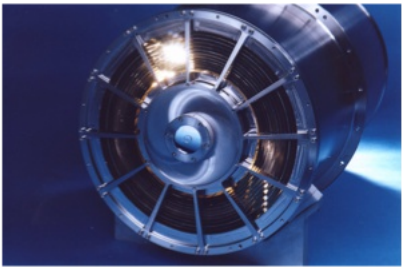
INAF

Osservatorio Astronomico di Brera



ISTITUTO NAZIONALE DI ASTROFISICA
INAF
NATIONAL INSTITUTE FOR ASTROPHYSICS

OSSERVATORIO ASTRONOMICO DI BRERA

STEPHAN'S

Hubble space telescope image of Stephan's Quintet, about 300 million light-years away. The four reddish galaxies are part of the group and busy in repeated close encounters. The blue object is much closer to us, a mere 40 million light-years distant and does not take part in the cosmic action. Credit: ESA/Hubble.

VIEWS OF TH

Image credit:
www.spacete

S QUINTET

BBLE

HE UNIVERSE

NASA, ESA
elescope.org

Our close neighbor twin sister Andromeda. This is how we might appear to an external observer. Credit: Robert Gendler.

Brief introduction to OAB

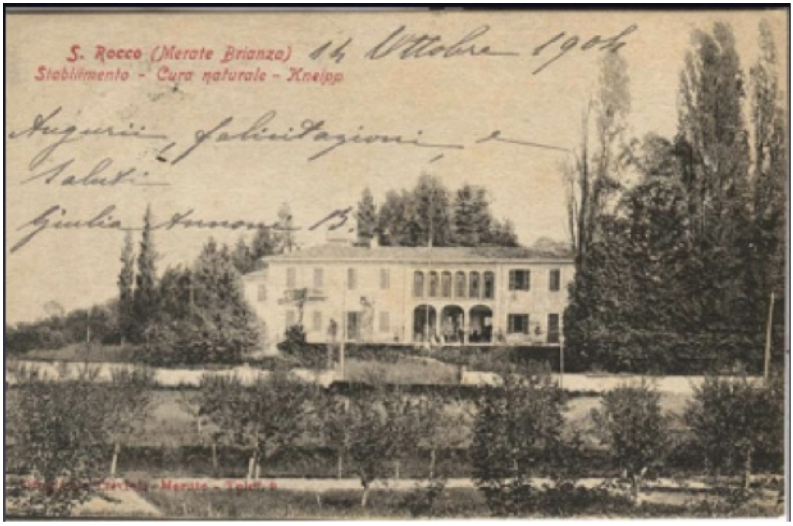
The Osservatorio Astronomico di Brera (OAB) is one of the Italian Astronomical Institutes with the longest tradition and it is the oldest scientific institution of Milano. It was founded in 1762 by Ruggiero Boscovich. Giovanni Virginio Schiaparelli, one of the most famous Italian astronomers, has been director of OAB at the end of the 18th century.

Since 1923 a second site of the observatory was opened in Merate (30 km from Milano).
In 1945 OAB became part of the scientific institutions of the newborn Italian Republic and since 2003 it is part of the National Institute of Astrophysics (INAF).

Besides Boscovich and Schiaparelli, OAB has been the workplace of several famous astronomers like Barnaba Oriani, Giovanni Celoria. Margherita Hack, to mention a few.

Now it is one of the top level research institutes in the world with more than hundred people employed.

The web site of the Institute is *www.brera.inaf.it*


S. Rocco (Merate Brianza) 14 Ottobre 1904
Stabilimento - Cura naturale - Kneipp
Auguri, felicitazioni e
Saluti
Giulia Amoni B.

The OAB sites

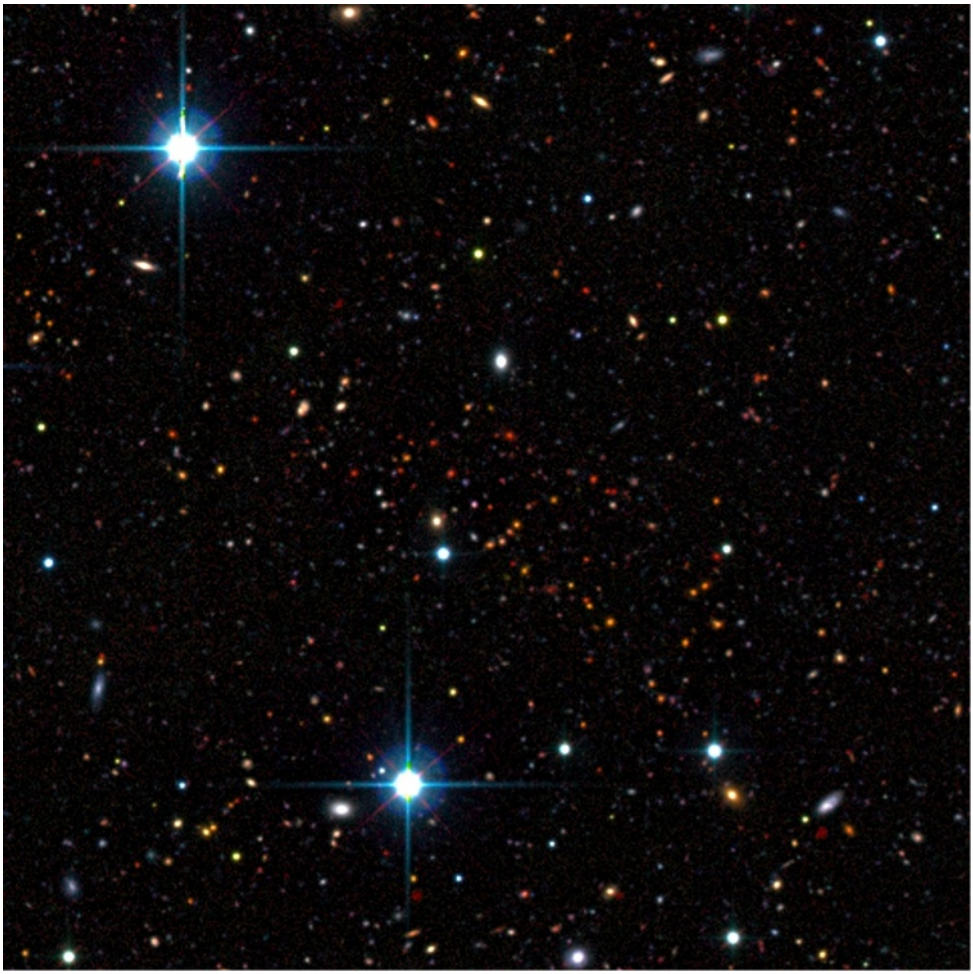
MILANO In the original site in Palazzo Brera there is an important historical archive of manuscripts and scientific documents, a library with more than 35,000 ancient books, besides the modern part with thousands of scientific books.
The completely renewed "cupola Zagar", once the location of instruments used for celestial observations, with the small "comet finder" dome, are now used for public conferences, workshops, public visits and didactic activities.
A permanent exhibition of ancient astronomical instruments used by the astronomers in Brera is open to the public. The Schiaparelli Dome hosts the fully restored first telescope used by Schiaparelli himself.

