Intensity spectrum of interstellar particles as a potential explantion of the Cosmic Microwave Background Radiation

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1 Introduction

The Cosmic Microwave Background Radiation (CMBR) is a type of radiation that is observed from all directions in the universe. The generally accepted 'Standard Model of Cosmology' attributes this phenomena to the Big Bang - at the point when electrons and protons were able to form hydrogen and make the universe transparent to radiation.

However, there are alternate models that could account for the CMBR. We consider here one of these possible models. In this model we imagine that the CMBR is caused by interstellar particles emitting at a particular wavelength.

2 Problem

We calculate the shape of the intensity/wavelength curve for particles in interstellar space emitting at a particular wavelength. This wavelength could be set at about 2 mm, since this the point at which the CMBR has peak spectral density.

We will assume here that these interstellar particles have a velocity distribution similar to gas particles. We can adjust the root-mean-square velocity of this distribution so that it matches the experimentally obtained CMBR

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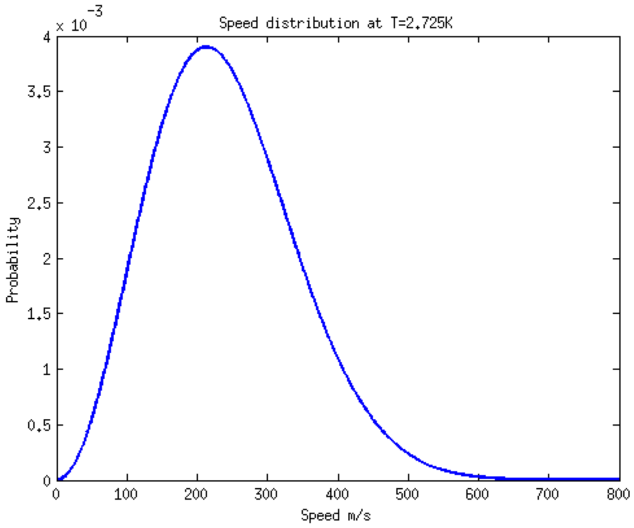

Figure 1: The distribution of single component of the velocity vector at a temperature of $T = 2.725\text{K}$. This is the observed mean temperature of the CMBR.

curves. Due to this motion, the radiation emitted by the particles will be Doppler shifted. This will distort the spectral curve received by an observer. We calculate this received spectral curve.

3 Solution

3.1 Velocity distribution of particles

Maxwell's law gives the speed distribution of of ideal gas molecules.

$$\rho(v) = 4\pi \left(\frac{m}{2\pi k_B T}\right)^{3/2} v^2 e^{-mv^2/2k_B T}. \tag{1}$$

Here v is the speed of a molecule, m is the mass of one molecule of the gas, k_B is the Boltzmann's constant and T is the temperature of the gas.

The crucial assumption here is that this distribution works for ideals gases only (low intermolecular interactions, large intermolecular distances). However, this is a fairly valid assumption for our scenario if the particle cloud is not gravitationally collapsing.

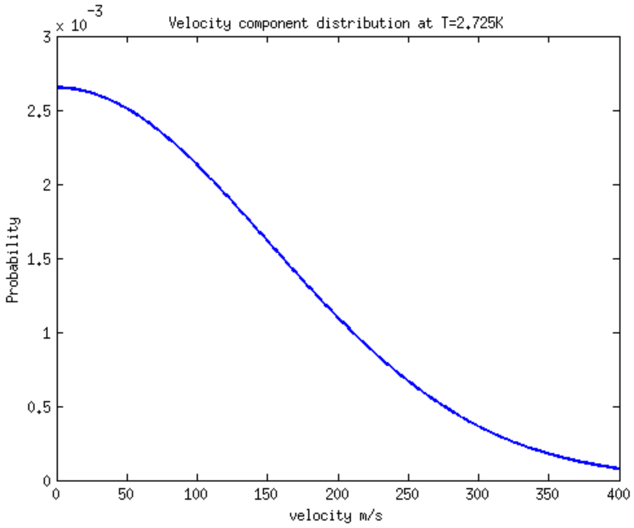

Figure 2: The distribution of single component of the velocity vector at a temperature of $T = 2.725\text{K}$. This is the observed mean temperature of the CMBR.

