Finanziato dall'Unione europea NextGenerationEU

Ministero dell'Università e della Ricerca

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

INFN

SICILIAE STVDIVM GENERALE 1434

Il telescopio sottomarino alla ricerca di neutrini cosmici nel Mar Mediterraneo

Obiettivi scientifici e astronomia multimessagera

G. Ferrara – I. Tosta e Melo

CATANIA, 21 GENNAIO 2025

KM3NeT4RR
Kilometer Cube Neutrino Telescope for Recovery and Resilience

Neutrini cosmici e astronomia con i neutrini

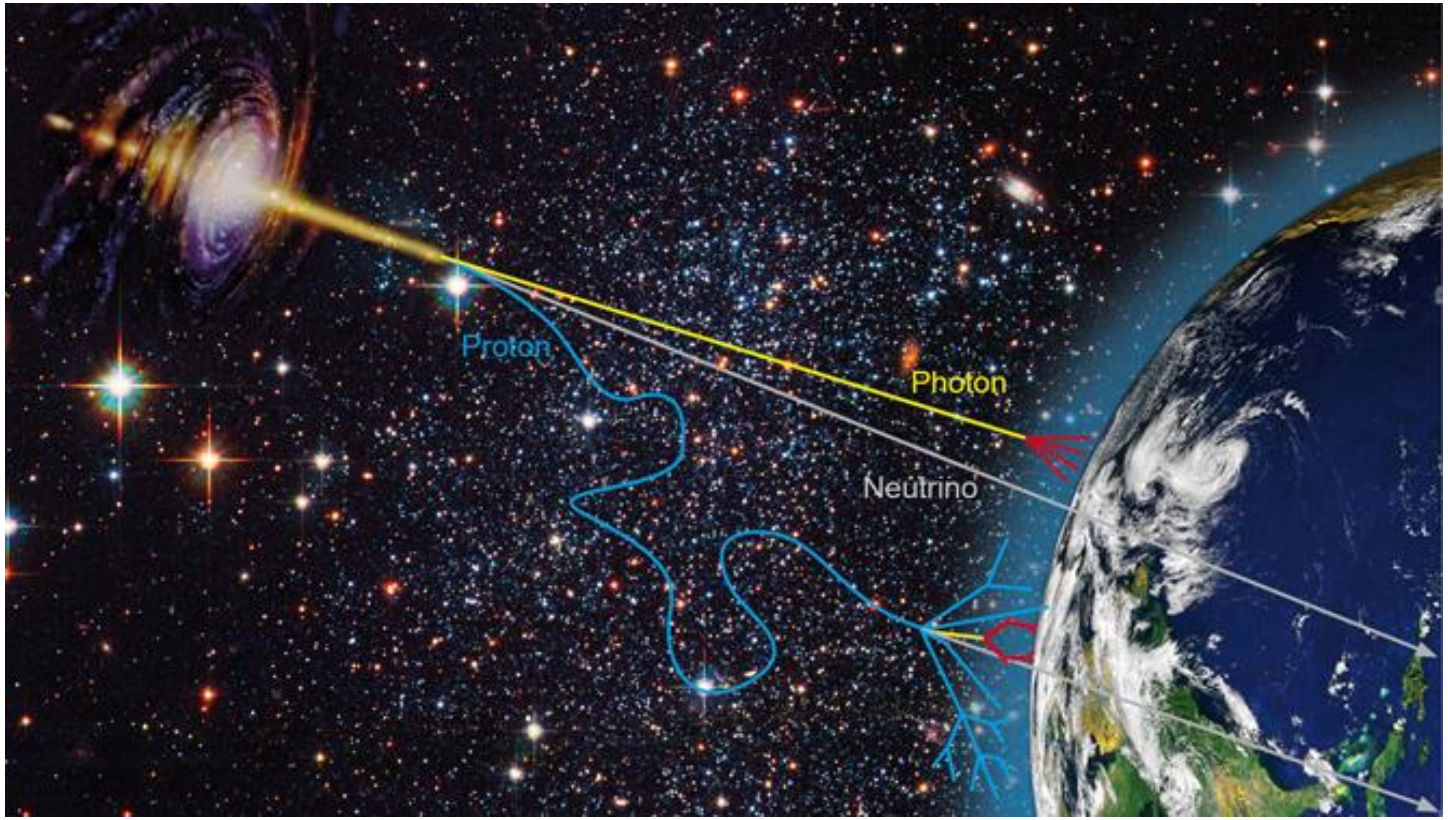
Neutrini:

- **Particelle neutre**: non sono deviati dai campi magnetici galattici o intergalattici
- **Interagiscono debolmente con la materia**: possono attraversare ambienti densi senza essere assorbiti

possono viaggiare in linea retta, consentendo osservazioni astronomiche su un ampio intervallo di distanze e di energia

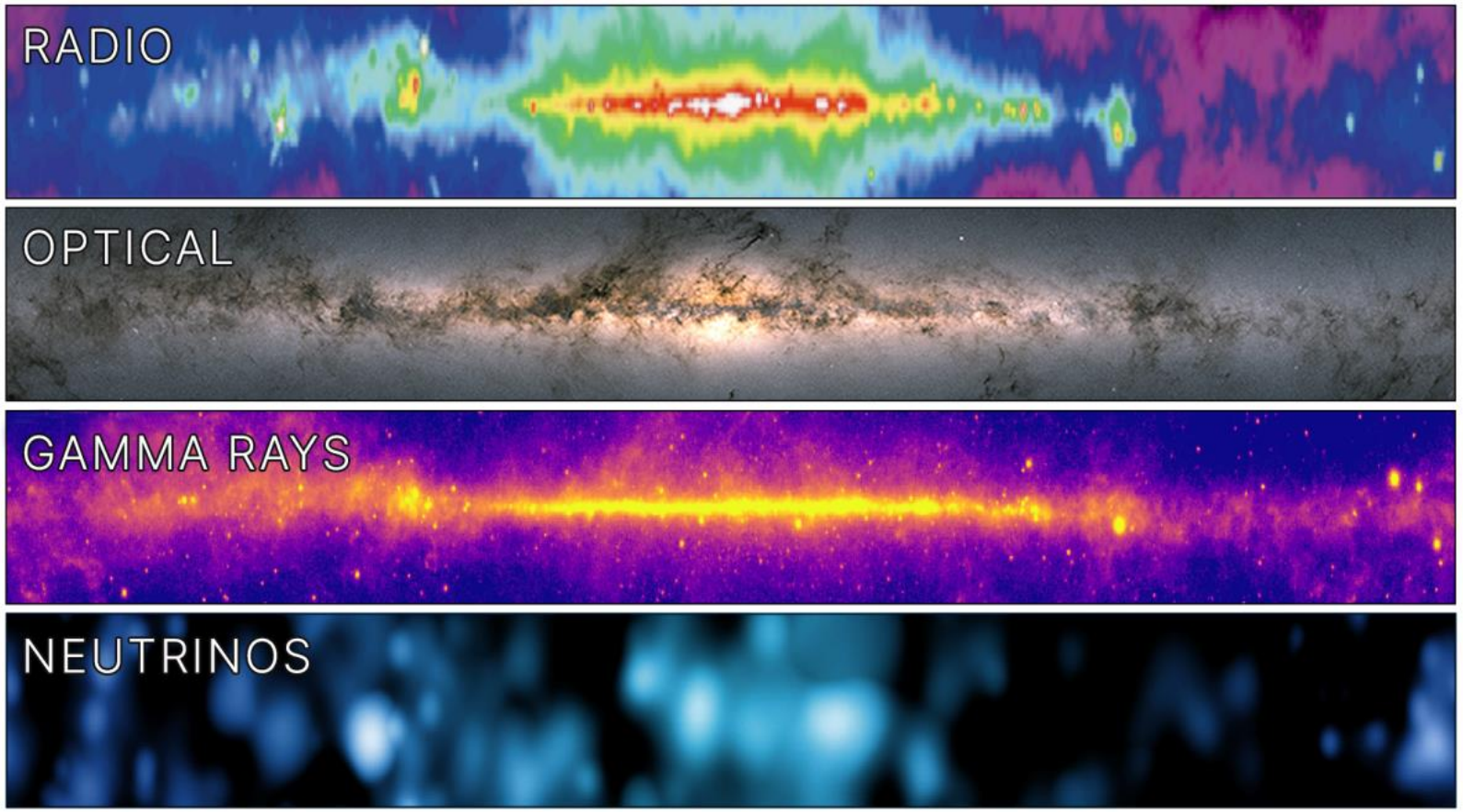
- forniscono una chiara evidenza dell'esistenza di processi che coinvolgono **adroni** (particelle costituite da quark)

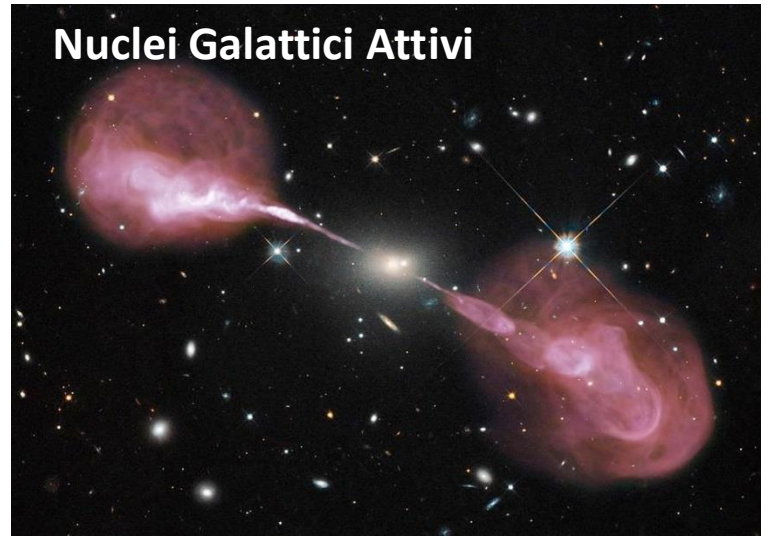
- **Correlati in tempo e direzione con le onde elettromagnetiche e onde gravitazionali:** consentono l'astronomia multimessaggera, ovvero l'osservazione di eventi cosmici attraverso diversi tipi di segnali (neutrini, onde elettromagnetiche, onde gravitazionali).

