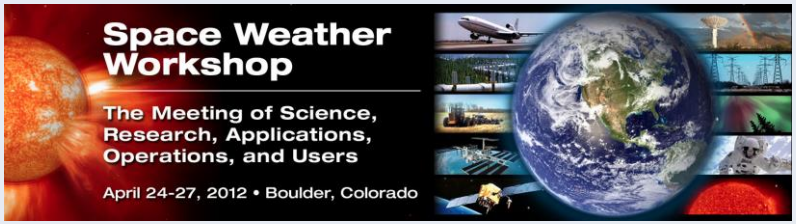


Space Environment Support to NATO SSA: Advances by the NATO SCI-229 Task Group

M. Messerotti[1,2,3] & SCI-229 RTG

NATO SCI-229 RTG, Chair

[1] *INAF-Astronomical Observatory of Trieste, ITA*

[2] *Department of Physics, University of Trieste, ITA*

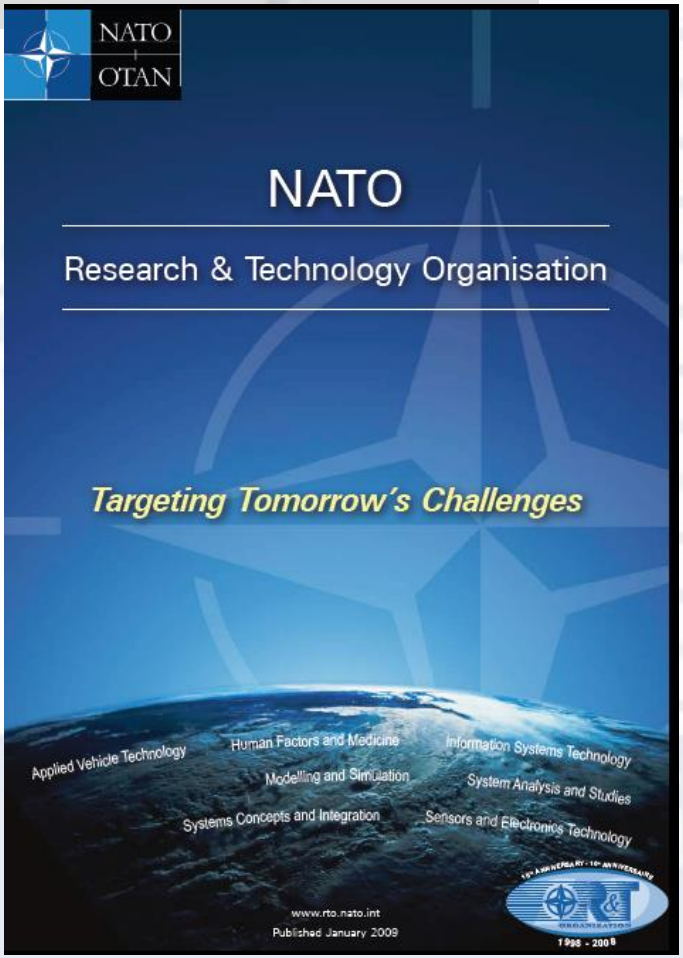
[3] *NATO Research and Technology Organisation, Paris, FRA*

Outline of the Talk

- The NATO RTO Framework
- The NATO RTO SCI-229 Rationale
- The NATO RTO SCI-229 Exploratory Team
- The NATO RTO SCI-229 Task Group
- SENECA: A Prototype Expert System
- Conclusions

THE NATO RTO FRAMEWORK

The NATO RTO Research & Technology Organisation



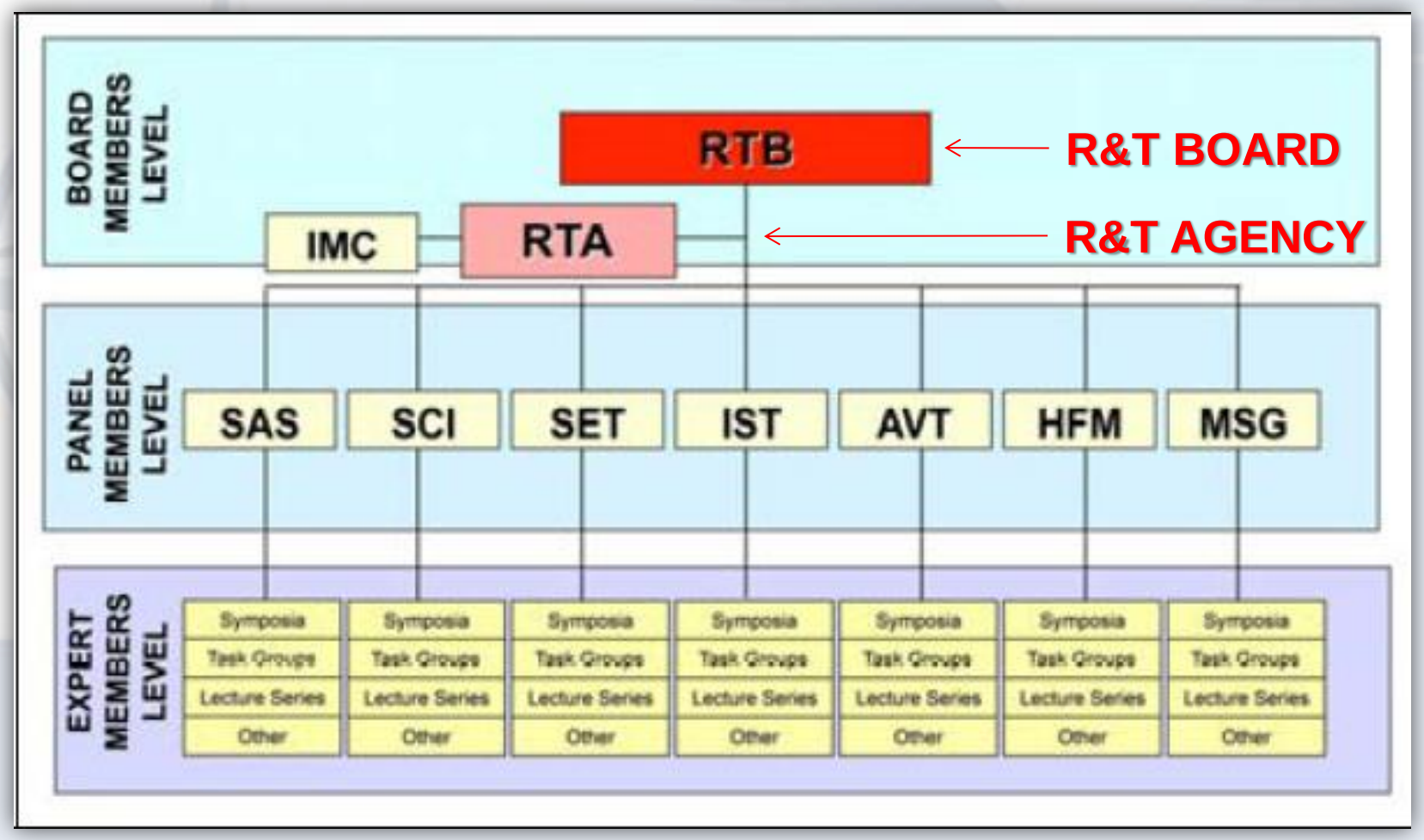
The **NATO Research and Technology Organisation** (**RTO**) promotes and conducts co-operative scientific research and exchange of technical information amongst 28 NATO nations and 38 NATO partners.

The largest such collaborative body in the world, the RTO encompasses over 3000 scientists and engineers addressing the complete scope of defence technologies and operational domains.

This effort is supported by an executive agency, the **Research and Technology Agency** (**RTA**), that facilitates the collaboration by organising a wide range of studies, workshops, symposia, and other forums in which researchers can meet and exchange knowledge.

www.rto.nato.int

NATO RTO Organisational Chart



NATO RTO
Technical Panels and Groups

Bodies made up of **national representatives**, **world-class scientists** and **information specialists**, that also provide a communication link to military users and other NATO bodies.

- **IMC** Information Management Committee
- **SAS** System Analysis and Studies Panel
- **SCI** **Systems Concepts and Integration Panel**
- **SET** Sensors and Electronics Technology Panel
- **IST** Information Systems Technology Panel
- **AVT** Applied Vehicle Technology Panel
- **HFM** Human Factors and Medicine Panel
- **NMSG** NATO Modelling and Simulation Group

NATO RTO S&T Workflow
The Exploratory Team

1. Under one or more of the RTO bodies an Exploratory Team (ET) is created
   a. For specific activities
   b. With specific duration
   c. Composed by experts in the field(s)

   1. To explore the science and operation framework specific to the sub-domain(s) of interest

   2. To formulate both a **Terms of Reference (TOR)** document and a **Technical Activity Proposal (TAP)** propaedeutic to a structured follow-up activity

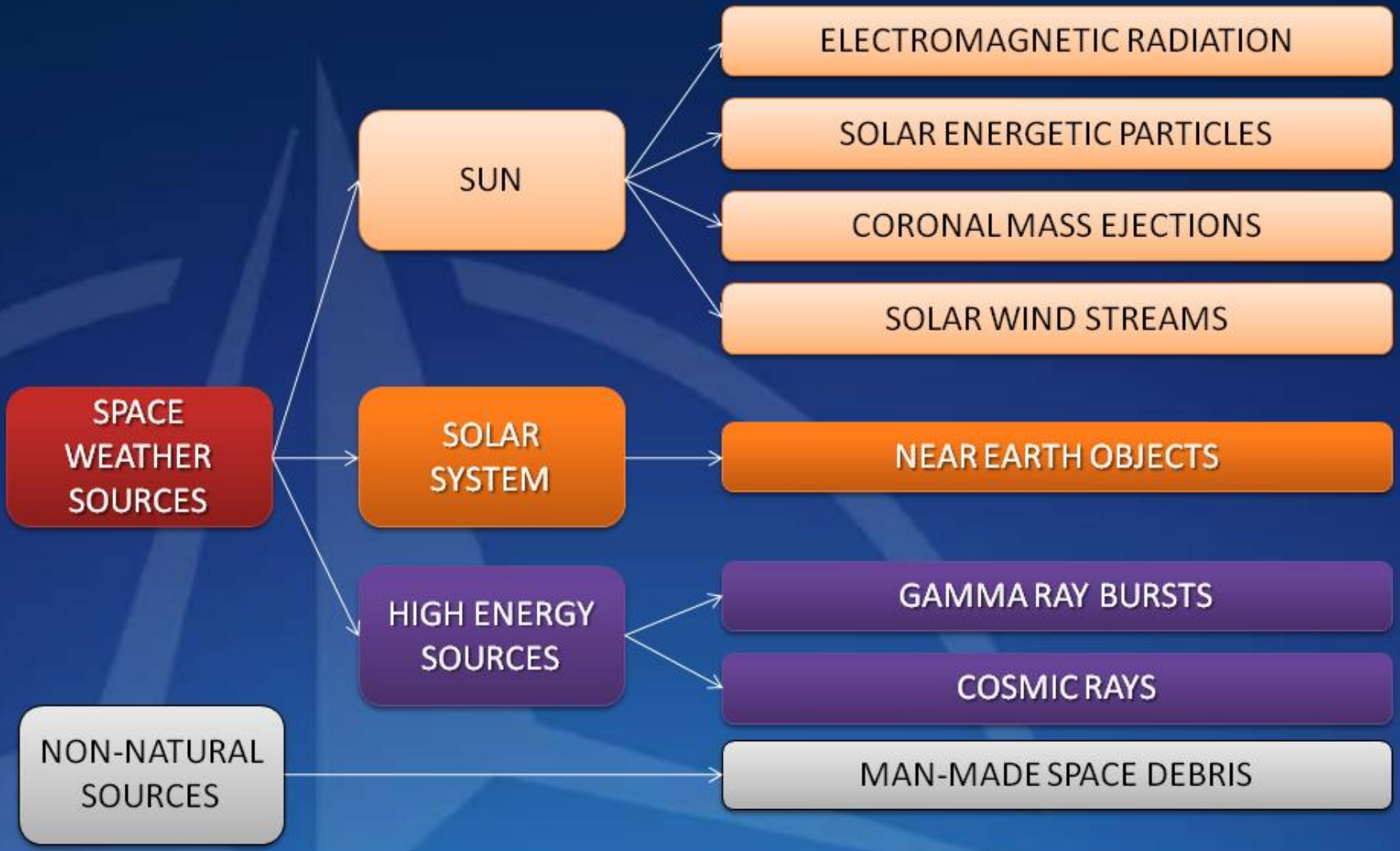
NATO RTO S&T Workflow
TOR and TAP

2. When approved, a TAP involves the **formation of a Technical Team** to coordinate a **set of focus groups** performing dedicated research activities in their area of scientific expertise.

