Abstract.
I examine possible futures for UV astronomy, in view of the past history and collected knowledge of the UV sky through various missions since the early days of Space Astronomy. The last all-sky survey has been by TD-1 in the early 1970s, resulting in reasonable mapping of discrete sources brighter than 9th mag (monochromatic, UV). Since TD-1, few advances were made in general knowledge of the UV through survey missions, but dedicated, single-object studies advanced mainly through the IUE spectroscopic results. Selected sky areas were surveyed to deeper magnitudes than by TD-1 with various balloon and rocket flights, Shuttle and MIR payloads, etc. The HST offered some UV capability with WFPC 1 and 2, FOC, and presently with STIS, but with small fields of view.

The future of UV astronomy seems bleak, with only FUSE with any certainty of being flown and with the recent recommendation of the Dressler committee to emphasize NIR and interferometry into the next millenium. The community’s hopes reside therefore with (a) better exploitation of existing data bases, (b) dual-usage missions, (c) piggy-back modern payloads, and (d) low cost alternatives such as long-duration balloon flights. These could demonstrate the advantage of a real UV sky survey mission, equivalent in the number of sources to the POSS I & II and ESO optical surveys.

INTRODUCTION

We are only a few years away from the beginning of the third millenium. This is a propitious instance to review the status of UV astronomy, and to predict how it is likely to develop in the next few decades. I concentrate here on the spectral band from \( \sim 100 \) nm to \( \sim 350 \) nm; the lower limit is near the border between the extreme UV (EUV) and the regular UV, between imaging optics which work by grazing incidence reflection and normal incidence telescopes. The long wavelength limit is close to the location where ground-based telescopes begin to be efficient.

In this paper I express the brightness of an object in “monochromatic magnitudes”, defined as:

\[ M_{\text{GaF}} \]

\( \text{MgF}_2 \) is transparent to UV, unlike silicate-based glasses.
\[ m_\lambda = -2.5 \log(F_\lambda) - 21.175 \]  

where \( F_\lambda \) is the source flux density at \( \lambda \) in erg sec\(^{-1}\) cm\(^{-2}\) \( \text{Å}^{-1} \).

The outline of this paper is as follows: first, the achievements of UV astronomy are reviewed in very broad terms. I concentrate mainly on imaging and photometric results, and mention briefly a few spectroscopic missions. I review then some critical decisions about the future developments of Astronomy, taken by the US astronomical community and adopted by NASA and the US government. These decisions serve as templates for other national agencies and, as will become clear below, do not bode well for the UV domain. I try to understand why those decisions were taken, and sketch possible ways of reversing the negative trend toward UV in the community at large.

**UV ASTRONOMY: THE PROMISE**

The UV range, from \( \sim 250 \) nm down to the limit considered here, is almost certainly the region where the sky is the darkest. This has been pointed out by O'Connell (1987) and has since been revised a number of times. Recently, the UV background (UVB) was evaluated from the UIT images (Waller et al. 1995), the FAUST data (Sasseen et al. 1995), and the long exposure Voyager UVS spectra (Murthy et al. 1996). The new evaluations were done at different wavelengths and require correction for Milky Way UV photons scattered into the line of sight by interstellar dust. This was done by correlating the UVB against the IRAS 100 \( \mu m \) emission (Waller et al.), or against the HI column density (Sasseen et al. and Murthy et al.). Both the UIT and FAUST data, at 250 and 165 nm respectively, indicate a residual UVB of about 40-100 count units (cu=photons sec\(^{-1}\) cm\(^2\) \( \text{Å}^{-1} \) ster\(^{-1} \)) for negligible 100 \( \mu m \) emission or HI column density; this value is normally taken as an upper limit to the extragalactic UVB (eUVB).

