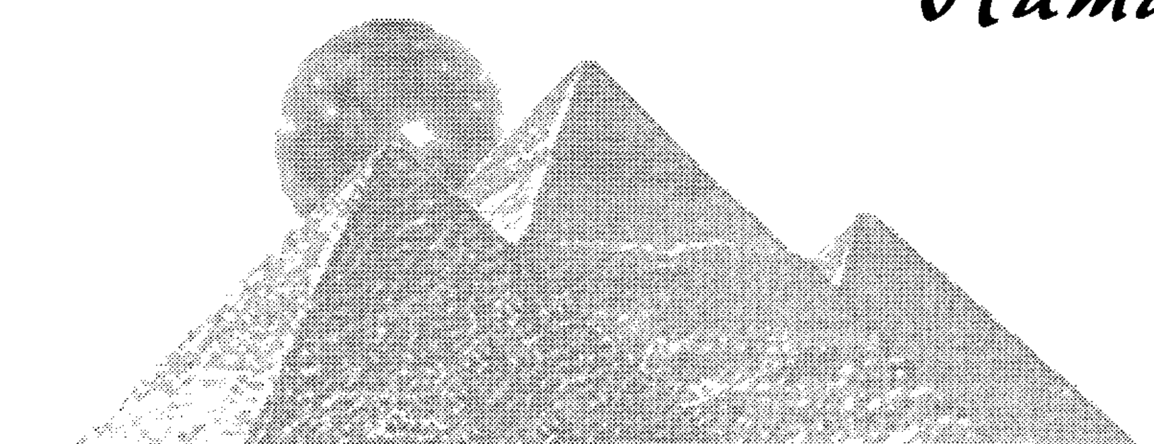
Ra

Final Report

The Sun for Science and Humanity



International Space University | Summer Session 1996 | Vienna, Austria

The 1996 Summer Session of the International Space University existed for ten weeks at the Technical University of Vienna, hosted by the Austrian Society for Aerospace Medicine.

The cover image of the Sun was taken by the Solar and Heliospheric Observatory Extreme Ultraviolet Telescope. The wavelength shown is 195 Angstroms, revealing highly ionised iron atoms in the lower corona at 1.5 million Kelvin. The North and South poles of the Sun clearly show coronal holes, a phenomenon not yet fully understood. The image was courtesy of the SOHO EIT Consortium (SOHO) is a joint endeavour by ESA and NASA.

Additional copies of the Design Project Executive Summary or the Full Report , *Ra: The Sun for Science and Humanity,* may be ordered through the ISU Headquarters in Strasbourg or the ISU North American Office .

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"I would say that man should live for loving, for understanding, and for creating. I think man should spend all his ability and all his strength on pursuing all these three aims, and he should sacrifice himself, if necessary, for the sake of achieving them. Anything worthwhile may demand self-sacrifice, and, if you think it worthwhile, you will be prepared to make the sacrifice."

Arnold Toynbee, Surviving the Future

Oxford University Press, 1971.

Over this summer at ISU, we spent most of our abilities and our strengths on appreciating each other and on understanding what "the Sun for Science and Humanity" could mean. Sacrifices have sometimes been necessary, and it was worthwhile. Here is what we have created...

The Ra Team.

Acknowledgements

To everyone who contributed their time, energy, and expertise to the Ra team, we wish to express a heartfelt: Danke, Thank you, Merci, Grazie, धन्यवाद, Gracias, Gracies, Spasibo, qJåpe©ΩwYc, Takk, Bedankt, Tack, Kiitas, 谢谢, Cam-on, Tak!

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Student Preface

The International Space University (ISU) was founded in April 1987 as a non-profit, non-governmental institution. It was created with the objective of becoming the world's leading centre for educating and training tomorrow's space professionals. The ISU Summer Session Program brings together international space experts from academia, industry, and government to educate students in multidisciplinary and advanced issues in space development in a ten week format. The design projects carried out by the students during the session have two purposes: first, to provide learning in international teamwork on problems requiring a multidisciplinary and multicultural approach, and second, to yield published results that can be influential in the world-wide space community.

This year's summer session was held in Vienna, Austria, and this report outlines the effort of one of its two groups of students. The team, composed of 53 professionals from 18 countries, brought to the project a variety of experiences, educations, and interests, from the societal through to the scientific, from the theoretical through to the applied. The members of our group used varied styles of problem solving, ranging from the ambitious and unconstrained to the more limited and immediately achievable.

