Astronomy. — *"Further Remarks on the Dark Nebulae in Taurus"*. By Dr. A. PANNEKOEK. (Communicated by Prof. J. C. KAPTEYN).

(Communicated at the meeting of October 30, 1920).

§ 1. In a previous communication, assuming that the star-voids in Taurus are caused by absorbing nebulae, we have determined the distance of those nebulae at about 140 parsecs. The light-absorption of a region with moderate absorption, for which data were available also for the 12[th] magnitude, proved to be 1 à 2 magnitudes; for the darkest regions A and B the average must then amount to about 2 magnitudes, which is not in conflict with the logarithmic defect for $15,^{m}9$; the blackest kernels therein have a far stronger absorption still. The existence of such extensive regions (the dimensions of A are 9° by 3°, that is to say 20 by 7 parsecs; B is most irregular, but about equal in area) of which the absorption is known, allows us to draw some conclusions regarding the density and mass of these gas-clouds.

We assume, therefore, the existence of such a gas-cloud in space, the molecules of which absorb the light through scattering. Lord RAYLEIGH in his investigations on the cause of the blue colour of the sky, has deduced a formula for the absorption of the light through a medium containing small particles in suspension in which the suspended particles scatter the light to all sides [1]). SCHUSTER pointed out, in 1909, that the extinction of the light in our atmosphere is to be attributed almost exclusively to such scattering, where the molecules of air themselves play the part of scattering particles, whilst the selective absorption constitutes but a minor factor [2]). As the absorption in magnitudes is proportional to the density × thickness, and therefore to the number of molecules the ray of light meets, the density and mass of a cosmic gas-cloud can be determined through comparison with the data of the atmospheric extinction. ABBOTT gives for Mount Wilson in the zenith a transmission-coefficient 0.95, an absorption therefore of 0,056 magnitude, valid for a column of air of 6 km., in height, and a density of 0,0013. If for the thickness of the gas-cloud in Taurus (after the linear dimensions

[1]) Philosophical Magazine, 1899, page 379.
[2]) Nature, 1909, page 97.

20 × 7) we take 10 parsecs (1 parsec is 3×10^{13} km.), we find, with an absorption of 2 magnitudes, 10^{-15} for the density of the gas-cloud. The mass is independent of the thickness assumed; per cm² diameter it is 2/0,056 × weight of air-column on Mount Wilson = 25 kg., for an area of 150 square parsecs therefore $M = 3,5 \times 10^{40}$ kg. As the mass of the sun is 2×10^{30} kg., the mass of the gas-cloud is equal to about 2×10^{10} sunmasses.

This can also be found directly, by means of the formula of RAYLEIGH for the absorption-coefficient k:

$$k = \frac{32\,\pi^3\,(\mu - 1)^2}{3\lambda^4\,N}$$

in which μ is the refractive index, λ the wave-length, N the number of particles (molecules) per cc. If we assume, that the gas-cloud consists of hydrogen, (which gives the smallest mass), with an ordinary pressure and density therefore $\mu = 1{,}000143$, $N = 2{,}7 \times 10^{19}$, and if we take $\lambda = 5{,}5 \times 10^{-5}$ cm., we get $k = 2{,}7 \times 10^{-8}$, or $2{,}7 \times 10^{-3}$ for unit of thickness one km., which is equal to $2{,}9 \times 10^{-3}$ magnitudes, whilst a column of 1 cm² width per km. length has a mass of $8{,}3 \times 10^{-3}$ kg. The mass of a column of 1 cm² diameter in an absorbing gas-layer is therefore $2{,}9\ \varepsilon$ kg., if ε is the absorption in magnitudes (for $\lambda = 550$). From this we find for a mass of gas with an area of 150 square parsecs and 2 magnitudes absorption

$$M = 8 \times 10^{39}\ \text{kg.} = 4 \times 10^{9}\ \text{sunmasses.}$$

The difference with the former result is due to the difference between hydrogen and air.

