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History of the Max-Planck-Institut für Aeronomie and its scientific projects (1958-2004)

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Abstract. The *Max-Planck-Institut für Aeronomie* located in Katlenburg-Lindau, Germany, had a clearly defined beginning and end. It commenced on 1 January 1958 with the merging of the *Max-Planck- Institut für Ionosphärenforschung* (ionospheric research) and the *Max-Planck-Institut für Physik der Stratosphäre* (physics of the stratosphere), and it concluded in 2004 with the renaming in *Max-Planck-Institut für Sonnensystemforschung* (solar system research - MPS). This manuscript reviews the organization, scientific research, and development that took place over these 47 years.

1. General remarks about Max Planck Institutes (MPI)

Throughout its 47-years history the *Max-Planck-Institut für Aeronomie* (MPAe in the following) was led by ten directors. Each of them served as *Geschäftsführender Direktor (m*anaging director) for one or several terms (Fig. 1). A prerequisite of becoming a Director is the membership as *Wissenschaftliches Mitglied* (scientific member) of the *Max-Planck-Gesellschaft* (society - MPG). Directors at a *Max-Planck-Institut* have completely autonomy in selecting the field of research and to organize it (This fact was originally called Harnack-Principle, Professor Adolf von Harnack (1851-1930) conceived the *Kaiser-Wilhelm-Gesellschaft* (KWG), the predecessor of the MPG). The directors receive a substantial annual budget from the society, and, for very expensive research projects they may apply for additional funds from national or international funding agencies. In particular from the times on when the MPAe became heavily engaged in space projects, external funding contributed a substantial part of the total budget of the institute, most of it provided by the German Space Agency (DLR). Usually a director is linked to a nearby university as an adjunct professor. This provides access to students in terms of lectures and supervising diplomas (master) and doctoral (PhD) theses. Nearly all the above mentioned directors of the MPAe were affiliated with the University of Göttingen, Pfotzer was honorary professor of the Technical University of Braunschweig. Until the mid-1960s most of the students were employed as scientific staff after their graduation.

Each *Max-Planck-Institut* has two important advisory boards: i) the *Kuratorium* (Board of Trustees) with representatives of all social groups relevant for the institute, notably representatives of political parties, commerce, science, and the media which are responsible for the link to the public. ii) the *Fachbeirat* (scientific advisory committee) consisting of national and international scientists to support the scientific work of the directors.

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Several accounts of the MPAe history have been published (Dieminger, 1972; Rosenbauer, 1981; Dieminger, 1995; Keppler, 2003; Czechowsky and Rüster, 2007), however, these are all written in German. This paper aims at a broader audience. Another reason for this manuscript is to preserve the important contributions of MPAe scientists, novel instruments as well as ground breaking results in atmospheric, ionospheric, space physics, and solar physics for posterity.

2. The Precursors

2.1 Max-Planck-Institut für Ionosphärenforschung

The *Max-Planck-Institut für Ionosphärenforschung* originated from a team of scientists and engineers, named *Zentralstelle für Funkberatung* (Central Radio Advisory Service), who produced reports on ionospheric wave propagation for the German *Wehrmacht* (military forces) during World War II. Since the German troops were dispersed across Europe and Africa, reliable communication paths had to be established. This group, led by Walter Dieminger, was very effective which was noticed by the Western allies: Britain, France and the USA. Thus these allies tried to capture this group. A task force from the British Air Force successfully located the German team in Austria and transported them in March 1945 into the British Zone in the village of Lindau am Harz. As a result of Dieminger's scientific merits and efforts, his team was incorporated as the *Fraunhofer-Radio-Institut* into the *Kaiser-Wilhelm-Gesellschaft*, the prestigious German research institution (see above). Its successor, the *Max-Planck-Gesellschaft,* adopted the institute as *Institut für Ionosphärenforschung* in 1952. A very detailed account of these early years was published by Dieminger (1972).

2.2 Max-Planck-Institut für Physik der Stratosphäre

Erich Regener (1881-1955), a Professor at the *Technische Hochschule* (Technical University) Stuttgart was interested in the physics of the stratosphere and founded a *Forschungsstelle für Physik der Stratosphäre* (Research Center for physics of the stratosphere) in the middle of 1930 in Friedrichshafen at Lake Constance. This *Forschungsstelle* was incorporated into the *Kaiser-Wilhelm-Gesellschaft* in 1938. Eleven years later it became a member of the *Max-Planck-Gesellschaft* and was renamed *Max-Planck-Institut für Physik der Stratosphäre* in 1952. After Regener deceased in 1955, Julius Bartels (1899-1964), Professor at the Universität Göttingen, was appointed as director, and upon his request, the institute was transferred to Lindau, because of its proximity to Göttingen (distance about 35 km). He also suggested the new name *Max-Planck-Institut für Aeronomie* which was accepted. After Bartel's death, Alfred Ehmert and Georg Pfotzer, already scientific colleagues of Regener, became directors. More details of these developments are found in Keppler (2003).

3. Forming the *Max-Planck-Institut für Aeronomie* (MPAe)

Aeronomie (aeronomy) covers the science of the upper layers of the terrestrial atmosphere. It therefore includes the stratosphere, the mesosphere as well as the ionosphere. The merging of the afore mentioned institutes on 1 January 1958 led

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to the establishment of an institution of about 100 employees, including scientists, engineers, technicians and service personnel. The merging of the two institutes concerned mainly a common administration. The research projects of both institutes remained quite different and independent. Dieminger was appointed as director of the *Institut für Ionosphärenforschung* and managing director of the entire MPAe, Bartels, Ehmert and Pfotzer were directors of the *Institut für Physik der Stratosphäre*.

Four eminent scientists acted as „Auswärtige Wissenschaftliche Mitglieder" (external scientific members): Prof. Dr. J.A. Fejer (in 1976), Prof. Dr. J. Geiss (in 1982), Prof. Dr. A.A. Galeev (in 1994), Prof. Dr. K.-H. Glaßmeier. (in 2001).

Until 1975 the staff of both institutes resided in different buildings. In 1969 a spacious and well-appointed new building was completed (Fig. 2).

3.1 Scientific projects of the *Institut für Ionosphärenforschung* until about 1975

These projects were all centered on ionospheric wave propagation and sounding. Already in the middle of the 1950s a powerful and sophisticated ionosonde was developed (Fig. 3) and continuously improved. An appropriate antenna system was erected on a meadow close to the institute. With this instrument regular hourly soundings were conducted, and the ionograms were evaluated by hand, since computers were not available at this time (Becker, 1959). The results were published and supplied to international organizations (e.g. IRI-International Reference Ionosphere). Close scientific collaborations had been established e.g. with Finnish colleagues in Nurmijärvi and Sodankylä from 1954 onwards (Möller, 1967), and with the British Radio and Space Research Station in Slough.

During the International Geophysical Year (IGY; 1957-1959) an ionosonde was established at Tsumeb (Namibia) in order to investigate transequatorial wave propagation. This station, approximately geomagnetically conjugate to Lindau evolved into the research station *Jonathan Zenneck* (academic teacher of Dieminger), with several sounding facilities. It was in operation also during the IQSY (International Quiet Sun Year) 1964/65 (Umlauft, 1965). In the middle of the 1980s the station was transferred to a South-African institution (CSIR).

During the IQSY measurements were also performed with an ionosonde onboard the German scientific vessel METEOR (Dieminger et al. 1966).

The data collected with the ionosondes and other wave propagation facilities were used to study various phenomena, like upper atmospheric dynamics (e.g. Kohl and King, 1967; Rüster, 1971), gravity waves (e.g. Klostermeyer, 1969), geomagnetic disturbances (e.g. Rüster, 1969), and solar-terrestrial relations (e.g. Schwentek, 1970). Important insights of the ionospheric plasma were obtained in theoretical studies (Stubbe, 1970).

