

Progress in Understanding the Diffuse UV Background

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Abstract The ultraviolet spectrometers aboard the *Voyager* spacecraft have been used to delineate, for the first time, the appearance of the diffuse component of the sky at wavelengths about 1000 Å to 1100 Å. To measure the diffuse background requires use of *appropriate* instrumentation. I explain how difficult it has been to ensure that investigation of the UV diffuse background radiation is carried out with instrumentation that is, in fact, capable of making the necessary measurements successfully.

Key words: techniques: ultraviolet – background radiation: ultraviolet

1 INTRODUCTION

This paper reports the fourth occasion on which I have presented an invited paper at the Frascati Workshop “Multifrequency Behaviour of High Energy Cosmic Sources.” On the first such occasion, in 1997, I presented (Henry 1999a) an overview of diffuse ultraviolet background radiation science, and also, in a contributed paper, I presented (Henry 1999b) information on the “Hopkins Ultraviolet Background Explorer” (HUBE), an Explorer proposal that had just been accepted by NASA to be the “Alternate Mission” to MAP (now known as WMAP, in honor of the late Dave Wilkerson). As the Alternate Mission, HUBE would have been implemented, had MAP not been confirmed. Of course, MAP *was* confirmed, and so HUBE remains a proposal.

I take the present opportunity to give an update on each of these two important topics.

2 DIFFUSE ULTRAVIOLET BACKGROUND RADIATION

Our understanding of the diffuse ultraviolet cosmic background radiation has been summarized by Bowyer (1991) and by Henry (1991; 1999c). In particular, Henry believes that the cosmic background *may* be due to recombination radiation from an ionized intergalactic medium. If that is so, this is, of course, very important news; and with my colleagues Jayant Murthy and J. B. Holberg I have labored for some years at using *Voyager* UV spectrometer data to try to strengthen—or, of course (if necessary) to refute—the case for this idea.

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2.1 Bright Patches in the Ultraviolet Sky

In Figure 1, we show the *Voyager* spectrum of a blank region of the sky in the constellation Virgo. The spectrum is labelled “429: Alp Vir +.5,” which is the designation of Murthy et al. (1999) who reported on seventeen years of observations of the diffuse ultraviolet background radiation using the ultraviolet spectrometers on the two *Voyager* spacecraft. The region that was observed to obtain the data of Figure 1 is *not* near the star Alpha Virginis: the label on this spectrum (and other similar spectra) is simply that of the original observer. Most of these spectra were taken as “background” spectra for comparison with observation of some object—and, perhaps, for background subtraction for that observation. These are believed to be truly spectra of the cosmic diffuse background radiation itself: Murthy and his colleagues took elaborate precautions to ensure that each of their 430 spectra contains little or no contamination from point sources.

Our greatest interest in our *Voyager* data has been in the observation of extremely low upper limits on the cosmic background at many locations on the sky. But, at the 2001 Frascati Workshop, I presented (Henry 2002a) not only the extremely low upper limits on the cosmic background that Murthy et al. observed with *Voyager* (see also Murthy et al. 2001 for a detailed defense of this upper limit), but also examples of those patches on the sky—which are quite numerous—that are *bright* in the spectral range 1000 Å to 1100 Å. Figure 1 is an example of

