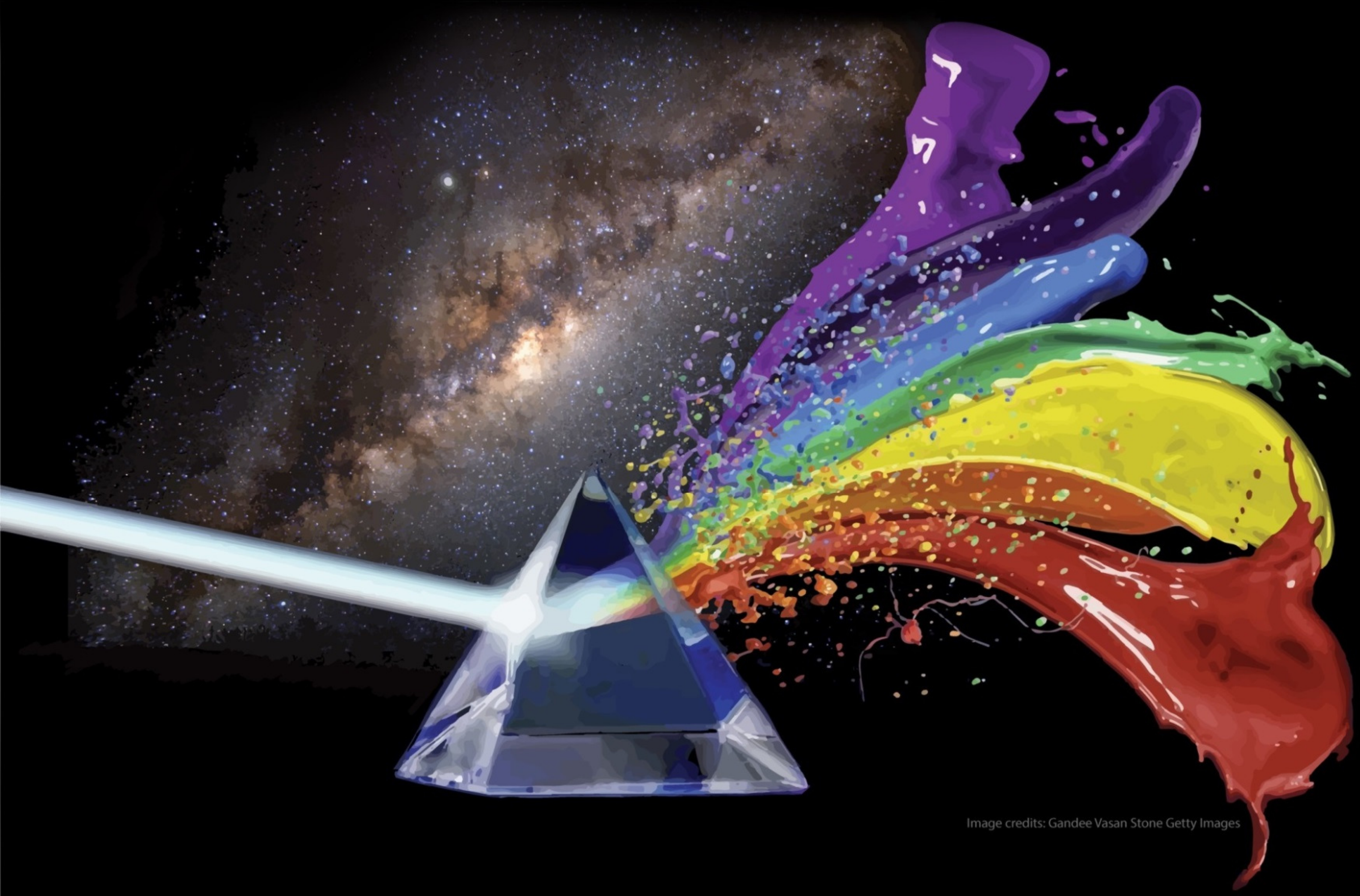

Dispersing elements for astronomy: New trends and possibilities

October 9 – 11, 2017

Acquario Civico Milanese, via G.B. Gadio 2, 20121, Milano

Daily schedule

	09/10/2017	10/10/2017	11/10/2017
9:00	Registration 9:30-11:00	**Instrumentation for the ELT** (S.Ramsay) 9:00-9:30 **GMT: instrument program** (R. Bernstein) 9:30-10:00	**Polarization gratings, and more fun with liquid crystals** (F. Snik) 9:00-9:30 **Waveguide dispersion techniques** (N. Cvetojevic) 9:30-9:55 **Freeform Gratings for Imaging Spectrometers** (V. Moreau) 9:55-10:20
10:00		**TMT: first light spectroscopic instrumentation** (R. Kupke) 10:00-10:30 Coffee break 10:30-11:00	Coffee break 10:20-10:45 **Diffraction grating manufacturing by numerically controlled ultrahigh precision machine tool** (Y. Yamagata) 10:45-11:10
11:00	Welcome and introduction 11:00-11:20 **Where are the astronomers going with optical and IR spectroscopy?** (M. Cirasuolo) 11:20-11:50 **Review of key requirement parameters for dispersion elements in optical/near-IR spectrometers** (C. Cunningham) 11:50-12:20	**Current Capabilities in Grating Manufacturing** (B. Bach) 11:00-11:25 **Large size and high performances gratings for Astronomy application** (C. Gombaud) 11:25-11:50 **Spectrometer gratings based on direct-write e-beam lithography** (U. Zeitner) 11:50-12:15	**Blazed Gratings on Convex Substrates for High Throughput Spectrographs** (I. Zhurminsky) 11:10-11:35 **New opportunities of freeform gratings using diamond machining** (C. J. Bourgenot) 11:35-12:00
12:00	**A perspective on the history and evolution of dispersing elements in optical astronomical spectrographs** (S. Barden) 12:20-12:50	Lunch 12:15-13:40	Discussion and Concluding remarks (SOC) 12:00-13:00
13:00	Lunch 12:50-14:10	**Silicon Diffractive Optics for Infrared Spectroscopy** (D. Jaffe) 13:40-14:10	
14:00	**Lessons from the OPTICON Trans-national Access programme** (J. Davies) 14:10-14:40 **Spectroscopy with Small and Medium-Sized Telescopes: Science and Technology** (A. Quirrenbach) 14:40-15:10	**The machined immersion grating for the absolute and simple solution of the downsizing concept in the high-precision infrared Spectroscopy** (T. Sukegawa) 14:10-14:35 **Immersed diffraction gratings for the Sentinel-5 earth observation mission** (R. Kohlhaas) 14:35-15:00	
15:00	**Future Spectroscopic Facility** (L. Pasquini) 15:10-15:40 Coffee break 15:40-16:10	**Development of Immersion Gratings at LLNL** (P. J. Kuzmenko) 15:00-15:25 Coffee break 15:25-15:50 **A summary of Kaiser VPH gratings/grisms, large/small format, high/low resolution, matrix, multiplex and plain for astronomical spectrographs** (J. Arns) 15:50-16:15	
16:00	**Spectroscopy at 8-10m telescopes: the GTC perspective** (R. Corradi) 16:10-16:40 **Large gratings for large telescopes** (T. Oliva) 16:40-17:10	**Transmission VPHGS in Silver Halide Sensitized Gelatin** (A. Fimia) 16:15-16:40 **Infrared transmission gratings manufactured using ultrafast laser inscription** (D. Lee) 16:40-17:05	
17:00	**Wavelength Calibration: The Quest for Perfection** (F. Kerber) 17:10-17:40 Poster session with welcome cocktail 17:40-19:00	**Advances in the manufacturing of photopolymer based VPHG for astronomy** (A. Zanutta) 17:05-17:30 Open discussion (R. Navarro) 17:30-18:30	
18:00			
19:00			
20:00		Social dinner 20:00	

Workshop on

DISPERSING ELEMENTS FOR ASTRONOMY: NEW TRENDS AND POSSIBILITIES

October 9 – 11, 2017, Milano

Program and Book of Abstracts

SPONSORS

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WELCOME

The aim of the workshop is to bring together researchers and engineers involved in the design, realization and construction of spectroscopic instrumentation, along with companies and institutes that produce dispersing elements or associated optical components.

The forum will provide us with the opportunity to discuss the scientific needs for future instruments and to address the technological challenges that will enable us to move forward in developing new types of dispersing elements in the coming years.

Indeed, there is a growing number of alternatives in the domain of diffraction gratings and dispersing elements is increasing thanks to the development of new technologies (from holography to lithography and micromachining). Some of these technologies are not specifically developed for astronomy, but have exciting potential applications in this field. In order to make the best design choices for new instrumentation, it is necessary to understand the advantages and the limitations of each technology.

Although many of the new developments will naturally focus on instrumentation for the new generation of Extremely Large Telescopes, the requirements of smaller facilities, which still have an important role in astronomical research, will also be discussed at the workshop.

We all are very pleased to have you join us in Milan and we look forward to a great workshop.

The SOC

Committees

Scientific Organizing Committee

Andrea Bianco - INAF Osservatorio astronomico di Brera (Italy)

Francisco Garzón - Instituto de Astrofísica de Canarias (Spain)

Ramon Navarro - NOVA, Netherlands Research School for Astronomy (The Netherlands)

Marco Riva - INAF Osservatorio Astronomico di Brera (Italy)

Wayne Holland - STFC - UK Astronomy Technology Centre (UK)

Antonio Manescau - European Southern Observatory (Germany)

Antonio de Ugarte Postigo - Instituto de Astrofísica de Andalucía (Spain)

Rebecca Bernstein - Carnagie Institution of Science (USA)

Local Organizing Committee

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Secretary

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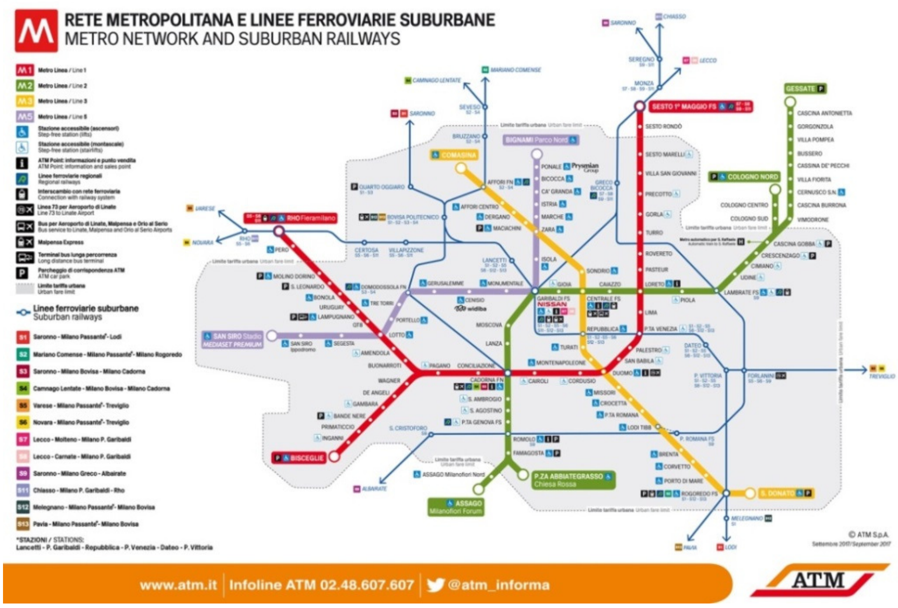
GENERAL INFORMATION

VENUE

The workshop will be held at the Milan city Aquarium (**Acquario Civico di Milano**, Viale G. B. Gadio, 2, 20121 Milano MI), which is located in Milan downtown inside the beautiful Parco Sempione, near the Castello Sforzesco. The city Aquarium is only 2 minutes walk from the **Lanza metro station** (green line M2). Coffee breaks and lunches will be held at the city Aquarium, while the social dinner will be at the restaurant ***I Caminetti del Sempione*** (via Giulio Cesare Procaccini, 60 – Milano).



