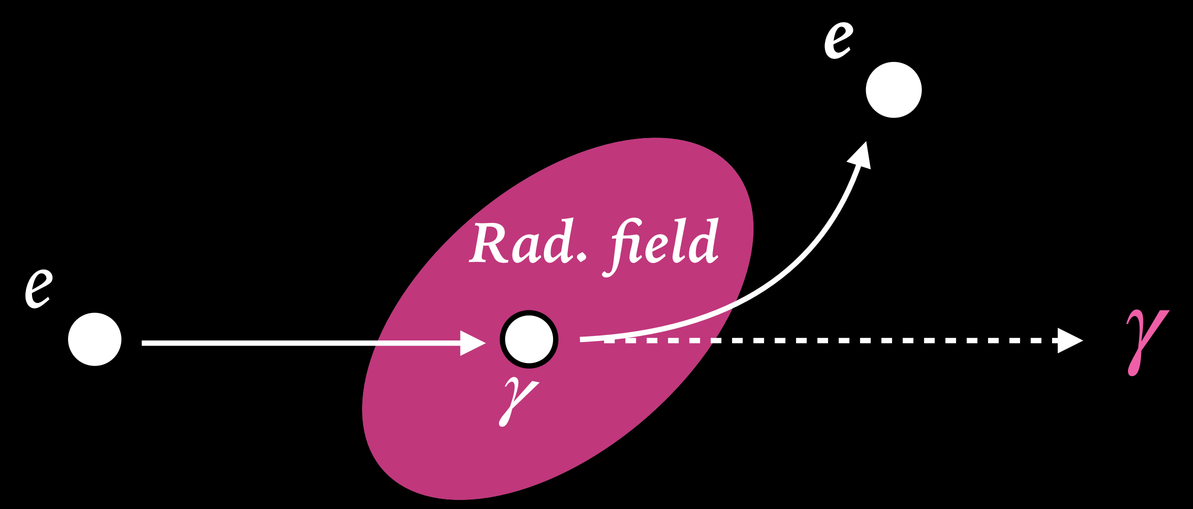
Pion Decay

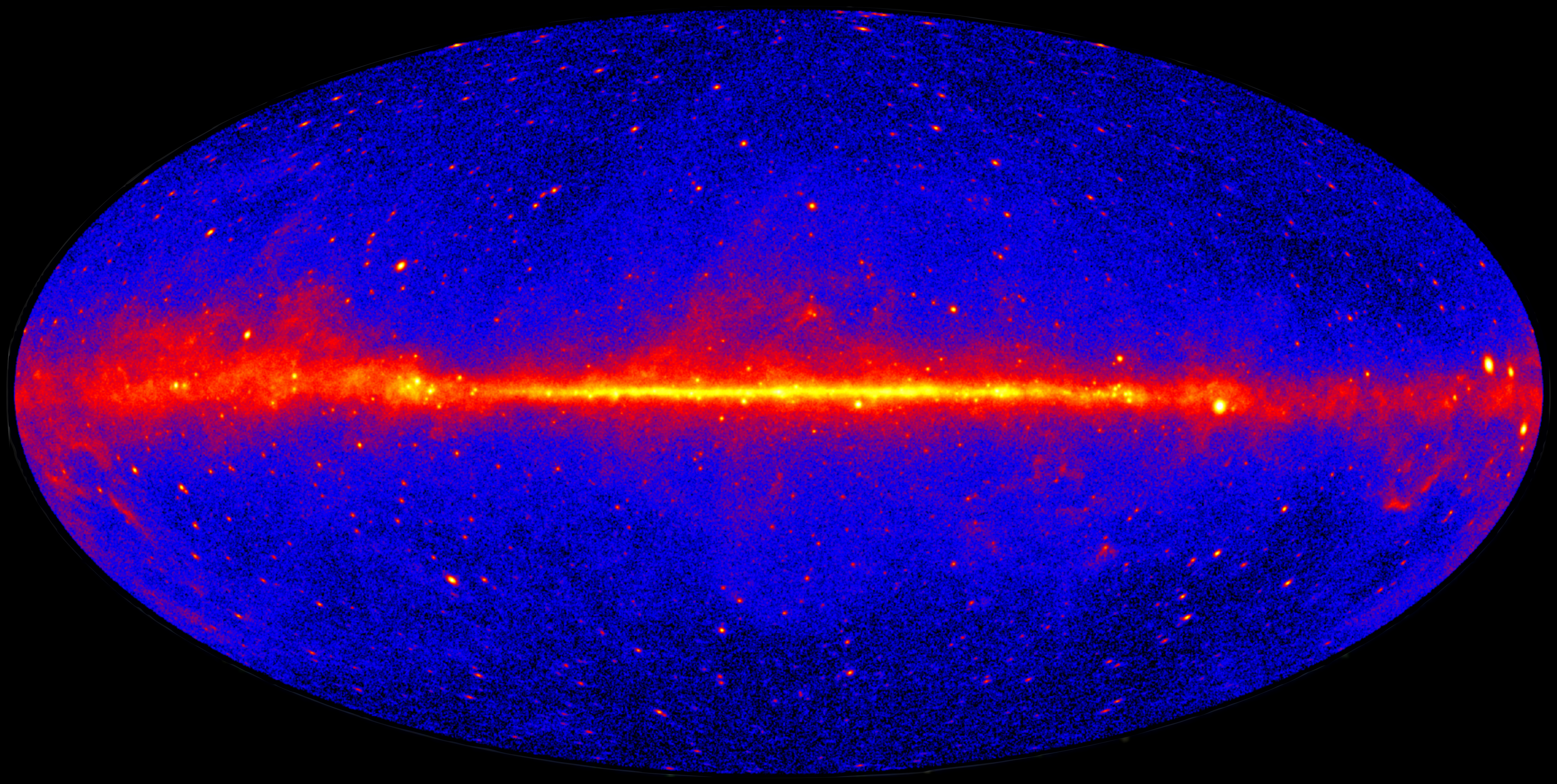


Bremsstrahlung/Synchrotron

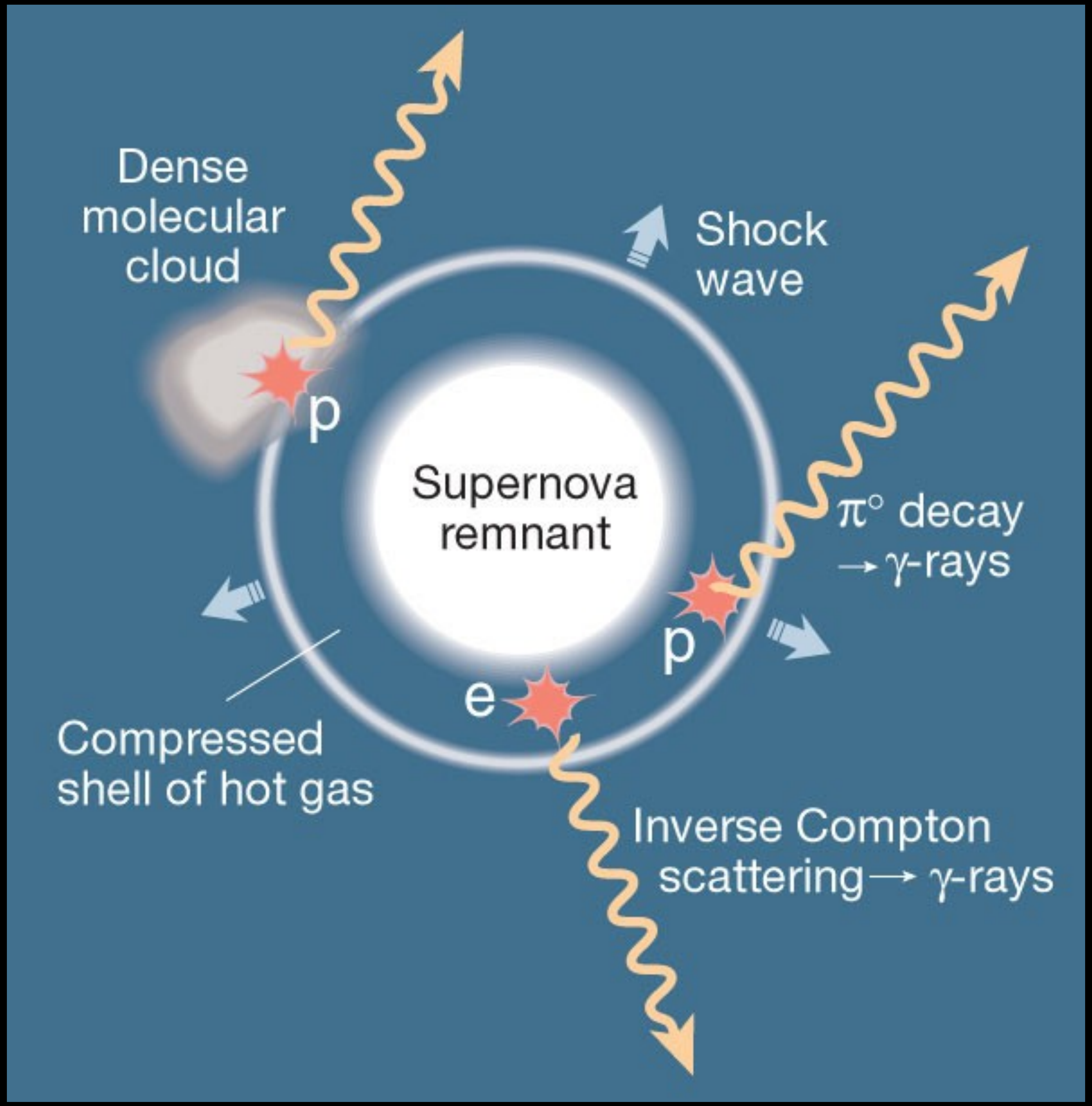


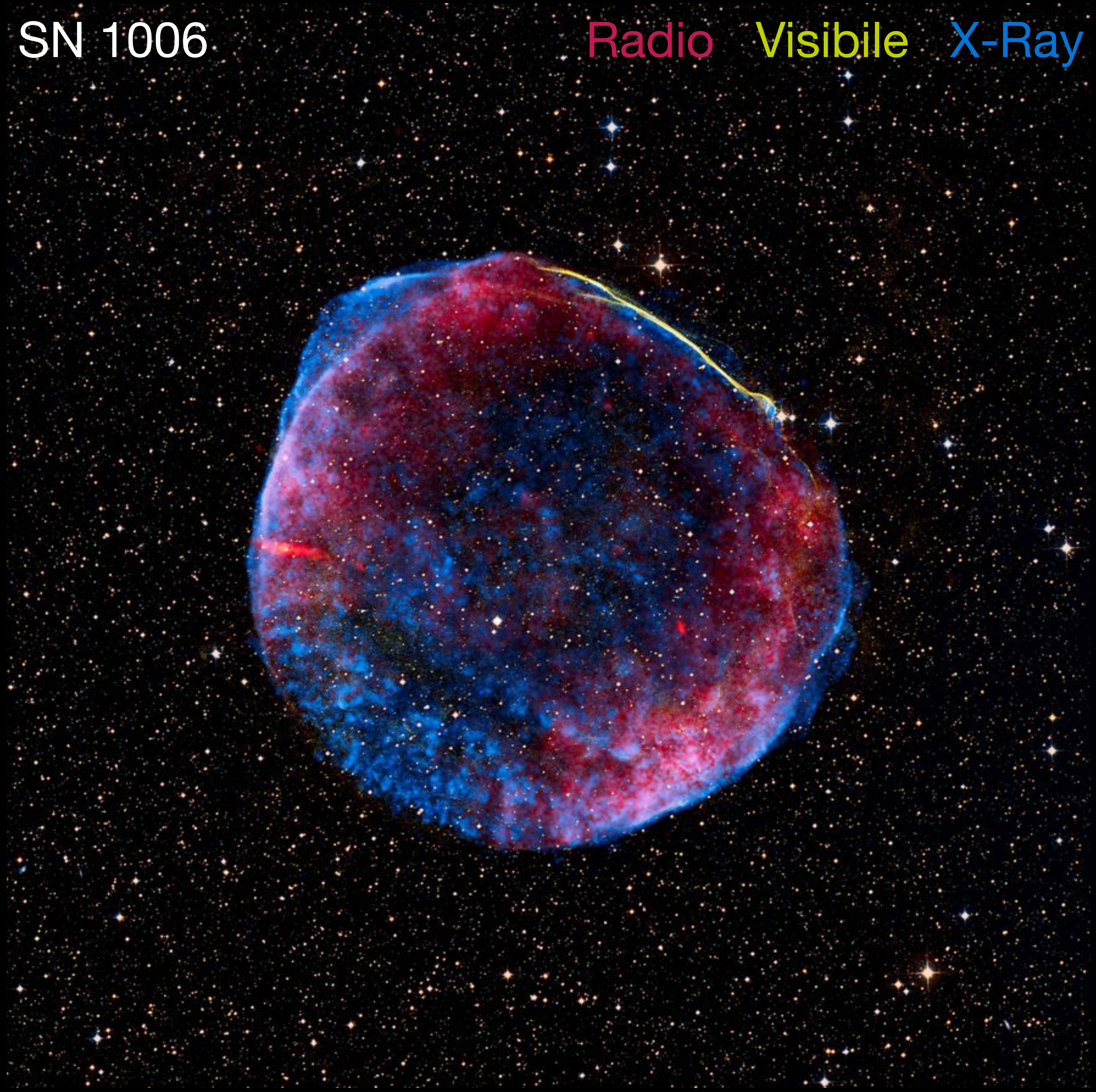
Inverse Compton



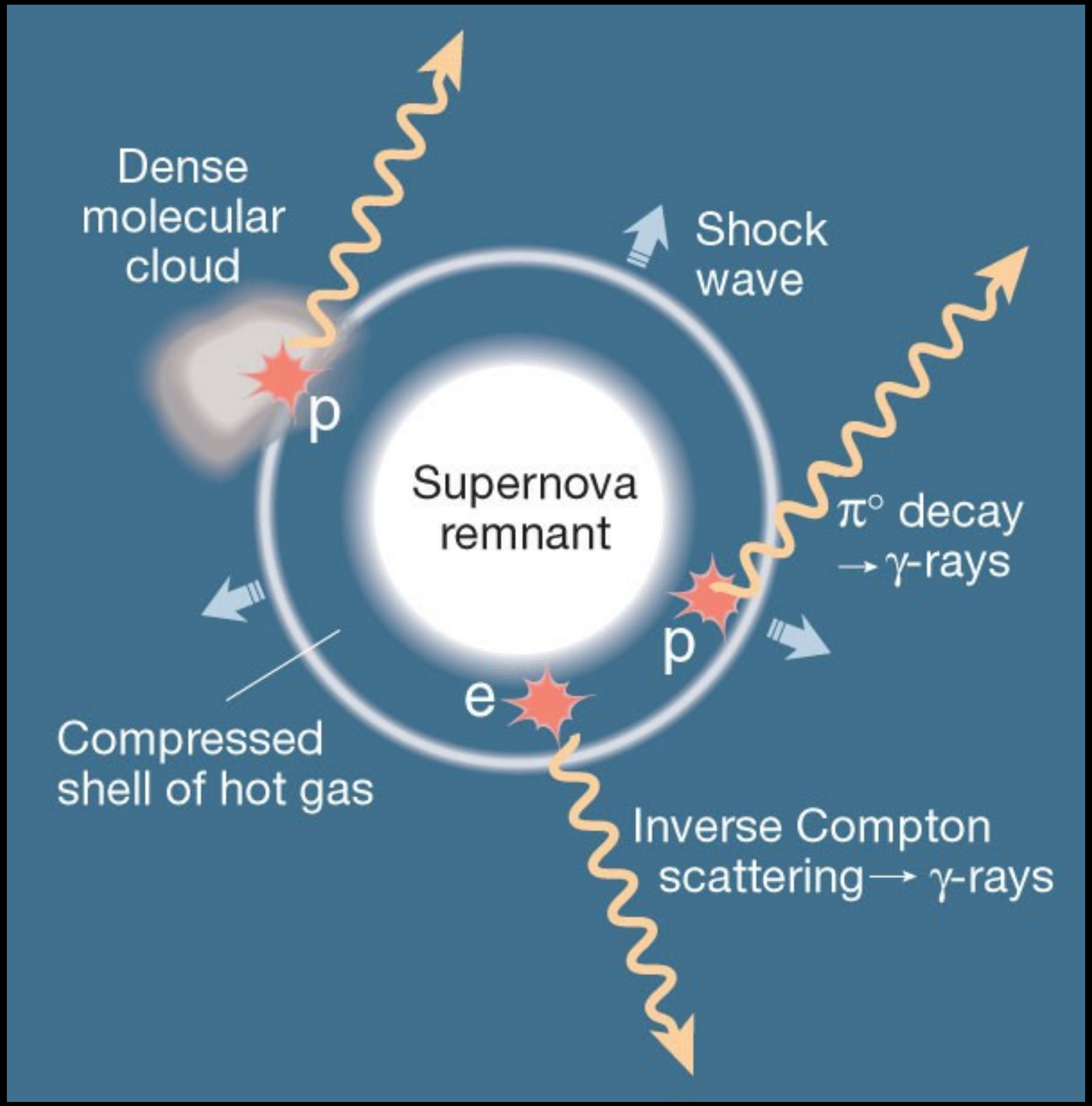


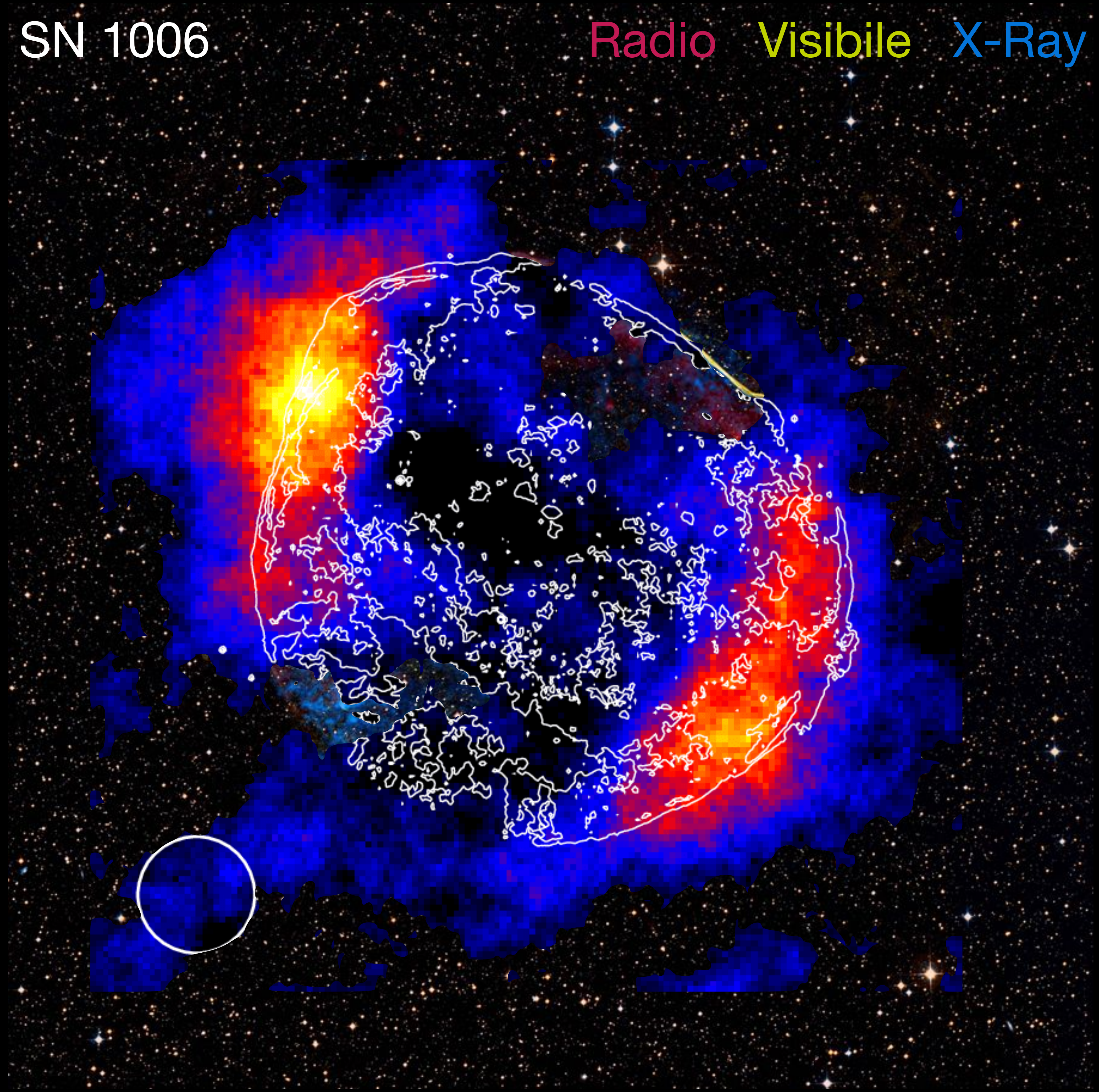
Acceleratori di particelle cosmici



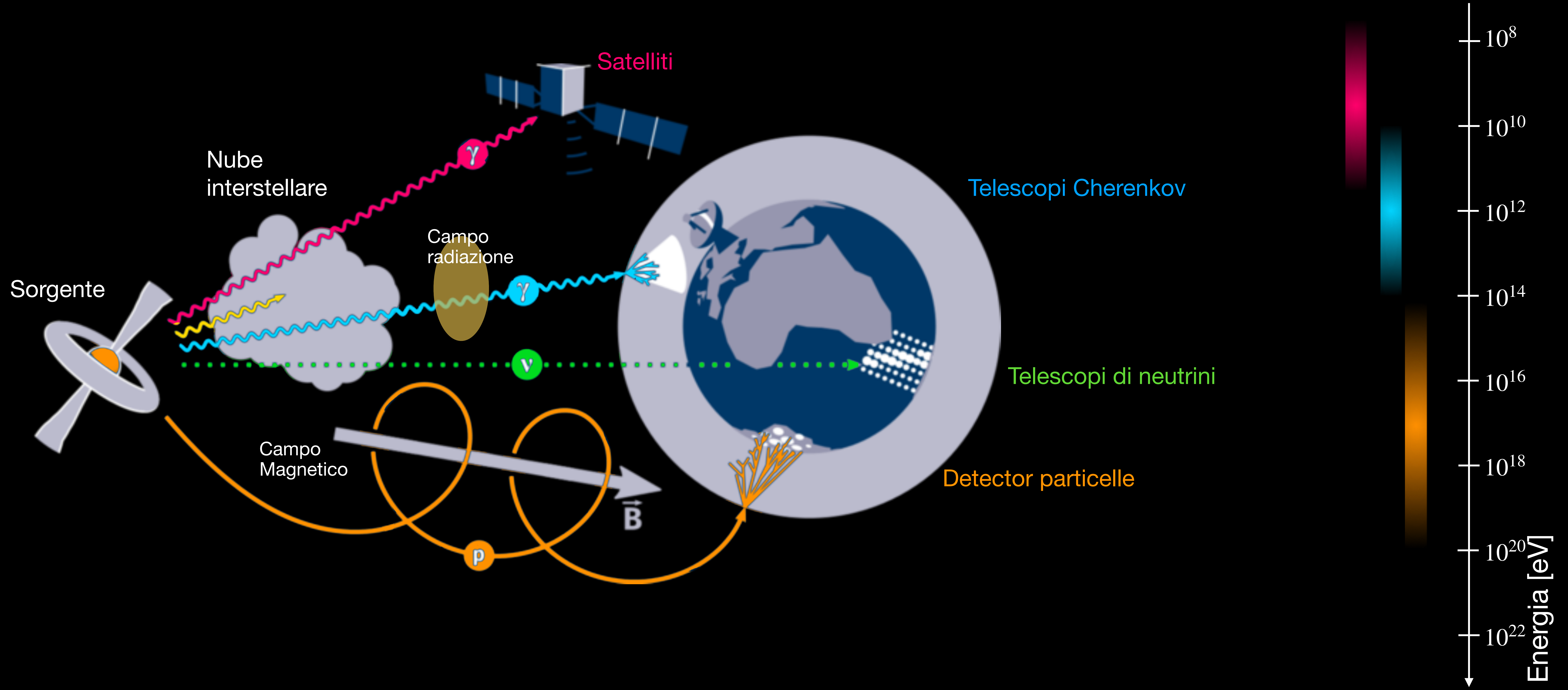


Acceleratori di particelle cosmici





Gamma ray detector



Al TeV

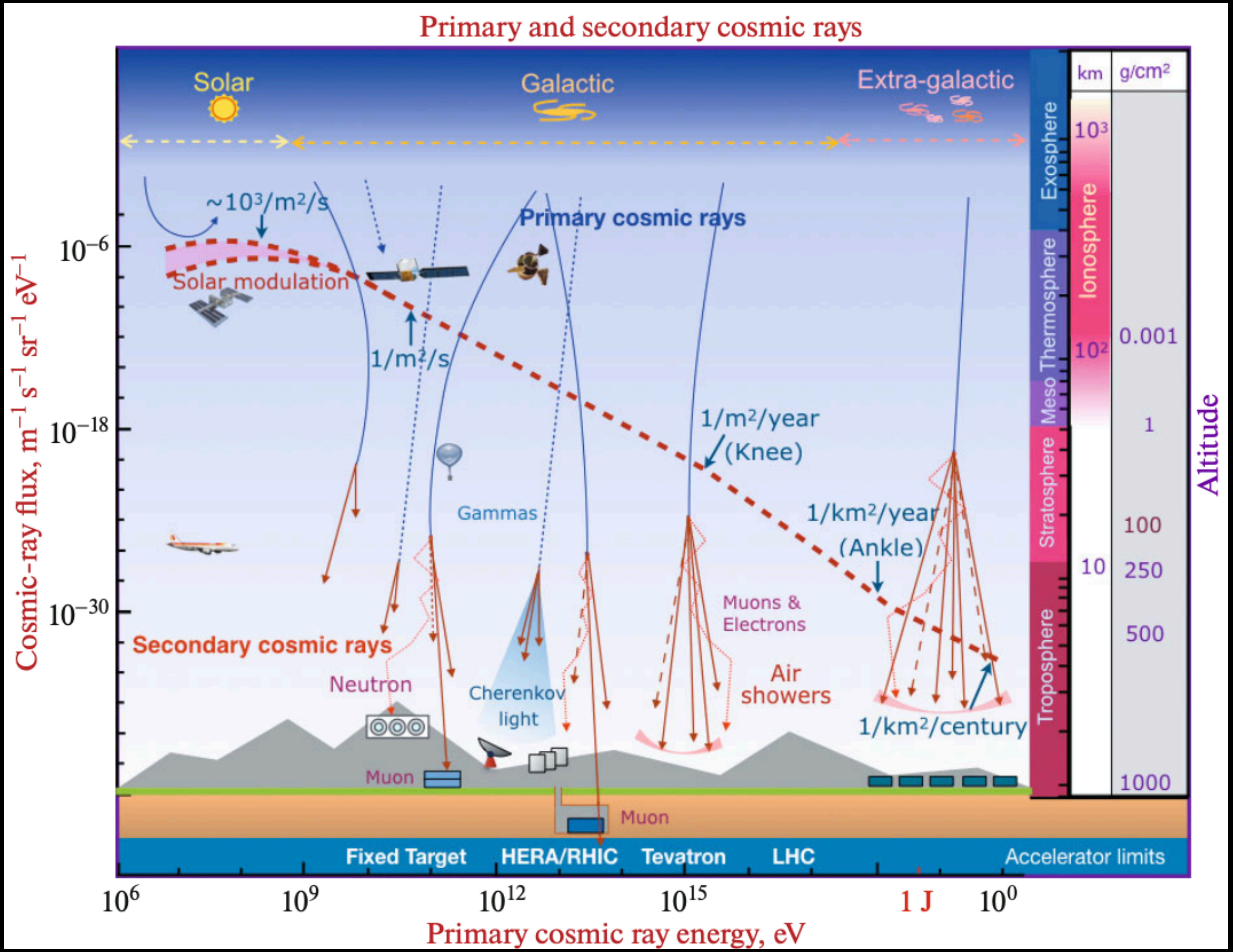