MERATE Two fully operational telescopes, "Ruths" and Zeiss", are now used for day-time visits and night-time observations for schools and the public.
Public lectures, workshops and didactic activities are routinely given in a modern multimedia room.
The library has more than 6,000 books, mostly of the twentieth century. In Merate there is also a guesthouse for students and visitors/astronomers.

The activities

The research area covers a wide range of fields: from planets to stars, from black holes to galaxies and from gamma-ray bursts to cosmology. The main projects are carried out in collaborations with national and international institutes.

OAB is also active in the technological research applied to the astronomical instrumentation and it is one of the world leaders in the development of X-ray astronomy optics and, more in general, of light instrumentation for space missions.



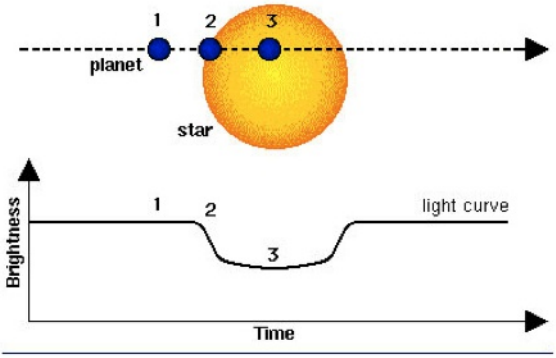
Color image of the most distant cluster known at the present time discovered at the Brera Observatory (Andreon et al. 2009).

Science: the fields of research

A specific aspect of the science programs is the focus on high-energy astronomy. On the scientific side, important observing programs carried out with *Beppo*SAX, XMM-Newton, Chandra, Swift, Rossi-XTE and INTEGRAL, together with large archival databases from past X-ray missions, allowed the realization and the participation to important projects.
The scientific objectives involve neutron stars and black holes in our galaxy, massive black holes at the centres of galaxies, hot plasmas in stars, galaxies and clusters of galaxies. Closely associated theoretical work includes the study of relativistic plasmas around black holes and in particular relativistic jets and the Gamma-Ray Burst phenomenon, possibly related to the collapse of a massive star into a black hole.

Concerning optical astronomy, the OAB stellar group is very active in the field of stellar pulsations and in the search of extrasolar planets. For these studies scientific data from CoRoT and Kepler satellites and ground based telescopes are exploited by OAB researchers.

For the observational extragalactic astronomy and cosmology a key aspect is the exploitation of cosmological surveys conducted at the international level. Nowadays our researches are exploiting VIMOS scientific data throughout very large redshift surveys like VVDS and COSMOS coming from the Very Large Telescope of ESO.


1
2
3
planet
star
Brightness
1
2
3
light curve
Time

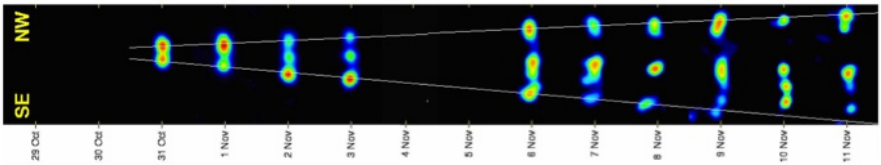
Extra-solar Systems

Astronomers discovered about hundres extra-solar planets since 1992. Their presence has been identified by means of both ground-based spectroscopic surveys, revealing the small Doppler effect produced by the orbital movements, and monitoring with space satellites, measuring the sudden dips in luminosity due to the transits of the planets in front of the parent stars.
Most of the extra-solar worlds are composed of giant gaseous planets, similar to Jupiter, Saturn, Neptune, and Uranus.
Moreover, they are very close to the stars harbouring them and the physical conditions are very extreme: hot temperature surfaces and short orbital periods. Nothing similar to our Solar System, at the moment.

The current challenge is first to discover planets similar to the Earth and then to investigate if they can host a sort of extraterrestrial life. Several candidates have been proposed and they are currently deeply studied, for instance measuring the ages, masses, and radii of the stars using the stellar oscillations (asteroseismology). New missions having a large involvement of OAB are planned.

The exciting discovery of a new Earth could be around the corner.

