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TITLE: MASTER A ROCKET BORNE SOLAR ECLIPSE EXPERIMENT TO MEASURE THE TEMPERATURE STRUCTURE OF THE SOLAR CORONA VIA LYMAN-α LINE PROFILE OBSERVATIONS

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A ROCKET BORNE SOLAR ECLIPSE EXPERIMENT

TO MEASURE

THE TEMPERATURE STRUCTURE OF THE SOLAR CORONONA

VIA

LYMAN-α LINE PROFILE OBSERVATIONS

BY:

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Abstract

A rocket borne experiment to measure the temperature structure of the inner solar corona via the doppler broadening of the resonance hydrogen Lyman-α (λ1216A) radiation scattered by ambient neutral hydrogem atoms was attempted during the 16 Feb 1980 solar eclipse. Two Nike-Black Brant V sounding rockets carrying instrumented payloads were launched into the path of the advancing eclipse umbra from the San Marco satellite launch platform 3 miles off the east coast of Kenya.

Introduction

Within the last several years a wealth of information concerning the physical state of the sun's chromosphere-corona transition region and lower corona have become available primarily as a result of the NASA sponsored skylab program. Although much effort has been expended, it is fair to say that very little concrete evidence is presently in hand concerning the basic heating and cooling mechanisms of either the quiet or active solar corona. In particular the form of the energy flux which maintains the corona and the radial dependence of the divergence of this flux are not understood. The primary cause of our uncertainty is a lack of information concerning the physical state of the coronal plasma beyond about 2×10^4 km above the photosphere. Present EUV and X-ray instrumentation literally run out of gas in this region.

Since the coronal temperature is the major uncertain factor in the modelling of the corona and solar wind, a knowledge of the temperature and its variation throughout the corona and solar wind is most important. The other factors - the coronal density and the magnetic field - are now accessible by ground based observations of the polarization of both the coronal continuum and coronal emission lines.

During the 1970 March 7 solar eclipse it was discovered that the solar corona emits a very intense radiation in the hydrogem Lyman-α line at 1215.7A. See Figure 1. Gabriel (1971) showed that the main mechanism responsible for this emission was the very efficient resonance scattering of the chromospheric Lyman-α radiation by the few neutral hydrogen atoms left in the hostile environment of the 1 - 2 million degree coronal plasma. Of secondary importance was the collisional excitation of the neutral atoms followed by photo de-excitation.

This discovery of Gabriel et al. led one of us (Jacques Beckers) to conceive this experiment which measures the coronal temperature and density distributions throughout the inner corona from a determination of the line profiles and intensities of the Lyman-α emission in this region. J. M. Beckers and E. Chipman (1974) subsequently showed that indeed in the inner corona ($\rho < 2$) the line width is a sensitive indicator of the coronal temperature.

In simplified but still applicable terms, if the corona were stationary the width of the emission line for a given atomic species would be proportional to the Doppler component of the mean thermal velocity of that atom, which in turn is inversely proportional to the square root of the mass. Thus the widths of lines of light hydrogen atoms are much more sensitive as temperature indicators than are those of the usually observed metallic ions. Furthermore, because of the light mass, the thermal velocities of the hydrogen atoms (approximately 300 km/sec) are substantially higher than the ever-present nonthermal motions which therefore have little effect on the Lyman-α line width. In contrast, the typical line used for similar studies, Fe XIV λ 5305 A, is affected by the unknown nonthermal motions which are believed to be comparable to the thermal motions and are virtually indistinguishable in their effect on line widths. In fact, a comparison of the Lyman-α line width with the heavy ion line widths would give the first direct determination of these turbulent motions of both types of lines originated in the same parts of the corona. It has been argued, however, that the coronal tem ures vary significantly from point to point in the corona, making the comparison between the hydrogen and heavy ion line width more complex. The Fe XIV green line originates for example only in regions of the corona within specific temperature boundaries (1.5 to 2.5 million degrees) corresponding to the temperatures at which most iron atoms are thirteen times ionized. The green line profile would therefore reflect the physical conditions in those regions only. The same is true for the Fe X λ 6375 A line. Since the degree of hydrogen ionization is much less sensitive to the coronal temperatures than the degree of ionization of other heavier atoms (Gabriel, 1971), the temperature derived from the Lyman-α line width should represent a very much better, truer average of the temperature than that derived from intensities of other lines. Line intensity methods of deducting plasma temperatures depend also on the accuracy of a host of uncertain complex atomic parameters, their interactions with radiation, and some knowledge of coronal density.

