Space Environment Support to NATO SSA: The Study by NATO STO/CSO SCI-229 RTG

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[3]Chair, NATO STO/CSO SCI-299 RTG

Outline of the Talk

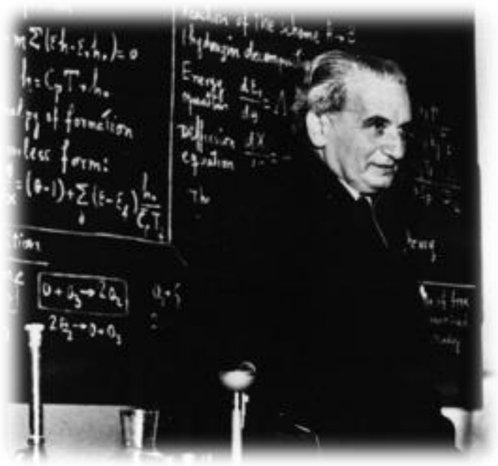
- Role and Structure of NATO STO/CSO
- The SCI-229 Research Task Group
- Highlights of the SCI-229 Study
- Conclusions and outlook

Science & Technology in NATO:
The STO, its Collaborative Network and the Collaborative Support Office

Adapted Excerpt from a Presentation

by René Larose, CSO Director

Science & Technology in NATO



"Scientific results cannot be used efficiently by soldiers who have no understanding of them, and scientists cannot produce results useful for warfare without an understanding of the operations."

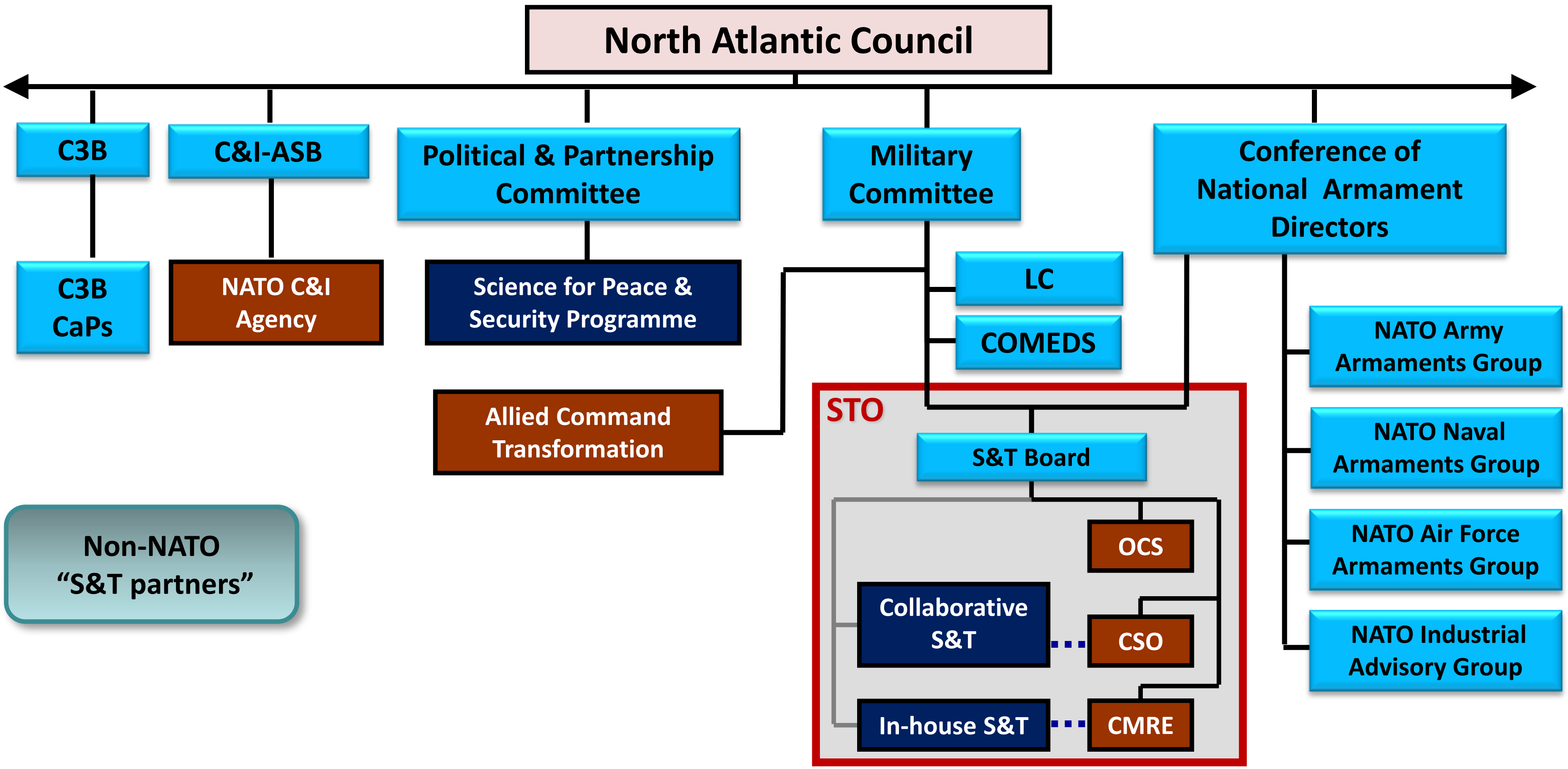
Theodore von Kármán (1881-1963)

50th Anniversary of the Award of the First U.S. National Medal of Science

On February 18, 1963 President J.F. Kennedy presented Pr. Theodore von Kármán at the White House with the first National Medal of Science, stating:

"I know of no one else who so completely represents all the areas involved in this medal - science, engineering and education."

The NATO S&T Community since 1 July 2012

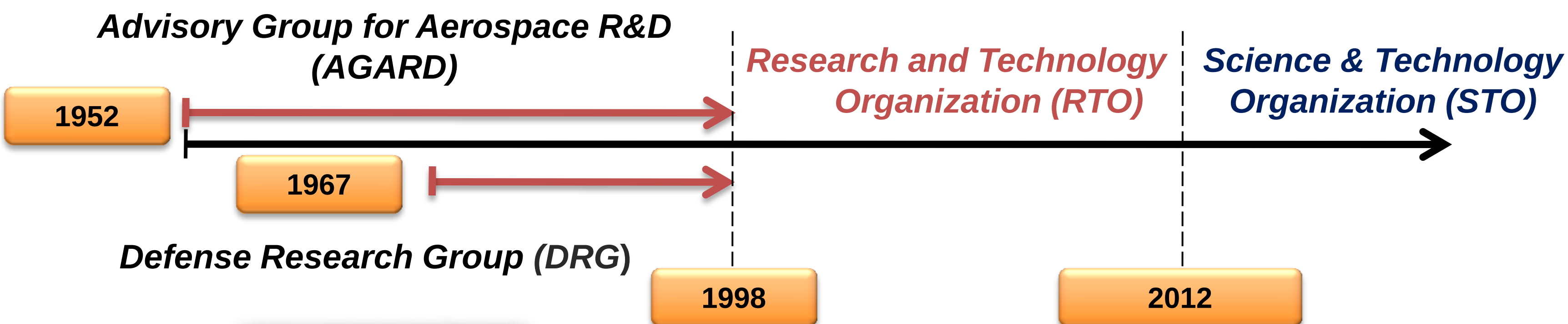


The Science and Technology Organisation

S&T organization

www.sto.nato.int

The STO – Building on a Long Legacy...



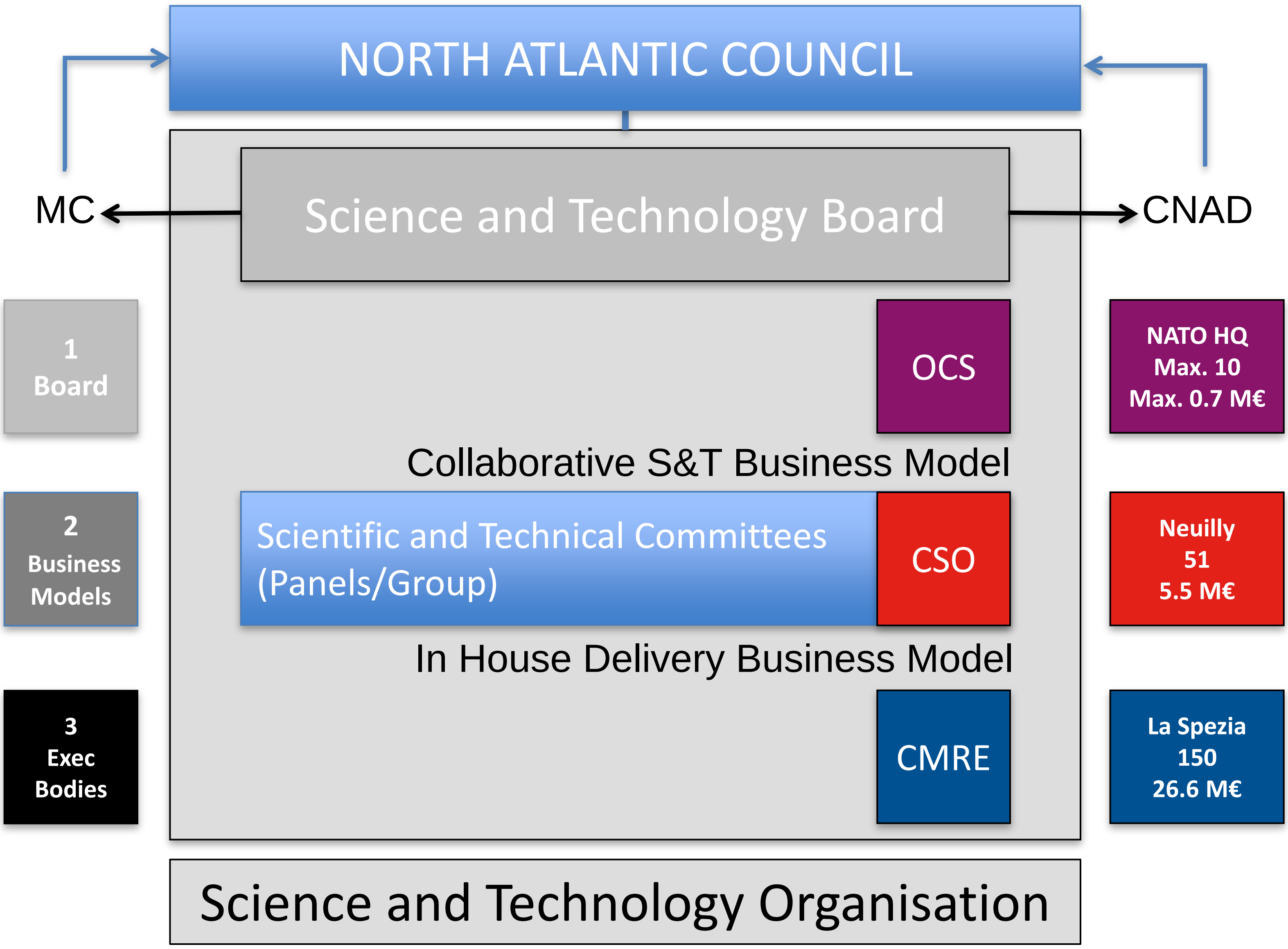
Over years this "long legacy" allowed a lot of scientists to forge very profound professional relationships based on **trust and confidence**

26 NATO Nations in STO

- ALBANIA
- BELGIUM
- BULGARIA
- CANADA
- CROATIA
- CZECH REPUBLIC
- DENMARK
- ESTONIA
- FRANCE
- GERMANY
- GREECE
- HUNGARY
- ITALY
- LATVIA
- LITHUANIA
- NORWAY
- POLAND
- PORTUGAL
- ROMANIA
- SLOVAKIA
- SLOVENIA
- SPAIN
- THE NETHERLANDS
- TURKEY
- UNITED KINGDOM
- UNITED STATES

STO Mission (Charter)

- To help position the Nations' and NATO's S&T investments as a strategic enabler of the knowledge and technology advantage for the defence and security posture of NATO Nations and partner Nations, by:
  - **Conducting and promoting S&T activities** that augment and leverage the S&T capabilities and programmes of the Alliance, of the NATO Nations and the partner Nations [...]
  - Contributing to NATO's ability to **enable and influence security- and defence-related capability development and threat mitigation** in [...]
  - **Supporting decision-making** in the NATO Nations and NATO


NORTH ATLANTIC COUNCIL
MC
Science and Technology Board
CNAD
1
Board
OCS
NATO HQ
Max. 10
Max. 0.7 M€
Collaborative S&T Business Model
2
Business
Models
Scientific and Technical Committees
(Panels/Group)
CSO
Neuilly
51
5.5 M€
In House Delivery Business Model
3
Exec
Bodies
CMRE
La Spezia
150
26.6 M€
Science and Technology Organisation

The STO Collaborative Network

Scientific and Technical Committees (Panels/Group)

"The Nations for the Nations and NATO"

Why Collaborative S&T in NATO?

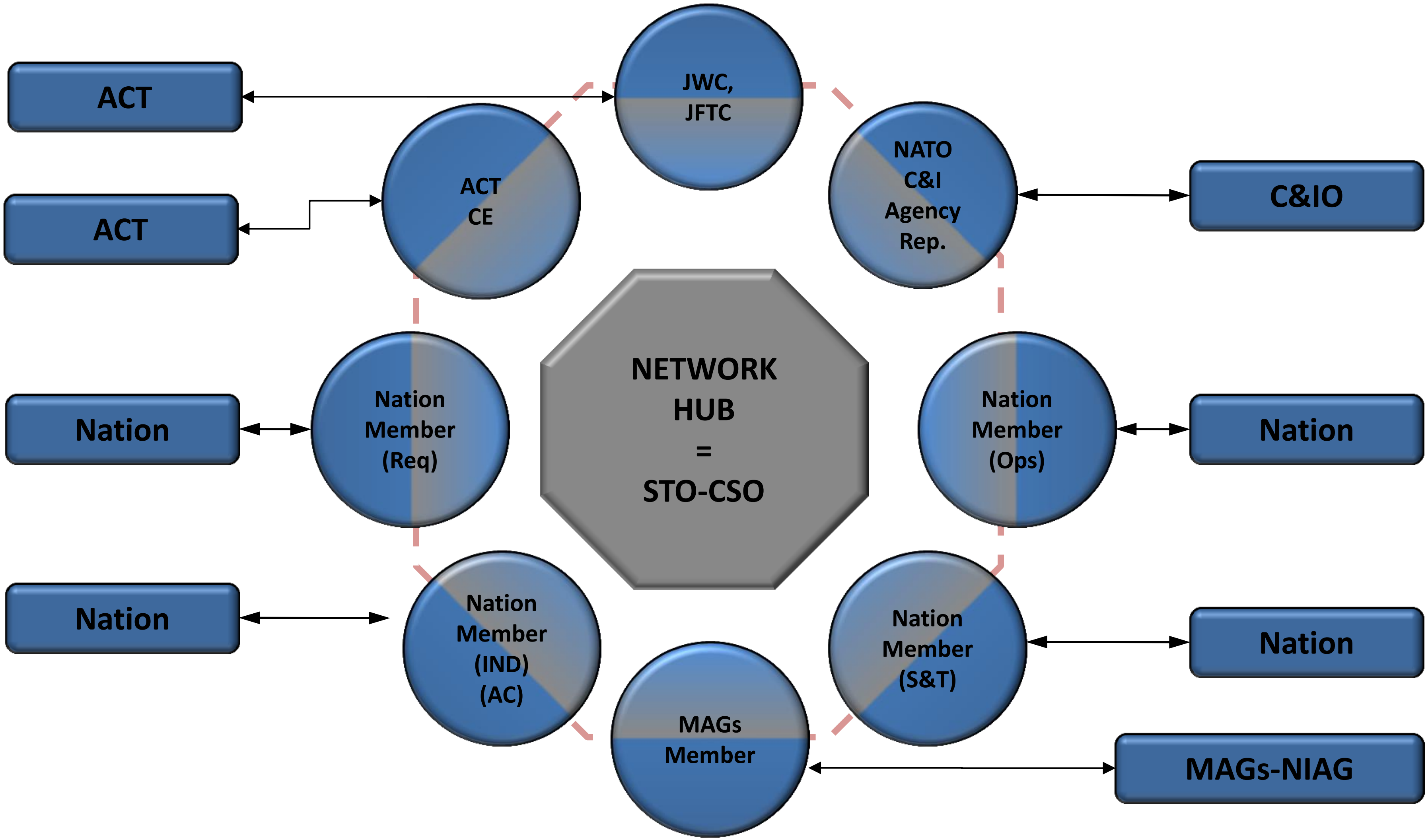
- It **federates and strengthens the Alliance** by:
  - Fostering the collective address of the common S&T needs of the Alliance and its Member Nations, demonstrating solidarity
  - Forging very profound professional relationships based on trust and confidence resulting in increased efficiencies
  - Providing commonly agreed advice to National and NATO decision makers
- It **leverages scarce resources** while providing **synergies** and **interoperability** by:
  - Enabling cost avoidance and cost sharing
  - Finding (common) solutions for increasingly complex problems
  - Benefiting from the best (specialised) resources in the Nations
  - Allowing shorter delays in reaching conclusions

Specialisation is a reality: no one has it all

The STO Panels/Group

- **AVT** **Applied Vehicle Technology**
- **HFM** **Human Factors and Medicine**
- **IST** **Information Systems Technology**
- **SAS** **System Analysis & Studies**
- **SCI** **Systems Concepts & Integration**
- **SET** **Sensors & Electronics Technology**
- **MSG** **Modelling and Simulation Group**

