ESMN European Solar Magnetism Network

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Underlined items: links on the actual WWW pages

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The ESMN was a collaboration of European research groups in solar physics concentrating on the measurement and understanding of solar magnetism. It started in 1998 with a TMR grant from the EC and was subsequently funded by a RTN grant from the EC. It ended on October 31, 2006.

Print copy of these pages ESMN mid-term photograph ESMN in memoriam

1 ESMN at a glance

The ESMN was a collaboration of European solar physics research groups aiming to measure and understand solar magnetism. It was initiated as the *European Solar Magnetometry Network* funded as TMR network by a 1.3 million ECU grant from the EC during 1998 - 2002, and then continued with a 1.4 million Euro grant from the Fifth Framework RTN Programme Commission during November 1, 2002 - October 30, 2006 as the *European Solar Magnetism Network*. Unfortunately, lack of further funding then terminated the ESMN.

The ESMN sucessfully integrated the utilisation of the European solar telescopes on the Canary Islands with space observation (in particular from SOHO), data interpretation, and theoretical analysis. It employed 30 young researchers from EU and Associated countries and it organised six schools. Over 350 research papers acknowledging the ESMN were published in refereed journals and conference proceedings. In addition, the ESMN performed a host of public outreach activities.

The ESMN partners were:

- Sterrekundig Instituut, Utrecht, The Netherlands (coordination)
- Instituto de Astrofísica de Canarias, La Laguna, Spain
- Osservatorio Astronomico di Capodimonte, Naples, Italy
- Osservatorio Astrofisico di Arcetri, Florence, Italy
- Institute of Theoretical Astrophysics, Oslo, Norway
- The Institute for Solar Physics, Stockholm, Sweden
- Astrophysikalisches Institut, Potsdam, Germany
- Observatoire de Paris, Meudon, France
- ESA Solar and Solar-Terrestrial Missions Division, Noordwijk, The Netherlands
- Astronomical Institute, Ondrejov, Czech Republic
- Astronomical Institute, Tatranska Lomnica, Slovak Republic
- Department of Astronomy Eötvös University, Budapest, Hungary

2 ESMN research

ESMN stands for "*European Solar Magnetism Network*". The name specified the ESMN research topic: solar magnetism in all its facets.

Solar magnetism is one of the great challenges of astrophysics. The intricate structure of the sun's magnetic fields, the solar activity cycle and the solar influence on the heliosphere represent major quests of (astro-)physics which bear directly on the human environment. The solar magnetic fields are generated by enigmatic dynamo processes in the solar interior, are organised into the highly complex patterns of solar activity observed in the solar photosphere, dominate the structure of the outer solar atmosphere (chromosphere, transition region, corona), regulate the solar wind, affect the extended heliosphere including near-earth space weather, and underlie the solar variability which influences life on Earth through climate modulation.

The ESMN went for the roots of space weather and coronal plasma behaviour by integrating complementary European efforts to chart and understand the structure and dynamics of solar surface magnetism, the patterns by which it betrays subsurface dynamo properties, and the electrodynamical coupling to the outer solar atmosphere. At the solar surface, the magnetic fields gain dominance over the gas pressure so that the surface field configurations control what happens further out. The ESMN therefore concentrated on joint observing and analysis programs with optical solar telescopes (solar surface and lower atmosphere) and space telescopes (outer atmosphere), with considerable interpretative support from theory.

The ESMN studied the structure and dynamics of solar surface fields, the topology and evolution of solar active regions, and the electrodynamical coupling between the solar interior, photosphere, and outer atmosphere by perfecting solar magnetometry, organising joint multi-telescope observing campaigns, and analysing the results through numerical inversions and simulations.

In practice, the ESMN exploited advanced European technology - five solar telescopes at the Canary Islands and ESA's SOHO mission in space - to gain understanding of the roots of solar magnetism.

2.1 Overview

The ESMN goal was to gain basic insight in the roots of solar magnetism by establishing the structure and dynamics of magnetic fields at the solar surface, charting the patterns that constrain the solar dynamo, and identifying the magnetic coupling between the different solar regimes from the interior to the corona. The ESMN science objectives were:

(a) structure and dynamics of solar surface fields;

(b) topology and evolution of solar active regions;

(c) magnetic coupling between the solar interior, photosphere, and outer atmosphere.

