Table 2 Calculated solution for the four low-mass binary radio pulsars

PSR	$M_2/M_\odot$	$R_g/R_\odot$	$L_g/L_\odot$	$\dot{M}(M_\odot\,\mathrm{yr}^{-1})$	$\log_{10}B_i(\mathrm{G})$
1855+09	0.22	6.43	11.3	7×10^{-10}	$\leqslant 9.0$
1953+29	0.30	30.1	131.4	8×10^{-9}	$\leqslant 9.6$
1831−00	0.16	1.53	1.0	4×10^{-11}	$\leqslant 10.7$
0820+02	0.45	172	1,987	9×10^{-8}	$\leqslant 12.3$

The second column shows the mass of the white-dwarf secondaries. R_g, L_g and $\dot{M}$ are the radius, (intrinsic) luminosity and tidal mass-loss rate of the (sub)giant just before it became a white dwarf of mass M_2. The last column gives an estimated upper limit for the neutron star's surface magnetic field strength at the beginning of its radio-pulsar phase.

The large differences between the derived field strengths for the various pulsars are probably due to the fact that the pulsars were born (by accretion-induced collapse) at different phases of the mass-transfer stage, so that the magnetic fields have decayed to different degrees. That would imply that PSR1855+09 was formed relatively early, whereas PSR0820+02 was formed not long before the end of the mass-transfer stage. This seems consistent with the deduced short timescale for mass transfer and the observed relatively high orbital eccentricity ($e = 0.0119$, ref. 1) in this system. It has been noted that the white dwarf in this binary is still relatively hot[13], so that the mass-transfer phase terminated less than the white dwarf's cooling time ago. Although our analysis is independent of pulsar mass or inclination angle it can set limits to these values. From the mass function F we deduce that the pulsar mass M_p is given by $M_p = -M_2 + (F^{-1}M_2^3 \sin^3 i)^{1/2}$. Requiring that $\sin i \leqslant 1$ yields $M_p \leqslant -M_2 + (F^{-1}M_2^3)^{1/2}$. For three of the systems studied this yields a not very stringent upper limit $M_u > 2.8\ M_\odot$ for the radio pulsar. For PSR1855+09, however, we obtain a much more interesting upper limit of only $\sim 1.2\ M_\odot$. Unless this pulsar is a remarkably low-mass star, the solar system must be close to the orbital plane of this binary system.

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The formation of a magnetic-field-free cavity at comet Halley

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One of the most important results of the Giotto mission to comet Halley was the discovery of a magnetic cavity surrounding the nucleus in which the magnetic field strength was apparently zero[1]. The boundary of the cavity, the ionopause, occurred at 4,760 km (3,840 km) and the maximum magnetic field strength was ~55 nT (65 nT), thousands of km outside the rather sharply defined transition to zero field on the inbound (outbound) part of the trajectory, respectively. We show here with the aid of a simple model that such a magnetic field structure can be explained as being largely the result of ion-neutral friction[2] rather than simple pressure-balance alone[3,4].

Consider first the extreme situation in which the pressure of the plasma in the cometary ionosphere is negligible, the neutral cometary wind is directed radially away from the nucleus with speed W and the magnetic field direction is transverse to the flow. Assuming that only gradients in the radial direction are important and that there is no radial component of plasma flow in the region containing the magnetic field, the electric current is given by

$$j = en(R_i + R_e)W \qquad (1)$$

where e is the charge on an electron, n the plasma number density and $R_i = m_i\nu_{in}/2eB$, $R_e = m_e\nu_{en}/eB$[5], B being the magnetic field strength, m_i and m_e the mass of an ion and an electron and ν_{in} and ν_{en} the ion and electron collision frequencies with neutrals, respectively. In addition to the transverse ion and electron motions which give rise to j, there is an electric field with a radial component $(R_e - R_i)WB$ and a transverse component R_iR_eWB, both perpendicular to the magnetic field vector.

Assuming a plane of symmetry such that

$$j = (1/4\pi)\,(1/r)\,\partial(rB)/\partial r \qquad (2)$$

where r is the radial distance from the nucleus, it is a simple matter to solve (1) and (2) for $B(r)$ for given values of the various parameters involved, notably the ion and neutral number densities, $n(r)$ and $N(r)$, respectively. We take $N(r) = Q/4\pi Wr^2$, where Q molecules s^{-1} is the total sublimation rate from the nucleus.