Conference website: http://www.brera.inaf.it/DispersingElements2017/
e-mail: dispersingelements@brera.inaf.it

DAY 1

9:30 – 11:00: Registration

11:00 – 11:20: Welcome and introduction – Acquario Civico, Auditorium

11:20 – 12:50: General overview (chair: Andrea Bianco) – Acquario Civico, Auditorium

Time	Title	Presenter
11:20	Where are the astronomers going with optical and IR spectroscopy?	CIRASUOLO Michele
11:50	Review of key requirement parameters for dispersion elements in optical/near-IR spectrometers	CUNNINGHAM Colin
12:20	A perspective on the history and evolution of dispersing elements in optical astronomical spectrographs	BARDEN Samuel

12:50 – 14:10: Lunch – Acquario Civico, Giardino d'Inverno

14:10 – 15:40: Small and large telescope perspective (chair: Wayne Holland) – Acquario Civico, Auditorium

Time	Title	Presenter
14:10	Lessons from the OPTICON Trans-national Access program	DAVIES John
14:40	Spectroscopy with small and medium-sized telescopes: science and technology	QUIRENNBACH Andreas
15:10	Future spectroscopic facility	PASQUINI Luca

15:40 – 16:10: Coffee break – Acquario Civico, Giardino d'Inverno

16:10 – 17:40: Small and large telescope perspective – 2 (chair: Rebecca Bernstein) – Acquario Civico, Auditorium

Time	Title	Presenter
16:10	Spectroscopy at 8-10m telescopes: the GTC perspective	CORRADI Romano
16:40	Large gratings for large telescopes	OLIVA Tino
17:10	Wavelength calibration: the quest for perfection	KREBER Florian

17:40 – 19:00: Poster session (welcome cocktail) – Acquario Civico, Giardino d'Inverno

DAY 1: ABSTRACTS

WHERE ARE ASTRONOMERS GOING WITH OPTICAL AND IR SPECTROSCOPY?

Michele Cirasuolo[a,*]

[a] ESO, Karl-Schwarzschild Strasse 2 85748 Garching bei Muenchen
* mciras@eso.org

I will present a brief overview of the current frontier of astronomical spectroscopy, from exoplanet characterisation to galaxy evolution and cosmology. I will then highlight the challenges and needs in terms of spectroscopic capabilities to push further our understanding of the Universe.

REVIEW OF KEY REQUIREMENT PARAMETERS FOR DISPERSION ELEMENTS IN OPTICAL/NEAR-IR SPECTROMETERS

Colin Cunningham[a,*]

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* colin.cunningham@stfc.ac.uk

From the time of Newton and Fraunhofer, dispersing elements incorporated into spectrometers have enabled the discovery of chemical elements and molecules in celestial objects, as well as understanding of their dynamics. I will review the development of these dispersing elements, leading to a summary of the key performance metrics that are used to determine the optimum device to solve particular astrophysical questions. I will conclude with a wish-list of future developments that could address the challenges of future instruments.

A PERSPECTIVE ON THE HISTORY AND EVOLUTION OF DISPERSING ELEMENTS IN OPTICAL ASTRONOMICAL SPECTROGRAPHS

Samuel C. Barden[a,*]

[a] Leibniz Institute for Astrophysics, Potsdam, Germany
* sbarden@aip.de

The analysis of the spectra of astronomical sources is one of the key methods for observing and understanding the nature of the Universe, from the detection of the fundamental elements that make up the stars to the measurement of the expansion rate of the Universe. For the past 200 years, the diffraction grating has been a primary component in the instrumentation used for astronomical spectroscopy. I will give an overview of the historical development of the optical dispersers used, the current state of the art and applications along with a brief introduction to the technical developments underway for potentially revolutionary devices.

LESSONS FROM THE OPTICON TRANS-NATIONAL ACCESS PROGRAMME

John Davies[a,*]

[a] UK Astronomy Technology Centre, Blackford Hill, Edinburgh, UK
* jkd@roe.ac.uk

SPECTROSCOPY WITH SMALL AND MEDIUM-SIZED TELESCOPES: SCIENCE AND TECHNOLOGY

Andreas Quirrenbach[a,*]

[a] Universität Heidelberg, Landessternwarte Koenigstuhl 12, 69117 Heidelberg, Germany.
* A.Quirrenbach@lsw.uni-heidelberg.de

Small and medium-sized telescopes play important roles amongst the facilities available to astronomers. They enable time-intensive surveys and monitoring programs, provide quick and flexible access for time-critical observations, serve as testbeds for advanced technologies, and form the backbone of student education and of outreach activities. The requirements for spectroscopic instruments on these telescopes are as varied as their applications, ranging from simple demonstration tools to large and complex state-of-the-art facilities. I will provide a few examples across this

spectrum, and discuss the impact of new technologies on the productivity of telescopes in the 0.7m to 4m size range.

FUTURE SPECTROSCOPIC FACILITY

L. Pasquini [a,*], B. Delabre [a], R. Ellis [a] , J.A. Marrero [a], L. Hernandez [a]

[a] ESO, Karl-Schwarzschild Strasse 2 85748 Garching bei Muenchen, D;
* lpasquin@eso.org

Several scientific reports indicate the need for a quantum jump in massive spectroscopy, and several projects are under development or design. I will concentrate on a novel concept developed at ESO for a facility dedicated to massive spectroscopy. With 11.3m diameter and 2.5 degrees corrected field of view, the new telescope will have the largest ever etendue, and will be able to easily host 15000 fibres for simultaneous low and high resolution spectroscopy. Alternatively, the light can be directed to a coude' focus hosting a giant IFU. Instrumentation is developed as part of the facility from the very beginning, as many low and high resolution spectrographs will be needed. The instruments' design and development need to be carefully engineered in order to optimize the performances and to contain the costs.

SPECTROSCOPY AT 8-10M TELESCOPES: THE GTC PERSPECTIVE

Romano L.M. Corradi[a,*]

[a] GRANTECAN, Cuesta de San José s/n, E-38712, Breña Baja, La Palma, Spain
* romano.corradi@gtc.iac.es

I shall present an overall view of the spectroscopic capabilities, in terms of spectral coverage, resolutions, and multiplexing capabilities, of the major optical and infrared ground-based telescopes in operation. The case of the 10.4m GTC telescope will be used to illustrate some of the details of the dispersion elements adopted at these large astronomical facilities.

LARGE GRATINGS FOR LARGE TELESCOPES

Ernesto Oliva[a,*]

[a] INAF-Arcetri Observatory, largo E. Fermi 5, I-50125, Firenze (I);
* oliva@arcetri.inaf.it

In this presentation I will discuss the challenges of designing and building spectrographs for (extremely) large telescopes operating at optical and infrared wavelengths. The main parameters of the spectrometer – in particular the size of the dispersing elements – will be evaluated using remarkably simple relationships derived from the fundamental principle of throughput conservation. Some of the published spectrometer designs will be briefly analyzed with a focus onto the parameters and feasibility of the dispersive elements. A representative list of requirements for dispersers will be presented to trigger the discussion with manufacturers.

WAVELENGTH CALIBRATION: THE QUEST FOR PERFECTION

Florian Kerber[a,*]

[a] ESO, Karl-Schwarzschild-Str. 2, 85748 Garching, Germany
* fkerber@eso.org

Spectroscopy is an essential tool for understanding the physical nature of astrophysical objects. Depending on the resolving power it serves a variety of exciting science cases ranging from the chemical abundances of stars, the search for extrasolar planets, to the dynamics of galaxies to the expansion of the Universe. The observations done with high-resolution spectrographs in many cases call for both precision and accuracy and are by nature demanding even for relatively bright objects. Recent developments such as the search for a potential variability of fundamental constants of physics also ask for excellent repeatability and stability. Hidden systematic effects can have devastating effects on the scienctific value of the observational data, hence these effects need to be properly characterised, understood and accounted for. In contrast to an experimental physicist working in the laboratory the observing astronomer is not in a position to control the experiment – her/his observations – to the required level as an individual. As a result the astronomical community is becoming more and more dependent on the observatories providing calibration sources and processes that guarantee the required levels of performance. This can only be achieved if the sources and processes have been validated with respect to calibrated laboratory standards and come with the appropriate calibration reference data. It is thus interesting to look at the currently available calibration sources and compare them to a hypothetical "perfect calibrator". I'll describe the properties of several commonly used sources and highlight their advantages and drawbacks as well as relevant special features. I'll also describe recent developments that will enable us to take the next step towards "perfect wavelength calibration" of astronomical spectrographs.

DAY 2

9:00 – 10:30: ELTs instrumentation program (chair: Antonio Manescau) – Acquario Civico, Auditorium

Time	Title	Presenter
9:00	Instrumentation for the ELT	RAMSAY Suzanne
9:30	GTM: instrument program	BERNSTEIN Rebecca
10:00	TMT first-light spectroscopic instrumentation	KUPKE Renate

10:30 – 11:00: Coffee break – Acquario Civico, Giardino d'Inverno

11:00 – 12:20: Technologies for dispersing elements (chair: Tino Oliva) – Acquario Civico, Auditorium

Time	Title	Presenter
11:00	Current capabilities in grating manufacturing	BACH Benny
11:30	Large size and high performances gratings for astronomy application	GOMBAUD Christophe
11:55	Spectrometer gratings based on direct-write e-beam lithography	ZEITNER Uwe

12:20 – 13:40: Lunch – Acquario Civico, Giardino d'Inverno

13:40 – 15:25: Technologies for dispersing elements: immersed gratings (chiar: Francisco Garzón) – Acquario Civico, Auditorium

Time	Title	Presenter
13:40	Silicon diffractive optics for infrared spectroscopy	JAFFE Daniel
14:10	The machined immersion grating for the absolute and simple solution of the downsizing concept in the high-precision infrared spectroscopy	SUKEGAWA Takashi
14:35	Immersed diffraction gratings for the Sentinel-5 earth observation mission	KOHLHAAS Ralf
15:00	Development of immersion gratings at LLNL	KUZMENKO Paul J.

15:25 – 15:50: Coffee break – Acquario Civico, Giardino d'Inverno

15:50 – 17:30: Technologies for dispersing elements: VPHGs (chiar: Ramon Navarro) – Acquario Civico, Auditorium

Time	Title	Presenter
15:50	A summary of Kaiser VPH gratings/grism, large/small format, high/low resolution, matrix, multiplex and plain for astronomical spectrographs	ARNS James
16:15	Transmission VPHGS in silver halide sensitized gelatin	FIMIA Antonio
16:40	Infrared transmission gratings manufactured using ultrafast laser inscription	LEE David
17:05	Advances in manufacturing of photopolymer based VPHG for astronomy	ZANUTTA Alessio

17:30 – 18:30: Open discussion – Acquario Civico, Auditorium

20:00 – 22:00: Social dinner – *I Caminetti del Sempione*

DAY 2: ABSTRACTS

INSTRUMENTATION FOR THE ELT

Suzanne Ramsay [a,*]

[a] European Southern Observatory, Karl-Schwarzschild-Strasse 2, 85748 Garching, Germany;
* sramsay@eso.org

This presentation will introduce the instruments currently being designed for the Extremely Large Telescope (ELT).
Three instruments are in construction and nearing the end of their preliminary design phase (HARMONI, MICADO and METIS). Conceptual design studies are underway for two further instruments, MOSAIC and HIRES. The instrument suite covers wavelengths from 400nm to 20microns. All of the instruments have important spectroscopic capabilities, even the first light imager MICADO. HARMONI (an optical to near infrared integral field spectrograph) and METIS (a mid-infrared imager and spectrograph) require spectroscopy with both low (few thousand) and high (10 000 – 100 000) spectral resolving power to reach their science goals. The multi object spectrograph MOSAIC offers moderate spectral resolving power for hundreds of objects. In contrast, HIRES, as the name suggests, aims to deliver high spectral resolving power (>~100 000) for one or a few objects simultaneously.
A general overview of the instrument concepts and status will be presented, with special emphasis on the design of the spectroscopic modes and dispersing elements. The perspectives for future instrumentation will also be mentioned.

