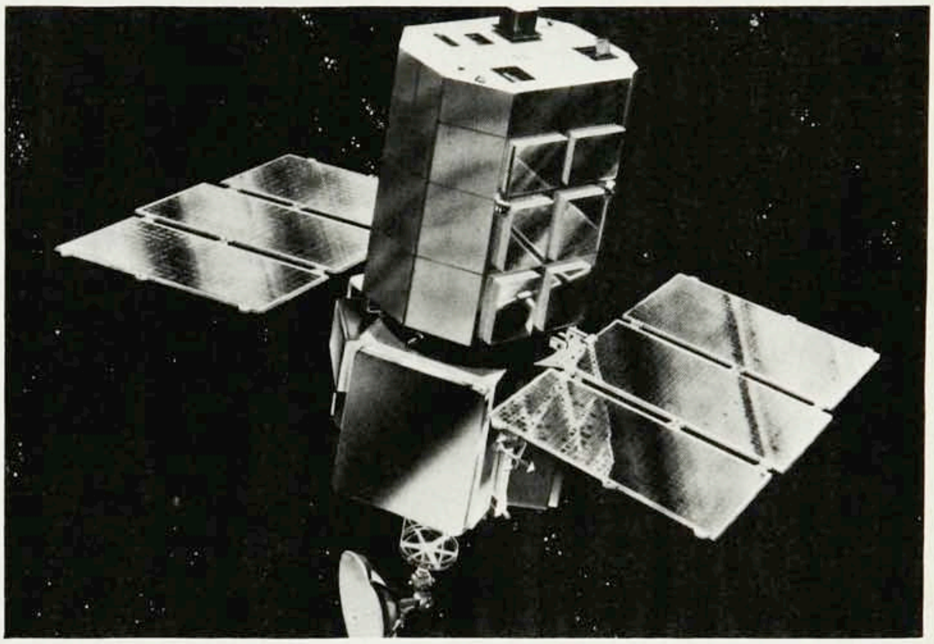
guest comment

Gearing up to answer question posed by the Sun



The pursuit of old problems in the active Sun and the new discoveries while pursuing the old have demonstrated the vast dimensions of solar physics. There has been little in the active behavior of the Sun that was anticipated—or could have been anticipated—from the physics known to the terrestrial laboratory. Neither the sunspot, nor the chromosphere, nor the corona, nor the solar wind, nor the spicules, nor non-LTE—to mention only a few—were anticipated until observations of the Sun thrust them upon us. And we still do not understand much of how they work. The Sun is an obstinate reminder that while we may possess all the basic partial differential equations of classical and quantum physics, the rich variety of solutions of those equations extends far beyond present knowledge and imagination. The Sun, then, is our Virgil, acting as guide through level after level of cooperative phenomena as we look more closely into the inferno. The problem is to guess from the observations what the underlying physical effects may be and then to establish the ideas firmly with the appropriate theoretical studies and further observation.

Why, for instance, does the magnetic field extending out through the surface of the Sun gather itself into isolated and enormously compressed bundles to form a magnetic knot (1500 gauss) or a sunspot (3000 gauss)? Such spontaneous clumping of field is in direct opposition to the enormous pressure $B^2/8\pi$ of the compressed field. It is a classical, large-scale, and nearly static, equilibrium effect, and yet it is without a hard scientific explanation at the present time. Why for that matter does the Sun possess a magnetic field at all? In particular, why does the magnetic field sometimes burst forth with a brilliant flare of plasma with local temperatures soaring to 10^7–10^8 K and with at least one percent of the energy going into fast particles extending into the relativistic range?

It is in pursuit of this sporadic flaring that the NASA Solar Maximum Mission (SMM) is to be launched into space in February. This mission will take advantage of the maximum in solar activity expected to occur in early 1980. The flare, like most other facets of solar activity, is a fast-paced collective effect with its vital functions on scales too small to be seen in detail from our distant location on Earth. Hence the strategy of the interested physicist must be to use the best instruments with the highest spatial, temporal and structural resolution he can devise, to provide simultaneous coverage of several regions of the electromagnetic and fast-particle spectra.

