Astroparticle physics GT4

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Outline

- White paper collection & Town hall meeting in Annecy
- Science drivers
- Scientific programs
- Projects
- Program-wide recommendations
- Project-specific recommendations

Call for white papers

Un groupe de travail (GT) est mis en place pour la thématique "physique des astroparticules" auquel sont invités à contribuer tous les chercheurs, ingénieurs et techniciens des laboratoires français. Les questions scientifiques concernent essentiellement

- **La nature et l'origine des rayons cosmiques (gammas, cosmiques chargés, neutrinos) de haute énergie**
- **La physique associée aux ondes gravitationnelles**

avec une forte priorité sur la déclinaison nationale des priorités stratégiques européennes de la feuille de route 2017-2026 par APPEC

White papers & Town hall meeting

- 32 white papers received by the Copil - **thanks to all contributors!**
- Regrouped into **13 topics** for the town hall meeting
- Thanks to : A. Lamberts, S. Babak, J. Margueron, M. Barsuglia, D. Horan, A. Goldwurm, D. Dornic, E. Parizot, D. Maurin, D. Semikoz, M.-A. Bizouard, B. Mours, N. Leroy

  The LAPP LOC!

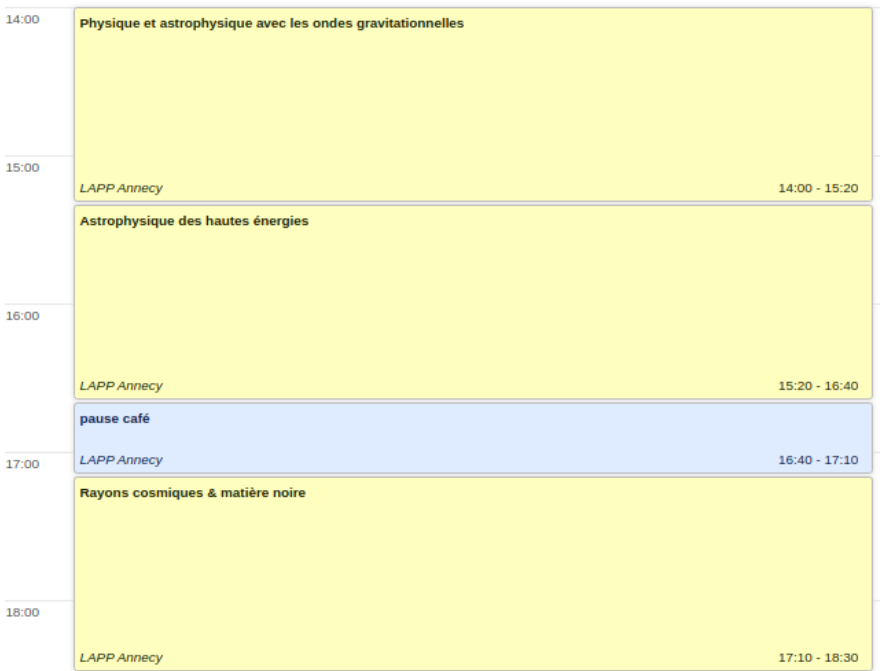
Physique des astroparticules

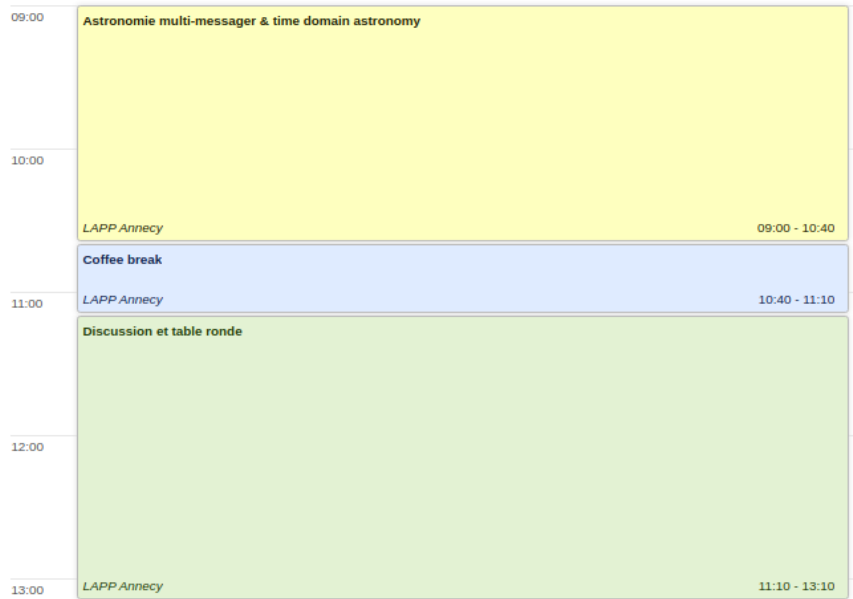
LAPP - Annecy
12-13 Novembre

Pour consulter l'agenda et obtenir plus d'informations sur l'exercice de prospective nationale :

https://prospectives2020.in2p3.fr

Town hall meeting





A huge thanks to all the speakers!

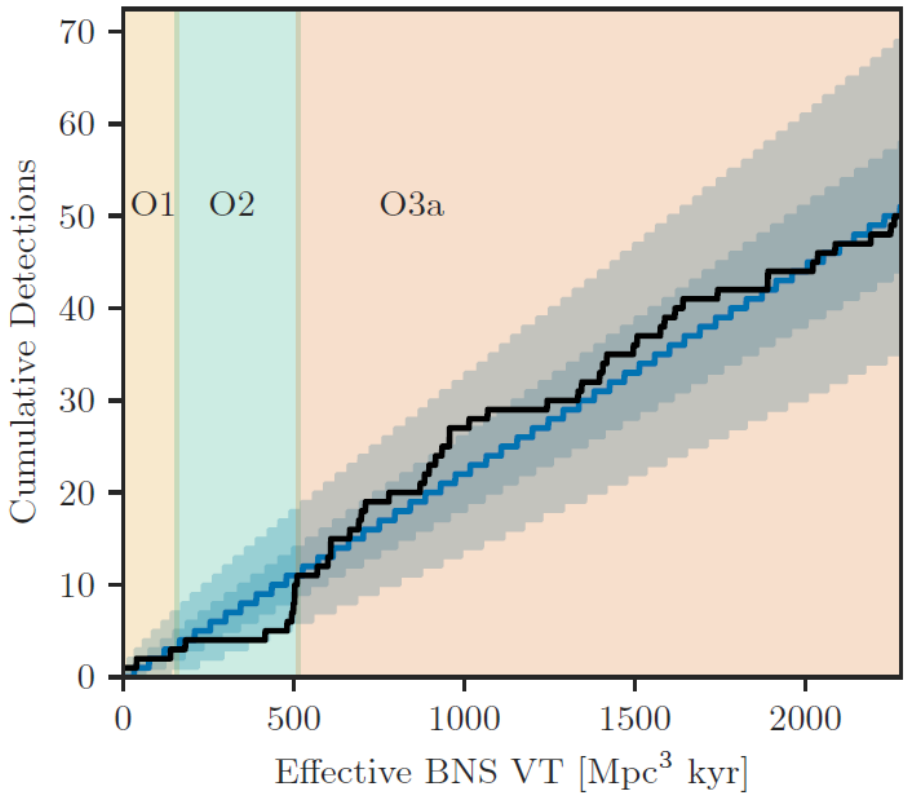
Science drivers

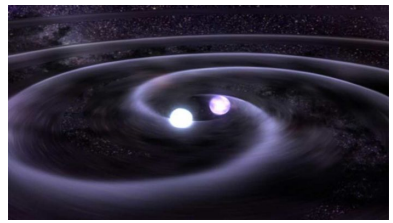
The committee distilled all those essential inputs into **three intertwined science drivers** for the field of astroparticle physics in France:

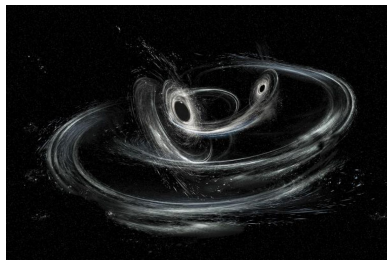
- **Use gravitational waves as a new tool to explore the universe and its fundamental laws**
- **Pursue the physics associated with high-energy messengers: origin, composition and propagation**
- **Probe extreme (astro)physical phenomena with multi-messenger observations**

Physics and astrophysics with gravitational waves

The beginning of a new astronomy!