GTM: INSTRUMENT PROGRAM

Rebecca Bernstein[a,*]

[a] Carnagie Institution of Science (USA)
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TMT FIRST-LIGHT SPECTROSCOPIC INSTRUMENTATION

Renate Kupke[a,*]

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Substantial progress is being made on the powerful suite of first-light instrumentation for the Thirty Meter Telescope (TMT). The TMT's first-light capabilities include a near-infrared integral field unit spectrometer and imager (IRIS) and a wide-field, multi-object spectrograph working at optical wavelengths (WFOS). Presently entering its final design phase, IRIS will take advantage of the near infra-red (0.8 – 2.4 micron) diffraction-limited images provided by NFIRAOS, the facility multi-conjugate adaptive optics system, and will be capable of integral field spectroscopy at multiple spatial scales. Under new leadership, WFOS, an optical (0.31 – 1.0 micron) seeing-limited workhorse spectrograph, has begun a conceptual design phase trade study, in which both slicer-based and fiber-based VPH spectrograph architectures are being explored as alternatives to the baseline (MOBIE) design. The WFOS team has made rapid progress on an aggressive schedule, focusing on feasibility, risk and cost for this down-select phase with a final architecture design expected in March 2018.

CURRENT CAPABILITIES IN GRATING MANUFACTURING

B. Bach Sr.[a], B. Bach Jr.[b], E. Bach[a,*], K. Bach[a]

[a] Bach Research Corporation, 4946 63rd Street, Boulder CO. 80301, USA;
[b] Department of Physics, University of Nevada, 1664 N. Virginia Street, Reno NV. 89509, USA;
* ebach@bachresearch.com

Bach Research Corporation is a manufacturer of custom optical components and diffractive optics for OEM, aerospace, research and space flight instrumentation. Bach Research is a key supplier of one of a kind optical components for programs such as: Hubble Space Telescope, Venus Express, the James Webb Space Telescope, and to the European Southern Observatory.

In this talk we would like to update conference attendees on Bach Research Corp's current range of manufacturing capabilities, and recent accomplishments. Topics that we will touch upon are our:

• Thin Film Coating Laboratory,
• Diamond Turning Capabilities,
• Ruling Laboratory,
• Metrology and Optical Testing Capabilities.

We will also present a few examples of diffraction gratings we have recently manufactured including:

• ZnSe & FS Grisms,
• Large gratings

• Echlon Gratings,
• Echelle Gratings,
and the results that were achieved.

LARGE SIZE AND HIGH PERFORMANCES GRATINGS FOR ASTRONOMY APPLICATION

C. Gombaud* [a], A. Cotel[a], F. Desserouer[a], A. Liard[a], Y. Bernard[a]

[a] HORIBA France SAS, Avenue de la Vauve - Passage Jobin Yvon, 91120 Palaiseau (FRANCE)
* christophe.gombaud@horiba.com

We present the latest developments of large size and high performances diffraction gratings for astronomy and space application. A new facility, called NANO-structure Larger Area Master (NANOLAM), has been built at HORIBA France SAS (Palaiseau, France), dedicated to the production of the largest gratings in the world (Fig. 1).
This new facility allows us to design and produce very large gratings, in reflection or transmission with various possibilities of groove profiles and densities. From meter size pure holographic gratings up to 6000gr/mm on any substrate shape, to ion-etched transmission gratings (Fig.2) competing favorably with VPH technology, HORIBA has developed the widest innovative diffraction gratings portfolio dedicated to astronomy application. The fused silica etched technology used to manufacture transmission gratings is unique and offer a number of consequent advantages over VPH technology such as a better wavefront, performances homogeneity or lifetime thanks to its bulky all glass material. This technology allows HORIBA to offer GRISMs (grating on a prism face. See Fig.2) as well.
Apart from these exclusive holographic and ion-etched capabilities, HORIBA is also offering ruled gratings, generally dedicated to infrared spectral range with low groove densities. Echelle grating and immersed grating are also part of the HORIBA new capabilities.
In addition, HORIBA continues to develop another proprietary technology, the Variable Groove Depth (VGD) gratings that allows in a single grating a continuous blaze wavelength adjustment.
All the HORIBA gratings product range is cryogenic compatible, TRL9 space qualified and shows the best straylight performances on the market.
Finally, HORIBA is also currently performing several studies in partnership with laboratories and space agencies to further improve the state-of-the-art gratings straylight performances, as well as developing gratings on free-form surfaces.

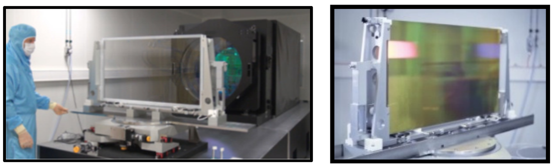

Fig. 1 : Largest grating in the world

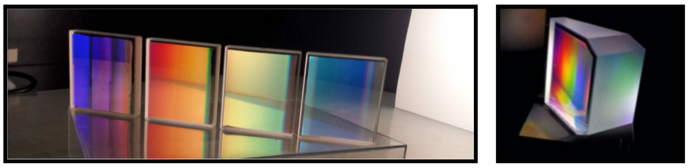

Fig. 2 : Transmission fused silica etched gratings (left) and GRISM (right)

SPECTROMETER GRATINGS BASED ON DIRECT-WRITE E-BEAM LITHOGRAPHY

U.D. Zeitner[a,b,*], T. Flügel-Paul[a], T. Harzendorf[a], M. Heusinger[b], E.-B. Kley[a]

[a] Fraunhofer Institute of Applied Optics and Precision Engineering, A.-Einstein-Str. 7, Jena, Germany
[b] Institute of Applied Physics, Friedrich-Schiller-University, A.-Einstein-Str. 15, Jena, Germany
* uwe.zeitner@iof.fraunhofer.de

Among the many different techniques used for the manufacturing of high-end spectroscopic diffraction gratings electron-beam lithography is rather new. The reason for this can be found in the sequential nature of the e-beam writing process and the resulting very long exposure times. However, driven by the demands of high-resolution pattern fabrication for photomasks for the microelectronics industry modern e-beam tools were developed to achieve a very high throughput and simultaneously conserve their ability to realize smallest structures with highest quality and unprecedented flexibility.
The optical characteristics of spectroscopic gratings is determined in first place by their diffraction efficiency over a given spectral bandwidth, but also by parameters like wave-front quality and stray-light level introduced by imperfections of the grating structure. The spectral dependent efficiency depends on the particular grating structure within one period of the grating. Due to the high pattern resolution of e-beam lithography a dedicated control of this structure, e.g. by precise control of grating profile, duty-cycle, or the generation of sub-wavelength pattern is possible. The high positioning accuracy of the lithographic tools allows to achieve writing induced wave-front qualities in the range of <5nm rms over large areas of up to 300mm size. Special effort has to be dedicated to the control of grating ghosts and stray-light level. Sequential writing processes are in general prone to introduce undesired secondary structures in the grating. As shown in Fig. 1 the impact of such structures on the spectral stray-light can be almost completely suppressed by optimizing the e-beam writing process. As a result it is possible to realize gratings fulfilling the highest demands on spectroscopic purity by electron-beam lithography.
Further more, by proper combination of the e-beam lithography with subsequent processes like plasma- or wet-chemical etching, overcoating of the grating structure by Atomic-Layer-Deposition (ALD), or the assembly of the grating with prisms, the gratings can be further tailored to a very broad range of spectroscopic concepts. In the

presentation different examples of all-dielectric high-efficiency gratings, immersed gratings (GRISMS), Si-echelle gratings, and monolithic resonant-waveguide gratings for gravitational wave-detection will be discussed.

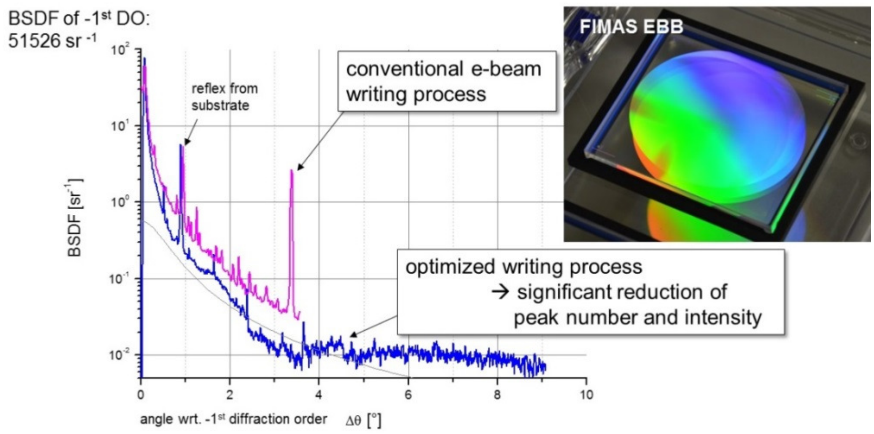

Figure 1: Example of a spectroscopic grating for the high-resolution NIR-channel of the FLEX-instrument (ESA). By optimization of the e-beam writing process a grating with very low stray-light level and grating ghosts could be realized.

SILICON DIFFRACTIVE OPTICS FOR INFRARED SPECTROSCOPY

Daniel T. Jaffe[a,*], Cynthia Brooks[a]

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* dtj@austin.utexas.edu

We discuss the current state of our program to produce precision silicon diffractive optics and describe the instruments that have included these devices as dispersers for infrared astronomical spectroscopy. Silicon diffractive optics, both grisms and immersion gratings, offer significant advantages as dispersive elements. The high thermal backgrounds in the infrared at ambient temperatures mean that we must cool dispersive instruments cryogenically. This requirement, in turn, puts a premium on instrumental compactness and simplicity. Instruments using silicon (n=3.4) grisms can have volumes an order of magnitude smaller than those of instruments with similar performance that use grisms made from lower-index materials. Silicon immersion gratings replacing front-surface gratings reduce instrument volumes by a similar factor. Both types of devices have a second significant advantage that derives from our ability to produce coarse, perfectly flat grooves using micromachining techniques. These coarse grooves enable highly efficient cross-dispersed instruments with continuous wavelength coverage at high spectral resolution. Our group currently produces diffraction-limited gratings with lengths up to 125 mm that operate efficiently in orders as high as m=200. We will describe the process for manufacturing Si grisms and immersion gratings, alternative manufacturing techniques, and the limitations on the size and precision of the devices. We also discuss some of the major design considerations for spectrographs that employ immersion gratings. The IGRINS spectrograph, now used at McDonald Observatory and the Discovery Channel

Telescope, has a resolving power of 45,000 and covers all of the infrared H and K bands (1.4-2.5 μm) in a single exposure. It has no moving parts. On a 4m telescope, IGRINS is competitive with the earlier generation of high resolution spectrographs on 8m telescopes while having many times the spectral grasp. GMTNIRS, our planned immersion-grating spectrograph for the Giant Magellan Telescope, will have R=60,000-90,000 across the entire range from 1.1 to 5.3 μm in a single exposure. The talk will describe some of the many science results from IGRINS in stellar and interstellar medium spectroscopy and illustrate the capabilities of GMTNIRS for even further progress.