Collaborative S&T Business Model



Collaborative S&T Environment

Collaborative Networking Environment

Reports & Standards

Technology Demonstrations

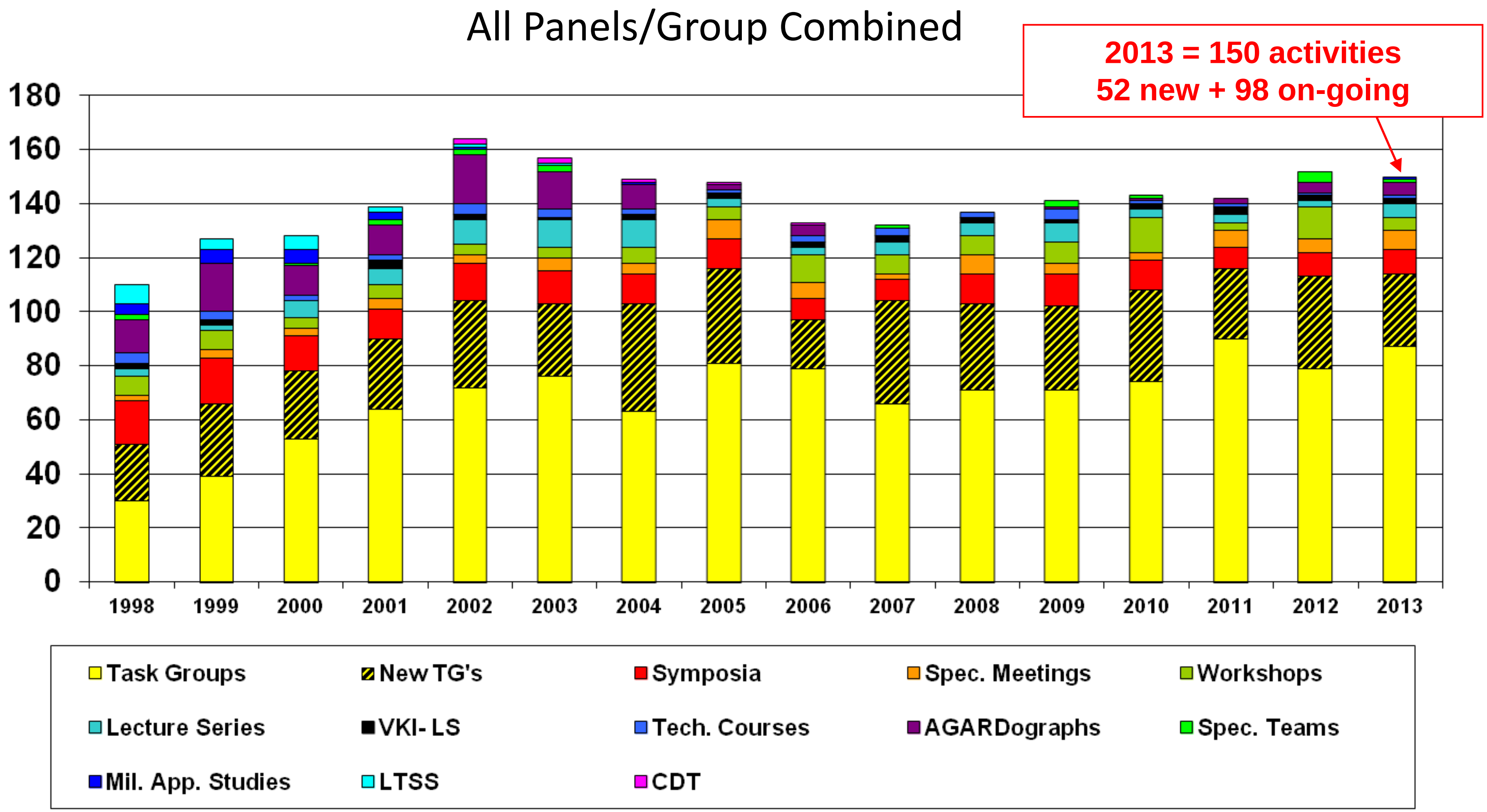
Educational Opportunities

A Knowledge & Information Base for NATO and the Nations

Toolbox:

- **SY:** Symposia (>100 people, 3-4 days)
- **SM:** Specialists' Meetings (<100 people, 2-3 days)
- **WS:** Workshops (selected participation, 2-3 days)
- **TG: Task Groups (study group, 3 years max.)**
- **LS:** Lecture Series (junior and mid-level scientists)
- **TC:** Technical Courses
- **ST:** Specialists' Teams (quick reaction)
- **ET: Exploratory Teams**

Total Number of Activities per Year



The Collaboration Support Office (CSO)

CSO Mission (STO Charter Art. 18.3)

- To provide **executive and administrative support** to the S&T activities conducted through the STO level 2 committees and level 3 working groups.

- In its areas of expertise, to provide **assistance and support** to the Science and Technology Board, its Chairperson, the Chief Scientist, and his/her office.

The CSO: the Executive Arm

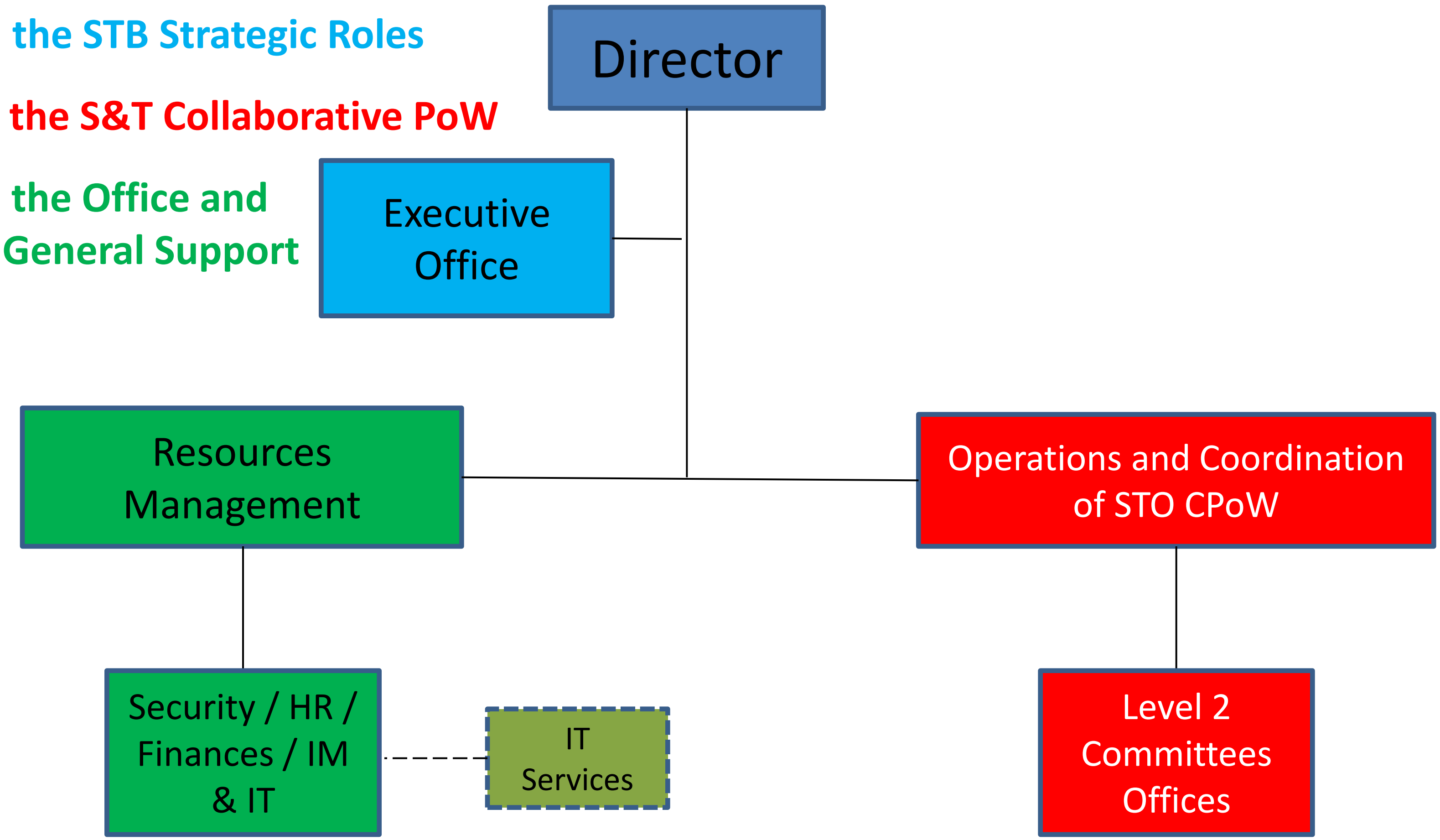
- *Node* of the Collaborative Network
  - Makes the STO Collaborative Programme of Work (CPoW) happen
- *Interface* between the scientific community and the military

- Science and Technology *Knowledge Manager*

Facilitate and Leverage NATO's Collaborative S&T

CSO Functional Areas

- **Three main functional areas**
  - **Assist in the STB Strategic Roles**
  - **Support the S&T Collaborative PoW**
  - **Operate the Office and provide General Support**



The Value of the STO CSO

- Provides executive and administrative support to the World's largest collaborative network for Defence and Security S&T
- Facilitates an average of 150 collaborative activities/year
  - Fostering the collective address of common S&T needs, demonstrating solidarity
  - Forging very profound professional relationships based on trust and confidence resulting in increased efficiencies
  - Connecting military operators with scientists
  - Leveraging huge national research investments and a vast pool of expertise
  - Providing synergies and interoperability
- Manages knowledge and supports the quick delivery of commonly agreed advice to decision makers

Systems Concepts and Integration (SCI)

- Mission: to address :
  - Advanced system concepts,
  - Systems integration,
  - Engineering techniques and technologies

across the spectrum of platforms and operating environments.

Space Capability Preservation

- LTA for Space Capability Preservation
  - *Preserve space capability/situational awareness for assets used by NATO through a combination of defensive measure of space- and ground based assets.*
- SCI given the lead
- Recruited a Member at Large (Dr. LEWIS)
- Established TAP and Program Committee for SCI-238

Additional SCI Space Activities

- SCI-229/TG *Space Environment Support to NATO Space Situational Awareness*
- SCI-ET-001 *SATCOM Radio Frequency Interference Characterization in support of NATO Space Situational Awareness*
- SCI-ET-002 *Space Orbital Regime Awareness support to NATO Space Situational Awareness*
- SCI-ET-003 *Systems Integration and Data Fusion Concepts to Support a common NATO Space Situational Awareness Operating Picture*

Space Environment Support to NATO Space Situational Awareness (SCI-229/RTG)

- Objectives:
  - Harmonizing studies related to Space Situational awareness (SSA) between ESA, EU, EDA, ESPI (European Space Policy Institute) and NATO
  - Working with the NATO JAPCC (Joint Air Power Competence Centre)
  - Developing a NATO SSA Technology Development Plan
  - Educating NATO SSA “Space Officers”
  - Conducting ESA/NATO/EU workshops and a final conference related to space systems, security and SSA

SCI-229 Task Group

- **Topic**
  - Space Environment Support to NATO SSA
- **STO CSO Panel**
  - Systems Concepts and Integration (SCI)
- **Duration**
  - 4 years (2011-2014)
- **Classification**
  - NATO Unclassified (NU)
- **Chair**
  - M. Messerotti (ITA)
- **Vice-Chair**
  - Ulf-Peter Hoppe (NOR)
- **Technical Editor**
  - Frank Jansen (DEU)
- **Participating NATO Countries**
  - CZE, ESP, FRA, GBR, HUN, ITA, NOR, ROM, SLO, USA

Recent Key Points of the Study

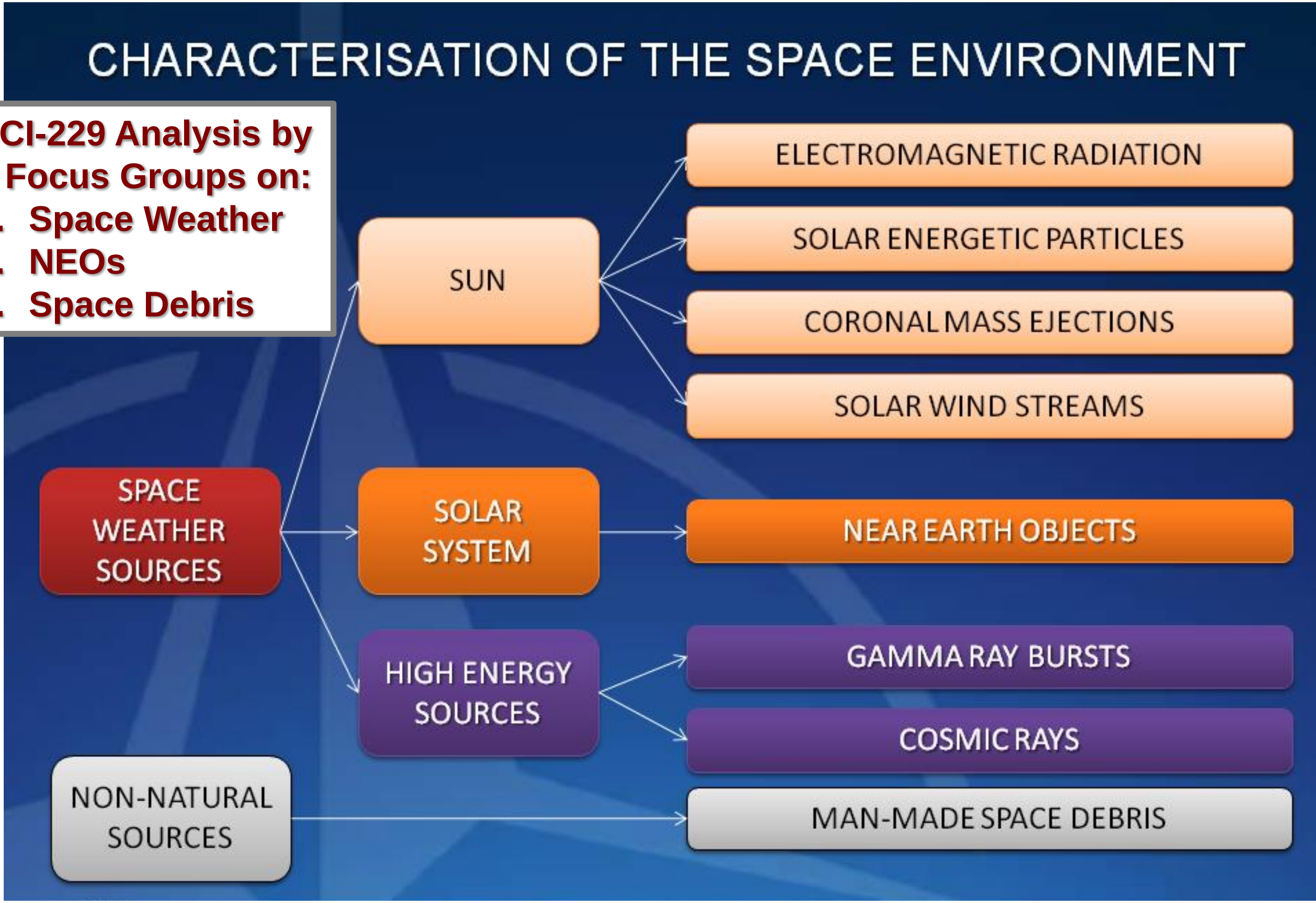
- Phenomenology
- Effects on Space Systems
- Survey of Monitoring Resources
- Predictability
- Response Protocols
- Knowledge Organisation
- System Analysis Methodology
- Tool Development Methodology
- Risk Analysis

NATO SCI-229 ANALYSIS

CHARACTERISATION OF THE SPACE ENVIRONMENT

SCI-229 Analysis by 3 Focus Groups on:

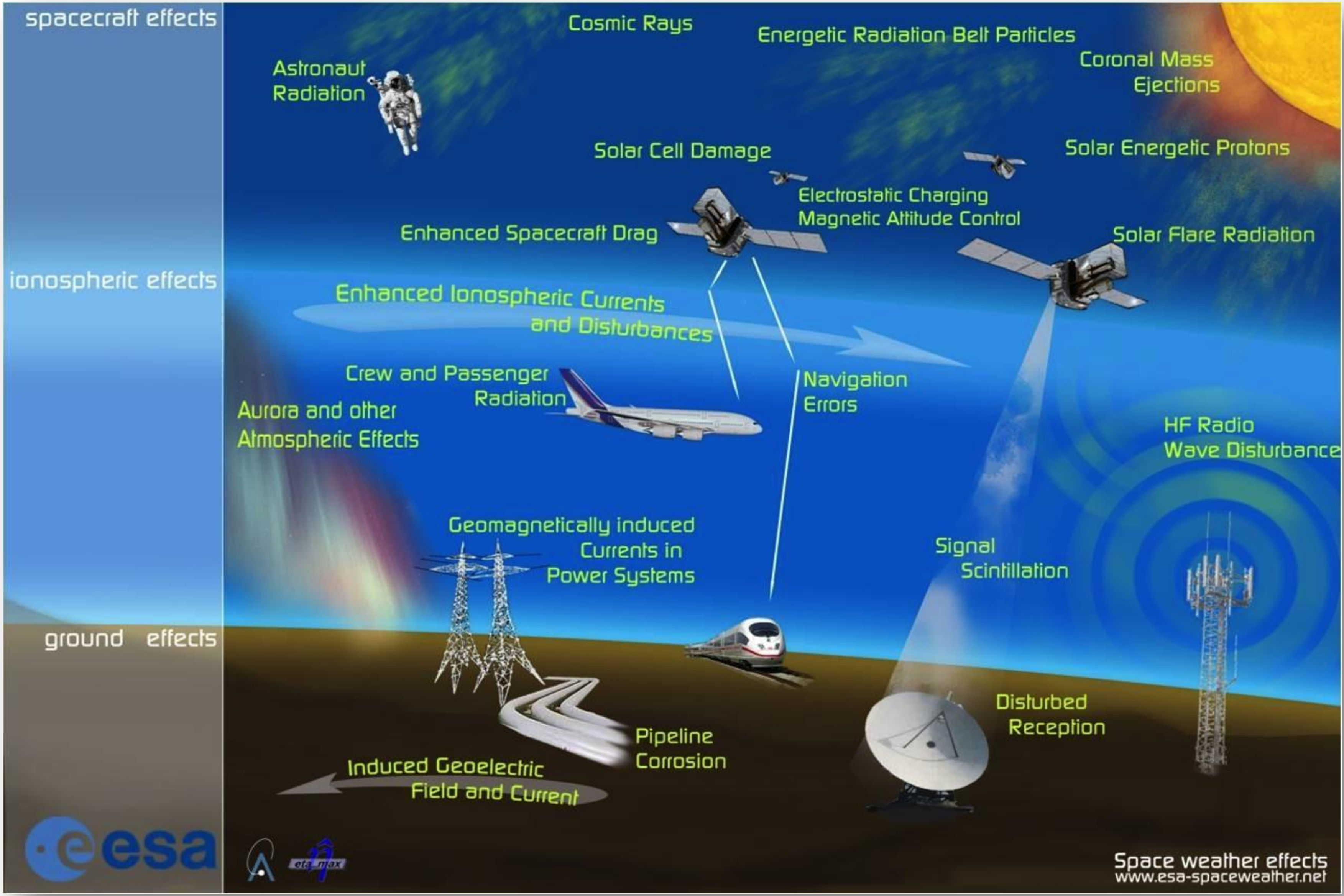
1. **Space Weather**
2. **NEOs**
3. **Space Debris**



NATO SCI-229 ANALYSIS

PHENOMENOLOGY OF SPACE PERTURBATIONS

Space Weather Effects Synopsis



“In the Dark” (Cogan, 2011)

A workshop to explore the threats, vulnerabilities, and preparedness with respect to an electromagnetic pulse (EMP) attack or a solar storm.

