

Recent Space Weather Advances by Research Community in Italy

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President of SWICO (Italian Space Weather Community)

Outline

Space weather-related thematic areas

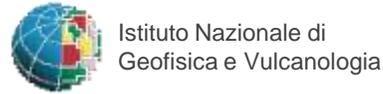
- Italian strategic Initiatives
- Research and Technology Development in the fields of:
 - Solar Physics
 - Interplanetary Space and Solar-Terrestrial Physics
 - Geomagnetism
 - Upper Atmosphere Physics





Italian Space Weather strategic initiatives

Italy at UN – Office for Outer Space Affairs



INGV and ASI are the Italian representatives at the **Space Weather Expert Group** of COPUOS (Committee on the Peaceful Uses of Outer Space)

Italy at ISWI



INGV and ICTP are the Italian co-coordinators in ISWI (**International Space Weather Initiative**).

Italy at SCAR – Scientific Committee for Antarctic Research



Italy leads the SCAR expert group called GRAPE (**GNSS Research and Application for Polar Environment**).



GRAPE is a joint GeoSciences and Physical Sciences Expert Group lasting from 2012 to 2020. 13 countries are involved (**new members are welcome!**).



Main Objectives

- GNSS ionospheric network coordination
- **Development of Space Weather tools**
- Investigate physical mechanisms
- Retrieve tropospheric PWV

<http://www.grape.scar.org>

Italy at ICAO



INGV in collaboration with ENAC (the Italian Civil Aviation Authority) is member of the PECASUS European consortium approved as one of the three **SPACE WEATHER INFORMATION GLOBAL PROVIDERS IN SUPPORT OF INTERNATIONAL AIR NAVIGATION BY ICAO**

Company/Organization	Country
Finnish Meteorological Institute (FMI)	Finland
Solar-Terrestrial Centre of Excellence (STCE)	Belgium
Met Office (UKMO)	United Kingdom
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)	Germany
Royal Netherlands Meteorological Institute (KNMI)	Netherlands
Centrum Badan Kosmicznych Polskiej Akademii Nauk (SRC)	Poland
Istituto Nazionale di Geofisica e Vulcanologia (INGV)	Italy
Seibersdorf Labor GmbH (SL)	Austria
The Cyprus Department of Meteorology (DoM)	Cyprus

SANSA, South Africa National Space Agency is in the process to join the PECASUS consortium

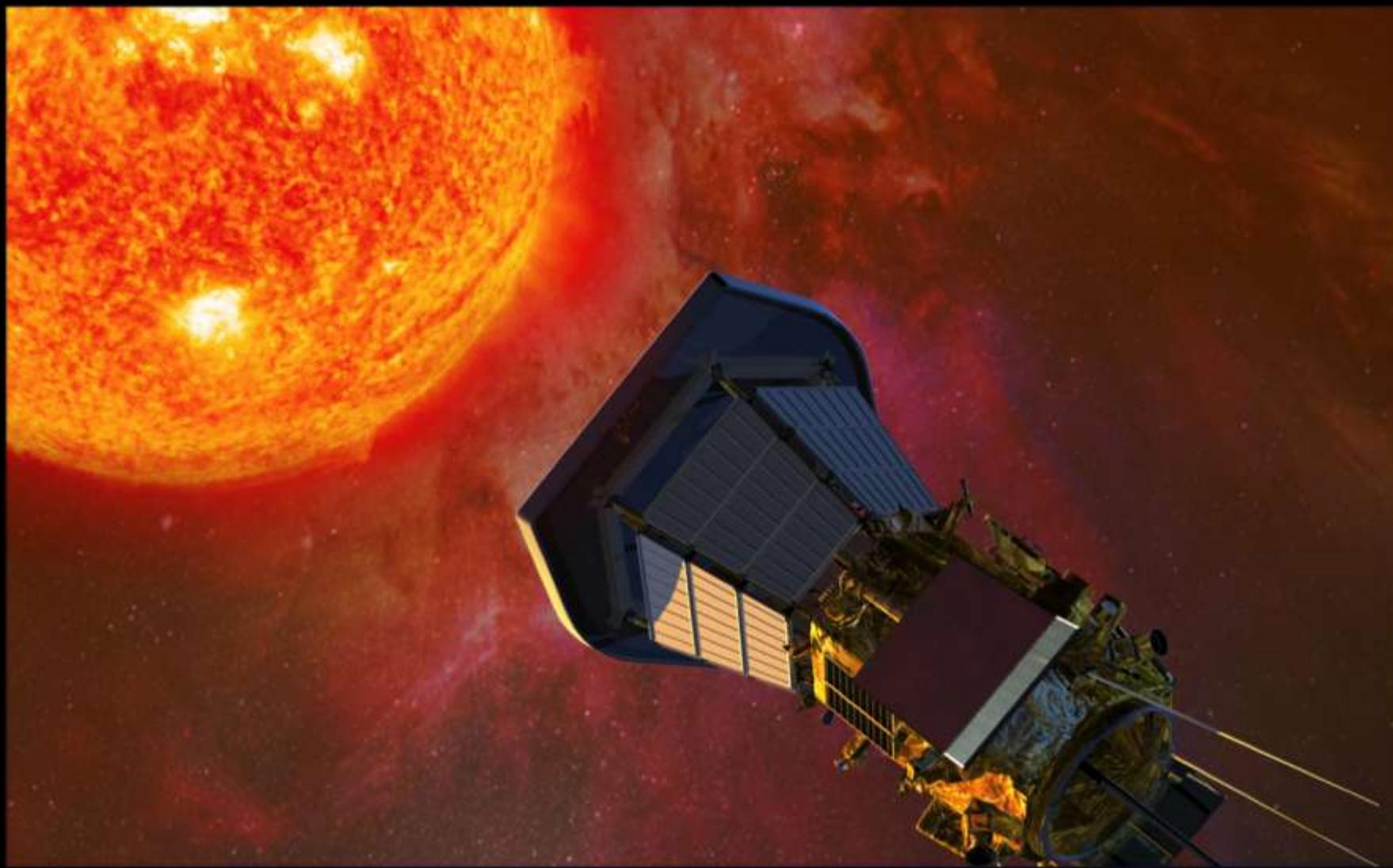


INAF National Space Weather Service Network (NSWSN)



INAF-Astrophysical Observatory of Turin	<ul style="list-style-type: none"> • HELIOSPHERIC DATA AND SWX CENTRE • SOHO & SOLAR ORBITER/METIS DATA ARCHIVES
INAF-Astronomical Observatory of Trieste	<ul style="list-style-type: none"> • TRIESTE SOLAR RADIO WEATHER CENTRE • SOLAR RADIO ARCHIVE
INAF-Astronomical Observatory of Rome	<ul style="list-style-type: none"> • PRECISION SOLAR PHOTOMETRIC TELESCOPE (PSPT) • HR SPECTROPOLARIMETER IBIS DATA ARCHIVE • HISTORICAL SOLAR IMAGES DIGITAL ARCHIVE • SOLAR ACTIVITY MOF MONITOR (SAMM) • SVIRCO NEUTRON MONITOR
INAF-Institute of Space Astrophysics and Planetology (Rome)	<ul style="list-style-type: none"> • DOME C EAST & NORTH HF RADAR IN ANTARCTIC (SUPERDARN) • MAGNETOSPHERIC AND IONOSPHERIC OBSERVATIONS • SOLAR WIND AND IONOSPHERIC PLASMA SIMULATOR (SWIPS)
INAF-Astronomical Observatory of Naples	<ul style="list-style-type: none"> • SOLAR MAGNETO-OPTICAL-FILTER IMAGING (VAMOS)
INAF-Astrophysical Observatory of Catania	<ul style="list-style-type: none"> • SOLAR H-ALPHA & 656.78 nm IMAGING
INAF-Astronomical Observatory of Cagliari INAF-Institute of Radio Astronomy	<ul style="list-style-type: none"> • K-BAND HR SOLAR RADIO IMAGING

Solar physics and Space Weather



Research Fields

Solar Physics

Solar-Terrestrial Physics

Physics of the Ionosphere

Planetary Space Weather

Study of technological and biological impacts
of space weather

Galactic Cosmic Ray Physics

Participation in **Missions** related to circum-terrestrial and planetary Space Weather

- ESA/SolarOrbiter
- ESA/JUICE
- NASA/JUNO
- ESA/JAXA BepiColombo (Launched 20 October 2018)

Scientific Research topics and related activities

- Study of the plasma and magnetic field perturbations and instabilities in solar active regions
- Study of the magnetic field tomography and evolution in the solar atmosphere through high resolution spectropolarimetric imaging
- Investigation of the interplanetary propagation of Solar Energetic Particles (SEPs);
- Modeling of the SEP-GLE coupling processes during extreme events
- Study of the solar wind thermodynamics during the expansion in the inner heliosphere;
- Investigation of dissipation mechanisms and particle acceleration in collisionless plasmas;
- Ionospheric disturbances and upper atmosphere processes investigations;
- Study of the dynamics of the plasma-environment interactions in different regions of the Outer Solar System, with special emphasis on the Jovian system;
- Study of the interactions of the solar wind and SEPs with the planets of the Inner Solar System, with special emphasis on Mercury and Venus;
- Definition of payload science objectives for future SW and PSW missions
- Participation in R&D activities related to Space Weather

Methods

- Theoretical and Numerical Modeling;
- Data Analysis;

Towards **ASPIS**, ASI's Scientific Space Weather Data center

C. Plainaki, B. Negri, M. Castronuovo, M. Giardino, A. Ippolito and the **ASI Space Weather Scientific Team**

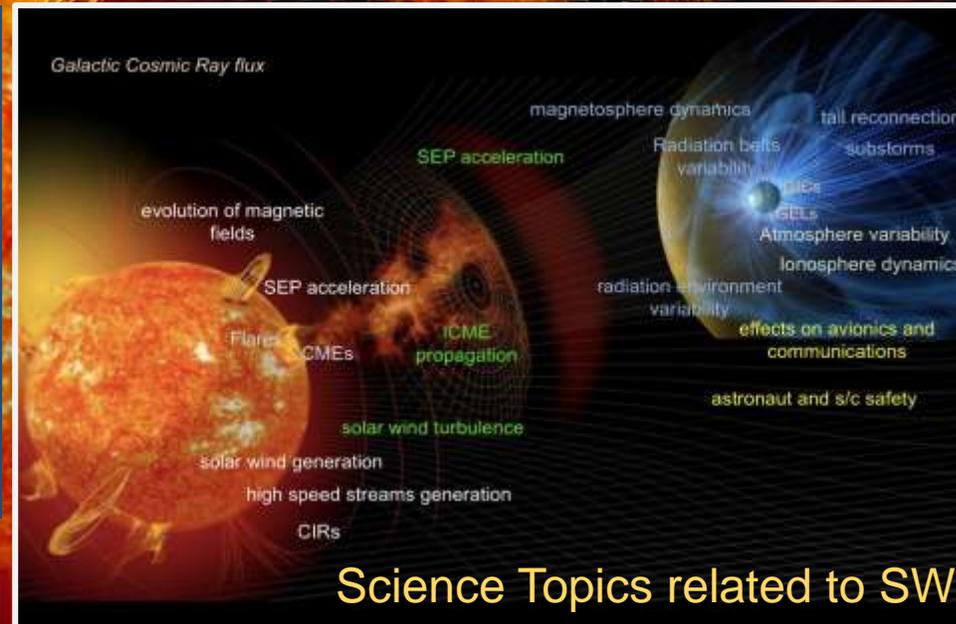
Since 2018, the Italian Space Agency coordinates the national **Space Weather Working Group** (ASI SW WG) which gathers experts from different National Institutions and Organizations, including ASI, INAF, INFN, INGV, Aeronautica Militare (Air Force), Università degli Studi di Perugia, Università degli Studi di Tor Vergata, Università degli Studi di Trento.

Recently, **"Italy's Roadmap towards Space Weather Science"** was agreed among the members of the ASI SW WG (Plainaki et al. (2019), under revision in SWSC), using as a starting point the initial proposal by ASI for a Roadmap envisioning the development of a prototype of a **National Scientific Space Weather Data centre (ASPIS)**. ASPIS will host the existing tools and related data archives obtained by the Italian Space Weather assets, to encourage **synergies** between different science teams with interest in the field and to **motivate innovation** and **new mission concept development**.

The proposed Roadmap is a long-term strategy for the development of Space Weather scientific activities in Italy.

