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Neutron Stars in Globular Clusters: Evidence of Young Age?

Paul Nethercott*

Abstract

The age of globular clusters and the stars they contain is thought to be on the order of 10 billion years. Neutron stars are believed to form via supernova explosions of massive stars, and their progenitor stars have very short evolutionary lifetimes, so neutron star production in globular clusters ought to have ceased billions of years ago. Neutron stars move at high velocities, which are probably the result of large kicks they receive during their formation. Their speeds are more than sufficient for neutron stars to escape from globular clusters within thousands of years. Hence, globular clusters should contain few, if any, neutron stars. Yet, globular clusters typically contain many neutron stars. This suggests that globular clusters may be much younger than generally thought.

Introduction

Globular clusters are centrally condensed, radially symmetric, tightly bound star clusters, containing between 50,000 and a million stars. Astronomers consider globular clusters to be some of the oldest structures in the galaxy, with an average age estimate of more than 10 billion years (Vandenberg, 2013). Recently, Meissner and Weiss (2006) estimated the ages of 46 globular clusters, with ages ranging 8–16 billion years. According to current understanding, the stars in globular clusters share in this age. These age estimates come from the comparison of observed color-magnitude diagrams with theoretical Hertzsprung-Russell diagrams (for a discussion of this technique in the creation literature, see Faulkner and DeYoung, 1991). It is believed that star formation ceased early in the history of globular clusters, so that virtually no star formation has happened since shortly after the formation of the clusters.

Neutron stars are very small, but very dense, stars primarily composed of neutrons at nuclear density. Neutron stars are thought to be the stellar remnants remaining from the core collapse of massive stars resulting in either type II, type Ib or type Ic supernovae. Stars rotate and possess magnetic fields, and neutron stars preserve these properties of their progenitor stars. However, as the cores collapse to form neutron stars, conservation of angular momentum requires that neutron stars rotate very quickly. A similar thing happens to the magnetic fields so that neutron stars have intense magnetic fields. Due to their small size, neutron stars are extremely faint in visible light and thus are difficult to detect in optical wavelengths. However, neutron stars emit considerable energy in the radio part of the spectrum. The radiation is powered through the interaction of charged particles with the very rapidly spinning strong magnetic fields carried along by the neutron stars' rotation. Most of the radio power of a neutron star is beamed

* Paul Nethercott, Beerwah, Queensland, Australia, paul_nethercott@live.com.au
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along a path aligned with its magnetic field axis. The magnetic field typically is tilted with respect to the rotation axis, so the neutron star's rapid rotation beam sweeps the beam around. This causes a neutron star's beam to sweep out a cone similar to a searchlight. If we happen to lie near the cone swept out by a particular neutron star, we can detect it by rapidly periodic pulses. However, if we lie sufficiently far from the cone, we do not. We call neutron stars detected this way pulsars. These observations normally are made in the radio part of the spectrum. Obviously, we cannot detect most neutron stars this way, so the number of neutron stars probably is far higher than those that we actually discover as pulsars.

The only other method for detecting neutron stars is when a neutron star is in a close binary system. The strong tidal force of the neutron star can pull matter from its companion onto the neutron star. The in-falling matter is heated to very high temperature, resulting in copious amounts of X-rays. These X-ray binaries can be observed only above Earth's atmosphere, because Earth's atmosphere is completely effective in blocking celestial X-ray sources. For more discussion of neutron stars in the creation literature, see the review of Faulkner (2008). For most of this paper, neutron stars will be discussed in the context of pulsars, so in some respects these terms will be used interchangeably.

High Velocity Neutron Stars

Neutron stars frequently have anomalously high velocities as compared to most stars in the galaxies. Neutron star velocities typically are on the order of hundreds of km/s or even thousands of km/s. This was first noted by Gunn and Ostriker (1970) on the basis of the higher dispersion of pulsar locations above the galactic plane as compared to O and B type stars, the presumed progenitors of neutron stars. The high velocities have been confirmed by later studies using the same approach but much more data that has been gathered. Additionally, many pulsars have now had their proper motions measured with radio telescopes, offering more direct evidence of the common high velocities of pulsars. Proper motions can be converted to tangential velocities, provided that we know the distances to the pulsars in question. Fortunately, distances of pulsars are relatively straightforward to measure by taking advantage of dispersion. Dispersion refers to a slight time difference in the arrival of pulses at various radio frequencies. Dispersion depends upon the frequencies used and the column density of free electrons in the intervening interstellar medium (ISM). We have a good understanding of the density of free electrons in the ISM, so observed dispersions can be converted to distances.

However, tangential motion is only one component of space motion, the other component being radial velocity. Radial velocities are much more difficult to determine for pulsars, so many studies find only tangential motion. Therefore, actual space motion would be greater than simple tangential motion. In statistical studies of a large number of pulsars, the average space motion would be the square root of 2 greater than the average tangential velocity.

