

ASTROPARTICLE Team

High Energy Neutrinos &
Gravitational Waves

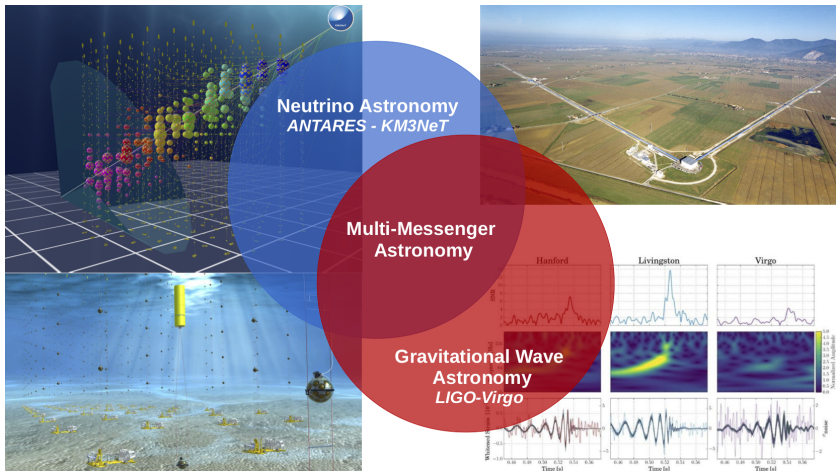
Thierry Pradier - thierry.pradier@iphc.cnrs.fr



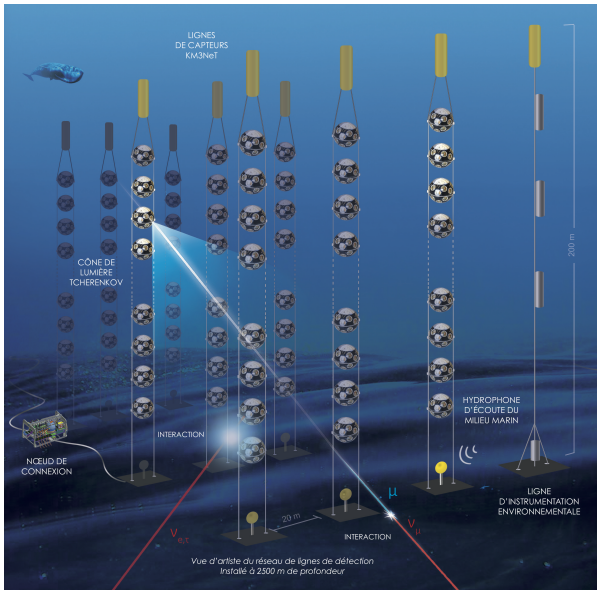
- GW Astronomy (since 2019) - VIRGO experiment
 - B. Mours (CNRS, 100%), D. Estevez (post-doc, 100%), V. Juste (PhD, 100 %), T. Pradier (Univ., 25%)
- HEN Astronomy (since 2002) - ANTARES and KM3NET experiments
 - T. Pradier (75%) + UHA-GRPHE : A. Albert (20%), D. Drouhin (5%)
 - currently no PhD Student on HEN astronomy
 - + 1 post-doc **F. HUANG** - 100% **KM3NET** - until November 2020



