

Fisica agli acceleratori (LHCb)

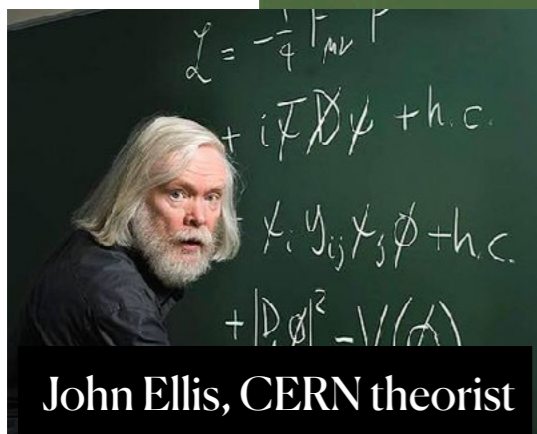
Paolo Gandini
INFN - Sezione di Milano



The Standard Model of Particle Physics

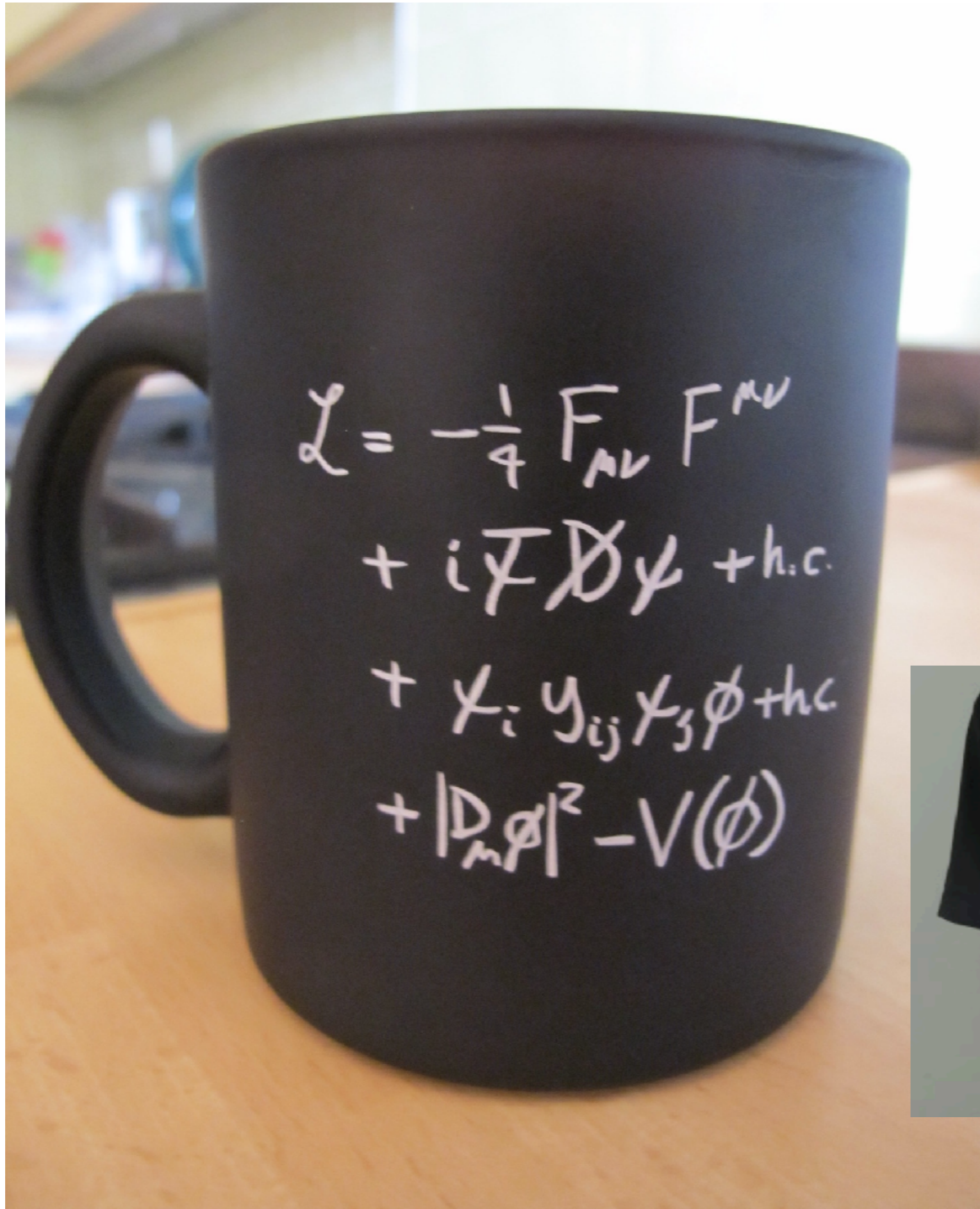
Andremo in dettaglio in questa fantastica formula...

$$\begin{aligned}\mathcal{L} = & -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\ & + i\bar{\psi} \not{D} \psi + \text{h.c.} \\ & + \bar{\psi}_i \gamma_{ij} \psi_j \phi + \text{h.c.} \\ & + |D_\mu \phi|^2 - V(\phi)\end{aligned}$$

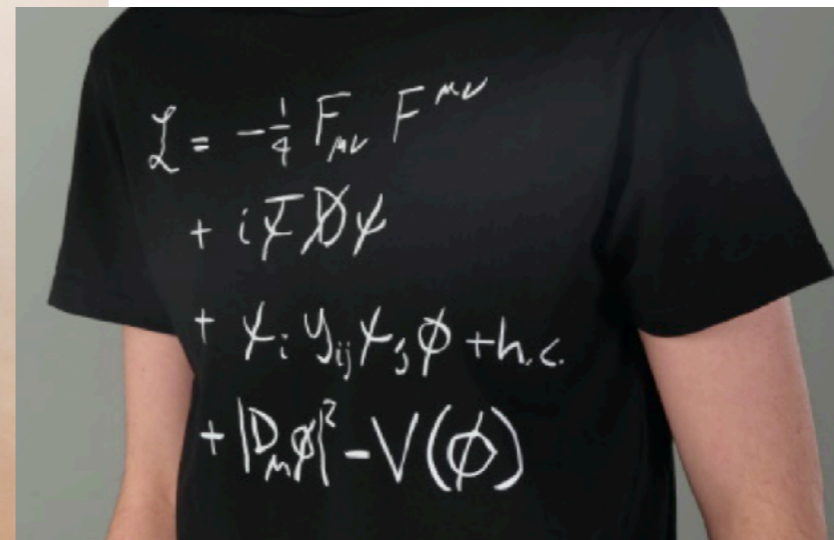


The Standard Model of Particle Physics

Disponibile anche su una tazza, strumento fondamentale del fisico



O su una maglietta...
Una vera rockstar

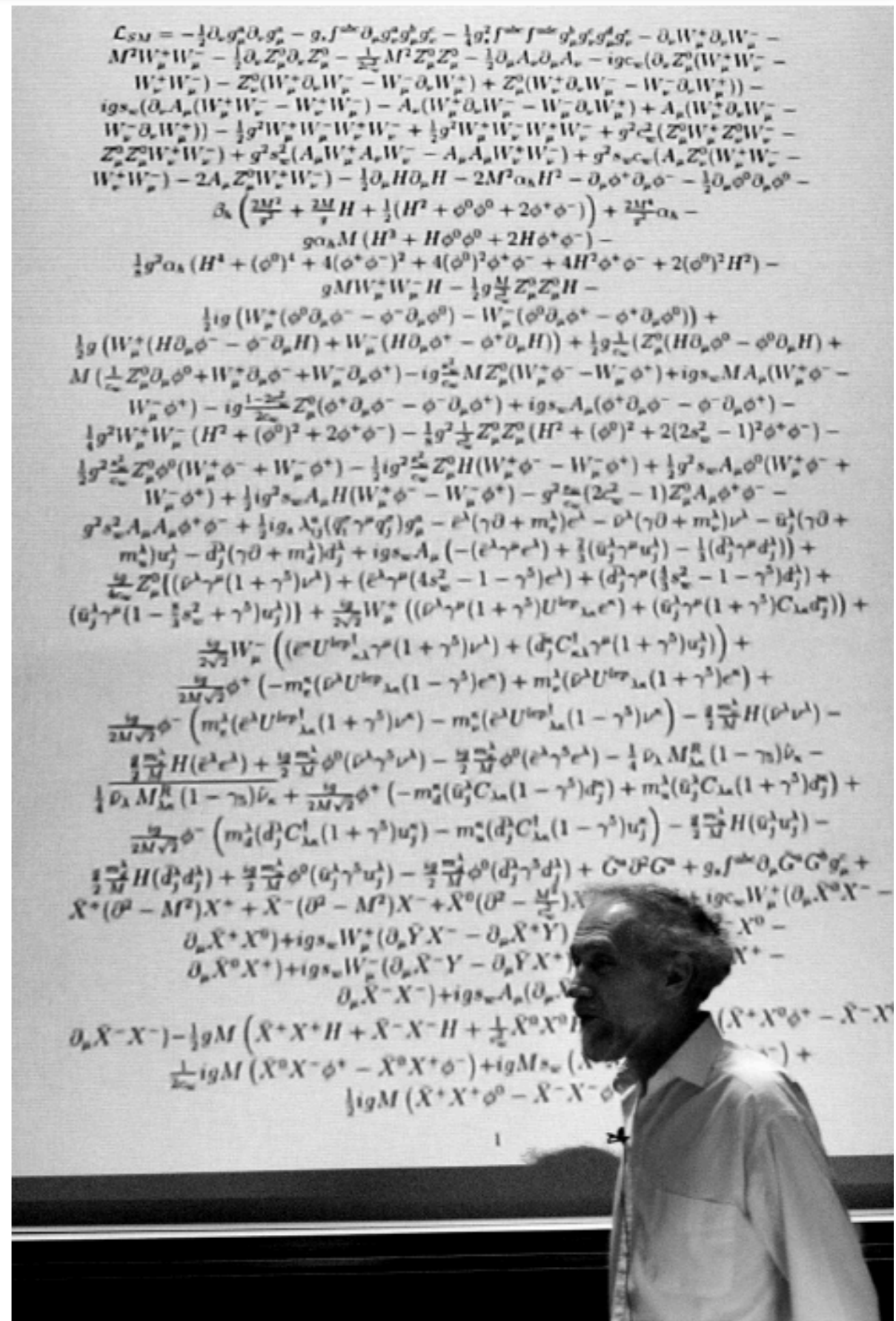


The Standard Model of Particle Physics

Lagrangiana del Modello Standard...
descrive la materia e le forze che la regolano

Andremo in dettaglio termine per termine!

Iniziamo!





**KEEP
CALM
AND**

**era uno
scherzo**

**La fisica delle particelle studia i costituenti
fondamentali dell'universo conosciuto (e non)
e come interagiscono fra loro**

The Standard Model of Particle Physics

Particelle come Onde - Onde come Particelle
 Forze sono mediate anche loro da quanti Sono alla fine tutti campi!

Standard Model of Elementary Particles

	three generations of matter (elementary fermions)			three generations of antimatter (elementary antifermions)			interactions / force carriers (elementary bosons)	
	I	II	III	I	II	III		
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	$-\frac{2}{3}$	$-\frac{2}{3}$	$-\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
	u up	c charm	t top	\bar{u} antiup	\bar{c} anticharm	\bar{t} antitop	g gluon	H higgs
	d down	s strange	b bottom	\bar{d} antidown	\bar{s} antistrange	\bar{b} antibottom	γ photon	
	e electron	μ muon	τ tau	e^+ positron	$\bar{\mu}$ antimuon	$\bar{\tau}$ antitau	Z Z ⁰ boson	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	$\bar{\nu}_e$ electron antineutrino	$\bar{\nu}_\mu$ muon antineutrino	$\bar{\nu}_\tau$ tau antineutrino	W⁺ W ⁺ boson	W⁻ W ⁻ boson

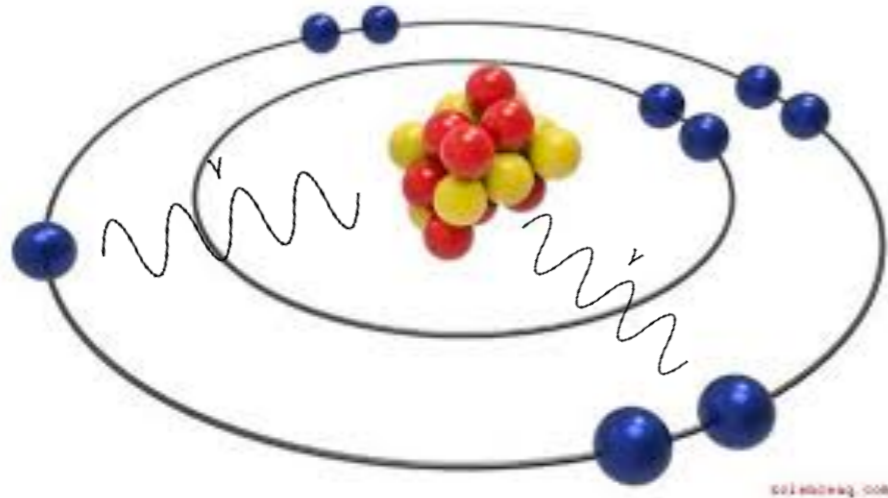
QUARKS (vertical label on the left, purple)

LEPTONS (vertical label on the left, green)

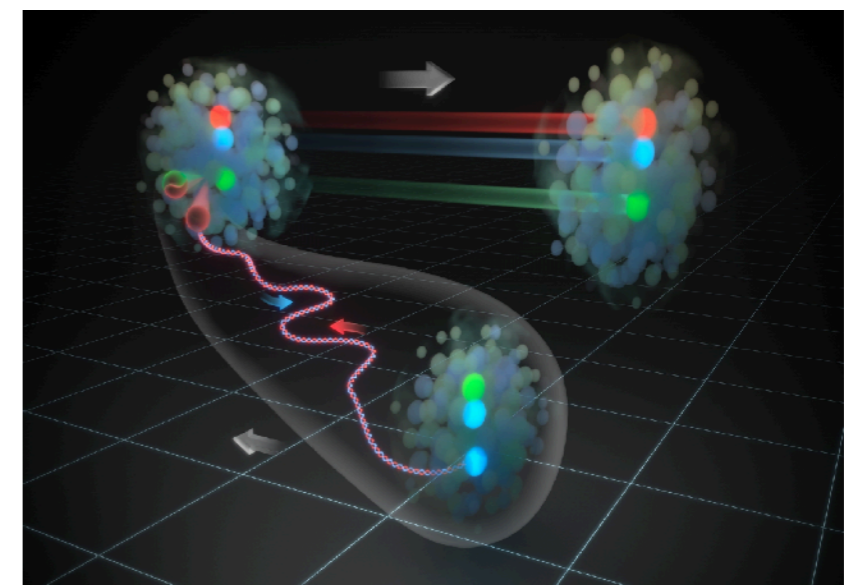
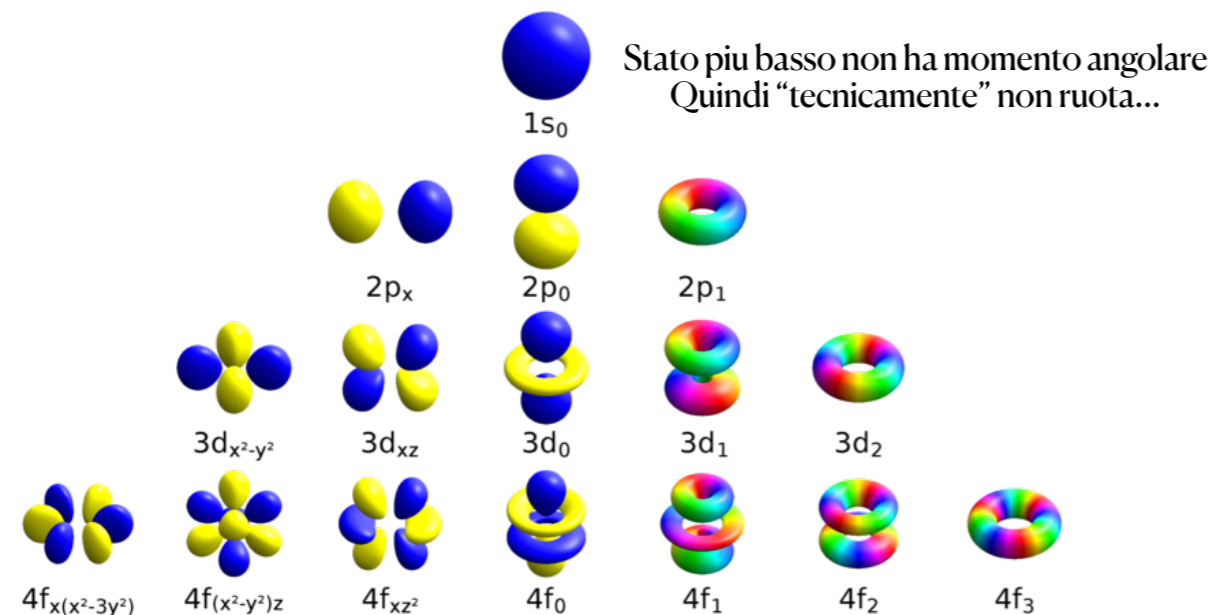
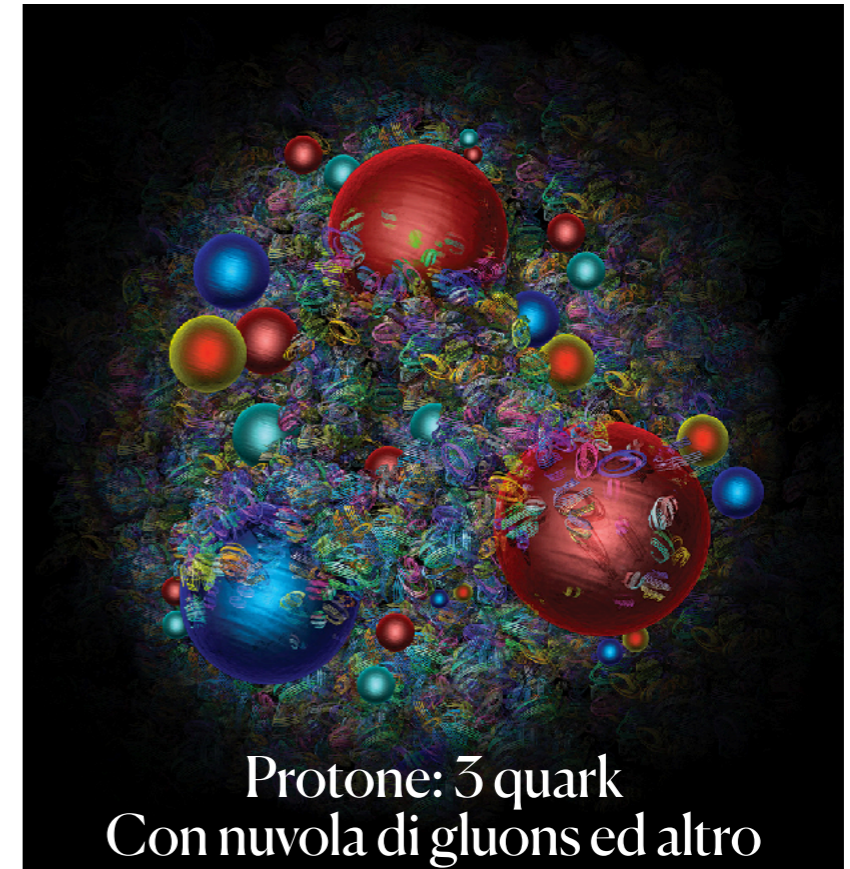
GAUGE BOSONS VECTOR BOSONS (vertical label on the right, red)

SCALAR BOSONS (vertical label on the right, yellow)

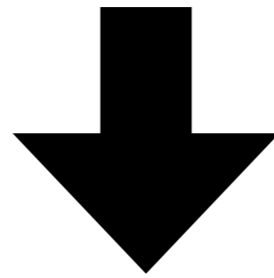
Esempio: l'atomo e il protone



O meglio una rappresentazione un po' più moderna...
 Meccanica quantistica → Nuvole di probabilità



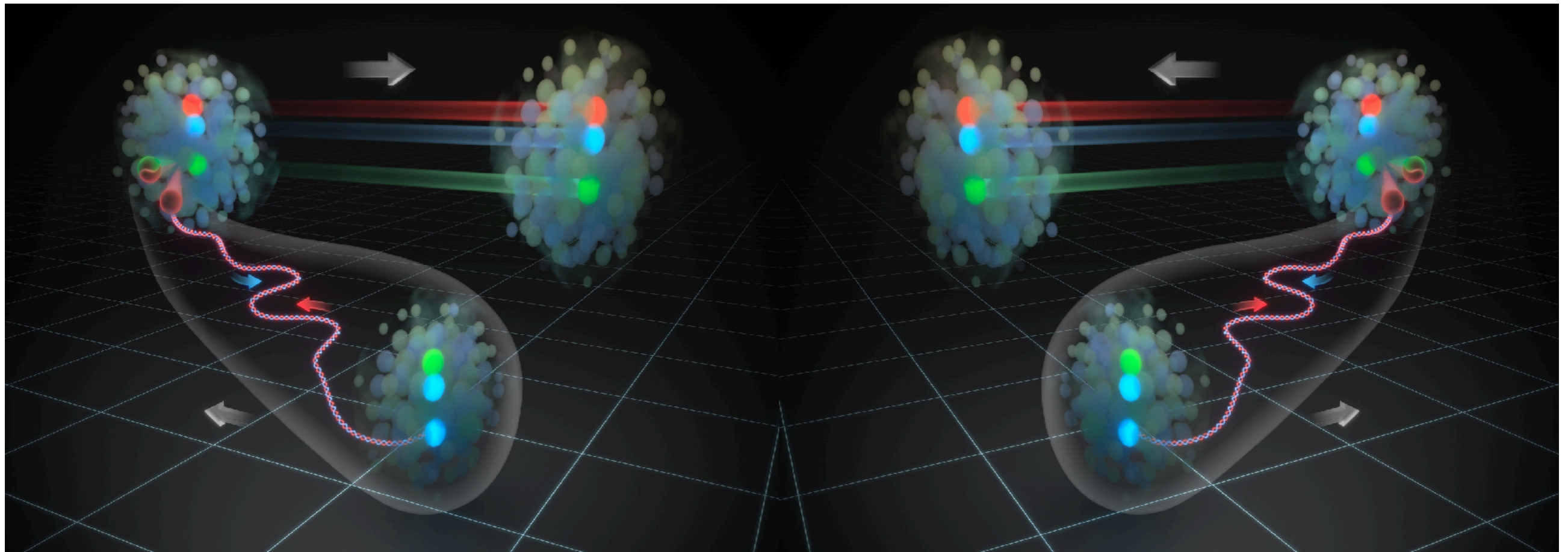
La fisica delle particelle studia i costituenti fondamentali dell'universo conosciuto (e non) e come interagiscono fra loro