According to KAPTEYN and VAN RHYN [1]) the density of the stars in the vicinity of the sun is $^1/_{22}$ per cubic parsec, so that in a globe with a radius of 2600 parsecs there are 4×10^9 stars. If we take their average mass as equal to that of the sun, this one gas-cloud, (one third perhaps of all absorbing gas-clouds in that region) only 140 parsecs distant, contains as much mass as all the stars within a globe extending 20 times further. Unless therefore this Taurus-cloud is unique for size and density, we may safely conclude that in the fixed stars only a small part of the world-substance is condensed.

§ 2. The assumption, however, that at a distance 140 parsecs there be a gascloud of such great mass, leads to a few most remarkable consequences. The attraction of this mass on our solar system is not

[1]) J. C. KAPTEIJN and P. J. VAN RHIJN, On the distribution of the stars in space. Astrophysical Journal **52**, 32.

imperceptible; it amounts to 5×10^{-6} times the force which the sun exercises on the earth. It deserves notice that this force is altogether independent of the assumed distance of the gas-cloud. It depends only on the amount of its absorption, and its apparent area in the sky. If this area is s square degrees, and the absorption ε magnitudes, the formula of RAYLEIGH gives, in the above manner:

$$\text{Force} = 10^{-7}\, \varepsilon s \times \text{attraction of the sun on the earth.}$$

If the absorption is ε' for photographic rays, ($\lambda = 440$) then $\varepsilon = \frac{1}{2}\,\varepsilon$ is to be taken. If therefore in various directions and at various distances there are such absorbing gas-clouds in space round us, the total influence on our solar system can be calculated from their apparent area and absorption.

For the time being we will consider only the influence proceeding from the Taurus gas-clouds. The perturbating forces are imperceptible also in the case of the most distant planets. But the force on the solar system as a whole is so immense, that (with a speed of 19 km., supposed about perpendicular on the force), it must move in a curved orbit with a radius of curvature of 4×10^5 astronomical units $= 2$ parsecs, and the direction of the apex in 3000 years must be modified 1° towards Taurus. Compared with the distance of 140 parsecs this slight radius of curvature indicates that our solar system must move in an elongated ellipse with excentricity $^{69}/_{70}$ around the gas-cloud, in a period of 2 à 3 million years, that at the present time it is nearly in the apocentre, and that in the pericentre it has practically to go through the gas-cloud. Something similar holds good for the Hyades, which run at a distance of about 100 parsecs from the gas-cloud, with a speed of 45 km. To run away and get free from the nebula in a hyperbolic orbit, their speed would have to exceed 270 km.; with their small speed however they are bound soon to precipitate towards the gas-cloud. Such a huge mass as calculated above, would render it a central body dominating all movements in this part of the universe, over many hundreds of parsecs. The speed of the stars would be enormous in the vicinity of the gas cloud; especially in the direction of Taurus therefore, we should observe great proper motions, far exceeding the usual values.

Also without the assumption of such a great attracting mass, the proper motions in the regions of absorption must be above the normal, because for a certain magnitude (on account of the dropping-off of stars behind the absorbing screen) the average distance there is smaller than elsewhere. Making use of the formulae of the previous

communication we find for the average parallax of the stars of the magnitude m in front of the absorbing screen:

$$\overline{\pi'}_m = \frac{1}{A'_m} \int_{-\infty}^{\rho_1} 10^{\,0,4\rho - \frac{1}{\alpha^2}(m - M_0 - \rho)^2 - \frac{1}{\beta^2}(\rho - \rho_0)^2}\, d\varrho.$$

The same integral taken between the limits $\pm\,\infty$ represents the normal value of $A_m\,\overline{\pi_m}$. If we put, therefore

$$x_3 = 0{,}22\,\varrho_1 - 1{,}078 - 0{,}132\,(m - 9) = x_1 + 0{,}452$$

and

$$\frac{1}{\sqrt{\pi \log e}} \int_{-\infty}^{x_3} 10^{-t^2}\, dt = \gamma_3$$

then

$$\frac{\overline{\pi'}}{\overline{\pi}} = \frac{\gamma_3}{\gamma_1}.$$

The average proper motions are enlarged in the same proportion as the average parallaxes. For $\varrho_1 = 6{,}05$, $r = 160$ parsecs (this value has been taken, because it allowed us to use the numbers of the previously calculated tables), we get for

m =	6	7	8	9
γ_3/γ_1 =	1,4	1,6	1,8	2,1.

