preliminary examination of Crossley plates taken in 1899, however, shows the image of the south-west component to be approximately the same brightness as on modern plates. Accurate limits to the amount of any brightness changes are difficult to set because of the possible effects of differences in the spectral response of old and new emulsions, but it is unlikely that the brightness has varied by more than a factor of two.

It should be noted that these observations, which confirm the earlier results[1-3], were obtained using an entirely different observational procedure. Because the field stars do not vary, the possibility that the observed flashes are produced by spurious electronic signals can be eliminated.

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Frequency of Events producing Pulsars

IF the pulsed radio source found near the Crab Nebula[1] is a remnant of the supernova event of 1054, then the secular change in its period (assumed to be intrinsic to the source) reported by Richards[2] can be used to estimate the age of typical longer period pulsars and hence the frequency with which pulsar-producing events occur in the galaxy.

The period of the Crab Nebula object is changing at a rate of about $1{\cdot}35\times10^{-5}$ s yr^{-1} (ref. 2). Rates of change of period for longer period pulsars on the other hand are at most of the order of 10^{-7} s yr^{-1} (refs. 3 and 4). This means that the rate of change of periods must be a decreasing function of time if the former sort of object is to evolve into one of the latter. If we make the simplest possible assumption—that rate of change of period is a linearly decreasing function of time—then the measured rates and upper limits suffice to determine a lower limit of 2×10^{5} yr for the age of a 1·5 s period pulsar.

About twenty pulsating sources have now been observed within a distance of 500 pc or so from the Sun. The region surveyed is about 1/400 or 1/6,000 of the volume of the galaxy depending on whether the objects belong to the disk or the halo population. The total number of pulsars in the Galaxy, allowing perhaps for a factor of two for the present incompleteness of the sample, is of the order of 16,000 or 240,000 depending on the population type.

Combining these numbers with the lower limit just found for the age of representative objects suggests an upper limit to pulsar-producing events in the Galaxy of one every 12 yr for disk objects, or one per year for halo objects. The former number is in reasonable agreement with recent estimates by Oort[5] and others of rates of supernovae.

If the present pulsar population is representative of that over the lifetime of the Galaxy, then the total number of pulsars created over that lifetime has been at most 5×10^{8} or 10^{10}. The former number is of some interest as it is the number of stars in the Galaxy earlier than FO, or the number of stars significantly more massive than the Chandrasekhar limit, if the luminosity function in the solar neighbourhood[6] is representative of the Galaxy as a whole.

The pulsating radio source found near the Vela *X* supernova remnant has a period of about 0·089 s (ref. 7) and, if truly associated with that remnant, strengthens the evidence that pulsar period is a function of age. A measurement of the rate of change of its period would provide another point on the curve of rate versus age, testing the assumption of linearity.

A rather more fruitful assumption is that it is the rate of loss of energy stored in a pulsating object which is a decreasing function of time. For the sake of exactitude and simplicity, let us consider the constant-amplitude pulsation of a constant-mass object with the amount of stored energy given by the equations of simple harmonic motion. Then, if dE/dt goes as $1/t$

$$\frac{dP}{dt} = \frac{-C_1}{2t}P^3$$

and

$$P^{-2} = C_1 \ln t + C_2$$

Fitting the observed period and its rate of change for the Crab object to these equations gives $C_1 = 680$, for P measured in seconds and dP/dt in s yr^{-1}. If the pulsation involves one solar mass of material and has an amplitude of 10 km (not unreasonable values for a neutron star) the rate of energy loss is 3×10^{38} ergs s^{-1}, which is of the same order as the total amount of energy radiated by the Crab Nebula, in all wavelengths.

A more typical pulsar with a period near 1·5 s, which is changing at a rate of 10^{-7} s yr^{-1}, has then an age of at most 7×10^{9} yr and is losing energy at a rate of 10^{32} ergs s^{-1}. This is ample to supply the observed radiation from longer period pulsars if they are at distances less than 1 kpc, as seems to be the case[8].

The rate of pulsar-producing events required to maintain the present density of objects in space with such lifetimes is 1 per 400,000 yr for a disk population or 1 per 30,000 yr for a halo population. The total number of pulsating sources created over the history of the galaxy is thus at most 25,000 or 300,000 for the two population types if their density in space has been constant. The consequent implication that the pulsar-producing event is a very unusual sort of supernova is in good accord with the observation that the Crab Nebula is a very unusual sort of supernova remnant (see ref. 9 for further references). It would not be fair, however, to count among the evidence for its uncommonness the fact that it probably contains a pulsar.

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