The study by Cordes and Chernoff (1998) produced space velocities for 49 pulsars. Table 1 reproduces their results. The average speed is 384 kilometers per second. The minimum speed is 162 kilometers per second. These results are conservative, for other studies have suggested higher averages. For instance, Zou et al. (2005) published tangential velocities of 74 pulsars. The average tangential velocity was over 1,000 km/s. However, if radial velocities were included, the space velocities would be even larger. Hobbs et al. (2005) reevaluated motions of 233 pulsars, in which they concluded that young pulsars have a mean velocity of 400 km/s, though some have velocities of over 1,000 km/s. The situation recently has been summarized by Wongwathanarat, Janka, and Müeller (2010):

> Young neutron stars (NSs) possess average space velocities around 400 km/sec, much larger than those of their progenitor stars, implying that they are accelerated during the birth in a supernova (SN) explosion.

In addition, there may be a selection effect against detecting the higher speed pulsars, because they likely have moved far from our location near the galactic plane or might even have escaped the galaxy. At such great distance from us, it is difficult to measure their proper motions. Hence, the true average neutron star velocity may be greater than measured.

There have been several proposed explanations for the prevalence of pulsars having high velocity. The most common explanation is asymmetries in the supernova explosions that formed the neutron stars. An asymmetry in a supernova explosion would impart a kick to the forming neutron star via Newton's third law of motion. Hence, astronomers call the high velocities of neutron stars kick speeds, or simply kicks. Lai (2000) has reviewed the various proposed mechanisms for neutron star kicks.

Neutron Stars in Globular Clusters

In recent years, it has become apparent that pulsars (and hence neutron stars) are common in globular star clusters. For instance, the recent catalogue of Freire (2012) lists 144 pulsars in 28 globular clusters. While conducting a deep Chandra X-ray satellite survey of the globular cluster 47 Tucanae, Heinke et al. (2005) estimated that the cluster contained at least 300 neutron stars. Note that this result was based upon the number of X-ray binaries that the authors thought that they detected.

Though it is difficult to measure directly the speeds of pulsars in globular clusters, globular cluster neutron stars would have to be fundamentally different from field neutron stars (neutron stars that do not appear to be part of a cluster) for them not to have kicks as well. Assuming that they have similar kicks as field neutron stars, neutron stars in globular clusters ought to exit their hosts within thousands of years, not millions or billions of years.

Astronomers are confident that neutron stars represent an end state of massive stars. But massive stars have short lifetimes, on the order of tens of millions of years, far shorter than the billions of years generally assumed for globular clusters. Therefore, no neutron stars should have formed in galactic globular clusters for billions of years. So why are there still neutron stars in globular clusters? A recent article admits this is a problem that secular astronomers need to resolve:

> There is mounting evidence that as many as 1000 neutron stars (NSs) may be present in some of the richest globular clusters in the Galaxy, which perhaps amounts to more than 10%–20% of the NSs ever formed in each cluster. Such a large NS retention fraction is seemingly at odds with recent estimates of the characteristic "kick" speeds of single radio pulsars in the Galaxy, ranging from roughly 5 to 10 times the central escape speeds of the most massive globular clusters. This retention problem is a long-standing mystery. (Pfahl, Rappaport, and Podsiadlowski, 2002, p. 283)

Or consider the words of Kuranov and Postnov (2006, p. 394):

> The hypothesis of high space velocities of young NSs immediately leads to the well-known problem of NS retention in GCs, since the escape velocity even in the densest clusters does not exceed several tens of km/sec. Most of the NSs born through the core collapse of massive stars should have escaped from the cluster shortly after its formation.

Adopting a kick speed typical of neutron stars, we can estimate the time required for a neutron star to escape from the center to the outer edge of a globular cluster. Using somewhat unconventional units, let t be the time of escape in years, c the velocity of light in km/s, v the kick velocity of a neutron star also in km/s, and r the radius of the globular cluster in light years.

$$t = \frac{c}{v} r \tag{1}$$

The energy required to overcome the gravity of a globular cluster would slow the neutron star, and hence increase the time for the neutron star to escape. However, the escape velocities from the cores of globular clusters are on the order of tens of km/s, about an order of magnitude less than a commonly accepted typical kick for neutron stars. Thus, this factor would increase the required escape time only marginally.

