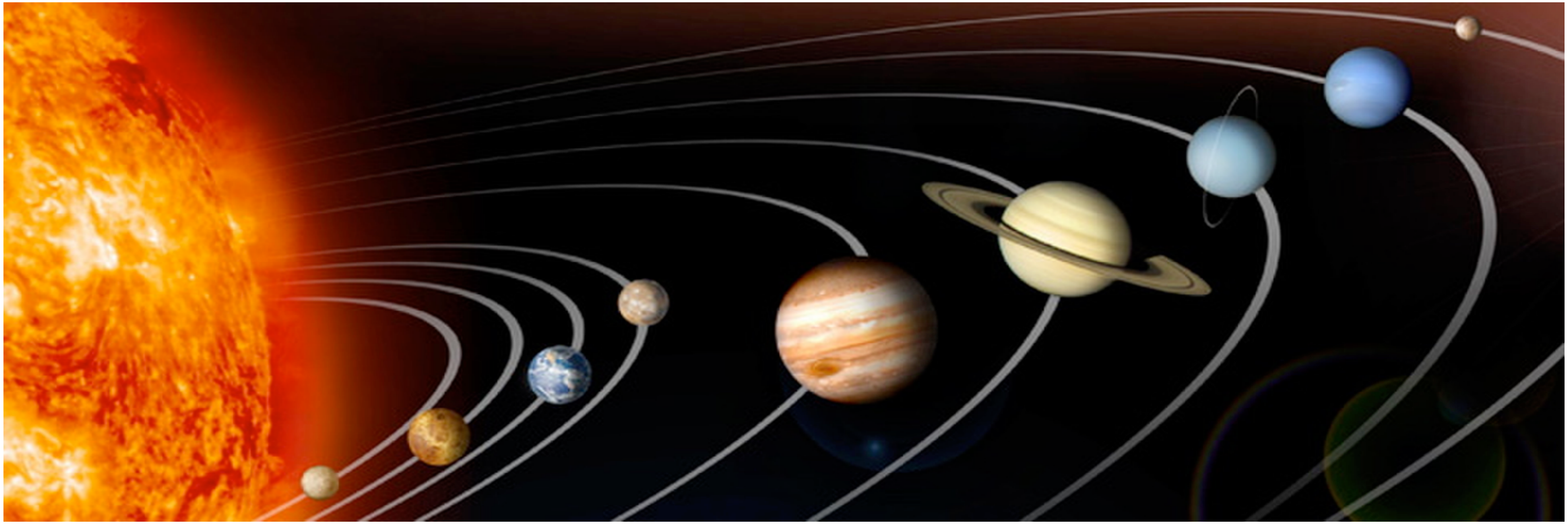
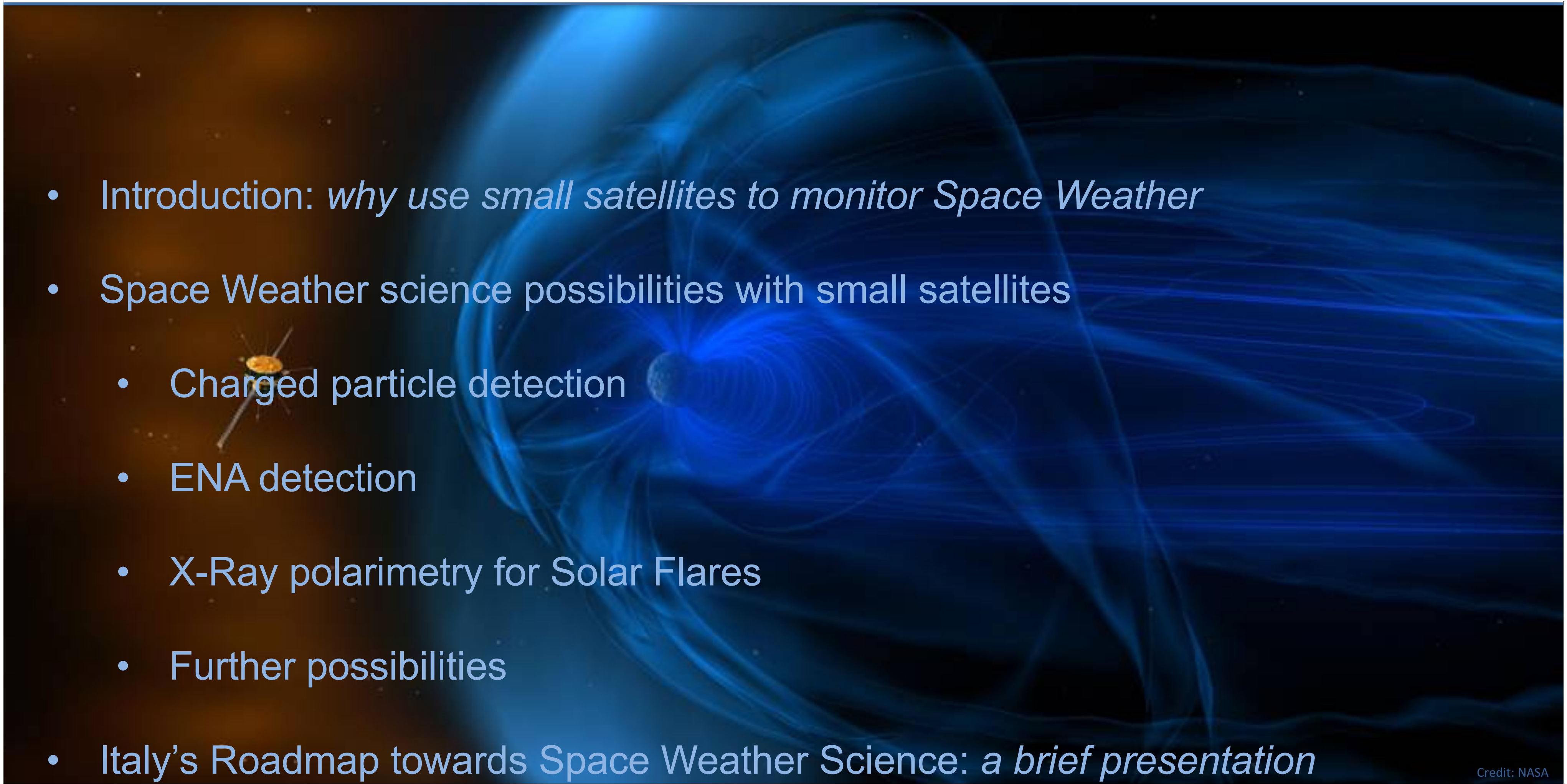
Small-satellite enabled science in Heliophysics within Italy's Roadmap towards Space Weather Science



Christina Plainaki and the ASI Space Weather Working Group

Scientific and Technical Subcommittee: 2019 - Fifty-sixth session (11-22 February 2019)
COSPAR Symposium on "**Space Weather and Small Satellites**" Vienna 11 February 2019

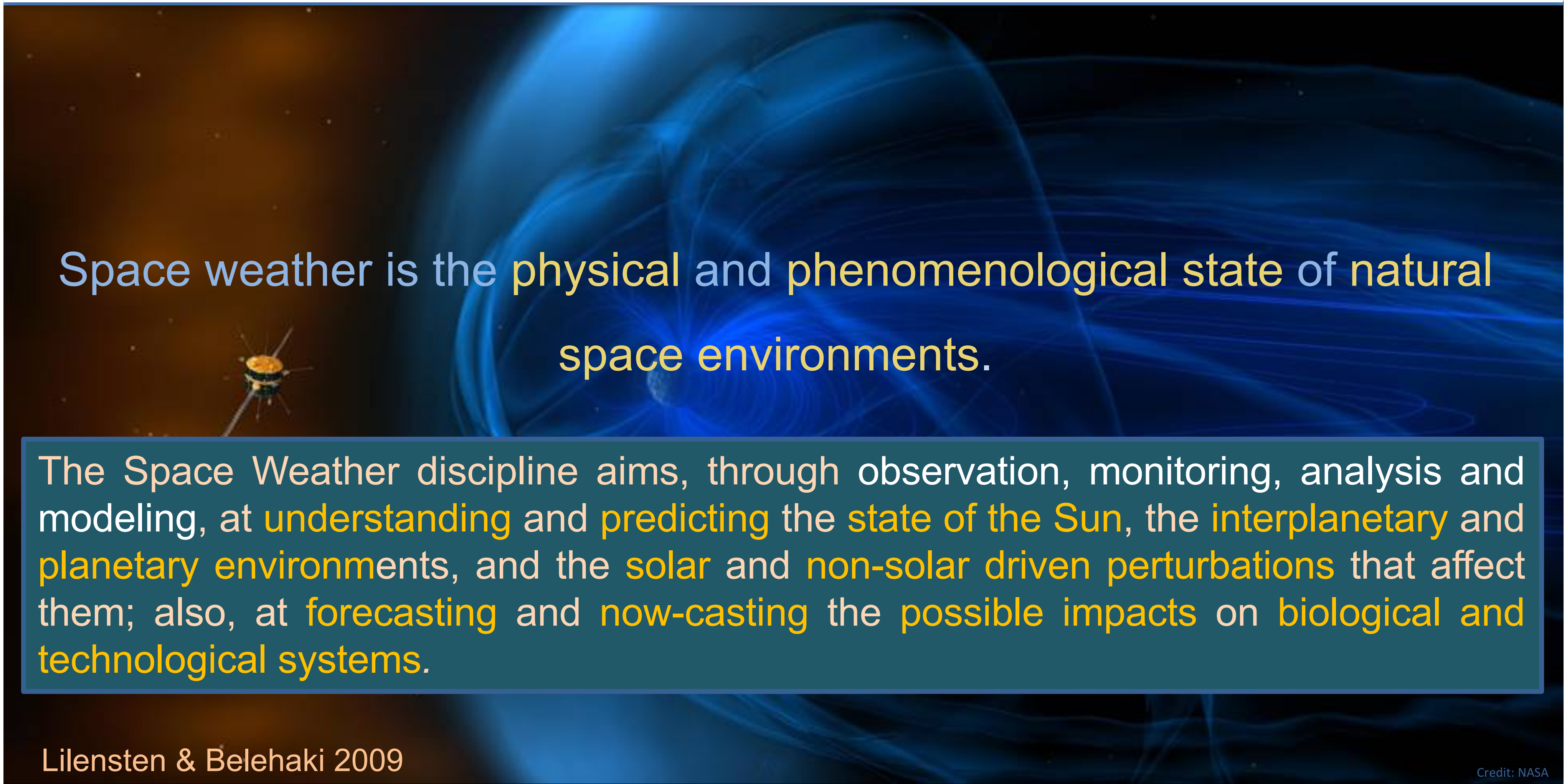
Outline



- Introduction: *why use small satellites to monitor Space Weather*
- Space Weather science possibilities with small satellites
  - Charged particle detection
  - ENA detection
  - X-Ray polarimetry for Solar Flares
  - Further possibilities
- Italy's Roadmap towards Space Weather Science: *a brief presentation*

Credit: NASA

Space Weather



Space weather is the physical and phenomenological state of natural space environments.

The Space Weather discipline aims, through observation, monitoring, analysis and modeling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them; also, at forecasting and now-casting the possible impacts on biological and technological systems.

Lilensten & Belehaki 2009

Space Weather with Small Satellites

Space weather is the physical and phenomenological state of natural space environments.

To understand Space Weather observations we need to understand in a quantitative way the interactions between space environments and the planetary body in question

Solar System Exploration is the key

Exploring our planet's magnetosphere we get hints on how fundamental processes related to photon and particle radiation work

To improve our ability to predict Space Weather we need to study the **Science** behind **circumterrestrial** and **Planetary Space Weather**

How and with what timescales the energy is transferred, stored and released within a system?

