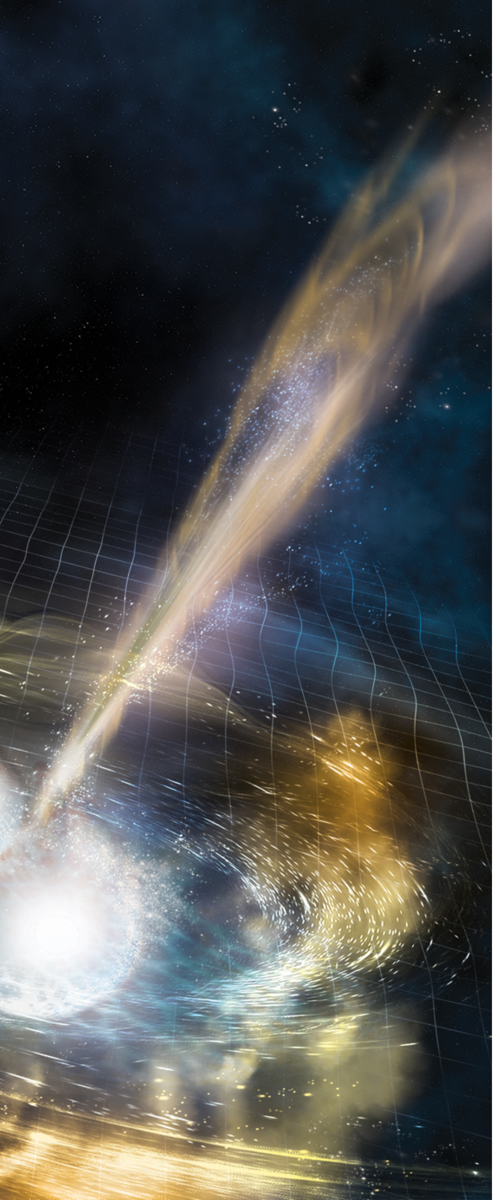

Compact object mergers & GRBs

B. Mours (IPHC) for the following contributions:

- Multi-messenger astroparticle physics (Nicolas Leroy et al.)
- Gamma Rays and Gravitational Wave (Nelson Christensen et al.)
- The Science of SVOM at IN2P3 (part) (Cyril Lachaud et al.)
- GWHEN -Gravitational Waves and High Energy Neutrinos (T. Pradier et al.)

Séminaire Thématique "Physique des Astroparticules" (GT-04)
November 13, 2019, LAPP

Exercice de prospective nationale en physique nucléaire, physique des particules et astroparticules

Multi-messenger astroparticle physics

Auteur principal
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co-auteurs:

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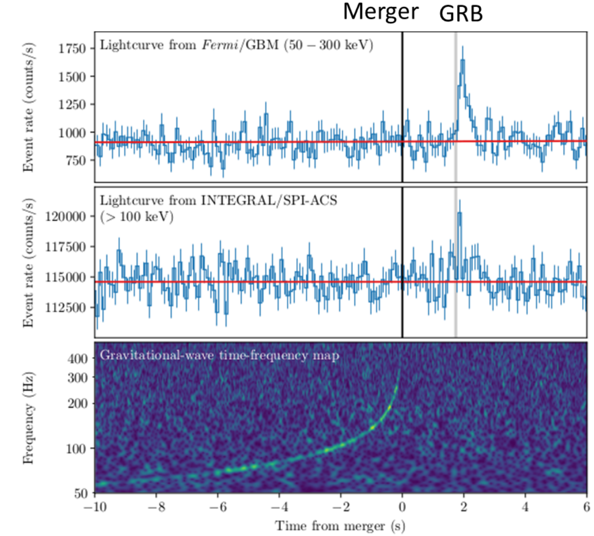
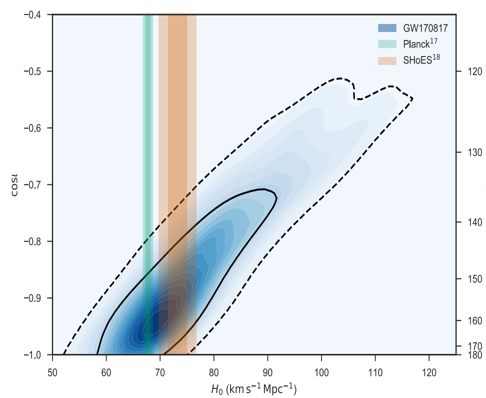
- F. **Piron** LUPM, CNRS/IN2P3
- F. **Schüssler**, E. **Le Floc'h**, D. **Götz**, J. **Guilet**, S. **Chaty** CEA/AIM, IRFU/DAp
- S. **Vergani** GEPI CNRS/INSU
- F. **Daigne** IAP CNRS/INSU