Physics and astrophysics with gravitational waves

GWs detection will allow to explore the observational and theoretical frontiers of the next decade in astrophysics, fundamental physics and cosmology

- Test validity of General Relativity and nature of dark components
  - Gravity in the strong-field regime and the nature of black holes
  - GW emission & propagation through space-time
  - Multi-messenger detection to test the fundamental nature of the messengers
  - Standard and dark sirens to test the accelerated expansion of the universe

Physics and astrophysics with gravitational waves

- Reveal population of sources
  - Inform astrophysical models, source progenitors, binary formation
  - Understand formation and evolution of black hole population across the entire mass range
  - Explore exotic approaches, e.g. primordial black holes
- Strong interdisciplinary potential of GW sources involving neutron stars
  - Connection with astrophysical phenomena (short Gamma-ray bursts, kilonovae...)
  - Statistics, precision measurements, post-merger signal... needed to probe structure of matter under extreme density and pressure conditions
  - Standard sirens to test the expansion of the universe

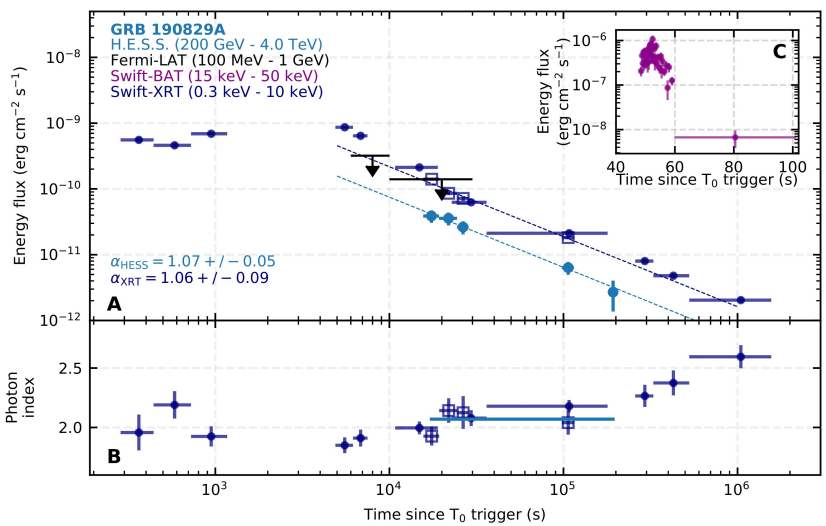
Physics and astrophysics with gravitational waves

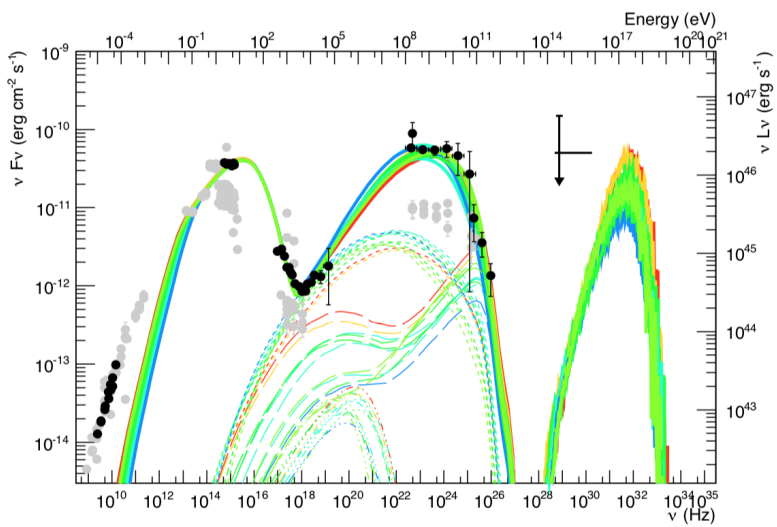
- New types of GW sources, e.g.
  - Supernovae: information on collapse process, coincident detection of neutrinos
  - Extreme mass-ratio inspirals: environment of galactic cores, tests of General Relativity
  - White dwarf binaries: stellar binary evolution, supernovae progenitors

- Stochastic GW background of primordial origin
  - Observational access to the early universe, filling the observational gap from Inflation to Nucleosynthesis
  - Insight on the theory of fundamental interactions beyond the TeV scale
  - Particle content of the universe (baryon asymmetry, dark matter, nature of the inflaton...)

High energy astro-(particle) physics

- Probing extreme environments
  - Physics of Gamma-ray bursts (GRB) and active galactic nuclei (AGN)
  - Jet launching and collimation mechanisms
  - Particle acceleration up to extreme energies
  - Physics of compact objects: neutron stars and black holes

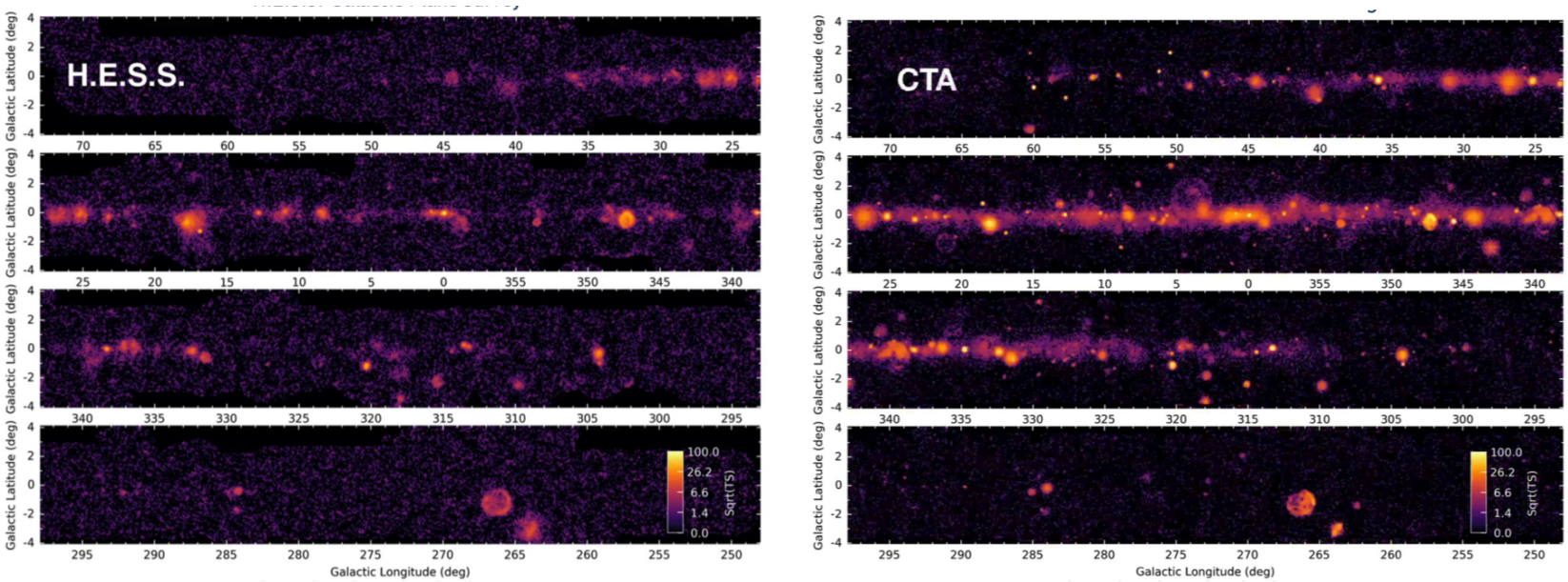




(l): GRB 190819A afterglow (HESS 2021). (r) TXS 0506 SED with lepto-hadronic model (Cerruti+ 2019)

