6. SPACE OBSERVATION OF SOLAR SYSTEM OBJECTS

Jurgen Rahe

The program of exploration of solar system objects from space is now in a more mature phase where third generation missions to inner as well as outer solar system bodies are developed. Emphasis in the inner solar system is on Mars and Venus, in the outer-solar system on Jupiter (Galileo Mission). The exploration of the primitive small bodies (comets, asteriods) has lagged in the past, partly due to technological considerations. Following the spectacular, but still reconnaissance-level flybys of Comets Giacobini-Zinner and Halley in 1985 and 1986, respectively, ISAS considers a cometary flyby and coma sample return mission, and NASA plans to initiate an even more comprehensive exploration by conducting a close flyby of a main-belt asteroid, followed by a multi-year rendezvous with a short-period comet (CRAF) in the early 1990s.

During its past apparition 1985/1986, Comet Halley was the focus of an unparalleled global scientific effort of exploration from the ground, from Earth orbit, from Venus orbit, from interplanetary space, and from within the comet itself.

Four space agencies - the European Space Agency (ESA), the Intercosmos of the USSR Academy of Sciences, the Japanese Institute of Space and Astronautical Science (ISAS), and the National Aeronautics and Space Administration (NASA) - sent six spacecraft to Halley's Comet. ESA launched Giotto, Intercosmos launched Vega-1 and Vega-2, ISAS launched Sakigake and Suisei, and NASA used its ICE spacecraft. The different missions complemented each other in their flyby distances, ranging from about 600 (Giotto) to about 30 million (ICE) kilometer, and comet heliocentric distances ranging for the time of the encounters from 0.8 to 0.9 A.U. The scientific experiments on the various spacecraft provided the full complement of experiments that can be flown on a flyby mission. In addition, there was a large overlap between the experiments on the different spacecraft allowing a comparison of data after the encounters. The missions also extended the total time of in-situ measurements in the cometary environment.

Realizing that many aspects of mission planning, spacecraft and experiment design, and data evaluation are essentially the same for all missions, and that the overall scientific return could be increased through cooperation, the four agencies formed in the fall of 1981 the Inter-Agency Consultative Group (IACG) for Space Science. The IACG undertook the task to coordinate matters related to the space missions to Halley's Comet, similar to the International Halley Watch (IHW) which coordinates the ground-based Halley observations. IHW and IACG are described in more detail e.g., in ESA Bulletin Nos. 38 and 39, 1985.

First results of these missions have been published in Nature, Vol. 321, 1986, and in the proceedings of the 20th ESLAB Symposium "Exploration of Halley's Comet" (ESA (SP-250).

Following a series of highly complicated orbital manuevers about the Earth and the Moon, the International Sun-Earth Explorer 3 (ISEE-3) which had been launched in 1978, was renamed International Cometary Explorer (ICE) and went through the tail of Comet Giacobini-Zinner on September 11, 1985 at a distance from the nucleus of 7800 km. The results of this flyby are reported in the April 18, 1986, issue of Science.

The comet nucleus was observed from the Vega and Giotto Missions. It appeared as peanut-shaped object both larger (about 16x8x8 km) and darker (albedo lower smaller than 4%) than previously thought, making it one of the darkest objects in the solar system. Gas and dust emanate in form of jets from only a few regions of the nucleus, while the rest is covered with a dark crust. Much of the cometary dust is made of organic material. As expected, water vapor was the dominant parent molecule in the coma. At the time of Giotto flyby, the total mass production rate was 6.9x10 mol/sec of which 80% were water molecules. The water vapor production amounts to 15 tons/sec.

The interaction between the solar wind plasma and the cometary ionosphere is characterized by two distinct boundaries, the bow shock and the contact surface. Outside the bow shock, is the undisturbed supersonic solar wind. Inside the contact surface, close to the nucleus, there are only cometary ions. In between these two boundaries is a mixture of cometary and subsonic solar wind ions. Some cometary neutral particles can travel large distances from the nucleus before they are ionized and picked up by the solar wind. Such "pick-up ions" were observed by the Vega and Giotto spacecraft out to distances of 10 million km, by ICE even at distances of 30 million km.

