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FINAL REPORT

NAG 5-2341

***Voyager* Investigation of the Cosmic Diffuse Background;**

Observations of Rocket-Studied Locations with *Voyager*

prepared by

Richard C. Henry

Principal Investigator

Due October 31, 1994

FINAL REPORT on NAG 5-2341

Voyager Investigation of the Cosmic Diffuse Background;

Observations of Rocket-Studied Locations with Voyager

Richard C. Henry, Principal Investigator

This is the final report on the referenced NASA grant.

This work is part of a much larger, partially NASA-supported effort to understand the Voyager archive, that Murthy, Henry, and Holberg are undertaking.

The present grant went to salary support for Murthy, and to participation by Henry in the Elba meeting in which the results were presented. I therefore focus on these relevant aspects of the work; however, I also take the opportunity to include an Appendix that presents a broader picture of "what this research is all about," that conveys a better sense of our excitment about the opportunity presented by Voyager data.

The bulk of the data reduction has been carried out by Murthy, with telephone conversations with Holberg on technical points, and regular meetings with Henry on scientific questions. During the period of the present grant, a tremendous amount of progress was made by Murthy on setting up software using IDL to analyse the whole Voyager archive. The fruit of this effort is still to come, and is being actively worked on at present.

However, the present state of the data is highly suggestive that we have a result that may be of profound significance. It is not out of the question that we have direct evidence for the baryonic dark matter that closes the universe, and indirect evidence for the non-baryonic dark matter which contributes to closure.

The evidence for this was presented by Henry in Elba, and was received with interest. It is safe to say that the result cannot yet be regarded as accepted, but there was great interest in the possibility that was raised.

As a result of this reception, a proposal was prepared by Henry and submitted to the STEDI program of USRA, a NASA-supported student-built satellite program. The proposal was accepted for study, along with five other proposals from other groups. In the spring of 1995, USRA will select two of the six for implementation.

What I proposed was to verify the results that we have obtained from Voyager, by making a measurement using a double-pass spectrometer to eliminate grating-scattered Lyman alpha radiation.

If we get to implement the satellite, a very big oak will have grown from the little acorn of the present grant, and associated grants.

A most important product of our work is of course the published results in the refereed literature., The papers connected with the Voyager work that have appeared most recently are:

(with Jayant Murthy, and J. B. Holberg), Constraints on the Optical Properties of Interstellar Dust in the Far Ultraviolet: *Voyager* Observations of the Diffuse Sky Background, Astrophys. J., **383**, 198 (1991).

Ultraviolet Background Radiation; Annual Review of Astronomy and Astrophysics, **29**, 89 (1991).

(with J. Murthy, M. Im, and J. B. Holberg), *Voyager* Observations of Diffuse Far-Ultraviolet Continuum and Line Emission in Eridanus; Astrophys. J., **419**, 739 (1993).

(with J. Murthy and J. B. Holberg), *Voyager* Observations of Dust Scattering Near the *Coalsack* Nebula; Astrophys. J., **428**, 233 (1994).

(with J. Murthy), Ultraviolet Background Radiation, Astrophys. J. (Letters),**418**, L17 (1993).

(with J. Murthy), Extragalactic Ultraviolet Background Radiation, invited paper presented at the Space Telescope Science Institute Symposium in honor of Riccardo Giacconi "Extragalactic Background Radiation," 1993 May 18 - 20, ed D. Calzetti, M. Fall, M. Livio, & P. Madau (Cambridge: Cambridge Univ. Press), *in press.*(1994).

Search for the Intergalactic Medium; invited paper presented at *The Physics of the Interstellar Medium and Intergalactic Medium, A Meeting n Honor of Prof. George B. Field*, Isola d'Elba, Italy (1994).

Additional papers will undoubtedly appear in the year or two to come.

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VOYAGER OBSERVATIONS OF DUST SCATTERING NEAR THE COALSACK NEBULA

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ABSTRACT

We present the results of four observations of the sky in the direction of the Coalsack nebula. These observations were made using the ultraviolet spectrometers aboard the two *Voyager* spacecraft in the spectral range between 912 and 1600 Å. Intense diffuse emission with a spectrum characteristic of an early B star was observed in all four targets, which we interpret as starlight forward scattered by interstellar dust in the foreground of the main mass of the Coalsack. While more detailed modeling is necessary to derive values for the optical constants of the dust grains, our data indicate that there is no decrease in the albedo toward shorter wavelengths, arguing that the far-ultraviolet rise in the interstellar extinction curve is due to an increasing number density of small particles rather than to a new population of low albedo grains.

Subject headings: dust, extinction — ISM: individual (Coalsack) — ultraviolet: ISM

1. INTRODUCTION

The albedo (a) and phase function (g) are among the most fundamental properties of the interstellar dust, yet they are poorly known over the entire spectral range. Not only is the determination of the optical constants crucial to understanding the nature and composition of interstellar dust but, as the dust plays a major role in the reprocessing of starlight, it is also necessary in modeling the energetics of the Galaxy. One of the best spectral regions to observe and interpret scattering by interstellar dust, and where the largest fraction of the incident energy is absorbed, is the ultraviolet, largely because of the lack of competing sources of diffuse emission. Technical difficulties have often limited the usefulness of such observations (Bowyer 1991; Henry 1991) and the derived optical constants have often been wildly divergent (see Table 2 in Bowyer 1991). While some of these variations may be due to actual differences in the properties of the grains in different environments, most probably reflect the difficulty of the observations and analysis.

We present here the results of three observations near the Coalsack nebula made with the ultraviolet spectrometers (UVSs) aboard the two *Voyager* spacecraft. While the planetary observations of the two *Voyager* spacecraft have been well documented, the UVSs have also carried on an active program of astronomical observations which ceased only early this year. The two spectrometers are almost identical, the primary difference being a factor of 2 in sensitivity in favor of the *Voyager 2* UVS. The spectral coverage is from about 500 Å to 1600 Å, although the sensitivity drops considerably at wavelengths greater than Lyα, with a resolution of 38 Å for diffuse sources (~18 Å for point sources), and a field of view of 0°.8 × 0°.1. A full description of the spacecraft and instrumentation is given by Holberg (1991).

The Coalsack nebula is one of the most prominent dark nebulae in the southern sky, easily visible to the naked eye as a dark patch against the rich star field of the Milky Way. Our observations of the Coalsack were part of a program to map the diffuse far-ultraviolet radiation field (Murthy, Henry, & Holberg 1991; Murthy et al. 1993). We had expected a moderate to low signal due to back scattering of the light from three nearby early B stars in front of the Coalsack—α Cru, β Cru, and β Cen—from dust in the nebula; instead we detected the brightest patch of scattered light (from the diffuse interstellar medium) yet observed in the UV. This emission, which reaches an intensity of about 30,000 photons cm^{-2} s^{-1} sr^{-1} Å^{-1} at 1100 Å, is primarily due to forward scattering of the light from the three stars above, which are three of the brightest FUV sources in the terrestrial sky, by a relatively small amount of dust in the foreground of the Coalsack, itself. While detailed modeling will be necessary to extract the actual values of the optical constants, we find no evidence for any change in the optical constants over the spectral range between 912 and 1400 Å.

2. OBSERVATIONS AND DATA ANALYSIS

Our observation log is in Table 1 with the locations of the targets plotted in Figure 1. Although the locations of targets A and B coincide, they were made using different spacecraft and hence had different orientations in the sky. The exact locations of the observations were chosen such that no stars of B9 or earlier were in the field of view; however, a post-observation search in the SKYMAP star catalog (Gottlieb 1978) and the SIMBAD database has revealed a faint B6 star in the field of view of target C. We will discuss the contributions of these stars to our observed signal below. Note that no star, regardless of its brightness, of spectral type later than A0 will contribute any flux shortward of 1200 Å.

The observations were made in the "Cruise 5A" mode consisting of individual 240 s integrations which we have summed over time. This integrated spectrum can be decomposed into three parts: an instrumental dark count, due to radiation from the spacecraft's radioisotope thermoelectric generator (RTG); emission lines from resonantly scattered solar radiation; and a residual containing any astrophysical signal. The shape of the dark count spectrum has been independently determined from observations of a shadowed region on the spacecraft (Holberg 1986) and the level in our data is

[1] Guest Observer with the *Voyager* Ultraviolet Spectrometers.

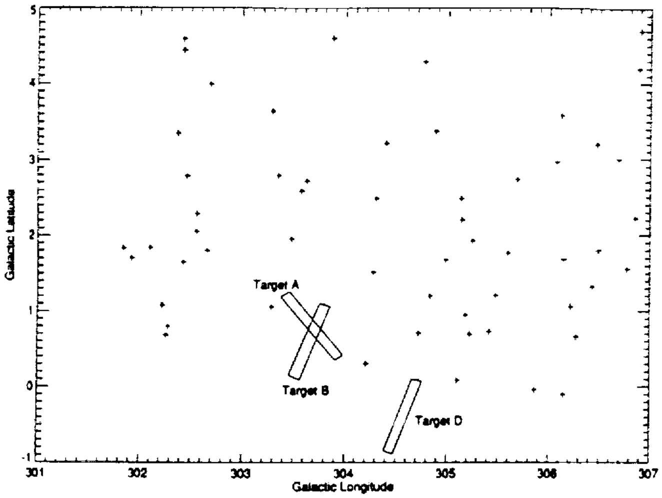

FIG. 1.—The positions of the UVS slits are shown for targets A, B, and D against those nearby stars nearer than 250 pc which were observed by Franco (1993). The two parallel slits are the *Voyager 2* observations while the other observation was made with *Voyager 1*. Target C is approximately 4° south of target D and is not in the field shown here. The star near the upper left hand corner of target A has an extinction (A_V) of 1 mag at a distance of 180 pc while the star to the lower right-hand corner has an extinction of 0.31 at a distance of 153 pc. The extinction is rather patchy over the whole field.

TABLE 1

OBSERVATION LOG

Target	l	b	Exposure Time (s)	Spacecraft
A	303.7	0.8	320,160	*Voyager 1*
B	303.7	0.8	135,662	*Voyager 2*
C	305.2	−5.7	62,494	*Voyager 2*
D	304.6	−0.4	31,230	*Voyager 2*

unambiguously set from the spectral region below the Lyman limit (912 Å), where the opacity of the interstellar medium (ISM) is so high that no astrophysical signal will be seen. Following the dark count subtraction, instrumental scattering is removed by applying a matrix operator determined from preflight calibrations. The resultant spectra, which still include the interplanetary lines of H I Lyα (1216 Å) and Lyβ (1026 Å), and He I (584 Å), are plotted in Figure 2.