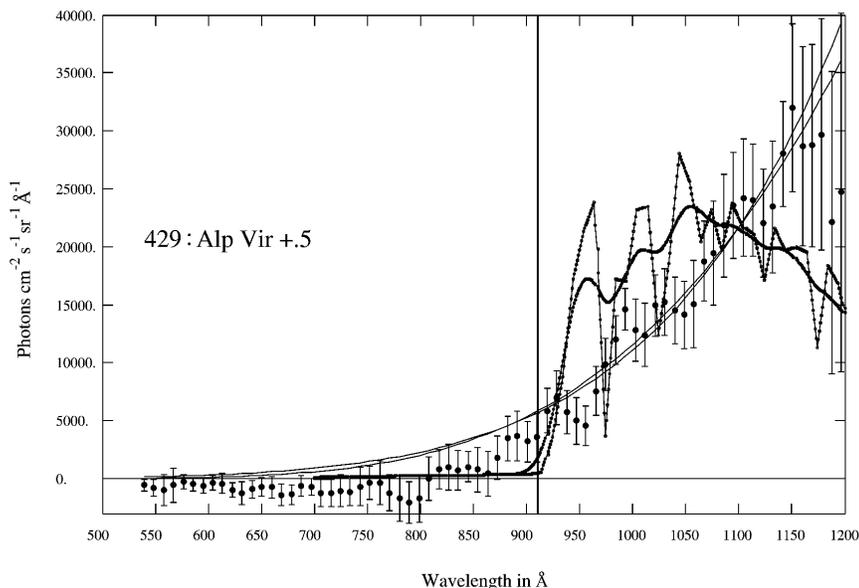


Fig. 1 *Voyager* spectrum of a patch of blank sky in the constellation Virgo, compared with the spectrum of a 25,000 K Kurucz stellar model. In Henry (2002a) the reader will find the same spectrum compared with a 30,000 K Kurucz model. In neither case is the fit at all plausible. (The stellar model spectrum is shown both in original form, and with its resolution degraded to the 28 Å resolution of *Voyager*.) Also shown are thermal bremsstrahlung and power-law “best fits” to the observed spectrum. These fit the data far better than does a stellar spectrum. Note that the emission is detected even shortward of 912 Å, indicating that the source of the emission is not at any great distance.

such a spectrum. It was my belief—in fact, quite erroneous—that all such patches were due to ordinary starlight scattering from ordinary interstellar dust. For, Murthy et al. (1994) had reported one important example of what *is indeed just such scattering*, from the Coalsack nebula. I showed the Vulcano audience (see Henry 2002a) two more such bright patches: HD 155555 and Alp Vir +0.5. Blinded by my prejudice as to the origin of the radiation, I did not see what Dr. Francesco Paresce saw from his place in the audience (as recorded in the discussion following my paper): that the spectrum Alp Vir +0.5 was *quite different* from that of HD 155555 (which *is* similar to that of the Coalsack).

Greatly impressed by Francesco’s acute remark, I have now carefully examined all 430 of the *Voyager* spectra of Murthy et al. (1999), and I have discovered that the great (indeed, the overwhelming) majority of them *are similar in shape to Alp Vir +0.5 and not to HD 155555*. This is an amazing discovery, and indicates that in the range 1000 Å to 1100 Å the diffuse-emission sky is quite different from that at any other energy range observed so far—and is of unknown origin.

