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The Role of Harvard College Observatory and UVCS in the Development of SOHO

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1 Introduction

The story of *SOHO*'s progression from a proposal to ESA for a *Solar High-resolution Observatory* in low Earth-orbit in November 1982 to its launch in December 1995 as the joint ESA–NASA *Solar and Heliospheric Observatory*[1] towards a halo orbit around Lagrange Point L1 and, by now, *SOHO*'s nearly 14 years of observations has been told before.

At this *SOHO* Workshop initiated by the UVCS group at the Harvard-Smithsonian Center for Astrophysics,[2] however, it is fitting to emphasize two items that have found little attention in the past: the role of the science to be achieved with the eventual UVCS instrument, and what could be called the role of Harvard College Observatory (HCO) as a breeding ground for *SOHO.* Indeed, the role of UVCS, particularly in the early study stage, has not yet been commemorated to the extent it deserves. Also, it is remarkable that many of the scientists and engineers at HCO who had been working in the "Solar Satellite Project" under Leo Goldberg's leadership during the 1960s and early 1970s were involved with *SOHO* later on. In fact, several of the post-docs and post-graduates, who had spent extended periods at HCO in the late 1960s and early 1970s, later became major actors; some of them even became principal investigators in the *SOHO* mission.

The scientists at HCO were a varied group of physicists and astronomers from the US and from overseas: John Kohl, Michael Kühne, Gethyn Timothy, Alan Title, Pino Tondello, George Withbroe, and myself. In addition, many long-term visitors, two of them actually present at *SOHO–23,* namely Alan Gabriel, then at Culham Laboratory, and Giancarlo Noci from Arcetri, helped to provide a lively international scientific atmosphere at HCO. Numerous people—among them Ester Antonucci, Roger Bonnet, Len Culhane, Carole

[1] *SOHO* was moreover one of the five spacecraft of the Solar-Terrestrial Science Programme (STSP), the first Cornerstone of the *Horizon 2000* long-term science program of ESA. The other four spacecraft formed the *Cluster* mission that was devoted to space plasma physics. Interestingly, although *SOHO,* a three-axis stabilized spacecraft, was often perceived to be the more expensive element of the STSP Cornerstone, the *Cluster* mission with its four identical spin-stabilized spacecraft was nevertheless the dearer element of STSP.

[2] The Smithsonian Institution and Harvard University formalized their collaboration as the Harvard-Smithsonian Center for Astrophysics (CfA) in mid-1973, to coordinate research activities of the Harvard College Observatory (HCO) and the Smithsonian Astrophysical Observatory (SAO) under a single director. George B. Field was the first Director; Irwin I. Shapiro succeeded him in 1982.

Jordan, Monique Arduini Malinovsky, and Peter McWhirter who later also got involved with *SOHO*—paid shorter visits to HCO. They visited not only the engineering offices and laboratories, where the *OSO* and *Skylab* instruments were being designed, developed, and calibrated, and spoke to the more observation-oriented astronomers. They also visited the "shock tube lab," where atomic and molecular data relevant to astrophysics were measured—first by high-resolution spectrographs and interferometers registering the radiation from shock-heated gases, later also by use of dye-lasers and other advanced experimental equipment. The shock tube laboratory, by the way, provided insurance for experimental physicists who spent some of their time testing and calibrating instruments; it assured scientific achievements if there were launch delays or even launch failures.

Given the international atmosphere at HCO it is not surprising that *SOHO* eventually became a joint ESA–NASA mission. To be sure, there were more people contributing to the exciting atmosphere in the same group at HCO who later pursued their astrophysics research in domains different from *SOHO.* Among these were Andrea Dupree, Peter Foukal, Robert Noyes, and Peter Smith, and, of course, William Parkinson and Edmond Reeves, the two Associates of Leo Goldberg who were responsible for the day-to-day work on space instruments and in the lab. Key support for both the space and laboratory activities came from engineers like Nathan Hazen and George Nystrom, to name just two.