New ways to observe universe

Virgo, Fermi, H.E.S.S., ANTARES, INTEGRAL, Auger
ENGRAVE, GRANDMA

- The latest generation of instruments have change the game:
  - GW detections from BBH to BNS with EM counterpart
  - Several GRBs detected at TeV energies
  - Candidate between neutrinos and EM emission
- Lot of physics can be done
  - Jets mechanisms in large diversity of objects : neutrinos and EM emission
  - Link with central engine through GW emission
  - Link to fundamental physics or cosmology (H0 measurement, speed of gravity, Lorentz invariance violation, …)
- IN2P3 is participating to most of the involved instruments
  - For example 14 groups from IN2P3 were involved in the GW170817 multi-messengers paper

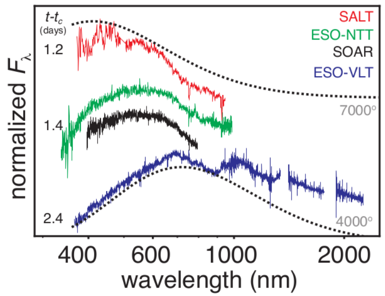




Needs for transient sky and multi-messengers astrophysics

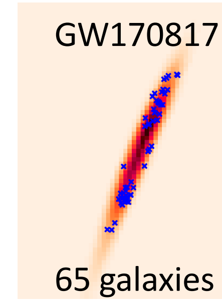
- Be able to scan quickly possible large error boxes (> 100 deg^2)
  - Importance of catalog of galaxies to optimize strategy
  - Good precision in localization and deepest as possible -> allow follow-up with larger instruments
  - Fast reaction -> events are fading quickly

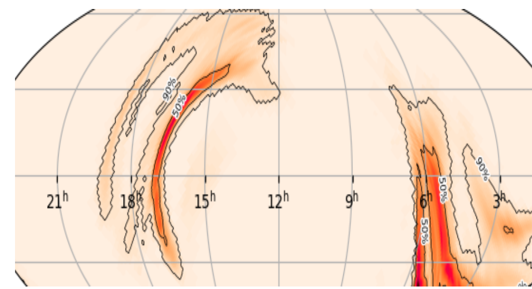
- Need to characterize candidates
  - Access to spectrometric measurements
  - Link to emission models to perform selections
- Follow-up on several months
  - GW170817 : cocoon vs jets using X-rays and radio data



Catalogs of galaxies

- With large error box, need to prioritize the sky coverage of the alerts
- Including distance allows can allow to weigth with galaxies properties
  - Need to be all-sky
  - Complete up to the distance of interest
  - Large wavelength to derive galaxies properties
- GLADE is the most used catalogs but have many defauts
  - Mainly with B luminosity -> sensitive to galaxy dust extinction
- Having good catalogs is also interesting for MM studies, see for example correlation between UHECR and star forming rate



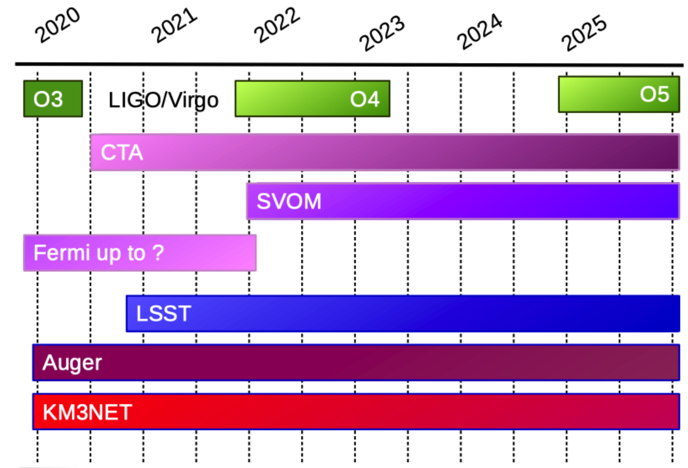


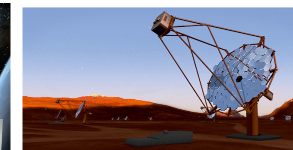
100 000 galaxies

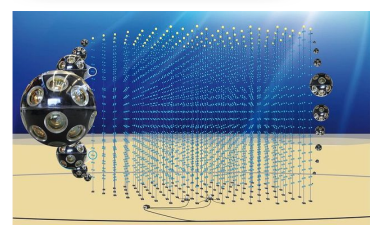
New players are coming

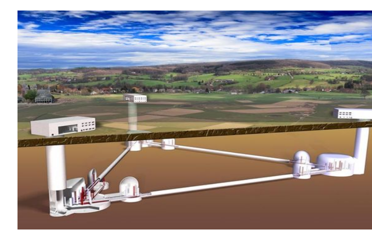
Virgo, LISA, Einstein Telescope
LSST, CTA, SVOM
KM3NET, Auger

- New observatories will arrive in the next years
  - Allow better follow-up of transient events
- Increase of coincident detections
- But also increase of alerts
  - LSST will bring millions of candidates per night
  - Broker will be essential for our field
- Need to prepare ourselves with our partners from INSU and Irfu
- Need to prepare the following generation for GW : LISA, Einstein Telescope