Our mandate was to use an international perspective to examine present and planned activities in solar-terrestrial science and applications, critically review current goals, investigate new organisational schemes, develop innovative mission concepts and define a comprehensive baseline project that represented a realistic alternative or follow-on to the projects now being considered in space agencies.

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Faculty Preface

At each ISU summer session the students carry out one or more design projects. Their purpose is to give experience in intercultural and multidisciplinary teamwork and at the same time to generate results that can be influential in the world beyond ISU and useful to the students in their later careers. At ISU 96 the two projects were about remote medical activities and solar-terrestrial science and applications, named by the students DOCC and Ra respectively. Of the 104 members in the ISU class of 1996, fifty-three people from eighteen countries and all ISU academic disciplines chose to work on Ra. This document delivers their results.

The charge to the student team was for them to use an international perspective to examine present and planned activities in solar-terrestrial science and applications, critically review current goals, investigate new organisational schemes, develop innovative mission concepts and define a comprehensive baseline project representing a realistic alternative or follow-on to the projects now being considered in space agencies.

Recognising that the realm of Sun-Earth interactions is huge and diverse, the students had to make choices using their own judgement as to what they could achieve in a short project. They developed a Strategic Framework containing near, mid, and far term activities for both science and applications and analysed those that they believed most promising. They used information and advice from their faculty and teaching assistants plus that contributed by other members of the ISU community and visiting experts. They made effective use of the new information facility provided by the World Wide Web.

The students' decisions on what to analyse and report, what to treat by reference, and what to omit from the project were entirely their own. We, the faculty and teaching assistants for this project, are honoured and proud to have been associated with this energetic, disciplined and creative group of students and we commend their results to the reader.

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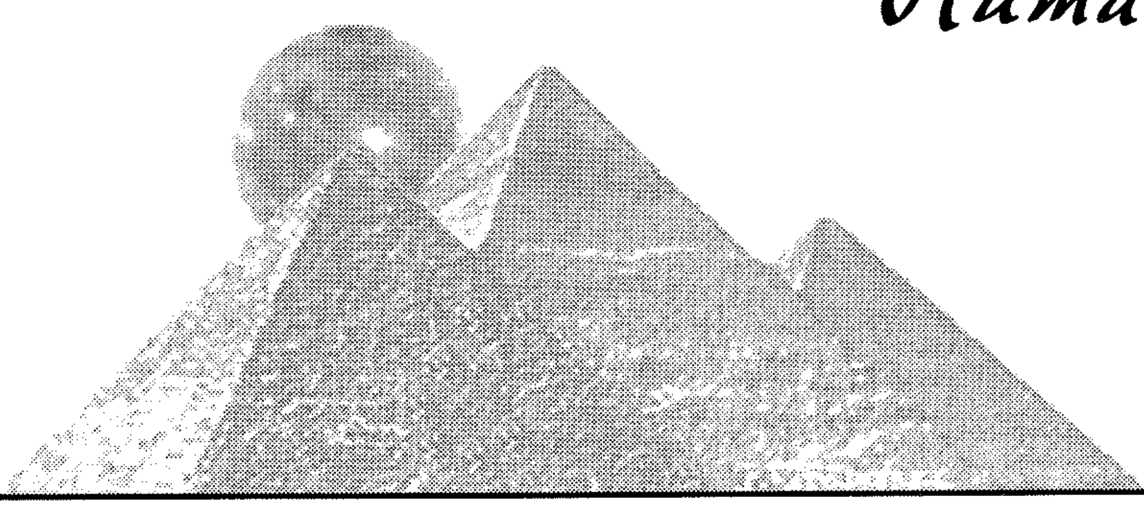
Ra

Executive Summary

The Sun for Science and Humanity



Introduction

In this report, we set out a framework for pursuing solar science and applications. As a guiding charter, we have chosen the following mission statement:

> *Through an international perspective, we will explore and document strategies which will increase our understanding of the Sun and its effects, and help us apply solar knowledge for the benefit of humankind.*
>
> **Ra Team Mission Statement**