The levels of the extragalactic UVB are very low; according to Martin (these proceedings) it is possible to account for at least 25% of the eUVB at 200 nm by the combined emission of unresolved galaxies in the nearby Universe, from rest velocity to \( z \approx 0.7 \). This is consistent with the evaluation by Armand et al. (1994) of 40–130 cu, from an extrapolation of the FOCA galaxy counts. The value of the eUVB at \( \sim 100 \) nm, resulting from the reconsideration of long Voyager UVS observations by Murthy et al. (1996), is even more intriguing. It implies an eUVB consistent with zero, thus a negligible contribution by nearby galaxies (to \( z \approx 0.2 \)) of photons longward of the Lyman break, and also indicates that there is no significant leakage of Lyman continuum photons from galaxies. This has been calculated also by Deharveng et al. (1997, preprint), from a consideration of H\( \alpha \) emission of galaxies.

The low sky background in the UV implies that very deep observations can be made there with only modestly sized optics. This is also because UV detectors are (almost) noise-free; there is no thermal noise and the main sources of detector
background originate from induced cosmic ray events, fluorescense of optics after South Atlantic Anomaly passage (in low Earth orbit), and detector hot spots. With reasonable care it is possible to achieve internal noise levels of order 1 count sec$^{-1}$ cm$^{-2}$ of cathode and with fairly high quantum efficiencies (20-40% for semi-transparent cathodes and up to 60% for opaque ones). The internal noise level is equivalent to 6.3 c.u. for TAUVEX (see below) with the SF-1 filter, and is about 6× lower than recent eUVB values.

The arguments presented above indicate that faint stars, and even more interestingly, low surface brightness (LSB) extended objects, can be detected advantageously in the UV by space experiments. This was already pointed out by O'Connell (1987); the importance of an unbiased survey of LSB galaxies cannot be overestimated. It is possible that a large fraction of the baryon content of the Universe resides in such objects (Impey & Bothun 1997). Among the point-like objects, the more interesting are the mixed-type binary systems where one component is a hot, evolved star. These systems can sometimes be detected optically only through spectroscopy, whereas a color-color diagram including UV would immediately show them as peculiarly UV-bright.

UV ASTRONOMY-THE REALITY

The present knowledge of the UV sky results mostly from (a) the all-sky survey by TD-1 in the early 1970s, (b) deeper surveys of small fractions of the sky by balloon, rocket, Shuttle and MIR based telescopes, and (c) detailed investigation of individual objects by IUE, HST, and other spectroscopic instruments.

The only all-sky survey in the UV ever performed was by the TD-1 mission (Boksenberg et al. 1973). This photometric survey measured stars in four spectral bands, three from 130 to 255 nm and a fourth centered at 275 nm. The TD-1 survey was published as a catalog with 31,215 sources; an unpublished version with 58,012 sources was later produced by Landsman (1984). The UV objects are mostly brighter than $m_{UV}=8.5$; this is also probably the limit beyond which the UV measurements are not linear. The total number of sources measured by TD-1 is similar to that of the HD optical catalog! Therefore, the status of the knowledge of the UV sky, close to the end of the second millenium, is like that of optical astronomy ∼100 years ago.

Among the many UV imaging missions it is worth mentioning a few with particularly high sky coverage. These are the S201 Moon-based experiment from NRL (Page et al. 1982), the FAUST experiment (Deharveng et al. 1979; Bowyer et al. 1993), the SCAP-2000 and FOCA telescopes operated by the LAS Marseille group (Laget 1980; Milliard et al. 1991), and the UIT missions (Stecher et al. 1992). The first two experiments have had very wide fields of view; 20° for S201 and 8° for FAUST. The latter, in particular, was equipped with a modern electronic-readout detector, while all the rest recorded their results on film. The FOCA project operates a 40 cm telescope from a high-altitude balloon; at 40+ km altitude it is
possible to observe through a \(~\sim 15\) nm wide atmospheric window centered near 200
nm. The highest resolution images (3") for a reasonably wide (40') FOV were
obtained by UIT. The data form the benchmark UV images on the morphology of
nearby galaxies (see papers by O’Connell, Waller et al., Marcum, and Ohl in these
proceedings).