Since 1983, substantial contributions to Venus research have been made. High resolution radar images obtained by Venera 15 and 16 revealed a variety of volcanic, impact, and tectonics features. Vega 1 and 2 deployed a pair of landers and instrumented atmospheric balloons, providing information on the surface composition and atmospheric conditions. The Pioneer Venus Orbiter continues to make excellent measurements, indicating, e.g., that the amount of SO above the cloud tops has declined by more than a factor of ten since these measurements started in 1978.

There is growing evidence that water has played an important role in the climate and geological evolution of Mars. A new international effort to explore Mars is underway which includes plans for Mars orbiters, balloons, landers, rovers, and Mars sample returns.

The two Voyager spacecraft have successfully explored Jupiter and Saturn and their satellites. Voyager 1 is leaving the solar system on a trajectory inclined above the ecliptic plane. Voyager 2 reached Uranus on January 24, 1986, and is now proceeding to Neptune where it will arrive in August 1989. All 11 Voyager 2 instruments operated perfectly at the Uranus encounter and sent to Earth volumes of data and thousands of images of uncalculable scientific value. In addition to the five known moons, 10 others were found with diameters averaging about 50 km. Oberon and Titania showed crater-packed surfaces with wide cracks, Miranda exhibited virtually all geological forms found elsewhere in the solar system. Uranus has a surprisingly strong magnetic field with a 55 degree tilt of the magnetic pole axis from the axis of rotation.

It is expected that the next report, covering the period through June 1990, will be dominated by results from the two Soviet Phobos missions which are scheduled to land on Mars in early 1989, from the Voyager 2 encounter with Neptune on August 25, 1989, and by measurements of Solar System objects obtained from the Hubble Space Telescope.

PLANETARY MISSIONS LAUNCHED SINCE 1983

NAME	COUNTRY	TARGET/MISSION	LAUNCH DATE	ARRIVAL DATE	HALLEY FLYBY(km)
VENERA 15	USSR	VENUS-ORBITER	6/2/83	10/10/83	
VENERA 16	USSR	VENUS-ORBITER	6/7/83	10/14/83	
VEGA 1	USSR	VENUS	12/15/84	6/11/85 V	
		COMET HALLEY		3/6/86 H	8.9x10
VEGA 2	USSR	VENUS	12/21/84	6/15/85 V	
		COMET HALLEY		3/9/86 H	8.0x10
SAKIGAKE	JAPAN	COMET HALLEY	1/9/85	3/11/86	7x10
GIOTTO	ESA	COMET HALLEY	7/2/85	3/14/86	605
SUISEI	JAPAN	COMET HALLEY	8/19/85	3/8/86	1.5x10
ICE	USA	GIACOBINI-Z	8/12/78	10/11/85	
		COMET HALLEY		3/25/86	2.8x10

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7. Solar Research From Space 1985 - 1987

S. D. Jordan

I. INTRODUCTION

The three year period 1985 - 1987 was a time of both continuing advances in our understanding of the Sun, as well as a period of planning at least three future space missions for solar physics during the next decade. The greatest advances in the study of solar physics from space observations during 1985 - 1987 probably came in the general area of solar flares, thanks to data from the Solar Maximum Mission (SMM) and HINOTORI satellites. In addition, significant new insights into small-scale photospheric turbulence (granulation) and into mass balance in the chromosphere-corona transition region were obtained from experiments deployed on Spacelab II. There is some concern over the difficulties the solar physics community has experienced in obtaining a suitable High Resolution Solar Observatory (HRSO). Nevertheless, significant progress was made toward realizing a Solar and Heliospheric Observatory (SOHO), to be launched in 1995 for studies of acceleration mechanisms for the solar wind and studies of the solar interior via observations of solar pulsations (helioseismology). Particularly encouraging during this period was the announcement that a SOLAR-A high-energy flare mission would definitely be developed for operation during the period 1991-1993 of the next solar maximum. In general, the world-wide scientific community seems to be developing a growing interest in solar physics, and in obtaining solar observations from space.

