Interdisciplinary Space Weather Research: a Road to Follow
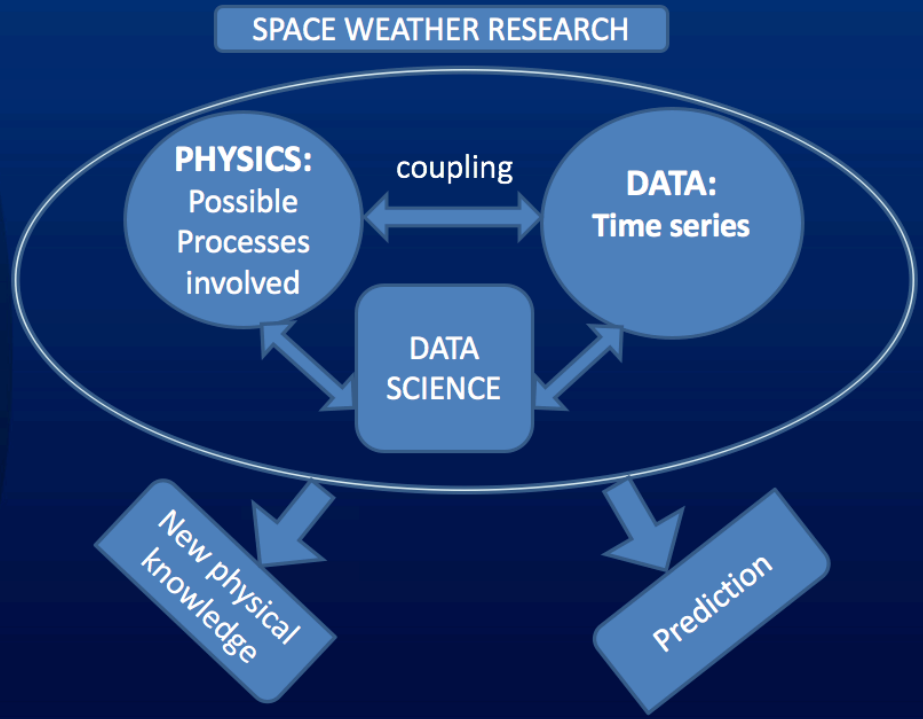
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The thesis of this talk

The road to follow is coupling *Physical Processes* models involved in *SPACE WEATHER* with *Chaos Science* and *Data Science*, using machine learning algorithms and statistical models to analyze and draw inferences from data patterns. This should be done by means of an *Interdisciplinary Approach.*

SPACE WEATHER RESEARCH

PHYSICS: Possible Processes involved — coupling — DATA: Time series

DATA SCIENCE

New physical knowledge

Prediction

Space Weather research

❄ The scope of SPACE WEATHER research is finally to **model and predict** the future behavior of representative variables data series.

❄ The Ability **to predict** contributes to understanding the **physical processes** involved (KNOWLEDGE).

❄ The Ability **to predict** makes effective contributions to human activities (APPLICATION).

To start I like to clarify in the next slides few semantics of words and phrases we use
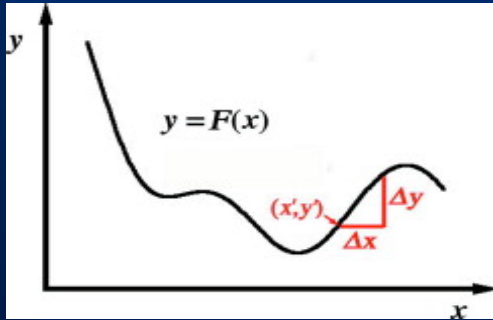

It is correct to say "Effect of Space Weather on the Earth's ionosphere, thermosphere, and magnetosphere system"

or

"Solar activity driven effect on the Earth's ionosphere, thermosphere, and magnetosphere as part of the Space weather system"?

Does the word "multidisciplinary" means the same thing that "interdisciplinary"?

