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# Laboratori Nazionali di Frascati

LNF-88/17(P)
22 Marzo 1988

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## ASTROMAG AND MANNED COSMIC RAY RESEARCH IN SPACE

Presented at 1st Meeting of the
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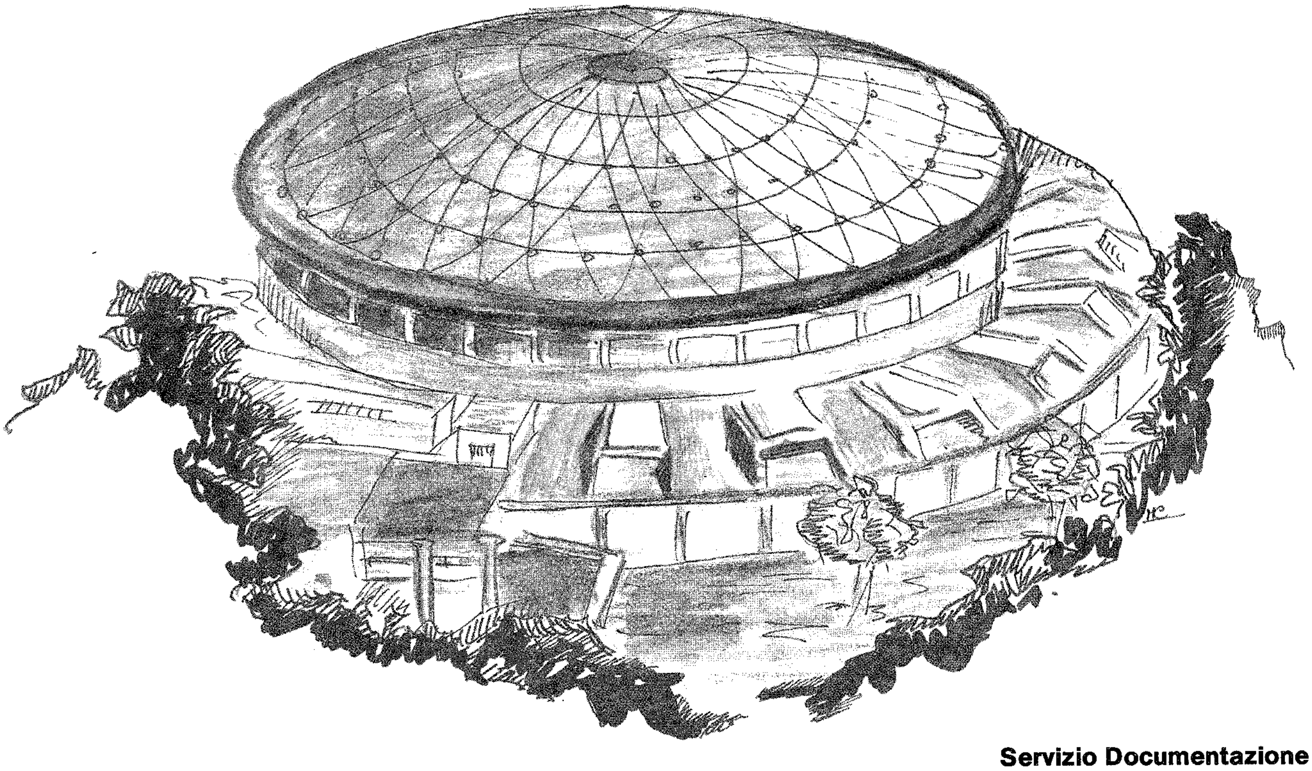
IFSUSS on Physics and Astrophysics in the Space Station Era
Venice, (Italy) October 4-7 (1987)



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# ASTROMAG AND MANNED COSMIC RAY RESEARCH IN SPACE

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## 1. - INTRODUCTION

Among elementary particle physicists there is currently a revival of interest in cosmic ray physics. New theoretical basis for the unification of fundamental laws of nature and new technical possibilities in particle detection have stimulated this interest and the possibility that much can be learned from systematic and careful measurements of cosmic ray fluxes and characteristics.

Furthermore, in the past decade unexpected experimental results demanded a better understanding of the behaviour of our galaxy and of the process of star formation. Namely, elementar and isotopic abundances of cosmic ray (CR) matter present substantial differences form those of solar system material (see Fig. 1 and 2). These abundances require an accurate comparison with prediction of nucleosynthesis calculations in order to understand how elements were formed and stars are born and process matter.

Finally the unexpected abundances of antiprotons and positrons at low energies, though still preliminary (see Fig. 3 and 4), raise the question of matter/antimatter symmetry, the most fundamental in cosmology. At higher energy the antiproton abundance could be linked to new unpredictable processes, possibly involving constituents of the invisible matter in the universe (such as annihilation of photinos and antiphotinos or decay of primordial black holes); in any case it will bring us to reconsider our ideas concerning the propagation of CR through the galaxy.

Unification theories, composition of CR matter and abundancies of antiprotons and positrons raise questions, the experimental answers to which will demand "LONG SPACE EXPOSURE OF LARGE INSTRUMENTS".