II. RECENT PROGRESS

1. Solar Flares

Great progress toward a more complete understanding of solar flares was made during and following the last solar maximum, thanks in large measure to two orbiting spacecraft, the Solar Maximum Mission (SMM), and the HINOTORI. This progress continued during the period of this review, both from continuing analysis of data taken during the early 1980's and by the extended operation of the SMM, following its repair by a Shuttle mission in 1984. Areas of significant advance included: evidence for beams of suprathermal electrons, prompt acceleration of protons, improved element abundance determinations, and the determination of a 154-day periodicity in flare activity.

A major problem in solar flare physics is the development of a satisfactory model for the flare process for a given flare or for a class of flares. One aspect of this problem is the discrimination between two different models which are sometimes proposed to explain the same flare phenomena. These are the thick-target model and the thermal model. The former involves the acceleration of a beam of suprathermal electrons in the corona, while the latter involves bremsstrahlung-producing electrons with a thermal velocity distribution. While the latter model can be considerably less taxing on the energy requirements for the electrons, evidence for beams of suprathermal electrons would demonstrate that certain features of the thick-target model are probably realized in at at least some flares. These features are either the existence of an "external" driver such as a shock wave to produce the acceleration or a high degree of current filamentation within the acceleration region. Such evidence for suprathermal beams has been found. During some flares, the SMM Hard X-Ray Imaging Spectrometer and the HINOTORI Solar X-Ray Telescope obtained images which are consistent with a "footpoint" hard X-Ray structure at energies around 20 KeV, indicative of the non-thermal impact signature of the thick-target model. The thick-target model is described in Lin and Hudson (1976) and Hoyng et al. (1976). The thermal model is described in Brown et al. (1979) and Smith and Harmony (1982). Recent observations bearing on this problem are described in Dennis at al. (1986).

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Evidence for the prompt acceleration of protons comes from gamma-ray lines in the 4- to 8- MeV range, observed with the Gamma-Ray Spectrometer (GRS) on SMM. These lines, produced by nuclear deexcitations, were observed to be emitted simultaneously with the hard X-Ray bremsstrahlung continuum to within the 1-s timing accuracy of the data. Since the excited nuclei responsible for the emission of these lines are produced by high-energy proton impact, it follows that impulsive proton acceleration is a significant feature of these gamma-ray producing flares (Murphy and Ramaty, 1985). Gamma-ray spectra obtained with the GRS have also proved useful in relative abundance determination, particularly in the chromosphere (Murphy et al. 1985). These analyses suggest lower abundances of C and O, relative to Mg, Si, and Fe, in the chromosphere compared to the photosphere. This in turn implies a variation in chemical composition with space and time in the solar atmosphere, in general, and may even have implications for our knowledge of cosmic abundances. Soft X-ray spectra are also useful in this context (Doschek et al. 1985).

Finally, evidence has been found in several energy regimes for a 154-day periodicity in solar flare activity. Recent Fourier analyses of gamma-ray, hard X-Ray, radio microwave, and H- alpha event-occurrence rates clearly show a variability in the rates with a period of approximately 5 months (Rieger et al. 1984, Dennis, B. R., 1985, Bogert and Bai, 1985, Ichimoto et al. 1985).

