FLARECAST:
THE FULLY AUTOMATED SOLAR FLARE FORECASTING SYSTEM

http://flarecast.eu

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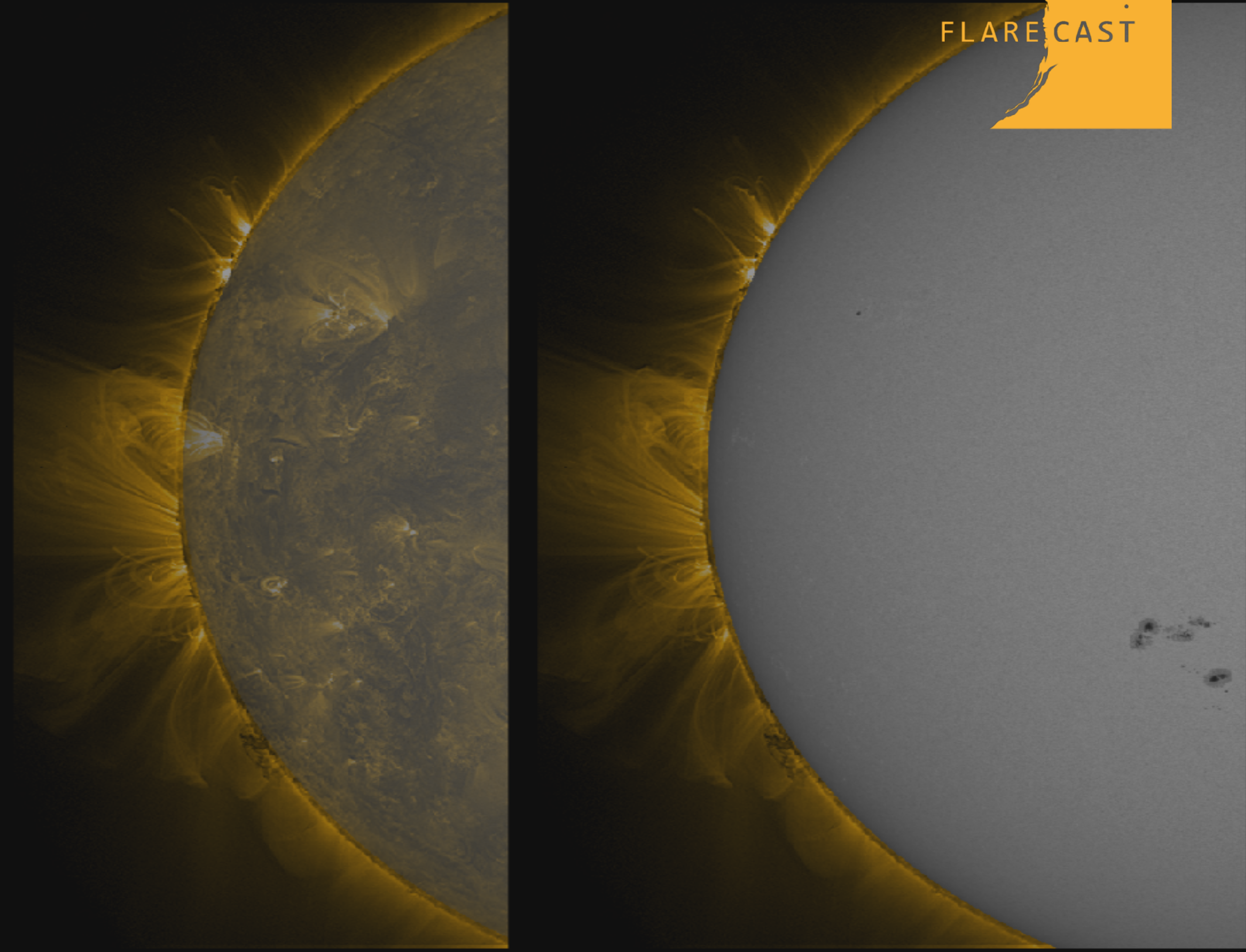
- Period of performance: 2015 - 2017
- Total budget: 2.4 MEUR

OUTLINE

- Why do we need solar flare prediction?
- The nature of flare occurrence
- Can flares be predicted?
- The FLARECAST project
  - Objectives
  - Organization
- Preliminary outcome
- Conclusions



Source: thesuntoday.org

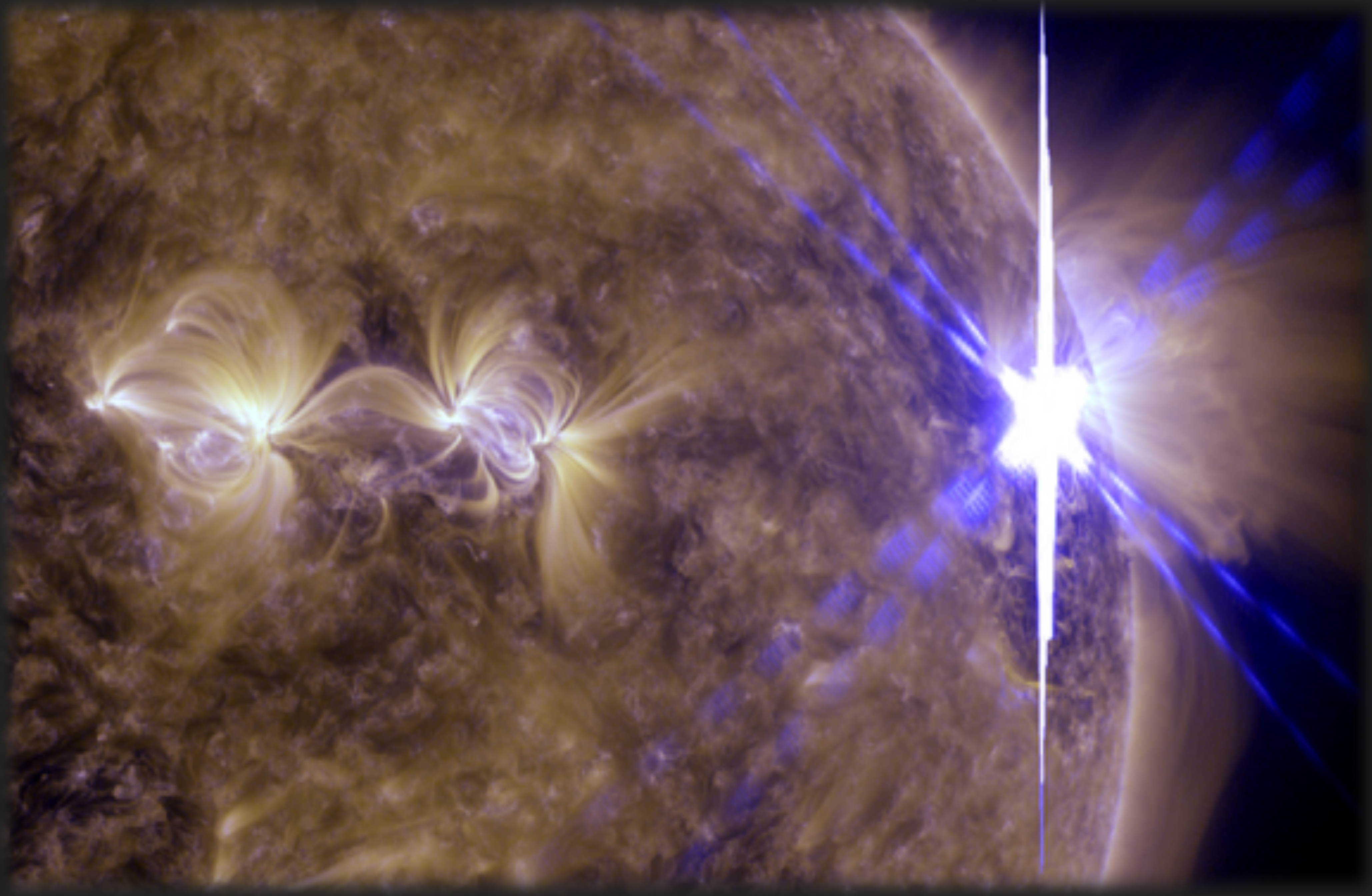
WHY SHOULD FLARES BE PREDICTED?

FLARECAST

solar flare | arrival of "hard" (X-, γ)-ray photons | arrival of first flare-accelerated particles | arrival of CME-shock-accelerated particles | arrival of CME

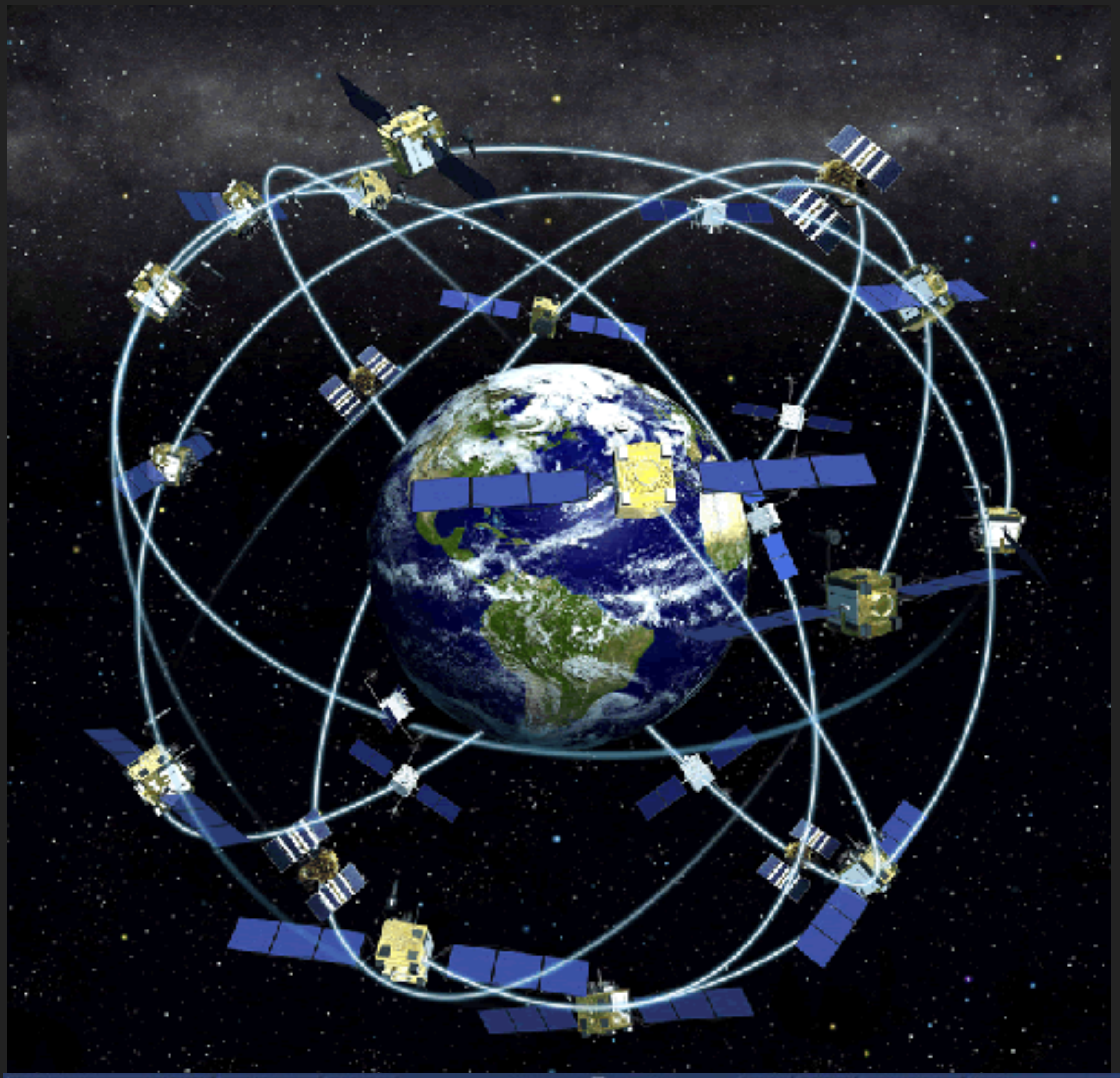
t_0 | t_0+ 8 min | ~ t_0+ 20 min | t_0+ 2-4 days

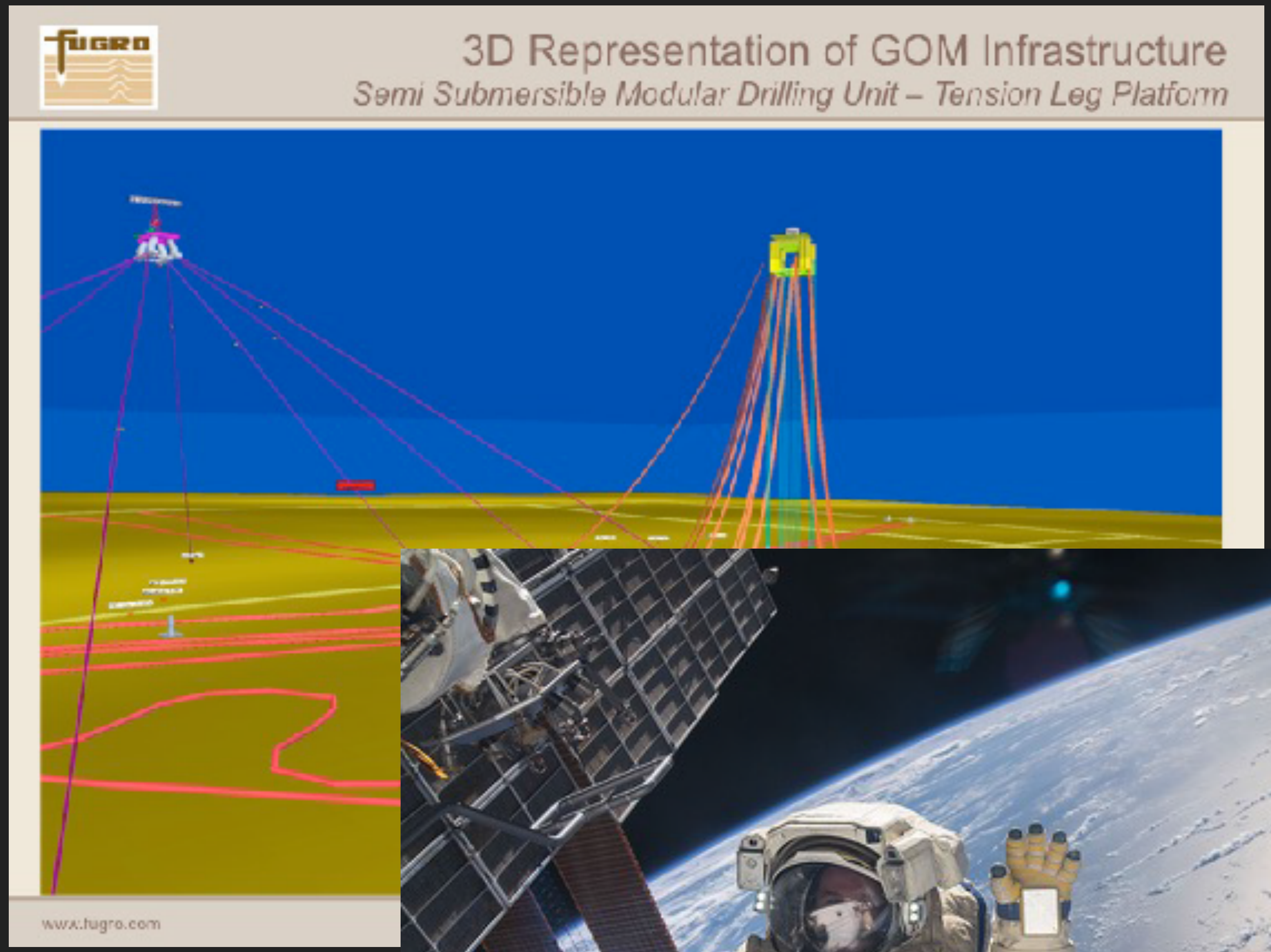
Hard flare photons and non-thermal particulate (mostly protons >10 MeV) affect humans beyond LEO and on solar system bodies lacking an atmosphere. Damages in space-based electronics, radio blackouts, etc., can occur as a result of flares

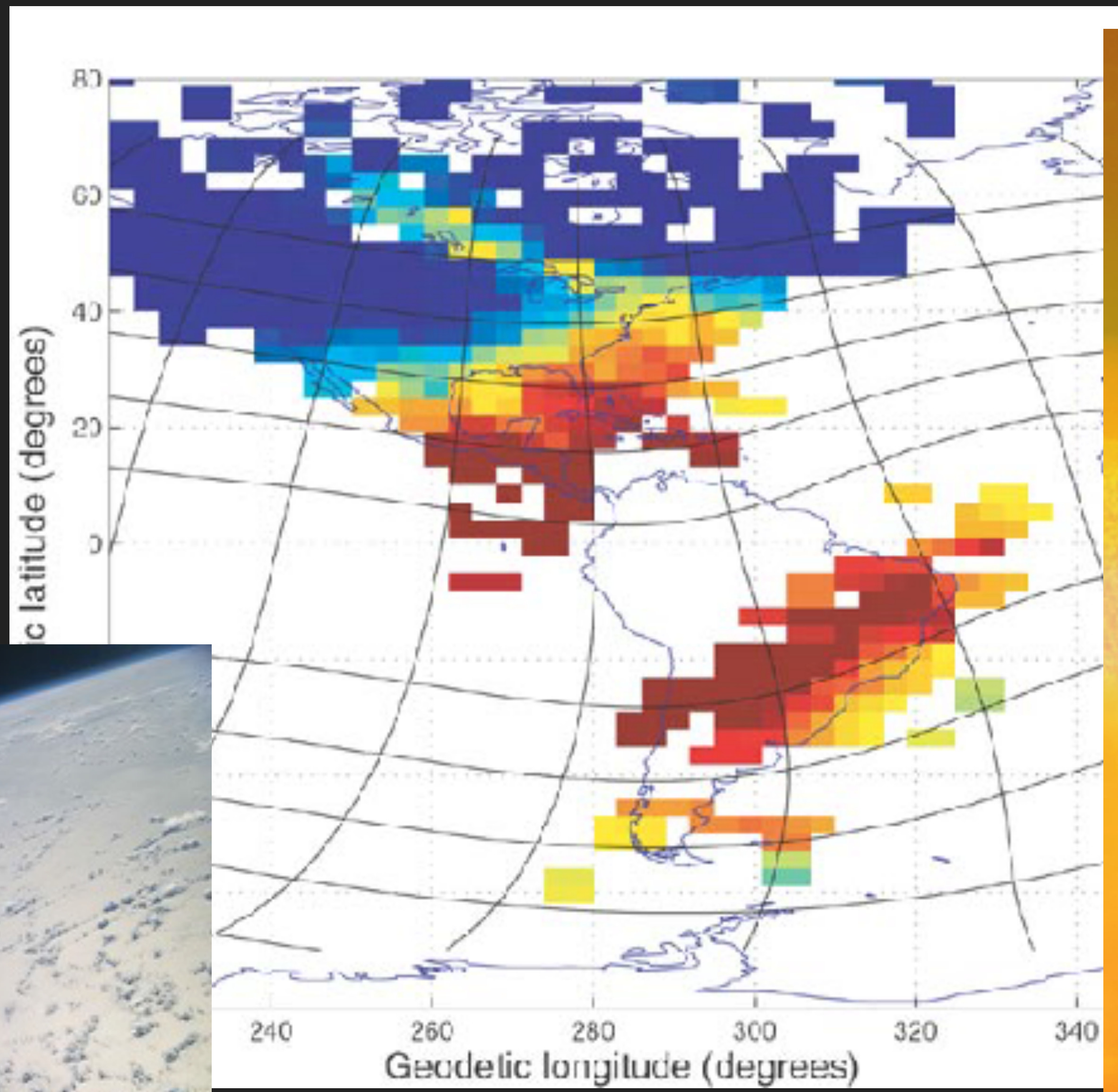


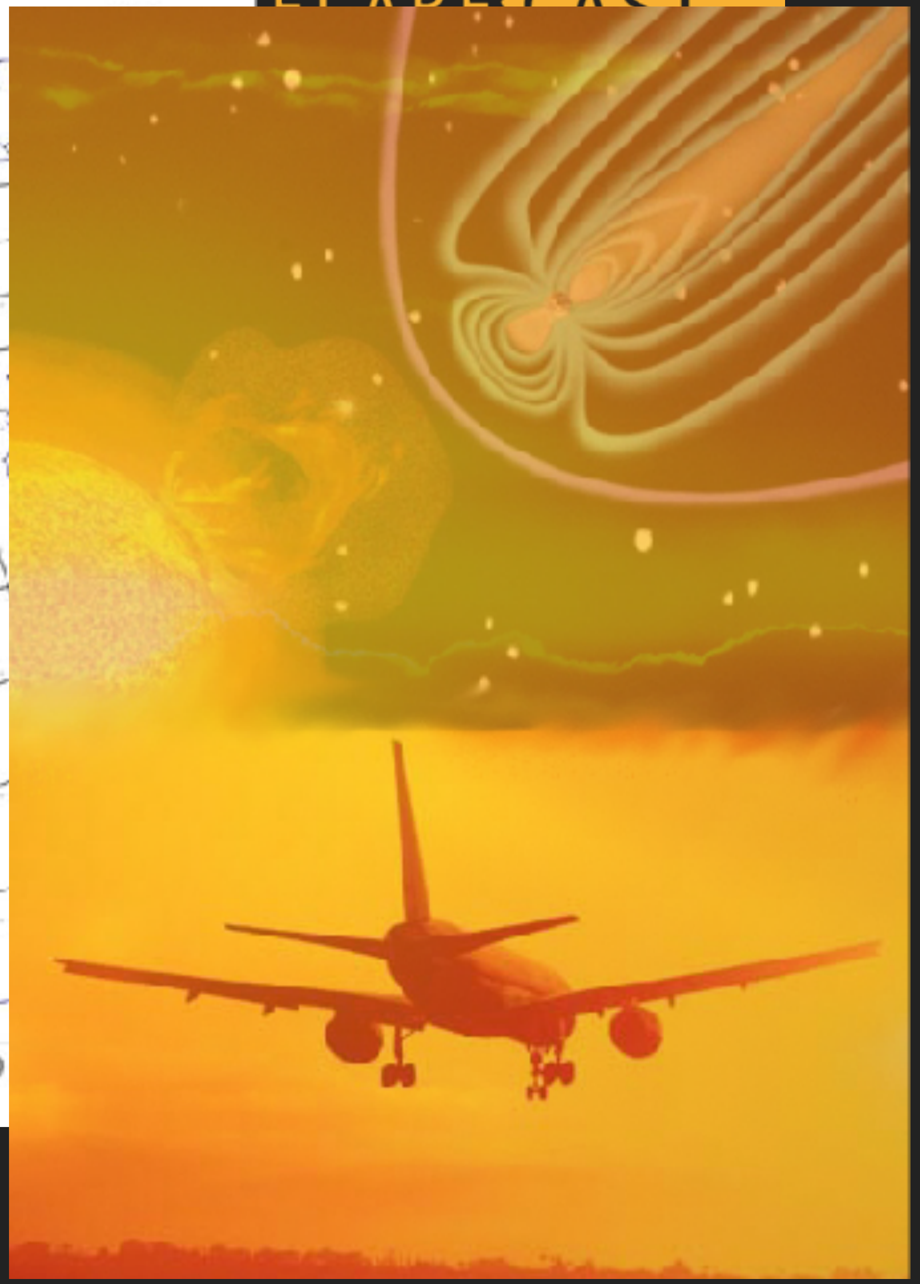
No early warning time for flare photons - slim window for particulate in worst case!