**Per farlo abbiamo inventato vari metodi
Esempio: far collidere particelle negli acceleratori**

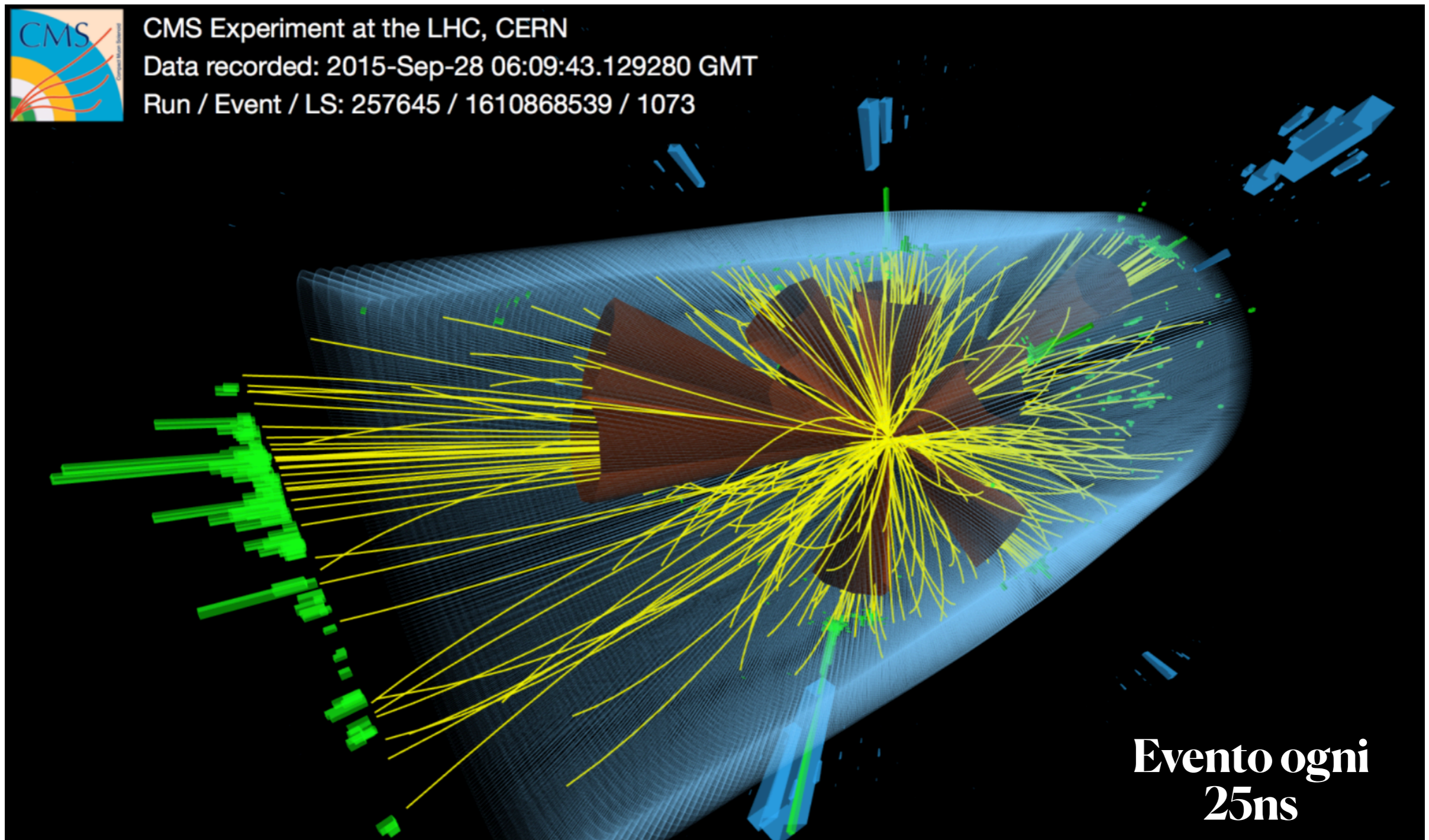
Come studiamo le particelle?

acceleriamo i protoni \rightarrow più energia disponibile
Più energia $==$ più massa
studiamo cosa accade nelle interazioni



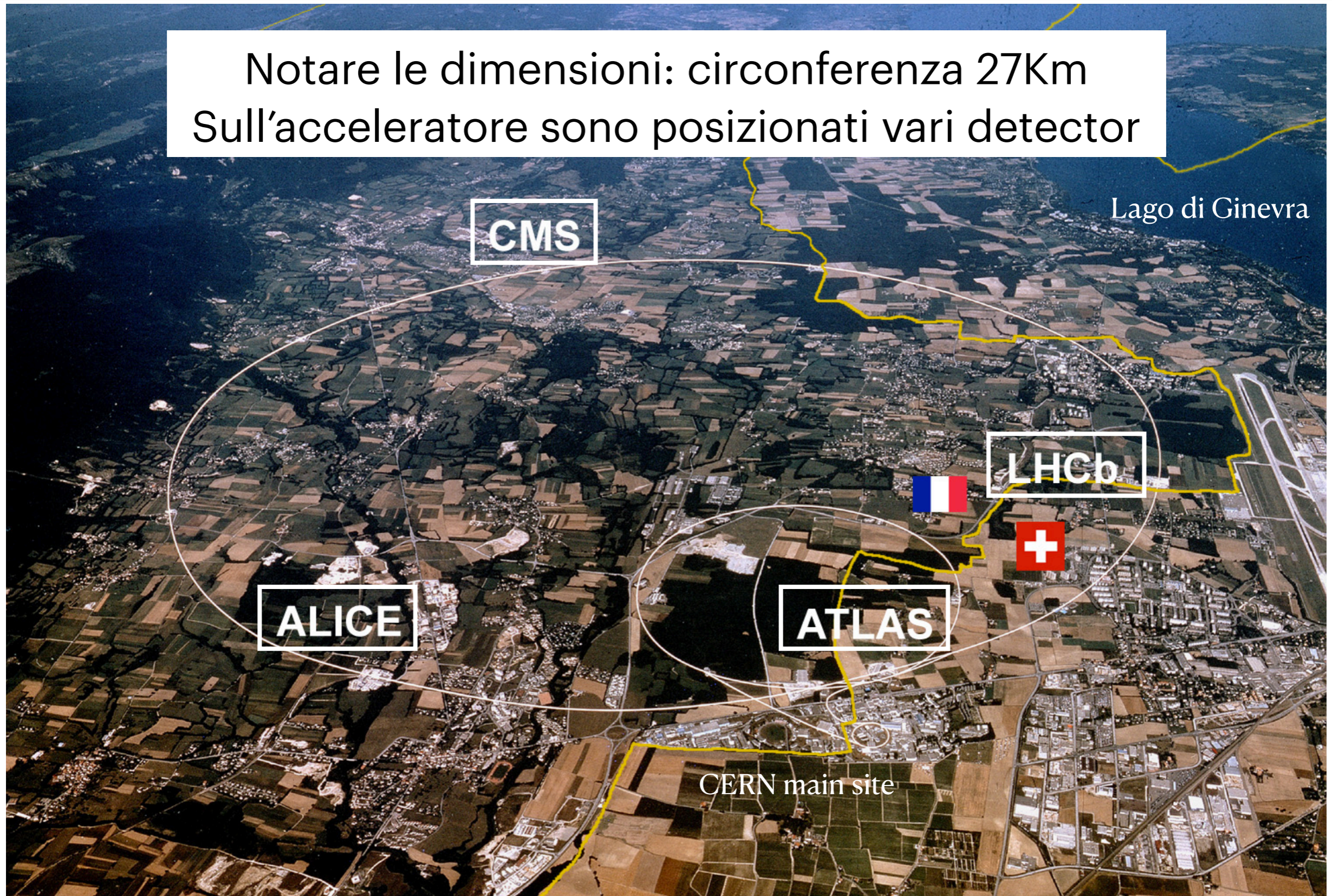
Collisioni e creazione di nuove particelle

Esempio di un evento (ovvero una collisione) con jet multipli osservato dall'esperimento CMS all'LHC

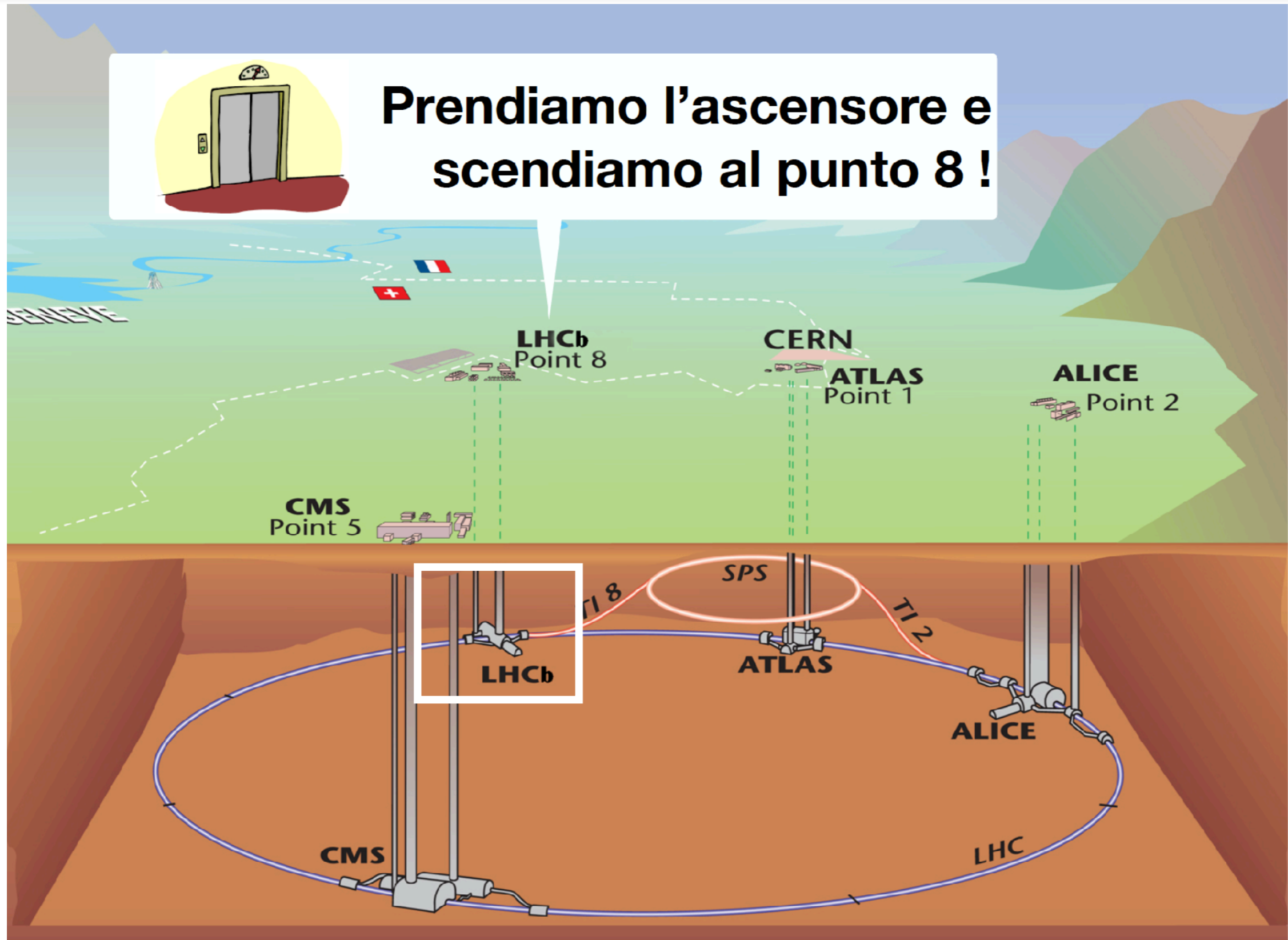


Large Hadron Collider (LHC)

Notare le dimensioni: circonferenza 27Km
Sull'acceleratore sono posizionati vari detector



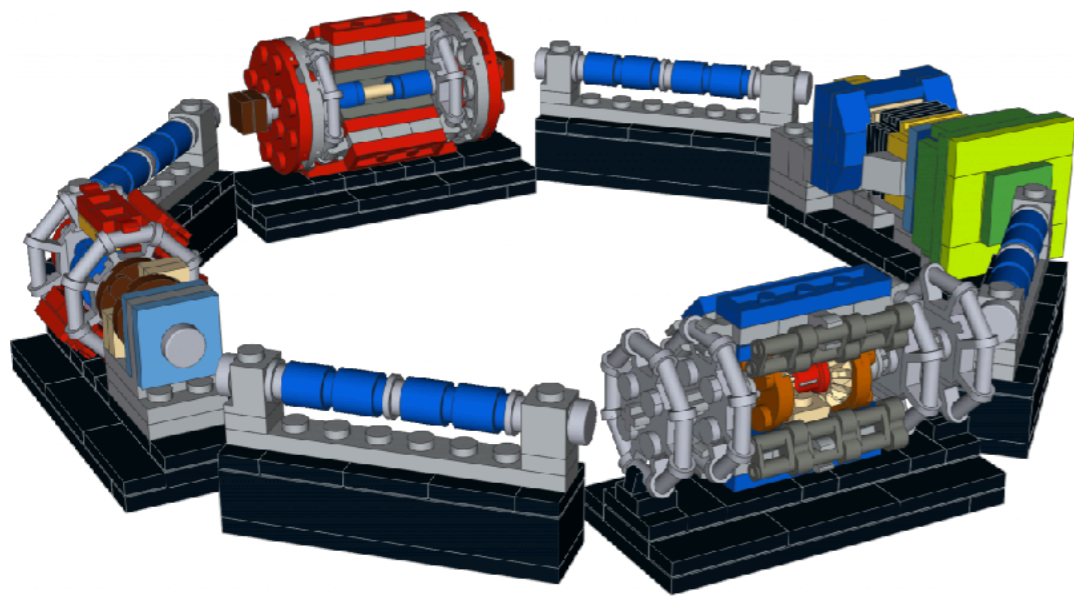
Large Hadron Collider (LHC)



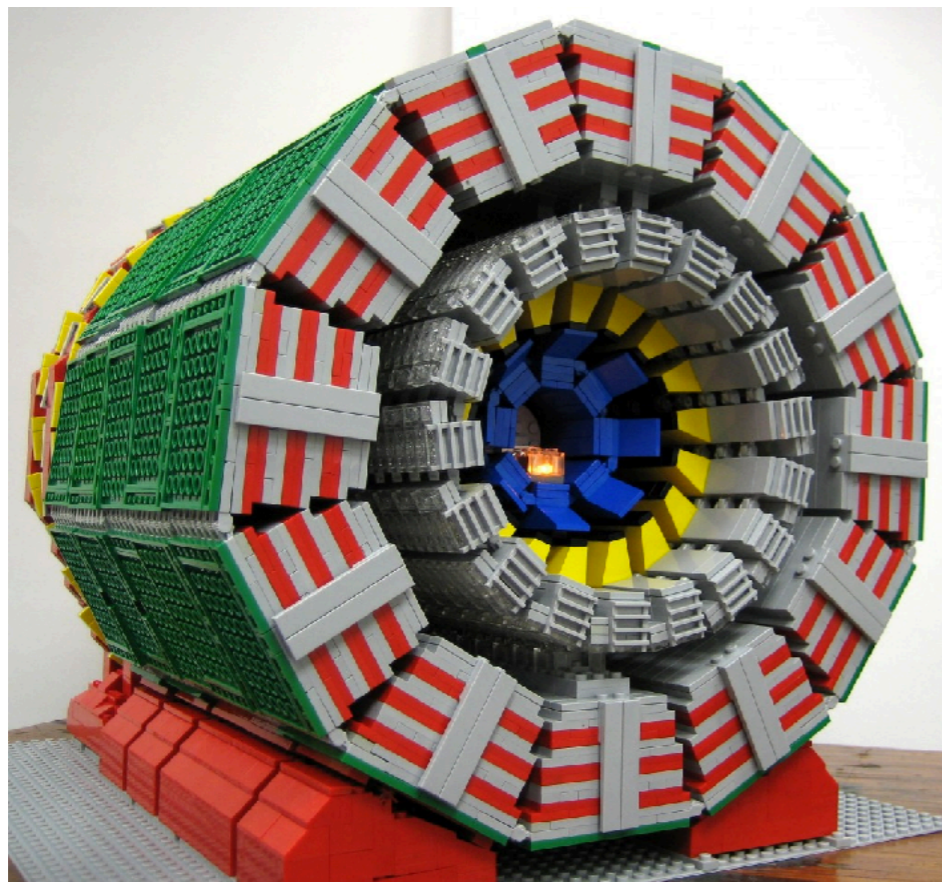
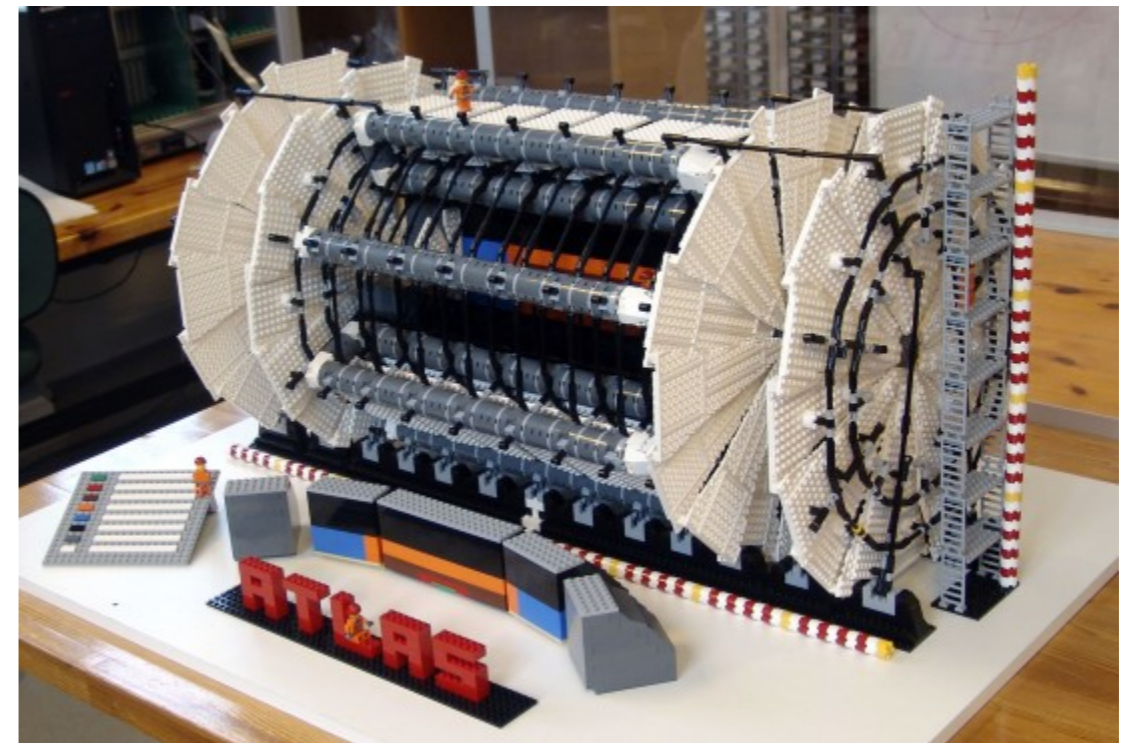
I detector sono macchinari enormi e complessi

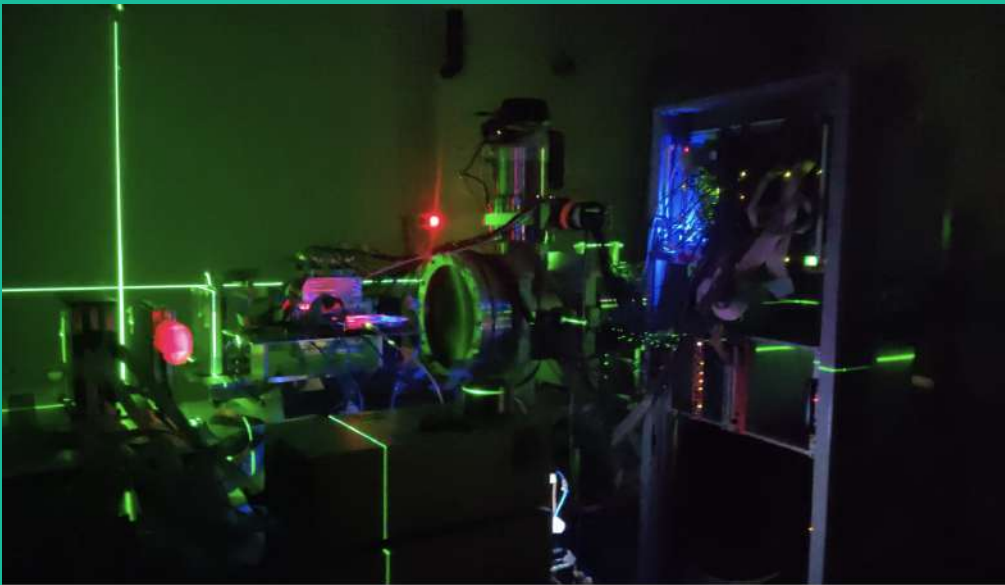


LEGO LHC



Questo ce lo abbiamo al quarto piano!





Nuclear physics for hadrontherapy

Yunsheng Dong & Ilaria Mattei *INFN Milano*

Lab2go

26/05/2025

Cross section

Angular differential and elemental fragmentation cross sections of a 400 MeV/u ^{16}O beam on a graphite target with the FOOT experiment

R. Ridolfi^{10,11}, M. Toppi^{22,12}, A. Mengarelli¹⁰, M. Dondi^{10,11}, A. Alexandrov³, B. Alpat⁴, G. Ambrosi⁴, S. Argirò^{5,6}, M. Barbanera⁴, N. Bartosik⁶, G. Battistoni⁷, M.G. Bisogni^{8,9}, V. Boccia^{2,3}, F. Cavanna⁶, P. Cerello⁶, E. Ciarrocchi^{8,9}, A. De Gregorio^{13,12}, G. De Lellis^{2,3}, A. Di Crescenzo^{2,3}, B. Di Ruzza¹⁴, M. Donetti^{15,6}, Y. Dong⁷, M. Durante^{2,17}, R. Faccini^{13,12}, V. Ferrero⁶, C. Finck¹⁶, E. Fiorina⁶, M. Francesconi³, M. Franchini^{10,11}, G. Franciosini^{22,12}, G. Galati⁹, L. Galli⁹, M. Ionica⁴, A. Iuliano^{2,3}, K. Kauxheri^{4,27}, A.C. Kraan⁹, C. La Tessa^{34,20}, A. Lauria¹, E. Lopez Torres^{21,6}, M. Magi^{22,12}, A. Manna^{10,11}, M. Marafini^{23,12}, M. Massa⁹, C. Massimi^{10,11}, I. Mattei¹, A. Merighetti¹⁵, T. Minniti^{24,25}, A. Moggi⁹, M.C. Montesi^{23,26}, M.C. Morone^{24,25}, M. Morrocchi^{1,8,9}, S. Muraro⁷, N. Pastrone⁹, V. Patera^{22,12}, F. Peverini^{4,27}, F. Pennazio⁹, C. Pisanti^{10,11}, P. Placidi^{4,28}, M. Pullia¹⁵, L. Ramello^{6,29}, C. Reidel¹⁷, L. Sabatini¹⁸, L. Salvi^{4,27}, C. Sanelli¹⁸, A. Sarti^{22,12}, O. Sato³¹, S. Savazzi¹⁵, L. Scavarda³², A. Schiavi^{22,12}, C. Schuy¹⁷, E. Scifoni²⁰, L. Servoli⁴, G. Silvestre⁴, M. Sitta^{6,30}, R. Spighi¹⁰, E. Spiriti¹⁸, L. Testa^{13,12}, V. Tioukov³, S. Tomassini¹⁸, F. Tommasino^{19,20}, A. Triglio¹⁸, G. Traini¹², G. Ubaldi^{10,11}, A. Valetti^{5,6}, M. Vanstalle¹⁶, U. Weber¹⁷, R. Zarrella^{10,11}, A. Zoccoli^{10,11} and M. Villa^{10,11}

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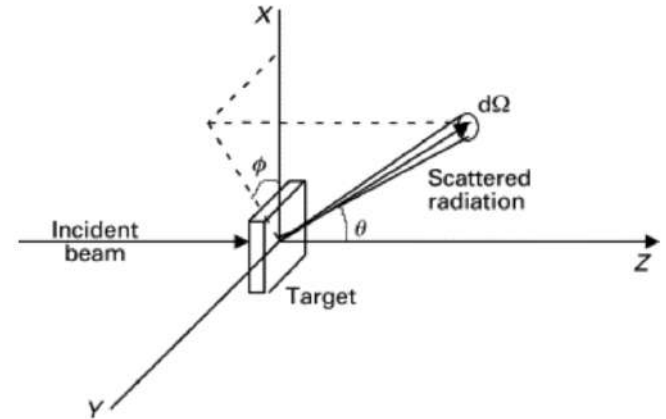
³¹Nagoya University, Department of Physics, Nagoya, Japan

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³³INFN Section of Bari, Bari, Italy and

³⁴University of Miami, Radiation Oncology, Miami, FL, United States

(The FOOT Collaboration)



$$\frac{d\sigma}{d\theta}(Z) = \frac{Y(Z, \theta)}{N_{\text{prim}} \cdot N_{\text{TG}} \cdot \Delta\theta \cdot \epsilon(Z, \theta)}$$

Align FOOT detectors and estimate angular acceptance

Extract fragment yields from TW

Calculate MC efficiencies for fragments

Cross section results

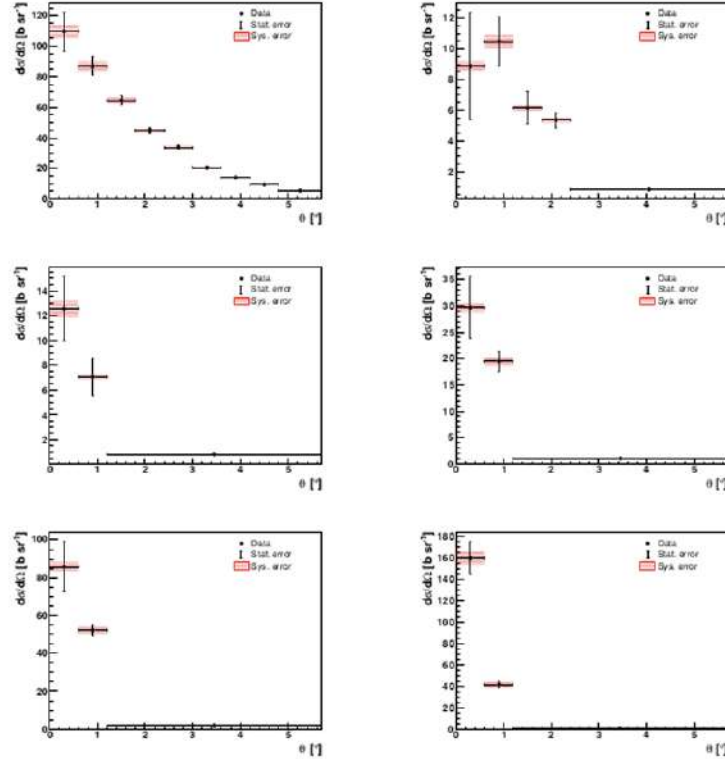


FIG. 6. Angular differential cross sections for fragments $2 \leq Z \leq 7$.

