Comparing the Flux of the Cosmic Background Radiation, Man-Made Telecommunication, and Radio Terrestrial Thermal Background Noise Over Channel Bands In the 0.5 - 1000 MHz Range

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A senior thesis submitted to the Carthage College Physics Department in partial fulfillment of the requirements for the Bachelor of Arts Degree in Physics

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Abstract

In 1964, when using the 20-foot horn-reflector antenna at the Crawford Hill Laboratory in Holmdel, New Jersey, Penzias and Wilson discovered the Cosmic Background Radiation while attempting to observe weak radio signals from the Milky Way Galaxy [10]. In "Origins," Neil deGrasse Tyson estimates that background radiation accounts for 1% of noise in between television channels [9]. Because Earth is enveloped in this background radiation I became curious to know what effect, if any, the CBR has on telecommunications. In deriving the dimensionless form of the Planck function and realizing that it is acceptable to utilize the Rayleigh-Jeans law, I calculated the flux of the CBR through integration of the Rayleigh-Jeans law over the frequency bandwidths that the Federal Communication Commission regulates for cell phone, radio, and television channels. The greatest value calulated is on the order of $10^{-14}\frac{W}{m^2}$. For comparison, the weakest local telvision signal is on the order of $10^{-7}\frac{W}{m^2}$. This means that locally the ratio of the flux between the CBR and man-made signals is never greater than $10^{-7}\frac{W}{m^2}$. This insures that the CBR virtually has no interference within the frequency bands in use for wireless communications. However, determining other possible sources of interference and concluding that the earth is only other main factor; calculating the flux of the thermal background noise of the earth, with a temperature of 290K, to be $1.242 \times 10^{-18}\frac{W}{m^2}$ and comparing it to the CBR it is found that the CBR is approximately 1/100 the strength of the earth [8]. I confirm this estimate by Tyson for the CBR's percentage of the static noise in an off-band channel.

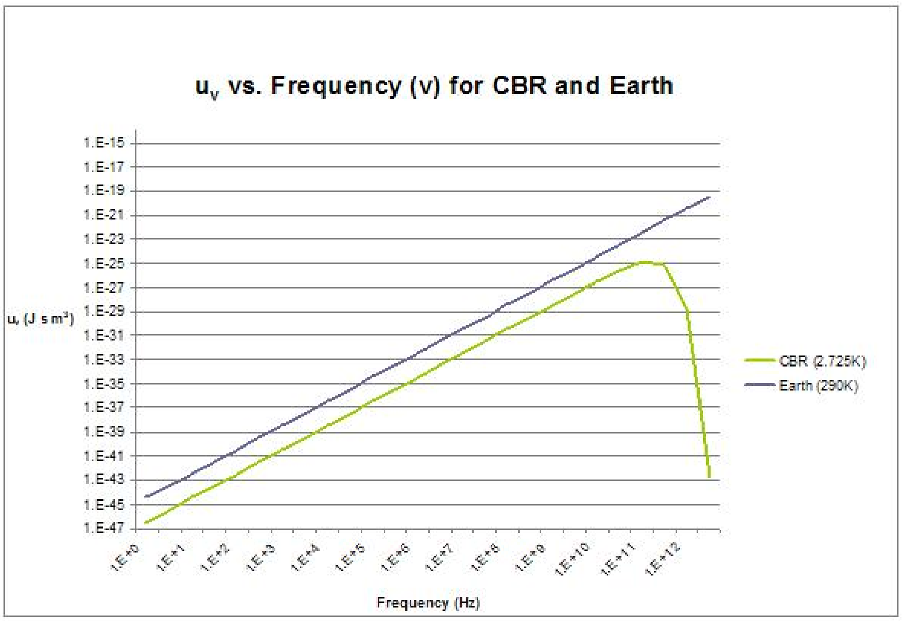

Figure 1: A comparison plot of the energy density per unit frequency between the CBR and earth. The earth is a 100 times greater in value which corresponds to why the CBR is 1% of the total background thermal noise in an off-band television channel

1 Introduction

Upon watching a NOVA program entitled "Origins" hosted by the director of the Hayden Planetarium, Neil deGrasse Tyson, I was introduced to the cosmic microwave background of the universe and was fascinated by it. In one segment, Tyson uses a rabbit-ear antenna television to demonstrate that if tuned in between channels, about 1% of the static noise on the screen, like in figure 2, is from cosmic background radiation (CBR)[9]. This lead me to wonder exactly to

Figure 2: Part of the static on a rabbit-ear antenna television is from the CBR [5].

what degree, if any, the background radiation interferes with local television, and radio stations, and cell phone signals. It's important to know this because the signal strength of communication devices will have to be adjusted accordingly. If it has enough strength to interfere and disrupt communication then new forms of communication must be considered for all efficiency and practical reasons.

2 Thesis Statement

The goal of this thesis is to carefully compute the CBR flux in the AM/FM radio, television, and cell phone frequency bands and compare it to the flux of real civilian signals around the Carthage College campus. I will gain knowledge of the degree of interference that the CBR can have on communication signals and determine whether or not the CBR truly makes up 1% of the entire background noise at the Carthage College campus.

3 The CBR Discovery

George Gamow first predicted the CBR in 1948 and since that time physicists set out to discover a way to detect and measure the CBR [14]. It was not until 1964, when a pair of physics wanted to do some radio astronomy using the Bell Telephone Laboratories 20-ft horn reflector that was used in cross Atlantic communications via satellite, accidently did so. They noticed more signal than they expected by about 3.5K, and it appeared to be isotropic [10]. They went to work around the antenna to search any possible sources for this excess noise: they tightened bolts, adjusted joints, cleaned out debris, and removed some nesting pigeons. They did all this in order to insure that the antenna was a proper receiver of signal. Despite all their hard work the excess signal remained.

At the same time a team of physicists: Dicke, Peebles, Roll, and Wilkinson, were working with the idea that the universe was filled with the black body radiation that Gamow had predicted. They had constructed a receiver to measure signals at a wavelength of 3 cm, but before they had collected any data, they were informed about the excess signal that Penzias and Wilson discovered at Bell Laboratories. From Penzias and Wilson's data, the team concluded that the signal Penzias and Wilson detected was indeed black body radiation from the universe[3].

The reasoning for this 17-year gap between prediction and discovery is a matter of technology. Back in 1948, the technology capable of detecting a weak signal, such as the CBR, had yet to be invented. Also, Gamow had predicted it to have a higher temperature than it was it was found to have. Scientists were looking within frequencies much higher than the CBR actually was strongest. Objects in space are radiating at these higher frequencies making the CBR indistinguishable from celestrial objects. The horn reflector that Penzias and Wilson were using was setup to use frequencies within the microwave portion of the spectrum, and they detected the excess noise because the CBR's spectrum peaks in the microwave range[14].

