

Gravitational Waves HE Neutrinos ElectroMagnetic

At IPHC :

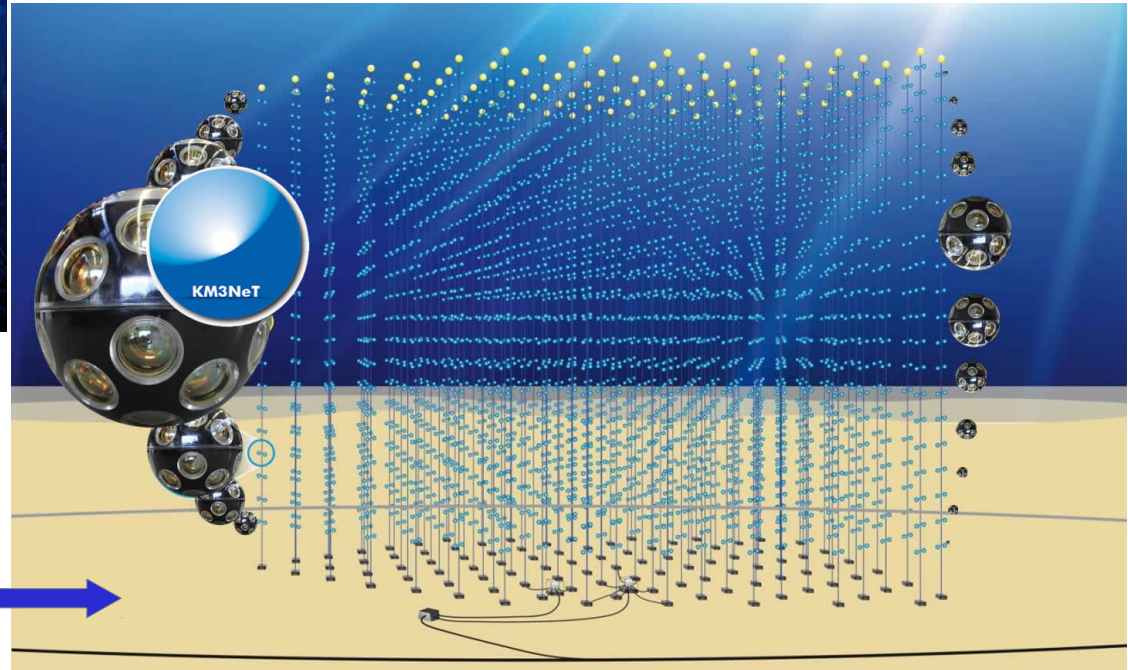
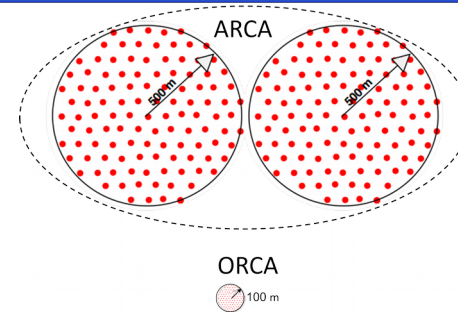
Φ : T.P. + R. Gracia-Ruiz (ANR) + M. Organokov (PhD)