High energy astro-(particle) physics

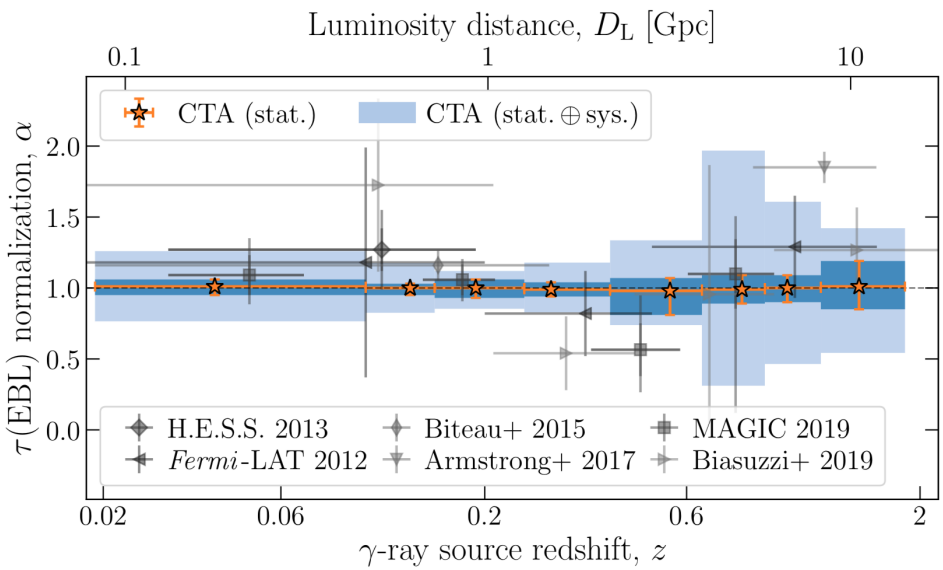
- Origin and role of relativistic cosmic particles
  - Identify the sources of VHE gamma-rays and neutrinos
  - Nature of cosmic-rays accelerators? Where are the PeVatrons?
  - Propagation and interactions of cosmic-rays
  - Sub-GeV cosmic-rays

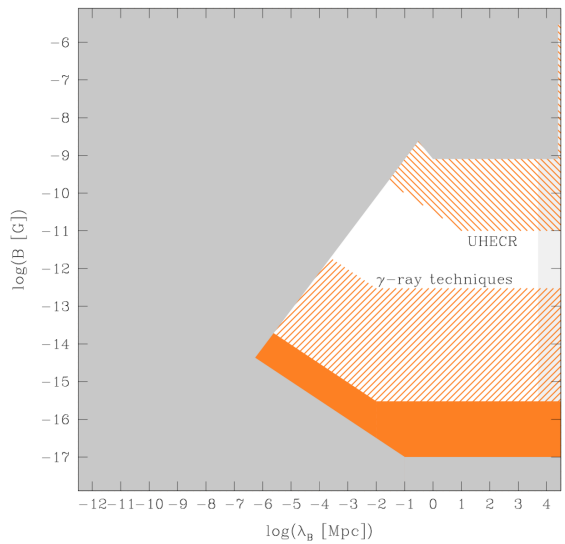


Galactic Plane Survey observed by HESS (HESS 2018) and simulated with CTA.

High energy astro-(particle) physics

- Connection with cosmology
  - Precision measurement of extragalactic background light thanks to AGN spectra pair attenuation
  - Independent gamma-ray measurement of H_0
  - Constraints on extragalactic magnetic fields in cosmic voids with gamma-ray and UHECR measurements

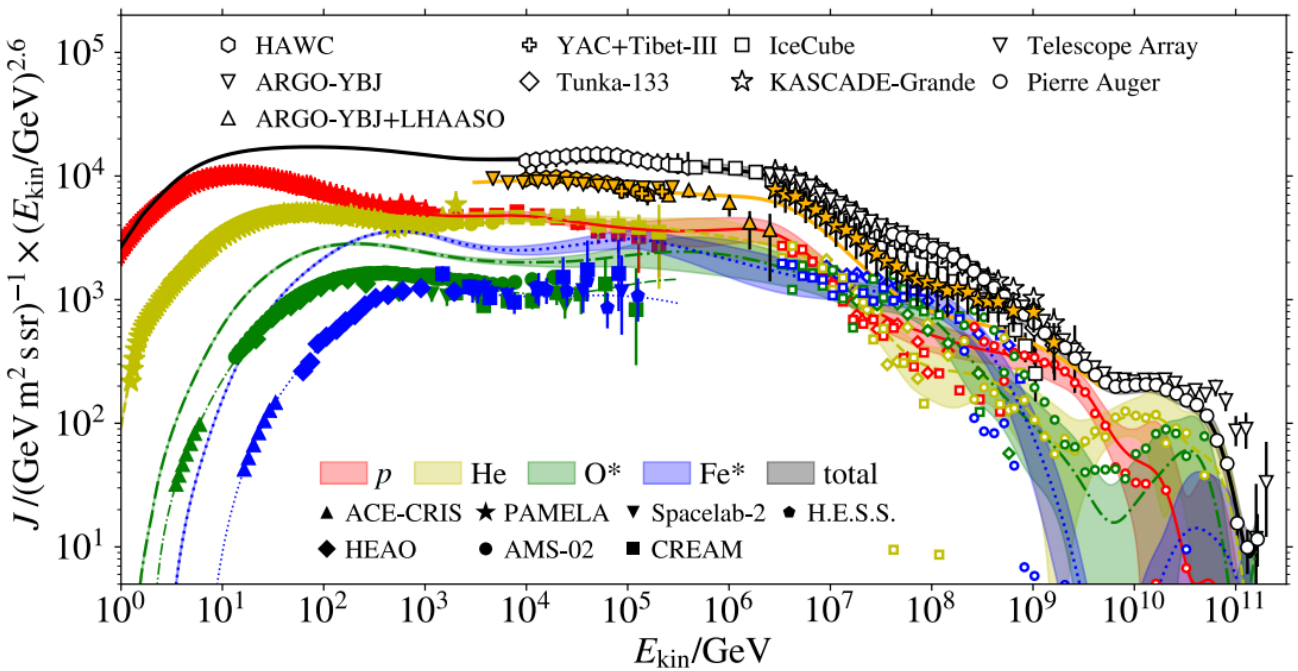




(l) Constraints on EBL attenuation with CTA (CTA 2021). (r) Sensitivity to EGMF for gamma-ray and UHECR (Durrer+2013)

Cosmic rays

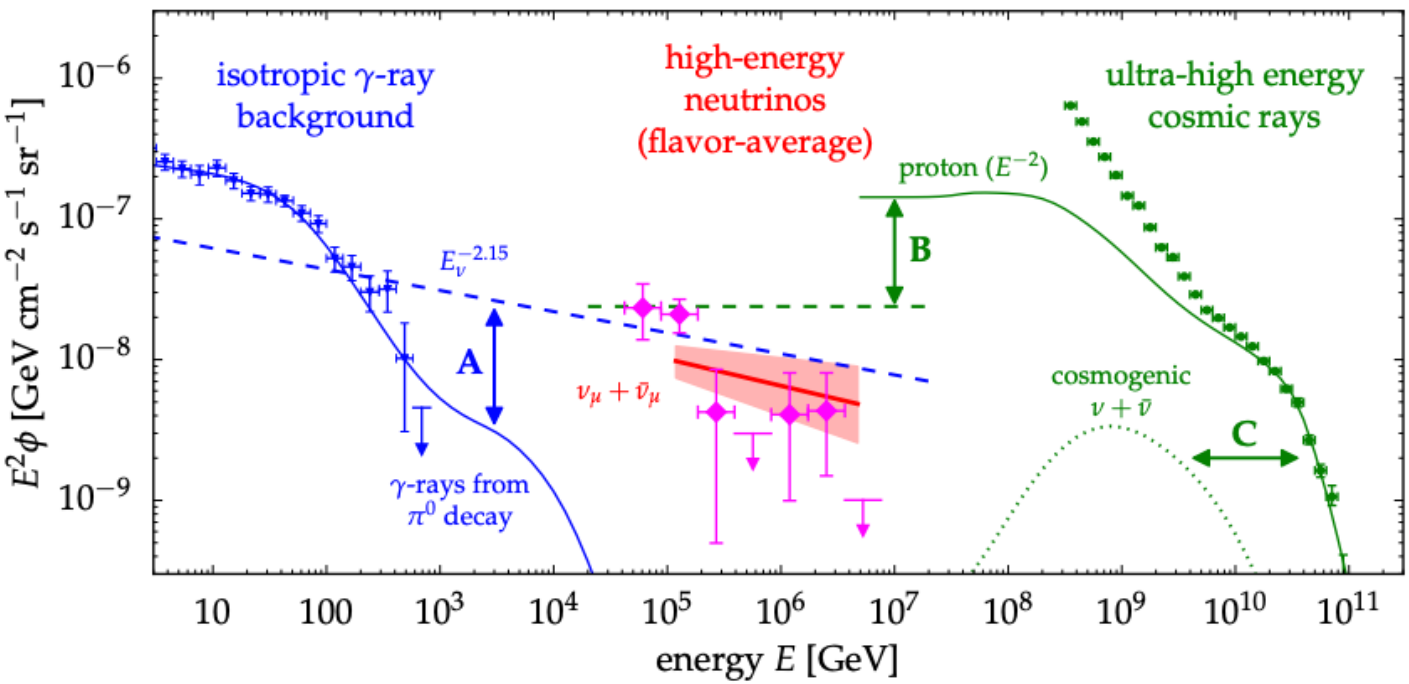
- The cosmic-ray spectrum has been measured from about 10^9 up to 10^{20} eV/particle
- New features in the propagation of GeV-TeV energy CRs (e.g. pulsar halos)
- "Knee" feature detected by ground-based experiments around 10^{16} eV/particle



