Nano-sat for space weather

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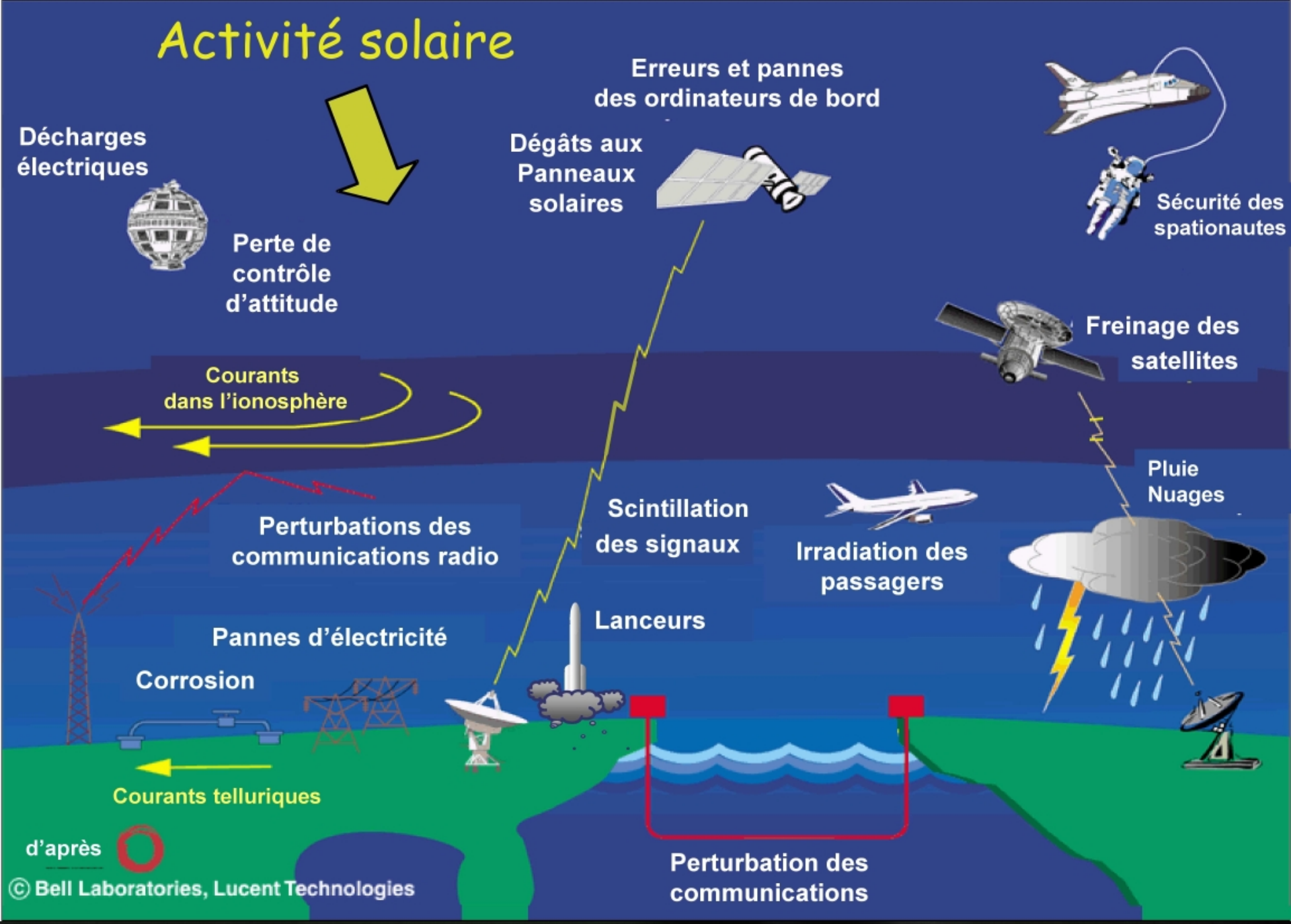
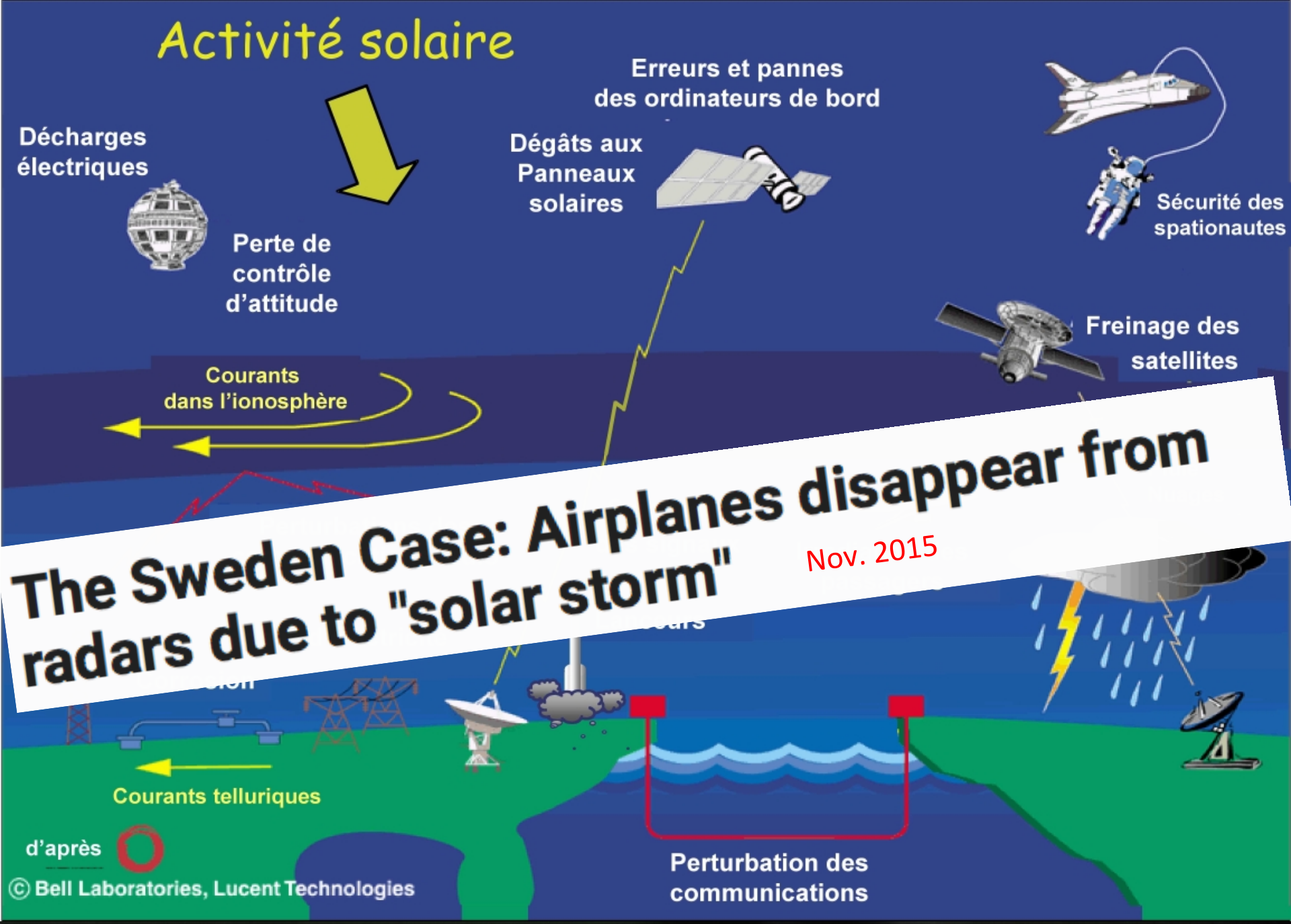
Space weather