The root-mean-square velocity is given by

$$v_{rms} = \sqrt{\frac{3k_BT}{m}}. \tag{2}$$

Remember that this is the speed distribution, and corresponding to each possible speed there are an infinite number of velocity vectors that satisfy $v^2 = v_x^2 + v_y^2 + v_z^2$. Notice that this speed distribution is not symmetric around the mean position, since the distribution can't stretch past zero as it can towards positive infinity.

More usefully, we can obtain the distributuion of just one component of velocity, v_i

$$\rho(v_i) = \sqrt{\frac{m}{2\pi k_BT}}e^{-mv_i^2/2k_BT}. \tag{3}$$

These distributions are however symmetrical and normal, since a component of velocity can range from positive infinity to negative infinity.

3.2 The Doppler effect

We consider the doppler effect which is responsible for the red/blue shift of radiation, in the limit where the velocity of both the observer and source is small compared to the speed of light. This is a valid assumption since both the earth and interstellar particles move at speeds several orders of magnitude slower than light.

We have $v_r = v_o - v_s$, as the relative velocity of the source and observer. It is positive when the source and receiver are moving towards each other.

$$\frac{f_o}{f_s} = 1 + \frac{v_r}{c}, \tag{4}$$

where c is the velocity of light.

3.3 Doppler broadening of the spectrum

The two effects outlined above can be used to obtain the doppler broadening of a particular wavelength. We need

$$\rho(f_o)df_o = \rho(v_r)\frac{dv_r}{df_o}df_o. \tag{5}$$

Now from (4) we can find

$$v_r = c\left(1 - \frac{f_o}{f_s}\right) \tag{6}$$

which leads to

$$\frac{dv_r}{df_o} = \frac{c}{f_s}. \tag{7}$$

This we can plug into (5) to obtain

$$\rho(f_o)df_o = \frac{c}{f_s}\rho\left(c\left(1 - \frac{f_o}{f_s}\right)\right)df_o. \tag{8}$$

Now we can use the Maxwell's probability distribution for a velocity vector component pointing from the observer towards the source as given in (3).

$$\rho(f_o)df_o = \frac{c}{f_s}\sqrt{\frac{m}{2\pi k_B T}} \exp\left(-\frac{mc^2\left(1-\frac{f_o}{f_s}\right)^2}{2k_B T}\right) df_o, \tag{9}$$

which can be simplified to

$$\rho(f_o)df_o = \frac{c}{f_s}\sqrt{\frac{m}{2\pi k_B T}} \exp\left(-\frac{mc^2(f_o - f_s)^2}{2k_B T f_s^2}\right) df_o. \tag{10}$$

$$\tag{11}$$

This is of course a Normal distribution with mean, $\mu = f_s$, and variance, $\sigma^2 = \frac{k_B T}{mc^2} fs^2$.

3.4 Assumptions and Limitation

Only doppler broadening has been discussed in this report. There are many other ways that spectral lines broadened. These include at the molecular level natural broadening - because of the spread of the wavefunction. At the inter-molecular level important mechanisms are collisional broadening - because of collisions between molecules - and Stark broadening - because of the Start effect at high number density.

A higher scales, turbulence changes the velocity distribution from Maxwell's. At even higher scales, the gas clouds may have macroscopic motion, such as the rotation of the whole cloud.

Another way that spectra in astrophysics are changed is when light passes through intervening gas clouds. Light is often scattered or absorbed by these clouds, leading to systematic changes in the spectra.

3.5 Explaining the CMBR

Unfortunately, this function is unable to explain experimental CMBR data [1], because it is of a incompatible functional form. It is not expected that the inclusion of natural or pressure broadening will help to explain the data. This is mainly because they cause broadening of smaller scale than Doppler effects.

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[1] `http://lambda.gsfc.nasa.gov/product/cobe/firas_monopole_get.cfm`

However, other effects discussed in the last subsection might change the functional form of the observed intensity and hence might be useful avenues of research.

One other useful avenue of research is if the gas clouds emit light at multiple frequencies. Then a superposition of the resulting spectra might approach experimental data. However, this will require knowledge of the various molecules and species present in stellar gas clouds as well as their natural spectra.