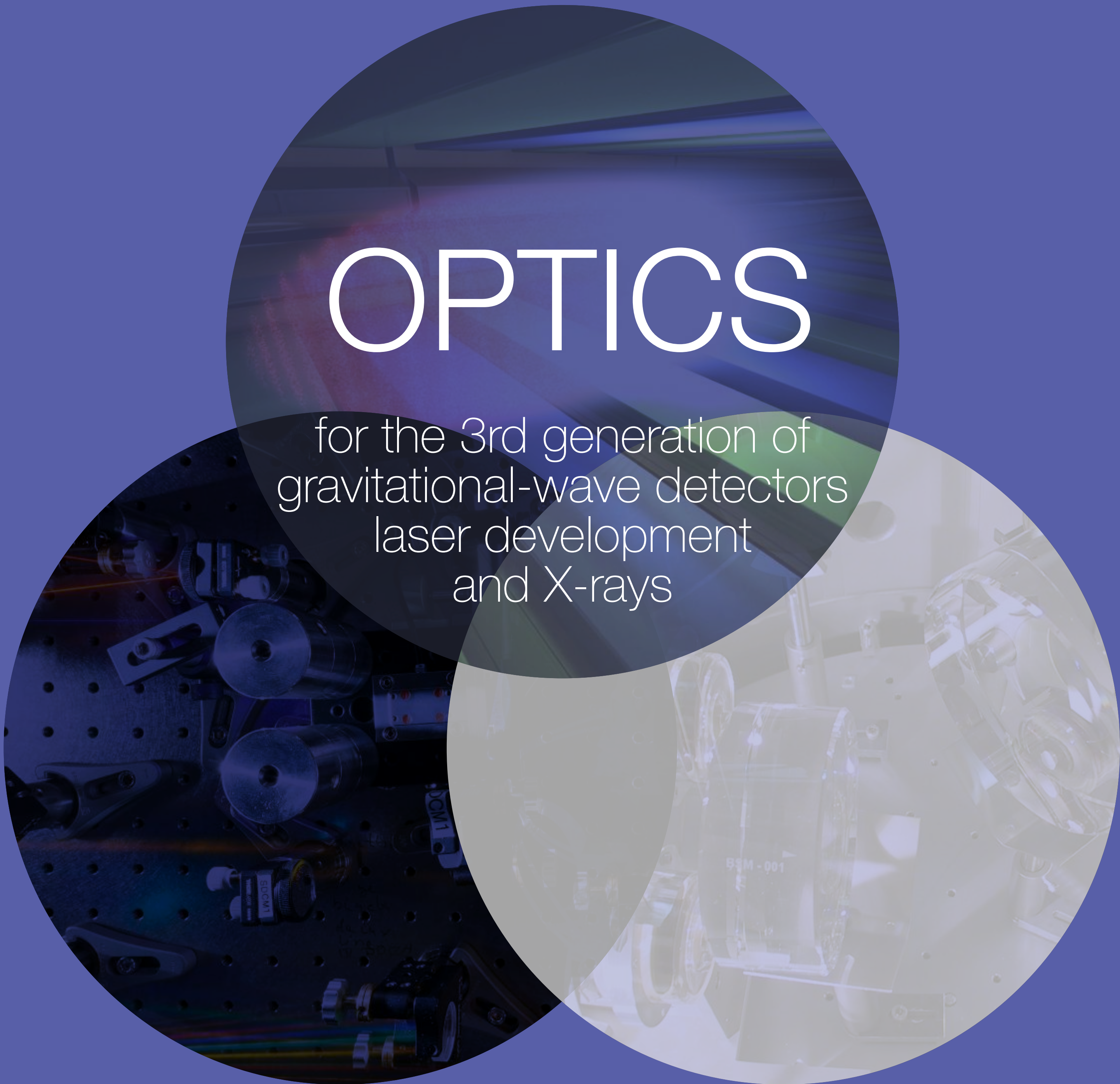
APPEC Technology Forum 2017

OPTICS

for the 3rd generation of
gravitational-wave detectors
laser development
and X-rays



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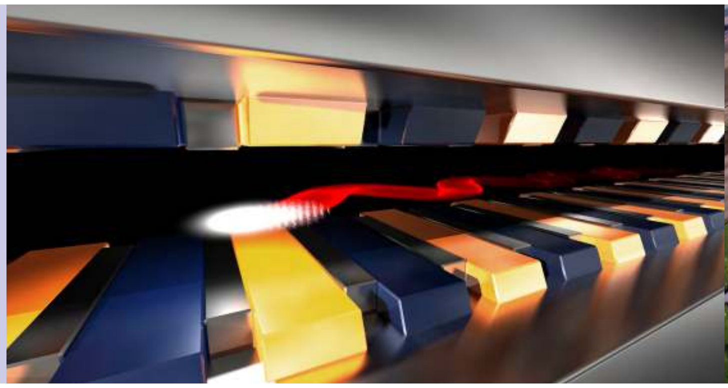
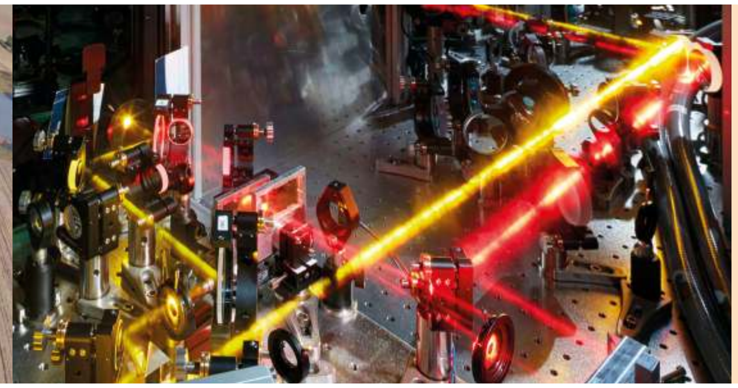




New synergies in optics

for an effective interdisciplinary collaboration in scientific and industrial R&D

2016 was a remarkable year for science and technology development.
In February, the official announcement of the first direct detection of gravitational waves (GW) became the symbol of how consequent improvements in technology can finally reward decades of experimental efforts.
A few months later, in October 2016, the commissioning of the world's largest X-ray laser, the European XFEL (X-ray Free Electron Laser), started. Building this facility was a real technological challenge and required revolutionary improvements for example in the fields of optics and synchronization.
In science, a next-generation experiment is usually defined by a new scientific goal to be reached, based on a continuous advancement in technology or even a radical new design. Developments in optics are a key feature in many fields.
From the particle- and astroparticle-physics perspective, there are many examples where, in order to move forward to the following generation of experiments, breakthroughs in optics, optomechanics and laser development have to take place simultaneously. GW detection is one of these fields.
In retrospect, for laser interferometers, which are the state-of-the-art instruments to detect GW, the required fundamental advancements in optics were mostly in the sectors of coating manufacturing and laser development. A low level of thermal noise of the coating of the main mirrors of the interferometric setup is one of the most crucial requirements. The laser system driving the interferometer is very demanding: diffraction-limited high-output-power levels, with narrow bandwidth and outstanding stability are substantial prerequisites.
After these examples, it is clear that advancements in optics, optomechanics and laser technology are rather important for many research fields. The innovation potential is enormous and the progress in these technologies finds often immediate applications in everyday life.
Altogether, this strongly motivated the organization of a technology forum addressing these topics.

