PANEL DISCUSSION "FROM WHENCE THE PULSES"†

CHAIRMAN: D.B. Melrose

PANEL: J. Arons, J.M. Cordes, D.C. Ferguson, F.D. Kahn, B.J. Rickett

Report prepared by the Chairman

PREAMBLE

The panel discussion started with five-minute contributions from each of the five panel members and was then open to all. No detailed record of the discussion was taken; R.J. Stoneham recorded the order and topic of each contribution. This report is based on individuals' written versions of their oral contributions. To maintain the sense of the discussion several relevant other contributions have been included based on the Chairman's memory of them several days later; below these are marked with an asterisk.

GENERAL DISCUSSION

KUNDT: 1. Arguments in favour of light-cylinder models:
(a) The power input into the radiating charges occurs near the speed-of-light-cylinder, and theory predicts strong radiative interaction with the forming wave, cf. Asséo et al. (this meeting).
(b) The induced scattering argument by Wilson and Rees (mentioned in my talk) constrains radio emission from inside the speed-of-light cylinder.
(c) Ardavan's contribution favours radiation from near the light-cylinder.
2. Radiation from near the speed-of-light cylinder may well be beamed near-radially (rather than tangentially) when the relativistic charges move near-radially, and radiate in the direction of their motion.

KAHN*: The direction of the radiation in the model I discussed is tangential to the light cylinder.

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†The Chairman was not responsible for the pleonasm in the title and, in the words of V. Radhakrishnan, he is not sure to whither it should be attributed.

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ARONS: Kahn is talking about closed field lines while Kundt is talking about open field lines, in the sense normally used in planetary magnetospheres. Whether pulsar magnetospheres make this distinction is a wide open question. For either class one ought to worry about the magnetospheric electric field being far from the corotation value even on closed field lines, which would make life quite different for both forms of relativistic beaming (as a start, particles on closed field lines would not corotate in the first place).

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CHENG: The observed "break" in many properties of pulsar radio emission near 1 GHz — including the variations with frequency of pulse components' widths and separations as well as spectral and polarization properties — can be accounted for in a natural way in polar-cap models with a radius-to-frequency mapping such that higher frequencies tend to be emitted nearer the star. For the pulsar models which Mal Ruderman and I have studied, frequencies above about 1 GHz tend to be emitted near enough to the star that non-dipolar magnetic field components become appreciable. The resulting deviation from a dipolar field geometry may yield the observed break in pulsar properties.

MANCHESTER*: In connection with the frequency-to-radius mapping, it is important to take account of the fact that the line of sight goes through the emission cone.

MICHEL: On the other hand, what was most impressive early on was the astonishing frequency <u>independence</u> (e.g. the integrated pulse profile of the Crab pulsar is nearly constant at all known frequencies of observation). Now the height/frequency mapping is based on rather minor features of a few pulsars. Is this really a "fact" that has to be reproduced by the models?

RICKETT*: The alignment of the γ-ray and radio pulses in the Crab pulsar is an important observational fact.

RUDERMAN: Bhat et al. reported that the 500 GeV γ-rays from the Crab pulsar come in the same double pulsed pattern as the mainpulse-interpulse radiation in radio, optical, and X-ray regimes. These γ-rays certainly must come from near the light cylinder or beyond to avoid electron-positron conversion in the magnetic field of the magnetosphere. Coincidences with the radio beams then strongly suggest that this part of the radio emission is also generated in the same region. It may then be that in this pulsar some of the radio emission comes from the inner magnetosphere (precursor) and some from a much greater distance (main pulse and interpulse). Perhaps, in some other pulsars, too, beams may come from both regions, but we may see only that from one of them. If so the answer to the emission location question would not necessarily be the same for every pulsar and we must be careful about drawing conclusions from any one special example.

HARDING: It is generally agreed now that at least the high energy γ-ray emission must be coming from fairly far out in the magnetosphere, and the radio emission is believed to originate from the pair plasma produced by these same γ-rays. Radius-to-frequency mapping puts the location of the radio emission at high frequency quite close to the star. Therefore, it would be very interesting to observe γ-ray pulses from pulsars with double components which show this radius-to-frequency mapping to compare the relative phases of the radio and γ-ray pulses.

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MANCHESTER*: I would ask those who support light-cylinder models to tell us how the high Q-factors of the pulsars can be produced. Just how good is corotation near the light cylinder?