The ESMN partners combined effort and expertise in a coordinated attack with the following implementation objectives:

(d) perfection of magnetometry instrumentation and methodology;

(e) solar magnetometry through multi-telescope observing campaigns;

(f) interpretation through numerical inversions and simulations.

2.2 Structure and dynamics of solar surface fields.

Solar surface magnetism consists of a remarkable hierarchy of discrete strong-field structures with highly dynamic patterning (as may be appreciated by playing the vivid speckle movies available on the DOT website. The basic entity consists of the tiny *flux tubes*. They constitute an important astrophysical paradigm, pertinent also to accretion disks and other faraway objects but directly observable only on the sun thanks to the advent of speckle image restoration and adaptive optics wavefront correction. They are arranged into a *magnetic network* pattern by convective surface flows and occur at larger density in *solar plage* (faculae) which is'¡ an important modulation ingredient in the solar irradiance. Detailed examination of the dynamical network configuration at the solar surface may also resolve the ongoing debate in what measure continuous *micro- or nano-flaring* contributes steady heating to the corona.

It is highly probable that much weaker fields permeate the *internetwork* areas between flux tube clusters, but internetwork fields were not yet diagnosed convincingly at the ESMN start. They may constitute a weak-field dynamo which may play an important role in setting solar variability.

The larger elements in the strong-field magnetic hierarchy (*pores, umbrae*, larger spots with *penumbrae*, and fully-developed *active regions*) also pose a rich variety of astrophysics research issues and contribute solar modulation input. For example, sunspot oscillations provide important lessons in magnetohydrodynamics. In particular, concerted observation and numerical simulation of wave modes have established how weak shocks travel up in the umbral chromosphere as *umbral flashes* and how *running penumbral waves* persist into the corona in the outer sunspot reaches.

Prominences are enigmatic cool condensations in the hot corona that are sustained and thermally isolated by highly complex magnetic fields. Advanced polarimetry including Hanle diagnostics permitted mapping the field configuration with unprecedented angular and temporal resolution and to establish the magnetohydrodynamical prominence structuring and instability mechanisms. These are also of interest to terrestrial studies of magnetic confinement in Tokamaks and related plasma fusion experiments.

Solar *eruptions* accelerate particles to relativistic speed and unleash powerful *coronal mass ejections* into space, producing significant effects in the near-earth environment. Multi-telescope observations combining magnetometry at high angular and temporal resolution with space diagnostics including HESSI X-ray mapping managed to catch flares and prominence eruptions while solar activity remained high during the ESMN years, and charted these events in diagnostic detail at different atmospheric levels.

2.3 Topology and evolution of solar active regions.

Active regions bring much large-scale magnetic flux to the solar surface, are the seat of eruptive activity, and provide key insights into the ill-understood dynamo processes that produce the solar activity cycle.

Bipolar active regions (simple sunspot pairs connected by coronal loops) are the building blocks of the larger and more complex active regions which produce eruptive activity when their topology favours formation of *current sheets* and occurrence of *magnetic reconnection*. Flares and prominence eruptions draw their energy from sudden relaxation of the magnetic field, but the trigger mechanism remains unknown. The precursor geometry can be identified through comparison of the before-and-after coronal field topology derived from high-resolution surface magnetometry, with extrapolative identification of magnetic nulls, separators, separatrices and quasi-separatrix layers where reconnection may occur, and with special emphasis on the topological role of field helicity.

Active regions result from the emergence of flux tube systems that rise from the base of the convection zone through buoyancy influenced by the Coriolis force, magnetic tension, drag, vorticity and other effects. The emergence and disappearance of active regions and their preferential grouping in *activity nests* over long time scales betray solar dynamo properties that also contribute to the erratic cyclical modulation of solar activity. The observational strategy to understand this behaviour was to combine solar surface magnetometry with sufficient resolution, field size and duration with numerical dynamo modelling. MDI on SOHO was the key long-sequence instrument while shorter-duration studies of individual active regions at higher resolution will shed light on active region emergence and decay.