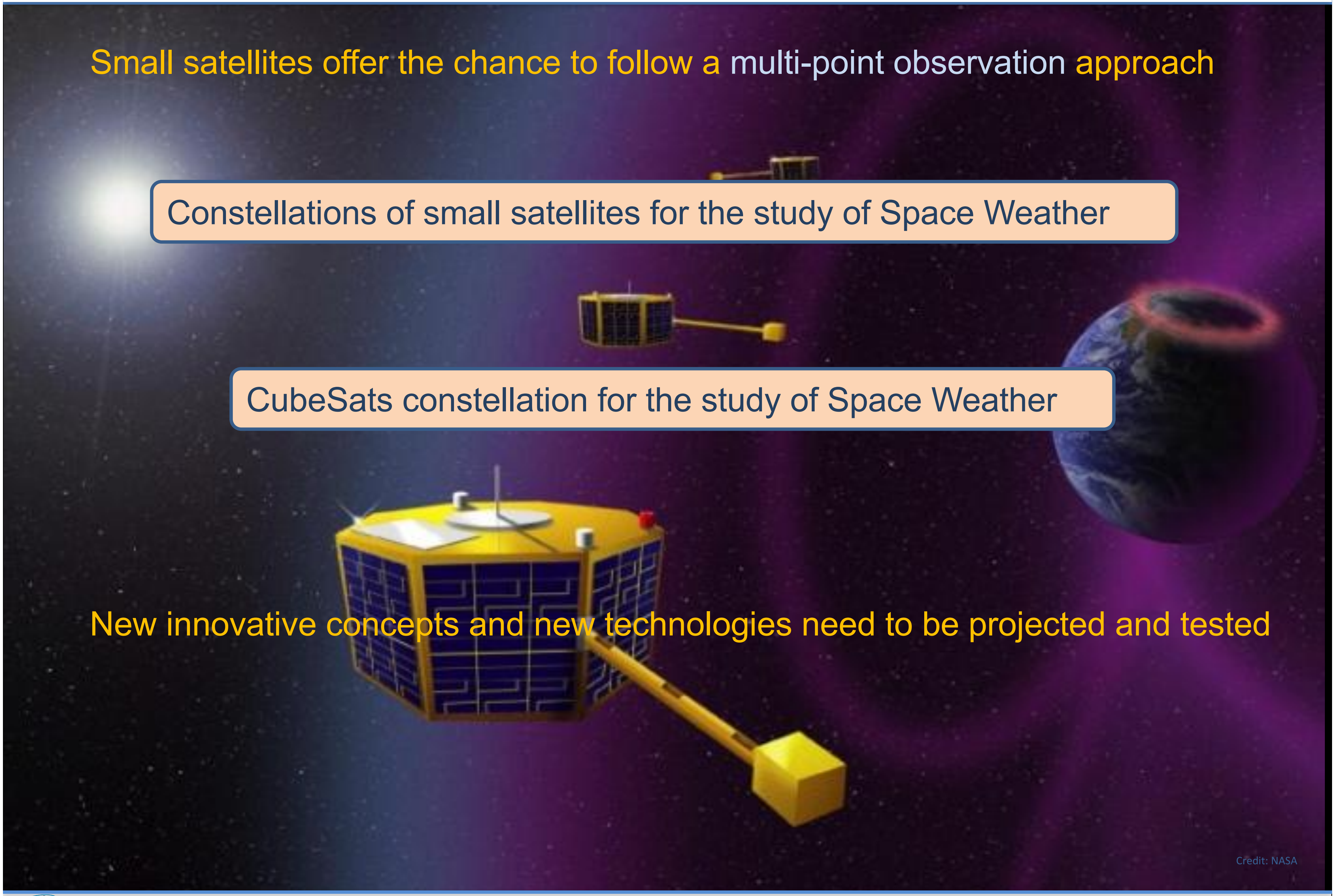
Space Weather with Small Satellites

Small satellites offer the chance to follow a multi-point observation approach

Constellations of small satellites for the study of Space Weather

CubeSats constellation for the study of Space Weather

New innovative concepts and new technologies need to be projected and tested



Credit: NASA

Space Weather with Small Satellites

Multi-point observation approach in Space Weather

Main goal: to promote original interdisciplinary scientific research in the field of Space Weather

How: by exploring original, innovative, and low-cost ways to provide Space Weather measurements

Add-on value: an important opportunity to educate next generations of Space Weather scientists and aerospace engineers

Constellations of small satellites for the study of Space Weather

Technological and scientific *plus*

- particle instruments and imaging instruments are on different s/c (i.e. s/c requirements are eased)
- interference among instruments on the same s/c is limited
- lower cost integration and testing
- lower schedule risk

Strategic interest

Constellation units can be distributed so that different space agencies can contribute with their own CubeSat and/or payload

Critical issues

- payload miniaturization
- advance subsystem technologies
- flight demonstrations of new technologies, capabilities and applications for small spacecraft
- advance the state-of-the-art

Space Weather with Small Satellites

Multi-point observation approach in Space Weather

A multi-point observation approach in Space Weather, based on different space observatories, can be always integrated with additional payload instruments onboard new small satellites to address further scientific goals and needs in the field.

Constellations of small satellites for the study of Space Weather

Technological and scientific *plus*

- particle instruments and imaging instruments are on different s/c (i.e. s/c requirements are eased)
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Small-satellite enabled instrumentation within Italy's Roadmap towards Space Weather

Charged particles with Small Satellites

PAN/Mini-PAN: Penetrating particle Analyzer(s)

UNIVERSITÀ DEGLI STUDI DI PERUGIA

INFN Istituto Nazionale di Fisica Nucleare

Magnetic spectrometers for deep space application aimed to make ground-breaking measurements crucial for space science and interplanetary exploration: composition and energy spectra in the10(100) MeV 5(20) GeV energy range

Innovative design based on the heritage of AMS: permanent magnets & silicon detectors successfully operated in LEO to measure particle fluxes in "standard" conditions, fast TOF + pixel detectors to count and identify particles in high rate mode (SEP events).

Team : Switzerland (UniGE, PI) , Italy (INFN/Univ. Perugia), Czech Republic (CTU Prague)

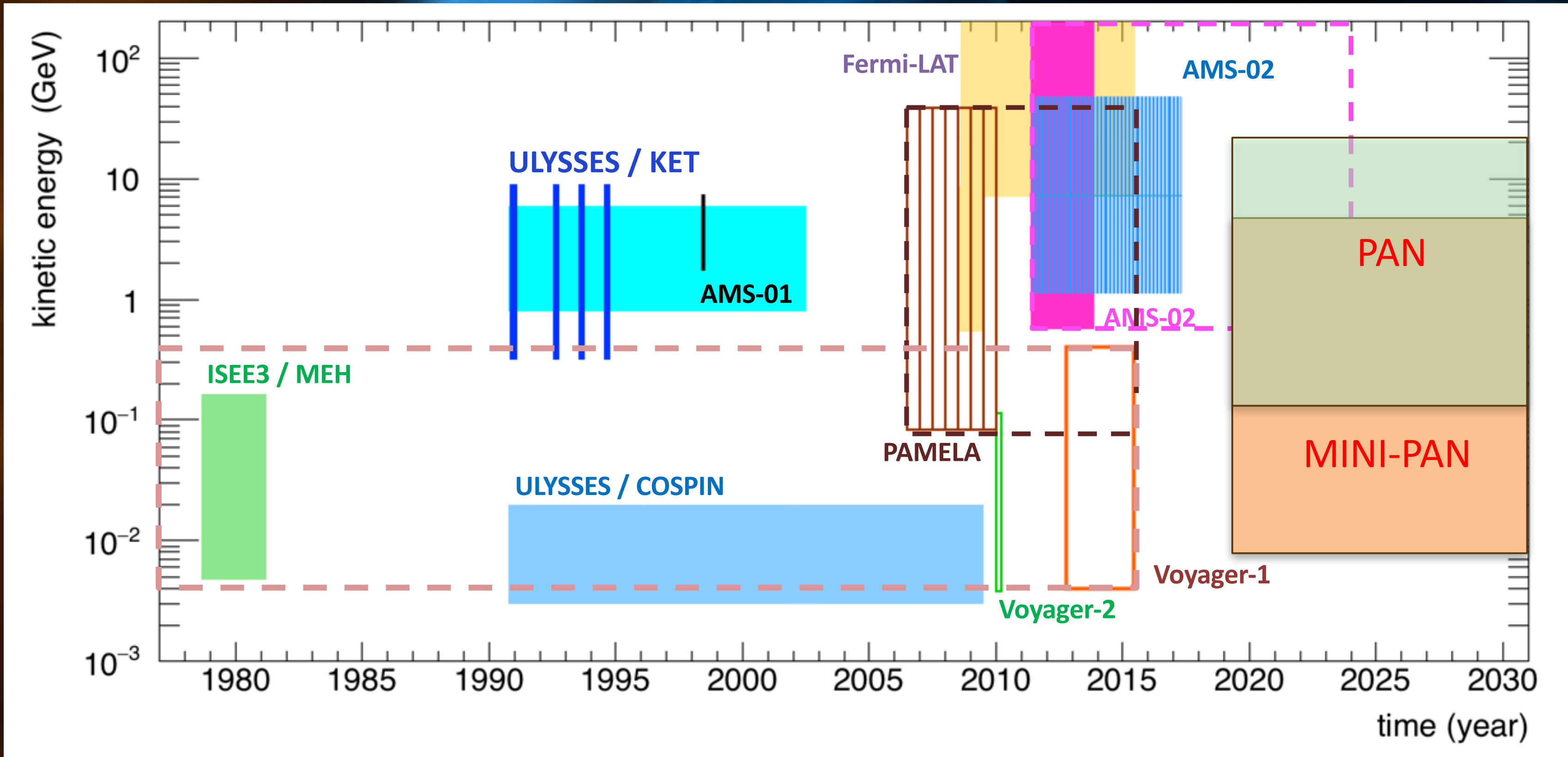
Silicon detectors & tracker from Italy

Key points:

- Modular concept to be adapted for different available upload masses (5-20 Kg)
- Covering the energy (and time) gap between low energy detectors (eg. ULYSSES, VOYAGER, SOHO, ACE, GOES..) operating in deep space and high energy spectrometers (PAMELA, AMS) operating in LEO.

