Distances and Other Parameters for 1315 Radio Pulsar

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Abstract. In this work we have collected observational data for 1315 PSRs. Distances and others parameters for these PSRs were estimated. We present improved distance estimates for radio pulsars by considering importance of their physical properties and improvement of distribution of SFRs (star formation regions) in the Galaxy. For this purpose, both a list of accurate calibrators was constructed and several accurate criteria were established. The following values were calculated from PSRs observational data: luminosities at 400 MHz and 1400 MHz, characteristic times, strength of magnetic field and rate of rotation energy. This compilation of data is mainly necessary for statistical investigations and for the physical properties of neutron stars. The whole data is prepared in a publicly accessible web page: http://www.xrbc.org/pulsar/.

Key words: pulsars: general, stars: neutron, astronomical data bases: miscellaneous

1. Introduction

It is a well known fact that no relation has been found in pulsar parameters to estimate their distance. For ordinary distant stars, however, one can use the relations either between luminosity and spectral class, or luminosity and pulsation period to estimate their distance. In the early days of pulsar astronomy, since origin of pulsars, mass of their progenitor and their birth rates were not well known, homogeneous electron density distribution was assumed. However, later on pulsars distances have been estimated according to the rough model of Galactic electron distribution and some natural requirements (Manchester and Taylor 1981; Guseinov and Kasımov 1981; Johnston et al. 1992; Taylor and Cordes 1993; Gök et al. 1996). In doing this, one should also know some of the pulsar distances independent to their dispersion measure (DM). 21 cm line of neutral Hydrogen was mainly used in choosing distance calibrators. However, nowadays, calibrators are chosen from members of globular clusters (GCs) or Magellanic clouds (MC), pulsars connected to Supernova remnants (SNRs) with well known distances and from pulsars (PSRs), where their distances are known from other available data.

Irregularities were observed in the distribution of dust, molecular clouds and neutral Hydrogen (HI) in the Galaxy. It is also normal to expect irregularities in electron distribution where the degree of irregularity is (naturally) considerably small. Considerable variations in opacity and polarization can be observed for stars with the same distance in a very small region of sky (~1° square) close to the Galactic plane. This is due to a very inhomogeneous distribution of dust clouds. For Hydrogen column density along the line of sight there are two surveys where they studied large number of stars; one with 554 stars (Diplas and Savage 1994) and the other with 594 stars (Fruscione et al. 1994). They both show that irregularities in HI distribution are quite different than the dust and molecular cloud distribution (Ankay and Guseinov 1998). The dispersion measure (DM), which is connected with the electron distribution, changes also for pulsars of similar distances, and for close regions of the sky. These irregularities in electron distribution are due to contribution of both HII regions and SNRs along the line of sight, and gravitational potential and gas temperature distribution in the Galaxy. But irregularities in electron distribution is considerably smaller than the ones in other components of interstellar medium that we have mentioned above. Even though these irregularities are small, there is no simple model for Galactic electron distribution to calculate each pulsar’s distance. Moreover, constructing a complex model which requires a lot of data for interstellar medium and PSRs, (e.g. Taylor and Cordes 1993) cannot avoid large errors for individual pulsars.
In order to investigate the arm structure around the Sun within a distance of 4–5 kpc, usually objects like OB associations and open clusters (OC) are studied. For these objects the relative errors in estimating their distances could reach 30% (Humphreys 1978; Efremov 1989; Garmany and Stencel 1992; Ahumada and Lapasset 1995). There is no single good method to estimate the distance of all extended objects belonging to the arms (molecular clouds, neutral Hydrogen clouds, SNRs and HII regions). In determining distances to these objects using HI 21 cm line and Galaxy rotation models, error exceeds 30% and it increases with distance and in the vicinity of longitudes $l = 0^\circ$ and $l = 180^\circ$. However, it is the most widely used model. For distant X-ray sources, Hydrogen column density is used as another method in estimating distances. However, error in this method is also large. Since progenitors of pulsars are massive stars, their birth places are in the star formation regions (SFRs). Furthermore, even though young pulsars with characteristic age of $\tau < 5 \times 10^3$ years have high space velocities, they cannot escape from their birth places. Thus, if number of young pulsars discovered increases and distances to these pulsars are well known then farther away arm structures could be studied.

