# Kick-off ACME

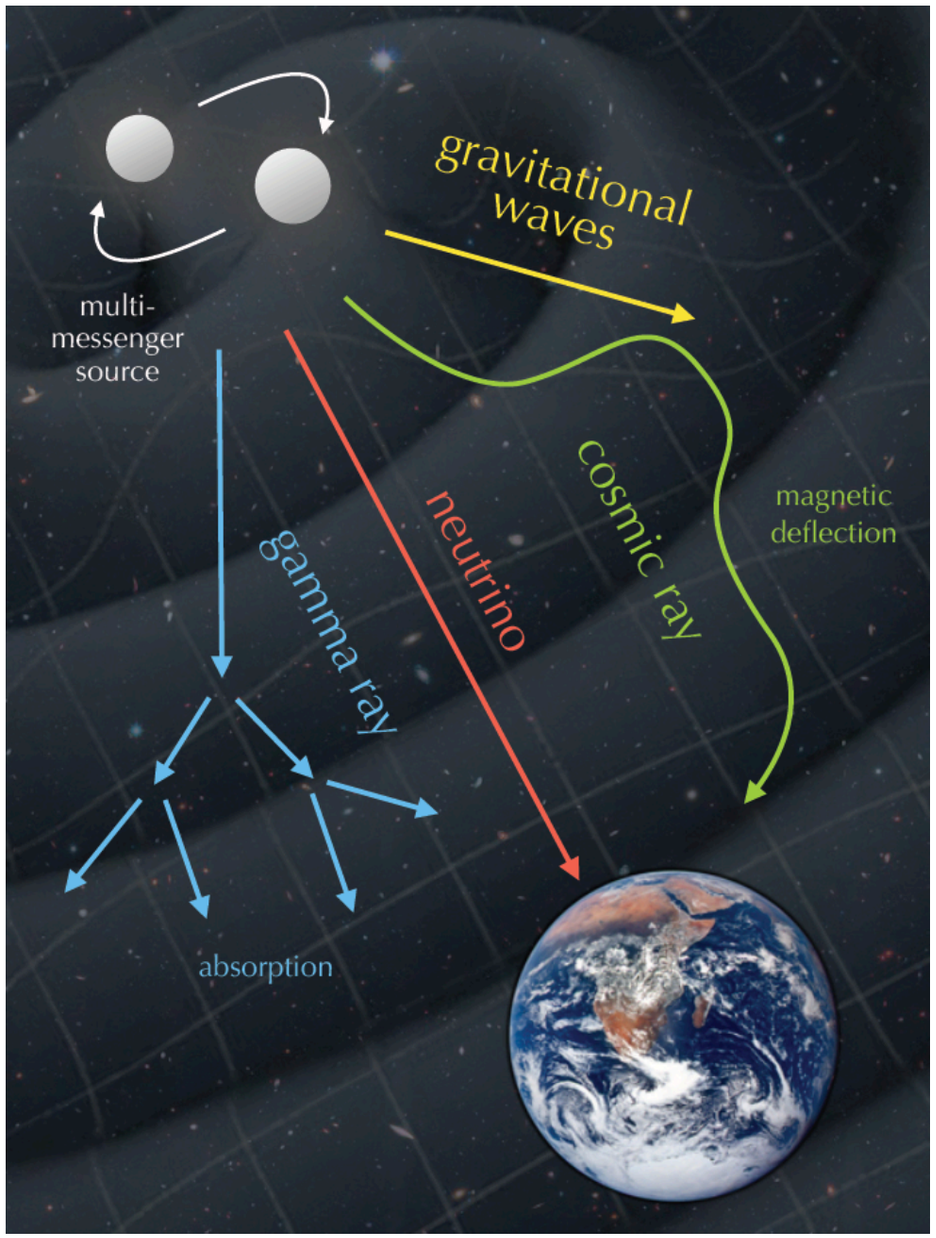
## MM & Neutrinos

## Challenges & significant results

**D. Dornic - Sept 16-17, 2024**

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