This experiment is the first attempt to obtain a reliable inner corona temperature distribution using the Lyman-α line profile. The experiment can be performed only during a solar exlipse when the scattered light conditions are optimum for probing the inner corona down to the chromosphere, the very region where the greatest temperature gradients exist and no direct measurements have been made.

INSTRUMENT DESCRIPTION

Figure 2 is a schematic of the instrument. It utilizes a 125 mm diameter cassegrain telescope with an effective aperture ration of f/8 to image the sun with about a 10 mm solar diameter. The useful image field ia about 25 mm square. Figure 3 shows the spectrometer slit configuration super-imposed upon the photograph of the corona in white light scattered by free electrons, taken by Dr. Gordon Newkirk during the 1970 March 7 solar eclipse. Since the distributions of free electrons and neutral hydrogen atoms are quite similar, this is a good simulation of the Lyman-α corona. The 22 slits located in the focal plane of the telescope give 22 cross-sections of the corona. Those slits normal to the lunar limb will give very detailed information about the height variation in the corona, and those slits more parallel to the lunar limb will provide more information on the temperature variation across coronal streamers and active regions.

This slit array in turn provides the entrance aperture for the 500 mm focal length modified Ebert-Fastie type spectrograph we have adopted. The Ebert-Fastie optical system was chosen in preference to the asymmetrical Czerny-Turner system both because of simplicity and ease of alignment and because an analysis of aberrations showed that parabolizing the Ebert mirror would permit both high spectraland spatial resolution over the full 25 x 25 mm square field depicted in Figure 3. A fortunate balance of field distortions between the f/8 cassegrain and the parabolized Ebert-Fastie spectrograph allows the use of linear slits the full length of the field, as shown.

A multiple slit system of alternate 20μ and 60μ slits was chosen to optimize the inevitable compromise between intensity requirements and the desire for spectral resolution compatible with the expected Lyman-α line widths of about 1 A (FWHM) for coronal temperatures near $1.5(10)^6$K. The system will resolve 1/5 to 1/10 of this over nearly all of the field.

The diffraction grating has a ruling frequency of 3600 grooves per mm and used in first order produces an 18μ image for a wavelength range of 0.1 A, a suitable match for the 20μ slits. The slits have 1 mm separation corresponding to 5.6A in a focal plane, which is ample to prevent overlapping of line images in the focal. The nearest coronal line that might interfere with the Lyman-α at 1216 A is the Si III λ 1206.5 A which is normally about a factor 50 down in intensity from the Lyman-α.

The instruments recorded the spectral images on Eastman type 101 spectroscopic film carried in water tight motorized film cassetttes that took sequences of exposures varying in length from 1 second to 60 seconds. On the basis of the 1970 March 7 eclipse data of Gabriel et al. the anticipated coronal Lyman-α intensities should give usable line intensities near the lunar limb with 1 second exposures and 20μ slits. The 60 second exposures and 60μ slits should probe further out into the corona. The overall dynamic range will be the normal film latitude times the factor 180 provided by the slit widths and exposure times. Table I lists the instrument sensitivity and exposure factors.

Two complete rocket payloads were prepared & launched to improve the overall probability of a successful launch and recovery. Orienting the two slit systems at 90° to each other during the eclipse data taking and combining the resultant images during the data analyses gives a two-dimensional grid of data to assist in interpretation.

