CONCLUDING REVIEW

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I am afraid the best I can do on the next few pages is to convey the personal impressions that I have been left with after listening to sixty odd talks on almost every topic connected with pulsars. It is obviously impossible even to mention, leave alone comment on, each one of the papers that have been presented in these four packed days. Those few I touch upon will naturally reflect my personal biases for which I ask that you please bear with me.

Some general remarks first. As this Symposium is the first IAU one on pulsars, which were discovered well over a decade ago, the program was somewhat crowded leaving less time for the discussion of individual papers than I would have liked. This situation was aggravated by the speakers themselves - the vast majority of whom exceeded their allotted time in spite of the efforts of the various chairmen - but alleviated somewhat by the panel discussion. A number of points for which there had been insufficient discussion time earlier were brought up and discussed there in a more leisurely fashion.

The meeting got off to a good start with Hewish's Introductory review in which he put his finger on a number of key problems connected with understanding pulsars. The fine observational papers following his review covered all aspects of pulsar emission observed to date. They represent the vast body of data which theory must explain if we are to have more than a rudimentary picture of how pulsars work. Among the points that remain in my mind, and which struck me as important clues are: micropulses were correlated at different frequencies; micropulses were symmetric unlike pulse shapes; there is a critical frequency around 1 GHz above and below which the behavior tends to differ; the 90° flips in the PA of the linear component are generally accompanied by a change in the sense of any circular polarization that is present i.e. the flip is to the truly opposite state of polarization; and most importantly, that when allowance is made for the flipping back and forth the polarization PA sweep across the pulse window conforms closely to what is expected from the magnetic-pole model.

W. Sieber and R. Wielebinski (eds.), Pulsars, 449–453.

If interpulses are to be attributed to radiation from the opposite magnetic pole, then the observations indicate that there must be some sort of communication between the two poles. It seems to me very important to observe the first pulse after nulling as this may provide a clue as to whether prolonged nulling results in a depletion or emptying out of the plasma in the magnetosphere. The most remarkable behavior of all, in my opinion, is that the drifting sub-pulse phase before nulling is remembered by the pulsar through the nulling period. I am forced to the conclusion that this information must be stored in the surface of the polar cap through a local modification of the surface relief, or the lattice structure, or the magnetic field at that point. It seems unlikely that a significant temperature difference can persist through a long null to restart the drifting sub-pulse where it left off.

Regarding observations at higher than radio frequencies I was happy to hear that more optical identifications were possible with present day sensitivities. It is unfortunate that the gamma ray detections of several pulsars which caused much understandable excitement sometime ago are now in doubt. Congratulations for making observations at the highest frequency yet are due to the TIFR group who have detected 1000 GeV photons from the Crab pulsar using the atmospheric Cerenkov technique at Ooty; and I was pleased to note the presence of colleagues from China.

The amazement with which the regularity of pulsars was regarded when they were first discovered has since given way to a curiosity about their minute irregularities. Very often, more can be learned from the deviations from a set pattern than from the pattern itself. I was impressed with the incredible wealth of pulsar timing information that has been painstakingly gathered. It appears as though the "timing noise" in the signals from most pulsars will prevent the determination of their proper motions and period second derivatives, but may hopefully provide clues as to the internal structure of neutron stars. There seems to be some disagreement even between veteran observers as to how to treat the data, but I have no doubt that this will soon be resolved. I would urge however, that uncomfortable looking bits of data are not "excised". If Jocelyn Bell had done the same with her scintillation data, this symposium on pulsars would not have been held.

A fine example of how much can be deduced from the analysis of the signal from one weakly emitting object was Taylor's account of the first binary pulsar. The present degree of agreement with theory for the change in orbital period due to gravitational radiation is comparable with that obtained years ago by Eddington for another of Einstein's predictions based on his theory. My guess is that the agreement will improve with time, just as in the other case, and remove any lingering doubts that the change in orbital period is due to other causes. A totally unexpected bonus from the measurements on 1913+16 was that for this pulsar at least, most traditional light-cylinder models could be ruled out as very unlikely, although this would not apply to the emission process discussed by Kahn in the Panel Discussion.

We now have three binary pulsars and although the two recently discovered ones are unlikely to show general relativistic effects they are of great interest from the point of view of the evolution of such binary systems. The highly circular nature of their orbits indicates that the systems underwent dynamical evolution since the neutron stars were formed and poses interesting problems as to how this could have happened.

