t_i (i=1 to N) denotes the arrival times, and int(x) is the nearest integer to x. When there are unpulsed neutrinos from the supernova or background events, the possibility that the first event is unpulsed will introduce an offset $\delta\phi$ that will drastically alter the detectability of the pulse. Identical pulse shapes which should have the same statistical significance will instead have very different values of y. This undesirable feature of the y-test is apparent in Fig. 1, which shows the probability density distribution for uniformly distributed times (a), together with the distribution in presence of a square pulse shape with a duty cycle of 25% but centered at half period (b) or at one period (c) with respect to the time t_0.

We have reported[2] the detection of a 202.4-ms periodicity in the same neutrino burst. They used the Z^2_n-test[3] to provide a sensitive test for a wide range of light curve shapes (De Jager[4] reviews the sensitivity of various periodicity search methods for sparse data sets). We applied the y-test to the pulse shape found by us (Fig. 2a) and obtained the value 0.18, as large as it would be for uniformly distributed neutrino times, but this apparent loss of significance for the 202.4-ms period is solely because the pulse shape happens to be centred around phase 0.5. In contrast, the pulse shape of the 8.9-ms period (Fig. 2b) happens to be displaced to phase 0.9, giving a small $y(f)$ value. We conclude that the y-test is only useful under the specific hypothesis of no unpulsed neutrinos and a narrow pulse duty cycle. This is not the case for the result found by Harwit *et al.*.

Regardless of the inadequacy of the y-test, Harwith *et al.* make an error in concluding that the probability for chance occurence of the 8.9–ms effect in the KAMIOKANDE data is 1.9×10^{-5} on the grounds that they have found five independent 'good fits' out of 67 trials. The frequency step used was $1/135 = 7.4\times10^{-3}$ Hz, more than an order of magnitude smaller than one independent Fourier step, which in thè case of the Kamiokande data is $1/12.44 = 0.08$ Hz. The five 'good fits' thus refer to only one independent Fourier step and only one value should therefore be used to evaluate statistical significance. Our estimate of the chance occurence probability of the 8.9-ms effect in the Kamiokande data, deduced from a Monte Carlo simulation that takes into account the number of frequency steps used, their spacing and the small degradation of the probability density distribution due to the low number of events, is 0.03. This value, combined with the probability of also finding 8.9–ms effect in the IMB data (quoted at 0.32 by Harwit *et al.*), gives $P = P_1P_2\,(1-\ln P_1P_2) = 0.05$, which is the significance of the 8.9–ms effect.

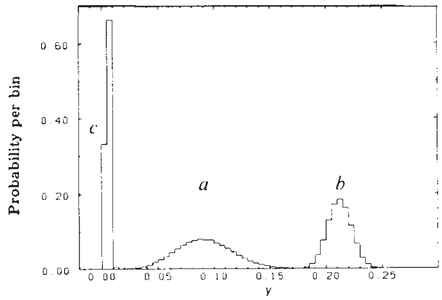

Fig 1 Probability density distribution of y(f): (a) for the case of 12 events uniformly distributed in 12 s; (b) for the case of 11 events in a pulse with 25% duty cycle placed at half period with respect to the first event at $t_0 = 0$, assumed to be not related to the pulse; (c) as in (b) but with the first event time t_0 coinciding with the centre of the pulse.

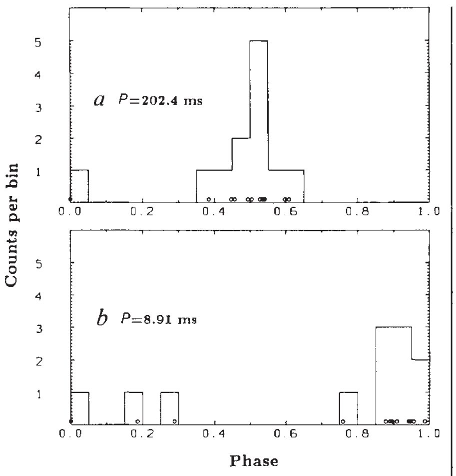

Fig 2 Light curves for the 202.4 ms (a), and (b) periods found by Ögelman and Buccheri[2]; and Harwit *et al.*[1] respectively. Circles indicate the phase positions of individual neutrino events.