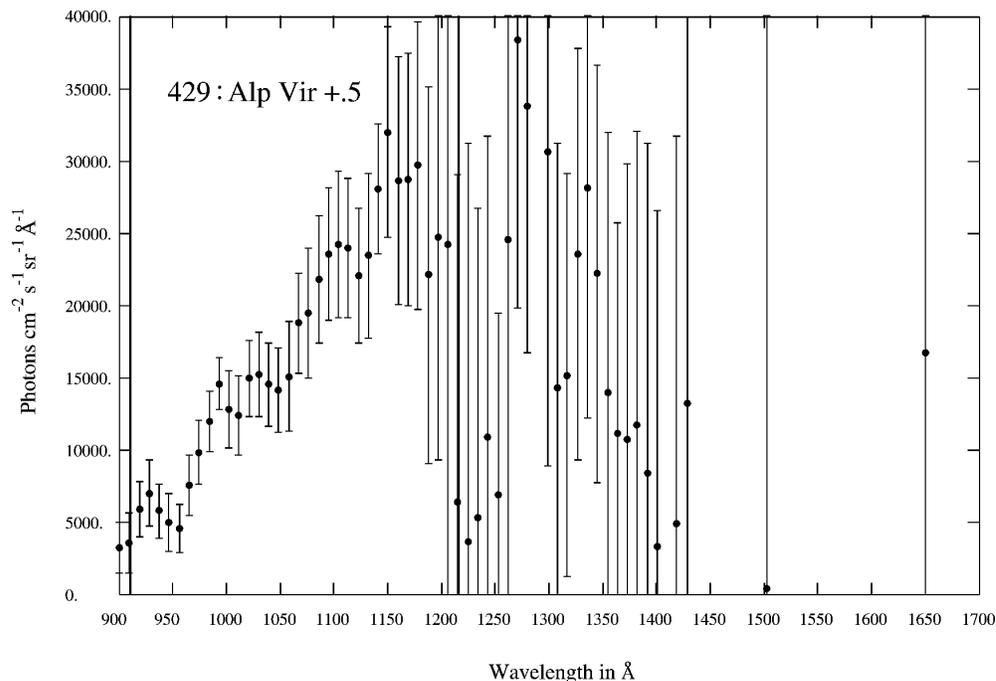


Fig. 2 This is a spectrum of the same patch of sky as in Figure 1, but is extended to show the poor-quality spectrum at longer wavelengths, where the *Voyager* spectrometer efficiency is low. We see that the exponential increase of Figure 1 comes to an end, and indeed, we see that the spectral intensity declines toward longer wavelengths.

2.2 Those Same Bright Patches Viewed at Longer Wavelengths

The spectrum that appears in Figure 1 is seen to be rising *exponentially*, which of course cannot be expected to continue indefinitely. Fortunately, the *Voyager* spectrometers do have a small degree of sensitivity *longward* of Lyman α . For example, Murthy et al. (1994) were able to obtain

a quite reasonable spectrum of the bright (at UV wavelengths) Coalsack nebula longward of Lyman α , leading them to an important conclusion regarding the albedo of the interstellar dust grains: those data *showed* that the albedo *does not* suffer any significant decline below Lyman α .

In Figure 2 we show the spectrum of target Alp Vir +.5 at *longer* wavelengths (the limit of the Voyager spectrometers being 1700 Å). We see that, indeed, the exponential increase terminates, at about 1150 Å, and we see that the spectral intensity declines sharply to longer wavelengths.

We include in the present paper *one* additional example of this new class of diffuse emission patches on the sky, the spectrum of target “Lam Lib,” (Figures 3 and 4). Figure 3 shows its spectrum over the *shorter* wavelengths, while Figure 4 may be compared with Figure 2 for Alp Vir +.5. Lam Lib is substantially brighter than Alp Vir +.5, and its longer wavelength spectrum is seen to be much better characterized, as a result of this.

2.3 What is the Physical Source of these Ultraviolet Bright Patches?

Eric Burgh, of the University of Wisconsin, on seeing these new data, suggested to me that one possibility is that what we are seeing, in the data of Figures 1 through 4, is the emitted spectrum of ultraviolet light from dust nebulae in which are concealed bright ultraviolet-emitting stars. Burgh has shown (Burgh, McCandliss, and Feldman 2002) that the albedo a of the interstellar grains is quite low in the ultraviolet, $a = 0.2$ to 0.4 and decreasing toward shorter wavelengths (in agreement with Henry 2002c), and that the grains are strongly forward scattering: Henyey-

