THE NON-MICROWAVE BACKGROUND AFTER BOOMERanG

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ABSTRACT. Diffuse backgrounds in various spectral ranges carry diverse information about cosmology and the history of the Universe. The successful launch of MAP will result in data which improve the preliminary understanding of cosmological parameters which we have gained from BOOMERanG. But these microwave experiments do not tell us everything we want to know about cosmology. I show the fascinating situation as far as the soft X-ray and far ultraviolet background radiation is concerned, and I display Voyager data which give a hint of what we might expect from a MIDEX Mission that is focused on spectroscopy of the diffuse ultraviolet and soft X-ray backgrounds.

1. Introduction

The BOOMERanG balloon results on the cosmic microwave background radiation (Netterfield et al. 2001) represent a triumph for the growth of our understanding of the universe in which we live. Shortly after the presentation of this paper at Vulcano, NASA launched MAP, a mission to use technology similar to that of BOOMERanG to map in detail the spectral character of the microwave background radiation.

NASA's MAP mission was selected in the first NASA MIDEX competition, in 1996. That competition featured the simultaneous selection of an "alternate mission," a mission to be implemented, only should the prime mission not be possible within its proposed budget. The alternate mission to MAP that was selected was the Hopkins Ultraviolet Background Explorer, HUBE, for which I am the Principal Investigator. The elements that make up HUBE have been laid out, in detail, by me at these Vulcano meetings and elsewhere (Henry 1997; 1999a,b,c; 2001).

Fortunately, the budget that was proposed for MAP must have been sufficient that no cost overruns occurred. At least, I was never called on, by the responsible official at NASA Headquarters, to implement HUBE.

A number of other candidate MIDEX missions survived to the second MIDEX round, indicating that they were of superb quality. Among these was HIMS, which stands for Hot Interstellar and Intergalactic Medium Spectroscopy mission, for which Wilton Sanders (University of Wisconsin, Madison) is the Principal Investigator. The aim of HIMS was exactly the same as the aim of HUBE, namely spectroscopic mapping of hot gas in the intergalactic and interstellar media. HIMS is a proposal to carry out such

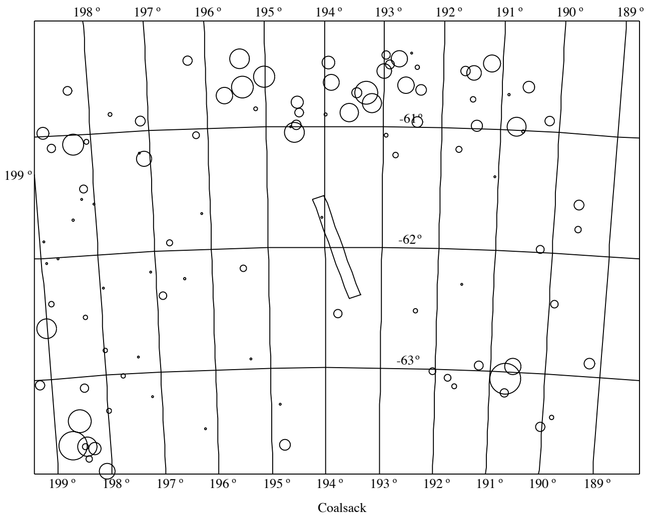

Fig. 1. This chart, reminiscent of my *Atlas of the Ultraviolet Sky* (Henry et al. 1988), but, in fact, created with my own fortran atlas program, shows the region of the Coalsack nebula, in celestial coordinates. The circles represent the brightness of TD-1 stars (Gondhalekhar, Phillips, and Wilson 1980) at 1565 Å. Notice how void of stars the Coalsack area is. The rectangle represents the location, dimensions, and orientation of the *Voyager* ultraviolet spectrometer slit (0.87° by 0.1°) during one of the observations that were reported by Murthy, Henry, and Holberg (1994), who found that the spectrum that was measured at this target corresponded closely to the spectrum that is expected for ultraviolet starlight scattered from interstellar dust. These Coalsack spectra indicate that the albedo of the interstellar grains is *constant*, that is, is independent of wavelength, in the entire spectral region that is covered by the *Voyager* spectrometers (Holberg 1986).

spectroscopy in the soft X-ray part of the spectrum, while HUBE is a proposal to do the same in the ultraviolet.