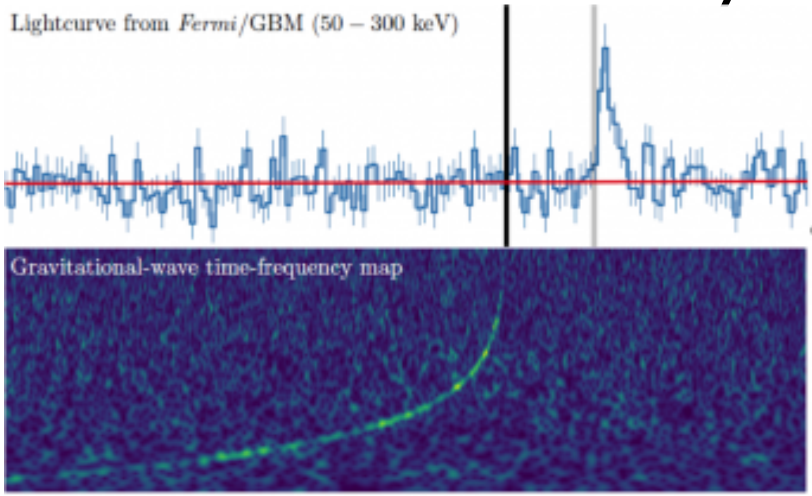


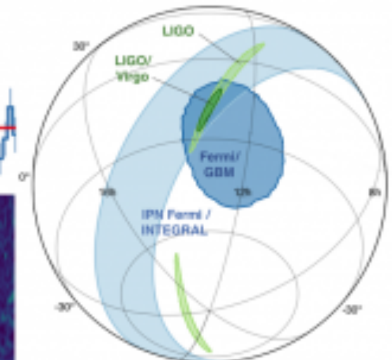






Gamma Rays and Gravitational Waves





- The coincident observation of these two messengers will elucidate the sources of gravitational waves (GW) and γ-rays and enable multimessenger science.
- This ultimately requires upgrades to the ground-based GW network and keV-MeV γ-ray coverage for observations of neutron star (NS) mergers.

Eric Burns (NASA Goddard)
Nelson Christensen, Cosmin Stachie (Artemis)
Tito Dal Canton, Nicolas Leroy (LAL)
Michal Was, Didier Verkindt (LAPP)
Sarah Antier (APC)

Neutron Star Mergers

- Binary NS and some NS -Black Hole (BH) mergers produce short γ-ray bursts (SGRBs) and kilonovae.
- Joint GW-γ detections of NS mergers give unique insights into relativistic jets, astroparticle physics, equation of state of supranuclear matter, and tests of fundamental physics.
- First SGRB figure of merit is the average sky coverage, corresponding to the probability a merger will be observed.
- Second figure of merit is the rate of SGRB detections, which directly corresponds to the likelihood of joint detections.
- Joint detections are limited by the GW detector sensitivity for on-axis SGRBs and by γ-ray detector sensitivity for moderately off-axis SGRBs.

Other Possible Joint Sources

- Core Collapse Supernovae (neutrinos too)
- Pulsars (continuous wave GW + γ-rays)
- Accreting Neutron Stars (intermediate duration GW)
- Pulsar Glitches (short or intermediate duration GW)
- Giant Magnetar Flares (short or intermediate duration GW)
- Supermassive Black Holes Binaries (LISA + PTAs)
- Unexpected (γ-rays after stellar mass Binary BH merger?)

Summary

- Joint γ-ray and GW searches will help to identify the sources and initiate coordinated follow-up.
- GW + γ : synergistic partners in the multimessenger era.
- Increase the LIGO/Virgo horizon and observing time to detect more coincident GW-SGRBs events.
- Increase γ-ray satellite sensitivity to find more slightly off axis SGRBs like GRB 170817A within the LIGO/Virgo horizon.
- Broad coverage of the γ-ray sky from keV to TeV energies in partnership with broad coverage of the GW spectrum must be a goal for the coming years of observations.

