About policies for multi-wavelengths/multi-messenger astrophysics

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This paper summarizes the status, opportunities and some future policy initiatives relevant to future multi-wavelength/multi-messenger (MW/MM) astrophysics. This summary is considered timely given the ramp-up in facilities and widening exploration of physics across the electromagnetic spectrum and beyond.

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1. Introduction

Science is driven by breakthroughs at the frontiers of knowledge. Increasingly, science advances on a broader front than any single discipline. Astronomy advances with breakthroughs in fundamental knowledge and also facilities. Moreover, astronomy has a legacy of being richly fed by its interdisciplinary nature: it has driven scientific enquiry across the widening electromagnetic spectrum (originating in the optical) to today's truly multi-wavelength discipline (MW).
New windows to unravelling the physics of the Universe have opened recently, with the recent detection of gravitational waves and of astrophysical neutrinos. We are moving into the era of multi-messenger astronomy (MM). Furthermore, the development of large and numerous facilities operating across the electromagnetic spectrum reinforces the fundamental multi-wavelength approach (MW) in our research. Time-domain astronomy is now providing a new view on the changing Universe and triggers many other facilities for complementary analysis. As a conclusion, it's clear that many lessons could be learned from the current expertise developed on the existing facilities by the community.
However, there are challenges. Critically, today's facilities are intrinsically complex and have a range of different, distributed, and usually worldwide organizations that operate them. This raises a range of issues for astronomers wishing to exploit a suite of these MW/MM facilities for a science topic.
The ASTERICS Policy Forum set out to review the current MW/MM landscape, and to derive some recommendations on proceed. These recommendations consider how it might be possible to harmonize joint and efficient scheduling, operation and interoperability of the various telescopes, and also to produce actionable outcomes in key policy areas. This paper does not intend to elaborate solutions. Instead its aim is to raise awareness of the stakeholders involved, and to embed itself as a living document in the community to progress this issue.

2. Highlights on the Science Framework

Current examples and the individual science cases of the major future research infrastructures provide the starting point for the policy discussions and recommendations. With the Science Vision and the Infrastructure Roadmap, ASTRONET has built a strong framework for the development of European Astronomy and Astrophysics. The space and ground cartography and its connections with related science fields is very rich. Another important aspect, and very relevant for our Policy Document, is the identification of actions that transverses the infrastructures like Virtual Observatory (VO), Laboratory Astrophysics, High Performance Computing, sharing of codes, and training and outreach.
MM astrophysics is clearly a reality today with the huge effort developed for the electromagnetic counterpart of the recent discovery of gravitational waves. The recent neutrino event detected by IceCube in September 2017 has been shown to be positionally consistent with the blazar TXS 0506+056 undergoing a flaring episode detected by both Fermi/LAT and MAGIC. Since its optical and IR spectral energy distributions are dominated by non-thermal emission, the determination of the redshift of TXS 0506+056 has required a large investment of telescope time (Paiano et al. 2018).
An outstanding example of a productive MW/MM science area is the study of transient phenomena. It is therefore no surprise to find that the study of gamma-ray bursts, fast radio bursts, neutrino events, gravitational wave detection, and as-yet unknown source types are clearly identified in the key science programs of the emerging large infrastructures. A range of different observing strategies are being considered: many will adopt the Virtual Observatory-Event approach and the Target of Opportunity frameworks in their time allocation committees. There is an obvious question whether this is a sustainable approach in the mid- and long-term. Moreover, common tools such as the analysis of spectral energy distributions and magneto-hydrodynamic simulations will need to be extended to support the source identification and characterization coupled with facilitated access to archival MW/MM data.
With the advent of very large facilities addressing major scientific questions (first light, epoch of reionization, cosmology - exoplanets and life in the Universe), a new trend has emerged where strong science justifications are required, but these are derived almost independently for each infrastructure. One of the emblematic examples are the suite of correlated surveys to advance cosmology, dark matter, and dark energy: for these SKA, ELT, and also KM3NeT and CTA together with new infrastructures or space missions like LSST, EUCLID, *Fermi*, and *Athena* must deliver vital contributions to these fundamental questions. Given the critical importance of the MW/MM information to enable these topics, observing

coordination and data-sharing policies, not immediately obvious with respect to the political and managerial constraints of each facility, are now necessary. Being able to access the data is key, and it is important that the data provided is science ready. In some cases immediate data access is needed, but in many cases archival data will be required. The data issue has broad attention both in the European context with the European Open Science Cloud, and globally with the UN Open Universe initiative.

3.A critical review of the situation of MW/MM astrophysics today

During the activities of the Policy Forum, we have progressively been confronted with a certain number of facts that indicate that MW/MM astrophysics is probably not working in an optimal way. Barriers have been expressed by scientists and/or representatives of research infrastructures and are, of course, important if one wants to propose ways of progress. We find that the nature of these barriers is varied. Whilst our list is not exhaustive, we believe these reveal key weaknesses that assist in defining the future:

3.1 Limited focus on synergies between Facilities from the outset:

The new and future (massive, billion-Euro-scale) facilities are supported by key science objectives demonstrating unique science and important progress. It is both natural and logical to give highest priority to the transformational aspects that a new infrastructure will bring. At the same time, there is limited focus on unexpected and unpredictable science cases resulting from complementarities with other facilities, while exploiting synergies will lead to additional opportunities. We find that it is important that scientists and research infrastructures keep an open mind, and consider to dedicate some time to challenging and sizable coordinated programs.
Also for the key science cases, the need for complementary views brought by other facilities is rarely extensively described. This is particularly true for space missions with respect to the important ground follow-up that is necessary, and is also true for ground facilities with respect to the potential opened by MW/MM astrophysics.
There is no existing natural platform to discuss complementarities and the added value of exploiting synergies between infrastructures at an early stage.