Summary of CR spectrum [Schröder, ICRC 2021]

Cosmic rays

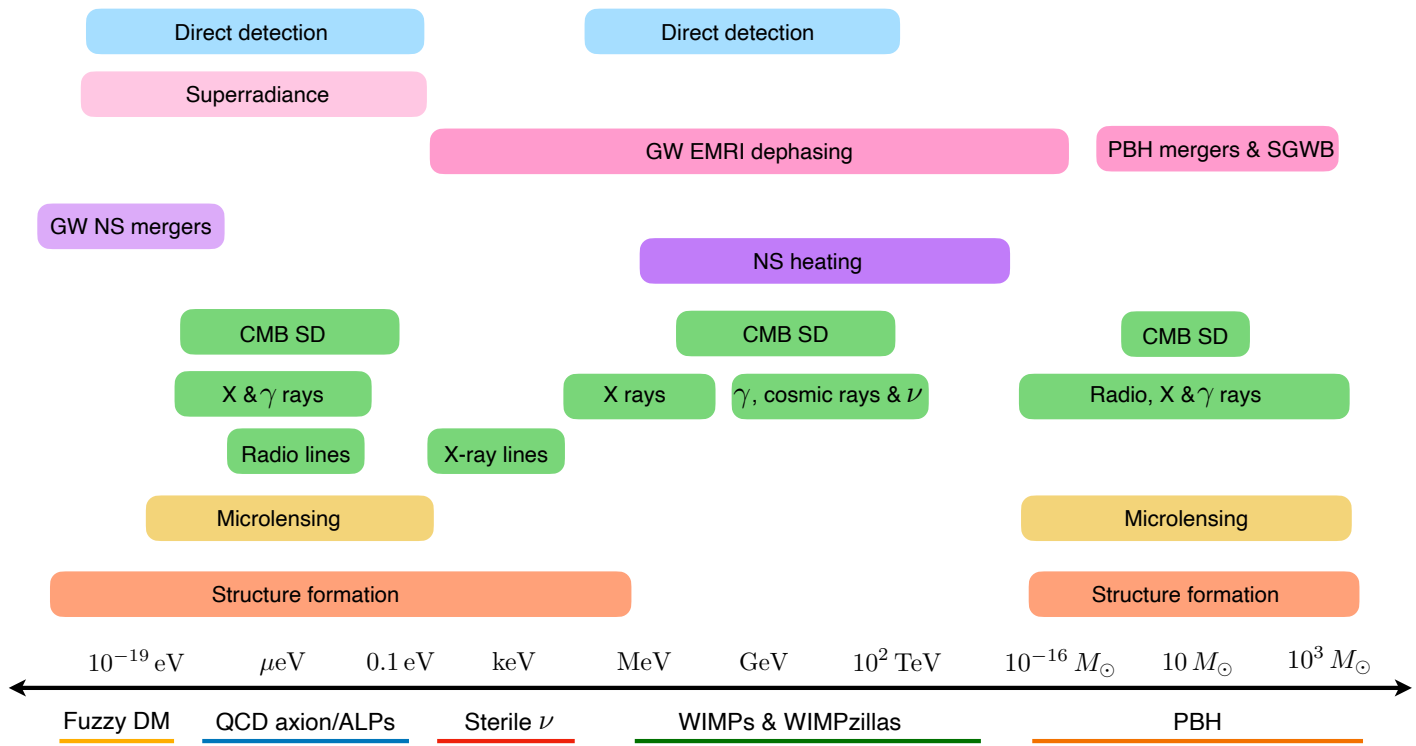
- Getting a bottom-up understanding of CR physics combining multiple experiments
- Characterising multi-messenger diffuse backgrounds is one of the major objectives of CR physics in gamma rays, neutrino and UHECR



Diffuse gamma, neutrino and UHE cosmic ray fluxes [arXiv:1903.04334].

Dark matter

- The fundamental nature of about 85% of total matter in the universe remains unknown
- Astroparticle observables can probe and constrain several dark matter candidates (WIMP, ALPs, PBH)



Summary of dark matter probes and candidates [EuCAPT White Paper (2021), arXiv:2110.10074]

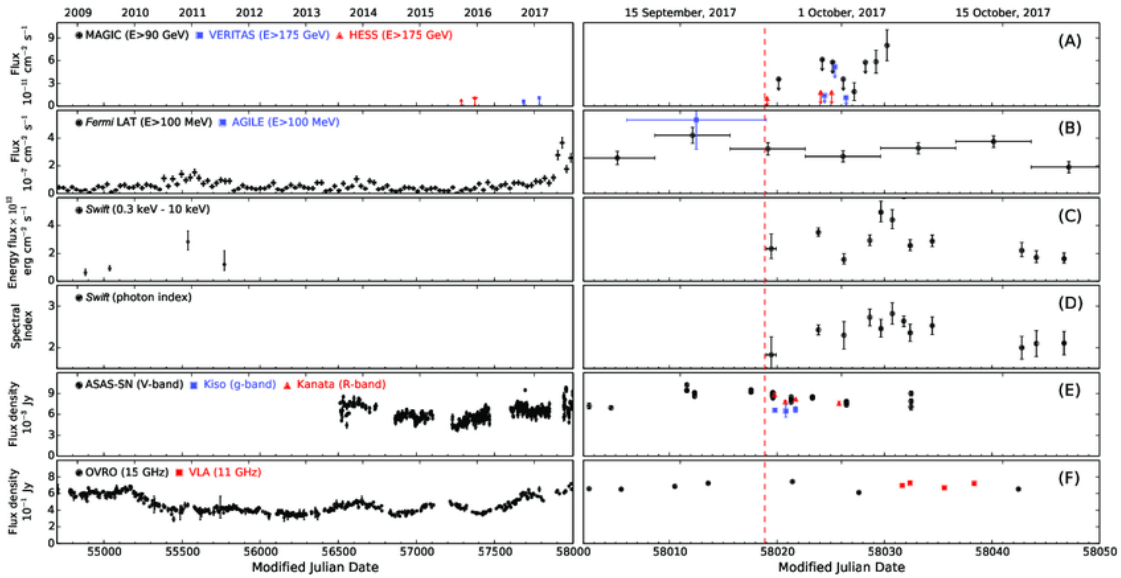
Dark matter

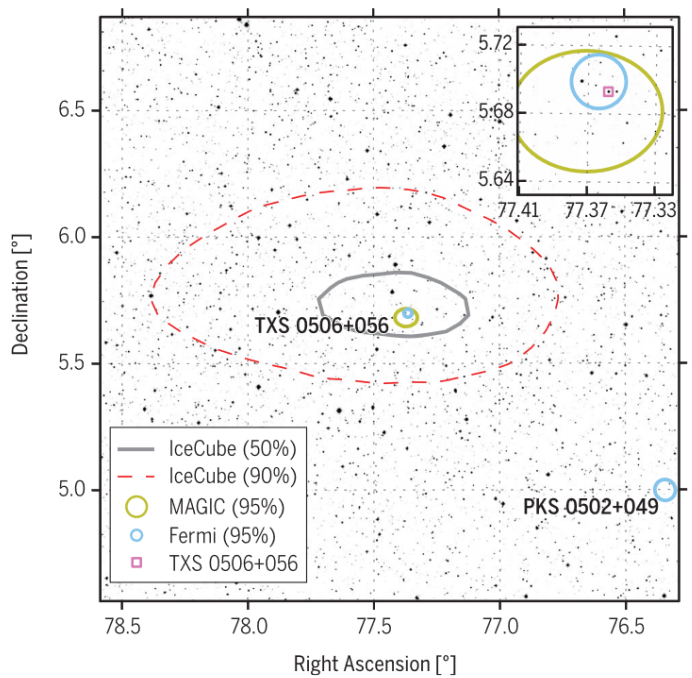
- Crucial role of *LHAASO*, *Tibet ASγ*, *CTA* for TeV dark matter particle candidates
- Fundamental need to cover the *MeV gap* with a future instrument to probe uncharted part of the parameter space
- Synergy with *future optical surveys* (Vera Rubin Obs.) to constrain dark matter dynamical properties and distribution
- New exciting avenues for dark matter searches with *compact objects* and *gravitational waves*