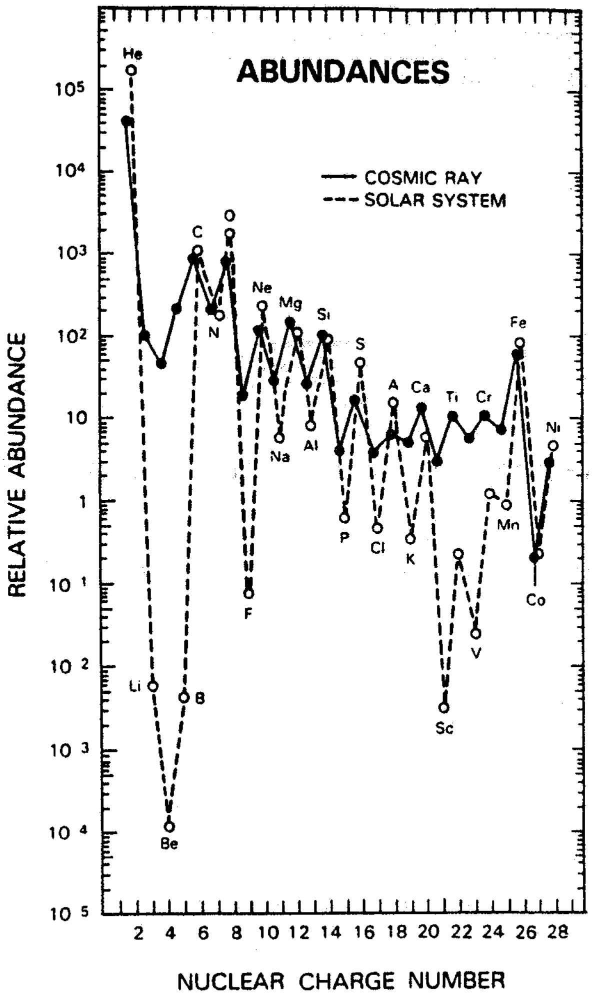


**FIG.1**- Comparison of relative abundances of cosmic rays and solar system materials.

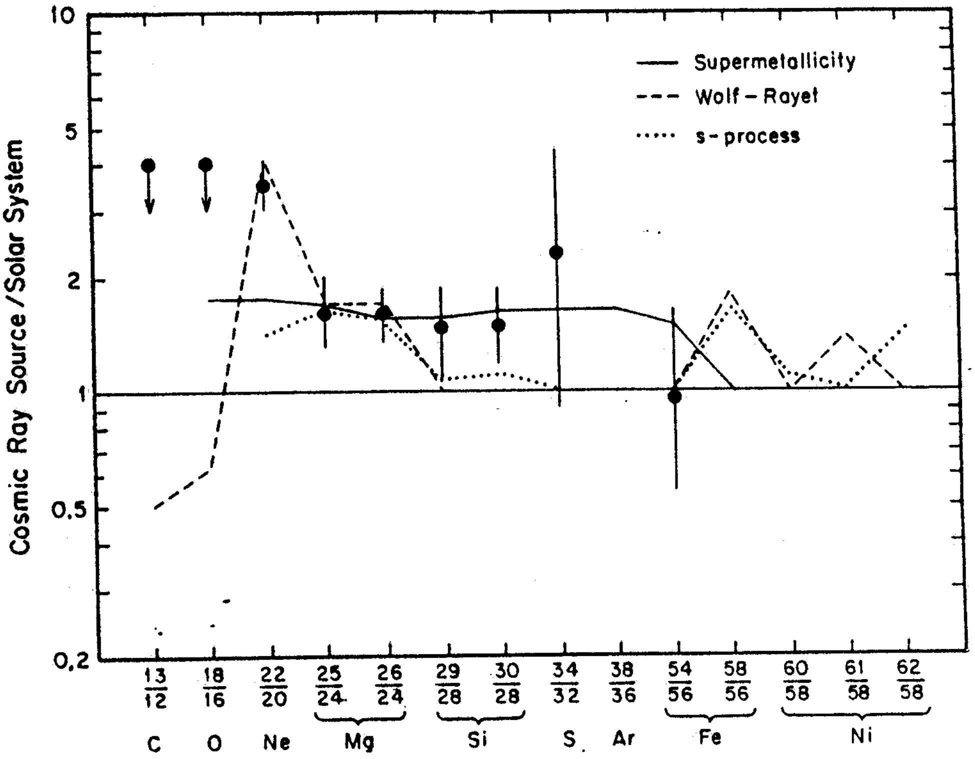


**FIG. 2** - A compilation of recent determinations of the isotopic composition of the cosmic ray source normalized to the solar system composition.

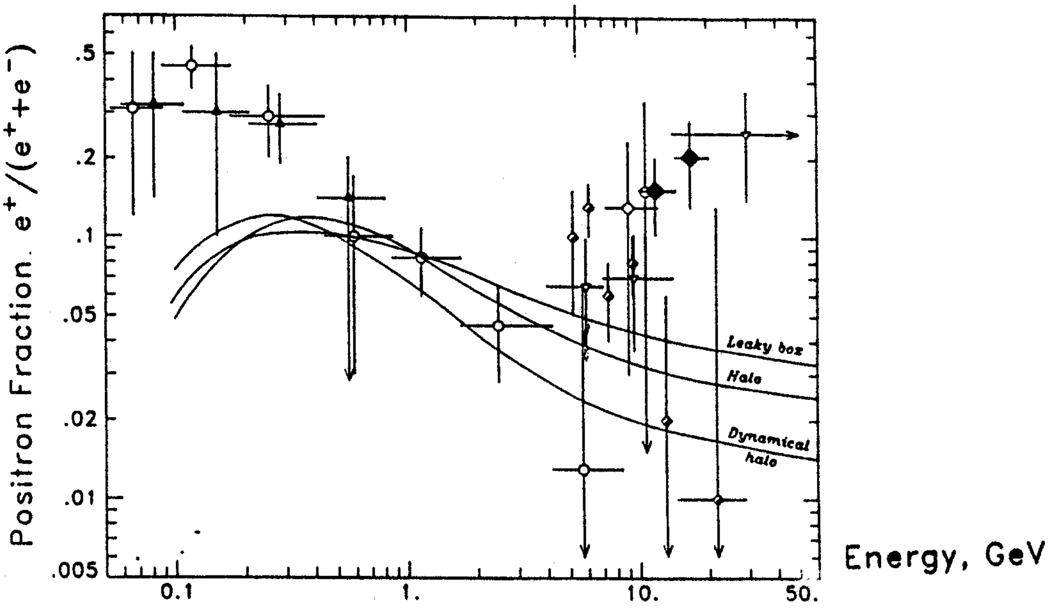


**FIG. 3** - Measurements of the positron to total electron ratio compared with the predictions of three cosmic ray propagation models.