Mr. Kevin Cogan

This workshop was held at the Collins Center, U.S. Army War College

DEFINING THE SPACE PERTURBATION TARGET

DEFINITION OF SPACE SYSTEM

2.2 The Three Main Parts of a **Space System**

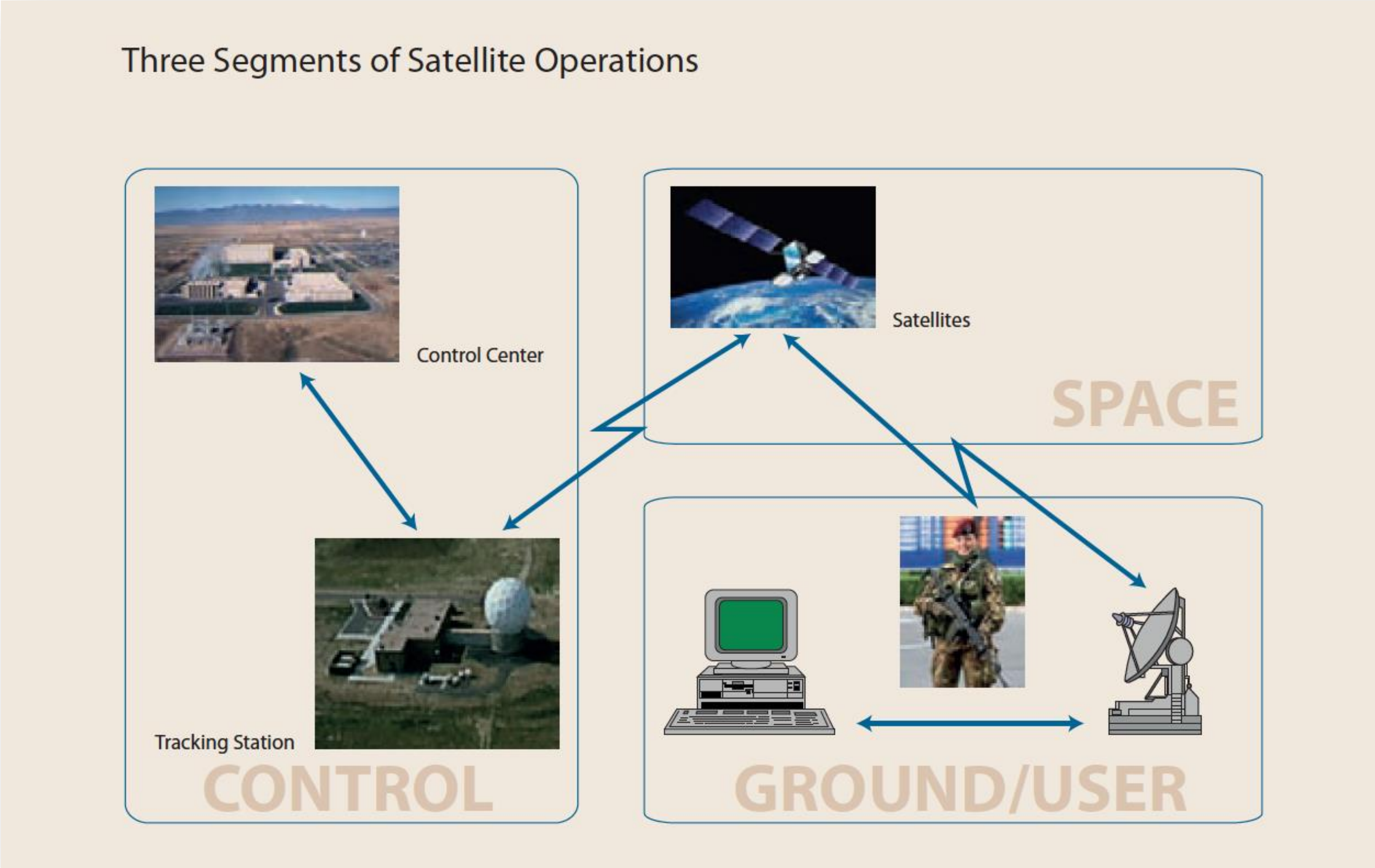
2.2.1 A **space-based system** notionally includes three main parts:

1. **A ground-segment** to conduct command and control of the satellite.
2. **A space-segment** consisting of the satellite itself.
3. **The end-user** (Figure 1).

These nodes are interconnected by electromagnetic uplinks/downlinks that carry commands, communication traffic, signals, telemetry and mission data. This is relevant because all elements of a space-based system must work in concert for reliable use of the capability.

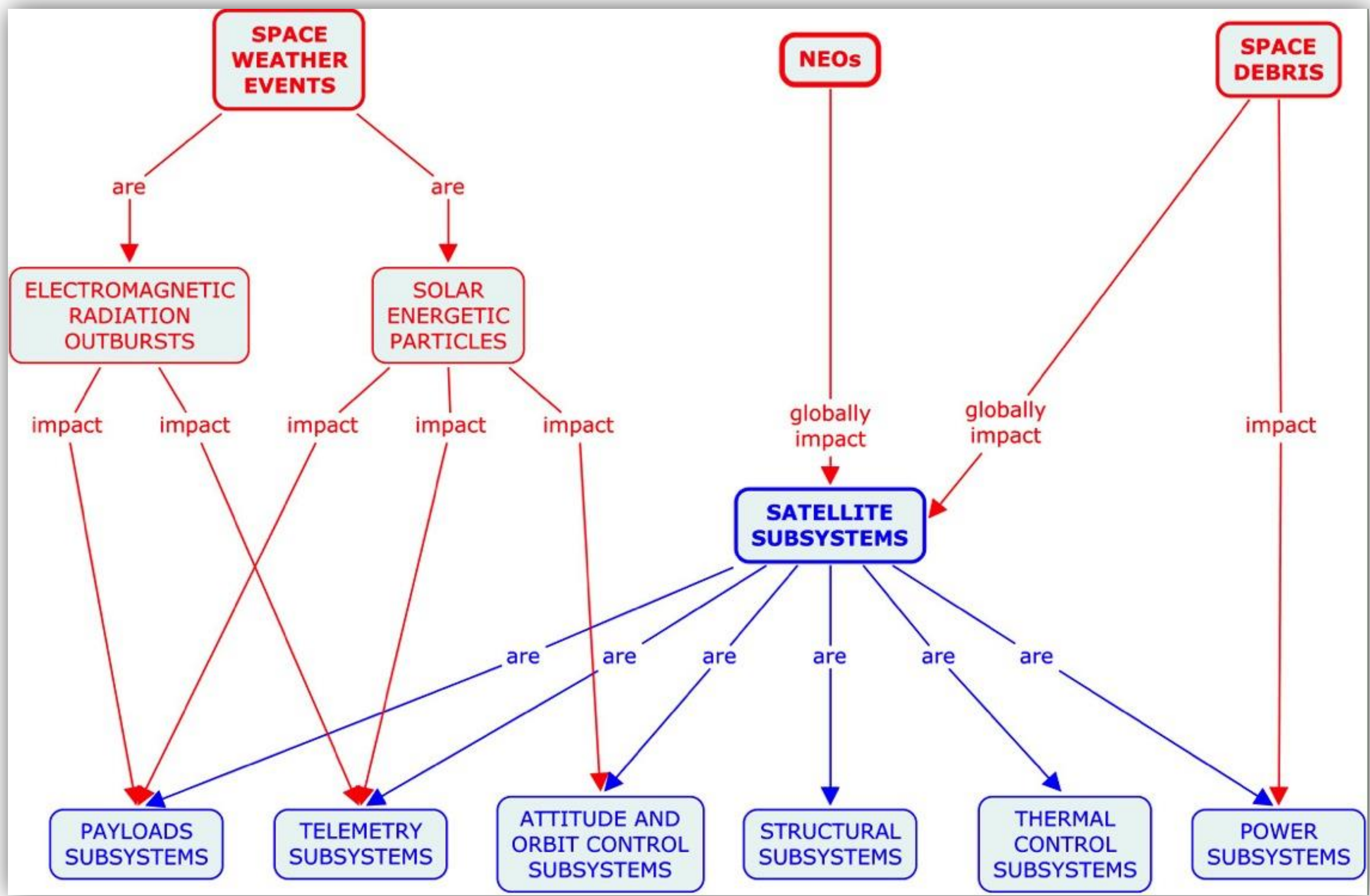
JAPCC, Filling the Vacuum – A Framework for a NATO Space Policy, 2012

Figure 1: The Three Segments of **Satellite Operations**

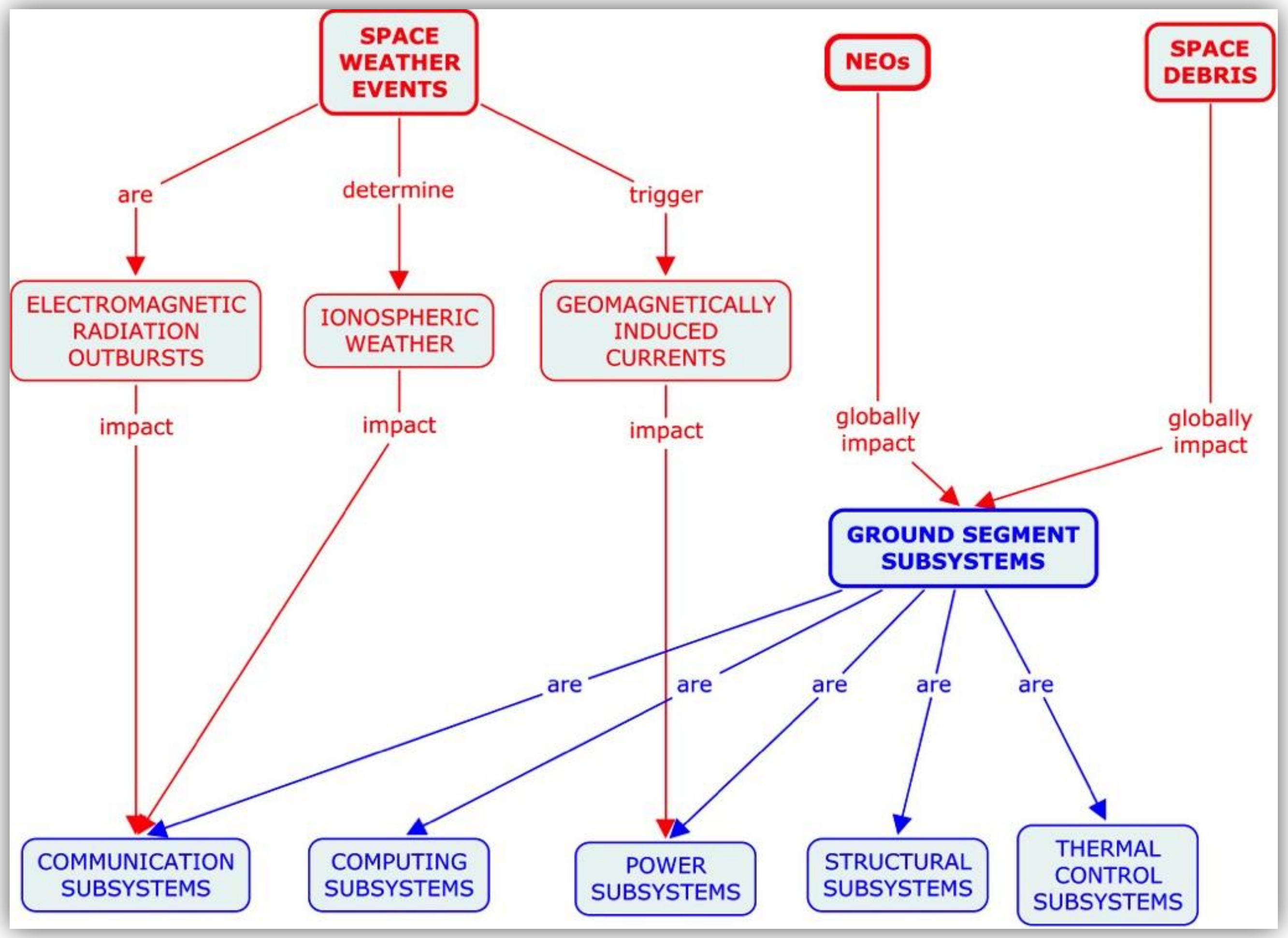


JAPCC, Filling the Vacuum – A Framework for a NATO Space Policy, 2012

Sample Space Environment **Impacts** Onto **Satellite-Segment Subsystems**



Sample Space Environment **Impacts** Onto **Ground-Segment Subsystems**



SPACE WEATHER

MONITORING RESOURCES ANALYSIS

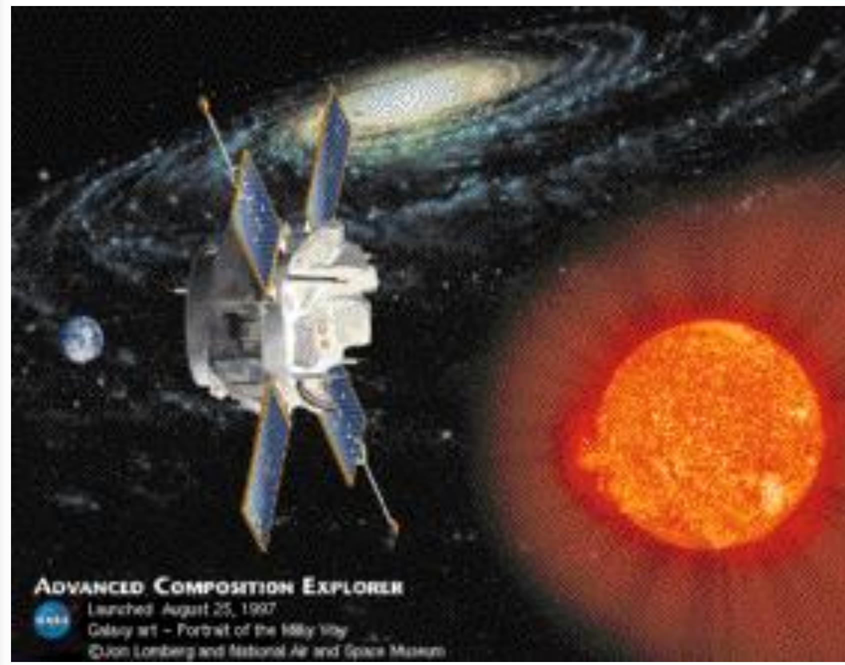
Ground- and Space-Based Space Weather Monitoring Systems

European Incoherent SCATter (EISCAT) Radar

Longyearbyen, Svalbard

Advanced Composition Explorer (ACE) Spacecraft @ L1

1997-? (Propellant to 2024)

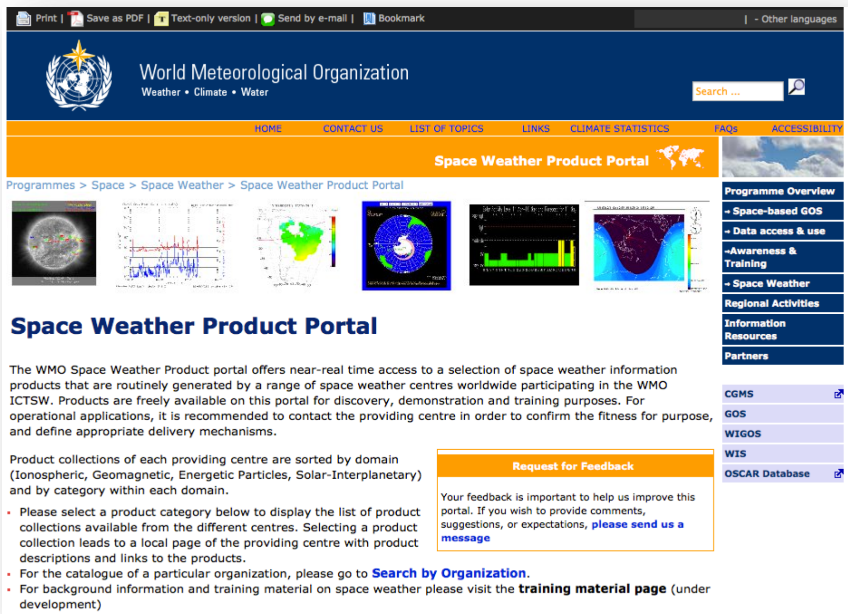


ITS END OF LIFE IS AN ISSUE !