Charged particles with Small Satellites

Electrons measurements : energy and time



Courtesy of N. Tomassetti (Univ. di Perugia)

Deep space mission: low energies, E –dE/dx technique, Cherenkov , no $e^{+/-}$ separation

LEO CR mission: higher energies, spectrometers e^+/e^- separation

PAN/MINI-PAN : covering a gap in energy/time

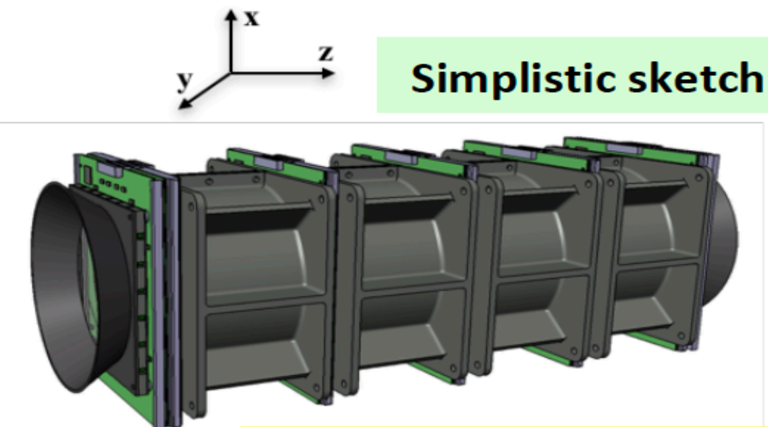
Charged particles with Small Satellites

PAN: Penetrating particle ANalyzer

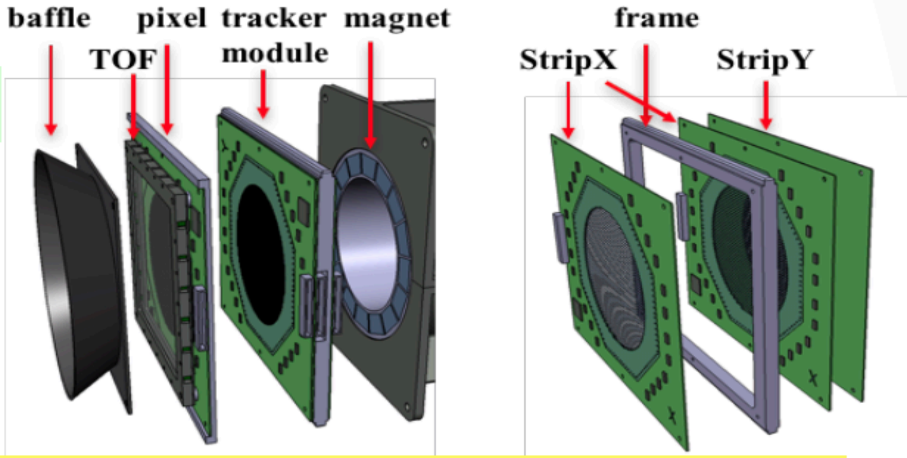
an energetic particle detector for deep space application based on an innovative concept, aiming to make ground-breaking measurements crucial for space science and interplanetary exploration.

Goal: to precisely measure and monitor over at least one full solar cycle (~11 years) the spectra, composition, and incoming direction of highly penetrating particles (from ~100 MeV/nucleon up to ~ 20 GeV/nucleon)

- Light weight (20 kg) low power (20 W) spectrometer with permanent magnet
- 4 Halbach permanent magnet sectors, each φ = 10 cm, L = 10 cm, provide a dipole magnetic field of ~0.2 Tesla, total weight ~11 kg



Simplistic sketch!



Measure particles coming in from both ends (symmetric)

PI: X. Wu (University of Geneve)
Lead Scientists:
B. Bertucci – University of Perugia; G. Ambrosi – INFN Perugia, Italy

Space Weather with Small Satellites

Mini-PAN for Space Weather *Small Satellite missions*?

- Smaller device for in-situ radiation measurement and monitoring
- 2 Halbach permanent magnet sectors, each ϕ = 5 cm, L = 5 cm, provide a dipole magnetic field of ~0.4 Tesla, magnet weight ~2 kg, total < 5 kg
- GF: ~6.3 or 2.1 cm2sr (x2 for isotropic sources), for crossing 1 or 2 sectors

Addition of a few layers of Si detectors would allow to measure 10 MeV – 20 MeV particles with the classical ΔE –E method (~2.4 mm of Si) → full range energetic particle monitor

It can be further simplified with only one-side sensitive

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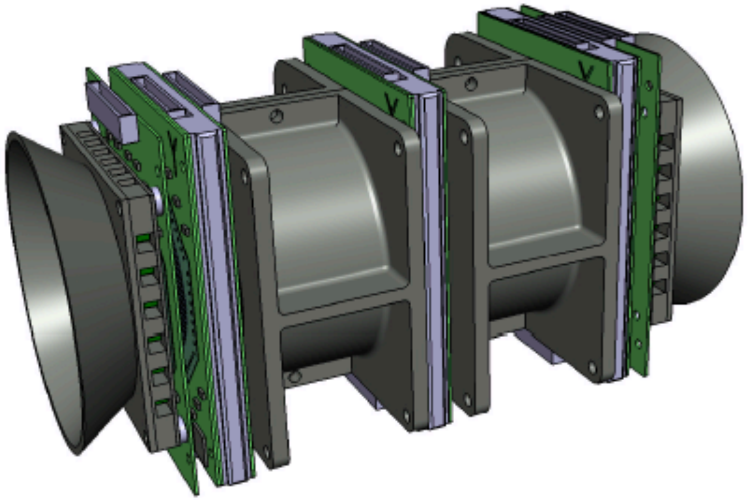
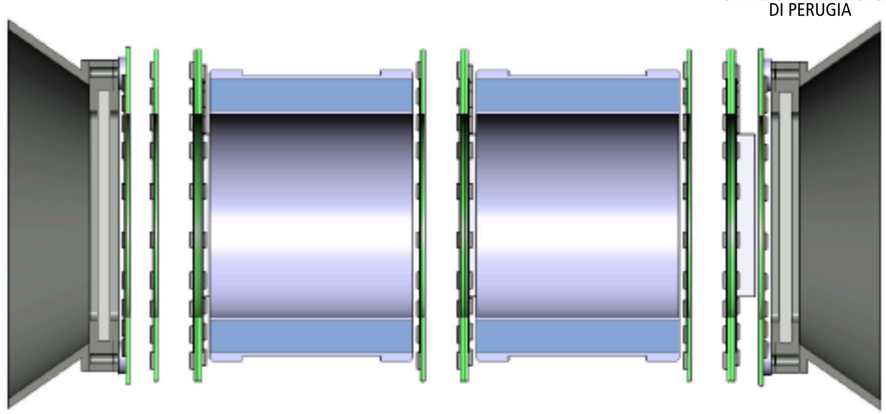




Imaging the Earth's environment via ENA: Space Weather applications

SWEATERS

(Space WEATher Ena Radiation Sensor)

Team	Stefano Orsini (INAF-IAPS), supervisor
Project leader	Elisabetta De Angelis (INAF-IAPS)
Science	Alessandro Mura (INAF-IAPS)
Experimental Team	Rosanna Rispoli (INAF-IAPS), Nello Vertolli (INAF-IAPS),Fabrizio Nuccilli (INAF-IAPS), Carlo Lefevre (INAF-IAPS)
Micro Pattern Gass Detector	Federico Pilo (INFN Pisa)
	Giovanni Bencivenni (INFN Frascati)
	Marco Poli Lener (INFN Frsacati)
	Carlo Avanzini (ex-INFN, consultant)
	Guido Castellini (ex-CNR, consultant)

SWEATERS project: a new technique for SW monitoring

Remote sensing of **Energetic Neutral Atoms (ENA)** in the Earth's environment has been proven to be a **successful technique** able to provide detailed information on the ring current and the shock front plasma population at energies below 100 keV.

ENA detection is the only way to **globally view** the ring current and shock-front population dynamics

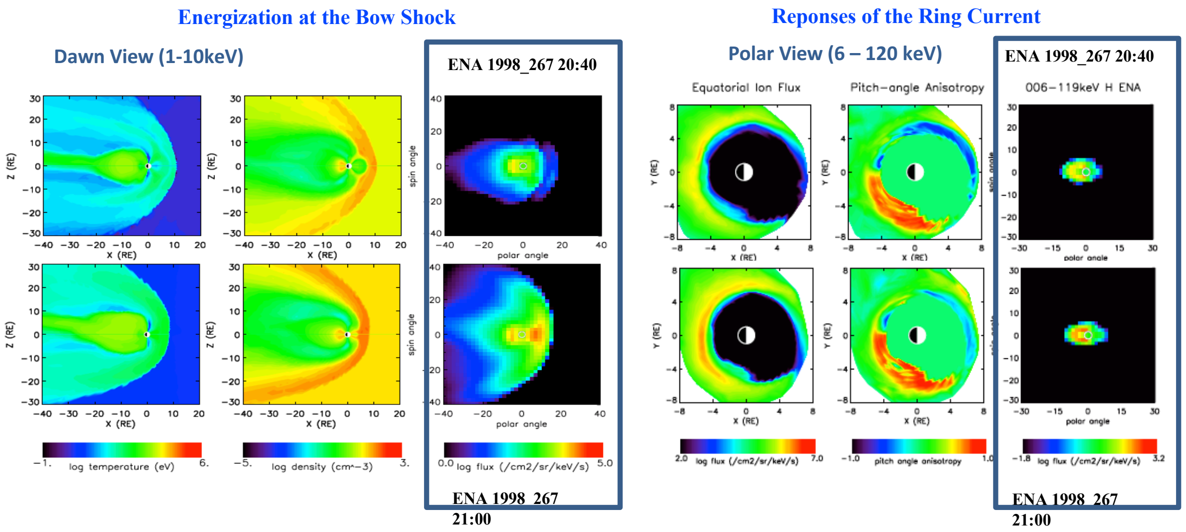


Figure: ENA emissions as detected from high distance on the equatorial plane (from dawn, left) and from the pole (right), outcoming from modeled plasma distributions during a magnetic storm occurred in 1998, day 267. *(Fok et al., 2017 AGU Fall Meeting)*

The SWEATERS concept is based on a cluster of platforms equally distributed around the Earth as **multiple vantage point** system for ENA imaging of various magnetospheric regions like ring current, shock front and high latitude plasma populations.

The **SWEATERS sensor** is an innovative philosophy of ENA detection based on the idea to have an ENA instrument able to detect particles in a **large energy range** (few keV-100keV) with a very compact system, based on MPGD technique (Micro-Pattern Gas Detector)

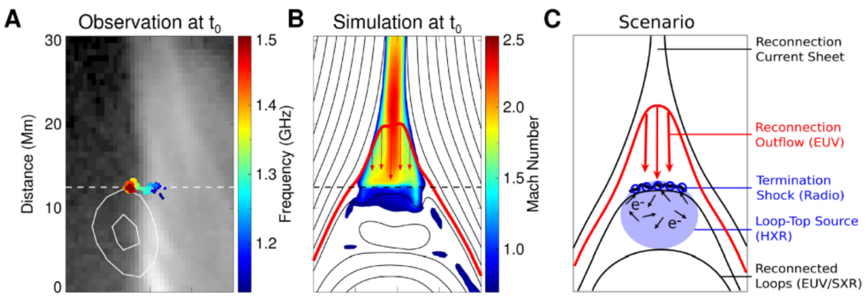
X-ray polarimetry of solar flares

Berrilli F, Soffitta P., Costa E.

Due to energetic events such as solar flares, the Sun is an astrophysical source with an **intense emission of x-rays**.

Their characterization will advance our understanding of the dynamics of the magnetic fields in the ARs of our star.

Magnetic reconnection is the cause of the sudden release of energy in flares and it is responsible for the acceleration of particles, including the downward beaming and the upward solar wind.



Observation and simulation of the dynamic termination shock. White contours show the coronal HXR source at 15–25 keV. The electrons produce a HXR source in the shock downstream region (blue shadowed region).
Credits Chen et al., 2015

The **X-ray solar polarimeter (XSPO)** Instrument - Gas Pixel Detector (GPD)

The GPD is a gas-filled detector devoted to study the polarization of x-ray radiation and it was developed by INFN/Pisa in collaboration with INAF-IAPS.

It exploits the dependence of the photoelectric cross section to the polarization of photons to perform the **polarimetric measurement**.

