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BULLETIN OF THE ASTRONOMICAL INSTITUTES
OF THE NETHERLANDS

1952 JULY 22 VOLUME XI NUMBER 434

COMMUNICATION FROM THE OBSERVATORY AT LEIDEN

ON THE LIGHT-VARIATION OF AI VELORUM

BY TH. WALRAVEN

The RR Lyrae-type variable AI Velorum has been observed photoelectrically with the 16″ telescope of the Leiden Station at Johannesburg during January and April—May 1951.

The light-variation shows a primary period, P_0, of $0^d.111574$, and a secondary period, P_1, of $0^d.0862075$, which by interference give a beat period of $0^d.379182$. The lightcurve may be represented as a certain distortion of the curve given by the formula:

$$m = 0^m.859 - 0^m.111 \sin 2\pi\Phi_0 - 0^m.083 \sin 2\pi\Phi_1,$$

where Φ_0 and Φ_1 are the phases corresponding to P_0 and P_1.

This distortion can be separated into a phase displacement, proportional to magnitude, or wave steepening, and a magnitude deviation which makes the maxima of the curve high and sharp.

It is assumed that the formula represents the basic underlying pulsation of the star and theoretical considerations are given about the nature of the processes which play a role in converting this into the observed lightcurve. The Riemann theory of the propagation of running waves is applied and it may account for the wave steepening.

It is suggested that shockwaves are responsible for the increase of the height of the maxima.

There are indications of the existence of two short-period oscillations, of the order of one hour, but the material does not suffice to describe these with certainty.

Introduction.

The star which is the subject of this article has been found as a variable star by HERTZSPRUNG [1]) on plates taken by VAN GENT with the Franklin-Adams camera at Johannesburg. HERTZSPRUNG considered it as a Cepheid variable and found the period as 0.111574 day. However, the observed lightcurves showed strong irregularities both in phase and shape, which was confirmed by investigations of ZAGAR [2]) and VAN HOOF [3]). Since then the star was considered as a semiregular cluster-type variable. It has been the object of two series of observations, during January 1951 and then during April and May 1951 at the Leiden Southern Station at Johannesburg. The first series was done with a straightforward photo-electric photometer, consisting of multiplier, amplifier and recorder. These observations revealed the real nature of the light-variation. They were interrupted often by unfavourable weather conditions as is usual in this time of the year. An other photoelectric photometer, of the differential type, which is much less sensitive to cloudy conditions, was put into use in March but at that time the weather was extremely bad and useful observations were started not before the middle of April. Unfortunately the star had a considerable hourangle already and although observations started immediately after twilight and ended when the star disappeared behind trees, the series obtained were rather short. New observations are planned therefore. Nevertheless from the available observations interesting conclusions could be drawn, worth while to be given in this paper.

The observations.

Some data of the variable and the comparison star are given below:

TABLE 1

	α_{1950}	δ_{1950}	HD	Sp.
	h m s	° ′ ″		
AI Vel	08 12 26	−44 25 22	69213	Fo
comp.	08 12 47	−45 40 53	69302	B3

For the January observations also other comparison stars have been used but as these observations have a lower degree of accuracy than the others, no use was made of them. For the same reason we describe only the observational method of the April—May period.

The photometer used in that period was attached to one component of the 16″ twin camera of the Leiden Southern Station. It was of the differential type, using the light of both variable and comparison star at the

[1]) *B.A.N.* VI, 147, 1931.
[2]) *B.A.N.* VIII, 169, 1937.
[3]) *B.A.N.* VIII, 172, 1937.

objectglass, which is a four-component type made by Zeiss, has a chromatic correction for the blue-violet part of the spectrum. Accordingly the blue lightcurves