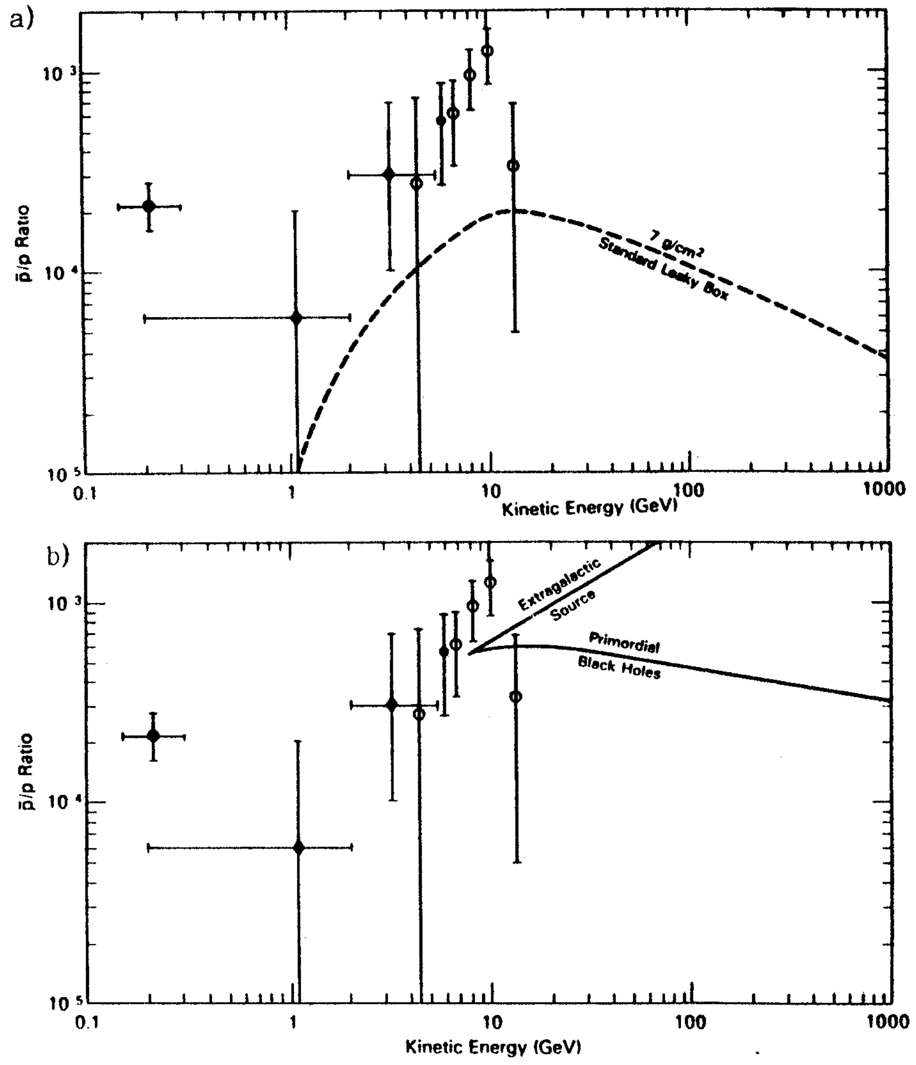


**FIG. 4** - A summary of measurements of the cosmic ray antiproton to proton ratio compared with the prediction of the "standard leaky box" model that fits heavier secondary nuclei (a). In full lines are reported the $\overline{p}$ spectra forseen by "exotic" proposals introduced to explain the low energy $\overline{p}$ excess (b).

## 2. - THE USA PARTICLE ASTROPHYSICS PROGRAM

This was a major point of the "Field Report"(1) that concluded a two-year study of the Astronomy Survey Commettee of the USA National Academy of Sciences.

A working group was convened by NASA in 1984 to plan these recommendations, whose concluding report(2) was published in december 1985. The planning was carried out in the context of the USA President directive that NASA develop a manned Space Station by early 1990's.

A Definition Study Team was indeed convened, composed for one third of foreign advisors, to define a superconducting magnet facility (later called ASTROMAG) for cosmic rays to be installed on the Space Station.

This schematic history requires some comments.

The starting sentence of the final report(2) of the NASA planning group recites: "Cosmic ray astrophysics stands today at a critical point of its development...".

And in effect the demand for "long space exposure of large instruments" will require a long duration effort of large teams, a new approach in experimental CR research. The only new RC flight experiment initiated in the 1980's was the Heavy Nuclei Collector (HNC) for the second flight of the Long Duration Exposure Facility (HNC/LDEF-2), a completely "passive" experiment to study Actinides in CR. Unfortunately HNC has not flown because of launch delays caused by the Challenger accident.

Furthermore several CR experiments approved for Spacelab flight were deleted for "overbooking" and Shuttle-Sortie missions were neither frequent nor easy , as NASA had hoped when the program was initiatied.

Finally also high-altitude balloon flights suffered from delays and increasing of technical difficulties during the decade from 1975 to 1985.

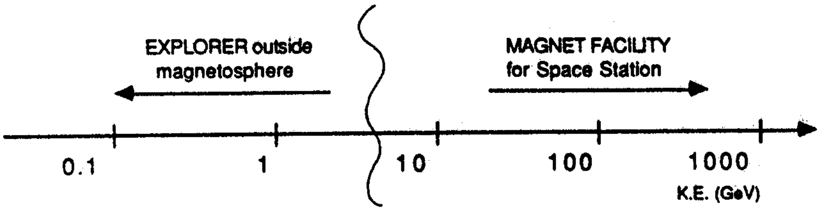
The NASA planning group, in reaffirming the scientific directions of the Academy report(1) took into consideration these critical points as well as the opportunities offered by Space Station and identified two major projects: a superconducting magnetic spectrometer facility for Space Station (ASTROMAG), and an explorer spacecraft flying outside the magnetosphere as the focus for CR research for the remainder of the century. The whole program is summarized in Table I.