Archiving radio pulsar data, dates back to 1981. The first full catalog included 333 pulsars which covered discoveries up to 1980 (Manchester and Taylor 1981). The next catalog which plays an important role in pulsar astronomy contained 706 pulsars (Taylor et al. 1996). This one covered both old (since 1981) and new pulsars (Dewey et al. 1985; Stokes et al. 1985, 1986; Clifton et al. 1992; Johnston et al. 1992; Taylor and Cordes 1993, and some others). This last catalog has not been updated since then. However, individual pulsars can be reached through a publicly accessible web page 1. Since 1996, several pulsar surveys have been carried out (Johnston et al. 1995; Manchester et al. 1996; Sandhu et al. 1997; Lyne et al. 1998, 2000; Camilo et al. 2001; Edwards and Bailes 2001a,b; Edwards et al. 2001a,b; Manchester 2001). In addition to this, inner regions of SNRs have been scanned to search for pulsars with connections to SNRs (Gorham et al. 1996; Lorimer et al. 1998; Kaspi et al. 1996). After 1996, the following pulsars with connections to SNRs or pulsars with confirmed association connections have been found and their distances were accurately determined (see Table 1):

- J0205+64/G130.7+3.1 (Murray et al. 2002),
- J1119-6127/G292.2-0.5 (Crawford et al. 2001),
- J1244-5916/G292.0+1.8 (Camilo et al. 2002a),
- J1803-2137/G8.7-0.1 (Finley and Ogelman 1994),
- J1846-0258/G292.7-0.3 (Gotthelf et al. 2000),
- J1952+3525/G69.0+2.7 (Koo et al. 1990),
- J2229+6114/G106.6+2.9 (Halpern et al. 2001).

Furthermore, Globular Clusters (GC) have been also searched for pulsars (Lyne 1995; Kulkarni and Anderson 1996; Biggs and Lyne 1996; Camilo et al. 2000, D’Amico et al. 2001). In globular cluster NGC104 (47 Tuc) 10 pulsar up to 1996 and 10 more pulsar after 1996 have been found. For the other known globular clusters no new pulsars were found. However, in each globular clusters NGC 6266, NGC 6342, NGC 6397, NGC 6544 and NGC 6752 one pulsar has been found after 1996 (Table 1).

In early days of pulsar observations a base frequency of around 400 MHz was used in the search. Since DM values of distant pulsars are high, 1400 MHz was used in surveys and in search for PSRs in SNRs and GC. As expected, the newly discovered pulsars are generally in the direction of the Galactic center. After 1996, no new pulsars have been found in Magellanic Clouds (MC). However, number of pulsars in GCs and number of millisecond pulsars with known ages ($P < 0.1$ sec and $P < \times 10^{-16}$ sec/sec) increased about 1.5 and 1.4 times, respectively. There is an considerable increase in number of pulsars found with low fluxes due to increase in both sensitivity of instrumentation used in pulsar surveys and the number of detailed surveys. For example in Arecibo’s survey window ($40^\circ \leq l \leq 65^\circ$; $|b| \leq 2.5^\circ$) 12 new pulsars were found. In this article our aim is to combine both old and new observational pulsar data and to calculate their parameters.

2. Pulsar Distances

Between 1970 and 1980, both the number of pulsars and the number of pulsars connected with an object having a well known distance (e.g. Magellanic clouds, some globular clusters and SNRs) were less. In addition to this, since at that time there was insufficient knowledge concerning Galactic electron distribution, it was difficult to find a good distance value using the DM value of pulsars. Thus, pulsars with distances estimated using HI line are used as an extra distance calibrator. It is known that it is impossible to calculate an object’s distance using HI line at 21 cm if the object’s radial velocity component of Galactic rotational velocity is small. In addition to this, in certain directions and distances the suitable distance to the shift of 21 cm line would be 2 instead of 1. Uncertainty in calculating the distance with this method is not less than 30–50%. Thus, in recent years, in determining calibrators for pulsars, distance estimates calculated using the 21 cm line are not accepted as a rule. For this reason it was not possible to find a distance estimate independent from a DM value for pulsars in certain directions and distances.

