Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008
Vol. 5 (HE part 2), pages 1105–1108

ID 1011

30TH INTERNATIONAL COSMIC RAY CONFERENCE

ICRC'07 Mérida, México

First generation Moon based CR experiments

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Abstract: The Moon based observation of cosmic rays must be part of the complete program at the forefront of the space science and technology of the set of Moon based observatories that will operate on the Moon in the next few decades. When compared with the cost of a dedicated vehicle and its launch, the installation of a CR experiment on the Moon, in a suitable equipped location, compensates for the cost of the Earth to Moon transportation. It will be discussed what could be obtained by installing on the Moon the experiments selected in the last two decades but never flown because of the shortage of flight occasions and of spacecrafts. Their evolution could constitute the 'first generation Moon based CR experiments'.

Preamble

In the seventies, in view of the shuttle operations, a complete program at the forefront of space science and technology was elaborated. It included the so called Great Space Observatories and the ground based Very Long Base Interferometer (VLBI), a number of cosmic ray facilities: the Advanced Composition Explorer (ACE) for low energy CR and, on board of the Freedom Space Station (FSS), the Heavy Nuclei Collector (HNC) and the ASTROMAG facility.

Nowadays, at the dawn of a major programme oriented toward the human exploration of the solar system using the Moon as a starting point, a new complete program at the forefront of space science and technology is being constructed,. It should include a set of Moon based observations to explore any aspect of the Universe, and the Moon based CR observation must be part of this program.

The Moon should be considered a huge Space Station. The installation of experiments in a suitably equipped location on its surface could compensate for the cost of the Earth-Moon transportation, taking also into account that this cost is anticipated to decrease by a sensible factor in the next decade. The recommendation of the USA Presidential Commission of engaging the community in a "*re-evaluation of priorities to exploit opportunities created by the space exploration vision*" was endorsed by the 'MoonBase initiative'[1], which in this framework studied the possibility of using the Moon for scientific observations in astronomy and astrophysics. The e.m. component was treated in its first workshop in Venice [2], and the possibilities offered for the observation of CR were discussed in the workshops in Washington [3] and in Moscow [4]. These studies showed the huge progress possible by dedicated experiments located on the Moon for the solution of the most relevant long standing problems in CR physics.

With the perspective of these potentialities, it is here discussed what it can be achieved in the period of the construction and first utilization of the Moon Base, by what could be called 'first generation experiments' on the Moon.

[1] The study the possibility of concentrating several experiments in an organized and serviced 'condominium' on the Moon ('MoonBase initiative' [1]) was afforded by a working group promoted by High Frontier Inc. (USA) and the 'Solidarietà e Sviluppo Association' (Italy), representing professionals working in Research Centers and in Space Industries.

Introduction

For most of the satellite borne CR experiments, as in general for satellite borne Astrophysics experiments, the mass and cost of the spacecraft and of its services (altitude and attitude control, power generation and distribution, telemetry, etc.) largely exceed the mass and cost of the instrument. The reduction of the total required investment by installing the instrument on an already organized and serviced habitat was proven for the many experiments performed on board of the MIR Space Station and of the ISS.

What Detectors for the First CR Experiments on the Moon?

We'll begin by discussing what could be obtained installing on a future Moon Base the CR experiments selected in the last two decades by different Institutions and Space Agencies, and at the stage of prototypes or precursors, although never flown due to cancellation of the FSS and lack of suitable carriers. In the perspective of the Moon Base program these experiments could be called 'zero generation experiments, whose adaptation constitutes the 'first generation Moon based experiments', subject of this report.

(a) Measurement of the fluxes of very high and extremely high Z CR

The flux of nuclei with charge higher than those of the iron group is extremely low and reflects their origin in violent processes in the Galaxy. Pioneer experiments have shown that for their observation it must be used tens of square meters of suitable sensible material to be exposed in space and recovered after several years in order to be chemically etched and analysed in laboratory. The HNC on FSS was conceived for this purpose. The project ECCO (heir of the HNC) is so far not founded, and now hampered by the coming casting off of the Shuttle. Its program can be recovered by exposing on the Moon surface modules of passive detectors, transported to the Moon in several trips distributed on several years, and brought back to the Earth a few years later for etching and analysis. The modules can consist of the BP-1 glass foils developed for ECCO, and be located in suitable lunar sites for minimizing the temperature excursion.
If the physics will require increasing the statistics of the registered events, this 'zero generation experiment' can involve more modules and continue in time toward a 'first generation Moon based experiment'. To reach other interesting physics items (such as the possible detection of nuclearites) the total exposed surface should be 100 time that of ECCO.