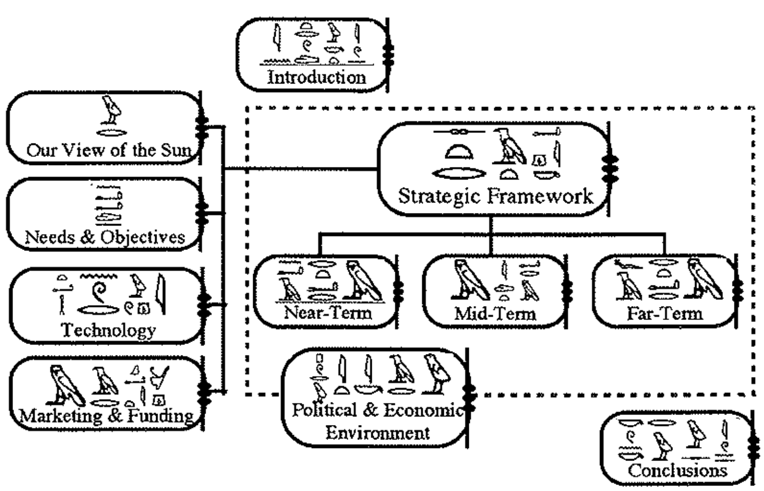
The timing is fortuitous.

The ESA Science Programme Committee (SPC) will be meeting in November 1996. After this meeting, the Call for Ideas for the M4 mission (part of the Horizon 2000 Plus programme) will most likely be released. The M4 has presently been reserved for a mission concentrating on the Solar System.

Also in the immediate future, the Inter-Agency Consultative Group for Space Science (IACG) will likely begin the process of choosing its next focal project. Currently, they have been co-ordinating the International Solar Terrestrial Physics Program (ISTP).

Furthermore, NASA is planning to bring its Sun-Earth Connections Roadmap to the American space science community for assessment. That meeting is set for the summer of 1997 at Woods Hole, Massachusetts.

We encourage the wider community to investigate the contents of our full report. Much of it has taken the form of recommendations for the future, and many ideas await your discovery within.



Report Overview Diagram: The hieroglyphs were found using the URL of Laurent Wacrenier, *Nom en hiéroglyphes*, http://yoko.ens-cachen.fr:8080/hiero, accessed August, 1996.

The International Situation

The global political environment within which space activities take place has been changed by a variety of economic, social, and technological factors. This altered paradigm has created both obstacles and opportunities for solar exploration and applications.

The end of the Cold War has had the most far-reaching implications for national space activities. Deep and integrated co-operation in space between the United States and Russia is no longer a political taboo, opening up a whole new array of international co-operative opportunities. Conversely, the loss of competitive Cold War rationales has been a primary driver of the decreasing national space budgets in both the United States and Russia. These same decreasing budgets stimulate increased national inter-agency co-operation and co-ordination. This trend toward greater collaboration presents an opportunity for a multilateral co-operative effort in solar exploration and applications.

The respective technological levels of spacefaring nations are no longer disparate. Although economic competition between spacefaring nations has partly supplanted the old political competition of the Cold War, less commercial sectors, such as space science, have experienced enhanced co-operation because of mutual payback opportunities and decreased concern about disproportionate or unilateral technology transfer.

The economic risks of insufficient global knowledge concerning dangerous solar phenomena have risen to new heights. The ever-increasing amount and level of complexity of the global space infrastructure, used by both developed and developing nations, points to an immediate need for improved solar warning and forecasting capabilities. The political environment recognises these economic needs, resulting in an enhanced opportunity for developments in solar warning and forecasting.

There has been an international trend toward greying the line between the basic and applied sciences. This greying has the potential to enhance the cohesion of the scientific community by diminishing traditional rivalries between speciality disciplines. The convergence is also notable for the movement toward interdisciplinary science missions, and the current climate is favourable toward joint science and applications endeavours.

The future of solar exploration and applications will be determined largely by how well the relatively low budgetary priority of solar and heliospheric physics and solar warning and forecasting services is overcome. The combination of diminishing national space budgets, increased opportunities for co-operation, and growing technological capabilities has led to a sustainable emphasis on smaller, modular, networked spacecraft with prioritised objectives. Disciplinary cohesion, inter-agency co-ordination, international co-operation, applications rationales, and smallsat technology offer a combination of effective means to sustain and even increase solar exploration and applications efforts.