In estimating pulsar distances, the model of Galactic electron distribution by Taylor and Cordes (1993) has been widely used in recent years. However, in estimating the pulsar distances, the approach of Gök et al. (1996) gave smaller distances than the ones calculated using the model of Taylor and Cordes (1993) for pulsars farther than 4 kpc and with Galactic latitudes greater than about $10^\circ$. To form a new model electron distribution, Gómez et al. (2001) have published a huge pulsar list which could be used for calibrators. We have decided to revise their distance values to use them as calibrators. In Table 1 we present 39 pulsars for which errors in distances should not be higher than 30%. Since distances of pulsars from the same GC are the same, only one pulsar from each GC has been included in the table. Instead of presenting a long table, the pulsar table is prepared in a publicly accessible web page (see section 3). In this table, the total number of pulsars having distances independent from the DM value is 68. In Table 1 the number of pulsars is considerably smaller

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1 http://pulsar.ucolick.org/cog/pulsars/catalog/
Table 1. Pulsars for which errors in distances are not more than 30%.

| Name          | l    | b    | d    | DM   | \(n_e\) | Location            | References                  |
|---------------|------|------|------|------|---------|---------------------|----------------------------|
| 0024-7204W    | 305.9| -44.9| 4.5  | 24.3 | 0.005   | GC NGC 104 (47 Tuc) | (Harr96, Hess87)            |
| 0045-7319     | 303.5| -43.8| 57   | 105.4| 0.002   | SMC                 | (Feas87)                   |
| 0205+6449     | 130.7| 3.1  | 3.2  | 140.7| 0.044   | SNR G130.7+3.1      | (Cam02)                    |
| 0455-6949     | 281.2| -35.2| 50   | 91.0 | 0.002   | LMC                 | (Feas87)                   |
| 0502-6625     | 277.3| -35.5| 50   | 65.0 | 0.001   | LMC                 | (Feas87)                   |
| 0529-6655     | 277.2| -32.8| 50   | 100.0| 0.002   | LMC                 | (Feas87)                   |
| 0534+2200     | 184.6| -5.8 | 2    | 56.8 | 0.028   | SNR G184.6-5.8 (Crab)| (Trim71)                   |
| 0540-6919     | 279.7| -31.5| 50   | 146.0| 0.003   | LMC                 | (Tay96)                    |
| 0826+2637     | 196.9| 31.7 | 0.4  | 19.5 | 0.049   | Parallax            | (Gwin86)                   |
| 0835-4510     | 263.6| -2.8 | 0.45 | 68.2 | 0.152   | SNR G263.9-3.3 (Vela)| (Cha99, Legg00, Guse02)    |
| 0922+0638     | 225.4| 36.4 | 1.21 | 27.3 | 0.020   | Parallax            | (Chat01, Foma99)           |
| 1119-6127     | 292.2| -0.54| 7.5  | 707.4| 0.101   | SNR G292.2-0.5      | (Cri99, Legg00, Guse02)    |
| 1312+1810     | 332.9| 79.8 | 18.9 | 24.0 | 0.011   | GC NGC 5024 (M53)   | (Harr96, Hess87)           |
| 1456-6843     | 313.9| -8.5 | 0.45 | 8.6  | 0.019   | Parallax            | (Bail90)                   |
| 1513-5908     | 318.9| 15.9 | 1.8  | 253.2| 0.060   | SNR G320.4-1.2      | (Tay96, Guse02, Kasp02)    |
| 1641+3627B    | 59.8 | 40.9 | 7.7  | 29.5 | 0.004   | GC NGC 6205 (M13)   | (Harr96, Palt98)           |
| 1721-30       | 353.6| 7.3  | 5    | 114.4| 0.023   | GC NGC 6266 (M62)   | (Harr96, Dam01, Broc96a)   |
| 1748-2021     | 7.7  | 3.8  | 6.6  | 220.0| 0.033   | GC NGC 6440         | (Harr96, Orto94)           |
| 1910-59       | 336.5| 25.6 | 4    | 34.0 | 0.021   | GC NGC 6626 (M28)   | (Harr96, Rees91)           |
| 2022+5154     | 87.9 | 8.4  | 1.1  | 22.6 | 0.021   | Parallax            | (Camp96)                   |
| 2129+1209H    | 65.1 | -27.3| 10   | 67.2 | 0.007   | GC NGC 7078 (M15)   | (Tay96)                    |