GRPHE (UHA) : A. Albert, D. Drouhin

Post-doc H2020 KM3NeT 2.0 to be hired

+ Technical Contributions for ANTARES → KM3NeT

ANTARES & KM3NeT

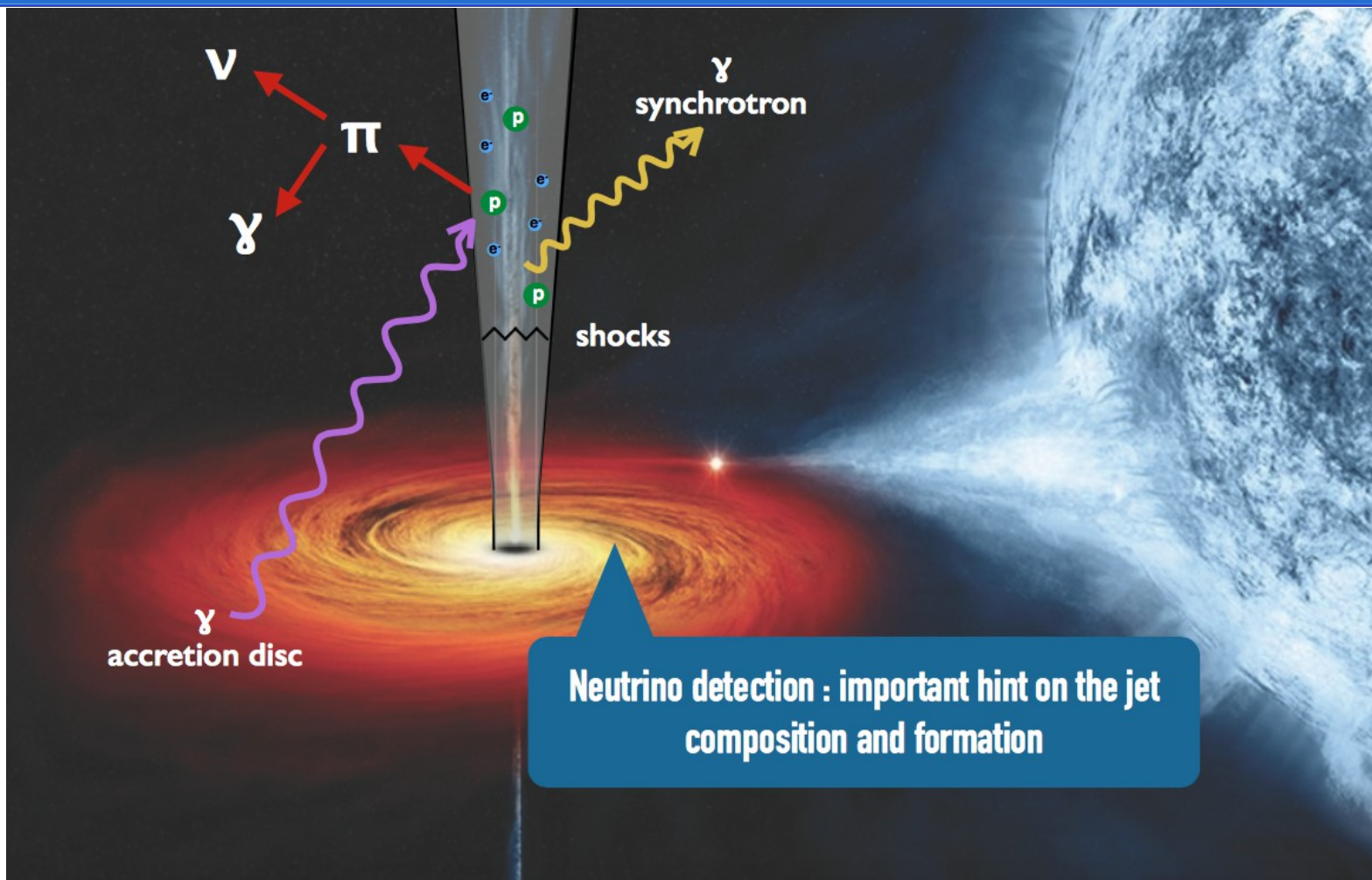


ANTARES ~1/10 IceCube
2008 → 2018 TeV - PeV

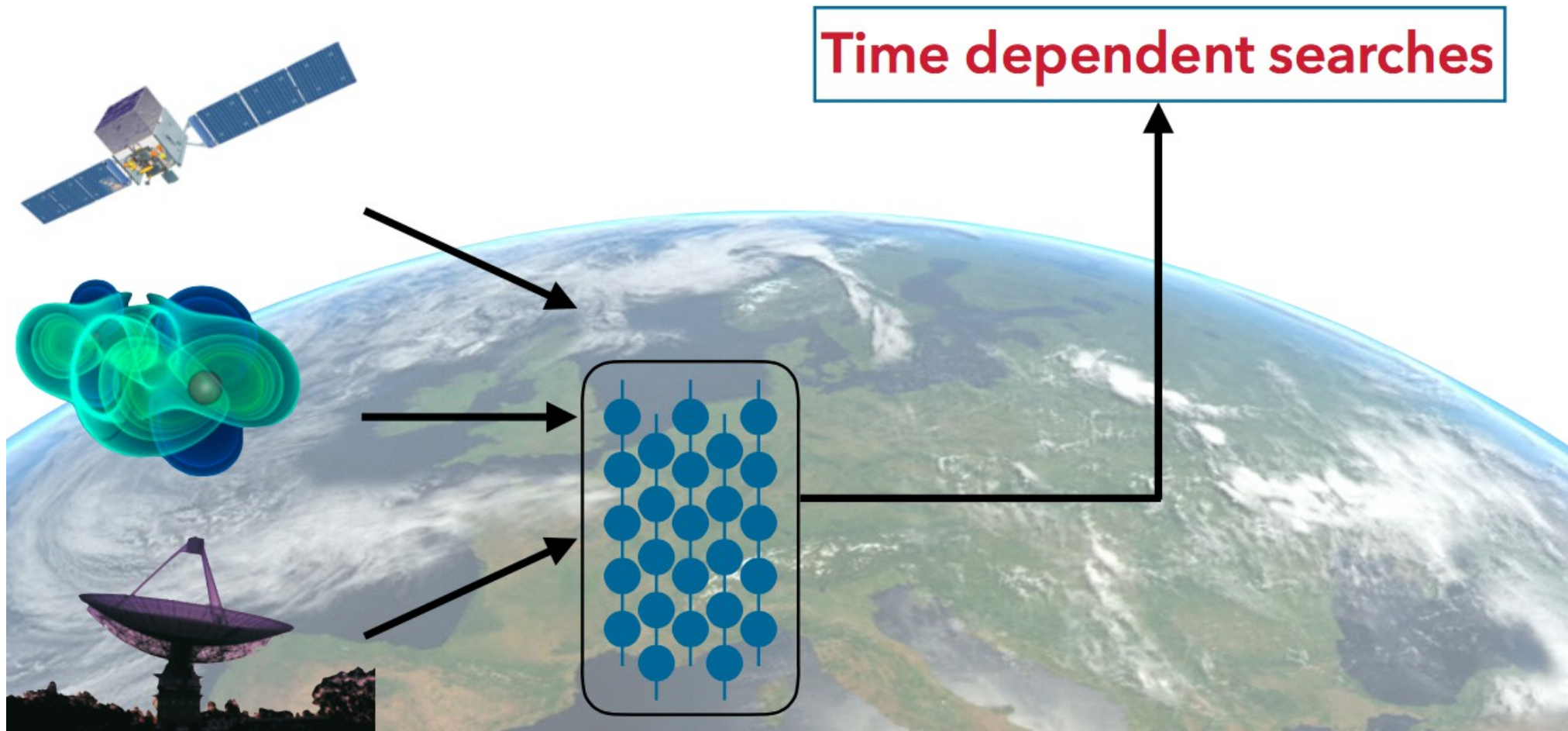
KM3NeT/ARCA ~2 x IceCube >2020
TeV-PeV

KM3NeT/ORCA – GeV – ν Mass Hierarchy

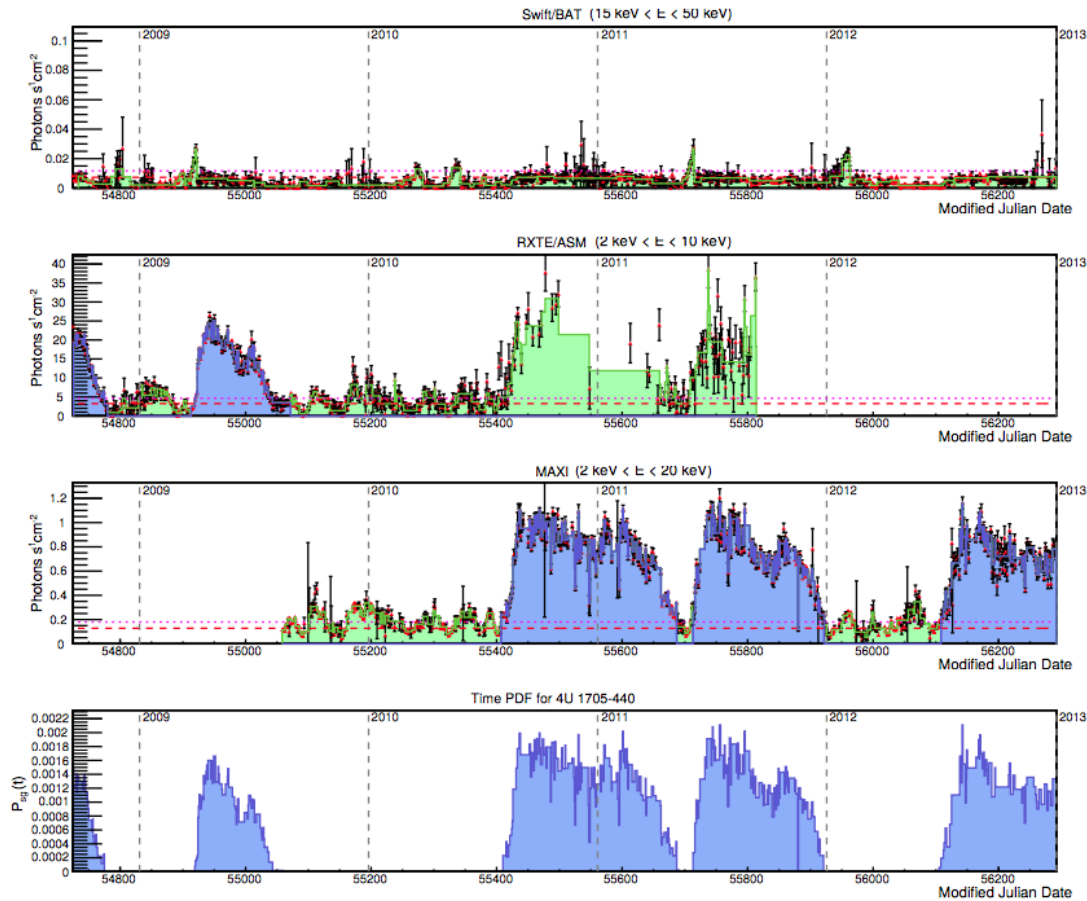
ANTARES-KM3NeT : Multi-Messenger Astronomy