Multimessengers and time-domain astrophysics

IC170922A & TXS 0506+056

- First evidence of the production of very high energy neutrinos in the jet of an AGN

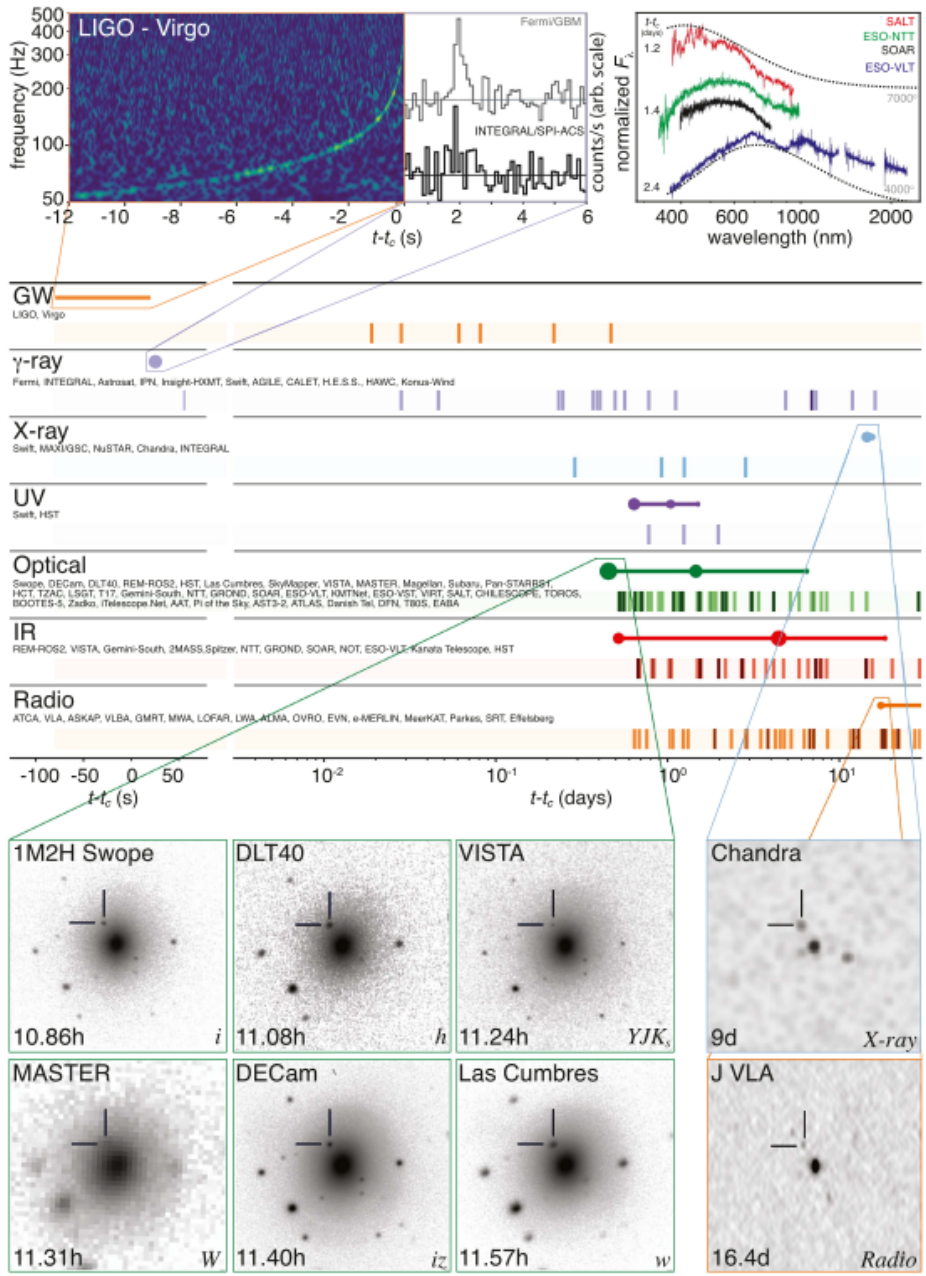




Multi-messenger and time-domain astrophysics

GW170817 & Co

- Binary neutron stars merger
- Short GRB
- GRB afterglow
- Kilonova
- Nucleosynthesis
- Fundamental tests from GW-GRB time delay



Multi-messenger and time-domain astrophysics

The diversity of extreme phenomena must now be explored through various wavelength and messengers to directly constrain physical parameters with an unprecedented precision.

- Physics of mergers
- Massive black hole binaries?
  - Accretion disk and MBHB environment
  - LISA + SKA, Athena, LSST and ELT
- Understanding the explosion mechanism in core collapse supernovae
  - GW emission
  - Detailed light curves for all flavours of low-energy neutrinos
  - Modeling and simulations
- Monitor explosive nucleosynthesis
  - Nuclear gamma-ray lines

Multi-messenger and time-domain astrophysics

For multi-messenger astrophysics to successfully provide a complete understanding of explosive phenomena, it is necessary to produce, distribute, and respond to real-time alerts

- Require rapid scanning to find counterpart and deep follow-up observations of its evolution
- Sky monitoring in hard X-rays is a fundamental element
  - SVOM will yield positions and temporal/spectral parameters on very short time scales
- LSST and SKA will produce thousands of alerts per day
  - Heavy realtime processing to distribute alerts for specific transients to follow-up facilities

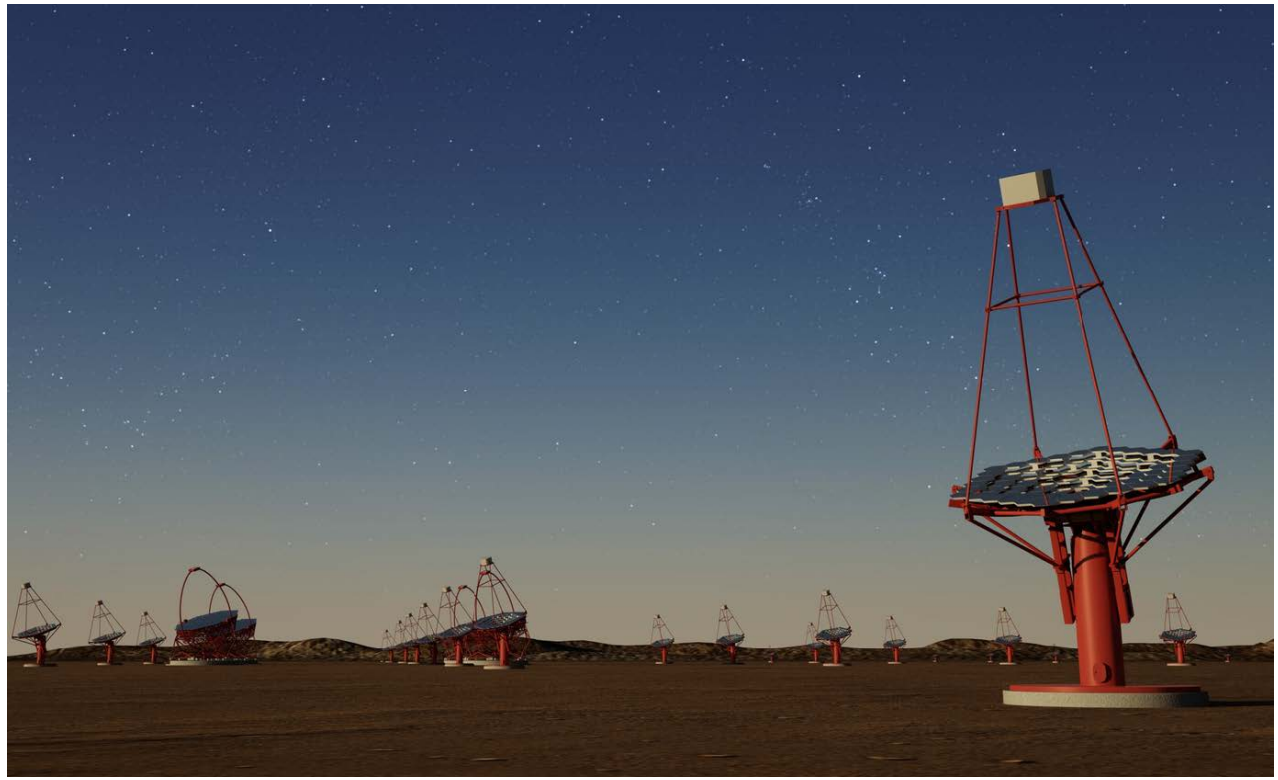
Projects

Project/Activity	GW tools	HE messengers	MM & extreme pheno.
Planned/Confirmed			
CTA		✓	✓
Advanced Virgo +	✓		✓
ET	✓		✓
LISA	✓		✓
KM3NeT/ARCA		✓	✓
AugerPrime		✓	✓
SVOM			✓
ATHENA			✓
SUPERK DUNE JUNO			✓
LSST			✓
Proposed/under study			
ASTROMEV			✓
EUSO-POEMMA		✓	✓
GRAND		✓	✓