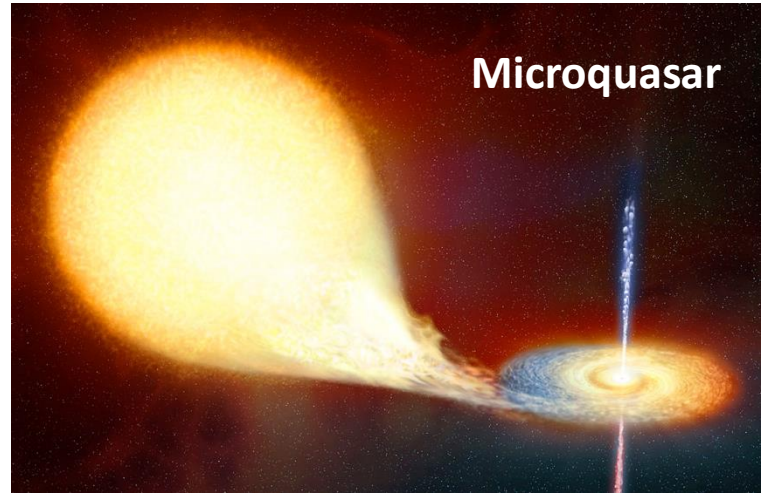


Neutrini eccellenti messaggeri cosmici per studiare l'Universo

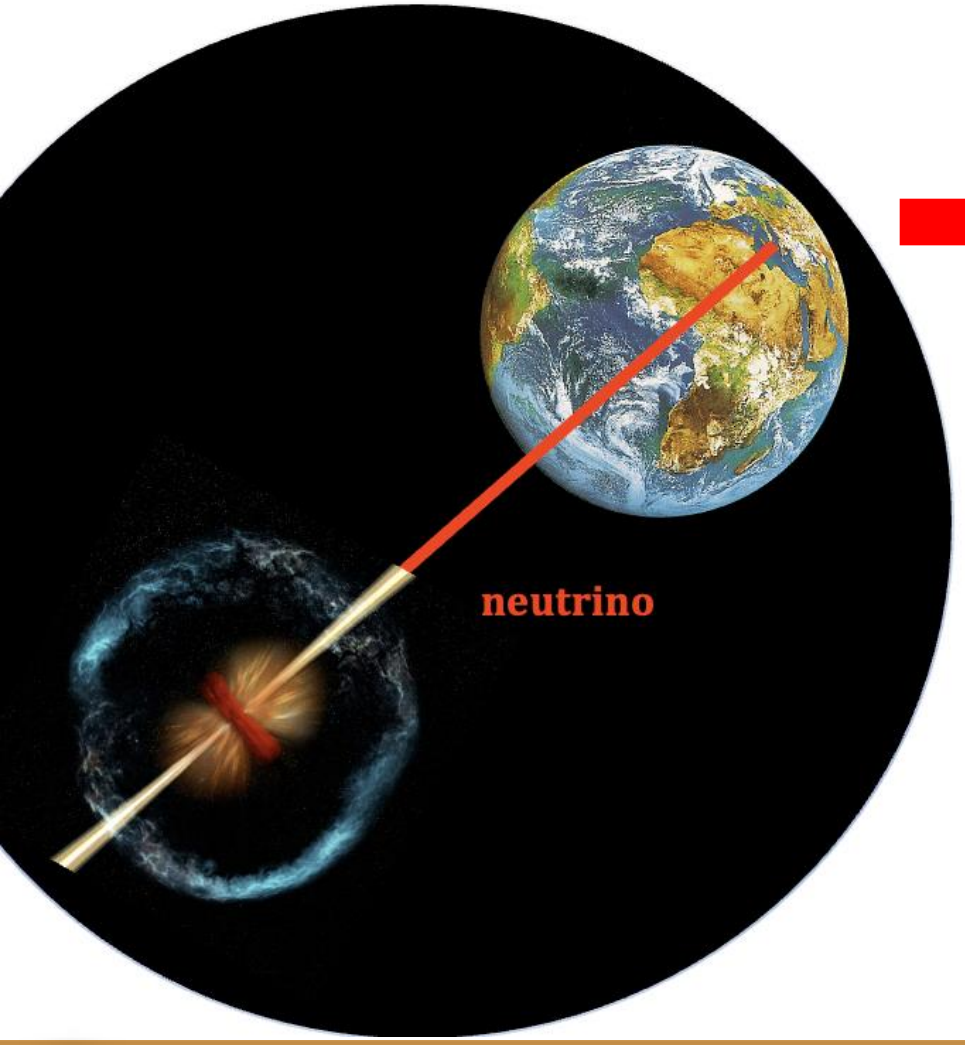
Astronomia con i neutrini

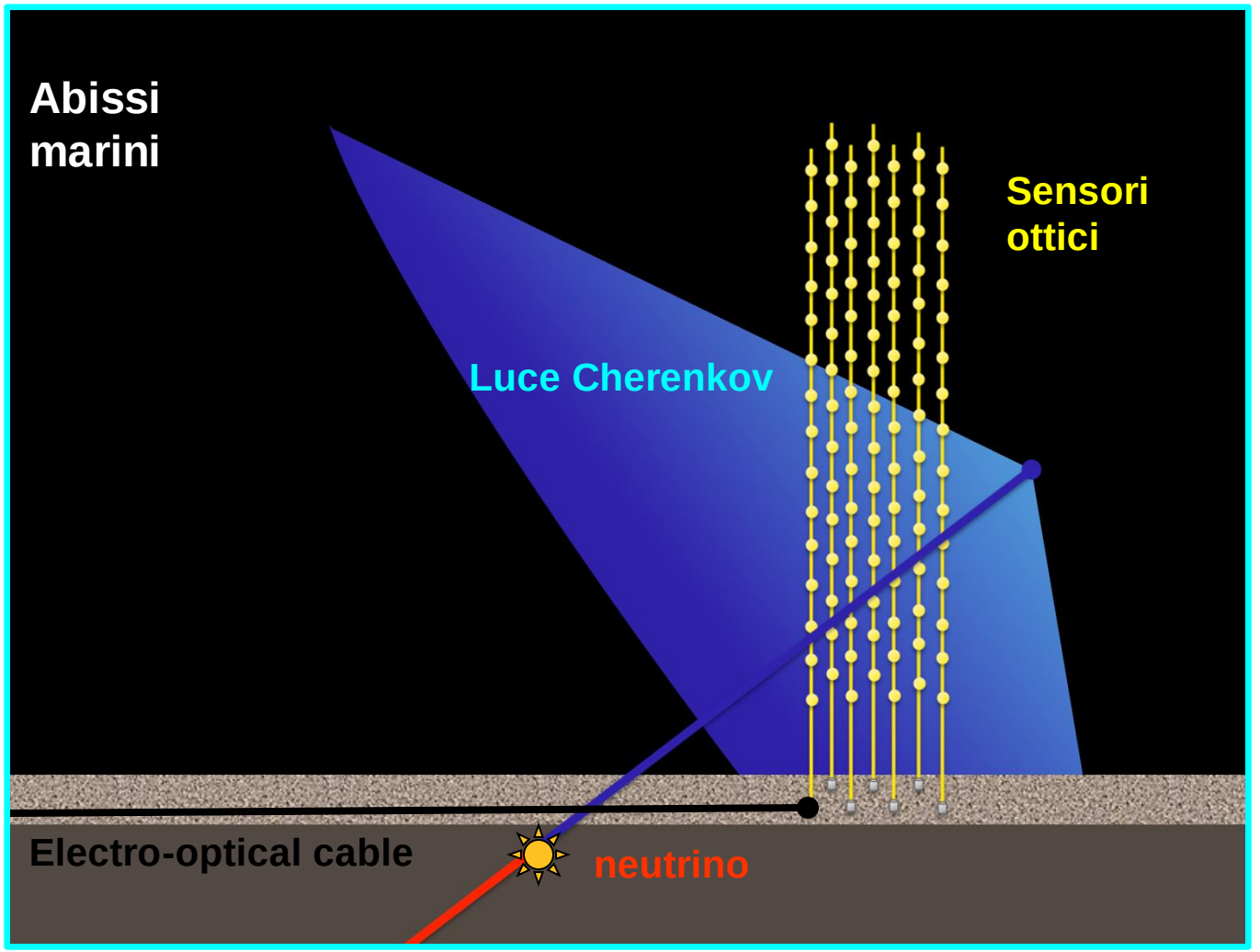


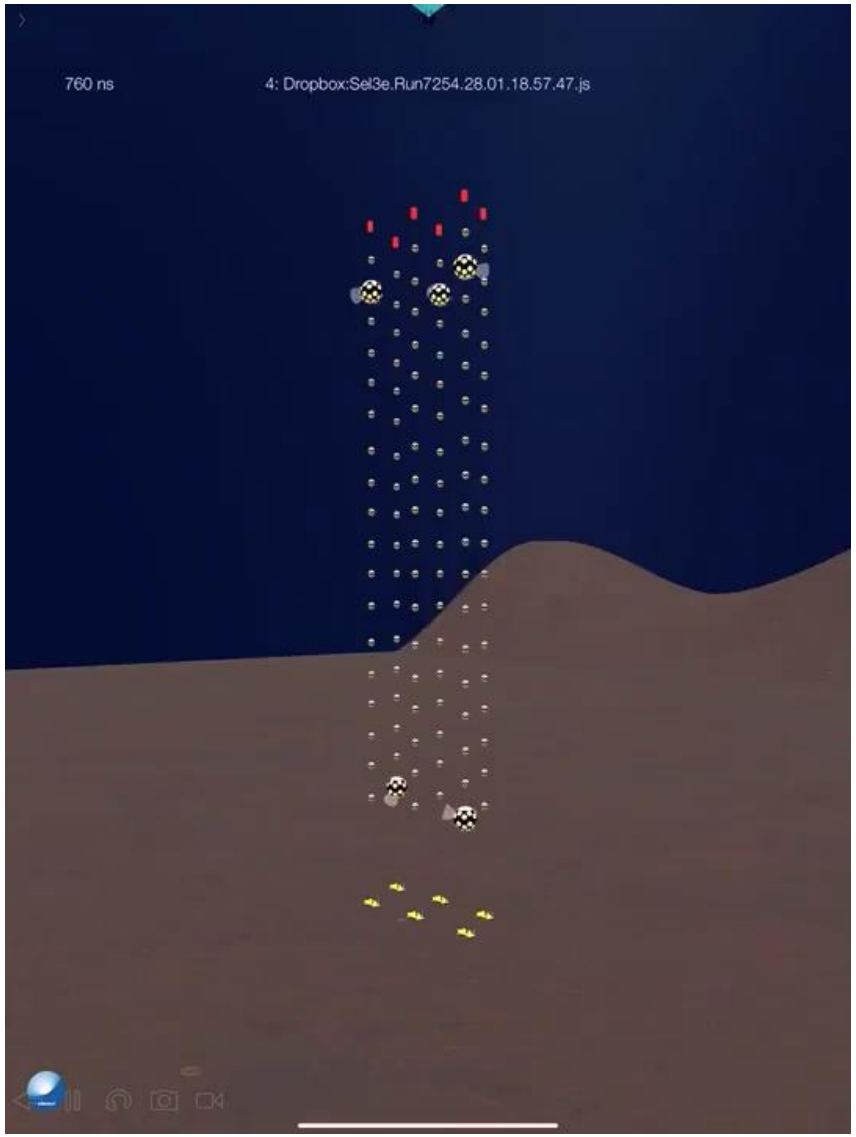




Rivelazione dei neutrini cosmici



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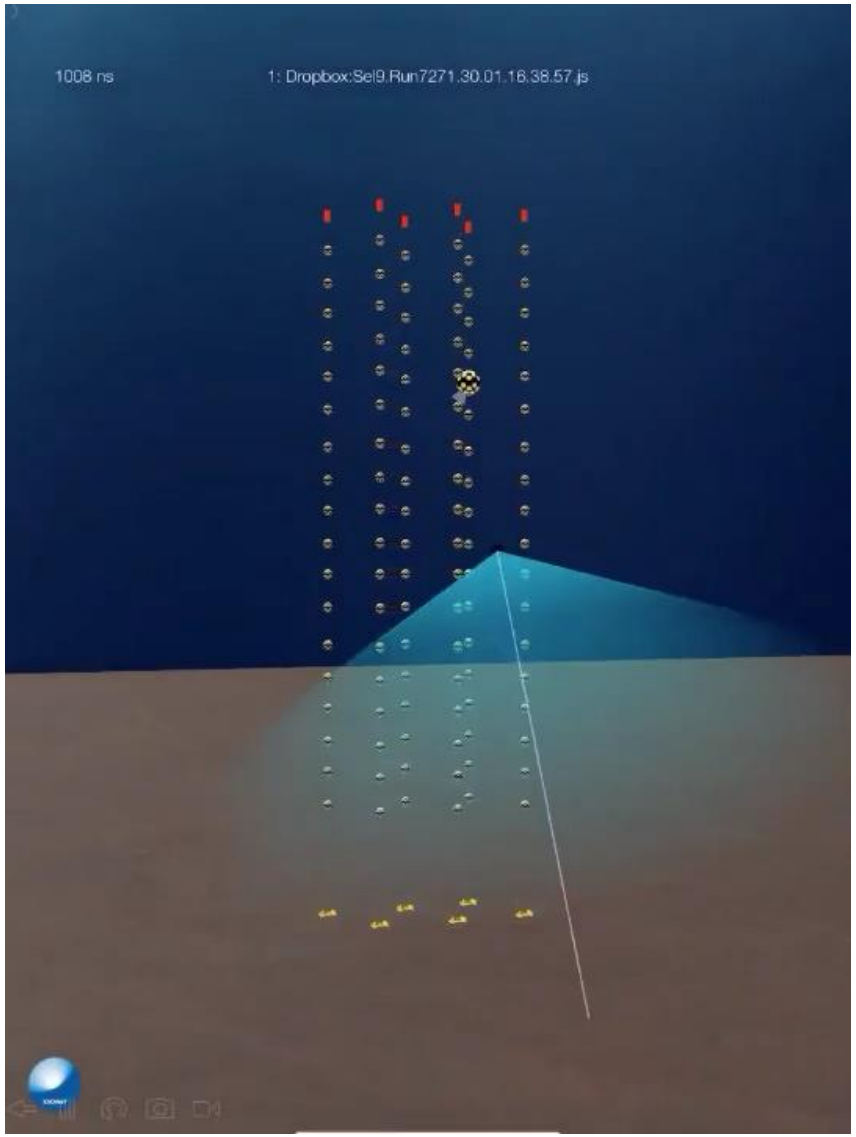
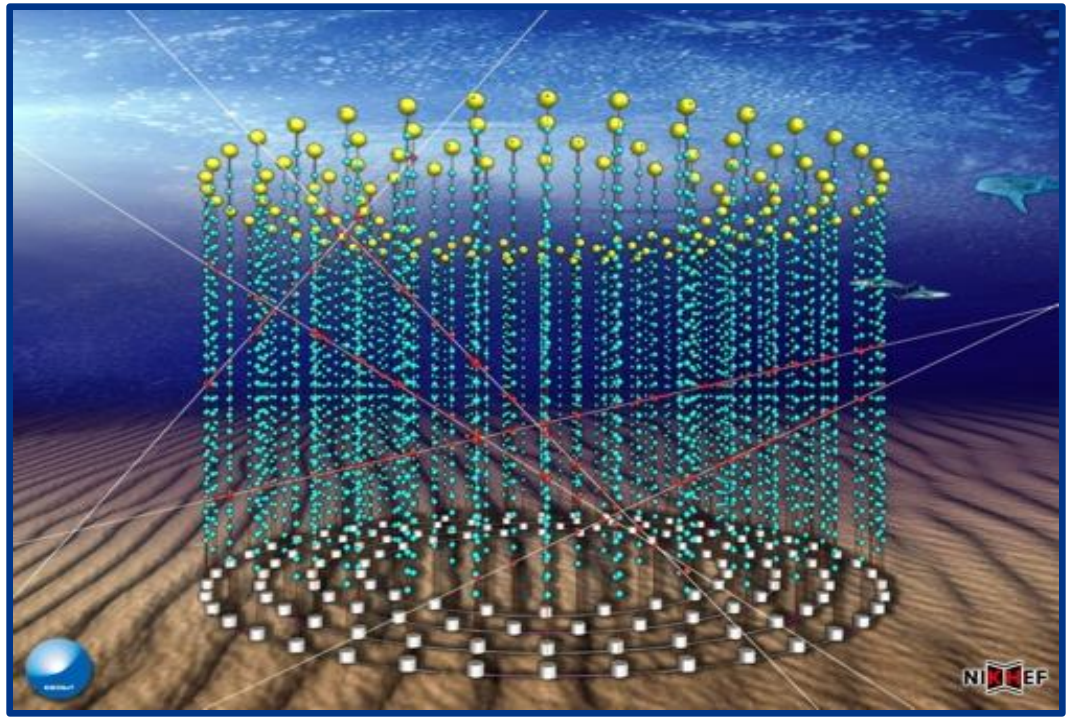
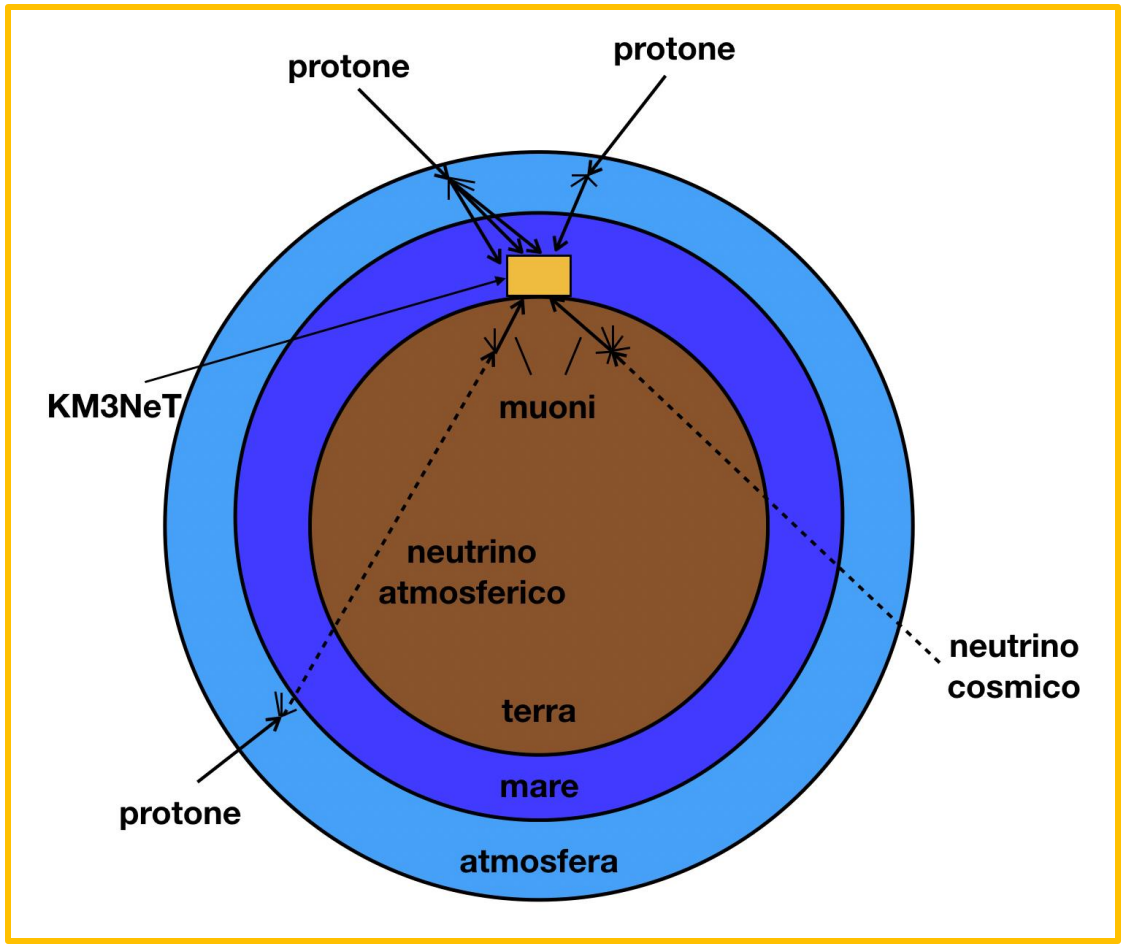

1008 ns
1: Dropbox:Sel9.Run7271.30.01.16.38.57.js

Perché in fondo al mare?

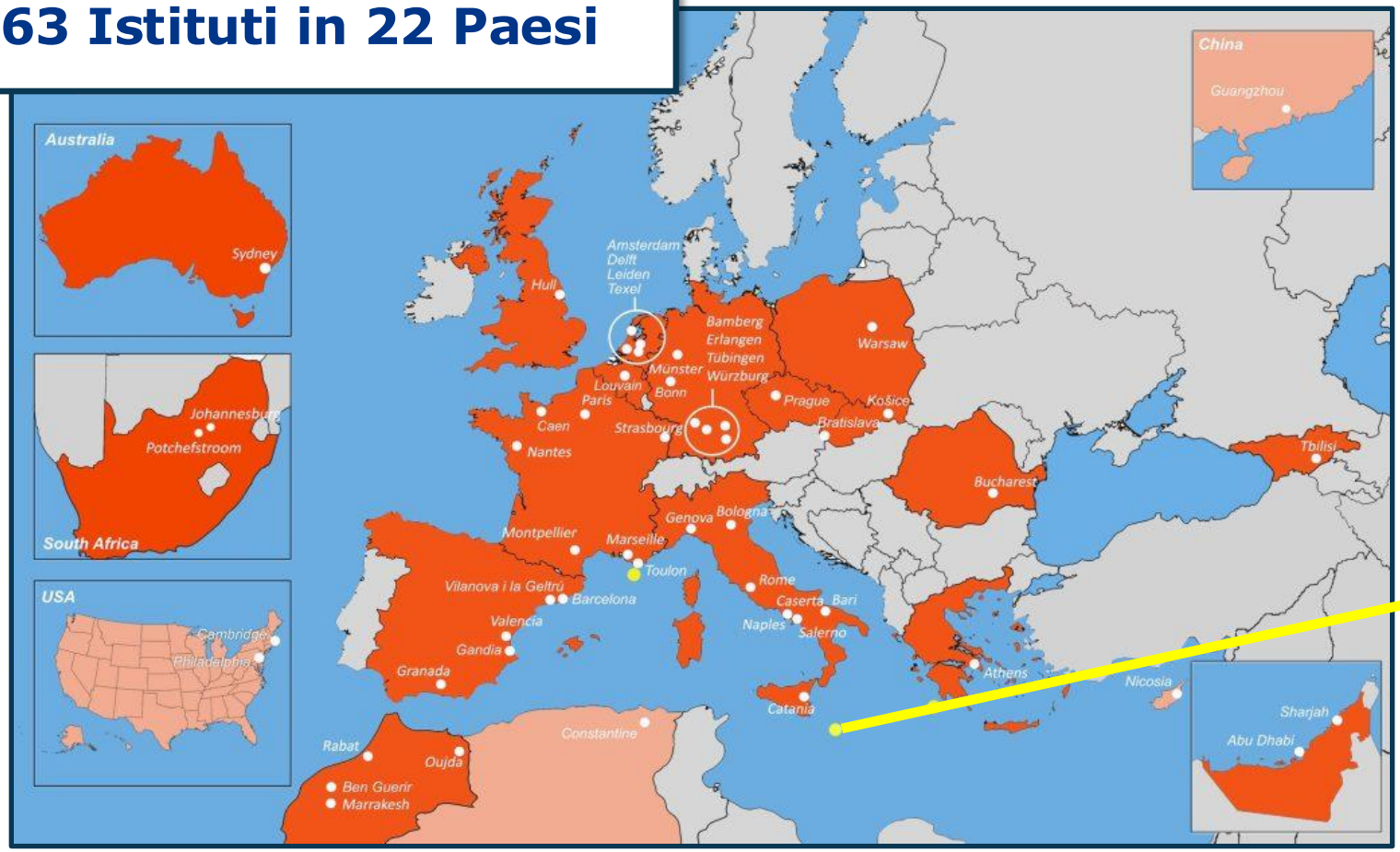
- Mezzo trasparente per la propagazione della luce Cherenkov
