Charged Cosmic Rays

For energies below $10^{14}$ eV the cosmic ray flux is high enough so that the primary elemental and isotopic composition can be studied by direct measurements with detectors above the atmosphere by means of balloons or spacecrafts. The main goal of these studies is to answer fundamental questions about the accelerators in the Universe and their energetic physical processes. Presently, due to their limited dimension and exposure, the measurements extend up to ~100 TeV/n.

Time to time there are opportunities to fly cosmic ray experiments on space missions on board of satellites. Satellite missions offer the possibility to maximize the exposure in space, without atmospheric background, for several years. Another opportunity is given by the International Space Station (ISS). Although the availability of ISS for scientific payloads will be limited, it could be especially useful for payloads that require servicing or extended exposure in space to measure very rare species. The stratospheric balloons are good opportunities in case of experiments that are not critically affected by few $g/cm^2$ of atmospheric background and that can be performed with exposure time of the order of a month. Despite the several limitations with respect to space missions, the lower cost of ballooning, the relatively shorter time scales for mission development and the relatively simpler ground infrastructures, makes this activity very appealing. However, given foreseeable balloon capabilities, it is hard to envision extending direct measurements higher than ~200 TeV with balloons.

Approved projects

Three projects are at present financed by INFN to measure cosmic rays with a direct technique in the region below the knee: PAMELA, AMS and CREAM. The main physics issue addressed by PAMELA and AMS is the study of antimatter and antiparticle content in cosmic rays, which is a unique tool to investigate several physics and astrophysical phenomena. The search of antimatter is strictly connected with the baryon-antibaryon asymmetry in the Universe, while the antiproton and positron measurements involve the search and the identification of possible primary sources, that is one of the major challenges in cosmic ray studies. In fact, several observations give us a coherent picture of a Universe dominated by dark matter and dark energy: the detection of an anomalous content of antiprotons or positrons in cosmic rays could be a clear signature of a source connected with the presence of dark matter, e.g. WIMPs annihilation. Also other exotic sources can be assumed, such as Kaluza-Klein particles or primordial black hole evaporation. Another open issue that PAMELA and AMS can help to clarify is the absolute intensity of the primary cosmic ray flux. Above a few tens GeV, some discrepancies between different recent data are evident. Such differences are of the order of 20%, a value above the quoted uncertainties. These discrepancies, probably of instrumental origin, have also consequences in the uncertainties on atmospheric neutrino calculations. It is worth noting that both these experiments have redundancy detectors to measure the particle energy. PAMELA will be launched into space by a Soyuz TM2 rocket in 2006: the orbit is elliptical and semi-polar, with an inclination of 70.4 degrees and an altitude varying between 350 km and 600 km; the mission will last at least three years. The geometric...
acceptance in the standard trigger configuration is ~21.5 cm\(^2\text{sr}\). Moreover \textbf{PAMELA} is equipped with another trigger based only on the calorimeter signals: it permits to increase the acceptance of the e\(^+\)+e\(^-\) measurement at high energy up to about 600 cm\(^2\text{sr}\).

\textbf{AMS} will take data on the International Space Station (ISS). A preliminary version of the AMS instrument (also known as AMS-01) has been flown on the Space Shuttle Discovery in June 1998 collecting a large set of experimental data (10\(^6\) triggers). 

\textbf{AMS} total acceptance for antinuclei is 0.4 m\(^2\text{sr}\): with this detector we expect to collect around 10\(^9\) nuclei and isotopes and to obtain 10\(^9\) in sensitivity for antimatter search in the rigidity range up to 140 GV. Besides of the antimatter and antiparticle studies, \textbf{AMS} will measure also the chemical and isotopic composition, and will make the observation of diffuse and source-emitted gamma rays. The launch of \textbf{AMS} is related to the schedule of the Space Shuttle flights which is being updated after the problems occurred during the latest Shuttle mission (STS-114) in 2005. Work is in progress at NASA to re-define the Shuttle flights planning manifest by the Flight Assignment Working Group (FAWG) with particular attention to those flights directed towards the ISS. NASA and DOE are jointly reviewing the AMS experiment in order to keep the AMS flight in the updated Shuttle schedule; at the same time, they are studying possible and viable alternative ways (e.g. unmanned vehicles) to bring AMS to the ISS.