Projects

CTA

Project/Activity	GW tools	HE messengers	MM & extreme pheno.
Planned/Confirmed			
CTA		✓	✓
Advanced Virgo +	✓		✓
ET	✓		✓
LISA	✓		✓
KM3NeT/ARCA		✓	✓
AugerPrime		✓	✓
SVOM			✓
ATHENA			✓
SUPERK DUNE JUNO			✓
LSST			✓
Proposed/under study			
ASTROMEV			✓
EUSO-POEMMA		✓	✓
GRAND		✓	✓

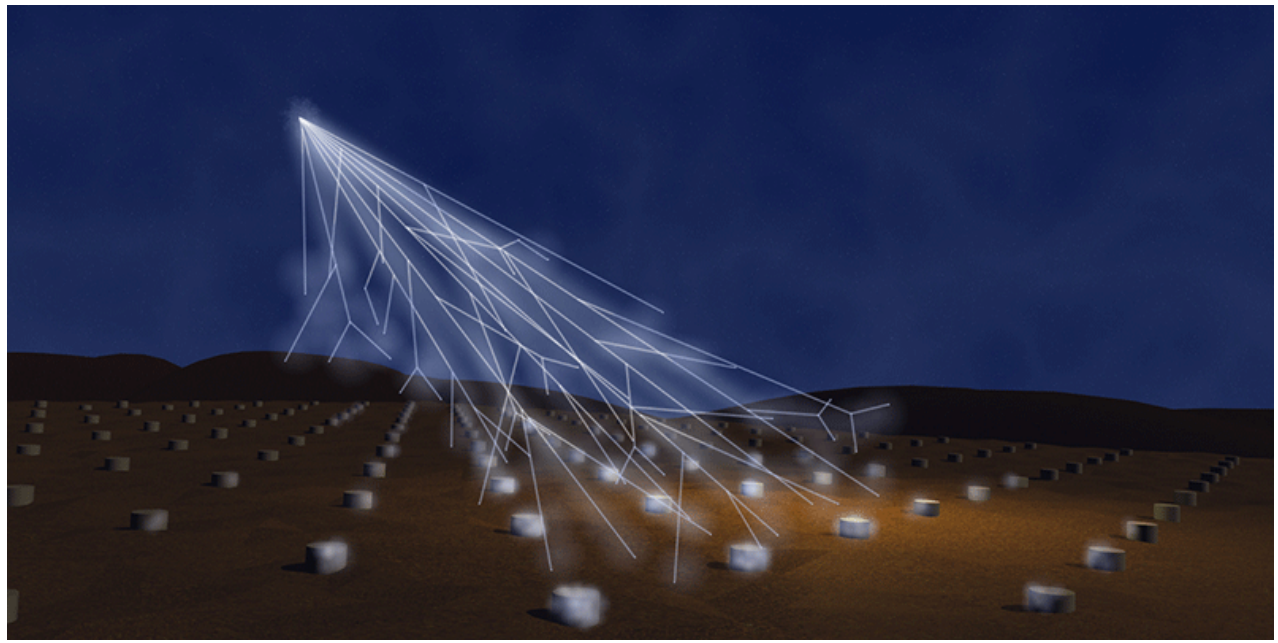


- Sensitivity and energy range
- Field of view and angular resolution
- 2 sites for Northern and Southern skies
- Slewing time

Projects

AugerPrime

Project/Activity	GW tools	HE messengers	MM & extreme pheno.
Planned/Confirmed			
CTA		✓	✓
Advanced Virgo +	✓		✓
ET	✓		✓
LISA	✓		✓
KM3NeT/ARCA		✓	✓
AugerPrime		✓	✓
SVOM			✓
ATHENA			✓
SUPERK DUNE JUNO			✓
LSST			✓
Proposed/under study			
ASTROMEV			✓
EUSO-POEMMA		✓	✓
GRAND		✓	✓

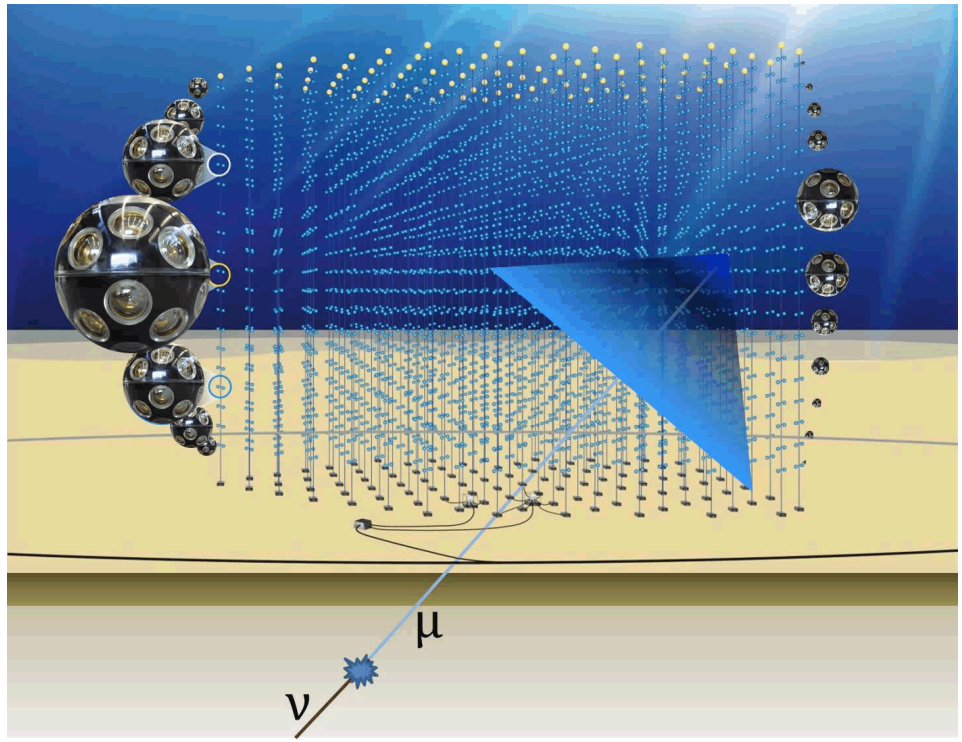


- Elucidate mass composition and the origin of flux suppression
- Search for a flux contribution of protons up to the highest energies
- Study extensive air showers and hadronic multiparticle production

Projects

KM3NeT

Project/Activity	GW tools	HE messengers	MM & extreme pheno.
Planned/Confirmed			
CTA		✓	✓
Advanced Virgo +	✓		✓
ET	✓		✓
LISA	✓		✓
KM3NeT/ARCA		✓	✓
AugerPrime		✓	✓
SVOM			✓
ATHENA			✓
SUPERK DUNE JUNO			✓
LSST			✓
Proposed/under study			
ASTROMEV			✓
EUSO-POEMMA		✓	✓
GRAND		✓	✓