Rather than attempt to subtract the interplanetary lines directly, we follow Murthy et al. (1993) in simultaneously fitting the data with a template for the interplanetary emission and a model for the diffuse radiation field. The template for the *Voyager 1* observation was constructed out of a long (10^6 s) exposure of the north Galactic pole in which no cosmic signal was detected (Holberg 1986). The corresponding template for

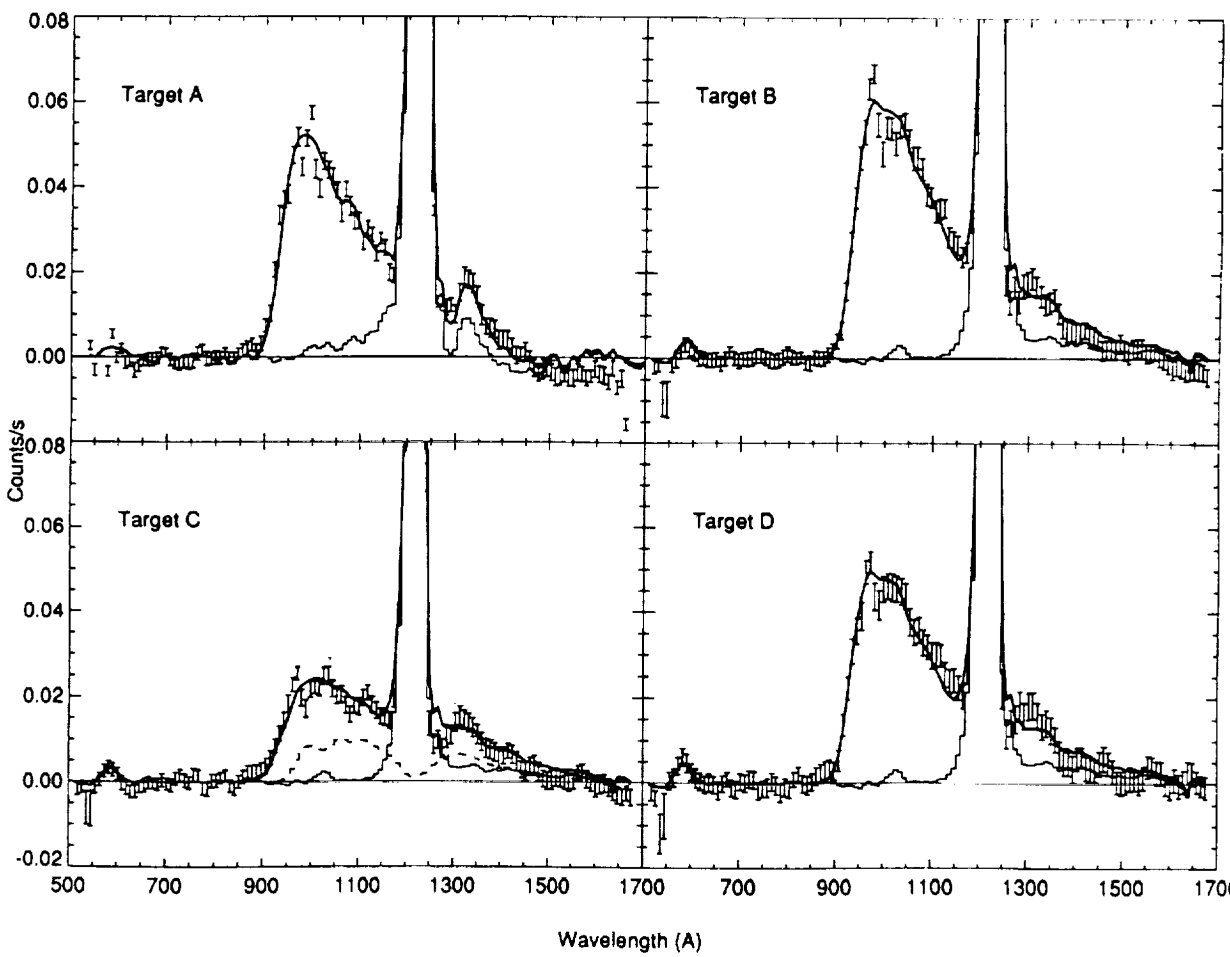

FIG. 2.—The observed data are plotted as $\pm 1\ \sigma$ error bars for each of the four targets. The dark line represents our best-fit model (which includes the interplanetary lines); the thin solid histogram is the scaled template; and the dashed line (in target C) represents the stellar contribution to the spectra, if any. Targets A, B, and D all have spectra representative of a B0 star; target C has been contaminated by a B6 star in the field of view.

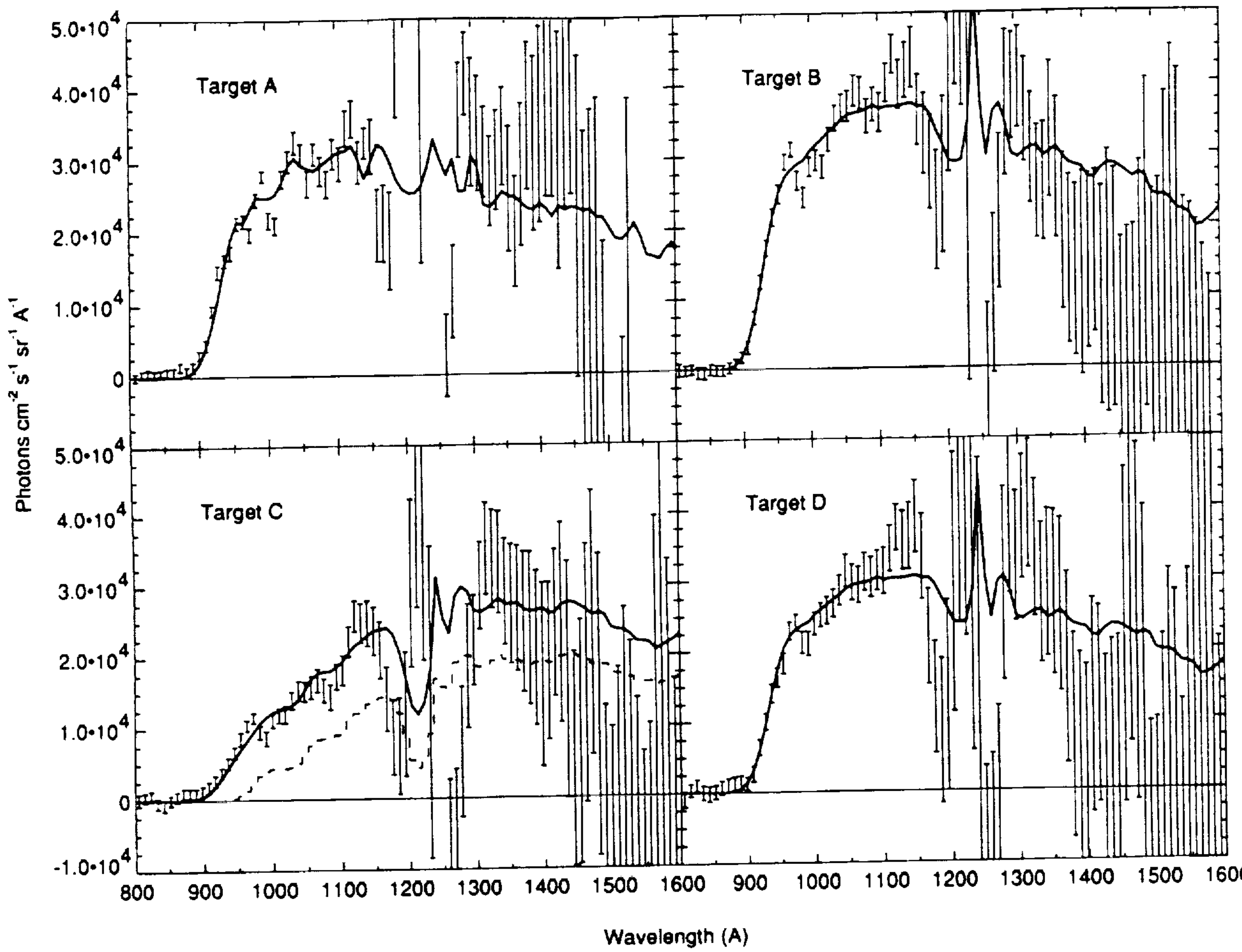

FIG. 3.—The calibrated intensities are plotted as $\pm 1\ \sigma$ error bars for each of the four targets after subtraction of the template. Note the low confidence of the data above 1500 Å.

the *Voyager 2* observations was constructed out of a weighted average of targets A, B, and D of Murthy et al. (1991) (their target C was rejected because of evidence for a weak cosmic signal) and a new observation of the high-latitude optical nebulosity first detected by Sandage (1976). In none of these observations was there any indication of a cosmic signal. We have checked the consistency of the template for *Voyager 2* by applying it to each of its components, finding no residuals. The two templates were scaled to the corresponding observations using a least squares method and subtracted with the resulting spectra plotted in Figure 3. In practice, our observed signals are so strong that only in the vicinity of the intense heliospheric Lyα line is the template subtraction important.

3. DISCUSSION

A detailed search of our fields of view using the SKYMAP star catalog and the SIMBAD database has found a B6 star [HD 115017; $V = 8.3$; $E(B-V) = 0.06$] in target C. We have modeled this star using Kurucz (1979) spectra of the appropriate temperatures and plotted its expected contribution to the observed signal in Figure 2*c*, where it provides almost half of the signal observed at wavelengths above 1000 Å. The star is too cool to emit significantly at shorter wavelengths and thus the continuum below 950 Å is entirely due to dust scattering. Because the instrumental response is not uniform across the aperture of the UVS, the signal due to a point source will vary with the attitude control motion of the spacecraft. Based on the lack of such variation in our data, we have set limits of about 20% on the contribution of any point sources to our diffuse signal in the other locations.

The dense mass of the Coalsack, at a distance of about 200 pc from the Sun, acts as a curtain blocking light from any star not in the foreground, especially in the FUV. In addition, three of the five brightest (as seen from the Earth) stars in the FUV are located at distances between 100 and 160 pc directly in front of the nebula (Table 2). Hence the radiation field at any point between the Sun and the Coalsack nebula is dominated by these three stars, all early B type, and can be well modeled by a B0 Kurucz (1979) spectrum. As mentioned above, we had originally expected to see only backscattered light from the dust in the nebula, which dominates the extinction in the line of sight. However, unless the scattering is predominantly backscattering ($g < 0$), the Coalsack itself can, under the most

TABLE 2

DOMINANT STARS

Star	Spectral Type	l	b	d (pc)	A_V (mag)
α Cru (HD 108248)	B0.5 IV	300.13	−0.36	114	0.09
β Cru (HD 111123)	B0.5 III	302.46	3.18	163	0.06
β Cen (HD 122451)	B1 III	311.77	1.25	90	0.09

favorable circumstances and assuming perfect reflectivity, produce no more than about 5000 photons $cm^{-2}\ s^{-1}\ sr^{-1}\ Å^{-1}$. Detailed extinction studies (Franco 1989; Seidensticker 1989) show a significant amount of dust in the foreground; i.e., between the Coalsack and the Sun, and, in particular, between the three hot stars and the Sun, and it is this dust which contributes the largest fraction of the observed signal.

We have attempted to model the amount of scattered light using a variety of dust distributions; unfortunately, small variations in this distribution have a relatively large effect on the observed intensity. While we can easily reproduce the observed data with as little as 0.1 mag of reddening in the foreground or an albedo as low as 0.1, the uncertainties in the distribution are large enough that we cannot place useful limits on the derived optical constants. We should note parenthetically that molecular hydrogen fluorescence (e.g., Sternberg 1989) cannot account for more than about 1%–2% of the observed signal.

Independent of any model we can derive the simple relationship $I_o/I_* \propto a\sigma e^{-n\sigma}$—where I_o and I_* are the observed and incident intensities, respectively, a is the grain albedo, σ is the extinction cross section per H I atom (from Draine & Lee 1984) and n is the total H I column density along the line of sight—if the phase function g is constant over the spectral range involved and if every photon observed has been scattered once and once only. Using this formulation, a lower limit of 10^{20} cm^{-2} on the H I column density [corresponding to an A_V of 0.3 mag from Franco 1993 with $A_V/E(B-V) = 3.1$ and $n(H)/E(B-V) = 5.8 \times 10^{21}\ cm^{-2}$; Bohlin, Savage, & Drake 1978), and arbitrarily fixing the albedo at 0.5 at 1400 Å, we can derive the spectral behavior of the albedo (Fig. 4). We have used only the spectrum from target B in this derivation; similar results are obtained if we use target D. If a new population of zero albedo small grains were responsible for the FUV rise in the extinction curve (cf. Witt et al. 1993), we would expect the albedo to drop significantly at short wavelengths. No such trend is seen in our data, perhaps implying an increase in the number density of the small grains rather than a dramatic change in their optical constants. It should be noted that the optical properties of the grains may be highly dependent on their environment and hence there should be no a priori expectation that the results derived here should match those elsewhere, particularly those obtained from a bright reflection nebula such as NGC 7023 (Witt et al. 1993), barring the aesthetics of minimizing the number of parameters involved.