Multi-Messenger Astronomy with GW and HEN

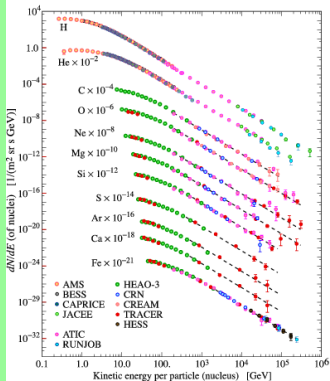


Principles of a Neutrino Telescope

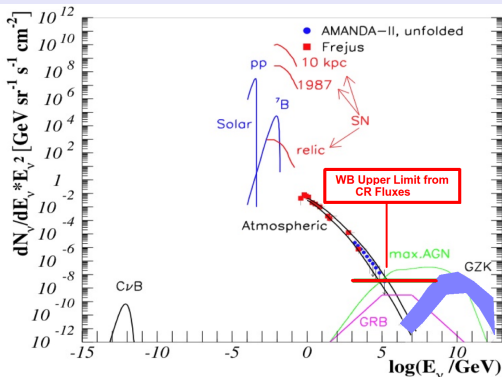


Cosmic Rays and High Energy Neutrinos

Hadronic CRs



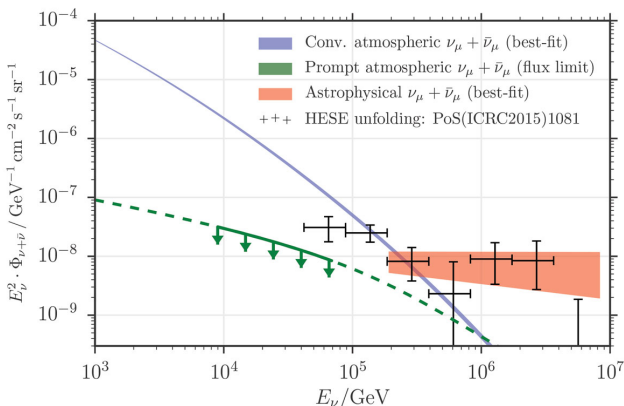
Spectrum of ν in the Universe



$$\bullet \quad p/A + p/\gamma \rightarrow \pi^\pm \rightarrow \nu \Rightarrow E_\nu^2 \Phi_\nu \lesssim 4.5 \times 10^{-8} \text{ GeV/cm}^2/\text{s}/\text{sr} \text{ (flux WB)}$$

\Rightarrow With $E_\nu = 100 \text{ TeV}$, $V \sim \text{km}^3$ needed for detection

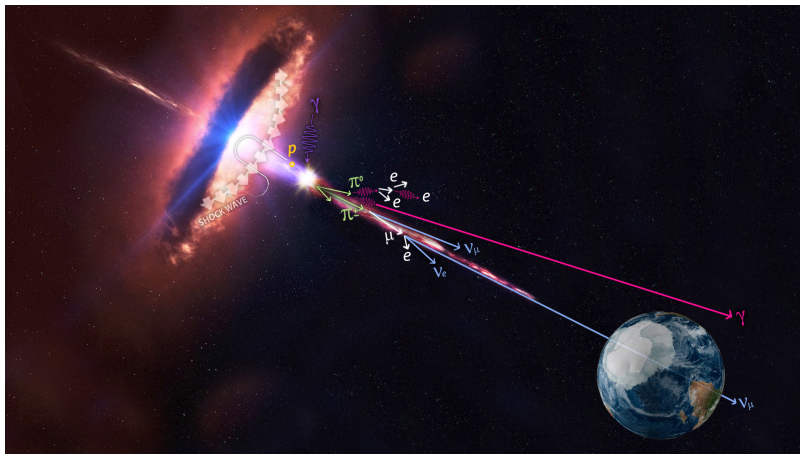
Cosmic Rays and High Energy Neutrinos



The dawn of High Energy Neutrino Astronomy

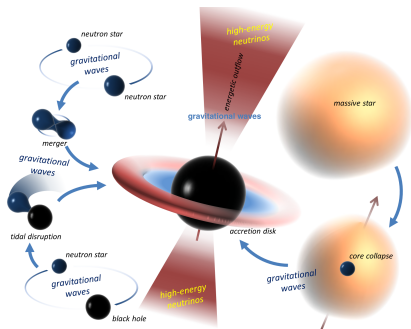
- **May 2013** : ICECUBE (1 km³ of instrumented ice, US, Antarctica) announces the first detection of cosmic ν at 100 TeV - PeV (few tens)
 - ⇒ Neutrinos at TeV - sources not identified/localized !

