Brussels, 13 November 2018

COST 089/18

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "Quantum gravity phenomenology in the multi-messenger approach" (QG-MM) CA18108**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action Quantum gravity phenomenology in the multi-messenger approach approved by the Committee of Senior Officials through written procedure on 13 November 2018.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA18108
QUANTUM GRAVITY PHENOMENOLOGY IN THE MULTI-MESSENGER APPROACH (QG-MM)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. “Rules for Participation in and Implementation of COST Activities” (COST 132/14 REV2);
b. “COST Action Proposal Submission, Evaluation, Selection and Approval” (COST 133/14 REV);
c. “COST Action Management, Monitoring and Final Assessment” (COST 134/14 REV2);
d. “COST International Cooperation and Specific Organisations Participation” (COST 135/14 REV).

The main aim and objective of the Action is to investigate possible signatures predicted by quantum gravity models in the observation of different cosmic messengers, by creating the conditions for a close collaboration between theorists and the various experimental communities involved in the detection of such cosmic messengers. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 56 million in 2018.

The MoU will enter into force once at least seven (7) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14 REV2.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14 REV2.

TECHNICAL ANNEX

OVERVIEW

Summary

The exploration of the Universe has recently entered a new era thanks to the multi-messenger paradigm. The detection of cosmic particles (photons, neutrinos, cosmic rays), now joined by the birth of gravitational wave astronomy, gives us information about the different sources in the Universe and the properties of the intergalactic medium. In particular, the most energetic events allow us to test our physical theories at energy regimes which are not directly accessible in accelerators. This is in fact the target of quantum gravity phenomenology, a quite recent field of physics that tries to set phenomenological models that may incorporate some of the effects of the Planck scale, thus providing a bottom-up approach to the largely studied quantum gravity problem.

The main objective of the proposed COST Action is to gather theoretical and experimental working groups from the relevant communities (with proper geographical, age and gender balance) to work in the prediction and possibility of detection of physical phenomena characteristic from quantum gravity theories. This cooperation is necessary to address this challenge properly, which may result in extraordinary advancements in fundamental physics. A second objective will be the formation of a generation of scientists that will be competent in the interdisciplinary expertise that is needed in the effective search of quantum gravity footprints in the production, propagation and detection of these cosmic messengers. Whatever the outcomes of this search may be, it will certainly have an important impact on science through a better understanding of the Universe and its fundamental laws.

Areas of Expertise Relevant for the Action	Keywords
● Physical Sciences: High energy and particles astronomy, X-rays, cosmic rays, gamma rays, neutrinos ● Physical Sciences: Particle physics (theory) ● Physical Sciences: Fundamental interactions and fields (theory)	● Lorentz invariance violation and deformation ● gamma-ray astronomy ● cosmic neutrinos ● ultra-high-energy cosmic rays ● gravitational waves

Specific Objectives

To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination

● To publish an updated state-of-the-art of the research on quantum gravity phenomenology, both by clarifying the possible scenarios and signatures coming from different theoretical frameworks, and by examining the reported constraints on such signals and the inherent limitations of existent analyses of experimental data for each type of cosmic messenger.

● To clarify some apparent contradictions obtained in different analyses of experimental data produced by different messengers, by comparing methods of analysis and theoretical hypothesis used in those studies and by producing complementary analyses with new methods and/or data.

● To systematically derive constraints for the different theoretical models from the experimental results coming from the different messengers, and to combine these constraints into a consistent picture (e.g., comparison of constraints in the presence of Lorentz invariance violation or deformed special relativity scenarios).

● To study further and attempt to resolve open theoretical issues associated with the prediction of modified dispersion relations for material probes that might characterise some but not all models of quantum gravity.

● To investigate the possible role of quantum gravity effects on: anomalies in the transparency of the Universe with respect to the propagation of high-energy gamma rays, the apparent ending of the cosmic neutrino spectrum, the production and propagation of ultra-high energy cosmic rays, and possible anomalies in gravitational wave propagation.

● To develop new strategies and optimize existing ones for performing studies of quantum-gravity effects in the different cosmic messengers, both separately and in combination in the framework of a real multi-messenger astronomy.

● To investigate how genuine effects due to quantum gravity could be disentangled from the intrinsic physical properties of the cosmic accelerators, and how the currently limited knowledge about their physical properties affect our ability to confirm or falsify quantum gravity models.

● To convert the efforts of separated research groups in a common, well-defined, research strategy.

Capacity Building

● To stimulate the development of the field of quantum gravity phenomenology by promoting the interaction and knowledge exchange between the different communities participating to the COST Action; in particular, between experimental and theoretical groups.

● To join the experimental communities working with different cosmic messengers (gamma rays, neutrinos, cosmic rays and gravitational waves) in order to promote combined analyses and a multi-messenger approach to the phenomenology of quantum gravity.

● To foster the future development of this field by training a generation of young scientists in the necessary combined expertise on quantum gravity theories and models, and in experimental and theoretical approaches to astroparticle physics.

● To strengthen the field of quantum gravity phenomenology by supporting and providing opportunities for recognition and visibility to Early Career Investigators, to researchers from COST Inclusiveness Target Countries and researchers from the underrepresented gender in the field, for instance by assigning leadership positions to them.

● To disseminate the results to the general public, school pupils, university students, and in particular, young women that could pursue a scientific career, as well as to scientists from other disciplines, including physicists working in other fields.

TECHNICAL ANNEX

1. S&T EXCELLENCE

1.1. CHALLENGE

The main aim and objective of the Action is to investigate possible signatures predicted by quantum gravity models in the observation of different cosmic messengers, by creating the conditions for a close collaboration between theorists and the various experimental communities involved in the detection of such cosmic messengers.

1.1.1. DESCRIPTION OF THE CHALLENGE (MAIN AIM)

One of the main fundamental open problems in physics is the quest for a quantum theory of gravity. This theory will presumably bring a revolutionary view on basic concepts such as the notion of spacetime, particles and fields, or modifications in the basic principles of quantum mechanics (like, for example, generalized uncertainty relations) and the laws of Nature.

Such a research program has followed mainly a theoretical path along several decades, resulting in a number of candidates for a theory of quantum gravity (QG; see list of acronyms at the final of this document), but without any experimental clue that would help in selecting a preferred alternative, and with the belief indeed that such experimental indications (being controlled by the Planck scale) would be hopelessly beyond reach in short and long-term prospects.

Since the beginning of the century, however, it has progressively emerged the possibility to explore a phenomenology of quantum gravity, mainly because of two reasons: the realization that tiny effects in the propagation of very high energy particles could be amplified by cosmological distances and produce observable consequences, and the continuously increasing quantity of experimental data from cosmic messengers that has become available in recent times.

Quantum gravity phenomenology is therefore a new field of basic research that involves different communities of physicists (both theoretical and experimental) whose cooperation will be essential to achieve the challenge of obtaining phenomenological indications of Planckian effects. To respond to such a challenge, the Action will promote this cooperation and the training of a generation of European scientists in the necessary combined expertise on quantum gravity theories and models, and in experimental and theoretical approaches to astroparticle physics.

