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COCOMAG: color-coded magnetograms as probes of active region evolution and complexity

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Abstract. We are proposing a visualization of vector magnetograms whereby the three components of the photospheric magnetic field vector are combined into RGB colored maps, creating color-coded magnetograms (COCOMAGs). In this configuration the primary and secondary colors represent magnetic field with different orientation. The areas occupied by different color hues are extracted, creating appropriate time series (color curves). The resulting, colored maps and color curves are used as proxies of the active region evolution and its complexity. The morphology exhibited in COCOMAGs is associated to typical features of active regions, such as sunspots, plages, and sheared polarity inversion lines. In complex regions, extended, twisted flux systems appear as continuous, color processions, while abrupt color changes signify sheared polarity inversion lines. Active regions in their decay phase are dominated by rather vertical magnetic field (pixels with green color), indicating a gradual relaxation of the magnetic field configuration. The color curves, which represent the area coverage of magnetic field with different orientation, exhibit varying degree of correlation with active region complexity. Particularly the red and magenta color curves, which represent strong, purely horizontal magnetic field, seem to be good indicators of future flaring activity. The proposed visualization can be adapted to different color tables, it facilitates a comprehensive view of the evolution of active regions and their complexity and offers a framework for pattern recognition, feature extraction and flare prediction schemes.

Method: Color-combined Magnetograms (COCOMAGs)

- B_x, B_y and B_z maps of Cylindrical Equal Area (CEA) Space weather HMI Active Region Patches (SHARP, *Bobra et al. 2014, SoPh, 289, 3549*).
- Absolute values of the photospheric magnetic field components B_x, B_y and B_z clipped between 0 - 2σ (the standard deviation of the values), scaled to 0-255, combined into RGB images.
- The number of pixels with fully saturated red, green, blue (RGB) and cyan, magenta, yellow (CMY) colors is extracted to create time series: “color curves”.

Color	RGB coordinates	Components
White	[255, 255, 255]	Bx, Bz, By
Red	[255, 0, 0]	Bx
Green	[0, 255, 0]	Bz
Blue	[0, 0, 255]	By
Cyan	[0, 255, 255]	Bz, By
Magenta	[255, 0, 255]	Bx By
Yellow	[255, 255, 0]	Bx, Bz
Black	[0, 0, 0]	

Results and conclusions

COCOMAGs as probes of morphology

- Hues reflect different orientations and strength of the magnetic field.
- Green at plage (vertical magnetic field dominates), red/magenta in between the two polarities (strong horizontal magnetic field dominates).
- Smooth color procession over the symmetric sunspot. Cyan and yellow strips: regions of B_x *and* B_y sign reversal.