Colour composite image of an active galaxy: Centaurus A. Two jets emanates from the galaxy's central massive black hole. Images taken in infrared, visible and X-ray light have been superposed. The dark stripe crossing the centre of the galaxy is due to a belt of dust, partially blocking the visible light.



Snapshots of the galactic source GRS1915+105 taken by an array of radio-telescopes. It shows bullets of ultra-hot gas being shot out of the centre, at a velocity close to the speed of light.

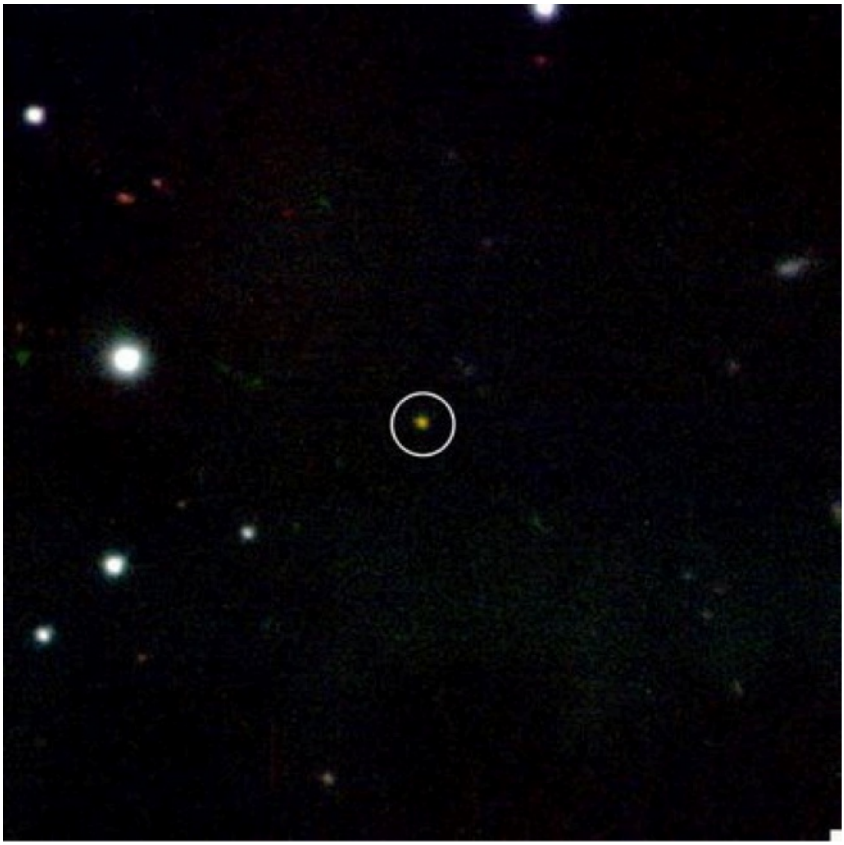
The violent Universe

We live in a quiet region of our Galaxy, around a normal star 5 billions years old. In other parts of the Galaxy, and at the centre of other galaxies, there are instead dramatically more active sources, whose power is difficult even to imagine. The "engine" at the core of these sources must necessarily be much more efficient than the thermonuclear reactions that power our Sun. It is the fall of matter pulled by the immense gravity of neutron stars and black holes that let these sources be so active.

Obeying the most famous equation of the world, $E=mc^2$, about 10% of the mass is transformed into energy, namely light. But this is not the light that our eyes can see. It is mainly X-rays and gamma-rays. In fact, most of the matter falling down is compressed and heated to very high temperatures before crashing onto the surface of a neutron star, or before being swallowed by the black hole. These X-rays and gamma-rays are (fortunately) blocked by our atmosphere, and it is mandatory to put receivers in orbit to detect them.

A tiny fraction of the falling mass, when it gets close to the central object, is instead violently expelled into two jets going into opposite directions, beginning a journey that can last for millions of years. The velocity of this expelled matter can be the 99,5 per cent of the velocity of light. Exactly how it happens is somewhat still a mystery, and one of the most fascinating problems we are here to solve for.

This enterprise needs good instruments that can fly on satellites, including "mirrors" able to concentrate X-rays to do an X-ray telescope, and it needs good ideas to make sense of the data. OAB is internationally recognized for both aspects.

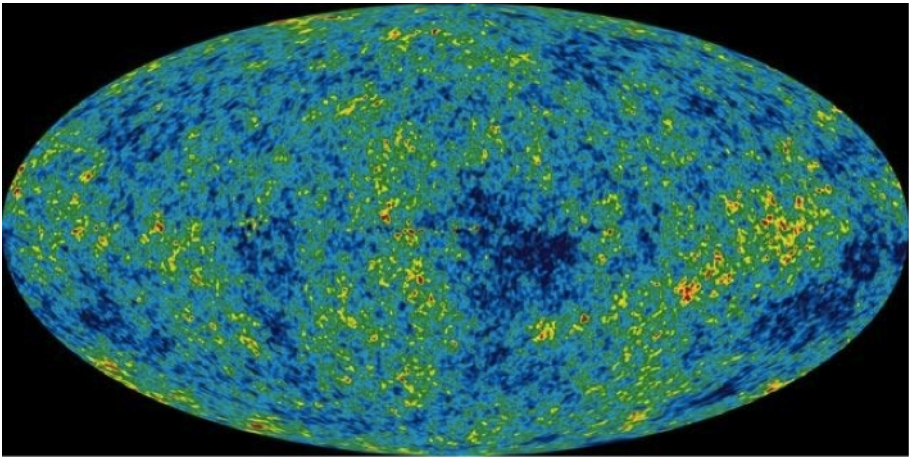


The record holder GRB 090423: it is the most distant stellar object known. Occurring only 630 million years after the Big Bang, GRB 090423 detonated so early that astronomers had no direct evidence that anything explosive even existed back then. The infrared emission from the GRB is circled in the above picture taken by the Gemini North Telescope. The distance has been first measured using the Italian Telescopio Nazionale Galileo with a fundamental contribution of OAB astronomers.

