artificial intelligence and the ESA solar orbiter mission

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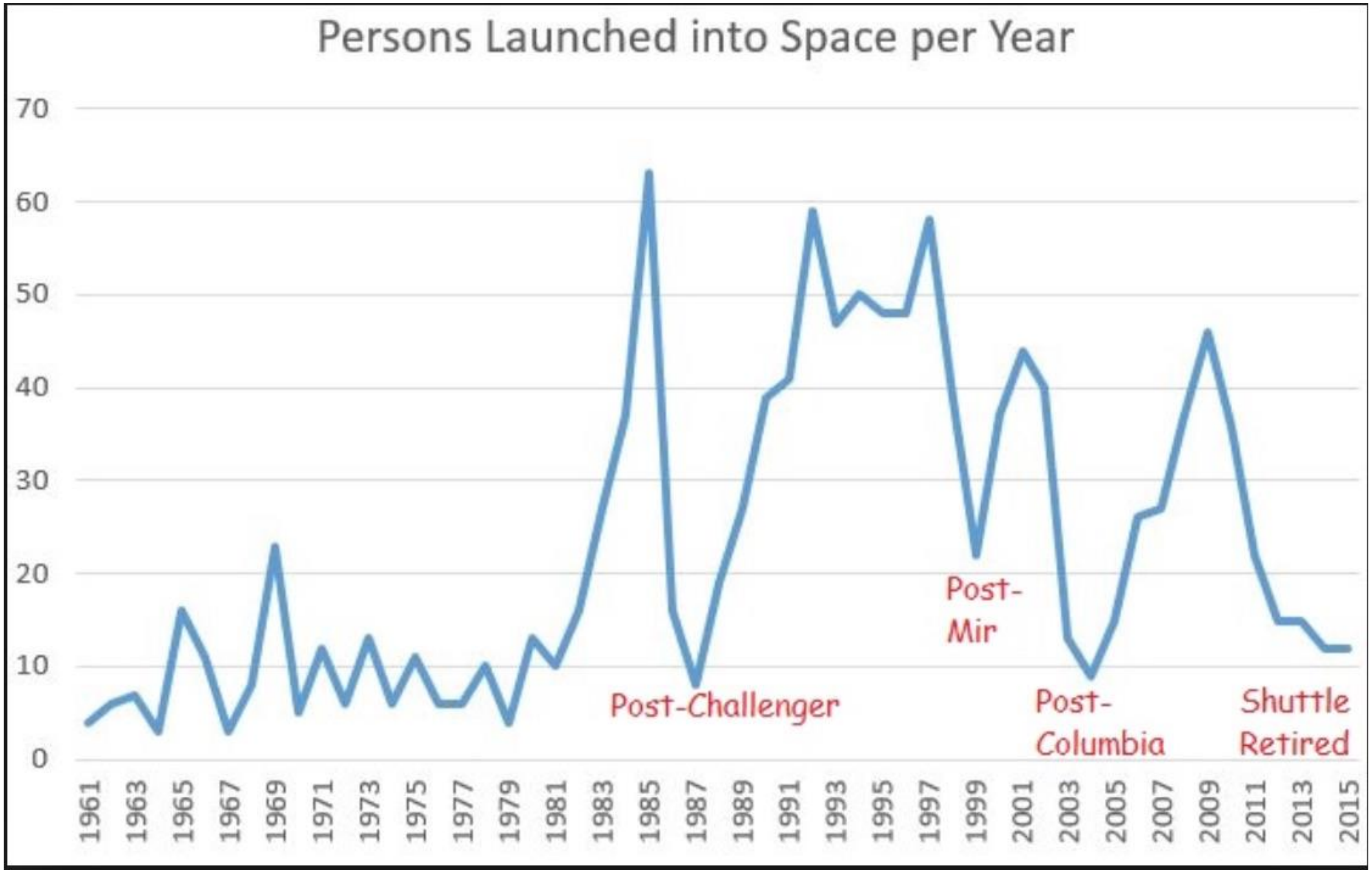
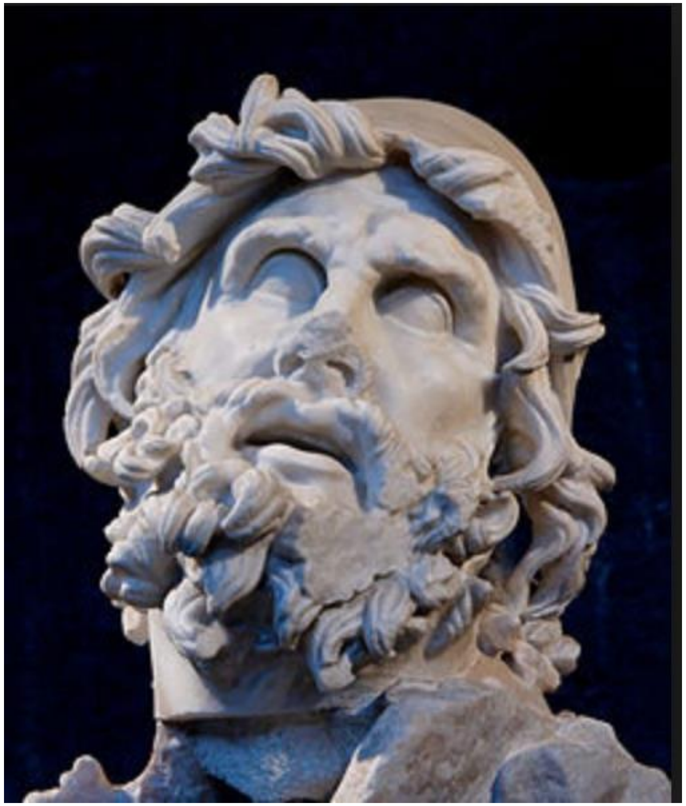

Persons Launched into Space per Year
70
60
50
40
30
20
10
0
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Post-Challenger
Post-Mir
Post-Columbia
Shuttle Retired

why is space travel worth it?

‘lo maggior corno della fiamma antica’

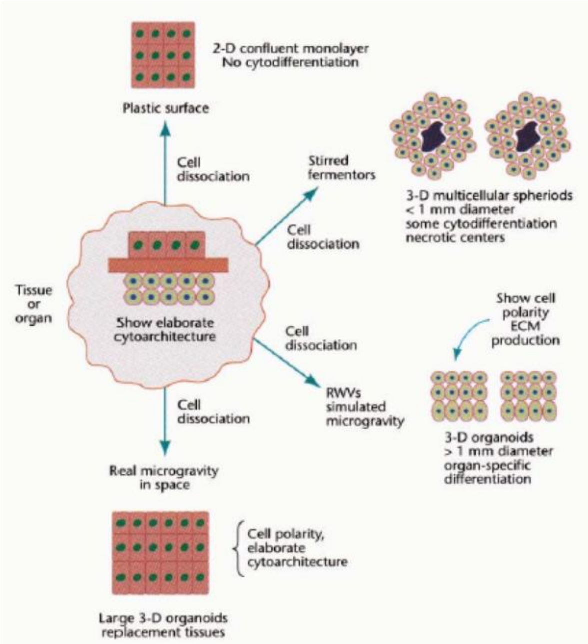
‘...quando
mi dipartì da Circe, che sottrasse
me più d’un anno là presso a Gaeta,
prima che sì Enea la nomasse,



né dolcezza di figlio, né la pieta
del vecchio padre, né ’l debito amore
lo qual dovea Penelopè far lieta,

vincer potero dentro a me l’ardore
ch’i’ ebbi a divenir del mondo esperto
e de li vizi umani e del valore;...’

