# African Skies

# Cieux Africains

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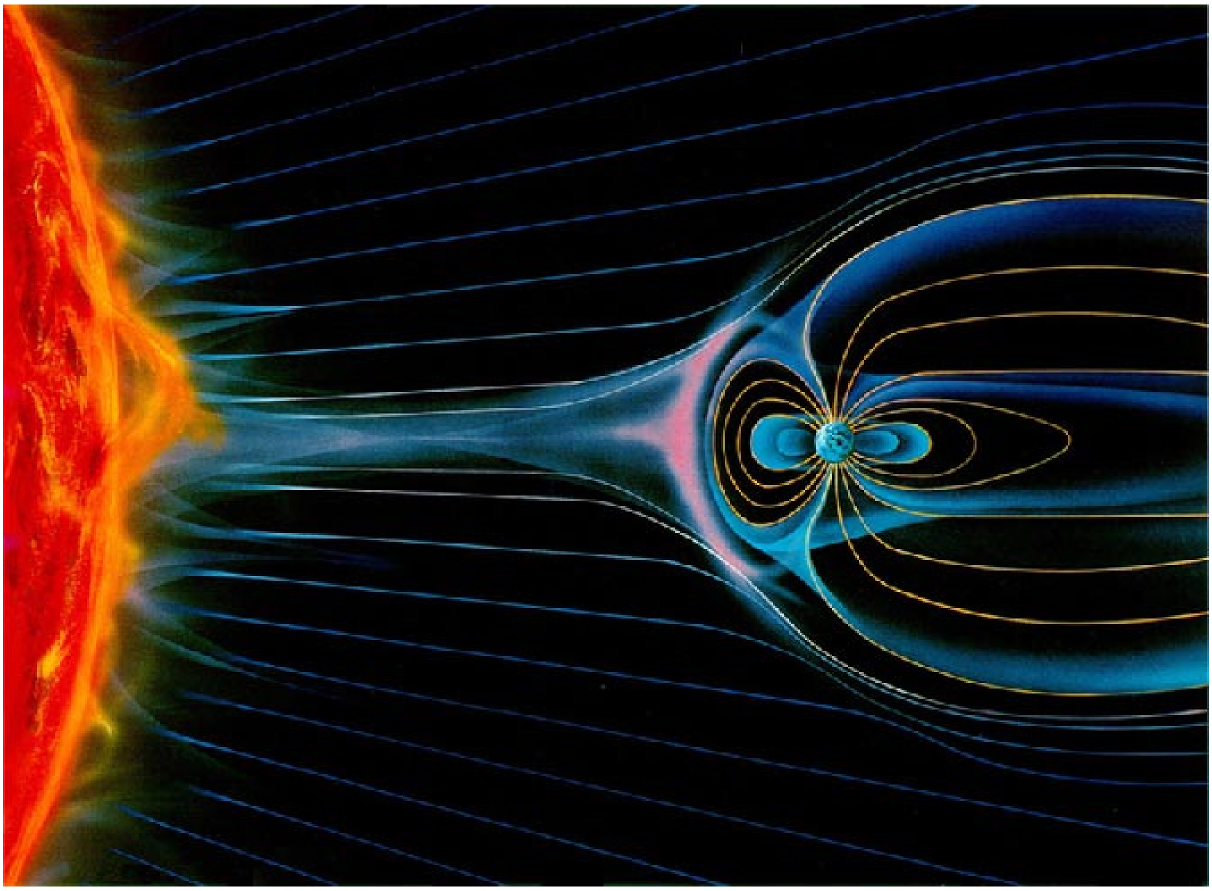

*Comet Bennett, discovered in 1969 by South African Amateur Astronomer Jack Bennett.*
(*Image Courtesy of Professor Yohsuke Kamide*)

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## The Working Group on Space Sciences in Africa

The Working Group on Space Sciences in Africa is an international, non-governmental organisation founded by African delegates at the 6th United Nations/European Space Agency Workshop on Basic Space Science held in Bonn on 9–13 September 1996. The scientific scope of the Working Group's activities is defined to encompass: (a) astronomy and astrophysics, (b) solar-terrestrial interaction and its influence on terrestrial climate, (c) planetary and atmospheric studies, and (d) the origin of life and exobiology.

The Working Group seeks to promote the development of the space sciences in Africa by initiating and coordinating various capacity-building programmes throughout the region. These programmes fall into a broad spectrum ranging from the promotion of basic scientific literacy in the space sciences to the support of international research projects. The Working Group also promotes international cooperation among African space scientists and acts as a forum for the exchange of ideas and information through its publications, outreach programmes, workshops, and scientific meetings.

The Working Group receives financial support from foundations and institutes committed to its objectives. One of its principal forms of support, however, is the time contributed freely by individual scientists.

## WGSSA Officers for the period 2004–2006



## African Skies/Cieux Africains


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# Editorial

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This 10th issue of *African Skies/Cieux Africains* coincides with the 10th anniversary of the Working Group on Space Sciences in Africa. Since its establishment by a handful of African scientists attending the UN/ESA Workshop on Basic Space Science in Bonn in September 1996, the Working Group has grown to a membership of over 150 space scientists from 20 African countries. The Working Group serves primarily as a platform for facilitating cooperation and information exchange among African space scientists. Training is also a focus of its activities. The Working Group has organised or facilitated Summer Schools and Visiting Fellowships to give African scientists and students a space science experience at a leading facility, or in conjunction with leading space scientists.

*African Skies/Cieux Africains* has also matured considerably in this time, evolving from a newsletter showcasing African space science facilities and opportunities to a more thematic publication. In 2000, the NASA Astrophysics Data Service (NASA ADS) began archiving *African Skies/Cieux Africains* in its database of physics and astrophysics literature. Thus, all papers appearing in this publication are accessible via the internet. The NASA ADS is an indispensable tool for astronomers as it provides access to the complete literature. For African scientists, the ADS is a fantastic resource allowing scientists with a reasonable internet connection to access papers in the leading research journals of the world. In October 2003, *African Skies/Cieux Africains* published an in-depth user guide to the ADS. I am delighted to report that since the publication of that article, ADS usage in Africa has increased. In particular, a number of countries that were not previously accessing ADS started to use the system.

By whatever measure one uses, Africa continues to be under-represented in the space sciences and in the applications of space technology. But it is becoming easier to pursue a space science career in Africa than it used to be. Increasing internet penetration and the advent of new large-scale facilities for astronomy on the continent, such as the Southern African Large Telescope (SALT), and new training programmes, are making it possible for African scientists to pursue their scientific interests on the continent, in their own national environments. In this context, we are pleased to note the announcement of the first scientific results of SALT, as described in this issue.

In keeping with the recent trend of *African Skies/Cieux Africains* to publish thematic issues, this issue is dedicated to the opportunities for Africa to participate in the International Heliophyiscal Year (IHY), 2007. The IHY is the 50th anniversary of the International Geophysical Year, and also the 50th anniversary of the start of the Space Age. The IHY presents a golden opportunity for space science institutes throughout Africa to initiate new collaborative programmes.

La présente édition de African *Skies/Cieux Africains* coincide avec le 10eme anniversaire du Groupe de Travail sur les Sciences de l'Espace en Afrique. Ledit groupe fut crée par les scientifiques Africains présents à l'atelier sur les sciences de l'espace, organisé par l'ONU et l'ESA. Il compte à ce jour 150 scientifiques originaires de 20 pays Africains. Le Groupe de Travail sert principalement de plateforme pour la cooperation et l'échange d'information entre les spatiologues Africains. La formation en est egalement une activite essentielle. Le Groupe de Travail a organisé ou facilité des universités d'éte ainsi que des stages d'études en sciences de l'espace, pour des étudiants et scientifiques Africains, dans une institution de pointe, ou aupres d'experts du domaine.

*African skies/Cieux africains* a considérablement evolué durant la decennie ecoulée, passant d'un bulletin d'information sur l'offre africaine en sciences de l'espace, à une publication plus thématique. En l'an 2000, le *NASA Astrophysics Data Service* (NASA ADS) a demarré l'archivage de *African Skies/Cieux Africains* dans sa base de données consacrée aux publications en physique et en astrophysique. Tous les articles de la présente édition sont donc accessibles via l'internet. Via cet acces à une vaste litterature, le *NASA ADS* est aujourd'hui devenu un outil indispensable pour les astronomes. Pour les scientifiques Africains, l'ADS constitue une ressource considérable, facilitant l'acces aux articles parus dans les journaux scientifiques de référence. En Octobre 2003, *African Skies/Cieux Africains* a publié un guide approfondi d'utilisation de l'ADS. C'est avec satisfaction que je puis rapporté, ici, la forte évolution de l'usage de l'ADS en Afrique, depuis la parution dudit guide. Nombreux sont aussi les pays ou un debut d'utilisation de l'ADS a été observé.

Quel que soit le canon utilisé, l'Afrique demeure sous-representée dans les sciences de l'espace et les applications des technologies spatiales. Il est toutefois bien plus aisé qu'avant, de faire carriere dans les sciences de l'espace, en Afrique. La pénétration croissante de l'internet, la mise en opération de larges infrastructures telles que le S*outhern African Large Telescope* (SALT) et l'émergence de programmes de formation, permettent aujourd'hui aux scientifiques Africains de poursuivre leurs interets scientifiques sur le continent et dans leurs milieux respectifs. Nous sommes – dans ce contexte – heureux de noter l'annonce des premiers résultats scientifiques obtenus via SALT, présentes également dans cette edition.

Dans la continuité du choix recent d'un African *Skies/Cieux Africains* a thèmes, la présente édition est dediée aux opportunités pour l'Afrique , de participer à l'Annee Heliophysique Internationale (IHY en Anglais) 2007. L'IHY est la célébration du 50eme anniversaire de l'Annee Geophysique International , et coincide avec le 50eme anniversaire du debut de l'ère spatiale. Pour les institutons Africaines vouées aux sciences de l'espace, l'IHY constitue une opportunité inestimable pour l'initiation de nouveaux programmes de collaboration.

## First Science with SALT: Observations of an Eclipsing Polar

The Southern African Large Telescope (SALT), inaugurated in November 2005, released its first public research results on 16 August 2006, giving new insight into an exotic pair of stars closely orbiting one another.

The new SALT results are for a 'polar' binary star system, which contains a compact star called a 'white dwarf' – a star which has used up its original store of nuclear energy, then shrunk to about one-millionth of the volume of a star like our Sun. In a polar this 'white dwarf' also has a very strong magnetic field, which strongly influences how the hot gases from its relatively ordinary companion reach the white dwarf surface.

Figure 1 is an artist's impression of what such a typical binary system might look like: the cool, red star is in the background with the stream of gas being sucked off by gravity shown in white, finding its way down to the white dwarf along a path shaped by magnetic forces. The light from the gas crashing on to the magnetic poles of the white dwarf completely outshines the light from everything else.

**Fig 1.** The artist Bob Watson's painting of a polar binary system.

Figure 2 shows a diagram of an Earth-bound observer's view of the system at the start of eclipse (left) when the red star is just about to block our view of one magnetic pole, labelled Spot 2, and at the end of eclipse (right) when the red star has just uncovered Spot 2.

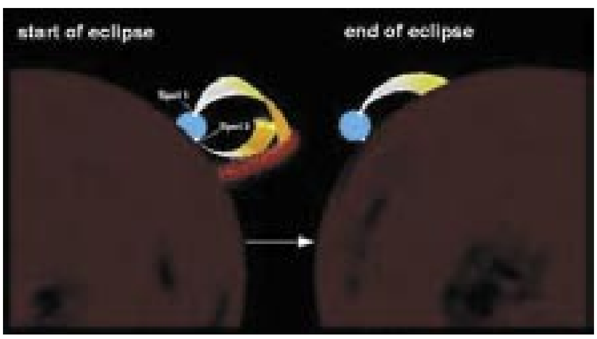


**Fig 2.** Earth-based observer's view of a polar at the start (left) and end (right) of eclipse.

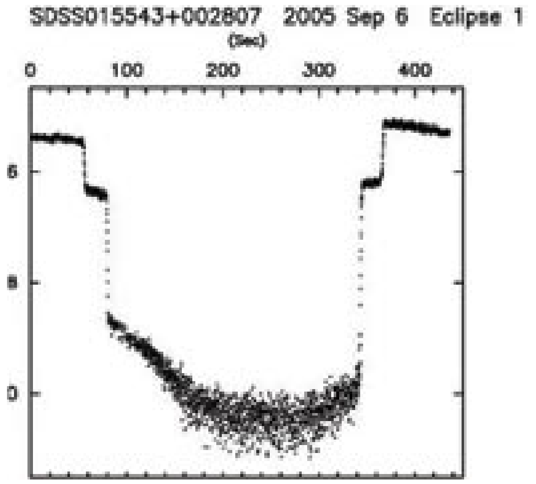


**Fig 3.** Sequence of brightness measurements of the polar. Each point is a 112 millisecond exposure.

Figure 3 is a sequence of brightness measurements and the evidence for what has just been described can be seen in the sequence. If you look closely at Figure 3, you will see it has a first sudden brightness drop (Spot 2 disappearing), followed about 25 seconds later by a second sudden brightness drop (Spot 1 disappearing). Towards the end of the sequence there are sudden rises in brightness corresponding to the earlier sudden drops as the spots are uncovered. The gas stream between the stars also gives some light, and this accounts for the rounded shape of the bottom of the eclipse.

This sequence of measurements is better than anything that has been obtained before, and SALT's advantages over all other large telescopes for this type of research should allow SALT astronomers to lead in probing the mysteries of these 'cannibal stars'.

An electronic preprint of the scientific article is available online at http://xxx.lanl.gov/archive/astro-ph, entry number 0607266.

## South Africa Shortlisted to Host the Square Kilometre Array (SKA) Telescope

South Africa and Australia have been short-listed as the two candidate sites for the Square Kilometre Array (SKA), a $1.9 billion project to build the largest radio telescope in the world. Commenting on 28 September 2006, South Africa's Minister for Science and Technology, Mosibudi Mangena said that South Africa's shortlisting as one of two possible sites for the Square Kilometre Array telescope is a great step for science in South Africa. The final decision on where to site the SKA will be taken by the major international science funding agencies by 2008.

South Africa initially intended only to be considered as a site for the SKA, but it soon became clear that the country could play a key role in the development of the technology and science as well. In 2005, South Africa assembled a team to build the Karoo Array Telescope (the KAT), which will be equivalent to approximately 1% of the SKA, and has in a short time been able to take a leading role in the global SKA development. The South African team has been recognised for its competence and is being called upon to assist and advise the International SKA Project Office on system engineering, costing and other technology areas. The KAT team, led by KAT Project Manager Anita Loots, is playing a leading role in collaboration with researchers in the UK, Holland, Australia and the USA in the development of digital signal processing for the telescope, software development and the development (with industry) of innovative telescope antennas, using composites.

The South African SKA/KAT office will host an international workshop in December 2006 on wide-field imaging and calibration, which is a key technology for the SKA and which pushes the boundaries on high-speed computing and software. For more information see http://www.ska.ac.za.

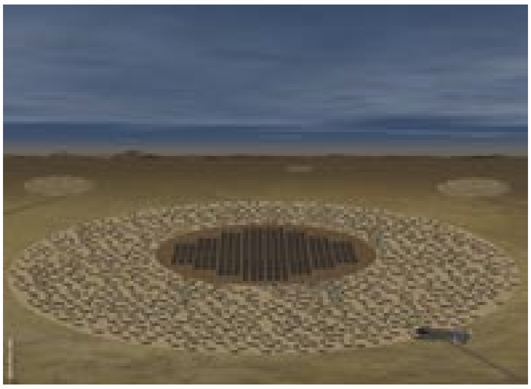

**Fig 4.** Artist's conception of the core of the Square Kilometre Array.

## Nigcomsat-1 Launch Approaches

Nigeria's communication satellite Nigcomsat-1 project is making good progress. The Federal Government of Nigeria has invested about $450 million in the project. This sum is expected to cover the cost of the satellite itself, the ground station, the training of engineers and other related expenses.

Nigcomsat-1 is being built by the China Great Wall Industry Corporation for the National Space Research and Development Agency (NASRDA) of Nigeria. The contract for the satellite programme was signed in December 2004 in Abuja. The satellite passed its preliminary design review on 7 July 2005.

Nigocomsat-1 will have 4 C-band, 18 Ku-band, 4 Ka-band and 2 L-band transponders and will be able to satisfy Nigeria's demands in telecommunications, broadcasting and broadband multimedia services. The satellite is based on the Dongfanghong-4 satellite platform. Two ground stations located in Abuja, Nigeria and Kashi, China will be built too. The Nigerian government hopes to sell 50% of the transponders before the satellite's launch. The satellite is to be launched by a Long March 3B rocket at the Xichang Satellite Launch Center in early 2007.

**Fig 5.** Artist's impression of Nigcomsat-1.

## African Alumni of ISU (ISU–AA) Unite

At the gathering of the First African Leadership Conference on Space Science and Technology for Sustainable Development held in Abuja, Nigeria, from 23–25 November 2005, African Alumni of the International Space University, France, "ISU", resolved to work towards the establishment of the ISU African Alumni Association, "ISU–AA".

The following are the objectives of ISU–AA:

- To popularise Africa in Space Science & Technology (SST) and SST in Africa;
- To contribute our knowledge to the development of Africa;
- To popularise ISU in Africa;
- To mentor African and other students in ISU;
- To send/assist other African students to participate in ISU programmes; and
- To keep in touch with Africans in Diaspora involved in the global space arena.

To establish this association, the group has as a next step to develop a constitution and regional representative structure. During this establishment stage, Dr Peter Martinez of the National Research Foundation (NRF), South Africa and Mr Tare Brisibe of the National Space Research Development Agency (NASRDA), Nigeria, have agreed to be responsible for the SADC and West African regions, respectively. Still needed are interim coordinators for the North and East African regions.

For further information on ISU–AA, any of the under-mentioned may be contacted at their respective email addresses:

- Mr Ayodele Faiyetole (Interim Secretary, ISU–AA): *ayodele.faiyetole@alumnimail.isunet.edu*..
- Dr Peter Martinez (Interim Coordinator, ISU–AA, SADC): *peter@saao.ac.za*;
- Mr Tare Brisibe (Interim Coordinator, ISU–AA, West Africa): *tare_brisibe@fsmail.net*; and

# The International Heliophysical Year (IHY) 2007

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**Abstract.** The International Geophysical Year (IGY) of 1957, a broad-based and all-encompassing effort to push the frontiers of geophysics, resulted in a tremendous increase of knowledge in space physics, the Sun-Earth connection, planetary science, and the heliosphere in general. Now, fifty years later, we have the unique opportunity to advance our knowledge of the global heliosphere and its interaction with planetary bodies and the interstellar medium through the International Heliophysical Year (IHY) in 2007. This will be an international effort which will raise public awareness of space physics. Because of its unique geographic position, Africa is well-positioned to play a critical role.

**Sommaire.** L'année Géophysique Internationale (AGI) de 1957 a été une tentative globale de pousser les frontières de la géophysique et a eu comme conséquence une amélioration substantielle des connaissances en physique spatiale, interaction soleil-terre, en planétologie et en physique de l'heliosphere en général. Aujourd'hui, cinquante ans après, nous avons une occasion unique au cours de l'Année Heliophysique Internationale (AHI) en 2007 d'améliorer nos connaissances de l'heliosphere et de son interaction avec le système planétaire et le milieu interstellaire. Ceci constituera un effort international, qui éveillera le grand public sur la physique spatiale. En raison de sa position géographique unique, l'Afrique est bien placée pour y jouer un rôle critique.

## Introduction

On 4 October 1957, only 53 years after the beginning of flight, the launch of Sputnik 1 marked the beginning of the space age as man took his first steps of leaving the protected environment of the Earth's atmosphere. Discovery of the radiation belts, the solar wind and the structure of the Earth's magnetosphere prepared the way for the inevitable human exploration that followed. Soon, cosmonauts and astronauts orbited the Earth, and in 1969 astronauts landed on the Moon. Today, a similar story is unfolding: the spacecraft Voyager has crossed the termination shock, and will soon leave the heliosphere. For the first time, man will begin to explore the local interstellar medium. During the next 50 years it is inevitable that exploration of the solar system including the Moon, Mars and the outer planets will be the focus of the space programme, and, as was the case 50 years ago, unmanned probes will lead the way, followed by human exploration.

The IHY 2007 will coincide with the fiftieth anniversary of the International Geophysical Year (IGY) in 1957, one of the most successful international science programs of all time. The tradition of international science years, however, began almost 125 years ago with the first international scientific studies of global processes of the Earth's poles in 1882–3 (Figure 1). A second International Polar Year (IPY) was organised in 1932, but a world-wide economic depression curtailed many of the planned activities. A more complete history of international years is given by Davila[3] and others[1,5,6]. The IHY will continue the legacy of these previous events, extending global synoptic study to the heliosphere.

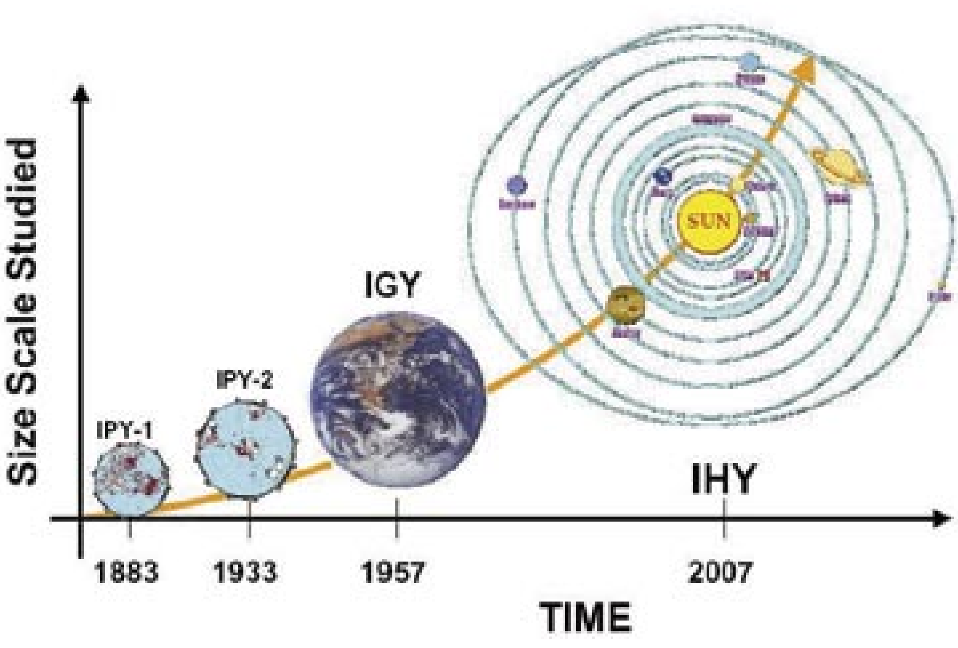


**Fig. 1.** The International Heliophysical Year is the natural extension of the International Geophysical Year and the previous International Polar Years to the larger heliospherical system.

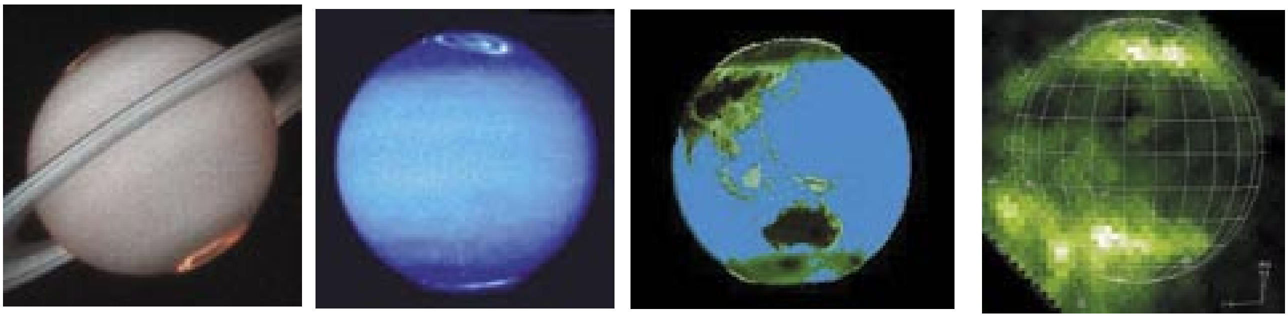

**Fig. 2.** Aurorae on Saturn, Jupiter, Earth and Ganymede are one example of universal physical processes at work in the solar system.