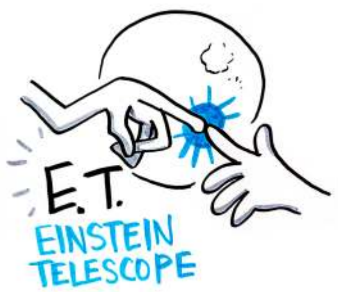
The APPEC Technology Forum 2017: aim and history

The major aim of the APPEC Technology Forum (ATF) is to foster cooperation and exchange between academia and industry. In this format, companies shall have the opportunity to present their products and developments and discuss with leading experts from academia. The technological challenges driven by science and the necessity of companies to develop new market-ready products shall be brought together to release the entire innovation potential.
Starting in 2010, this series of dedicated academia and industry events have been organized in the frame of ASPERA, the EU-funded network of national funding agencies active in the domain of astroparticle physics. Since 2015, this work is continued by APPEC, the astroparticle physics European consortium.
The precursor (ATF 2011[1]) focused mostly on astroparticle physics, namely on gravitational-wave detection and on Gamma-Ray astronomy.
In 2017, the aim was to support synergies also with fields outside of astroparticle physics and different ongoing cutting-edge topics.
In particular, the ATF 2017 was focused on three main applications of optics:

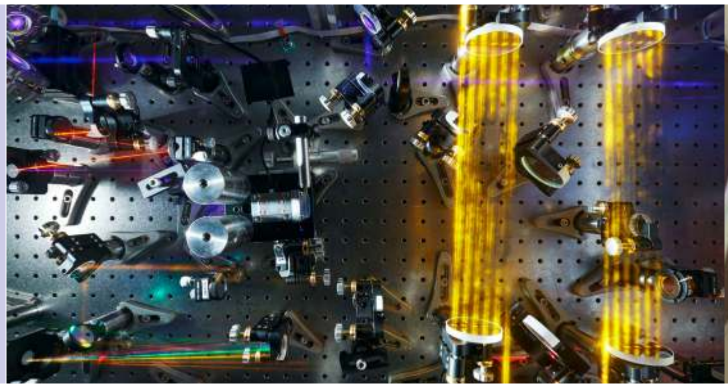
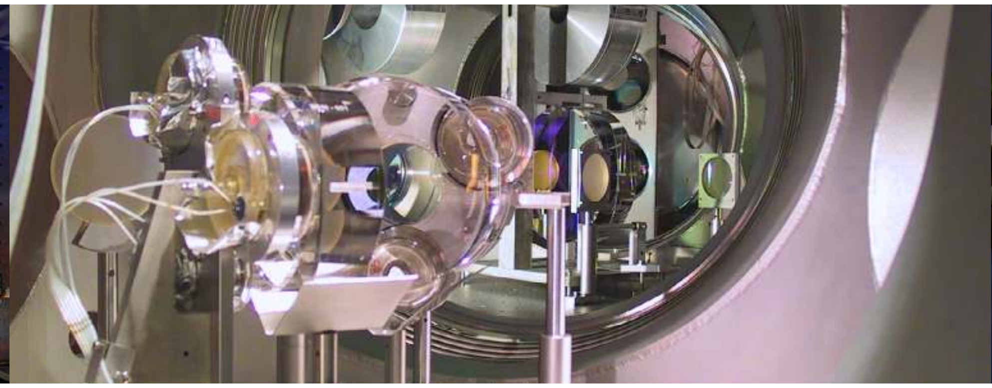
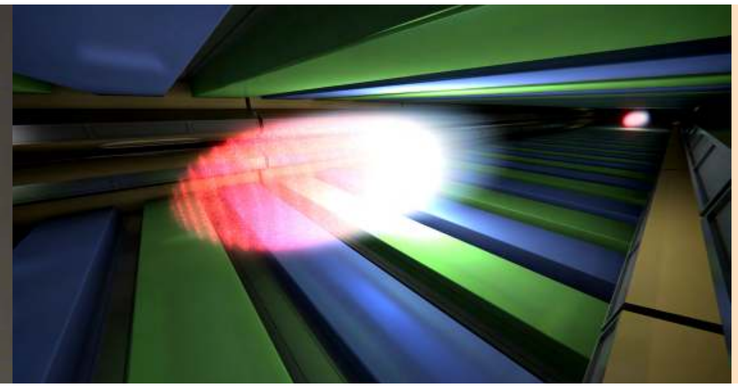
- development of the 3rd-generation gravitational-wave detectors
- laser development
- X-ray optics

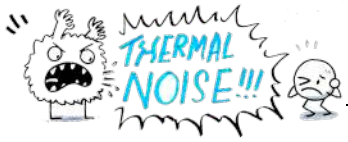
1 brochure: https://www.appec.de/doku.php?id=technology

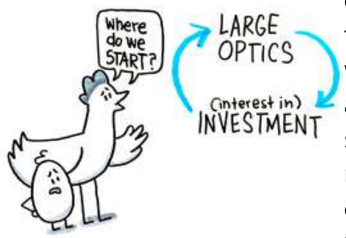
A Technology Forum can play a major role when the fields of interest are facing an active R&D period, with a past of gained experience and a future of new challenges to be confronted.
The experimental setup of the 2nd-generation GW detectors, Advanced LIGO (Laser Interferometer Gravitational-Wave Observatory) and Advanced Virgo, achieved the maturity needed to observe catastrophic events, such as black-holes mergers or binary neutron star coalescence. This milestone, together with the potentials for improvement hidden in multiple aspects of the present detectors, exponentially increased the urgency for the realization of very ambitious programs like ET - Einstein Telescope - and LISA - Laser Interferometer Space Antenna.
Numerous developers from companies and academia in Europe gathered in Hannover to discuss the next challenges in terms of coating and laser technology for the realization of the next generation of GW detectors.
The commissioning phase of European XFEL in Hamburg - approached after the experience gained with the free-electron laser FLASH, other FELs and the European XFEL installation period - witnessed similar situations in different R&D areas. Furthermore, the upcoming operational phase, which started a few months after the forum had taken place, was the main driver for the search for clarifications and discussions. Experts in the manufacturing and setting up of suitable optics, able to cope with high-energy X-ray pulses, and professionals in the development of optical lasers built to interact with these pulses, presented the issues that are currently open questions in their work.
For more than a century, X-ray pulses are the most powerful technique to investigate structure in condensed matter. For this reason, table-top alternatives to large facilities can offer the advantage of an affordable and higher accessibility to X-ray sources if benchmark performances are not mandatory. For the development of compact systems based on ICS - Inverse Compton Scattering - reliable high-repetition-rate optical lasers are needed in two different stages of the acceleration of the electrons that then generate X-ray pulses. Such laser systems are not radically new, but represent challenging evolutions of existing technologies tailored to ICS specifications.
ALPS - Any Light Particle Search - a project placed at the edge between particle and astroparticle physics, has reached its second phase (ALPS II). This experiment explores the physics beyond the Standard Model and aims to detect rare events, such as in GW detection. In the ALPS project, the evidence of the existence of the most famous WISP (very Weakly Interacting Sub-eV Particle), the axion, is investigated via a so-called *light-shining-through-a-wall* experiment, where as well as very stable high-power lasers, sophisticated polishing techniques and coatings for high-finesse optical resonators are required.



At the ATF 2017, companies had the chance to present their products through talks and at their stands. Developers from academia used the opportunity of an exchange with the companies.
By bringing together developers and experts from gravitational-wave, astroparticle and particle physics, laser experts and the FEL community, the ATF 2017 allowed the discussion of overlapping demands for technological advancements in the different scientific and technological fields and the possibility of joining forces in common R&D initiatives.





The APPEC Technology Forum 2017: what we have learnt

To particularly support discussions and the search for solutions of the present challenges, one or two representatives of each main topic had the opportunity, during extended open sessions, to focus on problems in their sector and interact with the audience.

During the timeslot dedicated to coatings for the 3rd-generation GW detectors, the two speakers represented the dualism that the field is facing at the moment under two different perspectives: a pure technological one and a political one. One speaker represented LMA - Laboratoire des Matériaux Avancés - as a public institution dedicated to the study and manufacturing of amorphous coatings; while the company CMS - Crystalline Mirror Solutions - proposes a new approach with self-developed crystalline coatings.

Thermal noise around 100 Hz is one of the most well-known problems to be overcome in coating technology for GW detection. Nevertheless, other issues, such as cavity round trip losses also need to be faced. Fundamentally, the challenges belong to two main technological aspects: the deposition and the metrology needed to test unequivocally the coatings. At LMA they are confident amorphous coatings will be able to sustain the 3rd generation of GW detectors, but only with further intensive and expensive research on amorphous materials. The implementation of the standard SiO$_2$ has been challenged by promising results given by Ti:Ta$_2$O$_5$. Nevertheless, it is not excluded that further studies on e.g. amorphous Silicon at different growth temperatures or Si$_3$N$_4$ will open new frontiers for amorphous coating development.