new achievements in science

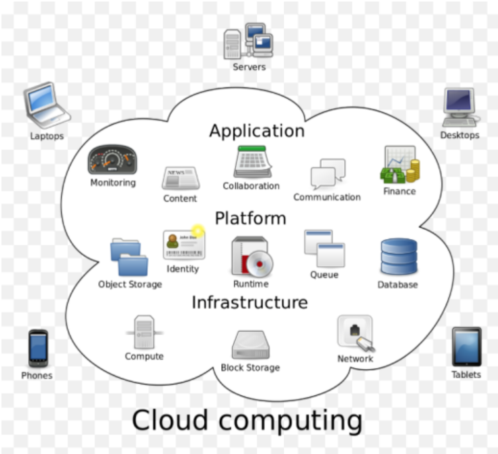


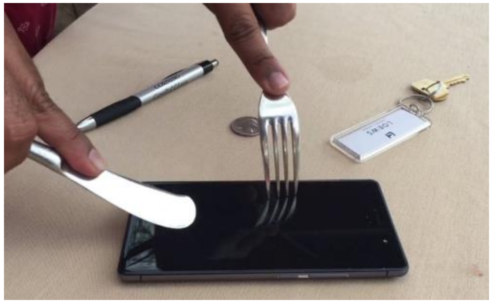
tissue growth in microgravity
(unsworth and lelkes, *nature medicine*, 1998)

analysis of cosmic rays:

- antimatter
- dark matter

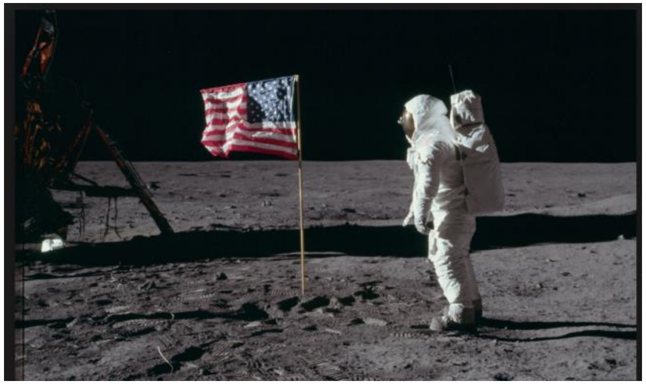
NASA spin-off technologies





why is space travel not worth it?

are we still ready to spend huge amounts of money?

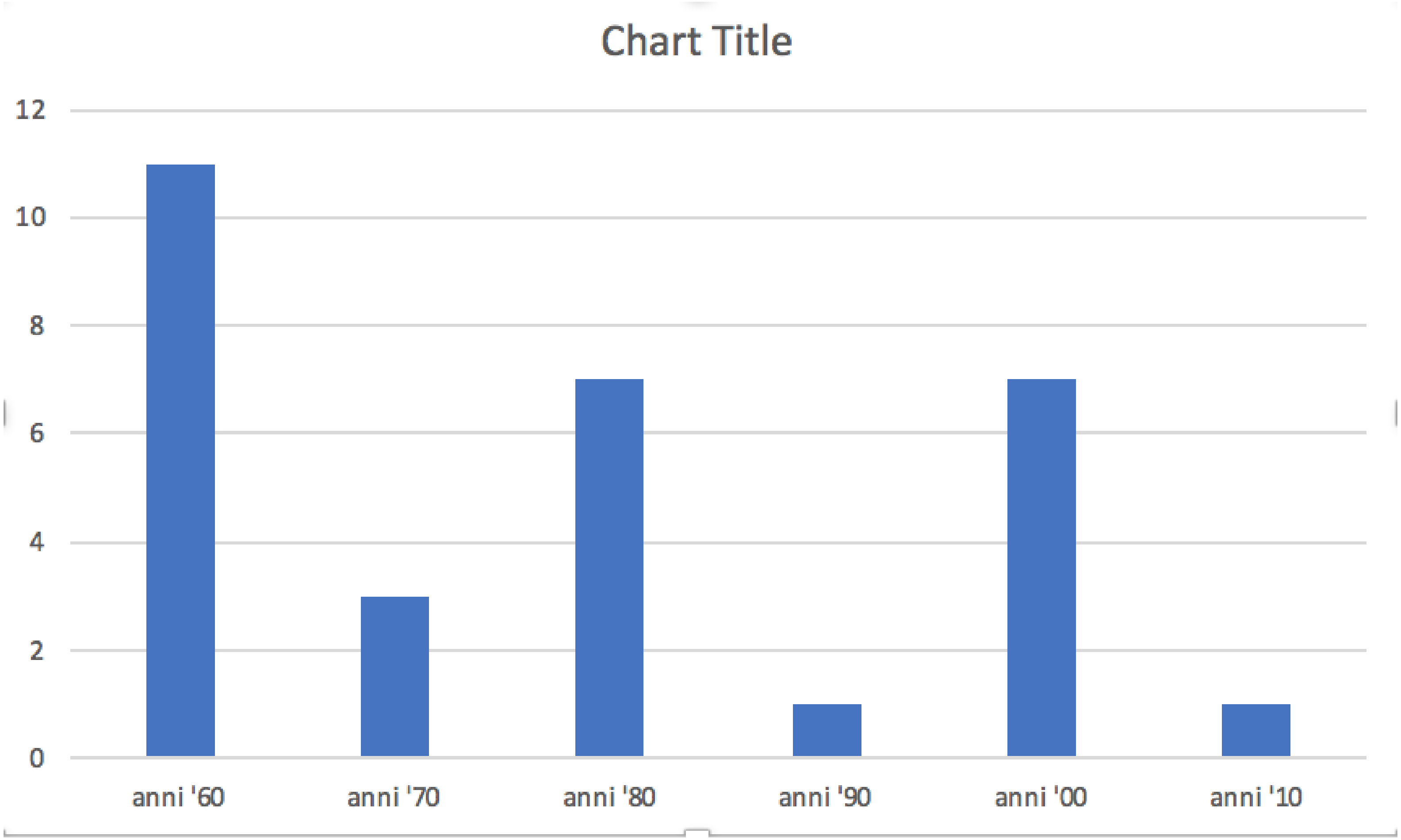


apollo space program
25.4 billion dollars

space shuttle program
196 billion dollars

international space station program
150 billion dollars (so far)

are we still ready to die?



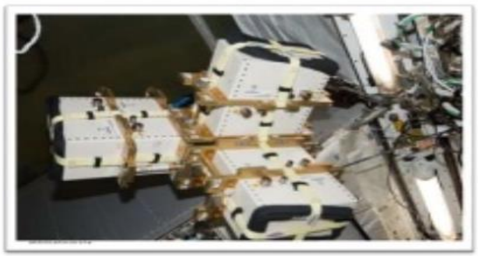
30:536=0.05

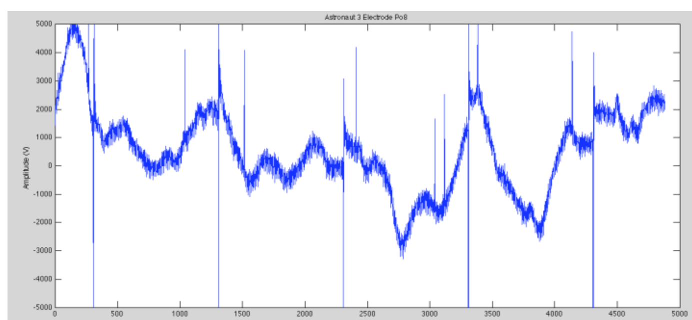
287:4,500,000,000=0,0000001 (2019)

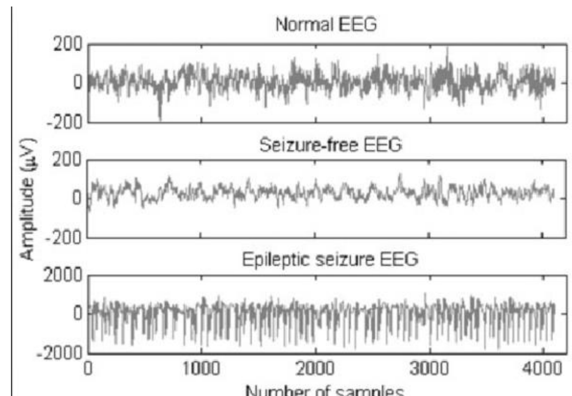
space is not a friendly environment

ALTEA

- 6 Rivelatori di particelle (SDU)
- Unità centrale (DAU)
- EEG
- Stimolatore visivo