Una delle sorgenti più brillanti nel cielo gamma è la Crab Nebula.

$$F_{Crab}(@1GeV) = 2 \cdot 10^{-7}\ ph/cm^2/s$$

Con Fermi-LAT misuriamo 2 fotoni ogni 15 min

$$F_{Crab}(@1TeV) = 6 \cdot 10^{-11}\ ph/cm^2/s$$

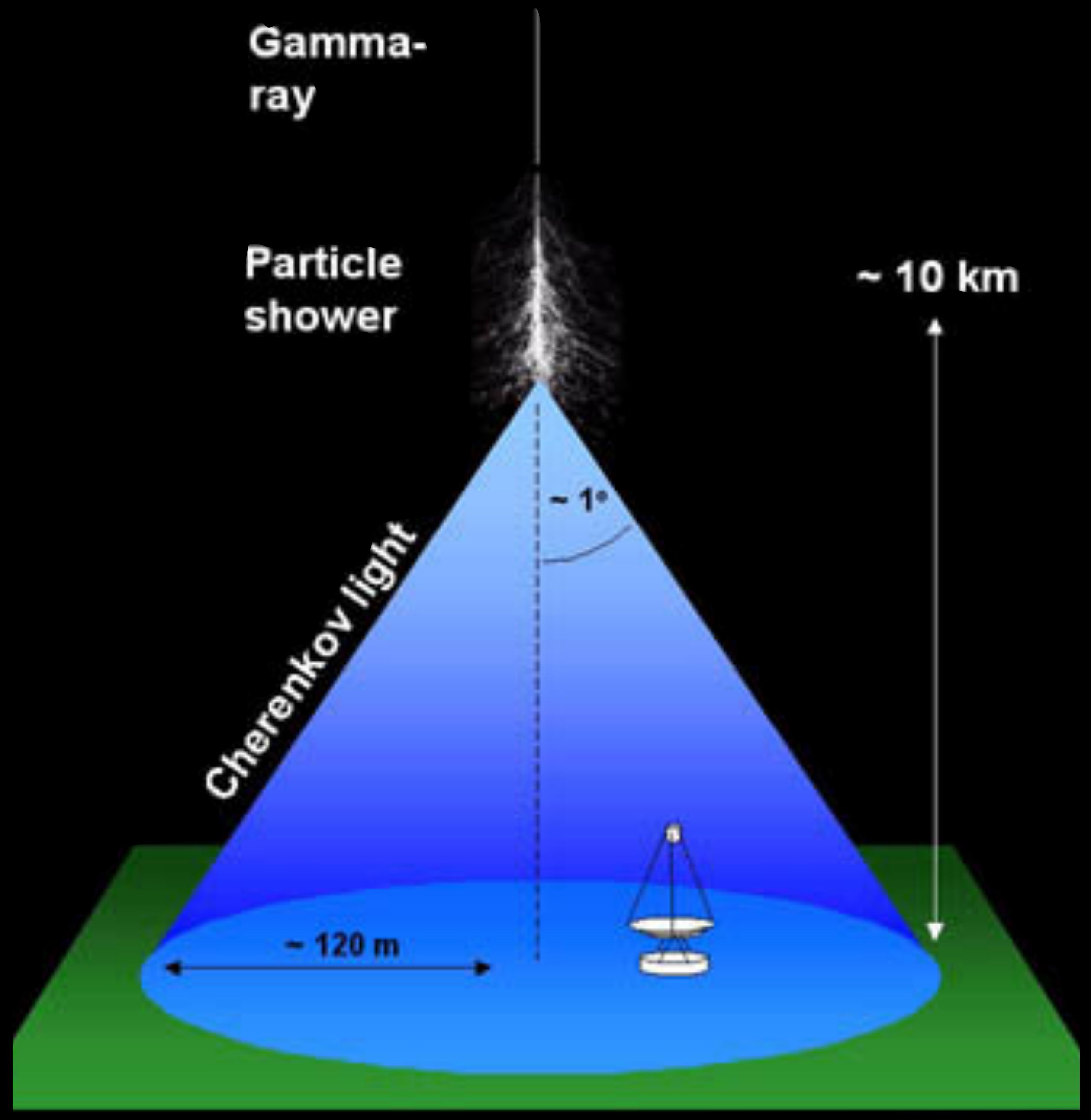
Cioè un fotone al mese!

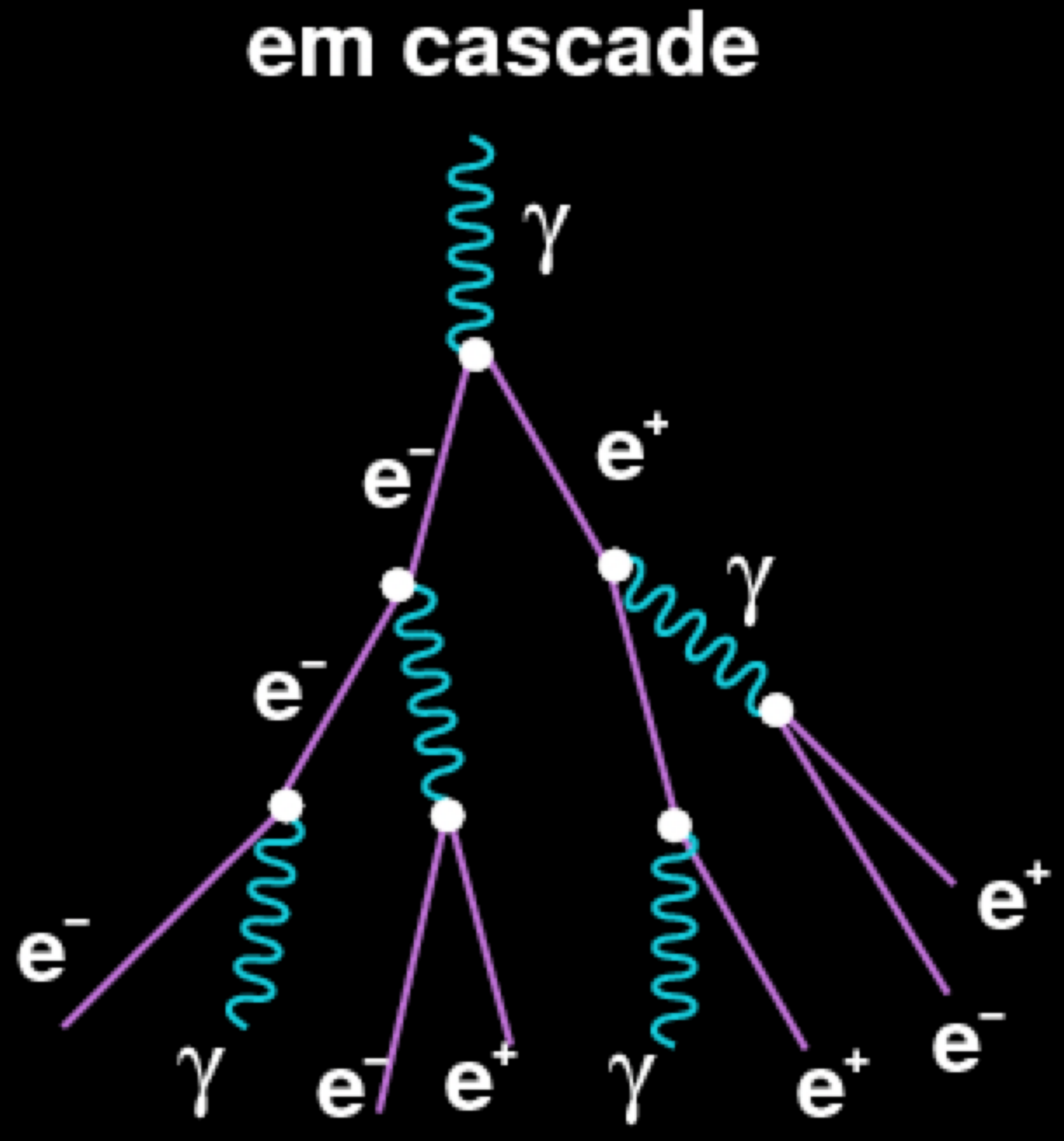


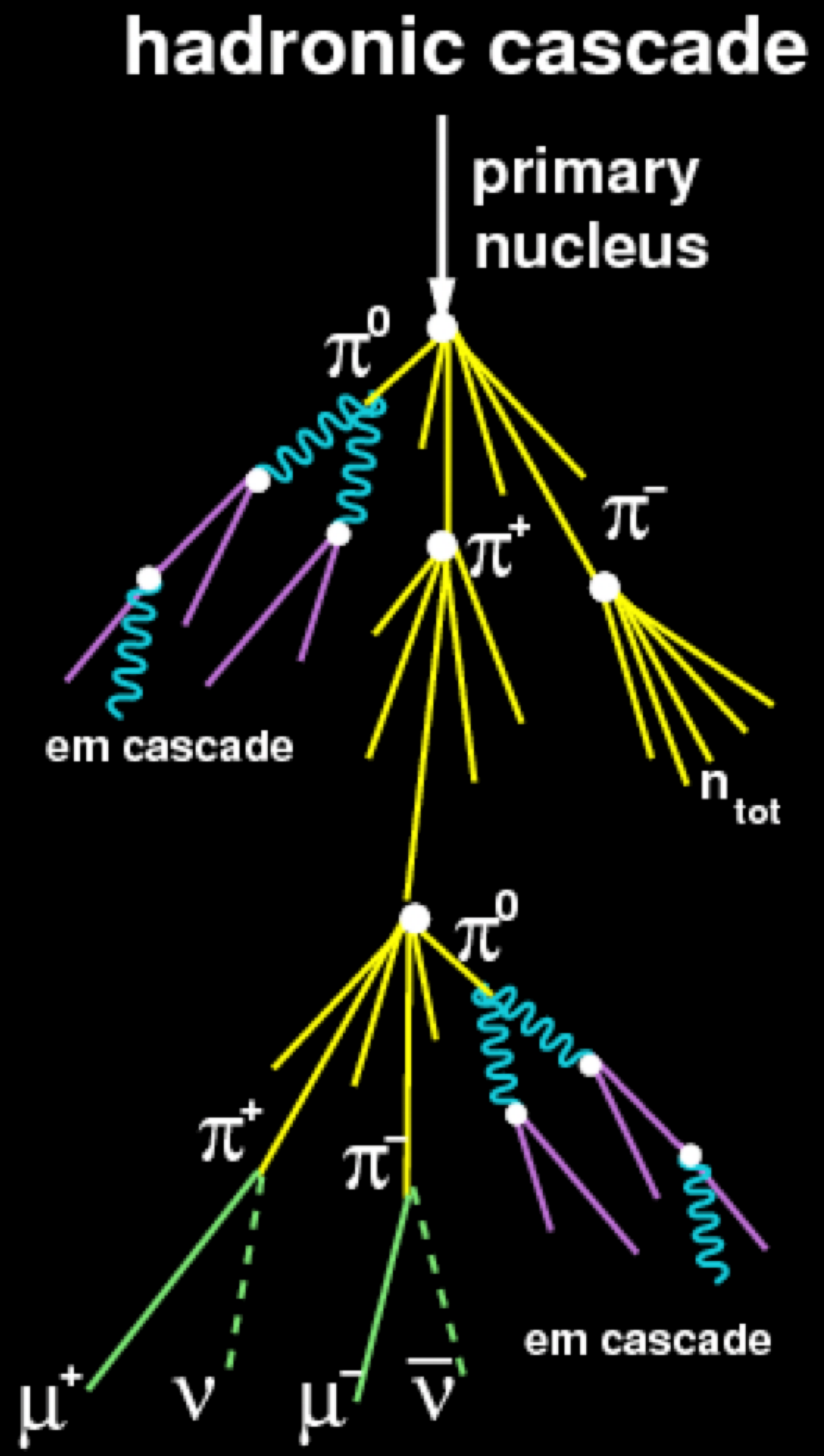
L’atmosfera come detector

Caratteristiche della luce Cherenkov:

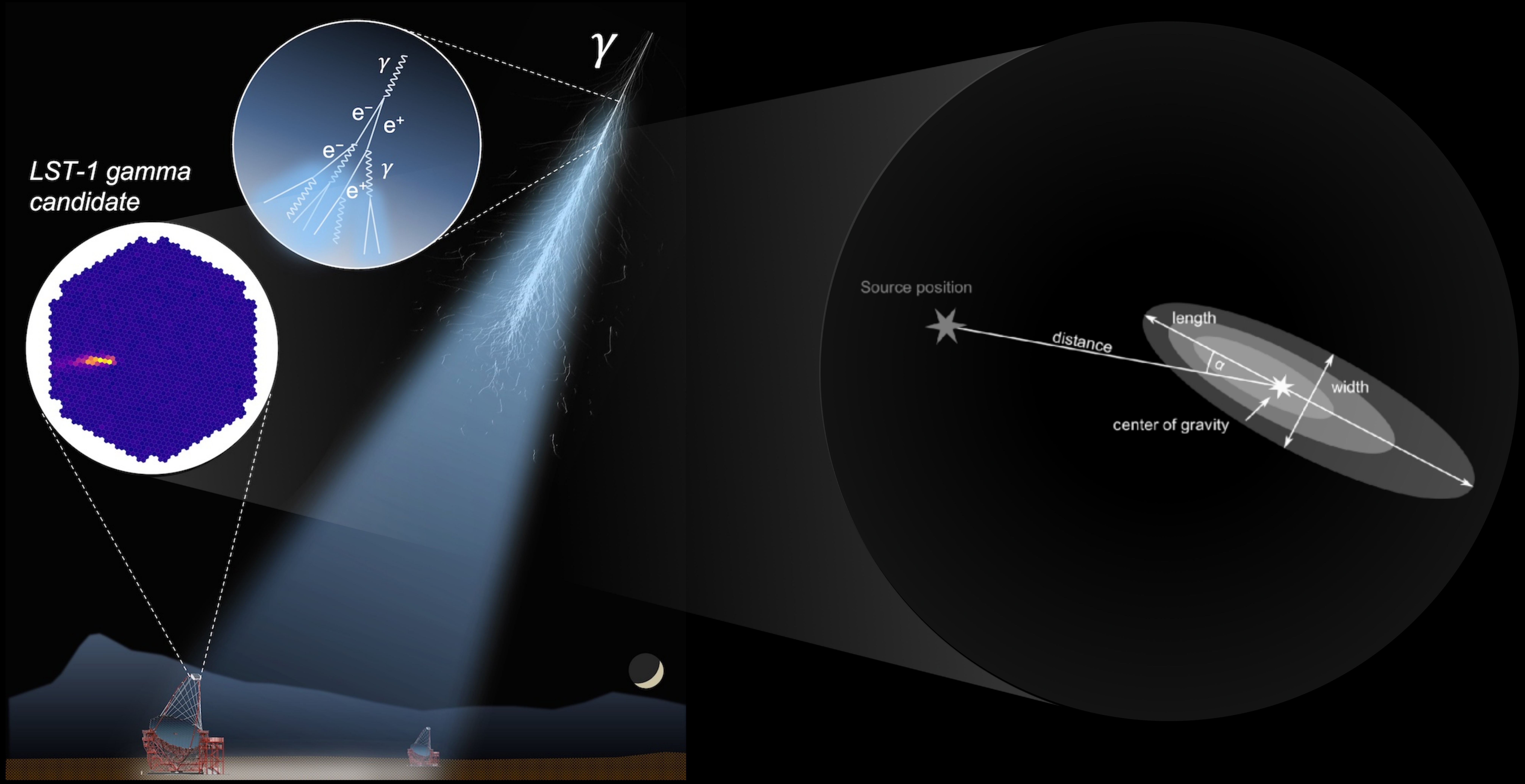
- Debole (~10 ph/m^2),
- Breve (~ns),
- Blue (300-550nm)



