Scientific Future of IRSOL

Report by the IRSOL Scientific Committee, July 2005

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Summary

With financial backing of the Swiss Nationalfonds through ETH Zurich, IRSOL (Istituto Ricerche Solari Locarno) has over the past decade acquired a set of highly unique instrumentation that has made it a **world-leading observatory in the area of solar spectro-polarimetry**. This unique instrumentation, which does not exist elsewhere, includes the **ZIMPOL** (Zurich Imaging Polarimeter) systems for high-precision imaging polarimetry and the **tunable narrow-band filter system** based on lithium-niobate Fabry-Perot etalons, which will become operational in 2006. It is being further enhanced with the present installation of a state-of-the-art **adaptive optics system** to compensate the atmospheric seeing effects in real time. Significant design advantages of IRSOL are its flexible and spacious experimental environment and the low and almost constant instrumental polarization due to the telescope optics.

As a national facility with unique instrumentation that brings leadership in the area of spectro-polarimetry, IRSOL is needed in various ways:

- as a national facility for specialized research projects,
- as a stepping stone for access to the foremost international telescope facilities,
- as an educational institute for thesis projects,
- as an observatory for long-term synoptic programs not possible to do elsewhere,
- as a laboratory for the development and test of novel instrumentation.

With the recent EURYI (European Young Investigator) Award to Dr. Svetlana Berdyugina at the Institute of Astronomy of ETH Zurich, **continuity of the present close collaboration between ETH and IRSOL**, including the ongoing research programs in astrophysical spectro-polarimetry and solar physics, **is guaranteed through at least 2010**, well beyond the retirement of Prof. J.O. Stenflo at ETH. The research group now being formed with the EURYI Award funds will bring new impetus with research programs in molecular spectro-polarimetry with the new, unique set of instrumentation at IRSOL.

It is strongly recommended not only to continue the financial support of IRSOL on a long-term basis, but also to significantly increase its staff and overall budget. The scientific return on the financial investments is found to be particularly high in the case of IRSOL.

Introduction

IRSOL (Istituto Ricerche Solari Locarno) was born in 1985, when the observatory was acquired from the German DFG by a newly created foundation, FIRSOL (Fondazione IRSOL). The observatory with its equipment has since not only been upgraded and modernized, but has also been greatly extended with added-on powerful new observing systems that have made it an internationally recognized facility for front-line research in solar spectro-polarimetry.

This development has been made possible through close collaboration with various institutes. The key collaboration for the scientific and instrumentation development has been with the Institute of Astronomy of ETH Zurich. In the 1980s the ETH institute used its Arosa observatory for observational work within Switzerland, but as the IRSOL facility developed into a much more powerful scientific tool than was available with the instrumentation at Arosa, ETH decided to give up the Arosa observatory in favor of IRSOL as the foremost solar observing facility in Switzerland. This new focus has contributed to the very positive development of IRSOL in recent years.

The Institute of Astronomy of ETH Zurich is currently the only place in Switzerland where university-based solar physics is being done. A new situation arises with the retirement end of 2007 of Professor Jan Stenflo, who is currently the institute head and who represents the only Swiss Chair in astronomy with a focus on solar astrophysics. However, there will be no discontinuity in the solar physics programs at ETH Zurich with Stenflo's retirement, since the recent EURYI Award to Dr. Svetlana Berdyugina (see below) guarantees a continuity of the research and the collaborative programs with IRSOL through 2010. In addition, the other senior solar physicist in Zurich, Professor Arnold Benz, will also be there and support these programs until then.

It is nevertheless timely to now review the scientific prospects for IRSOL, its position in the national and international context, and the nature and quality of the future science that can be done from IRSOL. While needing and profiting from the networks of close collaborations with various other institutes, IRSOL has in recent years developed an increasing degree of maturity and independence. This report aims at giving an overall assessment of the situation from the science point of view.