It is worth considering the capabilities of the HST in the area of UV imaging;
this can be done now with the WFPC2, covering a field of some 5 square minutes
of arc, but there are significant problems with the camera response. In the far-
UV region the sensitivity is fairly low, while at intermediate wavelengths the CCDs
introduce significant red leaks. These problems are compensated by the exquisite
image quality, with the possibility to resolve individual stars in nearby galaxies.
The FOC is more appropriate for UV, but it has a much smaller field of view. To
conclude, the HST is not a survey instrument, and was not designed specifically
with high performance requirements in the UV.

| Mission     | Year    | $\Omega$ (ster) | $m_L$ | $\lambda$ (nm) | $N_{sources}$ |
|-------------|---------|-----------------|-------|----------------|---------------|
| TD-1        | 1968-73 | $4\pi$          | 8.8   | 150-280        | 31,215        |
| S201        | 1972    | 0.96            | 11    | 125-160        | 6,266         |
| WF-UVCAM    | 1983    | 1.02            | 9.3   | 193            | ?             |
| SCAP-2000   | 1985    | 1.88            | 13.5  | 200            | 241           |
| GUV         | 1987    | 5 $10^{-3}$     | 14.5  | 156            | 52            |
| GSFC CAM    | 1987+   | 0.03            | 16.3  | 242            | \(~200\)       |
| FOCA        | 1990+   | 0.02            | 19    | 200            | \(~4,000\)    |
| UIT-1       | 1990    | 3.8 $10^{-4}$   | 17    | \(~270\)       | 2,244         |
| GLAZAR      | 1990    | 4.4 $10^{-3}$   | 8.7   | 164            | 489           |
| FUVCAM      | 1991    | 0.09            | 10    | 133, 178       | 1,252         |
| FAUST       | 1992    | 0.33            | 13.5  | 165            | 4,698         |
| UIT 1+2     | 1990, 95| 1.3 $10^{-3}$   | 19    | 152-270        | 6,000 ?       |
| HST WFPC    | 1990+   | 3.9 $10^{-4}$   | 21    | 120-300        | 50,000 ?      |
| MSX UVISI   | 1997+   | $4\pi$          | 20.0  | 180-300        | ?             |
| GIMI        | 1997+   | $4\pi$          | 13.6  | 155            | 2.5 $10^5$    |
| TAUVEX      | 1998+   | 0.06            | 19    | 135-270        | $10^6$ ?      |
| XMM/OM      | 1999+   | 0.05            | 20    | 150-550        | $10^6$ ?      |

The different instruments which performed all-sky, or partial, surveys yielded a
definite picture of the sky, which can be summarized as follows:

1. There are two different stellar components to the UV sky: hot massive young
   stars and old evolved hot stars. The two populations are not co-local; the hot
   evolved stars reside also in the halo and in globular clusters, while the young
   population resides in the disk.

2. A significant fraction of the diffuse UV emission is scattered starlight off dust
grains, even at high galactic latitudes. The dust scattered UV correlates with HI and FIR emission.

3. There is a small, if any, contribution from extragalactic objects. Projecting from the few galaxies of the UV-selected FOCA sample, and combining this with a likely redshift distribution, it may be possible to account for a quarter or even more of the UVB by unresolved galaxies.

4. The expectation that the UV is the region with the lowest sky background has been verified. In attempting to detect extended objects of very low surface brightness, one must be wary of extended dust patches which reflect UV light from the Galaxy and may be mistaken as LSB galaxies.

Table 1 summarizes information on past, present, and future UV survey missions. It gives the solid angle covered by the survey (Ω) and the limiting magnitude achieved in the UV (m_L). Simple-minded assumptions about future missions allow one to estimate how many sources are likely to be detected by each mission (N_{sources}).

In many UV survey missions it is possible to discern a similar trend; they resulted only in a catalog of sources and had limited scientific follow-up. This is very different from what has happened in the field of high energy astrophysics (HEA), which started in a very similar way. In both high energy and UV astrophysics a significant driver was military technology, detectors and detection alike. However, while the HEA field managed to initiate new missions one after the other, with a significant number of all-sky surveys, the UV was left behind. In the next section I attempt to understand why this happened.

