PLANETARY TRIGGERING AND STATISTICAL FORECASTING OF EXTREME EVENTS

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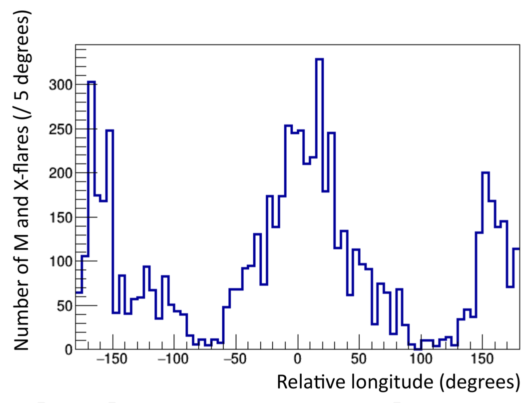
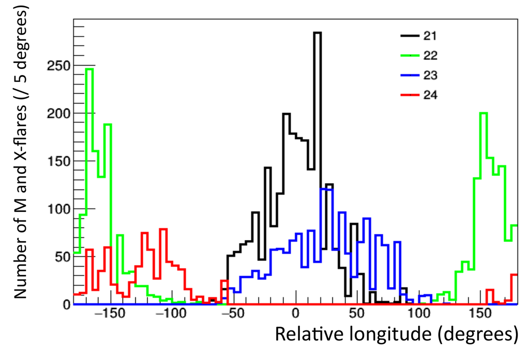
1. LONG TIMESCALES: SOLAR CYCLE MODELING

E.Petrakou: "A deterministic model for forecasting long-term solar activity", Journal of Atmospheric and Solar-Terrestrial Physics, Vol.176, 51-56, 2018 ⟶

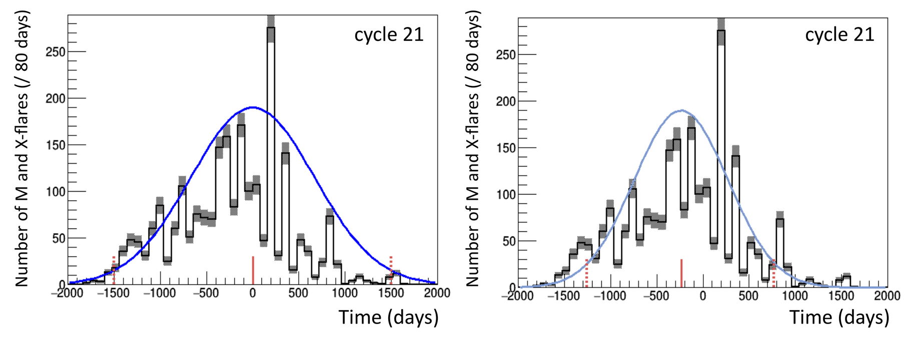


Empirical observation: Solar activity of energetic flares tends to peak around the dates of alignment of planets Jupiter and Saturn, and decrease towards the dates of their quadrature.



However, from cycles 21 to 24, there is a progressive "dragging" and reduction of activity – ostensibly compatible with the staggering between the two planets' half-synodic period (9.9*y*) and the mean solar cycle duration (11*y*).

So, it can be asked **whether the evolution of solar activity is the coupled effect of an internal solar (magnetic) mechanism and a triggering associated with the approach and retreat of Jupiter and Saturn.**

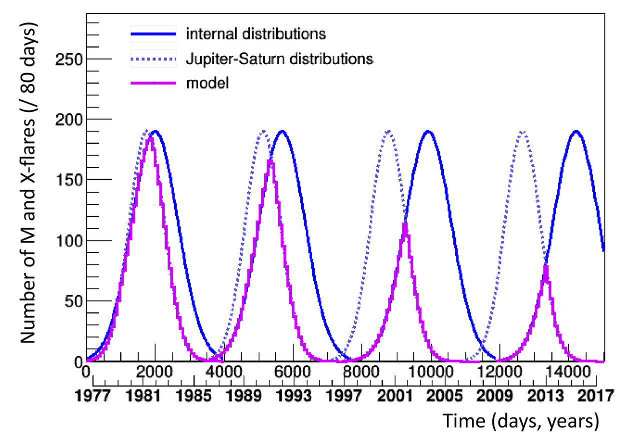


Assumptions about the two contributions:

- Can be expressed by Gaussian distributions.
- The "internal component" is centered on the temporal middles of cycles and spans somewhat less than 11 years.
- The "Jupiter-Saturn component" is centered on the dates of their alignments and, empirically, lies mostly between -45° to 45°.