2. Photospheric Turbulence and Magnetic Fields

One of the most spectacular recent observations in solar physics was the series of granulation pictures taken at sub-arcsecond spatial resolution and time intervals ranging from 10 to 60 seconds with the Solar Optical Universal Polarimeter (SOUP) instrument flown on Spacelab II during August 1985. This time-resolution permitted the creation of a movie which reveals clearly the difference between the large-scale flows in the lower solar photosphere and the five-minute oscillation (Title et al. 1986). The granulation was observed at higher spatial resolution than ever before achieved for a time longer than that required to produce a single snapshot. The phenomenon of "exploding granules," heretofore known to characterize only a, possibly small, fraction of the granules, was shown to be ubiquitous. Stated simply, the turbulent convective elements are seen to rise in the photosphere until contact with the overlying zone of predominantly radiative transport acts like an almost impenetrable wall, which forces the granule to impart its forward momentum to the atmosphere as a whole, while the material of the granule itself moves out in all directions perpendicular to the upward motion.

A second schievement of the operation of the SOUP on Spacelab II is the remarkable correlation of the photospheric flow field with the small-scale photospheric magnetic field, where the latter was observed simultaneously from the Big Bear Observatory (Simon et al. 1987). In this experiment, the white-light granules act as "corks," or tracers of the flow field. It is clear from comparing the flow field so mapped with the SOUP to the magnetic field mapped at Big Bear that the magnetic features move with the flow field, and thus congregate at the same locations where the flows converge, i.e., at the edges of the supergranulation pattern on the Sun. This confirms in great detail and with exceptional clarity a picture of solar surface convection and magnetic field migration which provide boundary conditions for modeling solar convection and dynamo activity.

The data set from the SOUP was acquired at the end of the Spacelab II mission, after a number of initial problems were successfully solved. The excellence of the brief data set, of about one hour's duration, demonstrated convincingly that sub-arcsecond solar observations, in this case with about a quarter of an arcsecond angular resolution, will reveal both new phenomena and also a convincing confirmation (or disconfirmation) of already studied phenomena to a remarkable degree.

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3. Outer Atmospheric Energetics

The Spacelab II mission also featured a solar High Resolution Telescope and Spectrograph (HRTS) for obtaining high resolution ultraviolet spectra of the solar chromosphere and transition regions. The HRTS consisted of a 30 cm Gregorian telescope, a slit spectrograph covering the 1190 - 1680 A region with 0.05 A spectral resolution, a broadband (90 A FWHM) spectroheliograph, and an H-alpha filter system (Brueckner et al. 1986). This experiment obtained sufficient spectra and images in the strong resonance doublet of C IV (1548 A and 1550 A) to permit statistical studies to be performed on the possible contribution of upward moving features in the solar transition region to coronal heating. It also revealed strong downflows in the transition region, thus contributing to a better understanding of the mass-balance problem in the outer solar atmosphere.

The upward moving features observed in the C IV resonance lines were considered as a possible mechanism for coronal heating. These features were of 1-8 arcseconds in angular extent, and moved with velocities up to 400 km/sec in the upward direction (as well as, in many cases downward, but never with such high velocities). From the frequency of occurrence of these upward moving "bullets," and local values of temperature and density in the solar transition region, the investigators estimated the contribution of these events to radiative loss, enthalpy flow, and kinetic energy flow in the solar atmosphere. The results were perhaps disappointing, but enlightening, with respect to coronal heating. From Withbroe and Noyes (1977), the energy loss of the quiet corona is estimated at 3×10^5 ergs cm^{-2} sec^{-1} for the quiet corona, and up to 10^7 ergs cm^{-2} sec^{-1} for coronal active regions. These events, on the average, provide an estimated 2.5×10^4 ergs cm^{-2} sec^{-1}, clearly insufficient to heat the corona.

The HRTS results have considerable significance for understanding the transition-region mass balance, however. It has long been known that the upward mass flow in spicules alone is more than an order of magnitude greater than the mass loss measured at 1 a. u. in the solar wind, if there is no downflow within the spicule itself. The upward and downward motions observed in the transition region, like upward and downward motions measured earlier in chromospheric Mg II from satellites, show that mass balance in the solar atmosphere is a complex phenomenon, with upflows almost balanced by downflows, as required by mass conservation.

