

# 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  $\alpha$  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 bremsstrahlung. 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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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 bremsstrahlung 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  $2.2 \times 10^6$  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 bremsstrahlung 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  $\alpha$  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  $\alpha$  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, & Rutgers 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<sup>-2</sup> s<sup>-1</sup> Å<sup>-1</sup> (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.





tude of explaining the Gunn-Peterson (1965) effect: space is very transparent at wavelengths where the neutral hydrogen Ly $\alpha$  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 particularly notice that some of the *Voyager* upper limits at the lowest galactic latitudes are very low. For comparison, the diffuse background longward of Lyman  $\alpha$  is almost everywhere  $\geq 300$  photons  $\text{cm}^{-2} \text{s}^{-1} \text{sr}^{-1} \text{Å}^{-1}$ . (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.

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

Target Number	$l^{II}$	$b^{II}$	RA	Dec	Flux <sup>a</sup>	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

<sup>a</sup> ph cm<sup>-2</sup>s<sup>-1</sup>sr<sup>-1</sup>Å<sup>-1</sup>

<sup>b</sup>Holberg 1990

<sup>c</sup>Sandel, Shemansky, & Broadfoot 1979

<sup>d</sup>Murthy, Henry, & Holberg 1991

<sup>e</sup>Murthy, Im, Henry, & Holberg 1993

<sup>f</sup>Murthy, Henry, & Holberg 1994

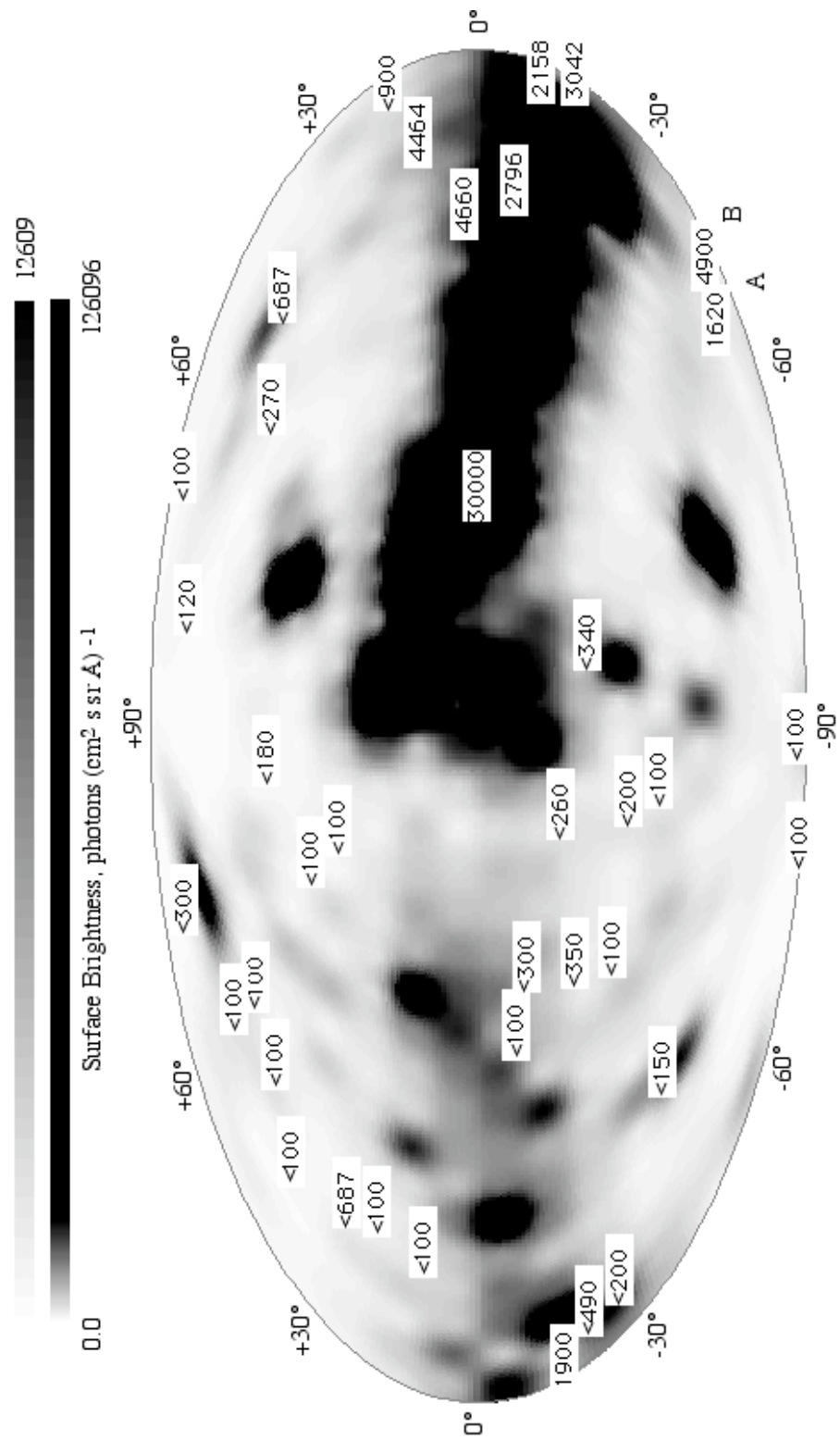


Figure 4. The *Voyager* Sky: mostly upper limits, in units of photons cm<sup>-2</sup> s<sup>-1</sup> sr<sup>-1</sup> Å<sup>-1</sup>. The Eridanus observations A and B of Murthy, Im, Henry, & Holberg (1993) are specially indicated at lower right.

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