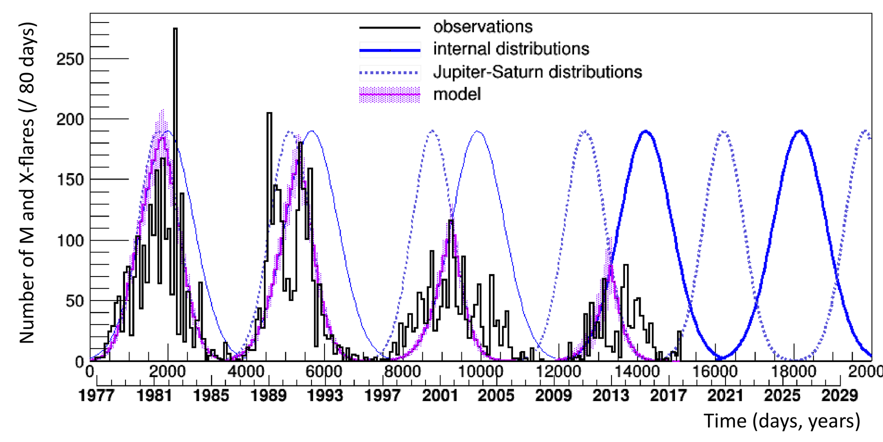
In cycle 21 the two centering dates lied close (237*d* away) and it is assumed that the full deployment of the two effects can be observed: Consequently, two Gaussians satisfying these constraints are extracted from the envelope of its activity.

- **Data**: NOAA SMS & GOES satellites X-ray flux measurements, 1977-2018.
- Selection: M and X-class solar flares (brightness $\geq 10^{-5} W/m^2$); 6,339 / 491 flares.
- Start of each cycle: Date of the first M-flare from a sunspot of reversed magnetic polarity.
- The quoted angles correspond to the relative heliocentric ecliptic longitude between Jupiter and Saturn.



These two distributions are used for subsequent cycles by their appropriate repetition: By centering the internal component on the cycles' temporal middles, and the Jupiter-Saturn component on the dates of alignments. (The temporal middle of cycle 24 is estimated from the average increase between the two centering dates.) Finally, the coupling of the two components is assumed to be expressed by their common area [purple].

A note about possible bias from observing only one side of the Sun:
The number of observed flares is about the same regardless of whether Earth is on the same or opposite side with respect to Jupiter, and for both cases of the side where Saturn is. So, preliminarily it is estimated that there is no large effect (more detailed calculations are nevertheless needed).



The resulting distribution is compared to the observations. There is notable agreement in the start and duration of each cycle, intensity and general evolution. Short-term departures need to be understood in more depth.

The extension of the model over the next years is also shown; a second overlap between the two distributions during the current cycle has led to the prediction of a resurgence of activity, which was compatible with the activity in 2017.

The results point to a correlation between the triggering of solar activity and the relative position of the two gas giants, with the activity increasing and declining respectively with their approach and retreat.

(For clarity: The internal distribution is not meant to correspond to the sunspot cycle; further work could reveal its origin, which is presumed to be an element of solar magnetic activity.)

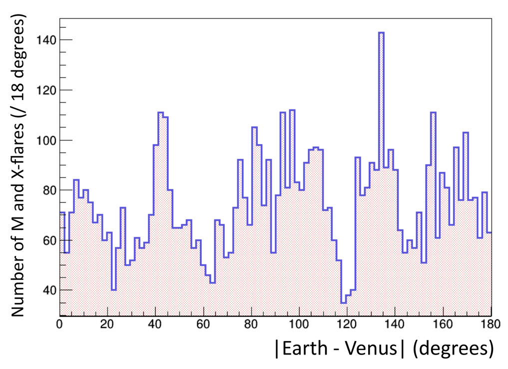
1. Recently, a phenomenological model was developed for the quantitative description of the features of individual solar cycles[1]. The description is made in terms of energetic flares, and also provides further predictions. The model is based on a synergy between the relative ecliptic motion of the planets Jupiter and Saturn and a quasi-periodic internal component of solar activity.

