Abstract.

I review the development of UV and EUV astronomy, covering the spectral range from 5 to 300 nm, with emphasis on sky surveys for discrete sources. I discuss studies which resulted in lists of sources observed by imaging and deliberately omit most spectroscopic studies. Technical issues, such as detector and telescope developments, are treated separately from descriptions of specific missions and their results, which contributed to the understanding of the UV sky. The missions are compared in terms of their “survey power”, a variable which combines sky coverage and survey depth. I use the existing knowledge of UV sources to predict views of the UV sky, which I then compare with those actually detected. Finally, UV missions which will detect fainter sources and will fly in the near future are described, and a wish list for low-cost ventures, which could advance considerably our knowledge of the UV sky is presented.

1. Introduction

Among all spectral bands, the ultraviolet has long been a neglected region, in which we hardly have a good idea of how the sky looks like. This is despite the fact that in the UV there is a distinct advantage of small payloads: first, the sky is very dark, thus detection of faint objects does not compete against an enhanced background (O’Connell 1987); second, the telescope construction techniques are very similar (at least longward of $\sim 70$ nm) to those used for optical astronomy. This apparent neglect is likely to change in the foreseeable future.

Another factor, which presumably acted against the initiation of new sky surveys in the UV, was the argument that not much can be learned about the Universe from new UV sky surveys. After all, it was said, we can infer about the appearance of the UV sky from a good data base in the optical. I shall show later that this is only approximately correct. The availability of a mechanism which allows one to predict the appearance of the UV sky is a necessary ingredient in the detection of outstanding sources, which may indicate the presence of new physical phenomena.

The short astronomical history of our knowledge of the UV sky can be divided into two eras, the first from the dawn of UV astronomy until the flight of TD-1 and the second since the availability of the TD-1 all-sky survey until today. Unfortunately, very little was accomplished in

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terms of general sky surveys during this second era. We still await results from a major, modern and sensitive UV all-sky survey, which hopefully will be performed in the early 2000’s.

Likewise, the UV domain may be divided into the “regular” ultraviolet, that is, the segment from just shortward of the spectral region observable from high ground-based observatories (∼320 nm) to just below the Lyman break at ∼90 nm, and the region from the Lyman break to the fuzzy beginning of the X-ray domain. This short wavelength limit may be arbitrarily defined as ∼6 nm (∼200 eV). I shall call the first segment “the UV” and the second the “extreme UV” (EUV) bands. As shall be shown below, the observational techniques used in the EUV band are more similar to those in X-ray astronomy, whereas the UV is more like the optical. Sometimes, the UV region as defined here is separated into the near-UV and far-UV segments; the separation is at ∼200 nm.

Although only few missions performed full sky surveys in the UV or EUV, a large number of instruments scanned or imaged restricted sky areas. Those provided partial, or very partial, information about the deeper UV sky. By thorough examination of their results one may form an idea on what could be expected from a full sky survey to a similar depth. A review of UV imaging experiments and their results, updated to 1990, was given by O’Connell (1991). A few UV imaging experiments were described and compared by Rifatto et al. (1995), with the aim of understanding galaxy UV emission.

In general, the sources of UV and EUV radiation can be either point or diffuse. A summary list of diverse sources, with the approximate order of importance in contribution, is shown below as Table 1, which is derived from the similar table of Gondhalekar (1990). A note of caution should be mentioned here: the relevance of the importance of various contributions to the background is for broad-band measurements. In special circumstances, e.g., for narrow-band or spectroscopic observations, line emission in the EUV domain may become the dominant contributor.

### Table 1. Sources of UV and EUV radiation

| Source               | UV | EUV |
|----------------------|----|-----|
| Direct starlight     | 1  | 1   |
| Scattering off dust  | 2  | 3   |
| Hot & tepid ISM      | 6  | 2   |
| H₂ fluorescence      | 3  | –   |
| Galaxies             | 4  | 4   |
| AGNs                 | 5  | 5   |

I shall not discuss exotic mechanisms for the production of UV radiation (e.g., decays of exotic particles), except in a single case where a UV observation by HUT (see below) puts the most stringent limits on the mass of a heavy neutrino. The other sources shall be discussed below, in the appropriate context.

It is clear that young stellar populations will emit copious amounts of UV radiation. To demonstrate this, I show in Figure 1 how the peak of the spectral energy distribution changes with age in case of a starburst galaxy model of star formation. For almost 150 Myrs the peak stays in the UV for the three different IMFs modeled here (Kroupa et al. 1993: heavy solid line, Salpeter 1955: dotted line, and Miller & Scalo 1979: filled squares). All three models represent instantaneous bursts, where 50% of the stellar ejecta is recycled into stars, all include nebular emission, and in all 70% of the Lyman continuum is absorbed by the ISM gas. The models were
calculated with the codes of Fioc & Rocca-Volmerange (Leitherer et al. 1996). The steady UV peak for \( \sim 150 \) Myrs is not due to Lyman \( \alpha \) emission; a comparison with models which do not include nebular emission shows that this line can be important only during the few first Myrs after the burst.

**Figure 1.** Peak of spectral energy distribution of different starburst galaxy models vs. age. The models differ in the IMF used to calculate the starburst. The dotted line represents the Salpeter IMF, the filled squares are for the Miller & Scalo IMF, and the solid line represents models calculated with the Kroupa et al. (1993) IMF.

Before embarking on a description of various missions and their results, I discuss briefly the units used in UV astronomy. A useful description of the brightness of astronomical sources is by “monochromatic magnitudes”. The monochromatic system is defined at wavelength \( \lambda \) (using the calibration of Vega by Hayes & Latham 1975) as:

\[
m_\lambda = -2.5 \log(f_\lambda) - 21.175
\]  

where \( f_\lambda \) is the source flux density in \( \text{erg/sec/cm}^2/\text{Å} \) at wavelength \( \lambda \). A variant of the magnitude units is the AB system sometimes used in the UV. This is defined (Oke & Gunn 1983) as:

\[
AB = -2.5 \log(f_\nu) - 48.60
\]

The constant was chosen to make \( \text{AB}=V \) for objects with flat spectra. The units of \( f_\nu \) are \( \text{erg/sec/cm}^2/\text{Hz} \). The conversion between the two systems of magnitudes is wavelength-dependent. For \( \lambda=200 \) nm, which is representative of the UV domain, the conversion is:

\[
m_\lambda = AB - 2.26
\]

Other units, useful for describing background brightness, are “photon units” (p.u. or c.u.=count units). These simply count the photon flux in a spectral band, per \( \text{cm}^2 \), per steradian, and per \( \text{Å} \).
At 200 nm, one count unit equals $10^{-11} \text{ erg/cm}^2/\text{sec}/\text{Å}/\text{steradian}$, or $10^{-13} \text{ W/m}^2/\text{nm}/\text{steradian}$, or $32.9 \text{ mag/arcsec}^2$. Of course, one can always use the “flux units” ($\text{erg/sec/cm}^2/\text{arcsec}^2/\text{Å}$) directly, or surface brightness units $\nu I_\nu$ (the units of $I_\nu$ are $\text{erg/sec/cm}^2/\text{steradian}/\text{Hz}$). One unit of surface brightness equals $5 \times 10^7 \text{ c.u.}$.

Waller et al. (1995) introduced the $S_{10}$ concept, used in the visible part of the spectrum to describe the diffuse sky background, to the UV domain. $S_{10}$ measures the number of 10th mag solar-type stars per square degree which would produce the same flux level as observed from the diffuse background. They quote for the region around 200 nm a conversion of

$$1 S_{10} = 3.3 \times 10^{-21} \text{erg/sec/cm}^2/\text{arcsec}^2/\text{Å} = 3.33 \times 10^{-10} \text{c.u.}$$

As the UV background does not originate from Solar-type stars, it is not clear what additional insight the $S_{10}$ unit introduces, except when considering the influence of the zodiacal light. This is because the evaluation of the zodiacal light contribution to the background relies on a transformation from the visible band measurements by Levasseur-Regourd & Dumont (1980). However, while the visible background is a manageable $\sim 200 S_{10}$ (Roach & Gordon 1973), the UV background is $\sim 10^8 S_{10}$, as will become clear below.

2. The Early Years.

2.1. THE "REGULAR" UV

The beginning of UV astronomy lies in the mid-1950s, with rocket flights during which the skies were scanned by the free (unstabilized) flight of the carrier vehicle. The first UV photometric data were obtained by Byram et al. (1957), Kupperian & Milligan (1957), and Boggess & Dunkelman (1959). In the early 1960s the first spectro-photometric observations were obtained using three-axis stabilized rockets (Stecher & Milligan 1962; Morton & Spitzer 1966). However, rocket flights offer only a limited amount of observing time, of order 5 minutes or less, thus these surveys were limited in depth and sky coverage.

The first instrument on a satellite which was dedicated to UV astronomy was a photometer, on a US Navy spacecraft launched in 1964 (Smith 1967). One of NASA’s first successful “Observatories” series of satellites was OAO-2, with UV cameras from the Smithsonian Observatory and a medium-dispersion spectrograph from GSFC, launched on 7 December 1968 (Davis et al. 1972, Code et al. 1970). The CELESCOPE imaging experiment, with its four 30 cm diameter telescopes, imaged $2^\circ$ wide fields with relatively low angular resolution. Its results, consisting of photometric measurements of some 5,068 stars in four spectral bands, make up the CELESCOPE catalogue (Davis et al. 1973).

Even manned space flights were harnessed into providing UV astronomical information; John Glenn was given a hand-held 35 mm camera with an objective prism to record the UV spectra of stars, but nobody checked whether the window of Freedom-7 was UV-transparent (it was not, and no images were obtained; Boggess & Wilson 1987). Later, manned flights provided valuable UV data from hand-held cameras on Gemini flights (Henize et al. 1975) and from an automated Moon-based telescope (Carruthers 1973). A similar attempt at UV astrophysics from a manned space platform was done on 19-24 December 1973, when the space observatory ORION-2 was operated from the Soyuz-13 spacecraft (Gurzadyan et al. 1985). The ORION-2 telescope was a 22 cm Cassegrain with an objective prism, and the spectra of $\sim 900$ stars were recorded on film.

Some information on the diffuse UV background between 135 and 148 nm was published by Hayakawa et al. (1969). The measurements were done during a rocket flight on 7 March 1967 and the experiment, along with three-band photometry of six bright stars, as described by Yamashita...
(1968). Approximately half the sky was mapped on 1 March 1970 in a UV band from 142.5 to 164 nm and with coarse angular resolution of about $10^\circ$ by a rocket-borne Geiger counter which had an effective collecting area of 0.62 cm$^2$. The experiment and its results were described by Henry et al. (1977). The results were compared with a model of the UV sky calculated by Henry (1977, see below).

The UV spectral range is blessed with very dark skies (O’Connell 1987), which permits achieving a good S/N ratio on faint sources with relatively small optics, provided one has a noiseless detector and keeps away from sources of background radiation. One well-known source of background emission is the geocoronal Lyman $\alpha$ (Ly$\alpha$), resonant scattering of Solar photons off hydrogen atoms in the halo around the Earth. A beautiful image showing the entire Earth with its Ly$\alpha$ halo, as well as the tropical UV airglow bands and the auroral ovals around the poles, has been obtained by the S201 experiment operating from the Moon during the Apollo 16 mission (Page et al. 1982, Fig. 4b).

The auroral emission is present essentially everywhere around the Earth, but its intensity varies with geomagnetic latitude (Meier 1991). The Ly$\alpha$ emission, and the aura and airglow, are the two most troublesome backgrounds influencing orbiting UV experiments at low and intermediate altitudes. The OI line emission at 130.2 and 135.6 nm band, and the $N_2$ Lyman-Birge-Hopfield bands in the 140-180 nm region, are restricted to the upper atmosphere and affect only observations done at low orbital altitudes, or at low incidence angles to the Earth limb. The OI lines, in particular, form at altitudes of 250-300 km (Leinert et al. 1998). Special LEO missions may, therefore, require special tailoring of mirror coatings and of filters to suppress this background. Note that Ly$\alpha$ resonant scattering is produced also off interplanetary hydrogen as well as off interstellar $H^0$ atoms passing through interplanetary space, thus no location in the Solar System is really free of this emission.

2.2. THE EXTREME UV

In parallel with the development of the UV astronomy field, first steps were taken to study the EUV sky. The EUV range is hampered by the opacity of the interstellar medium (ISM). From 91.2 nm shortward to about 10 nm the opacity is high, because of the photo-electric cross-section of hydrogen, and to a lesser extent of neutral helium (below 50.4 nm) and singly ionized helium (below 22.8 nm). The opacity of the ISM limits the detectable range to about 100 pc., with very few exceptions. The objects expected to be detectable in the EUV were hot early-type stars, hot white dwarfs, coronae of late-type stars, and bright non-thermal sources some of them possibly extragalactic. Note that some of the EUV emission from early-type stars was much more intense than expected from model atmospheres (e.g., $\epsilon$ CMa; Vallerga et al. 1993, Wilkinson et al. 1996). Also, not many very hot young stars were expected to be detectable because of the significant intervening hydrogen column density to such objects.

The first studies in the EUV range were mostly, as in the UV domain, by rocket-flown instruments (Henry et al. 1975 a, b, c), which measured a few very bright sources and established calibrators. The earliest observations below Ly$\alpha$ were by Belyaev et al. (1971) with Geiger counters on the Venera 5 and 6 spacecraft. These attempts were done with large field of view detectors and concentrated on the detection of the EUV background. The EUV background was also characterized (Kumar et al. 1974; Bowyer et al. 1977, 1981). The culmination of this work was the EUV instrument flown on the Apollo-Soyuz mission in 1975, when four EUV point sources were discovered (Lampton et al. 1976, Margon et al. 1976, Haisch et al. 1977, Margon et al. 1978). At the completion of these, first, preliminary pilot surveys, NASA initiated the EUVE survey, described in section 5.3.
The Voyager spacecraft explored the EUV sky with their Ultraviolet Spectrometers (UVS: Sandel, Shemansky & Broadfoot 1979). For a number of years, the UVS on the two Voyager spacecraft were the most distant astronomical observatories in operation (Holberg 1990, 1991). The operation of the UVS instruments is scheduled to end in 1998, in order to conserve power for other Voyager instruments as the radioisotope power generators degrade. A look onto the EUV sky, as side-benefit of an X-ray mission, was also offered by the ESA mission of EXOSAT. This sky survey was performed from 0.6 to 40 nm and covered the short wavelength end of the EUV range. The EXOSAT results were summarized by White (1991).

3. Technical issues

Before continuing with the description of UV missions in “modern” times, it is necessary to discuss technical issues involved in UV observations. These have to do with both telescope construction and detector development. Both aspects are driven not so much by scientific aspects as by military usage of the UV, mainly for targeting missile launches and re-entry bodies.

3.1. OPTICS

In the telescope construction section we recognize that down to about 115 or 105 nm (and in some cases even below that) “regular” telescope construction techniques apply. These imply parabolic-hyperbolic mirror combinations (Cassegrain, Ritchey-Chrétien, or even Schmidt configurations) made of glasses, ceramic materials, or light-weight metals. The primary difference from ground-based telescopes is that for space devices light-weightedness is a necessity. Therefore, space mirrors will usually be light-weighted by machining the blanks to reduce the mass as much as possible. Light-weighting to 40% of a solid blank is customary, although reports were published of light-weighted mirrors to 20% or lower values.

The requirements for a reflecting coating for UV wavelengths above 115 nm are fulfilled by aluminum overcoated by MgF$_2$. Another 10 nm to shorter wavelengths can be gained if the coating is LiF. Note that both materials are hygroscopic (LiF more than MgF$_2$) and the mirrors have to be maintained in a controlled atmosphere until deployed in space. For UV observations below 115 nm but above ~50 nm the coating of choice has until recently been osmium or iridium. These materials are inert at ground-level atmospheric conditions and offer reasonable reflectivities of ~20%. Recent missions (second flight of HUT, second flight of ORFEUS, etc.) used SiC mirror coatings. These allow high-efficiency normal-incidence reflections for $\lambda \geq 60$ nm (Keshi-Kuha et al. 1997). This mirror option was chosen also for the FUSE mission (Kennedy et al. 1996).

One important issue with UV optics, as well as with EUV, is optics contamination. Not only must dust particles be kept away, but also molecular contaminants. These are harder to drive off, because some have high molecular weights and will not evaporate fully during outgassing procedures. In space, under the influence of high-energy particles and UV photons, these substances change chemical form, may polymerize, and can form mono-layers over the mirrors with very high optical depths in the UV (Noter et al. 1993). The significant reduction of the UV throughput of HST’s WFPC-1 by molecular contaminants, polymerized under the diffuse UV radiation from the Earth, was confirmed by MacKenty et al. (1995). It is possible that a similar phenomenon was partially responsible for the sensitivity decrease of HUT in orbit (for a discussion of the HUT sensitivity see Davidsen et al. 1992).

Observations in the EUV range cannot rely (with one exception) on normal-incidence optics. For this spectral region the geometry of the telescope mirrors follows that used in the X-ray
domain, the Woltjer pairs, where the reflection is by grazing incidence. The one exception to this rule is for narrow-band observations where the mirror acts as filter, by being coated with multi-layers of different metals. To improve the efficiency, the telescope architecture normally used in these cases is with the detector at the prime focus of a single parabolic mirror. This technique was used for the ALEXIS telescopes and was planned for the first generation design of the EUVITA telescopes for the Spectrum X-\(\gamma\) (SRG) spacecraft (described by Courvoisier et al. 1993; the option to orbit this configuration has since been abandoned).