- World Meteorological Organisation (WMO) recent definition:
- 1. *[Space environment]*
  The physical and phenomenological state of the natural space environment, including the Sun and the interplanetary and planetary environments.
- 2. *[Meteorology of space]*
  The discipline which aims at observing, understanding and predicting the state of the Sun, of the interplanetary and planetary environments, their disturbances, and the potential impacts of these disturbances on biological and technological systems.


Activité solaire
Erreurs et pannes des ordinateurs de bord
Décharges électriques
Dégâts aux Panneaux solaires
Sécurité des spationautes
Perte de contrôle d'attitude
Freinage des satellites
Courants dans l'ionosphère
Pluie
Nuages
Perturbations des communications radio
Scintillation des signaux
Irradiation des passagers
Lanceurs
Pannes d'électricité
Corrosion
Courants telluriques
d'après
© Bell Laboratories, Lucent Technologies
Perturbation des communications

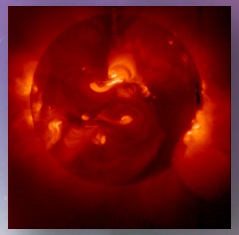


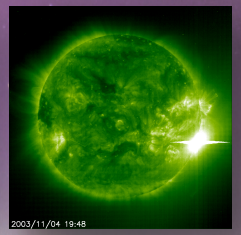
The Sweden Case: Airplanes disappear from radars due to "solar storm"

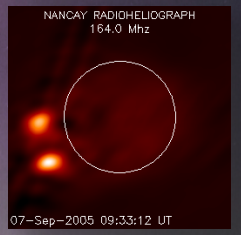
Nov. 2015

Eruptive events: large energy release

EM Radiation: from γ/X to Radio





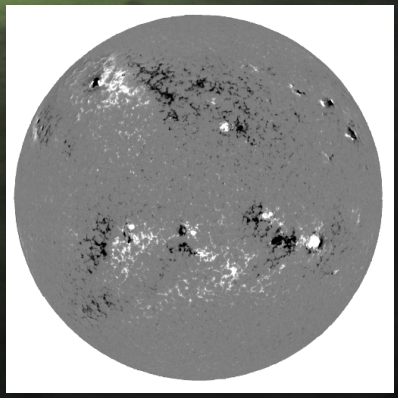


Energetic Particles

Electron: up to hundreds MeV
Protons : up to GeV

Main drivers: magnetic field reconfiguration

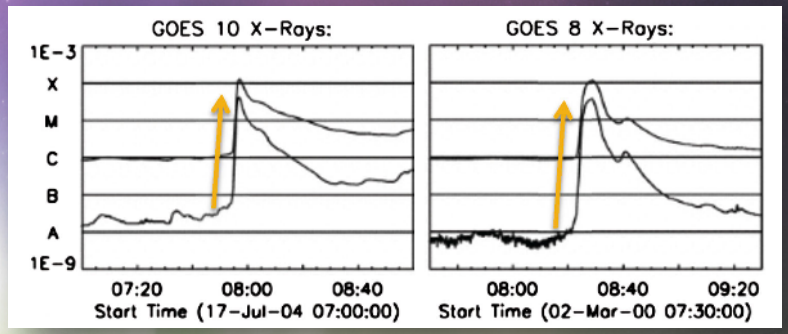
Emergence of new polarity, polarity complexity, MF topology, time evolution