Z	$\theta [^\circ]$	$\sigma \pm \Delta_{stat} \pm \Delta_{sys} [b \text{ sr}^{-1}]$	Δ_{stat}/σ	Δ_{sys}/σ
2	0 – 0.6	$110 \pm 13 \pm 5$	11.6%	4.3%
	0.6 – 1.2	$87 \pm 6 \pm 3$	7.2%	4%
	1.2 – 1.8	$65 \pm 3 \pm 2$	5.2%	3.1%
	1.8 – 2.4	$45 \pm 2 \pm 1$	4.7%	3.2%
	2.4 – 3	$34 \pm 1 \pm 2$	3.6%	4.4%
	3 – 3.6	$20 \pm 1 \pm 1$	4.2%	4.5%
3	0 – 0.6	$9 \pm 4 \pm 0.3$	40%	3.7%
	0.6 – 1.2	$11 \pm 2 \pm 0.4$	15%	4.2%
	1.2 – 1.8	$6 \pm 1 \pm 0.2$	17%	3.1%
	1.8 – 2.4	$5 \pm 0.5 \pm 0.2$	9%	3%
	2.4 – 5.7	$1 \pm 0.04 \pm 0.04$	5%	4.2%
	0 – 0.6	$13 \pm 3 \pm 0.7$	20%	5.3%
4	0.6 – 1.2	$7 \pm 1.5 \pm 0.2$	21%	3.2%
	1.2 – 5.7	$1 \pm 0.1 \pm 0.03$	9%	3.5%
	0 – 0.6	$30 \pm 6 \pm 1$	20%	3.1%
5	0.6 – 1.2	$19 \pm 2 \pm 1$	10%	4.7%
	1.2 – 5.7	$1 \pm 0.1 \pm 0.05$	7%	4.3%
	0 – 0.6	$86 \pm 13 \pm 3$	15%	3%
6	0.6 – 1.2	$52 \pm 3 \pm 2$	5.5%	4.3%
	1.2 – 5.7	$2 \pm 0.1 \pm 0.08$	5.6%	4.6%
	0 – 0.6	$160 \pm 15 \pm 6$	9%	3.9%
7	0.6 – 1.2	$42 \pm 3 \pm 3$	6.8%	7.5%
	1.2 – 5.7	$1 \pm 0.1 \pm 0.03$	13%	4.4%

TABLE II. Angular differential cross section measured in this work. The contribution of the statistical and systematic uncertainties is reported separately. The contribution of the statistical and systematic uncertainties to the final result is visible through the reported relative errors.

Cross section results



MO' ME LO SEGNO PROPRIO

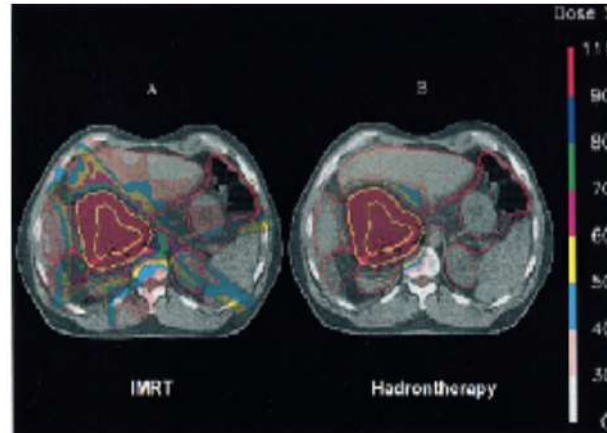
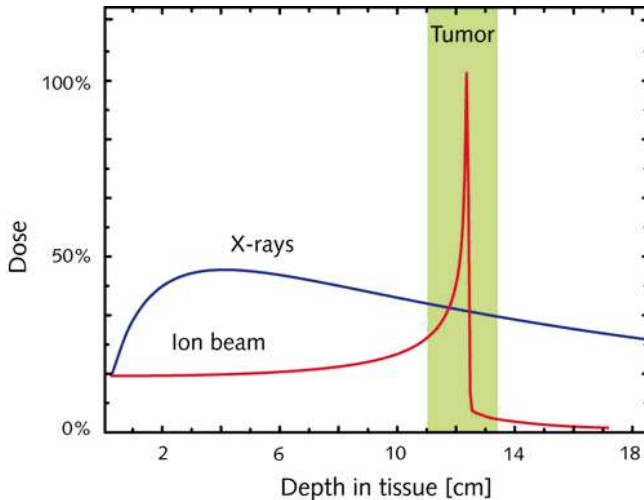


Hadrontherapy

Hadrontherapy: a form of radiotherapy that uses hadrons for the treatment of solid tumours

Main properties:

- Better dose conformation over the tumour volume, minimizing the damage in the healthy tissues
- Enhanced biological effectiveness for heavy ion therapy ($Z > 1$)
- Mainly proton and carbon ion treatment centres



Pancreatic tumor treatment planning

- A: Intensity modulated coplanar photon beam (9 beams)
B: Coplanar proton beam (4 beams)

Particle therapy brief timeline

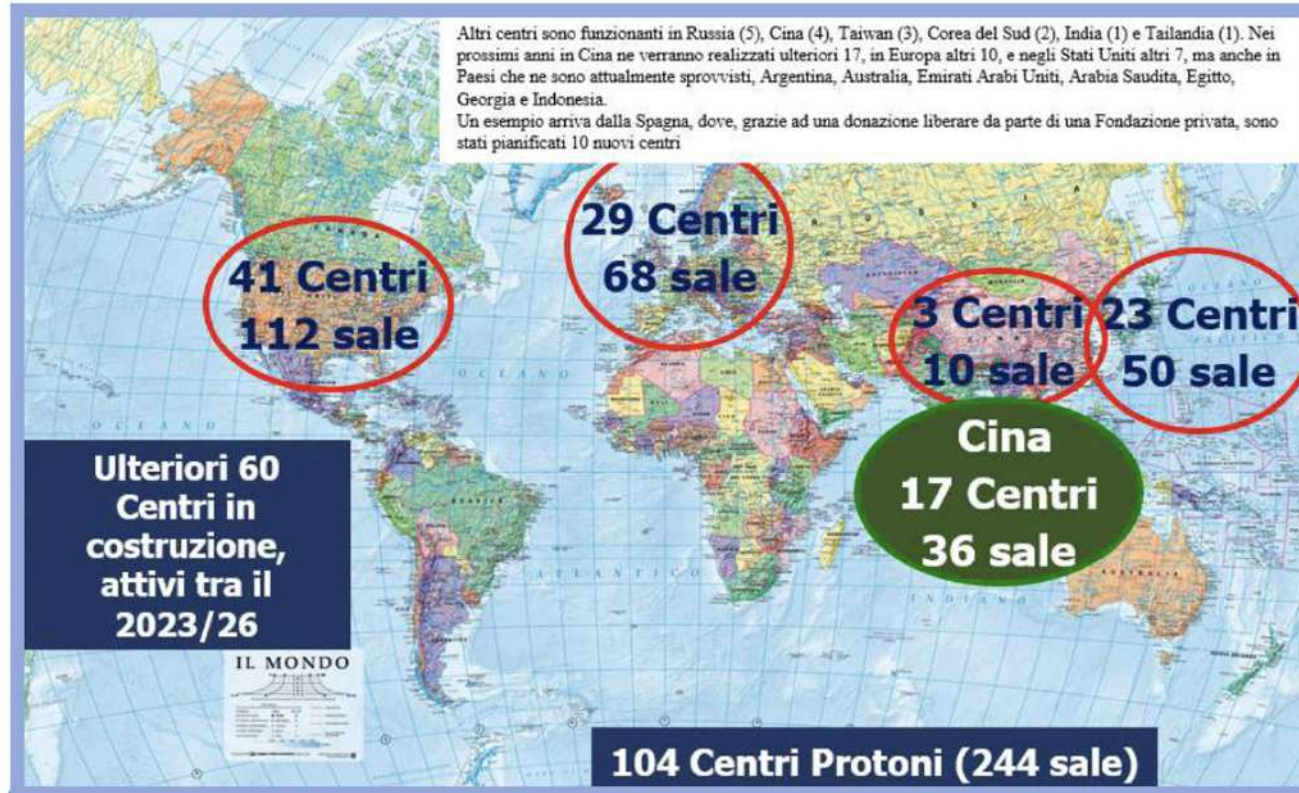


- 1954 – Berkeley treats the first patient and begins extensive studies with various ions
- 1957 – first patient treated with protons in Europe at Uppsala
- 1961 – collaboration between Harvard Cyclotron Lab. and Massachusetts General Hospital
- 1993 – patients treated at the first hospital-based facility at Loma Linda
- 1994 – first facility dedicated to carbon ions operational at HIMAC, Japan
- 2009 – first European proton-carbon ion facility starts treatment in Heidelberg
- 2017 – hadrontherapy treatments included in the Italian SSN

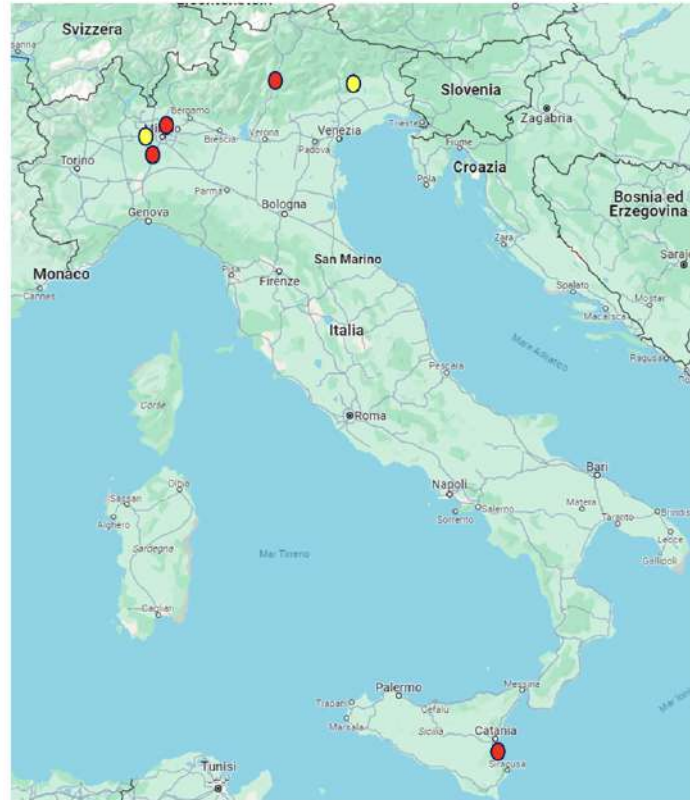


1st TAKE HOME MESSAGE: Science needs time!!!

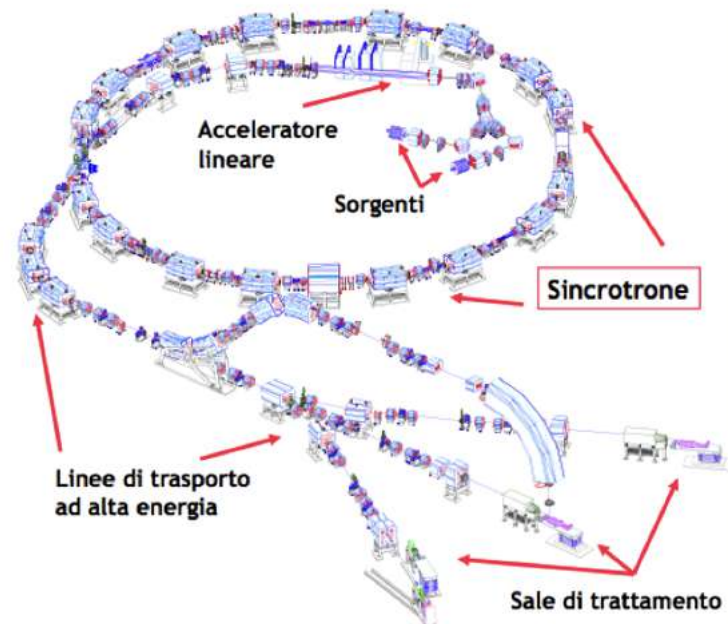
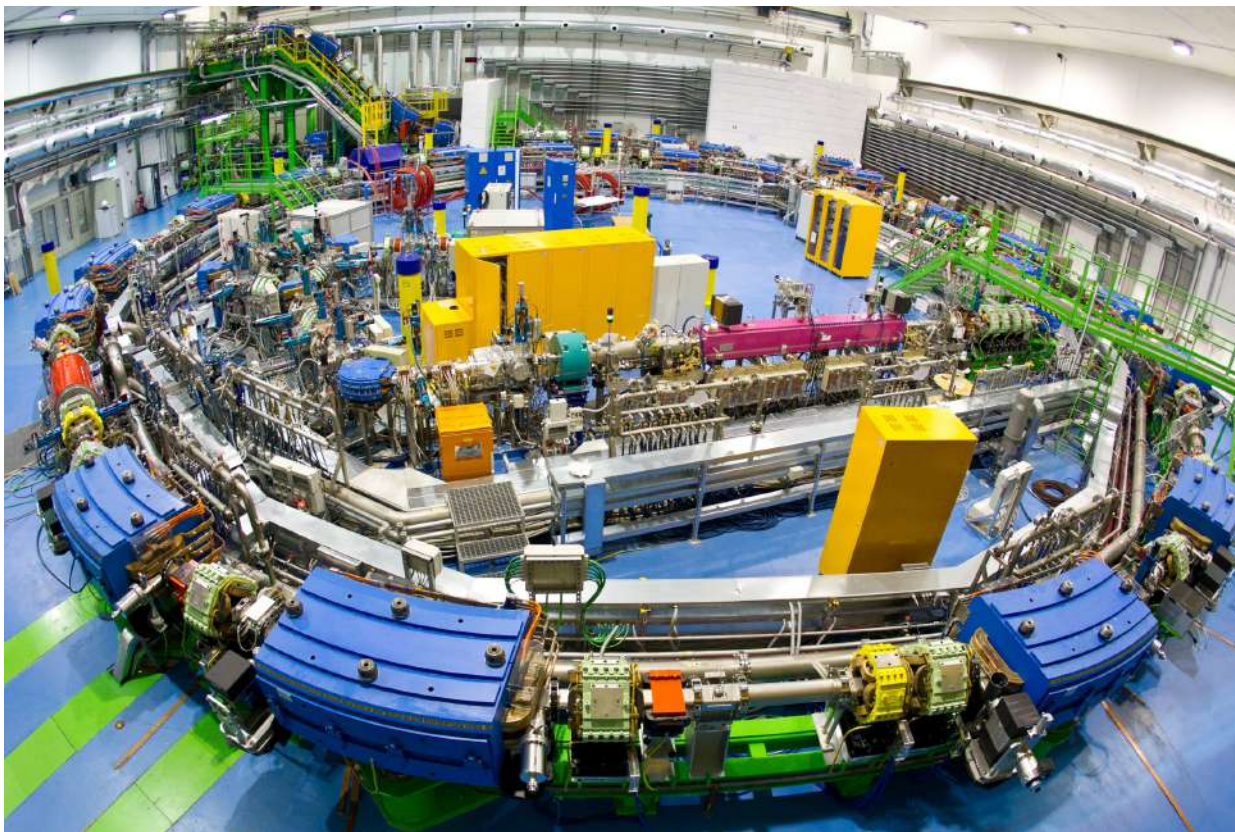
Particle therapy facilities at present



Particle therapy facilities in Italy



- Operating centers
- Centers under construction

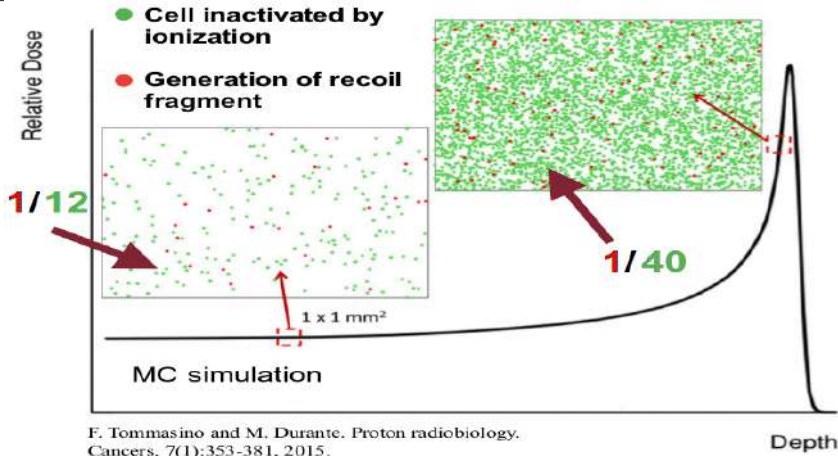


CNAO



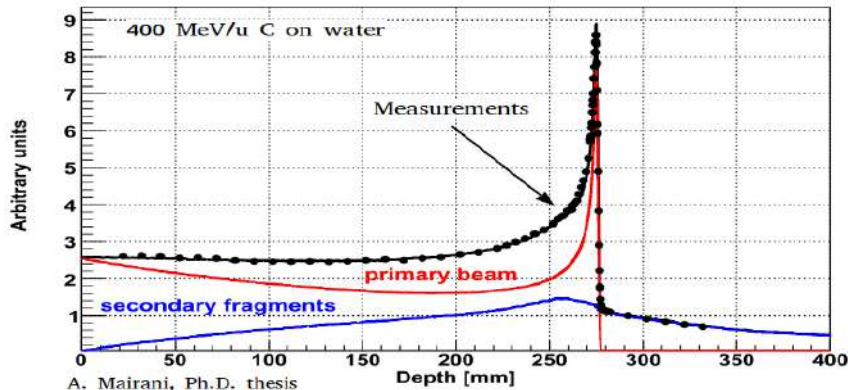
What does hadrontherapy have to do with cross sections?

Nuclear physics (for hadrontherapy)



Nuclear interactions not always included with sufficient details in the treatment planning systems (TPS), especially in proton therapy

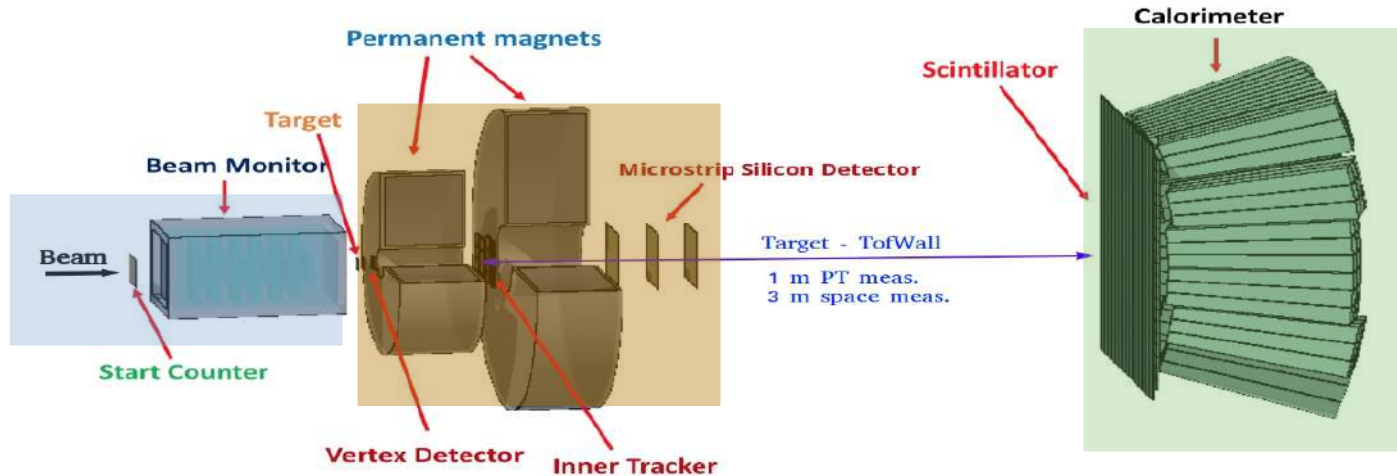
- Target fragmentation in proton therapy (Z=1; 50-250 MeV)
- Projectile fragmentation in heavy ion therapy (Z>1; 50-400 MeV/u)
- Data available with integrated cross sections
- Differential cross sections data only from Ganil (¹²C @ 50 and 95 MeV/u, 2011)



Need of differential cross section data to improve the TPS and explore the possibility to exploit new particles such as ¹⁶O and ⁴He (lack of data especially for ⁴He)

The FOOT experiment

Electronic spectrometer to detect the fragments with $Z \geq 3$ and $\theta < 10^\circ$



Pre target region:

- Plastic scintillator for TOF and trigger measurements
- Drift chamber for the beam direction and position meas.

Tracking region:

- Silicon pixel and strip detectors for track and momentum reco
- Permanent magnet in Halbach conf. $\sim 1.4 \text{ T} \perp$ the beam axys

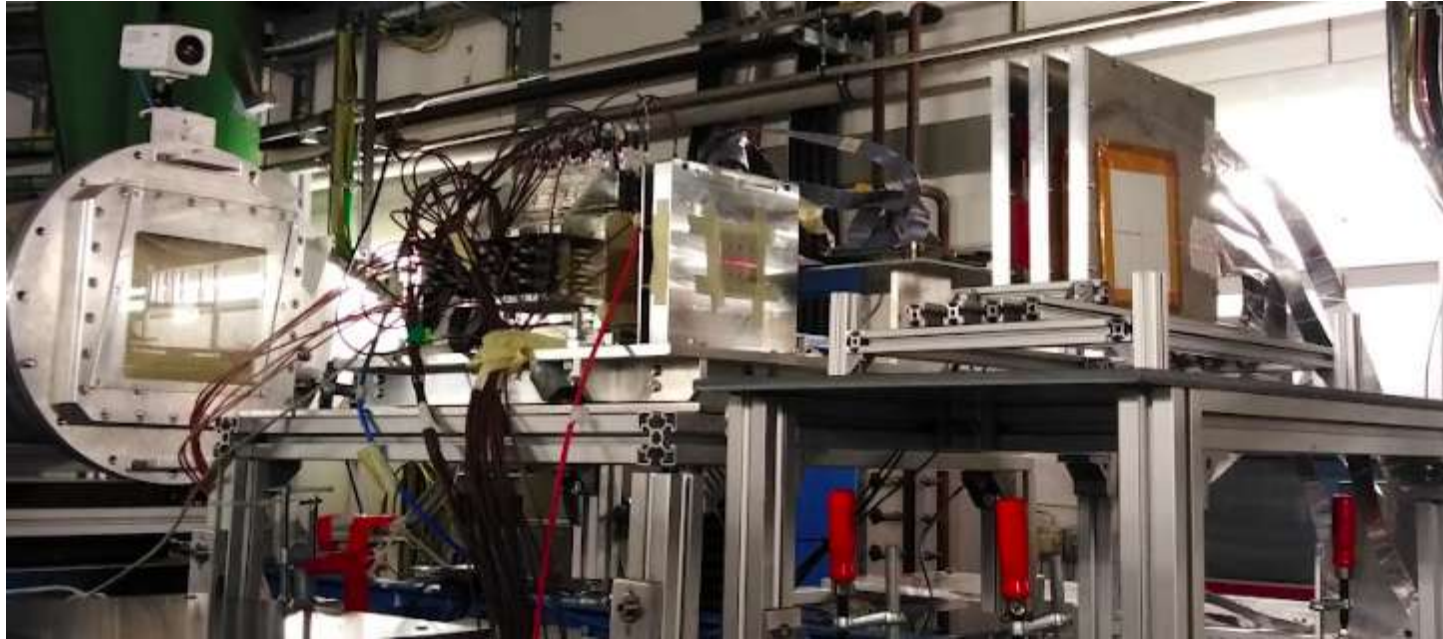
Downstream region:

- Plastic scintillator bars for the TOF and dE/dx measurements
- Calorimeter for the kinetic energy measurement

The FOOT experiment



Electronic spectrometer data takings



» Angular differential and elemental fragmentation cross sections of a 400 MeV/u ¹⁶O beam on a graphite target with the FOOT experiment

» R. Ridolfi^{10,11}, M. Topp^{22,12}, A. Mengoni¹⁰, M. Dondi^{10,11}, A. Alexandrov³, B. Alpat⁴, G. Amheo⁵, S. Argiro¹⁶, M. Barbarano⁸, N. Bartosik⁶, G. Battistoni⁷, M.G. Bisogni¹⁹, V. Boccia^{2,3}, F. Cavanna⁶, P. Cereilo⁶, E. Carrocci¹⁷, A. De Gregorio^{10,12}, G. De Lella^{1,3}, A. Di Crescenzo²⁰, B. Di Ruzza¹⁴, M. Donetti¹⁵, Y. Dong¹, M. Durana^{6,17}, R. Faccini^{10,12}, V. Ferrero⁶, C. Fiano⁶, E. Fiorini⁶, M. Francesconi⁵, M. Franzini^{10,11}, G. Francosini^{22,12}, G. Galati¹, L. Galli³, M. Louica⁴, A. Lullusa²⁰, K. Kauch^{18,27}, A.C. Krauss⁹, C. La Tessa^{10,20}, A. Lauria^{2,3}, E. Lopez Torres^{21,6}, M. Magi^{22,12}, A. Manna^{10,11}, M. Marafini^{23,12}, M. Maso⁹, C. Massimi^{10,12}, I. Mattei⁷, A. Meregaglia¹⁰, T. Mimiti¹⁰, A. Moggi⁶, M.C. Mostini¹⁰, M.C. Moroni^{24,25}, M. Morrocchi¹⁶, S. Munari⁷, N. Pastore⁶, V. Patrocchi^{2,12}, F. Poverini¹⁰, F. Puzanov⁶, C. Puzanov^{10,11}, P. Piacitelli²⁸, M. Pullia¹⁵, L. Ramello²⁹, C. Reddel¹, L. Sabatini¹⁴, L. Saba^{12,27}, C. Saccelli¹⁸, A. Sarti^{22,12}, O. Sato³¹, S. Savazzi¹⁰, L. Scavarda²⁰, A. Schiavo^{22,12}, C. Schuy¹⁷, E. Scifoni²⁰, L. Servizi⁴, G. Silvestre⁴, M. Sitta^{6,30}, R. Spighi¹⁰, E. Spiri¹⁰, L. Testa^{10,12}, V. Todorov⁴, S. Tomassini¹⁴, F. Tommasino^{10,20}, A. Trillo¹⁰, G. Trini²⁴, G. Urdali^{10,11}, A. Valeri¹⁶, M. Vascotto¹⁴, H. Weber¹, B. Zarrella^{10,11}, A. Zecchi^{10,11} and M. Villa^{10,11}

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» ²⁷University of Perugia, Department of Physics and Geology, Perugia, Italy
» ²⁸University of Piemonte Orientale, Department for Sustainable Development and Ecological Transition, Vercelli, Italy
» ²⁹University of Piemonte Orientale, Department of Science and Technological Innovation, Alessandria, Italy
» ³⁰Nagoya University, Department of Physics, Nagoya, Japan
» ³¹ALTEC, Aerospace Logistic Technology Engineering Company, Corso Marche 78, 10146 Torino, Italy
» ³²INFN Section of Bari, Bari, Italy and
» ³³University of Miami, Radiation Oncology, Miami, FL, United States
» (The FOOT Collaboration)

2nd take home message:

“Physics is like sex: sure, it may give some practical results, but that's not why we do it.”