CMS offers an alternative solution, proposing crystalline coatings which are directly transferred on crystalline substrates (e.g. GaAs/AlGaAs). This technology has demonstrated high mechanical Q, thermal conductivity and mid-infrared transparency over traditional ion-beam-sputtering coatings. At the moment, the major constraint is given by the scalability: mirrors larger than 200 mm cannot be built because of a fundamental limitation in the size of the GaAs wafers. Even if this can be overcome through collaborations with other companies, the reproducibility is an issue.

The common understanding of the discussions is that both approaches need more investment in personnel and prototyping to drive the developments further. From one side, more amorphous materials could be tested and from the other side more efforts could be put in extending the size of crystalline coatings.

In another session of the ATF2017, a representative of the University of West Scotland showed the capabilities and results of their laboratory in terms of development of both amorphous and crystalline coatings.

The GW-community decided so far to completely rely on public-funded laboratories like LMA and the University of West Scotland. They have the flexibility to evolve, depending on the requirements of the experiments (e.g. LMA could turn into LMA II, in order to fulfill the specifications for ET). Nevertheless, experiences in another large experiment community such as European XFEL have demonstrated that intensifying cooperation between companies and research centers may result in new solutions applicable to future laser interferometers for GW-physics.

The need for a global approach in the coating-development business has become clear and important steps in the direction of a world-wide intense communication and collaboration are planned to be taken in the second part of 2017.

Concerning the laser development needed for the next generation of GW-detectors, the community is confident that the present challenges can be solved by continuing the running R&D efforts and a global approach is not foreseen in the near future.

Nevertheless, specialists working in this field have a different point of view. They are aware of the numerous potentials hidden in the different stages of the development, which could be exploited if expertise and resources were applied on a global scale.

The LZH - Laser Zentrum Hannover - is a third-party funded institution and responsible for the laser development for GW-detection. They are engaged in a special niche field between science and pure engineering, which makes them key experts in the realization of reliable tools for scientific applications and original patents. They have an autonomous approach similar to the one of the coating-development laboratories, tending to be independent from any potential partner from the private sector, with the aim to acquire an overall competency in the development of specific laser systems. This attitude promoted a strong collaboration with spin-off companies of LZH (e. g. neoLASE and FiberBridge). The desire for a flexible and straightforward system pushed them towards a general reduction of the complexity of the developed lasers, on which the necessary regular maintenance can be carried out by less experienced people.

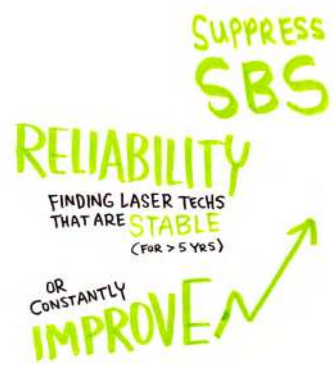
This is the opposite tendency if compared to the laser development carried out at European XFEL, where the cooperation with private companies has driven them towards extremely customized systems which fulfill a broad range of demanding requirements, but are also more challenging to be maintained.

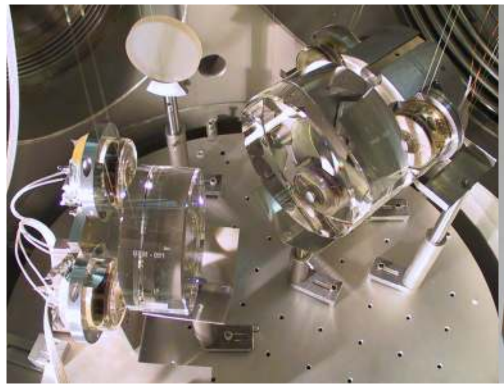
Nevertheless, common ground of the two communities is the choice for modular systems, which always simplify and accelerate repair and replacements in the case of damages.

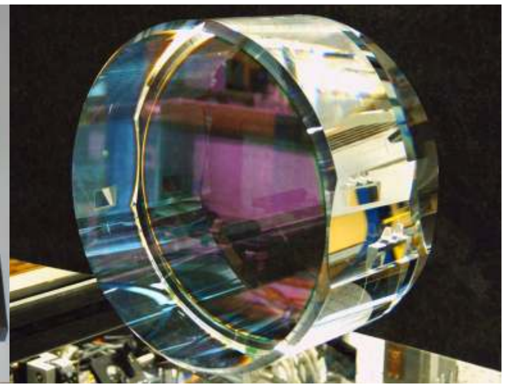
More technically speaking, laser development for GW-detectors is at the moment taking a revolutionary step from solid-state to fiber technology, in order to overcome the limits encountered by the previous generation. A major challenge is beam pointing, i.e. its origin and finding ways to suppress it. In addition, a certain degree of complexity in terms of diversification is being considered, in order to cover efficiently the detection of low-frequency GW: 1 µm lasers, efficient in high-frequency GW detection, could be supported by 1.5 to 2.0 µm lasers. In this last wavelength range, fiber technology is more advanced and promising for the development of a reliable system. Nevertheless, problems such as photo-darkening, mode instability, suppression of SBS - Stimulated Brillouin Scattering - and degradation of the components will have to be faced. These are the reasons why in general a lower emitted power of these systems is expected but tolerable, in comparison to the 1 µm lasers.

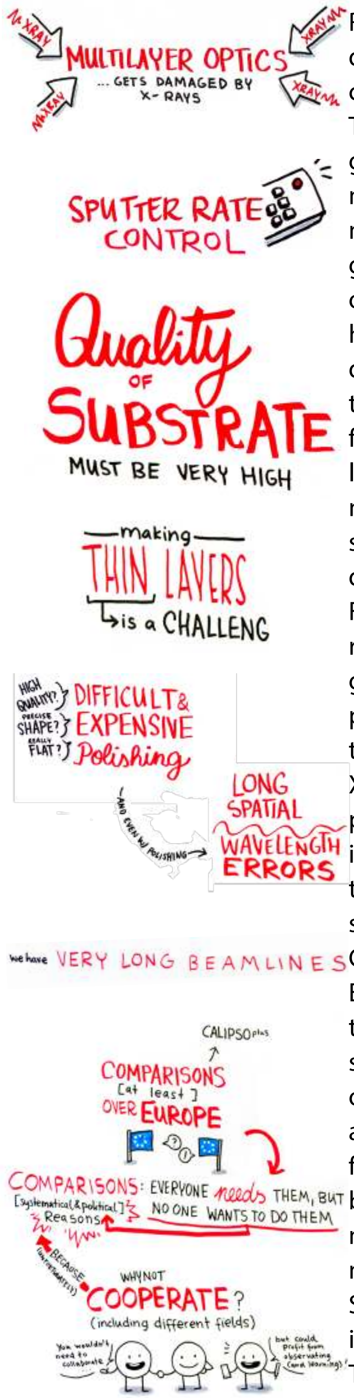
Finally, the reliability that the laser system should offer is still an open question.

The GW-community suggests a dynamical solution, where the laser can be modified/upgraded already after 5-6 years, while the laser engineers recognize that this period accounts only for the development phase. In order to cover a sufficient time for detection measurements, a reliability and durability period of at least 10 years should be guaranteed.









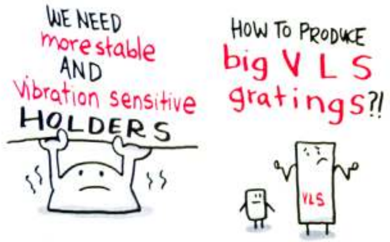
Regarding the development of X-ray optics, two different aspects could be considered: the fabrication and the installation.