\textbf{CREAM} is an experiment designed for direct measurements of cosmic ray composition and energy spectra, to the energy scale below 10\(^{15}\) eV over the elemental range from proton to iron (and beyond), in a series of balloon flights from McMurdo (Antarctica). The goal is to accumulate at least 500 particles each for proton, helium, CNO, Ne-Si and Fe group above 10\(^{14}\) eV in a series of balloon flights with Long Duration Balloons (LDB) or with the super-pressure (ULDB) balloon, currently under development by NASA (for flights of 100 days or more). Annual flights are planned by alternating two science instrument suites (CREAM-I and CREAM-II), since the same instrument cannot be flown in consecutive years due to the time required for recovery, return to the laboratory, and refurbishment. Due to its dimensions and to the 42 day long flight in December 2004, CREAM-I, in its first flight, has an exposure of the order of 10\% of the combined JACEE-RUNJOB exposure. CREAM-II was launched in December 2005 from McMurdo.

**New projects and ideas**

At the moment no defined proposals have been sent to the CSN2, but some people are working to different new projects and ideas. It is likely that the next generation of experiments for the observation of UHE Cosmic Radiation will be space-based to exploit the large instantaneous geometrical aperture which can be obtained from a space platform with respect to ground based experiments. A large part of the scientific community based on the experience of the Extreme Universe Space Observatory (EUSO), plans to propose to ESA a mission for UHE Cosmic Radiation observation from space. This proposal is coherent with the ESA road-map (ESA Cosmic Vision 2015-2025) which includes such a scientific theme among the ESA priorities for the decade 2015-2025. This experiment will be referred to \textbf{CROS}: Cosmic Radiation Observatory in Space. Moreover, ESA is expected to issue a Call for Mission Proposals by the end of 2006. \textbf{CROS} is devoted to the determination of the shape of the energy spectrum up to above the GZK energy, providing information on the source distribution and particle injection spectrum and on the identification of the sources, as well as providing totally independent measurements with respect to the Pierre Auger Observatory ones.
Moreover, the instantaneous aperture, two orders of magnitude larger than typical ground-based experiments, might open the observation of burst-like phenomena. The NUCLEON satellite mission (already included in the 2005-2010 Russian space program) is an experiment based on the KLEM method (Kinematic Lightweight Energy Meter), aimed to extend the direct measurements on the composition and spectra of charged cosmic rays to the PeV scale. The energy measurement is made by a kinematical detection technique where the rapidity of secondary products are measured in a high granularity silicon telescope preceded by a Carbon target and equipped with a tungsten-convertener. The effective exposure calculated for a 5 year long mission is \( \sim 170 \text{m}^2\text{sr} \) days for H and \( \sim 460 \text{m}^2\text{sr} \) days for Fe nuclei. NUCLEON-B is a pathfinder balloon mission to cross-calibrate the energy scale of the KLEM device by flying the NUCLEON instrument together with a conventional tungsten/Sci-Fi calorimeter, on a long duration balloon flight. The CALET (CALorimetric Electron Telescope) mission is projected to be installed on the Exposure Facility of the Japanese Experiment Module on the International Space Station. The purpose of the mission is to study the electron spectrum in the TeV region, the gamma-ray up to 10 TeV and the proton and nuclei spectra up to 1000 TeV. The CALET geometrical factor for electrons of about 1 m\(^2\)sr permits to study the electron spectrum (actually the e\(^+\)e\(^-\) spectrum) at high energy. In particular, a measurement of the electron spectrum above 1 TeV could show a peculiar structure due to the nearby sources.

**Gamma rays and electromagnetic spectrum**

Gamma-rays of cosmic origin are a manifestation of the most energetic phenomena in our Universe. Many astrophysical sources emit gamma-rays including relativistic compact stars, massive black holes in active galactic nuclei, gamma-ray burst sources, and our Sun during intense flares. The energy domain between 10 MeV and hundreds of GeV is an essential one for the multi-frequency study of extreme astrophysical sources. The understanding of spectra of detected gamma rays is necessary for developing models for acceleration, emission, absorption and propagation of very high energy particles at their sources and in space. After the end of EGRET on board the Compton Gamma Ray Observatory this energy region is not covered by any other experiment, at least up to 50 GeV where ground Cerenkov telescopes are beginning to take data. A group of INFN researchers begun in the 1993 to think to the follower of EGRET, making a project called GILDA, that was the progenitor of the two experiments almost ready to flight: AGILE and GLAST.