2.4 Magnetic coupling between the solar interior, photosphere and outer atmosphere.

The solar surface is not only the layer where the bulk of the solar radiation leaves our star and where the dynamo patterns generated in the interior are directly observable, but it is also the layer where gas pressure gives in to magnetic pressure. The dynamics of the photosphere with its granulation and turbulent wave excitation is hydrodynamically controlled outside active regions, but the coronal topology and dynamics are governed by magnetism. Since the coronal fields are rooted in the photosphere (no magnetic monopoles) their changing configurations are dictated by photospheric foot point motions: there is *magnetic coupling* between the regimes. It is also likely that MHD disturbances excited in the low atmosphere contribute substantially to coronal heating and the generation of the solar wind.

Just above the photosphere the flux tubes merge into the *chromospheric network*. It contributes most of the solar variability in the ultraviolet but the network heating process has not yet been identified. Likely candidates are various types of magnetohydrodynamic waves and dissipation of magnetic shear and stress induced by the perpetual displacements of the photospheric tubes. Mapping time-dependent flux tube topology and analysing flux tube dynamics is a high-priority quest for high-resolution magnetometry.

Yet higher up, the magnetic network expands into *magnetic canopies* above which all gas motions are constrained by the ambient field. Canopy geometries, canopy dynamics (including wave mode conversions from acoustic and internal gravity to Alfvén waves) and canopy linkages across network cells were key research topics for concerted photosphere-chromosphere imaging during the ESMN years.

At coronal levels, the basic building block is the *coronal loop*, delineating slender field configurations at specific temperature that become visible through density contrasts. The connection between the basic photospheric and coronal field structures is highly enigmatic–how do tubes turn into loops? Observations in H alpha and EUV lines indicate a plethora of low-lying finely-scaled structures with rapid large-amplitude dynamical changes, making clear that traditional assumptions as hydrostatic equilibrium and axial symmetry ("plane-parallel layers" with a "transition region") are now replaced by much more sophisticated magnetohydrodynamical modelling and interpretation based on multi-diagnostic ground- and space-based data gathering.

Interest in the electrodynamical coupling between the low and high solar atmosphere transcends solar physics because via the solar wind, cosmic ray modulation, and coronal mass ejections it extends to the near-earth environment and the terrestrial climate.

2.5 Canary Island Telescopes

A Europe-wide effort (by JOSO = Joint Organisation for Solar Observations) has established the Canary Islands as a "most-favoured" region for solar observing. A quintet of advanced solar telescopes on the Canary Islands constitutes the ESMN's "capital" in cutting-edge telescope technology. Each telescope represents represent the state of the art in key techniques. Collectively, they represent a formidable and unsurpassed facility for solar research, in particular solar surface magnetometry. The five telescopes are highly complementary, so that multi-telescope co-observing was a major ESMN strategy.

They are, respectively:

- VTT: the major German telescope on Tenerife, with 70 cm aperture and a focal length of 46 m. It uses a coelostat system to feed the light into the telescope. The VTT can be operated with an image stabilizing system. Postfocus instrumentation includes a vertical Echelle spectrograph with 15 m focal length, a filter device for simultaneous observation of solar images in several wavelengths, and an optical laboratory with a Fabry Perot interferometer. Website: www.kis.uni-freiburg.de/kiswwwe2.html.
- THEMIS: the major French-Italian facility for groundbased solar physics which came into full operation on Tenerife in 1999. At 90 cm aperture presently one of the larger solar telescopes in the world, it has excellent potential in high-precision polarimetry, including observation of the so-called "second solar spectrum" (near-limb linear polarisation). The THEMIS consortium is still designing an adaptive optics system to be integrated with the telescope in order to optimise the performance with respect to angular resolution, while the Arcetri team developed the Interferometric Bidimensional Spectrometer (IBIS). It is presently functional at the Dunn Solar Telescope in the USA. Website: www.themis.iac.es.
- DOT: a much smaller but revolutionary telescope on La Palma built and operated by the Dutch ESMN team. Its open structure represents the first test of the non-vacuum technology needed for future solar telescopes with apertures to exceed the size limit set by vacuum windows, a tactic now followed elsewhere in new telescope projects. After its initial test period including highly successful trials of speckle reconstruction, the DOT was equipped with a sophisticated six-camera speckle acquisition system that made it

an ideal high-resolution (0.2 arcsec) context mapper for nearly any ESMN observing campaign. Website: www.staff.science.uu.nl/ rutte101/dot.