1.1.2. RELEVANCE AND TIMELINESS

The challenge of identifying phenomenological indications of Planckian effects in astroparticle physics has not only relevance in the enormous implications for fundamental physics (such as a high-energy modifications in special relativity, at the core of our basic theories of Nature, the role of locality of particle interactions, or the underlying structure of spacetime), for cosmology (the understanding of the singularities at the Big Bang or at the centre of black holes), or for the unexpected consequences that this knowledge may produce. It is also relevant because it involves the cooperation of a large community of physicists working in different fields. The challenge includes the identification of phenomenological consequences of different models and frameworks of quantum gravity (involving mainly quantum gravity theorists), and the appropriate analysis of the data obtained from the experimental communities of physicists working in the high energy range of gamma-ray astronomy, neutrino astronomy, and cosmic ray physics, together with gravitational wave interferometry, with the collaboration of theoretical astrophysicists working in specific models for the emission of such astroparticles.

It is very plausible that the sought quantum gravity phenomenological indications may be revealed after comparison of data coming from the different astrophysical messengers. An example would be the detection of neutrinos from the same source producing a gamma-ray burst (GRB). In fact, one has very recently witnessed (August 2017) a breakthrough in the "multi-messenger" paradigm with the combined detection of electromagnetic and gravitational wave emission from a binary neutron star merger. It is just a matter of time to study other astrophysical phenomena (such as GRB emissions) from the multi-messenger approach. Therefore, the timeliness of the Action is optimal: it is with the beginning of this multi-messenger era (which has been possible with the extraordinary development in the last years of the appropriate telescopes to detect these cosmic messengers) that the chances of fulfilling the above-mentioned challenge have largely increased. This is then the optimal moment to boost the efforts to ensure cooperation between these communities and prepare European scientists that will have the necessary skills to complete this challenge.

Another possible situation is one in which some signal emerges in one type of cosmic messenger and not in others. This would be a footprint of non-universality, a feature present in some quantum gravity models. Even the non-observation of certain effects may help in the construction of a quantum theory of gravity by discarding or favouring some models over others. For example, models which violate the Lorentz symmetry of spacetime have typically much larger effects on modifications of thresholds of reactions than models in which this symmetry is just deformed. Effects in the propagation of cosmic messengers are also different in case of a systematic or a stochastic violation of Lorentz invariance. In this respect, it will be crucial to clarify the situation with respect to the propagation of high-energy gamma rays and neutrinos, where some analyses claim finding a signal, in contradiction with previous works. In any case, to give a correct interpretation of the experimental results it will be needed to devise strategies to disentangle propagation from astrophysical source effects in the production of these cosmic messengers, and to clarify the predictions of different theoretical frameworks with respect to: the propagation of particles in a quantum spacetime, the possibility that quantum-gravity effects are governed by an effective scale different from the Planck scale, and other important properties (such as non-local effects). Such an exercise will also be of help to define the corresponding search strategies.

1.2. OBJECTIVES

The main objectives of the Action are: the coordination and combination of expertise of different European research groups belonging to (both theoretical and experimental) communities relevant to the identification of a signature of quantum gravity in the physics of cosmic messengers, and the training of young scientists in this specific field, which will require bringing together different disciplines in a transversal way, thus providing Europe with the necessary talent to ensure its leadership in the achievement of such a challenge.

1.2.1. RESEARCH COORDINATION OBJECTIVES

1. To publish an updated state-of-the-art of the research on quantum gravity phenomenology, both by clarifying the possible scenarios and signatures coming from different theoretical frameworks, and by examining the reported constraints on such signals and the inherent limitations of existent analyses of experimental data for each type of cosmic messenger.
2. To clarify some apparent contradictions obtained in different analyses of experimental data produced by different messengers, by comparing methods of analysis and theoretical hypothesis used in those studies and by producing complementary analyses with new methods and/or data.
3. To systematically derive constraints for the different theoretical models from the experimental results coming from the different messengers, and to combine these constraints into a consistent picture (e.g., comparison of constraints in the presence of Lorentz invariance violation or deformed special relativity scenarios).
4. To study further and attempt to resolve open theoretical issues associated with the prediction of modified dispersion relations for material probes that might characterise some but not all models of quantum gravity.
5. To investigate the possible role of quantum gravity effects on: anomalies in the transparency of the Universe with respect to the propagation of high-energy gamma rays, the apparent ending

of the cosmic neutrino spectrum, the production and propagation of ultra-high energy cosmic rays, and possible anomalies in gravitational wave propagation.
6. To develop new strategies and optimize existing ones for performing studies of quantum-gravity effects in the different cosmic messengers, both separately and in combination in the framework of a real multi-messenger astronomy.
7. To investigate how genuine effects due to quantum gravity could be disentangled from the intrinsic physical properties of the cosmic accelerators, and how the currently limited knowledge about their physical properties affect our ability to confirm or falsify quantum gravity models.
8. To convert the efforts of separated research groups in a common, well-defined, research strategy.

1.2.2. CAPACITY-BUILDING OBJECTIVES

1. To stimulate the development of the field of quantum gravity phenomenology by promoting the interaction and knowledge exchange between the different communities participating to the COST Action; in particular, between experimental and theoretical groups.
2. To join the experimental communities working with different cosmic messengers (gamma rays, neutrinos, cosmic rays and gravitational waves) in order to promote combined analyses and a multi-messenger approach to the phenomenology of quantum gravity.
3. To foster the future development of this field by training a generation of young scientists in the necessary combined expertise on quantum gravity theories and models, and in experimental and theoretical approaches to astroparticle physics.
4. To strengthen the field of quantum gravity phenomenology by supporting and providing opportunities for recognition and visibility to Early Career Investigators, to researchers from COST Inclusiveness Target Countries and researchers from the underrepresented gender in the field, for instance by assigning leadership positions to them.
5. To disseminate the results to the general public, school pupils, university students, and in particular, young women that could pursue a scientific career, as well as to scientists from other disciplines, including physicists working in other fields.

1.3. PROGRESS BEYOND THE STATE-OF-THE-ART AND INNOVATION POTENTIAL

1.3.1. DESCRIPTION OF THE STATE-OF-THE-ART

The initial efforts in testing quantum gravity originated some decades ago, with the issue of bounding effects of potentially induced decoherence of quantum matter propagating in the environment of microscopic (Planck-scale) space-time fluctuations, in the form of microscopic black holes. Violations of CPT invariance (the symmetry of physical laws under the simultaneous transformations of charge conjugation, parity transformation, and time reversal) could be one of the possible consequences of this quantum-gravity-induced decoherence [1] that could be observable in entangled particle states [2]. In this way, neutral mesons were among the first particle systems where such ideas were tried more than thirty years ago [3].