# Multi-messenger astronomy



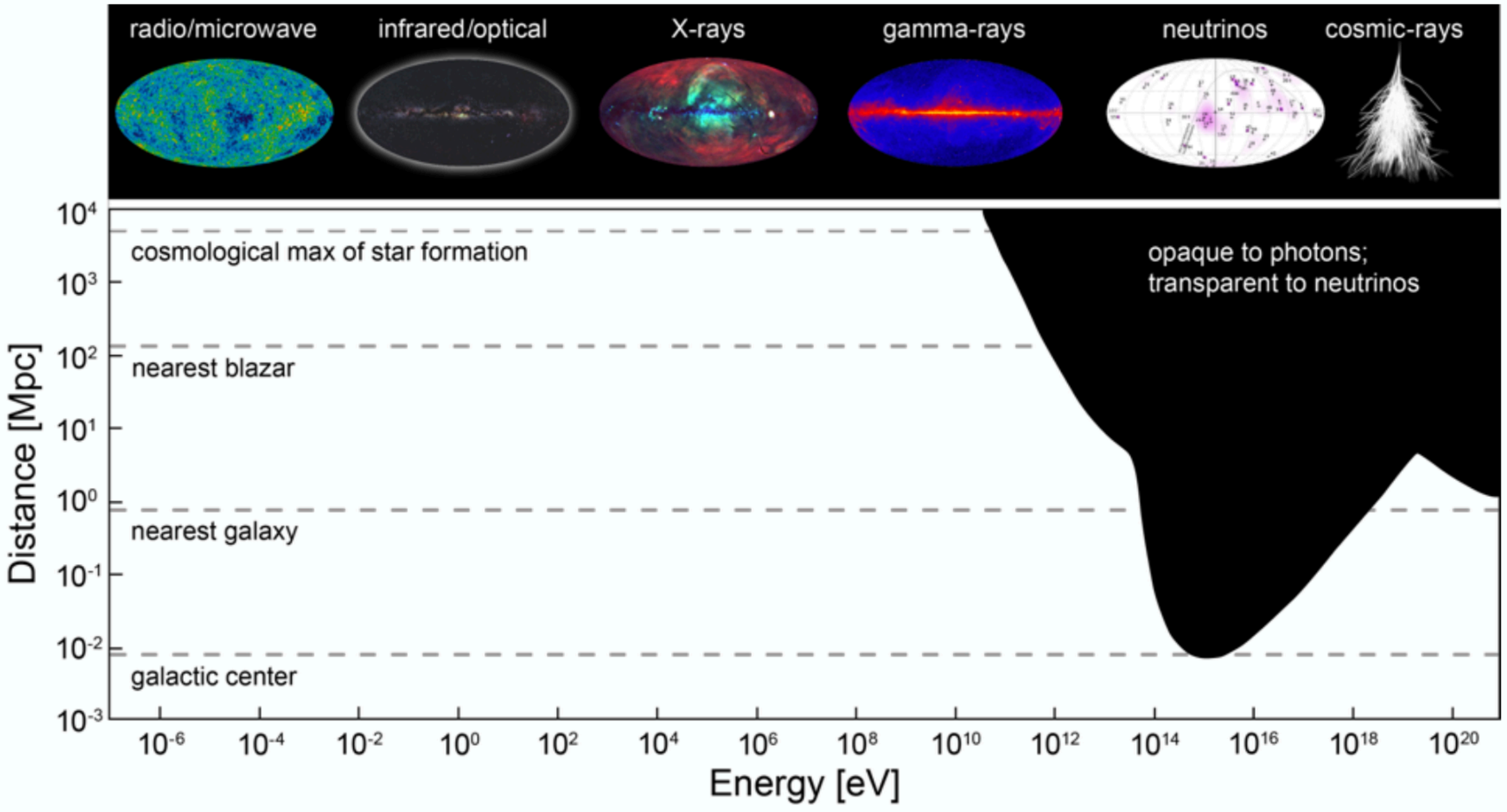

**Multi-messenger: use of the 4 messengers to study extreme astrophysical phenomena. Each one bring one piece of the puzzle.**