ANTARES-KM3NeT : Multi-Messenger Astronomy

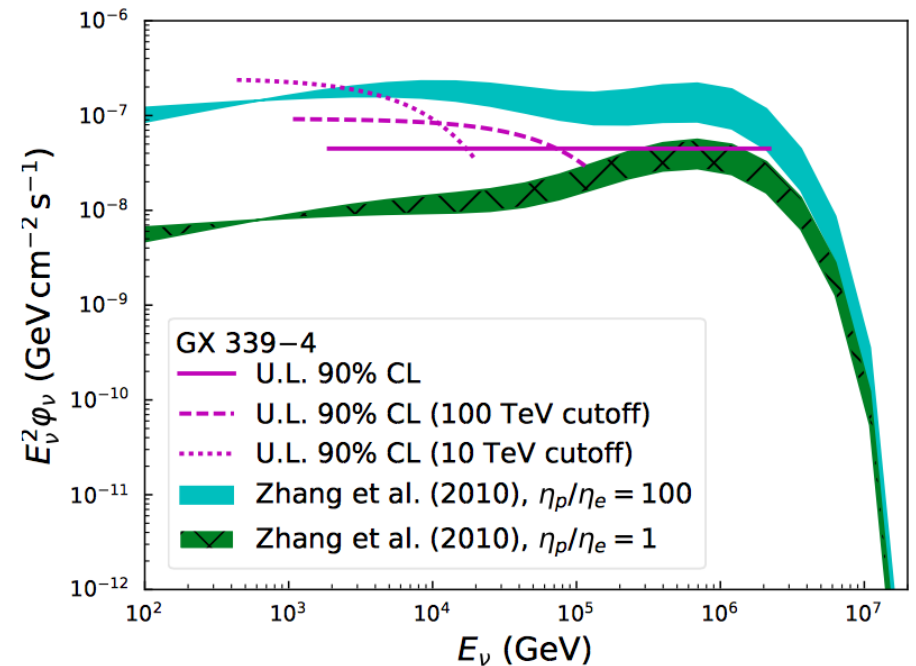


ANTARES-KM3NeT : Multi-Messenger Astronomy



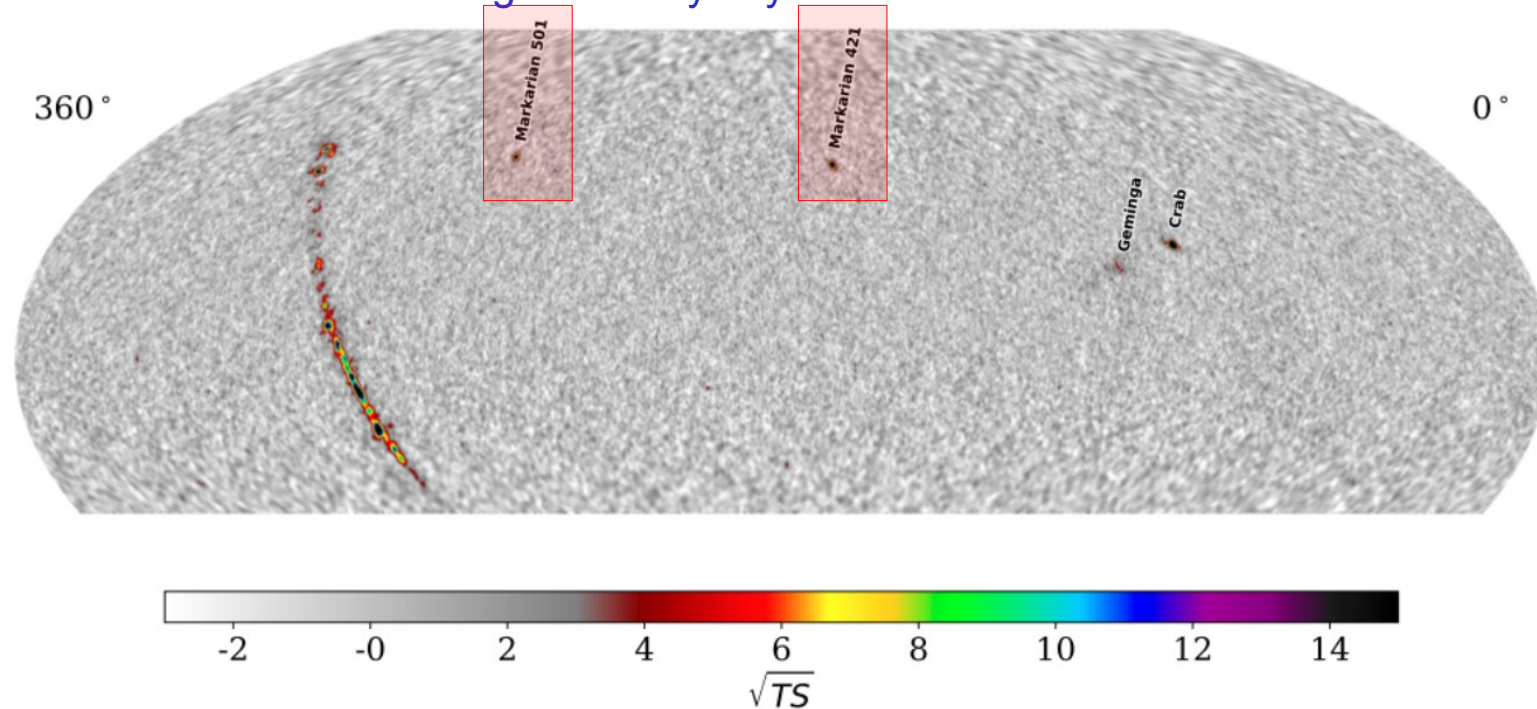
4U 1705-440

Time-dependent search for neutrino emission from x-ray binaries with the ANTARES telescope
A. Albert et al. - JCAP04(2017)019



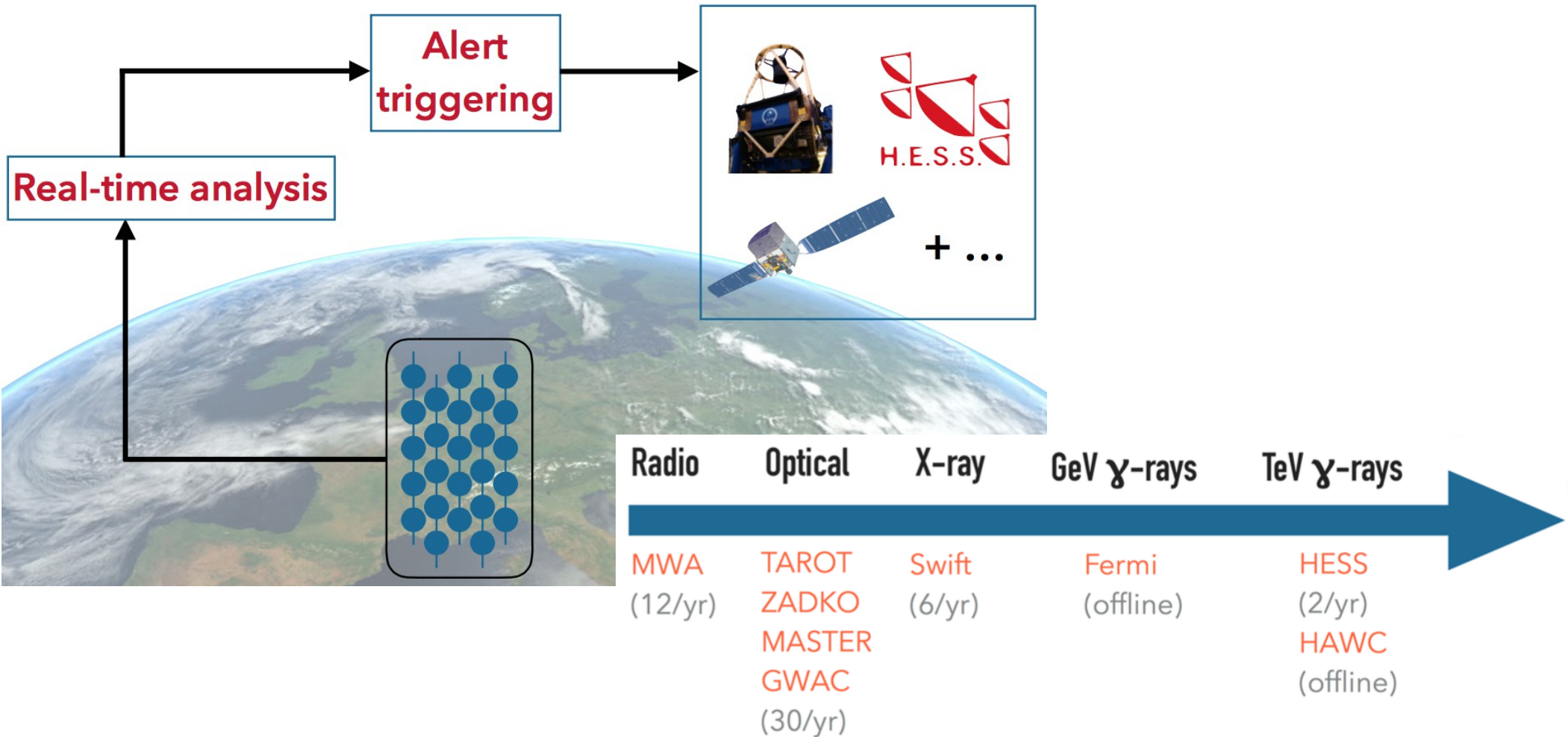
ANTARES-KM3NeT : Multi-Messenger Astronomy

- PhD@IPHC - Same philosophy : use of time/space information
 - Mrk 421 and Mrk 501 two brightest blazars
 - Flares measured in HE gamma-rays by HAWC



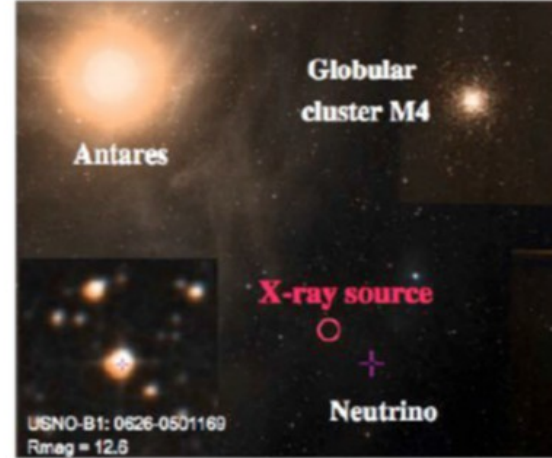
Equatorial full-sky TS map, for a point source hypothesis with a spectral index of -2.7 (Abeysekara et al. 2017, ApJ, 843, 40).

