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Determination of the Galactic Rotation Curve from B-Type Stars

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ABSTRACT. Radial velocities and distances of 1136 B-type stars brighter than 10 mag. and lying close to the galactic plane ($-10^\circ \leq b \leq 10^\circ$) are used to determine the rotation curve of our Galaxy in the region 7-13 *kpc* from the galactic center. The derived curve is found to be similar to that obtained from Cepheids Variables and in good agreement with the theoretical curve obtained from dynamical models.

Introduction

The disk of our galaxy is in a state of differential rotation around an axis through the galactic center[1]. The Sun, for example, is moving around the galactic center on a nearly circular orbit of radius R_o = 10 *kpc* with a circular velocity of $\Theta_o (R_o)$ = 250 $kms\ s^{-1}$ (these values were adopted by the IAU)[2]. The corresponding angular rotation rate is $w_o(R_o) = \Theta_o(R_o) / R_o$ = 25 $kms^{-1}\ kpc^{-1}$. If we plot the quantity $[w(R) - w_o(R_o)]$ as a function of the distance R from the galactic center, we get the so-called galactic rotation curve. From this curve we can obtain extremely valuable information about the dynamics of the galaxy.

The rotation curve near the galactic center (R < 4 *kpc*) is difficult to obtain due to effects of interstellar absorption. For 4 < R(*kpc*) < 9, the rotation curve is most reliably determined from radio observations of the 21 – *cm* line[3]. Our knowledge of the galactic rotation curve for $R > R_o$ is dependent on the determination of accurate distances and radial velocities for objects lying close to the galactic plane and out to several kiloparsecs from the Sun. Therefore, Cepheids, Galatic Clusters and B-type stars are often regarded as ideal objects for this purpose.

The galactic rotation curve derived from Cepheid variables[4] in the range 8 < R(*kpc*) < 13 was flat, while that obtained from young stars and molecular clouds associated with H-II regions[5], which to R = 12 *kpc*, was rising by about 20 *km* s^{-1}. These results indicate that much of the galactic mass lies beyond the Sun. More evidence for this fact comes from an analysis of the motions of distant globular clusters[6].

Accurate measurements of distances from the Sun, r, and radial velocities, ρ, are now available for a large number of B-type stars. In this work, we will try to determine the galactic rotation curve using 1136 B-type stars brighter than 10 mg. which are lying close to the galactic plane (i.e. $-10^{\circ} \le b \le +10^{\circ}$) and cover the range from R = 7 to 13 *kpc*.

2. Astronomical Data

Spectral types and celestial coordinates (α, δ) for stars brighter than 10 magnitudes have been taken from the SAO catalogue[7]. The celestial coordinates, for the Epoch and Equinox of 1950, are converted into galactic coordinates (ℓ, b) using the relations:

$$\ell = \tan^{-1}\left\{\frac{\sin\delta - \sin b \sin\delta_p}{\cos\delta \cos\delta_p \sin(\alpha-\alpha_p)}\right\}$$

$$b = \sin^{-1}\{\sin\delta \sin\delta_p + \cos\delta \cos\delta_p \cos(\alpha-\alpha_p)\}$$

where (α_p, δ_p) are the celestial coordinates of the north pole of the galaxy. To put these coordinates in the new system (system *II*), we use

$$\left\{\begin{array}{rcl} (\ell^{II}, b^{II}) & = & (\ell-\ell_a, b) \\ (\alpha_p, \delta_p) & = & (12^h\ 49^m, +27^{\circ}\ 24'') \\ \ell_a & = & 33^{\circ} \end{array}\right\}$$

Stars with $b^{II} > +10^{\circ}$ or $b^{II} < -10^{\circ}$ have been omitted. Stars with unknown distances or radial velocities have also been omitted. The distances r of the remaining number (1136 stars) are collected from several catalogues[9,10,11,12]. When the value of r is found in more than one catalogue for the same object, an average value is assumed. Radial velocities r have been taken from Wilson's[12] and Evans[13] catalogues. The solar space velocity components are taken to be[2]: U_o = 9 *km/sec*, V_o = 12 *km/sec*, W_o = 7 *km/sec*.