The coating technology has to face the challenges issued by ultimate X-ray sources, such as modern synchrotrons and FELs. The approach of multilayer optics does not impose only very stringent figures and finish - e.g. only a few angstroms of roughness are usually allowed - but also very high damage thresholds. The starting substrate quality has to be very high and the control over the sputter rate has to be absolute, in order to fabricate very thin layers and extended over a relatively large surface. In this case, an active diagnostic has to be implemented in order to have a stable deposition rate over days and it is typically driven by an optical laser beam.

For the special meter-long optics required at European XFEL, external companies have been engaged for the fabrication and one of the crucial points is the needed accuracy in polishing. The technology that at best fulfills the demands for X-ray optics is deterministic polishing, which is particularly accurate and expensive, being an iterative procedure with quality dependent on the number of applied loops. Nevertheless, long spatial-wavelength errors cannot be removed.

Concerning the installation of such mirrors at European XFEL, the main problems are given by the length of the beamlines, which require a very stable positioning. For this reason, the holders of the mirrors have to be particularly robust but also movable, which means two motor systems for active stabilization and fast adjusting are the best solution. Furthermore, the large size of the mirrors imposes other more sensitive optical elements to be as large, such as VLS - Variable Line Spacing - gratings, which still do not exist in the ideal dimensions for European XFEL.

The requirements for X-ray optics have given interesting room for discussion with the GW-detectors experts.



The polishing quality is an order of magnitude more stringent for X-ray then for GW-detection optics, but at LIGO a technology for moving mirrors is present and possibly inspiring for the European XFEL mirrors.

The topic that has the same level of priority for both groups of experts is the need for a common platform for metrology measurements, references and standards. This kind of platform could be interdisciplinary and fruitful for scientists from different fields. Its organization would certainly be time- and energy-consuming and a missing policy for sharing investments between different fields still represents an obstacle for these kinds of initiatives. Nevertheless, European funding is available for such applications and the project Calipso Plus (www.calipsoplus.eu) is just an example of its potential. It has, among others, the aim of sharing information and creating a database for metrology measurements.

In addition, the experience matured during the installation of European XFEL led to the constitution of a metrology laboratory in the local Hamburg area. In the past years, scientists learnt how to work in close collaboration with industry, undertaking different and more effective ways than generic calls for tenders. They typically generate mere competition among different companies, without promoting teamwork when specific strengths could be highlighted. The metrology laboratory will soon be available for interesting collaborations with scientists and companies also from other fields.

The APPEC Technology Forum 2017: what's next?

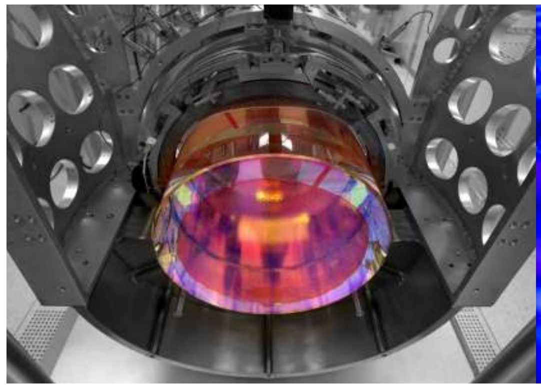
During the ATF 2017, the interdisciplinary exchange among all the developers has played a major role in the discussions and different perspectives and experiences have been compared.

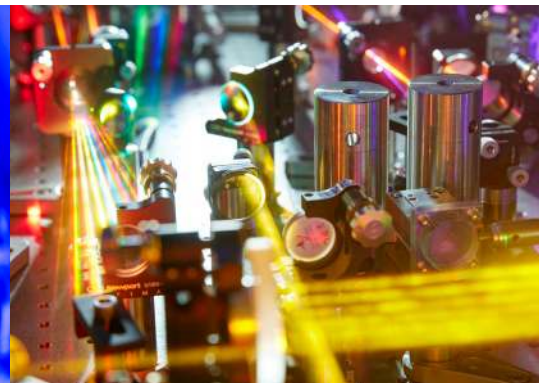
The foundations for new initiatives of intra- and extra-field teamwork have been laid and the formation of revolutionary platforms on a European up to worldwide level has been introduced.

The delicate relationship between science and industry has been treated under different aspects and from both points of view, including the collaborations between research centers and their own spin-off companies, up to long-term cooperations with large enterprises. Proposals for new deals have been officially stated during the meeting and traditional collaborators have confirmed their loyalty to each other for further future projects.

All these positive results suggest that a new event in 2018 will have a major resonance and will be able to aggregate similar communities with common challenges which have to be faced and solved.

From the needs of the X-ray optics installers and of scientists having an astroparticle- and particle-physics background, ultra-stable and damping holders for mirrors, but also for magnets and detectors is a topic which could interest a vast group of researchers and industry experts and could be chosen for the ATF 2018.





Scientific topics

Coating and thin-layer development

for GW-detection

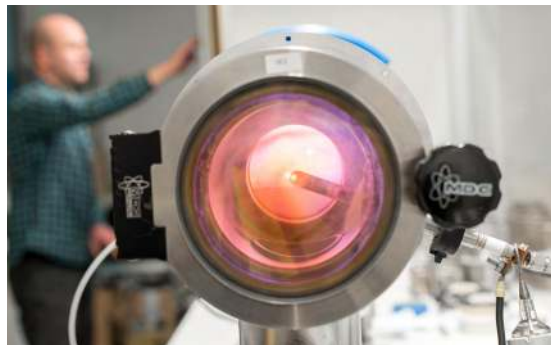
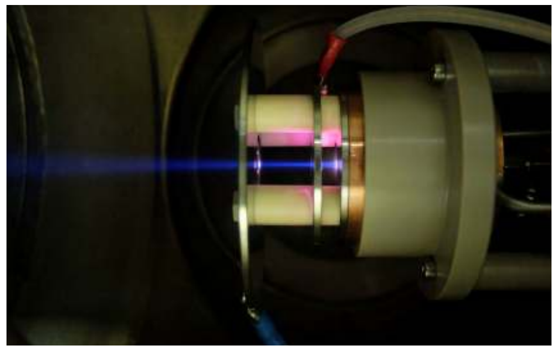
General

For future gravitational wave detectors to remain quantum noise limited instruments, further reductions in Brownian thermal noise will be required. The dominant source of Brownian thermal noise within the optical cavities of current detectors, such as Advanced LIGO, is associated with the dielectric mirror coatings, required for high reflectivity. The optical coatings currently comprise of ion beam deposited (IBD) multilayers of SiO_2 and Ta_2O_5 (with some fraction of TiO_2 mixed in the Ta_2O_5 layers) for the low-/high-index layers. Significant reductions in thermal noise will likely require a move towards cryogenics, selecting suitable substrate and coating materials with appropriate properties at these temperatures. The most attractive route, e.g. as detailed within the Einstein Telescope design study in Europe, is the use of silicon optics, and implementing laser wavelengths of 1.5 µm (or possibly longer).

During his talk, **Ross Birney** provided an overview of the status on amorphous coating materials suitable for use at 1550 nm, with a particular focus on amorphous silicon coatings. An overview on crystalline coatings has also been provided, including the status of AlGaP thin film growth capabilities being developed in Scotland for the gravitational wave community.