- Dobbiamo schermare il rivelatore dai raggi cosmici
- Per rivelare il flusso di neutrini cosmici occorre un rivelatore dal volume di 1 km^3





La Collaborazione KM3NeT

63 Istituti in 22 Paesi



+ UniFal Brasile

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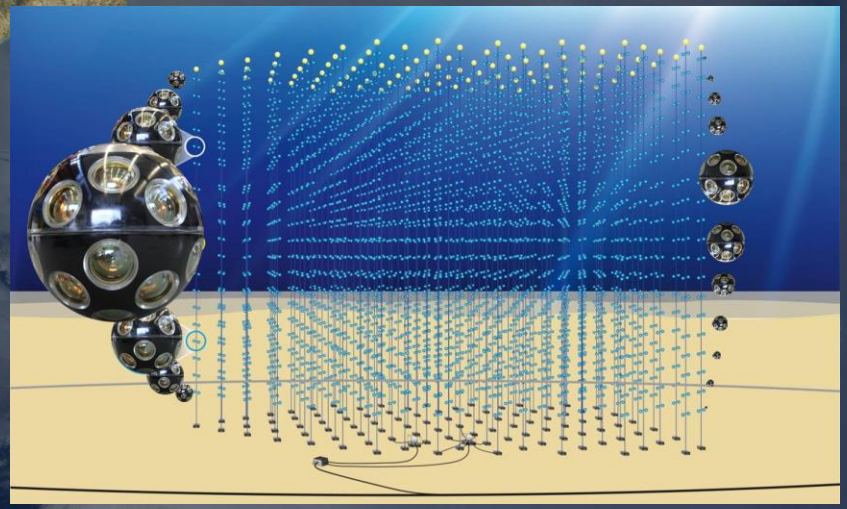
Il telescopio KM3NeT/ARCA

KM3 Neutrino Telescope

Astroparticle Research with Cosmics in the Abyss



Capo Passero
3500 m

Obiettivi Scientifici:

- **Ricerca di sorgenti di neutrini di alta energia nell'Universo**
- **Ricerca di Dark Matter**
- **Osservazioni multimessaggero dell'Universo**