III. FUTURE PLANS

1. High Resolution Solar Observatory

The world-wide solar physics community has for over a decade accorded a very high priority to the realization of a sub-arcsecond spatial resolution on the Sun. This spatial resolution, with correspondingly high spectral and, in some cases of strong lines, temporal resolution will provide the capability of addressing many problems in the fundamental physics of the Sun's surface magnetic field and convection, and of the heating and mass balance in the overlying atmosphere up to the corona. A spatial resolution approaching 0.1 arcseconds is needed for these studies, because this is the approximate scale (0.1 arcseconds = 73 km on the Sun) of the hydrodynamic scale height and of a continuum photon mean-free - path in the solar photosphere, i.e., the scale on which collective energy transport occurs in much of the solar atmosphere. Realization of this scale from the ground is virtually impossible for more than a fraction of a second, because of atmospheric effects. Thus dynamical phenomena on this scale, in particular, must be observed from space, even in the visible.

The High Resolution Solar Observatory (HRSO) is the current version of a program planned during the 1970's by a group of American and European solar physicists in cooperation with the National Aeronautics and Space Administration (NASA) to provide this capability. The HRSO is a somewhat descoped version of an earlier, more ambitious program called the Solar Optical Telescope (SOT).

The HRSO retains the very high spatial resolution capability of the SOT, approaching 0.1 arcseconds, but does not offer an ultraviolet capability below about 2200 A. (The SOT went down to about 1175 A.) As such, it is more limited than its predecessor for studies of the solar atmosphere above the temperature minimum, but it still provides an outstanding and needed capability for studying the fine structure and dynamics of solar photospheric convection and the Sun's surface magnetic field, in which a number of fundamental solar-stellar astrophysical processes occur.

2. Solar and Heliospheric Observatory

The Solar and Heliospheric Observatory (SOHO) has been planned as a major joint mission of the European Space Agency (ESA) and NASA. The mission will be part of a major Solar Terrestrial Science Programme (STSP) consisting of at least four free-flying satellites, of which three will focus on magnetospheric and outer-solar-wind problems and one, the SOHO, will concentrate on the physics of the inner solar wind and on solar pulsations. The experiments will fly on a satellite to be launched in 1995 to achieve a halo orbit around the first Lagrangian point in the Earth-Sun system. This way the satellite will be exposed to the unobstructed solar windstream well in front of the terrestrial magnetosphere. Measurements of comparatively small oscillatory motions on the solar surface will also be facilitated by this orbit, due to the small relative velocity between the satellite and the Sun.

The SOHO will address the following three fundamental and interrelated questions in solar and heliospheric physics:

- How is the solar corona heated?
- Where and how are the solar-wind streams accelerated?
- What is the structure of the solar interior?

The first question, on heating the solar corona, has been a fundamental question in solar physics since the mid-century. To date, no completely satisfactory answer has been offered. About the only thing now known reliably is that acoustic waves generated by convective turbulence in the lower photosphere do not heat the corona. On the other hand, certain magnetohydrodynamic waves cannot be ruled out, particular in the low-density coronal hole regions. Various current-dissipation mechanisms for extracting energy from ambient magnetic fields are attractive for coronal active regions, and an attempt has been made to identify the magnitude of the heating from the observed photospheric velocity power spectrum without determining the exact mechanism for the dissipation. All of these theories, including certain features of the latter, require a better determination of densities and associated energy fluxes in the corona than are currently available (Ionson, 1985). High-resolution extreme-ultraviolet spectroscopy on SOHO is expected to provide the needed data.

The second question concerns the need for a mechanism for accelerating the solar wind to the high velocities observed at 1 a. u. by satellites in Earth orbit. Acceleration by momentum transfer from Alfven waves and other mechanisms have been proposed, but no definitive solution has been found as yet (Axford, 1985). Since solar wind conditions must be measured out to many solar radii to cover a significant fraction of the acceleration region, a coronograph capable of providing information on the solar wind velocity at these distances is needed on the SOHO spacecraft.