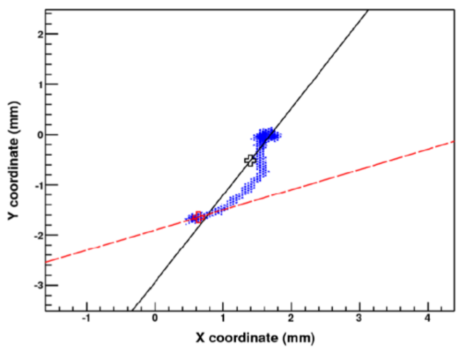
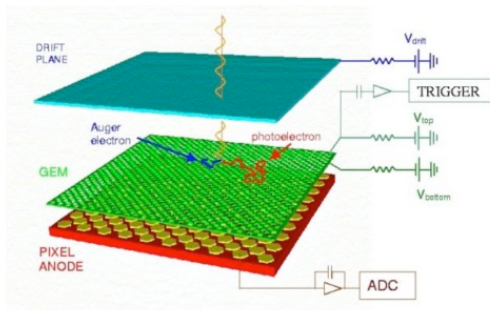


Fig. 4 Example of a photoelectron track produced by the absorption of a photon at 22 keV acquired with the GPD filled with an Ar (70%)–DME (30%) gas mixture at the pressure of 2 bar. The upper black cross is the barycenter of the charge distribution and the black solid line is the main axis of the track. The lower red cross is the absorption point and the red dashed line is the emission direction of the photoelectron.



Credits Berrilli et al., 2015

Heritage ADAHELI +

Adaheli +

***AD**vanced **A**stronomy for **HELI**ophysics*

Francesco Berrilli (PI) *University of Rome Tor Vergata (UTOV)*
Paolo Soffitta (Co-PI) *INAF Institute for Space Astrophysics and Planetology(IAPS)*
Marco Velli (Co-PI) *Università degli Studi di Firenze I-50125 Firenze*

Bando Piccole Missioni Scientifiche
Phase A study completed in 2008

Proposal for Small class mission
Cosmic Vision 2015-2025

Industrial team:

OHB CGS

Prime Contractor

ThalesAlenia Space
RHEINMETALL DEFENCE
TELESPAZIO
CEC by altran
WIS Wireless Solutions
Studiorum Universitas Florentina
Ingegneria Informatica ed Elettronica Università di Perugia
ANTARES

Scientific background

ADAHELI+ will address key questions concerning the physics of the Sun, photosphere and chromosphere.

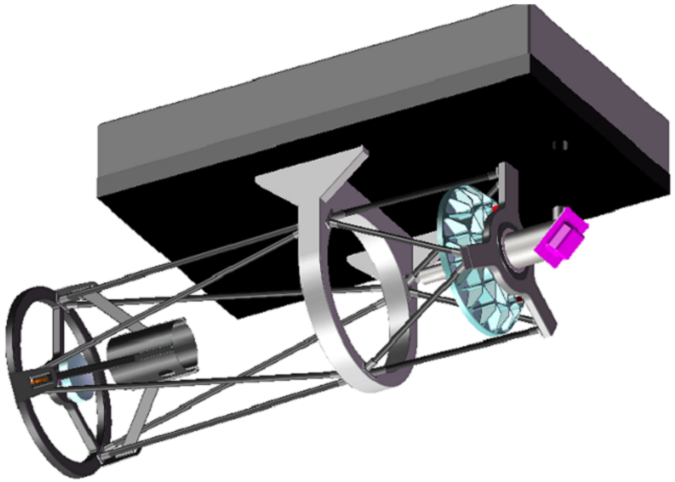
Understanding the Sun → understanding various process in modern astronomy
Provide a detailed observation and deeper understanding of the MHD processes (accretion disk/jet systems, X-ray, pulsars, stellar flare and γ-ray burst sources).

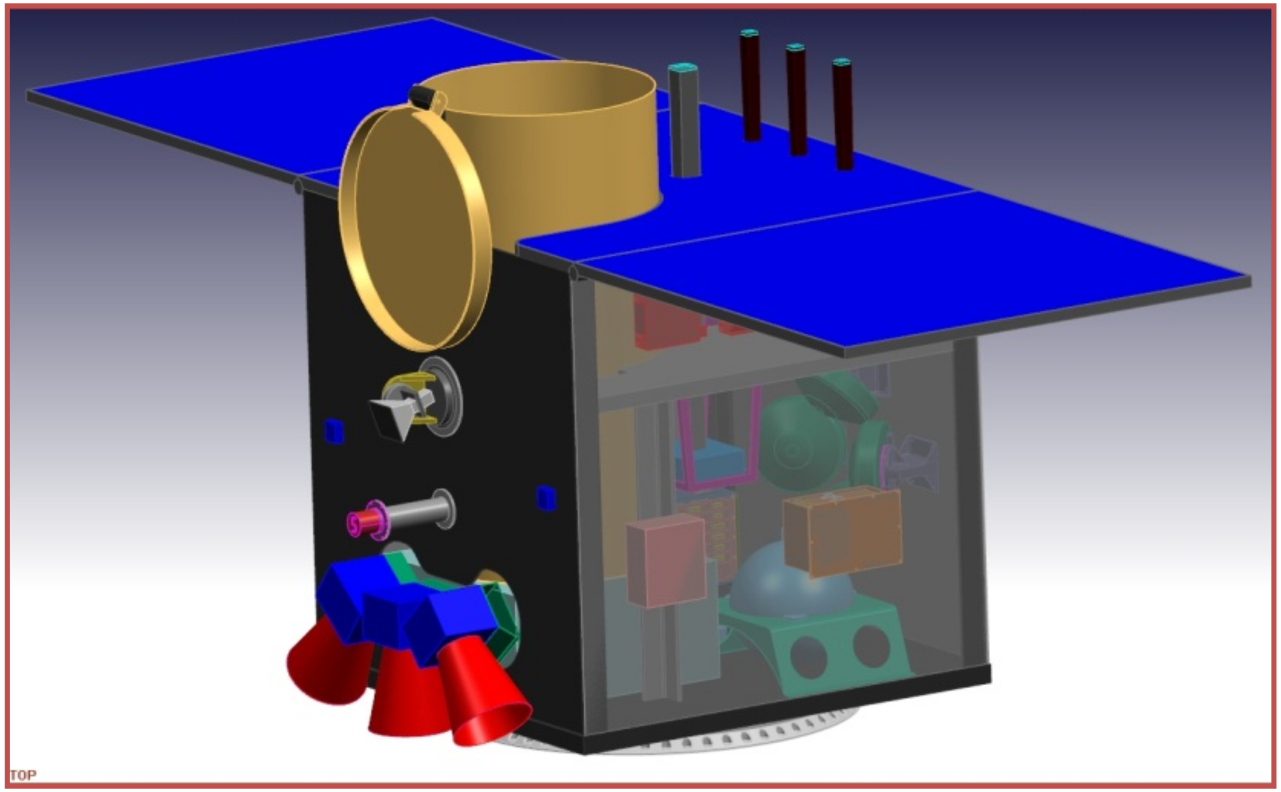
Studying the Sun → explain measurements of Sun-like stars for detection of habitable exo-planets around them.

The investigations include Near Infrared (NIR) spectropolarimetric imaging of the 3d solar atmosphere and X-ray measurements.

The mission is conceived as an innovative and very focused Space Observatory for NIR multi-line imaging, coupled with an ancillary solar flares X-ray polarimeter.

The mission ADAHELI+ carries two scientific payloads:
* The NIR telescope
* The X-ray polarimeter

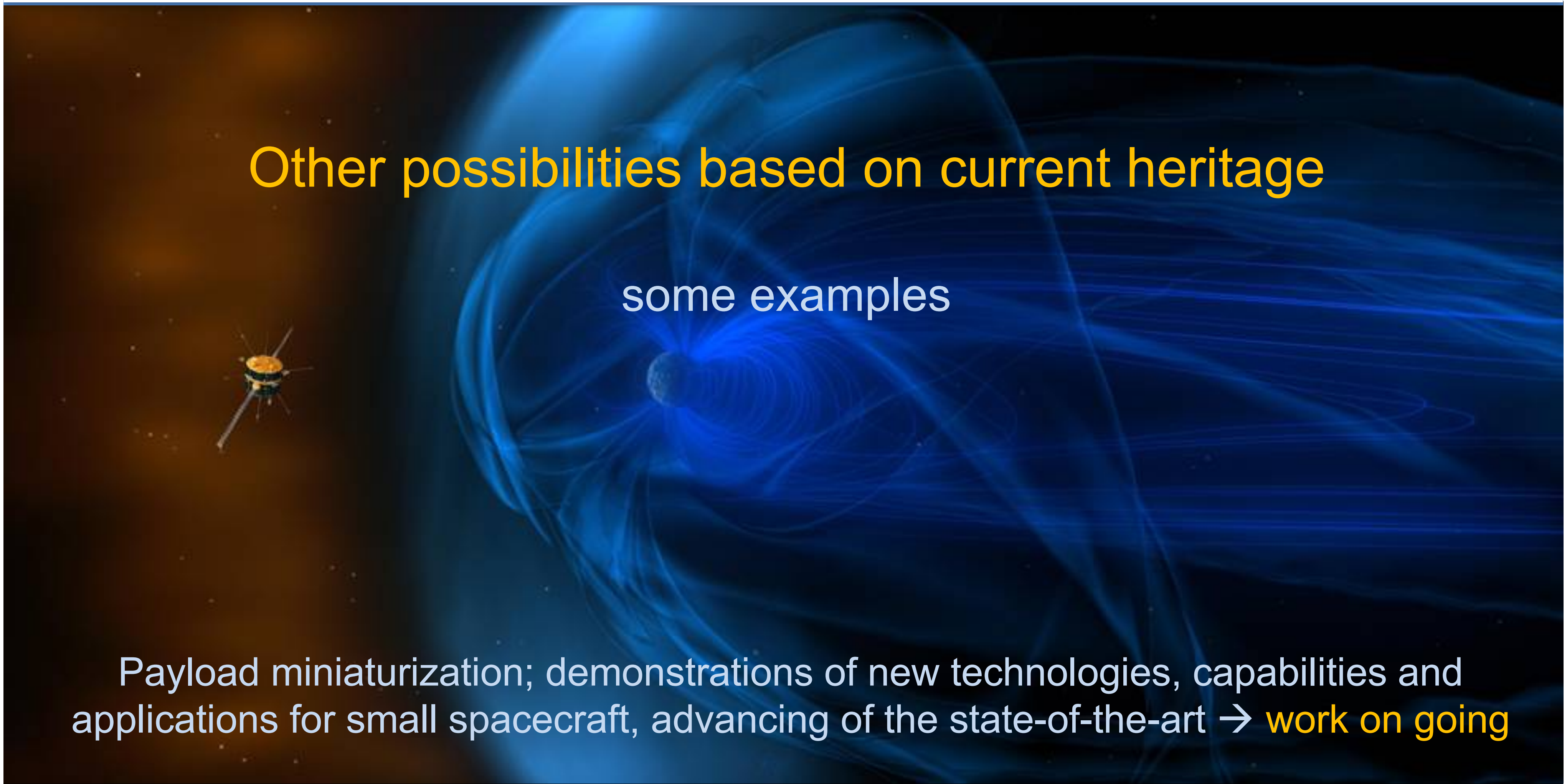




The NIR telescope is equipped with a panoramic interferometer based on a Fabry-Peròt etalon used in tandem configuration → it combines high-spectral resolution with short exposure times

The main task of the feasibility study of optics is to find configuration able to achromatize the instrument and to make it more compact.