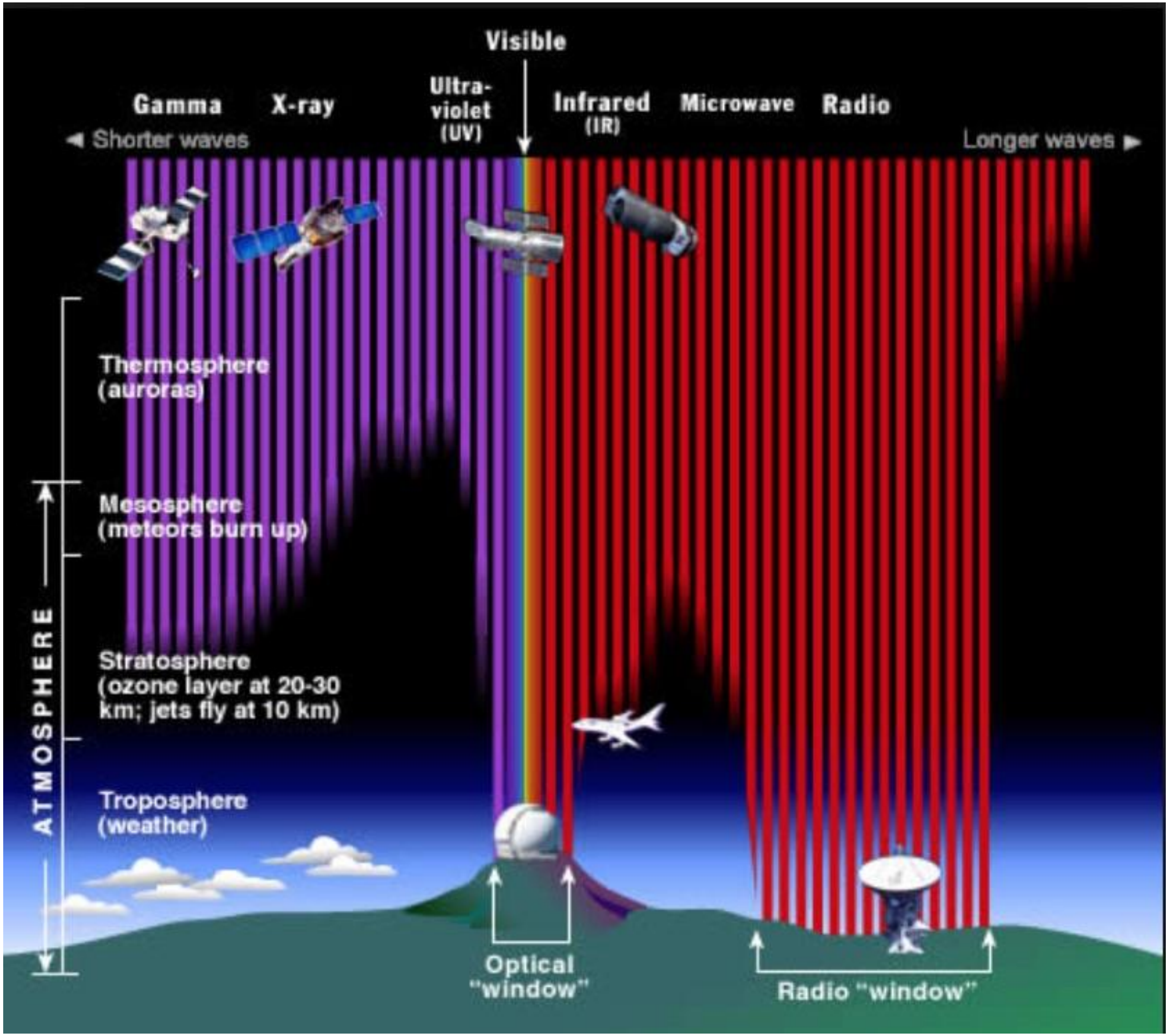


BRAINRAD

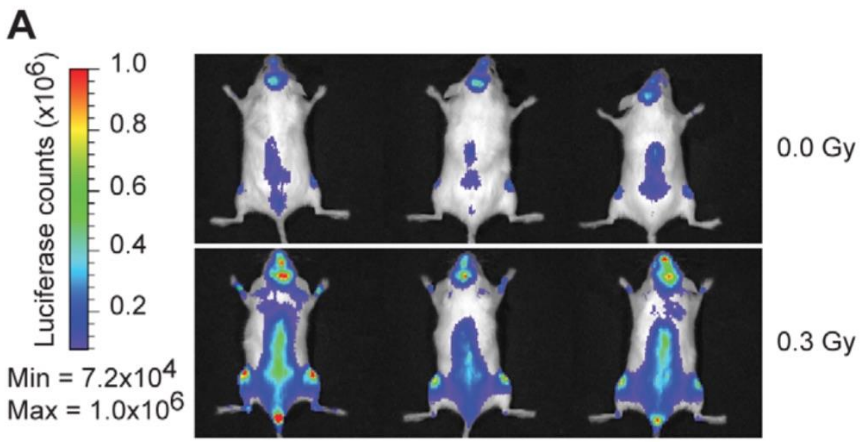
what can we do?

aldrin's list

1. propulsion for huge distance flights
2. technology for protection from radiation
3. appropriate oxygen, food and water supplying
4. domotics
5. psychological training

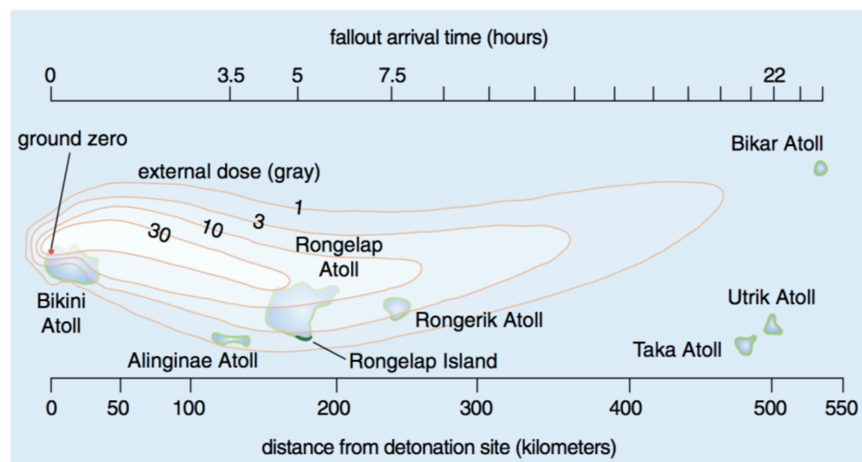

Visible
Gamma
X-ray
Ultra-
violet
(UV)
Infrared
(IR)
Microwave
Radio
◄ Shorter waves
Longer waves ►
Thermosphere
(auroras)
Mesosphere
(meteors burn up)
Stratosphere
(ozone layer at 20-30
km; jets fly at 10 km)
Troposphere
(weather)
ATMOSPHERE
Optical
"window"
Radio "window"

ionizing radiation



(vala et al, PLOS *one*, 2010)