## 3. - THE SCIENTIFIC OBJECTIVES OF ASTROMAG

ASTROMAG is a project which is strongly linked to the manned Space Station program. ASTROMAG needs SS, which can provide it with liquid Helium resupply, electric power to charge the coils, experiment assembly and changeout support, vertical orientation, services and consumables for the detectors, data buffering and transmission. In particular the detectors could have a complexity approaching that of the detectors used at the accelerators, so that a human intervent in the experiment could result in enhanced scientific return.

TABLE I - Particle Astrophysics Program for 1985-1995. Schematic from the report of NASA Cosmic Ray Program Working Group, dec. '85.

(A) MAJOR PROGRAMS: gain of a factor $10\text{-}10^{3}$ in
- K.E. range
- A x$\Omega$ acceptance
- time exposure



(B) LOW COST/FREQUENT FLIGHTS
- High altitude balloons
- Shuttle and Space Station attached payloads

(C) EXSISTING AND PLANNED PROGRAMS
- Continuation of exp.s in still operating spacecrafts
- International Solar Terrestrial Program for WIND spacecraft (ISTP/WIND)
- Refly of Cosmic Ray Nuclei experiment
- Heavy Nuclei Collector for second LDEF flight (HNC/LDEF-2)

(D) LABORATORY INVESTIGATION AND THEORY
- Cross-section measurements and accelerator calibrations
- Theory
- Instrument development
- Infrastructures

(E) STUDIES FOR THE FUTURE
- Assembly of large arrays in space

High energy, $10^{15+17}$ eV
Ultra Heavy Nuclei Z>30
Ultra HE (Fly's Eye)

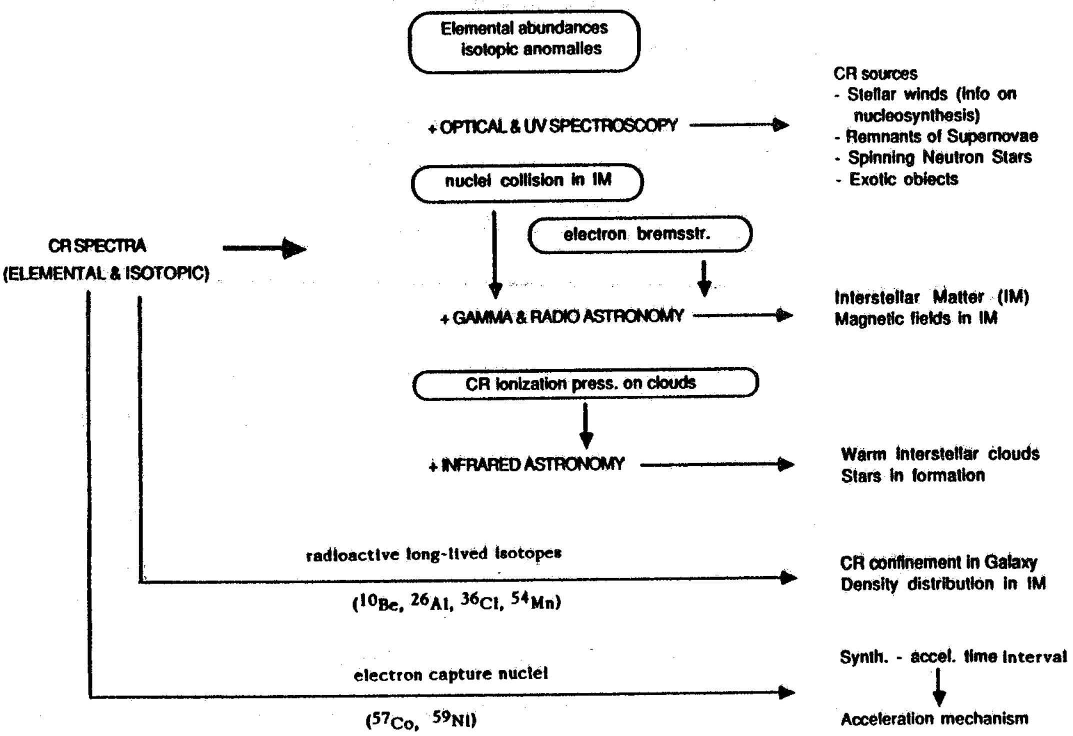
- Interstellar probe (till several 100 AU)
- Exp.s on Polar Platform (p, e , Ultra Heavy nuclei)

Furthermore, the technology is now available to undertake the operation of a superconducting magnet in space: superconducting magnets have become routine on the ground, liquid helium cryostats have been successfully operated in space and cryogen transfer of Superfluid Helium in zero g environment is scheduled.

But the main reason for ASTROMAG is linked to its scientific objectives: cosmological antimatter search, antiproton studies, accurate spectra of electron and positrons, systematic measurements of isotopic composition of CR matter as well as of its elemental composition and energy spectra up to several TV/c rigidities constitute the primary objectives. But ASTROMAG will offer also a unique opportunity for a high statistics and detailed study of high energy gamma ray sources, search for new collision phenomena of very high energy nuclei with various target nuclei, search for exotic particles (e.g. strange quark matter or nuggets), solar, solar-terrestrial and heliosphere studies through spectra, anisotropies and time profiles of protons, electrons, alpha-particles and neutrons produced in large solar events, use of the high flux cusp magnetic field of its coil configuration for unique and fundamental plasma physics experiments which are not addresable in laboratory programs.