In principle, multi-layer coatings can yield a total in-band reflectivity of about 40\%, with a bandwidth of about 10\% of the peak band wavelength (Roussel-Duprè & Ameduri 1993). In practice, it is extremely difficult to produce multi-layer coatings on mirror substrates larger than about 20 cm which are uniform, stable, and can survive the launch environmental stresses.

3.2. DETECTORS

The detector issue has been driven for many years by requirements of as high as possible quantum efficiency together with as good a resolution as possible. The first detectors used in UV and EUV astronomy were photomultipliers with cathodes sensitive to the spectral bands to be observed, or were just Geiger counters. TD-1 (see below) achieved spatial resolution by scanning the photomultiplier aperture on the sky.

Most modern UV imaging detectors are intensifiers or image converters, which use a UV-sensitive cathode as their main active ingredient. In most experiments the images were recorded on film. This was processed on the ground after the observation and was usually scanned to convert the information into digital pictures. Among the experiments which used this mode of image recording we count SCAP-2000, FOCA, WF-UVCAM, FAUST (first flight only), and UIT. These shall be discussed in detail below. At this point, it is worthwhile to remark that the main limitations of this method of image recording are (i) the limited and non-linear dynamic range, and (ii) possible film defects, that can be detected only after processing.

Carruthers (1973) developed a UV electronographic camera, patterned after visible-light ECAMs. This camera extracted photo-electrons from a cathode by UV light and accelerated them over \(\sim 1000\)V potential difference. The electron trajectories were confined by the strong magnetic field, parallel to the optical axis, of a permanent magnet wrapped around the camera. The image was created by the energetic electrons onto special electronographic emulsion placed at the focal plane. The readout was accomplished by micro-densitometry of the exposed and developed emulsion. To achieve a better dynamic range, the same scene was imaged with different exposure times. Modern versions of Carruthers’ cameras employ electron-bombarded CCDs (ECCCDs) in place of the electronographic emulsion; each accelerated electron creates many electron-hole pairs in the CCD, allowing high S/N detection of individual photons. The obvious advantage of Carruther’s design is that the quantum efficiency of the opaque cathodes he uses is much higher than that of the semi-transparent cathodes used in other designs. The disadvantage is the need of an extended, strong, and uniform magnetic field along the axis of the camera. This limits the size of the cameras built by his group to fairly small apertures.

It is also possible to use CCDs for UV observations, as done in the WFPC-1 and WFPC-2 of the HST. Even better UV performance is achieved by modern CCDs, with thinned, back-illuminated chips which have fluorescing, anti-reflection coatings. A comparison of CCD and other detectors, with specific application to low light level observations as encountered in astronomical situations, was done by Vallerga & Lampton (1987). While the authors concluded that the CCD and MCP (see below) devices are equivalent in terms of required number of incident photons to reach a set S/N, the disadvantage inherent in the cryo-cooling required for
most CCDs is evident. In addition, MCP-based detectors with electronic readout offer readily a photon-counting option.

With the advent of multi-channel plates (MCPs) it became possible to build position-sensitive detectors in the UV and EUV where photons could be “confined” to paths within individual channels, while being accelerated and multiplied. With three-stack MCPs, gains of $10^6$ to $10^7$ can be achieved. Examples of such detectors are those of FAUST (in its second Shuttle flight), and EUVE, where the readout is done by a position-sensitive anode (wedge-and-strip). The design of TAUVEK (see below) is based on similar detectors. A review of readout methods for photon-counting MCP-based detectors was presented by Lampón (1987).

At least three other forms of readout are available for MCP-based detectors. It is possible to have a phosphor output activated by the electron cloud emerging from the last MCP of the stack, which is optically-coupled to a regular, fast-readout CCD. Special fast phosphors, with fast analyzing circuitry and hardwired, or transputer-based centroiding algorithms, yield sub-pixel resolution of the center of each electron cloud. The resultant detector module is thus high-resolution, fast, and photon-counting. Similar detectors are operating on the MSX UVISI and on the future UV/optical monitor of XMM (see below). Recent results with this configuration report resolution below 6 µm, resolving individual MCP pores, while supporting high count rates (Vallerga et al. 1997).

A different readout mode employs a resistive anode, with outputs at opposite locations at the anode edges and fast timing circuits to measure the propagation delay of the charge cloud to each of the outputs. The centroid of the charge cloud is obtained by differencing the time delays in the same direction. The new detector of FOCA (see below) operates in this mode. Finally, another position-sensitive anode uses crossed pairs of helical delay lines behind the last MCP. The readout is conducted by measuring time differences between the charge pulses received at the two ends of a wire. Reported performance of helical delay line readouts appears to offer very high data rates (up to MHz counts) and very high resolution (about 20 µm, Siegmund et al. 1992). This, apparently, is the readout of choice for the GALEX UV sky survey mission.

The HST instrument Space Telescope Imaging Spectrometer (STIS), installed during the refurbishing flight of 1997, includes one CCD detector for $\lambda > 200$ nm and two Multi-Anode Microchannel Array (MAMA) cameras for the 115-170 and 165-310 nm bands. The MAMAs are essentially MCP intensifiers with CsI or Cs$_2$Te cathodes, where the location of the electron clouds is achieved by centroiding the readout of crossed micro-strip anodes.

A brief discussion of current detector technology for UV astronomy was presented by Ulmer et al. (1995), and a more extensive discussion is by Joseph (1995).

Two kinds of promising detectors have not yet been used in UV astronomy. One is the low-pressure multistep gaseous electron multiplier, which is used in high-energy physics for detecting Čerenkov photons in ring-imaging detectors (e.g., Chechik & Breskin 1988). Such detectors can reach very high UV quantum efficiencies, up to 60% depending on the type of gas filling the detector (A. Breskin, private communication), but have never been packaged for space applications. The other type of detector is superconducting tunnel junctions packaged in an array configuration (e.g., Perryman et al. 1994), which may prove to be the first energy-sensitive imaging array for UV applications. This will be discussed below, near the end of this paper.

New developments indicate that it may be possible to fabricate array devices similar to CCDs which will have good UV sensitivitiy in the UV coupled with sharp response cutoffs near the visible by using wide bandgap III-IV semiconductor materials, such as GaN and other nitrides (e.g., Kung et al. 1996).
4. The TD-1 Era

The “middle-ages” of UV and EUV astronomy witnessed a number of high-atmosphere or space missions, which shall be discussed below. In order to put these in proper perspective, I present in Table 2 a summary of vital statistics for these missions. The spectral resolution is given in $\Delta \lambda$ in the usual spectroscopic convention, where $\Delta \lambda$ is the typical width of the spectral bands used by each instrument. Only TD-1, IUE, and EUVE had spectroscopic capabilities. I include the instantaneous field-of-view of each instrument in column 2. The table is arranged in chronological order of missions and concentrates the three EUV surveys at its bottom. The entry for EUVE includes the approximate spectral resolution of the imagers as well as that of the spectroscopic telescopes.

TABLE 2. UV and EUV survey missions

| Mission name | Inst. FOV (deg.) | Apert. cm. | Spectral range (nm) | Spatial resol'n | Spectral resol'n | Launch year | End of mission | Responsible agency |
|--------------|-------------------|------------|---------------------|-----------------|-----------------|-------------|-----------------|-------------------|
| TD-1         | 0.25              | 27.5       | 157-274             | 2'              | 6               | 1972        | 1974           | ESRO              |
| S201         | 20                | 7          | 125-160             | 3'              | NA              | 1972        | 1972           | NASA (NRL)        |
| FUVCAM       | 11-20             | 10         | 123-200             | 3'              | 3               | 1978        | 1991           | NASA (NRL)        |
| IUE          | $4 \times 10^{-3}$| 45         | 110-320             | NA              | 285             | 1978        | 1996           | NASA, ESA, SERC   |
| SCAP-2000    | 6                 | 13         | 190-210             | 2'              | NA              | 1979        | 1990           | CNES, CNRS, FNRS  |
| GSFC CAM     | 11.4              | 31         | 140-262             | 1'              | 2               | 1979        | 1980           | NASA (GSFC)      |
| WF-UVC       | 66                | 20         | 125-280             | 5'              | 1               | 1983        | 1983           | CNES (LAS)        |
| GLAZAR       | 1.3               | 40         | 150-200             | 10'-40''        | NA              | 1986        | 1991           | Russia, Armenia   |
| GUV          | 4                 | 17         | 130-164             | 12'             | NA              | 1987        | 1987           | Japan (ISAS)      |
| UIT          | 0.67              | 38         | 125-290             | 3''             | 2               | 1990        | 1995           | NASA (GSFC)      |
| FOCA         | 1.5, 2.3          | 39         | 190-210             | 10'-20''        | NA              | 1991        | –              | CNES, CNRS, FNRS  |
| FAUST        | 8                 | 16.1       | 140-180             | 3.5             | NA              | 1992        | 1992           | NASA, UCB, CNES   |
| WFC          | 5                 | 57.6       | 17-210 eV           | 2'              | 9, 120 eV       | 1990        | –              | SERC (Leicester)  |
| EUVE         | 5                 | 40         | 10-60               | 1'              | 1, 200          | 1992        | –              | NASA (Berkeley)   |
| ALEXIS       | 33                | 10         | 13.3-18.8           | 15'             | 10              | 1993        | –              | NASA (LANL)       |

4.1. TD-1

The advent of modern UV astronomy can be marked as the first UV all-sky survey to a reasonable depth and with a reasonable angular resolution, by the TD-1 satellite. As one of the first satellites launched on 12 March 1972 by the European Space Research Agency (ESRO, later known as ESA), the UV experiment was known as S2/68 (the second scientific satellite of year 1968). The UV experiment was a collaboration of the British and Belgian scientists, and is described by Boksenberg et al. (1973). It consisted of an f/3.5 telescope with a 27.5 cm diameter primary mirror, feeding a spectrometer for the 130-255 nm region and a photometer with a single broad band centered at 275 nm. The entrance aperture of the spectrometer was $11'.8 \times 17''$ and the photometer aperture was $1'.7 \times 17''$. The calibration of TD-1 was described also by Humphreys et al. (1976).

Already during its operational period the TD-1 observations were used to search for outstanding UV-bright objects (Carnochan et al. 1975). The results, in the form of an all-sky catalog...
of UV sources, were published by Thompson et al. (1978). In order to produce the catalog, the spectroscopic data were binned into three photometric channels, each 33 nm wide: 135-175 nm, 175-215 nm, and 215-255 nm. These, and the purely photometric 274 nm (31 nm wide) channel, are the four TD-1 bands. The ESA-TD1 catalog contains 31,215 stars measured with S/N>10 in all four TD-1 bands. An unpublished version, with lower S/N restrictions, has 58,012 objects (Landsman 1984).

The results of TD-1 were discussed by many and it appears that the TD-1 sensitivity limit was not uniform across the sky. This was because of the variable number of scan repetitions of the same source (higher at high ecliptic latitude), and also probably because of variations of UV background, mainly in the 156.5 nm band due to geocoronal Lyα emission (Morgan et al. 1976). Gondhalekar et al. (1985) discussed the TD-1 results in the context of the galactic UV interstellar radiation field emission. They mentioned that TD-1 is probably not linear for fluxes fainter than $10^{-12}$ erg/s/cm$^2$/Å. Henry (1991) noted that the dark current of TD-1 varied with time, another possible reason for non-linearity at low signal levels.

![Figure 2](image)

Figure 2. The TD-1 sky at 156.5 nm. The 31,215 sources of the published catalog were binned (in flux) into “fat” pixels to provide a fuzzy view of the entire sky. The intensity is shown logarithmically, to stretch the grey scale, with brighter regions represented as darker pixels.

I show in Figures 2 and 3 the UV sky seen by TD-1. This was obtained by binning the flux from the stars in the published catalog in boxes of 4° × 4°, and displaying the resultant average surface brightness with a logarithmic scale. The view is in celestial coordinates; the Milky Way is the darker (brighter) “bullseye” ring centered on both figures. The high flux area in the Milky Way, visible on the upper right side of the image, is the Orion region. The dark region in the diametrically opposite direction is produced by UV-bright stars in Scorpius-Sagittarius. Nearby UV-bright stars produce isolated black fat pixels at random locations in the figures.

Based on the TD-1 results, Henry et al. (1988) produced an “Atlas of the Ultraviolet Sky”, which combines plots of the visible sky and of the corresponding 156.6 nm view. The faintest objects shown in these plots are at $10^{-12}$ erg cm$^{-2}$ s$^{-1}$ Å$^{-1}$, but among the objects fainter
than five times this value, some have had the UV brightness calculated from an optical-to-UV transformation.

The all-sky coverage and the relative depth of the TD-1 S2/68 experiment have set its results as a benchmark against which all other sky surveys are and will be measured. The TD-1 catalogs, both the published S/N\textgreater10 version and the lower S/N unpublished version, are possible mines of interesting objects. An example of the lasting value of the TD-1 survey is the report by Landsman et al. (1996), who found two cases of white dwarf components in binaries with F-star primaries. They selected sources with TD-1 156.5 nm UV excesses identified in the catalog as late-type stars and followed them up with IUE. In two cases (56 Peg and HR3643), UV signatures of white dwarf stars were detected.

Despite this long-lasting value, the TD-1 catalog is limited in the sky view it presents. The TD-1 survey is as shallow in the UV as the HIP catalog is in the optical; the sky knowledge it offers through the total number of sources is equivalent to that of the visible sky as was known in the early stages of astronomical photography, about 100 years ago (O’Connell 1992)! After TD-1, the various UV and EUV efforts can be characterized as either imagers or spectrometers. Among the imagers, some were orbiters and others were on short-duration flights (rockets, balloons, high-altitude planes). I shall list the various missions below, concentrating almost exclusively on imagers.

4.2. ANS

This mission was launched on 30 August 1974 and was described by Van Duinen et al. (1975), by Wesselius et al. (1982) and by de Boer (1982). The instrument consisted of a 22.5 cm diameter telescope, which focuses the light through a 2.5′ × 2.5′ slit onto a spectrometer with fixed slits in its focal surface. Each location is thus sampled in five spectral bands, defined by the sizes and locations of these exit slits. The spectral coverage of ANS was from 150 nm to 325 nm and each
band was about 15-20 nm wide. The maximal sensitivity of ANS, determined by the instrument design, was at 220 nm.

ANS did not perform a sky survey, but observed pre-selected targets. Wesselius et al. (1982) reported that only 3,573 objects out of the more than 5,000 observed by ANS were actually retained in the final catalog of the mission. These were objects with S/N > 4 in one band, or S/N > 3 in at least three of the ANS bands. Measurements of 13 elliptical galaxies were reported by de Boer (1982); in many cases only upper limits could be presented, because of the low reflecting efficiency of the grating, away from its blaze angle.

One important usage of the ANS data set was to derive UV-to-optical color indices from observations of 182 main sequence stars and 56 giants and supergiants (Wesselius et al. 1980). Note that the derivation of color runs only down to G0 stars; later-type stars were apparently too faint for ANS to register. This is a characteristic of most UV surveys; the late-type stars are under-represented, or absent altogether.

4.3. THE IUE OBSERVATORY

Undoubtedly, the greatest success ever of any orbiting astronomical instrument lies with the IUE observatory. Launched on 26 January 1978 for a nominal three years’ mission, the observatory operated for 18 years yielding more than 100,000 spectra of nearly 9600 diverse astronomical targets. IUE operations closed down on 30 September 1996. The experiment consists of a 45 cm diameter Cassegrain telescope feeding two alternative spectrometers, one for the range 110-190 nm and the other for 180-320 nm. Two different dispersions were available, low (R=300) and high (R=2 \times 10^4, with an echelle arrangement). The sensitivity of IUE, for low dispersion operations, was approximately m_{150}=15. An early description of IUE can be found in Boggess et al. (1978).

During the unexpectedly long operation period of IUE, its NASA operators at GSFC and ESA personnel at VILSPA devised work-around methods to do with less than the minimal number of gyros, and to operate despite unexpectedly high levels of straylight when a piece of thermal blanket or reflecting tape fluttered in front of the telescope aperture.

Although the IUE data set does not represent a uniform survey of the sky, the large variety of objects observed by it offers unique opportunities to derive “average” properties of populations. This has been used by many (e.g., Fanelli et al. 1987) to derive UV-to-optical color indices for various spectral types and luminosity classes. These are later used to derive transformations, to create models of the UV sky (see below), or to determine the level of the diffuse UV background. Observations of galaxies are used to determine average UV spectra of irregular, spiral, and elliptical galaxies, and of galactic bulges (Ellis et al. 1982, Burstein et al. 1988, Kinney et al. 1993, Storchi-Bergmann et al. 1994), important for the derivation of k-corrections.