The third question, on the structure of the solar interior, depends upon applying the methodology developed during the previous decade for inferring the structure of the solar interior from careful monitoring of velocity and luminosity oscillations of the solar surface (Gough, 1985). A Solar Oscillations Instrument on SOHO will obtain the needed data. One of the most promising possibilities here is the determination of the velocity structure of the solar convection zone, where the convective motions, combined with the Sun's differential rotation, are thought to be responsible for generating the Sun's magnetic field.

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3. SOLAR-A

A major space mission, to be called SOLAR-A has been planned for the next solar maximum in the early 1990's by the Institute of Space and Astronautical Science (ISAS) in Japan. The emphasis of this mission will be on the high-energy phenomena occurring in association with flares, particularly during the flares' early phases. Both X-ray and gamma-ray instruments will be carried on a spacecraft built and launched by ISAS. The proposed payload for the SOLAR-A consists of: a hard X-ray imaging instrument, a hard X-ray continuum spectrometer, a soft X-ray imaging telescope, a soft X-ray continuum spectrometer, a Bragg crystal spectrometer, a gamma-ray and neutron spectrometer, and a solar intensity monitor. All of the instruments but one will be built in Japan. The single exception is the soft X-ray imaging telescope, to be built in the United States and provided by NASA under terms of a joint agreement between the two governments. The SOLAR-A mission will continue the systematic study of high-energy solar processes begun by the SMM and HINOTORI missions of the early 1980's.

The core of the Solar-A payload is to be the hard X-ray imaging instrument and the soft X-ray imaging telescope. The hard X-ray instrument will yield new information above 30 keV (full range is to be 7 - 70 keV) on nonthermal electron acceleration in the flare, a process known to be one of the most important energetically among several energy-release mechanisms. The spatial resolution of 5 arcseconds will permit the flare kernel to be identified against the background. The soft X-ray telescope will complement the hard X-ray data by revealing the magnetic structures within which the flash phases of flares are known to occur, both before flaring and also thereafter, when these loop structures tend to fill up with hot, dense plasma. Imaging with an angular resolution of 2-3 arcseconds is the goal of this instrument. Obtaining simultaneous images of flares with comparable high temporal and spatial resolution in both hard X-rays and soft X-rays should reveal the morphology of the flaring plasma in sufficient detail to provide a deep understanding of the physical processes occurring during the flares' early phase.

Continuous measurement of the Sun's irradiance during the scheduled mission period of 1991-1993 will extend the data base already provided by SMM. The SOLAR-A solar intensity monitor will also introduce a new feature into solar irradiance measurements, a modest degree of spatial resolution across the solar disk. The data will be used to study active-region evolution and low-order global oscillations, as well as continuing the study of secular changes in the solar constant.

4. Other Programs

A large number of smaller programs and at least one other of major consequence are currently in various stages of planning or development. These include sounding rocket and balloon-borne solar experiments, possible solar payloads to be launched into orbit on Scout rockets by NASA, and Russian plans for a Mars mission named after the moon to be studied, PHOBOS. Of these, the PHOBOS mission is the most ambitious, for the spacecraft, during its journey to Mars, would obtain data on the solar wind and the interplanetary medium between Earth and Mars.

Proposals for high-energy solar experiments to be flown on small satellites launched by Scout rockets are likely to be submitted. Operation in the period of the next solar maximum is planned. One possibility being studied at this writing would involve flying a spacecraft developed by Argentina, launched by NASA on a Scout rocket, and carrying a solar high-energy experiment provided by American investigators.

It was evident from the scientists who attended the XIX General Assembly for the IAU in New Delhi during November 1985 that both India and China are developing significant groups of scientists pursuing solar physics. The discipline is rapidly achieving world-wide scope, and it is to be expected that major groups everywhere will be interested in pursuing solar physics from space in the near future.

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