Questions for APPEC SAC members

Submitted June 2024

Version with merged answers received.
Discussed at SAC meeting July 1st

The purpose of the following questions is to start collecting information to structure the work toward the new roadmap.

For now, we should work in subgroups and elaborate on the following questions based on the assignments proposed by the GA, as reported in the table enclosed. This could change after we analyse the results of this survey.
We should also allow the possibility that members of the SAC be associated to more than one topic on the basis of the expertise and willingness to contribute to the overall task.
In addition, theorists may contribute to one or more topics.

Cosmic rays	**High energy photons**	**Ultra-high energy neutrinos**	**GW**	**Neutrino properties**	**Dark Matter**	**Dark Energy**	**Cosmology CMB**	**Theory**
Ioana Maris	Mathieu de Naurois	Anna Nelles	Edwinge Tournefier	Christian Weinheimer	Aldo Ianni	Stéphanie Escoffier	Sotiris Loucatos	Joachim Kopp
Sijbrand de Jong	Paula Chadwick	Chad Finley	Marica Branchesi	Concha González-García	Marcon Kuzniak	Ofer Lahav	New one	Fedor Simkovich
		New one		Oliviero Cremonesi				Irene Tamborra

Questions.

1. *With reference to page 11 of the Roadmap, is there any question you would like to address differently or modify? Is there any question missing? Are there questions that have become less relevant or obsolete? Please motivate any suggested changes.*

    - I would change the question about GWs to "What do gravitational waves tell us about General Relativity, cosmology, **astroparticle, and particle physics**?" **What will gravitational waves teach us?**
    - In addition, one may argue whether the question about proton decay (do protons decay?) – albeit very interesting in my opinion – is a bit off topic, as it is a pure particle physics question without much of an "astro" component. (Except that the detectors are also the same.)
      Baryon-lepton symmetry framework; frame it within particle physics (neutrinos, …)

What is the synergy between astroparticle physics and other fields of fundamental physics ???

- **May be we can add "and beyond the standard model physics" to the gravitational wave question (previous to last) because there is quite some effort on that direction from the theorist**
- The questions are introduced as being "long-standing enigmas of fundamental physics and astronomy" but some of the questions are in reality not "enigmas" but more open questions, in particular:
  - 1-"Can we identify the sources of high energy neutrinos?"
  - 2-"What do GW tell us about General relativity and cosmology?"
  - 3-"What will multi-messenger astronomy teach us?"
  - To be more consistent and really address enigmas or fundamental questions, I would suggest to replace 1- with:
    "What are the different sources of high energy neutrinos and their relative contributions?" (it is just a re-phrasing)
    What are the different sources of high-energy neutrinos?
    And 2+3 with questions like:
    ~~"Is General relativity a correct theory of gravitation~~?"
    What are the limitations of the current theory of gravitation ?
    "**What is the physics of ultra dense matter** (e.g. neutron stars, black holes)?"
    "**What did the Universe look like in its earliest phases?**"
    "Do we understand structures and stellar formation and their evolution?"
- I have the same comment on the box of page 9 which mixes fundamental questions and tools to answer the questions. I would not mix the two: we have fundamental questions and these can be answered with dedicated tools which may evolve. One could start with the questions and then elaborate on the tools which are/will be used to answer them.

2. *With reference to the text preceding the recommendations, are there elements that should be considered for updating (dates, names, numbers, etc.)? If yes, motivate.*

- **I do not see anywhere any reference to the efforts to clarify if there are more than 3 neutrino states.**
  Heavy neutral fermions
- It is a minor thing, but concerning Virgo, we should mention the two upgrades: Advanced Virgo+ (planned to start mid-2027) and VirgoNeXT (only VirgoNeXT is mentioned in the present text). LIGO, KAGRA to be included, to be discussed.
- A relevant news is that LISA has been officially approved by ESA (Jan 2024) with a launching date planned for 2035.
- Concerning the recommendations for gravitational waves, I would revert the order: start with Virgo upgrades, then building the bridge between Virgo and ET and then support to ET.

