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ICTP-COST-USNSWP-CAWSES-INAF-INFN
International Advanced School
on
Space Weather
2-19 May 2006

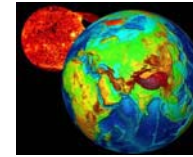
Introduction to Space Meteorology

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These lecture notes are intended only for distribution to participants



COST 296
Mitigation of Ionospheric Effects on
Radio Systems (MIERS)



An Introduction To Space Meteorology

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SCHEME OF THE TALK

- COST Action 724 and WG 1
- The Star-Planet Environment: Stellar Meteorology
- A Foundation Ontology for Space Meteorology
- Representing knowledge via Concept Maps
- The definition of foundation ontology
- Why do we need it?
- Ontology of Space Meteorology
- Ontology of Solar Weather
- Key Issues
- Monitoring, Modeling and Forecasting Space Weather: the Scenario
- The Dream Solar Weather Network...

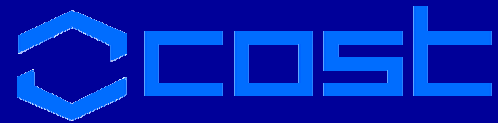


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The COST Action 724

Developing the Scientific Basis for
Monitoring, Modeling and Predicting
Space Weather



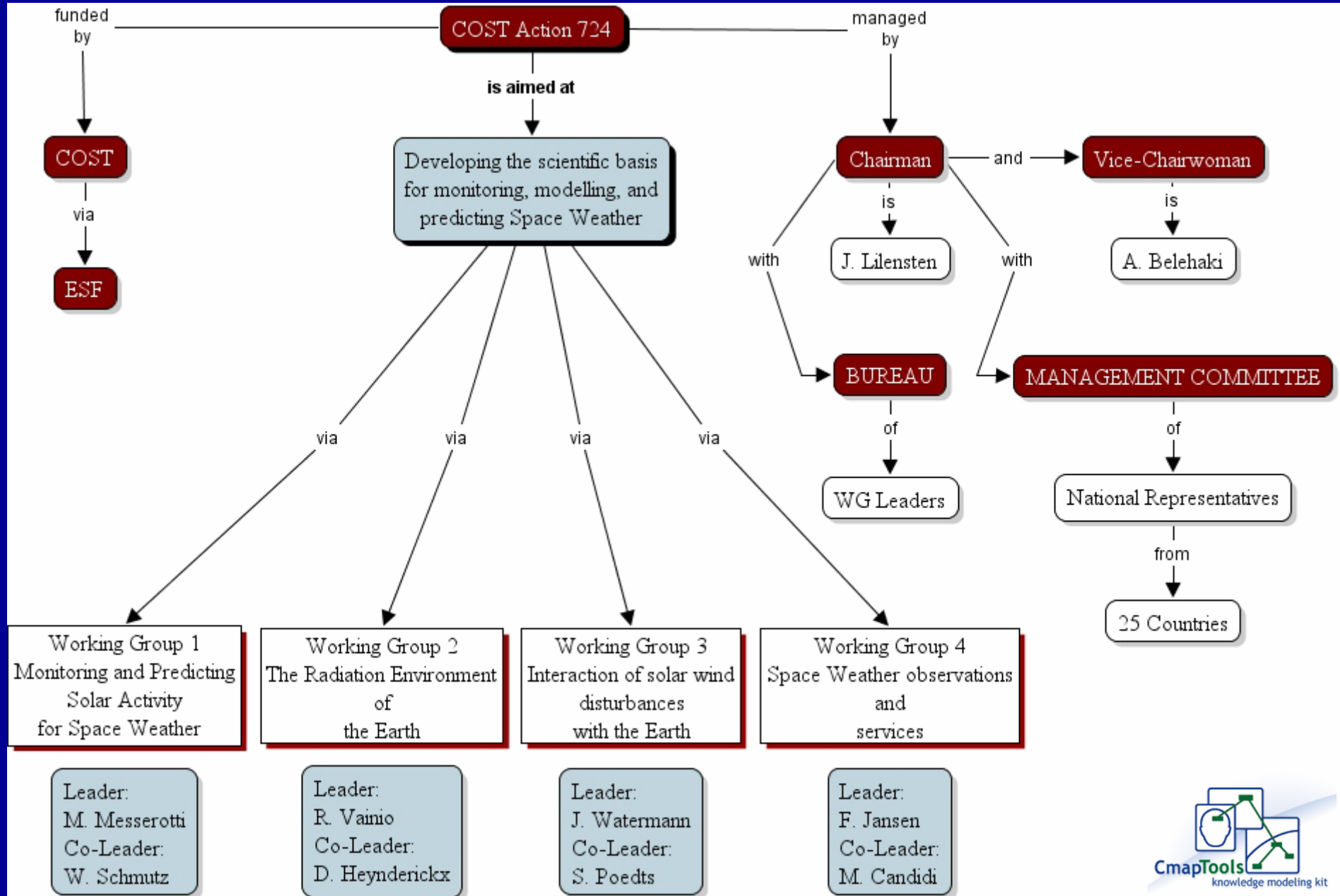
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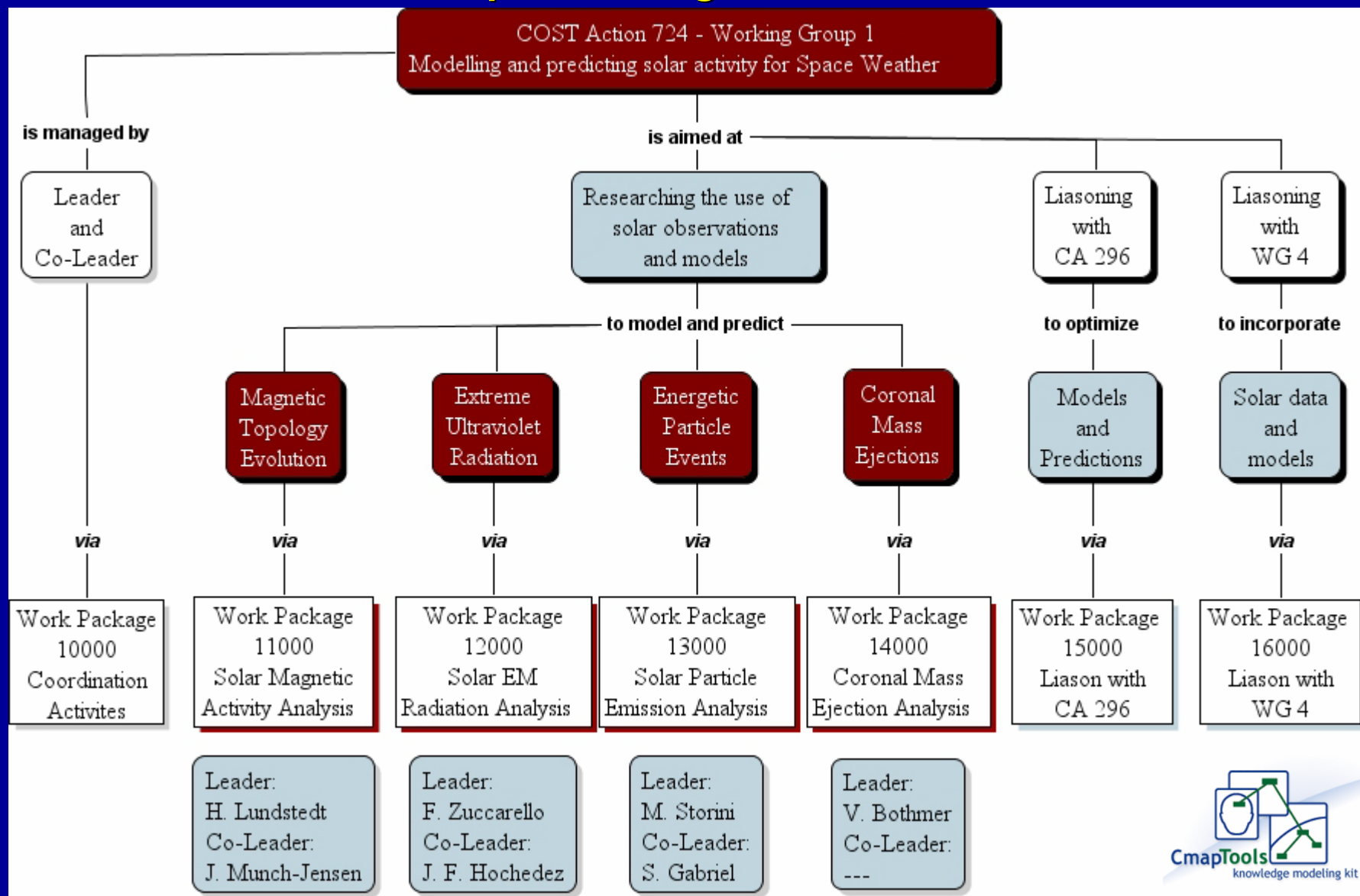
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Structure of COST Action 724 <http://cost724.obs.ujf-grenoble.fr>



Structure of COST Action 724 – Working Group 1

<http://ca724wg1.ts.astro.it/>



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The Star-Planet Environment

A Description
at the Highest Level of Abstraction



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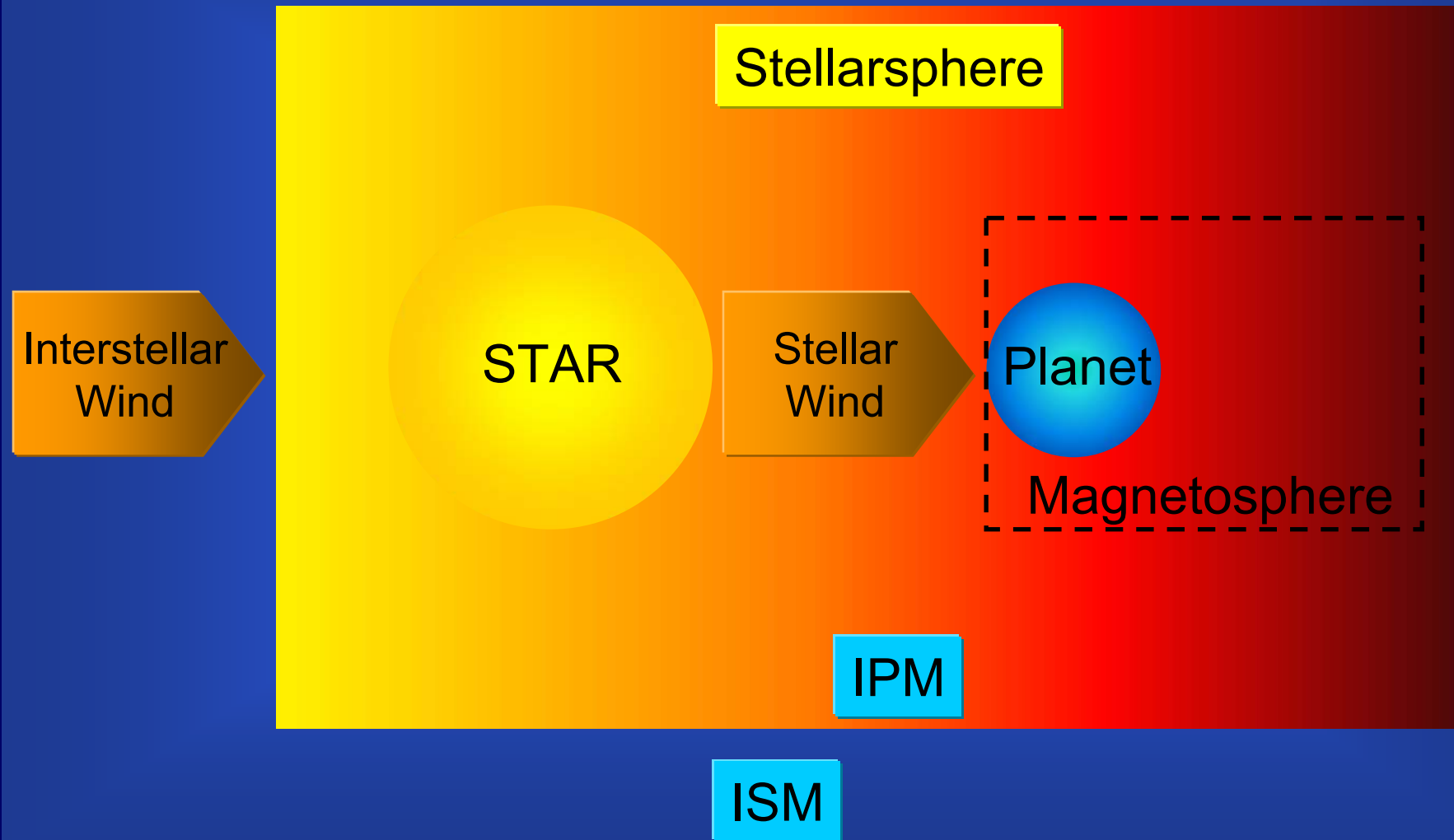
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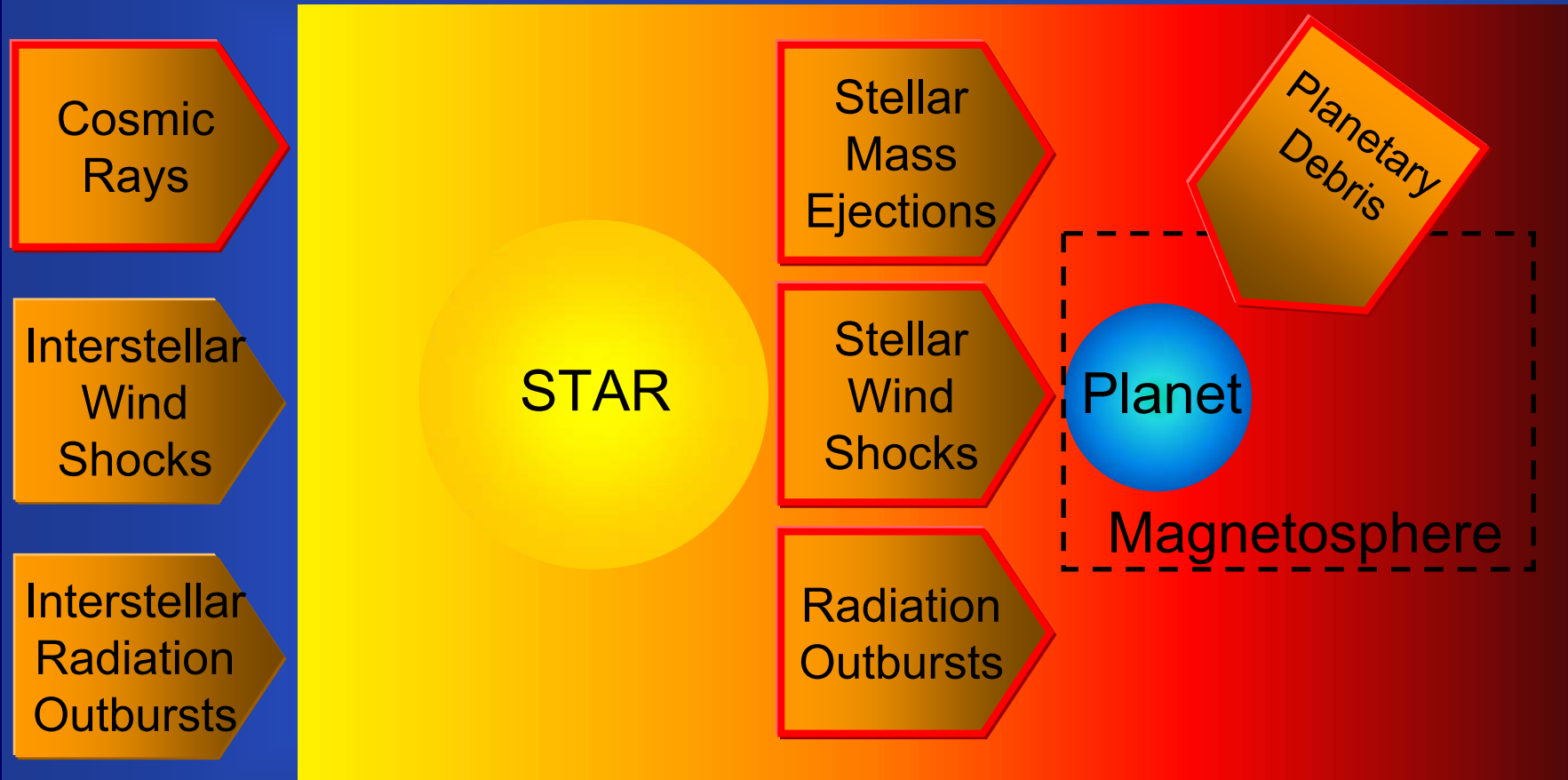
THE STELLAR ENVIRONMENT

