Chin. J. Astron. Astrophys. Vol. 6 (2006), No. 5, 625–628
(*http://www.chjaa.org*)

Chinese Journal of
Astronomy and
Astrophysics

Historical Evidence for the Birth of the Newly Discovered Pulsar PSR J1833–1034 *

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Received 2006 February 15; accepted 2006 April 6

Abstract Stimulated by the recent discovery of PSR J1833–1034 in SNR G21.5–0.9 and its age parameters presented by two groups of discovery, we demonstrate that the PSR J1833–1034 was born 2053 years ago from a supernova explosion, the BC 48 guest star observed in the Western Han (Early Han) Dynasty by ancient Chinese. Based on a detailed analysis of the Chinese ancient record of the BC 48 guest star and the new detected physical parameters of PSR J1833–1034, agreements on the visual position, age and distance between PSR J1833–1034 and the BC 48 guest star are obtained. The initial period P_0 of PSR J1833–1034 is now derived from its historical and current observed data without any other extra assumption on P_0 itself, except that the factor $P\dot{P}$ is a constant in its evolution until now.

Key words: stars: pulsars: individual (PSR J 1833–1034) — ISM: supernova remnants: individual (G21.5–0.9) — supernovae: individual (BC 48 guest star) — history of astronomy

1 INTRODUCTION

G21.5–0.9 as a famous Crab-like SNR (supernova remnant) has been extensively studied in the radio and X-ray bands for about 30 years (Wilson & Weiler 1976; Becker & Szymkowiak 1981). A hidden pulsar was once revealed in G21.5–0.9 (Seward & Wang 1988), but has not been seen in the radio (Kaspi et al. 1996; Crawford et al. 2002) and X-ray bands (Slane et al. 2000; Safi-Harb et al. 2001; Palombara & Mereghetti 2002) since. Recently, PSR J1833–1034 was discovered in G21.5–0.9 independently by two groups (Camilo et al. 2006; Gupta et al. 2005) with the Parks Telescope and Giant Meterwave Radio Telescope, respectively. The important parameters of PSR J1833–1034 detected by the two groups are basically the same and are as follows: spin period $P = 61.8\,\mathrm{ms}$; period derivative $\dot{P} = 2.0 \times 10^{-13}$; dispersion measure $\mathrm{DM} = 170\ \mathrm{cm}^{-3}$ pc; spin–down luminosity $\dot{E} = 3.3 \times 10^{37}$ erg s^{-1} and characteristic age $\tau_c = 4.9 \times 10^3$ yr. Both groups consider the age of PSR J1833–1034 to be not so old as the above characteristic age and suggest one younger than 1000 years. According to the identification principle of agreements in the four dimensional space (visual position, age and distance) between the historical supernovae and their possible remnants presented by us (Wang et al. 1986, Wang 1987), we demonstrate that PSR J1833–1034 as the central pulsar of SNR G21.5–0.9 was born from the BC 48 guest star, so PSR J1833–1034 is 2053 years old, about one half of its characteristic age and more than twice the age suggested by the two groups (Camilo et al. 2006; Gupta et al. 2005).

2 THE BC 48 GUEST STAR

The BC 48 guest star was observed by ancient Chinese in the Western Han Dynasty (Early Han, BC 206–AD 25) and was recorded in *Qian Han Shu* (History of the Early Han Dynasty). A copy of this record is

* Supported by the National Natural Science Foundation of China.

shown in Figure 1: it is the first time that a copy of the original ancient record for the BC 48 guest star is displayed in a contemporary astronomical investigation. Its translation in English is as follows:

"In the 1^{st} year of Chu-Yuan reign period of Yuan Di, the 4^{th} lunar month (May 3–31, 48 BC), a guest star as big as a melon with bluish-white color was seen about 4 feet east of the second star of *Nan-Dou*".