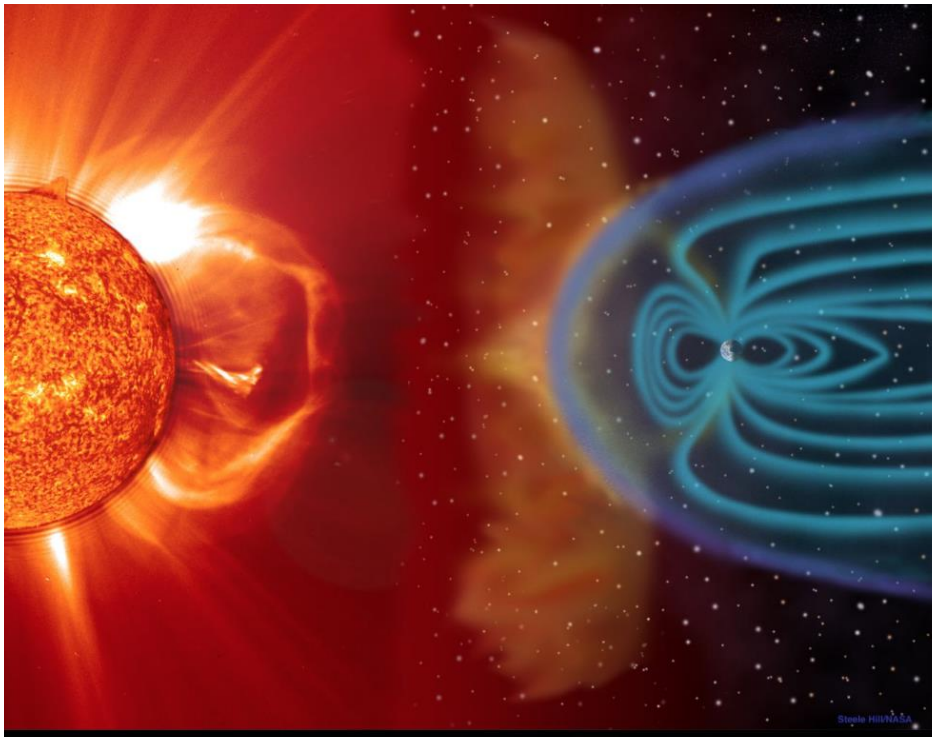
castle bravo, bikini
15 megaton



solar flares

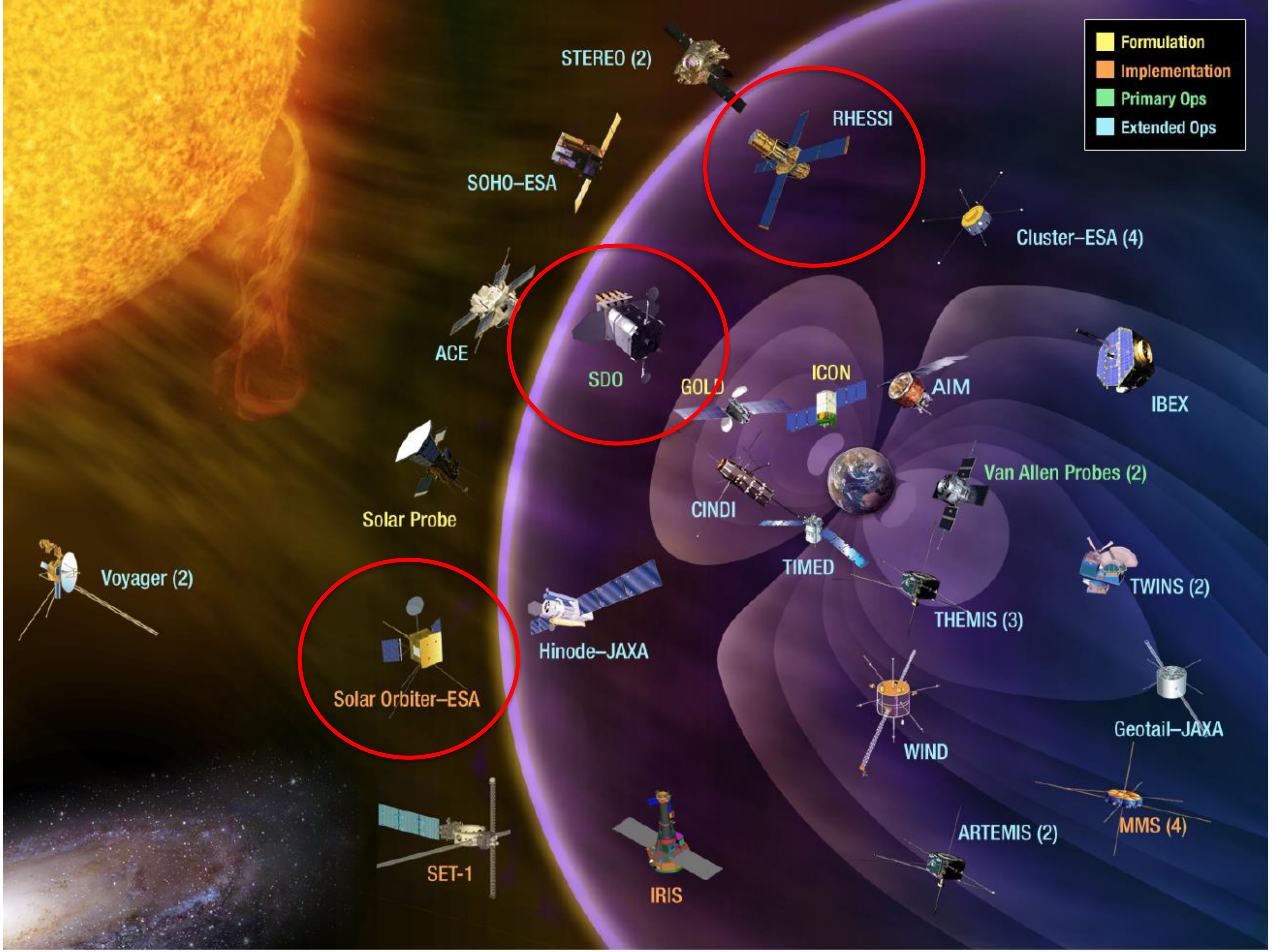
- released energy: about 10 billion megaton
- surface: 10,000 km^2
- billions of tons of accelerated matter up to 10^6 km/h
- electromagnetic radiation emitted at all wavelengths

space weather



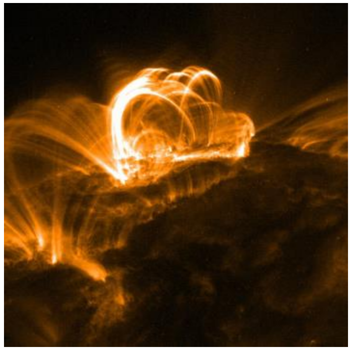
space weather is the combination of the following facts:

- the heliosphere is involved
- flares are the trigger
- solar wind, coronal mass ejections (CMEs) and solar energetic particles (SEPs) are included
- impacts on:
  - GPS
  - flight safety
  - power grids
  - human health


Formulation
Implementation
Primary Ops
Extended Ops
STEREO (2)
RHESSI
SOHO–ESA
Cluster–ESA (4)
ACE
SDO
GOLD
ICON
AIM
IBEX
Solar Probe
CINDI
Van Allen Probes (2)
TIMED
Voyager (2)
TWINS (2)
THEMIS (3)
Hinode–JAXA
Solar Orbiter–ESA
WIND
Geotail–JAXA
MMS (4)
ARTEMIS (2)
SET-1
IRIS