Two Nike-Black Brant V rockets carried the instrument payloads to altitudes near 350 km. The rockets were launched eastward from the San Marco Satellite Launch Platform 3 miles off the coast of Kenya, near Malindi.

Figure 4 is a schematic representation of the rocket payload and the trajectory into the umbral shadow. After nose cone ejection at 60 sec the attitude control system (ACS) had about 180 sec to orient the optic axes of the telescope toward the eclipsing sun and become stabilized before entering totality. Active control of the pointing was passed over to a stable platform prior to entering totality, and drift was limited to less than one arc sec per sec of time. A nominal trajectory gave over 500 sec in totality.

The recovery was by parachute into the water where a float system with light and radio beacons guided recovery aircraft to the site, and they, in turn, vectored recovery boats to the floating payloads.

RESULTS

The two Nike-Black Brant V rockets were launched precisely on schedule and performed as programmed. Unfortunately an idiosynchrosy in the complex ACS prevented the system from locking on to the eclipsed sun and no useful data were acquired.

DISCUSSION

This attempted measurement remains one of the most important measurements still to be made on the physical characteristics of the inner corona. Current technology restricts it to eclipse conditions. My colleagues and I will be happy to assist any other experimenters who would like to make a successful attempt during a future eclipse.

ACKNOWLEDGEMENTS

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FIGURE CAPTIONS

Figure 1: The 1970 March 7 Solar Eclipse Data by Gabriel, et al.

Figure 2: A schematic sketch of the cassegrain telescope – Ebert spectrograph system developed for the Lyman Alpha Eclipse Experiment. The optics are f/8.

Figure 3: A superposition of the multiple slit entrance aperture for the spectrograph upon the white light corona photograph. The Lyman alpha line profiles will be obtained at all points along the slits.

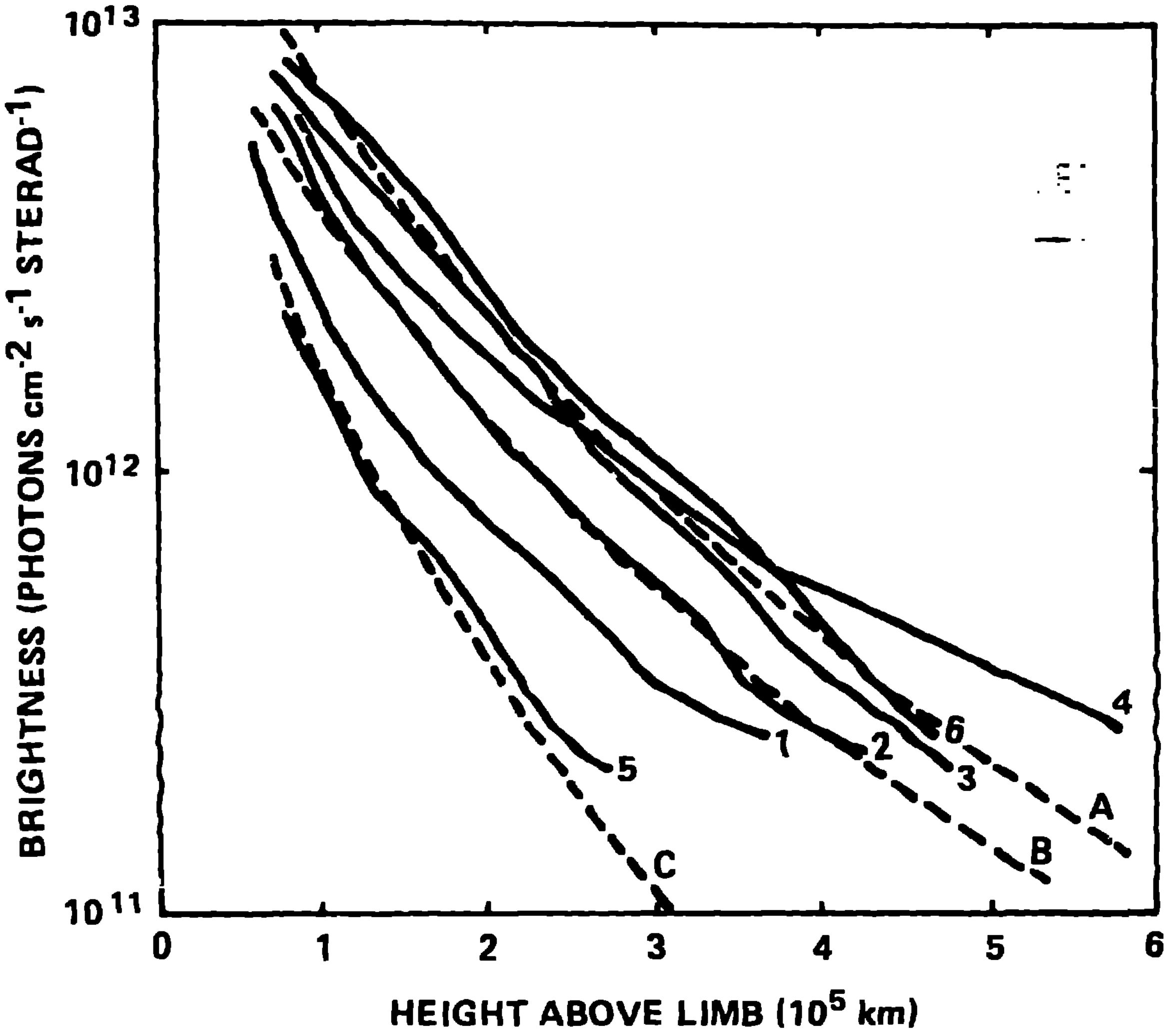
Figure 4: A schematic drawing of a typical payload trajectory intersection with the umbral shadow.