A Strategic

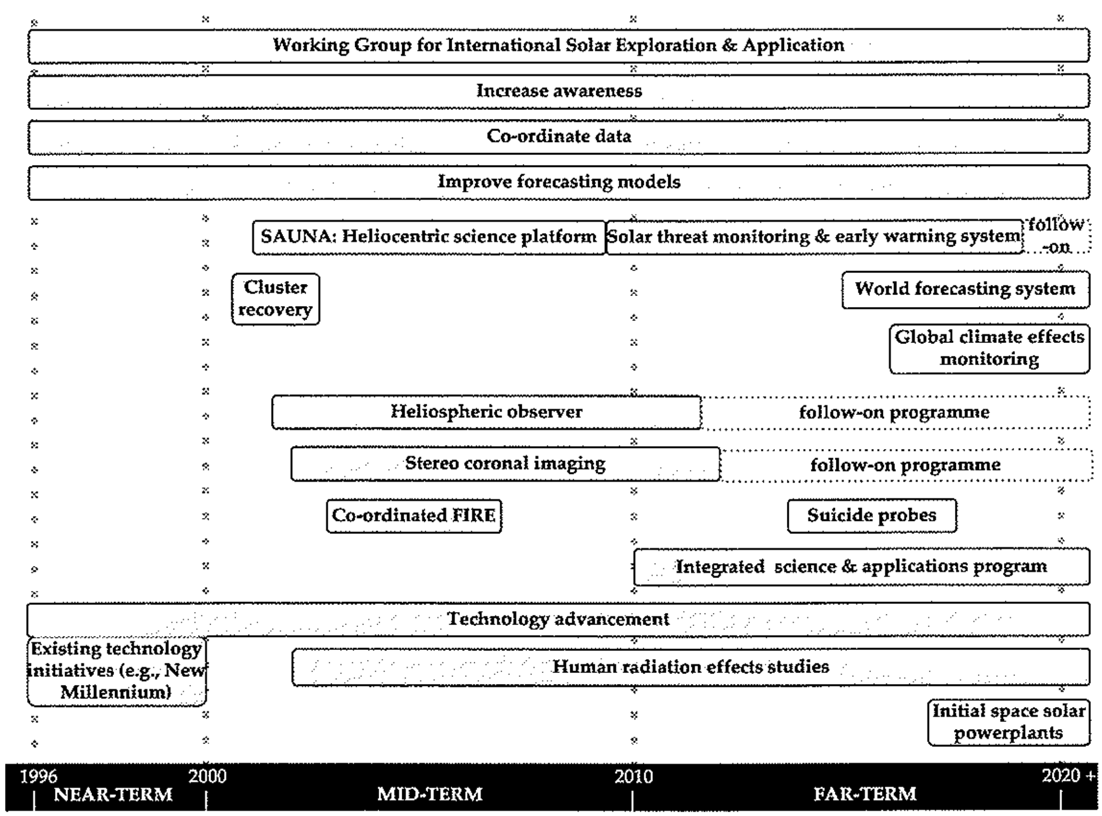
One of our goals in the report is to develop a Strategic Framework for solar science and applications, and from that programmes for the Near-Term, Mid-Term, and Far-Term. This Strategic Framework provides an integrated approach to solar exploration and applications, as illustrated in the figure below. Three time frames are defined as follows:

- Near-Term: Focuses on programmes that are achievable within the next few years (1996 to 2000). Elements tap into current capabilities and programmes; they also seek to improve management and co-operative structures in preparation for the future.

- Mid-Term: Focuses on more ambitious programmes, some requiring technology development, with implementation times in the first decade of the next century (2001 to 2010).

- Far-Term: Focuses on the period from approximately 2011 to 2020 (and beyond) and is characterised by higher-risk, advanced technology, and/or integrated programmes.

The elements of the Near-Term programme are primarily political and managerial in their scope, in keeping with the Near-Term philosophy of building on existing capabilities. Central to this programme is the creation of a "Working Group on International Solar Exploration and Applications" (WG ISEA). We envision the WG ISEA as a forum for co-ordinating and planning the many solar missions that individual nations have proposed for the next decade, while preserving their independent sources of support. These missions tend now to be rather random. Other



parts of the programme may not be as ambitious but can have profound implications. The sharing of science data, for example, may produce synergistic results and lead to better solar environment forecasting models. Overall, the Near-Term programme lays a foundation for the projects of the later parts of the Strategic Framework.