ANTARES-KM3NeT : Multi-Messenger Astronomy

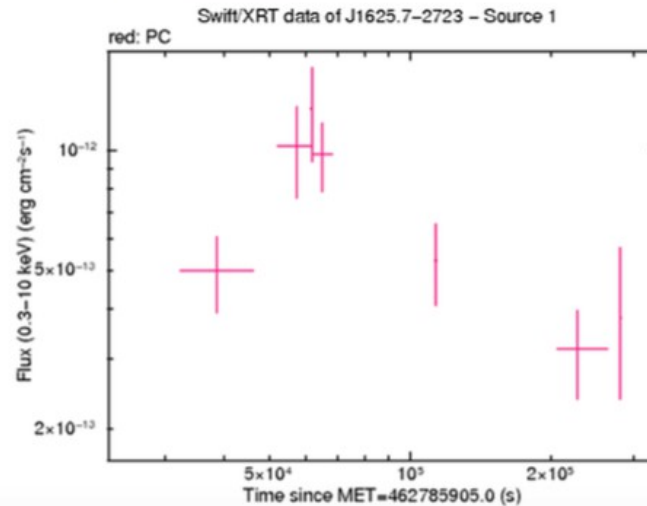
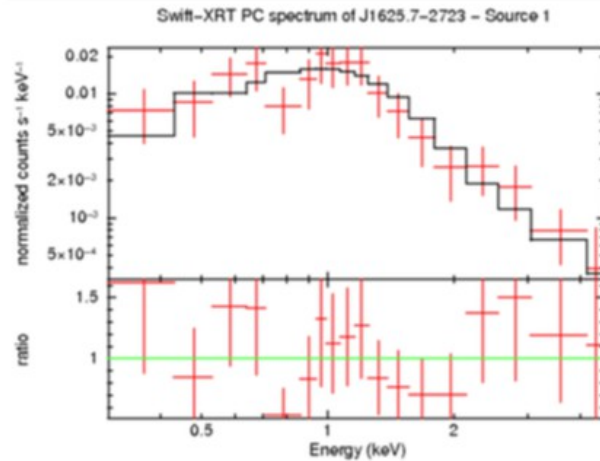


ANTARES-KM3NeT : Multi-Messenger Astronomy

- ▶ E ~50-100 TeV
- ▶ Error box=18 arcmin
- ▶ Sent in 10s to Swift and Master
- ▶ Swift obs: +9h
- ▶ Master obs: +10h

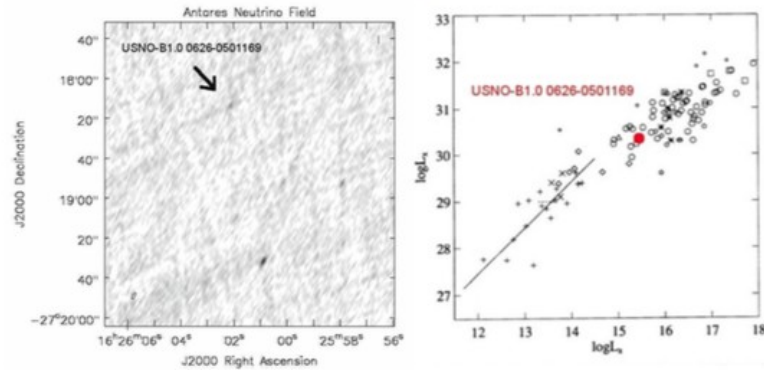


ANT150109A

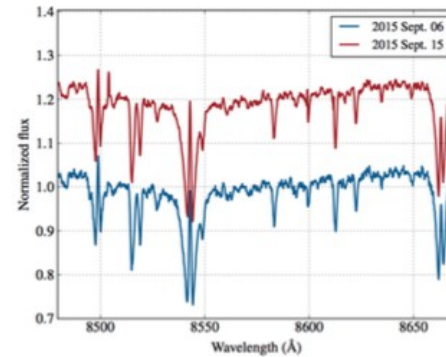
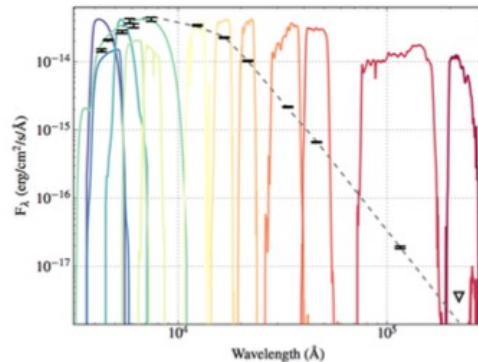
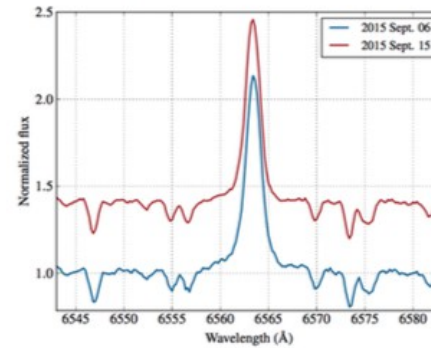


ANTARES-KM3NeT : Multi-Messenger Astronomy

VLA follow-up ATel #7999

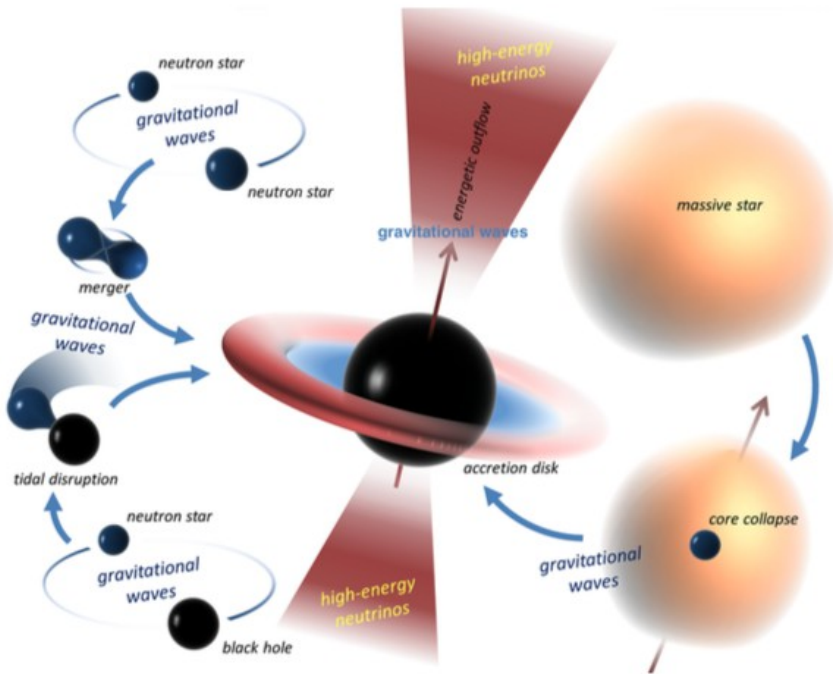


VLT / X-Shooter follow-up

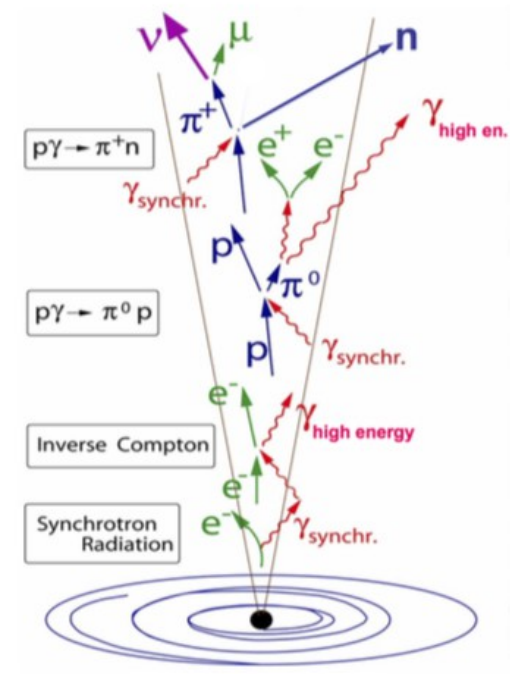


Probably an active X-ray star in a binary system (RS CVn)
Probability of chance coincidence : $\sim 3\%$

ANTARES-KM3NeT : GW+HEN



[↔ 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 Jet ?

