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Committee on the Peaceful Uses of Outer Space

Report on the United Nations/European Space Agency/National Aeronautics and Space Administration of the United States of America Workshop on the International Heliophysical Year 2007

(Abu Dhabi and Al-Ain, United Arab Emirates, 20-23 November
2005)

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I. Introduction

A. Background and objectives

1. The Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III), in particular through its resolution entitled “The Space Millennium: Vienna Declaration on Space and Human Development”,¹ recommended that activities of the United Nations Programme on Space Applications should promote collaborative participation among Member States at both the regional and international levels by emphasizing the development of knowledge and skills in developing countries.
2. At its forty-seventh session, in 2004, the Committee on the Peaceful Uses of Outer Space endorsed the programme of workshops, training courses, symposiums and conferences planned for 2005.² Subsequently, the General Assembly, in its resolution 59/116 of 10 December 2004, endorsed the United Nations Programme on Space Applications for 2005.
3. Pursuant to General Assembly resolution 59/116 and in accordance with the recommendation of UNISPACE III, the United Nations/European Space Agency/National Aeronautics and Space Administration of the United States of America Workshop on the International Heliophysical Year 2007 was held in Abu Dhabi and Al-Ain, United Arab Emirates, from 20 to 23 November 2005. The United Arab Emirates University hosted the Workshop on behalf of the Government of the United Arab Emirates.
4. Organized by the United Nations, the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA) of the United States, the Workshop was the first in a series of workshops on the International Heliophysical Year 2007 proposed by the Committee on the Peaceful Uses of Outer Space, based on discussion in its Scientific and Technical Subcommittee and reflected in the report of the Subcommittee (A/AC.105/848, paras. 181-192). The workshop was co-organized by the National Astronomical Observatory of Japan, the International Astronomical Union (IAU) and the Committee on Space Research.
5. The main objective of the Workshop was to provide a forum to highlight recent scientific and technical results in order to (a) develop the basic science of heliophysics (the connections between the Earth, the Sun and inter-planetary space) through cross-disciplinary studies of universal processes; (b) determine the response of terrestrial and planetary magnetospheres and atmospheres to external drivers; (c) promote research on the Sun-heliosphere system outward to the local interstellar medium; (d) foster international scientific cooperation in the study of heliophysical phenomena now and in the future; (e) preserve the history and legacy of the International Geophysical Year on its fiftieth anniversary; and (f) communicate unique results of the International Heliophysical Year to the scientific community and the general public.
6. The present report was prepared for submission to the Committee on the Peaceful Uses of Outer Space at its forty-ninth session and to its Scientific and Technical Subcommittee at its forty-third session, both of which will be held in 2006.

B. Programme

7. At the opening of the Workshop, statements were made by the Minister for Education and the Chancellor of the United Arab Emirates University, on behalf of the Government of the United Arab Emirates, and by representatives of ESA, NASA and the Office for Outer Space Affairs of the Secretariat. The Workshop was divided into scientific sessions, each focusing on a specific issue. Presentations by invited speakers describing the status of their findings in research and education were followed by brief discussions. A total of 70 papers were presented by invited speakers from both developing and developed countries. Poster sessions and working groups provided an opportunity to focus on specific problems and projects in preparation for the International Heliophysical Year 2007 and in basic space science.

8. The Workshop focused on topics such as (a) solar heliospheric processes; (b) education programmes on space science and technology; (c) low-cost, ground-based instrument array initiatives for worldwide studies in space science: potential instrument providers and prospective instrument hosts; (d) astrophysical research in Arab countries; (e) astronomical telescope facilities in developing countries; (f) International Year of Physics 2005 celebrations in the United Arab Emirates and non-extensive statistical mechanics and astrophysics; (g) virtual observatories; and (h) astrophysical data systems.

C. Attendance

9. Researchers and educators from developing and industrialized countries from all economic regions were invited by the United Nations, ESA, NASA and the United Arab Emirates University to participate in the Workshop. Participants held positions at universities, research institutions, observatories, national space agencies and international organizations and were involved in all the aspects of basic space science covered by the Workshop. Participants were selected on the basis of their scientific background and their experience in programmes and projects in which the International Heliophysical Year 2007 and basic space science played a leading role. The overall preparations for the Workshop were carried out by an international scientific organizing committee, a national advisory committee and a local technical organizing committee.

10. Funds provided by the United Nations, ESA, NASA and the United Arab Emirates University were used to cover the travel, living and other costs of participants from developing countries. Funds for the holding of the Workshop were also provided by the United Arab Emirates Telecommunications Regulatory Authority, Dubai Silicon Oasis, Thuraya Satellite Telecommunications Company, the Standing Committee for Scientific and Technological Cooperation of the Organization of the Islamic Conference, the Emirates Heritage Club and the Al-Ain Rotana Hotel. A total of 150 specialists on the International Heliophysical Year 2007 and in basic space science attended the Workshop.

11. The following 39 Member States were represented at the Workshop: Algeria, Armenia, Bahrain, Brazil, Cameroon, Canada, Cape Verde, Côte d'Ivoire, Egypt, Eritrea, France, Germany, Georgia, India, Indonesia, Iran (Islamic Republic of),

Iraq, Japan, Jordan, Kuwait, Lebanon, Libyan Arab Jamahiriya, Malaysia, Netherlands, Nigeria, Oman, Pakistan, Republic of Korea, Russian Federation, Saudi Arabia, South Africa, Spain, Sri Lanka, Syrian Arab Republic, Ukraine, United Arab Emirates, United Kingdom of Great Britain and Northern Ireland, United States of America and Yemen.

II. Observations and recommendations

12. The Workshop observed with satisfaction that the regional centres for space science and technology education affiliated to the United Nations, which had been established in Brazil, India, Mexico, Morocco and Nigeria, were operational. The Workshop emphasized that the establishment of such a regional centre in Western Asia would be beneficial.

13. The Workshop noted with satisfaction the continued installation of telescopes and planetariums in developing countries through the official development assistance programme of the Government of Japan, in particular its continuing support for astronomical telescopes in Bolivia, Ethiopia and Pakistan and planetariums in Cuba, El Salvador and Romania.

14. The Workshop noted with satisfaction that the report *Developing Basic Space Science World-Wide: a Decade of UN/ESA Workshops*¹ had been widely distributed and that it served as a guide for activities related to space science in developing countries.

15. The Workshop noted with appreciation that the Office for Outer Space Affairs had received indications of interest from India, Japan and the Republic of Korea to host future workshops.