4 What is the CBR?

The CBR is a type of radiation that falls into the category called black body radiation. Black body radiation is given specific attention because everything emits it, because it is a result of matter having a temperature above absolute zero. The intensity of it depends on the temperature of the object. Perfect black bodies are objects having uniform temperature, thermal equilibrium, throughout there entire volume; this is rarely the case, if ever, but in most cases scientists care about objects that are very near perfect blackbodies. The universe can be considered to be such an object if it is closed and homogenous. None of the heat in the universe can escape and fills all of space equally, creating the thermal equilibrium condition needed for an object to emit black body radiation

Black body objects emit photons, packets of energy in the form of light. They are emitted through the de-excitation of electrons within atoms as a result of energy conservation. When a photon of a specific energy interacts with an electron in an atom, the photon can cause the electron to "jump" to a higher energy orbital. The tendency of electrons is to fill the lowest possible energy level available, therefore in time, the electron that "jumped" to the higher energy level will fall back into a lower energy level, but to do so it has to lose energy. The loss of energy is through the emission of a photon with the energy of the difference between the energy.

A special characteristic of the CBR is that it is isotropic[10]. This means that when measuring it, its intensity is constant regardless of the location of the instrument; for any other black body this is not true. When making measurements of the spectrum of a black body source such as the sun or distant star the strength of the spectrum changes as the angle between the object and instrument changes. The CBR's measured spectrum nearly traces over the expected spectrum for a black body of a temperature of 2.725K according to the Planck function [6].

5 COBE and WMAP Missions

Since the time of its discovery, physicists have attempted to improve on the sensitivity of their instruments to get clearer and more accurate measurements of the CBR. The difficultly in this is trying to keep stronger signals from interfering with the CBR signal, plus having the need for a sensitive enough receiver because the CBR is so weak. The simplest and cheapest way to measure it is to build an earth-based receiver. However, there are interfering signals from the earth itself and man-made communication signals; therefore, such devices need to be built in remote places high above the earth's surface. Another option is to hook up a receiver to a balloon and raise it high in the atmosphere to avoid the earth signals. A third option is to put a satellite out in space. The COBE team accomplished this feat first and was followed up by the WMAP team who improved upon it.

The Cosmic Background Explorer (COBE) was launched in 1989 and its mission, headed by John Mather and George Smoot, was to measure the temperature of the CBR using its FIRAS instrument and compare it to the black body spectrum [14]. It was put into an orbit around the Earth at an altitude of 900km. The orbit around the Earth kept the instruments on board pointed 90 degrees from the direction of the sun as the earth rotated around the sun, see figure 3. This insured that the data collected would have the least amount of interference from the sun, but still some interference from the earth and moon is present.

The FIRAS is a differential instrument consisting of two separate interferometers that record the difference in temperature. It produced an average temperature that agreed with the black body curve at a temperature of 2.725K [6]. This further agrees with the prediction that the CBR is black body radiation. As you can see in figure 4, a graphical representation comparing the numerical data collected by the FIRAS instrument and the spectrum of a black body at

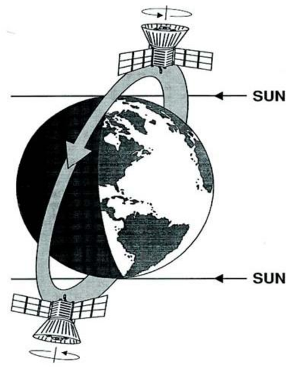

Figure 3: An illustration of COBE's orbit around the Earth [14].

2.725K. There was given a 1% of error which the boxes in the figure represent.

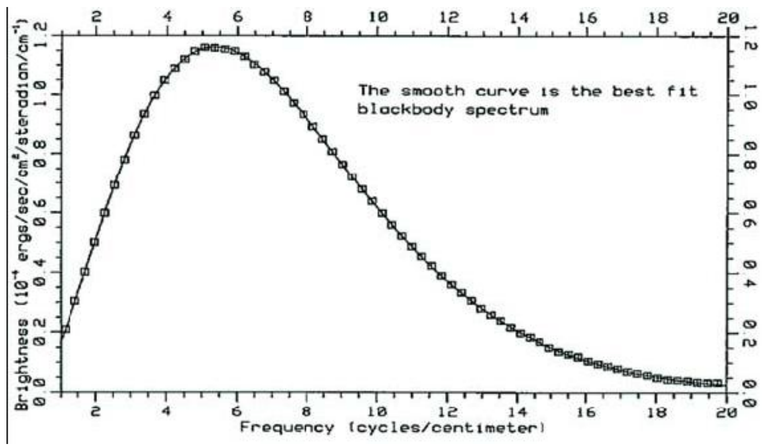

Figure 4: This is the blackbody curve from the COBE FIRAS data during the first nine minutes on observation. The small squares show measurements within 1% of error. The smooth curve is the best fit curve for the data, which overlays a blackbody curve at a temperature of 2.725 K [14].

Though COBE was successful and exceedingly so, it was still not as accurate as some desired. Therefore a team, led by David Spergel and David Wilkinson, was put together to expand on the COBE mission and engineer a new satellite that had more sensitive instruments. This new satellite was name the Wilkinson Microwave Anisotropy Probe (WMAP) and it is located in a much more isolated and thermally stable point in space at the L2 point. L2 is a point in space where a satellite can orbit at a fixed distance from the Earth and Sun, but the L2 is unstable in its location, therefore WMAP has to correct its position every 23 days [7]. The L2 point is 1.5 million km from Earth and being pointed away from the Sun, Earth, and Moon, there is little if no interference from them [7]. WMAP was launched in 2001 and it took 3 months for the probe

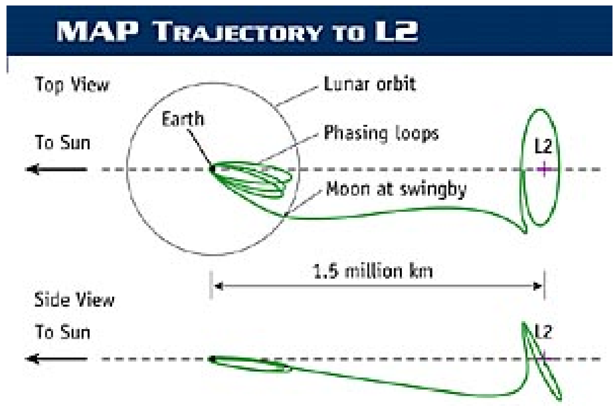

Figure 5: Here is an illustration of the path WMAP had to take to get to L2. [7].

to reach L2 before it could start recording data, figure 5 provides an illustration of WMAP's course. Just like COBE, WMAP also used a differential instrument to record the difference in temperature between two points in space. The data helped to create the full-sky anisotropy map, and as can be seen in figure 6 the detail comparison between WMAP and COBE. The average temperature recorded by WMAP is in agreement with the COBE at 2.725K.

