



European Quantum Standards and Metrology (EuroQUASAR)

Final evaluation of the EuroQUASAR programme Summary

Scientific Achievements

The reviewers found EuroQUASAR to have been an impressively productive programme in terms of scientific achievements, drawing together European experts and some leading American researchers to advance atom/molecule/condensate-based quantum measurement in a wide variety of configurations. Much of the work has been at the leading edge of the respective fields of the Individual Projects. The scientific achievements are demonstrated by many high-level publications in such journals as Nature, Science, and Physical Review Letters. The programme appears to have encouraged some very valuable collaboration: it has forced the quantum instrumentation outside the laboratory so that it can be compared to classical and photonic instrumentation for measuring inertial effects, giving Europe a head-start in the application of quantum instrumentation to real-life measurements.

The three CRPs (IQS, QuDegPM and MIME) addressed the metrological applications of quantum coherence in complementary systems (respectively atoms, atomic degenerate gases, molecules) and targeted different technological levels (practical geodesy, prototype entanglement exploitation, fundamental quantum physics and molecular properties), thus overlapping only in their general principles. It is noted that the level of co-operation across the programme has been somewhat uneven, with some IPs having taken to the collaborative aspects of the programme with a high degree of interest while others have been less involved. In particular, MIME has been extremely successfully making use of the collaborative opportunities offered by the EuroQUASAR framework, while the overall level of involvement of IQS and QuDegPM has been less intense. Nonetheless, a remarkable degree of synergy across a broad spectrum of mainly experimental activities has been achieved and it has led to the exchange of ideas between theory and experiment. It is noted that the scientific scope of work has broadened relatively to the original proposal as new and interesting questions arouse, which is a positive development. Overall, the programme has greatly strengthened the European effort and cohesion in quantum physics and metrology.

A number of significant scientific highlights have been achieved by the programme, some of which are truly impressive:

- QuDegPM CRP explored Anderson localisation (PRL 104 220602), super-Tonks-Girardeau gases (Science 325 1224) and Luttinger liquids (Nature 466 597), and demonstrated its application in large atomic ensembles for interferometry beyond the classical limit (Science 334 773);
- IQS CRP pursued the technical development of atom interferometers for real geodesy applications, carrying out the first comparison between classical and atomic gravimeters (Metrologica 47 L9), moving beyond proof-of-principle experiments and establishing true interactions between geodesy and matter wave optics communities. A range of forward looking technologies were explored including a levitated gravimeter and compact large area matter wave interferometers;

- MIME CRP, by adopting a truly integrated approach that combined disciplines from physics to chemical synthesis, has spectacularly pushed matter wave interferometry to nearly 7,000 amu (Nature Comms 2 263).

Collaboration and networking

The programme of network-wide scientific events has been excellent, as have been the network wide training events. Multiple workshops, summer schools and conferences were held under the auspices of the programme, which have been very well received by the junior participants. In particular, the Frontiers of Matter-Wave Optics (FOMO) and Young Atom Optician (YAO) conferences were important milestones to exchange ideas and evaluate advances of various topics. The programme's participants have also contributed extensively to the Les Houches summer school. These events have brought a large visibility to the EUROQUASAR programme.

All three CRPs have been highly successful in training a large number of PhD students and postdocs, disseminated their work through a large number of publications in high impact journals and through conference presentations. It is noted, however, that the number of joint publications is not as high as it could have been expected. There have been exchanges of PhD students and postdocs in the programme, but this mode of networking was not fully exploited.

The involvement of the APs in the programme has been limited, apparently due to financial restrictions imposed by the EUROCORES scheme. It is recommended for future programmes to consider whether allocation of some specific funding for travel and visits of APs would be of benefit. A good example was demonstrated by IQS, which had applied for external funds to encourage US/European collaboration.

Overall, this programme has laid the groundwork for a great deal of future collaboration as demonstrated by the number of pending applications for funding by the various contributors. The commitment to continue the FOMO conference series after the end of funding shows the level of interest, and the perceived benefits, of this collaboration.

Exploitation of the programme's potential

All three CRPs have demonstrated valuable contributions to the EuroQUASAR programme and to European activity and progress in quantum atomic and molecular physics.

The MIME CRP has made a very good use of the EuroQUASAR programme to perform research that required interdisciplinary research that would be difficult to fund and/or foster otherwise. It should be particularly noted that the MIME consortium offered to European research a high visibility in molecule quantum interferometry field. The impressive scientific results obtained during the period show the relevance of this collaborative approach.

The collaboration stimulated by this programme within IQS is expected to lead to the emergence of very ambitious European projects, for example, new joint projects to conduct fundamental tests with atomic sensors in space.

Despite the impressive scientific output of QuDeGPM, it is noted that in the case of IQS and QuDeGPM there were very few joint publications between different IPs.

Overall, it can be concluded that EuroQUASAR has achieved some very important aims, and ones that would be unlikely to be achieved without the overarching support of the EUROCORES scheme.

The programme has allowed the researchers to overcome several important and practical issues bringing them closer to quantum instrumentation that can be used in the field. It can be anticipated that this process will continue beyond the end of EuroQUASAR, which will give Europe an advantage in developing useful quantum sensors. The EuroQUASAR programme is likely to generate a legacy of new collaborations, joint conferences and workshops as well as new joint research grants. EuroQUASAR is likely to strengthen European/USA collaboration in this field if new funds are forthcoming.

Recommendations

From the results achieved by EuroQUASAR it is evident that the opportunities offered by the EUROCORES scheme are really excellent for research in Europe, they are extremely valuable in energising and linking European research in topical areas. Such initiatives should be maintained.

A number of observations have been made from the assessment of the EuroQUASAR programme that may help to improve EUROCORES type schemes in the future:

- (i) the timespan from the initial proposals to actual funding was too lengthy;
- (ii) unevenness of research funding of individual IPs throughout the programme has been noted, largely due to the national rules;
- (iii) as highlighted by the project leaders, the fact that funds have been coming to each IP separately from the local funding agencies was a burden and reduced the positive effects of the programme;
- (iv) the EUROCORES scheme does foresee only short-term researchers' visits, while medium term exchanges between IPs, and between IPs and APs, would be of benefit;
- (v) for programmes such as EUROCORES to have the greatest impact, it is clear that the widest level of participation of member countries needs to be encouraged;
- (vi) the management of EuroQUASAR could have been substantially improved if the funding of the entire programme was distributed directly via the ESF, in particular in what concerns unduly lengthy subsequent delays or individual changes to the funding profile within components of individual CRPs.