WMO Space Weather Product Portal

http://www.wmo.int/pages/prog/sat/spaceweather-productportal_en.php

Portal Homepage

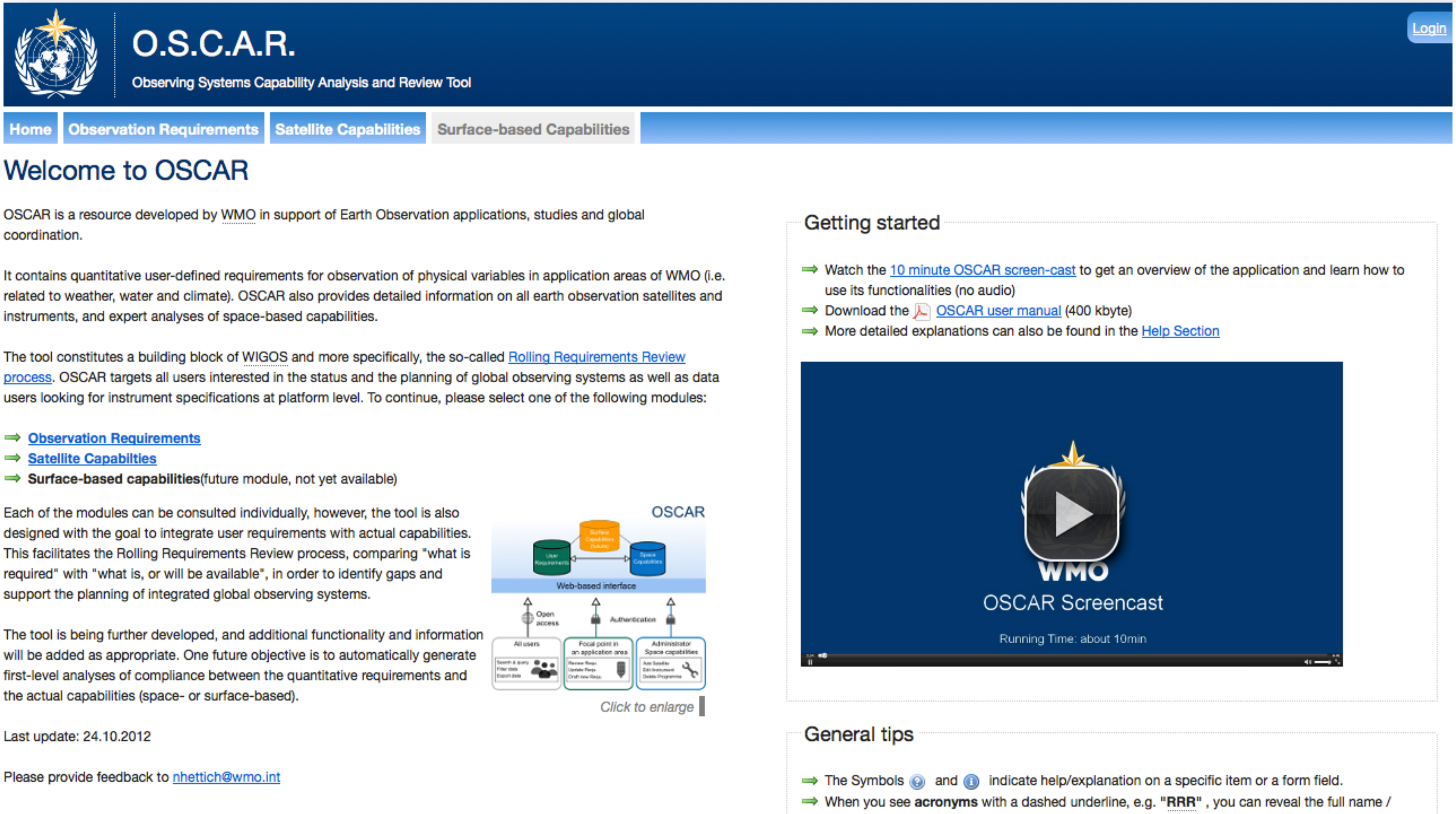


Product Menu by Topic

- **Ionospheric**
  - HF communications
  - Total Electron Content
  - Ionospheric irregularities
- **Geomagnetic**
  - Auroral activity
  - Geomagnetic activity
- **Energetic Particles**
  - Solar Energetic Particles
  - Magnetospheric Particles
- **Solar and interplanetary**
  - Solar activity
  - Solar wind
  - Solar Cycle

WMO Observing Systems Capability Analysis and Review Tool

http://www.wmo-sat.info/oscar/



Login

O.S.C.A.R.

Observing Systems Capability Analysis and Review Tool

Home | Observation Requirements | Satellite Capabilities | Surface-based Capabilities

Welcome to OSCAR

OSCAR is a resource developed by WMO in support of Earth Observation applications, studies and global coordination.

It contains quantitative user-defined requirements for observation of physical variables in application areas of WMO (i.e. related to weather, water and climate). OSCAR also provides detailed information on all earth observation satellites and instruments, and expert analyses of space-based capabilities.

The tool constitutes a building block of WIGOS and more specifically, the so-called Rolling Requirements Review process. OSCAR targets all users interested in the status and the planning of global observing systems as well as data users looking for instrument specifications at platform level. To continue, please select one of the following modules:

- **Observation Requirements**
- **Satellite Capabilities**
- **Surface-based capabilities**(future module, not yet available)

Each of the modules can be consulted individually, however, the tool is also designed with the goal to integrate user requirements with actual capabilities. This facilitates the Rolling Requirements Review process, comparing "what is required" with "what is, or will be available", in order to identify gaps and support the planning of integrated global observing systems.

OSCAR

Web-based interface

Open access

Authentication

All users

Focal point in an application area

Administrator Space capabilities

Click to enlarge

The tool is being further developed, and additional functionality and information will be added as appropriate. One future objective is to automatically generate first-level analyses of compliance between the quantitative requirements and the actual capabilities (space- or surface-based).

Last update: 24.10.2012

Please provide feedback to nhettich@wmo.int

Getting started

- Watch the 10 minute OSCAR screen-cast to get an overview of the application and learn how to use its functionalities (no audio)
- Download the OSCAR user manual (400 kbyte)
- More detailed explanations can also be found in the Help Section

WMO

OSCAR Screencast

Running Time: about 10min

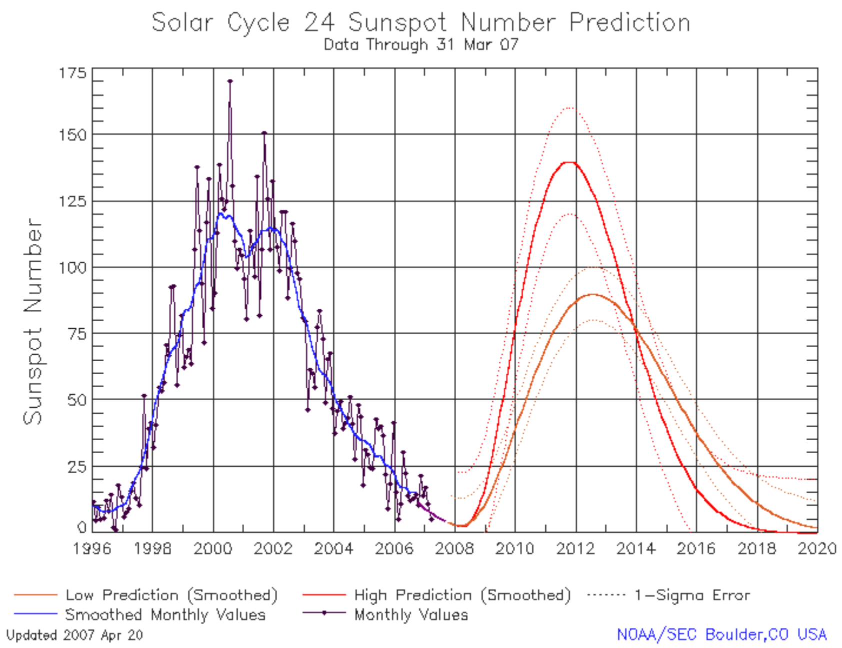
General tips

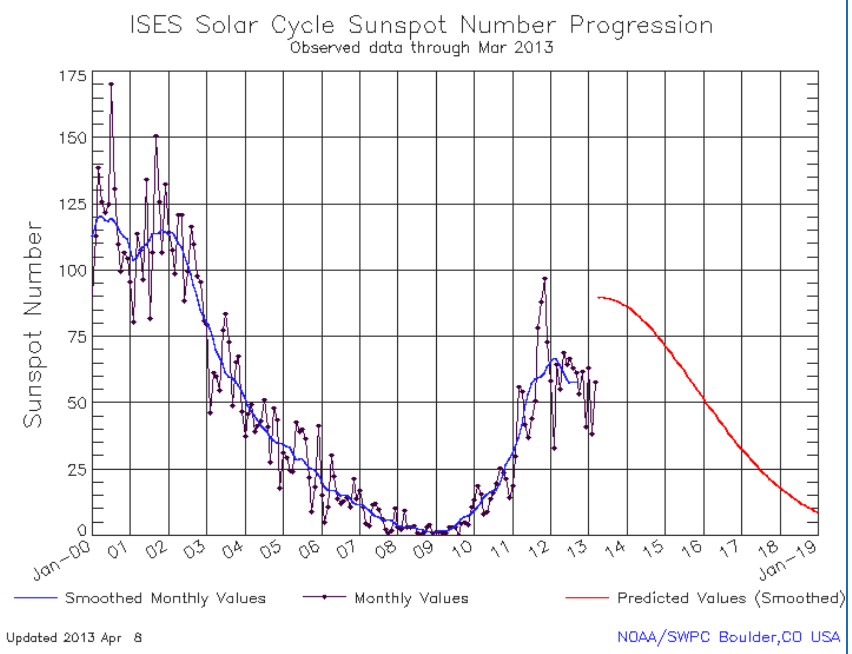
- The Symbols and indicate help/explanation on a specific item or a form field.
- When you see **acronyms** with a dashed underline, e.g. **"RRR"** , you can reveal the full name /