More recent efforts in quantum gravity phenomenology looked “at the stars” by extending the searches to cosmic ones. The first such efforts employed observations of light from distant intense celestial sources of cosmic light, such as gamma-ray bursters [4] and subsequently expanded to a plethora of other cosmic observations [5]. These searches motivated experimental tests of special relativity [6] and the development of different theoretical frameworks for Planck-scale modifications to special relativity. Most prominently, they include the Standard Model Extension (SME), which considers a violation of Lorentz invariance (LIV) in terms of an effective field theory [7], and Doubly Special Relativity (DSR) theories, which consider a deformation of the Poincaré symmetry while maintaining a relativity principle [8].

From the theory side, these two scenarios (a violation versus a deformation of the symmetries of special relativity) give different phenomenological predictions: while delays in the time of flight of massless particles can be a signature of both, other constraints, coming from modifications or appearance of thresholds of reactions, or birefringence constraints, do not apply in the same form [6]. A debate on the consistency of photon time of flight delays in DSR models [9] gave even rise to the concept of relative locality [10], which shows that the notion of spacetime is profoundly different in these two scenarios.

This also calls for a different interpretation of time of flight experiments in the DSR case, which is not yet completely clear at the moment [11].

From the experimental side, the situation is rather intriguing. In 2014 the IceCube collaboration reported [12] the first detection of cosmic neutrinos. This marked the beginning of extra-galactic neutrino astronomy, since isotropy and constraints in the diffuse galactic neutrino flux set by the ANTARES [13] and IceCube [14] detectors indicate that the bulk of these cosmic neutrinos are indeed of extra-galactic origin. However, the absence of neutrino events with energies close to the Glashow resonance [15] may be pointing to a cutoff in the neutrino spectrum that could be explained by LIV that makes high-energy neutrinos unstable [16].

With respect to photon time-of-flight delays, measurements of the time structure of arrival of photons from gamma-ray bursts by the Fermi or the MAGIC and HESS telescopes have reached enough precision to put strong bounds on first order corrections in the photon energy over the Planck mass [17]. These results have been very recently challenged by new analyses that suggest a positive effect in data from GRBs [18].

Therefore, on the one hand, the previous explanation of the apparent "anomaly" in the observed neutrino spectrum seems to favour a violation of Lorentz invariance against a deformation of Poincaré symmetry, since in the latter case there exists a relativity principle that forbids the apparition of energy thresholds for particle decays. On the other hand, both LIV and DSR theories could be compatible with a positive signature in time-of-flight photon delays, but such a signature would however defy birefringence constraints in the LIV case, at least in the SME framework [6].

The physics of ultra-high-energy cosmic rays has also been used to search for quantum-gravity effects [19]. In particular, the existence and position of the Greisen-Zatsepin-Kuzmin (GZK) cutoff [20] can test Planck-scale physics [21]. The GZK feature has been one of the primary questions addressed by the Pierre Auger observatory [22]; however, its definitive confirmation depends on details about the composition of these very high energetic cosmic rays, and about their sources, which are difficult and are still being examined at the moment. In this task, comparison with other cosmic messengers, like gamma rays and neutrinos, are, and will be, extremely important [23].

Very recently, the detection of gravitational waves (GW) has provided the opportunity to search for modifications to special relativity in a new type of messenger. A study of dispersive effects caused by a modified dispersion relation in gravitational waves was already made in their first experimental observation [24], which was also used to tentatively constrain the difference between the speed of light and that of a GW [25]. A more reliable constrain was possible by last year's coincident detection of gravitational waves and gamma rays from a binary neutron star merger, an event that marked the beginning of a real multi-messenger astronomy [26]. Still, new ideas are being developed [27] to test possible modifications to special relativity associated to this last cosmic messenger.

1.3.2. PROGRESS BEYOND THE STATE-OF-THE-ART

The Action will foster progress on several aspects of the phenomenology of quantum gravity. With respect to time delay experiments, the situation is at present confusing and intriguing, as explained above. A number of analyses of time profiles from GRBs [17] put severe constraints on first-order Planckian corrections to the photon dispersion relation. These have been challenged however by recent works that use all available GRB data and a different strategy of analysis [18], and seem to find some remarkable regularities which are indeed compatible with Planckian effects. The scientists involved in all these works belong to different theory and experimental communities that, by means of the Action, will have the opportunity to meet together, discuss and compare the different approaches, and establish a common strategy that should clarify the situation and confirm or not this signal, for which an input from quantum gravity models and GRB emission models will also be necessary.

There also exist intriguing results in studies that try to correlate the highest-energy neutrinos detected by IceCube with known GRBs [28], suggesting a time delay effect in the propagation of high-energy neutrinos. It is clear that further studies are in order, while one waits for the first confirmed neutrino and photon observation of a GRB, which will surely happen in the near future. In this sense, the multi-messenger approach promoted by the Action will serve as a preparation for such an event, which should provide new indications on the possibility of a quantum gravity effect in the propagation of photons and/or neutrinos.

Finally, experimentalists are used to interpret their results in terms of a violation of Lorentz invariance, but they should also be analysed in the light of DSR models. To do so, theorists have first to clarify the situation on time delays in DSR models in the line expressed above, and different phenomenological results should be put in context. As mentioned before, threshold effects like those which would explain a cutoff in the neutrino spectrum observed by IceCube, or those which could affect the GZK cutoff of the highest energetic cosmic rays are only valid in the context of LIV, while DSR could help to make compatible a positive photon time delay with the absence of birefringence effects.

1.3.3. INNOVATION IN TACKLING THE CHALLENGE

There are three strategies of the present Action that can be considered as innovative and will help in tackling the challenge, allowing progress in the directions indicated above.

The first one is the involvement of different communities that rarely have the opportunity of meeting together and discuss. They include both theory and experimentalists, and they cover different fields, such as astrophysics (GRB models, photon propagation...), gamma-ray, neutrino and gravitational wave astronomy, cosmic-ray physics, or theory and phenomenology of quantum gravity. As explained above, a common forum for discussion is perceived as fundamental to tackle the challenge of the identification of quantum gravity signals.

The second one is the multi-messenger approach. The comparison of the phenomenology of the different cosmic messengers may be essential to uncover the presence of Planckian effects that could otherwise be attributed to intrinsic effects of the physical phenomenon. Although there has been some attempt along this line (as in [28], for example), this has not been a conventional approach, mainly because experimentalists of cosmic messengers interested in quantum gravity phenomenology belong to different communities, and also because until recently we lacked a real multi-messenger astronomy, something which has already changed with the multi-messenger detection of a binary neutron star merger and will progress towards the multi-messenger detection of other astrophysical phenomena in the near future. It is, therefore, an excellent moment to consider such an approach as a very relevant tool in the analysis of the implications of quantum gravity phenomenology.

The third strategy will consist in the training of young researchers in a new scientific profile that will combine the relevant skills and a transversal background in the fields of astrophysics and quantum gravity. They will be familiarized with theoretical models and experimental techniques, and be able to follow progress in the different subareas discussed in quantum gravity phenomenology. It is an innovative strategy because that scientific profile does not exist yet. However, it will be of the greatest importance to have such type of experts in Europe to lead the future development of the field.