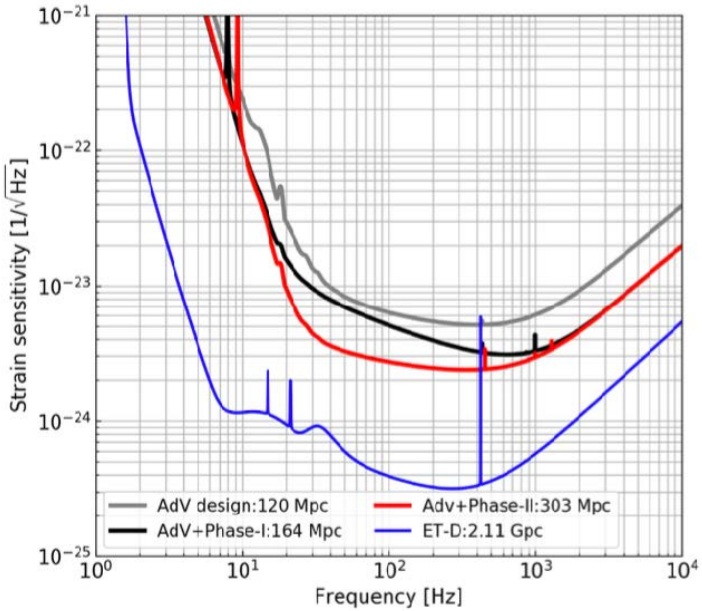


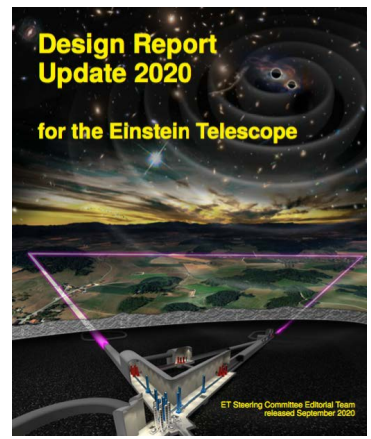
- KM3NeT/ORCA detecting low energy transient neutrino signals
- KM3NeT/ARCA detecting sources and measuring the VHE neutrino diffuse emission
- Large volume, superior angular resolution and view of the Galactic plane

Projects

Virgo - Einstein Telescope

Project/Activity	GW tools	HE messengers	MM & extreme pheno.
Planned/Confirmed			
CTA		✓	✓
Advanced Virgo +	✓		✓
ET	✓		✓
LISA	✓		✓
KM3NeT/ARCA		✓	✓
AugerPrime		✓	✓
SVOM			✓
ATHENA			✓
SUPERK DUNE JUNO			✓
LSST			✓
Proposed/under study			
ASTROMEV			✓
EUSO-POEMMA		✓	✓
GRAND		✓	✓



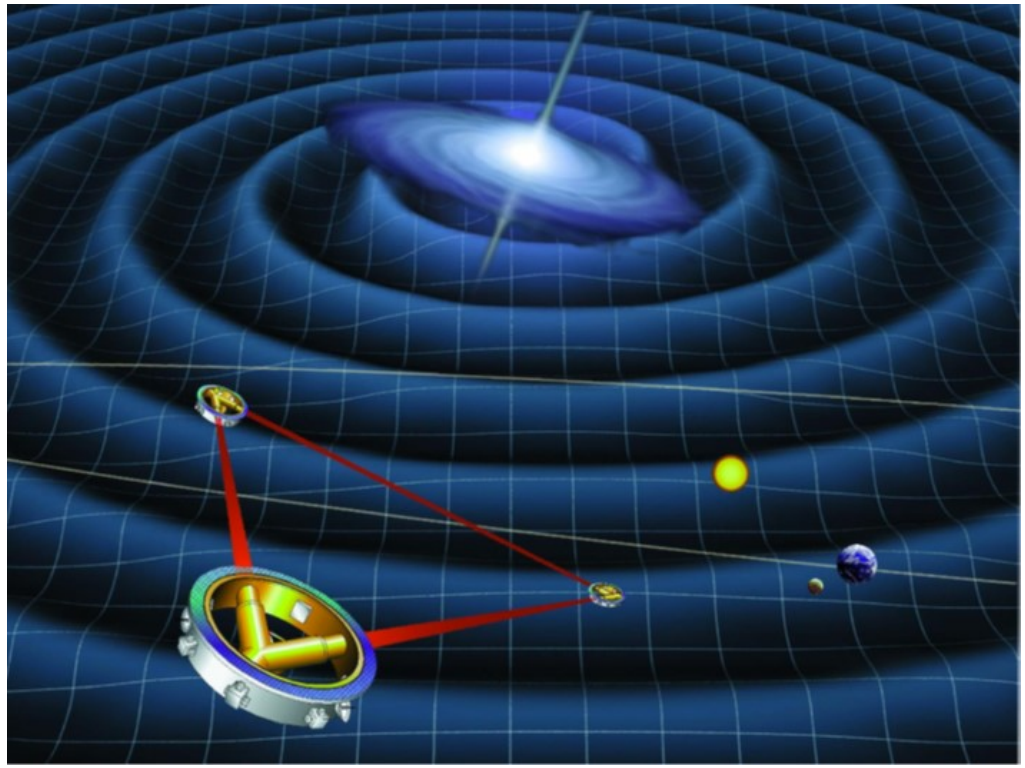


- Keep improving Virgo sensitivity within current infrastructure
- Build new infrastructure for next generation Einstein Telescope

Projects

LISA

Project/Activity	GW tools	HE messengers	MM & extreme pheno.
Planned/Confirmed			
CTA		✓	✓
Advanced Virgo +	✓		✓
ET	✓		✓
LISA	✓		✓
KM3NeT/ARCA		✓	✓
AugerPrime		✓	✓
SVOM			✓
ATHENA			✓
SUPERK DUNE JUNO			✓
LSST			✓
Proposed/under study			
ASTROMEV			✓
EUSO-POEMMA		✓	✓
GRAND		✓	✓

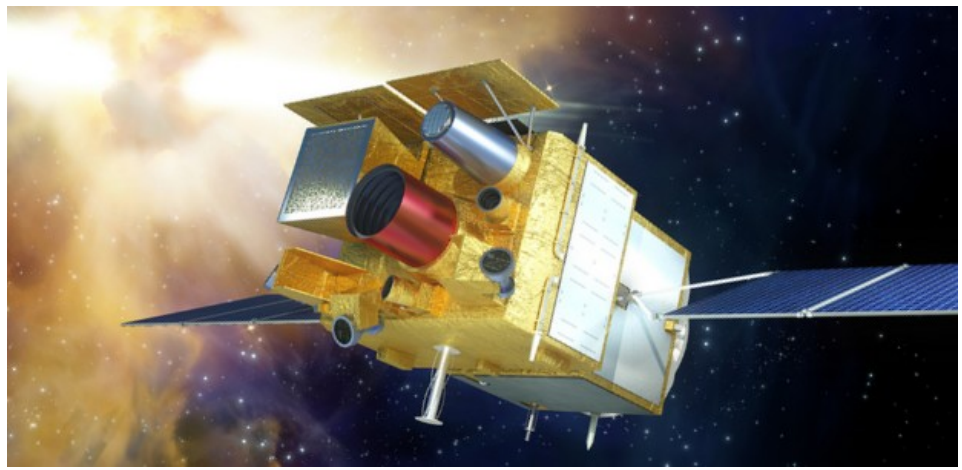


- Space observatory opening 0.1 mHz - 1 Hz frequency band
- Mission selected by ESA following LISA Pathfinder success