Several techniques have been used to study the lower ionosphere (D-Region,70-100 km). A novel partial reflection system based on a chirp-technique was established in the middle of the 1970s, yielding very promising results (Rinnert et al., 1976). Unfortunately, its operation had to be terminated after a few month because of interference with commercial radio systems. Long wave length propagation data have been used as well to obtain data about the electron density in the lower ionosphere.

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In-situ measurements in the D-region have been conducted using small rockets. They carried payloads to measure electron density, neutral density and temperature. For drift measurements a foil cloud (chaff) was released at altitudes above 90 km and tracked with a radar during its descent (Rose and Widdel, 1972). These rocket experiments, mainly with SKUA rockets, had been performed at the rocket range El Arenosillo (near Huelva, Spain) from 1968-1976 in collaboration with the Spanish „Instituto Nacional de Técnica Aeroespacial" (INTA).

A substantial project was total-electron-content (TEC) measurements. For this purpose the signals from earth orbiting satellites were used. The differential-Doppler method yields the TEC (Hartmann, 1965). Since these signals are quite weak, their reception at the MPAe location in Lindau was difficult due to the interference from the powerful ionosonde. Consequently, a new facility was built in 1965 in Gillersheim, about 7 km away form Lindau, with the necessary electronic equipment and antennas. The studies lasted until 1977. TEC data are still used today for many purposes, like satellite communication and positioning.

An comprehensive commemorative publication described the research and its results at the Institut für Ionosphärenforschung in great detail (Festschrift, 1972).

3.2 Projects at the *Institut for Physik der Stratosphäre* until about 1975

The scientific projects of this institute comprised mostly in-situ measurements with balloons, rockets or satellites, and measurements of the Earth-magnetic field.

Particle detectors, like thin-walled Geiger counters and ionization chambers were developed specifically for balloon payloads. More than 40 balloon launches took place at the Kiruna Geophysical Observatory (Sweden) between 1960 and 1964, in order to study auroral phenomena (e.g. Kremser, 1967). Based on the experience with these particle detectors, electron and proton spectrometers were developed and utilized from 1969 onwards in rocket experiments launched from Kiruna and Andenes (Norway) (e.g. Wilhelm, 1979).

The scientific management for the first German satellite **AZUR** (launched 8 November 1969) was in the hands of a MPAe scientist (Keppler, 1971). Out of the total of seven experiments, two, Geiger Tube Electron Counters and Geiger Mueller proton Counters were supplied by the MPAe. The satellite provided important results about the radiation belts until 29 June 1970.

For the German-US solar probes **HELIOS A** and **B,** the institute provided proton-electron spectrometers, respectively (Keppler et al., 1977). The mission was intended to explore the space near the Sun (e.g. Rosenbauer et al. 1977). The two probes approached the Sun to a distance of 0.3 AU. No other spacecraft came so close to the Sun before. It should take more than 40 years until another spacecraft, the NASA Parker Probe launched in 2018, broke this record. Helios A was launched on 10 December 1974, Helios B on 15 January 1976. Both probes operated for more than 10 years.

A ground-based experiment was a magnetometer chain from Germany to Siberia (10°E to 85°E, 49° to 59° N invariant latitude). It was utilized for studies of auroral zone current systems and magnetic pulsations (Wilhelm et al. 1977).

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Another ground-based instrument was a neutron monitor to measure the intensity of cosmic rays impacting the earth. It was an important link in a world-wide chain of such instruments (Ehmert, 1958).

The study of Ozone commenced with early experiments by Regener in the 1930s. Within the project „Tropospherical Ozone“ a chain of 19 ground based stations was established between Tromsø (Norway) and South Africa during the 1960s and provided continuous data about near Earth ozone. In order to study the interaction of other trace gases with ozone a „cryosampler“ (Fig. 4) was developed. In a Dewar vessel filled with 15 l of liquid neon, eight probe cylinders are inserted and connected to the ambient air via valves. The vessel was launched with a balloon into the stratosphere, and the valves were opened at defined times. The cooled sample cylinders acted like a cryopump, and the inflowing air was frozen in its interior. Consequently, air samples of different heights could be collected during the ascent of the balloon. After retrieving the vessel, the air samples were analyzed in the laboratory. The probes were also archived and re-analyzed later when more advanced laboratory techniques were available or when scientific interest arose in new, so far ignored trace gases. In this way trace gas profiles of e.g. CO, CO_2, N_2O, and chlorofluorocarbons between about 5 and 30 km altitude were established (Fabian et al., 1979).

3.3 The *Institut für Langzeitforschung* (Institute for Long-Term Research)

One of the last important initiatives by director Dieminger was the effort to preserve the long-term data of geophysical quantities collected at the MPAe and its continuation. In a memorandum of 1974 he proposed to the President of the MPG the establishment of an *Institut für Langzeitforschung* (IFL). It should combine the activities of not only MPG-institutes but of other institutes in Germany as well. The initial response was in principle favorable, but its implementation proved difficult. Consequently, as a first step, the corresponding working groups of the MPAe were combined in an *Institut für Langzeitforschung am MPAe* located in a different building (Hartmann, 1976). Their primary goal was the synopsis of atmospheric and ionospheric data as well as their influence on radio wave propagation. Regrettably, by the end of 1978 it became evident that no funding source could be found for the IFL. As a result, the IFL was officially closed in 1980, the staff were reintegrated in the MPAe and their scientific activities ended with their retirement.

4. The era of Axford and subsequent directors

With the appointment of William Ian Axford as director (he was knighted by Queen Elisabeth II. of the United Kingdom in 1996), see Fig. 1, the structure of the MPAe changed dramatically. As he preferred to focus on scientific research rather than in the day-to-day duty of running the institute, he established a *Direktionsbeirat* (DB), a council of about a dozen scientists elected by the entire institute staff. This council convened weekly together with one of the Directors and assisted to run the institute. A parallel body, the *Technische Konferenz* (technical conference, TK) addressed technical and engineering issues and was headed by a *Technischer Direktor* (technical director). Axford also changed the institute structure from the former hierarchical structure (as it was under Dieminger) to a project-oriented structure and working method. He further united the staff of the former *Institut for Physik der Stratosphäre* together with the staff of the former *Institut für Ionosphärenforschung* in the main building (Fig. 2).

The number of scientists and engineers rose from 34 in the mid-1960s to 58 in 1975 and remained at that level until the end. The total number of established positions reached 252 in 1978 and decreased to approximately 200 by 2004.

Axford also initiated a generous guest scientist program. Every MPAe-scientist was encouraged to invite foreign colleagues for collaboration. These guests were well looked after: Several furnished guest apartments were built in older buildings of the institute, and German language classes were arranged for the guest scientists and their spouses, in order to facilitate integration into the local community.

4.1 Ground-based facilities

4.1.1 SOUSY

The atmospheric radar SOUSY (Sounding System) was a powerful VHF-radar (53.5 MHz, pulse peak power 600 kW), developed in 1974. A total of 196 phase controlled Yagi antennas (Fig. 5) had been erected in a valley in the Harz mountain, in order to minimize interference. The antenna system had an opening angle of 5° and the beam could be steered phase controlled by 24° from the vertical to each side. Transmitter, receiver and the control system were installed in a transportable container. Important results about tropospheric, stratospheric and mesospheric wind systems, clear air turbulence, atmospheric waves, and other atmospheric phenomena have been published (e.g. Röttger et al., 1978; Rüster et al., 1986; Rüster 1994, Czechowsky and Rüster. 1997). In 1980 a smaller transportable radar system (without antennas) had been developed which could be connected to existing antenna system at various sites, e.g. Arecibo Observatory (Puerto Rico) to study equatorial atmospheric phenomena, and at the Andøya Rocket range (Norway) where it was equipped with another narrow-beam steerable antenna system designed and built at the MPAe. Here the radar results could be combined with in-situ rocket measurements. In the US, the mobile system was utilized to detect turbulence prior to rocket launches at Cape Canaveral and at the White Sands rocket range. The mobile system was finally installed close to Longyearbyen (Svalbard) in order to study atmospheric processes in the polar cap. In 1988 SOUSY was extended by a LIDAR system in order to derive atmospheric temperatures.