DYSON and MELOTTE in their article have already compiled the proper motions of the stars in the darkened regions of Taurus, and have established, that they are not greater than anywhere else. We find, indeed, for their average 0″,044, whilst stars of that magnitude (1 of the 6[th], 1 of the 7[th], 5 of the 8[th], 9 of the 9[th] magnitude) at such a galactic latitude give a normal average of 0″.041. For the small number of stars the negative conclusiveness of this result is not strong enough in itself to refute the existence of an absorbing nebula. Of a greater average speed, however, through the effect of a gigantic attractive mass, there is no trace.

§ 3. The difficulties, and as yet unconfirmed consequences, resulting from the assumption, that the star-voids in Taurus are caused by absorbing gas-masses, give rise to the question, as to whether no other explanation is possible. BARNARD has always emphasized the fact that not all dark spots and regions in the Galaxy are to be attributed to absorption, but that a great number of them are undoubtedly due to actually void space. In many cases the aspect furnishes an indication: the fantastically twisted and ramified shapes of the dark regions in their various gradations of blackness, which present themselves on the chart of DYSON and MELOTTE, and are even more marked on the photographs by BARNARD [1]), are a strong indication to the existence of absorbing nebulae in these Taurus regions. This indication is corroborated, if we calculate the influence of actual star-voids in space on the number of stars of different magnitudes.

We assume that in the line of sight the space from r_0 to $r_1 = 1,585 r_0$ is completely empty (over a region from ϱ_0 to $\varrho_0 + 1$ therefore). In the integral, representing the number of stars A_m of the magnitude m, the part between the limits ϱ_0 and $\varrho_0 + 1$ is lacking, thus

$$A'_m = A_m \left(1 - \frac{1}{\sqrt{\pi \log e}} \int_{x_0}^{x_0+0,22} 10^{-x^2}\, dx \right)$$

in which x has the same signification as in the previous communication. If we calculate these values for a certain value of ϱ_0 (e.g. $\varrho_0 = 6,95$, whereby the falling-off of stars becomes a maximum for $m = 9$), and from that the total numbers $N'_{m+1/2}$ and the logarithmic defect $\log N'/N$, we find:

m.	$\log N'/N$	m.	$\log N'/N$
3		10	
	−0,028		−0,080
4		11	
	− 040		− 069
5		12	
	− 055		− 056
6		13	
	− 069		− 043
7		14	
	− 080		− 031
8		15	
	− 086		− 021
9		16	
	− 086		− 014
10		17	

With a void, extending over a unity in ϱ, there is therefore a lack of 18 % at the utmost in the total number of stars. To produce such a strong defect as observed in the Taurus regions, the void must extend over many unities in ϱ. If such holes do not extend

[1]) E. E. BARNARD. On a nebulous groundwork in the constellation Taurus. Astrophysical Journal **25**, 3.

further in the line of sight as perpendicularly to it, one unity in ϱ means a lateral dimension of 26°, and two unities in ϱ (a void therefore from r_0 to $2,51\ r_0$), a lateral extension over 50°. Hence, if we want to explain a clearly evident defect of stars (over 20 % for instance, $\log N^1/N > 0,10$) over a small area (below 10°) by real spatial voids in the star universe, we come to the hardly acceptable assumption of protracted, tubular cavities, all running in the direction of the line of sight. It is only in those places, where the stars do not extend equably alongside of the visual line, but are clustering into actual clouds and other objects, that real voids between them can play an important part in the aspect of the Galaxy.