The Roadmap was presented to the scientific and industrial communities as well as to Institutions and Organizations involved in Space Weather activities, during a dedicated Workshop organized by ASI in Dec 2018

<https://www.asi.it/it/eventi/workshop/workshop-space-weather-0>



The whole scheme is intended in the frame of a collaborative environment for research and technology development

Credit: Christina Plainaki, ASI - Italy

Currently, the **ASI SW WG** is working on the development of a Roadmap Implementation Plan



Solar Physics Group in Catania

Personnel

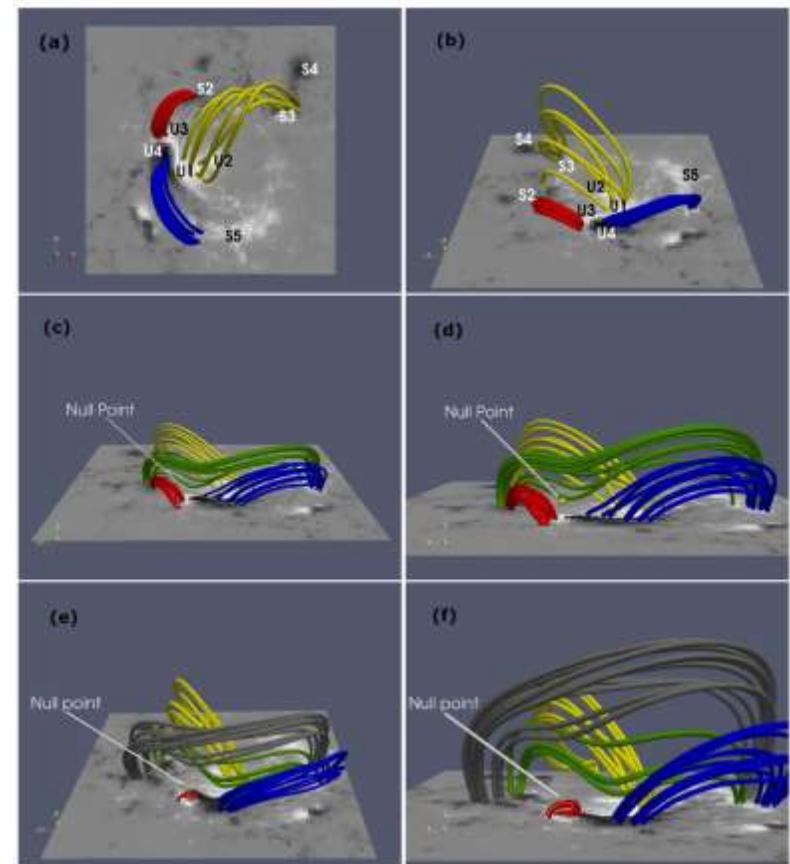
P. Costa (INAF), S. Dolei (INAF), M. Falco (INAF), S.L. Guglielmino (UniCT), P. Romano (INAF), D. Spadaro (INAF), R. Ventura (INAF), F. Zuccarello (UniCT).

Main Research Fields

Participation in the European Solar Telescope Design Phase; Participation in the Solar Orbiter mission; Participation to the ESA - Space Situational Awareness Program; Emergence of magnetic flux tubes in the solar atmosphere; Formation and evolution of solar active regions; Flares and Coronal Mass Ejections: drivers, early coronal propagation and effects on the space environment; Solar Wind source regions, Space Weather.

Methods

- Coordinated observing campaigns using ground-based and space-based satellites
- Analysis of spectroscopic and spectro-polarimetric data acquired from space and ground.
- Design and development of new instrumentation for future ground-based observations.



Falco et al., JSWSC, in press

Dolei et al., A&A, in press

Murabito et al., ApJ, 873, 126, 2019

Romano et al., Sol. Phys., 294, 4, 2019

Romano et al., ApJ, 852, L10, 2018

Guglielmino et al., ApJ, 871, 82, 2019

Murabito et al., ApJ, 855, 58, 2018

Guglielmino et al., ApJ, 856, 127, 2018

Guglielmino et al., IAUS, 340, 251, 2018

Dolei et al., A&A, 612, A84, 2018



Main projects of Solar Physics Group in Catania

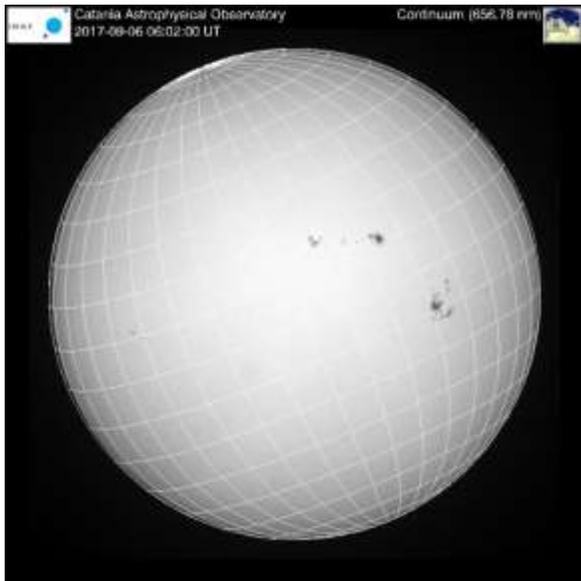
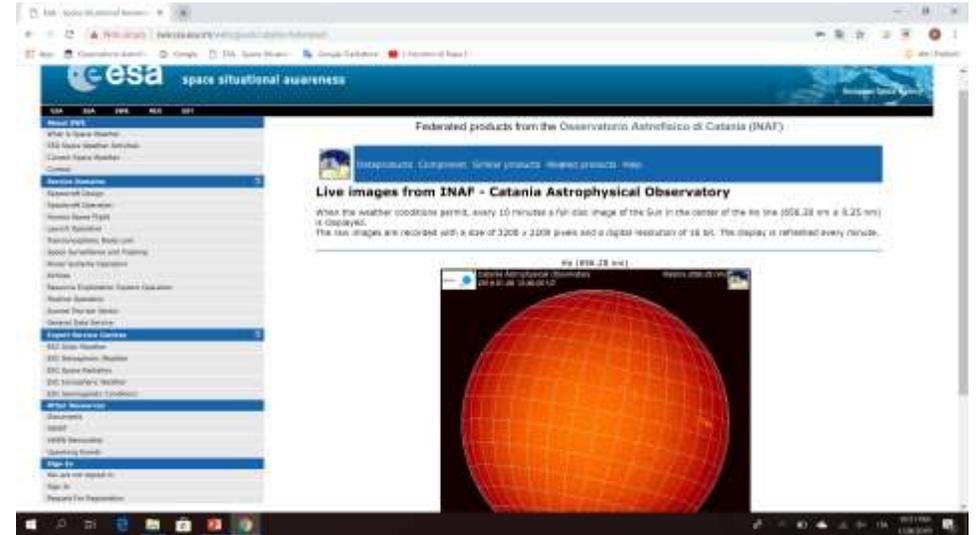
Project Name	Short description	Role	Timeline
PRE-EST 	To provide both the EST international consortium and the funding agencies with a detailed plan regarding the implementation of the European Solar Telescope.	Participation of UniCT and INAF-OACt Teams	2017 April 1 – 2021 March 31
SOLARNET 	To integrate the major European infrastructures in the field of high-resolution solar physics and to define the exploitation of the future 4-meter European Solar Telescope.	Participation of UniCT and INAF-OACt Teams	2019 January 1 – 2022 December 31
Metis 	WL and UV Coronagraph for ESA-Solar Orbiter spacecraft → first close-up (0.3 AU) observations of coronal plasmas	Participation to Science Team	Launch: February 2020, nominal mission 7.5 years
ESCSOLAR-2 	To provide near real-time full-disc images of the photosphere at 656.78 nm and of the chromosphere at 856.28 nm to the portal of ESA Space Situation Awareness Space Weather.	Participation of INAF-OACt Equatorial Spar Team	2017 December 11 – 2019 June 10



Space Weather services of Solar Physics Group in Catania

Flare forecasting service

When weather conditions permit, on the base of the morphology of sunspot groups in photosphere, Catania Observatory provides daily an indication of the probabilities that each active region visible on the solar disc may host solar flares of C1.0+, M1.0+ and X1.0+ class at: http://ssa.oact.inaf.it/oact/Flare_forecasting.php



Flare Forecasting

Using the daily observation of the photosphere performed by the Equatorial Spar of INAF - Catania Astrophysical Observatory, we provide an indicator of the probabilities that each sunspot group visible on the solar disc may host solar flares of C, M and X class. The probabilities shown below are calculated using the USSPS algorithm as of 06 September 2017 at 06:46 UT. They are valid for the subsequent 24 hours.

The sunspot group capability of hosting flares is based on the Poisson statistic of five parameters: number of sunspots and pores, projected area of sunspot group in tens of millionths of the solar hemisphere, group type according to Zurich classification, type of penumbra of the main sunspot, and relative importance between leading sunspot and density of the sunspot population.

NOAA ARI	Catania Sunspot Group	Flare C-class	Flare M-class	Flare X-class
2673	46	61%	24%	6%
2674	47	60%	19%	3%
2676	49	7%	0%	0%

Expert Service Center of ESA SSA

Catania Observatory provides its full disc images to ESA portal dedicated to the Space Situational Awareness programme.

Full-disc images in the H-alpha line at 6562.8 Å and in the continuum at 652.8 + 0.5 Å

Spatial resolution: 2''

FWHM: 0.25 Å

Time cadence: 10 min

Observation time interval: from 7:30 to 13:30 CET

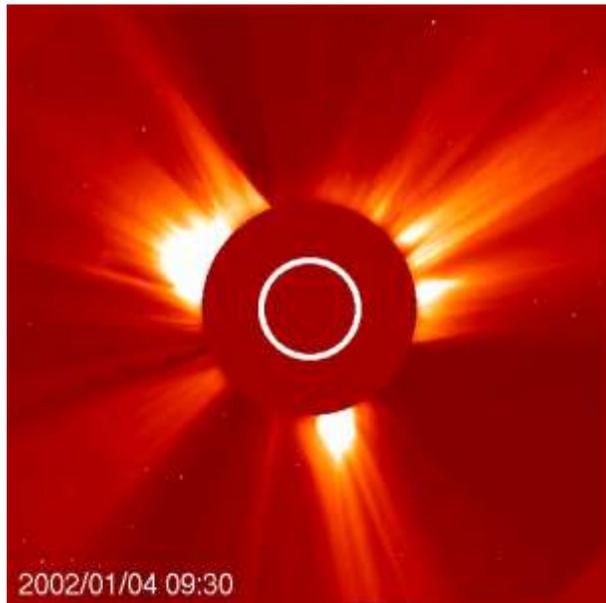
Solar Physics Group in Turin

Personnel

E. Antonucci, S. Fineschi, A. Bemporad, C. Benna, G. Capobianco, M. Casti, F. Frassati, S. Giordano, F. Landini, A. Liberatore, S. Mancuso, G. Massone, G. Nicolini, R. Susino, D. Telloni, L. Zangrilli.

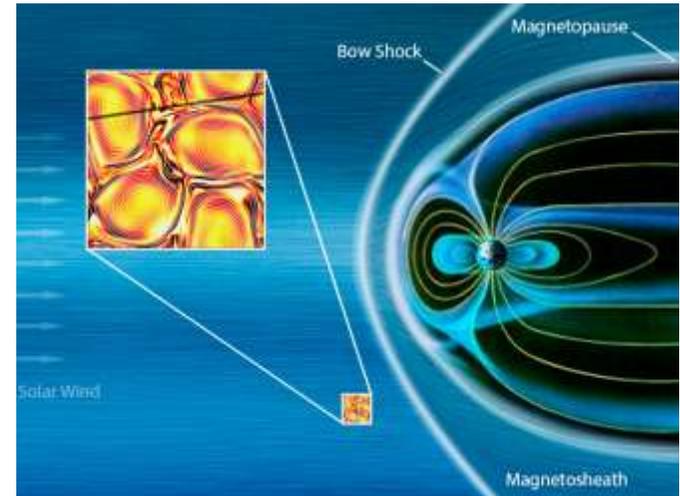
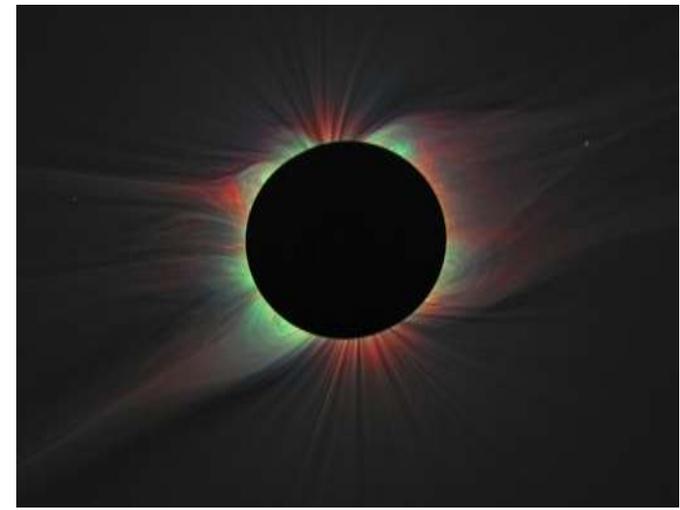
Main Research Fields

- Physics of the solar corona, understanding the origin and evolution of the main drivers of Geomagnetic Storms on Earth: solar wind and Coronal Mass Ejections (CMEs), study of the solar wind turbulence



Methods

- Coordination of observational campaigns from space and ground (total solar eclipses)
- Development of diagnostic techniques for the analysis of coronagraphic and spectroscopic data acquired from space and ground, and for the study of plasma and magnetic field measurements acquired in-situ at L1
- Development of new instrumentation for future space missions and ground based observations



Solar Physics Group in Turin

Project	Short description	Role	Timeline
METIS 	WL and UV coronagraph for ESA-Solar Orbiter spacecraft → first close-up (@ 0.28 AU) observations of corona	Leader of the international science consortium (PI: M. Romoli)	Launch: February 2020, nominal mission 7.5 years
ASPIICS 	WL coronagraph for ESA-PROBA3 satellite → first eclipse-like, long-term observations of the inner corona	Italian leader for Formation Flying metrology (Lead Co-I: S. Fineschi)	Launch: 2022, nominal mission 2 years
SCORE 	Helium Sounding rocket coronagraph → first determination of coronal Helium abundance	Leader of the italian instrument consortium (PI: S. Fineschi)	First launch: September 2009, Second launch: 2020
ESCAPE 	Coronagraph in Antarctica (Concordia base) → first long-term coronal magnetic-field monitoring	Leader of the italian instrument consortium (PI: S. Fineschi)	Deployment: Antarctic summer 2018/2019, duration 3 years
HELIOSPHERIC DATA CENTER 	Heliospheric Data Centre is a joint ALTEC & INAF-OATo project → evolve the SOLAR (SOHO Long-term Archive), and develop a Heliospheric Space Weather Centre for forecast	Hosted and maintained by ALTEC, developed in joint collaboration with INAF-OATo	Established in 2017, currently under development

