MOLECULES IN COMETS: A TOOL TO ESTIMATE THE LOW ENERGY COSMIC RAY FLUX OUTSIDE THE SOLAR SYSTEM ?

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ABSTRACT. It is described a method for evaluating the low energy cosmic ray flux outside the heliosphere. It is based on the chemical modifications induced in cometary nuclei by impinging ions and on the release of synthesized chemical species by comets entering for the first time into the inner solar system.

1. THE METHOD

Our knowledge of cosmic ray fluxes is substantially based on measurements performed either from the top of the atmosphere or from satellites; in any case well inside the heliosphere. Measurements of fluxes are then biased by the presence of the interplanetary magnetic field which acts as a selective screen preventing mainly low energy particles from reaching the inner region of the solar system, where we can measure them. The possibility to get reliable informations on the low energy flux of cosmic rays, which permeate our galaxy, have been based till now on theoretical estimates of particle transport (e.g. Morfill et al., 1976) or on the evaluation of the ionization rate induced in interstellar clouds by these penetrating ions (e.g. Lepp and Dalgarno, 1987).

Another possibility, in my opinion, exists. It is based on the generally accepted idea that cometary nuclei formed almost contemporaneous with the solar system about 4.6×10^{9} years ago. For about that long and till when they are injected into the planetary region, they have been staying in the so called "Oort cloud". This either whether they formed there or around giant planets and then were expelled there by gravitational perturbations. In the Oort cloud cometary nuclei, which according to the well accepted Whipple model (Whipple, 1950) consist of a matrix of meteoric material mixed with forzen gases, unscreened by magnetic fields have been bombarded by cosmic rays of high and low energies recording in their external layers chemical modifications induced by their passage (Pirronello, 1985).

Recently in the laboratory it has been shown infact (Pirronello et al., 1982) that energy released by fast ions in mixtures of frozen gases, formed by equal parts of water vapor and carbon dioxied (two

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species very abundant in comets) mixed in gas phase and then deposited on a cold finger at about 10 K, produce substantial amounts of formaldehyde. The measured production rate per impinging MeV helium ion in a layer ~ 1.8×10^{18} mol cm^{-2} thick has been found to be $Y \sim 3.7$ H_2CO molecules.

These experimental results can be applied to a comet to obtain informations on the energy spectrum of cosmic rays "dJ/dE". The number of formed molecules (for instance formaldehyde) per cm^2 in a layer of thickness "dr" at depth "r" in the nucleus is infact given by the sum of molecules reduced by the arrival, at that depth, of cosmic particles whose differential distribution outside the nucleus is dJ/dE, during the life of the nucleus in the Oort cloud.

Then at each depth "r" it is

$$\frac{dN(r)}{dr} = \int_0^T \int_0^{E_{max}} \frac{dJ(E')}{dE'} Y(E')\, dE'\, dt$$

with $T = 4.6 \times 10^9$ yr

$E' = E - E_\ell$

where E = energy of the ion impinging on the surface of the nucleus

E_ℓ = energy lost by the ion for reaching depth "r" in the nucleus

When the comet enters for the first time into the inner region of the solar system it starts sublimating its external layers and then releasing stored molecules synthesized by ion bombardment. Getting dN/dr from measurements of the production rate of formaldehyde Q (s^{-1}) (probably the most suitable are radioastronomical observations) one can than deduce dJ/dE the flux of particles impinging on the nucleus. More exactly differences between couples of values of the production rate of some molecules $\Delta Q = Q_2 - Q_1$, obtained at different times "t_1" and "t_2" and corresponding to different depths "r_1" and "r_2" in the cometary nucleus, are due to particles penetrating to a depth $r_1 \le r \le r_2$. Observations performed restricting the time interval (t_1 , t_2) which corresponds to a small depth range (r_1 , r_2) would give (forgetting in the first approximation straggling effects) quantitative knowledge on the spectrum, which for $\Delta r \to 0$ is almost mono energetic.

2. CONCLUSIONS

A new method for obtaining fluxes of low energy cosmic rays has been described. It is based on the idea that chemical species are produced by the energy loss of ions in the ice mixture of cometary nuclei, while they are spending their long life in the Oort cloud where they are not screened by the interplanetary magnetic field carried by the solar wind; such species are then released by sublimation from the comet when it enters into the inner region of our planetary system for the "very first time", giving us the possibility to deduce quantitative informations on

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the differential spectrum of cosmic rays even at $E < 1$ GeV, once we know from experimental determinations the production rates per impinging ion of the chemical species to be monitored.

The proposed method, together with some difficulties, has at least in principle two advantages over that one which estimates the flux of cosmic rays through the evaluation of the ionization rate in interstellar clouds. The first one is just that one can have informations also on the energy spectrum and not only on the total flux. The second advantage is that magnetic fields in clouds do not interfere with the evaluation. The main problem in obtaining meaningful estimates of chemical effects induced by cosmic rays in the frozen matrix will probably be due to the formation of dust halos and mantles of the type described by Mendis (1985), which will strongly interfere with the sublimation of volatiles; an effect relevant for comets close to the sun but that should be less important at higher distances from it.

REFERENCES

Lepp S., Dalgarno A.: 1987, this volume

Mendis D. A.: 1985, 'The Effect of Dust Halos and Dust Mantles on Nuclear outgassing', in Ices in the Solar System, eds J.Klinger et al. p.487, Reidel Publ. Co., Dordrecht, Holland

Morfill G.E., Völk H.J., Lee M.A.: 1976, 'On the Effect of Directional Medium-Scale Interplanetary Variations on the Diffusion of Galactic Cosmic Rays and Their Solar Cycle Variation', J. Geophys. Res., 81, 5841

Pirronello V., Brown W.L., Lanzerotti L.J., Marcantonio K.J., Simmons E.H.: 1982, 'Formaldehyde Formation in a H_2O/CO_2 Ice Mixture Under Irradiation by Fast Ions', Astrophys. J. 262, 636

Pirronello V.: 1985, 'Molecule Formation in Cometary Environments', in Ices in the Solar System, eds J.Klinger et al. p.261, Reidel Publ. Co., Dordrecht, Holland

Whipple F.L.: 1950, 'A Comet Model. I. The Acceleration of Comet Encke', Astrophys. J., 111, 375

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