The Science of SVOM at IN2P3

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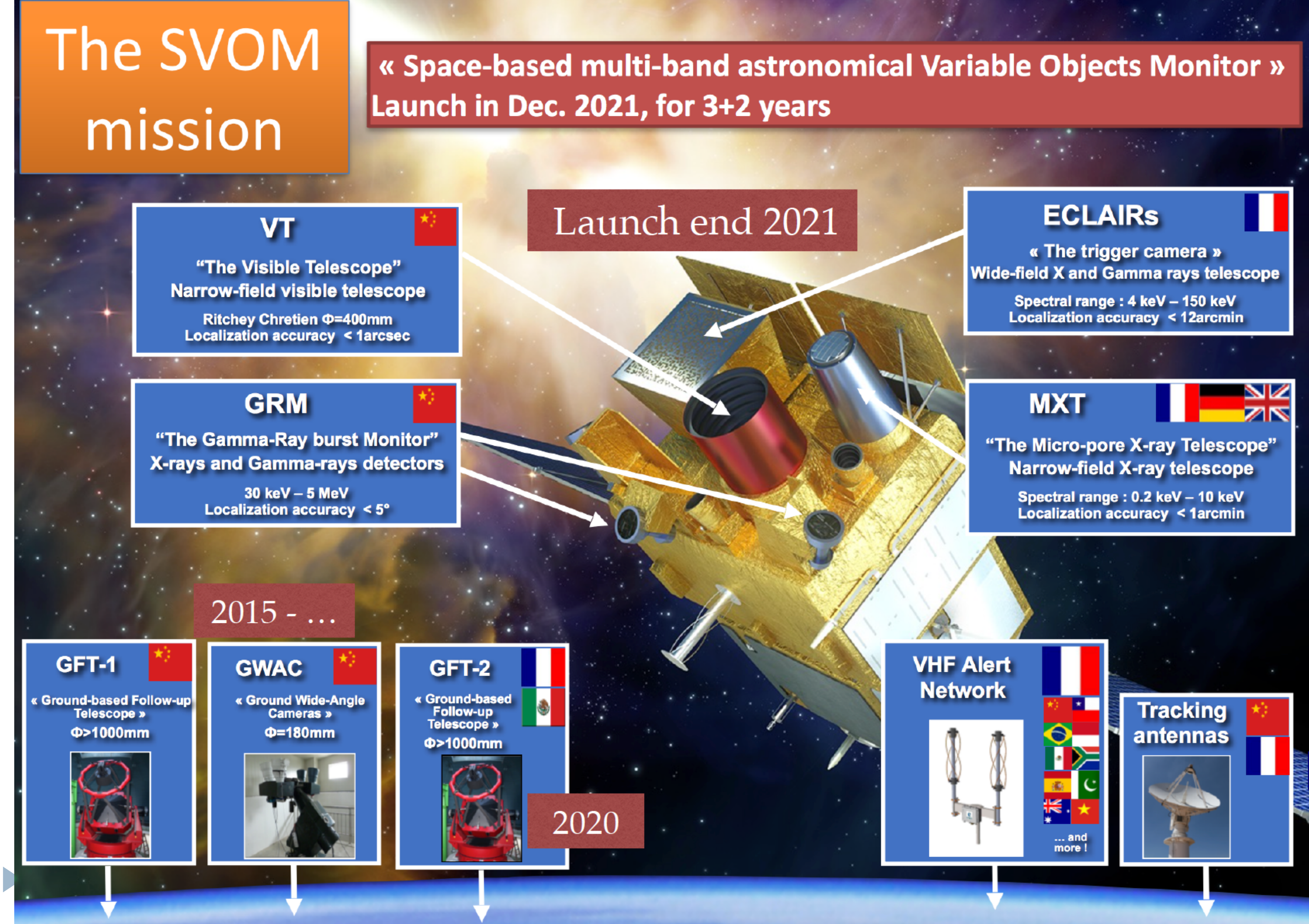
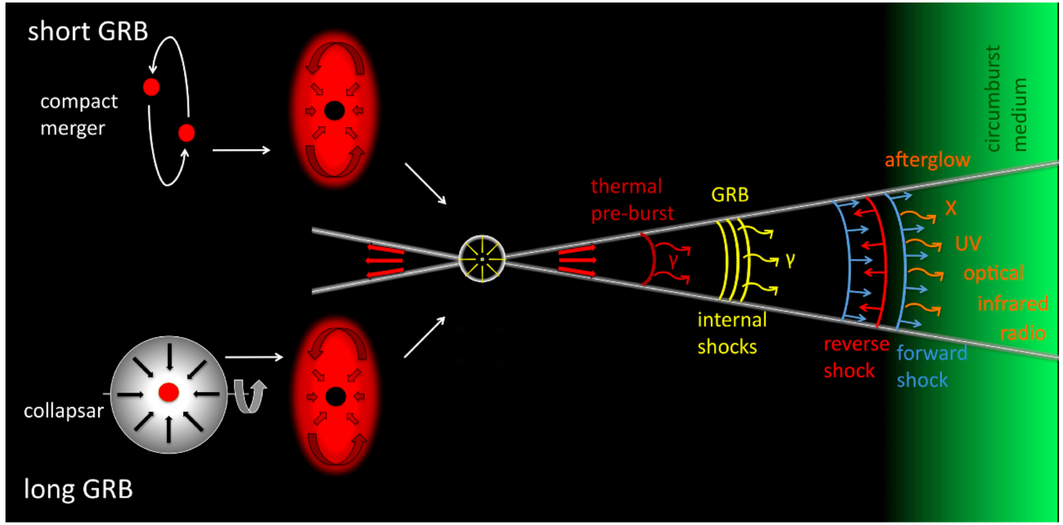