THE MACHINED IMMERSION GRATING FOR THE ABSOLUTE AND SIMPLE SOLUTION OF THE DOWNSIZING CONCEPT IN THE HIGH-PRECISION INFRARED SPECTROSCOPY

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Because an immersed grating provides n (refractive index of its material) times higher spectral resolution compared to a conventional reflective grating of the same size, an immersed grating is a powerful optical device for the infrared high-precision spectroscopy. On the other hands, there is no practical immersed grating for high-precison spectroscopy except Si immersed grating by anisotropic etching. It was very difficult for a fragile IR crystal to manufacture a diffraction grating precisely. Canon succeeded in fabricating immersed gratings with three kinds of materials by machining(cutting). Three materials are CdZnTe, Germanium and InP, each refractive index are about 2.6,4 and 3.1 respectively. By combining these devices, a spectroscopy can be used with an immersed grating in the wavelength range of 1.4-20um. Thereby, the realization of these immersed gratings has led to a dramatic improvement in the downsizing concept of a high-precison spectroscopy. Our machined immersion grating is the absolute and simple solution for the downsizing concept in the high-precision infrared Spectroscopy.

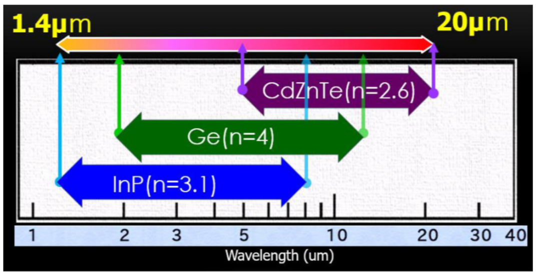

Fig.1 The cover wavelength range with three materials.

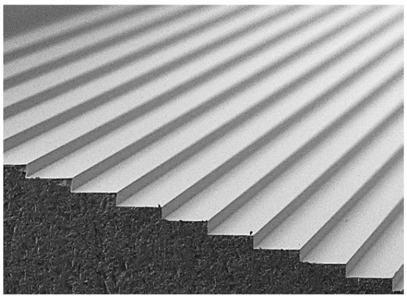

Fig.2 The SEM picture of Germanium grooves by machining with 91.74μm pitch.

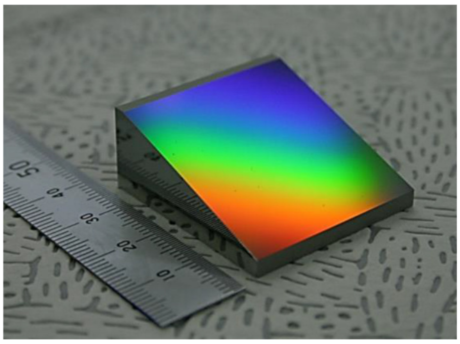

Fig.4 The picture of Extremely-high-order Germanium immersion grating (EGIG) with 476μm pitch.

Fig.3 The picture of Germanium grism by machining with 2.2μm pitch.

[1] Sukegawa, et al.“Three types of Immersion Grating for Next-generation Infrared Spectrometer” SPIE 101000M (2017).
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IMMERSED DIFFRACTION GRATINGS FOR THE SENTINEL-5 EARTH OBSERVATION MISSION

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The resolving power of a diffraction grating scales inversely with the operating wavelength. By immersing the diffraction grating in a medium of refractive index n, the wavelength is effectively shortened by the same factor and the resolving power of the diffraction grating is increased correspondingly. At SRON, this principle is used for the production of silicon immersed gratings for the earth observation mission Sentinel-5 [1]. We describe the manufacturing process of our immersed gratings and show the measurement results of the critical optical performance parameters. The results are compared to previous work on an immersed grating bread board model for the METIS instrument of the E-ELT [2] and an outlook is given for potential immersed gratings for astronomy applications.

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[2] Tibor Agócs et al; “Optical tests of the Si immersed grating demonstrator for METIS”, Proc. SPIE 9912, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation II, 991215 (July 22, 2016)

DEVELOPMENT OF IMMERSION GRATINGS AT LLNL

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Work on immersion gratings began at LLNL soon after their practical realization was demonstrated by Wiedemann in 1994. Their advantages in increasing the spectral resolution of an instrument or permitting size reductions while maintaining resolution are compelling. Later that year we fabricated our first silicon grating by anisotropic etching.

However, there are atmospheric windows where silicon is not transmissive. We began to consider other materials and alternate means of fabrication. Many infrared optical materials can be diamond machined. We were able to leverage the extensive R&D on diamond machining conducted at LLNL in the 1970's and 1980's. We were also able to make use of a precision research lathe (PERL) constructed in that era. Although not designed to machine gratings, it has several features that make it suitable for that task.

We first machined a small (roughly 1 cm^2) germanium grating in 2002 for a Department of Energy project. A few years later with a goal of demonstrating the technology in the near infrared and visible we cut test gratings in ZnSe, ZnS, and GaP. Since then we have fabricated a number of gratings for internal projects as well as a set of germanium grisms for LMIRCAM on the Large Binocular Telescope and the GR700 grism in ZnSe for NIRISS on the James Webb Space Telescope.

The remainder of this talk will discuss what might be possible for immersion gratings and grisms. I will describe the limitations of the PERL lathe and of diamond machining in general as well as practical considerations of the various grating materials.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

A SUMMARY OF KAISER VPH GRATINGS/GRISMS, LARGE/SMALL FORMAT, HIGH/LOW RESOLUTION, MATRIX, MULTIPLEX AND PLAIN FOR ASTRONOMICAL SPECTROGRAPHS

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Kaiser Optical Systems introduced VPH gratings to instrument builders of astronomical spectrographs in 1995 and has been actively involved with continuous development, production, and delivery of custom gratings for use on telescopes ever since.

The following table identifies a selection of Kaiser VPH gratings designed and manufactured for astronomical spectrographs.

Year	Instrument	Telescope/Organization
1999	FORS2	VLT/European Southern Observatory (ESO)
2000	Subaru	National Astronomical Observatory of Japan (NAOJ)
2001	FTSP	U.S. Naval Observatory
2003	FORS2	VLT/European Southern Observatory (ESO)
2004	FTSP	U.S. Naval Observatory
2005	FORS2	VLT/European Southern Observatory (ESO)
2006	FRODOSPEC	Liverpool Johns Moores University Telescope
2007	SWIFT	Hale Telescope/University of Oxford
2007	EFOSC2	U of Sheffield
2009	ACAM	William Hershel Telescope/Isaac Newton Group of Telescopes (ING)
2009	BOSS	SDSS Telescope/Astrophysical Research Consortium (ARC)
2009	OSMOS	Hiltner Telescope/The Ohio State University
2009	VIRUS-P	H.J. Smith Telescope/McDonald Observatory
2010	KOSMOS	Mayall Telescope/National Optical Astronomical Observatory (NOAO)
2010	VIRUS-W	H.J. Smith Telescope/Max Planck Institute for Extraterrestrial Physics
2010	APOGEE	SDSS Telescope/Astrophysical Research Consortium (ARC)
2011	PEPSI	Large Binocular Telescope/Astrophysics Institute Potsdam
2011	VIMOS	VLT/European Southern Observatory (ESO)
2011	MUSE	VLT/European Southern Observatory (ESO)
2013	HERMES	AAT/Australian Astronomical Observatory (AAO)
2014	IGRINS	H.J. Smith Telescope/McDonald Observatory
2015	APOGEE-S	Irénée du Pont Telescope/ Las Campanas Observatory
2015	ESPRESSO	VLT/European Southern Observatory (ESO)
2015	MAROON-X	Magellan Telescope/ Magellan Project, Gemini North / Gemini Observatory
2016	PFS	Subaru Telescope/National Astronomical Observatory of Japan
2017	DESI	Mayall Telescope/National Optical Astronomical Observatory (NOAO)

Grating sizes range from a few millimeters to more than half-meter. Grating line frequency can be less than two hundred lines/mm upward to nearly six thousand lines/mm. Kaiser’s VPH technology enables production of gratings that can operate within the range of wavelengths from about 350 nm to 2800 nm. Final configurations of planar gratings and complex grisms in quantities of single units to 24 units of a single design have been delivered to instruments and telescopes located around the world. These gratings demonstrate the variety and versatility of Kaiser’s production capability.

TRANSMISSION VPHGS IN SILVER HALIDE SENSITIZED GELATIN

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Volume phase Holographic gratings (VPHGS) are commonly used in Astronomy and they are an interesting alternative to diffraction gratings, and grims. For this purpose, some materials are used to highlight Dicromated gelatin (DCG)[1]. This material has very high diffraction efficiency and good transmissions even at IR radiation but this material has a low energetic and spectral sensitivity. Another alternative with high sensitivity are bleached emulsions although they have right mechanical properties at cryogenic temperatures, it has print out effect and are not good candidates to Astronomical instruments[2]. It has also been test gratings in photopolymers however this material does not have good sensitivity[3].
Silver halide sensitized gelatin (SHSG) are alternative for VPHG. The main properties that this material must have for astronomical application are high optical quality and mechanical resistance in cryogenic temperatures.
For this purpose, we aim to perform the optical characterization of an array of VPHG gratings using SHSG process. The plate was BB640, ultrafine grain emulsions with a nominal thickness of 9 μm. The recording was performed with asymmetric geometry a 30 degrees between the light beams of wavelength 632.8 nm (He-Ne laser), which give a raise of spectral frequency of 800 l/m. The exposure was between 46 to 2048 μJ/cm^2.
The SHSG has been tested in cryogenic temperature environment to 77 ºK, measured in the IAC using specific equipment. The measurements have been taken in the spectral range between 400nm and 1100nm, with a diffracted angle have been between 18º and 42º. All test runs have included a reference measurement, off grating, before and after the grating test.
In figure 1 we have the diffraction efficiency as function of wavelength for SHGS before and after the cryogenic process. We can see is that the VPHGs have resisted and have not significantly changed their behaviour, even performance has risen.
This mean that SHSG is an excellent process in Astronomical application, because has less thickness variations in cryogenic process and has good mechanical stability at low exposure.

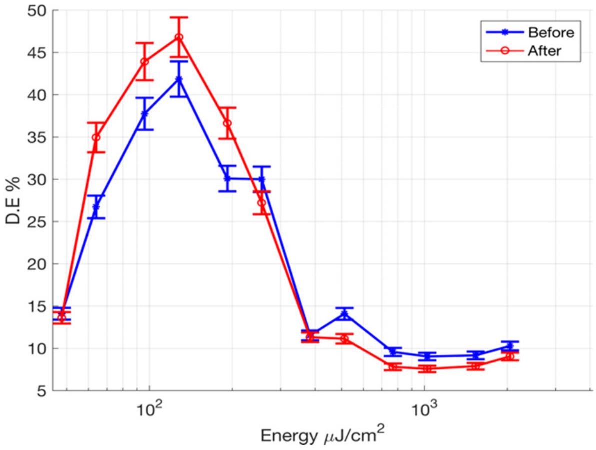

Figure 1. Diffraction efficiency for SHSG as function of energy before and after cryogenic process measured at 632,8 nm.