Astronomy with HEN

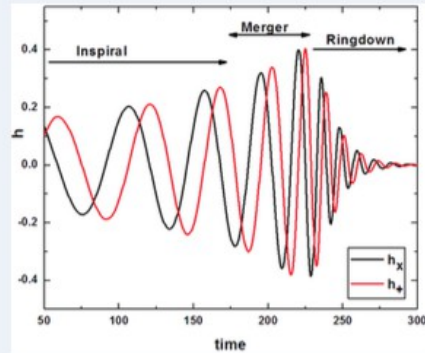
- HEN produced in Jet

ANTARES-KM3NeT : GW+HEN



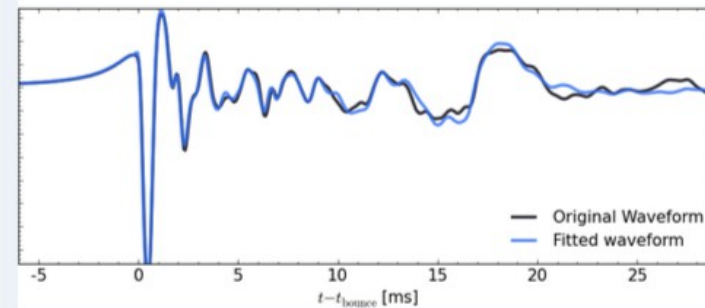
Short Gamma-Ray Bursts (GRBs)

Merger of Black Holes/Neutron Stars



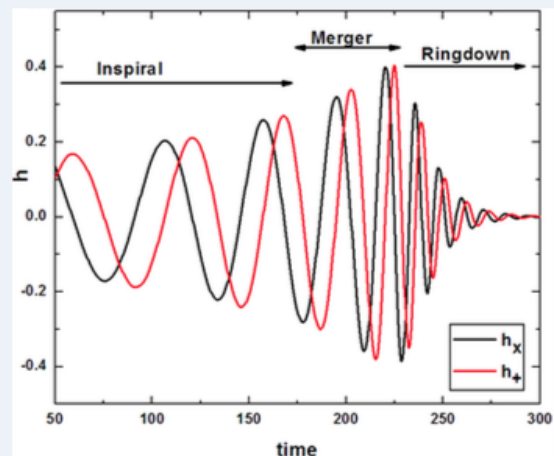
Long GRBs

Collapsars - massive star collapse



Short Gamma-Ray Bursts (GRBs)

Merger of Black Holes/Neutron Stars



- GW \approx 100 Mpc

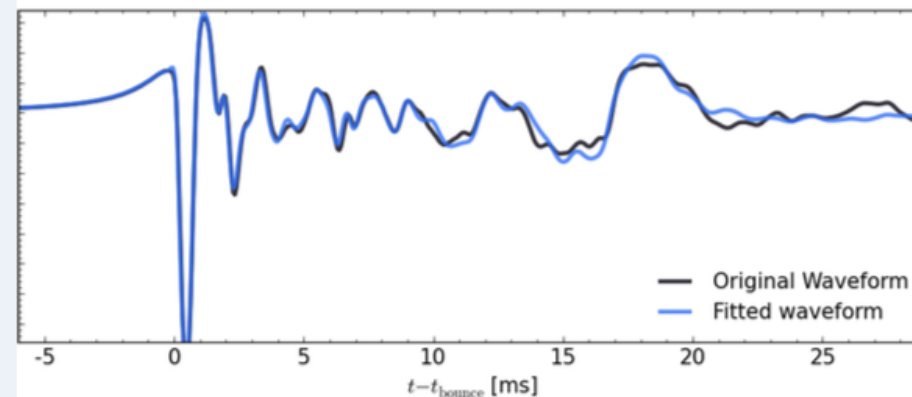
[LIGO/VIRGO, ApJL, L21 (2016)]

- HEN \approx 10 Mpc (ANTARES)

[ANTARES, JCAP 06 (2013) 006]

Long GRBs

Collapsars - massive star collapse

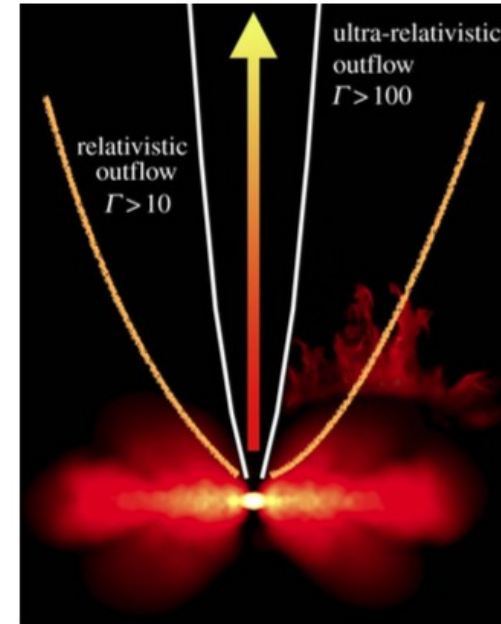
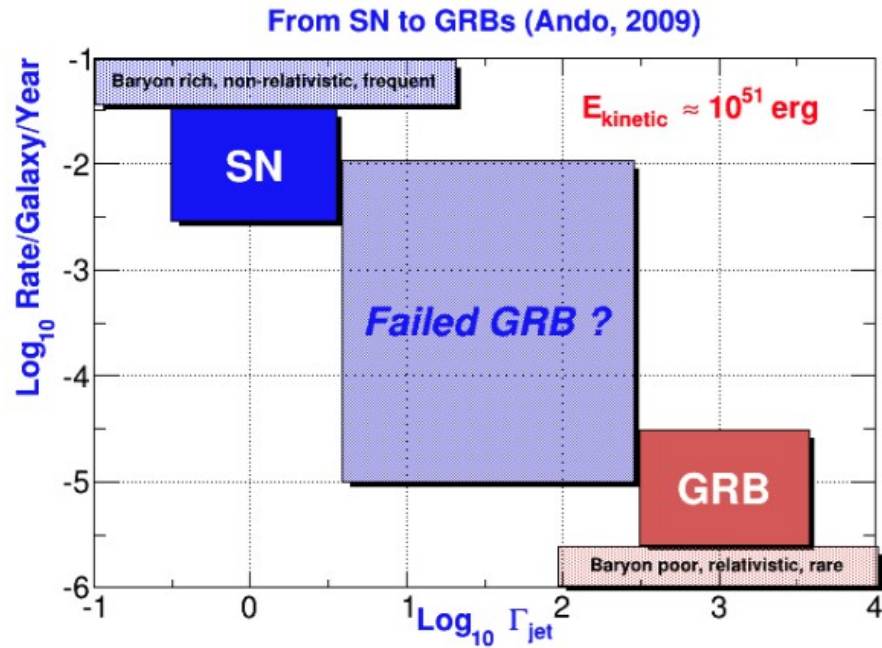


- GW : realistically \ll Mpc - $\mathcal{O}(10)$ Mpc

[e.g. Gossan et al., PRD93 042002 (2016)]