16. The Workshop strongly recommended support for the scientific activities related to the International Heliophysical Year 2007. The following concepts and projects were discussed and endorsed during the Workshop:

(a) The “Tripod” concept, which was developed and implemented by previous United Nations/ESA Workshops on Basic Space Science, should be adopted for the International Heliophysical Year 2007; installation and operation of scientific instruments, taking data with the scientific instruments and using scientific instruments and data for university education should be considered equally important in each of the activities on scientific instruments;

(b) Groups of countries to host scientific instruments, which would provide sites in locations where measurements were desirable, were identified. Potential scientific instrument host groups that showed interest came from various parts of Africa, Western Asia, India, Malaysia, Indonesia and countries in Latin America;

(c) Potential providers of scientific instruments discussed their interactions with potential scientific instrument hosts during the course of the Workshop and expressed overall satisfaction with the amount of interest shown by Workshop participants;

¹ W. Wamsteker, R. Albrecht and H. Haubold, eds., *Developing Basic Space Science World-Wide: a Decade of UN/ESA Workshops* (Dordrecht, Kluwer Academic Publishers, 2004).

(d) All scientific instrument providers discussed the status of development of their instruments and the degree of readiness to deploy those instruments. It was noted that the installations would remain quasi-permanent throughout the period of the International Heliophysical Year 2007 activities and thus there was no time pressure on the scientific instrument providers;

(e) Workshop participants were ready to provide voluntary support for the preparations and coordination of the above-mentioned scientific instrument activities as part of the overall activities of the International Heliophysical Year 2007.

17. The Workshop strongly supported the proposed collaboration of scientists from Georgia and Ukraine within the framework of the International Heliophysical Year 2007, with the aim of creating a complex electromagnetic polygon at the base of the Abastumani Astrophysical Observatory as well as a student-developed microsatellite, to be launched in 2007.

18. The Workshop noted that collaboration in the context of the International Heliophysical Year 2007 would require the exchange of personnel and scientific instruments between participating scientific organizations from different countries. Governments should be encouraged to facilitate such exchanges as much as possible.

19. The Workshop observed that Internet access was now available in almost all countries and encouraged support for increased use of the Internet as a tool for education and research, in view of the fact that many educational resources were now available online and could be accessed in a cost-effective manner. In that context, note was taken of a discussion group on the topic of the “digital divide”, which had been established by IAU. Developing countries were encouraged to participate in that discussion group.

20. The Workshop noted that the mirror sites of the NASA-funded Astrophysics Data System (ADS) in Brazil, Chile, China, France, Germany, India, Japan, the Republic of Korea, the Russian Federation and the United Kingdom had been enthusiastically accepted by the scientific community and had become important assets for developing countries to improve their access to the astronomical literature. The Workshop commended ADS for that work.

21. The Workshop appreciated the ongoing development of virtual observatories by major scientific organizations. The Workshop strongly recommended that every effort should be made to allow usage of those research tools, as well as access to the data and to the analysis software, by scientists from developing countries.

22. The Workshop observed that the scanning of historical observatory publications by ADS now provided easy access to a part of the astronomical literature that hitherto had been difficult to obtain in developing countries.

23. The Workshop encouraged close cooperation between the virtual observatory community and ADS, with the goal of allowing scientists from developing countries to compete at the highest level of scientific research.

24. The Workshop appreciated the increased availability of hands-on educational websites produced by major research organizations, which greatly facilitated science

education in developing countries. Space science professionals in all countries should be encouraged to support such efforts.

25. To mark the centenary of Albert Einstein's *annus mirabilis*, the United Nations, in General Assembly resolution 58/293, had declared 2005 the International Year of Physics. The Workshop commended the United Arab Emirates University for organizing national activities at all educational levels throughout 2005 to observe the International Year of Physics and in particular to reach the next generation of students and teachers.

26. It was brought to the attention of the Workshop that the principal co-organizer of the basic space science workshops from 1991 to 2004, Willem Wamsteker of the European Space Agency, had passed away. The Workshop took the opportunity to commend his seminal contributions to the organization of this series of workshops in the spirit of true international cooperation, in particular for the benefit of developing countries.

III. Summary of projects

A. Atmospheric Weather Educational System for Observation and Modelling of Effects

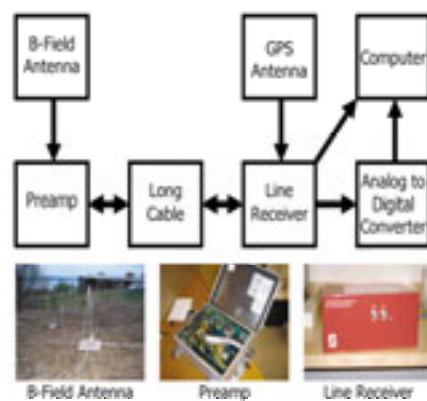
27. The Atmospheric Weather Educational System for Observation and Modelling of Effects (AWESOME) instrument is an ionospheric monitor that can be operated by students around the world. The monitors detect solar flares and other ionospheric disturbances.

28. About 60 kilometres (km) above the ground lies the Earth's ionosphere, where continual blasts of particles and energy from the Sun hit the Earth's atmosphere so strongly that electrons are stripped away from their nuclei. The free electrons in the ionosphere have a strong influence on the propagation of radio signals. Radio frequencies with a very long wavelength (very low frequency or VLF) bounce back off the ionosphere allowing radio communication over the horizon and around the curved Earth. The ionosphere reacts strongly to the intense X-ray and ultraviolet radiation released by the Sun during a solar flare, solar storm or coronal mass ejection. By monitoring the signal strength from distant VLF transmitters and noting unusual changes as the waves bounce off the ionosphere, these disturbances can be monitored and tracked. To monitor a VLF signal, a radio receiver is needed that can tune to VLF stations, together with an antenna to pick up the VLF signals and a computer to keep track of the data. Since most consumer radios cannot pick up VLF signals, a radio receiver and an antenna need to be built. This combination of receiver and antenna is called a VLF receiver.

29. The key elements of the AWESOME monitoring system are the computer, the Stanford monitor and the antenna. An Internet link is important; otherwise a good quality digital versatile disc (DVD) burner could be used. The set-up is illustrated in figure I. The line receiver gets VLF signals from two antennas. There is usually one antenna in the north-south orientation and another in the east-west orientation. These signals are sent to a 200 kilohertz (kHz) analogue-to-digital converter (ADC) card attached to the Peripheral Component Interconnect (PCI) slot of the computer. The ADC will capture data from the two antennae at 100 kHz each. The timing signal from the Global Positioning System (GPS) is also fed into the ADC card, allowing for very precise acquisition of data. Now in development is a Universal Serial Bus (USB) interface to replace the ADC card, which will enhance the ease of use and substantially reduce the cost.

Figure I

Very low frequency data acquisition system



Note: The data acquisition system works in conjunction with a true-time Global Positioning System receiver, a line receiver and north-south and east-west receivers.

Source: R. Moore and E. Kim, Very Low Frequency Data Acquisition Software User Manual.

30. There are two types of data saved by the receiver. Narrowband data means monitoring the amplitude and phase of a single frequency, corresponding to a VLF transmitter. Broadband data involves saving the entire waveform from the antenna, thus enabling studies of many more ionospheric phenomena. The VLF data acquisition software controls precisely when the system should acquire broadband and narrowband data. Upon data acquisition, various types of user-specified signal processing can be performed on the data. The data may be sent to another computer at Stanford University, via the Internet, where it will be made available to anyone through a Web interface, so that interested parties at different sites can share their data and collaborate. The data produced by AWESOME is of the same quality as that being used by researchers at Stanford University; the receiver sensitivity has exceeded the point where any detectable signal above the ambient noise floor will be recorded.