## Universal Processes

The International Heliophysical Year (IHY) will focus on the cross-disciplinary study of universal physical processes in the solar system, observed in a variety of settings. It is now widely recognised that evolution in the solar system proceeds through a set of universal processes[2] *i.e.* reconnection, particle acceleration, plasma wave-generation and propagation, *etc*. By studying these universal processes in diverse environments and in comparative ways, new scientific insights will be gained. This is perhaps best understood by citing a few examples:

(1) Shocks are observed *in situ* in the interplanetary medium. Shocks are believed to play a role in the acceleration of particles in the solar corona, and standing bow shocks and termination shocks separate the major regions in the heliosphere. Shock formation and particle acceleration are universal processes. (2) Aurorae (Figure 2) are observed on Earth, Saturn, and Jupiter, and Jovian auroral "footprints" have been observed on Io, Ganymede and Europa. The formation of aurorae is observed to be the universal response of a magnetised body in the solar wind. The cross-disciplinary study of these processes will provide new insights that will lead to a better understanding of the universal processes in the solar system that affect the interplanetary and planetary environments, and pave the way for safe human space travel to the Moon and planets in the future, and will serve to inspire the next generation of space physicists.

## Objectives and Goals of the IHY

The IHY has three primary objectives:

- Advancing our understanding of the fundamental helio-physical processes that govern the Sun, Earth and heliosphere;
- Continuing the tradition of international research and advancing the legacy on the 50th anniversary of the International Geophysical Year; and
- Demonstrating the beauty, relevance and significance of space and Earth system science to the world.

More specifically, we have identified six goals of IHY, each corresponding to a unique opportunity afforded by IHY:

1. Develop the basic science of heliophysics through cross-disciplinary studies of universal processes.
2. Determine the response of terrestrial and planetary magnetospheres and atmospheres to external drivers.
3. Promote research on the Sun-heliosphere system outward to the local interstellar medium – the new frontier.
4. Foster international scientific cooperation in the study of heliophysical phenomena now, and in the future.
5. Preserve the history and legacy of the IGY on its 50th anniversary.
6. Communicate unique IHY results to the scientific community and the general public.

The IHY is an integrated programme of many diverse activities working at an international level to achieve all of these goals.

## Plans for the IHY

The International Heliophysical Year Programme has four main components, which are called programmatic thrusts:

1. Science activities, consisting primarily of Coordinated Investigation Programmes (CIPs) dedicated to the study of the extended heliophysical system and the universal processes common to all of heliophysics;
2. The United Nations Basic Space Science (UNBSS) Observatory Development Programme, dedicated to the establishment of observatories and instrument arrays to expand greatly our knowledge of global heliophysical processes, while increasing the viability of space science research and education in developing nations and regions that traditionally have not been active in space research;
3. Education and public outreach, increasing public awareness of heliophysics and educational activities for "students" of all ages, and
4. The "IGY Gold" History Initiative, preserving the history and legacy of the IGY of 1957 by identifying and recognising planners of and participants in the first IGY preserving and making available items of historical significance and organising commemorative activities and events.

The four programmatic thrusts of IHY are roughly related to the above goals of IHY as follows:

| | |
|---|---|
| Science Activities | Goals 1 – 4 |
| UNBSS Observatory Development | Goals 3 & 4 |
| Education & Public Outreach | Goal 6 |
| IGY Gold History | Goal 6 |

Each of the four Programmatic Thrusts of IHY is planned as part of one integrated programme. The plans, progress and current state of these individual activities will be discussed throughout this publication.

## Science Activities

During the IHY, Coordinated Investigation Programmes (CIPs), utilising space- and ground-based observatories will be organised to study universal processes at work throughout the solar system[4]. Maximum use of the internet and world-wide-web infrastructure will be used to facilitate communication and organisation. These research campaigns will operate similar to SOHO Joint Observing Projects.. The resulting data sets will be processed and assembled for easy access to the global science community. Coordinated data analysis will be performed during a series of workshops and the results will be published and made available to the science community.

CIPs will be entered by individuals within the research community (Figure 3); discipline coordinators will review all suggestions and organise similar CIPs into observing programmes that can actually be implemented. Observatory coordinators, representing each of the instruments participating in the IHY will assist in this process. Later, the observing programmes will be organised into cross-disciplinary topical Universal Process Workshops to discuss and communicate the scientific results of the IHY campaigns.

Joint campaigns with organisations having overlapping goals will minimise the resources required for the IHY. The IHY will seek to identify areas where it can support programmes like CAWSES (Climate and Weather of the Sun-Earth System), IPY (International Polar Year), eGY (Electronic Geophysical Year), perhaps for example, by providing the web-based campaign planning database software developed to support IHY to these groups. Detailed discussions on areas of support were carried out during 2005, leading to detailed cooperation and coordination in 2006. IHY workshops and coordination meetings will be held in conjunction with major scientific meetings whenever possible to minimise travelling time and expense.

## United Nations Basic Space Science (UNBSS) Observatory Development Programme

Through a cooperative programme with the United Nations Basic Space Science (UNBSS) programme for 2005–2009, the IHY will facilitate the deployment of a number of arrays of small instruments to make global measurements of space physics related phenomena. These may range from a new network of radio dishes to observe interplanetary coronal mass ejections (CMEs) to extending existing arrays of GPS receivers to observe the ionosphere. These instrument concepts are mature, and are developed and ready to be deployed. A coordination meeting was held between IHY and UNBSS representatives in October 2004 in Greenbelt, Maryland in the United States of America. As a result, the UNBSS programme has dedicated its resources and activities through 2009 to providing the IHY with a link to developing countries. The programme has provided more than 2 000 scientist contacts in almost 200 countries, many of whom are eager to participate in international space science activities.

The purpose of the Observatory Development Programmatic Thrust of the IHY is to develop activities and facilitate partnerships that stimulate space and Earth science activities throughout developing regions of the world, such as the establishment of ground-based instrument arrays and research programmes. This includes the deployment of small, inexpensive instruments such as magnetometers,

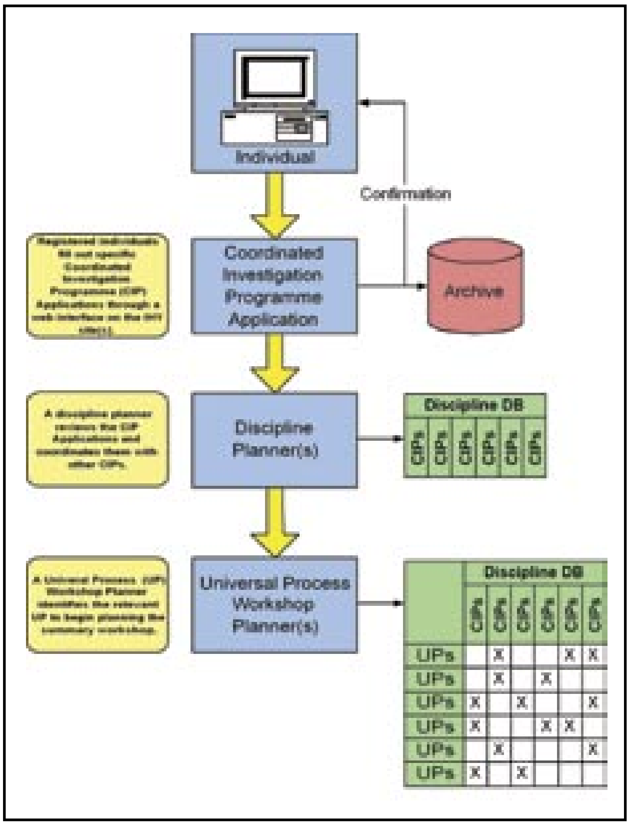


**Fig. 3.** The Coordinated Investigation Programmes (CIPs) lead to observational plans organised by Discipline Coordinators. Scientific results are communicated through a series of topical Universal Process Workshops.

radio antennas, GPS receivers, all-sky cameras, *etc.* around the world to provide global measurements of ionospheric and heliospheric phenomena. Nearly all of the proposed instruments require global coverage to be effective; however, there are notable (and scientifically important) geographical gaps where coverage is minimal. The continent of Africa is one of these gap regions. The IHY Observatory Development Programme will attempt to address this by facilitating instrument deployment in these sparsely covered regions of the world.

The basic Observatory Development concept is summarised as follows

- The lead scientist or principal investigator will provide instrumentation (or fabrication plans) for the instruments in the array;
- The host country provides the workforce, facilities, and operational support to obtain data with the instrument, typically at a local university;
- The instrument host scientists become part of PI teams;
- All data, and data analysis activity is shared with all members of the group; and
- Publications and meetings involve the participation of all team members when possible.

The Observatory Development Programme facilitates partnerships between instrument providers and instrument host institutions. The tripod approach, with the three legs of the tripod consisting of instrumentation, education and observation, leads to scientific cooperation which produces excellent science and improves viability of space science around the world, providing an important link between scientific outreach and first-class science research.

This joint programme, a collaboration between the IHY and the United Nations Basic Space Science (UNBSS) Initiative, centres around a series of annual workshops hosted in varying international locations (including the 2005 Workshop in Al-Ain, United Arab Emirates). The Al-Ain Workshop brought together instrument providers and interested instrument providers for the first time to discuss facilities and requirements for each of the planned arrays. Attendees of the Workshop included approximately 20 instrument providers, and 30 potential instrument hosts selected from over 150 applicants. The first element of a new North African AWESOME VLF array has already been delivered to the University of Tunis. Efforts are underway between the University of Tunis and Stanford University to bring this element into full operation.

### Education and Public Outreach

One of the primary objectives of the IHY/UNBSS programme is to encourage the study of space science in developing countries providing the opportunity to participate in space science research, while at the same time developing the curriculum and facilities to demonstrate and teach space science in the university environment. The IHY fully supports these objectives, and will be preparing booklets describing a space science curriculum for each of the deployed instrument arrays. Scientists at participating institutions will use these as a guide in teaching, and fully participate in the analysis of the data from the array and in the scientific discoveries that follow.

### "IGY Gold" History Initiative

During 2004, the IGY Gold Club was established to commemorate the achievements of the IGY participants. The first recipient, Dr. Alan Shapley, was presented with the award at the IHY Workshop in Boulder, Colorado in February 2005. The Gold Club award consists of a certificate and a pin upon which the IGY logo is embossed. To be eligible for membership, one must: (1) have participated in the IGY in some manner, and (2) provide some historical material (copies of letters, books, *etc.*) to the IHY history committee. This material will provide a lasting legacy of the IGY for generations to come. This is a cooperative effort between the IHY, the History Committee of the AGU and the IAGA History Committee.

## Schedule and Basic Plan

Planning for the IHY is organised into seven regions; North and South America, Africa, Europe, Western Asia, Eastern Europe/Western Asia, and Asia-Pacific. Each of these regions has formed a regional planning committee to coordinate regional IHY participation. Representatives from each of these regions met in Toulouse, France in July 2005 to commence the joint international planning process. International planning will continue at regional and international organising meetings. Additional information on planned meetings and regional organisations is available at the IHY website (http://ihy2007.org).

Major planning activities have taken place for all aspects of the IHY programme. Hundreds of local, regional and international planning conferences and meetings have taken place. Teams continue to form, implementing IHY activities in all the regions of the globe. The basis for the four main Programmatic Thrusts of IHY (Science, Outreach, Observatory Development and History) and a means by which all of these activities will be coordinated, are necessary to enable the individual organisations and institutions to develop unique IHY programmes that suit their own goals and challenges. It is the activities and programmes developed by these individual organisations and institutions that form the "building blocks" of the IHY. Therefore, the IHY's international planning activities have focussed on the establishment of the four main components of IHY and on enabling the individual IHY regions and nations to commence with their planning activities.

The numerous local and regional planning activities have consisted primarily of IHY team meetings and special sessions at scientific meetings. IHY team meetings have occurred in each of the IHY's seven regions and local planning teams continue to develop and implement elements of their programme in coordination with international efforts. Numerous special sessions on IHY have occurred at a wide range of scientific meetings, addressing all four of the IHY Programmatic Thrusts. These special sessions provide a venue for members of the community to learn about IHY activities and begin to contribute to the IHY effort.

As one would expect, the number of IHY events has increased exponentially in the past several years. The "Events" section of the IHY website (http://ihy2007.org) lists a representative number of these activities, especially those pertaining to the "Science" and "Observatory Development" aspects of the programme.

In preparation for the "official launch" of IHY activities in 2007, many precursor activities are required for the 2005–2006 timeframe. For the science component, the regional coordinators have already established a list of several hundred observatories planning to participate in IHY science activities, and members of the international scientific community have begun proposing their Coordinated Investigation Programmes for implementation during the IHY. Scientific sessions on IHY science activities at various meetings have focussed on bringing discussions of IHY science to the forefront and identifying campaigns to be implemented as CIPs. The Observatory Development component has been the focus of intensive activity in concert with the United Nations Basic Space Science Initiative. In particular, the deployment of individual instruments at remote sites has already begun as an essential step towards the establishment of global arrays by 2007. New instrument programmes and new "host" sites for these activities continue to be identified on a regular basis. The component has already launched several activities worldwide, emphasising the linkage to individual local programmes, while the IGY Gold History Programme was implemented in 2004 with plans to continue through 2009.

A general description of the IHY timeline is as follows:

- 2001–2003: establishment of IHY Secretariat; establishment of the main elements of the IHY programme; initialisation of planning activities on all continents;
- 2004: national and regional coordination meetings begin

# Science on a Global Scale: Connecting Local Ionospheric Disturbances over the Hawaiian Islands to Global Processes

The figure below shows the effects on the naturally occurring ionospheric emissions caused by an instability process generated at the magnetic equator in addition to a geo-magnetic storm. The local structures, seen in the data as depletions in the airglow intensity, are caused by an instability process generated at the magnetic equator. The turbulence within these local structures can disrupt transionospheric communication and navigation signals. The local structure typically drifts from west to east. In this example, simultaneously with the development of this equatorial instability process, a travelling ionospheric disturbance (TID) propagates equatorial-ward from the polar region, launched by energy input in the auroral region due to the onset of a geomagnetic storm.

Within this TID are electric fields and neutral winds which can differ significantly from their respective quiet-time values. As the TID passes over Hawaii, the perturbed electric fields and neutral winds affect the observed local structure by both reversing the drift direction to the west and initiating the development of secondary instabilities on the eastern edge of the primary local structure.

The instabilities introduced by TIDs and other ionospheric phenomena impact our ability to communicate through the ionosphere (e.g. GPS and satellite communications). The lack of ability to predict such phenomena leads to unanticipated transionospheric communications outages that negatively impact everyday aspects of life in the 21st century. In order to mitigate the effect of those outages, we need a global predictive capability. A global capability requires comprehensive and extended observations that can resolve both the fine scale structures as well as the global coupling effects that influence the development, structure, and impact of ionospheric disturbances on transionospheric radio signals.

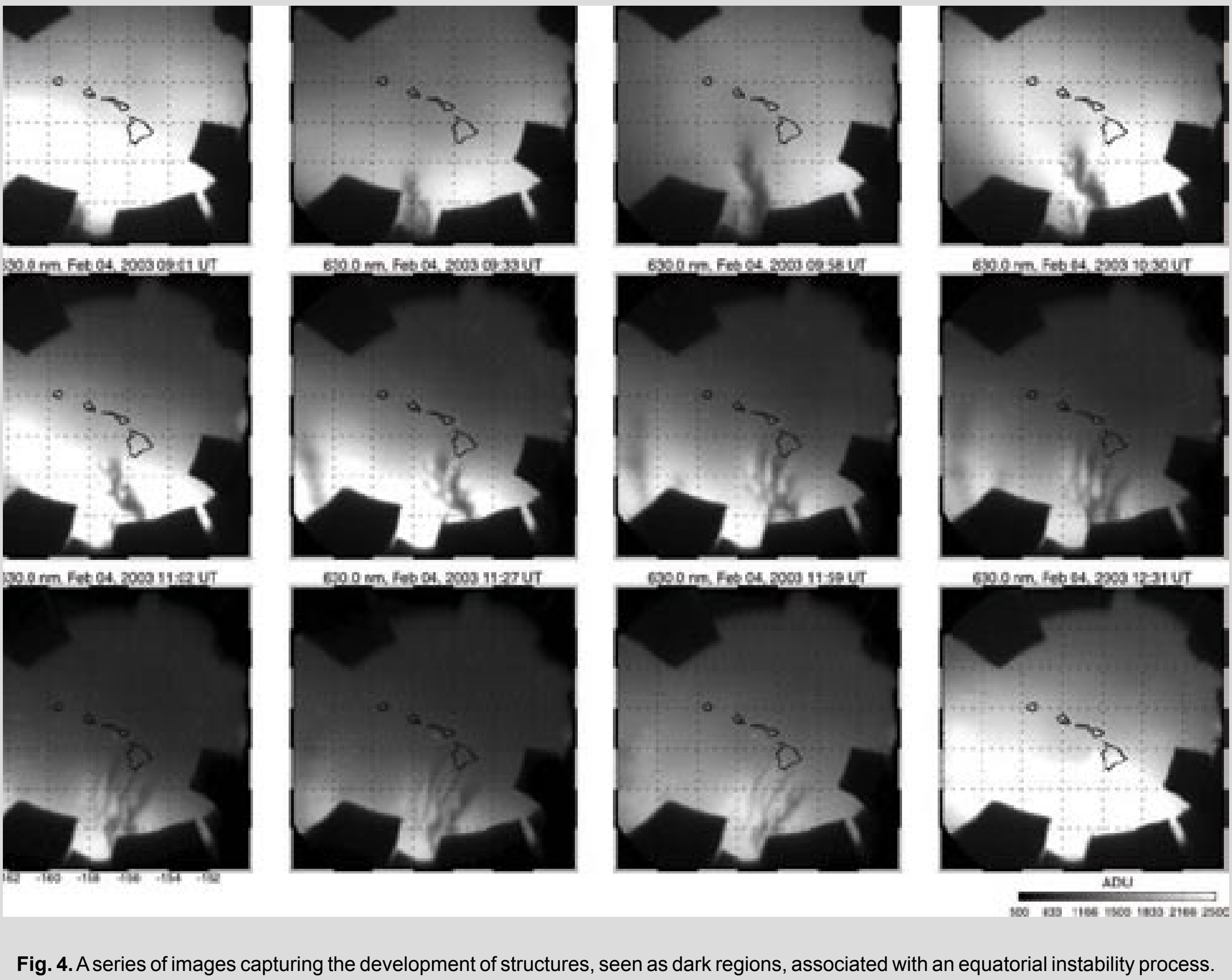


**Fig. 4.** A series of images capturing the development of structures, seen as dark regions, associated with an equatorial instability process. The images are of the 630.0-nm emission that occurs naturally in the Earth's ionosphere/thermosphere system and were recorded from the site of the Haleakala Volcano on Maui, Hawaii. These structures are modified by the passage of a traveling ionospheric disturbance, seen as an enhancement traveling from northeast to southwest, associated with energy input in the auroral region.

to take place; the four essential components of IHY are defined; synergy/coordination discussions with professional organisations; establishment of CIP structures; launch of the IHY UNBSS and IGY Gold History Programmes;
- 2005: continuation of national and regional coordination meetings; synthesis and coordination from regional to international; precursor activities for each of the four main components continue; instrument deployment begins and CIPs proposed by individual community members begin to form the fabric of the IHY science campaigns;
- 2006: focus on the implementation of the four main IHY components and on the integration of national and local activities with the international IHY community; prototyping year, particularly for numerous CIPs and outreach activities that serve as trailblasers and/or testbeds;
- 2007–2008: IHY is launched as an integrated international programme. Science, Observatory Development, Outreach and History activities occur around the globe, and the efforts of each individual component and region are multiplied in impact by their coordination with the worldwide effort; and
- 2008–2009: IHY activities continue. Results of the IHY CIPs and science campaigns are analysed at a wide range of workshops and analysis activities; Observatory Development continues through IHY UNBSS legacy programmes; Outreach activities incorporate major scientific results and breakthroughs.

## Summary

The International Heliophysical Year, on the 50th anniversary of the International Geophysical Year, is a tremendous opportunity to advance our understanding of the Sun-Earth system, and to demonstrate the beauty, relevance, and significance of Earth science to the people of the world. Scientists and educators in African nations will play important roles in the IHY, and each of the IHY's four programmatic thrusts benefits from strong African participation. For the Scientific Thrust, African scientists participating in and leading research programmes will result in scientific advances that make optimal use of instrumentation currently in place in Africa or to be deployed in Africa as part of the IHY. For the Observatory Development Thrust, Africa is the most crucial region because of its positioning relative to the equator and because of the scientific advances made possible by establishing instrument arrays throughout the African continent.The Education Thrust benefits greatly because of special activities, such as the March 2006 trans-African solar eclipse, and because of the educational opportunities made available by coordination with and among African scientific institutions. The History Thrust will be able to focus on the contributions of individual scientists during the IGY, as well as the developments in space science over the past 50 years. The richness of IHY activities occurring on the African continent and the dedication of the African scientists and leaders are fundamentally important to the global success of IHY.

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# Africa and the International Heliophysical Year (IHY): Potential, Prospects, Participation

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**Abstract.** Beginning from the historical perspective of the much-anticipated International Heliophysical Year (IHY), this paper highlights the relevance of Africa in this global event. With the passing of the dip equator through the continent, Africa is presented as a key region for ground observation and measurements of geo- and helio-physical variables. The relevance of Africa in IHY is discussed and African scientists are sensitised and invited to participate in, IHY. Opportunities of IHY for Africa's development, as well as its scientists are highlighted. The need for integration of African national governments and scientists in the scheme of IHY is stressed. A call is made for an African IHY regional coordinating team to involve the New Partnership for Africa's Development, NEPAD, Science and Technology Forum as a continental body.

**Sommaire.** Partant de la perspective historique tant anticipée de l'année internationale heliophysique (IHY), cet article aborde l'importance de l'Afrique dans cet événement global. Incluant une partie de l'équateur magnétique, l'Afrique est une région principale pour l'observation et la mesure au sol des variables géophysiques et heliophysiques. L'auteur sensibilise les scientifiques africains sur l'importance de l'Afrique dans l'IHY et les invites à participer activement à cette manifestation. Des opportunités pour le développement de l'Afrique et de ses scientifiques durant l'IHY sont présentées. L'auteur souligne aussi le besoin d'associer les gouvernements nationaux et les scientifiques africains dans l'organisation de l'IHY. Un appel est ainsi lancé pour qu'une équipe régionale africaine pour l'IHY implique le NEPAD -forum pour le développement de la science et de la technologie en l'Afrique- en tant qu'organisme représentatif du continent africain.

## Introduction

International Geophysical Year (IGY) in 1957 was an international multidisciplinary programme to study global phenomena of the Earth and geospace, and was inspired by the success of the International Polar Years of 1882–83 and 1932–33. The spectrum of investigation covered by IGY included meteorology, geomagnetism, airflows, aurorae, ionospheric physics, solar activity, cosmic rays, glaciology, oceanography, seismology and gravimetry. The IGY involved about 60 000 scientists from 66 nations, working at thousands of stations from pole to pole to obtain simultaneous, global observations on Earth and in space. The years preceding the IGY witnessed the establishment of new geophysical observatory sites all over the world in a global cooperation effort. Geophysical activities were closely coordinated for the first time in history. The extension programme to IGY in 1958 was called the International Geophysical Cooperation (IGC). Detailed reports on IGY and its cooperation programmes are documented in the 48 volumes of the annals of IGY[4] (1959–1970). During the IGY preparation, most African nations were still in the pre-independence dispensation and when it became obvious that most African nations were not going to be involved, a Scientific Council for Africa (SCA) was inaugurated and held its first joint meeting with the Special Committee for the International Geophysical Year (CSAGI) at Bukavu in the then Belgian Congo between 11–15 February 1957. CSAGI was the international coordinating committee of IGY. The presidents of CSAGI and SCA were Professor Sydney Chapman and Dr P J du Toit respectively. The African nations whose names eventually made it to the Annals of IGY were Algeria, Cameroon, Egypt, Ethiopia, Ghana, Nigeria, Tunisia and South Africa. Most of these nations participated in IGY without national organising committees due to the difficulty in pulling the indigenous scientists together as the African continent was still in the colonial era.

The fiftieth anniversary of the International Geophysical Year will be observed in 2007 and is to be commemorated by a similar programme of multidisciplinary scientific collaboration called the International Heliophysical Year (IHY). IHY will focus on the problem of solar variation effects on Earth. The four cardinal objectives of the IHY are to:

- provide benchmark measurements of the magnetosphere, the ionosphere, the lower atmosphere and Earth surface to identify global processes and drivers that affect climate and the near space environment;
- coordinate global study of the Sun-heliosphere system outward to the heliopause; to understand the external, and historic drivers of geophysical change;
- foster international scientific cooperation in the study of heliophysical phenomena, now and in the future; and to
- communicate the unique scientific results of the IHY to the interested scientific community and to the general public.