The following updates and points to discuss are with respect to the longer text we prepared for the 2022 APPEC Town Meeting and from which we extract the shorter version of the mid-term roadmap

- Update the LIGO, Virgo, KAGRA O4 results. Virgo observing → stress the importance of the network
- **Define the bridge from current detectors up to the next generation**
- ET large collaboration, involvement of diverse communities (now **1600 members**). Site selection and design (triangle vs 2L, science, risk and risk mitigation). Avoid tension for the best selection of the optimal site (science vs political decisions). International scenarios, development for CE – report of the Next Generation Gravitational Wave Observatory Subcommittee.
- **LISA adopted by ESA**. Importance of the scientific and data analysis synergies with ground-based detectors.
- **Support theoretical effort** on waveform development to exploit the precision obtainable by ET and LISA and innovative data analysis techniques to exploit low-frequencies and deal with overlapping signals.
- Include discussion on CMB probing GW produced during inflation period

3. *Is there any emerging project/technology, ongoing R&D, or effort in theory of your knowledge that you would like to point out as important for the next roadmap?*

- At the methodological level, we should discuss to what extent machine learning, artificial intelligence, and potentially quantum computing should be mentioned. Some of these have already become standard tools of the trade, others may play that role in the not too distant future.
- **I think there is a lot of activity in new interactions of neutrinos in the framework of low mass mediators which is not mentioned. There is also an effort in clarification of SBL anomalies with a whole SBN program at fermilab and dedicated reactor experiments which I did not see mentioned in the roadmap.**
  Neutrino-nucleus interactions within particle physics
  Separate particle physics properties of neutrinos
- For gravitational waves detectors, an important effort needs to be made to obtain very high quality mirror substrates and coatings.
- In the past roadmap, PTA was not included in roadmap considering it an astronomy topic. Do we still consider it outside APPEC? Synergies with other GW detectors? It is mentioned in page 19 Pulsar Timing Array will open a window to observations …
- DeciHz band science and moon detectors, rapid increase of interests due to the run to the Moon and Mars (developed also in synergy with EM moon detectors), ESA selection of sound-checks for LGWA. Is it time to add it? Timeline?
- It is worth to emphasize the convergence and coordination of instrumentation R&D efforts by CERN-affiliated DRD collaborations. Most large next generation experiments require new technologies which do not exist yet, however the

roadmap to developing them has been defined, and groups interested in doing the work are identified. While this is in place for dark matter and neutrino experiments (DRD1 and DRD2), it may be less so for other fields (?).

- Particularly critical for the next generation cryogenic searches is the development of scalable, radiopure, digitally read-out and highly efficient photonsensors, which is well covered by DRD2 and DRD4 collaborations.

- At low WIMP-masses R&D on understanding and limiting the so-called "low-energy excess" is absolutely critical. Notably, the community has started to join forces to address these issues.

Original text from the mid-term update is pasted below, with new content in blue.

- The nature of Dark Matter (DM) is one of the most important questions of contemporary physics. The current generation liquid xenon (LXe) direct Dark Matter detection experiments, PandaX-4T, XENONnT, and LZ, came online in 2020-2022, with active target masses of 4-7 tonnes and projected cross-section sensitivities of the latter two of 10^{-48} cm² scale at 30 GeV DM mass (with 10^{-47} cm² reached already). The XENON, LZ and DARWIN collaborations joined forces in 2021, forming the XLZD consortium, aiming to build and operate a liquid xenon 40-60 tonne detector with a projected reach beyond 10^{-48} cm² in the next decade, while in China a >30 tonne PandaX-xT detector is proposed. The liquid argon (LAr) detector community has joined in the Global Argon Dark Matter Collaboration in 2017 to build DarkSide-20k, currently planned to start operation in 2026~~7~~, with 50 tonnes active target and an expected reach of $2x10^{-48}$ cm² scale at 100 GeV. GADMC ultimately plans a 300 tonne fiducial mass Argo detector to be constructed in the next decade, with the high-mass WIMP sensitivity at the level of the neutrino fog, with R&D already in progress.
  At 5 GeV DarkSide-50 has reached a limit of $1x10^{-43}$ cm², and demonstrated the ability to search for dark matter with masses down to the 50 MeV scale. Moving forward, DarkSide-20k aims to improve the limit at 5 GeV by an order of magnitude, with a further factor of 10 improvement within reach of a potential dedicated tonne-scale detector optimized for low-mass WIMP searches. Experimental confirmation of the Migdal effect, pursued by multiple groups, and likely to be resolved within the next several years, will boost the sensitivity of multiple detection techniques in the low-mass regime.
  At masses below 1 GeV, cryogenic solid-state experiments, e.g., SuperCDMS and CRESST, as well as skipper CCDs, e.g., SENSEI and DAMIC-M, expect to achieve a 10^{-42} cm² cross-section reach on a 5-year time scale.
  Very significant efforts invested over the past decade into independent cross-check of the DAMA/LIBRA signal claim have begun to bring fruits, as COSINE-100, ANAIS-112 and the future SABRE and COSINUS detectors, which all use a similar detection medium to DAMA/LIBRA are approaching decisive sensitivities; ANAIS-112 expects to reach 5σ sensitivity by the end of 2025.
  Expanding the accessible mass range has created new connections between astroparticle physics and quantum sensor technology, which led to new funding initiatives in Europe and elsewhere. Given the broad parameter space for Dark Matter candidates, a diverse experimental approach remains essential, including R&D in directional detection and new technologies, e.g., based on quantum sensors.

