NUCLEAR PARTICLE TRACK STUDIES IN THE LUNAR REGOLITH : SOME NEW... TRENDS... AND... SPECULATIONS. J. Borg, J. C. Dran, G. Comstock, M. Maurette, B. Vassent, Laboratoire René Bernas, 91406 Orsay ; J. P. Duraud, C. Legressus, Département de Physicochimie du C. E. A., Gif-sur-Yvette.

Abstract

In this report we discuss two recent trends in our studies of lunar tracks: the " aging " of fossil tracks in the lunar regolith and the peculiar track distribution that can be expected from the motion of the solar system in the galaxy. The latter we investigate by using a theory of C. C. Lin and new results concerning the gaseous shells of supernovae.

" Aging " of fossil nuclear particle tracks in the lunar regolith.

The following characteristics show that the " old " fossil tracks due to VH ions in lunar dust grains are very different from " fresh " tracks produced with artificial beams of iron nuclei : 1. The old tracks are very stable in the electron beam of the 1 MeV electron microscope ; on the contrary the fresh tracks disappear very quickly under the beam ; 2. their thermal annealing temperatures seem to be slightly higher ($\sim$50°C) than those measured for the fresh tracks ; 3. both their etching rates and their maximum lengths are markedly smaller than the corresponding values obtained for tracks produced by 10 MeV/amu iron nuclei^{+}. For exemple the decrease in track length can be as high as 80 % ; furthermore this effect seems to depend on the mineral species and it is more pronounced for lunar than for meteoritic materials.

Additional experiments suggest that the stability of the " old " tracks in the electron beam possibly results from the exposure of the lunar dust grains in the " ancient " solar wind. Furthermore their marked shortening is best explained by a very mild thermal annealing. Thus it is quite clear that " aging " processes have modified several characteristics of fossil track distributions in extraterrestrial matter. Therefore at the present time it is not possible to use such parameters as track etching rates and track lengths either to identify Pu^{244} tracks or to measure the chemical abundance of the very heavy cosmic ray nuclei. However, we will present a new method that we call the " giant track in track " method, and that can greatly help in correcting the length distribution of the fossil tracks with a view to tackle these 2 problems.

The Moon as a probe of galactic arm structure

C. C. Lin has proposed that a star like the Sun has a residence time of about 50 million years in a galactic arm and travels from one arm to the other in about 200 million years. Furthermore, it is also known that

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" matter " (supernovae, turbulent clouds of gas and dust, low energy cosmic rays, etc..) is concentrated into the galactic arms. Therefore every 200 million years the moon is immersed during periods of about 50 million years in a medium enriched in " matter ", and it is interesting to check if our satellite could possibly keep a memory of such periodic effects which could in turn help to fix a sedimentation time scale in the regolith.

The results of our preliminary computations show that only the gaseous shells* emitted by supernovae could produce measurable effects in the lunar regolith. Indeed, even by the most favorable alternative process, the accretion of cosmic dust by the moon is still too small ($<10^{-3}$g/cm^2) to be easily measured. Furthermore the intensity of low energy (E <100 MeV/amu) galactic cosmic rays is severely decreased by solar modulation as they diffuse through the solar cavity to reach the moon ; therefore their contribution to the track density in lunar materials can hardly exceed that of the solar flare cosmic rays.