- HEN \approx 20 Mpc (ANTARES)

[ANTARES, JCAP 06 (2013) 006]

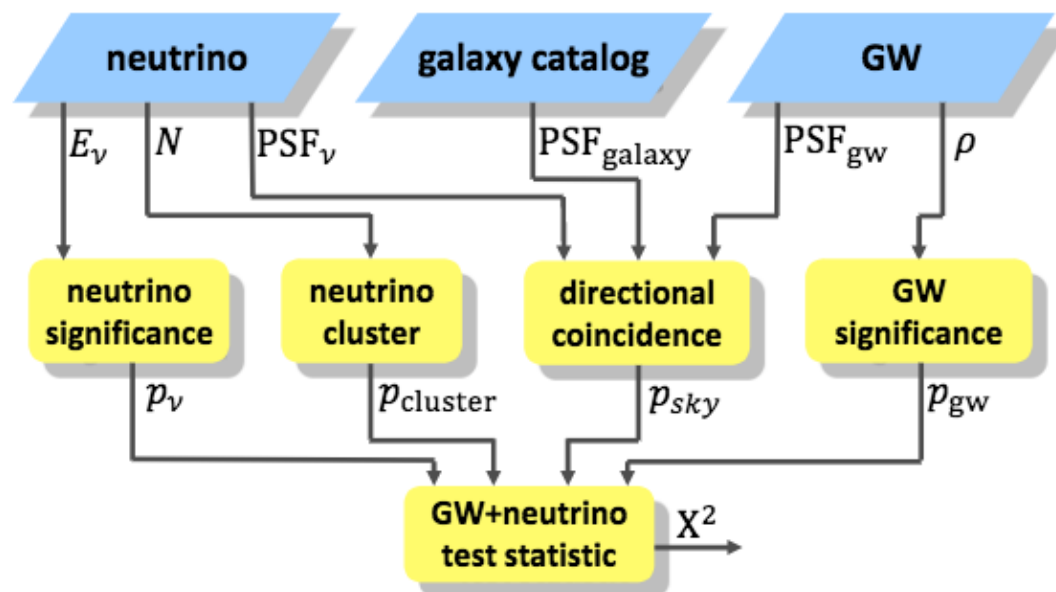
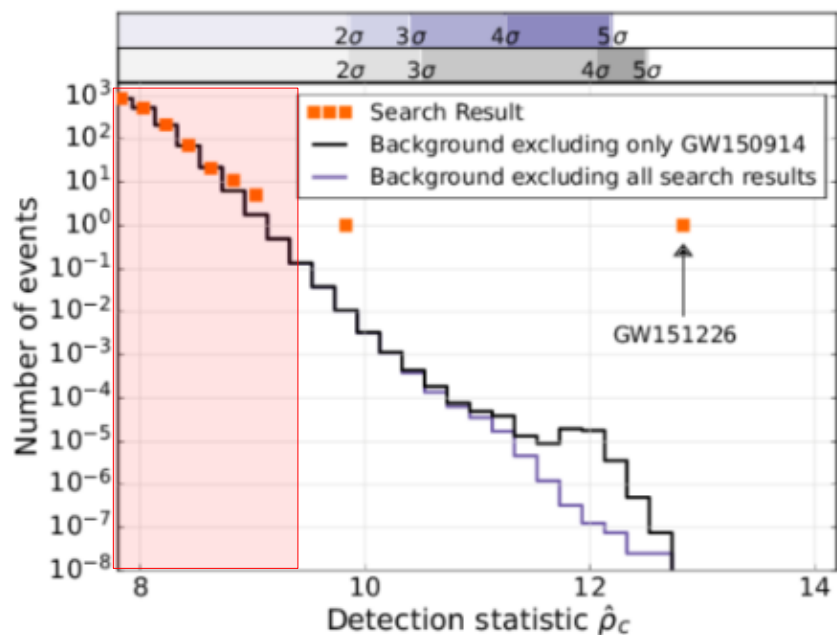


From Supernovae to Gamma-Ray Bursts

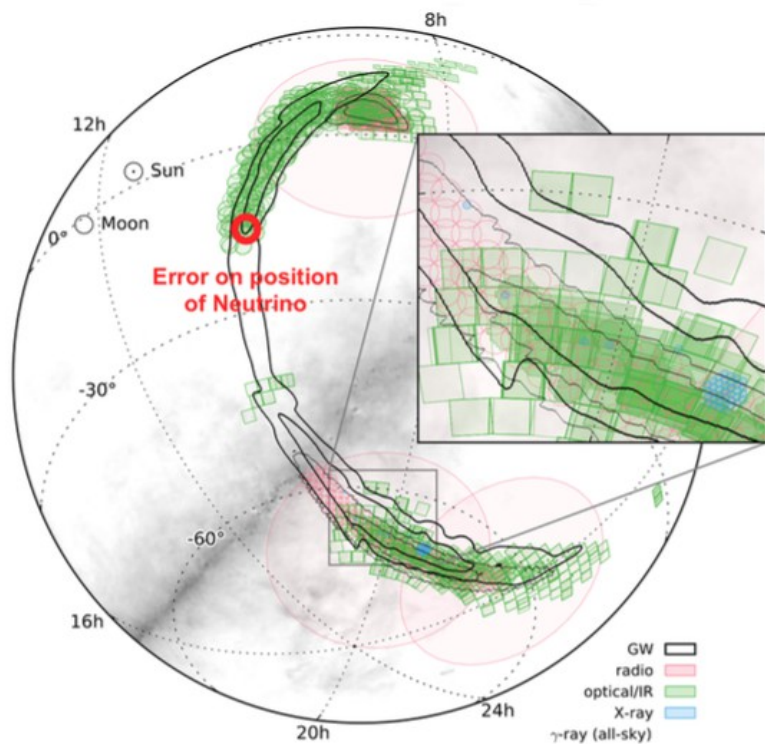
- SNe : frequent, baryon-rich, $\Gamma \sim 1$ + emission poorly beamed
- GRBs : rare, baryon-poor, $\Gamma \gg 1$ + emission in $\theta \sim 5^\circ$
- Failed/low luminosity GRBs : $\theta \sim 30^\circ$ + no/weak electromagnetic emissions

ANTARES-KM3NeT : GW+HEN *pre-discovery*

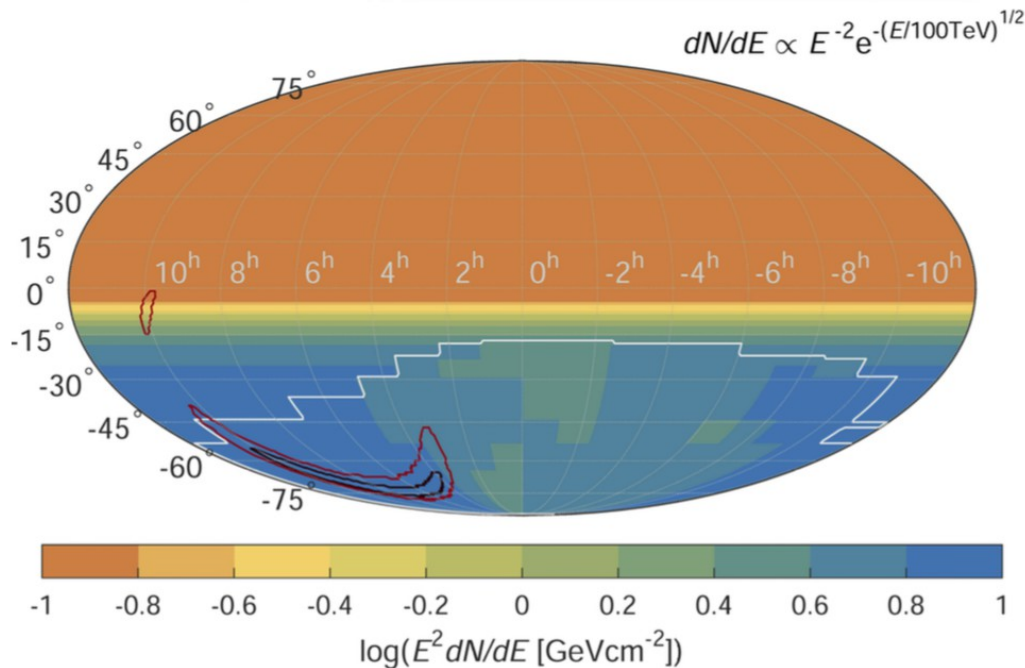
- Long experience @ IPHC :
 - Proposal T.P. (2008) → MoU with Virgo/LIGO (2009)
 - First joint analysis with 2007 data : 2009-2012 → *Publication 2013*
 - Second optimized analysis with 2009-2010 data : 2012-2015 → *Methods Published*
 - Review stalled because of GW detection → no results published



