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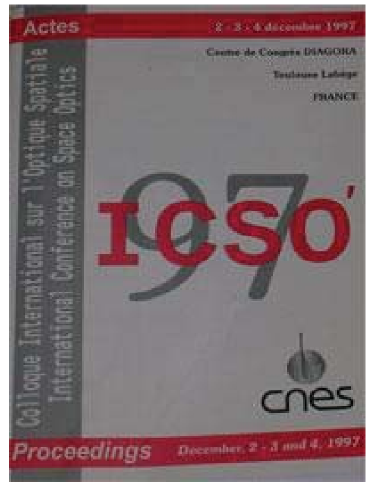

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GERMAN ACTIVITIES IN OPTICAL SPACE INSTRUMENTATION

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ABSTRACT - In the years of space exploration since the mid-sixties, a wide experience in optical space intrumentation has developed in Germany. This experience ranges from large telescopes in the 1 m and larger category with the accompanying focal plane detectors and spectrometers for all regimes of the electromagnetic spectrum (infrared, visible, ultraviolet, x-rays), to miniature cameras for cometary and planetary explorations. The technologies originally developed for space science, are now also utilized in the fields of earth observation and even optical telecommunication.

The presentation will cover all these areas, with examples for specific technological or scientific highlights. Special emphasis will be given to the current state-of-the-art instrumentation technologies in scientific institutions and industry, and to the future perspective in approved and planned projects.

1. INTRODUCTION

Germany has been active in space exploration since the mid-sixties. In the beginning, special emphasis was laid upon in-situ measurements, in particular in upper atmosphere research, plasma and field investigation of the Earth's magnetosphere and the interplanetary medium Outstanding highlights of these investigations are the two HELIOS probes (1974, 1976) which approached the sun to about one third of the Sun-Earth-distance. One of the instruments in this mission, the Zodiacal Light experiment, already employed three small telescopes with photometers to determine the Zodiacal Light distribution

With the increase of the knowledge and the research experience, the experimental methods were widened also into other fields. As one other example, upper atmosphere research may be used: From the limited mass spectrometer data the need arose to measure the atomic oxygen line of 63 µm by means of cooled infrared spectrometers (1978 by the University of Wuppertal).

Shortly thereafter for the planned visit of the comet Halley by the ESA GIOTTO probe, a sophisticated camera was developed in the Max-Planck-Institute for Aeronomy (MPAe). This Halley Multicolor Camera (HMC) provided spectacular images of Halley's comet

In addition, optical systems in other regimes of the electromagnetic spectrum were developed for space investigations, e. g. the x-ray optics for the German Roentgensatellite ROSAT (1990), infrared spectrometers for ISO (1996) and CRISTA-SPAS (1994, 1997) and spectrometers and telescopes for the extreme ultraviolet regime.

When defining „optical" as „connected with wave phenomena" like reflection and/or diffraction governing the processes in the detection devices, Germany now is active in almost all areas of optical space instrumentation. This will be outlined in the following presentation.

2. Status of German optical space instrumentation

The status decription will be structured according to the different regimes of the electromagnetic spectrum, and also into general observation modes (e. g. imaging or spectroscopy). Only a selection of all developments can be given.

2.1 Infrared instrumentation

Two separate fields of science employ infrared detecting sensor

remote sensing of infrared emissions of the components of the Earth´s atmosphere
observation of infrared radiation from celestial objects.

In remote sensing, first efforts started in the seventies. The first goal was - as indicated in the introduction - the determination of the „forbidden" emission line of atomic oxygen at 63 μm. The first successful measurement was achieved with a helium cooled spectrometer on a sounding rocket in 1978

Building on this experience, the responsible research institute, the University of Wuppertal, developed a large liquid helium cryostat carrying three telescopes and four spectrometers (of the Ebert-Fastie-type) for the atmospheric limb sounding of the minor species in the atmosphere. This instrument CRISTA (CRyogenic Infrared Spectrometers and Telescopes for the Atmosphere) was flown successfully on the ASTRO-SPAS science satellite, carried in orbit by the Space Shuttle (1994 and 1997) During the second mission, 43.000 altitude scans from about 15 km upwards of typically 17 atmospheric gases were collected, an example for the power of the instrument.

For infrared astronomy, the instrument development for space applications built on previous experience with high altitude balloons For the ESA ISO satellite, two major German contributions to the focal plane instruments are described:

In the Short Wavelength Spectrometer (SWS), the Max-Planck-Institute for Extraterrestrial Physics (MPE) in Garching/Munich provided the Fabry-Perot-Interferometer (15 - 35 micro-meters) to the leading group in the Netherlands. The most complex instrument, ISOPHOT, was conceived in the MPI for Astronomy (MPAs) in Heidelberg, and developed and built in industry with major contribution from the C. ZEISS company and Dornier Satellite Systems. ISOPHOT operates in the regime between 2,5 and 200 micrometers and offers 13 apertures and 25 spectral filters and polarizers, with a limiting sensitivity of 10^{-18} watts.