About Physical Sciences

The physical sciences of XX century, including Relativity and Quantum Mechanics, were based on "calculus", a key example of linear approach.
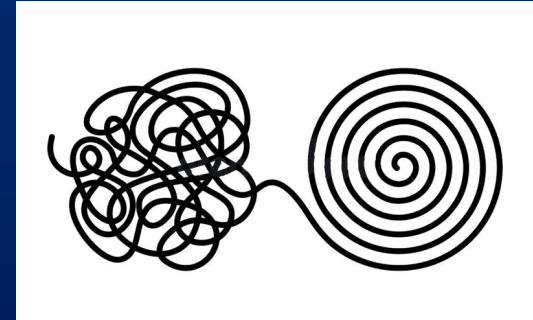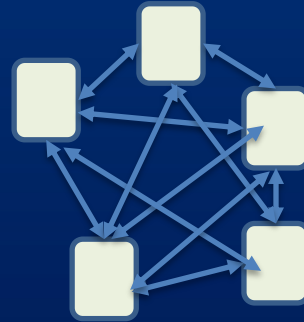

The physical sciences of the XXI century are "coming out of the chaos revolution, it will be about complexity and its principal tool will be the computer" (generalizing from M. Baranger, 2000)

About Systems (1)

A **linear system** is one that can be described by the calculus introduced by Newton and Leibnitz.

A **complex system,** is a system composed of many interacting components. It can be described by non linear differential equations. Complex systems are predictable for a while and then 'appear' to behave random.

❄ **To say that a complex system is chaotic does not mean, of course, that it is dominated by disorder.**

❄ **It has a kind of deterministic order without periodicities and its time evolution is highly dependent on the initial conditions.**

Chaotic Systems (2)

A way to quantify the presence and degree of chaos in a complex system is to measure the Correlation Dimension (D_2) and the Kolmogorov entropy (K_2).

An estimate of time predictability of a given variable is given by $1/K_2$

The characteristic dimension of a complex system is a non-integer value

Higher dimensionality
Lower predictability

$D_2 > 4$
$K_2 > 0.2$ min-1
$1/K_2 < 5$ min

$D_2 < 4$
$K_2 < 0.1$ min^{-1}
$1/K_2 > !0$ min

Lower dimensionality
Higher predictability

Chaos meet Machine Learning

Using a reservoir computing ML model in conjunction with Chaos Theory equations, scientists were able to predict farther into the future than any other method (Pathak et Al. 2018)

❄ Chaos theory says that apparently random processes can actually be described and predicted using a set of complex mathematical non-linear differential equations

❄ One way to combine Machine Learning model with Chaos Theory equations solving is to train a Machine Learning model on data obtained from chaos equations.

We need to go from a **"linear thinking"** to a **"complex thinking"**
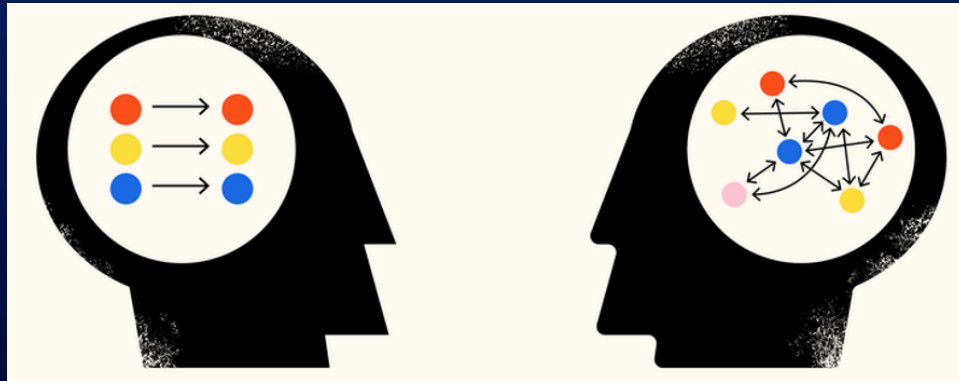
Linear and Complex thinking

LINEAR THINKING:

❄ It is a <u>systematic</u> and analytical way to describe processes in systems, following a known step-by-step progression similar to a straight line.

❄ It considers a process to begin from a point, follow a series of connected steps, and end at a point.

COMPLEX THINKING:

❄ It is to handle a complex system in a <u>systemic</u> and inclusive way.