Both HIMS and HUBE were proposed again in the second MIDEX competition, losing to FAME and SWIFT, missions which addressed more immediate NASA needs.

I am pleased to announce that Wilt Sanders and I have now merged HUBE and HIMS to form a joint mission that we will propose for the third MIDEX round, the Announcement of Opportunity for which appeared on 2001 July 16. The new proposal, called BEST, for "Baryonic Extragalactic Structure Tracer," will be an equal merger of HUBE and HIMS: but NASA *does* require a *single* Principal Investigator. To my great relief, Wilton Sanders has agreed to accept that responsible position.

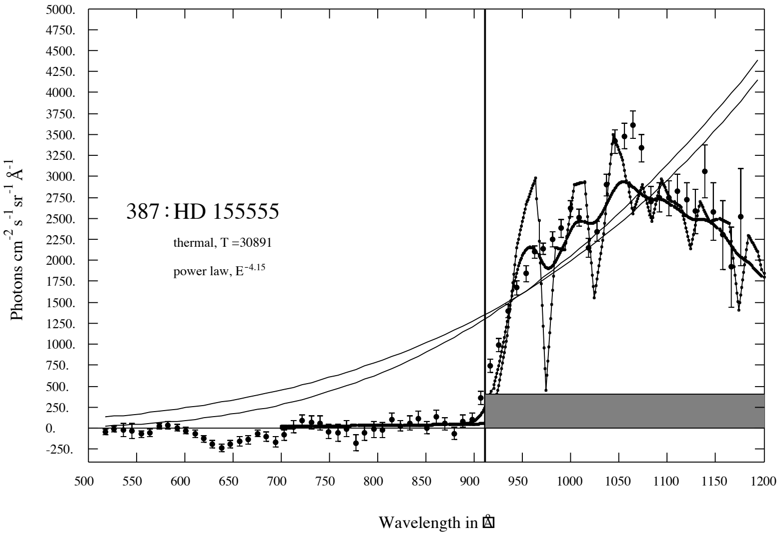

Fig. 2. Here we see a *Voyager* spectrum of the target called "HD 155555." After presenting this figure in the Vulcano meeting *without* a stellar comparison spectrum, I found that I had two Kurucz stellar spectra on my laptop, one of 30,000 K and one of 25,000 K. We see here how excellently the 25,000 K Kurucz model fits this HD 155555 spectrum, confirming that this "bright patch" is due to starlight that is scattered from interstellar dust. The stellar model spectrum is shown both at 1 Å resolution, and also degraded to the 28 Å resolution of *Voyager*. "Best-fit" power law and exponential spectra are also shown; they clearly do *not* fit the data.

2. Voyager

In my verbal paper that I presented in Vulcano in 2001 May, I briefly reviewed the situation regarding the soft X-ray background, but the main thing that I want to accomplish in the present, written, version of this paper is to document my review of my views, at that time, of the observational situation in the far ultraviolet regarding diffuse ultraviolet background radiation.

There have been no recent results involving observations at ultraviolet wavelengths longward of Lyman α; instead, all the action is shortward of Lyman α, and involves reports of observations made with the *Voyager* ultraviolet spectrometers.

There has been one particularly large accomplishment as far as *Voyager* is concerned, and that is the publication by Murthy, Hall, Earl, Henry, and Holberg (1999) of a preliminary study of seventeen years of Voyager spectroscopy of the diffuse background radiation. We intend to follow up this work with more detailed study of the individual