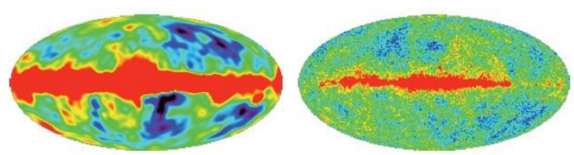

Figure 6: Here is a comparison between COBE's anisotropy map, left, and WMAP's, right [7].

6 Physics of Blackbody Radiation

When I speak of radiation I am referring to mass less particles called photons; basically tiny packets of energy. Not all are alike because not all photons have the same energy. There is an entire spectrum/range of energy that these particles can have. The spectrum includes radio, infrared, microwave, visible, ultraviolet, x-ray, and gamma ray photons, all of which are different forms of light, and figure 7 provides an illustration of the spectrum. The energy a photon, which

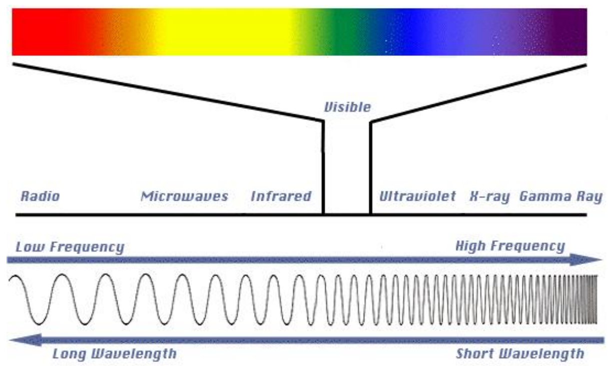

Figure 7: The spectrum of light starting on the level with low energy/frequency radio waves to high energy/frequency gamma rays [12].

is related to its frequency and wavelength, solely determines what part of the spectrum it's in. In this section I will be using this relation to work through the derivation of the Planck function (formula to predict the black body curve). I will use the Planck function to help determine the flux of the CBR within part of the spectrum that radios, televisions, and cell phones use. This will provide insight into the possible interference the CBR has with the man-made signals.

A black body spectrum is a representation of the distribution of photons in the light spectrum for a black body at a given temperature. Black bodies don't radiate one specific frequency of photons, but a distribution of them. The temperature is the only free factor in determining this curve.

6.1 Derivation of the Planck Function

The Planck function was derived by Max Planck around 1900. He started with the classical Rayleigh-Jeans law, equation 1, which states that the energy density, u, at a given frequency, ν for a black body is proportional to its temperature,

$$du = u_\nu d\nu = \frac{8\pi k_B T}{c^3}\nu^2 d\nu; \tag{1}$$

where ν is frequency in hertz, k_B is the Boltzman constant, and T is temperature in kelvin. The Rayleigh-Jeans law agrees with experimental results only at low frequencies, and this lead to "ultraviolet catastrophe." As can be seen in figure 8 that as frequency increases the Rayleigh-Jeans law continues onto infinity for the energy density. The Rayleigh-Jeans allows this because

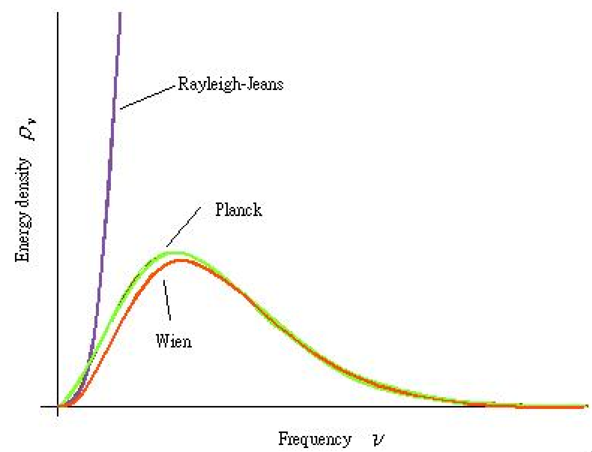

Figure 8: The Rayleigh-Jeans curve, purple curve, continues to increase to infinity with increasing temperature [1].

it says that each increase in frequency a photon has an addition $k_B T$ of energy. This is unreasonable as this would go against the conservation of energy, because photons cannot have an infinite amount of energy.

To solve this issue, I will consider a thermally isolated oven with sides of length L, therefore the volume of the oven is L^3. A photon has energy of

$$\frac{hc}{\lambda} \tag{2}$$

or

$$h\nu, \tag{3}$$

where h is the Planck constant that Planck introduced in order to provide a floor limit and incrementer of the amount of energy for a photon.

The longest wavelength a photon in the oven can have is 2L, but the three dimensions a photon can travel need to be accounted for; therefore I need to multiply by the square-root of the sum of the squares of the modes in x,y,z:

$$E = \frac{hc}{2L}\sqrt{n_x^2 + n_y^2 + n_z^2} \tag{4}$$

$$E = \frac{\pi \hbar c}{L}\sqrt{n_x^2 + n_y^2 + n_z^2}. \tag{5}$$

where n is the mode of the photon in the box. To simplify this I can call the whole square-root n:

$$E = \frac{hcn}{2L} \tag{6}$$

To get the total energy, U, within the oven I need to sum up the total number of photons in each mode accounting for the two possible polarizations of a photon. Therefore, I need to sum over all the modes allowed in the oven, and this results in a triple sum:

$$U = \sum_{n_x=1}^{\infty} \sum_{n_y=1}^{\infty} \sum_{n_z=1}^{\infty} \frac{hcn}{L} \frac{1}{e^{\frac{hcn}{2Lk_BT}} - 1} \tag{7}$$

Planck introduced the Boltzmann factor into his derivation: $e^{\frac{hcn}{2Lk_BT}}$. The Boltzmann factor is fundamental in statistical mechanics and describes the probability of a photon's energy based on temperature. It is not a probability on its own, but rather a weighting factor of probabilities[2]. Planck intuitively introduced this into his derivation, and subtracting one from it in the denominator is only a correction adjustment to fit the experimental data blackbody curves with his mathematical curve.