- COMPLEX PHYSICAL SYSTEM composed of
- COUPLED PHYSICAL SYSTEMS as
 - Interstellar Wind (diluted magnetized plasma)
 - STAR (magnetized plasma in organized state)
 - Stellar Wind (diluted magnetized plasma)
 - PLANET (gaseous or condensed organized matter)
- at DIFFERENT PHYSICAL CONDITIONS defined by
 - Temperature
 - Density
 - Gravity
 - Magnetic Field
 - Chemical Composition

SCHEME OF A STELLAR ENVIRONMENT



PERTURBATIONS IN THE STELLAR ENVIRONMENT



STELLAR SPACE METEOROLOGY

The **Stellar Space Meteorology** observes

- the physical state of the stellarsphere
- the perturbative phenomenology which affects it

on a

- short time scale → **STELLAR SPACE WEATHER**
- long time scale → **STELLAR SPACE CLIMATE**

and tries to predict the potential perturbations on a

- short time scale → **SSpW NOWCASTING**
- long time scale → **SSpW FORECASTING**

STELLAR SPACE METEOROLOGY DRIVERS

- STAR

- L, M, R, Te, cc
- Magnetism
- Variability
- Wind

- PLANETARY SYSTEM

- Orbital dynamics
- Population diversity

PLANETARY RESPONSE DRIVERS

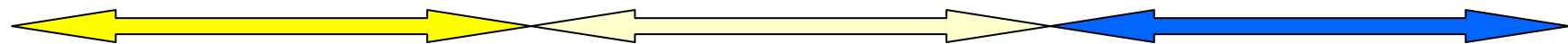
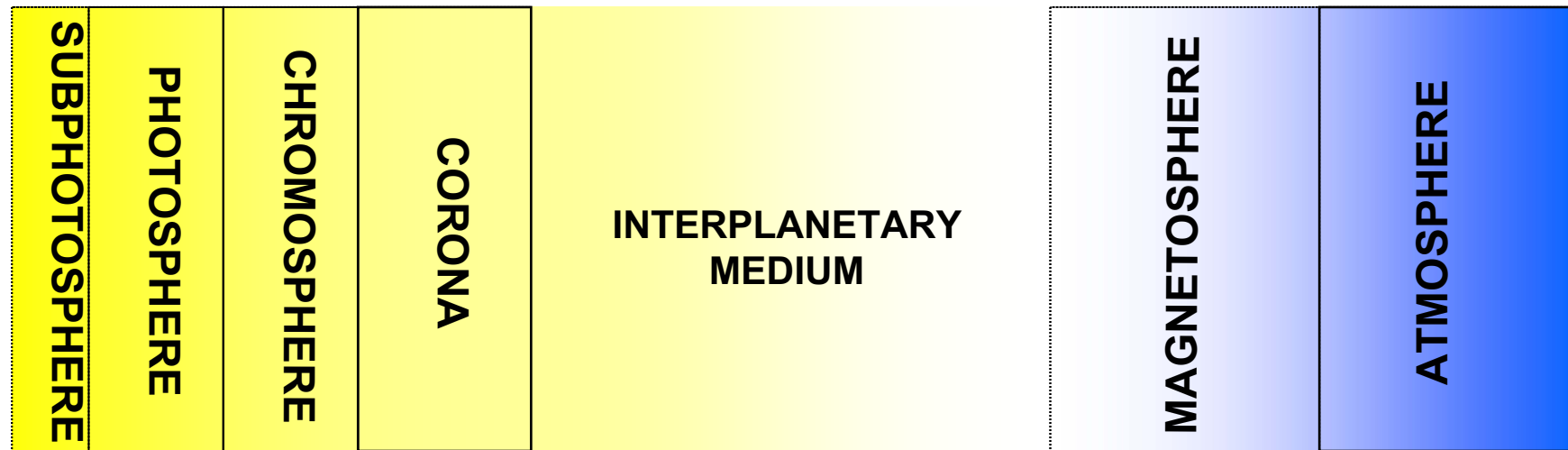
- Mass
- Radius
- Density
- Orbital dynamics
- Surface morphology
- Atmosphere
- Magnetosphere

The Solar-Terrestrial Environment

PHYSICAL CONDITIONS

- defined as SPACE WEATHER
- strongly affected by SOLAR ACTIVITY but
- HIGHLY NONLINEARLY COUPLED with it
- QUITE COMPLEX TO FORECAST

COUPLING IN THE SUN-EARTH SYSTEM



SUN

INTERPLANETARY SPACE

EARTH ENVIRONMENT

Radiated Power
 $3.82 \cdot 10^{23}$ kW

1.36 kW/m²

Total SW Mass Flow
 10^6 tons/s

Energy in SW
 $4.1 \cdot 10^{20}$ W

10^{13} W / $30 R_E$

Energy in CME
 $7 \cdot 10^{18}$ W

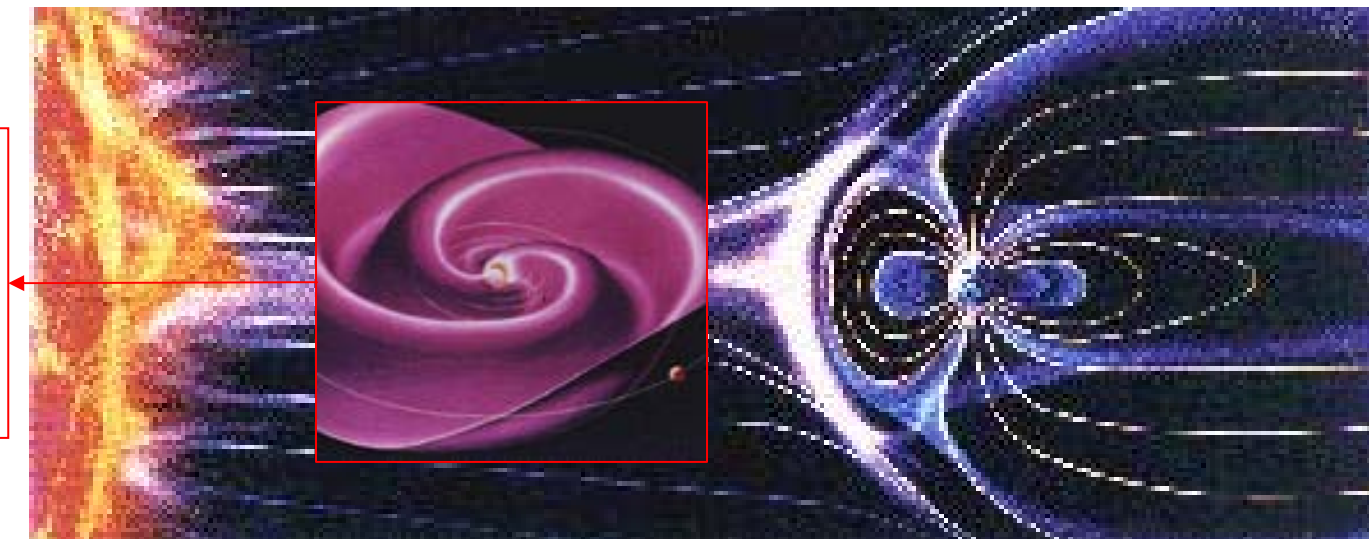
$1.73 \cdot 10^{17}$ W

Messerotti (1999, 2001)

CHARACTER OF THE MAGNETIC FIELD

SUBPHOTOSPHERE	PHOTOSPHERE	CHROMOSPHERE	CORONA	INTERPLANETARY MEDIUM	MAGNETOSPHERE	ATMOSPHERE
DIPOLAR AZIMUTHAL		RADIAL		SECTORED WARPED	DIPOLAR ASYMMETRIC	
MAGNETIC FIELD						

- Arch. spiral
- 0.1-80 nT
- 4 SSBs
- +/- 7.25° lat
- 45° cross angle



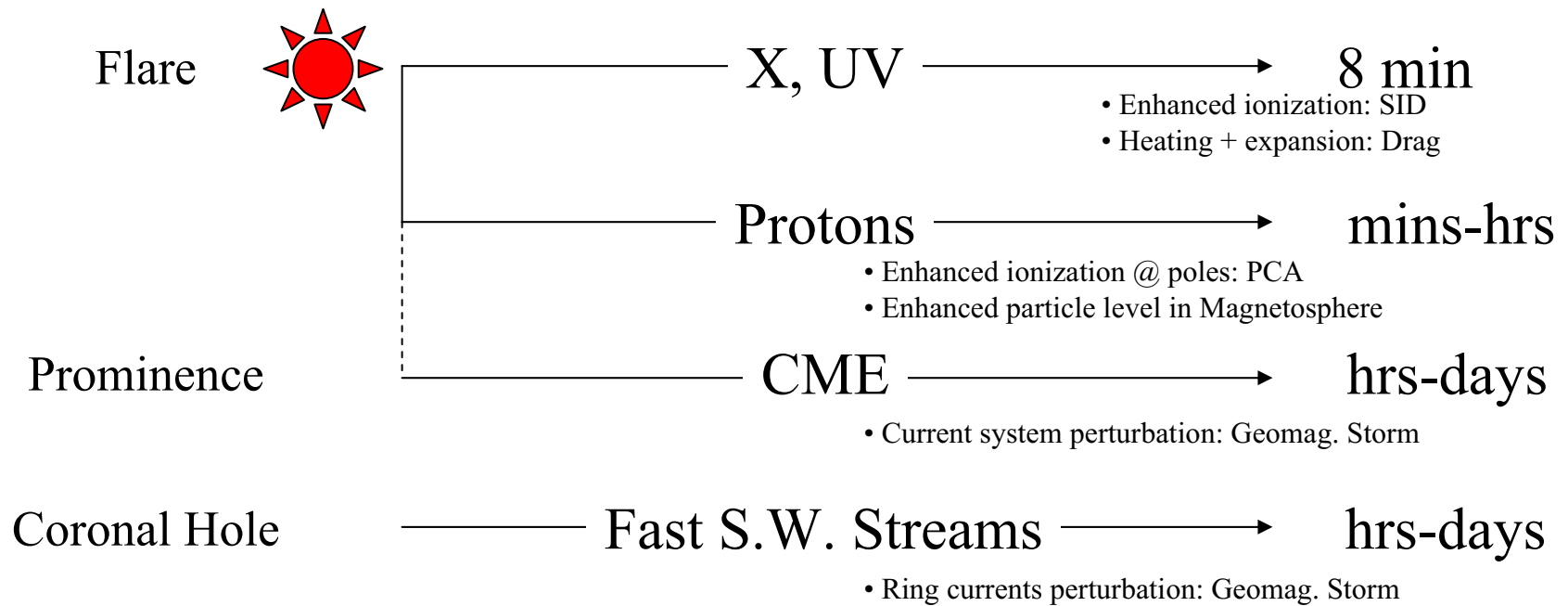
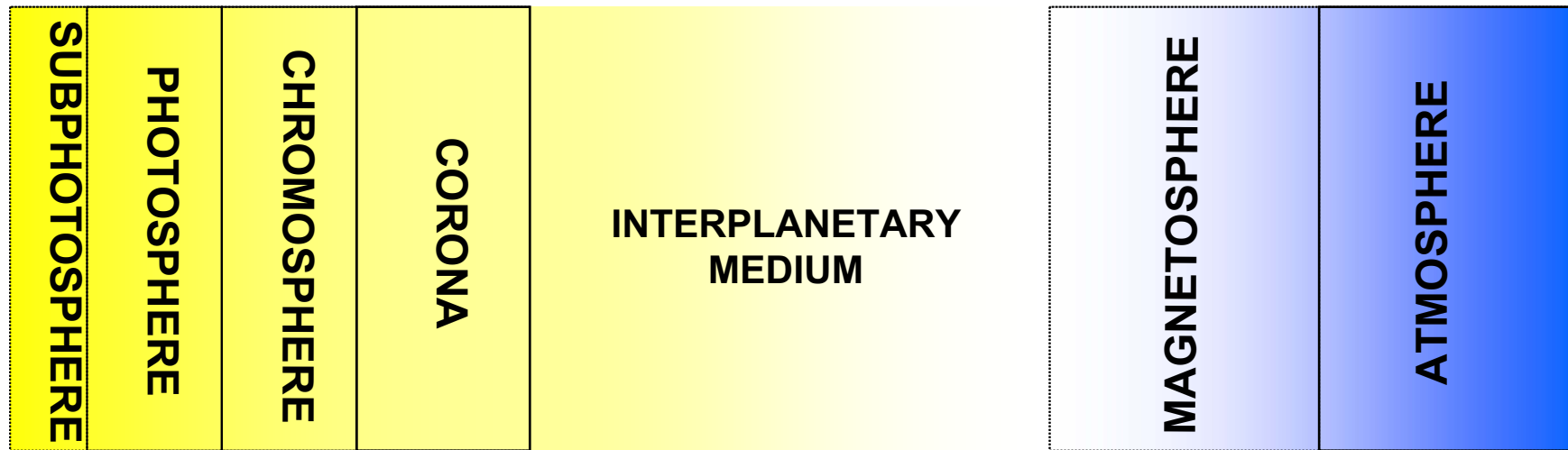
Messerotti (1999, 2001)

SOLAR DRIVERS OF IPM & EARTH PERTURBATIONS

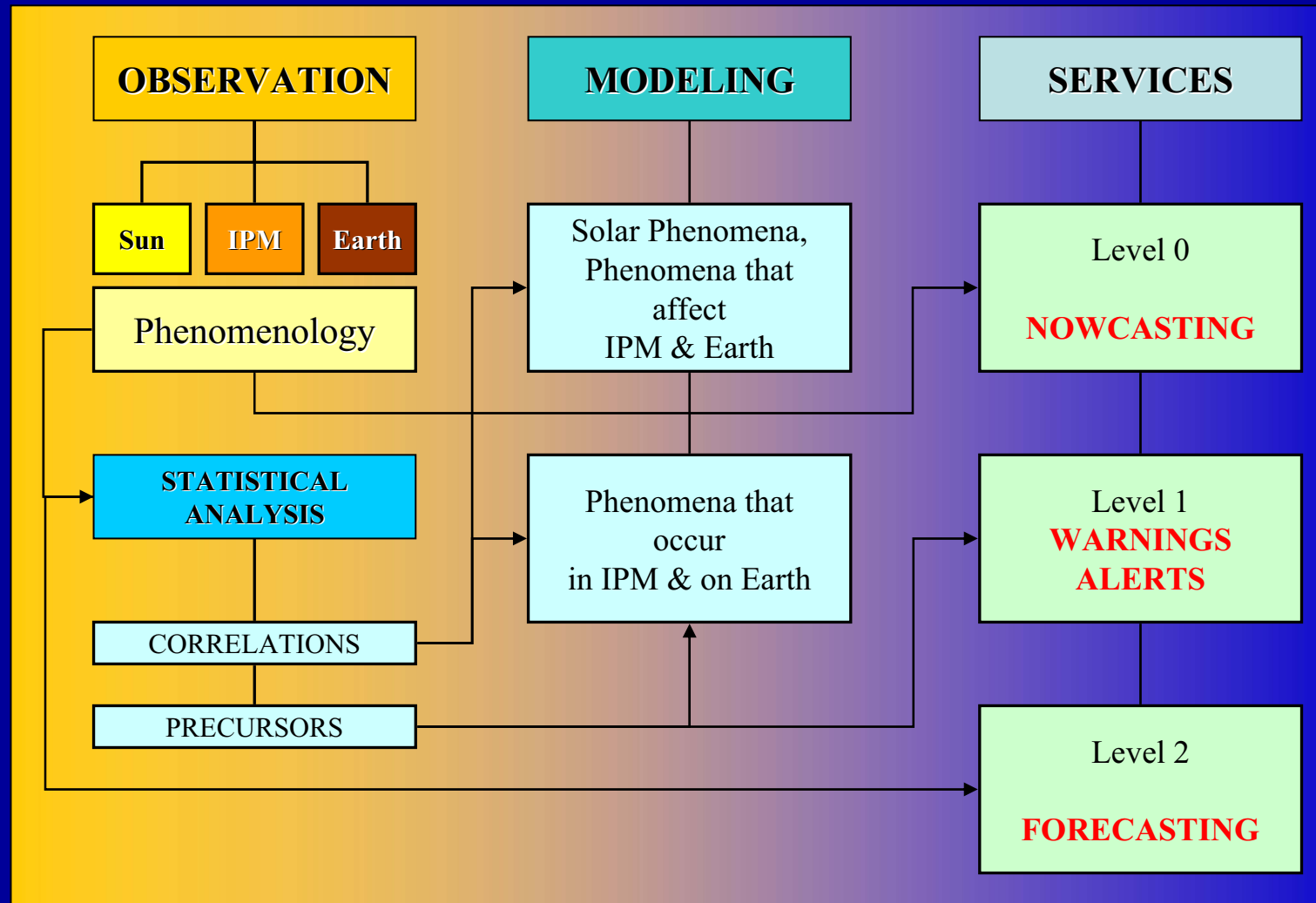


Fluid motions				
Sunspots				
Flares		γ , X, UV p, e		e.g. SID PCA
Prominences Filaments		CME		
Condensations				
Streamers		Slow SW		
Coronal Holes		Fast SW		Recurrent & n.-rec. Geomagnetic Storms