**Approved projects**

AGILE is an ASI Small Scientific Mission done by a collaboration between the Universities and INFN. The AGILE instrument is designed to detect and image photons in the 30 MeV ÷ 50 GeV and 10 ÷ 40 keV energy bands, with a large field of view covering \( \sim 1/5 \) of the entire sky at energies above 30 MeV. Primary scientific goals include the study of AGNs, Gamma-Ray Bursts, Galactic sources, unidentified gamma-ray sources, diffuse Galactic gamma-ray emission, high-precision timing studies, and Quantum Gravity testing. The construction of AGILE is finished. The launch will be in middle 2006 and AGILE will be the only Mission entirely dedicated to
high-energy astrophysics above 30 MeV to support multi-wavelength studies during the period 2006-2007. The AGILE Science Program will be open to the international scientific community.

**GLAST** is a next generation high-energy gamma-ray observatory designed for making observations of celestial gamma-ray sources in the energy band extending from 20 MeV to more than 300 GeV. The principal instrument of the GLAST mission is the Large Area Telescope (LAT) that is being developed as a mission involving an international collaboration of particle physics and astrophysics communities from 26 institutions in the United States, Italy, Japan, France and Germany. The **GLAST** detector is ready and the launch will take place in August 2007. The main characteristics of the detector are an energy range between 20 MeV and 300 GeV, a field of view of ~3 sr, an energy resolution of ~5% at 1 GeV, a point source sensitivity of $2 \times 10^{-9} \ \text{ph cm}^2\text{s}^{-1}$ at 0.1 GeV, an event deadtime of 20_s and a peak effective area of 10000 cm$^2$.

GLAST will dramatically extend the number of observed AGN, as well as the energy range over which they can be observed. Indeed, GLAST might be called the "Hubble Telescope" of gamma-ray astronomy as it will be able to observe AGN sources to $z\sim 4$ and beyond, if such objects actually existed at such early times in the universe. GLAST, in concert with the Gamma-ray Burst Monitor, will measure the energy spectra of GRBs from a few keV to hundreds of GeV during the short time after onset when the vast majority of the energy is released. GLAST will also promptly alert other observers, thus allowing the observations of GLAST to be placed in the context of multi-wavelength afterglow observations, which are the focus of HETE-2 and Swift missions. The additional information available from GLAST spectral variability observations will be the key to understanding the central engine. GLAST will discover many gamma-ray pulsars, potentially 50 or more, and will provide definitive spectral measurements that will distinguish between the two primary models proposed to explain particle acceleration and gamma-ray generation: the outer gap and polar cap models. From observations made with gamma ray experiments through the EGRET era, seven gamma-ray pulsars are known. GLAST will detect more than 100 pulsars and will be able to directly search for periodicities in all EGRET unidentified sources. Because the gamma-ray beams of pulsars are apparently broader than their radio beams, many radio-quiet, Geminga-like pulsars likely remain to be discovered. GLAST could be of particular interest for the search of dark matter candidates. For example the EGRET telescope has identified a gamma-ray source at the Galactic center and the spectral features of this source are compatible with the gamma-ray flux induced by pair annihilations of dark matter weakly interacting massive particles (WIMPs). The discrimination between this interpretation and other viable explanations will be possible with GLAST as well as the possibility to discover dark matter signals in other direction of the sky.

**New projects and ideas**

The energy range between 10 MeV and 100 MeV with good angular resolution is still open for exploration and it can be studied only from space. This is why the Russian-Italian Collaboration involved in NINA and PAMELA is proposing the **GILDA** project dedicated to this energy range. The improvement in the angular resolution can be as high as a factor ten at 50 MeV and this will give a complete new vision of the gamma ray sky in the 10 MeV and 100 MeV. The experiment is already included in the Russian Space Program for a flight on the satellite METEOR-B after the 2012.
Many astronomical objects, such as active galactic nuclei or spinning bodies (pulsars and black holes) emit **polarized radiation at X-ray wavelengths**. Measuring this polarization we will provide fundamental information about the geometry and internal structure of these sources allowing to uncover how matter behaves in extremely intense magnetic and gravitational fields. To capture the polarization of faint and weakly polarized sources INFN Pisa has developed a new instrument based on the photoelectric effect, a process very sensitive to photon polarization and with a large cross-section in the low energy range (2÷10 keV) of great astronomical interest. This instrument belongs to the class of Micro Pattern Gas Detectors of which it represents the latest stage of development. The performance of the tested prototypes looks like a significant step forward, compared with traditional X-ray polarimeters and promises a large increase in sensitivity. In its final configuration the target performance of the device is the detection of ~1% polarization for few milli-Crabs sources (in the XEUS focal plane, for example). This sensitivity will likely allow polarimetry measurements to be made on thousands of galactic and extragalactic sources: a real breakthrough in X-ray astronomy.