ANTARES-KM3NeT : GW+HEN *since Advanced Interferometers*



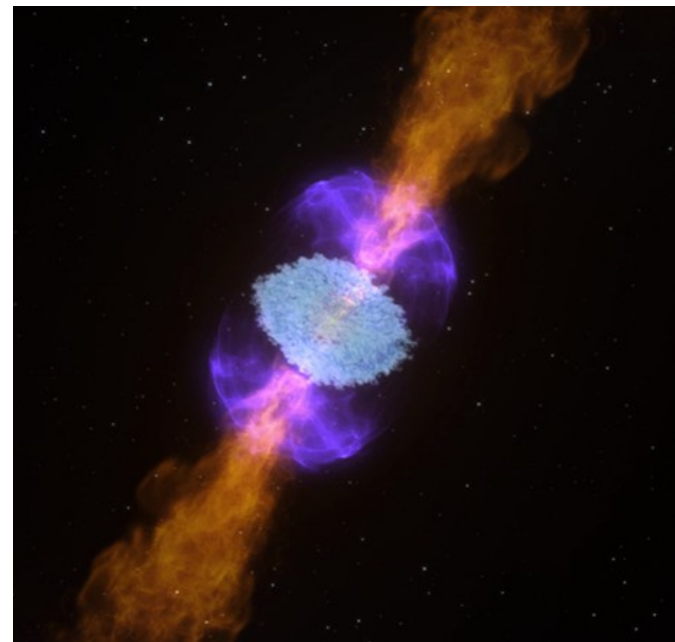
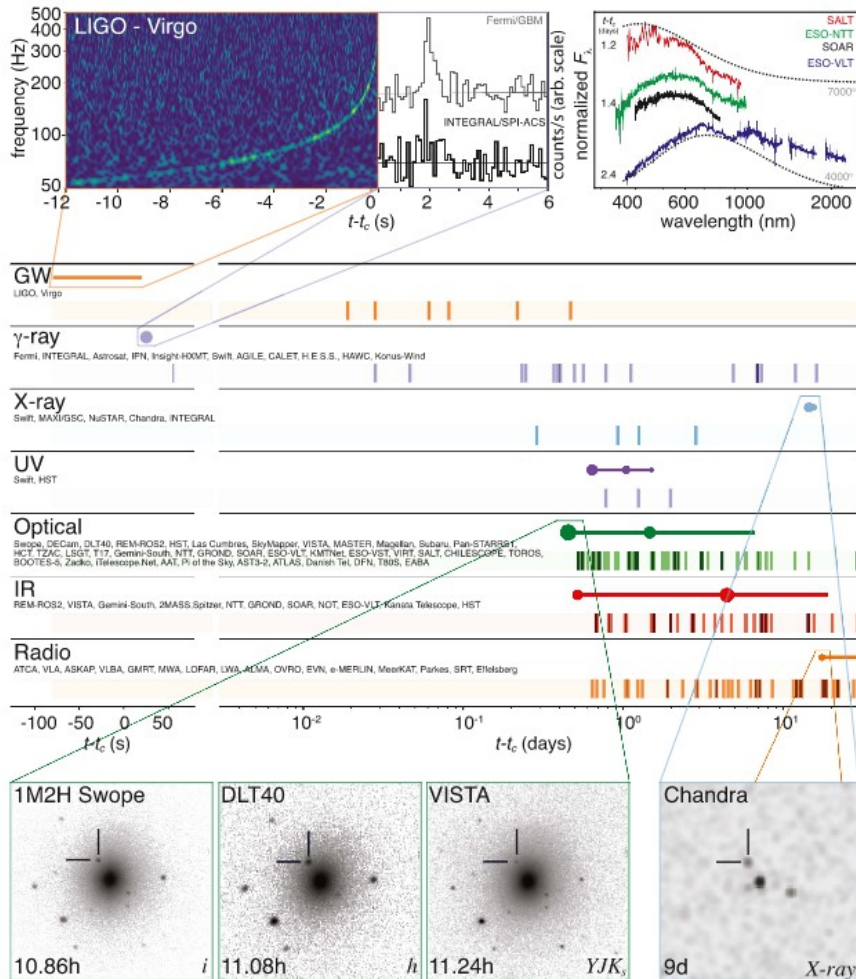
- O1 – Sept. 2015 → Jan. 2016
- BBH coalescences
- ANTARES follow-ups offline



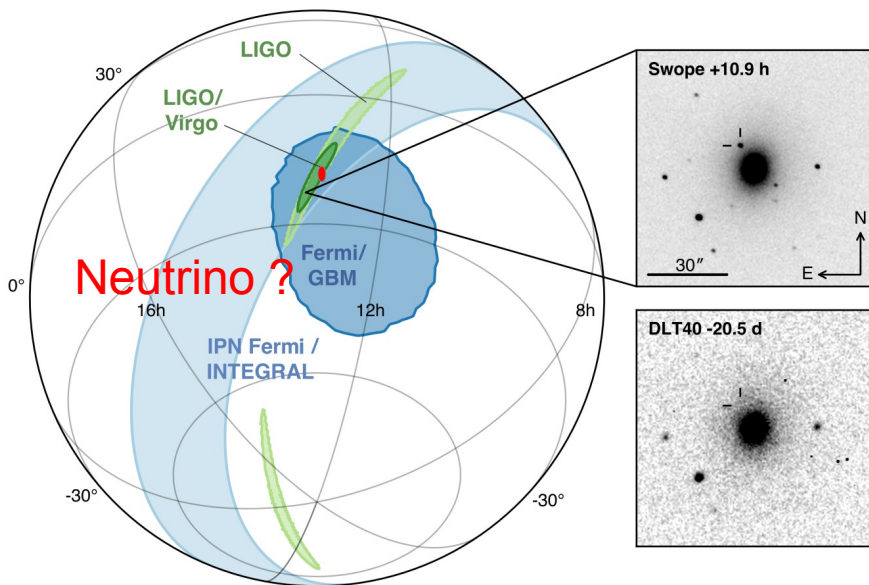
Better localization of source with HEN
[Here GW150914]

GW150914 - ANTARES+IceCube+Virgo/LIGO
Phys. Rev. D 93, 122010 (2016)