1.4. ADDED VALUE OF NETWORKING

1.4.1. IN RELATION TO THE CHALLENGE

The identification of quantum gravity signatures will be a complex task requiring the collaboration and expertise of researchers in a wide spectrum of areas. In particular, it will need a close cooperation between the theoretical and experimental communities. Due to the complexity of the Action’s challenge and due to the fact that we have just entered the multi-messenger era, it is essential to improve the interactions between the theoreticians and phenomenologists, and the experimental multi-messenger astronomers.

On the one hand, it is necessary that theoreticians and phenomenologists develop models that account for the technological limitations imposed by the different instruments that will be used to test them. This will not be possible without the advice from experimentalists. On the other hand, some of the works that have been recently presented at the most important international conferences dedicated to multi-messenger astronomy [see for instance, the proceedings of the 2017 International Cosmic Ray Conference (ICRC) at https://pos.sissa.it/cgi-bin/reader/conf.cgi?confid=301] show that there is a non-negligible interest from the experimental community on the search for quantum gravity signatures. These works, which are focused on using astrophysical observations to constrain different effects from quantum gravity, also suggest that there is the need of coordinating the efforts from those experimentalists working on the different astrophysical messengers in order to address more efficiently the Action’s challenge. This requirement cannot be satisfied without the collaboration of experts in quantum gravity theory and phenomenology.

The present Action provides an excellent opportunity for fulfilling the previously mentioned needs by creating a network of experts in quantum gravity theory and phenomenology and in experimental multi-messenger astronomy, including astrophysicists working on emission mechanisms at the sources, whose understanding is crucial to undertake the challenge properly. This network would help its members to improve their knowledge with respect to each other's fields of expertise and help them to combine efforts with the common goal of meeting the Action's challenge. Additionally, it would increase the international visibility of the challenge and trigger the interest of other researchers on it, eventually enlarging the community of scientists devoted to such a fundamental problem for high-energy physics.

Given the complexity of the task, the amount of expertise needed to address it, and the wide range of sub-disciplines of high-energy physics involved in it, it seems that a network-based approach is not only a good way of tackling the challenge, but the ideal way of doing it. The Action will thereby enhance the chances of meeting this challenge in an unprecedented way.

1.4.2. IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

The Action's activities are closely related to European efforts in the field of astroparticle physics, which include large international experimental collaborations funded by national government agencies. They are guided by the recommendations of the Astroparticle Physics European Consortium (APPEC). In its strategy document for 2017-2026, APPEC remarks the high priority of those research infrastructures that exploit all confirmed high-energy messengers, which include gamma rays, neutrinos, cosmic rays and gravitational waves. The Action will take profit of these efforts to advance in the field of quantum gravity phenomenology.

With a more specific relation, there exists at present a COST Action (MPNS COST Action MP1405, "Quantum Structure of Spacetime" [QSPACE]) which addresses the problem of quantum gravity from the point of view of noncommutative geometry and string theory or loop quantum gravity models. That Action, which ends its fourth year on the first semester of 2019, is focused on a top-down approach to the quantum gravity problem, considering the mathematical consistency of candidate theories of quantum gravity from a fundamental approach, and involve mainly theoretical physicists and mathematicians.

On the contrary, the present Action follows a bottom-up approach, with an emphasis in phenomenology as a way to deduce properties which would derive from an unknown quantum gravity theory. In this way, the focus is put on experimental signatures in the physics of cosmic messengers, and the participation of experts from the corresponding communities is therefore essential. In fact, the cooperation between theorists and experimentalists, together with the training of young scientists in both aspects of the research program of quantum gravity phenomenology, is the added value that singles out the present Action with respect to the above mentioned initiative.

There are also connections between some of the activities carried out inside one of the Working Groups of the present Action (gravitational waves) and the COST Action CA15117 "Cosmology and Astrophysics Network for Theoretical Advances and Training Actions (CANTATA)", which started in 2016.

2. IMPACT

2.1. EXPECTED IMPACT

2.1.1. SHORT-TERM AND LONG-TERM SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS

Although this Action concerns primarily fundamental science, one can expect some impact on instrumental technological development, and, in particular, an important long-term impact on climate research that will be achieved through connecting expertise in Cherenkov gamma-ray astronomy and atmospheric studies.

Short-term impact:

Scientifically, the Action will help to resolve the existing tension between different experimental results that search for quantum gravity effects in the propagation of cosmic messengers. This, together with the development of new strategies of analysis, may lead to the possibility to uncover signals that will affect the interpretation of many astrophysical phenomena. Results, either positive or in the form of constraints, may also affect other fields of high-energy physics, such as axion physics (a branch of high-energy physics that relies on the existence of hypothetical particles called axions, allowing for non-conventional effects in the propagation of photons, for example), or dark matter physics.

It is also expected that the Action will trigger the interest in the challenge among the astrophysical experimental community, where at present only small groups with a particular interest in quantum gravity phenomenology participate in the search for non-conventional physics in the experimental data. This can produce a feedback effect that may expedite the development of the field.

The Action, in general, is expected to have a prominent role in establishing the young discipline of quantum gravity phenomenology as a mature subfield of high-energy physics.

The outreach activities that will be carried out by the Action will also have a direct impact on society, helping to promote and shape its scientific education and culture.

Long-term impact:

One of the main objectives of the Action is the training of young researchers in the new scientific profile that the field of quantum gravity phenomenology demands, with a transversal expertise on theoretical and experimental aspects of astrophysics, and theoretical and phenomenological aspects of quantum gravity. As a result of this Action's labor, it is expected that a future generation of European experts can lead the development of the field in future years.

On the other hand, the results achieved by the Action could motivate the physics case for future upgrades or the development of the different instruments used in astroparticle physics. In this sense, the studies carried out in the framework of the Action may have a direct impact on stimulating technological development. This can of course result in applications without any relation to physics as a side effect, as it often happens when basic research uses instrumental devices that push technology beyond its limits.

Characterization of aerosols in the atmosphere, important for precise calculations of data measured by Imaging Atmospheric Cherenkov Telescopes (IACTs), and needed for studies proposed in this project (Working Group 3), will have a long-term impact on the development of environmental research and its application to climate research. In particular, physical and chemical properties of aerosols will be assessed at the remote sites where IACTs are located.

The collaboration between different experimental communities stimulated by the present Action, even if it is focused on the specific topic of quantum gravity phenomenology, may also serve as a driving force in the development of a real multi-messenger astronomy, a field with an enormous technological and scientific potential. In this respect, the timeliness of the Action with respect to the birth of the field is remarkable.

Finally, it is expected that the Action will have a crucial impact on the development of a quantum theory of gravity, by providing results that will guide the construction of such theory. For example, experimental data might favor models with a modification of special relativity compatible with a relativity principle, instead of a violation of the symmetry. This would have consequences on fundamental properties, such as the idea of locality or the structure of spacetime. At the same time, it would require an extension of the standard relativistic quantum theory compatible with the new notion of locality and the modified space-time symmetry.