**Neutrinos are neutral, weakly-interacting, elementary particles.**

**⟹ Smocking gun of the cosmic-ray sources.**

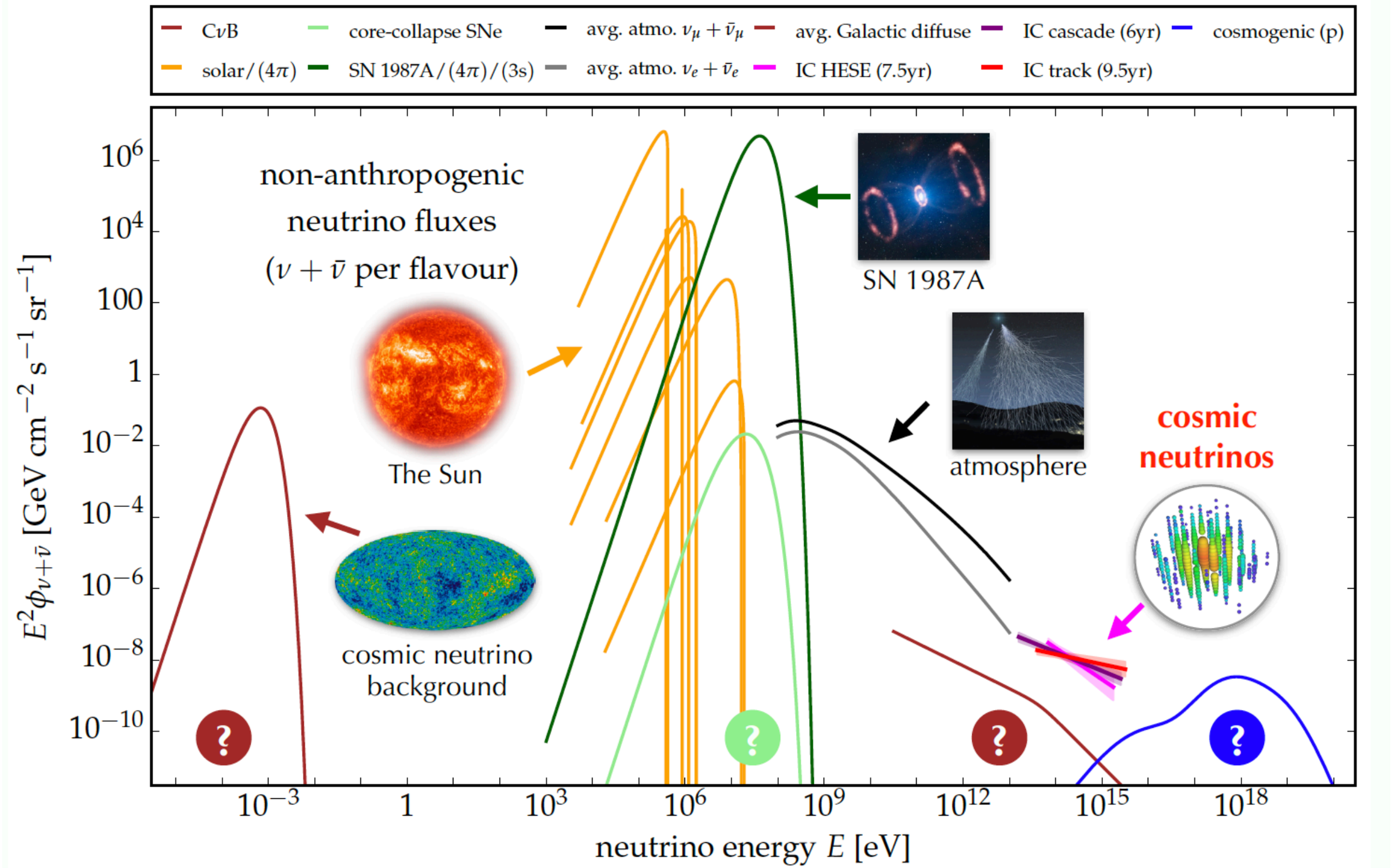
**⟹ However, finding neutrino sources is still challenging [large background contamination and tiny fluxes]**

# Terra Incognita




The Universe is opaque to EM radiation for ¼ of the spectrum,
i.e. above 10-100 TeV where IceCube sees cosmic neutrinos.