2 Space Science at an Early Stage

The time just described, namely the late 1960s and early 1970s, was an era of space science that may be called "the early epoch of space science," where experiments in space were regarded as daring but rather extravagant. At that time, the community was not yet strictly segmented into instrument builders, operations specialists, and observers or astrophysical modelers. As a result, the people who later engaged themselves for *SOHO* got an opportunity to learn about many technical, organizational, and scientific aspects of a project, and that obviously helped later on. Politics was not yet a part of our curriculum then, because opportunities and funding were almost without limits at that golden time—and difficulties could easily be taken care of by our advisers. Politics had to be learned the hard way later.

Solar physics in space was thus blossoming in the US, and particularly at HCO. But, when some of us returned to Europe in the early 1970s, we found a rather different scene. In the absence of any space missions addressing solar physics in Europe, the trade of laboratory astrophysics, which had earlier only insured us against launch delays or failures, was now crucial for maintaining scientific productivity.

In the 1970s ESA's Scientific Directorate[3] got five missions going. Three addressed space-plasma and solar-wind physics (namely *GEOS 1, ISEE 2, and*

[3] ESA's Directorate of Scientific Programmes had been created in mid-1973, when the European Space Research Organisation (ESRO), which had dealt exclusively with scientific space projects, was merged with the hitherto unsuccessful European Launcher Development Organisation (ELDO) into the European Space Agency. ESA, an Inter-governmental Research Organisation, was empowered to pursue not only scientific space research, but also to develop

GEOS 2, launched, respectively, in April and October 1977 and in 1978) and two were devoted to astronomy (the γ-ray observatory *COS-B* and the ESA/NASA/UK *International Ultraviolet Explorer,* a spectroscopic telescope, launched in 1975 and 1978, respectively). The following decade saw three launches: ESA's X-ray Observatory *Exosat* in 1983, the Halley-nucleus fly-by probe *Giotto* in 1985, and the astrometry satellite *Hipparcos* in 1989.[4]

The first space science launch in the 1990s was *Ulysses,* the joint ESA–NASA mission, which dealt with the heliosphere. This mission had been approved in 1977 with a provisional launch date in 1983, but several delays, among them the consequences of the Challenger accident, resulted in a launch in 1990 only. ESA and NASA originally had planned to provide one spacecraft each. But in the course of time—while the mission's original name, *Out-of-Ecliptic Mission,* was changed to *Solar Polar Mission,* and in the end to *Ulysses*—there was only the ESA spacecraft, albeit with a complement of American and European instruments. NASA's Space Shuttle and a special propulsion module brought *Ulysses* out to Jupiter for a planetary swing-by, which flipped the orbit plane so that *Ulysses* followed a trajectory leading over the solar poles.

Ulysses concentrated on particle and field measurements and eventually carried no solar telescopes, although a white-light coronagraph had originally been part of the payload of the ultimately canceled NASA spacecraft. This coronagraph would have produced spectacular pictures of the spiral coronal streamers, as seen from above the ecliptic, and particularly from a position above the solar poles.

The eventful history of *Ulysses* now brings us to the roots of *SOHO.* In the mid 1970s the roomy Spacelab, and particularly the so-called Instrument Pointing System (IPS), seemed to offer a possibility to carry out studies of the outer solar atmosphere with one-arcsecond resolution. A *Grazing Incidence Solar Telescope* (*GRIST*) was planned to investigate the so-called grazing-incidence wavelength range, which on the one hand was particularly well suited for density and temperature diagnostics in the hot outer layers of the solar atmosphere, yet on the other hand had been covered only scantily in earlier missions. And it was the *GRIST* Phase-A study where the earlier HCO visitors and residents Monique Arduini Malinovsky, Alan Gabriel, Pino Tondello, and I met again. Having realized the potential of vacuum-ultraviolet solar spectroscopy, which is only possible in space, we were keen to assure that ESA got involved in solar physics as well.

During the Phase-A study of *GRIST,* a possible collaboration with NASA was discussed; *GRIST* was to form a Spacelab Payload together with NASA's *Solar Optical Telescope* (*SOT*).[5] The cancellation of the NASA spacecraft of *Ulysses* in 1981, however, led ESA Science Director Ernst A. Trendelenburg—

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launchers and address space applications; such as communication and Earth-observation satellites, and more recently also the positioning system *Galileo.*

[4] The launch of a Spacelab pallet in 1983 offered flight opportunities for a number of scientific experiments as well.