The scientific breakthrough from a possible identification of quantum gravity signatures cannot therefore be overestimated. It would not only foster the long-sought unification theory of the fundamental forces of Nature, but it would also bring us new ideas on basic physical concepts that may have future technological applications that cannot even be imagined at the moment.

2.2. MEASURES TO MAXIMISE IMPACT

2.2.1. PLAN FOR INVOLVING THE MOST RELEVANT STAKEHOLDERS

The target groups of the present Action are experts and young researchers belonging to different areas and communities relevant to the scientific challenge of the Action. They include both theorists and experimentalists working in the fields of quantum gravity theory and models, with an emphasis on phenomenology, in gamma-ray astronomy, cosmic-ray physics, neutrino and gravitational-wave astronomy. A large number of scientists have been contacted and have expressed their interest in the Action. Most of the relevant international experimental collaborations will have one or several representatives in the Action, and they will help to spread the objectives and results obtained to the rest of their collaboration, so that more interested people can join the Action.

2.2.2. DISSEMINATION AND/OR EXPLOITATION PLAN

The Action will set up a website which, apart from all the information relative to its structure, objectives, results, and relevant information around its working (events, news, conferences, etc.), will also include an outreach section developed for a general audience. This section will contain frequent questions and answers, and the possibility to freely ask questions to an expert. There will also be a section on gender balance which will highlight the participation of female scientists in the Action.

The Action plans to create social networks (creation of profiles in Twitter, Facebook, and a Telegram channel) to disseminate news and interesting information in relation with the progress of the Action.

Scientific results will be published in international scientific journals and presented at the conferences organized by the Action, and other related conferences, such as the biennial "Experimental search for quantum gravity", or the "International Cosmic Ray Conference". The Action will also ponder (depending on the available budget) the edition of proceedings of the annual Main Conference organized by the Action. In order to increase the visibility of both the Action and the role of female researchers, the annual conference will also contain an open public lecture given preferentially by a woman scientist participating in the Action.

Finally, it is planned to set up a YouTube channel in which we will publish short videos of participants in the Action telling about their work in a simplified way, addressing a general audience. Women and young scientists will be given preference to appear in these videos. The Action pursues a threefold objective: communicate our science in a simple way, stand out the participation of women in science, and stimulate young people to pursue a career in science.

2.3. POTENTIAL FOR INNOVATION VERSUS RISK LEVEL

2.3.1. POTENTIAL FOR SCIENTIFIC, TECHNOLOGICAL AND/OR SOCIOECONOMIC INNOVATION BREAKTHROUGHS

The main innovative approaches to the challenge (set up a common forum of discussion for the different communities, a multi-messenger approach to quantum gravity phenomenology, and the training of young researchers in the adequate scientific profiles) have a strong potential for scientific breakthroughs (like what it would mean to find a signature of a quantum gravity effect in the propagation or interaction of particles) and, as discussed above, important potential technological and social impacts. The risk level is low because the scientific activities are already being performed by the different communities (that is, they do not need the support of the Action to carry out their work); the Action will act (through the sharing and comparison of strategies of analysis, or the input from theorists to experimentalists and vice versa) as a catalyst to extract from the existing data the information that may help to either identify a positive signal or constrain the possible theoretical models.

3. IMPLEMENTATION

3.1. DESCRIPTION OF THE WORK PLAN

3.1.1. DESCRIPTION OF WORKING GROUPS

The COST Action will be organized into seven Working Groups (WGs). WG1 and WG2 will be focused on the theory and the phenomenological implications of quantum gravity frameworks and specific models. WG3-WG6 will be devoted to the specific cosmic messengers, and, though they will be focused mainly on experimental activities related to those messengers, will include both experimentalists and theorists (which also work on the first two WGs). Each of these WGs will have specific meetings that will be organized by the WG. Finally, WG7 will organize the annual conferences that will join together all participants of the Action, as well as the training schools for young researchers, and will be also in charge of gender and outreach activities.

WG1-2: Theoretical workgroups

The objectives, tasks and milestones of the working groups 1 and 2 are described below. Their common activities and major deliverables are stated here.

Major deliverables: Publication of at least 8 papers per year in major, high impact, international journals. A comprehensive wrap-up report of each year's progress and insights.

Activities: Organization of regular video conferences/visits - Organization of workshops for specific topics involving also WG3-6 - Publication of results of studies in the webpage (in cooperation with WG7).

WG1: Theoretical frameworks for gravity effects below the Planck energy

Objectives: Development and extension of theoretical frameworks, from DSR, SME, non-local/non-commutative effective field theory (EFT) and modified dispersion relations, to quantum-gravity-induced black hole mimickers and Finsler geometries, aiming at describing possible scenarios for low energy (sub-Planckian) effects induced by quantum gravity theories.

Tasks: Improve the mathematical consistency and our physical understanding of these models, in order to bring them to the level of development that is necessary to provide reliable predictions and admit experimental constraints. Determine how experimentally-accessible observables are derived from the fundamental assumptions of the different models; in particular, how to describe observers, their measurements and measurement comparison in the presence of LIV or DSR scenarios. Identify equations which connect the sub-Planckian theories to fundamental approaches to quantum gravity.

Milestones: Compile a comprehensive review of existing theoretical frameworks for QG phenomenology and organization of a workshop bringing together people working on fundamental QG theories and QG phenomenology.

WG2: Phenomenology of quantum gravity

Objectives: Study the influence of the models constructed in WG1 on the observables seen by WG3-WG6. Develop a parametrization of possible effects for systematic comparison between theory and experiment, similarly to what is accomplished by the Parametrized Post-Newtonian (PPN) formalism for General Relativity (GR) and modified/extended theories of gravity. Systematically derive, from the experimental results coming from the different messengers, constraints on the theoretical models, and combine these constraints into a consistent picture. Develop a phenomenology of multi-messenger events and identify the theoretical predictions/models for which these events offer improved constraining power.

Tasks: Develop and set up a systematic scheme to identify, in the experimentally-accessible observables, quantum gravity effects such as: unexpected time delays, anomalous frequency dependencies, deviations from general relativistic particle trajectories, modifications to the dynamics of black hole mergers and other GW sources, irreducible noise in precision measurements, QG-induced decoherence, violations of CPT symmetry and/or matter-antimatter asymmetry, modifications of astrophysical thresholds, and others. Introduce parameters connected to the different effects and predict the values of the parameters from the theoretical models. Clearly differentiate between effects due to quantum gravity and effects due to the physics of the sources of the observables. Use the data provided by the experiment to determine the value of the theoretically-calculated parameters, and provide feedback to the theorists to guide further theoretical developments.

Milestones: Development of a suitable parametrization for describing QG induced phenomenological effects. Derivation of the values of the parameters in the models discussed in WG1. Establishment of the experimental constraints on these parameters from experiments with WG3-6. Publication of the results and dissemination in workshops and conferences.