– Richard P. Feynman





Did you enjoy the Lab2go experience?

Lab2go

LAB2GO È UNA ... PAZZESCA



92 MINUTI DI APPLAUSI !

Scientists (what people think)

Some people think scientists exclaim



When doing experiments.

Elemental fragmentation cross sections for a ^{16}O beam of 400 MeV/u kinetic energy interacting with a graphite target using the FOOT ΔE -TOF detectors

M. Toppi^{1,2}, A. Sarti^{1,3}, A. Alexandrov^{4,5}, B. Alpat⁶, G. Ambrosi⁶, S. Argirò^{7,8}, R. A. Diaz⁹, M. Barbanera⁶, N. Bartosik⁸,

Contents lists available at ScienceDirect

 Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima



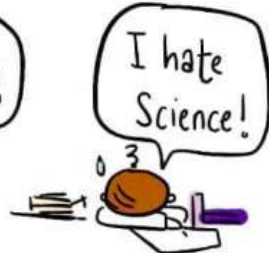
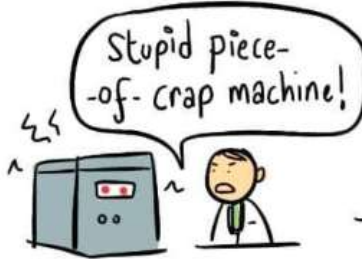
The Drift Chamber detector of the FOOT experiment: Performance analysis and external calibration

Dong Yunsheng^{8,23,*}, Silvestre Gianluigi^{11,24}, Colombi Sofia^{15,16}, Alexandrov Andrey^{10,19,33,34}, Alpat Behcet¹¹, Ambrosi Giovanni¹¹, Argirò Stefano^{28,17}, Artech Diaz Raul³⁰, Barbanera Mattia^{4,35}, Bartosik Nazar¹⁷, Belcari Nicola^{3,2}, Bellinzona Elettra¹⁵, Biondi Silvia^{5,20}, Bisogni Maria Giuseppina^{3,2}, Bruni Graziano⁵, Carra Pietro^{3,2}, Cerello Piergiorgio¹⁷, Ciacciochi Eberhard^{3,2}, Clozza Alberto⁷, De Lellis Giovanni^{10,19}, Del Guerra Alberto^{3,2}



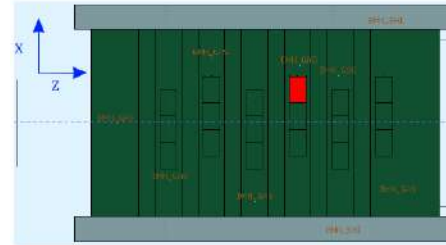
Scientists (reality)

But they're way more likely to say...



@twisteddoodles

Channel lost



- The capacitors used in the voltage stabilizer circuit have been damaged.
- During the substitution of the capacitors, one sense wire of a cell has been broken and it has been extracted.

3rd take home message: physics (actually, not just physics) is trial and error. The important thing is to have fun

Scientists (reality)



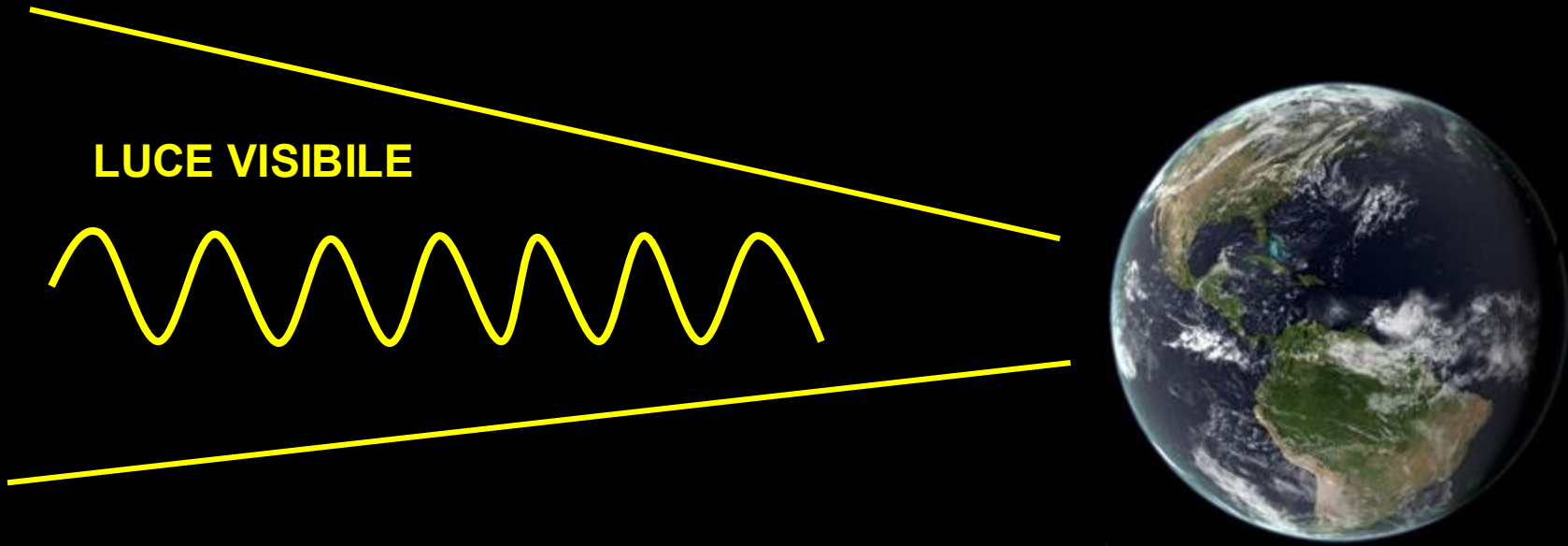
That's all Folks!



RAGGI COSMICI

Lab2go
26/05/2025

Lorenzo Apollonio
lorenzo.apollonio@unimi.it



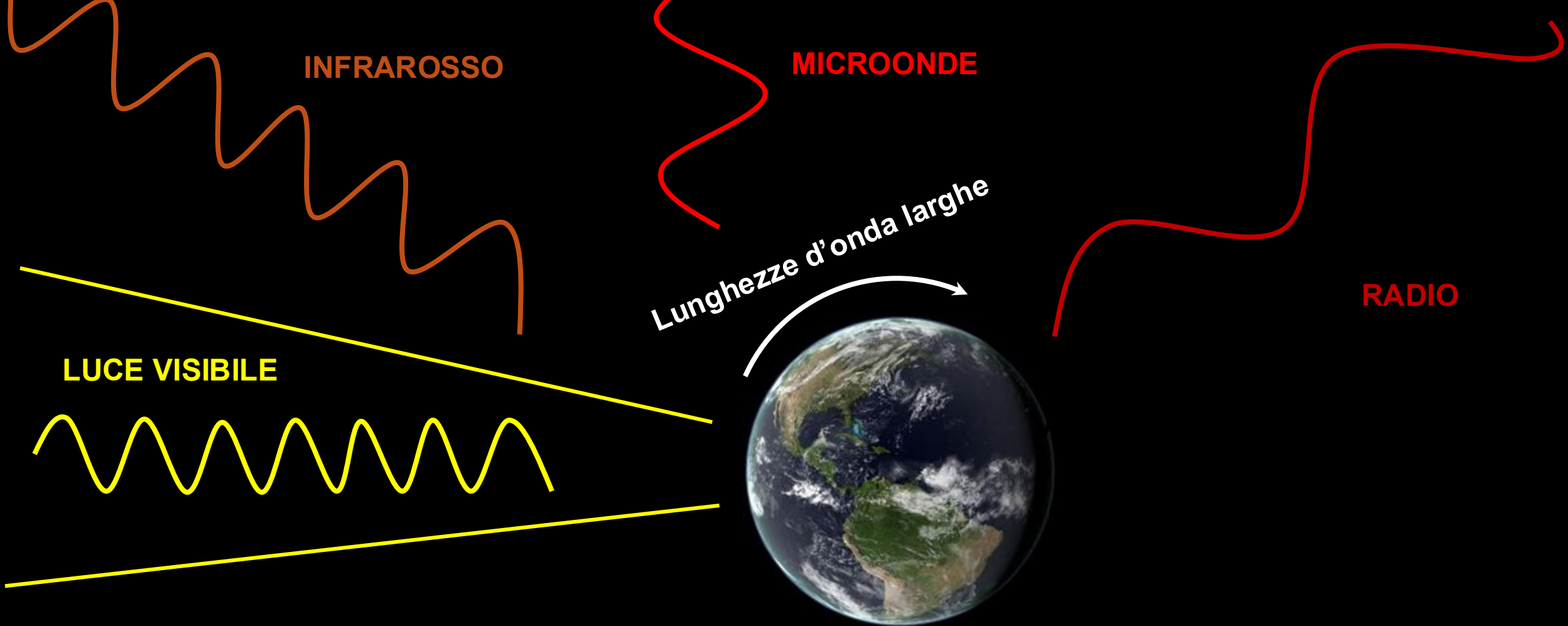
INFRAROSSO

MICROONDE

Lunghezze d'onda larghe

RADIO

LUCE VISIBILE



INFRAROSSO

MICROONDE

RADIO

LUCE VISIBILE

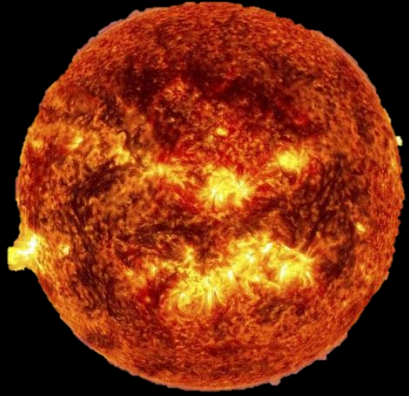
Lunghezze d'onda larghe

ULTRA VIOLETTO

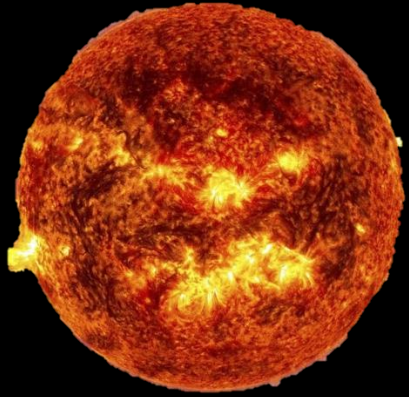
Lunghezze d'onda corte

γ -RAYS

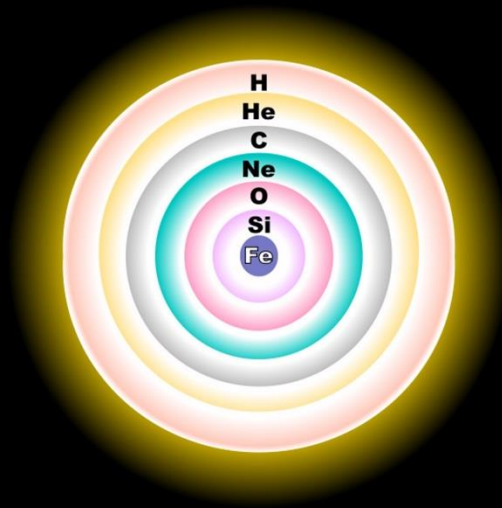
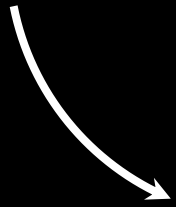
X-RAYS



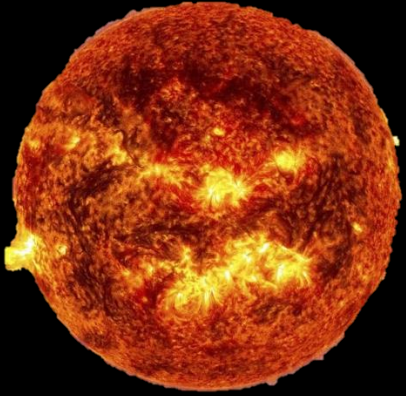
**Una stella è un ambiente
vivo e brucia elementi
leggeri per formare
elementi più pesanti che
bloccano il collasso su se
stessa**



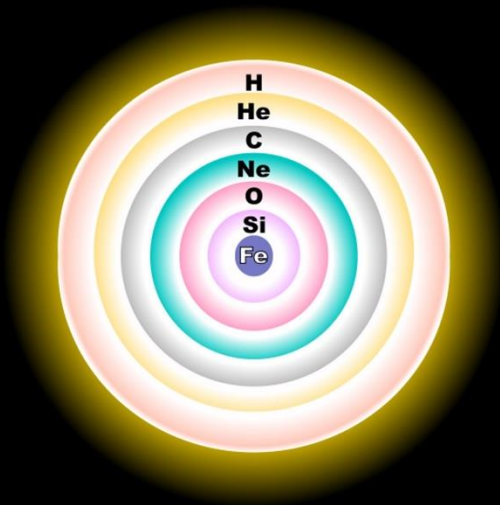
**Una stella è un ambiente
vivo e brucia elementi
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elementi più pesanti che
bloccano il collasso su se
stessa**



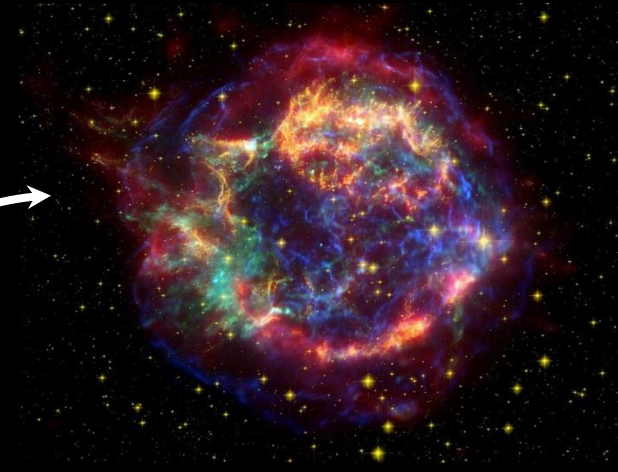
**Dopo il ferro le stelle non
riescono a produrre più
elementi pesanti da elementi
leggeri**



**Una stella è un ambiente
vivo e brucia elementi
leggeri per formare
elementi più pesanti che
bloccano il collasso su se
stessa**

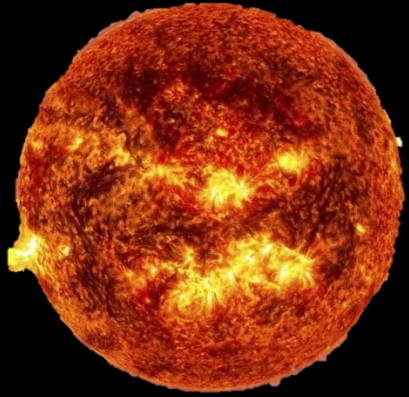


**Dopo il ferro le stelle non
riescono a produrre più
elementi pesanti da elementi
leggeri**

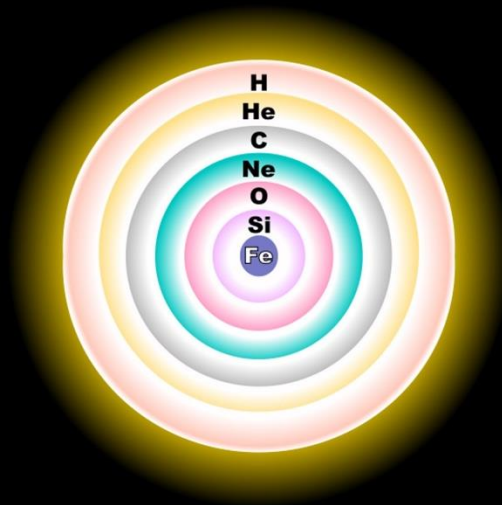


**Dopo che non riesce più a
produrre elementi pesanti la
stella inizia a collassare su
se stessa.**

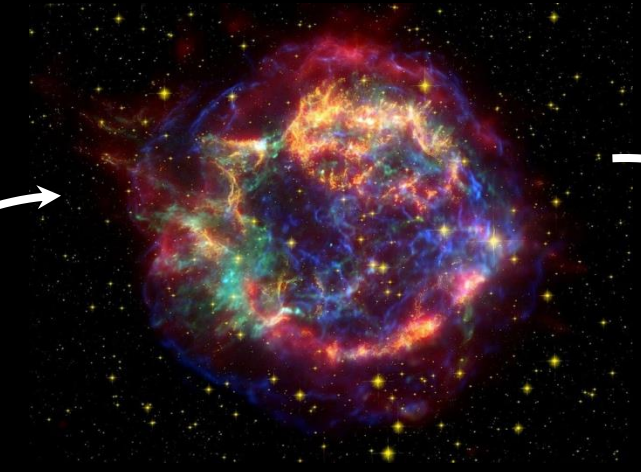
**Questo processo porta
all'emissione del materiale
stellare tramite
un'esplosione**



Una stella è un ambiente vivo e brucia elementi leggeri per formare elementi più pesanti che bloccano il collasso su se stessa



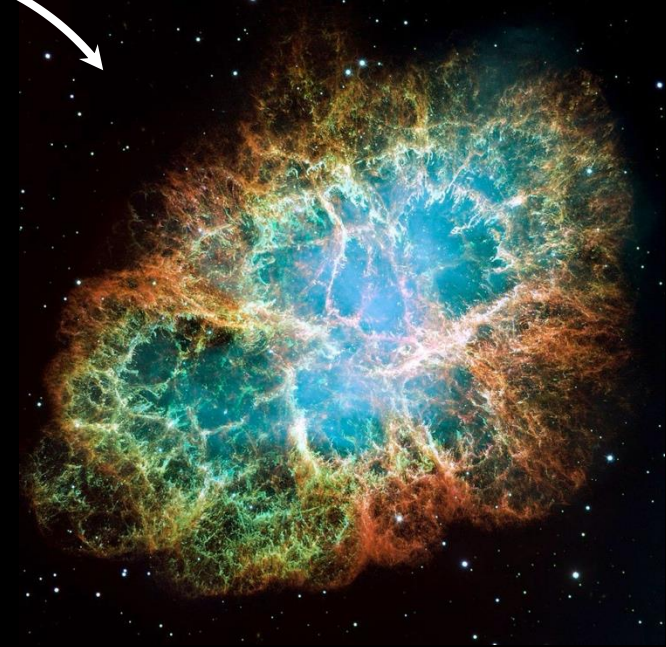
Dopo il ferro le stelle non riescono a produrre più elementi pesanti da elementi leggeri



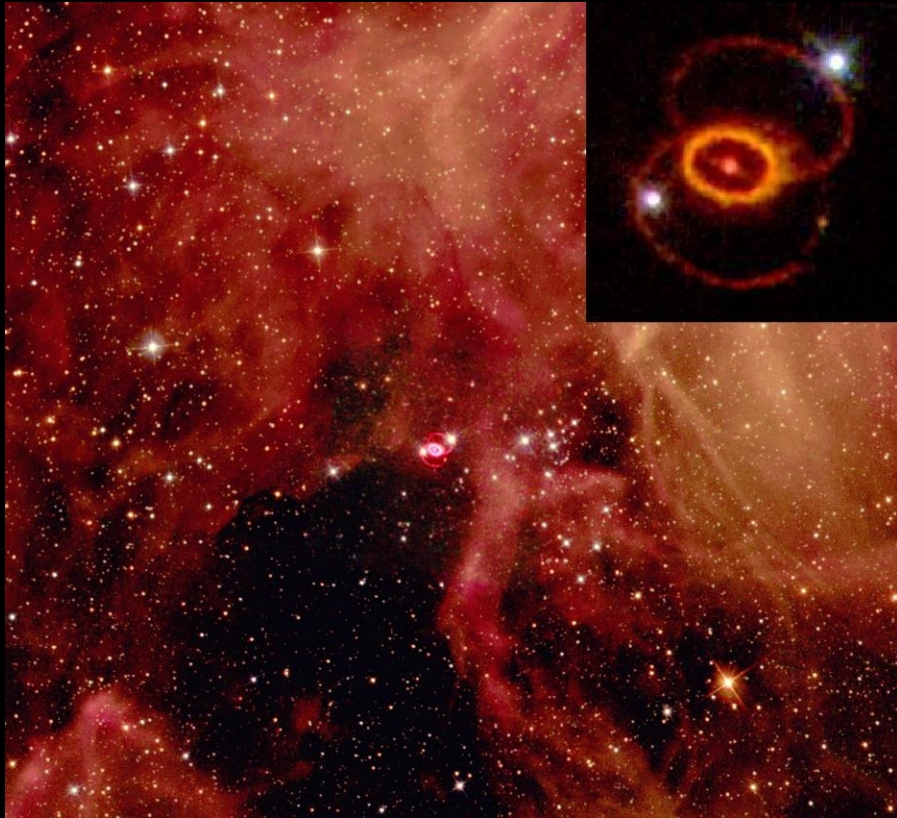
Dopo che non riesce più a produrre elementi pesanti la stella inizia a collassare su se stessa.

Questo processo porta all'emissione del materiale stellare tramite un'esplosione

L'esplosione di una stella si chiama Supernova e può portare alla formazione di una stella di neutroni o un buco nero!