# Astrophysical neutrino fluxes

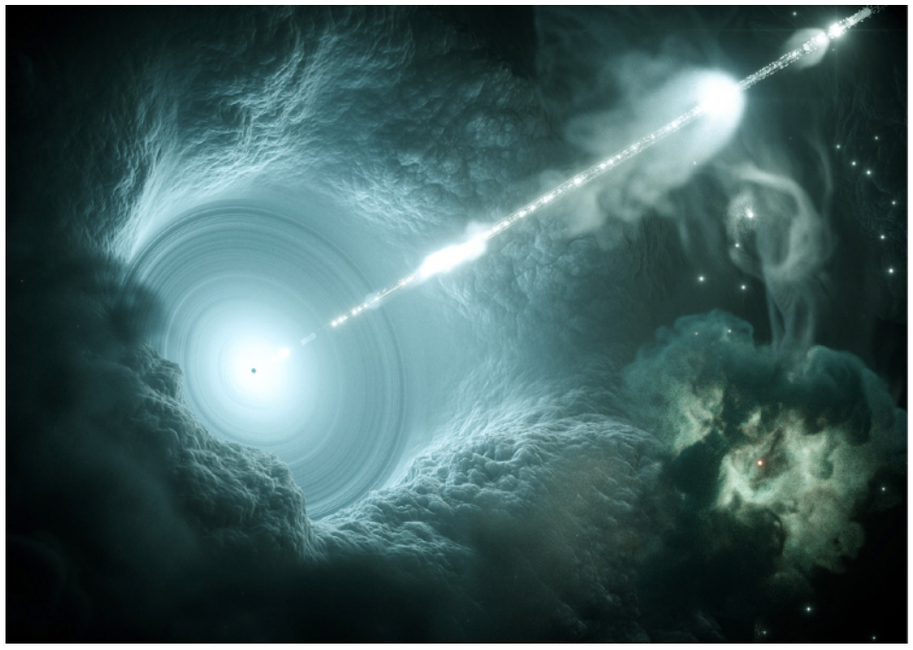


# 3 opened windows on the neutrino Universe

o(MeV)

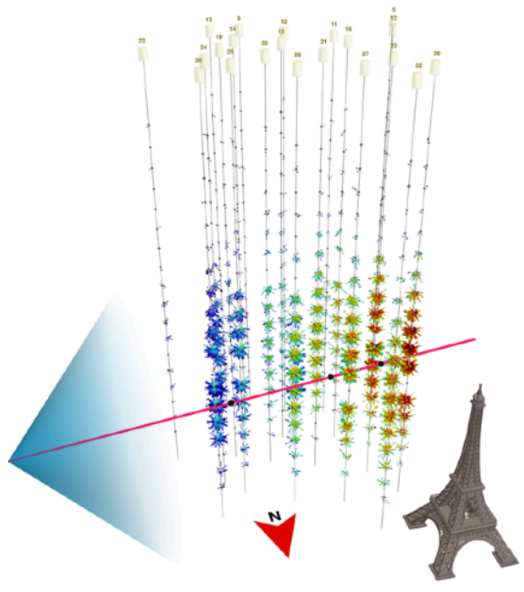
Core-Collapse Supernovae
(SN1987a, next Galactic SN ?)

o(TeV-PeV)



Diffuse astrophysical flux (all-sky, Milky Way)
First evidences on individual sources (AGN, TDE…)

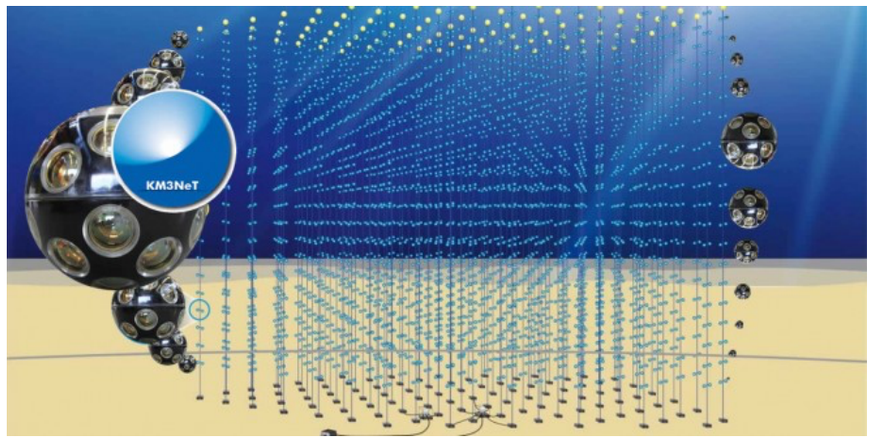
o(PeV-EeV)