WG3-6: Gamma rays, neutrinos, cosmic rays and gravitational waves

We list here common objectives, activities and major deliverables for the four WGs devoted to each of the cosmic messengers. Specific tasks and milestones for each WG are indicated below.

Objectives: These WGs have several objectives. First, to analyze the current state of the art of the experimental astronomy of each type of cosmic messenger with respect to the Action's challenge and identify opportunities for improving the analysis strategies which are currently being followed, in the light of the theoretical frameworks and considerations of WG1 and WG2. A second objective is to provide WG1 and WG2 with the technical details related to the detection of each type of astrophysical messenger, which need to be considered for a correct phenomenological and theoretical interpretation of the experimental results. In the third place, these WGs will have to develop new analysis strategies that combine the observations of gamma rays, cosmic rays, neutrinos and gravitational waves for the search of quantum gravity signatures in the framework of multi-messenger astronomy. These new strategies should be developed in close cooperation with WG1 and specially with WG2. Finally, these WGs will transfer the Action's motivations, progress and results, to their respective communities of experimentalists to promote their interest on the Action's challenge.

Activities: Organization of regular video conferences - Organization of workshops for specific topics involving also WG1-2 - Publication of results of LIV studies in the webpage (in cooperation with WG7).

Major deliverables: Publicly available web page with results of LIV studies based on each cosmic messenger. Optimal strategy and method for performing LIV studies (including future experiments and a multi-messenger approach). Publications, and contributions to conferences. Contributions to the communication and outreach activities developed by WG7.

WG3: Gamma rays

Tasks: Set-up, maintain and regularly update a database of all existing results on LIV based on time of flight studies with gamma-rays; compare the methods and results of different studies; establish a common strategy and optimal method for analyzing data from different source classes [GRB, active galactic nuclei (AGN), pulsars] and different instruments (ground-based Cherenkov telescopes, satellite detectors), using the triggers from observations in other wavelengths and messengers, and taking into account both the status of already published proto-population studies (mostly with GRBs), and future population studies that will consider data from tens of objects and different experiments (IACTs, satellites) combined together; work on our understanding of the sources themselves in order to isolate source-intrinsic temporal effects, which will allow to put more stringent constraints on LIV; develop a standard to characterize atmospheric aerosols based on LIDAR (Light Detection and Ranging) and stellar extinction measurements, and provide the corresponding corrections to IACT data, based on tailored Monte Carlo simulations; devise strategy for observing more astrophysical phenomena suitable for LIV studies with pointing instruments (e.g. AGN flares observed with IACT); in cooperation with WG1-2, identify possible signatures in gamma-ray signals of other hypothetical phenomena (e.g. axion-like particles).

Milestones: Year 1: Set-up a database of all existing results on LIV based on gamma-rays and publish it on web page. Compare the results and methods used. Year 2: Optimization of strategies and methods for performing LIV studies based on gamma-rays, benefitting at best from AGN flare observation strategies conceived for astrophysical studies. Year 3: List of possible signatures in gamma-ray signals of other hypothetical phenomena and possible methods for detecting signatures. Year 4: Development of multi-messenger search strategies based on the phenomenological models developed by WG1 and WG2.

WG4: Neutrinos

Tasks: Work on the update of phenomenological models used in previous works concerning the use of astrophysical neutrinos to search for quantum gravity signatures; clarify the situation with respect to the cosmic neutrino spectrum in terms of its apparent ending at energies higher than ~PeV and of the presence of different components; clarify the situation with respect to the flux of GZK neutrinos; evaluate how neutrinos could be included in other searches for quantum gravity effects through the use of other cosmic messengers; develop new strategies for the search of quantum gravity effects by combining the observations of multiple messengers.

Milestones: Year 1: Review, improve and update the already existing searches for quantum gravity signatures through cosmic neutrinos. Year 2: Refine constraints in LIV phenomenology taking into account the theoretical predictions and observed properties for high-energy neutrinos from astrophysical sources and other components in the neutrino spectrum, such as GZK neutrinos. Year 3: Study with the other messenger working groups how to include neutrinos in their searches. Year 4: Development of multi-messenger search strategies based on the phenomenological models developed by WG1 and WG2.

WG5: Cosmic rays

Tasks: Tackle the problem of the possibility of observing quantum gravity effects in the propagation of ultra-high-energy cosmic rays, given the experimental observation of a high-energy suppression in the all particle spectrum; consider the implications of quantum gravity phenomenology in the extragalactic electromagnetic cascades produced by the propagation of ultra-high-energy cosmic rays, clarifying the different implications of LIV and DSR frameworks; study the effects of quantum gravity phenomenology on the production processes of ultra-high-energy cosmic rays, also relating the observed spectrum with that of the (possible) associated messengers (e.g. neutrinos and gamma rays); consider the possibility of deriving limits for LIV and DSR parameters from the modifications in the development of the extensive air showers which are induced by cosmic-ray particles in the Earth's atmosphere, also relating these effects to the observed muon excess in the Auger surface-detector data.

Milestones: Year 1: Review, improve and update the already existing searches for quantum gravity signatures through cosmic rays measurements. Year 2: Constrain quantum gravity phenomenology from the available experimental data in the different cases of LIV and DSR. Year 3: Definition of new analysis strategies taking into account the theoretical frameworks developed in WG1-2. Year 4: Development of multi-messenger search strategies based on the phenomenological models developed by WG1 and WG2.

WG6: Gravitational waves

Tasks: WG6 will aim to further constrain possible deviations from the post-Newtonian description of binary inspiral, eventually down to the sub-percent level, by combining information from tens to hundreds of GW sources. Continued GW dispersion measurements will lead to increasingly better bounds on local Lorentz invariance violations and on the mass of the graviton. However, qualitatively new tests of GR and of the black hole nature of massive compact objects will become possible during the timespan of the Action. Anomalous tidal effects during the late inspiral of presumed binary black holes would be indicative of "black hole mimickers". For example, if dark matter consists of fermionic particles then they may form dense stars, which if present in a binary system would betray their nature by the presence of tides. Next, the remnant object resulting from the merger of two compact bodies will undergo "ringdown" as it asymptotes to a quiet state. The associated GW signal involves characteristic frequencies and timescales which for standard black holes should only depend on mass and spin, as a result of the black hole no-hair theorem. Deviations from this would be tell-tale signs of a horizon modification, or of an entirely different kind of object having formed. Finally, prompted by Hawking's information paradox, some have proposed macroscopic quantum modifications of black hole structure ("firewalls" and "fuzzballs"), which would lead to GW "echoes" being emitted after the ringdown signal has died down. Though the above is GW-focused, we note the value of a multi-messenger approach: for example, should an electromagnetic counterpart be seen to a binary merger in the black hole mass range, then this will be a further indication of new physics, and it would help elucidate the nature of black hole mimickers.