❄ It avoids dividing systems into independent subsets, looking at the interactions between components of the system.

❄ It aims for a better understanding of complexity through an <u>interdisciplinary work</u>.

About disciplinarities (1)
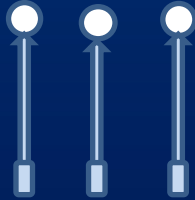
Disciplinary: confined to one Academic discipline; objectives fixed by the discipline; gain knowledge relevant to the discipline.
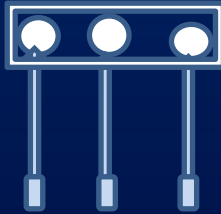
Multidisciplinary: relative to multiple disciplines; multiple disciplinary objectives under one thematic umbrella.
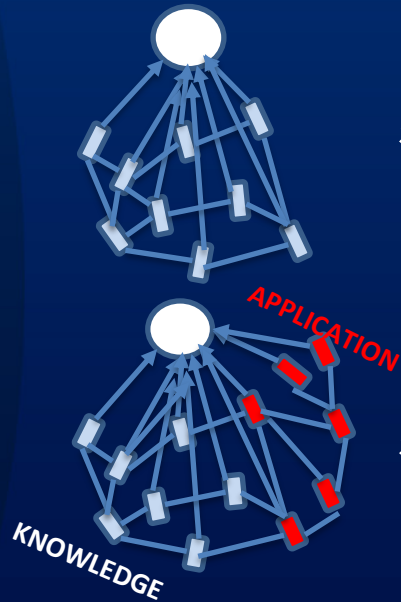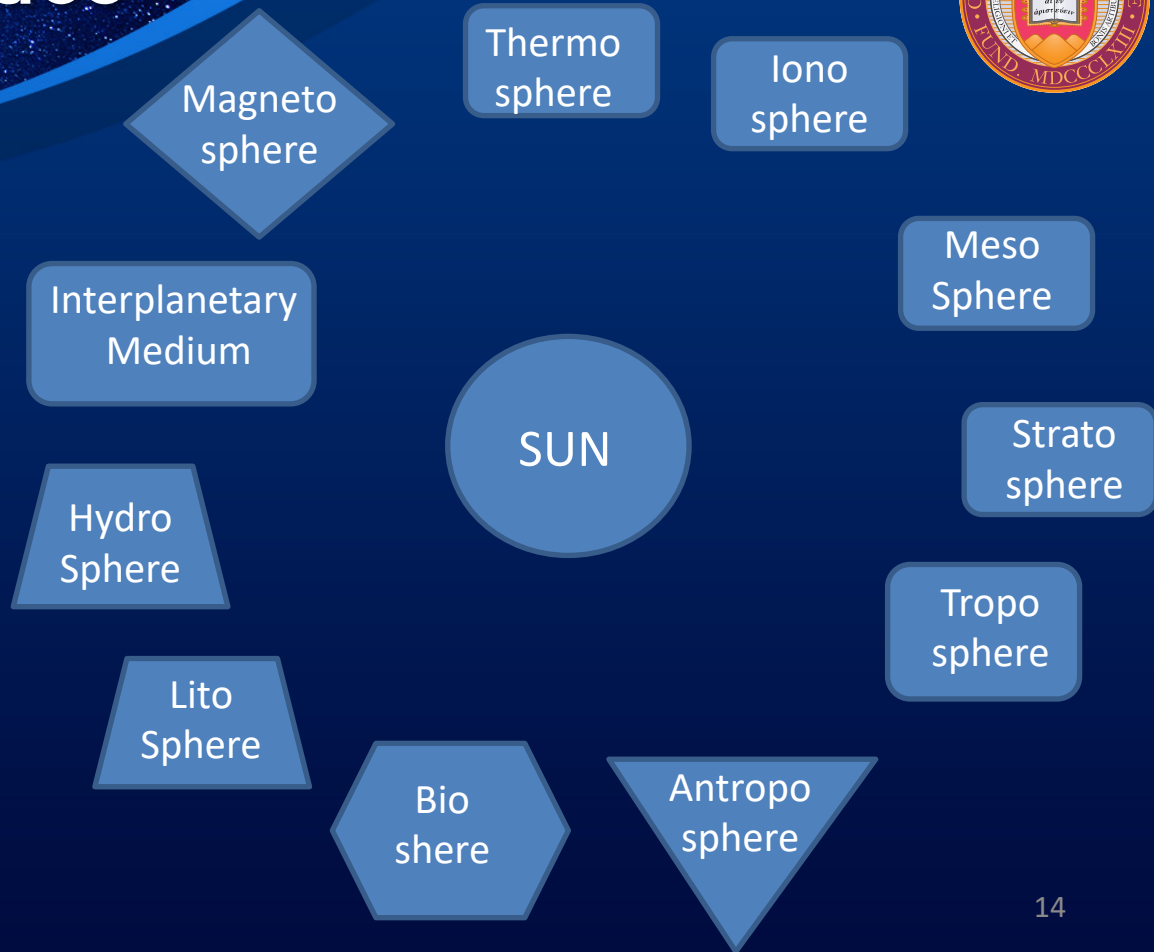
Interdisciplinary: share and integrate specialized knowledge beyond discipline boundaries; search for common objectives.

