THE SOLAR OPTICAL TELESCOPE (SOT)*

STUART D. JORDAN

SOT Project Scientist, Laboratory for Astronomy and Solar Physics, Goddard Space Flight Center, Greenbelt, MD, U.S.A.

(Received 5 January, 1981)

Abstract. The Solar Optical Telescope (SOT), which NASA plans to operate on Spacelab, should provide resolution down to 0.1 arc sec, thus offering the capability for solving a number of fundamental problems in solar magnetism and in atmospheric heating and dynamics.

1. The SOT Program

The Solar Optical Telescope (SOT) is a 1-meter class, high-resolution solar telescope which NASA currently plans to operate on the Shuttle Spacelab during the mid and late 1980's. Beyond the 1980s, the SOT may be rated for continuous operation on a suitable space platform, but this mode of operation is not currently part of an official plan and the latter option is thus still under study. Because proposals to build the basic telescope are still under review by NASA, it is not possible at this time to reveal the details of the final designs. However, some idea of the type of telescope the solar physics community can expect can be had from the description which appears in the article by R. B. Dunn in this issue. Dunn's description is based on the preliminary design prepared under his leadership by the One Meter Class Telescope Facility Definition Team. Further information on SOT is provided in the Executive Summary (1978) and in the Solar Optical Telescope Summary (1980). An artist's conception of what the SOT might look like in operation on the first flight, which is called SOT-1, is given in Figure 1.

The schedule for the SOT program through the first flight is of course approximate at this stage. Milestones already passed include approval within the general framework of the NASA Spacelab program in October 1979, the release of an Announcement of Opportunity (AO) for scientific participation in February 1980 and the receipt of proposals for scientific participation in August 1980, issuance of a Request for Proposals to build the telescope in January 1981, and receipt of proposals from industry during April 1981. Further activities planned for 1981 are the selection of scientific experiments and other scientific participation for SOT-1, and the evaluation of the proposals to build the SOT.

Launch and operation of SOT-1 on Spacelab is scheduled for the late-1980's. Optimum launch times are near the summer and winter solstices, since at these times a morning launch in winter (or an evening launch in summer) from the Kennedy Space Center (KSC) provides the largest possible orbital angle for

maximizing solar observing time. In effect, the orbital plane is tilted to the ecliptic by an angle which is the sum of the launch inclination (up to 57° from KSC) and the Earth’s declination (∼23°) under these conditions. By allowing for a 4.5° per day precession of the Shuttle’s orbit, a launch 5 days prior to the appropriate solstice provides, for a 10-day mission, the maximum possible solar viewing time, with several days of continuous solar visibility. Whether all of this time can be used for solar viewing is a mission-operations thermal problem that will be addressed during the mission planning for SOT-1. It should be noted that there is a launch window of about two months centered on the December and June solstices, within which total solar viewing time does not change greatly. Thus, there are excellent potential flight opportunities for SOT on Spacelab for four months out of every twelve.
2. Science on the SOT

The key to the success of the SOT will be its ability to observe phenomena in the solar atmosphere on the spatial scale where at least some of the fundamental physical processes are occurring. The diffraction limited performance of about 0.1 arc sec in the visible is less than the atmospheric density scale-height, which in turn is generally comparable to the mean-free-path of photons escaping from that region. This means that many problems of solar atmospheric structure and dynamics that have been discovered, but not solved, by ground-based observations and earlier space missions will become amenable to solution with the data the SOT should acquire. The SOT will obtain data which should, for the first time, permit an experimentally verifiable solution to a number of important problems in the radiative transfer, hydrodynamics, and in some case magnetohydrodynamics of the solar atmosphere.

