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Early solar space research

The Sun, the most luminous celestial object as viewed from Earth, was the first target for space experiments when such possibilities opened up. It is convenient to distinguish between the quasi-permanent and slowly changing solar features, for which incidental rocket observations suffice, and the rapidly changing, transient phenomena, which need satellite monitoring. In the first category are objects such as the photosphere, including the fairly slowly changing features, like centres of activity, the basic features of the chromosphere and of the coronal regions. Solar flares and coronal mass ejections come into the second category.

It is therefore only natural that in the rocket era the emphasis was on the (quasi-)stationary parts of the Sun, while, once satellites were orbiting the Earth, the rapidly varying aspects could be studied. These two different aspects – stationary versus transient – govern the organization of this chapter. That distinction does not lead to a strict chronological description, though we attempt to stick more or less to chronology. Rocket observations persisted until long into the satellite era, while there were occasional flare observations being made in the rocket era; for example, when a rocket was fired accidentally or deliberately during the occurrence of a solar flare.

Like any history, ours has a prelude. During World War II the first ideas for observing the Sun by means of rockets were developed in Germany. These ideas, though at one time very close to their realization, never materialized. The story, though, constitutes an essential part of the history of space research.

This chapter deals with the period between about 1940 and 1970–75, which was dominated by rocket observations and by the first – mostly fairly simple – satellites. We conclude with a description of the major results of Skylab, but it should be realized that the scientific influence of this space laboratory persisted for a long time after it had been put out of service.

THE WARTIME ERA: KIEPENHEUER AND THE V-2

During World War II German military authorities, under Wernher von Braun, developed the A-IV rocket (later called V2, from *Vergeltung-zwei*, 'Revenge 2'), in order to be able to bombard targets many hundreds of kilometres away. The V2 was able to climb to altitudes of over 100 km. This ability attracted the attention of scientists who realized that – in principle – the V2 could make it possible to study both the structure of the upper atmosphere and solar radiation from wavelengths that are inaccessible from ground-based sites. This fascinating episode is described by Hufbauer (1991, pp. 120–124) and Wolfschmidt (1993).

Wolfschmidt starts her review by quoting Heraclitus: 'War is the father of all things.' This evidently exaggerated statement does indeed apply to many scientific developments that began in that period and would come to dominate the second part of the twentieth century. During that period the technique of radio astronomy was developed, and the foundations of space research were laid. In the USA, Walter Orr Roberts founded, under war pressure, the High Altitude Observatory for solar monitoring, and on the European continent Karl Kiepenheuer founded six solar observatories. The impetus behind these developments was the knowledge that the Sun influences long-distance radio

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communications, and the expectation that understanding the origins of solar variability would lead to greater control over long-distance radio communications. The military importance of the latter is obvious. With some scientific opportunism, solar scientists on either side of the front line thus hoped that military funding would enable them to continue and intensify their research.

The fact that the Sun influences the ionosphere and thus the efficiency of radio propagation was known by the early twentieth century, but the origin of the disturbances was unknown, despite well-organized worldwide solar monitoring since the IAU General Assemblies of 1924 and 1928. At that time a large co-operative project started, to which the names of George Ellery Hale, Sydney Chapman, Charles St John, Giorgio Abetti and others are associated. It had been known for some years that radio disturbances were associated with the occurrence of sunspot groups, and Howard Dellinger (1935) found, on the basis of synoptic solar data (obtained by Henri d'Azambuja) that the just-discovered solar flares were responsible for at least part of the radio disturbances.

As a post-World War I punishment by the victorious allied nations, Germany was excluded from international scientific co-operation during the period between the wars, a humiliation to which decent scientists should never have lent support. German scientific institutions were therefore not included in the campaigns for global solar monitoring. Before the war, Germany had few solar observatories and no modern monitoring equipment. Apparently, in order to cope with that, Grotrian started systematic sunspot observations in Rechlin, some 100 km north of Berlin, at the end of the 1930s. To improve the quality and continuity of solar monitoring, Hans Plendl and Kiepenheuer, the latter then in Göttingen, proposed at the end of 1939 to establish a solar observatory at the Wendelstein mountain.