Using the above formula, I computed the escape time for neutron stars for the 29 globular clusters in the Messier Catalogue. The physical sizes of the globular clusters were taken from various sources in the literature. The results are tabulated in Table 1. I computed two escape times. The faster escape times assume a kick speed of 450 km/s, a commonly accepted value, while the slower escape times assume a much more modest kick speed of 100 km/s. Even using the slowest speed, the maximum age is only 660,000 years. Again, consideration of overcoming the gravitational binding of a kicked neutron star originating near a globular cluster's core would increase these escape time estimates only marginally. This sample represents about 20% of the total number of galactic globular clusters. These are the brightest globular clusters (a result of being among the closer globular clusters to us) visible from temperate latitudes of the Northern Hemisphere. However, astronomers believe that the Messier Catalogue globular clusters represent a good sample. Since the neutron star formation rate within globular clusters is assumed to have been zero for billions of years, how can there still be neutron stars within globular clusters?

Since this has been a long-standing problem for the currently understood theory of stellar evolution, it is not surprising that astronomers have addressed this issue. In their estimation, the most promising solution to the problem is to appeal to neutron stars existing in close binaries. When two stars are in close proximity as they are in close binaries, the two stars affect each other's development. Indeed, binarity appears to be implicated in a host of astrophysical processes, such as all types of novae and some types of supernovae. They are implicated in millisecond pulsars (MSPs) as well. Millisecond pulsars have rotational periods on the order of a millisecond. It is believed that some pulsars may be created with millisecond periods. However, the radiation that pulsars emit is powered by rotational kinetic energy. As pulsars age, their rotation periods decrease. The age of a pulsar can be estimated by the spin-down rate, the age given by P/(dP/dt). Hence pulsars, regardless of their initial periods, rapidly increase their periods far out of the millisecond range. Why are there so many millisecond pulsars? In close binary stars, matter and angular momentum transfers from one star to its companion. In this manner, millisecond pulsars have been spun up from the original longer periods. These rejuvenated millisecond pulsars sometimes are called recycled pulsars. There is much observational evidence to support this understanding. A close companion can reduce the kick that a forming neutron star receives by absorbing some of the kick. There is observational evidence of this. Toscano, et al. (1999) presented velocities of 23

Globular Clusters Name	Low Kick Max Age Years	Average Kick Max Age Years	Cluster Radius Light Years	Secular Age Years
Messier 2	261,900	58,200	87	13 billion
Messier 3	270,000	60,000	90	8 billion
Messier 4	105,000	23,333	35	12.2 billion
Messier 5	240,000	53,333	80	13 billion
Messier 9	135,000	30,000	45	12 billion
Messier 10	124,800	27,733	41.6	11.39 billion
Messier 12	111,600	24,800	37.2	12.67 billion
Messier 13	252,000	56,000	84	11.65 billion
Messier 14	150,000	33,333	50	14.2 billion
Messier 15	264,000	58,667	88	12 billion
Messier 19	210,000	46,667	70	11.9 billion
Messier 22	150,000	33,333	50	12 billion
Messier 28	90,000	20,000	30	12 billion
Messier 30	279,000	62,000	93	12.93 billion
Messier 53	660,000	146,667	220	12.67 billion
Messier 54	459,000	102,000	153	13 billion
Messier 55	144,000	32,000	48	12.3 billion
Messier 56	126,000	28,000	42	13.7 billion
Messier 62	147,000	32,667	49	11.78 billion
Messier 68	159,000	35,333	53	11.2 billion
Messier 69	126,000	28,000	42	13.06 billion
Messier 70	102,000	22,667	34	12.8 billion
Messier 71	39,000	8,667	13	9.5 billion
Messier 72	126,000	28,000	42	9.5 billion
Messier 75	201,000	44,667	67	9.5 billion
Messier 79	354,000	78,667	118	11.7 billion
Messier 80	144,000	32,000	48	12.54 billion
Messier 92	357,000	79,333	119	14.2 billion
Messier 107	118,500	26,333	39.5	13.95 billion

Table 1. Messier Globular Clusters, Escape Times

millisecond pulsars with an average of 85 km/s:

> Most of the ordinary pulsars have velocities up to 500 km/sec, with a small number of pulsars with velocities as high as 1000 km/sec: The vast majority of MSPs, however, have velocities less than 130 km/sec and average just 85 km/sec +-13 km/sec. (Toscano, et al, 1999, p. 929).

However, even these lower velocities are more than adequate to overcome the gravity of globular clusters, because the average core escape velocity for globular clusters is at most 50 km/s. All this would succeed in doing would be to retain the few MSPs on the extreme low-energy tail of the distribution and slightly lengthen the escape time of the others.

Since the typical lower kick speeds of binary neutron stars is insufficient to solve the neutron star retention problem for globular clusters, another proposed solution is that there is a bi-modal distribution of velocities with one mode having essentially zero kick velocity. For instance, Podsiadlowski et al. (2004, p. 1044) observed:

> Further observational evidence that at least some NSs receive low kicks at birth is provided by the fact that a large number of NSs are found in globular clusters; some massive globular clusters may contain more than 1000 NSs. Since the central escape velocity is generally 50 km/sec, essentially all of the NSs born in a globular cluster should escape from the cluster if they received a kick consistent with the kick distribution for single radio pulsars.