After the renaming of the MPAe the stationary SOUSY was transferred to the Jicamarca Observatory (Peru), and the mobile system was taken over by the University of Tromsø.

4.1.2. STARE

A radar system to study the so-called „radio aurora“ had already been operational since 1963 (Czechowsky et al., 1974). STARE (Scandinavian Twin Auroral Radar Experiment) was a completely new development, started in 1974. With an auroral radar irregularities in the ionospheric E- region are detected. The backscatter is maximal when the antenna beam points perpendicular to the geomagnetic field, therefore transmitter and receiver have to be based far south of the auroral

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zone (Fig. 6). From the Doppler shift of the bi-static received signals, the horizontal drift velocity of the field-aligned irregularities could be determined. Subsequently the electric field causing the drift could be derived. Since both antenna systems formed eight narrow beams, a high spatial resolution over a wide area of the auroral zone could be obtained. More details of the STARE radar can be found in Greenwald et al. (1978). In 1982 the system was expanded by two additional stations in Scotland and Sweden in collaboration with the University of Leicester (SABRE). Another extension and improvement was „New STARE“ in collaboration with the Finnish Meteorological Institute in the 1990s. The history of all these developments has been documented by Nielsen and Schmidt (2014). STARE proved to be a very valuable extension of all the other ground-based installations within the auroral zone (e.g. EISCAT, HEATING; magnetometer network, all-sky cameras) and related rocket and satellite projects.

The experiences and technical expertises gained with STARE ultimately led to the SuperDARN radar system (Greenwald et al. 1995).

A comparable, albeit smaller, project was the Sporadic E Scatter experiment (**SESCAT**), a continuous-wave bi-static 50 MHz radio Doppler system designed to study E-region coherent backscatter from magnetic field-aligned irregularities and plasma instabilities at midlatitudes. It was established in the island of Crete, in partnership with the Physics Department, University of Crete at Heraklion (Haldoupis and Schlegel, 1993). SESCAT was quite successful in obtaining several new results, particularly the (unexpected) detection of the Farley-Buneman Instability in midlatitudes.

4.1.3 EISCAT

EISCAT (European Incoherent SCATter Association) was established in 1975 after several years of preparation as a joint project (with the respective funding agency shown in brackets), involving Germany (MPG), Finland (SA), France (CNRS), Norway (NAVF), Sweden (NFR) and the UK (SRC). The incoherent scatter technique allows to determine several quantities of the ionospheric plasma simultaneously, like electron density, electron and ion temperatures, ion composition and ion drift. It was set up in northern Scandinavia, with a fully steerable transmitting and receiving antenna located near Tromsø (Norway), and two steerable receiving antennas in Kiruna (Sweden) and Sodankylä (Finland). Trough this tri-static operation, the vector of the ion drift could be determined. It operated in the UHF frequency range, a VHF transmitting and receiving facility was located near Tromsø as well.

A detailed description of the system and its operation was published by Wannberg (2022) and the participation of the MPG was explained by Haerendel (2016).

Scientists of the MPAe were notably active and successful in utilizing EISCAT and publishing their results. They studied gravity waves (e.g. Kirchengast et al., 1995), auroral current systems (e.g. Araki et al., 1989), electric fields (e.g. Rinnert et al., 1986), E-region plasma instabilities (e.g. Schlegel, 1988), and used EISCAT as a tri-static auroral radar (Schlegel and Moorcroft, 1989). It was an important diagnostic instrument in studying artificially-induced plasma phenomena produced by the HEATING project (e.g. Hagfors et al., 1983). Due to Axford's strong support for EISCAT and the invitation of foreign

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guest scientists (see above), over a dozen guest scientists joined the MPAe-EISCAT team between 1985 and 2000. Five PhD students strengthened this group as well.

Following the renaming, the institute and the MPG left the association in 2004. but EISCAT continued to be used by scientists from other German institutions.

4.1.4 HEATING

HEATING is a powerful transmitting facility to modify the ionospheric plasma by radio waves. While most atmospheric and space experiments just observe their environment, HEATING was one of the few experiments in this field which actively modified the medium it observed. It was set up near EISCAT in Norway, in order to use these radars to observe the heated ionospheric plasma. Construction started in 1978 and was completed in 1980. Powerful radio waves within the frequency range of 2.5 to 8 MHz were transmitted using three fields of 6x6 crossed full-wave rhombic dipoles with an effective power (ERP) of 290 MW. The antenna system was designed and constructed by MPAe engineers and technicians (Fig. 7). A detailed description of the facility, its development and operation is published in Rietveld and Stubbe (2022). Since important results have been reviewed by Stubbe (1996), only a few will be mentioned here: ionospherically induced currents in the lower ionosphere (ca. 70–110 km) generated extra low frequency (ELF) to very low frequency (VLF) radio waves in the audio-frequency range and below, stimulated electromagnetic emissions (SEE) consisting of the generation of secondary HF waves due to plasma processes in the ionosphere, Langmuir turbulence results, Earth–ionosphere waveguide propagation of ELF and VLF waves.

Unlike the US heating facility HAARP located in Alaska, which was funded and controlled by the military, no military projects were carried out at HEATING. HEATING was largely financed by the *Deutsche Forschungsgemeinschaft* (German Research Foundation), and all results were openly published.

The HERO (HEating and ROcket) project was the first project especially designed to conduct in-situ measurements of the HF-generated Langmuir waves and their influence on the surrounding plasma, led by scientists from the MPAe. The rockets were launched from the Andøya Rocket Range and flew through the heated region (Rose et al., 1985).

The HEATING facility was transferred to the EISCAT association in January 1993 and continues to provide new discoveries in plasma physics and ionospheric and atmospheric science to the present day (June 2026).

4.1.5 Riometer

The relative ionospheric opacity meter, or riometer, offers a routine ground-based method for monitoring energetic particle precipitation, by measuring the absorption of cosmic radio noise, typically in a narrowband somewhere between 20 and 70 MHz. Corresponding measurements had already been conducted in the 1960s. In the late 1990s a rio-Imager was conceived (Nielsen and Hagfors, 1997) and installed 2006 as the MPS-project ARIES near Tromsø. With this instrument simultaneous measurements of absorption over a large field of view (300x300 km^2) could be obtained with good spatial and temporal resolution. Observations of the spatial variations of absorption and its dynamics allow a detailed analysis of particle

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precipitation. The instrument performed joint observations with many other experiments in Northern Scandinavia. like STARE, EISCAT, optical and rocket measurements.

4.1.6 Optical Instruments

Scientists of the MPAe operated optical instruments in northern Scandinavia as well in order to support EISCAT, STARE, HEATING and rocket experiments. A **Fabry-Perot-Interferometer** was located in Skibotn (about 60 km south-east of Tromsø)**.** It recorded the Doppler shift and Doppler broadening of atmospheric airglow lines (e.g. 557.7 nm, green; 630 nm, red) from which neutral wind and temperature data in the thermosphere were derived. The site also housed a digital and a slow-scan CCD **All-Sky Imager**. The digital imager was primarily utilized to observe optical emissions excited by HEATING, while the slow-scan imager was used to provide cloud cover estimates. (e.g. Kosch et al., 2002).