At about the same time (1940) Kiepenheuer, guided by Grotrian and Otto Heckmann, constructed a spectroheliograph in Göttingen. In co-operation with Plendl he established during wartime a network of solar monitoring stations in Germany and Italy, thus providing those involved in radio communication with reliable solar data. By including observatories in occupied countries in the network (for example, Meudon, Pic du Midi, Ondřejov) he provided these institutes with some protection against military interference with their other scientific work.

Earlier (1936–39), Kiepenheuer had realized the importance of the solar UV flux in controlling the ionization of the ionosphere. In order to obtain information about solar UV radiation, and particularly its variations with time, he made observations at the Jungfraujoch observatory (altitude 3600 m) and (from 1939) with stratospheric balloons (Kiepenheuer 1938). The instrument was a double monochromator based on quartz optics. The Jungfraujoch observations showed him that even at that altitude the solar UV could not be detected, and even using stratospheric balloons did not significantly improve detection. The reason was rapidly found in absorption by terrestrial ozone at heights above a few tens of kilometres.

An immediate challenge resulting from these investigations was therefore to try going higher, above the ozone layer, which means above about 50 km. When the military authorities started developing the A-IV (V2) rocket, the project leader, von Braun, was eager to collect information on the medium through which the rockets were supposed to fly: the upper atmosphere. He succeeded in interesting Erich Regener, who had strong anti-Nazi sentiments, but who was attracted by the prospects of doing pioneering research with the new vehicle. Overcoming his political sentiments, Regener started developing a scientific payload for measuring atmospheric densities and temperatures with the A-IV. Somewhat later, Regener realized the importance of flying a spectrograph in order to study the absorption of solar radiation by the residual atmosphere above the rocket. To that end he asked for the assistance of Paetzold, a specialist in optics, and Paetzold recruited Kiepenheuer into the project. From a letter dated 8 July 1942 we quote:

> The A-IV offers the possibility of using the newly developed methods to carry out measurements in the upper atmosphere. [There follows a description of proposed instrumentation] … above all, an ultraviolet spectrograph. This must be above the absorbing ozone layer, which is to say at an altitude of 50 km or more, if it is to record the solar spectrum. (Author's translation)

At Peenemünde, Paetzold developed a prototype of the spectrograph. A second, more sophisticated flight instrument, conceived by Kiepenheuer and constructed by Paetzold, was a spectrograph based on LiF optics (in order to be able to observe wavelengths less than 2000 Å). In spite of the increasingly difficult war situation, von Braun planned a prototype flight in the winter of 1944–45, to be followed by a scientific flight in the spring. The instrument and nose cone arrived in Peenemünde in January 1945, where they were subsequently integrated and underwent their pre-launch tests. No launch ever took place. Ultimately, the increasing severity of the war prohibited the use of V2 rockets for scientific experiments.

FIRST SOLAR NEAR-UV RADIATION DETECTED BY ROCKETS

After the war the USA took the lead in space research with rockets. The first years after the war set the direction for the subsequent development of solar space research, and showed all the elements that would prove to be so characteristic of the initial phases of various subdisciplines of space research. A slightly humorous aspect was that the scene in the USA was complicated by competition between army, navy and air force.

After the military collapse of Germany in the spring of 1945, a US army intelligence unit under Colonel Holger N. Toftoy rapidly rounded up von Braun's team and captured, almost from under the nose of the approaching Soviet army, sufficient material for assembling around a hundred V2 rockets. Toftoy, realizing the importance of establishing good relations between the military and scientific communities, charged Major James G. Bain with the task of finding scientists who might be interested in assembling payloads for rocket-borne scientific experiments that could be launched from the newly established range at White Sands.

Initially there was great enthusiasm, particularly among the leading scientists, about the new potential for doing research in a spectral region that had so far been inaccessible. Later, though, when confronted with the large technical obstacles and the new and unconventional techniques, along with the timescale for realizing the goals set, scientists showed a tendency to step back and resume their previous modes of research. In the meantime, physicists and engineers who were familiar with the new techniques entered the field from other areas of science or engineering. They seized the initiative and became the main people responsible for the experiments. In later phases, when the scientific results became available and were reaching the level of specifications set by the astronomers, the latter returned. Then, however, they often found that the physicists had in the meantime acquired sufficient knowledge of the field and hardly needed assistance from traditional astronomers. This development could be witnessed in several disciplines, particularly in space research. In addition to solar space physics this same dynamic of community development could also be observed in the disciplines of X-ray and gamma-ray astronomy, where cosmic ray physicists came to dominate this typically astrophysical field. To a lesser degree this development also took place in radio astronomy.