Harwit *et al.* consider as a possible explanation for this periodicity the rotation of the underlying neutron star. The birth periods of neutron stars may be very short (collapse calculations[5] may give 8 ms, and pulsar statistics[6] suggest 1–50 ms), but Chevalier and Emmering[7] have shown that the pulsar statistics can also be interpreted in terms of long birth periods (90–250 ms), offering a possible explanation for the 202.4–ms period found by us.

We thank R. Treumann for useful conversations. This work was partially supported by the Deutsche Forschung Gemeinschaft.

R. Buccheri

Instituto di Fisica Cosmica e
Applicazioni dell' Informatica,
CNR, Palermo, Italy

H. Ögelman

Max Planck Institut für
Extraterrestrische Physik,
Garching, München, FRG

1. Harwit, M., Biermann, P.L., Meyer H. & Wassermann I.M. *Nature* **328**, 503–504 (1987).
2. Ogelman, H. & Buccheri, R. *Astr. Astrophys.* **180**, L23–L25 (1987).
3. Buccheri, R. *et al. Astr. Astrophys.* **128**, 245–251 (1983).
4. DeJager, O.C. thesis (Univ. Potchefstroom, 1987).
5. Meier, D.L., Epstein, R.I., Arnett, W.D. & Schramm D.N. *Astrophys. J.* **204**, 869–878 (1976).
6. Stollmann, G.M. *Astr. Astrophys.* **178**, 143–152 (1987).
7. Chevalier, R.A. & Emmering, R.T. *Astrophys. J.* **304**, 140–152 (1986).

WASSERMAN REPLIES — Our analysis has been criticized by Schaefer, Buccheri and Ögelman on two grounds. First, they point out that we oversampled in testing our 'target set' of IMB candidate periods in the Kamiokande data. This is indeed true, an unfortunate careless error on our part. Rather than the spectacularly low probabilities of coincidence quoted in our paper, one should find agreement several per cent of the time, as noted by our critics. Second, Schaefer, Buccheri and Ögelman feel that our period search technique itself was inappropriate. Here I find their arguments less convincing, although they quite correctly point out that we have required 'periodic emission' to imply that all arrival times cluster tightly about zero phase. This was a subjective, generally restrictive choice of which our critics clearly disapprove. Personally, I stick by our opening statement that "searching for periods in sparse sets of data is a subjective enterprise". That three different ways of testing for periodicities yield discrepant results merely reinforces that view. Moreover, as we discussed, strictly periodic, narrowly pulsed emission is clearly an overly simple model. Realistic beaming patterns, for example from a surface hot spot, would imply relatively large duty cycles. The substantial mass loss due to escaping neutrinos could also cause period changes $\Delta P/P \gtrsim 10$ per cent over the duration of the emission. Timing models that are sophisticated enough to include these effects should yield plenty of 'good fits', but at a low level of significance. Including an unpulsed component of emission would further complicate the model, adding more parameters and consequently diminishing the number of remaining degrees of freedom in the data. Moreover, it should be borne in mind that the reality of individual neutrino detections may be suspect, so that in testing models seriously one should probably account for background events unrelated to SN1987A.

Finally, observations may already be used to strongly limit possible spin periods for any still-veiled pulsar inside SN1987A. To the extent that the SN1987A light curve is well-fitted by models fed by radioactive ^{56}Co decay, constraints on the extra pulsar-driven emission (J.P. Ostriker, *Nature* **327**, 287; 1987) may be established. As reported at the recent George Mason Conference, implied pulsar periods must exceed ~ 10 ms, ruling out periods as low as 8.91 ms.

Ira Wasserman

Venter for Radiophysics and
Space Research,
Cornell University, Ithaca,
New York 14853, USA