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Report on the Workshop

Dispersing Elements for Astronomy: New Trends and Possibilities

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Astronomical spectrographs play an important role in addressing some of the biggest challenges in modern astronomy. One of the most critical components of any spectrograph is its dispersing element, since it determines the resolution and dispersion of the spectrograph, and is typically one of the least efficient optical components of the instrument. The aim of this workshop was to bring together researchers and engineers involved in the design, development and construction of spectroscopic instrumentation, with companies and institutes that produce dispersing elements and associated optical components. The forum provided the opportunity to discuss the scientific needs of future instruments, and to address the technological challenges that will allow the development of new types of dispersing elements in the coming years.

In order to adequately address open questions in astronomy, there is a drive for the development of bigger, more sensitive telescopes and instruments — both ground-based and in space — with a very wide spectral range. In respect of ground-based facilities, the current Extremely Large Telescope (ELT) projects provide clear evidence for this, and spectrographs play an essential role in their planned instrument suites. Dispersing elements are at the core of these instruments, since they define the spectral resolution and dispersion of the spectrograph and hence the final performance of the instrument. On the other hand, because of their nature, dispersing elements are often the least efficient optical elements of the whole spectrograph, and therefore dominate the final instrumental throughput. This, of course, also holds true for smaller telescopes, which can typically address a broad range of science cases provided they have adequate instrumentation.

Starting from the design phase of any spectrograph, it is crucial to be aware of the different possibilities that are available on the market, including those that have not specifically been developed for astronomy. Indeed, thanks to new technologies, the possibilities in the field of diffraction gratings and dispersing elements are increasing as a result of a number of different approaches, for example, holography, lithography and micro-machining. This is not always easy, since the requirements can vary across different fields. However, it can be possible to adapt the latest technological advances to specific scientific needs. On the other hand, it is also important for companies and research institutes that are active in the design and production of dispersing elements, and that are involved in the design of the spectrographs, to understand how to adapt technological developments towards becoming feasible products for astronomical research.

This workshop[1] brought together researchers and engineers involved in the design, development and construction of spectroscopic instrumentation, as well as companies and institutes that produce dispersing elements and associated optical components. The forum provided an opportunity to discuss the scientific needs of current and future instruments and to address the technological challenges that will enable the community to progress with the development of new types of dispersing elements in the coming years.

The focus was mainly on dispersing elements based on gratings and prisms; alternative approaches such as Fabry-Perot interferometry or Fourier-transform spectrometers were not considered. The workshop was organised into the following three main sessions:
– An overview of the scientific questions to be addressed, both with large and small ground-based astronomical facilities. In this session, the status of the three ELTs currently under construction was presented, including their instrumentation programmes.
– Properties of dispersing elements for astronomy, their evolution, the issues and constraints of the optical design of spectrographs for large telescopes and, finally, their calibration.
– Technologies for the production of gratings and prisms. This session was divided according to the different manufacturing technologies and spectral range of use of the diffractive elements.

Discussions and outcomes

In general, the instrumentation suites proposed for the three ELT projects are similar, and require a wide range of spectral and spatial resolutions. They resemble the instruments developed for the 8–10-metre-class telescopes and all face the challenges of wide focal planes and the conservation of the "étendue" — a property of the light used to characterise the area and angle over which it is spread out. Large-sized gratings/prisms are required to reach the target resolution, but it is important to keep the total size of the instrument within bounds by means of strategic choices in the optical design (through pupil and image slicing).

The 8–10-metre-class telescopes will require new instrumentation and new concepts in the era of the ELTs. One example may be the efficient spectroscopic telescopes currently under study, which are designed to simultaneously collect thousands of spectra of targets that are fed from wide field surveys. The same approach applies to small- and medium-class telescopes, where the scientific cases are often diverse, and which may also need to develop or focus on specific science cases with very efficient, dedicated instruments.

Figure 1. Workshop participants.

The dispersing elements for the spectrographs have a large set of requirements. Aside from achieving the highest possible diffraction efficiency, it is also important to understand and know their dispersion, price, weight/size, availability on the market, ghosts, wavefront error (WFE), etc. Being able to obtain repeatable and consistent wavelength calibrations is essential to get the best out of the spectrographs, especially for highly stable high-resolution spectrographs.

The different technologies discussed at the workshop related to the manufacture of diffraction gratings can be summed up under the following headings.

High-performance first-order diffraction gratings

Volume Phase Holographic Gratings (VPHGs) are considered the baseline for instrumentation in the visible and near-infrared bands, on the basis of the excellent results obtained over the last decade. However, some limitations were apparent, such as their size, WFE, and their efficiency at high dispersion. Other techniques are becoming available, in particular lithographic gratings based on either electron-beam lithography or on holography. There are some degrees of freedom in the structure of the periodic pattern and in the material, which allow for the maximisation of the diffraction efficiency — even in the ultra-violet. As there are markets that require such gratings in very large formats, it is now feasible to reach sizes of the order of a square metre, and these possibilities are worth considering when designing future instrumentation.

Dispersing elements for the infrared

In the infrared, immersed gratings have become an interesting option since the availability of materials with high refractive index makes it possible to increase the resolution significantly while keeping the size under control. Moreover, other technologies, such as VPHGs, are not suitable for wavelengths above 2.5 μm (new approaches based on direct laser inscription are being developed to extend the range to longer wavelengths). Depending on the material, different spectral ranges can be covered and non-standard materials (like silicon, germanium, zinc selenide, indium phosphate) show excellent properties and results, especially in terms of roughness and WFE.

High-precision machining techniques (in particular diamond turning) make it possible to obtain unconventional gratings on curved surfaces or freeform gratings. The benefit of this could be a simplification of the optical design or an improvement of the capabilities (such as in the case of multi-blazed gratings). Moreover, such machines are suitable for working on large-sized substrates, matching the requirements of modern telescopes and instrumentation. In the case of spectropolarimeters, the use of liquid crystal gratings can provide interesting advantages, being able to control both the dispersion and the polarisation. A completely different approach is related to the use of photonic techniques, which exploit the dispersion induced in an optical waveguide system.

Conclusions and Remarks

This very focused workshop was characterised by a good mix of science and industry. There were more than 70 participants, coming mainly from Europe but also from the USA, Japan and Australia, interacting with representatives from 15 companies and research institutes that develop and manufacture dispersing elements and instrumentation.

The three days involved many animated discussions that extended beyond the workshop schedule. Indeed, there were several opportunities to network and discuss a range of related topics, including specific projects as well as new ideas.

One of the issues identified, was that numerous large gratings would be required over the next years to satisfy the requirements of the ELT instrumentation programmes as well as other existing and future spectroscopic facilities. Although astronomy is not a big industrial market, it is clear that there is room for many players as the requirements are challenging. The availability of many new technologies and capabilities will open up new alternatives, but in order to fully take advantage of all of the possibilities, interactions between instrument designers, industry and research institutes is crucial. This workshop was a successful first step in this direction.

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Links

[1] Workshop web page: http://www.brera.inaf.it/DispersingElements2017