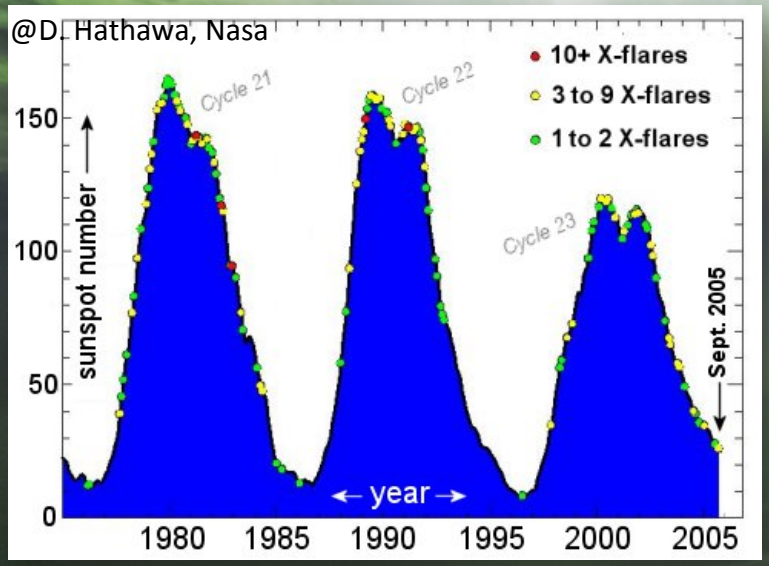
Magnetic field **vector**

Temporal consideration

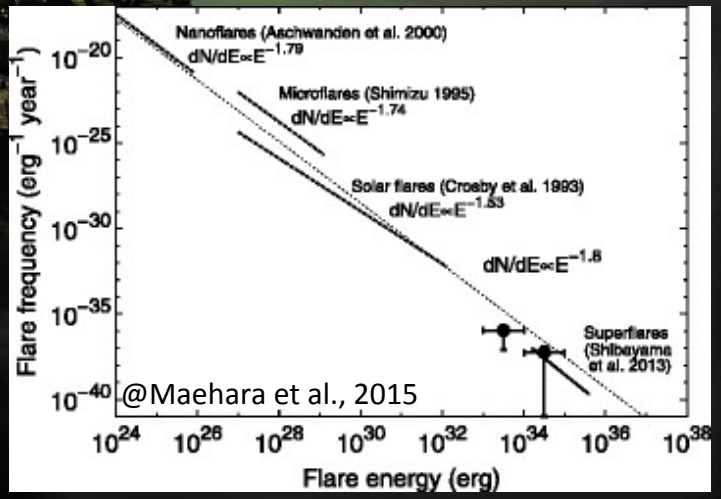
@Wang & Zang 2007



Energy release within a few minutes



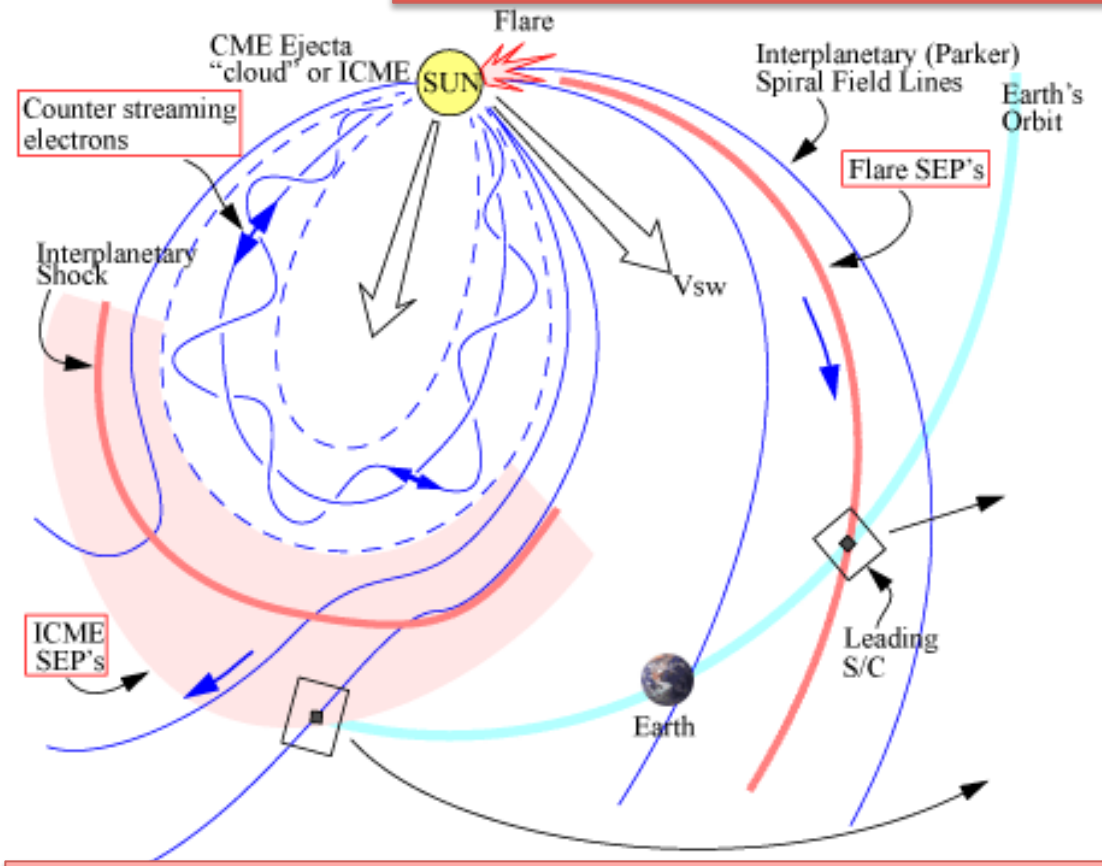
Number of eruptive events mostly follows the solar cycle but energetic events also occur far from the maximum (red dots)