Table 1

INTENSITY AND EXPOSURE FACTORS

- GABRIEL (1970) REPORTS A MEASURED BRIGHTNESS AT 1.3 R_o OF $5(10)^{12}$ PHOTONS/cm^2 SECOND STERAD LYMAN α λ 1216 Å.
- THIS INSTRUMENT WILL DELIVER $\geqslant 1.3(10)^4$ PHOTONS/SECOND ONTO A 20 μ SQUARE OF FILM, GIVEN $5(10)^{12}$ PHOTONS/cm^2 SECOND STERAD INPUT.
- LABORATORY CALIBRATION OF THIS INSTRUMENT ON 101 FILM SHOWS $3(10)^4$ PHOTONS/20 μ ELEMENT WILL GIVE IMAGE ABOVE BACKGROUND.
- ON THE BASIS OF THE ABOVE FLUXES, A 20μ SLIT IMAGING NEAR THE LIMB SHOULD GIVE USEABLE LINE INTENSITIES WITH A 1 SECOND EXPOSURE.

1970 MARCH 7 SOLAR ECLIPSE DATA BY GABRIEL, ET AL



RADIAL BRIGHTNESS VARIATION OF THE LYMAN α CORONA. CURVES I, 2, AND 3 REPRESENT OBSERVATIONS AT SOLAR N, W, and E, 4 IS AT AN INTENSE WHITE LIGHT STREAMER, 5 IS A QUIET COOL REGION AND 6 IS AT A CORONAL CONDENSATION.

