Optics for EUV, X-Ray, and Gamma-Ray Astronomy VII

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Editors

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Contents

Authors

Numbers in the index correspond to the last two digits of the six-digit citation identifier (CID) article numbering system used in Proceedings of SPIE. The first four digits reflect the volume number. Base 36 numbering is employed for the last two digits and indicates the order of articles within the volume. Numbers start with 00, 01, 02, 03, 04, 05, 06, 07, 08, 09, 0A, 0B...0Z, followed by 10-1Z, 20-2Z, etc.

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Session Chairs

1 Cherenkov Telescopes
Nicolas M. Barrière, cosine Science & Computing B.V. (Netherlands)

2 Laue Lenses
Giovanni Pareschi, INAF - Osservatorio Astronomico di Brera (Italy)

3 X-ray Telescopes
Ryan Allured, Harvard-Smithsonian Center for Astrophysics (United States)

4 Design and Analyses
Yuzuru Tawara, Nagoya University (Japan)

5 Silicon-pore Optics
William W. Zhang, NASA Goddard Space Flight Center (United States)

6 Slumped-glass Optics
Marcos Bavdaz, European Space Research and Technology Centre (Netherlands)

7 Other Mirror Technologies
Daniele Spiga, INAF - Osservatorio Astronomico di Brera (Italy)

8 Alignment and Assembly
Stephen L. O'Dell, NASA Marshall Space Flight Center (United States)

9 Dispersion Gratings
Randall L. McEntaffer, The University of Iowa (United States)

10 Polarimetric Optical Elements
Mark L. Schattenburg, Massachusetts Institute of Technology (United States)

11 Multilayer Coatings
Mikhail V. Gubarev, NASA Marshall Space Flight Center (United States)

12 Differential Deposition
Suzanne E. Romaine, Harvard-Smithsonian Center for Astrophysics (United States)

13 Coating Stress Control
David L. Windt, Reflective X-Ray Optics LLC (United States)

14 Active Optics
Vadim Burwitz, Max-Planck-Institut für extraterrestrische Physik (Germany)

15 Testing and Metrology
Melville P. Ulmer, Northwestern University (United States)

Introduction

The conference *Optics for EUV, X-Ray, and Gamma-Ray Astronomy VII* met 10–13 August, in San Diego, California, as part of the **SPIE Optics + Photonics 2015** international symposium ***Optical Engineering + Applications***. As with the previous conferences in this series, it provided an effective forum for discussion of recent progress in imaging and spectroscopic optics for EUV, x-ray, and gamma-ray astronomy. More than 60 papers presented in the 15 Conference sessions reported upon advances in optical science and technology relevant to such optics.

Currently operating x-ray observatories—*Chandra*, XMM-*Newton*, *Swift*, *NuSTAR*, and *Hinode*—demonstrate the importance of imaging optics to x-ray astronomy. Launching within the next few years, *Spectrum Röntgen Gamma*'s eROSITA will conduct the most sensitive x-ray all-sky survey; *Astro-H* will provide soft- and hard-x-ray focusing telescopes—including a soft-x-ray imaging micro-calorimeter. In this same period, India and China will each launch its first dedicated astronomical satellite—the multi-band *Astrosat* and the Hard X-ray Modulation Telescope (HXMT), respectively. Collectively, these missions significantly advance technologies for high angular resolution, large collecting areas, high spectral resolution, broad spectral coverage, and lightweight optical components.

NASA, ESA, and JAXA continue to develop technologies for lightweight, large-area, high-resolution x-ray mirror and grating systems that will enable future x-ray observatories. Indeed, ESA recently selected ATHENA—an x-ray mission enabled by development of innovative x-ray optics—to be launched by 2018 as the second large-class Cosmic-Vision mission. Meanwhile, NASA is starting to study the "X-ray Surveyor", with a goal to implement a mission having the exquisite angular resolution of *Chandra* but a throughput 10–30 times larger. Together with research into more futuristic topics—including diffractive or interferometric imaging and active optics—significant progress continues worldwide toward meeting the future needs of EUV, x-ray, and gamma-ray astronomy.

Session 1 treated normal-incidence mirrors for Imaging Atmospheric **Cherenkov Telescopes** (IACTs). This approach employs arrays of ground-based telescopes with moderate angular resolution and large collecting areas, to detect visible Cherenkov light produced by atmospheric charged-particle showers initiated by γ-ray photons in the 20 GeV to 100 TeV band. Currently, three main IACT systems—HESS, MAGIC, and VERITAS—are operating; the Cherenkov Telescope Array Observatory (CTAO) is under development. Papers discussed recent progress in a mirror manufacturing technique based upon cold-shaping glass, as well as development of prototype telescopes of different sizes for the CTAO.