31. In addition to the AWESOME monitor, there is an inexpensive version known as the Sudden Ionospheric Disturbance (SID) monitor. The Stanford Solar Center, in conjunction with the Very Low Frequency Group of the Department of Electrical

Engineering at Stanford University and local educators, have developed inexpensive SID monitors that students can install and use at their local high schools. Students can join the project by building their own antenna, a simple structure costing less than \$10 and taking a couple of hours to assemble. Data collection and analysis is handled by a local personal computer, which does not need to be fast or elaborate. Stanford University will be providing a centralized data repository and blog site where students can exchange and discuss data.

32. Deployment of one of the AWESOME monitors has recently been completed in Tunisia. Umran S. Inan of Stanford University and Zohra Ben Lakhdar of the University of Tunis have started this collaboration under the International Heliophysical Year/United Nations Basic Space Science Initiative programme. This project will provide a basis for quantitative comparison of lightning-induced disturbances of the ionosphere and the radiation belts in the American and European sectors. Most of the current data on such phenomena has so far been obtained in the western hemisphere and the weight of scientific information indicates that lightning-induced effects at high altitudes and in the radiation belts may dominate other processes on a global scale. The proposed programme will facilitate the establishment and conduct of VLF observations in the European sector, thus providing a basis for comparison to facilitate global extrapolations and conclusions. As part of this collaboration, Hassen Ghalila of the University of Tunis visited Stanford University to learn about how to operate the VLF receiver and all of its scientific applications.

B. Magnetometer networks

1. International Heliophysical Year magnetometer observatories

33. Magnetometer arrays provide a relatively low-cost method for monitoring solar-terrestrial interaction. Magnetometer stations provide monitoring of current systems local to monitoring stations, as well as local wave populations. Multi-continental International Heliophysical Year arrays would provide an excellent basis for meso- and global-scale monitoring of magnetospheric-ionospheric disturbances and would provide scientific targets for middle and low latitudes and opportunities for developing countries to host instruments and participate in the scientific investigations.

34. Magnetometer observatories can be developed under the International Heliophysical Year/United Nations Basic Space Science Initiative programme based on the achievements of the Canadian Array for Realtime Investigations of Magnetic Activity (CARISMA). CARISMA is the magnetometer element of the Canadian GeoSpace Monitoring (CGSM) project. It is the continuation of the Canadian Auroral Network for the OPEN Program Unified Study (CANOPUS) magnetometer array, which ran from 1986 to 2005, with upgrading to include higher time resolution and more complete time coverage. It utilizes the same 13 fluxgate magnetometers but with an upgraded site infrastructure and data transmission system.

35. Each proposed International Heliophysical Year magnetometer observatory will consist of magnetometer station pairs separated meridionally by approximately 200 km. Other requirements are two 3-component fluxgate magnetometers, a data

logger, GPS timing and a power source. For remote locations, solar panels or wind turbines could possibly be used. The data retrieval method depends on available infrastructure: telephone-line modem or local Internet where available.

36. The approximate cost of each observatory is \$22,000 for a 3-component fluxgate with RS232 output (approximately \$6,000 for each component); an industrial grade data logger/personal computer with GPS (approximately \$2,000); and a solar panel power system (approximately \$2,000). Commercial fluxgates are available from industrialized countries. However, an excellent low-noise supplier also exists at the L'viv Centre of the Institute for Space Research in Ukraine. Ukraine benefits from export trade and tax agreements with some industrialized countries, including Canada. The International Heliophysical Year magnetometer array could aid development in countries such as Ukraine where suitable expertise exists.

37. For the CANOPUS array, the University of Alberta in Canada is developing a solar cell/wind generator stand-alone power source that could be modified for International Heliophysical Year use in developing countries with little infrastructure (this also allows site deployment in environmentally magnetically quiet locations and avoids problems with local power grid stability). Under the International Heliophysical Year/United Nations Basic Space Science Initiative programme, the University of Alberta, together with other partner institutes, could develop a GPS-timed personal computer data logger interface for the magnetometer, develop solar-cell/turbine power sources for the International Heliophysical Year magnetometer observatories, integrate systems prior to delivery to scientists from participating countries and organize and run a number of regional or continent specific "deployment schools", where scientists from developing countries can attend a single deployment, which will help them to deploy their own observatories independently in their respective countries.

38. The International Heliophysical Year array data are more powerful than data from any single observatory, although data from a single observatory may be used, especially in combination with partner International Heliophysical Year data sets. Project involvement should require data delivery to the International Heliophysical Year (perhaps in partnership with the Electronic Geophysical Year (e-GY)). It is valuable to have a central International Heliophysical Year magnetometer array data centre to collect, store and archive the data. The scientific value of the collective International Heliophysical Year array data set encourages collaboration between International Heliophysical Year magnetometer array scientists from participating countries. This data set could also provide the basis for International Heliophysical Year science workshops/conferences with active involvement from the participating scientists.

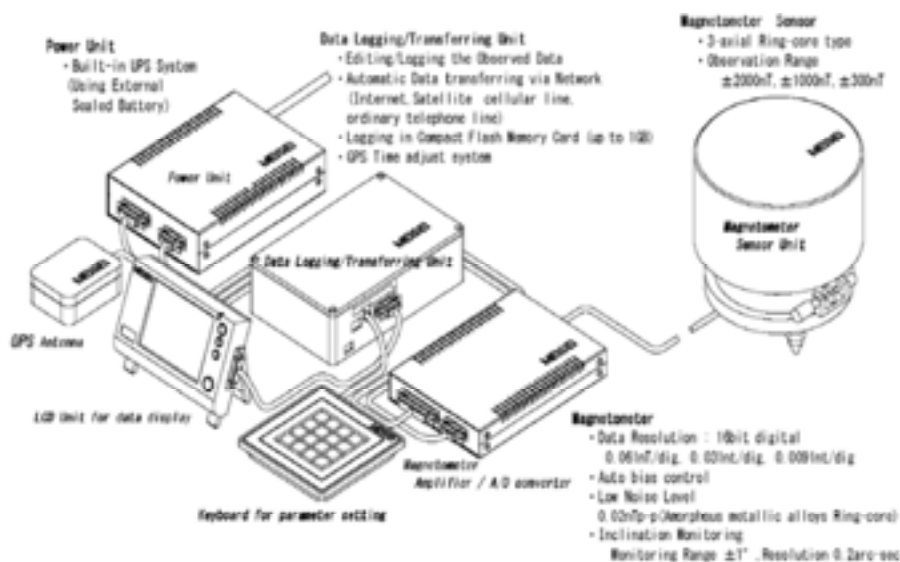
2. Magnetic Data Acquisition System project

39. The Magnetic Data Acquisition System (MAGDAS) (see figure II) is being deployed for space weather studies during 2005 to 2008, overlapping heavily with the International Heliophysical Year/United Nations Basic Space Science Initiative programme. The project will aid the study of the dynamics of geospace plasma changes during magnetic storms and auroral sub-storms, the electromagnetic response of the iono-magnetosphere to various solar wind changes, and the penetration and propagation mechanisms of DP2-channel ultra-low-frequency

(ULF) range disturbances from the solar wind region into the equatorial ionosphere. With the help of MAGDAS data, real-time monitoring and modelling can be conducted of (a) the global three-dimensional current system; and (b) the ambient plasma density in order to understand the electromagnetic and plasma environment changes in geospace.