The SVOM mission
« Space-based multi-band astronomical Variable Objects Monitor »
Launch in Dec. 2021, for 3+2 years
Launch end 2021
VT
"The Visible Telescope"
Narrow-field visible telescope
Ritchey Chretien Φ=400mm
Localization accuracy < 1arcsec
GRM
"The Gamma-Ray burst Monitor"
X-rays and Gamma-rays detectors
30 keV – 5 MeV
Localization accuracy < 5°
ECLAIRs
« The trigger camera »
Wide-field X and Gamma rays telescope
Spectral range : 4 keV – 150 keV
Localization accuracy < 12arcmin
MXT
"The Micro-pore X-ray Telescope"
Narrow-field X-ray telescope
Spectral range : 0.2 keV – 10 keV
Localization accuracy < 1arcmin
2015 - …
GFT-1
« Ground-based Follow-up Telescope »
Φ>1000mm
GWAC
« Ground Wide-Angle Cameras »
Φ=180mm
GFT-2
« Ground-based Follow-up Telescope »
Φ>1000mm
2020
VHF Alert Network
… and more !
Tracking antennas

SVOM advances on GRB science



- **Physical Origin of GRB emission**
  - The nature of the **physical mechanism that launches GRB ultra-relativistic jets** is not elucidated, and the **composition of the jet** is currently the subject of an intense debate, as well as the **internal dissipation mechanism** responsible for the prompt emission (photospheric emission vs internal shocks vs magnetic reconnection). Regarding the **physical origin of the afterglow**, several emission regions are invoked: forward/reverse/late internal shocks. Some of these models have strong implications on the **lifetime and energetics of the central engine** as they imply late energy injection by the source or relativistic ejection at late times. A good description of both the prompt and afterglow emissions simultaneously is also necessary to test models linking some afterglow features with the prompt emission.

SVOM advances on GRB science

- **Short GRBs and the compact star merger model**
  - The **compact star merger model of SGRBs** leads directly to two predictions (and confirmed in the case of GW170817): the **simultaneous production of strong gravitational wave emission** from the final stages of orbital decay and merger, **and the substantial production of r-process elements** in the neutron-rich merger ejecta. The **complementarity of the SVOM instruments** will allow us to get **redshift measurement** in a large fraction of event but also a **complete coverage of the visible light emission** through the GWAC, GFTs and VT (also catching the kilonova emission if existing). The **combination of ECLAIRs and GRM** will allow for a better understanding of the **prompt emission** and the **MXT** instrument will permit a **precise localization and measurement of the early phase of the afterglow emission**.
- **GRBs as particle accelerators**
  - **Electrons and hadrons are accelerated** on a very short timescale at the shock fronts in the jets to ultra-relativistic speeds. The recent detections of VHE emission from 3 GRBs up to a **few hundreds of GeV by MAGIC and H.E.S.S.** have also proven the acceleration of particles up to these very high energies. **CTA should detect multiple GRBs with a relatively high statistics.** GRBs have been proposed as one of the potential sources for ultra-high energy cosmic rays (UHECRs) and the detection of a high-energy neutrino (HEN) signal in coincidence with a GRB would be a direct proof of the existence of a hadronic component in the jets. **Joint analyses between CTA and KM3NeT of SVOM GRBs** will provide insights on their capability to be efficient cosmic accelerators.
- **Cosmology and fundamental physics**
  - **Jet opening angle and redshift correlations** can in principle be used to extend the **Hubble diagram to high redshift** and to **determine cosmological parameters** (still debated). Analysing the **times of arrival of high energy photons** emitted during GRB prompt emission can set stringent **constraints on Lorentz Invariance Violation (LIV)**.

Multi-Wavelength and Multi-Messenger Astronomy with SVOM

- **Follow-up of astrophysical neutrinos**
  - A **HEN diffuse flux of cosmic origin has been identified** by the IceCube telescope in 2012 and confirmed later with all neutrino flavours. One of the major results is undoubtedly the **detection of a high-energy neutrino detected by IceCube on September 22, 2017, likely associated with a flare of the blazar TXS 0506+056** seen by gamma-ray, X-ray, optical, infrared, and radio telescopes. If confirmed in the future, this association may mark the real birth of the high-energy neutrino astronomy. With the **new generation of neutrino telescopes**, we can expect a larger statistics with IceCube Gen2 and an **angular precision lower than 0.1(1.5)º for ν"(νe,τ) neutrinos with KM3NeT**. SVOM with its ground- and space-based instruments will offer large and complementary follow-up capability through ToOs. **The performances of SVOM (fields of view and instrument sensitivities) are perfectly tailored to follow all neutrino alerts with the MXT and VT instruments on-board and ground-based telescopes (GFTs and GWAC).**

GW and High Energy Neutrinos (GWHEN)