Solar Physics in Trieste



ESA Space Weather Working Team, Steering Board Member



European Space Weather Week Programme Committee, Chair



ESF ESSC WG on “Assessment and Consolidation of Space Weather in Europe”

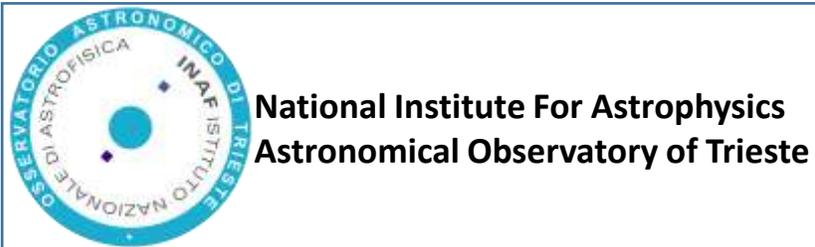
NATO SCI-318 RSM on “The Space Domain and NATO Operation: A Critical S&T Review”, Programme Committee



Solar Orbiter/METIS
Co-Investigator, Responsible for the Italian segment data handling



Senior Advisor for Space Weather to the INAF President and INAF Science Director



National Institute For Astrophysics
Astronomical Observatory of Trieste



TSRWC

Trieste Solar Radio Weather Centre

Solar & Space Physics Group in Rome Tor Vergata

<https://www.fisica.uniroma2.it/~solare/en/>



TOR VERGATA
UNIVERSITY OF ROME

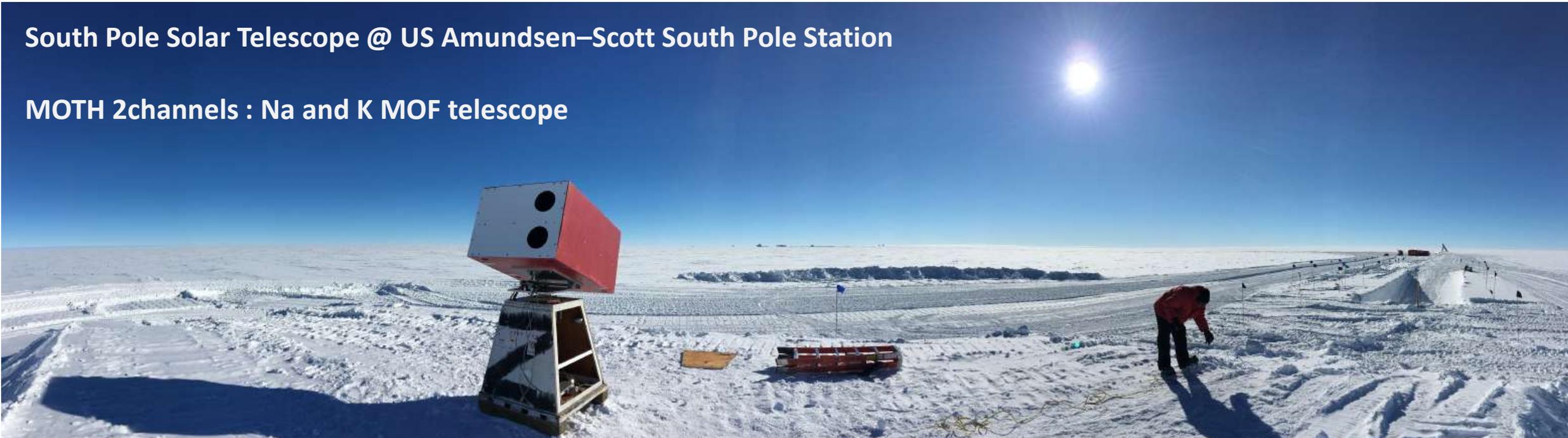
Personnel:

F. Berrilli, D. Del Moro, L. Giovannelli (staff), D. Calchetti, D. Galuzzo, V. Penza, G. Viavattene (PhD students, PostDoc)

Main Research Projects: European Solar Telescope, Ionosphere Prediction Service – IPS, Space Weather @ Tor Vergata – SWERTO, Tor Vergata Synoptic Solar Telescope (2channels : H α and K MOF), South Pole Solar Telescope (2channels : Na and K MOF), SOLARNET (large etalon and digital control), GREY (Telescope Thermal Control and Heat Rejecter).

South Pole Solar Telescope @ US Amundsen–Scott South Pole Station

MOTH 2channels : Na and K MOF telescope



Space Weather @ Tor Vergata - SWERTO

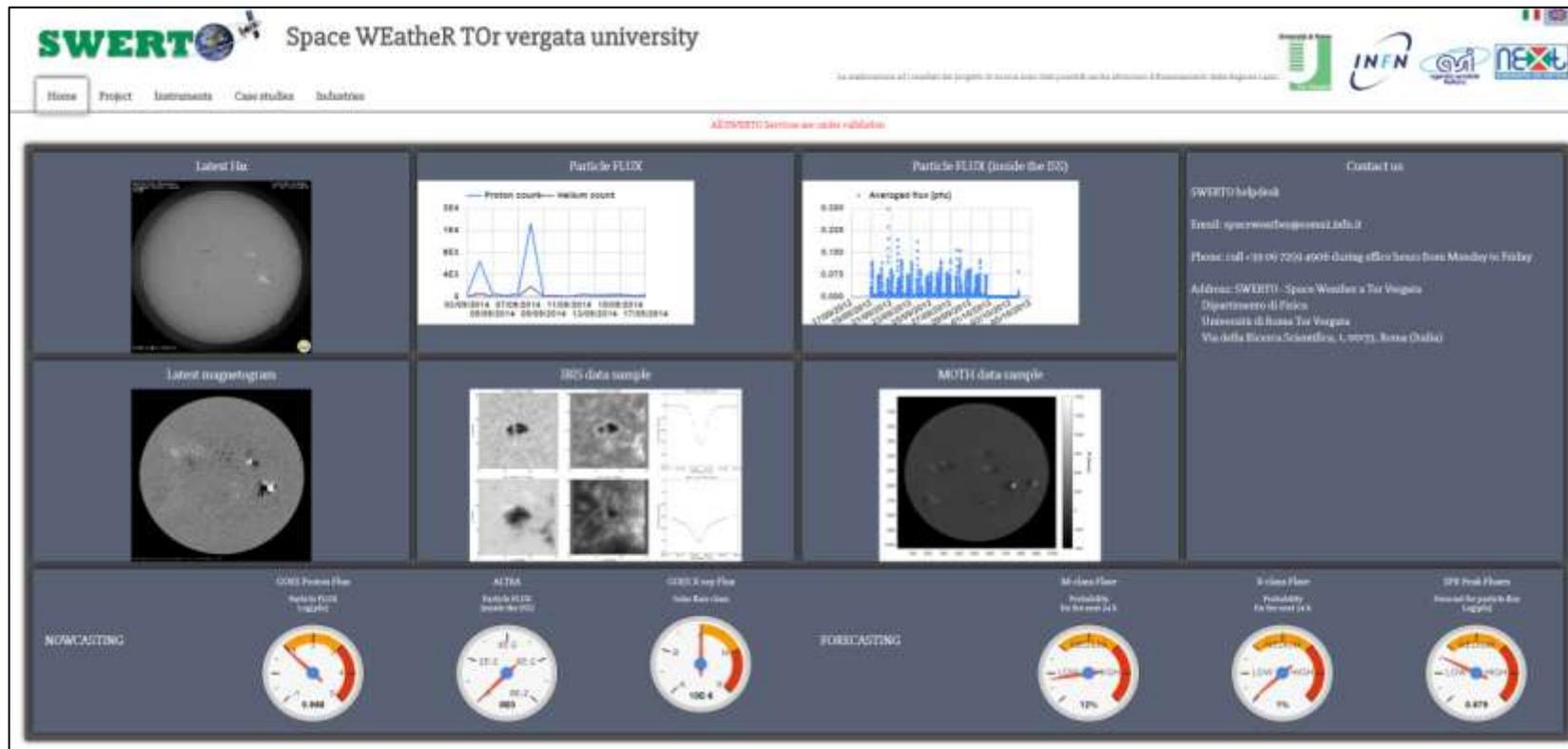
<http://swerto.roma2.infn.it/>

<http://spaceweather.roma2.infn.it/>

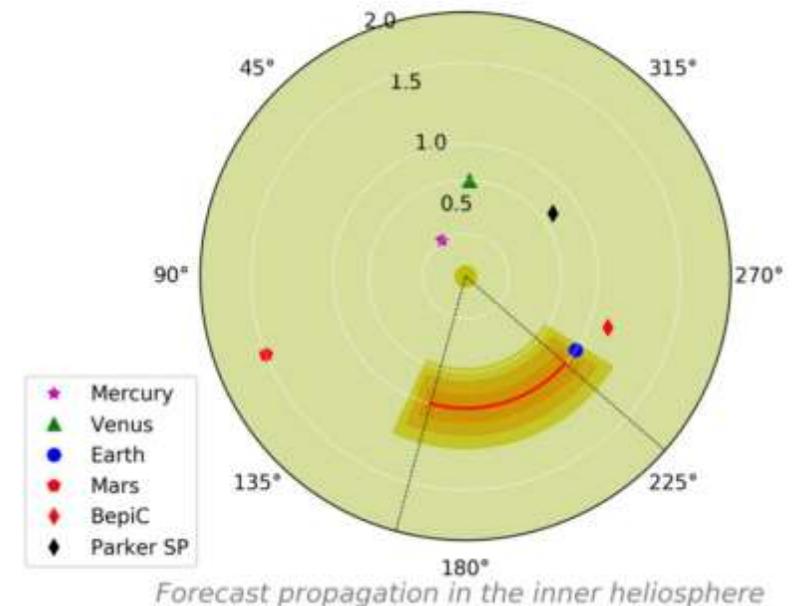


TOR VERGATA
UNIVERSITY OF ROME

F. Berrilli, M. Casolino, D. Del Moro, L. Giovannelli, R. Forte, M. Lovric, M. Martucci, M. Mergè, L. Narici, V. Penza, G. Pucacco, F. Pucci, A. Rizzo, S. Scardigli, R. Sparvoli



CME expected at 1AU at: 2019-05-17 02:03:20 UT
Timestamp= 2019-05-13 11:35:21 UT



Forecast propagation in the inner heliosphere

Solar Physics Group in Palermo

• Personnel

- A. Ciaravella (INAF/OAPa), S. Orlando (INAF/OAPa), G. Peres (UniPa), F. Reale (UniPa)

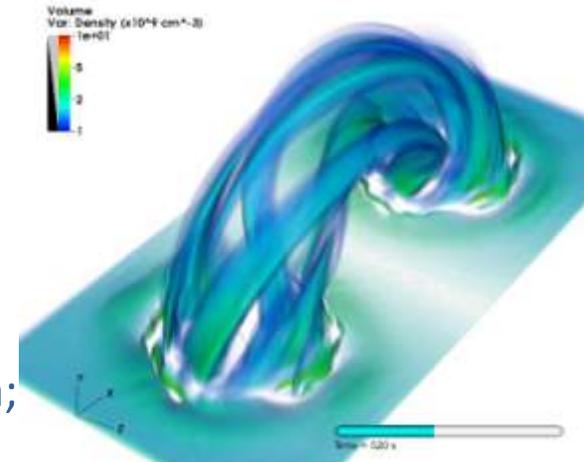
• Main Research Fields

- Heating and dynamics of magnetically confined and not confined coronal plasma;
- Solar and stellar flares;
- Coronal Mass Ejections;
- Plasma diagnostics.