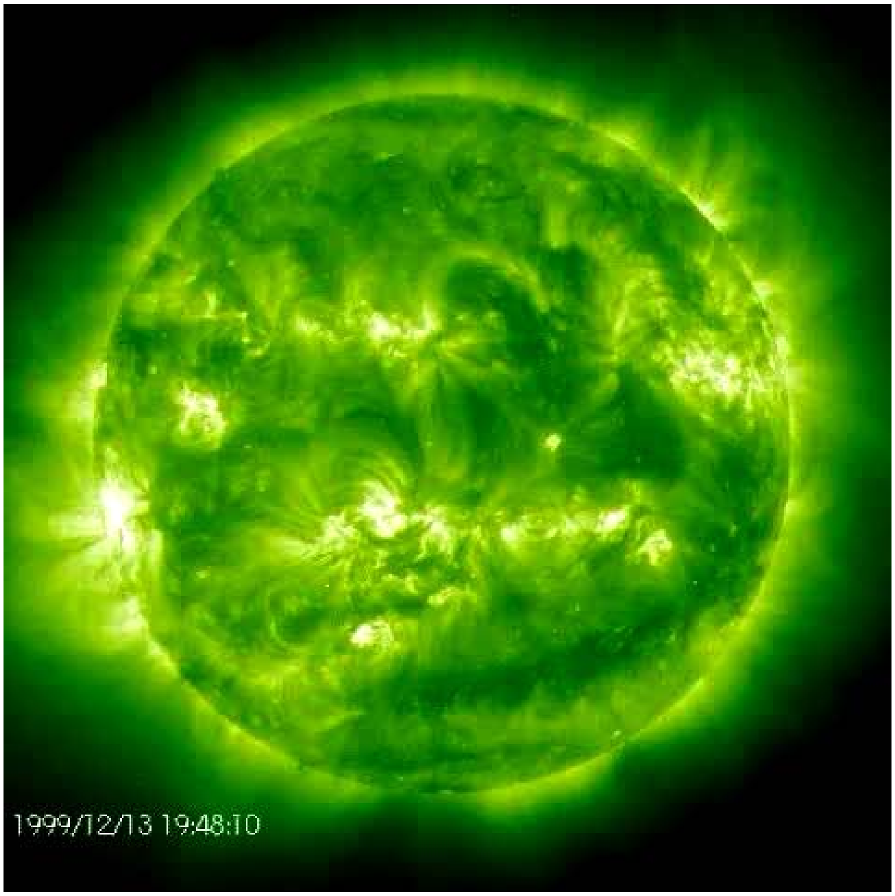
Role of solar physics in science

Solar physics is a discipline with relations to several other branches of science because of the uniqueness of the Sun: it is the only star that can be explored in great detail, and being the energy source of our solar system it affects everything in our cosmic neighborhood.

The Sun is often called the “Rosetta Stone of astrophysics”, since many astrophysical processes and tools that are needed for exploring and understanding the more distant universe are initially discovered, explored, and tested in the astrophysical laboratory that the Sun provides. Examples are the atomic-physics and radiative-transfer tools that are needed for analysing astrophysical spectra, the plasma physics, dynamo, and acceleration processes that also occur in various forms elsewhere in the universe, magnetic variability and structuring, heating processes and the generation of stellar winds, and asteroseismology to determine the internal structure of stars.

The Sun with its solar wind, eruptions and coronal mass ejections governs the violently fluctuating space weather, which is a major factor to reckon with for all manned space travel. The magnetic variability of the Sun also influences its brightness, which affects the Earth's ozone layer and the global climate in the troposphere. For the quantitative understanding of global climate change and the man-made greenhouse effect one needs to properly identify and sort out the component in the global climate system that is linked to the variable solar irradiance. This hot topic has led to collaborations between solar physicist and climatologists (in Switzerland within ETH Zurich, with the WRC/PMOD in Davos and with EAWAG in Dübendorf).

The renaissance that solar physics currently experiences is expressed by the impressive array of new and major telescopes/facilities that have come online or will do so soon. Among the new ground-based telescope projects are GONG+ (international network of observing stations for helioseismology), SOLIS (instrument system at Kitt Peak for solar synoptic observations), SST (Swedish Solar Telescope on La Palma), Gregor (next-generation German solar telescope on Tenerife), and ATST (Advanced Technology Solar Telescope, which will become the world’s largest solar telescope, to be placed on Maui, Hawaii, and become operational in 2012). In the next three years three major solar space missions will be launched (Solar B, STEREO, SDO – Solar Dynamics Observatory). The currently operating SOHO (Solar and Heliospheric Observatory) keeps producing vast amounts of excellent data about our highly dynamic, magnetized Sun. An example of an image of the Sun taken from SOHO in extreme ultraviolet radiation is seen below. In spite of these large facilities and major investments in solar science, IRSOL fills a unique ecological niche that enables it to contribute to front-line science, as we will try to clarify below.



Comparison of IRSOL as a small, national observatory with large, international facilities

It may be a common, although incorrect belief that front-line science in astrophysics can only be done at the largest telescopes at locations with the very best atmospheric seeing conditions. Each telescope facility however has its advantages and disadvantages. When comparing IRSOL, which is a medium-size, national facility, with the largest solar telescopes in the world, in the USA and on the Canary Islands, we can identify the following main advantages and disadvantages:

Advantages of IRSOL

- Telescope design, which better optimizes certain aspects that often plague the existing larger telescopes. Examples: The world's largest solar telescope, the McMath-Pierce facility at Kitt Peak (Arizona), has large and rapidly time-varying instrumental polarization, which causes serious problems when trying to do highly accurate spectro-polarimetry, as we do with ZIMPOL. In contrast, the instrumental polarization with IRSOL is much smaller and constant over the day. Another of the largest telescopes, the French THEMIS on Tenerife, has a closed design that does not easily lend itself to modifications or upgrading with new technologies or instrument ideas. In contrast, the IRSOL facility has an open environment with much space for experimentation and installation of new equipment.

- Uniqueness of ZIMPOL. No other solar observatory in the world has a ZIMPOL system, which is superior for work in the area of high-precision imaging polarimetry. The combination of IRSOL with such unique focal-plane instrumentation gives it a significant edge over other observatories for work in solar polarimetry, which has become a central topic in contemporary solar physics (see below).

- Availability of unlimited observing time, to allow observing programs that would be impossible at the larger facilities because of time limitations.

- Instant access, allowing to react immediately to events on the Sun, or to try out new scientific ideas without delay.

- Availability as an experimental facility for the development of novel instrumentation that can be transported for use at telescope facilities abroad. Examples: ZIMPOL (**Z**urich **Im**aging **Pol**arimeter) systems for imaging polarimetry, Fabry-Perot filter system.

- Educational facility (e.g. for PhD and Master thesis work) for young scientists to become mature, independent scientists.

Disadvantages

- Size (photon-collecting area). The main mirror of IRSOL has a diameter of 45 cm, while that of the world's largest solar telescope, at Kitt Peak, is 1.5 m. Since the photon-collecting area is thus about 10 times smaller at IRSOL, one would have to integrate 10 times longer to achieve the same signal-to-noise ratio in the observations as compared with Kitt Peak. If the integration time is kept the same, the noise level will be about three times larger at IRSOL.