4.1.7 Microwave facilities

The first spectrometers operating at frequencies of 22 and 142 GHz to measure water vapor and ozone concentrations between 15 and 85 km altitude were established in the middle of the 1970s. Between 1995 to 1996 an improved version was installed at the ALOMAR observatory located in Andenes (Norway). Starting 1983, a space-borne instrument from the MPAe became part of the international ATLAS-MAS project and flew several times onboard NASA Space shuttles. For the first time the global distribution of ozone, water vapor and chlorine monoxide was measured with the „limb sounding" technique (Hartmann et al., 1996).
For the **ROSETTA** mission (see section 4.4 below) the instrument **MIRO** was developed in collaboration with the NASA Jet Propulsion Laboratory. It is designed to measure water vapor, carbon monoxide, ammonia and methanol in the Coma of the comet.

4.2 Space Projects

4.2.1 Particle Analyzers

The development progressed from the Geiger counters of the 1960s: through semiconductor detectors and channeltrons to complete mass spectrometers. Instruments using the so-called time-of-flight technique have been developed at the MPAe (Wilken and Stüdemann, 1984) and proved to be particularly successful. This technique measures the time it takes for a particle to traverse a predefined distance within the instrument. Using this technique, along with electrical and magnetic deflection, the energy, mass, and charge of a charged particle can be determined. Certain configurations provided pitch-angle (the angle between the magnetic field vector and the particle's trajectory) data as well. Spectrometers designed for neutral particles consist of an ion mass spectrometer preceded by an ionization chamber which converts incident neutral particles into singly ionized ions. A comprehensive description of all these instruments is beyond the scope of this manuscript; their

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diversity will henceforth be referred to as **particle analyzers**. A review of the different particle analyzers has been published by Wilken (1984), which includes those developed at the MPAe.

These particle analyzers proved to be highly accurate and reliable and were utilized in numerous missions, sometimes as standalone instruments, sometimes as components of a package with instruments from other scientists of national and international institutions.

4.2.2 Rocket Campaigns

MPAe scientists participated with their particle analyzers in various sounding rocket campaigns, primarily conducted in the auroral zone at Andenes (Norway), Kiruna (Sweden), Ft. Churchill (Canada), and Poker Flat (Alaska). They aimed at the investigation of auroral processes where both high and low energy particles play an important role (e.g. Wilhelm, 1979). In several cases these campaigns were coordinated with satellite projects: the rockets were launched when the satellite was overhead, in order to obtain horizontal and vertical particle distributions from different heights of the same magnetic field line.

4.2.3 Earth orbiting satellite missions

Particle analyzers from the MPAe were utilized in numerous Earth-orbiting satellites to study the magnetosphere and the Sun-Earth region:

- **GEOS-1** (Geostationary Earth Orbiting Satellite, ESA, start: 20 April 1977, duration: 14 month).
- **ISEE-1** and **2**: (International Sun Earth Explorer, ESA and NASA, start: 22 October 1977, both burned up in the atmosphere on 26 September 1987).
- **GEOS-2** (see above, start: 14 July 1978, provided data for 2 years).
- **AMPTE** (Active Magnetospheric Particle Tracer Explorer, 3 satellites, Germany, UK, USA, start: August 1984, last contact 1 July 1998).
- **VIKING** (Sweden's first satellite, start: 22 February 1986, operations ended on 12 May 1987).
- **CRRES** (Combined Release and Radiation Effects Satellite, NASA and US Army, start: 25 July 1990, last contact 12 October. 1991).
- **CLUSTER** (4 satellites flying in a fixed formation, ESA, start 4 June 1996, rocket failure, automatic destruction during start).
- **GEOTAIL** (Japan and NASA, start: 24 July1992, deactivated 28 November 2022).
- **INTERBALL** (Russian Space Agency and international partners, four satellites, launched 3 August 1995 and 29 August 1996, end of operation 1999 and 2000).
- **FREJA** (continuation of the VIKING mission, Sweden, start: 6 October 1992, last contact October 1996).
- **WIND** (NASA; start:1 November 1994, still in operation, June 2026).

- **POLAR** (NASA, start: 24 February 1996, deactivated 28 April 2008).
- **ASTRID 1** and **2** (named after the Swedish author Astrid Lindgren, Sweden, MPAe provided a UV spectrometer; start: 24 January 1995 and 10 December 1998, operations ended: 1 March 1995 and 24 July 1999).
- **EQUATOR-S** (Germany, start: 2 Dec. 1997, last contact: 1 May 1998).
- **CLUSTER-2** (reanimation of CLUSTER, ESA, start: 16 July and 9 August 2000, the cientific mission ended 8 September 2024).

All these missions yielded important results which were published in peer-reviewed journals. Some typical and groundbreaking publications are: (Daly et al., 1984; Woch et al., 1990; Kremser et al., 1995; Wilken et al., 1998; Korth et al., 2000). Theories of magnetospheres were addressed by Vasyliūnas (1979), and Vasyliūnas et al. (1982).

The MPAe provided a particle analyzer to measure the low energy electron flux (1ES019) onboard the manned spacecraft **SPACELAB 1** in Nov/Dec 1983. (Wilhelm et al., 1984) Preceding the start, the crew visited the institute to learn how to operate the instrument.

4.2.4 Planetary missions

In the Russian **PHOBOS 1** and **2** Mars missions MPAe scientists contributed several particle analyzers. Start was on 7 July and 12 July 1988, respectively. On the probe's way to Mars contact was lost with PHOBOS 1. Phobos 2 orbited Mars until 27 March and provided interesting results (e.g. Rosenbauer et al. 1994).

Again a failure was the Russian mission **MARS-96**.The probe crashed into the sea during launch. MPAe contributed particle analyzers as well as a long-wave radar and a UV-spectrometer.

The **Mars Pathfinder Mission** (NASA) was launched on 4 December 1996, the probe landed softly on 4 July 1997, and the mobile rover „Sojourner" was released. The MPAe provided an improved version of the HMC camera (see section 4.2.6, below) which provided the first stereo color photographs of the Mars surface (Fig. 8). A worldwide response in newspapers, radio and TV reports brought the MPAe to prominence. For the camera team and the whole institute H.U. Keller received the „Goldener Löwe" (golden lion) award of the TV channel RTL in Berlin.

Since the cameras developed the MPAe supplied excellent photographs and were reliable under space conditions, MPAe scientists were invited to participate in other space projects with their camera.

A MPAe-particle analyzer was mounted on the Japanese Mars mission **NOZOMI**, launched on 3. July 1998. However, it did not reach Mars due to a loss of fuel.

Unfortunately the **Mars Polar Lander** (NASA) which included two cameras from MPAe, crashed during the landing operation on Mars on 3 December 1999.

The ESA mission **Mars Express** successfully entered the Mars orbit on 25 December 2003. The lander „Beagle" crashed during descent, but the orbiter still provides data today (June 2026). MPAe supplied a particle analyzer and as co-investigator a radar system to probe the Martian ionosphere and its subsurface (Nielsen, 2004).

A camera with a further improved CCD array was installed on the NASA/ESA **Cassini Huygens** mission**.** Cassini served as a Saturn orbiter, while Huygens was a daughter probe designed to land on Saturn's moon Titan. Start was on 15 October 1997, the probe arrived at Saturn on 1 July 2004. Huygens landed softly on Titan on 14 January 2005. This was humanity's first successful attempt to land a probe on another world in the outer Solar System. The Descent Imager/Spectral Radiometer (DISR) for which MPAe provided the CCD detector supplied photographs of Titan's surface (Fig. 9). In addition to the camera, MPAe provided a particle analyzer and a UV spectrometer (Lagg et al., 2001). The mission ended on 15 September 2017 with a controlled burn-up in Saturn's atmosphere.