INDICATIVE TIMING OF S-T PERTURBATIONS



Space Weather Science & Service Scheme



A Foundation Ontology for Space Meteorology

For a Structured Organization
of the Knowledge on the Subject



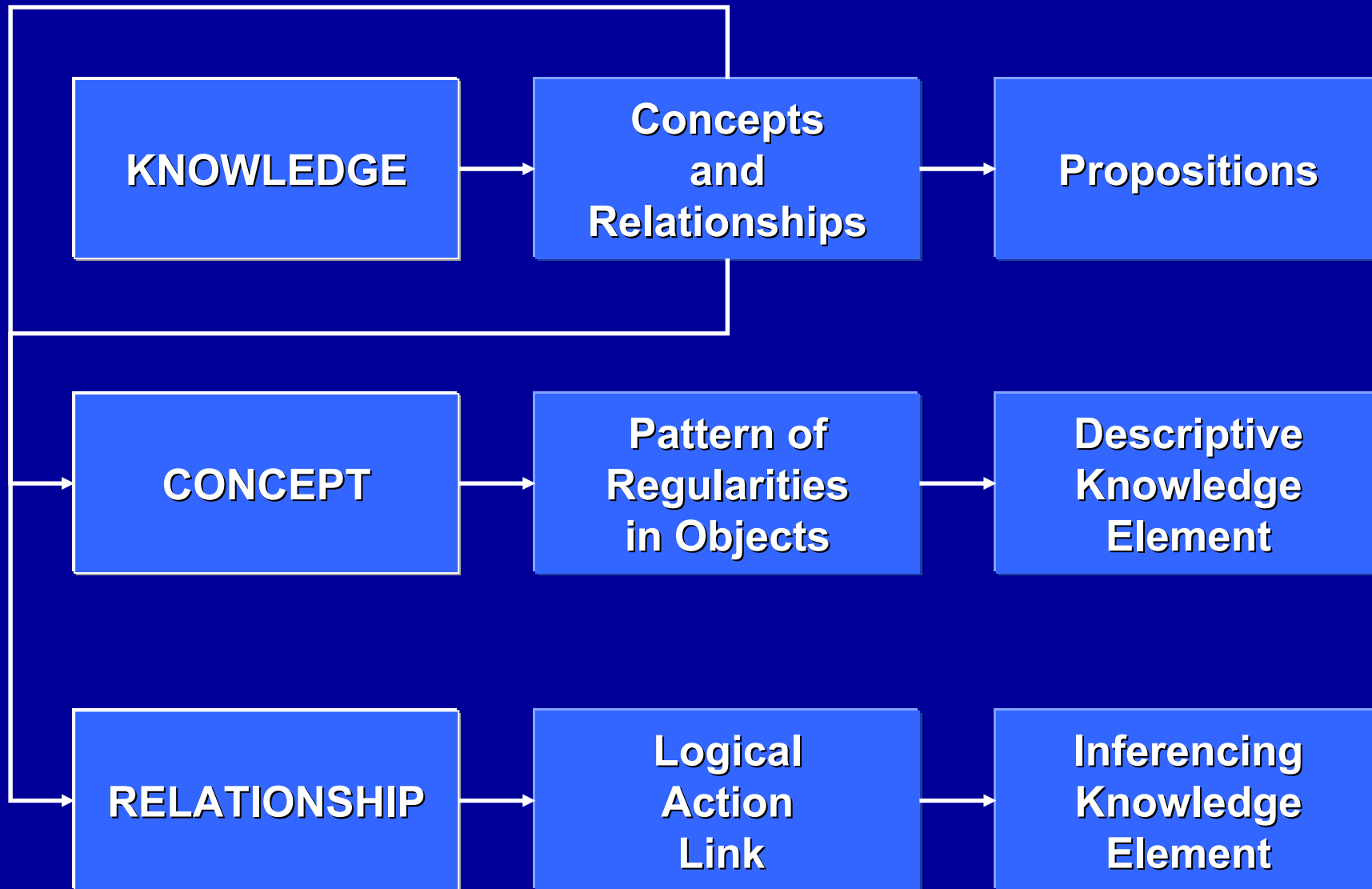
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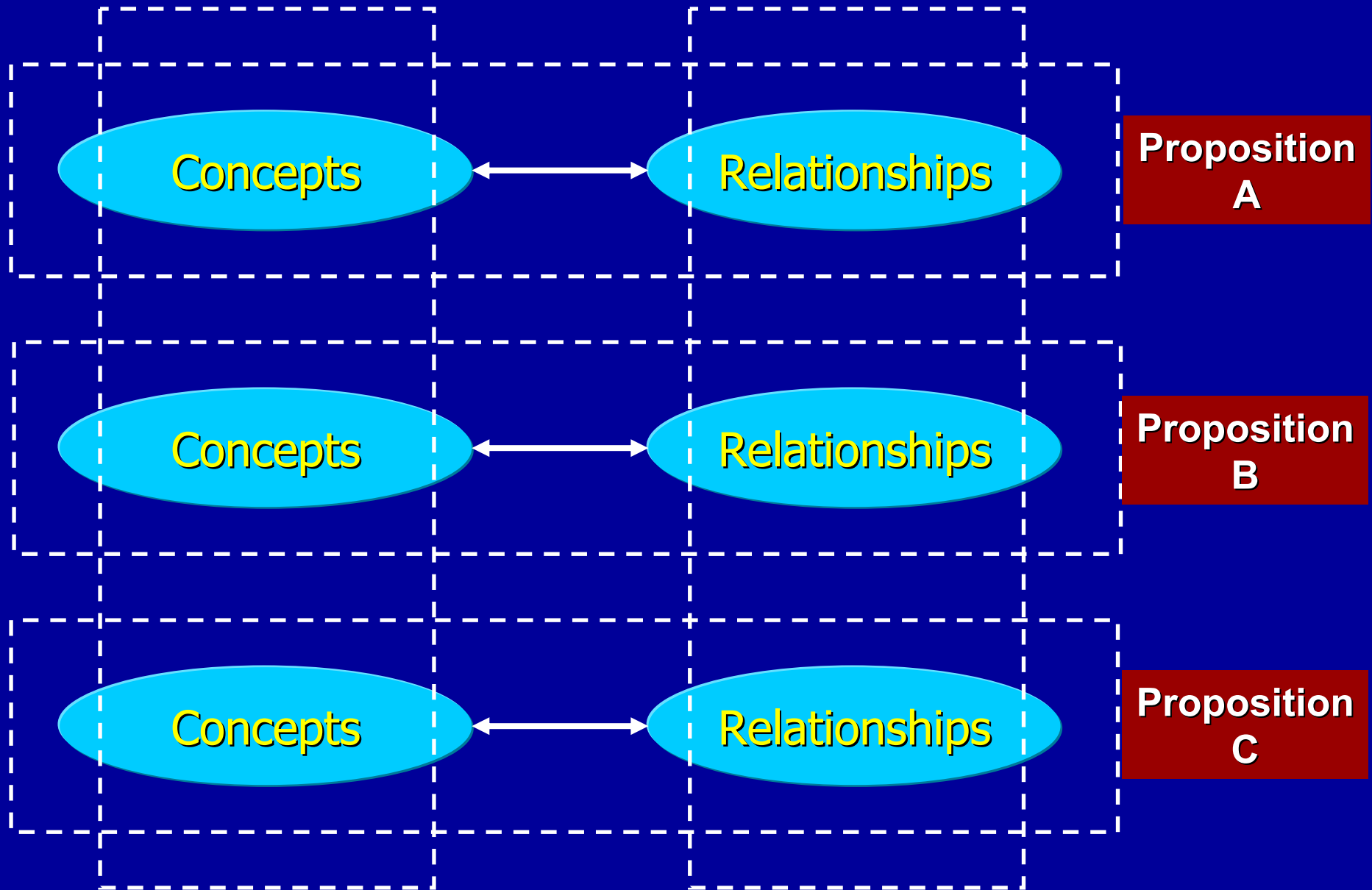
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A Semantic Model for Knowledge



Knowledge Representation Scheme



IHMC¹ Concept Map Features

- Represent a graphical scheme of knowledge in organized form
- Are interactively generated by means of a multi-platform software tool
- Are implementable as XHTML/XML documents
- External resources can be associated to concepts (e.g. scripts, hyperlinks, etc.)

¹Institute for Human and Machine Cognition, FL, USA



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IHMC Concept Map Development Tool



Institute for Human and Machine Cognition
A University Affiliated Research Institute