Section 2 dealt with the development of **Laue Lenses** to focus γ rays with energies from a few tens keV to 1 MeV. These systems, which use Bragg diffraction in transmission, will greatly improve the sensitivity for soft γ-ray astronomy over that provided by the non-focusing detectors used thus far. Having demonstrated the basic technology in balloon experiments, current efforts to consolidate the technology aim for implementation in a satellite mission. In particular, very interesting reports described integration methods to align and to assemble many crystal tiles into a large Laue lens for such a mission.

Session 3 described **X-ray Telescopes** that are in preparation or proposed. The ART-XC hard-x-ray instrument based upon focusing optics, is part of *Spectrum Röntgen Gamma*, which will be launched in 2017. In a more preliminary stage, efforts continue toward development of a high-throughput four-reflection x-ray telescope for a future mission—such as DIOS.

Session 4 discussed computational tools for **Design and Analyses** of x-ray optics. New ray-tracing and analytical approaches for simulating x-ray optical systems are important for optimizing performance and for identifying issues potentially impacting the scientific utility of future observatories.

Session 5 reported progress in **Silicon-pore Optics**. ESA is supporting development of this novel technology for segmented optics with high throughput and good angular resolution, as a baseline for its ATHENA mission. Having obtained promising results thus far, the current goal is to demonstrate definitively the capability to meet ATHENA's performance requirements—about 2-m^2 effective area (1 keV) and 5-arcsec resolution (HEW) over a 40-arcmin field of view.

Session 6 reported progress in **Slumped-glass Optics**. Presentations described various approaches and aspects of this technology that are being developed in the US and in Europe. The NuSTAR mission demonstrated the capabilities of slumped-glass x-ray optics for medium-resolution (<1-arcmin) imaging. Recent results show that this technology can achieve <10-arcsec resolution (HEW).

Session 7 addressed **Other Mirror Technologies** for fabrication of x-ray optics. Direct fabrication or replication of thin monolithic full-shell mirrors remains attractive due to the simplicity of alignment and assembly relative to those processes for segmented mirrors. However, for very-large-area x-ray telescopes, segmented mirrors have an advantage in scalability and modularity. Recent advances in precision fabrication of thin single-crystal silicon segmented mirrors is particularly exciting.

Session 8 described approaches for **Alignment and Assembly** of future high-angular-resolution x-ray optics. Several papers reported recent accomplishments on these themes, including a "cold" shaping mirrors and integration using reinforcing ribs to impart appropriate curvature to initially flat substrates. This could be a fast and cost-effective solution for making low-weight and low-cost x-ray optics.

Session 9 discussed **Dispersion Gratings** for high-resolution spectroscopy for soft x-ray astronomy. This field is progressing rapidly in the USA through the development of high-efficiency blazed (critical-angle) transmission gratings and off-plane reflection gratings.

Session 10 reported recent investigations on **Polarimetric Optical Elements** for x-ray astronomy, which utilize multilayer coatings operating at the Brewster angle (45°) for analysis of linear polarization, as foreseen for the Chinese LAMP experiment. In a novel variation of this approach, laterally graded multilayers in combination with dispersion gratings provide spectral polarimetry over a broad range of soft-x-ray energies.

Sessions 11, **12**, and **13** covered various topics in coatings for x-ray optics—**Multilayer Coatings**, **Differential Deposition**, and **Coating Stress Control**, respectively. The research in **Multilayer Coatings** seeks to enable focused imaging of cosmic sources at hard-x-ray and soft-gamma-ray energies—up to a few hundred keV, as an alternative to Laue lenses. Efforts in **Differential Deposition** aim to use this additive-machining process as a low-force method for post-fabrication figure correction of thin mirrors at mid-to-high spatial frequencies. **Coating Stress Control** is particularly important for the thin x-ray mirrors needed for large-area focusing x-ray telescopes. Its objective is either to minimize the stress so as to avoid distorting a thin mirror, or to manipulate the stress in order to correct predictably the figure of the mirror at low-to-mid spatial frequencies. Stress manipulation is achieved either through control of the coating parameters during deposition or through post-deposition stress modification—e.g., through ion implantation.

Session 14 reported progress in development of **Active Optics** for x-ray astronomy. Using the piezoelectric bimorph (or an analogous magnetostrictive) effect, active optics enables adjustment of a mirror's figure after fabrication and mounting, at low-to-mid spatial frequencies. In order to achieve sub-arcsecond imaging using highly nested, lightweight x-ray mirrors, the X-ray Surveyor may require a combination of static and active post-fabrication figure correction.

Finally, **Session 15** addressed **Testing and Metrology**. Papers on Testing described two new methods to produce a parallel, monochromatic x-ray beam of large size, using optical elements that collimate x rays generated by conventional sources. Such an approach would facilitate testing and calibration of large-diameter focusing x-ray telescopes—e.g., ATHENA. Papers on Metrology reported development of specific instruments for reflectometry and for deflectometry of x-ray mirrors.

We thank the Conference Committee for helping to organize the technical program and for fostering broad participation, and the session chairs and

presenters for a successful and stimulating conference. We also appreciate the efforts of the SPIE staff in organizing the Conference and in publishing the Proceedings.

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