The **GALILEO** mission (NASA) aimed at the investigation of Jupiter and its moons. Start was on 18 October 1989. In the vicinity of Jupiter an atmospheric probe was released on 7 December 1995, entering the Jovian atmosphere and collecting data for 61 minutes, before it was crushed by the immense atmospheric pressure. The orbiter conducted several flybys of the Galilean moons Io, Europa, Callisto and Ganymede. MPAe scientists participated together with US colleagues with a particle analyzer (Krupp et al. 2004) and a lightning detector (Rinnert et al., 1998). The mission ended on 21 Sept. 2003 when the orbiter was directed to lower altitudes and eventually burned up in the Jovian atmosphere.

SMART1 was a moon orbiting mission of ESA, started on 27 September 2003. The Moon's orbit was reached on 15 November 2004 with MPAe providing an infrared spectrometer (Keller et al. 2001). The mission ended on 3 September 2006 with a planned impact on the lunar surface. Electric fields around Moon were addressed by Mall and Borisov (2002).

Theoretical issues of planetary magnetospheres have been investigated by Axford (1991), Vasyliūnas (1986) and Vasyliūnas and Dessler (1981).

As future (from MPAe perspective) planetary missions for which instruments were designed and built at the MPAe, but became operational under MPS, the following should be mentioned:

- A high resolution camera and a particle analyzer was mounted on the **ESA Venus Express** mission which orbited Venus. Since 11 April 2006 it provided first photographs of the Venus surface.
- A special system was the Robotic-Arm-Camera on the NASA **Phoenix Mars Mission**. After landing on Mars on 25 May 2008, it supplied detailed photographs of the Martian soil in the shovel of the digging arm.
- **DAWN**, a NASA mission to investigate the asteroids Ceres and Vesta started on 27 September 2007. MPAe provided part of a camera system. DAWN orbited Vesta in 2011-2012 and Ceres in 2015-2018 and provided detailed images of their surfaces.

4.2.5 Solar missions

The **International Solar Polar Mission** (NASA/ESA), later renamed **ULYSSES,** was designed to fly over the poles of the sun. The spacecraft, started on 6 October 1990, and flew out of the ecliptic with the help of a flyby at Jupiter on 8 February 1992 (Krupp et al. 1993). It conducted three passages over the poles of the sun until 29 June 2009 when the nuclear power

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generator was exhausted. One of the two particle analyzers provided by MPAe employed for the first time in space a new technique to detect low-energy He-atoms by sputtering charged secondary particles from a clean LiF-surface (Witte et al., 1992). With this instrument the distribution of He-atoms was measured along the orbit of Ulysses. As these atoms are the most prominent representatives of the local interstellar matter, the properties of the interstellar medium (e.g. velocity, direction, temperature) could be determined with so far unprecedented accuracy (Witte, 2004).

SOHO (Solar and Heliospheric Observatory) was an ambitious ESA-NASA project, launched on 2 December 1995.The spacecraft reached its stable position at the libration point L1, where the gravitational force of the Sun and the Earth together with the centrifugal force of the orbiting probe just balance. The MPAe provided a sophisticated ultraviolet spectrograph: **SUMER** (Solar Ultraviolet measurements of Emitted Radiation) which was the largest and most elaborate instrument ever built at the institute (with important contributions of France, USA, and Switzerland). It monitored UV lines in the range 66 - 162 nm, and allowed from their spectral width and Doppler shift to measure temperatures and velocities (with a resolution of 2 km/s) of various ions in the solar chromosphere and lower corona. The spatial resolution of 1 arcsec corresponds to a resolution of approximately 750 km on the solar disk (Fig. 10). Details of the instrument can be found in Wilhelm et al. (1995). The data from this instrument were of exceptional quality and were made accessible online to the scientific community, resulting in several hundred publications to date. SUMER was finally shut down in April 2017 after its detectors reached the end of their lifespan.

A second instrument on SOHO, **LASCO** (Large Angle and Spectrometric Coronagraph) was partly realized from MPAe scientists under the PI-ship of the Hulburt Center for Space Research, NRL, USA. A coronagraph takes photographs of the sun with the bright solar surface occulted with a disc, allowing the observation of the extremely faint solar corona. The instrument consists of a set of three coronagraphs that image the solar corona from 1.1 to 32 solar radii. The MPAe was responsible for the C1 coronagraph, which images the corona from 1.1 to 3 solar radii. A detailed description and first results have been published by Schwenn et al. (1997). The LASCO results (e.g. Fig. 11) provided a unique possibility to predict space weather events on Earth, as well as the detection of solar grazing comets. LASCO C2 and C3 are still operational (June 2026) and deliver spectacular pictures of the solar corona. However, the C1 telescope could not be revived after SOHO lost ground contact for four months in 1998. The misorientation of the spacecraft with respect to the Sun caused the loss of its thermal balance during this interval which subsequently destroyed the temperture-sensitive Fabry-Perrot in C1.

A particle analyzer on SOHO was the third instrument provided by MPAe.

Another solar project (instruments constructed at MPAe, continuation of the project by MPS) is the NASA mission **STEREO**. With two spacecrafts providing photographs of the Sun and its environment up to 1 AU, stereo reconstructions of phenomena on the solar surface and of coronal mass ejections could be produced. Start was on 26 October 2006. One of the spacecrafts is out of service since 2016 but the other is still working.

Another project that had already been conceived at the MPAe, but was ultimately realized at the MPS is **SUNRISE**. It is a balloon-born UV telescope looking at the sun from an altitude exceeding 30 km in the stratosphere, in order to avoid solar UV absorption by the lower atmosphere. SUNRISE conducted three successful flights in 2009, 2013, and 2024.

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Some important findings in solar physics resulting from MPAe participations can be found in publications of Axford (1996), Livi and Marsch (1986), Innes et al. (1997), Keppler (1998), Inhester et al. (1999), Marsch (1999), Schüssler (2002), and Witte (2004).

4.2.6 Comet Missions

The MPAe was involved in the **GIOTTO** mission to comet 1P/Halley contributing the Halley Multicolour Camera (HMC). Its development started already in 1981. The heart of the camera was a CCD array (392x584 pixel) with special readout electronics that had been developed at the institute (Kramm et al., 1993). The camera was designed to autonomously search for and to detect the comet nucleus with the help of a sophisticated software. This was successful (with online support from the ground), and HMC supplied the first detailed images of the nucleus of a comet in different colors (Fig. 12). The closest approach of Giotto to Halley was 596 km on 14 March 1986. The images revealed that Halley's nucleus was 15 km long and 8 km thick. This achievement made the MPAe and the HMC Group famous worldwide (Keller et al., 1986).

MPAe scientists also participated in the Russian comet missions **VEGA** 1 and 2. The launch of VEGA 1 was on 15 December 1984, followed by VEGA 2 six days later. Both probes passed first Venus in June 1985 and subsequently comet 1P/Halley in March 1986 at a distance of 10,000 and 3,000 km. respectively. MPAe provided particle analyzers on both spacecrafts.

A project for the future (from MPAe perspective), is the **ESA ROSETTA Mission** (launched 2 March 2004). Rosetta orbited the comet 67P/Tschurjumow-Gerassimenko from 2014-2016, carrying the MPAe-designed camera system OSIRIS. The lander Philae, build at the MPAe (collaboration with DLR), landed on the surface in 2014. In addition, MPAe supplied various particle spectrometers, a microwave spectrometer, and a radio wave sounding instrument. MPAe/MPS was the institute worldwide with the most extensive participation in Rosetta.

Important results about 1P/Halley were published by Richter et al. (1991) and Kirsch et al. (1995).