New generation experiments plan to use bolometer arrays in order to measure the **Polarization of the CMB (Cosmic Microwave Background)**. The WMAP experiment has provided cosmological parameters measurement with unprecedented precision. From the measurement of cosmic ray anisotropy the content of dark matter and dark energy and the contribution of hadronic and neutrino components to the total mass of the universe has been determined to a level of precision of about few percent. The forthcoming Plank experiment, that will take data in 2007, will enhance this level of precision by one order of magnitude. After Planck, the next generation of experiments, that will take data in 10 to 15 years from now (2006), should also measure the Polarization of the CMB in order to have deep insight of the Inflation mechanism, the history of the universe before the Grand Unification period and the possible pre-big-bang scenarios. The Kinetic Inductance Detector (KID) technology for the bolometer arrays seems the most viable choice for the Italian groups working on this field. The technology of the readout of such an array of detectors is based on microwave electronic components similar to those used in cell phones. The experiments that will use and develop these technologies are ground based (Experiments CLOVER and BRAIN) or hosted on balloons flight from the South Pole (Experiment OLIMPO). The 5th CSN of INFN is currently founding a research and development activity for KID bolometer arrays named RIC. It must be point out that both the polarized X-ray astronomy and the Cosmic Microwave Background experiments would open new fields in the INFN activity.
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<td>GLAST</td>
<td>Osservatorio spaziale per raggi gamma della NASA. (20 MeV-300 GeV)</td>
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<td>SWIFT per i GRB, INTEGRAL per gamma di bassa energia, HESS, MAGIC, VERA, AMS per gamma di altissima energia. Sensibilita’100*EGRET</td>
<td>Costruzione iniziata nel 2004, completata nel 2006</td>
<td>500 M$ la missione 180 M$ il payload</td>
<td>INFN 50%, ASI 50%</td>
<td>1 M€ / yr</td>
<td>9 anni fino al 2012</td>
<td>Silicon Strip Tracker (80m2) porta a maturità la tecnologia del Silicio per lo spazio</td>
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<td>AMS-02</td>
<td>Spettrometro magnetico su ISS</td>
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<td>-AMS-02 circa 5000 cm^2 s^-1 x 3 anni, MDR di circa 3 TV. - Pamela, nello spazio, circa 25 cm^2 s^-1 x 3 anni, MDR circa 0,7 TV - BessTeV: circa 3000 cm^2 s^-1 x circa 30 giorni, MDR circa 2 TV.</td>
<td>AMS-01 1995-1998 AMS-02 2000-2008</td>
<td>144 M€</td>
<td>Circa 19% INFN</td>
<td>360 k€ / yr</td>
<td>2011</td>
<td>Spazializzazione di rivelatori di particelle, di elettronica di lettura, DAQ e processing ad alte performance Primo magnet superconduttore nello spazio</td>
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<td>Globale</td>
<td>ATIC su pallone. CREAM ha un maggior fattore geometrico. Statistica e qualità’ dati superiore rispetto a esperimenti precedenti.</td>
<td>2003-2007 4 anni</td>
<td>Globale circa 25 M$ 8 M€ x solo ‘Science instruments</td>
<td>INFN 10% di Science instruments</td>
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**Osservazione della Radiazione Cosmica di Altissima energia dallo spazio (grande apertura istantanea).**

**Studio della Radiazione Cosmica di Altissima energia post-AUGER**

**Globale**

**OWL (NASA): per ora sembra disolto. TUS/KNL/PVE (Russia). EUSO Coll.**

**Proposta per una missione nel 2015 (ambito ESA Cosmic Vision) (e 2006 bando ESA, inizio 2007-08)**

**Da definire**

**Da definire**

**Da definire**

**Prevedib. 3 anni presa dati in orbita**

**Ottiche per spazio grande apertura e grande campo. Sensori singolo fotone.**

**30 FTE**