3. The Rotation Curve

The theory of galactic rotation was first discussed by Oort[1]. Since the pioneering efforts, numerous studies have been made to refine and develop this theory[2,14]. From these sources, we can write the following expressions for the radial velocity, corrected for solar motion:

$$\grave{\rho} = - \{w(R) - w(R_o)] R_o \cos b^{II} \sin \ell^{II}$$

in terms of the angular velocity variation, or

$$\grave{\rho} = \rho + U_o \cos b^{II} \cos \ell^{II} + V_o \cos b^{II} \sin \ell^{II} + W_o \sin b^{II}$$

in terms of the observed radial velocity and space velocity coordinates of the sun. The galactocentric distance R is related to the heliocentric distance r by

$$R^2 = R_o^2 + (r \cos b^{II})^2 - 2 R_o r \cos b^{II} \ell^{II}$$

The above equations are used to calculate the quantities $[w(R) – w(R_o)$ and R for all stars in question. The derived galactic rotation curve is shown in Fig. (1), together with the theoretical curve which was derived from dynamical models.

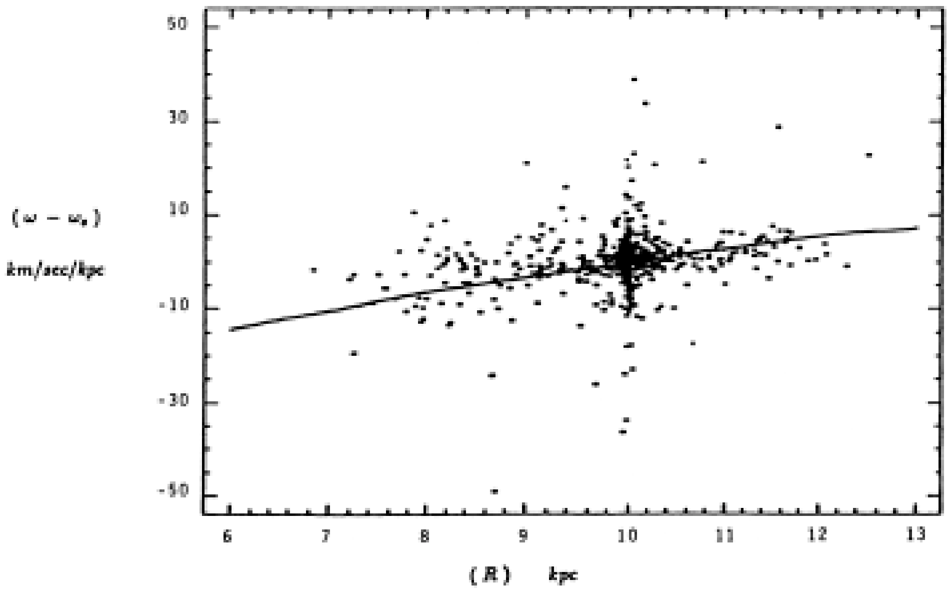

FIG. 1. Part of the rotation curve of our galaxy derived from B-type stars: the points are from this work and the smoothed curve is from dynamical models[2].

Discussion

It is clear from Fig. (1) that B-type stars with $–10^o \leq b^{II} \leq + 10^o$ are able to reproduce the theoretical rotation curve of our galaxy with accuracy sufficient to prove the reality of the dynamical models in the range 7-13 *kpc* from the galactic center. The derived curve from B-type stars has the same shape as that derived from cepheid variables [see Fig. (2)]. As is apparent in Fig. (1), the rotation curved derived from B-type stars is not smooth, but it fluctuates by about ± 15 kms^{-1} kpc^{-1} with respect to the mean theoretical curve. The difference in the values of r and ρ which were taken from different catalogues can not explain the scatter of the points seen at 10 *kpc*. The only possible explanation for these fluctuations is that there are local irregularities in the velocity field of the stars. However, the observed fluctuations are only a few percent of the basic rotation speed and therefore they are not likely to be important dynamically. In general, if the angular velocity of a distant object can be established, its kinematic distance can be determined directly from the theoretical rotation curve with great accuracy in this manner, kinematic distances to many distant planetary nebulae have been determined[15].