SPACE WEATHER

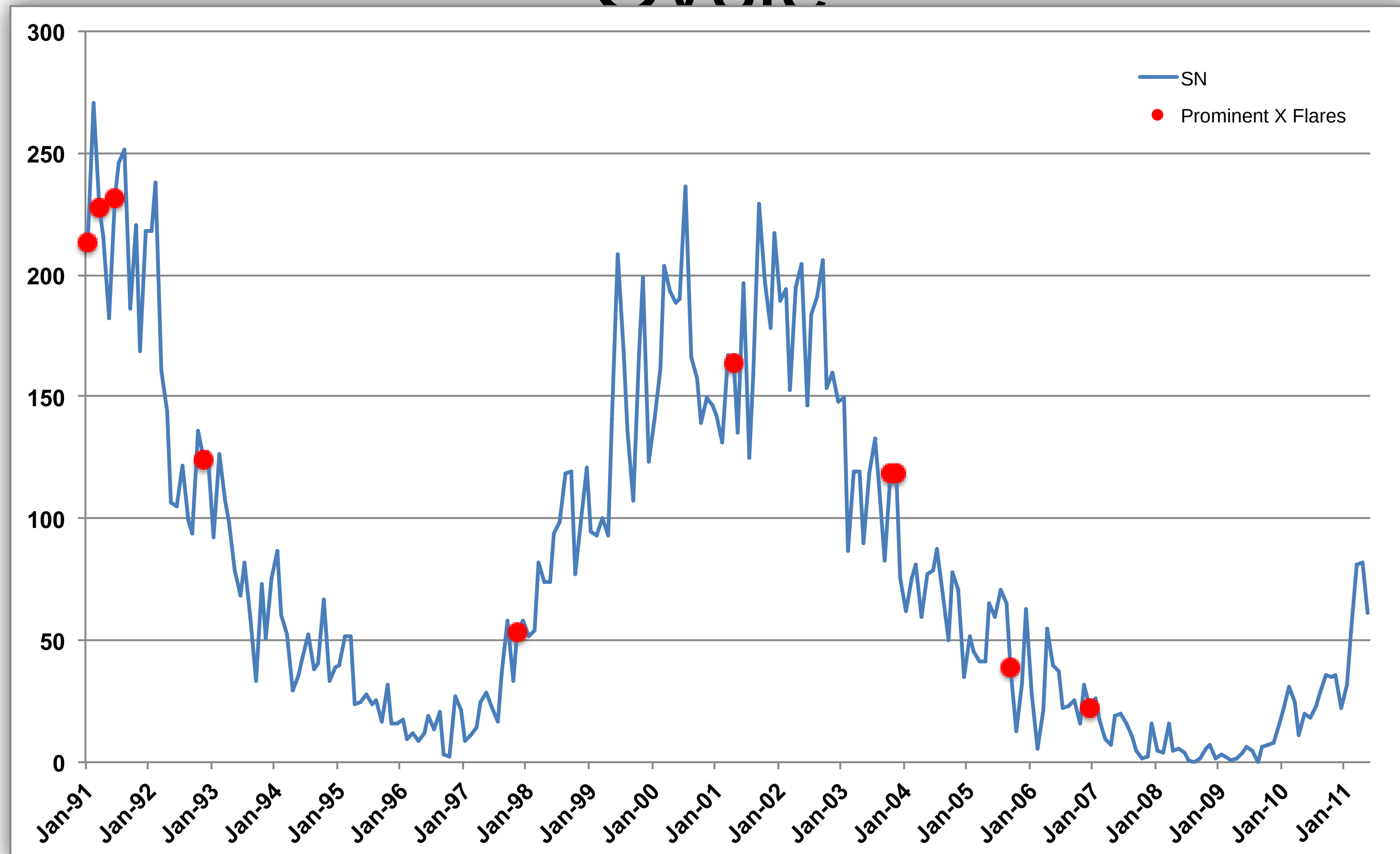
PREDICTABILITY

Limited Knowledge on the Physics

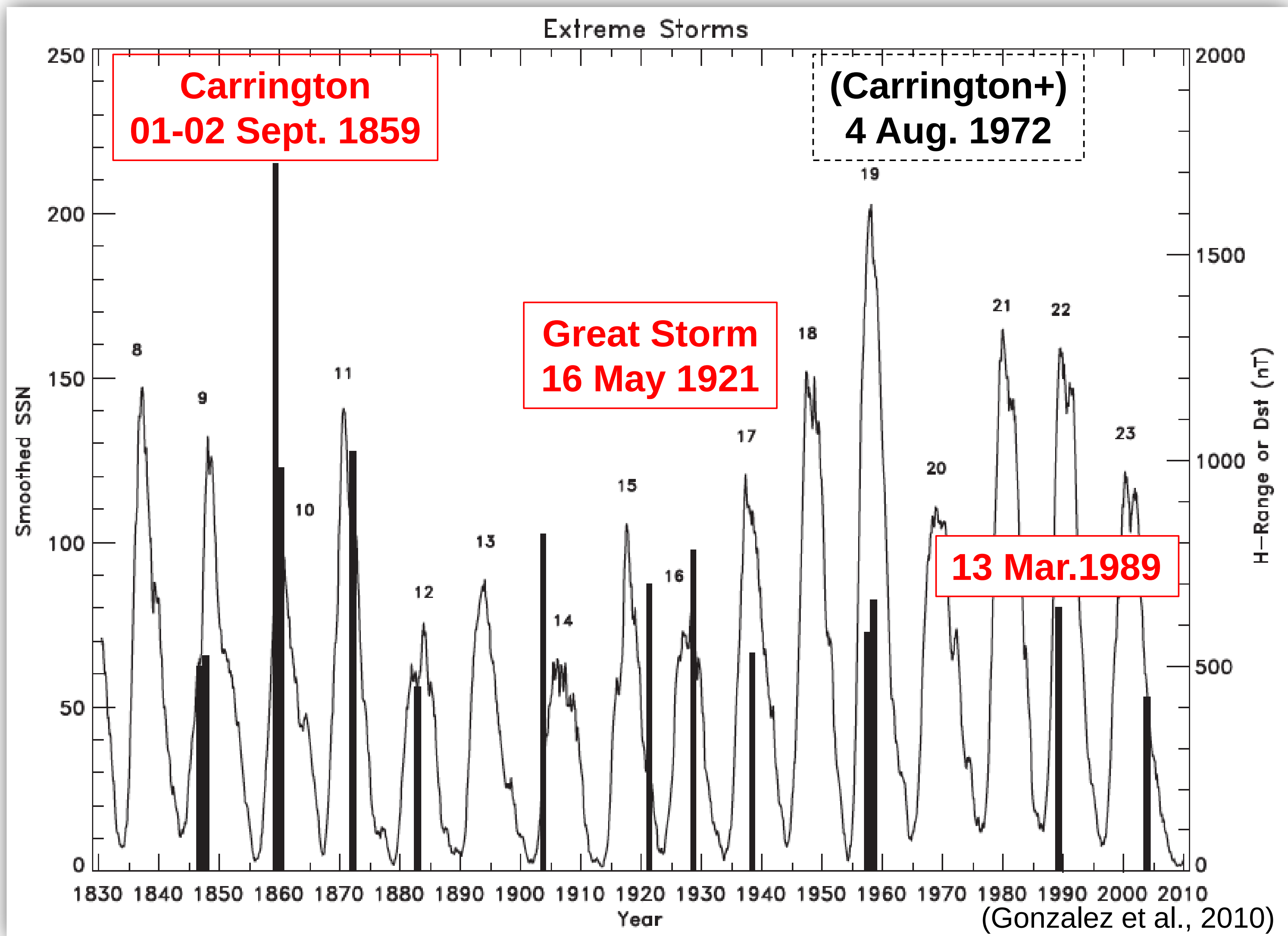




Most Intense X-Ray Solar Flares Can Occur at Any Time of the Cycle



Extreme Geomagnetic Storms Can Occur at Any Time of the Cycle

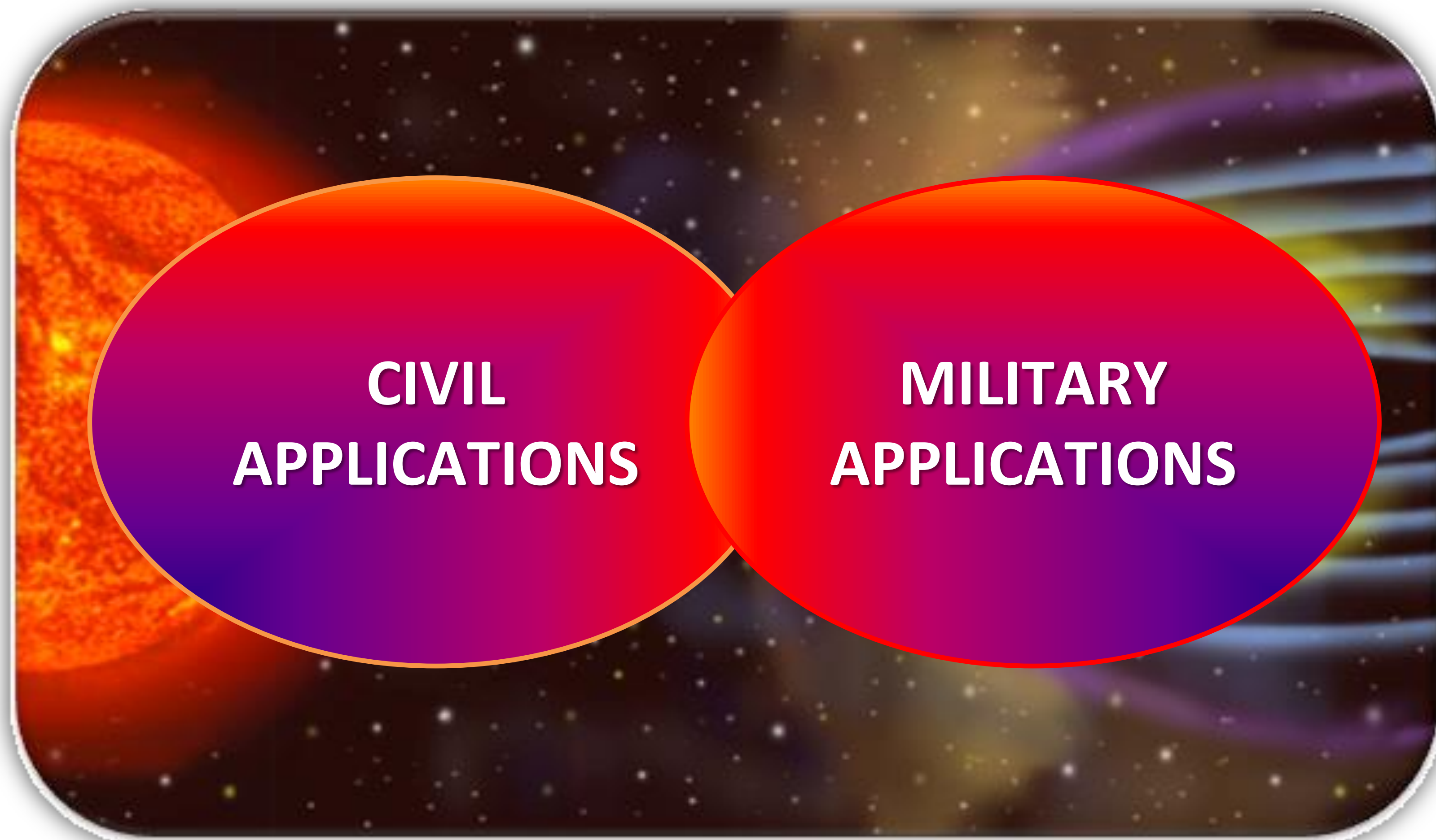


(Gonzalez et al., 2010)

SPACE PERTURBATIONS

RISK ASSESSMENT

Diversity of Risk Assessment for Civil and Military Applications



LOW PROBABILITY-HIGH IMPACT EVENTS CANNOT BE DISREGARDED !

Occurrence Probability of Extreme SWx Storms

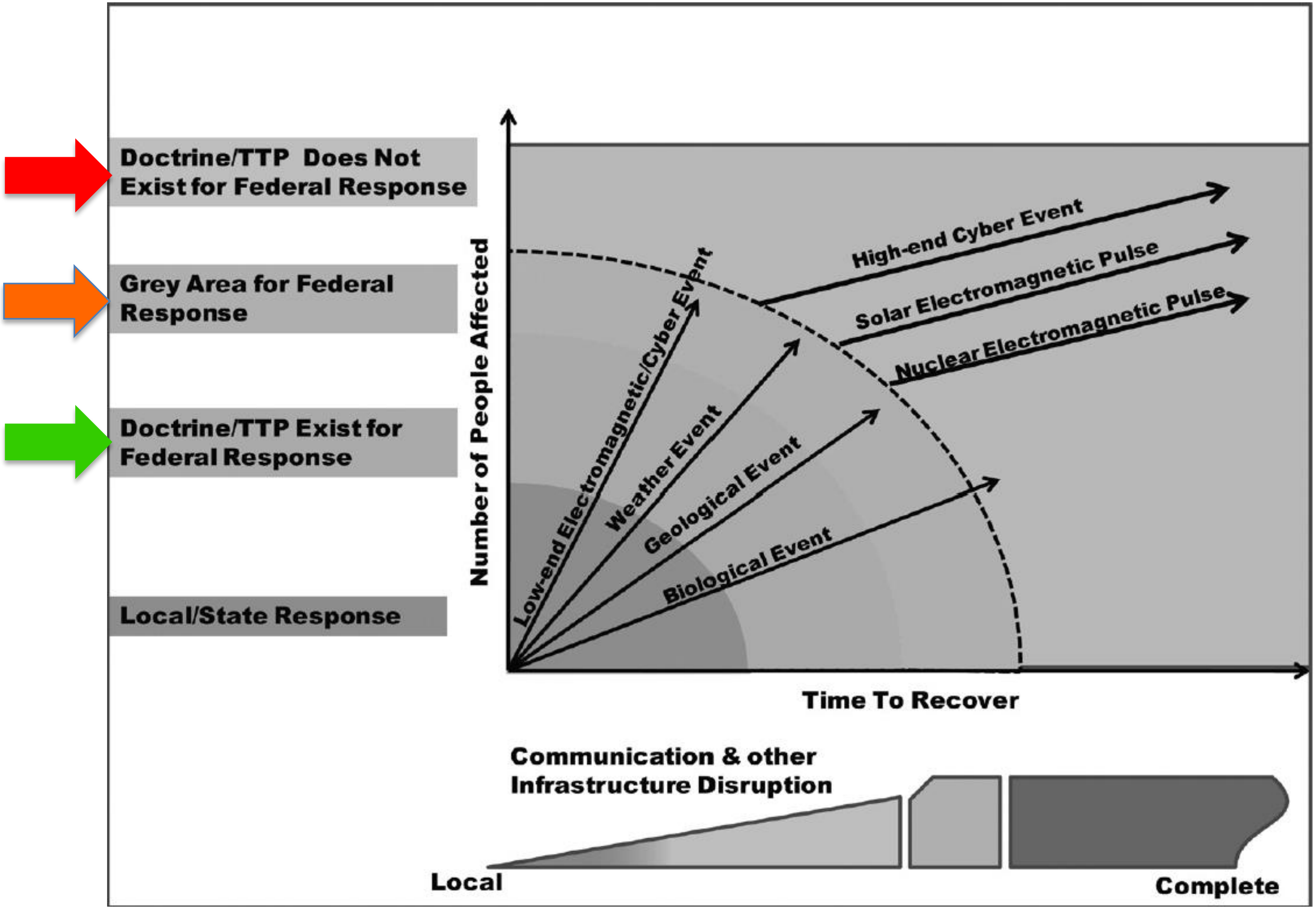
- "Carrington-Hodgson"-like superstorms:
  - Cadence: ~ 500-600 yrs
  - From last: 153 yrs
- "1921 Great Storm"-like superstorms:
  - Cadence: ~ 100 yrs
  - From last: 91 yrs
- "1989 Storm"-like extreme storms:
  - Cadence: ~ 11 yrs
  - From last: 8 yrs

SIMPLISTIC STATISTICS

SPACE PERTURBATION IMPACTS

RESPONSE PROTOCOLS

Response Protocols (Cogan, 2011)



The Global Perspective for Civil and Military Frameworks

- **CIVIL** To successfully manage a catastrophic scenario, which can involve millions people for a prolonged period of time a global coordination effort is needed, based upon:
  - **Preparedness** on a variety of domains
  - **Monitoring** and **prediction** capabilities
  - **Redundancy** in critical infrastructures
  - Established **recovery** protocols
- **MILITARY** No military organisation can ignore and/or underestimate the strategical impact of such events that can create weaknesses easy to be exploited by adversaries.

The Civil Framework (US framework; EU has just started)

- Coordination among diverse organisations is not trivial but works effectively.
- Common response protocols exist.
- Military Forces are involved in the process.
- Monitoring and prediction capabilities are very advanced and under continuous refinement.
- Awareness is widespread.
- Preparedness is being improved.
- Redundancy is applied as much as possible.
- Money is an issue.

NATO SCI-229-TG

KNOWLEDGE ORGANISATION AND EDUCATION

NATO SCI-229 Space ENvironment EffeCts Advisor

SENECA: A PROTOTYPE EXPERT SYSTEM

SENECA
Space **EN**vironment **E**ffe**C**ts **A**dvisor

- A prototype expert system as a knowledge support and as a didactic tool

- Its implementation requires the availability of domain knowledge organised in schematic form ➔ <u>synoptic tables of space events impacting on space systems have been costructed by SCI-229-TG</u>

Expected Dialogue Between Space Operator (SOP) and SENECA (SEN)

SOP> *GPS rx does not provide position since minutes*

SEN> Possible causes and relevant probability:

1. **Ionospheric perturbation 99.5%**
2. **Solar Radio Interference 0.0%**
3. **Electronic Warfare 0.5%**

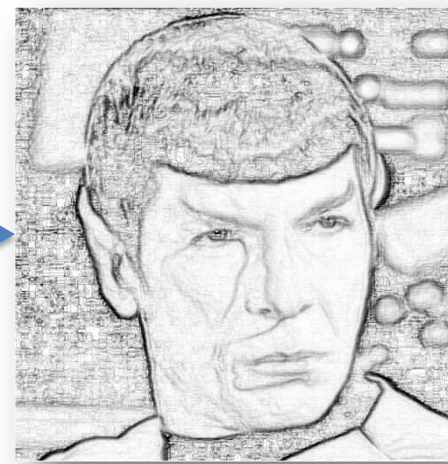
SOP> *Explain*

SEN> Solar activity level: high;
CME hit Earth;
Geomagnetic Storm: intense, in progress;
Ionosphere: highly perturbed;
No identified space and ground activity in the theater.

Educationally Valuable BUT **Operationally Impractical**

Possible Evolution: From SENECA to SPOCK

SENECA
Space Environment Effects Advisor



SPOCK
Space Operator Councellor and Knowledgebase

BUILD-UP OF SCENARIOS BY SCI-229

SYSTEM ANALYSIS SCHEME

GENERAL SCHEME

- EVENT TYPE
  - Timing
  - Statistics
  - Monitoring
  - Prediction

- IMPACTED SUB-SYSTEMS
  - List with criticality ranking

- EFFECTS ON SUB-SYSTEMS AND SYSTEM CAPABILITIES
  - List with severity ranking, possible fixing, recovery time

- RESPONSE PROCEDURES
  - Information distribution and target
  - Decision makers
  - Mitigation actions

BUILD-UP OF SCENARIOS BY SCI-229

THE SPACE WEATHER PHENOMENOLOGY

Non-Comprehensive Synopsis

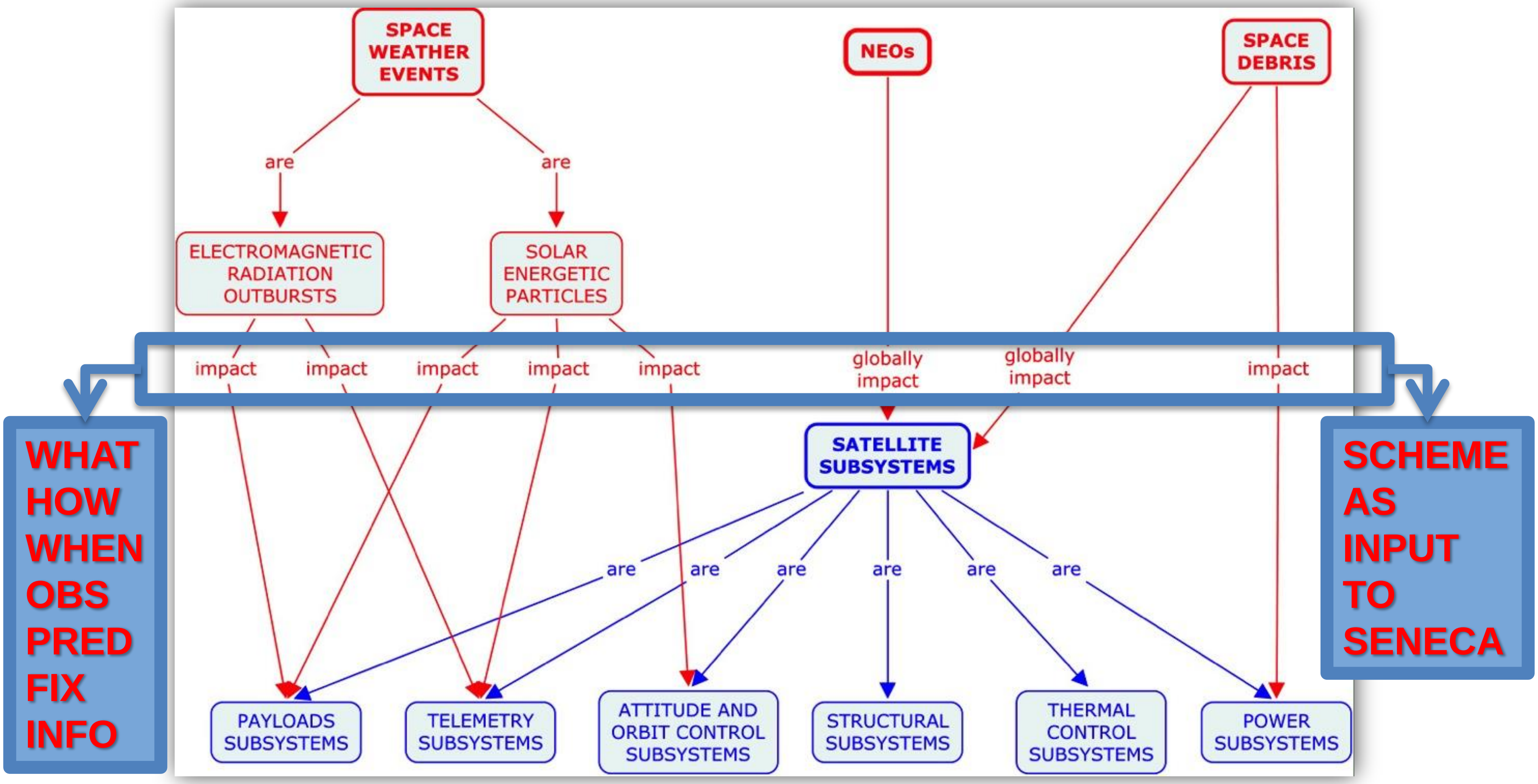
- Solar Interior
  - Solar Dynamo at Tachocline
  - Subphotospheric Convective Flows
  - Large-Scale Meridional Flows
- Solar Photosphere
  - Faculae
  - Sunspots
  - Solar Flares → EM, Particles, CME
- Solar Chromosphere
  - Solar Flares → EM, Particles, CME
  - Erupting Prominences → CME
- Solar Corona
  - Coronal Holes (CH)
  - Coronal Streamers
  - Erupting Prominences → CME
  - Coronal Mass Ejections (CME)

- Extended Solar Corona and Interplanetary Medium
  - Corotating Interaction Regions (CIR)
  - Stream Interaction Regions (SIR)
  - Interplanetary Shocks
  - Magnetic Clouds
  - Coronal Massa Ejections (CME)
- Earth Magnetosphere
  - Van Allen Belts
  - Ring Current
  - Geomagnetic Storms
- Earth Ionosphere
  - Equatorial ElectroJet (EEJ)
  - TEC variations / Scintillation
- Earth Lithosphere/Hydrosphere
  - Geomagnetically Induced Currents (GIC)

BUILD-UP OF SCENARIOS BY SCI-229

EXAMPLE OF SYSTEM ANALYSIS OF IMPACTS

Conceptual Example
Analysis of Impacts on Satellite Subsystems



TOOL USABILITY

THE MOST CHALLENGING ASPECT

Tools Usability for Military Purposes

All the above stuff has to be incorporated in a smart system that is easy to be used by the non-expert operator, i.e.,

- that provides RYG[1] answers + details if required
- that can be easily used in the theatre.