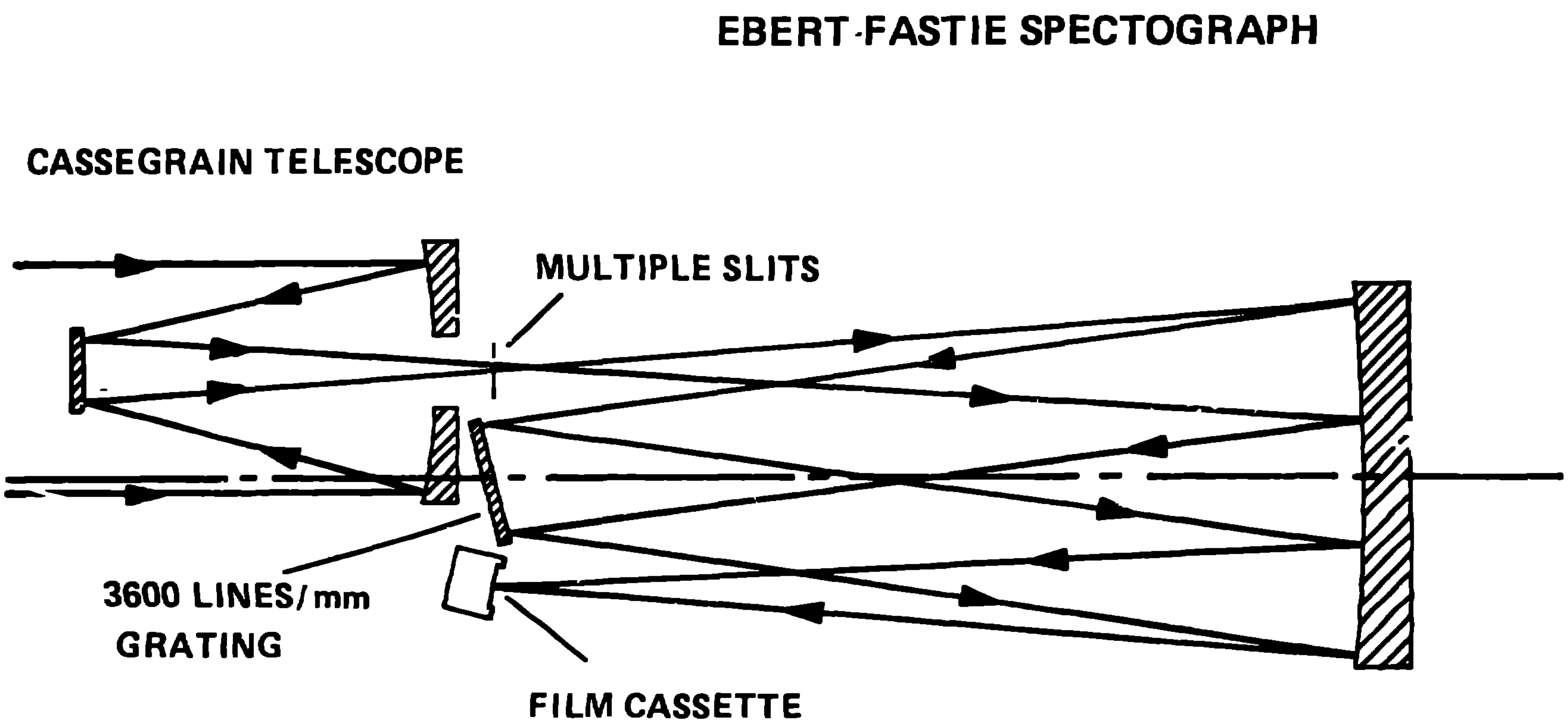

EBERT-FASTIE SPECTOGRAPH
CASSEGRAIN TELESCOPE
MULTIPLE SLITS
3600 LINES/mm
GRATING
FILM CASSETTE

Fig 2