- …

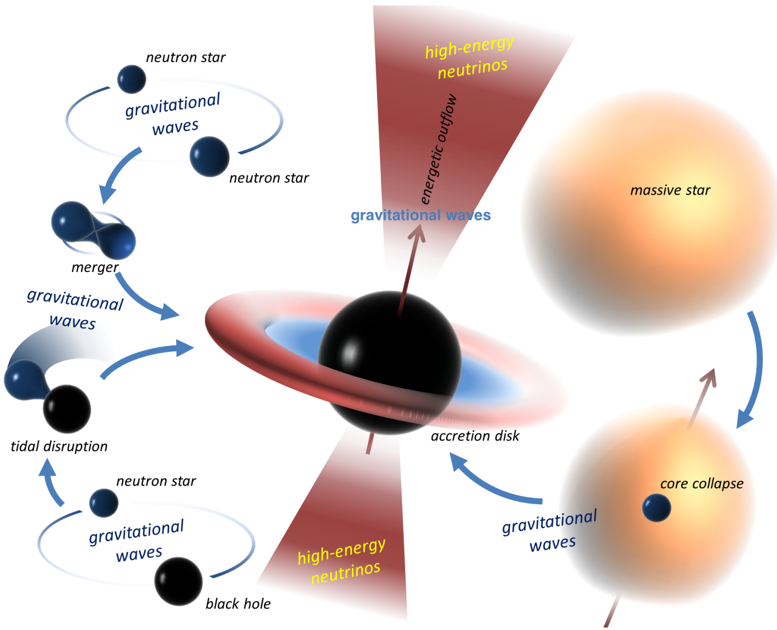
Prospectives IN2P3 - GT04 ASTROPARTICLE PHYSICS

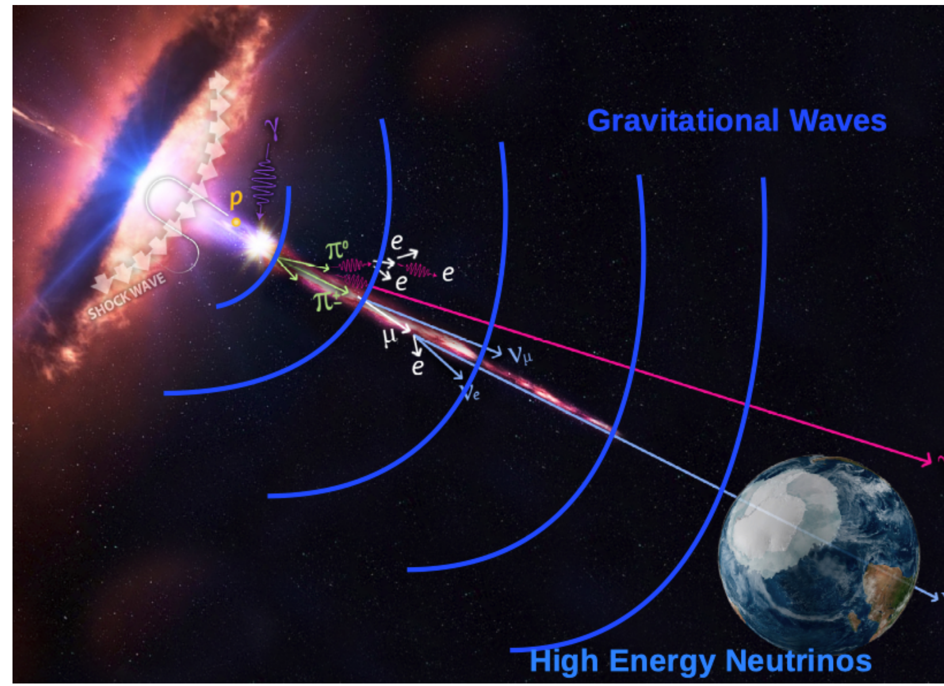
GWHEN - Gravitational Waves and High Energy Neutrinos, the next multi-messenger connection

T. Pradier [a], Université de Strasbourg/IPHC,
for the APC, CPPM, IPHC, LUPM and Subatech KM3NeT groups

[a] also member of the VIRGO Collaboration

GW and High Energy Neutrinos (GWHEN)





Sources communes GWHEN :

Coalescences de Binaires + Jet

CC Supernovae + Jet ?

GW and High Energy Neutrinos (GWHEN)

Analyses réalisées

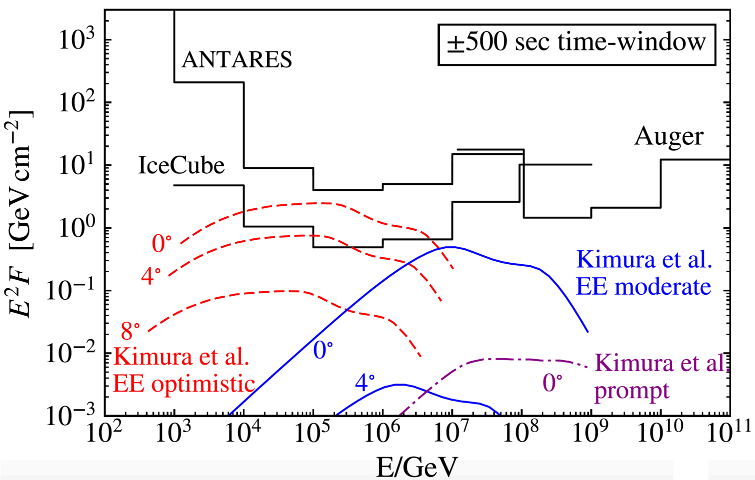
→ Détecteurs « initiaux »

