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THE DIFFUSE ULTRAVIOLET BACKGROUND RADIATION

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ABSTRACT. I review the nature of the diffuse cosmic ultraviolet background radiation. The ultraviolet background is the last frontier: all the other diffuse backgrounds have been examined, at least at some level. The ultraviolet background has only *begun* to be explored; it offers rich promise of new astrophysical knowledge.

1. Introduction

The study of diffuse backgrounds has played an important role in the recent history of astronomy. From the microwave discovery of the 2.7 K background, to the soft X-ray detection of coronal gas, to the diffuse Hα emission from warm interstellar gas in our galaxy, to the infrared mapping of wisps of dust at high galactic latitudes, diffuse background astronomy has provided fundamental insights into the nature of the universe. As the various regions of the electromagnetic spectrum have been explored, their diffuse backgrounds have been found to arise from the widest possible range of sources: from the local interstellar medium to the farthest reaches of the observable universe; from the wrinkled echo of the Big Bang to the million degree plasma between the stars.

Over the past twenty years, it has become increasingly clear that one relatively narrow portion of the spectrum, the far ultraviolet band from the Lyman edge at 912 Å to 2000 Å, has a unique significance in the context of diffuse background astronomy (Bowyer 1991, Henry 1991). While the background in most bandpasses is dominated by a single emission mechanism, mounting evidence suggests that the far ultraviolet background is produced by a remarkably rich combination of processes, of both galactic and extragalactic origin, sampling a wide range of astrophysical conditions. And fortunately, the sky is extraordinarily black, in that very same band, as has been demonstrated by O'Connell (1987).

The study of the far ultraviolet background was approached historically in the hope of detecting redshifted recombination radiation from a dense intergalactic medium (Weymann 1967; see Davidsen, Bowyer, and Lampton [1974] for a review of early work). That and other exciting cosmological possibilities remain. However, recent results, both observational and theoretical, have identified a variety of additional sources of the far ultraviolet background which are of fundamental importance in their own right (Bowyer 1991, Henry 1991). Let us first briefly highlight these expected contributors.

2. Overview

Within our own galaxy, diffuse ultraviolet radiation is produced by several components of the interstellar medium, from the cold neutral phase to the hot highly ionized phase. Conclusive evidence that the cold neutral phase has already been seen in the far ultraviolet background comes from Voyager: Holberg (1990) detected extended radiation in Ophiuchus that has the spectrum of a hot star. It is clear that this is starlight in the range 912 Å to 1150 Å, scattering from dust.

Additional emission from the cold neutral phase is expected from H_2 fluorescence (Duley and Williams 1980). The principal destruction mechanism regulating the abundance of interstellar H_2 is thought to be absorption of UV radiation in the Lyman and Werner bands; the subsequent de-excitation paths include dissociation of the molecule (Stecher and Williams 1967). H_2 fluorescence has been observed by Witt et al. (1989), in an exceptionally favorable case. Observation of the continuum emission accompanying dissociation and of the far ultraviolet band emission in the non-dissociative decay paths offers unique information on the cycling of this important interstellar molecule.

Also of great significance is the expected detection of far-ultraviolet line radiation from collisionally ionized gas at temperatures of up to $10^{5.5}$ K, gas which is observable in emission at no other wavelengths, except for the highly obscured region shortward of 912 Å. The extensive presence of such gas in the interstellar medium has been inferred from absorption line studies, such as the detection of OVI by the Copernicus satellite (Jenkins 1978 a,b) and of other highly ionized species in the IUE wavelength range (Jenkins 1984). The power of combining absorption line strengths, which are determined by the average line of sight density, with emission line strengths, determined by the square of the density, to determine filling factors, is well known. Feldman, Brune, and Henry (1981) first reported detection of such line emission in the far ultraviolet background, at intensities far above the sensitivity level of our proposed experiment. While Murthy, Henry, Feldman, and Tennyson (1989) could not confirm this result with their UVX experiment on Space Shuttle STS-61C, Martin and Bowyer (1990) do report definite detection of such line emission at somewhat lower intensities in many directions. These observations represent the first step in the development of an extremely powerful technique for studying the interstellar medium. If line emission is present at the levels claimed by Martin and Bowyer, a simple sky survey experiment (Henry 1997) could map such line emission with great precision over the sky.