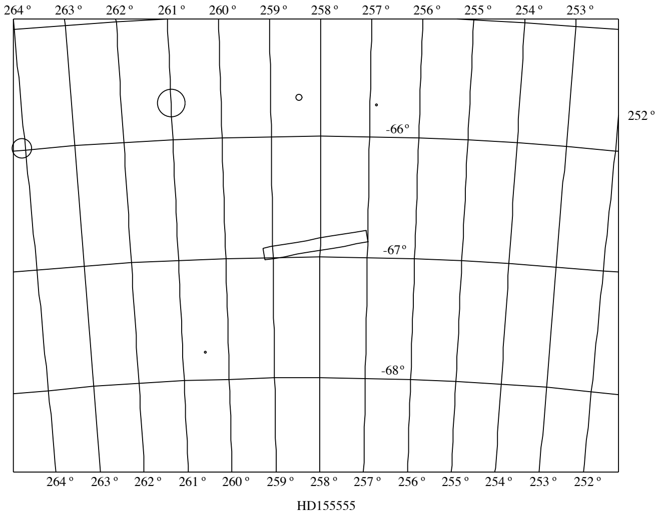

Fig. 3. This chart shows the location of *Voyager* target "HD 155555." The relatively bright TD-1 star could be any one of five ∼ 11 mag stars that Simbad indicates are near that location, except, I suppose, the one that Simbad says is spectral type F0.

observations, but, as a "sighting shot," in this paper I will briefly indicate just how interesting such detailed study should prove.

In particular, until now we have emphasized the fact that for large numbers of locations on the sky, the *Voyager* ultraviolet spectrometers see *nothing*. That is a very exciting result, because all observers of diffuse background radiation at *longer* wavelengths report that there is a general diffuse background of about 400 photons cm^{-2} sr^{-1} s^{-1} Å^{-1} . The *Voyager* observations show that that is *not* the case below Lyman α.

What is the implication of these observations? Henry (1991, 1999) has suggested that the diffuse background radiation that is observed longward of Lyman α is redshifted Lyman α recombination radiation. That is a radical suggestion, because, while such redshifted recombination radiation is guaranteed to exist (since no one questions that there *is* an ionized baryonic intergalactic medium of *some* density), the intensity of the observed background radiation is so high that if it is attributed to this source, the baryonic intergalactic medium must be much more highly clumped than current models (Cen et al. 1994) predict. And this clumping has serious consequences: the recombination time will necessarily be short compared with the age of the universe, and this in turn requires that there be a source of re-ionizing photons present to maintain the observed

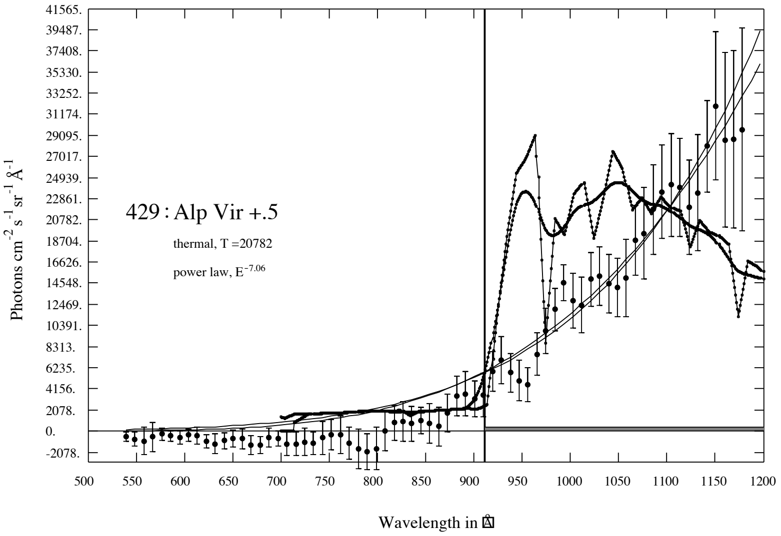

Fig. 4. This *Voyager* spectrum is also that of a bright patch, but the spectrum matches neither the 25,000 K Kurucz model (of Fig. 2) nor the 30,000 K Kurucz model (which is shown here). I do not have cooler Kurucz models with me in Vulcano. The dip in the spectrum at 950 Å makes one think of Lyman γ, but the latter is at 975 Å.

highly-ionized state of the intergalactic medium. No other source than radiative decay of the particles that make up the non-baryonic dark matter could possibly provide sufficient ionization. Thus, Henry (1991, 1999) is suggesting that he has detected the presence of not only the baryonic, but also the *non-baryonic* dark matter in the universe. The notion that the non-baryonic dark matter might decay with the emission of an ionizing photon is supported, remarkably enough, by a host of independent evidence that has been gathered by Sciama (1993).