A first search for coincident gravitational waves and high energy neutrinos using LIGO, Virgo and ANTARES data from 2007 JCAP 06 (2013) 006

→ Détecteurs « avancés »

e.g. GW170817

Analyses on/offline O1 → O3

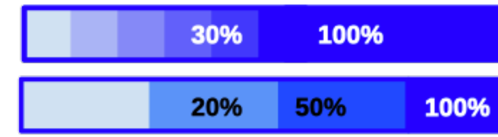


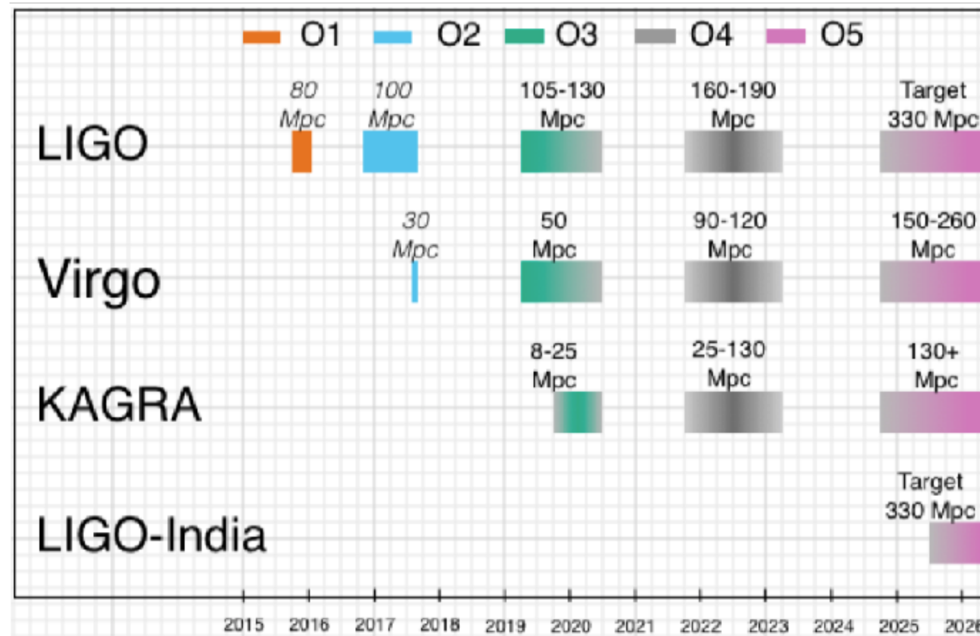
GW170817 ANTARES, IceCube, AUGER

Détecteurs futurs

ORCA (E_{HEN} = 1-100 GeV)

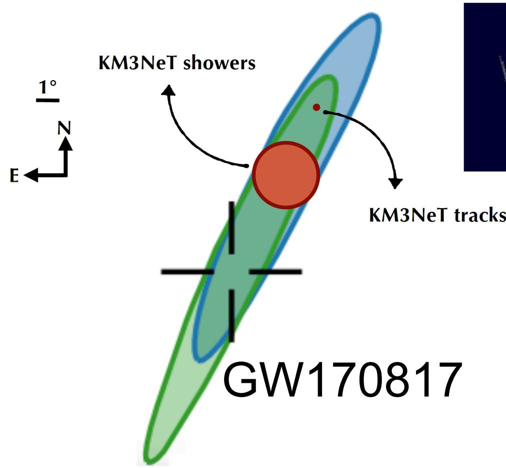
ARCA (E_{HEN}>TeV)

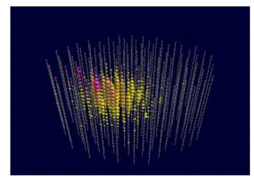




GW and High Energy Neutrinos (GWHEN)

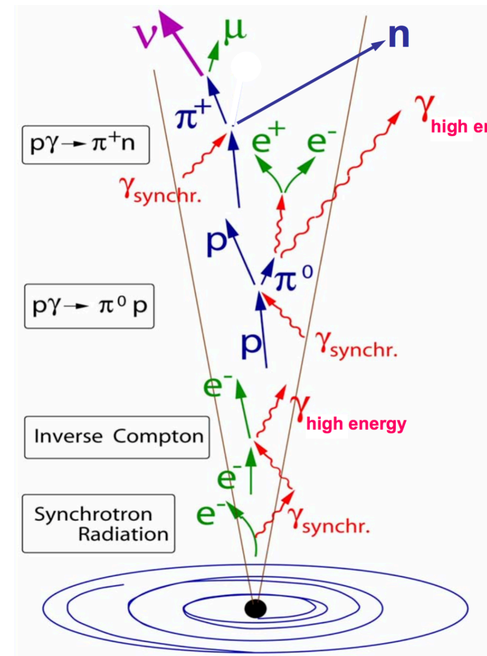
« Physics case » - court terme





angular resolution:
<deg (tracks) /
~deg (showers)

field-of-view:
> 2π sr



Pour astro GW :

Confirmer le signal GW ?