<http://cmap.ihmc.us>

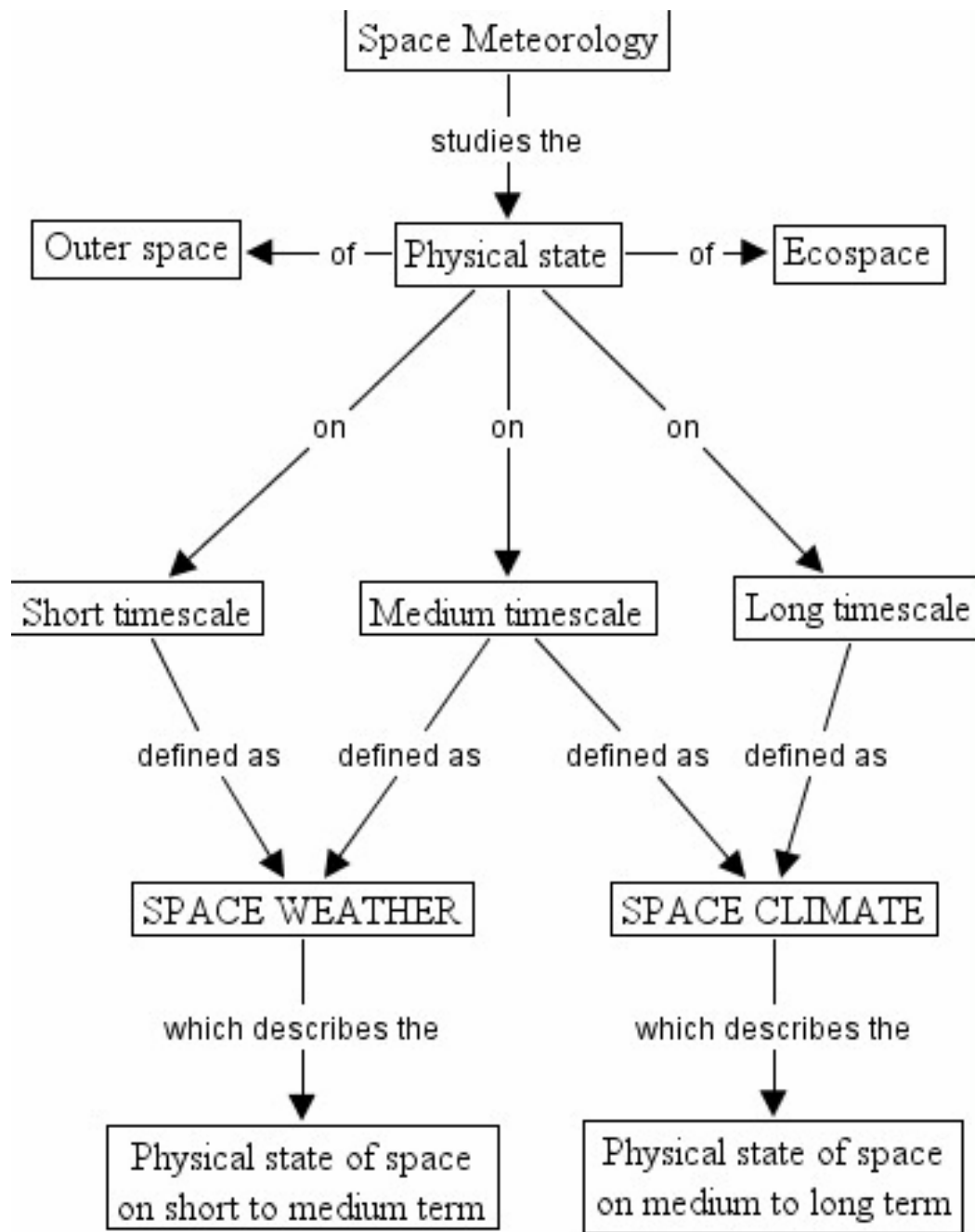


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A Sample Cmap

**2-D REPRESENTATION
OF
A SET OF CONCEPTS
AND
THEIR INTERRELATIONSHIPS**

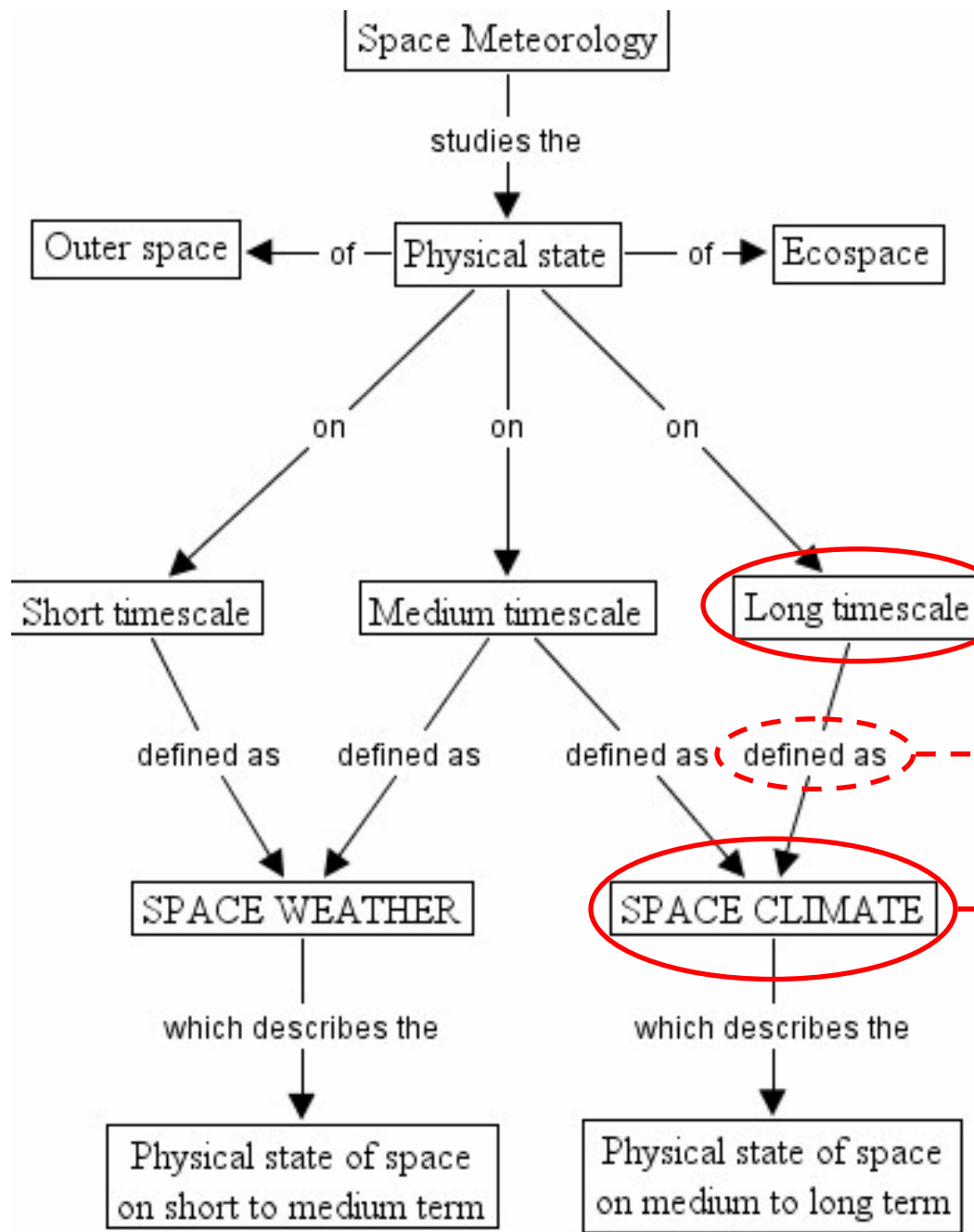


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Cmap Structure

Proposition

CONCEPT

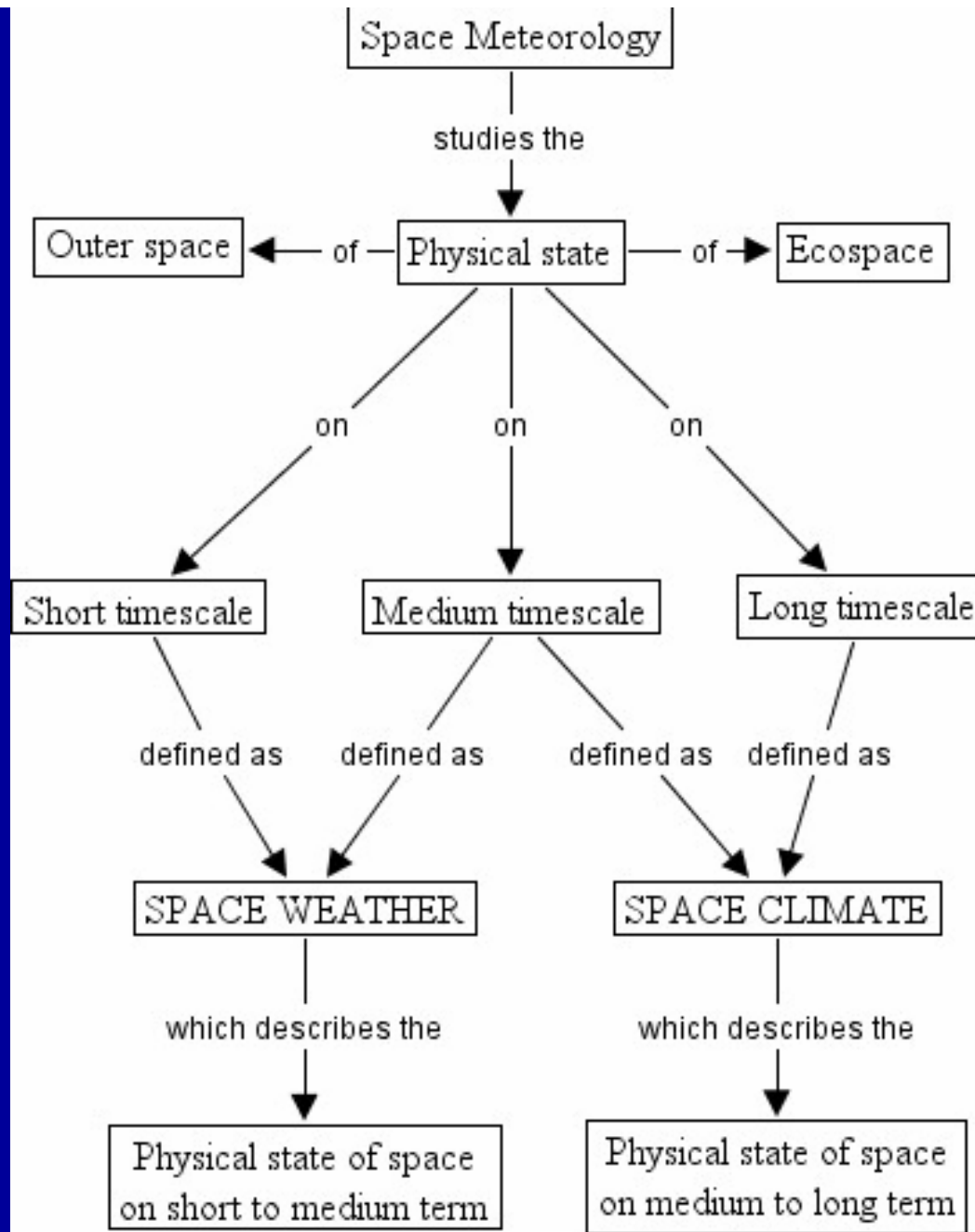
RELATION

CONCEPT

KNOWLEDGE



HIERARCHY



Most inclusive

CONCEPT FRAMEWORK

Least inclusive

GENERALIZATION

What is a Foundation Ontology?

- **ONTOLOGY** describes knowledge and it is the **formulation of a conceptual schema about a domain** constructed by:
 - Defining the precise meaning of domain entities (**semantics**)
 - Identifying the relationships between entities (**associativity**)
 - Stating the rules between entities/set of entities (**operativity**)



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Why do we need a Foundation Ontology?

- No clear definition of the terminology
- No clear definition of the physical domains
- Interrelationships defined only on a fragmentary basis and limited to sub-domains



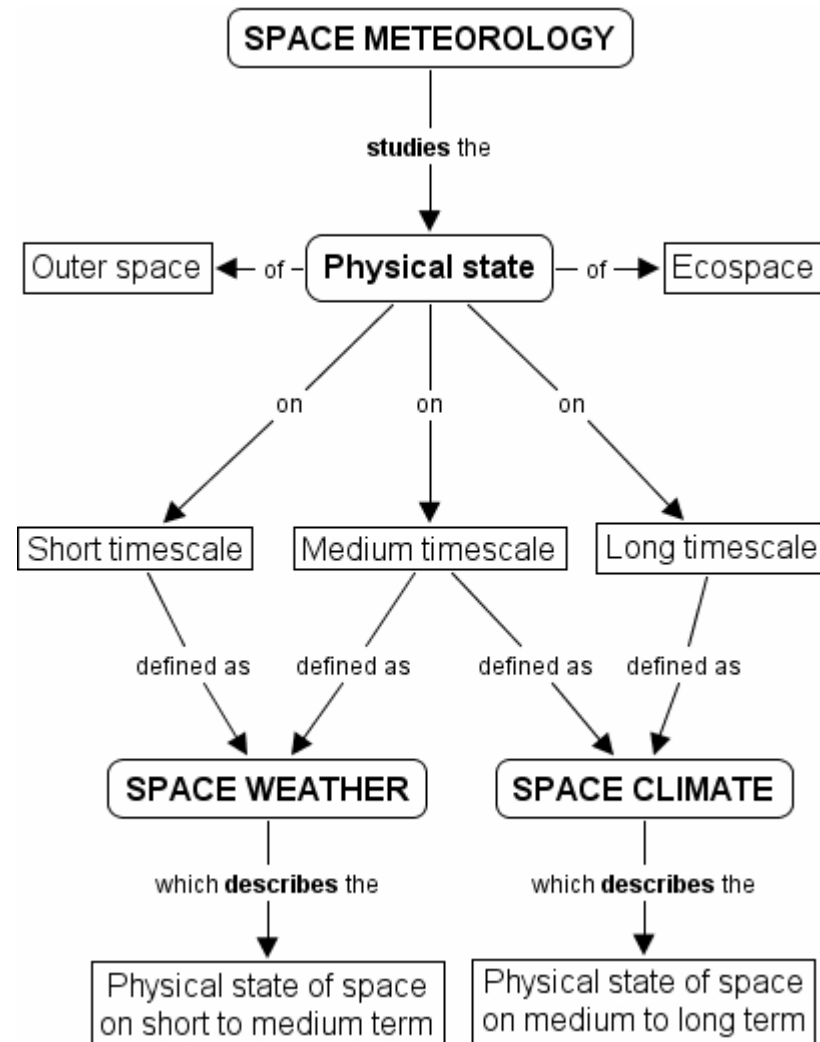
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Definition of Space Meteorology



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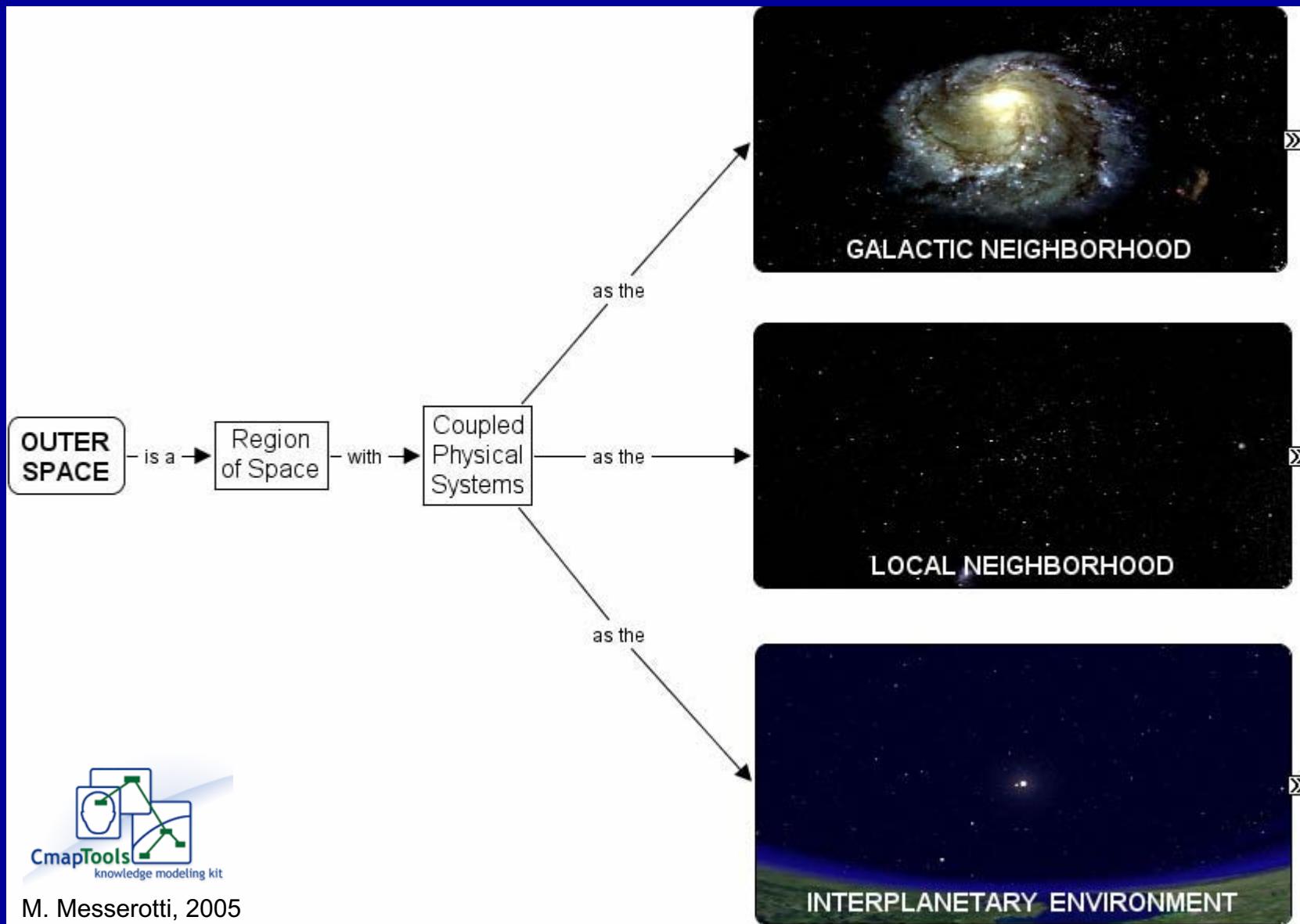
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Definition of Outer Space



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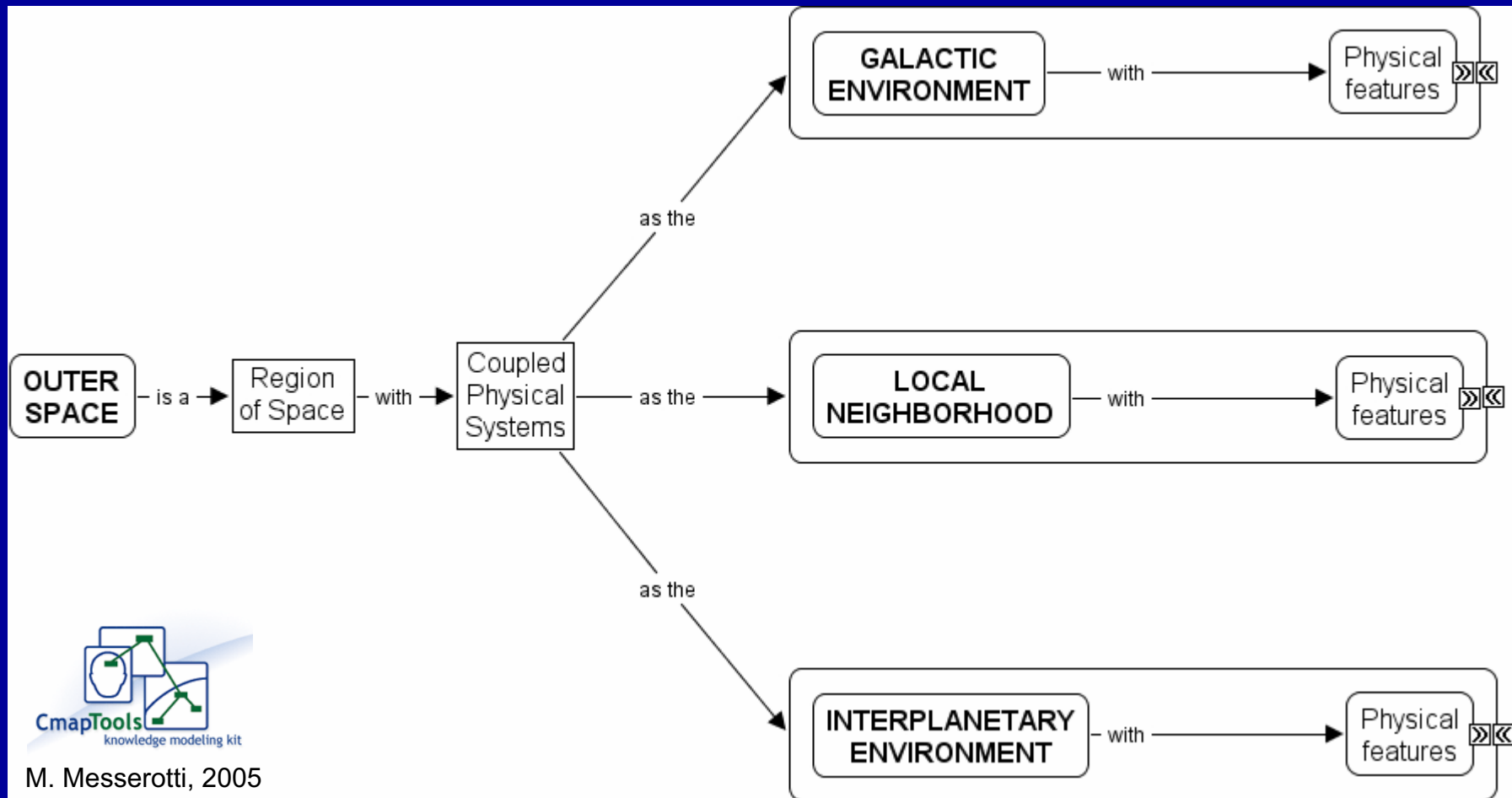
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Integration of Terrestrial Effects on
Radio Systems (ITERS)



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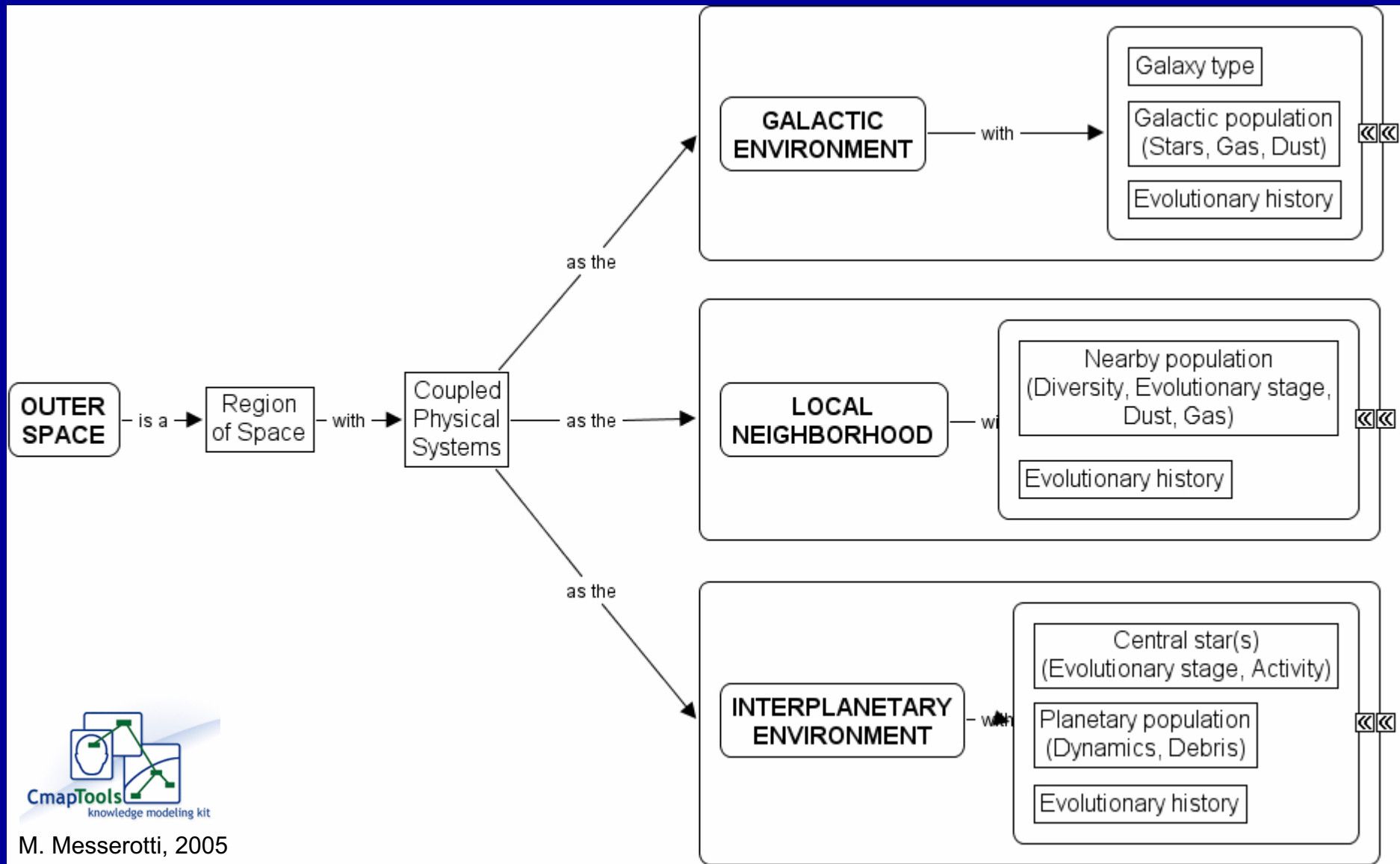
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Characterization of Outer Space