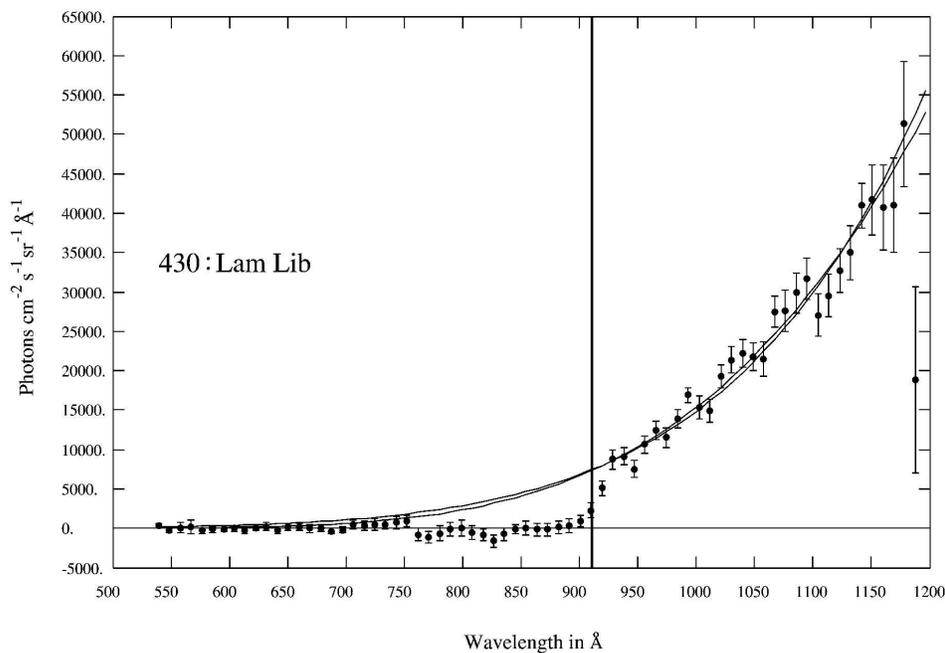


Fig. 3 Here is the spectrum of a still brighter diffuse patch of emission on the sky, “Lam Lib,” in the constellation Eridanus. Just as in the case of the previous spectra, this is truly diffuse emission, negligibly contaminated by point source emission. Note the sharp cutoff of the spectrum at the interstellar hydrogen photoionization edge at 912 Å.

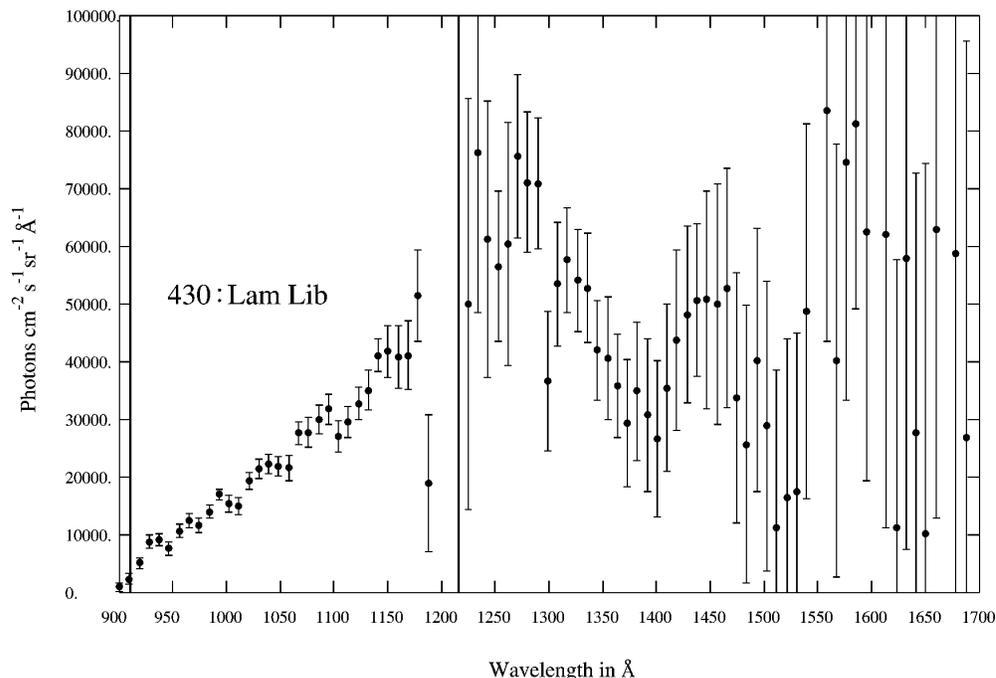


Fig. 4 The extension of the spectrum of Lam Lib to longer wavelengths shows a decline similar to that which appears in Figure 2 for the spectrum of Alp Vir+.5, but with better signal-to-noise, because the Lam Lib target is so much brighter.

Greenstein parameter $g \simeq 0.85$. If this is so, the ultraviolet emission from a star deep inside a dust cloud will tend to be (*some* of it—but not much, because of the low albedo) sent in a predominantly *outward* direction, exiting the nebula with the result that the entire extended nebula glows rather brightly (the *source* star being, by hypothesis, intrinsically very bright).

Murthy (private communication) has had the same idea as did Eric Burgh; and Murthy, Henry, and Holberg (2003 in preparation, to be submitted to the *Astrophysical Journal*) are testing the idea, by looking for the (obviously expected) correlations with IRAS infrared brightnesses.