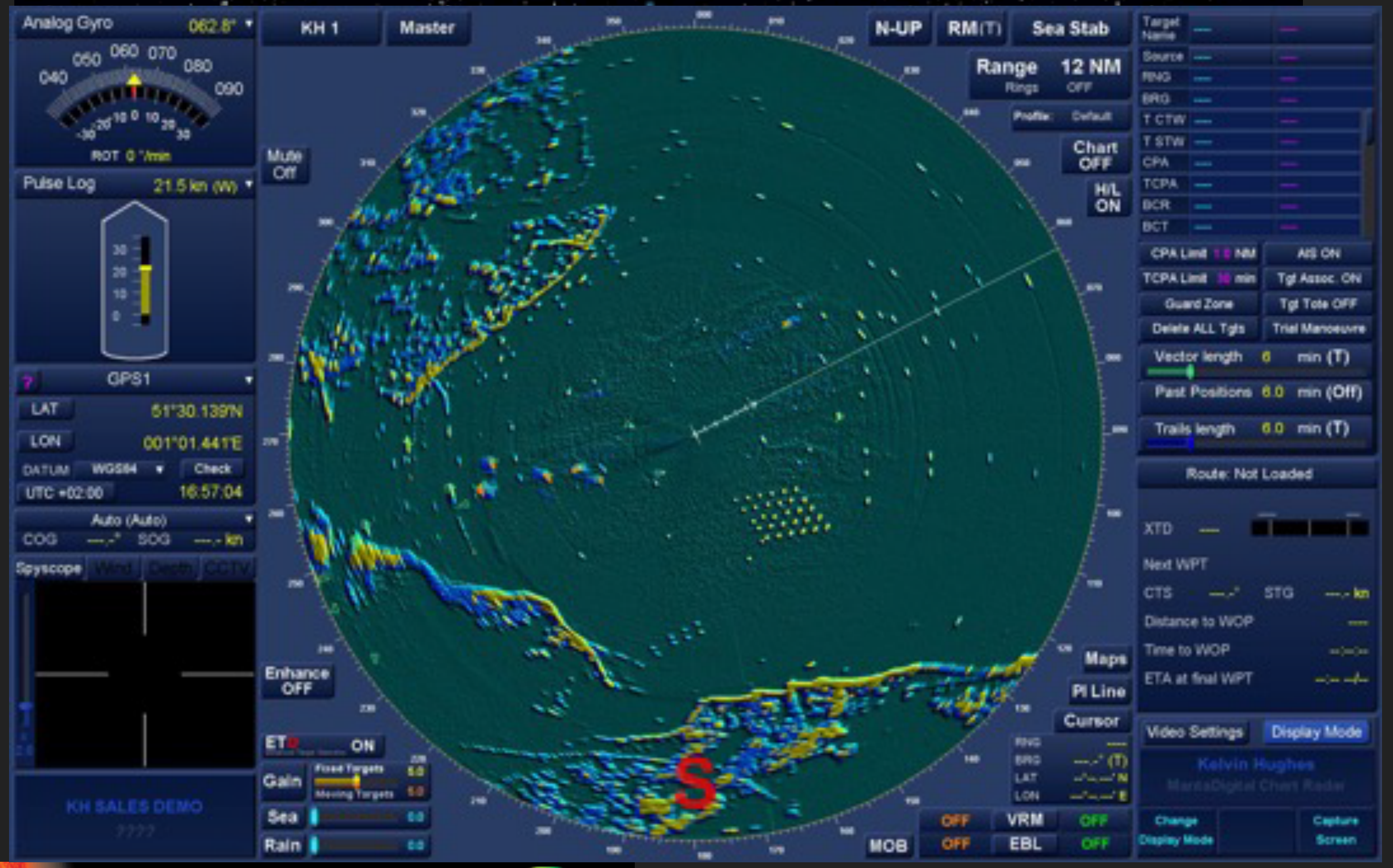
MAJOR FLARE REPERCUSSIONS: EVERYTHING UNDER THE SUN

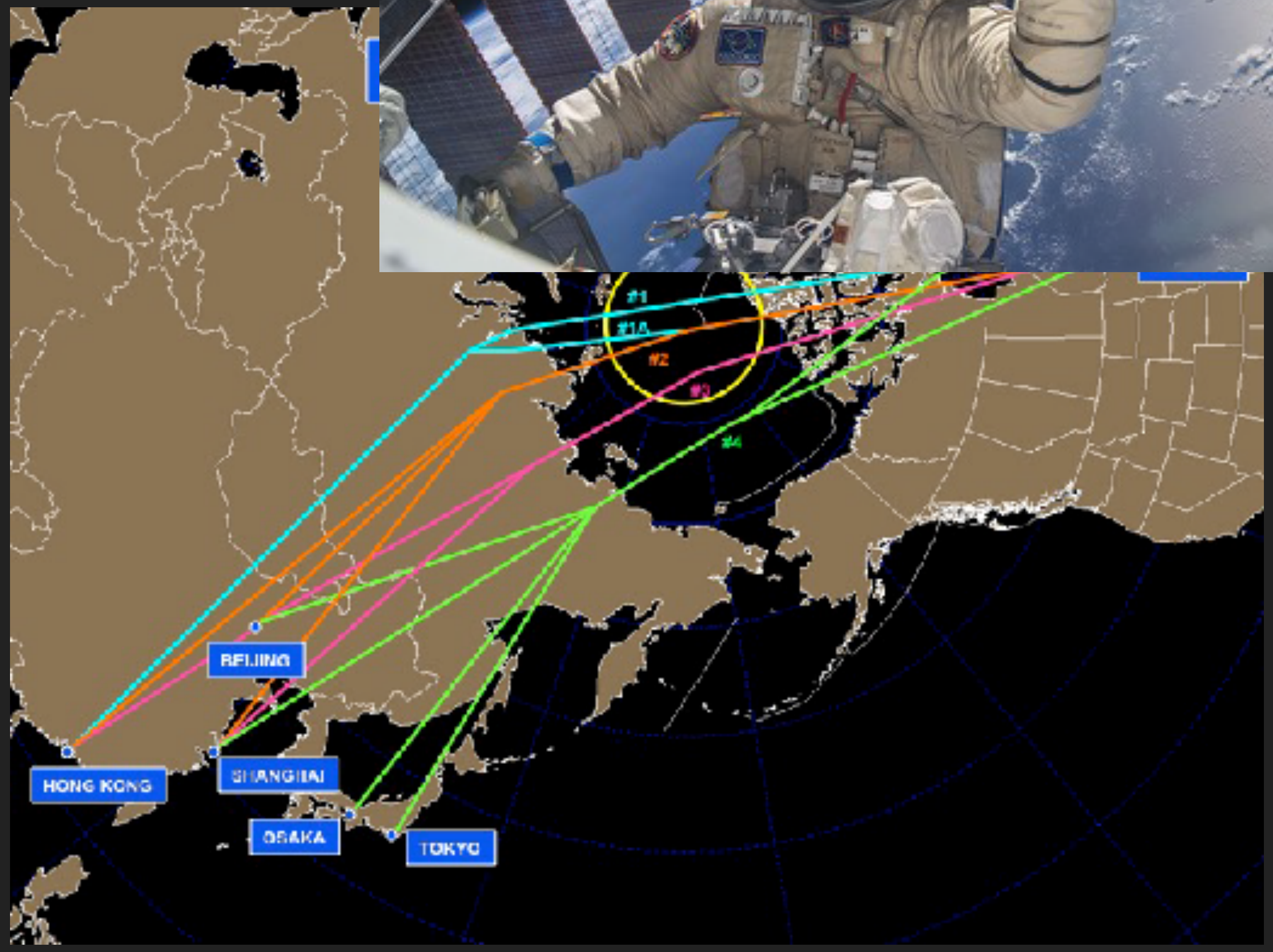




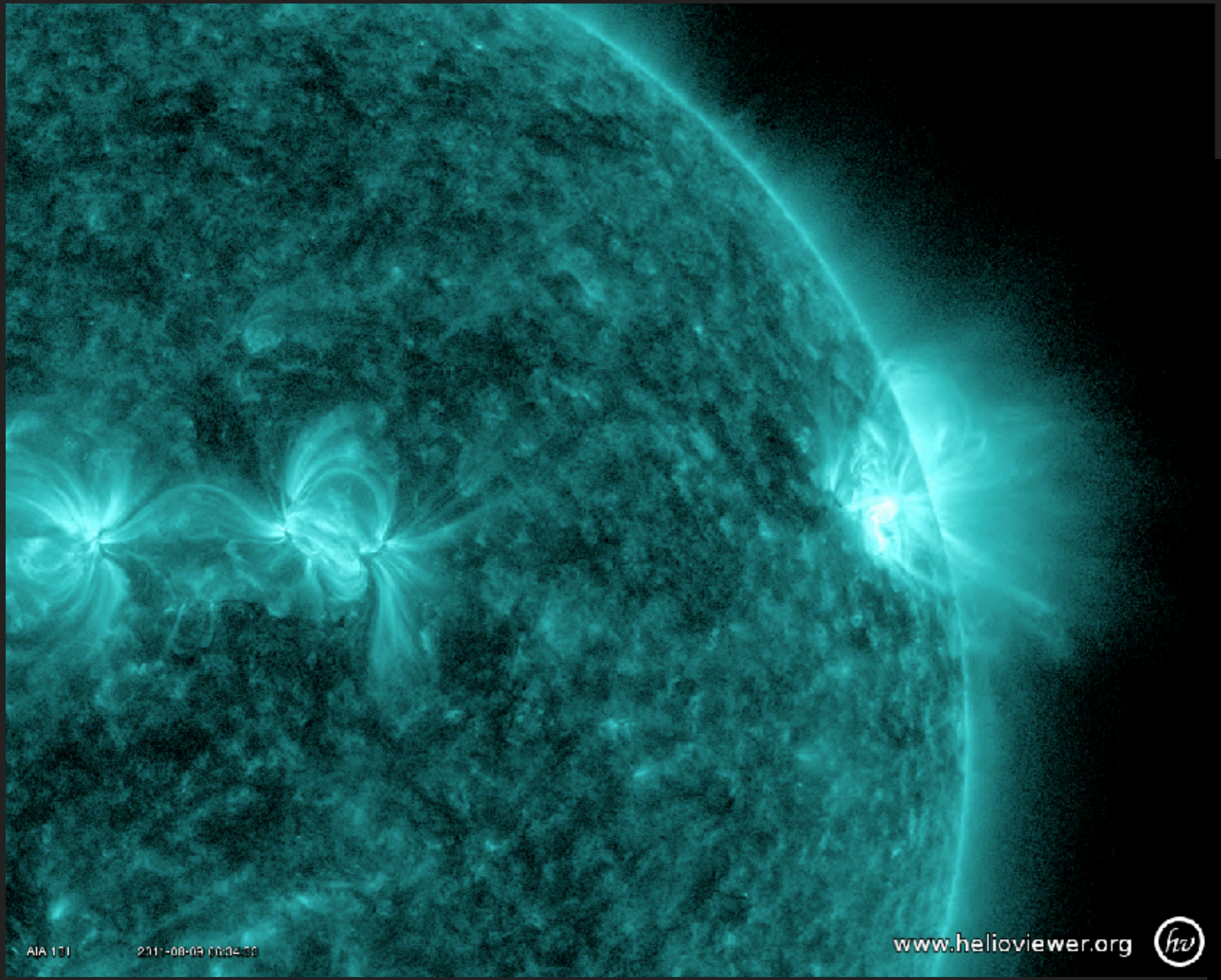


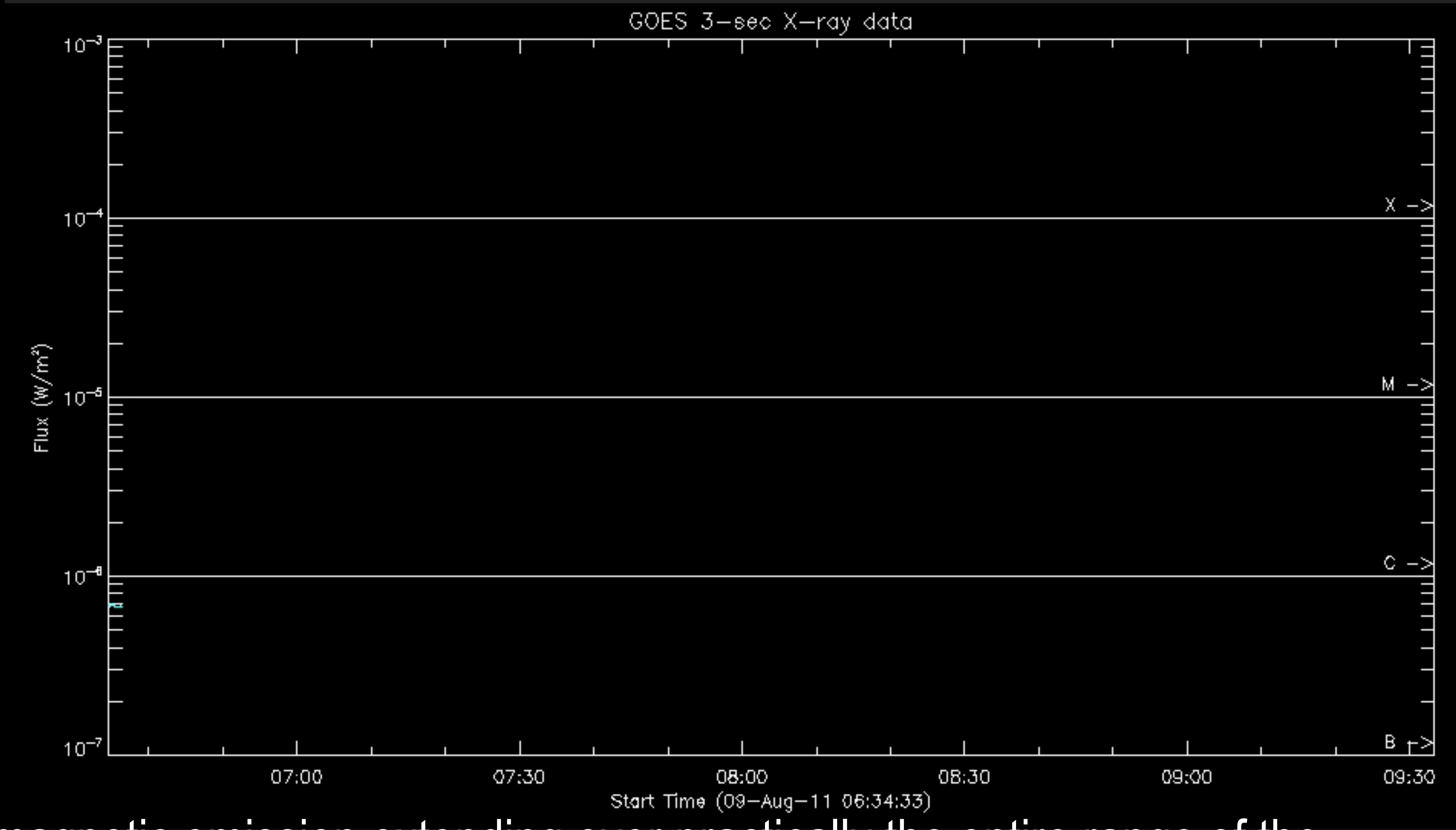






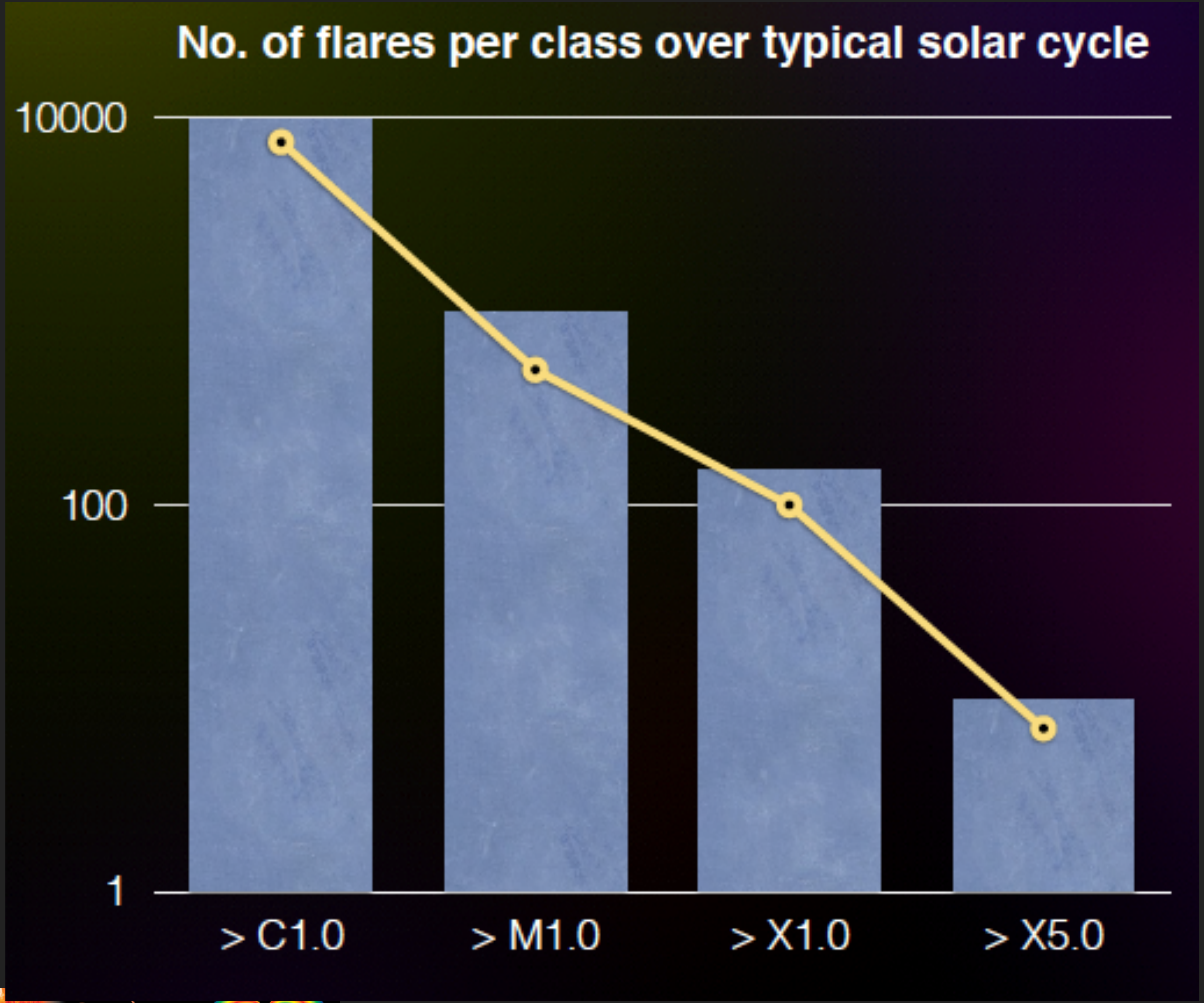
SOLAR FLARES: A PHENOMENOLOGY DEFINITION

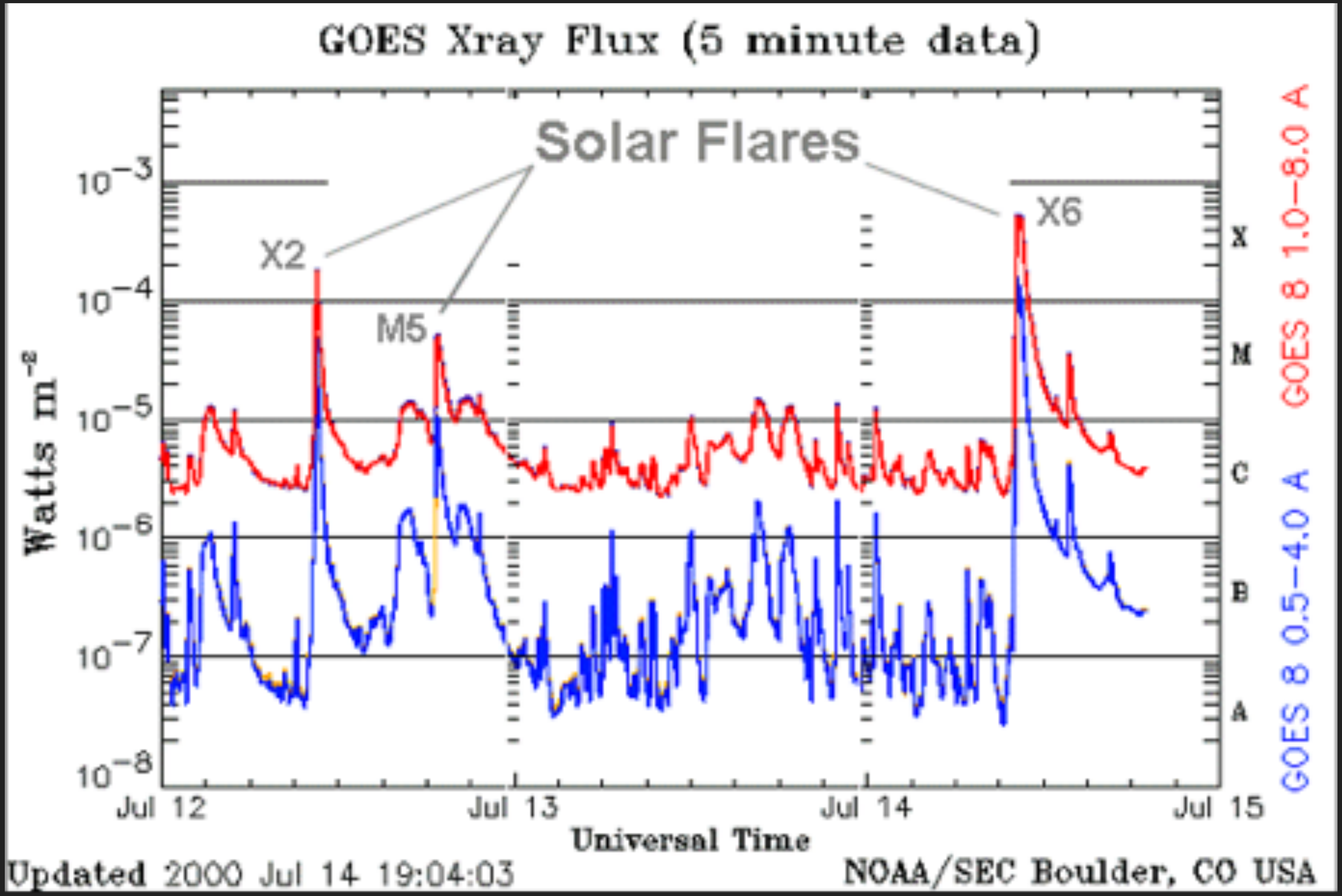




A sudden commencement of enhanced, localized electromagnetic emission extending over practically the entire range of the electromagnetic spectrum. Typically measured in 1 - 8 Å SXR. Sizable flares originate from solar active regions.

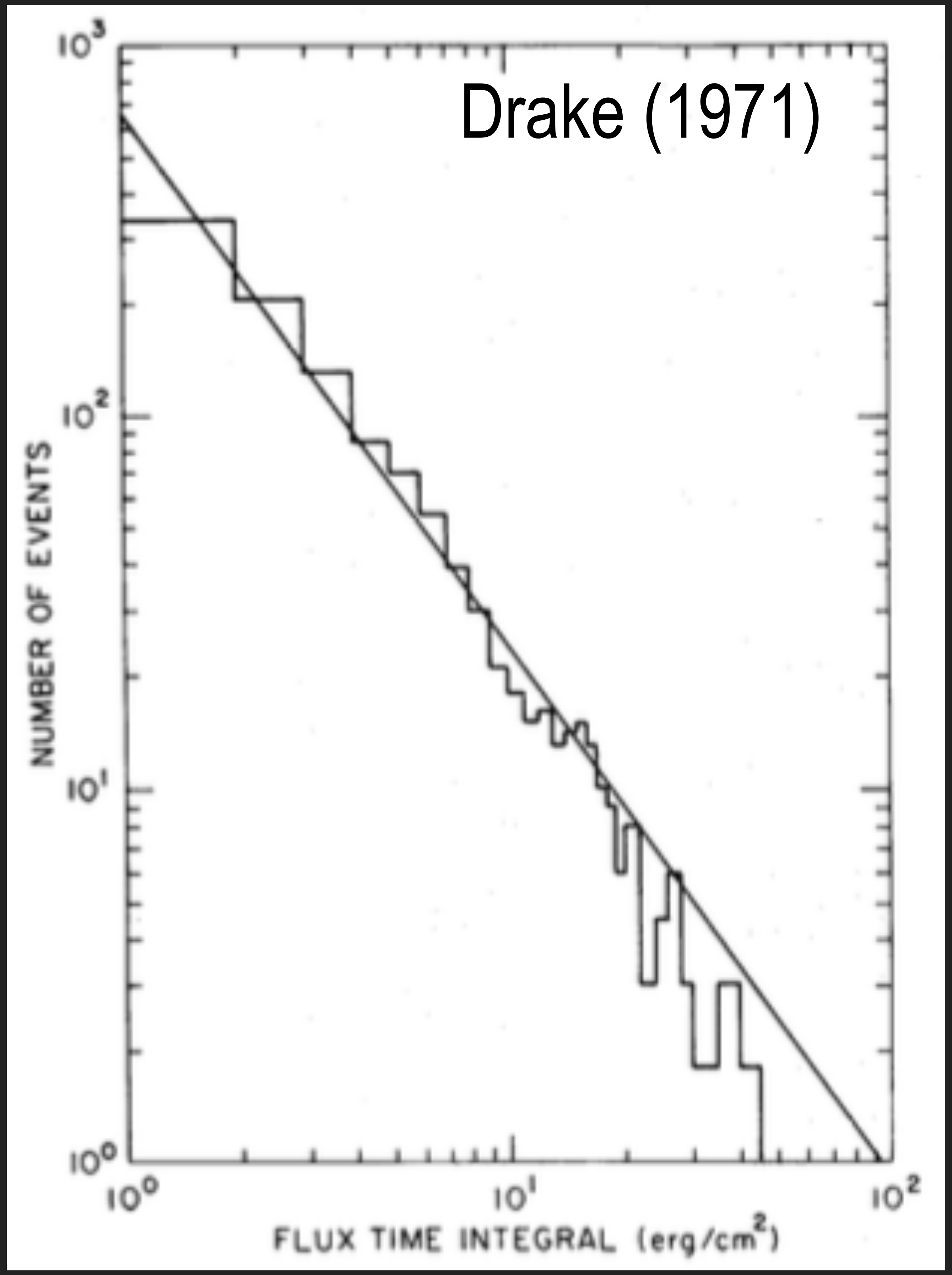
SOLAR FLARES: STATISTICAL BEHAVIOR





"Active" solar conditions over a 3-day period in July 2000

THE NATURE OF FLARE OCCURRENCE



Flare occurrence number vs. integrated photon flux

Flares are (**Rosner & Vaiana 1978**):

- Stochastic relaxation (storage and release) processes
- Physically uncoupled / independent
- Brief, comparing to intermediate times between flares

$$P(t) = \bar{\nu} e^{-\bar{\nu} t}$$

- Leading to a power-law occurrence frequency for flare energies

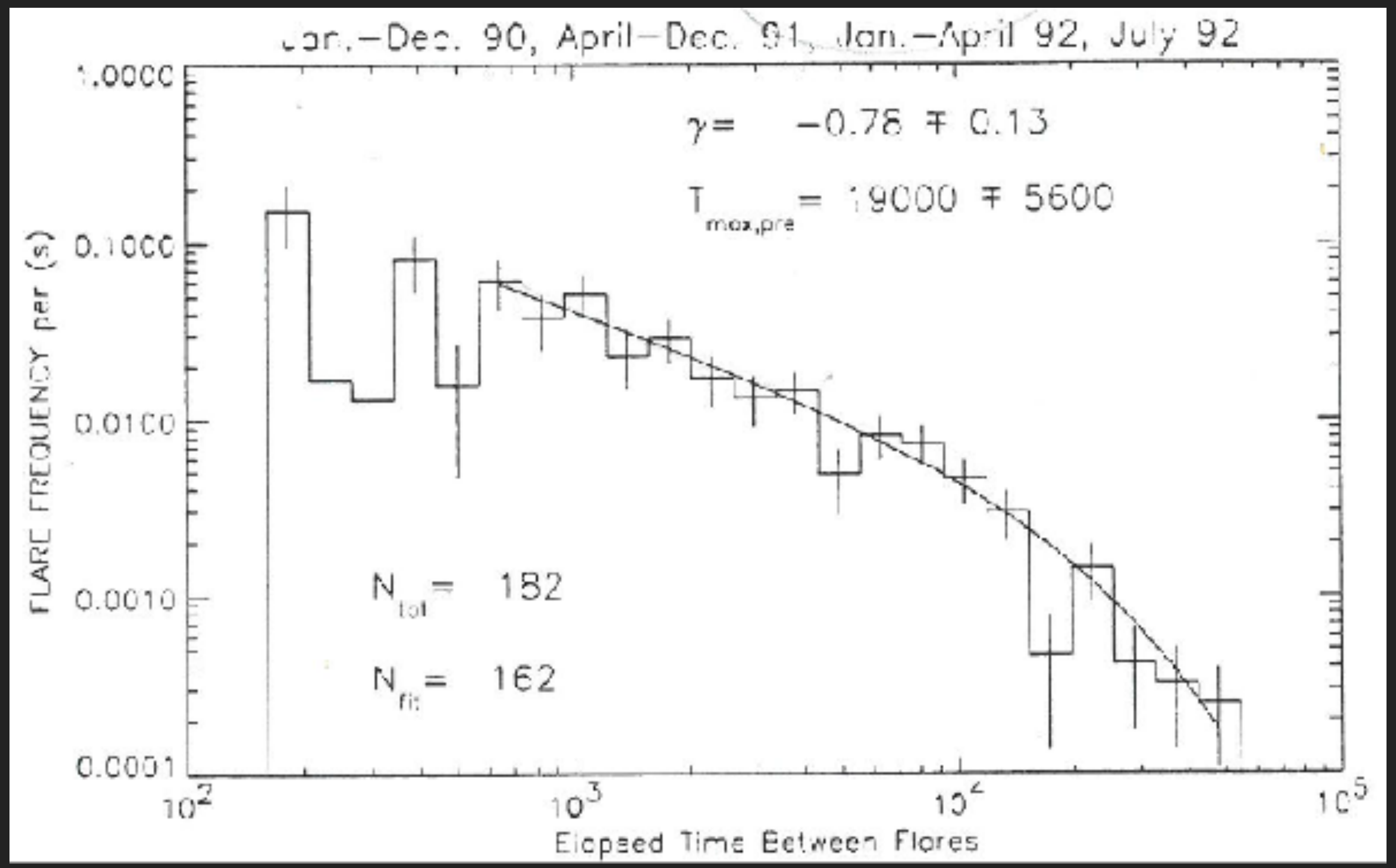
$$P(E) \sim \left(1 + E/E_0\right)^{-\gamma}$$