Notice that they have converted the problem into "evidence" (their term) for the solution to the problem! As of yet, there is no clear empirical evidence that there is bimodal distribution in neutron star velocities.

Conclusion

The high velocity nature of neutron stars is well established. It also is a well-established fact that globular clusters contain a significant number of neutron stars. These conclusions are based upon empirical data collected in recent decades. It is the consensus position that globular clusters and the stars that they contain are very old. However, this is a matter of interpretation of data based upon evolutionary assumptions. There are no theoretical or observational reasons why neutron stars within globular clusters are fundamentally different from field neutron stars. Therefore, neutron stars within globular clusters probably have high velocities as well. These velocities are sufficient for the neutron stars to have escaped from the globular clusters in thousands of years. Hence, the large number of neutron stars in globular clusters is a dilemma for the evolutionary worldview. The existence of so many neutron stars in globular clusters may be evidence of recent creation.

How do biblical creationists explain high velocity neutron stars? That is not clear. There are reasons to accept the usual explanation of neutron stars as the result of certain supernova explosions (Faulkner, 2008), but perhaps at least some neutron stars might have alternate explanations. Did God create some neutron stars at the beginning? If so, did He make them with high velocities? If so, why? In a recent creation, might we expect fewer supernovae in the history of globular clusters than in the evolutionary model and hence fewer neutron stars in globular clusters today? Unfortunately, these answers await a more fully developed creation theory of astronomy.

References

Cordes, J.M., and D.F. Chernoff. 1998. Neutron star population dynamics II: three-dimensional space velocities of young pulsars. *Astrophysical Journal* 505:315–338.

Faulkner, D.R., and D.B. DeYoung. 1991. Toward a creationist astronomy. *CRSQ* 28:87–92.

Faulkner, D.R. 2008. A review of stellar remnants: physics, evolution, and interpretation. *CRSQ* 44:76–84.

Freire, P.C.C. 2012. Pulsars in globular clusters. http://www.naic.edu/~pfreire/GCpsr.html

Gunn, J.E., and J.P. Ostriker. 1970. On the nature of pulsars III: analysis of observations. *Astrophysical Journal* 160: 979–1002.

Heinke, C.O., J.E. Grindlay, P.D. Edmonds, H.N. Cohn, P.M. Lugger, F. Camilo, S. Bogdanov, and P.C. Freire. 2005. A deep Chandra survey of the globular cluster 47 Tucanae: catalog of point sources. *Astrophysical Journal* 625:796–824.

Hobbs, G., D.R. Lorimer, A.G. Lyne, and M. Kramer. 2005. A statistical study of 233 pulsar proper motions. *Monthly Notices Royal Astronomical Society* 360:974–992.

Kuranov, A.G., and K.A. Postnov. 2006. Neutron stars in globular clusters: formation and observation manifestations. *Astronomy Letters* 2006, 32(6):438–451.

Lai, D. 2000. Physics of neutron star kicks. In Cheng, K.L., H.F. Chau, K.L. Chan, and K.C. Leung (editors), *Stellar Astrophysics*, pp. 127–136. Springer, Berlin, Germany.

Meissner, F., and W. Weiss. 2006. Global fitting of globular cluster age indicators. *Astronomy Astrophysics* 456:1085–1096.

Pfahl, E., S. Rappaport, and P. Podsiadlowski. 2002. A comprehensive study of neutron star retention in globular clusters. *Astrophysical Journal* 573:283–305.

Podsiadlowski, Ph., N. Langer, A.J.T. Poelarends, S. Rappaport, A. Heger, and E. Pfahl. 2004. The effects of binary evolution on the dynamics of core collapse and neutron star kicks. *The Astrophysical Journal* 612:1044–1051.

Toscano, M., J.S. Sandhu, M. Bailes, R.N. Manchester, M.C. Britton, S.R. Kulkarni, S.B. Anderson, and B.W. Stappers. 1999. Millisecond pulsar velocities. *Monthly Notices Royal Astronomical Society* 307:925–933.

Vandenberg, Don A. 2013. The ages of 55 globular clusters. *The Astrophysical Journal* 775:134–171.

Wongwathanarat, A., H.-T. Janka, and E. Müeller. 2010. Hydrodynamical neutron star kicks in three dimensions. *Astrophysical Journal Letters* 725:L106.

Zou, W.Z., G. Hobbs, N. Wang, R.N. Manchester, W.J. Wu, and H.X. Wang. 2005. Timing measurements and proper motions of 74 pulsars using the Nanshan Radio Telescope. *Monthly Notices Royal Astronomical Society*, 2005, 362:1189–1198.