A more detailed description of all these scientific objectives has been included in the interim report of the Definition Study Team$^{(3)}$. Here I tried to summarize in Table II only the items of astrophysics to whom a systematic and detailed knowledge of elemental and isotopic compositions of CR matter will give a decisive contribution; the rich interconnections with other astrophysics researches and with astronomy are also indicated. It must however be stressed that the real challenge concerns the fundamental cosmological question of matter/antimatter symmetry. The preliminary antiproton results mentioned above, as well as the serious questions about thories predicting a matter dominated universe, fueled by the "elusive" nature of proton decay events, of free magnetic monopoles and of neutrino masses and oscillations, raised the present keen interest in antimatter research experiments. Besides the decisive evidence of an even very small flux of heavy antinuclei, indirect evidence could be obtained by an accurate antiproton spectrum measurement on a wide energy range (see Fig. 4b).

TABLE II



## 4. - THE ASTROMAG FACILITY

The Definition Study Team for ASTROMAG considered a configuration based on two distinct spectrometers operating in the magnetic field produced by the s.c. coil system: one spectrometer dedicated essentially to identification and spectrum determination of low Z particles and optimized for antimatter search (MAS = Matter Antimatter Spectrometer), and the other one aiming for the momentum resolution at the highest rigidities to obtain the isotopic compositions at the highest Z, at least till the iron and nickel, the final key products of star combustion. In effect this was the guiding criterium in dimensioning the geometrical acceptance and the maximum useful magnetic field of ASTROMAG (see in Fig. 5 the expected rates for single isotopes till the Fe-Ni region).

The subdivision in two spectrometers corresponds also to a technical opportunity because the system of coils, in order to have no net dipole moment to preserve the SS stability, produce a useful magnetic field in at least two separate region around.

The above considerations are at the origin of the scheme of ASTROMAG sketched in Fig. 6 and of its main parameters reported in Table III. Possible auxiliary detectors useful for specific researches and specialized spectrometer for high energy gamma rays and electrons working in the fringing fields of the magnet are also indicated.

**TABLE III** - Astromag characteristics.

| | | |
|---|---|---|
| Size: | Coil Diameter | 1.3 m |
| | Coil Separation | 1.7 m |
| | Facility, Except Net | 4.5 m x 4 m x 3 m |
| Spectrometer: | Field integral | 0.2 to 0.5 T-m (Tesla Meters) |
| | Tracking Resolution | 30 to 50 μm |
| | Max Detectable Momentum | 1 to 5 TeV/c |
| | Stored (Field) Energy | 5 to 10 MJ |
| | Coil Unbalance | < 1 percent |
| | Persistance | 10 per cent decay per year |
| Cryostat: | Volume | 3000 liters |
| | Lifetime | 2 to 2.5 years |
| | Coolant | Superfluid Helium at $\leq$ 1.7 K |
| | Vent Rate | 7 L/Day |
| Facility: | Power | 1 to 2 kW, continuous |
| | Data Rate | 100 to 500 kb/s, continuous |
| | Total Mass | 5000 kg |

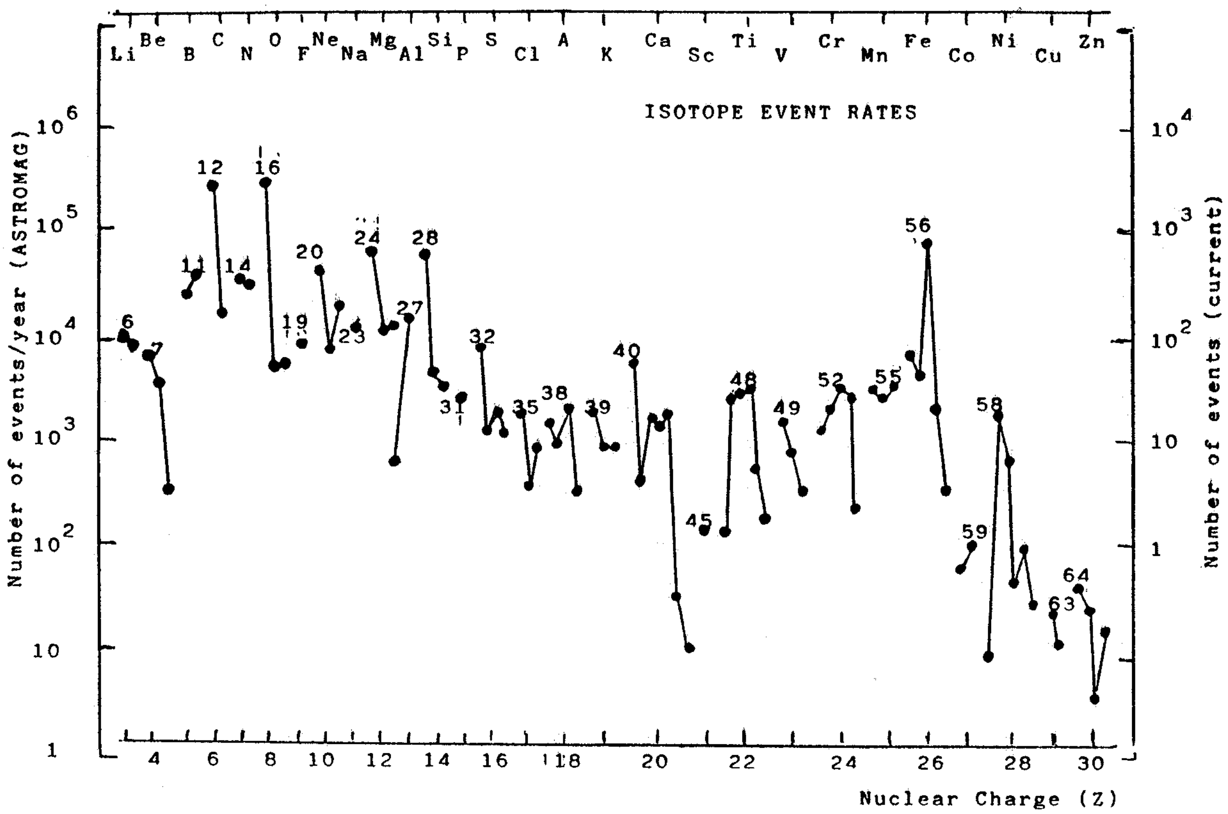


FIG. 5 - Expected isotope event rates in ASTROMAG.