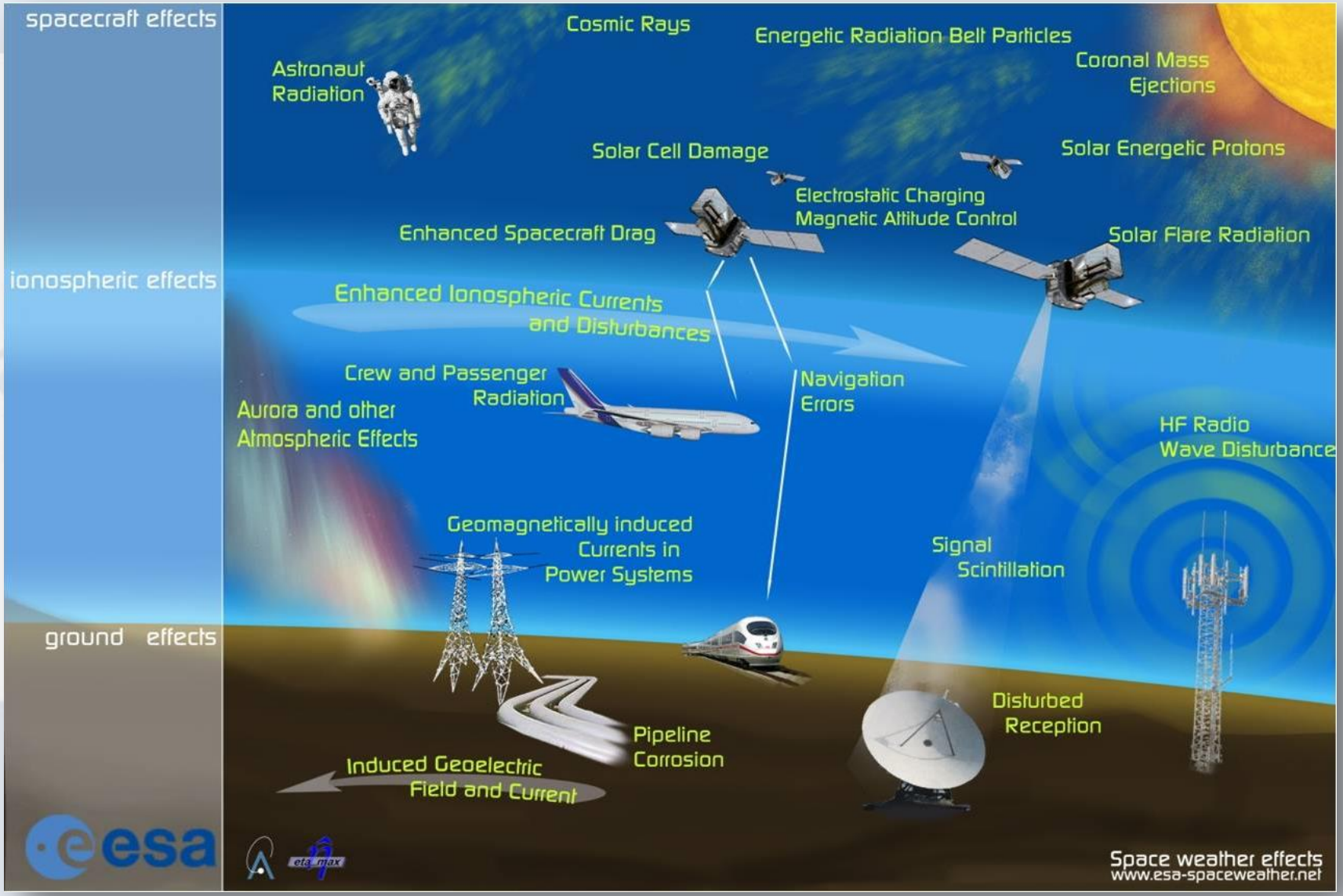
Research activities often involve workshops, symposia, field trials, lecture series and training courses, in all cases leading to the publication of highly valued scientific literature, much of which is published in the general scientific research outlets as well as specific peer-review journals.