Power-law distribution of flare size later attributed to the concept of self-organized criticality (1990s) & the concept of marginal stability

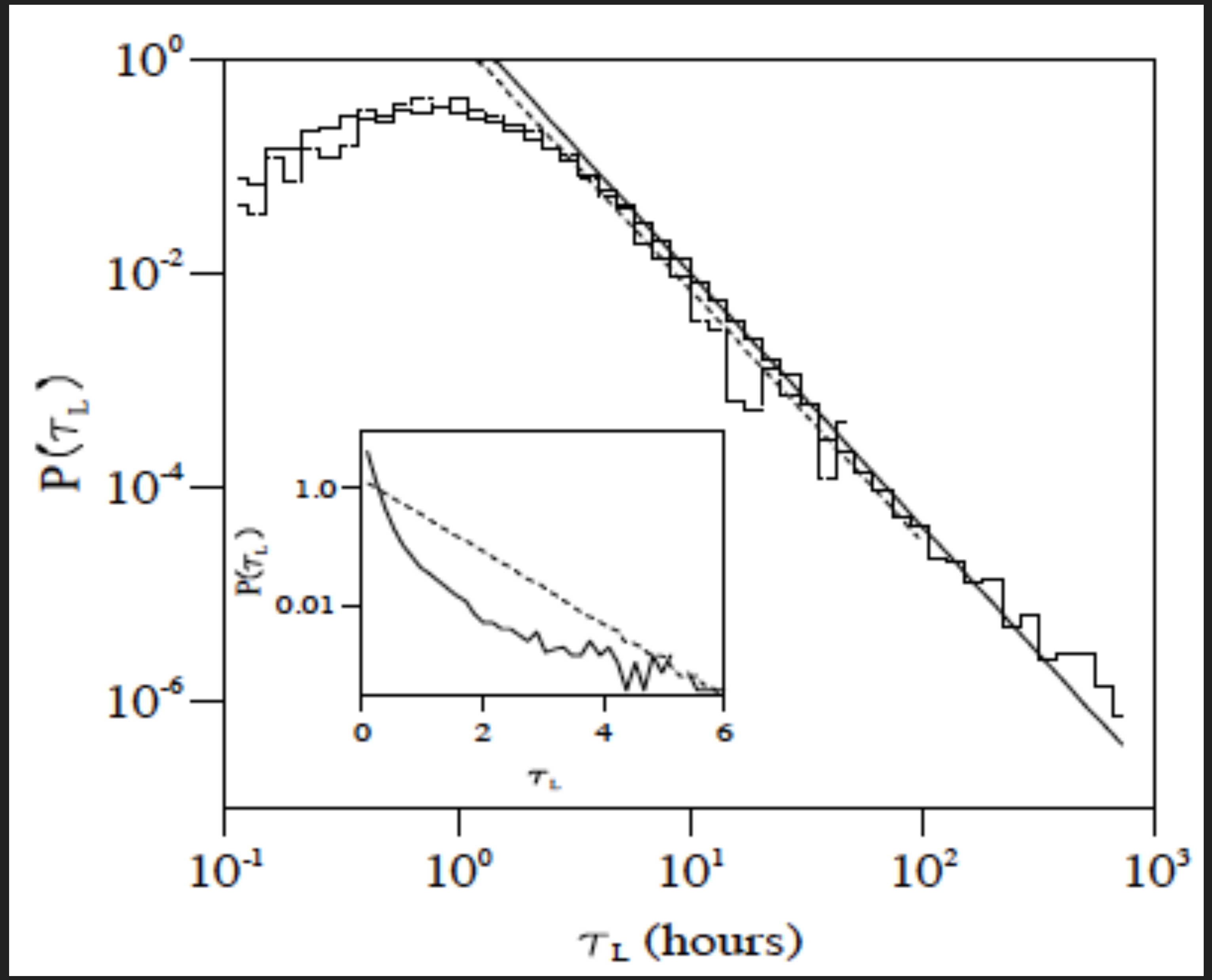
A RATHER GRAPHIC EXAMPLE OF MARGINAL STABILITY

Credit: Aaron Mak - YouTube

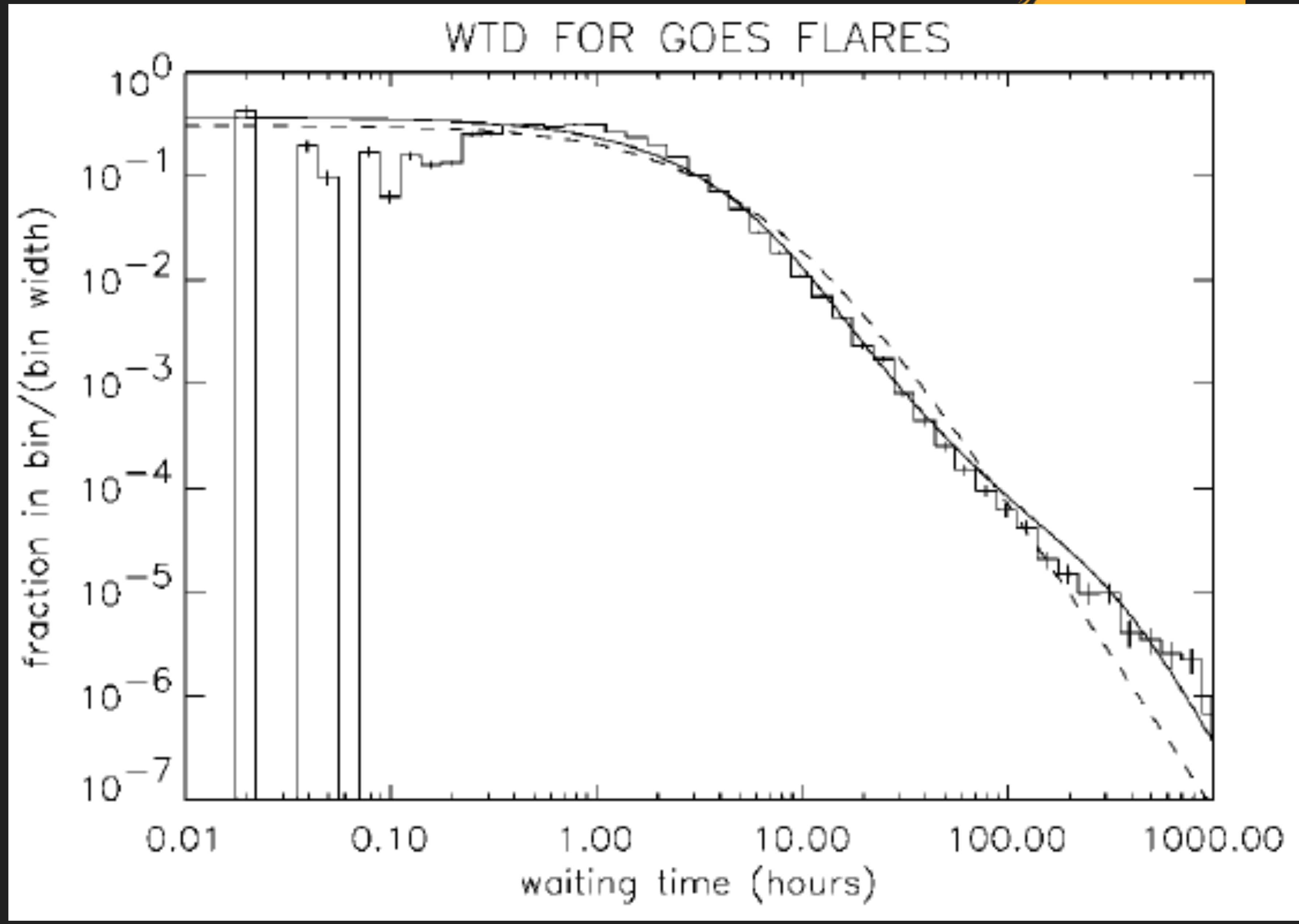
HOWEVER, ARE FLARES RANDOM?



Crosby, PhD Thesis (1996)



Bofetta et al., (1999)



Wheatland (2000)

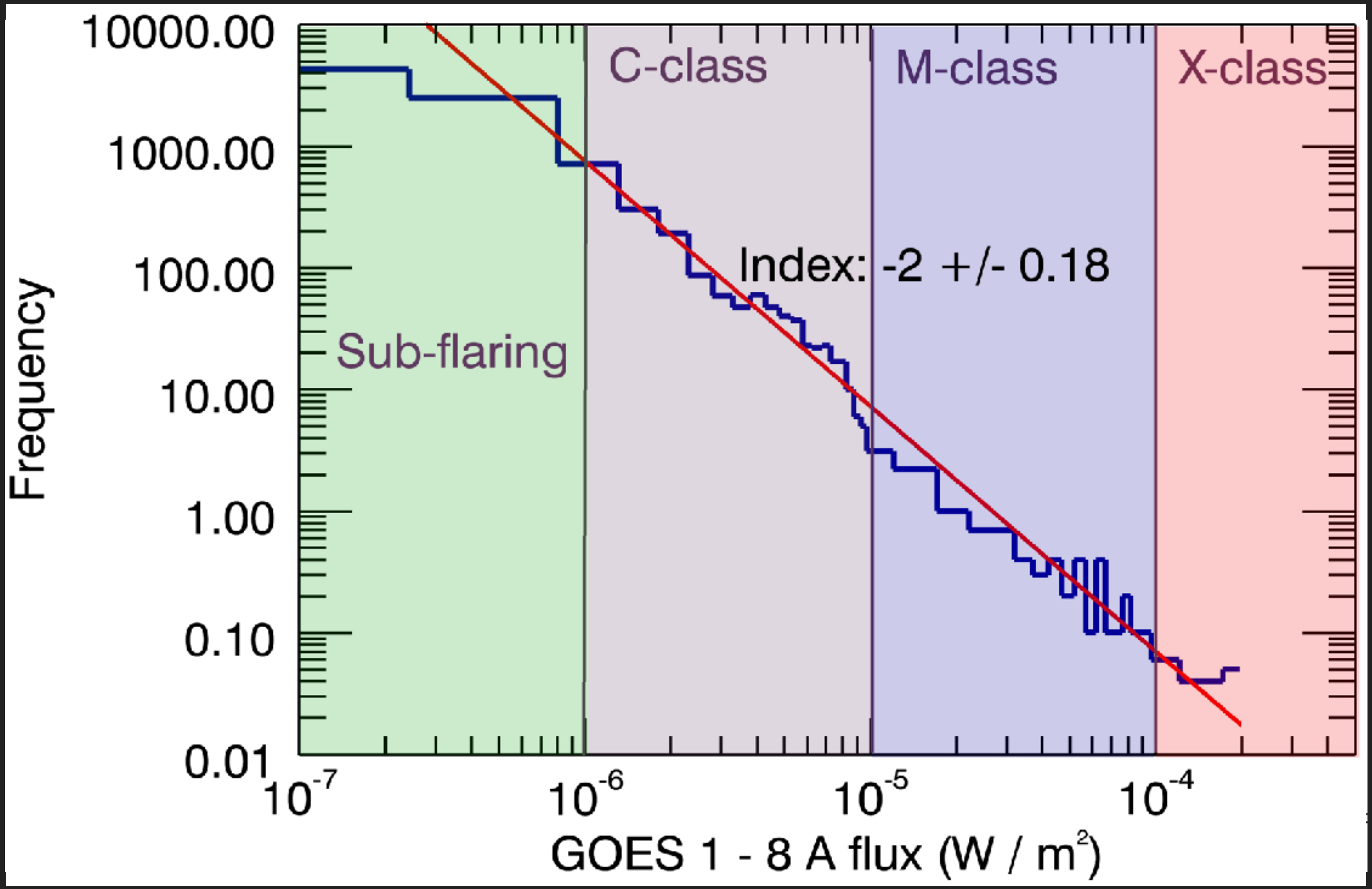
Exponential law of waiting times: a totally random, memoryless flare occurrence along the classical self-organized criticality concept

Robust power-law of waiting times: a system perfectly keeping a memory in giving flares

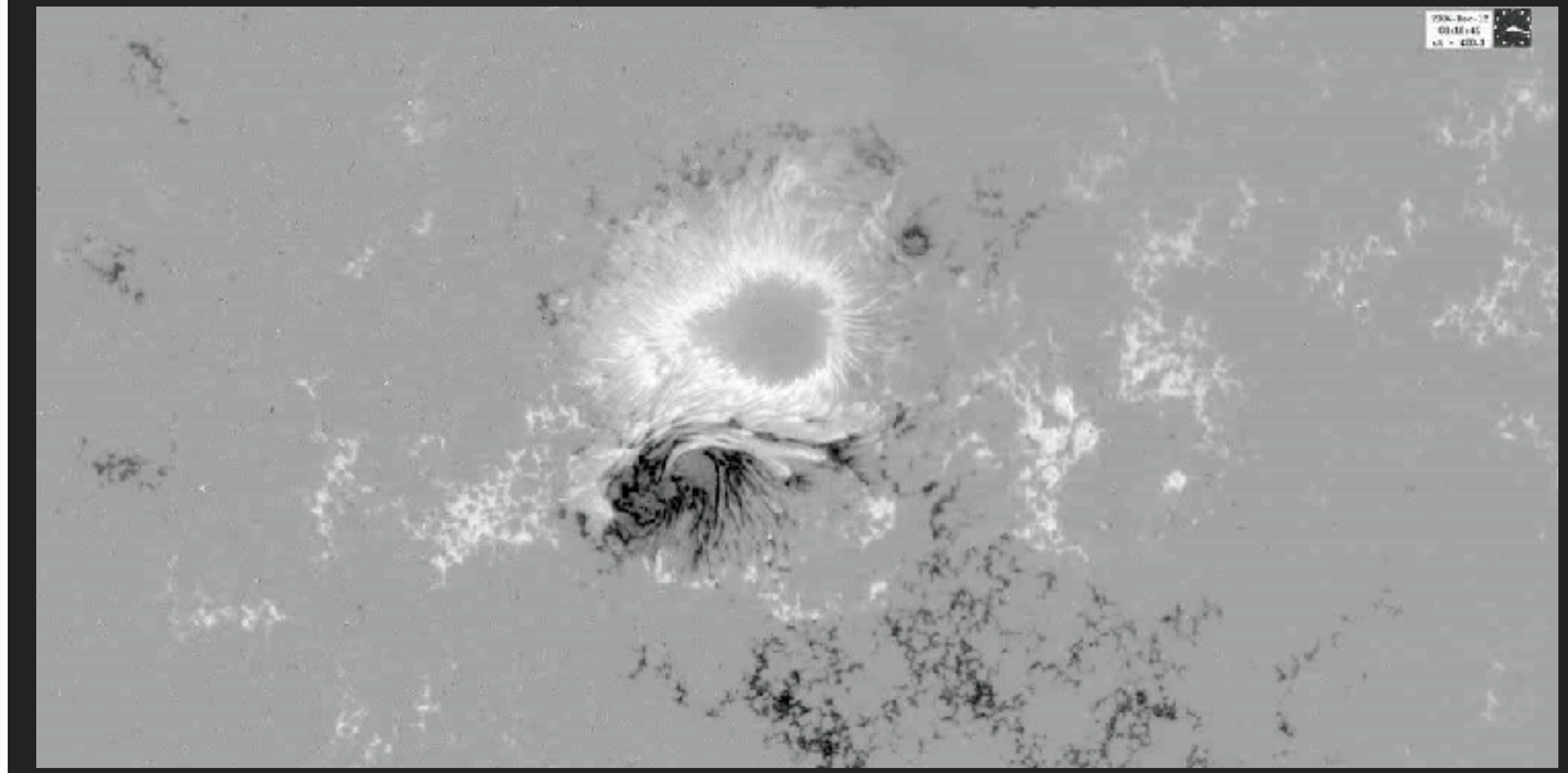
Time-dependent Poisson scaling in waiting times: some memory kept, with stochasticity demonstrated in an exponential distribution of different flaring rates

FLARES: A MIX OF STOCHASTICITY AND MEMORY – NOT RANDOMNESS

- NOAA AR 10930
- Period observed: ~16 days



Response of NOAA AR 10930 over a two-week period in Dec 2006



- Clustering of flares in a flaring active region
- Flaring features of active regions, i.e., complex magnetic PILs, continuously and consistently driven
- Typical situation of a pink-noise dynamical response timeseries

SOLAR FLARE PREDICTION: WHAT DOES IT MEAN?

FLARECAST

BINARY FORECASTING

A flare with the following characteristics will / will not occur:

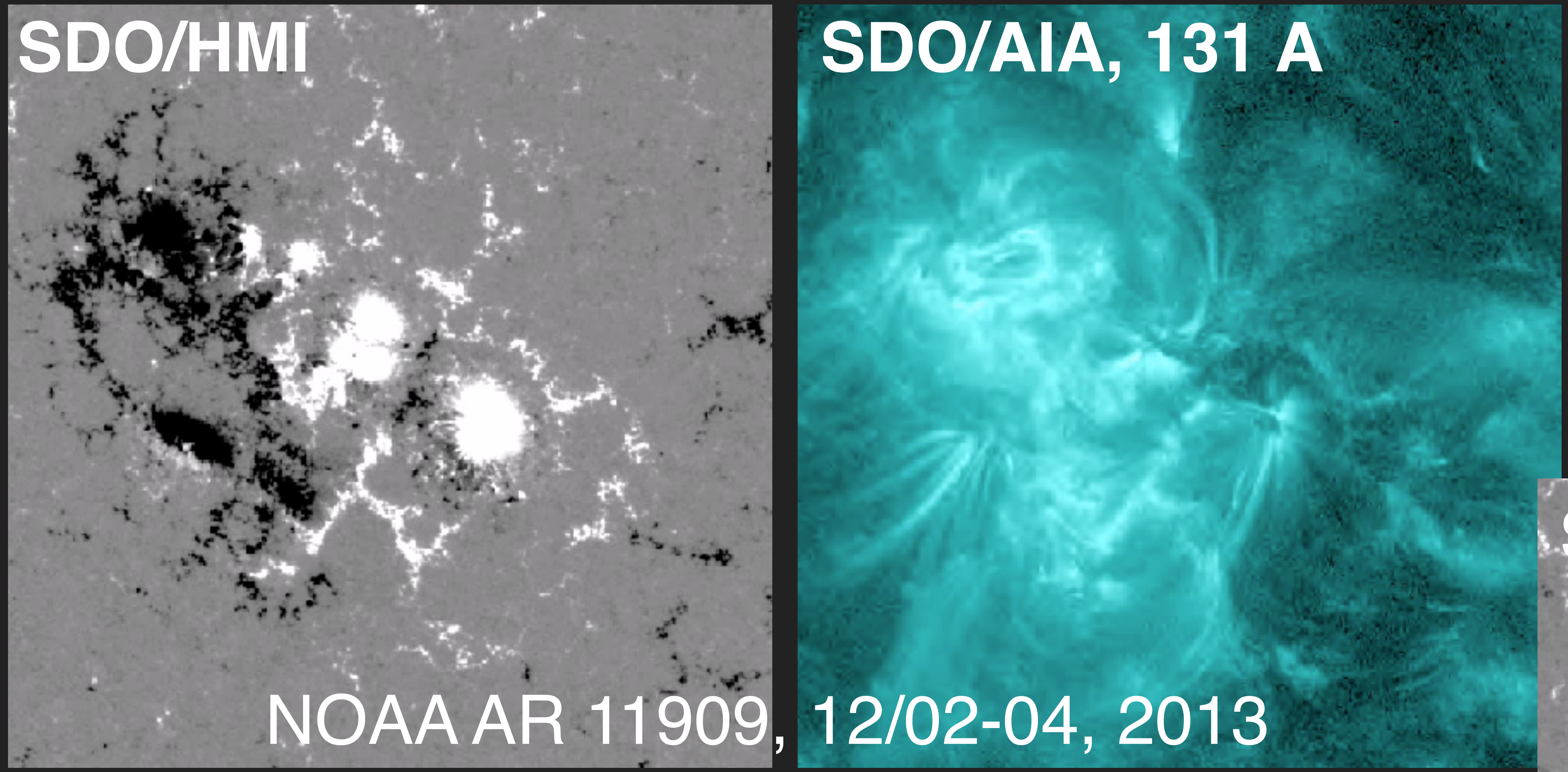
- Flare class, differential or cumulative *(e.g., M1-M9.9 or M1+)*
- Forecast window *(e.g., 24 hours)*
- Latency or not (e.g., effective forecast window starts after xx (≧ 0) hours

PROBABILISTIC FORECASTING

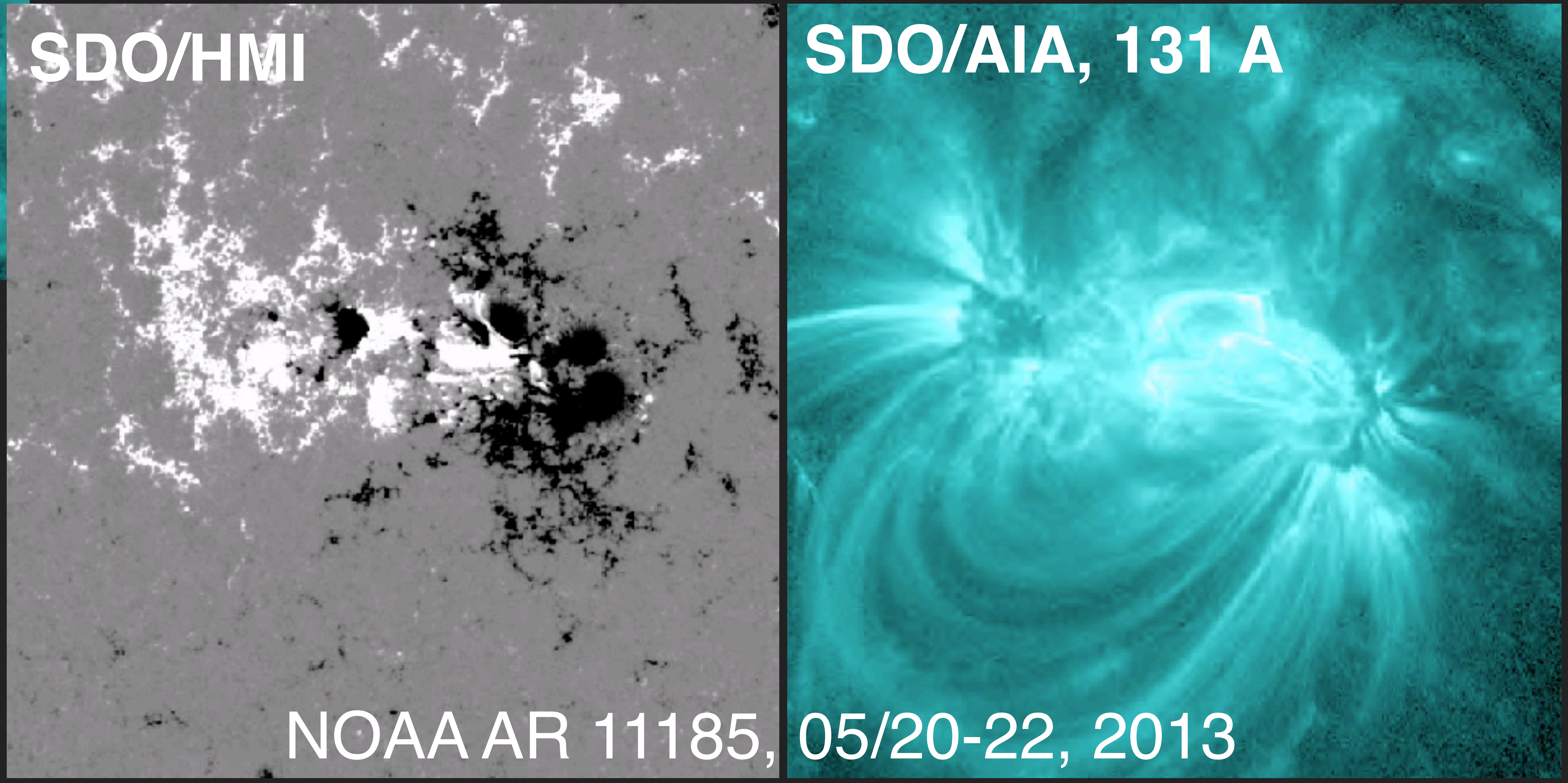
A flare with the following characteristics will occur with probability p ($0 < p < 1$):

- Flare class, differential or cumulative *(e.g., M1-M9.9 or M1+)*
- Forecast window *(e.g., 24 hours)*
- Latency or not (e.g., effective forecast window starts after xx (≧ 0) hours

SOLAR ACTIVE REGIONS: FLARE HOTSPOTS, BUT NOT ALL OF THEM



What is the difference between NOAA AR 11909 that did not host major eruptions, and NOAA AR 11185, that did?