Cosmic Rays and High Energy Neutrinos

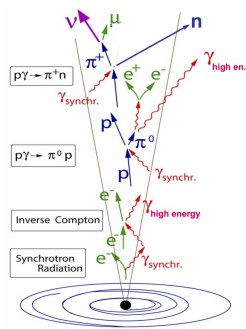


Multi-Messenger Astronomy - 09/2017 Blazar TXS 0506+056 probable source of HEN

Multi-Messenger sources !



[↔ I. Bartos et al., Class. Quantum Grav. 30 (2013) 123001]



[↔ U. Katz, Prog. Part. Nucl. Phys. 67 (2012) 651-704]

Astronomy with GW

● Collapse/Merger \Rightarrow GW + Jet ?

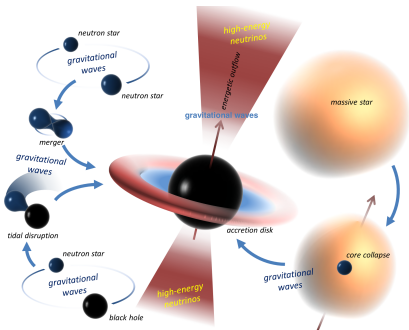
- ADVANCED LIGO : started 09/2015
- ADVANCED VIRGO : Summer 2017
- Now under upgrading (\rightarrow 2022)

Astronomy with HEN

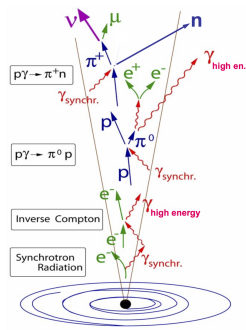
● Jet \Rightarrow Cosmic-Rays \rightarrow HEN

- ANTARES continuously since 2008
- KM3NET under construction

Multi-Messenger sources !



[↔ I. Bartos et al., Class. Quantum Grav. 30 (2013) 123001]



[↔ U. Katz, Prog. Part. Nucl. Phys. 67 (2012) 651-704]

Astronomy with GW

- Collapse/Merger \Rightarrow GW + Jet ?

Astronomy with HEN

- Jet \Rightarrow Cosmic-Rays \rightarrow HEN

GWHEN : Identify the sources of Cosmic-Rays/HEN through their GW signature !

ANTARES - 2008-2021



0.1 km²

- **2000** : IPHC
- **2006** 1st Line
- **2008** 12 Lines
- **2020-21**
⇒ **Dismantling**

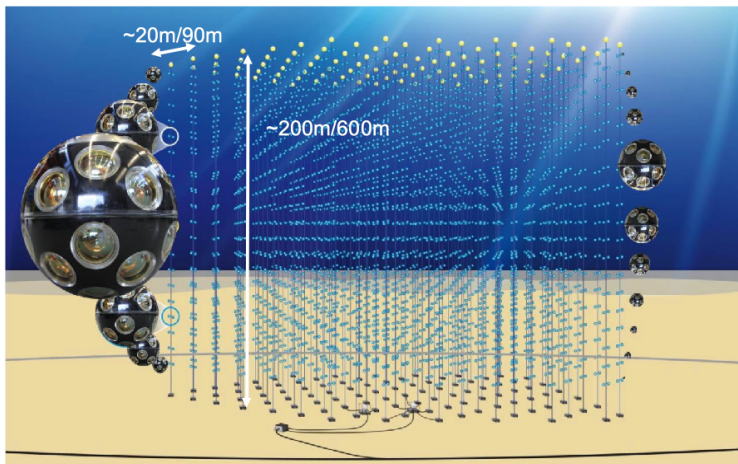
KM3NET - under deployment



KM3NET : Low Energy (Fr) + High Energy (It)