RATIONALE FOR THE NATO SCI-229 TASK GROUP STUDY

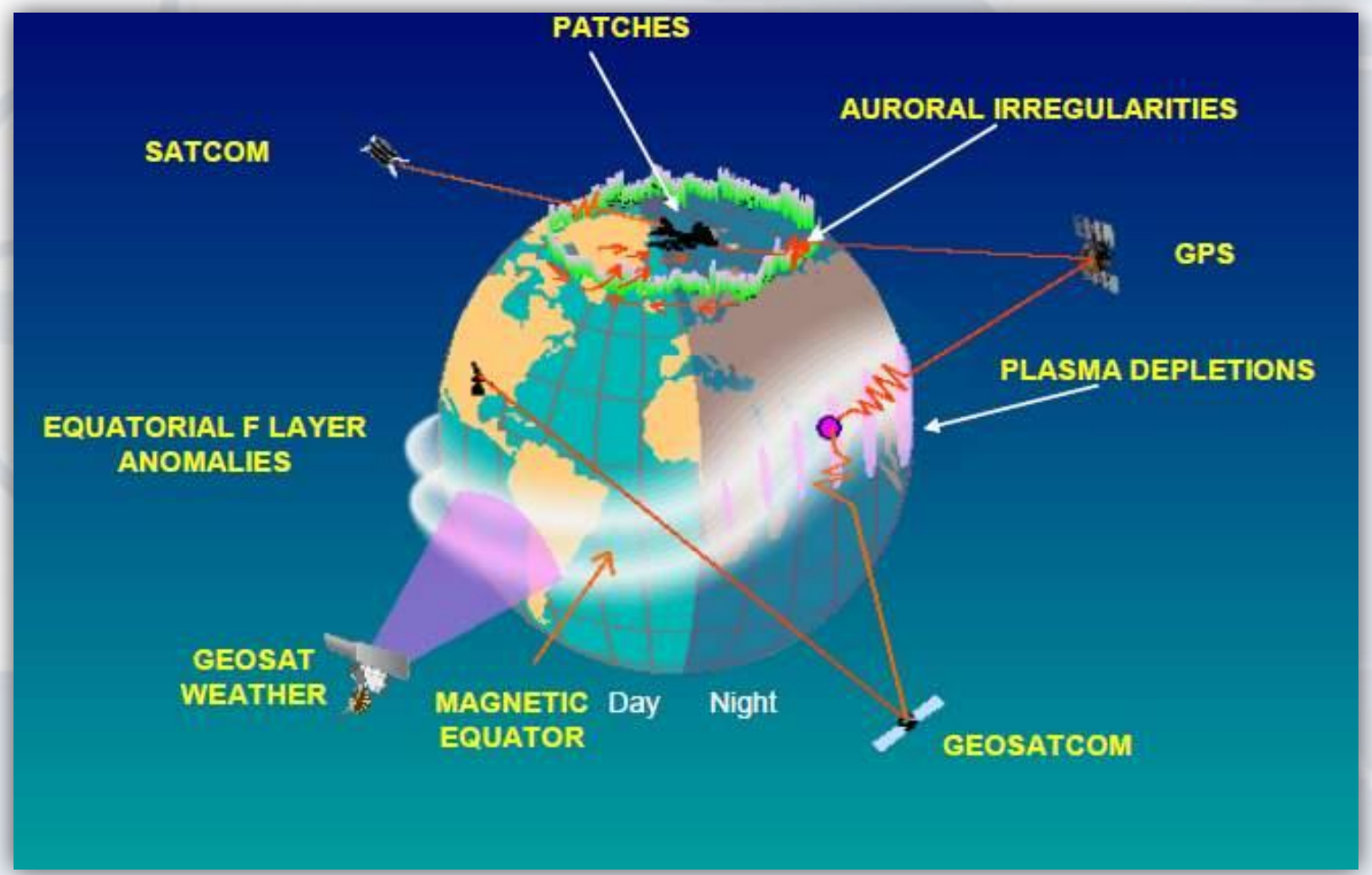
CHARACTERISATION OF THE SPACE ENVIRONMENT



Synopsis of Space Weather Effects

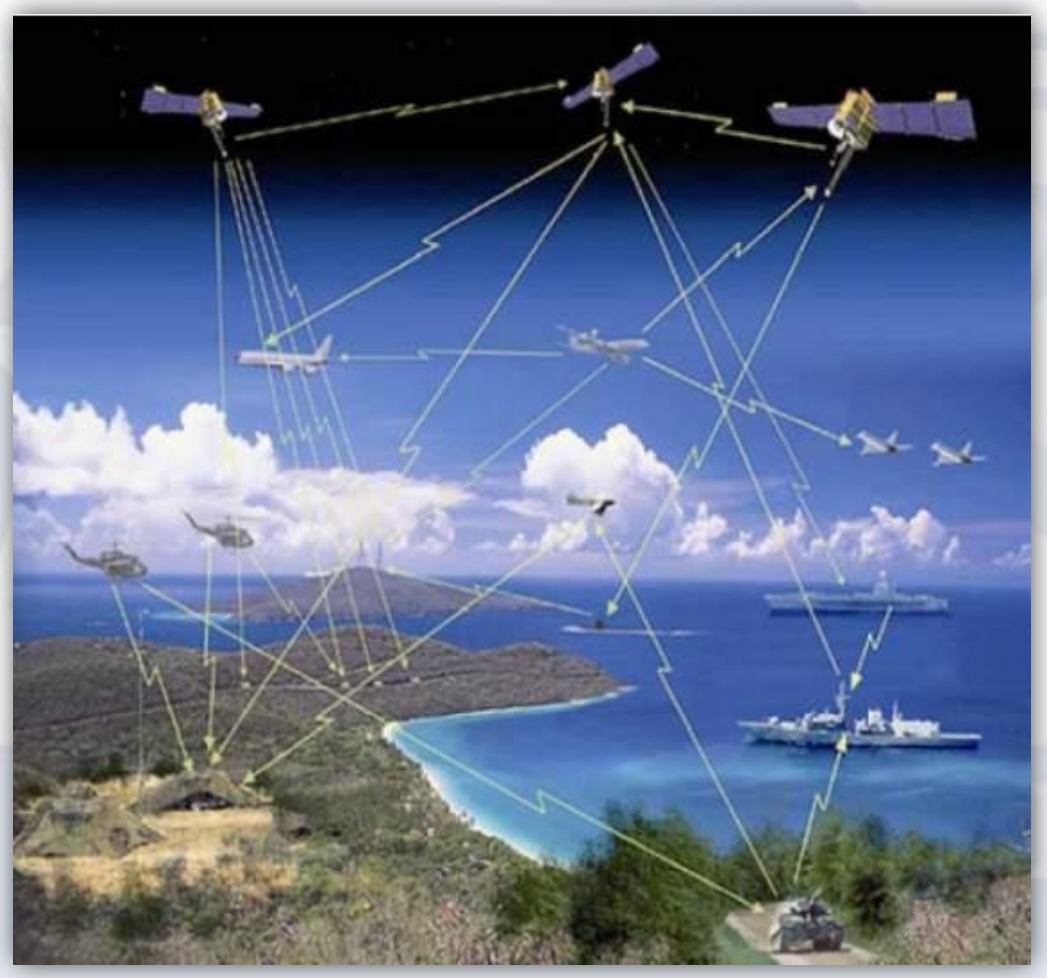


A Use Case:
Global SatCom Outage Regions



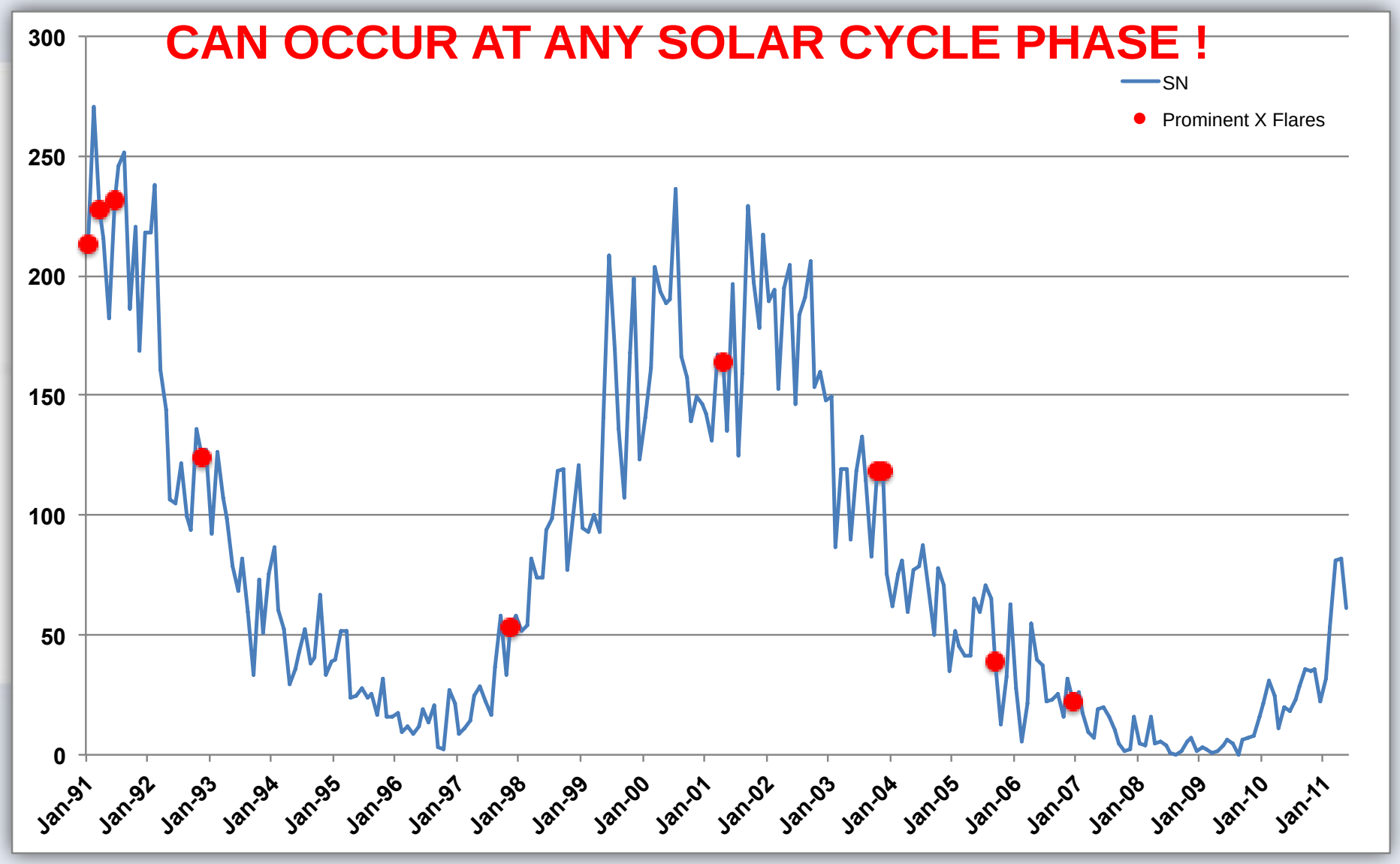
Courtesy H.C. Carlson

Impact on the NATO Wide Information Exchange Scenario

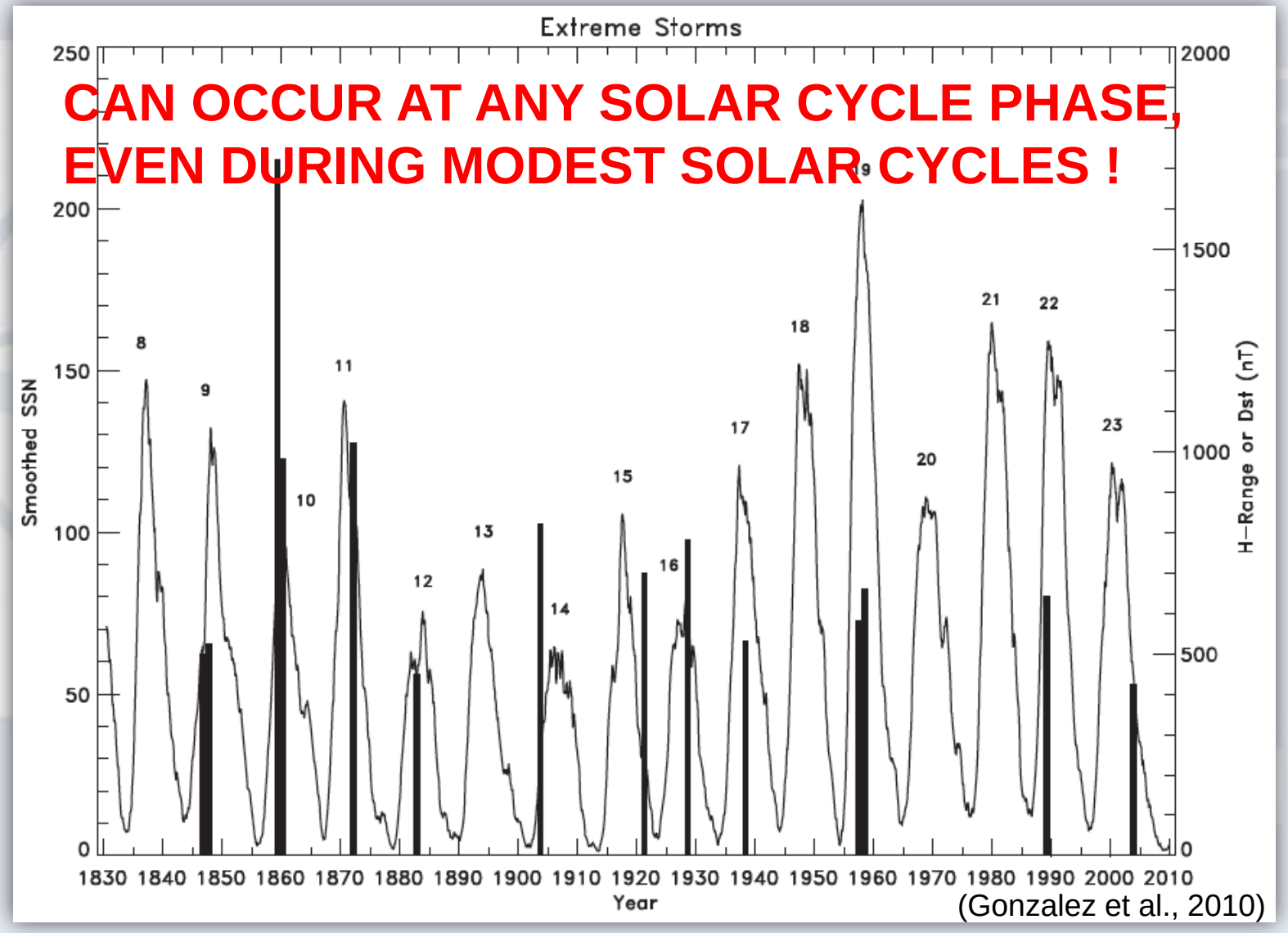


From NATO RTO Pamphlet

Largest Solar Flares With Geoeffects

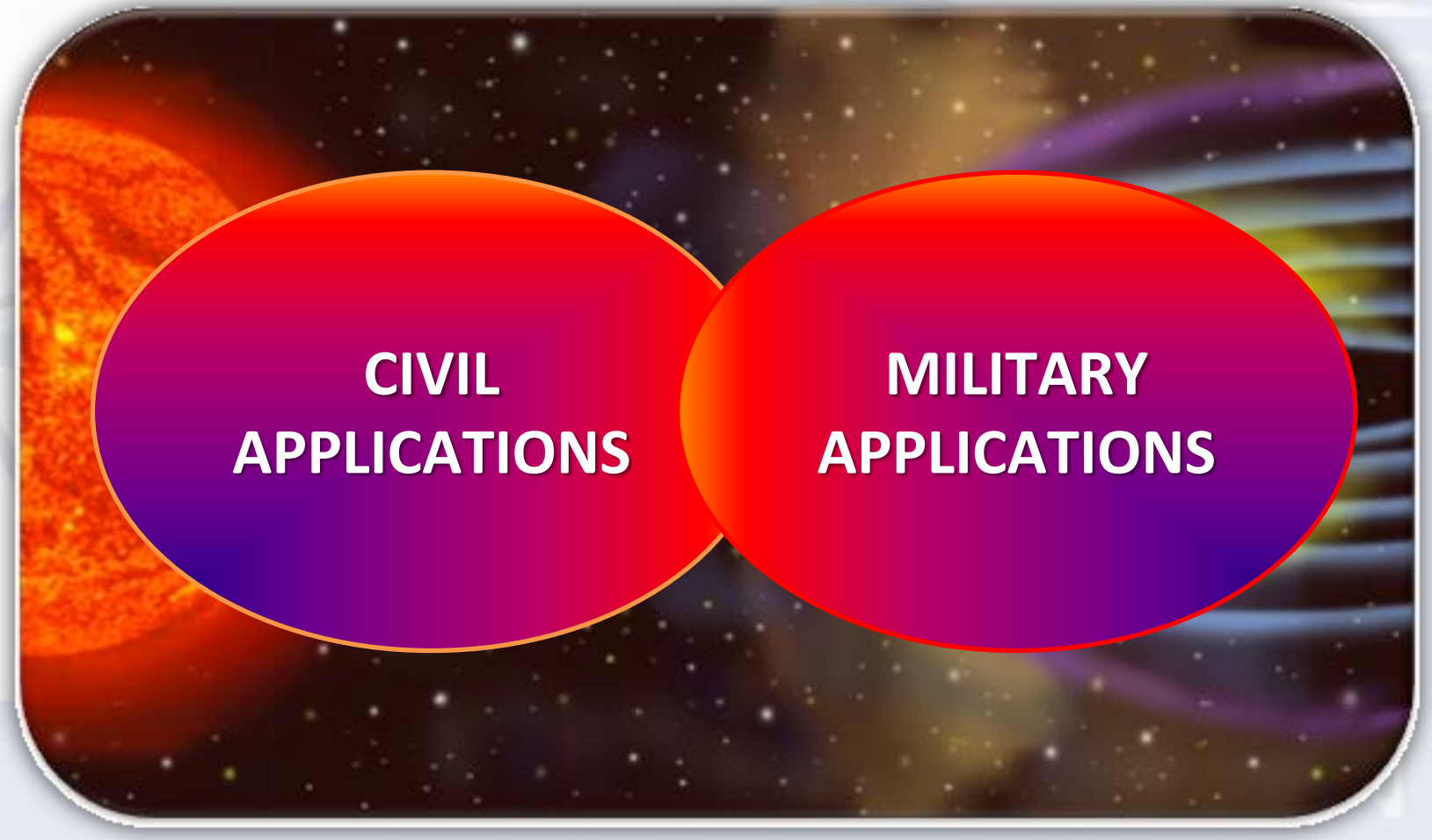


Extreme GeoMagnetic Storms



(Gonzalez et al., 2010)

Diversity of Risk Assessment for Civil and Military Applications



LOW PROBABILITY-HIGH IMPACT EVENTS CANNOT BE DISREGARDED !

Not convinced?...

- Sunday, 22 April 2012
- California (USA)
- 8 a.m. PDT (UTC-8)
- Fireball explosion
  - Size: 2m 1.75m 5m (W H L)
  - Mass: 70 t
  - Released energy: 5 kt
- Cadence: 1 per year

(Tunguska, RUS, 1908: 15 Mt, 2,150 sq.km)

NATO SSA Background

The political, military and security world rapidly changing, leading NATO to increasingly be dependent on space support: NATO operations will continue to depend on capabilities provided by space: communications, weather, missile warning and tracking, navigation and timing data, ISTAR; and, as NATO continues to transform to a joint expeditionary military force, there will be increasing demands for support from space-based assets.

Ensuring that such support will be available when needed, requires NATO to rely on appropriate space situational awareness, defined as (**SCI-229 Exploratory Team, 2010**)

"**NATO Space Situational Awareness is the knowledge and the understanding of military and non-military events, activities, circumstances and conditions within and associated with the space environment or space related systems that are relevant for current and future NATO interest, operations and exercises**."

SCOPE:

- NATO Space Situational Awareness applies whenever and wherever NATO plans, conducts own operations, exercises and NATO activities; as directed by the NAC (North Atlantic Council) and in accordance with international law.
- NATO Space Situational Awareness considers the integrity of space assets and space-related systems affected by space-originated natural or artificial hazards. NATO Space Situational Awareness also comprises such effects on society and individuals.

Space related military requirements differ significantly now than they did just a decade ago. Examples are the Chinese antisatellite test in January 2007, the space debris collision of US / Russian owned satellites in February 2009 as well as the published US report (January 2009) on "The Economic and Societal Impact of Space Weather".

US and EU SSA Initiatives

- **In the United States** the Air Force established the **Space Command**. Strong and close cooperation exists in the U.S.A. between civil and military space situational awareness (SSA) activities.

- **In Europe** several activities related to space weather, space debris and Near Earth Objects (NEOs) were carried out in the last decade by ESA, national space organisations and supported by the European Commission. During ESA Ministerial Conference in November 2008 the **Space Situational Awareness** program was signed. SSA is an implementation of the EU space policy. In Europe, SSA is a security related program with the three fields: space weather, space debris and NEOs. The first phase of SSA at ESA was carried out between 2009 and 2011. A second phase is foreseen after 2012.

However **the SSA programmes in the USA, in the EU respectively from ESA are for high priority to NATO and are not yet transformed into NATO military long term capability requirements (LTCR) respectively to NATO operations** ➔ **A NATO Space Integrated Project Team (IPT) has been actively working to create the basic framework for that (Chair: LCL Daniel Hugueny, SACT, Norfolk, USA)**.

These programmes are also relevant to NATO research topics and addresses the LTCR on Space Capability Preservation.

THE NATO RTO SCI-229 ET

NATO RTO SCI-229 Exploratory Team "NATO Operations and Space Situational Awareness"

- The Mission of the **Systems Concepts and Integration (SCI)** Panel is to advance knowledge concerning advanced systems, concepts, integration, engineering techniques and technologies across the spectrum of platforms and operating environments to assure cost-effective mission area capabilities.

- In this context, the **SCI-229 ET** has been formed **(2009-10; Chair: F. Jansen, DLR, GER ← Triggered at SWx Workshop 2008 by LTC K. Hand, CTR USAF)** to consider:
  a. The study of Space Weather, Space debris and Near-Earth Objects for NATO needs
  b. Co-operative research and information
  c. Development of technological lead related to SSA purposes within the Alliance
  d. Development of SSA tools for NATO
  e. SSA education for NATO space operation officers.

NATO SCI-229 ET Deliverables and Follow-Up

1. NATO Space Situational Awareness Definition

1. NATO SSA Terms Of Reference (TOR) Document

1. NATO SSA Technical Activity Proposal (TAP)

2. Approval of the NATO SCI-229 Task Group

THE NATO SCI-229 RTG

Activity Characterisation

- NATO Research and Technology Organisation (RTO) Panel: *Systems Concepts and Integration (SCI)*
- In coordination with: *AVT, HFM, IST, SAS, SET, NAFAG, NIAG, ACT*
- Panel POC: *Dr. D.A. Lewis (USA)*
- Duration: *01.01.2011-31.12.2013*
- Lead Nation: ITA 
- 10 Participating Nations: *CZE, ESP, FRA, GBR, HUN, ITA, NOR, ROM, SLO, USA*

- Security classification: NATO UNCLASSIFIED (NU)

Contact People

- **SCI Panel Executive**

  LTC Matthew A. Romagnuolo, NATO Research & Technology Agency, Paris, FRA (RomagnuoloM@rta.nato.int)
- **SCI Panel POC**

  Dr. Donald A. Lewis, Principal Director, Project West Wing, The Aerospace Corporation, USA (Donald.A.Lewis@aero.org)
- **SCI Panel Assistant**

  Dr. Carlotta Rossi, NATO Research & technology Agency, Paris, FRA (RossiC@rta.nato.int)

- **SCI-229 TG Chair**

  Prof. Mauro Messerotti, INAF-Trieste & Trieste University, ITA (messerotti@oats.inaf.it)
- **SCI-229 TG Vice-Chair**

  Prof. Ulf-Peter Hoppe, FFI & Oslo University, NOR (u.p.hoppe@fys.uio.no)
- **SCI-229 TG Technical Editor**

  Dr. Frank Jansen, DLR, Bremen, DEU (Frank.Jansen@dlr.de)

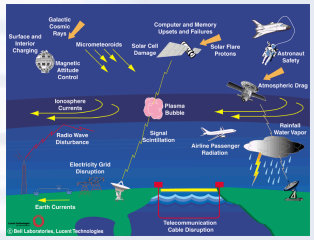
SCI-299 RTG - Topics

1. Effects of space hazards on NATO interests, including civilian capabilities.
2. Assessment of space hazard prediction tools and products.
3. Proof of concept and demonstration of selected space hazard tools and recommended responses.
4. Identification of potential gaps and shortfalls.
5. Education of NATO space planners.

