Energy loss of light in interstellar and intergalactic space

reproduced with kind permission of Società Italiana di Fisica
original publication in Italian on Il Giornale di Fisica, Vol. 44, issue 2, 2003
https://www.sif.it/riviste/sif/gdf/econtents/2003/044/02/article/4

M. Missana

via Libertà 40, Ceriale (SV)

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* by 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 plane surface of thickness one.

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

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

Dr. Roberto Monti (Tesre, Bologna), about 20 years ago, explained to me a second method, mathematically much more simpler, 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

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

Cosmological *red shift* is the shift toward longer wavelenghts of the wavelenghts of spectral lines observed in the spectra of distant galaxies with respect to the corresponding laboratory wavelenght; shift that on average is as greater as smaller is the luminous intensity of the galaxy.

Attenuation is the decreasing in intensity of the luminosity of galaxies when increases their distance, distance determined by some astronomical method (variable 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, molecules and corpuscoles 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 we find ourselves solving an integral equation to partial derivatives containing finite differences.

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

In fig.1 the main plane of these coordinates (x-y plane) coincides with the surface of the star or galaxy (taken flat for simplicity) in which the spectrum, which is then absorbed and diffused, is generated.

In this study I've used the 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

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

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 is the

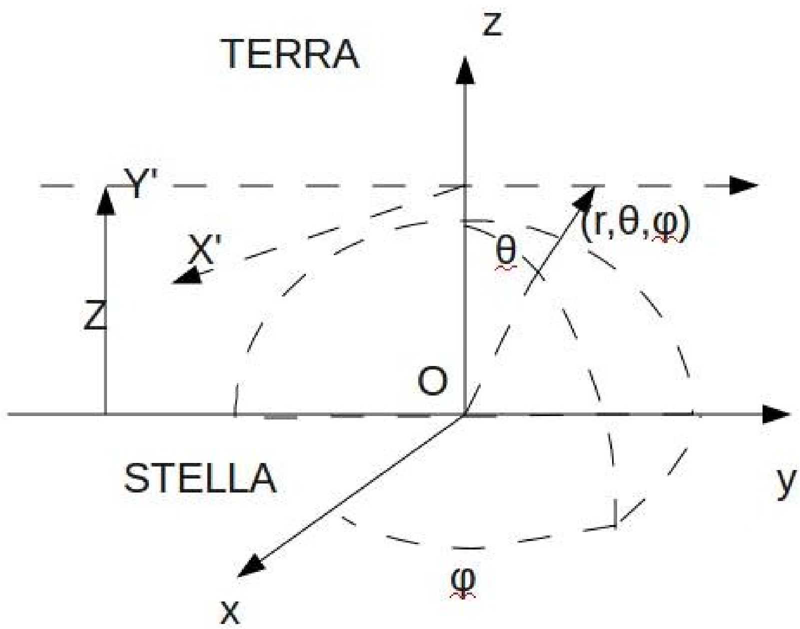

Figure 1 Interstellar medium between the planes (x, y) and $(x^{'}, y^{'})$. (Figure of D. Garegnani)

Compton wavelength of the electron, σ_a is the total absorbtion cross-section, σ_T the total Thomson cross-section for diffusion $= 6,7 \times 10^{-29} m^2$ in the case of free electron at rest, for the wavelengths of the visible spectrum under conditions of linear diffusion; in the non-linear theory the cross-section is proportional to the wavelenght according to Prof. Mario Verde of the Turin University (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 crossed by light on the way from the source to the Earth, the 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 imposed by the physical conditions.

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

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

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

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

with i imaginary unit and

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

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

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, of order n, in the variable x [8]. Remember that to get the formulas (4) and (5) the Gaussian quadrature formulas in the case $n = 2$ were used [2]

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

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

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

W_o / τ	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

Table I

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

From these formulas it can be deduced by that program above, that the central intensity of the broad lines and hence the intensity of the continuous spectrum 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 the Fourier transform of $\Psi(\lambda)$, defined in eq.(3), equal to $I_c\delta(\alpha)$, $\delta(\alpha)$ 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.

It is worth noting that the verification of the numerical stability of results was done partially, only for those optical thickness τ_s lower than unity 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.

W_o / τ	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	0,0229	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

Table II

In Table II there 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.

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 transfer equations, 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 it is assumed as a first approximation $\sigma_a = cost.$, independent of λ and the following formula is obtained, always in the two-flux approximation:

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

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

D_a is the number of absorption centers per unit volume and λ'_0 is the value of λ' for which the maximum intensity of the spectral line is obtained after being diffused for the interaction with the interstellar matter.

Actually the results of Table I show that $\lambda_0' - \lambda_0$ increases with progressive non-linear law 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, the transfer equation in polar coordinates must be used, 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 factor $1/R^2$, in the case of only two fluxes of radiation, for large values of R. In fact, the transfer equation in polar coordinates, in the above cases, is [2]:

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

with

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

From eq.(1) for spherically symmetric waves in absence of diffusion and absorption 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, it was put tentatively 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), it follows

$$\frac{\delta}{\delta\mu}I(\mu_J) \sim \sum_{i=1}^{n} I_i d_{i,j} \tag{6}$$

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

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

It is evident that for large r eq.(8a) asymptotically coincides with eq.(2) in $\tau^{''}$ and therefore $I' = I$; it follows that the central intensity of the wide lines and hence 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 formula (2b),

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

as previously written, 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; in absence of absorption and diffusion ($D_a = 0, R_0 = \infty$) formula (9a) is that of a spherical wave and justifies a posteriori the equation (9).