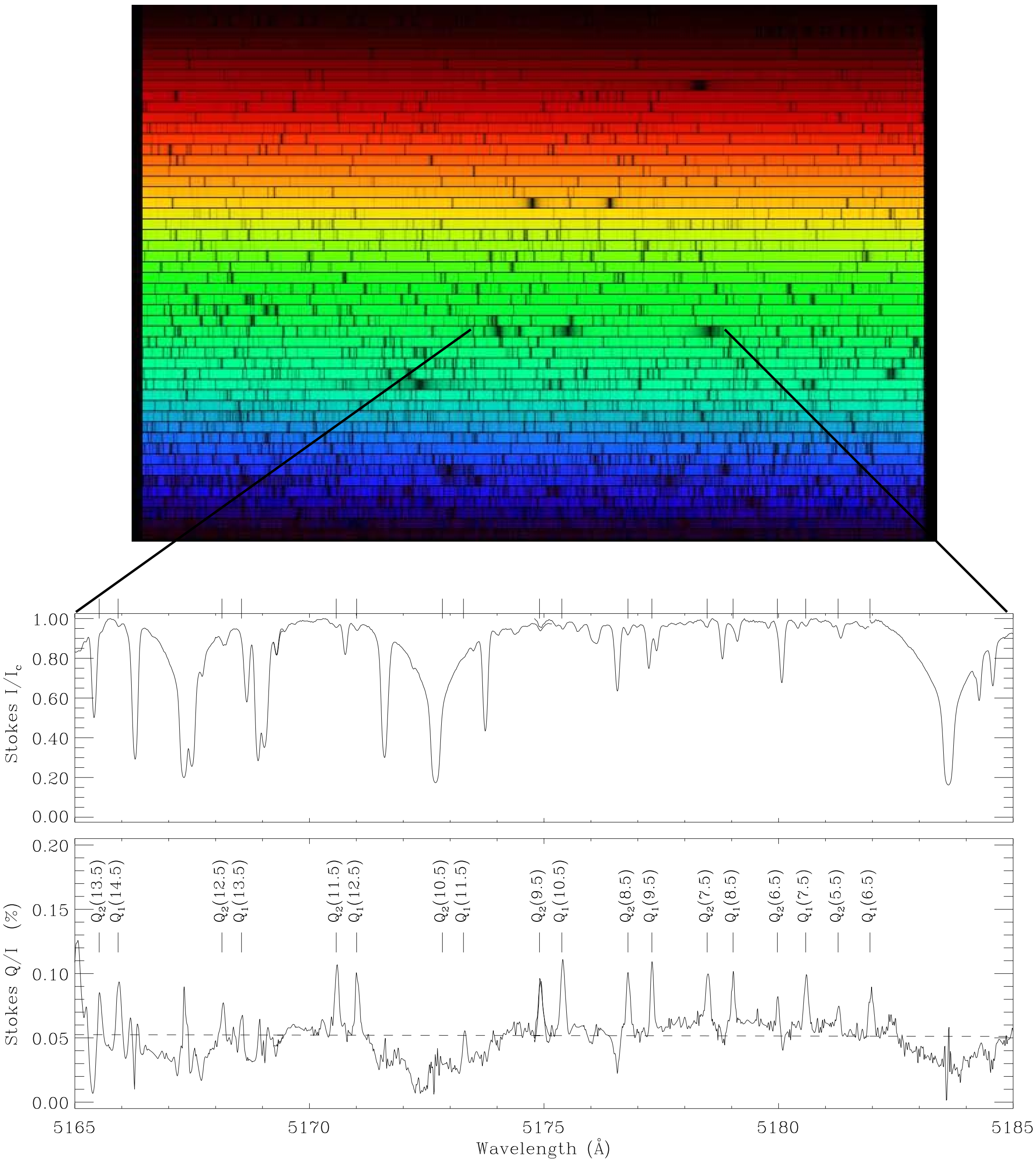
- Atmospheric seeing (image distortions due to atmospheric turbulence) at Locarno is not as good as on the Canary Islands.

The increased noise level for a smaller telescope can be partly offset by the advantage of unlimited observing time, which allows longer integrations to be better accommodated in the observations. However, when aiming for high angular resolution there are limitations on the lengths of the integration times set by the evolutionary time scale of small solar structures. Also, due to variable seeing, it is harder to achieve high image sharpness if one integrates too long. Therefore the observations at smaller telescopes need to be complemented by focused observing campaigns at the larger telescopes when the aim is for the highest spatial resolution on the Sun.

The problem of seeing degradation, both due to the non-optimum atmospheric conditions at Locarno and due to the longer integration times, can be at least partially offset by the use of the new technology of adaptive optics. In collaboration with SUPSI in Manno an adaptive optics system for IRSOL is currently under development.

Optimization for spectro-polarimetry

In solar observing programs the four main observing parameters, spatial, spectral, temporal resolution, and photometric or polarimetric accuracy, cannot all be optimized at the same time, but trade-offs are always necessary, even with the largest solar telescopes. At IRSOL, combined with the ZIMPOL systems, the polarimetric accuracy and spectral resolution have been optimized to levels not reached by anybody else (unavoidably at the expense of spatial and temporal resolution). The resulting unique advantages of IRSOL have led to the discovery of new and unpredicted polarization phenomena, in particular with respect to the so-called **“second solar spectrum”** and its properties (see illustration below). This choice of priority has given IRSOL a distinct research profile and allowed IRSOL to establish itself as an internationally leading facility in high-precision imaging spectro-polarimetry. With the implementation of the new Fabry-Perot filter and adaptive optics systems at IRSOL the trend will be to combine precise imaging polarimetry with improved spatial resolution.