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INFRARED TRANSMISSION GRATINGS MANUFACTURED USING ULTRAFAST LASER INSCRIPTION

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We will present an overview of our on-going research activity to develop efficient infrared transmission gratings manufactured using the technique of ultrafast laser inscription. This technique uses a high power laser beam focused within a glass substrate to generate permanent refractive index modifications within the material. We will describe how a periodic grating structure can be built up using multiple scans of the laser beam. We will discuss the advantages of the ultrafast laser inscription manufacturing technique and its applicability for the production of gratings within

infrared transmitting materials such as chalcogenide glass. Inscription of the grating directly into the substrate creates a robust optical component that has application for a variety of scientific applications including near and mid-infrared astronomical spectrometers operating at cryogenic temperatures.
We have manufactured a series of prototype gratings and tested their diffraction efficiency over the wavelength range 1 – 6 μm. At the blaze wavelength we have measured first order diffraction efficiency exceeding 60% compared with an un-coated substrate transmittance of 67%. We will also present our optical model of the grating structure, theoretical efficiency predictions, and comparison with the measured results. Finally we will present our new results on optimization of the laser inscription manufacturing parameters to produce gratings with good second and third diffraction order efficiency and future prospects for advanced grating structures.

ADVANCES IN THE MANUFACTURING OF PHOTOPOLYMER BASED VPHG FOR ASTRONOMY

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Within the astronomical field, the progressive increase in telescope size and in complexity of the spectroscopic instrumentation has highlighted how the current technologies and traditional materials for dispersing elements do not completely meet the present and future requirements. Therefore, new materials and solutions have to be developed not only to realize future astronomical facilities, but also to improve the performances of already available instruments and devices. In this context, numerous advances have been made thanks to the introduction of photopolymeric materials for the production of Volume Phase Holographic Gratings (VPHGs) [1], devices that are already considered the baseline for dispersing elements in modern astronomical spectrographs thanks to their high and customizable diffraction efficiency response [2,3]. Beside the ability to precisely provide the tuning feature, these materials bring also advantages such as self-developing, high refractive index modulation and ease of use thanks to their insensitiveness to the external environment (such as humidity). The versatility of these materials allowed us to propose and realize novel architectures of the spectroscopic dispersive elements that were hardly feasible with the common holographic materials. Compact and unique single prism devices were realized for FOSC spectrographs (as plug-and-play upgrades) [4] and new multi-layered devices are proposed, stacking thin films containing VPHGs one on top of the other to obtain many spectra in the instrument's detector, with advantages as increase of resolution and signal to noise ratio with respect to the classical single dispersive element [5]. Moreover, the easy processability and the reliability of the photopolymers could also, for the first time, open the doors to the VPHGs for more industrial processes that can enable this technology for even more complex devices and solutions.

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DAY 3

9:00 – 10:20: Innovative technologies and approaches for future instrumentation (chair: Colin Cunningham) – Acquario Civico, Auditorium

Time	Title	Presenter
9:00	Polarization gratings, and more fun with liquid crystals	SNIK Frans
9:30	Waveguide dispersion techniques	CVETOJEVIC Nick
9:55	Freeform gratings for imaging spectrometers	MOREAU Vincent

10:20 – 10:45: Coffee break – Acquario Civico, Giardino d’Inverno

10:45 – 12:00: Innovative technologies and approaches for future instrumentation (chair: Antonio de Ugarte Postigo) – Acquario Civico, Auditorium

Time	Title	Presenter
10:45	Diffraction grating manufacturing by numerically controlled ultralight precision machine tool	YAGAMATA Yutaka
11:10	Blazed gratings on convex substrates for substrates for high throughput spectrographs	ZHURMINSKY Igor
11:35	New opportunities of freeform gratings using diamond machining	BOURGENOT Cyril J.

12:00 – 13:00: Discussion and concluding remarks – Acquario Civico, Auditorium

DAY 3: ABSTRACTS

POLARIZATION GRATINGS, AND MORE FUN WITH LIQUID CRYSTALS

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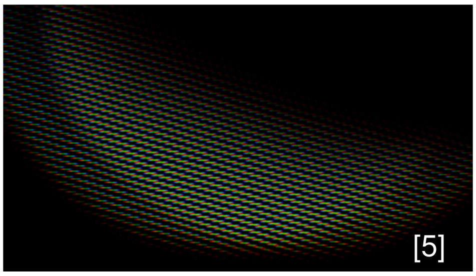
The implementation of patterned liquid crystals allows the application of *any* phase pattern by a flat optic, through the so-called geometric phase. In contrast to the well-known classical phase, the geometric phase is inherently achromatic, and acts upon circular polarization states with opposite phase for opposite handedness. The highest diffraction efficiencies are obtained when the liquid crystal layers act as a half-wave retarder, and the resulting geometric phase pattern is equal to ±2× the fast axis orientation pattern. By using a direct-write method[1] and "multi-twist retarders"[2], high-efficiency, broadband diffractive elements can be manufactured with a pattern resolution of ~5 μm, and with an optical footprint as large as ~30 cm.
By patterning a liquid crystal element such that the axis orientation varies in one direction in a linear fashion, one obtains a so-called polarization grating[3]. If the retardance of the element is close to half-wave over the operational spectral range, the diffraction efficiency in orders ±1 is close to 100%. Offsets from half-wave retardance induce leakage in the zeroth order, but, thanks to the local nature of the geometric phase, light is not diffracted into higher orders[4]. Polarization gratings with multiple liquid crystal layers to yield an "achromatic" half-wave retardance therefore constitute optimally efficient low-order gratings. Moreover, as they split opposite circular polarization states into diffraction orders ±1, they also serve as polarizing beam-splitters (possibly in combination with an additional quarter-wave plate to effectively split linear polarization).
We provide an overview of design implementations with polarization gratings in astronomical spectrometers, or, indeed, spectropolarimeters. We have also successfully applied a polarization grating in a spectropolarimetric integral field unit[5]. Furthermore, as any desired phase pattern can be written, we combine polarization grating patterns with e.g. focus terms, coronagraphic phase patterns[6,7], and holograms that enable focal-plane wavefront sensing[8]. Moreover, by designing the retardance profile to be particularly chromatic, one can even produce polarization gratings that diffract one wavelength, and simply transmit another wavelength[9]. Finally, we have also used polarization gratings for a spectacular art project at the Amsterdam train station[10].



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WAVEGUIDE DISPERSION TECHNIQUES

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FREEFORM GRATINGS FOR IMAGING SPECTROMETERS

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Over the past few years a new breakthrough in the conception and design of optical systems has emerged: Freeform optics. Freeform refers to surfaces without rotational symmetry. Such surfaces can provide major advantages in terms of optical performance and system integration. The use of freeform mirrors or lenses could conjointly reduce the number of components in optical systems, offer larger field of view, improved image quality or enable the use of 3D-tilted configurations.
For spaceborne hyperspectral applications, grating-based spectrometers are of special interest due to the high spectral resolution and optical throughput that can be achieved. Nevertheless, most of the available manufacturing techniques, such as direct ruling,

holography, lithography or e-beam writing, are typically applicable on simple shape of the grating surface, such as flat or spherical surface. The capabilities of manufacturing Freeform grating could offer new degree of freedom for the optical design of compact and well-corrected spectrometers.

In the frame of ESA Technological Research Programs, several activities have been conducted for bringing benefits and additional function of freeform optics to the gratings spectrometers. AMOS came with several designs that offer increased flexibility and throughput performances in the sense that it combines imaging, de-magnification and dispersing functions in a system with only three power surfaces enclosed in a compact volume. In addition, such designs offer excellent keystone and smile performances required for push broom space instrument. It can be shown that the use of free-form gratings allow a reduction of about a factor of 4 in volume with respect an Offner-Chrisp spectrometer with equivalent performances.

A breadboard of a medium spectral resolution Spectro-imager (2.5 nm bandwidth), called ELOIS (Enhanced Light Offner Imaging Spectrometer), has been manufactured and the tests have confirmed the achievement of the challenging design specifications.

The blazed grating itself has been characterized independently in terme of Surface Error (< 60 nm RMS), diffraction efficiency (>85% max and >70% in mean over the VNIR range), Polarization sensitivity (< 5%) and scattering (ghost < 10^{-3}; grass < 10^{-5}).

A new activity has been recently launched for demonstrating the potential of ELOIS configuration for Atmospheric chemistry. Such application requires extreme signal-to-noise ratio (~1000) and a spectral resolution of about 1500 (bandwidth~0.5 nm). It includes a convex freeform grating with 1000 grooves/mm. A blazed holographic grating will be manufactured through holographic replication process at Horiba Jobin-Yvon in early 2018.

DIFFRACTION GRATING MANUFACTURING BY NUMERICALLY CONTROLLED ULTRAHIGH PRECISION MACHINE TOOL

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Diffraction gratings are manufactured by several different techniques. Mechanical machining is one major way of manufacturing diffractive optics elements. The advantage of mechanical machining is relatively high freedom in diffractive optics geometry, such as surface curvature, pitch variation and blaze angles. On the other hand, there have been some disadvantages of mechanically machined diffractive optics such as surface roughness and pitch accuracy. Those mechanical machining of diffractive optics have been conducted by so-called "ruling engine", which is a specialized machine tool for precise pitch groove generation. Numerically controlled ultrahigh precision machine tools are developed for the purpose of manufacturing aspherical optics or dies for optical disc pick-up lenses or digital camera lenses. The precision of diffractive optics manufactured by such machine tools have not been satisfactory in the past, but due to recent progress in precision of machine tools, they are coming close to acceptable precision.

The authors have been working on the development of such ultrahigh precision machine tools (fig.4) and diffractive optics using them. We will introduce some examples of diffractive optics research and development such as diffraction grating mold for spectrometer (fig.1), holographic optical element for optical disks (fig.2), and germanium immersion grating for mid-infrared spectrograph (fig.3). And near future perspective for the development of ultrahigh precision machine tool will be mentioned.

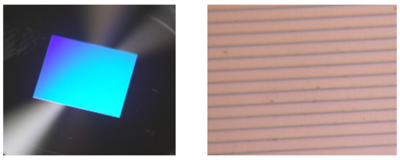

Fig.1 Diffraction grating mold for spectrometer.

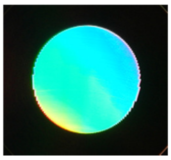

Fig.2 Test fabricated holographic optical element.

Fig.3 Germanium immersion grating for mid-infrared spectrometer.

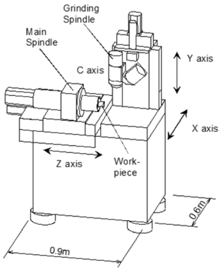

Fig.4 A typical ultrahigh precision machine tool.

BLAZED GRATINGS ON CONVEX SUBSTRATES FOR HIGH THROUGHPUT SPECTROGRAPHS

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The Digital-Micromirror-Device-based MOS instrument under development should be mounted on the Galileo telescope. This two-arm instrument provides in parallel imaging and spectroscopic capabilities. The compact spectrograph design contains a low density convex grating to disperse light [1]. In order to optimize the spectrograph efficiency, this convex grating must be blazed at the right angle for maximizing the light in the first order of diffraction.

A reflective grating blazed on the 1st order of diffraction, designed with a period of 3300 nm and a blaze angle of 5.1° (see Fig. 1), has been fabricated onto and into convex substrates with 225 mm radius of curvature and a footprint diameter of 63.5 mm. The blaze is optimized for the center wavelength of 580 nm within the spectral range of 400 – 800 nm.