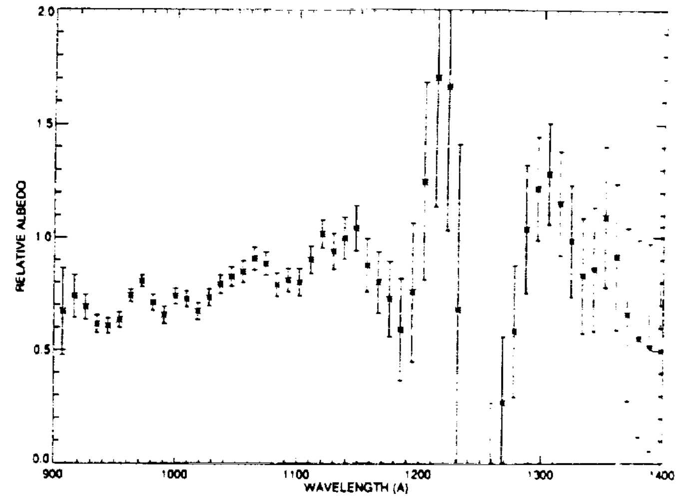

FIG. 4.—The relative spectral behavior of the albedo, fixed to be 0.5 at 1400 Å, is plotted as $\pm 1\ \sigma$ error bars (using photon statistics only). Only target B has been used in this analysis; similar results are obtained from target D. Targets A and C are of lower quality with target C being contaminated by a star in the slit. There is no significant decrease in the albedo toward short wavelengths suggesting that the FUV rise in the extinction curve is not due to a new population of low albedo particles. We have assumed an extinction (A_V) of 0.3 mag; higher extinctions will cause the relative albedo to be even higher at short wavelengths.

4. CONCLUSIONS

We have observed intense diffuse FUV radiation in several locations in the direction of the Coalsack nebula. This radiation is primarily due to the forward scattering of starlight from three bright early B stars by dust in the foreground of the Coalsack itself. While we cannot place useful constraints on the actual values of the optical constants, we find that, assuming no change with wavelength in g, the albedo does not change significantly over the spectral range from 912 to 1400 Å, arguing against the presence of a zero albedo population of small grains.

We plan to investigate this region further using more detailed models and, we hope, with new observations in different locations. Because the radiation field is precisely defined and the predominance of single scattering eases the modeling, this region provides one of the best opportunities to unambiguously deterime the scattering function of interstellar grains, if the observations can be chosen appropriately.

We have profited considerably through conversations with Dr. Gabriel Franco. Criticisms by an anonymous referee helped increase the readability of this work. This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France. We thank the National Space Science Data Center (NSSDC) for providing much of the ancillary data used in this work and the IDL Users Astronomy Library at NASA/GSFC for several IDL programs. This research has been supported at the Johns Hopkins University by NASA grant NAGW-1890 and at the University of Arizona by NASA grants NAGW-587 and NAGW-2648.

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Search for the Intergalactic Medium

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invited paper, presented at the meeting

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A Meeting in Honor of Prof. George B. Field

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Elba, Italy

To Appear in the Conference Proceedings

Search for the Intergalactic Medium

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Abstract. I recapitulate a thirty-three-year effort to identify the nature of the intergalactic medium. There is a *prima facie* case that the high-galactic-latitude diffuse ultraviolet background longward of 1216 Å is due to redshifted Lyman α radiation from intergalactic clouds. *Voyager* ultraviolet observations that bear on this problem are summarized.

1. Introduction

In the fall of 1961, Sidney van den Bergh returned to Toronto from Santa Barbara and IAU Symposium No. 15, "Problems of Extragalactic Research," (McVittie 1962) to tell us beginning graduate students the amazing news that clusters of galaxies (and in particular, the Coma Cluster) might contain 90% dark matter, perhaps ionized gas. How to detect it? I suggested that if there is an intergalactic magnetic field, the free electrons could "flip and emit" just as they do in emitting 21-cm in the *neutral* hydrogen atom. When subsequently, at Princeton, George B. Field asked me if I had any ideas for a term research project, I told him my idea, and he pointed out that the radiation would be of such low frequency that it would bounce off our (partially ionized) galaxy, but that *he* had an idea: thermal bremstrahlung. I was so slow in trying to explore the idea that Hoyle (1963) & Gould and Burbidge (1963) published before us, but Field & Henry (1964) did appear, and I am sure it helped me get a post-doctoral position with Herb Friedman.

2. U.S. Naval Research Laboratory

Friedman wanted me to focus on ultraviolet astronomy rather than X-ray astronomy, but I did both. I believe that my ultraviolet map (Figure 2 of Henry, Swandic, Shulman, & Fritz 1977), which shows parts of the galactic plane to be remarkably dark, is still of importance, since the detector had a very wide field of view and hence was sensitive to *diffuse* as well as to point-source radiation.

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[2]Director, Maryland Space Grant Consortium

[3]Consultant, Los Alamos National Laboratory

I have described our X-ray adventures elsewhere (Henry 1984). We (Henry, Fritz, Meekins, Friedman, & Byram 1968) confirmed the important result of Seward, Chodil, Mark, Swift, & Toor (1967) that the X-ray background spectrum breaks toward lower energies, and we also found a substantially higher flux at 1/4 keV at high galactic latitudes than did Bowyer, Field, & Mack (1968). This "break" led George Field to decades of continued interest in the thermal bremstrahlung possibility for the origin of the general extragalactic X-ray background (interest that only ended with the recent COBE results which exclude such) but for some reason I was much more impressed with the high 1/4 keV flux, and I attributed it to thermal radiation from much lower temperature intergalactic gas. However, since we also saw a substantial flux of 1/4 keV radiation even at the lowest galactic latitudes, I should have realized that the situation was too complicated for instant conclusion. We subsequently (Davidsen, Shulman, Fritz, Meekins, Henry, & Friedman 1972) mapped the 1/4 keV radiation over half the sky, and we (Henry, Fritz, Meekins, Chubb, & Friedman 1971) also discovered that the low-energy excess in the background persisted to 0.68 keV. At the present conference, Wilt Sanders showed us the incredibly beautiful recent Max Planck Institute Rosat soft X-ray images of the sky, among other things confirming in spades the complexity. Despite that complexity, Wang & McCray (1993) find that the 0.68 keV radiation might partially arise in an intergalactic medium at 2.2×10^6 K, a possibility that I of course find very cheering.

3. The Coma Cluster of Galaxies

3.1. X-Ray Observations

In 1971, we (Meekins, Fritz, Chubb, Friedman, & Henry 1971) discovered soft X-rays from the Coma cluster of galaxies. We attributed the emission, correctly, to thermal bremstrahlung from intracluster gas. Improbably, I had actually succeeded in the goal that I had set for myself in 1961! However, we showed that the hot gas which we had discovered could amount to only 2 % of that required for gravitational binding. Gursky, Kellogg, Murray, Leong, Tananbaum, & Giacconi (1971) confirmed our result, and also reported "indications" that the source is extended, consistent with origin in hot gas. The *coup de grace* was administered by Selemitsos, Smith, Boldt, Holt, & Swank (1977), whose discovery of iron-line X-ray emission provided proof of the origin in thermal emission from gas.

3.2. Ultraviolet Observations

That still left the problem of *what* was binding the Coma Cluster of galaxies.

Recombination Radiation Joe Silk pointed out to me that cooler ionized gas still might do the job; would not be detected in the X-ray; and would necessarily emit Lyman α recombination radiation. Fortunately, I had already made the necessary observation, so (Henry 1972) I was able to place "severe (and perhaps fatal)" new restrictions on hot ionized gas models for the gravitational binding of the cluster. However, King (1972) pointed out that I had used too small a value for the radius of the Coma Cluster, and that better upper limits would be needed to finally rule out the hot gas model. These were subsequently provided by Holberg, Bowyer, & Lampton (1973).

Radiation from Neutrino Decay At a certain point (see below) it became clear that most of the dark matter was non-baryonic, possibly neutrinos. In particular, De Rújula & Glashow (1977) started a small industry of neutrino-decay-radiation hunters, which we joined. We examined the Coma Cluster of galaxies (Henry & Feldman 1981), and the diffuse background (Murthy & Henry 1987), without positive result.

4. The Johns Hopkins University

I became an Assistant Professor at Hopkins in 1968, actually beginning teaching in 1969. The year 1970-71 I spent travelling around the world, hitch-hiking across the Sahara; down the Nile on a barge; on to India, New Zealand, and Samoa. Then at Hopkins I began teaching physics (instead of astrophysics), and fell in love with it (Henry 1990). With Hopkins colleagues, I thought I was getting into stellar chromospheres, with the discovery of Lyman α emission from Arcturus (Rottman, Moos, Barry, & Henry 1971). But I could not escape from either cosmology or that Princeton influence: Don York pointed out to me that with Copernicus, I could study the deuterium-to-hydrogen ratio using such observations, so we (Henry, Murthy, Moos, Landsman, Linsky, Vidal-Madjar, & Gry 1986) helped confirm that there are not enough baryons to close the universe (and, perhaps, there are not *nearly* enough [Songaila, Cowie, Hogan, & Rugers 1994]). About the same time, inflation led to the concept of non-baryonic dark matter and a "just barely open" universe.

4.1. Excursion to NASA

One day in 1976 Mr. Bland Norris phoned me and said that he was at Woods Hole with George B. Field and they were looking for a Deputy Director for NASA's Astrophysics Division. I spent two fascinating years in the black box on the mall. After a while, Bland trusted me enough to tell me that he (an engineer) was taking a night-school course in astronomy at a Virginia community college: what that teacher would have thought, had he known that the Director of NASA's Astrophysics Division was a member of his class! I also recall telling a friend of yours and mine how hard it was to get astrophysicists to serve on our committees; and he kindly told me to my face that it was understandable since "any astronomer worth his salt does research full time" (This has led me to understand better the budget cuts that our field has unfortunately been so subject to in recent years.) At NASA, I joined Warren Keller and Nancy Roman in arguing vigorously that a Princeton site should not be pre-selected for STScI. (I felt no conflict of interest in so arguing, since it was inconceivable to me that Johns Hopkins was a potential STScI site.)

4.2. The Field Committee

Perhaps as a reward for my service in the black box, George B. Field and his Committee made me a full member, and I chaired the Panel on Organization, Education, and Personnel. This was a truly wonderful experience, getting to know better such people as the late Harlan Smith. The Field Committee became a legend of the Washington bureaucracy, as "scientists with the guts to prioritize", but the bottom line is not all that we would wish: our highest priority for the '80s, for example, was AXAF.

4.3. The Soviet Union

In 1984 I participated in a panel, supported by an agency of the United States government, that looked into the quality of space science in the Soviet Union. We were surprised to find that the high quality experimental science was entirely in areas that supported future manned activity, and that the experimental work in other areas was so poor as to suggest that it was not serious. We concluded that the only reason for the Soviet "science" program was the support of strategic objectives. This activity caused me (a former member of the Canadian Officers' Training Corps, after all) to think strategically about the solar system, identifying Phobos and Diemos as key resources. *National Commission on Space* member George B. Field wrote to me in 1985, concerning my manuscript, that he thought that "the world population should begin the process of accepting limits to national sovereignty in certain specified areas, in order to avoid the holocaust which is virtually inevitable if they do not." The Soviet Union of course subsequently collapsed, and the validity of differing views on approach were fortunately never tested. And ironically, what is currently happening to the United States space "science" program makes me wonder if the above analysis did not go far enough.

5. Diffuse Ultraviolet Background Radiation

I finally started doing the ultraviolet background work, that Herb Friedman had suggested, in 1973 (Henry 1973). It has come to dominate my research, and there is not space enough to summarize it here. Fortunately, there is an Annual Reviews article (Henry 1991), supplemented by an "up-dating" Astrophysical Journal Letter (Henry & Murthy 1993), and a more recent review article (Henry & Murthy 1994), to which the fascinated reader can turn.

5.1. Ultraviolet Starlight

One component of the diffuse ultraviolet background that surely exists and that has been presented as being particularly important, in his review, by Bowyer (1991), is ultraviolet starlight that is scattered from interstellar dust. To get a handle on this, I published the *Atlas of the Ultraviolet Sky* (Henry, Landsman, Murthy, Tennyson, Wofford, & Wilson 1988), showing the TD-1 observations of 25,314 stars. I have integrated this starlight at 1565 Å to exhibit (Figure 1) the source function for such scattered light. Note the drastic departure from galactic symmetries. For the present paper, I have integrated the TD-1 data again, this time *excluding* all stars brighter than 7.46 photons cm^{-2} s^{-1} Å^{-1} (Figure 2). Note that the fainter, and hence on average more distant, stars adhere much better to the *a priori* expected symmetries. (The stars that were excluded in Figure 2 are only 1100 out of the total of 58,013 stars in our electronic TD-1 catalog; the remaining 56,913 stars, however, contributed only 17.9 % of the total flux that appears in Figure 1. Both figures are linear, and just-saturated.)