2.4 Distribution of the Bright Patches on the Sky

In Figure 5 we show the distribution over the sky of the 430 *Voyager* observations (which can be compared with Figure 1 of Murthy et al. 1999, which shows the location on the sky of all 8,376 *Voyager* observations, from which they extracted our 430 spectra as those that were due essentially entirely to diffuse celestial emission, with negligible point-source contamination). The field of view of the *Voyager* ultraviolet spectrometers is $0^{\circ}.1 \times 0^{\circ}.87$, but in Figure 5, for greater clarity, each observation is shown as a larger circle. The shading in each circle is proportional to the *logarithm* of the brightness, with the brightest *Voyager* target (Lam Lib) shown as black, and with targets for which only an upper limit could be obtained shown as white.

The distribution of both “bright patches,” and those patches for which “only an upper limit” could be obtained, is very interesting indeed. Bright patches are seen at *both* high and low galactic latitudes. Blank patches are *also* seen at *both* high and low galactic latitudes.

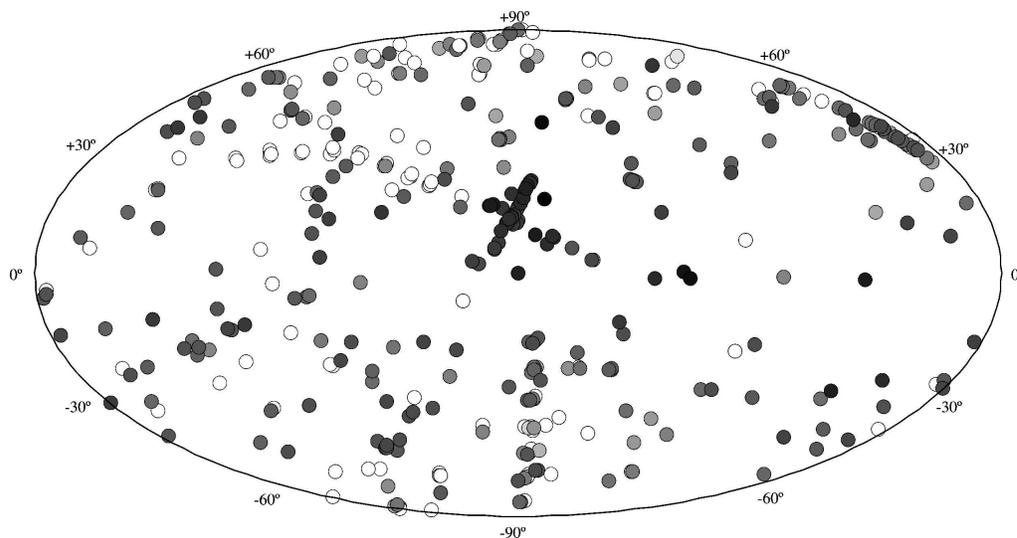


Fig. 5 Map of the sky, showing the distribution of the diffuse ultraviolet background radiation at $\sim 1100 \text{ \AA}$. Patches that are *darkest* in the figure, are *brightest* on the sky, while patches that are *blank* in the figure are *Voyager* targets for which only an upper limit on the diffuse background radiation could be measured. The lowest upper limit is about $30 \text{ photons cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ \AA}^{-1}$ (Murthy et al. 2001), which is much lower than any observation at longer wavelengths of the diffuse UV background. The center of the galaxy is at the center of this Aitoff equal area projection, with galactic longitude increasing to the left. North is at the top.

The possibility that the mysterious new spectra of Figures 1 to 4 might be due to radiation from extragalactic sources of some kind may be excluded by recognizing that some of these sources are seen at very low galactic latitudes. Such ultraviolet radiation could not possibly traverse our entire galaxy to be detected, then, by *Voyager*.