⇒ ORCA : 1-100 GeV - ARCA : TeV-PeV

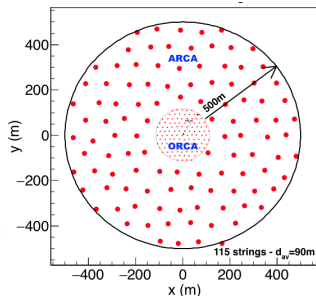
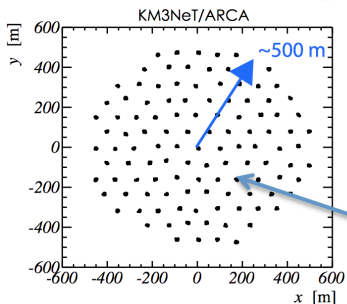
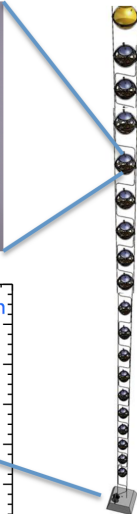
KM3NET - under deployment



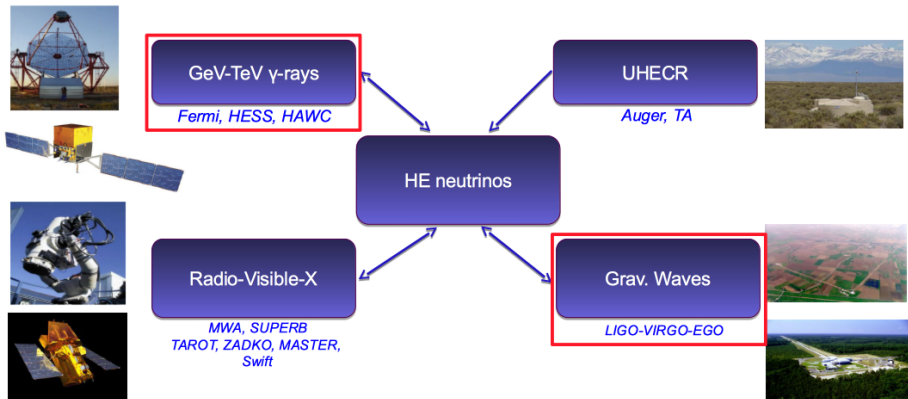
KM3NET : telescope 2-3 km³, on 2 sites (Fr, It)

⇒ 6 lines (Fr) + 1 line (It) → 20-30 in 2021-22 ? → 2 + 1 × 115 lines ~25

KM3NeT - under deployment



In short... Multi-Messenger connections

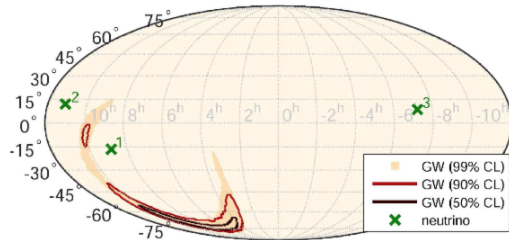
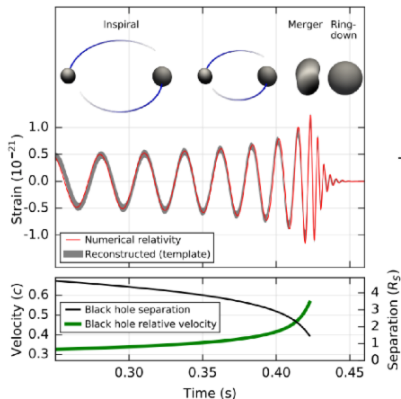


Distinguish a cosmic ν from a non-cosmic ν

Correlation (time and/or space) with other messengers !