Alca87 : Alcaino et al. (1987)  Alla97 : Allakhverdiyev et al. (1997)  Arma88 : Armandroff (1988)  Back82 : Backer and Sramek (1982)  Bail90 : Bailes et al. (1990)  Bris00 : Brinkmann et al. (2000)  Broc96a: Brocato et al. (1996a)  Broc96b: Brocato et al. (1996b)  Buon86 : Buonanno et al. (1986)  Cam92 : Camilo et al. (2002b)  Casw92 : Caswell et al. (1992)  Ch99 : Chatterjee et al. (2001)  Cra91 : Crawford et al. (2001)  Cudw90 : Cudworth and Rees (1990)  Dami94 : Damour et al. (1994)  Feas87 : Feast and Walker (1987)  Foma99: Fomalont et al. (1999)  Fros93 : Furst et al. (1993)  Guse02 : Guseinov et al. (2002)  Harr96 : Harris (1996)  Heit99 : Heitsch and Richtler (1999)  Hess87 : Hess et al. (1987)  John94 : Johnston et al. (1994)  Kaspi : Kaspi and Helfand (2002)  Kas94 : Kaspi et al. (1994)  Legg00 : Legg et al. (2000)  Legg00 : Legg (2000)  Paltr98 : Paltrinieri et al. (1998)  Rees91 : Rees and Cudworth (1991)  Rees96 : Rees et al. (1996)  Salt79 : Saltzer et al. (1979)  Sand96 : Sandquist et al. (1996)  Sara94 : Sarajedini and Norris (1994)  Tay96 : Taylor et al. (1996)  Weis80 : Weisberg et al. (2000)  Weis80 : Weisberg et al. (1998)
than the one in the calibrator list of Gómez et al. (2001). In this table, one of the most important calibrators is PSR J0835-4510 (in Vela SNR). The distance for this pulsar has been adopted as 0.45 kpc, which was given as 0.25 kpc by Gómez et al. (2001). This huge discrepancy needs some more explanation.

Recent estimates of Vela SNR are as follows. $d=0.25$ kpc (Oegelman et al. 1989), $d=0.25\pm0.03$ kpc (Cha et al. 1999), $d=0.28$ kpc (Bocchino et al. 1999) and $d=0.25\pm0.03$ kpc (Danks 2000). In estimating the distance one should also consider that Vela SNR expands in a dense environment. Its magnetic field is $B\approx6\times10^{-5}$ Gauss (de Jager et al. 1996) and its explosion energy is $(1-2)\times10^{51}$ erg (Danks 2000). Of course these values have really large errors, however, they are themselves big too. If we take into account all of these values then it is not acceptable to have Vela at the same position with SNR G327.6+14.6 in the $\Sigma-D$ diagram (remnant of the type supernova explosion at 500 pc above the Galactic plane; Hamilton et al. 1997) which expands in a dense environment of low matter density. Thus, Vela must be close to other SNRs which expand in a dense environment.

In the direction of the Vela remnant, none of the young open clusters (OC) and OB associations have distances as small as 0.25 kpc (Efremov 1989; Berdnikov and Efremov 1993; Aydin et al. 1997). The distance of OC Pismis 4 ($l=262.7$, $b=-2.4$) which belongs to the nearest Vela OB2 association and is in the direction of Vela, is 0.6 kpc (Ahumada and Lappaset 1995). Since the progenitors of SNRs (or pulsars) are massive stars, one would expect the Vela remnant to be closer to the star formation region instead of a distance value of 0.25 kpc.