Convergence: crosses disciplinary and sectorial boundaries; develops integrated knowledge for science and society.

Let us go back to Space Weather

Earth and Space Environment Systems

Magneto sphere

Thermo sphere

Iono sphere

Meso Sphere

Interplanetary Medium

SUN

Strato sphere

Hydro Sphere

Tropo sphere

Lito Sphere

Bio shere

Antropo sphere

Each of them is a **COMPLEX** system studied by a single discipline or in a multidisciplinary way

Are they interrelated? YES

A possible indication
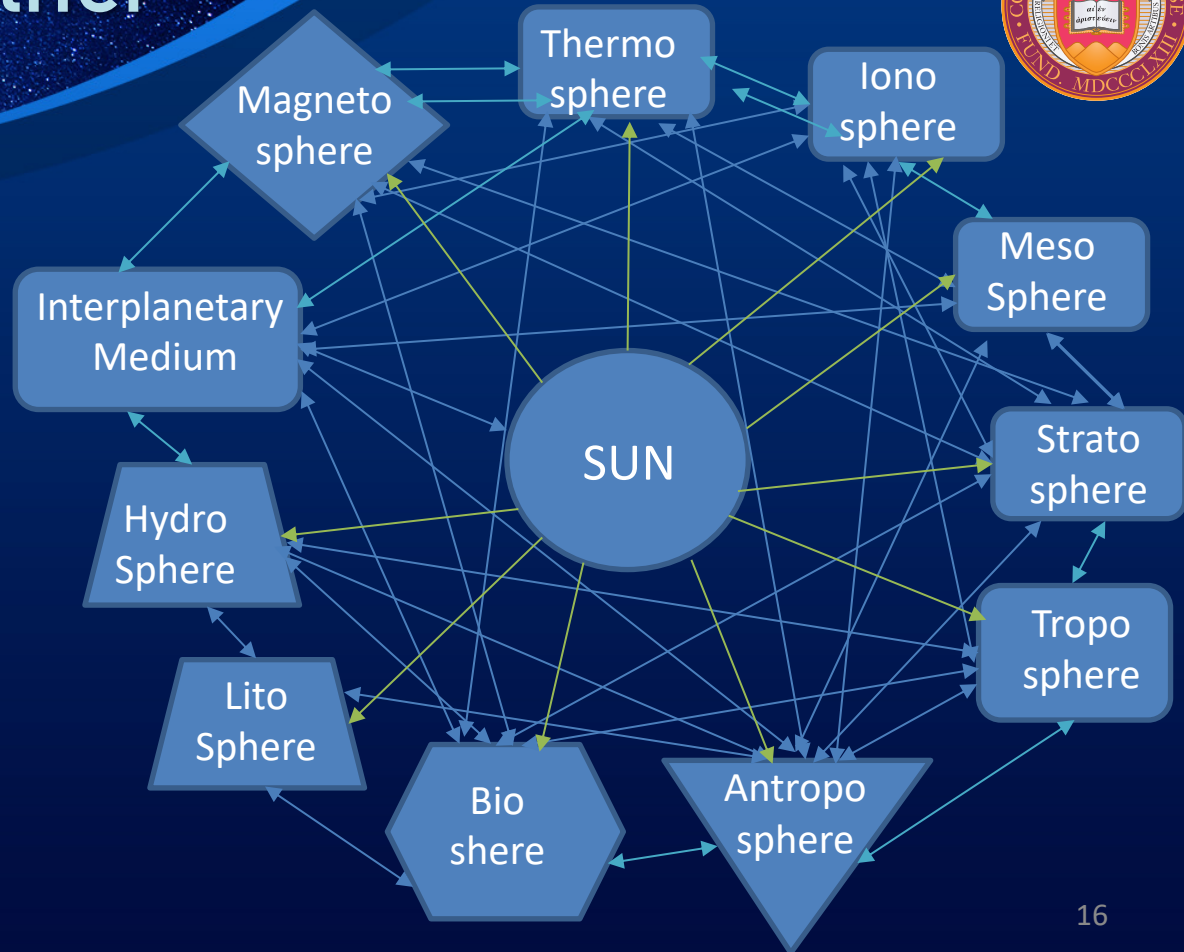
Each of the components of Space Weather behaves as a low dimensional chaotic system