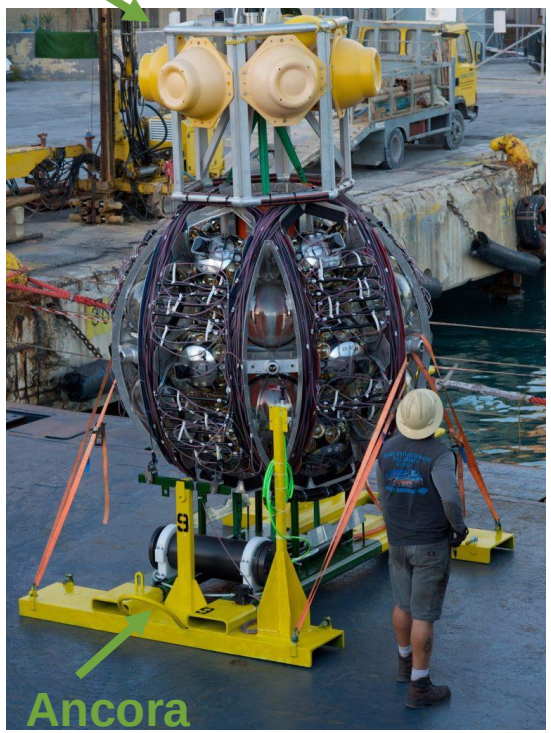
KM3NeT: tecnologia e infrastruttura

- Sensori ottici: DOMs (Digital Optical Module)
- Stringhe: DU (Detection Unit)
- Infrastruttura sottomarina: cavi elettro-ottici di interlink, JBs (Junction Boxes)

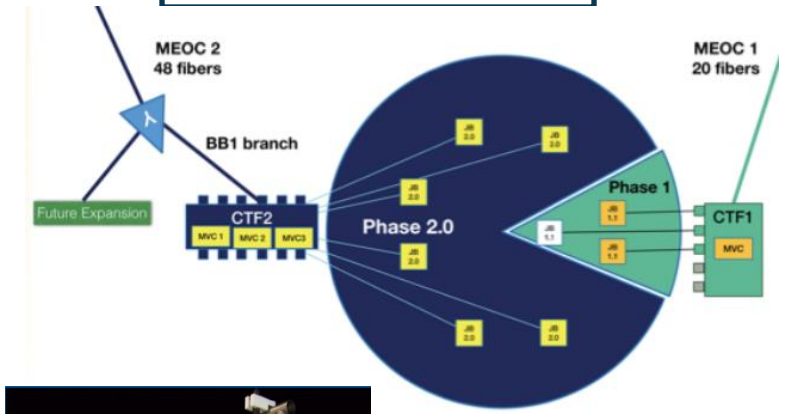
DOM

Sfera di vetro di 17''
31 3" PMTs
LED and Piezo
Elettronica di front-end

DU

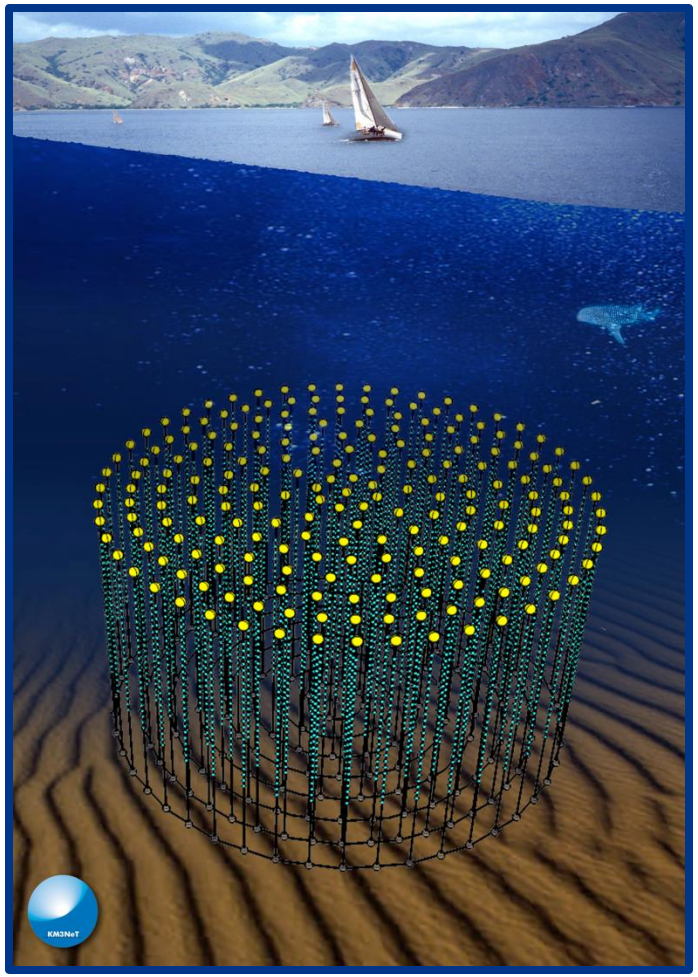


Infrastruttura/IL



Junction Box

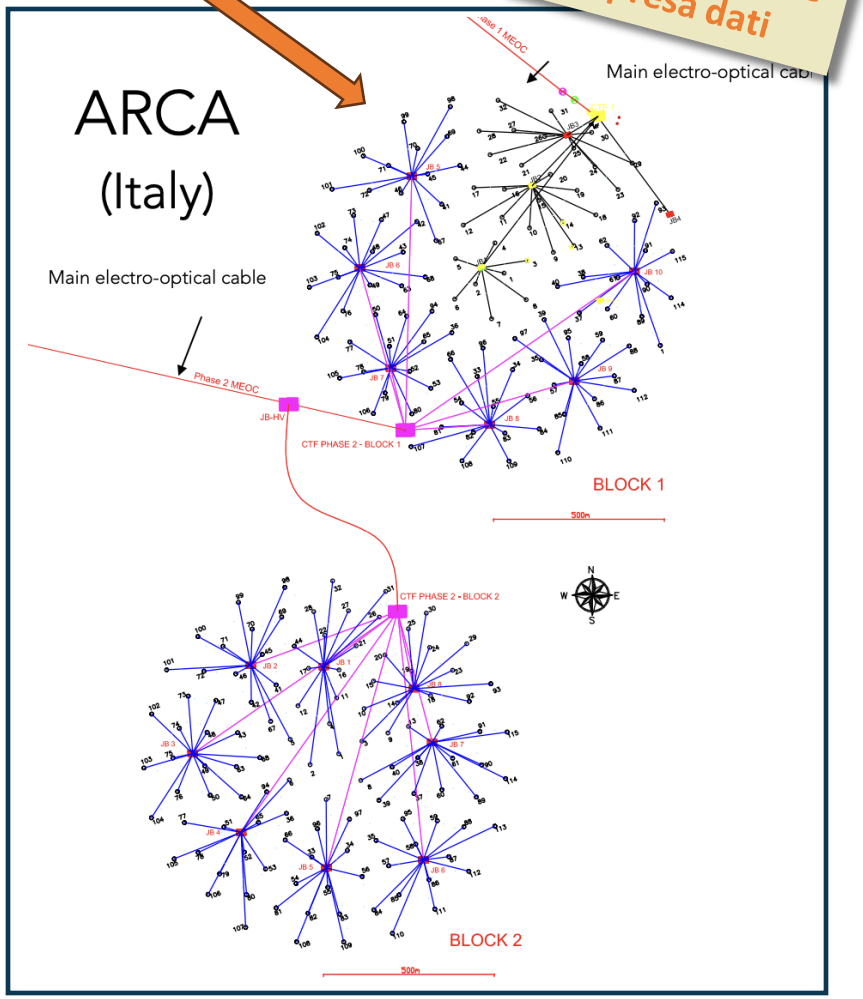
Il telescopio KM3NeT/ARCA



- 2 × 115 Detection Units
- 4140 DOMs
- 3500 m di profondità
- ~ 90 km dalla costa

Building Block

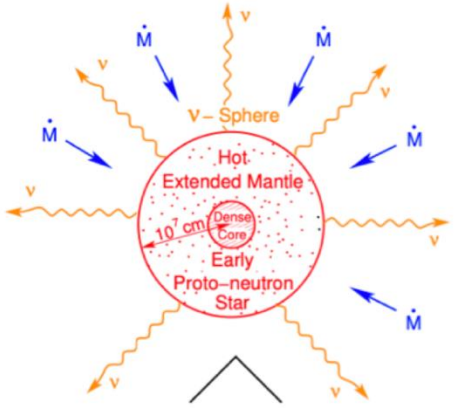
33 DU installate e in presa dati

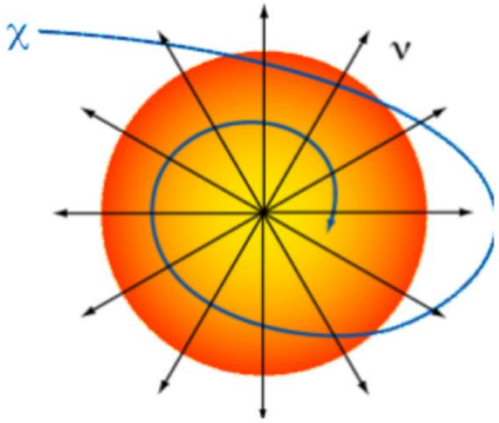


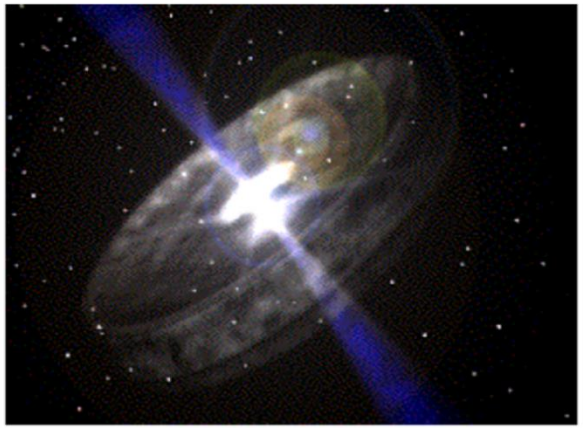
KM3NeT/ARCA: esplorando l'universo a diverse energie

Il telescopio KM3NeT/ARCA permette di studiare fenomeni astrofisici su un ampio spettro di energie.

