Production rate of ^{41}Ca in Interplanetary Dust Particles and the possibility to measure by AMS

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Interplanetary Dust Particles (IDPs) also called micrometeoroid, micrometeorite, or cosmic spherules are small grains, generally less than a few hundred micrometers in size. Their main source is the Asteroid Belt located between Mars and Jupiter. During their flight from the Asteroid Belt to the Earth they are irradiated by solar and galactic cosmic rays and some radionuclides are formed, like ^{41}Ca and ^{53}Mn. Thus, ^{41}Ca ($T_{1/2}$=1.03×10^5 y) can be used as a unique tracer to determine the accretion rate of IDPs on Earth because there are no significant terrestrial sources for this radionuclide. The procedure to measure ^{41}Ca has been optimized at the Maier Leibnitz Laboratorium, the only facility which is at the moment capable to measure the low expected ^{41}Ca concentrations.

INTRODUCTION

Based on the analysis of cosmic spherules sampled in the stratosphere, in deep sea sediments and in Antarctic ice, it has been proposed that the chemical composition is similar to CM chondritic composition [1] or CI chondritic composition [2]. It is widely believed that the most important source of IDPs is the Asteroid Belt located at approximately 3AU (1AU=1 Astronomical Unit=1.5×10^{13} cm) between Mars and Jupiter, where the dust is formed by collisions between asteroids [3]. The comets are also another but minor source of IDPs [4].

The concentration of nuclides in the IDPs when accreted by the Earth depends on the irradiation history of the particles and consequently on their age and orbital trajectories.

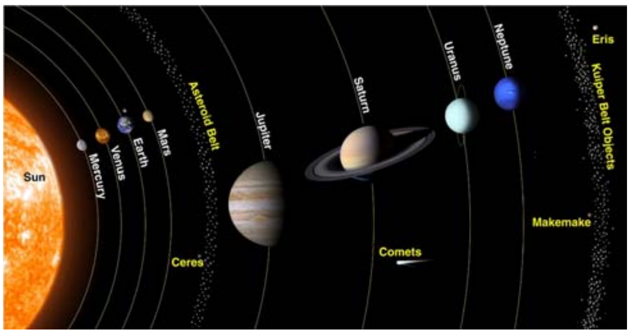

Figure 1: Major features of our solar system.

IRRADIATION OF IDPs IN THE INTERPLANETARY SPACE

A significant proportion of IDPs accreted on Earth is believed to originate from the Asteroid Belt at about 3 AU in our solar system. After production, IDPs approach to Earth due to the combined action of solar gravitation and Poynting-Robertson-Effect.

During their flight approaching the Earth, IDPs are irradiated by cosmic rays, that can be divided into a solar (SCR, solar cosmic rays) and a galactic (GCR, galactic cosmic rays) component. Both components consist mainly of protons.

The irradiation of IDPs by cosmic rays is described by the Bateman equation of radioactive decay of a nucleus with two production terms, P_G and P_S, as shown in Equation 1, where P_G is the galactic component, $P_S(0)$ is the solar component of the cosmic rays at 1 AU, a_e=1 AU, a_0=3 AU, k is a constant with value 1.3×5.12×10^{11} [5], and ρ and r are, respectively, the density and radius of the IDPs.

$$\frac{dN(t)}{dt} = -\lambda \cdot N(t) + P_G + P_S(0) \cdot \frac{a_e^2}{a_0^2 - \frac{2 \cdot k \cdot t}{\rho \cdot r}} \qquad (1)$$

Solving this differential equation from t=0 to the IDP's time of flight allow us to obtain the number of atoms of any radionuclide (^{41}Ca in our case) in dependence of the dust particle's radius *r*.

PRODUCTION RATE OF EXTRATERRESTRIAL ^{41}Ca IN IDPs

To solve the above mentioned differential equation, it is necessary to determine the above defined P_G and $P_S(0)$. The expected galactic (P_G) production rate was obtained by comparison of the ^{53}Mn extra-terrestrial production rate, using data of Fe(p,x)^{41}Ca and Fe(p,x)^{53}Mn reactions cross sections given by [6,7], and the GCR proton fluxes given by [8,9]. The ratio between those two production rates was calculated to be (0.19±0.05). A recent study (M. Auer et al., unpublished results) has estimated the production rate of ^{53}Mn due to galactic cosmic rays to be 34 dpm/kg. Using this data and the ratio calculated above results in a ^{41}Ca production rate due to galactic cosmic rays of P_G=(6.5±1.7) dpm/kg.

For ^{41}Ca the decay constant has a value $\lambda=\ln(2)/T_{1/2}=6.73\times10^{-6}$ y^{-1} and the solar production rate at 1 AU $P_s(0)$ is estimated as follow: if the ^{41}Ca saturation activity of (24±1) dpm/kg given by Nishiizumi et al., (1997) [10] is assumed to be the sum of the galactic and solar components ($P_G+P_S(0)$) at the Earth's orbit (1 AU), the solar component at 1 AU can be deduced by subtracting the galactic component. This allows us to calculate the solar component at 1 AU as $P_S(0)$=(17.5±2.7) dpm/kg. By integration of the differential equation (Equation 1) over all particles' radii, the weighted average production rate of ^{41}Ca in IDPs is (8.5±1.3) dpm/kg.

ANNUAL ACCRETION RATE OF IDPs ON EARTH

The mass accretion rate on Earth (F_{IDP}) is an important information on the micrometeoroid flux arriving in our atmosphere that can be used as an input in the analysis of deep-sea sediments and ice core samples. Different F_{IDP} values have been found, although until now, a discrepancy among them still exist: [11] published $(40\pm20)\times10^6$ kg per year, [12] determined a rate of extra-terrestrial accretion of $(0.22\pm0.11)\times10^6$ kg per year and most recently, [13] have provided a new calibration of the flux of submilimiter particles impacting the Earth of $(7.4\pm1.0)\times10^6$ kg per year if the Asteroid Belt is assumed as the major source of dust.

Since a large fraction of the extra-terrestrial matter, including IDPs is evaporating during the entry in the atmosphere, the ^{41}Ca in the IDPs is set free and could be measured by using aerosols and/or ice samples by AMS. In freshly deposited samples the atomic ratio ^{41}Ca/^{40}Ca is equal to the deposition rates ratio as stated by Equation 2.

$$\frac{F(^{41}Ca)_{IDP}}{F(^{40}Ca)_{nat}} = \left[\frac{^{41}Ca_{IDP}}{^{40}Ca_{nat}}\right]_{AMS} \qquad (2)$$

The key in this study is to find the perfect place to get samples to measure the atomic ratio ^{41}Ca/^{40}Ca. Thus, the Antarctica is an extremely interesting sampling site because terrestrial contributions are minimized due to its remoteness from continental sources. Due to its extremely low temperatures, the precipitated materials are perfectly preserved. Once the accretion rate of ^{41}Ca ($F(^{41}Ca)$) is known by Equation 2, the IDPs accretion rate on Earth could be determined by Equation 3 where $C(^{41}Ca)_{IDP}$ is the ^{41}Ca production rate in IDPs previously determined and S_{earth} is the surface of the Earth in cm^2.

$$F_{IDP} = \frac{F(^{41}Ca)_{IDP}}{C(^{41}Ca)_{IDP}} \cdot S_{earth} \qquad (3)$$

If the most recent IDPs accretion rate on Earth ($(7.4\pm1.0)\times10^6$ kg per year) is assumed, this leads an atomic ratio ^{41}Ca/^{40}Ca in the Antarctic samples in the range 10^{-15}-10^{-16}, a ratio actually only possible to be measured at the MLL in Garching.

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