The American and European communities are already advanced in their preparations for IHY. Asian/Pacific nations are equally catching up with the pace of preparations. Up-to-date information on IHY, meetings and developments, are available online at http://ihy.gsfc.nasa.gov/newsroom/newsroom.shtml. The primary objective of this paper is to strengthen the campaign for the coordinated involvement of African scientists in IHY by presenting the potential of the continent and the prospects of IHY in the region. The ultimate goal is to strive towards effective participation in the global event.

## Relevance of Africa

Africa stands to play a major role in ground-based observational studies of the Earth-Sun interaction. The magnetic dipped equator, a line drawn on a map or chart connecting all points at which the magnetic inclination (dip) is zero for a specified epoch, passes though the continent (Fig. 1) making it the second continent after South America where

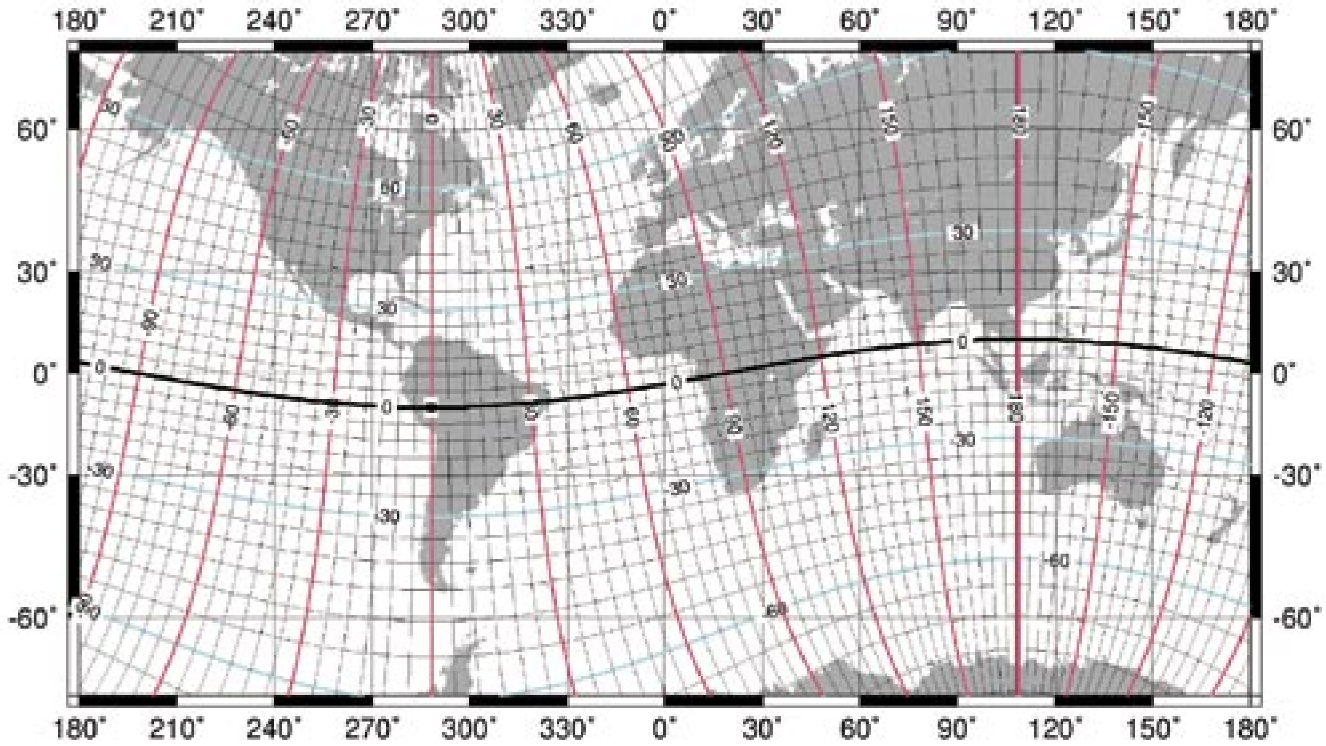


**Fig. 1.** World map illustrating the passing of dip equator through Africa (2000).
(*Picture courtesy of the National Geophysical Data Center, Co., USA.*)

the anomaly, known as Equatorial Electrojet (EEJ) can be studied in detail across its width[10]. The Equatorial Electrojet is the intense non-uniform east-west current which flows within $\pm$ 3 degrees in the neighbourhood of the magnetic equator at an altitude of 106 $\pm$ 2 km[1,6,7,8]. This intense eastwards current often changes direction on certain days, mostly in the morning and evening periods and flows westwards. This westwards flowing electrojet was named "Counter Electrojet" by Gouin[4]. The EEJ is responsible for the manifestation of an enhanced non-uniform horizontal field with sharp spatial gradients resulting in large vertical field variations in the region. The equatorial region is noted for its characteristic complexities that are of great interest in ionospheric studies due to the presence of this Equatorial Electrojet. The natural geographical position of Africa may be used to advantage to study solar and terrestrial phenomena from ground-based observations in great detail. The Sun is abundantly available throughout the year along the equatorial Africa for averages of 12 hours daily with average irradiances of 400 watts per square metre.

Over the years, the number of African experts in atmospheric and space studies has grown tremendously. African physicists, atmospheric and space scientists have made significant contributions to the knowledge of solar-terrestrial physics at the international level. The classical treatise on the Equatorial Electrojet by Onwumechili[6] and the results of the International Equatorial Electrojet Year (IEEY) as discussed[3,10] are among several articles that lend credence to the growth of geophysical studies on the continent. Although a good number of research institutes and universities are involved in solar and atmospheric studies, it is pertinent to note that research in solar and terrestrial physics has remained at a low level due to many problems peculiar to developing Africa and the lack of state-of-the-art facilities for observations.

International support and cooperation have been the back-bone of geoscience on the continent. Cohen[2], while writing on the International Equatorial Electrojet Year programme, asserted that the African magnetic data set has, on larger scales, been used for global ionospheric modelling that demonstrates that the magnetic disturbance produced by auroral phenomena may extend to the planetary scale. A large number of French institutes participated in the IEEY studies in collaboration with African institutes. Funding was provided by the Ministère Francais de la Coopération (Département de la Recherche et des Formations, and Departement Télé-communications); ORSTOM (Département Terre Ocean Atmosphère); CNET (France-Télécom Centre Lannion); the Ministère Francais de la Recherche et de la Technologie; Centre National de la Recherche Scientifique (Departement Sciences de l'Univers); the Centre d'Energie Atomique; the Université à Paris-Sud; Abidjan University, Ivory Coast and Dakar University, Senegal. During the IEEY (November 1992 to October 1994) many different instruments were operated in Africa and, as observed by Cohen[2], the entire activity made a significant contribution towards improving our knowledge of the aeronomy, electrodynamics and physics of the equatorial ionospheric plasmas, as well as of the associated current circuit.

IHY has enormous opportunities for Africa. This global event will bring together all interested parties in the multidisciplinary fields of interest to IHY programmes. An inventory of all scientists and facilities for solar and atmospheric terrestrial investigations in Africa will be taken. This will obviously produce a useful continental directory. There will be opportunities for continental and intercontinental collaboration. African scientists will be able to contribute significantly to IHY. Training of African scientists and technologists to operate ground observatories throughout Africa is imminent. IHY shall undoubtedly generate results that will be applicable in various applications of interest to African citizenry and growth which include drought control, climate observations and forecasting, agriculture, radio communications, space applications etc.

The United Nations Office for Outer Space Affairs, in conjunction with the European Space Agency, held international workshops on Basic Space Science thrice in Africa; in 1993 in Lagos, Nigeria, in 1994 in Cairo, Egypt and in 2001 in Reduit, Mauritius. It is noteworthy that African scientists recorded significant participation in these three UN/ESA workshops (UNBSS Reports)[9]. This time around, we have strong reasons to establish a strong and effective coalition in our mutual effort to participate in IHY. There is a need for integration of African scientists in the scheme of IHY. We need to come together and establish working groups for IHY. An ideal working group should cover all aspects of solar terrestrial interactions and applications *e.g.* climate and earth atmosphere, magnetospheres and ionospheres, heliosphere and solar wind, space weather and solar drivers.

## Recommendations and Conclusions

Every African scientist in the field of study relevant to IHY is encouraged to visit the official site of IHY[5] located at http://www.ihy2007.org and register in the international coordination database. The Nigerian experience has paid off; more than 40 researchers have identified with IHY Nigeria (email: IHY_Nigeria@yahoo.com). Efforts should also be geared at initiating national movements for IHY in all African countries. It is further recommended that all scientists should keep contact with the international coordinating group by regular visits to the website while watching out for announcements of regional meetings geared at formulating plans for IHY.

Africa has natural and human resources adequate for meaningful participation in IHY, but the major bane of the continent is lack of direction and sustainable assimilation/transfer of information to the appropriate quarters where policies are formulated. This calls for a coordinated approach in our effort at ensuring full representation in IHY, and also underscores the need for African scientists to give broad and relevant information to the populace and national governments about IHY and its programmes. If African sportsmen can convince the populace and governments to seek hosting rights for international tournaments, then African scientists can give relevant information to citizens and government regarding IHY and its programmes. Today's world is not driven by wealth of nations in terms of natural resources but by technological advances amongst which space technology is one of the driving forces. The understanding of weather in space is one of the objects of concern in IHY.

Africa must rise and take her rightful place in the scheme of worldwide scientific exploration about to resume in IHY. This paper closes with a strong call for national and continental coordination for IHY in Africa. This regional coordinating team should involve the New Partnership for Africa's Development, NEPAD, Science and Technology Forum.

## Acknowledgements

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# The Conjugate Sprite Campaign: A Potential North-South Collaborative Project for the International Heliophysical Year

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**Abstract.** Red sprites are luminous phenomena which occur at high altitude above thunderstorms. It is thought that a beam of relativistic electrons may be generated during the formation of a red sprite and that this beam should travel along a magnetic field line to the conjugate hemisphere. A campaign was organised to detect evidence of this energetic electron beam. During the campaign more than 100 sprites were observed over Europe but no indication of the electron beam was detected near the conjugate point in the southern hemisphere. However, several interesting auxiliary observations were made with various instruments in Europe.

**Sommaire.** Les sylphes rouges sont des phénomènes lumineux qui se produisent à haute altitude au dessus des orages. On pense qu'un faisceau d'électrons relativistes est généré lors de la formation d'un sylphe rouge et que ce faisceau voyage le long des lignes de champ magnétique vers l'hémisphère opposé. Une campagne d'étude a été organisée pour détecter ce type de faisceaux d'électrons énergétiques. Durant cette campagne, plus de 100 sylphes ont été observés au-dessus de l'Europe mais aucune indication de la présence de faisceaux d'électrons n'a été trouvée près du point opposé dans l'hémisphère sud. Cependant, plusieurs observations auxiliaires intéressantes ont été faites en Europe avec divers instruments.

## Introduction

Red sprites, blue jets and elves, collectively known as transient luminous events (TLEs), are weakly luminescent upper atmospheric phenomena occurring at high altitudes above active thunderstorms [21]. These entities, although predicted towards the beginning of the twentieth century [25] and reported intermittently in the literature, have only recently attained credibility as a topic for serious research as a result of a chance observation which irrefutably established their existence [12].

A selection of red sprite images is presented in Figure 1. These fleeting events, with typical duration of 5 to 300 ms (average 98 ms), are produced in the mesosphere at altitudes between 40 and 90 km. Their horizontal extent is 10 to 100 km, with an emission volume ~10 000 km$^3$. Fine structure, suggesting a vast collection of luminous channels with scales ~10 m, has been revealed by telescopic imaging [14], perhaps reflecting the transitory non-uniform structure of the mesosphere resulting from the incidence of cosmic rays and meteors[22].

Red sprites have been observed to follow a few ms after intense lightning discharges. Lightning results from charge separation within a thundercloud, where convection causes positive charge to accumulate at the top of the cloud, while negative charge gathers at the bottom. Since the Earth and

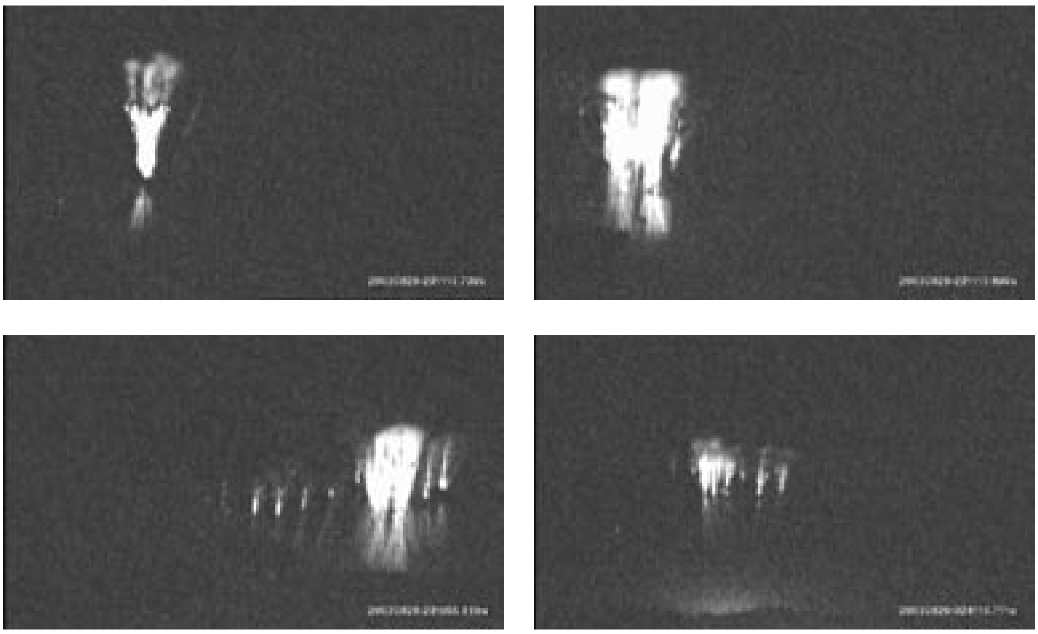


**Fig. 1.** Red sprites observed over Europe during August 2003.

(a) Observatoire Midi-Pyrénées, France.

(b) SAAO, Sutherland, South Africa.

**Fig. 2.** Principal sites involved in the conjugate sprite campaign.

ionosphere are good conductors, charge is redistributed such that the ionosphere above a thundercloud is slightly negative, while the ground below is fractionally positive. At a distance from the cloud, the situation is reversed and a downward fair weather electric field exists. Lightning strikes most frequently transport negative charge from the base of a thundercloud to Earth. These discharges are known as negative cloud-to-ground (–CG) strikes. Powerful positive cloud-to-ground (+CG) discharges may also occur in which electrons move from the ground to the positive charge centre at the top of a thundercloud. Following a +CG discharge a quasi-static electric field remains between the upper reaches of a thundercloud and the lower ionosphere. Since the electric field intensity decreases more gradually with altitude than the atmospheric pressure, a level exists at which dielectric breakdown of the rarefied upper atmosphere occurs. The electric field accelerates the resulting free electrons to energies sufficient for collisional excitation of atmospheric neutrals, which produce faint optical emissions principally in the red portion of the spectrum [23].

Theoretical studies [19] suggest that a relativistic electron avalanche may also account for sprite formation. The seed electrons, thought to arise from cosmic rays, are accelerated upwards by the quasi-static electric field, penetrate the ionosphere and generate a beam travelling along the Earth's magnetic field lines through the magnetosphere. The existence of these beams was first suggested by terrestrial $\gamma$-ray flashes detected on the Compton Gamma Ray Observatory (CGRO) coincident with +CG strikes below the satellite [11, 17]. The $\gamma$-rays are likely to be produced by bremsstrahlung. Although all the electrons in the beam are initially within the loss cone, pitch-angle and energy scattering result in only a fraction of the initial population remaining in the loss cone at the conjugate point. The remaining electrons are trapped and may form a detectable curtain as they bounce and drift around the Earth. Those that precipitate into the atmosphere should excite relatively intense optical emissions (up to 1 MR[*]), $\gamma$-ray production, and secondary ionisation [18]. The precipitating particles should also be detectable through modification of propagation conditions in the Earth-ionosphere waveguide.

Red sprites are most commonly observed following a +CG strike, but they have also been observed in association with –CG strikes [2]. Sprites occur with roughly 1 out of every 20 to 40 +CG discharges [24]. The global lightning flash rate [5] is around 44 $s^{-1}$, of which ~10% are +CG discharges. It is, therefore, likely that on average a red sprite occurs somewhere approximately every 7 s.

Although it was initially supposed that a large peak lightning current was necessary for sprite formation [4], it is now thought that the total charge transferred between the thundercloud and the Earth, as characterised by the charge moment (the product of the charge removed and the vertical length of the discharge channel) is a more reliable indicator. The charge moment change required to initiate a sprite lies in the range 100 – 2000 C km [8]. Sprites are most often triggered by +CG strikes with charge moment in the order of 1000 C km [3, 7]. The prevalence of sprites following +CG strikes may be attributed to the fact that this form of lightning, although rarer than –CG, generally has larger changes in charge moment.

In addition to being an optical spectacle, red sprites also manifest themselves in other ways. They produce distinct radio and sonic signatures. The discharge leads to electrodynamic coupling between tropospheric thunderstorms and the lower ionosphere, and therefore contributes to the global atmospheric electric circuit. Red sprites may also play an important role in atmospheric chemistry, producing oxides of nitrogen which are known to diminish the levels of atmospheric ozone.

## The Campaign

The conjugate sprite campaign [22] has been run for a number of years during the northern hemisphere summer in an attempt to detect evidence of sprite-generated relativistic electron beams. Observations have been coordinated at a number of sites in Europe and near the conjugate region in the southern hemisphere. The European component of the campaign centred around optical observations from the French astronomical observatory, Observatoire Midi-Pyrénées (OMP), located at Pic du Midi de Bigorre (42°56'N 0°8'E, altitude 2877 m, $L \simeq 1.6$). In the southern hemisphere measurements were conducted from the South African Astronomical Observatory (SAAO) near Sutherland (32°23' S 20°49'E, altitude 1759 m, $L \simeq 1.8$). These sites are depicted in Figure 2.

**Northern Hemisphere**

The location of the OMP affords a panoramic view of the surrounding country from an altitude which permits observation of the activity occurring above distant storm systems. Sprite images were recorded by a low light level CCD video camera, forming part of an automated system [1]

*1 MR = 1 megarayleigh. One rayleigh is a column emission rate of $10^{10}$ photons per metre squared per second.

operated remotely from the Danish Space Research Institute. The system includes automatic flash detection software which identifies the impulsive optical emissions produced by lightning and TLEs. Images from the video system and lightning strike data were posted to an internet site in near real time.

The location, time, peak current and polarity of all cloud-to-ground lightning strikes in south-western Europe and the western Mediterranean were obtained from the Météorage network. Additional lightning data with only a limited coverage, but including intra-cloud strikes, were obtained from Vaisala's SAFIR system. A variety of auxiliary measurements were also made at other locations in Europe.

**Southern Hemisphere**

At SAAO the principal observations were optical, made with the Wide-angle Array for Sprite Photometry (WASP)[20], run by Stanford University. Broadband Very Low Frequency (VLF) radio signals were recorded using the Digital VLF Recording and Analysis System (DVRAS)[6], and an OMNIPAL narrow-band receiver was used to monitor the amplitude and phase of transmitter signals propagating in the Earth-ionosphere waveguide. The latter two instruments were operated by the Geospace Physics Group of the University of KwaZulu-Natal (UKZN).

The WASP is designed to observe optical emissions resulting from particle precipitation. The device consists of six photometers, each with a 3° × 6° field of view. In addition, a video camera was bore-sighted on top of the instrument. Five of the photometers were equipped with 665 nm highpass filters to observe emissions from the $N_2$ first positive band, while the remaining unit had a narrow-band filter centred on 427.8 nm for the $N_2^+$ first negative band. The WASP was directed towards the locations of the expected optical emissions as calculated by mapping the lightning strike locations to their conjugate points.

The broadband VLF receiver consists of a pair of orthogonal magnetic loop antennae, aligned geographic north-south and east-west, a preamplifer and signal conditioner. The resulting signal is band-pass filtered over the range 0.3 to 10 kHz and sampled at 20 kHz.

## Results

Although the campaign has been run for a number of years, only results for the 2003 campaign, extending from 18 July to 18 September, will be presented here. The atmospheric conditions over Europe were not conducive to thunderstorm activity during the middle of this period. However, a number of storms occurred at the beginning and end of the campaign and resulted in the observation of 133 TLEs, which are summarised in Table 1. The outcomes of the campaign are detailed elsewhere[22], while only the principal results are outlined here.

The weather conditions, spatial and temporal distribution of lightning strikes over Europe for the period 00:00 to 04:00 UTC on 29 August 2003 are presented in Figure 3. The spatial distribution of strikes during this interval is reflected in Figure 3(a) where it is evident that a few storm centres were operative. The locations of the strikes mapped

Table 1. TLEs observed during the 2003 campaign.

| Storm | Start Date | Day Number | No. TLEs |
|---|---|---|---|
| 1 | 21/07/2003 | 202 | 29 |
| 2 | 22/07/2003 | 203 | 3 |
| 3 | 23/07/2003 | 204 | 16 |
| 4 | 27/07/2003 | 208 | 2 |
| 5 | 20/08/2003 | 232 | 1 |
| 6 | 22/08/2003 | 234 | 7 |
| 7 | 24/08/2003 | 236 | 2 |
| 8 | 25/08/2003 | 237 | 20 |
| 9 | 28/08/2003 | 240 | 53 |

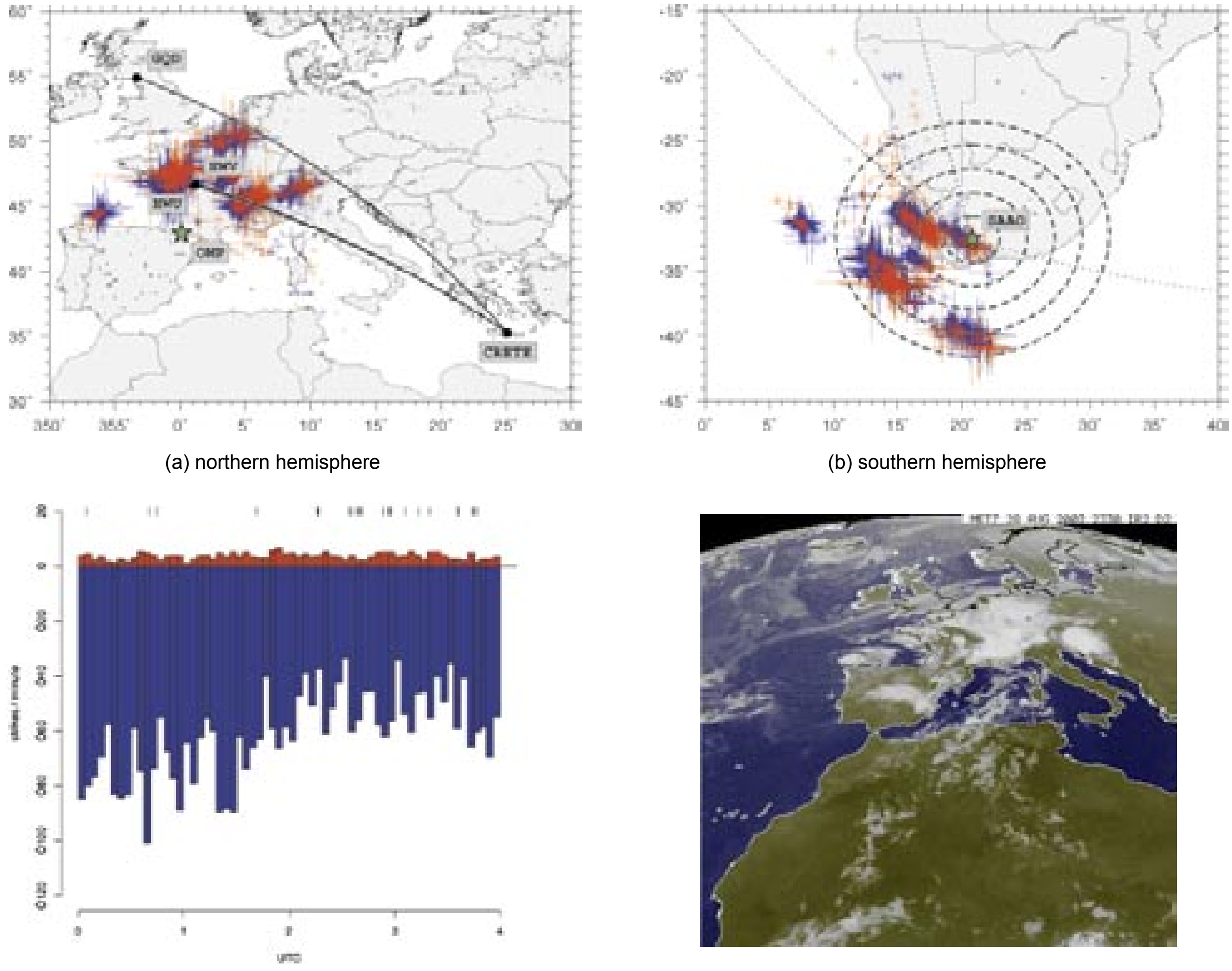
to their magnetic conjugate points in the southern hemisphere are displayed in Figure 3(b). The locations of the conjugate points were calculated using the International Geomagnetic Reference Field (IGRF). Many of the strikes are conjugate to points within a few hundred km of SAAO and are thus within range for the WASP. In Figure 3(c) the frequency of –CG and +CG strikes are plotted. It is apparent that the –CG strikes predominate, outnumbering the +CG discharges by a factor of ~13. The situation reflected in Figure 3 is representative of the more active intervals of the campaign.