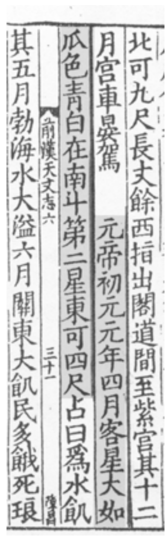
北可九尺長丈餘西指出閣道間至紫宮其十二
月宮車晏駕　元帝初元元年四月客星大如
瓜色青白在南斗第二星東可四尺占曰爲水飢
前漢天文志六　三十一
其五月勃海水大溢六月關東大飢民多餓死琅

Fig. 1 Copy of the ancient Chinese record of the BC 48 guest star (the shaded paragraph) in the Astronomical Chapter No. 6 of *Qian Han Shu* (History of the Former Han Dynasty), originally written by Ban Gu in AD 100.

The ancient record of the BC 48 guest star is widely known in China, in such compilations as *Wen Xian Tong Kao* (Historical Investigation of Public Affairs) of Ma Duan-lin of the 13th century, and *Xi Han Hui Yao* (Essential Records of the Former Han Dynasty) by Xu Tian-lin of the 13th century, and in the West, through Biot in the 19th century. It was also continually quoted in Lundmark (1921), Xi (1955), Ho (1962), Xi & Bo(1965), Chen (1986) and Zhuang & Wang (1987) in the last century. They all regarded the BC 48 guest star as a supernova.

In the above ancient record, the BC 48 guest star was described as at 4 feet east of the second star of *Nan-Dou* (the "Southern Dipper"), an asterism with a similar shape to the Big Dipper (the Plough) but located south of equator, in the constellation Sagittarius. The second star of *Nan-Dou* is λ Sgr; see the color star map #5 in the Chinese Encyclopaedia (Astronomy Volume) (1980) and Chen (1984). As to the unit "foot" usually used by the ancient Chinese to describe separations on the sky, the conversion of the foot to the degree was given by Kiang (1972) as 1 foot $\simeq 1.5 \pm 0.24$ degrees. So the BC 48 guest star was $\sim$6 degrees east of λ Sgr. Transferring the positions of G21.5–0.9 with PSR J 1833–1034 and λ Sgr respectively to the time of 48 BC, we find that the supernova/progenitor of G21.5–0.9 with its central PSR J1833–1034 was located to the north east of λ Sgr, $\sim$6 degrees east of λ Sgr along the east-west line. It is just the location of the BC 48 guest star given in the ancient record. Thus we have obtained the first agreement in the visual position for both the BC 48 guest star and G21.5–0.9 with its central pulsar PSR J1833–1034.

In the May of 48 BC, the visual position of the BC 48 guest star would be in the night sky between $\sim$10 p.m. – 5 a.m., surely visible for the Chinese observers at Xi'an, the Capital of the Early Han Dynasty. Its maximum altitude would be nearly 30° at midnight.

The BC 48 guest star was described as big as a melon in the ancient record. It can be explained by the effect of visual sense for a bright object and its interacting or scattering with the material along its line-of-sight where three clouds of CO exit (Camilo et al. 2006; Dame, Hartmann & Thaddeus 2001). The above scattering effect would be further strengthen if the BC 48 guest star was observed in the evening or before dawn near the horizon. Since it was described as a guest star in the ancient record but without mentioning its visible duration, it could not be as bright as the other well known guest stars. An estimate of visual magnitude at maximum of between around zeroth and second magnitude seems plausible. The main reason is the strong extinction for the BC 48 guest star. This is consistent with its remnant's current result of $N_{\rm H}/{\rm DM} \simeq 40$ pointed out by the two groups (Camilo et al. 2006; Gupta et al. 2005), our analysis and more discussion in Section 4.