2. Furthermore, the inclusion of the innermost planets leads to the possibility of classifying individual days according to expected activity. The efficiency of using random forests for such classification is discussed for cycles 21-24. The current results look promising enough for a deeper look into both phenomenological and physics analysis.

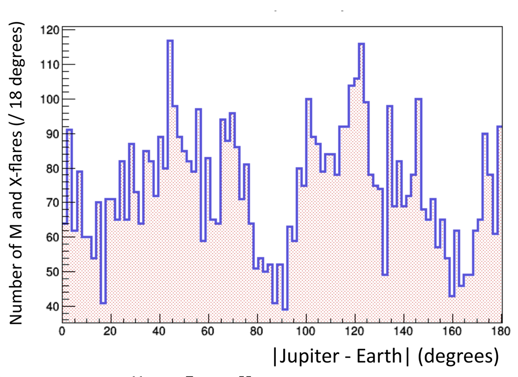
2. SHORT TIMESCALES: FORECASTING OF EXTREME EVENTS

The relative angles between the five innermost planets appear to be strongly related to the occurrence of individual energetic flares (M,X classes). This can be seen in qualitative indications in the flares' distributions, and in their characterization through the training of random forests.

"Qualitative indications" Relations seem to emerge between pairs of the five innermost planets (some similar indications were shown in [2]). For instance:

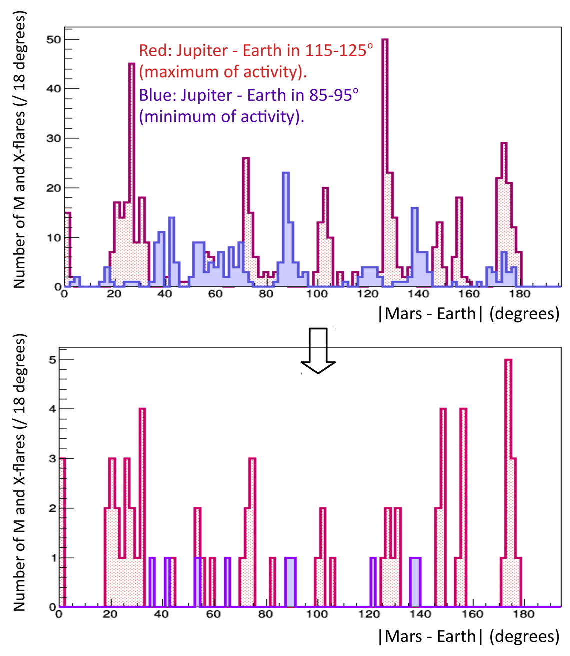


The distributions of flares vs. the relative angles between planets are highly non-random. (Example with Earth-Venus.)

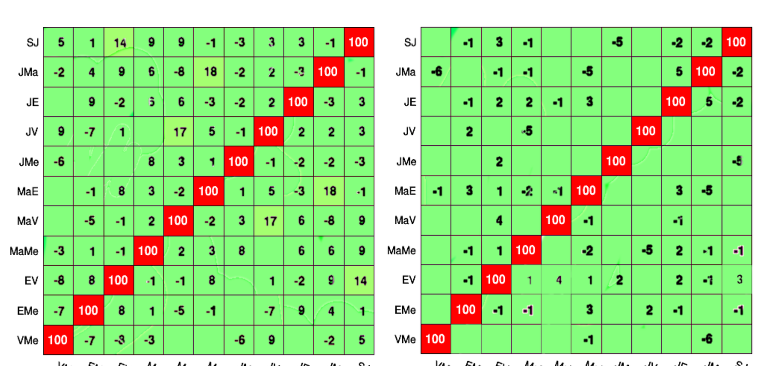


Certain "rules" seem to appear. E.g. pronounced reduction of activity around Jupiter-Earth quadrature.

Correlations between the relative angles appear for only the days with flares. ⟶



Emerging patterns seem to involve more than two planets [top]. Furthermore, these persist when looking at only X-class flares [bottom].



Relative angles of planets, denoted by their first letters. Left/right: days with/out flares.