New source population,
Cosmogenic neutrino

# HE Neutrino panorama

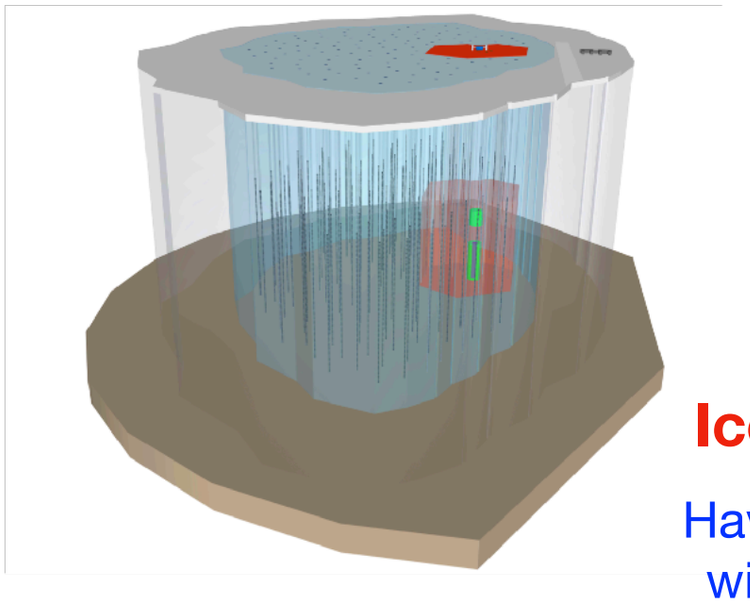

**Precision Frontier**




**KM3NeT, GVD, P-ONE**

Having the best angular resolution with a reasonable instrumented volume

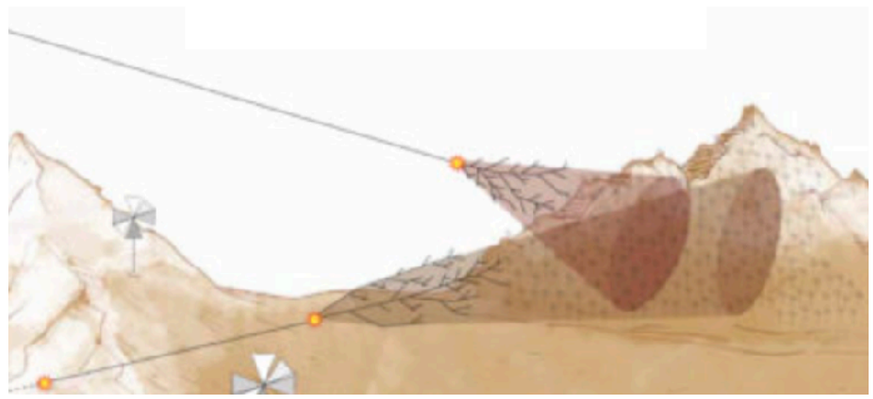
**Intensity Frontier**



**IceCube Gen2, TRIDENT**

Having the largest statistics with reasonable precision

**Energy Frontier**



**GRAND, ARA, ARIANNA, POEMMA**

Tracking cosmogenic ν at UHE

# Multi-messenger strategies

**Neutrino data are most of the time private. To have an outside access, use the public releases (event samples every few years, or alert public informations). Joint MM/MWL analyses are generally performed in context of data exchange agreements (MoU).**

**Offline analyses:**

~Yearly processing
~Refined detector calibration
~Final analysis products [Diffuse fluxes, sources, transients]
=> Results available in conferences or papers

**Online analyses:**

~Not the best detector calibration used
~Correlation analysis products for the most interesting external triggers
~Neutrino alert sending
=> Scientific products available almost in real-time