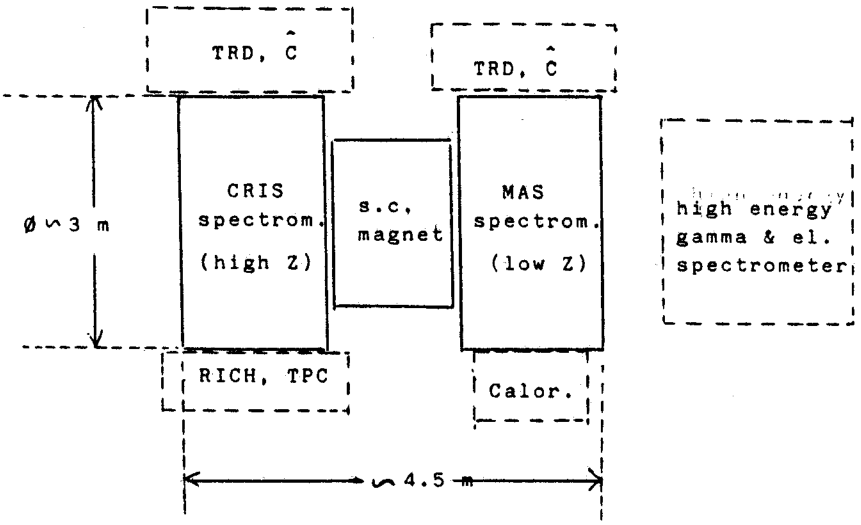


FIG. 6 - Sketch of the overall ASTROMAG scheme.

## 5. - ASTROMAG ON SPACE STATION

ASTROMAG will be carried to SS orbit in the Space Shuttle cargo-bay. The global external dimensions and weight, while determined by the scientific requirements, are consistent with this choice.

The magnet, launched cool, will be charged with electric current using the services of the SS, in order to avoid any electromagnetic interaction with the Shuttle. The maximum magnetic field, and the dimensions and configuration of the coils, match, besides the weight optimization and the technical requirements concerning the liquid Helium consumption and the time needed to charge and discharge the magnet, the request of a minimum impact on the SS and its environment. If installed on the SS already in its phase one (i.e. when the SS will essentially consist of its central horizontal structure without the two vertical beams) ASTROMAG should stay 10 m apart from the central horizontal structure (see Fig. 7). A protective net all around will prevent astronauts and objects to fall under the action of the magnetic field gradient.

In Fig. 8 is reported the time schedule to have ASTROMAG mounted on SS-phase 1, i.e. beginning 1996.

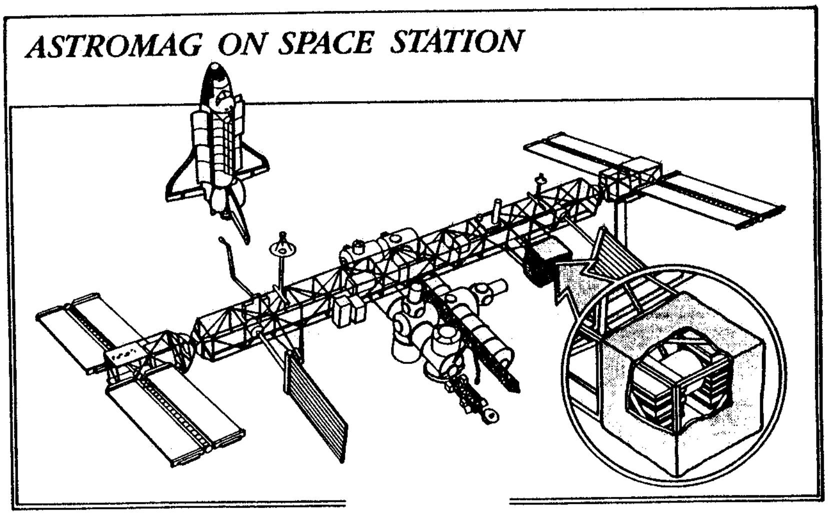


FIG. 7 - Location of ASTROMAG on the SS-phase 1 inside one of the 5 meter cubes constituting the basic SS structure and protective netting around it.