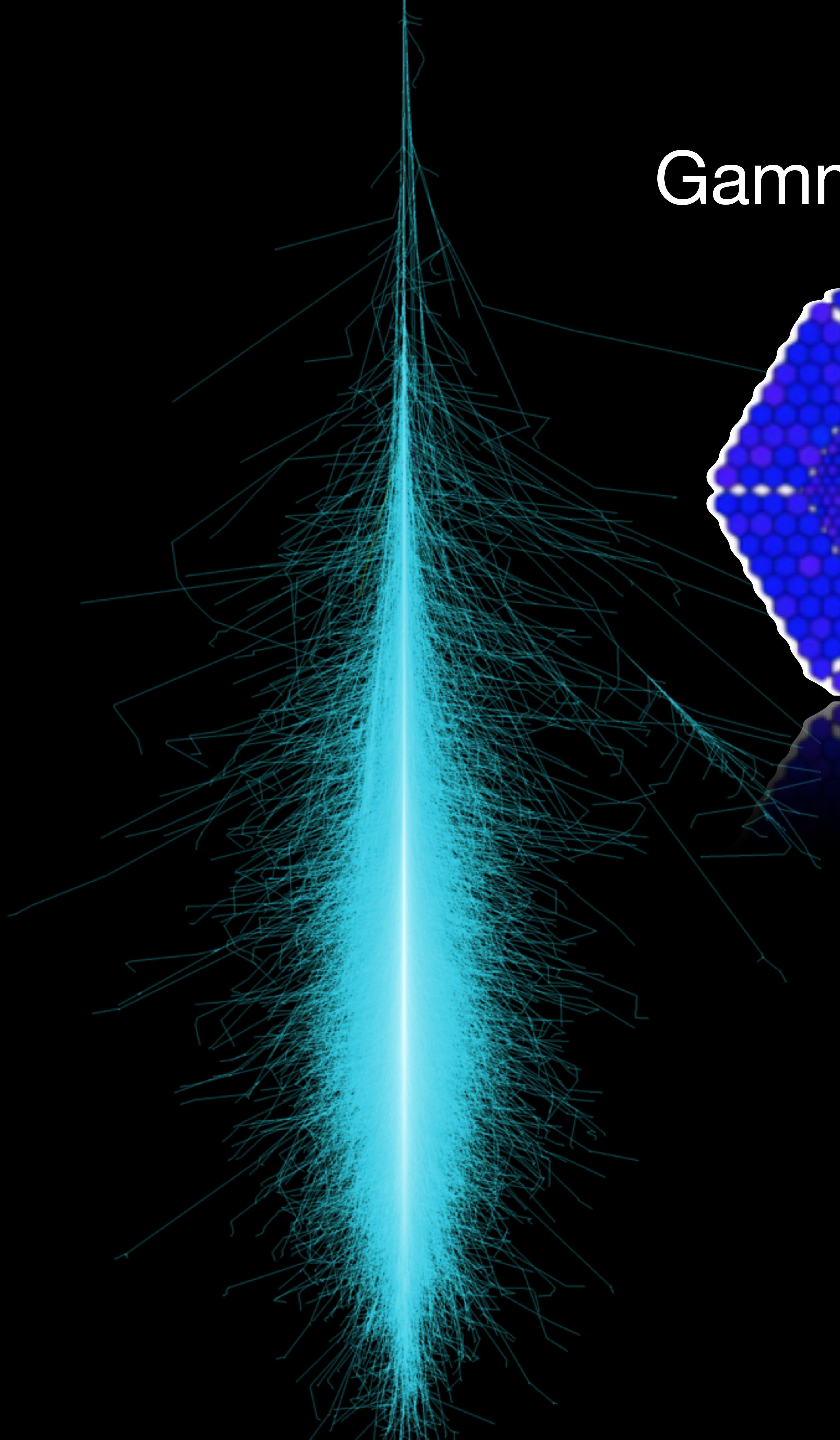




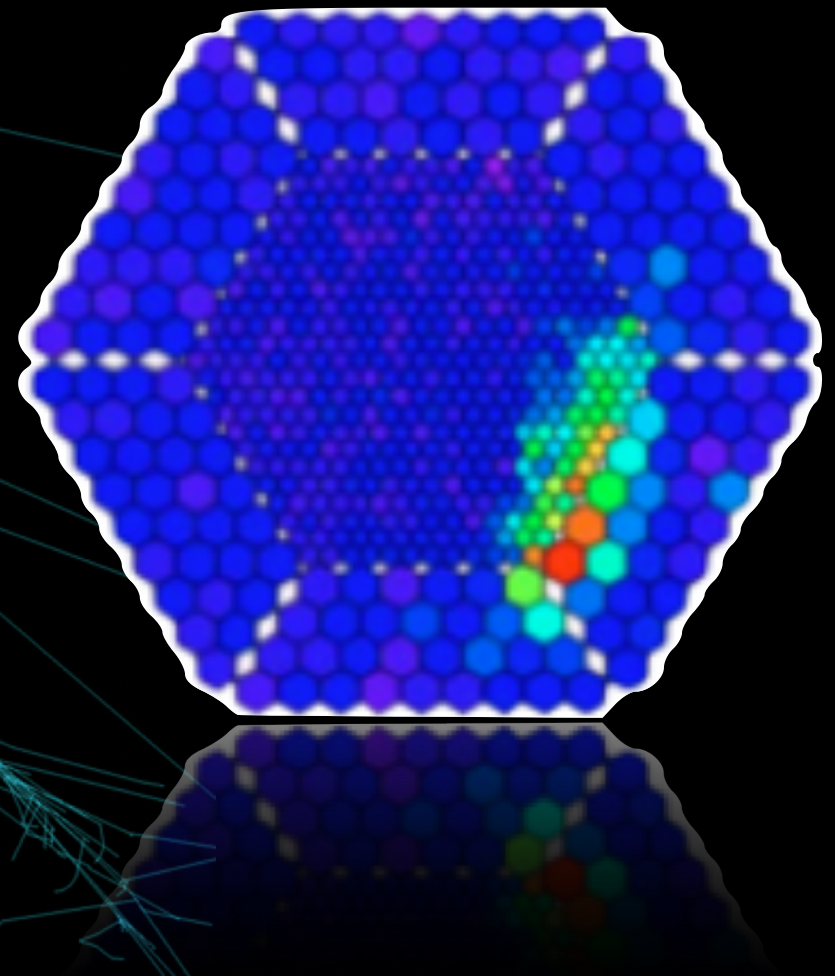
L’atmosfera come detector



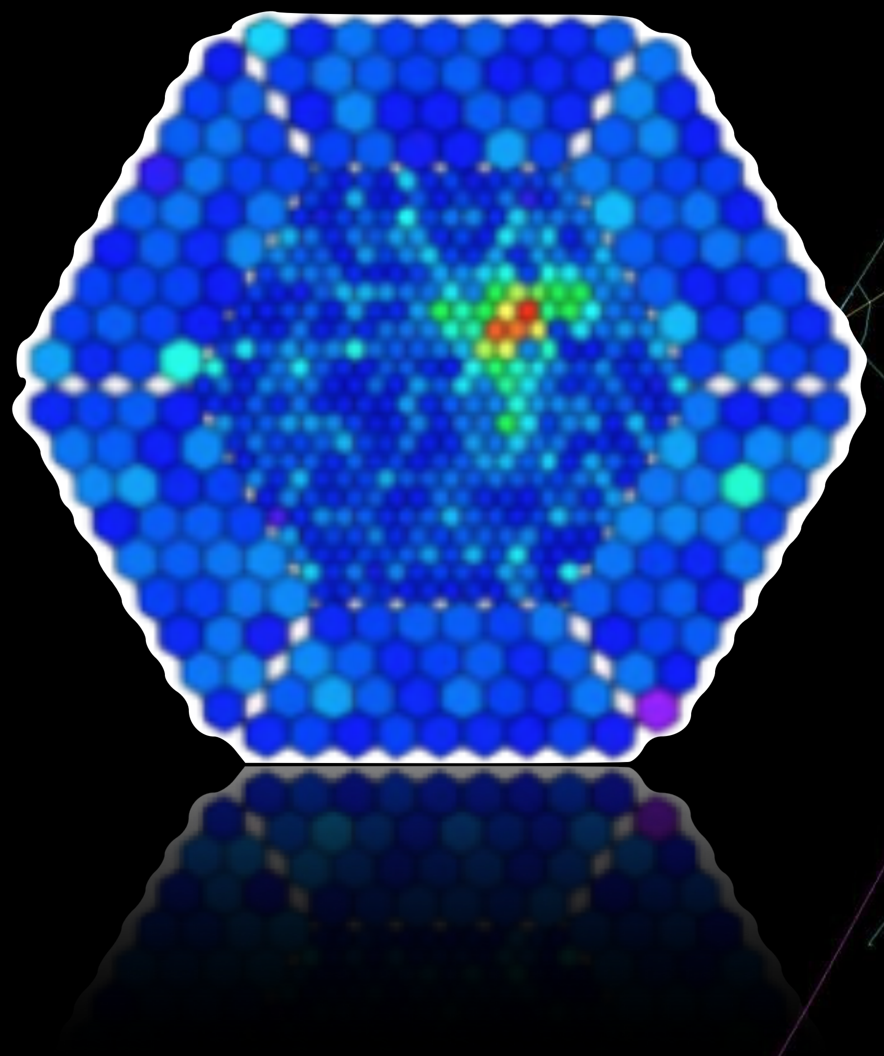
Gamma o protoni?

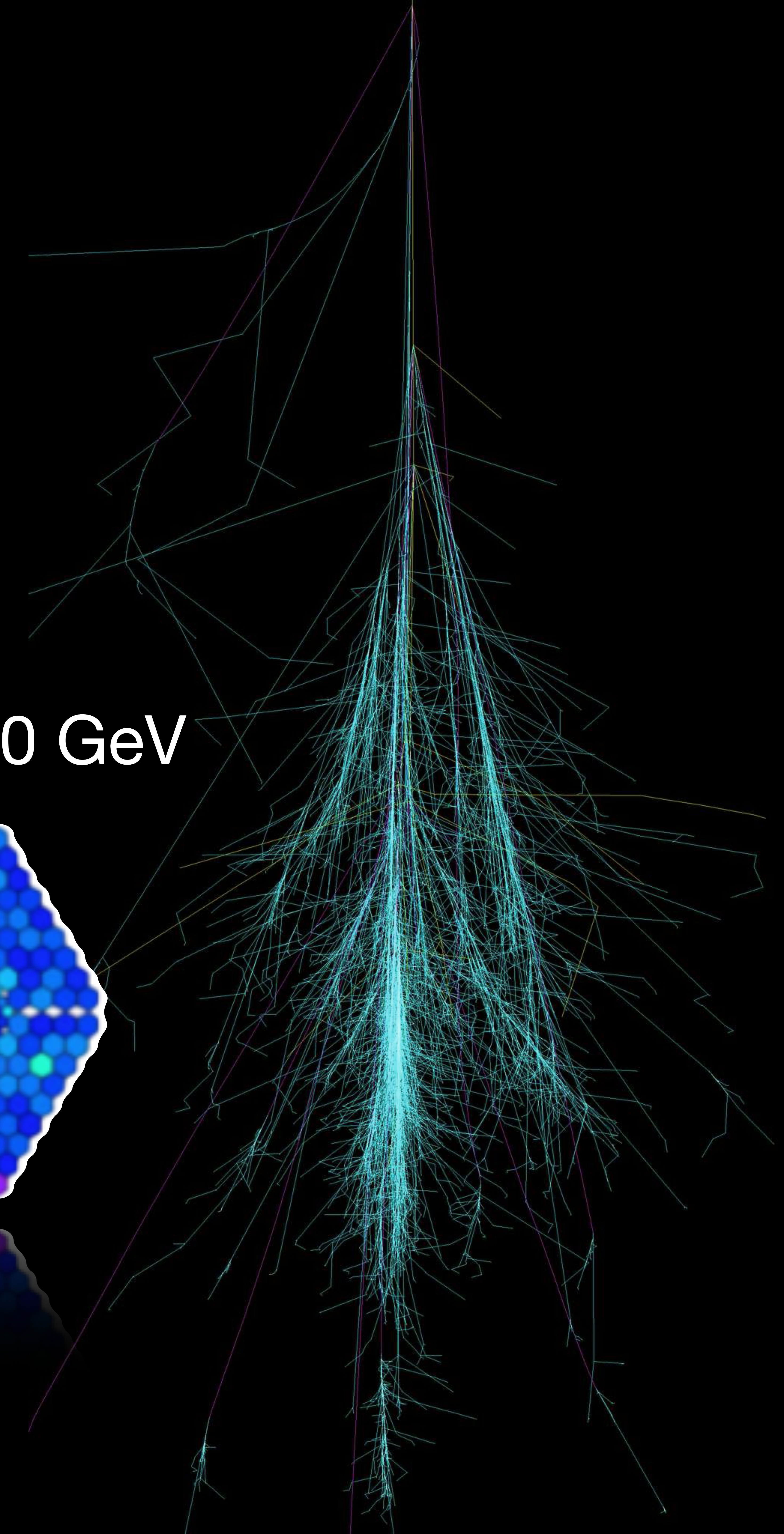


Gamma 100 GeV

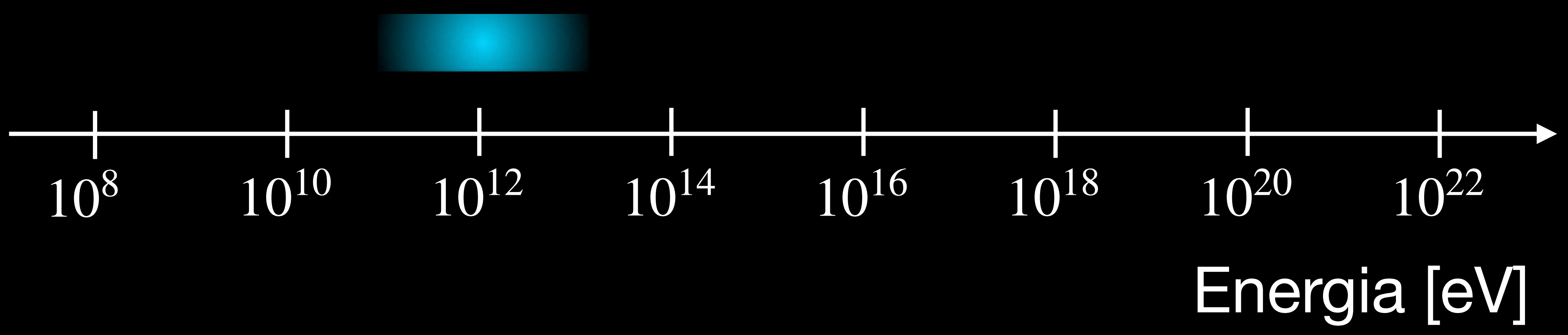


Protone 100 GeV





Attuali telescopi Cherenkov



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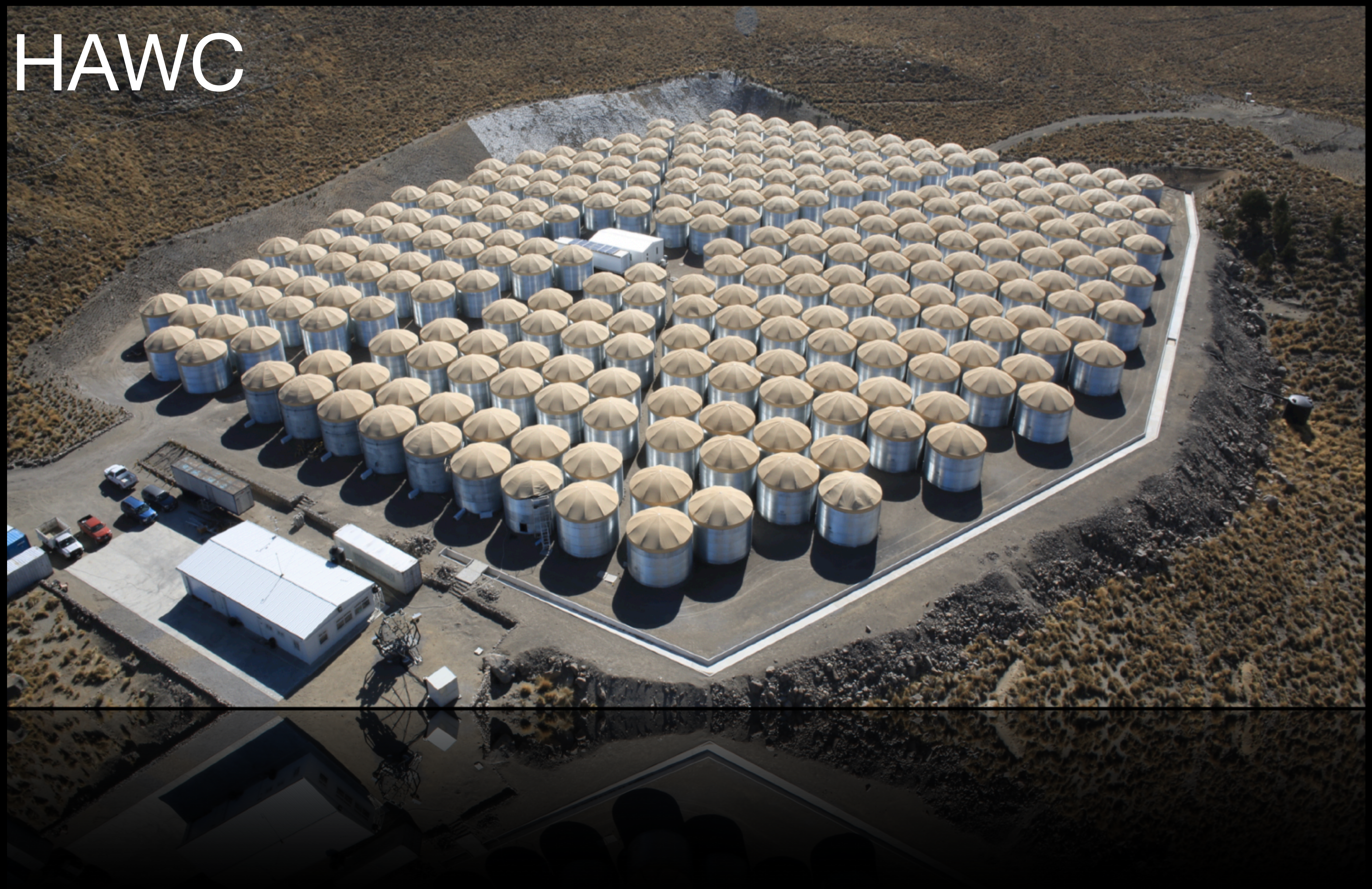
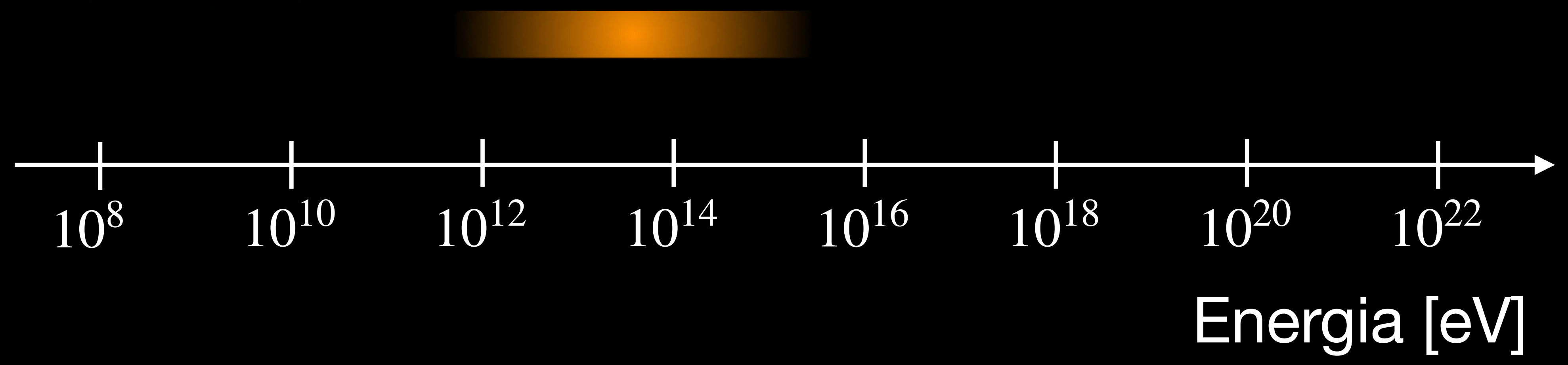
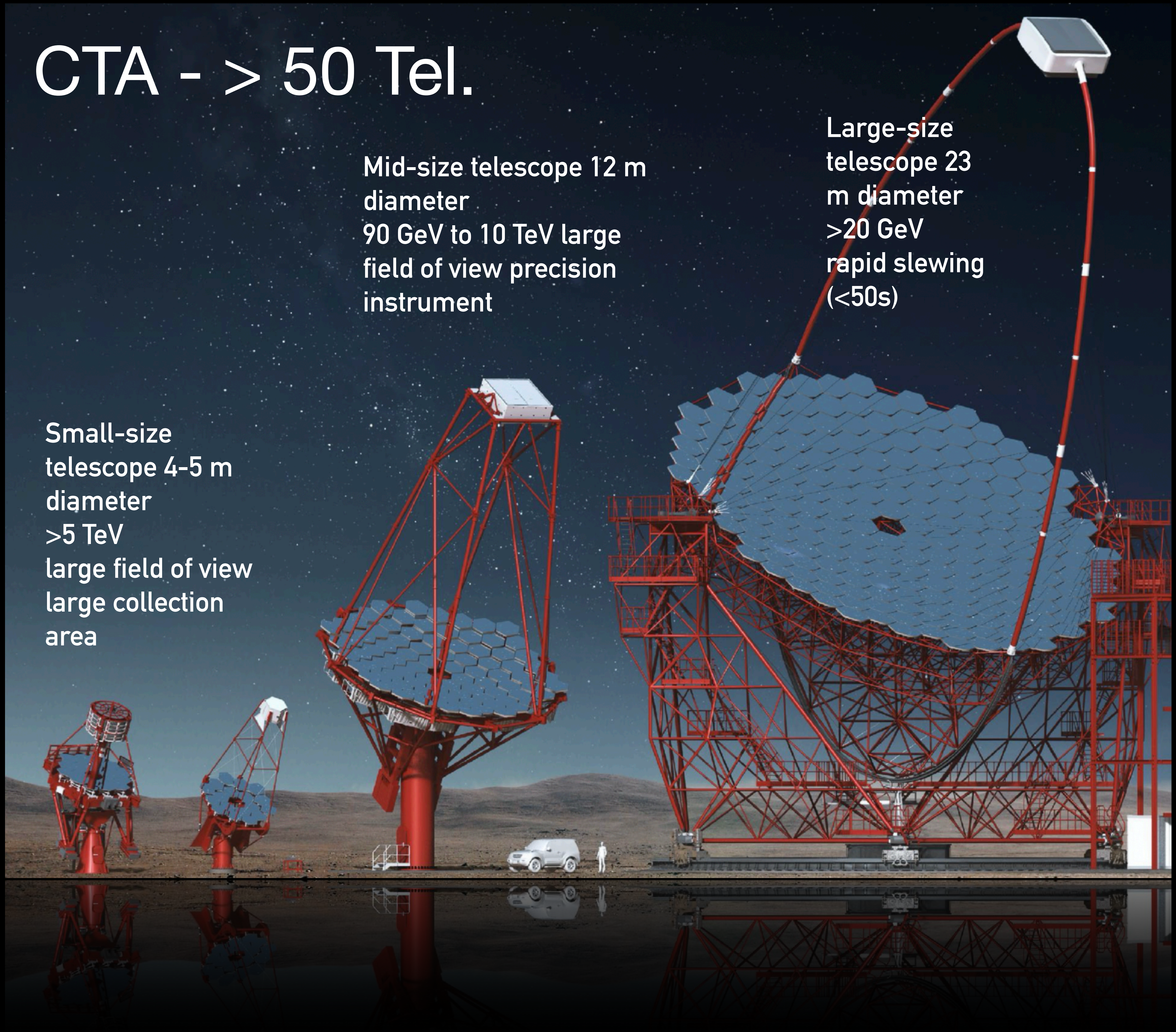
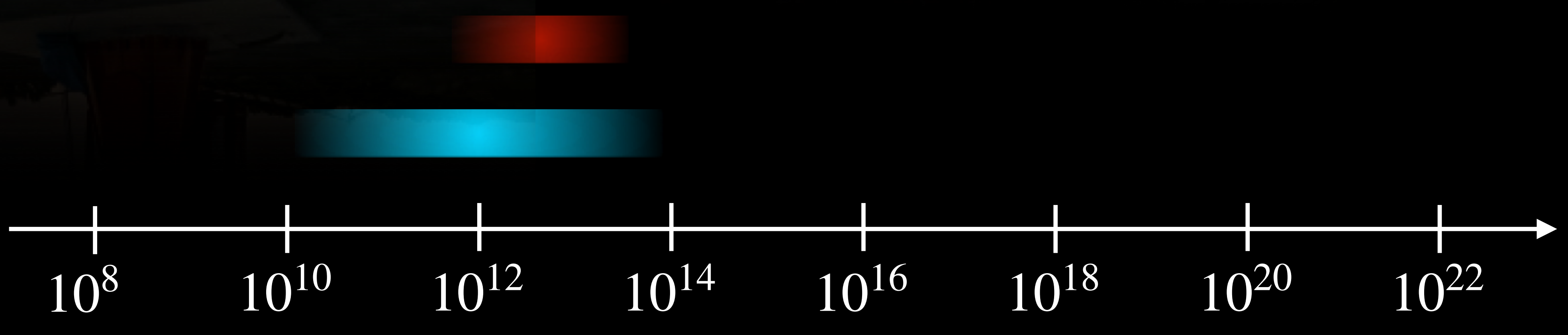