• Methods

- MHD modeling and high performance computing (EU/PRACE, NASA)
- Analysis of EUV and X-ray data from space missions (e.g., SoHO/UVCS, Hinode/XRT, Solar Dynamics Observatory/AIA, IRIS)
- Mission involvements: SoHO/UVCS, Hinode/XRT, Coronas-Photon/SphinX, Solar Orbiter/METIS

MHD modeling of magnetically confined coronal plasma



«astro-lab» at the MIDA group

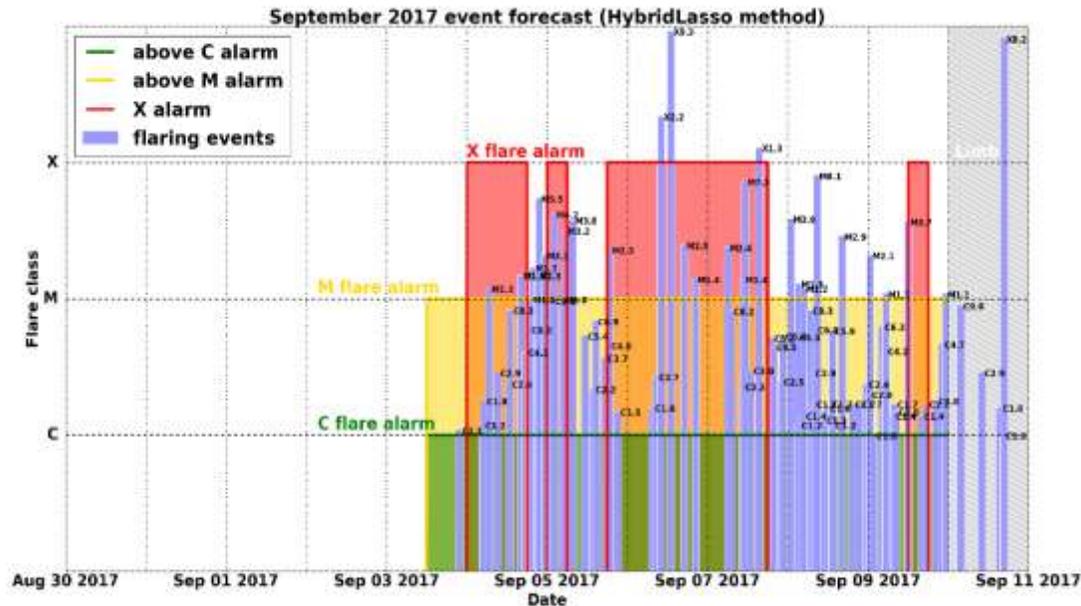
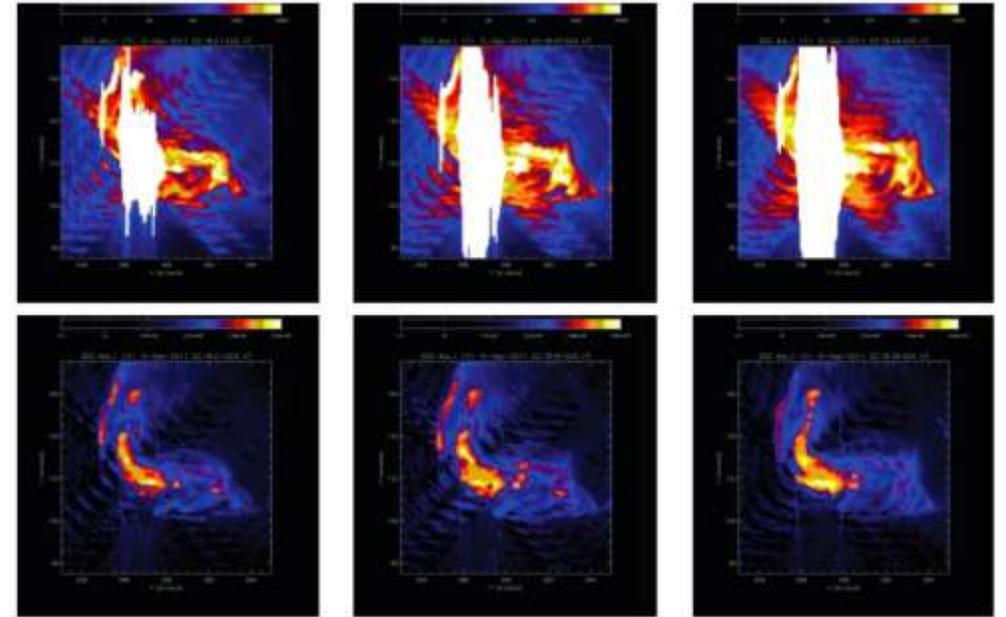
Dipartimento di Matematica Università di Genova

Personnel

M. Piana, A. M. Massone, A. Sorrentino, C. Campi (UNIPD), F. Benvenuto, F. Sciacchitano, S. Guastavino, P. Massa

Main Research Fields

- Imaging, spectroscopy and imaging spectroscopy for hard X-ray emission; desaturation of EUV images; flare prediction; mathematical models for solar flare physics

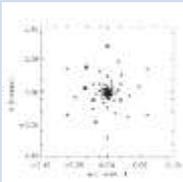


Methods

- Inversion methods for RHESSI and STIX image reconstruction, electron spectra modelling and reconstruction of electron maps
- Inverse diffraction for the desaturation of SDO/AIA images
- Machine learning applied to SDO/HMI full disk magnetograms for flare now- and forecasting with feature ranking.
- Inversion methods for the reduction of MHD equations in solar plasma physics

«astro-lab» at the MIDA group

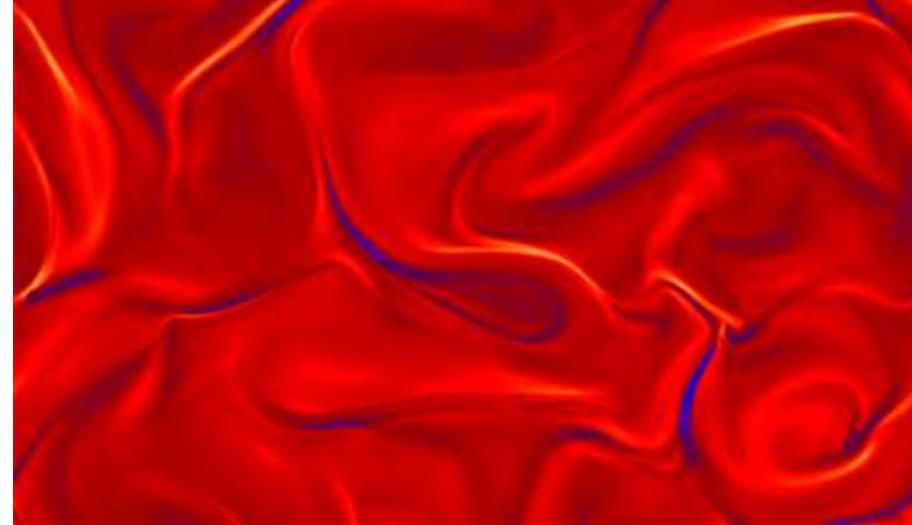
Dipartimento di Matematica Università di Genova

Project	Short description	Role	Timeline
STIX 	hard X-ray telescope in ESA-Solar Orbiter spacecraft → first close-up (0.3 AU) observations of flare emission	Two co-Is in the international science consortium (PI: S. Krucker)	Launch: February 2020, nominal mission 7.5 years
FOXSI SMEX 	Telescope for focusing hard X-rays emitted by solar flares	Two co-Is in the international science consortium (PI: S. Christe)	Under evaluation
FLARECAST in H2020 	Machine learning and technological platform for flare prediction from SDO/HMI magnetograms	Leader of the machine learning WP; leader of the technology WP (PI: M. Georgoulis)	Ended in december 2017; inclusion in ESA SSA under construction
HESPE in FP7 	Imaging, spectroscopy and imaging spectroscopy science products for high-energy solar data	Project coordinator (M. Piana)	Ended in november 2013

V. Carbone, A. Greco, F. Lepreti, F. Malara, G. Nigro, F. Pecora, S. Perri, G. Prete, L. Primavera, S. Savaglio, A. Settino, S. Servidio, L. Sorriso-Valvo (CNR), F. Valentini, P. Veltri, G. Zimbardo

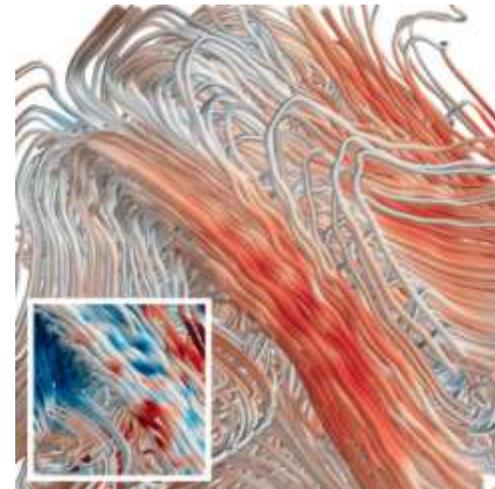
- **Main research fields relevant for Space Weather**

- Solar activity, precursors of flares and Coronal Mass Ejections
- Magnetic reconnection and turbulence in the solar atmosphere and interplanetary space
- Particle acceleration and transport in the heliosphere and near Earth environment



- **Methods**

- Advanced techniques for the analysis of remote sensing and in situ solar and space observations
- Development of theoretical plasma models and numerical simulation codes (both magnetohydrodynamic and kinetic) involving high performance computing techniques



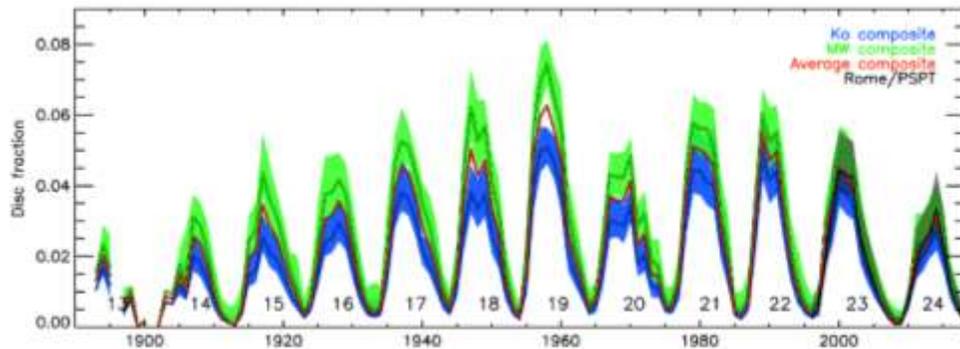
Personnel

Solar Physics: I. Ermolli, F. Giorgi, M. Murabito, T. Chatzistergos

SAMM: R. Speziali, R. Piazzesi & DS Group srl

Main Research Fields

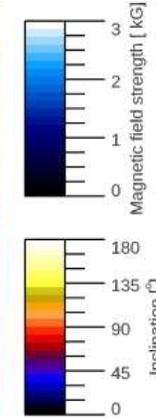
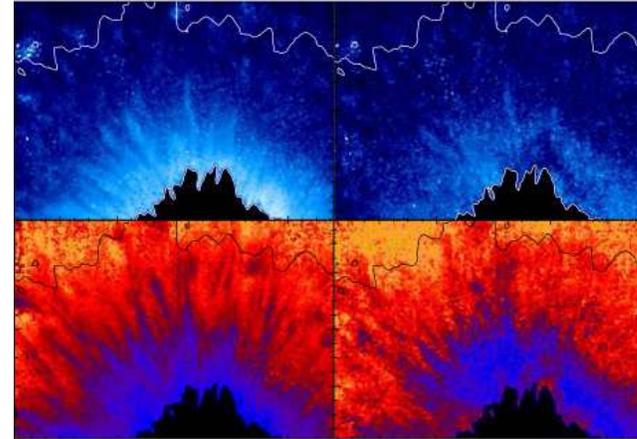
- Formation and evolution of **magnetic regions in the solar atmosphere.**
- Modelling of **solar irradiance** variations.



Composites of the fractional disc coverage of plages as a function of time from analysis of 9 archives of Ca II K observations (Chatzistergos et al. 2019).

Methods

- Acquisition and analysis of solar data.
- Numerical modelling.
- Data provision and archiving.
- Design and development of new instrumentation.

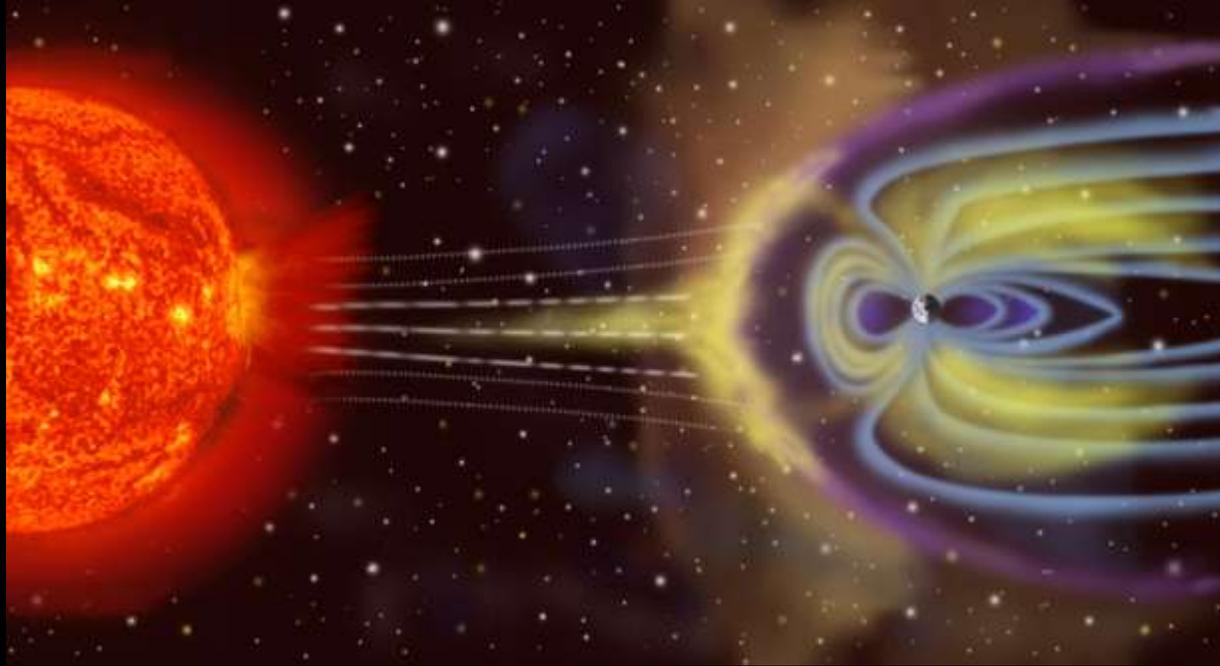


Maps of the magnetic field strength and inclination in a sunspot from inversion of photospheric (left) and chromospheric (right) full-Stokes measurements (Murabito et al. 2019).