**Northern Hemisphere**

On 23 July 2003, a singular observation of a sprite was made for which no cloud-to-ground (CG) stroke was detected although the storm fell within the range of both the Météorage and SAFIR systems. There was, however, significant cloud-to-cloud (CC) activity, suggesting that in this case the sprite may have been triggered by an intra-cloud discharge[22]. One cannot, however, preclude the possibility that in this case both lightning detection systems – neither of which is infallible – failed to detect a CG.

Recordings of infrasonic (frequencies less than ~10 Hz) pressure perturbations were carried out using an array of micro-barometers at a station in Flers, France. On 21 July 2003 a number of pressure perturbations were detected in association with sprites at a distance of ~400 km from Flers. The perturbations could not be attributed to lightning as the effects of lightning are only observed up to a distance of ~50 km. These data indicate that sprites have a distinctive ascending tone chirp-like infrasound signature[10]. The duration of the infrasound signals, typically in the order of tens of seconds, reflects the horizontal dimensions of the sprite. The fact that similar signatures were observed after sunrise suggests that infrasonic observations may be used to detect sprites even when optical techniques are impractical.

The large body of ionisation produced in a red sprite perturbs signals propagating in the Earth-ionosphere waveguide. Observations of the amplitude and phase of signals from an array of VLF transmitters may be used to detect these perturbations. Modification of ionospheric conductivity resulting either from the energy released in a +CG flash or from the sprite discharge leads to a class of "early" VLF transients[9,16], where the perturbation follows very shortly after the lightning strike. A narrow-band VLF receiver located on the island of Crete monitored the signals from a set of ground-based VLF transmitters. The locations of these transmitters and the great circle paths to the receiver are indicated in Figure 3(a). The great circle path for transmitter station HWV passed through




(a) northern hemisphere

(b) southern hemisphere

(c) temporal distribution

(d) Cloud cover from METEOSAT

**Fig. 3.** Geographical distribution of –CG (blue) and +CG (red) lightning strikes for the period 00:00 to 04:00 UTC on 29 August 2003 (a) over Europe and (b) mapped to the conjugate hemisphere. In (b) distances in intervals of 200 km centred on SAAO are indicated. The variation in strike rate during this period is plotted in (c), where the lower and upper histograms reflect the frequency of –CG and +CG strikes respectively. The lines at the top of (c) indicate the instants of TLE occurrence. In (d) the cloud cover over Europe just prior to the period considered is imaged.

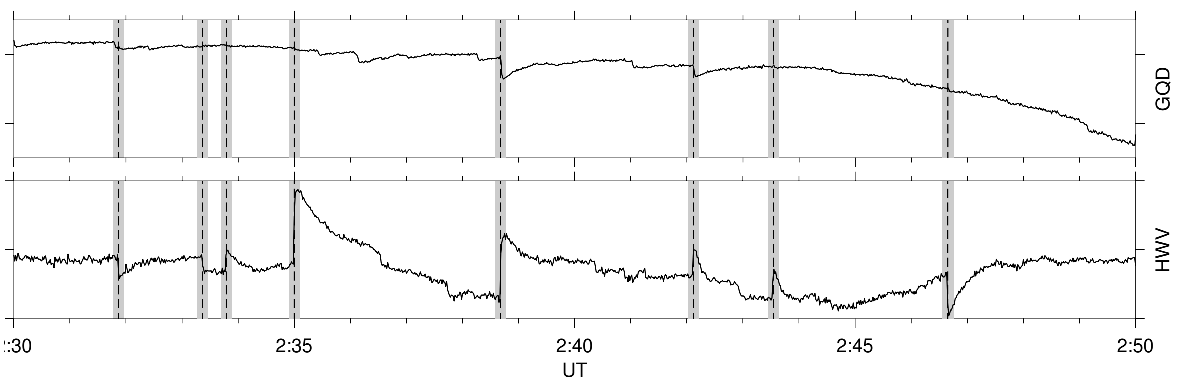



**Fig. 4.** Amplitudes of VLF transmitters HWV and GQD observed from Crete on 21 July 2003.
TLE observation times are indicated by the dashed vertical lines.

a region of high storm activity. A sample of the narrowband VLF data for an active period on 21 July 2003 is given in Figure 4. A one-to-one correspondence between early VLF perturbations on transmitter HWV, located on the far side of a sprite-producing storm and sprite occurrence was observed [15]. No such perturbations were observed for CG strikes, even highly energetic ones, not associated with sprites.

Another mechanism which produces disruption on transmitter signals is known as a Trimpi or Lightning-induced Electron Precipitation (LEP) event, where whistler mode waves propagating through the magnetosphere scatter radiation belt electrons into the loss cone, resulting in their precipitation and subsequent local modification of the Earth-ionosphere waveguide. In this case, there is a finite delay of less than a second between the causative lightning discharge and the signal transient. In some cases, generally after the strongest CG discharges, the early VLF perturbation was followed by a Trimpi on the GQD transmitter, whose great circle path was located poleward of the storm.

Lightning radiates electromagnetic energy over a wide range of frequencies. Those strikes which produce sprites radiate intense electromagnetic pulses with peak power of around 20 GW, which are known to excite Earth-ionosphere cavity resonances [13], or Schumann Resonances (SRs), with a fundamental frequency of 7.8 Hz. These appear in Extremely Low Frequency (ELF) data as "Q-bursts", transients which stand out above background noise from global lightning activity.

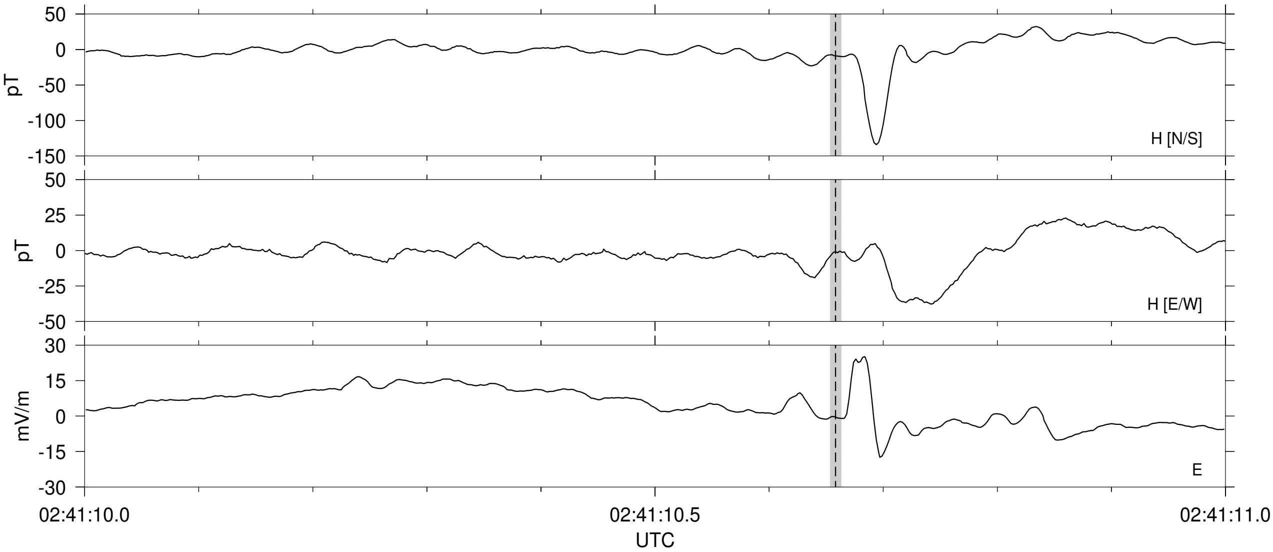
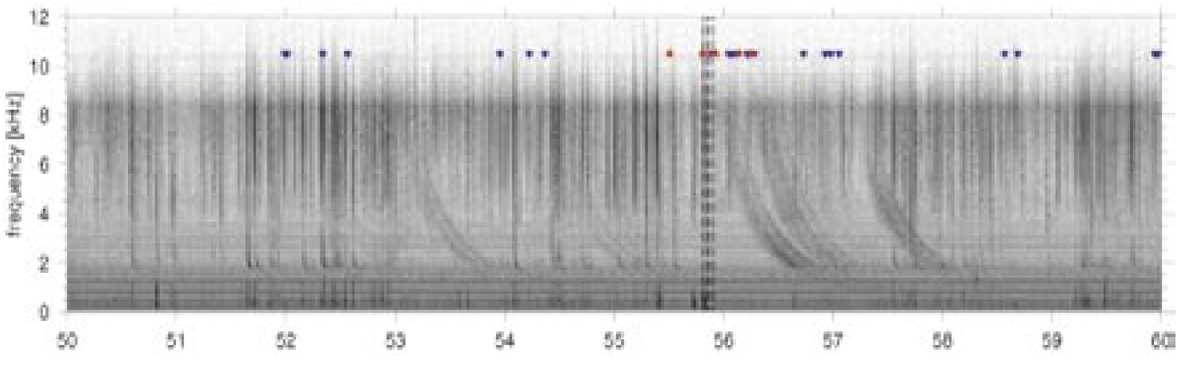
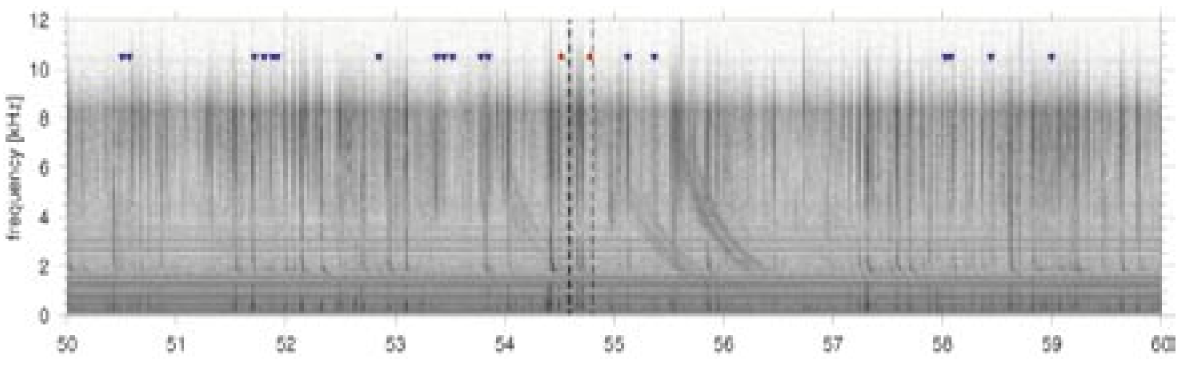



**Fig. 5.** Variations in the two horizontal components of the magnetic field and the vertical electric field measured at Nagycenk, Hungary for a sprite on 29 August 2003. The passband of the ELF receiver is from 5 to 30 Hz. An ELF transient follows shortly after the red sprite at 02:41:10.651 UTC.




(a) 23:16 UTC on 28 August 2003.




(b) 23:21 UTC on 28 August 2003.

**Fig. 6.** Broadband VLF data from Sutherland. Triangles indicate the occurrence of +CG (Δ) and –CG(∇) strikes. The dashed lines indicate the times of TLE occurrence.

ELF measurements, recording horizontal magnetic field and vertical electric field variations, were conducted at Nagycenk, Hungary (47°36'N 16°42'E), allowing the lightning location and polarity, as well as the source current moment to be deduced. Figure 5 illustrates a sprite-induced ELF transient.

**Southern Hemisphere**

In the southern hemisphere no evidence of precipitating relativistic electrons was observed [20]. The maximum charge moment change recorded during the campaign was 2 500 C km. Simulations [19] indicate that a signicantly larger charge moment is required to initiate an electron beam which would produce emissions at the conjugate point with an intensity greater than the background noise. This suggests that the lightning discharges over Europe had insufficient intensity to generate a relativistic electron beam able to excite detectable optical emissions.

The broadband VLF data yielded a number of periods of intense whistler activity. These events are interesting in their own right, however, an issue which is presently being explored is whether a sprite-producing lightning discharge may be identified from the properties of the resulting whistler. The data plotted in Figure 6 reflect two intervals during which sprites occurred and whistlers were observed at Sutherland with propagation delays indicating that they could be attributed to the same lightning strike.

The OMNIPAL monitored the following transmitters: NWC (19.8 kHz), HWV (18.3 kHz), NAA (24.0 kHz) and NLK (24.8 kHz). The great circle paths between these transmitters and SAAO are indicated in Figure 3(b). No perturbations of these transmitter signals in either amplitude or phase could be correlated with any of the sprites detected during the campaign, providing further evidence for the absence of relativistic electrons.

## Conclusion

The southern hemisphere observations were not able to confirm the precipitation of sprite-associated energetic electrons. This is most likely due to the sprite activity being insufficiently intense to generate a relativistic electron beam. However, a number of other notable observations were made. An infrasound sprite signature has been established which will allow sprite detection during daylight hours. The identification of an unambiguous sprite signature on VLF transmitter signals will provide another means of identifying events in the absence of optical observations. A better understanding of the VLF perturbations will also allow estimates of the ionospheric electron density enhancements produced by sprites.

The investigation of TLEs promises to provide a better understanding of charge dynamics above active thunderstorms. In addition, it may have important implications for the chemistry of the upper atmosphere, the energetic population of the radiation belts, and modification of the Earth-ionosphere waveguide. It would thus be appropriate to include a similar campaign in the portfolio of activities planned for the International Heliophysical Year (IHY).

The SAAO at Sutherland is well situated for observations over the southern tip of Africa and has a relatively noise-free environment with excellent meteorological and astronomical conditions. It would be an excellent location for a node in the proposed South African network of OMNIPAL receivers.

## Acknowledgements

We gratefully acknowledge the SAAO for providing facilities for the campaign in Sutherland. The Euro-Sprite2003 campaign was conducted as part of the Research Training Network “Coupling of Atmospheric Layers” sponsored by the EU 5 Framework Programme under contract HPRN-CT-2002-00216. The contributions of G Sátori and J Bór were supported by Grants T034309 and TS 408048 from the Hungarian Science Foundation.

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# The Hermanus Magnetic Observatory, Space Physics and IPY/IHY

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**Abstract.** This paper presents the proposed participation of the Hermanus Magnetic Observatory (HMO) and the South African Space Science community in the coordinated Space Physics research envisaged during the International Heliophysical Year 2007 and International Polar Year 2007–2008. The history of the Hermanus Magnetic Observatory (HMO), its activities, its involvement in Space Science and its potential as a regional space weather warning centre is presented, together with details of the international projects in which it will be involved during IPY/IHY. A unique campaign for ionospheric measurement on board the South African research ship, the SA Agulhas, during its expeditions to Antarctica and the South Atlantic Islands is described. The involvement of South Africa in IPY/IHY Space Weather research is presented as an opportunity for participation by developing countries in Africa.

**Sommaire.** Cet article rend compte de la participation de l'Observatoire Magnétique d'Hermanus (HMO) et de la communauté spatiale sud-africaine dans la recherche en physique spatiale envisagée à l'occasion de l'Année Heliospherique Internationale 2007 (IHY) et de l'Année Polaire Internationale 2007–2008 (IPY). L'auteur présente l'historique de l'Observatoire Magnétique d'Hermanus (HMO), ses activités, sa participation dans la recherche en sciences spatiales, ses atouts comme centre régional d'alerte en météo spatiale, ainsi que les projets internationaux dans lesquels il sera impliqué à l'occasion de IPY/IHY. L'article décrit aussi la campagne de mesure ionosphérique réalisée à bord du bateau sud-africain SA Agulhas durant ses expéditions vers l'Antarctique et les îles de l'atlantique sud. L'implication de l'Afrique du sud dans la recherche en météo spatiale de l'IPY/IHY est présentée comme une occasion de participation pour les pays africains en voie de développement.

## Introduction

### IHY Overview

The International Heliophysical Year (IHY 2007) will coincide with the 50th celebration of International Geophysical Year (IGY) 1957 and run concurrently with the International Polar Year (IPY 2007–2008). The International Geophysical Year (IGY 1957–58) involved about 60 000 scientists from 66 nations who were involved in simultaneous, global observations on Earth, which preceded the beginning of space exploration. The International Heliophysical Year is an international programme to expand the famous IGY 1957 concept to a much larger realm, certainly from a space physics point of view and to extend the coordinated research to the entire solar system, the heliosphere up to the interstellar medium. It is a grassroots organisational effort, with a science focus and international cooperation. IHY–USA team members have already initiated a wide variety of activities in conjunction with other "International Years" *i.e.* activities occurring on the 50th Anniversary of the IGY, with the three main initiatives: the Electronic Geophysical Year (eGY), International Polar Year (IPY) and the International Year of Planet Earth. The IHY activities also overlap with the other international years in each of the IHY's primary activities: Science (ICSU), UNBSS Observatory Development, "IGY Gold" History and Outreach. There is also coordination with the AGU, IUGG and IAU. Endorsements for IHY have been given by COSPAR, IAU and many other international science coordinating organisations. Through ICSU, the IHY has a strong coordination with the aims of the International Polar Year (IPY).

### The Hermanus Magnetic Observatory (HMO)

The HMO traces its roots to the establishment of a magnetic observatory in Cape Town following a request by the International Commission for the Second International Polar Year (1932–33). Isolated observations of the geomagnetic

**Fig. 1.** Hermanus Magnetic Observatory.

field by early explorers, although of interest, were of little scientific value for developing an understanding of the global nature of the magnetic field. In order to develop a scientific understanding of the global nature of the Earth's magnetic field, a requirement is to have simultaneous observations at many places on the Earth's surface. It was for this reason that Prof A Ogg, Professor of Physics at the University of Cape Town (UCT), was requested to establish a magnetic observatory in Cape Town on the campus of the University using funding and instruments supplied by overseas institutions. By 1940, however, the developing suburban electric railway system was adversely affecting the geomagnetic field observations and it was necessary to relocate the observatory to a *magnetically clean* site. A suitable site was found in Hermanus and the new Hermanus Magnetic Observatory (HMO) officially commenced operation on 1 January 1941. Since then, the HMO has continually functioned as an active participant in the worldwide network of magnetic observatories which monitor and model variations of the Earth's magnetic field.

In 2001, the HMO became a research facility of the South African National Research Foundation (NRF). It has since expanded its research to become a leading centre for space physics research in Southern Africa, conducting research in collaboration with a number of international partners in order to improve our understanding of dynamic processes in the Earth's space environment.

With the endorsement of its involvement in IPY/IHY by the Minister of Science and Technology of South Africa, Mr Mosibudi Mangena and financial support through the SANAP programme for its IPY research proposal "Polar Space Weather Studies during IPY 2007–2008", the HMO in February 2006 became an active partner of an international consortium of research institutions that will participate in coordinated measurements of the Earth's space environment during IPY/IHY 2007–2008.

In April 2006, the HMO was approached by the Director of the International Space Environment Centre (ISES), Dr David Boteler, to become an ISES Regional Warning Centre in Africa due to its research in areas such as magnetic pulsations, Geomagnetically Induced Currents (GIC), energetic electrons, Total Electron Content (TEC) and ionospheric modelling, which all overlap with the work done at many of the ISES regional warning centres worldwide.

**ISES Regional Warning Centres**

ISES has its origins in the service started by URSI in 1928 to transmit information about radio propagation conditions. ISES acts as the umbrella organisation for space weather forecasting centres around the world. It operates under the auspices of URSI, IAU and IUGG. The mission of ISES is to encourage and facilitate near real-time monitoring international and prediction of the space environment. It provides standardised rapid free exchange of space weather information and forecasts through its network of Regional Warning Centres (RWC). Most RWCs were set up during the IGY and are located in every continent except South America and Africa. As part of ISES involvement in the IGY+50 anniversary. ISES will pursue the establishment of Regional Warning Centres in the two remaining continents: South America and Africa.

## IHY Objectives

The objectives of the IHY are to:

- provide benchmark measurements of the magnetosphere, the ionosphere, the lower atmosphere, and the Earth's surface to identify global processes and drivers affecting terrestrial environment and climate;
- promote a global study of the Sun-Earth-heliosphere system outward to the heliopause to understand the external drivers of geophysical change;
- foster international scientific cooperation in heliophysical phenomena now and in the future; and to
- communicate the unique scientific results of the IHY to the interested scientific community and to the general public to promote appreciation of the Earth-Sun-heliosphere–interstellar space connection, space weather and space climate.

A major thrust of the International Heliophysical Year (IHY) is to deploy arrays of small, inexpensive instruments such as magnetometers, radio antennas, GPS receivers, all-sky cameras, *etc.* around the world to provide global measurements of ionospheric and heliospheric phenomena.

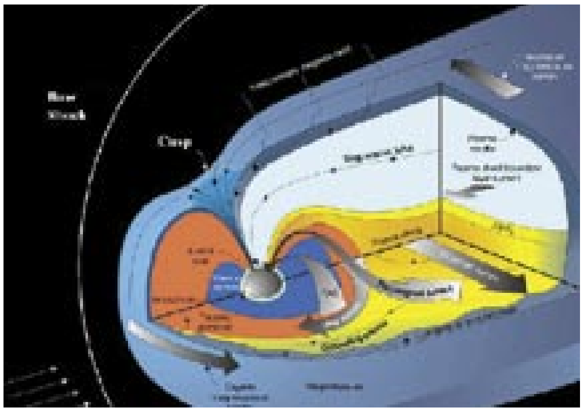

**Fig. 2.** Earth's magnetospheric environment.

The small instrument programme is envisioned as a partnership between instrument providers and instrument host countries. The lead scientist will provide the instruments (or fabrication plans for instruments) in the array; the host country will provide manpower, facilities, and operational support to obtain data with the instrument typically at a local university. Funds are not available through the IHY to build the instruments; these must be obtained through the normal proposal channels. However all instrument operational support for local scientists, facilities, data acquisition, *etc.* will be provided by the host nation. It is our hope that the IHY will be able to facilitate the deployment a number of these networks worldwide.

The general benefits of the IHY 2007 will be to:

- develop a deeper understanding of physical processes in the heliosphere through a programme of comparative study;
- provide insights into energetic events in the solar system, paving the way for safe travel to the Moon and Mars in the future;
- inspire the next generation of space scientists;
- provide a community consensus structure to unite Earth and space science into the new field of "helio-science";
- broaden the use of space science data, and involve new science groups while leveraging data analysis funds; and
- provide national and world-wide public visibility for space and astronomy programmes at all levels.

**UN Basic Space Science Initiative**

The United Nations Basic Space Science Initiative (UNBSSI) for developing nations will be dedicating their workshops and activities through 2009 to the IHY developing nations programme. Drawing on nearly fifteen years of workshops on basic space science for the benefit of scientists and engineers from developing nations, the United Nations Office for Outer Space Affairs, through the UNBSSI, will assist scientists and engineers from all over the world in participating in the preparations for IHY 2007.

The UNBSSI joint programme will target activities which stimulate space and Earth science activities in developing nations, such as the establishment of ground-based instrument arrays and research programmes. The programme consists of a series of annual workshops hosted in varying international locations. The first of these, the four-day workshop organised by UNOOSA (http://www.unoosa.org/) and co-sponsored by the European Space Agency (ESA) and the National Aeronautics and Space Agency (NASA) of the United States was held in Abu Dhabi in the United Arab Emirates, 20–23 November 2005. The workshop was attended by Prof Marius Potgieter of the School of Physics, North West University in South Africa who went as member of the IHY International Steering Committee, African Regional Representative and as a representative of the South African national IHY committee.