Extreme events are rare but are the most dangerous

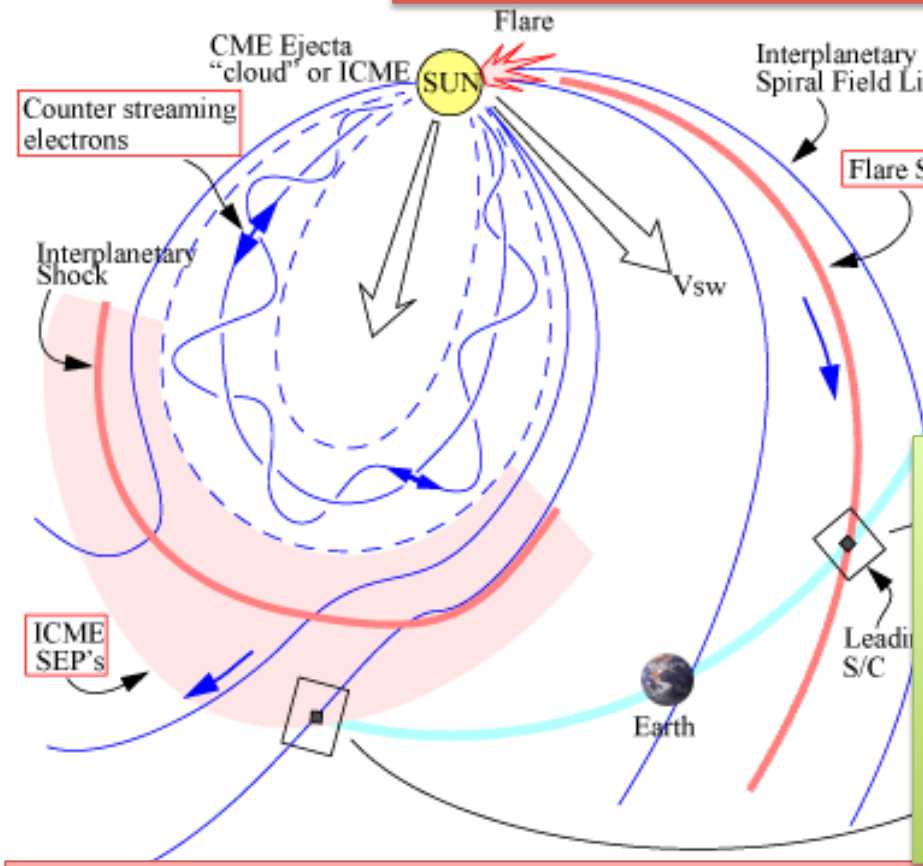
INTERPLANETARY SPACE

Energetic electron beam popagation (0.1 – 0.5c)



Acceleration of protons/ions at interplanetary shocks (MeV-GeV)

Energetic electron beam popagation (0.1 – 0.5c)



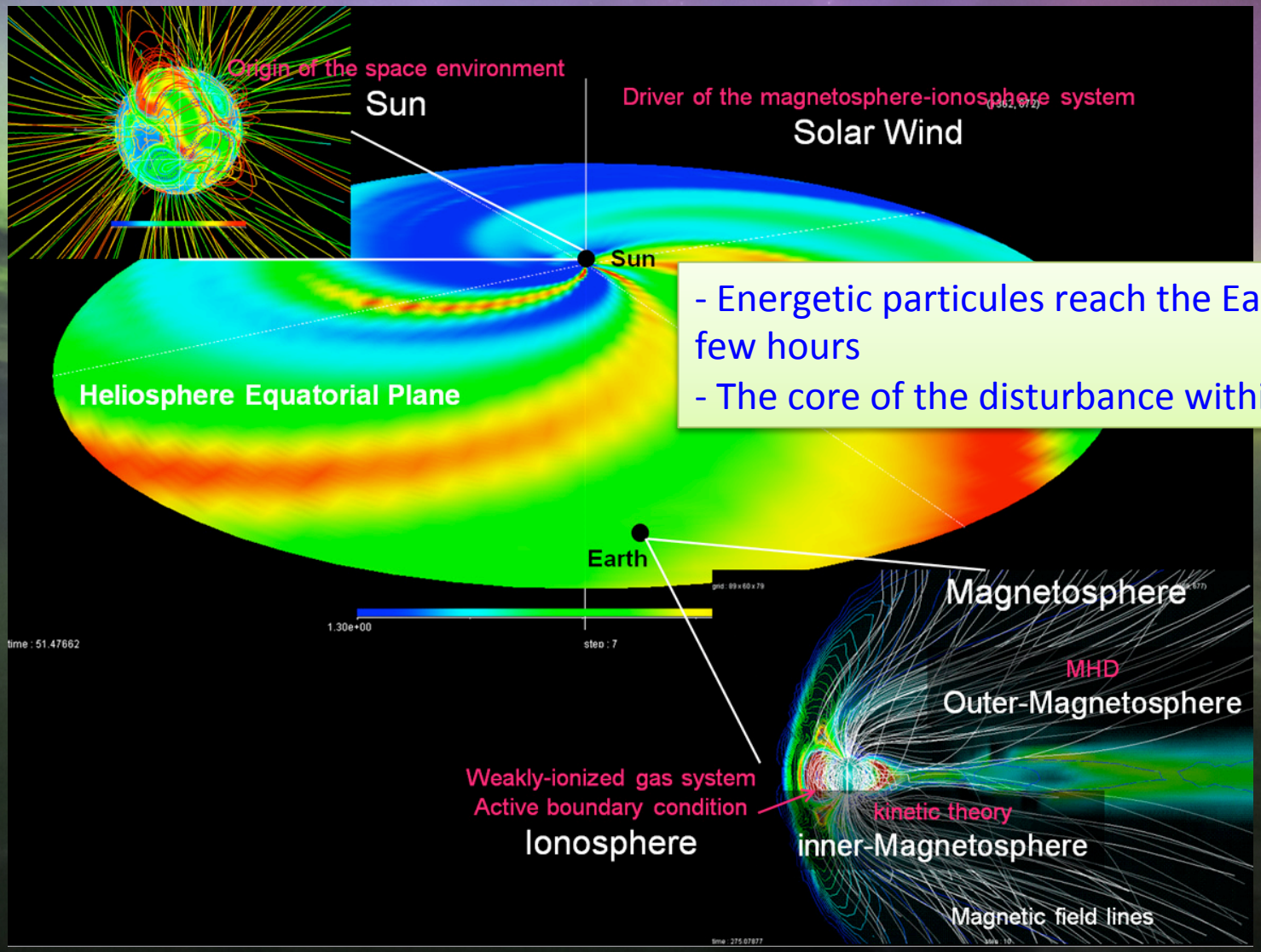
Remote sensing radio and white light

In situ measurements of:

- Particles
  - distribution function/pitch angle
  - Density / velocity
- Fields
  - Magnetic (continuum → HF)
  - Electric (waves)

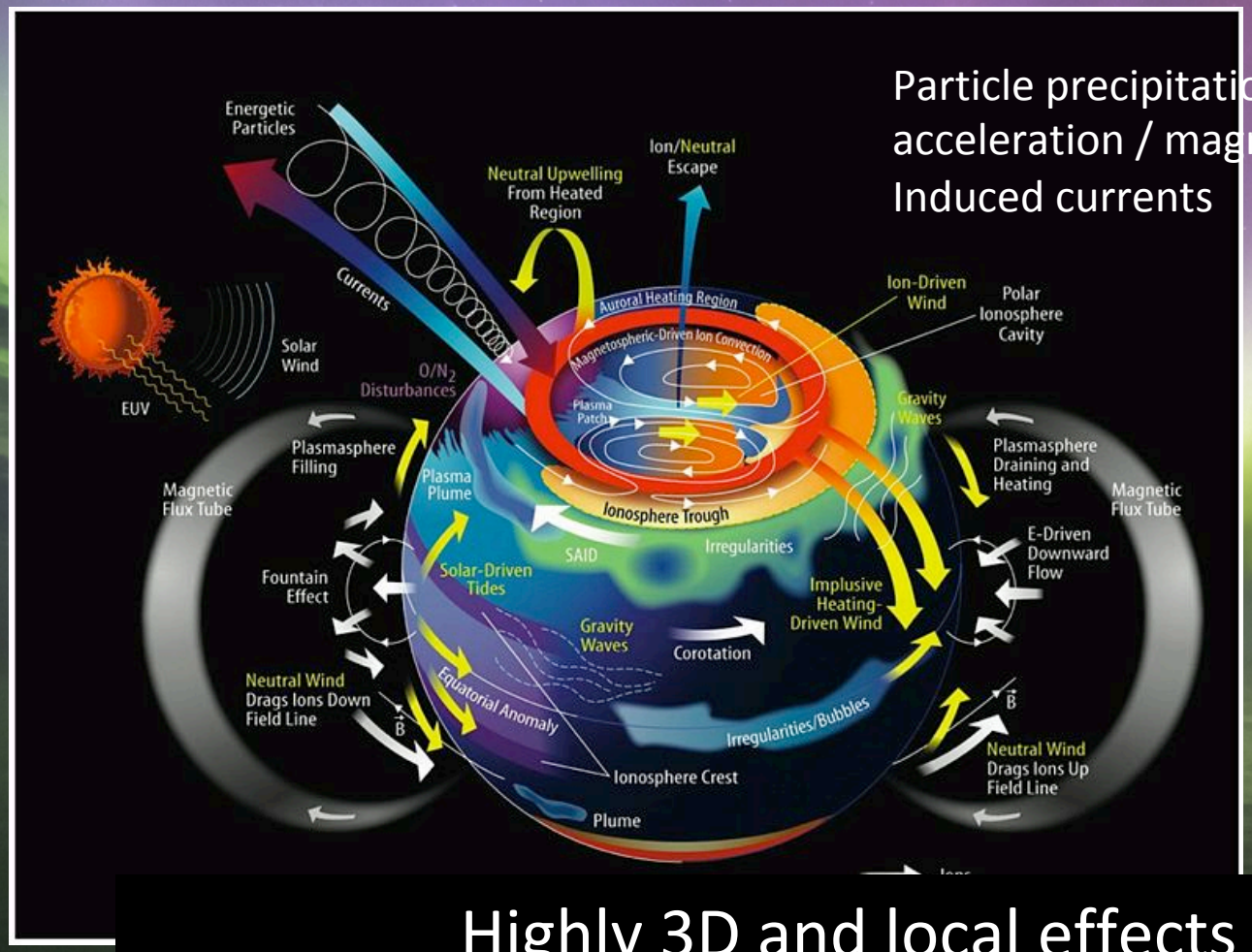
Acceleration of protons/ions at interplanetary shocks (MeV-GeV)

Magnetosphere/ionosphere



- Energetic particules reach the Earth within a few hours
- The core of the disturbance within a few days

Magnetosphere/ionosphere



Particle precipitations / particle acceleration / magnetic reconnection / Induced currents

Highly 3D and local effects

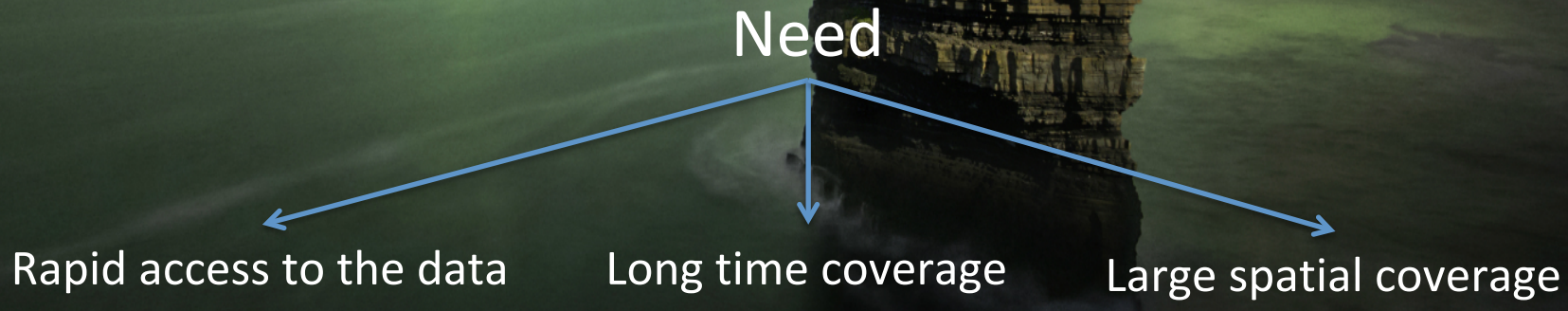
Non stationary system : highly time dependent

