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The Redshift of Extragalactic Nebulae

by F. Zwicky.

(16.II.33.)

Contents. This paper gives a representation of the main characteristics of extragalactic nebulae and of the methods which served their exploration. In particular, the so called redshift of extragalactic nebulae is discussed in detail. Different theories which have been worked out in order to explain this important phenomenon will be discussed briefly. Finally it will be indicated to what degree the redshift promises to be important for the study of penetrating radiation.

§1. Introduction.

It has been known for a long time that there exist in space certain objects which, when observed with small telescopes, appear to be quite fuzzy, self shining spots. These objects have different structures. Often they are spherical, often elliptical, and many of them have a spiral-like appearance, and are therefore occasionally called spiral nebulae. Thanks to the enormous resolving power of modern giant telescopes astronomers were able to establish that these nebulae lie beyond the limits of our own Milky Way. Photographs made with the Hundred-Inch-Telescope on Mount Wilson reveal that these nebulae are stellar systems, similar to our own Milky Way System. The extragalactic nebulae are on the whole homogeneously distributed over the sky and are, as could be shown, also homogeneous in space. They are seen as individuals or grouped in clusters. The following lines aim to give a short account of the most important characteristics and a description of the methods which made it possible to establish them.

§2. Distances and general characteristics of extragalactic nebulae

As mentioned, it is possible to resolve, with the help of modern telescopes, quite a number of nebulae totally or partially into single stars. In the large nebula in Andromeda e.g. a great number of individual stars have been observed. In this nebula there have recently been found spherical star clusters, similar to those which lie in the area of our own Milky Way system. The fortunate circumstance of the observability of single stars in nebulae opens two possibilities for determining their distances.

A) *Determination of distance with the help of the relation between the period and the luminosity of the Cepheids.*

Cepheids are stars with periodically changing luminosity. The periods vary usually between one and up to sixty days. The absolute luminosity is a unique function of the period, a function which has been determined for stars of our own system. Therefore the absolute luminosity can be deduced from the known period. If, in addition, one determines the apparent luminosity and compares that with the calculated absolute luminosity, one obtains directly the distance of the stars. In the Andromeda nebula quite a number of Cepheids have been observed, and with their help its distance and diameter has been fixed to about 900,000 resp. 42,000 lightyears. Remember, for comparison, that our own system has a diameter whose upper limit is estimated to be about 100,000 light-years. In a similar way the distances of eight other nebulae have been found. In nebulae with a distance of more than a few million light-years individual Cepheids cannot be resolved any more. To determine their distance therefore other methods have to be thought of.

B) *Statistic of stars with greatest luminosity in a nebula.*

This method relies on the assumption that in extragalactic star systems the relative abundance of absolute luminosities of stars is the same as in our own system. Results from those neighbouring systems which have been studied up to now are in fact in agreement with this assumption. The absolute luminosity of the brightest stars in our own and in neighbouring systems turns out to be on average −6.1 with a dispersion of less than half a magnitude. We only hint here at similar distance measurements with the help of novae.

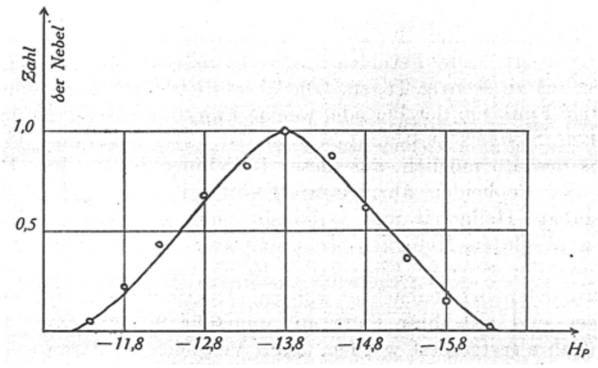

Figure 1: H_P – photographical luminosity.

C) *Determining the distance of nebulae with the help of their total apparent luminosity.*

With the help of the first two methods, up to now the distances of about sixty extragalactic nebulae have been determined. From the measured apparent luminosity and the known distance we can immediately deduce their absolute luminosity. This way we get the following distribution (Fig.1).