- SST: the Swedish ESMN team has successfully rebuilt their former solar telescope (SVST) on La Palma into a twice-larger telescope, the Swedish 1-m Solar Telescope, which delivers the first 0.1 arcsec angular resolution, a quantum jump in observational solar physics. The project originated from adaptive optics tests at the SVST which demonstrated that this technology is sufficiently mature to become a standard asset in optical solar observing (harder than in nighttime astronomy since the sun is an extended low-contrast object and actually low on photons at high resolution within the solar scene change time). The SST now defines the state of the art in high-resolution solar imaging. Website: www.astro.su.se/groups/solar.
- GREGOR: a similar rebuilding of the former German Gregory-Coudé Telescope on Tenerife to larger aperture, being undertaken as a national German project involving the Potsdam and Ondrejov teams. GRGEOR will be a 1.5 m open reflector with adaptive optics that will advance the state of the art in high-resolution magnetometry to well beyond the one-meter aperture class reached (almost) by THEMIS and SST. The axially symmetric design will allow high-precision spectropolarimetry with very low instrumental polarisation. It may be operational by 2011, hopefully. Website: gregor.kis.uni-freiburg.de.

2.6 Space missions

SOHO (Solar and Heliospheric Observatory) remained the flagship of spacebased solar physics durng the ESMN years. SOHO keeps operating very successfully while orbiting the first Lagrangian point of the sun-earth system. The US TRACE mission adds ultraviolet imaging, often in concert with SOHO's Michelson Doppler Imager (MDI) and groundbased magnetometry. The Japanese-led Hinode mission was launched in 2006 and put the first Stokes vector spectropolarimeter in space. Subsequently, the Solar Orbiter mission accepted by ESA will put a solar magnetograph as close as 0.2 AU to the sun at steadily increasing out-of-ecliptic latitude. These major space projects effectively confirm the importance of the ESMN research topic and represent an important career perspective for the young ESMN researchers.

2.7 Spatial resolution enhancement

The atmospheric seeing, the bad influence of the earth's atmosphere on solar image sharpness, is a limiting factor to image quality even at the Canary Island sites. Improvements are possible through phase diversity plus speckle restoration and through the application of adaptive optics. These techniques are presently coming of age. By advancing these techniques, ESMN collaborations effectively enhanced the frequency of top-resolution data gathering at the Canaries by as much as a factor of three to four, a capital increase in telescope efficiency.

2.8 Stokes magnetometry

The state of the art in Stokes vector spectropolarimetry (measuring all four Stokes parameters I, Q, U and V through complex polarisation diagnostics and calibration procedures) is currently reached most prominently by the TIP (Tenerife Infrared Polarimeter) installed by the La Laguna at the German VTT telescope. The further development of Stokes spectropolarimetry was a large-priority activity in many ESMN teams.

In additon, the La laguna, Meudon and Arcetri teams together were world leader in the theory and calibration of polarised radiative transfer, with much ESMN-linked effort on inversion methodology. These programs strengthen the diagnostic value of solar magnetometry because Stokes vector spectropolarimetry requires sophisticated spectral-line modelling to derive the magnetic field vector amplitude and orientation. The huge amounts of data that the new instruments generate are handled efficiently by artificial neural networks as developed by the Potsdam team.

2.9 Polarised radiative transfer

The ESMN also encompasses efforts in the theory and numerical modelling of polarised radiative transfer, including new inversion methodology. These programs strengthen the diagnostic value of solar magnetometry. Stokes vector magnetographs require sophisticated spectral-line modelling to derive the magnetic field vector amplitude and orientation. The new magnetographs require such elaborate methods for optimum data interpretation.