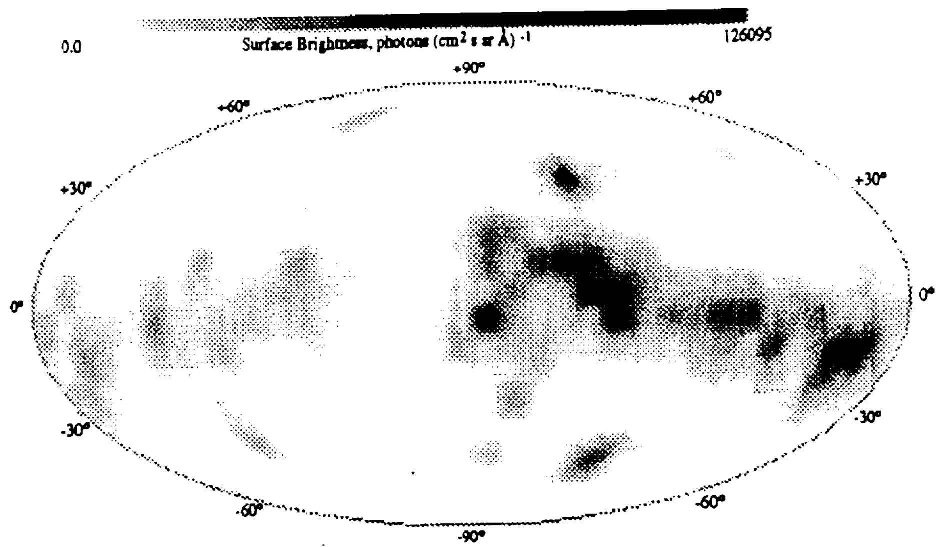

Figure 1. An Image of the TD-1 Ultraviolet Sky at 1565 Å. The galactic center is at the center, in this figure and in all figures in the present paper.

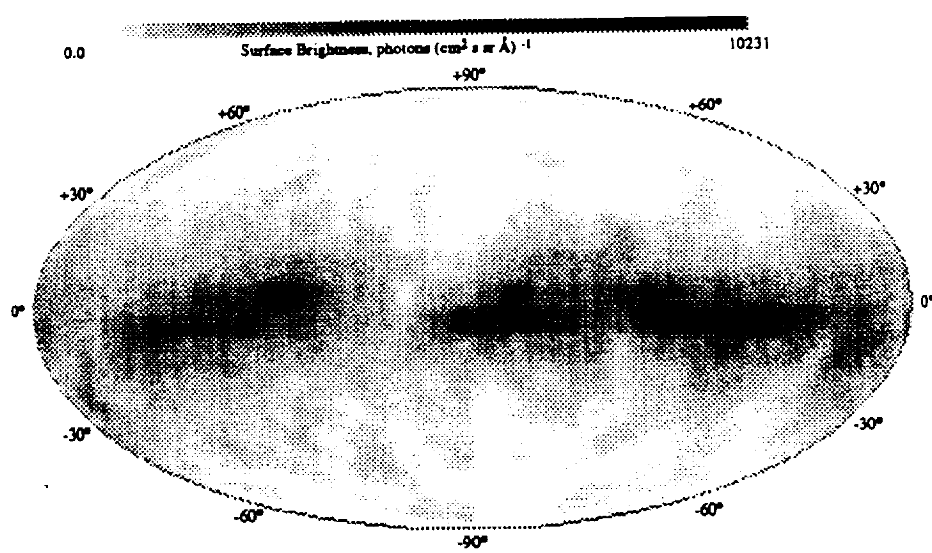

Figure 2. The same image of the TD-1 ultraviolet sky as in Figure 1, but with the contribution of the brightest stars excluded. Note that the fainter stars are much more severely confined to the galactic plane, and that there is much greater (but still not great) symmetry with galactic longitude.

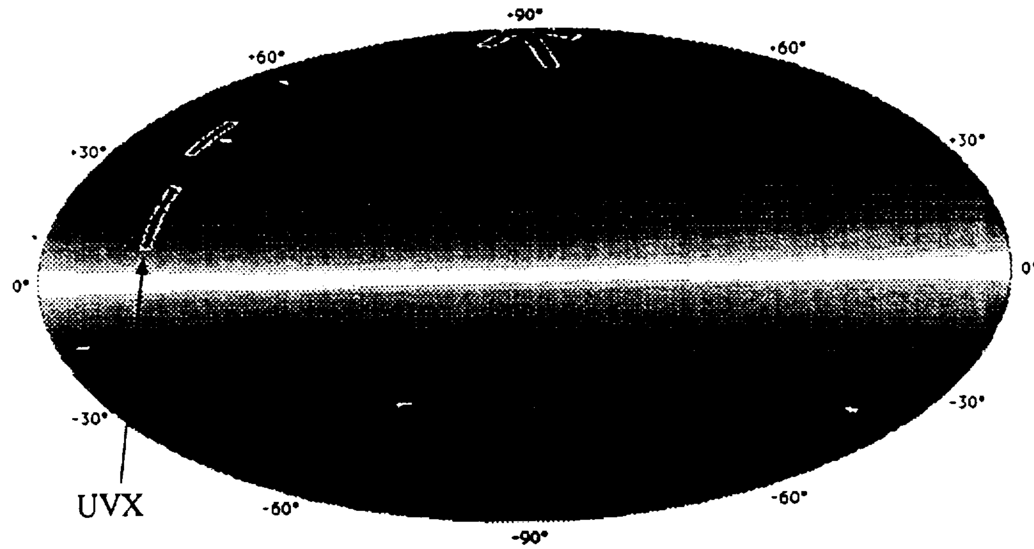

Figure 3. Simulation of a uniform extragalactic ultraviolet radiation field extinguished by a *csc b* dust layer. The optical depth at the pole is 0.4, but I assume a grain albedo of 0.65 and totally-forward scattering, so the effective optical depth is 0.14. The location of the UVX observations (Bowyer 1991, Henry & Murthy 1993) are indicated: even the lowest-galactic-latitude target (arrow) could receive a significant extragalactic contribution.

5.2. Extragalactic Ultraviolet Background

The observations of the diffuse background at high galactic latitudes are summarized in Figure 1 of Henry & Murthy (1994), where one sees many (and only) positive detections of a diffuse background longward of 1216 Å, but only an upper limit (from *Voyager*) shortward of Lyman α. The observations on their face suggest that the diffuse ultraviolet background longward of 1216 Å is redshifted Lyman α recombination radiation from unbound intergalactic clouds (they must be unbound, and hence denser and more emissive in the past, to account for the persistence of the radiation to long wavelengths as observed). Such extragalactic radiation could be detected even to quite low galactic latitudes, as is shown in the simulation in Figure 3.

Scenario The observed intensity longward of 1216 Å is so large that the ionized intergalactic clouds must be clumped to such an extent that they would recombine on a time scale that is short compared with the Hubble time, absent an additional source of ionizing radiation. Just such a source has been suggested by Sciama (e.g. 1993, and also the present volume), and such an ionizing source may be needed in any case, for although it has been suggested (see, e.g., other papers in this volume) that quasars and/or galactic stars are sufficient to ionize the intergalactic medium, I want to call attention to what I think is a very important remark by Cen, Gnedin, & Ostriker (1994), "However, the overall transparency of the IGM is still a mystery. In the series of papers preceding this one we have not found any model which comes within several orders of magnitude of explaining the Gunn-Peterson (1965) effect: space is very transparent at wavelengths where the neutral hydrogen Lyα line can absorb."

It may be that the clouds that I find necessary are the "Cheshire Cat" galaxies of Salpeter (present volume). The scenario that I have in mind is that following recombination, collapse occurred into pre-existing Sciama-neutrino balls. In cases of exceptionally low total angular momentum, galaxies resulted; in that, and every other, case most of the matter was re-ionized; "bounced"; and is bouncing still.

Observations There are two crucial observational questions: first, is the break at 1216 Å real (and in particular, are the *Voyager* upper limits correct), and second, even if the break is real, can the spectrum possibly be accounted for simply as starlight scattering from high-galactic-latitude dust? Evidence that the answer to the second question is "no" is provided by Murthy, Henry, and Holberg (1993) who used *Voyager* to examine the spectrum of starlight scattered from dust in the direction of the *Coalsack* nebula: no break appears in the spectrum. However, the *Coalsack* dust is illuminated by exceptionally hot stars; perhaps the general galactic ultraviolet radiation field has such a break, or perhaps high-latitude dust has a break in the albedo as a function of wavelength. As for the first question, Murthy, Henry, and Holberg (in preparation) are engaged in a massive reexamination of the entire *Voyager* archive, with a view to greatly increasing the number of observations, and also to improving the understanding of the data set as thoroughly as possible.

In the meantime, let me collect and display the published *Voyager* observations (Table 1). Most of these observations are to be credited to Holberg (1990), but the present paper should be cited as well, since Holberg's paper does not actually include a table of these results. All of the measurements of Table 1 appear in Figure 4, superimposed on a copy of Figure 1, but a copy in which the TD-1 starlight has been saturated by a factor of ten.

The saturated map of direct starlight in Figure 4 is of interest in its own right: notice how dark parts of the galactic plane appear! But particularily notice that some of the *Voyager* upper limits at the lowest galactic latitudes are very low. For comparison, the diffuse background longward of Lyman α is almost everywhere ≥ 300 photons cm^{-2} s^{-1} sr^{-1} Å^{-1}. (The positive detections by *Voyager* are all near the brightest part of Gould's belt, and are undoubtedly mostly dust-scattered starlight.)

Conclusion The intergalactic medium detected at last? *No* instant conclusion.

Acknowledgments. I am immensely grateful to, among others, Sidney van den Bergh, George B. Field, Donald Morton, Dimitri Mihalas, and my PhD thesis advisor, the late Bengt Strömgren, for trying to educate me. This work was supported by NASA grant NAG6-619 and United States Air Force Contract F19628-93-K-0004.

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Table 1. *Voyager* Measurements of the Diffuse Ultraviolet Background.