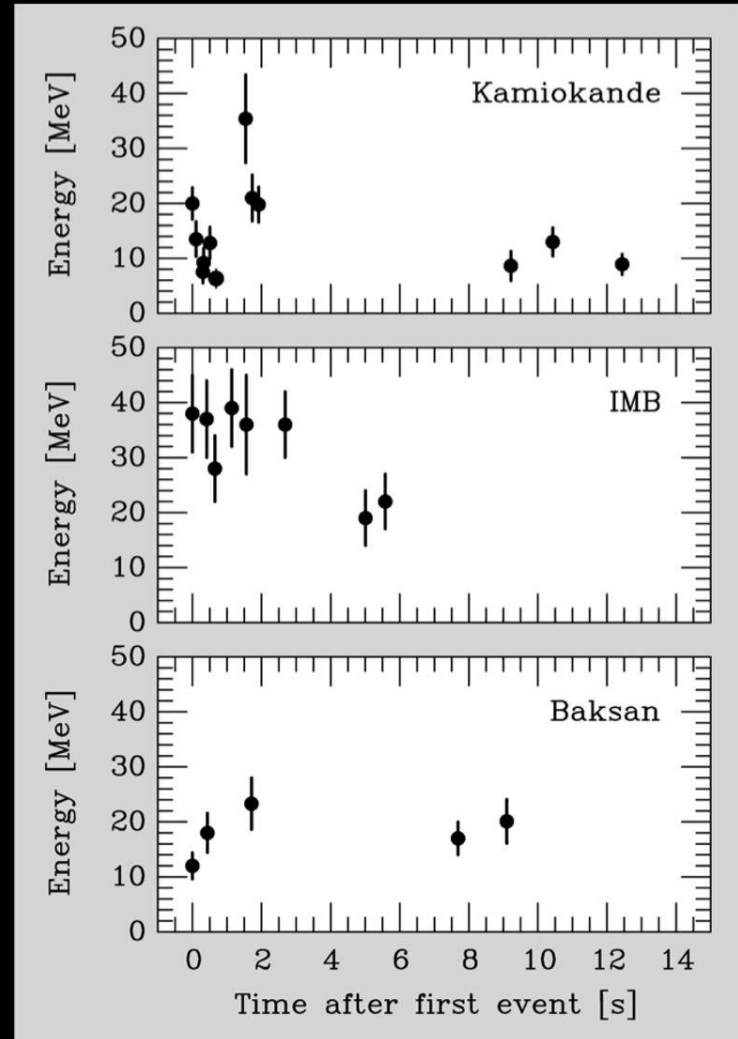


SN 1987 A

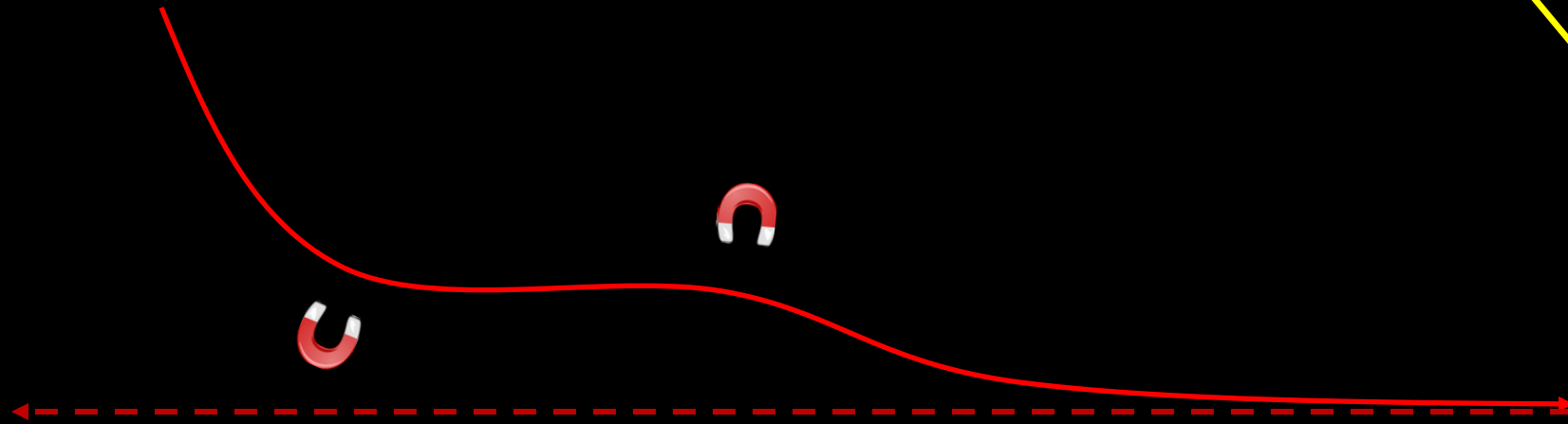
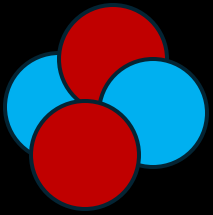


**GRANDE NUBE
DI MAGELLANO**

**ABBIAMO VISTO ANCHE I
NEUTRINI PROVENIRE DA
QUESTA SUPERNOVA!**



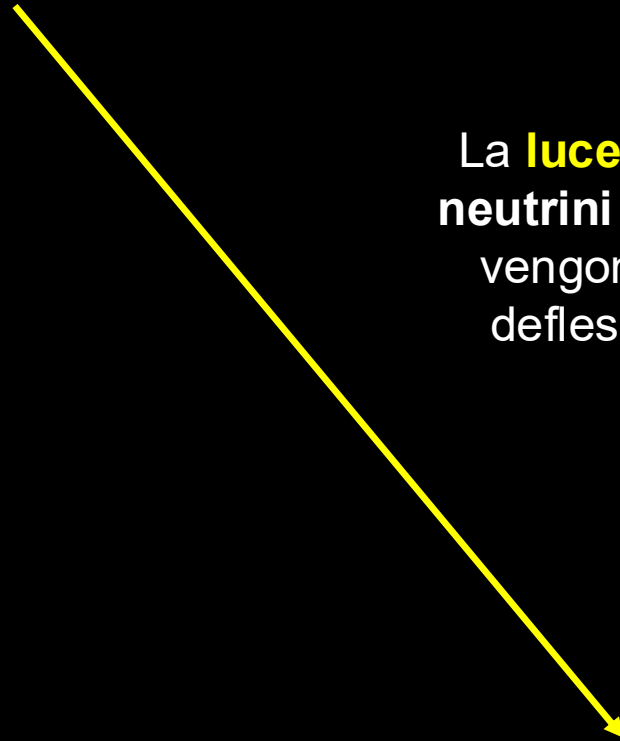
Nuclei atomici che viaggiano nell'Universo



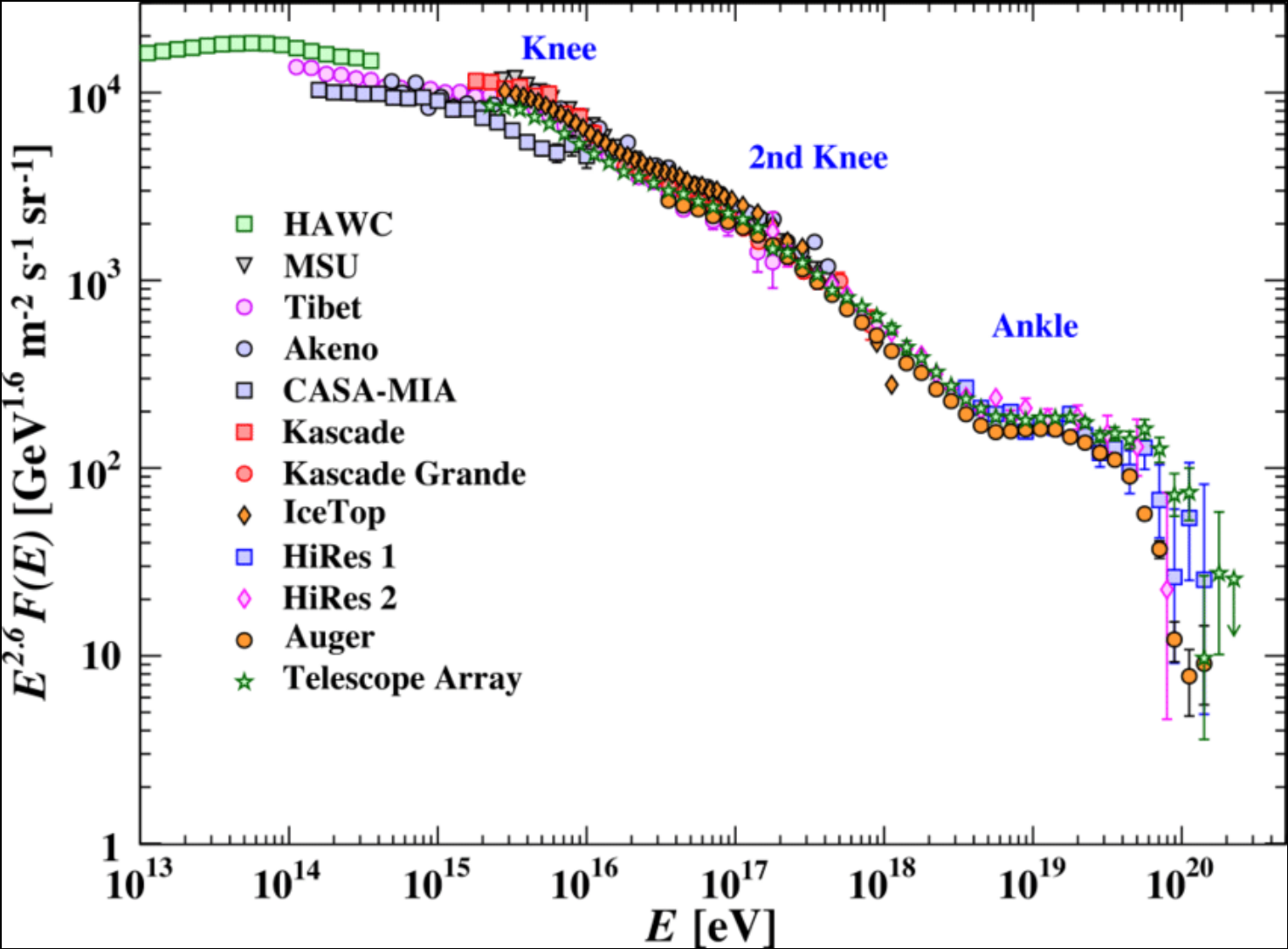
Sappiamo da che direzione arrivano ma non cosa li emette



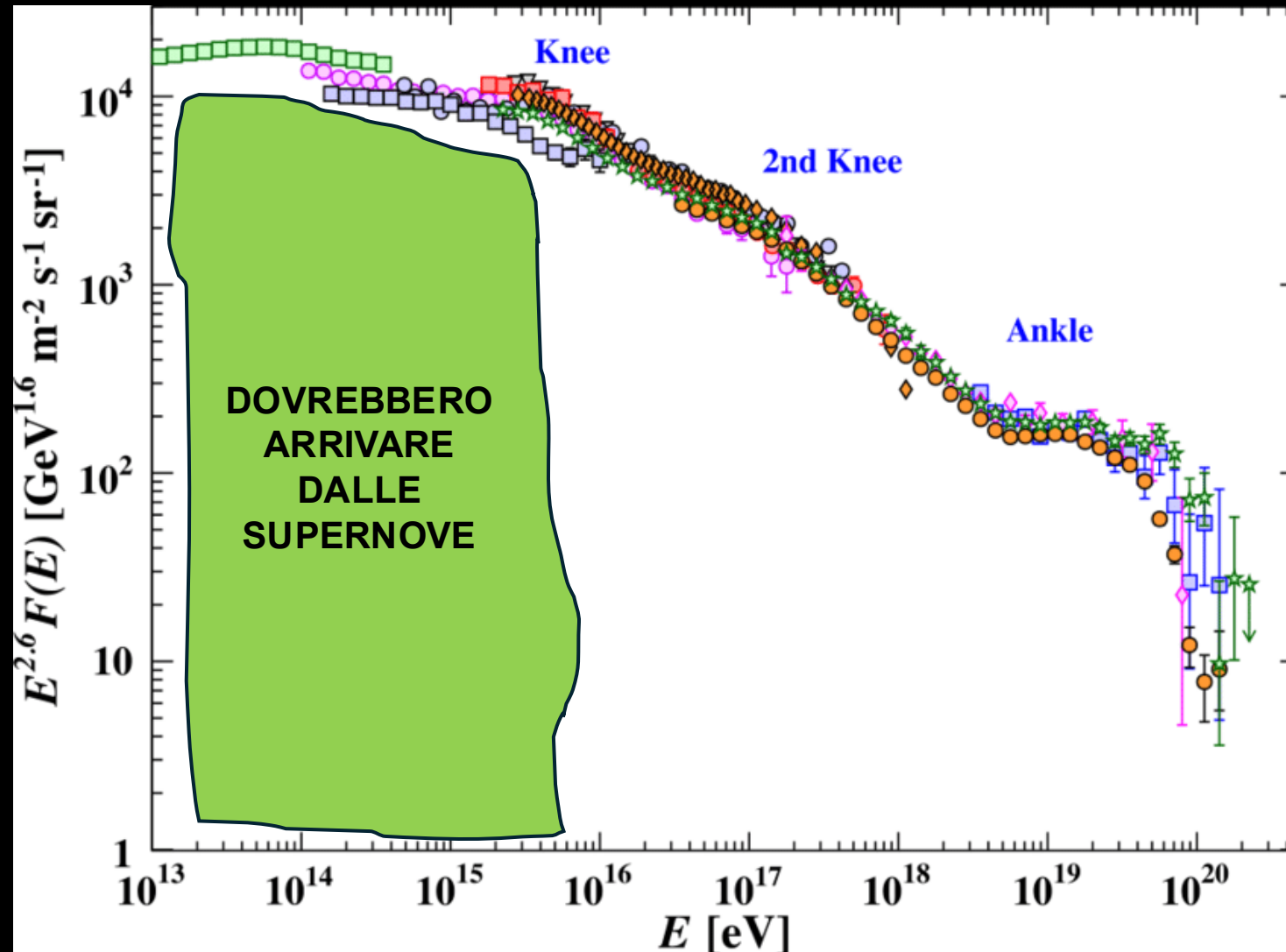
La **luce** e i **neutrini** non vengono deflessi