Complexity: compactness, flows, magnetic polarity inversion lines

Only ~1.8% of active regions in solar cycle 23 gave at least one X-class flare

SOLAR FLARES AND MAGNETIC COMPLEXITY

- Flares occur in sunspot complexes
- Sunspots with increasing complexity will lead to higher flare rates for all classes (McCloskey et al., 2016)

- **But what does "complexity" mean?**
    - Nonlinear evolution
    - Irreversibility (i.e., dissipative progression)
    - Far from equilibrium (metastability / marginal stability)

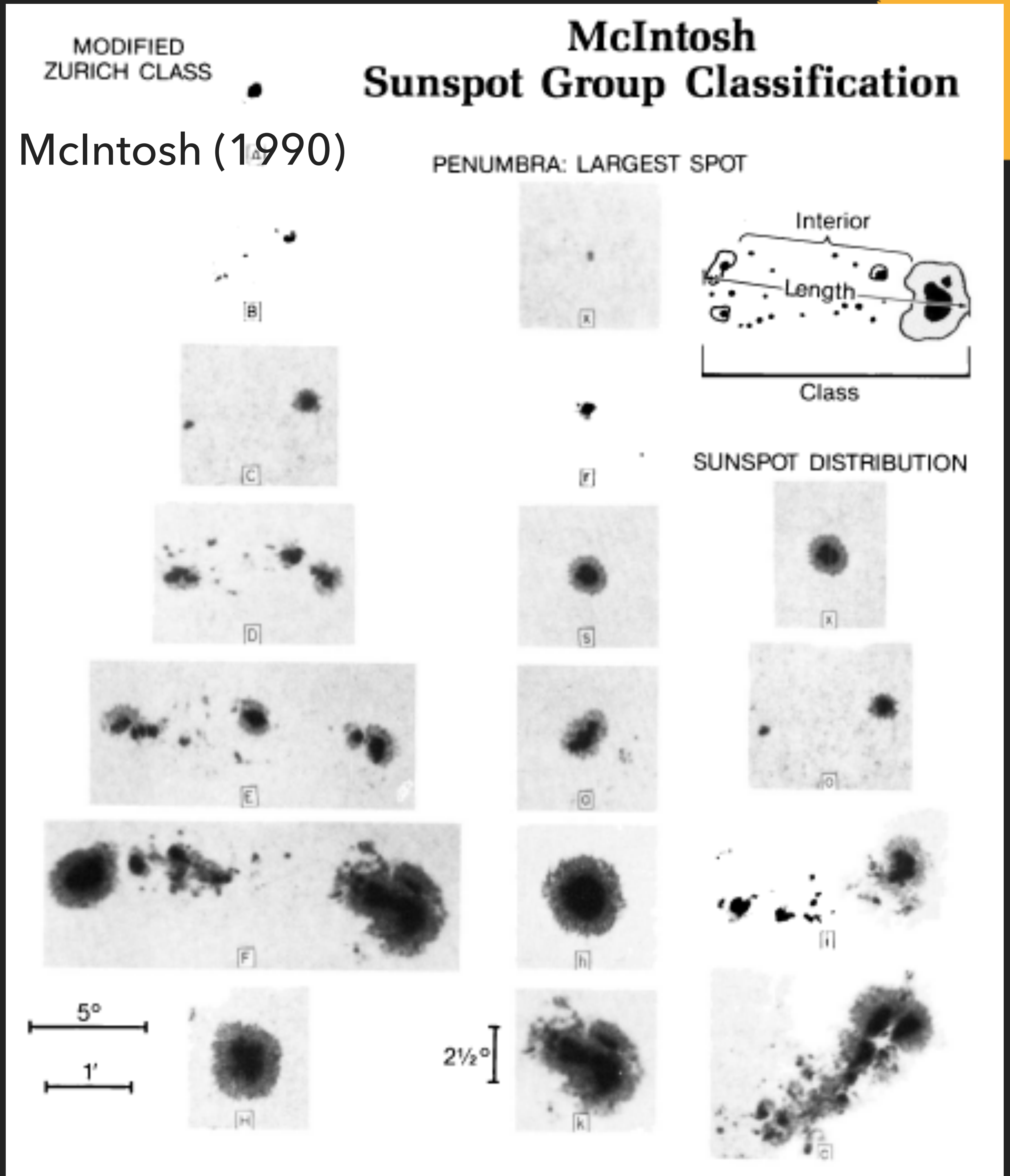


Fig. 1. The 3-component McIntosh classification, with examples of each category.

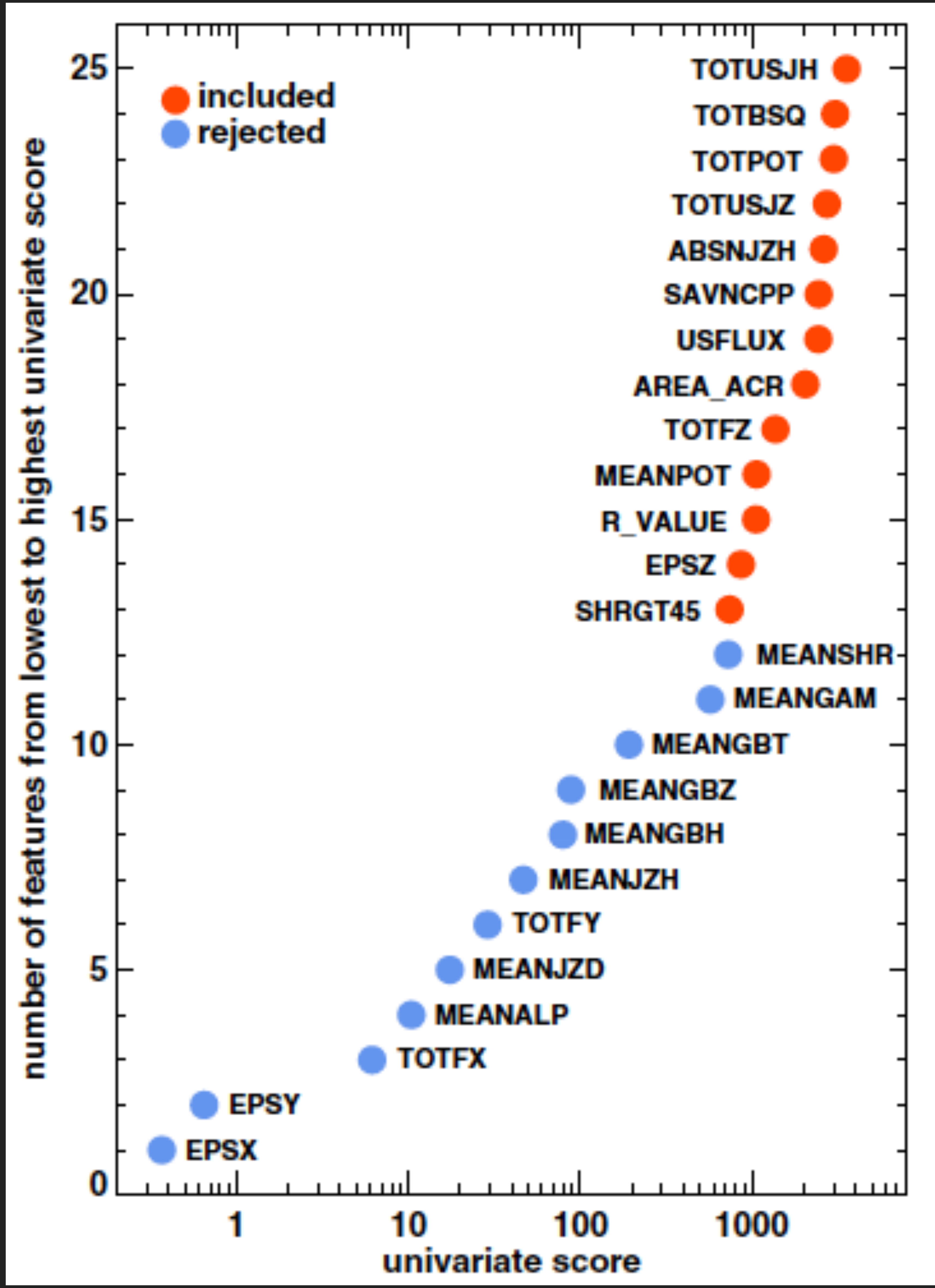
QUANTITATIVE COMPLEXITY CLASSIFICATION AND SOLAR FLARE PREDICTION

Numerous methods over the past 20 years. An effort to categorize them results in the following (*Georgoulis, 2012*):

- Monoscale / multiscale methods — Abramenko et al. (2002, 2003); McAteer at al. (2005); Georgoulis (2005, 2012); Uritsky et al. (2007, 2013); Hewett et al. (2008); Conlon et al. (2010); Kestener et al. (2010), McAteer (2015)
- Morphological methods — Falconer et al. (2001, 2002, 2003, 2008, 2009, 2011); Georrgoulis & Rust (2007); Schrijver (2007); Mason & Hoeksema (2010); Leka & Barnes (2003a; b); Cabnfield et al. (1999); Barnes & Leka (2008), Korsos et al. (2015)
- Statistical methods (on historical & archived data) — Wheatland (2001); Moon et al. (2001); Gallagher et al. (2002); Wheatland (2004, 2005a, b)
- Machine-learning, combinatorial, & assimilation methods — Belanger et al. (2007); Qahwaji & Colak (2007); Colak & Qahwaji (2008, 2009); Qahwaji et al. (2008); Al-Omari et al. (2010); Yu et al. (2009; 2010a, b); Huang et al. (2010) ; Bobra & Couvidat (2014); Bobra & Ilonidis (2015); Boucheron et al., (2015); Nishizuka et al., (2016)
- Analytical methods — Wheatland & Glukhov (1998); Wheatland (2008)
- Local helioseismology methods — Reinard et al. (2010); Komm et al. (2011), etc.
- Other (slightly exotic) methods — Jenkins & Fischbach (2009); Javorsek et al. (2012); Strugarek & Charbonneau (2014)

WHY MACHINE LEARNING METHODS?

- Need for complete automation
- Accommodation of both binary & probabilistic forecasting methods
- Multiple flare predictors – possibility of ranking them
- Complex parametric investigation
- Automated validation
- A posteriori physical understanding in case of ranking of predictors



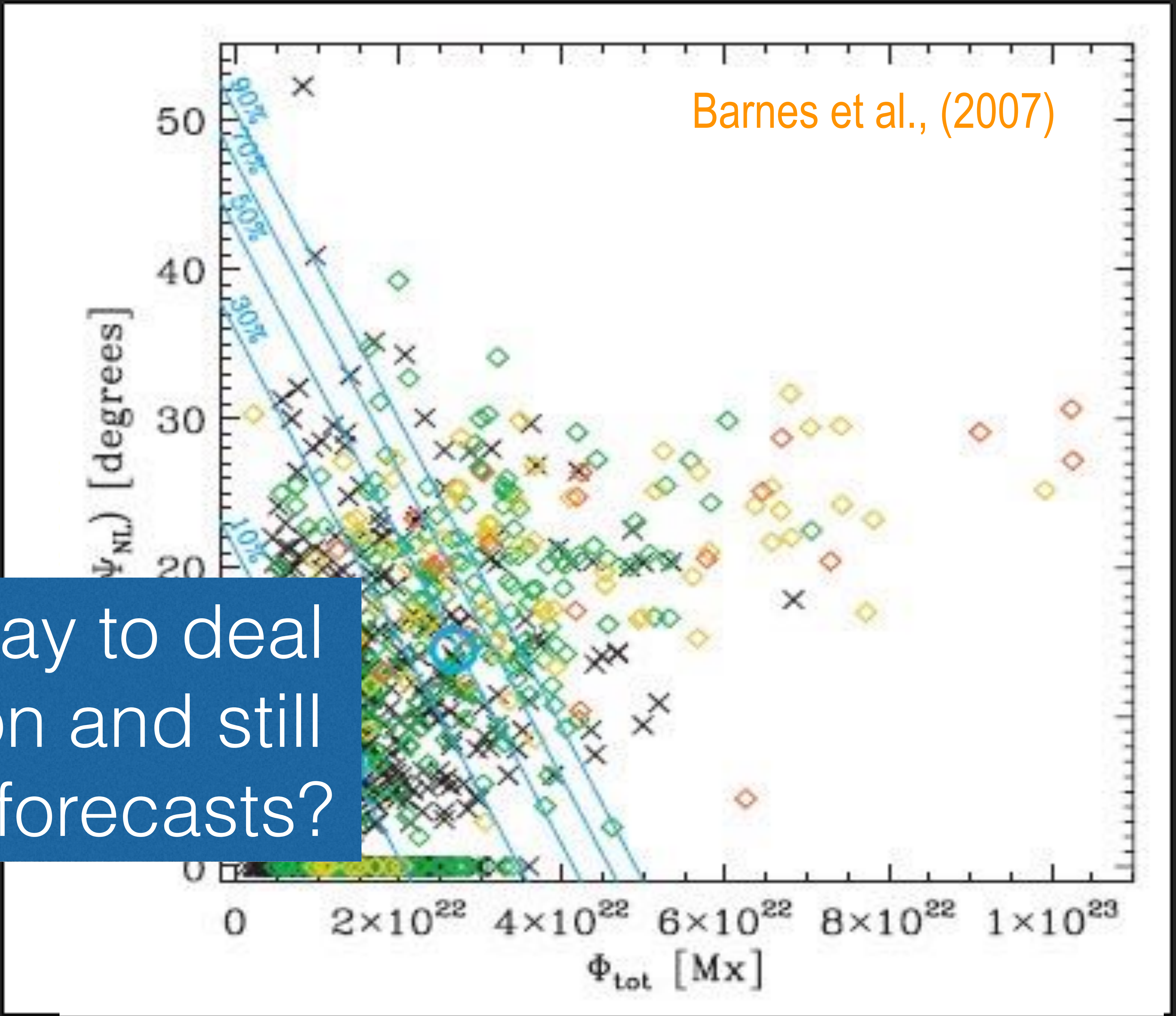
Bobra & Couvidat (2015)

PROPERTIES TRANSLATED TO PREDICTIVE PROBABILITIES

Keyword	Description	Formula	F-Score	Selection
TOTUSJH	Total unsigned current helicity	$H_{c_{\text{total}}} \propto \sum \lvert B_z \cdot J_z \rvert$	3560	Included
TOTBSQ	Total magnitude of Lorentz force	$F \propto \sum B^2$	3051	Included
TOTPOT	Total photospheric magnetic free energy density	$\rho_{\text{tot}} \propto \sum (\mathbf{B}^{\text{Obs}} - \mathbf{B}^{\text{Pot}})^2 \, dA$	2996	Included
TOTUSJZ	Total unsigned vertical current	$J_{z_{\text{total}}} = \sum \lvert J_z \rvert dA$	2733	Included
ABSNJZH	Absolute value of the net current helicity	$H_{c_{\text{abs}}} \propto \lvert \sum B_z \cdot J_z \rvert$	2618	Included
SAVNCPP	Sum of the modulus of the net current per polarity	$J_{z_{\text{sum}}} \propto \left\lvert \sum^{B_z^+} J_z dA \right\rvert + \left\lvert \sum^{B_z^-} J_z dA \right\rvert$	2448	Included
USFLUX	Total unsigned flux	$\Phi = \sum \lvert B_z \rvert dA$	2437	Included
AREA_ACR	Area of strong field pixels in the active region	$\text{Area} = \sum \text{Pixels}$	2047	Included
TOTFZ	Sum of z-component of Lorentz force	$F_z \propto \sum (B_x^2 + B_y^2 - B_z^2) dA$	1371	Included
MEANPOT	Mean photospheric magnetic free energy	$\overline{\rho} \propto \frac{1}{N} \sum (\mathbf{B}^{\text{Obs}} - \mathbf{B}^{\text{Pot}})^2$	1064	Included
R_VALUE	Sum of flux near polarity inversion line	$\Phi = \sum \lvert B_{LoS} \rvert dA$ within R mask	1057	Included
EPSZ	Sum of z-component of normalized Lorentz force	$\delta F_z \propto \frac{\sum (B_x^2 + B_y^2 - B_z^2)}{\sum B^2}$	864.1	Included
SHRGT45	Fraction of Area with shear > 45°	Area w[illegible]	[illegible]	[illegible]
MEANSHR	Mean shear angle	$\overline{\Gamma} =$ [illegible]	[illegible]	[illegible]
MEANGAM	Mean angle of field from radial	$\overline{\gamma}$ [illegible]	[illegible]	[illegible]
MEANGBT	Mean gradient of total field	$\overline{\lvert \nabla B_{\text{tot}} \rvert}$ [illegible]	[illegible]	[illegible]
MEANGBZ	Mean gradient of vertical field	$\overline{\lvert \nabla B_z \rvert} =$ [illegible]	[illegible]	[illegible]
MEANGBH	Mean gradient of horizontal field	$\overline{\lvert \nabla B_h \rvert} =$ [illegible]	[illegible]	[illegible]
MEANJZH	Mean current helicity (B_z contribution)	$\overline{H_c} \propto \frac{1}{N} \sum B_z \cdot J_z$	46.73	Discarded
TOTFY	Sum of y-component of Lorentz force	$F_y \propto \sum B_y B_z dA$	28.92	Discarded
MEANJZD	Mean vertical current density	$\overline{J_z} \propto \frac{1}{N} \sum \left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y} \right)$	17.44	Discarded
MEANALP	Mean characteristic twist parameter, α	$\alpha_{\text{total}} \propto \frac{\sum J_z \cdot B_z}{\sum B_z^2}$	10.41	Discarded
TOTFX	Sum of x-component of Lorentz force	$F_x \propto -\sum B_x B_z dA$	6.147	Discarded
EPSY	Sum of y-component of normalized Lorentz force	$\delta F_y \propto \frac{-\sum B_y B_z}{\sum B^2}$	0.647	Discarded
EPSX	Sum of x-component of normalized Lorentz force	$\delta F_x \propto \frac{\sum B_x B_z}{\sum B^2}$	0.366	Discarded

Bobra & Couvidat (2015)

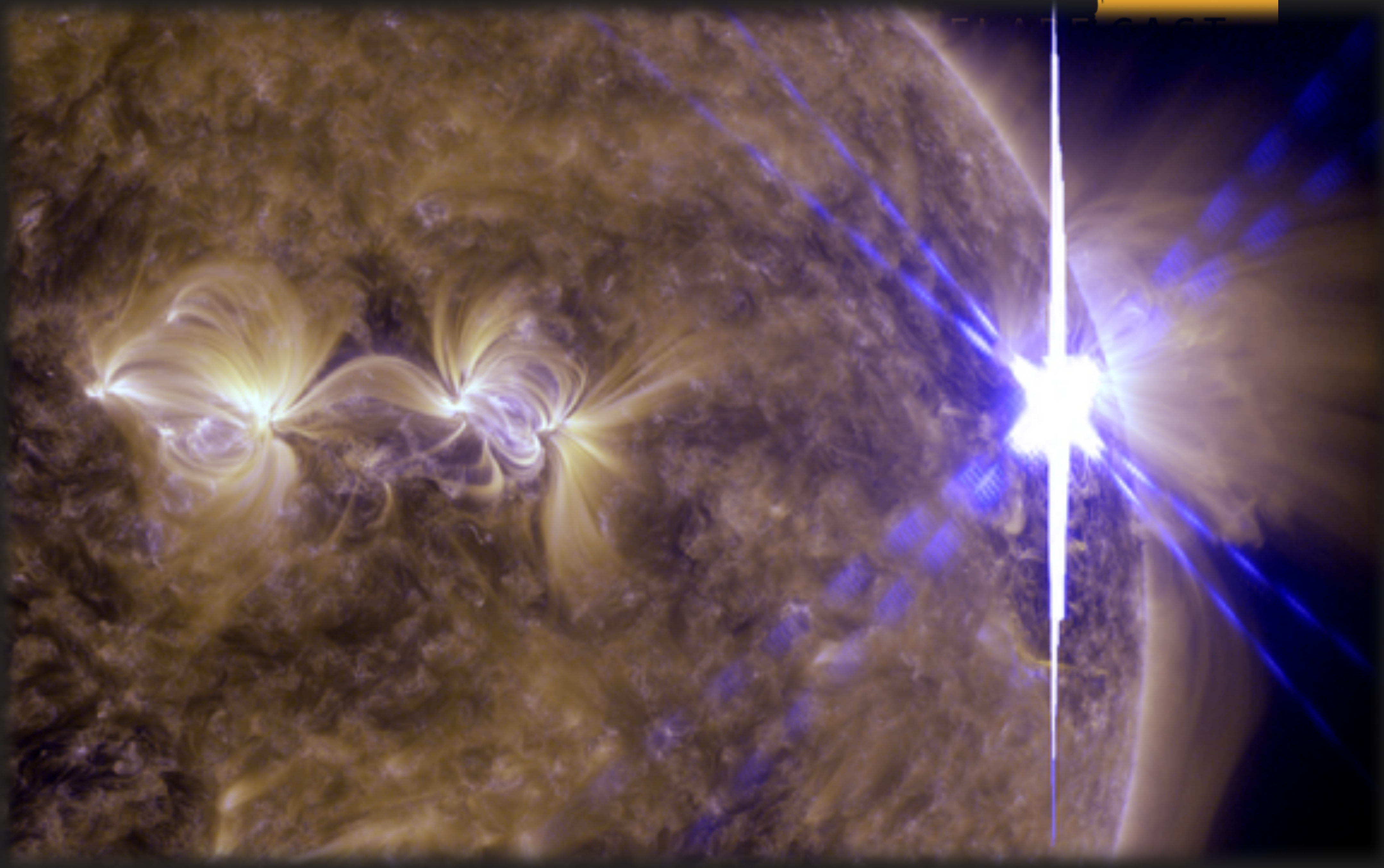
What is the optimal way to deal with all this information and still achieve reliable NRT forecasts?



Discriminant analysis: Two-function, linear DA for four-class prediction (non-flaring, C, M, and X-class)

WHAT IS FLARECAST?

FLARECAST is an EC H2020 project aiming to develop an advanced solar flare prediction system based on automatically extracted physical properties of solar active regions, coupled with state-of-the-art solar flare prediction methods and validated using the most appropriate forecast verification measures.

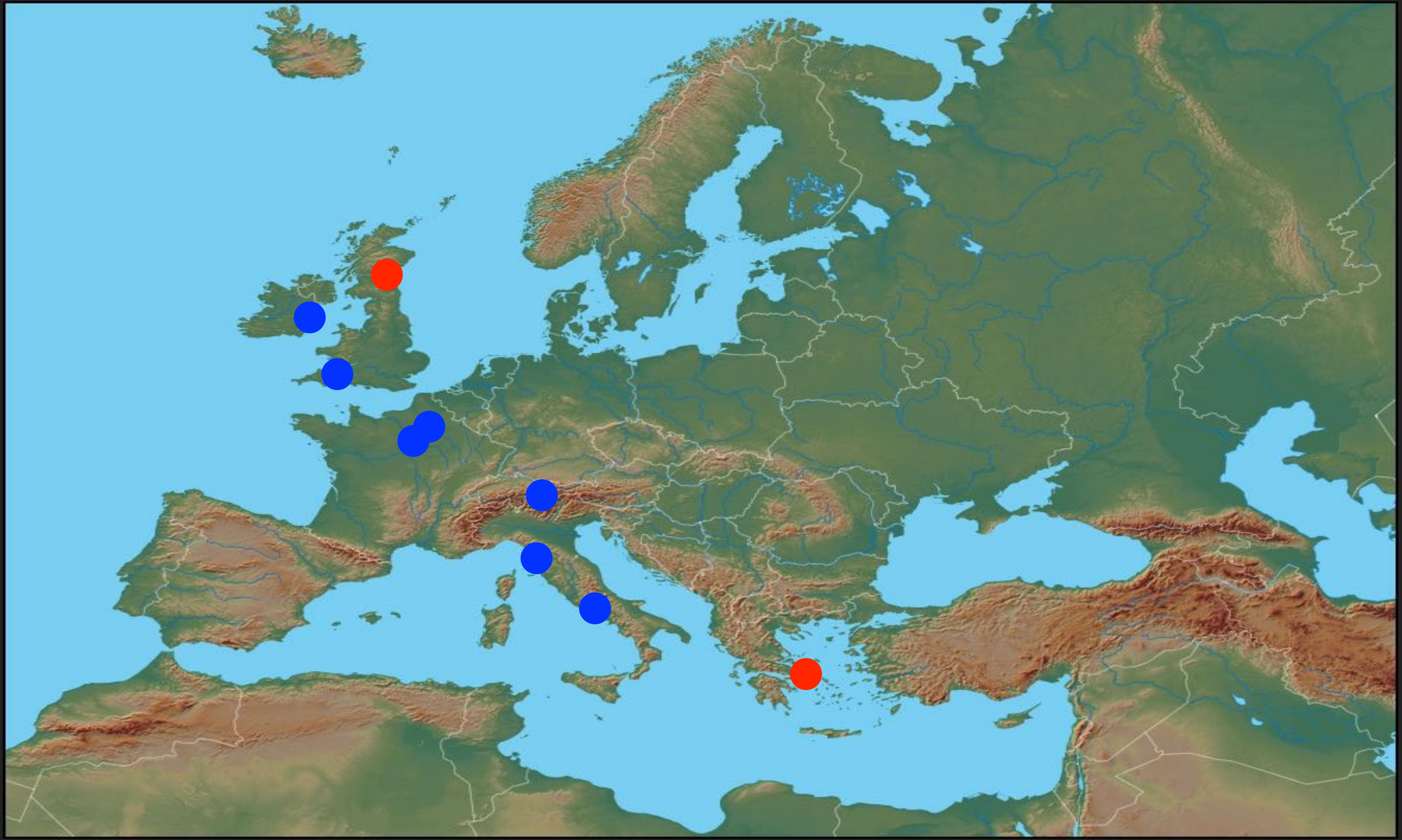


Source: NASA SDO

FLARECAST top-level objectives:

- To understand the drivers of solar flare activity and improve flare prediction
- To provide a globally accessible flare prediction service that facilitates expansion
- To engage with space weather end users and inform policy makers and the public

THE FLARECAST CONSORTIUM



THE FLARECAST CONSORTIUM

Institution	Country	Expertise
Academy of Athens (AA) **Project Coordinator**	GR	Solar physics, flare forecasting
Trinity College Dublin (TCD)	IE	Solar physics, flare forecasting
Università degli Studi di Genova (UNIGE)	IT	Mathematical techniques
Consiglio Nazionale delle Ricerche (CNR)	IT	Mathematical techniques
Centre National de la Recherche Scientifique (CNRS)	FR	Solar physics, magnetic field simulations
Université Paris-Sud (PSUD)	FR	Infrastructure (MEDOC)
Fachhochschule Nordwestschweiz (FHNW)	CH	Computer science
Met Office (MO)	UK	Operational SpWx, verification
Northumbria University (UNN) **Project Scientist**	UK	Solar physics, flare forecasting, verification

FLARECAST DATA TYPES

FLARECAST

Overarching science question: how far can we go in predicting solar flares?