Projects

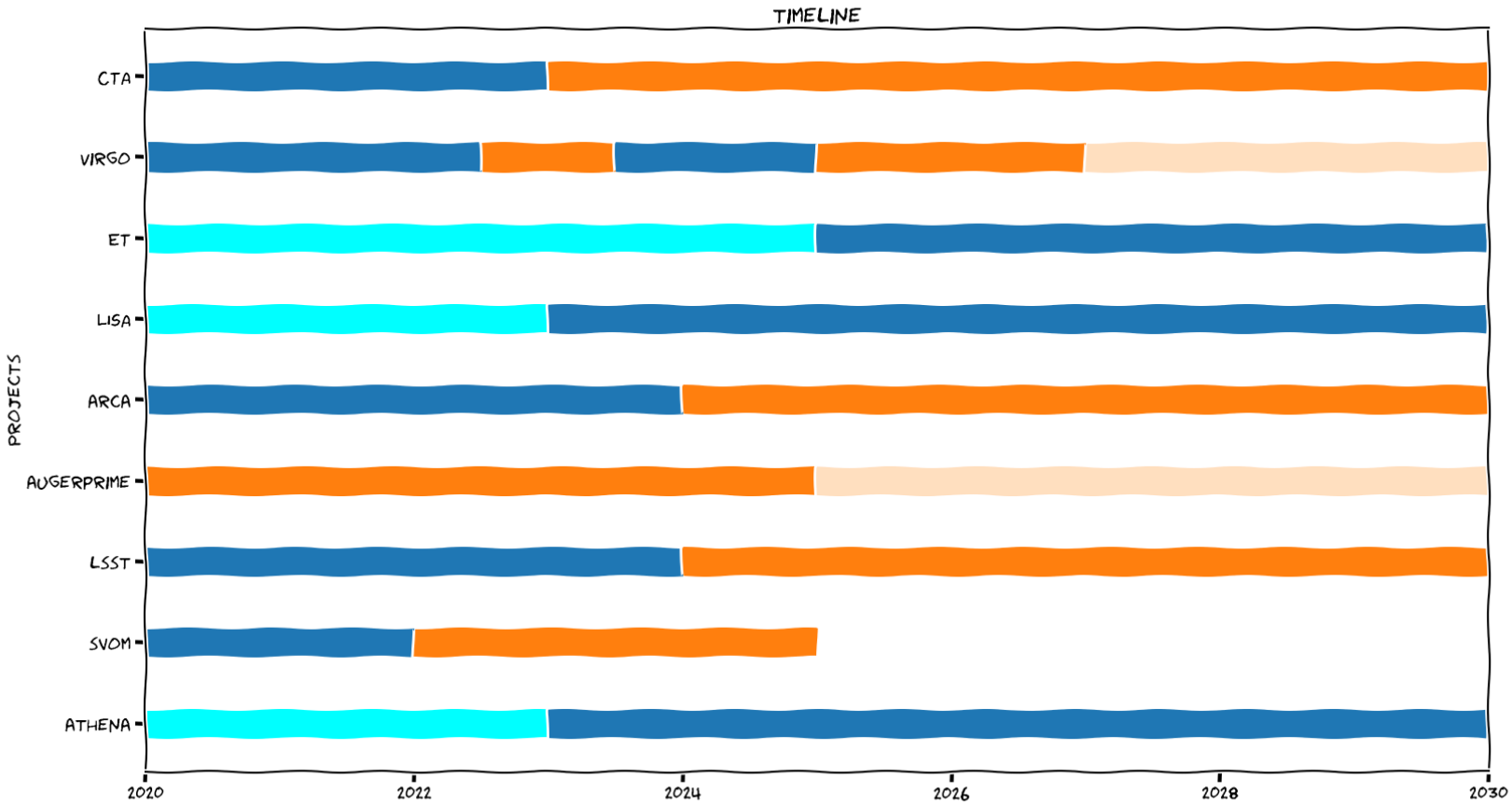
SVOM

Project/Activity	GW tools	HE messengers	MM & extreme pheno.
Planned/Confirmed			
CTA		✓	✓
Advanced Virgo +	✓		✓
ET	✓		✓
LISA	✓		✓
KM3NeT/ARCA		✓	✓
AugerPrime		✓	✓
SVOM			✓
ATHENA			✓
SUPERK DUNE JUNO			✓
LSST			✓
Proposed/under study			
ASTROMEV			✓
EUSO-POEMMA		✓	✓
GRAND		✓	✓



- Wide and narrow FoV instruments on-board to detect and localize GRBs
- Ground segment with wide angle optical camera for sky monitoring and 2 1-m telescopes for follow-up

Projects


TIMELINE
PROJECTS
CTA
VIRGO
ET
LISA
ARCA
AUGERPRIME
LSST
SVOM
ATHENA
2020
2022
2024
2026
2028
2030

Recommendations

As a conclusion, the committee defined five program-wide recommendations and five project-specific recommendations

Program-wide recommendations

- **Recommendation 1: Pursue a scientific program to address the three science drivers**

  France should support and develop theoretical and experimental research programs addressing the three science drivers in the coming decade. Since the drivers are intertwined they are not prioritized.

Program-wide recommendations

- **Recommendation 2: Support theoretical work as the underlying tool for interpretation and progress**

  A thriving theory program is essential for identifying new directions for the field, accompanying the current experimental program, and advancing knowledge of the universe and its fundamental laws.

Program-wide recommendations

- **Recommendation 3a: Develop French DM experimental and theoretical exchanges**

  Given the broad scientific and technical reach of DM studies, which transcends these perspectives GTs (direct DM studies also in GT06, DM studies through cosmological observations in GT05 or colliders in GT1), scientific exchanges on this major physics topic need improved structuration through e.g. recurrent meetings, collaboration projects, and a consistent training and hiring strategy.

Program-wide recommendations

- **Recommendation 3b: Develop exchanges among the French GW, cosmology and theoretical communities**

  Given the broad scientific and technical reach of these topics, which transcends these perspectives GTs (for example, the nature of the universe constituents and of the fundamental interactions are at the interface of GT01, GT02, GT04, GT05), scientific exchanges on this major physics topic need improved structuration through e.g. recurrent meetings, collaboration projects, and a consistent training and hiring strategy.

Program-wide recommendations

- **Recommendation 4: Raise up to the promises and challenges of time-domain multi-messenger astronomy**

  While this flourishing field shows outstanding promises, it also comes with challenges that need to be addressed in order to reap the expected scientific benefits. The first obvious requirement is to operate simultaneously various types of instruments. Characterizing transients also requires issuing and distributing timely alerts, developing tools to identify relevant alerts deserving follow-up observations and efficiently planning the latter, and bringing together transverse expertise for interpretation. Raising up to these challenges requires tight coordination within France and internationally.

Program-wide recommendations

- **Recommendation 5: Maintain a program of smaller contributions to projects relevant for multi-messenger and astroparticle physics strategies.**

  In recent years the French astroparticle physics program has invested substantially in the construction of large experimental facilities. A well-defined involvement in X-ray and MeV astronomy will provide a key synergy with these large astroparticle experiments. Advances in astroparticle physics also come from R&D for advanced detector and experimental techniques, which can provide opportunities for future projects.

Project-specific recommendations

The experimental program should include projects covering all the messengers needed to address the science drivers. The decade to come will be a time to reap the benefits from existing or soon to be available instruments, to work toward making planned experiments become a reality, and to pursue R&D to design and kick-start future projects.

Project-specific recommendations

- **Recommendation 6: Complete CTA as planned**

  The Cherenkov Telescope Array (CTA) is the world's major step forward in ground-based gamma-ray astrophysics and France is among the pioneers of the detection technique. French groups propose strong contributions to the projects which are supported across institutes and organizations since the broad science reach of CTA transcends fields.

Project-specific recommendations

- **Recommendation 7: Complete the Advanced Virgo + upgrade and support the Einstein Telescope initiative**

  Within the next 5 to 10 years, GW science will be done with the current or soon to be available infrastructures. It is therefore essential to push the sensitivity of Virgo to the limit permitted by its infrastructure, through and beyond the Advanced Virgo + upgrade. This will allow to bridge the gap, scientifically and technically, to the next generation of ground-based instruments, of which the Einstein Telescope is the most advanced project. France is among the pioneers of this experimental field and French groups propose strong contributions to ET, which should be supported across institutes and organizations as its broad science reach transcends fields.

Project-specific recommendations

- **Recommendation 8: Support the development of LISA**

  The impressive results of the LISA-Pathfinder satellite have opened the way for space-based laser interferometry to detect GWs. France is one of the leading countries in the LISA mission, and must continue to support a significant contribution to it, to maintain and enforce its leadership in LISA's technology development, data processing and science. France must sustain and strengthen the synergies coming from the complementarity with the future ground-based interferometers.

Project-specific recommendations

- **Recommendation 9: Complete KM3NeT/ARCA as planned**

  The physics case for the ARCA astrophysical neutrino detection array of KM3NeT has been reinforced by the 3-sigma detection in 2017 by the IceCube experiment of a gamma-ray blazar in 2017. Since ARCA observes a different part of the sky it will be perfectly complementary to IceCube.

Project-specific recommendations

- **Recommendation 10: Complete the AugerPrime upgrade and define a path forward in UHECR physics**
  Complete the AugerPrime upgrade, and study the composition and muon content of showers at UHE. The scientific return should be kept at the height of the investments made. Maintain multimessenger capacity with UHECR experiments. Develop a strategy for future opportunities for a ground- or space-based UHECR physics experiment.

- Scientific Advisory Committee – Mid term review
- Town meeting Berlin 9-10 Juin 2022
  - Mise à jour de la feuille de route

EuCAPT White Paper: Opportunities and Challenges for Theoretical Astroparticle Physics in the Next Decade

arXiv211010074A

- Workshop Low-latency alerts & Data analysis for MMA, Paris, Jan 13-14 2022
  - https://indico.in2p3.fr/event/25290