PROBLEMS OF UV ASTRONOMY

Many imaging experiments, in which large fractions of the sky were surveyed, suffered from relatively low angular resolution and low sensitivity. For instance, FAUST and FUVCAM (Carruthers et al. 1992) produced images with a resolution of ∼3′. The identification with optical counterparts in sparse regions of the sky is relatively easy, but some of the identifications close to the Galactic plane, such as those by Schmidt & Carruthers (1993 et seq.) are problematic. These are obtained by unconstrained correlations against existing star catalogs, such as the SAO and the HD, and in many cases a UV source is identified with a late-type star while an early type is within the error ellipse but its visual magnitude is below the catalog threshold.

Another problem with low Earth orbit missions is contamination by atmospheric scattered Sunlight. In case of Shuttle-based telescopes, an additional difficulty are the attitude jets; whenever these fire, wide field imagers collect many stray photons. Electronic readout detectors can eliminate these instances from the data stream when creating the final image, but this is not possible with film recording systems.
Finally, a major problem is conceptual; it is easy to believe that everything to be observed by UV imaging surveys can be predicted just from enough information gathered in the optical domain. If this were the case, “cheap” information from ground-based instruments could be used to economize on “expensive” space adventures. In principle, this works for stars, provided one knows the spectral type and luminosity class of an object, but is much harder for galaxies. The situation becomes very complicated when one wants to account properly for the very patchy galactic extinction. These difficulties caused at least two major decisions against further advance in the UV research.

The report of the Astronomy and Astrophysics Survey Committee, published in March 1991, was one of the two important decision-making events which shaped the field of observational astronomy for more than one decade. Bahcall, who chaired the committee, writes of the mode the decisions were taken, mostly by consensus among its members and within the community (Bahcall 1991). The survey committee assigned highest priorities for IR space facilities, for large ground-based telescopes, and for the millimeter array. Lower priorities were assigned to “moderate programs”, but note that the only UV mission to be included within this portion of the recommendations was FUSE. Finally, the Bahcall committee did not prioritize small programs, but gave three illustrative such undertakings; all three are infrared studies.

Half a decade later, the report of the “HST & Beyond” committee (Dressler 1996) charted the UV-O-IR astronomy well into the next century. The Dressler committee identified two major goals on which special effort should be expended: detailed study of the formation and evolution of normal galaxies, and detection of Earth-like planets and search for life on them. To achieve these goals the committee recommended the continued operation of HST beyond its designed termination in 2005, the development of the Next Generation Space Telescope optimized for near-IR imaging and spectroscopy, and development of space interferometry. Note, in particular, that the HST would become the main UV instrument beyond 2005. To conclude, the only UV undertakings likely to be supported in the coming decades, in a limited way, by academic or NASA establishments, are FUSE and HST. It is worth considering just what these missions will contribute to the general UV knowledge.

FUSE is designed for high spectral resolution (R=30,000) observations in the 90.5-119.5 nm band. It will be equipped with four telescopes with ~36 cm apertures feeding large, dense holographic gratings, and using delay-line detectors. Each telescope is optimized for a different region in the full band and the effective area peaks at 105-110 nm to ~100 cm². This allows observation with the full spectral resolution, with S/N=20, for objects as faint as \(5 \times 10^{-14} \text{ erg cm}^{-2} \text{ sec}^{-1} \text{ A}^{-1} \) \((m_{UV} \approx 12)\). However, reaching this good S/N requires 100,000 sec observations.

FUSE, being in a low Earth orbit, will not be able to access an object continuously (except in the CVZ) and it is reasonable to assume a 35% duty cycle, as for HST. The mission duration is three years, thus it will be possible to observe ~300 faint targets (but many more brighter ones). It is clear that the basic observations
by FUSE will allow first rate abundance studies and characterization of physical conditions in astrophysical plasmas, in the Milky Way and in some nearby galaxies, but this will not be a survey mission.