We propose several mission flight opportunities in the Mid-Term period. A stereoscopic solar imaging system is envisioned to fulfil the high priority science objective of understanding the corona, as is a heliocentric near-Sun science platform (which we have named SAUNA). The corona is currently scheduled to be probed by the combined Russian-US FIRE mission. These missions will be supported by a new global heliospheric observation system (possibly one of the stereo observation platforms), since SOHO may have expired and not been replaced by the time it is needed to support FIRE and other missions. We envision a continuously operating solar threat monitoring and early warning system, perhaps one involving near-Sun platforms that build on the technology demonstrated by SAUNA. This system will mark the beginnings of a solar applications system, an idea central to Ra. Finally, we envision that humanity will be taking serious steps toward the establishment of human lunar outposts or Mars exploration; in which case, study of solar radiation's effects on tissue will be essential to the design of these missions. In summary, the Mid-Term programme elements represent a maturing of solar science and the beginnings of solar applications.

The elements of the Far-Term programme look toward the more distant future. Building on the foundations created earlier — better forecasting models, data co-ordination, increased solar awareness, and the WG ISEA (whose international activities will have continued and expanded in importance) — we envision an integrated programme for space science and applications. This integrated programme may have combined platforms, or it may share common resources (such as spacecraft bus designs, or a communication system to relay data from a new generation of solar spacecraft). The space threat monitoring and early warning system begun earlier should be mature enough by this time to create a global forecasting system, one that provides benefits to developing nations. Furthermore, applications will begin to focus on solar benefits, such as the beginnings of space solar power plants. Finally, as we look back on years of integrated data, we see these data, combined with new long-term missions, enabling scientists to study the relationship between the Sun and the Earth's climate.

We believe the Ra Strategic Framework is significant because it:

- is a coherent plan over time.
- relies on existing and planned programmes, and benefits from them.
- considers the political and economic environment, including future trends, and seeks to shape that environment for the advancement of solar science and applications.
- integrates solar science and applications, showing how one can complement the other.
- is an international framework that

Objectives

To guide the development of the Ra Strategic Framework, we defined scientific and applications objectives. For our primary areas of scientific interest, we chose the corona, the solar wind, the Sun's effect on the Earth, and solar theory and model development. For secondary areas of scientific interest, we selected sunspots, the solar constant, the Sun's gravitational field, helioseismology and the galactic cosmic rays. We stress the importance of stereoscopic imaging, observations at high spatial, spectral, and temporal resolutions, as well as of long duration measurements. Further exploration of the Sun's polar regions is also important, as shown already by the Ulysses mission.

From an applications perspective, we adopted three broad objectives that would derive complementary inputs for the Strategic Framework. These were to identify and investigate: possible application spin-offs from science missions, possible solar-terrestrial missions dedicated to a particular application, and possible future applications that require technology development. The Sun can be viewed as both a source of resources and of threats. Our principal applications focus was that of threat mitigation, by examining ways to improve solar threat monitoring and early warning systems.

We compared these objectives to the mission objectives of past, current, and planned international solar missions. Past missions (1962-1980) seem to have been focused on improvement of scientific knowledge, using multiple instrument spacecraft. A ten year gap followed this period, during which the results from previous missions were analysed and solar study programmes were prepared in international organisations. Current missions (1990-1996) focus on particular topics such as the corona, solar flares, and coronal mass ejections. In planned missions, Sun/Earth interactions and environmental effects of solar activity are becoming more important. The corona is the centre of interest of almost all planned missions. It seems that no international long-term strategy has yet been adopted. For these plans the number of necessary future missions can be reduced and the onboard instrumentation can be optimised by performing a comparative analysis.

The study of the corona must be done from different observing locations, orbits closer to the Sun, and by different means. The Cluster mission replacement is in progress; however, if the replacement is not implemented, the ISTP programme will fade after 1998. Furthermore, the physics of the Sun's interior should be emphasised more in the Mid- and Far-Term programmes. Finally, more emphasis should be placed on monitoring space weather and forecasting Sun/Earth interactions.

The continued expansion of solar understanding will necessitate research rationales that include both basic and applied scientific objectives. To properly integrate these rationales, a single forum for solar exploration and applications co-ordination and planning is optimal. The Ra Strategic Framework calls this forum the Working Group on International Solar Exploration and Applications (WG ISEA). To take full advantage of current events in space science, the WG ISEA should be formed before the Summer 1997 NASA Woods Hole Sun-Earth Connections Roadmap meeting.