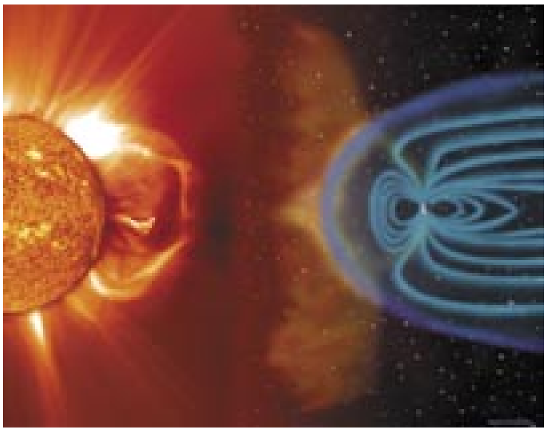

**Fig. 3.** Illustration of a coronal mass ejection (CME) blasting off the Sun's surface in the direction of Earth. The geomagnetic storms on the Earth, resulting from CMEs, can disrupt communications and navigational equipment, damage satellites, and even cause electricity blackouts. *Note*: Objects in the illustration are not drawn to scale. (*Credit SOHO/LASCO/EIT/ESA & NASA*)

**The IHY in South Africa**

A South African National IPY and IHY Committee was established and had two meetings: in August 2005 and in January 2006. Prof Dave Walker of the University of KwaZulu-Natal is the chairperson of this Committee. A special IPY and IHY workshop is being planned by the NRF/ICSU Africa Regional Office and stakeholders from Africa will be invited. A special session on IHY/IPY will be held during the annual South African Institute of Physics (SAIP) Conference at the University of the Western Cape (UWC) in July 2006. Researchers from Africa may apply to the NRF for travel grants. IHY sessions will also be proposed for the SAIP conferences in 2007 and 2008.

The Hermanus Magnetic Observatory arranged a stakeholders' workshop involving space physicists in South Africa at the HMO in April 2006 with a special session devoted to South African IHY/IPY activities. A list of all IHY-related research projects in South Africa is being compiled. Projects will be submitted to the SA National IPY and IHY Committee for recognition as formal IHY 2007 projects.

**Scientific Activities at HMO**

Besides its observatory-related functions of providing geo-magnetic field data and information, the scope of the HMO's activities include fundamental and applied space physics research. This includes the training of students, science outreach, and the provision of geomagnetic field related services on a commercial basis. In order to facilitate achieving its objectives, the HMO is structured into four operational groups, namely geomagnetism, space physics, science outreach and technology.

**Geomagnetism Group**

The Geomagnetism Group is responsible for studying and monitoring variations of the Earth's magnetic field, the derivation of geomagnetic field models and indices, and the distribution of geomagnetic field information. In order to record geomagnetic field variations, magnetometers are operated on a continuous basis at Hermanus, Hartebeesthoek and Tsumeb (Namibia) and the data then processed in accordance with INTERMAGNET standards. The processed data are distributed to a number of international agencies (*e.g.* the World Data Centres (WDC) in Kyoto and Boulder) to facilitate access by researchers and utilised for the computation of geomagnetic indices. In addition, data from 40 secular variation field stations distributed over southern Africa and data from two low Earth orbit (LEO) magnetic field satellites, namely, the Danish Ørsted and the German CHAMP satellites, whose data are made available to approved research scientists, are used for the derivation of geomagnetic field models.

**Space Physics Group**

The Space Physics Group carries out research in order to add to the present understanding of plasma behaviour in the Earth's ionosphere and magnetosphere and its impact on Earth. Research methods include theoretical, modelling, and data analysis studies, the results of which are presented at conferences and published in ISI-indexed journals. Researchers in the group collaborate with researchers at universities and research institutes, both locally and internationally. The current research fields and collaborations include the following:

- **Theoretical studies of waves in dusty plasmas:** The study of plasmas with massive negatively charged dust grains has become the focus of research in the past decade due to the widespread occurrence of such plasmas in space and astrophysical environments. The theoretical prediction of the existence of the low-phase velocity (in comparison with ion and electron thermal speeds) dust acoustic wave (DAW) has been the starting point of many theoretical studies. The existence of the DAW has been experimentally confirmed in a number of laboratory experiments. This research is being carried out in collaboration with researchers at the University of KwaZulu-Natal and the Indian Institute of Geomagnetism (IIG) in Mumbai, India.

**Fig. 4.** Aurora at the South African Antarctic research station SANAE IV as observed during the extreme magnetic storm of 15 May 2005. (*Photo courtesy of Brian Bowie, NWU*)

- **Studies of ULF waves using ground-based and satellite data:** The objective of this research is to gain a better understanding of the magneto-hydrodynamic (MHD) wave modes responsible for the propagation of ultra low frequency (ULF) geomagnetic pulsations within the Earth's magnetosphere. In particular, uncertainty exists about the manner in which Pi2 geomagnetic pulsations propagate from the source region in the near-Earth plasma sheet to the low latitude ground. Consequently, a specific objective is to shed light on this problem by making comparative studies of Pi2 pulsations observed above and below the ionosphere. Low latitude Pi2 geomagnetic pulsations play an important role in this research since they are considered to be one of the most reliable and accurate indicators of substorm onsets. Data from the CHAMP fluxgate magnetometer is used to observe pulsation signatures in the region above the ionosphere, while data from the Hermanus Magnetic Observatory and other ground stations provides information on the signatures below the ionosphere. Studies of magnetospheric substorms and their related space weather effects are currently regarded as an essential aspect of magnetospheric physics research. This research is being carried out in collaboration with researchers at the GeoForschungsZentrum, Potsdam, Germany.

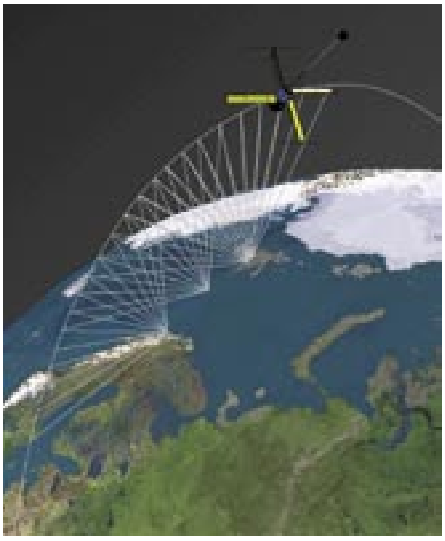

**Fig. 5.** Ionospheric tomography using observations along multiple ray paths from GPS satellites to dual frequency GPS receivers. (*Copyright © 2001 The Institute of Mathematical and Physical Sciences, University of Wales, Aberystwyth, UK*)

- **Pc5 field line resonant pulsation observations using the SuperDARN HF-radars:** The Super Dual Auroral Radar Network (SuperDARN) is an international collaborative network of HF radars that monitors ionospheric plasma convection over the majority of the northern and southern polar regions. SuperDARN currently comprises nine radars in the northern hemisphere and five radars in the southern hemisphere. South Africa's involvement in SuperDARN is through the Southern Hemisphere Auroral Radar Experiment (SHARE). SHARE is a collaboration involving the University of KwaZulu-Natal (UKZN) in Durban, the North-West University (NWU) in Potchefstroom, the British Antarctic Survey (BAS) in Cambridge, UK, the Johns Hopkins University Applied Physics Laboratory (APL) in Baltimore, USA and also recently the HMO. The main objective of SuperDARN is to measure ionospheric plasma convection with relatively high spatial and temporal resolution on a global scale. The overlapping fields of view of the radar pairs provide independent plasma drift measurements in two directions. Each of the radars in a SuperDARN pair has a 16-beam field of view, so the radar pair has, in principle, 256 beam intersection cells. Each beam measures the projection of the full velocity vector onto the beam, and from the two overlapping velocity measurements the full vector can be reconstructed or "merged". One of the remarkable results of the velocity data was the radar's ability to measure and characterise Pc5 field-line resonant pulsations. Although the structure and characterisation of these events is well-known, the cause and propagation mechanism is still the topic of much debate. A co-ordinated investigation involving HF-radar, magnetometer and satellite data is being carried out in order to better understand these dynamics.
- **Ionospheric characterisation using dual frequency GPS observations:** The phase delay in global positioning system (GPS) satellite radio signals can be used to determine certain parameters of the ionosphere. Recent research at the HMO has focused on the use of GPS signals received by the ground-based network of South African dual frequency GPS receivers to provide a denser and more timely characterisation of the total electron content of the ionosphere than is currently available using only ionosonde data. This work is being expanded to determine profiles of ionospheric electron density using the technique of ionospheric tomography through the integration of GPS data, ionosonde data, and occultation data from low earth orbit (LEO) satellites using GPS signals. Besides the purely scientific interests, the ionospheric soundings using GPS signals are of practical application for the provision of HF predictions for radio communications and radio direction finding. The results of this research will also be important for characterising the ionosphere in the planning for and operation of the SKA project. This research is being carried out in collaboration with researchers at the Department of Electronic and Electrical Engineering, University of Bath, UK and at the Institute of Radio engineering and Electronics (IRE) of the Russian Academy of Science (RAS).
- **Modelling of the lower and bottomside ionospheres using the technique of neural networks:** Researchers at Rhodes University pioneered this technique for ionospheric modelling. From this research, a South African ionospheric model, called SABIM (South African Bottomside Ionospheric Model), has been developed and is currently being implemented in the Direction Finding Systems in industry. A neural network based model, called IMAZ, is presently being developed and tested for predicting the lower ionosphere in the Auroral zone. The research for the IMAZ model is being undertaken in collaboration with the Graz University of Technology in Austria.

A key objective of the space physics group is to increase the number of postgraduate students and researchers (particularly from groups who were previously disadvantaged by either race or gender) trained in basic plasma physics, geomagnetism, ionospheric physics and magnetospheric physics. The training programme for post-graduate students typically comprises the following:

- A two-week practical for MSc students in the National

Astrophysics and Space Science Programme (NASSP) (http://www.star.ac.za), who take the Space Physics modules;
- A summer school on Space Physics for NASSP Honours students;
- A winter school entitled "Introduction to Space Physics" for final year BSc students majoring in physics;
- A summer school entitled "Scientific Computer Programming and Digital Signal Processing" for final year BSc students planning to continue with post-graduate studies in space physics;
- Students taking a BSc (Honours) in plasma or space physics come to the HMO to do their Honours projects.
- Technikon students taking a diploma in electronic engineering come to the HMO for their experiential training.
- Students doing an MSc in space physics do part of their thesis work at the HMO; and
- PhD students in plasma/space physics are appointed as research assistants for the duration of their PhD thesis research.

**Science Outreach Group**

The Science Outreach Group strives to create a better understanding and appreciation of science and technology amongst school educators and learners and to promote a public understanding of geomagnetism and space physics. The main objective of the science outreach activities is to improve the enjoyment and understanding of the physical sciences at school level and thus ensure that more school leavers will be willing and able to study physics at university. The science outreach programme:

- is primarily directed at rural and township schools;
- runs educator workshops with the objective of improving their understanding of physics concepts, which they are required to teach in the school syllabus, through lectures and hands on practical classes;
- Runs workshops for learners, primarily in grades 10 to 12, where demonstrations are presented to clarify physics and chemistry concepts and where learners have the opportunity to "play" with equipment in the Interactive Science Centre and to complete work-sheets based on these activities.

**Technology Group**

The Technology Group utilises the unique magnetic field calibration facilities and infrastructure, located in a magnetically clean environment, to provide quality controlled magnetic field and sensor related services to clients in the defence and aerospace industries on a commercial basis. The main activities over the past year have been:

- calibration and maintenance of landing compasses;
- presentation of technical training courses on aircraft compass swing procedures;
- magnetic surveys of aircraft compass swing areas;
- construction and evaluation of space-qualified magnetometers for Sunspace;
- support with the integration and evaluation of a magnetometers on missile systems;
- measurement and construction of magnetic targets, used during flight tests for anti-tank missiles;
- acquisition and calibration of magnetometers for clients;
- support to Iziko-Museums with the magnetic survey of an area near Struisbaai in search of the Meermin, a ship that sank in 1765 while transporting slaves between Madagascar and the Cape.

**HMO African Collaborations**

In terms of North-South collaborations in Africa the HMO is involved in the following:

1. Geomagnetic surveys in Zimbabwe, Namibia, and Botswana which involve close cooperation with their Geological Surveying Departments;
2. Characterisation of the ionosphere over proposed SKA sites including nodes in a number of African countries, particularly those in SADC which involves cooperation with departments of Science and Technology and Communications and Surveyor-Generals from 12 Southern African countries via the South African SKA Bid Committee;
3. Determination of the total electron content (TEC) over proposed sites for the SKA remote antennas in Africa, using GPS dual frequency receivers of the AFREF African surveying network, among others from GPS receivers operated by CNES and UNAVCO in Libreville and Franceville, Gabon, ESOC in Malindi, Kenya, the Zambia Survey Department in Lusaka, Zambia and the Observatoire Volcanologique in Le Tampon, Reunion; and
4. Occasional contact with colleagues in the Ivory Coast on Ionospheric Science.
5. Collaborative ionospheric research projects are being established in Nigeria.

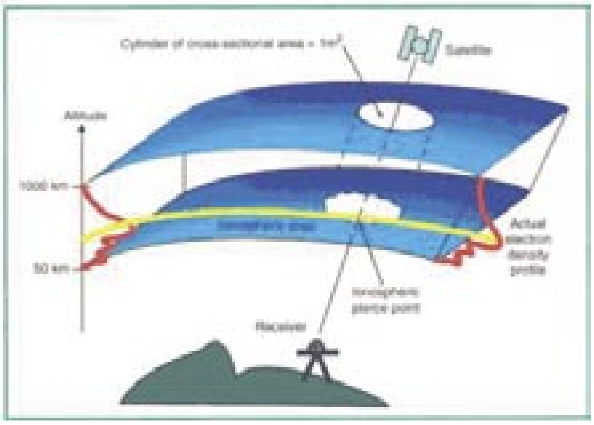


**Fig. 6.** Total electron content (TEC) along a ray pay through the ionosphere

## HMO Involvement in Space Weather Studies during IPY/IHY

**The Solar-terrestrial Environment**

The solar-terrestrial environment offers a natural laboratory of great complexity for the study of Space Plasma Physics. The high latitude ionosphere is a key region of the near-Earth space plasma into which the signatures of solar-wind/magnetosphere/ionosphere coupling processes are mapped by the geomagnetic field. Study of the high latitude plasma is critical to understanding the energetics and dynamics of many fundamental processes in solar-terrestrial physics.

Heliospheric Physics deals with a very complicated system involving energetic particles and high and low energy plasmas, strongly coupled to changing magnetic fields. To understand

**Figs. 7 (L) and (R).** HF Radar Antenna Array at SANAE IV which forms part of the SuperDARN network of Auroral region radars.

it, it is necessary to make observations on a global scale of a variety of phenomena, using different techniques, both in space and on the ground. There is a particular lack of data from the Southern mid- and high-latitudes to support global models of heliospheric phenomena. At an international workshop on energetic particle precipitation held at the HMO in March 2005, the need for the integration of terrestrial and satellite observations in research on the South Atlantic Anomaly (SAA) was identified.

**Variability of the Space Environment**

The variability of the space environment occurs on several time scales. The physics of geospace is strongly influenced by solar activity which varies substantially on the 11-year sunspot cycle. The investigation of the physical processes causing this variability is an important goal. In addition there are longer period changes in solar activity; sunspot activity differs from cycle to cycle with consequential effect on geospace. IPY/IHY 2007–2008 will take place near the minimum of the solar cycle and provide a valuable baseline of data against which to compare date from previous and future peaks in the sunspot cycle. On a time scale of minutes there are variations in the geomagnetic field induced by currents in the ionosphere which give rise to geomagnetically induced currents on power grids, which have led to major power outages in the past. On the time scale of tens of seconds there are variations in the ionosphere due to travelling wave disturbances which give rise to scintillations which affect GPS location accuracy, radio-astronomy and trans-ionospheric radio communications.

**Aims and Affordability of Space Weather Research**

The aim of Space Weather Studies during IPY/IHY is among others to extend and renew polar geospace research with future experiments in fields such as absolute measurements of the geomagnetic field, computerised ionospheric tomography (CIT), additional ionospheric measurements with a digital ionosonde, an ionospheric scintillation receiver and extension of these measurements to Marion Island and other sites in the Southern Oceans and in Southern Africa as appropriate.

This aim represents modern thinking about affordable ways to conduct space weather research. At the December 2004 meeting of the American Geophysical Union, for instance, a session with the title "Low-Cost, Ground-Based Instrument Arrays for Worldwide Studies in Space Science" was held with the motivation:

"Interest in low-cost, easily-deployed, ground-based instrument arrays is growing rapidly as we approach the International Heliophysical Year in 2007 and as we implement plans for the next decade of research in solar and space physics and aeronomy. These distributed arrays could make a decisive contribution to our understanding of the dynamic and multi-scale processes that couple the heliosphere, magnetosphere, ionosphere, and atmosphere. Papers are solicited on new ideas for correlating and studying data from already existing ground-based arrays, on the development of innovative new instruments and on ideas for how measurements achieved with these arrays can improve our understanding of the Sun-Earth system."

The involvement of the HMO in space weather studies during IPY/IHY aims to exploit the unique opportunity provided by IPY/IHY to integrate observations from many instruments in the polar regions of both hemispheres to investigate the solar-terrestrial coupling processes.

**ICSU IPY Proposal**

In December 2003, Dr Pierre Cilliers of the HMO and Dr Cathryn Mitchell of the University of Bath submitted an original individual proposal for IPY/IHY "Multi-instrument Mid- and high latitude Ionospheric-Magnetospheric Observations" to ICSU IPY (idea 95).

The proposal comprised participation in IPY/IHY through a cooperative endeavour to set up ground-based equipment (ionosondes, GPS dual frequency receivers, receivers for polar orbiting satellites and other satellite beacons, VLF receivers) in Southern Africa, the Arctic, the Antarctic, and the Southern Atlantic Islands, for coordinated polar observations and analysis that would not otherwise occur. The observations from these instruments would be combined and inverted using radio tomography to derive dynamic images of the near-earth space plasma over large latitudinal regions.

The participants in this project are the South African National Antarctic Programme (SANAP), the Institute for Satellite and Software Applications (ISSA), the Hermanus Magnetic Observatory (HMO), the Hartebeesthoek Radio Astronomy Observatory (HartRAO), the Space Physics Group at North-West University (NWU), Radio Communications group at the University of Pretoria (UP), the School of Pure and Applied Physics at the University of KwaZulu-Natal in Durban (UKZN) and the Telecommunications, Space and Radio Research Group, Dept of Electronic and Electrical Engineering, University of Bath, UK (Bath).

**Fig 8.** Marion Island base station where several instruments for Space Weather monitoring are to be installed during IPY/IHY.

**Italian Collaboration in Atmosphere Monitoring**

In January 2005, the expression of Intent for the proposal 'Upper Atmosphere Monitoring for Polar Year 2007/8' (UAMPY) was submitted to IPY following first consolidation of proposals by the IPY committee, and the incorporation of idea 95 in IPY–UAMPY (EoI idea 367) with that of similar proposals under the leadership of the Italian Group at INGV with Lucilla Alfonsi as the PI.

The objectives of the UAMPY proposal, in which the South African Space Physics consortium will be a key participant, are to create the necessary international cooperation to develop a polar upper atmosphere observation network on both the hemispheres. It will allow unprecedented observation of the polar ionosphere, with extended auroral and polar coverage, making possible the mapping of features from mid-through polar latitudes and the studies of associated polar ionospheric processes. The project includes a unique ability to monitor polar scintillation globally.

The institutions with whom the HMO and the other collaborators of the South African Space Physics community will cooperate on UAMPY are INGV (Istituto Nazionale di Geofisica e Vulcanologia – Rome, ITALY), IFAC/ISC-CNR (Istituto di Fisica Applicata "Nello Carrara"/Istituto dei Sistemi Complessi, Florence, ITALY), University of Bath (UK), SRC-PAS (Space Research Centre, Polish Academy of Sciences Warsaw, POLAND), University of Calgary (Canada).

**ICESTAR/IHY**

Following a second consolidation of proposals by the IPY committee in June 2005, UAMPY was incorporated with similar proposals of 24 international consortia under the leadership of Kirsti Kauristie of the Finnish Meteorological Institute under the proposal 'Interhemispheric Conjugacy in Geospace Phenomena and their Heliospheric Drivers" (ICESTAR/IHY). The focus of ICESTAR/IHY is to install new instruments in the polar regions to significantly improve the spatial coverage and resolution and to provide pairs of geomagnetically conjugate observations from both the hemispheres. The resulting observations and value-added data products will be used together with state-of-the-art models and simulations to improve our quantitative understanding of the near-Earth space environment. The scientific goals of ICESTAR/IHY are to study: (i) Coupling processes between the different atmospheric layers and their connection with the solar activity; (ii) Energy and mass exchange between the ionosphere and the magnetosphere; and (iii) Inter-hemispheric similarities and asymmetries in geospace phenomena. The 14 participating countries include Australia, Brazil, Canada, Denmark, Finland, Italy, Japan, Malaysia, Russia, South Africa, Sweden, UK, Ukraine, and the USA.

**UK IHY Coordinated Investigation Programme**

A proposal for a Coordinated Investigation Programme (CIP) was submitted to the UK IHY Committee in August 2005. The objective of the CIP are coordinated measurements of the magnetosphere and ionosphere in both hemispheres as recorded by a number of instruments including fluxgate and induction magnetometers, aurora cameras, beam forming riometers, HF radar, VLF receivers, ionosondes, dual frequency GPS receivers and scintillation receivers. Most of the measurements are to be done at the South African Antarctic base at SANAE IV but measurements on the South Atlantic Islands Gough and Marion are also envisaged, as well as measurements on board South Africa's polar research vessel, the SA Agulhas, during its trips to these Islands and to Antarctica. These observations are to be matched with measurements at geomagnetic conjugate sites in the Northern Hemisphere. The observations will be used to test existing theories for ionospheric variation and understand them better and to extend and renew them with future experiments in fields such as absolute measurements of the geomagnetic field, computerised ionospheric tomography (CIT), additional ionospheric measurements with digital ionosondes, sounding experiments of the upper regions of the neutral atmosphere. The work will support the prediction of space weather for the European Space Agency and the proposed South African Space Agency and improve the prediction of scintillations which affect Radio Astronomy, GPS positioning and both transionospheric and HF radio. In November 2005 the ICSU/WMO Joint Committee for the International Polar Year 2007–2008 endorsed this proposal for consideration as an IPY activity.


**Fig 9.** GPS Antenna on board the SA Agulhas for making ionospheric measurements in the South Atlantic Ocean during IPY/IHY.

**SANAP Funding for IPY/IHY Space Weather Studies**

The South African participation in IHY received a boost in February 2006 when the proposal "Polar Space Weather studies during IPY/IHY" comprising the South African part of the international ICESTAR/IHY proposal was endorsed

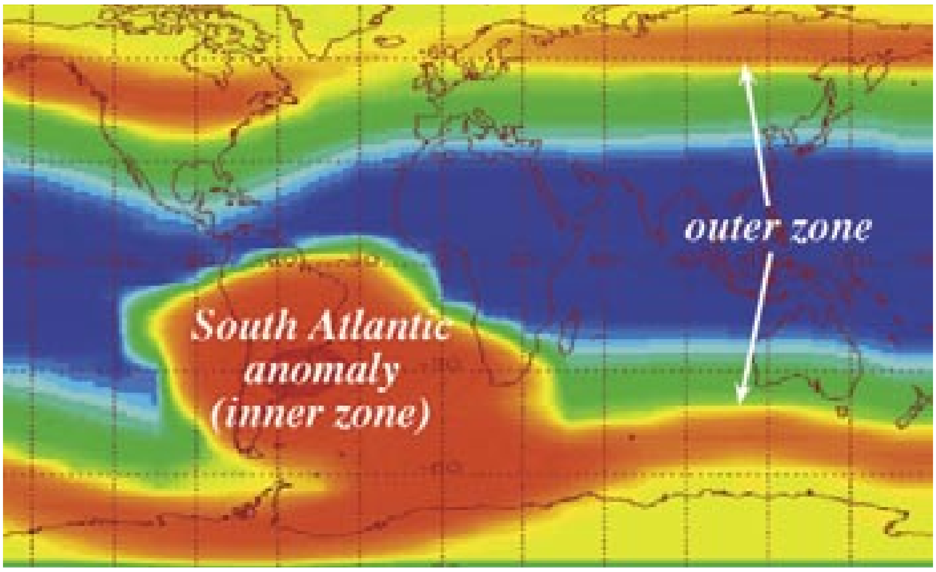


**Fig. 10.** Count rate of protons and electrons greater than 0.5 MeV in low Earth orbit measured by the NASA/SAMPEX satellite, showing the increased count over the South Atlantic Anomaly where the radiation belts come closest to the Earth, due to the weakness of the magnetic field in this region (*from http://www.aero.org/ Copyright (c) 1995–2004, The Aerospace Corporation. All rights reserved*)

by the South African Minister of Science and Technology, Mr Mosibudi Mangena, and approved for funding through the South African National Antarctic Programme (SANAP). Part of the funding provides for one Antarctic over wintering expedition member to take responsibility for setting up and running the new instruments at the South African SANAE IV base in Antarctica.