Requirements:

- reduction of Brownian thermal noise associated with the dielectric mirror coatings required for high reflectivity
- cryogenics (possibly)
- silicon optics


University of Glasgow
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http://www.uws.ac.uk/staff-profiles/engineering/ross-birney

Fiber-optic development

for GW-detection

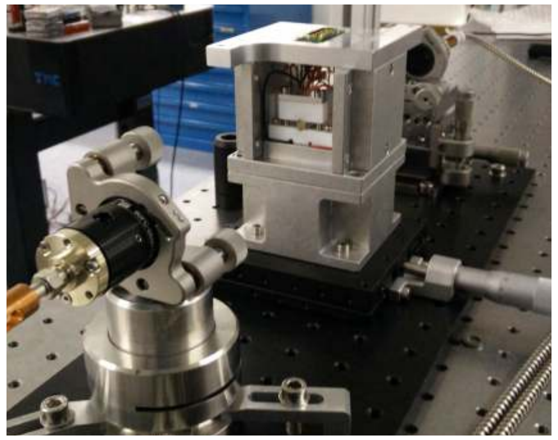
General

In 2007, LIGO and Virgo, the interferometric gravitational-wave detector of EGO (European Gravitational Observatory), agreed to join in a collaborative search for GW from sources in and far beyond our galaxy. This means that since then the three LIGO detectors in USA and its German partner GEO600 are linked with the Virgo detector to increase the lieklihood of detecting GW. Nine years later, after the implemantation of different fundamental upgrades in any key stage of the setup, the collaboration gave an outstanding result with the first detection of GW.
Nowadays, in the multiple different laboratories supporting the upgrades in the three main facilities, the R&D teams are coordinated to apply and further improve cutting-edge technology in order to significantly increase the sensititivity in the GW-detection.
In the specific, at EGO they are investigating the use of optic fibers for the injection part of gravitational-wave detectors (optics located between the main laser and the interferometer). The idea is to have components, electro-optics modulators and Faraday isolators, that are fully fibered in order to ease the whole injection subsystem, from the laser (eventually fibered as well) to the Input Mode Cleaner. This would especially be useful for the propagation of the beam between the different benches.

During the talk, **Eric Genin** gave an overview of the project and the laser development at EGO, while **Matthieu Gosselin** described the results, challenges and perspectives of the experiments he is carrying out.

Requirements:

- management of high power density (hundreds of Watts over hundreds of squared micrometers):
  - non linear effects inside the fibers
  - damaging of the fibers
- design improvements of the components



https://www.ego-gw.it/

Amorphous-coating development

for GW-detection

General

Thermal noise in optical coatings is the main fundamental limitation to the detection of GW in the frequency band around 100 Hz where the detectors are more sensitive.
The technology used for the Advanced Detectors (i.e. 2nd generation) is based on the amorphous coatings adapted for the 1064 nm wavelength. In the next generation the challenges are given by a reduction of the thermal noise level, the cryogenic temperature operation as well as the room temperature one, and the size that should grow from the 350 mm of today to the 600 mm in the future.
An extensive research of all these challenges has already started at LMA in collaboration with several local and Virgo laboratories. Amorphous coatings have the potentiality to fulfill the requirements for the 3rd-generation detectors.

During his contribution, **Gianpietro Cagnoli** gave a general introduction about the problem of mirror thermal noise in GW detectors; the requirements for the 3rd-generation detectors; a short introduction of LMA and its collaborations on coating thermal noise research; a description of the technological challenges.

Requirements:

- reduction of thermal noise in optical coatings, especially at 100 Hz
- increasement of the size of the coated surfaces
- room-temperature and cryogenic operation

http://lma.in2p3.fr/Lmagb.htm

ALPS II

Any Light Particle Search (2nd phase)

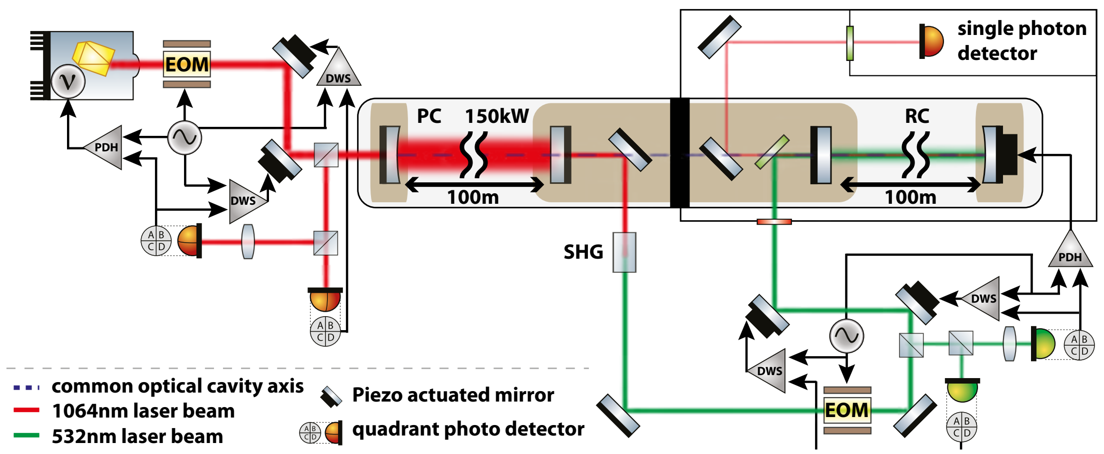
General

The ALPS Collaboration started in 2007 its first *light-shining-thorugh-a-wall* experiment (ALPS I) searching for photon oscillations into weakly interacting sub-eV particles (WISPs). DESY could show the best laboratory limits for WISPs in 2010, improving previous results by a factor of 10.
After this success, the ALPS Collaboration decided to persue further the search of WISPs and designed the ALPS II experiment. In this phase, the driving observations are of astroparticle-physics nature (e.g. stellar evolution and the TeV-transparency). The Standard Model is not able to explain such phenomena and ALPS II aims to probe into their characteristic regions.

During his talk, **Jan Hendrik Pôld** described the concept of the ALPS II experiment and outlined the challenges, focussing on the precision optics required.

Requirements:

- ultra stable laser sources,
- resonant optical enhancement techniques,
- string of dipole magnets
- special photosensors with e.g. low dark count and background rates and high efficiency for infrared photons.



https://alps.desy.de/e191931/

Development of ultrafast optical lasers

for Inverse Compton Scattering X-ray sources

General

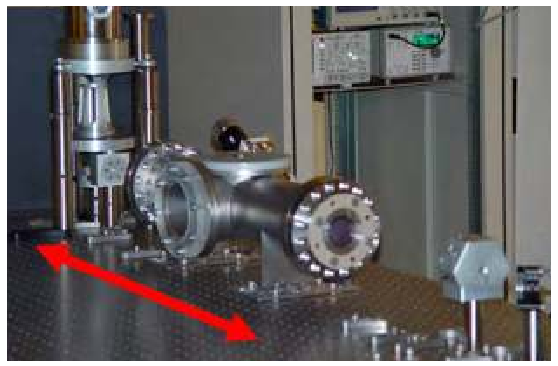
For scientific applications in the study of ultrafast dynamical processes in matter, the Ultrafast Optics and X-Rays Group at DESY is developing ultrafast laser drivers to serve as the primary power in a compact, laboratory sized Inverse Compton Scattering (ICS) X-ray source.
Liquid-nitrogen cooled DPSSLs (diode-pumped solid-state lasers) based on Yb^{3+} offer a clear advantage with regards to all the requirements (on the right). Engineering leverage is gained by an intrinsic several-fold improvements in thermo-optical and thermo-mechanical properties as well as ~ decade higher gain-coefficients, which enable simple, passively switched multipass architectures to be implemented. Our progress in scaling chirped-pulse amplifiers has produced 250 Watt at 100 kHz and 160 mJ at 250 Hz based on liquid-nitrogen cooled Yb:YAG in rod and composite thin disk geometries.

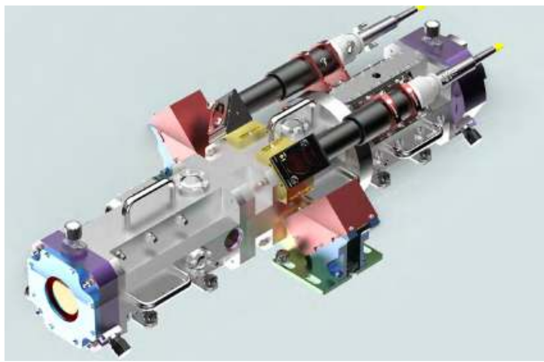
In his talk, **Luis E. Zapata** presented operational parameters for these systems as they are presently using them. He also reviewed the design of the power amplifier stage, now in the building stage, in scaling with a 20-mm-diameter cryogenic composite thin-disk towards 1-Joule pulse energy at 1 kHz.

