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GHOST SUPERNOVA REMNANTS: EVIDENCE FOR PULSAR REACTIVATION IN DUSTY MOLECULAR CLOUDS?

by

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There is ample albeit ambiguous evidence in favour of a new model for pulsar evolution, according to which pulsars may only function as regularly pulsed emitters if an accretion disc provides a sufficiently continuous return-current to the radio pulsar (neutron star). On its way through the galaxy the pulsar will consume the disc within some My and travel further (away from the galactic plane) some 100 My without functioning as a pulsar. Back to the galactic plane it may collide with a dense molecular cloud and turn-on for some ten thousand years as a Röntgen source through accretion. The response of the dusty cloud to the collision with the pulsar should resemble a supernova remnant ("ghost supernova remnant") whereas the pulsar will have been endowed with a new disc, new angular momentum and a new magnetic field1).

The cladistic view of pulsars associates at least four different classes of objects with neutron stars:

1) the radio pulsars
2) the Röntgen pulsars and some Röntgen point sources
3) the Röntgen bursters which are exploding neutron stars
4) the γ-ray bursters, where the burst mechanism may be due to cometary collisions with neutron stars.

While for the Röntgen and γ-ray sources accretion is vital for the radiation mechanism it has been argued2-3) that for radio pulsars accretion is lethal in so far as it may suppress the basic radiation mechanism or even turns-off radio pulsars completely[4]. In fact the Röntgen pulsars may provide indirect evidence as none functions as a radio pulsar that too much accretion and therefore too much plasma around the neutron star inhibits the radio radiation mechanism or at least its detection[5] due to the large dispersion of the radio waves in the plasma. However just how much accretion a radio pulsar can undergo before it turns-off is not clear. Here we shall pursue the alternative idea that pulsars only function as such if they accrete electrodynamically rather than gravitationally via a return-current from a small accretion disc.

Pulsar evolution may then be determined completely by the presence or absence of an accretion disc and its properties. The following scenario puts the four classes of neutron stars into an evolutionist's perspective: Neutron stars with a massive companion will function as Röntgen sources.

Neutron stars with a light companion have smaller accretion discs and the accretion flow may be unstable leading to irregular Röntgen emission[2]. Some of the X-ray bursters may belong to this group.

Neutron stars with an accretion disc freshly acquired from a dense dust cloud may mark the transition from a binary to a single neutron star and may also be related to some burst sources. Fragmentation of the disc may under favourable circumstances lead to the formation of asteroids or comets and their collision with the neutron star may give rise to γ-ray bursts.

Most of these objects will be runaways as at least one supernova has occurred at their births and single neutron stars will consequently leave the galactic plane where they were born and may consume or loose their accretion discs so that they turn-off. Back to the galactic plane these single neutron stars may collide with a dense dust cloud and acquire a new accretion disc together with a new magnetic field and new angular momentum[1].

We will show below that there is ample indirect observational evidence supporting the existence of a disc so we shall not defend the theoretical neccessity of it here in detail. Suffice it to say that the standard pulsar model[6-7] suffers from one major defect in that it does not explain how the steady current which brakes the pulsar's rotation comes about without charging-up the neutron star indefinitely. One way out of this dilemma[8-9] is to give up force freeness of the magnetosphere and to consider a net charge on the pulsar

$$Q = \frac{\vec{\Omega}\vec{M}}{c} \quad .$$

($\vec{\Omega}$ is the spin angular velocity vector, $\vec{M}$ the magnetic dipole moment and c the velocity of light). Although its electric force on a proton is some 10^8 times larger than the gravitational force such a net charge on the pulsar will not lead immediately to a return current from the interstellar medium since the pulsar is well shielded by a relativistic wind[9-10-11]. Consequently this wind will blow a hole in the interstellar matter[4,11] and if the pulsar "collides" with a cloud of molecules and dust the wind will sweep-up the cloud material, ionize it and generate an equipartition magnetic field. The shock front will act now like a magnetic bottle if cooling via dust is efficient enough and as a result we will have strongly enhanced accretion. Note that gravity alone is not sufficient to provide the neccessary accretion rate[4,11,12)] for supersonically moving pulsars to build up an accretion disc which can quench the relativistic wind of the pulsar. However for a velocity $v \sim 10^7$ cm $\sec^{-1}$ of the pulsar we find that the equipartition magnetic field in the shock is $B \sim (8\pi\ m\ n\ v^2)^{1/2} \sim$ $\sim 10^{-3,5}$ Gauss for $n = 100$ cm^{-3}, i.e. typical for the magnetic field of a young supernova remnant. A particle in such a field will be trapped provided its Larmor radius r_L is much smaller than the shock thickness and provided cooling is efficient enough to inhibit appreciable evaporation (diffusion out of the bottle) and it is here that dust may play the essential role. Hence dense molecular clouds are the best sites for pulsar regeneration and for the formation of ghost supernova remnants. In fact careful observations[14-15)] of active radio pulsars have shown that the interaction of a pulsar with the interstellar medium does not lead to the formation of radio halos or (mini) ghost supernova remnants as proposed originally by Blandford et al.[16)], which lends support to the idea the dust may in fact play a crucial role. Once enough matter has been accreted and cooled down a Rayleigh-Taylor instability will develop[4)] and the matter will come down in blobs of size