Global system vision mandatory

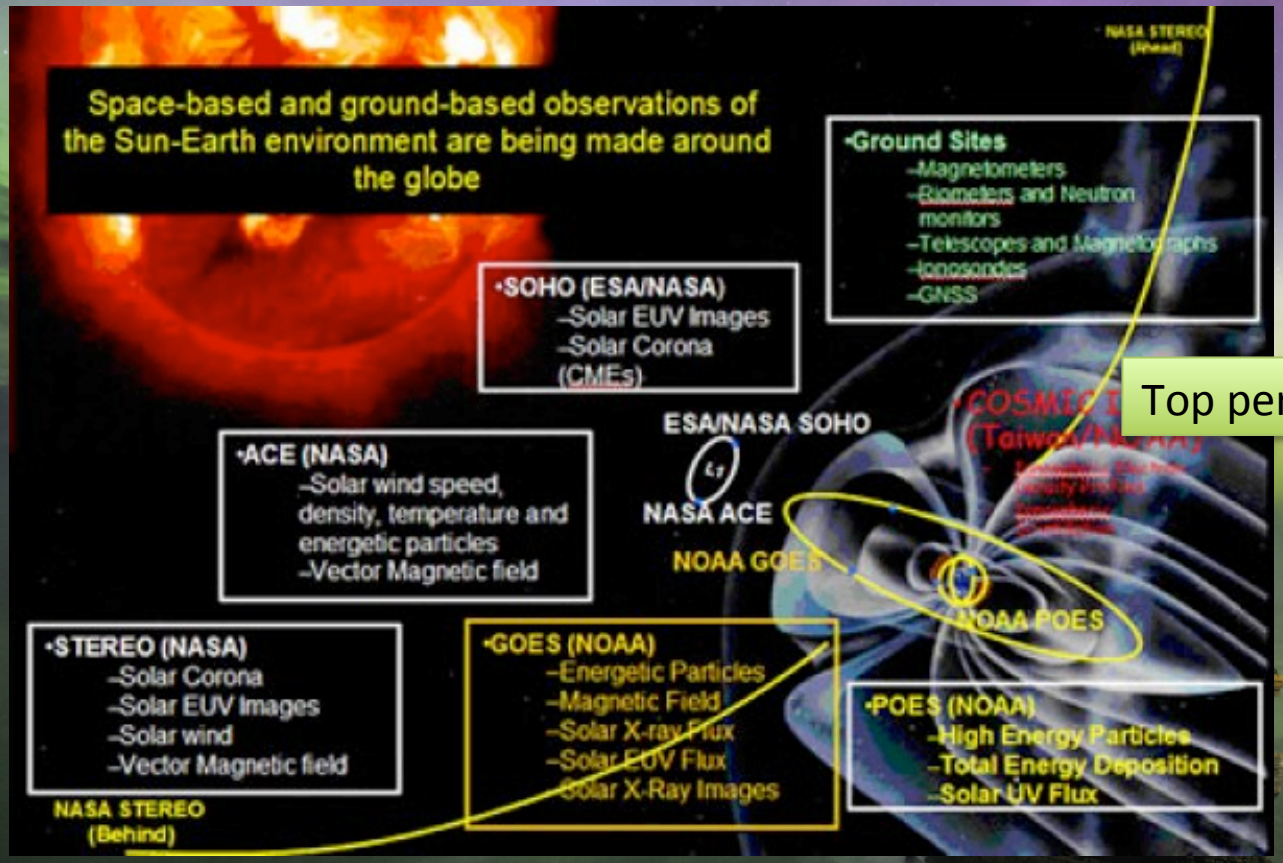
Most of the models are strictly scientific,
i.e. runs are too long for forecast, not constraints by observations

Towards forecasting models

Models with data-assimilation are developped
(*solar magnetic maps, solar wind, ionosphere …*)