3.2 Perception that MW/MM astrophysics is already well-organised:

From a different perspective, key science programs are highly emblematic of the strengths of a facility and they are usually highly publicized. Therefore, and as presented before, during the analysis of the science examples, these key science programs benefit greatly from coordinated programs among large infrastructures. The drawback of this situation is that we may consider that MW/MM astrophysics starts to be somehow well organized. Moreover, the politics of Targets of Opportunity (ToO) seems very well developed across the facilities, but this concerns a very small amount of time that may not be sufficient in the future. We consider also that only few examples of coordinated programs have been established in the past (like ESA-ESO agreement on XMM-VLT) for facilitating MW astrophysics. And finally there is no existing framework (like conditional acceptance by TACs) for proposals addressed to multiple facilities. All of this may generate a fracture in the community depending on whether or not you (as an individual) are involved in a particular key science program.

3.3 Cross domain differences

There are significant differences between domains, in particular between physics and astronomy. Cultural differences and a lack of general knowledge on developments in other domains, add a complexity to MM/MW astrophysics. An example are difficulties encountered with the identification of sources, related to different bands, different names, and different classes. VO standards have progressed a lot and *has become again on the forefront scene* with the detection of new messengers for astrophysics. Nevertheless, it is important that scientists understand each other's languages.

3.4 Need for Regional Centres & expertise

The extreme complexity of modern instruments, in their operation and/or in their data analysis, has demanded the development of expert centres, which extends the knowledge of the consortium. With the

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increasing data flow, the existence of these centres will be of crucial importance in the coming decades. In addition, the communication among these centres will be vital if one wants to fully exploit MW/MM astrophysics, given it is clearly impossible to have the expertise on all the facilities involved in any one science question. At the national level, coordination between expert centres might be a future requirement.

4. Recommendations for the future

We propose three different recommendations intended to encourage and support the efforts towards an improved situation for MM/MW Astrophysics. These recommendations should be considered as guidelines and items for analysis. They are general and their actual implementation will need to be considered at many different levels. It is not the purpose of this document to enter into these details of organization.

4.1 Raising awareness

It is crucial that scientists, research infrastructures and funding agencies are aware of the challenges that MW/MM astrophysics is facing. The critical review - based on the input of science working groups - has identified a number of barriers for current and future MW/MM ambitions. Recognizing these difficulties – even if solutions are not available on the short term for practical or political reasons – is important. Science is the driver for MW/MM and it is important that scientists keep pushing for solutions. It is key to take responsibility and to continue to raise awareness of the issues we have to deal with.

4.2 Towards an enhanced coordination for the benefit of MW/MM astrophysics

The starting point here is to recognize and accept the important differences in the nature of the facilities we are talking about. Physics experiments and telescopes do not share the same operating model. This is the same for space missions and ground facilities, or for intergovernmental organisations versus consortium-facilities. For the mutual benefit of all the actors, we recommend to enhance the detailed communication on the key science programs and to analyse the possibilities for coordination in the early phases of development of the infrastructures. This has to be done well beyond the importance of advocating the uniqueness of each facility and this could be done through a better description of the parameter's space where complementarity is obviously more visible. This is illustrated by the recent example of the plans for EUCLID and PLATO with respect to ground-based follow-up observations. The success of the campaign to study the electromagnetic counterpart of gravitational waves is also a formidable example where lessons can be learned from both positive and negative aspects. In the future, more energy will have to be devoted to this aspect in the early phase of studies but also for the benefit of the community through an easier access to science-ready data. This coordination could take the form of an open forum of Research Infrastructures in Astrophysics dedicated to set a place for exchanges.

4.3 Possible actions towards an enhanced MW/MM Astrophysics framework

Considering the complexity of the organizations behind the infrastructures, we do not recommend the implementation of a super Time Allocation Committee across the facilities. We recommend to continue to reinforce the ToO approach and to analyse the pertinence of this model in the growing demand for multi-facility programs. We also recommend to develop joint programs between facilities with delegation of time allocation. And to complement this recommendation towards a larger community beyond the previous agreements, we encourage the Time Allocation Committees to consider conditional approval of proposals submitted to multiple facilities.

We also recommend a strong recognition of the importance of VO compliance and we recommend to continue the formation on the added-value of VO compliance for all the actors of Astrophysics, based on the high benefit brought by already existing actions.

Finally we push for continuing and even further developing the implementation of expertise centres. This should be accompanied by a wider communication on the services offered by these centres, and the exact help that could be provided. We recommend also to these centres to share, in the framework of a network to be built, their business models and their key features towards science-ready data and an easy access to the data.

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5. Conclusions

While MW/MM is facing a number of challenges, there are no immediate solutions: common policies at different levels need to be developed, supported and implemented. Recognizing the difficulties and keeping to raise awareness amongst scientists, research infrastructures and funding agencies is a crucial first step towards implementation.
Science is the driver for common policies, and it is important to keep pushing for a framework in a bottom-up way. At the same time, interaction between research facilities should be continued, and open discussions to share best practices need to be initiated. To address the recommendations, it is important that somebody takes up responsibility and ownership. The ASTRONET Science Vision could be instrumental for this objective.

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[3] https://www.asterics2020.eu

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