Thus, if we abide by the explanation through absorption, but without the enormous mass, the particles that cause the scattering must have a mass, smaller than hydrogen-molecules, thus they would have to be for the greater part free electrons. The question as to whether there really is absorption, could be settled by means of an investigation into the colours of the stars in the poor regions. The absorption through scattering is inversely proportional to λ^4, so that the stars behind the gas-cloud must be strongly reddened. For a number of nebulous stars, stars which are surrounded by visible nebulous halos, in Monoceros, Scorpio and Ophiuchus, SEARES and HUBBLE have recently found [1]) that their colour is considerably more red than it should be according to their spectral type, that therefore their light is scattered and dimmed by the nebula through which they shine. On calculating what portion of the stars of each magnitude lies behind the gas-cloud, assuming for its distance once more 160 parsecs ($\varrho_1 = 6,05$), we get for

$m =$	5	6	7	8	9	10	11	12
	0,4 %	1 %	2 %	4 %	9 %	17 %	31 %	50 %

It is only with stars fainter than the 12th magnitude, therefore, that the majority will show this reddening through absorption. As in the case of such faint stars a comparison with the spectral type is difficult to accomplish, it will not be feasible directly to determine the reddening with absolute certainty; it may be, however, that a statistic determination of the colour or the effective wave-length of the fainter classes will lead to a decision.

Postscript. Professor DE SITTER has drawn my attention to the fact, that the absorption of a mass consisting of opaque particles

[1]) F. H. SEARES and E. P. HUBBLE. The color of the nebulous stars. Astrophysical Journal, **52**, 8 (July 1920).

surpasses so much the absorption of an equal mass of scattering gas, that by assuming a dust-cloud instead of a gascloud, a moderate mass will suffice to account for the observed extinction. In this case the absorption does not depend on colour. If a reddening of the stars is observed, indicating an absorption through scattering, we may still find a moderate mass, if the gascloud is mixed with dust particles. This would be in harmony with the views of ARRHENIUS, who has found in his studies on cosmogony that the small particles in space, driven away by lightpressure, are caught and collected in the extensive world nebulae.

Physics. — *"The so-called cyanogen-bands"*. By G. HOLST and E. OOSTERHUIS. (Communicated by Prof. H. KAMERLINGH ONNES).

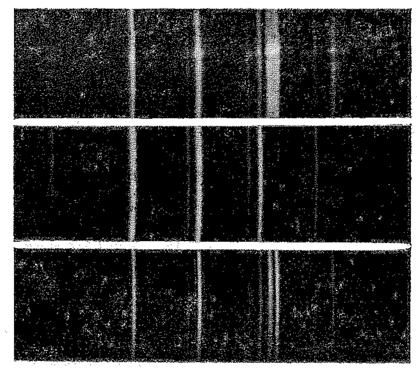
(Communicated at the meeting of May 29, 1920).

In photographing the nitrogen-spectrum one usually observes a number of bands, which were formerly ascribed to cyanogen [1]).

The most prominent of these bands lie between 3855 and 3883 Å. and between 4158 and 4216 Å. In 1914 GROTRIAN and RUNGE [2]) made some experiments, from which they concluded, that these bands are due to nitrogen and should not be ascribed to cyanogen. Many later observers [3]) have considered this view to be the right one.

We have made a new investigation on this point and came to the conclusion that these bands are not due to nitrogen, but to one of its compounds which condenses at a much higher temperature. In our experiment the discharge tube was a cylindrical glass tube with one electrode connected to a Tesla-transformator. The gas in the tube was an argon-nitrogen-mixture containing about 15 % of nitrogen. The gaspressure was about 55 cm. Under these circumstances the spectrum shows no argon lines, only the nitrogenbands and the so-called "cyanogen-bands". (Fig. 1).

A. B.



1.
2.
3.

The bands 3855—3883 Å can be seen at *A*, the bands 4158—4216 Å at *B*.

In order to discriminate whether these bands are due to nitrogen or to cyanogen, we immerged the lower half of the discharge tube into a glass filled with liquid oxygen and so obtained the spectrum fig. 2.

---

1) See KAYSER, Handbuch der Spectroskopie. Bd. 5.

2) W. GROTRIAN and C. RUNGE. Phys. Z. S. 15, 545. 1914.

3) W. STEUBING. Phys. Z. S. 20, 512. 1919.
L. GREBE und A. BACHEM. Verh. D. Phys. Ges. 21, 454. 1919 and Zeitschr. f. Physik, 1, 51. 1920.