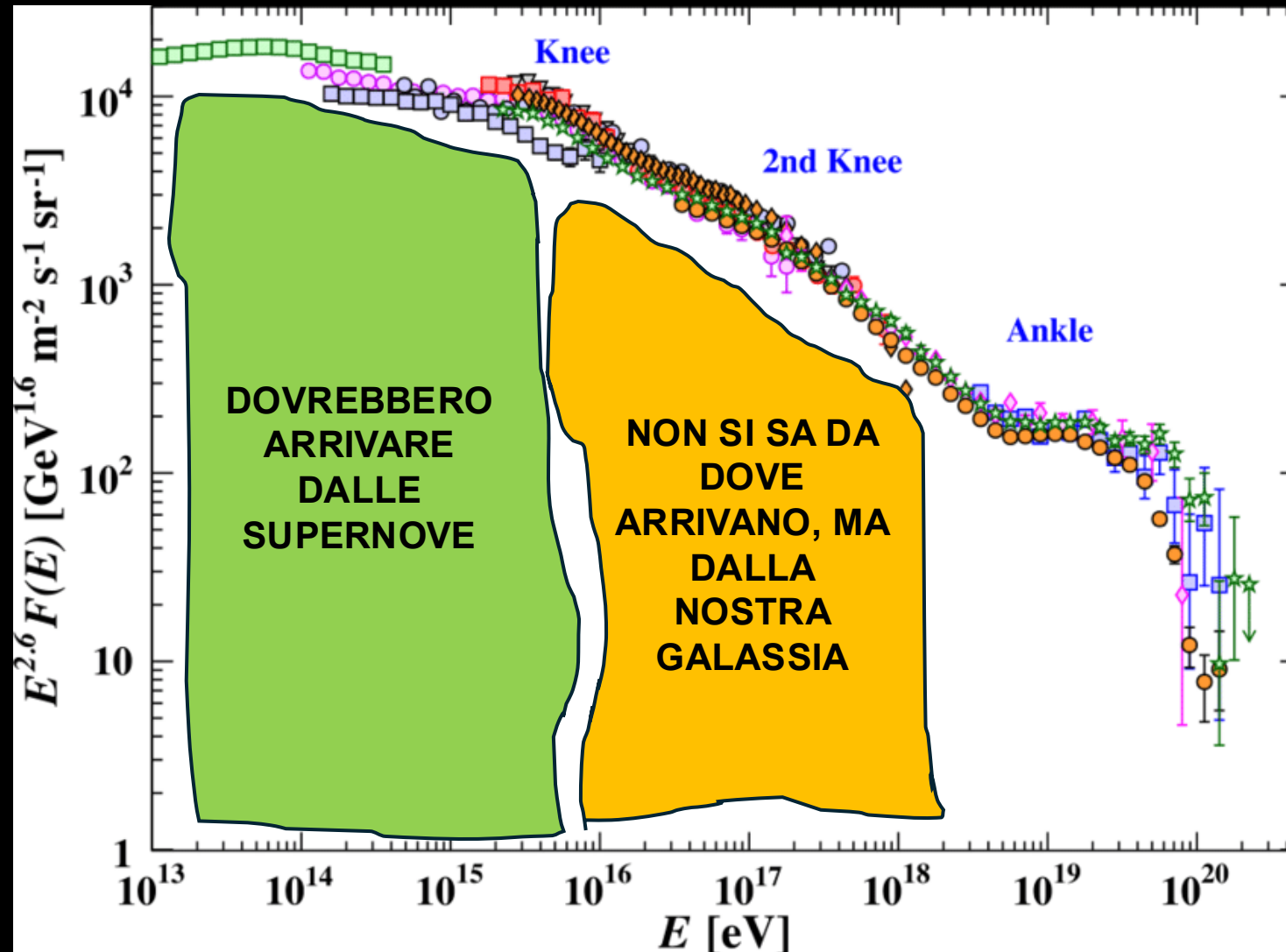
LO SPETTRO DEI RAGGI COSMICI



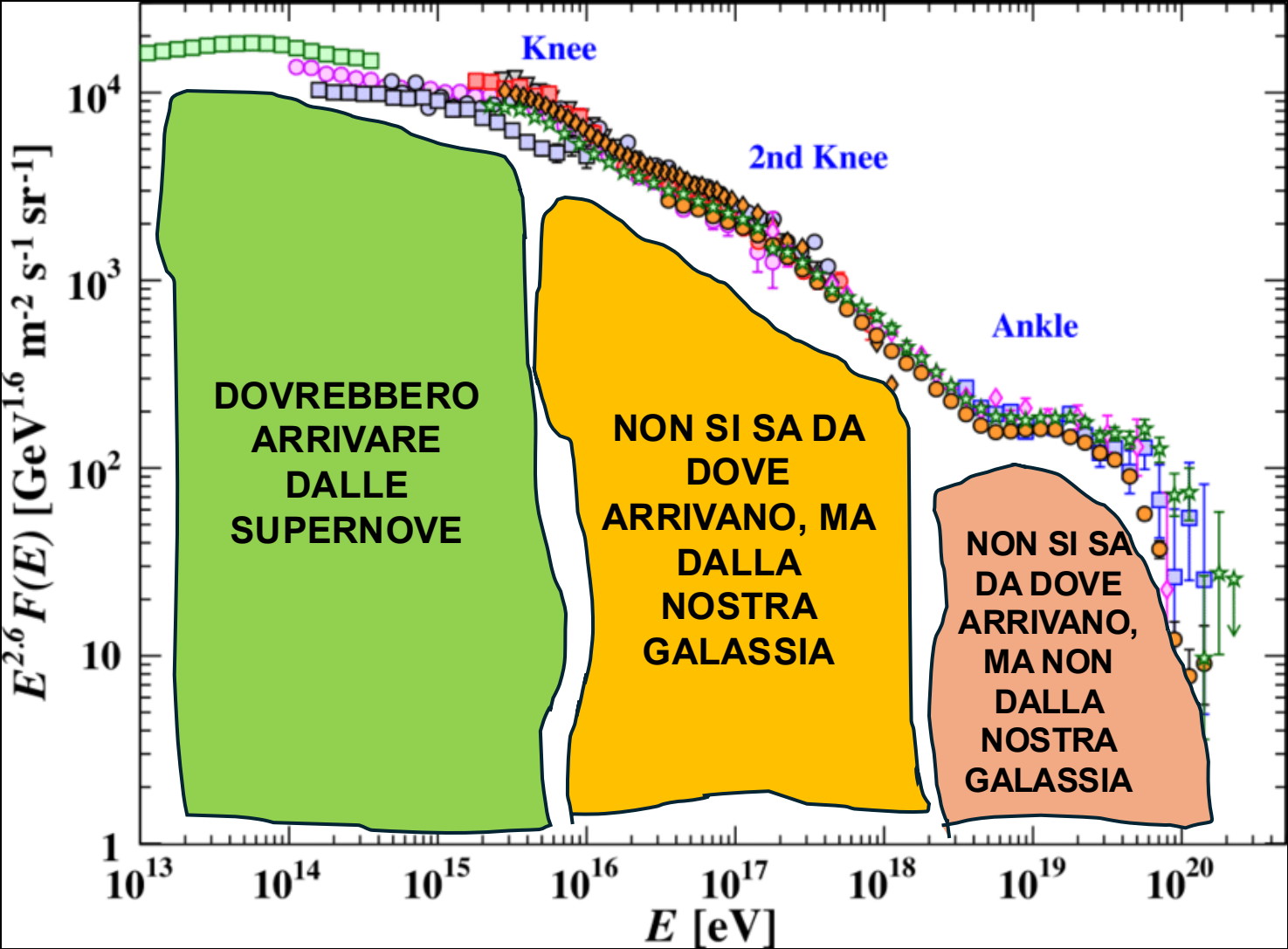
LO SPETTRO DEI RAGGI COSMICI



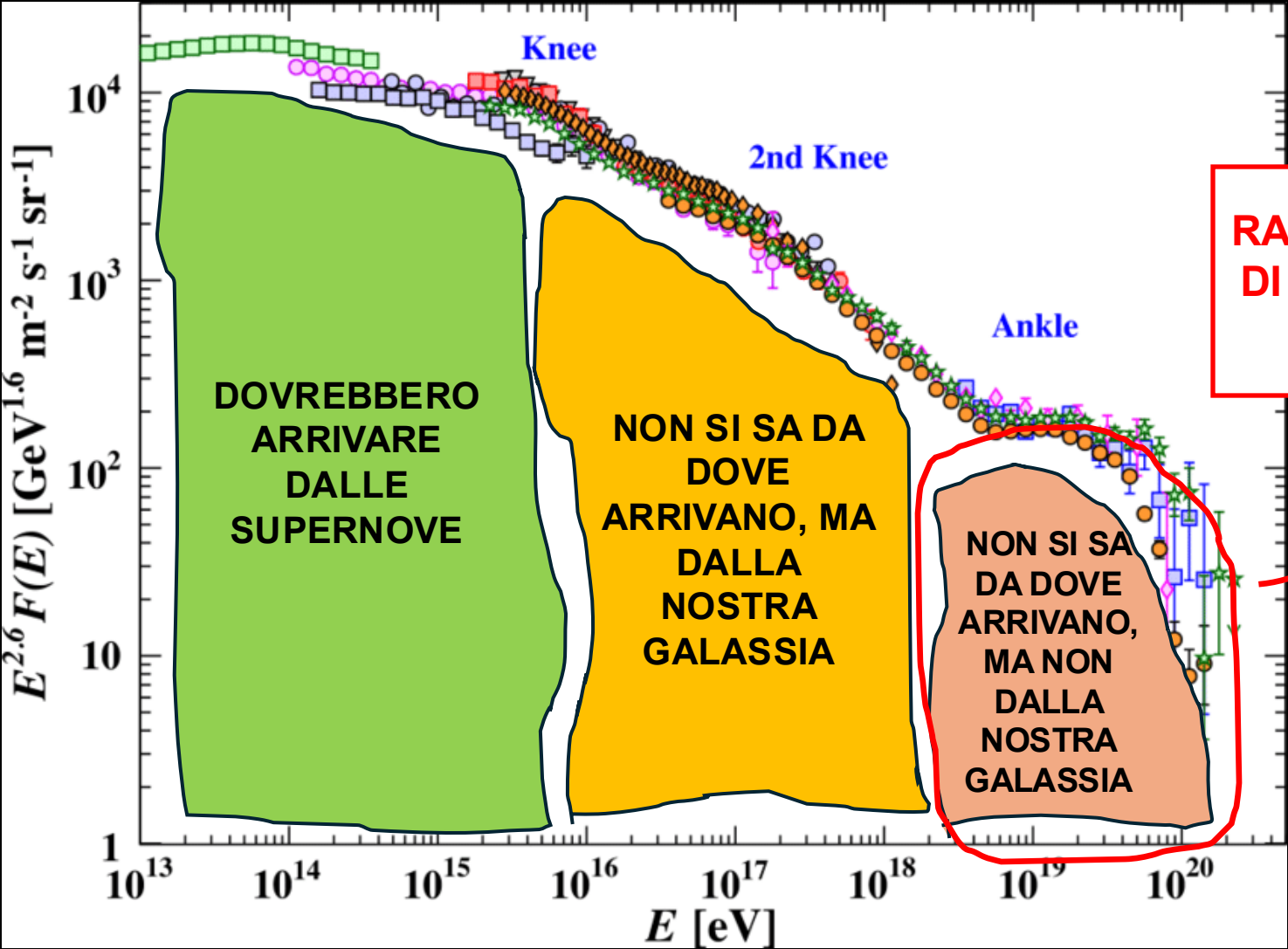
LO SPETTRO DEI RAGGI COSMICI



LO SPETTRO DEI RAGGI COSMICI

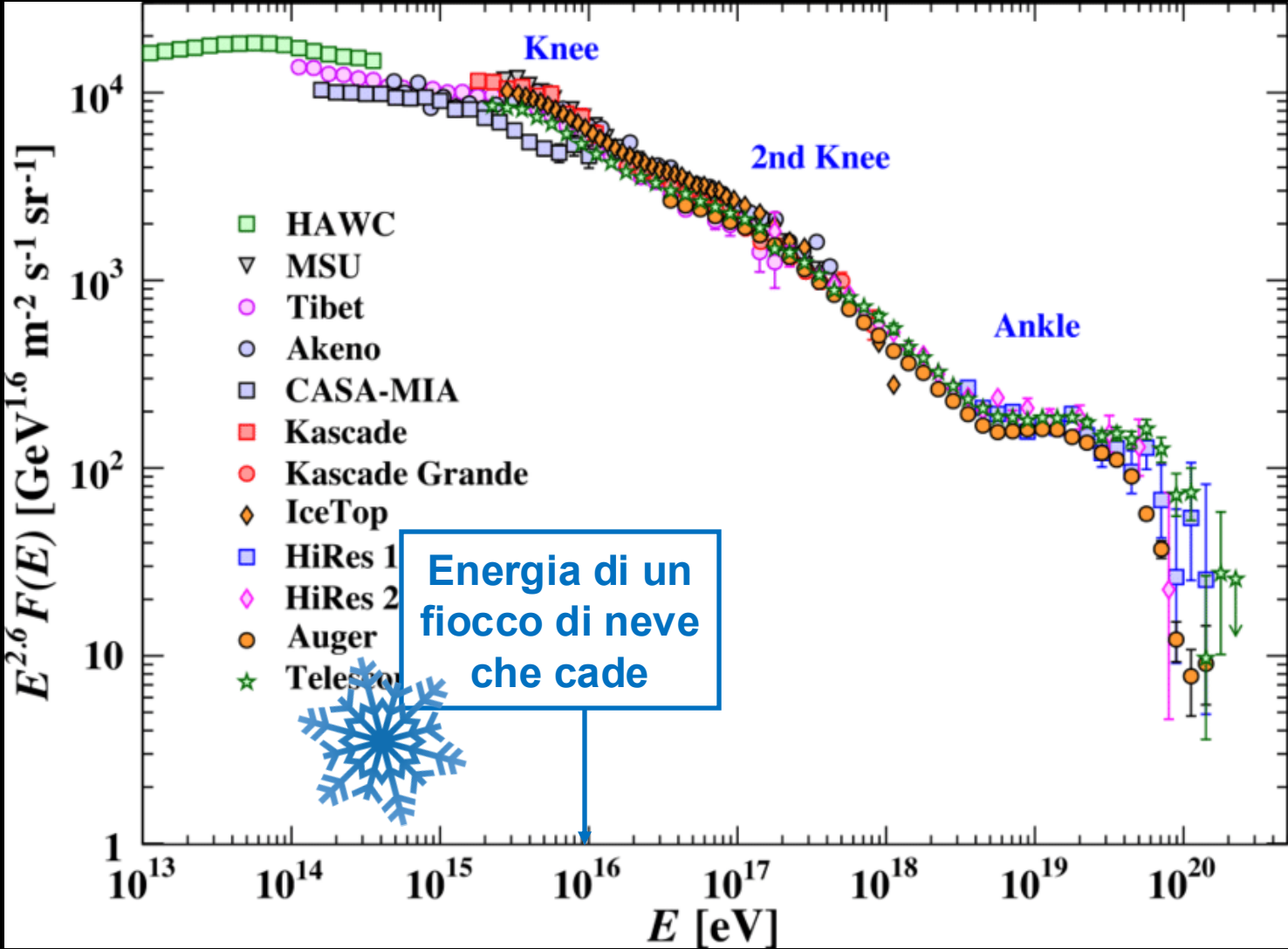


LO SPETTRO DEI RAGGI COSMICI

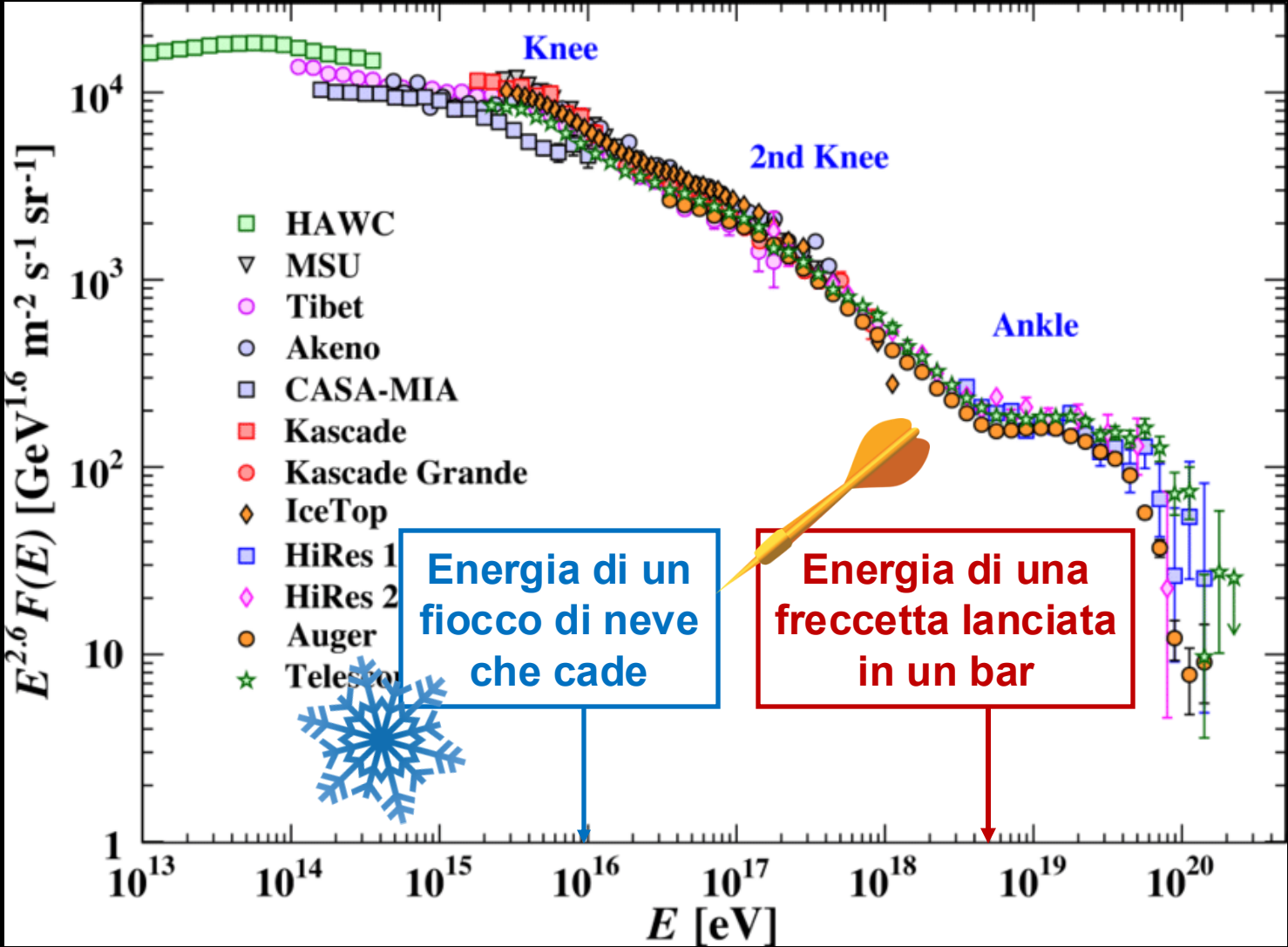


**RAGGI COSMICI
DI ULTRA-ALTA
ENERGIA**

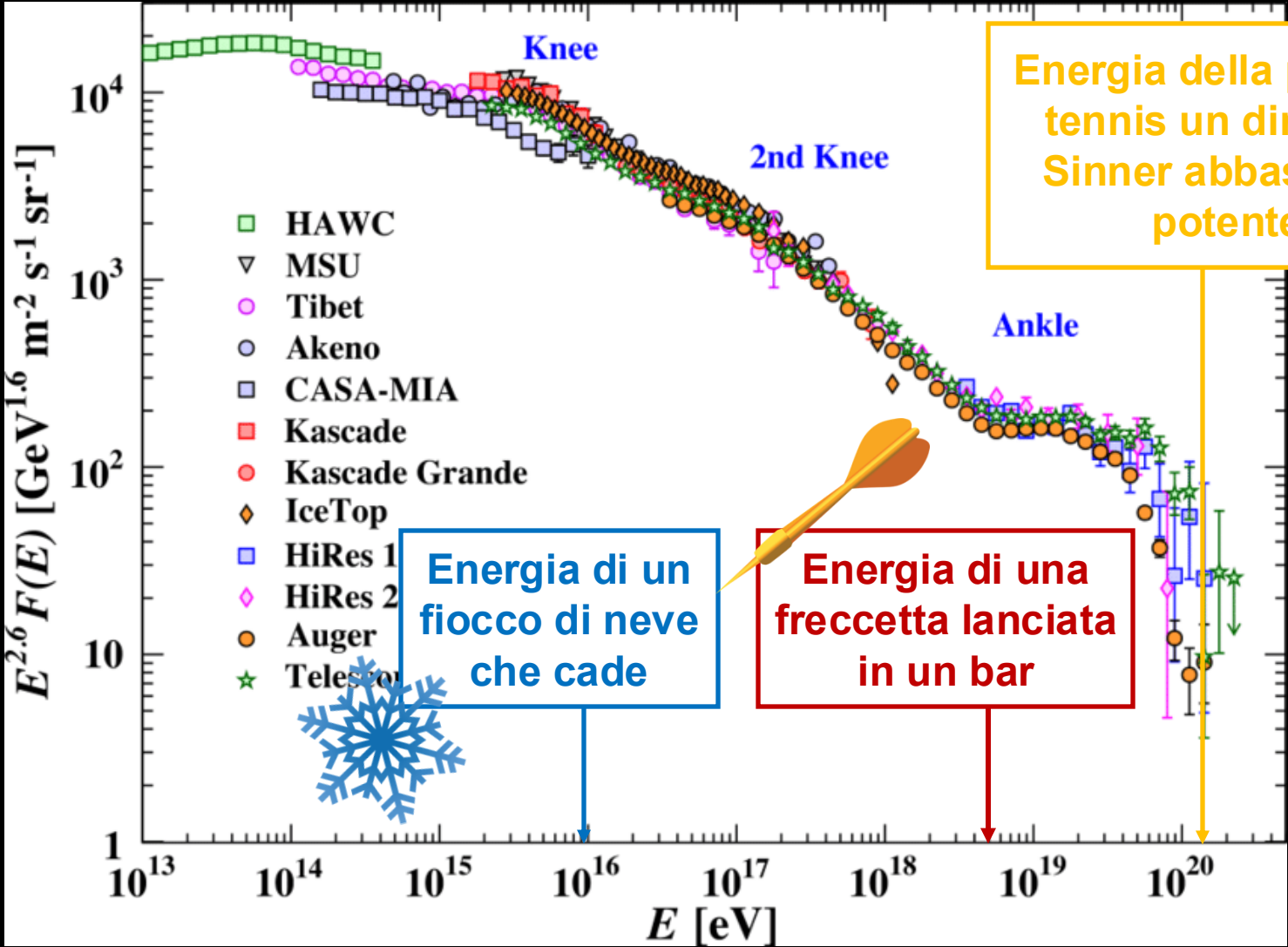
LO SPETTRO DEI RAGGI COSMICI



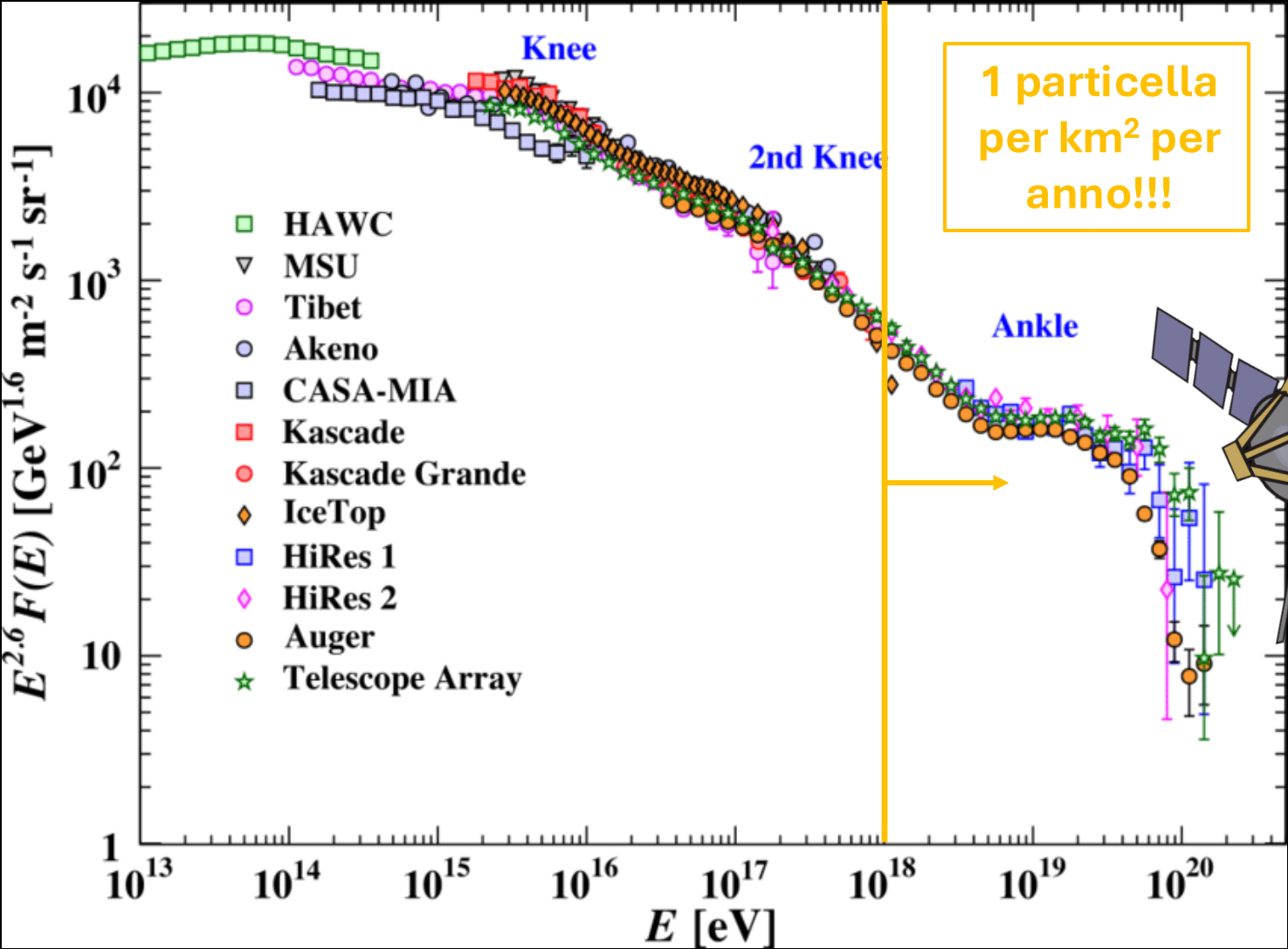
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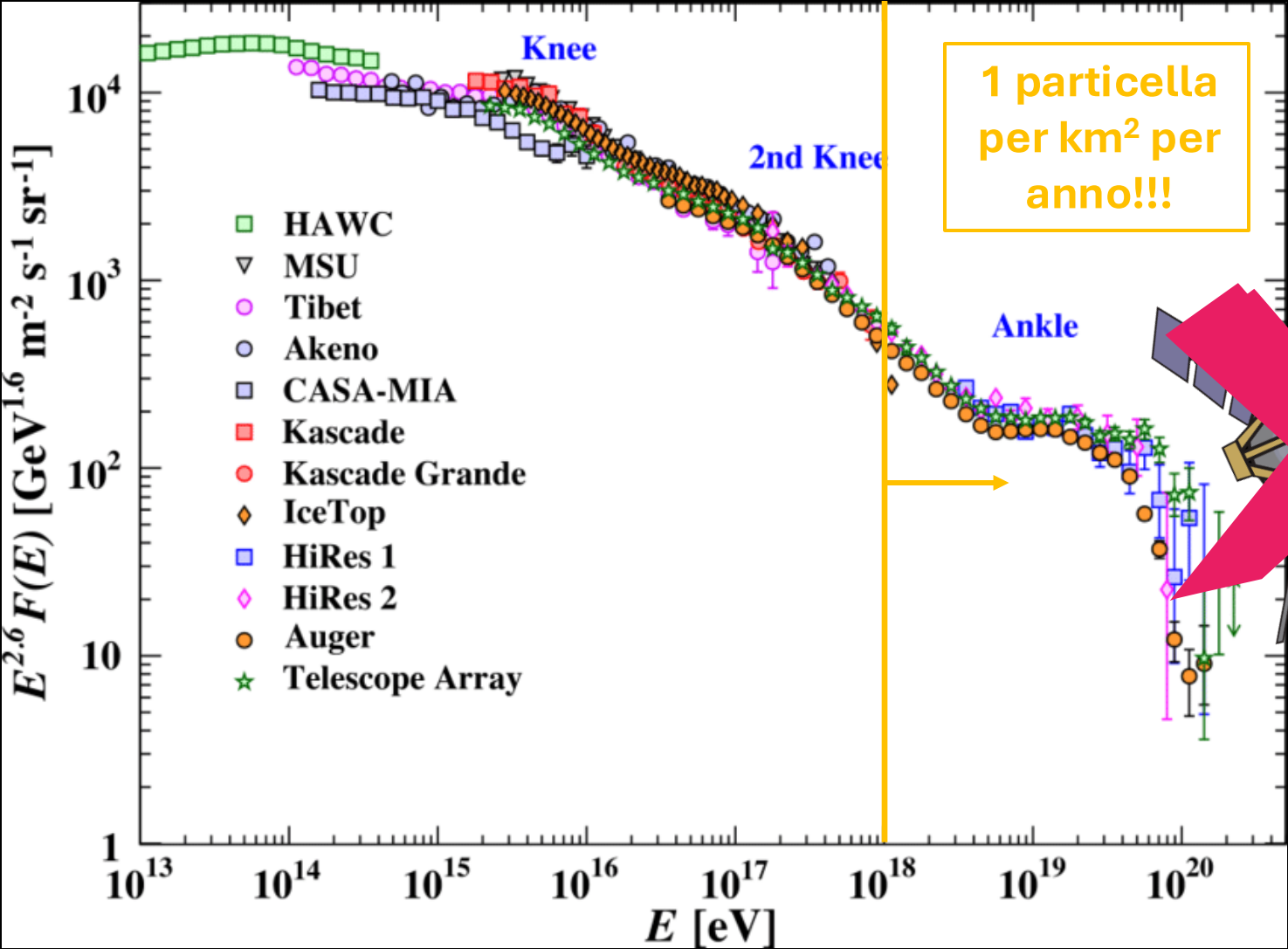
LO SPETTRO DEI RAGGI COSMICI