Requirements

For ICS X-ray sources:

- laser-driven THz sources producing tens of millijoules of single-cycle and multi-cycle THz pulses efficiently to accelerate electrons to 15 MeV
- a high energy infrared laser pulse colliding with the electron beam provides the optical undulator to generate the X-rays
- operation at high repetition rates i.e. high average power lasers) to shorten the time necessary in the collection of scientific data
- size, weight and reliability, which are strongly tied on their complexity, have to be suitable





https://ufox.cfel.de/

Fiber-laser development

for GW-detection

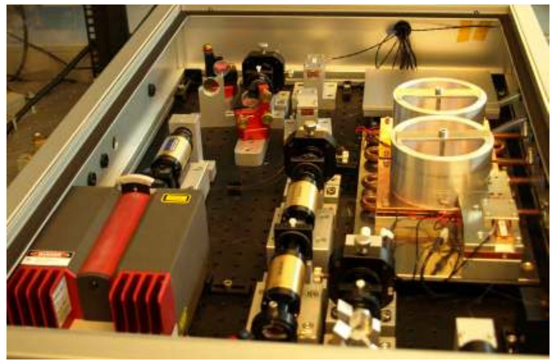
General

For the first generation of km-scale GW-detectors, solid-state laser technology turned out to be very promising, in particular in the form of non-planar ring oscillators (NPROs) at 1064 nm, because of their linewidth and intrinsic stability.
LZH together with the Albert-Einstein Institute (AEI) and the LZH spin-off neoLase have been responsible for the development of several generations and upgrades of the detectors of LIGO, Virgo and GEO600. The goal has been reached when the LIGO detectors were equipped with the optimized laser systems and in 2016, as part of the advanced LIGO upgrade, they were involved in the first detection of gravitational waves.
The GW-detectors community is already making plans for the next generation of detectors that will allow for a new era of astronomy.

In his talk, **Michael Steinke** presented the latest challenges and laser developments, which address the new frontiers of reliability and sensitivity in detection. In particular, the new laser systems are based on fiber technology, which allows for high single-pass gain levels and does not require complicated injection-locking schemes. Furthermore, due to a parallel detector development, longer wavelengths in the range of 1.5-2.0 µm are required, where fiber systems have shown good aspects for power-scaling. As result of a collaboration between LZH and AEI, a single-frequency fiber amplifier at 1064 nm has been developed, long-termed tested and will be further upgraded. In addition, a comparable fiber amplifier prototype at 1550 nm will be developed, after the successfull tests of a monolithic system with more than 100 W of output power in the TEM_{00} mode and an investigation of 2 µm single-frequency fiber systems is already planned.

Requirements:

- so far solid-state lasers with:
  - diffraction-limited high output-power levels
  - narrow bandwidths
  - outstanding stability
- for the new generation of GW-detectors, lasers have to provide:
  - even higher output-power levels
  - longer wavelengths
  - enhanced reliability by simple and user-friendly optical concepts all-fiber technology



http://www.lzh.de/en/departments/laserdevelopment/fiberoptics

Development of ultrafast optical lasers

for X-ray free electron lasers

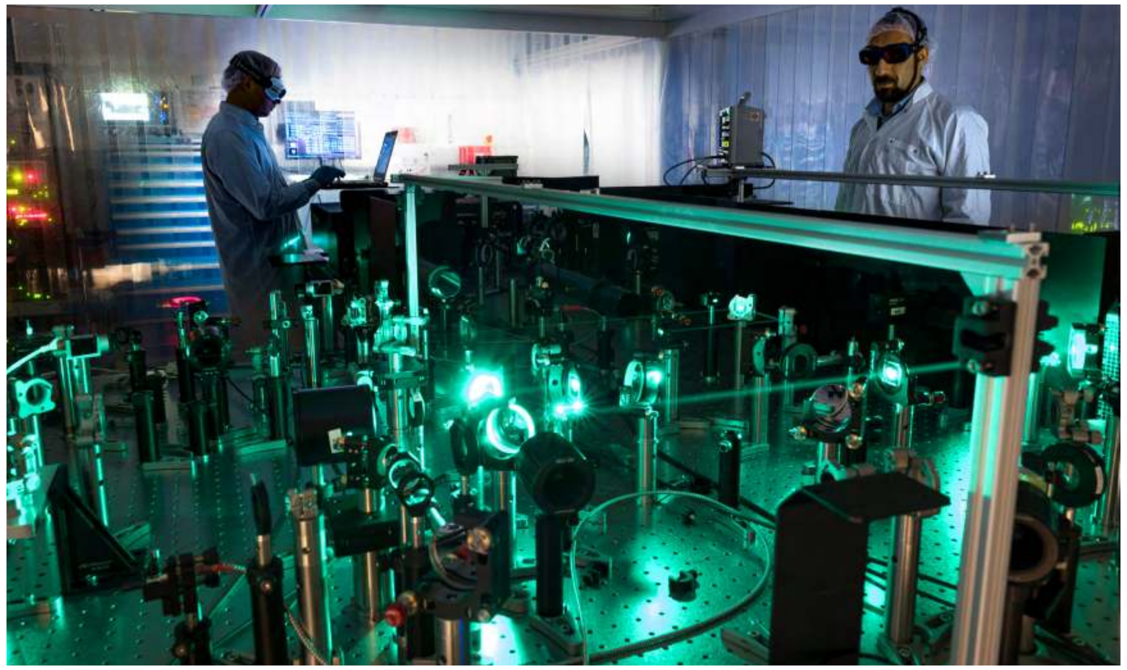
General

The European XFEL will start its operation in 2017, enabling innovative atomic-scale measurements at high repetition rates and with femtosecond time resolution. Helping to facilitate such experiments are highly specific, synchronized, ultrafast optical lasers, which can be used, for instance, to excite specimens before they are probed with x-rays. At the European XFEL a development of such a laser source aimed at the MHz/millijoule/ /femtosecond performance level, hence substantially outside the realm of commercial lasers.

In his talk, **Maximilian J. Lederer** presented the main results of the laser development taking place in his group and also highlighted some of their long-term collaborations with industry in the process.

Requirements:

- customization on demanding requirements of the accelarator facility and the users
- synchronization to X-ray beam
- support of industry
- versatile system in terms of:
  - energy scaling through a broad frequency change
  - generation of nearly transform-limited pulses in the femtosecond-range
  - generation of multiple wavelengths



http://www.xfel.eu

Development of diffractive X-ray optics

for high-brightness X-ray sources

General

Multilayers are artificially layered structures that can be used to create optics and optical elements for a broad range of wavelengths. Among other applications, they are enabling technology for extreme ultraviolet lithography (EUVL).
High-brightness X-ray sources, such as next generation synchrotrons and FELs, pose unique challenges but also great opportunities for the development of X-ray optics. The peak intensities of X-ray pulsed sources, such as FLASH in Hamburg, LCLS (Linear Coherent Light Source) in Stanford or upcoming European XFEL in Hamburg, are high enough to convert any material placed in the focused beam into a plasma. Hence, the optics do not only have to meet extremely demanding specifications in figure and finish but also in damage threshold and lifetime, as well as high efficiency and high numerical aperture.

In her talk, **Saša Bajt** presented how she and her group address these challenges and take advantage of the opportunities given by the work experience with FELs. In particular, she introduced the multilayer Laue lenses - novel diffractive X-ray optics with high-aspect-ratio structures, based on thick multilayers.

https://cid.cfel.de/team/multilayer_x_ray_optics/

Requirements:

Optics for high-brightness X-ray sources have to be characterized by:

- demanding specifications in figure and finish
- high damage threshold
- long lifetime
- high efficiency
- high numerical aperture

Development and implementation of X-ray optics

for X-ray free electron lasers

General

The European XFEL will be comprised of a lineear accelarator and three FEL beamlines (SASE1, SASE2 and SASE3) covering the energy range from 250 eV to 24 keV.
For the filtering and the transport of the X-ray pulses to every experimental station, different kinds of special optical elements of unprecedent precision have been developed.