*The figure above shows a small, 20 Å section from the Atlas of the Second Solar Spectrum, which was compiled from IRSOL observations carried out by Achim Gandorfer and published in book form in the year 2000. The diagram labeled Stokes I/I_c represents the normalized intensity spectrum (which may be considered as the "first solar spectrum"), while the bottom diagram labeled Stokes Q/I represents the simultaneously recorded degree of linear polarization. This polarized spectrum is called the "**second solar spectrum**" since it has little resemblance with the intensity spectrum and is formed by very different physical processes, and therefore gives complementary information about the Sun as if it were an entirely new spectrum. The spectral* *features that are identified in the above diagram are due to molecular lines from the so-called Q branch of MgH.*

Main topics in contemporary solar physics, and where IRSOL fits in

The Sun as a typical star consists of hot, magnetized plasma. The complex interaction between magnetic fields, turbulent plasma motions, and the Sun's rotation leads to a richly structured and highly variable and dynamic Sun. One wants to understand the basic mechanisms governing the various physical processes that are involved, since they are prototypical for corresponding processes that go on all the time elsewhere in the universe. Current outstanding problems in solar physics are:

- dynamo processes, by which magnetic fields are generated everywhere in the universe, including stars and galaxies, and by which sunspot and starspot cycles are produced,
- the turbulent nature of magnetic fields at the spatial scales where the fundamental astrophysical processes occur,
- heating of outer solar and stellar atmospheres, acceleration processes, and the origin of solar and stellar winds,
- plasma instabilities (which lead to eruptions and mass ejections),
- origin of the solar irradiance variability and its role for the global terrestrial climate.

In all these topical areas the magnetic field is the key physical parameter. The most direct way to remotely diagnose or measure magnetic fields on the Sun is through spectro-polarimetry, since magnetic fields imprint polarization signatures in the radiation that is emitted from the solar plasma. These magnetic-field induced polarization effects are caused by a multitude of atomic-physics processes. With the much higher polarimetric sensitivity of ZIMPOL in comparison with other corresponding instrumentation systems entirely new aspects of this polarization physics have been uncovered, which open up a number of novel diagnostic possibilities. With ZIMPOL's sensitivity IRSOL has a major advantage with respect to other solar observatories in terms of the exploration of previously “hidden” aspects of solar magnetic fields.

Examples of scientific achievements made at IRSOL

By exploiting the unique capabilities of the IRSOL instrumentation a number of internationally highly recognized scientific results and discoveries have been made at IRSOL. The following incomplete list gives some examples:

- Detection of supersonic convection on the Sun.
- Production of the widely used standard atlas of the “Second Solar Spectrum”.
- Determination of novel constraints on impact polarization in solar flares.
- First measurements of the magnetic vector in the quiet solar chromosphere.
- First clear observation of the Hanle effect in molecular lines.
- Discovery of vast amounts of hidden magnetic energy in the solar photosphere (see illustration below from the journal *Nature*).

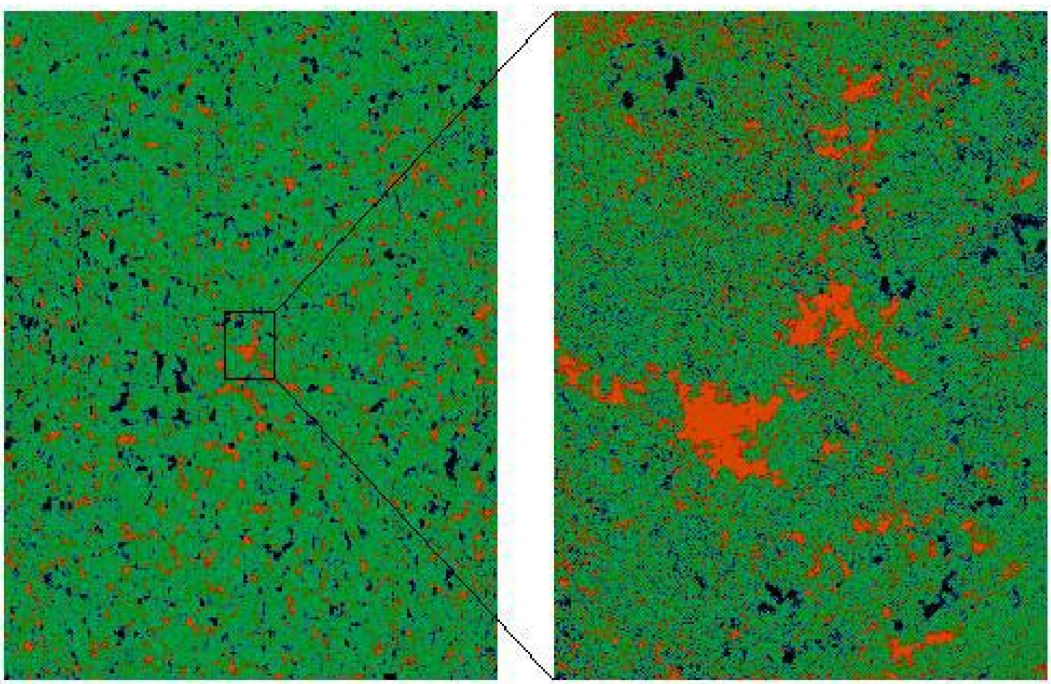


Illustration of the fractal-like pattern of magnetic fields on the quiet Sun. The rectangular area covered by the left map is about 15% of the area of the solar disk, while the map to the right covers an area that is 100 times smaller. The two maps represent patterns of circular polarization caused by the Zeeman effect. The blue and red areas correspond to magnetic flux of positive and negative polarities, separated by green voids of seemingly no flux. Analysis of Hanle-effect observations of atomic and molecular lines made at IRSOL have now shown that these green regions are actually no voids at all, but are teeming with turbulent magnetic fields that carry a significant magnetic energy density. Since these turbulent fields are tangled *with mixed polarities on very small scales, they are invisible to the Zeeman effect, while they get revealed by the Hanle effect, based on the Second Solar Spectrum. From Nature **430** (2004), 304-305 and 326-329.*