Figure II

MAGDAS/CPMN magnetometer system for real-time data acquisition



40. In order to produce a global three-dimensional current system, MAGDAS data will be used to map the ionospheric equivalent pattern of currents on a daily basis. The current and electric fields at all latitudes are coupled, although those at high latitudes and those at middle and low latitudes are often considered separately. By using the MAGDAS ionospheric current pattern, the global electromagnetic coupling processes at all latitudes will be clarified.

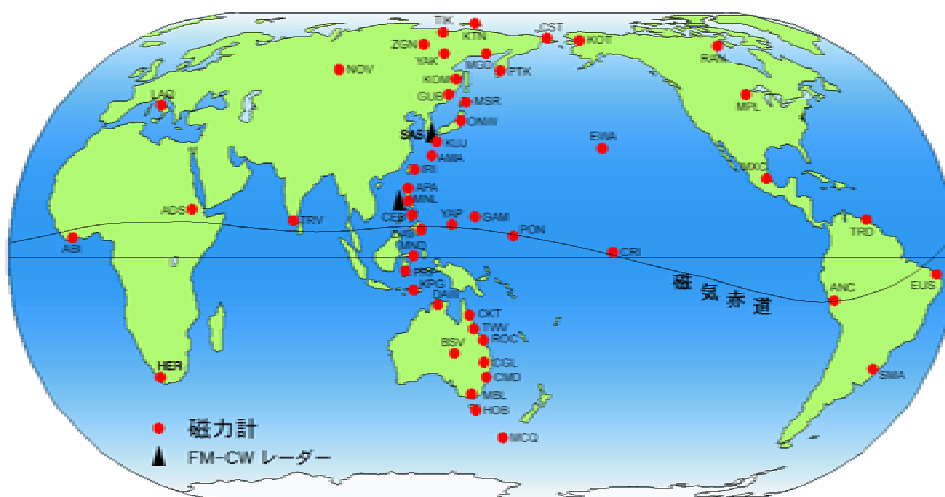
41. In order to measure ambient plasma density, new MAGDAS magnetometers will be deployed at several pairs of stations along the 210 degree magnetic meridian to observe the magnetic field line resonance (FLR) pulsations. Each pair will be separated in latitude by approximately 100 km. The FLR oscillations are useful for monitoring temporal and spatial variations in the magnetospheric plasma density. The MAGDAS data will be analysed by the amplitude-ratio and cross-phase methods to identify the FLR events and measure their eigenfrequencies, providing the measurement of plasma density varying with time. These measurements will be highly valuable in understanding the variations of the ambient plasma density and the location of the plasma pause during magnetic storms and auroral sub-storms.

42. MAGDAS will utilize the Circum-pan Pacific Magnetometer Network (see figure III) involving a number of countries around the globe (Australia, Indonesia, Japan, the Philippines, the Russian Federation, the United States and Taiwan Province of China). Additional locations where the magnetometers could be

deployed are Brazil, Canada, Côte d'Ivoire, Ethiopia, Micronesia (Federated States of), India, Mexico, Peru, South Africa and Trinidad and Tobago.

Figure III

Stations of the Circum-pan Pacific Magnetometer Network



C. International Heliophysical Year radio telescope networks

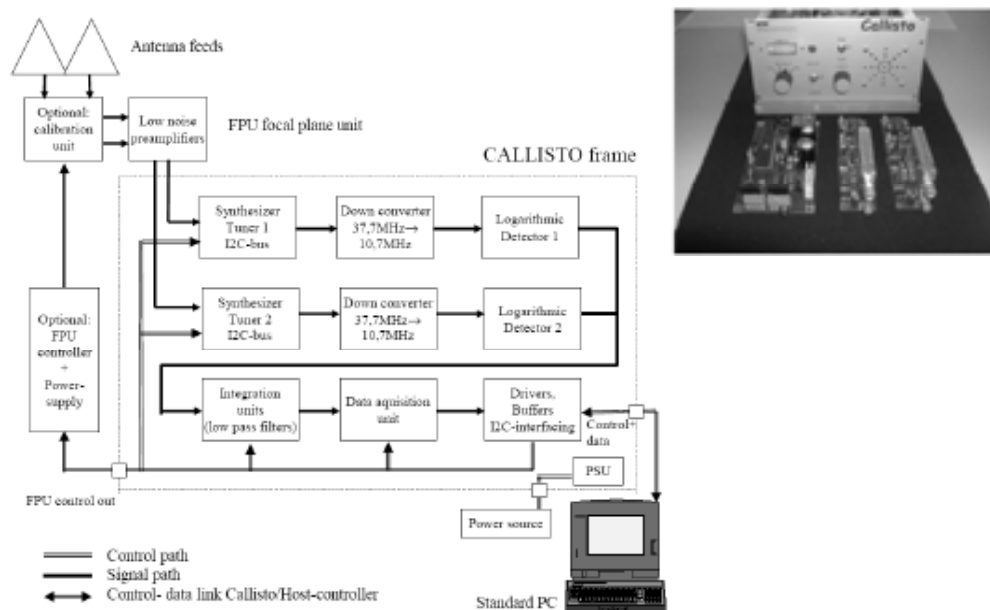
1. Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory

43. The Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory (CALLISTO) is a dual-channel frequency-agile receiver based on commercially available consumer electronics (see figure IV). The low cost for hardware and software and the short assembly time make this an ideal instrument for the International Heliophysical Year/United Nations Basic Space Science Initiative programme. The total bandwidth of CALLISTO is 825 megahertz (MHz) and the width of individual channels is 300 kHz. A total of 1,000 measurements can be made per second. The spectrometer is well suited for solar low-frequency radio observations pertinent for space weather research and applications. Space weather has become a topic of interest to society that increasingly depends on satellites for day-to-day activities. One prime example is cellular telephones, which can be seriously affected by space weather. Space weather refers to the variable conditions in the Earth's space environment, primarily caused by changing conditions on the Sun. Radio observation is a simple means of detecting the solar disturbances when they are still near the Sun. The early detection of solar disturbances such as shock waves is possible from the ground using radio spectrometers such as CALLISTO. The Sun produces various types of radio emissions, so spectrometers such as CALLISTO are necessary to identify the nature

of coherent solar radio emissions from solar eruptions, relevant to space weather. One of the important types of radio emissions occurring in the CALLISTO spectral range are the shock-related radio bursts known as type II radio bursts. These bursts are caused by shocks driven by coronal mass ejections. Occurrence of these bursts marks the formation of shocks near the Sun, which might arrive at Earth after a few days and mark the start of geomagnetic storms.