Gamma ray burst

200-300 million years after the Big Bang stars began to form, providing the Universe with the first sources of light and heat. The direct investigation of this cosmic epoch has been revolutionized in the last decade through the study of Gamma-ray Bursts (GRBs). GRBs are short (seconds) gamma-ray flashes, produced by rare types of massive stellar explosions. The GRB research field has been revolutionized in the last few years by the Swift space mission, based on a collaborative effort among USA, Italy and UK. OAB is deeply involved in this project.
Through Swift, OAB discovered the more distant GRB, which exploded when the Universe was only 630 million years old, providing a tool to probe the Universe in its youth.

GRBs are tightly related to supernovae. Supernovae are also spectacular events, producing the same amount of energy as trillions of nuclear bombs detonating simultaneously. Typically, they occur when a massive star - more than eight times the mass of the Sun - runs out of fuel and collapses to form a neutron star, or, if more massive, even a black hole. After the collapse the supernova is expected to reach its peak brightness in about two weeks.
With Swift, OAB discovered a peculiar close-by GRB connected to the explosion of a supernova caught in the act of breaking out through the star's gaseous outer layers - blowing it to smithereens.



The Cosmic Microwave Background: a snapshot of the Universe when it was only 300,000 years old. The different colours correspond to tiny differences in temperature (one part in a million!). Inside the hot (yellow and red) spots, billions of years after, the galaxies were formed.

What is the Universe made of?

After the colossal explosion of the Big Bang, regions that were only a little denser than their surroundings started to slowly contract under the influence of their own gravity. These regions were the primordial seeds of galaxies and clusters of galaxies.

But all the visible matter of galaxies, and all we are made of, is only 4% of the total content of the Universe as we know it. The dark side of the Universe makes the remaining 96%: dark matter (26%) and dark energy (70%). “Dark” because these components do not emit light, and “dark” because we do not yet understand them. While Dark Matter pulls things together through gravity, the dark energy pushes things apart, making distant galaxies accelerate their motion of recession from one another. This is one of the deepest mysteries of our world. Whilst it will be hard to know why, we can more easily investigate how and when Dark Energy took the lead in the expansion of the Cosmo.

We do that studying how clusters of galaxies form, how they evolve, and studying the details of the motion of the galaxies within their environment. We end up having a detailed map of the Universe that at the same time reveals its history, since the light we receive from distant galaxies started its journey billions of years ago, when the Universe was at its infancy.

Swift official logo. Swift is a NASA satellite with important contributions from the Italian (ASI) and UK (PPARC) space Agencies. Various INAF institutes, coordinated by OAB, are involved in this project.
Credits: NASA EPO, Sonoma State University.

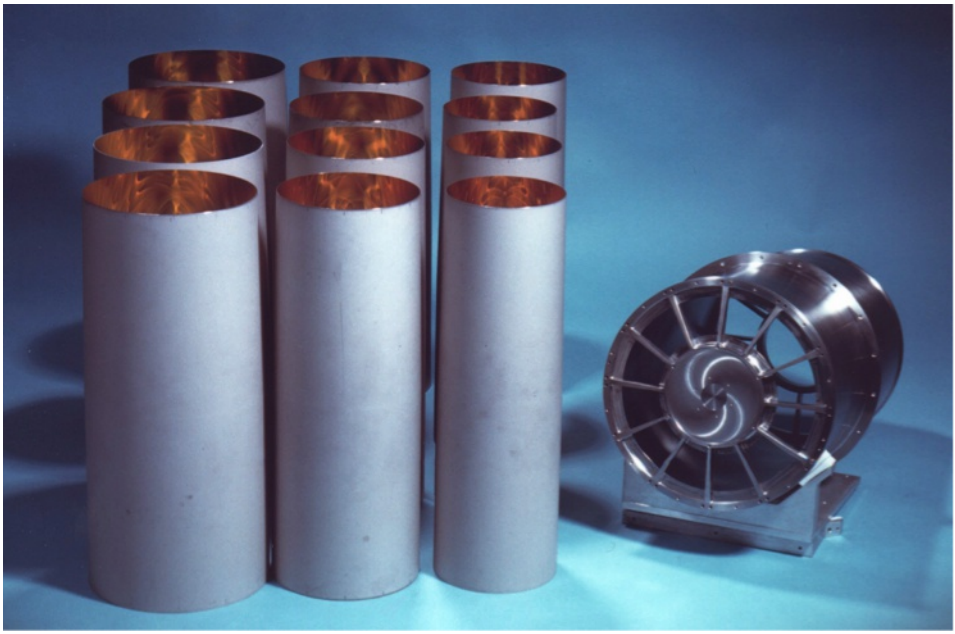
The Delta II launcher is lifting from Cape Canaveral, Florida, launch station. In the fairing on top of the launcher seats the Swift satellite (NASA credits).

The Swift satellite

The Swift satellite has been launched from the Kennedy Space Center (Florida) on November 2004.

Swift detects about 100 GRBs every year and sends their position on ground in just a few seconds. Here robotic telescopes such us REM, built by an Italian consortium led by INAF-OAB and located in Chile, perform the optical/NIR follow-up in less then one minute from the burst. In the meantime Swift repoint itself in a few tens of seconds putting the GRB inside the narrower field of view of the on board X-ray telescope (XRT) and optical/UV telescope (UVOT). These fast reactions allow us to study in detail the GRB phenomena and the associated afterglow emission also at very high redshift, up to the very young Universe.