Consider first the case in which the plasma density is determined by the condition of photochemical equilibrium so that $n(r) = \sqrt{(\beta/\alpha N(r))}$, where β is the photoionization rate of cometary H_2O molecules and α the dissociative recombination coefficient for the resulting ions and electrons. Defining

$$(B_m r_m)^2 = 4\pi(\beta/\alpha)^{1/2}(Q/4\pi W)^{3/2}(m_iK_i/2 + m_eK_e)\,W \qquad (3)$$

with $\nu_{in} = K_iN$, $\nu_{en} = K_eN$, we find from (1) and (2) that

$$B = B_m(r_m/r)\sqrt{(1 + 2\ln r/r_m)} \qquad (4)$$

The constants have been chosen so that $B = B_m$, the maximum value of B, at $r = r_m$. The field strength is zero at a finite distance from the nucleus, namely $r_0 = r_m\exp(-0.5) = 0.61r_m$. It is noteworthy that r_m is sensitively dependent on Q, the other quantities in (3) varying only weakly with distance from the Sun. If we take $\beta = 10^{-6}\,\mathrm{s}^{-1}$, $\alpha = 10^{-7}\,\mathrm{cm}^3\,\mathrm{s}^{-1}$, $W = 10^5\,\mathrm{cm\,s}^{-1}$, $Q = 8\times10^{29}$ molecules s^{-1}, $m_iK_i = 10^{-31}\,\mathrm{g\,cm}^3\,\mathrm{s}^{-1}$ and neglect m_eK_e, we obtain $r_mB_m = 3.2\times10^{10}$ nT cm. Thus on the sunward side of the nucleus, where the magnetic field strength may be as large as 90 nT[6], the maximum field strength should occur at a distance of about 3,500 km and the ionopause at about 2,200 km. To the extent that our analysis is valid on the flanks of the ionopause where it was encountered by Giotto, the corresponding distances (with $B_m = 60$ nT) are 5,300 km and 3,300 km.

As an alternative we also consider the case in which the plasma density is uniform, at least in the region where the current is strong; thus $n(r) = n_i$, with n_i a constant. Defining

$$B_m^2\, r_m = n_i(m_iK_i/2 + m_eK_e)Q \qquad (5)$$

we obtain

$$B = B_m\sqrt{(2r_m/r - r_m^2/r^2)} \qquad (6)$$

and the magnetic field strength is zero at $r_0 = r_m/2$. With the above values of Q and m_iK_i and with $n_i = 8\times10^3$, we obtain $r_mB_m^2 = 3.2\times10^{12}\,\mathrm{nT}^2$ cm. This implies that the ionopause should

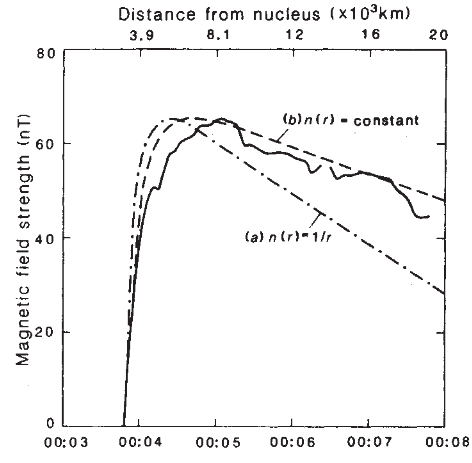

Fig. 1 A comparison of model magnetic field profiles with that observed by the Giotto magnetometer during the outbound pass of comet Halley[1]. The case of constant $n(r)$ (*a*, plain broken line) provides the better fit to the observed profile than when $n(r) \propto 1/r$ (*b*, dotted broken line), but this could be partly a consequence of the fact that the pass was transverse to rather than along the comet-Sun direction. To fit the location of the magnetic field cut-off ($r_0 \approx 3{,}800$ km) and the peak field value ($B_m \approx 65$ nT), it is required that $Q = 1.1 \times 10^{30}$ molecules s^{-1} in case (*a*) (photochemical equilibrium) and $n_i = 6{,}000$ cm^{-3} with the same value of Q in case (*b*). Note the S/C event time is in UT.

occur at a distance of about 2,000 km if $B_m = 90$ nT and at about 4,500 km if $B_m = 60$ nT.