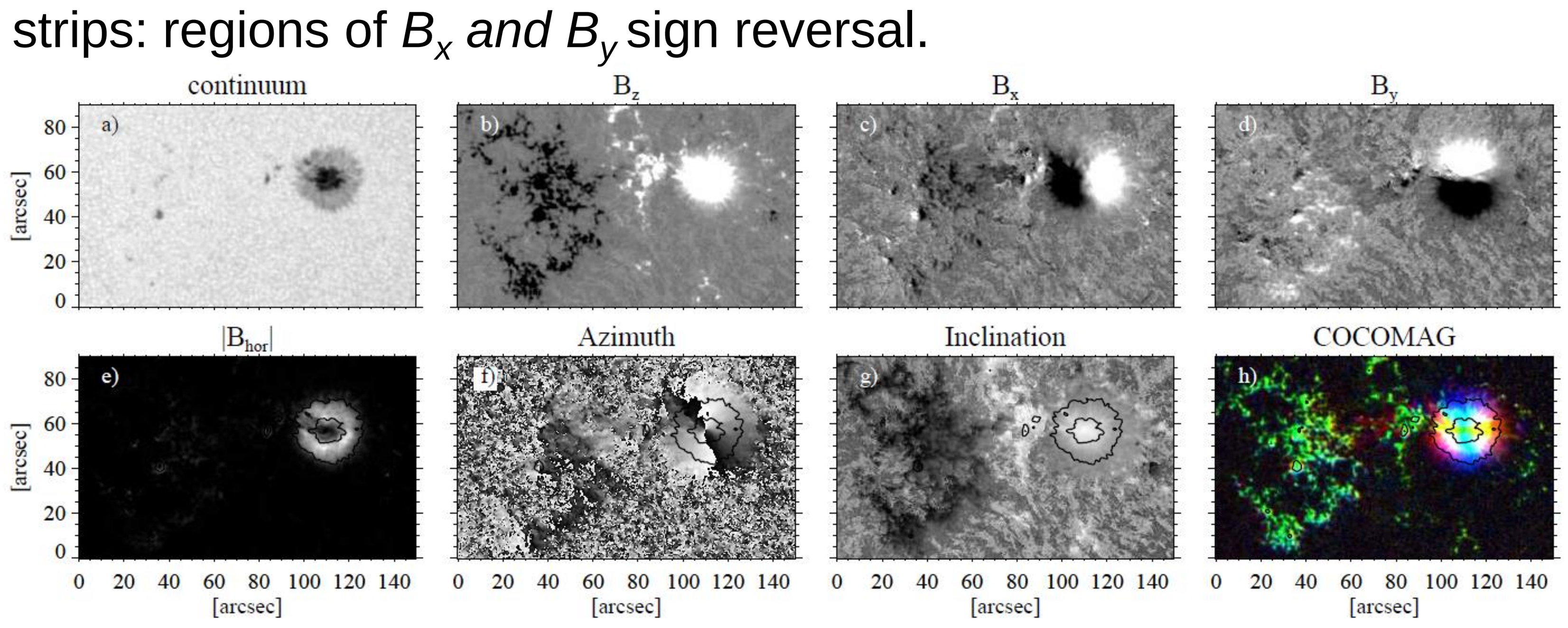

Fig. 1*. Continuum intensity, magnetic field components, and COCOMAG of the active region NOAA 11072. Contours mark the boundaries of umbra and penumbra.*

COCOMAGs as probes of flux emergence and decay

- Green-yellow-cyan patches separated by red hues. Blue and, mainly, magenta hues as twist develops.
- Initially inclined magnetic field dominates (red, yellow, cyan are highest).
- Decay: vertical magnetic field dominates (green curve overtakes).