Figure IV

Basic design and hardware of the Compound Astronomical Low-cost Low-frequency Instrument for Spectroscopy and Transportable Observatory



Note: The main board for data acquisition and interface with the RISC processor ATmega16 and two synchronous receivers are shown in the foreground of the right panel. The complete spectrometer is shown in the background. The width of the instrument is 24 centimetres. It is extremely cheap and suitable for easy copying and for deployment in many locations.

44. It is important to have continuous monitoring of the Sun, which requires a network of spectrometers at several locations in the world. Five CALLISTO instruments have been constructed so far and have been put into operation at several sites, including Bleien in Zurich, Switzerland, and the National Radio Astronomy Observatory in the United States. Arrangements are being made to deploy one in India at the Radio Astronomy Center in Ooty. This network, in addition to the existing spectrometers at Hiraiso in Japan, the multichannel radiospectrograph ARTEMIS in Greece and the Culgoora Solar Observatory in Australia will form an excellent radio network for International Heliophysical Year science and for achieving the goals of the International Heliophysical Year/United Nations Basic Space Science Initiative programme.

45. The software is distributed on a Reduced Instruction Set Computer (RISC) processor, ATmega16, and a standard personal computer or laptop. On the RISC, the driver, buffer and interfacing software is programmed in C++, using an interrupt-

driven state machine concept. The host software on the personal computer is also in C++ and operates under Windows 2000 and Windows XP. The relevant parameters are locally stored in a text file, which can be easily adapted to other observing configurations. Additional RS232 ports are preconfigured to communicate with an extended GPS system and external temperature and humidity sensors. It is also possible to control CALLISTO via the Internet, using an RS232 network adapter. A file-controlled scheduler starts and stops measurements in relation to local time (Universal Time). The scheduler repeats every day automatically and can be changed online and remotely.

2. Low-frequency radio antenna arrays

46. Low-frequency radio arrays can be deployed at two levels: option one is low-frequency monitoring of solar radio bursts with single dipoles; and option two is 8-16 element arrays for monitoring of the whole sky.

47. Opportunities are being explored to install a low-frequency radio telescope at the Gauribidanur radio telescope site in India to work in conjunction with CALLISTO in Ooty.

D. Global Positioning System in Africa

48. The overarching plan is to increase the number of real-time dual-frequency GPS stations worldwide for the study of ionospheric variability. Of particular interest is the response of the ionospheric total electron content (TEC) during geomagnetic storms over the African sector. This programme is particularly compatible with magnetometry.

E. Remote Equatorial Nighttime Observatory for Ionospheric Regions

49. The Remote Equatorial Nighttime Observatory for Ionospheric Regions (RENOIR) is a suite of instruments dedicated to studying the equatorial/low-latitude ionosphere/thermosphere system, its response to storms and the irregularities that can be present on a daily basis. The occurrence of equatorial plasma instabilities, commonly referred to as equatorial spread-F, equatorial plasma bubbles or depletions, can cause radio signals propagating through the disturbed region to scintillate. This results in a fade in the signal power that is received, translating to a loss of the signal. Scintillations on frequencies from several gigahertz (GHz) and below are known to occur and are a concern for many sectors. Through the construction and deployment of a RENOIR station, it is possible to achieve a better understanding of the variability in the night-time ionosphere and the effects this variability has on critical satellite navigation and communication systems.

50. A typical RENOIR station involves the following: (a) an array of single-frequency GPS scintillation monitors, which provide measurements of the size, orientation and speed of the irregularities present; (b) a dual-frequency GPS receiver, which provides measurements of ionosphere TEC (if a site could be located that already fields a dual-frequency GPS receiver, this would not be needed; (c) an all-sky imaging system, which measures two different

thermosphere/ionosphere emissions from which the two-dimensional structure/motion of irregularities can be observed (the data can also be used to calculate the density and height of the ionosphere); and (d) two miniaturized Fabry-Perot interferometers (MiniME), which provide measurements of the thermospheric neutral winds and temperatures (the two interferometers are separated by approximately 300 km or so, allowing bistatic, common-volume measurements).

51. Deployment of RENOIR stations is being planned in collaboration with the International Heliophysical Year/United Nations Basic Space Science Initiative programme. Ideally, the RENOIR stations would be fielded in Africa at a longitude of approximately 7 degrees from the magnetic equator. The instrumentation that make up a RENOIR station have all been used in the field in previous experiments and are at a moderately mature level of development. The optical systems can be housed in individual, self-contained housing units, requiring very little infrastructure. If an optical facility is available at a host institution, the optical equipment could easily be modified to interface with available optical domes. The facility should be located in a region with relatively dark skies (away from any major cities) and away from any tall structures (buildings and trees). If two Fabry-Perot interferometers are to be fielded, the second system should be located approximately 300 km away from the main site.

52. The dual-frequency GPS receiver is quite rugged and simply requires a location to mount the antenna and minimal space to locate the control computer. The array of single-frequency GPS scintillation monitors requires a space of approximately 100 metres (m) by 100 m over which to space the five antennae in a cross formation. Again, minimal space is needed to locate the control computers for each receiver. The facility should be located away from any tall structures (buildings and trees).

F. South Atlantic Magnetic Anomaly very low frequency array

53. The South Atlantic Magnetic Anomaly VLF array programme has three main goals: monitoring solar activity on long and short timescales; monitoring ionospheric perturbations over the South Atlantic Magnetic Anomaly (SAMA); and atmospheric studies.

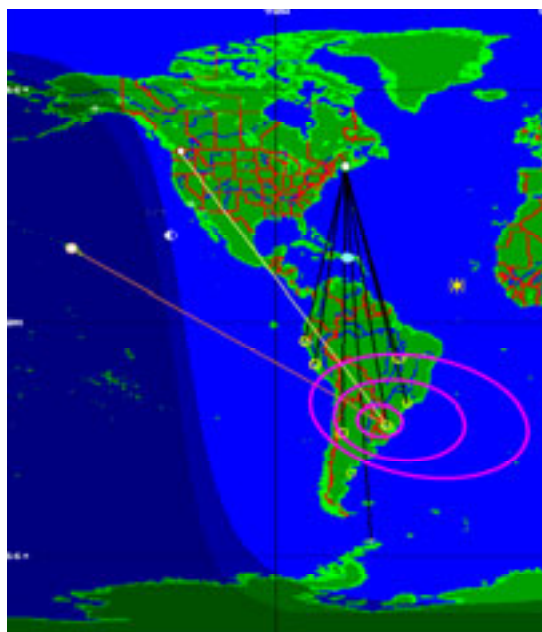
54. The VLF network will be deployed in a region where the coverage at similar frequencies is currently very poor. This will allow the study of the SAMA region at low ionospheric altitudes and its structure and dynamics during geomagnetic perturbations. The monitoring of transient solar phenomena will improve scientific knowledge of the low ionosphere and of the chemical processes occurring there. On longer timescales, it will be possible to define an ionospheric index of the solar activity characteristic of the ionizing agent of the low ionosphere (extreme ultraviolet and Ly-alpha). Currently these are poorly monitored and only accessible through models. The proposed instrument will also permit the study of the VLF counterpart of newly discovered atmospheric phenomena related to lightning and thunderclouds. The proposed science is relevant to the following International Heliophysical Year themes: impact of space weather phenomena on the Earth's climate; and the ionosphere/magnetosphere.