The values of the various parameters we have used are not precise and any coincidence with the observed magnetic field configuration in the vicinity of the ionopause is to some extent accidental. However, it is possible to match the observations rather well, as Fig. 1 indicates, where the parameters have been adjusted so that the correct values of r_0 and B_m are achieved. The assumption that $n(r)$ is constant provides the better fit and is more consistent with the observed ion density distribution[7,8].

We have neglected the plasma pressure in the above, but this can be included provided that the temperature is known, or can be determined separately. Thus (1) should be modified to

$$j = en(R_e + R_i)W - (1/B)\,\partial P/\partial r \qquad (7)$$

where $P = nk(T_i + T_e)$ is the pressure, k is Boltzmann's constant and T_i and T_e are the ion and electron temperatures, respectively. For a given $P = P(r)$, we can integrate (7) and obtain a modified form for the magnetic field. In particular, if $P(r) = P_1$ for $B = 0$ and $P(r) = P_2$ otherwise, with $P_1 > P_2$, then the solution proceeds as before but the ionopause occurs where $B^2/8\pi = P_1 - P_2$ as would be expected. In the limit, where the effects of friction are negligible, the solution is easily found to be $B = B_m(r_m/r)\,H(r - r_m)$, with $H(r)$ the step function and $B_m^2/8\pi = P_1 - P_2$. One can allow for more general forms for $P(r)$ but this is of little value unless an appropriate model is used, in particular for T_e[9].

We suggest that the ionopause observed surrounding the nucleus of comet Halley must have been principally the result of friction[2] rather than a difference in plasma pressure[3,4]. This is supported by the good qualitative and even quantitative agreement outlined above and also the apparent macroscopic stability of the observed structure and the difficulty of accounting for the necessary pressure difference required otherwise. An ionopause determined by pressure balance alone is highly susceptible to Kelvin-Helmholtz and Rayleigh-Taylor instabilities, which should lead to an irregular and diffuse boundary with internal 'flux ropes' as seen at Venus, for example[10]. The stability analyses made so far do not allow for photochemical and compressibility effects, which could be of some significance, but most importantly they do not allow for the effects of friction self-consistently in the configuration before it is disturbed[11,12]. We have not yet succeeded in finding any instability of the configuration described by (4) or (6) and note that even on the microscopic level little is to be expected as the differences in the electron and ion drift motions contributing to j are comparable with the ion acoustic wave speed, for example, only in a region about 1 km thick where the field is weak and the current is a maximum.

To make a significant contribution to the overall stress balance the plasma pressure and especially the pressure differences must be of order $B_m^2/8\pi$. With $B_m \approx 60$ nT this implies that the product $n(T_e + T_i)$ must be $\sim 10^8$ K cm^{-3}. With the above values for the parameters involved, the assumption of photochemical equilibrium suggests that the plasma number density at the ionopause was about 3,000 cm^{-3}, requiring a rather high electron temperature of about 30,000 K, assuming that $T_i \lesssim 300$ K as expected and as indicated by the observations[7]. In fact there is no direct information about the value of nT_e but it is reasonable to assume that the electron temperature within the ionopause is less than that in the region surrounding it because the density of neutrals, which are the main cause of electron cooling, is greater. Because there is also little change in the plasma density across the boundary of the diamagnetic cavity[7,8], it is difficult to see how plasma pressure differences could provide the desired effect. Based on existing models[9] we would in fact expect the plasma pressure to be an order of magnitude less than the observed $B_m^2/8\pi$.

Note added in proof: After submission of the original manuscript we learnt that T. E. Craven, in an independent work (*Adv. Space Res.*, in the press), had obtained a solution in part similar to the present model.

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Atomic-scale surface modifications using a tunnelling microscope

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The desire to modify materials on the smallest possible scale is motivated by goals ranging from high-density information storage to the purposeful transformation of genetic material. Here we report an atomic-scale modification of the surface of a nearly perfect germanium crystal, effected by the tungsten tip of a tunnelling microscope. We believe this to be the smallest spatially controlled, purposeful transformation yet impressed on matter and we argue that the limit set by the discreteness of atomic structure has now essentially been reached.

Significant progress in the field of surface physics over the past 25 years has provided the tools (ultra-high-vacuum (UHV) environments, argon-ion sputtering, low-energy electron diffraction, Auger electron spectroscopy) to prepare crystal surfaces in a chemically pure and structurally homogeneous state. This homogeneity is manifest as a nearly perfect, periodic, two-