The master of the blazed grating structure has been originated on a flat substrate starting from a rectangular grating with a period of 3300 nm. The rectangular grating was UV replicated twice using Sol-Gel material and subsequently converted into a blazed shape by angular Ar ion etching. The desired blazed grating parameters like depth and blaze angle have been reached by adjusting the initial grating depth in Sol-Gel as well as the Ar etching angle and duration.

Two approaches have been studied to transfer the blazed grating from a flat surface onto a convex substrate.

In the first approach, a flexible stamp was generated by UV replication of the blazed grating, utilizing a flexible nanoimprint material. The flexible stamp was used to emboss Sol-Gel spin-coated on the convex substrate. In this approach the final component is a convex substrate with a Sol-Gel layer carrying the grating structure.

In the second approach, nanoimprint material is used as a masking layer for Reactive Ion Etching of the convex substrate. Again, the flexible stamp was used to emboss a thin layer of nanoimprint material spin-coated on the convex surface. After curing, the structure was transferred into the quartz substrate by etching. With this approach, the final component is a convex quartz substrate with the grating structure etched into the volume.

We demonstrated the successful realization of a blazed grating on convex surfaces for next generation compact and highly efficient spectrographs. The monolithic approach is considered more preferable due to the absence of a quartz to Sol-Gel interface prone to fatigue.

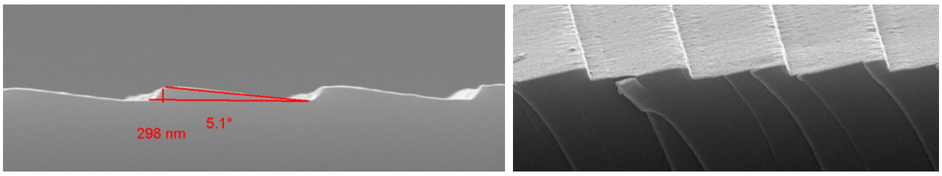

Fig. 1: SEMs of the blazed grating on a convex substrate: profile (left) and general view (right).

[1] F. Zamkotsian et al., "Building BATMAN: a new generation spectro-imager on TNG telescope", Proc. SPIE **9908**, (2016).

NEW OPPORTUNITIES OF FREEFORM GRATINGS USING DIAMOND MACHINING

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With the recent development of new ultrafine aluminum alloys, and progress in the field of directly machined freeform surfaces, diamond machined freeform gratings could play an important part in future spectrographs, particularly at SWIR and LWIR wavelengths where the improved thermal performance of metal optics at cryogenic temperatures is well established. Freeform diamond machined gratings can offer a cost-effective, compact, and flexible alternative to gratings fabricated by other methods such as ion beam etching or complement these technologies.
In this presentation, we discuss both the advantages and limitations in the manufacturing of freeform gratings using 5 axis diamond machining and investigate potential applications for astronomy.

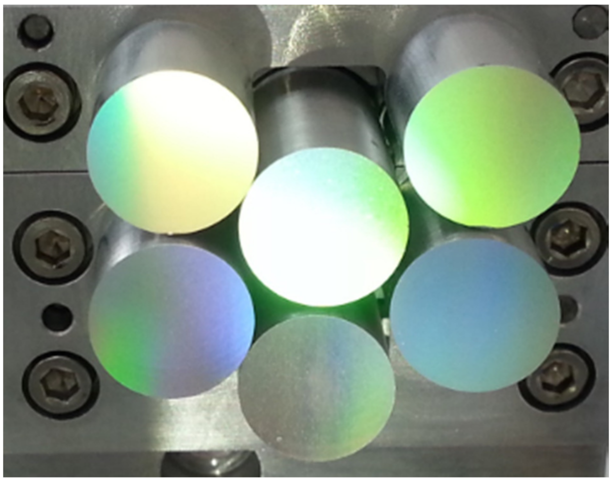

Figure 1: Example of curved gratings manufactured at Durham University using diamond machining.

Poster Session

The poster session is scheduled for day 1 (17:40 – 19:00) at Giardino d'Inverno exposition room. The posters will be hung from Monday morning until Wednesday morning with the following order:

P1. Innovative GRISM design for BFOSC and DOLORES spectrographs (Paola Galli, INAF – Osservatorio Astronomico di Brera, Italy)

P2. Grating Requirements for ELT-HARMONI (John Capone, University of Oxford, UK)

P3. BATMAN, a new generation spectro-imager on TNG telescope (Frederic Zamkotsian, LAM, France)

P4. Arrayed Waveguide Gratings for High-Resolution NIR Spectroscopy (Andreas Stoll, AIP, Germany)

P5. Optimisation of freeform gratings for ultra-compact Integral Field Spectrographs (Ariadna Calcines, University of Durham, UK)

P6. Spectrograph with a multiplexed holographic dispersive unit for a 1m class telescope (Eduard Muslimov, LAM, France)

P7. A Large Diameter Capacitance Stabilized Etalon for the European Solar Telescope (G. Viavattene, Università di Roma Tre, Italy)

P8. Novel Gratings for Astronomical Observations (Noboru Ebizuka, RIKEN, Japan)

P9. The end-to-end simulator for the E-ELT HIRES high resolution spectrograph (Matteo Genoni, Università dell'Insubria, Italy)

P10. MITS: Multi-Imaging Transient Spectrograph for SOXS (Adam Rubin, Weizmann Institute of Science, Israel)

P11. New series of high resolution and efficiency gratings (Will Saunders, Australian Astronomical Observatory, Australia)

P12. The SOXS spectrograph for ESO-NTT (Matteo Munari, INAF – Osservatorio Astronomico di Catania, Italy)

P13. OCTOCAM: Gemini's future multichannel imager and spectrograph (Antonio de Ugarte Postigo, Instituto de Astrofísica de Andalucía, Spain)

POSTER ABSTRACTS

INNOVATIVE GRISM DESIGN FOR BFOSC AND DOLORES SPECTROGRAPHS

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BFOSC is an imager/spectrograph mounted at 152 cm Cassini Telescope (Loiano). DOLORES is the low resolution spectrograph mounted at 358 cm TNG telescope, La Palma. In order to improve the performances of those instruments, new dispersing elements based on VPHG technology have been commissioned. We show here the design and manufacturing of two GRISMs for BFOSC and one for DOLORES. The key features of such VPHGs are the new photopolymers used to impress the grating, the very good overall efficiency performances and the innovative design. One of the two GRISMs for BFOSC is designed to work in the 330-550 nm range and it is based on a 640 lines/mm VPHG. The other one covers the Hα region (600-750 nm range) and it is characterized by a higher dispersion (910 lines/mm). For both, we focused on the optimization of the diffraction efficiency of the gratings and on the minimization of the optical components (aiming at reducing efficiency losses). The GRISM for DOLORES is designed to cover a wide wavelength range, namely from 0.35 µm to 1 µm. Such wide range suffers of diffraction orders overlap. Therefore, narrower ranges or multi-exposures were mandatory to cover that range. The design, that we present, tackles this problem and allows for splitting the 1st and the 2nd order spectra on the CCD, making both usable for the scientists. The element shows a very low dispersion (220 lines/mm) and the combination of three prisms. The first prism defines the incidence angle on the grating, which diffracts the light parallel to the normal to the grating. In this way, the system behaves as a classic single prism GRISM. The second and third prisms are aligned at 90° with respect to the grating and act as a cross disperser.

GRATING REQUIREMENTS FOR ELT-HARMONI

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The High Angular Resolution Monolithic Optical and Near-infrared Integral field spectrograph (HARMONI) will be among the first light instruments of the Extremely Large Telescope (ELT). The instrument is designed to address a range of key science cases between 0.47 and 2.45 μm. HARMONI will be cryogenically cooled to reduce noise from thermal emission at the longest wavelengths in this range. An integral field unit (IFU) will map on-sky spatial pixels (spaxels) into four "slits" which will pass into four spectrographs. The optical layout of a spectrograph is presented in Figure 1.

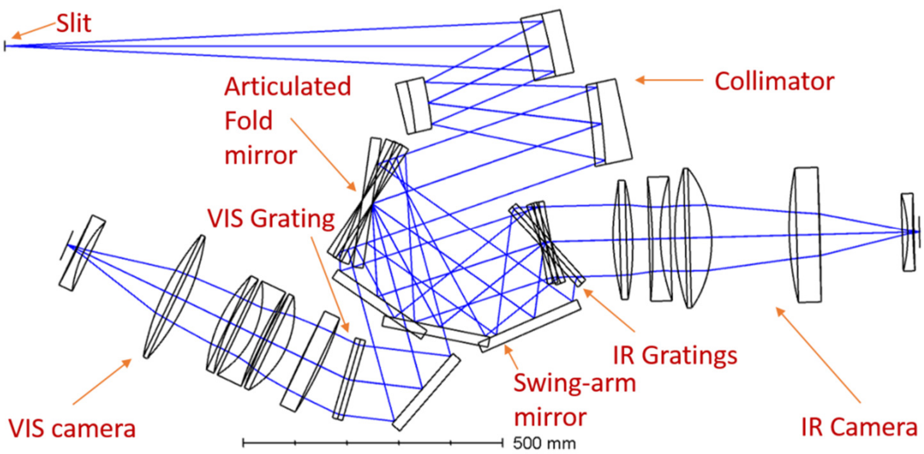

Figure 1 – each of the 4 spectrographs will have NIR configurations, but only two are planned to have visible modes.

Each spectrograph will collimate the corresponding slit using three off-axis, aspherical mirrors. In NIR configurations, the pupil will be positioned on a transmission grating with the angle of incidence set for one of three families of gratings by an articulating fold mirror and a fold mirror on a rotating "swing-arm". Two spectrographs will have a visible configuration, which positions the pupil on a transmission grating using the articulating fold mirror and a fixed fold mirror. The pupil will be approximately 160 mm in diameter. Following the dispersive element, the beam will be imaged by either a NIR or visible camera. The baseline grating designs uses volume phase holographic gratings (VPHGs) with non-slanted fringes; however, alternatives are being considered. In particular, designs with grating prisms (grisms) could simplify the design of or remove the need for the swing-arm.

BATMAN, A NEW GENERATION SPECTRO-IMAGER ON TNG TELESCOPE

Frederic Zamkotsian[a,*], Patrick Lanzoni[a], Nicolas Tchoubaklian[a], Marco Riva[b], Luciano Nicastro[c], Emilio Molinari[d], Paolo Di Marcantonio[e] and the BATMAN team

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In order to investigate the formation and evolution of galaxies, next-generation infrared astronomical instrumentation for ground-based and space telescopes will be based on MOEMS programmable slit masks for multi-object spectroscopy.
BATMAN is a 2048x1080 Digital-Micromirror-Device-based (DMD) MOS instrument to be mounted on the 3.6m Telescopio Nazionale Galileo (TNG), in the Canarias Islands (Spain). A two-arm instrument has been designed for providing in parallel imaging and spectroscopic capabilities. The field of view (FOV) is 6.8 arcmin x 3.6 arcmin with a plate scale of 0.2 arcsec per micromirror. The wavelength range is in the visible and the spectral resolution is R=560 for 1 arcsec object (typical slit size). The two arms will have 2k x 4k CCD detectors. Building BATMAN is under way, with all optics delivered and tested and some other major instrument parts delivered and tested (hexapods, fore-optics, detectors …). Remaining optomechanical parts are ordered and integration and alignment of the instrument is scheduled during spring 2018. The DMD could then generate dynamically any slit pattern for sending the light of the selected objects towards the spectrograph. The optical design is based on two Offner relays and the spectroscopic arm needs a blazed convex grating for optimizing the throughput of the instrument. **The blazed grating has been fabricated by CSEM Bâle (to be presented in this workshop).**
ROBIN, a BATMAN demonstrator, has been designed, realized and integrated. It permits to determine the instrument integration procedure, including optics and mechanics integration, alignment procedure and optical quality. First images and spectra have been obtained and measured: typical spot diameters are within 1.5 detector pixels, and spectra generated by one micro-mirror slits are displayed with this optical quality over the whole visible wavelength range. Observation strategies are studied and demonstrated for the scientific optimization strategy over the whole FOV.
BATMAN on the sky is of prime importance for characterizing the actual performance of this new family of MOS instruments, as well as investigating the operational procedures on astronomical objects.
BATMAN will be mounted on the TNG telescope by the end of 2018.