Target Number	l^{II}	b^{II}	RA	Dec	Flux[a]	Ref.
1	11.89	54.89	225.39	11.09	< 180	b
2	17.40	-45.40	321.13	-29.69	< 100	b
3	19.40	-18.07	292.82	-19.95	< 400	b
4	21.32	-20.22	295.68	-19.13	< 260	b
5	22	-42	318.19	-25.71	< 200	c
6	28.06	-86.24	8.02	-27.66	< 100	b
7	28.38	35.21	248.59	11.93	< 100	b
8	40.5	42.2	245.33	23.25	< 100	d
9	58.44	-11.34	304.84	16.45	< 300	b
10	60.45	-22.94	315.77	11.38	< 350	b
11	61.17	-31.94	323.41	6.43	< 240	b
12	61.72	-32.15	323.86	6.67	< 100	b
13	75.64	-8.67	313.54	31.67	< 100	b
14	98.7	53.7	219.80	58.20	< 100	d
15	109.05	-41.65	1.21	19.75	< 150	b
16	115.29	46.67	207.72	69.79	< 100	b
17	119.98	57.35	195.51	59.97	< 100	b
18	133.7	25.2	91.74	80.16	< 100	d
19	134	28	108.33	80.25	< 687	c
20	135.5	11.5	51.09	70.24	< 100	d
21	135.79	72.28	186.79	44.65	< 300	b
22	140	40	148.46	71.12	< 100	e
23	155	-24	46.25	30.04	< 200	c
24	162	-21	54.26	28.63	< 490	c
25	167.04	-79.72	19.83	-19.81	< 100	b
26	167.36	-79.72	19.87	-19.85	< 100	b
27	175.68	-15.20	69.05	23.50	1900	b
28	181.86	16.43	103.84	34.79	< 900	b
29	183	-14	74.71	18.63	3042	c
30	185	-11	78.49	18.75	2158	c
31	190.0	-45.0	53.01	-4.59	4900	e
32	193.41	67.52	166.93	32.62	< 100	b
33	197.3	-49.2	52.11	-11.02	1620	e
34	205	12	109.42	12.51	4464	c
35	216	42	141.76	15.87	< 687	c
36	222	-7	100.10	-11.17	2796	c
37	230	3	112.97	-13.59	4660	c
38	247.75	48.14	159.00	0.29	< 270	b
39	267.17	74.66	183.04	14.679	< 120	b
40	303.7	0.8	193.71	-61.79	30000	f
41	338.33	-26.76	289.37	-58.65	< 340	b

[a] ph cm^{-2}s^{-1}sr^{-1}Å^{-1}

[b] Holberg 1990

[c] Sandel, Shemansky, & Broadfoot 1979

[d] Murthy, Henry, & Holberg 1991

[e] Murthy, Im, Henry, & Holberg 1993

[f] Murthy, Henry, & Holberg 1994

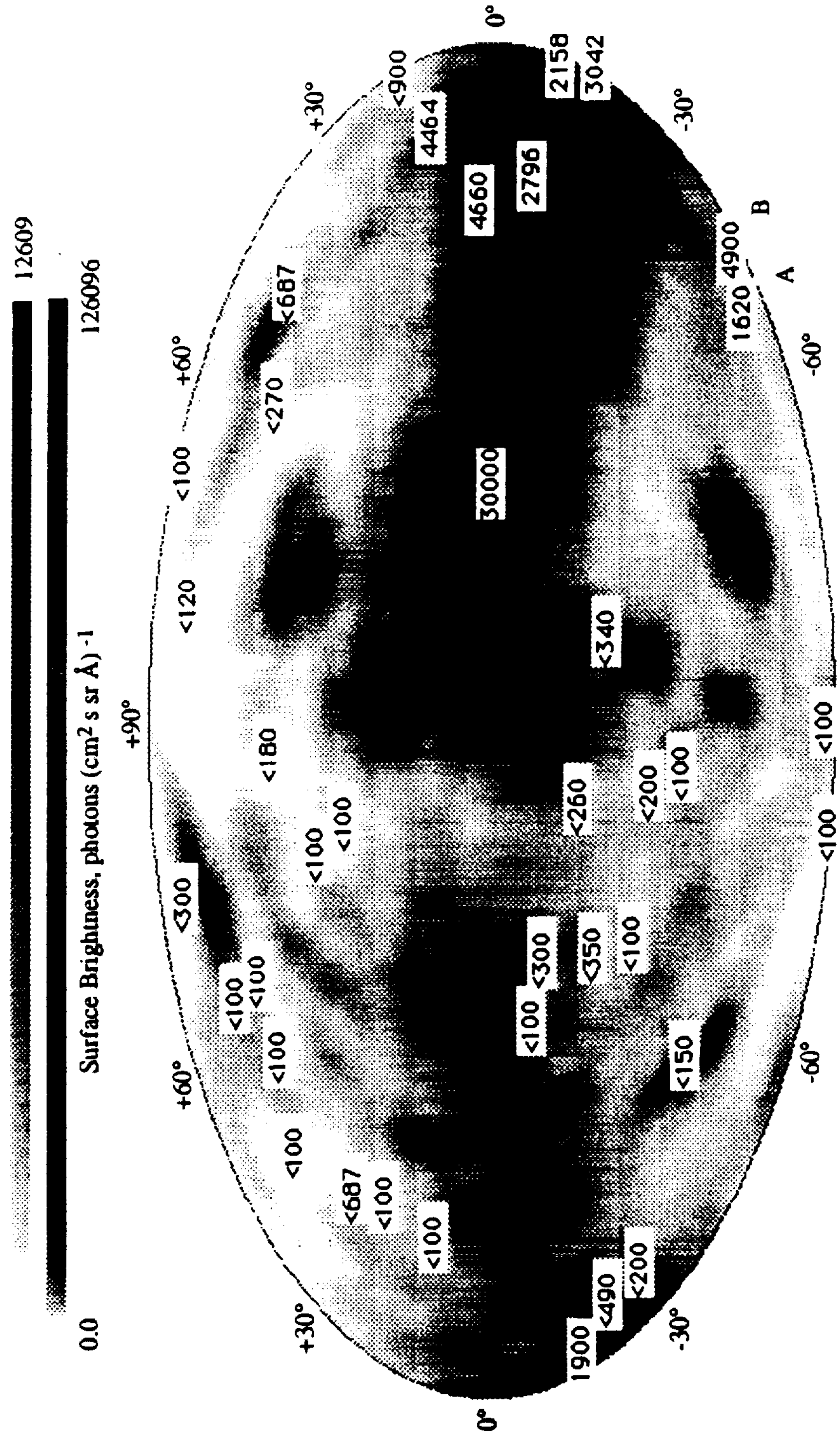

Figure 4. The *Voyager* Sky: mostly upper limits, in units of photons $cm^{-2}\ s^{-1}\ sr^{-1}\ Å^{-1}$. The Eridanus observations A and B of Murthy, Im, Henry, & Holberg (1993) are specially indicated at lower right.

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Appendix

The 12 one-page write-ups listed below (and given on the following pages) were prepared by the Principal Investigator in connection with another program, called UVISI, also supported (partiallly) by NASA. The reader will find a lot of reference to UVISI and to MSX (the DoD mission carrying the UVISI instruments) and much less reference to *Voyager*; nonetheless, the write-ups provide an excellent and readable science context for the work we are doing with *Voyager*.

1. Sky survey of UV point sources to 600 times fainter than previous (TD-1) survey
2. Diffuse galactic light: starlight scattered from dust at high galactic latitude
3. Optical properties of interstellar grains
4. Fluorescence of molecular hydrogen in the interstellar medium
5. Line emission from hot interstellar medium and/or hot halo of galaxy
6. Integrated light of distant galaxies in the ultraviolet
7. Intergalactic far-ultraviolet radiation field
8. Radiation from recombining intergalactic medium
9. Radiation from re-heating of intergalactic medium following recombination
10. Radiation from radiative decay of dark matter candidates (neutrino, etc.)
11. Reflectivity of the Asteroids in the Ultraviolet
12. Zodiacal Light

UVISI Celestial Backgrounds Science Objectives

1. Sky survey of UV point sources 600 times fainter than previous (TD-1) survey

The major existing survey of the sky for point sources (stars, quasars, etc.) is the so-called TD-1 survey. TD-1 was a satellite of the European Space Research Organization (ESRO), and was launched from the U.S. Western Test Range, California, in March 1972. Among the experiments on board was an ultraviolet astronomy experiment called S2/68. The data from that experiment have been published in the form of paper catalogs and are also available on CD-ROM. In addition, the TD-1 S2/68 data were the basis for the ATLAS OF THE ULTRAVIOLET SKY, published in 1988 by the Johns Hopkins University press. The flux limit of the Atlas was 1.0×10^{-12} ergs cm^{-2} s^{-1} $Å^{-1}$, which is the flux to which the TD-1 data are believed to be complete over the sky. The Celestial Backgrounds Experiment on MSX includes an Experiment Plan, Experiment Plan 10, "Systematic Ultraviolet Sky Survey," which if carried to completion (about a two-year post-cryogen phase effort) will provide an all-sky catalog and atlas that is complete to approximately 1.0×10^{-15} ergs cm^{-2} s^{-1} $Å^{-1}$, which is to say a factor of one thousand better than TD-1. The factor 600 that appears in the bullet is conservative, and also allows for the fact that TD-1 did go fainter at the ecliptic poles than the flux limit to which it is complete.

The importance of such a sky-survey improvement is enormous. The overwhelming majority of the TD-1 objects are simply normal O and B type (that is, very hot) stars. These stars are of interest, but are not of extremely great scientific importance. In contrast, the MSX all-sky survey, by going much fainter, will for the first time bring in whole new populations of objects, that are almost entirely absent from TD-1. Examples include:

Quasars. MSX may go faint enough to detect the distant quasars that will allow us to probe the intergalactic medium, subsequently, using the Hubble Space Telescope and/or Lyman (an HST successor or adjunct mission that has been approved by NASA). The idea is to use the quasars as light sources, and see what absorption of those light sources is caused by the intergalactic medium. It is particularily important to find quasars that are distant enough, and yet that have light that is not all absorbed by the intergalactic clouds, that can be used for the so-called Gunn-Peterson test for intergalactic helium. That test applied to hydrogen shows that there is no general neutral intergalactic medium, to extraordinarily low levels. Yet we know that among the various "missing masses" in the universe, there are large amounts of missing baryons. Could they be in the form of ionized intergalactic gas, hot enough that the hydrogen is ionized, but not so hot that the helium is ionized? Yes they could, and the key to detecting this missing mass is finding the necessary quasars: MSX is right at the edge of being capable of performing that task. What is needed for success is that the instruments perform as advertised, and that sufficient time be devoted to do a complete, or at least almost complete, deep all-sky survey.

X-ray emitters. Accretion of matter onto compact objects (white dwarf stars, neutron stars, and black holes) leads to copious emission of ultraviolet light. MSX could lead to large numbers of discoveries of such objects, and to better understanding of those already known.

Galaxies. The existing ultraviolet data on galaxies is very skimply. MSX will result in a truly massive increase in our knowledge of the ultraviolet emission of galaxies other than our own. This is very important for improving our understanding of why galaxies occur in the variety they do; how galaxies evolve with time; and the nature of galaxies and their component parts.

Supernovae. These exploding stars are very useful as "standard candles" for trying to resolve the controversy concerning the size and age of the universe. In the course of an all-sky survey, MSX will detect many supernovae in other galaxies. Ultraviolet data should be very useful in resolving controversy concerning what kinds of stars eventually become supernovae, as well.

Faint, hot stars. There are many types of faint hot stars known: white dwarfs, OB subdwarfs, distant runaway OB stars, blue horizontal branch stars, post-asymptotic giant branch stars...most of which are too faint to appear at all in the TD-1 sample. Thus, MSX could make a major contribution to stellar astronomy.

UVISI Celestial Backgrounds Science Objectives

2. Diffuse galactic light: starlight scattered from dust at high galactic latitude

When we observe the milky way; that is, when we look out into our galaxy, we see a sample of the 100 billion stars of our galaxy, and we also see regions apparently lacking in stars. This lack is only apparent; the dark regions are caused by vast clouds of interstellar dust, that are of not-well-determined composition (see bullet 3).

If, instead of looking into our galaxy, we do our best to look out of our galaxy; that is, we look up out of the galactic plane into the depths of the universe, we are presented with a potential problem. We do know that above and below our location in the outskirts of the galaxy there is more of the interstellar dust that we see right in the galactic plane. We know this because of detection of thermal emission from such dust at 100 micrometers by IRAS, and also because the dust leads to the polarization of the light of stars that are observed at high galactic latitudes.

Why is that potentially a problem? Well, of course such dust will partially absorb the light of distant objects that we are interested in. But there is a much more serious potential problem. We know that there are very large numbers of extremely bright hot young stars in the galactic plane (many of them visible to the naked eye). The light of these hot stars will illuminate the dust clouds at high galactic latitudes and depending on the nature of the dust particles, could potentially reflect back, making the sky very bright in the ultraviolet. This would be very unfortunate indeed, for it would mean much greater difficulty in detecting potential sources of extragalactic light that are of the very greatest interest (see bullets 4, 5, 6, 7, 8, 9, 10).