The SANAP IPY/IHY proposal comprises three projects namely:
**Project 1:** Multi-instrument observation and modelling of the high latitude ionosphere and magnetosphere using GPS Receiver at SANAE IV, Ionospheric Scintillation Receivers at SANAE IV and Marion Island, VLF Receivers at SANAE IV and Marion Island, GPS/LEO Occultation from CHAMP satellite, and dual frequency GPS receiver on board SA Agulhas research ship;
**Project 2:** Magnetic Field Observations in the polar regions using existing pulsation magnetometers at SANAE IV, a new suspended dIdD absolute magnetometer, and a new dI-flux magnetometer-theodelite. These measurements will be coupled with simultaneous measurements at the near-conjugate INTERMAGNET Narsarsuag (61.2°N, 45.43°W) magnetic observatory in Greenland; and
**Project 3:** Promotion of public interest in Space Science through presentation of IPY/IHY research activities and outcomes at Schools, Science Fairs, at NASSP Colloquia, Summer and Winter Schools offered at the HMO, local conferences and in the public media. The participation in IPY/IHY will serve as a focus for the Science Outreach programmes of the Interactive Science Centre of Hermanus Magnetic Observatory and will be made known via the South African Agency for Science and Technology Advancement (SAASTA).

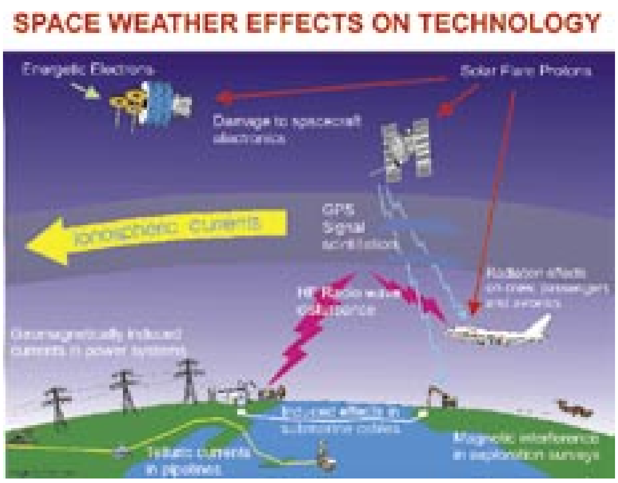


**Fig. 11.** Space Weather Effects on Technology (*Credit Space Weather Canada*)

## SA Agulhas Ionospheric Measurement Campaign

Because of the large inclination of the geomagnetic field at high latitudes, the high latitude southern oceans and Antarctic regions are particularly important for ground based observations of ionospheric and magnetospheric phenomena. A unique feature of the geomagnetic field in the region close to southern Africa is the weakness of the field in the south Atlantic region relative to the rest of the Earth at equivalent altitudes; this feature is known as the South Atlantic Anomaly (SAA). As a consequence, the shielding effect of the magnetic field is severely reduced, thus allowing high energy particles originating in solar flares which produce so-called killer electrons in the hard radiation belt to penetrate deeper into the upper atmosphere than anywhere else on Earth. Killer electrons with energies greater than 1 MeV are the main environmental hazard to Earth-orbiting satellites. The hazards of this region appear to lack recognition outside the space science community, although most spacecraft crossing this region at altitudes below 1 000 km have experienced damage or degradation to some extent, and measurements by sensitive instruments on board the Space Shuttle are usually suspended during passage through the SAA because the radiation causes unacceptably high noise levels in the sensors.

The SA Agulhas research vessel frequently traverses areas of the SAA on research visits between Cape Town, Gough, Marion and Tristan da Cunha islands and SANAE IV, making it an ideal platform for ionospheric measurements along these routes. Ionospheric data logged along these routes will supplement SHARE radar measurements from Antarctica and be invaluable for space physics research.

In December 2005, the HMO initiated an Ionospheric Measurement Campaign (IMC 2005) on board the South African Polar Research Ship, the SA Agulhas. Using data from an Ashtech Z-FX dual frequency GPS receiver on board the SA Agulhas during its trips from Cape Town to Antarctica and back in December 2005 to March 2006 and to Marion Island and back in April/May 2006, ionospheric total electron content (TEC) and ionospheric tomography will be done over a region close to the South Atlantic Anomaly. The IMC 2005 campaign is a trial run for a similar experiment which forms part of the IPY/IHY proposal for IPY/IHY 2007. The SA Agulhas will be equipped with a dual frequency GPS receiver for ionospheric monitoring during IPY 2007/2008 during its service trips to the SANAP research bases in the Southern Ocean, Marion Island, Gough Island, Tristan da Cunha and Antarctica.

The GPS receiver installed on Marion Island in March 2004, which provides important data for Geodesy and ionospheric coverage over a key part of the South Atlantic Ocean, was successfully repaired by two IPY/IHY team members from HartRAO during the Marion Island Relief Voyage in April 2006. The data from the Marion Island receiver, logged at 30s intervals is transmitted daily to the IGS archiving centre at HartRAO.

### Opportunities for Developing Nations

Through its endorsed and funded participation in Polar Space Weather studies during IPY/IHY, the South African Space Science Community has the opportunity to lay a foundation for years of productive research and international cooperation on an unprecedented scale. It will be a fitting celebration of the 75th year since the establishment of the HMO. The South African participation in IPY/IHY offers opportunities for research in solar and space physics for students from Africa through the National Astrophysics and Space Science Programme (NASSP) and other institutions in Southern Africa which offer Space Science programmes. Participation of other African countries in the projects is encouraged. African countries can use IPY/IHY as a potential focus for attracting young scientists. A number of students in the NASSP programme at the University of Cape Town are already involved in space weather-related research at the HMO.

The infrastructure of measuring equipment, communications equipment and web-based data-bases that is proposed to facilitate South African participation in IPY/IHY, the data that will be collected during 2007/2008, and the international data base to which the data will be submitted, will provide a basis for many years of subsequent research and training of many young scientists in Space Science.

### Acknowledgements

The author thanks all his colleagues at the HMO and Prof Marius Potgieter of NWU and many others of the South African Space Science Community for their contributions which have been incorporated into this paper. The Chief Directorate, Surveys and Mapping is gratefully acknowledged for making available the GPS receiver used on board the SA Agulhas in the IMC 2005 campaign.

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# Establishing a Cosmic Ray Station and Other Space Research Facilities in Ethiopia


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**Abstract.** This paper describes the potential of Ethiopia in establishing space research facilities and conducting collaborative research and training. It also describes the goals and objectives of a proposed cosmic ray station in Ethiopia which would greatly improve the abilities of the existing worldwide network for heliospheric and cosmic ray research. The station will be located at the geomagentic equator, which is a very unique place for geomagnetic and heliospheric studies. Moreover, the paper presents an overview of the research and training activities in space physics and the successful collaborative project between Ethiopia and Finland, which facilitated the installation of a pulsation magnetometer and a photometer at Entoto Mountain in a suburb of the Ethiopian capital, Addis Ababa.

**Sommaire.** Cet article décrit le potentiel de l'Ethiopie à établir des centres d'études spatiales et à conduire en partenariat un travail de recherche et de formation. Il décrit également les objectifs du projet d'installation en Ethiopie d'une station de mesure du rayonnement cosmique qui apporterait une amélioration sensible aux capacités existantes du réseau mondial de recherche sur les rayonnements heliospheriques et cosmiques. La station sera située à l'équateur géomagnétique qui est un endroit unique pour les études géomagnétiques et heliospheriques. De plus, cet article présente une vue d'ensemble des activités de recherche et de formation en physique spatiale et de la collaboration réussie entre l'Ethiopie et la Finlande. Cette collaboration a facilité l'installation d'un compteur magnétique de pulsation et d'un photomètre au sommet de la montagne Entoto dans la banlieue de la capitale éthiopienne Addis Ababa.


## Introduction

Ethiopia (formerly Abyssinia) has been a first-class research field for geologists and more especially, seismologists from early in the last century. This is largely due to the presence of the Great Rift Valley, a great tear across the surface of the Earth, extending nearly 6 000 km from Syria, through the Red Sea, Ethiopia, and down to Mozambique. Ethiopia's geographical extent (from about 35°E–45°E and 3°N–15°N) and magnetic location (the magnetic equator crosses Ethiopia) make it perfect for investigations related to many topics of space physics.

The Equatorial Electro Jet (EEJ) is an electric current flowing across the country from north to south at an altitude of about 105 km. It comes, therefore, as no surprise that pioneering work in the exploration of the EEJ was carried out at observation sites including Ethiopia and other African countries located in the equatorial region[3]. At the beginning of the seventies of last century, experiments in space physics were conducted in Ethiopia, thanks to the initiative and interest in coherent radar observations of a French team[2] and the Geophysical Observatory of Addis Ababa University (AAU). The Geophysical Observatory on the campus of AAU is still operational and its present contribution to the scientific community is, among other activities, maintaining an INTERMAGNET station of the world-wide, real time, satellite-linked, magnetometer network (http://www.intermagnet.org/).

Although the facilities installed by French scientists have provided valuable data, the expansion and continuous operation of these facilities did not materialise in Ethiopia. This may be because the involvement of Ethiopian scientists in research and development of these facilities was very limited. Moreover, there was no formal space physics training at Ethiopian universities in that time.

Formal education in space physics commenced in Ethiopia recently with the commencement of a space physics graduate programme jointly by Addis Ababa University and Bahir Dar University. In order to expand and strengthen this programme, a collaborative project in atmospheric research is being initiated with many national and international stakeholders, including commercial enterprises such as Eigenor, heading towards development and operation of weather radars (http://www.eigenor.com/BERCAB/index.php/Main Page). This paper presents an overview of the research and training activities in space physics in Ethiopia and also describes a successful collaborative project between Oulu University (Finland) and Bahir Dar and Addis Ababa Universities (Ethiopia). Moreover, a brief description of future collaborations is presented with the intention of attracting the attention of potential collaborators and funding agencies.

## The Ethio-Finno Observatory (EFO)

Researchers from Bahir Dar and Addis Ababa Universities, in collaboration with their counterparts from the University of Oulu in Finland, successfully established an ionospheric monitoring station called EFO (Ethio-Finno Observatory) at Entoto Mountain using a scanning photometer and pulsation magnetometer from Finland. The project was funded by the Academy of Finland. After safe transport, the instruments were tested thoroughly at Addis Ababa University. After a search for an optimal site for the observatory, the Entoto Mountain on the outskirts of Addis Ababa was chosen. Finally, the instruments were successfully installed there.

Figures 1 and 2 show the scanning photometer and the pulsation magnetometer, respectively, on Entoto Mountain.

**Fig. 1.** The Photometer operating at EFO (Ethio-Finno Observatory) at the top of Entoto Mountain in Ethiopia.

These instruments make measurements on a regular basis and the data are recorded automatically with the acquisition system shown in Figure 3. An example of an analysis of data from the pulsation magnetometer is shown in Figure 4.

**Fig. 3.** One of the authors (B.D.) with the data acquisition system of EFO.

### Education and Research in Space Physics

The Departments of Physics at Bahir Dar University and Addis Ababa University have started a graduate programme in space physics. The curriculum is designed so that students take core general physics graduate courses at Addis Ababa University in their first years and in the final year, they take two space physics graduate courses at Bahir Dar University. Also, they write their theses in space physics during their stay at Bahir Dar University. A similar arrangement may be adopted in many African countries with a shortage of resources and manpower. In future, we plan to strengthen our programme by collaborating with other countries.

Studies on ionospheric physics are carried out with special emphasis on system development for ionospheric radars[1]. Investigations are being carried out to develop a method of suppressing the sidelobes in filtering chirp waveforms

**Fig. 2.** The pulsation magnetometer operating at EFO (Ethio-Finno Observatory) at the top of Entoto Mountain in Ethiopia.

by means of matched filters. Magnetic pulsations are also studied. The group is also initiating research in the system development of weather radar. A precursor for this initiative is the invention of a method that can solve the Doppler range dilemma[6] which states that there is an inverse relationship between the unambiguous range and the unambiguous velocity.

### Establishing A Cosmic Ray Research Facility in Ethiopia

The fact that the Ethiopian site is located at the geomagnetic equator provides a good opportunity to study solar and heliospheric physics by means of the ground-based cosmic ray measurements. Cosmic rays (CR) are an important object to be studied. On the one hand, they form an outer space factor affecting the Earth's environment; on the other, they carry unique information on the physical conditions in the regions of their origin and transport. It is proposed to extend the existing collaboration and to establish a cosmic ray station in Ethiopia. The corresponding research proposal was submitted to the Academy of Finland. The scientific objective for research of this kind is two-fold: (a) heliospheric modulation of cosmic rays; and (b) solar neutrons.

**Heliospheric Modulation of Cosmic Rays (CR)**

Both the intensity and energy spectrum of CR are subject to the modulation in course of the solar activity cycle. Accordingly,

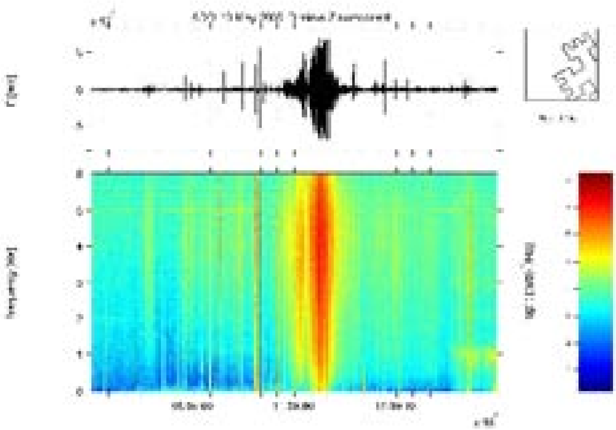

**Fig. 4.** An example of the spectral analysis of pulsation magnetometer data.

continuous data on the cosmic ray differential spectrum allows studies of physical conditions in the heliosphere, including the solar global magnetic field, the solar wind and the heliospheric structure. Unfortunately, direct measurements of the CR energy spectrum are difficult since they must be done outside the Earth's atmosphere using satellites. However, obtaining long-term, continuous data is a problem because of finite satellite life times. The situation can be resolved by using data from the world-wide network of ground-based neutron monitors which presently consists of about 50 stations around the globe. A neutron monitor measures superthermal neutrons produced as a result of nuclear interactions of the cosmic ray particles with the air. Since cosmic rays are charged particles, they are affected by the geomagnetic field; therefore, the low energy CR are deflected by the field and cannot reach the ground. Since the deflecting effect strongly depends on the geomagnetic (*i.e.* with respect to the geomagnetic dipole axis) latitude $\lambda_g$, the world-wide network of neutron monitors acts as a rough spectrometer to evaluate the spectrum of cosmic rays in the vicinity of the Earth. It is important, in this respect, to use a large number of neutron monitors covering a wide range of geomagnetic latitudes. The present network covers the range of geomagnetic latitudes from 90° (polar stations) to about 15°. At present, there is no cosmic ray station at the geomagnetic equator (there was one in Ahmedabad, India, but it was unfortunately closed in 1976). Therefore, the Ethiopian site, located at the geomagnetic equator, will allow for a better determination of the long-term galactic cosmic ray energy spectrum.

**Solar Neutrons**

Eruptive energy releases, which occur during solar flares, may accelerate ambient protons to high energy (up to several GeV) in the solar atmosphere. A fraction of these particles can escape into the interplanetary space and can be observed as solar cosmic rays. The other fraction can be trapped in a flare magnetic loop structure and suffer nuclear interaction in the dense loop's foot points. As a result of such interactions, energetic neutrons can be produced[5]. Since neutrons are not affected by magnetic fields, their path is a straight line, and they carry direct information on the physical conditions at the flare site, and are therefore of great interest in solar physics[4]. Ground-based neutron monitors are able to detect strong energetic solar neutron events[7]. Since the neutron signal should be separated on the background of ever present galactic cosmic rays, several measures can be undertaken to increase the signal-to-noise ratio. One can increase the neutron signal, attenuated in the atmosphere, by placing a neutron monitor at higher altitude but this equally increases the galactic cosmic ray background. In order to decrease the background level, one has to place a cosmic ray station at low geomagnetic latitude. The best location to study solar neutrons, therefore, is a high-altitude site at the geomagnetic equator, which allows for the lowest background and the highest neutron signal.

Figure 5 shows the sensitivity of the world neutron monitor network to a solar neutron event similar to that of 3 June 1982[7]. One can see that the existing network is able to detect a strong solar neutron event reliably about 55% of the time (lower panel of Figure 5). While the summer months are well covered by numerous stations in the northern hemisphere, winter months are less covered. The upper panel shows the sensitivity of the network including the proposed cosmic ray station in Addis Ababa – its coverage is shown by the dashed oval. It covers the late morning (09 – 12 UT) hours over the whole year, so that the overall coverage reaches 63.5%, which implies an 8.5% absolute or a 15% relative increase.

The proposed cosmic ray station will be a result of a wide international collaboration, planned and designed in Finland (University of Oulu and Sodankylä Geophysical Observatory). It will be built in South Africa (North-West University), installed in Ethiopia (Addis Ababa University) and operated by Ethiopian personnel (Addis Ababa and Bahir Dar Universities). It will complete a meridional chain of cosmic ray stations located at the same longitude and covering the whole range of latitudes, which includes stations from Finland, Germany, Italy, Israel, Russia, Slovakia, South Africa and Switzerland.

### Establishing a Weather Radar System

A significant development has been made recently in the system development of a weather radar. Markku Lehtinen from Oulu University in Finland has developed a method of solving the long-standing problem in the weather radar, the "Doppler range dilemma." His method, which has a US patent[6], enables one to determine the spectrum of the signal scattered from a target. However, this method needs to be thoroughly tested and investigated. The climatological conditions in Ethiopia are suitable for routinely testing and refining the method. Hence, we would like to initiate a collaborative project to establish a weather radar system in Bahir Dar, Ethiopia.

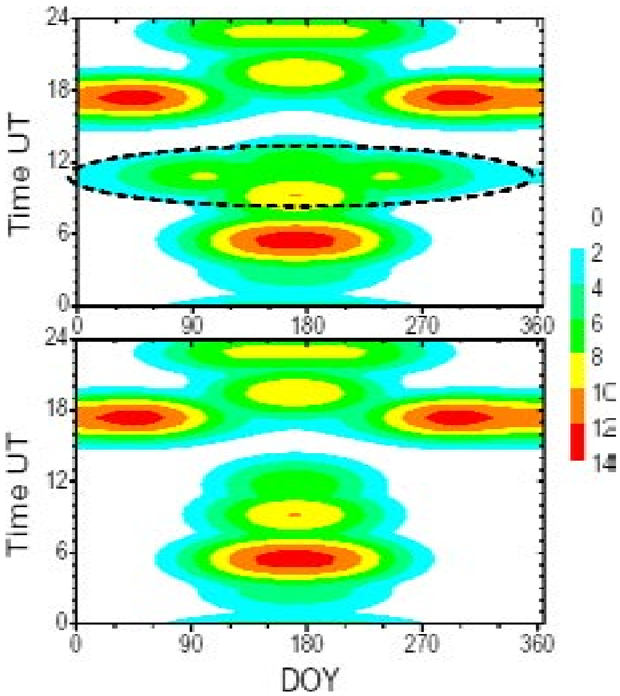


**Fig. 5.** Sensitivity of the world neutron monitor network to a solar neutron event similar to that of 3 June 1972. The lower panel corresponds to the existing network, and the upper includes the proposed station in Ethiopia whose contribution is denoted by the dashed oval. Values are given in standard deviations from the background of galactic cosmic rays[7] (refer colour scale). The X- and Y-axes correspond to the day of year and to the time in UT, respectively.

## Conducting a Sandwiched Graduate Programme in Space Physics

In order to improve both the quality and the quantity of the graduate study programme in space physics, it is vital for Ethiopian scientists to work in collaboration with researchers from other countries. Conducting collaborative research projects and running sandwiched graduate programmes can be carried out. This kind of arrangement will provide a platform for graduate students and scientists to exchange ideas and skills with researchers and students from other countries.

## Conclusion

The location of Ethiopia, together with the presence of many worthy students interested in space physics, needs to be exploited by the international space physics community. Ethiopian decision-makers and other stakeholders are very supportive of scientific endeavours. Institutions, research groups, individuals and funding agencies are most welcome to collaborate with the authors in a friendly working atmosphere to realise the project concepts presented and discussed briefly in this paper.

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# Cosmic Rays in the Heliosphere

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**Abstract.** The international heliospheric year (IHY) has the purpose to promote research on the Sun-Heliosphere system outward to the local interstellar medium - the new frontier. This includes fostering international scientific cooperation in the study of heliophysical phenomena now and in the future. Part of this process is to communicate research done on the heliosphere, especially to the scientific community in Africa. A short review is given of the numerical modeling of the heliosphere, and of the modulation of cosmic rays and how these particles are used to probe the heliosphere to understand its basic features. Projects of both a theoretical and numerical nature are proposed for the IHY.

**Sommaire.** L'année heliospherique internationale (IHY) a pour but la promotion de la recherche sur le système Soleil - Heliosphere extérieur du milieu interstellaire local - La Nouvelle frontière. Ceci inclut la stimulation régulière de la coopération scientifique internationale pour l'étude des phénomènes heliophysiques. La valorisation de la circulation de l'information sur la recherche heliospherique, particulièrement vers la communauté scientifique en Afrique constitue l'un des volets de cet effort. Cet article passe en revue les techniques de modélisation numérique de l'heliosphere ainsi que la modulation des rayons cosmiques et explique comment ces particules sont employées pour sonder le heliosphere dans le but de comprendre sa structure. Des projets de recherche théoriques et numériques pour l'IHY sont aussi présentées.

## Introduction

One aim of the International Heliophysical Year (IHY) is to establish and foster interdisciplinary ties between space physics, astrophysics and astronomy. "Heliophysical" embraces atmospheric and solar-terrestrial physics (the main purpose of the International Polar Year – IPY), studies of other planets, magnetospheres, ionospheres, and also the outer reaches of the heliosphere and its interaction with the interstellar medium, even the influence of cosmic rays on climate. The IHY therefore reaches out to the frontiers of heliophysical research in the same way that the International Geophysical Year reached to the frontiers of geophysical research in the late 1950's. As pointed out by Crooker[4], a primary goal for the coming years is a study of what the three-dimensional features of the heliosphere will look like during the coming solar minimum activity period compared to the previous minima of opposite solar magnetic polarity. Observations from the existing earthbound observatories and the network of space missions, which together form an unprecedented heliophysical observatory, can play an important role in understanding the full 22-year solar cycle. Understanding the heliosphere as probed by cosmic rays will also bring understanding of the role of galactic cosmic rays in long-term climate variations.

The Heliospheric Physics Group in the Unit for Space Physics on the Potchefstroom Campus of the North-West University in South Africa has been doing heliospheric research over the last three 11-year solar cycles. The research, both theoretical and experimental, is of a fundamental nature, focused on understanding and explaining the mechanisms for the transport and modulation in the global heliosphere of galactic cosmic rays, the anomalous and solar particle component, and Jovian electrons. The purpose is to understand their propagation and transport through a study of the solar wind plasma and the heliospheric magnetic field with its turbulence, the consequent three-dimensional diffusion tensor with its nine elements, and the geometry and features of the global heliospheric structure and its interface with the very local interstellar medium. These aspects are combined in comprehensive numerical models that simulate cosmic ray modulation from where they cross the heliospheric boundary up to the Earth. The theory and models are continuously refined to establish compatibility to major observations from a network of cosmic ray (neutron) monitors on Earth and from several space missions, some of which are discussed below.