OAB provided the optics of the XRT, realized in collaboration with the Media Lario Technology Company under a contract financed by the Italian Space Agency (ASI). OAB hosts the Swift Italian project office and participate to the scientific management of the satellite.



The mirror shells of the X-ray telescope on board of the Swift satellite.

High technology labs

The development of mirrors able to reflect X-rays started at OAB in 1987 when Prof. Oberto Citterio joined the Institute. Since then OAB is a worldwide leading Institutes in this field. X-ray mirrors developed by OAB are onboard the Swift and the XMM-Newton satellites, as well as the past *Beppo*SAX mission.

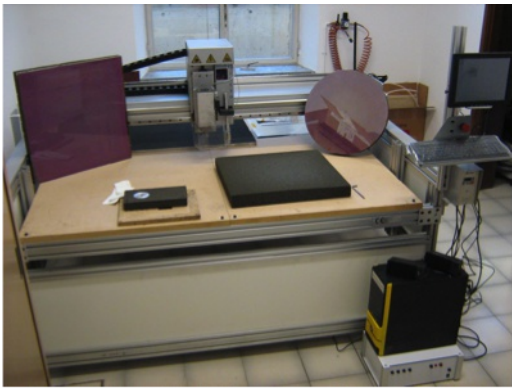
Surfaces able to reflect X-rays do not tolerate a roughness larger than a few atoms: one can then understand the challenge required to obtain such surfaces at the minimum cost, minimum weight, and maximum reliability.

Besides these developments, OAB is now involved in the realization of mirrors for the Imaging Atmospheric Cherenkov Telescopes for the detection of very high energy Gamma rays (i.e. in the TeV band) as currently done by the MAGIC telescopes and in future by the CTA (Cherenkov Telescope Array).

Another activity is related to the developments of instruments for the visible and Infrared light. OAB coordinated the Italian participation to the ESO spectrograph X-Shooter for the Very Large Telescope in Chile. With this instrument, astronomers can now study the infrared and the visible light of celestial objects in one shot.

In a few years the European astronomical community will build a huge telescope with a primary mirror of more than 40 meters of diameter. OAB is expected to equip this monster with suitable instruments to exploit its enormous collecting area, such as the very high-resolution spectrometers CODEX.

Cold slumping lab: clean room (top) and 3D pantograph (bottom).



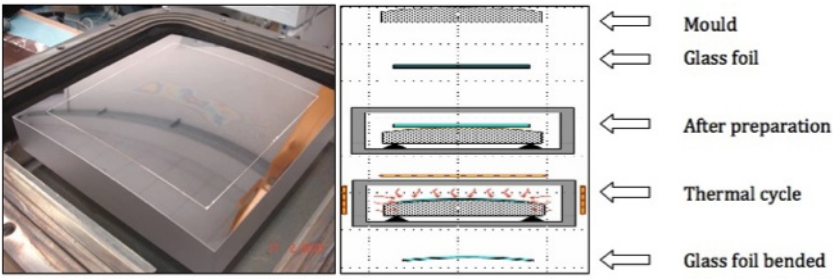
Facilities, labs and tools

Labs for glass forming process
Mechanical Workshop with computer controlled grinding machines
Metrological lab
Clean rooms (class: 100 000, 10 000, 1000, 100) covering a total area of more than 200 m2
X-ray test lab
Optics lab: interferometers
UV optical bench
2 ion figuring labs
Hot and cold slumping labs

LABS FOR GLASS FORMING PROCESSES

The cold glass slumping lab is divided in two rooms: one clean room equipped with pump suction devices, heat curing of glues and precision mandrels for mirror replication; one room equipped with a 3D pantograph for the machining of porous substrates.
These labs have been used for the production of the mirrors of the MAGIC-II TeV telescope (world's largest telescope, 17 m in diameter) and are now dedicated to the development of the mirrors for CTA (Cherenkov Telescope Array).

Oven used for the slumping (left) and muffle inside the oven (right).



Mould inside the muffle and sketch of the thermal process.

The hot glass slumping lab is equipped with 2 customized, programmable ovens, a clean room area, handling tools for heavyweight equipment and pump suction devices.

The lab is used to develop high precision optical mirrors (both normal and grazing incidence) in glass material. These glasses are thermally bended against a suitable mould with a proper shape. These processes are based on the replication concept that allow to create a large number of segments at low cost, fast production rate and high reliability.

The hot slumping technique is developed in the framework of international collaborations such as the E-ELT project of the European Southern Observatory (ESO) and the IXO/ATHENA telescope of the European Space Agency (ESA).

Ion figuring facility chambers: 350 mm capability chamber (left) and 1.7 m capability chamber (right).

Ion figuring facility chamber interior (350 mm capability) and example of profile correction via ion beam figuring.

ION BEAM FIGURING

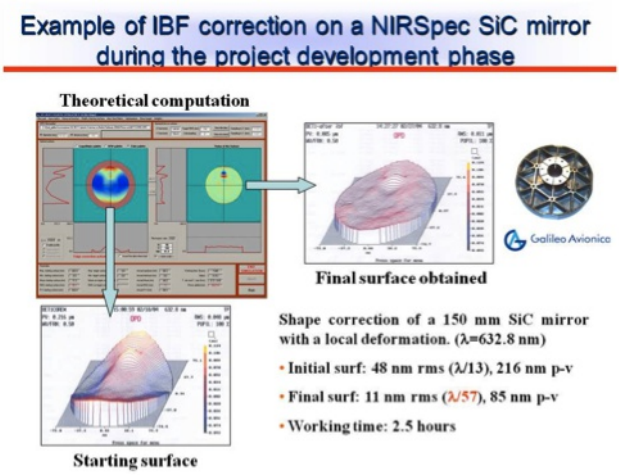
OAB operates two facilities for the high precision figuring of optical surfaces based on the Ion Beam Figuring technique.