When considering FUSE and its goals, it is worth comparing it with HUT and ORFEUS. HUT is a 0.9-m telescope which did low resolution spectroscopy ($R \approx 300$) below Ly-$\alpha$ from the Shuttle bay (Davidson et al 1992). ORFEUS is a 1-m telescope which flew twice on the ASTRO-SPAS platform (Kraemer et al. 1988). ORFEUS offers low and intermediate-resolution spectroscopy in a spectral band similar to that of FUSE, and through the parallel IMAPS spectrograph, an even higher spectral resolution, up to $R=120,000$. IMAPS has an effective collection area of $\sim 4.5 \text{ cm}^2$ and is mechanically collimated to $\sim 2^\circ$. It is designed specifically to measure the spectral line profiles of the hot ISM.

The other UV instrument for the next decades is HST. In principle, its UV imaging capabilities have always been secondary to those in the visual range; only the STIS and the FOC have some pure UV imaging capability, but both have tiny fields of view. The Advanced Camera for Surveys will be installed during the 1999 HST refurbishing mission and it is possible that then WFPC2 will be turned off. The ACS is equipped with two UV channels, one with CCDs and another with a STIS-like MAMA with a solar-blind CsI cathode. Both channels will cover $\sim 30^\prime$. We have seen here a proposal for an advanced instrument for HST beyond 2002; the COS by Heap et al. This would provide $R=20,000$ spectra in the 120-170 nm range, equivalent to the high dispersion mode of the SW camera of IUE, but with a much larger telescope. Note that there is no proposal for a wide-field UV imaging facility with HST, although in principle something could be designed to have the FOV of the WFPC2 or maybe even larger, taking advantage of the possibility that WFPC2 will not be used after 1999, and replacing it on HST.

It is clear that the recommendations of the Bahcall and Dressler committees effectively blocked any new initiative in the UV domain, witness the unsuccessful competition for SMEX/MIDEX missions by JUNO, MUSIC, HUBE, etc. This unfortunate development reflected badly in prioritizing space astronomy in other countries as well; to witness, no UV mission is being developed in Europe or Japan, where most space activities outside of the US take place. Given this situation, it is worth mentioning two UV missions being operated or prepared in the US by non-academic organizations and two which piggy-back on international high-energy astrophysics missions.

**MSX, ARGOS, SRG, AND XMM**

MSX is the Mid-Course Space Experiment, designed to detect and characterize celestial backgrounds and atmospheric properties. It is equipped with two UV imagers (UVISI; Heffernan et al. 1996; Murthy, private communication), one with low ($\sim 3^\prime$) and another with higher ($\sim 20^\prime$) resolution. The latter, in particular, is capable of observing in the 180-300 nm band and is probably sensitive to sources
brighter than $m_{UV} \approx 20$ with its widest spectral band. It is not clear how much of the sky will be covered by UVISI, and not even when will the calibrated data become available. One source of optimism is that the cryogenic material for the IR instrument was exhausted ahead of time, leaving much observing time to be allocated for UV studies. This is, however, only a possibility which depends on the actual priorities of BMDO, who operates MSX.

ARGOS is a USAF mission dedicated to celestial backgrounds characterization, which includes a UV survey instrument from NRL. This is GIMI (Global Imaging Monitor of the Ionosphere; Carruthers & Seeley 1996), which consists of two Schmidt cameras with $10^\circ.5$ fields of view, imaging the spectral range form $\sim 70$ to 200 nm in three separate bands. The calculated sensitivity of GIMI is such that it will detect 13.6 mag objects, which will be imaged with 3'.9 resolution. At the time of this meeting, GIMI has been mated with the carrier platform (the ARGOS satellite) and will probably be launched late in 1997 or in early 1998. The important aspect of GIMI is that an all-sky survey is planned and will probably be accomplished within the first year in space. Another advantage is that simultaneous observations shall be obtained in two bands for most of the objects, and in three bands with short time differences. The disadvantage is that the angular resolution is coarse and the imaging sensitivity is not very high; hopefully this will relieve the possibility of confusion with optical counterparts at least at high galactic latitudes.