## The Heliosphere

The space between the Sun and nearby stars is filled with interstellar plasmas, magnetic fields and energetic neutral and charged particles. The Sun prevents the interstellar medium from flowing into the large volume surrounding it, which is called the heliosphere. From a particle astronomy point of view, the heliosphere is considered to be a small but typical astrosphere. The extent of an astrosphere depends on the ram pressure of the stellar wind compared to the total pressure of the interstellar medium. In this context, the heliosphere extends over some 500 AU along the equatorial regions and 250 AU along the polar regions. Because it is moving through the interstellar medium, the heliosphere is asymmetrical with respect to the Sun, with the tail region

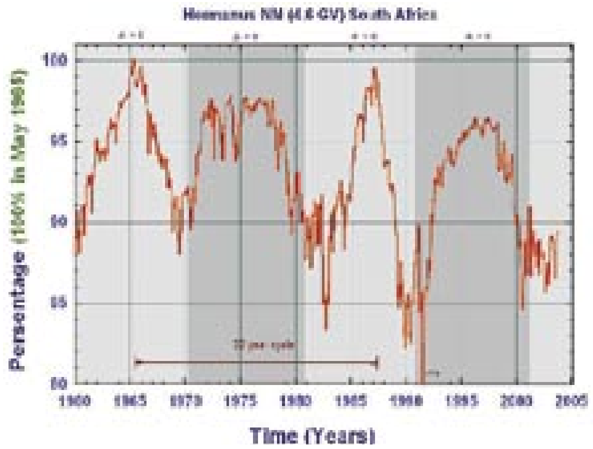


**Fig. 1.** The 11- and 22-year cycles for cosmic rays observed by the Hermanus Neutron Monitor in South Africa, with a cutoff rigidity of 4.5 GV. The intensity was normalised at 100% in May 1965. Note the different profiles for the two solar magnetic field polarity cycles, A > 0 and A < 0, during solar minimum activity around 1965, 1976–77, 1987, 1997–98.

much longer than the nose region. A prediction of magnetohydromagnetic modelling is that the solar wind creates a termination shock where it goes from supersonic (400 – 800 km $s^{-1}$) to subsonic at ~ 90 AU, and that this shock is almost spherical, only somewhat elongated in the polar directions[23]. The latest data from the Voyager 1 spacecraft[15] indicate that it the termination shock in December 2004 at a distance of ~94 AU from the Sun. This observation is of major importance and is quite an accomplishment. A heliopause that separates the solar and interstellar plasmas is also predicted and is considered the outer modulation boundary, with the heliosheath the region between the heliopause and the termination shock. A bow shock may also form further out although it is expected to be rather weak[29].

The solar wind and the associated magnetic field prevent the low-energy interstellar medium and magnetic field to penetrate into the heliosphere but interstellar energetic neutrals, dust, and high-energy cosmic rays enter the heliosphere. Their properties are changed by the interaction with the heliospheric magnetic field by solar radiation and gravity. The well-known 11-year and 22-year solar cycles are driven by changes in the Sun's magnetic field. At solar minima, the field is basically a dipole but changes to higher orders during solar maximum when strong fields develop in many active regions. At extreme solar maximum, the field reverses direction (and sign) to cause the 22-year polarity cycles, and, together with gradient and curvature drifts, generate the 22-year cosmic ray solar modulation cycle. At solar minimum, the rotating polar fields are the major source of the spiraling heliospheric magnetic field and the heliosphere is divided in two hemispheres in which the field has opposite signs, separated by a wavy current sheet. With increasing solar activity, the waviness increases until it becomes unrecognisable at solar maximum. It forms, owing to current sheet drifts, an excellent proxy for solar activity from a cosmic ray modulation point of view[26].

## Cosmic Rays and Heliospheric Modulation

Cosmic rays are charged particles with energies ranging from a few hundred keV to as high as $10^{21}$ eV. Those present in the heliosphere are classified in four main populations: (1) Galactic cosmic rays which originated far outside our solar system, probably accelerated during supernova explosions. When arriving at Earth, these particles are composed of ~ 98% nuclei, fully stripped of all their electrons in the distant galaxy, and ~ 2% electrons and positrons. They travel at nearly the speed of light. (2) Solar energetic particles which originate mainly from solar flares, coronal mass ejections and shocks in the interplanetary medium. They may have energies up to hundreds of MeV but are sporadically observed on Earth, usually only for several hours when occurring during solar maximum activity. (3) The anomalous components which are originally interstellar neutral atoms that get singly ionised relatively close to the Sun. They are then transported as so-called pick-up ions to the solar wind termination shock where they are accelerated up to 1 GeV through a process of first-

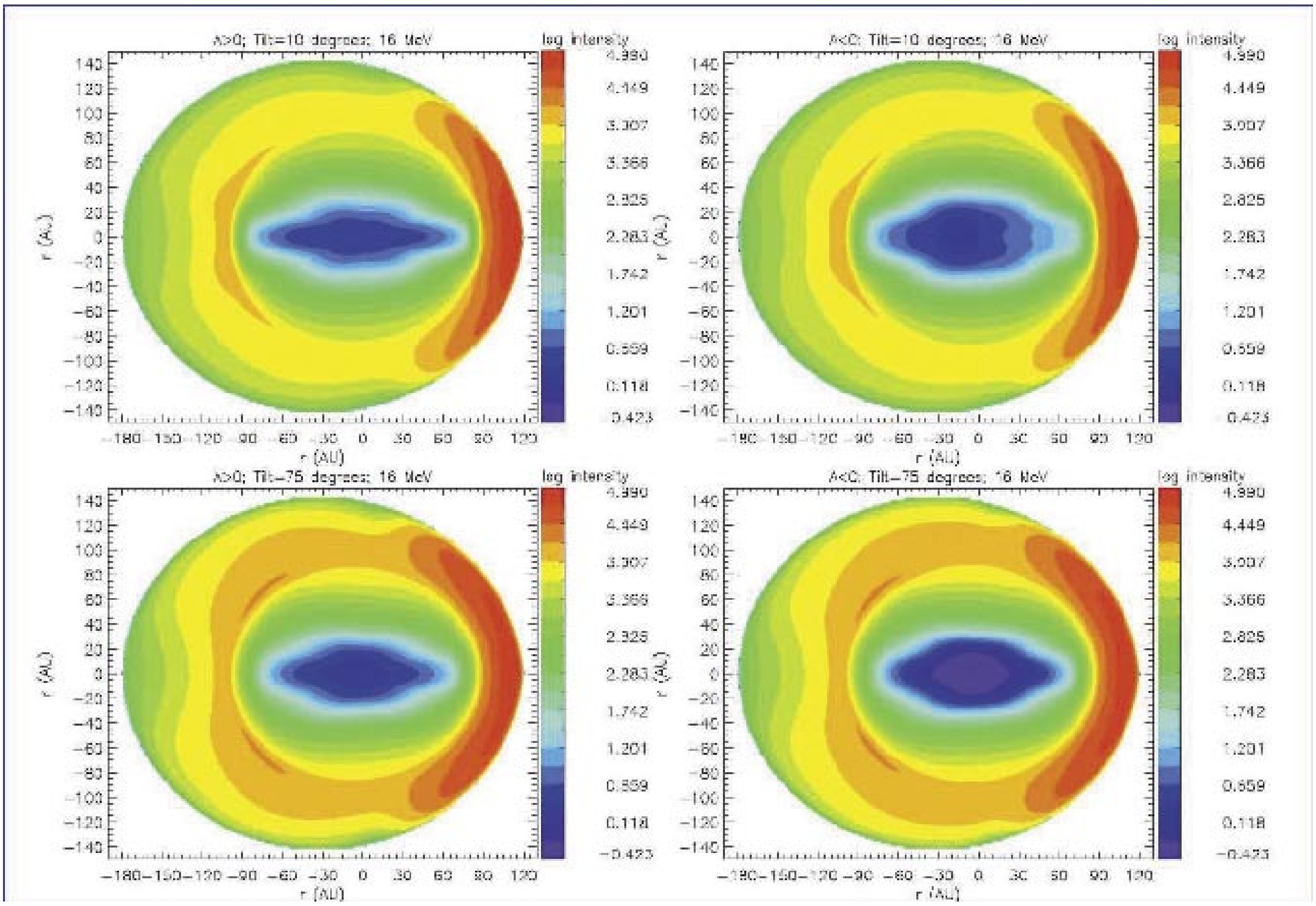


**Fig. 2.** Computed contour maps of the intensity distribution (red is highest intensity) in the meridional plane of the heliosphere for anomalous protons at 16 MeV, for solar minimum (upper panels) and solar maximum (lower panels) and for the two solar magnetic field polarity cycles, left panels for A > 0 polarity (e.g., from 1970–1981; 1990–2001), right panels for A < 0 polarity (e.g., 1981–1990; 2001–2012). The simulated heliosphere is moving from the left to the right, so that the nose of the heliosphere is on the right side of evey panel. In the nose direction the termination shock is at ~90 AU and the heliopause at ~120 AU.

order Fermi acceleration, gaining energy by multiple crossings of the termination shock (refer Fichtner[8]). (4) The Jovian electrons which dominate the low energy electron intensities within the first 10 AU from the Sun when released into the interplanetary medium from Jupiter's massive magnetosphere[13].

Galactic cosmic rays encounter an outward-moving solar wind with ever-present magnetic field fluctuations and turbulence, which constitutes the two basic processes, convection and diffusion. They also lose energy as they diffuse and drift inward, the latter because of the current sheet and global curvature and gradients in the heliospheric magnetic field. As a result, the intensity of cosmic rays decreases to the inner heliosphere to reach a minimum level during solar maximum. Understanding this solar modulation of cosmic rays is a major research goal and very essential for understanding the comic ray intensities in the local interstellar medium and beyond *e.g.* in the spiral arms of galaxies. The importance of the structure of the heliosphere, in particular of its outer boundaries, was first pointed out only a decade ago. This has been re-emphasised with the notion that long-term variations of the order of 100 – 200 years, or longer, exist in the flux of galactic cosmic rays, which could be attributed to the dynamics of the heliosphere, especially in and beyond the region of the termination shock. The effect of the dynamics of the outer heliosphere on the cosmic ray modulation and subsequently on climate has been studied quantitatively only very recently[24], an aspect that will become increasingly important.

## Space Missions

One of the essential parts in the successful study of the heliospheric modulation of cosmic rays is the accumulation of data from *in situ* space observations of amongst others IMP at Earth, Pioneer 10 and 11, Voyager 1 and 2 and the Ulysses space mission, and also large balloon experiments.

The Ulysses spacecraft was the first spacecraft to undertake measurements far from the ecliptic plane and over the polar regions of the Sun, thus obtaining first-hand knowledge concerning the high latitudes of the inner heliosphere[28]. It was launched on 6 October 1990, moved close to the ecliptic plane to Jupiter (at ~5 AU), from where it moved to higher southern latitudes. In mid 1994, the highest southern heliolatitude ($\theta \approx 170°$) was reached. From there it moved quickly through the ecliptic plane to the northern polar region which was reached in 1995. It returned to the ecliptic plane in 1998 to start a second out of the ecliptic orbit. In February 2004, the spacecraft again went close to Jupiter. On board Ulysses are nine scientific instruments of which the Cosmic and Solar Particle Investigation (COSPIN) and the Kiel Electron Telescope (KET) provide a wide range of observations of nuclei and electron fluxes. The Ulysses mission is highly successful and has contributed significantly to the current knowledge regarding the inner and polar regions of heliosphere[16]. Refer to the website http://helio.estec.esa.nl/ulysses.

Since its launch in October 1990, Ulysses has continuously sampled the heliosphere between Earth and Jupiter in three dimensions. With the varying heliomagnetic distance to Jupiter and changing solar activity, the Jovian electron population varied considerably during this time. In 1992 and 2004 respectively, Ulysses had encounters with Jupiter that allowed studying the propagation of Jovian electrons originating from an off-centre point source in the heliosphere. These observations are crucial for evaluating and testing particle propagation models. The closest approach to Jupiter was 0.003 AU in 1992 and 0.803 AU in 2004 (6 RJ and 1682 RJ respectively). In addition, Jovian electron "jets" were observed during both encounters in the 3–10 MeV range as events with sharp increases and decreases, a strong anisotropy and durations of up to a few hours. While the global observations have been discussed in detail, the Jovian "jet" measurements made by the COSPIN/KET as far out as 2.2 AU from the planet after the distant encounter in 2004 are presently being studied[14,18].

The Pioneer 10 spacecraft, launched in March 1972, was the first spacecraft to travel through the asteroid belt and to obtain close-up observations and images of Jupiter. It stayed close to the equatorial regions with a maximum latitude of 3.1°. It eventually reached a radial distance of ~70AU when its science mission ended in March 1997. Pioneer 11 was launched in April 1973 and obtained a speed of 173 000 km $hr^{-1}$. It reached Jupiter in December 1974, then looped high above the ecliptic plane towards Saturn. In September 1995, routine daily mission operations were stopped. It is important to note that the two Pioneer spacecraft went in opposite directions, one towards the heliospheric nose and the other in the tail direction. The two spacecraft made valuable scientific investigations in the middle to outer regions of our solar system (http://spaceprojects.arc.nasa.gov/).

Another two important space probes for cosmic ray studies are the Voyager 1 and 2 spacecraft. They were launched separately in 1977 on a journey of exploration of the planets Jupiter, Saturn, Uranus and Neptune. The fortunate alignment of these giant planets was such that the two spacecraft were headed in the nose direction of the heliosphere. For nearly 30 years, the cosmic ray experiments onboard these spacecraft have been used to study the spatial and temporal variations of galactic cosmic rays and anomalous cosmic rays at distances now extending beyond 90 AU and to heliolatitudes from 35° N to 48° S for Voyager 1 and 2 respectively (http://voyager.jpl.nasa.gov/). Voyager 1 is escaping the solar system at a speed of about 3.6 AU per year, while Voyager 2 escapes at about 3.3 AU per year. Both are so far away from the Earth that the largest of the Deep Space Network antennas, the 70-metre dish, is needed to send command information. Both are expected to keep functioning well into this century and spectacular discoveries should unfold as they cross the termination shock and move into the heliosheath.

## Basic Information for Comprehensive Modelling

Modelling of the modulation of cosmic rays in the heliosphere requires basic but mostly unknown information. Firstly, the local interstellar spectra for the different species are needed as initial conditions at the assumed outer heliospheric boundary. Little is known about most of these galactic spectra at energies below a few GeV because of solar modulation, but significant progress has been made in modelling these spectra using galactic propagation models[19].

Secondly, the structure and geometry of the heliosphere must be specified, for example, at what distance from the Sun is the termination shock and where is the outer boundary located? In modelling, the heliosphere is considered as a sphere in the majority of cases; an assumption which is reasonable for the termination shock, but too simple for the heliopause. No clear cosmic ray azimuthal dependence was observed by Pioneer 10 and 11 which had trajectories in opposite directions to the Sun, although an azimuthal dependence is predicted for the outer heliosphere by models with only a slight asymmetry with respect to the Sun.

Thirdly, knowledge about the global solar wind and heliospheric magnetic field profiles is required for realistic modeling. Before the Ulysses mission, little was known of the latitudinal dependence of these entities with the exception of the limited latitudinal range that the Pioneers covered and which the Voyager missions still explore. Now, we can specify the solar wind profile with better detail, while for the magnetic field it was realised that it may not be approximated in the heliospheric polar regions by a simple dipole. This aspect has contributed to interesting developments in cosmic rays modulation. Currently, a significant modification to the Parker-field is applied in the polar regions, while the "ultimate" substitution was proposed by Fisk[10]. Unfortunately, the Fisk-field is too complex to handle straightforwardly in standard modulation models[3]. The wavy current sheet has turned become one of the most successful modulation proxies, once it was realised that gradient and curvature drifts should play an important role. The "tilt angle" of the current sheet has become a prime indicator of solar activity from a drift-modulation point of view and is widely used in cosmic ray data interpretation (http://quake.stanford.edu/~wso/). The modulation effects of the current sheet and drifts, the subsequent 22-year cycle and charge-sign dependence are being studied in detail. Periods of maximum cosmic ray modulation are more complex; they may last only three years (1969–1971), or up to six years (1979–1984), or may be dominated by a massive cosmic ray decrease (1991). Underlying patterns are obscured by an apparent randomness which makes modelling of long-term modulation very difficult. Nevertheless, there exist several concepts (not yet well-developed theories) on how long-term modulation occurs over 11 years, the most recent attempt being by Ferreira & Potgieter[6].

In the fourth place, a great concern in modulation modelling is the spatial, energy (rigidity) and time-dependence of all the diffusion coefficients. As yet, no *ab initio* modulation theory exists; one in which the diffusion coefficients are determined on the basis of turbulence and diffusion. For example, the slope of the turbulence spectrum determines the energy dependence of the scattering mean free path parallel to the background magnetic field, obviously of vital importance to cosmic-ray propagation studies. By working from the basics to phenomenological approaches, however, progress is being made. The time dependence of the transport of energetic particles results from the time dependence of the turbulence, as well as heliospheric magnetic fields both carried by the time-varying solar wind.

The contribution of Jupiter as a source of few tens-of-MeV electrons has been studied. It has become possible to disentangle the galactic and Jovian electron populations in the total electron (negatron) measurements with the aid of models[7]. For reviews on cosmic rays in the heliosphere and an illustration of the features of the heliosphere mentioned above, see Potgieter[20], Potgieter & Ferreira[21], Heber & Potgieter[12] and Potgieter *et al*[22].

## MHD Modelling

A major challenge to the modelling of cosmic ray modulation is the development of self-consistent "hybrid" models that describe the dynamical structure of the heliosphere embedded in the local interstellar medium and simultaneously allow for a kinetic treatment of cosmic ray transport and modulation. Models of the dynamical heliosphere, with cosmic rays based on the kinetic transport equation, have only recently been presented for example by Florinski *et al*[11] and Scherer & Ferreira[23]. A common finding of all these analyses is that the energetic particle transport is affected by the structure and dynamics of the heliosphere as a result of the influence of the latter on the various transport parameters. It has also been demonstrated that especially anomalous cosmic rays and energetic neutral atoms are well-suited to obtain information about structure and dynamics of the heliosphere and its boundaries. Fully three-dimensional hydrodynamical models of the interaction of the solar wind and the interstellar medium are being developed[9]. Much can be learnt about astrospheres in general from these dedicated modelling studies.

## Cosmic Rays and Climate

Besides the internal driver of heliospheric dynamics, *i.e.* solar activity, the structure of the heliosphere is also determined by external means due to a changing interstellar environment. While the corresponding variations are characterised by periods far longer than that of solar activity, those related to cosmic ray flux variations and to the conditions of the Earth's environment have received increased attention during recent years as discussed by Scherer *et al*[24]. The intensity of galactic cosmic rays is significantly reduced as they traverse our heliosphere from interstellar space to the orbit of Earth. As McCracken *et al.*[17] noted, the systematic study of the temporal variation of this modulation began in the 1930s and found that there are well-defined 11- and 22-year cycle periodicities that are closely related to the heliomagnetic cycles. Using the well-established measurements[1] of $^{10}$Be and $^{14}$C, it is now possible to extend these observations back to much earlier time periods such as the Spoerer (1420–1530), Maunder (1645–1715) and Dalton (1810–30) minima when solar activity was much lower than during the last 70 years[5]. In the case of $^{10}$Be, the atoms become attached to aerosols which are removed mainly by precipitation on a timescale of about a year. In the polar region, this precipitation is incorporated into snow layers that are eventually compressed into ice so that the $^{10}$Be records from ice cores allow us to study thousands of years of cosmic ray history that can be related to climatic studies of increasing complexity[24,25,27].

## Projects

Projects in this field have the purpose of promoting research on the Sun-Heliosphere system, and outward to the local interstellar medium and local galaxy, considered to be the new frontier for heliospheric physics. This provides various opportunities:

- Experimental and observational analysis of excellent data sets in collaboration with the principal investigators of the Ulysses and other space instruments;
- Extension of the global neutron monitor network, in the context of 'Spaceship Earth'[2];
- Theoretical and numerical modelling in collaboration with the principal modellers in South Africa, the USA and Europe. The group in Potchefstroom has access to an IBM SP computer and PC-clusters. This includes modeling of the detailed geometry and structure of the heliospheric magnetic field and solar wind and the effects on cosmic rays;
- Modelling of the HD and MHD aspects of the heliosphere and its interface with the very local interstellar medium and eventually the local galactic environment;
- Bridge the field between the astrophysics of the galaxy and the astrosphere physics of the heliosphere;
- Basic research on space and astrophysical plasmas, turbulence and diffusion;
- Establish and foster stronger astrophysical ties to astronomy experiments in South Africa (SALT, HESS and SKA);
- Research on the Jovian magnetosphere and the propagation of these electrons in the inner heliosphere;
- Studying the apparent connection between cosmic rays entering the Earth's magnetosphere, clouds and climate;
- Studying the very long term variations (periods >>22 years) of cosmic rays and how this may have influence climate and life on Earth.

## Acknowledgements

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# Algerian Contribution to the IHY 2007 Network

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**Abstract.** The Algiers Observatory has a strong tradition of performing solar observations. This paper describes the facilities of the Algiers Observatory for solar studies with a view to participate in the IHY.

**Sommaire.** L'observatoire d'Algers s'est longtemps durant consacré à l'observation du Soleil. Cet article décrit les équipements pour l'étude du Soleil à l'observatoire d'Algers, avec en perspective la participation à l'IHY.

### Introduction

The main research axis for the Algiers Observatory has for many years been oriented towards the study of the sun and solar physics. Beginning in 1990, many young researchers have joined the Observatory to put in place some ambitious teams intent on studying the different aspects of astrophysics and astronomy. Despite the absence of any astrophysics education in Algerian universities, many students have been supervised by the Algiers Observatory in order to get their masters degrees and start their PhD theses.

Algiers Observatory, a department in the Centre de Recherche en Astronomie, Astrophysique et Geophysique (CRAAG), has a team of about 20 researchers and engineers working mainly in the fields of solar physics, solar astrometry, atmospheric turbulence, helioseismology, gamma ray astrometry and studies of variable stars. Concerning ground-based instruments at the Algiers Observatory, four instruments dedicated to solar studies are being developed and are expected to become fully operational during 2006.

### The 15-cm Refractor

This is a telescope intended to survey solar activity and is associated with a CCD-cooled camera, with H-alpha and calcium filters. This instrument will provide the main data in our study of the solar cycle.

The forecasting of solar maxima or minima is very important. The study of past solar activity can be a valuable asset for forecasting. The distribution of maxima and minima will be deduced from the raw data using a new technique. Information concerning features of the solar cycle (periodicity, minima and maxima, rate of variations) are extracted using decomposition in terms of Tchebychev polynomials. This new method has the advantage of computing statistical quantities by using a variable window over data.

Sunspot data will also be used to study the total solar irradiance. The total irradiance of the sun is modulated by the solar activity and especially by the sunspots on the surface of the sun. This irradiance will be computed using the available data of sunspot area vs time and latitude. The computed irradiance will be compared with the measured one using the ACRIM data (also available) and in the near future, the Picard satellite. An optimisation of the fit will be used to constrain free parameters like the limb-darkening function, distribution of the blocked energy, *etc.*

**Fig. 1.** The Algiers Observatory.

### AWESOME Ionospheric Monitor

During the IHY Workshop held at Al-aïn in the United Arab Emirates in November 2005, contacts were made with Prof Umran Inan from Stanford University in the United States of America to obtain and install an ionosonde instrument (AWESOME) in northern Algeria and thereby to participate in a global network survey and the study of the propagation properties of the ionosphere. A computer code has been developed in order to simulate the propagation of an electromagnetic pulse through inhomogeneous plasma. Also, 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 and is subject to strong geomagnetic storms which make the study of the ionosphere variation with solar activities very important.

The group is also involved in a theoretical study of the propagation of acoustic waves in an atmosphere imbedded in magnetic fields. This study has been the subject of many publications in the past. The current research concerns the absorption of the solar *p*-modes by sunspots.

### Doraysol Instrument

Many studies have been done to find a correlation between solar diameter variations and solar activity. From 1975, the Danjon Astrolabe has been used to observe the apparent solar diameter from Calern Observatory in France. Visual measurements, followed by CCD images gave nearly the same results for more than 25 years. The Doraysol Telescope, a second-generation instrument, keeping the strong points of the Danjon Astrolabe, has been designed to increase CCD measurements, prevent turbulence through optics, and is fully automated. Doraysol is an alt-azimuthally mounted instrument working as a Danjon Astrolabe where all refractors have been replaced by reflectors. The principle of operation consists of measuring the difference between the crossing times of two successive solar edges by the same almucantar (*i.e.* the line of altitude parallel to the horizon).

The instrument consists of:

- *The filter*: a silicium entrance window which reduces the the solar brightness close to that of the moon;
- *The mercury mirror*: making the horizontal reference, and forming the reflected image of the solar edge;
- *The reflector variable prism*: allowing measurements on different zenithal distances;
- *The telescope*: a primary mirror of 120-mm, coupled with CCD detector mounted on the focus to get an image of the solar edge; and
- *The rotating shutter* will switch between the direct image and the reflected image of the solar edge.

The crossing point of the two edges will define the exact zenithal distance of the solar border. The solar radius is measured using the inflexion point of the radial intensity curve. The CCD images are acquired at a frequency of 100 images/s. On each image, appropriate corrections for diffraction, jitter and diffusion are applied on a limb window of 128 pixels. A precision of 10 milli arcseconds is achieved.