They show similar Correlation Dimension
And Kolmogorov Entropy (examples)

System	D2	K2	Authors
SUN			
Radio Pulsations	3.2-3.8	0.04	Kurths_ Herzel (1987)
F10.7	3.3-4.5	0.02-0.04	Romanelli_et_al. (1987)
F10.7	3.5	0.07	Romanelli_et_al. (1988)
MAGNETOSPHERE			
AE	3.3	0.08	Romanelli_et_al. (1988)
AE	3.6	0.2	Vassiliadis_et_al.(1990)
AE & SYM-H	1.0-4.0	0.2-0.02	Consolini_et_al (2018)
IONOSPHERE			
foF2	3.4	0.04	Romanelli_et_al. (1988)
TEC	2.78	0.12-0.13	Materassi_et_al (2023)

To sum up

SPACE WEATHER RESEARCH

PHYSICS: Possible Processes involved — coupling — DATA: Time series

DATA SCIENCE

New physical knowledge

Prediction
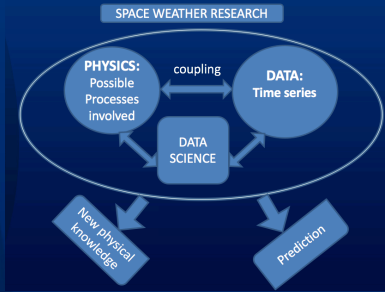
SPACE WEATHER
is a CHAOTIC COMPLEX System
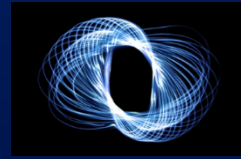SPACE WEATHER SCIENCE

If we accept that

The physical sciences of the XXI century
Are "coming out of the chaos revolution,
it will be about complexity and its
principal tool will be the computer"
(generalized from M. Baranger, 2000)

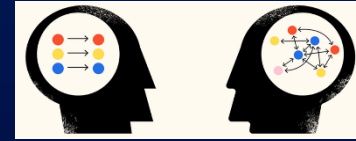We need to go from a "linear thinking"
to a "complex thinking"

Data Science
(Machine Learning)

Chaos
Science

And This
brings to

All of this guided by physics!

By the way

It is correct to say "Effect of Space Weather on the Earth's ionosphere, thermosphere, and magnetosphere system"

Accepting the Thesis, this is more correct

or

"Solar activity driven effect on the Earth's ionosphere, thermosphere, and magnetosphere as part of the Space Weather system"

Does the word "multidisciplinary" means the same thing that "interdisciplinary"? **NO**

A road to follow

Thank you for Your attention 👋

References

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About words used

Semantics refers not only on how words express meaning but also on how words, phrases and sentences create meaning in language.

Systematic describes something done or acting according to a fixed plan or system; methodical.

Systemic refers to the deal with the whole complexity of a system and not to a particular part of it.