The programmatic means by which the WG ISEA achieves its international collaborative objectives should be flexible to maximise the political sustainability of the effort. The WG ISEA should include a Mission Co-ordination Group to synthesise co-ordination and data sharing between national solar science and applications missions outside, with, and beyond the International Solar Terrestrial Physics programme (ISTP). To supplement the inevitable gaps in solar observing capabilities that will still exist, the WG ISEA should also form a Mission Planning Group to recommend a strategic framework for solar exploration and applications that takes advantage of existing, cheap platforms, such as university mini-satellites, for quick response solar observation or solar instrument technology demonstration.

Discrete national hardware contributions to international efforts optimise the political environment for space activities. The use of standardised, common spacecraft systems, however, is also a key to reducing the cost of solar system exploration. To take advantage of this economic opportunity while realising its political realities, the WG ISEA should include an engineering group for the international design of reference models for solar spacecraft. This Reference Model Design Group provides a first step towards realising the benefits of international co-operation in space exploration beyond the co-ordination of scientific data acquisition and data dissemination.

Increased understanding of solar and heliospheric physics will generate advances in solar forecasting models, and current national plans to consolidate agency-level solar warning and forecasting resources will incorporate these advances. Existing international solar warning and forecast data distribution networks like the International Space Environment Service will feed data into these forecasts, but the advances needed to make solar warnings and forecasts relevant to potential users will require capital investment in hardware, especially in instruments placed between the Earth and Sun. National solar warning and forecasting plans should look abroad for opportunities to co-ordinate the deployment of dedicated but nationally discrete solar warning spacecraft. Meeting user needs will provide horizontally integrated commercial opportunities within the larger government space warning and forecast services. A solar warning spacecraft will also likely be the first operational deep space endeavour outside exploratory and technology demonstration missions, marking an important transition point in humanity's expansion into the universe.

Markets and Funding

There is a market transformation taking place from the public sector to a combination of the public and private sectors. Our vision is to support this transformation and to expand and fully use existing and potential markets. Our research has found three major markets for Ra:

- Space environment forecasting is an increasing market, and the next ten years will see it increase from $100 to $200 million U.S. annually. Potential markets are influenced by insurance companies and financial institutions. These markets are sensitive to failures of telecommunication satellites and energy suppliers.

- The science market will expand as Ra increases the benefits through augmenting scientific and technological knowledge. This increase will help develop and implement solar illumination and solar heating infrastructure systems. Including these in buildings and transportation systems has the potential to significantly influence the well-being of the global population.

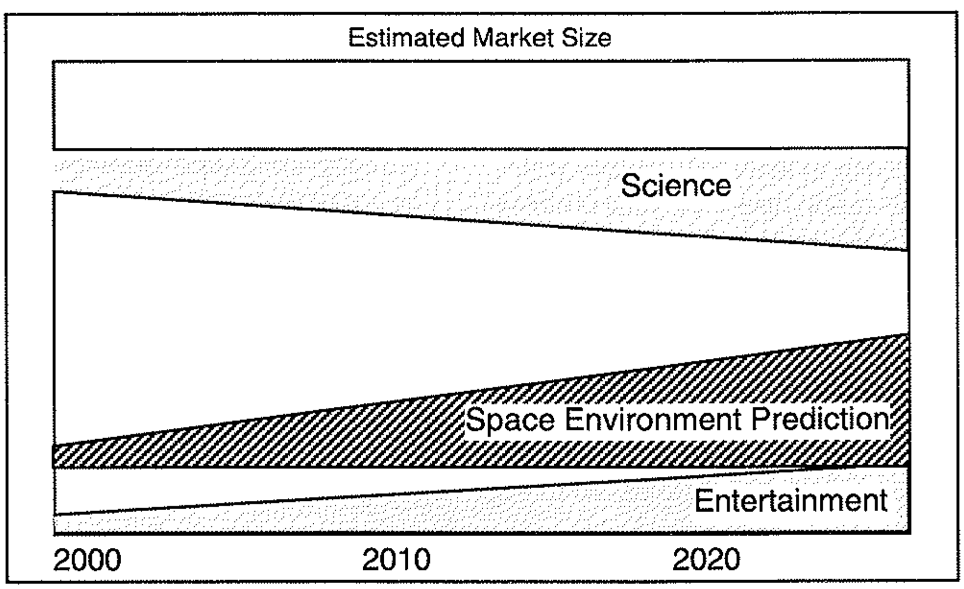
- Entertainment and education markets can be served by converting the Ra scientific results. This will increase the public awareness about the Sun and its effect on the Earth and human life.