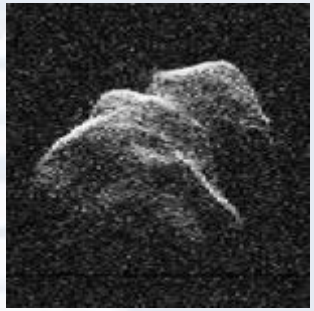
Organisation of Work for Space Event Risk Assessment and Mitigation

Three main topics ➔ Three Focus Groups:

1. **Space Weather** (SWx)
   - Leader: C. Cid (Univ. Alcalà, ESP)
   - Co-Leader: D. Buresova, (ASCR, CZE)



2. **Near Earth Objects** (NEOs)
   - Leader: E. Perozzi (Telespazio, ITA)
   - Co-Leader: G. Valsecchi (INAF, ITA)



3. **Space Debris** (SDs)
   - Leader: A. Rossi (CNR-ISTI, ITA)
   - Co-Leader: F. Pina (Deimos Space Comp., ESP)

Activities and Deliverables

Research, Dissemination & Education

- Synoptic tables for space events
  - [v 1.0 – February 2012]
- Participation in NATO Space IPT
- Topical meetings for dissemination
  - [NOAA/SWPC Space Weather Workshop, USA, April 2012; EGU, Vienna, April 2012; ESWW, Bruxelles, November 2012]
- Participation in MNE 7
  - [September 2012, tbc]
- Series of lectures for education
  - [Nato School & other courses, tbd]

Deliverables

- Prototype Expert System as didactic tool
  - [v 0.1 – Fall 2012]
- Near-Real-Time Monitoring System for SWx Key Components
  - [Fall 2012, work in progress]
- Completion of prototype expert system
  - [Spring 2013]
- Testing of selected SWx tools by NATO operators.
  - [Summer 2013]
- Final Report
  - [Spring 2014]

Space Environment EffeCts Advisor

SENECA:
A PROTOTYPE EXPERT SYSTEM FEASIBILITY STUDY AND IMPLEMENTATION

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 and space-related systems</u>

Expected Space Operator-SENECA Dialogue

SOP *GPS rx does not provide position since minutes*

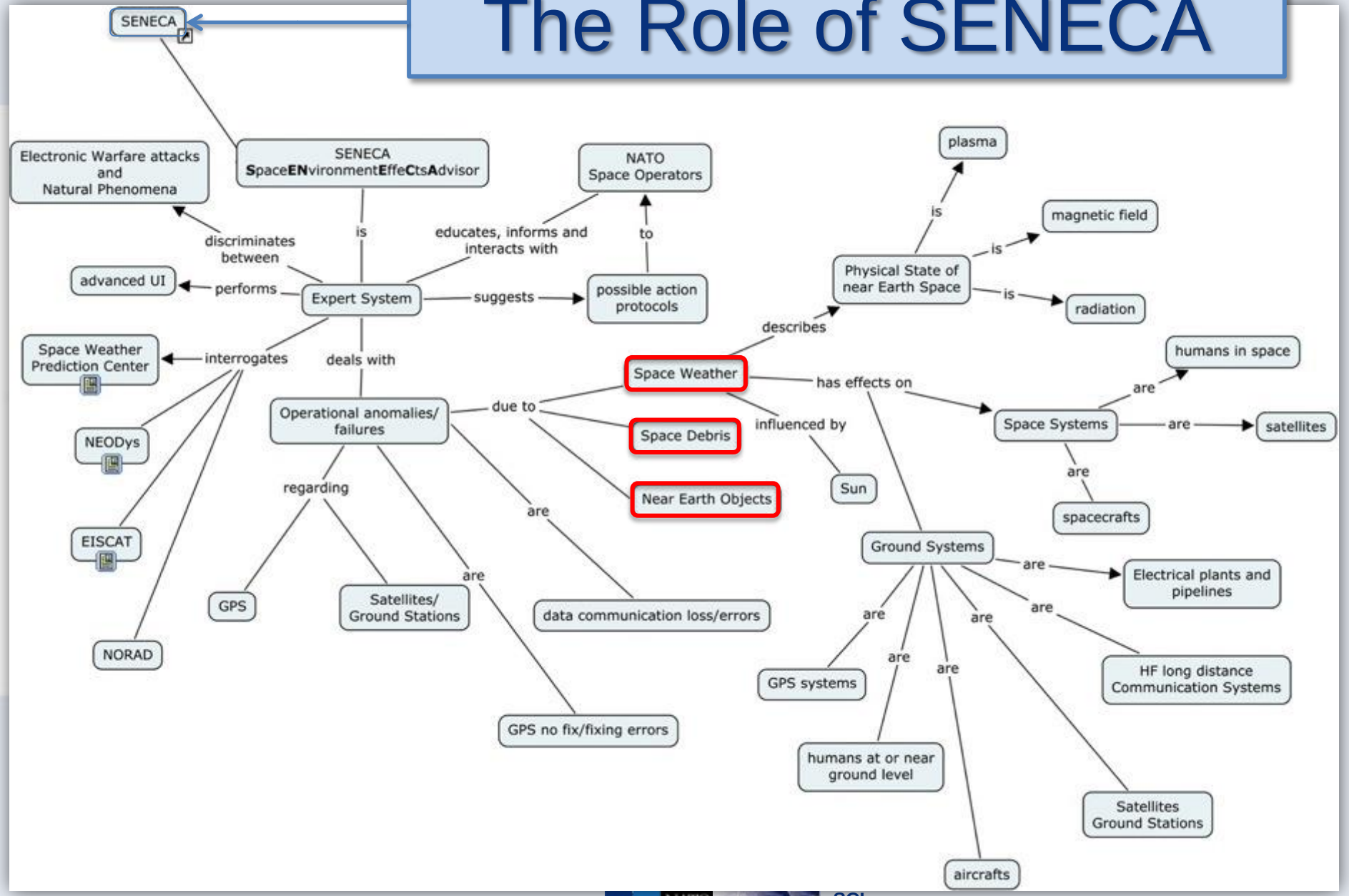
SEN Possible causes and relevant probability:

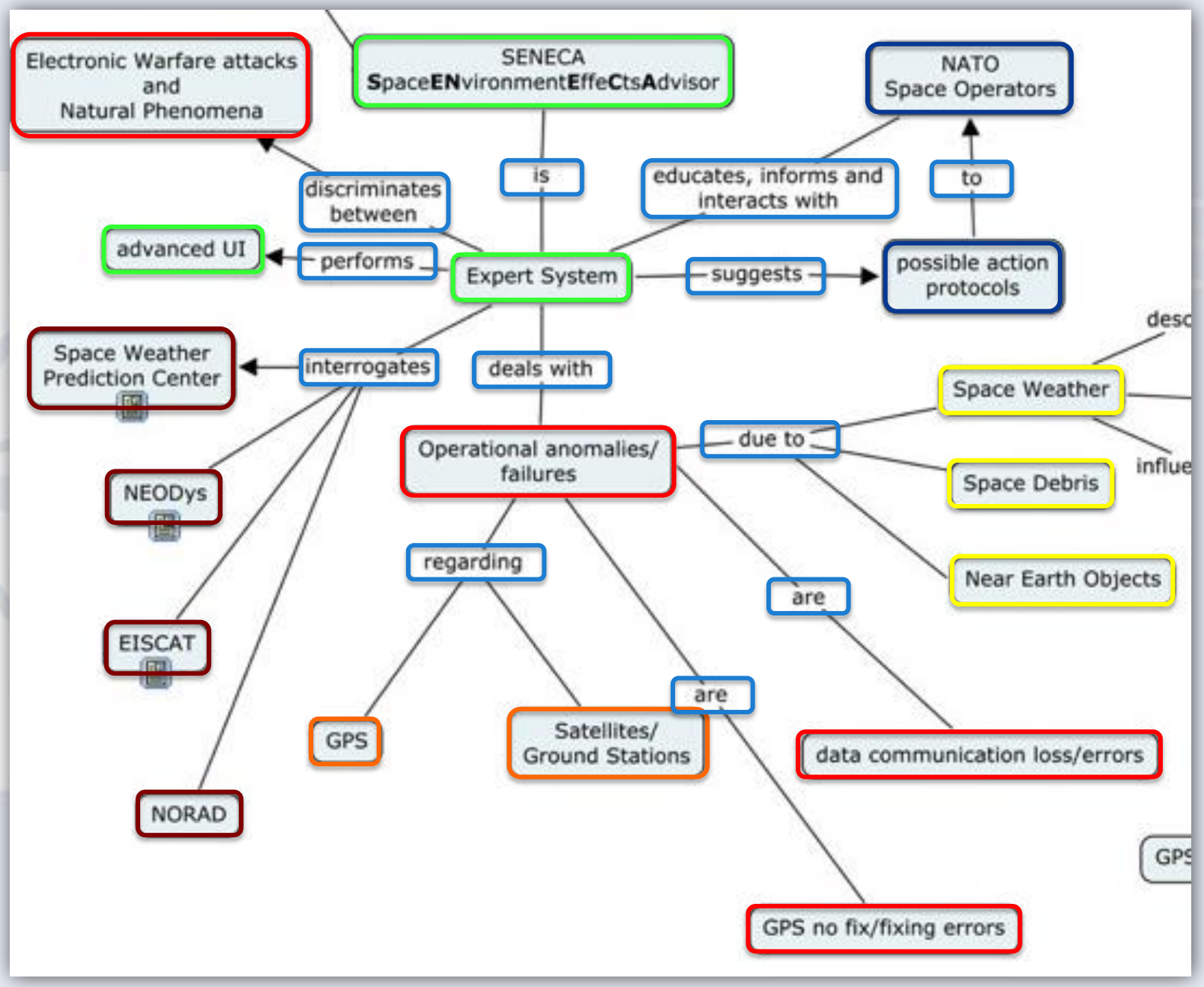
1. **Ionospheric perturbation 99.5%**
2. **Solar Radio Interference 0.0%**
3. **Electronic Warfare 0.5%**

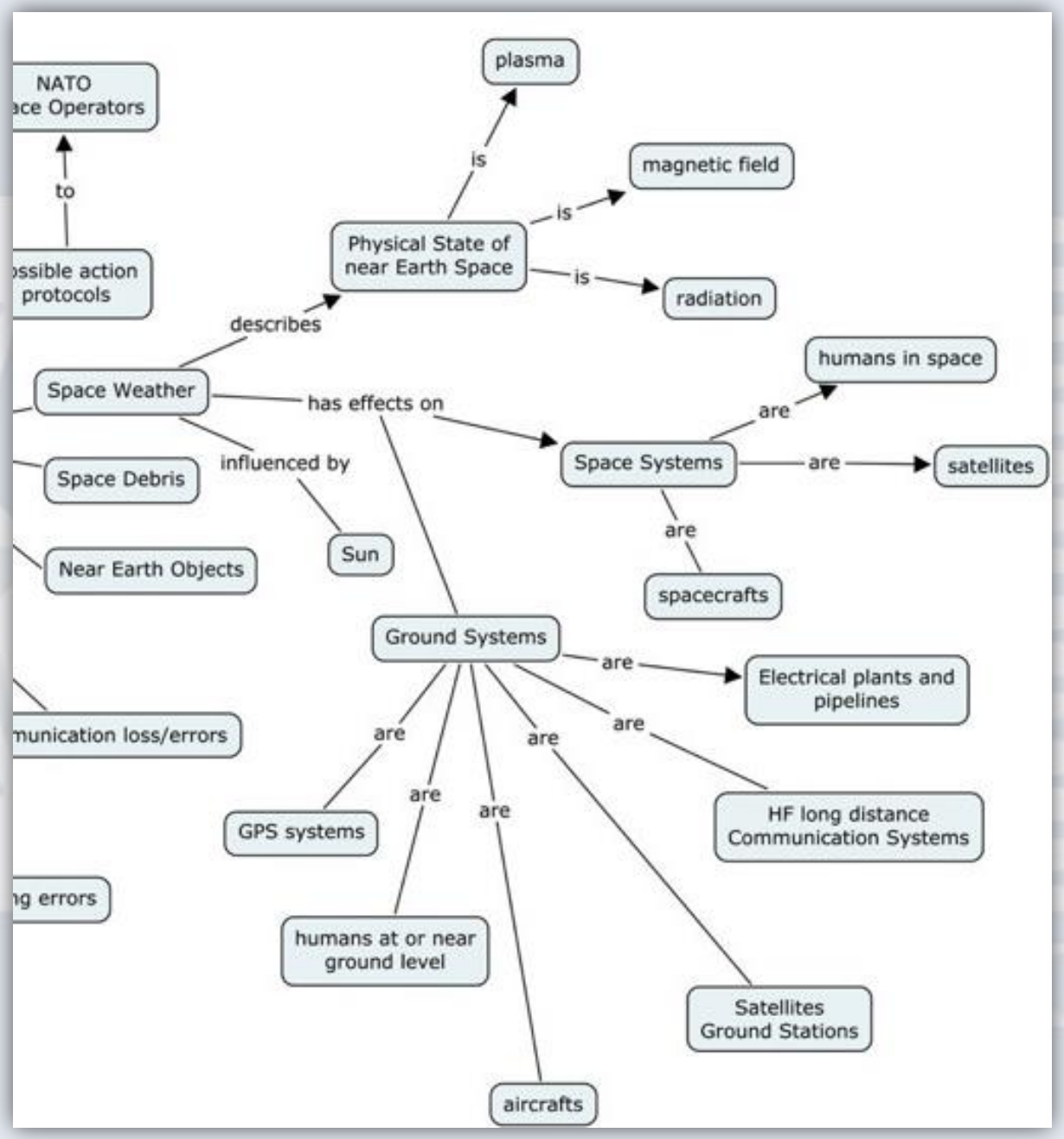
SOP *Explain*

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.