Projects

- EST European Solar Telescope
- IBIS Interferometric Bidimensional Spectrometer 2.0
- IBIS-A The IBIS data archive
- PSPT Precision Solar Photometric Telescope – synoptic observations
- Archive of historical and modern full-disc solar observations
- SAMM Solar Activity MOF Monitor





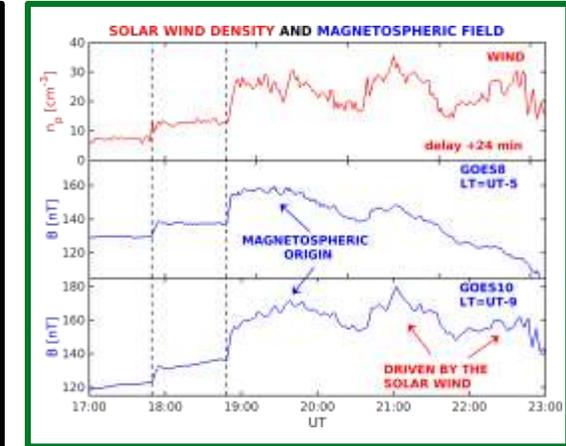
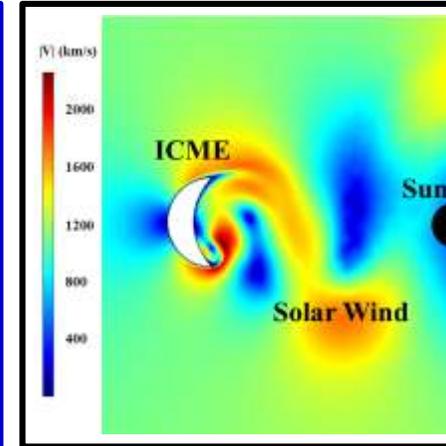
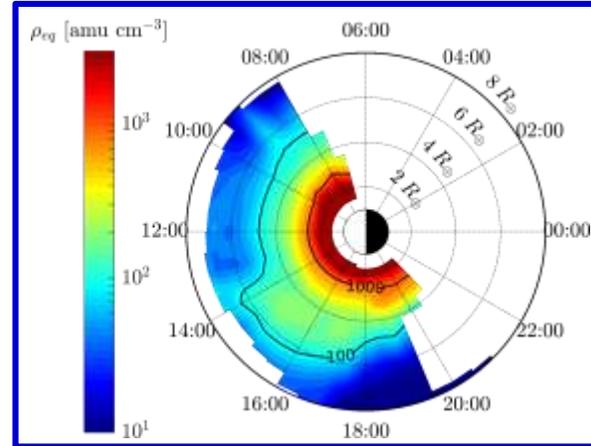
Interplanetary Space and Solar-Terrestrial Physics

Experiments:

EMMA (European quasi-Meridional Magnetometer Array) 27 stations, $1.6 < L < 6.2$

GEOWAVES experiment at Concordia Station, **Dome C**, Antarctica

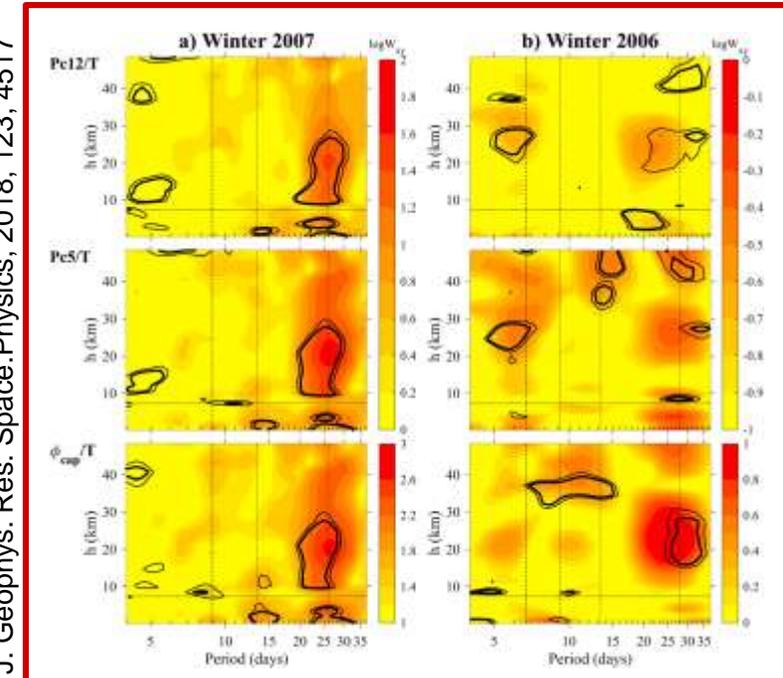
ULF experiment at Zucchelli station, **Terra Nova Bay**, Antarctica



Main Research Fields:

- Remote monitoring of the cold plasma in the inner magnetosphere
- Generation of magnetospheric ULF Pc5 (2–7 mHz) and Pc1–2 (0.1–5 Hz) waves by the solar wind.
- Magnetosphere-ionosphere-atmosphere interaction at polar latitudes.
- CME travel time forecasting from coronagraphic images and models
- Identification of fluctuations at discrete frequencies in the solar wind and in the magnetosphere

Francia P., Regi M. & De Lauretis M., J. Geophys. Res. Space Physics, 2018, 123, 4517



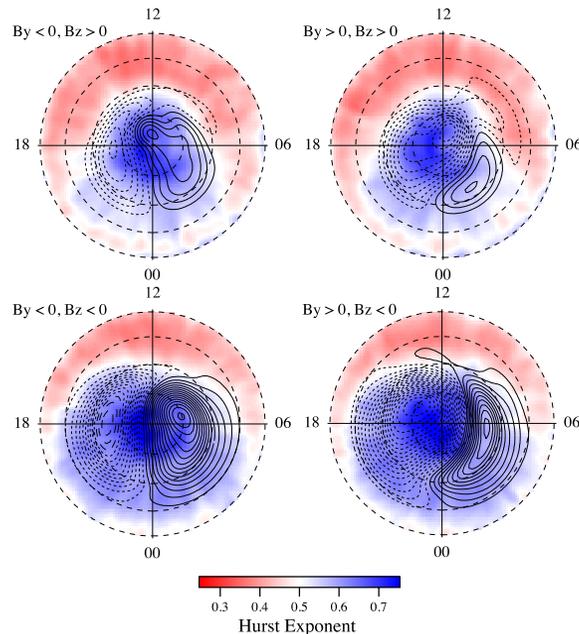
Solar-Terrestrial Physics at INGV (1)

Personnel: Paola DE MICHELIS, Iginò COCO, Fabio GIANNATTASIO, Lucia SANTARELLI, Roberta TOZZI

Science: Ionospheric Turbulence

Identification of proxies of the magnetospheric and ionospheric responses to space weather events oriented to the *forecast of magnetosphere and ionosphere dynamical status*. In particular of those proxies related to the development of **turbulence in the ionosphere** since it **strongly impacts on the operability of all communication systems affected by the ionospheric medium**.

ESA has recently funded a project within EO program to characterise **IoNospheric TurbuLENce level by Swarm constellation (INTENS)**

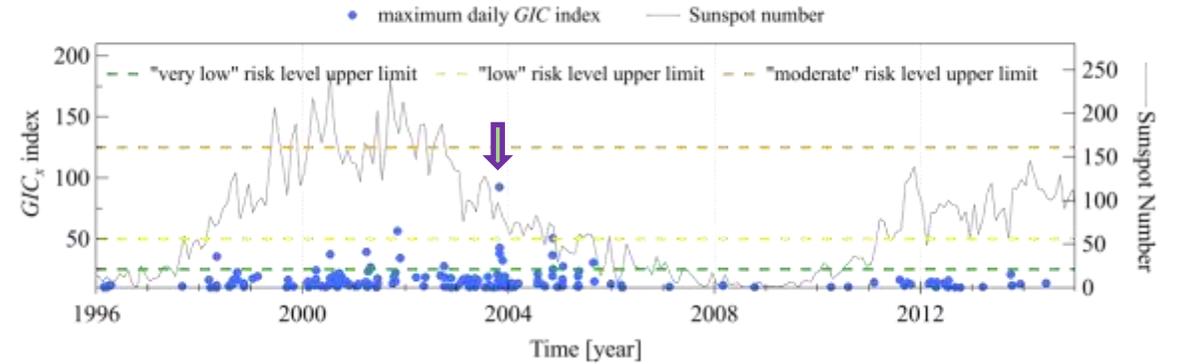


De Michelis et al., JGR, 2017

Comparison between the average spatial distributions of Hurst exponent estimated by Swarm magnetic data and the convection patterns obtained using SuperDARN.

Science: Geomagnetically Induced Currents

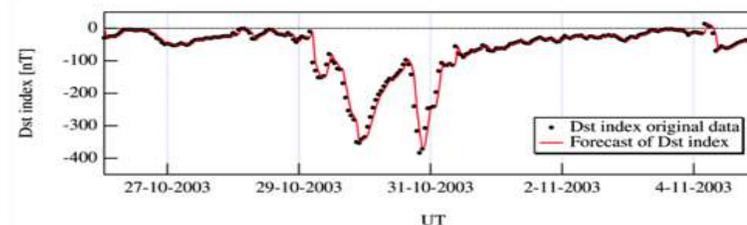
GIC index is a proxy of *geomagnetically induced currents* (GIC). GIC index estimation using 1-min magnetic data recorded in Italy (during the last two solar cycles) has been performed for a **preliminary risk assessment of GIC over the Italian Territory**. Results has shown that *the impact of space weather on the power grids in Italy, as well as in the Mediterranean countries, needs a deeper assessment including the consideration of coastal effects, ground conductivity, and failure reports*.



Tozzi et al.
Space Weather, 2019

GIC index estimated from the magnetic observatory of Castello Tesino (Northern Italy). A "moderate" risk of damage due to GIC has been reached during the 2003 Halloween geomagnetic storm.

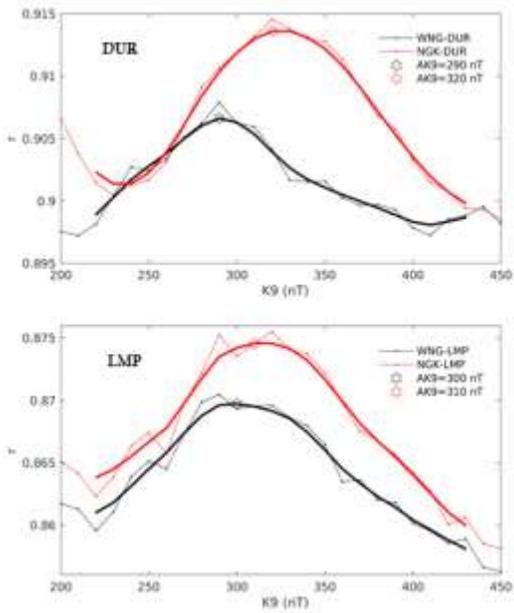
Tool: Dst index Forecasting



Present stage of the tool:
forecast 1 hour in advance of the Dst index starting from interplanetary and magnetospheric data using neural networks.

Validation of K Index Values at Italian Geomagnetic Observatories

Local K index and the consequent global Kp index are well established three-hour range indexes used to characterize the geomagnetic activity at global level. K is one of the parameters which INTERMAGNET observatories can provide and it's widely used since several decades. It is used also **in the frame of Space Weather monitoring procedures and as a proxy for the elaboration of other parameters** used in ionospheric observations. The modern automatic methods for determining the K index values should be the same for all observatories and the validation of their values, correctly estimated, is fundamental. **By Kasm code applied at Italian observatories dataset**, K index determination is found with its own specific scale, regulated by the K9 lower limit determined by statistically comparative analysis with some European observatories.

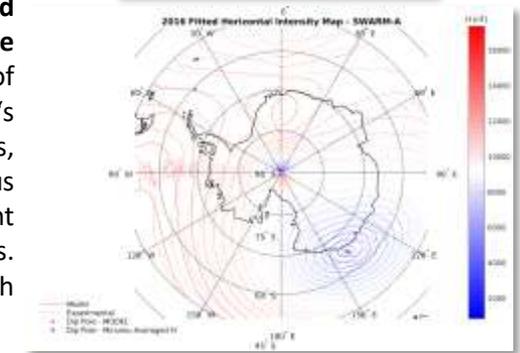


Correlation analysis between K index at NGK (Niemegk obs, Germany) and WNG (Wingst obs, Germany) with k index computed at DURONIA obs (top panel) and LAMPEDUSA obs (bottom panel) by Kasm code for different k9 levels.