External data:

- SDO / HMI NRT SHARPs
- NOAA / SWPC SRS data
  - Active region numbers
  - AR locations
  - Flare occurrences

Science data:

- Extracted properties
- Prediction algorithm config.
- Predictions
- Validation

Infrastructure data:

- Algorithm management
- Workflow management

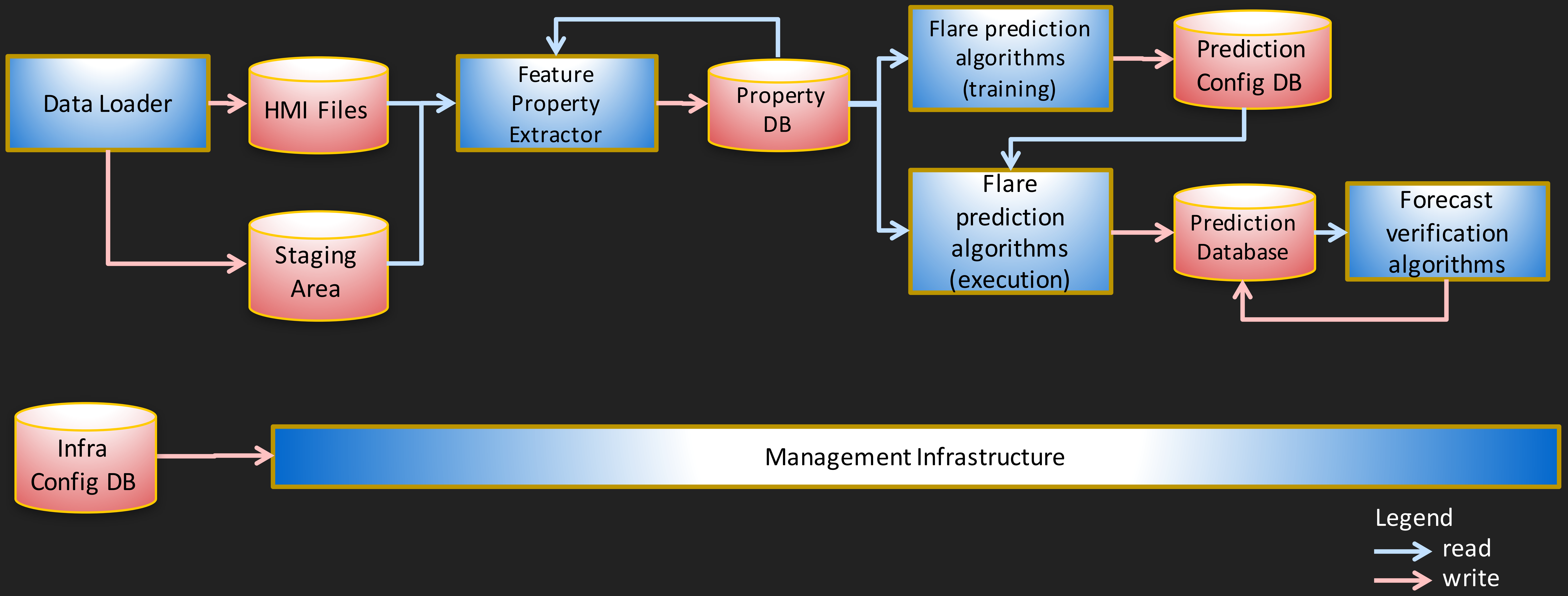
FLARECAST ARCHITECTURE

Step 1: Data acquisition

Step 2: Feature property extraction

Step 3: Prediction training / execution

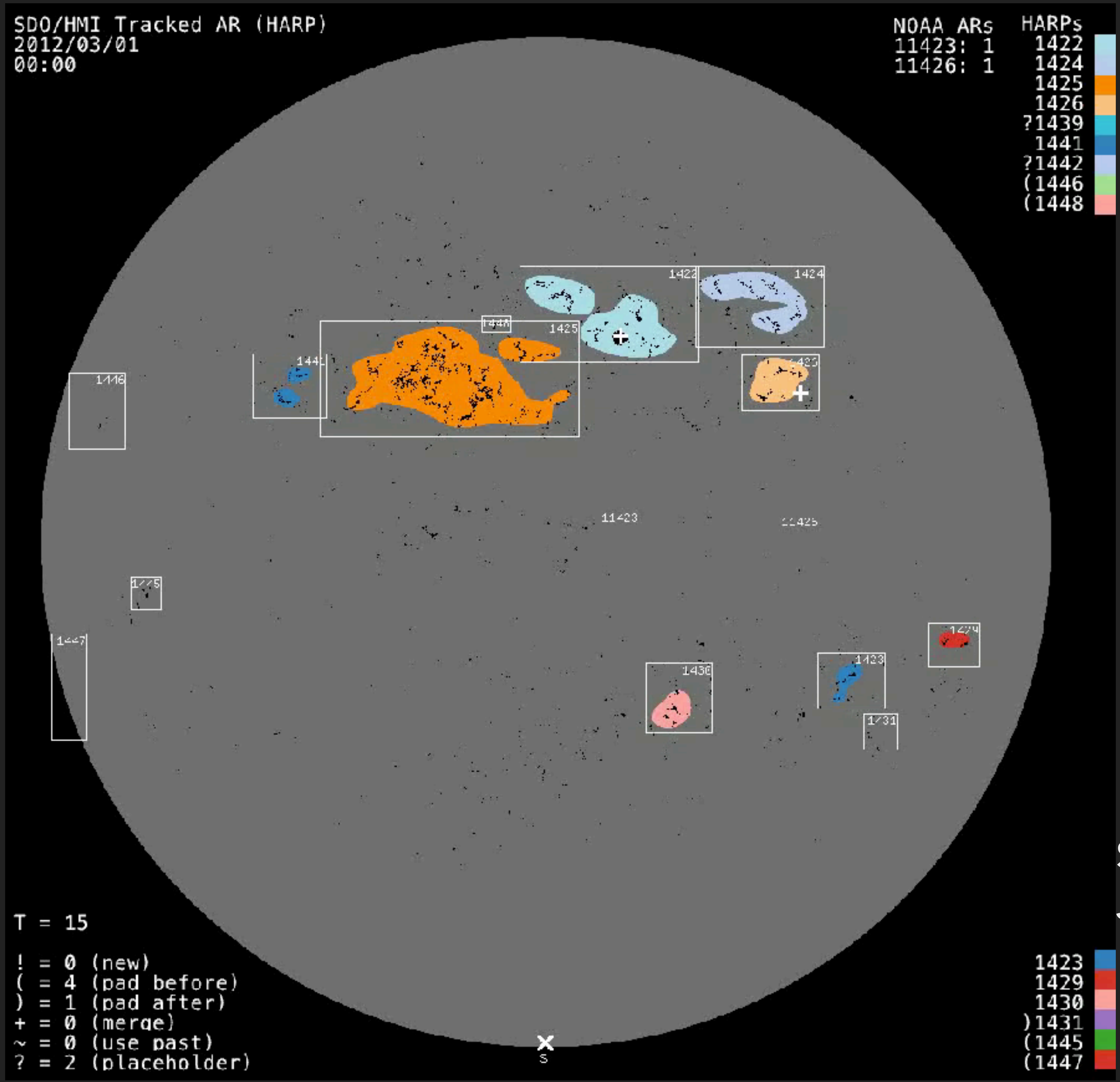
Step 4: Data verification



FLARECAST EXTERNAL DATA

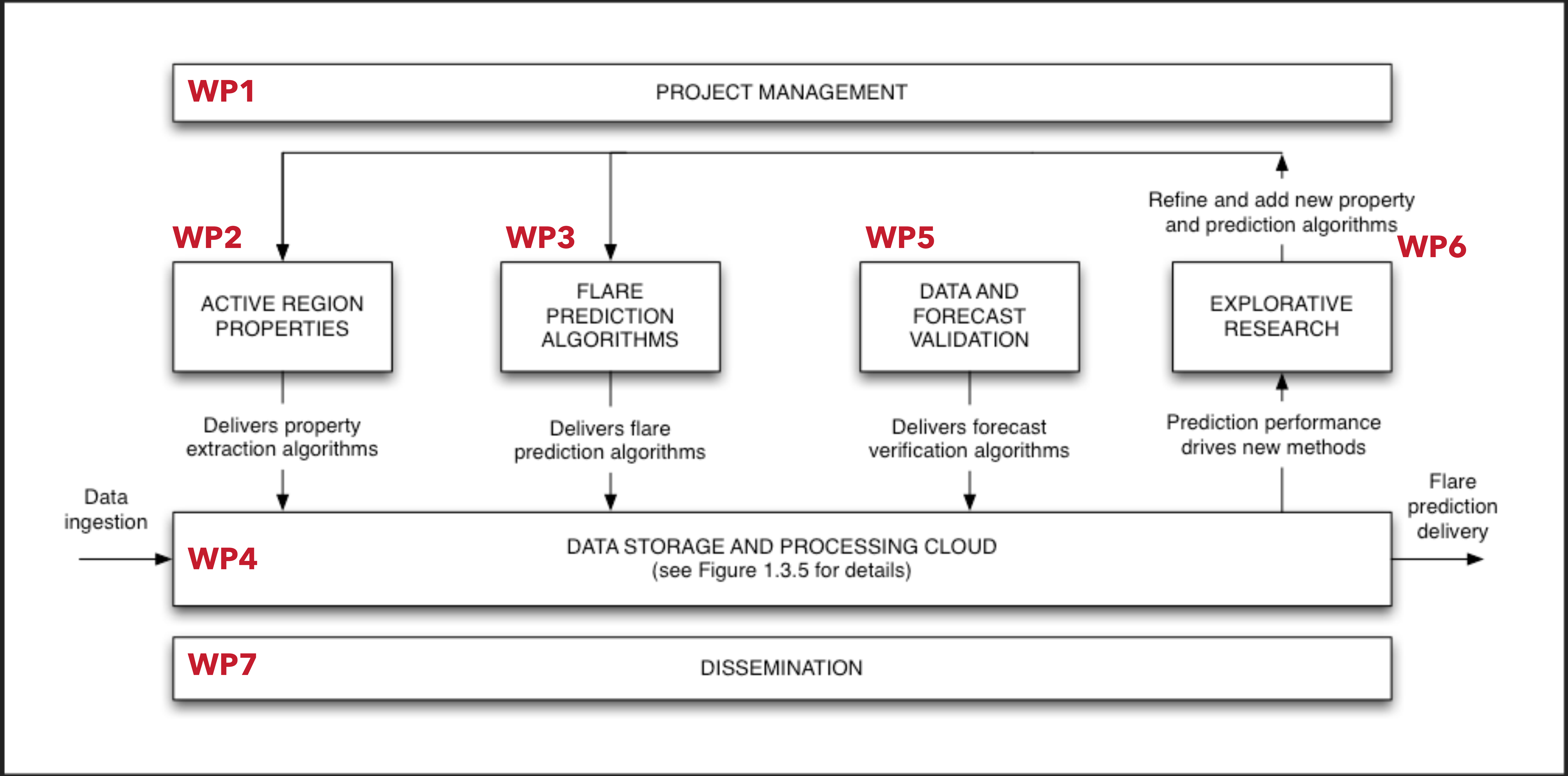
- **SDO / HMI data**
  - SHARP vector magnetograms - NRT (*hmi.sharp_720s_nrt*)
  - LOS magnetograms (*hmi.M_720s*)
  - SHARP vector magnetograms - definitive (*hmi.sharp_720s*)
- **SRS active region & flare data**

  (*YYYY_events.tar.gz*)



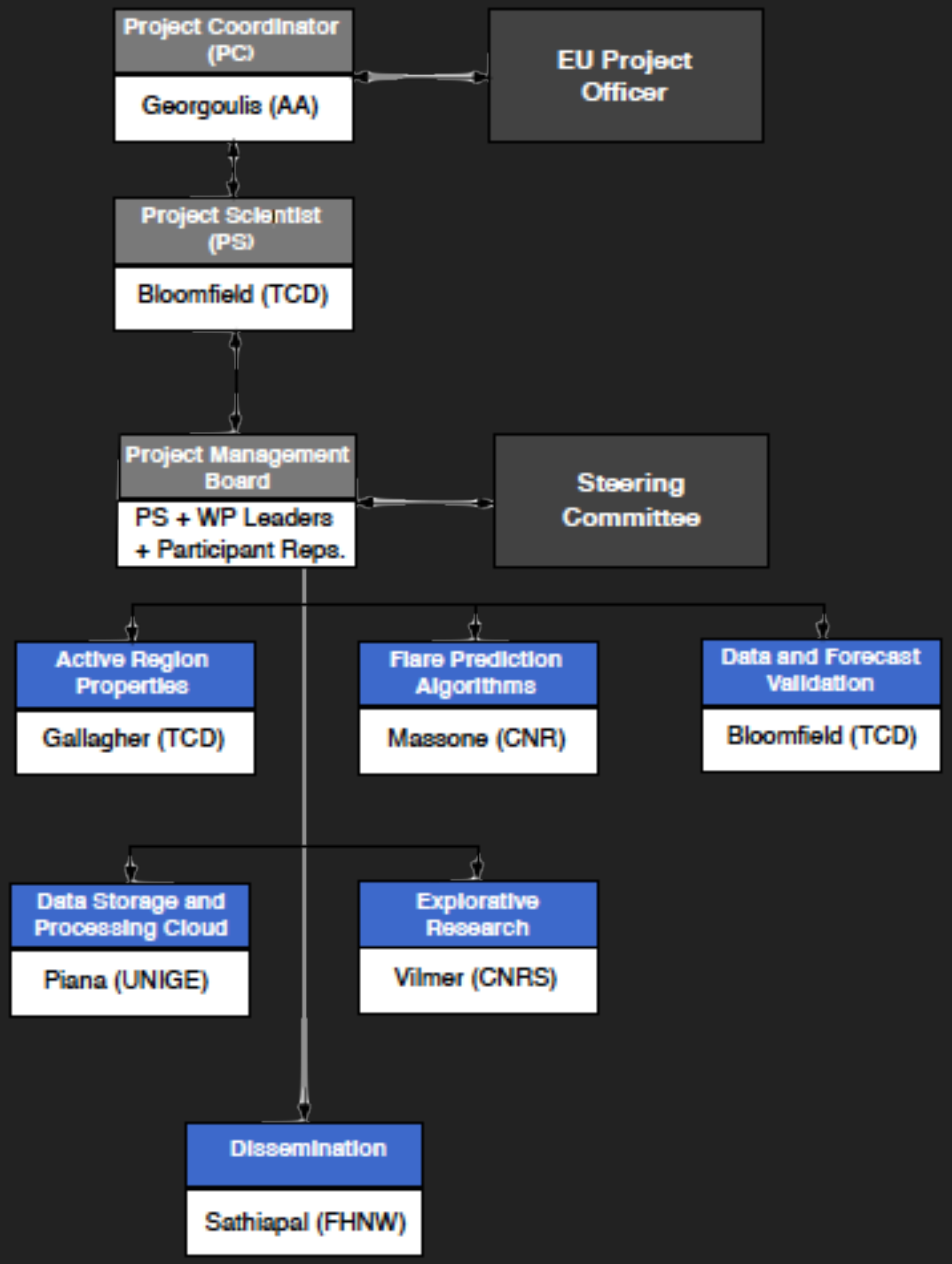
Source: SDO / HMI JSOC

FLARECAST WORK PACKAGE STRUCTURING



WP1: PROJECT MANAGEMENT

- **Project Management Board (PMB)**
  - Project Coordinator
  - Project Scientist
  - WP Leaders (at least 1 rep from each partner)
- **Steering Committee**
  - Neal Hurlburt (LMSAL - USA), **Chair**
  - Graham Barnes (NWRA/CoRA - USA)
  - Doug Biesecker (NOAA / SWPC - USA)
  - Pedro Russo (Leiden Obs. - NL)
  - Silvia Villa (Milano Pol. School - IT)

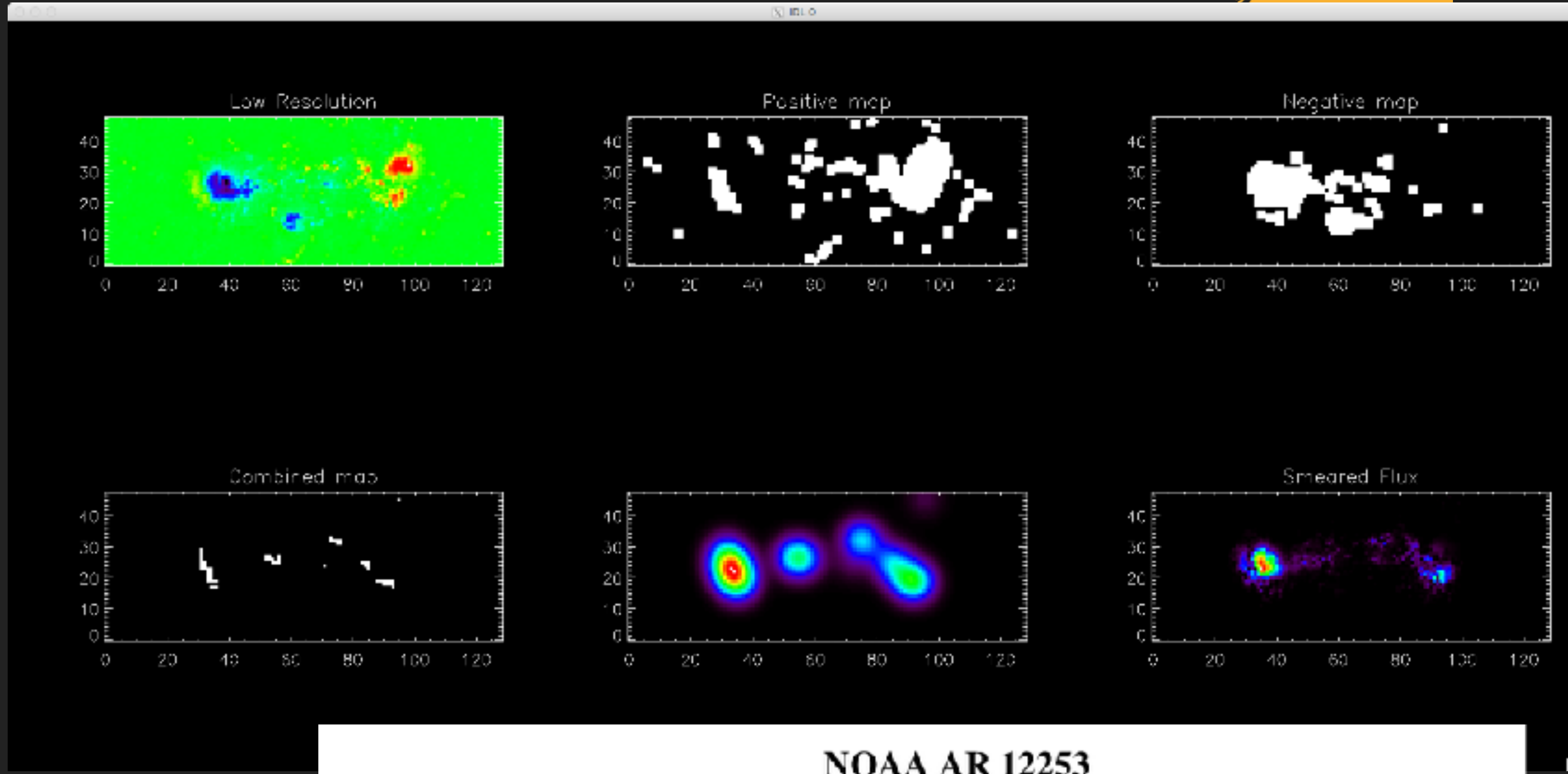


WP2: ACTIVE REGION PROPERTIES AS PREDICTORS OF FLARING ACTIVITY

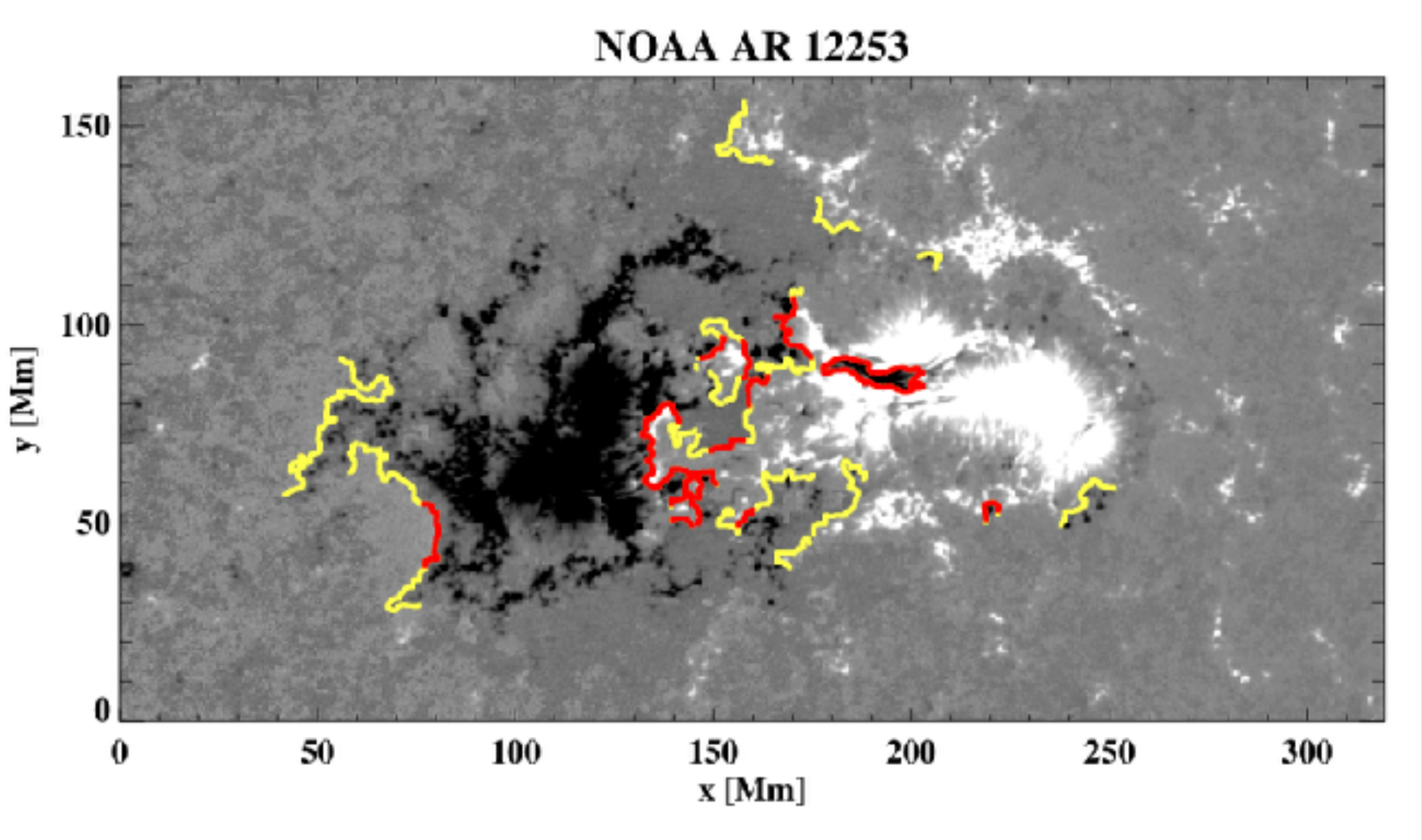
FLARECAST

Data Source	Property Group	Developer	Status
SWPC catalogues			(To do / In progress / Under testing / Delivered)
	Solar Region Summary properties	TCD / FHNW	
	GOES X-ray events	TCD / FHNW	
LOS magnetograms			
	SMART-derived properties (Ahmed et al., 2013)	TCD	In progress
	SMART delta finder (Padinhatteeri et al., 2015)	TCD	To do
	Effective connected magnetic field strength (B_{eff}) (Georgoulis & Rust, 2007)	AA	Under testing
	Fractal dimension (Georgoulis, 2012)	AA	Under testing
	Multi fractal structure function s(q) inertial range index k (Georgoulis, 2012)	AA	Under testing
	Fourier power spectral index (Guerra et al., 2015)	AA / TCD	Under testing / Under testing
	CWT power spectral index (Hewett et al., 2008)	TCD	Under testing
	Generalised correlation dimension (Georgoulis, 2012)	AA	Under testing
	Holder exponent h (Conlon et al., 2010)	AA	To do
	Hausdorff dimension D(h) (Conlon et al., 2010)	AA	To do
	WTMM (Conlon et al., 2010)	AA	To do
	Decay index (Zuccarello et al. 2014)	TCD	Under testing
	3D magnetic null point (Reid et al. 2012)	TCD	In progress
	R (Schrijver 2007)	TCD	To do
	$^{L}WL_{SG}$ (Falconer et al. 2008)	Code not yet available	
	Ising energy (Ahmed et al. 2010)	TCD / AA	To do / To do
	WG_M and S_{IH} (Korsos et al. 2015)	TCD / AA	To do / To do
	Helicity injection rate (Park et al. 2010)	TCD	In progress
Vector magnetograms			
	SHARP properties (Bobra et al. 2014)	TCD	To do
	Helicity (multiple works [e.g. Bobra & Couvidat 2015])	Code easily reproducible - developer to be decided	
	Free magnetic energy (multiple works [e.g. Bobra & Couvidat 2015])	Code easily reproducible - developer to be decided	
	Non-neutralized currents (Georgoulis et al., 2012)	AA	Under testing
	Flow fields (Wang et al. 2014)	TCD	Under testing
Intensity images			
	Flow fields		