To sum all the modes I need to sum over a small distance Δn each time:

$$U = \sum_{n_x=1}^{\infty} \Delta n_x \sum_{n_y=1}^{\infty} \Delta n_y \sum_{n_z=1}^{\infty} \Delta n_z \frac{hcn}{L} \frac{1}{e^{\frac{hcn}{2Lk_BT}} - 1} \tag{8}$$

Since "n-space" is not continuous we need to change variables, as mentioned earlier, so that we can sum all modes. To do so, I will use the relationship

$$n = \frac{Lk}{\pi}. \tag{9}$$

to change the n's into k's. Therefore in terms of "k-space:"

$$E = \hbar ck \tag{10}$$

and

$$U = \sum_{k_x=0}^{\infty} \Delta k_x \sum_{k_y=0}^{\infty} \Delta k_y \sum_{k_z=0}^{\infty} \Delta k_z (\frac{L}{\pi})^3 \frac{2\hbar ck}{e^{\frac{hcn}{2Lk_BT}} - 1} \tag{11}$$

The equation is still one for energy, but dividing by L^3 I have an equation representing the energy density within the oven. The sums are now continuous and as a result they can be turned into integrals, which gives me a triple integral in "k-space:"

$$\frac{U}{V} = \frac{2\hbar c}{\pi^3} \int_0^{\infty} dk_x \int_0^{\infty} dk_y \int_0^{\infty} dk_z \frac{k}{e^{\frac{\hbar ck}{k_BT}} - 1} \tag{12}$$

From "k-space" I need to convert to polar coordinates make the triple integral mathematically sound:

$$\frac{U}{V} = \frac{2\hbar c}{\pi^3} \int_{k=0}^{\infty} \frac{k^3}{e^{\frac{\hbar ck}{k_B T}} - 1} dk \int_{\theta=0}^{\frac{\pi}{2}} sin\theta d\theta \int_{\phi=0}^{\frac{\pi}{2}} d\phi \tag{13}$$

The integrals with respect to θ and ϕ are 1 and $\frac{\pi}{2}$ respectively, which leaves me with a"k-space" integral. I can convert this to something more understandable by utilizing the relationship between k, frequency, and angular frequency, ω which will helps me because our man-made signals work with frequency. So

$$\omega = kc \tag{14}$$

and

$$\omega = 2\pi\nu \tag{15}$$

therefore,

$$k = 2\pi\frac{\nu}{c} \tag{16}$$

and

$$dk = \frac{2\pi}{c} d\nu. \tag{17}$$

My complete integral for finding the energy density, u, of the CBR in terms of frequency is:

$$u = \frac{\hbar c}{\pi^2} \int \frac{(2\pi\nu/c)^3}{e^{\frac{h\nu}{k_B T}} - 1} d\nu. \tag{18}$$

I can also change this integral into a dimension-less quantity, because the exponential term in the denominator is dimension-less, by introducing

$$x = \frac{h\nu}{k_B T} \tag{19}$$

and substituting carefully using

$$v = \frac{k_B T x}{h} \tag{20}$$

and

$$dv = \frac{k_B T}{h} dx; \tag{21}$$

the final demension-less integral is:

$$8\pi \frac{(k_B T)^4}{(hc)^3} \int \frac{x^3}{e^x - 1} dx. \tag{22}$$

Equation 23 is the result of integrating equation 22 with limits from 0 to ∞: making it possible to determine the total output power from a black body.

$$u = aT^4 = \frac{8}{15}\pi^5 \frac{(k_B T)^4}{(hc)^3} \tag{23}$$

7 Rayleigh-Jeans Limit

Equation 22 that I derived in the previous section is an equation that holds true for experimental situations in both high and low frequencies. I mentioned before that this equation, the Planck function, is an expansion of the Rayleigh-Jeans law which is only experimentally correct for "low" frequencies. "Low" frequencies is not a universal interval for all black bodies; the frequencies that are considered low are dependent on the temperature of the black body.

Now I will determine if the Rayleigh-Jeans law is acceptable to use for the frequencies I am looking at by reconsidering the dimensionless form of the Planck function, equation 22, and realizing that if $x << 1$, then

$$e^x = 1 + x + \frac{1}{2}x^2 + \frac{1}{3!}x^3 + \cdots \tag{24}$$

Since $x << 1$, e^x can become $1 + x$ and substituting back in for x using equation 20, the Planck function will become the Rayleigh-Jeans law, equation 1. It is now necessary to determine the limit of when $x << 1$; because of equation 19 I can set

$$\frac{h\nu}{k_B T} << 1 \tag{25}$$

and using algebra see that when $x << 1$ then

$$\nu << \frac{k_B T}{h}. \tag{26}$$

Plugging in the values of k_B, h, and T for the CBR, the left-side equals 5.6826×10^{10} Hz, and comparing this to the highest frequency I have considered, 893.97 MHz = 8.9397×10^8 Hz there is a difference of a factor of 10^2. This difference is enough to say that indeed $\nu << \frac{k_B T}{h}$ and that within the frequencies I am looking at, the Rayleigh-Jeans law is applicable. Figure 9 compares the plots for the CBR using the Rayleigh-Jeans and the Planck function. The red line defines where the plots are evaluated at 1GHz and the frequencies I am concerned with are left of the line. The plot verifies that the Rayleigh-Jeans law is acceptable in calculating the flux for the CBR within the telecommunication bands I am concerned with.

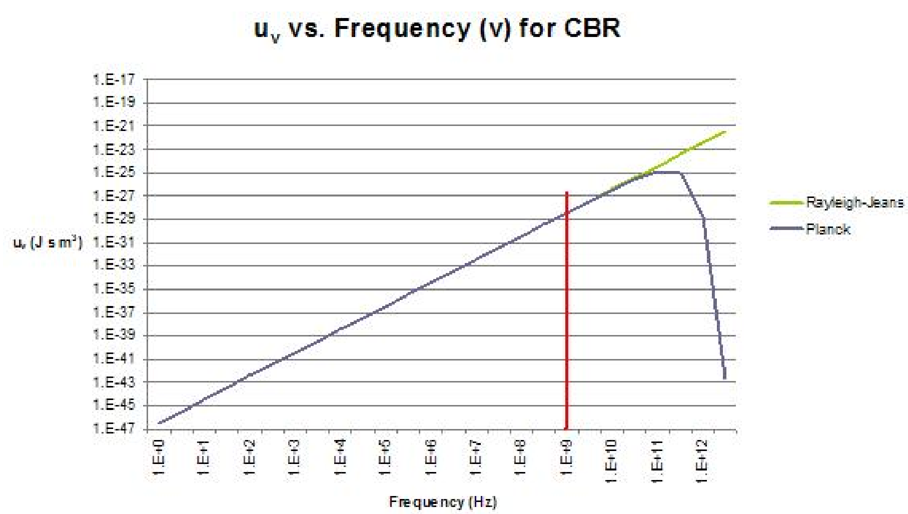

Figure 9: The plot verifies that the Rayleigh-Jeans law is acceptable in calculating the flux for the CBR within the telecommunication bands under 1GHz.

