Energy loss of light in interstellar and intergalactic space

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1 Introduction

The study of energy loss of electromagnetic waves passing through matter, interstellar or intergalactic, was suggested to me about in 1965 by L. Rosino and G. Righini because Rosino had tried, unsuccessfully, to measure the so-called cosmological *redshift* through the $Lyman_\alpha$ line of hydrogen atom in galactic spectra. It seems to me that this kind of study can be done by two methods.

The one I've been following for about 35 years, considers diffusion (and absorbtion) of electromagnetic waves by free or bound electrons in atoms; study suggested in those years also by L. Pasinetti to interpret spectra of stars like 41 Tauri, by A. Masani to study the spectrum of the Orion Nebula and by other colleagues.

I calculated cross-sections of diffusion by quantum mechanics and by quantum theory of electromagnetic field.

Cross-section of diffusion of an electromagnetic wave by an electron or another particle is the ratio between the scattered (diffused) wave intensity and the incident wave intensity, when there is one electron per unit volume, electrons being on a planar surface of thickness one.

Absorption cross-section of an electromagnetic wave by an electron or another particle is the ratio between (incident wave intensity - transmitted wave intensity) and incident wave intensity, minus the backward diffusion total cross-section, when there is one electron per unit volum, electrons being on a planar surface of thickness one.

Absorption cross-sections of a lot of elements are tabulated by Wiese [1].

Dr. Roberto Monti (Tesre, Bologna), about 20 years ago, explained to me a second method, much more simpler mathematically, but it requires some *ad hoc* hypotheses. It simply consists in introducing in the equations of electromagnetic waves propagating in interstellar or intergalactic matter, an appropriate index of refraction n, different from one, an appropriate current $\overrightarrow{J}$ and an appropriate charge density Q. The value of these quantities is determined *a posteriori* by Monti imposing that the solution of electromagnetic wave equation

$$\left[-(\overrightarrow{\nabla})^2 + \left(\frac{n}{c}\right)^2 \frac{d^2}{dt^2}\right] A^\alpha \cong J^\alpha, \tag{1}$$

gives the cosmological *red shift* and the observed attenuations in intensity; with $J^\alpha \equiv (\overrightarrow{J}, Q)$, A^α 4-potential of electromagnetic wave, $\alpha \equiv (1, 2, 3, 4)$, c constant of the speed of light in vacuum; (x, y, z) Cartesian coordinates, t time and

$$\vec{\nabla} \equiv \Big(\frac{d}{dx}, \frac{d}{dy}, \frac{d}{dz}\Big).$$

Cosmological *redshift* is the shift toward longer wavelenghts of the wavelenghts of spectral lines observed in the spectra of distant galaxies; shift that on average is longer than the light intensity of galaxy is less.

Attenuation is the diminish in intensity of the brightness of galaxies from increased distance, distance determined by some astronomical method (varying stars, etc.).

2 The equation of radiative transfer

Coming back to the method I followed, once obtained cross-sections for diffusion and absorption of electromagnetic radiation by atoms, moleculesle and corpuscles of the interstellar medium, they are included in the equation of radiative transfer, equation that should be solved with the help of the computer as nobody has managed to solve it with algebraic or special functions except in simple cases; in fact, you are to solve a partial integro-differential equation containing finite differences.

We introduce now a polar coordinate system $x^j \equiv (r, \theta, \phi)$, $j \equiv (1, 2, 3)$, and a Cartesian coordinate system superimposed on it $x^j \equiv (x, y, z)$; for convenience of writing $\mu = \cos\theta$ and $z = r\mu$ is the distance along the polar axis, which is directed towards the observer on Earth.

In fig. 1 the fundamental plane of these coordinates coincides with the surface of the star or galaxy (assumed for simplicity flat) where the spectrum, which is then absorbed and diffused, arises.