# Astronomy with the future generation neutrino detectors

**What we wanted to do 5-6 years ago ?**

- Identify the next **Galactic supernova**
- Characterize precisely the diffuse neutrino flux (spectral features, galactic component, UHE tail…)
- Identify individual **sources** responsible for high energy neutrinos diffuse flux
- Neutrino **flavour ratio** and its indication of the source properties
- Constrain the production mechanisms of high-energy cosmic particles
- Link with UHECR - detection of c**osmogenic** neutrinos

# Astronomy with the future generation neutrino detectors

**What we wanted to do 5-6 years ago ?**

- Identify the next **Galactic supernova**
  ⇒ Worldwide project SNEWS2.0 almost in place, ready for the next event (o($10^4$-$10^6$) neutrinos)

- Characterize precisely the diffuse neutrino flux (spectral features, galactic component, UHE tail…)
  ⇒ Galactic diffuse flux detected, evidence for spectral features, first UHE event

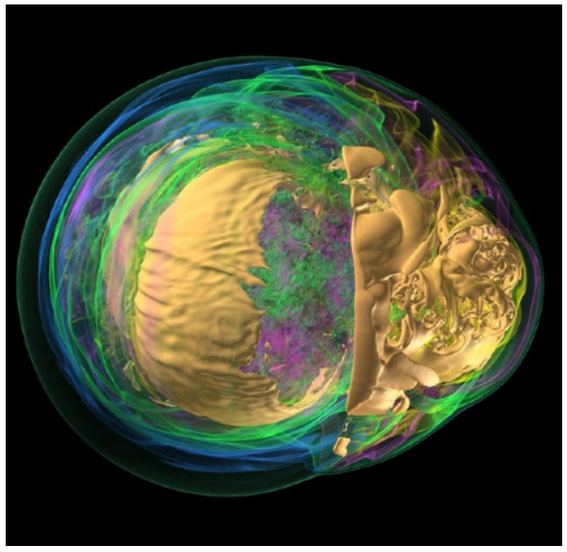
- Identify individual **sources** responsible for high energy neutrinos diffuse flux
  ⇒ First detections (TXS0506, NGC1068…)

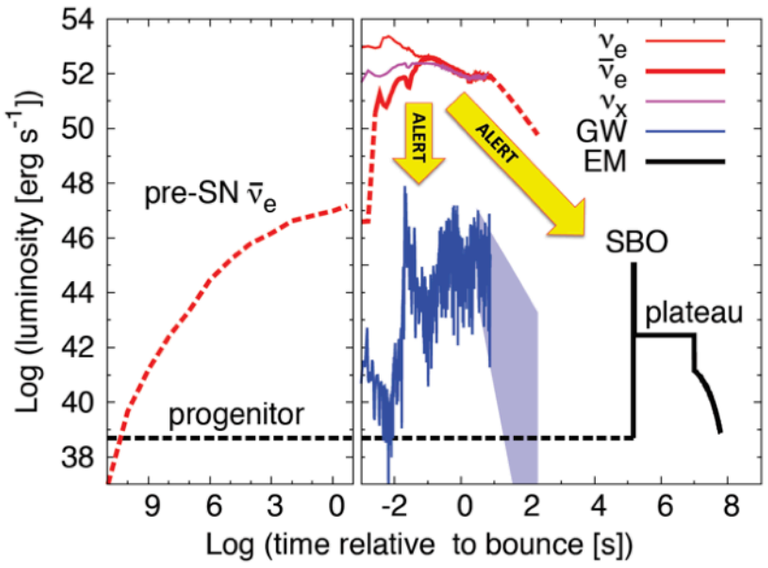
- Neutrino **flavour ratio** and its indication of the source properties
  ⇒ **Not enough statistic yet**

- Constrain the production mechanisms of high-energy cosmic particles
  ⇒ Many new developments in (lepto-)hadronic models, not yet, conclusive answers