There is also some evidence for an extragalactic component. The observed correlation of the diffuse ultraviolet background with hydrogen column density is not found to account for the entire background signal; a residual signal is inferred. The contributions from galactic processes cannot account for that residual, so an extragalactic component is implied. One obvious extragalactic possibility is the integrated light of spiral galaxies. Under the assumption that little radiation below the Lyman limit escapes such galaxies, spirals out to a z of about 1.2 will contribute to the sub-2000 Å background. Calculations of the expected signal due to the integrated light of galaxies show that, barring substantial evolution in the UV brightness of spirals, they can account for no more than 1/10 to 1/2 of the minimum observed signal. A systematic mapping of the sky could, however, reveal fainter regions where the integrated light of galaxies is indeed the dominant component.

Finally, we come full circle to the original motivation for studies of the far ultraviolet background. There remains a strong possibility that the source of the isotropic component is the intergalactic medium. Radiation from an ionized intergalactic plasma is no longer the only

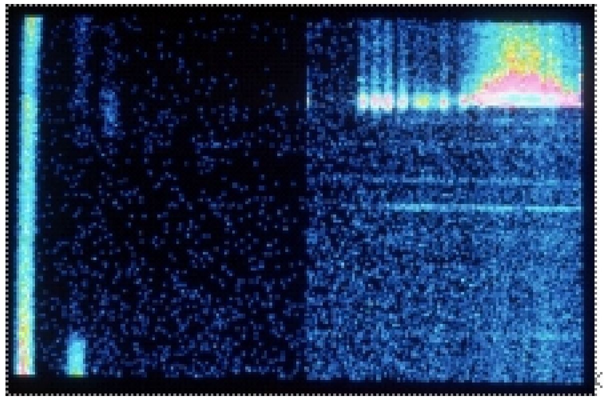

Fig. 1. A sample of diffuse UV background spectral data from the Johns Hopkins UVX cosmic background experiment. Time increases down the page; wavelength is from Lα (bright emission line at the extreme left, 1216 Å) to 3200 Å at the right edge of the photograph. Intense airglow is seen early in the spatial scan at the longest wavelengths (upper right). As the spatial scan proceeds, stars (horizontal bands at long wavelengths) enter and leave the field of view, and two airglow lines of variable intensity are seen near Lα. Zodiacal light (faint vertical bands at far right) appears throughout the spatial scans at an intensity of about 1500 photons cm^{-2} s^{-1} sr^{-1} $Å^{-1}$. The vertical discontinuity in the middle of the figure shows that most of the residual signal is due to instrumental dark counts in the two scanning spectrometers.

possibility: the far ultraviolet background may contain signs of a decaying non-baryonic (massive neutrino?) intergalactic medium.

3. An Example of Observation of the Diffuse Ultraviolet Background

In Figure 1, we show a sample of actual spectroscopy of the diffuse ultraviolet background, from the UVX experiment which flew on STS-61C (the last shuttle flight before the Challenger accident). The experiment is described by Murthy et al. (1989, 1990). In the figure, time increases down the page. The lowest intensity seen is 100± 200 photons cm^{-2} s^{-1} sr^{-1} $Å^{-1}$. Wavelength increases from 1216 Å (Lyman α) on the extreme left, to 3200 Å at the right edge of the spectrum. These data are a spatial scan across a high-latitude region of the sky. Though a sky-survey free-flying satellite would have very much greater sensitivity and spectral resolution than our UVX experiment, these data very nicely illustrate some important points:

- Though Lyman α is heavily attenuated by a CaF_2 filter, it is nevertheless the brightest airglow feature in the spectrum.
- OI 1304 Å and 1356 Å are clearly visible in the UVX data, even at the 340 km altitude of STS-61C. The higher altitude (600 km) that would be available to a free-flying sky-survey satellite would be very important in minimizing these emissions.

● The UVX line of sight crossed the terrestrial limb early in this scan, and NO and O_2 bands are prominent at the longer wavelengths. With my colleagues, I also have detailed rocket measurements of the NO emission (Tennyson et al. 1988): I conclude that a sky survey mission should probably be restricted to the range 912-1800 Å (i.e., approximately the left half of the figure, plus shorter wavelengths).

● At longer wavelengths, a few horizontal bands are seen; these are the spectra of stars lying on the scan path. Notice how most stars fade out completely in the spectral range that is recommended for a sky survey.

● Delicate, broad vertical bands of emission are seen in the far right-hand part of the figure. These are peaks in the spectrum of the zodiacal light. My colleagues and I have measured the zodiacal light before (e.g. Tennyson et al. 1988): the UVX data, which are of excellent quality, are described by Murthy et al. (1990). Notice, again, how zodiacal light (which we regard as noise!) fades to insignificance in the recommended sky-survey spectral range.