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Characterization of Outer Space Constituents



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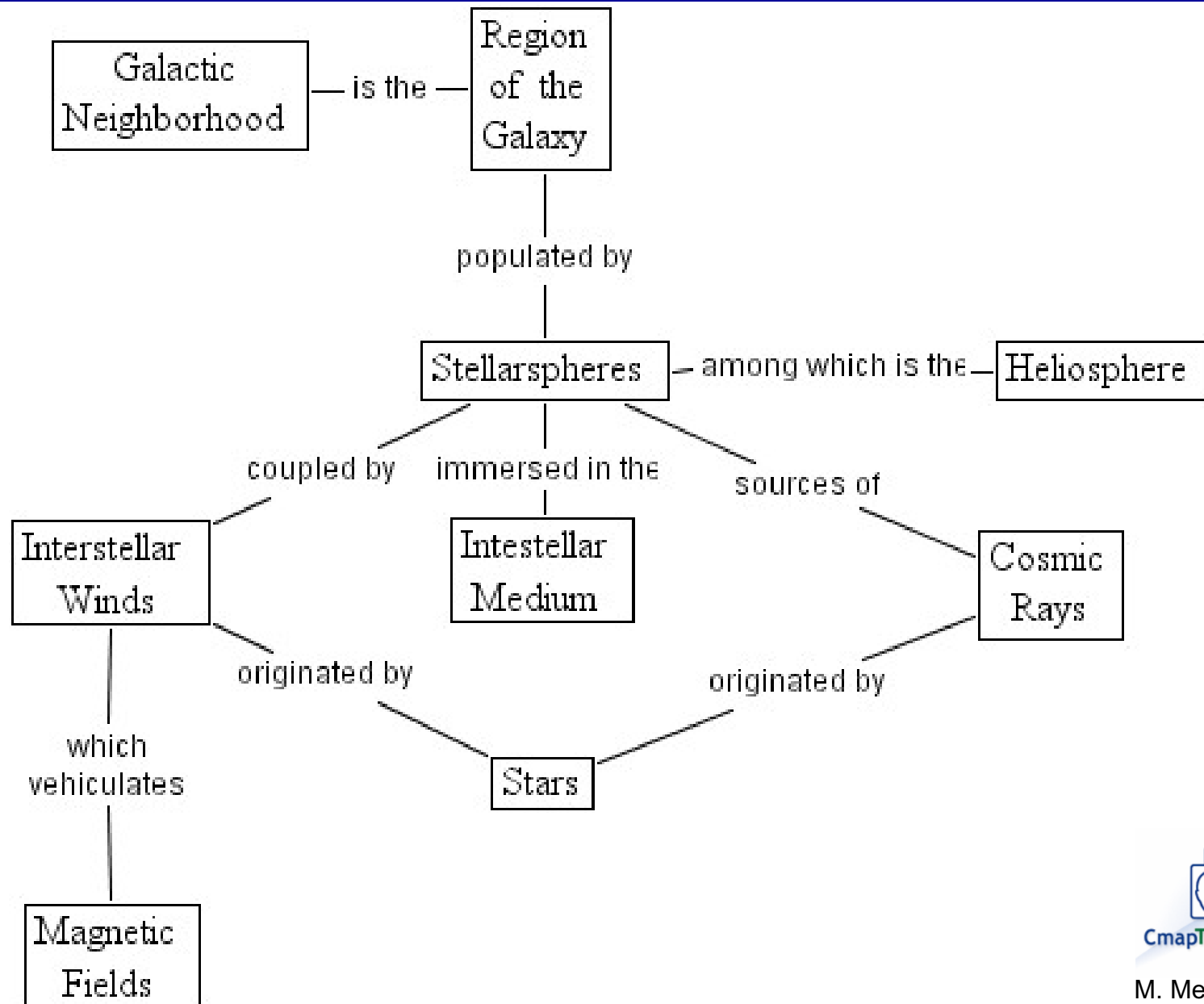
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Space Systems (ITESP)



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The Galactic Neighborhood



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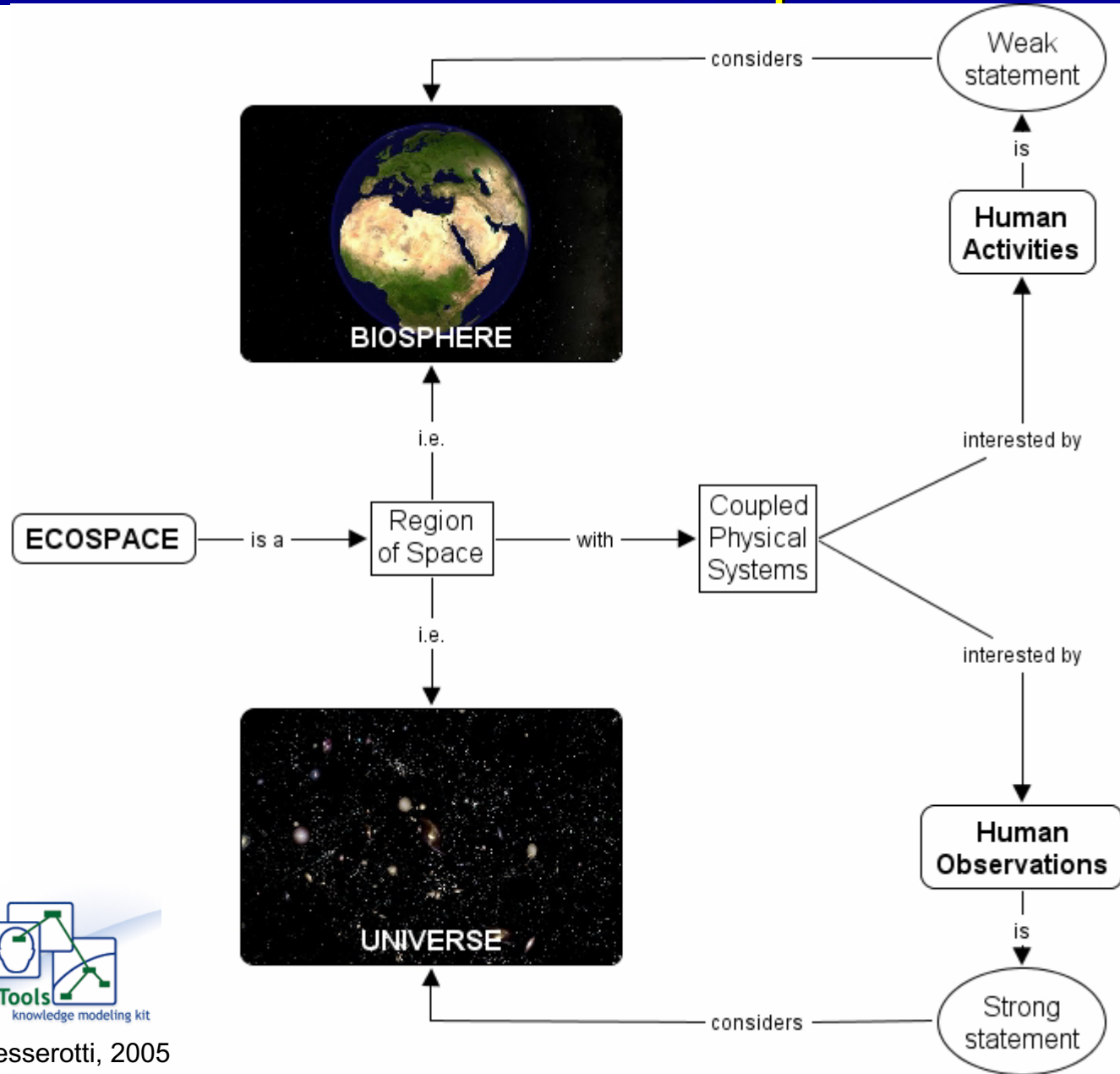
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Definition of Ecospace

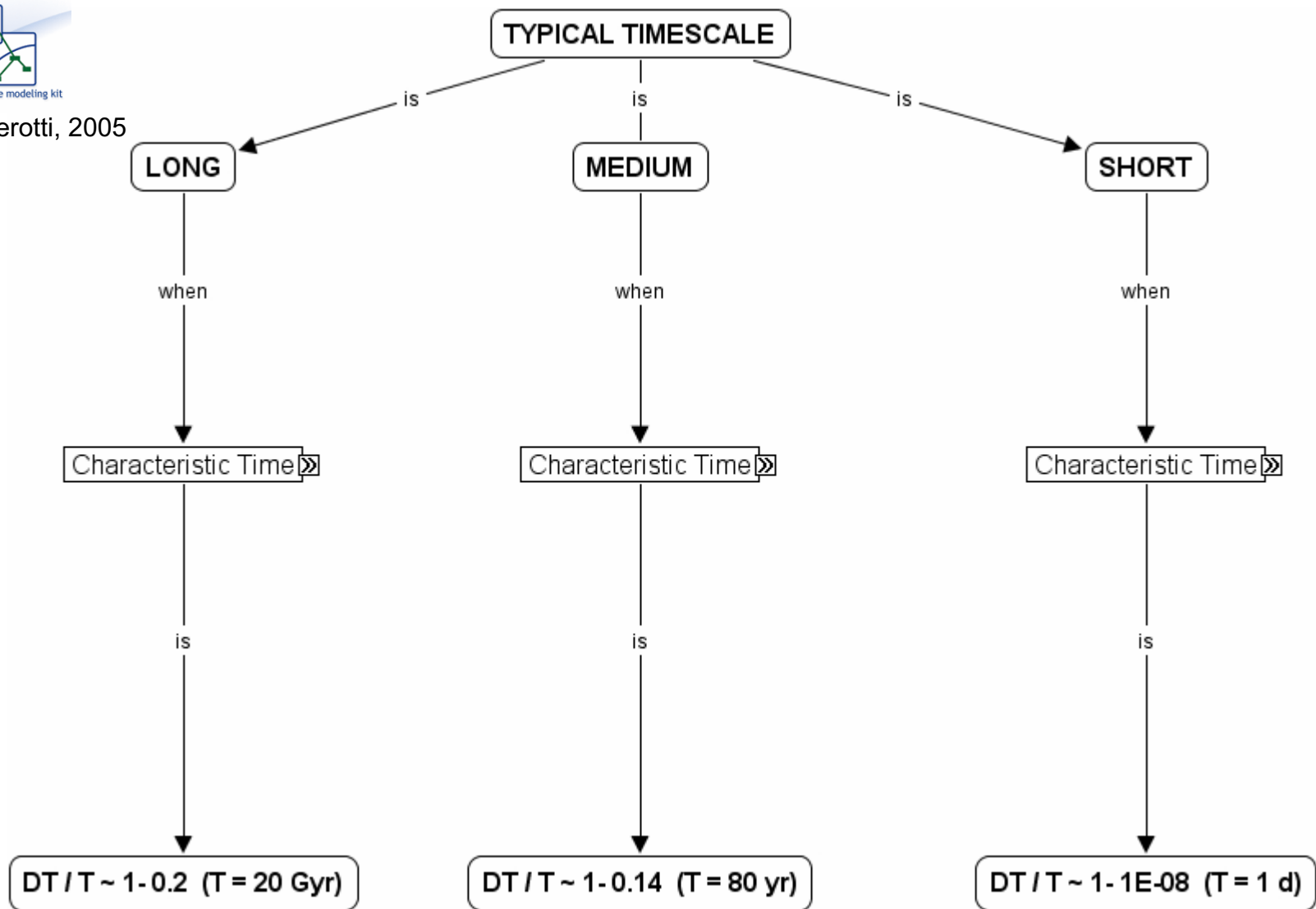


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Characterization of Time Scales



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Public Systems (MISPE)



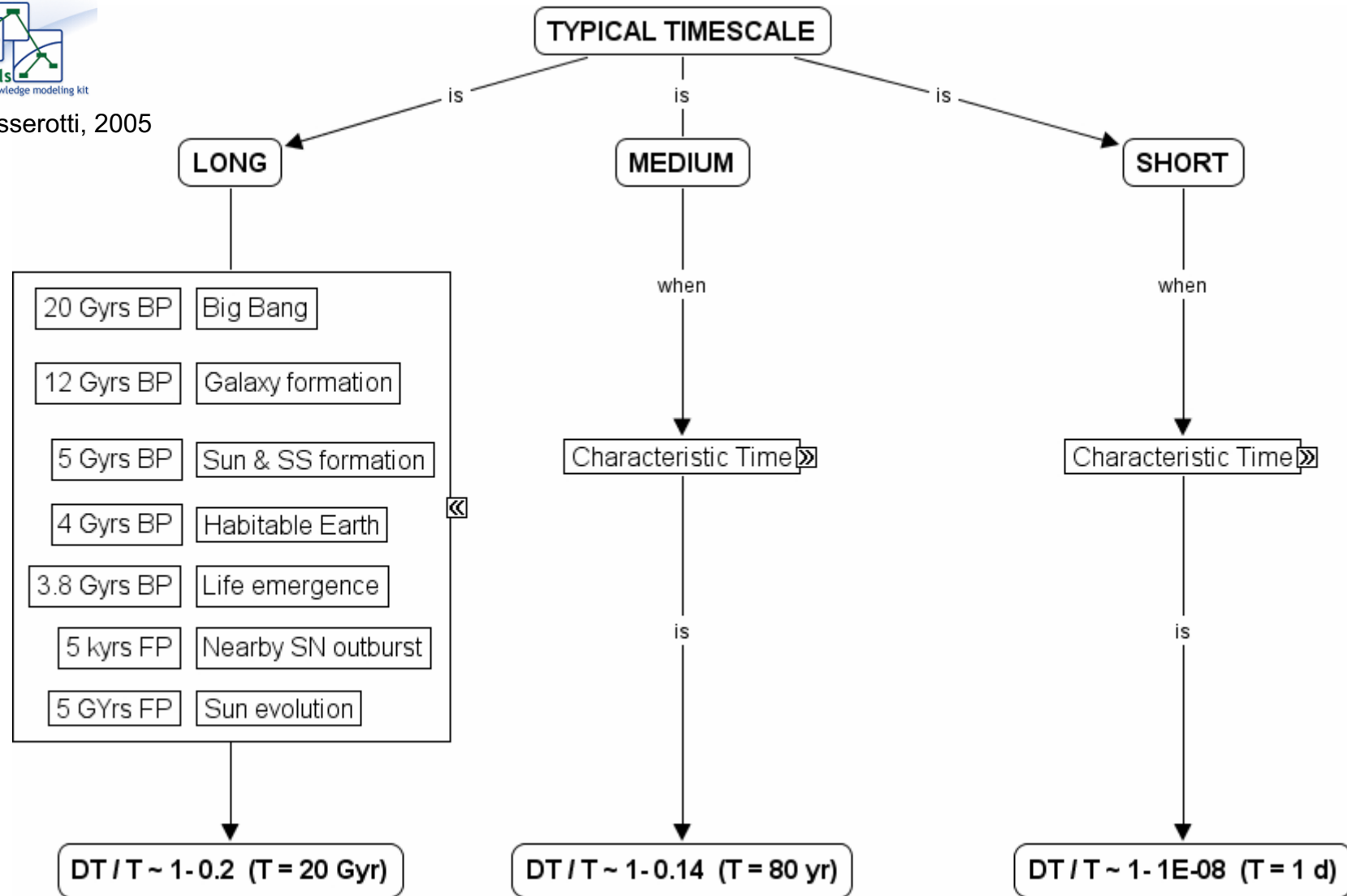
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Examples of Long Characteristic Times



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Public Systems (IOWE)