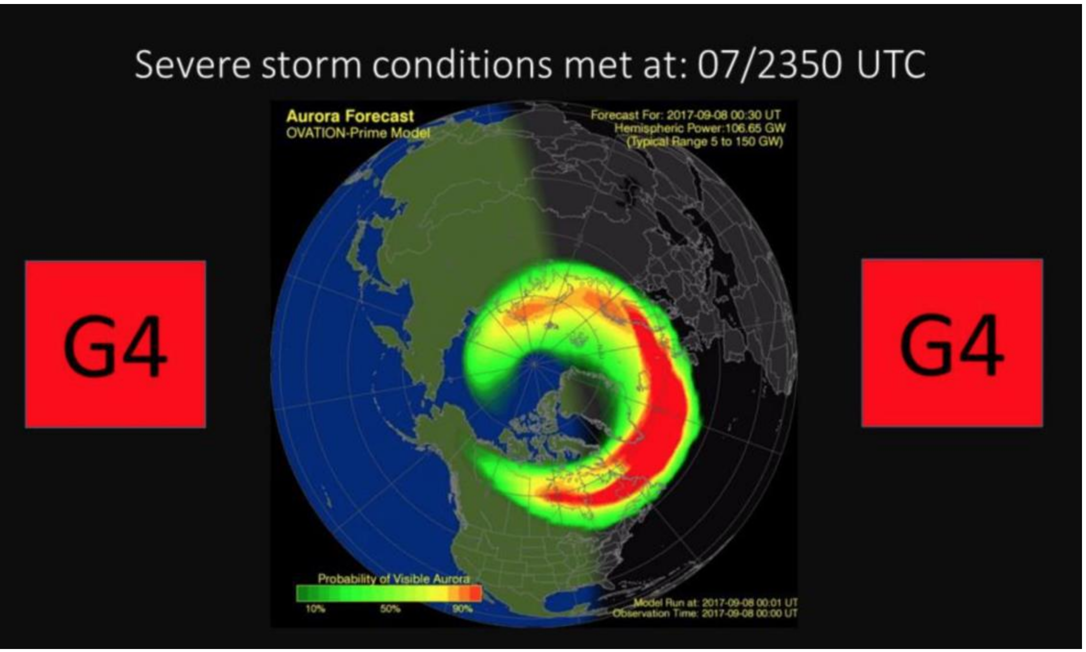
flare paradox

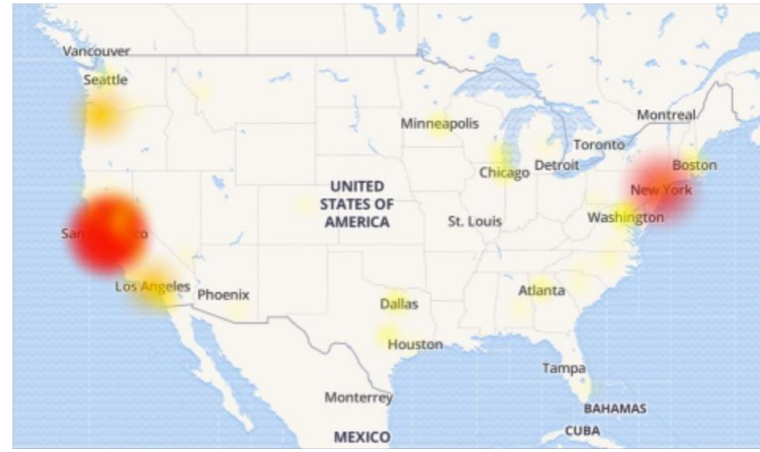
inductance: 10^{-6} henry
electric potential: 220 V
light-up (predicted): 10^{-9} s
light-up (observed): instantaneous

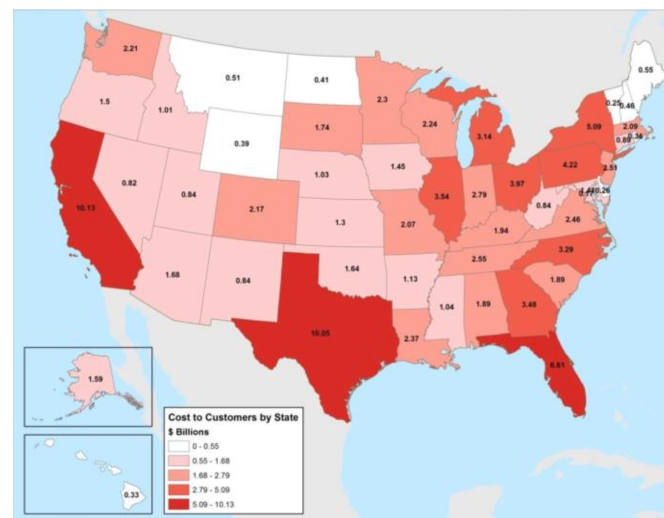


inductance: 10 henry
electric potential: 10^{6} V
light-up (predicted): 300,000 anni
light-up (observed): some minutes

space weather







how to explain the flare paradox
how to forecast space weather

- simulation: numerical simulation of the magnetohydrodynamic equations

- **data analysis: artificial intelligence for flare modeling and prediction**
  - **data**
  - **mathematics**
  - **technology**

AR 12673

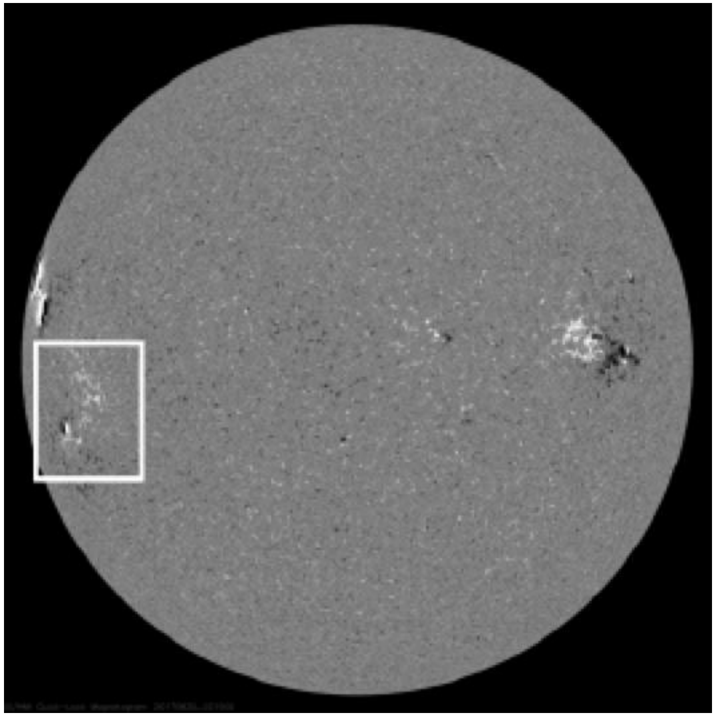
each flare is originated by an
active region (AR)

not all ARs originate a flare

SDO/HMI provides AR images
(magnetograms) every
12 minutes since february 2010

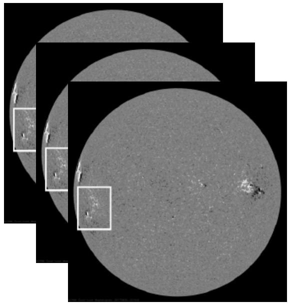
on august 30 2017 AR 12673 becomes
visible on an HMI magnetogram:
would it be possible to predict whether
AR 12673 will originate a flare?

SDO/HMI

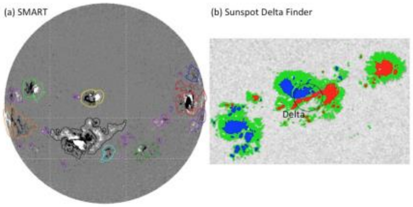


machine learning - ingredients

- HMI archive

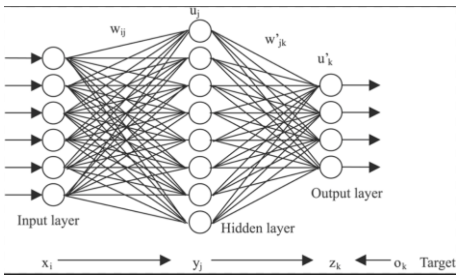


- an AI algorithm
  for extracting properties (features)
  from AR images



- a set of labels associated to the set of extracted properties (flare occurrence: yes/no; flare intensity)

- a neural network



machine learning - paradigm

- the neural network is trained (optimized) by exploiting sets of properties extracted from images in the HMI archive and the corresponding labels