Values of K9 corresponding to the maximum correlation with NGK
K9_{DUR} = 320 nT
K9_{LMP} = 310 nT

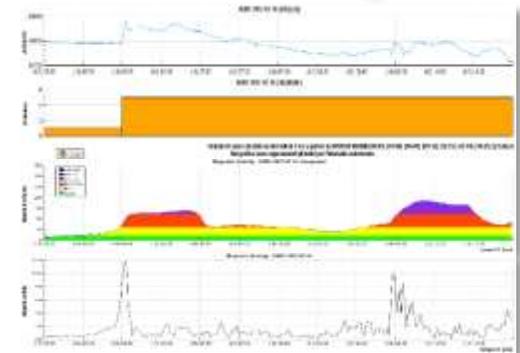
The Location of the Dip Magnetic Poles from circum-terrestrial Observations

The magnetic poles, known also as dip poles, are the points where the geomagnetic field is vertical; they are different from the geomagnetic poles and can be determined from experimental data, finding where the horizontal component of the geomagnetic field vanishes. The determination of the dip pole from specific ground surveys is not simple, due to the harsh environmental conditions of the remoteness of the areas where they are located; moreover, **as a manifestation of the magnetosphere-solar wind interaction, a continuous minor and cyclic input for the displacement, few tens of kilometers, of the magnetic poles takes place.** We statistically estimate the position of the magnetic poles using data measured from the Swarm ESA's constellation of satellites along their almost polar orbits over 5 years, from 2014 to 2018. The availability of several years of data allows us to investigate its long term variation and dynamics under different geomagnetic activity levels and interplanetary medium conditions. The position inferred from experimental data is also compared with the one provided from analytic models.



Tool: Implementation of an algorithm for detection of magnetic storms

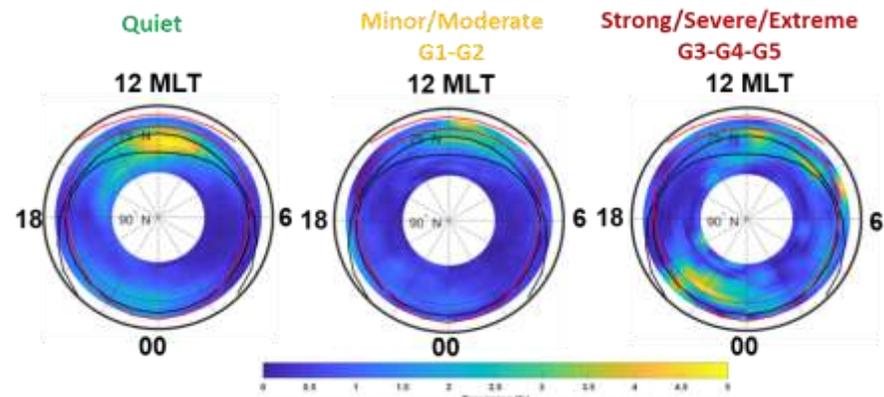
The Italian geomagnetic data are stored in a MySQL database which is interfaced with a web portal for data visualization and downloading. The implementation of **an algorithm for the classification of the geomagnetic activity conditions and of real-time alerting for their anomalous variations** is under progress, aiming also at their characterization, as a proxy **in the frame of the space weather alerting services.**



Solar-Terrestrial Physics at INGV (3)

G. De Franceschi, L. Alfonsi, C. Cesaroni, I. Hunstad, V. Romano, L. Spogli

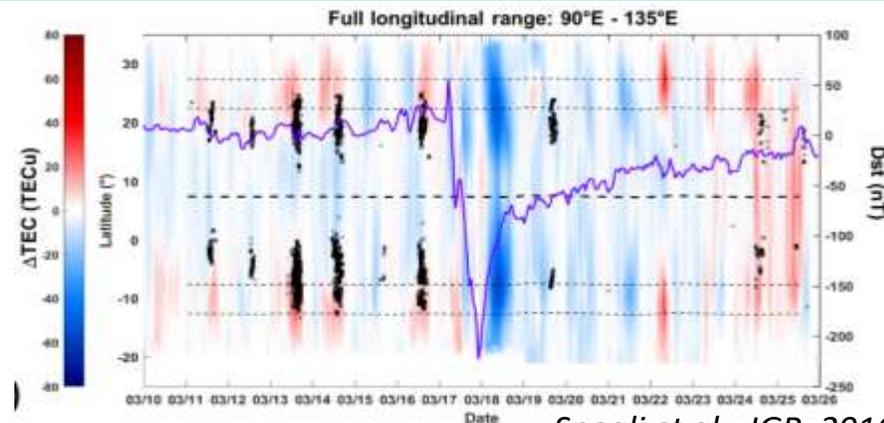
Scintillations and refractive effects derived from the **longest data series ever collected** to study the ionospheric response to the geospace conditions. The data are acquired by a GNSS receiver operating at Ny Ålesund (Svalbard, Norway) and show the **presence of ionospheric irregularities from the auroral oval boundaries to the polar cap** sorted according to different levels of geomagnetic activity. Such assessment can significantly help the development of **forecasting models supporting the GNSS-based operations**.



NEW: De Franceschi et al, 2019, Scientific Reports, 2019

L. Alfonsi, C. Cesaroni, D. Di Mauro, M. Pezzopane, L. Spogli

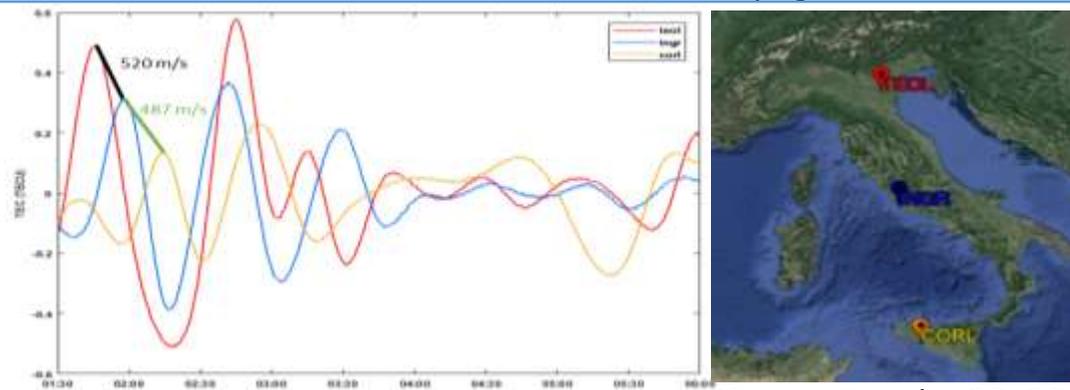
Study of **TEC and ionospheric scintillation** during the St. Patrick storm 2015 over South-East Asia. The longitudinal mean of **Δ TEC values** is compared with **S4 values** greater than 0.1 (black dots). To relate Δ TEC and scintillation to the different phases of the storm evolution, the Dst index has been also superimposed in the figure (purple line). Black tick dashed and isoclinic lines represent the magnetic equator and the average position of the EIA crests. This study provided **new insights on enhancement and inhibition of low latitude scintillations**



Spogli et al., JGR, 2016

L. Alfonsi, C. Cesaroni, M. Pezzopane

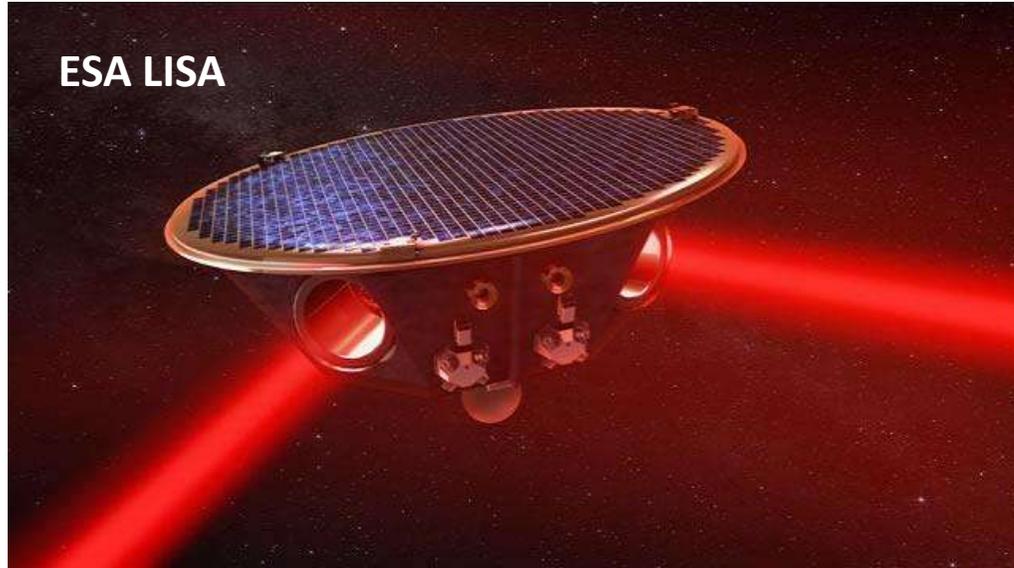
Study of auroral activity from all-sky imager in Asiago and TEC response from INGV RING network in Italy. Auroral activity was responsible for the presence of **small amplitude TEC waves propagating at about 500 m/s and wavelength of ~1350 km typical of LSTIDs**, revealed by the application of the EEMD method to TEC measurements from ground-based GPS stations.



Cesaroni et al., JGR, 2017

University of Urbino and INFN – Florence

Space mission dedicated to environmental studies and LISA contribution to space weather



- **Personnel**

- C. Grimani, S. Benella, M. Fabi, M. Villani

Main Research Fields

Solar activity and solar polarity modulations of galactic cosmic-ray fluxes

- Galactic cosmic-ray flux short-term variations and their effects on the solar modulation parameter
- Monte Carlo simulations of the role of galactic and solar cosmic rays in limiting the instrument performance in space
- LISA contribution to both space weather science and space weather: multi-point cosmic-ray and solar energetic particle observations at 1 a.u., 50×10^6 km near the ecliptic behind Earth after 2034

Methods

- The Fluka Monte Carlo program is used to estimate the test mass charging aboard the space interferometers and the dose released in the METIS coronagraph to be flown aboard the Solar Orbiter.

See <https://pasmе.uniurb.it>

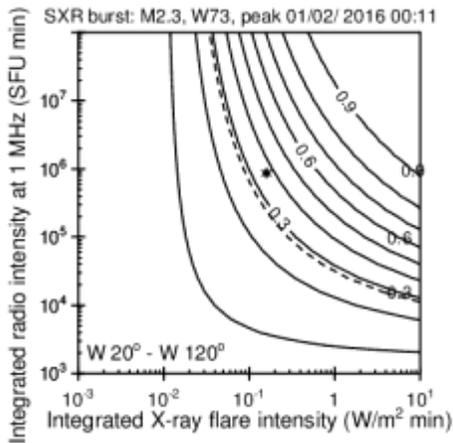


Physics of Space Plasmas and Space Weather @ INAF/IAPS – PPSW Group

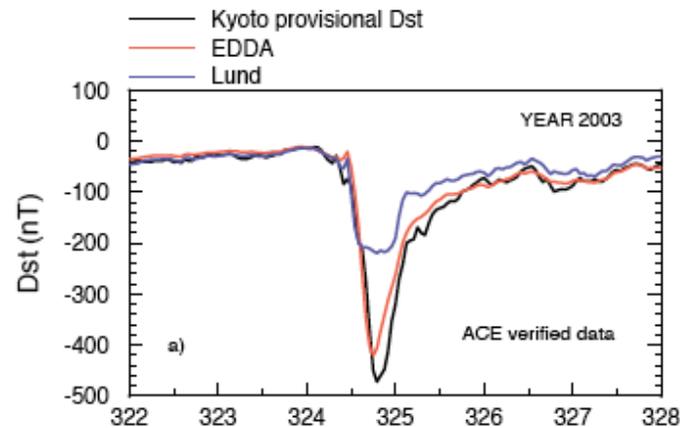
T. Alberti, A. Aronica, I. Bertello, D. Brienza, R. Bruno, G. Consolini, R. D'Amicis, E. De Angelis, R. De Marco, P. Diego, M. Laurenza, F. Lazzarotto, V. Mangano, M.F. Marcucci, S. Massetti, A. Milillo, A. Mura, S. Orsini, G. Pallocchia, V. Quattrocioni, F. Re, R. Rispoli, N. Vertoli.

Research Fields:

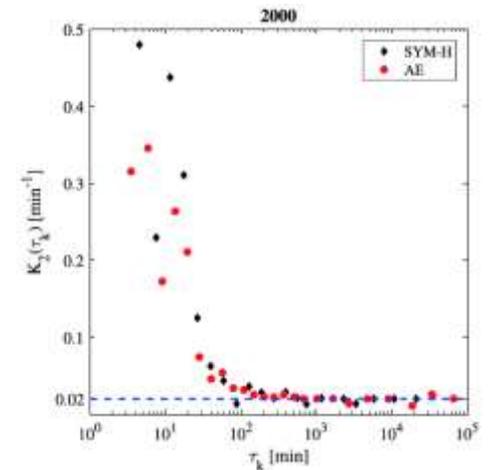
- Solar wind and interplanetary space plasma physics and dynamics;
- Solar-wind/magnetosphere and planetary environment interaction;
- Solar Energetic Particles acceleration, propagation and forecast of particle flux;
- Auroral observations;
- Geomagnetic activity forecast; magnetospheric/ionospheric and geomagnetically induced currents modeling
- Planetary Space Weather and effects of the solar variability on Earth's and planetary environment;
- Studies of ionospheric parameters through INAF-IAPS plasma chamber;
- Galactic Cosmic Rays modulation and impact on space missions and high energy astrophysical hazards for habitability.