In this study I've used equation of transfer of Chandrasekhar [2], for plane waves, substituting the cross section of the isotropic diffusion with the most likely Thomson cross-section and adding only absorption [3]; it is

$$\Big(\frac{\sqrt{3}}{2}\mu\frac{d}{d\tau} + 1\Big)I(\tau, \mu, \lambda) = -\frac{\sigma_a D_a}{\sigma_T D} \cdot I(\tau, \mu, \lambda) + \frac{3}{16\pi} \cdot \\ \cdot \int_0^{2\pi} d\phi' \int_{-\pi}^{\pi} d\mu' (1 + \cos^2\Theta) \cdot \\ \cdot I[\tau, \mu', \lambda - \gamma(1 - \cos\Theta)], \qquad (2)$$

with

$$\cos\Theta = \mu\mu' + \sqrt{1-\mu^2}\sqrt{1-\mu'^2} \cdot \cos(\phi - \phi'),$$

$$\tau = \frac{\sqrt{3}}{2}\sigma_T \int_0^z D dz \qquad (2a)$$

(different from that of Chandrasekhar) D number of diffusion centres per unit volume, D_a number of absorbing centres per unit volume, $I(\tau, \mu, \lambda)$ electromagnetic wave intensity, λ electromagnetic wavelength, $\gamma = 2,4 \times 10^{-12}$ m Compton wavelength of the electron, σ_a is the total absorbtion cross-section, σ_T the total Thomson diffusion cross-section $= 6,7 \times 10^{-29} m^2$ in the case of the free

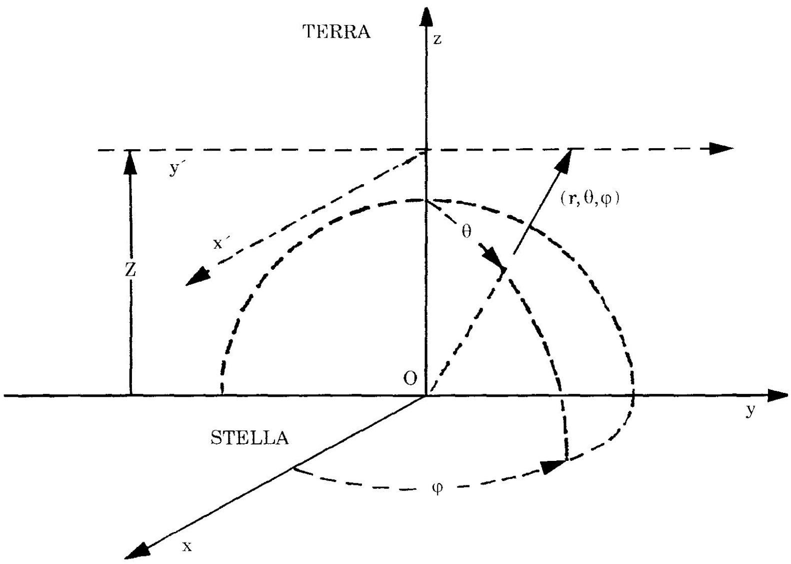

Fig. 1 - Interstellar medium between planes (x, y) *and* $(x^{'}, y^{'})$. *(Figure of D. Garegnani)*

electron at rest, for the wavelengths of the visible spectrum (under conditions of linear diffusion, according to prof. Mario Verde of the University of Turin, about 1974).

Be

$$\tau_S = \frac{\sqrt{3}}{2}\sigma_T \int_0^R D dz \cong \frac{\sqrt{3}}{2}\sigma_T D R, \tag{2b}$$

with $Z = R$ the distance traversed by the light on the way from the source to the Earth, boundary conditions are

$$\begin{cases} I(0, \mu, \lambda) = \Psi(\lambda) \text{ per } \mu > 0 \ (z = 0), \\ I(\tau_S, \mu, \lambda) = 0 \text{ per } \mu < 0 \ (z = R), \end{cases} \tag{3}$$

where $\Psi(\lambda)$ is an arbitrary function dictated by physical conditions.