The Role of SENECA




Electronic Warfare attacks and Natural Phenomena
SENECA SpaceENvironmentEffeCtsAdvisor
NATO Space Operators
discriminates between
is
educates, informs and interacts with
to
advanced UI
performs
Expert System
suggests
possible action protocols
Space Weather Prediction Center
interrogates
deals with
Space Weather
Operational anomalies/ failures
due to
Space Debris
NEODys
regarding
Near Earth Objects
are
EISCAT
are
GPS
Satellites/ Ground Stations
data communication loss/errors
NORAD
GPS no fix/fixing errors


plasma
NATO
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Physical State of
near Earth Space
ssible action
protocols
is
radiation
describes
humans in space
Space Weather
has effects on
are
influenced by
Space Systems
are
satellites
Space Debris
are
Sun
Near Earth Objects
spacecrafts
Ground Systems
are
Electrical plants and
pipelines
munication loss/errors
are
are
are
are
HF long distance
Communication Systems
GPS systems
are
are
ng errors
humans at or near
ground level
Satellites
Ground Stations
aircrafts

Project Pros-Cons

PROS	CONS
Software tool to support space planners in taking decisions and in raising awareness, based on: • Organised knowledge base • Extensive help for augmenting knowledge • Natural Language Parser (NLP) [Follow-up project!]	The full implementation of an operational system compliant with the military requirements involves: • Non-trivial development • Critical validation and security • Development time beyond the duration of the RTG

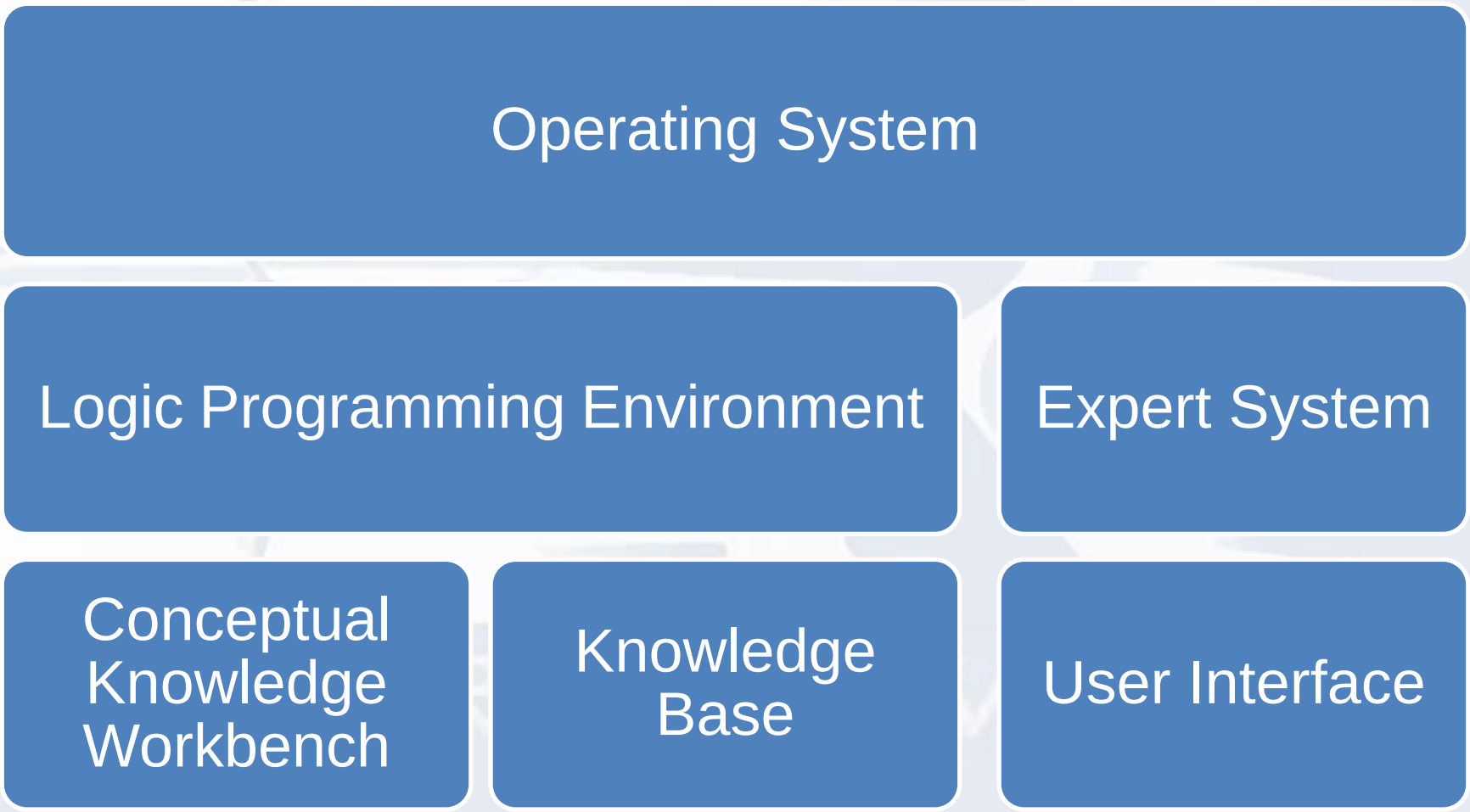
Benefits of the Development

- Innovative approach
- Prototype feasibility
- Seed for a follow-up applied activity
- Great opportunity to organise knowledge

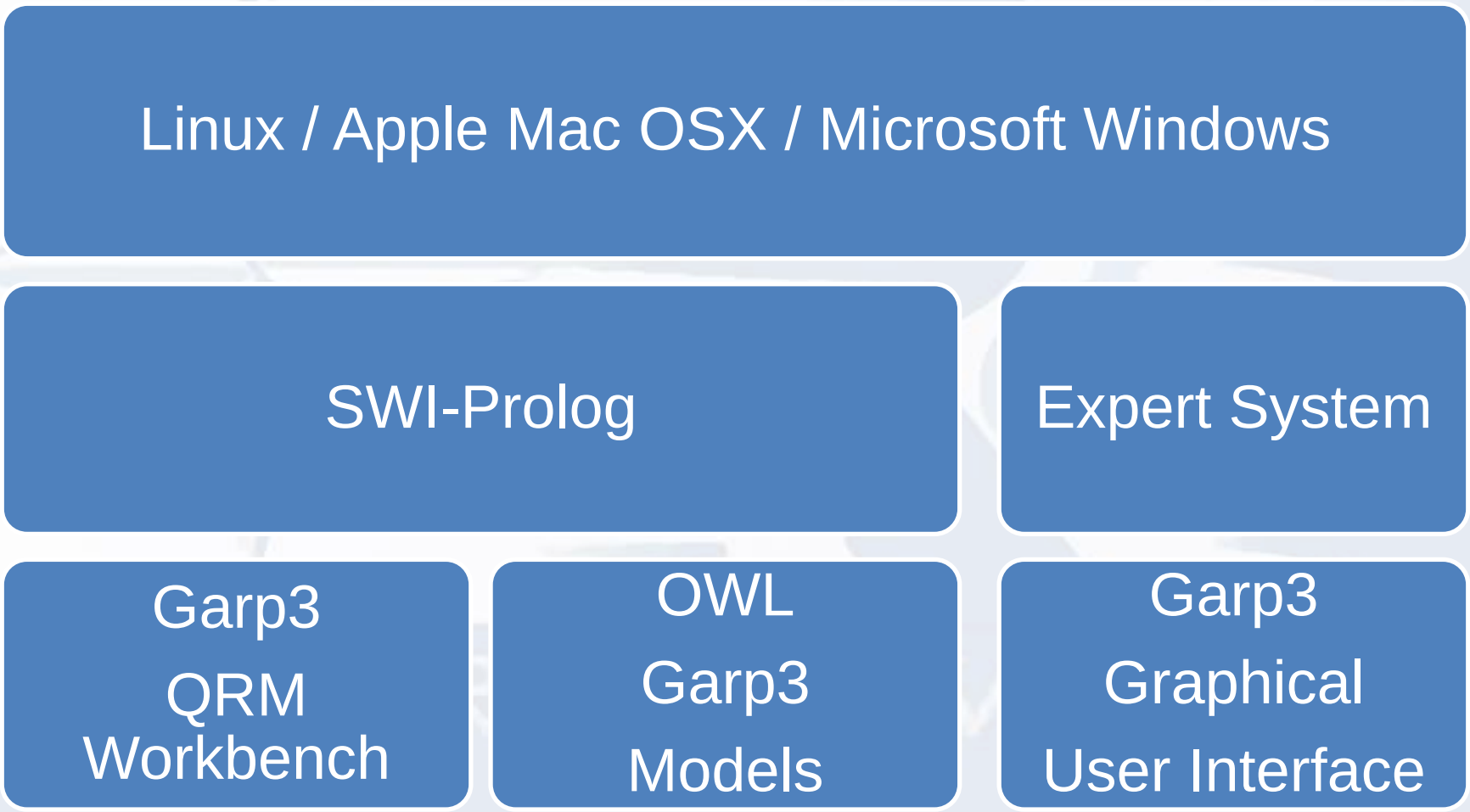
SENECA

ARCHITECTURAL PRINCIPLES

Software Architecture



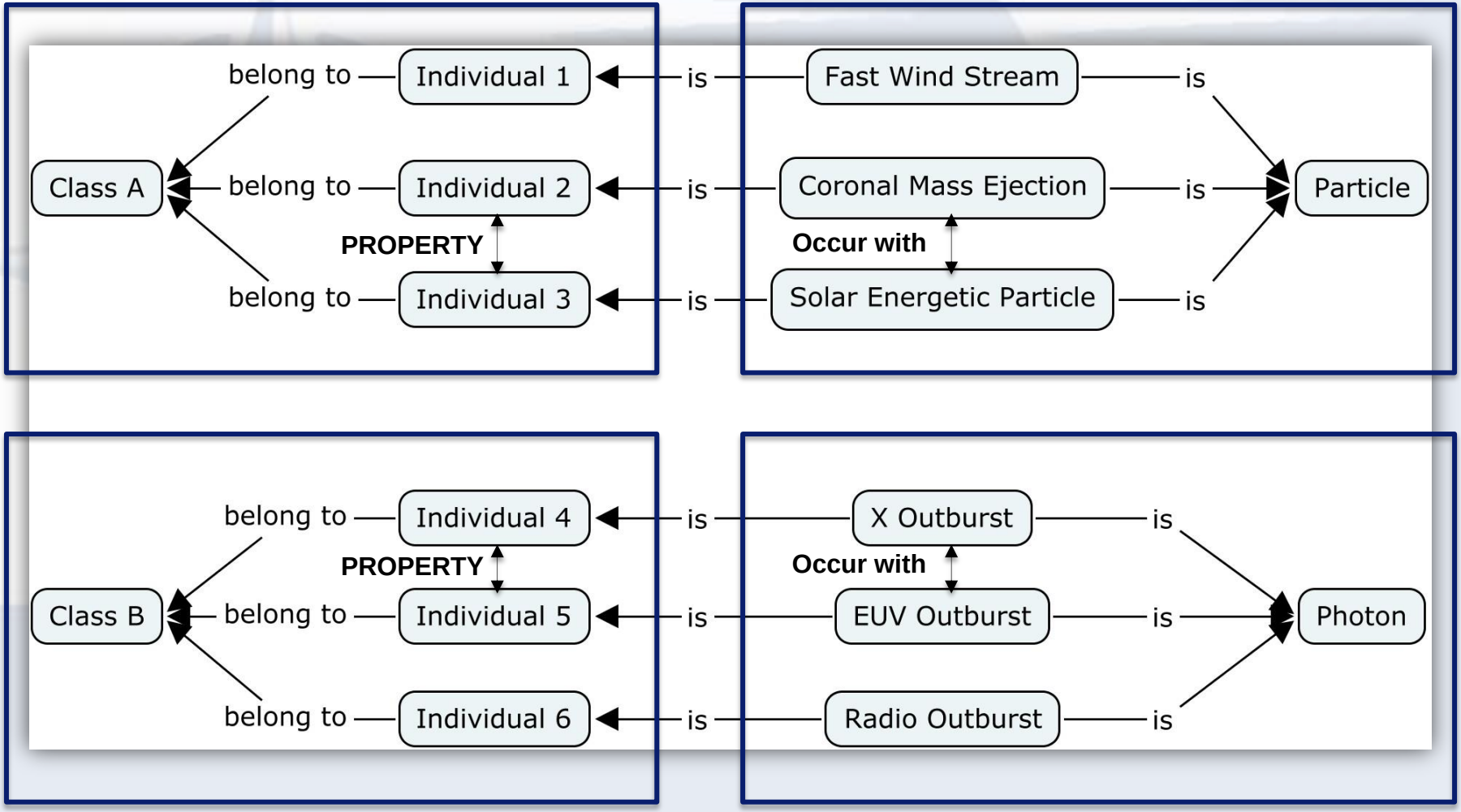
Software Components



Knowledge Base for Models and Scenarios

- Built as Concept Maps via Graphical Tools like IHMC CmapTools by IHMC
- Exported as OWL documents
- Imported into Garp3