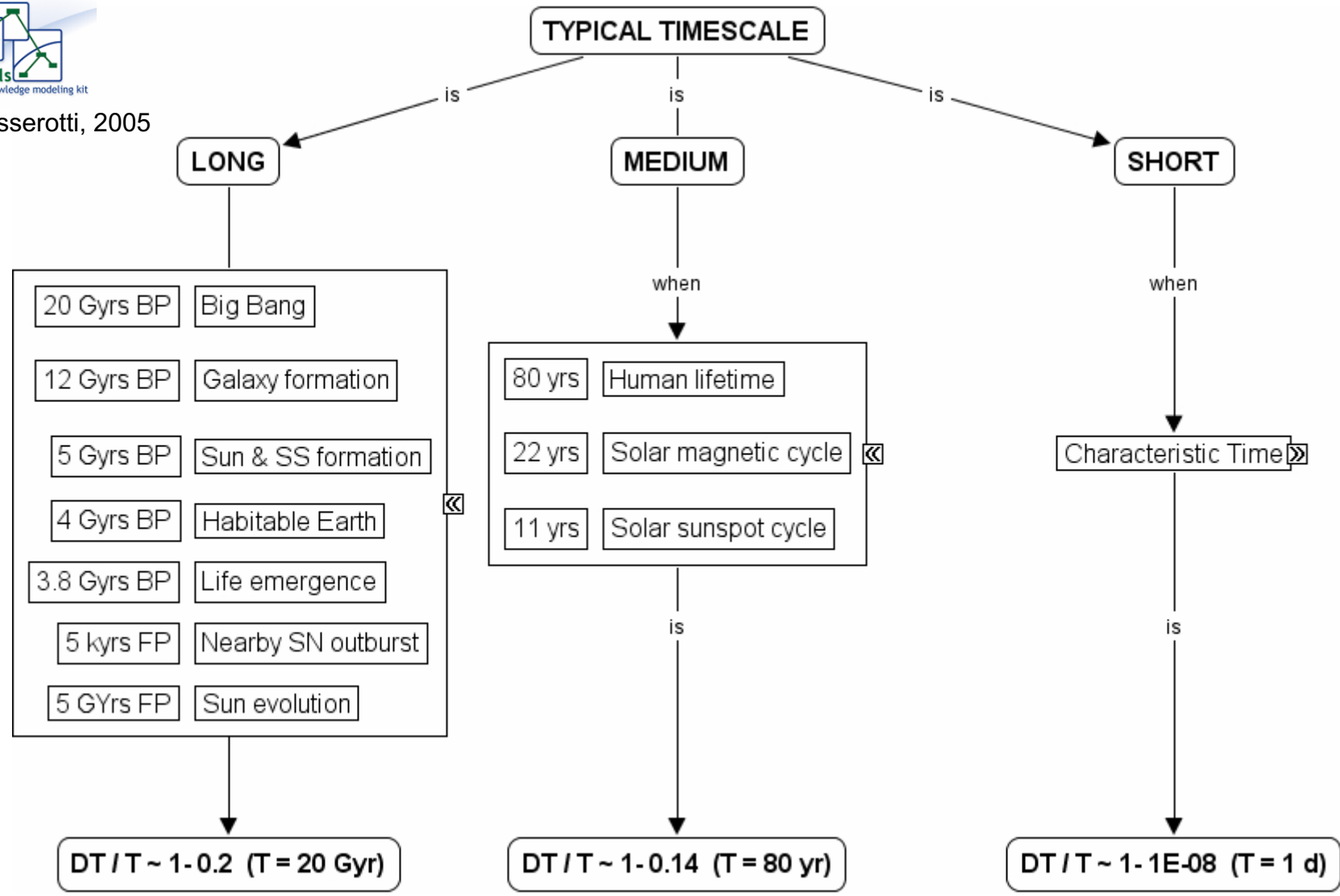
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Examples of Medium Characteristic Times



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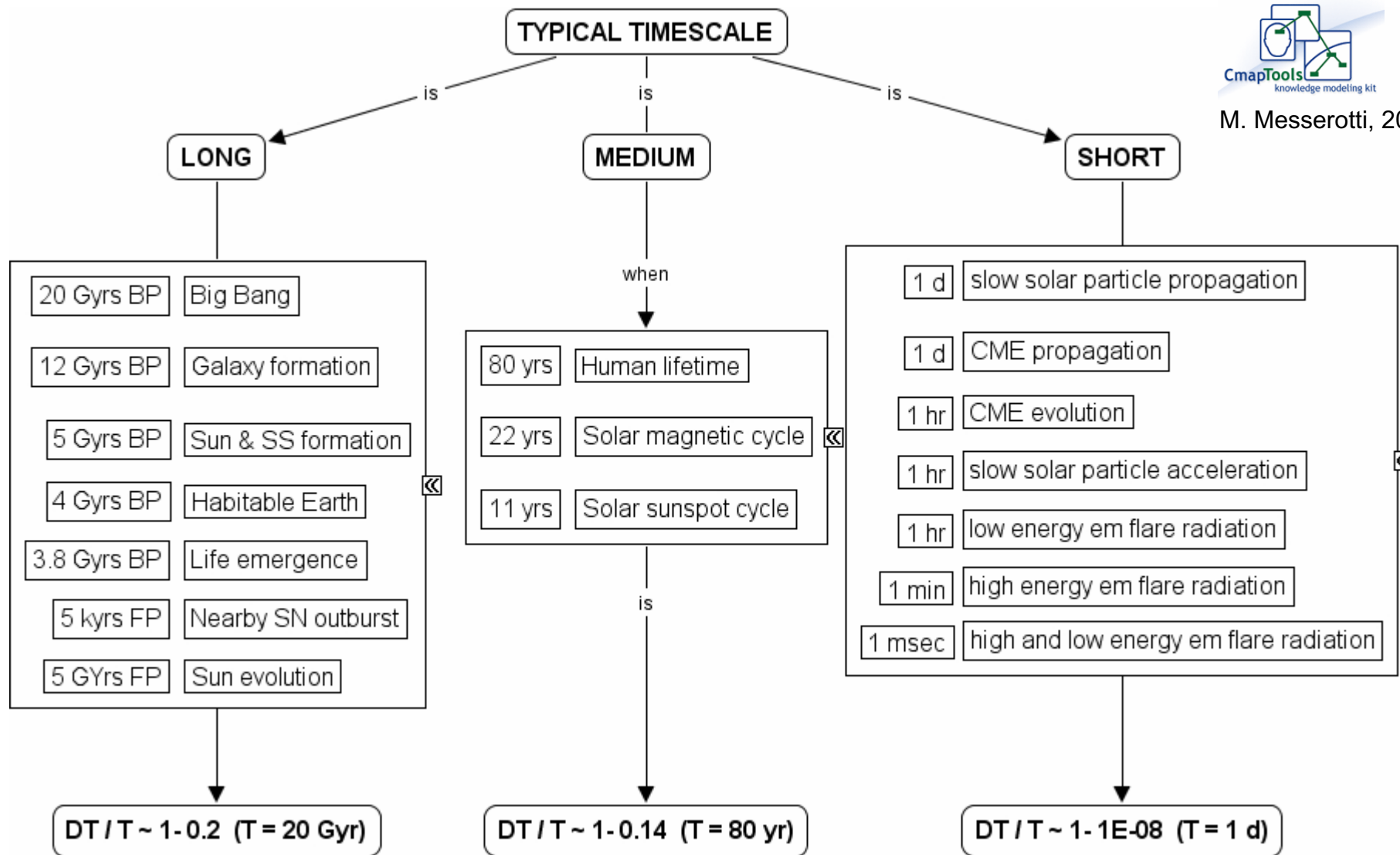
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Examples of Short Characteristic Times



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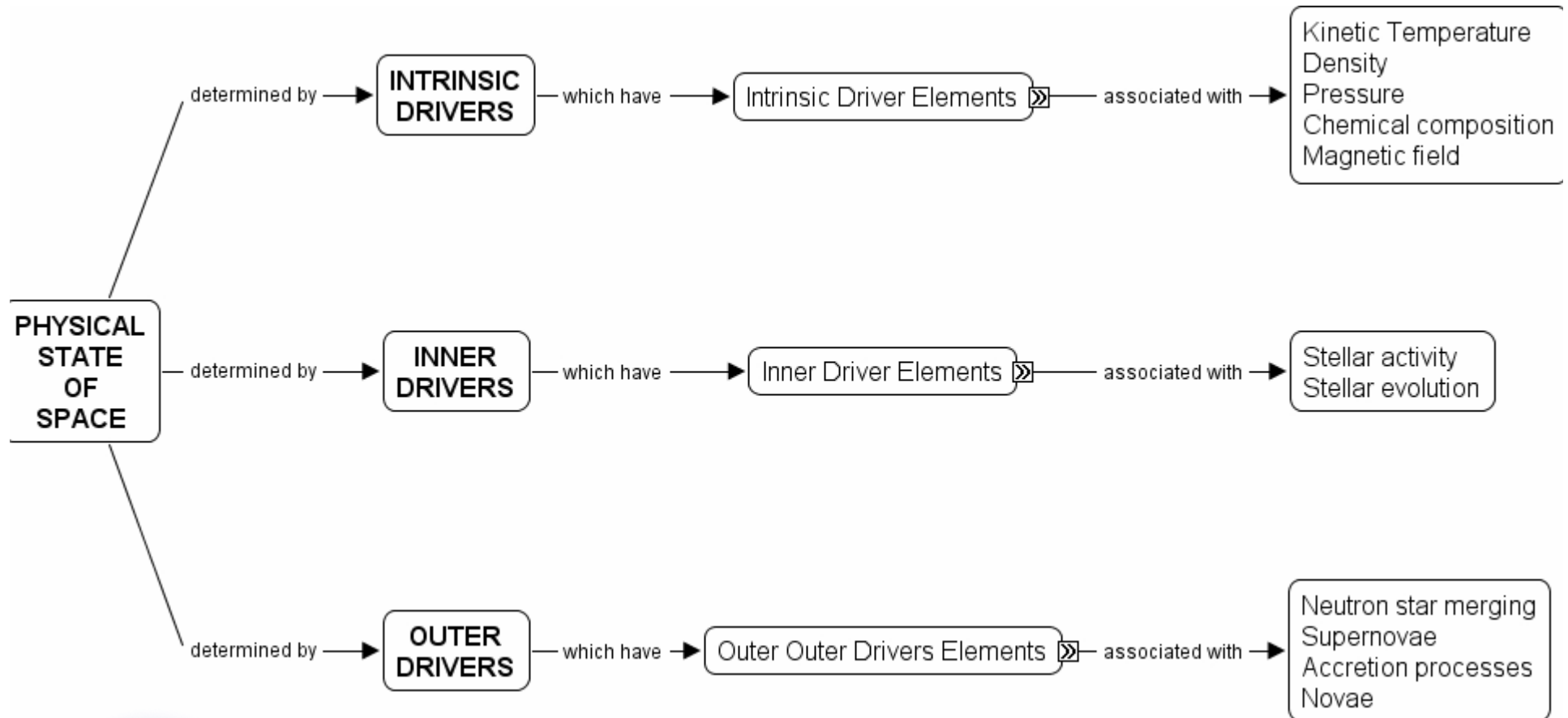
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Characterization of the Physical State of Space



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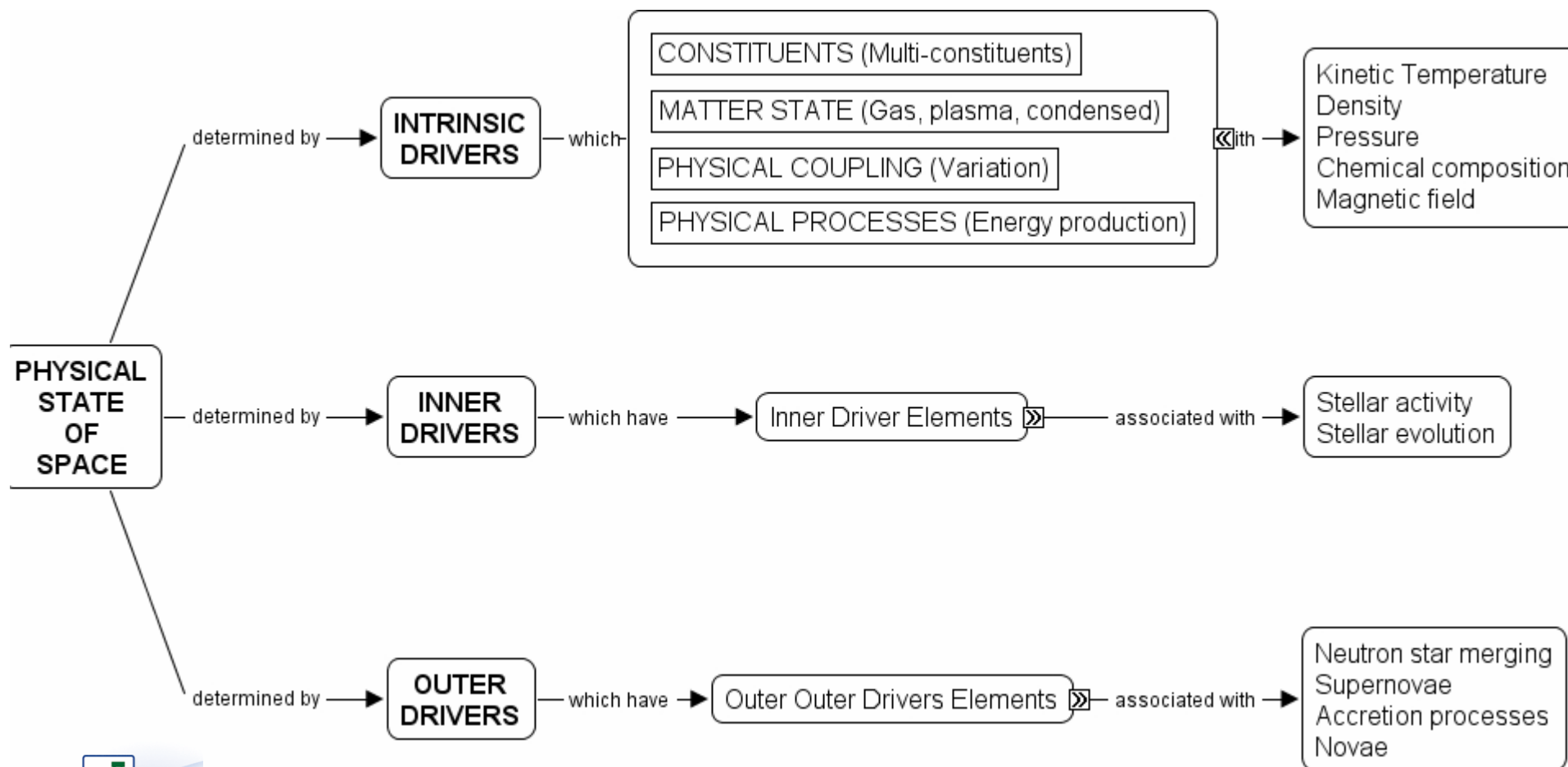
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Integration of Spacepheric Effects on
Radio Systems (ISERS)



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Definition of Intrinsic Driver Elements



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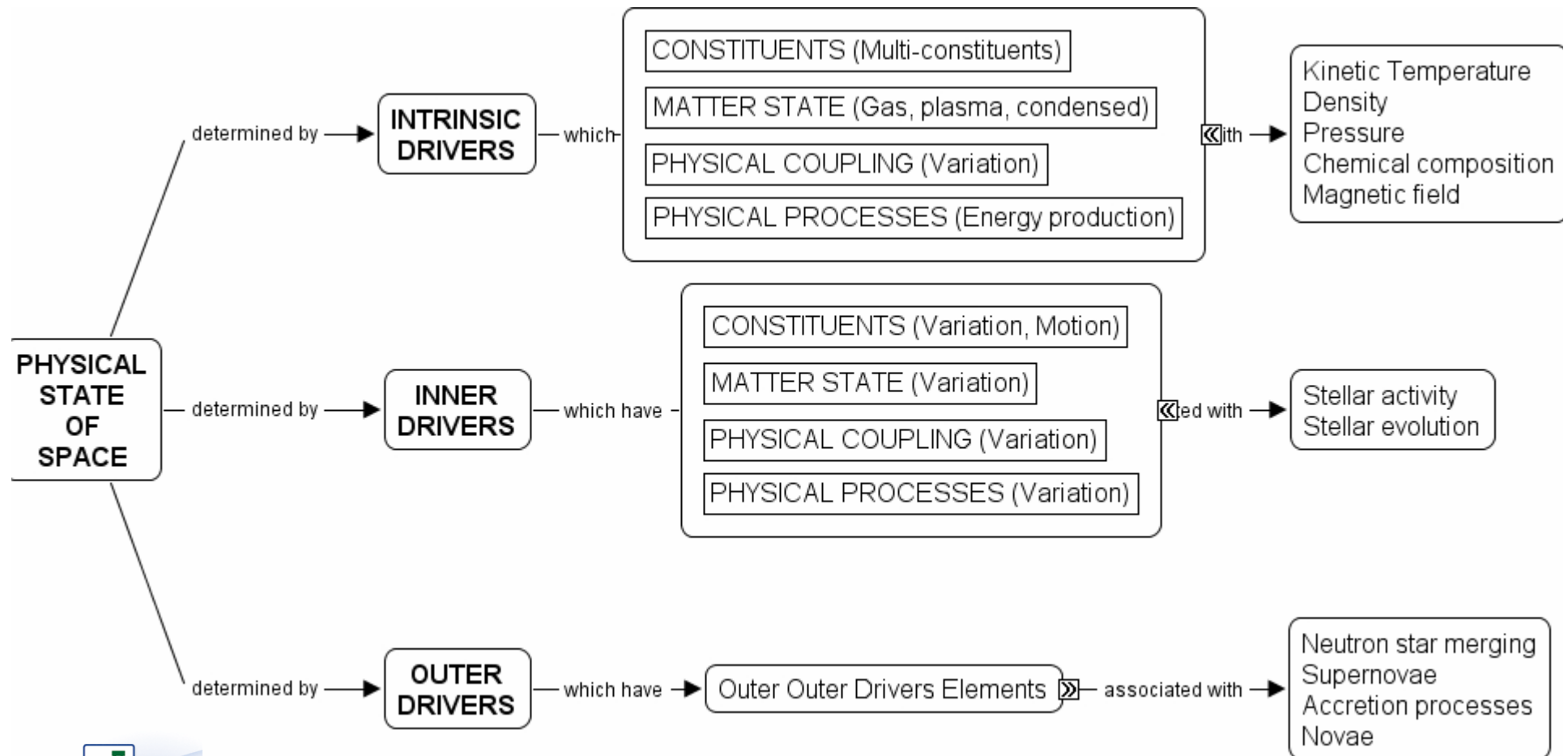
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Integration of Space- and Earth-based Observations (ISEO)