- Link with UHECR - detection of c**osmogenic** neutrinos
  ⇒ First UHE event

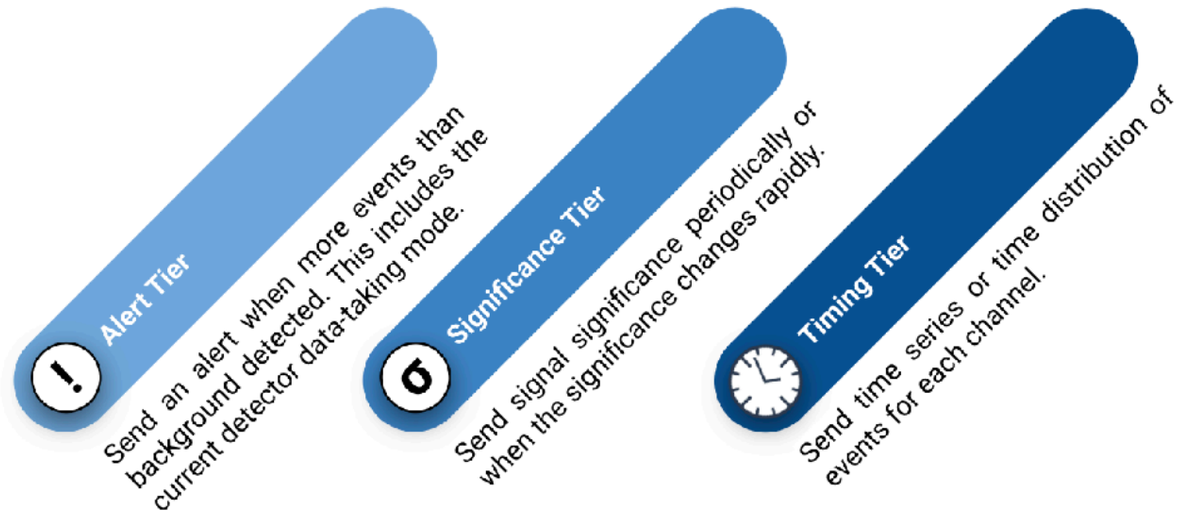
# Ready for the next Galactic CCSN






- Humans haven't seen a galactic SN since Kepler
- Expected rate is very low ~1.6±0.5 per century !!!
- Multi-messenger observation expected…

SNEWS 2.0 (in development)
Modern multi-messenger scenario, low-threshold alerts are common => Richer multi-messenger program.
3 level of alerts: Significance-based alerts, time-series sharing, real-time analysis capabilities (e.g. triangulation).



# Take home messages

**Neutrino astronomy is a very active field: characterisation of the diffuse fluxes, neutrino source population studies, first evidences of cosmic sources, first UHE neutrinos…**