Gamma rays and hard x rays provide information on accelerated nucleons and electrons while the radio emission reveals the presence of relativistic electrons in magnetic fields. The soft x rays show the extremely hot, dense plasma (10^7–10^8 K, 10^{10} particles/cm^3), and the H-alpha shows the cool (10^4–10^5 K) portion of the flare. Observations in the visible portion of the spectrum above the limb of the sun show the ejection of gas out through the corona into interplanetary space. Thus, the SMM is designed to provide broad coverage of the electromagnetic spectrum of the flare backed up by simultaneous ground-based observations at visible and radio frequencies and by studies (with instruments carried in other spacecraft) of the composition and energy distribution of the fast particles and plasma emitted from the flare into interplanetary space.

The SMM is instrumented to look at the gamma rays (0.0–150 MeV) and the neutrons emitted from the hard collisions of the fast protons with other nuclei in the background plasma in the flare. (This instrumentation was developed at the University of New Hampshire, Max Planck Institute at Garching and the Naval Research Laboratory.) The SMM also carries a spectrometer (developed at Goddard Space Flight Center) to look with high time resolution at the hard x rays (20–300 keV) and an imaging x-ray spectrometer (3.5–20 keV) to give pictures of the x-ray emitting regions. (The imaging spectrometer is the result of efforts at the Space Research Laboratory at Utrecht and the University of Birmingham, UK.) Lockheed-Palo Alto, University College London and Appleton Laboratory have provided two soft-x-ray (0.15–2.3-nm) spectrometers that yield both pictures and high-resolution spectra of the hot flare and ambient plasma. An ultraviolet spectrometer/polarimeter (110–300 nm) (developed at Marshall, Goddard and Lockheed-Palo Alto) will provide sharp pictures, well-resolved spectra, and measurements of velocities and strong magnetic fields in flares. A visible light coronagraph/polarimeter from the High Altitude Observatory at Boulder will trace coronal effects of flares

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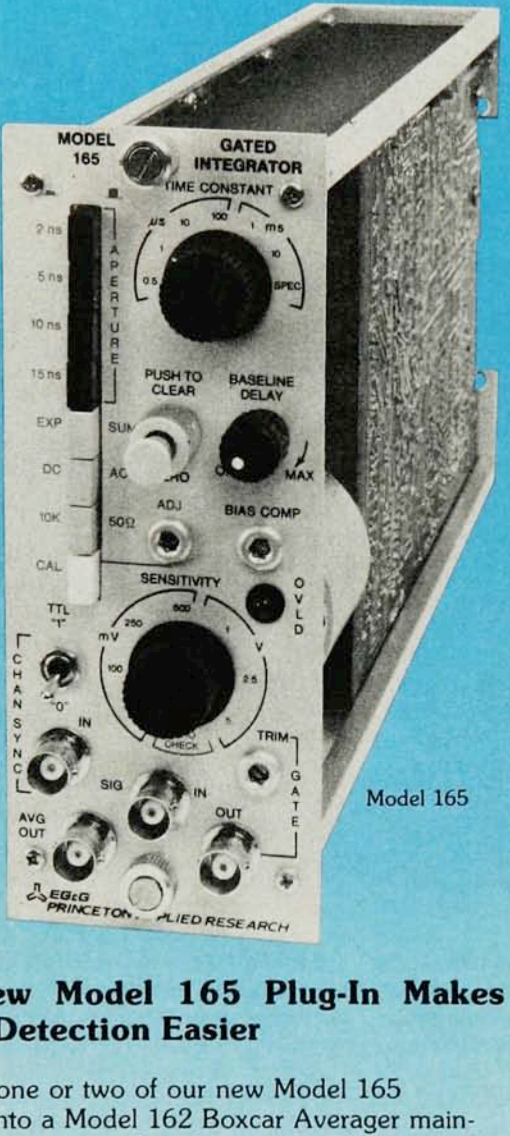

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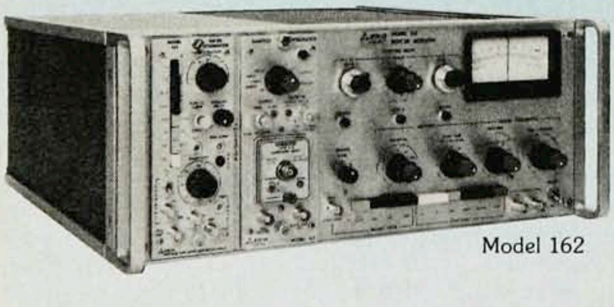

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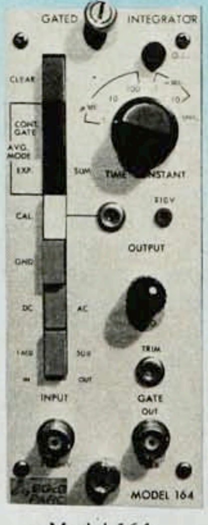

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that sometimes put a major fraction of their energy into plasmoids ejected into interplanetary space. Finally, a total solar irradiance monitor from the Jet Propulsion Laboratory will measure the solar constant to an accuracy of ±0.1%.