Space Weather with Small Satellites



Other possibilities based on current heritage

some examples

Payload miniaturization; demonstrations of new technologies, capabilities and applications for small spacecraft, advancing of the state-of-the-art → work on going

HIGH ENERGY PARTICLE DETECTOR (HEPD) FOR CSES MISSION

Instrument: High Energy Particle Detector (HEPD-02 for CSES-02)

Developers: INFN, University of Trento, University of Rome Tor Vergata, University of Naples, University of Turin

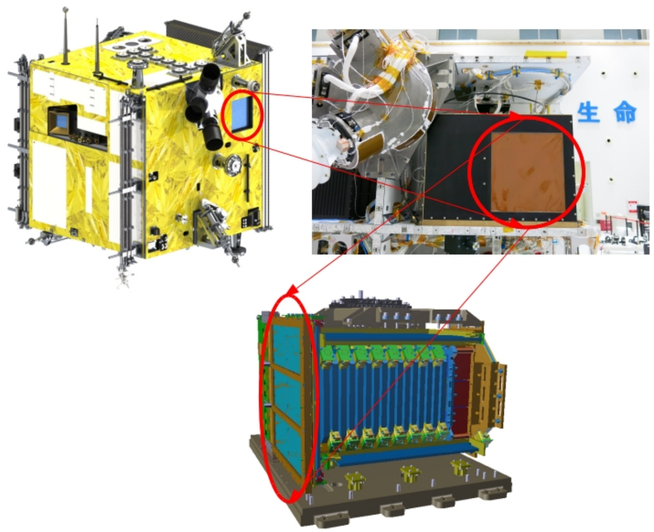
PI: Piergiorgio Picozza, National Institute for Nuclear Physics (INFN)

Deputy PI: Roberto Iuppa, University of Trento

Mission: China Seismo-Electromagnetic Satellite (CSES)

Countries: China, Italy, Austria

Satellites: CSES-01 (launched Feb. 2018), CSES-02 (launch 2021)



agenzia spaziale italiana

INFN Istituto Nazionale di Fisica Nucleare

Objectives: Study of Litosphere-Ionosphere-Magnetosphere Coupling (LAIC), Solar Physics and Space Weather through concurrent measurements of 9 different instruments including an Italian particle detector (HEPD).

Heritage: HEPD-01 on-board CSES-01, PAMELA, AMS-02

Industrial contribution: Italian Small and Medium-sized Enterprises (SMEs) involved in the development.

HEPD is designed to provide good **energy** and **angular resolutions** for electrons in the energy range 3 to 100 MeV and for protons in the energy range 30 to 200 MeV.

HEPD-02 will measure **increases of electron and proton fluxes** due to **short-time perturbations of the radiation belts** caused by solar, terrestrial and anthropic phenomena.

Operating temperature	-10 °C - +45 °C
Data budget	≤100 Gb/day
Mass budget	≤ 45 kg
Energy range (electron)	3 MeV ÷ 100 MeV
Energy range (proton)	30 MeV ÷ 200 MeV
Angular resolution	at least 8° at E > 5 MeV
Energy resolution	at least 10% at E~5 MeV
Power Budget	≤ 45 W

ELECTRIC FIELD DETECTOR (EFD) FOR CSES MISSION

Instrument: Electric Field Detector (EFD-02 for CSES-02)

Developers: INFN-Rome Tor Vergata & INAF-IAPS

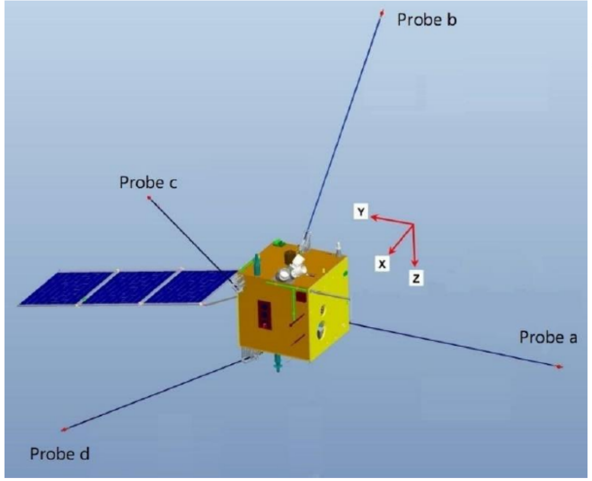
PI: Piergiorgio Picozza, National Institute for Nuclear Physics (INFN)

Deputy PI: Piero Diego, National Institute for Astrophysics (INAF)

Mission: China Seismo-Electromagnetic Satellite (CSES)

Countries: China, Italy, Austria

Satellites: CSES-01 (launched Feb. 2018), CSES-02 (launch 2021)



Objectives: Study of Litosphere-Ionosphere-Magnetosphere Coupling (LAIC), Solar Physics and Space Weather through concurrent measurements of 9 different instruments including an Italian particle detector (HEPD).

Heritage: Engineering Model for CSES-01 developed by research groups of INFN - Division of Rome Tor Vergata and INAF - Institute for Space Astrophysics and Planetology (IAPS).

Industrial contribution: Italian Small and Medium-sized Enterprises (SMEs) involved in the development.

EFD measures electric field between DC-3.5 MHz in 5 bands to identify the different contribution to ionospheric anomalies by separating external (Space Weather) from internal ones (LAIC)

Band	Type	Frequency Band	# Channels	Sampling Frequency	Resolution (bit)
ULF*	wave	0 – 100 Hz	4	240 Hz	20
ELF	wave	13 Hz – 2 kHz	3	4.8 kHz	20
VLF	wave + FFT	1 kHz – 50 kHz	3	120 kHz	16
VLF2*	wave + FFT	21 kHz – 100 kHz	1	240 kHz	12
HF	FFT	21 kHz – 3.5 MHz	1	12 MHz	12

Italy’s Roadmap towards Space Weather Science
(brief presentation)

The ASI Space Weather Working Group

The **ASI Space Weather Working Group** (ASI SW WG, or "Gruppo di Lavoro Nazionale su Space Weather") was officially established on 13 April 2018 with the purpose to coordinate and promote activities related to Space Weather science.

The current composition of the ASI SW WG is the following (in alphabetical order):

1. Antonucci Marco, *Aeronautica Militare Italiana*
2. Bemporad Alessandro , *INAF-OATo*
3. Berrilli Francesco, *UNITOV*
4. Bertucci Bruna, *UNIPG*
5. Castronuovo Marco, *ASI/EOS*
6. De Michelis Paola, *INGV*
7. Giardino Marco, *ASI/SSDC*
8. Iuppa Roberto, *UNITRENTO*
9. Laurenza Monica, *INAF-IAPS*
10. Marcucci Federica, *INAF-IAPS*
11. Messerotti Mauro, *INAF-OATs*
12. Narici Livio, *UNITOV*
13. Negri Barbara, *ASI/EOS*
14. Nozzoli Francesco, *INFN-TIFPA*
15. Orsini Stefano, *INAF-IAPS*
16. Plainaki, Christina, *ASI/URS*, Group Coordinator
17. Romano Vincenzo, *INGV*

Unità di Esplorazione e Osservazione dell'Universo

Unità di Ricerca Scientifica

Space Science Data Center

The Italian Space Weather Community (SWICO) is vastly represented within the WG hence contributing at large in the creation of the Roadmap's first version.

The ASI Space Weather Working Group

The ASI SW Working Group has recently created "Italy's Roadmap towards Space Weather Science". envisioning the development of a prototype of a National Scientific Space Weather Data centre.

This Roadmap provides a general perspective of the development of Space Weather activities in Italy.
It is therefore a proposal for a long-term strategy.

In the context of this strategy, ASI aims to assess, as a first step, the possibility to develop a National Scientific Space Weather Data Center in ASI/SSDC, to encourage synergies between different science teams.

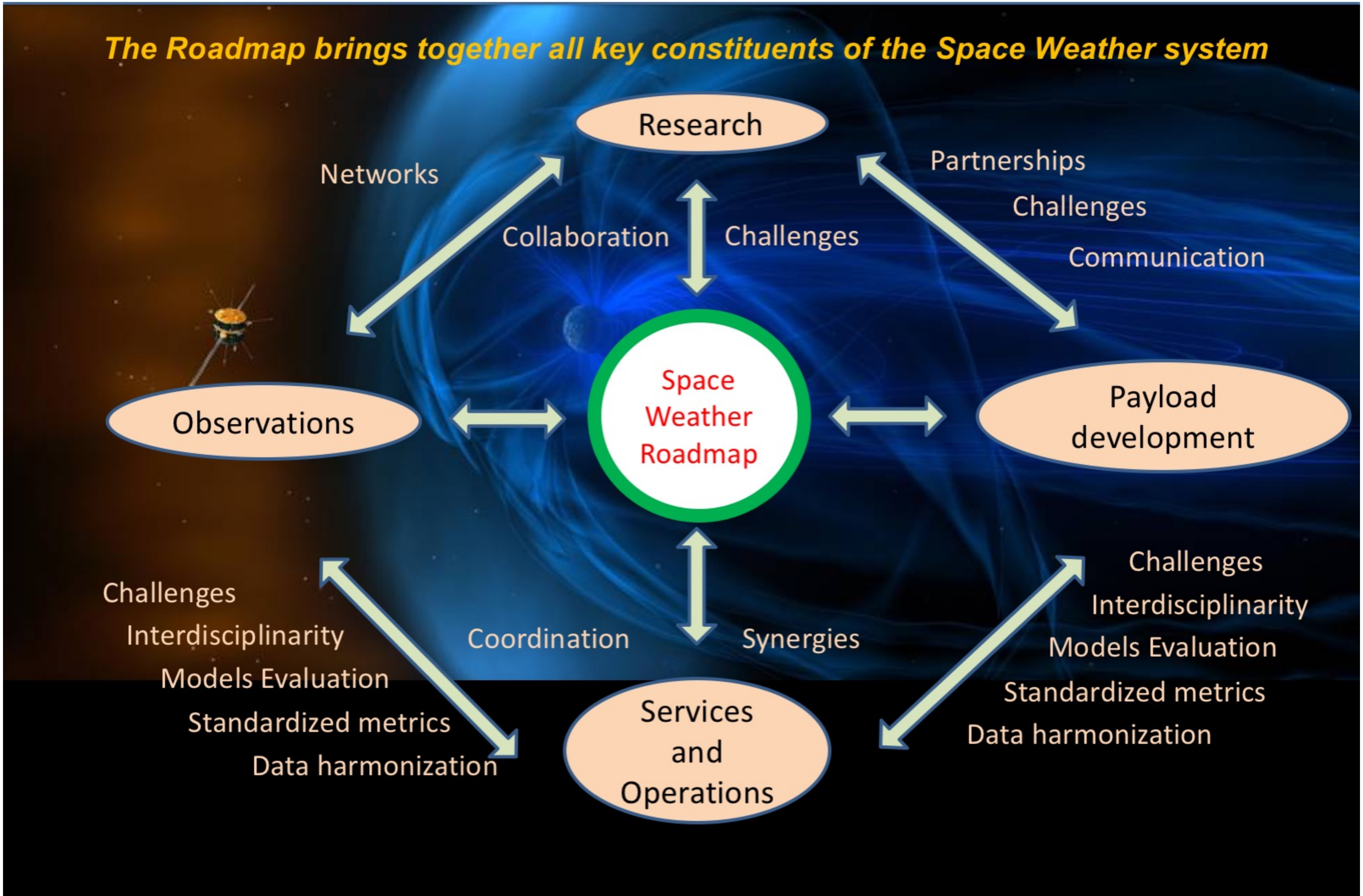
The ASI SW Working Group is currently developing a "Roadmap Implementation plan" taking into account all required scientific, technological and programmatic activities.