It is - both with regard to the number and the duration of the observation requests - the „most wanted" instrument on ISO.

The know-how for infrared technology in Germany is concentrated in university institutes (Wuppertal), Max-Planck-Institutes (MPAs, MPE), in DLR (Berlin) for detector technology in the future, and in industry (in particular C. ZEISS, Dornier, but also smaller companies like Kayser-Threde).

2.2 X-ray instrumentation

Here, only that part of the x-ray regime is considered which can be imaged via reflecting telescopes, i. e. up to an x-ray energy of about 10 keV

Building on the experience of sounding rocket telescopes at MPE, x-ray grazing incidence mirror systems (Wolter type 1 and 2) were developed, culminating in the ROSAT telescope. The mirror surfaces of this telescope, manufactured at the C. ZEISS company, are still unprecedented in their surface smoothness quality. In its scientific achievements, ROSAT constitutes a highlight of European space astronomy.

Further new developments are the different x-ray detector types, like the proportional counters employed in ROSAT (with about 0,3 mm spatial resolution), the solid state detectors for the EPIC focal instruments on XMM (pn-CCDs with high efficiency, good spectral, spatial and temporal resolution adapted to the XMM requirements), transmission gratings with self-supporting gold structures for the NASA x-ray mission AXAF, and the mandrels for the XMM mirrors system, again built by C. ZEISS.

2.3 Instrumentation for the visible and ultraviolet regime

Although the Earth's atmosphere is transparent to visible light, many scientific objectives require to use optical instruments in space. This is in particular necessary for close-up or in-situ observations of non-terrestrial objects, or for observations covering large areas of the Earth itself. Due to the multitude of optical applications, a further subdivision will be used, into telescopes, cameras, focal plane detectors and spectrometers.

2.3.1 Telescopes

To counter the limited access to observational data in the extreme ultraviolet spectral data, a sounding rocket telescope with 1 m mirror diameter was built in Germany under the leadership of the astronomical institute of the University of Tübingen. Having proven the feasibility of such an instrument, a successor was developed, again with a 1 m lightweight ZERODUR primary mirror. Two focal instruments can be served, a Rowland spectrometer (built by the University of California in Berkeley) in the direct beam, and an Echelle spectrometer, developed by the Landessternwarte in Heidelberg, via a collimating deflection mirror. This „ORFEUS(Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer)-Telescope" was flown twice on the ASTRO-SPAS science satellite, collecting spectral data from many galactic and even extragalactic sources.

In the scientific instrumentation for the ESA SOHO (Solar and Heliospheric Observatory) three of the experiments with large German contributions are (small) telescopes. SUMER, a scanning ultraviolet spectrometer for the wavelength regime between 50 and 160 nanometers was developed under the leadership of the Max-Planck-Institute for Aeronomy (MPAe); for the extreme ultraviolet spectrometer CDS (17 to 79 nanometers) the mirror system of the Wolter-Schwarzschild-type was built by the C. ZEISS company under the scientific guidance of MPE, and major contributions to the white light and spectrometric coronograph LASCO were again provided by MPAe.

2.3.2 Cameras

Space-borne cameras serve two purposes. Either they are used to downlook at the Earth, for research and reconnaissance purposes or to observe celestial objects, like comets, asteroids, planets and moons. One example for the first application is the DLR-developed MOMS (Modular Optoelectronic Multispectral Stereo-Scanner), which was built by Dasa/Ottobrunn and flown twice, the first time on the German Spacelab Mission D2 (1993) and currently with the PRIRODA element on the MIR space station. It contains 7 viewing channels, with different optical band width in the visible and near infrared spectral regime, with a ground resolution between 4,5 and 13,5 m per pixel from an altitude of 300 km.

The MOS (Modular Optical Scanner), built by Dasa Jena Optronics (DJO) is a down-looking earth observation camera with CCD line arrays. One of its channels serves to correct for atmospheric effects, the other delivers images in several spectral channels to investigate both the water and solid surface. Two instruments are flown, one on the MIR station, the other on the Indian IRS mission.

Cameras with similar concepts - linear CCD arrays combining the linear picture elements to complete images via the motion of the satellite or other carrier - are used in two other DLR cameras

Both were originally developed for the Russian MARS-96 Mission, which was lost in the Pacific Ocean in November, 1996. The development of the High Resolution Stereo Camera (HRSC) started in the Western part of Germany, the Wide Angle Optical Stereo Scanner (WAOSS) in the former Institute for Cosmic Research (IKF) in (East)-Berlin, and both were finally built in two newly founded DLR institutes on the former IKF location.