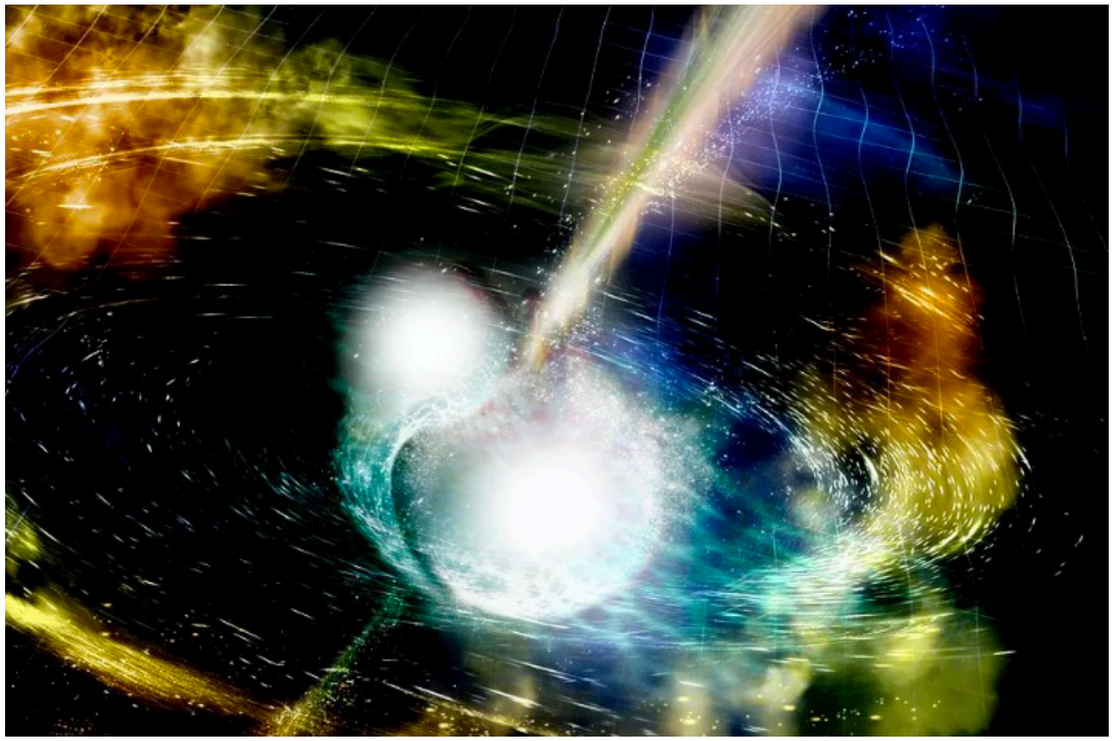
**Instruments:**

- **World wide effort toward the detection of the next Galactic SN** (all nu detectors in the World)
- **IceCube, GVD, KM3NeT** are now monitoring constantly the neutrino sky and future projects are planned to arrive in the next future: **P-ONE, TRIDENT**
- **At UHE,** in addition to the previous detectors, **Auger** and the **radio neutrino telescopes** are (or will be) in the game.

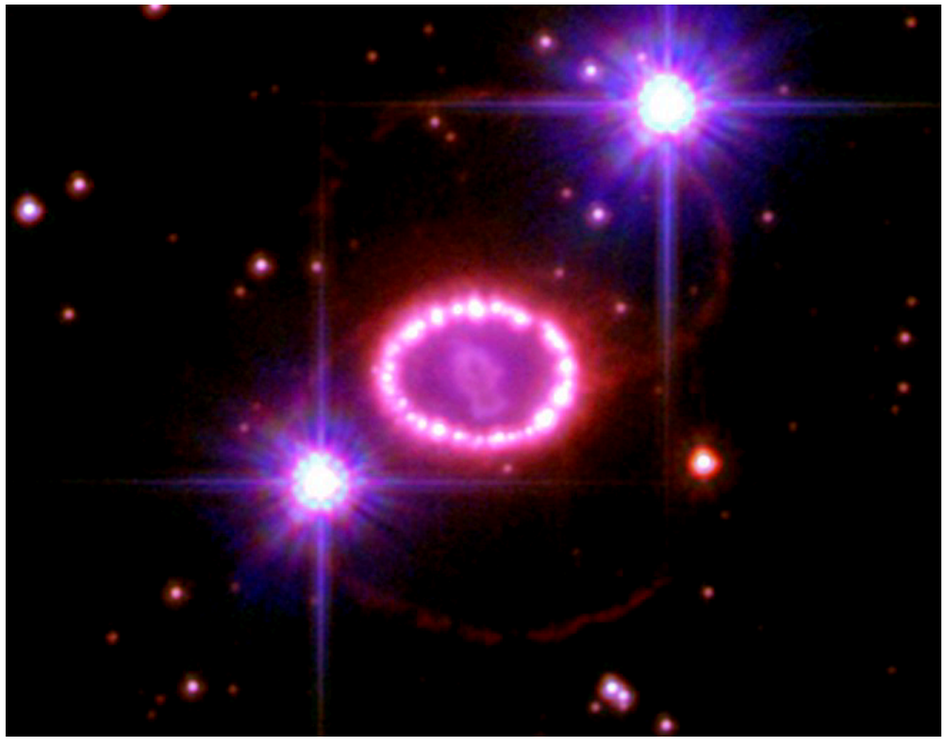
**The scientific returns of all these experiments rely in a large part on multi-messenger analyses, ie combining different messengers. Most of the potential cosmic sources are transients, and therefore simultaneous MWL/MM observations and fast data exchange are keys for the success.**

# Our Graals

One source with a triple MM detection



One Galactic CCSN



Let’s be optimistic for the start of ACME…