3 THE INITIAL PERIOD AND THE AGE OF PSR J1833–1034

Now we regard G21.5–0.9 with PSR J1833–1034 as being born from the BC 48 guest star, and see whether this is reasonable for the evolution of PSR J1833–1034. Start with the simple differential formula $dP = \dot{P}dt$, where P and $\dot{P}$ are the spin period and period derivative of PSR J1833–1034 respectively, multiply both sides by $2P$, assume the factor $P\dot{P}$ to be a constant, integrate, and we obtain a simple formula for the age of the pulsar, $t = \frac{P^2-P_0^2}{2P\dot{P}}$, where P_0 is its initial period. Now, let the age of PSR J1833–1034 be 2053 year as inferred from the BC 48 guest star, then from $P = 61.8$ ms and $\dot{P} = 2.0 \times 10^{-13}$ given by the recent observations (Camilo et al. 2006; Gupta et al. 2005), we obtain $P_0 = 47$ ms from the above formula, which only depends on a very simple assumption: $P\dot{P}$ is a constant. The same result $P_0 = 47$ ms can be arrived at by the following formula (Camilo et al. 2006) $t = P\dot{P}^{-1}(n-1)^{-1}[1-(P_0/P)^2]$ from a constant magnetic moment with braking index $n = 3$. The derived result $P_0 = 47$ ms from the historical data is a reasonable value for the initial period of pulsars. Moreover, the age of PSR J1833–1034 of 2053 years since its birth in the BC 48 guest star is consistent with the normal physical model of pulsars.

4 THE DISTANCE OF PSR J1833–1034

As to the distance of PSR J1833–1034, there is a contradiction between the value of $N_{\rm H}$ and DM: $N_{\rm H}/{\rm DM} \simeq 40$ as pointed out by Camilo et al. (2006) and Gupta et al. (2005). The high value of $N_{\rm H}$ is obviously due to the extra absorption by CO clouds that exists along the line of sight (Camilo et al. 2006; Gupta et al. 2005; Dame, Hartmann & Thaddeus 2001). In view of this specific circumstance of PSR J1833–1034, its distance should be given by its DM value, in the range of 3.3–3.7 kpc (Gupta et al. 2005). We take its median value 3.5 kpc as its distance, and reasonably reserve the high value of $N_{\rm H}(1.83 \times 10^{22}$ cm^{-2}, Safi-Harb et al. 2001) to derive the absorption $A_v = 8$ mag by the formula (Gorenstein 1975) A_v (mag)$= 4.5 \times 10^{-22} N_{\rm H}$. From the well known formula of the absolute magnitude, the BC 48 guest star is estimated as -19 mag to -21 mag, an acceptable result considering the range of absolute magnitude of supernovae. The estimate of the visual magnitude for the BC 48 guest star of course is approximate or even crude. If the BC 48 guest star is estimated brighter than 0 mag, then it is likely to be a hypernova/γ-ray burst, and then it is reasonable to attribute its bluish-white color and as large-as-a-melon size, as described in the ancient record, to the scattering of invisible radiation of higher frequencies by CO clouds along the line of sight and the visual sense of its high brightness.

5 CONCLUSIONS

PSR J1833–1034 was probably born from the supernova, the BC 48 guest star, based on its ancient record and physical parameters. This is consistent with the normal law of pulsar evolution. Both the BC 48 guest star and PSR J1833–1034 are in satisfactory agreement with regard to the age, distance and visual position. The initial period P_0 of PSR J1833–1034 is derived from its historical and current observed data without any other extra assumption on P_0 itself, except that the factor $P\dot{P}$ is a constant in its evolution until now. The uncertainty of the distance for G21.5–0.1 and PSR J1833–1034 is a most important factor which needs to be, and hopefully will be improved in the future, for further study on the birth and evolution of this interesting composite SNR and its central pulsar PSR J1833–1034.

Acknowledgements Z. R. Wang thanks to Nan, H. J. for his gift of a set of books (Chinese Astronomy History, Vol.1–Vol.6 by Chen, Z. G.) in 1987, to Xi, Z. Z. and Kiang, T. for helpful related discussion respectively, to Chen, Y. and Li, X. D. for reading our manuscript in detail, to Wan, X. S., Chen, W. C. and Jiang, B. for some help in the typing, and to Jiang, S. Y. for his valuable comments. This work was supported by the National Natural Science Foundation of China, Grant Nos. 10273005 and 10573009.

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