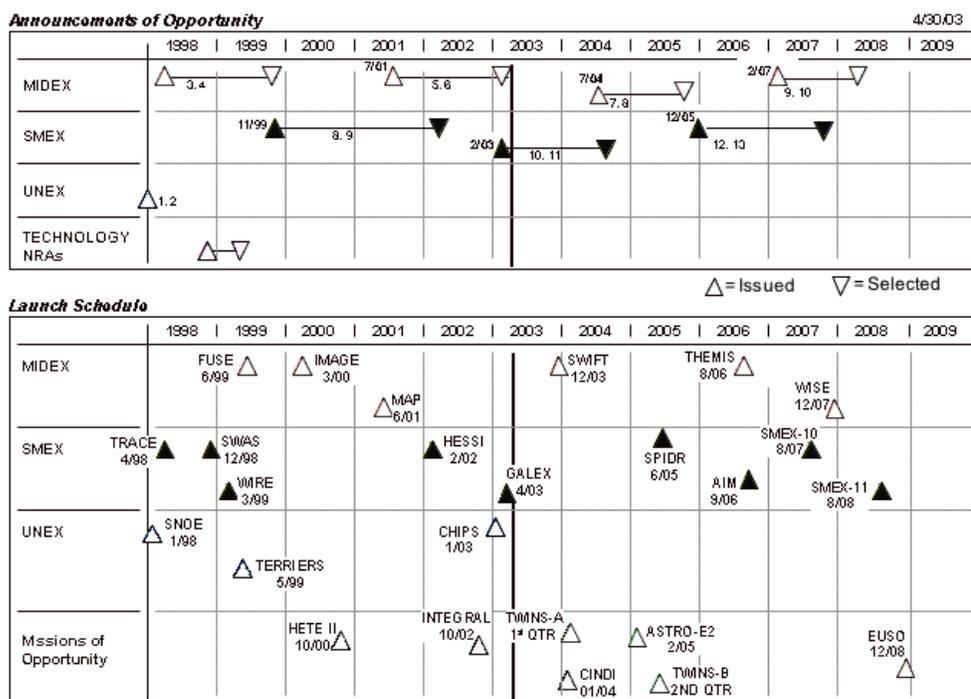
There is a concentration of bright patches in Eridanus (just above the center of the figure) that is reminiscent of the bright region of $3/4 \text{ keV}$ X-ray emission that appears in Figure 6b of Snowden et al. (1997).

The presence of extremely faint (upper limit) patches at even very low galactic latitudes suggests, to me, that the albedo of the interstellar grains at these wavelengths must be very low. This conclusion must be treated with caution, however, for Mathis, Whitney, and Wood (2003) have shown that it is very difficult to characterize the albedo of the interstellar grains in the ultraviolet.

3 ATTEMPTS TO CARRY OUT SPECTROSCOPY OF THE DIFFUSE BACKGROUND BY SATELLITE

Henry (1999b, 2002b) described the “Hopkins Ultraviolet Background Explorer,” (HUBE) which, I am pleased to say, has again, now, in 2003, been proposed to NASA for the Small Explorer (SMEX) program. In April of 2003, NASA’s Explorers Schedule web site showed (Figure 6) a mission, SPIDR, that NASA had in development, and which was intended by its science team to carry out spectroscopy of the diffuse ultraviolet background radiation. It would

Explorers Schedule



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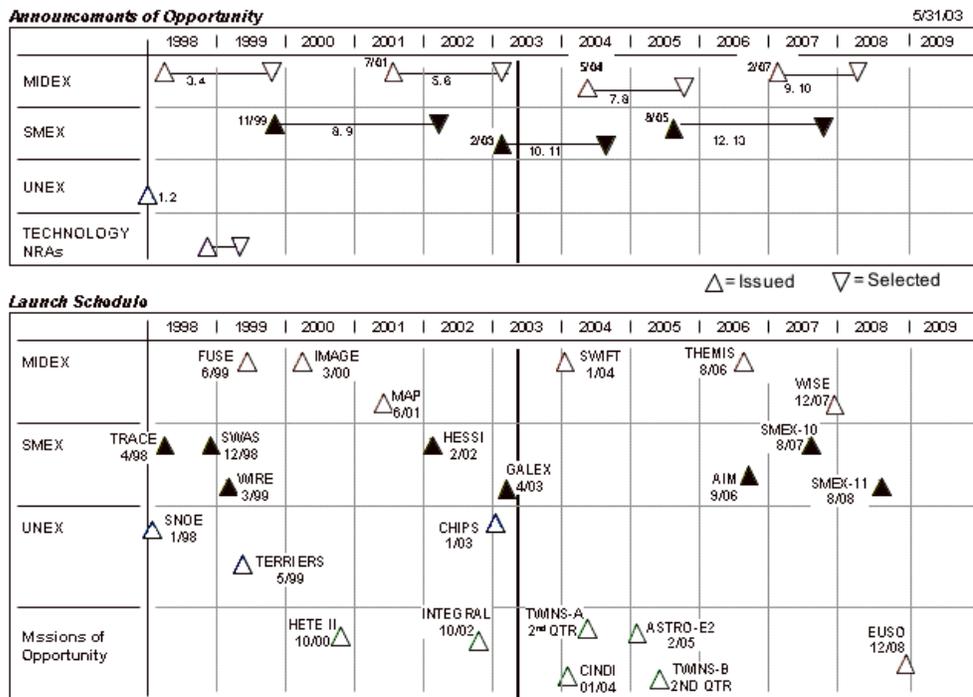
Fig. 6 Small Explorers (SMEX) are shown as black triangles in this printed version of the NASA Explorers Schedule web page, with open triangles used for all other elements of the overall NASA Explorer program. On 2003 April 30, the web page still showed the SPIDR mission’s planned launch date.