ARONS: I get worried about corotation beaming models just because an oblique rotation is likely to be causing conduction current densities of magnitude near B/P, which induce changes in the vacuum field of order the vacuum field itself. If these induced fields form a static pattern in the corotating frame to better than 10%, pulsar magnetospheres will be an enormous exception to what we see happening in planetary magnetospheres. The reverse attitude may be useful: one can use the stability and narrowness of the waveform to set limits on the magnitudes of plasma currents which are allowed, in the corotation beaming hypothesis or in the relativistic compression hypothesis outlined here by Kundt.

KAHN*: A magnetic dipole rotating in vacuo is steady in the rotating frame. The corotational stability implied by the observed pulse stability cannot be ruled out a priori.

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HEWISH*: I would like to ask how one is to get only one pulse per period in a light-cylinder model.

F.G. SMITH: There is no example of a symmetrical dipole field, even in the optical radiation from the Crab. It is of course easier to depart from a dipole configuration close to the surface than it is at the light cylinder. The origin of the asymmetry is therefore more likely to be at the surface, even if the radiation is from far out.

FERGUSON*: One pole has to be different from the other.

F.G. SMITH: The separation between pulse and interpulse is never 180°.

ENDEAN: One can produce only one beam per rotation in a light-cylinder model provided we have two fan beams, one from each pole, beamed up from one pole and down from the other. This ensures that all observers see one pulse from each pulsar. This could be an advantage over polar

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cap models which predict that most pulsars should not be seen at all by a given observer.

KAHN*: I agree. This removes the difficulty of the high birth rate implied by the assumption that we see only one in five pulsars due to their narrow beaming factor.

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WRIGHT*: It seems to me that a multipole model is an unnecessary complication. I suggest that we should restrict ourselves to dipole models.

MELROSE: Other astrophysical objects such as the planets and magnetic stars are known to have substantially non-dipolar components.

KUNDT*: Both planets and white dwarfs tend to have offset dipoles.

KAHN*: However only the dipolar component is important near the light cylinder.

LAMB: Even though the magnetic field near the light cylinder may be very little affected by multipole components that are strong near the surface, the existence of such components can strongly affect the electrodynamics near the light cylinder, since they determine how a given field line at the light cylinder maps back to the stellar surface.

In considering the likelihood of significant multipole moments in pulsars, we should bear in mind that the evidence from pulsing X-ray sources, limited as it is, suggests that these neutron stars, which probably were formed 10^6 to 10^8 years ago, have complex surface fields with higher multipole moments which are comparable to or stronger than their dipole moments.

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F.G. SMITH: The geometric approach of the relativistic beaming theory was addressed (1) to the longitudinal distribution of field directions round a circumference and (2) to the width and polarisation of subpulses.

MANCHESTER*: The stability of slow pulsars argues, however, against light cylinder models. Subpulses have a high energy density which could not be contained by the magnetic field at the light cylinder. Only for the Crab and Vela is this not a problem.

MICHEL: I would like to mention some more arguments: (1) Hewish's comment - yes it is definitely a challenge to reproduce the rich variety of pulse shapes observed in a natural manner, and (2) there are not, plausibly, enough particles at the light cylinder to coherently boost synchrotron radiation to the observed brightness temperatures. Also (3) from time to time one encounters calculations showing extraordinary

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behaviour exactly at the light-cylinder, but all too often these are found to be mathematical artifices and do not actually represent interesting new physics there.

TAYLOR: As an observer, I like to stick fairly closely to the facts when looking at questions of this type. In this respect, I would like to re-emphasize the results I presented earlier, which suggest that for the binary pulsar PSR 1913+16, the emission angle appears to be about 45°, rather than the $\sim$ 90° required by light cylinder models. Furthermore, there are a few pulsars with very broad pulse profiles (such as PSR 1541-09, 1831-04, ...). These sources are easy to understand as cases in which the spin axis points nearly in our direction, and the "emission angle" is small. They are difficult to reconcile with light-cylinder models.

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STINEBRING: I would suggest that further thinking about the shape of the subpulses may be worthwhile, both in polar-cap and light-cylinder models. There has been the implicit assumption here that subpulses are a smooth, well-ordered modulation of the radio emission, but an inspection of individual pulses shows that this is not so — there are a host of subpulse shape variations (some perhaps longitude dependent) which need to be understood. Whether the subpulses are angular beams, as is generally believed, or whether they are temporal modulations as Arons has suggested, the average shape of the subpulses (which does not seem to be symmetrical) should be addressed by any comprehensive emission theory.

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The Chairman closed the meeting remarking that although no consensus had been reached, the major points of difference between polar-cap and light-cylinder models had been clarified.

D.B. Melrose
Chairman of the Panel

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