\Rightarrow At IPHC : GW+HEN and correlations with γ instruments (GeV-TeV)

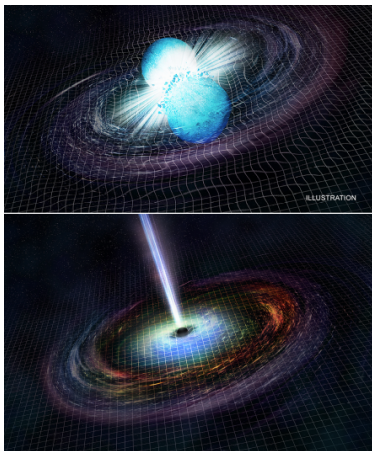
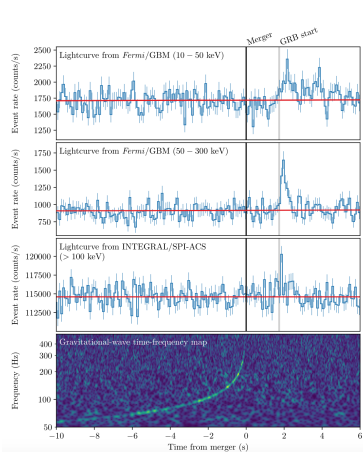
GWHEN : joint analyses ANTARES+VIRGO/LIGO



GW150914 : 1st search for HEN from Black Hole-Black Hole binaries

- No HEN in coincidence \Rightarrow limit on total energy in HEN

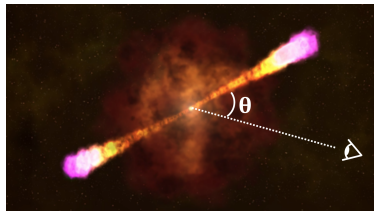
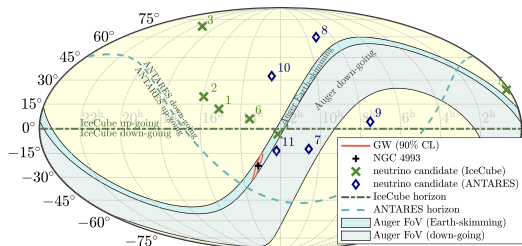
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GW170817 : 1st coalescence of 2 Neutron Stars

Possible Jet \Rightarrow search for HEN

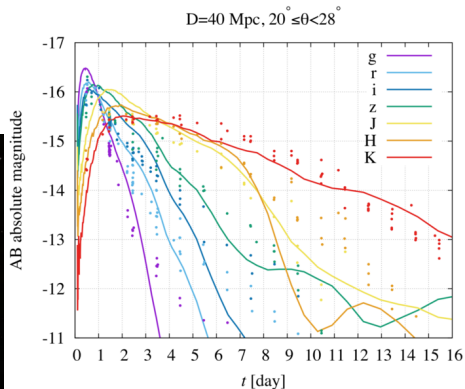
GWHEN : joint analyses ANTARES+VIRGO/LIGO



Search for neutrinos $100\text{-}10^{11}$ GeV with ANTARES-ICECUBE-AUGER

● No coincidences \Rightarrow Gamma-Ray Burst observed *off-axis*

Project ANTARES/ORCA/ARCA : from Merger to Kilonova



Possible project on ANTARES - ORCA/ARCA

- Probable Kilonova(s) without associated GW signals (pre-discovery)
- Determine date of probable merger → define Time Coincidence window
- HEN Upper Limit / Sensitivity for ANTARES/ KM3NET - **Simulations and/or real data**

Project KM3NET : DOMs

Le 1^{er} Digital Optical Module alsacien de KM3NeT

Dernière mise à jour : mardi 31 juillet 2018, par [Nicolas Busser](#)

Le détecteur KM3NeT [1] est un télescope à neutrinos de seconde génération installé dans les abysses de la Méditerranée pour détecter des neutrinos cosmiques de haute énergie. En France, deux laboratoires de l'IN2P3 - Subatech et l'IPHC - se partagent la production des "Digital Optical Module", le coeur du détecteur.

La ligne de production, dont la mise en place a commencé fin 2017 est à présent parfaitement opérationnelle. A la mi-juillet 2018, la production du 1^{er} DOM (Digital Optical Module) alsacien de l'expérience KM3NeT est terminée. Ce DOM a été testé et répond parfaitement aux spécifications.