ANTARES-KM3NeT : GW+HEN since Advanced Interferometers

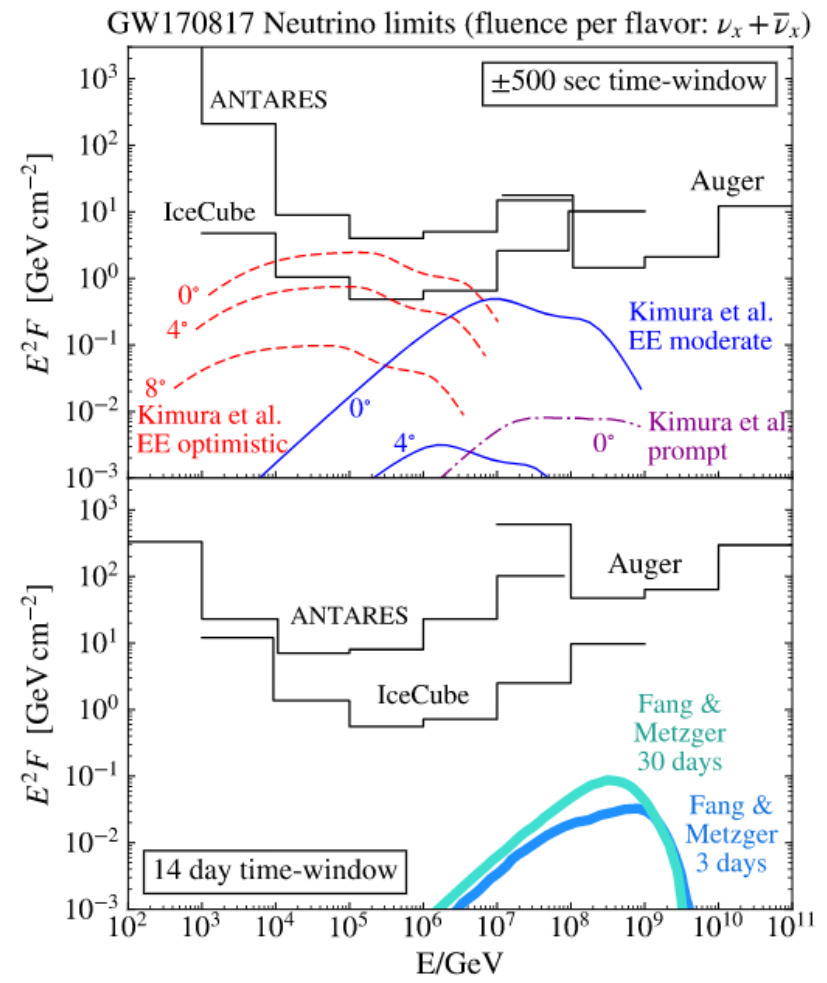


ANTARES-KM3NeT : GW+HEN *since Advanced Interferometers*



- O2 – Nov. 2016 → Aug. 2017
- Reception of online GW alerts
- Follow-up of GW170817

GW170817 - ANTARES+AUGER+IceCube+Virgo/LIGO
Astrophys. J. Lett. 850, L35



- **Fundamental Physics : Quantum Gravity**

- COST Action in preparation : QG Phenomenology in the Multi-Messenger Approach
 - Lorentz Invariance Violation with photons-photons, photons-neutrinos, neutrinos-GW...
 - José Manuel Carmona (Zaragoza), Giovanni Amelino-Camelia...

$$c^2 p^2 = E^2 \left[1 + \xi \left(\frac{E}{E_{\text{QG}}} \right) + \mathcal{O} \left(\frac{E^2}{E_{\text{QG}}^2} \right) + \dots \right]$$

$$\Delta t_{\text{QG}}^{\text{ms}} \simeq 0.15 \left(\frac{d}{10 \text{ kpc}} \right) \left(\frac{E_\nu}{1 \text{ TeV}} \right) \left(\frac{10^{19} \text{ GeV}}{E_{\text{QG}}} \right)$$

$$\begin{aligned} \Delta t_{\text{prop}} &= \frac{L}{2c} \left(\frac{m_\nu c^2}{E_\nu} \right)^2 \\ &\simeq 5.15 \text{ ms} \left(\frac{L}{10 \text{ kpc}} \right) \left(\frac{m_\nu c^2}{1 \text{ eV}} \right)^2 \left(\frac{10 \text{ MeV}}{E_\nu} \right)^2 \end{aligned}$$

Synergies ElectroMagnetic – GW - HEN

- **Cosmology**

- BBN = Standard Candle : $h(t) \propto \frac{\mathcal{M}_z}{D_L}$ with Chirp Mass $\mathcal{M}_z \propto (1+z)$
- Redshift with Optical Counterparts but need precise localization...
- **Neutrinos to facilitate localization !**

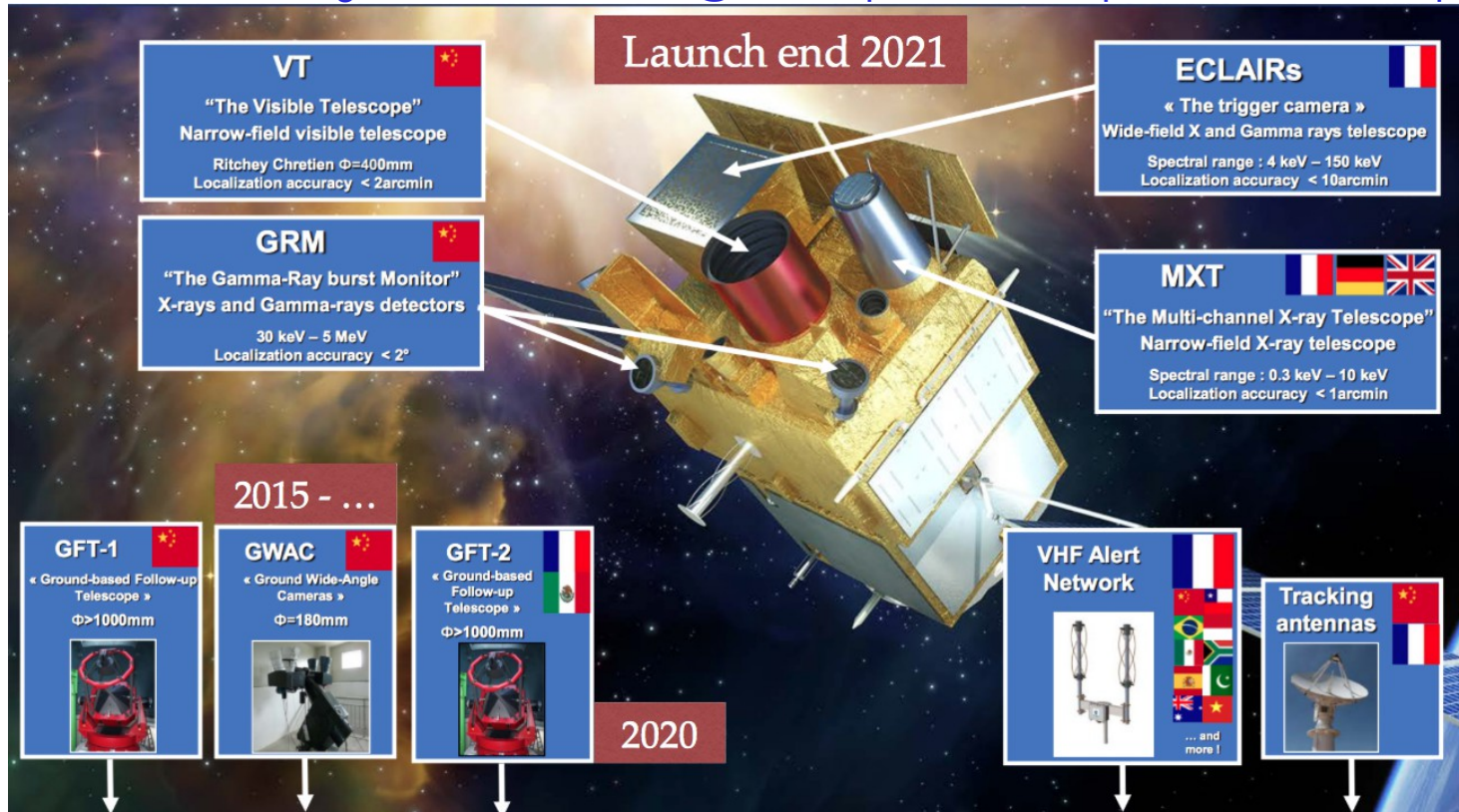


Credit : LIGO/Caltech/MIT/Leo Singer (Milky Way image : Axel Mellinger)

Synergies ElectroMagnetic – GW - HEN

• Transients in General : Organization of the French Community

- PNHE → Workshop in LAL June 2017 <http://ts2020.lal.in2p3.fr/en/>
- Meeting in December 2017 @ LAL <https://indico.in2p3.fr/event/16783/> password O2O2MM



2020: French ground follow up 1.3-m telescopes with near-infrared sensitivity

2021: SVOM satellite with gamma-ray trigger camera (ECLAIRs), gamma-ray monitor (GRM), X-ray follow-up telescope (MXT), visible follow-up telescope (VT)

Synergies ElectroMagnetic – GW - HEN

- **Transients in General : Organization of the French Community**
 - Access to X-Ray Facilities – Contact Diego Götz (CEA)
 - O3 starts end 2018
 - XMM-Newton → Deadline October 2018 for Observation early 2019
 - Chandra : Deadline March 2018 ?

