closer to the Earth. In a small magnetic storm, for example, the plasmapause was observed at 4 Earth radii and the Earthward termination of the ring current was at 3 Earth radii. Another interesting feature of the storm observations was the disappearance of the pre-midnight trough in electron energy density separating the plasmapause and the plasma sheet.

These observations should make it possible to construct more realistic models of the magnetosphere and increase our understanding of the dynamic process occurring within. There will now be great interest in further observations of this type from OGO 3, particularly observations relating to a complete range in local time.

GRAVITY

On the Crest of a Wave

by our Cosmology Correspondent

THE bandwagon started by the experiments of J. Weber is now rolling along under its own momentum, even in the absence of firm confirmation that the Weber pulses represent gravity waves. Three consecutive recent issues of *Physical Review Letters* contain contributions concerning gravitational waves, as do the March and April issues of *Il Nuovo Cimento B*. These range from esoteria such as the gravitational shock waves expected from a supermassive tachyon (L. S. Schulman, *Il Nuovo Cim. B*, **2**, 38; 1971) to the more prosaic experimental limit found for any high energy neutrino flux associated with Weber pulses (F. Reines *et al.*, *Phys. Rev. Lett.*, **26**, 1451; 1971).

Although it seems that a rather large tachyon with the density of nuclear matter could produce gravitational "shock waves" in our universe, with all that this implies for causality, more serious attention will probably be paid to the more straightforward cosmological consequences of the existence of strong bursts of gravitational waves at the rate indicated by Weber. B. Bertotti and A. Cavaliere suggest that if these bursts are typical of the activity occurring in the centres of galaxies, then so much mass energy is being, or has been, converted into gravitational radiation that the universe is, although not yet dead, rapidly approaching senility (*Il Nuovo Cim. B*, **2**, 223; 1971). The trapping of the majority of the universe's matter in black holes would certainly solve the problem of the missing mass which has so puzzled cosmologists. The most widely accepted cosmological models all suffer from a great excess of mass when compared with the visible universe, and it has so far seemed a little too much to swallow to accept that about fifty times as much matter as that in the visible galaxies is present in the form of cold intergalactic gas or collapsed objects. Now, however, extrapolation of Weber's results to the universe as a whole points exactly to this previously unpalatable suggestion.

Another consequence of the presence of large numbers of collapsars at the galactic centre holds whether our galaxy is typical or not. For our galaxy, the implications of Weber's report of one burst of radiation at 1,660 Hz coming from the nucleus each day are that the total flux is at least 10^{10} erg cm^{-2} day^{-1}, and that the galaxy is losing mass at roughly 2×10^{4} $M_{\odot}$ yr^{-1}. This raises interesting questions concerning the efficiency with which mass energy is converted into gravitational radiation, and S. W. Hawking has attempted to answer some of these questions by determining limits on the efficiency of the collision or coalescence of two collapsars as a means of energy generation (*Phys. Rev. Lett.*, **26**, 1344; 1971). Working with the Kerr family of solutions (see p. 148 of this issue of *Nature Physical Science* for a report on some features of the Kerr metric), Hawking finds that successive coalescence of pairs of black holes can result in the extraction of a very large fraction of their original mass, each step in the process of amalgamation producing longer and stronger bursts of radiation. Under certain conditions, even the rotational energy of the black holes can be extracted by interactions with particles and fields on their event horizons.

Two pieces of work with experimental leanings complete this recent burst of papers on gravitational waves. P. G. Bergmann has considered the possibly detectable effects of the passage of gravitational waves on the transmission paths of light from distant sources (*Phys. Rev. Lett.*, **26**, 1398; 1971). Although the disturbance caused by one wave train of the kind detected by Weber would not be sufficient to affect observations of distant objects significantly, superposition of wave trains might produce an observable effect. This possibility is certainly a straw worth grasping, because it offers a possibility of detecting gravity waves at frequencies well below the 10^3-10^4 Hz where Weber's detectors are effective. But because the source being observed must provide an accurately periodic signal, such as a pulsar signal, in order to detect the sort of variation envisaged by Bergmann, this idea is unlikely to yield a definitive test of Weber's work. The critical variation of magnitude with path length goes as $(L/l)^3\langle h^2\rangle$ where L is the path length, l the coherence length, and $\langle h^2\rangle$ the variance of the index of refraction which is unlikely to exceed 10^{-22}.

In fact, Bergmann recognizes several ways in which this principle might be used to detect gravitational waves at frequencies several decades below the range covered by Weber. The fluctuations in the refractive index of the light path due to the passage of gravitational waves may be manifested as fluctuations in the travel time of the light beam—fluctuations in the optical path length in other words—or as changes in the apparent position of the source because of deflections of the wave front, as well as by the variations in intensity of the source described by the expression in the previous paragraph. It is for observations of gravitational radiation *via* its effect on the path length that a periodic source is required, of course, but Bergmann concentrates on the possibility of detecting the intensity fluctuations. The chances are not high, but Bergmann is encouraged by the large uncertainties in his calculations.

The most recent report in this series is also somewhat frustrating to the theoreticians. A large team from the University of California, Case Western Reserve University, and the University of Witwatersrand have collaborated in obtaining neutrino flux data from a deep underground detector, and have attempted to relate this to the occurrence of Weber pulses. Despite poor statistics, their conclusion is that the ratio of neutrino energy to gravitational wave energy resulting from the processes observed by Weber must be so low that no more than two detectable neutrino pulses occur each year, compared with a detectable Weber pulse every day or two (*Phys. Rev. Lett.*, **26**, 1451; 1971). This may temporarily dampen the enthusiasm which has produced so much theoretical activity in this field, but the fire will undoubtedly be rekindled at the first hint of more positive results.

Earlier this year J. N. Bahcall and R. Davis used equipment aimed at the search for neutrinos from the Sun to place an upper limit on the neutrino energy that could be associated with Weber's pulses (*Phys. Rev. Lett.*, **26**, 662; 1971). The disadvantage of their experiment, however, compared with that of Reines *et al.*, was that Bahcall and Davis had to use what amounts to a radiochemical method to search for neutrinos, thus averaging the flux over long periods of time. Reines *et al.* report that during a period which contained 227 days when Weber's apparatus and the neutrino experiment were both running, there were two occasions when particle events occurred within ±2 minutes of Weber pulses. This compares with an expected 0.7 chance coincidences in that period. In future, Reines *et al.* hope to be able to measure their arrival times to better than twenty seconds, reducing the expected chance coincidences by an order of magnitude.