If the distance value of 0.45 kpc is accepted for Vela, than the average electron density along the line of sight would be $n_e=0.153$ cm$^{-3}$. The pulsar with the second biggest $n_e$ value (about 0.113 cm$^{-3}$) is for PSR J1302-6350 ($l=304.2$, $b=-0.9$; companion is a B9 type star; $d=1.3$ kpc; variable wind in the environment). The next biggest $n_e$ value (0.107 cm$^{-3}$) is for PSR J1644-4569 ($l=339.2$, $b=-0.2$). Since luminosity of PSR J1644-4569 at 1400 MHz is bigger than any other known pulsar we could estimate its distance as no more than 4.5 kpc. Average value of $n_e$ for the rest of pulsars is around 0.04. So, it is impossible to accept a value of 0.25 kpc for Vela PSR and Vela SNR. We could only reduce our initial distance estimate of 0.45 kpc to 0.4 kpc the most.

For PSR J1701-30 ($l=353.6$, $b=7.3$), D’Amico et al. (2001) and Gómez et al. (2001) adopted a distance value of 6.7 kpc and they believed that the pulsar is inside the GC 6266 (M62). If such a high distance value is adopted for the pulsar, then the electron number density along the line of sight should considerably be lower than the values for the pulsars in the same direction and approximately at the same distance. It is much more realistic to accept a distance value of 5 kpc for this pulsar. Space density of both HII regions in the direction of Galactic center and SNRs, and a higher value of $n_e$ in the direction line of sight do not allow to have a very different $n_e$ value for the pulsars in the same direction and approximately at the same distance. Thus a question mark is added for PSR J1701-30 while accepting it as a calibrator due to doubts concerning in its distance value. The distance values of pulsars in other GCs are within the error limits of the ones given by (Gómez et al. 2001). Distances of PSRs connected with SNRs have been studied in an another unpublished work (Guseinov et al. 2002). Thus, their accurate distance values have been listed in Table 1. Among the pulsars that were used as calibrators and were a member of GC, the ones with the most varying distances were PSR J1748-2445A and B, J1804-0735 and J1910+0004 in GCs Ter 5, NGC 6539 and NGC 6760, respectively. These variations are due to the fact that new distances of these GCs are more than two times bigger than the estimates before 1996.

It is a well known fact that dynamical equilibrium could be achieved within the old populations (both halo and disk; characteristic time is $\approx10^{10}$ years). However, these populations are not in dynamical equilibrium with each other. Total mass of stars and gas which belongs to Galactic arms is about 1% of the total mass of Galaxy and parameters of arm structure changes with time. Characteristic time of these changes is about $10^{8}$ years. On the other hand, SFRs which are far from dynamical stability have an order of magnitude smaller ages than the characteristic time of arm structures. Therefore, one should not expect any coincidence between the geometric plane of arms and the Galactic plane throughout the whole Galaxy. SFRs might be found either below or above the Galactic plane. Optical observations of Cepheids with high luminosities (variables with long pulse periods) and red supergiants at a distance of $\approx5-10$ kpc from the Sun in the direction of $l\approx200-330^\circ$ have shown that SFRs lie about 300 pc below the Galactic plane. Similarly at the same distance and in the direction of $l\approx70-100^\circ$ SFRs lie about 400 pc above the Galactic plane. Finally, between 3 and 5 kpc distance and in the direction of $270-320^\circ$ massive Cepheids and red supergiants have been located about 150 pc below the Galactic plane (Berdnikov 1987).

In Figure 1, we present $l-b$ distribution of pulsars with a characteristic time of $\tau\leq5\times10^{7}$ years. As can be seen from the Figure, in the direction of $l\approx260-290^\circ$, some young pulsar are located below the Galactic plane. Distance of these pulsars show that their locations coincide with the location of Cepheids and red supergiants. For pulsars with distances of $d>5$ kpc, average distance from the Galactic plane is about 135 pc. From the Figure we see a similar deviation from the Galactic plane in the direction of $l\approx50-80^\circ$. These pulsars have an average $Z$ of about 150 pc and they probably belong to the Perseus arm. In distance estimation of pulsars we take into account all of these facts (distribution of young pulsars in the direction of $0^\circ < l < 20^\circ$ give rise to some inhomogeneity in pulsar surveys).