Futuri telescopi cherenkov

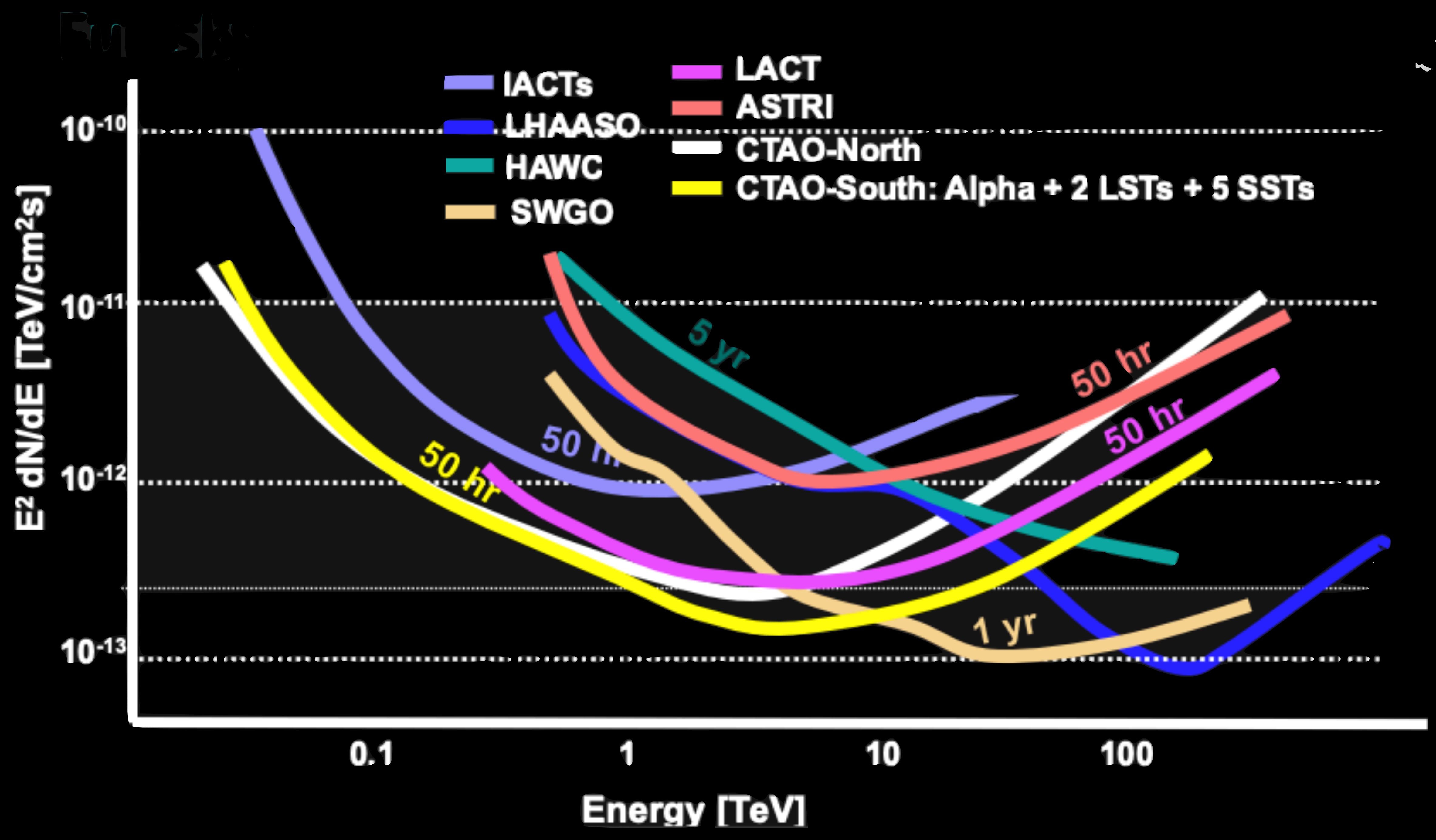


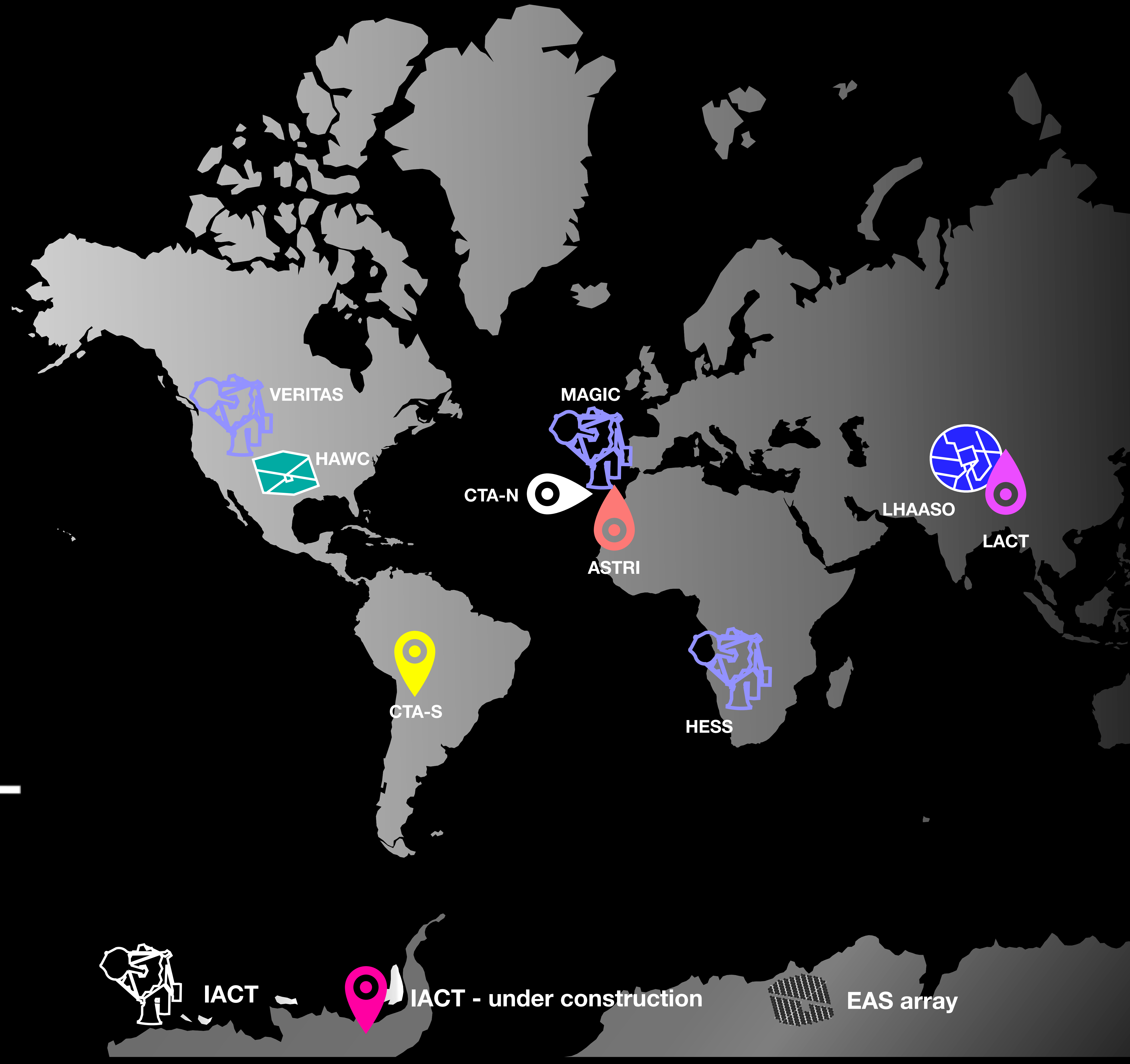
ASTRI-Horn



Futuri esperimenti

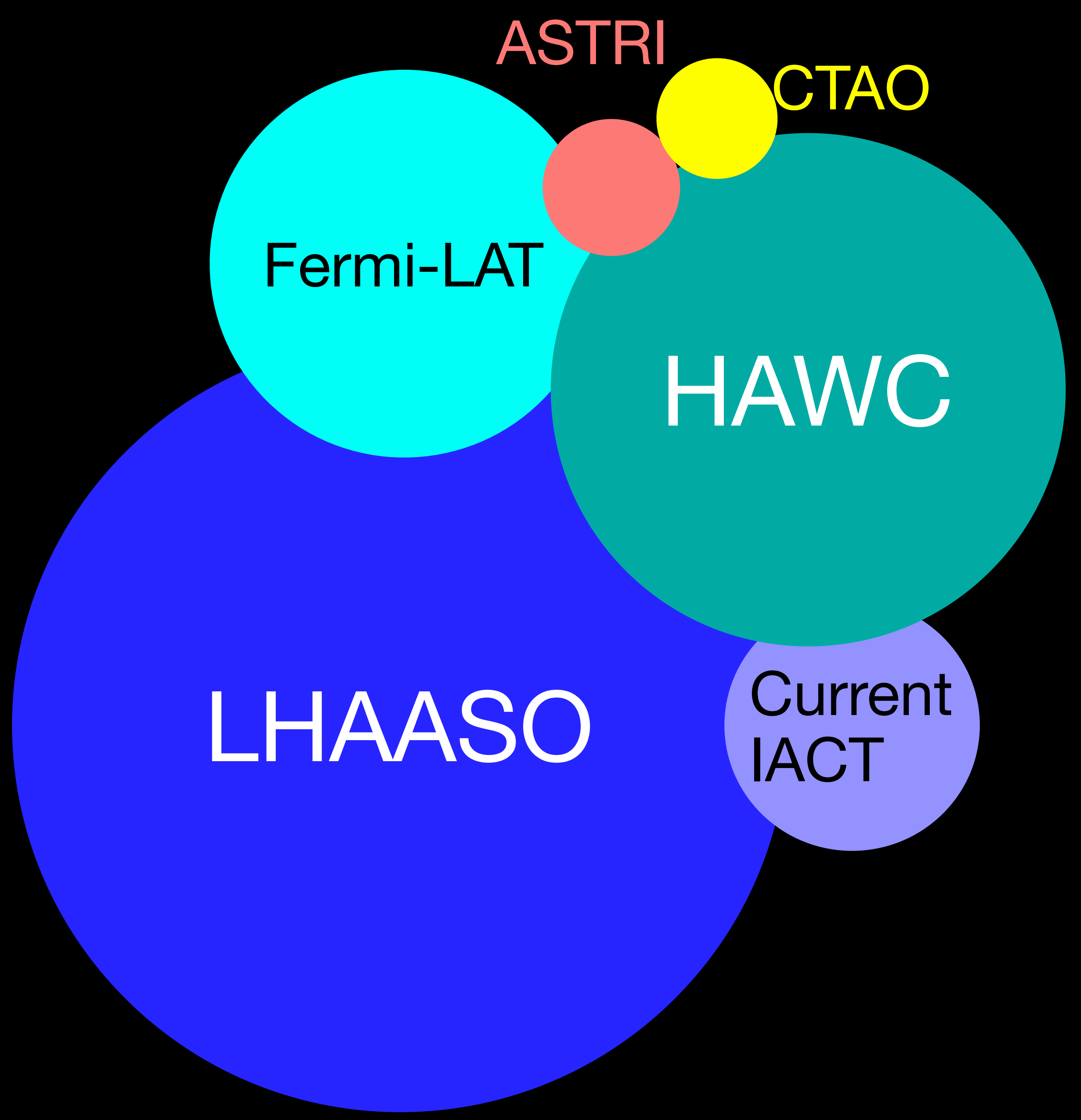
Sensitivity of current and future experiments