The IUE data bank represents a valuable archival resource, even more so after the final reprocessing of all the low-dispersion spectra into the final Uniform Low-Dispersion Archive (ULDA) will be complete. To help the logical usage of the ULDA, atlases of UV spectra of selected types of objects, based on IUE data were published (i.e., Longo & Capaccioli 1992). Apart from the special-purpose atlases, note those dedicated to the classification of UV stars by ESA and by NASA (Heck et al. 1984; Wu et al. 1991). The last distributed version of ULDA (V4.0), including 54,247 spectra obtained until 31 December 1991, has been installed at 27 regional or national centers. The final version of the archives contains 104,471 spectra reprocessed with the most up-to-date calibration and includes echelle spectra binned to the resolution of the low dispersion observations.
4.4. ASTRON SPACE STATION

The ASTRON space station was launched by the USSR on 23 March 1983. It was built on a Venera-type platform and included a $3^\circ \times 3^\circ$ (FWHM) proportional counter for observations in the 2-25 keV X-ray regions and a 80 cm telescope for UV astronomy. ASTRON operated from a highly elliptical orbit ($\sim$2000 km $\times$ $\sim$ 200,000 km, four-day duration) until June 1989. Some results on galaxy photometry in 2.8 nm wide bands, from 160 to 350 nm, were published by Merkulova et al. (1990). Spectroscopy of SN1987A, and of flares on the red dwarf EV Lac, were reported by Liubimkov (1990), by Burnasheva et al. (1989), and by Katsova & Livshits (1989). An interesting and unique feature was the ability to perform fast UV spectro-photometry, with a time resolution of 0.61 sec (Katsova & Livshits 1989).

The UV telescope on the ASTRON station did not operate in a survey mode, and the number of objects observed by it was probably very restricted.

4.5. S201

The NRL experiment S201 was described by Page et al. (1982), where the revised list of sources is given. A summary of results was given by Carruthers & Page (1984c). It consisted of an electrographic Schmidt camera, which operated automatically on the Moon during the Apollo 16 mission in April 1972. The camera had a field of view of 20$^\circ$ and an angular resolution of about 3'. The limiting magnitude of the longest exposures, about 30 minutes long, was $m_{UV}=11$ (typically $m_{UV}=10$) in the spectral band 125-160 nm. The camera did not compensate for the rotation of the Moon. This caused trailing of the long exposure images, by 0'.54 per minute.

The S201 experiment obtained the first UV image of the LMC (Page & Carruthers 1981) and demonstrated the difference between its optical appearance, dominated by old, evolved stars, and the UV where hot, young stars dominate. In total, ten fields each 20$^\circ$ in diameter were observed, thus the experiment covered $\sim$7% of the sky. The results of the S201 experiment were discussed in a series of papers (Carruthers & Page 1983, 1984a, 1984b). A discussion of the UV properties of nebulae in Cygnus was published by Carruthers & Page (1976).

4.6. GUV

The GUV experiment, flown on 21 February 1987 on sub-orbital flight with the S520-8 rocket, was described by Onaka et al. (1989). It consisted of two 17 cm diameter Ritchey-Chrétien telescopes, which imaged fields 4$^\circ$ in diameter. The telescopes were of f/3.2 F=36 cm design, and the detectors used were CsI cathodes, tandem MCPs, and resistive anode readouts. The cathode response, combined with the transmission of the BaF$_2$ windows, defined a spectral band centered at 142 nm with a FWHM of 22 nm. The two sky field positions were offset by about 3 degrees and the final angular resolution, 16'x8'.2, was determined by the pixel size (2'.4), the quality of the optics, and the stability of the platform in the pointing phase.

The GUV experiment produced rather shallow stellar photometric data on general sky regions during the 133 second spin-stabilized ascent, in which 48 stars were detected, and deeper one-band photometry of the Virgo cluster during the pointed phase, which lasted 181 seconds. The limiting magnitude of the GUV experiment was approximately $m_{156}=14.6$. Unfortunately, the recovery of the S520-8 payload was not successful and the payload sank at sea, preventing the possibility of post-flight recalibration.

The GUV observations were re-analyzed by Kodaira et al. (1990), and more than 40 galaxies were detected in the Virgo cluster. The authors found correlations of UV emission with HI
flux and with FIR emission for spiral galaxies, and with X-ray and radio emission for elliptical galaxies.

4.7. SCAP 2000

This is a very interesting collaboration between the Observatoire de Genève and the Laboratoire d’Astrophysique Spatiale du CNRS of Marseille, running over more than two decades. The collaboration (supported by CNES and CNRS in France, and by FNRS in Switzerland) produced a stabilized balloon gondola (Huguenin & Magnan 1978) carrying a telescope tuned for imaging observations in the UV. The experiment was described by Laget (1980), by Donas et al. (1981), and by Milliard et al. (1983). It consists of a 13 cm Schmidt-Cassegrain reflector with a field of view of $6^\circ$ and an effective collecting area of $\approx 95 \text{ cm}^2$.

The detection was accomplished by an image converter-intensifier, which together with the mirror coatings and absorption of the few mbar atmosphere at the balloon altitude defined a bandpass centered at $\sim 200 \text{ nm}$ and $\sim 15 \text{ nm}$ wide, and was acheived mainly by multi-layer coatings of the primary and secondary mirrors. The bandpass in identical to that of the newer experiment FOCA (Milliard et al. 1991; see below). The final images of SCAP 2000 had a resolution of about 1.5-2 arcmin and a limiting magnitude of about 13.5 for sources with a spectrum similar to that of an A0 star.

SCAP-2000 surveyed about 15% of the sky, and some results, pertaining to galaxies and their derived star formation rates, were published by Donas et al. (1987) and Buat et al. (1987, 1989).

4.8. WIDE-FIELD UV CAMERA

This instrument flew in December 1983, on the same SPACELAB-1 flight which carried FAUST (see below) on its first orbital flight. The experiment was 1ES022 and was designed to image a $66^\circ$ wide field with a resolution of 5 arcmin with an all-reflective camera. The WF-UVC was affected by the high orbital background, just as was FAUST alongside it in the STS bay. Despite this deficiency, due mainly to the high straylight at the Shuttle altitude in that specific orbit, the best WF-UVC images reached $m_{193}=9.3$. A description of the WF-UVC and its results was given by Courtés et al. (1984). An interesting result was the detection of UV-bright stars along the bridge connecting the Magellanic Clouds, an extension of the Shapley wing.

4.9. FOCA

The FOCA experiment flies a 39 cm diameter telescope on a balloon gondola to altitudes higher than 40 km. There are two optical assemblies, one yielding a field of view of $1^\circ.5$ and another with $2^\circ.3$, with image resolution of $10^\prime$-20$^\prime$. The flights take place from a French launching ground (Aire-sur-Adour) and end a few hours later in Italy.

The detectors were, as for SCAP 2000, image converter-intensifiers, and the image was recorded on film. The measurements were done by PDS-ing the films, with proper calibration of the intensities. The problem with both SCAP 2000 and FOCA were altitude changes of the balloon, which modified the bandpass of observation because of the influence of the atmospheric transparency. The FOCA experiment was described by Milliard et al. (1991). The bandpass excludes contributions larger than 10% from the near UV to the visible for objects hotter than the Sun, provided the balloon altitude is higher than 3-5 mbar and the zenith distance less than 55$^\circ$ (Laget et al. 1991b).
FOCA surveyed some 70 square degrees of the sky. Some results on galactic metal-poor globular clusters were reported by Laget et al. (1991a, 1991b). One interesting feature found by the FOCA imaging is a small dark patch observed in visible against M13, which is considered to be a foreground dark cloud, but which does not show up in the UV (Laget et al. 1991a). FOCA results on UV images of nearby galaxies were reported by Vuillemin et al. (1991), and analyzed (among others) by Courtès et al. (1993, NGC 4258), Buat et al. (1994, M33), Bersier et al. (1994, M51), Reichen et al. (1994, M81) and Petit et al. (1996, M51). A study of UV galaxies in the Coma cluster was published by Donas et al. (1995). Galaxy counts and color distributions for objects in the magnitude range 15.0 to 18.5 were published by Milliard et al. (1992); these served as basis for a prediction of UV galaxy counts by Armand & Milliard (1994), which requires more late-type galaxies than predicted by optical data, or faster evolution of the galaxies.

The LAS group have a parallel ground-based observational follow-up program, for systematic identification of their UV sources. Some of their UV sources are fainter than the limit of POSS-I, requiring POSS-II data and dedicated observations at large telescopes, conducted (with collaborators) at Palomar, Keck and WIYN telescopes. This confirms the identification as blue galaxies, and their high projected density, which apparently reaches out to z=0.68 (Milliard 1996, private communication; Martin 1997). The 1°.5 field centered on the Abell 2111 cluster of galaxies contains ~450 galaxies and ~350 stars. The partial redshift survey mentioned above indicates that most galaxies are in the foreground and background, only ~20% of them belonging to the cluster. A similar study on the FOCA field centered on SA57 identified 45 sources with m_{UV} ≤18.5 with 40 galaxies, 3 QSOs and two stars (Treyer et al. 1997). The galaxies are mostly later than Sb and their UV emission is interpreted as indicating enhanced star formation rates in these objects.

During some test flights of FOCA in 1996 and 1997 the telescope was equipped with a 25 mm diameter detector which has electronic readout (resistive anode). No results have been reported yet from these flights. FOCA shall be upgraded with a 40 mm diameter detector, which matches better its focal plane, and which shall have a crossed-delay-line anode readout for high angular resolution observations.

4.10. FUV CAM

The NRL group headed by G. Carruthers flew a number of far-UV wide-field imagers (FUV CAMs) on rockets (Carruthers et al. 1978, 1980), which observed M31 and the North American Nebula. These flights used the Mark II FUV CAM, an electrographic Schmidt camera with a field of view of 11° and a (theoretical) resolution of 30". FUV CAMs flew on a number of rocket flights, and on a longer-duration space flight from 28 April to 6 May 1991, when it operated from the bay of the Space Shuttle Discovery (STS-39). The experiment was constructed by the UV astronomy group of the Naval Research Laboratory (G. Carruthers and collaborators). It consists of two electrographic cameras mounted side-by-side and bore-sighted. Each camera covers a field of view of 10°.5 square, with a final resolution of ~3 arcmin.

The images were recorded on film, which was later digitized. In order to overcome the limited dynamic range problem, each field was imaged three times, with exposure times increasing by about 3 to 10 times. The camera comprised two electrographic devices, one for the 105-160 nm band (123-160 nm with a CaF\textsubscript{2} filter), and the second for the 123-200 nm band (165-200 nm with a SiO\textsubscript{2} filter). The experiment was described by Carruthers et al (1992) and its calibration is described by Carruthers et al. (1994).
The results from the FUVCAM observations were published in a series of papers dealing with individual fields: Monoceros (15 November 1982 rocket flight, Schmidt & Carruthers 1993a, 1994), Orion (6 December 1975 and 15 November 1982 rocket flights, Schmidt & Carruthers 1993b), and Sagittarius and Scorpio (Shuttle flight, Schmidt and Carruthers 1995). Not all flights used exactly the same optical configuration, however the field of view was always very wide.

Generally, the limiting magnitude of FUVCAM is $m_{UV}=9-10$ mag and the observing band was always shorter than 200 nm and longer than Ly$\alpha$. The identification of UV sources was done routinely by correlating against the SIMBAD data base. Thus, typically about 60% of the sources were identified and between 24 and 40% of all sources could be attributed to blends of early-type stars. Among the identified sources, about half are early-B stars. The raw, uncalibrated FUVCAM images from the STS-39 flight are available on the web.

4.11. GSFC CAMERA (UIT PROTOTYPE)

A wide-field UV imager was flown by the Goddard Space Flight Center on a number of rocket flights and with different focal plane assemblies. The 31 cm diameter telescope had a field of view of $11^\circ.4$ and its spatial resolution was about 50" FWHM. The detector was, in all cases, a UV sensitive cathode with an MCP intensifier coupled to film.

Bohlin et al. (1982) described the instrument and its observations of the Orion nebula in four spectral bands (140, 182, 224, and 262 nm) obtained during a flight on 11 December 1977. Observations from a flight on 21 May 1979, when M51 was observed, are described by Bohlin et al. (1990).

Smith & Cornett (1982) reported observations of the Virgo cluster with this telescope, where the response band peaked at 242 nm and was about 110 nm wide. The sensitivity, for the Virgo cluster exposure obtained during a flight on 22 May 1979, reached $m(242 \text{ nm})=16.3$.

The experiment also imaged the LMC (Smith et al. 1987) in two UV bands, 149.5 and 190 nm with FWHM of 20 and 22 nm respectively. In the LMC, Smith et al. measured UV fluxes from 122 stellar associations, from which they derived a model for the progress of the star formation process in this very nearby dwarf galaxy.

4.12. GLAZAR

A 40 cm telescope operated briefly on the Mir space station. This is the GLAZAR-2 telescope, described by Tovmassian et al. (1991a), a direct follower of the GLAZAR-1 telescope (Tovmassian et al. 1988). Its existence and results were described mainly in Soviet publications, thus it was not well-known in the West. The limiting magnitude of GLAZAR-1 at 164 nm was originally 11 mag, but it steadily declined by about 2.5 mag from the launch and operation start in 1987 during the subsequent 2.5 years (Tovmassian et al. 1991b). This was probably a detector-related problem (Tovmassian, private communication). A few scientific results were reported in this describing paper.

The two GLAZAR telescopes have identical optical designs. They are 40 cm Ritchey-Chrétien designs, imaging a $1^\circ.3$ field of view onto a 40 mm multi-channel plate intensifier with phosphor output. The instantaneous image quality is $\sim 10^\prime$ and the images are recorded on film. The spectral range of observation is determined by a filter close to the focal plane, with $\lambda_c \approx 164$ nm and $\Delta \lambda \approx 25$ nm. The filter acts as a vacuum barrier between the telescope tube (open to space) and the detector-film transport mechanism. The film is exchanged with the telescope in a parked position against a small airlock.
GLAZAR-1 was rigidly fixed to the MIR station; the low stability of this platform yielded images of \( \sim 40'' \) FWHM, thus the low sensitivity of the detections. GLAZAR-2 was mounted on double gimbals and was equipped with coarse and fine star trackers, allowing access to wider sky areas and better image quality through independent tracking of the telescope. This allowed it to achieve \( \sim 10'' \) resolution. The film was retrieved from the MIR by the supply spaceships, was developed, digitized, and analyzed. Unfortunately, the film transport mechanism and the airlock handle were damaged soon after launch and no results were obtained. Since then (\( \sim 1990 \)), the GLAZAR-2 telescope has not been used.

Results from the GLAZAR flights, having to do with distribution and identification of blue stars, were reported by Tovmassian \textit{et al.} (1991c, 1992, 1993a, 1993b, 1994a, 1994b, 1996a). The latter, in particular, emphasizes the decrease in sensitivity of the GLAZAR; only 217 stars were detected in a field some 12 square degrees in size, with a limiting monochromatic magnitude of \( m_{164} <8.7 \) mag. The observations concentrated on OB associations. About 12 different celestial directions were observed and in each case an area of 10-20 degrees\(^2\) was imaged. On all exposures a total of 489 stars were measured.

4.13. FAUST

FAUST is the Fusée Astronomique pour l’Ultraviolet Spatiale, or the Far Ultraviolet Space Telescope. It started life as a Wynne telescope (reversed optics: the secondary being larger than the primary), whose purpose was to image the UV sky. The instrument was described by Deharveng \textit{et al.} (1979) and was originally intended for a rocket launch. This version of the instrument was used for at least two successful flights, mainly used for calibrations.

The field of view of FAUST was \( \sim 8^\circ \) and the angular resolution was 1-2 arcmin. On SPACELAB-1, during a flight on board the Space Shuttle in December 1983, FAUST did not succeed to obtain significant data, although 47 exposures of 22 targets were obtained on film, behind an image converter-intensifier. Unfortunately, the on-orbit background was very high and almost no objects were recorded. From the few exposures which could be analyzed it is worth mentioning an interesting image of the Cygnus Loop, published by Bixler \textit{et al.} (1984).

For its second orbital flight FAUST was equipped with a new detector, which incorporated a CsI cathode, a three-stage chevron arrangement of MCPs, and a novel wedge-and-strip anode. The flight took place on board the Shuttle Atlantis in March 1992, and was described by Bowyer \textit{et al.} (1993). During this flight FAUST telemetered every detected photon. This allowed the rejection of spurious photons, originating from the firing of the Shuttle attitude jets or from high orbital background. FAUST observed 22 fields, among which were the North Galactic Pole, the Virgo cluster of galaxies, and other galaxy clusters and regions of interest. FAUST’s observations yielded a catalog of 4698 UV sources (Bowyer \textit{et al.} 1995), measured in a band about 30 nm wide which was centered at 165 nm. The band was defined by the CsI cathode and a CaF\(_2\) window with multi-layer coatings. The detection was by an impartial automatic algorithm, and the identification was through correlations with existing catalogs.

Selected results were published from the FAUST imagery obtained during the second flight. Deharveng \textit{et al.} (1994) analyzed the UV emission of galaxies. Haikala \textit{et al.} (1995) imaged a galactic cirrus cloud and showed the good correlation between the UV diffuse emission and the IRAS 100\(\mu\)m emission, from which they constrained the albedo \( a \) and the isotropy parameter \( g \) of the dust particles. Sasseen \textit{et al.} (1995) used the spatial power spectrum of FAUST images to search for an extragalactic UV background component. Sasseen & Deharveng (1996) correlated the UV background detected by FAUST with the 100\(\mu\)m FIR emission measured by COBE/DIRBE.
An interesting result was published by Courtés et al. (1995). It is a confirmation of the UV extension of the Shapley wing of the SMC, first detected with the WF-UVCAM (Courtés et al. 1984). The FAUST observations are deeper (m_UV < 13.9) and have better angular resolution than those of the WF-UVCAM. The observations confirm the earlier findings that the Shapley wing contains a population of young stars formed at most 5 Myr ago with an IMF which is flatter than that of the stars in the SMC core (M_up < 30M☉), i.e., later than mid-O type. The FAUST observations of the SMC, combined with FIR, HI and Hα data, form part of the thesis of Okumura (1993).

