Geminga: new period, old γ-rays

SIR — It was there all the time. The ROSAT results of Halpern and Holt reported in last week's issue[1] and the EGRET results of Bertsch *et al.* on page 306 of this issue[2] finally clinch the identification of the Einstein X-ray source 1E0630+178 (ref. 3) with the high-energy (greater than tens of MeV) γ-ray source Geminga, discovered by the satellite SAS-II and observed in more detail during the COS-B mission. Because of the paucity of γ-ray photons, it is unrealistic to search for unknown periodicities in the sub-second period range, and thus neither SAS-II nor COS-B could find any convincing time signature from the source. Armed, however, with the ROSAT and EGRET findings (the former known to one of us as referee and the second to both of us as friends), it made sense to search through the existing COS-B database[4].

The table gives a journal of the COS-B observations when Geminga was at a reasonable distance from the pointing directions. For each observation, γ-ray photons with energies >50 MeV, and with the standard photon quality parameters used for pulsar search[4], were selected within a few-degree cone from the source, resulting in the numbers of photons given in the table. Their barycentrized arrival times were then folded in 5,000 independent steps of 1×10^{-9} each, over a period interval from 0.23709000 to 0.23709500 s, predicted on the basis of a fixed P, taken for simplicity, as 1×10^{-14} s s^{-1}. Consistently significant light curves, very reminiscent of the Crab and Vela pulsars, with two peaks separated by 0.5 in phase, were found for observations 0, 14, 39 and 64 (Fig. 1). The period values maximize the χ^2 in each individual observation. Observation 54 does not show a significant effect at the predicted period. There appears to be no obvious explanation for this, other than to note that 54 is the observation where COS-B had its lowest efficiency (47%) and the lowest photon number (224) from Geminga. According to Wills *et al.*[5], this is the observation which also yielded the worst Crab pulsar light curve.

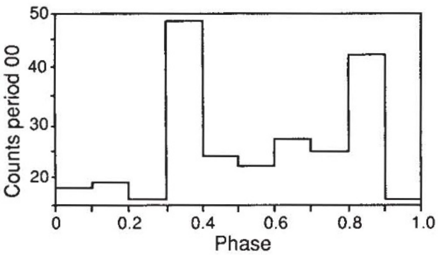

FIG. 1 Geminga γ-ray 10-bin light curve for COS-B observing period 00. The γ-rays per bin are 18, 19, 16, 49, 24, 22, 27, 25, 43, 16. Numbers for three other observing periods — 14, 39 and 64, respectively — are:
40, 37, 50, 91, 51, 38, 63, 55, 75, 64
43, 33, 31, 83, 27, 23, 36, 27, 63, 26
33, 34, 27, 70, 44, 47, 41, 40, 75, 36.

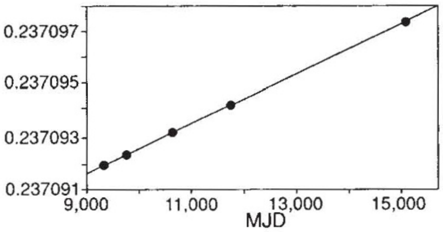

FIG. 2 Period history of Geminga, showing the four (1975–82) COS-B points and the 1991 ROSAT one. Note that each data point is enlarged for visibility, the associated error being significantly smaller. The fit regression coefficient is 0.999998, and the derived $\dot{P}$ is $1.099 \pm 0.001 \times 10^{-14}$ s s^{-1}. Fit residuals are within ±2.5 ns, close to the folding independent step. MJD, modified Julian day.

The secular evolution of the Geminga period can then be inferred from Fig. 2, showing the four COS-B points (1975–82) together with the ROSAT one. Over 16 years, the data fit exceptionally well to a straight line, yielding $\dot{P} = 1.099 \pm 0.001 \times 10^{-14}$ s s^{-1} with fit residuals comparable to the precision of our period search.

The 1991 observations, supported by the old COS-B data, point to Geminga being a rotating neutron star with timing parameters that compare well to those of the population of radio pulsars. Standard formulae yield $B = 1.5 \times 10^{12}$ G, an age of 3.7×10^5 years and $\dot{E} = 3.2 \times 10^{34}$ erg s^{-1}. For a Vela-like γ-ray production efficiency, this places the source at ≤ 40 pc from Earth.

It is thus likely that Geminga, up to a short while ago the brightest unidentified γ-ray source in the sky, is the nearest example of a magnetized, rotating, middle-age neutron star. Despite repeated searches, however, Geminga is not a radio pulsar, at least so far: the vast majority of its energy flux is emitted in γ-rays (2×10^{-9} erg s^{-1} cm^2), with a fraction (10^{-3}) in X-rays and an extremely faint optical counterpart[6,7]. As successfully shown for Vela[8,9] (at 450 pc), a search for proper motion of G″, the proposed optical counterpart[6,7], if indeed at a few tens of parsecs, could be pursued.

To gain clues about isolated neutron stars, which are not radio pulsars, it is important to find other, similar objects. In this context, we draw attention to 1E 1257.4–5209 (ref. 10), an HRI Einstein X-ray source with no optical counterpart ($L_x/L_{opt} > 1{,}000$), at the centre of a $> 10^4$-year-old SNR, soon to be observed by ROSAT, but not yet observed in γ-rays.

COS-B OBSERVATIONS OF GEMINGA

Obs. no.	Date	Pointing direction (l, b)	Relative efficiency	Photons	Period	Red χ^2 (9 d.o.f.)
00	75/08/17 75/09/17	186°, − 6°	1.00	259	0.237091993	4.95
14	76/09/30 76/11/02	195°, + 4°	0.97	564	0.237092385	5.32
39	79/02/22 79/04/03	190°, 0°	0.69	392	0.237093213	9.49
54	80/09/04 80/10/17	188°, − 3°	0.47	224	—	—
64	82/02/18 82/04/25	190°, 0°	0.55	447	0.237094249	5.57

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Big Bang contd. . .

SIR — There are several points in the article by Peebles *et al.*[1] on the standard relativistic hot Big Bang cosmology with which we could take issue, but here we confine ourselves to the most important ones.

Contrary to what Peebles *et al.* claim, if a thermalizing agent absorbing and re-emitting microwave radiation operates after clusters of galaxies are formed, there is no difficulty in explaining the unique temperature and extreme smoothness of the background. Their claim referred to the classical steady-state model, which was not the model discussed by us[2].

The correct argument runs as follows: as an initially non-thermodynamic radiation field is thermalized to black-body form, irregularities in the distribution of the thermalizing agent are lost, becom-