ENERGIA DEL NEUTRINO

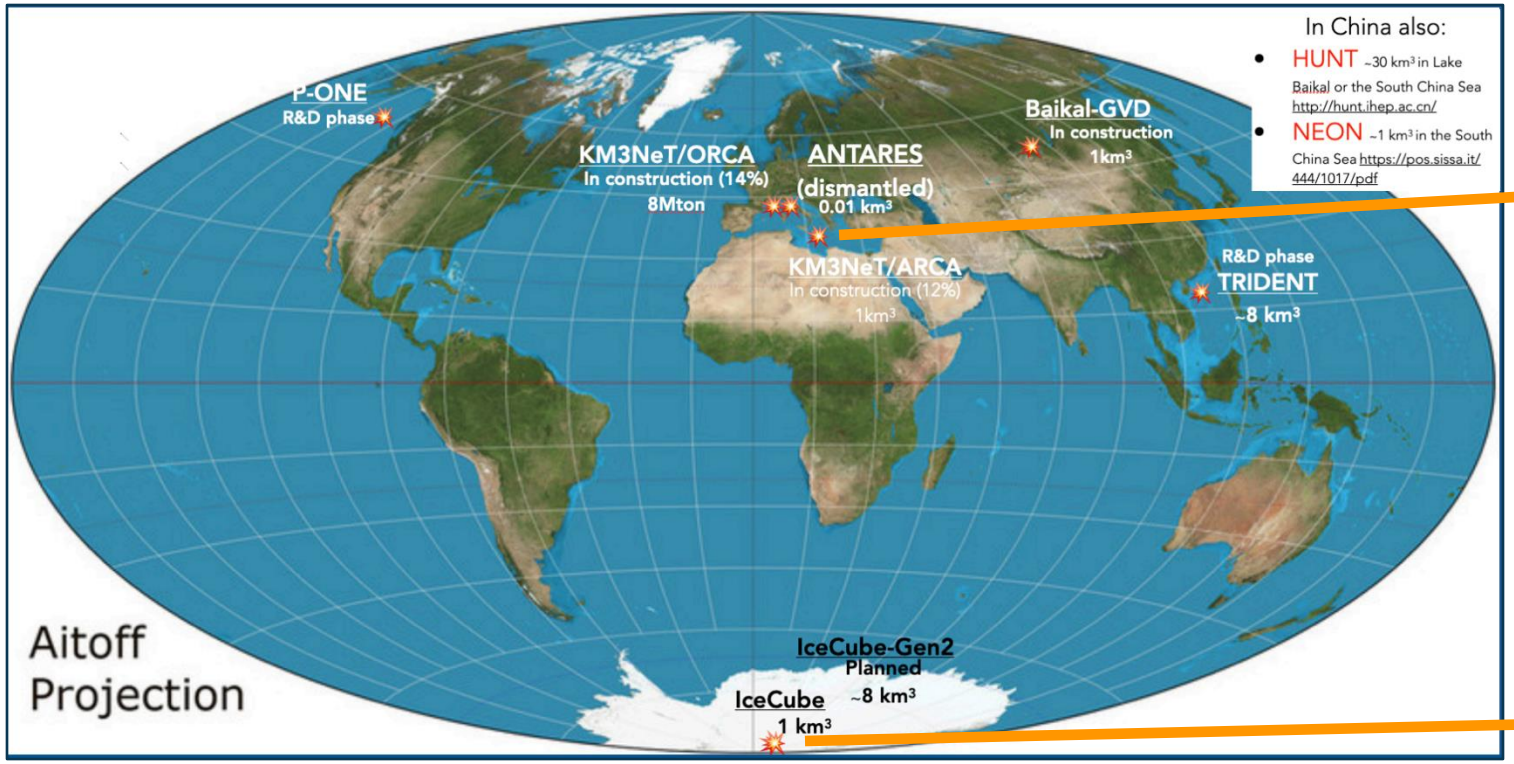




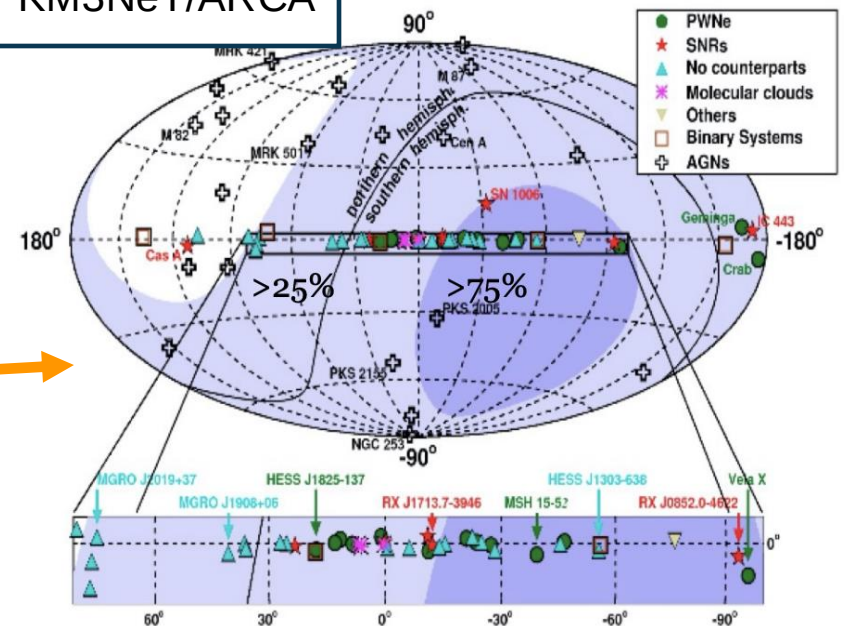


Esplosioni di Super Novae	Ricerca indiretta di Dark Matter	Rivelazione di sorgenti neutrini cosmici Astronomia multimessagera
MeV	TeV	TeV

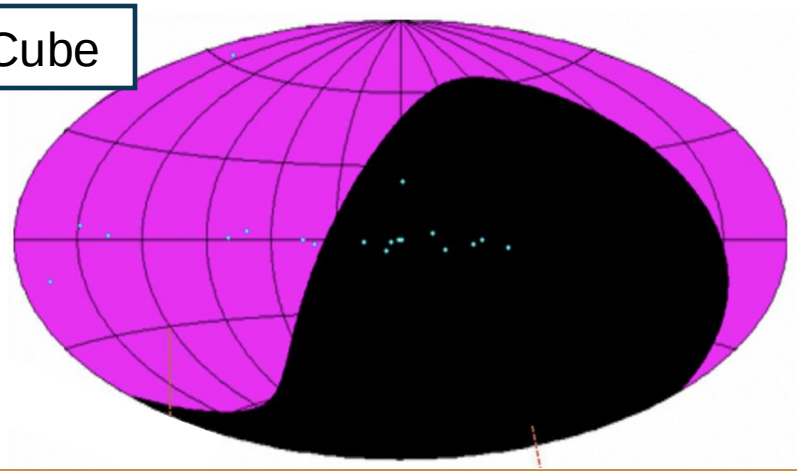
Perché nel mar Mediterraneo?



KM3NeT/ARCA



IceCube



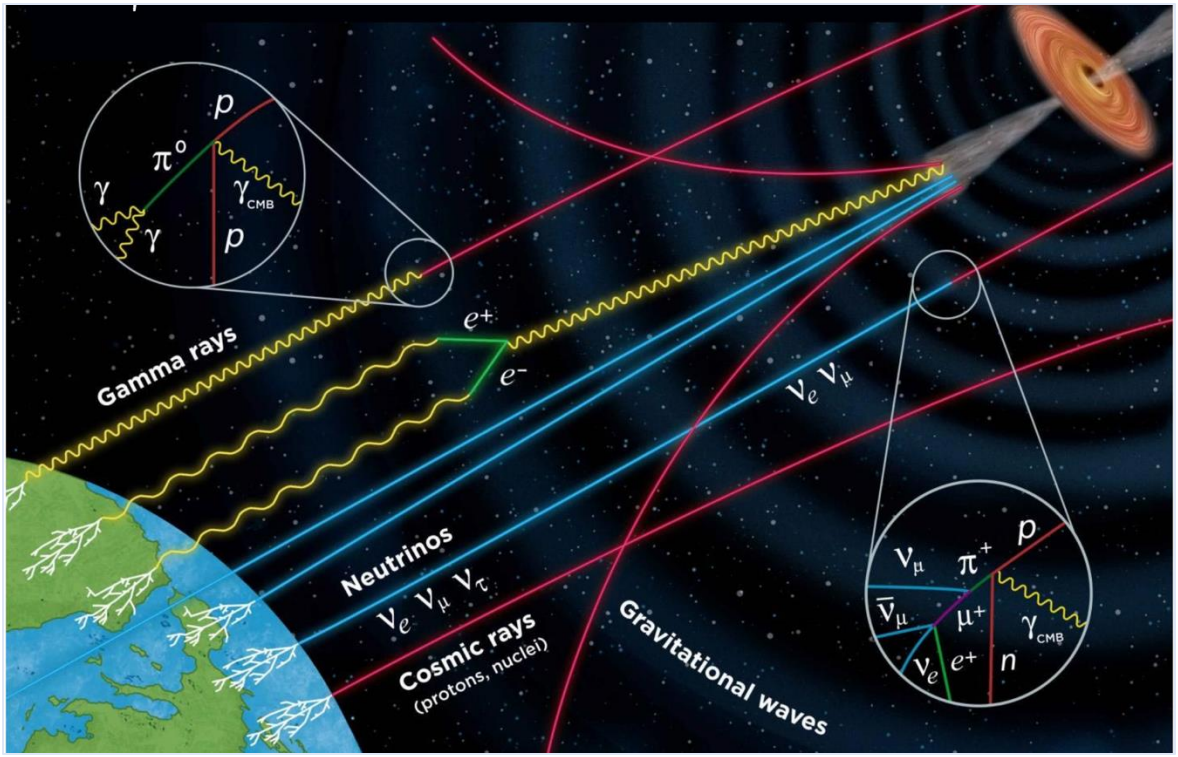
Operativo: ICECUBE dal 2011 (1 km³), **ANTARES** 2008-2022 (0.01 km³)
In costruzione e operativi: KM3NeT (1 km³), **GVD-Baikal** (1 km³)
Futuri: ICECUBE-Gen2, **P-One** (R&D Canada), **Trident** (R&D China, 8 km³)

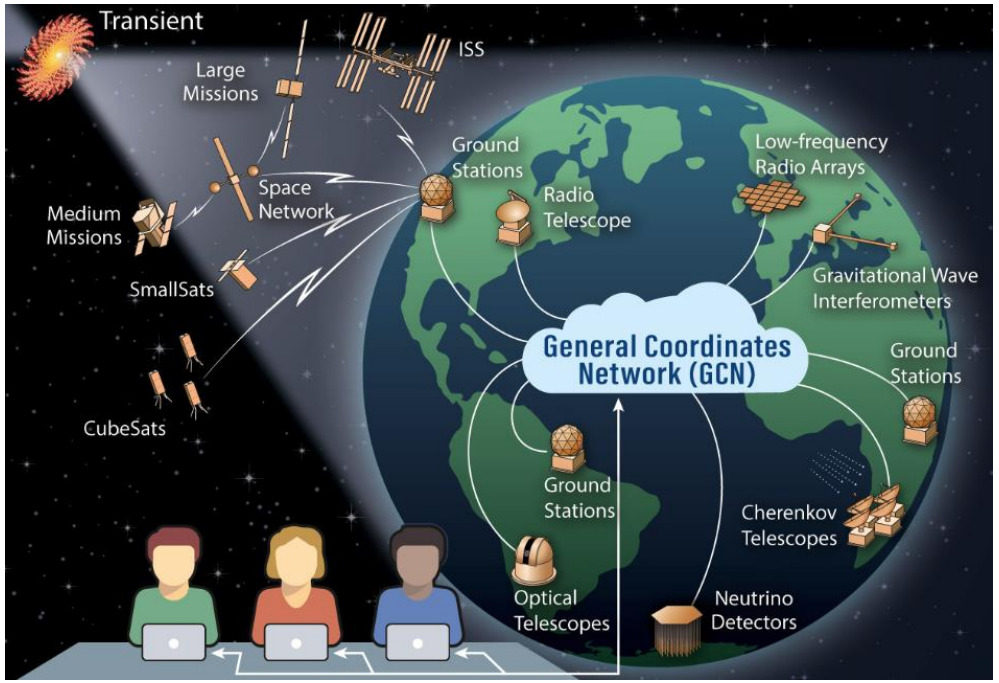
KM3NeT4RR

KM3Net4RR in DFA UNICT

Obiettivi scientifici: potenziamento dell'astronomia con i neutrini con il telescopio KM3NET/ARCA:

- Implementazione delle **Multimessenger liaisons**: calibrazione del rivelatore, analisi dei dati e supporto alle attività multi-messaggero e astroparticellare;



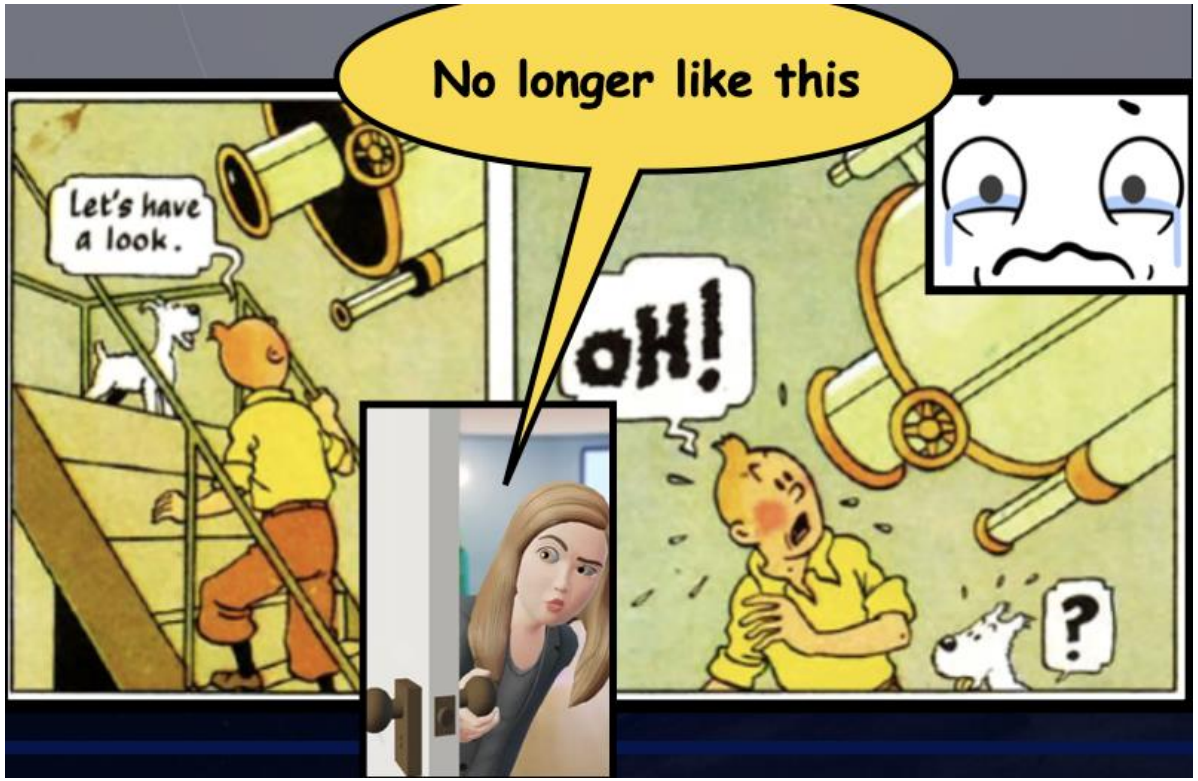


- sviluppo e implementazione di algoritmi e strumenti per l'analisi in tempo reale di **alet** esterni, nonché la configurazione dei software per la generazione di **alert** KM3NeT da distribuire alle comunità multi-messaggera**.**