55. Ideally the VLF receivers should be able to measure amplitude perturbations of 1 decibel (dB) (relative to the unperturbed level) and phase changes as low as 0.5 μ s, corresponding to changes observed, for example, during very small solar flares. The basic data output is composed of these phase and amplitude measurements. There are no strong requirements on the location of the receivers, except for minimal man-made interferences. Some potential sites with existing infrastructure are Piura in the north of Peru (05°12'S; 80°38'W); Punta Lobos near Lima, Peru (12°30'S; 76°48'W); Palmas, Tocantins, Brazil (10°10'S; 49°20'W); Santa Maria, Rio Grande do Sul, Brazil (29°43'S; 53°43'W); and the Complejo Astronómico El Leoncito (CASLEO), San Juan, Argentina (31°32'S; 68°31'W).

56. These new sites will complement the existing VLF sites at Atibaia, São Paulo, Brazil (23°11'S; 46°36'W), and the Brazilian Antarctic Comandante Ferraz research station (62°05'S; 58°24'W). It will be possible to compare the VLF propagation characteristics from paths that completely cross SAMA, paths for which the receivers are located at the border or outside the SAMA and paths that end at the SAMA centre location (see figure V). The estimated cost of the instrumentation is \$5,000 per unit (there are 5 units) and an additional cost of \$10,000 for travel between stations for installation, testing and maintenance.

Figure V

South Atlantic Magnetic Anomaly locations and paths from the NAA transmitter in the United States



Note: SAMA locations and the nearly north-south oriented paths from the NAA transmitter in the United States (44°39'N; 67°17'W) will enable a comparison of examples of simultaneous measurements from the totally sunlit path NLK (48°12'N; 121°55'W) and the partially sunlit path NPM (38°59'N; 76°27'W), which are also shown. This will allow scientists to obtain a two-dimensional view of the SAMA region. In the case of NAA transmission, the path over Puerto Rico should also be noted, where ionospheric radio measurements are made at the Arecibo (18°30'N; 68°31'W) radio facilities in association with the sprites phenomena.

G. Scintillation Network Decision Aid

57. Ionospheric disturbances can cause rapid phase and amplitude fluctuations of satellite signals observed at or near the Earth's surface; these fluctuations are known as scintillation. Scintillation affects radio signals up to a few GHz frequency and seriously degrades and disrupts satellite-based navigation and communication systems. The Scintillation Network Decision Aid (SCINDA) consists of a set of ground-based sensors and quasi-empirical models, developed to provide real-time alerts and short-term (less than 1 hour) forecasts of scintillation impacts on UHF satellite communication and L-Band GPS signals in the Earth's equatorial regions.

58. SCINDA is a real-time, data driven, communication outage forecast and alert system. Its purpose is to aid in specifying and predicting degradation of communications due to ionospheric scintillation in the equatorial region of the Earth. Ultra-high frequency (UHF) and L-band scintillation parameters are measured, modelled and propagated in time to provide a regional specification of the scintillation environment in an effort to mitigate the impacts on the satellite communications community.

59. The data drives a semi-empirical model that produces simple three-colour graphical representations of large-scale equatorial scintillation structures and associated communication impact regions.

60. The SCINDA system (see figure VI) concept is presently being demonstrated using eight equatorial stations in South America, South-West Asia and South-East Asia (figure VII). The scintillation maps are available to users for prototype operational support via a secure network. Analysis of data collected during the recent solar maximum period (2000-2002) indicates that both single and dual-frequency GPS receivers are subject to significant errors during severe scintillation events. All SCINDA sites are now equipped with GPS scintillation monitors and model development is in progress. Following the solar cycle, L-band scintillation activity will decline over the next few years and should remain relatively benign until around 2008. The goal is to have accurate GPS navigation error products available to support the SCINDA operations before the next solar maximum.

Figure VI

Set-up of very high frequency antenna (left) and very high frequency receiver chain and data acquisition system (right)

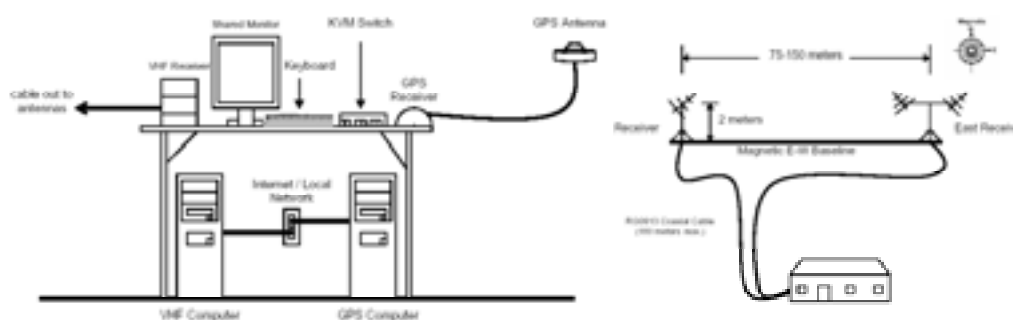
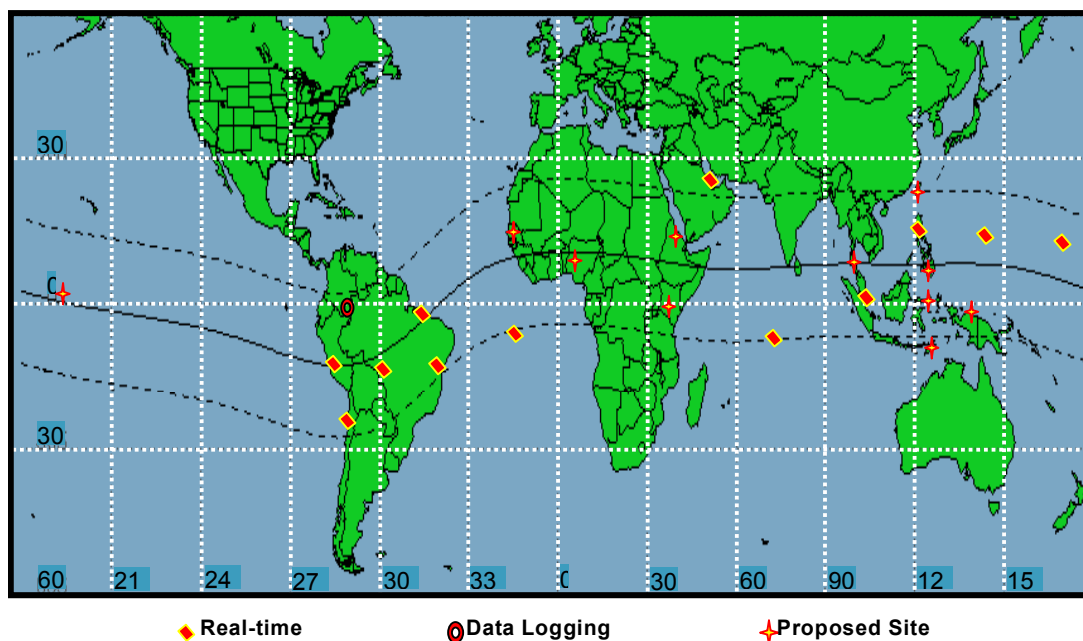