5. A difficult time

After the unification of Germany on 3 Oktober 1990 the MPG was obliged to establish new institutes in the territory of the former GDR. Since the overall budget of the MPG could not be increased accordingly, it was considered to close MPG-institutes in the western part of Germany. Institutes lead by directors close to their retirement, like the MPAe at that time, were especially focussed on. Several meetings of commissions initiated by the MPG concerning the future of the MPAe, did not yield a satisfactory solution. Finally, on 8 October 1996, the President of the MPG, Hubert Markl, confronted the directors with the unfortunate news that four institutes, including the MPAe, would be closed. In reaction the MPAe-directors, especially Tor Hagfors, initiated various rescue efforts:

- A large demonstration by the employees (together with the staff of the MPI for History, which was also threatened with closure) in Göttingen was organized. Professor Dr. Rita Süssmuth, President of the *Bundestag* (German Parliament) from 1988 to 1998 (and holder of the *Bundestag* direct mandate for Göttingen) and other high ranking politicians demanded in speeches the preservation of the institutes. Dr. Süssmuth visited the MPAe on 2 May 1997, in order to obtain information about the scientific work.
- For similar reasons the *Ministerpräsident* (Prime Minister) of Lower Saxony Gerhard Schröder visited the institute on 20 August 1997.
- The informed Science Minister of Lower Saxony, Helga Schuchardt and the Lower Saxony State Parliament demanded preservation, based on consultations with Professor Glassmeier, Chairperson of the Kuratorium of the MPAe at that time.
- The directors Axford and Hagfors sent 750 letters to distinguished geo-and astrophysicists worldwide as well as to international institutes and organizations requesting them to write to the President of the MPG. They should emphatically explain to him the importance and achievements of the MPAe and to persuade him to reverse the planned closure.
- On 26. November 1996 six selected scientists of the MPAe presented the results and achievements of the institute at the Chemical-Physical-Technical Section of the MPG in Munich. These presentations left a significant impact on the section members.
- A similar presentation was given on 25 June 1997 in the *Niedersächsiche Landesvertretung* (Representation of Lower Saxony) in Bonn, where Mrs. Schuchardt (see above) expressed her appreciation for the scientific achievements of the MPAe.

All these activities ultimately led to a reorientation within the MPG, leading to the decision to reduce the institute's staff by 90 positions by 2007. The institute should be continued from 2004 onwards with two departments: solar science and planetary science (see section 11). Some interesting aspects about the internal problems within the MPG at that time are mentioned in Haerendel's biography (Haerendel, 2022).

6. Workshops and test facilities

The mechanical workshop at the MPAe was equipped with all essential tools required to construct the complicated housing of the scientific instruments and detectors including CNC milling machines. In an electroplating laboratory, components could be coated with gold or silver. In a specialized electronic workshop the electronic components of the scientific instruments were designed, built and tested.

The metalworking shop employed specialists in antenna construction. Apprentices were trained in the workshops often with remarkable success. Several apprentices secured first places in the performance competitions of the state chambers of crafts.

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Various test facilities were available, eg, thermal vacuum chambers to simulate space conditions, a vibration stand and several clean rooms.
A variable particle accelerator was designed and constructed to calibrate the particle analyzers.
The IT department comprised a powerful central computer along with an extensive network of personal computers, all maintained by a skilled staff.
It must be emphasized that the engineers, technicians and craftsmen at the MPAe played an extremely important role in the success of the scientific instruments.

7. Library, Documentation and Administration

A well-equipped library with more than 10 000 monographs on atmospheric and space science and techniques, about 15 000 Journal volumes featuring about 50 current issues, helped scientists and engineers with their work.
Technical draftsmen, in collaboration with scientists, engineers and technicians, provided the necessary drawings for the workshops. Specially trained staff members prepared the documentation for collaboration with external institutions, and they monitored compliance with the specifications for ESA and NASA missions.
All matters related to accounting, payment transactions, ordering and procurement were handled in the administration department. Since external funding made up a substantial part of the institute's budget, managing these funds was also one of the tasks of the institute's administration. Additionally, they supported guests of the institute as well with the first necessary steps, e.g, providing advice on finding childcare.
An internal newsletter, the *Institutsinformationen* was published weekly by a group of secretaries. It provided information about significant internal events, recent publications, and birthday wishes for employees.

8. Public Relations

Already in the early 1970s, information boards were set up in the entrance area of the new building, informing visitors about the scientific work at the institute.
On 24 March 1979 the first open house event was organized which was a great success: more than 5 000 visitors could be welcomed. Following open house events were arranged in 1986, 1990, 1996. Ministers, members of parliament and other high-ranking individuals were invited and visited the MPAe.
In the 1990s mobile exhibition stands were prepared (Fig. 13) which were utilized on various occasions such at fairs, museums and exhibitions in cities throughout Europe.
The so-called „Erich Regener Lectures“ were introduced which aimed the local population. They were held several times a year and educated the public about current scientific findings. Numerous popular science lectures by staff members at various occasions and places must also be mentioned.

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Articles in various daily newspapers, journals, and on television, also played a significant role in public relations efforts. A brochure, which was published in several editions up to 2004, as well as leaflets titled *Forschungsinformationen* (research information) and a video, also provided information about the scientific achievements of the MPAe.

9. International Max Planck Research School for Solar System Science (IMPRS)

The contact to the University of Göttingen has already been mentioned in section 1. In order to institutionalize and intensify this relationship IMPRS was founded in 2001. Partner was not only the University of Göttingen, but also the Technical University of Braunschweig (about 80 km away from Lindau). The school is a research-oriented graduate program, offering students a training towards a PhD degree in physics in a vibrant geo- and astrophysics research environment. In this unique environment, the IMPRS School is run jointly with three institutes at the University of Göttingen and three institutes at TU Braunschweig. Junior researchers joining the doctoral program will find that these institutes offer excellent facilities, internationally renowned researchers and experienced teachers, and provide excellent conditions to specialize in the field of Solar System science. Research topics range from solar physics to astrophysics, planetary sciences and beyond. After the renaming of the MPAe, IMPRS was continued by MPS, details can be found on its website at https://www.mps.mpg.de/solar-system-school.

10. The institute and COPERNICUS

The *Copernicus Gesellschaft e.V.* (Copernicus Society) was a spin-off from the MPAe. It was established on 5 February 1988 by the directors, the administrative manager and three members of the scientific staff. The primary aim was to ensure the continuity of the European Geophysical Society (EGS) and the organization of its annual conference. The directors of the MPAe provided long-term support to the EGS by maintaining a permanent office at the institute. The Copernicus Society evolved into Copernicus GmbH with the two branches Copernicus Publications and Copernicus Meetings and moved to a new office in Göttingen in 2009 (for further details see https://www.copernicus-gesellschaft.org/history.html). As of today (June 2026), Copernicus publishes 37 peer-reviewed, open-access, disciplinary journals and organizes 10 scientific conference per year (see https://www.copernicus.org/facts_and_figures.html).

11. The MPS

On 19 March 2004 the Senate of the MPG decided to rename the MPAe into „Max-Planck-Institut für Sonnensystemforschung" (solar system research, MPS). The decision became effective on 1 July 2004. It should be stressed that is was not a true „end" of the the institute under consideration, many MPAe-projects were continued at the MPS (as mentioned above several times). Directors at that time were Ulrich Christensen for the planetary science department and

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Sami Solanki for the solar physics department (see Fig 1), Solanki served as Managing Director. At the beginning of 2014 the MPS was moved into a new building on the campus of the University of Göttingen.

Details of this institute can be found under its website www.mps.mpg.de.

Personal remark and Acknowledgements

The author was a member of the scientific staff from 1968 until his retirement in 2003. He was elected as member of the *Direktionsbeirat* (see above, section 4) several times, and managed the public relations from 1979 until 2003, and he wrote several publications and books for public outreach. He gave lectures at the University of Göttingen as adjunct professor as well.