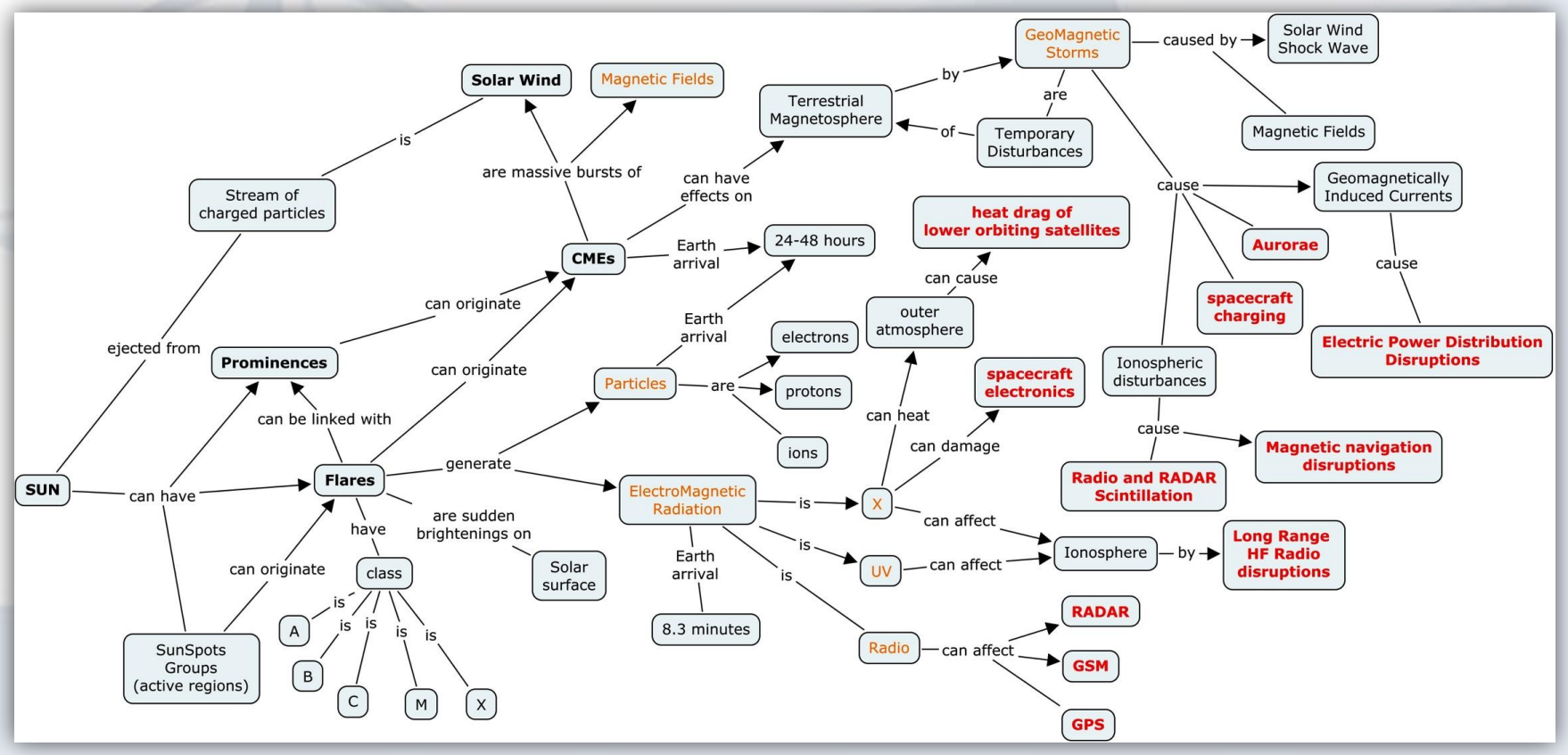
Definition of Ontological Entities



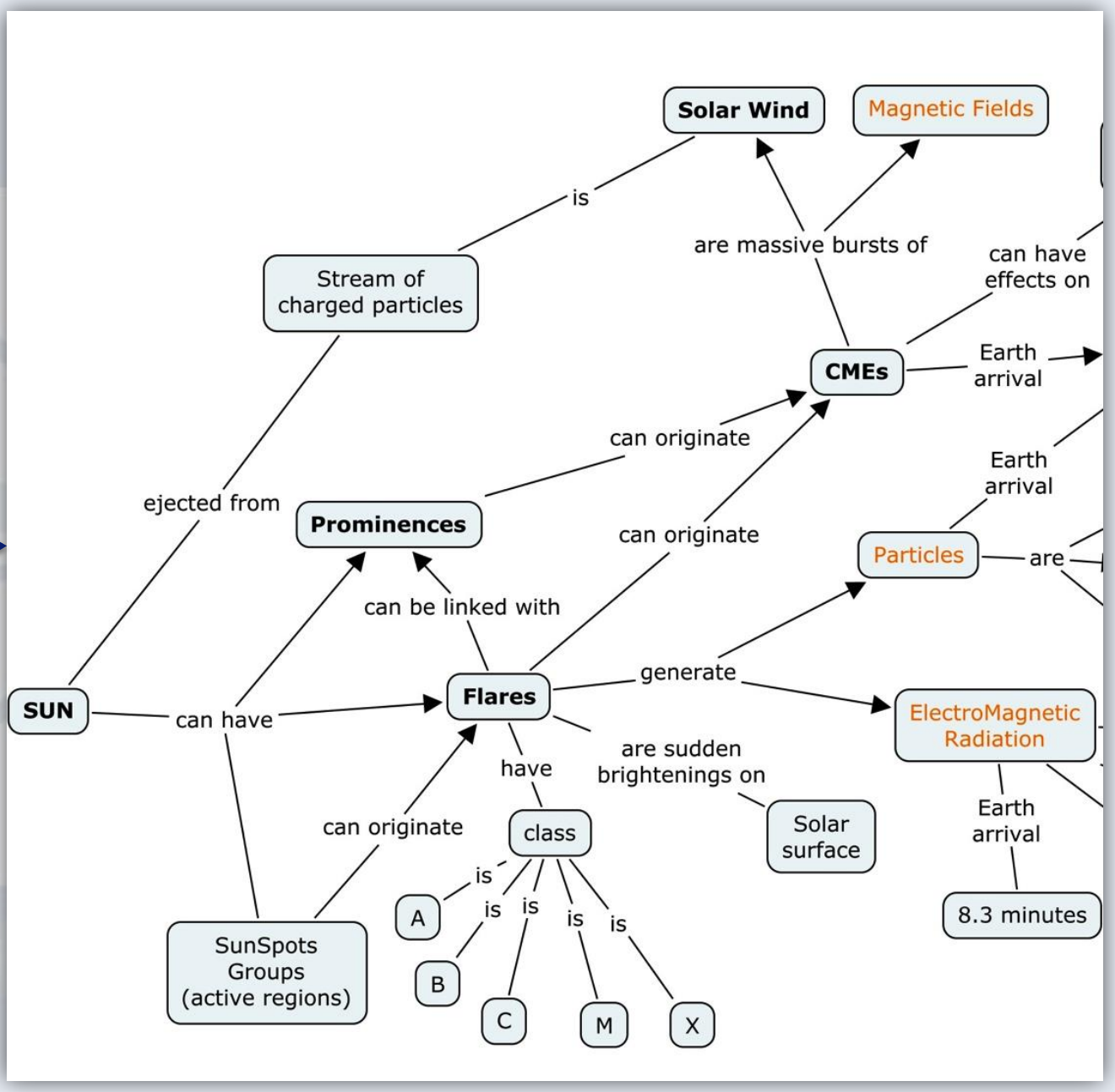
SENECA

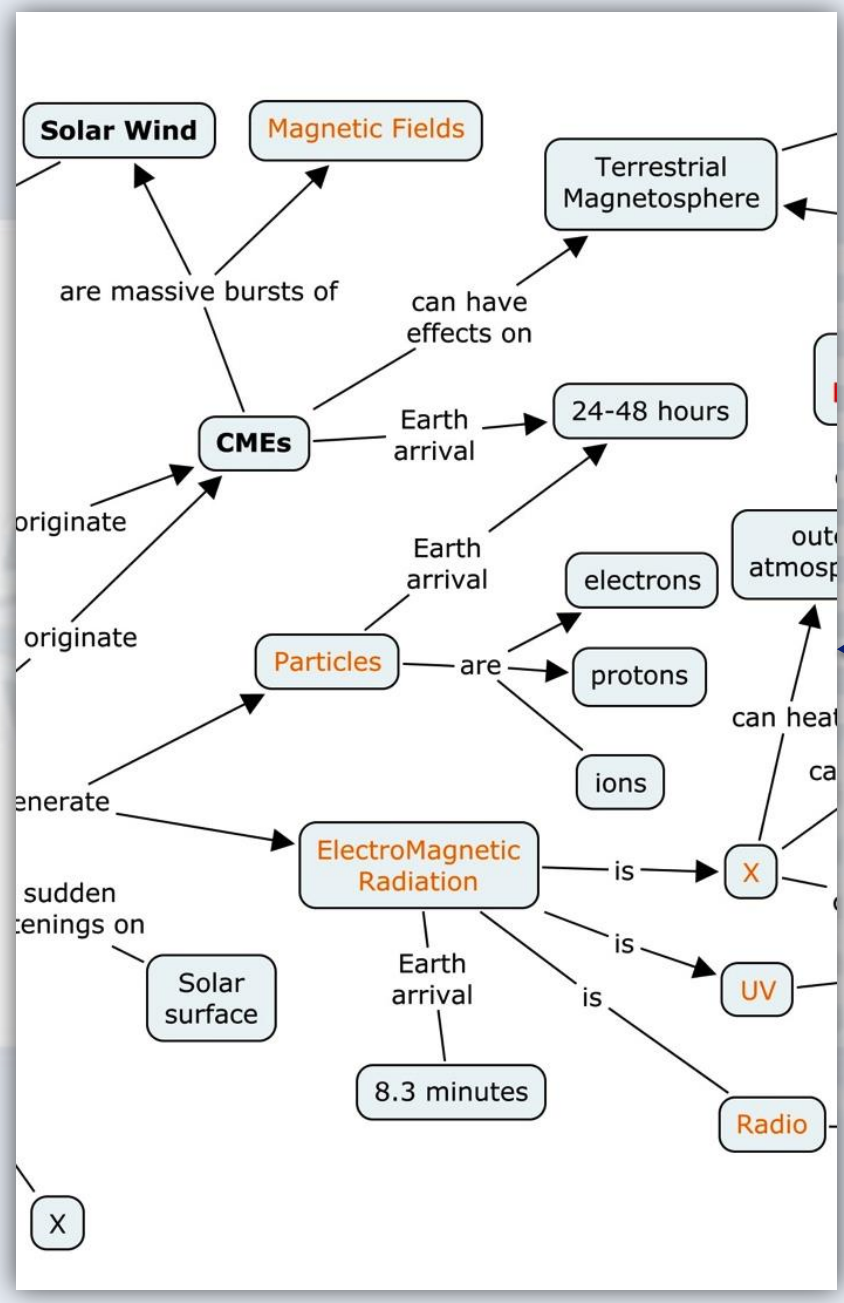
SAMPLE CONCEPT MAPS

Concept Map of Solar Weather Effects



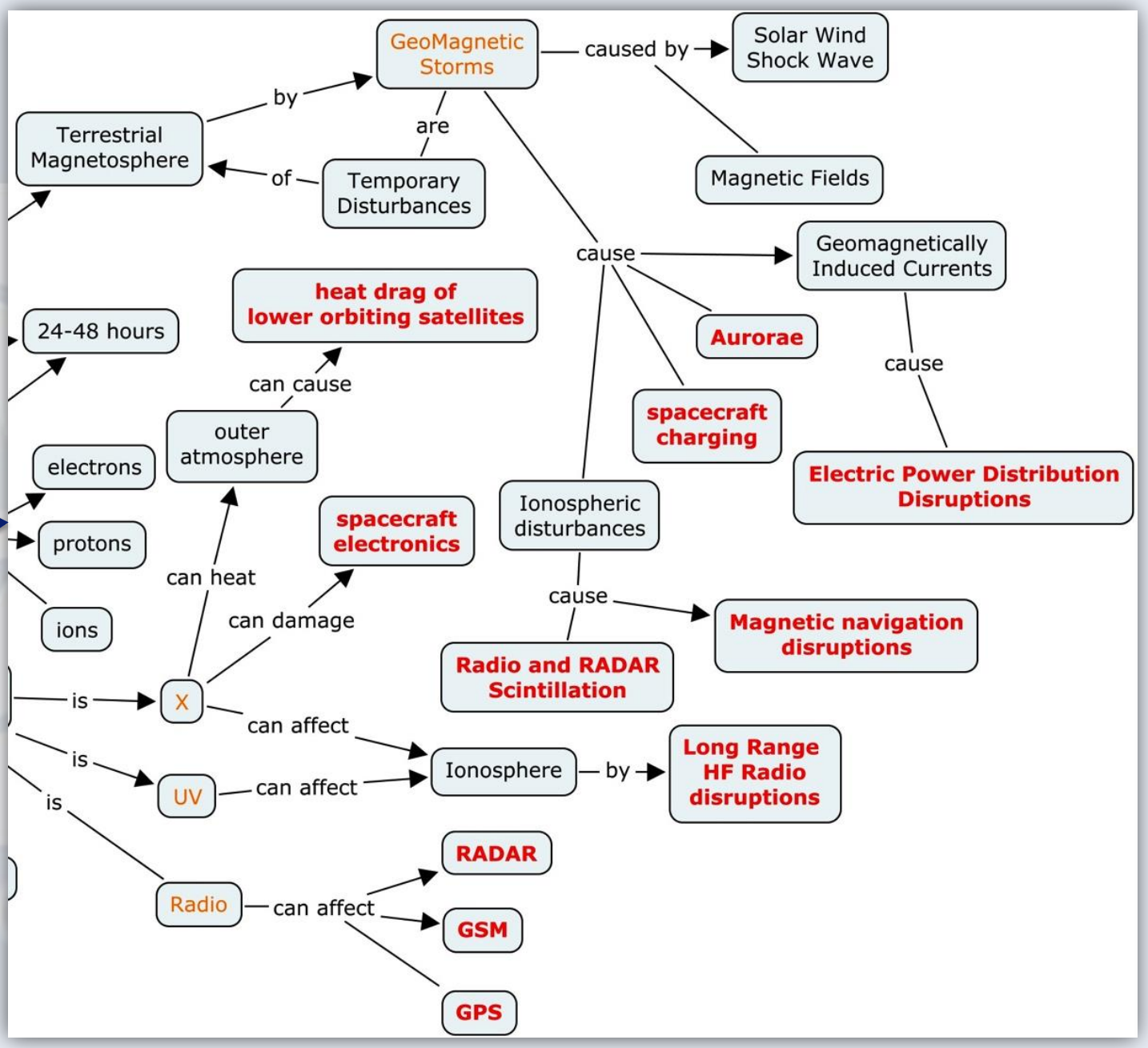
Solar Weather



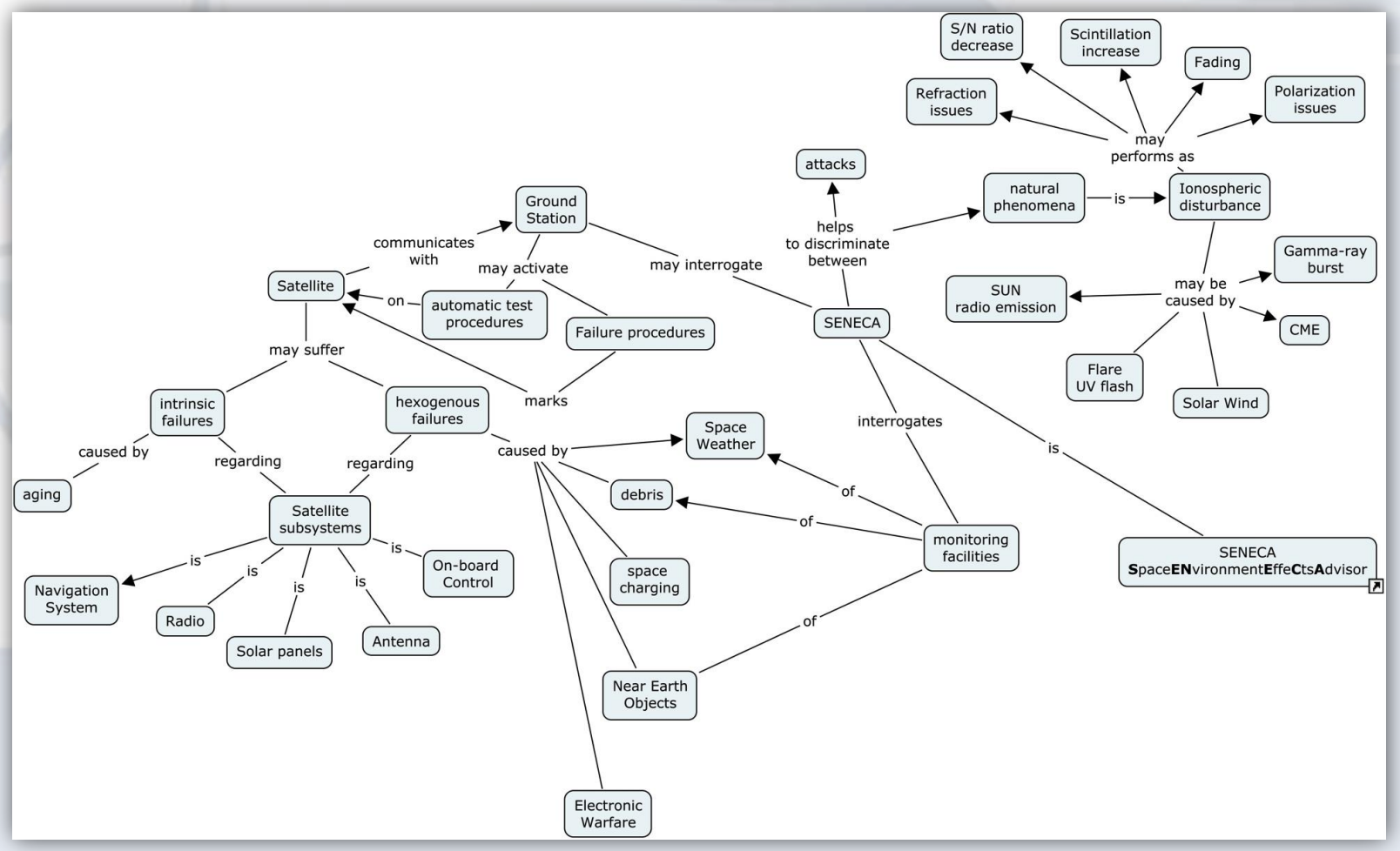


Sun-Originated Space Weather Phenomena

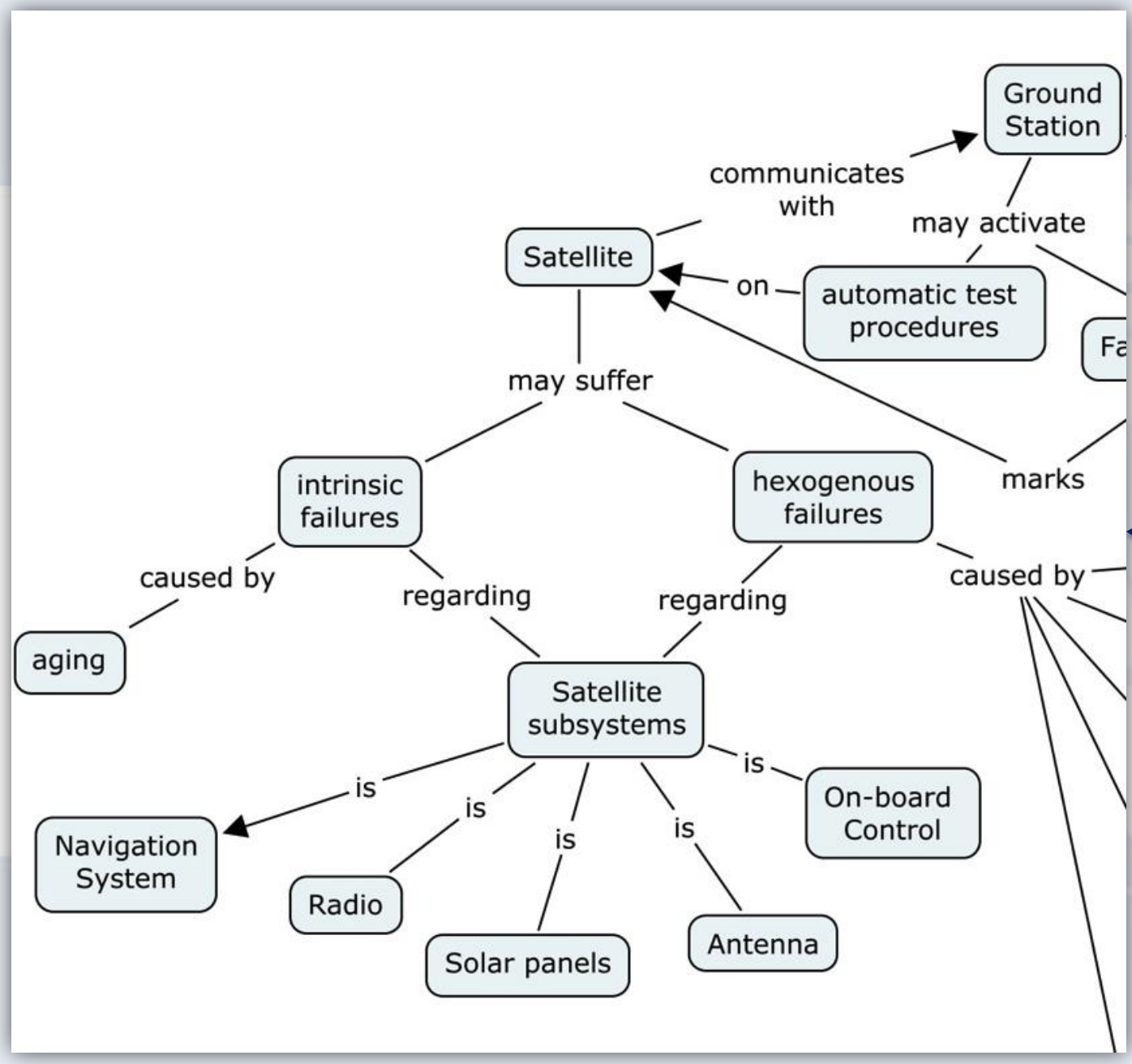
Impacts Onto Geospace

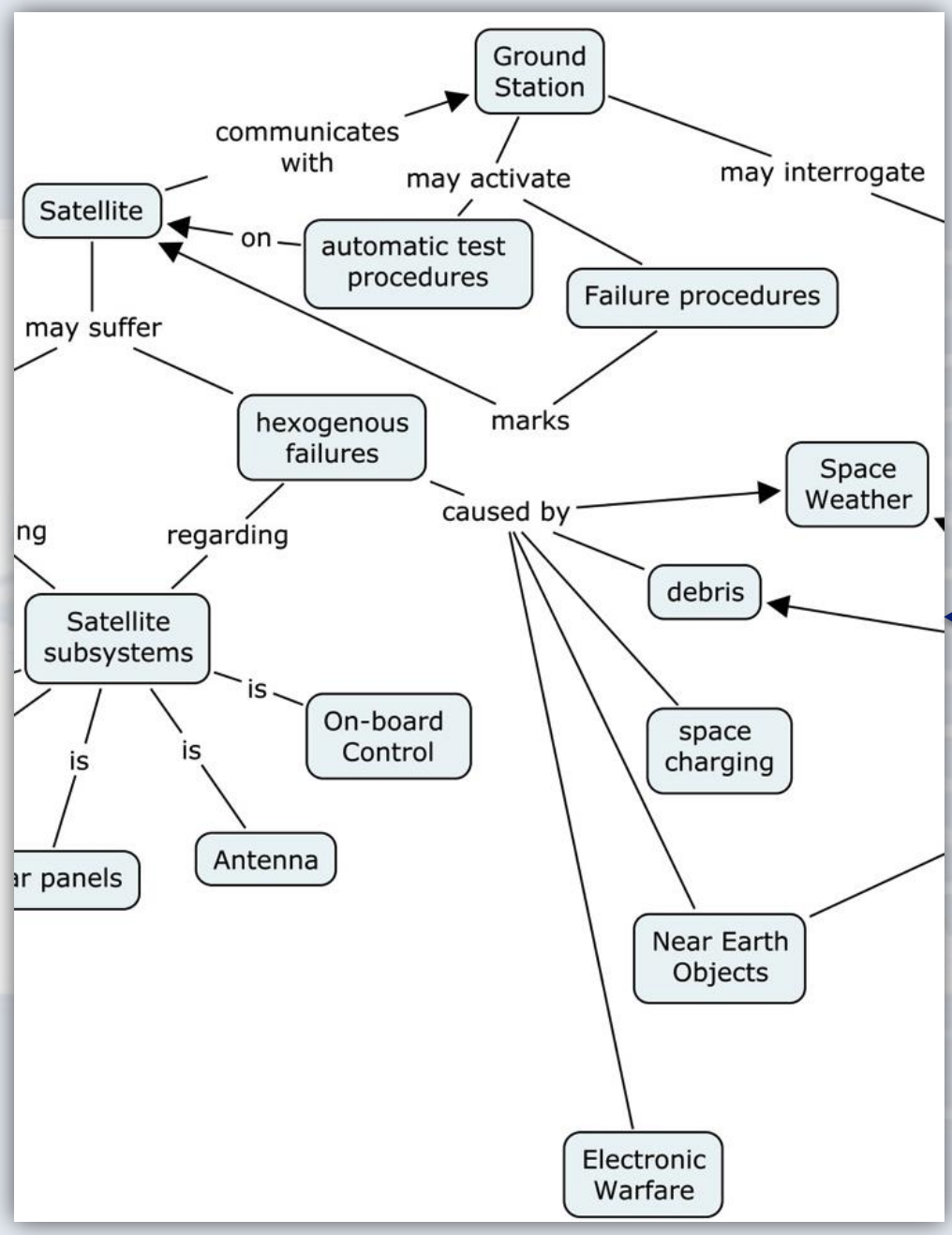


Concept Map of SENECA Response for Possible Satellite Failures



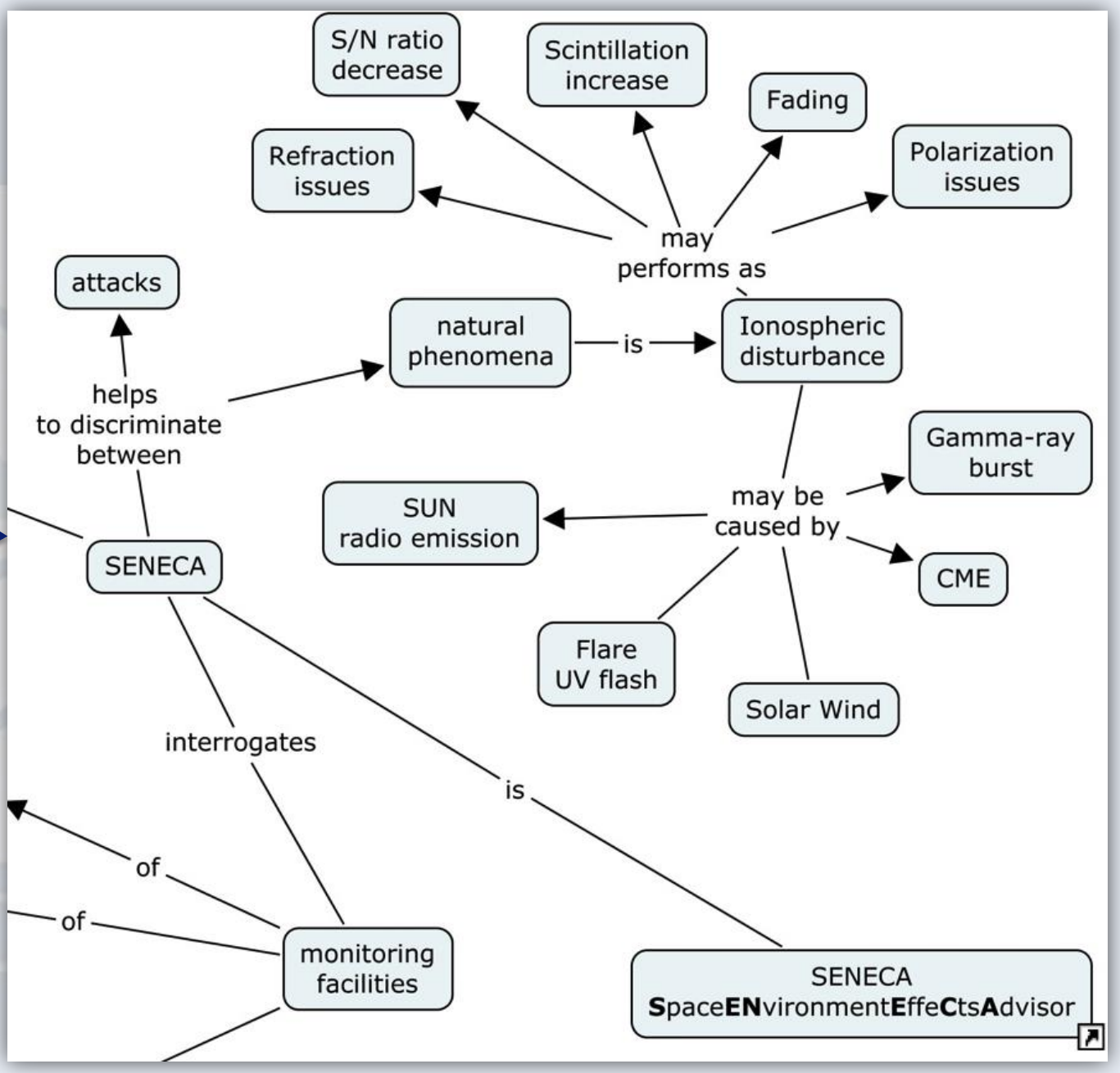
Satellite Failures





Possible Causes of Satellite Failures

SENECA Helps to Discriminate Between Natural Phenomena and Attacks



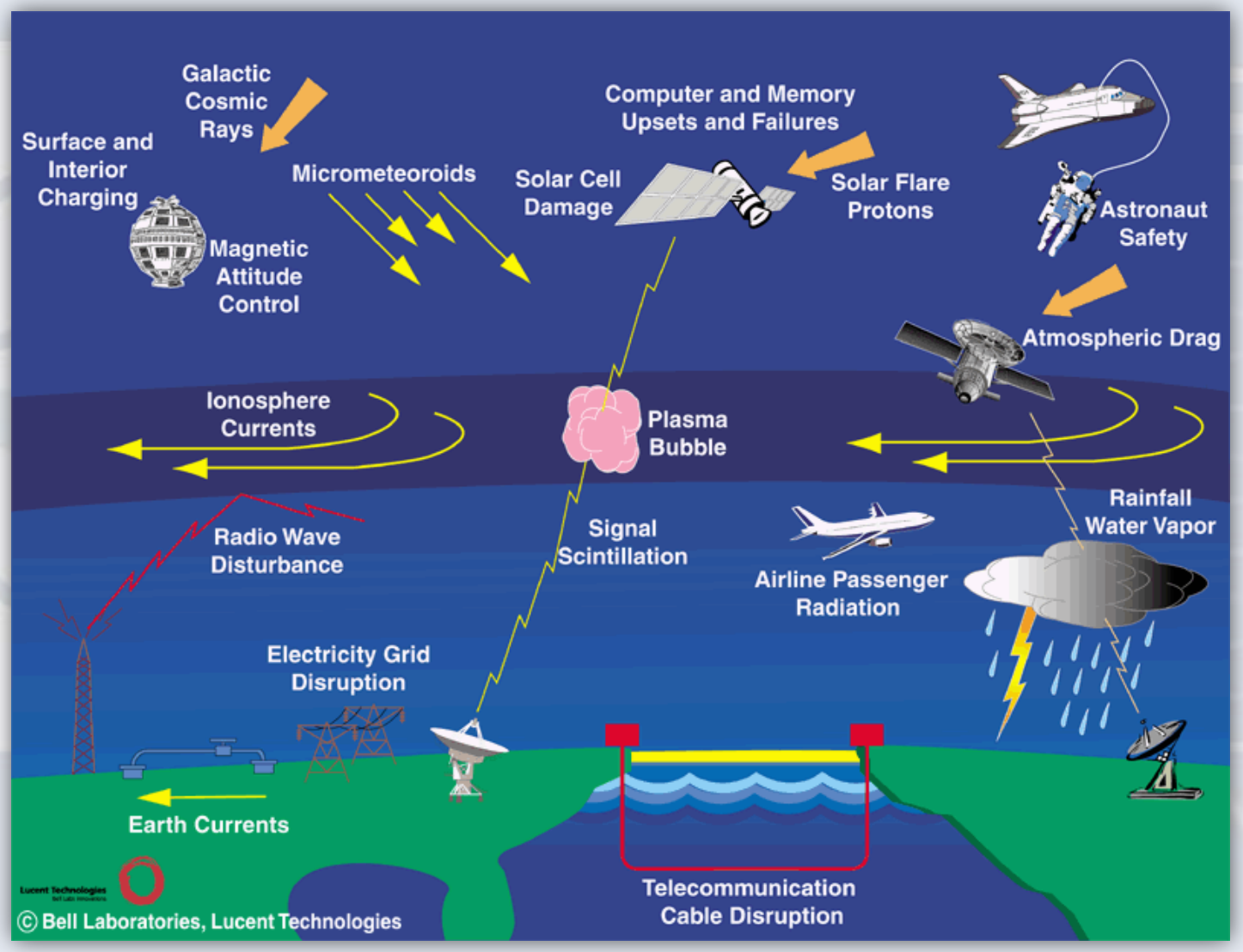
Synoptic Tables of Space Events Impacting on Space and Space-Related Systems

- Are needed as an organised knowledge base, because the available information is typically:
  - Fragmentary
  - Incomplete
  - Inhomogeneous
  - Distributed over a variety of sources
  - Biased according to the context (e.g. academic textbook, operational manual, etc.)

SENECA

SYNOPTIC TABLES OF SPACE EVENTS

Space Weather Event Synopsis



NATO RTO SCI-229 RTG Focus Group 1
Prototype SWx Event Synopsis
v 1.0

EVENT TYPE	SOLAR SOURCE	SIGNATURES	TIME TO REACH THE EARTH	CONSEQUENCES	SECTORS AFFECTED	PREDICTION TOOL/MODEL (examples)	FORECASTING TOOL/MODEL (examples)	WHAT SCIENCE CAN OFFER TO NATO
EM RADIATION	FLARES	BURST IN X-RAYS AND UV	8 min		TELECOMMUNICATION (problems in radio and HF)	NONE	http://spaceweather.inf.brad.ac.uk/	CONFIRM THAT THE FAILURE IS DUE TO NATURAL EVENTS
ENERGETIC PARTICLES	FLARES AND CMES	LARGE PEAK FLUX AND/OR LARGE FLUENCE	30 min- 24 hours		SPACECRAFT in night sector	www.spaceweather.eu/es/solpenco		
ENERGETIC PARTICLES	CORONAL HOLES	NOT A HIGH PEAK FLUX, BUT A LARGE FLUENCE	~3 days		SPACECRAFT in night sector			
GEOMAGNETIC DISTURBANCES	CMES, CORONAL HOLES	SEVERITY RELATED TO LARGE SOUTHERN IMF	1-4 days	CURRENTS INDUCED IN LARGE CONDUCTORS	ELECTRIC (power plants), TRANSPORTS (railways), LARGE CONDUCTIONS (pipelines,,,) Ground infrastructures Telegraph problems??	http://rwc.lund.irf.se/rwc/dst/models/dstdoc/index.html http://sd-www.jhuapl.edu/UPOS/kp_dst/kp_dst.html	http://spaceweather.uah.es	FORECASTING AND PREDICTIONS
GEOMAGNETIC DISTURBANCES	CMES	SEVERITY RELATED TO LARGE DINAMIC PRESSURE	2-3 days	COMPRESSION OF MAGNETOSPHERE	SPACECRAFT in day sector			