Where do matters stand? There are two parameters of the dust grains that affect the answer. The first is the albedo of the grains; that is to say, their reflectivity. Obviously, if the grains were to absorb all of the ultraviolet that strikes them, none would be available to reflect back and spoil our ultraviolet view of the universe. But suppose the grains do reflect very substantial amounts of light. That is not the end of the story, because the *way* the grains reflect is very important. There are many possibilites. The scattering properties of small grains are usually characterized by what is called the Henyey-Greenstein scattering function g (Astrophysical Journal, 1941, volume 93, page 70). A value of $g = 0$ signifies isotropic scattering (equal amounts of light scattered in all directions.) A positive value means that most of the light is forward scattered: $g = 1$ means that all of the reflected light continues in exactly the same direction it was going. A negative value means back-scattering; the light is reflected predominatly back in the direction from which it came. So what we would like to see, is either a very low albedo (not much reflected light), or failing that, at least a large positive g value, in which case the scattered light would proceed out of the galaxy and be lost in intergalactic space. What we would like *not* to see, is a high albedo and isotropic, or worse, back scattering.

Perhaps the best determination of the ultraviolet scattering properties of the interstellar grains is the recent paper by Witt, Petersohn, Bohlin, O'Connell, Roberts, Smith, and Stecher (Astrophysical Journal, 1992, volume 395, page L5), which involves analysis of light scattered in the nebula NGC 7023. They find a high albedo (~0.7) and a high g value (~0.7). We are currently carrying out calculations to determine what background we can expect at high galactic latitudes, if these are the correct parameters of the grains. We also have preliminary data from our Voyager observation of the scattering of the light of very bright stars near the Coalsack nebula in our galaxy. Preliminary analysis yields albedo = 0.4, and $g = 0.9$. If these latter values are correct, we can be sure that there will be little or no scattered starlight at high galactic latitudes to trouble our MSX search for more interesting forms of radiation.

MSX can not only use the results of the above studies, it can also contribute very substantially to the resolution of the remaining controversy. Ideally, with an all-sky survey using MSX, we will be able to correlate the signal that we do observe at high galactic latitudes with indicators of the presence of interstellar dust, such as IRAS 100 micrometer emission. And deep pointings with MSX could clearly show back-scattered light, if such exists in significant amounts.

UVISI Celestial Backgrounds Science Objectives

3. Optical properties of interstellar grains

Why do we care about the optical properties of the interstellar grains? In fact, why to we care about the interstellar grains at all? Furthermore, as we shall see, the nature of interstellar grains is a problem where MSX will have only a tiny, incremental effect on the ultimate solution of the problem. If that is so, why do we bother with this bullet at all? The answer to these questions goes to the heart of the scientific process. The Greeks invented "science", in terms of the Questions: what is the nature of reality; what is the nature of matter; what is the nature of the universe? And the Greeks provided a huge piece of the fundamental tool for expressing the answers to these profound questions, namely, mathematics. What the Greeks did not provide was the successful technique for solving these deep problems. The techniques that work, are those that were developed by the scientists of the renaissance and their successors. The fundamental approach that has been found to work, is to try first to answer the small questions, not the big questions. The experience and insight that is gained by answering small, comparatively easy, questions, then leads to success in the case of the more and more deep and difficult questions that follow. In practice what this means is that a huge amount of scientific research is involved with questions that look, in isolation, perhaps not very interesting or important. But we have learned since the renaissance that if we want the big, deep, and interesting questions answered, we must patiently labor at the smaller, less intrinsically interesting questions.

How does this apply to our topic, "optical properties of interstellar grains?" Let's work backward from the MSX bottom line, which is simply that MSX, if it carries out a full sky survey in the post-cryogen phase, should utterly unambiguously determine the albedo and scattering pattern of the interstellar grains (see bullet 2). In turn, that will further constrict the possibilities as far as the question "what are the grains made of" is concerned. It will not answer that question. The all sky survey could also reveal that interstellar grains in different parts of the galaxy have different values for the albedo and scattering function, which would imply that their composition varies from place to place. Now, why we care about the interstellar grains (and their composition) is that they are a key element in determining the formation of the stars. The formation of the stars is a fundamental problem of astronomy, and of course human life exists only thanks to a locally formed star, the sun. Stars form from interstellar gas and dust by a complex process involving gravitational collapse of interstellar clouds. In order to collapse, the stars must radiate away large amounts of energy, and the grains play an important role in that process, directly and indirectly. Directly, the grains heat up, and emit themal radiation. Indirectly: the grains are the site of formation of molecular hydrogen (such homopolar molecules cannot form by direct radiative combination). The molecular hydrogen (and DH) can then be collisionally excited leading to infrared radiation, thus again acting to cool the cloud. Another coolant that is undoubtedly important is H_2O, water. Without grains, would there be stars? Probably there would, for the grains, whatever they are made of, are made of something other than hydrogen and helium, the products of the big bang. The heavier elements were essentially all made in supernova explosions....of stars. Thus, the first stars must surely have formed in the absence of heavier elements; that is; in the absence of grains. Understanding grains is a key element in understanding the evolving process of star formation. And there are other related questions that are of great interest. For example, once a tiny grain has formed, it is fairly easy to see how it could grow, through atom-by-atom accretion of interstellar gas atoms. It is also fairly easy to see how grains could be destroyed: interstellar clouds move at velocities of kilometers per second, and when clouds collide, the collision of grains with each other (or even with gas atoms) could lead to their destruction. What is not so easy to see, is where those original tiny grains come from. It is unlikely in the extreme that gas-phase coagulation under interstellar conditions could lead to their formation on any reasonable time scale: the density is simply too low. This has led to the idea that the grain nuclei form in the thin outer atmosphere of cool giant stars. Cool stars, so the grains are not destroyed; giant stars, so the grains are far enough out that they can conceivably escape from the gravitationl influence of the parent star.

MSX can make an important incremental improvement in our understanding of interstellar grains!

UVISI Celestial Backgrounds Science Objectives

4. Fluorescence of molecular hydrogen in the interstellar medium

We have already seen, in the discussion of bullet 3, some indication of just how important molecular hydrogen is as a constituent of the interstellar medium. But interstellar molecular hydrogen is extremely difficult to detect! MSX will likely make an enormous contribution to our understanding of the distribution of molecular hydrogen in the galaxy, if a sensitive all-sky survey is carried out. To understand why this is so, let us briefly review the history of the discovery of interstellar matter in general, and of interstellar hydrogen in particular. In the discussion of bullet 2, we saw that interstellar dust was discovered as apparent voids in the galaxy. Interstellar gas was discovered through the fact that when the gas occurs near a hot star, the light of that hot star excites the atoms of the gas, which then re-radiate, revealing the location and physical state of the gas. The atoms that are revealed in this way are atoms of sodium, oxygen, etc.; that is to say, elements that were manufactured in stars and dispersed through supernovae, and also hydrogen and helium, the elements that were made in the big bang.

It was Cecelia Payne, of Harvard, who discovered just what the stars are made of. (Her son Mike Gaposhkin is an important MSX participant.) The stars are made of "90% hydrogen; 10% helium; and 1% everything else," so to speak! Thus, if we want to truly understant the interstellar gas, we must understand the distribution of hydrogen. Yet the technique described above only reveals the hydrogen if it is located near a hot star. This problem was considered during the Nazi occupation of Holland by the Dutch astronomer van de Hulst, who came to the remarkable conclusion that *cold* interstellar hydrogen should radiate in the radio spectrum, through the spin of its electron flipping. The probability of such a flip is astonishingly small, but what van de Hulst realized was that there should be astonishing amounts of interstellar hydrogen, thereby making up for the extremely low transition probability. Following the end of World War II, his technique was validated by the discovery of 21 cm emission and absorption by the interstellar medium, and a mapping of the distribution of cold atomic hydrogen throughout the galaxy was carried out. What is the result? Throughout the part of the galaxy where the sun is located, and in the regions farther out in the galaxy, and to some extent farther in toward the center of the galaxy, there is a vast, semi-uniform distribution of interstellar hydrogen gas, with condensations in the gas outlining and indeed defining the spiral arms of the galaxy. But if you go far enough in, suddenly the amount of atomic hydrogen is vastly reduced.

What is going on? That brings us (finally!) to the question of molecular hydrogen. Why is the interstellar hydrogen atomic, and not molecular? In a gas bottle, the hydrogen is all molecular, and there are no individual hydrogen atoms. The answer is, that the gas bottle has walls, but the galaxy does not. As was mentioned in the discussion under bullet 3, molecular hydrogen cannot form by direct radiative recombination (well, actually it can, but the probability is excruciatingly low). Thus, in a gas bottle, if the gas were not already molecular, atoms would stick to the walls and there would join with each other to form hydrogen molecules. Similarily, in the interstellar medium the only way any significant quantity of molecular hydrogen could form, is on the surface of the interstellar grains. The supposition then is, that the hydrogen in the inner part of the galaxy is in the form of molecular hydrogen, not atomic hydrogen. So, where do we stand on the detection of interstellar molecular hydrogen? In the same place we stood for atomic hydrogen before van de Hulst's technique had been applied. Interstellar molecular hydrogen has been discovered in a few locations, but it has not yet been possible to map it generally. The detection of the molecular hydrogen in those few locations is a dramatic story of the space age. Professor Lyman Spitzer of Princeton, father of the Hubble Space Telescope, predicted absorption of the light of hot stars by molecular hydrogen, and initiated NASA construction of OAO-3, "Copernicus," to detect it. He was beaten out of the discovery by an African-American scientist, Dr. George Carruthers of the US Naval Research Laboratory. The next stage, where MSX can be the determinant, is the recent detection of molecular hydrogen fluorescence near an extremely bright star using IUE. That proves the technique; MSX can provide the all-sky map. The point is that the UVISI instruments are so sensitive, they should detect molecular hydrogen fluorescence anywhere, excited just by the general interstellar radiation field.

UVISI Celestial Backgrounds Science Objectives

5. Line emission from hot interstellar medium and/or hot halo of galaxy

Our galaxy is tens of thousands of light years across, but is only a few hundred light years thick. The interstellar matter in the galaxy is mostly confined to that thin plane, the Milky Way disk. It was long thought that the interstellar matter consisted only of cold gas, plus dust grains, except near hot stars, where the interstellar matter should be heated by the nearby hot star.

However, there are numbers of stars that are far up out of the plane of the galaxy, and when their spectra were examined, absorption lines of interstellar matter were seen. Very early the question was asked, why does that interstellar matter not fall down into the galactic plane? That was the first hint that there might be a hot component to the interstellar medium, and in particular that there might be a hot halo of the galaxy: the temperature needed to support the gas against gravity was estimated as hundreds of thousands or a few million degrees.

The next suggestion that there might be a hot component to the interstellar medium came from X-ray astronomy: it was discovered that at low galactic latitudes (and at high galactic latitudes as well) there is a general soft-X-ray glow to the galaxy. The idea was that this is due to emission from ~million degree gas.

This concept was made solid by observations with the satellite "Copernicus." The spectra of distant hot O and B type stars were found often to include strong broad interstellar absorption lines at 1031.9 Å and 1037.6 Å, the resonance wavelengths of OVI (Oxygen five times ionized). Now, the ionization potential of OV is 113.9 volts, so it was clear that the gas in question must be at a temperature of hundreds of thousands of degrees, to achieve the degree of ionization observed.

The OVI observations were essentially all of gas in the plane of the galaxy, because that is where the O and B type stars are located. However, there are also plenty of O and B type stars in the Magellanic Clouds, which are small nearby satellite galaxies to our own galaxy. Thus, observers using the International Ultraviolet Explorer satellite (IUE) were able to look for absorption lines due to highly ionized species in the direction of the Magellanic Clouds. Such lines were duly found, but the question remained (and still remains), exactly how far away is the hot gas that is observed? The only clue is the doppler shift of the wavelengths of the lines, which yields the velocity of the gas, not its distance. Modelling of the gas, which is very uncertain, is needed to try to estimate the distance.

A completely different approach, however, is not to look for absorption produced by the hot gas in the light of distant stars, but instead to look for direct emission of ultraviolet light from the gas itself. One can calculate how much emission should be produced by what quantity of gas at what temperature; the result is that for reasonable models of hot gas in the plane of the galaxy, and also for reasonable models of a hot halo of the galaxy, the UVISI imaging spectrometers should readily detect the emission, in such lines as 1549 Å (CIV). And with an all-sky survey, UVISI should map these emissions over the sky, delineating the structure of the hot halo of the galaxy for the first time. The various different emission lines that the UVISI spectrometers are capable of detecting each originate in gas of a somewhat different temperature, and so it should be possible to construct maps of the sky that in effect are maps of the distribution on the sky of gas of various temperatures. For example, 1663 Å emission of OIII corresponds to a temperature of ~80,000 degrees, while the CIV corresponds to ~100,000 degrees.