A program to systematically investigate the FAUST data set takes place at Tel Aviv University. We re-detect sources with a different automatic algorithm, based on local S/N ratio. After attempting correlations with existing catalogs, we apply astrophysical criteria to identify the sources. About 10-15% of the sources remain unidentified after this procedure. These are identified with possible counterparts on the Palomar Sky Survey and the counterparts are observed from the Wise Observatory. To date, we analyzed completely five FAUST fields, the North Galactic Pole (Brosch et al. 1996a), three fields covering most of the Virgo cluster (Brosch et al. 1997), and one image in the direction of Coma (Brosch et al. 1998). Analysis of other fields (Ophiuchus and other southern fields) is very advanced.

The main results concern the distribution of UV stars, and in the case of the Virgo cluster, also measurements of some 90 galaxies. In the Coma field we identified a large population of hot evolved stars, which are probably connected with the open cluster Mel 111. In total, the FAUST frames analyzed so far at Tel Aviv yielded ~100 galaxies and a few hundred stars.

4.14. UIT

The Ultraviolet Imaging Telescope (UIT) was described by Stecher et al. (1992). It consists of a 38 cm diameter Ritchey-Chrétien telescope with a 40 arcmin field of view (about 200 times larger than the WFPC2 of the HST). The telescope was mounted on the Instrument Pointing System in the Space Shuttle bay for the ASTRO-1 (December 1990) and ASTRO-2 flights (March 1995). In addition to the tracking capabilities of the IPS used in the ASTRO flights, the UIT was equipped with an articulated secondary mirror, which provided even finer tracking.

The focal plane consisted of two image converter-intensifiers, one for the far-UV and the other for the mid-UV range. The image tubes were coupled to film on which the images were registered. The film frames were digitized to a 2048×2048 pixel format, and to enhance the dynamic range, multiple exposures of different duration were taken through each filter. During the ASTRO-1 flight more than 800 exposures were taken. The evaluation of the UIT results from the ASTRO-1 flight indicates a resolution of about 3" and a sensitivity sufficient to register stars of UV monochromatic magnitude 19.5 (for a hot, unreddened source: O’Connell 1992). However, for an indication of the actual sensitivity, see below.

First results from the UIT mission were published in a 1992 dedicated volume of the Astrophys. J. Letters (vol. 395). The papers discuss the UV scattering properties of dust in NGC 7023 (Witt et al. 1992), observations of the Cygnus Loop (Cornett et al. 1992), of the Crab Nebula (Hennessy et al. 1992), of globular clusters such as M79 (Hill et al. 1992a) and ω Cen, M3 and M13 (Landsman et al. 1992), of SN 1987A (Crots et al. 1992), the SN environment and 30 Doradus (Cheng et al. 1992), of the association NGC 206 in M31 (Hill et al. 1992b), of M81 (Hill et al. 1992c), of NGC 628 (Chen et al. 1992), of M33 (Landsman et al. 1992), of nearby galaxies (O’Connell et al. 1992), and of NGC 1275 (Smith et al. 1992).

Most of the final results from both UIT flights have not yet been published, but some were reported at meetings (notably, at AAS meetings). I mention in particular published studies of
nearby galaxies (M31: Hill et al. 1995a, and Magellanic Clouds: Hill et al. 1993, 1994, 1995b), mostly from the ASTRO-1 flight. Pica et al. (1993) mention a catalog of ~2,200 sources observed near 250 nm derived from images of 66 fields obtained in the ASTRO-1 flight. Of these, about 300 did not have counterparts in published catalogues. The catalog (Smith et al. 1996) covers 16 square degrees of the sky and contains 2,244 objects culled from 48 pointings. The identification was done through correlations with optical catalogs and, in fact, most sources are from the HST Guide Star Catalog. The percentage of identified sources is 88%, mainly because of the good spatial resolution of the images.

Unfortunately, the UIT catalog was based only on the near-UV (165-290 nm) observations of the ASTRO-1 mission; during the ASTRO-2 mission this camera failed and no observations were obtained. The catalog lists the sources obtained in the 48 selected fields, where the typical exposure depth (though by no means the completion limit) was 17.2 mag.

From the ASTRO-2 flight, Neff et al. (1995) reported that some 30 peculiar galaxies have been observed in one or two UV bands (B1: 125-180 nm and/or B5: 140-180 nm). The galaxies include interacting, starburst and/or active objects. Smith et al. (1995) reported at the same meeting that five clusters of galaxies were observed during the ASTRO-1 flight, and additional clusters were included among the targets observed during the ASTRO-2 flight. A recent interesting paper (Hill et al. 1997) combines ASTRO-2 UIT observations at 152 nm and optical imagery to determine the colors and extinctions of HII regions in M51. The authors find that the total-to-selective extinction $A(152)/E(B-V)$ in M51 increases with radius (or with decreasing metallicity). In addition, they find that the Hα flux is depleted in the inner regions of the galaxy; this they interpret as increased Lyman continuum extinction. Parker et al. (1996) studied a few OB associations in LMC using ASTRO-2 data at 152 nm.

O’Connell & Marcum (1996) remarked, from UIT images of galaxies, that a comparison of visible and UV images of the same nearby galaxies indicates a trend from normal to abnormal, galaxies turning into later morphological types with a higher incidence of irregular galaxies as the wavelength of observation gets bluer. A similar claim was also made by Giavalisco et al. (1996), based on simulated HST images using UIT images of nearby galaxies. Other papers on galaxies, resulting from UIT imagery are by Waller et al. on M101 (1997), by Smith et al. on NGC 3310 (1996b), on the SMC by Cornett et al. (1997), and a number of papers in the proceedings of the Seventh Astrophysics Conference (Holt & Mundy 1996) by Waller et al., Fanelli et al., Neff et al., Hill et al., Smith et al. and O’Connell.

The UV images of nearby galaxies obtained by UIT are the baseline templates showing how galaxies appear in the UV, with which one can begin to understand the images of distant galaxies taken by HST in optical bands; these correspond to rest-frame UV, proving the comparison valid (Giavalisco et al. 1996).

4.15. UVISI

The UVISI instrument operated on-board the Mid-Course Space Experiment (MSX) satellite. The mission was primarily military in character (BMDO), aiming at detecting and characterizing sources of UV emission (or atmospheric opacity), which could affect the detection, identification, and tracking of missiles and warheads. As side-benefits, these missions will produce full or partial sky surveys in the UV. MSX was launched on 24 April 1996 and the operation of UVISI started in 1997 and ended in early 1998.

The UVISI instrument consists of five spectrographic imagers and four imagers (Carbary et al. 1994). The narrow-field UV imager is of interest to UV sky surveys. It images a $1^\circ.6 \times 1^\circ.3$ field of view with a resolution of $\sim 20^\prime$ in one of three spectral bands from 180 nm to 300 nm (180-300,
200-230, or 230-300 nm; J. Murthy, private communication). There is also a wide field imager, with a FOV of 10° × 13° and a resolution of ∼3’. The detectors are CCDs coupled through fiber-optic tapers to the phosphor outputs of image intensifiers. Based on the description of UVISI (Heffernan et al. 1996), the narrow field UV imager with no filters is sensitive to sources which produce 2 photons/cm²/sec; this should be equivalent to a limiting magnitude of 13.9 (monochromatic, at the band center, 240 nm). However, J. Murthy communicated an effective sensitivity limit of m_UV = 20.0. The results of the UVISI observations have not yet been put in the public domain.

4.16. HST

Although far from being a survey instrument, the HST has some UV capability with its WFPC-1 or WFPC-2 cameras, and with the FOC instrument. However, the long-wavelength rejection of light by the WFPC filters is not fully satisfactory, with the notable exception of the F160BW “Woods” filter. Far UV observations suffer from red leaks, requiring complicated compensatory measurements. The FOC has better rejection of optical light because of its cathode. Both cameras have small fields of view: 2.6’ for WFPC-1, 2.5’ for WFPC-2 (total sky coverage 5.02 arcmin²), 44” for the pre-COSTAR FOC, and 28” for the post-COSTAR FOC (7” with full sampling of the PSF and with ∼1.55% efficiency). An example of the UV capability of the FOC is the snapshot survey of nuclei of galaxies (Maoz et al. 1996), where circumnuclear star-forming rings were identified in a few objects through 230 nm imaging.

The new instrument STIS has significant UV capabilities with the MAMA detectors. These have a throughput higher by one order of magnitude or more than the WFPC-2 with UV filters (F160BW or F170W), but their largest field of view is only 25” × 25”. In particular, the far-UV (FUV) MAMA with the Csi cathode and SrF₂ short band cutoff filter allows one to reach very low background values while retaining reasonable throughput (∼2.5% at peak). STIS with the FUV MAMA and the SrF₂ cutoff filter have a throughput higher by ∼27× than that of WFPC-2 with the F160BW filter. This “almost” compensates for the field-of-view, which is smaller by ∼29× than that of the WFPC-2, disregarding the region vignetted when the F160BW filter is used.

The next servicing mission for the HST, currently scheduled for December 2 1999, will see the installation of the Advanced Camera for Surveys (ACS). This instrument is designed with three separate channels, of which one has a UV capability and another is a solar-blind channel. The High Resolution Camera shall cover a field of view of 27” × 26” with a plate scale of 0”.025/pixel using a 1024×1024 CCD. The spectral range covered shall be from 200 to 1000 nm with a net efficiency of ∼15% in the UV part of the band. The Solar Blind Camera shall cover a FOV of 33” × 30” (1.6× that of the STIS FUV MAMA) with a plate scale of 0”.03/pixel using a spare MAMA detector from STIS, with a net efficiency of ∼4% at 140 nm.

The latest instrument (for the time being) selected for an HST upgrade is the Cosmic Origins Spectrograph (COS). This shall replace COSTAR during the fourth HST servicing mission in 2002. It is an instrument optimized for high-throughput spectroscopy of point sources in the 115-205 nm band. The high throughput is achieved by minimizing the number of reflections between the aperture and the detector (a single reflection, at the grating), allowing more than one order of magnitude improvement in this aspect relative to STIS. The spectral resolution can be high (R∼20,000-24,000) or intermediate (R∼2,500-3,500). The estimated sensitivity is such that, in high resolution mode, a source with monochromatic magnitude 15.6 will produce a spectrum with S/N=10 per resolution element in 10,000 sec.

Based on the “survey power” parameter θ to be described below, UV imaging by the HST
has significant survey potential, despite the small sky area it can cover. In fact, while a STIS-based survey would only be $\sim 1.6 \times$ more effective than one with the WFPC-2, a survey with the ACS/SBC would be $\sim 45 \times$ better.

4.17. BACKGROUND MEASUREMENTS

Attempts to measure the diffuse UV background in the TD-1 era are lumped together in one section. They consist of observations by the UV photometer on the Apollo-Soyuz mission (Paresce et al. 1980), the measurements of the D2B-Aura satellite (Maucherat-Joubert et al. 1980, Joubert et al. 1983, Lequeux 1982), sky measurements from a rocket flight (Jakobsen et al. 1984), and from the Dynamics Explorer satellite (Fix et al. 1989), and by the two Shuttle-borne UVX instruments from JHU and Berkeley (Murthy et al. 1989; Hurwitz et al. 1989). In addition, observations done for other purposes but used to derive the UV background were by Zvereva et al. (1982), Weller (1983), Onaka (1990), and Jakobsen et al. (1984). The UVX observations yielded one of the lower background values at 160 nm: $280 \pm 35$ c.u. (Martin et al. 1991).

The FAUST instrument has been used to derive the UV background, with the emphasis on an attempt to disentangle the Galactic from the extragalactic signal based on spatial power spectra (Sasseen et al. 1995). Their best explanation for the signal detected is that it is due to starlight scattered off dust grains. This is apparently confirmed by the correlation between the UV background measured by FAUST and the 100$\mu$m FIR emission measured by COBE/DIRBE (Sasseen & Deharveng 1996).

The observations of UIT have also been used to analyze the UV background. Waller et al. (1995) quote orbital night-time background levels of $\sim 3000$ ph/sec/cm$^2$/ster in the near-UV band ($\sim 250$ nm) and $\sim 5000$ ph/sec/cm$^2$/ster in the far-UV band ($\sim 150$ nm). After correcting for instrumental and orbit-dependent effects, and compensating for galactic diffuse UV radiation through a correlation of UV and FIR diffuse emission, Waller et al. identified a possible extragalactic component of $200 \pm 100$ c.u. As will be discussed later, the UIT background measurements and some deep Voyager UV spectra are now the strongest constraints for a cosmologically interesting UV background. It appears that these constraints conflict extrapolated UV observations of faint galaxies.

5. Modern EUV observations

5.1. ROSAT WFC

The EUV sky was explored almost simultaneously by two instruments. The ROSAT EUV Wide Field Camera was an add-on instrument to the ROSAT X-ray all-sky survey satellite. Its first results, and a description of the instrument, were published by Pounds and Wells (1991). The camera consists of a nested three-mirror Wolter-I telescope with a MCP detector equipped with a CsI cathode at the common focus of the mirrors. Selectable filters allow observations in four spectral bands: 52-73 nm (17-24 eV), 14.9-22.1 nm (56-83 eV), 11.2-20 nm (62-111 eV), and 6-14 nm (90-210 eV).

The first EUV all-sky survey was performed by this instrument during 1990-1991 (Pye 1995). The survey was done in two bands: S1 (6-14 nm) and S2 (11.2-20 nm). The effective spatial resolution was 3 arcmin and the source location was good to within one arcmin. The initial results were reported by Pounds et al. (1993) as the WFC Bright Source Catalog (BSC). The reprocessed data, with more sources, were published by Pye et al. (1995) as the 2RE catalog.

The 2RE catalog contains 479 EUV sources, 120 more than the BSC, observed with a median exposure of about 1600 sec. Of the entire 2RC catalog 52% of the sources are identified as active,
late-type (F, G, K, and M) stars; 29% are hot white dwarfs, and less than 2% are extragalactic sources (AGNs). Thirty-four sources (about 7%) were still unidentified in 1995 (Pye et al. 1995). The cumulative source distribution indicates that the late-type stars dominate the source counts at faint count rates (< 0.02 cps), surpassing the contribution from white dwarfs.

5.2. ALEXIS

The region bordering the EUV and the X-rays was explored by the ALEXIS spacecraft (Priedhorsky 1991). ALEXIS stands for “Array of Low Energy X-ray Imaging Sensors” and consists of an array of six wide-field small telescopes with multi-layer coated mirrors with prime-focus imaging detectors, and sensitive to radiation at 66, 71, or 93 eV (18.8, 17.2, and 13.3 nm). The passbands are defined by the mirror coatings and by filters positioned in front of the detectors. Recent descriptions of ALEXIS are by Bloch (1995) and by Roussel-Dupré & Bloch (1996).

Unfortunately, during the Pegasus launch on 25 April 1993 the satellite was damaged, lost one of its four solar panels, damaged the on-board magnetometer used for position-sensing, and entered an uncontrolled spin. This reduced the available electrical power and questioned the effectiveness of the survey. The spacecraft was eventually stabilized and effective observations could be made from mid-July 1993. ALEXIS points its six telescopes perpendicular to the Sun-Earth line and scans the sky with them every 50 seconds. The attitude of the satellite is known to better than 0.5° and the information collected is received at a Los Alamos ground station.

The EUV telescopes of ALEXIS are arranged in three co-aligned pairs. Each has a 33° field of view and a resolution of 0.25 (limited by the spherical aberration of the mirrors). The first sky maps of ALEXIS were produced on 4 November 1994. Since 1995, the daily maps are searched for EUV transient sources, with a 12-24 hour response time. The transients are then searched for in the error ellipse of ALEXIS by ground-based telescopes, and are followed up. Among the more interesting EUV transients the more notable are the super-outburst of VW Hyi in June 1994, the ALEXIS J1114+43=1ES 1113+432 outburst in November-December 1994, and the fast transient ALEXIS J1139-685. In addition, outbursts from U Gem, AM Her, and AR UMa were also detected. Some results on transient EUV sources were reported by Roussel-Dupré et al. (1996).

Using the pre-flight information, the ALEXIS team calculated that ~10% of the brightest EUVE sources (see below) should be detectable (Jeff Bloch, private communication), and apparently this is the situation. Most of the sources are WDs, and it is expected that the catalog from the first three years of operation will contain ≤ 50 sources.

5.3. EUVE

The EUV sky was thoroughly investigated by the Extreme Ultraviolet Explorer (EUVE) spacecraft, launched on June 7, 1992. (Bowyer & Malina 1991). The instrument consists of three “scanning” telescopes, co-aligned and perpendicular to the spacecraft spin axis, which have a 5° field-of-view, and a deep survey spectrometer telescope looking along the spin axis and pointing away from the Sun. The angular resolution is ~1 arcmin.

EUVE mapped the sky in four spectral bands, from 7 to 70 nm (18 to 170 eV). The initial results were published as “The First EUVE Source Catalog” (Bowyer et al. 1994), which contains 410 sources. A Second EUVE Source Catalog has also been published (Bowyer et al. 1996). For the foreseeable future, the EUVE catalogs set the standard in the knowledge of the EUVE sky.

The second EUVE catalog includes additional observations to those from the all-sky survey. In total, there are 734 sources, of which about 65% have optical, UV, X-ray, and/or radio
counterparts. It is noteworthy that 211 of these sources were never before observed in the EUV range. The majority of the identified sources (55%) appears to be late-type stars (G, K, and M), which presumably have active chromospheres.