$$r_{RT} \simeq L/4\pi G\rho Mc \simeq 10^{14}\text{cm}\ L_{30}\ \rho_{-21}^{-1}\ M_{\odot}^{-1}$$

(L is the luminosity of the pulsar, ρ the matter density in the shock). Due to angular momentum conservation the matter may not fall directly on the neutron star (as is usually assumed) but it may be stored in a disc as discussed for accreting Röntgen (binary) sources[12-13,17] or radio pulsars[18-19]. Regulated by the net charge and not by gravity the disc may now provide a sufficiently regular return current so that away from the molecular cloud the Röntgen pulsar may turn into a radio pulsar again and continue its journey through the galaxy.

In the light of this new model for pulsar evolution we wish to reassess the observational data. Clearly the model was devised from the beginning so that it explains the most important discordant observations: the large discrepancy between the inferred birth-rate of pulsars and the observed occurrence rate of supernovae[1] and the observed absence of neutron stars at the sites of young supernova remnants[20]. To see this we note that the encounter probability of a pulsar with a dusty dense cloud is of order unity[3] as between one and ten percent of the total mass of the galaxy is found to be in dense clouds[21] concentrated in the galactic plane so that the major uncertainty of our estimate lies in the amount of dust needed to allow for the formation of a ghost supernova remnant. With an encounter probability of order unity the number of pulsars actually born in supernovae is reduced by the factor $A_G/T_p \simeq 100$ where A_G is the age of the galaxy and T_p the period of oscillation across the galactic plane ($T_p \simeq 100$ My). The actual birth of a neutron star, i.e. a supernova, may therefore well be a rare event and many supernova remnants may actually be ghost supernova remnants. To estimate where the line must be drawn for the latter we accept for the Röntgen-luminosity of the neutron star[12] $L_x \simeq 10^{38}$ erg sec^{-1} and a typical cloud diameter of 1 pc so that the accreting neutron star will radiate some 10^4 years depositing 10^{49} ergs in the cloud typical of a type I supernova. Apart from the occurrence rate of true supernovae our model agrees with every aspect of the standard model: the pulsars are concentrated near the galactic plane since the dusty clouds are there, and the velocity vectors of the radio pulsars point predominantly away from the galactic plane as the radio pulsars turn on as such only after leaving the cloud.

While none of the aspects of our model are radically new the combination of them does lead to a major revision of the presently accepted scenario of pulsar evolution and we have sought therefore for further evidence for or against the present model. Surprisingly the predictive power of the model is quite large and we find it convenient to group predictions and observations into two categories: active radio pulsars and dead radio pulsars associated with ghost supernova remnants or non binary Röntgen sources.

1. Active Radio Pulsars

If pulsars do in fact have a disc around them some dispersion must be intrinsic and therefore interesting changes of the dispersion measure may be observable. A prediction of our model would be that the dispersion measure changes on a time scale of 10^6 years. Such changes of dispersion measure are observable for pulsars which show fine structure in the pulses and have in fact been observed$^{22)}$ at the level of 10^{-4} over five years in case of the Crab nebula pulsar and such changes are not easily explainable by any extant model. Clearly the effects of a time varying accretion disc should be strongest for nearby pulsars where most of the dispersion measure could thus be intrinsic and of special interest would be the observation of a pulsar with freshly acquired disc or a disappearing disc. The loss of a disc should therefore be correlated with an anomalously low dispersion measure. As a matter of fact there is observational evidence for all of these effects which are difficult to explain otherwise.