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Competing interests

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Figures

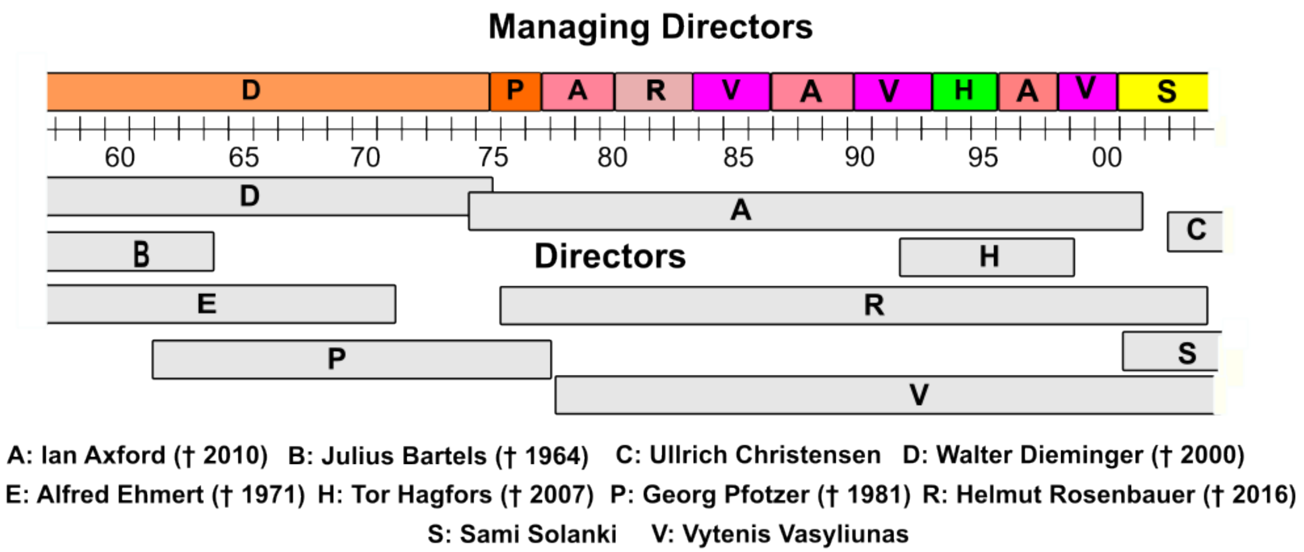

Fig. 1: Directors and Managing Directors at the MPAe from 1957 to 2004.

Fig. 2: New Institute Buildings. A: first floor: Library, Administration, Lecture Hall, second and third floor: scientists' studies, B: first floor: drawing and documentation, computer center, test facilities, clean rooms, first floor: scientists' and engineers studies. C: Electronic workshop, D: mechanical workshop, mechanical and electronic supply, E: Cafeteria and meeting rooms, F: Garage, G: Power plant. (Source: MPAe)

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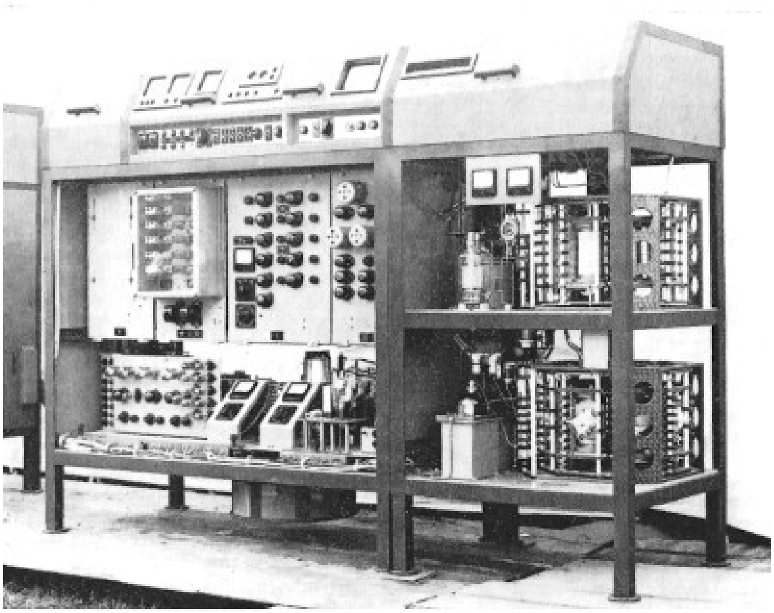

Fig. 3: Ionosonde from 1957 (Source: MPAe)

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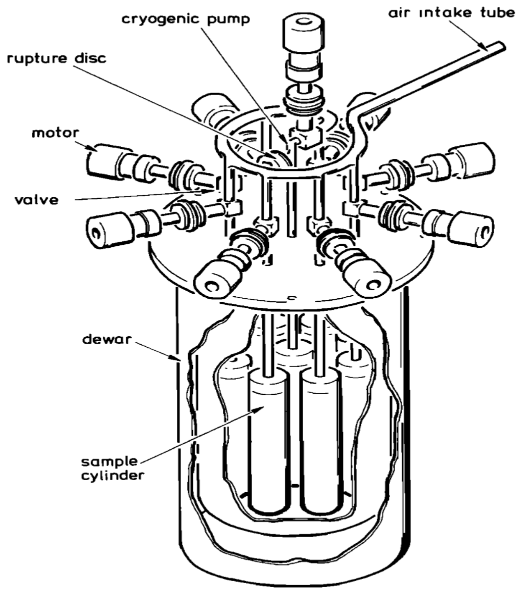

Fig. 4: Cryosampler for atmospheric trace gases, for details see Fabian et al. (1979).

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Fig. 5: SOUSY antenna array near Bad Lauterberg in the Harz Mountain (Source: MPAe)

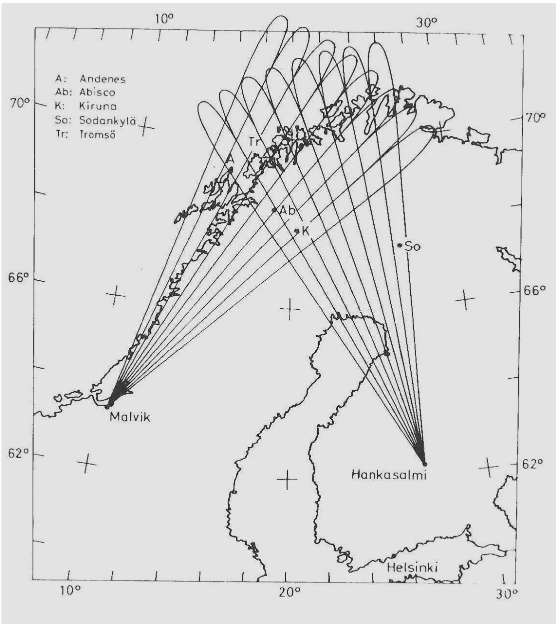

Fig. 6: STARE antenna beam pattern, the field of view covered a geomagnetic latitude range from 65 ° to 70°.

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775 **Fig. 7**: Detail of one of the HEATING antenna arrays. The aluminium pipes on the ground serve as co-axial cables to feed the power to the dipoles. In the background the EISCAT VHF antenna is visible (Source: M.T. Rietveld).

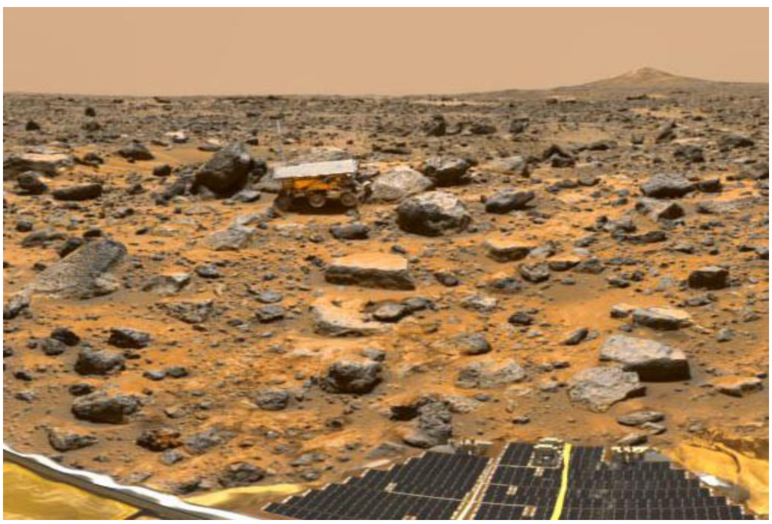

Fig. 8: Martian landscape with the rover „Sojourner" photographed during the MARS Pathfinder Mission, July 1997 (Source: NASA/MPAe).