The mean absolute visual luminosity of the nebulae turns out to be −14.9, with a dispersion of about five magnitude classes and a half-width of the distribution curve of about two magnitude classes. Unfortunately this dispersion is too big to allow for an accurate determination of the distance for an *individual* nebula on the basis of its apparent luminosity and the distribution curve of the absolute luminosities. We will discuss later how the distances of individual nebulae can be determined with great accuracy. The following fact however allows us to determine the distance of a large number of extremely weak nebulae. As already mentioned, nebulae often group in dense clusters with a hundred to a thousand individuals. It is of course extremely probable that such apparent clustering corresponds to an actual clustering in space, and that therefore all those nebulae lie at about the same distance. It is relatively easy to determine the distribution curve of apparent luminosities of the nebulae in a cluster. This curve is in practice the same as the distribution curve of absolute luminosity of those sixty nebulae, the distances

Table I.

Nebular cluster	Distance in millions light years
Coma-Virgo	6
Pegasus	23.6
Pisces	22.8
Cancer	29.3
Perseus.	36
Coma	45
Ursa Major I	72
Leo	104
Gemini	135

of which have been found under A) and B). That proves that the apparent clustering of nebulae corresponds to a real clustering in space. A comparison of average apparent luminosities of nebulae in the cluster and the average absolute value – 14,9 gives directly the distance of the cluster. This way the distances of the following nebular clusters have been determined.

The number of nebulae per unit volume in one of these dense clusters is at least hundred times larger than the corresponding average number of nebulae distributed over space.

It is of interest to insert here some short remarks concerning other characteristics of nebulae, which are, with the help of the Hundred-Inch-Telescope, accessible to research.

With regard to the structure of the Universe it is of foremost importance whether the distribution of nebulae over space is homogeneous or not. In the case of homogeneity we expect for the number of nebulae in a spherical shell of radius r and constant thickness dr a number of nebulae proportional to r^2, if we assume space to be Euclidian. This expectation corresponds pretty well to reality, i.e. for that part of the Universe that is within the view of the Hundred-Inch-Telescope. That does not mean, of course, that space could not eventually turn out to be non-Euclidian, if at some future time it will be possible to reach further depths.

We must not fail to mention that the preceding conclusions are valid only if absorption and scattering of light in space can be neglected. It is, however, in itself almost a proof for the validity of the assumption that a homogeneous distribution of nebulae up to the largest reachable distances is obtained with a method that actually presupposes absence of absorption and scattering. As a matter of fact absorption would distort any actually homogeneous distribution of nebulae in such a way that the number of nebulae in spherical shells of constant thickness would increase with distance slower than r^2 and eventually even decrease. In view of the fact that in the interstellar space of our system gas and dust can definitely be shown to exist, it would however be of foremost importance to give an independent proof for the transparency of intergalactic space and to show that it is not the curvature of space, combined with absorption and dispersion that gives the illusion of a homogeneous distribution of nebulae. A statistical examination of apparent diameters of nebulae e.g. would be appropriate for this purpose.

Theoretically, the existence of intergalactic matter should correspond to the pressure of the systems of stars present. Assuming that space has reached a stationary state, this pressure can be estimated.[1] It proves to be extremely small and would practically exclude finding intergalactic matter.

Another interesting question connects to the spectral types of nebulae. Most extragalactic nebulae have absorption spectra similar to that of the Sun with strongly prominent *H*- and *K*-lines of calcium and a strong *G*-band of Ti (4308 Å), Fe (4308 Å), and Ca (4308 Å). Nebulae therefore belong to spectral type *G*. The spectral type is independent of the distance, as far as observations reach up to now. We will discuss later a displacement of the whole spectrum that is dependent on the distance. The width of the absorption lines is usually several Ångstrom and also independent of the distance.

A small percentage of all observed nebulae also has emission lines (Nebulium), which usually originate in the nucleus of the nebula. Regrettably, we still know very little about the physical conditions in those systems.

Thirdly, of importance is the exploration of occurrence of the different forms of nebulae that have been mentioned. The statistical distribution is about 74% spirals, 23% spherical nebulae, and about 3% show an irregular appearance.

Fourthly, I would like to mention the determination of the brightness within an individual nebula. This examination has recently been made by E. Hubble on Mount Wilson. Hubble obtains the following preliminary result.

[1]F. Zwicky, Proc. of the Nat. Academy of Sci., Vol. 14, p. 592, 1928.