8 Civilian Sources

The Federal Communication Commission is a government organization that regulates what frequencies certain communications are allowed and the width of the frequency bands for radio and television transmissions. The frequency band of a channel is the interval of frequency which a registered radio or television station can transmit a signal. AM radio frequency bands are 10 kHz and FM is 200 kHz wide. What this means is that a station such as 620 AM can transmit between 615 kHz and 625 kHz and 103.7 FM transmits between 103.6 MHz and 103.8 MHz. Television frequency bands are the widest at 6 MHz wide: channel WISN ABC 12 out of Milwaukee, WI can transmit between 204 MHz and 210 MHz [4].

The purpose of these frequency bands is to keep stations from interfering with one another. It allows for equal competition for listeners and keeps more powerful stations from "leaking" into the weaker ones. Radio and television signal strength is classified according to ERP, effective radiated power. ERP is not the total usage of power that the antenna draws. In fact, antennas typically draw about 10-20% of their registered ERP. ERP takes into account a system's losses and gains and the TPO (total power output, power that it draws). ERP represents the radiating power of the antenna if in fact it where a true radiator of that power[11].

The FCC restriction I am solely concern about for stations is on the bandwidth they are allowed to transmit in. The super power radio stations can transmit up to 50,000 watts of ERP and some television stations are greater than that. Some weaker radio stations can generate only 10 watts of ERP. The power of the signal correlates to how far from the source the signal can be "heard" clearly.

The cell phone industry is given two frequency bands, A and B. The A band, that the base stations (towers) transmit in, is from 824.04 MHz to 848.97 MHz and the B Band, that mobile phones transmit in, is from 869.04 MHz to 893.97 MHz [4]. The purpose of these different bands between towers and mobile phones is to allow for normal back and forth conversations. If towers and phones were working in the same frequency band then only one person could talk at a time; it would be like talking on a walkie-talkie. Though this provides the need for complex circuitry, it's necessary for what people desire phones to do though.

The cell phone system in use today has 832 channels within the allowed bands each having a bandwidth of 30 kHz[4]. Not all the channels are voice channels, channels that cell phone conversations are carried over. Cell phones don't have their own frequency, and for any one call that a phone receives the frequency used may not be same for the next call. The frequency used depends on the availability of frequencies, and is determined by the control channel within the cell. Control channels dictate which frequency a call will be transmitted over to a phone within the cell. Control channels initiate the call and when connection is made to the phone, the control channel passes the data stream to the voice channel and the phone rings[4].

832 channels may not sound like it can cover the number of cell phone users in America, but if used effectively they can. That is why coverage providers divide regions into "cells." If the towers covering that cell are low power transmitters, then neighboring cells can use the same channel without interference. Each cell has its own monitoring channel that can determine whether a phone is within its boundary. Cell phones constantly send out a signal with their identification code and when the monitoring channel of a cell picks it up, then it knows that the phone is in its cell[4]. If a cell phone leaves a cell, that cell's monitoring channel will drop connection with the phone and the phone will gain a connection with the new cell's monitoring channel.

The objective of cell phones is to allow people to move wherever they want and be able to maintain a phone conversation. Cells are bordered with towers that transmit into the cell, as can be seen in the figure 10. It may first appear to be more logical that a tower would stand at the center of a cell. However, if a tower were standing in the middle of a cell and a cell phone user moves towards the edge of the cell, the signal would get weaker and the likelihood of a dropped call would substantially increase. The neighboring cell would also not have a strong signal and not pick up the cell phone's identification code in order to maintain the conversation.

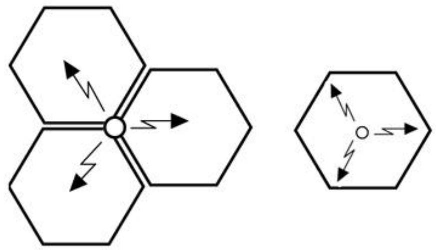

Figure 10: Here is an illustration of the hexangonal make-up of cells where a tower transmits into multiple cells instead of being the center of a cell [4].

The outer regions of cells would in fact be "dead-zones."

9 Calculating the Flux of Man-Made Narrow-band Telecommunicaion Signals Over Channel Bands

To determine the flux from civilian sources I need to know what the sources power output is. I will use the ERP of an antenna for the power output. Antennas transmit their signals radially and the signal spreads out over the area of a sphere. To calculate the flux I need to divide the ERP by the surface area of a sphere, $4\pi R^2$. R is the distance from the antenna to the middle of the Carthage College planetarium dome; which I determined using Google Earth and figure 11 is an image of the program. Table 1 includes some radio AM/FM stations' tower flux; Table 2 includes the flux for both tower and phone sources for six cell towers near Carthage College, where the ERP for the tower is 100 watts and .6 watts for a cell phone [4]. Table 3 presents the flux from five television stations.