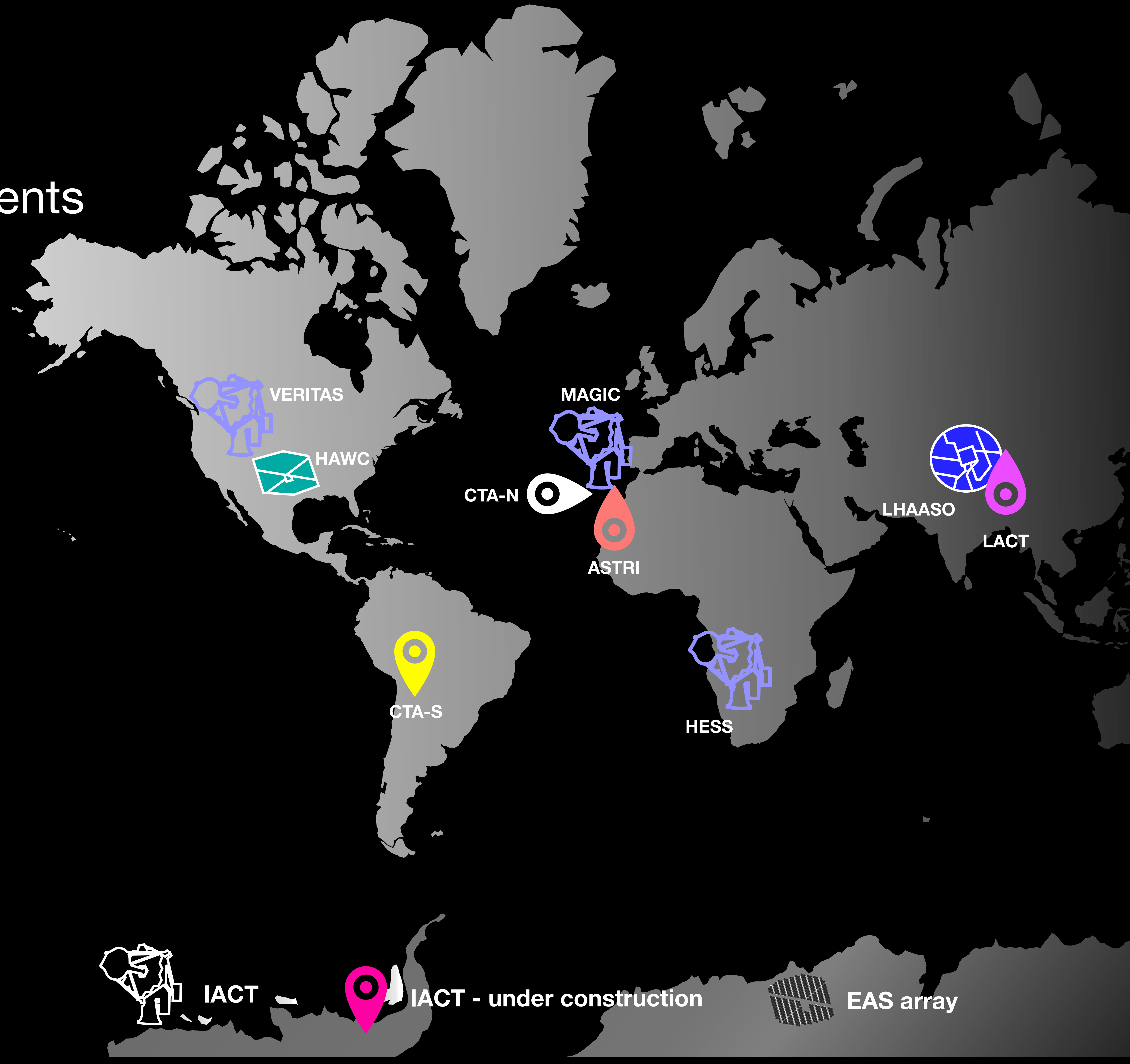




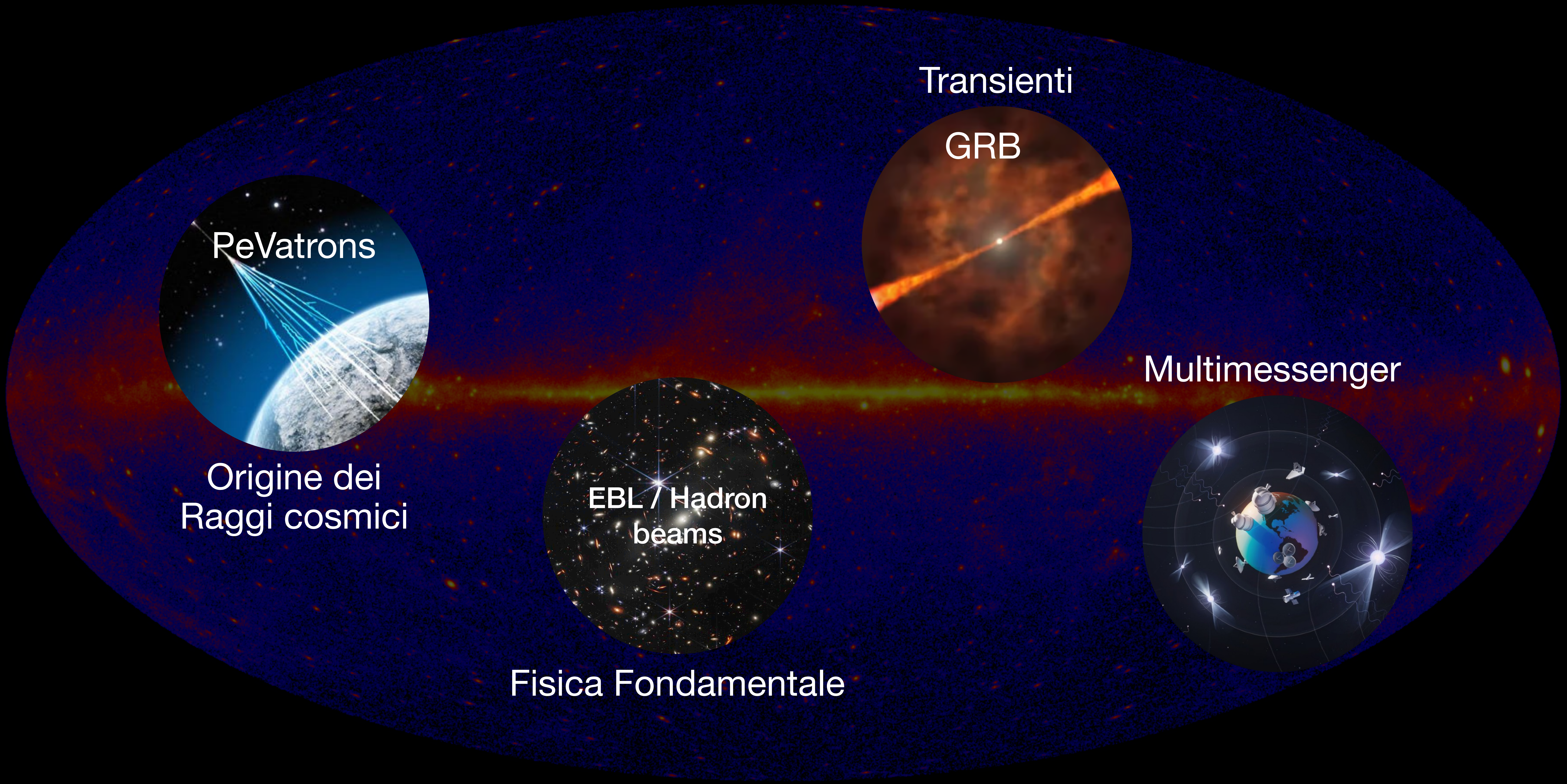
Futuri esperimenti

Angular resolution of current and future experiments

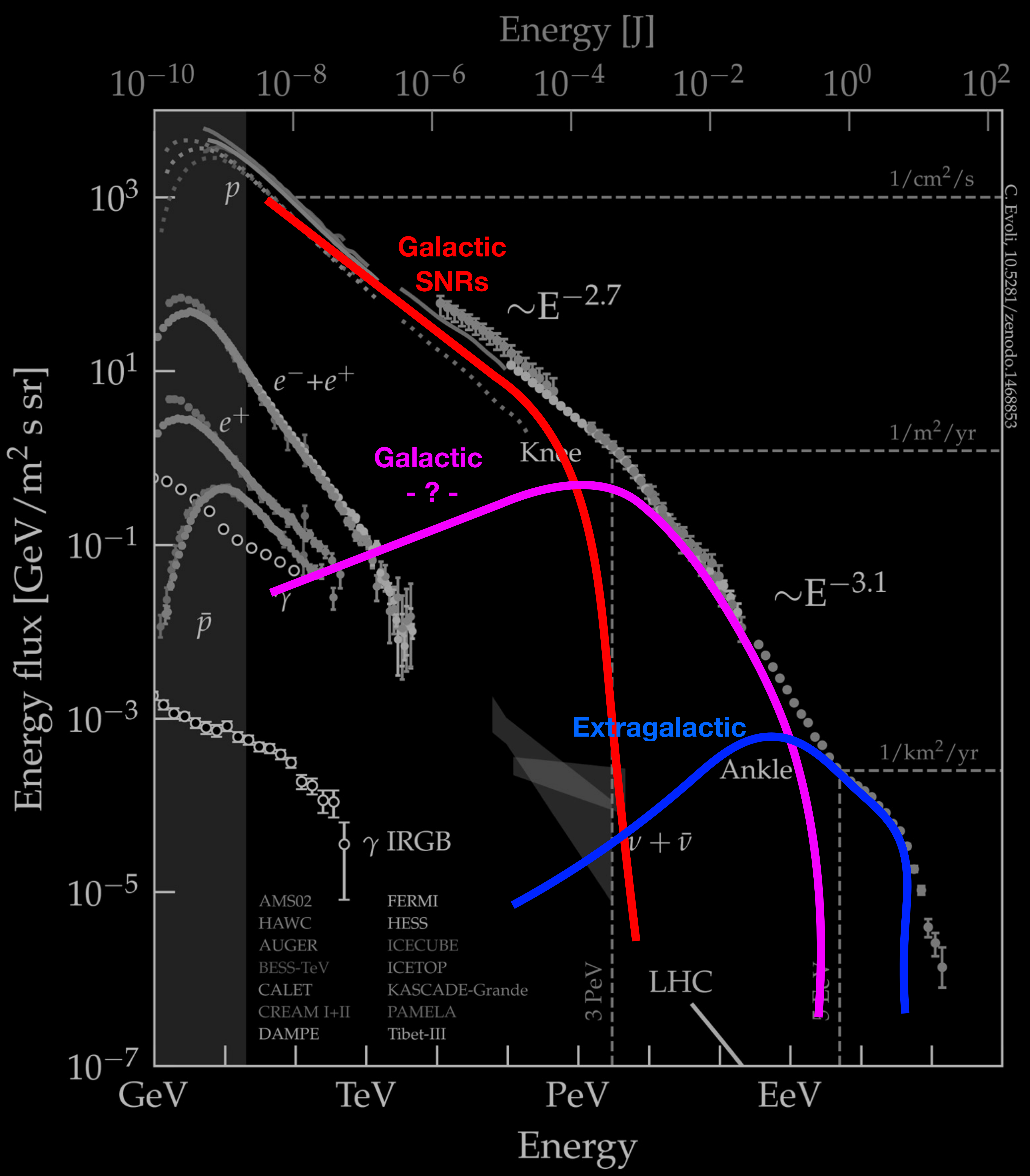




Astronomia gamma



PeVatrons



I raggi cosmici fino a 100 PeV sono di origine galattica. Questo significa che ci devono essere sorgenti (PeVatroni) in grado di accelerare particelle a quelle energie.

I resti di supernova storicamente sono i principali candidati.

$$L_{CR} = W_{CR}/\tau_{CR} \sim 10^{41} \text{ erg/s}$$

$$L_{SN} = E_{SN}/\nu_{SN} \sim 10^{42} \text{ erg/s}$$

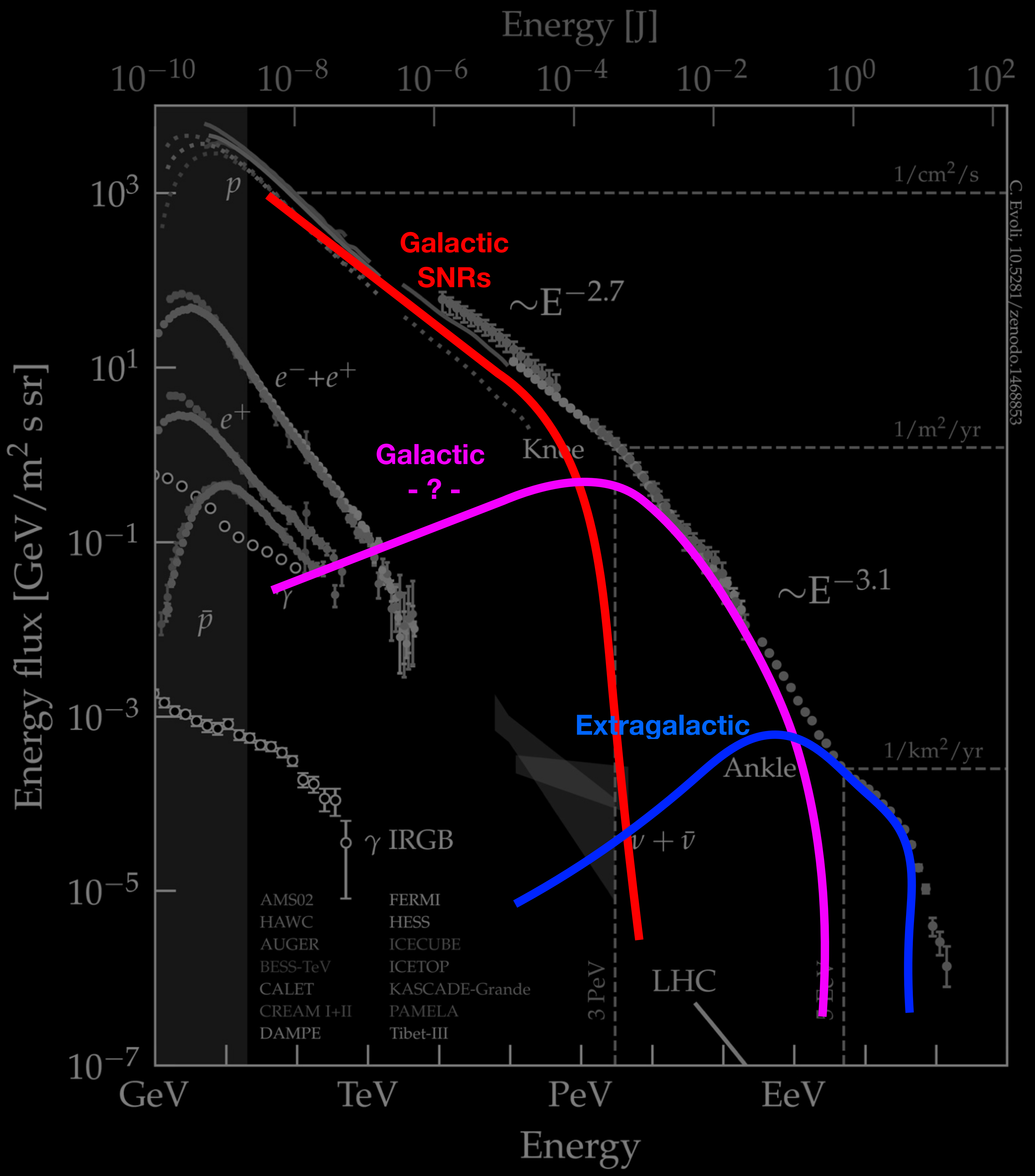
Ma…

$$E_{max} = zeBUL \sim 100\, TeV - 1\, PeV$$

Richiede condizioni limite:

- Shock molto veloci (vero nei primi 100 anni)
- Campi magnetici amplificati
- Bohm diffusion (upper limit)

PeVatrons



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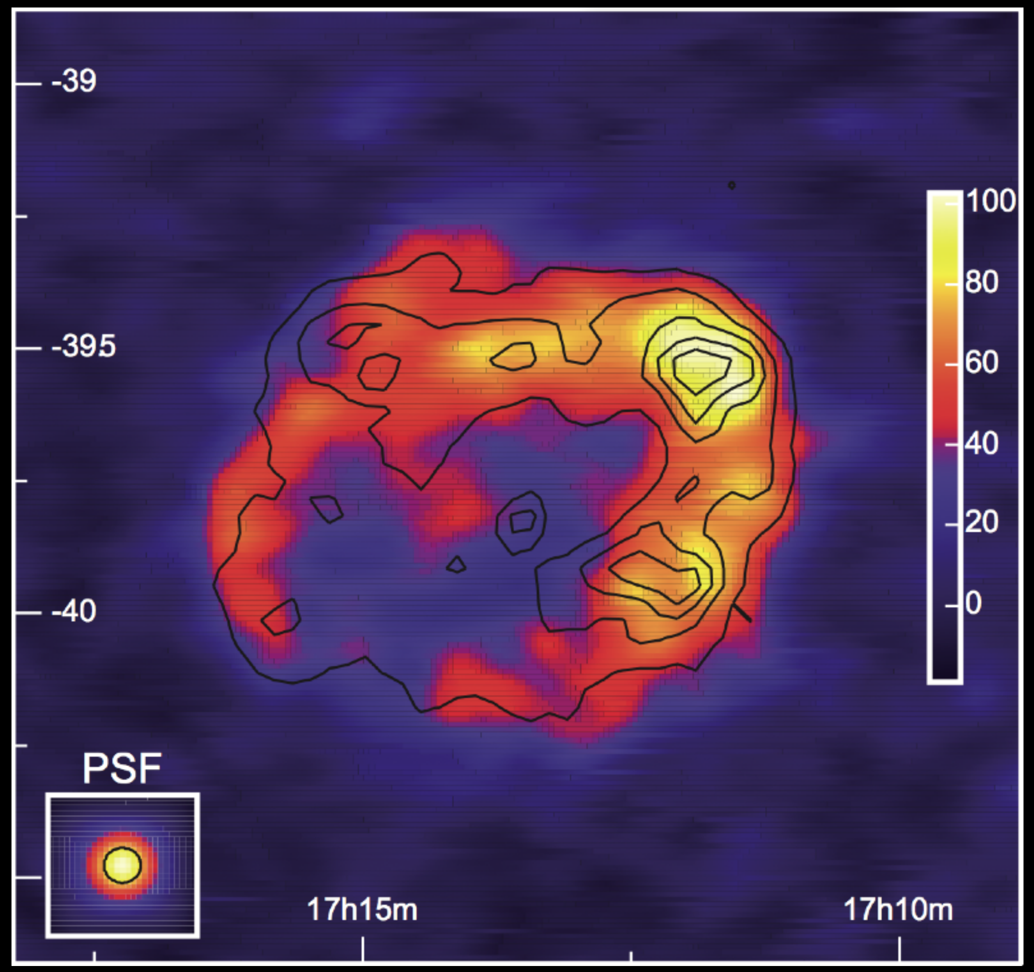
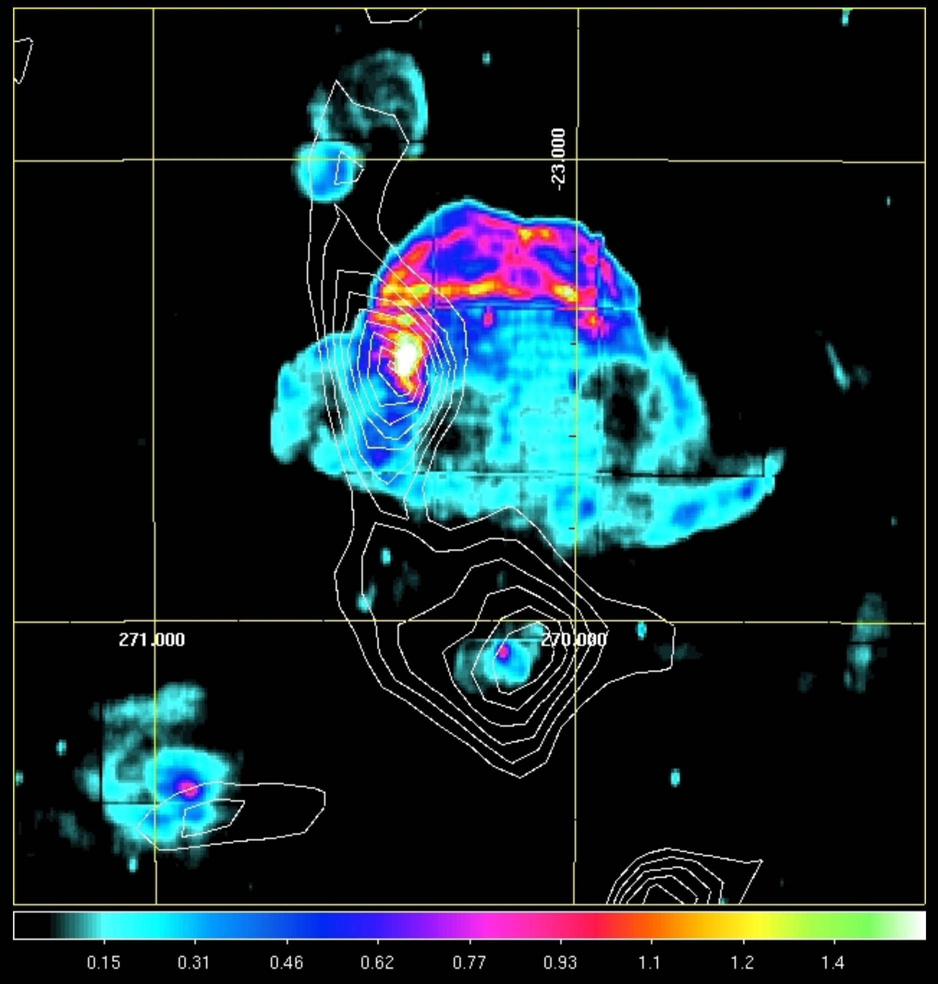
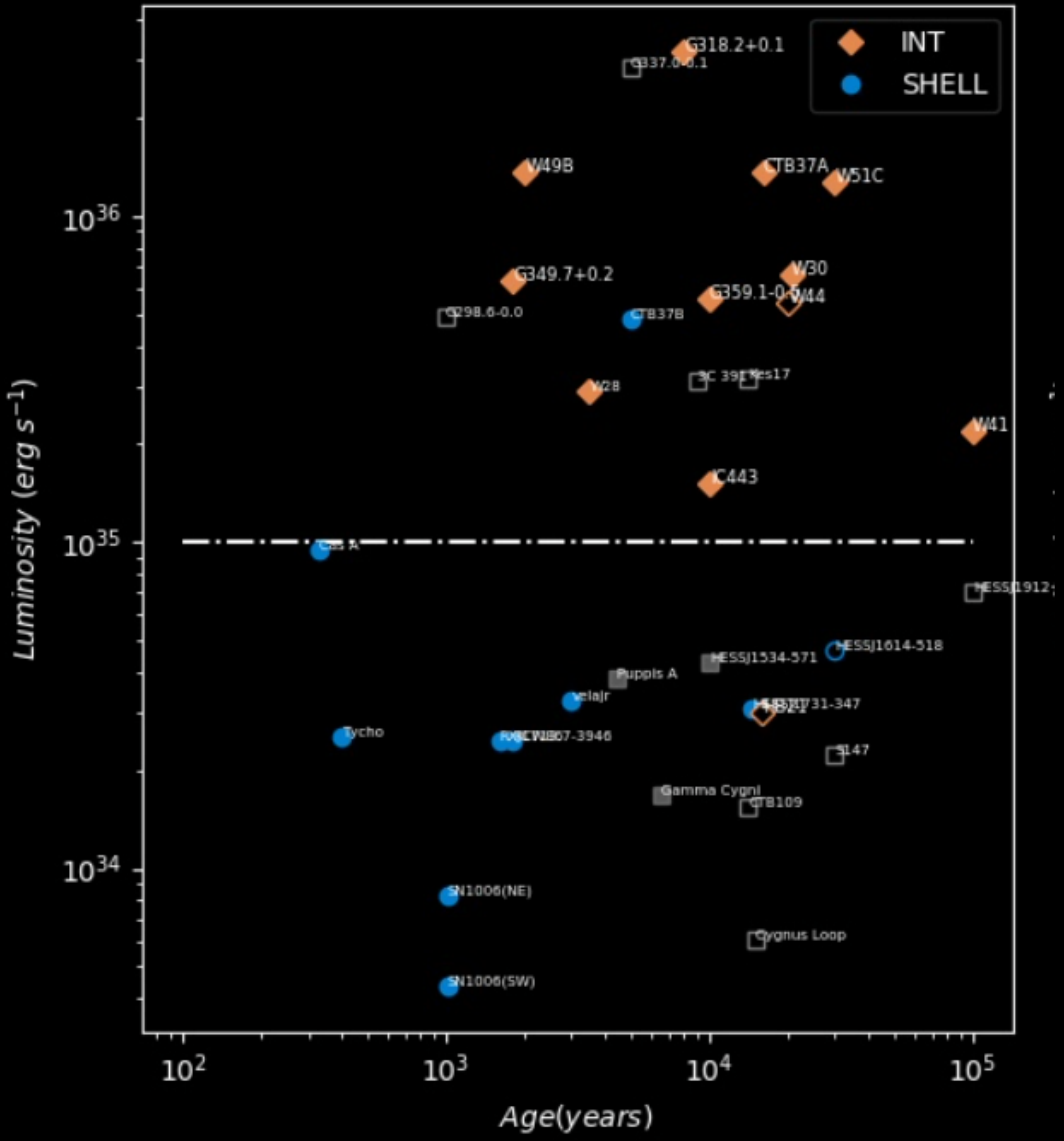
PeVatrons candidates

I resti di supernova si possono dividere in due classi:

- Shell-like
- Interagenti con nubi molecolari



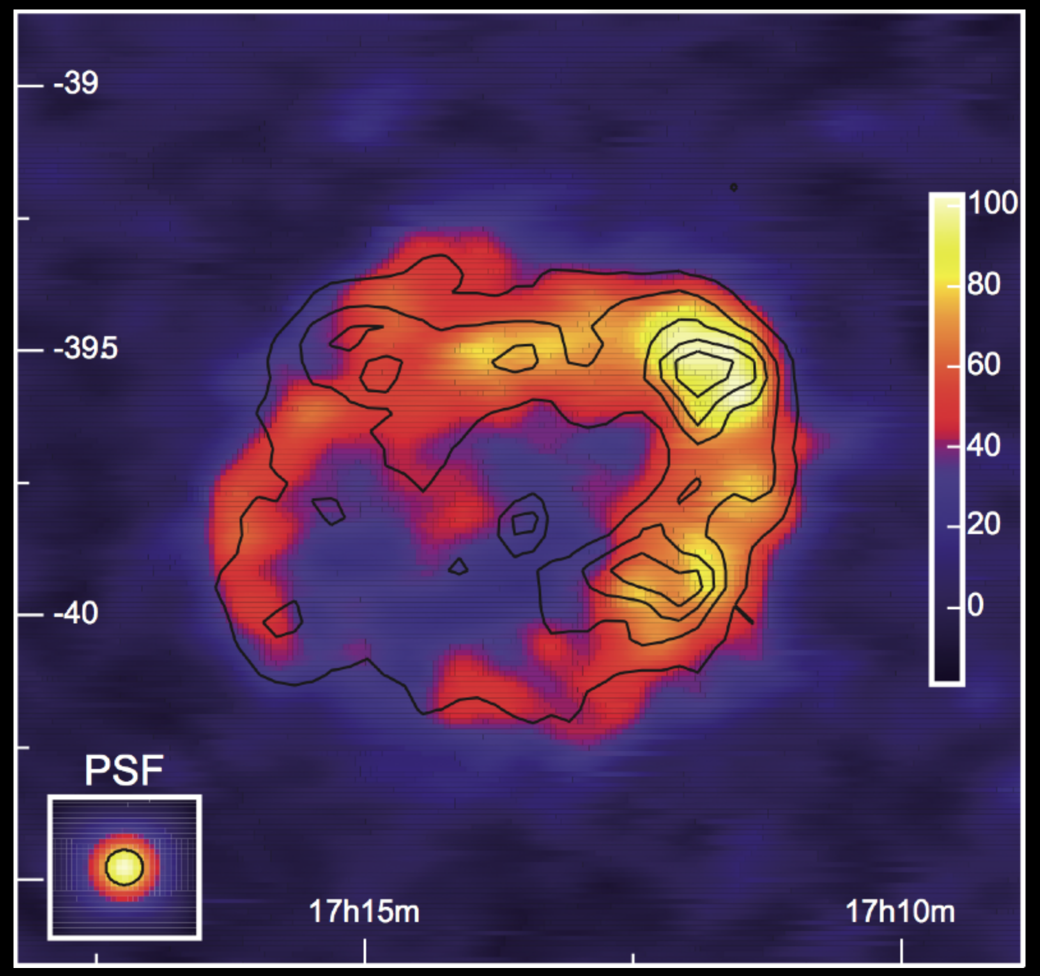


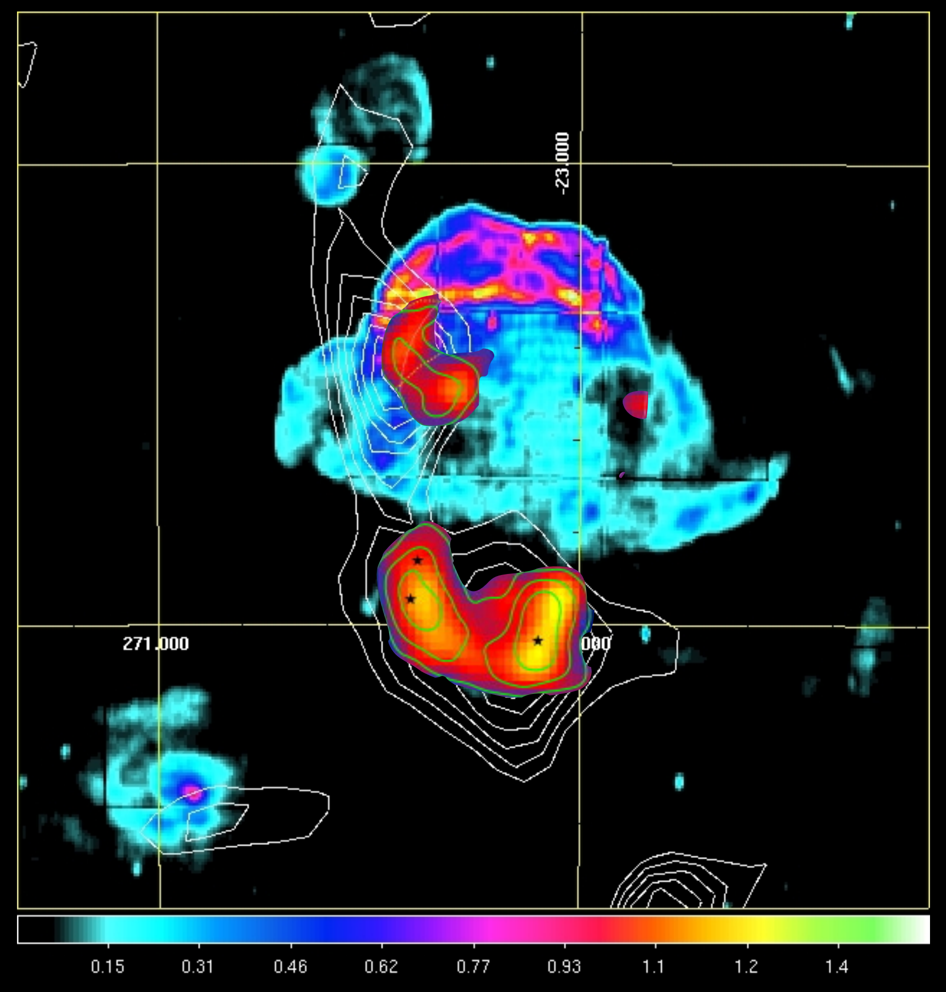


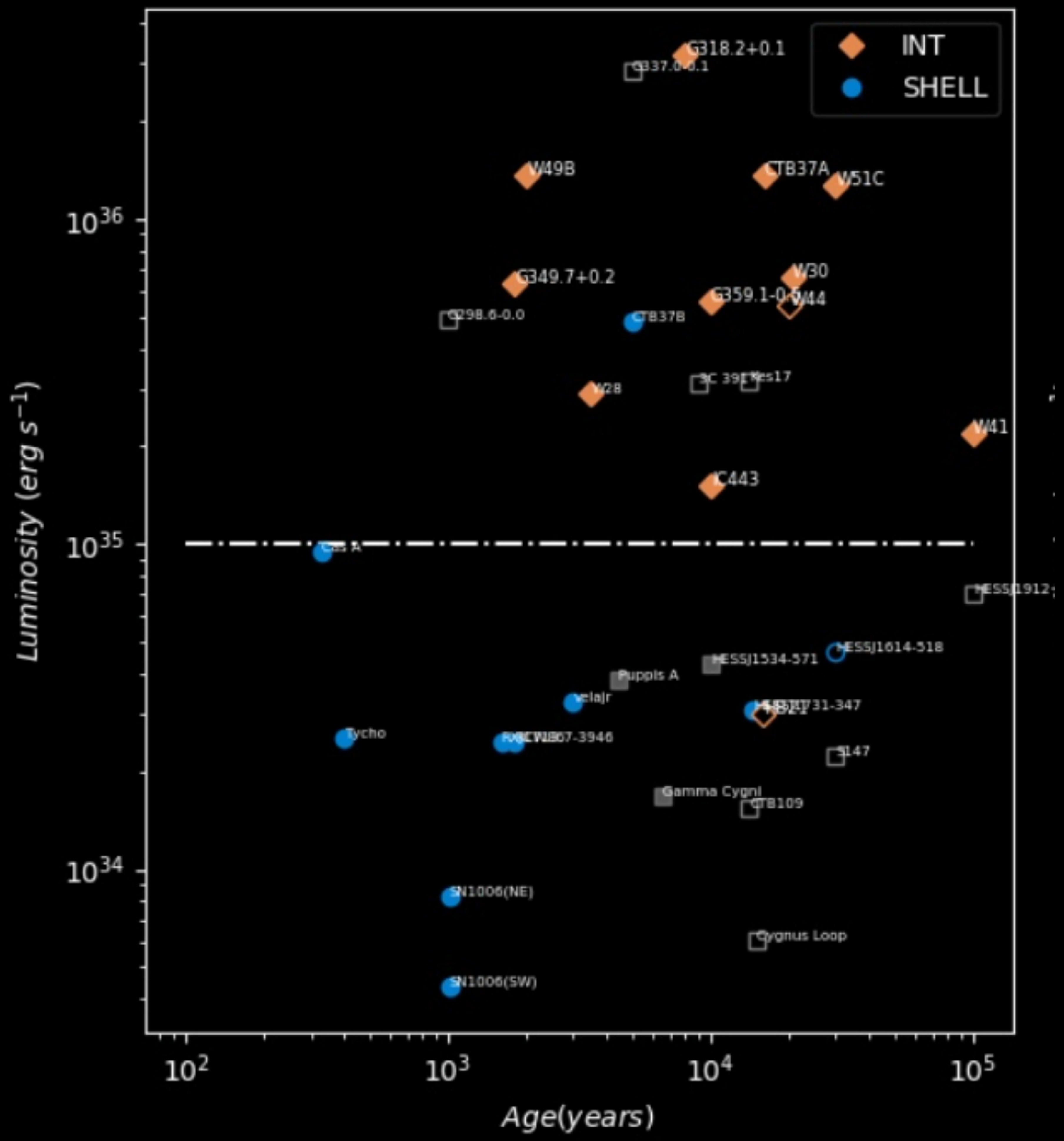
PeVatrons candidates

I resti di supernova si possono dividere in due classi:

- Shell-like
- Interagenti con nubi molecolari







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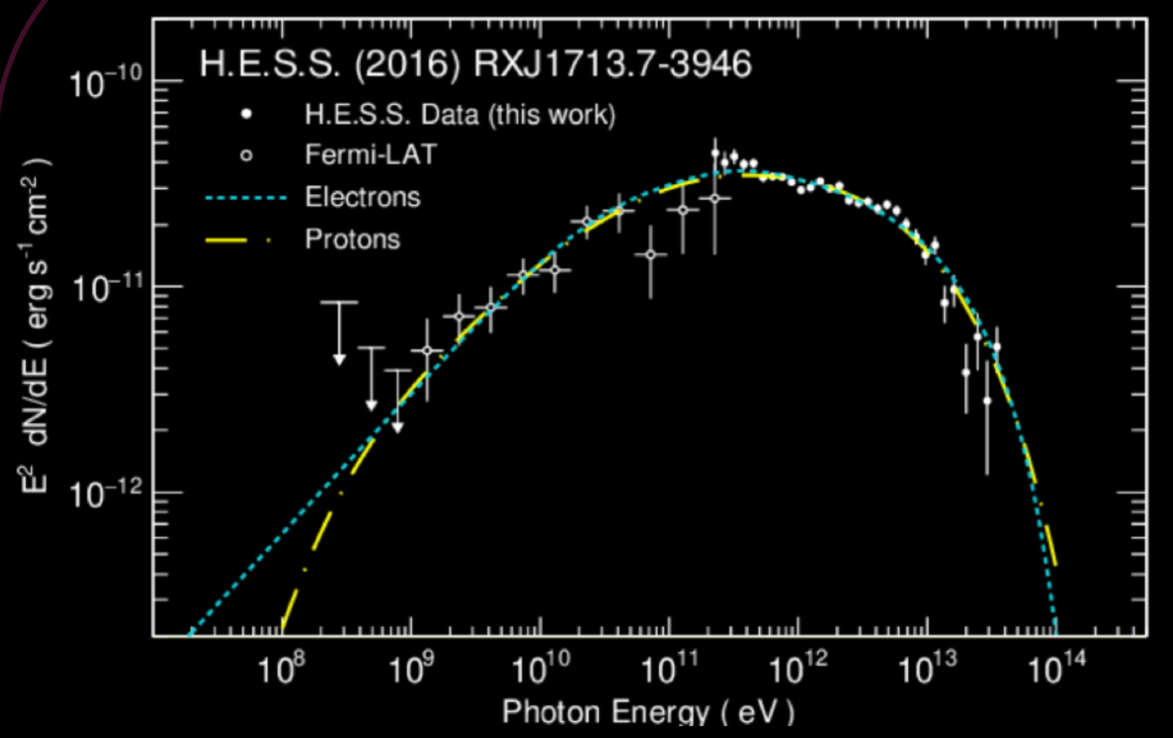
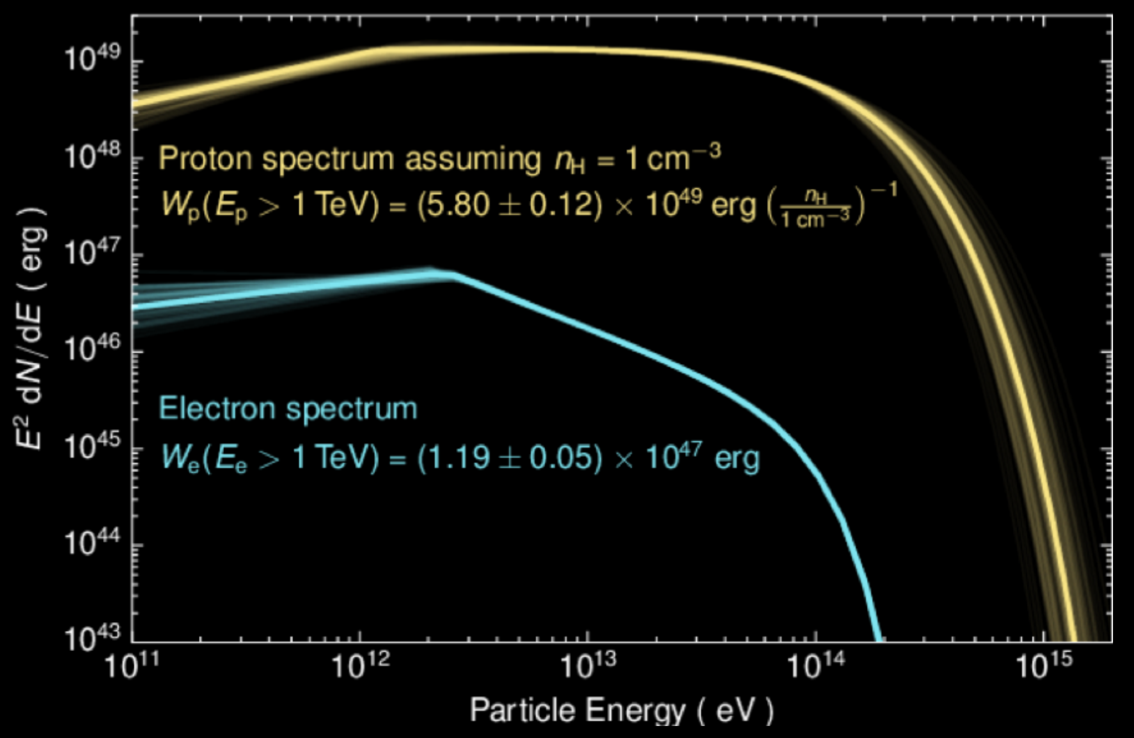


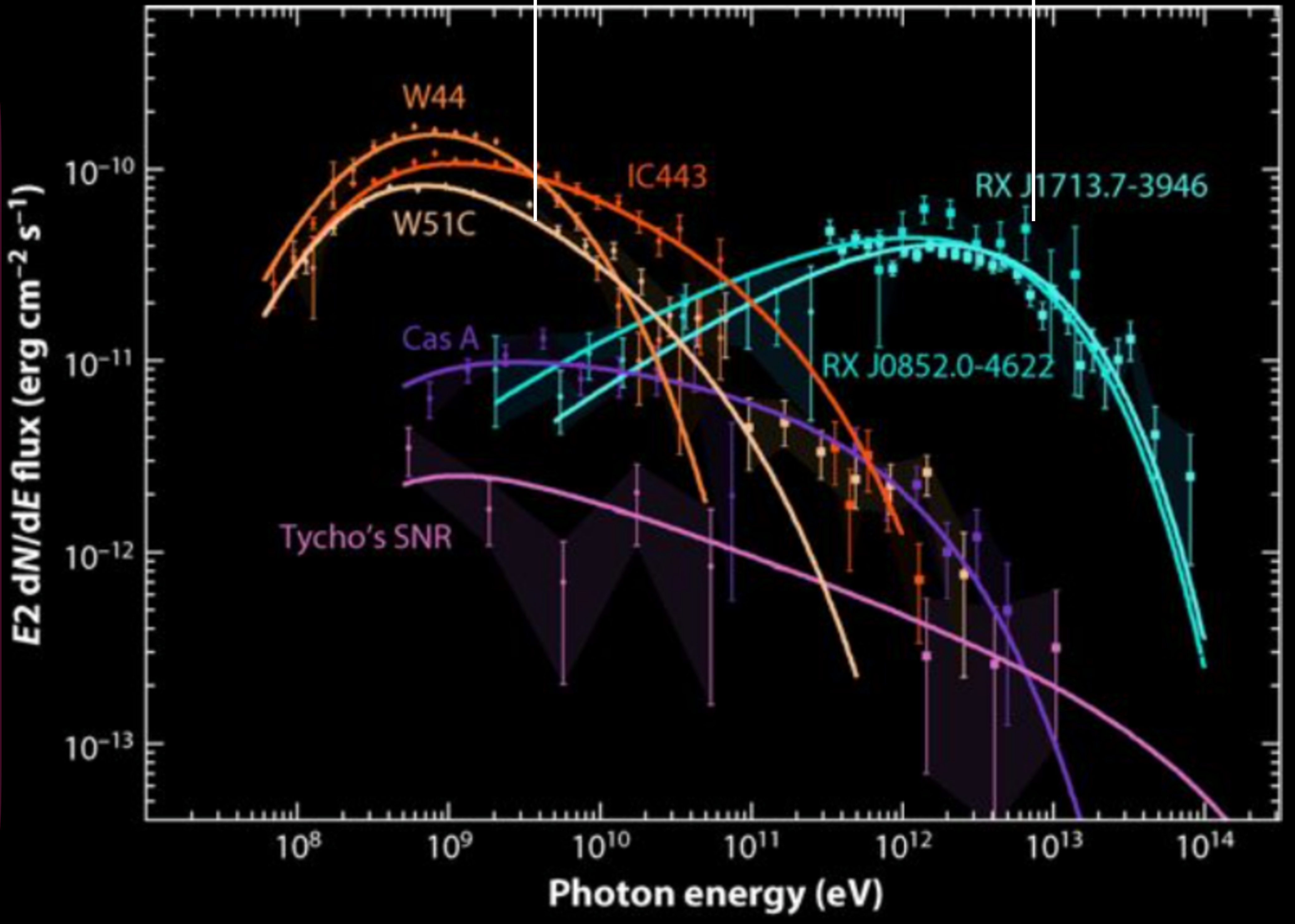


$$E_{max} = zeBUL \sim 100\,TeV - 1\,PeV$$

Richiede condizioni limite:
Shock molto veloci (vero nei primi 100 anni)
Campi magnetici amplificati
Bohm diffusion (upper limit)

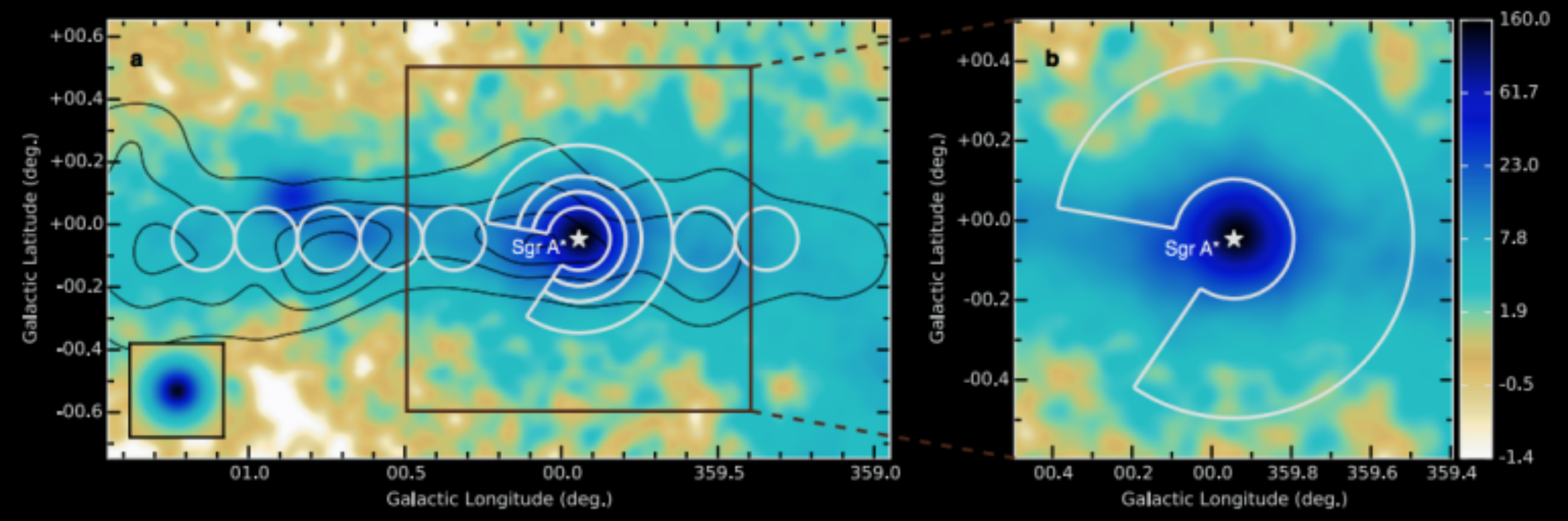
- Cut-off at 10 TeV
- Non è chiaro che l'emissione sia di origine adronica

Cut-off at GeV



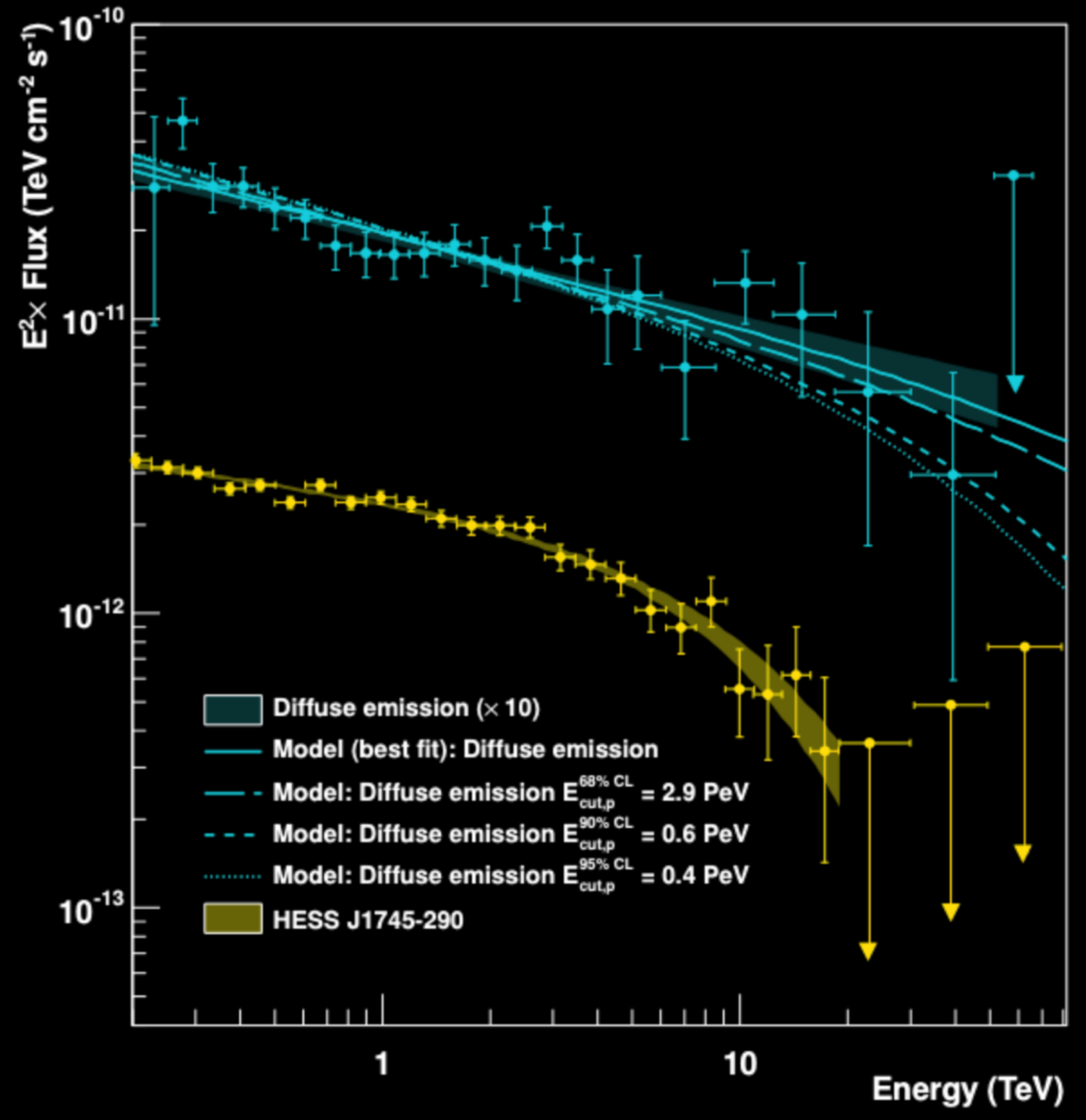
PeVatrons - Centro galattico

Emissione diffusa attorno al centro galattico, molto brillante in gamma



Non è chiaro quale sia la sorgente in grado di accelerare protoni al PeV. SMBH o Stellar cluster?