Credit: NASA

Overall scope and main points

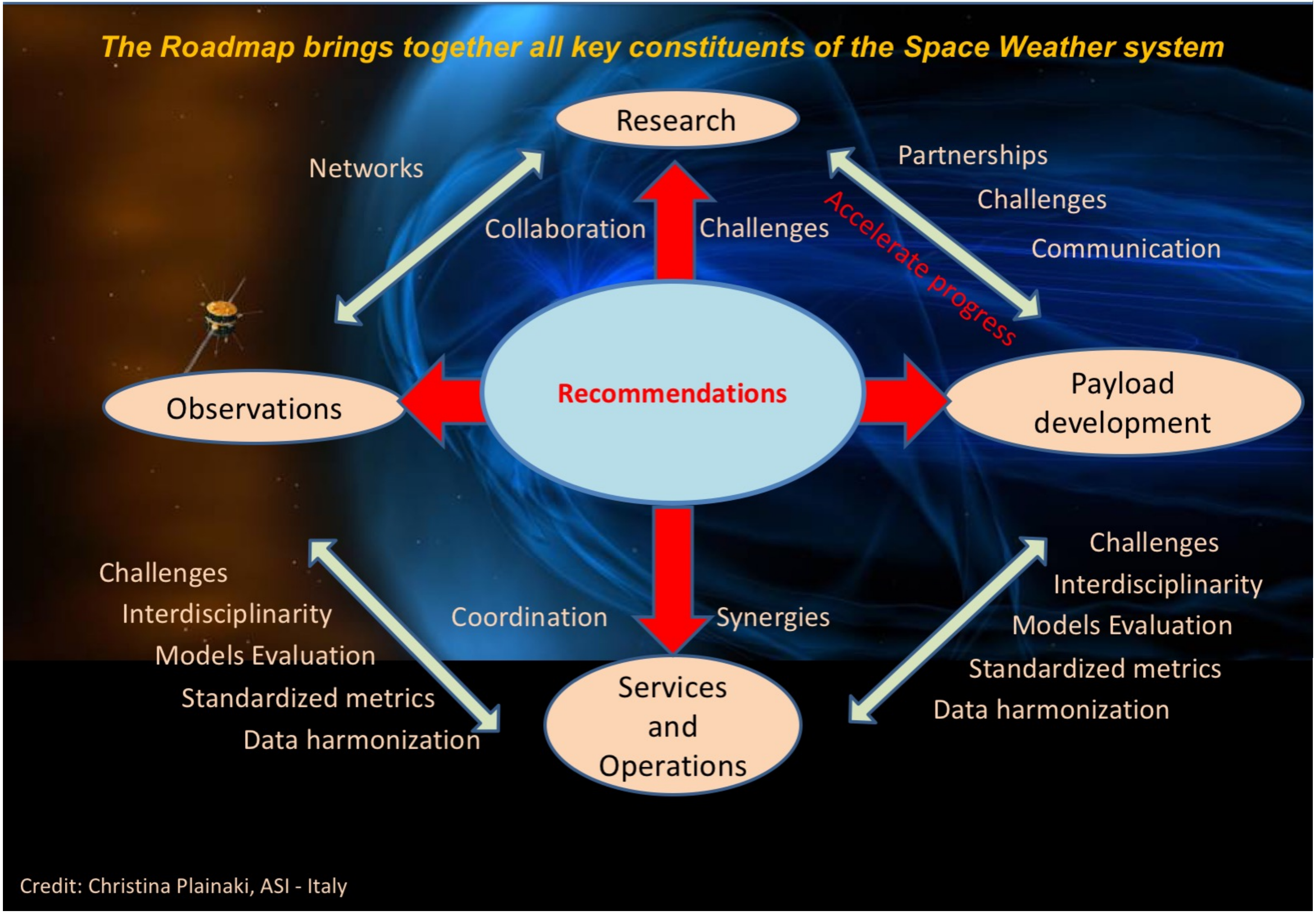
We aim to achieve a better understanding of space weather phenomena that would allow the future development of reliable nowcast and forecast services.

Italy's Roadmap towards Space Weather

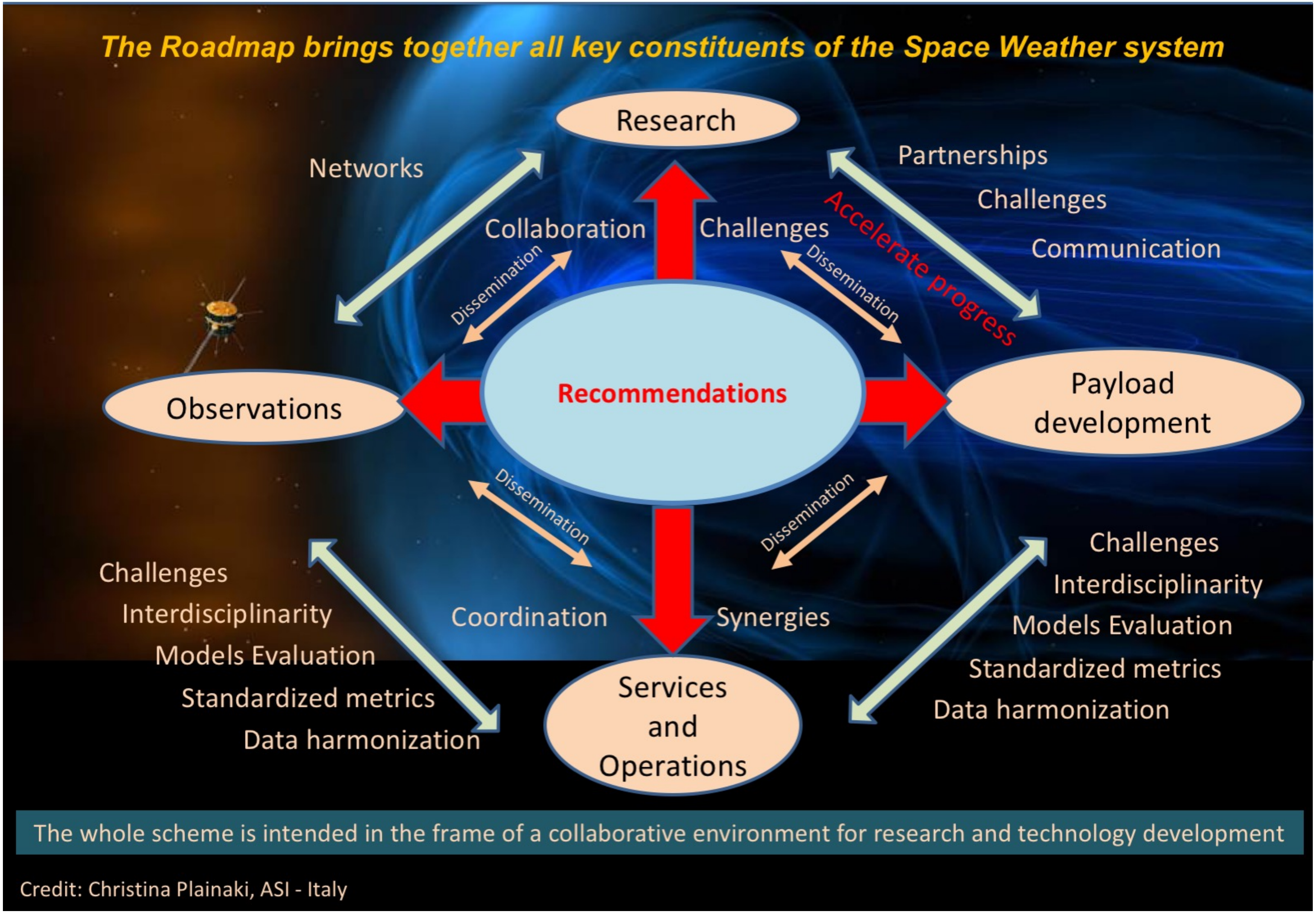


Credit: Christina Plainaki, ASI - Italy

Italy's Roadmap towards Space Weather



Italy's Roadmap towards Space Weather



Experience of the Italian Space Weather Community

Space weather scientific research in Italy has been focused in the following fields:

- Solar Physics
- Solar-Terrestrial Physics
- Geomagnetism
- Physics of the Ionosphere
- Planetary Space Weather
- Study of technological and biological impacts of space weather
- Galactic Cosmic Ray Physics

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- Geomagnetism
- Physics of the Ionosphere

Payload development

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- Geomagnetism
- Physics of the ionosphere
- Planetary space weather
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- Ground-based instrumentation

Experience of the Italian Space Weather Community

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- Solar Physics
- Solar-Terrestrial Physics
- Geomagnetism
- Physics of the Ionosphere
- Planetary Space Weather
- Study of technological and biological impacts of space weather
- Galactic Cosmic Ray physics

Laboratories and facilities

Experience of the Italian Space Weather Community

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- Solar Physics
- Solar-Terrestrial Physics
- Geomagnetism
- Physics of the Ionosphere
- Planetary Space Weather
- Study of technological and biological impacts of space weather
- Galactic Cosmic Ray Physics

Space Weather Service development

ASPIS Vision

Asi SPace weather InfraStructure (ASPIS)

Key Goal → **to disseminate high-quality interdisciplinary Space Weather data to support scientific research in the field.**

To increase the excellence in circumterrestrial and planetary Space Weather research motivating the development of solutions to current **science challenges**.

ASPIS, with the support by the scientific Space Weather community, aims at being

- a ***reference point*** for ***data analysis activities*** and ***joint investigations***
- a node joining research activities of at least seven ***science communities*** interested in Space Weather

Synergies | Collaboration | Opportunities

ASPIS Science Objectives

- to provide **efficient storage**, **sophisticated organization**, and **explanative visualization** of interdisciplinary Space Weather data and to offer user friendly data access and related documentation;
- to provide **first-order products** derived from the original data to be further used in scientific Space Weather models;
- to **coordinate interdisciplinary data products** that can potentially provide relevant inputs for advanced scientific Space Weather models;
- to provide **test-beds for forecasting models** to be run on historical data;
- to promote education and awareness in Space Weather;
- to maintain a **long-term close relationship** with the **Italian scientific community** through the continuous update of the ASPIS representatives on the national Space Weather activities and through the organization of dedicated Space Weather workshops and meetings