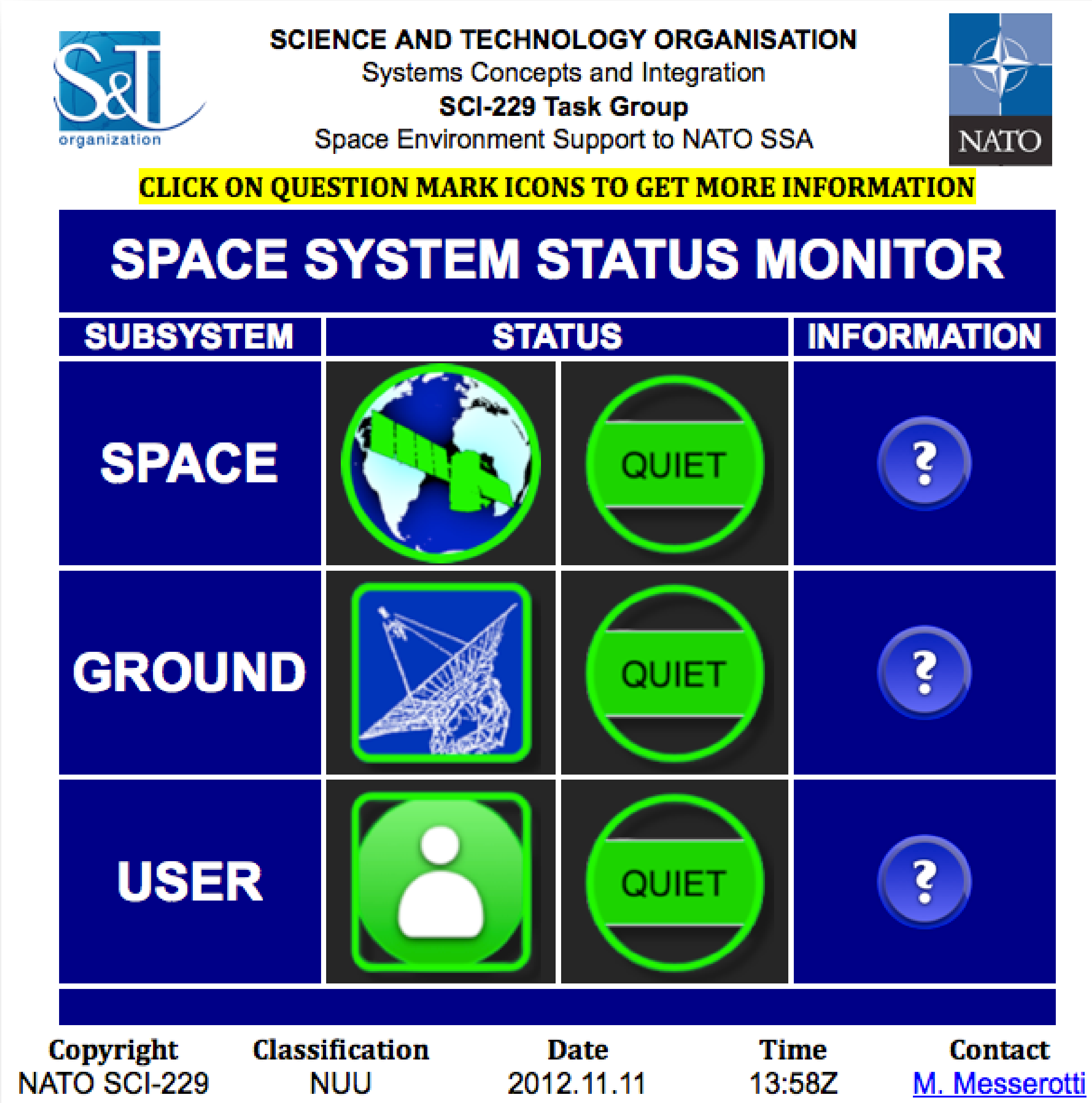
Preferred development approach: KISS[2]