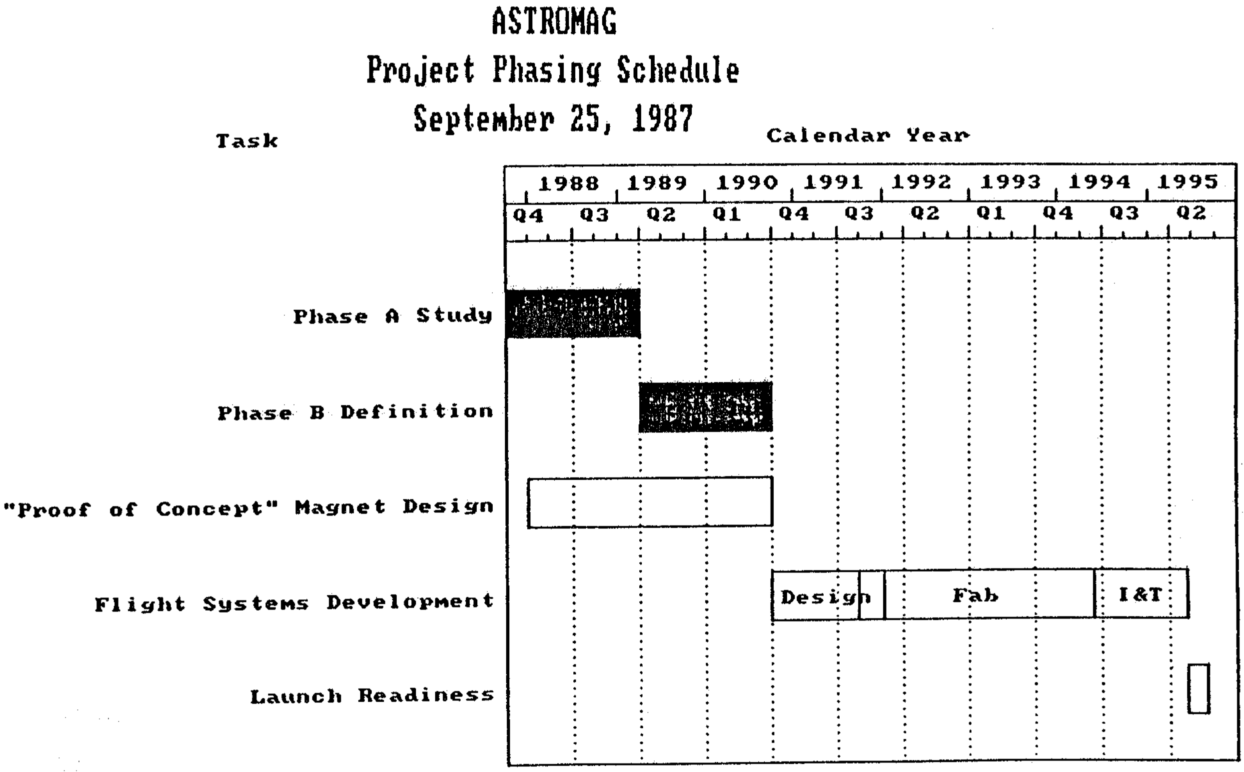


FIG. 8 - ASTROMAG Phasing Schedule.

Complementary detectors and substitutions should be carried to the SS orbit in separate flights, not necessarily of Shuttle type, and their weight and dimensions chosen also according to the chosen carrier.

For further details concerning ASTROMAG and its interaction with SS I refer the reader to other talks given during this conference(4) and to the ASTROMAG interim report(3). Here I want to underline two aspects of ASTROMAG.

The first one is its character of facility. I will give two meaningful examples. Complementing the basic configuration by improved velocity detectors or possibly implementing the track detector of CRIS spectrometer with a better one when available, it will be possible to extend the isotopic composition study in the heavy nuclei region, beyond the iron and nichel, or new researches (e.g. very high energy nuclei collisions, strange quark matter or nuggets; see Fig. 9) will become accessible. Complementary detectors and a possible similar track detector implementation could optimize the MAS spectrometer for low Z isotopes experiments (D, $^3$He/$^4$He) and/or for gamma ray detection (see Fig. 10).

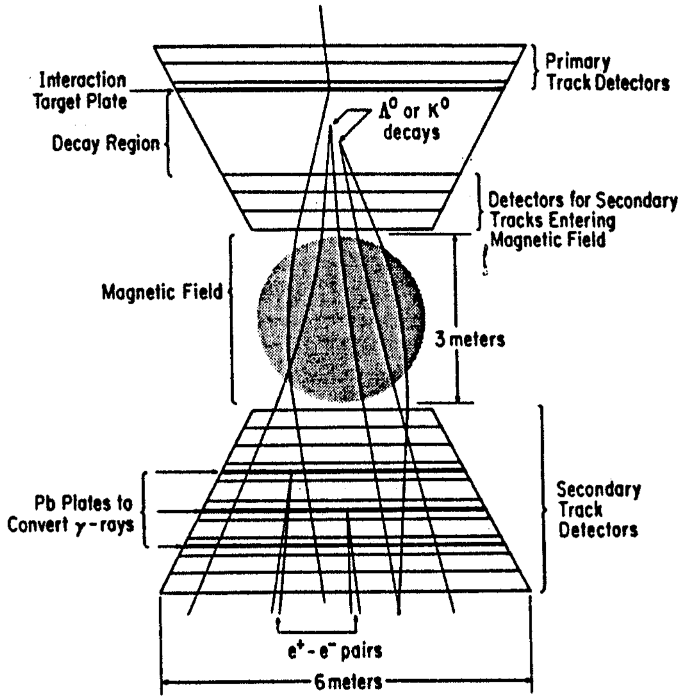


FIG. 9 - Cross-section of a detector system designed to search for strange-quark matter and other exotic particles and to study nuclear interactions. A hypotetical event with two strange particle decays ($\Lambda^0 \to p + \pi^-$ and $K^0 \to \pi^+ + \pi^-$) and two gamma rays is shown.

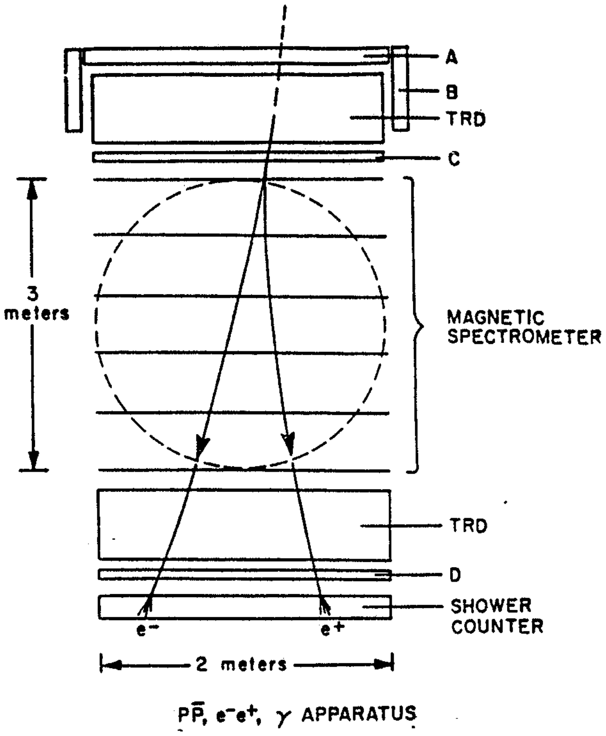


FIG. 10 - An apparatus for p, $\bar{p}$, $e^-$, $e^+$ and gammas.