Milestones: Year 1: Computational optimization of analyses of binary merger dynamics, and of searches for anomalous GW propagation. Year 2: Development of concrete data analysis tools to search for anomalous tidal effects during inspiral, tests of the no-hair theorem, and GW echoes. Year 3: Formulation of a comprehensive multi-messenger framework to search for black hole mimickers. Year 4: Application of the resulting analysis tools to detections made with Advanced LIGO and Advanced Virgo at final design sensitivity.

WG7: Schools, Main Conference, gender and outreach activities

Objectives: WG7 will be in charge of promoting scientific culture and awareness to young students and general public, highlighting the work of the female scientists participating in the Action. It will be also in charge of the organization of the Main Conferences of the Action (including the open public lecture that will form part of the conference) and the Training Schools.

Tasks: Organize the annual Main Conferences that will join together the Action participants, and the Training Schools for young researchers; disseminate information on these activities to Action participants, and carry out a program of gender and outreach activities.

Activities: Maintenance of a web page - Maintenance of social networks - Maintenance of a YouTube channel, editing and publishing short videos of participants in the Action, especially women and young scientists - Annual organization of the Main Conference of the Action - Annual organization of the Training School for young researchers.

Milestones: Year 1: Set-up of a web page with all the relevant information about the structure, objectives, and results of the Action, and an outreach section addressed to the general public; set-up of social networks in Twitter, Facebook, and a Telegram channel; organization of the 1st annual Main Conference; organization of the 1st annual Training School. Year 2: Maintenance of the web page (with a news and event sections) and social networks; set-up of the YouTube channel; organization of the 2nd annual Main Conference; organization of the 2nd annual Training School. Year 3: Maintenance of the web page and social networks; maintenance of the YouTube channel; organization of the 3rd annual Main Conference; organization of the 3rd annual Training School. Year 4: Maintenance of the web page and social networks; maintenance of the YouTube channel; organization of the 4th annual Main Conference; organization of the 4th annual Training School.

Major deliverables: Web page. Social networks in Twitter and Facebook and Telegram channel. YouTube channel. Annual Main Conferences (including open public lectures) and Training Schools.

3.1.2. GANTT DIAGRAM

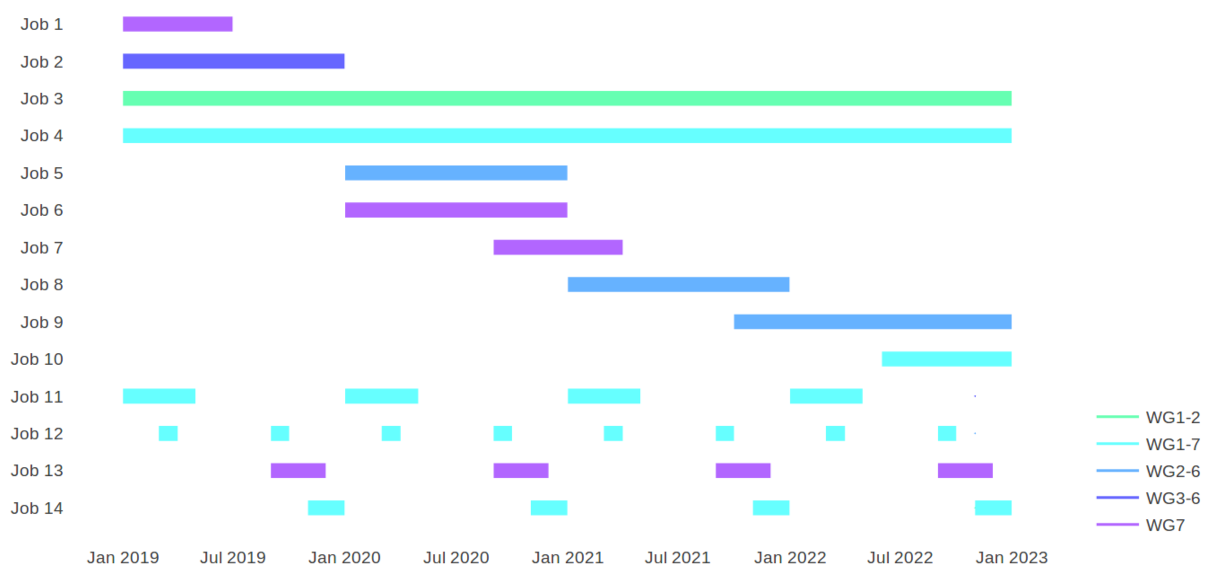

Figure 1: GANTT diagram showing the temporal distribution of a summarized list of jobs from the tasks, activities and milestones described in Sec. 3.1.1. In the colour legend, "WG1-7" means that all groups from 1 to 7, including both of them, are involved in the corresponding job. To make the interpretation of the figure easier, it has been assumed that the Action starts on 01/01/2019 and ends on 31/12/2022.

Job 1: Set up of the Action's web page. Job 2: Previous observational studies and comparative analysis. Job 3: Comparison of theoretical models and associated phenomenology. Job 4: Publication of results in the web page. Job 5: Preparation of strategies of analysis in view of theoretical frameworks. Job 6: Setup of social networks. Job 7: Setup of YouTube channel. Job 8: Application of the new strategies of analysis to constrain and/or favour different theoretical models. Job 9: Development of new analysis strategies in the multi-messenger approach and their implementation. Job 10: Plan extending the network's lifetime beyond that of the Action. Job 11: Preparation of summer conferences. Job 12: Organization of internal workshops. Job 13: Preparation of Annual Conference and Training School. Job 14: Preparation of the Annual Report.

3.1.3. PERT CHART (OPTIONAL)

COST
EUROPEAN COOPERATION
IN SCIENCE & TECHNOLOGY

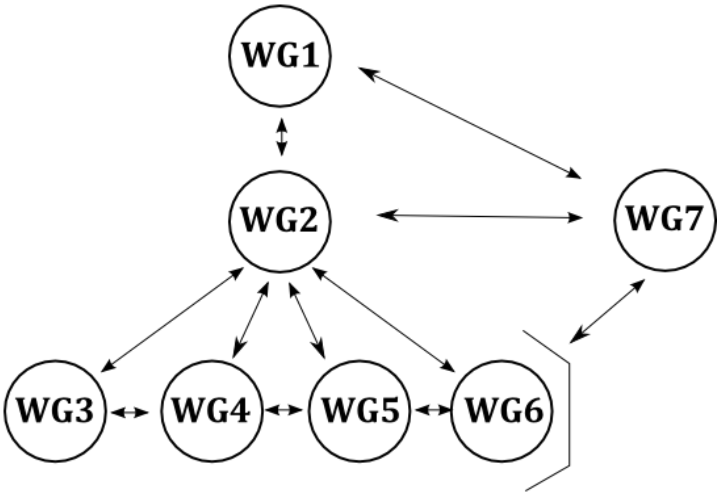

Figure 2: Graphical representation of the different WGs showing their inter-relation.