The pulsar 0904 + 77 was discovered clearly[23)] in 1969 and has disappeared since then for more than 10 years. Its dispersion measure was very low[24)] (DM ≃ 10 ± 10) and compatible with zero. This pulsar may actually be considered as an extreme case of nulling pulsars and it is generally believed that nulling pulsars are turning off their radiation. According to the present model such pulsars should have weak return-currents and hence small $\dot{P}$ a fact which is known to be true already[25)]. Since timing noise is correlated with[26)] $\dot{P}$ we have a natural explanation for this fact. Analysis of Ritchings' data[25)] for nulling pulsars gives an average dispersion measure DM = 37,7 pc cm^{-3} whereas <DM> = 100 pc cm^{-3} for all pulsars[24)]. This result is probably not a selection effect as the absolute radio fluxes of nulling pulsars do not deviate from those of the remaining pulsars.

Evidence for freshly accumulated discs may therefore come from pulsars which show appreciable timing noise. Here the noisiest pulsar is PSR 0611+22 and this pulsar turns out to be one of the most interesting radio pulsars discovered so far. It has been associated with the (ghost ?) supernova remnant[27)]

IC 443 and with the H II region[28)] Sh 249, so that IC 443 could actually be an old ghost supernova remnant. We shall come back to this source below. PSR 0611+22 is noisier than the (younger) Crab- and Vela- pulsars. It shows the second largest speed-ups ever observed[29)] in pulsars. The next noisiest pulsar is[29)] PSR 0740-28 a pulsar which shows pulsed γ-radiation[30)]. An example contrary to our model would be PSR 1055-52 if it were really associated with the unpulsed X-ray source[31)] of intensity $L_x \sim 10^{33,6}$ erg sec^{-1} as this pulsar is rather noise-free. However the offset between the radio pulsar and the Röntgen source is 3" and the two sources may therefore not be related.

A complete statistical analysis is certainly required to add more weight to our findings and this will be possible soon if the complete Röntgen data collected by the Einstein satellite have been published and if the timing noise analysis is extended to a larger set of pulsars than is available at present.

2. Ghost Supernova Remnants and Non Binary Röntgen Point Sources

As mentioned already IC 443 may actually be a ghost supernova remnant. Our main arguments in favour of this interpretation are its estimated energy[37)] of $E \sim 10^{49}$ ergs and the pronounced one sidedness of the remnant[32,37)]. As a second possibility for a ghost supernova remnant we suggest SNR G 109.1-1.0. It contains an X-ray pulsar of the right period $P = 3,48$ sec, it may be related to the molecular cloud[39)] Sh2 - 152 and is unusually bright optically[40)].

Further candidates may be found among the objects listed by Ryle et al.[41)] and Montmerle[42)], who actually calles our ghost supernova remnants SNOBS (Supernova Remnants associated with OB stars).

In addition we mention three further candidates not included in these lists: 1) the North Galactic Spur , which is commonly interpreted as due to a supernova and which seems to end into a neutral interstellar cloud[43]. 2) the γ-ray sources in the Orion molecular cloud and in the ρ-Ophiuchi complex[44,46].

As far as the bursters and the Sco-like sources are concerned models have already been developed[12,47,48] which although different in detail agree with the present one in that they depart from the general belief that Röntgen point sources must be of binary nature. The observational situation can be interpreted in two alternative ways. After vigourous efforts to uncover the binary nature of the bursters[49,50] finally a Sco-like source[51] and an X-ray burster[52] show evidence of binary nature. This then either means that it is very difficult to detect a binary orbital period in such systems (because they have a light companion) or else that most of such systems are not of binary nature. In any case the general argument that Röntgen point sources must be of binary nature because of the high accretion rate needed to make a neutron star shine as a Röntgen source can be countered by the observation that especially the burst sources are related to the galactic bulge[53,54] and eight burst sources out of fourteen within 10° from the galactic outer lie in globular clusters, condensation islands for molecular clouds ?

To conclude the list of evidence in possible favour of our model we note that on purely theoretical grounds but model independently[55-57] it has been shown that the pulsar birth rate is $0.048^{+0.014}_{-0.011}$ pulsars yr^{-1} galaxy^{-1} and that many pulsars make their first appearance at periods greater than 0.5s. This "injection", which runs counter to present thinking is probably connected with the physics of pulsar radio emission and can now be understood in the context of our model.

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