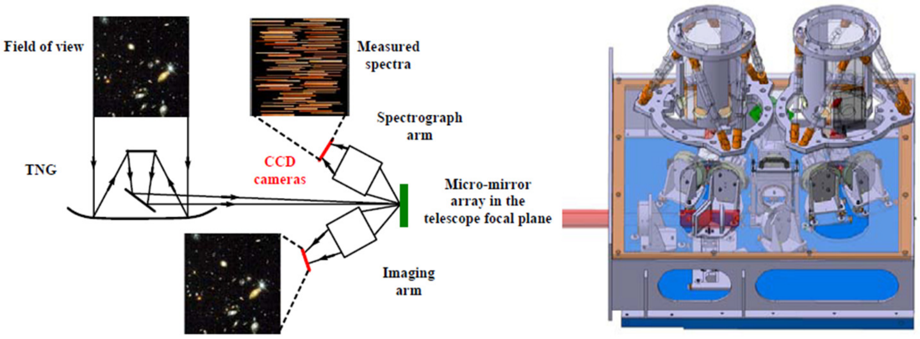

Fig. 1: Principle of the MOEMS-based spectro-imager BATMAN and its opto-mechanical design

Reference:

F. Zamkotsian et al., "Building BATMAN: a new generation spectro-imager on TNG telescope", Proc. SPIE **9908**, (2016)

ARRAYED WAVEGUIDE GRATINGS FOR HIGH-RESOLUTION NIR SPECTROSCOPY

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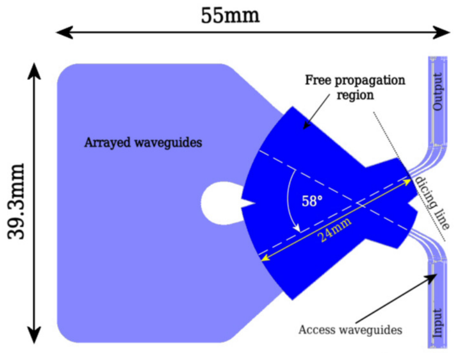
The development and application of integrated optics is currently a much discussed topic in the field of astronomical instrumentation. Photonic integrated circuits, such as interferometers, microring-resonators, multimode-singlemode reformatters (photonic lanterns) and integrated photonic spectrographs (IPS) for deployment in astronomy are being actively researched [1, 2]. Arrayed waveguide gratings (AWGs) have been identified as promising candidates for the realization of compact IPS devices. Research and development of high-performance AWG spectrographs at the Leibniz-Institute of Astrophysics, Potsdam, is aiming at the realization of prototypes with resolving powers R = λ/Δλ between 15.000 and 60.000 at H-band NIR wavelengths (~1500 nm-1800 nm) [3]. The AWG designs on the SiO_2 platform at 1.5% and 2% refractive index contrast have foot-prints between 20mm x 16 mm (Δ = 2%, R_{max} = 15.000) and 55 mm x 39.3 mm (Δ = 1.5%, R_{max} = 60.000) and contain 181 - 800 waveguides. The impact of wafer nonuniformities on the AWG performance was studied numerically using 2D beam propagation method with randomly generated effective index profiles. Diffraction images were compared with the unperturbed case using a normalized overlap integral as the figure-of-merit (FOM) function. Simulation results show severe degradation of the diffraction image for n_{eff} nonuniformity $RMS>5\cdot10^{-5}$, as well as a dependence on the correlation length L_C of the n_{eff} distribution.



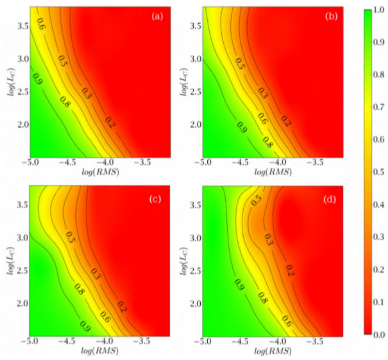


Fig. 1 - High-resolution SiO2 1.5% RI contrast AWG design

Fig. 2 - FOM maps for R = 60k (a), R =45k (b), R = 30k (c), R = 15k (d)

References
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OPTIMISATION OF FREEFORM GRATINGS FOR ULTRA-COMPACT INTEGRAL FIELD SPECTROGRAPHS

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Efficiency, mass and volume are regular problems present in the design of Integral Field Spectrographs. This communication presents the design and optimisation of freeform gratings for custom solutions which can potentially be used in an Image Slicer based IFU to make it more compact, less complex and lighter.
This work, developed in the framework of a CEOI (Centre of Earth Observation Instrumentation) pathfinder project, investigates the optical design of gratings optimised in efficiency with a range of resolutions up to R=50,000 to be manufactured on aspheric or freeform metal surfaces with full control of the blaze micro-structure.
These gratings can be specifically designed for a range of science cases and optimised to target a specific spectral resolution. Both, the design and manufacturing have been developed at Durham University. We present some examples optimised for spectral bands in the visible and near-infrared regions for a wide range of resolutions with diffraction limited optical quality.

SPECTROGRAPH WITH A MULTIPLEXED HOLOGRAPHIC DISPERSIVE UNIT FOR A 1M CLASS TELESCOPE

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We propose an optical scheme of moderate-resolution spectrograph working in the visible domain. The scheme is based on the principle described in [1]: the key optical element represents a grism with three musltiplexed volume-phase holographic (VPH) gratings (see Fig. 1a). Each of the gratings creates a spectral image in a narrow spectral range – 464-532 nm, 532-611 nm and 611-701 nm for the Blue, Green and Red grating respectively. With a high-quality commercial camera lens this scheme allows to reach the spectral resolving power of 4972-5793 covering the entire working region without gaps.

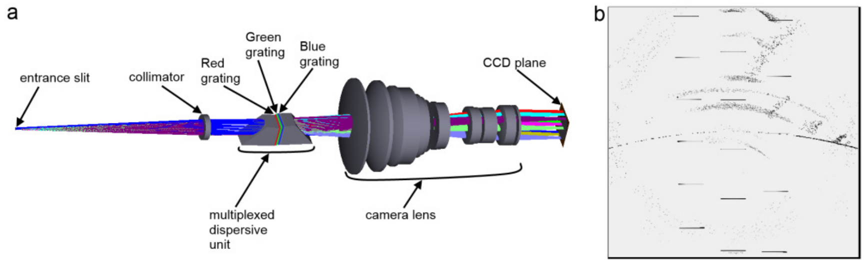

Fig.1. Spectrograph with a multiplexed dispersive element: a – general view of the optical scheme, b – simulated image (log scale).

The modelling technique presented in [2] was applied to the current scheme (Fig.1b). It was shown that if the reflection and absorption losses are accounted for, the total throughput of the optical system can reach about 60% in the peak. Intensity of stray light and ghost images caused by double diffraction is negligible. It is important to emphasize that the modelling results and preliminary analysis have shown that the scheme with multiplexed VPH grating has significant advantages in comparison with the configuration using separate gratings mounted in a cascade. This advantages include elements arrangement, reflection losses and toleracning. The current spectrograph configuration covers the spectral lines important for stellar astrophysics in the best possible way. The developed optical scheme is intended for building of a new instrument coupled with 1m-class Zeiss-1000 telescope at Special Astrophysical Observatory.

References

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A LARGE DIAMETER CAPACITANCE STABILIZED ETALON FOR THE EUROPEAN SOLAR TELESCOPE

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The next generation 4-meters class solar telescopes (e.g. DKIST, EST) will be optimized for spectro-polarimetric imaging and will require large diameter (up to 250-300 mm) tunable filters for imaging spectroscopy.
Such tunable filters will be used to select quasi-monochromatic images to obtain spectro-polarimetric data with high spatial, spectral and temporal resolution.
The Capacitance Stabilized Etalon (CSE) represents the most suitable device to operate in the visible and near-infrared ranges with the required performances.
The wavelength selection of a CSE is obtained by multiple beam interferometry in the optical cavity created by two partially reflective flat plates.
The CSE is a Fabry-Perot interferometer (FPI) whose optical cavity is controlled by piezo-actuators and measured by capacitors.
The combined use of the CSEs and narrow band filters will allow us to perform a high resolution spectral scan of the chosen spectral lines of extended astronomical sources, such as the solar photosphere and chromosphere.
The high transparency of such an instrument allows for the required temporal cadence to sample the fast dynamics processes with the resolution they deserve.
We present a study on the performances of a large diameter CSE (150 mm diameter) performed under the SOLARNET FP7 project.

NOVEL GRATINGS FOR ASTRONOMICAL OBSERVATIONS

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In this presentation, we will introduce novel gratings for next generation instruments of the TMT (Thirty Meter Telescope), the 8.2 m Subaru telescope, other ground-based and space-borne telescopes. The reflector facet transmission (RFT) is a surface relief

grating with sawtooth shaped ridges with an acute vertex angle in which an incident beam from one facet of a ridge is reflected on the other facet of the ridge and the beam is exited from the rear surface of the ridge as shown in Fig. 1 [1, 2]. In the case of the incident and the diffraction angle are 45°, and the refractive index of ridges is n=1.54, the vertex angle of the ridges is 38.3°. The RFT grating aims at practical use for WFOS (Wide-Field Optical Spectrograph) of TMT [3]. As a prototype of the RFT grating, a hybrid grism which combines a high index prism and surface relief grating with sawtooth shape ridges of an acute angle [1, 2], is developing for the MOIRCS (Multi-Objects Infrared Camera and Spectrograph) of the Subaru Telescope [4]. The left panel of Fig.2 is the mold for the replication experiments of the hybrid grism, and the middle and right panels of Fig.2 are the color contour of the wavefront error of diffracted beam of the master and the 2nd generation replica, respectively. We are developing a volume binary (VB) grating which functions as a quasi-Bragg (QB) grating [5] for an echelle grism of the MOIRCS. As a fabrication method for a VB grating, a silicon grating of ridges with a high aspect ratio is used as a mold (Fig. 3) [1]. In addition, we also introduce a birefringence volume phase holographic (B-VPH) grating which is combined an optically anisotropic medium such as a liquid crystal with an isotropic medium, or two kinds of optically anisotropic media [1, 2], and a QB immersion grating in which consists of silica substrates laminated by bonding of gold fusion in the room temperature [6] is cut with tilting of 30°, Littrow prism (30-60-90 triangle) and surface reflection mirror [1].

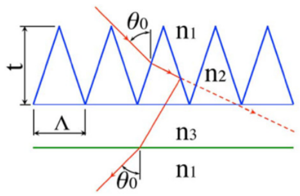

Fig. 1 Schematic representation of RFT grating [1, 2].

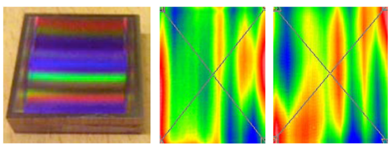

Fig. 2 Mold of hybrid grism(left) [1]. Wave front error of diffraction beam of mold (middle, PV: 0.89λ, RMS: 0.13λ) and 2nd genelation replica (right, PV: 0.48λ, RMS: 0.07λ).