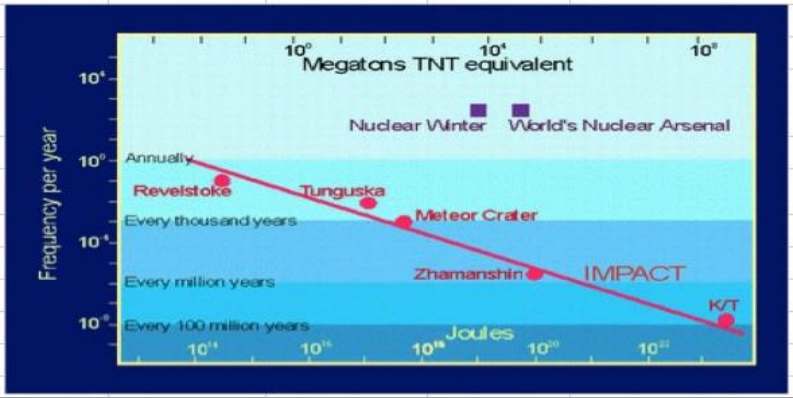
NEO Event Synopsis

NATO RTO SCI-229 RTG Focus Group 2

Prototype NEO Event Synopsis

v 1.0

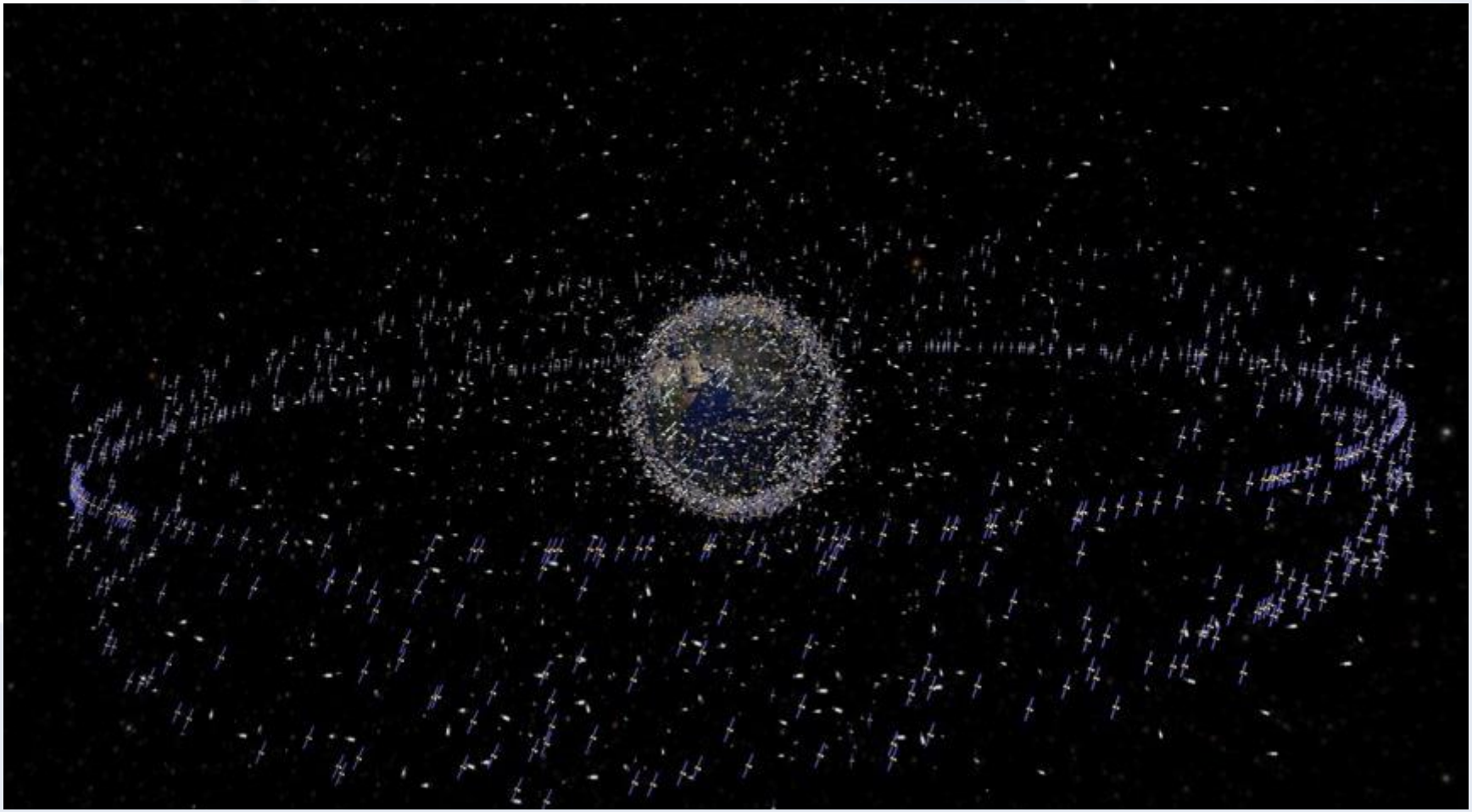
Event Type	Diameter of impactor	Consequences	Energy liberated	Rough impact interval (yr)	Examples	notes
Impact	1km and larger	Civilization affected on global scale	>100000 MT	5.00E+05	Nördlinger Ries; Chicxulub	Nördlinger Ries is an impact crater in S. Germany with a diameter of 24 km and an age of about 15 million yr. Chicxulub is a 170 km crater whose formation is thought to be responsible of the Cretaceous/Tertiary mass extinction event (K/T boundary, see plot below)
Impact	100 m and larger	Local; tsunami if on ocean, potentially millions of deaths if on large city	>100 MT	10000	Iso Naakkima, Zhamanshin	The Zhamanshin crater (14 km) can be considered as a limiting case between local and global consequences
Impact	30 m and larger	Local; potentially serious loss of life in urban area	>1 MT	100	Tunguska, Meteor Crater	The outcome depends on the impactor composition and dynamics. The Tunguska event was a large airburst producing no crater; the Meteor Crater was formed by a metallic impactor
Airburst	1 m and larger	Flash	> 1 kT	0.1	Revelstoke, 2008TC3, Carancas, Kamil	The outcome depends on the impactor composition and dynamics. The Revelstoke fireball led to the recovery of meteorite fragments; 2008TC3 was the first meteorite fall observed prior to atmospheric entry; Carancas was a slow high altitude event producing a 12m crater; the Kamil crater (40m) was originated by a 1m iron impactor.
Meteor	1 cm and smaller	Meteors, possible consequences on spacecraft	negligible	Continuous flux, enhanced when Earth passes through cometary debris	Perseids, Leonids, Geminids	Sporadic meteors and meteor showers of cometary or asteroidal origin (e.g. comet 109P/Swift-Tuttle, comet 55P/Temple-Tuttle, asteroid 3200 Phaeton, respectively)



The plot relates the energy released by an Earth impactor to the frequency of occurrence. According to it, an impact event with energy greater than the world's nuclear arsenal occurs on a time-scale of less than a million years. Source http://www.passc.net/EarthImpactDatabase/IntrotoImpacts.html

NOTE: The rough impact intervals in the table are estimates of the mean intervals between impacts of objects in the given size categories; they are uncertain by at least a factor 2.