The TAUVEX experiment was built in Israel to provide deep UV imaging with reasonable resolution and wide field. It consists of three co-aligned 20 cm diameter telescopes imaging a $0^\circ.9$ field of view with 10” resolution onto position-sensitive photon-counting detectors. The spectral region from 130 to 290 nm is analysed with six different bands, from one $\sim 80$ nm wide to one which is only 15 nm wide. TAUVEX is one of the instruments which will operate on board the international observatory Spectrum X-$\gamma$ (SRG), which is dedicated to high energy astrophysics.

The calculated performance of TAUVEX is such that in typical SRG observations it will detect $m_{UV} \leq 19-20$ mag objects with S/N>5. The specific advantage of TAUVEX is the possibility of simultaneous imaging in three UV bands; it is even possible, for selected objects in the field of view, to perform fast photometry with integration times down to 10 msec. Note also that because of the special detectors, the TAUVEX bandpasses are “solar-blind”. In this it has much in common with the XMM UV/Optical Monitor (Sasseen, these proceedings). The differences are that the XMM OM is a single 30 cm telescope, has about twice the collecting area of a single TAUVEX telescope, and in principle offers higher angular resolution, up to one arcsec. In principle, the XMM OM can register very faint images, down to $m=24$, but this is in the “open” configuration, i.e., UV and optical photons mixed together.
A PRESCRIPTION FOR THE FUTURE

It is clear that not much is likely to happen in the coming decade(s) unless the UV community manages to convince the Space Agencies that it is worthwhile to initiate a UV all-sky survey. A decision to proceed to a full, sensitive, all-sky survey must be driven by the desire to discover new phenomena and to clarify puzzling problems. I argued above that the questions of LSB galaxies and a survey for mixed-type binaries are attractive and solvable by a UV survey. However, before proceeding with planning such an undertaking, it would be advisable to initiate a similar one without recourse to spacecraft technologies (and requirements); this would be much less expensive and could be used to highlight the necessity of a space-based follow-up.

I propose that the heritage of SCAP-2000 and FOCA be used to conduct a full sky survey in the 200 nm band using long-duration balloon flights. The history of the FOCA experiment shows that suitable wide field and high resolution imaging can be obtained from a high altitude balloon in this specific atmospheric window. Long-duration balloon flights, of many days and even weeks, have been conducted in the context of high energy and IR astrophysics. It is likely that such modes of observation will become more popular in the near future. Also, NASA developed a TDRSS data relay system just for these long-duration balloon flights.

In order to assemble a long-duration mission for surveying a large fraction of the sky in the UV one has to combine a FOCA-like telescope with a digital-readout, position-sensitive detector and electronics, and ensure TDRSS availability. Observations would be conducted only at night, and during daytime the payload will charge its batteries with satellite-like solar panels. If flights as long as a number of weeks would be possible, as demonstrated for Antarctic and trans-oceanic balloons, with a few flights it will be possible to map the entire sky at least to \( m_{UV} \approx 18 \). This will be a large step forward, compared with the present situation, and one which is doable for a few M$.

Other worthwhile ventures, which can help in acquiring unique UV information, require securing launch and operation facilities on Planetary Astronomy missions. Such spacecraft normally carry small-sized optics for optical-UV imaging which are dormant during most of the cruise-phase of a mission. Despite the smallness of the optics, with good planning it may be possible to survey significant segments of the sky in spectral bands which cannot be observed from balloon-borne telescopes and provide multi-spectral UV information for \( m_{UV} \leq 15 \) objects. Only after such an exploratory phase it would make sense to initiate a new sky survey. In case there would be an official decision to stop operating WFPC-2 while keeping HST operational beyond 2002, it is advisable to study a WFPC replacement dedicated exclusively to UV imaging. This would offer excellent imaging with a reasonable FOV and would be unique for studying the structure and evolution of galaxies.
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