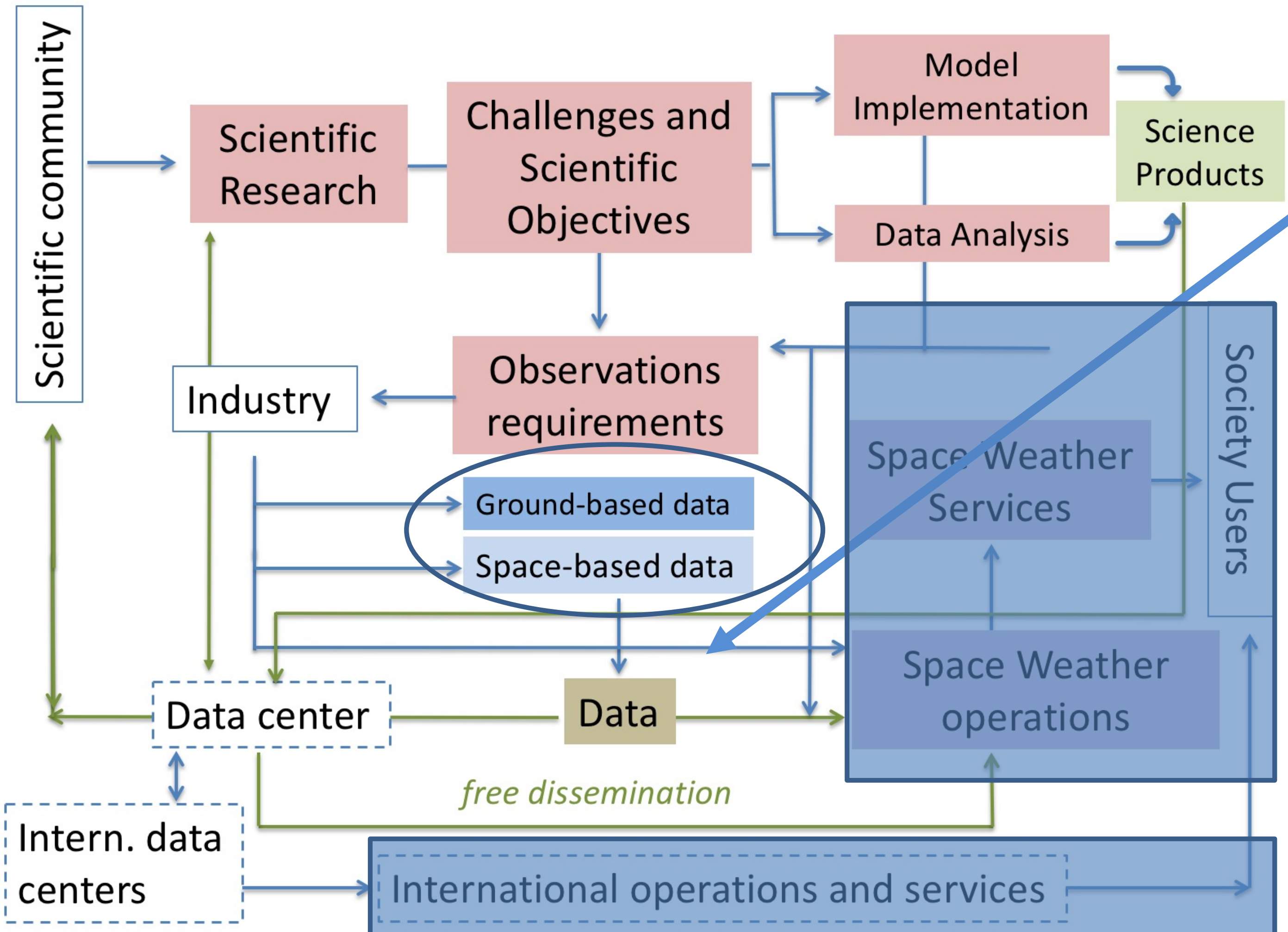
Synergies | Collaboration | Opportunities

Development of a national scientific space weather data centre

Asi SPace weather InfraStructure

ASPIS

Framework with the logical associations corresponding to the proposed roadmap for national space weather research



- Space data of Italian property/co-property
- Ground-based data obtained through facilities of different institutes

The National facilities providing the ASPIS data will be responsible for the acquisition and delivery of high-reliable and quality controlled data

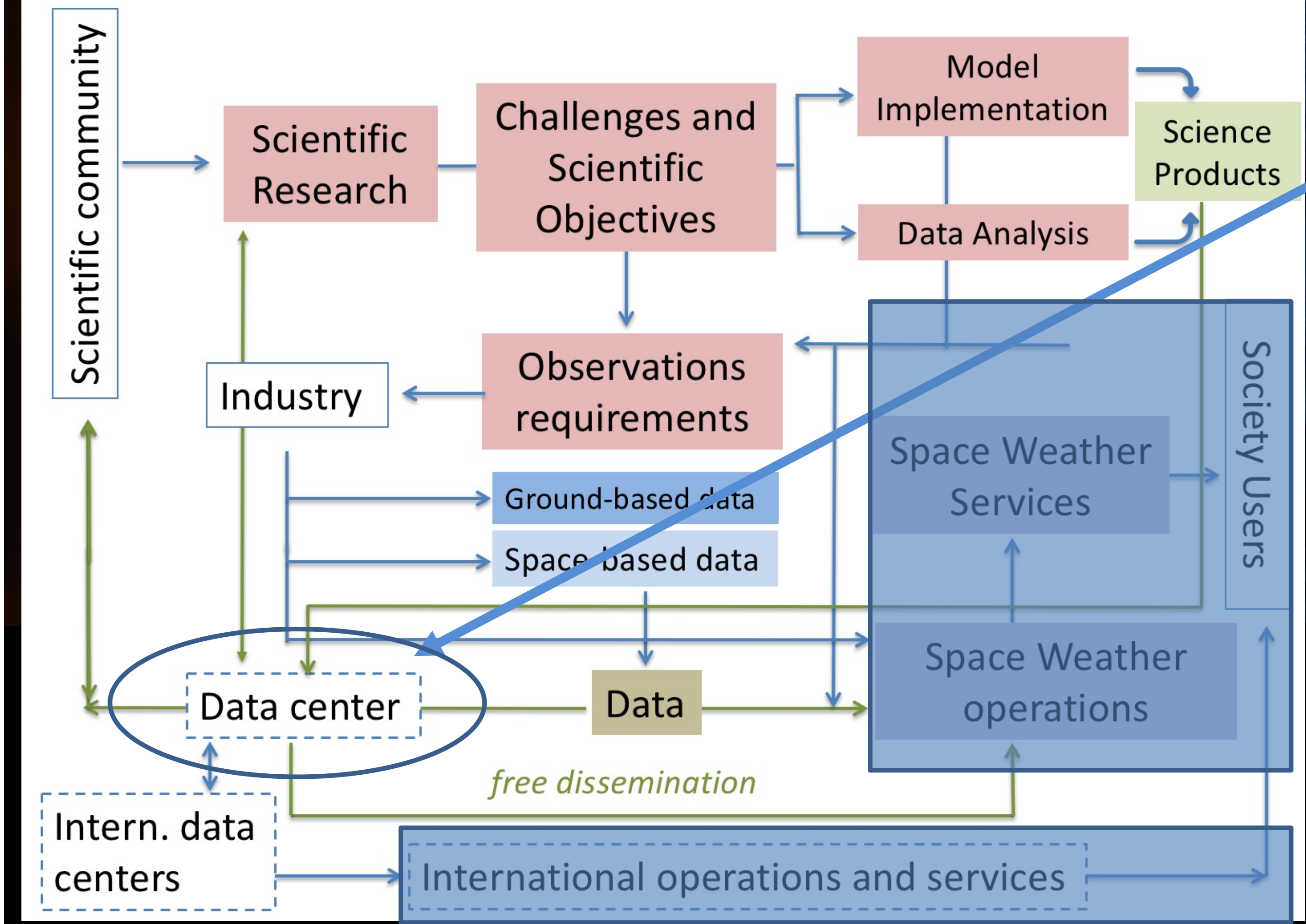
ASPIS will be responsible for handling the data (e.g. images, spectra, fluxes).

Development of a national scientific space weather data centre

Asi SPace weather InfraStructure

ASPIS

Framework with the logical associations corresponding to the proposed roadmap for national space weather research



- Data **organization** and display
- 1rst or 2nd order **science products**
- Tools for **joint investigations**
- Documentation

The National facilities providing the ASPIS data will be responsible for the acquisition and delivery of high-reliable and quality controlled data

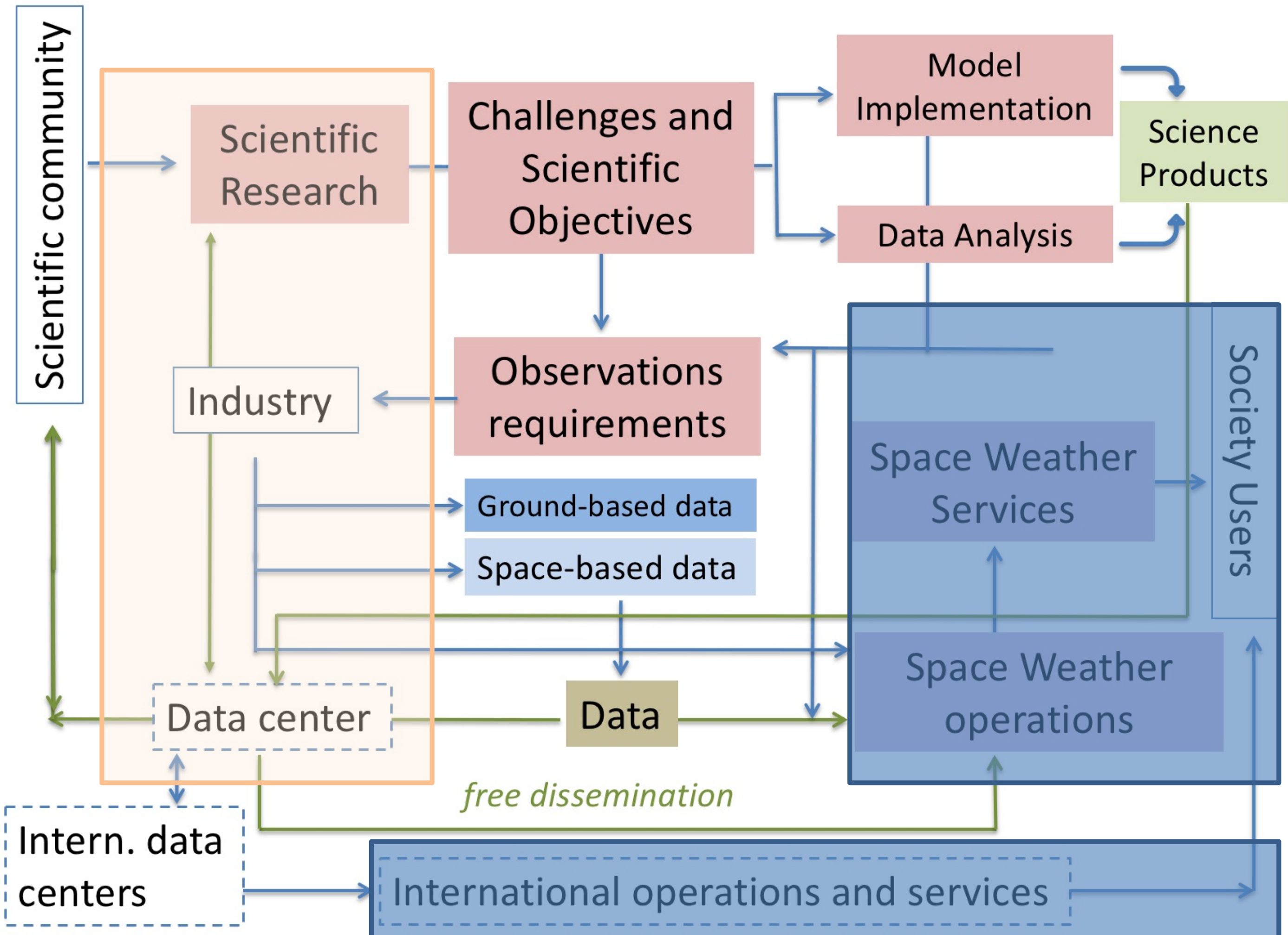
ASPIS will be responsible for handling the data (e.g. images, spectra, fluxes).