- a new HMI image arrives

- the AI algorithm extracts all properties

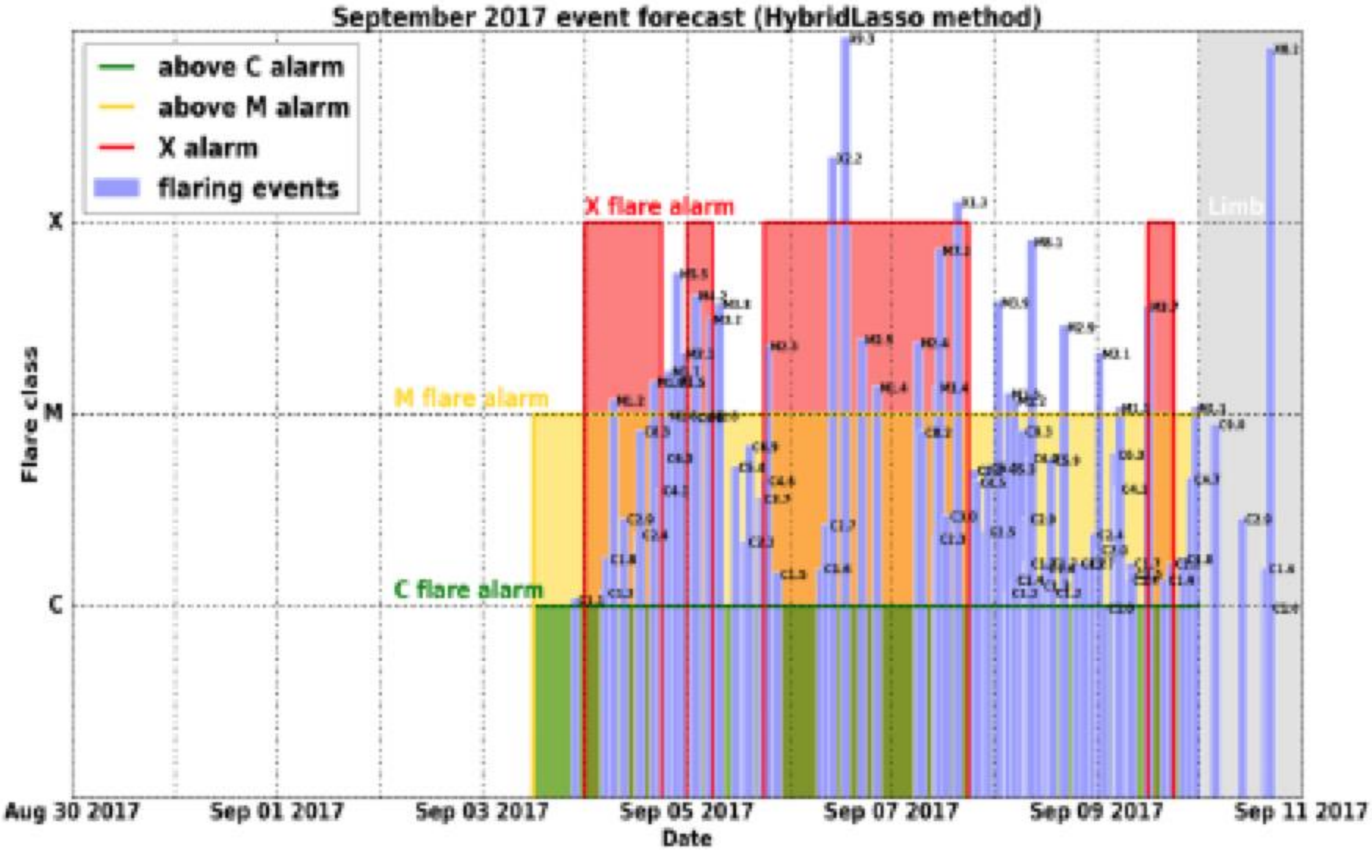
- the trained neural network performs its prediction

AR 12673 - training

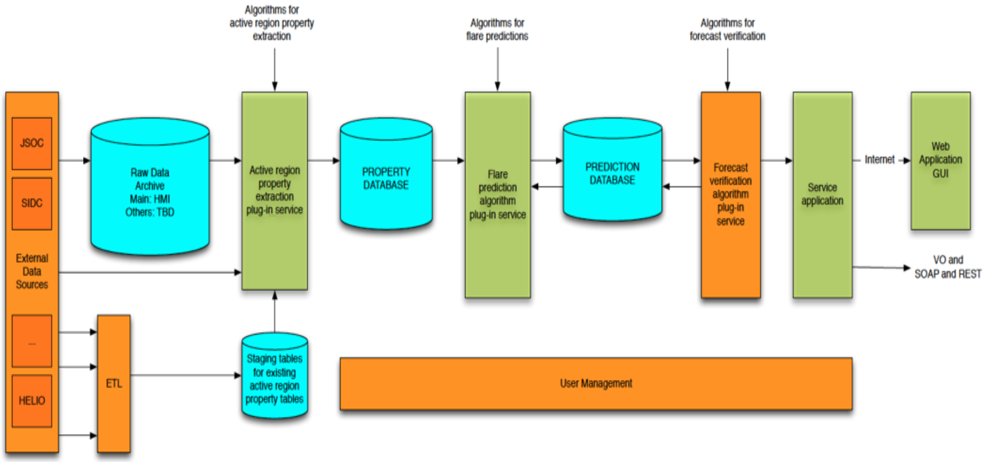
- HMI archive: 7300 images in the time range 2012-2016 (cadence: 6 hours)
- 200 properties extracted from each image by AI
- labels: yes/no + a letter indicating the flare intensity (C, M, X)