A solution of this equation, valid for plane waves that propagate along the direction of z, in a Cartesian coordinate system, can be expressed by the integral of algebraic and special functions given in the form below, in the approximation of pure absorption and Thomson absorbtion, namely

$$\sigma = \frac{3}{16\pi}\sigma_T(1 + \cos^2\Theta)$$

and

$$d\lambda = \gamma(1 - \cos\Theta)$$

as specified in equation (2), in presence of Compton effect with electrons at rest [4, 5] (errata corrige [6]). Assuming for simplicity of calculation $\sigma_a = 0$, $\sigma_T = cost.$ and that in the conditions (3) at the source the profile of spectral lines is a Gaussian of amplitude W_0, i.e. [7]

$$\Psi(\lambda) = I_0 exp\Big[\frac{-(\lambda-\lambda_0)^2}{W_0^2}\Big] =$$
$$\frac{1}{2\pi}\int_{-\infty}^{\infty} I_0\sqrt{\pi}W_0 exp\Big[\frac{-\alpha^2 W_0^2}{4}\Big]\cdot$$
$$\cdot\, exp[i\alpha(\lambda-\lambda_0)]d\alpha, \tag{3a}$$

in the approximation of a single intensity that propagates forward and only one that turns back, the solution, for the intensity that propagates forward, is given by

$$I\Big(\tau,\frac{1}{\sqrt{3}},\lambda\Big) = Re\Big\{\frac{1}{\pi}\int_0^{\infty} F_+(\tau,\alpha)exp[i\alpha(\lambda-\lambda_0)]d\alpha\Big\}, \tag{4}$$

with i imaginary unit and

$$F_+(\tau_s,\alpha) = \frac{-\omega 2\sqrt{\pi} I_0 W_0 exp\Big[\frac{-\alpha^2 W_0^2}{4}\Big]}{[P_1 exp(\omega\tau_s^*) - P_2 exp(-\omega\tau_s^*)]}, \tag{5}$$

$$\omega = (C^{*2} - C^2 - 2KC^* + K^2)^{1/2},$$

I_0 spectral line intensity at the source, defined in the equation (3a), W_0 spectral line width ($\cong 0,6$ FWHM), at the source,

$$K = 2exp[i\alpha\gamma],$$

$$\tau_s^* = \tau_s exp[-i\alpha\gamma] = \tau_s 2/K,$$
$$P_1 = C^* - K - \omega,$$
$$P_2 = C^* - K + \omega,$$

C^* is the complex conjugate of C

$$C^* = exp[i\alpha\gamma/3][J_0(2\alpha\gamma/3) - J_2(2\alpha\gamma/3)/6] + iJ_1(2\alpha\gamma/3),$$

where $J_n(x) = (-1)^n J_n(-x)$ is the Bessel function of the first kind, order n, of the variable x [8]. I remember that to get the formulas (4) and (5) has made use of Gaussian quadrature formulas in the case $n = 2$ [2]

$$\int_{-1}^{1} f(\mu)d\mu \sim \sum_{i=1}^{n} f(\mu_i)a_i \sim f(\mu_{-1})a_{-1} + f(\mu_1)a_1, \tag{5a}$$

with $\mu_{\pm1} = \pm 1/\sqrt{3}$, $a_{\pm1} = 1$ and of the special integral [9]

$$\int_0^{2\pi} exp[itcosx]cos(nx)dx = 2\pi exp\Big[\frac{in\pi}{2}\Big]J_n(t), \quad n = 0,1,2...$$

The expression (4) of the diffuse intensity can be assessed by the program INOXC.f in Fortran77, obtainable from the author upon request.

From these formulas can be deduced with the program said that the central intensity of the broad lines and then the intensity of the continuous spectrum

τ \ W_o	500	1000	2000	6000	10000	20000	50000	100000
0	0	0	0	0	0	0	0	0
1	$37,6$	$38,4$	$38,6$	$38,7$	$38,7$	$38,7$	$38,7$	$38,7$
2	108	$113,3$	$115,1$	$115,6$	$115,6$	$115,6$	$115,6$	$115,6$
3	200	$216,6$	$223,5$	$225,8$	$225,8$	$225,8$	$225,8$	$225,8$
6	$553,5$	642	707	745	750	$751,2$	$752,5$	$752,5$
9	1008	$1172,5$	1349	1520	1549	1562	1567	1567
12	1590	1795	2089	2495	2591	2649	2668	2670
15	2327	2531	2916	3610	3834	3991	4049	4058
18	3230	3408	3835	4830	5228	5559	5707	5732

