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.

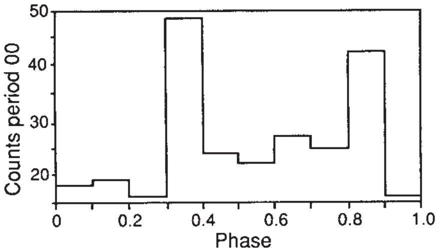

FIG. 1 Geminga γ-ray 10-bin light curve for COS-B observing period 00. The γ-rays per bin are 18, 19, 16, 49, 24, 22, 27, 25, 43, 16. Numbers for three other observing periods — 14, 39 and 64, respectively — are:
40, 37, 50, 91, 51, 38, 63, 55, 75, 64
43, 33, 31, 83, 27, 23, 36, 27, 63, 26
33, 34, 27,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

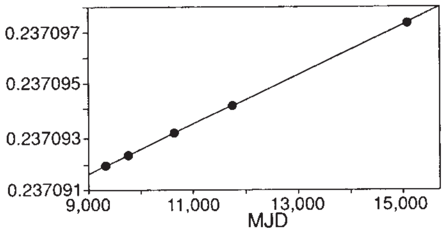

FIG. 2 Period history of Geminga, showing the four (1975–82) COS-B points and the 1991 ROSAT one. Note that each data point is enlarged for visibility, the associated error being significantly smaller. The fit regression coefficient is 0.999998, and the derived $\dot{P}$ is $1.099 \pm 0.001 \times 10^{-14}$ 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.

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

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.

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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, becoming undetectable when the black-body spectrum is reached. Suppose the initial background before the operation of the thermalizing agent is mottled by the piecewise structure of our model, so that an observer viewing the initial situation in the absence of thermalization would find the background to be variable, like a chessboard seen with the sides of its squares subtending an angle of a few degrees. Now place an isotropically scattering screen of optical depth τ between the observer and the chessboard. Only three or four scatterings are sufficient to reduce the contrast in the main radiation field well below the observational limit on the smoothness of the microwave background. For $\tau >>1$ the contrast of the chessboard squares is essentially completely lost in the scattered field. All that remains of the original mottling is then carried by the small fraction, $exp - \tau$, of the radiation which penetrates the screen without being scattered. Even an initially high contrast is effectively lost when $\tau \approx 10$ or more. Such an opacity, when produced by absorption and re-emission rather than by simple scattering, also maintains the black-body spectrum emerging from each of the inflationary pieces.

Writing $\tau_0 H_0/c$ for the present-day optical depth per unit path length, the optical depth τ extending to the lookback redshift z when the overlap of pieces is considered to have taken place is given to sufficient accuracy by $\tau \approx \tau_0 (1 + z)^{3/2}$. With $\tau_0 \simeq 1$ (which is not contradicted by any data) we have $\tau \simeq 10$ for a lookback redshift $z \simeq 4$. The overlap of pieces at this redshift can be considered as the transition between cosmology and astrophysics. From an observational point of view, it is interesting that the transition can be at a lookback redshift which is accessible to the telescopes of today and tomorrow. This contrasts favourably to the situation in the standard model where the conditions responsible for astrophysics are claimed to lie in an early universe far outside the observable range of tomorrow as well as today.

There is nothing in our model that should be objectionable to the particle physicists, since the detailed physical conditions applying to each inflationary piece are no different from what is proposed in the standard model. The situation is indeed improved on in the same way that it is for astrophysics, by bringing the connection between theory and observation within a practical range. We do not believe that it is possible to advance science profitably when the gap between theoretical speculation and observation/experiment becomes too wide, as we feel it has done in cosmology over the past two decades, and as it is tending to do now in particle physics, for what then happens is that scientists are impelled to chase after chimaeras instead of real beasts. Effects are expected but not found, which has indeed become the rule rather than the exception. Of the many failures are the failure to explain galaxy formation, the failure to find fingerprints of galaxy formation in the microwave background, the failure to identify 'missing mass', the age problem, the baryon-to-photon problem, the top quark mass problem, the Higgs boson mass problem, the inflationary switch-on problem, the inflationary switch-off problem and, ultimately, the origin problem. In view of this negative record, we find the enthusiastic claims made by Peebles *et al.* surprising. The time has surely come to open doors, not to seek to close them by attaching words like 'standard' and 'mature' to theories that, judged from their continuing non-performance, are inadequate.

Finally, a comment about the evidence for non-cosmological redshifts of quasi-stellar and related objects which we have taken into account in our model. Peebles *et al.* cast doubt on this argument by invoking as others have "subjective selection effects and lack of rigorous control in the surveys". We ask them and the reader only to look without prejudice, particularly at our extensive work[3] addressing all these questions.

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PEEBLES *ET AL.* REPLY — A central point of our review article is that the measured properties of the thermal cosmic background radiation seem to require that the Universe has expanded from a state denser and hotter than it is now[1]. We are glad that Arp *et al.* have come to accept this conclusion.

Another central point of our article is that the observed abundances of the lightest elements seem to require that the expansion and cooling of the Universe traces back to an expansion factor (redshift) greater than about 10^{10}. The extensive unsuccessful efforts to find a way around this conclusion can be traced from the references in our article. Arp *et al.* do not comment on this evidence; if they can see a sensible way around it the cosmology community surely would respond with great interest.

Scientific Correspondence

Scientific Correspondence is intended to provide a forum in which readers may raise points of a scientific character. They need not arise out of anything published in *Nature*. In any case, priority will be given to letters of fewer than 500 words and five references.

Arp *et al.* correctly note that in the standard relativistic hot expanding cosmological model there are many open problems: we cannot explain how the galaxies formed or even the nature of their dominant component, the massive dark halos. The many ideas for how these problems might be resolved is the focus of much of contemporary research in cosmology. Perhaps this research will lead to an impasse showing there is something wrong with the framework provided by the standard cosmological model, but as we emphasized[1], that certainly has not happened yet. No well-established phenomenon or problem is known to contradict the standard model.

The standard model traces back to a formal singularity from which one presumes we are rescued by new physics. That may turn out to be inflation, but inflation is not part of the standard model because there are not yet reasonably convincing tests of the idea. Perhaps the new physics will go some other way. We mentioned[1] the idea first put forward by Hoyle and Narlikar in 1966, and noted by Arp *et al.*, that material may be created in bursts between which the Universe expands as in the standard model. If the bursts are hot and dense enough they can produce the conditions for thermalization of the cosmic background radiation and for light element production. It thus appears to us that when the parameters in the model discussed by Arp *et al.* are adjusted to fit the observations their picture reduces to what is commonly known as the hot Big Bang model.

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