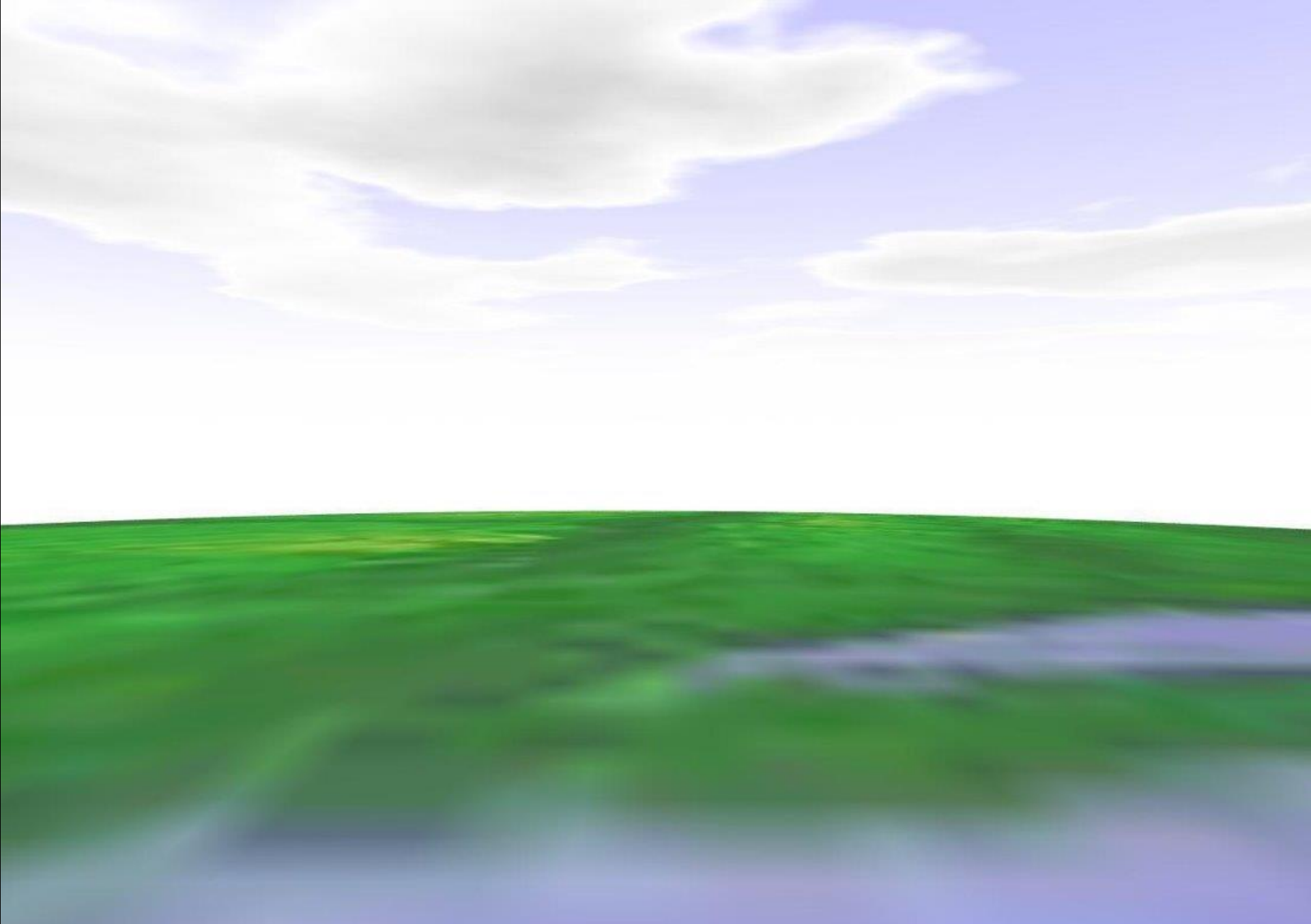


LO SPETTRO DEI RAGGI COSMICI



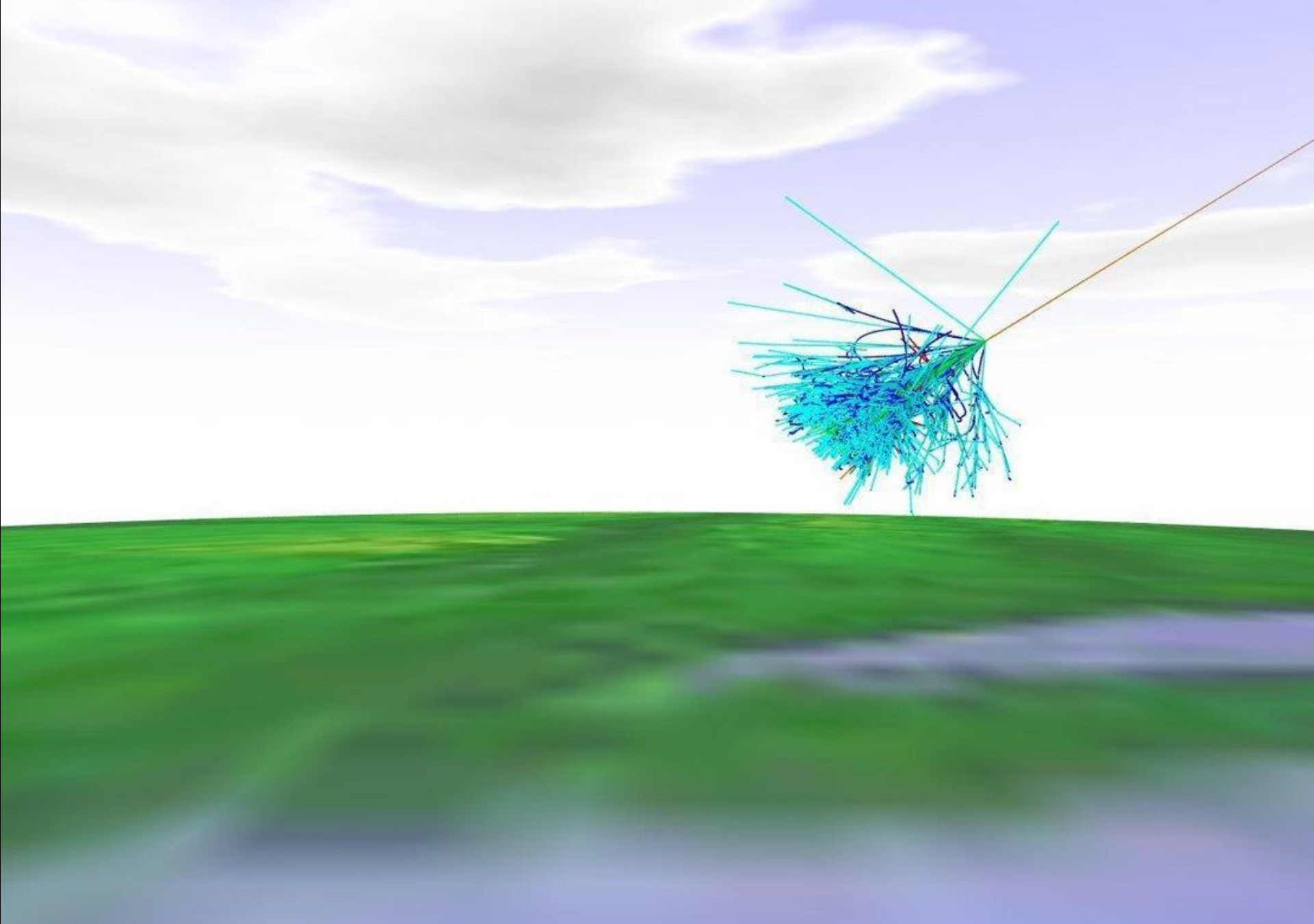
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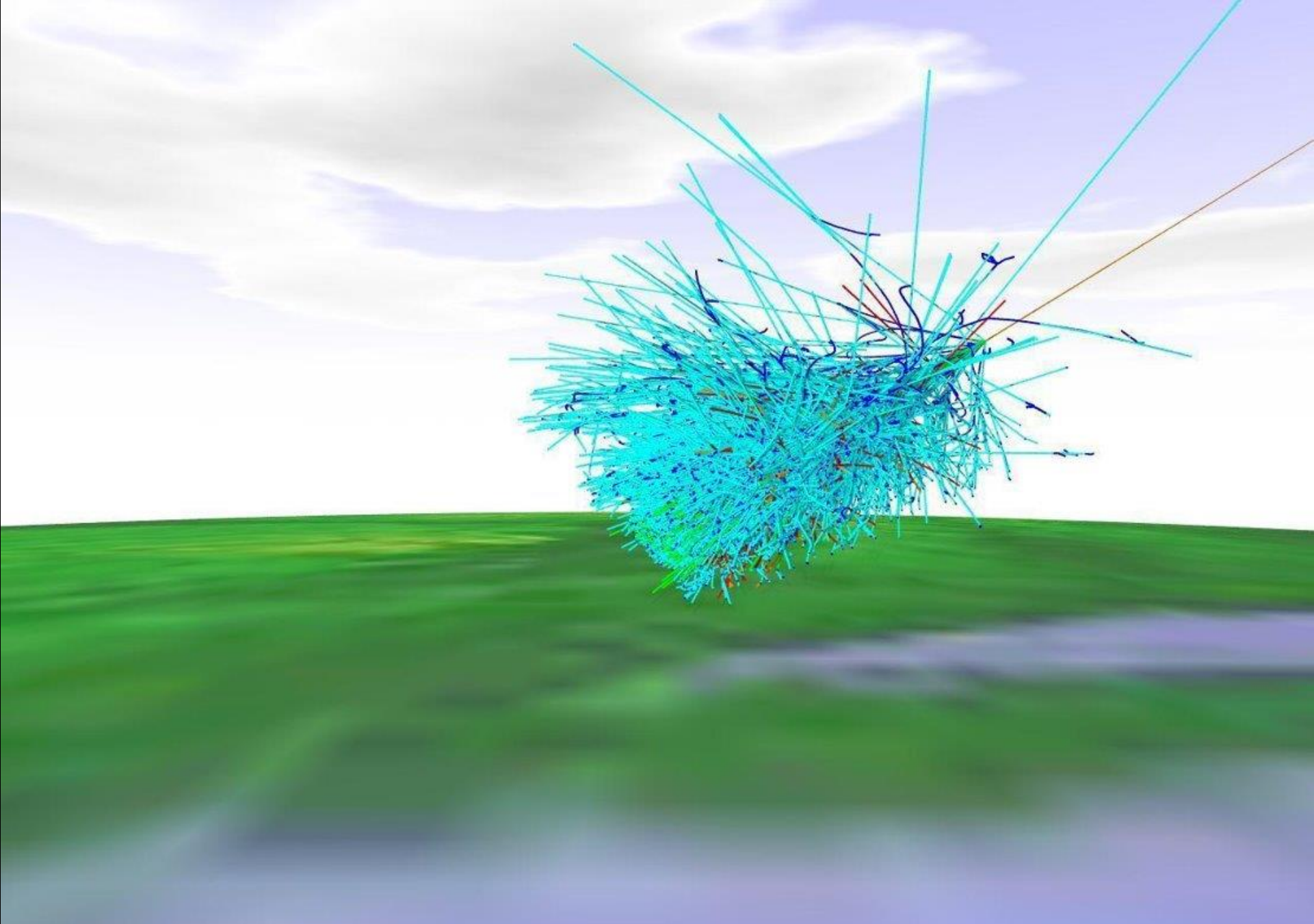


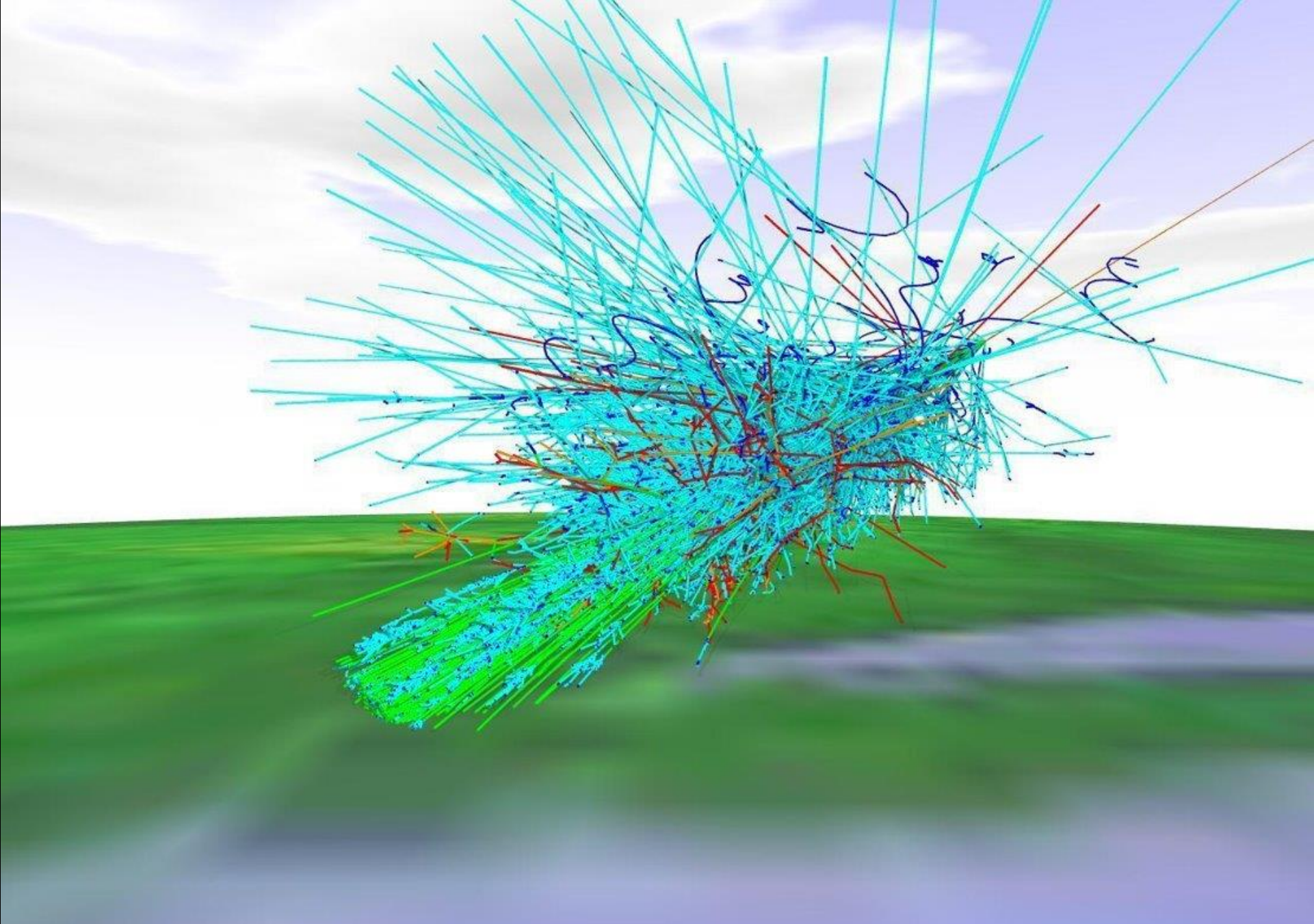


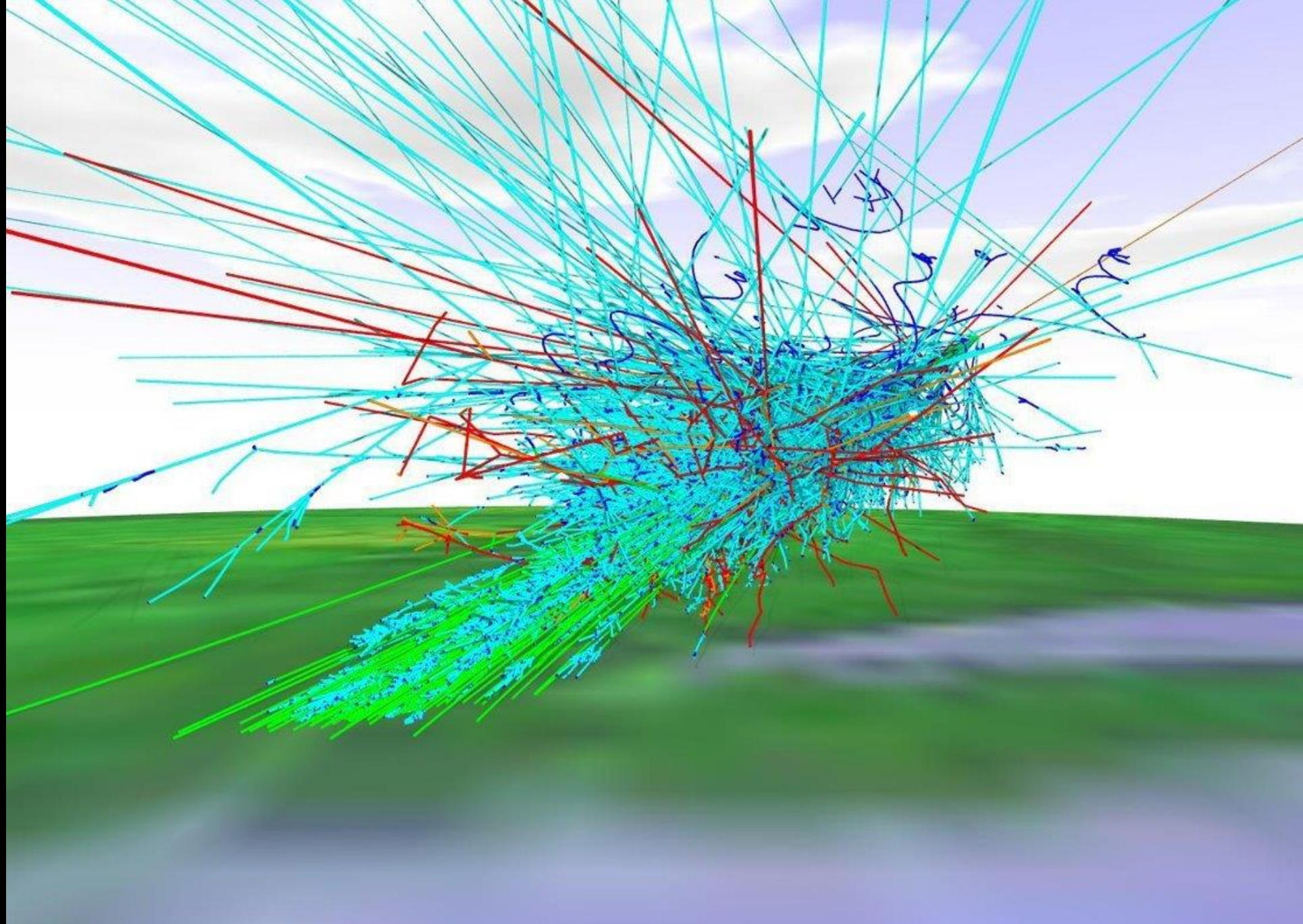






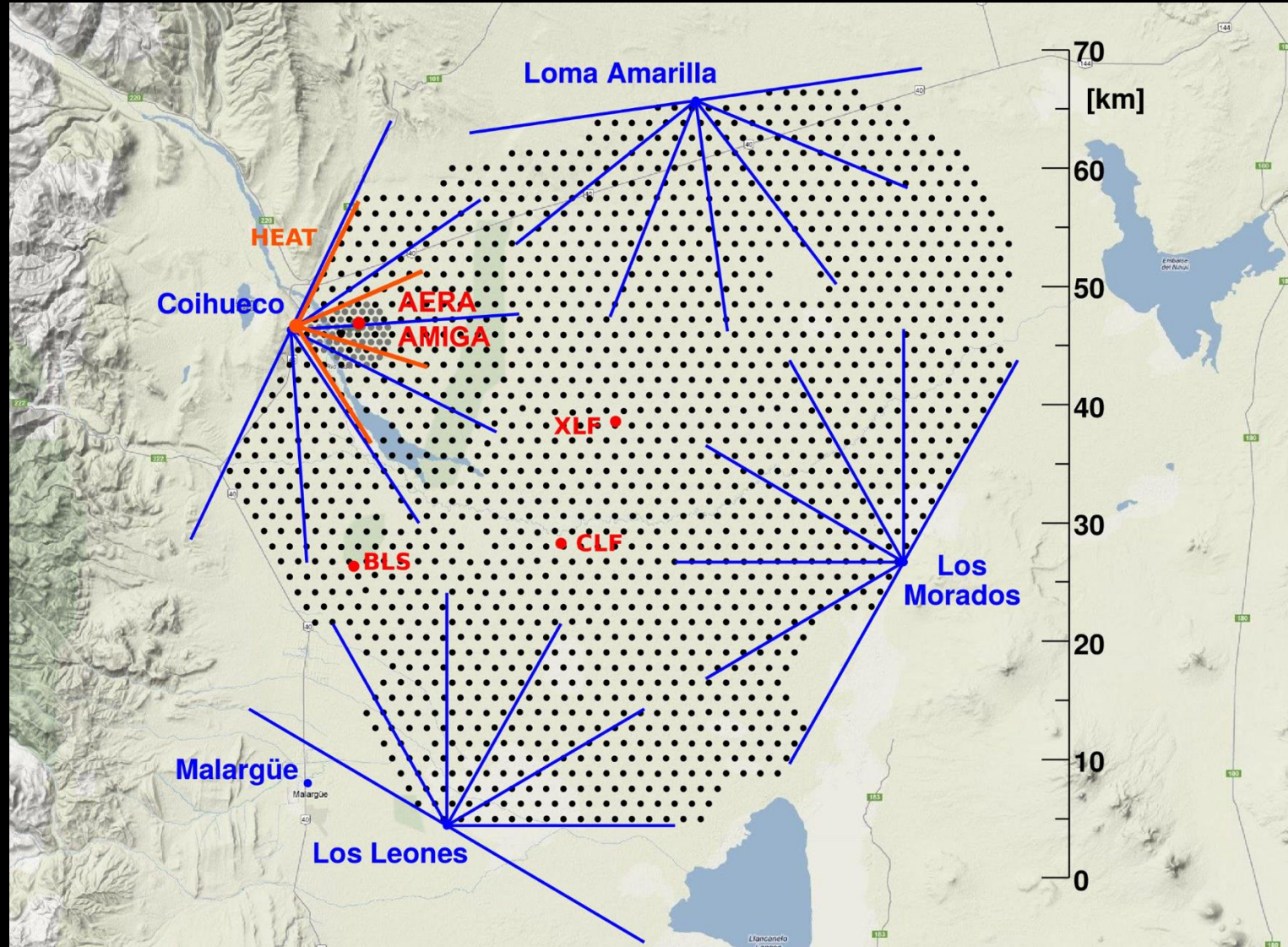






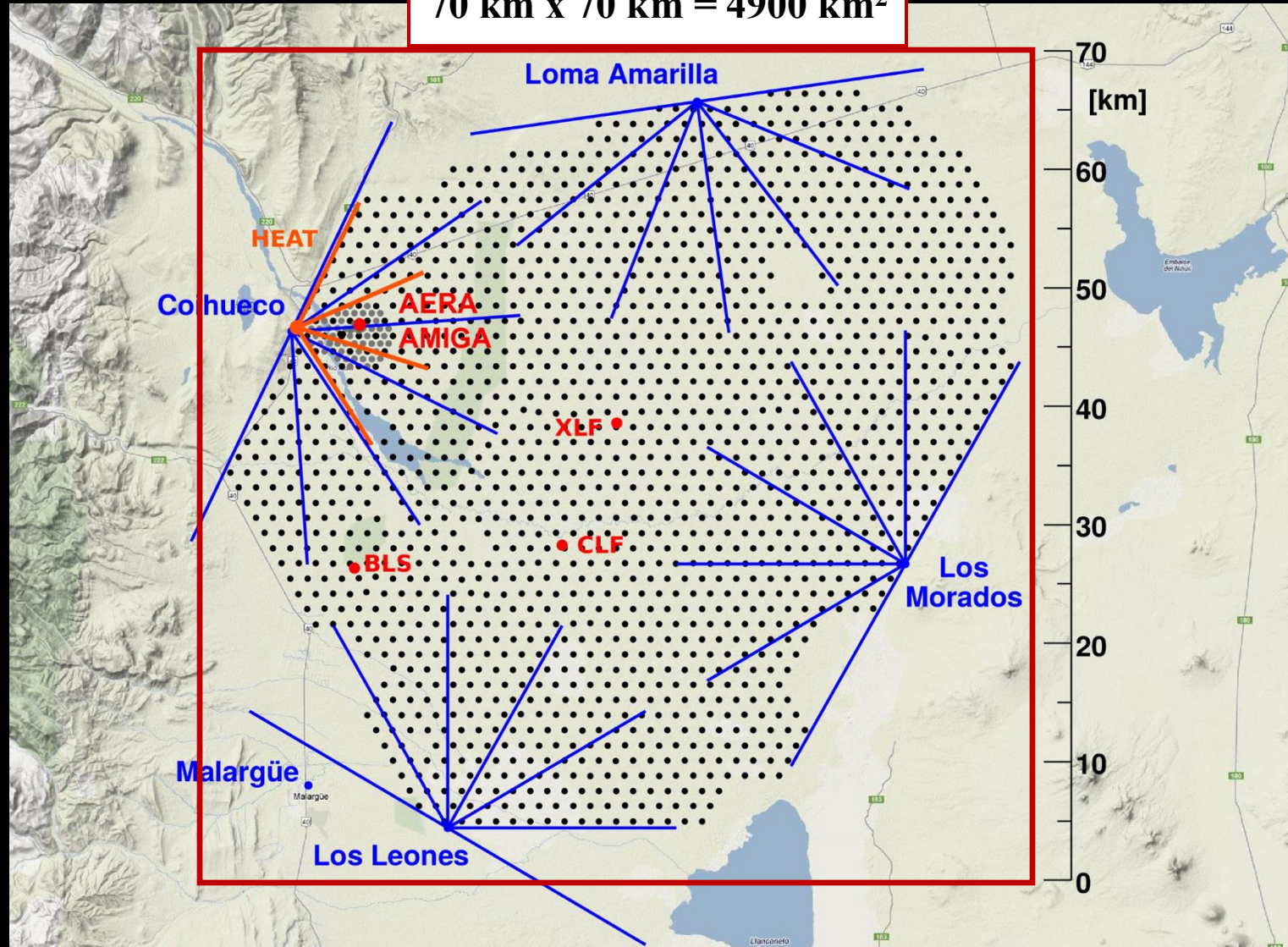
Hajo Drescher, Frankfurt U.