Maurizio Vannoni introduced the different challanges that he and his colleagues in the frame of different collaborations had to face for the realization and installation of such opticl elements.
Reaching high quality polishing is very difficult. To ensure that a mirror is really as flat as needed or that it has a particular and precise shape, is challenging. Furthermore, during installation the mechanics could be affected and therefore a perfect optics could change its shape in an unpredictable way. Piezo-actuated silicon optics have been experimented and even commercially produced, but it is questionable if they could be controlled on a single nanometer of reproducibility. In FELs- setups is also very important to have a low vibration level of the optics. Improvements in active or passive dumping of the vibrations by allignment and control of optics holders need to be performed. In addition, there are still unsolved technological issues characterizing the soft-X-ray wavelength range, e.g. how to produce large Variable Line Spacing (VLS) gratings up to 500 mm of length.
A strategy which would optimize the efforts made by different teams is the organization of a platform, at least at European level, where different methods and results are routinely compared among each other. Such opportunity has also been discussed at the forum.

Requirements:

- single-nanometer reproducibility of adaptive optics.
- vibration-insensitive holders
- large gratings for soft X-rays
- periodic comparisons of methods and results at least within Europe

http://www.xfel.eu

Companies

AXILON

AXILON serves the worldwide synchrotron, accelerator and photon science community with state-of-the-art instrumentation and engineering services

Free electron lasers as well as the newest synchrotron light sources demand X-ray optics with extremely low surface errors and highest pointing stability, which results in very challenging requirements for the optic mounts and its adjustment units.

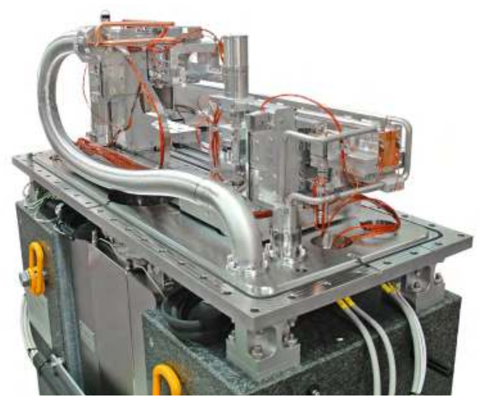
AXILON designs and builds mirrors systems, monochromators and all sorts of other beamline components as well as complete solutions serving those demands.

Based on their competencies and long-term experience of their experts, they can deliver excellent and efficient solutions to the worldwide synchrotron, accelerator and photon science community.

AXILON is interested to build up partnerships to apply their knowledge and experience, e.g. with high-precision mechanics in vacuum, in other fields.

At the Forum, **Timm Waterstradt** introduced the company to the audience.

http://www.axilon.de



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Bernhard Halle Nachfolger

Bernhard Halle Nachfolger provides the design and the production of a great variety of precision optical elements. Their workshop produces optical components of the highest quality made from crystals and optical glasses. With a team of scientists, they also provide optical design services as well as support in identifying the optimized solution for customers' tasks

Range of services

Bernhard Halle Nachfolger offers quick delivery for many components from their catalogue containing more than 500 products. Furthermore, they have in-house capabilities for design and production of custom optics.

A special focus is put on:

- polarizers
- wave plates (retarders)
- lens systems (UV to IR)
- reflective optics
- prisms and beam splitters
- design of polarization optical systems
- design of lens systems

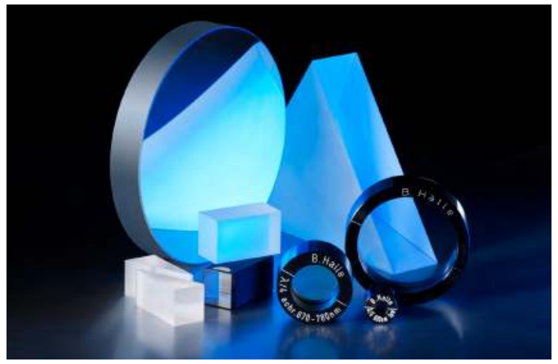
Special equipment

The combination of traditional production techniques with modern measurement equipment enables them to manufacture small series with reasonable effort. This opportunity can give their partners a key advantage in research projects as well as in meeting the increasing demand for customized products.

Current state-of-the-art technologies

- polarizers with extinction ratio down to 10^{-8}
- superachromatic waveplates for the range 310 - 1100 nm
- apochromatic lens systems for the range 190 - 1100 nm

In his talk, **Jakob Silbermann** gave a short introduction to the history of the company Bernhard Halle Nachfolger and the range of products it provides. Furthermore, he focused on broadband achromatic waveplates and on an example how they can be customized. The talk was summarized by the description of an experimental setup that includes such a customized broadband achromatic waveplate to generate circular polarized light in the extreme ultraviolet.



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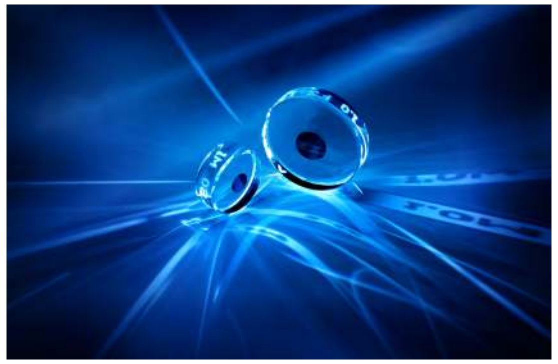
CMS - Crystalline Mirror Solutions

Crystalline Mirror Solutions manufactures low-noise refelctive optics using a proprietary coating technology

Ultrastable optical interferometers require mirrors that simultaneously exhibit excellent optical and mechanical quality. The current bounds of stability and sensitivity in these systems are dictated by the mechanical dissipation and thus the corresponding Brownian noise level of the high-reflectivity interference coatings that comprise the cavity end mirrors.

A spin-off of fundamental quantum-optics research from the University of Vienna, Crystalline Mirror Solutions, has developed a novel microfabrication technique that enables the transfer of low-loss single-crystal semiconductor heterostructures onto arbitrary optical surfaces. These "crystalline coatings" simultaneously exhibit minimal mechanical and optical losses, with mechanical loss angles an order of magnitude below that of ion-beam sputtered dielectric coatings at room temperature and over a factor of one hundred lower at cryogenic temperatures, coupled with sub-ppm levels of optical absorption and scattering losses at the few-ppm level for relevant wavelengths spanning 1000 to 2000 nm. The excellent optical quality in these crystalline mirrors has enabled cavity finesse values in excess of 300,000 in the near infrared for coatings on fused silica, sapphire, and silicon substrates, with coating sizes from the single-centimeter level up to diameters of 10 cm, with a clear path to manufacture 20-cm transferred coatings. The remaining technical hurdle lies in the further scaling of these optics to a size larger than 30 cm in diameter.

In his presentation, **Garrett D. Cole** outlined the development steps required for the successful implementation of their crystalline coatings in future generations of laser-interferometer-based gravitational-wave detectors.



http://www.crystallinemirrors.com

CMS
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Coherent

Coherent is one of the world's leading suppliers of laser solutions.
Their portfolio of laser tools and optical components are used in scientific, industrial and medical applications

Considering the broad market of products that Coherent can offer, at the ATF 2017 the focus was pointed on the Mephisto product line - ultimate low-noise laser performance.

Mephisto single-frequency ultra-narrow line-width lasers were successfully integrated in Coherent's scientific products portfolio in recent years while continuing to serve most demanding low noise applications.

In his talk, **Mantas Butkus** reviewed the current status of Mephisto product line with the focus on GW applications. The potential methods of power and wavelength scaling was also discussed.

https://www.coherent.com

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Cycle

The mission of Cycle is to commercialize femtosecond laser technology and related developments of the Ultrafast Optics and X-rays group at DESY

Cycle GmbH is a spin-off company from DESY founded in 2015 by Franz X. Kärtner and co-workers from his research group at DESY.

A first series of products solves the timing and synchronization problems of customers that need to time and synchronize multiple laser and microwave sources with femtosecond or even sub-femtosecond accuracy.