The observation that large numbers of late-type stars are detected as EUV sources is supported by the findings of the “right angle” survey, which has the deepest sensitivity. These observations are typically $10^4$-$10^5$ sec, whereas the typical observations used for the derivation of the catalog are $\sim$500 sec, thus the right angle survey can detect much weaker sources than in the general survey. The late-type stars make up almost half the sources in the right angle survey, whereas they are only less than a third of the sources in the general sky survey. The late-type stars are also the absolute majority among the EUV sources detected in the “ecliptic deep survey”, another sky region with very high exposure ($\sim$20,000 sec/pixel over a $2^\circ\times 180^\circ$ area along the ecliptic). Among all the sources, $\sim$8% are identified with extragalactic objects. Bowyer et al. (1996) compared the second EUVE catalog with other EUV surveys. They find that 263 (of the 479) 2RE sources appear in the new catalog, and note that the undetected sources are either variable or belong to the “unidentified” category of faint sources that may be spurious.

A new catalog, reaching sources fainter by $\sim$60% than the second EUVE catalog, has been produced by Lampton et al. (1997). The catalog is based on coincident sources between the EUVE 10 nm list and the ROSAT all-sky survey sources detected in the broadband event window (0.1-2 keV). It contains 534 EUV sources, of which 166 were not previously discovered. Of these, 105 have been identified and 77% of them are late-type stars. White dwarfs and early-type stars make up only $\sim$14% of the sources, and there are no extragalactic objects at all among them.

One important outcome from the EUVE mission is the first Spectral Atlas in the EUV range (Craig et al. 1997). The Atlas contains EUV spectra of 95 stars ranging from bright B stars to M dwarfs, white dwarfs, and cataclysmic binaries.

5.4. UVS, HUT AND ORFEUS

One should note that some information about the EUV properties of stars and galaxies was obtained with the Voyager Ultraviolet Spectrometers (UVS), and with the Hopkins Ultraviolet Spectrometer (HUT) and ORFEUS (Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometer) flights. While the UVS instruments use non-imaging optics to record the EUV spectra of bright objects, HUT and ORFEUS used imaging telescopes to study spectra in the FUV range.

The generic UVS instrument installed on both Voyager spacecraft was described by Broadfoot et al. (1977). It consists of a mechanically collimated objective grating spectrometer covering the range 50-170 nm with 1 nm resolution and was included in the Voyager missions primarily to study the composition and structure of the atmospheres of giant planets and their satellites. Due to the long cruise periods between planetary encounters, the Voyager UVS instruments were uniquely able to make deep FUV observations of stars (e.g., Chavez et al. 1995), galaxies (Alloin et al. 1995), and the interstellar medium (Lallement 1993).

HUT is a 0.9-meter telescope which operated from the Space Shuttle bay while mounted on the instrument pointer of ASTRO, alongside the UIT and WUPPE telescopes. A description of the instrument and its calibration was published by Davidsen et al. (1992). Briefly, HUT performed spectroscopy in the 91.2-185 nm band with a resolution of $\sim$0.3 nm, and in the second order, in the 41.5-91.2 nm band with $\sim$0.15 nm resolution. The effective area of HUT ranged up to 10 cm$^2$ for the ASTRO-1 flight, and up to 25 cm$^2$ for the second flight. Note that
HUT suffered a steady decrease of sensitivity at short wavelengths throughout the flight; a 25% reduction at 80 nm from flight start to close to the end of the ASTRO-2 flight. The results from the two flights of HUT were reported in some 60 papers, ranging from the Moon’s UV emission (Henry et al. 1995) to a search for the signature of decaying heavy neutrinos (Davidsen et al. 1991).

ORFEUS flew twice on the ASTRO-SPAS platform with a 1.0-meter telescope and spectrographs covering the range 40-115 nm (R=3000) and 90-125 nm (R=10,000). The same ASTRO-SPAS platform carried the Interstellar Medium Absorption Profile Spectrograph (IMAPS; Princeton University). In this instrument, a mechanical collimator restricts the FOV to $\sim 1^\circ$ and feeds an echelle spectrograph with R$\leq 120,000$ in the range 95 to 115 nm. This is intended for the study of ISM absorption profiles in the spectra of bright stars. Results from the IMAPS experiment were reported by Jenkins et al. (1996).

OREFUS had $\sim 5$ cm$^2$ effective area in the 40-90 nm band and $\sim 9$ cm$^2$ in the 90-120 nm. Its main results, from the first flight, include the discovery of the S and P elements in the photospheres of two white dwarfs (Vennes et al. 1996), various studies of coronal gas (e.g., Hurwitz et al. 1995; Hurwitz & Bowyer 1996) and an analysis of the DO white dwarf HD149449B (Napiwotzki et al. 1995). An interesting result was also the analysis of the O3If star HD93129A (Taresch et al. 1997); this object has a ZAMS mass of 120 M$_\odot$. The ORFEUS results from the second flight are being prepared for publication in a special Astrophys. J. Letters issue.

6. Modeling the UV sky

In parallel with observations by rocket and satellite instruments, attempts to simulate the UV sky were made, e.g., by Henry (1977). He used a transformation from optical to UV based on Apollo 17 measurements of bright, early-type stars and data from other experiments for cooler stars at 148.2 nm. Data for other spectral regions were based on model atmospheres from Kurucz et al. (1974). The transformations used are described in Henry et al. (1975) and are essentially linear relationships between the photon flux and the (B-V) color of a star for all UV bands longward of Ly$\alpha$. Henry (1977) calculated that to approximate the total UV starlight it is not necessary to observe very faint stars; most of the UV light originates in relatively bright (apparent) stars because of the influence of the interstellar extinction.

Gondhalekar & Wilson (1975) used a simple model for the distribution of stars (plane-parallel distributions of different scale heights for various types of O, B and A stars) to calculate the interstellar radiation field between 91.2 nm and 274 nm. Gondhalekar (1990) used this model to calculate the integrated UV emission by starlight in the Galaxy. The UV observations of TD-1 were used along with model atmospheres to derive stellar properties in the UV. These were combined with parameters of interstellar dust and the spectrum of the diffuse UV background was derived. This was then compared successfully with measurements by Kurt & Sunyaev (1968), Hayakawa et al. (1969) and Henry (1972).

Two UV sky models were published in the last decade, by Brosch (1991) and by Cohen (1994), later adopted for the FAUST bandpass by Cohen et al. (1995). The Cohen (1994) model consists of a complicated model of the galaxy, with a disk, a halo, the bulge, spiral arms and two local spurs, as well as the Gould belt. The model of Brosch (1991) is a much simpler adaptation of the Bahcall & Soneira (1980) disk-bulge galaxy model, to which the Gould belt was added, along with a thick disk of white dwarfs, where the distribution followed the scale height of Boyle (1989).

The two models use different approaches in modeling the UV sky. While Cohen (1994) creates absolute UV magnitudes for every class of objects used by the model, Brosch (1991) calculates
a transformation from visible to UV using observed properties of IUE standard stars. The approach used by Cohen employs model atmospheres from Kurucz (1991) and integration across the filter bandpasses to yield the required [UV-V] color indices. Later unpublished developments of the Brosch (1991) transformations use Kurucz (1992) stellar atmosphere models to extend the optical-to-UV transformation to later stellar types.

Cohen (1994) tested successfully his model against the TD-1 results and against those of the S201 Apollo 16 Moon telescope measurements. In a later paper (Cohen et al. 1995) the predictions of the model were tested against the detailed spectral distribution of stars in the North Galactic Pole region identified by Brosch et al. (1996) in the FAUST observation.

Similar encouraging results were obtained by Brosch (1991) in comparisons with the S201 measurements. The visible-to-UV transformation, derived by Brosch (1991) from IUE spectra, was later used by Bilenko (1995) to verify a method of determining the three-dimensional distribution of UV extinguishing ISM clouds. The method uses the transformation to predict the apparent UV magnitude of a star, based on its known optical properties as listed in the Hipparcos Input Catalog (HIC). The expected UV magnitude is compared with that measured by TD-1 and the total UV extinction is determined. Knowledge of the distance modulus (from the HIC data) for an entire stellar population in a given sky region, allows one to locate the extinguishing dust clouds in 3D space.

In Figure 4 I show how well can one predict the UV magnitude of a star, when the only known parameters are the V and B magnitudes. The comparison is done for stars in the direction of Virgo, appearing on three images obtained by the FAUST experiment. The optical information of magnitude and color is obtained from the Tycho data set.

**Figure 4.** Predicted vs. observed UV magnitudes at 165 nm for stars in the three FAUST fields on Virgo. The transformation relies on IUE observed spectra of stars as well as on Kurucz (1992) model atmospheres.
The diffuse UV sky background has been modeled by Murthy & Henry (1995). In this paper there are references to previous models accounting for the UV background. Note though that not all published simulations attempt to explain the faint UV sources. Extragalactic objects, such as large or dwarf galaxies, AGNs, and QSOs, are not included in any simulation. Nor has there ever been a satisfactory accounting for the patchiness of the interstellar dust in the models, with the possible exception of a recent account by Witt et al. (1997), when analyzing the UV observations of FAUST.

7. Comparison of Survey Missions

The various missions surveying the UV sky can be compared in terms of a “power” parameter \( \theta \) introduced by Terebizh (1986) and used by Lipovetsky (1992) in a comparison of optical surveys:

\[
\theta = \frac{\Omega}{4\pi} 10^{0.6(m_L - 10)}
\]

where \( \Omega \) is the sky area covered by the survey (\( 4\pi \) for TD-1) and \( m_L \) is the limiting (monochromatic) magnitude of the survey. An all-sky survey to a limiting magnitude \( m_L \approx 8.5 \) (such as done by TD-1), has the same “survey power” as a single HST WFPC-2 image exposed to show 21st mag UV objects. The different UV and EUV missions discussed here are compared in Table 3 in terms of their survey power.

A parameter similar to \( \theta \), to compare missions whose goal was to estimate the diffuse UV background, was introduced by Henry (1982):

\[
S = \frac{100}{A \Omega \Delta \lambda}
\]

where \( A \) is the collecting aperture of the experiment, \( \Omega \) is the solid angle of its field of view, and \( \Delta \lambda \) is the spectral bandpass of the observation. Henry compared a number of experiments and concluded that the Voyager UVS had the largest \( S \)-parameter.

In order to evaluate the UIT performance as a survey instrument for point sources, I assume that the ASTRO-1 flight imaged 66 fields and ASTRO-2 flight another 100 fields, and that the depth of the UIT survey was \( m_L = 20 \). For the diffuse background case, I take the spectral bandwidth to be 100 nm. Among the “future missions” categories I assume that GIMI will ultimately conduct a full sky survey. In comparing TAUVEX and the UV/Optical monitor of XMM, I assume the same mission duration and mode of operation for SRG and XMM. For HST, I assume that 1000 independent WFPC-2 pointings with the F160BW filter, 1000 with STIS FUV MAMA and SrF\(_2\) and 1000 pointings with the ACS/SBC (see below) could be assigned under a parallel imaging program. The sensitivity of the ACS/SBC is assumed to be slightly higher than that of the STIS FUV MAMA, because of their reduced number of reflections.

For MSX/UVISI the sensitivity is that of the high resolution imager. A full analysis of this data set is not yet available. For the purpose of comparison, I assumed that UVISI performed 400 independent pointings, yielding a sky coverage of 400 degrees\(^2\) with the high resolution images and perhaps 4,000 degrees\(^2\) with the wide field imager. The difference in the expected performance of the XMM/OUVM and that of the SRG/TAUVEX lies in the multiple-telescope design of TAUVEX, which allows pure-UV simultaneous observations in three bands, compounded by its larger field of view. The large value of \( \theta \) for GALEX, despite the similar \( m_L \) to that of TAUVEX, results from the all-sky coverage. For GALEX, the comparison is done with the published expectations for the all-sky survey phase, and the limiting magnitude for 200 nm has been transformed from the AB system to 200 nm monochromatic magnitudes.
TABLE 3. UV and EUV survey missions

| Mission      | Year  | Ω (ster) | mL     | θ (°/′) | λλ (nm) | N_{sources} | Notes                  |
|--------------|-------|----------|--------|---------|---------|-------------|------------------------|
| TD-1         | 1968-73 | 4π      | 8.8    | 0.19    | 150-280 | 31,215      | 1                      |
| S201         | 1972   | 0.96     | 11     | 0.30    | 125-160 | 6,266       |                        |
| WF-UV CAM    | 1983   | 1.02     | 9.3    | 0.03    | 193     | ?           |                        |
| SCAP-2000    | 1985   | 1.88     | 13.5   | 18.9    | 200     | 241         | 2 Pointed phase        |
| GUV          | 1987   | 5 10^{-3} | 14.5  | 0.2     | 156     | 52          |                        |
| GSFC CAM     | 1987+  | 0.03     | 16.3   | 14.4    | 242     | ~200 Virgo observation |            |
| FOCA         | 1990+  | 0.02     | 19     | 377     | 200     | ~4,000 Estimated |                        |
| UIT-1        | 1990   | 3.8 10^{-4} | 17     | 0.48    | ~270    | 2,244 UIT catalog |            |
| GLAZAR       | 1990   | 4.4 10^{-3} | 8.7    | 6 10^{-4} | 164     | 489         |                        |
| FUVCAM       | 1991   | 0.09     | 10     | 7.5 10^{-3} | 133, 178 | 1,252       | 3                      |
| FOUST        | 1992   | 0.33     | 13.5   | 3.3     | 165     | 4,698       |                        |
| UIT 1+2      | 1990, 95 | 1.3 10^{-3} | 19    | 26      | 152-270 | 6,000 ? 4  |                        |
| HST WFPC     | 1990+  | 4.3 10^{-4} | 21.0   | 134.8   | 120-300 | 50,000 ? 5  |                        |
| HST STIS     | 1997+  | 1.5 10^{-5} | 23.8   | 222.7   | 120-200 | 10,000 ?    |                        |
| HST ACS/SBC  | 1999+  | 2.4 10^{-5} | 24.0   | 480     | 120-170 | 10,000 ?    |                        |
| MSX UVISI    | 1997-98 | ~0.01   | 18.0   | 50      | 180-300 | ? 6         |                        |
| ARGOS GIMI   | 1998+  | 4π       | 13.6   | 136     | 155     | 2.5 10^{5} | 7                      |
| SRG TAUVEX   | 1999+  | 0.06     | 19     | 1200    | 135-270 | 10^{6}     | 8                      |
| XMM OUVM     | 1999+  | ~6 10^{-3} | 19     | ~100    | 185-600 | 10^{5} ?    |                        |
| GALEX        | 2002+  | 4π       | 19.4   | 4.4 10^{6} | 130-300 | 2 10^{7} | 9                      |
| WFC          | 1992   | 4π       | -      | -       | 10, 16  | 479         |                        |
| ALEXIS       | 1994+  | 4π       | -      | -       | 13-19   | 50 ?        |                        |
| EUVE         | 1992   | 4π       | -      | -       | 7-70    | 734        | 10                     |

Notes to Table 3:
1: The unpublished extended version has 58,012 sources.
2: 92 stars (Laget 1980) and 149 galaxies (Donas et al. 1987).
3: Only the Sag and Sco fields (Shuttle flights) included.
4: Assumes 66 pointings for ASTRO 1 and 100 for ASTRO 2.
5: Assumes 1000 observations with HST for each of the following combinations: WFPC-2+F160BW, STIS FUV MAMA+SrF2, and ACS/SBC.
6: Numbers are calculated for the high resolution imager; the wide field imager has a much smaller θ. 7: Assumes 2× stars per magnitude w.r.t. TD-1.
8: Assumes 5000 independent pointings to end-of-life.
9: mL transformed from AB; data refers to the all-sky imaging survey (AIS) phase.
10: Number of sources in the 2nd EUVE catalog.

Because of the “unfair” comparison based on θ, and because not all surveys cover the entire sky, it may be more useful to look at another estimator, the density of sources detected (or which are expected to be detected) by a certain experiment, shown in Figure 5. Expected results from a hypothetical HST survey with the ACS/SBC have not been plotted in the figure, but they are expected to be significantly deeper than those of GALEX DIS.

8. The Resultant Sky Picture

Any idea we may form of the appearance of the UV sky is necessarily limited by the existence of a single all-sky survey in the UV (TD–1) and by the deeper surveys in limited regions of the
Figure 5. Source density in the UV for various sky surveys. All-sky and partial surveys (past or future) are included.

sky. Comparing the number of UV sources charted by TD–1 with similar mapping done in the optical we are forced to conclude that the status of UV astronomy is now at par, in the number of sources, with the Carte du Ciel catalogs from the end of the last century. The importance of knowing the properties of a large number of sources is the astronomical analog of the biological “diversity of species” argument; the more species are identified, the higher is the chance of discovering a new phenomenon. By skipping the stage of deep and extensive mapping of the sky in the UV, the astronomers may be missing the discovery of some new types of sources.

I compared above the status of the UV sky knowledge in the post-TD-1 era to that which prevailed in optical astronomy at the turn of the 20th century. In the same vein, our knowledge of the EUV sky in the post-EUVE era can be compared to a naked-eye look at the sky on a misty night; very few stars, only the brighter or nearer ones, can be seen. The present EUV catalogs are at par, in the number of sources, with the catalogs of Hipparcos (127 BC), Tycho Brahe (1601), and Hevelius (1660). If a full-sky survey could be conducted to the depth of the right angle survey of EUVE, it would presumably record some 50,000 sources, about 100 times fainter than those of the “Second EUVE Source Catalog” from the full-sky survey.