In our galaxy supernovae are concentrated in a thin disc where extreme population I stars are found, and the effective volume where the majority of the SN occur, at a rate of about 1/30 years, is only a small fraction ($\sim$0.03 to 0.003) of that of the galactic disc ($\sim 3 \times 10^{11}$pc^3). During the explosion a gaseous shell with a total mass of about 2×10^{33}g is emitted. The shell expands at constant speed, $V_s \sim 10.000$ kms/sec, over distance r$\sim$1.5 parsecs (1.5 pc). Beyond this distance the shell gets decelarated and V_s decreases to about 3000 km/sec at r $\sim$5 pc. With these very simple characteristics, which have been beautifully summarized by Ilovaisky and Lequeux (1), we deduce the following tentative conclusions concerning the possible interactions between the SN shell and the lunar surface : 1. if the SN occurs within r <5 pc from the solar system, then the dynamic pressure of the shell can counterbalance that of the solar wind ; therefore solar modulation is considerably decreased (or even eliminated !) and very high integrated fluxes of low energy (0.05 < E < 0.5 MeV/amu) ions bombard the lunar surface ; 2. the resulting track distribution is characterized by high superficial track densities ($>10^{12}$ tracks/cm^2) that extend to depths ranging from about 1 to 5 microns.

Last year we reported the observation of very steep track gradients in 200 Mesh lunar dust grains which we tentatively attributed to low energy ions (E< 0.3 MeV/amu) in the interplanetary space. The depth extensions of the gradients (1 to 5 microns) could be taken as a good evidence for the implantation of SN shells in the lunar regolith, as they correspond to particles with speeds ranging from about 3000 to 10.000 km./sec. However this interpretation requires SN occuring at distances r <5 pc to " blow away " solar modulation. With this condition the two following characteristics of the gradients are not well explained : 1. the track densities ($\sim 10^{10}$ to 10^{11} tracks/cm^2) are about 10 times smaller than those expected for a shell of 1 solar mass, ejected

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at r <5 pc ; 2. the average proportion, P, of the grains showing a steep gradient is $\sim$10%, for grains that have an integrated solar flare residence time on the top surface of the moon of $\lesssim 10^6$ years. From this we deduce that the frequency of SN that are effective ($r \sim 5$ pc) to produce implantation effects in the moon is $\sim 1/10^7$ years. With this value we then get a frequency of SN in the galaxy which is at least 10 times higher ($\sim$1/3 years) than the accepted value.

Therefore, more work is needed before claiming that SN remnants are implanted in the lunar regolith. In particular we have both to obtain a more accurate value of P and to evaluate the contribution of the sun by examining the mica from the Apollo 17 cosmic ray experiment. Nevertheless there are already several exciting implications of this hypothesis that can hold even if the steep gradients are not due to SN shells : 1. within $r \sim 5$ pc of a supernova, a high proportion of the dust grains in interstellar clouds should be very heavily radiation damaged. Then the large amount of energy stored as radiation damage in the grains could considerably aid their sticking if the clouds subsequently evolve to give a " Cameron " type nebula, in which planets can be formed. Furthermore, the peculiar properties of such grains could affect their oprical properties as well as the possible synthesis of organic matter in the grains ; 2. it has been suggested that the remanent magnetization of lunar rock could be due to an early and intense solar wind, interacting with the moon, but the requirement of a magnetizing field of about 100 to 1000 γ is very difficult to satisfy with this model. A similar type of interaction between the hot plasma of the SN shells (that can carry a magnetic field of up to $\sim$100 γ) and the moon, could in fact explain much more easily the remanent magnetization of lunar rocks ; 3. the spatial configuration of the Earth's magnetosphere could drastically change when the supernova " tornados " blow through the solar cavity, and interesting phenomena can possibly be produced on the earth ; but it is time now to stop any further speculations.

References

1. Ilovaisky S.A. and Lequeux J., (1972), Astron. Astrophys. 18, 189.
2. Lingenfelter R., (1969), Nature 224, 1182.

Footnotes

+ To determine these characteristics we use artificial krypton tracks that are registered perpendicularly to the surface of the sample, to etch out the maximum length of both fossil and calibration tracks inside the volume of the same sample.

* The burst of cosmic rays emitted during " nearby " SN explosion can possibly produce various effects in the solar system that have already been discussed by others (2). However, such particles reach the solar system at an earlier time than the SN shell and therefore their intensity (like that of " ordinary " cosmic rays) should be strongly affected by the still unperturbed solar modulation. Therefore we do not expect that they produce marked effects in the lunar regolith.