[1]RYG – Red-Yellow-Green

[2]Keep It Simple, Stupid

RECENT WORK IN THIS FRAMEWORK BY SCI-229

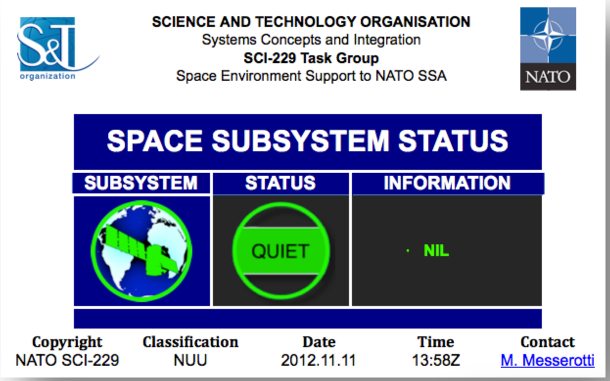
PROTOTYPE SPACE SYSTEM STATUS MONITOR WEB PAGE

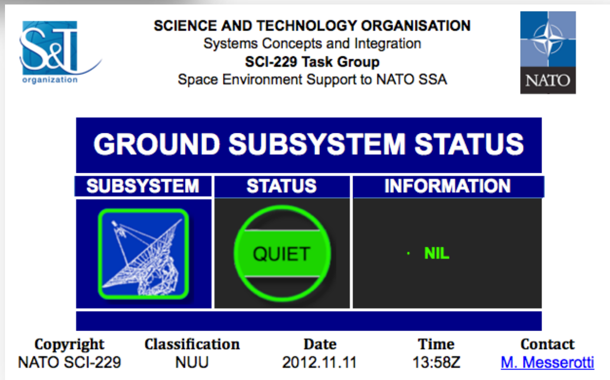


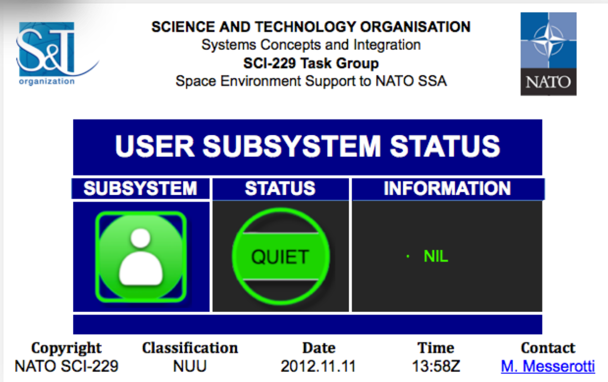
Prototype Web GUI

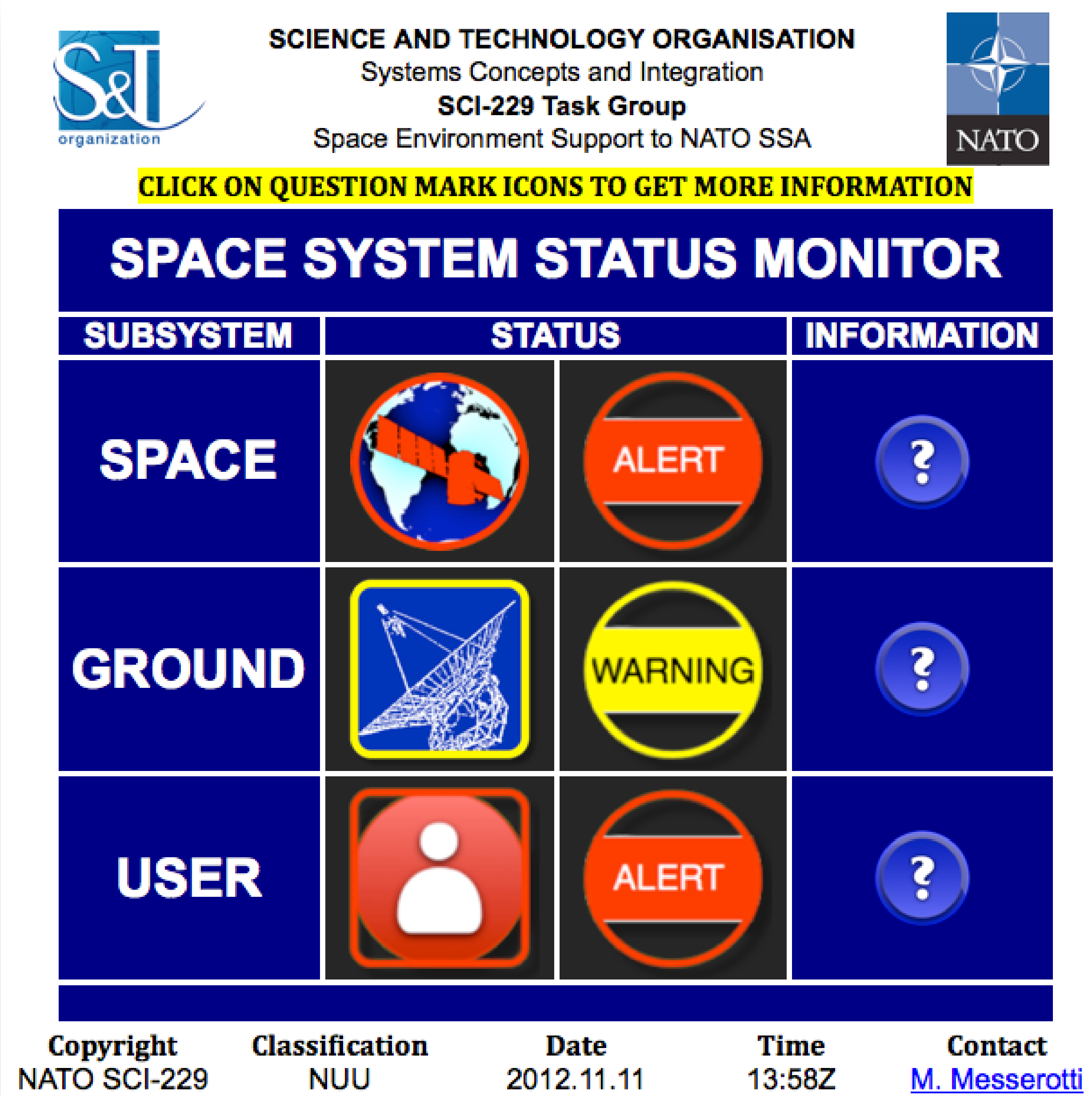
Quiet Conditions

Prototype Information Pages



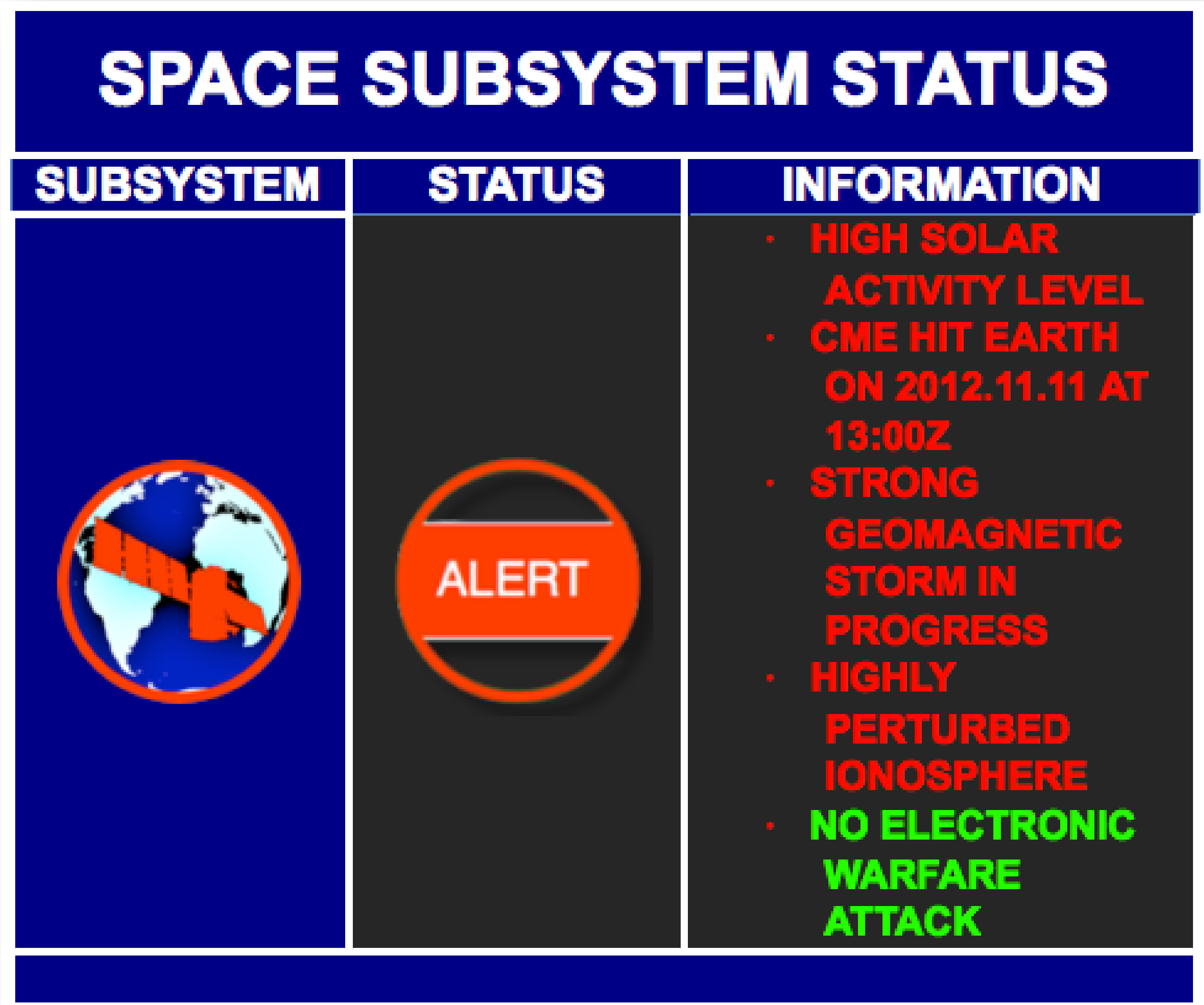




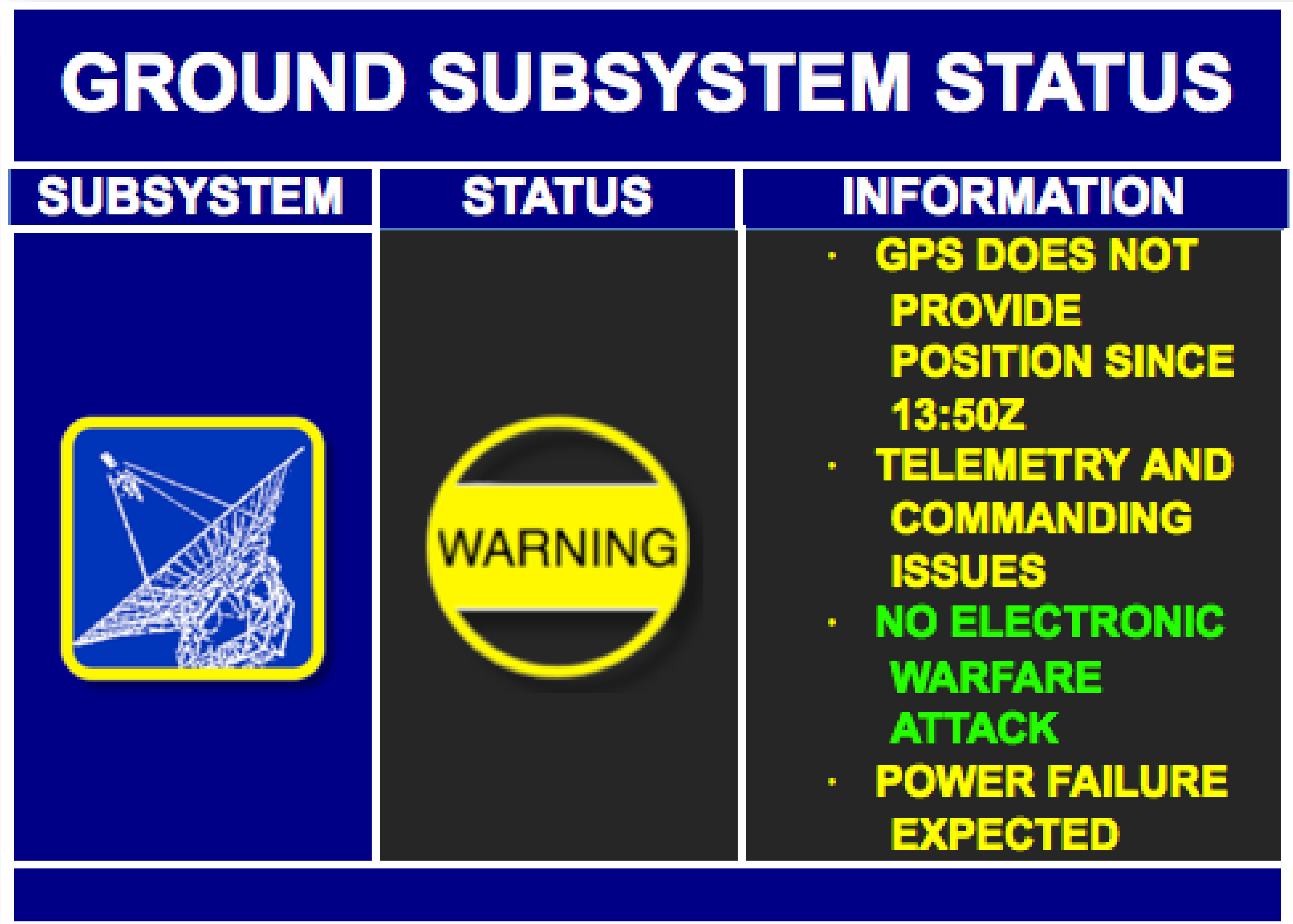


Prototype Web GUI

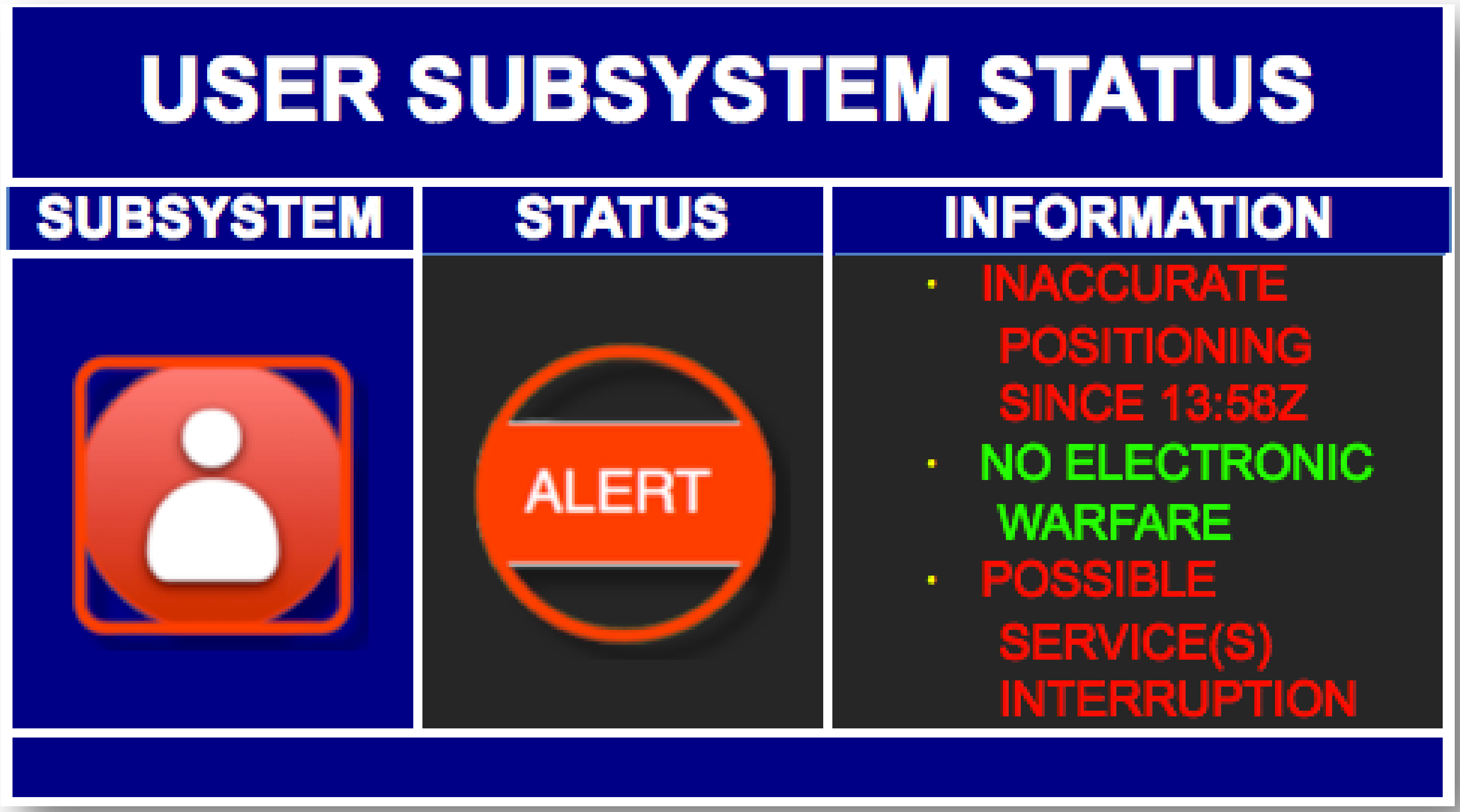
Perturbed Conditions



Information Page for Space Segment



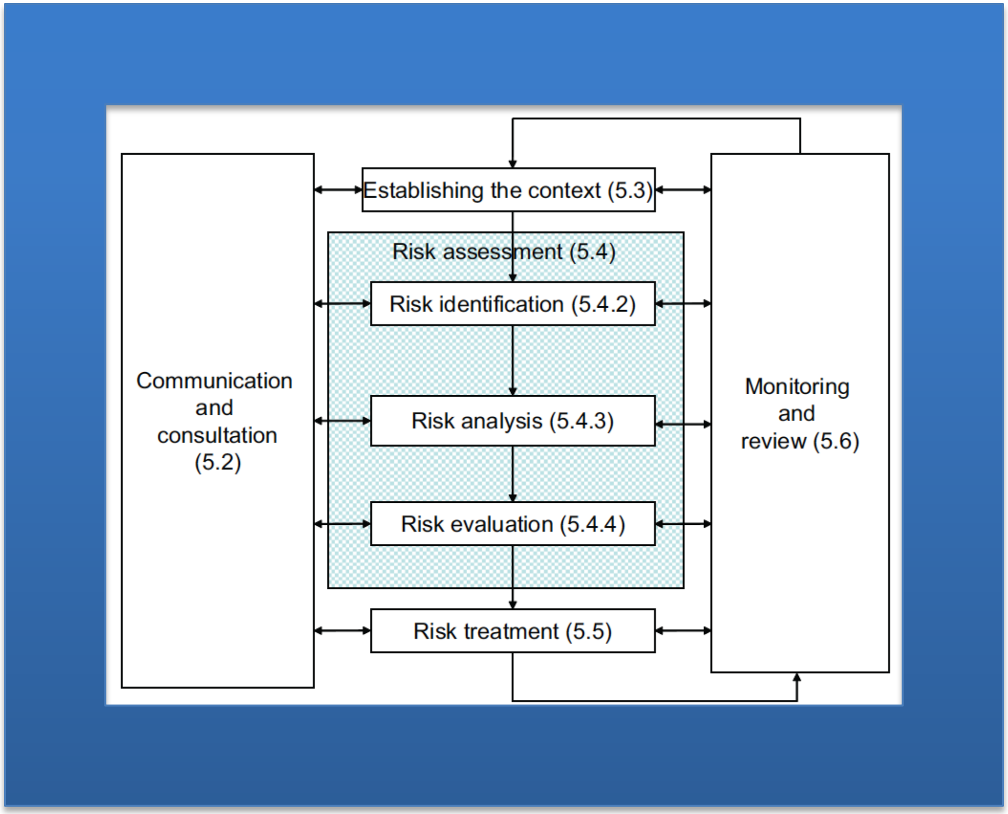
Information Page for Ground Segment



Information Page for User Segment

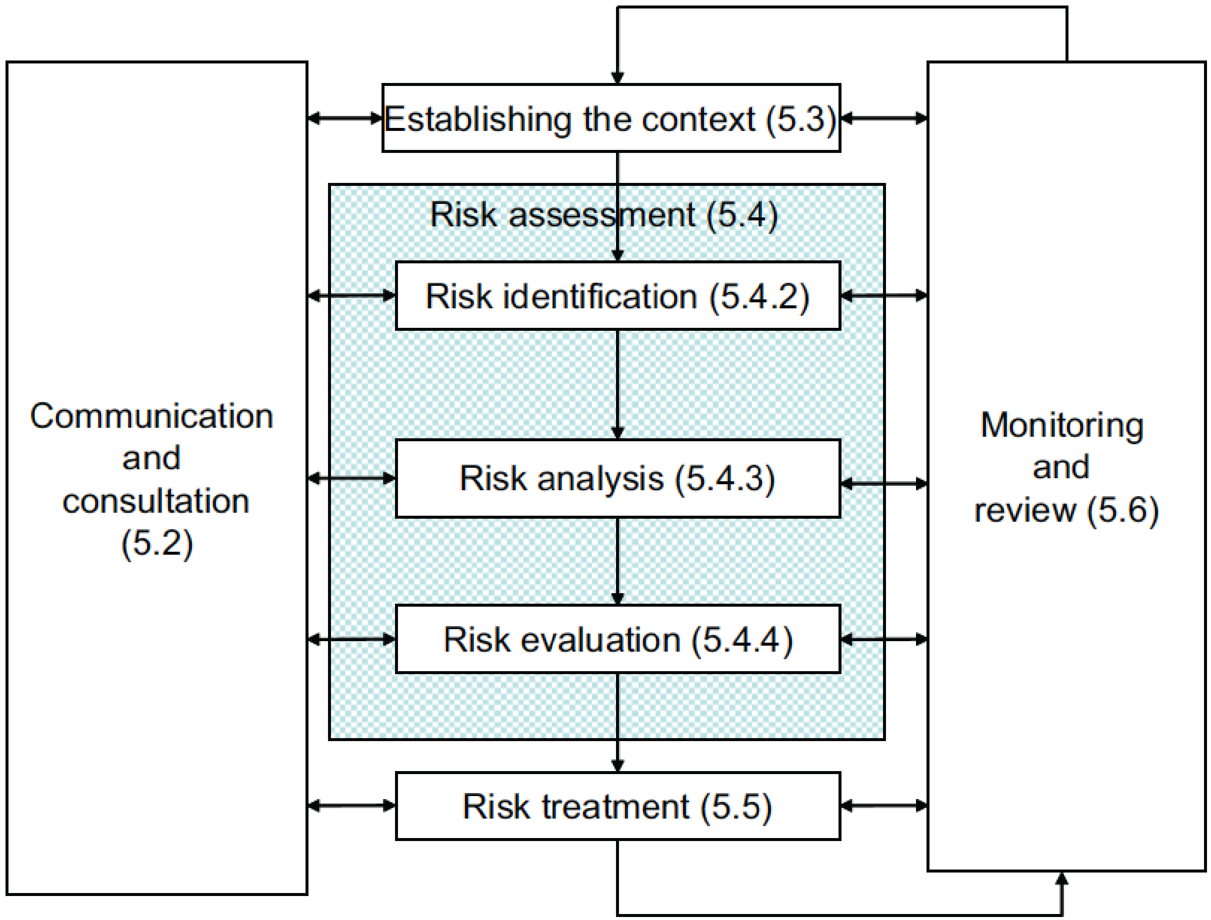
NATO SCI-229-TG

SPACE WEATHER EVENT RISK MANAGEMENT

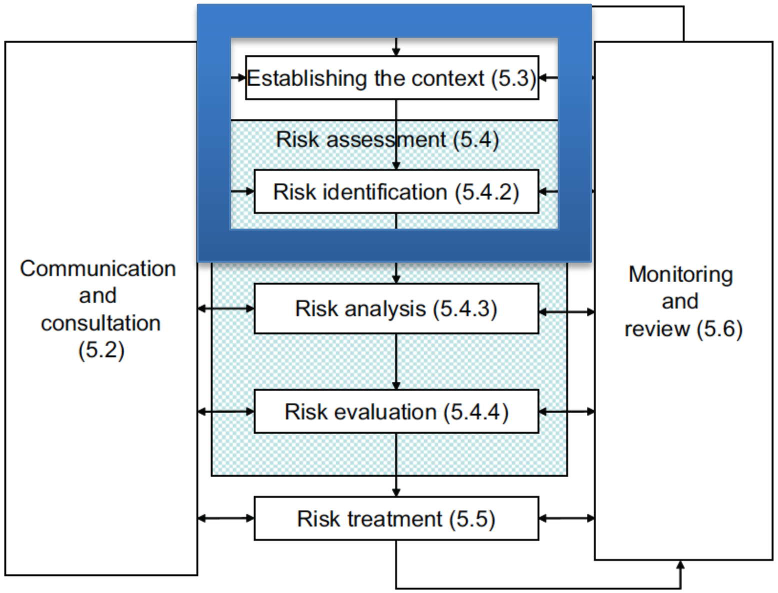


THE RISK MANAGEMENT PROCESS

Risk Management Process[1]



[1]Risk management – Principles and guidelines, ISO 31000:2009(E)

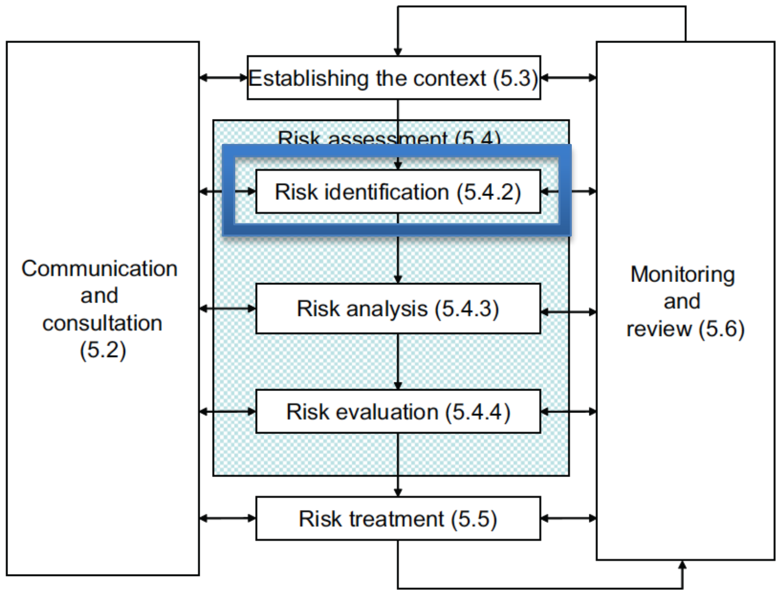


ESTABLISHING THE CONTEXT

Establishing the Context

Identifying for a specific mission:

- Involved Space Systems according to provided services
- Possible Space Environment Effects on Sp.Sys.
- Risks by Space Environment Effects
- Mitigation procedures
- Communication protocols

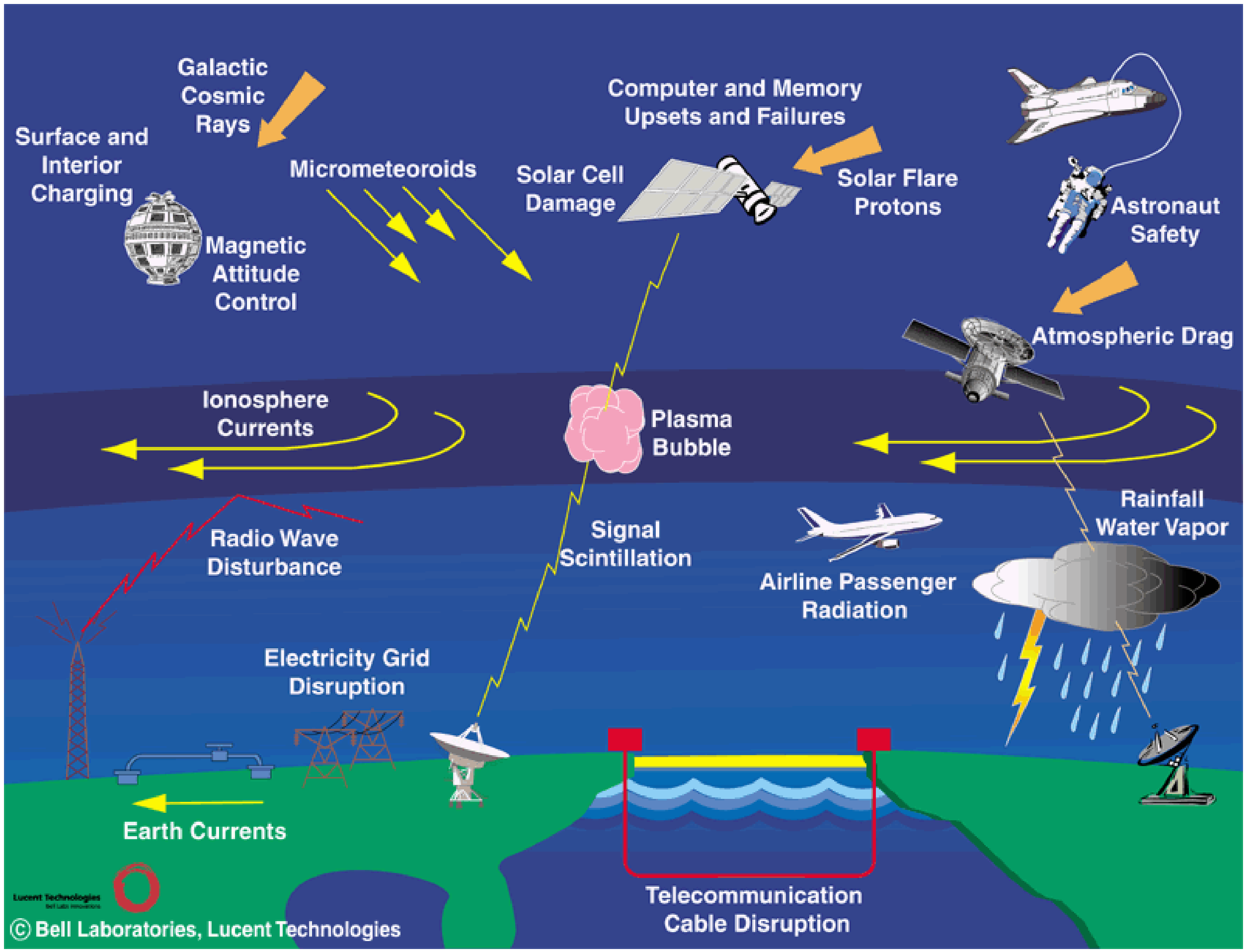


SPACE ENVIRONMENT AND SPACE SYSTEMS

Space Environment and Space Systems

- The design and fabrication of space systems must be oriented to obtain a system which operates in a hostile environment.
- The dependencies on space-based systems have been increasing faster than the detailed knowledge of the environment in which the systems are placed.
- Hence the vulnerability due to loss of a space capability or asset has increased as well.
- The study and analysis of the space environment are an important way to mitigate this vulnerability.
- The correct approach must consider the space system as a set of the three segments (SPS, GCS, EUS).

Simplified Synopsis of Space Weather Effects



Main Categories of Solar Radiation Events Affecting Space Systems

Associated with solar events like flares, CMEs, Coronal Holes, Coronal Streamers, etc.

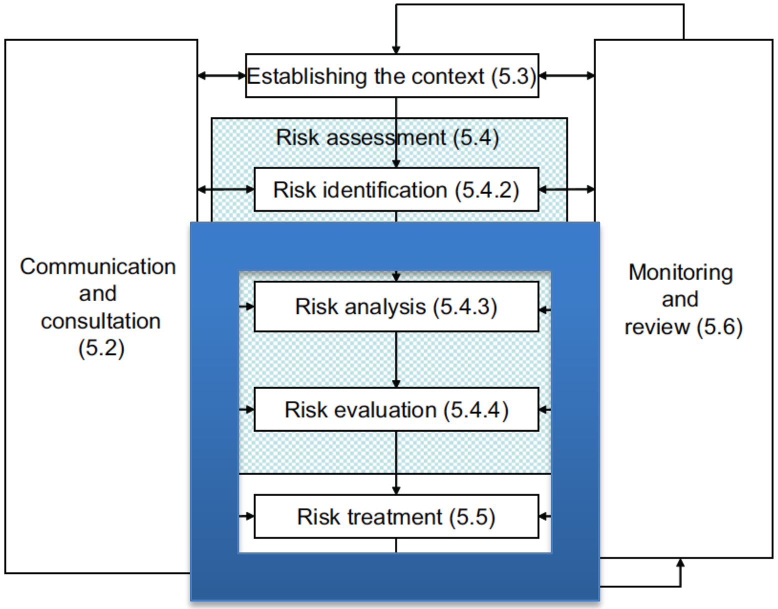
a. Electromagnetic Radiation (EMR) in the X, XUV, EUV, UV, and Radio bands.

b. High-Energy Particle Radiation (HEPR), e.g. protons impacting the Earth's polar caps.

c. Low- to Medium-Energy Particle Radiation (L/MEPR), e.g. protons and electrons channelled to the Earth's mid latitudes.