The picture resulting from the all-sky survey of the TD-1 mission, from the EUVE and ROSAT WFC surveys, and from the limited surveys performed previously is that of a UV sky dotted with many stellar and extragalactic sources, where the background is produced by natural emissions ($\text{Ly}_\alpha$, other emission lines), and/or by UV light scattered off dust clouds. In sharp contrast, the opacity of the ISM is such that in the EUV range, only the more intense and/or nearby sources are detectable.

In this section I discuss the accumulated knowledge on different types of celestial objects and
on the diffuse background, both for the UV and for the EUV ranges. The various sources have been listed in Table 1. The main conclusions of this section are, for the UV, that (a) most of the brighter UV sources are early-type stars, where the spectral type contributing mostly depends on the UV band of the observation, (b) at faint 200 nm magnitudes most sources are galaxies, (c) the UV background is mostly starlight from within the Milky Way, scattered by interstellar dust, (d) the small fraction of extragalactic UV background can be explained by integrated light from galaxies. For the EUV, the conclusions are that (a) most of the sources are late-type, coronally-active stars, and (b) there are only very few extragalactic sources, presumably because of the opacity of the ISM and the intrinsic source opacity for EUV photons.

8.1. WHAT IS KNOWN ABOUT STARS?

The various experiments construct a picture in which most of the stars detected by TD-1, FAUST, SCAP and FOCA are relatively early-type B, A and F. However, most of the stars included in the UIT catalog are probably late-type (G and later). Specifically for TD-1 (Thompson et al. 1978) the spectral classes B, A, and F make up 95.9% of all the stars in the published version of the catalog. Carnochan & Wilson (1983) found many TD-1 stars with more intense UV emission than B8 stars ($m_{156.5} - m_{274} \leq -1.30$). They identified these objects as unreddened subdwarfs, with a scale height in the Milky Way similar to that of the central stars of planetary nebulae.

I show in Tables 4, 5, 6, and 7 a comparison of the TD-1 spectral distribution with that from the FAUST observations of the North Galactic Pole, Virgo, and Coma regions. The column labeled HES indicates the number of hot evolved stars (horizontal branch, subdwarfs, white dwarfs) in each magnitude bin. Note that while the FAUST statistics refer to the sources detected at 165 nm, the TD-1 values are for sources fulfilling the selection criteria for catalog inclusion, in particular a S/N $\geq 10$ at 156.5 nm.

| UV mag | O0–O9 | B0–B9 | A0–A9 | F0–F9 | G0–K9 | M0–M9 | Other | Total |
|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| $\leq 6.9$ | 34    | 2132  | 2998  | 1886  | 1033  | 19    | 2     | 8104  |
| 7.0–7.9 | 22    | 2411  | 4397  | 2388  | 41    | 0     | 10    | 9269  |
| 8.0–8.9 | 24    | 3185  | 6260  | 611   | 13    | 1     | 37    | 10131 |
| $>9.0$  | 17    | 1757  | 1928  | 12    | 5     | 0     | 115   | 3834  |
| Total  | 97    | 9485  | 15583 | 4897  | 995   | 20    | 138   | 31338 |

A comparison of the tables shows that at high $|b|$ there are few B stars, thus the A and F types dominate the source counts in the FAUST data. The Coma region shows an unexpectedly high number of hot evolved stars; these are probably related to the high galactic latitude open cluster Mel 111 (Brosch et al. 1998).

Except for the FAUST fields studied at Tel Aviv University (Brosch et al. 1995, 1998), most surveys used exclusively correlations with existing catalogs to identify sources. In the fields of NGP-NB and Virgo, where the reduction and identification processes are complete, we find almost equal fractions of A-F stars (70 and 75%). The only disturbing fact is that we identify no white dwarfs in the three Virgo fields, whereas about 7 are expected; it is possible that these hide among the small fraction of unidentified sources, or that they were identified as “normal”
TABLE 5. UV sources in the North Galactic Pole region (l≈281, b≈84)

| UV mag | B0–B9 | A0–A9 | F0–F9 | G0–K9 | HES | AGN/galaxies | Total |
|--------|-------|-------|-------|-------|-----|--------------|-------|
| < 6.9  | 0     | 3     | 0     | 0     | 1   | 0            | 4     |
| 7.0–7.9| 0     | 1     | 0     | 0     | 1   | 0            | 2     |
| 8.0–8.9| 0     | 2     | 1     | 0     | 1   | 0            | 4     |
| 9.0–9.9| 1     | 3     | 3     | 1     | 0   | 0            | 8     |
| 10.0–10.9| 0   | 4     | 5     | 0     | 3   | 2            | 14    |
| 11.0–11.9| 1   | 5     | 5     | 1     | 2   | 3            | 17    |
| 12.0–12.9| 1   | 2     | 7     | 3     | 2   | 2            | 17    |
| 13.0–13.9| 1   | 3     | 5     | 3     | 0   | 1            | 13    |
| Total   | 4     | 23    | 26    | 8     | 10  | 8            | 79    |

TABLE 6. UV sources in the Virgo region (l≈279, b≈77)

| $m_{UV}$ | B0–B9 | A0–A9 | F0–F9 | G0–G9 | HES | AGN/Galaxies | No ID | No Sp | Total |
|----------|-------|-------|-------|-------|-----|--------------|-------|-------|-------|
| 5.0–5.9  | 0     | 2     | 0     | 0     | 0   | 0            | 0     | 0     | 2     |
| 6.0–6.9  | 0     | 5     | 0     | 0     | 1   | 0            | 0     | 0     | 6     |
| 7.0–7.9  | 1     | 3     | 0     | 0     | 0   | 0            | 0     | 0     | 4     |
| 8.0–8.9  | 0     | 4     | 0     | 1     | 1   | 0            | 0     | 0     | 6     |
| 9.0–9.9  | 2     | 5     | 2     | 0     | 0   | 1            | 0     | 0     | 10    |
| 10.0–10.9| 3     | 2     | 2     | 0     | 2   | 6            | 2     | 0     | 17    |
| 11.0–11.9| 3     | 6     | 14    | 0     | 2   | 16           | 2     | 0     | 43    |
| 12.0–12.9| 4     | 8     | 8     | 1     | 0   | 31           | 3     | 2     | 57    |
| 13.0–13.9| 2     | 5     | 6     | 0     | 1   | 20           | 6     | 0     | 40    |
| 14.0–14.9| 0     | 2     | 0     | 0     | 0   | 3            | 0     | 0     | 5     |
| ≥15.0    | 0     | 1     | 0     | 0     | 0   | 0            | 0     | 0     | 1     |
| Total    | 15    | 43    | 32    | 2     | 7   | 76           | 14    | 2     | 191   |

stars. The Coma field includes the open cluster Mel 111; for this reason it is not typical of other high-b fields.

In the EUV range it is possible to compare the different findings of the survey instruments described in the relevant section, with the exception of ALEXIS, whose sources have not yet been collated into a table. I show the ROSAT WFC and EUV lists in Table 8. It is clear that the large majority of EUV sources mapped by the different experiments are late-type stars; the number of extragalactic objects is extremely limited.

8.2. WHAT IS KNOWN ABOUT GALAXIES ?

The information about galaxies is very sparse and we still lack a large sample of a few 1000’s galaxies, from which to perform good statistical studies.

Significant information on selected objects, mainly on stellar populations and the nature of the ISM, was obtained from IUE spectra (O’Connell 1992). Similar observational data, combining UV with optical and near-IR spectrophotometry through matched apertures, was recently used
TABLE 7. UV sources in the Coma region ($l$≈60, $b$≈88)

| $m_{UV}$ | B0–B9 | A0–A9 | F0–F9 | G0–G9 | K0–M9 | HES | Total |
|----------|-------|-------|-------|-------|-------|-----|-------|
| <7       | 0     | 1     | 0     | 0     | 0     | 0   | 1     |
| 7.0-7.9  | 0     | 1     | 0     | 0     | 0     | 0   | 1     |
| 8.0-8.9  | 0     | 1     | 0     | 0     | 0     | 1   | 2     |
| 9.0-9.9  | 1     | 1     | 0     | 0     | 0     | 2   | 4     |
| 10.0-10.9| 0     | 4     | 3     | 1     | 0     | 3   | 11    |
| 11.0-11.9| 0     | 5     | 7     | 1     | 0     | 2   | 15    |
| 12.0-12.9| 0     | 5     | 2     | 1     | 0     | 3   | 11    |
| 13.0-13.9| 0     | 0     | 0     | 0     | 1     | 0   | 1     |
| Total    | 1     | 18    | 12    | 3     | 1     | 11  | 46    |

TABLE 8. Nature of identified EUV sources

| Source nature | WFC | WFC | EUVE | EUVE | EUVE | EUVE | ROSAT |
|---------------|-----|-----|------|------|------|------|-------|
|               | BSC | 2RE | BSL  | 1st  | 2nd  |      |       |
| AGN, QSO      | 7   | 18  | 10   | 9    | 6    | 0    |
| XRB, CVs      | 20  | 10  | 14   | 16   | 15   | 5    |
| O-A-B stars   | 8   | 8   | 13   | 32   | 18   | 43   |
| F-G-K-M stars | 181 | 251 | 172  | 184  | 161  | 411  |
| WDs (PNN)     | 119 | 140 | 117  | 109  | 98   | 27   |
| Total         | 335 | 421 | 326  | 350  | 298  | 486  |

to derive template spectral energy distributions (SEDs) for various types of galaxies (Storchi-Bergmann et al. 1994; McQuade et al. 1995). A combination of IUE observations and data from other UV imaging missions was used to extract “total” UV information on galaxies (Longo et al. 1991; Rifatto et al. 1995a, 1995b).

There is hope to derive the star-forming histories of galaxies through a combination of data from the UV to the near-IR, in the manner of the Storchi-Bergmann et al. (1994) templates. However, we have recently shown (Almoznino & Brosch 1997a, 1997b) that such decompositions are not unique, at least for a sample of blue compact dwarf galaxies (BCDs). In order to account for recent star-formation bursts, it is necessary to include information about the ionizing continuum; as the ISM in the Milky Way and in the target object prevents direct observation of the ionizing continuum, this can be derived from Hα observations under simplifying assumptions. UV data collected by IUE or UIT are usually at $\lambda > 140$ nm. This region contains mainly radiation from A-type stars and requires extrapolation of the stellar population to earlier types, to account for Lyman continuum photons.

To understand large populations of galaxies, in terms of stellar populations and star formation histories, it is impractical to rely only on the detailed modeling of spectral features in the optical region. One should combine information from many spectral bands, covering a spectral region as wide as possible.

In the absence of very deep UV surveys in more than a single spectral band, such as those expected to result from the UIT exposures, our information about a significant number of galaxies
originate from the SCAP-2000 (Donas et al. 1987) and FOCA (Milliard et al. 1992) measurements. These consist of integrated photometry at 200 nm of a few hundred galaxies. In the 200 nm band and in the brightness range 16.5-18.5 galaxies apparently dominate the source counts. The corresponding blue magnitudes of these galaxies are $B = 18-20$ and their typical color index is $[200 - V] \approx -1.5$. Comparing this index with the template spectra of Kinney et al. (1996), the FOCA galaxies fit the SB2 template, i.e., a slightly reddened starburst galaxy.

The galaxy counts from the FOCA flights originate from the analysis of three high latitude fields covering about 4.5 square degrees, which include galaxy or globular clusters (M3, Abell 2111, and SA 57, which contains a few Coma cluster galaxies). Milliard et al. (1992) indicate negligible contamination of their galaxy counts by either UV stars or cluster galaxies. In order to reproduce the observed galaxy density distribution, Armand and Milliard (1994) find that a simple transformation to the UV of the known visible galaxy counts is not sufficient. They require a larger contribution by star-forming galaxies in the recent past, such as late-type spirals or blue dwarf galaxies.

In the field of A2111, Milliard et al. (1996, private communication) find that the UV galaxies are mostly in the foreground or the background of the cluster, ranging as far as a redshift of 0.68. Note that the Lyman break in the rest frame of a distant galaxy will enter the FOCA window only at $z \approx 1.3$. Spectra of some of these optically faint galaxies reveal narrow emission lines, justifying a link with star-forming galaxies. A larger fraction of star-forming galaxies at high $z$ was claimed also from HST data, i.e., the HDF or the MDS. However, note that Giavalisco et al. (1996) claim that not all HST faint galaxies are starbursts or peculiar galaxies; being observed at UV wavelengths in their rest frame their morphological appearance is later than would be determined from optical studies.

Using the “field” galaxy luminosity function in the UV, derived by Deharveng et al. (1994) from the smooth linking of the projected density of UV galaxies from the FAUST and FOCA counts, it appears that:

$$\log N(m) = 0.625 \times m_{200} - 9.5$$  \hspace{1cm} (7)$$

There is a faster increase in the number density of galaxies at faint UV magnitudes than it is for stars.

The UIT results, derived from the analysis of the 48 independent pointings from the ASTRO-1 mission, indicate that the majority of UV sources recorded by this instrument are stars (Smith et al. 1996). This is at odds with the analysis of Milliard et al. (1992). One possible explanation could be the longer wavelength response of UIT; most of the analyzed images were taken through the A1 filter. This filter has a significant color term because of its considerable width, thus its effective central wavelength is 230 nm for early-type stars and about 280 nm for G stars. In contrast, the FOCA bandpass is much narrower and better defined. The difference in the amount of recorded stars could then be the result of UIT seeing more late-type stars, to which FOCA would be “blind”.

To check this possibility, we calculated models of stellar densities patterned after those of Brosch (1991), with the difference that the present models were calculated for the UIT A1 band. Specifically, we derived an optical-to-UV transformation based on IUE spectra convolved with the A1 filter response, shown in Fig. 6, calculated the cumulative stellar densities in the direction of UIT targets, and compared the expected and the measured source counts and properties, in the deepest UIT exposures (all with the A1 filter and with 600 sec exposure or longer). We found that we can reproduce the total counts, the distribution of star counts by magnitude bins, and the [UIT–V] color distribution with a model cutoff at $V \approx 18$. Results for the UIT field centered at (06:22; –13:03) are shown in Figures 7 and 8, and the error bars on the experimental points originate from an assumption of Poisson statistics in the number counts. It follows that UIT
could indeed have detected mostly stars, and that the Galaxy model in Brosch (1991), with its subsequent modifications and transformation to the UIT A1 band, reproduces faithfully the observed stellar distribution.

![UIT A1 vs LUM V](image)

**Figure 6.** Derived transformation between observed B-V of a star and its UV–B color for main sequence stars. The UV magnitude is derived by convolving the UV spectrum (from the IUE observations) with the transmission of the A1 filter of UIT.

One must be wary of the UV–V colors quoted in the UIT catalog; the V magnitude is derived in many cases from the “quick-V” magnitude in the HST Guide Star Catalog, which may be significantly off (0.15 mag=1σ for objects near the plate center calibrating sequences, going as high as 0.30 mag=1σ for objects far from the sequence: Russell *et al.* 1990).

Another comparison of UIT and FOCA performance is possible using the studies of M51 by both instruments (Bersier *et al.* 1994, Petit *et al.* 1996 for FOCA; Hill *et al.* 1996 for UIT). I measured the integrated flux of 22 HII regions in M51 on the calibrated FOCA image (kindly provided by D. Bersier), out of the 28 identified in the UIT B1 image of Hill *et al.* (1995). The comparison is shown in Figure 9. In general, the m200 and the m152 magnitudes correlate well. There is no significant calibration offset between UIT and FOCA, at least in this image, and the HII regions do not show strong reddening effects between 152 nm and 200 nm. This nice correspondence demonstrates fully the advantage of a balloon-borne UV survey telescope, at a fraction of the cost of UIT or of other orbital telescopes (see below).

One missing ingredient to a fuller model of the sky consists of a proper representation of galaxies and AGNs/QSOs. The latter, in particular, are UV-bright objects. Their detection in deep UV surveys should be relatively easy. Moreover, their spectral energy distribution is very different from that of stars, thus using UV and optical colors it is possible to discriminate them from the foreground stars. The claim by the FOCA group of a large contribution of UV galaxies
Figure 7. Predicted vs. observed UV star counts at the UIT A1 band, for a field at (06\(^{h}\)22\(^{m}\): -13\(^{\circ}\)03\('\)'). In general, and up to \(m_{\text{UV}} \approx 16.5\), the model predictions are within one standard deviation of the real star counts. For fainter stars there is progressive incompleteness.

is supported by theoretical arguments requiring a fast-evolving population of perhaps dwarf galaxies for \(z=0.2-1.0\), in order to explain the faint source counts in other spectral domains (Ellis 1997). A similar possibility, that \(\sim 60\) of the almost star-like blue objects in the Hubble Deep Field are distant extragalactic sources, has been proposed by Méndez et al. (1996). One possibility could be that these sources are distant blue dwarf galaxies or starbursting galaxies, which are smaller than their present-day counterparts. This is apparently confirmed by the Keck spectra of some of these objects, though the inferred star formation activity in these objects appears much higher than in local starbursts (e.g., Guzman et al. 1997).

8.3. WHAT IS KNOWN ABOUT THE ISM?

Studies by UIT and FAUST emphasize the relative importance of the dust in understanding the UV emission. Bilenko (1995) analyzed the TD-1 catalog and a version of the Hipparcos Input Catalog transformed to the TD-1 band with information derived from IUE spectra of different types of stars. They showed that the UV extinction is very patchy, with very different values of extinction per kpc on scales smaller than 10\(^{\circ}\).