Ultimately, this process appeared to be enriching astronomy, because of the entry of eminent physicists into the field. There were Bernard Lovell, Martin Ryle, Wilbur Christiansen and others in radio astronomy, and a multitude of scientists in space research: Bruno Rossi, Richard Tousey, Herbert Friedman, Sergei Mandel'shtam, Saito Hayakawa, Guiseppe (Beppo) Occhialini, and many others.

We illustrate the situation with an example. In September 1945, confronted for the first time with the possibility of observing the Sun from space, Leo Goldberg wrote to Donald Menzel (Hufbauer 1991, p. 136):

> If anyone asked you what technological development could, at one stroke, make obsolete all our textbooks written in astronomy, I am sure your answer and mine would be the same, namely the spectroscopy of the Sun outside the Earth's atmosphere … I would like nothing more than to be involved in such a project, even if it meant shaving my head and working in a cell for the next ten or fifteen years.

But already in 1948 Goldberg was having doubts when he wrote to Lyman Spitzer (Hufbauer 1991, p. 139):

> I have been somewhat disappointed in the development of the rocket project since its inception. It had been my hope and I think also yours, that the rockets would open a new field of solar research … At least thus far … they have hardly opened a new field of investigation … at the moment I would not want to ask for a renewal of the contract solely on the basis of the V2 investigations.

Goldberg's disappointment has been echoed many times in the initial period of development of space research, particularly by theoretically inclined scientists who are essentially interested in the scientific results, and have difficulty in grasping the time and effort needed for solving the technical problems encountered when a new field of research is facing unconventional and often new technological challenges.

In the hectic period immediately after the war, things in the USA went ahead remarkably well, under able leadership. An informal V2 panel set up under Ernest H. Krause identified in a relatively short time institutions and scientists willing and able to develop scientific experiments for the new vehicle. It is remarkable that at that time most of the solar scientists were from two institutions only. One was the Naval Research Laboratory (NRL), directed by Edward O. Hulburt, who had for a long time been deeply interested in the relationship between solar energetic radiation and the ionosphere; the other was the Applied Physics Laboratory of Johns Hopkins University, directed by Merle Tuve.

Richard Tousey's group at the NRL had the first success: on 10 October 1946 a rocket-borne camera took the first photograph of the solar UV spectrum down to 2200 Å. The spectrum was obtained from a height of 55 km.

In 1947 the chairmanship of the V2 panel passed to James Van Allen, while Homer A. Newell became head of the section for rocket research of the NRL. These appointments greatly strengthened the programme.

When, in 1948, the stock of V2s became exhausted, US-made rockets were introduced, first the Aerobees and Vikings. The first Aerobees did not reach sufficient altitude to be scientifically useful, but after increasing the length of the rockets they attained heights of 150 km or more, thus surpassing the greater altitudes reached by the V2s.

None of the people involved in the first rounds of solar experiments had much prior knowledge of solar physics. Richard Tousey's background was in UV spectroscopy, and this made him well suited for the new tasks. But new problems arose. In the first few years, when Sun-pointing devices had still to be developed, methods had to be generated for directing sunlight into the spinning, yawing spectrograph. One remedy was to use large-field spectrographs, but that was not a sufficient solution. Various methods (Tousey 1953) were tried of placing reflecting objects in front of the spectrograph slit. In one of the most successful versions, introduced by the NRL group, two polished spheres of LiF, 2 mm in diameter, were positioned some distance in front of the entrance aperture of the spectrograph. Thus a point-like solar image was produced, at the position usually occupied by the spectrograph slit. A slit was then no longer needed. The introduction of *two* spheres was needed to compensate partly for the rocket's spinning. The drawback was that the 'slit' was smeared out, causing degradation of resolution. Another method, used by the Johns Hopkins group, was based on a diffuse reflector consisting of rough aluminized glass. In that case a slit was necessary. Other variants are described by Tousey (1953) and are shown in Figure 1. In all cases the spectrographs had luminous efficiencies below 1%.