have been wonderful if true, but the mission, in fact, as designed and proposed, and as accepted by NASA, could not, in fact, carry out spectroscopy of the diffuse ultraviolet background *at all*; and when I finally succeeded in convincing NASA that this was so, earlier this year, NASA’s Explorers Schedule web site was changed (Figure 7) to reflect the fact that NASA had cancelled SPIDR. I am of course now hoping that NASA will accept my HUBE proposal, and that high quality spectroscopy of the diffuse ultraviolet background will ensue.

My *technical* critique of SPIDR (Henry 2003) is “in press,” in the prestigious refereed European scientific journal “Astronomy and Astrophysics,” and I have good reason to believe that my paper played a major role in the process leading to the cancellation of SPIDR. It is important that the scientific community understand the sequence of events leading to this catastrophe for our community: the waste of possibly as much as ten million dollars of precious *Explorer* funding.

I had long been aware of SPIDR and its proposed technology of tomography, and knew that it had been proposed more than once to NASA for an Explorer mission. I was not concerned about SPIDR as a threat to HUBE, because I felt that NASA, surely, recalled that tomography

Explorers Schedule



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Fig. 7 The same NASA web site on 2003 May 31 shows the result of cancellation of the SPIDR mission. (see <http://explorers.gsfc.nasa.gov/schedule.html>)

had had to be resorted to, when the Hubble Space Telescope was discovered to have spherical aberration: the results were *extremely unpleasant*. One *uses tomography only* if that is *absolutely necessary*. Nonetheless, I (fortunately) very carefully preserved the American Astronomical Society handouts of poster papers where SPIDR was described (Cook et al. 1999, 2000, 2001), against the almost inconceivable possibility of NASA selecting SPIDR. It is well that I did so.

In 2000 April, I was asked to referee a paper (Cook, Gsell, Golub, and Chakrabarti 2003) giving the results of the rocket version of SPIDR. Examination of the paper confirmed that the tomographic technique had no value for study of the faint diffuse ultraviolet background: simply intercompare the three different results that are obtained (their Figures 23, 24, and 25) to see that *quite different* results are obtained, depending upon *which algorithm* is used to rectify the convolved data. I naturally recommended that the paper be rejected, and it was.

Then, in 2002 September, to my astonishment, NASA selected SPIDR (along with several other astrophysics SMEX candidates), for a Phase A study, with the idea that one of the selected missions would actually be further selected for construction and flight.

In the meantime, with Wilt Sanders as Principal Investigator, HUBE was again proposed to NASA, this time as a MIDEX (to include Sanders' X-ray microcalorimeter, the latter device not being part of HUBE). Our proposal was declined by NASA, but the debrief that we received at

Table 1 The SPIDR Science Team: ADS Citations as of 2002

Scientist	Number of Citations
Jerry Ostriker	14,217
Carl Heiles	9,020
Alex Dalgarno	7,104
Mike Shull	5,584
Ed Jenkins	4,645
Runyue Cen	2,991
Adolf Witt	2,408
Ken Sembach	1,931
Hugh R. Miller	1,500
Supriya Chakrabarti	75
Tim Cook	49

NASA Headquarters showed nothing but extremely positive reactions from the peer reviewers of our proposal, and in particular, SPIDR was not mentioned by the peer reviewers. At the conclusion of the debriefing, I gave the NASA debriefer a memo containing the objective alert that *no publication of any of the SPIDR precursor rocket data had occurred*, and that selection of SPIDR would therefore be extremely risky.