L'OSSERVATORIO PIERRE AUGER



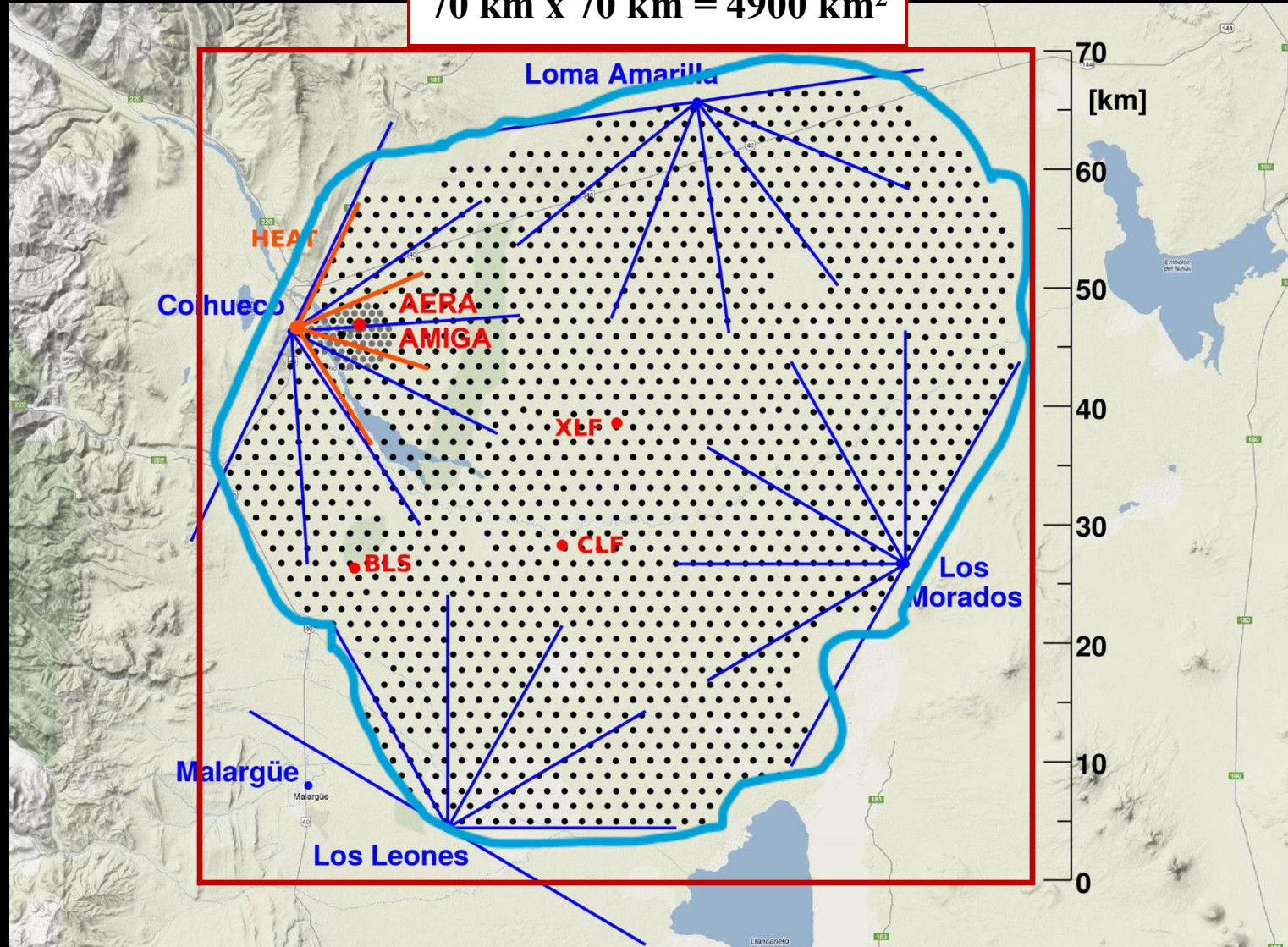
L'OSSERVATORIO PIERRE AUGER

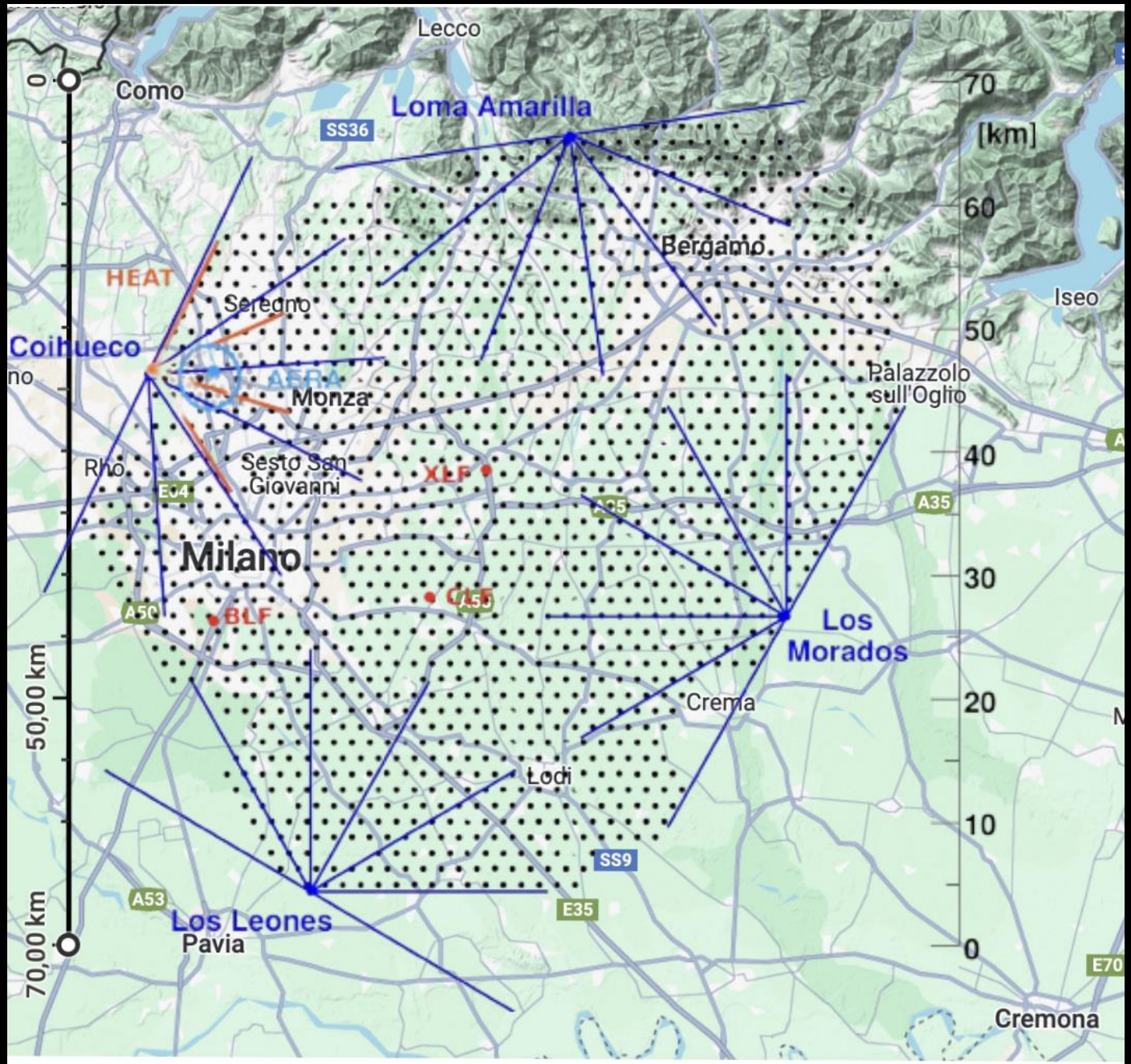
70 km x 70 km = 4900 km²



L'OSSERVATORIO PIERRE AUGER

70 km x 70 km = 4900 km²





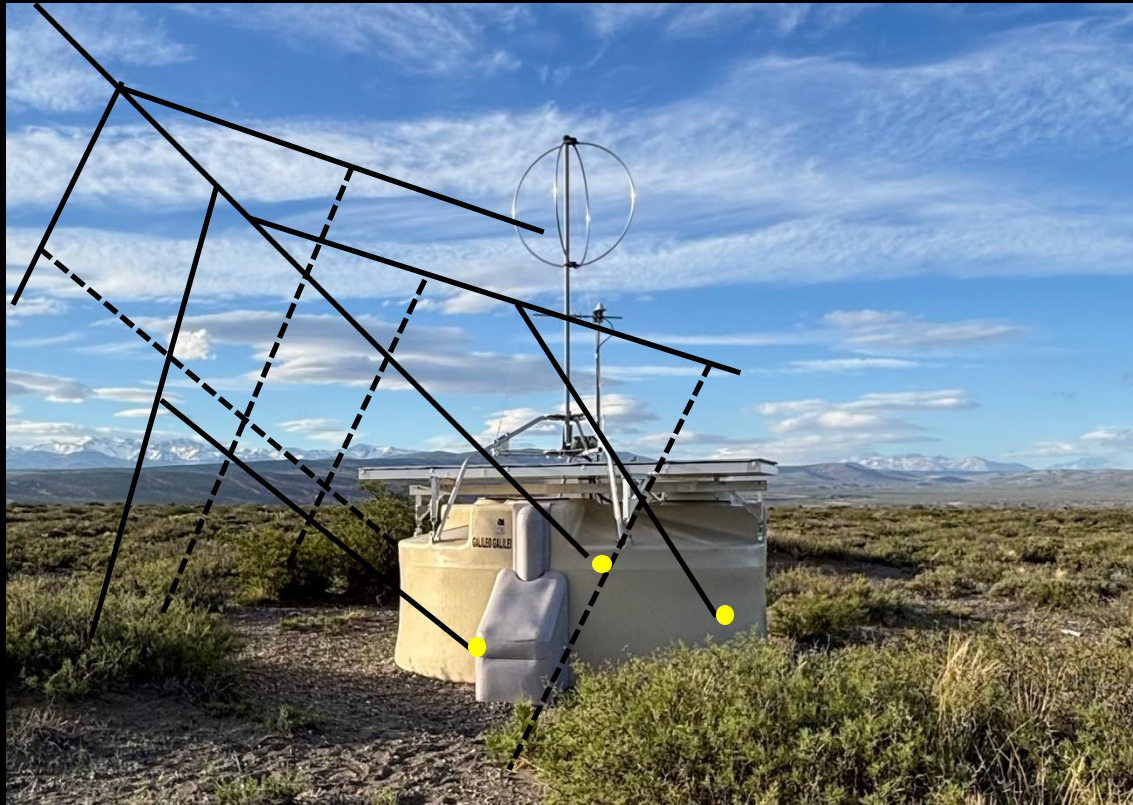
SURFACE DETECTOR



FLUORESCENCE DETECTOR



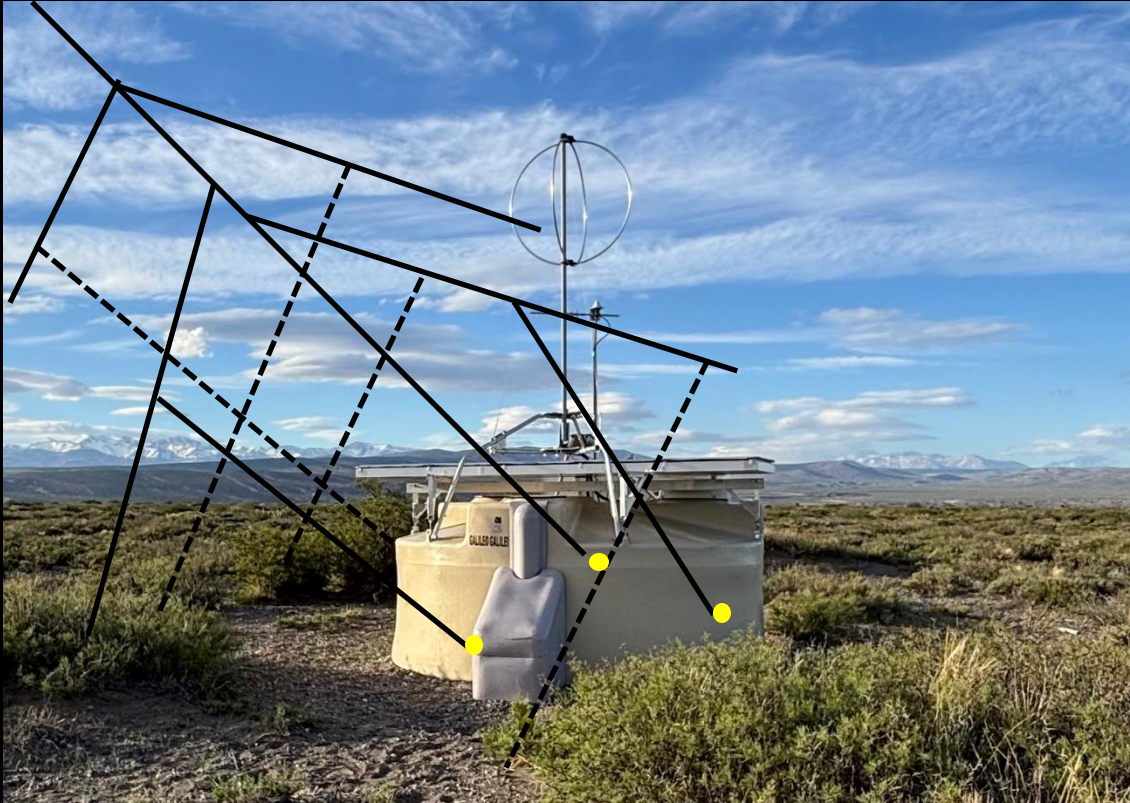
SURFACE DETECTOR



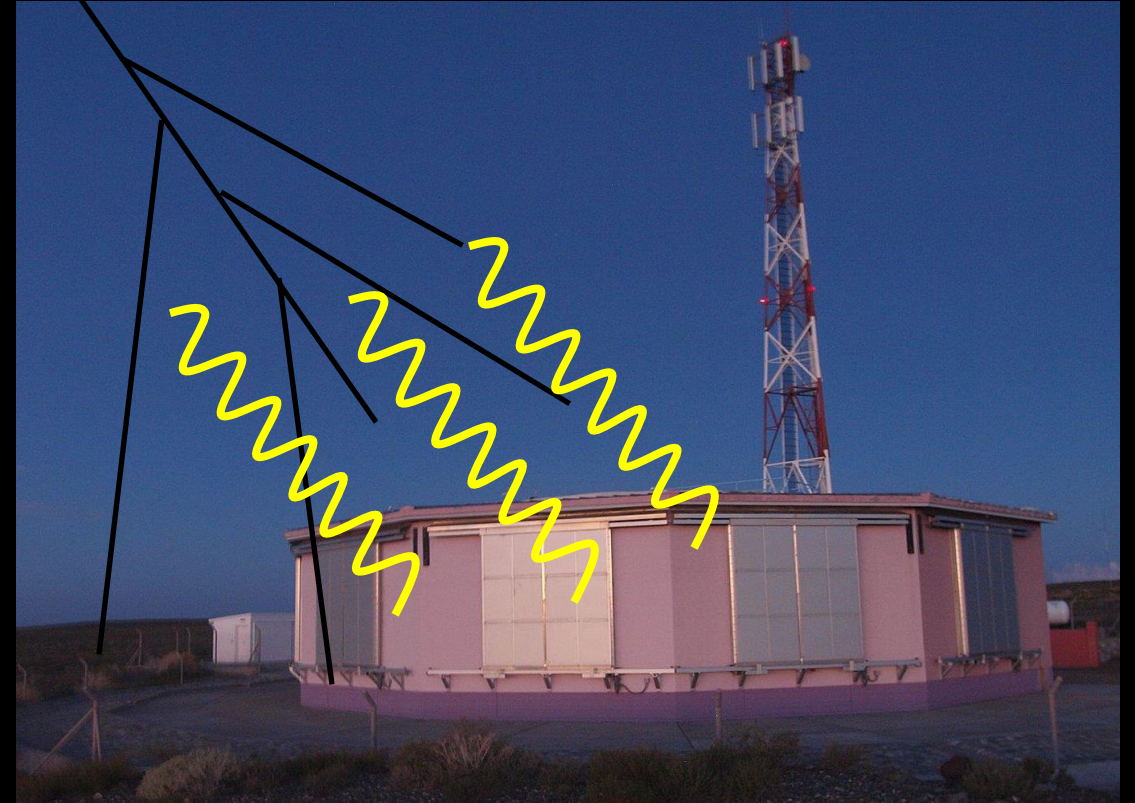
FLUORESCENCE DETECTOR



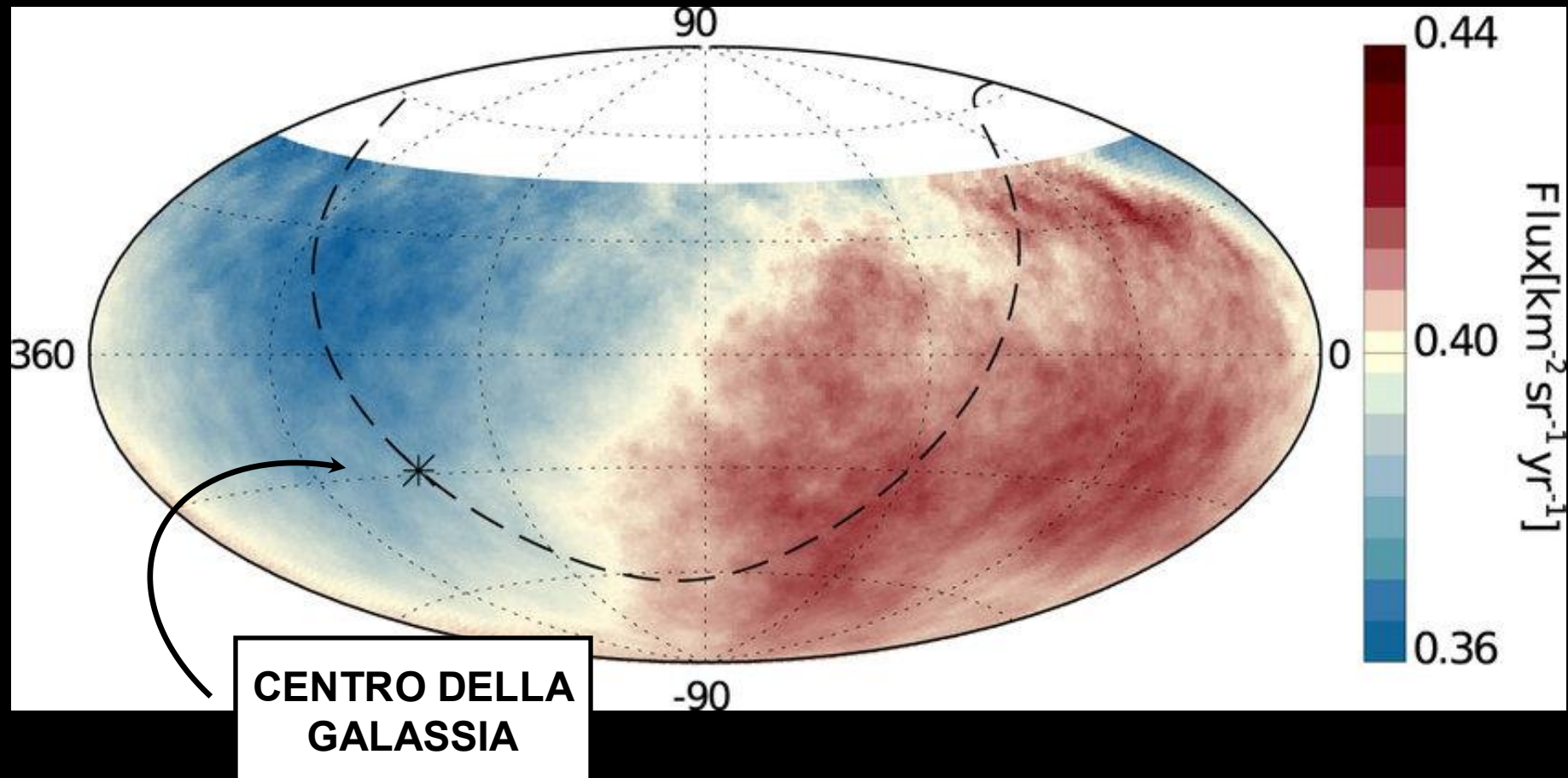
SURFACE DETECTOR



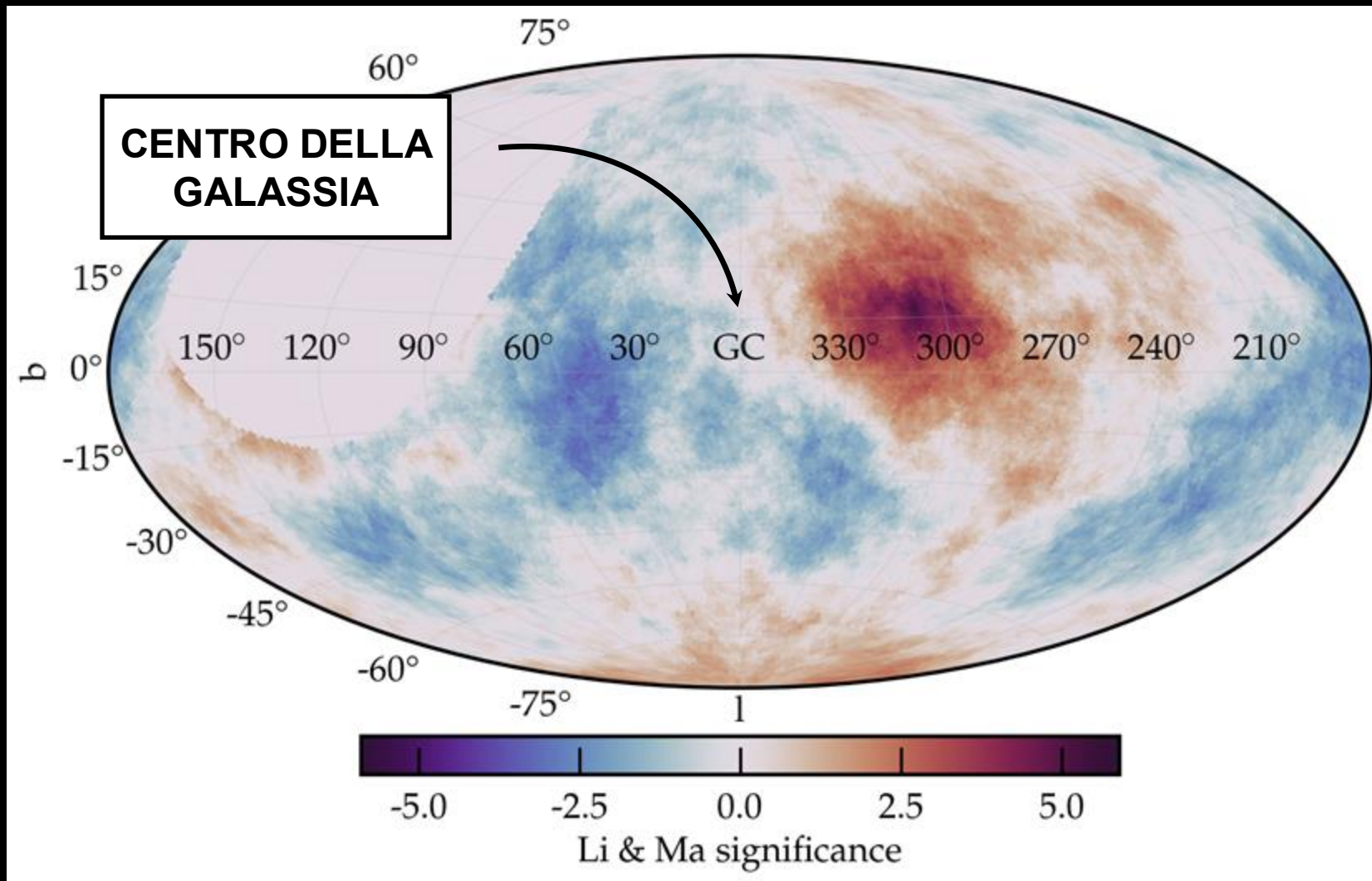
FLUORESCENCE DETECTOR



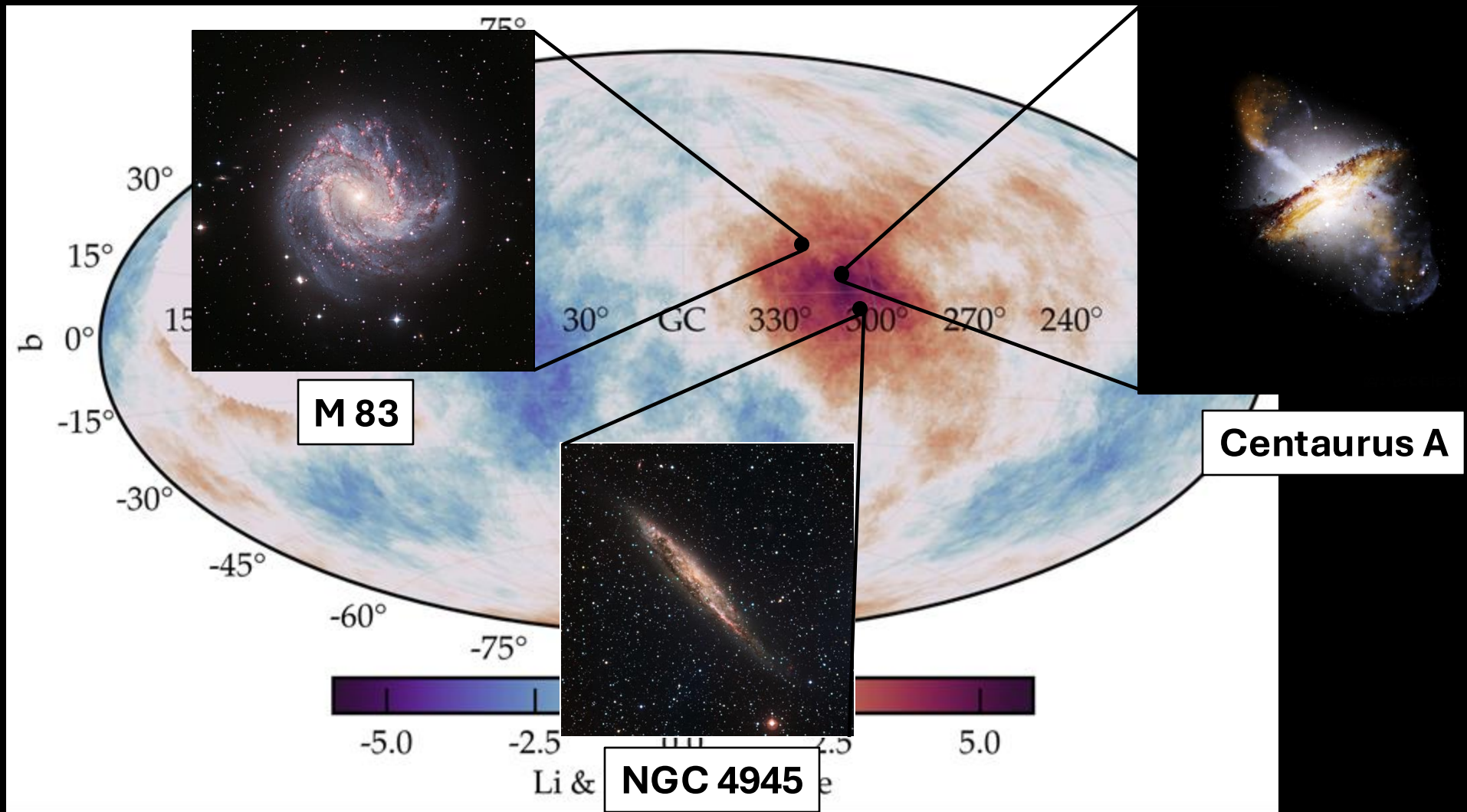
COSA ABBIAMO VISTO DOPO 20 ANNI?







COSA ABBIAMO VISTO DOPO 20 ANNI?



COSA ABBIAMO VISTO DOPO 20 ANNI?



Conclusioni

- **Non solo luce arriva dall'universo** 
- **Tra le altre cose ci sono i raggi cosmici, che sono le particelle più energetiche dell'universo**  
- **Dato che sono carichi e deviati è difficile scoprirne le sorgenti** 
- **Ma c'è un bellissimo Osservatorio in una parte isolata del mondo che ci può aiutare a scoprirlo** 