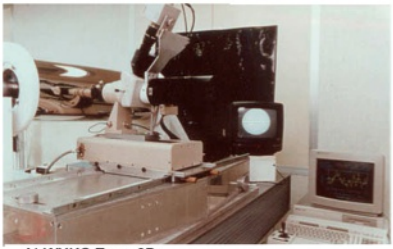
This procedure employs an Argon ion beam source, moved along the surface with different speed, to remove in a very controlled way material from the optical surface to be corrected.

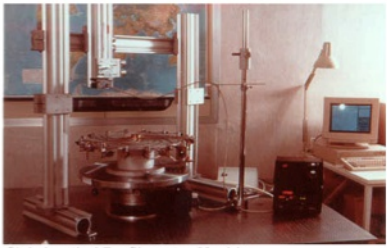
The first facility is able to correct optics up to 350 mm in diameter. The second one can correct surfaces up to 1.7 meters in diameter and is among the largest in Europe (volume of 200 cm x 300 cm).

In this context OAB has also developed a proprietary technology for the correction of high frequency profile errors.

Very good results have been obtained in a number of projects like the SUBARU LLT and the prototype mirrors for NIRSPEC/JWST (in collaboration with Selex Galileo).

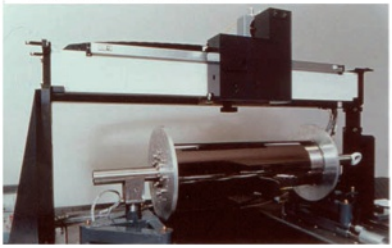


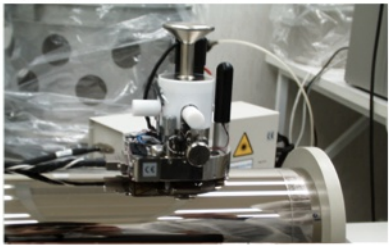


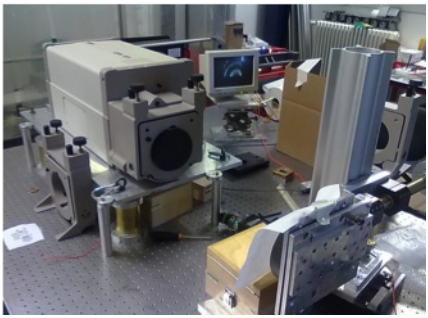


A) WYKO Topo 2D
B) Long Trace Profilometer

C) Azimuthal Profilometer Machine
D) Atomic Force Microscope







ZYGO optical interferometer (left) and Nomarsky phase contrast microscope (right).

CHRocodile® distance and glass thickness optical sensor.

METROLOGY LAB AND OPTICAL TEST INSTRUMENTATION

The metrological lab is based on a large number of facilities for the characterization of profiles and microroughness of optical surfaces. The instrumentation covers a wide range of scan sizes and lateral resolutions to achieve a consistent diagnostic of the defects that concur to degrade the angular resolution of the optics:

WYKO TOPO 2D optical profilometer for roughness measurements;

Azimuthal profilometers for roundness measurements of mandrels and grazing incidence optics (from XMM production);

Long Trace Optical Profilometer II (LTP) by Continental Optics, for axial profiles of mandrels and mirrors;

Long Trace CMD Contact Profilometer ZEISS (from XMM production);

Stand-alone Atomic Force Microscopes (AFM) DIGITAL *Nanoscope III* and VEECO *Explorer* for roughness measurements;

Coordinate Measuring Machine (CMM) Galaxy-Poli up to 50 cm;

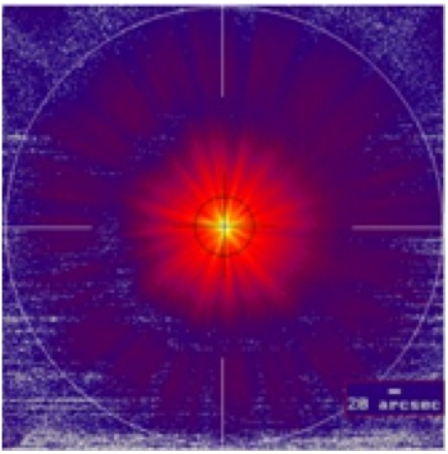
3D Zygo GPI optical interferometer for high-resolution sample mapping (< 10 cm diam.);

Roughness Meter MITUTOYO Surftest Formtracer 301;

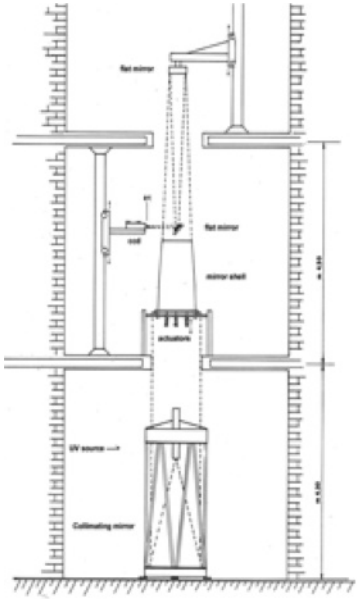
CHRocodile optical sensors for surface and glass thickness mapping;

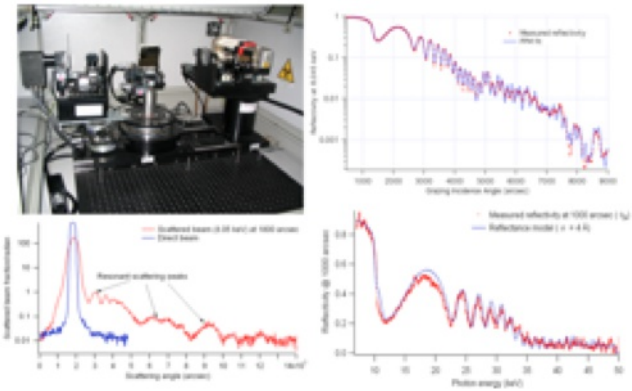
Nomarsky Phase Contrast Microscope OLYMPUS BX30M for surface roughness inspection;

Vertical UV bench for test and integration of grazing incidence optics



The focus of a grazing incidence mirror in UV at the vertical optical bench.



