IMAGING LARGE- AND SMALL-SCALE STRUCTURES OF THE FAR ULTRAVIOLET BACKGROUND WITH THE FAUST INSTRUMENT

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ABSTRACT. The FAUST telescope is an ultraviolet survey instrument that features a wide 8° field of view, ~1′ angular resolution, and a photon counting detector. Operating in the 1400–1800 Å band, it will be sufficiently sensitive to detect blue $m_v = 17$ objects in a single 20 minute night. The instrument is part of the ATLAS-1 shuttle mission, presently scheduled for flight in May 1991. A substantial number of high galactic latitude fields will be investigated, with particular emphasis on studies of the origin of the diffuse far UV background.

1. INTRODUCTION

At wavelengths shorter than the atmospheric cutoff at 3000 Å, astronomical observations are necessarily conducted from spacecraft. Most UV imaging instruments have been designed to furnish high angular resolution and high sensitivity for compact objects such as stars. In contrast, the FAUST instrument is an ultraviolet telescope that has been developed for the precise photometry of diffuse sources of ultraviolet radiation that subtend large fields of view, with particular emphasis on achieving the maximum practical throughput for diffuse objects or extended fields ranging in size from a few arc minutes to many degrees. In this paper, we describe the scientific approach of the FAUST project, and sketch the history of the development of the FAUST flight hardware. We include a brief description of the ATLAS-1 shuttle mission, aboard which FAUST will conduct its observations in 1991.

To accurately determine the intensity of faint diffuse light levels in a limited amount of observing time, it is imperative that the instrument have a very high throughput in order that statistically precise brightness determinations can be made. Moreover, it is vital that the observing plan provide for tests that permit systematic error contributions—due to spacecraft-related emissions and geophysical nightglow processes—to be assessed.

2. SHOT-NOISE-LIMITED DIFFUSE PHOTOMETRY

Consider an ideal photon counting photometer whose light gathering aperture area is A and whose field of view subtends a solid angle Ω. In an exposure of time duration T, the accumulated photon count will be

$$N = B\ A\ \Omega\, E\ T, \tag{1}$$

S. Bowyer and C. Leinert (eds.), The Galactic and Extragalactic Background Radiation, 449–452.

where B is the diffuse sky brightness per unit wavelength averaged over the field of view and over the observing waveband, and where

$$E = \int e(\lambda)\, d\,\lambda \tag{2}$$

is the photon counting efficiency of the system integrated over wavelength. The Poisson counting distribution determines the shot noise component of the measurement error. The resulting statistical uncertainty in the diffuse brightness determination is given by

$$\frac{\delta B}{B} = \frac{1}{\sqrt{(B\ A\ \Omega\, E\ T}}. \tag{3}$$

The $A\,\Omega$ product of the telescope can be replaced with the product of the detector's area and the solid angle of the light beam illuminating the detector. The distinguishing feature of the FAUST instrument is the very large value of its $A\,\Omega E$ product embodied in its design concept: by adopting a 25 mm diameter detector and illuminating it with a very fast f/1.1 beam, an $A\,\Omega E$ product of the order of 10 cm^2 sr Å can in principle be obtained. In practice this means that even very low galactic UV background levels, of the order of $B=100$ photons/cm^2 s sr Å,* can be determined to a statistical accuracy of a few percent in only a few seconds of observing time, when an average over the entire instrument field of view is sought. Longer integration times would of course allow the detection of background features having an angular scale correspondingly smaller than the entire field of view. Detection and identification of "point source" contributions (in this context, objects subtending less than ~arcminute) will necessarily entail integration times that last 1 to 10 min. Specifically, the shot noise photometric error in the determination of a unidirectional flux F will be

$$\delta F = \frac{\sqrt{(F + B\,\omega)}}{\sqrt{(A\ E\ T)}}. \tag{4}$$

Here, ω denotes the solid angle subtended by the angular resolution of the instrument. This expression includes the shot noise contributions from the object and its coadded diffuse continuum. FAUST offers an AE product of the order of 1000 cm^2 Å and therefore, even in regions where B is as large as 1000 photon/cm^2 s sr Å, stars down to fluxes of 2E-4 photon/cm^2 s Å ($m_\lambda = 17$) should be measurable to 10% error in a 1000 s integration. In practice, this means that an extensive series of deep FAUST exposures will allow an accurate determination of the contributions of an enormous variety of sources to the local UV radiation field.