3. Spectra of Voyager Targets

Despite this richly-deserved attention to those Voyager targets that are so extraordinarily dark (and I will show some of these), I do want now to begin the process of fully understanding the bright *Voyager* targets, particularily those at high galactic latitudes. Murthy et al. (1999) were surprised and even embarrassed at the number of such bright targets. The spottiness of their distribution on the sky presumably is a result of the interstellar grains having a very strongly *forward scattering* Henyey-Greenstein phase function g (as has been determined by Witt et al. 1992), for this means that in favorable

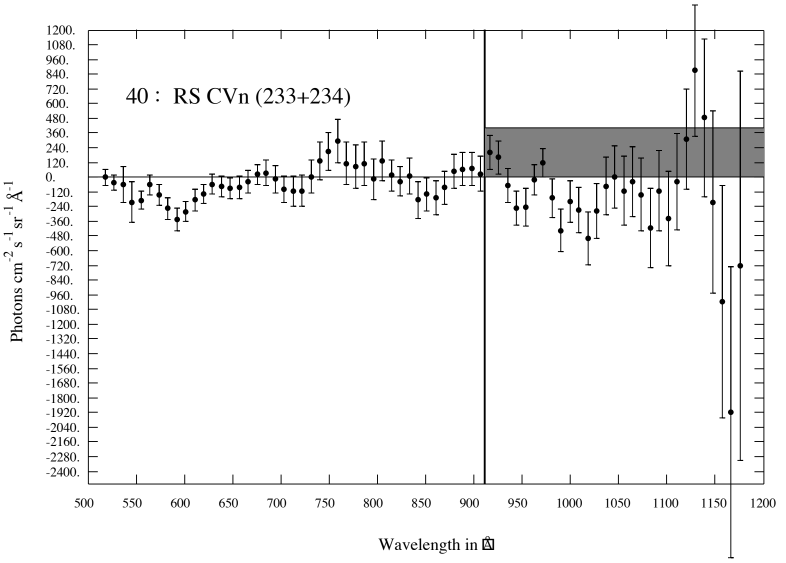

Fig. 5. This shows the *Voyager* spectrum of the target called "RS CVn." It is typical of the extremely dark spectra that are found at a large number of locations and that have been reported by Murthy, Hall, Earl, Henry, and Holberg (1999). The shaded band from 912 Å to 1200 Å in this and other figures shows the level of diffuse cosmic background radiation that is seen at wavelengths longward of Lyman α, as reported by many observers (Henry 1991); it is utterly absent in large numbers of *Voyager* targets.

circumstances the scattered starlight will be beamed toward the observer, while in most circumstances it will not (please see the detailed models of Murthy & Henry 1995). The *albedo* of the interstellar grains in the ultraviolet is widely agreed to be high, having a value of perhaps $a = 0.5$ (Henry 1981).

In Figure 1, I show a map giving the location of one of our *Voyager* observations of the Coalsack nebula. The corresponding *Voyager* spectra are shown in Murthy, Henry, and Holberg (1994), and clearly demonstrate that we are seeing, with *Voyager*, scattered ultraviolet starlight, just as was reported by Holberg (1990) for another location.