Daily classification This is a first approach to the training of machine learning algorithms for estimating the probability of energetic flares on a day-to-day basis.

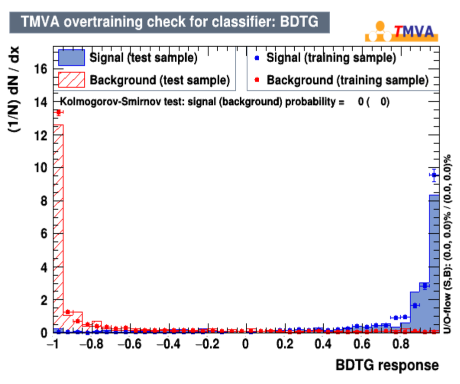
Statistically on the whole dataset, the training of random forests bears significant results [left column]. However, the day-to-day classification [right column] is biased by the total strength of the cycle at any particular moment; this can be partly accounted for by selections based on the value of the total strength.

The results reinforce the **indications that the appearance of flares depends on the relative positions of planets, and the possibility that refined searches can lead to their improved forecasting.**

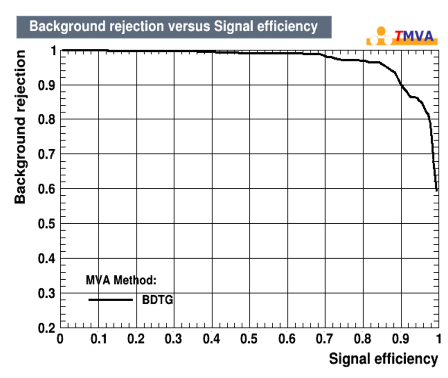
- Training of 200 boosted decision trees[3] on all available data (1977 - mid-2018).
- Input: 6 pairs of relative planetary angles + value of the solar cycle model [described above].
- Signal ≡ all days with either M or X-class flares. Background ≡ all days with either no flares or only C-class.
- Each "event" corresponds to one calendar day.

Validation

Training: 3,085 signal, 11,471 background events.
Validation: 200 signal, 400 background events, randomly selected.



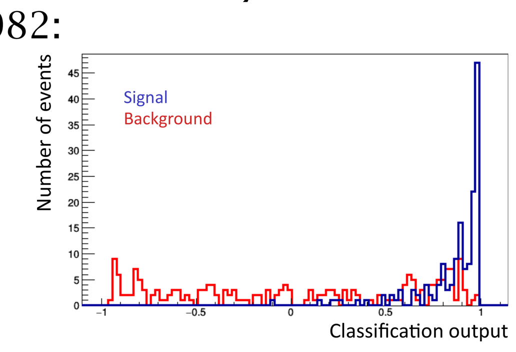
Training and validation output of the forest



ROC curve (background rejection vs. signal efficiency)

Application

Each day is assigned a value, representing the proximity to either signal or background. The cut which separates the two cases is determined by the user. Example of output for the year 1982:



So far, the cycle intensity at any particular moment biases the results. At next steps, this effect has to be taken into account, or other machine learning methods might prove more appropriate e.g. rules mining. (Or, if the apparent emerging rules become connected to physical mechanisms, forecasting could come from first principles.)

Contact ⟶
(The author is sad for not visiting ESWW15 in person!)

References

[1] E.Petrakou, J. Atmospheric Sol.-Terr. Phys., Vol.176, 51-56, 2018.
[2] S.Bertolucci et al., Phys. Dark Universe 17, 13, 2017.
[3] ROOT & TMVA packages:
R.Brun, E.Rademakers, Nucl. Inst. & Meth. in Phys. Res. A389, 81, 1997.
A.Hoecker et al., PoS ACAT 040, 2007.

Indications are presented for a role of planetary motion in solar flares activity, including a model for the quantitative description of solar cycles.

Although no physical mechanism is proposed at this stage, the motion of planets is one of the few conceivable steady perturbations on solar activity. It is a possibility that the more distant and slower giants affect long-scale phenomena while the closer and faster planets affect short-term ones. Combining this analysis with the use of more solar observables could lead to clues about underlying mechanisms.

Even at the purely phenomenological level presented here, refinement of the analysis for space weather forecasting looks worthwhile. Connection to the current prediction chain could contribute considerably to the forecast of influential solar events.