Space Debris Event Synopsis



NATO RTO SCI-229 RTG Focus Group 3
Prototype Space Debris Event Synopsis
v 1.0

Event Type	Object involved (target in case of collisions)	Object involved (projectile in case of collisions)	Event Nature	Consequences	Trigger	Epoch of event	Orbital zone	Orbital elements of target (a,e,i,node) [km and deg]	Orbital elements of projectile (a,e,i,node) [km and deg]	Affected altitude range [km]	Number of tracked objects	Estimated number of non-trackable objects [larger than 1 cm]	References
Explosion	SL 1 R/B		Fragmentation	Lethal	Residual propellant		LEO						
Explosion	BrizM		Catastrophic fragmentation	Lethal	Propulsion related	02/28/06	LEO						
Explosion	COSMOS XX		Localized damage	Lethal	Battery discharge	NN/NN/NN	LEO						
Collision	Cerise	Ariane R/B debris	Localized damage	Non-lethal		07/24/96	LEO				2		
Collision	Iridum 33	Cosmos 2251	Catastrophic fragmentation	Lethal		02/10/09	LEO	7175, 2.2e-4, 86, 122	7170,1.6e-3,74,19	600-1000	~ 2500	10000 – 100000	Rossi, Valsecchi and Farinella, *Nature*, 1999
Collision (ASAT test)	Feng Yun 1C	Ground launched warhead	Catastrophic fragmentation	Lethal		01/11/07	LEO				~ 3700	10000	
Low energy release			RORSAT drops				LEO			600-1000	1000		
Low energy release			Mission related objects release				LEO-MEO-GEO			0- 2000 2000 30000 30000 - 40000	~ 3		
Low energy release			Delamination				GEO			10000-37500	2		
Solid rocket motor exhaust	XXXX R/B		Slag+dust release		Solid rocket motor burn	NN/NN/NN	GTO			700-36000	15	100	

Activity Status

WORK IN PROGRESS ➡ NATO SCI-229 WANTS YOU !

CONCLUSIONS

- The NATO RTO SCI-229 RTG has been carrying out an extensive study on space environment support to NATO SSA.
- This study is:
  - Relevant both to military and civil applications.
  - Synergetic to all other SSA initiatives.
  - Open to collaboration by interested organisations and individuals.
- The prototype expert system “SENECA” will be an effective educational tool, whereas only its full implementation in a follow-up project can lead to a validated operational tool.
- A set of existing tools for SWx application is under consideration to be extensively tested in order to assess the level of compliance with NATO operational requirements.
- NATO SCI-229 is open to collaboration with organisations and individuals with similar goals. Contact: messerotti@oats.inaf.it

THANK YOU
FOR YOUR ATTENTION !