Potential customers are ultrafast laser laboratories in general that may only need to tightly synchronize two femtosecond lasers up to km-scale X-ray Free-Electron Laser facilities such as the European XFEL.

In his talk, **Franz X. Kärtner** explained the principles of operation of such timing distribution systems and discussed the specifications reached today.

http://www.cyclelasers.com

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FiberBridge Photonics

FiberBridge Photonics offers customized fiber components, fiber assemblies - for a wide range of fiber types in the wavelength range between 400 and 2200 nm - and customized fiber component machinery

FiberBridge Photonics is a spin-off company of the Laser Zentrum Hannover e.V. - founded based on 10 years of experience in fiber-component manufacturing and fiber-based laser development.

FiberBridge Photonics - your partner for fiber-based light guiding solutions.
Challenging scientific projects often need cutting edge technology. For the laser development of the 3rd-generation GW-detectors fiber laser systems seems to be a very promising solution. Key advantages are power scalability, high optical-to-optical efficiency, modularity and the possibility for a monolithic all-fiber structure accompanied by low frequency- and power noise as well as extreme low laser beam pointing. For the realization of monolithic all-fiber structures FiberBridge Photonics provides precisely manufactured customized fiber components, such as fiber couplers or splitters and highly integrated fiber assemblies, such as fiber amplifier modules.

https://www.fiberbridge-photonics.com

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Incoatec

Incoatec develops and manufactures sophisticated multilayer and total-reflection X-ray optics as well as microfocus X-ray sources for in-house crystallography and synchrotron applications

For synchrotrons Incoatec developed coatings with a length of up to 150 cm for beam conditioning (together with their partners from HZG - Helmholtz-Zentrum Geestacht), multi-stripe multilayer optics for tomography beamlines and 2-dim beamshaping multilayer optics, so called Montel-Optics, for inelastic scattering applications.
In the home-lab multilayer-based Montel Optics are widely used as an essential component in modern X-ray diffractometers. These optics consist of bent substrates with shape tolerances below 100 nm, upon which multilayers are deposited with single-layer thicknesses in the nanometer range and up to several hundreds of layer pairs. The multilayers are designed with lateral thickness gradients within ± 1% deviation from the ideal shape. Very low shape tolerances below 100 nm and figure errors below 5 arcsec are required for multilayer mirrors to ensure a superb flux density of more than 4 x 10^{11} photons/s/mm^2 in combination with very high-brightness microfocus X-ray sources, such as the novel liquid metal jet X-ray source.
Incoatec uses sputtering technology for deposition, optical profilometry in order to characterize the shape and X-ray reflectometry and the multilayer thickness distribution, both laterally and as in-depth. For X-ray analytics the important beam parameters are monochromaticity, flux, brilliance and divergence. They demonstrate the quality of the combination of suitable X-ray sources with selected multilayer optics.

In his contribution, **Jörg Wiesmann** gave an overview on current developments of multilayer optics for analytical X-ray applications in the laboratory as well as for synchrotron applications. He explained the manufacturing process of the optics, summarizing the different types of optics and giving some examples of typical applications which benefit from the new possibilities, especially in combination with modern microfocus X-ray sources.

Furthermore, he showed first results of a 50 cm laterally-graded multilayer optic, developed for a special mini-synchrotron and a multi-stripe multilayer optic with an optimized coating for different beam energies in the range of 10 to 45 keV which is used at the tomography beamline at the Swiss Light Source.

http://www.incoatec.de

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Laseroptik

LASEROPTIK focuses on the development and production of optical coatings and components for high-power laser applications and precision metrology in industry, medicine and research

LASEROPTIK employs a wide and increasing range of measuring equipment for quality inspection and process optimization to the benefit of their customers.

In his talk, **Robin Bähre** presented an overview of their coating technologies for high-power and low-loss applications, very large optics and other special configurations, such as dispersive mirrors, low-stress coatings to meet high-flatness requirements and qualification for spaceborne conditions.

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neoLASE

neoLASE provides Master Oscillator Power Amplifier - MOPA - laser systems by combining innovative seed laser sources with well-established and reliable solid state laser amplifiers

The increasing demands in laser technologies require high flexible and comprehensive laser system designs.

For these areas the neoVAN amplifier family allows power and energy scaling from highly stable and low-noise single-frequency radiation up to high energy picosecond laser pulses. The flexibility of the amplifier modules allow configurations with more than 40 dB gain, output power levels up to 100 W or high-energy milijoule-class laser pulses with excellent beam quality.

In his presantation, **Maik Frede** introduced the new neoVAN amplifier family of products of neoLASE and their potentials in different fields.

https://www.neolase.com

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Zygo Corporation

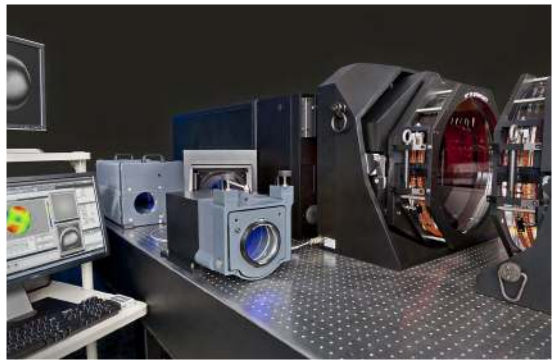
Zygo Corporation is a worldwide supplier of optical metrology instruments, high precision optical components, and complex electro-optical system design and manufacturing services

Zygo Corporation is specialized in different business segments.
Zygo's Optics business segment is a world-leading manufacturer, featuring innovative and proprietary manufacturing technologies combined with a synergistic relationship with its Metrology business segment.

Zygo's Metrology business segment is a global leader in non-contact interferometric metrology. Zygo's solutions include production, process control, and R&D tools for semiconductor, optics, display technologies, precision machining, photovoltaic, and research applications.

Torsten Glaschke's talk was about the fabrication and metrology of demanding optics for scientific applications.
In details, he introduced:

- optics for GW interferometers
- advanced LIGO
- Beam-line Grating Blank Substrates manufacturing
- Zygo interferometric metrology
- laser interferometers
- scanning coherence interferoemters
- displacement interferometers and interferometric absolute position sensors



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Websites

www.appec.org
www.appec.de

August 2017

APPEC, the Astroparticle Physics European Consortium, has been founded in 2012 by major funding agencies active in Astroparticle Physics. Ministries, funding agencies or their designated institutions from Belgium, Croatia, Finland, France, Germany, Ireland, Italy, Netherlands, Poland, Portugal, Romania, Russia, Spain, Sweden, Switzerland, and UK joined the consortium until beginning of 2017. Based on the achievements of the EU-funded ERA-NET ASPERA, the partners of APPEC agreed to coordinate their funding activities and undertake common actions to support Astroparticle Physics in Europe.

The development of a common European strategy for Astroparticle Physics and the update of the roadmap for this research field for the period 2017--2026 are important achievements of APPEC. Related to this, APPEC is continuing to release common calls for funding of common R&D projects and establish a common public outreach. Furthermore, APPEC aims at supporting synergies between Astroparticle Physics and other scientific domains as well as R&D cooperation with industry in Europe.

Astroparticle Physics itself is a young and very active science discipline comprising a lot of R&D activities in advancing detection methods and technologies to the maximum. Programmatically, it is both, performing particle physics with cosmic accelerators and performing astronomy at highest (particle) energies.

Astroparticle physicists search for the tiniest amount of energy released by a dark matter particle in their experiments, fine tune their antennas to discover the infinitesimal small squeezing of the earth when passed by a gravitational wave, and – to the other extreme – build detector arrays of the size of 3000 km^2 to measure the footprint of the most energetic cosmic particles hitting the earth atmosphere.

Altogether, Astroparticle Physics in Europe covers:
- Astronomy at Gamma-ray energies
- Direct dark matter search
- Dark energy surveys
- Gravitational wave astronomy
- Determination of neutrino properties
- Neutrino astronomy
- Determination of the nature and origin of cosmic ray
- Physics of the cosmic microwave background radiation
- Multimessenger astronomy

APPEC

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