Table 1: AM/FM Radio Flux

AM Call Sign	$\nu(MHz)$	ERP(W)	Distance(m)	$\rho_\Phi(\frac{W}{m^2})$
WTMJ	.615 - .625	50000	22153.93	8.107×10^{-6}
WGN	.715 - .725	50000	70275.65	8.057×10^{-7}
WISN	1.125 - 1.135	50000	25838.7	5.960×10^{-6}
WSSP	1.245 - 1.255	5000	40755.37	2.395×10^{-7}
WRJN	1.395 - 1.405	1000	9582.58	8.666×10^{-7}
FM Call Sign	$\nu(MHz)$	ERP(W)	Distance(m)	$\rho_\Phi(\frac{W}{m^2})$
WMBI	90.0 - 90.2	100000	78799.97	1.282×10^{-6}
WIIL	95.0 - 95.2	50000	10008.24	3.972×10^{-5}
WMYX	99.0 - 99.2	50000	40701.51	2.402×10^{-6}
WXSS	103.6 - 103.8	19500	52849	5.556×10^{-7}
WVCY	107.6 - 107.8	43000	42856.02	1.863×10^{-6}

Table 2: Cell Phone and Tower Flux

Tower Location	Distance(m)	$Tower \rho_\Phi(\frac{W}{m^2})$	$Phone \rho_\Phi(\frac{W}{m^2})$
2205 Washington Rd	3442.73	6.714×10^-7	4.028×10^{-9}
3300 30th Ave.	3045.89	8.578×10^-7	5.147×10^{-9}
22nd St & Hwy 31	4550.32	3.843×10^-7	2.306×10^{-9}
2380 47th Ave.	3854.83	5.355×10^-7	3.213×10^{-9}
1521 Green Bay Rd.	4706.67	3.592×10^-7	2.160×10^{-9}
505 22nd Ave.	3947.53	5.110×10^-7	3.060×10^{-9}

Table 3: Television Flux

TV Call Sign	$\nu(MHz)$	ERP(kW)	Distance(m)	$\rho_\Phi(\frac{W}{m^2})$
6 WITI	82-88	100	52096.37	2.932×10^{-6}
12 WISN	204-210	316	54729.74	8.395×10^{-6}
32 WFLD	578-584	5000	82132.77	5.898×10^{-5}
50 WPWR	686-692	5000	84109.37	5.624×10^{-5}
58 WDJT	734-740	5000	54804.5	1.325×10^{-4}

Figure 11: Here is an image from using Google Earth of the Carthage Campus. The red box highlights the planetarium dome on top of the Straz Accedemic building.

10 BroadBand Sources of Interference

As the use of wireless communication technology has grown into a necessity over the past 30 years there has been enormous growth in the number of signal transmitting structures. The result of this is a sky filled with the electromagnetic "noise" from these devices. This has caused some to become concerned about the degree of exposure and the effect this has on people.

An inclination is that with all this "noise" that somehow the signals out there would criss-cross and interfere with each other. This obviously doesn't happen because radios and televisions do not pick up more than one station at a time. The FCC divides up the communication spectrum into bands that are set-up for specific purposes. Check out the website, http://www.ntia.doc.gov/osmhome/allochrt.pdf, to view a pdf file that displays the FCC spectrum chart and the division of the frequency bands; it also provides a short description of what each band is used for [12]. The FCC in fact helps cut down the amount of "noise." Electromagnetic signals generally carry useful information that can be translated into something people can distinguish audibly or visually. Signals that do not are considered to be noise.

Because stations transmit in narrow bands of frequency they can be more efficient in the usage of power by focusing the power they draw into generating a precise frequency instead of a wide range of frequencies. If stations did not transmit in narrow bands the sky would be filled with noise and stations would be interfering with one another. The carrier wave would also be less efficient at carry the necessary information that is translated into sound or an image. Instead of coming from other communication sources, interference comes from unregulated signals that span over multiple bands of frequency, also known as broadband sources.

These unchecked signals are usually not man-made. Most electrical devices do produce some noise, but not in any amount of power that can affect a television signal unless it is within the television itself. This leaves atmospheric anomalies such as lightning, cosmic radiation, and the earth. Atmospheric anomalies are events that I will not consider due to their inconsistent presence and strength. Cosmic radiation is also inconsistent. Solar flares increase the flux of electromagnetic radiation that passes by the earth, but these are not constant. Radiation from the galaxy is not isotropic like the CBR; the greatest amount of radio frequency noise from the galaxy comes from the center of the galaxy. Solar flares and RF noise from the galaxy are sources I won't consider either [15].

The one thing that is consistent is the earth, but the earth is not a perfect black body. A perfect black body is an object that absorbs all, and reflects none of the energy that hits it. If the earth could be considered a black body with a temperature around 300K, the Rayleigh-Jeans could still describe its blackbody spectrum within the frequencies I am concerned with as figure 12 shows[13]. The earth is not a perfect black body because the atmosphere reflects some of the Sun's energy. The energy that is emitted from the earth is not entirely released because the atmosphere reflects back some of it. The earth also releases heat so that it does not over-heat. These three characteristics of the earth actually bring down the mean temperature of the earth to around 290K [8]. However, a more precise calculation would include the emissivity of the earth, therefore my results represent the lower limit of the percentage of thermal background noise that the CBR contributes to.

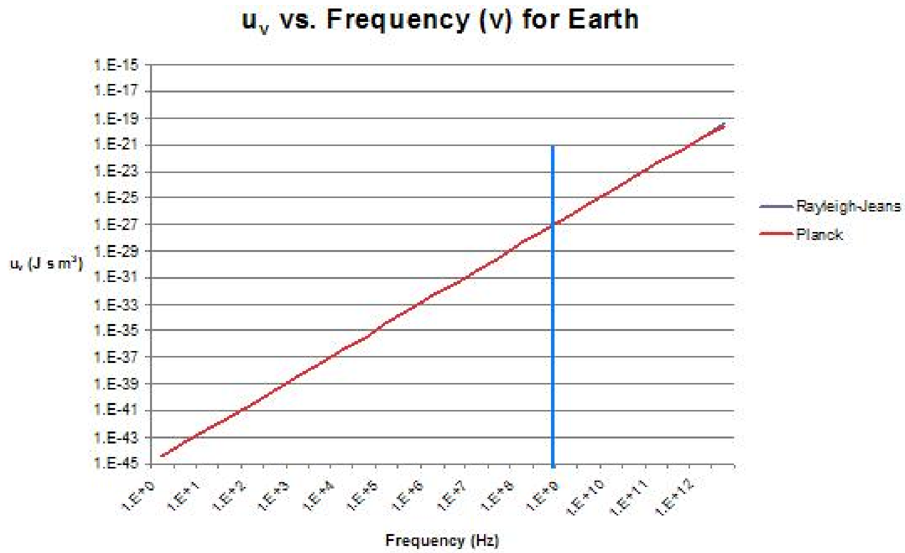

Figure 12: This plot comparing the Rayleigh-Jeans law and the Planck function for the earth verifies that it is acceptable to calculate the flux within man-made telecommunication bands under 1GHz from the earth using the Rayleigh-Jeans law.