Tabella I

of value $I(0, 1/\sqrt{3}, \lambda_0) = I_c$ at the origin, varies in good approximation by the following formula [3, 7, 10]:

$$I\left(\tau_s, 1/\sqrt{3}, \lambda_0^{'}\right) \sim \frac{I\left(0, \frac{1}{\sqrt{3}}, \lambda_0\right)}{1+\tau_s} = \frac{I\left(0, \frac{1}{\sqrt{3}}, \lambda_0\right)}{1+\frac{R}{R_0}}, \tag{6}$$

$$\lambda_0^{'} > \lambda_0 + \gamma\tau_s 2/\sqrt{3}; \tag{6a}$$

with τ_s optical thickness of the diffusing medium defined in the formula (2b), $R_0 = \frac{2}{\sqrt{3}\sigma_T D}$, D number of diffusion centers per unit volume, as defined above, with λ_0' wavelenght of a line observed in a distant galaxy (after diffusion) and λ_0 is the corresponding wavelength of a line observed in a laboratory spectrum.

This formula (6), can be obtained for the intensity of the continuous spectrum, without numerical calculations, using distributions [8], putting $I_c\delta(\alpha)$ equal to the Fourier transform of $\Psi(\lambda)$ defined in eq. (3), $\delta(\alpha)$ is the Dirac delta function; this is also reported in article [7], where however in eq. (12) there is erroneously $\vec{\Phi_0}(\vec{x}, t)$ instead of $\vec{\Phi_0}(\vec{x}, \omega)$ and then $\vec{\Phi_0}(\vec{x}, \omega) \sim cost.$ instead of $\vec{\Phi_0}(\vec{x}, \omega) \sim \delta(\omega)$, as has been pointed out by P. Mantegazza of the Observatory Brera in Merate.

For thinner lines, on the other hand, numerical results indicate a decrease in intensity much more accentuated with increasing optical thickness τ_s, as follows from the numerical results reported in table II, taken from [7]; these were obtained with the program INOXC.f, which uses double precision.

Incidentally it is worth noting that the verification of the numerical stability of the results was done partially, only for those lower unit optical thickness τ_s that can interpret the *redshift* of the lines observed in the sun [4, 11].

In Table I there are the wavelength shifts of spectral lines $\lambda_0' - \lambda_0$ in m$\mathring{A} = 10^{-13}$m as a function of the amplitudes W_0 given in the first raw, always in m$\mathring{A}$ and of the optical thickness τ (dimensionless) in the first column.

In Table II are the central intensities of spectral lines, assuming $1 = I_0$ the intensity of the lines before diffusion, as a function of the amplitudes W_0 given in the first row, in units of m$\mathring{A} = 10^{-13}$m and in function of the optical thickness τ (dimensionless) given in the first column; the fourth decimal place is not significant.

τ \ W_o	500	1000	2000	6000	10000	20000	50000	100000
0	1	1	1	1	1	1	1	1
1	0,495	0,499	0,4995	0,4995	0,5	0,5	0,5	0,5
2	0,319	0,329	0,333	0,333	0,333	0,333	0,333	0,333
3	0,2245	0,242	0,248	0,25	0,25	0,25	0,25	0,25
6	0,0926	0,1195	0,134	0,142	0,1425	0,1425	0,1428	0,1428
9	0,043	0,0655	0,0841	0,0972	0,099	0,0995	0,1	0,1
12	0,0221	0,0378	0,0548	0,0718	0,0748	0,0763	0,0768	0,0769
15	0,0125	0,0299	0,0366	0,0547	0,0589	0,0615	0,0623	0,0624
18	0,0076	0,0145	0,0251	0,0424	0,0475	0,051	0,0523	0,0525

Tabella II

They have been obtained only for not very large values of optical thickness; they also are not satisfactory because, having assumed a constant σ_T to integrate the equations of transport, give a cosmological $redshift$ constant, independent of the wavelength of the lines observed, in contrast to the measures that give a $redshift$ proportional to the wavelength.