Although the result of this formula is approximated, it allows to deduce that the visible spectrum, besides decreasing with the increase in distance, also tends to disappear completely because it moves to another region of the spectrum. Therefore 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 is indicated 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.

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

$$dI_K(\lambda) = N 4\pi R^2 dR I_{Am}/R^2; \tag{11}$$

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

However, if absorption and diffusion are introduced by the formula (9a), (where $I(0, 1/\sqrt{3}, \lambda_0)$ is replaced 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, the following equation is obtained:

$$dI_K(\lambda) = \frac{N 4\pi dR I_{Am} exp[-\sigma_a D_a R]}{1 + R/R_0}. \tag{11a}$$

From this equation, in the case of pure absorption, neglecting the effects of diffusion and integrating, 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, always for the formula (11a), neglecting the effects of absorption and integrating, one has a logarithmic infinity, very weak and that is

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

and from eq.(6b) it 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 λ_m' indicates an average value of the wavelength in the corresponding spectral range observed after the diffusion of light in intergalactic space. Concluding, there is also in this case a total extinction of visible light because, for the formula (13a), the spectrum moves in the extreme infrared, from a given distance forward. 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 = $3,08567810^{16}$ m.

Remember that in Eddington's theory it is assumed that the interstellar matter is in thermodynamical equilibrium with the radiation coming from the stars and radiates like a blackbody. With this simple hypothesis, from the density of the observed light, the temperature of the interstellar medium and the brightness of the background radiation are obtained; 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 recently measured by Woody *et al.* [14].

Since from Allen [15] $\sigma_a \sim 10^{-13}\text{m}^2$, $D_a \sim 0,5 \times 10^{-6}$ 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 $0,21 N 4\pi d R I_{Am}$, i.e. is marginal and most of the 3K radiation that is observed is produced within 700 pc from the galactic plane, on which the Earth is roughly located.

Remembering 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, it would be advisable to obtain again the values of σ_a and D_a with a theory that distinguishes between absorption and diffusion.

4 Discussion

Mario Carpino:

Where the infinite background energy ends up at long wavelengths?

Answer:

In part, it goes to the stars that emitted it at short wavelengths, in part it goes to the intergalactic matter that reemits it as the background radiation (with the same formulas of Eddington [13] and the observative data of Allen [15], the temperature of the intergalactic matter can be calculated assuming that it is in a state of thermodynamic equilibrium with the optical radiation and in a first approximation I remember to had found, several years ago, that 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:

Data on cross sections of diffusion of light are scarce, in the case of the free electron σ, according to the current literature, it is given by Klein-Nishima formula; for the bound electron additional terms must be added due to interaction with other electrons, with the atomic nucleus, with the other atoms in addition to non-linear terms which, according to Mario Verde, are proportional to the wavelenght as in the Breemstrahlung effect.

The editing of this transaltion is due to Michela J. Missana and Natalia Missana (natalia.missana@gmail.com) and the INOXC.f program is also available

from Natalia Missana.

References

[1] WIESE W. L., SMITH M. W. e GLENNON B. M., *Atomic Transition Probabilities*, NSRDS-NBS 4-, U.S. Governement Printing Office, (Washington D.C. 20402, 1966).

[2] CHANDRASEKHAR S., *Radiative transfer*, (Dover pub. inc., New York, 1960) pp. 329, 61, 364.

[3] MISSANA M., *Solution of the radiative transfer equations in the presence of generalized Compton effect*, Osservatorio Astronomico di Brera, printed on its own, 1987 pp. 1, 22.

[4] MISSANA M. and PIANA A., *Astrophys. Space Sci.*, **37** (1975) 263.

[5] MISSANA M. and PIANA A., *Astrophys. Space Sci.*, **43** (1976) 129.

[6] MISSANA M. and PIANA A., *Astrophys. Space Sci.*, **50** (1977) 518.

[7] MISSANA M., *Astrophys. Space Sci.*, **50** (1977) 409.

[8] TRICOMI F. G., *Istituzioni di Analisi Superiore* (Gheroni, Torino, 1961) pp. 426, 138.

[9] GRADSHTEYN I. S. and RYSZHIK I. M., *Table of Integrals, Series and Products* (Academic Press, London, 1965) pp. 406, 482.

[10] MISSANA M., *Distance of far galaxies and scattering of the photons in the space, in Structure and Evolution of Active Galactic Nuclei* by Giuricin *et al.* (D. Reidel Publishing Co., Dordrecht, 1986) p. 645.

[11] MISSANA M., *Astrophys. Space Sci.* **85** (1982) 137.

[12] MISSANA M., *Astrophys. Space Sci.* **33** (1975) 245.

[13] EDDINGTON A. S., *The Internal Constitution of the Stars* (Cambridge University Press, 1926) p. 371.

[14] WOODY D. P. and RICHARDS P. L., *Phys. Rev.* **42** (1979) 925.

[15] ALLEN C. W., *Astrophysical Quantities*, (Athlone Press, London, 1973) pp. 265, 289.

[16] VERDE MARIO, *Private comunication, Universitá di Torino*, about 1974.