11 Results

The following tables are my calculations for the CBR energy density and flux within the frequency bands of some of the sources I have considered. I integrated equation 22 with limits of x that are determined by the frequency band as according to equation 19. Then by multipling the energy density of the CBR by the speed of light I can compare the flux of the CBR to the local man-made signals. Table 4 presents some sources from AM/FM radio stations. Table 5 presents the CBR energy and flux within the highest frequency bands that both cell towers and cells phones use. Table 6 displays data within the television frequency bands. Comparing this to the television portion of the table 4 it is obvious that the CBR in these bands has the greatest amount of energy density. This is expected since television signals have the widest frequency band, 6 MHz, as compared to the other communication methods, as can be shown in figure 14. Therefore, if I am going to find any interference in any communication frequency bands it is going to be within television frequency bands.

Table 4: CBR Flux in AM/FM Bands

AM Call Sign	$\nu(MHz)$	$u(\frac{J}{m^3})$	$\rho_\Phi(\frac{W}{m^2})$
WTMJ	.615 - .625	1.346×10^{-31}	4.037×10^{-23}
WGN	.715 - .725	1.815×10^{-31}	5.444×10^{-23}
WISN	1.125 - 1.135	4.470×10^{-31}	1.341×10^{-22}
WSSP	1.245 - 1.255	5.469×10^{-31}	1.641×10^{-22}
WRJN	1.395 - 1.405	6.861×10^{-31}	2.058×10^{-22}
FM Call Sign	$\nu(MHz)$	$u(\frac{J}{m^3})$	$\rho_\Phi(\frac{W}{m^2})$
WMBI	90.0 - 90.2	5.68×10^-26	1.70×10^{-17}
WIIL	95.0 - 95.2	6.33×10^-26	1.90×10^{-17}
WMYX	99.01 - 99.2	6.87×10^-26	2.06×10^{-17}
WXSS	103.6 - 103.8	7.52×10^-26	2.26×10^{-17}
WVCY	107.6 - 107.8	8.11×10^-26	2.43×10^{-17}

Table 5: CBR Flux in Cell Phone Frequencies

Tower $\nu(MHz)$	$u(\frac{J}{m^3})$	$Tower \rho_\Phi(\frac{W}{m^2})$
848.82 - 848.85	7.567×10^-25	2.270×10^{-16}
848.85 - 848.88	7.568×10^-25	2.270×10^{-16}
848.88 - 848.91	7.680×10^-25	2.270×10^{-16}
848.91 - 848.94	7.569×10^-25	2.271×10^{-16}
848.94 - 848.97	7.569×10^-25	2.271×10^{-16}
Phone $\nu(MHz)$	$u(\frac{J}{m^3})$	$\rho_\Phi(\frac{W}{m^2})$
848.82 - 848.85	8.391×10^-25	2.517×10^{-16}
848.85 - 848.88	8.391×10^-25	2.517×10^{-16}
848.88 - 848.91	8.392×10^-25	2.518×10^{-16}
848.91 - 848.94	8.392×10^-25	2.518×10^{-16}
848.94 - 848.97	8.393×10^-25	2.518×10^{-16}

Table 6: CBR Flux in Television Frequencies

TV Call Sign	$\nu(MHz)$	$u(\frac{J}{m^3})$	$\rho_\Phi(\frac{W}{m^2})$
6 WITI	82-88	1.52×10^-24	4.554×10^{-16}
12 WISN	204-210	8.98×10^-24	2.700×10^{-15}
32 WFLD	578-584	7.05×10^-23	2.127×10^{-14}
50 WPWR	686-692	9.91×10^-23	2.991×10^{-14}
58 WDJT	734-740	1.21×10^-22	3.4224×10^{-14}

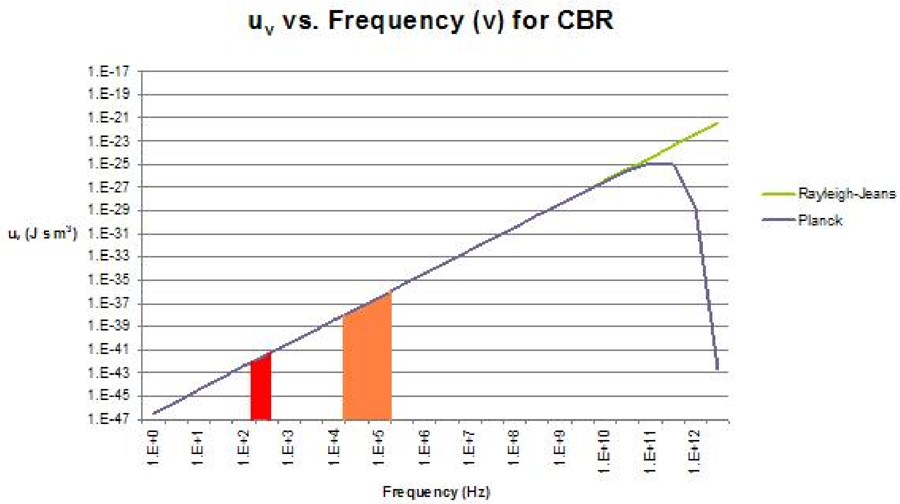

Figure 13: Integrating the Rayleigh-Jeans law at higher frequencies results in calculating more flux, also the wider the band of integration the more flux will be calculated.

In table 7 I compare the values of the CBR flux in the AM/FM radio, cell phone, and television frequencies that are present within the region of Carthage College, which I previously calculated. The value in table 7 that displays the degree of interference the CBR has on communication signals is the ratio of the CBR flux to Man flux.

As it can be seen in table 7 that the ratio of CBR flux to man-made flux is never greater than a factor of 10^{-7}. This means that for every one CBR photon there are 10,000,000 photons or more from regional sources in each frequency band.

It is interesting to compare the flux of the CBR to the earth's. I mentioned earlier that deGrasse Tyson estimated that about 1% of the noise between stations is from the CBR. If the earth is the greatest contributor to the static, then the CBR flux should be 1/100 of the earth's. To compare the CBR energy density and flux I integrate equation 22 with the limits from 0 to 1 GHz for both the CBR at a temperature of 2.725K and then for the earth at a temperature of 290K. Figure 14 provides a plot on which an estimate can be made of the ratio of the flux between CBR to the earth without having to calculate it thoroughly.