It is easy to demonstrate the need for high resolution with a few illustrations. Figure 2 is a white light filtergram taken at the 65 cm Photoheliograph at Big Bear Observatory. The field-of-view covered is about $15 \times 25$ arc sec. Sub arc sec structure is apparent both in the sun-spot penumbra and in the surrounding photosphere, where the granulation shows up particularly well. Ground-based photographs of this quality are rare; sequences of such photographs are practically non-existent. Yet, to study the dynamics of solar granulation and the convective rolls encountered in the penumbrae of sunspots requires sequences of photographs each of which is of quality superior to this one. Only the SOT can do this. Figure 3 is a filtergram of the Sun in $\text{L}\alpha$ ($T = 2 \times 10^4$ K) taken from a sounding rocket. Note the gossamer thin, arc-second scale threads on the limb. Structure was observed on this flight down to the resolution limit, perhaps as low as one-half arc sec. There is every reason to believe these effects will persist down to 0.1 arc sec. There is also evidence for sub arc sec structure in the transition region. This can be seen in the $\text{C IV}$ resonance lines ($10^5$ K) observed from three different sounding rocket flights of the Naval Research Laboratory's HRTS ultraviolet spectrograph. (See the paper by G. Brueckner in this issue.) We therefore conclude that there is sub arc sec structure that cannot yet be adequately studied in the three major atmospheric subregions (and temperature regimes) for which the SOT is uniquely well suited. More to the point, the key to the underlying physics often lies in obtaining sequences of such images and spectra, to follow the temporal developments.

What are a few of the fundamental physical problems of solar physics, and indeed stellar astrophysics, for which SOT should be able to provide much of the definitive data? Consider the following four:

(1) What is the source of the Sun’s magnetic field? If one assumes that a dynamo is expected to be effective in generating this field, what is the nature of this dynamo? To provide data to further constrain theories for solar dynamos, small-scale magnetic field structures must be observed down to sub arc sec scales to obtain the complete ‘spectrum’ of solar magnetic features. The associated velocity fields must
also be observed (Gilman, 1981). The evolution of these features with time must be studied. In the process, current theories for the stability of solar flux tubes can be checked (Spruit, 1979). These theories postulate that the apparent downflow in the middle of small flux tubes produces an inward collapse of the structure until the increasing magnetic flux density has increased enough to produce an equilibrium configuration. The SOT can check this; it can also check theoretical sunspot models by measuring the predicted, sharp gradients in $B$ and $v$ across large flux tube boundaries and check how the small-scale solar magnetic field breaks down and diffuses, a problem again related to dynamo theory.

(2) How much power in waves is generated in the photosphere? This relates directly to the next question on chromospheric heating. In effect, one is asking
what is the spectrum of the velocity field in the photosphere, particularly the high
spatial and temporal frequency components in the low photosphere. The latter are
particularly important, since they determine the power generated in ‘high frequency’
sound waves (periods ≤ 100 s) and also in fast mode hydromagnetic waves, if the
local, possibly turbulent, magnetic field strength is high enough (see Kulsrud, 1957;
Osterbrock, 1961; Stein, 1967). Current granulation observations are inadequate
to establish the character of the high frequency components better than what is
required to calculate the acoustic power generated to within an order of magnitude
(Deubner and Mattig, 1975; Cram, 1977).

(3) What heats the solar chromosphere? This question has been the subject of
extensive research for over three decades, and it has not been answered satisfactorily
yet. While the theoretical work of Ulmschneider et al. (1978) strongly suggests that
substantial radiative dissipation of high-frequency sound waves in the photosphere
is occurring and must be included in modeling photospheres for most late-type
stars, their conclusion that there is enough residual energy in these waves to heat
the chromosphere must be regarded as tentative until we have answered fully two
still only partially answered questions: The first is question (2) above. The second
question is how much wave energy is available in the chromosphere itself. The
work of Athay and White (1978), based on data obtained from the OSO-8 mission,
while open to some interpretation due to the inherent limitations of the data
available, nevertheless strongly suggests that energy in sound waves is inadequate
for heating as high as the upper chromosphere where Lα is formed. The SOT
should be used to settle once and for all the issue of the chromospheric high-
frequency wave spectrum for all MHD modes.