Tovmassian et al. (1996b) used the results of GLAZAR observations of a 12 degrees\(^2\) area in Crux, to establish that the distribution of ISM dust is very patchy, with most of the space between stellar associations being relatively free of dust. They did not attempt to delimit better the location of dust clouds in 3D space, because of the rather sparse sky coverage of the GLAZAR stars.

Much of our present understanding of the structure of the local ISM comes from studies in
the EUV range. In particular, the various EUVE catalogs (Bowyer et al. 1994, 1996; Lampton et al. 1996) confirm the previously known features of the local ISM (a “tunnel” to CMa with very low HI column density to 200 pc. and close to the Galactic plane first identified by Gry et al. (1985) from the COPERNICUS data, a cavity connected with the Gum Nebula in Vela, a shorter 100 pc. tunnel to 36 Lynx, and the very clear region in the direction of the Lockman hole). It is clear that the present EUV catalogs are not deep enough to reveal finer, or deeper details.

The new UIT study of M51 shows that $A_{\lambda E(B-V)}$ changes with decreasing metallicity (or galactocentric distance). This is reminiscent of the finding by Kiszkurno-Koziej & Lequeux (1987), that the extinction law in the Milky Way changes with distance away from the galactic plane. The authors find that the Hα flux is depleted in the inner regions of M51; this they interpret as increased Lyman continuum extinction in the inner parts of M51.

8.4. WHAT IS KNOWN ABOUT THE UV AND EUV BACKGROUNDS?

The accurate measurement of the UV sky background (UVB), with the expectation that it could put meaningful cosmological limits, has been the goal of many rocket, orbital, and deep space experiments. Many observational results were summarized in reviews by Henry (1982), Bowyer (1990), Bowyer (1991), and Henry (1991). It is worth noting the many pitfalls of accurate UV background measurements: sensitivity to instrumental dark current, atmospheric emissions at low orbital and rocket altitudes, etc. Leinert et al. (1998) discuss observations and interpretation relevant to the UV and EUV backgrounds in a general discussion of the sky background in many
Figure 9. Comparison of UIT and FOCA UV photometry of the same regions of M51.

wavelengths.

Bowyer (1991) separates the various origins of the diffuse UVB into “galactic” and “high latitude”. The latter forms an \( \sim \) uniform pedestal, onto which the galactic component is added in various amounts depending on the direction of observation. The “galactic” component can be \( \sim \) one order of magnitude more intense than the “high latitude” one. Most of this intensity is probably from light scattered off dust particles in the ISM, and the rest is from the gaseous component of the ISM (HII two photon emission and H\(_2\) fluorescence in molecular clouds). The majority of the “high latitude” component is probably also galactic, originating from light scattering off dust clouds at high galactic latitude.

An analysis of the diffuse UV emission (Murthy & Henry 1995) indicates that the extragalactic component of the UV background can be at most 100-400 photon units. Whenever the column density of HI is larger than 2 \( 10^{20} \) cm\(^{-2}\), the main contributor to the UVB originates from dust-scattered starlight. The low levels of the extragalactic component are produced probably by the integrated light of galaxies (Armand et al. 1994), or the integrated light of the Milky Way scattered off dust grains in the Galactic halo (Hurwitz et al. 1991). Even the Lyman \( \alpha \) clouds in intergalactic space may contribute, through their recombination radiation (Henry 1991).

The confirmation that most UVB originates from dust-scattered light was obtained by Sasseen et al. (1995) and Sasseen & Deharveng (1996). Sasseen et al. showed that the spatial power spectrum of the diffuse UVB on FAUST images is consistent in spectral index and amplitude ratio with the IRAS 100 \( \mu \)m signal in the same sky areas, while Sasseen & Deharveng found that the UV background correlates with the FIR measurements of COBE/DIRBE. Galactic cirrus clouds apparently scatter back significant FUV radiation from the Milky Way;
Harkala et al. (1995) found such UV emission with FAUST from the direction of a dark cloud detected at 100 µm by IRAS.

The low levels of UV background, away from orbital and galactic contaminants, have been confirmed by an analysis of 489 UIT images from the ASTRO-1 flight (Waller et al. 1995). After correcting for orbital background and zodiacal light, and after accounting for scattered Galactic light by ISM cirrus clouds (through the IRAS 100 micron emission), the authors extrapolated the UV-to-FIR correlation to negligible FIR emission to find that the extragalactic (cosmic) UV background must be 200±100 count units. Note one effect in all Shuttle-based experiments, which was not accounted for in the UIT UVB analysis; the influence of background light produced by the Shuttle attitude jets firing. During the FAUST flight this was observed as an enhanced background in the photon stream, which was ∼4× higher than the level from all other sources (Sasseen 1996, private communication). As this is diffuse light, the influence is clearly dependent on the solid angle of observation and on the size of the aperture. For UIT, this should have resulted in a level ∼2.5% that of FAUST. Because of this, the minimal UVB levels estimated by Waller et al. (1995) must be considered upper limits.

![Sky background](image)

**Figure 10.** UV and optical sky background from orbit vs. ground observatories. This is a revised version of a similar figure by O’Connell (1987), where the values related to the optical domain have been retained.

The shorter wavelength background has been observed by *e.g.*, Holberg (1986) with the Voyager UVS, reaching as far down as 50 nm. The UV range shortward of Lyα but longward of the Lyman break was studied from an integrated data set of all the Voyager UVS observations (Murthy et al. 1996). They identified 272 UVS observations of which ∼50% have intensities under 100 count units. In particular, note the observations on the North Galactic Pole region, which give consistently a zero background level (upper limit 100 c.u., 1σ-to be revised). Murthy *et al.* concluded, after accounting for the scattered light in the Lyα and Lyβ line wings and
for the radiation-induced background from the radio-isotope thermal generator on-board the Voyager spacecrafts, that the minimal sky background between 91.2 nm and 115 nm is $0 \pm 100$ c.u. ($1\sigma$). This is, by far, the lowest value of any extragalactic UVB component, and the formal $1\sigma$ upper limit is the value plotted in Fig. 10. Its implication is that in the nearby Universe, to $z \approx 0.2$, there is only a very small contribution of photons with $\lambda > 912 \text{Å}$. It is also clear that galaxies at any redshift are rather opaque to Lyman continuum photons; these could contribute in the Voyager band from any (reasonable) redshift.

It is possible to evaluate the level of the “true” extragalactic background which would be detected by instruments with moderate angular resolution, from the FOCA galaxy counts at 200 nm (Milliard et al. 1992). Their actual galaxy counts, for $15.0 \geq m_{200} \geq 18.5$, give (when extrapolated to $m_{200}=20.0$) a contribution of $\sim 100$ c.u.’s already from the UV-detected galaxies. Note that such faint objects would hardly be detectable in the UIT exposures. Armand et al. (1994) used the FOCA counts at 200 nm, with a limiting magnitude of 18.5, to calculate the contribution to the UV background from galaxies. They estimated that 40–130 c.u. can be due to galaxies. A similar analysis by Martin (1997), using FOCA galaxies, indicates that at least 25% of the UV background can be due to galaxies.

Treyer (1997, private communication) calculated the expected UV background due to galaxies. This was done by integrating the present-day 200 nm luminosity function, obtained from the FOCA observations, to high redshifts. Under the assumption of “no evolution”, she finds that the diffuse 200 nm surface brightness should be $\sim 10^{-9}$ erg s$^{-1}$ cm$^{-2}$ Å$^{-1}$ ster$^{-1}$, which is equivalent to a surface magnitude $\sigma_{200} \approx 28$ mag arcsec$^{-2}$, or $\sim 100$ c.u. This must be considered a lower limit to the background produced by galaxies, as evolutionary considerations, such as having more star formation at high redshifts (e.g., Madau et al. 1996), would increase the value of the EUB.

Any reasonable spectral energy distribution one would invoke for the FOCA UV galaxies should have a SED rising into the UV, thus even higher flux levels are expected in the 100 nm region than at 200 nm where FOCA observes. The Voyager results of Murthy et al. are in strong conflict with the assumption that the differential count numbers of UV galaxies extend unmodified to $m_{UV}=24$, and in mild conflict ($2\sigma$) with the assumption that they extend to $m_{UV}=20$. In the latter case, the entire extragalactic UVB could be due to unresolved galaxies, leaving no room for hydrogen-recombination photons from the Ly$\alpha$ clouds, photons scattered off extragalactic dust clouds, etc. The result of Treyer presented above indicates a difficulty with the longer wavelength UVB as well; the contribution by galaxies accounts for almost the entire UVB measured by UIT!

A very deep EUVE spectroscopic observation of a large region on the ecliptic has recently been reported (Jelinsky et al. 1995). It indicates that the only emission lines observed are He I and He II (58.4, 53.7, and 30.4 nm), which originate from scattered Sunlight by the geocoronal and/or interplanetary medium. The spectrum of the EUV background (Fig. 2 in Jelinsky et al.) shows a tantalizing continuum, which decreases from 800 c.u. at 16 nm to 100 c.u. at 35 nm. This is probably grating scattering of the 58.4 and 30.4 nm helium lines (Jelinsky, private communication). It is expected that the knowledge of the EUV background will improve, as more data from the full ecliptic survey (3 $10^6$ sec exposure) will be processed. The lowest value for the EUV background originates from a ROSAT observation (Barber et al. 1996). The detection of the shadow cast by the nearby galaxy NGC 55 on the diffuse 250 eV (49.6 nm) background sets a level of the EUV background coming from extragalactic sources at $29.4 \pm 7.2$ keV cm$^{-2}$ sec$^{-1}$ keV$^{-1}$ ($\approx 9.5 \pm 2.3$ c.u. at 49.6 nm).
9. Future missions

The future development of UV Astronomy, at least in the context of a full sky survey, has been influenced strongly by the decisions of two major committees in the US. The first is the “Decade Survey of Astronomy and Astrophysics for the 1990s”, a committee formed in 1989 by the National Research Council in the US and chaired by John Bahcall to set priorities in an age of diminishing funds. The workings of the Decade Survey committee have been described by Bahcall (1991) and the report itself was published in 1991.

The Bahcall committee attempted to prioritize by “democratic consultation” throughout the astronomical community. It is interesting that among the large and moderate programs recommended by the Bahcall committee there is only one program in the UV domain (FUSE, see below), and the emphasis is on infrared and optical programs. The sociological trend continued well into the small programs, which the committee did not specify beyond a few examples; none of these relate to UV astronomy.

The second very influential committee was charted by the Association of Universities for Research in Astronomy (AURA) with support from NASA, and is called “HST and Beyond”. The committee was formed in 1993, was chaired by Alan Dressler, and produced its report in 1995 (Dressler 1996). The Dressler committee identified two goals for the Space Astronomy of the early-21st century: the detailed study of the birth and evolution of normal galaxies, and the detection of Earth-like planets around other stars and the search for life on them. The goals identified by the Dressler committee were to be realized by the Next Generation Space Telescope (NGST), by a space interferometer, and by extending the operation of the HST beyond 2005. In particular, note that HST was to be the major instrument for UV astronomy beyond that date.

The decisions of the Bahcall and Dressler committees have been adopted by NASA and by the NRC, which control the major funding in the US. In particular, NASA headquarters has been restructured into four major “themes”, of which the two most related to space astronomy are “Structure and Evolution of the Universe”, and “Search for Origins”. It is possible that these decisions have also had far-flung influences beyond the borders of the US, and that other Space Agencies are prioritizing their programs in a hidden race against the US Space Program. This could have had the effect of blocking UV astronomy, at least in the direction of conducting a new all-sky survey, by the major players in space astronomy.

In the immediate future, only one space mission (GIMI, see below) has the potential of yielding results relevant to the derivation of a full UV sky survey. GIMI will reach only the relatively brighter objects, an extension of a few magnitudes below the TD-1 limit. With the exception of nearby galaxies, no extragalactic objects are expected to be measured by it. In addition, there is the FUSE mission, which will hopefully begin to operate within 1998.

Given these rather pessimistic constraints, it is gratifying that NASA selected in late-1997 the GALEX mission (see below), which was mentioned above in the context of a comparison of surveys. GALEX will conduct an all-sky UV survey, comparable to that of the Palomar Sky Survey in the optical domain. The results from GALEX will become available in the second half of the next decade.

Before describing the future UV missions, I review a few examples of missions which did not succeed to launch.

9.1. POSSIBLE MISSIONS

A number of missions to map the sky to depths comparable with the Palomar Sky Survey (PSS) in the optical have been proposed, but none bar one was accepted by the suitable funding agency. An early attempt was to create a geo-synchronous updated UIT (Largefield Ultraviolet
Explorer=LUX), proposed in 1986. Another proposed attempt was to have a SMEX for a UV imaging and spectroscopy all-sky survey (PAX, JUNO), then a MIDEX for a similar purpose (MUSIC). These proposals, although very good, did not survive the NASA selection. A third attempt, GALEX (from the same PI as PAX, JUNO, and MUSIC), was finally selected in 1997 for a 2001 launch.

A mission to study the diffuse UV background (HUBE) was retained by NASA as backup for a selected mission. A Canadian group proposed to study a mission similar to JUNO for a National Canadian small satellite. Some of its members were among the initiators of STARLAB, a one-meter class Space Schmidt proposed for UV surveys, which was scrapped in the late-80s. It is possible that the Canadian option will be to fly on a Shuttle-carried long duration platform.

A conceptual design for a very ambitious survey telescope, dedicated to UV astronomy, was presented by the Byurakan Observatory (Armenia) and by the Astronomical Institute of Potsdam, Germany (Tovmassian et al. 1991d). The Astrophysical Schmidt Orbital Telescope (ASCHOT) would be able to image a 2°.5 field of view with 2" resolution, using an all-reflecting Schmidt design with an 80 cm aperture. The calculated performance indicated a detection limit with S/N=10 at $m_{150}=24.0$ in a 30 min exposure. However, there are formidable aspects in dealing with a 9000×9000 pixel array. The primary mirror (diameter 120 cm) and the reflective corrector plate (diameter 80 cm) of ASCHOT have been fabricated by Carl Zeiss Jena prior to the re-unification of Germany. The realization of the ASCHOT project remains a possibility worth exploring.

In Russia Boyarchuck and collaborators are building Spectrum UV (SUV), an HST-like mission intended for deep spectroscopy in the UV of selected targets. Note that this mission, third in line among the SPECTRUM spacecraft, will not be a survey instrument but will be dedicated to studies of known celestial objects. The SUV mission will be almost exclusively dedicated to intermediate resolution spectroscopy, but its focal plane camera has imaging possibilities similar to those of the IIST ACS (B. Shustov, 1997 private communication). Also, given the delays in launching the first Spectrum mission (Spectrum X-γ), it is doubtful whether SUV will be realized before the year 2000.

9.2. REAL MISSIONS

The one space experiment constructed exclusively for UV astronomy is FUSE (the Far Ultraviolet Spectroscopic Explorer mission), manifested for a late-1998 launch. This satellite is designed to provide high spectral resolution observations ($\frac{\Delta \lambda}{\lambda} = 30,000$) in the band 90.5 to 119.5 nm. FUSE is designed for a three year life in low Earth orbit and has significant effective area peaking at ~100 cm² near 105 nm. This allows high resolution spectroscopy with S/N=20 of objects with monochromatic magnitude 12 in 100,000 seconds of observation, which is equivalent to about 3.3 days, given the expected operating efficiency. Most of the observing time will be dedicated to a number of key program, such as the study of deuterium abundance in the interstellar and intergalactic space.

The GIMI imaging instrument is integrated into its carrier spacecraft (ARGUS, from the USAF). It is primarily military in character aiming at detecting and characterizing sources of UV emission (or atmospheric opacity), which could affect the detection, identification, and tracking of missiles and warheads. ARGUS is expected to be launched in late-1998 on a Delta II vehicle.

The GIMI instrument on ARGOS has as one of its declared goals the production of a full sky survey in three UV bands. The most recent description of GIMI is by Carruthers & Seeley (1996). GIMI consists of two bore-sighted EBCCD cameras, each imaging a $10^\circ.5 \times 10^\circ.5$ field
of view with a resolution of ~3'.9. The paper gives also the sensitivities expected (Fig. 9). The GIMI imagers cover three spectral regions with two detector-telescope assemblies. Camera 1 has a KCl cathode sensitive to the 75-110 nm band and with a nominal field-of-view (FOV) of 10°.5 × 10°.5. Camera 2 has a split FOV: an area of 7° × 10°.5 is covered by a KBr cathode sensitive to the 131-160 nm band, while an adjacent area of 3°.5 × 10°.5 is imaged on a CsI cathode sensitive to the 131-200 nm region. The most sensitive arrangement is Cam. 2 with the CsI cathode, whereas Cam. 1, with its KCl cathode, has a sensitivity about 1/20 lower. In its sky survey mode, GIMI will stare for at least 100 sec at each source; from this, its magnitude limit is expected to be ~13.6 in the CsI band.

The TAUVE (Tel Aviv University UV Explorer) payload (Brosch et al. 1994) represents the most advanced attempt to design, build and operate a flexible instrument for observations in the entire UV band. The experiment is built for Tel Aviv University by El-Op, Electro-Optical Industries, Ltd., with the largest part of the funding from the Government of Israel through the Ministry of Science and Arts and the Israel Space Agency. TAUVE images the same 0°.9 FOV with three co-aligned telescopes and with an image quality of about 10". It was originally conceived for a small satellite of the OFEQ or SMEX class, but is now part of the scientific complement of the SRG spacecraft scheduled to launch in late-1999 or in 2000.