AR 12673 - previsione

la tempesta del settembre 2017

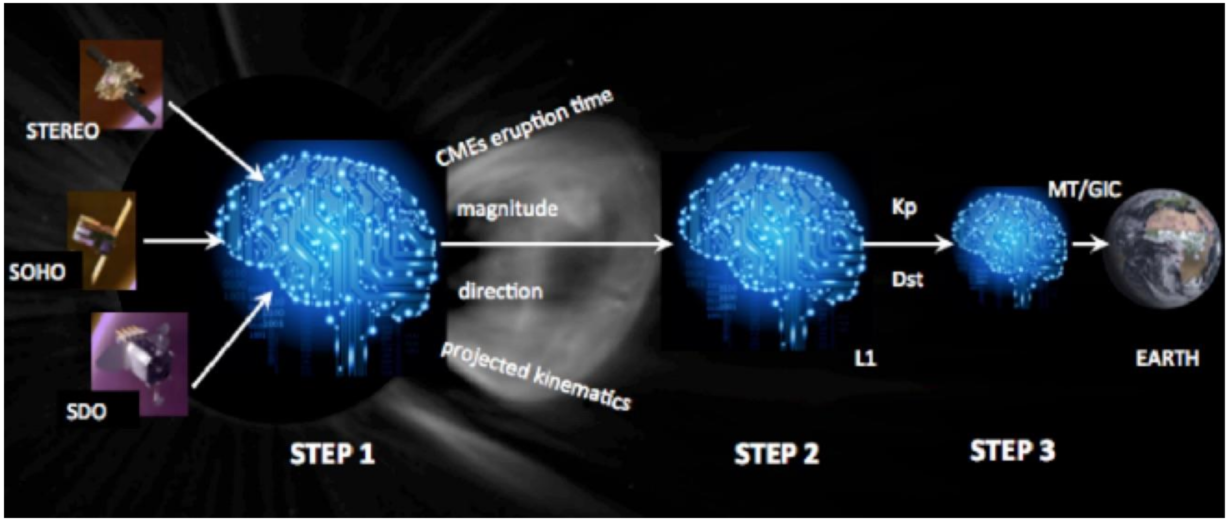


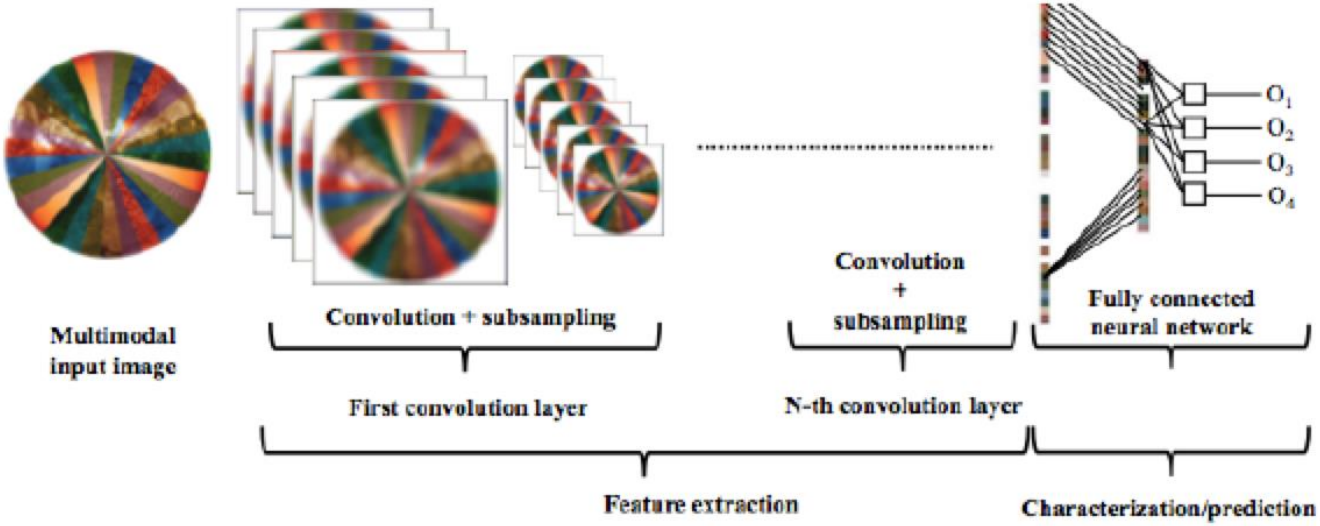
FLARECAST



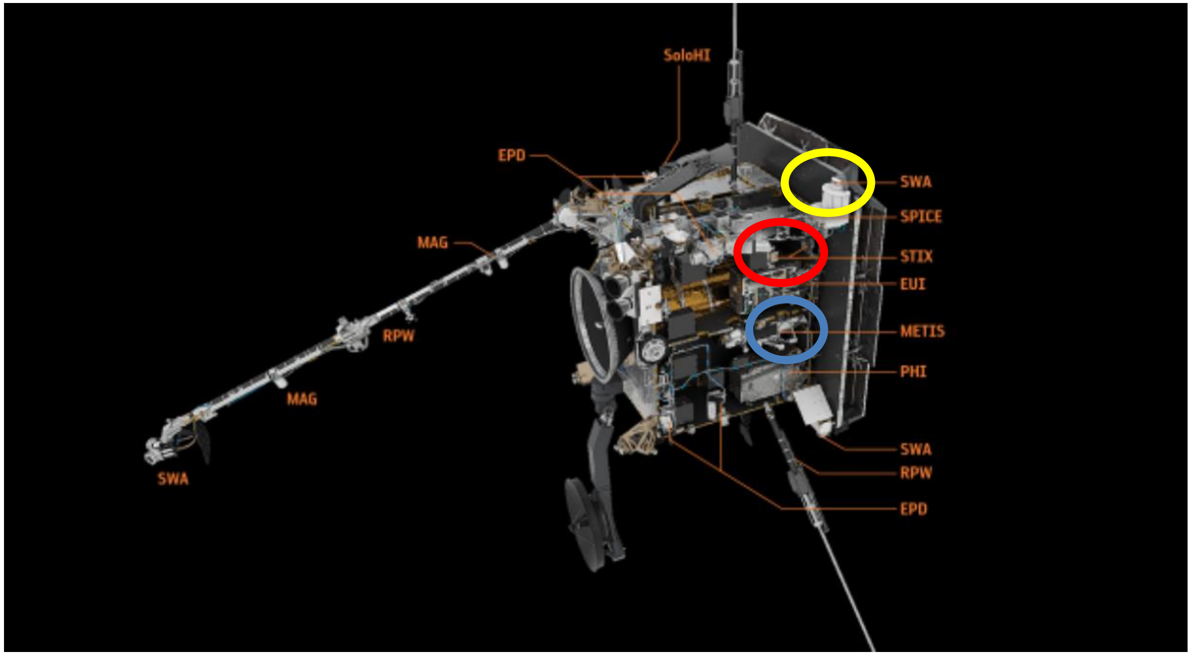
ESA space situation awareness (SSA) space weather service network

prossimi passi





solar orbiter

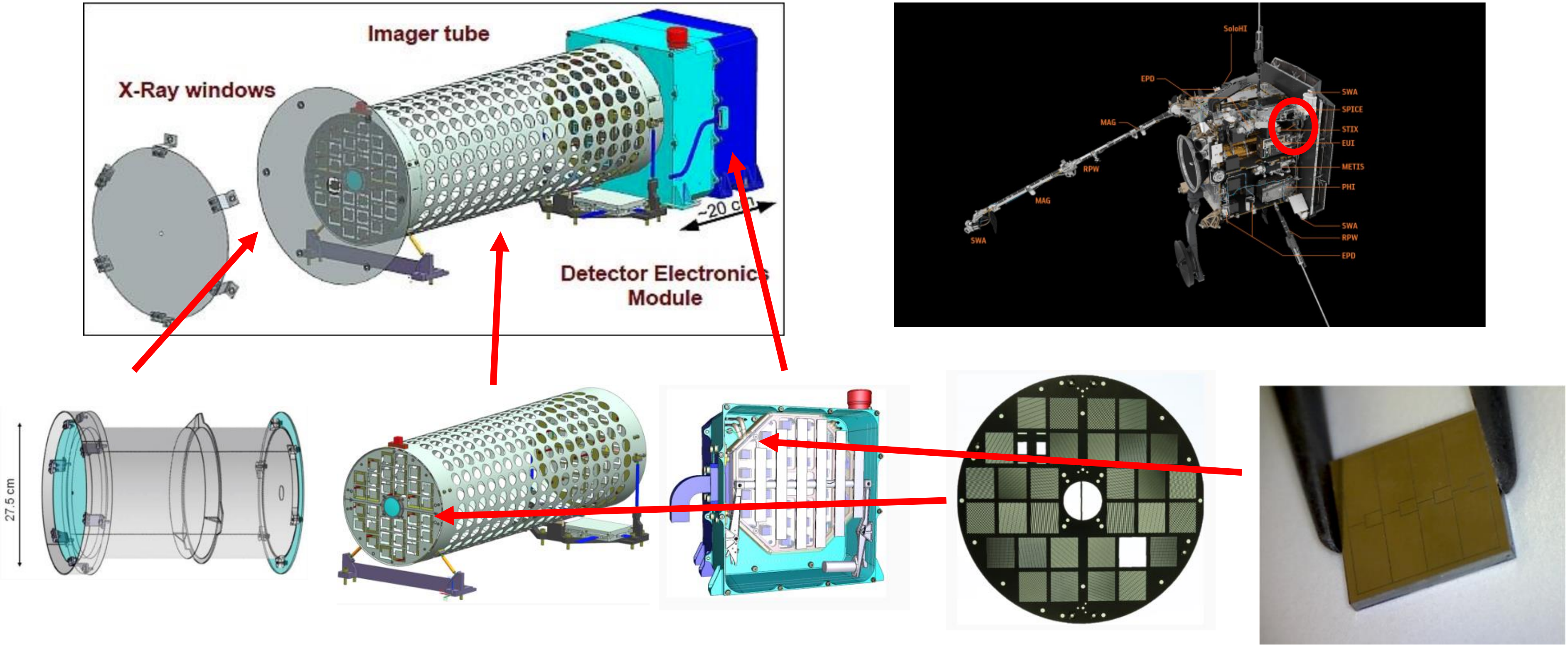


- 9 instruments altogether looking at the sun
- STIX + EUI: flare morphology + acceleration mechanisms
- STIX + METIS: connection between flares and CMEs

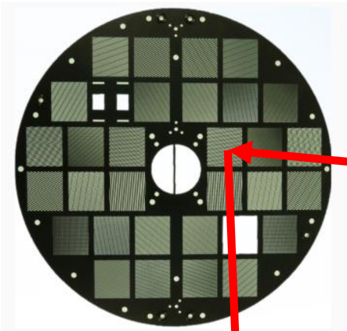
launch: february 10 2020, cape canaveral

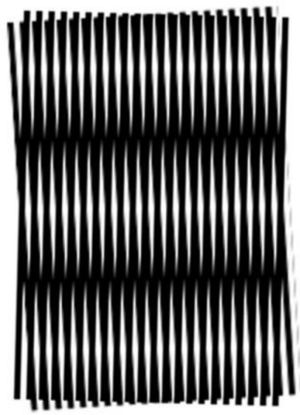
the spectrometer/telescope for imaging X-rays (STIX)