A discussion of the dependence of the cross section of diffusion σ_T on the wavelength will be subject to further communication. Including now the effect of absorption, the intensity of the lines and of the continuous spectrum, in the case of plane waves, can be obtained with the formulas of the publication [3]; the calculations are quite complex, however here we assume in first approximation $\sigma_a = cost.$, independent of λ and we obtain the following formula, always in the two-flux approximation:

$$I\left(\tau_s, \frac{1}{\sqrt{3}}, \lambda^{'}\right) = I\left(0, \frac{1}{\sqrt{3}}, \lambda_0\right) \cdot \cdot exp[-\sigma_a D_a R] \cdot \cdot Re\left\{\frac{1}{\pi}\int_0^\infty F_+(\tau,\alpha) exp[i\alpha(\lambda-\lambda_0)]d\alpha\right\}, \tag{7}$$

$$I\left(\tau_s, \frac{1}{\sqrt{3}}, \lambda_0^{'}\right) = \frac{I\left(0, \frac{1}{\sqrt{3}}, \lambda_0\right) exp[-\sigma_a D_a R]}{1+\tau_s}, \quad \lambda_0^{'} > \lambda_0 + \gamma\tau_s 2/\sqrt{3}; \tag{6b}$$

D_a is number of absorption centers per unit volume and $\lambda_0{}'$ is the value of $\lambda^{'}$ why we have the maximum intensity of the spectral line after being diffused for the interaction with the interstellar matter.

In fact the results of Table I show that $\lambda_0^{'} - \lambda_0$ increases with progressive law non-linear with the increase of τ_s.

3 Olbers' paradox and the background radiation

In order to solve the Olbers' paradox and study the background radiation, we must make use of the transport equation in polar coordinates, in a medium with spherical symmetry. I have studied this problem in the article [12] with a program of which perhaps there is a copy at the Department of Astronomy, University of Oxford while the copy of Brera was unfortunately destroyed. This program is much more complex than the program INOXC.f but doesn't differ significantly from it in the results, apart from the $1/R^2$ factor, in the case of only two fluxes of radiation, for large values of R. In fact, the transport equation in polar coordinates, in the above cases, is [2]:

$$\left(\frac{\sqrt{3}}{2}\mu\frac{\delta}{\delta\tau''}+\frac{1-\mu^2}{D\sigma_T r}\frac{\delta}{\delta\mu}+1\right)\cdot$$
$$\cdot I^{''}(\tau^{''},\mu,\lambda)=-\frac{\sigma_a D_a}{\sigma_T D}I^{''}(\tau^{''},\mu,\lambda)+$$
$$+\frac{3}{16\pi}\int_0^{2\pi}d\phi^{'}\int_{-\pi}^{\pi}d\mu^{'}(1+cos^2\Theta)\cdot$$
$$\cdot I^{''}[\tau^{''},\mu^{'},\lambda-\gamma(1-cos\Theta)] \tag{8}$$

with

$$\tau^{''}=\frac{\sqrt{3}}{2}\sigma_T\int_0^r Ddr.$$

From eq.(1) we know that for spherically symmetric waves there are solutions of the type: $A(r,\theta,\phi,t)=f(r,\theta,\phi,t)/r$, where $f(r,\theta,\phi,t)$ describes a spherical wave, etc..; therefore, since the intensity I is obtained from A with Poynting's formula, we put in eq. (8)

$$I^{''}(\tau^{''},\mu,\lambda)=I^{'}(\tau^{''},\mu,\lambda)/r^2, \tag{9}$$

with $I^{'}(\tau^{''},\mu,\lambda)$ unknown function.