Exactly a week later, NASA announced that SPIDR had been selected for construction and flight.

This put me in a dreadful and delicate position. There had been *no publication of any of the results from the SPIDR precursor rocket flights*, so there was nothing at all in the scientific literature to show that SPIDR would not work. I *knew* it would not work, from my à priori understanding, but also from having refereed Cook et al. (2003), and I could not, in good conscience, let the project simply go forward. I also strongly felt that I must *not* work “behind the back” of the SPIDR Principal Investigator, so, with great reluctance, I sent him an email that very day, requesting a copy of his (now-accepted) proposal, and letting him know of my doubts as to the feasibility of the mission. I also asked him to let his (extremely prestigious—see Table 1) team of Co-Investigators know of my concerns. He did not reply to my email, and I have never been able, to this day, to obtain a copy of the proposal.

I visited the NASA Explorer Program Scientist at NASA Headquarters, and explained to him that SPIDR would not work, and that furthermore, the problem was *not* subtle, it was *obvious*.

I advised the Astrophysical Journal that, in light of the fact that NASA was planning to spend \$89 million in public funds on SPIDR, the paper by Cook et al. (2003) should be published after all. The Astrophysical Journal responded that if the paper should be re-submitted, they would again choose me as referee. Fortunately, the paper *was* resubmitted, and was immediately accepted upon my recommendation, and the evidence was in the public domain. I now could (and did) write my paper (Henry 2003) detailing the fatal defects of the tomographic technique. As soon as my paper was submitted, I gave a paper copy of the manuscript to the NASA SPIDR Project Scientist at Goddard Space Flight Center, and I spent two hours with him, going over the problems that made SPIDR a mission that could produce no useable results.

Some time later, a reliable non-NASA source indicated to me that NASA was planning to cancel SPIDR on 2003 April 22. Shortly after that date, the same source indicated that SPIDR had *not* been cancelled, because of intervention by the Massachusetts Congressional Delegation. I therefore did what I had never done before: I briefed (by letter) Senator Barbara Mikulski

with regard to the history of HUBE, and the SPIDR situation. A few days later I received a telephone call from Senator Mikulski's office, telling me that NASA had cancelled SPIDR.

4 CONCLUSIONS

We conclude without difficulty that the science of diffuse ultraviolet background radiation is exciting and is important, and that it holds great promise for the future, and also that (Henry 1999b, 2002b) the scope of the necessary mission is well-matched to the budget of NASA's Small Explorer Program.

It is harder to draw a conclusion regarding blame for the waste of as much as ten million dollars on the aborted SPIDR mission. NASA itself is not to blame for this disaster—NASA relies, and rightly so, on professional peer reviewers. (Those peer reviewers are anonymous. Also, the NASA Explorer Program Scientist has *repeatedly* warned the community against loading proposals with large numbers of prestigious Co-Investigators who have no defined project role, making those individuals not available for selection as peer reviewers.) Consultation of Table 1 suggests to me that the SPIDR Principal Investigator and his senior aide (the last two entries in the list) cannot be blamed *at all*, for this or anything else. I am afraid one must strongly recommend reflective self-examination to the incredibly prestigious Co-Investigators, who lent their names and their scientific reputations to this request for public funds. The American Physical Society (APS News, 2003 January, Volume 12, No. 1, page 1, "APS Expands and Updates Ethics and Professional Conduct Guidelines for Physicists") is currently studying the degree of co-authors' responsibility for the correctness of papers (e.g. Chakrabarti et al. 2003) on which they permit their names to appear. But I suggest that the APS investigation be extended to proposals, where the matter is even more serious, as expenditure of public funds is involved.

Acknowledgements This work was funded by Maryland Space Grant Consortium.

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