[5] *SOT,* a one-meter telescope for the visible domain, was planned to provide 0.1″ observations with the aid of internal image stabilizers. Incidentally, Jacques M. Becker, who had also spent some time at HCO in the mid-1960s, turned out to be one of the champions of *SOT.*

often referred to as EAT—to abandon all collaborations with NASA, except for the *Hubble Space Telescope* and *Ulysses,* where agreements already existed. Nevertheless, because the *GRIST* study group (under the guidance of George Haskell) had impressed EAT by its smooth working style, he gave the group the possibility to continue with spectrograph studies.

Another Sun-related study at the time was the *Dual Spectral Irradiance and Solar Constant Orbiter* (*DISCO*), whose orbit was going to be around L1. *DISCO* had three aims: highly accurate measurements of the solar constant and imaging the extreme-ultraviolet Sun—both undertakings that are only possible in space—as well as pursuing the then-new technique of helioseismology, where access to space, and especially to L1, was offering definite advantages. *DISCO* had gone through a Phase-A study and came up for selection as a project in the spring of 1983, but *ISO,* the *Infrared Space Observatory,* was eventually preferred over *DISCO.*

The *SOHO* mission combined the objectives of both *DISCO* and *GRIST.* In addition, on the insistence of EAT, particle-detecting instruments were added to the *SOHO* payload for the Phase-A study. Given *SOHO*'s originally envisaged low-Earth orbit, this did not promise any significant advances, but it made the proposers aware that looking for support by other communities was important if a mission should succeed in the ESA selection process. In fact, most ESA missions, especially those in "new" fields—and solar physics was a new field for ESA—were the result of an evolution rather than a single proposal. Aligning several communities behind one coherent proposal involves a number of steps and thus takes quite some time. However, in hindsight, eventual success may also have been the result of lucky turns.

One of these lucky turns was the existence of by then recent, but still ambiguous measurements of Doppler-shifted coronal emission (implying a solar wind outflow starting already in the inner corona). In addition, John Kohl and Giancarlo Noci had just demonstrated innovative measurements of transverse coronal outflows by the so-called "Doppler-dimming" method. This provided additional motivation for a spectroscopic solar physics mission; it was to include techniques that clearly went beyond those of the by then classical *OSO* and *Skylab* missions.[6] The prospect of studies with high spectral resolution and the potential inclusion of a UVCS instrument in the *SOHO* payload were—at least for some of us—an additional motivation to promote *SOHO.* Later on, the change from *SOHO*'s original low-Earth orbit to an orbit around L1 enabled both helioseismology and solar wind studies, and thus offered the opportunity for a mission design that comprised a study of the Sun from its core to the extended corona. In fact, the addition of the SWAN (Solar Wind Anisotropies) instrument during the payload selection extended the horizon of *SOHO* far into the heliosphere.

It was a happy turn in the fate of *SOHO* that shortly after the proposal had been made, the new ESA Director of Scientific Programmes, Roger Bon-

[6] The series of *Orbiting Solar Observatories* (*OSO*s) and the Apollo Telescope Mount (ATM) on *Skylab* provided early platforms for solar observations from space with pointing accuracy and stability improving from a few arcminutes to about one arcsecond between the 1960s and the early 1970s.

Figure 1. The *"Horizon 2000"* Survey Committee, members of the ESA Executive, and invited experts at the final meeting of May 1984 in Venice. From left to right: Andrew C. Fabian, Ian W. Roxburgh, Edward P. J. van den Heuvel, Franco Pacini, Henk Olthof, Alan H. Gabriel, Johannes Geiss, George P. Haskell, Edgar Page, Bengt Hultqvist, Martin C. E. Huber, Gerhard Haerendel, Michel P. Lefebvre, Roger M. Bonnet, Dieter Stöffler, James Lequeux, Kerstin Fredga, Hugo Fechtig, Johan A. M. Bleeker, Giancarlo Setti, Léon van Hove, Gillian Auclert, Vittorio Manno, Gordon P. Whitcomb, and Herb Schnopper. (Photo: Mrs. Schnopper)