We expect these markets to evolve as shown in the figure below.

Increasing public interest in the Ra programme will likely increase the availability of governmental funding. We recommend further studies.

Space agencies are interested in solar science and space environment forecasting. Improved measurements and models of the space environment will benefit both manned and unmanned space programmes and thereby constitute a ground for funding.

There is a trend toward joint ventures between universities and industry. The universities' research is relevant to industry, and industry funds part of it. We see a trend where Sun activities are moving from being research driven to product/service driven.



A Near-Term Programme

Each part of the Near-Term programme is relatively low in cost and either builds upon existing systems and infrastructure or incorporates modest developments. We believe that the recommendations are realistic and play an important role in realising important science and applications objectives. They also provide a foundation for the projects described in the Mid- and Far-Term programmes.

To build on existing solar observation instruments (namely SOHO) and to continue with a logical sequence of solar observation satellites, we recommend recovery of the Cluster programme. As we believe space environmental forecasting will become more important to the space community in the Mid- and Far-Term, we recommend immediate work on improving forecasting models. As the amount of archived data continues to grow and additional solar observation satellites are launched, we advise co-ordination of and accessibility to both the new data and those from the past. We call for the Working Group for International Solar Exploration & Application (WG ISEA) to be started in the Near-Term. To help advance the Mid- and Far-Term programmes through to fruition, we advocate increasing awareness of solar science and solar-terrestrial connections, thereby fostering support beyond the scientific community. Finally, in the Near-Term programme, we support actively incorporating existing technology initiatives.

Programme	Description
Cluster recovery	A replacement for the Cluster programme and direct new Cluster mission toward Ra's objective
Improve forecasting models	Perform correlation studies; innovative acquisition of new forecasting models
Co-ordinate science and other data	Continue ground-based observations; create an international data centre; research with and co-ordinate science data; co-ordinate future planning of independent groups
Working Group for International Solar Exploration and Application (WG ISEA)	Incorporates science and applications interests from government and private sectors; submits to government agencies specific recommendations for actions necessary for the fulfilment of the solar exploration and application strategic plan, while encouraging independent complementary efforts
Increase awareness of solar science and Sun-Earth interaction	Develop a "common language" for solar science and applications; work with planetariums and museums; educators via WWW; correlation study on satellite anomalies, ground power station anomalies and solar activity
Actively incorporate existing technology initiatives	Examples include: Japan Nereus, ESA TRP (esp. Theme 10) and GSTP, NASA New Millennium, University Small Sat, Clementine, DC-XA, Commercial bus

The most significant suggestions are two correlation studies: one to establish the relationship between solar activity and satellite anomalies, and a second to evaluate the accuracy of current solar activity forecasting models. These are interrelated and each serves, in the Near-Term, to get the applications objectives "off the ground".

The major components of the Near-Term programme are summarised in the above table.

A Mid-Term Programme

The Ra Mid-Term framework aims to:

- provide a solar science programme to address fundamental issues of solar physics.
- improve the capability for solar applications, and do so in co-ordination with the science programme.

The second objective is served by a transient phenomena monitoring and early warning system, and a small but important human dosimetry payload. The latter is clearly needed for the safety of manned interplanetary missions, and as such must fly before a crewed expedition to Mars or a lunar base become reality. The stereoscopic mission will open the third dimension for solar physics, flying moderately capable remote sensing instruments at 1 AU on small spacecraft buses, sharing heritage with existing small satellites. This will also serve as a precursor to an operational stereoscopic solar event prediction and early warning system. The SAUNA mission aims to send a medium-sized science payload to a moderately close heliocentric orbit inside that of Mercury, at about 0.2 AU. This mission will provide long-term high resolution monitoring of the solar disk in the extreme ultraviolet and of the corona in white light. Stereoscopy and contextual measurements will be possible when the data are combined with those from observations made on or near the Earth. SAUNA will also act as a technology demonstrator for subsequent long-term missions in closer orbits such as a heliosynchronous/polar constellation system. SOHO is showing the value of long-term heliospheric measurements from an orbit not significantly nearer the Sun than the Earth. Although it will probably remain operational until 2004, the planning of a replacement must start now if new and outstanding questions about the Sun are to be investigated effectively. The new platform should aim to reduce mission cost while improving capability, since SOHO itself is clearly a "monster mission" using large-scale 1980's technology. The currently proposed joint Russian-US FIRE mission, a simultaneous dual-spacecraft close flyby of the Sun to investigate the corona, is included in Ra's Strategic Framework. The dual mission is of far higher scientific value than if only a single spacecraft were flown.