(4) What is the local, and in some cases, the global mass and energy balance in
the solar transition region? The current general idea on the global balance, based
largely on Skylab ATM data (Krieger, 1977) is that energy conducted down from
the low corona must ‘boil off’ mass from the chromosphere which, raised to coronal
temperatures and heights, then radiates away the ‘excess’ energy that exists in the
corona due to the heating (which raises coronal plasma to locally higher tem-
peratures at which its cooling efficiency goes down). Is this general picture correct
on all scales? Are there strong temperature and pressure gradients in coronal active
region loops (Foukal, 1975) which might promote circulation of material in conjunc-
tion, perhaps, with surface heating (Irons, 1978), or are these loops largely devoid
of material at transition-region temperatures (Krieger, 1977) with heating sources
imbedded throughout (Rosner et al., 1978)? The SOT will provide the capability
of probing for these transition-region phenomena, and may, in a coronagraph mode
with an ultraviolet spectrograph (i.e., by suitable masking within the spectrograph),
even obtain data in strong coronal lines like Fe xii 2405.68 Å, which has an intensity
contrast against the background continuum much greater than the well-known
green line Fe xiv 5303 Å of conventional visible light coronagraphy.

It should be apparent that a solution of these fundamental problems of solar
magnetism and solar atmospheric heating and dynamics will have great value to
stellar astrophysics, where similar questions abound. It also should be noted here what the SOT will probably not do. The SOT cannot observe on the very small scale where many current theoreticians think important plasma processes are occurring (see, for example, Ionson, 1978; Rosner et al., 1978; Spicer and Brown, 1981; Wentzel, 1981). To the extent that we must observe on the scale below that for collective behavior of the fluid (~10 km for viscous effects in the corona) or even of the ion gyro-frequency (~100 cm in the corona), SOT will leave some important solar atmospheric problems unsolved. Some future, very advanced probe of the atmospheric regions of interest may ultimately be required. However, when one considers that many solar phenomena of interest for the past three decades have resisted complete solution for lack of the high-resolution data the SOT should provide, there is little doubt that the SOT will represent a giant step forward toward the goal of completely understanding these phenomena.

3. The SOT Scientific Working Group (SWG)

The scientific community will make its wishes on the SOT program known through the SOT Science Working Group (SWG). The official, 'elected' membership of this group will consist of all Principal Investigators (PI's) of the instruments selected to fly on the SOT in response to the AO already described, and all SOT Facility Scientists chosen in the same manner. Thus the 'voting' membership will consist of scientists selected by the usual peer review process, and will draw upon the successful proposers from an international scientific competition. The SWG will be chaired by the SOT Project Scientist at the Goddard Space Flight Center; and NASA Headquarters will be represented by the SOT Program Scientist, who is currently Eric Chipman. The Facility Scientists will be chosen both for the scientific research they have proposed and for their perceived ability to offer mature, broadly based scientific judgment in helping to guide the SOT scientific program, particularly in its early stages of development.

It is anticipated that, in the course of time, other scientists, NASA personnel, and others involved in the SOT program will participate in the activities of the SWG. The PI's of some other solar instruments, in particular those selected for Spacelab and capable of flying on the SOT truss as co-observing instruments, will undoubtedly be asked to participate in some of the SWG meetings and will probably become members at such time as NASA determines they should fly on a particular SOT mission (not currently planned for SOT-1). The SOT Project Manager at Goddard and the Program Manager from NASA Headquarters will undoubtedly participate in at least some of the sessions, as may a representative from the telescope contractor in attendance with the Project Manager during construction of the SOT. It is likely that the SWG will meet at least twice yearly for several days per meeting, often at Goddard and elsewhere as appropriate. Meetings will probably consist of both executive sessions for SWG members only, during which
the scientific agenda will be considered, and open sessions for all participants, in which implementation of the scientific program can be considered.

The major areas in which the SWG will undoubtedly make contributions are: (1) the development and continuous updating of an overall scientific plan for the SOT, and for SOT-1 in particular; (2) offering recommendations to the SOT Project and the scientific instrument PI's concerning optimizing the instrumentation to achieve the scientific goals of the program; (3) helping NASA to prepare the scientific mission-operations plan for SOT-1, etc., including the development of joint observing programs for the several scientific instruments as appropriate; (4) helping NASA to prepare an overall plan for managing the scientific data. The SWG will probably also help NASA to develop operational plans for including additional co-observing instruments that may be added in the future to the SOT. Ultimately, a Guest Investigator Program is planned, and the SWG will respond to the needs of these additional users when they are selected, mainly by ensuring the smooth incorporation of their scientific programs into the overall scientific mission-operations plan.

References


© Kluwer Academic Publishers • Provided by the NASA Astrophysics Data System