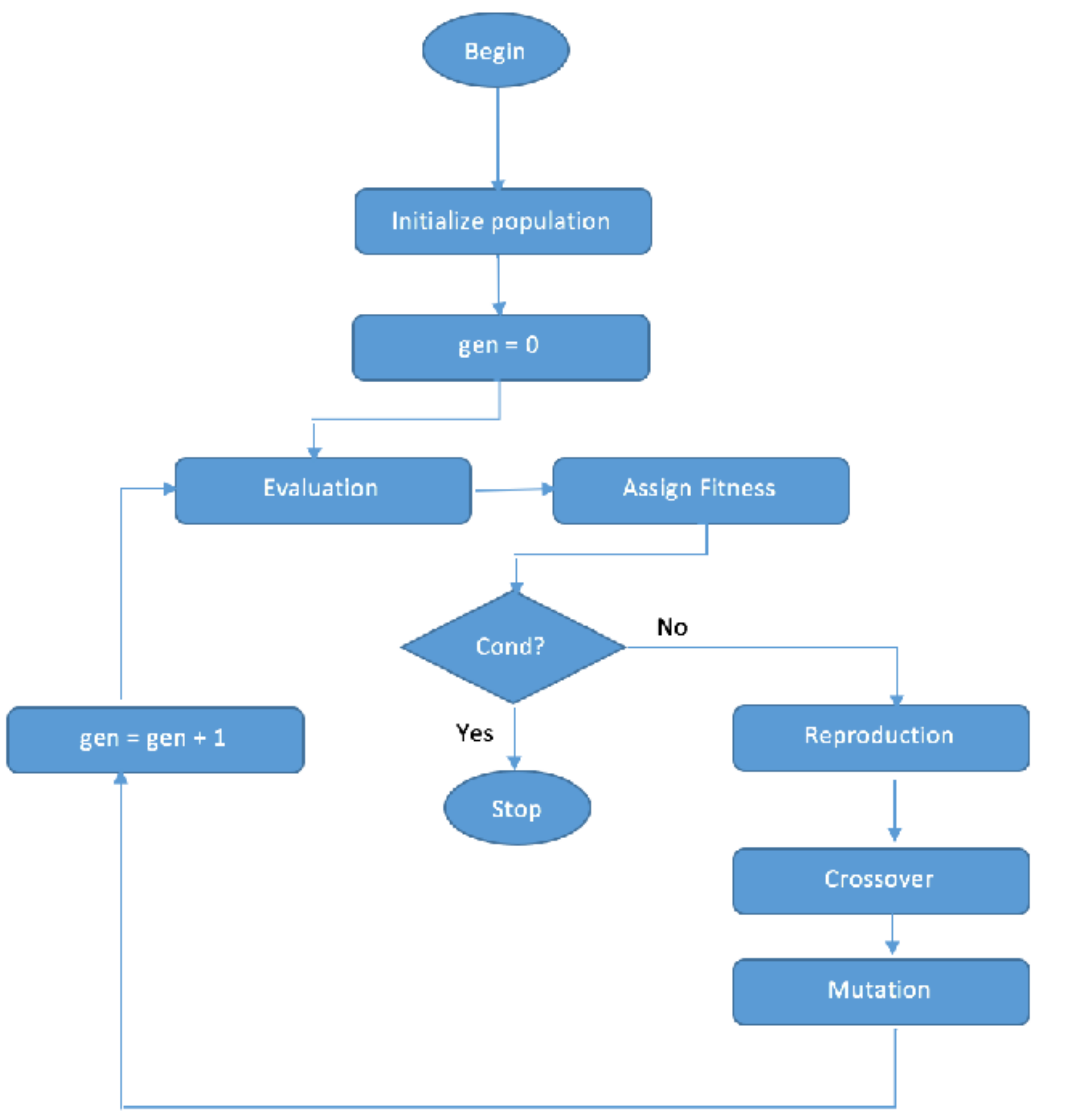
+ SHARP data properties



Predominantly photospheric active region magnetograms

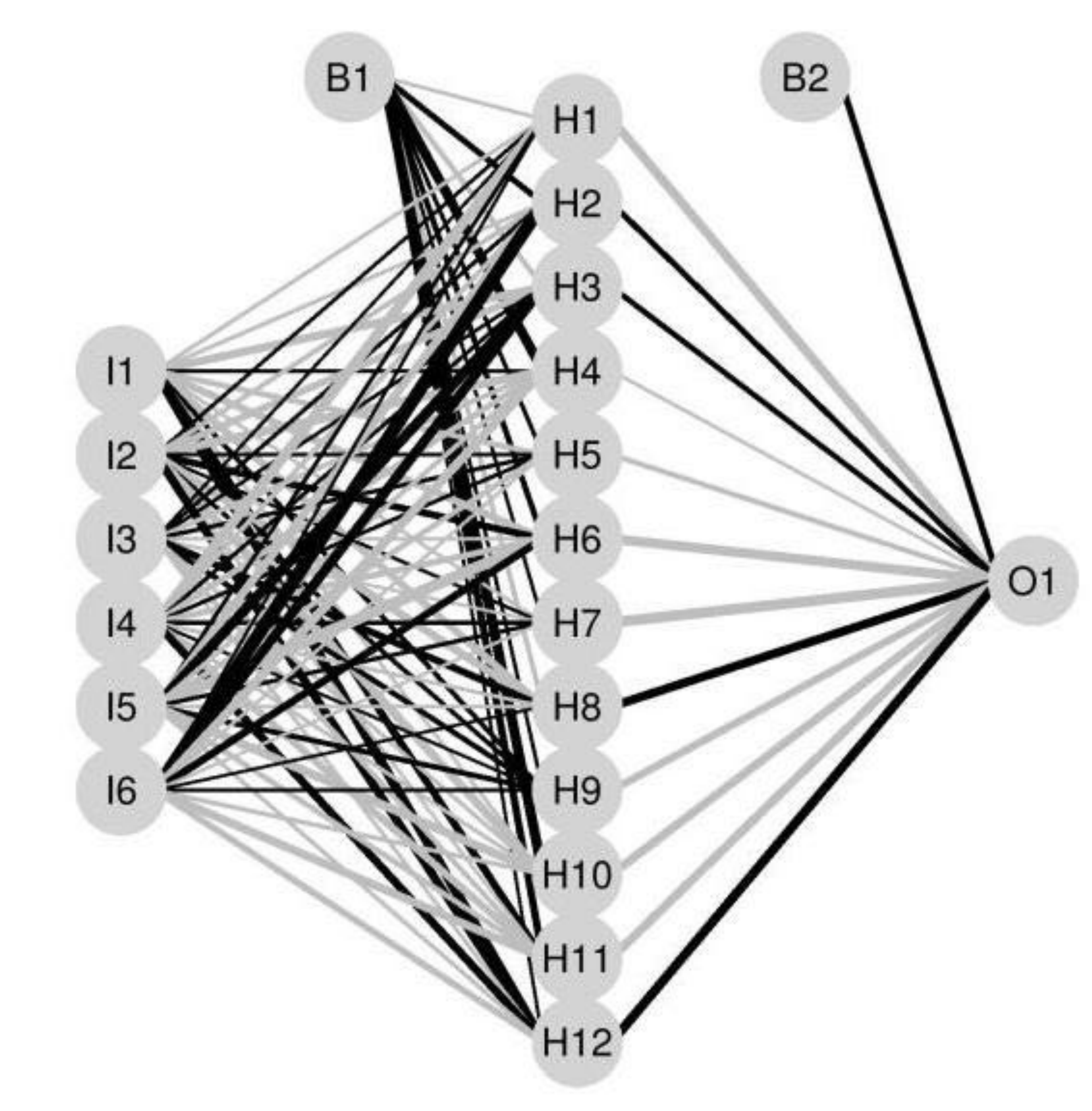


WP3: FLARE PREDICTION ALGORITHMS



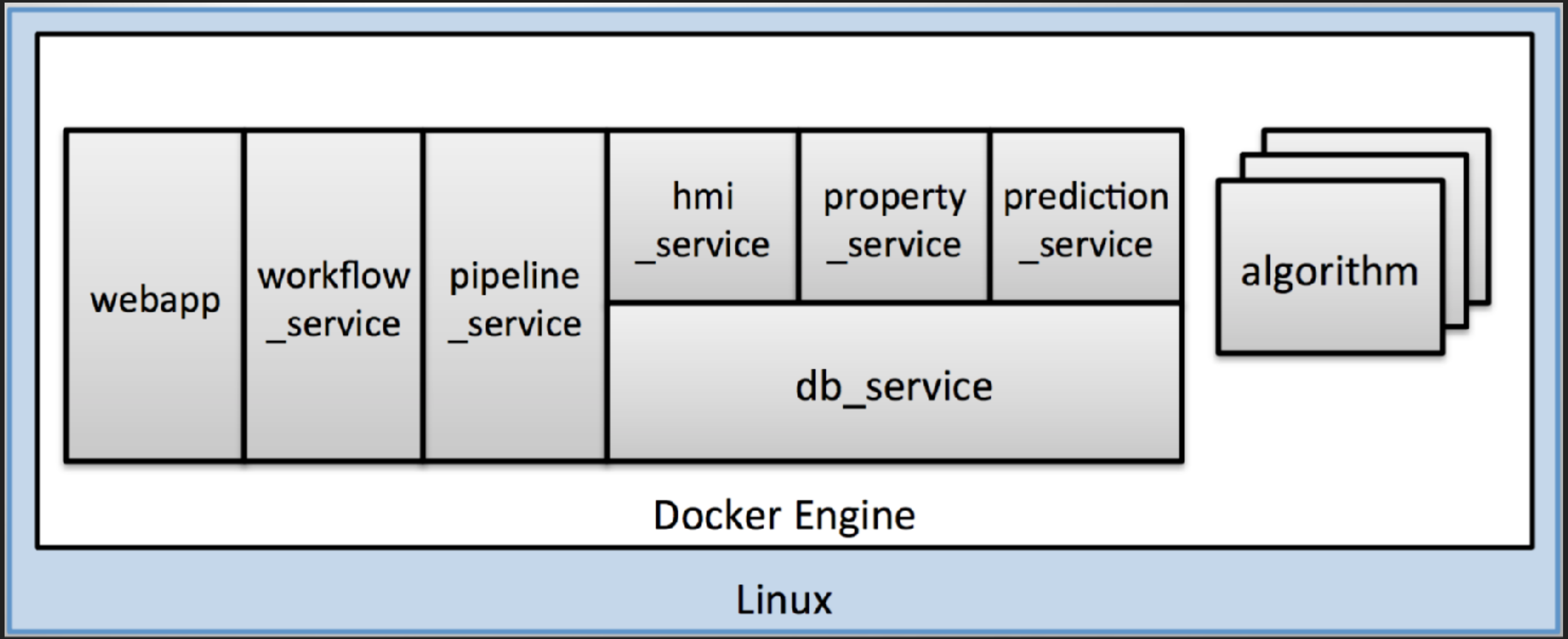
Typical flowchart of a genetic algorithm

- Supervised / unsupervised ML methods (standard, advanced, innovative)
- Non-ML methods
- Genetic algorithms
- Statistical methods



Example of multi-layer perceptron

WP4: DATA STORAGE AND PROCESSING CLOUD



- Open-source architecture of Docker containers within Docker engines
- pick and mix installation

WP5: DATA AND FORECAST VALIDATION

Binary validation: Flare (YES) or No Flare (NO)

	Forecast Flare	Forecast No-flare
Observed Flare	TP	FN
Observed No-flare	FP	TN

Table courtesy: Shaun Bloomfield

2 x 2 contingency table

- TP : true positives
- FN : false negatives
- FP : false positives
- TN : true negatives

- Generalized skill score:

$$SS = \frac{score - score_{reference}}{score_{perfect} - score_{reference}}$$

Tailoring according to different end user needs

- Heidke skill score (ref: random prediction):

$$HSS = \frac{2(TP + TN) - N}{N}$$

- Appleman skill score (ref: climatology [v]):

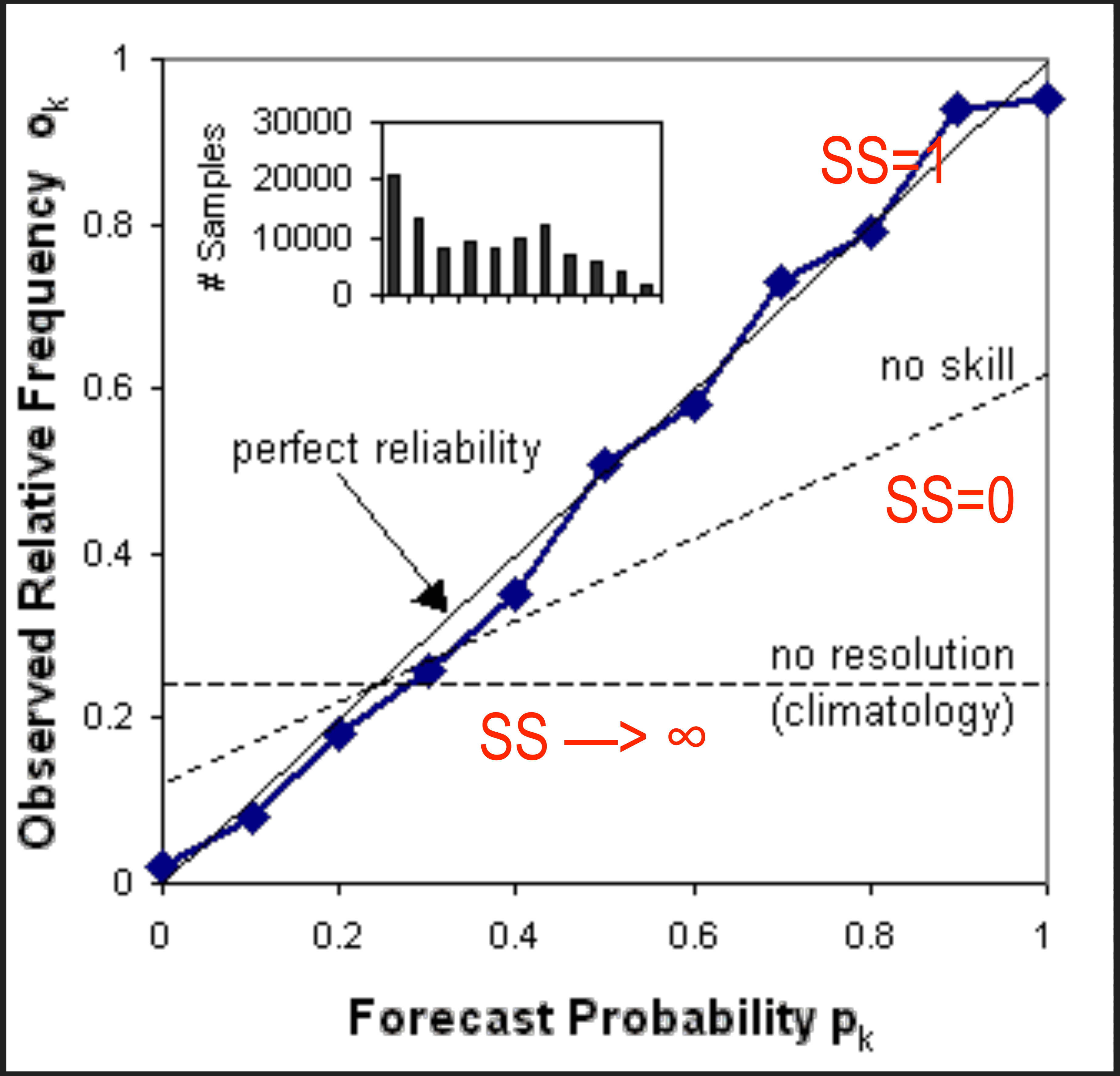
$$ApSS = \frac{TP - FP}{N}$$

- True skill statistic (ref: weighting POD w. POFD):

$$TSS = POD - POFD$$

WP5: DATA AND FORECAST VALIDATION

Accept that a probability 0 < p < 1 is assigned to each prediction



Reliabillity diagram

- Correlate forecast probability with observed frequency
- Compare your skill against climatology (mean flaring rate within forecast window)
- Generalized skill score:

$$SS = 1 - \frac{MSE_{forecast}}{MSE_{reference}}$$

$$MSE = \; <(o-p)^2>$$

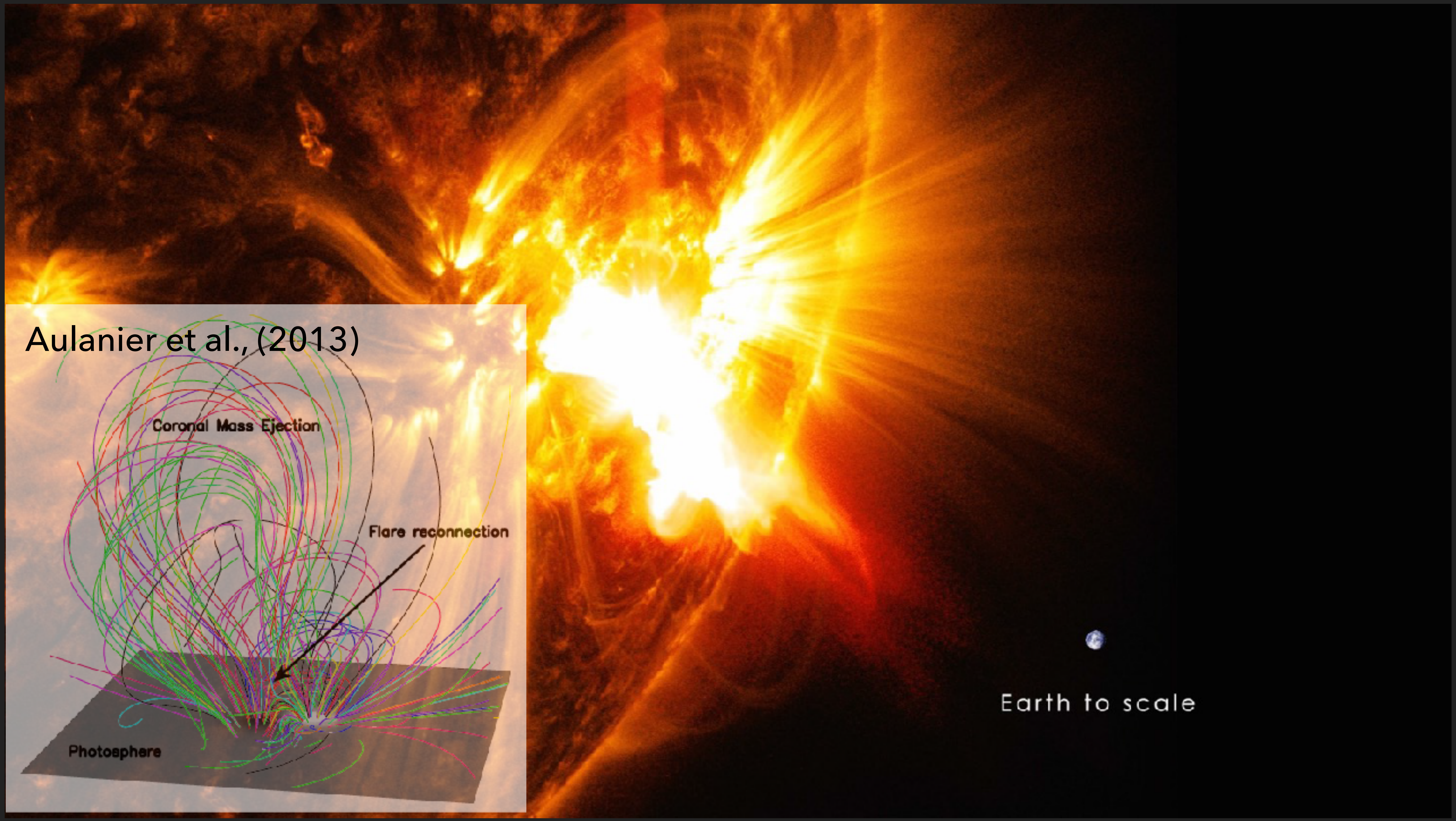
- Brier skill score (reference: climatology):

$$BSS = 1 - \frac{\left\langle (\tilde{o}-p)^2 \right\rangle}{\left\langle (\tilde{o}-\bar{o})^2 \right\rangle}$$

$$\tilde{o} \equiv \{0,1\}$$

$$BSS \in (-\infty, 1)$$

WP6: EXPLORATORY RESEARCH



- Understand solar magnetic eruptions
- Improve future flare prediction, including using timeseries
- Investigate suitability of the flare forecast window
- Advance CME prediction

WP7: DISSEMINATION – SCIENTIFIC COMMUNITY

FLARECAST

http://flarecast.eu/research/publications

Pages / Management / Publications and Conferences

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FLARECAST Publication Plan

Created by D. Shaun Bloomfield, last modified by Etienne Pariat on Mar 31, 2017

At least thirteen (13) envisioned refereed papers, of which:

- Four (4) have been already published
- Two (2) have been accepted
- Five (5) have been submitted
- Two (2) are in preparation

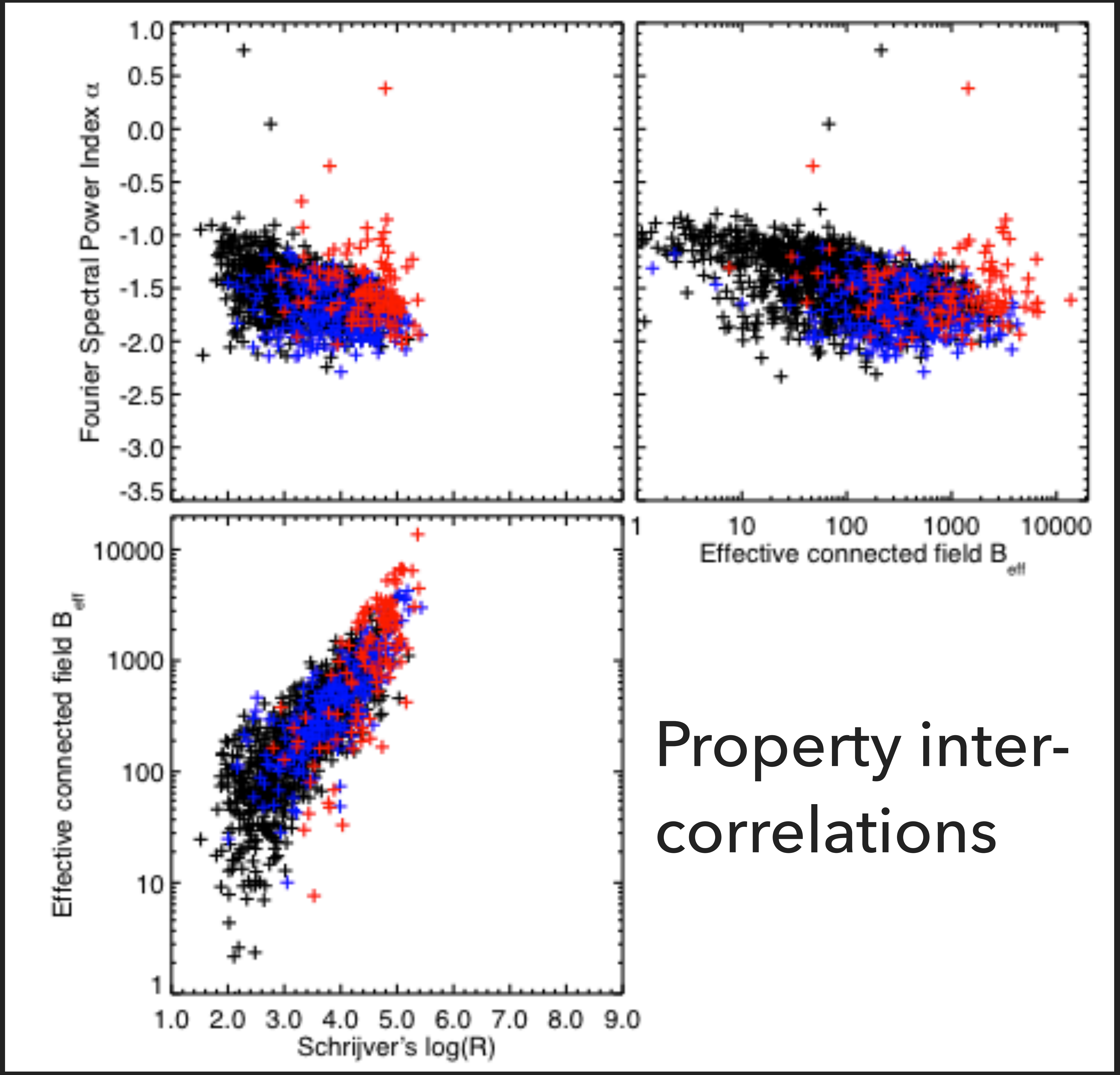
A&A 601, A125 (2017)
DOI: 10.1051/0004-6361/201630043

Astronomy & Astrophysics

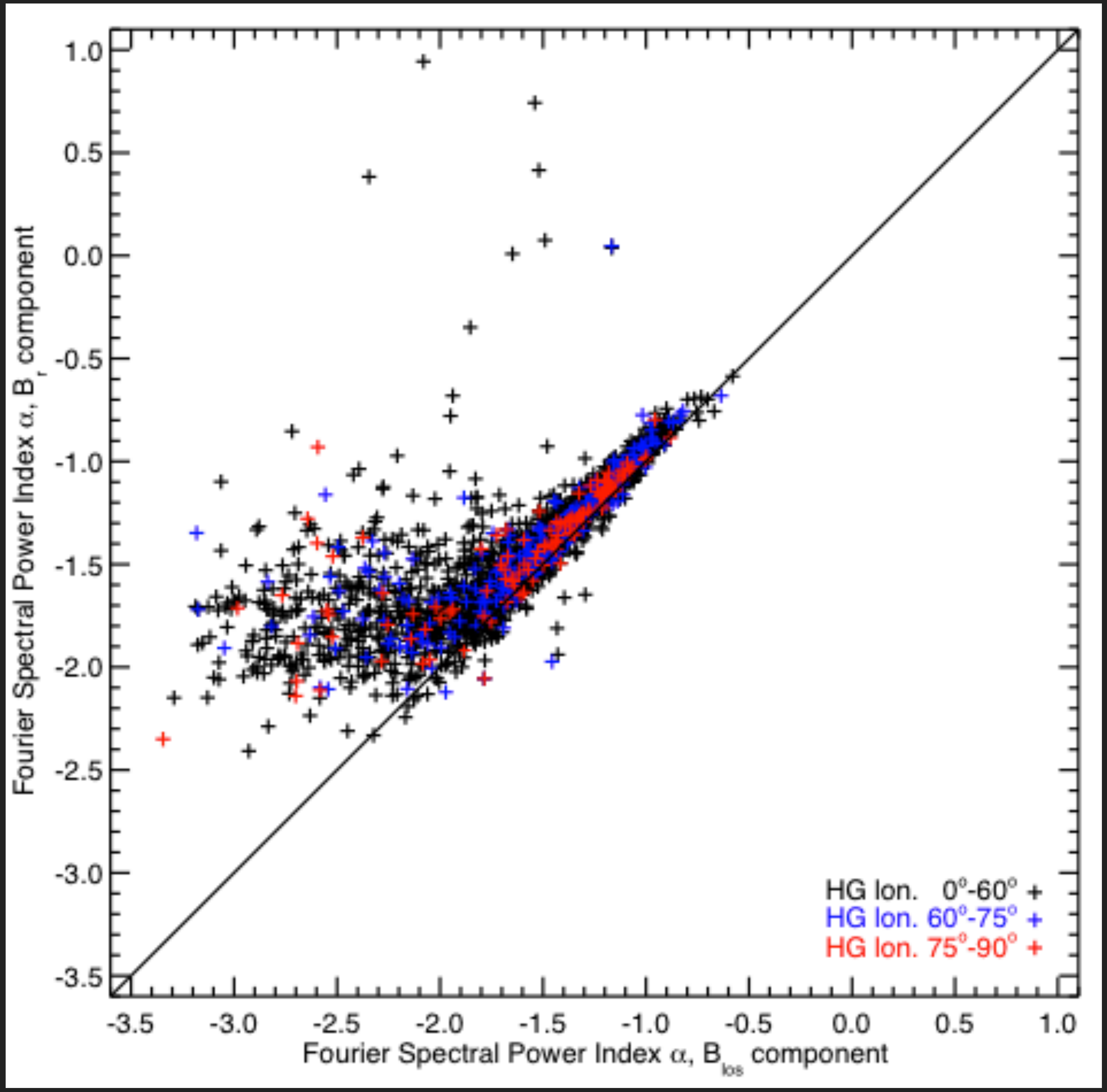
Relative magnetic helicity as a diagnostic of solar eruptivity