Figure VII

Existing and proposed stations of the Scintillation Network Decision Aid system

Note: Magnetic equator and northern and southern magnetic latitudes at 20° are shown by dashed lines. The most intense natural scintillation events occur during night-time hours within 20° of the Earth's magnetic equator. SCINDA observations in the 20° belt on either side of the magnetic equator are sought. Current plans include expansion of the network to new geographic regions.

H. New type of particle detectors for space weather forecasting network

61. Particle beams accelerated at the Sun are superimposed on the uniform and isotropic cosmic ray background from galactic and extragalactic sources. Spaceborne spectrometers measure the time series of the changing fluxes with excellent energy and charge resolution. Surface detectors measure the time series of secondary particles, born in cascades originated in the atmosphere by primary ions. Studies of these particles shed light on the high-energy particle acceleration by flares and shocks driven by coronal mass ejections.

62. Time series of intensities of high-energy particles can provide highly cost-effective information on the key characteristics of the interplanetary disturbances. Because cosmic rays are fast and have large scattering mean-free distances in the solar wind, this information travels rapidly and may prove useful for space weather forecasting. Size and occurrence of the southward magnetic field component in interplanetary coronal mass ejections (ICMEs) is correlated with the modulation effects that the ICME poses on the ambient population of the galactic cosmic rays

during its propagation up to 1 astronomical unit (AU). On the way to Earth (15-50 hours), the magnetic cloud and shock modulate the galactic cosmic ray (GCR) flux, making it anisotropic. Surface monitors located at the Aragats Space Environmental Center (ASEC) on Mount Aragats in Armenia, at 2,000 and 3,200 m altitude (40°30'N, 44°10'E). At cut-off rigidity of 7.6 gigavolt (GV) it is possible to detect charged and neutral components of the secondary cosmic rays with different energy thresholds and various angles of incidence (see figure VIII for a schematic view of the new detector at ASEC). This richness of information (see the table below and also figure VIII), coupled with the simulation of the physical phenomena, can be used to estimate the shock size and the magnetic field “frozen” in the ICME. Consequently, one can predict upcoming geomagnetic storms hours before the ICME arrival at the magnetometers on the Advanced Composition Explorer and the Solar and Heliospheric Observatory. The half-hour lead time provided by the L1-monitors is a bit short to take effective mitigation actions and protect surface industries from harm of major geomagnetic storms. To identify the major sources of error in the predictions, it is necessary to measure, simulate and compare (a) time series of neutrons, low-energy charged component (mostly electrons and muons) and high-energy muons; (b) the correlation between changing fluxes of various secondary particles; and (c) directional information.

Table

Characteristics of Aragats Space Environmental Center monitors

<i>Detector</i>	<i>Altitude (metres)</i>	<i>Surface (square metres)</i>	<i>Threshold(s) MeV</i>	<i>Operation (Year)</i>	<i>Count rate (min⁻¹)</i>
NANM (18NM64)	2 000	18		1996	2×10^4
ANM (18NM64)	3 200	18		2000	4.5×10^4
SNT-4 thresholds +	3 200	4 (60 cm thick)	120, 200, 300, 500	1998	5.2×10^{4a}
Veto		4 (5 cm thick)	10		1.3×10^5
NAMMM	2 000	5 + 5	10 + 350 ^b	2002	2.5×10^4
AMMM	3 200	45	5 000	2002	1.2×10^{5c}
MAKET-ANI	3 200	6 x 16 groups	10	1996	1.5×10^5

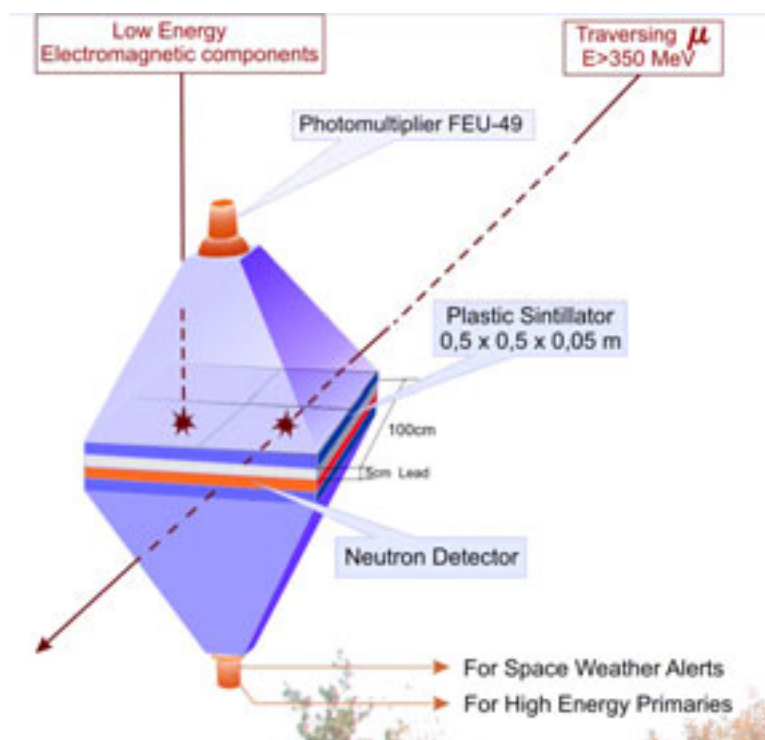
^a Count rate for the first threshold; near vertical charged particles are excluded.

^b First number—energy threshold for the upper detector, second number—bottom detector.

^c Total count rate for 45 muon detectors from 100.

63. Based on experience with correlation analysis of multivariate time series from ASEC monitors, several new-type particle detectors are being designed and fabricated. In order to keep the instrument inexpensive, the options are kept flexible by using modular design. The price of a fully autonomous unit, with the capability to send data to the Internet, will not exceed \$20,000, so that the network of countries involved in space research can be significantly expanded to enable them to participate in the International Heliophysical Year 2007. At any time, one can cascade units to achieve additional functionality, for example by adding several new observational directions. The advantage to be gained by the world network of neutron monitors will be the investigation of the additional populations of primary ions.