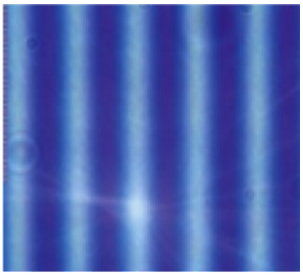


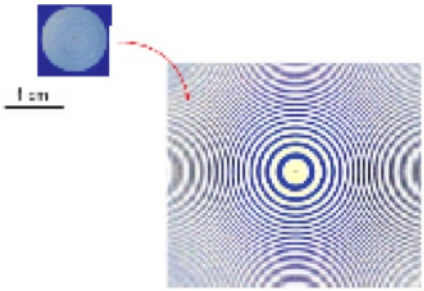
X-RAY TEST LAB

The X-ray laboratory is suitable equipped to measure the X-ray performances of mirror and coating samples.
The instrument is a multi-purpose BEDE-D1 X-ray diffractometer comprising 3 changeable X-ray tubes (Cu, Mo, W anode), a set of Channel-Cut-Crystal monochromators ($\Delta E/E \approx 10^{-4}$) to select the X-ray Kα line of Cu (8.045 keV) or Mo (17.45 keV) and to increase the angular resolution of the measurement, a sample holder, and a highly-linear X-ray scintillation detector.
Moreover, the monochromators can be removed and the polychromatic beam (usually from the W anode tube) used to probe the reflectivity of the sample at 5 to 50 keV. In this case, the reflected beam is analyzed by a solid-state spectroscopic detector, with 150 eV energy resolution.
The system is equipped with a set of rotary stages for precise alignment.

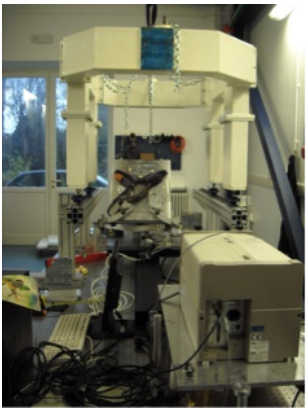
The sample measurements that can be performed are:

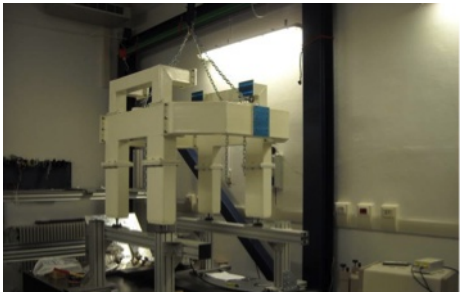
1. *X-ray reflectivity angular scans in monochromatic mode*, suited for X-ray coating structure analysis along with an accurate fit of the scan;
2. *X-ray reflectivity in polychromatic mode*, suited to a direct check of the reflectivity performances in hard X-rays;
3. *X-ray scattering measurements*, for measurement of the samples roughness and of the interfacial roughness in multilayer coatings;
4. *X-ray diffraction measurements*, to characterize the microcrystalline structure of thin films.





The microscope image of the impressed photochromic VPHG (left); a photochromic CGH of a spherical lens (right).





The interferometric optical set-up for adaptive optics.

LAB OF HOLOGRAPHY

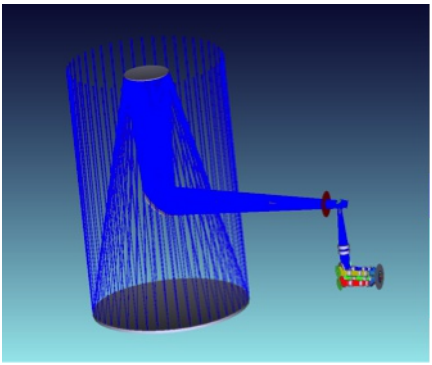
The laboratory is equipped with an holographic optical set-up in a Lloyd mirror configuration with a DPSS 532 nm laser for making Holographic Optical Elements and in particular Volume Phase Holographic Grating (VPHGs) based on photopolymers and photochromic materials. The devices are characterized in terms of efficiency using a custom made instrumentation working at different wavelengths (multiline Ar+ laser, red and NIR diode lasers, He-Ne laser). Computer Generated Holograms are also obtained on photochoromic substrates using a simple maskless lithography technique

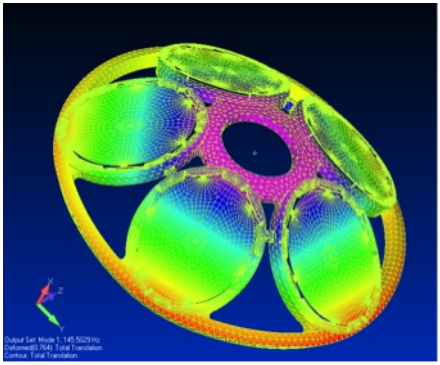
LAB OF MATERIAL PREPARATION AND CHARACTERIZATION

The laboratory is devoted to the preparation of photoactive substrates in a laminar flux hood and their characterization through the UV-vis-NIR spectroscopy and other custom made instrumentations designed to measure the quantum yield of photochromic materials in solid state and solution. Theoretical models of the materials photoresponse are also developed.