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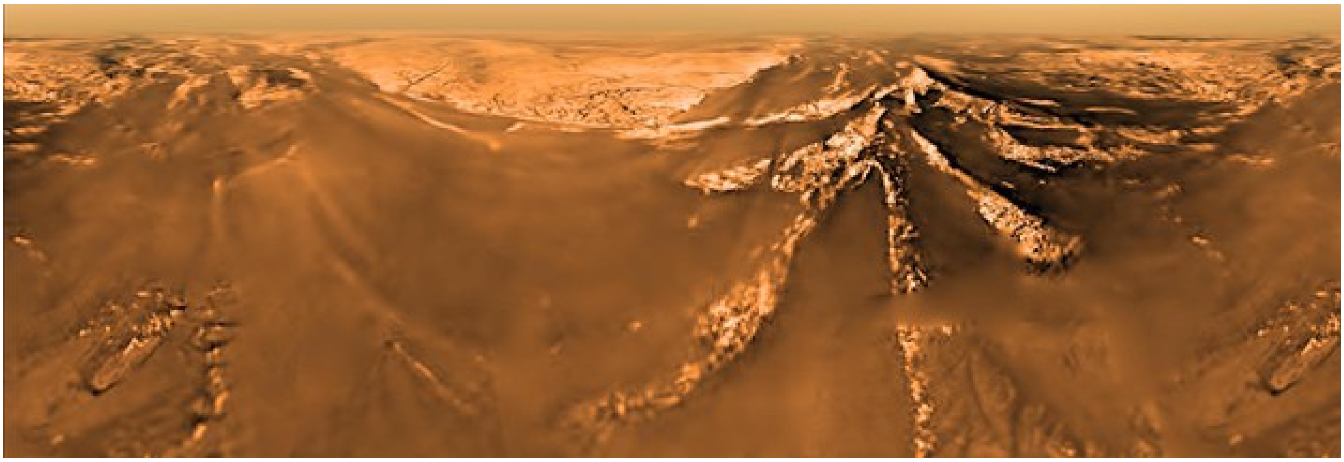

Fig. 9: Surface of TITAN photographed with DISR DESCENT IMAGER on Huygens on 14. July 2005 from an altitude of 2 km (Source: Lunar and planetary Laboratory, University of Arizona, MPAe).

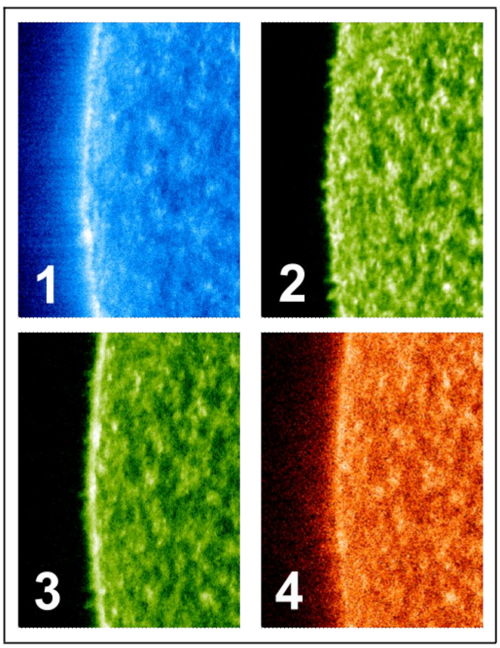

Fig. 10: East Limb Scan of the Sun with SUMER in four spectral lines, taken on 6 March 1996. 1: Ne VIII 780.324 Å (630 000 K), 2: O IV 790.20 Å (170 000 K), 3: C IV 1548.20 Å (1000 000 K), 4: Fe II 1563.79 Å (12 000 K). (Source: MPS, SUMER study #134)

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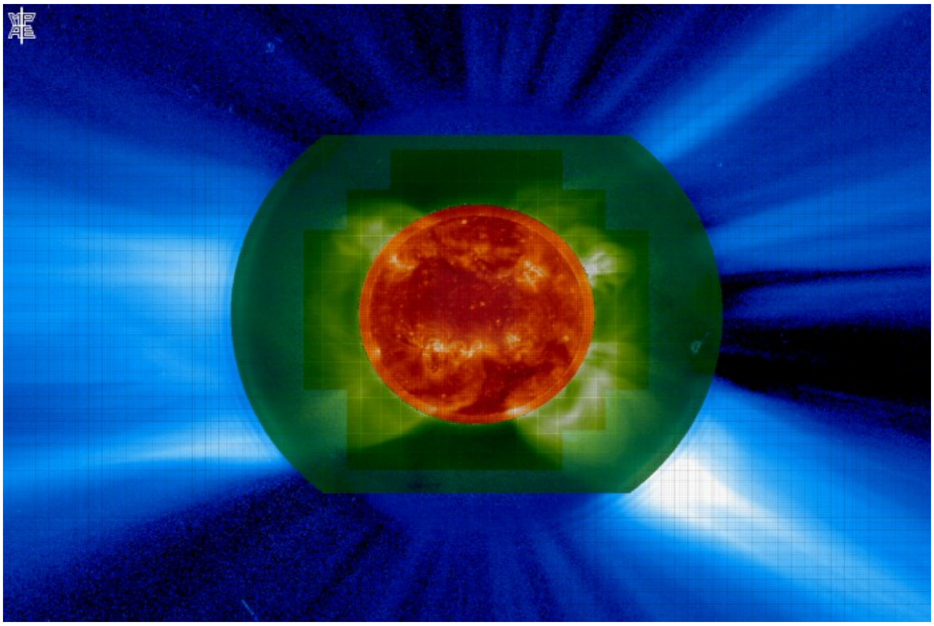

Fig. 11: LASCO photograph of the solar corona. A stacked combination of photographs of the coronagraphs C1, C2, C3; the solar disk is covered with a photograph taken with the Extreme UV Imaging Telescope (EIT) which shows the emission of He II at 304 Å (Source: B. Podlipnik, MPAe)

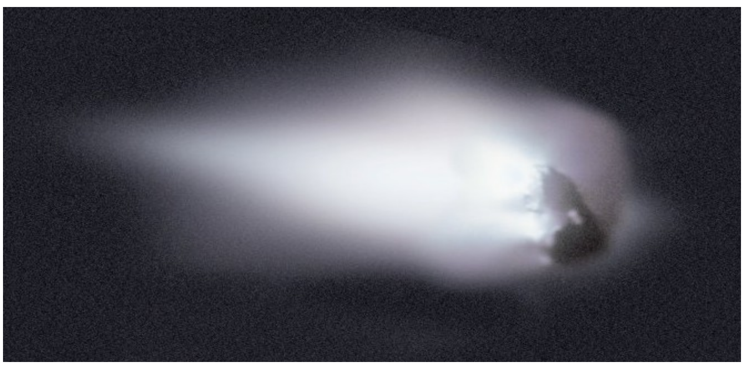

Fig. 12: Nucleus of Comet Halley photographed from a distance of 596 km on 14 March 1986 (Source: MPAe).

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Fig. 13: Mobile exhibition stand of the MPAe.