Probability contour-plot for SEP forecast by ESPERTA model [Alberti et al., 2017]



A sample of Dst forecast by EDDA model [Pallocchia et al., 2006]



Forecasting horizon as estimated by Kolmogorov entropy as a function of timescale [Consolini et al., JGR, 2018]

Physics of Space Plasmas and Space Weather @ INAF/PSPSW



Solar Orbiter - A high-resolution mission to the Sun and inner heliosphere. The PSPSW group has a CoPi-ship in the plasma suite SWA (Solar Wind Analyzer) with the commitment of providing the common DPU (Data Processing Unit) for the whole suite. The PSPSW group participates to SWA, a plasma feature instrument suite, with the responsibility of the development of the on board DPU.



BepiColombo an ESA mission to Mercury – The PSPSW group has the Pi-ship of the SERENA (Search for Exospheric Refilling and Emitted Natural Abundances) particle package on Mercury Planetary Orbiter and is involved in the MEA (Mercury Electron Analyzer) and SIXS (Solar Intensity X-ray and particle Spectrometer) experiments onboard Mercury Magnetospheric Orbiter and Mercury Planetary Orbiter, respectively. The ELENA sensor, part of SERENA package, has been almost fully developed at INAF/ PSPSW with the participation of CNR and IRAP.



Super Dual Auroral Radar Network international network of HF ionospheric radars dedicated to the study of the magnetosphere-ionosphere system - The PSPSW group is responsible for the Dome C East and Dome C North radar located at the research station Concordia (Dome C – Antarctica), in collaboration with CNR and funded by the Italian PNRA.



The plasma chamber developed at INAF/IAPS is an facility capable to reproduce a large volume ionospheric environment, which is particularly suitable to perform studies on a variety of plasma physics subjects



CSES (China Seismo-Electromagnetic Satellite) is a scientific mission dedicated: to monitoring electromagnetic field and waves, plasma and particles perturbations of the atmosphere, ionosphere and magnetosphere induced by seismic events



The **SVIRCO** is the Roma Tre/INAF-IAPS observatory dedicated to the study of cosmic rays modulation and relativistic SEP generation. It provides real time data to the "Real-time database for high-resolution neutron monitor measurements" (NMDB) and to ESA-SSA for Space Weather services.

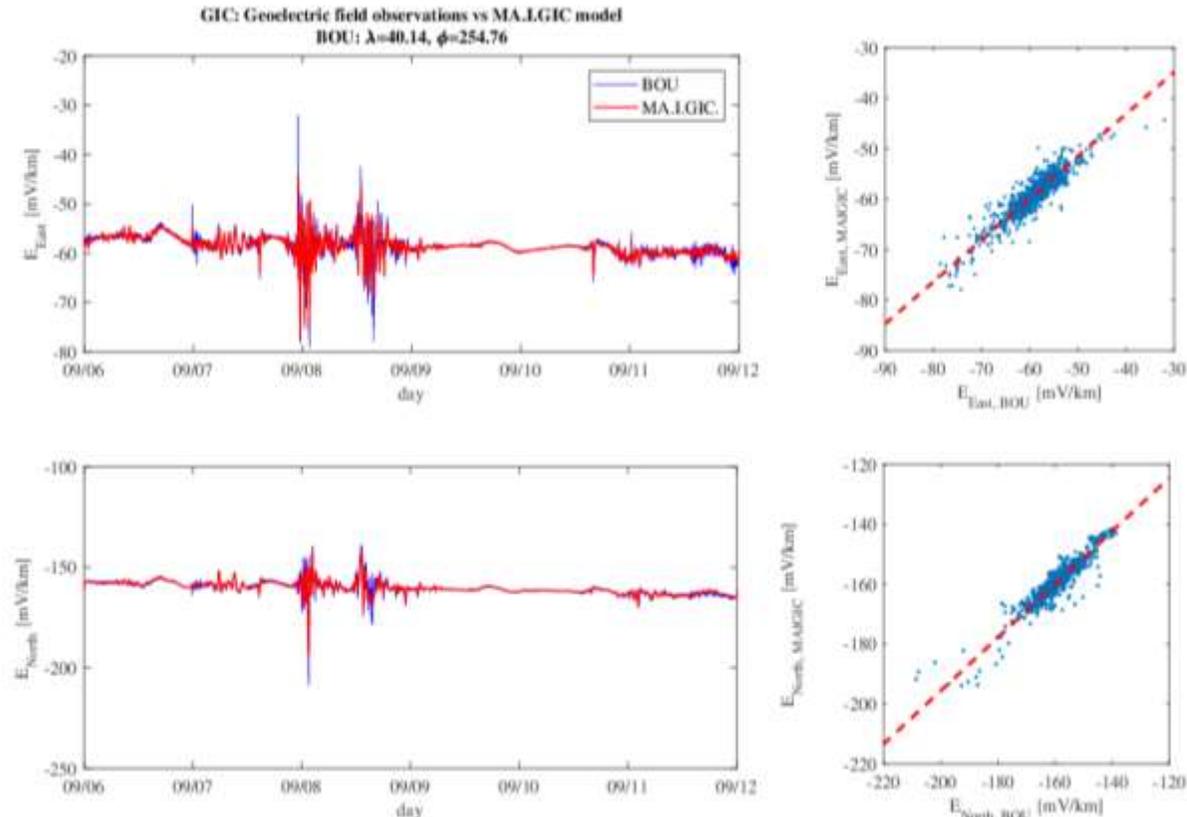


Mirko Piersanti¹, Simone Di Matteo², D'Angelo Giulia¹

- 1) I.N.F.N. - University of Rome «Tor Vergata», Rome, Italy.
- 2) Dpt. of Physical and Chemical Sciences, University of L'Aquila, Italy.

A new global **MA**gnetospheric – **I**onospheric and **G** geomagnetically **I**nduced **C**urrents (**MA.I.G.I.C.** – Piersanti et al. 2019) model has been developed.

- Starting from the Solar Wind observations, it is able to:
 1. Evaluate the geomagnetically induced currents (GIC) at ground from magnetic observations.
 2. Discriminate between, and evaluate, the magnetospheric and ionospheric origin contribution from ground magnetic observations;



E _{East}			E _{North}		
ρ	m	RMSE [mV/km]	ρ	m	RMSE [mV/km]
0,97	0,93	7,01	0,9	0,88	8,01

Multi-scale physics of the Solar-Terrestrial Processes: use of ALIF



Stepping into the Equatorward Boundary of the Auroral Oval: preliminary results of multi scale statistical analysis.

M. Materassi¹, M. Piersanti², G. Consolini³, P. Diego³, G. D'Angelo⁴, I. Bertello³ and A. Cicone⁵

ACCEPTED ON ANNALS OF GEOPHYSICS, 61, 2018; Doi: 10.4401/ag-7801

Confidential manuscript submitted to *Journal of Space Weather and Space Climate*

Role of the external drivers in the occurrence of low-latitude ionospheric scintillation revealed by multi-scale analysis

L. Spogli^{1,5*}, M. Piersanti^{2,6}, C. Cesaroni¹, M. Materassi³, A. Cicone^{4,10,11}, L. Alfonsi¹, V. Romano^{1,5} and R.G. Ezquer^{7,8,9}

Stochastic processes in Geospace Plasma: functional formalism



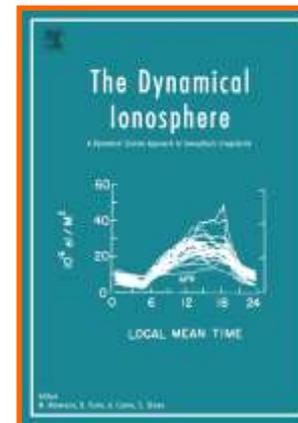
On Geometrical Invariants of Magnetic Field Gradient Tensor in Turbulent Space Plasmas: Scale Variability in the Inertial Range

VIRGILIO QUATTROCIOCCHI,¹ GIUSEPPE CONSOLINI,¹ MARIA FEDERICA MARCUCCI,¹ AND MASSIMO MATERASSI²

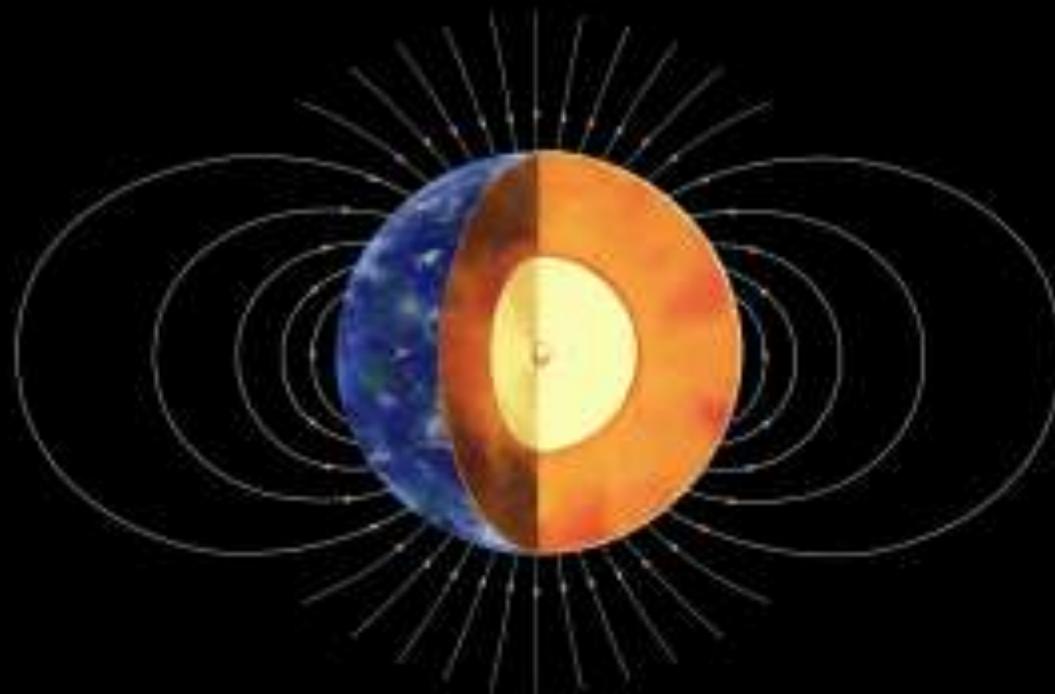
¹INAF-Istituto di Astrofisica e Planetologia Spaziali, Roma, Italy

²Istituto dei Sistemi Complessi, CNR, Sesto Fiorentino (Italy)

Submitted to ApJ



• “The Complex Ionosphere”, chapter of the book “The Dynamical Ionosphere”, Elsevier (Materassi, Forte, Coster, Skone - editors)



Geomagnetism

Geomagnetic Observatories



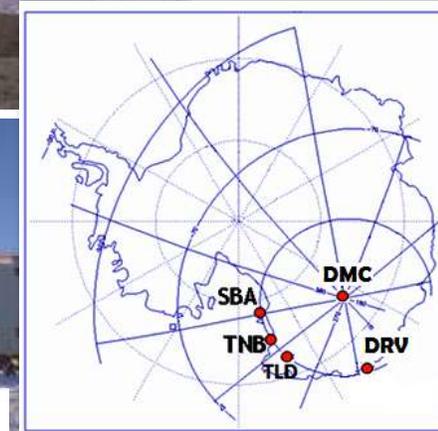
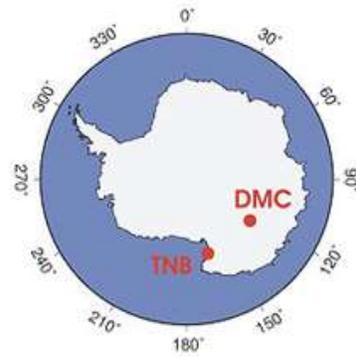
ISTITUTO NAZIONALE
DI GEOFISICA E VULCANOLOGIA



Italy



Antarctica



ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

GEOMAGNETIC INGV DATA PORTAL

Observatories in Italy	INGV code
Castello Tesino	CTT
L'Aquila	AQU
Duronia	DUR
Lampedusa	LMP

Observatories in Antarctica	INGV code
Base Italia (Antarctica) Base B. Torii (Italy)	TLD
Base Italiana (Antarctica)	DMC

Systems marked with * are not currently in operation

ISTITUTO NAZIONALE DI GEOFISICA E VULCANOLOGIA

Lampedusa (Observatory)

Latitude: 35.377780° Longitude: 13.340000° Altitude: 90.000 m

Previous Interval: Today Date: 2019-01-19 Time: 00:00:00

Home | All Systems | Download data | Login

Observatory data are available **in real time** at the following URL address:
<http://geomag.rm.ingv.it>

During the next Antarctic campaign will be installed a temporary magnetometer network for longitudinal and latitudinal monitoring in Antarctica at Talos Dome and Mid Point

Upper Atmosphere Physics



Ionospheric Observatories



Istituto Nazionale di
Geofisica e Vulcanologia



Gibilmanna (Italy)



Rhombic Antennas
(TX and RX)



AIS - INGV



Rome (Italy)



AIS - INGV



Antennas (TX and RX)

S. Miguel de Tucumán and Bahia Blanca (Argentina)



Delta Antennas
(TX and RX)



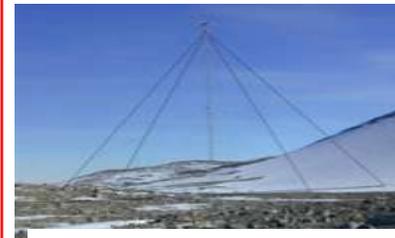
AIS - INGV
with
AUTOSCALING



Mario Zucchelli Station (Antarctica)



AIS - INGV



Antennas (TX and RX)



Space Weather forecast

Achievement of forecasting and nowcasting three dimensional (3-D) electron density mapping of the ionosphere.