Figure VIII
Schematic diagram of new detector for muons and neutrons at the Aragats Space Environmental Center



64. It is proposed to deploy such detectors in countries such as Azerbaijan, Georgia, Iran (Islamic Republic of), Israel, Kuwait, Turkey and the United Arab Emirates. Additional deployments in Bulgaria and Croatia are possible.

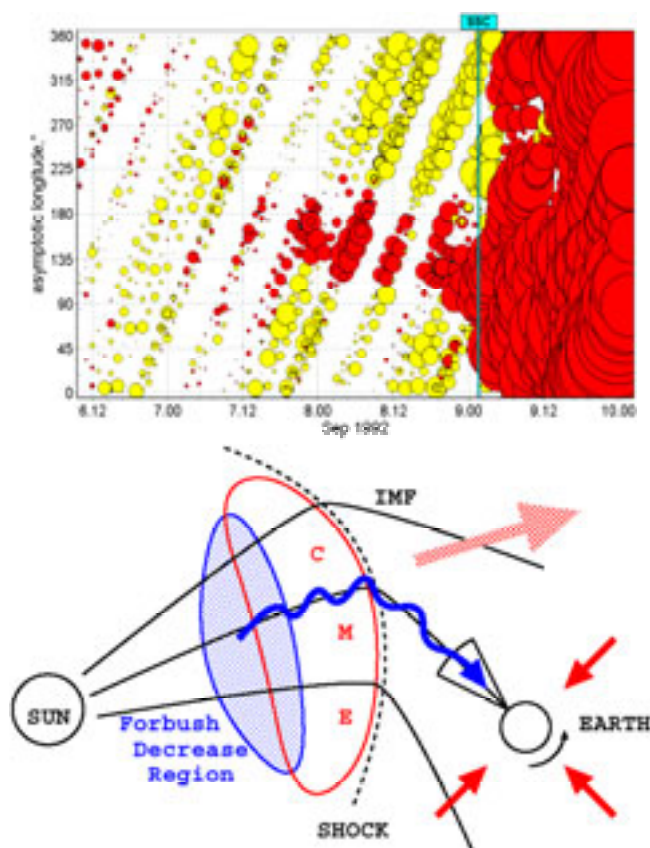
I. Muon network

65. Muon detector network collaboration consists of nine institutes from seven countries (Armenia, Australia, Brazil, Germany, Japan, Kuwait and the United States). Many of the countries are already operating muon detectors and some have recently installed them.

66. The utility of the muon detector for detecting ICMEs is shown in figure IX. Each circle represents an hourly measurement by a single telescope as a function of time (day of year on the abscissa) and the asymptotic longitude of the viewing direction (in degree on the ordinate). The light and dark circles represent, respectively, an excess and deficit of cosmic ray intensity relative to the average and the size of each circle is proportional to the magnitude of excess or deficit. The precursory decrease (dark circles) of cosmic ray intensity from ~135 degrees longitude (sunward direction along the nominal interplanetary magnetic field) is

clearly seen more than one day prior to the sudden commencement of the storm (arrival of shock driven by coronal mass ejection at the Earth). The physical mechanism for the precursory decrease is illustrated in figure IX (bottom). A coronal mass ejection propagating away from the Sun with a shock ahead of it affects the pre-existing population of GCR in a number of ways. Most well-known is the Forbush decrease, a region of suppressed cosmic ray density located downstream of a coronal mass ejection shock. Some particles from this region of suppressed density leak into the upstream region and, travelling nearly at the speed of light, they race ahead of the approaching shock and are observed as precursory loss-cone anisotropy far into the upstream region. Loss-cones are typically observed four to eight hours ahead of shock arrival for shocks associated with major geomagnetic storms.

Figure IX
Detection of interplanetary coronal mass ejections

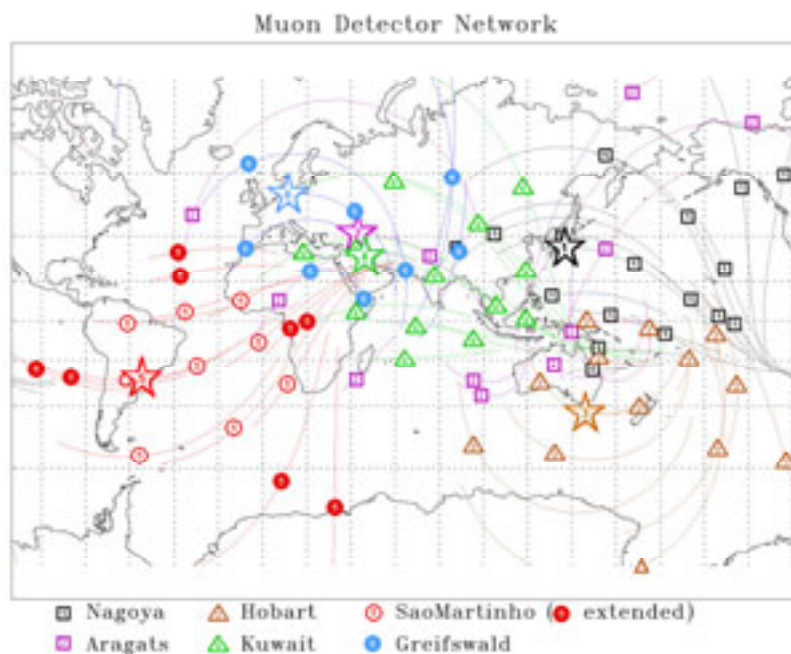


Note: The chart at the top of figure IX shows a depiction of the “loss-cone” precursor observed prior to the arrival of a coronal mass ejection at Earth on 9 September 1992. The diagram at the bottom shows the physical mechanism causing the loss-cone precursor. The coronal mass ejection from the Sun (region marked CME), and the depletion region (Forbush decrease region) are also shown. The coronal mass ejection drives a shock shown by a curved dashed line. Particles entering the detector are denoted by the helical arrow. Three interplanetary field lines are also shown.

67. The current muon detector network (see figure X) is almost complete except for a desired detector in United States (Hawaii or the West Coast) and another in South Africa.

Figure X

Muon detector network



Note: The geographic location of each detector is indicated by a large star and identified by number. Each of the symbols (squares, triangles and circles) shows the asymptotic viewing of a particle incident on each telescope with the median primary rigidity. Open symbols display the existing viewing directions, while full symbols represent the directions to be added by the planned installation and extension of detectors. The track through each symbol represents the spread of viewing directions corresponding to the central 80 per cent of each telescope's energy response.

Notes

¹ *Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space, Vienna, 19-30 July 1999* (United Nations publication, Sales No. E.00.I.3), chap. I, resolution 1.

² *Official Records of the General Assembly, Fifty-ninth session, Supplement No. 20 and corrigendum (A/59/20)*, para. 71.

Annex

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