net, initiated the elaboration of a long-term plan—what later became known as *Horizon 2000.*[7] In addition, the Inter-Agency Consultative Group (IACG), a discussion forum comprising the heads of the American, European, Japanese, and Russian space science programs, turned their attention to the area of solar-terrestrial physics, where plans for missions had become so numerous that some rationalization on an international level was definitely called for. A group of US, European, and Japanese scientists meeting in mid-1983 at NASA under the Chairmanship of Stan Shawhan recommended—on the instigation of Gerhard Haerendel, one of the main proponents of *Cluster*—that *SOHO* and the four-spacecraft space plasma physics mission *Cluster* should be included in an International Solar-Terrestrial Physics (ISTP) program that was to be undertaken jointly by ESA, NASA, and ISAS. In May 1984, the Survey Committee, i.e., the committee that supervised the elaboration of *Horizon 2000,* identified *SOHO* together with *Cluster* as the Solar-Terrestrial Physics (STP) "Cornerstone" of

[7] Some might be inclined to think that the happy turn resulted from Roget Bonnet's earlier career as a solar physicist. Quite the contrary! A Director must maintain neutrality among disciplines, and rather err in the opposite direction, lest he be suspected of giving unfair advantage to his own field.

the ESA long-term program "Space Science: Horizon 2000" (see Figure 1). Now also the space plasma physics community was among those interested in *SOHO.*

Although the ESA Executive had initially tried to suppress the inclusion of STP into *Horizon 2000* by ignoring the existence of the proposal, it was soon realized that it would balance the long-term plan. The two main areas of the ESA Science Programme, Solar System Sciences and Astronomy, would now have equal weight; rather than two Cornerstones for Astronomy and only one for Solar System Sciences, there were now two Cornerstones for each. Instead of the single "big" planetary mission that had originally been foreseen, and for which a consensus on the planet to be investigated could not be obtained anyway, a visit of a comet—now *Rosetta*—was chosen. The two Astronomy Cornerstones—an X-ray and an infrared mission, now *XMM-Newton* and *Herschel*—were accepted without much discussion.

The potential observations with UVCS had provided a major motivation during the early *SOHO* studies. When the payload selection committee initially preferred the Large Angle and Spectrometric (visible-light) Coronagraph (LASCO) to UVCS, the promise of progress through a new observing technique was going to be lost. Fortunately, both coronagraphs were eventually included in the payload.

Obviously both coronagraphs have contributed to the success of *SOHO.* LASCO, with its wide-angle view of the Sun and the surrounding heliosphere (actually out to 32 solar radii, i.e., about one seventh of an astronomical unit), has enabled studies of the outer corona, particularly also through the investigation of coronal mass ejections (CMEs). What's more, LASCO on *SOHO* has become the most prolific discoverer of comets in astronomical history.

Observations by UVCS, on the other hand, have led to fundamentally new views of the acceleration regions of the solar wind and of CMEs. UVCS revealed surprisingly large apparent temperatures, outflow speeds, and velocity-distribution anisotropies in coronal holes, especially for minor ions, so that constraints could be set on the choice of actual physical processes involved in solar wind acceleration. Consequently several candidate physical processes could be excluded, and investigations of ion cyclotron resonance and related processes were stimulated.

SOHO, with its comprehensive observational capabilities, has definitely left its imprint on solar and heliospheric physics. The "Solar Satellite Project" at HCO may with some justification be seen as a major source for *SOHO* scientists. And it is fair to say that because *SOHO* has been available over roughly half a "scientific life span," i.e., during half of the approximately three decades of the scientifically productive life of a scientist, it also has helped to create further generations of solar physicists.

That we now seem to be in an unusual solar minimum is, of course, not the merit of *SOHO,* but it will help to maintain interest in the subject of solar and solar-terrestrial physics and *SOHO*'s successor spacecraft will continue to make significant contributions to these subjects and to climate studies as well.