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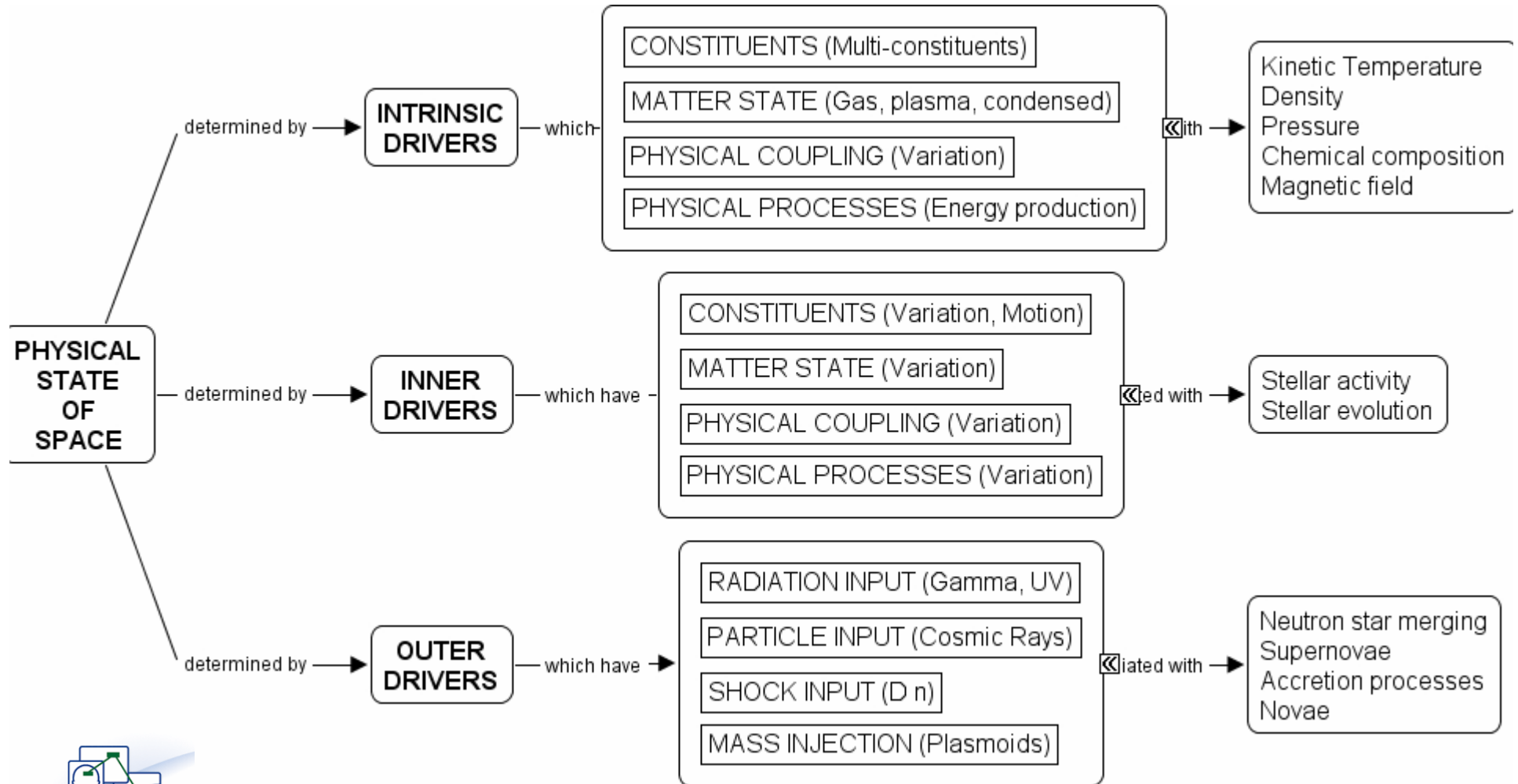
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Definition of Inner Driver Elements



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Definition of Outer Driver Elements



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Public Systems (ISPEPS)



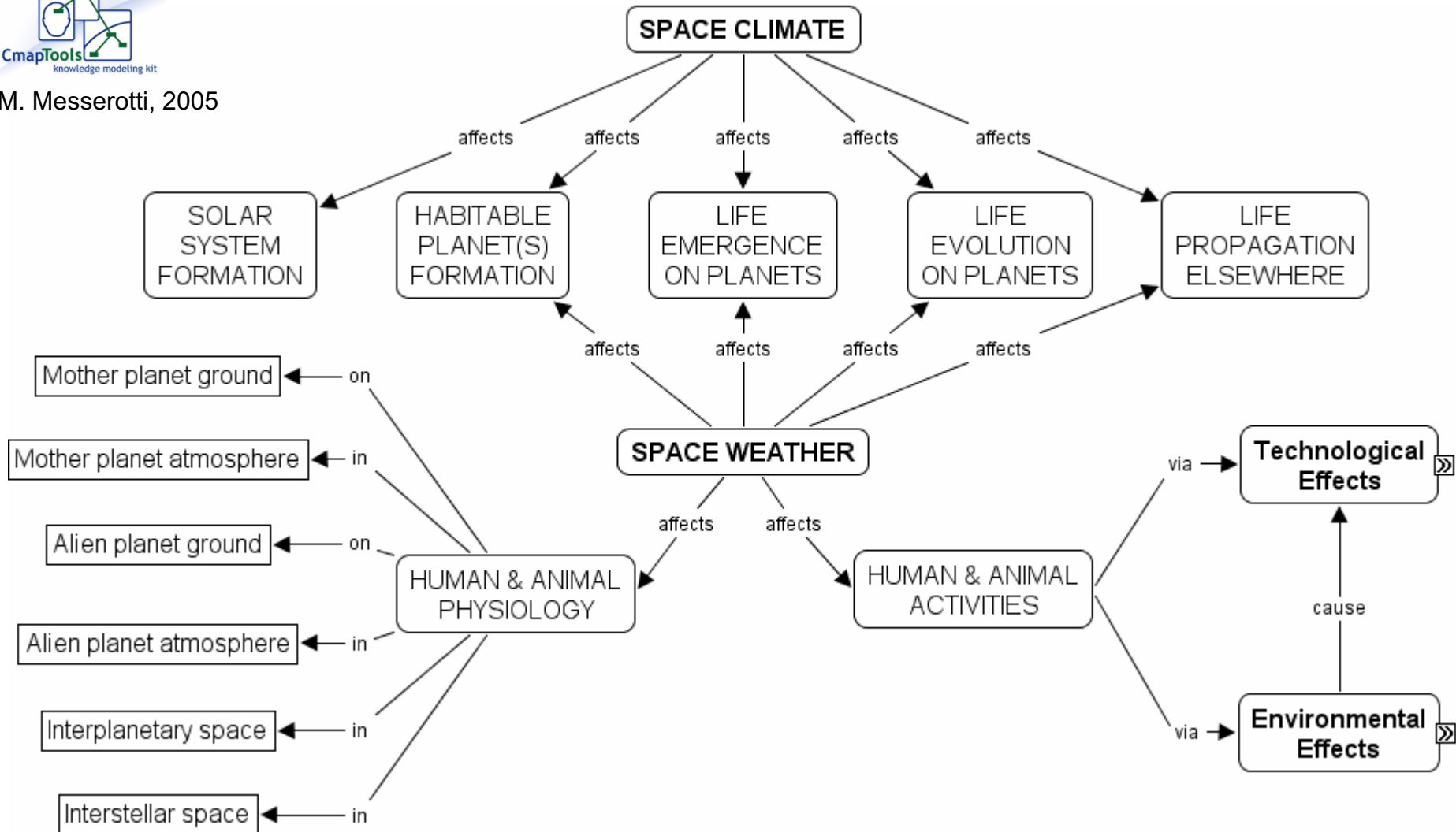
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Impacts of Space Conditions



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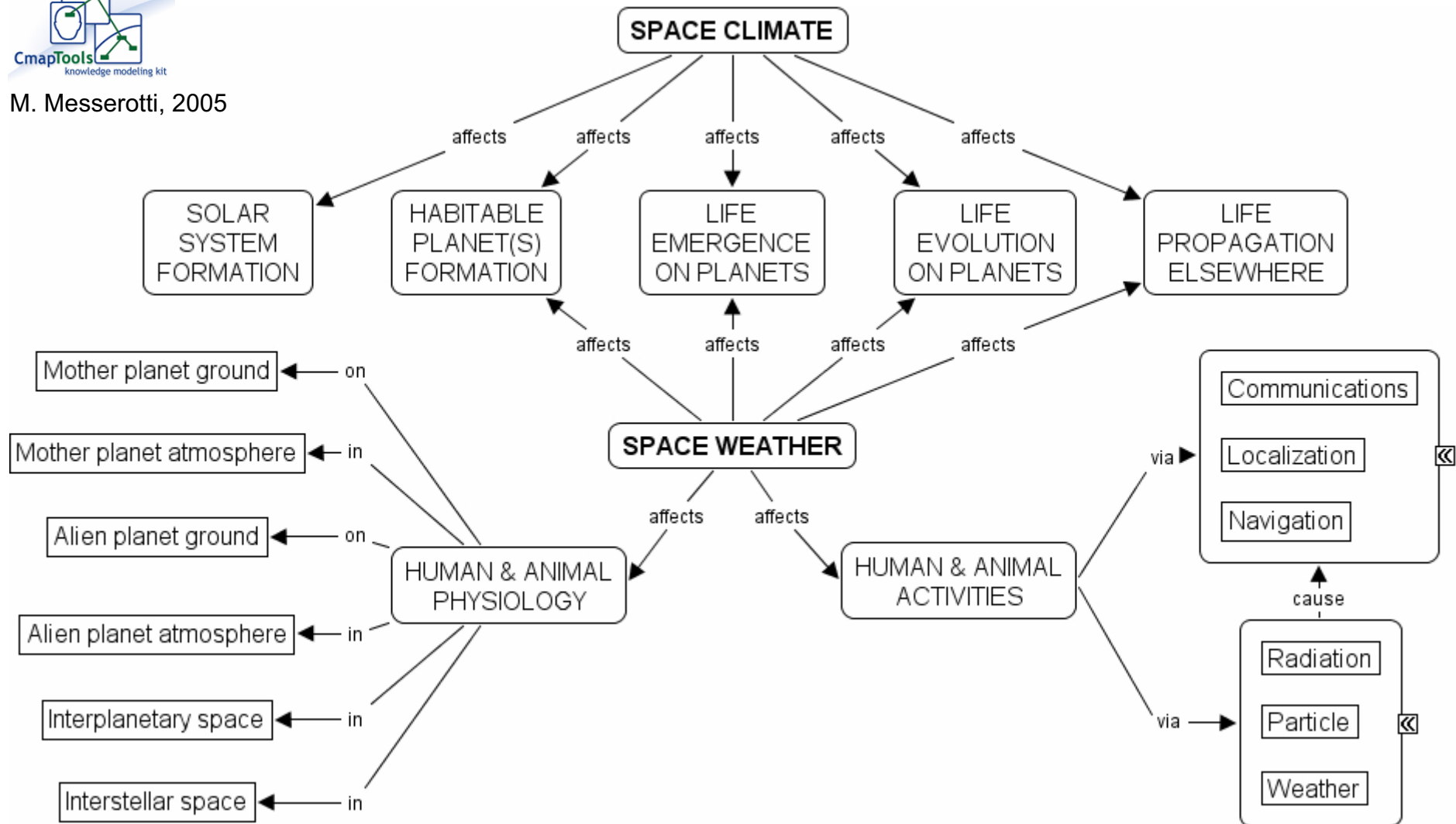
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Technological and Environmental Effects



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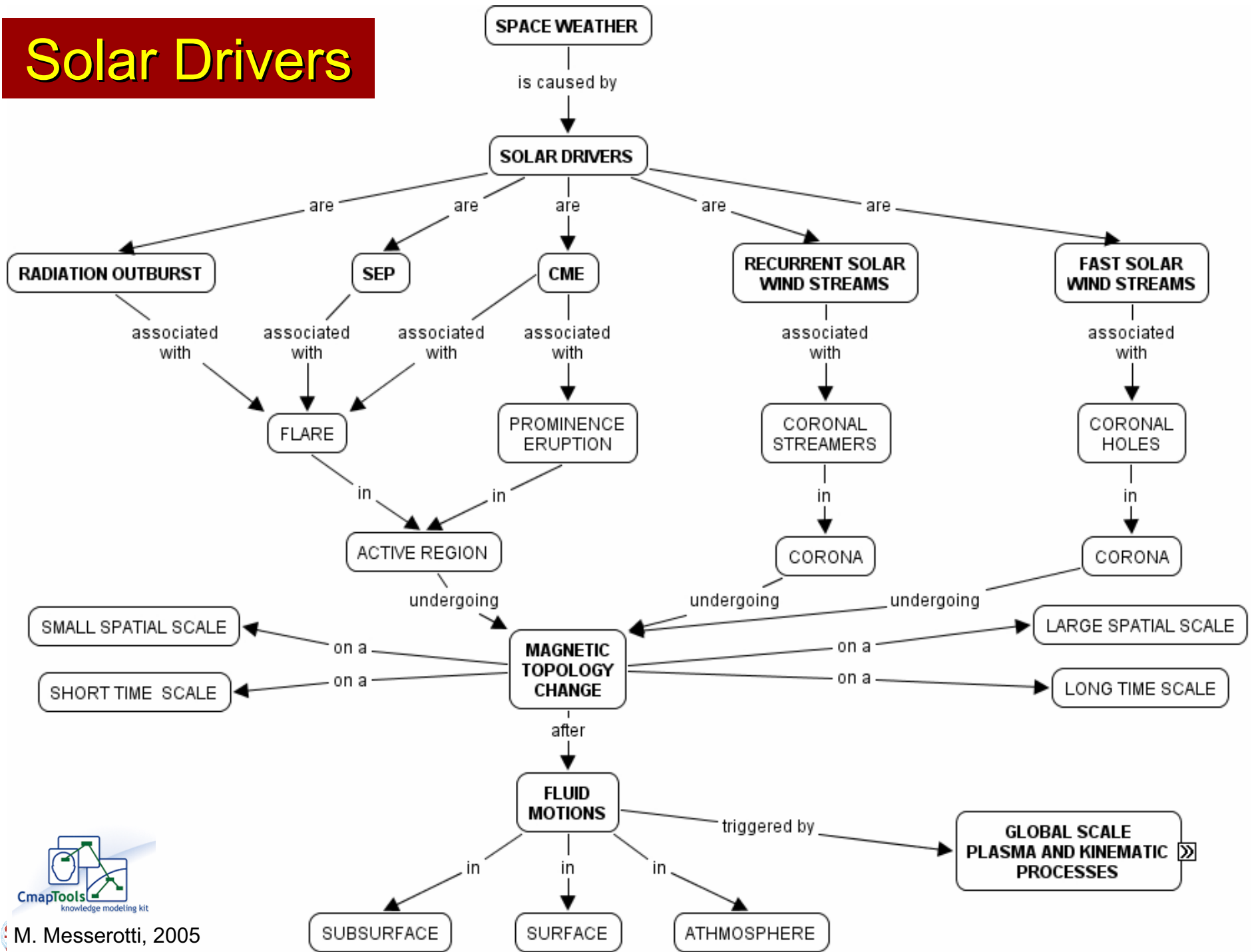
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Integration of Technological Effects on
Human Activities (ITESA)