The brightness can be represented by a universal function $L(r, \alpha)$, where r is the distance from the center of the nebula and α a suitable parameter. By variation of α, the brightness distributions in all nebulae can be reduced with great accuracy (about 1%) to the same function, and this up to values of r, for which the brightness has fallen to 1/1000 of that at the centre. With regard to the practical absence of absorption and dispersion in intergalactic space it is also of importance that the distribution function of the α's in the different nebular clusters is independent of the distance. As an aside I mention that L coincides with that function that corresponds to the brightness distribution in an isothermal Emden gas sphere.

Fifthly, it is of great importance that the spectra of very distant nebulae are shifted to the red, with the shift increasing with distance. The discussion of this so-called redshift is the main topic of this paper.

§3. The redshift of extragalactic nebulae. Relation between distance and redshift.

V.M. Slipher from the Flagstaff Observatory in Arizona was the first to observe that some nebulae show displacements of their spectra, which correspond to a Doppler effect of up to 1800 km/sec. Slipher, however, did not establish a relation between redshift and distance. Such a connection was first suspected by G. Strömberg[2], while studying the velocity of the Sun relative to further and further removed objects. He found that the average velocity of the Sun, referred to the system of nebulae close to us is very large, i.e. of the order of magnitude of 500 km/sec, and that the group of nebulae considered has an expansion, which seems to depend on the distance of the individual nebulae.

Since at the time of Strömberg's investigation no reliable determinations of distance were known, K. Lundmark tried to find a connection between the observed large velocities and the "compactness" of the photographic images. This proved later to lead into the right direction. His attempt remained with no positive result, though, since it turned out that the apparent diameters of equally distant nebulae show great variation.

E. Hubble on Mount Wilson worked along the same lines. He also attempted at first to tie the redshift with the apparent concentration of the

[2] G. Strömberg, Astrophys. Journal **61**, 353-388 (1925).

nebula. He started with the idea that the redshift would correspond to the well known Einstein effect. It turned out, though, that rational connections could not be discovered in this way.

E. Hubble then tried to find a connection between the redshift and the distance of the different nebulae. This attempt has, as is well known, been crowned by great success. The nebulae initially available for such examination, were at distances of one up to six million light-years. The discussion of all data showed a linear relation between the redshift and the distance, with the result that the shift corresponds to an apparent recession velocity of 500 km/sec per one million parsec (1 parsec equals ca. 3,28 light-years). The dispersion though was relatively large, inasfar as e.g. the neighbouring Andromeda nebula shows a *shift to the violet* of ca. 200 km/sec, i.e., is moving toward us, either apparently or really. In spite of this, the very first calculation of the shift of the spectra proved to be extraordinarily good. The best proof of the astonishing carefulness of Hubble's way of working is probably that he, on the basis of the above relation, could up to now predict the redshift in every case up to a few percent, even for distances that were greater by up to thirty times than the ones originally considered.

The difficulty in photographing the spectra of very remote nebulae lies in the necessity of extraordinary long times of exposure. In fact it was necessary to expose plates up to fifty hours and more, and it seemed hardly possible to reach much further into space in this way. Recently, however, great advances have been achieved by using a spectrograph with an opening of the camera lens of $F/0.6$. That resulted in sacrificing much on the side of the dispersion, and the obtained spectra are only about two millimeters long. The exposure time, though, could be reduced to a few hours. Still, it does not seem possible to reach deeper than about 200 light-years into space. The reason for that is partly the location of the Hundred Inch Telescope, in the proximity to the city of Los Angeles, for the illumination of the night sky and the corresponding strong scattering of light into the telescope unfortunately put a limit to the astronomical observations on Mt. Wilson that is lower than the actual capability of the telescope. For the 200-inch-telescope, currently in construction for the California Institute of Technology, therefore a more favourable place will have to be chosen.

The redshifts of the different clusters of nebulae, expressed as apparent Doppler recession velocities, are shown in Table II. [3]

[3]See E. Hubble and M.L. Humason, Astrophys. Journal LXXIV, 1931. This paper

Table II.[3]

Nebular cluster	Number of nebulae in the cluster	Apparent diameter	Distance in 10^6 light-years	Average velocity km/s
Virgo	(500)	12°	6	890
Pegasus	100	1°	23.6	3810
Pisces	20	0.5	22.8	4630
Cancer	150	1.5	29.3	4820
Perseus.	500	2.0	36	5230
Coma	800	1.7	45	7500
Ursa Major I	300	0.7	72	11800
Leo	400	0.6	104	19600
Gemini	(300)	—	135	23500

These results are shown graphically in Fig. 2.