A second aspect to be stressed concerns the coil system itself. The experience gained constructing and operating in space for a number of years a superconducting coil system of sizeable dimensions will accumulate a precious experience for conceiving and constructing superconducting coil systems for plasma physics, growth of crystals, processing of materials, NMR in zero-g and variable thrust rockets.

## 6. - WHAT AFTER ASTROMAG?

Also when complemented with the best detectors nowdays conceivable ASTROMAG will approach but not cover the energy region where the bend in the overall cosmic ray spectrum occurs, at about $10^{15}$ eV, and where characteristic changes in the elemental composition of CR matter should appear, related to both the inefficiency of acceleration mechanisms at these high energies and to the CR escape from the galactic disk. Furthermore, not accessible to the study of Astromag is the 2/3 of the periodic Table which lie above the iron-nickel region. Planned to be explored by HNC, this region of the periodic Table would add a new dimension to the elemental and isotopic composition study because of the different histories of nucleosynthesis and propagation of these heavier elements.

These are just examples to state that ASTROMAG is a huge step forward in the CR astrophysics, but not the last step in the direction of long space exposure of instruments of large acceptance, possibly complete of momentum and velocity analysis.

If ultra high energies, $\geq 100$ TeV, inaccessible to the larger accelerators in project, could be reached, the "cosmos" will become a "superaccelerator" to be studied and possibly exploited. The assembly of large arrays in space could cope with this task allowing to reach the necessary acceptances to have a useful rate. It is worthwhile to note that circular structures, carried packed to orbit and there "opened" (see Fig. 11, from ref. (5)), can cover acceptances that increase quadratically with the linear dimensions, and hence the weight, of their radial components (see Fig. 12, adapted from ref. (5)).

In the meantime the development of track detectors that can give resolutions approaching the micrometer on huge volumes, as needed for experimentation at new supercolliders, should give the necessary know-how to afford momentum measurement in this ultra high energy region.

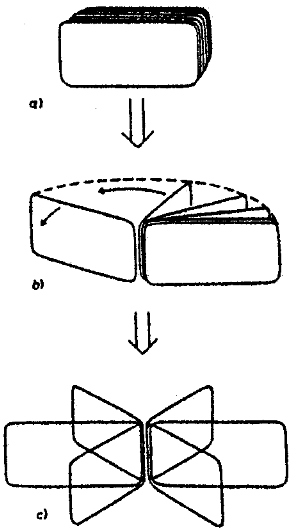


**FIG. 11** - Fan opening cylindrical structure: a) packed for the transportation system, b) opening of the radial elements, c) final configuration.

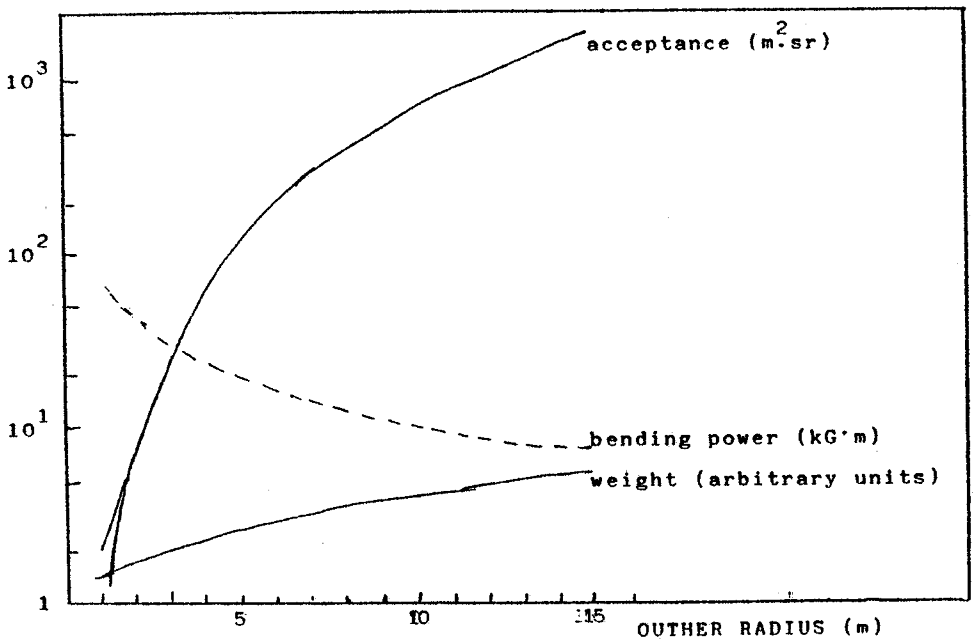


**FIG. 12** - Acceptance bending power and trend of the weight of the outer radius for a cylindrically symmetric (toroid-like) system of coils.

## REFERENCES

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(2) "The Particle Astrophysics Program for 1985-1995", Report of the NASA Cosmic Ray Working Group, December 1985.

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(4) R.A. Mewaldt, "Cosmic Ray Isotope Spectroscopy from the Space Station", and J.F. Ormes, "Search for Antimatter at the Space Station", this conference.

(5) G. Basini et al., "Toroidal Coil Configuration for a Large-Acceptance Space Spectrometer", Il Nuovo Cimento, 9C (1986), 953.