This comprehensive data set will provide a firm basis for pushing farther in the development of a physical understanding of the flare and the associated active phenomena. It remains to be seen what existing ideas on the nature of flares can be discarded and how adequate are the quantitive theoretical models constructed from the surviving ideas. The coordination of so many different space and ground-based observations will be a sizable task but one that seems to be tractable within the present spirit of cooperation. The ensuing interpretation of the simultaneous observations to achieve the goals of physical understanding will be a gigantic task indeed.

Development of the necessary theoretical diagnostic tools is a major effort in preparation for the mission, and more work needs to be done on the theory of coronal loops and arches, and on the acceleration of particles, as well as a host of other problems.

The interpretation of the SMM data will require understanding of the atomic and ionic properties of gases at temperatures from 10^4 K (where there has been substantial work in the past) to 10^7–10^8 K (where only recently have the tokamak and the laser made it possible to do quantitive work). Then the collective radiative effects of these atoms and ions must be worked out to provide a basis for interpreting the forthcoming observations, whatever they may choose to reveal.

In recognition of this massive problem in plasma physics, atomic physics, and radiative transfer, the Solar Physics Division of the American Astronomical Society conducted a Workshop on Flare Research and the Solar Maximum Mission, at the University of Michigan in November of last year. The meeting included reviews of the major branches of effort, ranging from summaries of the solar programs in the Federal agencies to specific problems in the physics of solar flares. The latter were discussed in reports from the Skylab Flare Workshop Teams on the pre-flare phase, the primary energy release mechanism, the energetic particles, the mass motions, and the thermal phase. There were also papers on plasmas, devoted to topics such as resistive tearing instabilities, anomalous resistivity, and runaway electron currents and posters featuring a variety of exhibits, from radar probing of noise-storm radio sources in the solar atmosphere, to gamma-ray observations of flares, to observations of post-flares loops.

It was clear from the information presented at the AAS meeting that the SMM data will be vigorously exploited. The theoretical progress in diagnostics is impressive. We may be certain, too, that however thoroughly we exploit past observations to anticipate the theoretical problems in interpreting the SMM data, the active Sun will throw a curve or two. Old problems will be advanced toward ultimate solutions and new twists will be discovered to become the new problems of the future.

It should be pointed out that the present concentrated effort of solar physicists to understand the peculiar behavior of magnetic fields in the Sun and the pernicious activity of those fields is central to astrophysics is a whole. Similar activity on a grander scale is exhibited by other stars and by many galaxies. The Sun is so pedestrian a star that it may be presumed to be less complex than many of the more active exotic objects at a distance, and yet, the activity of the Sun is in fact so complex and so varied and is composed of so many cooperative effects unknown in the terrestrial laboratory that only the most precise, detailed observations can hope to unravel the puzzle presented by the various active features. The active coronal arches, the eruptive prominences, the sprays, the spicules, and the various forms of the flare that occur on all scales from 10^3 to 10^5 km are all part of the activity caused by emerging magnetic fields. They are observationally diverse and yet have common effects within them. We know a lot about them, but their essential features are generally not understood. What then can the physicist say about the colossal and complicated activity that appears in so many distant objects when limited to analyzing the light integrated over space and time?

We are fortunate that the Sun provides a central astrophysical demonstration laboratory for those with an interest in understanding the universal phenomena of magnetic activity. Of course, the solar demonstrations are by no means comprehensive, but they are extensive and provide an education for the interested astrophysicist. New effects are lurking in the basic partial differential equations of physics, waiting to be discovered by the imaginative physicist who allows himself to be puzzled by the observations. The open field of inquiry into the Sun holds excitement and a promise of the considerable progress in the years ahead.

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Based on an invited summary address at the Workshop on Flare Research and the Solar Maximum Mission; co-sponsored by the University of Michigan and the Solar Physics Division of the American Astronomical Society at Ann Arbor, Michigan, on 16 November 1978.

E. N. Parker
University of Chicago
Chicago, Illinois □