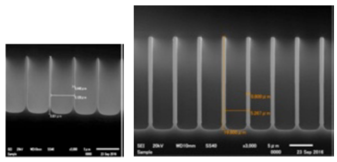

Fig. 3 SEM photograph of silicon VB grating, left; grating period: Λ=5.1μm, height: t=10μm, width: s=0.44μm, right; Λ=5.1μm, t=20μm, s=0.80μm [1].

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THE END-TO-END SIMULATOR FOR THE E-ELT HIRES HIGH RESOLUTION SPECTROGRAPH

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We present the design, architecture and results of the End-to-End simulator model of the high resolution spectrograph HIRES for the European Extremely Large Telescope (E-ELT). This system can be used as a tool to characterize the cross dispersed echelle spectrograph both by engineers and scientists. The model allows to simulate the behavior of photons starting from the scientific object (modeled bearing in mind the main science drivers) to the detector allowing to perform evaluation of the different parameters of the spectrograph design. The architecture of the simulator and the computational model are described in details. These are strongly characterized by modularity and flexibility that will be crucial in the next generation astronomical observation projects like E-ELT. Finally, we present synthetic images obtained with the current version of the End-to-End simulator based on the E-ELT HIRES requirements (especially high radial velocity accuracy**).** Once ingested in the Data reduction Software (DRS), they will allow to verify that the instrument design can achieve the radial velocity accuracy needed by the HIRES science cases.

MITS: MULTI-IMAGING TRANSIENT SPECTROGRAPH FOR SOXS

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Son Of X-Shooter (SOXS) is a medium resolution spectrograph designed for the ESO 3.6 m New Technology Telescope (NTT). The main science goal of SOXS is the study of transients, and therefore it is designed to cover the entire band from 350-1750 nm with high throughput at a resolution of $\lambda/\Delta\lambda$~5000. As the name implies, SOXS was designed based on the successful 4-C design of X-Shooter. The classical 4-C design uses an echelle grating which is a source of significant throughput losses.
We present an alternative design for the UV-VIS arm of SOXS. Our Multi-Imaging Transient Spectrograph (MITS) splits the spectral band into four ~120 nm sub-bands. This allows the use of high efficiency gratings which are optimized for a narrow band (e.g. VPH), as well as optimization of the camera optics and their coatings. As a result our design drastically increases the throughput while maintaining similar spectral resolution. The design has been accepted by the collaboration and has passed a preliminary design review.
We show the preliminary design, resolution and throughput estimates. We also discuss optical and mechanical design considerations.

NEW SERIES OF HIGH RESOLUTION AND EFFICIENCY GRATINGS

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Certain combinations of incidence angle, DCG thickness and index modulation lead to high efficiencies for high resolution VPH gratings, because the efficiency is simultaneously maximized for both *s* and *p* polarizations. These ‘Dickson’ gratings are well known and already in use in astronomy. However, other series of gratings, with even larger incidence angles and higher resolutions, share this same property but appear to have been overlooked to date. All these gratings require large prisms bonded to the grating to avoid total internal reflection at the air/substrate interface. At shorter wavelengths, the line density exceeds 6000/mm and similar prisms are also needed for the recording.
One of these series has dispersion twice that of the Dickson gratings, and looks feasible with current recording technology. Other series have even larger grating angles and dispersions; in principle, the only limit to the

grating angle is set by total internal reflection between the substrate and the DCG.
The MSE telescope requires high resolution (R~38,000) spectroscopy for ~1200 simultaneous targets. Because of the large AOmega of the telescope (11.25m primary, 0.8 arcsec fibers), the required grating and beam sizes are very large for traditional (or even Dickson) gratings. The proposed gratings offer a way to greatly reduce the size of the spectrographs, and make the gratings with current beamsizes.

THE SOXS SPECTROGRAPH FOR ESO-NTT

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SOXS (Son Of X-Shooter) will be the new spectrograph for the ESO-NTT (New Technology Telescope) at La Silla. It has been selected by ESO in 2015 out of 19 proposals, and the design has passed the PDR in July 2017; observations are expected in early 2021 (commissioning late 2020). Mounted at the Naismyth focus, highly efficient and full-time available, it will be mainly devoted to the study of transient sources, with a resolution of R~4500 for a 1 arcsec slit and a complete simultaneous spectral coverage of the [350-1750] nm range.
The spectrograph is actually composed by two arms (UV-VIS and NIR), fed by a common path subsystem. The NIR arm follows the 4C design (already successfully used in X-Shooter), while the UV-VIS will employ an innovative design based on VPH and dichroics to produce an echelle like spectrum. A Calibration Unit and an Acquisition Camera, capable of scientific grade photometry in ugrizy filters, complete the instrument.

OCTOCAM: GEMINI'S FUTURE MULTICHANNEL IMAGER AND SPECTROGRAPH

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OCTOCAM is an 8-chanel imager and spectrograph capable of obtaining simultaneous imaging in g, r, i, z, Y, J, H, and Ks bands of a field of view of 180"x180". It will also perform long slit spectroscopy covering the range from 3700 to 23500 Å with a resolution of ~4000. By using state of the art detectors OCTOCAM will be able to perform high-time resolution observations and minimize the dead time between exposures. This poster will present the technical aspects of the project, which has just gone through the preliminary design phase, and discuss its scientific motivation.

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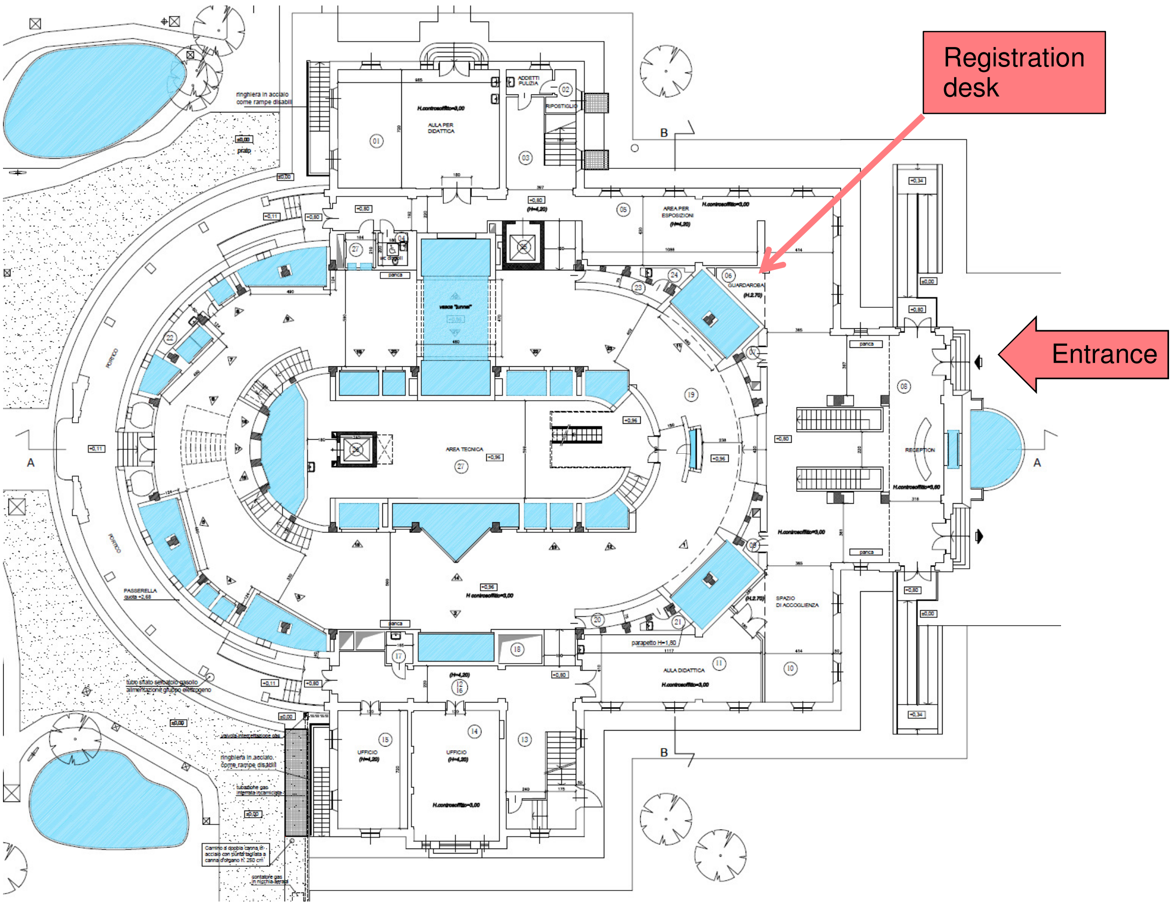
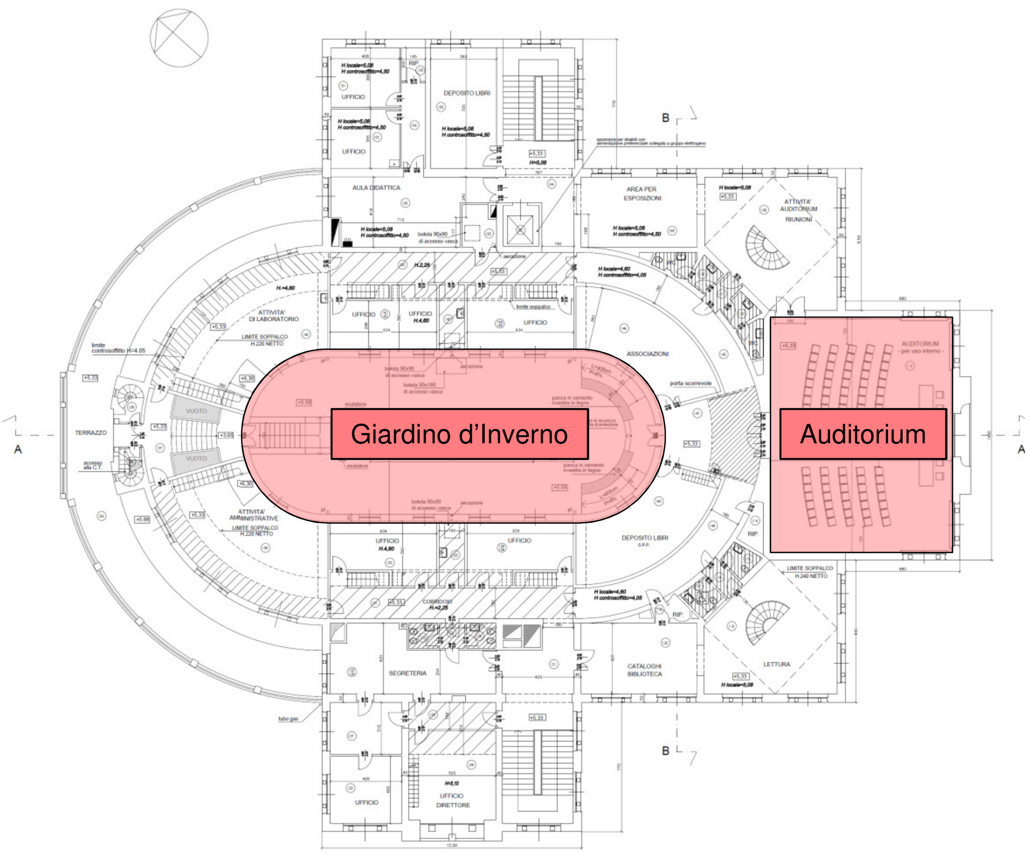
NOTES

Acquario Civico Milanese

Ground floor



First floor



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