Aux côtés des 17 autres modules qui seront produits dans les prochains mois à Strasbourg (IPHC) et à Nantes (Subatech), il fera partie d'une ligne 100% française du télescope à neutrinos KM3NeT ORCA [2].

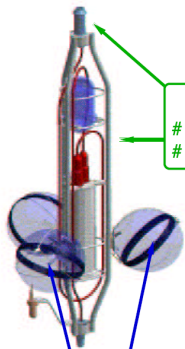
Félicitations à toute l'équipe technique !



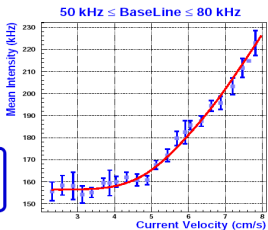
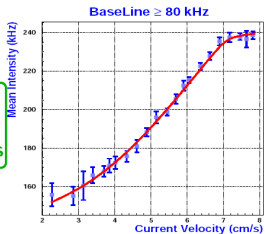
Digital Optical Module Production @ IPHC

- 1st DOM July 2018
- Half a line produced → 1-2 DOM/week in late 2020

Project KM3NET : Bioluminescence



Cylinders
 # Threshold : 2 cm/s
 # Saturation : 7.5 cm/s



Spheres
 # Threshold : 4 cm/s



Bioluminescence in KM3NET

- Correlation with water currents, effect of structures, periodicities...



TXS 0506+056 ?

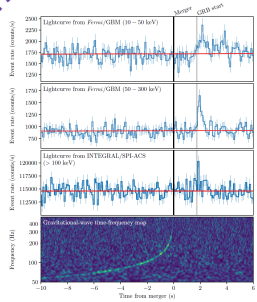
HEN Astronomy
GeV-EeV
ANTARES,
KM3NET/ARCA,
IceCube

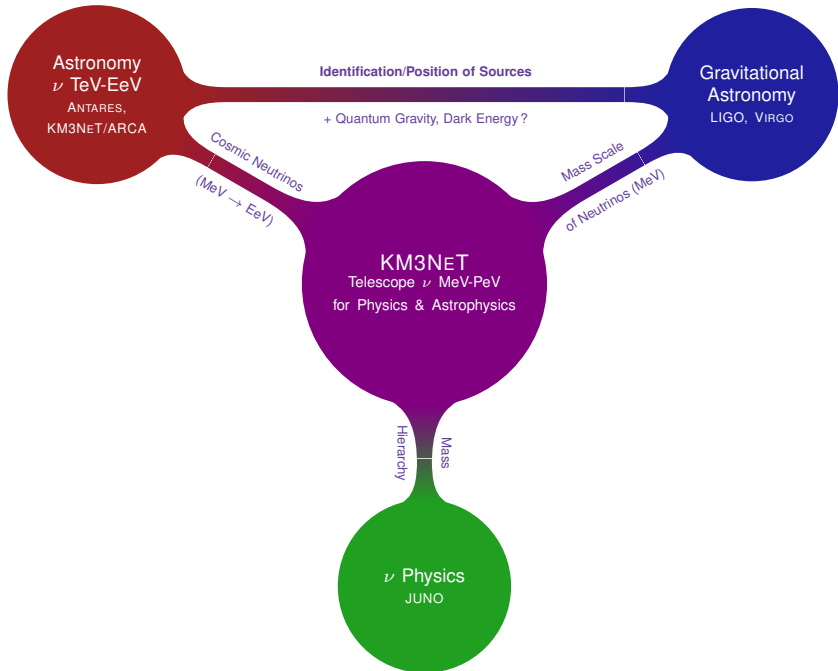
γ -ray
Astronomy
FERMI, HESS, CTA...

*Still to be revealed
??*

GW Astronomy
LIGO, Virgo, KAGRA

GW170817







Questions...

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