EUROMAP forecasting model
24 hours in advance -
FORECASTING OF CRITICAL
FREQUENCY OF F2 LAYER

Using Ne data from the Swarm constellation, a new formulation of the topside NeQuick has been implemented for mid-latitude regions

New Ionospheric Observatory in Lampedusa has been approved!

INGV GNSS receivers network for ionospheric scintillation and TEC (including Galileo)

- First receiver installed at Ny-Alesund (Svalbard) in 2003
- Polar ionosphere
 - Svalbard islands (3 | NyAlesund, Longyearbyen)
 - Antarctica (5 | MZS, Concordia, SANAE)
- Mid latitude ionosphere
 - Chania (Crete)
 - Lampedusa (Sicily, Italy)
- Equatorial Ionosphere
 - Tucuman (Argentina)
 - Sao Paulo (Brazil)
 - **New station has been installed in Kenya last week**



ingrid.hunstad@ingv.it
carlo.marcocci@ingv.it

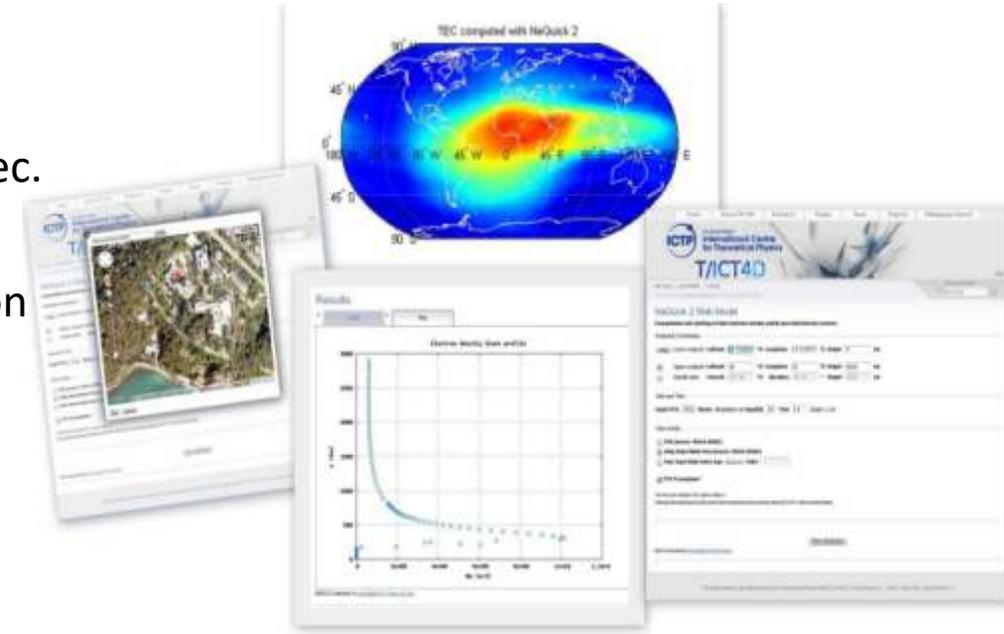


Data are accessible at the *electronic Space Weather upper atmosphere* website
eSWua
www.eSWua.ingv.it
www.spaceweather.it

SW studies in the ICTP @Trieste

NeQuick Ionospheric model

- **NeQuick** recommended by ITU-R for trans-ionospheric RP applications (Rec. P531).
- Basis of the model for the GALILEO single frequency ionospheric correction algorithm.
- **NeQuick** recommended by ICG Working Groups.



ICTP Web services: <http://t-ict4d.ictp.it/>:
NeQuick 2 online and TEC online calibration



WORKSHOP ON SPACE WEATHER EFFECTS ON GNSS OPERATIONS AT LOW LATITUDES, ICTP
Trieste, Italy 23 April – 4 May 2018

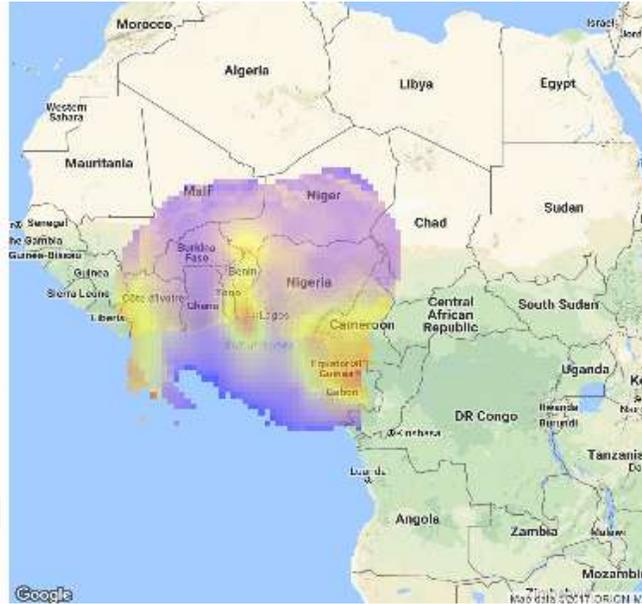
The **ICTP** and **Boston College** cosponsored by **UNOOSA**, have been organizing schools and workshops since 2009 in Trieste and in Africa to promote activities related to satellite navigation science and technology, ionosphere and Space Weather studies.

Projects related to SW studies:

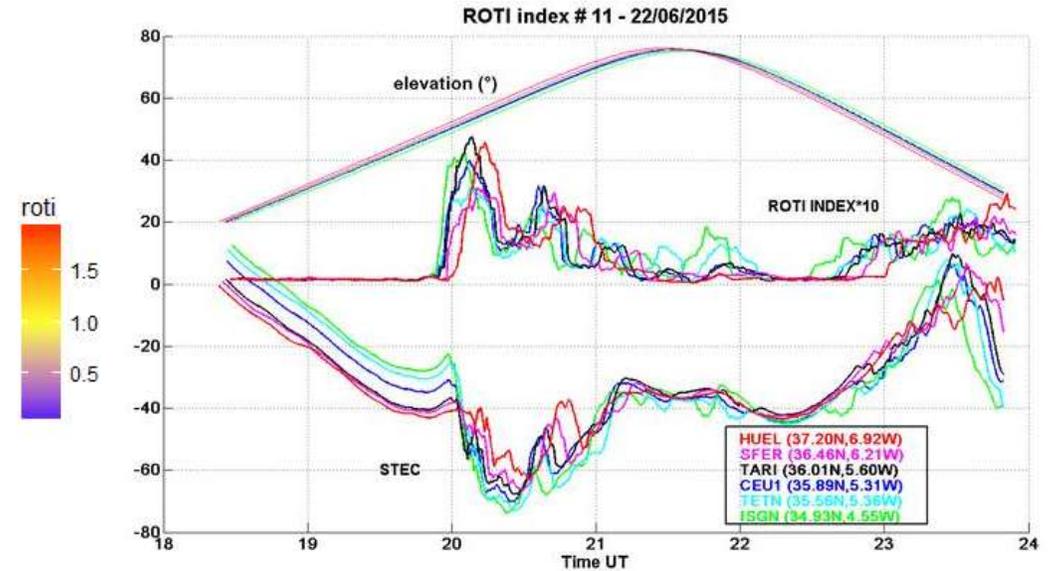
- ESA ALCANTARA Initiative: Total Electron Content Characterization Study over Africa and Application to BIOMASS mission (TECA)

- ESA MONITOR 

- ATMOSFILLER: Completing the Atmospheric Sounding System with GNSS and Platform Integrated Sensors



ROTI maps projected on West Africa to evaluate presence of irregularities (ESA-TECA Project).



ROTI index, STEC and elevation angle computed for links to PRN#11 at 6 GPS stations located at middle latitudes on day 22 June 2015 showing a plasma bubble occurrence (Kashcheyev et al, 2018).

Latest Publications related to SW studies:

J.N. Yao, B. Nava, O.K. Obrou, S.M. Radicella (2018). *Validation of NeQuick2 model over West African equatorial region using GNSS-derived Total Electron Content data.* Journal of Atmospheric and Solar-Terrestrial Physics, 181, A, 2018.

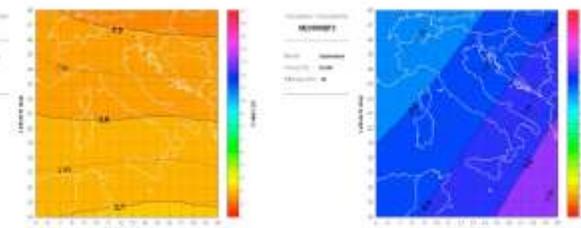
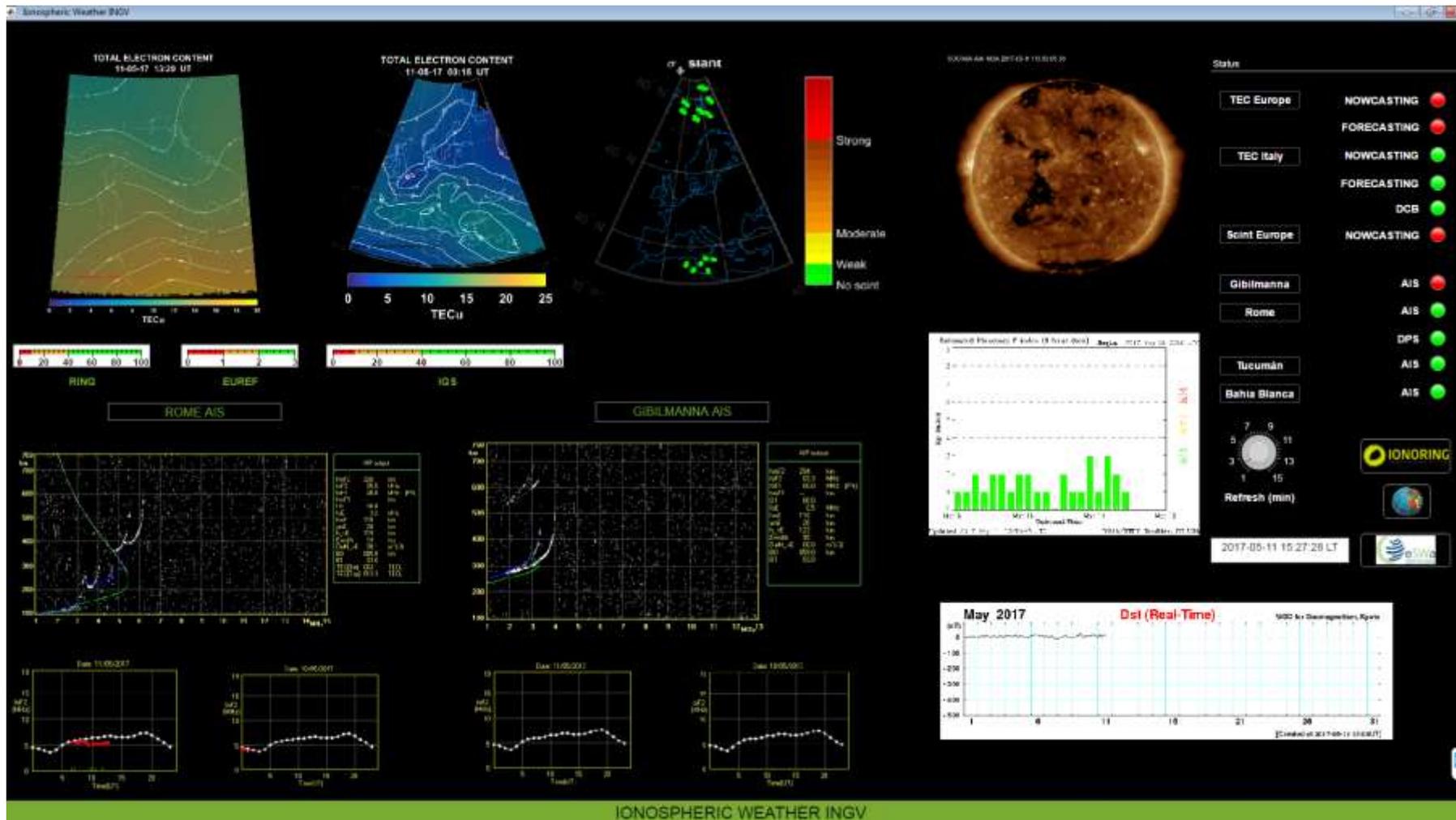
Kashcheyev, A., Migoya-Oru , Y., Amory-Mazaudier, C., Fleury, R., Nava, B., Alazo-Cuartas, K., Radicella, S. M. (2018). *Multivariable comprehensive analysis of two great geomagnetic storms of 2015.* Journal of Geophysical Research: Space Physics, 123, 2018.

Parihar, N., Radicella, S. M., Nava, B., Migoya-Oru , Y. O., Tiwari, P., and Singh, R.: *An investigation of the ionospheric F region near the EIA crest in India using OI 777.4 and 630.0 nm nightglow observations,* Ann. Geophys., 36, 809-823, 2018.

P. Mungufeni, Y. Migoya-Oru , J. B. Habarulema et al., *Estimation of equivalent ground-based total electron content using CHAMP-based GPS observations,* Advances in Space Research, 2019.



IONOSPHERIC WEATHER SERVICE



The ionospheric weather service at ionolab at INGV

www.eswua.ingv.it www.spaceweather.it

Long term prediction (left) and now casting (right) map of foF2 and M(3000)F2 respectively



THANK YOU!

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US AF

NASA

ESA

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