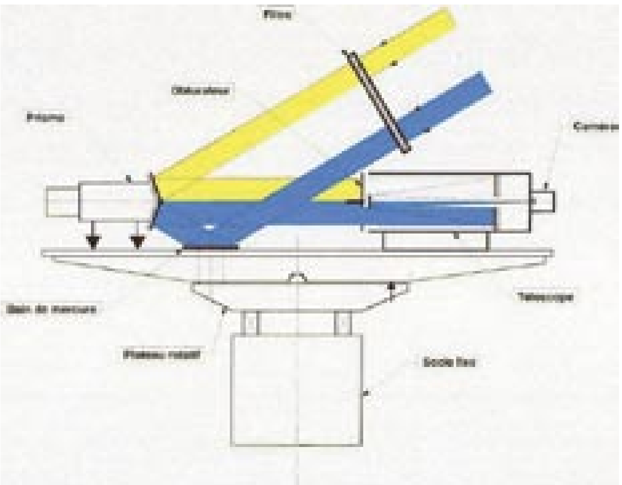

**Fig. 2.** The Doraysol Instrument.

**R2S3: Reseau de Suivi au Sol du Rayon Solaire,** a ground survey network for measurements of the solar radius initiated by Calern Observatory which is in place in many different latitudes all over the world, based on solar Danjon Astrolabes and Doraysol instruments will verify the Laclare results for the next solar cycle. Coupled to a solar-seeing monitor, solar CCD images obtained with Doraysol will be corrected and cleared from the atmospheric turbulence effects and therefore solar diameter variations will be explained with more accuracy.

### Solar-Seeing Monitor

A solar-seeing monitor is intended to quantify the effects of atmospheric turbulence on solar diameter measurements. The instrument is based upon the measurement of the angle-of-arrival fluctuations, defined as the slope in each point of the deteriorated wave-front arriving on the instrument pupil. The pupil images enable us to evaluate all the spatial-temporal parameters of the incident wave-front.

The instrument is a 12-inch Meade LX200 Schmidt Cassegrain telescope. A box at the instrument's focus contains the necessary optics and detectors for the pupil measurement method. The pupil method consists of forming the pupil image through a slit of 250 $\mu$m wide and 5 mm long, placed on the solar edge at the focus of the telescope. It serves mainly to evaluate the wave-front temporal parameter $\tau_0$ using photodiodes. The phase fluctuations of the wave-front are transformed into intensity fluctuations on the pupil image. Detectors of different diameters, connected to the pupil image, are intended to measure the intensity fluctuations and to transform them into temporal signals which will qualify the turbulence parameters.

This seeing monitor associated to Doraysol is essential to understand the atmospheric effects on ground observations of the apparent solar disk. It will provide all the spatial-temporal parameters of the wave-front affected by the turbulence, as well as the turbulence profile. The results will enable the elaboration of models that can explain those effects induced by atmospheric turbulence, and the corrections to apply to such measurements.

### Conclusion

It will be clear from the above that our main interest is the Sun, its activity on different time scales, its effects on the geosphere and its relationship with atmosphere and climate.

With these four ground-based instruments, Algiers Observatory is preparing to celebrate the IHY during 2007 and will be taking part in an interesting research network where observed data will be shared amongst international scientific teams. Thus, young Algerian scientists hope to make more contacts with their colleagues from different parts of the world in order to validate their work and results and to exchange exciting experiences and knowledge.

# Possible Participation of Nigeria in Studies of Global Phenomena of Geospace During the IHY


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**Abstract.** One of Nigeria's major tasks during the International Heliophysical Year (IHY) is to reactivate research on the Equatorial Electrojet (EEJ) phenomenon. Nigeria, being close to the magnetic equator, is ideally suited to extend the observations of this phenomenon made at other longitudes. Since 1993, magnetic observatories have declined in Nigeria, but there is an enthusiastic group of young physicists ready to revitalise former programmes. One of the most effective routes will be to establish links with other groups working in this field, perhaps enabling them to set up and run modern magnetometers in Nigeria. In this paper, we summarise the possibilities that are available in Nigeria and briefly outline work that has been done on the EEJ.

**Sommaire.** L'un des objectifs majeurs du Nigéria durant l'année heliospherique internationale (IHY) est de réactiver sa recherche sur l'electrojet équatorial (EEJ). Avec sa position près de l'équateur magnétique, le Nigéria est idéalement situé pour compléter les observations de ce phénomène faites à d'autres longitudes. Depuis 1993, le nombre d'observatoires du champ magnétique n'a cessé de diminuer au Nigéria, mais il existe aujourd'hui un groupe de jeunes physiciens enthousiastes prêts à réactiver les anciens programmes. Une des voies efficaces sera d'établir des contacts avec d'autres groupes travaillant dans ce domaine, leur permettant d'installer des compteurs magnétiques modernes au Nigéria. Dans cet article nous récapitulons les possibilités qui sont disponibles au Nigéria et nous décrivons brièvement le travail qui a été effectué sur l'EEJ.


## Introduction

It has been clearly stated that the International Geophysical Year (IGY) in 1957 was organised with the primary goal of studying global phenomena of the Earth and geospace. This objective has not been fully achieved; hence, there is a need for intensified research work in order to accomplish this mission. Nigeria, being near the dip equator (Figures 1a and 1b), makes her more relevant to engage in one important area of such studies – the Equatorial Electrojet (EEJ) phenomenona.

## Equatorial Electrojet Phenomena and the Magnetometer Signature it Produces

At the magnetic dip equator, the midday eastward polarisation field generated by global scale dynamo action gives rise to a downward Hall current. A strong vertical polarisation field is set up, which opposes the downward flow of current due to the presence of non-conducting boundaries. This field in turn gives rise to the intense Hall current which is called Equatorial Electrojet (EEJ). The basic reason for the existence of EEJ is as a result of large Hall polarisation and hence large value of Cowling conductivity at the dip equator where the Earth's field is horizontal. The above is true, since Cowling conductivity ($\sigma_3$) is an effective conductivity given by:

$$\sigma_3 = \sigma_1 + \sigma^2{}_2 / \sigma_1$$

(where $\sigma_1$ is the transverse or Pedersen conductivity and $\sigma_2$ is the Hall conductivity). It has long been ascertained that specific conductivities are functions of latitude (Figures 2 and 3).

The EEJ is a day-time phenomenon and it shows itself as a large horizontal geomagnetic field strength variation observed at the magnetic equator. The enhancement in the horizontal component (H) of geomagnetic field is due to overhead currents that flow from west to east in a narrow belt a few degrees in latitude along the dip equator on the sunward hemisphere.

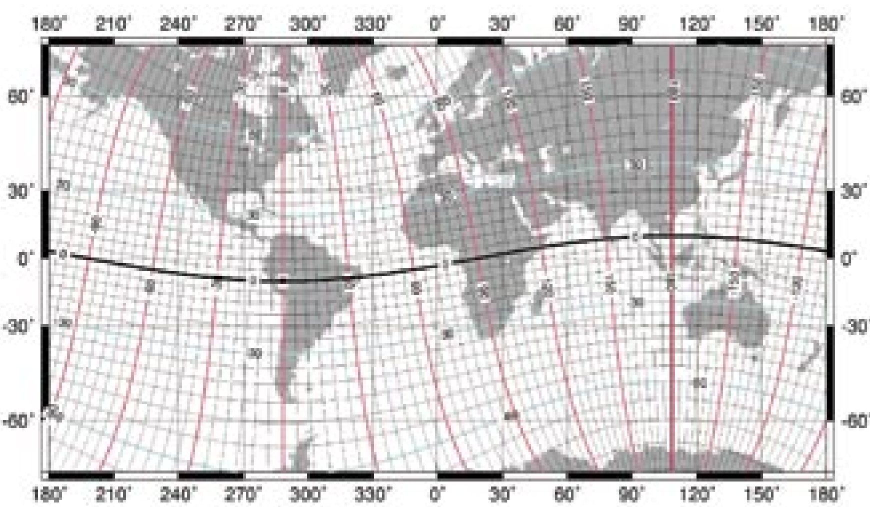
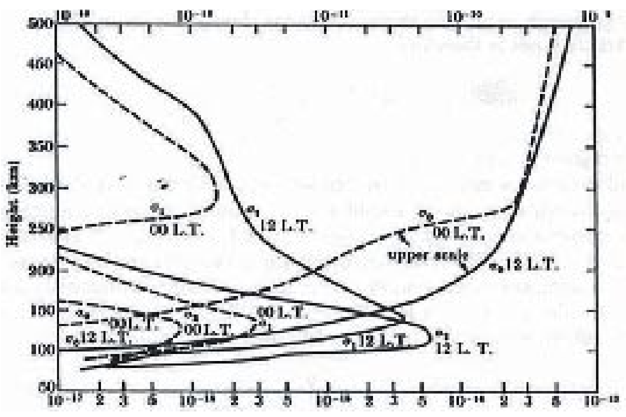



**Fig. 1a.** Global map showing Nigeria along the dip equator.


**Fig. 1b.** Map of Nigeria showing the dip equator and the proposed locations of observatories.

In the equatorial region, the geomagnetic field has contributions from worldwide solar quiet (WSq) current systems and electrojet current systems. The field produced by the electrojet is larger than the field produced by the worldwide current system. The field produced by the electrojet is centered on the dip equator while that produced by the worldwide current system is centered on the mean equator. The field due to the electrojet goes to zero at about the same latitude range that it takes the worldwide system to reach its maximum value (*i.e.* at 15° or 14° on each side of the mean equator). The field due to the electrojet reaches its maximum at about 4° and is asymmetric. The reason for this asymmetry is due to the fact that the electrojet current is centered at the dip equator while the worldwide current system is centered at the mean equator and therefore, they are out of phase. The EEJ, therefore,

Conductivity $\sigma_0$ (e.m.u.)

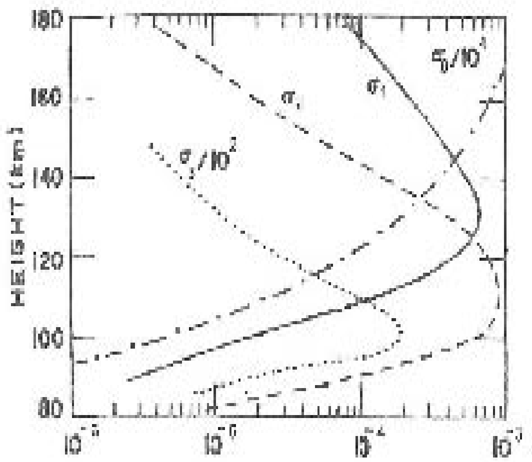



Conductivity $\sigma_1$ and $\sigma_2$ (e.m.u.)

**Fig 2.** The height distribution of electrical conductivities, parallel, Pedersen and Hall in the ionosphere in mid-latitudes. (After Maeda and Matsumoto 1962)

is a region approximately 600 km wide in the north-south direction around the magnetic dip equator where an enhanced current flows in the east-west direction. It represents an enhancement of diurnal variation in the geomagnetic field near the dip equator[12].

EEJ phenomena exhibit diurnal variation, seasonal variation, latitudinal variation, and variations in EEJ parameters; such as current intensity ($J_o$) and total current (I), electrojet irregularities and others. Magnetic field data, mostly for quiet days, has been used to study the equatorial electrojet phenomena. The EEJ strength has been computed using using satellite data and using ground magnetic observatory data. A typical signature of the latitudinal profile of the residual field observed at Ørsted satellite height is indicated in Figure 4.




Conductivity $\sigma_1$ and $\sigma_2$ (e.m.u.)

**Fig 3.** Pedersen, Hall, Cowling and parallel conductivities as a function of height under noontime, equatorial equinox and average solar conditions. (After Forbes in the Lindzen 1976)

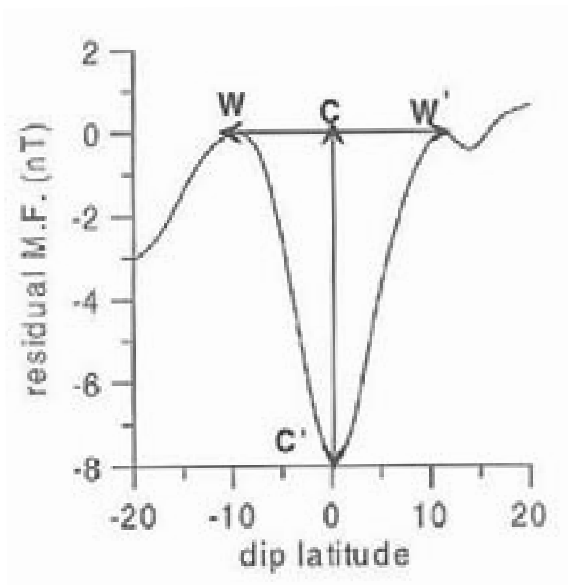



**Fig 4.** Typical signature of the latitudinal profile of the residual field observed at Ørsted satellite height for 135°E longitude pass, on 2nd August 1999. (After Jadhav *et al.* 2002)

Ground magnetic signatures can be studied using data relating the latitudinal structure and variability with respect to the local time, longitude, season and solar cycle of the ground magnetic variations associated with the equatorial electrojet.

## Equatorial Electrojet Research: Past, Present and Future

Over the years, several authors have worked on the EEJ all over the world, Nigeria included. Only a few, however, will be discussed, some only mentioned. The regular daily variation in the Earth's magnetic field was first noted by Graham[8]. Later, Stewart[36] concluded that daily oscillations

| TABLE 1<br>Geographic and geomagnetic locations of the proposed magnetic observatories | | | | |
|---|---|---|---|---|
| Stations | Geographic latitude (°) | Geographic longitude (°) | Geomagnetic latitude (°) | Geomagnetic longitude (°) |
| Nsukka | 6.9N | 7.5E | 8.7 | 80.7 |
| Sokoto | 13.0N | 5.3E | 15.9 | 77.1 |
| Zaria | 11.1N | 7.7E | 12.0 | 79.3 |
| Ago-iwoye | 7.0N | 3.9E | 9.4 | 77.2 |
| Port Harcourt | 4.9N | 7.0E | 6.8 | 79.8 |
| Maiduguri | 11.8N | 13.2E | 12.5 | 87.2 |

| TABLE 2<br>Locations of the previously active observing observing stations | | | | | |
|---|---|---|---|---|---|
| Stations | Abbreviations | Geographic longitude (°) | Geographic latitude (°) | Geomagnetic longitude (°) | Geomagnetic latitude (°) |
| Huancayo | HUA | -75.20 | -12.06 | 356.12 | 1.40 |
| Kiritimati | KTM | -157.50 | 2.05 | 273.49 | 3.09 |
| Pohnpei | PON | 158.33 | 7.00 | 229.19 | 0.99 |

were due to thermally forced motions of air moving across the magnetic field in the upper atmosphere. Gauss[7] and Schuster[35] proved that the current responsible for the daily ground magnetic variations consisted mostly of an external (upper atmosphere) portion and a smaller, internal (induced Earth current) contribution.

Earlier work on the variability of the current intensity and total forward current of the EEJ and WSq current layers has been studied[18,5,37,38,39,2]. Also Forbush and Casaverde[6] studied the features of the EEJ in D, H and Z across the dip equator and assumed that the EEJ produced negligible D-field variations. Recent works by Rastogi[32], Onwumechili[31] and Okeke[20], however, have shown that the D-field of the EEJ does exist. Manju and Viswanathan[17] recently studied the response of the EEJ to solar flare related X-ray flux enhancements. It was observed that there was a sharp fall in the ratio of the field line integrated Hall conductivity to the field line integrated Pedersen conductivity in the dynamo region during strong flare times in relation to normal times.

Previous studies of the EEJ by various workers *e.g.* Ogbuehi[18], Cain and Sweeney[3], Fambitakoye and Mayaud[5], MacDougall[15], Onwumechili[26], Raghavarao and Anandarao[30], Mann and Schlapp[16], Rastogi[31,32], Okeke *et al.*[20,21,22] (Figures 5(a), 5(b) and 5(c)) have contributed immensely towards understanding the atmosphere in regions around the magnetic dip equator. Dourmouya[4] used the hourly mean values from ten magneto-telluric stations from November 1992 to October 1994 in West Africa to study the structure of the regular diurnal variation $S_R$ of the three components to characterise the EEJ during magnetically quiet days. Vassal[40] further showed that the diurnal variations in the electric field and magnetic fields do not show the same day-to-day variability in the equatorial regions. A summary of other results from this campaign can be seen in Amory-Mazaudier[1]. Kim[13] while using satellite data from the POGO series of satellites, confirmed the local time model presented by Dourmouya[4].

In the east African region, Haile[10] analysed the daily variation of the horizontal component of geomagnetic field H at Addis Ababa during different seasons of a solar maximum and a solar minimum year. His work showed that the midday peak of ΔH occurred later in local summer months than during local winter months. Peaks of ΔH for autumnal and equinoctial months showed a consistent time delay of one

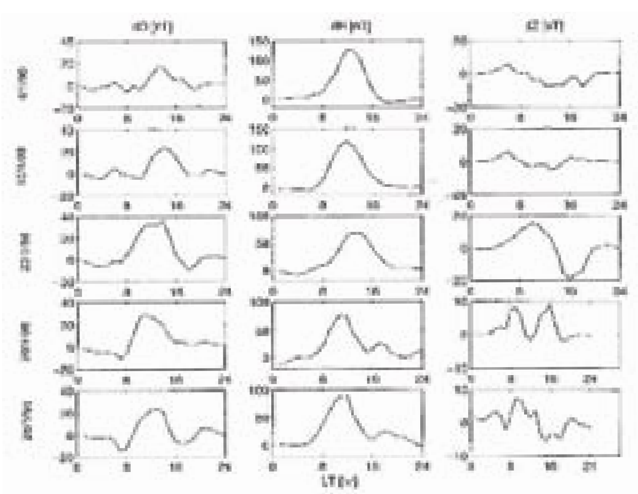


**Fig 5a.** Daily variations of dD, dH and dZ at Huancayo on 5 quiet days in January 1998. (After Okeke F.N. and Hamano Y. 2000)

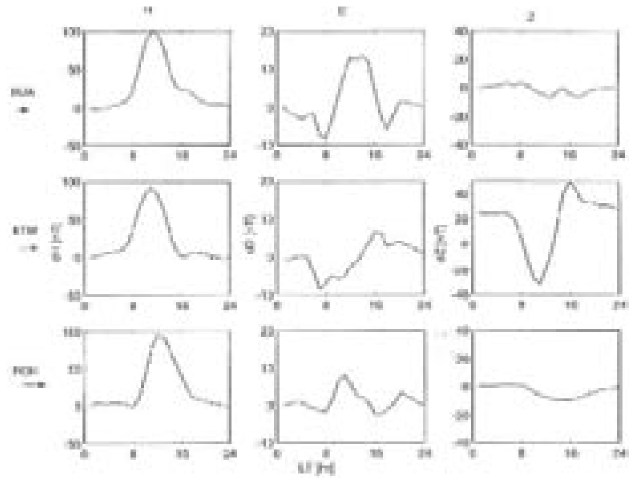


**Fig 5b.** Diunal variation of the monthly means of dH, dD, dZ at HUA, KTM, PON in February 1998. (After Okeke F. N. and Hamano Y. 2000)

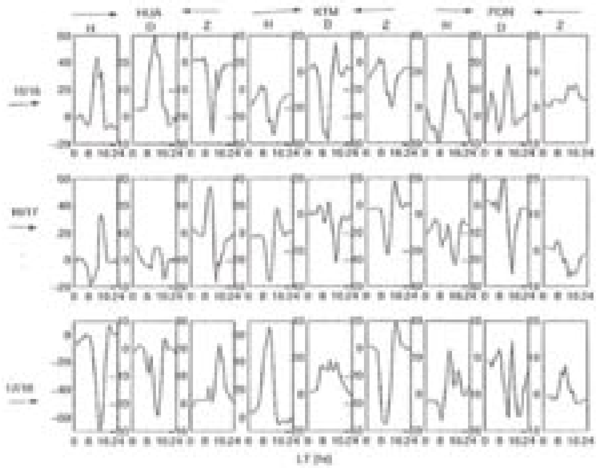


**Fig 5c.** Day-to-day variability [D-D] of H, D, Z on four consecutive IQDs in the EEJ regions in August 1998.(After Okeke F.N. and Hamano Y. 2000)

hour between the pairs at this east African station.

Rastogi[34] studied the effect of solar flares on the H, Z, and Y components of the geomagnetic field at the equatorial electrojet stations of Yauca, Chimbote, Chiclayo Talara and Fuguene. He observed that the amplitude of solar flare effects in both H and Y fields at the stations were enhanced at about 2 hours before noon, but the effects on the Z-fields were small. This was in contrast to the large solar flare effects in Z and small solar flares in Y at Trivandrum, the equatorial station in India.

The study of the EEJ has, therefore, been to many scientists of great interest. The urgent need to intensify research efforts in the EEJ was emphasised during the second United Nations/European Space Agency Workshop on Basic Space Science for developing countries which was held in November, 1992. This emphasis was passed as a motion by the United Nations General Assembly. Also, at the third United Nations/ European Space Agency Workshop on Basic Space Science for developing countries held in Nigeria in October 1993, emphasis was again laid on ways and means of improving research work on the EEJ. See the Reports on the Third, Fourth and Tenth United Nations/European Space Agency Workshop on Basic Space Science; Numbers A/AC 105/ 560/Add.I, A/AC.105/580, A/AC. 105/766. United Nations office for Outer Space Affairs publications. The report can be found on the website: http://www.unoosa.org.

## Current Research Efforts in Nigeria

Over the years, several authors in Nigeria have worked on the EEJ. Pioneering works by Profs Onwumechili, Ogunade and Ogbuehi are rewarding evidence of our current knowledge on the EEJ. The variability of current intensity and total forward current of the EEJ, as well as their morphological parameters have been studied by Onwumechili[24]. Onwumechili and Agu[25], Onwumechili *et al.*[27], Onwumechili[28] and Okeke *et al.*[20,21] They have all studied day-to-day variability of geomagnetic hourly amplitudes at low and mid-latitudes, seasonal, latitudinal variations of EEJ, solar flare effect of equatorial H, D, and Z, as well as many others. The data used in many of the works by the said authors are from data derived from Russian, Asian and Indian observatories. Observatories in Ibadan and Zaria were particularly useful for past EEJ campaigns. Ogunade[19] showed induced electromagnetic fields in oil pipelines under electrojet current sources.

Since 1994, no significant results have been achieved in the EEJ studies using ground-based data from West Africa especially Nigeria. In contrast to this, the Indo-Russian, Asian and American sectors of the EEJ belt have continued to improve their respective campaigns as evidenced by the works from many authors using data from these sectors (Rastogi[33,34] and Gurubaran[9]).

In the past, the most significant campaign on the EEJ was carried out after the Vancouver Assembly of IAGA in 1987 when the Interdivisional Commission on Developing Countries (ICDC) supported the intensification of studies of the Equatorial Electrojet Year (IEEY).

During the last few years, significant work on the EEJ was carried out by our group. The work was mainly on data analysis, using data obtained from other countries *e.g.* India and Japan. Some years ago, data from parts of Nigeria were also analysed. Unfortunately no more data are currently being generated from Nigeria due to the lack of modern equipment and the retirement or death of previous researchers. The younger researchers took over the batten but have no modern equipment to continue with data acquisition and also have no current data to continue with the analysis.

## Opportunities Associated with the IHY

The IHY presents an exciting opportunity to revive geomagnetic research in Nigeria. In order to to do, we propose that:

(a) The international space science community should assist Nigeria in setting up well-equipped geomagnetic observatories in Nsukka, Akure and a few other strategic locations in Nigeria. Nsukka is the National Centre for Basic Space Science, and has funds to maintain the instruments as well as to coordinate the geomagnetic observations in Nigeria.
(b) The observatories should have standard geomagnetic equipment, as well as geomagnetic libraries for references. There should be good linkage between the observatories and other geomagnetic observatories, thereby faciliting the exchange of data for analysis and interpretation.
(c) There is a need for the training of Nigerian scientists and technologists to man the ground-based equipment and the handling of data. Nigeria is therefore willing to collaborate with established geomagnetic observatories especially in the area of manpower development for the planned stations.

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## Advice to Contributors

The purpose of this publication is to provide a forum for communication among space scientists in Africa. In addition to recording the activities of the Working Group, *African Skies/Cieux Africains* features articles on current research developments in the space sciences in Africa as well as educational material intended for general readers and science educators. Contributions relevant to these themes will be considered for publication in *African Skies/Cieux Africains*. Shorter communications will be considered for publication in the News, Letters or Announcements sections of *African Skies/Cieux Africains*.

The official languages of *African Skies/Cieux Africains* are English and French. Contributions in either of these languages are acceptable. Authors fluent in both these languages are encouraged also to provide a translated one-page summary of their contribution. Papers in Arabic are also acceptable provided that (i) they are accompanied by a summary in one of the two official languages and (ii) a camera-ready copy of the Arabic text is submitted.

Contributions may be submitted by electronic mail, fax, or post to the address inside the front cover. Line drawings and photographs may be submitted for publication. Where possible, electronic copies of illustrations should also be submitted. Line drawings submitted electronically should preferably be in PostScript format. Photographs or other images should be scanned at the highest possible resolution to produce images in a common graphics image format.

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