Development of a national scientific space weather data centre

Asi SPace weather InfraStructure

ASPIS

Framework with the logical associations corresponding to the proposed roadmap for national space weather research



Strong link between **ASPIS** and **Scientific Research**

Development of a national scientific space weather data centre

Asi SPace weather InfraStructure

ASPIS

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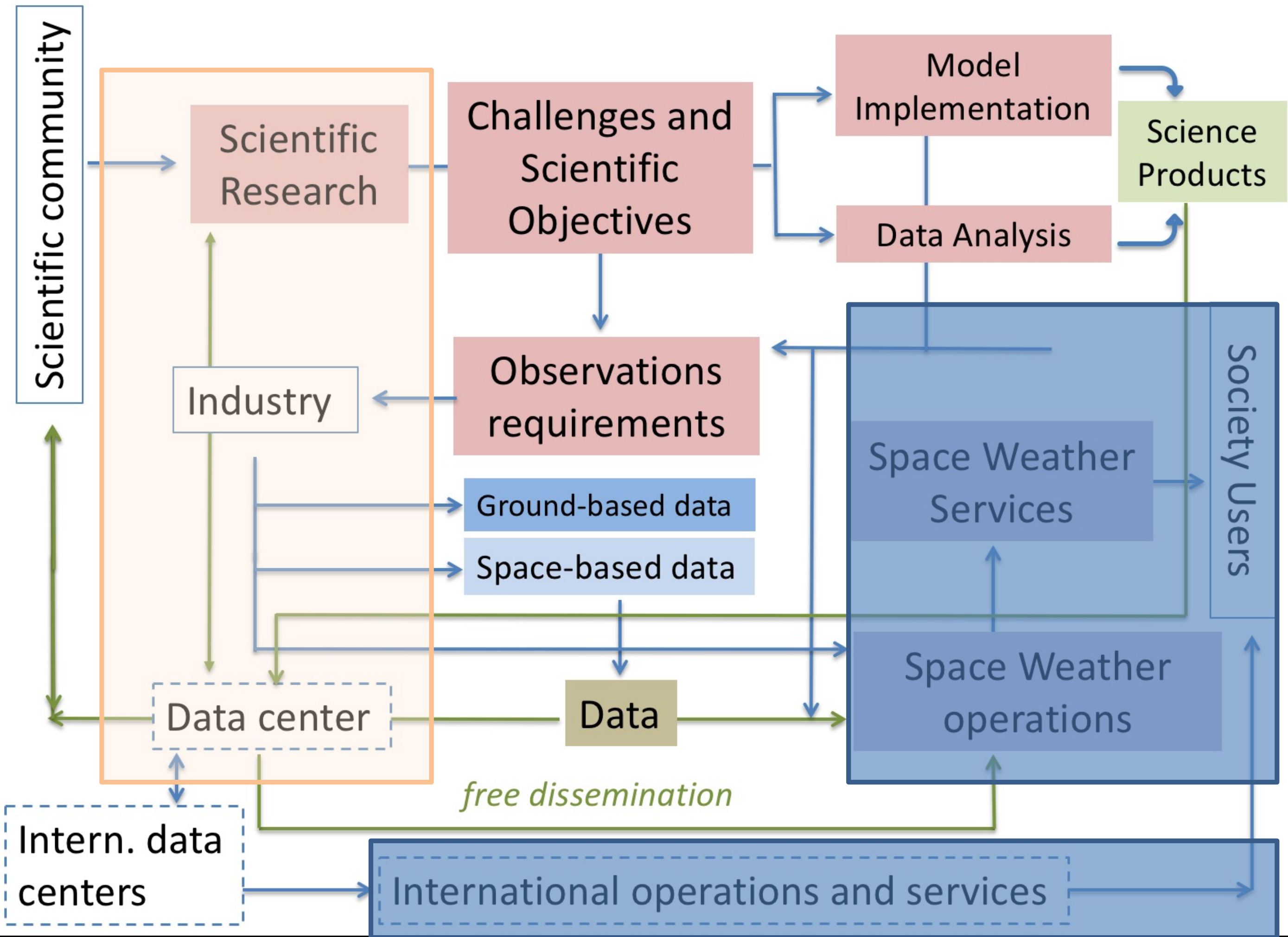

Strong link between **ASPIS** and **Scientific Research**

and

Contribution to the definition of **Observation Requirements** in a continuous and coherent way

Development of a national scientific space weather data centre

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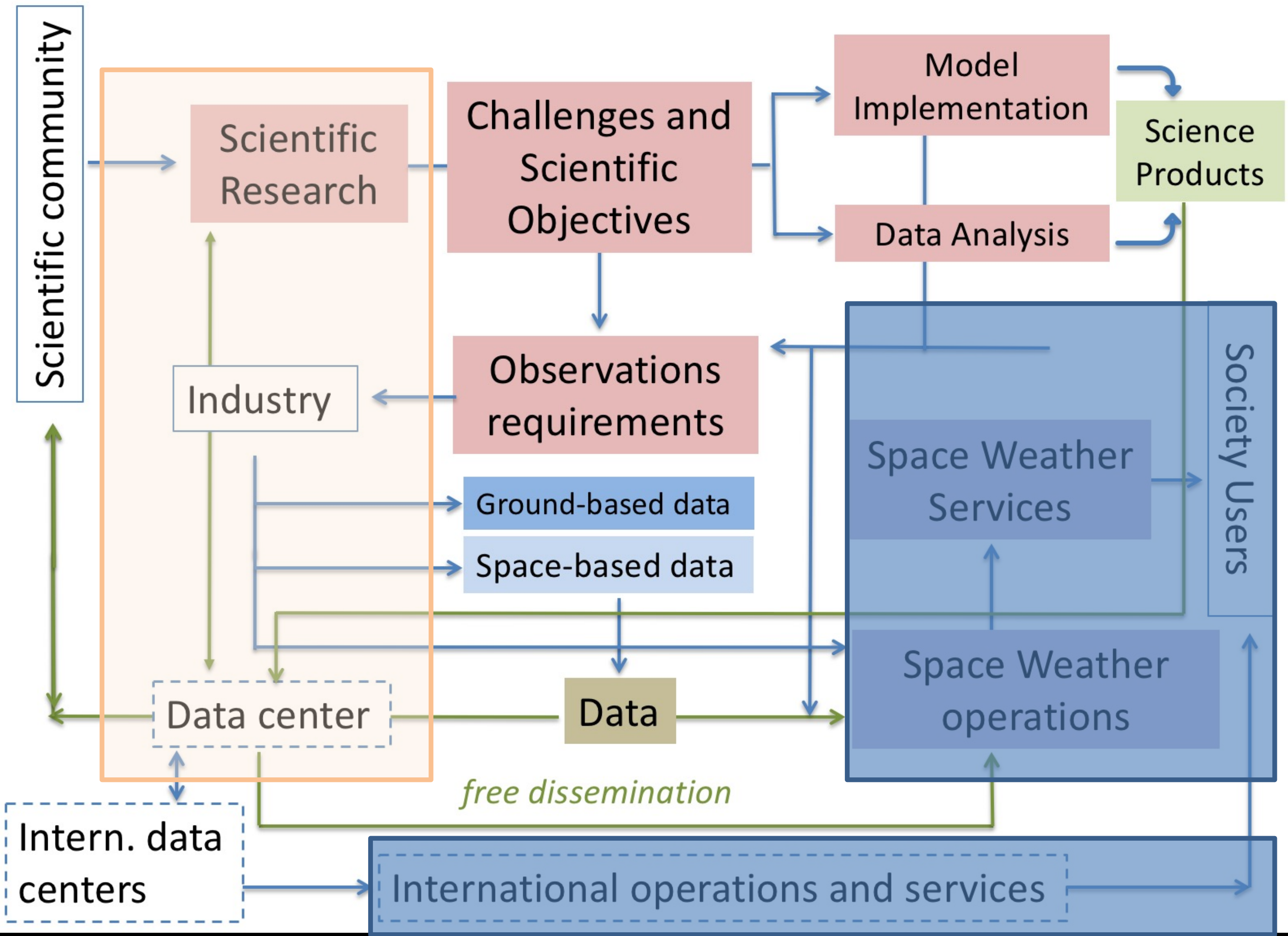
Framework with the logical associations corresponding to the proposed roadmap for national space weather research



Strong link between **ASPIS** and **Scientific Research**

and

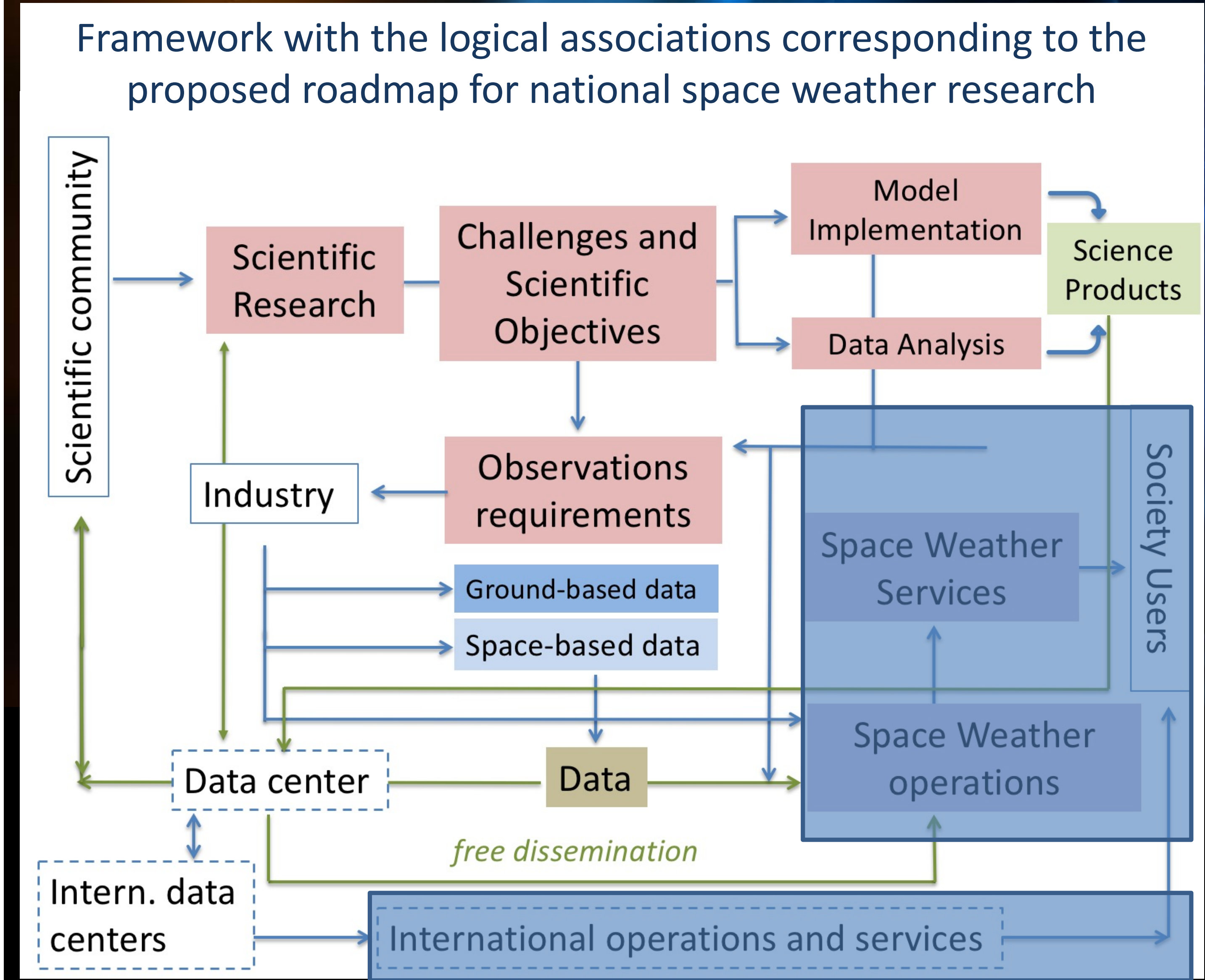
Contribution to the definition of **Observation Requirements** in a continuous and coherent way

Feedback for model improvements

Development of a national scientific space weather data centre

Asi SPace weather InfraStructure

ASPIS



Although ASPIS will not include **any operational function**, it can serve as a reference point for operational services


Thank you for your attention