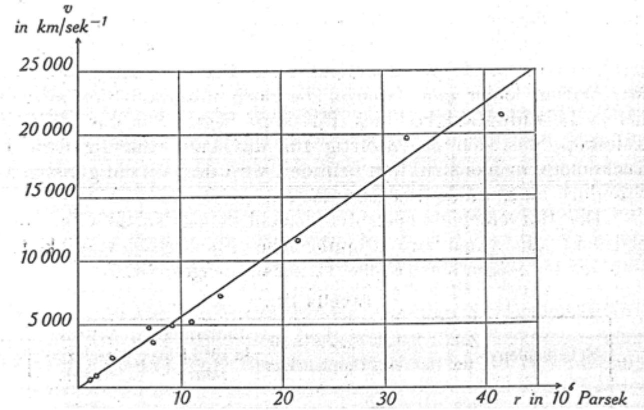

Figure 2:

From this summary it follows that the velocities of extragalactic nebulae are proportional to their distance. The specific velocity per million parsecs is

$$v_s = 558 \text{ km/s}. \tag{1}$$

The redshift of every individual nebula is on the average deduced from the shift of at least three spectral lines. These are usually the H- and K-lines, the G-Band ($\lambda = 4303$ Å) and sometimes one of the lines H_δ (4101 Å), H_ν (4340 Å), Fe (4384 Å) and H_β (4861 Å). The uncertainty in the redshift of the nebular cluster in Leo thus turns out to be, e.g.,

$$v = 19621 \pm 300 \text{ km/s}.$$

The different absorption lines suffer the same relative displacement, exactly as with the Doppler effect. Thus for a given nebula we have

$$\Delta\lambda/\lambda = \text{constant} = K = v/c = \kappa r \tag{2}$$

independently of the wavelength λ, and the displacement can, as we have done, conveniently be expressed as a velocity. The same value of K applies therefore to the displacement of the maximum of the continuous emission spectrum, too.

It ought not to be neglected that in Fig. 1 we showed the average Doppler velocity of the nebular clusters. This velocity is the average of the values of several individual nebulae (from 2 to 9) in the single clusters. It is of utmost importance for the theory of the effects discussed here that the velocities of individual members of a cluster may differ considerably from the mean. In the Coma system, e.g., which has been best discussed up to now, the following individual values have been measured:

Apparent velocities in the Coma cluster

$v =$	8500 km/s	6900 km/s
	7900	6700
	7600	6600
	7000	5100 (?)

It is possible that the last value of 5100 km/s corresponds to a so called field nebula, which does not belong to the Coma system, but is projected into

gives also the essential references to the literature.

it. The probability for this assumption is not very large, however, (1/16). Even when this nebula is omitted, the variations in the Coma system are very large. In this context it is interesting to recall that the average density in the Coma cluster is up to now the largest ever observed.

Since now the relation between distance and redshift is known, we can, conversely, deduce the distances of individual nebulae from their redshifts, if those have been measured spectroscopically. Furthermore we may again test the reliability of our methods for the determination of distance measurements independently. In fact we need only determine the distribution curve of the luminosities of all individual nebulae with equal redshift. This new distribution curve must agree with that in Fig. 1, if our original distance determination was correct. This is indeed approximately the case.

As already mentioned, the redshift means a displacement of the whole emission spectrum of the nebula. In addition to the decrease of the apparent photographic luminosity in geometric dependence on the distance, there is also a decrease due to the redshift. The problem of the spatial distribution of nebulae at large distances is thus not only connected to the curvature and absorption of space, but also tightly connected to the redshift, and this is complicating the situation considerably.

In conclusion we have to mention some of van Maanen's results that seem to contradict Hubble's determination of distance. Van Maanen measured for about twenty years the apparent movements (in angular measure) of nebulae on the sky. Since the corresponding angular velocities of the nearest nebulae are not more than about 0.01 arc sec per year, only nebulae with well defined, starlike "kernels" can be used, since otherwise fixing the coordinates of the nebula becomes very difficult because of the fuzziness of the photographic image. Combining van Maanen's angular velocities with Hubble's distances gives extremely high velocities. For N.G. 4051, which according to Hubble has a distance of 4 million light-years and an apparent radial velocity of 650 km/sec, van Maanen gives an angular velocity of 0.015" per year, which leads to a real velocity of 94,000 km/sec. This poses a big problem. A trivial solution does not seem excluded a priori, in as far as the movement observed by van Maanen may be attributed not to the nebula, but to the background of stars used as a reference frame. It has to be noted, however, that van Maanen found similar discrepancies for 13 nebulae. This also led to the result that all these nebulae seem to move away from the pole of the Milky Way system, and that is hardly to be explained by the assumption of a movement of the reference system.