The only data on this topic that exist at the present time are fragmentary results from an Aries rocket flight and from the UVX experiment that was carried on the Space Shuttle in 1986. These data are of sufficient quality to strongly suggest that the MSX observations should be extremely successful. Again, the recipe for excellent results will be deep (= long) pointings, and the surveying of as much of the sky as can be managed.

UVISI Celestial Backgrounds Science Objectives

6. Integrated light of distant galaxies in the ultraviolet

The spiral galaxy within which the sun is located is made up, overwhelmingly, of stars: about 100 billion stars. Beyond stars, about ten percent of the mass of our galaxy is in the form of interstellar gas and dust; and, in addition, there may be a black hole (spent quasar?) of about a million solar masses located at the center of the galaxy.

Looking out from our own galaxy, there are about a dozen nearby galaxies. These galaxies appear to be related to each other; that is, they form a small cluster, or group, of galaxies. This cluster is imaginatively named "the Local Group." The Local Group is totally dominated by just two galaxies, our own and the Andromeda Galaxy. These two giant galaxies appear to be almost twins, and are among the largest galaxies known. The last statement is somewhat controversial, because judging the size of distant galaxies requires knowledge of their distance, and the distance scale for galaxies beyond the local region is uncertain to at least a factor of two. Nonetheless, our galaxy and Andromeda are large galaxies. The remaining members of the Local Group are dwarf galaxies.

What is the appearance of a Local Group galaxy in the ultraviolet? Remarkably, extremely little is known about this. The reason is that overwhelmingly, astronomical observations in the ultraviolet have been made with extremely small fields of view, of point objects. There have been few wide-field observations in the ultraviolet of anything, including galaxies. For example, the satellite OAO-2 looked in the ultraviolet in the very center of the Andromeda galaxy, and discovered a strong totally unexpected small ultraviolet-emitting source. The reason this was unexpected was that the central regions of spiral galaxies, including our own and Andromeda, are dominated by the light of red giant stars, which should emit essentially no ultraviolet radiation at all. The source of the ultraviolet radiation from the centers of galaxies is still not well understood, and observations with the ASTRO Space Shuttle mission and with the Hubble Space Telescope are continuing.

Rocket and Space Shuttle ultraviolet photos of a few galaxies from Goddard Space Flight Center astronomers have shown, in addition, what was naturally expected: the outer reaches of spiral galaxies, where large numbers of very hot young O and B type stars are being continually created, shine very brightly in the ultraviolet. That simple fact leads to the reason for the interest in the integrated light of distant galaxies in the ultraviolet. Once we look beyond the Local Group, we find billions of galaxies in the more distant reaches of the universe. Many of these are spirals like Andromeda; many are elliptical galaxies, that are almost entirely free of ultraviolet-emitting O and B type stars.

What does one expect to see, then, in looking at a patch of sky at high galactic latitude? One is "looking to the end of the universe," so to speak; why does one not see an infinite amount of ultraviolet light from the infinite number of distant spiral galaxies? Two reasons! *First*, the light of more and more distant galaxies is more and more redshifted by the expansion of the universe: the light that was emitted as ultraviolet light from extremely distant galaxies is redshifted so much that it is received by us as visible light, not ultraviolet. (But would not still more energetic emission be redshifted into the ultraviolet? It would if it existed, but galaxies are expected to be much fainter short of 912 Å, the interstellar absorption edge of neutral hydrogen. So there is no emission to be shifted.) *Secondly*, by looking farther into the distance we are of course looking backward in time ..... to times before the galaxies formed! No galaxies; no light.

That is the clue to the interest in the integrated light of distant galaxies: it gives us a direct handle on the evolutionary history of the galaxies. The particular value will be in tracing the history of star formation in galaxies over the last few billion years. If star formation was much more active in the past, the sky will be brighter; if spiral arms just formed, the sky will be dimmer in the ultraviolet. Notice that all that is really needed is a typical spectrum of the darkest part of the sky in the ultraviolet. MSX should provide an excellent background spectrum for this research project.

UVISI Celestial Backgrounds Science Objectives

7. Intergalactic far-ultraviolet radiation field

What is our universe like? We tend to think that we know the answer to that question, because we live in this universe and because we have learned, through astronomical research, that the universe is homogeneous and isotropic, which is to say that if you've seen one spot in the universe, you've seen them all. However, we lose sight of the fact that we actually live in a very atypical location, namely a galaxy. Suppose you were to choose a location at random in the universe, and place yourself there. Looking around, you would see what our universe is *really* like, since you have now chosen a genuinely typical location. And of course what you would see is: next to nothing. Around you would be the intergalactic medium, if one exists (which is unknown). Not a single star would shine, since the chance is overwhelming that your random spot will be far outside any galaxy. In fact the only thing you would see at all, would be the faint pale light of the few nearest distant galaxies.

Of course if you had a millimeter-wave radiation detector, you would also detect the famous 3-degree background radiation, which is the only component of the universe that is known to be present everywhere in the universe. So, we believe we know the microwave radiation field in which you would be bathed. We also are pretty sure we know the visible light radiation field in which you would be bathed, and of course that would be very faint indeed.

What about the ultraviolet radiation field in which you would be bathed; and why is it important?

We can predict a certain amount of ultraviolet radiation would be present, because we know the density of galaxies and we think we know roughly what their ultraviolet luminosity is. But that may not be all of the radiation field; there may be totally unknown sources, and there are additional known sources that are not so easy to model, such as ultraviolet emission from distant quasars.

The reason all of this is important goes to the early history of the universe. Following the big bang, the universe expanded and cooled. When the universe was about 100,000 years old, the hot ionized gas (the matter of the universe) recombined to form colder neutral gas. The radiation that had been being emitted and reabsorbed by the ionized gas was now free, and could expand and redshift to become (today) the 3-degree background. What became of the matter? That is a burning question! Of course some of it became the galaxies and quasars, but how and why did that happen? What precipitated the gravitational collapse? For example, we do not even know if the clusters of galaxies formed first (and then the individual galaxies formed from the gas within the cluster), or if the galaxies formed first, and then were drawn together by gravitation to form the clusters.

Using large ground-based telescopes and the Hubble Space Telescope, there is much active investigation of these questions in progress. A powerful tool is the study of the most distant quasars. The quasars are believed to be black holes ingesting matter, which shines extemely brightly just before falling into the black hole. That bright light source reaches us across the universe, and across billions of years of time. Its light can be partially absorbed, in transit, by any intergalactic matter. And indeed, for the most distant quasars, hundreds of narrow absorption lines are seen. These are confidently believed to be Lyman alpha absorption lines produced by small intergalactic clouds of neutral hydrogen.

Now remarkably, there is a pronounced dearth of such clouds very close in redshift (and hence very close in space) to the quasar itself. This "proximity effect" as it is called is easily explained: if the quasar is emitting copious quantities of ionizing ultraviolet radiation, that radiation could destroy the clouds. The radiation from the quasars is in addition to the general ambient radiation.

A redshifted record of these radiation fields is present today in the universe, and will be observed by MSX as a component of the general diffuse ultraviolet background radiation. Thus, observations by MSX at the present day can help to elucidate the process of destruction of the intergalactic medium in the very eary history of the universe.

UVISI Celestial Backgrounds Science Objectives

8. Radiation from recombining intergalactic medium

Is there an intergalactic medium? Between the stars in our own galaxy, there is of course an interstellar medium, composed of gas and dust. Is there a similar (or any) medium between the galaxies?

The astrophysical mechanisms for detecting such a medium are exactly the same as for detecting and studying the interstellar medium. Since there do not seem to be intergalactic stars (this is a delicate idea not often discussed!) and the heavier elements, we believe, are all created in stars, we would expect any intergalactic medium to be composed almost exclusively of hydrogen and helium. Thus, intergalactic dust (which is made of the heavier elements) is not expected. Of course dust could blow out from galaxies in some quantity into intergalactic space, but certainly the first and strongest candidate for an intergalactic medium is hydrogen and helium.

Neutral hydrogen is easily detected by its emission and absorption of 21-cm radiation. Professor George Field very early used the techniques of radio astronomy to establish that no substantial intergalactic medium of cold neutral hydrogen exists. This was very important, because of course about 100,000 years after the big bang the universe recombined and the whole universe was "cold" (~3000 degrees) neutral hydrogen. In 1965 Gunn and Peterson invented another technique, much more powerful than 21-cm techniques, for sensing intergalactic neutral hydrogen. The quasars had just been discovered, and had been found to radiate a continuous spectrum far into the ultraviolet, even beyond 1216 Å, the resonance wavelength of the neutral hydrogen atom (and indeed, even beyond 912 Å, the wavelength short of which atomic hydrogen continuously absorbs.) Gunn and Peterson pointed out that a photon emitted by a quasar at, say, 1000 Å, would redshift as it travelled, eventually spending some period of time at or near 1216 Å. During that period, if any neutral hydrogen were in the vicinity, the photon would be absorbed. Of course it would be re-emitted a small fraction of a second later, but in a random direction, and so it would never reach our observer on earth.

Different wavelengths would pass through 1216 Å at different positions along the line of sight, and as the emission spectrum of the quasar is continuous, every position along the line of sight would be "sampled" by 1216 Å radiation from the quasar. Any location on the line of sight that had any significant amount of neutral hydrogen would remove a chunk from the emitted spectrum of the quasar, and would be detected by the observer on earth as an absorption line in the spectrum of the quasar.

The Gunn-Peterson test turns out to be enormously sensitive .... and turns out to show that intergalactic space is truly extraordinarily free of neutral hydrogen. How can this be? Could the process of galaxy formation be enormously efficient, trapping essentially all atoms? This seems highly unlikely, because the process of star formation (as we observe it in detail in our own galaxy) is very inefficient: the bright light of the hot young stars blows matter away from the region of star formation by means of light pressure.

Thus, a very strong case exists for an intergalactic medium; and it is not neutral.....so it must be ionized. If it were ionized and very hot, it could be detected by its X-ray emission. Indeed, there is a strong X-ray background observed in the universe, and for a time many thought that some of the X-rays originated in emission from an intergalactic medium. However, for a variety of reasons, that idea is in disfavor: for example, where would the enormous energy come from, to heat the gas to so high a temperature? Instead, the remaining possibility is a "lukewarm" intergalactic medium, of ionized gas at say 200,000 or 300,000 degrees.

How might we detect such a medium? Well, any ionized plasma will tend to recombine. Radiative recombination of ionized hydrogen produces Lyman alpha radiation. MSX would observe this radiation as a redshifted ledge of emission longward of Lyman alpha. Thus, there is a possibility that MSX could reveal the baryonic dark matter of the universe.

UVISI Celestial Backgrounds Experiment Science Objectives

9. Radiation from re-heating of intergalactic medium following recombination

We have already seen (in bullet 8) the case that there might exist an ionized intergalactic medium. And we have seen that once created, such a medium must necessarily radiate (via recombination radiation), and that the UVISI instruments on MSX have some hope of detecting such radiation.

But now we will re-examine the process of creating such an ionized intergalactic medium. We will find another powerful emission process, one that offers additional hope both of detecting an intergalactic medium, and even more interesting, of tracing the process of the creation of that medium. Recall that the universe began (10 to 20 billion years ago) in a big bang. We do not know for sure whether the universe is open (infinite) or closed (finite in volume, but without an edge). The best current ideas strongly suggest that the universe should be "just on the border" between being open and closed: which would mean a perfectly flat expanding universe of infinite volume. We naturally tend to think of the big bang as an explostion from a point, and indeed the portion of the universe that we see today surely originated in a volume of space smaller than a single proton ..... but if the universe is infinite (as we believe it is), it was always infinite, and the big bang occurred everywhere at once in infinite space. The portion of that infinite big bang that became our present visible universe was just a proton-volume's worth. As we have seen, 100,000 years after the big bang the universe recombined, and continued expanding, the radiation field cooling to be the present-day 3-degree background radiation observed by COBE, and the matter expanding, and cooling even faster as a thin almost perfectly uniform gas. Then the gas collapsed under the influence of gravity to form quasars, and ultimately stars, galaxies, and clusters of galaxies ..... in some order!