4. *With reference to the above table, do you think the division into the indicated categories is satisfactory for the work toward the new roadmap, or would you like to propose changes? Please report a brief motivation, including the possibility that you could cover more than one topic.*

- highly appreciated the fact that Theory is listed as a separate topic. This is crucial to highlight its importance and to send the message that theory is worth funding for its own sake, not only insofar as it immediately benefits a particular experimental program. But of course much of what theoretical astroparticle physicists do is done in close contact with experiment. So I feel that every topic in the roadmap should have an experimental and a theoretical component; the pure theory section would then be reserved for somewhat more formal developments (model building beyond the SM, theoretical cosmology, inflation, …) Discuss how to display this point in table of topics
- **SAC "neutrino properties": there is of course a clear overlap with High-energy neutrinos and with Cosmology/CMB since those are also used to study neutrino properties.**
- I think important to add multi-messenger and probes, it is transversal to many of the above categories, but it should be treated as an additional category. It requires to discuss electromagnetic observatories that enable to maximally exploit astroparticle observations, optimization of observational strategies and operations, alerts infrastructure and format, data access. New topic Multi-messenger, multi-wavelength and time domain

SOME POINTS for the MM

Some updates and points to discuss relative to MM

- Very Interesting results on X-ray transients by Einstein Probe, SVOM launched, wide-FoV UV status

- Swift and Fermi, Chandra and XMM in the long term we could have a hole of high-energy satellites. New-Athena status and THESEUS selected for Phase-A to be launched in ~2037. Heritage of Europe lost? Role of CubeSat.

MeV-GeV satellites? ASTROGAM-AMEGO (LAT)

- ESO after ELT: WST?

- Rubin Observatory-LSST will dictate format and standard for transients, brokers, Fair principle, info distribution… Tight link with this community to bring attention an d include astroparticle observatories peculiarities.
- Data policy: open vs proprietary, FAIR principle, what is the right compromise. Particularly important for transient science

- How to stimulate the best use of all the information from current observatories such as JWST and Euclid? Synergies astroparticle-astronomy

- European projects: synergy among astroparticle/astronomy, some example ESCAPE, AHAED2020. New project ACME → this project shows some issues…totally based on TNA/VA while some astroparticle communities need (to really arrive to concretely give TNA/VA) JRA. The project is showing the difference among the level of readiness of different communities (see radio vs neutrino/GW communities). Some differences can be resolved but there are differences that will remain so in the future. Discuss the needs of the astroparticle communities.

Agreed timeline for roadmap exploitation

	2024						2025												2026											
	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
SAC activity	SM		QO SM		QC	SM																								
					KFM preparation								Roadmap preparation												Roadmap finalization					
EU community												KFM												TM						

SM = SAC meeting
QO = questionnaire out
QC = questionnaire closing
KFM = kick-off meeting
TM = Town meeting (Berlin ?)

Proposal for *main questions* APPEC is aiming to answer in the framework of next roadmap (modification of list at pag 11 mid-term roadmap)

- What is dark matter?
- What is dark energy?
- What will gravitational waves teach us?
- What are the limitations of the current theory of gravitation?
- What will multi-messenger astronomy teach us?
- What are the different sources of high-energy neutrinos?
- What did the Universe look like in its earliest phases?
- What is the origin of cosmic rays?
- What is the physics of ultra dense matter?
- What caused our Universe to become dominated by matter and not anti-matter?
- Do we understand structures and stellar formation and their evolution?

Homework (to be completed by our next meeting)

- Finalize new list of main questions
- Elaborate a better way to display connections between scientific topics, experiment and theory in the SAC assignments table