Of equal importance is van Maanen's determination of the eigenrotation of extragalactic spiral nebulae. In Messier 33, which according to Hubble has a distance of 900,000 light-years, van Maanen observed, superposed on the transversal movement mentioned above, a rotation which must be ascribed to the whole nebula, the components of which for single objects are of the order of magnitude of 0.012" up to 0.024" per year. With this distance there result rotation velocities of the order of magnitude 33,000 km/s, whereas e.g. F.G. Pease measured an eigenrotation of only 800 km/s from the Doppler effect at both ends of his diameter.[4]

Thus, if one does not ascribe the results of van Maanen to observation errors, but takes them as characteristic for the nebulae, and if one holds on to the distance determinations of Hubble, then one is confronted with a serious problem.

§4. Speculations concerning the redshift

A complete theory of the redshift must lead to results satisfying the following requirements:

1. The redshift is analogous to a Doppler effect, i.e. $\Delta\lambda/\lambda$ for a given nebula is a constant.

2. The apparent Doppler velocity is proportional to the distance r and amounts to 558 km per second and million parsecs.

3. There is no appreciable absorption and scattering of light in space which could be connected to redshift.

4. The quality of the optical images of the nebulae is as good as to be expected from the resolving power of the instruments. The distance of the objects obviously plays the role which is to be expected from geometrical considerations.

5. The spectral types of the nebulae are essentially independent of the distance.

6. The large dispersion of individual values of velocities of nebulae in dense clusters must be explained in the context of redshift.

7. The velocity of light on the long way from the nebula to us is in practice the same as the velocity of light known from terrestrial measurements. This

[4]The observations on Messier 33 itself the measurements have not yet come to a close. The rotation velocities are at most about 50 km/s.

was found by STRÖMBERG and also BIESBROEK by measuring the aberration at the nebulae.

8. A theory of redshift which does not simultaneously give an explanation of van Maanen's results is unsatisfying, to say the least.

The facts listed here reflect the observational material up to a distance of about 150 million light-years. For their explanation there exist up to now two general proposals. The first comprises all theories of cosmological character relying on the theory of general relativity. The second prosupposes an interaction between light and matter in space.

A) *Cosmological theories*

During the last years there have been a large number of attempts to explain the redshift on the ground of relativity theory. Some essential ideas are the following.

The theory of General Relativity leads to two points of view concerning the structure of space. One is represented by Einstein's quasi spherical world, whereas DE SITTER deduced the possibility of a hyperbolic space in the case of vanishingly small mass density.

Whereas the geometry of Einstein's space does not directly lead to a redshift, a shift is necessarily connected to the de Sitter world. R.C. TOLMAN though has shown that $\Delta\lambda/\lambda$ depends not only on the distance, but also on the eigenvelocity of the nebula. Consequently one should expect, apart from redshifts, shifts to the violet, which would on the average be smaller but of the same order of magnitude as the redshifts, which contradicts observations. The redshift therefore could not directly be connected to the curvature of space.

Another important proposal was made by FRIEDMANN, TOLMAN, LEMAITRE and EDDINGTON, whose work shows that according to the theory of relativity a static space is dynamically unstable and therefore tends to contract or expand. This result was interpreted by him[5] to imply that the redshift would correspond to a factual expansion of space. This proposal has since been discussed extensively by many researchers. Recently Einstein and de Sitter[6] gave the simplest formulation. These two scientists give up, for

[5]Editor's remark: Zwicky did not say which of the four names he meant by "him", but in reality this proposal was first made by Lemaître.