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AJ Velorum

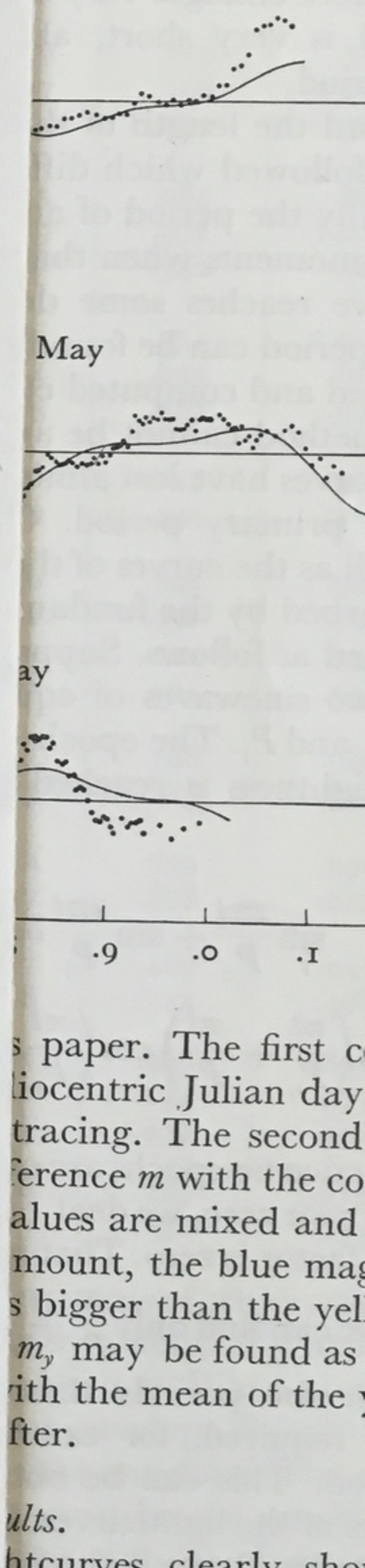
Lichtkromme die bij ons kan worden reproduceerd (dwz alle
dik. getrokken krommen daardoor + enkele onderbroken gestreken),
zodat de waarnemingen - de vergelijkstermen goed te zien zijn) en
daarboven de residukromme, die de kleine trillingen te zien geeft die
overblijven
als de beide langdurige trillingen afgetrokken zijn.

In het artikel duidelijk uiteengezet die weg hoe bij een gelaagd
om deze residukromme te herleiden tot de enkele trillingen. Om eerst P_1 kromme
en alle mogelijke verschillen phasen φ_0 opgemeld en vice versa[1], dan
de dikke krommen opgemeld voor bepaalde waarden van $\varphi_0 - \varphi_1 = \psi$; als
abscissen van deze lichtkrommen gekozen $P_0 + \varphi_1$ ..[2]
Hij heeft uit deze getrokken de amplitudes der basis trillingen te vinden
(a en b) corresp. met $P_0 - P_1$. Dan $P_0 = a \sin 2\pi\varphi_0$, $P_1 = b \sin 2\pi\varphi_1$. Hij
leidt uit a - b af uit de amplitudes van de lichtkr. waar deze t.b.v. is, en
a + b uit de phase verschillen in deze kurve. Wordt φ_0 a - b en de andere
0m.1. Zie onder (A) aan 0.2. ook
Lies Rosseland's boek hier aan een beetje na.
(het onderste)
Merkwaardig ~~dat~~ Wolfer's werk hiermee het zijn recht komt.
Belangrijk licht uit dat de verhouding $\neq P_1 : P_0$ bij alle drie
deze sterren, AJ Vel, ζ Sculpt. - HD 223065 (ξ Gruis ster),
origineel precies gelijk is (0.80) en dat deze afwijkt van de drie bekende
veel mogelijke verhouding - ca 0.6. Dit wijst dat een verandering
in het model of in de theorie nodig is. Vraag Martin hier eens over.

Als in de kleine trillingen niet bij een twee langdurige (die door
hetzelfde zijn door de periode en ca 0d.1 en de grote trillingen) meer die
deze of de een of andere wijze met samenhangen. Tegelijk gaat het

2) Deze krommen berekend door gebruik te maken van de lichtkromme
als functie van de twee variabelen φ_1 en φ_2 (bedoeld in de tekst "hoogland kaart"). Met
behulp van deze twee-dimensionale gemiddelde lichtkromme is de residu-kromme ge-
maakt.
Vraag nog of hier een orbit de meting van minder juist in mindere mate is.