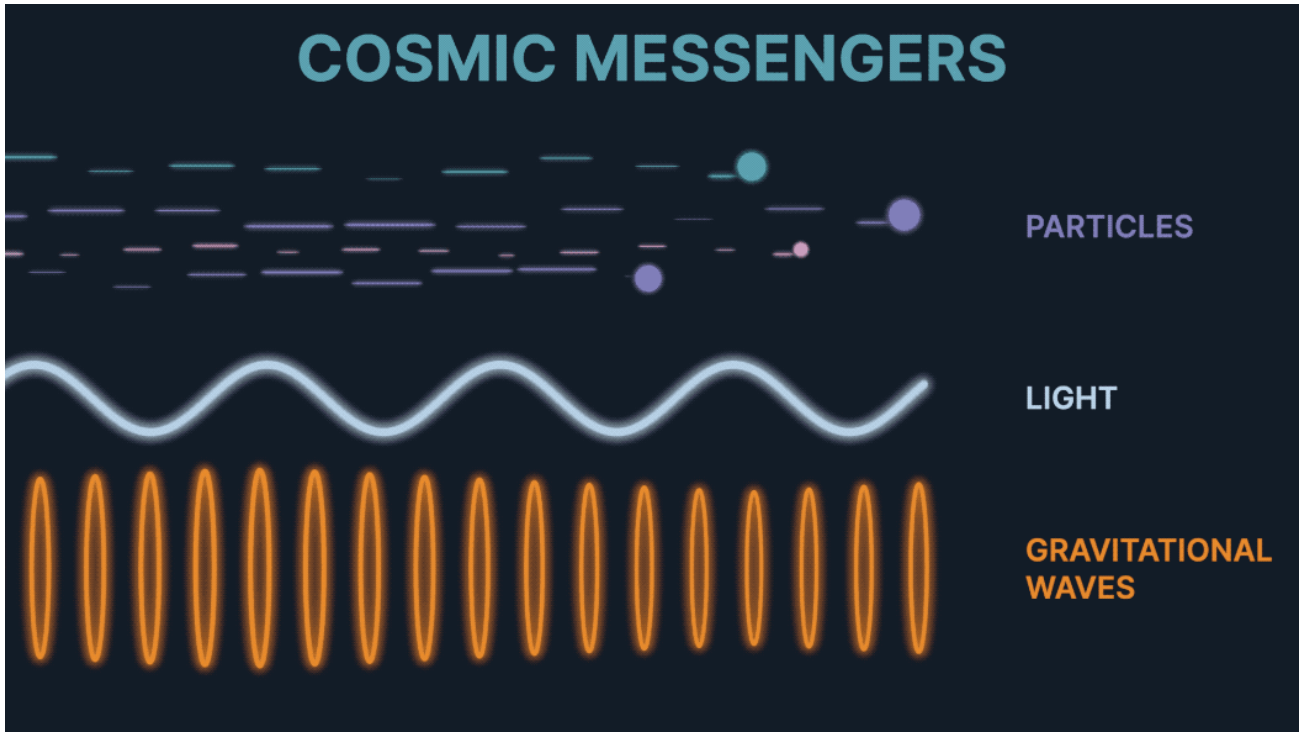
KM3Net4RR in DFA UNICT

MULTIMESSENGER ASTRONOMY WITH KM3NET

- Traditional astronomy is no longer the only way to observe the high energy Universe



- Multi-messenger astronomy is astronomy based on the coordinated observation and interpretation of signals carried by different "messengers":



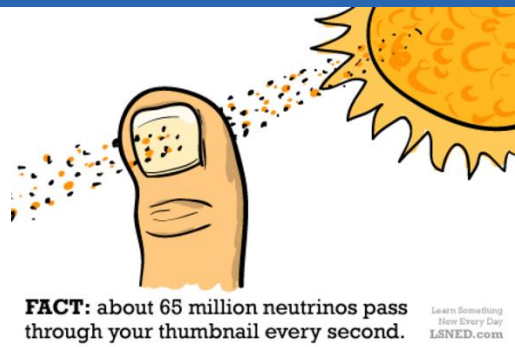
KM3Net4RR in DFA UNICT

MULTIMESSENGER ASTRONOMY WITH KM3NET

- One cosmic accelerator, or astrophysical source, can emit more than one messenger
- The multi-messenger astrophysics involves **combining observations of the same events with different messengers**

KM3Net4RR in DFA UNICT

MULTIMESSENGER ASTRONOMY WITH KM3NET



- Neutrinos are produced during the process of nuclear fusion in the sun: the nucleus from the simplest element, hydrogen fuse together to form a heavier element, helium.

NOT ONLY… BUT ALSO COSMIC RAYS

- Solar cosmic rays are photons emitted by the Sun during periods of intense flare activity

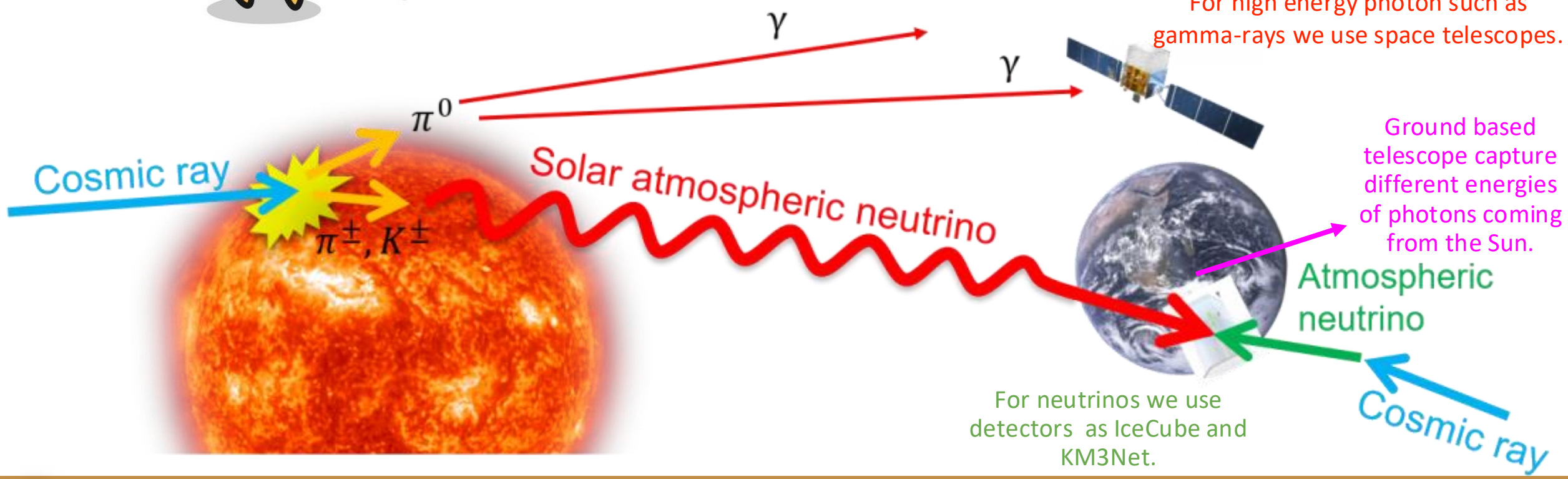
KM3Net4RR in DFA UNICT

MULTIMESSENGER ASTRONOMY WITH KM3NET

But ALSO…

… gamma rays are generated in the solar atmosphere.

Different eyes are needed to capture information such as light, neutrinos and cosmic rays.



For high energy photon such as gamma-rays we use space telescopes.

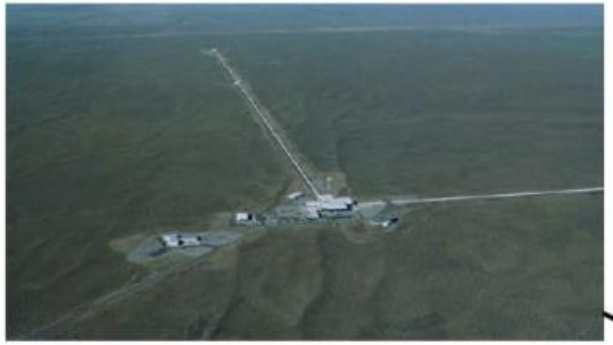
Ground based telescope capture different energies of photons coming from the Sun.

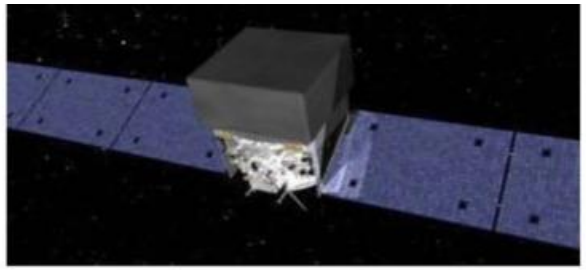
For neutrinos we use detectors as IceCube and KM3Net.

KM3Net4RR in DFA UNICT

MULTIMESSENGER ASTRONOMY WITH KM3NET

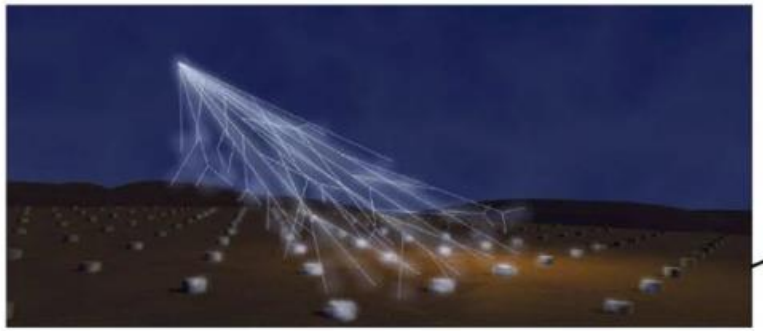
http://www.ifae.es/eng/magic-gallery.html

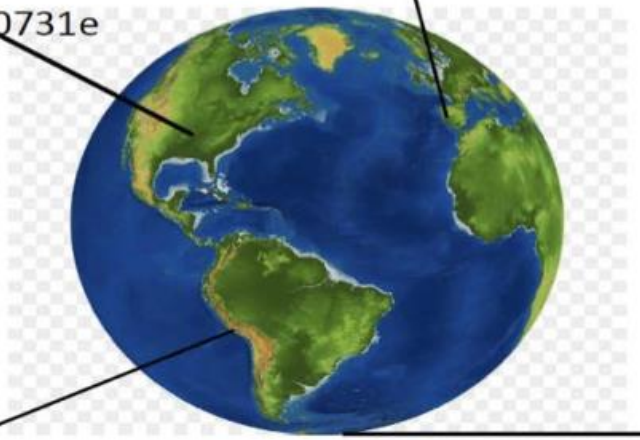


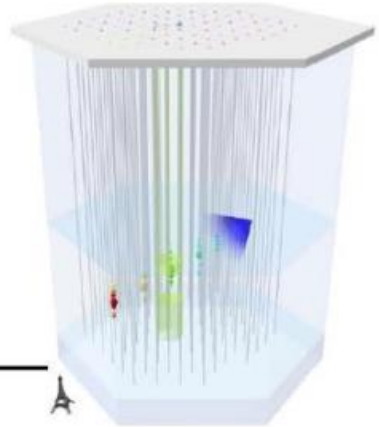


https://www.nasa.gov/content/fermi/overview

https://www.ligo.caltech.edu/image/ligo20150731e







http://www.ung.si/en/research/cac/projects/auger/

https://icecube.wisc.edu/gallery/press/view/1336

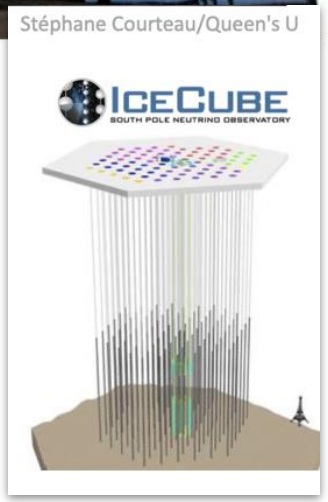
KM3Net4RR in DFA UNICT

MULTIMESSENGER ASTRONOMY WITH KM3NET

We have a large variety of wide-field and pointed instruments

Different observational strengths:

- **Gamma ray**: timing, spectrum, particle acceleration signature
- **X-ray**: timing, good localization, low background
- **Visible/IR**: precise localization, spectroscopy (& redshift), thermal signature
- **Radio**: late-time synchrotron afterglow, precise localization
- **Neutrino**: timing, particle acceleration signature
- **Gravitational waves**: timing, distance, mass parameters

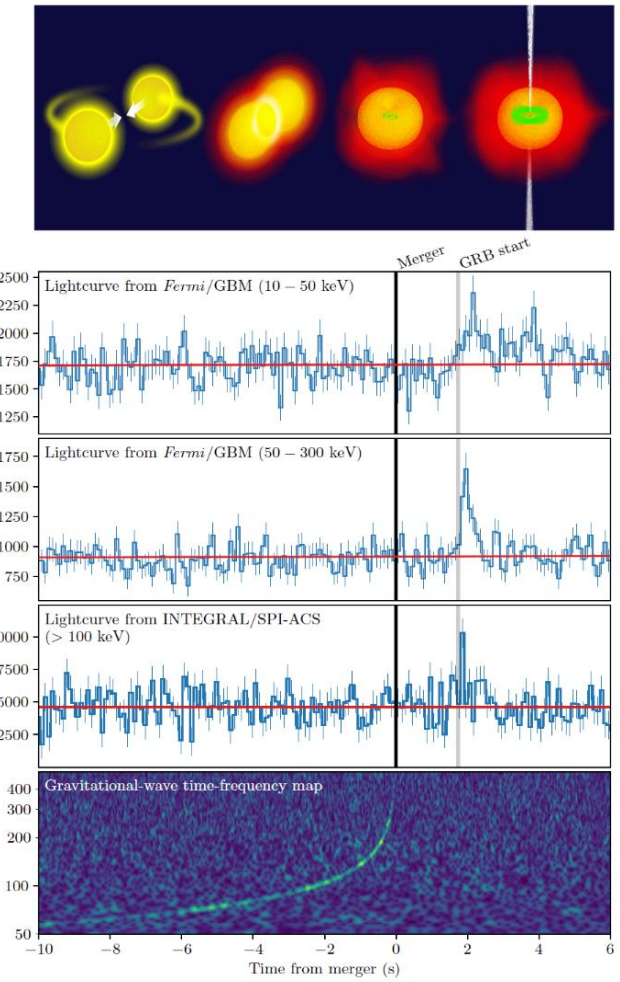


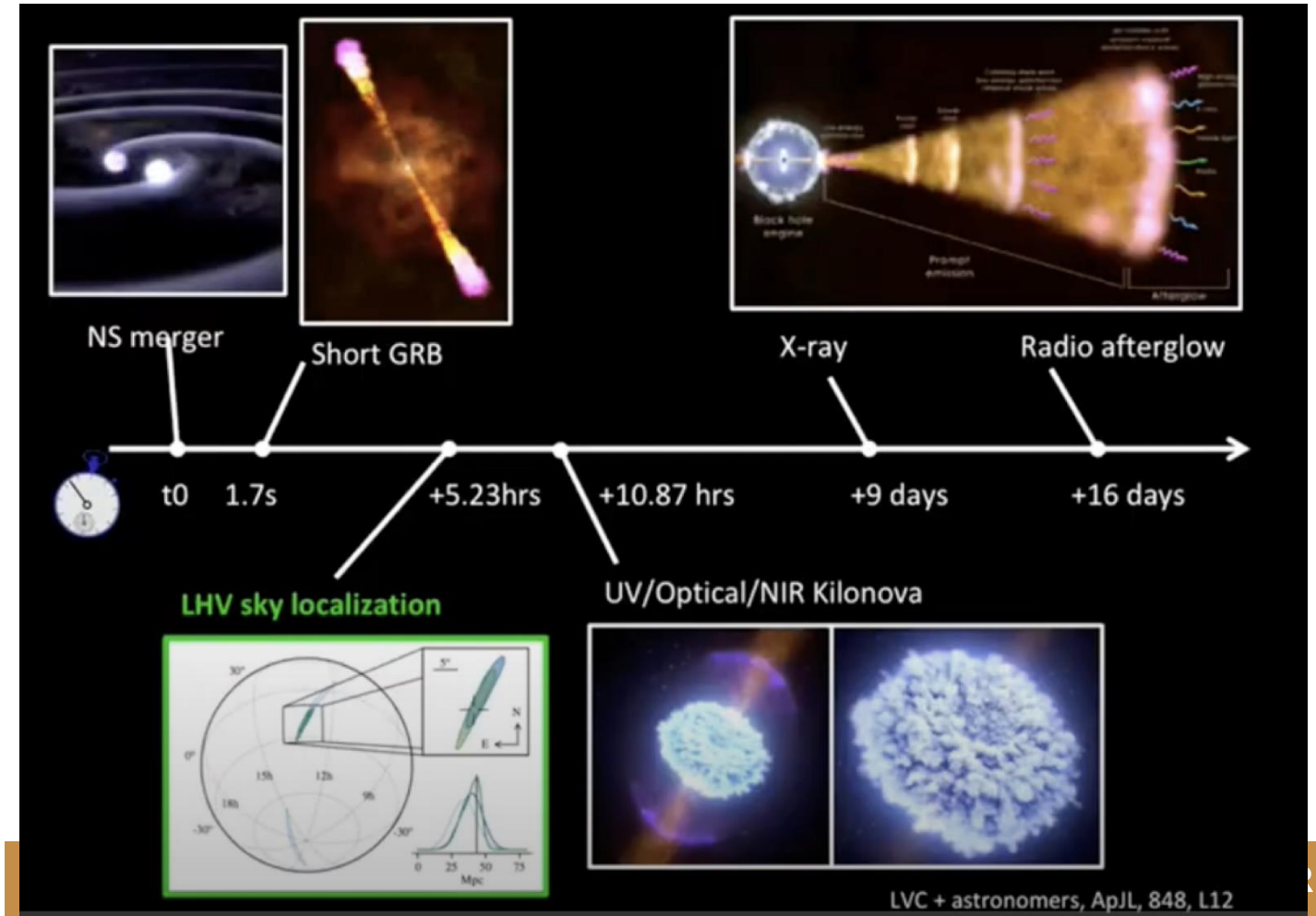
nuclear reactions occurring inside stars: **to learn how matter evolved from simple particles into more complex composites of particles**

KM3Net4RR in DFA UNICT

Successul MM event: GW170817

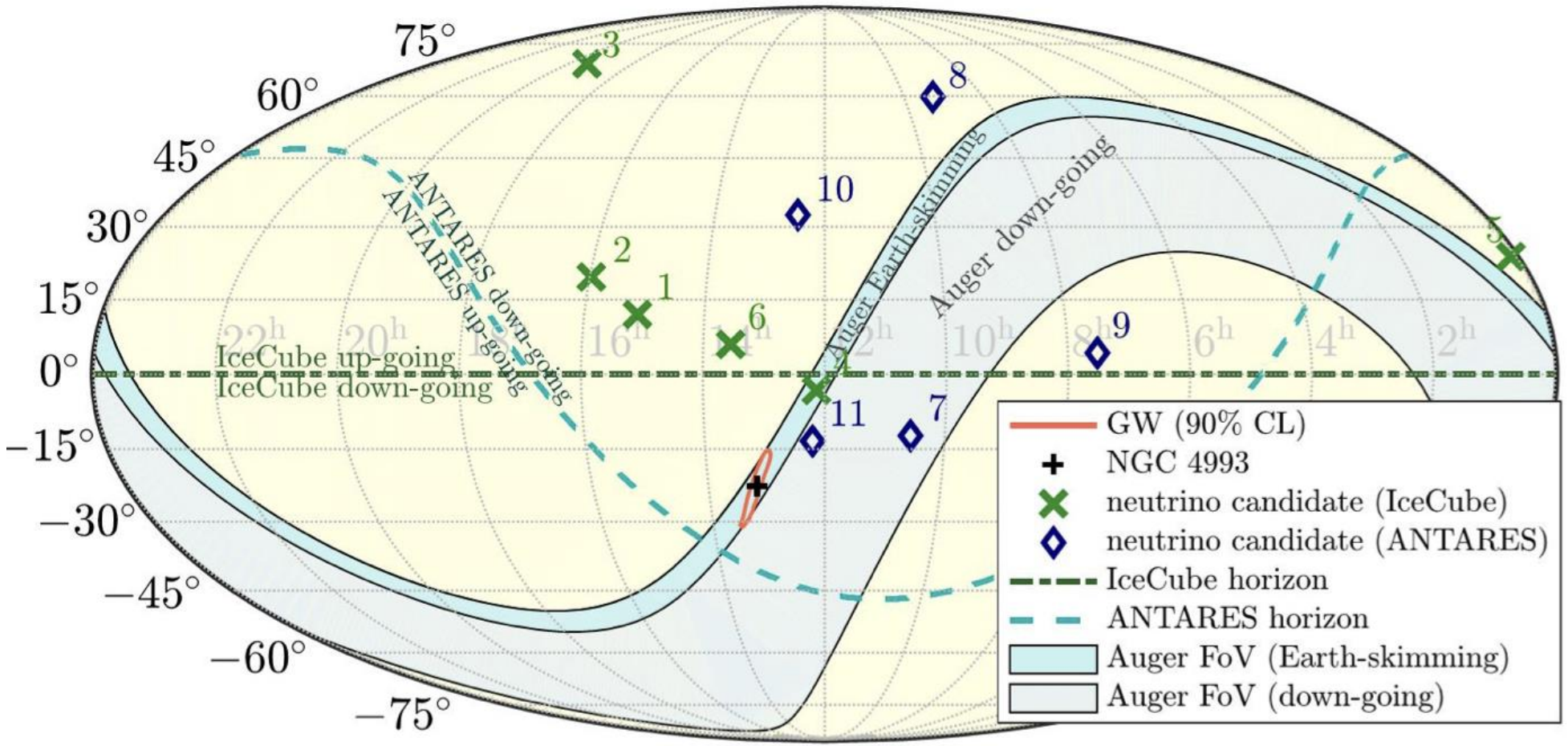
- On 17th of August 2017, multi-messenger astronomy related to GWs had its breakthrough: the LIGO-Virgo network observed a GW signal of two low-mass compact objects consistent with a neutron star binary (GRB170817, GRB170817A)





KM3Net4RR in DFA UNICT

No Neutrino Counterpart to GW170817

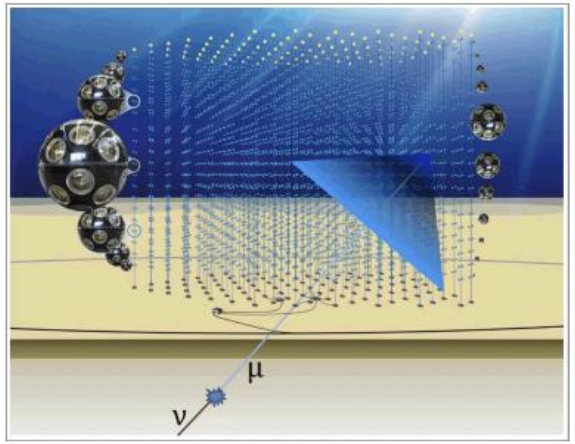


[Albert et al. (ANTARES, IceCube, Pierre Auger, LIGO and Virgo) 2017, ApJL 850, L35]

KM3NeT: the multimessenger program

PoS (ICRC2023) 1125

Data AcQuisition (DAQ)



KM3NeT ORCA and ARCA

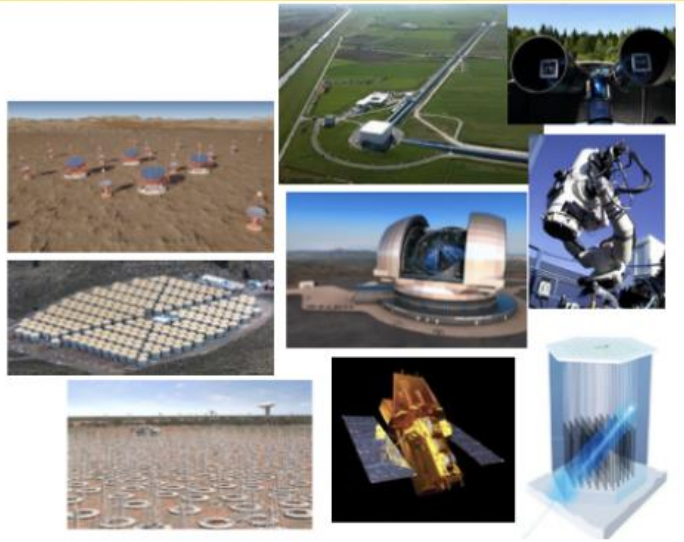
SENDING ALERTS

Send neutrino alerts to external communities for subsequent follow-ups

- Follow-up of EM/GW alerts
- Offline time/space correlation search with catalogues (GRB, AGN, SN, etc.)