Remembering also that for the formula (7) of article [12], (in the same approximation of the Gauss quadrature formulas) indicating $I(\mu_i)=I_i$, introducing the discrete values of μ defined in eq. (5a), we have

$$\frac{\delta}{\delta\mu}I(\mu_J)\sim\sum_{i=1}^{n}I_i d_{i,j},$$

with $d_{i,j}$ constants in this case, and therefore from eq.(8) written above, multiplied by r^2 we get

$$\left(\frac{\sqrt{3}}{2}\mu_j\frac{\delta}{\delta\tau''}+1\right)I^{'}(\tau^{''},\mu_j,\lambda)+$$
$$+\frac{1}{D\sigma_T}[(1-\mu_j^2)\sum_{i=1}^{n}I^{'}(\tau^{''},\mu_i,\lambda)\cdot$$
$$\cdot d_{i,j}-2\mu_j I'(\tau^{''},\mu_j,\lambda)]/r=$$
$$=-\frac{\sigma_a D_a}{\sigma_T D}I^{'}(\tau^{''},\mu_j,\lambda)+\frac{3}{(16\pi)}\cdot$$
$$\cdot\int_0^{2\pi}d\phi^{'}\int_{-\pi}^{\pi}d\mu^{'}(1+cos^2\Theta)\cdot$$
$$\cdot I^{'}[\tau^{''},\mu^{'},\lambda-\gamma(1-cos\Theta)]. \tag{8a}$$

It is evident that for large r eq. (8a) asymptotically coincides with eq. (2) in $\tau^{''}$ and then we have $I'=I$; it follows that the central intensity of the wide lines and thus the intensity of continuous spectrum, due to a flux of radiation in spherical symmetry, for the formulas (9) and (7), is given in good approximation by the following formula:

$$I^{''}\left(\tau_s,\frac{1}{\sqrt{3}},\lambda_0^{'}\right)\sim$$
$$\sim\frac{I\left(0,\frac{1}{\sqrt{3}},\lambda_0\right)exp[-\sigma_a D_a R]}{R^2(1+\tau_s)}=$$
$$=\frac{I\left(0,\frac{1}{\sqrt{3}},\lambda_0\right)exp[-\sigma_a D_a R]}{R^2\left(1+\frac{R}{R_0}\right)} \tag{9a}$$

$$\lambda_0{'}>\lambda_0+\gamma\tau_s 2/\sqrt{3}; \tag{6b}$$

with τ_s optical thickness of the diffusing medium defined in the formula (2b),

$$R_0=\frac{2}{\sqrt{3}\sigma_T D},$$

as was said previously, with $\lambda_0^{'}$ wavelength of a line observed in a distant galaxy and with λ_0 wavelength of a line observed in a laboratory spectrum.

Although the result of this formula is approximated, it allows us to deduce that the visible spectrum, as well as to diminish with distance, also tends to disappear because it moves to another region of the spectrum. In fact with these formulas it is possible to solve the so-called Olbers' paradox and demonstrate that even if the sky is endless, the brightness of the night sky is finite, as long as there is intergalactic and interstellar matter.

This paradox says that the average brightness of the night sky, of course far away from stars and galaxies, that we indicate I_K, should be infinite if the sky is infinite being given by

$$I_K(\lambda)=\lim_{R\to\infty}(4\pi R I_{Am} N)=\infty, \tag{10}$$

where N is the average number of stars per unit volume, I_{Am} is the average intensity of one of them, which can be obtained from the absolute magnitude and R is the distance from Earth.

The formula (10) can be deduced with the following simple considerations:

– the average intensity that comes per unit area from a source of avarage intensity I_{Am} at a distance R, in absence of intergalactic medium is I_{Am}/R^2;

– the average brightness that comes from all the stars at the distance between R and $R + dR$ is

$$dI_K(\lambda) = N4\pi R^2 dR I_{Am}/R^2; \tag{11}$$

it follows that integrating between zero and infinity we have the Olbers'formula (10).