1) Deze P_2 krommen zijn gelijk verschillende in amplitude en de verschillende
phasen φ_1, en vice versa. Het is dus zijn simpele superpositie



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BULLETIN OF THE ASTRONOMICAL INSTITUTES
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1957 NOVEMBER 9 VOLUME XIV NUMBER 480

COMMUNICATIONS FROM THE NETHERLANDS FOUNDATION FOR RADIO ASTRONOMY AND THE OBSERVATORY AT LEIDEN

ROTATION AND DENSITY DISTRIBUTION OF THE ANDROMEDA NEBULA DERIVED FROM OBSERVATIONS OF THE 21-cm LINE

BY H. C. VAN DE HULST, E. RAIMOND AND H. VAN WOERDEN

The atomic hydrogen emission from the Andromeda nebula (M31) was observed with the 25-metre telescope at Dwingeloo; the beamwidth was 0°.6. Line profiles were measured at 20 points of the major axis (Figure 5). The mean error of the brightness temperature measured at one frequency in one direction was 0.2 to 0.3°K except in the frequency range contaminated by galactic foreground radiation. The line was observable to 2°.5 at either side of the centre. The central velocity with respect to the local standard of rest is − 296 km/sec. The velocity of rotation slowly falls from 278 km/sec at 0°.6 from the centre to 221 km/sec at 2°.5 (Table 7). The accuracy is well within 10 km/sec. The density distributions determined from the integrated profiles in the SW and NE halves of the system separately show pronounced peaks at 1° from the centre in each half (Table 6). Model line profiles were computed with the average density distribution of the two halves on the assumption of circular symmetry, taking full account of the antenna pattern. They fit the observed profiles quite well if a broadening effect is introduced corresponding to random cloud motions with a root mean square velocity of 8 km/sec. The total mass of atomic hydrogen in the system is $0.25 \times 10^{10}\ c^2$ solar masses if the distance of M31 is 500 c kpc; it is 0.01 c times the total mass of M31 determined by SCHMIDT in the succeeding paper. Both the hydrogen mass and the total mass exceed those of the Galactic System. A local excess of radiation found at $v = -224$ km/sec in the NE part of the system has been investigated by more complete measurements but no satisfactory explanation has been found.

1. *Observations*

Among the very first programmes of the 25-metre radio telescope at Dwingeloo (VAN DE HULST, HOOGHOUDT, SCHOR, HUISMAN, SCHIERBEEK, JÖBSIS, 1957) was an investigation of the 21-cm hydrogen radiation from the Andromeda Nebula (M31). The observations reported here were made from October 12 to November 5, 1956, and January 3 to 27, 1957. The total observing time was about 320 hours. The altitude at each observation was $> 23°$.

In the preceding period the telescope had been equipped with a receiver for measuring the continuous radiation near 21 cm and a dipole-disk feed at the focus. The disk was somewhat bent toward the dipole in the H-plane in order to make the antenna pattern in the E- and H-planes equally wide. Table 1, kindly supplied to us by Mr WESTERHOUT, gives the pattern for this feed, based on measurements of the Cas A source and corrected for the non-linear detector law (see Figure 1).

Observing the 21-cm line with a reasonably flat zero line over a wide frequency range necessitated bringing the mixer and first stage of i.f. amplification to the focus. They were mounted in a cubic box with sides of 20 cm, attached behind the disk of a new dipole-disk feed, carefully dimensioned after the first one. The antenna pattern of this feed determined at the frequency of the deepest absorption line in the Cas A spectrum (MULLER, 1957) matched the pattern given in Table 1. We assume that the pattern

TABLE 1

Antenna pattern

r	$p(r)$
°	
0.0	1.00
0.1	0.92
0.2	0.71
0.3	0.45
0.4	0.24
0.5	0.10
0.6	0.02
0.7	0.00

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THE DISTRIBUTION OF MASS IN M31

BY M. SCHMIDT[1]

A model of the distribution of mass in M31, which represents closely the radial velocities obtained in the preceding article, is presented. The total mass of the system is $3.4 \times 10^{11}\,\odot$, half of which is at less than 13 kiloparsec from the axis of rotation. The mass-luminosity ratio has a practically constant value of about 27 between 3 and 16 kiloparsec from the centre. The mass-luminosity ratio for the entire nebula is 23 in the present model. Accurate observations of the distribution of light and colour over the entire nebula are urgently needed.