Da solo potrebbe spiegare il bulk di raggi cosmici al ginocchio se avesse mantenuto la stessa potenza nell'ultimo milione di anni



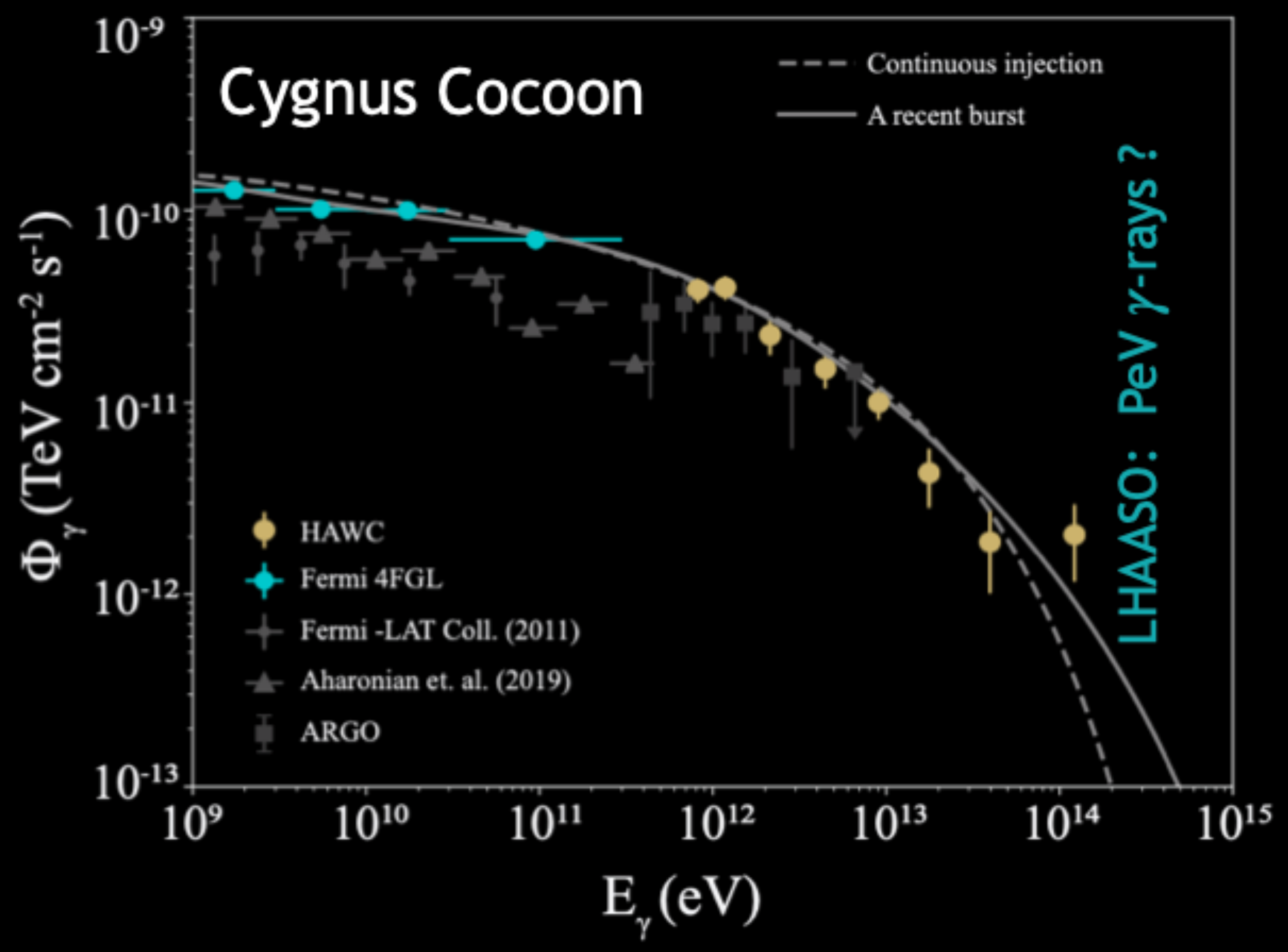
Non c'è evidenza di cut-off sopra centinaia di TeV (0.4 PeV in protons energy)

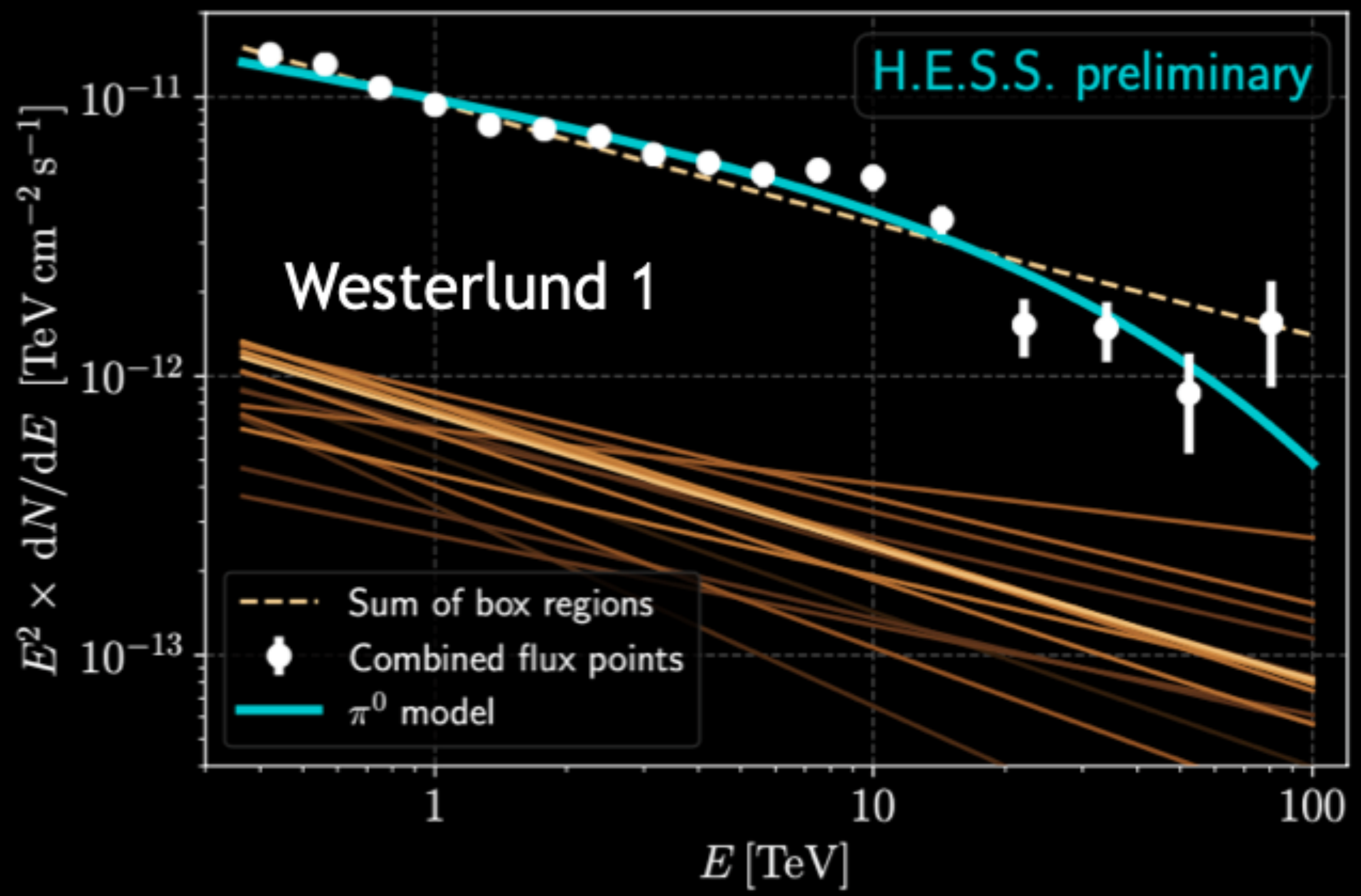
PeVatrons - Stellar cluster

Gli ammassi stellari sono gruppi di decide di stelle massicce (O, WR) che rimangono legate durante la loro vita (1-10 Myr).

I venti stellari e le esplosioni di supernova in questi sistemi possono formare “superbolle” di plasma in cui ci sono shock e campo magnetico -> accelerazione di particelle.

Le condizioni sono più favorevoli rispetto ai resti di supernova isolati

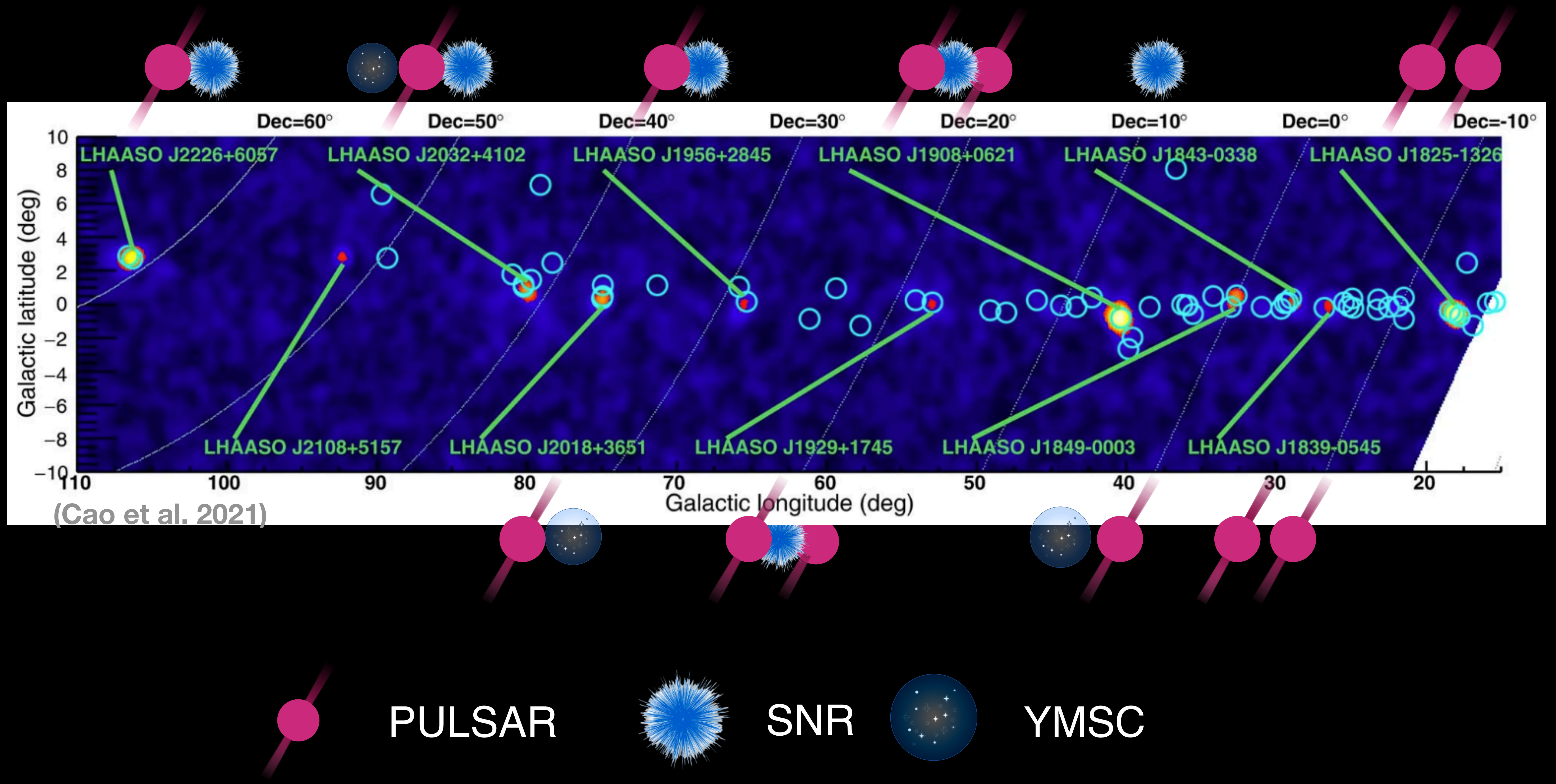




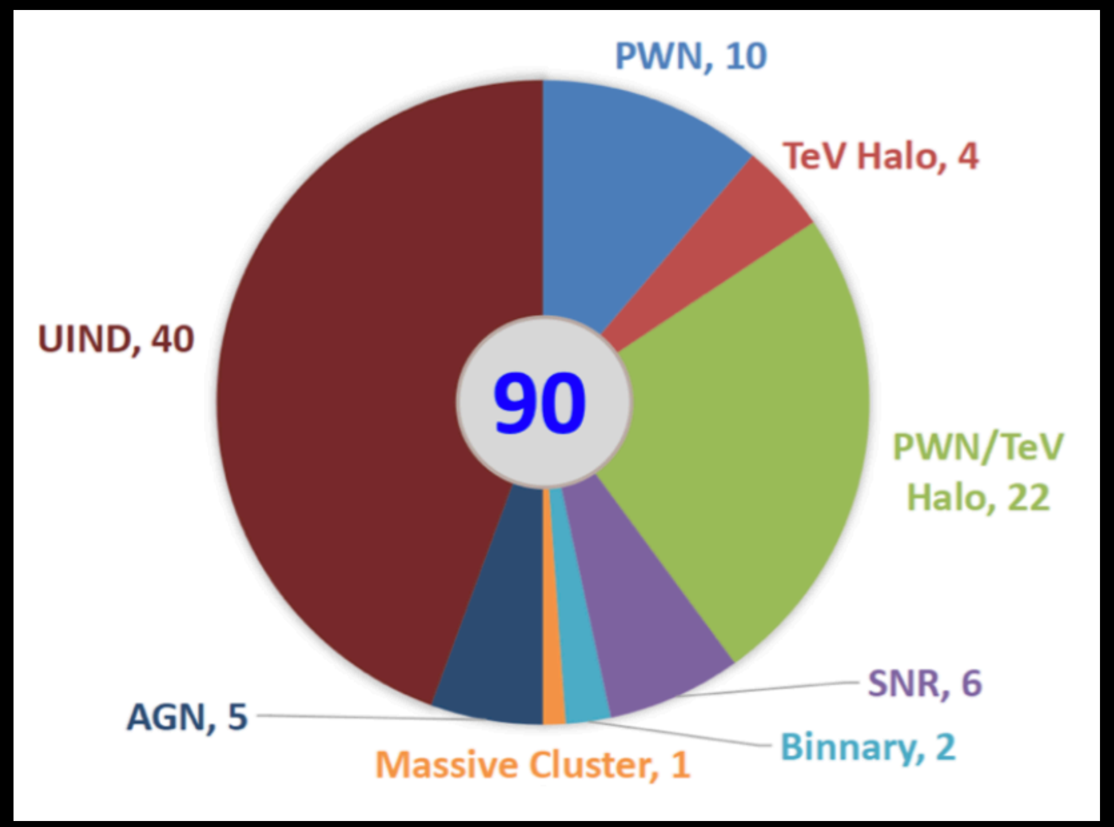
LHAASO PeVatrons

Negli ultimi anni LHAASO ha dato un forte impulso alla ricerca dei PeVatroni.

2021



2023

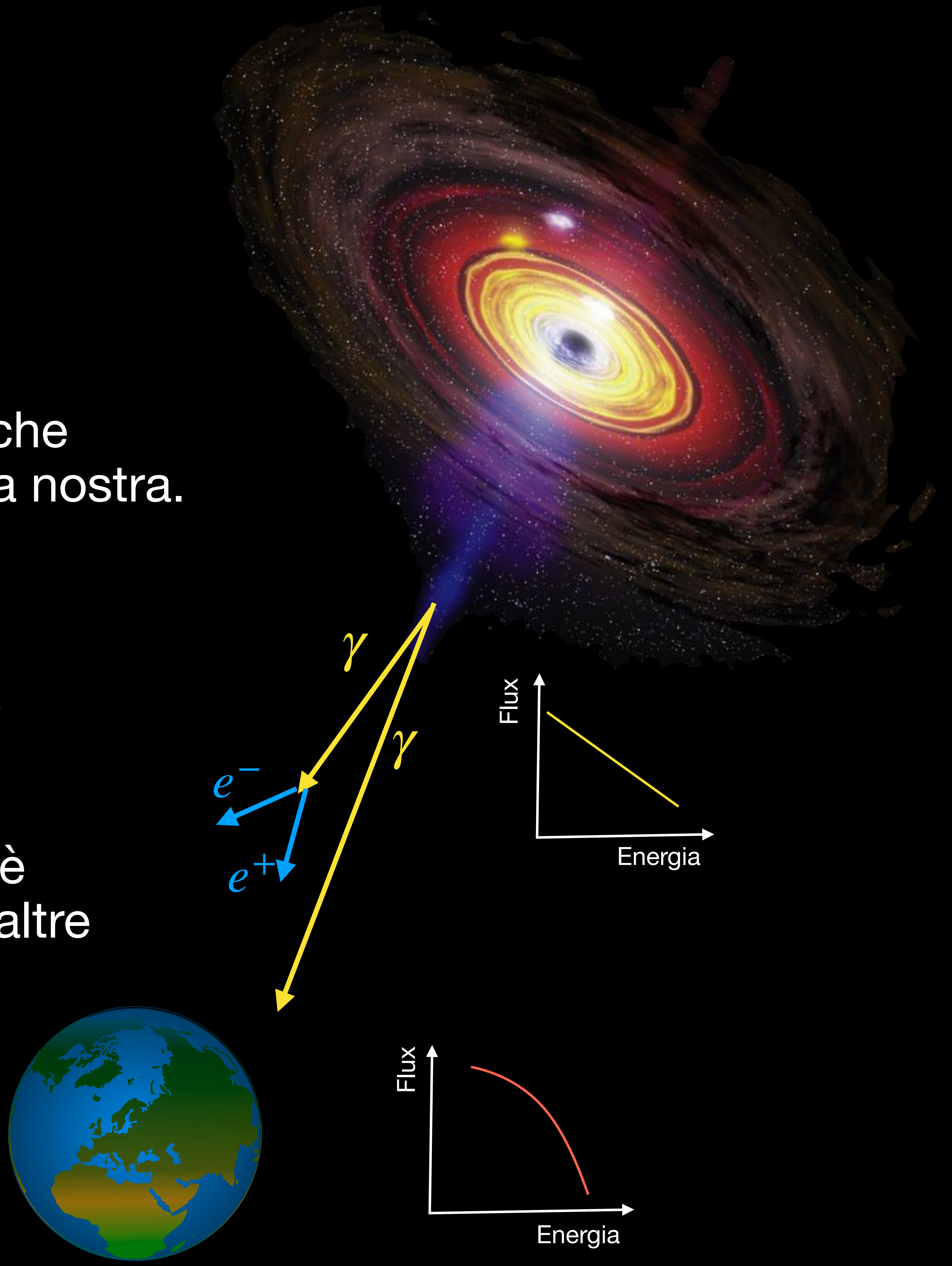


Fisica Fondamentale - EBL

L' Extragalactic background light è la radiazione diffusa che permea l'universo e che proviene da galassie esterne alla nostra. Copre quasi tutte le lunghezze d'onda dello spettro elettromagnetico.

I fotoni cosmologici altamente energetici (>TeV) vengono attenuati dalla produzione di coppie con fotoni EBL.