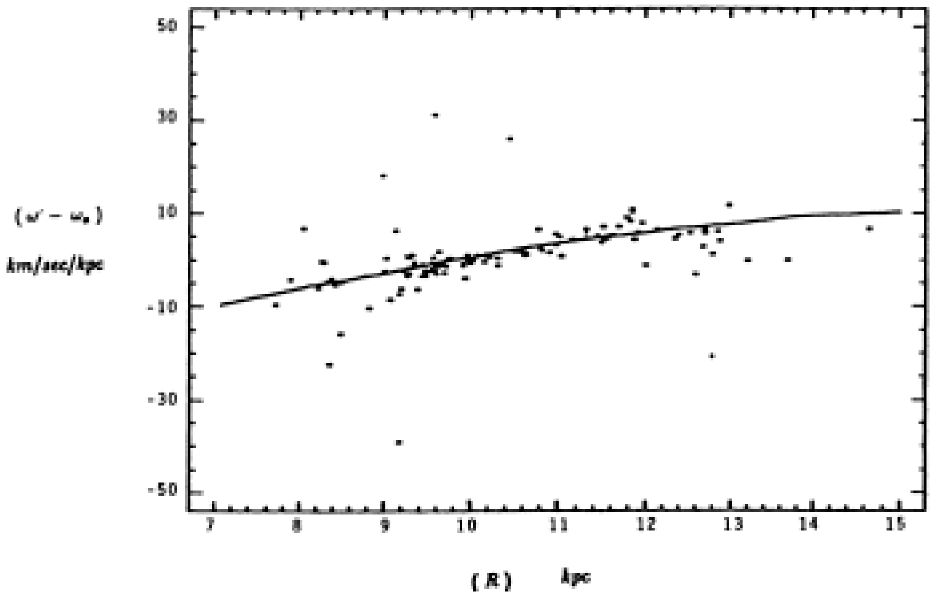

FIG. 2. Part of the rotation curve of our galaxy derived from Cepheid Variables: the points are from this work and the smoothed curve is from dynamical models[16].

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References

[1] **Oort, J.H.,** *Bull. Astron. Inst. Netherlands,* **3:** 275 (1927).

[2] **Mihalas, D.** and **Binney, J.,** Galactic Astronomy, Structure and Kinematics, W.H. Freeman and Co., San Francisco (1981).

[3] **Shane, W.A.** and **Bieger-Smith, G.P.,** *Bull. Astrn. Inst. Netherlands,* **18:** 263 (1966).

[4] **Kraft, R.P.** and **Schmidt, M.,** *Ap. J.,* **137:** 249 (1963).

[5] **Blitz, L.,** *Ap. J. Letter.,* **231:** L115 (1979).

[6] **Hartwick, F.D.** and **Sargent, W.L.W.,** *Ap. J.,* **221:** 512 (1978).

[7] **SAO Staff,** *Star Catalogue,* version 1989 (1966).

[8] **Eggen, O.J.,** *Space Velocity, Catalogue No.* WDC-5008 (1962).

[9] **Warren, W.H.,** *Wooley et al. 1970 Catalogue.* Stars within 24 pcs of the sun, Catalogue No. WDC-82-03 (1982).

[10] **Mead, J.M.** and **Hill, R.S.,** *Rubin et al., 1962 Catalogue of kinematic data for O-B5 stars,* SSD-T-5069-0052-82 (1981).

[11] **Lesh, R.J.,** *Kinematic of OB stars, Catalogue No. WDC*-5009 (1972).

[12] **Wilson, R.E.** (1953) *General catalogue of stellar radial velocities, Cat. No. WDC*-3021 (1953).

[13] **Evans, D.S.,** *Catalogue of stellar radial velocities, Cat. No. WCD*-3047B.

[14] **Schmidt, M.,** *Galactic Structure,* Chicago: University of Chicago Press, Eds. A. Blaauw and M. Schmidt (1965).

[15] **Dalgarno, A.** and **Layzer, D.,** *Spectroscopy of Astrophysical Plasma*, Cambridge University Press, Cambridge London (1987).

[16] **Burton, W.B.,** *Ann. Rev. Astrn. and Astrophys.,* **14:** 275 (1976).

تعيين منحني دوران المجرة من نجوم النوع الطيفي بي

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المستخلص . استخدمت الأبعاد والسرعات القطرية لعدد ١١٣٦ نجم من نجوم النوع الطيفي بي التي تزيد شدة لمعانها عن ١٠ أقدار نجمية والواقعة بالقرب من مستوى المجرة (+١٠ درجات ≤ العرض المجري ≤ -١٠ درجات) لتعيين منحني دوران المجرة في المنطقة المحصورة مابين ٧ و١٣ كيلوبارسك عن مركز المجرة . ولقد وجدنا بأن هذا المنحني يشبه تماماً منحني الدوران الذي تم اشتقاقه من القيفاويات المتغيرة . كما أنه يتفق مع المنحني النظري المشتق من النماذج الديناميكية .