3.1.4. RISK AND CONTINGENCY PLANS

The main objectives of the Action are the coordination and creation of a common forum of discussion for the different theoretical and experimental communities involved in the identification of quantum gravity signatures, as well as the training of young scientists in the appropriate skills to carry out forefront research in this field. These objectives are perceived as essential by many scientists from the different communities, as the extensive and diverse list of proponents shows. It is expected, therefore, that the Action will be welcomed and joined by a large community that will embrace its objectives and contribute to its success.

In any case, in order to promote interest inside collaborations working in astroparticle physics experiments for which the topic of quantum gravity phenomenology may not be their primary research objective, it is planned to disseminate the existence and objectives of this Action in the different conferences, through the advertising of participants already present in the Action and the rich outreach program explained above.

The Action also notes that, since there are many independent planned and ongoing experiments relevant to the scientific challenge pursued by the Action, there are no significant risks on what concerns the availability of experimental data which will be needed to test the models and strategies of analysis that will come out as a result of the Action activities. However, with respect to the ambitious goal of multi-messenger search strategies that are planned for Year 4, there may be a risk associated to the possible lack of multi-messenger data from definite astrophysical events (for example, a GRB). In this case, alternative strategies will be developed, but their specific application will have to wait for a real multi-messenger observation of a given event.

3.2. MANAGEMENT STRUCTURES AND PROCEDURES

The Action will be governed by a *Management Committee* (MC), chaired by the Action Chairperson, assisted by a Vice-Chair, both elected during the MC inaugural meeting. The MC will coordinate the Action's activities and supervise the use of the COST funds to ensure the achievement of the final objectives.

The MC will also elect other key leadership positions that, apart from the Chair and Vice-Chair, will constitute a *Core Group* (CG) in charge of the operative management of the Action: the seven WG Leaders and Vice-leaders, and a Coordinator for the Short Term Scientific Missions (STSM). The CG will be responsible for the preparation of all documentation required for the MC meetings.

The working groups WG1-6 will organize research activities within the main lines described in Sec. 3.1.1. Interactions between these groups will be frequent and natural, with participants being able to belong to more than one WG. As described in Sec. 3.1.3, the most natural synergies will be among WG1 and WG2 (theory: models and application to phenomenology), WG2 and each of WG3-6 (phenomenology applied to each messenger, either separately or in a combined way, in order to consider the multi-messenger approach), and interactions between WG3, WG4, WG5, WG6 for specific multi-messenger phenomena.

In particular, scientific coordination and networking of the different WGs will be achieved through:

- One annual *Main Conference* that will join all the participants, allowing them to present the different lines of research and produce rich discussions (organized by WG7).
- One annual *Training School* that will promote interactions between young researchers and scientists from different nodes (organized by WG7).
- *Workshop* meetings organized by the WGs (that may join more than one WG) to discuss particular scientific topics. Specific *Training Courses* and/or *Seminars* may be organized in connection with these workshops, making them available to all parties.
- The CG will produce an *Annual Report* describing the progress of each WG and of the network as a whole.

WG7 will carry out a specific program for the dissemination of the Action and the promotion of gender activities along the lines exposed in Sec. 2.2.2: a complete webpage for the Action, the management of social networks spreading news about the Action (Facebook, Twitter and a Telegram channel), and the setup of a YouTube channel with the testimonials of young researchers, with the objective to reach and stimulate young people, and specially young women, to follow a scientific career.

An open lecture for the general public will be also given on the occasion of each annual Main Conference, delivered, if possible, by a female scientist participating in the Action. This will help to meet the goal of dissemination of the Action's activities to society and, at the same time, highlight the role of women in scientific research. Apart from this, the Action will ensure the active participation of women scientists in its management, structure and research objectives, as well as as speakers in the organized Workshops, Training Schools or Conferences.

In order to stimulate the participation of young researchers at the Main Conferences, a prize will be awarded to the best poster and talk presentation produced by a PhD student or young postdoctoral fellow (under the age of 30).

Finally, the STSM will support individual mobility and stimulate collaboration between different research groups. The Action webpage will contain an electronic request form and applications will be managed by the STSM Coordinator. The evaluation of the received applications will be done by the Action MC, or by the CG if the MC gives them the mandate to perform this task on their behalf. The final selection will have into account the scientific value of the mission, with special considerations with respect to supporting COST policies on promoting gender balance, enabling Early Career Investigators (ECI), and broadening geographical inclusiveness.

3.3. NETWORK AS A WHOLE

A total of 78 secondary proposers have actively participated in the preparation of the Action or otherwise indicated their interest in joining.

Some of the proposers from the corresponding institutions belong to important international collaborations on gamma-ray astronomy, neutrino astronomy, cosmic-ray astronomy, and gravitational wave-astronomy, in different experimental, technical or theoretical aspects. A group of experts in atmospheric studies also participate in the Action, in connection with the practical applications on climate research mentioned in section 2.1.1.

Other proposers work as theorists in different approaches to quantum gravity theories and models, covering a range of subareas of expertise, from more mathematical topics, such as noncommutative geometry, to more phenomenological approaches, including also areas such as general relativity, cosmology, particle physics or astrophysics.

Five International Partner Countries (IPC), Canada, Chile, China, Japan and United States, also participated in the preparation of this Action. This will bring a complementary expertise from these countries, which are first-rate international actors in the areas developed in the Action. Firstly, the corresponding proposers are specialists in specific topics that are relevant for the objectives of the Action; secondly, they will help spread the activities of the Action internationally and make easier the contacts between researchers from the corresponding regions. European researchers will benefit from the interaction with non-European scientists, their participation as trainers in the Training Schools, and the possibility to visit non-European institutions. The benefit from scientific exchange will of course be mutual, and non-European institutions will profit from participating in an Action that will lead the worldwide efforts in the field of quantum gravity phenomenology.

The present proposal, therefore, contains the critical mass, expertise and geographical distribution needed for addressing the challenge and the objectives of the Action. It contains, in particular, representatives from most of the relevant international collaborations. In this way, the international community can effectively be aware of the activities carried out in the framework of the Action, which will also benefit its future development.

List of acronyms used in this document (in order of appearance):

QG	Quantum Gravity
GRB	Gamma-ray burst
CPT	Charge conjugation, parity transformation, and time reversal
SME	Standard Model Extension
LIV	Lorentz invariance violation
DSR	Doubly Special Relativity
GZK	Greisen-Zatsepin-Kuzmin (ref. [20])
GW	Gravitational waves
ICRC	International Cosmic Ray Conference
APPEC	Astroparticle Physics European Consortium
IACT	Imaging Atmospheric Cherenkov Telescope
WG	Working Group
EFT	Effective Field Theory
PPN	Parametrized Post Newtonian
GR	General Relativity
AGN	Active galactic nuclei
LIDAR	Light Detection and Ranging
MC	Management Committee
CG	Core Group
STSM	Short Term Scientific Missions
ECI	Early Career Investigators
ITC	Inclusiveness Target Countries
IPC	International Partner Country

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