(b) Measurement of the fluxes and energy spectra of the rare CR isotopes

The LISA project on the FSS was the extension to high energy of the ACE mission. It was devoted to the study of the energy spectra of a number (≈80) of isotopes and rare components.
A LISA-like instrument would be relatively small, but somewhat complex for the need of a good determination of the mass and charge of the incoming nucleus, the basic scheme consisting of a magnetic superconducting spectrometer, complemented by detectors measuring the nucleus velocity. The superconducting coils should produce a magnetic field of several kgauss on a volume of a few hundreds cm^3 equipped by thin silicon sensors. They must be transported from the Earth to the Moon base, but there they could enjoy of a very low coolant consumption due to the local thermodynamic conditions, and could be charged (and re-charged in case of quenching) by the power supplies of the Moon base.

(c) Measurement of the fluxes and energy spectra of the antiparticles

The same scheme suitable for the identification and spectra measurement of the isotopes, and hopefully the same physical instrument complemented by suitable devices for identifying the electromagnetic CR component, could be used for measuring the rare elementary antiparticles (positrons, antiprotons) and hunting for antinuclei. In the next few years PAMELA and AMS-2 will determine the positron and antiproton spectra beyond 100 GeV, and will hunt for antinuclei with a very high sensitivity. In order to push the spectra measurements toward the TeV region the geometrical acceptance and intensity of the magnetic field must be of the 'tesla' class in a volume of a few cubic meters, and instruments PAMELA-like or AMS-like would not be sufficient. For the measurement of the e^+ and p^- spectra an interesting possibility is offered by the use of the powerful bending power of the terrestrial magnetic field. In order to use it as a spectrometer the scheme of the apparatus should foresee a precise determination of the direction of the incoming particle on an area of several m^2 and a good energy determination. The reachable energy is determined by the physics dominating the antiparticle flux and the area and precision of the direction detector. With an area $\geq$ 10 m^2 and $\leq$0.1 mrad angular resolution the antiproton spectrum can be measured up to 100 TeV in case that it is dominated by the existence of primary antiprotons, as it should be for a baryon-antibaryon symmetric Universe. The mass of such a system could be a few tons, its final minimum mass strongly depending by the technical detail of the project. The direction measurement must be complemented with a good determination of the energy, either by velocity measurements (Cherenkov and TRD) or by calorimetric measurements. Possible scheme of calorimeters are discussed in ref. [3], [4] and [5], but it is rather difficult to conceive them available for a 'first generation experiment'. Probably for a first generation experiment it should be brought from the Earth an already assembled system of TRD's and Cherenkov counters. It could be dimensioned and equipped both for the detection of very high energy gamma rays (in the TeV region) and of primary CR's up to the PeV region, as discussed in the next sub-section.

(d) Measurement of the CR chemical composition at the 'knee'

After that the SCINATT-MAGIC project on the FSS was halted, several ballooning campaigns were performed, and many Extended Air Shower ground based experiments continued, but the composition at the 'knee' still is a puzzle. The ACCESS experiment was proposed for the ISS, but never supported, as well several free-flyers proposals in Russia. An ACCESS-like instrument located on the Moon, possibly adding later the calorimeter for the proton component, would be adequate for solving the knee problem.

Obviously the mass should be optimized for the Earth-Moon flight and the detectors conveniently chosen for the lunar environment. Such an approach would also allow a smooth shift from an instrument fully imported from the Earth, toward a 'first generation Moon based experiment' where the most massive part, such as the absorber of the calorimeter, could be provided on the Moon. If realized by a water pool, as envisaged in (3), (4) (fig.1), its acceptance would be of the order of $\approx$100m^2sr, and its dimensions similar of that needed for the measurement of the rare CR components above considered. The possible rates are indicated in fig.2.