LAB OF INTERFEROMETRY

A phase-shifting Fizeau interferometer with a 10cm collimated beam is operated over a large vibration-free optical bench, to measure flat and spherical optical surfaces down to few nanometers accuracy. Also a stitching setup can be operated to measure flat surfaces up to 1-m size. Measures can run remotely, when a quiet environment is required. Typical thermal gradients are below 0.1 °C/hr. Measurements on adaptive optics have been carried out in the last years.





Zemax optical rendering, FEA analyss and the picture of X-shooter arm with the involved people.

LAB OF OPTO-MECHANICAL DESIGN AND INTEGRATION

Fully integrated optical and mechanical design, together with FEA analysis, is routinely carried out to design, optimize and develop ground-based and space instrumentations for astronomical purposes. After procurement, pieces can be tested, integrated and aligned together before final performance checks.
Optical benches and a telescope simulator are available to run through integration, alignment and verification of medium-sized optical and infrared instrumentations. E.g., the ultraviolet and visible spectroscopic arms of the X-Shooter instrument on the Very Large Telescope (ESO, Chile) have been integrated here.

THE OPTICAL POLISHING LAB

It is now jointly run in cooperation with Media Lario as part of the Center of Excellence. This center hosts two super-polishing ZEISS machines for pseudo-cylindrical mandrels (used for the realization of the XMM mandrels and now used for further developments such as Simbol-X and NHXM); polishing machines for flat samples and a high precision profilometer from ZEISS.

The Observatory conference hall in Merate.

Cupola Fiore - The Observatory conference hall in Milano.

Public Outreach and Education

OAB scientists interact with many students supervising them for the Laurea degree thesis. The most intense and fruitful interaction is with the PhD students coming from various Universities in Milano.

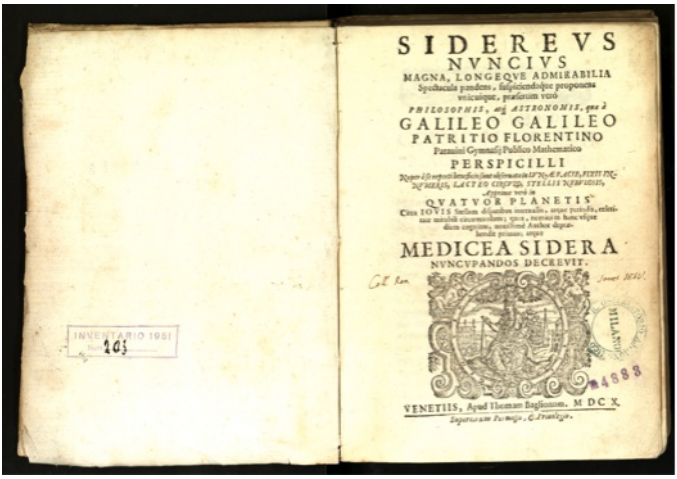
OAB was the first Italian Observatory to recruit specialized staff for setting up a dedicated office for Public Outreach and Education activities (POE) in order to foster science communications at several levels from young students to the general public.

The two OAB sites have different and complementary facilities able to offer a wide range of approaches to science communication activities. Whilst the main attractions in Merate are the astronomical observations with the telescopes, the Milan seat offers a number of innovative multi-disciplinary proposals that can compete with the vast offer available in the city and in accordance with the overall cultural outlook of Palazzo Brera.

In both sites professional staff organizes visits to the institute for the public and the schools, didactic laboratories and multi-subjects expositions. These activities are supported by grants from ESA, NASA, MIUR, ASI and Fondazione Cariplo.

The image represents a map of planet Mars traced by Schiaparelli. The map is in the first scientific memory that was published after 1877 opposition. Schiaparelli's maps were the most exhaustive ever published.

Sidereus Nuncius by Galileo Galilei. Published in only 500 copies in 1610. The OAB archive has one.



SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim vero
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt detecta in LVNA, FIXIS, STELLIS NEBVLOSIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS, Apprime vero in
QVATVOR PLANETIS
Circa IOVIS stellam disparibus interuallis, atque periodis, celeritate mirabili circumuolutis; quos, nemini in hanc vsque diem cognitos, nouissime Author depræhendit primum, atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.

The historical Instruments, Libray and archive

The OAB historical archive preserves books and diaries, calculations documents, pictures, notes, invitations, pass, travel reports. In addition it has more than 15,000 letters of astronomers like Laplace,Boscovich, Herschel, Secchi, but also Cesare Beccaria and Napoleone I. Valuable is the Giovanni Virginio Schiaparelli's “Fondo” which contains the diaries with the observations of Mars. They have been recently digitalized with the help of Fondazione Cariplo.

OAB holds an invaluable historical patrimony in documents, ancient instruments, and 35,000 volumes from the XV to the XIX centuries. Among them we have the Stellar Atlas of Johannes Hevelius, the “Tavole Alfonsine” (1492 edition) which guided Columbus, Ptolomaeus' “Almagesto”, Copernicus' “De Revolutionibus”, Galileo's “Sidereus Nuncius” and others.

OAB supports the National Edition of the Complete Works of R. G. Boscovich, founder of the Observatory, including more than 3,000 letters, to make them accessible in a data base, to be released for 300th anniversary of his birth (1711-2011).

There is also an exhibition area where visitors can see the historic instruments of OAB.

The historical archive is located at the Milano site, in Palazzo Brera, via Brera 28. It is open for consultation, by appointment only, from Monday to Friday from 9:30 to 16:00.

www.brera.inaf.it

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