I understand so little about neutron star structure that I cannot meaningfully comment on the papers that dealt with this topic. Overall, I have the impression that most theoretical papers in this field are remote from the observations and cannot therefore be easily tested. Exceptions are those papers which deal with glitches and those which predict the surface temperatures of neutron stars. You may have noted that the latter have undergone rapid modifications recently to accord with the spectacular observations made by the Einstein X-ray telescope, and which were reported on at this symposium. I think it is extremely significant that no point sources were found in the supernova remnants like Cas A, Tycho, Kepler etc., to explain which it was suggested that most supernovae which give rise to classical SNR do not leave behind a neutron star. My own interpretation would differ in that I believe all supernovae must leave behind a neutron star but not all neutron stars function as pulsars; those that do would have higher surface temperatures due to the backflow of energetic particles to the surface and thus be more easily detectable by their X-ray emission.

Thursday morning's session on magnetospheric theory served to bring home the extreme difficulty of solving the electrodynamics of the magnetosphere even with simplifying and idealizing assumptions galore. Even though the discussions were beyond my comprehension, it was still quite clear that they were a very long way from the observations. It is possible that much of the difficulty is because the radio frequency emission, which is our main source of information, is such a minute fraction of the total energy output of pulsars. The gamma radiation would probably be a much better diagnostic, but as we saw earlier there are very few such measurements available.

The session on pulse emission mechanisms was started off with a bang by Ruderman, who has led one of the major groups in the model building business for some years now. The bewildering array of possibilities he presented in rapid-fire succession accounted not only for pulsars of all ages but seemed designed to take care of all observations, past, present and future. In all of these models the alignment of the angular momentum vector and magnetic moment is assumed to be of such a sense that the polar caps tend to be positively charged. I have often wondered whether the reverse would, as one might expect, be equally likely, and if so what do such neutron stars do. I was happy to note that the models discussed by Arons and one other speaker did treat this case, i.e. where electrons are emitted from the polar caps.

The difficulty with the various models presented is our inability

at present to completely reject or completely accept any one of them. Each model can explain one or a few of the observed characteristics of pulsar emission, but none can satisfactorily explain all or even most of what has been observed. That there were basic difficulties, even at a theoretical level, with some of the mechanisms that have been proposed to explain the pulse emission was brought out by Melrose in his invited review.

If very young and very old pulsars do function in a qualitatively different fashion we may have to accept more than one model. As an example of this possibility I could perhaps cite the case of the Crab pulsar. The agreement in pulse arrival times all the way from radio frequencies to GeV gamma rays suggests that the same region emits at all these frequencies. The path length for high energy gamma rays to produce a pair is so minute in strong magnetic fields that the gamma rays must be generated well away from the surface if they are to reach us. On the other hand there is a vast body of accumulated evidence discussed at this symposium, to support the idea that the radio emission of most pulsars must emanate from close to the magnetic pole.

This point of view and the opposing one reviewed by Ferguson yesterday formed the main theme of this morning's panel discussion "From whence the pulses". As I mentioned earlier, the atmosphere during the panel discussion was more relaxed than during the previous three days when I got the impression that there was a determined conspiracy to do away with all light cylinder models.

The last session yesterday and the one earlier this afternoon were devoted to the Distribution and Evolution of Pulsars. It was clear from the review by Lyne that the formation rate of pulsars in the Galaxy cannot be easily reconciled with the occurrence rate of SN suggesting perhaps that many pulsars are formed from white dwarfs or in other ways unaccompanied by SN explosions. On this subject, I feel that we should think more seriously about the idea put forward by Ostriker and Gunn almost ten years ago that SN explosions are powered by the rotation of the collapsed core and are not thermonuclear in origin. If this really is so, as I tend to believe, our understanding of SNR and their relationship to pulsars will be considerably advanced.

Among the various points made in this afternoon's interesting discussions on binary systems and pulsar evolution I'd like to recall two made by van den Heuvel and which strike me as very important to keep in mind. One is that the majority of stars are in binary systems and hence must be accounted for in terms of the end products of stellar evolution. The other related point is that some of the properties of pulsars, most of which are single, might be comprehensible only in terms of an origin in binary systems.

I am sorry to have not taken enough time off to look at all the poster papers and I shall therefore not comment on any of them. As something for the future, one should perhaps put aside an afternoon both

to look at poster papers and to discuss them with their authors. Let me conclude by mentioning some lines of investigation which may lead us to understand a little more about how pulsars really work:

1) The magnetic field structure at high altitudes from low frequency polarization studies.

2) The time behavior and polarization of interpulses and other components to determine if there are one or two poles of radiation.

3) What is the nature of the polar cap surface if excavation is really taking place; could there be irregularities which would be reflected in the average pulse structure.

4) Depolarization of the pulses and what it means in terms of matter in the radiation path.

5) Observation of the next Vela spin-up.

6) A deep search in filled SNR for pulsars.

Finally let me add my thanks to all of yours for the fine arrangements made by the local organizing committee for this symposium.

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