Current instrumentation developments at IRSOL

The **imaging polarimeter system ZIMPOL** (**Z**urich **Im**aging **Pol**arimeter), which has its observational home base at IRSOL, reaches a polarimetric accuracy of about 5 $x10^{-6}$. This is close to two orders of magnitude better than other systems in the astrophysical world. The development that has made this possible is the creation of fast, hidden image buffers within a CCD sensor, so that one can shift the photo charges back and forth between the illuminated and storage areas in synchrony with fast, electro-optic light modulation in the kHz range, much faster than the fluctuations of the atmospheric seeing. No other group in the world can do this. Thereby the two main noise sources, seeing noise and gain-table noise (fluctuations of the pixel sensitivities) get completely eliminated, so that the accuracy is only limited by photon statistics. ZIMPOL allows high-precision imaging polarimetry throughout the visible spectrum and the ultraviolet, down to the atmospheric cut-off near 300 nm. The ZIMPOL systems are continually being upgraded by applying the newest technologies to optimize the performance

Another major instrumentation development within the coming two years is the construction of a fully **tunable narrow-band optical filter** based on two lithium niobate Fabry-Perot etalons. In combination with ZIMPOL it will provide a new scientific dimension to the work in imaging spectro-polarimetry. The two Fabry-Perot etalons are made of an electro-optical material, lithium niobate ($LiNbO_3$), whose refractive index can be changed by an applied electric voltage. The transmission of a lithium niobate etalon can therefore be rapidly tuned in wavelength electrically. The $LiNbO_3$ crystal can be cut in different ways. The etalons chosen for IRSOL are unique in the astrophysical world by being so-called Y-cut, making the crystals birefringent. The transmission spectra are then different for the two states of polarization. This property opens the way to drastically increase the effective finesse of the system by using the etalons in double pass, a property that is not available to any other Fabry-Perot system.

A state-of-the-art **adaptive optics system** for IRSOL is currently under development in collaboration with SUPSI, the University of Applied Science in nearby Manno. The deformable mirror that will compensate the atmospheric seeing fluctuations in real time has 37 actuators. The system is near completion and will be implemented at IRSOL this year. It should allow observations close to the diffraction limit of the telescope, thus significantly enhancing the capabilities of IRSOL. In combination with ZIMPOL and the Fabry-Perot filter system, it will increase even more the potential for front-line research in spectro-polarimetry.

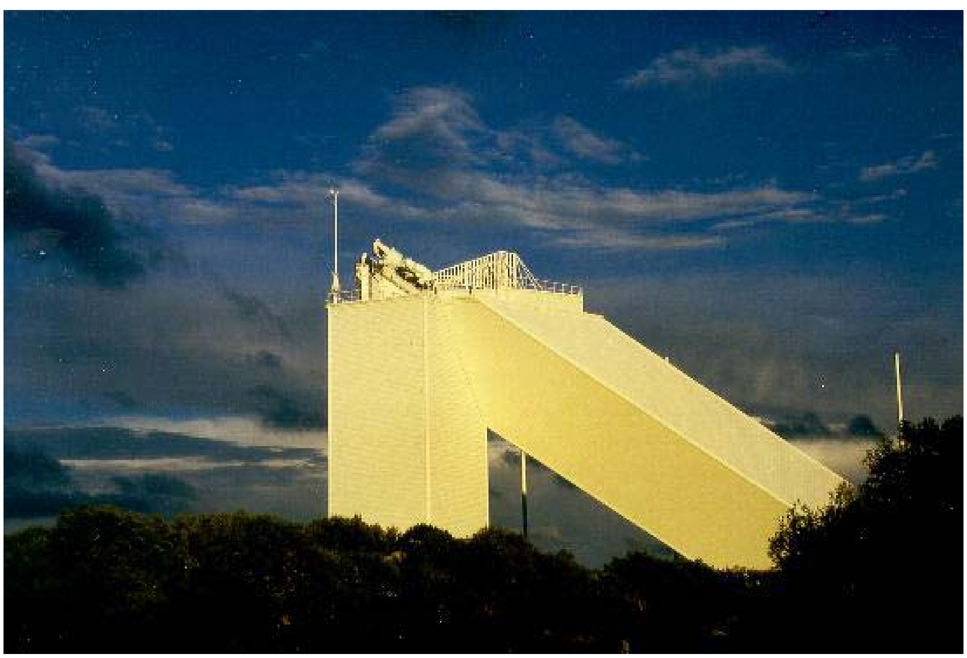
The development of novel instrumentation is expected to continue at IRSOL, to maintain the momentum and leadership in astrophysical spectro-polarimetry. One example is the recently started collaborative project with the University of Como (Italy) for the application of CMOS detectors in astrophysics.

National and international connections

IRSOL has developed a network of close links and collaborations with a number of other organizations, both nationally and internationally. Here we will first give an overview of the international connections and then have a look at the national base.