We discussed the fact that Galactic arms (SFRs) deviate from the Galactic plane in the outer parts of the Galaxy. However, for the inner part of the Galaxy (closer than the Sun distance i.e. about 8.5 kpc to the center) there is no evidence that the deviation from the Galactic plane is bigger than 100 pc. Therefore PSRs with the same age should have the same distance from the Galactic plane because average space velocity of pulsars do not depend on environmental conditions of a pulsar.
It is normal to neglect the influence of deviation from the Galactic plane for pulsars older than \( \approx 5 \times 10^6 \) years due to typical high space velocities of pulsars (on the average between 250 km s\(^{-1}\)) and 450 km s\(^{-1}\)) (Lyne and Lorimer 1994). On the other hand, the space velocity of some pulsars reaches 1000 km s\(^{-1}\); e.g. PSR J1801-2451 (Frail and Kulkarni 1991). But since the number of these type of pulsars are few, old pulsars with the same age must have the same average value of \( |Z| \) in all parts of the Galaxy, except the young ones.

Radio luminosity of PSRs should not depend on their birth place and should not considerably exceed luminosities of the strongest pulsars (e.g. Crab with a very well known distance and being the strongest pulsar in Magellanic clouds). Luminosity of Crab is \( \approx 2.6 \times 10^3 \text{ mJy kpc}^2 \), 56 mJy kpc\(^2\) for 400 MHz and 1400 Mhz, respectively. Luminosity of the strongest pulsar in Magellanic Clouds (PSR J0529-6655) is \( \approx 1.4 \times 10^4 \text{ mJy kpc}^2 \) at the 400 MHz (no measurement exists for 1400 MHz). Therefore the upper limit for luminosities of PSRs might be close to the value of \( 1.6 \times 10^3 \text{ mJy kpc}^2 \) and \( 3.5 \times 10^3 \text{ mJy kpc}^2 \) for 400 MHz and 1400 Mhz, respectively (spectral indices of PSRs have been also taken into account). In our list of 1315 PSRs the strongest one is PSR J1644-4559 with luminosities of \( 6.29 \times 10^3 \text{ mJy kpc}^2 \) and \( 7.58 \times 10^3 \text{ mJy kpc}^2 \) for 400 and 1400 MHz, respectively.

Since PSRs on the Galactic plane were born in the Galactic plane and surveys have scanned the Galactic plane many times, most of PSRs, especially the farthest ones, have small Galactic latitudes \((|b| < 5^\circ)\). As can be seen in our calibrator table (Table 1), for 12 PSRs \(|b| > 30^\circ\), for 10 PSRs \(30^\circ > |b| > 7^\circ\), for 6 PSRs \(7^\circ > |b| > 3^\circ\), and only for 11 PSRs \(|b| < 3^\circ\). Thus, the calibrators in Magellanic Clouds, GCs and calibrators with known trigonometric parallax’s becomes insignificant for PSRs with small \(|b|\). Only 3 from our calibrator list belong to \(|b| < 3^\circ\) and have distances greater than 5 kpc. Therefore, for the PSRs with large distance and low \(|b|\) values there are almost no calibrators. In addition to this, for such distances it is quite difficult to judge the electron density value.

Considering the reasons given above in adopting distances for PSRs, the following criteria become very important:

1. In the direction of \(40^\circ < l < 320^\circ\) we see the strongest pulsars throughout the Galaxy.
2. For all Galactic longitudes \((l)\), pulsars with equal characteristic times \((\tau)\) must have, on the average, similar \( |Z| \) values except PSRs with \( \tau \approx 5 \times 10^6 \) years in the regions where SFRs are considerably above or below the Galactic plane.
3. PSRs with \( \tau < 5 \times 10^5 \) years must still be near to their birth places i.e. in the SFRs.
4. The pulsar luminosity does not depend on \( l \) and \( d \), and it should not exceed the luminosity of known strongest pulsars at 400 and 1400 MHz.
5. Electron density in the Galaxy must be correlated with the number density of HII regions and OB associations, and it must increase as one approaches to the Galactic center.
6. PSR distances must be arranged in such a way that their value should correspond to a suitable distance value of PSRs in Table 1 (value of DM and the direction of the PSR have to be taken into account).

### 3. Pulsar Data

All of the collected parameters (both observational and calculated ones) for 1315 pulsars are given separately in a publicly accessible web page: http://www.xrbc.org/pulsar/. Description of each column is given in Table 2.

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