Solar Radiation Events Characteristics

	EM[2] Radiation	*High-Energy*	*L/M-Energy*
Location	Sunlit	sunlit (Polar Caps)	nighttime
Arrival time	Immediately	15 min to hours	2-4 days
Duration	1-2 hour	few days	several days
Particles	x-rays/UV[3]/radio burst	protons	protons/electrons
Effects	SATCOM[4] RADAR SRF[6]	SAT Disorientation S/C[5] Damage RADIO B/O[7]	S/C Charging SAT Drag Power B/O



RISK ASSESSMENT AND MANAGEMENT

Definition of Risk

- **Effect of uncertainty on objectives**[1]

- **Uncertainty** can be caused by
  - Events, e.g. hazards, threats
  - Lack or ambiguity of information
  - Action or inaction

- **Effect on objectives** is
  - Partial to total missing

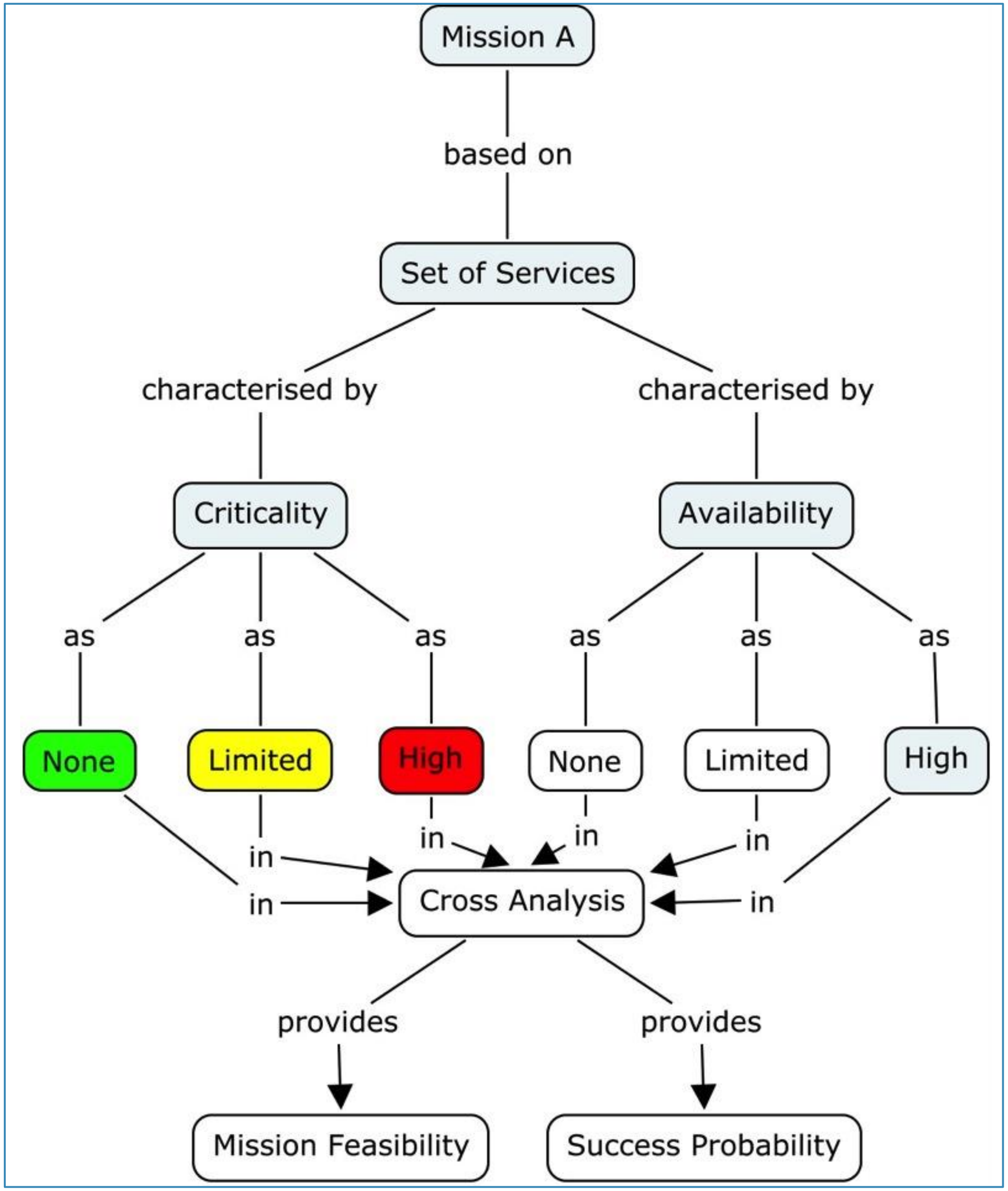
[1] Risk management – Principles and guidelines, ISO 31000:2009(E)

Definition of Risk

$$R_{total} = \sum_{i} L_i p(L_i)$$

R	Total Risk Value
L_i	Loss by event i
$p(L_i)$	Occurrence probability of loss by event i

Mission Risk Analysis



Risk Assessment & Management

EVENT		IMPACT			
		Low	Medium	High	Extreme
PROBABILITY	Low	0	1	2	3
	Medium	1	2	3	4
	High	2	3	4	5
	Very High	3	4	5	6

MANAGEMENT PRIORITY

Risk Assessment & Management in the NATO Framework

EVENT		RELEVANCE OF IMPACT FOR MISSION			
		Unaffected	Important	Essential	Critical
PROBABILITY	Low	?	?	?	?
	Medium	?	?	?	?
	High	?	?	?	?
	Very High	?	?	?	?

PRIORITY ASSIGNMENT IS THE MOST CHALLENGING EXERCISE DUE TO:

- THE VARIETY OF NATURAL EVENTS.
- THE INTERRELATIONSHIPS AMONG EVENT CATEGORIES.
- THE VARIETY OF POTENTIALLY AFFECTED SUBSYSTEMS.
- THE VARIETY OF POSSIBLE IMPACTS.
- THE POSSIBILITY OF CASCADING EFFECTS OF IMPACTS.
- THE VARIETY OF POSSIBLE PRIORITY PERSPECTIVES ACCORDING TO THE MISSION SCENARIO AND GOALS.

Space Environment
Risk Analysis and Evaluation

- Risk analysis and evaluation are to provide quantitative/qualitative risk levels for the considered events (SWx, NEOs, SDs) within the framework of interest

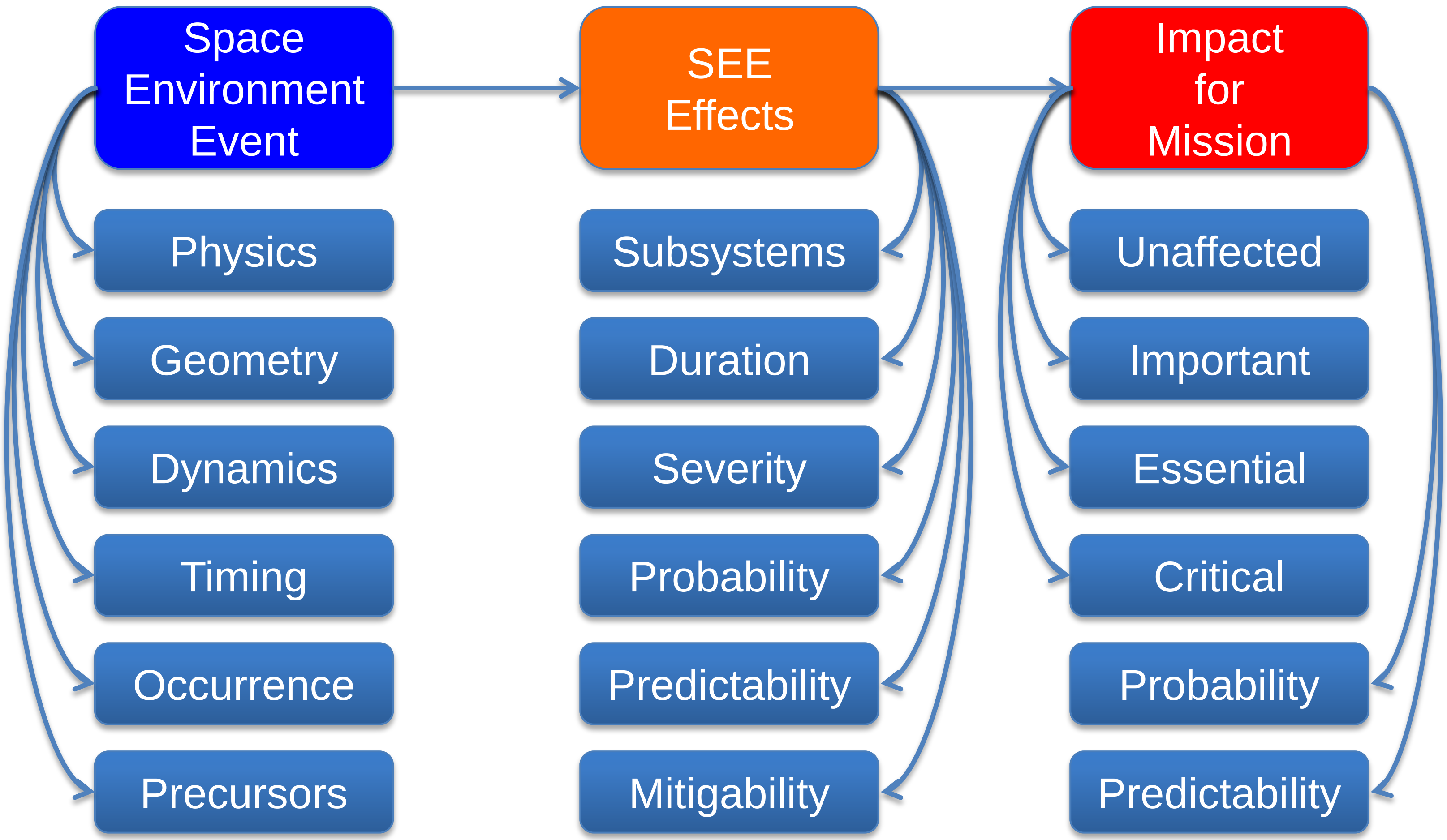
- Very difficult to be carried out for natural hazards whose observations are relatively fragmentary, and whose physics knowledge is quite limited

Space Environment Risk Treatment

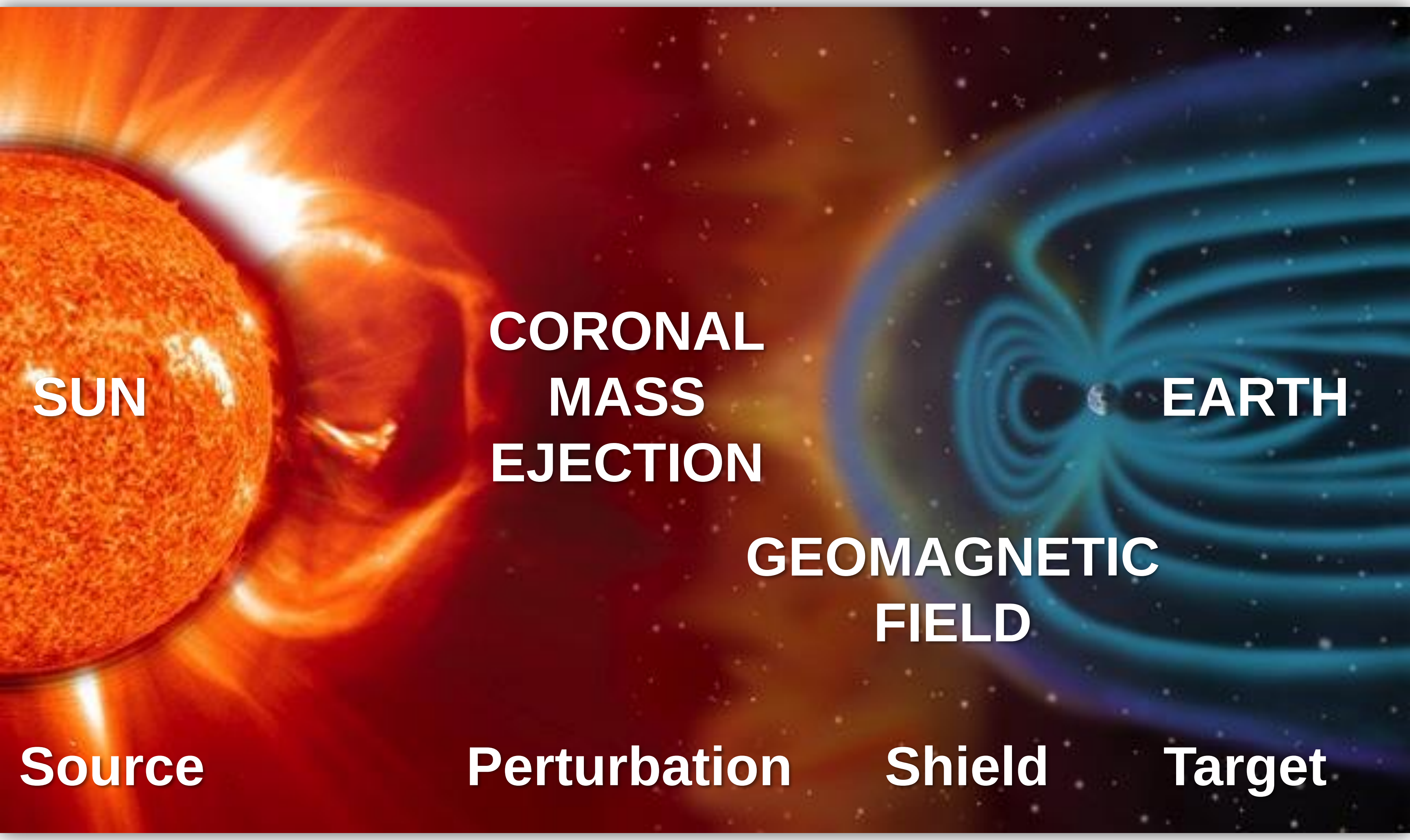
- Identification of possible mitigation techniques

- To date, most SWx, NEOs, and SDs events for their intrinsic nature do not allow any mitigation technique

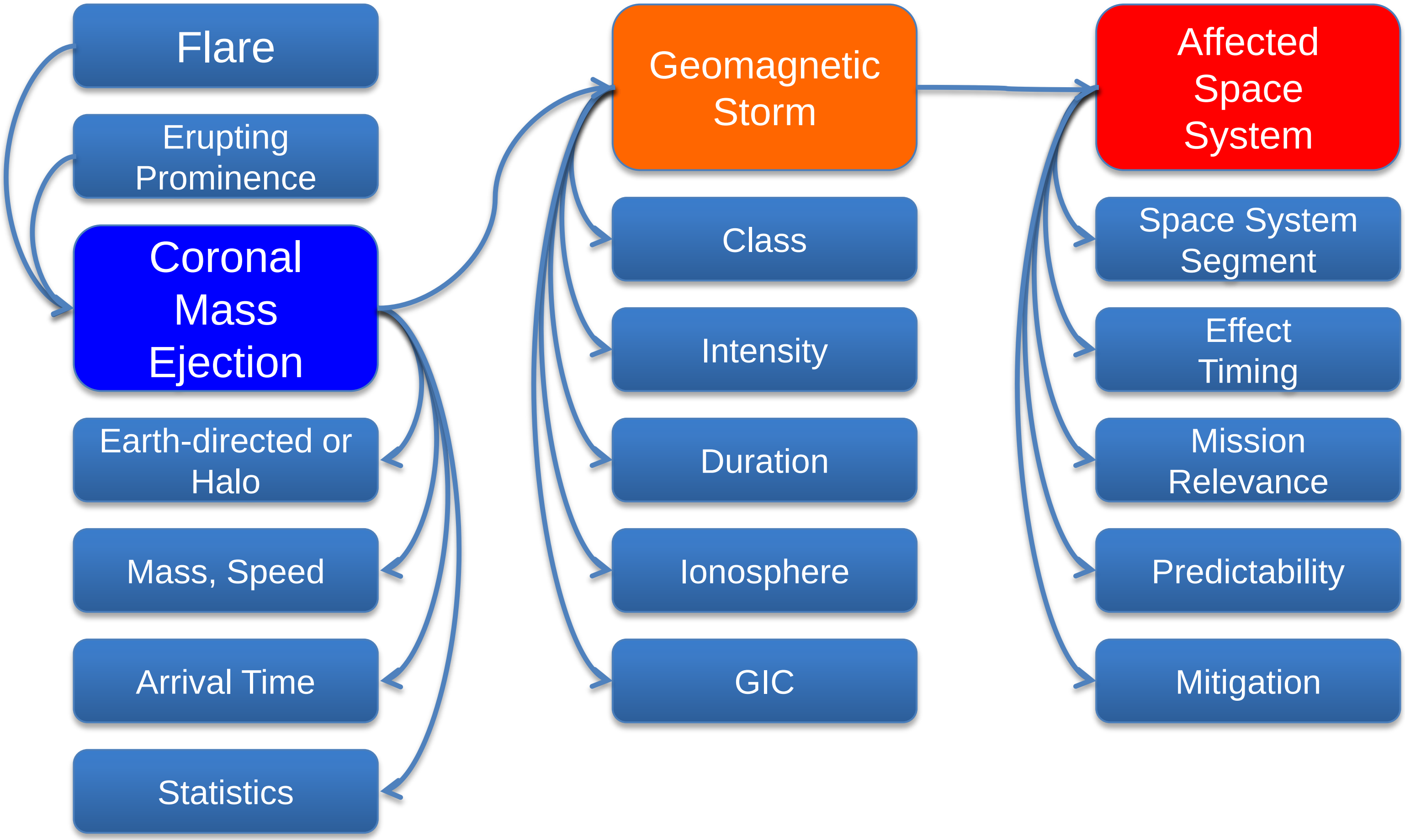
An Integrated Approach for Risk Assessment



Perturbation in the Sun-Earth Space Environment



A Sample Use Case



Conclusions and Outlook

- We have been considering the space environment risks in the framework of NATO needs.
- This exercise has been carried out for SWx, NEOs, and SDs events.
- The **risk analysis** and **evaluation** is **<u>challenging</u>** for the **lack of comprehensive observations** and **lack of deep physical understanding** for the majority of phenomena.
- Notwithstanding, a first evaluation is in progress based on the available knowledge and will serve as a basis for future refinements.

THANK YOU
FOR YOUR ATTENTION !