The detectors used in TAUVEX are tailor-made by DEP-Delft Instruments of Roden, the Netherlands. They consist of CsTe cathodes deposited on CaF₂ windows. The photo-electrons are amplified by a three-stack chevron arrangement of MCPs and the detection is by a wedge-and-strip anode. The light passes through filters defining six spectral bands, from a very wide one which is essentially a “blue cutoff” at ~200 nm, to three intermediate (~300 nm wide) bands spanning the working range 135-290 nm, to two “narrow” bands at selected regions of interest. A view of TAUVE as it would look in space is shown in Fig. 11, where the TAUVEX thermal model (now at Lavotchkin Industries in Moscow) is installed in a solar simulator chamber in preparation of a thermal vacuum test. The apertures of the three telescopes are visible on the right part of the figure and the telescopes themselves are wrapped in their thermal blankets.

TAUVEX offers significant redundancy at component and system levels in comparison with other missions. The projected performance is detection of objects 19 mag (monochromatic) and brighter, with S/N>10 and in three ~40 nm wide bands, after a four hour pointing. At high galactic latitudes each such pointing is expected to result in the detection of some tens of QSOs and AGNs (mainly low-z objects) and some hundreds of galaxies and stars. It is expected that a three-year operation of TAUVEX on SRG will yield a deep survey of the UV sky to m(UV)=19 mag in at least three UV bands, which will cover ~5% of the (high galactic latitude) sky. This is based on the size of the field of view and the expectation that the total number of independent pointings after three years in orbit will add up to ~3,000.

On the same SRG platform, co-aligned with TAUVEX and the rest of the higher energy instruments, will operate also the F-UVITA instrument. It consists of a pair of 20 cm telescopes imaging a 1°.2 field with 10" resolution in spectral bands between 91 and 99 nm. Each band is ~9 nm wide. The most up-to-date description of F-UVITA can be found in its homepage at the Paul-Scherrer-Institute in Switzerland, where its sensitivity is advertised as adequate to detect V=15 B0 stars.

Some UV capability has been constructed into the Optical/UV Monitor (OUVM) of XMM (Mason et al. 1996). The OUVM is a 30 cm modified Ritchey-Chrétien telescope which images a 17° FOV with ~1" resolution. The light is analyzed with filters and with a grism. The UV-optical detector operates in the 160-600 nm spectral range and consists of a fast readout 256×256 pixel CCD, coupled by fiber boule to the phosphor output of an image intensifier. The CCD readout is analyzed by a transputer-based processor and each photon event is centered to ~0.2 pixel (0.5")
Figure 11. The thermal demonstrator model of TAUVEK is identical in external appearance to the flight model. It is shown here during installation in a space environmental chamber, prior to qualification under simulated Solar radiation. The three telescope apertures are visible in the front of the instrument.

for normal operations). The difference from TAUVEK lies in the XMM OUVVM being a single telescope time-sharing between the optical and UV ranges, and in the higher spatial resolution, realized at the expense of the smaller FOV.

In fall of 1997 NASA announced the selection of a Small Explorer Experiment (SMEX) dedicated to a new all-sky survey in the UV. This is the Galaxy Evolution Explorer (GALEX: C. Martin P.I.; Bianchi & Martin 1997) whose prime goal is the survey of galaxy evolution effects for the range $0 \leq z \leq 2$. GALEX is a collaboration of CALTECH, University of California-Berkeley, the Johns Hopkins University, Columbia University, and the Laboratoire d’Astrophysique Spatiale du CNRS of Marseille, France.

GALEX is a single wide-field imaging telescope with a 50 cm diameter primary mirror and a 26 cm diameter secondary. Its focal plane is $1^\circ.2$ wide and is equipped with two photon-counting position-sensitive detectors. The angular resolution is $3''-5''$ at 80% encircled energy. The light is shared between the two detectors by a dichroic beam splitter and a folding flat mirror. The detectors cover the spectral region 135-300 nm, selected by detector window transmission, cathode response, and beamsplitter coatings. The nominal performance of the detectors, which are cathodes with stacked MCPs and crossed, helical delay lines as anodes, allow for 4096 pixels across the field-of-view. The two GALEX bands, as presently defined are 135-180 nm (CsI and CaF$_2$), and 180-300 nm (CsTe and fused silica).

The GALEX mission is very ambitious, as it has both imaging as well as spectroscopic aspects. It shall be conducted from a low Earth orbit, into which the Pegasus launcher will insert the satellite. GALEX will observe by scanning the sky during the orbital night. The all-sky imaging survey (AIS) phase is baselined to last four months, after which a two-color catalog
of sources to \( m_L \approx 19.4 \) will be produced. In addition, it is expected that the sky background will be detected by binning the data to 1 arcmin\(^2\) and after subtracting the point sources. GALEX will then conduct a deep imaging survey (DIS) of \( \sim 200 \) degrees\(^2\) of the sky, which will include areas surveyed by the HDF North and South, the ESO Imaging Survey regions, areas of the Sloan survey, \textit{etc.} The deep imaging survey will detect sources \( \sim 4 \) magnitudes fainter than the all-sky survey. Some indication of source variability will be obtained from the 80-100 field revisits done during the AIS and DIS phases.

The spectroscopic survey, to \( \sim 1 \) nm resolution, shall be completed during additional four-month periods by inserting a grism in the converging beam, before the beamsplitter. A shallow spectroscopic survey to \( R \approx 150 \) shall be conducted in the first period over the entire region of the DIS, after which two additional periods shall be dedicated to deeper surveys of 20 degrees\(^2\), then 2 degrees\(^2\), for the Medium Spectroscopic Survey and the Deep Spectroscopic Survey, respectively. The planned mission allows for a four-month contingency/Associate Investigator programs.

It is now possible to compare the performance of the future missions which will bring significant information about the deep UV universe. The three experiments, XMM UV/Optical monitor, TAUVEX, and GALEX, reach approximately similar limiting magnitudes. GALEX has a significant advantage in its global sky coverage, but it is restricted to two simultaneous bands \( \textit{vs.} \) three for TAUVEX. In comparison with the other two instruments, GALEX also does not include a long-term continuous photometric monitoring option. Its spatial resolution is advertised to be similar to that of the OUVM, twice better than that of TAUVEX. Both the XMM UV/Optical monitor and TAUVEX shall operate alongside high energy imagers, allowing a good determination of the nature of emitting sources. Their deployment in high-altitude orbits \( \textit{vs.} \) a LEO environment for GALEX will presumably ensure a better S/N, given a lower sky and particle background.

9.3. WISH LIST

It is clear that ideally “clean” observations of the UV sky background should be made far from the Earth’s geocorona, only out of the Galactic plane, to avoid the dust-scattered starlight. For practical purposes, we shall have to settle in the foreseeable future with observations which avoid the dust in the Solar System. For this, a telescope must be located beyond the orbit of Saturn, and this requires a specialized instrument. One possibility is to design multi-purpose missions to the outer planets. These, during their cruise phase or when not collecting encounter data, could be used to measure astronomical targets, such as the UV sky background. Toller (1983) and Toller \textit{et al.} (1987), for instance, used the Pioneer imaging photopolarimeter to map the optical emission from the Milky Way in blue (395-485 nm) and in red (590-690 nm) from beyond the asteroid belt, where the contribution of the zodiacal light was found to be negligible.

The findings by Toller were confirmed by the analysis of Schuerman \textit{et al.} (1997), where the boundary beyond which the zodiacal light contribution becomes very small, in comparison with the diffuse Galactic background, was set at 2.8 a.u. Gordon (1997) performed an analysis of the Pioneer 10 and 11 data from beyond this limit and found an excess red component over that predicted from the blue light distribution (which could be fully attributed to scattering by dust). A location beyond the zodiacal dust cloud, therefore, would be ideal for a measurement of the diffuse UVB and of the exceedingly faint UV galaxies. Note also that some missions adopt an “above the ecliptic” trajectory to their target; this also would minimize the contamination by zodiacal light and offer the deepest astronomical observations.

Two possibilities, one real and another potential, are to include UV observations during the
cruise phases of either the Fast Pluto Flyby ("Pluto Express") or a possible Neptune orbiter. The Pluto Express mission was being designed when its funding was frozen in 1996 with a probable launch date not before the turn of the century. The Neptune Orbiter has not yet even been proposed officially, but would be a logical extension of the Cassini mission. Assuming that Cassini will reach Saturn by 2004, a Neptune Orbiter could launch by 2010 for a Neptune arrival 5-10 years after that. Most of its cruise phase could be made available, if so planned, for astronomical observations. Similar possibilities exist for a putative Interstellar Precursor mission.

Another, much cheaper option, although restricted in its spectral band of observation, is to follow up and expand on the experience gained by the Geneva/LAS group in UV observations from balloons. Observations from stratospheric altitudes are limited to a spectral band \(~15\) nm wide centered near 200 nm. For a while, it looked like the SR-71’s turned to NASA by the USAF could be used for this type of observation. However, these planes are again no longer available for scientific research. Despite this limitation, much can be gained from such a mission, if it would rely on the heritage of long-duration balloon flights with updated hardware.

Super-pressure balloons, flying at 40-45 km altitude, can perform missions of weeks to months. If launched in the Antarctic, the wind patterns keep the balloon mostly over the Antarctic continent. A launch in the Arctic will probably have the same characteristics, but may intrude too much in patterns of civilian and military flights over the North Pole. Trans-oceanic flights at intermediate or equatorial latitudes are also possible and may be more convenient power-wise. Present day technology allows real-time operation of a long-duration balloon mission by using the TDRSS data relay satellites while having a high data rate (Israel 1993). Adding solar panels to a regular long-duration balloon is not a difficult task, and is one of the possibilities offered in the latest (1997) NASA draft call for “University Explorer” missions (note though that super-pressure, extremely high altitude balloons are not included in the UNEX AO). Such a mission is therefore doable and will have a reasonable cost. I thus propose to study the possibility of designing a UV sky survey at 200 nm from a long-duration balloon platform.

A major cost of any sky survey mission lies in building and qualifying space hardware. These components could have been saved in the cost of such a mission if the GLAZAR-2 telescope could have been reactivated. This requires first an assessment of the status of the optics, the tracking mechanism, and the gimbals which compensate motions of the MIR, which were left attached to the space station for almost one decade with no use. A new focal plane needs to be designed, built, tested, assembled in place of the damaged one, and the new instrument can be activated in space. However, the limitation now lies with the MIR itself, which has surpassed its design lifetime.

Finally, an interesting possibility is to conduct a deep UV survey of a very small fraction of the sky with the HST. The WFPC-2 has the capability to image \(~21\) mag UV sources to S/N\(\approx\)10 with deep observations using the F160BW and/or the F218W filters while covering a significant sky region. It is thus possible to design a survey of UV sources as a “parallel” program. A set of such observations could provide information about the faintest UV sources, beyond the capability of UIT, FOCA, TAUVE, or GALEX, with good morphological information, which could be used to settle the issue of the cosmological UVB. Interestingly, observations with the F160BW filter will be almost devoid of stars! Our UV-galaxy model, using the bandpass of F160BW, predicts less than one star/square degree (down to V=20) which could be detected in \(\sim\)1000 sec exposures.

Using the WFPC-2 exposure time calculator, one finds that a 2,000 sec exposure at high galactic latitude reaches a S/N of 1.8 with F160BW and 7.8 with F218W for an unresolved V=20 Sbc galaxy. Adopting the FOCA galaxy count from Armand & Milliard (1994) and assuming the
objects have \( \sigma_V \approx 20 \text{ mag arcsec}^{-2} \), a 10,000 sec exposure with F218W will yield a S/N\( \approx 1 \) per WFPC-2 pixel. At least one such object should appear on almost any deep F218W exposure. This will be, in principle, even deeper with the STIS, once parallel observations with this instrument will be allowed. The HST has therefore the potential of making important observations in the mode of an unbiased survey for faint stars and galaxies.

A possible instrument studied for the 2002 HST servicing mission is the Wide Field Camera 3 (WFC-3), which will replace WFPC-2. Its CCDs will probably have high quantum efficiency in the UV, perhaps an order of magnitude better than WFPC2. The existence of this camera, with a field of view of 160"\( \times \)160" and a pixel size of 0.04 arcsec, will make a UV survey with the HST even more attractive.

In the domain of wishes valid for every branch of astronomy one must include a wavelength-sensitive, photon-counting imaging detector. One line of such detectors was described by Perryman et al. (1992, 1993, 1994). They consist of superconducting tunnel junctions (STJs) in which a photon creates a cloud of charge carriers, which provide essentially a low resolution imaging spectrometer with \( \lambda/\Delta \lambda \approx 30 \). Presumably such detectors would be even more useful in the UV, because of the higher energy of the analyzed photons, allowing a better energy resolution. A single-pixel device of this type was already tested successfully in the laboratory (Peacock et al. 1996) and a quantum efficiency of \( \sim 50\% \) was demonstrated for \( \lambda \) 200-1000 nm, with a spectral resolution of 45 nm. A large-format array of such devices, possibly mounted at the WFPC position on HST, would provide an imaging spectrometer with unique properties. This apparently has been proposed to ESA as a follow-up instrument for the 2002 HST refurbishing mission (Peacock et al. 1997) but was not selected, presumably because the difficulties of a cryogenic system to maintain the detector at \( T \leq 1 \text{K} \) in the HST environment seen daunting.

10. Conclusion

I have shown here that while UV astronomy flourished in the early and mid-70’s, the field stagnated, at least where sky surveys are concerned, from then on. In the early days of UV studies, a valuable resource appeared with the production of the TD–1 catalog. This is still, 20 years after its publication, the only all-sky survey in the UV. The TD–1 survey detected mostly stars, but more sensitive instruments revealed very interesting extragalactic sources (AGNs, star-bursting galaxies, etc.). The most sensitive instrument now available for UV imaging is the HST, which can hardly qualify as a survey instrument. In terms of surveys, a success of the GIMI and UVISI missions will extend the TD–1 survey by about five magnitudes, and even then, only few extragalactic objects would be accessible. The big step forward will come with the GALEX, TAUVEX and XMM UV/Optical monitor surveys.

The EUV range was explored by the ROSAT WFC and by the EUVE, but due to the opacity of the ISM, only relatively nearby objects were detected. The outstanding sources are viewed through “windows” in the ISM, where low HI column densities are encountered. At present, there are no prospects for an EUVE follow-up mission, but the extension of the EUVE operations promises more and interesting data.

It is clear that, with the existing attitude toward pure research and space activities in general, it will be extremely difficult to channel funds for new space missions which will perform additional UV sky surveys deeper than and beyond that by GALEX. Therefore, the improvement in human knowledge of the astronomical UV sky can only come about through judicious use of existing, or multi-purpose platforms, where the UV science piggy-backs on other spectral ranges. Not only astronomy missions must be considered as able to yield good UV data, but also planetary or upper-atmosphere science platforms are eligible. Fully new, revolutionary designs tend to be
costly; at the present stage they should be avoided. The heritage of past missions should be fully realized before embarking on new adventures. In this light, the extension of the EUVE mission in a low-cost mode is commendable; the continuation of the right-angle surveys should reveal more faint EUV sources.

Science needs the multi-spectral all-sky UV imaging survey to 19-20 monochromatic magnitude which will be provided by GALEX, as well as a combination of cheaper alternatives, including a long-duration, very high-altitude balloon with a FOCA or ASCHOT-type telescope and a high-resolution detector with electronic readout for a sky survey in the 200 nm band. A mini-survey with HST in the UV, perhaps with an STJ camera, will take advantage of the exquisite imaging capabilities of this facility. An extended EUV all-sky survey, ~100× more sensitive than EUVE and with better angular resolution, is also required. The inclusion of a UV sky survey phase in planetary missions bound for the outer Solar system, to observe from beyond the zodiacal dust cloud, is advocated.

Acknowledgements

UV research at Tel Aviv University is supported by special grants from the Government of Israel the Ministry of Science and Arts, through the Israel Space Agency, and from the Austrian Friends of Tel Aviv University, as well as by a Center of Excellence Award from the Israel Science Foundation. I acknowledge support from a US-Israel Binational Award to study UV sources imaged by the FAUST experiment, and the hospitality of NORDITA, the Danish Space Research Institute, and the Space Telescope Science Institute, where parts of this review were prepared. I am grateful for the help of many individuals in producing this review. Benny Bilenko calculated sky models, Liliana Formiggini recalculate the optical-to-UV transformation and compared the predicted and actual UV brightness for Virgo, Hrant Tovmassian explained intricacies of the GLAZAR series, and Jeff Bloch from the ALEXIS team supplied sky charts and information. Bruno Milliard from LAS Marseille clarified a number of points related to FOCA observations and allowed me to look at a FOCA UV image and optical spectra of a few galaxies in it, Michael Lampton from the Berkeley’s SSL/CEA explained intricacies of the EUVE source count, Jesse Hill from the UIT team explained UIT results, David Bersier from the Observatoire de Gêneè added information on M51 and supplied its calibrated FOCA UV image, Jayant Murthy added information about UVISI, Luciana Bianch provided GALEX details in advance of publication, and David Israel from GSFC explained the TDRSS-balloon connection; for these I am very grateful. Mark Hurwitz supplied information and a list of publications from the ORFEUS flights; Bill Waller did the same for UIT, read an early version of the paper, and provided some useful remarks. I thank Alan Dressler for some information on his committee’s report, Marie Treyer for calculating the contribution to the UV background from FOCA galaxies, and Prab Gondhalekar for constructive remarks upon reading one of the final drafts. Boris Shustov kindly supplied details about the Spectrum-UV mission. I am grateful to the referee for very constructive remarks.
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