The major components of the Mid-Term programme are summarised in the following table:

Programme	Description
SAUNA: a heliocentric, near-Sun science platform	Ion-propelled single spacecraft to 0.2 AU heliocentric orbit. 5 yr. mission duration
Solar threat monitoring and early warning system	Heliocentric orbiters; Other options included: L4/L5 tripwire and solar wind event imaging and tracking
Stereoscopic corona imaging system	Small remote sensing platforms at L1, L4 and L5
New heliospheric observing platform	Extended SOHO mission, then smaller follow-on
Co-ordinated FIRE Mission: Russian Plamya and U.S. Solar Probe	Dual spacecraft close flyby mission to 4 R_S and 10 R_S
Human radiation studies on host spacecraft	Tissue-equivalent dosimeter measuring direct radiation and secondary radiation from shielding

A Far-Term Programme

The Far-Term programme of the Ra Strategic Framework is designed to build upon the experience gathered during the Mid-Term programme. We assume that more ambitious and higher-cost projects are possible in the Far-Term, providing that these are balanced by a proportionally increased economic viability in terms of commercial exploitation and direct benefits to society.

- Propulsion: further improvements in ion engine performance, development of prototype solar sailing vehicles for the inner solar system, further research into advanced concepts like mass drivers
- Power: high efficiency heat resistant solar arrays

Programme	Description
Integrated solar science and applications programme	Options: science "piggybacking" on applications; application prototype sensors on science platforms; use of common buses
Small suicide probes	Wide range of concepts available
World-wide space environment forecasting system	Characteristics include: distributed, provides information to developing nations, integrates military, civil, commercial data; independently maintained in participating nations
Preliminary space solar power applications	Prototype space-based solar power station for small-scale distributed use
Monitoring the Sun's effect on Earth's climate	Long-term space-based observation programme to monitor solar output and Earth's climate

Integrated solar science and applications programmes would succeed in reducing cost through co-operation in areas of common interest and through exploiting available opportunities. Small suicide probes would explore the acceleration and heating in the solar corona by means of *in situ* measurements. A world-wide space environment forecasting system would offer benefits to all humankind. Preliminary solar power applications would be instrumental in exploring ways to solve the imminent global energy crisis on Earth. Monitoring the solar constant and its effect on the Earth's climate would allow study of the impact of variations in the solar output on the Earth's climate.
In order to succeed in the Far-Term, the following technological developments will be required:

- Materials: high-temperature ceramics and alloys
- Electronics: radiation hardened high-temperature electronics, more powerful small lasers
- Communications: optical communication techniques
- Guidance, Navigation and Control: autonomous interplanetary navigation techniques (e.g. based on planetary ephemerides), increased on-board intelligence
- Launchers: low-cost access to orbit by means of fully reusable launch vehicles

The major components of the Far-Term programme are summarised in the above table.

Conclusion

The Ra report is a call to action. Knowledge of the Sun is vital to us as humans and to our planet. Our star deserves our attention and study.

The global political environment within which space activities take place is changing for a variety of economic, social, and technological reasons. The current international situation presents both obstacles and opportunities for solar exploration and applications. This situation is ideal for the introduction of Ra.

We present in our report a Strategic Framework for pursuing solar science and applications. From this Framework a programme emerges for the Near-Term, Mid-Term, and Far-Term. We believe the Ra Strategic Framework is significant because it:

- offers coherency over time.
- utilises, benefits from, and adds to current programmes.
- harmonises with our political and economic environment.
- integrates solar science and applications.
- capitalises on global talents and resources.

By defining and analysing objectives, we give impetus and focus to the Strategic Framework. We have identified potential markets and sources of funding.

We recommend that a Working Group for International Solar Exploration and Applications (WG ISEA) be established immediately. The WG ISEA would:

- ensure that a Strategic Framework is put into action.
- synchronise independent efforts in different countries.
- facilitate the interaction between science and applications.
- help to combine the output into products useful on a global scale.

The time is opportune, ideal for the introduction of our ideas into the space science and applications community. Having in place a Strategic Framework dedicated to solar science and applications, and forming a small but broadly-based international WG ISEA would prove most beneficial. We hope that our report will help to make this happen.

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