2.10 Numerical modelling

Direct confrontation of observations with concerted numerical modelling has proven to be a particularly fruitful solar physics venue. ESMN collaborations led by the group at Oslo used (and use) actual data as simulation input in order to enable direct comparison with diverse observational diagnostics including spectral sequences from Canary Island telescopes and from SOHO. The same forward-modeling-plus-reproduction approach was taken by the Budapest team with regards to active region patterning and by the Potsdam group in simulating magneto-atmospheric waves in sunspot atmospheres.

2.11 Task division

The ESMN program divided the research objectives over detailed tasks in which the partner teams collaborated in various combinations according to their expertise. By and large the topic distribution was as follows:

- Sterrekundig Instituut (Utrecht):
  DOT tmomographic magnetometry, magnetic topology, chromospheric dynamics, observing campaigns, network coordination
- Instituto de Astrofísica de Canarias (La Laguna):
  Liquid-crystal magnetometry, polarised radiative transfer, magnetic topology, activity patterns
- Osservatorio Astronomico di Capodimonte (Naples):
  Theory of line formation, MOF development
- Osservatorio Astrofisico di Arcetri (Florence):
  Theory of polarised radiative transfer, IBIS development, solar activity
- Institute of Theoretical Astrophysics (Oslo):
  Numerical modelling, magnetic topology, dynamical processes, SST and SOHO observations
- Institute for Solar Physics (Stockholm):
  SST high-resolution observing, spatial resolution enhancement, spectropolarimetry
- Astrophysikalisches Institut (Potsdam):
  Numerical modelling, magnetic topology, dynamical processes, observing campaigns, GREGOR development
- Observatoire de Paris (Meudon):
  THEMIS magnetometry, polarised radiative transfer, solar activity and activity patterns
- ESA Solar and Solar-Terrestrial Missions Division (Noordwijk):
  SOHO observations, magnetic topology, dynamical processes
- Astronomical Institute (Ondrejov):
  High-resolution data analysis, inversion techniques, prominence modeling, observing
- Astronomical Institute (Tatranska Lomnica):
  High-resolution data analysis, observing, solar activity
- Astronomy Department Eötvös University (Budapest):
  Dynamo theory, activity patterns

3 ESMN Fellows

The European Commission funded young-researcher Fellowships at the ESMN partner institutes in Utrecht, La Laguna, Naples, Arcetri, Oslo, Stockholm, Potsdam, Meudon, and Noordwijk:

Peter Sütterlin
Olaf Dittmann
Cristina Gabellieri
Laura Merenda
Klaus Pushmann
Regina Aznar Cuadrado
Carla Gil
Jack Ireland (twice)
Etienne Vogt
Colin Rosenthal
Bertil Dorch
Boris Gudiksen
Karin Muglach
Marcelo Lopez Fuentes
Kostas Tziotziou (twice)
Eoghan O'Shea
Axel Settele
Arek Berlicki (twice)
Moncef Derouich
Katja Janssen
Andrés Asensio Ramos
Luc Rouppe van der Voort
Kai Langhans
Monica Sánchez Cuberes
Peter Gömöry
Arek Berlicki (twice)
Jaroslav Dudík
Stéphane Régnier.

The eligibility for ESMN vacancies was limited by strict EC rules specified in detail at the pertinent EC site. They were open exclusively to nationals of European Union countries (*Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, Sweden, United Kingdom plus the new member countries Republic of Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Malta, Poland, Slovakia, Slovenia*) and to nationals of the so-called Associated States (*Bulgaria, Romania, Iceland, Liechtenstein, Norway, Israel, Switzerland*). They were only available to persons from such countries that were not a national of the hiring country nor had been working there for more than 12 out of the past 24 months. Applicants had to be below 36 years of age, excepting allowance for military service or maternity leave.

Applications had to be sent by email to the pertinent scientists in charge. Unless stipulated otherwise, applications had to include a curriculum vitae, a publication list, a summary of past and current research expertise and interests, the names and email addresses of two persons willing to supply references, a motivation why the applicant selected this group, and the prefered starting date. The documentation had to be provided as ASCII or pdf files in email attachments or made downloadable from WWW. Microsoft Word .doc files were not accepted.

4 ESMN schools

One action of the ESMN Training Programme concerned the organisation of advanced schools. There have been six ESMN schools in total.