However, if we introduce the absorption and diffusion by the formula (9a), (where you replace $I(0, 1/\sqrt{3}, \lambda_0)$ with I_{Am}) thus putting in eq. (11)

$$I_{Am} exp[-\sigma_a D_a R]/[R^2(1 + R/R_0)]$$

instead of I_{Am}/R^2, we obtain the following equation:

$$dI_K(\lambda) = \frac{N4\pi dR I_{Am} exp[-\sigma_a D_a R]}{1 + R/R_0}. \tag{11a}$$

From this equation, in the case of pure absorption, neglecting the effects of diffusion and integrating, we see that the intensity is always finite and is

$$I_K(\lambda) \sim N I_{Am} 4\pi/(\sigma_a D_a). \tag{12}$$

If there is no absorption, but only diffusion, again for the formula (11a), neglecting the effects of absorption and integrating, we have an infinite logarithmic, very weak and that is

$$I_K(\lambda^{'}) \sim$$
$$\sim \frac{I_{Am} N}{\sigma_T D} \lim_{R\to\infty} \log \left[1 + \frac{\sqrt{3}}{2}\sigma_T D R\right], \tag{13}$$

e from eq.(6b) follows

$$\lambda_m^{'} > \lambda_m + \gamma \lim_{R\to\infty} \sigma_T D R; \tag{13a}$$

where λ_m is an average value of the wavelength of a certain spectral region, before diffusion in the interstellar matter, and $\lambda_m^{'}$ indicates an average value of the wavelength in the corresponding spectral range observed after the diffusion of light in intergalactic space. Ultimately, there is also in this case a mass extinction of visible light because for the formula (13a) the spectrum moves in the extreme infrared, from a distance on. With this formula (11a) we demonstrate now that according to Eddington's theory [13] the background radiation (also known as 3K) originates within 700 pc from Earth, 1 pc $= 3,085678 \cdot 10^{16}$ m.

Remember that in Eddington's theory we assume that the interstellar matter is in thermodynamic equilibrium with the radiation from the stars and radiates like a blackbody. With this simple hypothesis from the density of the observed light we obtain the temperature of the interstellar medium and the brightness of the background radiation; with the data of that time Eddington had found for the interstellar matter a temperature of 3.18 K, close to the temperature of 2.96 K measured recently by Woody *et al.* [14].

Since from Allen [15] we have $\sigma_a \sim 10^{-13}\mathrm{m}^2$, $D_a \sim 0,5 \times 10^{-6}$ granules m^{-3}, placing these numerical values of the formula (11a), neglecting the effect of diffusion which is not known and is not given by Allen, it follows that the interstellar medium, which radiates the 3K, and is at a distance equal to or greater than 1 kpc from us, gives a contribution to the illumination of our night sky less than $0,21 N 4\pi dR I_{Am}$, ie is marginal and most of the 3K radiation we observe is produced within 700 pc. from the galactic plane, on which the Earth is roughly located.

Recalling that the thickness of the galactic disk around the Earth is about 1 kpc (2 kpc total thickness of the disc) it follows that the 3K is of local galactic origin. However, should be useful regain the values of σ_a and D_a with a theory that distinguishes between absorption and diffusion.

4 Discussion

Mario Carpino:

Where did the infinite background energy go at long wavelengths?

Answer:

In part, it goes to the stars that emitted it at short wavelengths, in part goes to the intergalactic matter that re-emits it as the background radiation (with the same formulas of Eddington [13] and the observative data of Allen [15], we can calculate the temperature of the intergalactic matter assuming that it is in a state of thermodynamic equilibrium with the optical radiation and in a first approximation I remember to have found, several years ago, it is less than 2.7 K) and then maybe it is absorbed for other effects.

It should not be forgotten also that the cross section of Thomson used has an approximate value and therefore the results are a first approximation.

Luigi Guzzo:

Does the cross section of the diffusion σ_T vary with the wavelength?

Answer:

The data on cross sections of diffusion of light are scarce, in the case of the free electron σ according to the current literature is given by Klein-Nishima formula; for the bound electron we must add additional terms due to interaction with other electrons, with the atomic nucleus, with the other atoms in addition to non-linear terms.

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