Figure 2 gives an example of a similar spectrum, this time of the *Voyager* target called "HD 155555." I should say, that these labels for targets do not necessarily have any meaning; they are the names that were assigned by the original *Voyager* observers, not by us. For example, in the present case, HD 155555 (the star, not the target) is an RS CVn type star, of spectral class K1Vp, and one might certainly wonder if it has some ultraviolet emission (which possibility presumably interested the astronomers who originally proposed this target to NASA), but—the coordinates on the sky are near,

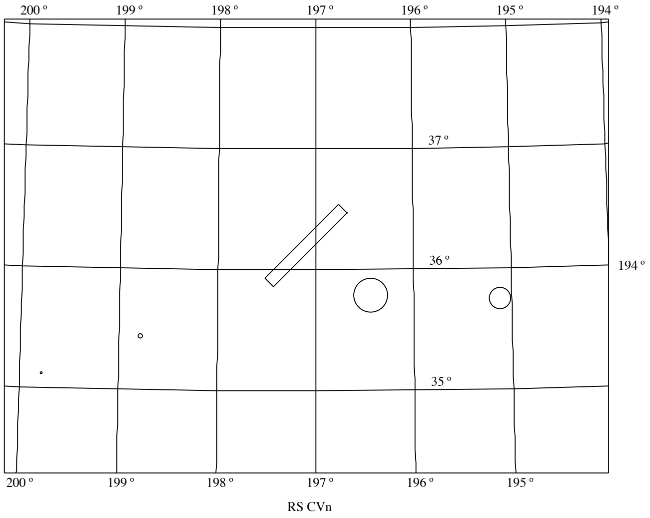

Fig. 6. This chart shows the celestial location of the target "RS CVn." The bright TD-1 ultraviolet star nearest the *Voyager* spectrometer slit is 14 CVn (HR 4943), a $V = 5.25$ magnitude B-type star. Notice how excellently the *Voyager* spectrometer rejects instrumental scattered light—there is no sign of this star's light in the spectrum that appears in Fig. 5.

but not *at*, the location of that star. So, this is undoubtedly an "off-target" reference spectrum. Murthy et al. (1999) did not investigate individual targets in this way (I did it, for just this one, now, for fun) but instead we relied on spacecraft jitter to allow us to reject *all* targets for which the signal was due to *any* point source, and therefore *not* due to diffuse background (see Murthy et al. 1999 for details regarding the method).

A more puzzling spectrum is shown in Figure 3, for the target "Alp Vir +.5." I do not show a map of the location, as Jay Holberg has advised me that this measurement was taken actually over a variety of blank sky locations that were indeed roughly in the direction of Spica. Spica is, of course, one of the brightest ultraviolet stars in the sky, but if the observed spectrum is due to starlight scattered from dust, it must be from some cooler star than Spica, which is of spectral class B1 V. (I have also been reminded that there is nebular emission near Spica (Reynolds 1985), and the possibility that what we are seeing is nebular emission should be investigated.)

More typical of the spectra that have had our highly-focused attention over the last several years is the one that is shown in Figure 5, for the target "RS CVn." The shaded square in Figure 5, as in other figures in this paper that show spectra, is to give an

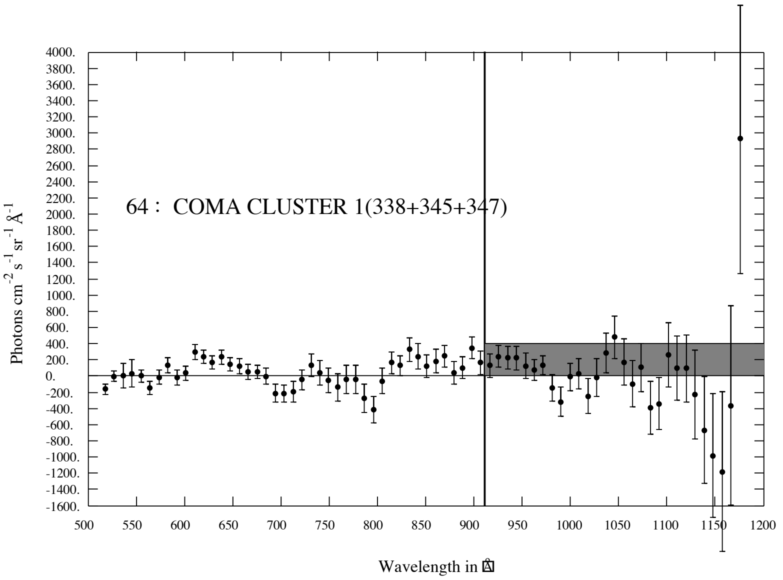

Fig. 7. Here is the *Voyager*spectrum of the target "Coma Cluster," another very dark high-galactic-latitude target.