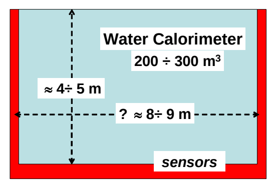

Figure 1

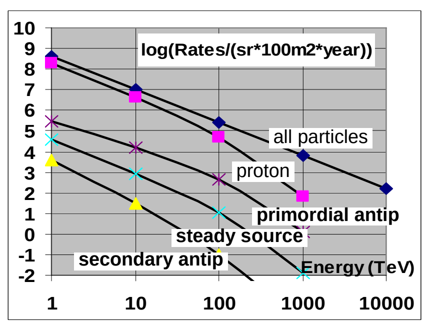

Figure 2: Primary CR rates as a function of the energy. Antiproton rates are also reported for the 3 possible trends.

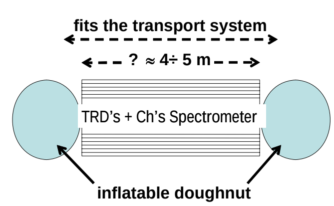

Figure 3

For the measurement of the CR composition the calorimeter must be complemented by direction and charge measurements of the incoming particle. Such a calorimeter, suitably equipped by other instruments, could also be fitted for extending the high energy gamma ray astronomy well beyond the limits that will be reached by the GLAST experiment in next future[2].

A possibility complementary or alternative to the calorimetry, is to use transition Radiation Detectors (TRDs) and gas Cherenkov counters for energy and charge measurement. A suitable choice of the parameters of a set of TRDs allows to identify the nucleus and measure its energy on a wide range, from 1,000 up to more than 100,000 of the gamma kinematical parameter, i.e. from 1 TeV to more than 100 TeV for the proton and 50 TeV to more than 5 PeV for the iron. In this range a system of ≈4 m diameter guarantees a useful rate. It matches the diameter of the spacecraft in preparation for the transportation to Moon, still leaving room around to an inflatable doughnut for stretching the many sheets of radiator and sensors (fig.3). A TRD and Cherenkov counter spectrometer could be also envisaged for the identification of the particle and the determination of its energy for the measurement of the energy spectra of the high energy rare components (isotopes, rare radioactive nuclei, antiparticles), and in this case the measurements of the CR composition at knee and of the rare CR components could be integrated in one facility.

(e) Measurement of the fluxes and energy spectra of the Ultra High Energies CR

The missions, suggested in the original NASA program and studied in the meantime, dedicated to the measurement of the flux of CR in the extreme energy region (UHECR), such as EUSO in Europe, OWL in USA and KLYPVE in Russia, could not be until nowadays implemented, hampered by the uncertain future of the ISS, the shortage of occasions of flight and the required investments. The goal of the UHECR observation is not only the determination of their energy spectrum and of their composition, but also the identification the UHE neutrino component and the determination of its angular distribution. It would be an UHE neutrino observatory, which would open a new fundamental window in astronomy, allowing pushing the astronomical observation to the very beginning of the Universe. Presently an effort is underway for extending the performance of EUSO-like experiments for registering and identifying atmospheric showers produced by UHE neutrinos. The Moon seems not competitive with this effort, and in general not a convenient location for the observation of UHECR.

An alternative experimental approach is that developed by the Lebedev Institute of the Russian Academy of Science in Moscow. The UHECR are detected and their energy measured by registering in an instrument in lunar orbit the radio-signal of their interaction with the Moon soil. The precursor experiment LORD-10 [6] is currently in preparation and should orbit around the Moon in the near future. It is mainly a demonstration instrument that should set up the method and can be considered a ‘first generation Moon based experiment’ for measuring the UHECR flux around and beyond the GKZ cut off energy. The possibility of refining this method for the identifying of UHE neutrinos and the determining their arrival direction must be deeply studied for understanding if it could be used for a future UHE neutrino observatory.

[2]GLAST will recover, 20 years later, the physics program of the ASTROGAM project, devoted to the high energy gamma ray astronomy beyond the limit reached in the eighties by the EGRET/CGRO experiment, cancelled by the halt to the FSS.

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