L'interazione dipende dallo spettro dell'EBL che tuttavia è difficilmente misurabile poiché molto debole rispetto ad altre fonti di radiazione (come la luce delle stelle o il CMB),



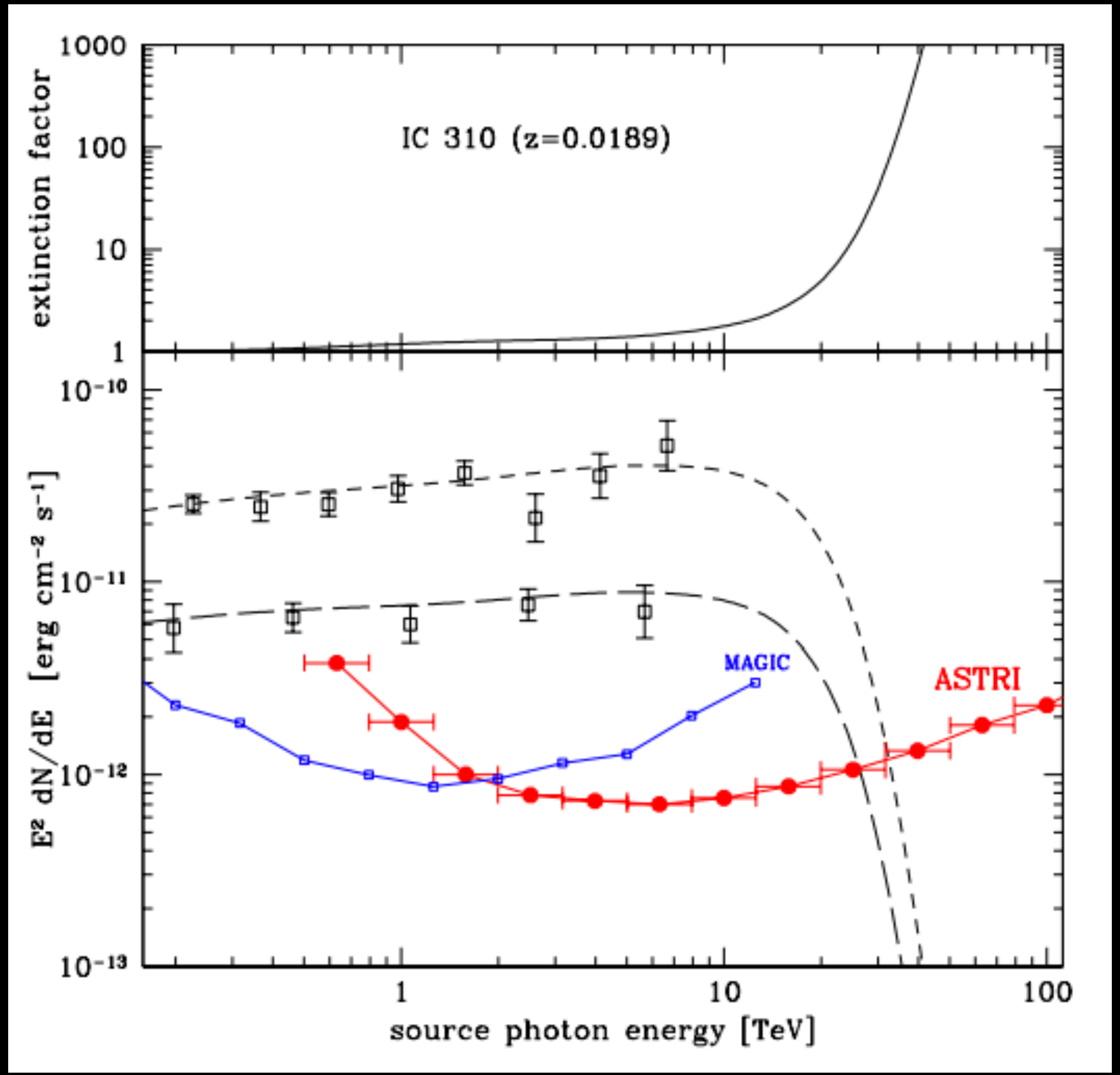
Fisica Fondamentale - EBL

In particolare nell'infrarosso dove il background è massimo la misura diretta dell'EBL è impossibile.

Si potrebbe misurare indirettamente sfruttando l'attenuazione dei fotoni molto energetici (>10 TeV)

$\lambda_{max} \sim 1.24 \times E_{TeV}$ [μm] —> 10-30 [μm]

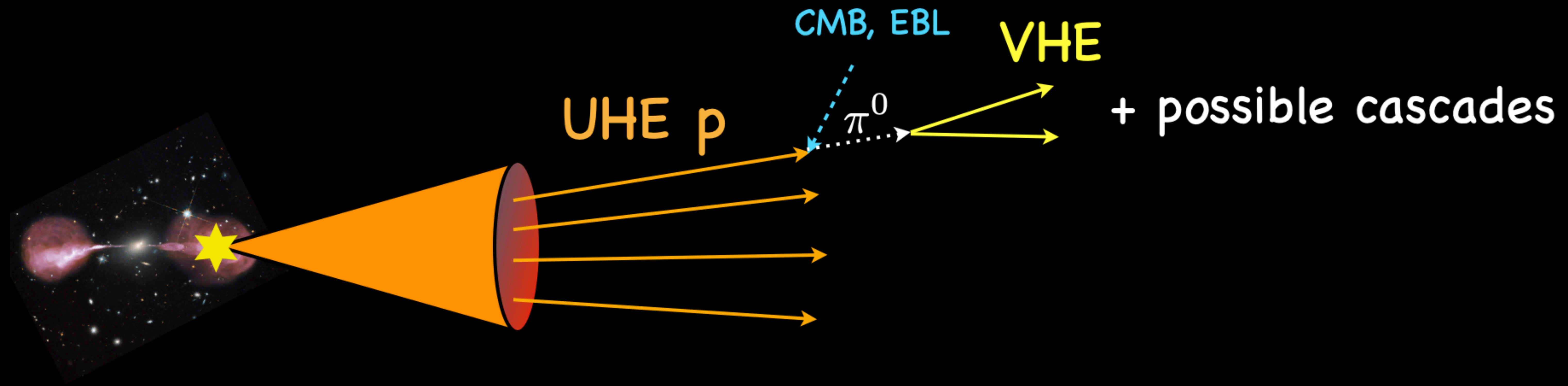
Se misuro l'attenuazione dovuta a EBL riesco a vincolarne lo spettro.

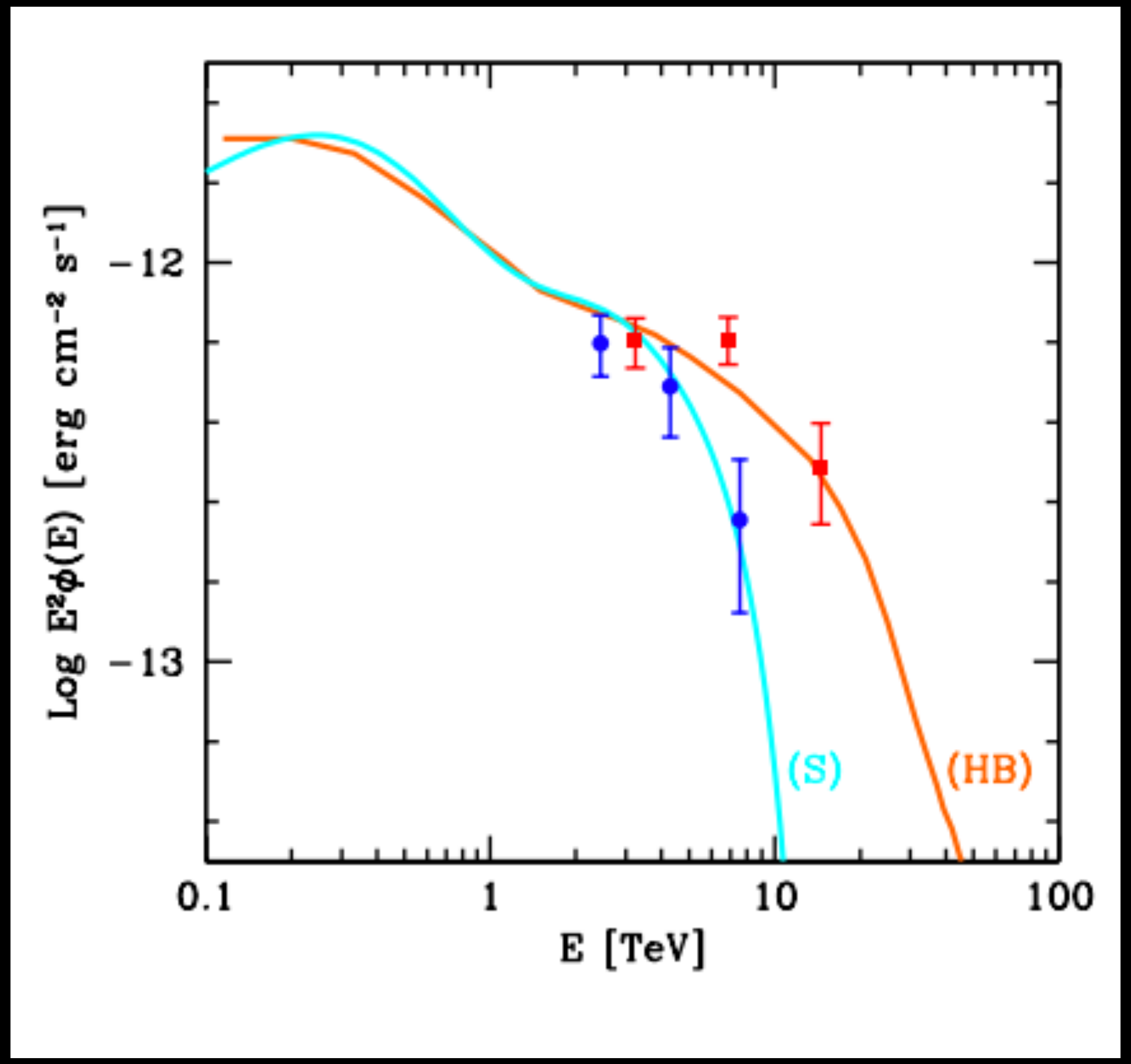


Hadron beams

Anche l'origine dei RC extragalattici è piuttosto incerta e di difficile spiegazione anche a causa del bassissimo numero di particelle rivelate.
Tra i potenziali acceleratori di UHECR, ci sono i getti relativistici extragalattici.

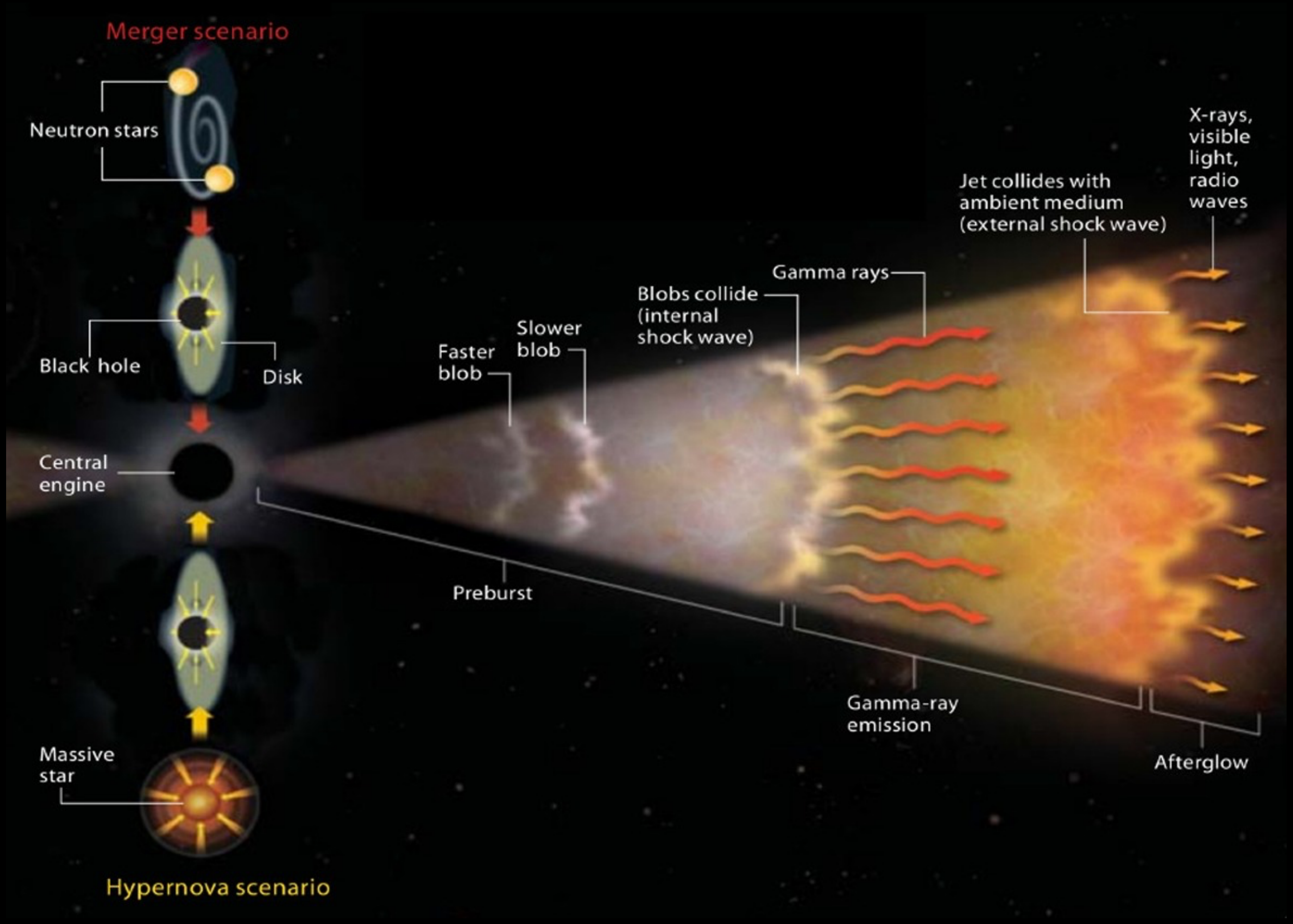
Un'ipotesi è che oggetti come Blazar particolarmente estremi possano accelerare protoni ad altissima energia che interagiscono con i fotoni del fondo generando fotoni gamma di alta energia





Gamma Ray Burst

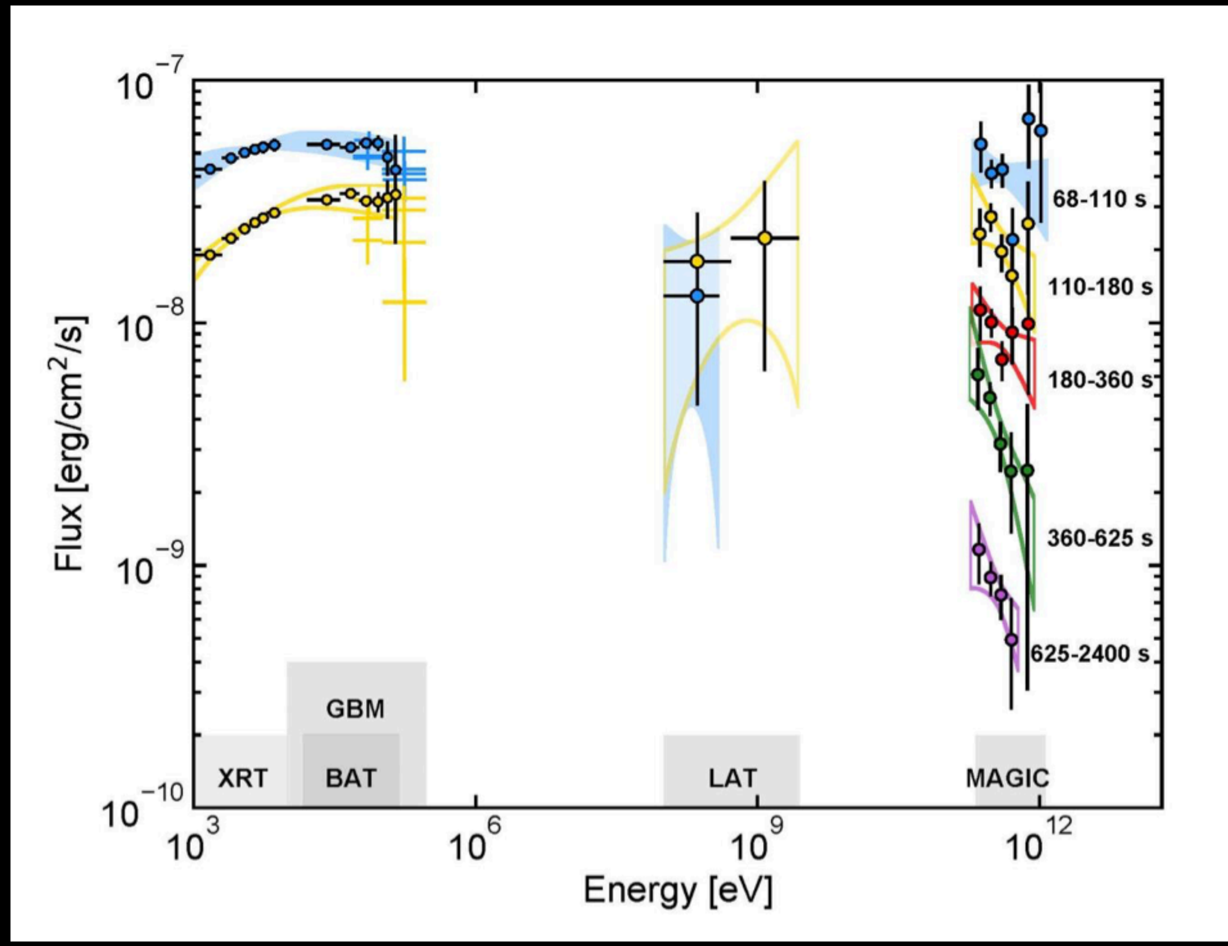
I lampi di raggi gamma sono le esplosioni cosmiche più luminose dopo il Big Bang. Sono originati dal collasso di stelle molto massicce o dalla fusione di oggetti compatti NS-NS NS-BH.



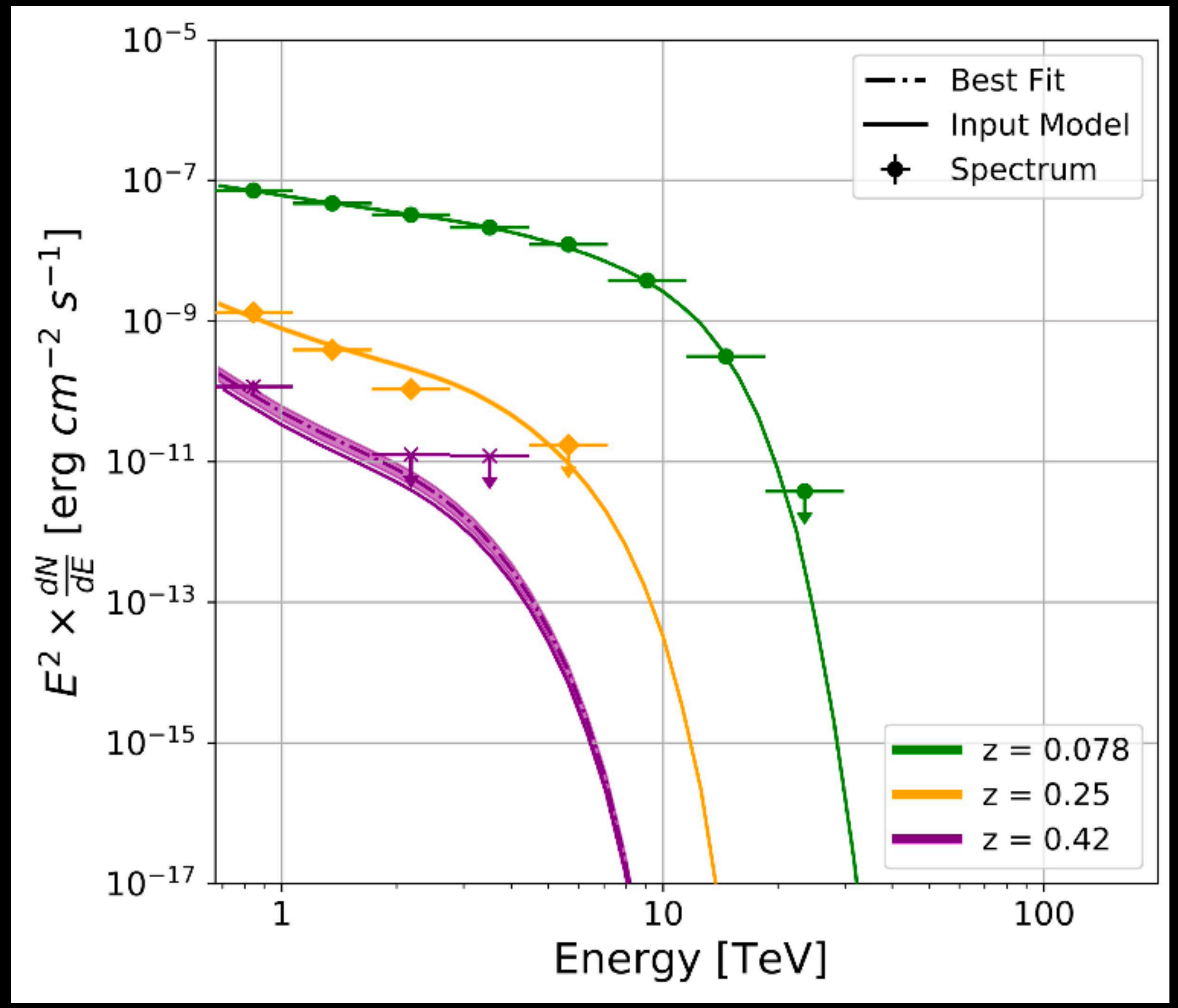
Sono caratterizzati da un' emissione "prompt" (al MeV) seguita da una fase di "afterglow" con emissione che decade gradualmente nel corso delle ore a settimane o più e in tutte le bande d'onda.

Gamma Ray Burst

MAGIC ha rilevato l'emissione dell'afterglow di un GRB a 1 TeV -> GRB sono TeV- emitters



I futuri strumenti saranno in grado rilevare anche $E >$1 TeV anche per GRB più lontani.
Potremmo misurare il cut-off, sia in caso sia originato dall'assorbimento dell'EBL o che sia intrinseco



Molte delle proprietà fisiche di base dei GRB rimangono poco comprese, come la natura del motore centrale e i meccanismi di formazione del getto, accelerazione delle particelle.


Neutrini - Gamma-ray
CR - Gamma-ray
Neutrini - Gamma-ray
CR - Gamma-ray
GW - Gamma-ray
In recent years, a large network of observatories has been deployed on remote places in the land, in the sea, underground and in space, to detect the signals coming from the "visible" Universe and even earlier, in the first moments beyond the "recombination wall" when nuclei and electrons formed neutral atoms and the Universe became transparent.
LISTENING TO NEW
COSMIC MESSENGERS
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Reference

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[4] LHAASO (https://english.ihep.cas.cn/lhaaso/)

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[7] MAGIC (https://magic.mpp.mpg.de/)

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[9] HAWC (https://www.hawc-observatory.org/)