[6]A. EINSTEIN and W. DE SITTER, Proc. of the Nat. Acad. Sci. Vol. 18, p. 213, 1932

the time being, a curvature of space as a whole. The curvature of space was essentially a result of the introduction of a so-called cosmological constant Λ into Einstein's field equations, and that corresponds to the postulate of a repulsive force which compensates Newton's attraction for very large distances. This postulate was historically required in order to understand the existence of a nonvanishing average mass density which otherwise in the limit of an infinite static space would have led to infinite gravitational potentials. This last difficulty resolves itself automatically if all masses in space move either towards one another or away from one another. The expansion of matter may then, omitting Λ and the average curvature, be connected directly to the average density. According to EINSTEIN and DE SITTER, an expansion of 500 km /s per million parsec corresponds to an average density of $\rho \cong 10^{-28}$ g/cm^3. From observations of luminous matter HUBBLE estimates $\rho \sim 10^{-31}$ g/cm^3. It is possible, of course, that luminous plus dark (cold) matter together would give a much higher density, and therefore the value of $\rho \cong 10^{-28}$ g/cm^3 does not seem unreasonable. The theory gives further, according to EINSTEIN, the following more exact relation for the redshift

$$\Delta\lambda/\lambda = \kappa r[1 + 7\Delta\lambda/4\lambda]. \qquad (3)$$

This means that for large distances the redshift should increase faster than linearly with distance. Alas, it is not possible to check this important conclusion on the grounds of the now known observational material. Recently observed values $\Delta\lambda/\lambda \sim 1/7$ for largest distances, however, are large enough to let us expect considerable deviations (25%) from the linear relation.

The theory also leads to certain conclusions concerning the distribution of luminosities, number of nebulae, diameters etc, in dependence on the distance, which also could not be tested.

None of the cosmological theories has, up to now, considered the problem of the great dispersion of velocities in dense nebular clusters like the Coma system.

B) *Direct effect of matter present in space on the light frequency*

Some years ago already, I attempted to explain the redshift by different physical effects like Compton-effect at electrons, whether at rest or moving in space, Raman effect etc.[7] As it turned out, none of these effects can

[7]F.Zwicky, Proc. of the Nat. Acad. Sci., Vol. 15, p. 773, 1929.

play an essential role. Assuming effects which have their origin in direct spatial interaction between light and matter shows that this cannot explain the transparency of intergalactic space.

I proposed then another possible effect, which can however hardly be observed on earth, for the existence of which, nevertheless, some theoretical reasons can be given. According to the theory of relativity there corresponds to each photon or light quantum of frequency ν a gravitational as well as an inertial mass $h\nu/c^2$. Thus there is an interaction (attraction) between light and matter. If the photon is emitted resp. absorbed at two points P_1 and P_2 which have the *same* gravitational potential, it loses on the way from P_1 to P_2 a certain momentum and gives this to matter. The photon gets redder. This effect, which could be called gravitational friction, is caused mainly by the finite velocity of gravitational interaction. Its amount depends on the average density of matter and on its distribution. The redshift $\Delta\lambda/\lambda$ in this case depends not only on the distance but also on the distribution of matter. Explorations to test this second conclusion are being done now.

Finally it has to be said that none of the proposed theories is satisfying. All of them have been developed on a most hypothetical basis, and none of them has succeeded to uncover any new physical relationships.

§5. Remarks concerning the dispersion of velocities in the Coma nebular cluster.

As the data in §3 show, there are in the Coma cluster differences in velocity of at least 1500 to 2000 km/sec. In the context of this enormous variation of velocities the following considerations can be made:

1. Under the supposition that the Coma system has reached, mechanically, a stationary state, the Virial Theorem implies

$$\bar{\epsilon}_k = -\tfrac{1}{2}\bar{\epsilon}_p, \qquad (4)$$

where $\bar{\epsilon}_k$ and $\bar{\epsilon}_p$ denote average kinetic and potential energies, e.g. of the unit of mass in the system. For the purpose of estimation we assume that the matter in the cluster is distributed uniformly in space. The cluster has a radius R of about one million light-years (equal to 10^{24} cm) and contains 800 individual nebulae with a mass of each corresponding to 10^9 solar masses. The mass M of the whole system is therefore

$$M \sim 800 \times 10^9 \times 2 \times 10^{33} = 1.6 \times 10^{45} \text{ g}. \qquad (5)$$

This implies for the total potential energy Ω:

$$\Omega = -\frac{3}{5}\Gamma\frac{M^2}{R} \tag{6}$$

Γ = Gravitational constant

or

$$\overline{\varepsilon}_p = \Omega/M \sim -64 \times 10^{12}\ \mathrm{cm}^2\mathrm{s}^{-2} \tag{7}$$

and then

$$\overline{\varepsilon}_k = \overline{v^2}/2 \sim -\overline{\varepsilon}_p/2 = 32 \times 10^{12}\ \mathrm{cm}^2\mathrm{s}^{-2}$$

$$\left(\overline{v^2}\right)^{1/2} = 80\ \mathrm{km/s}. \tag{8}$$

In order to obtain the observed value of an average Doppler effect of 1000 km/s or more, the average density in the Coma system would have to be at least 400 times larger than that derived on the grounds of observations of luminous matter.[8] If this would be confirmed we would get the surprising result that dark matter is present in much greater amount than luminous matter.