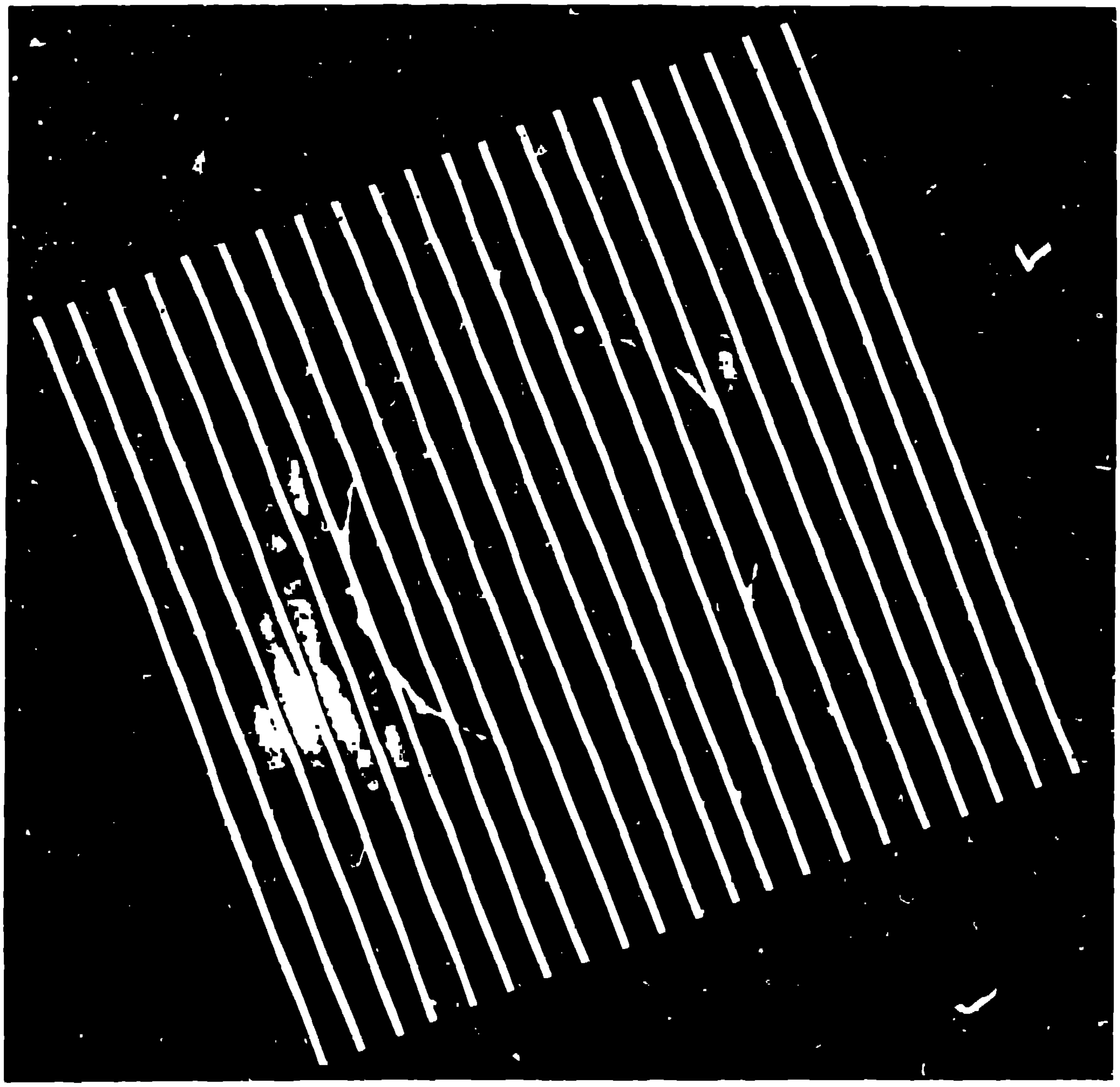
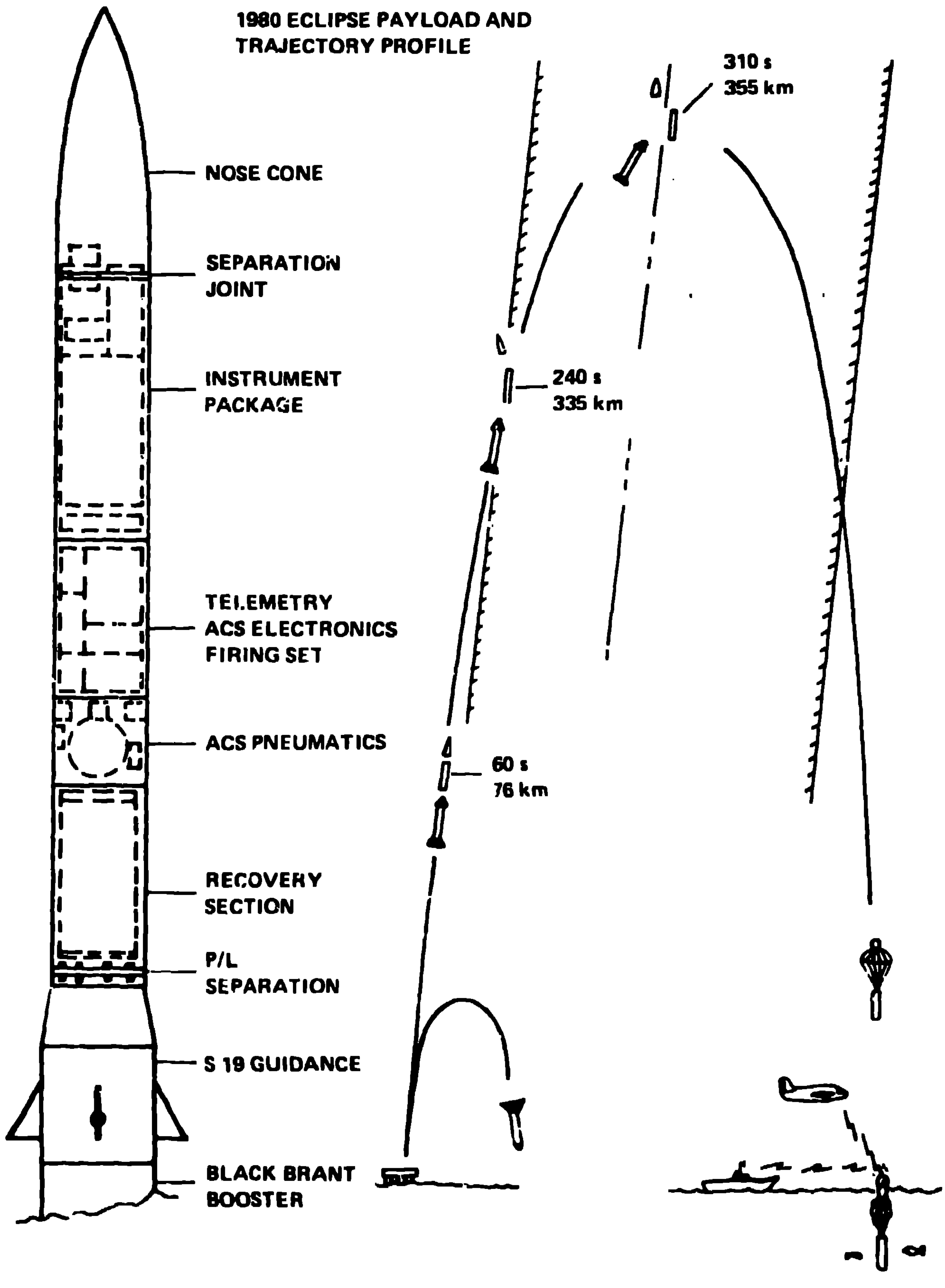


Figure 1


1980 ECLIPSE PAYLOAD AND
TRAJECTORY PROFILE
NOSE CONE
SEPARATION
JOINT
INSTRUMENT
PACKAGE
TELEMETRY
ACS ELECTRONICS
FIRING SET
ACS PNEUMATICS
RECOVERY
SECTION
P/L
SEPARATION
S 19 GUIDANCE
BLACK BRANT
BOOSTER
310 s
355 km
240 s
335 km
60 s
76 km