3. THE FAUST INSTRUMENT

FAUST comprises an optical telescope assembly, a detector unit, and an associated electronics system. Originally developed for flights aboard Veronique rockets, FAUST has also been flown aboard the space shuttle as an element of the Spacelab 1 mission. The mechanical

* In conference units, $\lambda F_\lambda = \nu F_\nu = 2E{-}11 w/\mathrm{m}^2$ sr at 1 photon/cm^2 sr s Å, at any wavelength.

https://doi.org/10.1017/S0074180900241259 Published online by Cambridge University Press

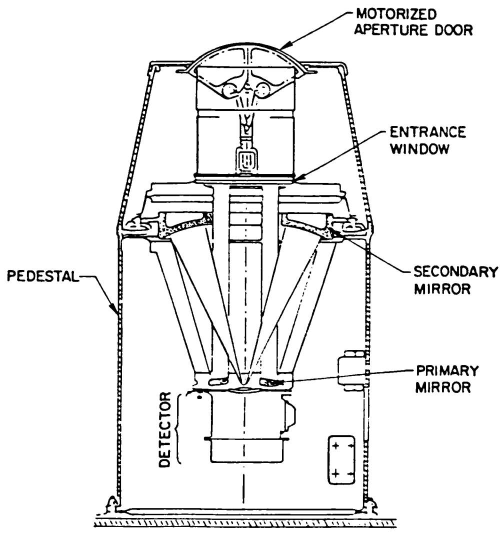

Figure 1. Mechanical arrangement of the FAUST telescope, with pedestal, as prepared for flight aboard Spacelab.

The FAUST optical system is a fast two-mirror wide-angle flat-field telescope of the Schwartzschild (1905) type. The first detailed design and analysis of this configuration was carried out by Wynne (1969). The primary mirror is convex and has a central opening for the detector. The large secondary mirror is concave; its central opening must be larger than the diameter of the primary mirror, to pass the incoming light. Both the primary and secondary mirrors are highly aspherical. Internal baffling against stray light is critical due to the large range of angles involved. Details of the adopted optical design are given by Deharveng et al. (1979). Briefly, FAUST has an aperture of 161 mm and a speed of f/1.12, with vignetting of 7.5% at 4.5° off axis. Its focal length is 180 mm for a plate scale of 3.14 mm/degree. An entrance window of calcium fluoride with a multilayer coating sets a short wavelength cutoff at about 1400 Å. The long wavelength cutoff is determined by the detector employed.

On its initial flights, FAUST was equipped with an ultraviolet image converter and a photographic image recording system. Due to the limited dynamic range of film, especially when coupled to a high gain intensifier, the instrument proved to be very sensitive at low light levels but was easily overloaded at higher light levels. FAUST images from Spacelab 1 showed heavy overexposure, due to the fact that the Spacelab 1 mission planning constraints allowed only brief umbral passages and small solar depression angles; consequently the foreground atmospheric column illuminated by the Sun was excessive, and the desired dark sky was never achieved (Bixler et al. 1984).

Since that time, we have equipped FAUST with a new fully electronic pulse counting image detector (Lampton et al. 1986; Siegmund 1986) that can be regarded as a position-sensitive UV photomultiplier tube. The device employs a microchannel plate upon which a cesium iodide photocathode has been deposited. Behind the microchannel plate, a wedge-and-strip charge collecting anode is located (Martin et al. 1981). Here, each detected photoevent delivers a charge pulse whose wedge and strip fractions encode the X and Y coordinates of the event. Support electronics then digitizes each event and downlinks it via the Orbiter high-rate data system. Image accumulation and analysis is done on the ground. FAUST relies on the Orbiter for electrical power, electrical commands, and attitude control.

4. FAUST ABOARD ATLAS-1

The first Atmospheric Laboratory for Applications and Science (ATLAS-1) is a Spacelab shuttle mission that will accommodate a complement of twelve research instruments and associated Spacelab systems (Craven and Torr 1988). Atlas-1 is presently scheduled for launch in March 1991. The orbit will be circular at 300 km altitude, inclined 57° to the equator. The planned mission duration is nine days. During the mission the two payload specialists, supported by the five other crew members and the ground operations teams, will operate these experiments 24 hr/day in alternating 12 hr crew shifts. For this mission, FAUST has been assigned approximately 40 orbit nighttime passes.

To provide quantitative assessment of the contributions of systematic local UV effects, we have organized the observations in such a way as to give repeated observations of selected target fields under widely varying local conditions. In our orbit, a single nighttime pass will have a time duration of 20 to 30 min, during which the ram velocity direction will swing through an angle of 80–120° and the local ionospheric state will range from sunset (high excitation) conditions to sunrise (low excitation) conditions. Reobservation of a given target field throughout a night will allow us to probe these effects. Time varying ambient phenomena, such as caused by passage through the tropical airglow arcs, or by Orbiter attitude control thruster operation, will be revealed by overall changes in the system photon count rate. By recognizing these longitude and time dependencies, we hope to be able to identify and remove the systematic local phenomena and better quantify the true UV background flux.

Acknowledgments—The FAUST project is supported by NASA contract NAS-8-32577 and the CNES science program.

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K. Mattila: *When trying to measure in absolute terms an isotropic background component, how can you avoid the scattering from all the dust and dirt expected to swim around the Shuttle?*

M. Lampton: At night, Shuttle particulates are not expected to be bright, constant, or isotropic, and are not likely to be a problem. Attitude thruster firings will be bright but have an obvious time signature. Orbiter "glow" phenomena have a characteristic dependence on ram view direction, which may help in identifying them. Finally, nadir observations will be used to establish an instrumental/environmental zero point response.