Table 7: Comparison of Flux

AM			
$\nu(MHz)$	CBR$\rho_\Phi(\frac{W}{m^2})$	Man$\rho_\Phi(\frac{W}{m^2})$	$\frac{CBR}{Man}$
.615 - .625	0	2.668×10^{-8}	4.979×10^{-18}
.715 - .725	0	8.057×10^{-7}	6.757×10^{-17}
1.125 - 1.135	0	5.960×10^{-6}	2.250×10^{-17}
1.245 - 1.255	0	2.395×10^{-7}	6.850×10^{-16}
1.395 - 1.405	0	8.666×10^{-7}	2.375×10^{-16}
FM			
$\nu(MHz)$	CBR$\rho_\Phi(\frac{J}{m^2})$	Man$\rho_\Phi(\frac{J}{m^2})$	$\frac{CBR}{Man}$
90.0 - 90.2	5.679×10^{-26}	1.282×10^{-6}	1.329×10^{-11}
95.0 - 95.2	6.327×10^{-26}	3.972×10^{-5}	4.778×10^{-13}
99.0 - 99.2	6.869×10^{-26}	2.402×10^{-6}	8.580×10^{-12}
103.6 - 103.8	7.522×10^{-26}	5.556×10^{-7}	4.062×10^{-11}
107.6 - 107.8	8.113×10^{-26}	1.863×10^{-6}	1.306×10^{-11}
Cell: Tower to Phone (848.97 MHz)			
Tower	CBR$\rho_\Phi(\frac{J}{m^2})$	Man$\rho_\Phi(\frac{J}{m^2})$	$\frac{CBR}{Man}$
1	2.254×10^{-16}	6.714×10^{-7}	3.382×10^{-10}
2	2.254×10^{-16}	8.578×10^{-7}	2.647×10^{-10}
3	2.254×10^{-16}	3.843×10^{-7}	5.908×10^{-10}
4	2.254×10^{-16}	5.355×10^{-7}	4.240×10^{-10}
5	2.254×10^{-16}	3.592×10^{-7}	6.321×10^{-10}
6	2.254×10^{-16}	5.107×10^{-7}	4.447×10^{-10}
Cell: Phone to Tower (893.97 MHz)			
Tower	CBR$\rho_\Phi(\frac{J}{m^2})$	Man$\rho_\Phi(\frac{J}{m^2})$	$\frac{CBR}{Man}$
1	2.498×10^{-16}	4.028×10^{-9}	6.250×10^{-8}
2	2.498×10^{-16}	5.147×10^{-9}	4.892×10^{-8}
3	2.498×10^{-16}	2.306×10^{-9}	1.092×10^{-7}
4	2.498×10^{-16}	3.213×10^{-9}	7.836×10^{-8}
5	2.498×10^{-16}	2.155×10^{-9}	1.168×10^{-7}
6	2.498×10^{-16}	3.064×10^{-9}	8.217×10^{-8}
TV Channel/Freq (MHz)	CBR$\rho_\Phi(\frac{J}{m^2})$	Man$\rho_\Phi(\frac{J}{m^2})$	$\frac{CBR}{Man}$
6/82-88	4.551×10^{-16}	2.932×10^{-6}	1.553×10^{-10}
12/204-210	2.695×10^{-15}	8.395×10^{-6}	3.216×10^{-10}
32/578-584	2.116×10^{-14}	5.898×10^{-5}	3.606×10^{-10}
50/686-692	2.973×10^{-14}	5.624×10^{-5}	5.318×10^{-10}
58/734-740	3.400×10^{-14}	1.325×10^{-4}	2.584×10^{-10}

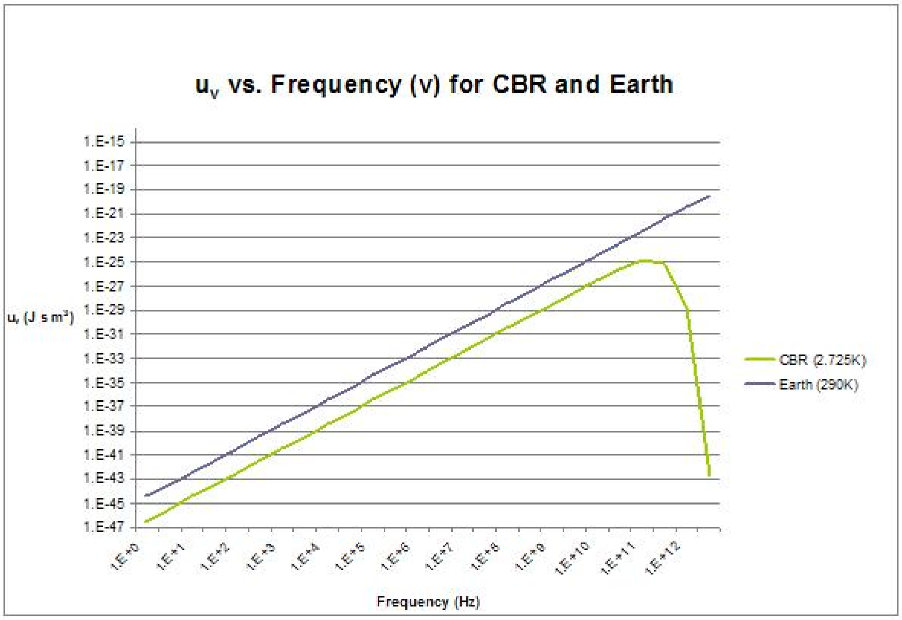

Figure 14: A comparison plot of the energy density per unit frequency between the CBR and earth. The earth is a 100 times greater in value which corresponds to why the CBR is 1% of the total background thermal noise in an off-band television channel

Table 8: Comparison of CBR and Earth Flux

Source	Temperature (K)	$\rho_{u_\nu} \frac{W}{m^3}$
CBR	2.725	1.167×10^{-20}
Earth	300	1.242×10^{-18}
Ratio (CBR/Earth)	.939%	

12 Conclusion

Because of equation 22 I am able to determine the CBR flux and compare it the man-made flux. The ratio of CBR to man-made flux is never greater than by a factor of 10^{-7}. It can be assumed then that the CBR has virtually no interference with communication signals around Carthage College. The narrow bands that communication devices use allows the power of the signals to be focused in order to overcome any sources of interference. This means that stations don't need to consume a great amount of energy to generate a signal that can be "heard" above the CBR and helps keep cost less. This is a good thing for those who rely on wireless forms of communication.

The answer to Tyson's 1% estimate is the earth as it has a greater degree of interference and as described in table 8, the earth's energy density is about 100 times bigger than the CBR's within the same frequency band. This also makes sense because I am bascially taking the ratios of equation 1 for the CBR and the earth and if I integrate over the same frequencies the ratio of energy densities is simply a ratio of the the termperatures: $\frac{2.725}{290} = 0.0094$, take note of the ratio of the CBR flux to earth's flux in table 8. This is in agreement with Neil deGrasse Tyson's estimation that the CBR accounts for about 1% of the static in between channels on a rabbit-earred television.

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