The rotational velocities, which were computed from the radial velocities of neutral hydrogen in M31 in the preceding article, were used in the present investigation to derive a model of the distribution of mass in the nebula. Previous models of the distribution of mass in M31 have been given by WYSE and MAYALL (1942) and SCHWARZSCHILD (1954). These authors used rotational velocities based on radial velocities of hydrogen emission regions measured by MAYALL (1950). SCHWARZSCHILD found that the data were not inconsistent with the assumption of a constant mass-luminosity ratio throughout the nebula.

The preceding article essentially gives the radial velocity of hydrogen clouds on the major axis of the nebula. On the assumption of circular motion in the plane of the nebula the rotational velocity is given by $V_{rad} = V_{rot} \sin i$. We shall use the value $i = 75^\circ.5$, which was adopted in the reductions in the preceding article. The actual value of i may be somewhat larger and will be discussed below.

The model which gave the best fit to the rotational velocities consists of two non-homogeneous spheroids. Surfaces of constant density in each of the spheroids are spheroidal surfaces with a constant axial ratio. This axial ratio was arbitrarily chosen as 0.07, which is the value found for the axial ratio in the Galactic System (SCHMIDT, 1956). The first non-homogeneous spheroid is composite. In the inner part, up to the surface $a = 0^\circ.790$, the density is given by

$$\rho_1 = -29.324 + \frac{30.888}{a},$$

where

$$a = \sqrt{\varpi^2 + \left(\frac{z}{0.07}\right)^2}$$

in which ϖ is the distance to the axis and z the distance to the plane of the nebula. All densities are given in 10^{-24} g/cm^3. For points with $a > 0^\circ.790$ the density in the spheroid is given by

$$\rho_1 = \frac{3.807}{a^4}.$$

The transition is such that density and density gradient are continuous across the surface $a = 0^\circ.790$. The density of the second spheroid is

$$\rho_2 = -0.494 + \frac{2.447}{a}.$$

This spheroid is cut off at the surface $a = 4^\circ.957$, where the density becomes zero. Formulae for potentials and forces due to non-homogeneous spheroids with density laws as used here are given in an earlier paper (SCHMIDT, 1956).

The apparent distance modulus (BAADE, 1955, 1956) of M31 is $24^m.25$.*) The total correction for absorption seems to be quite small according to BAADE (private conversation). We shall assume a true distance modulus of $24^m.0$, corresponding to a distance of 630 kpc, so $1^\circ = 11.0$ kpc. The first two columns of Table 1 give the distance in the plane of the nebula from its centre. The next two columns give the observed rotational velocities and those computed from the model. The agreement is satisfactory. The total density in the plane is given in column 5. It should be noted that the densities are very sensitive to the assumed axial ratio of the mass distribution. The dependence is approximately such that density $\times$ axial ratio = constant. The surface mass density σ'_M in a column perpendicular to the equatorial plane of M31 is given in column 6. This surface density is nearly independent of the assumed axial ratio.

The total mass of the model is $M = 3.38 \times 10^{11}\,\odot$. The mass distribution given extends further outward than the region where the rotational velocities have been measured. Thus the densities outside the surface $a = 2^\circ.5$ are not much more than a reasonable extrapolation. The mass outside this surface is 33% of the total mass. The seventh column of Table 1 gives the percentage of the total mass inside a cylinder with radius ϖ. Half of the total mass is at less than $1^\circ.2$ from the axis of rotation. The velocity of escape from the centre of the nebula is 703 km/sec. At $\varpi = 1^\circ$ the velocity of escape is 468 km/sec; at 2° it is 368 km/sec.

The distribution of light along the major and minor axes of the nebula has been given by REDMAN and SHIRLEY (1937). Their investigation seems to be the only one which gives the surface brightness on the major axis to a distance of 2°. Their photographic magnitude system was calibrated by comparison with photoelectric work by BAUM and SCHWARZSCHILD (1955) and STEBBINS and WHITFORD (1934). BAUM and SCHWARZSCHILD give magnitudes P_∞, an ultra-

1) Temporary Carnegie Fellow at Mount Wilson and Palomar Observatories.