The process, we have emphasized, is not at all well understood: but a very reasonable case exists that the process was inefficient; that is, that a great deal of the matter did not end up in objects, but remains as an ionized intergalactic medium. Highly in accord with this notion is the fact that we cannot account for most of the normal (called "baryonic") matter that we feel sure exists. Our certainty about how much baryonic matter there is, arises from "Copernicus" observations of deuterium in the interstellar medium and also from ground-based observations that have led to a determination of the helium abundance in the universe. It turns out that deuterium and helium were manufactured in the first three minutes of the big bang, and that the abundance of both is sensitively dependent on the density of matter. From the observed abundance, we can calculate what the density must have been. The result is that we believe we know how much baryonic matter must be out there ..... but we can only account for perhaps 10 percent of it in the form of stars and galaxies. Thus, the famous "missing matter" (baryonic component of; see bullet 10 for the rest!). Now the intergalactic medium of course started out neutral (the universe having recombined). But as quasars in particular form, they emit copious quantities of hard ionizing radiation, which will tend to re-ionize the intergalactic medium. This is what we believe happened.

So, now, look at the physics of that re-ionization process: first hydrogen is ionized, then helium (as the intergalactic medium becomes more and more transparent through being ionized.) The hydrogen tends to recombine again and again, but be re-ionized again and again. Each cycle produces a Lyman alpha photon: vast numbers of them. First-ionization of helium similarily produces vast numbers of 584 Å photons, but these are efficiently destroyed by ionizing the residual hydrogen. However, by the time second ionization of helium occurs, the universe is transparent to ionizing radiation, and the 304 Å photons survive just as did the 1216 Å Lyman alpha photons.

These vast numbers of photons would redshift, and might be detected today. The 1216 Å radiation is likely present now in the visible, and difficult or impossible to detect against strong zodiacal light. But the 304 Å radiation might form a broad bump in the far ultraviolet, potentially detectable by MSX.

UVISI Celestial Backgrounds Experiment Science Objectives

10. Radiation from radiative decay of dark matter candidates (neutrino, etc.)

The universe is believed, on the basis of the theory of inflation, to be just on the borderline between being open and closed.

The theory of inflation is a theory of the big bang's origin that is firmly rooted in modern theories of elementary particle physics. According to inflation, the universe expanded not linearly, but exponentially, for a tiny fraction of a second near the very beginning. During that tiny fraction of a second the universe expanded by an amount entirely inconceivable to the human mind. The universe then went over into the kind of normal linear expansion that we observe today.

That something like inflation did occur seems certain. The reason that we can have such confidence is because of what we observe of the big bang ourselves, namely the residual 3-degree background radiation. The fact is, that apart from doppler shifts due to the earth's motion through the universe, and tiny wrinkles that were recently discovered by COBE, we find the radiation temperature to be precisely the same over the sky, to a high degree of accuracy. Now, that that should be so, is truly remarkable. In particular, consider two points on the sky that are diametrically opposite to each other. In one direction, we are detecting 1-mm wavelength photons that were emitted, off in that direction, 10 or 20 billion years ago; that is, that were emitted by gas that is 10 to 20 billion light years away in that direction. And the same thing, of course, in the opposite direction. So it appears that the two samples of emitting gas, located 20 to 40 billion light years apart ...... are of exactly the same temperature. How could this incredible coordination have occurred? The two gas samples, given the observed rate of expansion of the universe, could never have been in thermal contact with each other so as to achieve the observed perfect equilibrium! But according to inflation, they *were* in thermal contact at the big bang, and they are so distantly separated mostly because of the much faster exponential expansion that occurred during the inflation stage. So our observations almost certainly require that inflation (or something very much like it!) did occur. There are also additional reasons for believing that inflation occurred. For example, the ordinary matter that we observe in the universe is about 2 percent of the amount needed to "close" the universe. The traditional old equations of cosmology then allow us to figure backward in time, toward the big bang, to see how close to being closed the universe was way back then. The answer is, incredibly close. It seems unnatural that the physical laws should not have made it right on the line exactly ... as inflation predicts. So, many believe that the universe is indeed just on the border, and that the 2 percent of closure density that we have seen so far, is only a small fraction of the actual mass density of the universe. The rest is the "missing mass."

We have already discussed missing baryons (bullets 9 and 10). But baryons are apparently only about 10 percent of closure density. What is the non-baryonic missing matter, the 90 percent of the matter of the universe that did not participate, because of its nature, in the chemistry of the first three minutes?

No one knows; speculation abounds! Many exotic particles, theorized but not known to exist (the "etc's" of our bullet) are speculated upon. But one nice candidate is known to exist: neutrinos. These have been detected, and exist in three varieties, electron-neutrinos, muon-neutrinos, and tau-neutrinos. We are bathed in neutrinos left over from the big bang in exactly the same way that we are bathed in the 3-degree background radiation. Neutrinos were long believed to be of zero rest mass (in which case they would contribute no more to closure than does the 3-degree radiation field). But there are recent suggestions that this is not so, that they have a tiny rest mass. There are so many neutrinos that all it would take is about 30 eV or so of rest mass for the neutrinos to be successful as the missing non-baryonic dark matter! And 30 eV is a magic number, for if a heavier neutino were to decay into a lighter neutrino with emission of a photon, that photon would thus be of energy of order 10 eV, which is to say ultraviolet....the range that will be meaured sensitively by UVISI on MSX.

UVISI Celestial Backgrounds Experiment Science Objectives

11. Reflectivity of the Asteroids in the Ultraviolet

The Earth is a fragile haven for life in the solar system. NASA exploration of the Moon and the planets has not reveled life elswhere in the solar system, and evidence has accumulated that the solar system is a very violent place, hostile to life. The climate on Mars may vary drastically over the eons, with water present in the distant past. With Venus, perhaps there was a relentless loss of water followed by massive greenhouse heating. For our own Moon, there was a colossal bombardment by asteroids very early, leading to the mare or "sea" features we see on the Moon today.

The Earth itself underwent a similar bombardment at the same time, but the evidence has been largely buried by the extremely active geological processes at work on Earth. Nontheless, the Meteor Crater in Arizona, and the record of such recent events as the Tungusku explosion in Siberia, remind us that we still exist "at the whim of the Gods". Most significantly, the evidence has increased massively in recent years for the theory that 65 million years ago the Earth was struck by an asteroid or a pair of asteroids leading to the extinction of the dinosaurs, and the succession of the mammals.

The fact that we are hostage to the asteroids suggests that we should make every effort to understand them well.

In all the history of the space program, only one image of an asteroid, Gaspra, has been obtained. All other data are remotely obtained data, but astronomers have long and excellent experience with making the most of remotely obtained data. In particular, spectral data measurements on the asteroids have led to the classification of asteroids on the basis of their nature, and in particular their composition. Observations may be compared with "ground truth," laboratory measurements of actual meteorite samples. The result is a great deal of knowledge concerning the orbits of the thousands of known asteroids, and also their composition. Special interest of course centers on the so-called "Earth-crossing asteroids," those asteroids having orbits that nearly intersect with the orbit of Earth. These are the candidate objects for being the next to wipe out the dominant life form on Earth!

As usual in any area of scientific investigation, knowledge grows most effectively by a multi-pronged approach, in which relevant data of all kinds are accumulated and checked against each other.

Very little data exist at present concerning the appearance of the asteroids in the ultraviolet. All we have to go on are a few IUE spectra, plus existing spectra of the Moon from Apollo 17, recently supplemented by measurements with Galileo on its fly-by of Earth. What we have realized from the work so far is that, compared with measurements in the visible, measurements in the ultraviolet have a significant advantage. The reason is that visible light penetrates significantly into the interior of rock before being reflected. The result is that very minor impurites in the rock can have a very big effect on the amount of light that is reflected, and hence on the observed brightness and spectrum of the asteroid. In comparison, ultraviolet light reflects directly from the surface of rock, and the reflectivity is determined by the bulk index of refraction of the material of which the rock is made. Thus, the ultraviolet brightness is determined by the bulk composition; the visible brightness by the amount and nature of unimportant contaminants. The case for carrying out classification of asteroids in the UVISI ultraviolet imager and spectrometer range appears compelling. In the course of a systematic all sky survey, UVISI should detect hundreds if not thousands of asteroids. A great virtue of an all sky survey is that all of these asteroids would be observed with exactly the same instruments. Thus a consistent and homogeneous database would exist for the first time for the classification of asteroids on a physical basis, complementing and supplementing the important infrared measurements that exist.

UVISI Celestial Backgrounds Experiment Science Objectives

12. Zodiacal Light

In an age of city lights, few of us have experienced the "false dawn," light on the eastern horizon that turns out not to herald the sun, but to be direct visual experience of a vast cloud of dust that pervades the inner part of the solar system. This light that is seen so easily and so brightly by the naked human eye is called zodiacal light. Its source does not have a name, unless it is called the zodiacal cloud.

The cloud is called zodiacal because the band of light follows the constellations of the zodiac in the sky, those constellations through which the planets of our solar system wander. That is the clue that the zodiacal cloud is indeed part of our own solar system. The variation of the brightness of the cloud as the Earth passes through it gives us an idea of its geometry. Many and difficult measurements are necessary, for except near the sun the zodiacal light is very faint, and must be disentangled from the light of stars, and from the glow of our atmosphere .... which we tend to be unaware of, but which is an bright as the integrated light of the stars.

What is the origin of this vast cloud of dust? The thought that the cloud is an original part of the furniture of the solar system can be dismissed, for particles as small as those that make up the zodiacal cloud are subject to light pressure and the Poynting-Robertson effect, which remove them from the cloud on a time scale of only ten thousand years. There are two obvious candidates for producing a more or less continuous supply of dust in the inner solar system: asteroids, and comets. Comets are particularily obvious as a candidate, for comets enter the inner solar system frequently, and they clearly emit matter, witness their tails. The asteroids are less obvious candidates, for they are very solid objects. However, the asteroids exist in very large numbers, and were two asteroids to collide, the violent collision would surely generate large amounts of rock dust. The analysis and study of the zodiacal light procedes according to the agenda of all astronomical investigations: observe the subject of interest in all possible ways at all possible wavelengths and try to construct physical models that have the observed properties. As has been mentioned, observation of zodiacal light in the visible is difficult because of the stars. In the infrared, the zodiacal light has been measured by IRAS, which made the remarkable discovery of bands of infrared zodiacal light, seemingly hovering like halos above and below the solar system. It turns out that this is an optical illusion, and furthermore that the bands can be associated with the orbits of particular groups of asteroids!

In contrast, the ultraviolet is virtually terra incognita as far as observations of the zodiacal light are concerned. The only measurements that exist are rocket and space shuttle measurements by the Johns Hopkins group. Observation of zodiacal light in the ultraviolet is difficult for another reason: the zodiacal light is all reflected sunlight, and the sun is a cool star, emitting very little ultraviolet light. As a result, zodiacal light has never been detected shortward of about 2500 Å. The fragmentary near-ultraviolet measurements that exist are very interesting. First, the distribution of the zodiacal light on the sky appears to be very different in the ultraviolet, in comparison with the distribution in the visible. In the visible, the ecliptic plane (the zodiac) is about three times brighter than the ecliptic pole. Thus, the dust cloud seems to be rather flattened and confined to the plane. In contrast, there is much less variation over the sky of the ultraviolet zodiacal light. Yet there is no doubt that the light that is seen is true zodiacal light, for the spectrum of the light closely ressembles that of the sun. This would indicate that in the ultraviolet we are seeing a new component of the dust, presumably smaller particles than those responsible for the visible zodiacal light. Second, odd spectral features appear near 2800 Å that are completely unexplained.

UVISI on MSX can make the first complete spatial and spectral maps of zodiacal light in the ultraviolet, significantly increasing our knowledge of this interesting component of our own solar system.