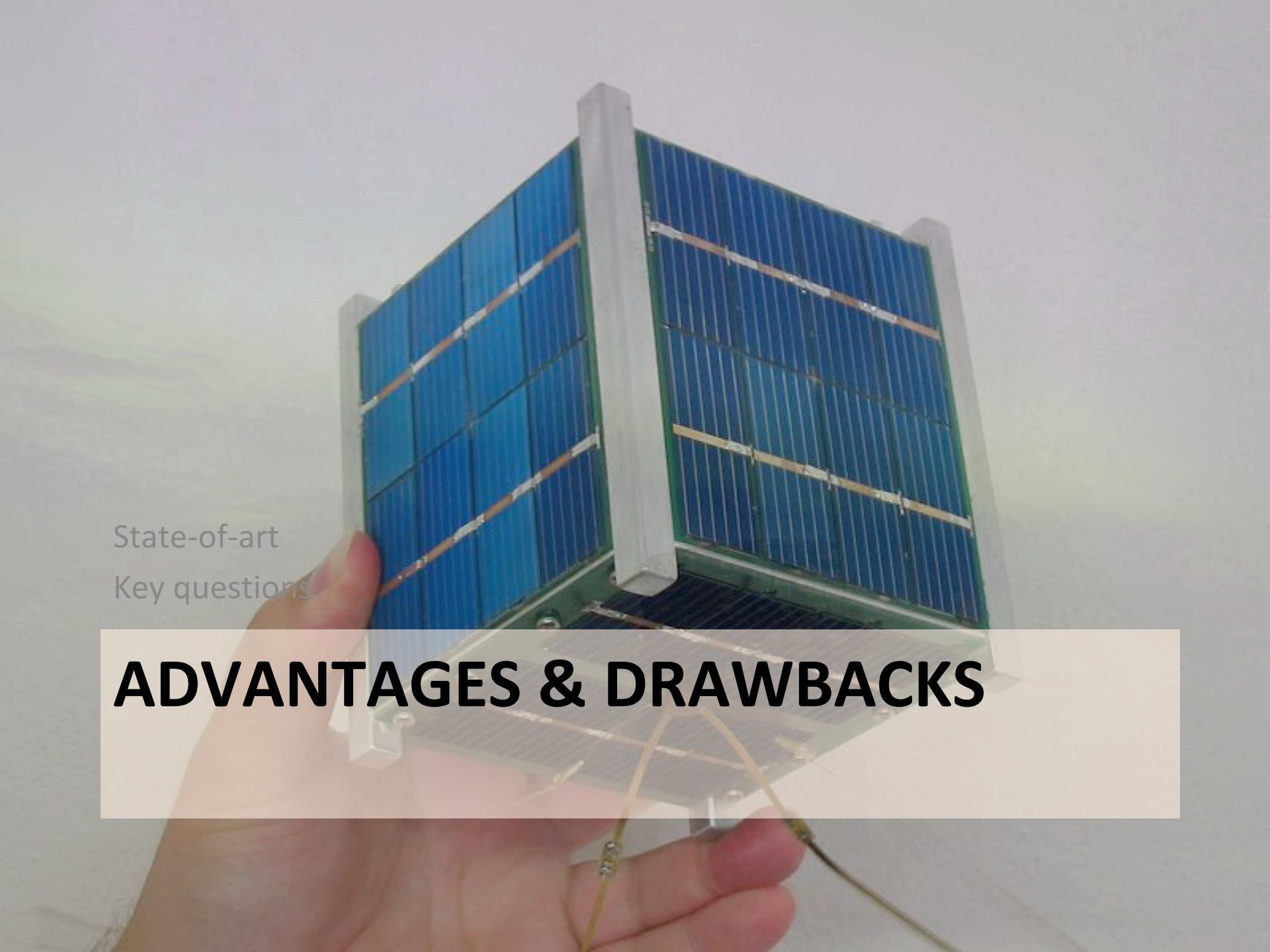


Nowaday observations



Top performance instrumentation

Limited spatial (single point) and temporal coverage (long time between revisit)
Not always compatible with data assimilation/forecast



State-of-art

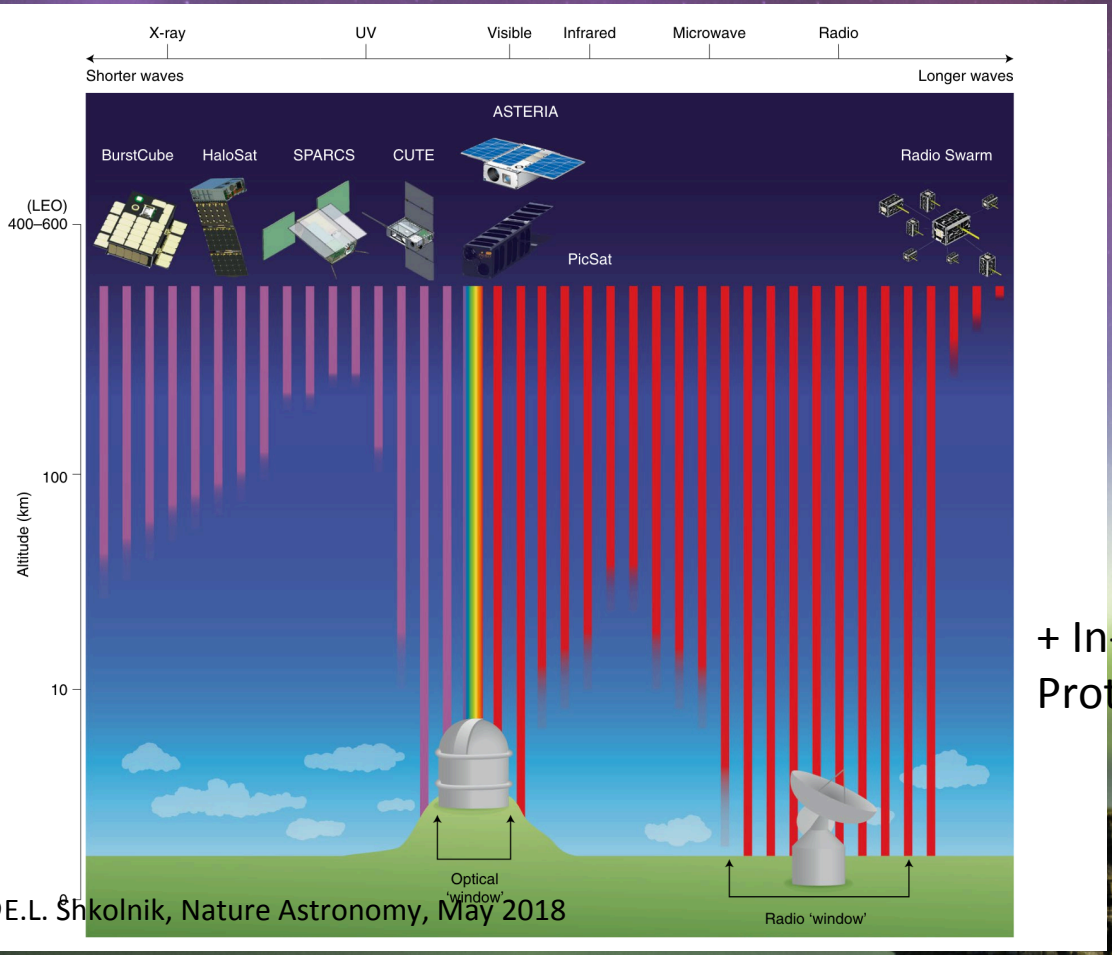
Key questions

ADVANTAGES & DRAWBACKS

Science & Cubesat

- Science:
  - ADS « cubesat » : 32 papers in 2016, 79 in 2018 (from 2001 -- all domains concerned)
  - At the beginning, mostly for educational purposes