Examples of international connections

- **National Solar Observatory**, Tucson, Arizona, through the frequent use of its Kitt Peak observing facility (see illustration below), and through the participation in the **ATST** (Advanced Technology Solar Telescope) project, a future solar telescope facility to be placed on Hawaii. Prime contact person in Tucson has been the tenured staff member Prof. Christoph Keller, who earlier made his PhD at ETH Zurich within Stenflo's group, and who in June 2005 has taken up a position as Chair of Experimental Astrophysics at the University of Utrecht, Holland. Keller has developed the adaptive optics system at the Kitt Peak solar telescope and has helped design the adaptive optics system that is now being implemented at IRSOL.



The McMath-Pierce facility at Kitt Peak, which has been used on a regular basis by the ZIMPOL group to complement the IRSOL observations.

- The astronomy facilities on the **Canary Islands**. The Swiss ZIMPOL system has been used at the Swedish La Palma observatory and at the German VTT telescope on Tenerife. A close collaboration exists with Dr. Trujillo-Bueno and the scientists of his group on "Solar Magnetism and Astrophysical Spectro-polarimetry" at the IAC (Instituto Astrofisico de Canarias), La Laguna, Tenerife, who also come to IRSOL to observe with ZIMPOL. Thus the exchange goes in both directions.

- **Max-Planck-Institute for Solar System Research** in Katlenburg-Lindau, Germany. A director of this leading German institute, Prof. Sami Solanki, did his PhD at ETH Zurich within Stenflo's group.

- **Indian Institute of Astrophysics**, Bangalore. This collaboration includes regular extended visits to IRSOL by an Indian scientist, and the joint guidance of PhD thesis work at the institute in Bangalore.

- **Yunnan Observatory, Kunming**, China. They are constructing a major Chinese solar telescope for spectro-polarimetric work on the shore of a lake outside Kunming and are consulting with IRSOL to get guidance in the design of their system. For this purpose a scientist from Kunming spent one month at IRSOL last year.

- **University of Utrecht**, Holland, in particular with the appointment of Christoph Keller as the new Chair in Experimental Astronomy there.

- **University of Como**, Italy, for the development and application of CMOS detectors in astrophysics, and to receive students for thesis work at IRSOL.

- **Fachhochschule (University of Applied Science) in Wiesbaden**, Germany, for joint projects in control electronics with the research group of Prof. Gerd Küveler, in particular in the form of Master thesis projects at IRSOL by students from Wiesbaden. In this way various telescope control systems have been developed free of charge, most importantly the excellent automatic guiding and pointing system at IRSOL.

National base

- The link with the **Institute of Astronomy at ETH Zurich** has provided the backbone for the direction and activities at IRSOL. The ZIMPOL developments and the present Fabry-Perot filter system and adaptive optics implementation are funded through grants to the ETH group from the Swiss Nationalfonds. ETH has provided the students and the thesis projects that have been carried out at IRSOL. In addition to Stenflo's research group a very active and internationally highly recognized research program in solar radio and X-ray astronomy is carried out by the group of Prof. Arnold Benz. Although Stenflo will retire end of 2007, the continuation at ETH of the ZIMPOL programs in solar spectro-polarimetry will be secured until end of 2010, as explained next.

- One of the scientists in Stenflo's group, **Dr. Svetlana Berdyugina**, this year received the prestigious **EURYI (European Young Investigator) Award**. Through this award she will receive **EU funding that secures for the next 5 years a complete research group** of her own, including her own salary, one postdoc, and three PhD students. The purpose of these awards is described as follows: "... to enable and encourage outstanding young researchers from all over the world, to work in Europe for the benefit of the development of European science and for the building up of the next generation of leading researchers. EURYI Awards promote scientific excellence, with wide international recognition, by supporting these distinguished researchers to develop and pursue an independent research career, including developing a research group where appropriate. The funding available will support research aimed at opening up new lines of research including novel methodologies." In all of Switzerland and in all scientific disciplines only two scientists received a EURYI Award, Dr. Berdyugina being one of them. Dr. Berdyugina has already used IRSOL for her observations with the ZIMPOL system and has a keen interest in the development of IRSOL as a national solar facility. As her 5-year grant will start late this fall, her very dynamic solar physics research group at ETH will have a secure existence until end of 2010.

- Another major solar physics partner at the national level in Switzerland is the **PMOD/WRC (Physical-Meteorological Observatory Davos / World Radiation Center) in Davos** under the direction of Prof. Werner Schmutz. Since a number of years the Davos institute has been leading a so-called Polyproject with the title "Variability of the Sun and Global Climate", in collaboration with Stenflo's ETH institute and the Institute for Atmospheric and Climate Science at ETH. The aim has been to establish and understand the role that the Sun's magnetic variability plays in the climate system, in particular to understand the mechanisms of climate change and be able to separate the solar contribution from the anthropogenic enhancement via the greenhouse effect. Although IRSOL was not directly involved in this Polyproject, the topic is so closely related that an institutional partnership is natural. Such a partnership is already materializing with the joint project with Wiesbaden/IRSOL/Davos for a robotic telescope in Locarno to synoptically measure the Earth's albedo (through monitoring the radiation from the unilluminated side of the moon).