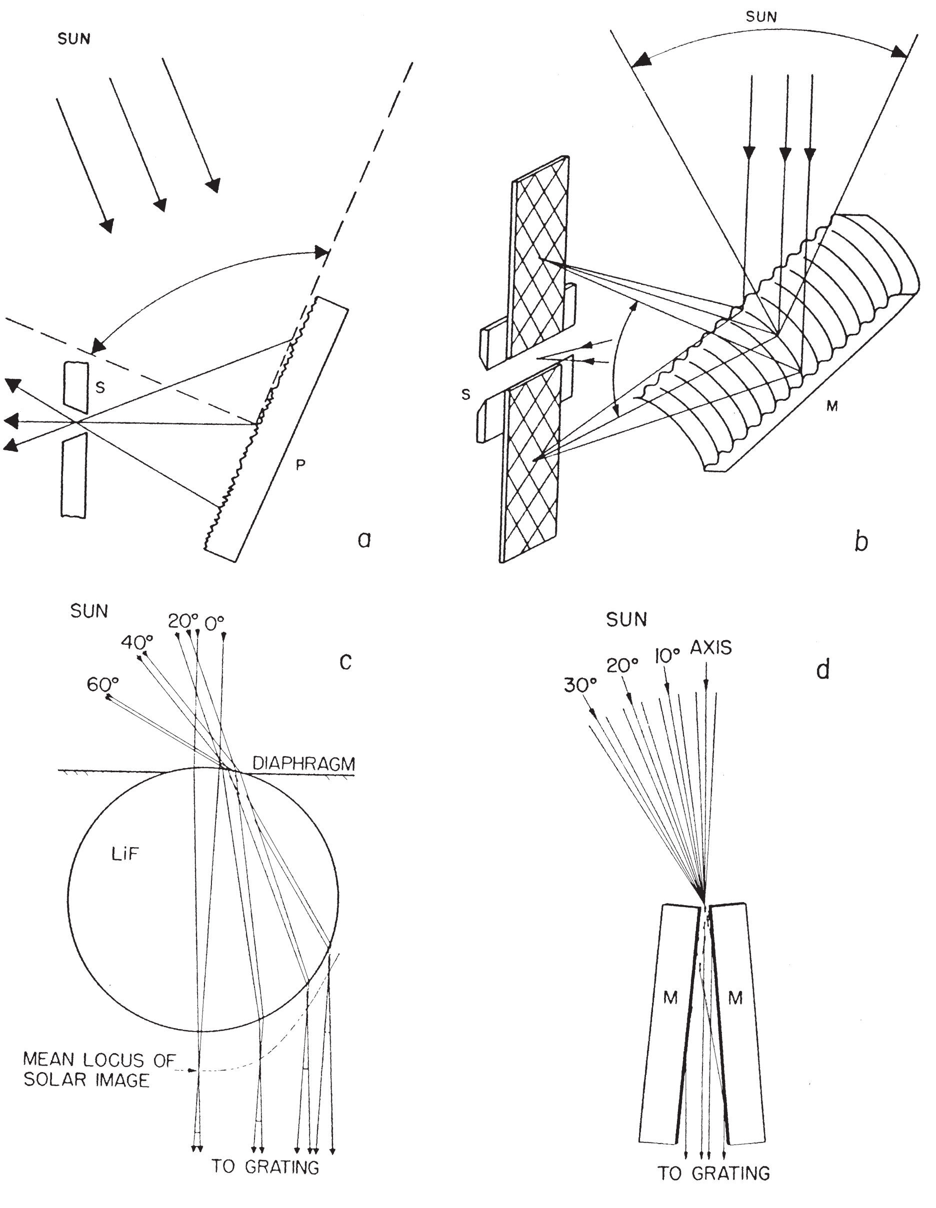

Figure 1 Wide-field-of-view entrance aperture systems for rocket spectrographs: (a) diffuse reflector and slit; (b) corrugated cylindrical mirror and slit; (c) lithium fluoride sphere (diameter 2 mm); (d) mirror-jawed slit. (From Tousey 1953. Reproduced with the permission of the University of Chicago Press.)