The progress achieved is easily visible in the resource reductions in mass, power and volume for HRSC and WAOSS compared to MOMS (in the order of factors 3 - 5)

Complementing effort is done at the MPAe in Lindau Building on the experience gained with the scanning live camera on the GIOTTO mission, HMC, which was the first camera to „take a picture" of the nucleus of a comet in 1986, future emphasis was laid on two-dimensional CCD array cameras. This lead to the participation of the MPAe in the NASA Mars Pathfinder mission, where MPAe provided the CCD and the front end electronics to the Mars Pathfinder Camera, which took the exciting Mars images with the Sojourner travelling in the neighbourhood.

2.3.3 Focal plane instruments

Beyond the instruments described above, which all obviously contain focal instruments, one focal plane instrument deserves special attention The Faint Object Camera; Europe's science contribution to the Hubble Space Telescope. This instrument was built under the leadership of the German industry, at Dasa-Dornier Satellite Systems. It delivered many exciting new scientific discoveries

2.3.4 Spectrometers

The major part of the German spectrometer activities is already contained above, like e. g. SUMER or ORFEUS. Additionally two more developments should be indicated One, although not yet flown in space, as a high resolution spectrometer for solar physics. A balloon borne development model was flown in the 1970s, and discussions are under way to explore a future space utilization in the next generation sun exploration mission to improve both spatial and spectroscopic data of the Sun's photosphere. The other is the GOME (Global Ozone Monitoring Experiment) on the ESA Earth Resources Satellite ERS. It is a nadir-looking spectrometer, conceived by the Max-Planck-Institute for Chemistry (MPICh) in Mainz, and built in the Netherlands

3. FUTURE PROSPECTS

This section will be divided in two segments, the first describing approved instruments under development, in the second an outlook will be given into potential future applications

3.1 Instruments under development

Considering the experience of the past, it is obvious, that there is a large number of German optical instrument expertise employed in on-going space endeavors. Only those with a high visibility will be described.

For the instrumentation of the ESA science cornerstone mission ROSETTA, which will be launched early in 2003 to the comet Wirtanen, both the camera experiments on the orbiter - OSIRIS - and on the lander - CIVA/ROLIS - are either led or co-led by German science groups.

The ESA earth observation mission ENVISAT carries two instruments with strong German influence: SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Chartography) under joint development in Germany at Dornier Satellite Systems and in the Netherlands, is a large multipurpose spectrometer telescope. The scientific requirements were defined at the MPICh, the technical realisation is under Dutch responsibility. It measures atmospheric emissions and backscattered light from the ultraviolet to the near-infrared in eight separate grating spectrometers with linear CCDs. Besides nadir and limb sounding also occultation measurements can be performed

MIPAS (Michelson Interferometer for Passive Atmospheric Sounding) is a high resolution interferometer for limb sounding studies of the atmosphere in the infrared regime between 4 and 14 µm. Based on pre-developments at the Forschungszentrum Karlsruhe, it is built under an ESA contract with Dasa/Ottobrunn as prime contractor.

As a success for ROSAT, a „small satellite" is under development, aimed at achieving a complete sky survey of x-ray sources with energies up to 10 keV, thus complementing the ROSAT survey. The technologies employed are derived from XMM, both for the multiply nested mirror systems of the Wolter type 1 and the focal plane detector, which is identical to the EPIC detectors. The planned launch data is spring 1999.

After the Announcement of Opportunity for the ESA cornerstone mission FIRST has been published, two of the three planned focal plane instruments will be proposed with German contribution, the photoconductor experiment PHOC under the leadership of the MPE, and the heterodyne spectrometer HIFI under Dutch lead, but with contributions from the University of Cologne and MPAe.

3.2 Outlook

Many of the above described instruments are based on the experience of scientific groups and were mostly built to achieve scientific knowledge. The know-how is transferred to industry, and gradually other applications are feasible. There are, for example, plans to convert the HRSC and WAOSS cameras into tools for reconnaissance or for geodesy. And, in addition, optical communication through space has the potential for nearly unlimited transmission capabilities. Thus, first developments were started to define optical mini-terminals as small standardized elements of future communication satellites.

4. CONCLUSION

The history of the German activities in Space Optics is a striking example for the benefits of basic research for later technological and even commercial utilization: After using space optics solely for scientific purposes, the implications of these technologies for other fields like earth observation, even cartography and geodesy were recognized and are in process of being exploited in the future. Likewise, methods learned are transferred even to potential commercial applications, as are the prospects of optical communications. Although by no means justifying the funds invested into science, the return in the technological progress is a significant asset of space research.