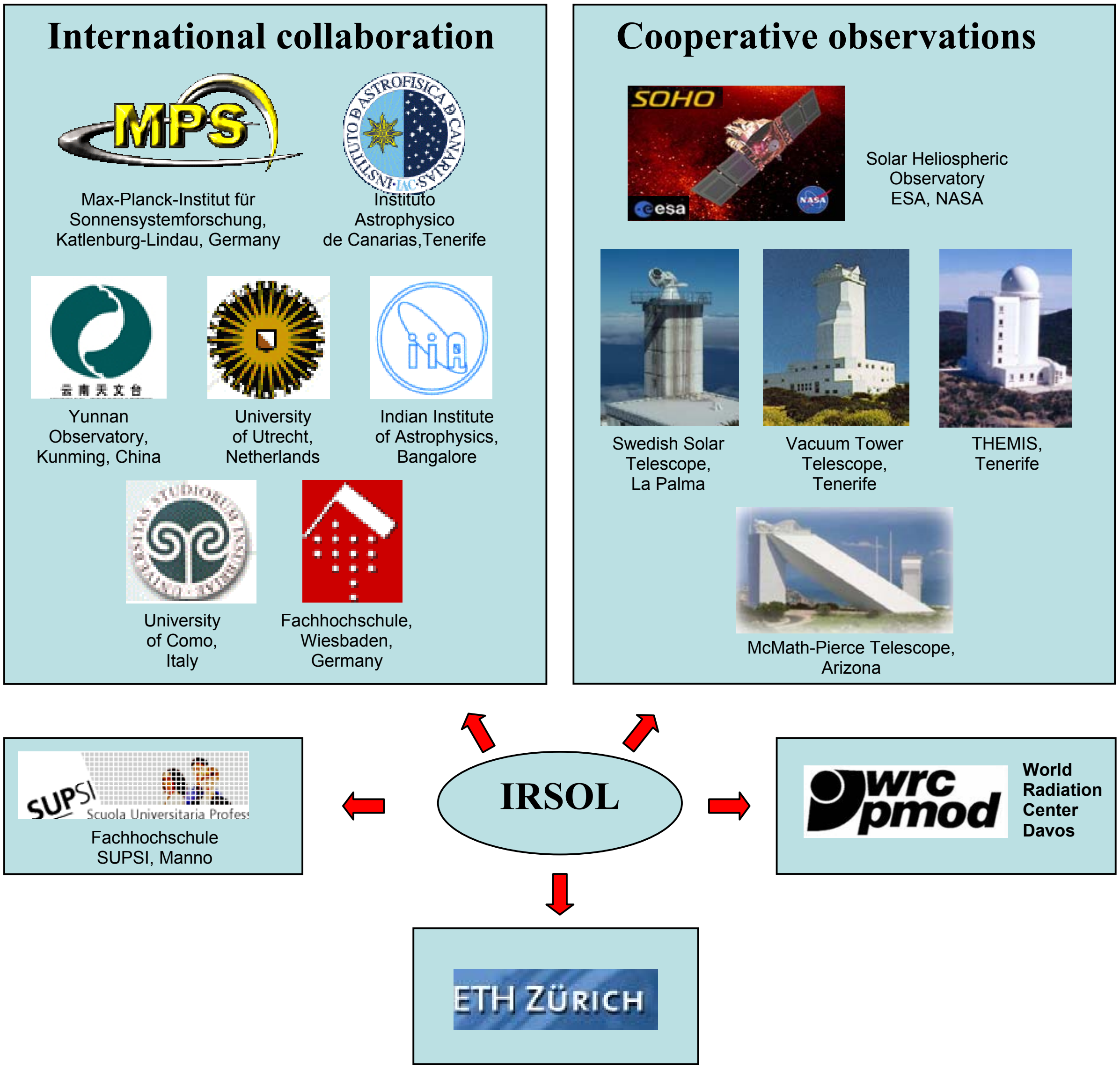
- There is a close collaboration with the **Fachhochschule (University of Applied Science) SUPSI in Manno**. In a joint project between IRSOL and the research group in mechatronics at SUPSI under the direction of Prof. Silvano Balemi, an adaptive optics system that uses a deformable mirror with 37 actuators is currently being developed at SUPSI and will be installed for use at IRSOL this year. Other collaborative projects with SUPSI are also foreseen, including student projects at IRSOL.

- There is also a link to the **Fachhochschule in Brugg (Aargau)** through Prof. André Csillaghy, who received his PhD from ETH Zurich through work at the Institute of Astronomy in the interdisciplinary area between computer science and solar astronomy. He is currently receiving US funding for his solar physics work at Brugg, and is also a member of an international consortium for a major new facility (FASR) for solar radio astronomy. Since FASR will measure the magnetic field in the solar corona while IRSOL measures it in the chromosphere and photosphere, the combination of such observations can be used to deduce the 3-D structure of solar magnetic fields.

- **EAWAG in Dübendorf** has been involved in solar physics through Dr. Jürg Beer, who is world-renown for his outstanding work on isotopic analysis of ice cores drilled in the Greenland ice, which he has used to reconstruct both the variations of the cosmic ray particle flux from the Sun and the Earth's climate over time scales of many thousands of years. He has been closely affiliated with the Polyproject mentioned above.

- The **University of Bern** has since several decades a very strong and internationally leading program in solar system science, in particular for projects to explore the solar wind and comets with in situ spacecraft, as well as planetary science. While not directly linked with IRSOL, the programs are topically related and complement each other. During past years scientists from the Institute of Applied Physics of the University of Bern have conducted optical observations of solar flares in Locarno. The International Space Science Institute (ISSI) in Bern is doing research in solar and heliospheric physics and has been conducting a series of international workshops, which often have been on solar-physics related topics.

- There are plans to establish a “Swiss **virtual solar institute**”, an umbrella organization to coordinate the solar-physics activities of the various groups within Switzerland.