E. Pariat[1], J. E. Leake[2,6], G. Valori[3], M. G. Linton[2], F. P. Zuccarello[4], and K. Dalmasse[5]

PRELIMINARY RESULTS: PREDICTOR STATISTICS

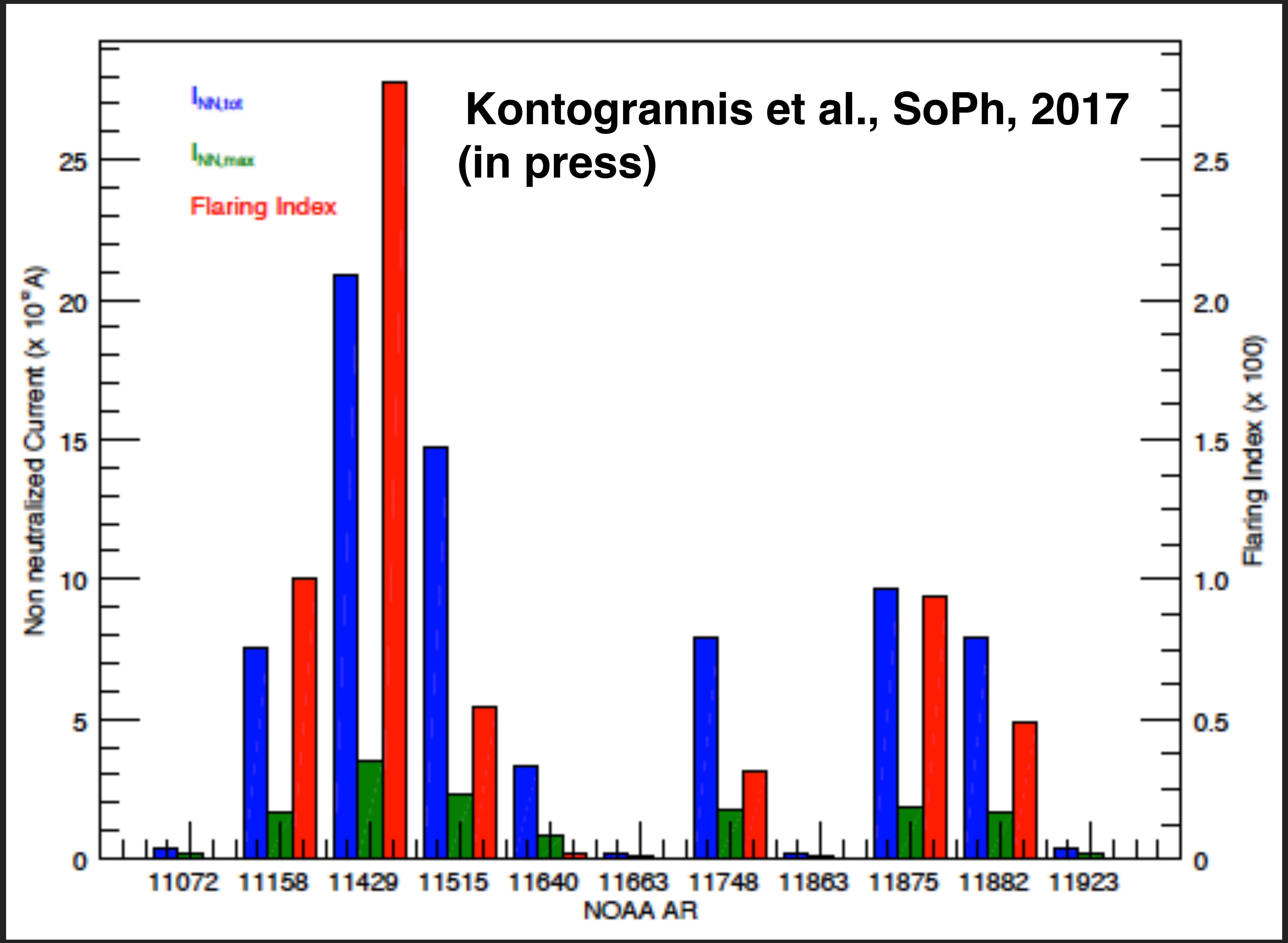


Property inter-correlations

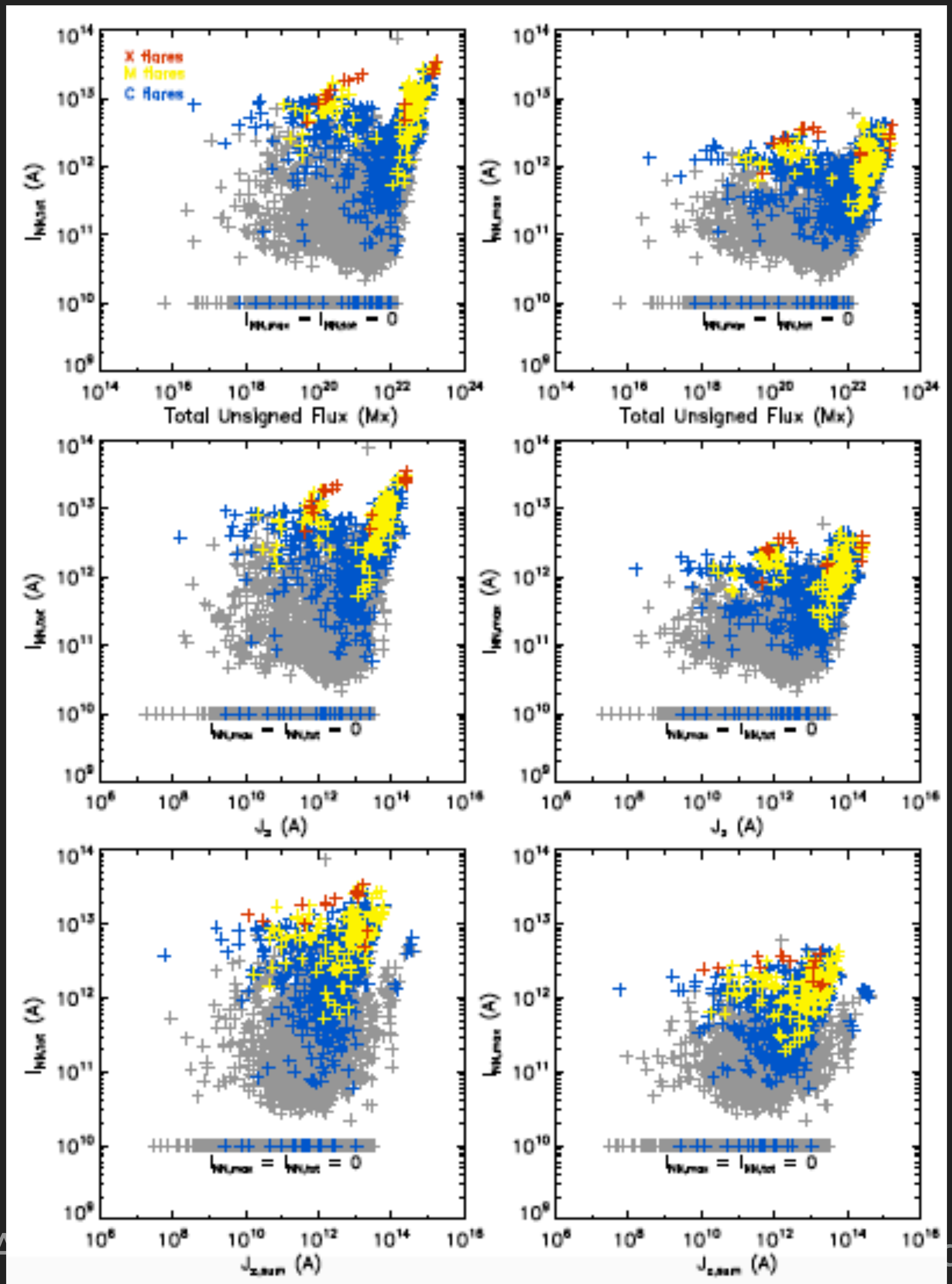


Correlation of same property values between using line-of-sight and heliographic (de-projected magnetic field components)

NEW PREDICTORS: NON-NEUTRALIZED ELECTRIC CURRENTS; ISING ENERGY

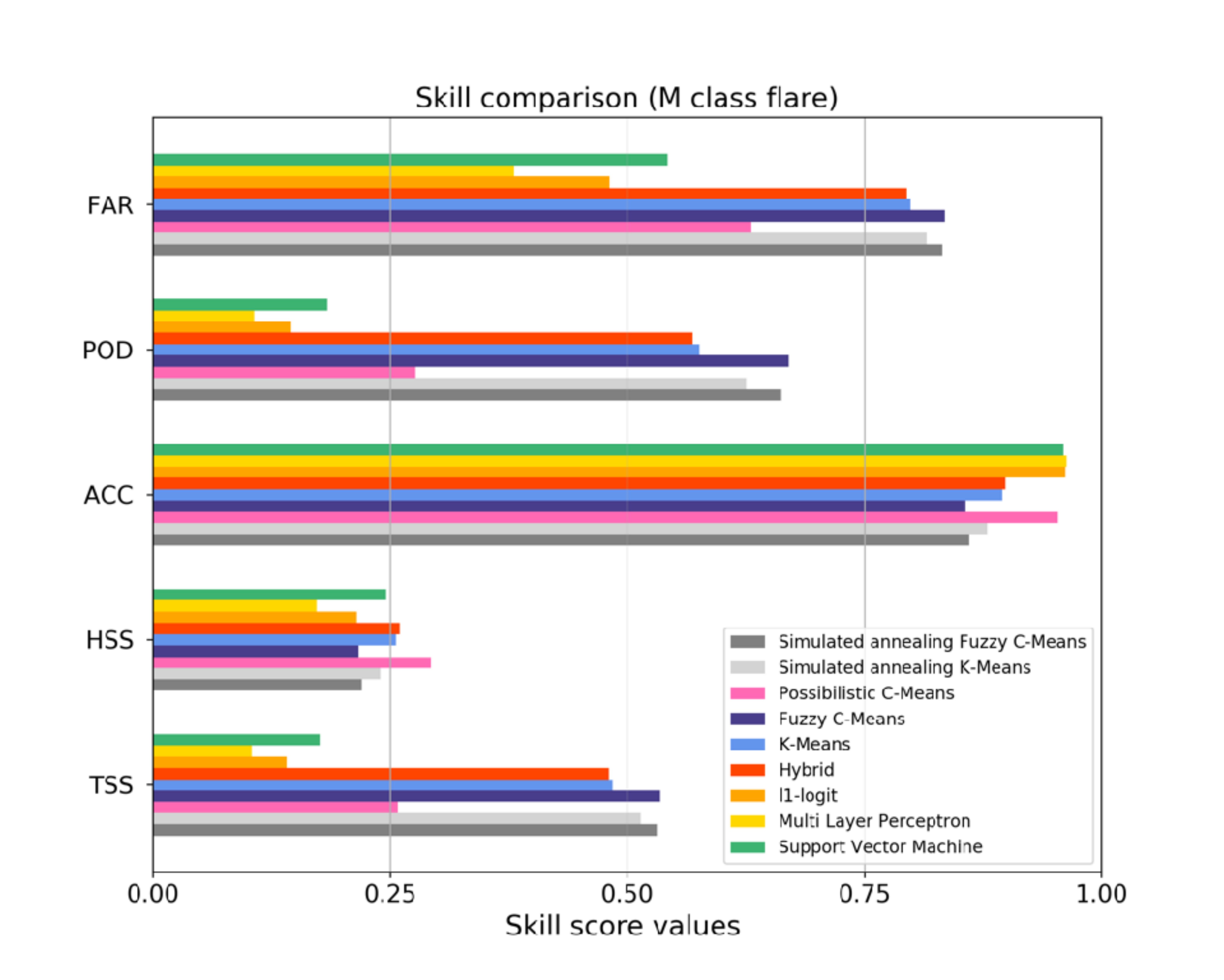


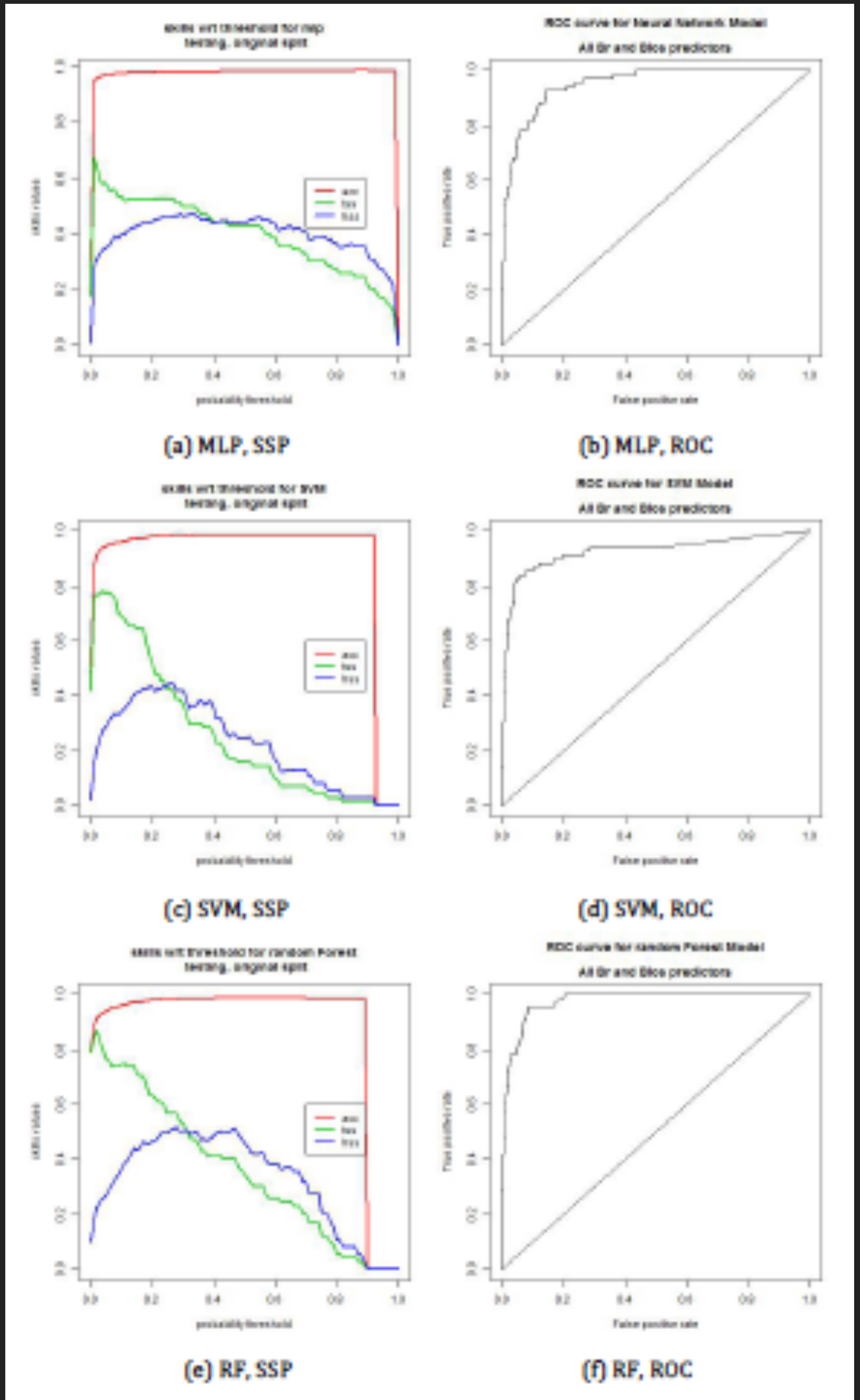
- Eleven (11) solar active regions
- Total net current positively correlated with the overall flare index in these regions



Nonlinear information added by the inclusion of net electric currents into solar flare analysis

PRELIMINARY RESULTS: FORECAST ATTEMPTS





Comparative performance of different prediction algorithms

WP7: DISSEMINATION – GOVERNMENT & INDUSTRY

Lord Soley, UK

and Research

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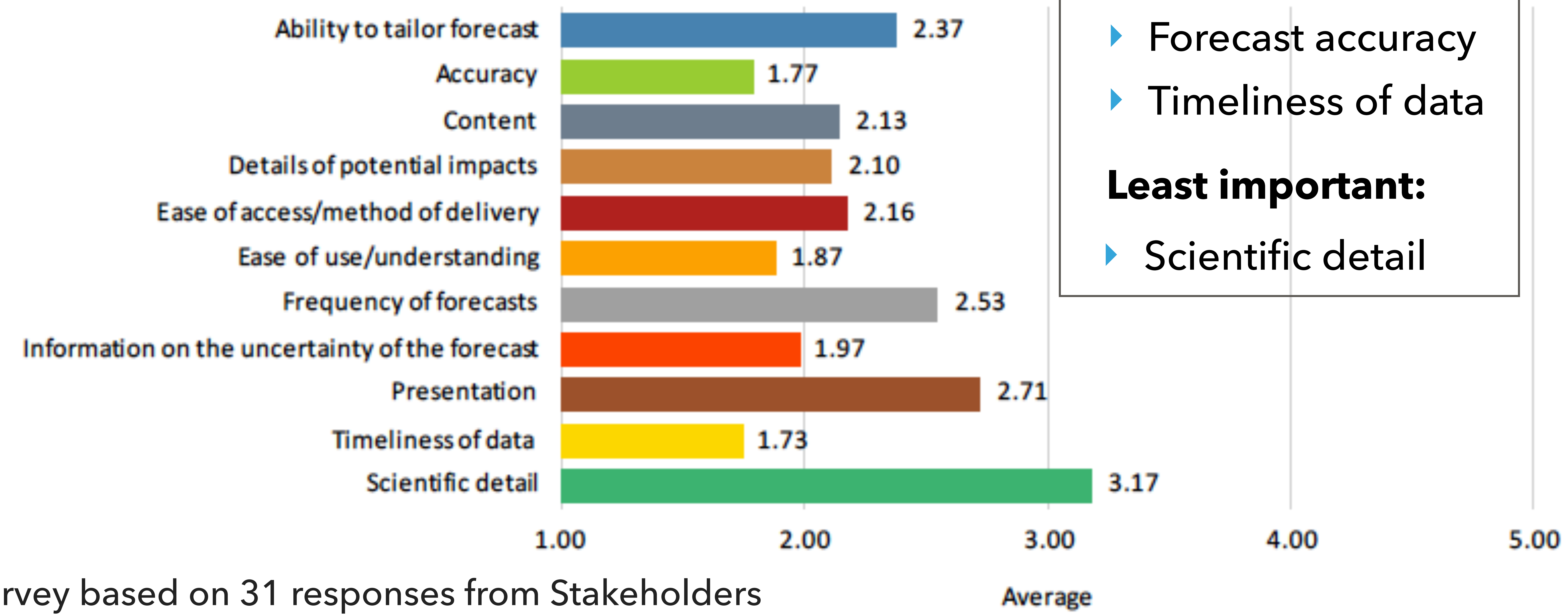
– but what is
funding beyo

Source: politi

9. Which factors are/would be important to you in a flare forecasting service? (please score the importance of each in the grid below).



Most important:

- Forecast accuracy
- Timeliness of data

Least important:

- Scientific detail

Survey based on 31 responses from Stakeholders

WP7: DISSEMINATION – PUBLIC

http://flarecast.eu/outreach-activities

EU Researchers Night, TCD, Dublin, 30.09.2016

Science Café, Zurich, 11.11.2016

Fete de la Science, Paris, 16.10.2016

Il Secolo XIX, Genova, 13 September 2016

20 MARTEDÌ 13 SETTEMBRE 2016 genova IL SECOLO XIX

Il futuro è in città

UN SOFTWARE SARÀ CAPACE DI PREVEDERE I BRILLAMENTI, FENOMENI PERICOLOSI NELLO SPAZIO

Ricercatori a caccia di tempeste solari

Università e Cnr stanno creando una squadra di tecnici e scienziati internazionali

FRANCESCO MARGIOCCO

PER NOI CHE SIAMO sulla terraferma non rappresentano un problema, anzi ci incantano quando creano quei giochi di luce che sono le aurore polari. Le cose cambiano se invece di starcene coi piedi per terra voliamo su un aereo a 10 mila metri d'altezza. È lì che le tempeste solari, o brillamenti, possono farci male, ed è per questo che gli scienziati sono alla ricerca del modo migliore per prevederle. Su mandato della Commissione europea, un gruppo dell'Università di Genova e del Cnr sta creando insieme ad una squadra internazionale di tecnici e scienziati un

Michele Piana

Anna Massone

probabilità che una tempesta solare si verifichi nell'immediato futuro». Flarecast, questo il nome del sistema per prevedere le tempeste solari, è finanziato dalla Commissione europea, nell'ambito del programma Horizon 2020, con 3 milioni di euro, e oltre all'Italia coinvolge altri cinque Paesi coordinati da Manolis Georgoulis, fisico dell'Academy of Athens.

Tra un anno e mezzo Flarecast sarà pronto. A gennaio Georgoulis e colleghi lo presenteranno a Londra ad un simposio di aziende produttrici di satelliti, interessate a limitare i danni ai loro apparecchi. Negli Stati Uniti un si-

COSA SONO?

Tempeste solari
Improvvisi rilasci di energia – pari a qualche milione di bombe di Hiroshima – e di materia da parte della superficie del sole

PERCHÈ PREVEDERLE?

Le tempeste solari non danneggiano la terra che è protetta dall'atmosfera. Lo scontro tra le tempeste e l'atmosfera produce le aurore boreali. Le tempeste solari possono però danneggiare gli aerei in volo e i loro passeggeri, esposti ai raggi x, possono colpire e danneggiare i satelliti e colpiscono frequentemente anche la Stazione spaziale internazionale il cui equipaggio in caso di tempesta si ripara

@FLARECAST_EU

Winter solstice, Duebendorf, 21.12.2016

CURRENT STATUS OF THE PROJECT

- **Project progressing nominally; minor delays in some components**
- Property extraction alorithms: INTEGRATED
- Property database: DEVELOPED
- Prediction algorithms: INTEGRATED
- Prediction database: DESIGNED
- Forecast verification algorithms & uncertainties: DEVELOPED, UNDER INTEGRATION
- Verification database: BEING DESIGNED
- Near-realtime forecasting system: BEING DESIGNED
- Forecast & verification visualization: BEING DESIGNED

CONCLUSIONS

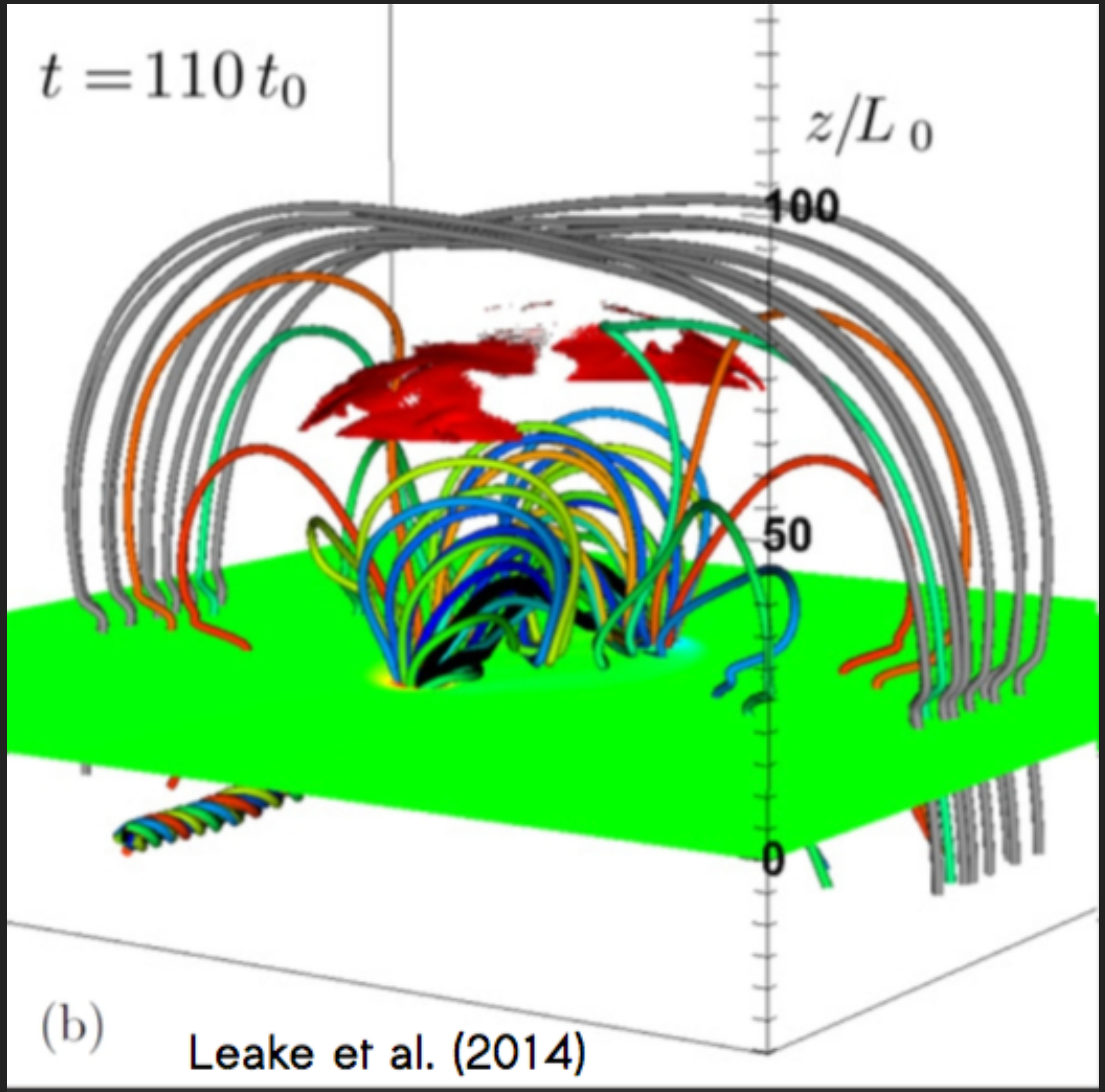
- Consensus that solar flare forecasting should be part of our SWx strategic toolbox
- FLARECAST is arguably the most systematic effort undertaken so far
- Diversity is necessary: different backgrounds and expertise on the task
- An EU project, it is fully open-source and free access (data + infrastructure)
- The near-realtime forecast tool will be delivered in early 2018
- The key science question is how far we can go in credibly predicting solar flares

An answer? Still TBD - it looks, however, that stochasticity cannot be completely lifted, so we are effectively left to deal with probabilistic forecasts