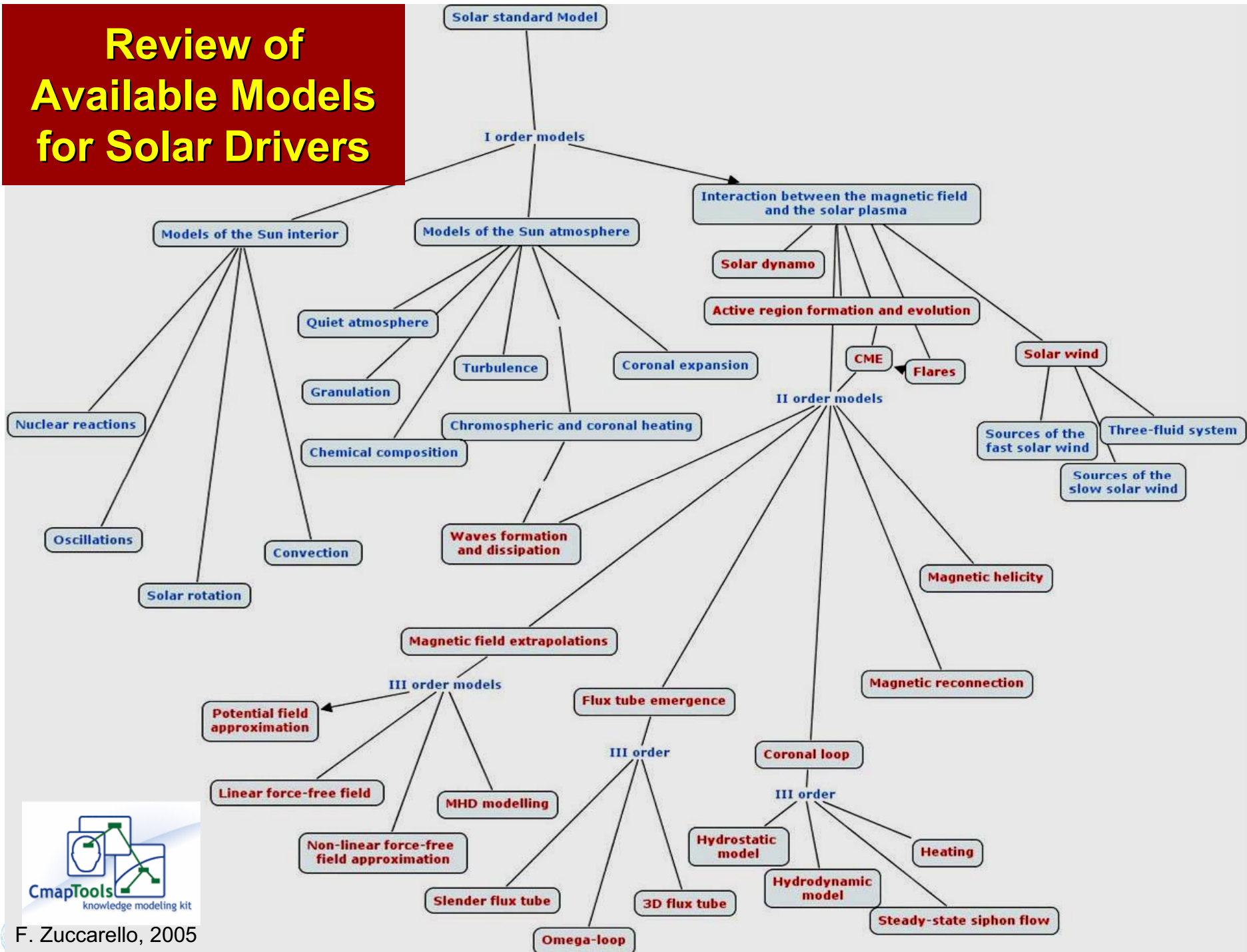
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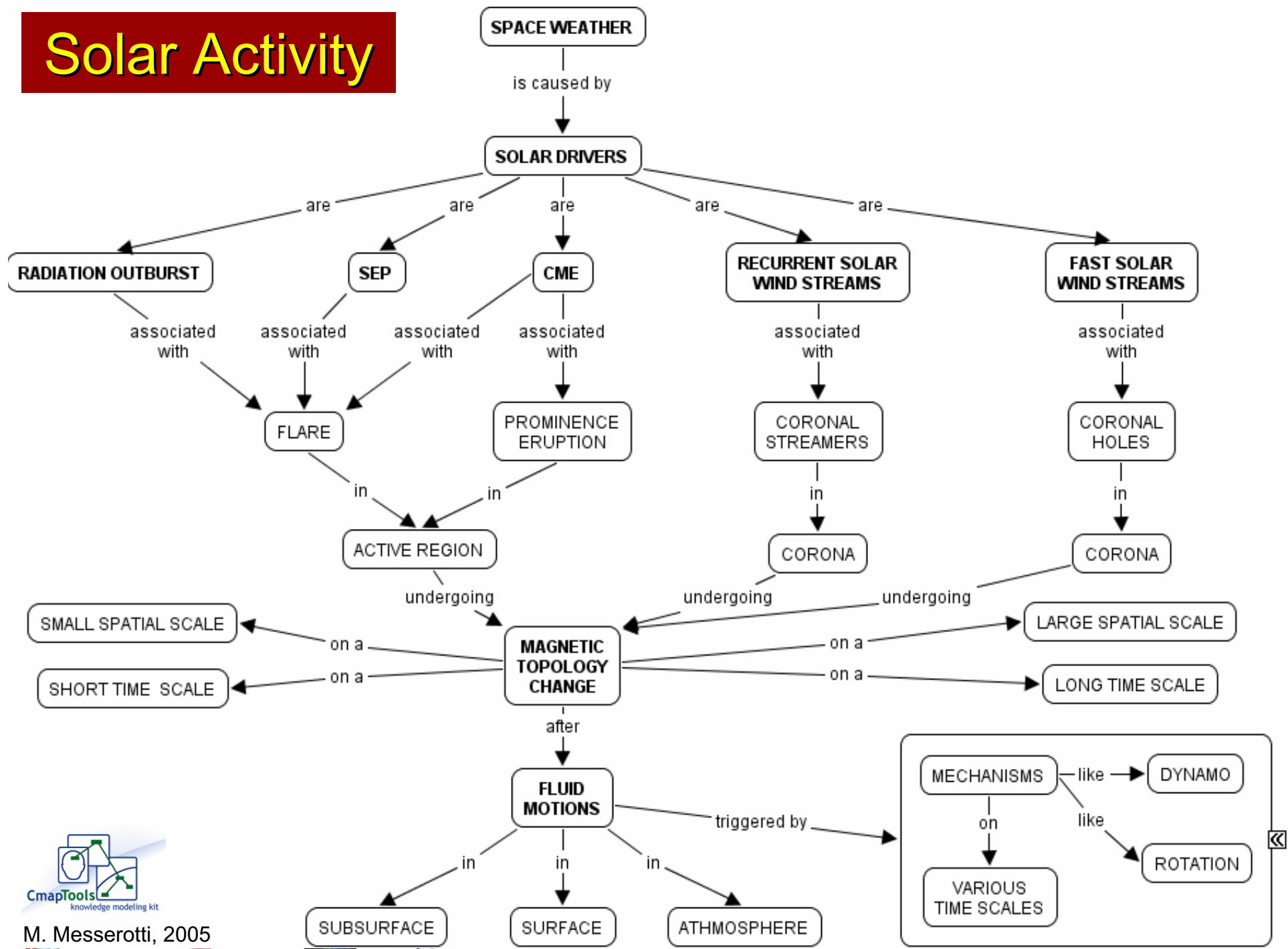
Solar Drivers



Review of Available Models for Solar Drivers

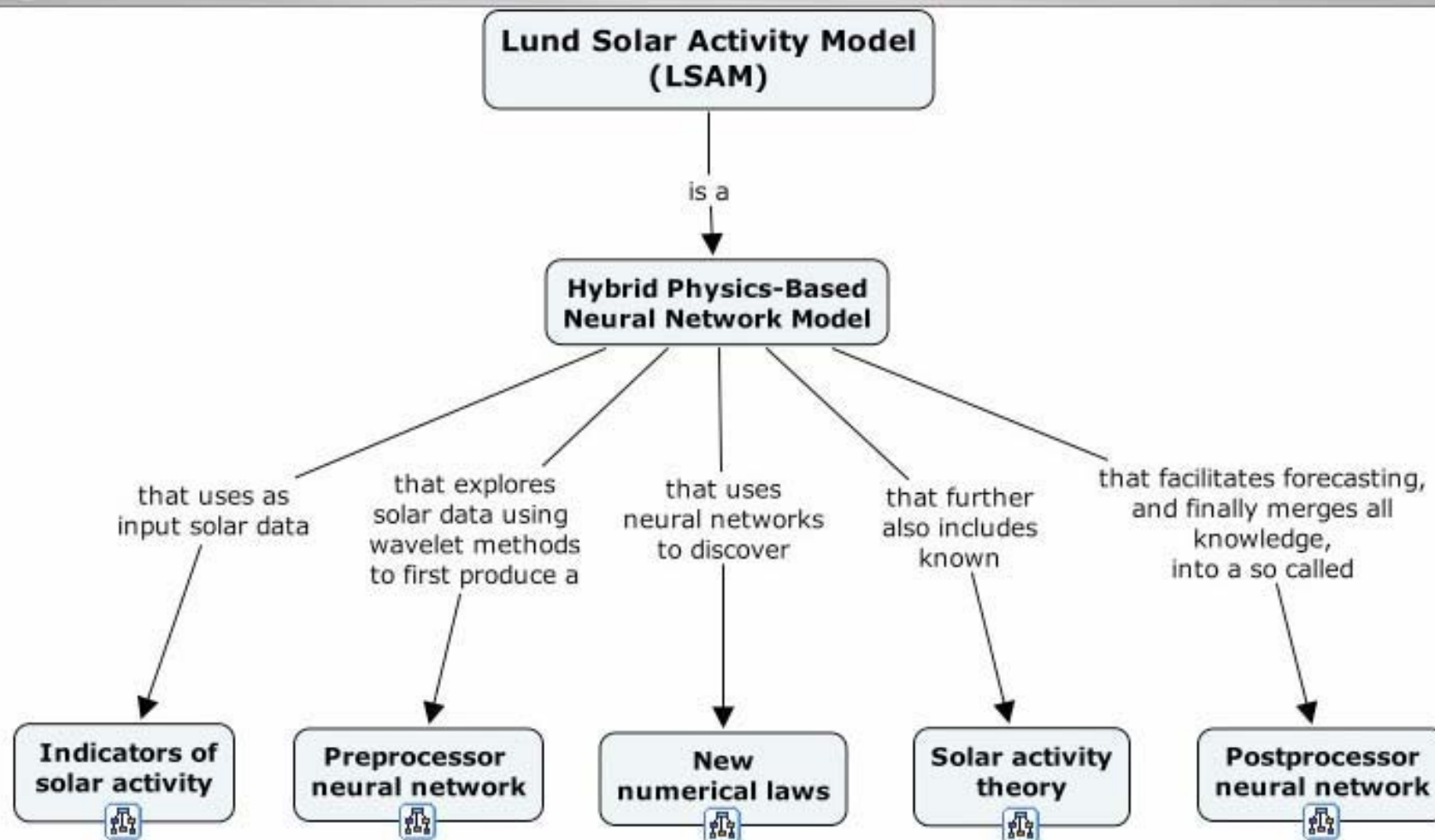


Solar Activity



Hybrid Model for Solar Weather Prediction

lsam.html



This Concept Map was created with
IHMC CmapTools

H. Lundstedt, 2004



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Radio Systems (ISPE)



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Key Issues

- A foundation (domain) ontology for Space Meteorology and Solar Weather has been built by means of Concept Maps in the framework of COST Action 724 – Working Group 1
- A clear and analytical definition of the terminology and of the physical domains is a fundamental guideline in categorizing and interpreting the phenomenology
- The identification of the interrelationships between entities is a fundamental guideline in modelling the drivers
- An approach based on a balance between synthesis and analysis is the most promising one for a deeper understanding of the solar activity complexity and its predictability



Monitoring Scenario: The Pros

- **SOLAR WEATHER MONITORS**

- **Radiation & particles**

- Space-based detection (e.g. SOHO)
 - Ground-based detection (many instruments)

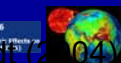
- **Monitored phenomenology**

- Inner plasma
 - Photospheric plasma
 - Chromospheric plasma
 - Coronal plasma
 - Extended coronal plasma



Monitoring Scenario: The Cons

- **SPACE-* and GROUND-BASED MONITORS**
 - INCOMPLETENESS in
 - Phenomenology coverage
 - Spatial coverage
 - Temporal coverage
 - Energy coverage
 - MOSTLY NON-REAL-TIME OPERATIONS
 - LIMITATIONS IN TELEMETRY*
 - UNGUARANTEED MISSION*/OPERATION CONTINUITY
 - LIMITED MISSION*/OPERATION DURATION
 - MISSION*/INSTRUMENTATION DESIGN DRIVEN BY “ALCHEMIC POLITICAL” CONSTRAINTS



Monitoring Scenario: The Data Issues

- **COMMON TO SPACE- AND GROUND-BASED MONITORS:**

- HUGE NUMBER OF DATA SETS
- LARGE NUMBER OF DATA STANDARDS
- LIMITED DATA AVAILABILITY
- NON-REAL-TIME AVAILABILITY
- LIMITED DATA ACCESSIBILITY
- NON-USER-FRIENDLY SEARCH AND RETRIEVAL
- DIFFICULT DATA CALIBRATION
- COMPLEX DATA ANALYSIS
- LIMITED CROSS-DATA AN.

- **POSSIBLE SOLUTIONS TO MOST ISSUES:**

- NONE: WILL INCREASE TO PBs
- COORDINATION ON COMMON STANDARDS
- AGREEMENT ON DATA POLICIES
- DEVELOPMENT OF VIRTUAL MONITORS
- IMPROVEMENT IN WEB ACCESSIBILITY
- ADVANCED DATA HANDLING
- INCORPORATION OF S/W LIBRARIES
- DEVELOPMENT OF VIRTUAL OBSERVATORIES

HS NETWORKING, HPC, I-GRID



Modelling Scenario: The Cons

- NO SELF-CONSISTENT THEORY for:
 - AR formation & evolution
 - FLARE triggering, acceleration, radiation
 - PROMINENCE formation & eruption
 - CME generation & propagation
 - CME plasmoid structure and magnetic field
 - SLOW SW generation, evolution & topology
 - FAST SW generation, evolution & topology
 - IP MAGNETIC FIELD topology
 - INTERACTION with GMF



Forecasting Scenario: The Cons

- LIMITED RESULTS for:
 - AR formation & evolution
 - Expert Systems based on a posteriori modelling
 - FLARE occurrence & class
 - Statistical methods based on precursors & SOC
 - Mainly nowcasting
 - CME formation & evolution
 - Statistical methods based on precursors
 - Mainly nowcasting
- STATE-OF-THE-ART based on hybrid approach involving AI TECHNIQUES
- **THE MAIN ISSUE is THE LACK of / LIMITED SCIENTIFIC KNOWLEDGE on the PHYSICS**



SOLAR WEATHER VISIONS

- Improved knowledge of
 - Physics of solar activity processes
 - Propagation & coupling
 - Precursors, timings & occurrence frequencies
- Comprehensive network of space- & ground-based real-time observatories
- Solar-Terrestrial Virtual Monitor I-Grid
- Geospace models fully incorporate Solar Weather key parameters



IMPROVED NOWCASTING & FORECASTING



The Dream Solar Weather Network

- 3-D solar in situ monitoring (6 RTT spacecrafts)
- 3-D IP in situ monitoring (3 RTT spacecrafts)
- 3-D Earth in situ monitoring (6 RTT spacecrafts)
- Complete ground-based observing network
- Real-time data storage & indexing
- Real-time data availability & analysis
- Real-time modelling & forecasting

Messerotti & Lundstedt (2004)



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Glossary

1

AI	Artificial Intelligence
AR	Active Region
CME	Coronal Mass Ejection
CR	Cosmic Rays
CR-I	Primary Cosmic Rays
GCR	Galactic Cosmic Rays
GMF	GeoMagnetic Field
HPC	High Performance Computing
HS	High Speed
I-Grid	Intelligent Grid
IP	InterPlanetary
PB	PetaByte
RTT	Real-Time Telemetry
SCR	Solar Cosmic Rays
SOC	Self-Organized Criticality
SOHO	Solar and Heliospheric Observatory
SW	Solar Wind
S/W	SoftWare



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- Chela-Flores, J., Messerotti, M.: *Space Weather : a new frontier in bioastronomy*, Astrobiology newsletter, C. Sivaram, A.P. Sastry (Eds.), Indian Institute of Astrophysics, Bangalore, India, Vol. I, No. 4, 1, 2005.
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