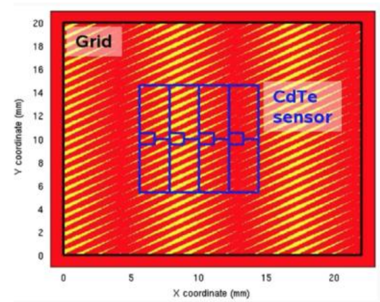
the instrument

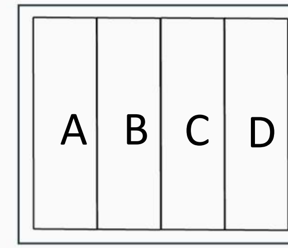


the STIX imaging concept

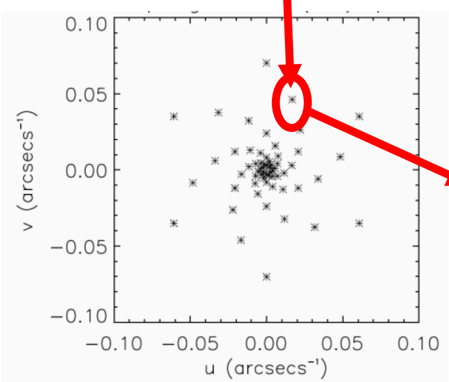






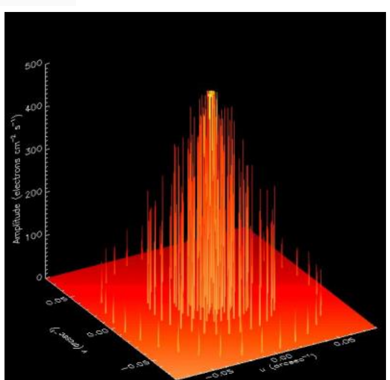


$$V(\xi) \simeq \frac{1}{4M_1}[(\boldsymbol{C}-\boldsymbol{A})+i(\boldsymbol{D}-\boldsymbol{B})]\exp\left(i\frac{\pi}{4}\right)$$

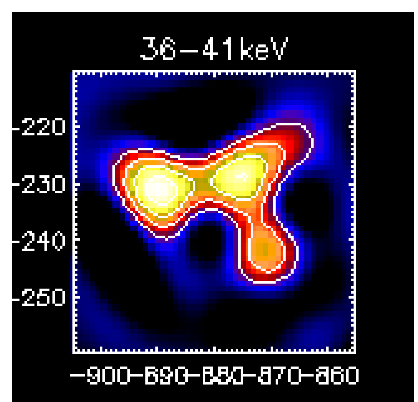


$$\xi = \mathbf{k}^f \frac{L_1+L_2}{S} - \mathbf{k}^r\frac{L_2}{S}$$

$$V(\xi)=\int_{\mathbb{R}^2}\phi(\mathbf{x})\exp(2\pi i\xi\cdot\mathbf{x})\,d\mathbf{x}.$$



AI



STIX science objectives

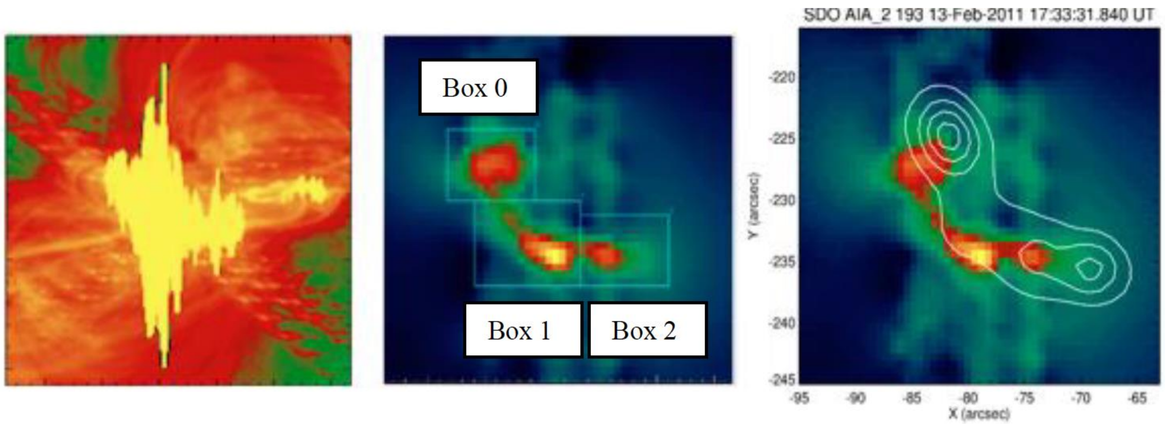
STIX major science goal are:

- **understanding the energy release and particle acceleration mechanisms at the sun**
- **understanding the particle transport mechanisms into the interplanetary space**

warning: these objectives are the same of previous missions

STIX and the rest of SOLO (reflections)

flares morphology

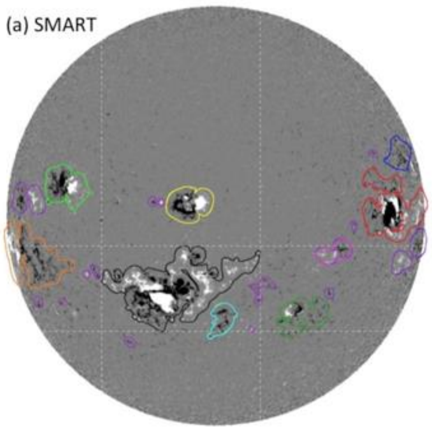


credit:
brian dennis
NASA GSFC

computational pipeline for the automatic integration of EUV (EUI) and hard X-ray (STIX) images of solar flares

- image reconstruction from STIX visibilities
- desaturation of EUI images
- image processing for multimodal image coregistration

flares/CMEs connection



hard X-ray data
associated to flares

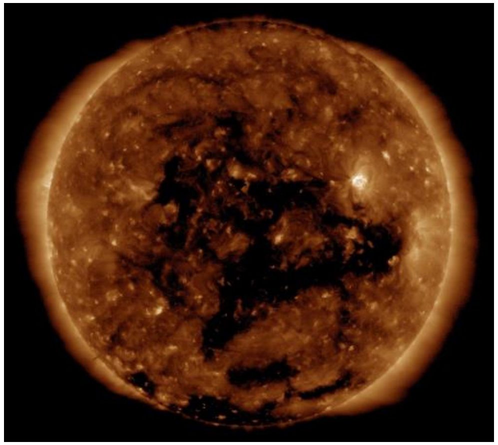
coronagraph data
associated to CMEs

machine learning allows ranking the ARs properties mostly correlated with flares and CMEs

available data:
magnetograms (PHI);
hard X-rays (STIX);
coronagraph (METIS)

analysis of features should allow connecting flares and CMEs physics

coronal holes



- solar wind variations
- CMEs
- hard X-ray emission

- machine learning should allow automatic multi-modal stratification and characterization of data associated to coronal holes
- machine learning should allow investigation of coronal holes properties mostly correlated with the different kinds of eruption
- kinds of data needed: EUV (EUI); X-ray (STIX); coronagraph (METIS); solar wind (SWA)

take home messages (in my view)

- STIX alone will likely not do much better than previous instruments (although confirmation of results from previous missions would be a result)

- STIX data integrated with other SOLO data (EUI, METIS, SWA, PHI) could provide breakthroughs in heliophysics and space weather

but

AI-based computational data analysis is needed

take home messages (addendum)

AI applied to experimental observations:

- we are not starting from scratch:
  - EU projects (HESPE, FLARECAST)
  - technologies from other disciplines
- AI methods are not a miracle cure:
  - stability issues
  - skill scores in machine learning
  - deep learning is not the cure-all for sophisticated data

warning: AI without physics is not reliable

credits

- anna maria massone (UNIGE, CNR)
- federico benvenuto (UNIGE)
- cristina campi (UNIGE)
- sabrina guastavino (UNIGE)
- paolo massa (UNIGE)
- emma perracchione (UNIGE)
- sam krucker (FHNW)
- richard schwartz (NASA GSFC)
- gordon emslie (west kentucky university)
- brian dennis (NASA GSFC)