BACKUP SLIDES

WP6: EXPLORATIVE RESEARCH

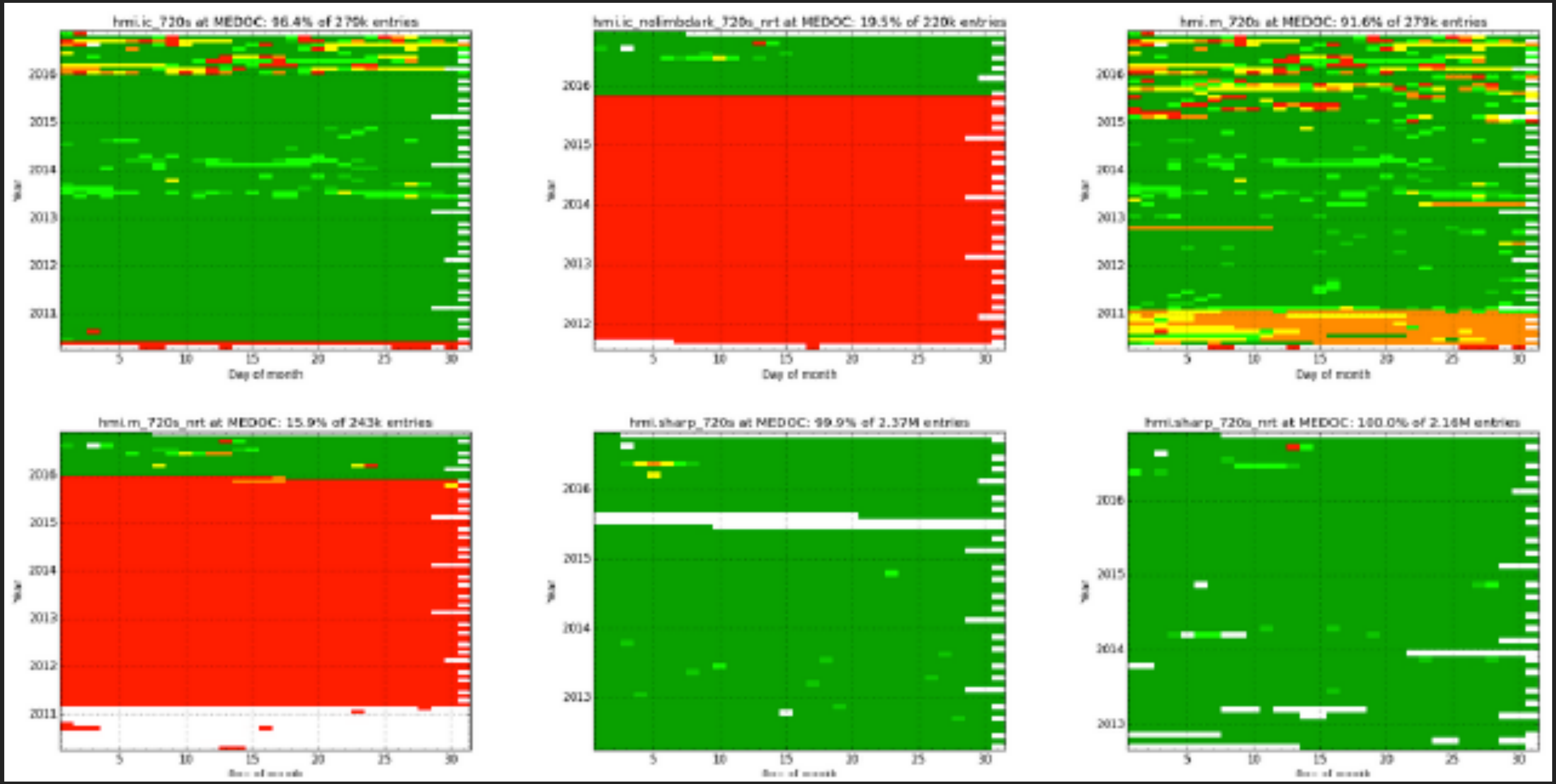
- **Understanding solar magnetic eruptions**
  - Exploitation of existing 3D MHD simulations
  - Investigation of properties and types of evolution that trigger eruptions
- **Improving flare prediction**
  - Investigation of new properties / predictors
  - Timeseries vs. point-in-time prediction

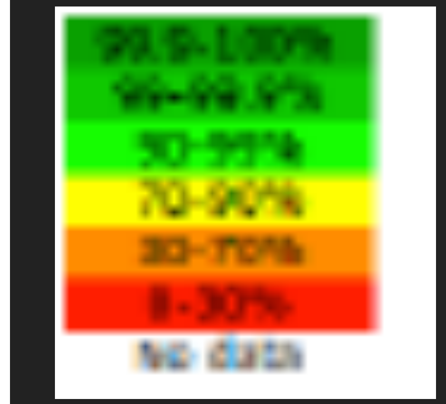


Content courtesy: Shaun Bloomfield

FLARECAST

CURRENT HMI JSOC DATA AVAILABILITY





Total data allocated space: ~240 TB

Courtesy: E. Buchlin

FLARECAST SCIENCE DATA : PROPERTIES

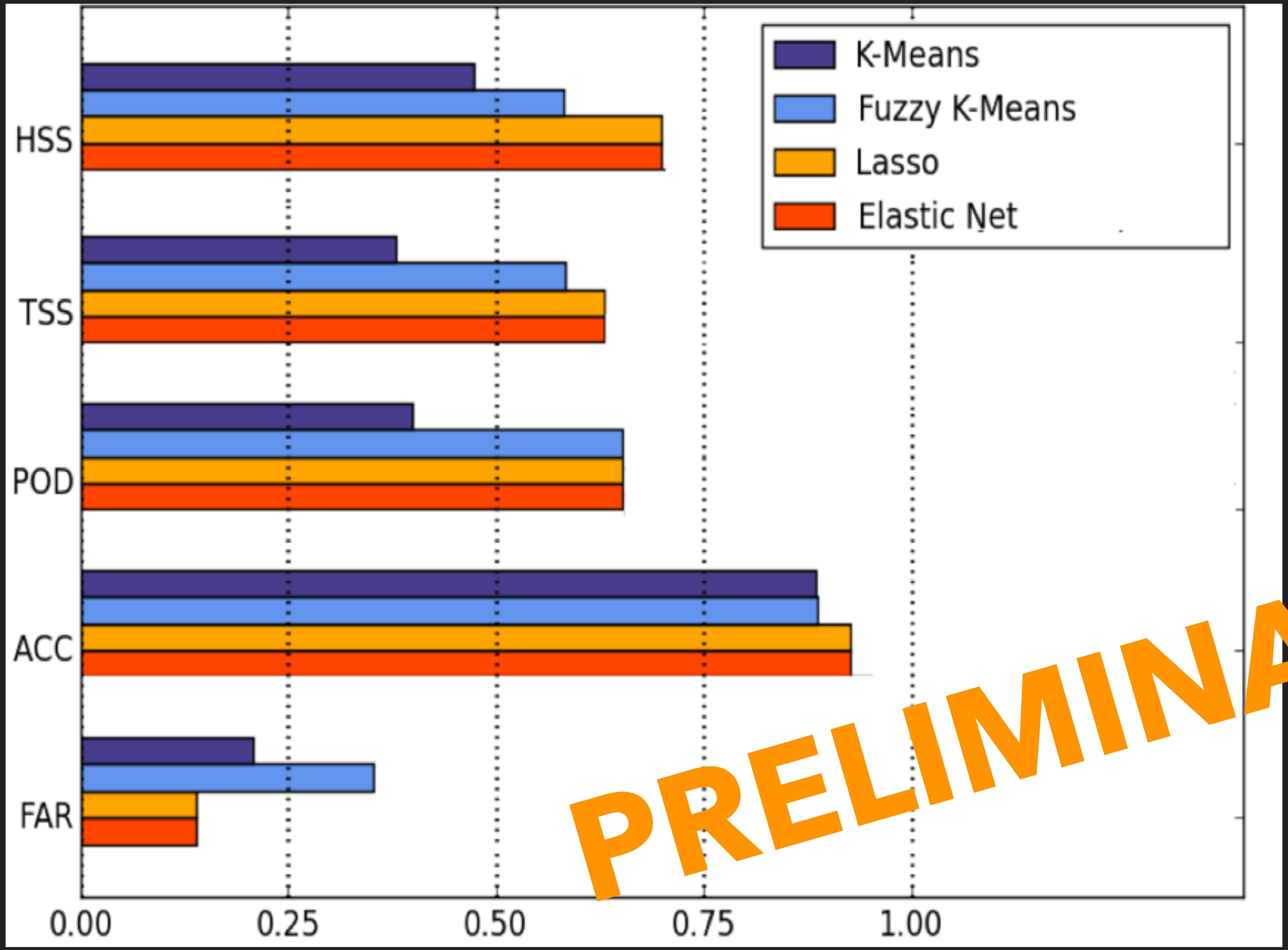
Properties utilizing LOS magnetograms

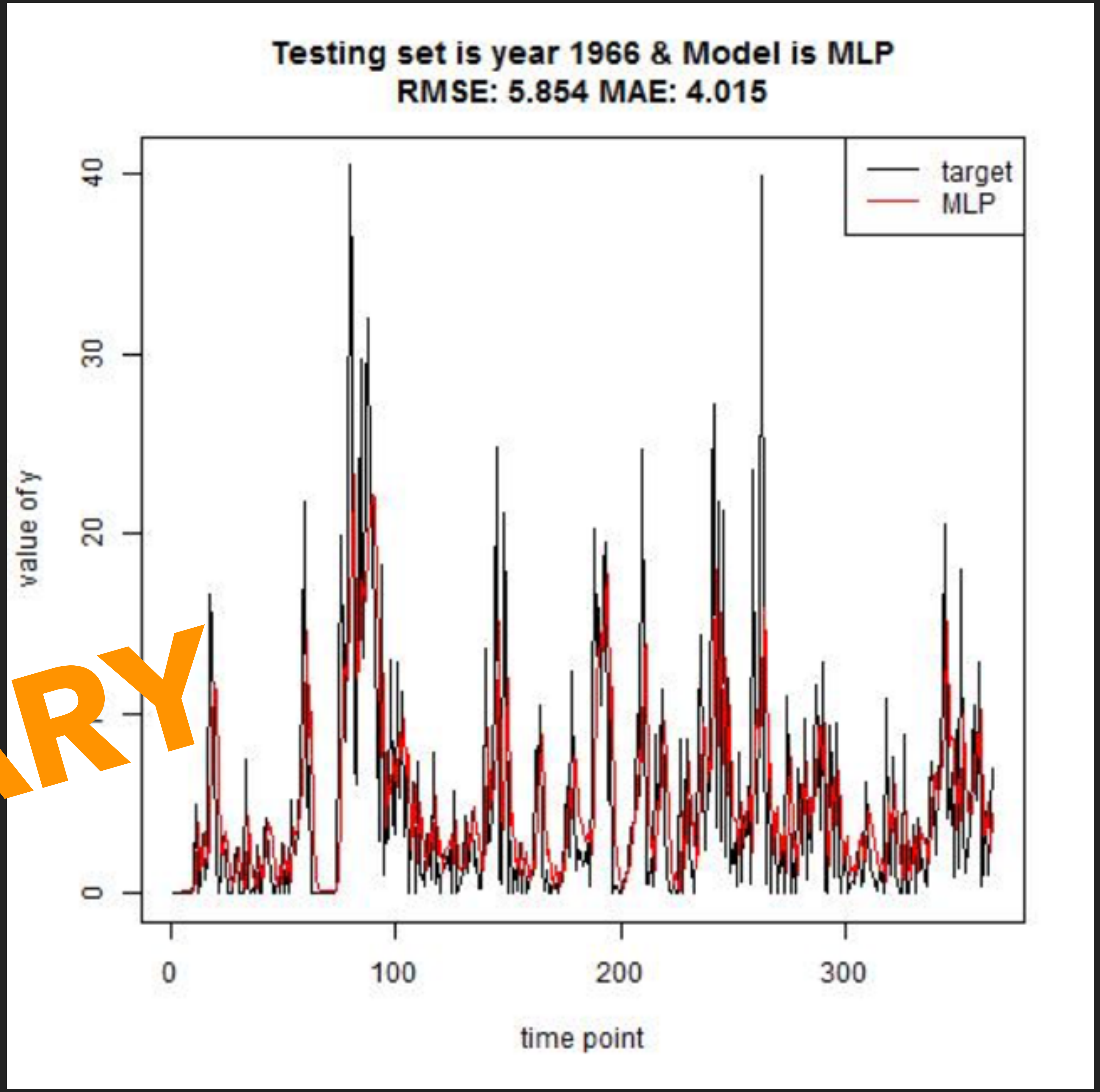
Properties provided by SHARPs + published over last ~25 years, until today

Properties utilizing vector magnetograms

Data Source	Property Group	Developer	Status
SWPC catalogues			(To do / In progress / Under testing / Delivered)
	Solar Region Summary properties	TCD	
	GOES X-ray events	TCD	
LOS magnetograms			
	SMART-derived properties (Ahmed et al., 2013)	TCD	In progress
	SMART delta finder (Padinhatteeri et al., 2015)	TCD	To do
	Effective connected magnetic field strength (B_{eff}) (Georgoulis & Rust, 2007)	AA	Delivered
	Fractal dimension (Georgoulis, 2012)	AA	Delivered
	Multi-fractal structure function s(q) inertial range index k (Georgoulis, 2012)	AA	Delivered
	Fourier power spectral index (Guerra et. al., 2015)	AA / TCD	Under testing / Delivered
	CWT power spectral index (Hewett et. al., 2008)	TCD	Delivered
	Generalised correlation dimension (Georgoulis, 2012)	AA	Delivered
	Holder exponent h (Conlon et al., 2010)	AA	In progress
	Hausdorff dimension D(h) (Conlon et al., 2010)	AA	In progress
	WTMM (Conlon et al., 2010)	TCD	In progress
	Decay index (Zuccarello et al. 2014)	TCD	Delivered
	Magnetic polarity inversion line characteristics (Mason & Hoeksema 2010)	TCD	Delivered
	3D magnetic null point (Reid et al. 2012)	TCD	Under testing
	R (Schrijver 2007) *	TCD	Delivered
	$^{L}WL_{SG}$ (Falconer et al. 2008) *	TCD	Delivered
	Ising energy (Ahmed et al. 2010)	AA	Delivered
	WG_M and S_M (Korsos et al. 2015)	AA	Under testing
	Magnetic helicity injection rate proxy (Park et al. 2010)	TCD	Under testing
Vector magnetograms			
	SHARP properties (Bobra et al. 2014)	TCD	Under testing
	Magnetic helicity injection rate (Berger & Field 1984)	TCD	Under testing
	Magnetic energy injection rate (Kusano et al. 2002)	TCD	Under testing
	Non-neutralized currents (Georgoulis et al., 2012)	AA	Delivered
	Flow fields (Wang et al. 2014)	TCD	Under testing
	Magnetic bipolar feature characteristics	TCD	Under testing
Intensity images			
	Flow fields	TCD	Under testing

FLARECAST SCIENCE DATA: VALIDATION





PRELIMINARY

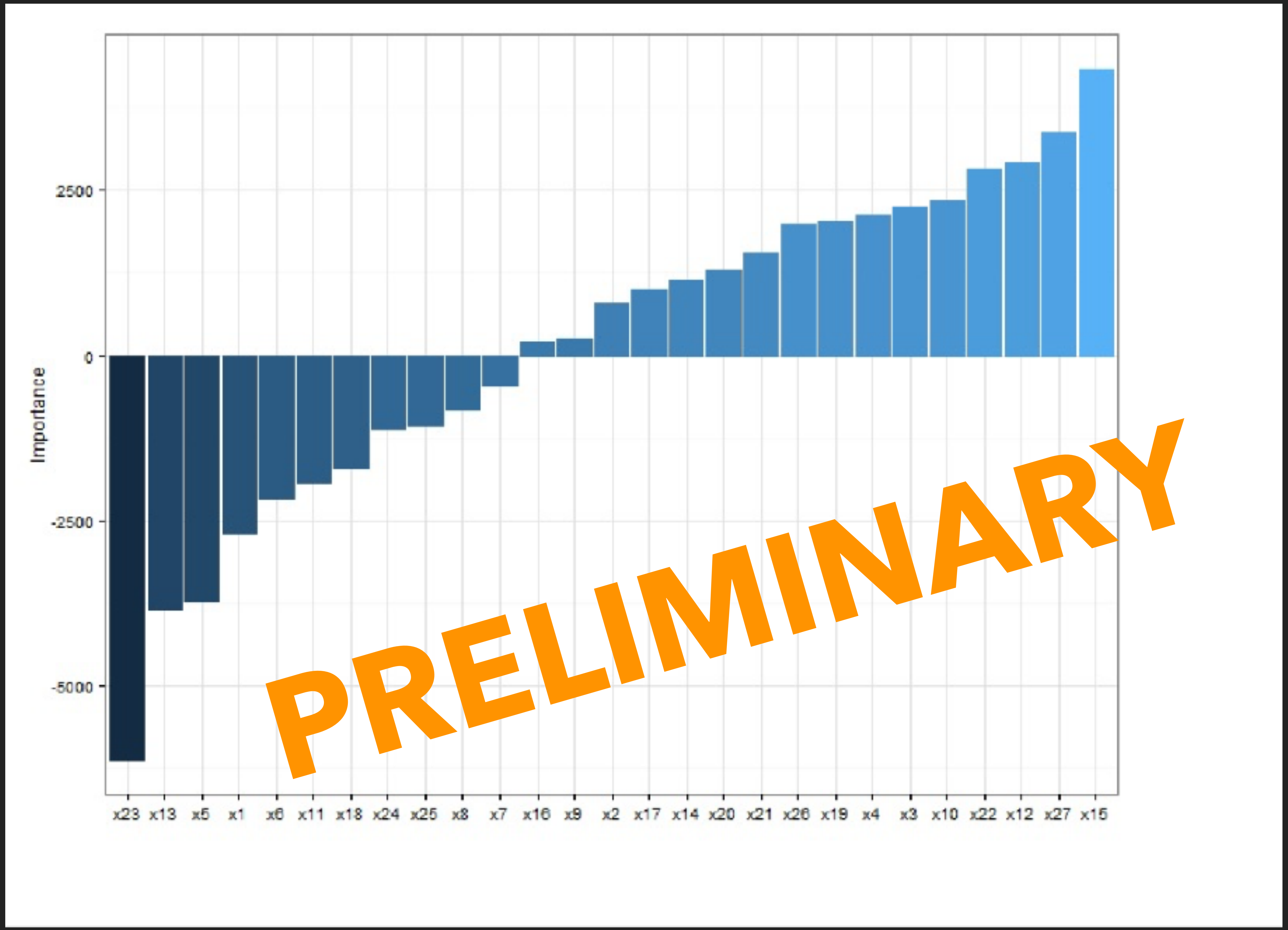
Some validation results on specific methods and data subsets

FLARECAST SCIENCE DATA: ALGORITHMS

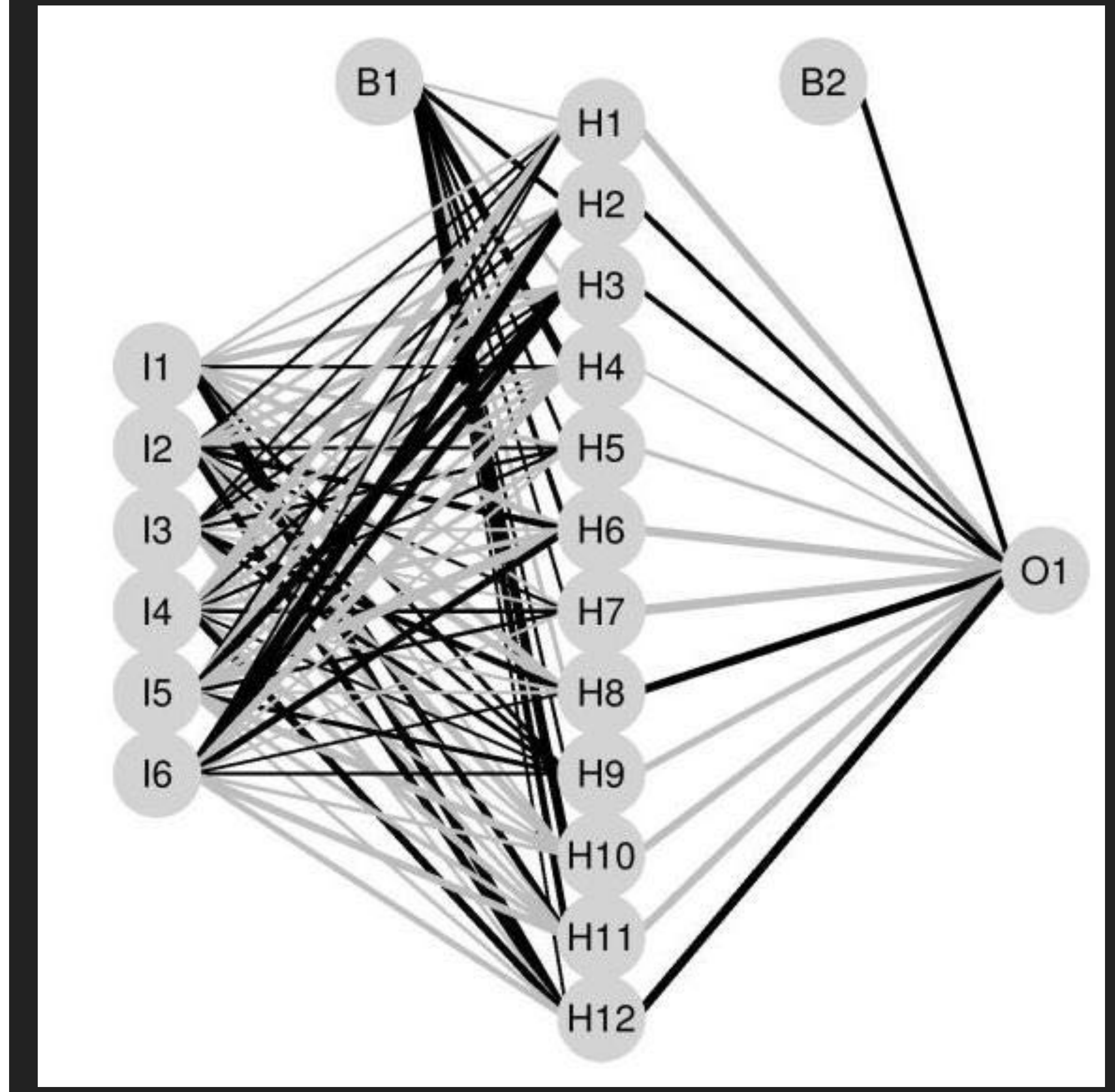
FLARECAST

- **Algorithms considered**
  - Standard ML
  - Advanced ML
  - Non-ML
  - Innovative ML

Parameter classification by means of their importance for prediction, using an advanced method

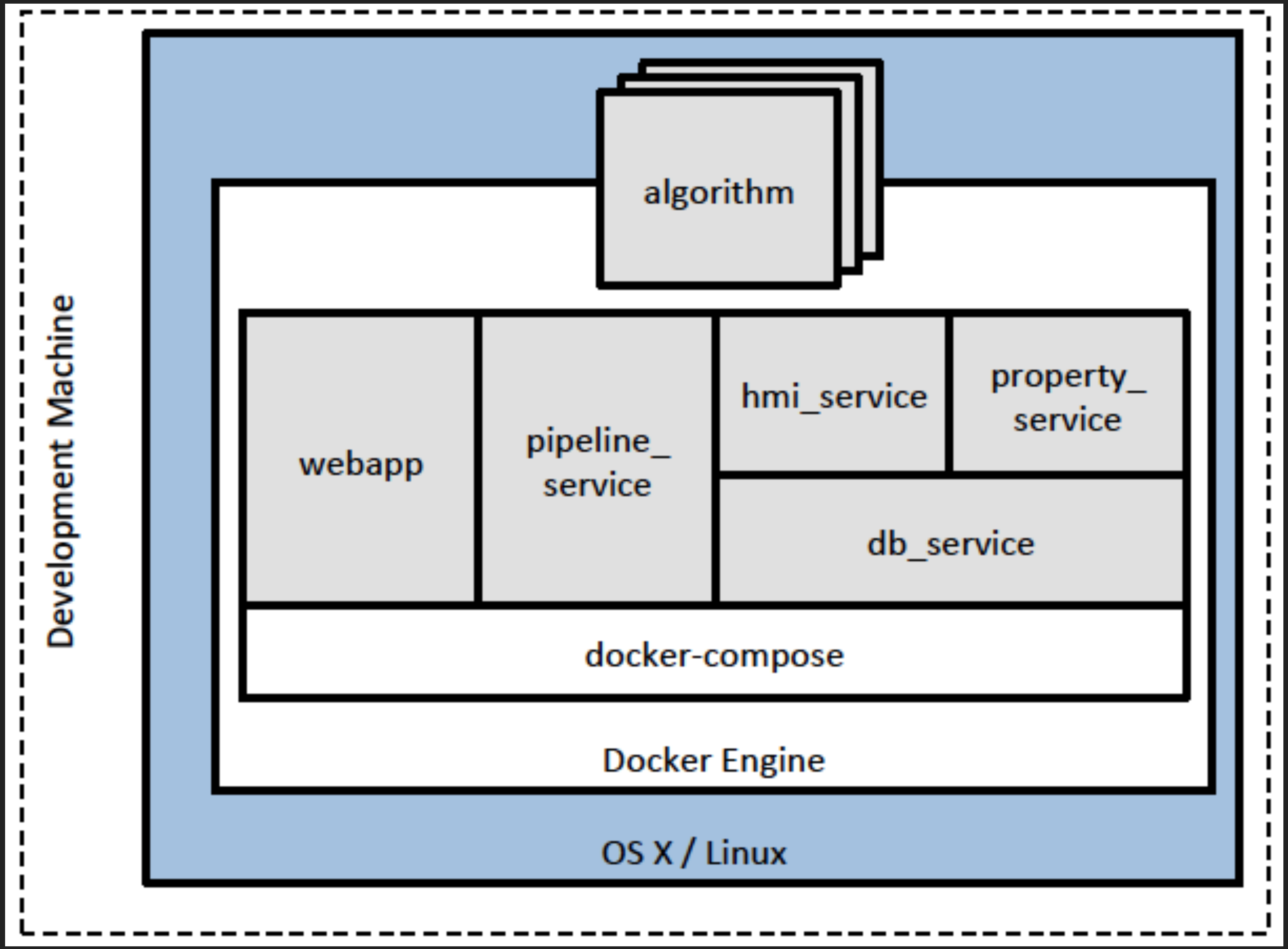


Courtesy: A. M. Massone et al.



Example of a multi-layer perceprton algorithm

INFRASTRUCTURE AND MOBILITY



- Totally open-source software, allowing:
  - Making local copies of the entire infrastructure
  - Using any part or the entire FLARECAST databases
  - Plugging-in one's favorite algorithm for test and validation

CONCLUSION

FLARECAST

- FLARECAST: a project in full swing
- Work delivered independently and at different levels – watch out for project-supported refereed papers in the next months
- **Science data model**: two [2] types of external data (HMI, SRS); four [4] types of science data (predictors, algorithms, prediction, validation
- First comprehensive prediction results due in a few months – project expiring at the end of 2017
- Data, databases and infrastructure fully accessible worldwide