● This figure represents a merging of data from two spectrometers with different internal background levels. That difference is clearly noticeable in the figure. There must be careful and sophisticated continuous monitoring of the spectrographs' internal background, in any sky survey mission!

4. Molecular Hydrogen Fluorescence

A very important spectral signature which is almost certain to be present in the diffuse ultraviolet background is fluorescent emission of H_2 (Duley and Williams 1980). Molecular hydrogen is, of course, a major constituent of the interstellar medium (see, for example, Shull and Beckwith 1982); a simple means of directly mapping its distribution over the entire sky would be extremely valuable.

Molecular hydrogen emission has been detected using IUE in very favorable circumstances very near an extremely bright star, γ Cas (Witt et al. 1989). In addition, Martin, Hurwitz, and Bowyer (1990) have presented statistical evidence of detection of hydrogen fluorescence emission from their UVX space shuttle data, but Murthy et al. (1991) could not confirm that detection, based on their Voyager observations at shorter wavelengths. Nevertheless, the Martin et al. observation is a mark to shoot at for sensitivity calculations: and it is clear that simple spectrometers could map the entire sky with good sensitivity, if the H_2 emission *is* at the intensity suggested.

5. Emission Lines from Highly Ionized Atoms

The presence of absorption lines attributable to highly ionized species in the spectra of hot stars has been interpreted as strong evidence for the existence in interstellar space of a tenuous, possibly pervasive, gas at or near coronal temperatures (York 1982; Jenkins 1984; Cowie and Songaila 1986). This is related to the crucial idea, first put forward by the late Lyman Spitzer (1956), that the galaxy may have a hot halo. These ideas have received further support from the discovery of the diffuse sky background in the soft X-ray and the EUV, which can only arise as a consequence of collisional excitation and radiative decay of a plasma at approximately coronal temperatures (McCammon et al. 1983; Paresce and Stern 1981).

6. High Latitude Dust Scattering

There is substantial evidence (e.g., polarization of starlight and IRAS detection of cirrus) that there is dust in some quantity at most locations at moderate and high galactic latitudes. That dust is illuminated by galactic-plane stars. One may construct a model for the dust-scattered light, using the TD-1 stars or some model of the stellar distribution as the source. The most recent model is that of Murthy and Henry (1995). In developing that model, rather than assume that the interstellar radiation field arises from a smooth plane-parallel distribution of stars, we have allowed for the concentration of the source starlight to Gould's Belt, and the drastic asymmetry in longitude, that are well known, and that were discovered by Henry (1977).

The model of Murthy et al. uses individual stars, in catalogs such as the Bright Star Catalog or Skymap, as a source, and produces a detailed prediction of dust-scattered light. The Murthy et al. model for the case that the albedo is 0.1 and the well-known Henyey-Greenstein (1941) scattering parameter $g = 0.9$, which corresponds to very strong forward scattering, shows strong peaks produced by individual stars; peaks that are completely absent in all (published) competing models. A sky survey could (and should) map this dust-scattered light over the whole sky, with great sensitivity and precision. Spectrometers could unambiguously identify the component of the light that is dust-scattered starlight by its spectral shape. Comparison with the models would lead to accurate measurement of the albedo and scattering parameter of the dust grains in the ultraviolet.

7. Extragalactic Sources of the Far Ultraviolet Background

The current observational situation regarding the *extragalactic* cosmic ultraviolet background is intriguing. The remarkable fact is that virtually all observers agree on a residual high galactic latitude background longward of Lyman α (1216 Å) of about 300 photon units, but Holberg (1986), Murthy, Henry, and Holberg (1991), and Murthy, Hall, Henry, and Holberg (1997) find, from Voyager, only an upper limit (at many high-galactic latitude locations) of about 100 units below Lyman α. The natural, if speculative, interpretation of such a sharp break in the spectrum near 1216 Å is that the longer-wavelength radiation is Lyman α from a recombining intergalactic medium. The intensity is too great (but not drastically too great) to fit that explanation in conventional cosmology, but that does not mean that the explanation is wrong.

8. Conclusion

I conclude that an all-sky survey, spatially and spectrally mapping the diffuse ultraviolet background radiation, is urgently needed, and will provide rich rewards of new astrophysical knowledge and insight.

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