Trouver les contreparties EM

$\Delta\Omega_{HEN} << \Delta\Omega_{GW}$

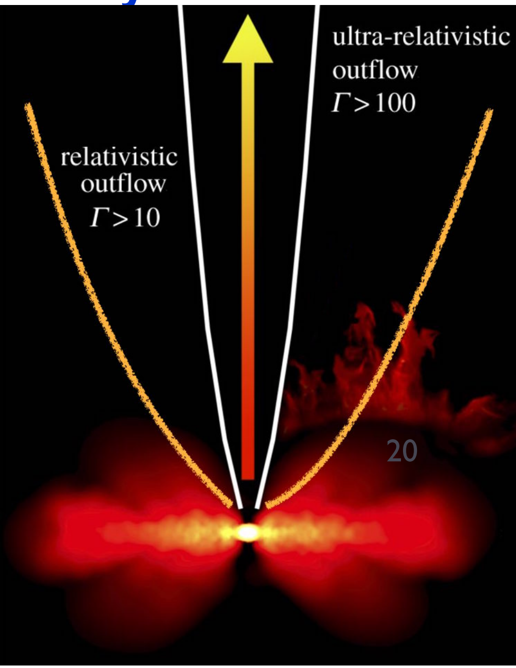
Pour Astro HEN

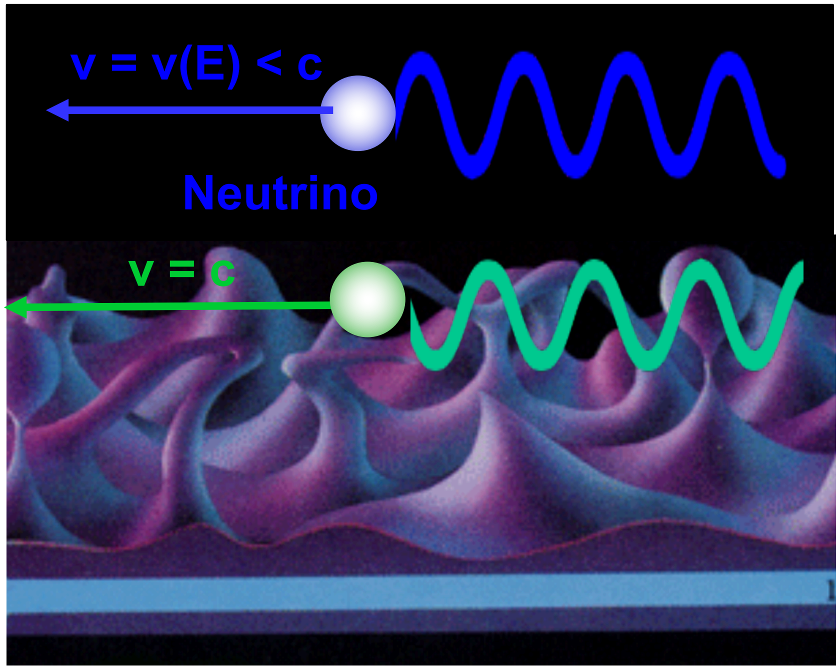
Origine des RC

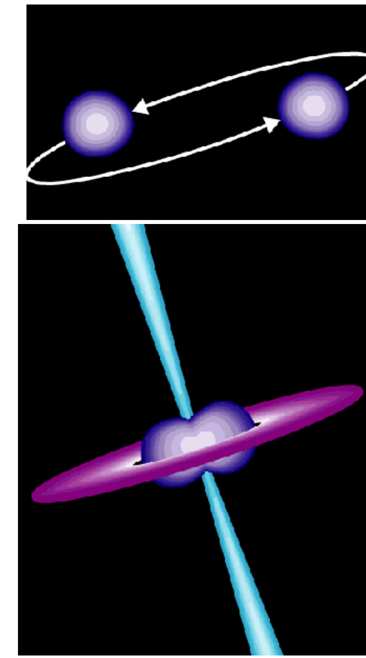
HEN ↔ RC hadronique

GW and High Energy Neutrinos (GWHEN)

« Physics case » - long terme







Accrétion-Ejection

Δt GW-HEN dans CBC ?

Jets dans CC SN ?

Gravité Quantique

$$\Delta t_{\text{GW-HEN}} \propto \frac{E_{\text{HEN}}}{E_{\text{QG}}}$$

Cosmologie – Sirènes Standards

HEN → contreparties EM

→ constante de Hubble

CBC+GRB: overall summary and comments

- Compact Binary merger + GRB: a rich program
  - GW170817 + GRB170817A an enlightening demonstration
    - But a nearby event…
- Since most SGRB are far away, the challenge is to find the GW counterpart
  - A challenge for GW detectors
  - BNS (or NSBH) detection could trigger search for off axis SGRB
    - A challenge for GRB detectors
- Tens (hundred?) of French physicists have declared interest
  - Involvement in Virgo (LIGO), ET, Fermi, SVOM, CTA, Antares/KM3Net…
  - + Optical, see next presentation
- Will require the use of all information to extract all the science