2. One could also assume that the Coma system is not in stationary equilibrium, but that all available energy has the form of kinetic energy. Then we would have

$$\overline{\varepsilon}_k = -\overline{\varepsilon}_p, \tag{9}$$

This assumption thus allows to get rid of a factor of only 2 compared to 1., and the necessity of an enormously large density of dark matter stays the same.

3. Let the average density in the Coma cluster be wholly determined by the presence of luminous matter (mass M above). Then the large velocities cannot be determined by considerations of type 1. or 2. If the observed velocities are indeed real ones, the Coma system should disperse in the course of time. The result of this expansion would be 800 individual nebulae (field nebulae), which, as follows from 2., would have eigenvelocities of the original order of magnitude (1000 to 2000 km/sec). From analogies it is to be expected that field nebulae with such large eigenvelocities would be observable also in the state of development the world is in today. This conclusion however

[8] In order of magnitude this would agree with the view of Einstein and de Sitter discussed in §4.

hardly agrees with the facts gained from experience, since the variation of eigenvelocities of isolated nebulae does not exceed 200 km/s.

4. One can also try to see the velocities as apparent ones, by trying to interpret them as caused by Einstein's redshift. Presupposing the above mass M one would get the relative change of wavelength λ

$$\Delta\lambda/\lambda \sim \varepsilon_p/c^2 \sim 3.5 \times 10^{-8}, \tag{10}$$

which corresponds to a velocity of only 10 m/s. To explain in this way the large variation of velocities one would have to admit a far higher density of dark matter than under 1. and 2.

These considerations show that the great dispersion of velocities in the Coma system (and in other dense nebular clusters) harbours a problem that is not yet understood.

§6. Penetrating radiation and redshift

Comparing the intensity of the visible light of our Milky Way (L_m) and the intensity of the light (L_w) which reaches us from the rest of the Universe we get

$$L_m/L_w \gg 1. \tag{11}$$

Assuming that the penetrating radiation is of non local character, this gives the ratio of intensities S analogous to (11) as

$$S_m/S_w < 0,01. \tag{12}$$

This is a consequence of the practical absence of diurnal variations of penetrating radiation. As I analyzed elsewhere[9] the inequality (12) is hard to understand, because cosmic rays originating in very large distances reach the Earth with much decreased energy, due to the redshift. If, e.g., the redshift would be proportional to distance throughout light quanta from distances of more than 2000 million light-years would reach us with energy zero. (As an aside: From this consideration follows that the intensity of light has a finite, well defined value everywhere, even in the presence of infinitely many stars in space.) Under reasonable assumptions about the type of reaction that

[9] F. Zwicky, Phys. Review, January 1933.

produces cosmic rays it is very hard to understand the inequality (11), the main difficulty being, as was indicated, the existence of redshift.[9]

Finally I would like to point out that the coexistence of the two inequalities (11) and (12) will pose great difficulties for some newer concepts about the origin of the penetrating radiation. G. Lemaitre, e.g., proposed that the cosmic rays could be seen as remnants of some super radioactive processes which took place a long time ago. But at the same time a correspondingly huge amount of visible and ultraviolet light must have been emitted. Since interstellar gases (like our atmosphere) absorb penetrating radiation stronger than visible light, the coexistence of the inequalities (11) and (12) cannot be understood.

In this context the following interesting fact is of importance, too. A belt with irregular boundaries running along the Milky Way and reaching from about $-10°$ up to $+10°$ galactic latitude completely blocks our view of extragalactic space, i.e. no extragalactic nebulae can be observed in this belt. It is known that part of the absorption is due to very extended, dense masses of dust. If the penetrating rays are of extragalactic origin, it should be expected that they, too, would be absorbed along the Milky Way, i.e. on the Earth a diurnal variation of intensity of cosmic rays should be observed. Since such a variation has not been found, one is tempted to conclude that the penetrating radiation cannot be of extragalactic origin. There is, however, more research necessary to determine the density and extension of interstellar matter in the Milky Way.

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