RECEIVING ALERTS

EM/MM external facilities



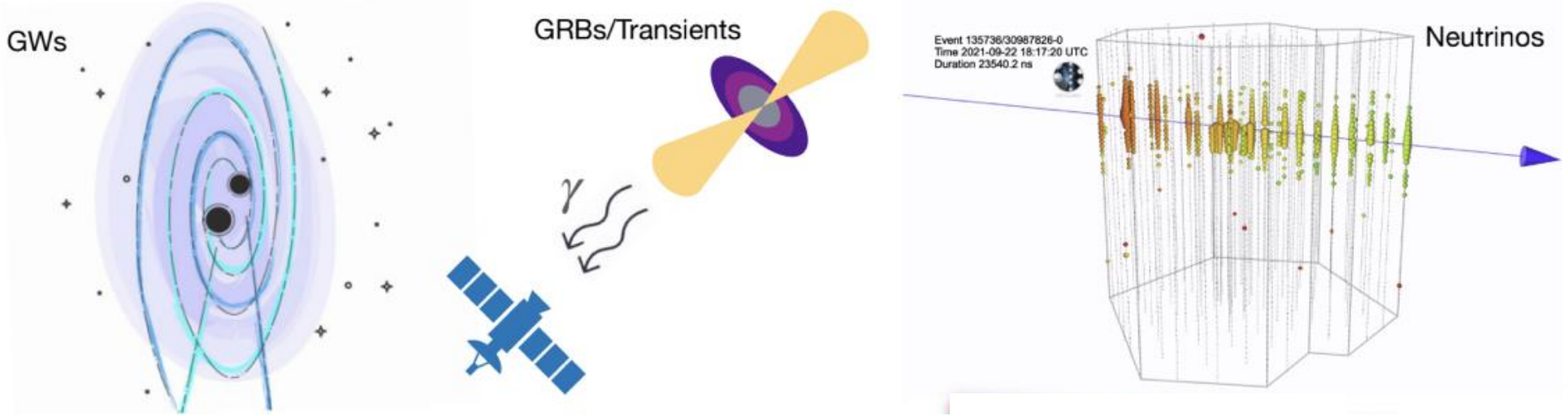
- Sending alert system → ongoing (high-energy neutrino alerts will be sent in real-time be the end of 2024)

WORK IN PROGRESS

In the project KM3Net4RR
DFA UNICT is DIRECT involved to the multi-messenger analysis, especially in:
- Multimessenger analysis between neutrinos from KM3Net and gravitational waves

In the project KM3Net4RR, the DFA UNICT is DIRECT involved to the multi-messenger analysis

KM3NeT follow-ups of MM external alerts



Four kinds of **online analyses** are in place to look for temporal and spatial coincidences among the KM3NeT reconstructed events and either:

- GRBs;
- GW extended region;
- Neutrinos identified by IceCube;
- Transient events (e.g., flaring/variable objects).

PoS (ICRC2023) 1125, PoS (ICRC2023) 1521

Current analysis consider only track-like events due to their best angular resolution

In the project KM3Net4RR, the DFA UNICT is DIRECT involved to the multi-messenger analysis

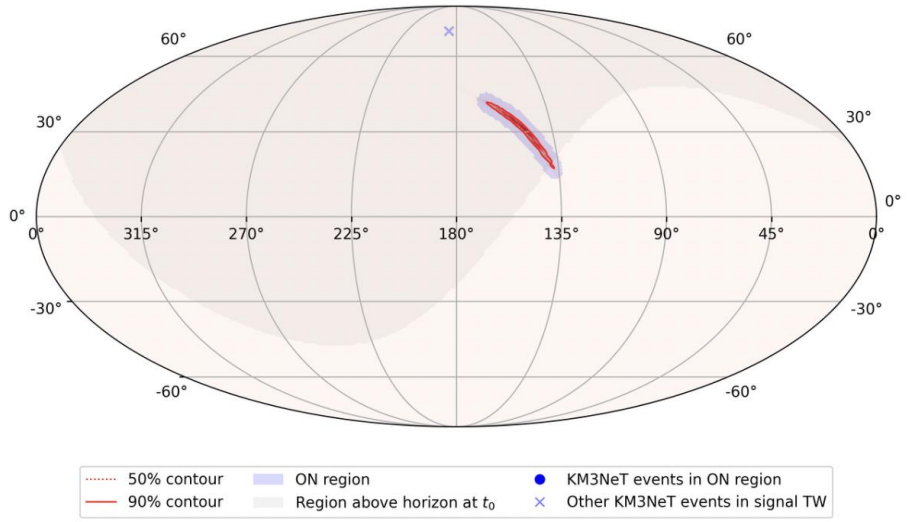
MULTIMESSENGER ASTRONOMY WITH KM3NET

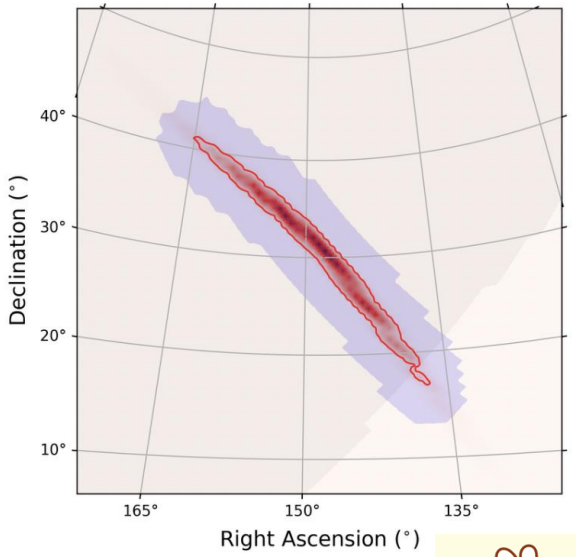
- **GW-HEN coincidence analysis, example:**

A GW alert was sent out to the community, with the following information:

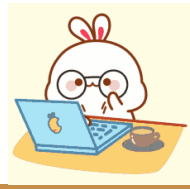
```
//////////////////////////////////////////////////////////////////////
TITLE:            GCN/LVC NOTICE
NOTICE_DATE:      Tue 14 Jan 25 08:22:33 UT
NOTICE_TYPE:      LVC Preliminary
TRIGGER_NUM:      S250114ax
TRIGGER_DATE:     20689 TJD;    14 DOY;   2025/01/14 (yyyy/mm/dd)
TRIGGER_TIME:     30123.222656 SOD {08:22:03.222656} UT
SEQUENCE_NUM:     1
GROUP_TYPE:       1 = CBC
SEARCH_TYPE:      1 = AllSky
PIPELINE_TYPE:    5 = spiir
FAR:              4.112e-27 [Hz]  (one per 281440282161563828224O.0 days)  (one pe
PROB_NS:          0.00 [range is 0.0-1.0]
PROB_REMNANT:     0.00 [range is 0.0-1.0]
PROB_BNS:         0.00 [range is 0.0-1.0]
PROB_NSBH:        0.00 [range is 0.0-1.0]
PROB_BBH:         1.00 [range is 0.0-1.0]
PROB_MassGap:     0.00 [range is 0.0-1.0]
PROB_TERRES:      0.00 [range is 0.0-1.0]
TRIGGER_ID:       0x10
MISC:             0x1898403
SKYMAP_FITS_URL:  https://gracedb.ligo.org/api/superevents/S250114ax/files/bayesta
EVENTPAGE_URL:    https://gracedb.ligo.org/superevents/S250114ax/view/
COMMENTS:         LVC Preliminary Trigger Alert.
COMMENTS:         This event is an OpenAlert.
COMMENTS:         LIGO-Hanford Observatory contributed to this candidate event.
COMMENTS:         LIGO-Livingston Observatory contributed to this candidate event.
```

- After "digesting" the GCN information
- Online pipelines starts
- Temporal and local coincidence between KM3Net neutrino and the GW



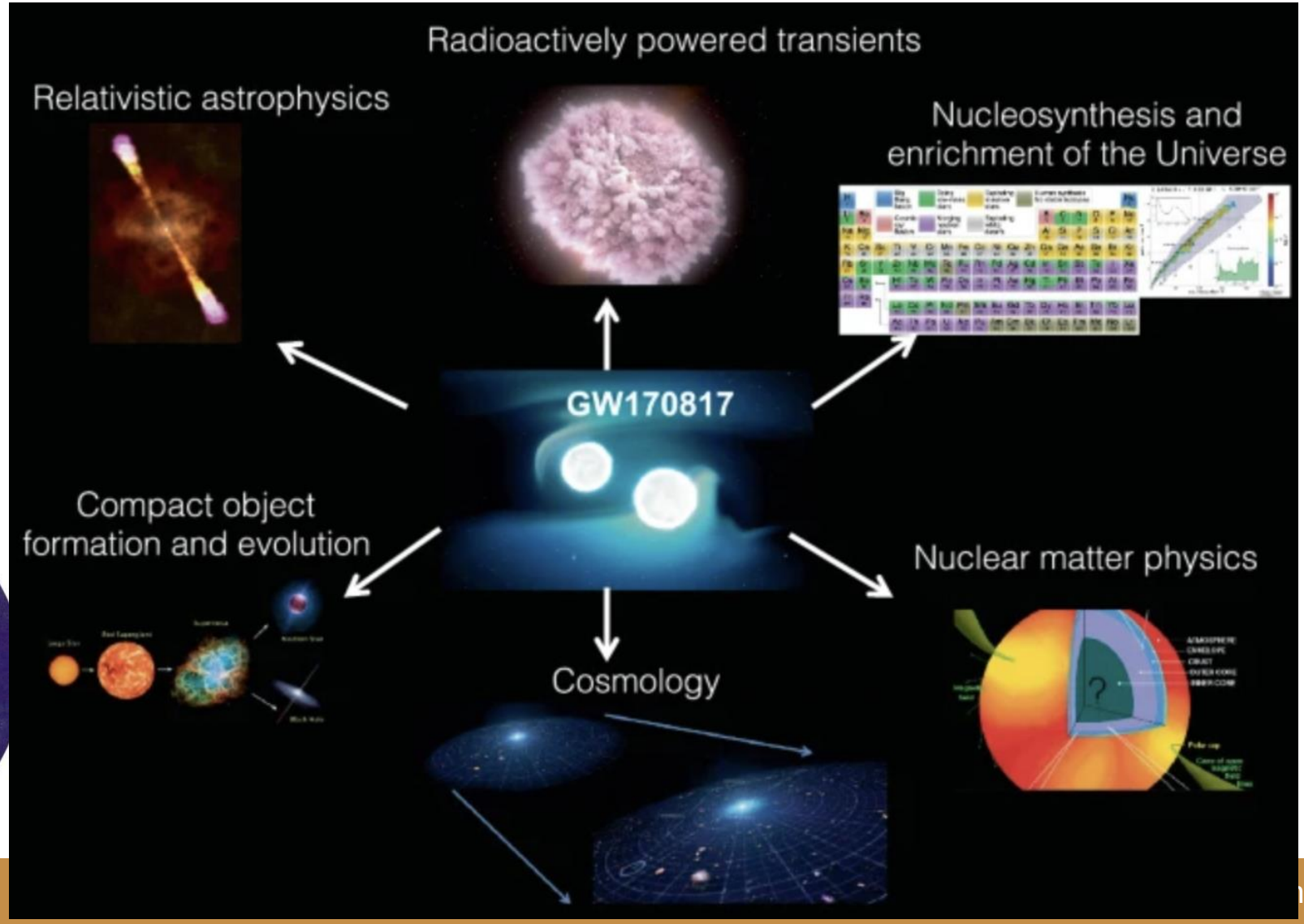


No neutrino coincidence related to the time and localization of the GW



Successful MM analysis can have impact in major astrophysical fields

as for example the discovery of GW170817



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Grazie

KM3NeT4RR
Kilometer Cube Neutrino Telescope for Recovery and Resilience

CATANIA, 21 GENNAIO 2025