Future scientific programs at IRSOL

When considering the future scientific activities at IRSOL it is important to remember the national and international context in which IRSOL is embedded. The activities at IRSOL gain strength by being closely linked to other organizations. These already well established networks to the rest of the world-wide scientific community should be nurtured and whenever possible further developed. IRSOL should not be judged as if it existed in isolation. On the contrary it serves as a home base or home facility for observational solar physics in Switzerland and is a stepping stone to the rest of the solar physics world.

To clarify the role of IRSOL in this wider context, we list the future programs at IRSOL:

- With its unique set of equipment (ZIMPOL, Fabry-Perot filter system, adaptive optics) a variety of **specialized observing programs in solar magnetism and spectro-polarimetry** will be carried out at IRSOL. In the section below we describe as an important example the planned research program at IRSOL of the EURYI Award group of Dr. Svetlana Berdyugina.

- IRSOL serves as a **stepping stone** for access to the foremost solar telescope facilities elsewhere in the world. The ZIMPOL instrumentation is transportable and has been brought on a regular basis for focused observing campaigns at the best overseas observatories, at Kitt Peak in Arizona and on the Canary Islands. It is foreseen that the past pattern of regular observing campaigns at various international facilities will continue in the future. These observations will be followed up and complemented by home-based programs at IRSOL.

- Being a national facility, IRSOL serves as an **educational institute** through a variety of student projects, from practical semester thesis projects, to more extensive Master and PhD thesis work. IRSOL allows students and young scientists to obtain concrete training in experimental science and to get in direct contact with front-line research.

- With the practically unlimited observing time available at IRSOL it becomes feasible to establish **synoptic-type programs** that are impossible at larger facilities, which are designed for short-term programs by a variety of users with different scientific aims. One such program that is currently being considered is to explore how the Hanle-effect signatures of the "hidden" magnetic flux on the Sun varies with heliographic latitude and phase of the solar cycle. This would provide a highly unique data set that would cast light on the nature of the solar dynamo, which is at the origin of solar activity in general.

- With its unique capabilities and its links to other observing facilities in the world, IRSOL can be a partner in **coordinated programs with other observatories**, either (a) for supporting-type observations that would complement the science of another project, or (b) for simultaneous observations of the same solar features with complementary sets of equipment. Under category (a) IRSOL responded in support of the RHESSI space mission for observing the Sun in hard X-rays. IRSOL generated a novel data set that provided new observational constraints on the properties of particle beams from flares. Under category (b) during the past year IRSOL did simultaneous spectro-polarimetric observations with German and French telescopes on the Canary Islands to study solar prominences and molecular scattering, and also conducted coordinated and simultaneous observations with the MDI instrument on the SOHO satellite. IRSOL should remain open for participation in such coordinated programs whenever the needs emerge.

- IRSOL serves as an **advanced solar laboratory for the development and test of new instrumentation**. This is possible in particular due to the flexible design of IRSOL, with direct access to the beam at many locations and lots of experimental space both in the observing room and in the spacious basement, where the spectrograph is located. In addition to serving as a test facility for the development of the ZIMPOL, Fabry-Perot, and adaptive optics systems, a new collaboration has recently been initiated with the University of Como (Italy) for the implementation of the new technology of CMOS detectors in astronomy. A first test of such a CMOS detector was carried out in February 2005.

Future IRSOL program of the EURYI Award group: Molecular astrophysics

IRSOL with its unique instrumentation is an excellent laboratory for developing a new field of astrophysics: studying solar and stellar magnetism by means of molecular spectro-polarimetry. This is the major goal of the EURYI Award project lead by Dr. S.V. Berdyugina. Molecules are found in a large variety of astronomical objects, ranging from comets in the solar system to galaxies at high redshifts. On the Sun, molecules are formed in the outer parts of the solar atmosphere and particularly in cool sunspots. For these regions molecular spectroscopy provides a unique tool to study their physical properties, including temperature, chemical composition and magnetic fields. Recently Dr. Berdyugina made significant progress in the quantum theory of the molecular Zeeman effect, in particular for strong magnetic fields, when internal molecular momenta strongly interact with an external magnetic field. This subject is now beginning to arouse considerable interest, giving some urgency to the development of new diagnostic techniques for studying magnetism of the Sun, cool stars and sub-stellar objects based on molecular spectroscopy. The unique instrumentation implemented at IRSOL, including the high-resolution spectrograph and ZIMPOL, enables observations of polarization in molecular lines and to recover the full vector of the magnetic field in sunspots. This is vital input for modeling solar irradiance variability and studying its effect on the Earth's climate. Molecular transitions also dominate some parts of the Second Solar Spectrum, which is caused by resonance scattering in the solar atmosphere. Moreover, turbulent magnetic fields as weak as 10 Gauss can be detected with the help of molecular transitions. One of the goals of this project is to map turbulent fields on the Sun at different levels of solar magnetic activity and to clarify their role in the generation of the global solar magnetic field. Finally, many molecular transitions, such as AlH, CaH and

FeH, have never been previously analyzed in the presence of magnetic fields. Thus the facilities of IRSOL also serve as a physical laboratory for studying internal molecular structure at extreme conditions.

Recommendation

In spite of modest financial resources IRSOL has been able to establish itself as a world-leading observatory in the area of solar spectro-polarimetry. It has developed a network of collaborations with leading observatories and solar physics groups all over the world. In addition to its ZIMPOL systems for high-sensitive imaging polarimetry it is in the process of developing and implementing a set of advanced and unique instrumentation.

We strongly recommend not only to continue the financial support of IRSOL on a long-term basis, but also to significantly increase its staff and overall budget. We conclude that the scientific return on the financial investments is particularly high in the case of IRSOL.