- From 2008 also projets with genuine scientific goals
  - NSF started a program to support CubeSat based mission (in particular for SW & atmospheric research)
  - A succesfull example : CSSWE
    - 9 scientific papers (JGR, GRL)
    - 1 thesis (« small satellite passive magnetic attitude control »)
- Monitoring all the Earth SYSTEM for SW forecast



@E.L. Shkolnik, Nature Astronomy, May 2018

+ In-situ sensors (particles – Electrons, Protons --, E&B Fields)

Almost all domains accessible yet, technics improving very quickly

Large missions : versatile instruments for scientific objectives and observations set-up

CubeSat: focus on specific, limited number of objectives but complementary to large space missions

https://www.nanosats.eu/

Why CubeSat For space weather

- Solar observations: **single point observation OK** (remote images)
- Solar wind/Magnetosphere/ ionosphere: **multi-points mandatory**
  - Different orbits (altitudes & type) to catch in-situ measurements related to the disturbances due to solar wind

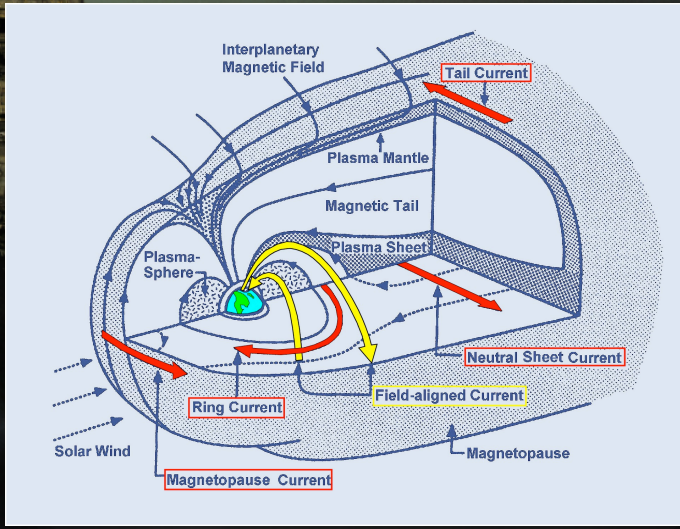
Temporal coverage

- Solar Observations:
  - solar cycle, irradiance : Long term, stable instrumentation (calibration)
  - Eruptive phenomenon: high cadence (few images / s), polarization
- Solar wind /magnetosphere/ ionosphere:
  - Almost continuous monitoring for alert of “non standard” periods

Constellation of cubesat to :

- capture **3D information** from the low ionosphere up to the bow-shock (25 Re - ~9.104km)
- **Frequent revisits** of specific regions

Nano like ground-based instruments used to monitor the Earth’s atmosphere

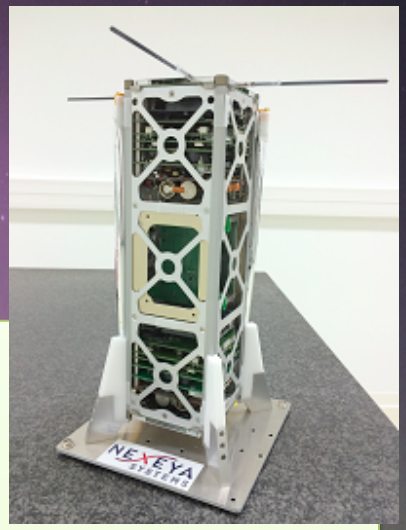


Some limitations but …

- Orbit
  - Most low orbit (between 450 up to 800km) - propulsion
  - Ionosphere and exosphere
  - Only HeL1Nano to L1
- Lifetime
  - Short (a few months up to one year)
  - However, other Nano have been working for 10 years (average mission 40months)
- EMC compatibility
- Stabilisation
  - HeL1Nano: sun stabilized
  - Under development for exoplanet's studies

- NASA strong interest (support R&T, e.g. CuSPP or EXOCUBE)
- ESA: techno. demonstraters + SIMBA (TSI); PICASSO (stratosphere); RadCud (radiation and B field) + …
- Increasing interest of the industry (*commercial purposes but not only*)
  - ASTRA (DICE, DIME …)
  - Airbus Defense & Industry
  - Lockheed Martin Space Systems Company
  - Orbital Sciences (US), Kosmotras (Russian)
  - Pumpkin, Clide Space, Google, Space X …

Future



- Larger and higher
  - NEXEYA:
    - Work on 9U, 12U, 27U
    - Would bring the nano up to 800-900km
  - Google, SPACE-X : also
- Change of paradigm: Push towards new technical developments, e.g.
  - Photon sieve telescopes, deformable mirrors (DeMi)
  - Solar sails
  - X-rays detectors, radiometer …
- Many field of astrophysics
  - Exoplanets (stabilization of the plateform)
  - Interferometry (communication)
  - dwarfs, SN, AGN … (UV astronomy)
  - Interplanetary dust (polarization)
  - Earth sciences and monitoring (constellation, response time and coverage)
  - …
- SSA context : common instruments for a complete survey of the space risks