communications physics

MEETING REPORT

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Mixing waves and communities to brighten the future of ultrafast science

The WavemiX (Wave mixing in the X-ray) network has made significant progress in bringing together theoreticians, experimentalists, and machine scientists from more than 50 institutions and XFEL (X-ray Free Electron Laser) facilities. At its third edition, its flagship workshop is reaching the critical mass to foster innovation in femtosecond and attosecond spectroscopy equipment and techniques and to actively support the investigation of matter.

The keyword of the WavemiX2023 workshop is *useful*. As straightforward as it may sound, it is warmly inviting its highly influential attendees to Freiburg im Breisgau, to momentarily take a break from their academic merits and investments in favor of open and constructive discussion. This approach is directed at fostering collaboration and dismantling barriers between different scientific communities.

Following an introductory session that showcased the foundations and potential of non-linear X-ray spectroscopies, the first day addressed the technical challenges of wave mixing with X-ray Free Electron Lasers (XFELs) and High Harmonic Generation (HHG) sources, with an open perspective towards time-resolved imaging. The sessions showcased the potential of these technologies in advancing both fundamental research and advanced imaging applications, tackling the challenge of spatial and time resolution.

The second day's objective was to establish a common language between theory and experiments. It introduced emerging spectroscopic techniques to measure -and to some extent manipulate- covariance and correlations. The session prepared the audience to venture in the ultrafast processes occurring at molecular level, where the speakers showcased the power of non-linear X-rays spectroscopies in probing system with strong coupling between nuclear and electronic degrees of freedom.

The closing day elaborated on the capabilities of core-level transient grating spectroscopies in probing condensed matter systems, and the workshop closed with the last two sections returning on Extreme-ultraviolet (EUV) and X-Ray wave-mixing. The circular structure of the program enabled the audience to integrate and corroborate notions coming from different communities and form a comprehensive landscape. This process resulted in the most stimulating aspect of the workshop: the panel discussions. The rich sessions featured the daily speakers as panelists, involved in an open discussion with the audience. The open format acted as a bridge between different communities, bringing to light opportunities and challenges.

It emerged that the theoretical development is a valuable support for breaking down the complexity of femtosecond and attosecond dynamics features. Simulations allow to individuate interesting systems, carrying the potential to inspire techniques and experiments directed to probe fundamental features of molecules, for example, attosecond probing of conical intersections, electronic charge migration in molecules and chiral-sensitive X-ray spectroscopies. The major barrier for theory to actively support the experimental development comes from the limited capability of current methods to fully understand and simulate the complexity of experimental systems, accurately accounting for realistic noise sources that are very present in each experimental realization.

The developments of experimental techniques and platform have shown how emerging non-linear techniques and transient grating carry the promise of achieving exceptional spatial and temporal resolution, in the complete range from the EUV to the hard X-rays. For example, probing the nano- and meso-scale with transient grating spectroscopies allows to observe heat and spin diffusion in condensed matter systems at hitherto inaccessible length scales, and it is a powerful protocol to probe electronic coherences and non-linearities. However, the technical development can be impaired by practical limitations, for example realizing diffractive gratings

for XFELs robust to radiation damage, achieving a reduction of the repetition rate and devising multi-pulse techniques, or the presence of strong noise and highly non-linear interactions that typically result in an arduous interpretation of the results.

WavemiX2023 is a step towards the bigger picture of establishing a common language in different scientific communities and understanding the unique needs and challenges faced by scientists across different fields in exploiting the vast potential of novel free electron laser and HHG sources. The long-term goal of ensuring that advanced nonlinear spectroscopy, imaging and attosecond techniques are developed and applied in genuinely useful and beneficial applications is ambitious. However, the talents of the WavemiX network are surely up to the challenge, and we await with curiosity and expectation the next edition WavemiX 2024, yet to be officially announced on the WavemiX webpage.

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Competing interests
The author declares no competing interests.

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