indication of how much diffuse ultraviolet background radiation would be expected, if the ultraviolet background that is observed at *longer* wavelengths persisted *shortward* of Lyman α. Which, clearly, *it does not!* Figure 6 maps the location on the sky at which this observation was made, and it can be seen that a quite bright TD-1 star is close to the slit, yet nothing appears in the observed spectrum. (We have many such measurements that show that the *Voyager* spectrometers do have *excellent* instrumental scattered-light rejection properties.)

Another example of this important class of "dark" targets is shown in both Figure 7 (the spectrum) and Figure 8 (the location map). Again, there are nearby bright ultraviolet stars that could, in principle, contribute instrumental scattered ultraviolet light to the observed spectrum, but that, clearly, do not.

4. Conclusion

Ever since, in 1963, I learned of the "missing mass" (as it was then called), in the Coma Cluster of galaxies (McVittie 1963), I have relentlessly pursued the dark matter of the universe. I have given an account of my multifarious efforts (Henry (1995); and see also Murthy, Henry, & Holberg (1991) and Henry & Murthy (1994)). In the present paper, I report how we have used the *Voyager* spectrometers, over many years, to explore diffuse

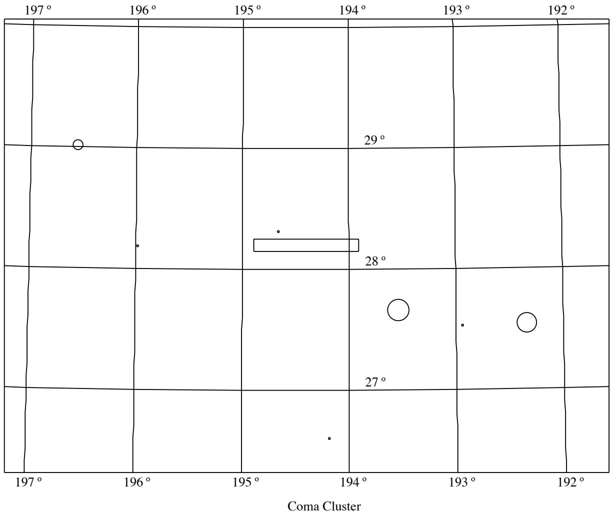

Fig. 8. Chart showing the Coma Cluster target location. The bright UV star at Right Ascension 192.5° is 30 Com (HR 4869), a 5.78 magnitude A-type star.

far ultraviolet background radiation on the sky. In some places, we see line emission from interstellar gas (Murthy, et al. 1993), but in most locations we do not (Murthy et al. 2001). We do sometimes see starlight scattered from dust (as we have seen, for example, in the present paper), and we also see many regions that are utterly lacking in diffuse ultraviolet background radiation.

We feel that the *Voyager* data represent a treasure-trove that we have only *begun* to exploit.

Acknowledgements

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DISCUSSION

J. BECKMAN: Steidel, Pettini, & Adelberger (2001) published recently an observational result in which they stacked up spectra of Lyman break galaxies at redshift ~ 3 and found a measurable flux of Lyman continuum in the resulting spectrum. This would provide a significant energy density which might be a source for the Lyman recombination radiation you are proposing more locally (and also globally).

R. C. HENRY: The Steidel et al. paper is very interesting, but sources of the kind that they have discovered are not nearly adequate to provide the needed ionization. If I have discovered anything at all, I have discovered, too, the *non*-baryonic dark matter.

F. PARESCE: Why does the spectrum above 912 Å increase dramatically? (See, for example, the case of α Virginis). If the albedo is constant over this wavelength region, I would expect the spectrum to be also rather constant.

R. C. HENRY: I don't know, because I don't know what is the physical origin of the radiation. Stimulated by your excellent question, Francesco, I have carried out the additional investigation of targets such as HD 155555 and α Virginis, that I report here, in this, the written version of my Vulcano paper.