The first three ESMN schools were organised in Oslo (1999), Tenerife (2000), and Dwingeloo (2002) during the initial ESMN incarnation as *European Solar Magnetometry Network*.

ESMN-4, the first school of the second ESMN, was organised by and took place at the Oslo Institute of Theoretical Astronomy during June 2 - 13, 2003. The school title was em Radiative Transfer and Numerical Magnetohydrodynamics. It taught basic understanding of radiation, radiative transfer, polarimetry and numerical magnetohydrodynamics in the context of stellar atmospheres. Special emphasis was given to applications through practical work with numerical methods. More detail is available here.

ESMN-5, the second school of the second ESMN, was integrated into the regular sequence of Canary Island Winter Schools organized by the IAC as number XV, *Mission and Payload Definition in Space Sciences*. It was a two-week course during 17 - 28 November, 2003 in which many aspects of space science missions were treated by experts from around the world, concentrating on the ESA program Cosmic Vision 2020 programme. More information is found here and in the detailed school program.

ESMN-6, the third school of the second ESMN, taught "Solar Magnetometry and Solar Magnetism" and took place at Tatranska Lomnica during November 3 - 10, 2004. It was an extensive and intensive introduction in the methodology and results of current solar physics research concentrating on solar magnetism. More information is given here.

5 ESMN training

The ESMN training component was designed to meet the following needs:

- *Space weather:* the increasing global importance of the influence of explosive events in the solar atmosphere on the Earth's magnetosphere and of solar activity on the terrestrial climate increases the need for young researchers that are trained in gathering, analysing and interpreting solar magnetism data.
- *Utilisation of European facilities:* the Canary Island telescopes and the SOHO mission are large investments that have brought Europe to the forefront in the field. This position is to be exploited and strengthened, the more so since solar magnetism and space weather will constitute a field of intense world-wide endeavour also after the project duration.
- *Job perspectives:* the Network schools young researchers in techniques that are highly valuable also outside solar physics or space weather applications, gaining much experience in high-speed data acquisition, large-volume data handling, sophisticated analysis techniques, and more generally in complex problem solving including numerical simulations at the forefront of computational physics. Such researchers are an asset to Europe's high-technology economy.

The ESMN training program encompasssed extensive Fellow training in solar physics research at each partner, 30 Fellowships in total. It additionally contained the following specific elements:

- *Optical observing technology:* optical solar telescopes, secondary optics including adaptive optics, polarimetry technology, fast-readout CCD technology, and large-volume data acquisition.
- *Observing strategies:* through sharing in the joint observing campaigns including the pre- and post-campaign planning and evaluation.
- *Data reduction and analysis techniques:* training in sophisticated computer methods to handle large amounts of data, often involving large-volume electronic transfer.
- *ESMN schools.* Six postdoctoral schools were organised by th ESMN, respectively on radiation hydrodynamics, spectropolarimetry, and solar magnetism and space weather.
- *Advanced seminars.* Fellows located at the university partners took part in the advanced seminars run at these institutions.

- *Postdoc exchanges.* The ESMN established frequent Fellow exchange between partners, and also between partner telescopes.
- *International meetings.* The ESMN made all Fellows attend Network meetings at least once a year, and made them participate in other meetings of interest such as solar physics Euroconferences.
- *Presentation training.* All ESMN Fellows were required to represent the ESMN and to present their own work frequently at international meetings, and described their work in ESMN context including formal EC reporting and reviewing.
- *Multidisciplinarity.* Most ESMN Fellows received extensive training in advanced computing and computer system management, in particular in handling large data rates and data volumes.
- *Training at industry.* The ESMN exploited its linkages to industry in its Fellow training.

6 ESMN documents

The following links supply ESMN documents in time-reverse order:

- ESMN-2 periodic report November 2005 - October 2006 and Final Report
- ESMN-2 periodic report November 2004 - October 2005
- ESMN-2 periodic report November 2003 - October 2004 and Mid-Term Report
- ESMN-2 periodic report November 2002 - October 2003
- European Solar Magnetism Network
- ESMN-1 final report
- ESMN / European Solar Physics Research Area