LETTERS TO THE EDITOR

PHYSICAL SCIENCES

Planetary Nebulae as Possible X-ray Sources

THERE is still the problem of the identification of galactic X-ray sources in the energy interval of 4–8 keV, and it seems reasonable to consider whether they can be identified with such common objects of the galactic disk as planetary nebulae. A planetary nebula is a slowly expanding gaseous shell with a very hot star inside, and in such a system X-ray emission could originate both in the nebula and in the star. We consider the nebula as a uniform spherical shell with a radius of $\sim 2\times 10^{17}$ cm and mass $0{\cdot}1\ M_\odot$; the radius of the central star can be taken as $1\ R_\odot$, and its temperature as $\geq 2\times 10^5$ °K (ref. 1). A value of 1 kpc seems a suitable characteristic distance.

In applying this model of planetary nebulae the following mechanisms were considered: (1) black body radiation of the nucleus; (2) thermal radiation of a hypothetical hot corona to the nucleus; (3) synchrotron emission of relativistic electrons; and (4) the inverse Compton effect in the scattering of fast electrons by photon radiation in the nebula.

Simple calculations show that mechanism (1) must be abandoned because of the low temperature of the star, and the second mechanism demands an absurd value, $10^4\ M_\odot$ for the mass of the optically thin corona to produce an observable X-ray source in the 4–8 keV region. Mechanism (3) must also be abandoned, because we have no evidence for relativistic electrons and strong magnetic fields in planetary nebulae.

The conditions for the inverse Compton effect are more favourable, due to the trapping of L_α radiation in the nebula. This results in a relatively high density of the radiation field energy, $w_p = 6\times 10^{-6}$ ergs cm^{-3}. To produce X-ray quanta with an energy 4–8 keV, subrelativistic electrons with an energy $E = 10^7$ eV are needed. Supposing these electrons to be injected from the nucleus, and applying the condition that the X-ray source must be observable ($F(4\text{–}8\ \text{keV}) \geq 5\times 10^{-9}$ ergs cm^{-2} s^{-1}), we can estimate the energy of injection to be $\geq 4\times 10^{38}$ ergs s^{-1}, which is equal to some 10 per cent of the energy of the ionizing radiation of the nucleus.

These energy requirements are reasonable. The calculation of the characteristic lifetime shows, however, that subrelativistic particles leave a nebula freely. If there are 10^4 planetary nebulae in the galaxy, the energy of injection of subrelativistic cosmic rays from planetary nebulae alone would be at least 10^{42} ergs s^{-1}. The contradiction between this value and the modern view of the energetic equilibrium of galactic subcosmic rays[2] shows that mechanism (4) is probably also inconsistent.

I have compared the statistics of the X-ray sources listed in refs. 3 and 4 with those of the planetary nebulae, using the data in ref. 5, and have found that because of the high density of planetary nebulae near the galactic centre and the low positional precision of X-ray surveys, the statistics coincide rather well. Theoretically, there ought to be eight coincidences of X-ray sources with non-stellar planetary nebulae for the survey in ref. 3, and four coincidences for the survey in ref. 4, when sources definitely detected are considered. In fact, we have found the actual coincidences to be seventeen and four, respectively. If stellar planetary nebulae are also involved, the probability of coincidences is higher by a factor of about 10.

Planetary nebulae should therefore be treated as field objects rather than as subjects for the identification of X-ray sources in the energy interval 4–8 keV. The situation may alter, however, when passing to low energies. There are reasons to suggest that the hot nuclei of planetary nebulae will be observable at energies of about 0·25 keV (~ 50 Å).

I thank Professor I. S. Shklowsky for useful discussions.

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Received August 22, 1968.

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Lunar "Mascons"

THIS communication concerns recent developments in the determination of the lunar gravity field from the accelerations experienced by the lunar Orbiters during their motion around the Moon. I shall refer to the papers by Muller and Sjogren[1,2] which present, in the form of a map of equigravity contours, the final result of their reduction of the raw doppler data recorded during the actual motion. The adopted datum is the accelerations due to the second order gravity harmonic, so that in the contour map they give the surface gravity of the locus minus the local accelerations corresponding to the second harmonic.

In brief, Muller and Sjogren processed the raw data by least-square fitting using a theoretical model of the gravity conditions near the Moon (the model assumed the Moon to be a triaxial ellipsoid) in the first stage, and cubic polynomials to extract the residues of the accelerations not accounted for by the theoretical model in the second stage. The details of this complicated problem presented Muller and Sjogren with many difficulties demanding heavy work and correct judgments, and their results are evidence of success.

The "unexpected result" found by Muller and Sjogren deserves the attention it has drawn. They found that the residues of the acceleration over all ringed maria of the near side (Imbrium, Serenitatis, Crisium, Nectaris and Humorum) are positive, while the same is true for the area between Sinus Aestuum and Sinus Medii (the authors conclude that this area must be an ancient disfigured mare) and mare Orientale. On the remaining parts of the visible hemisphere, the sign of the acceleration residues lacks any systematic character.

The finding is important in itself, and must be taken into account in discussing the processes responsible for the present condition of the upper crust and external appearance of the Moon. It is certain from the systematic character of the residues that the cause is not very deep in the lunar globe. This view is shared by Muller and Sjogren[2], who advance the hypothesis that very large concentrations of matter beneath the centre of all five nearside ringed maria are responsible for the positive residues, in very much the way that Urey[3] has suggested. They further suggest these mass concentrations consist of high density matter, such as nickel or iron, and give them the name "mascons".

Many authors have suggested the plausible view that the density of all maria, not only the ringed ones, is larger than that of the terrae, and it has been accepted by