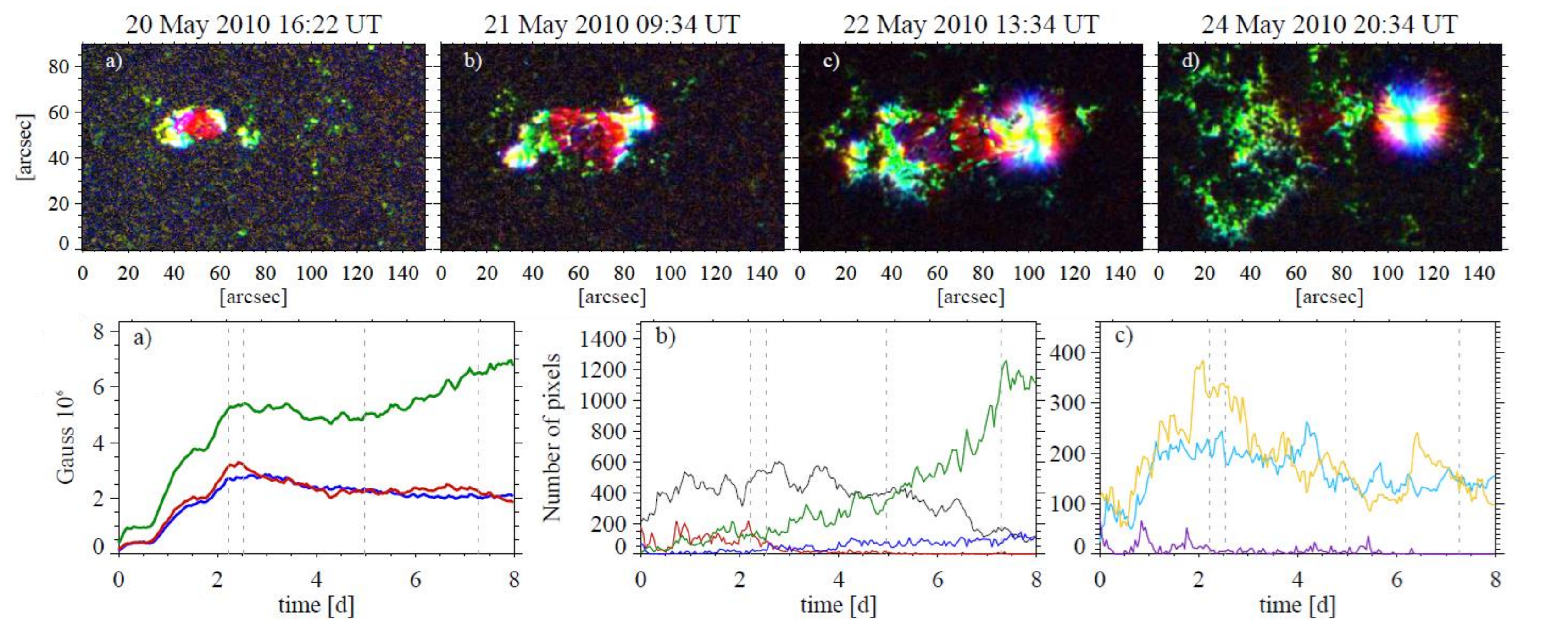

Fig. 2*. Top: Evolution of NOAA 11072 in COCOMAGs. Bottom: a) Time series of total B_x, B_y, B_z (red, blue, green). b-c) Color curves. Dashed lines indicate B-class flares*

COCOMAGs as probes of complexity

- Strongly twisted magnetic field: distorted cyan and yellow strips over main polarities, predominance of yellow, red and magenta hues between the polarities
- Abrupt color transitions: strong shear and polarity inversion lines
- Red, magenta, cyan, yellow and white color curves: moderate correlation with non-potentiality parameters.

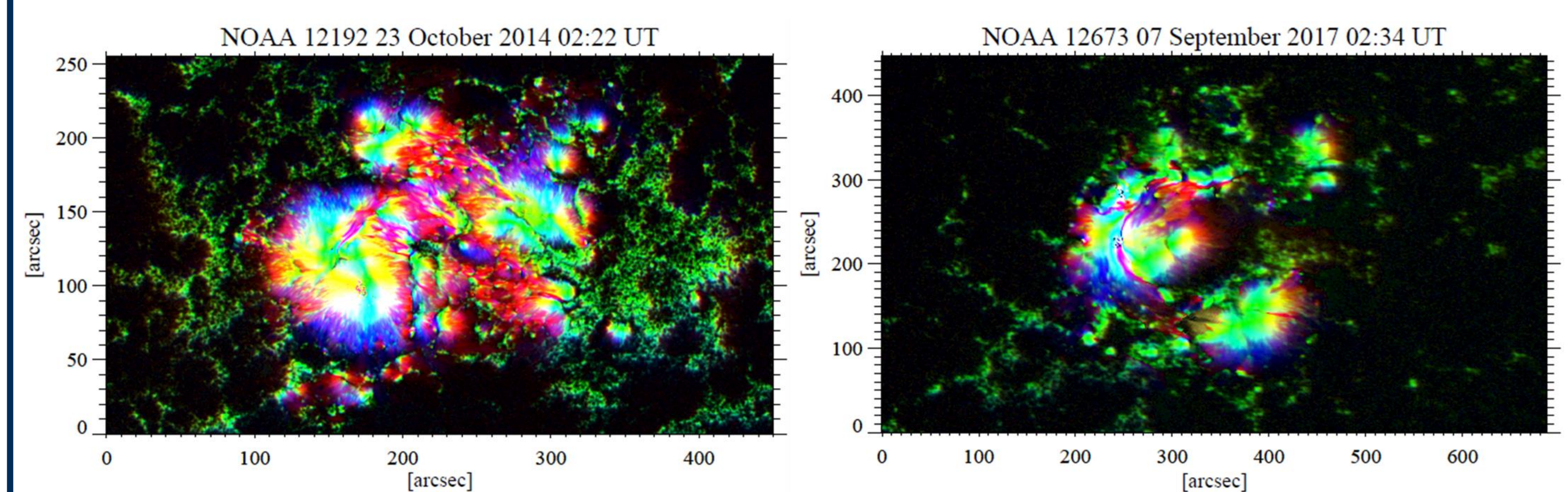

Fig. 3*. COCOMAGs of active regions NOAA 12673 and 12192.*

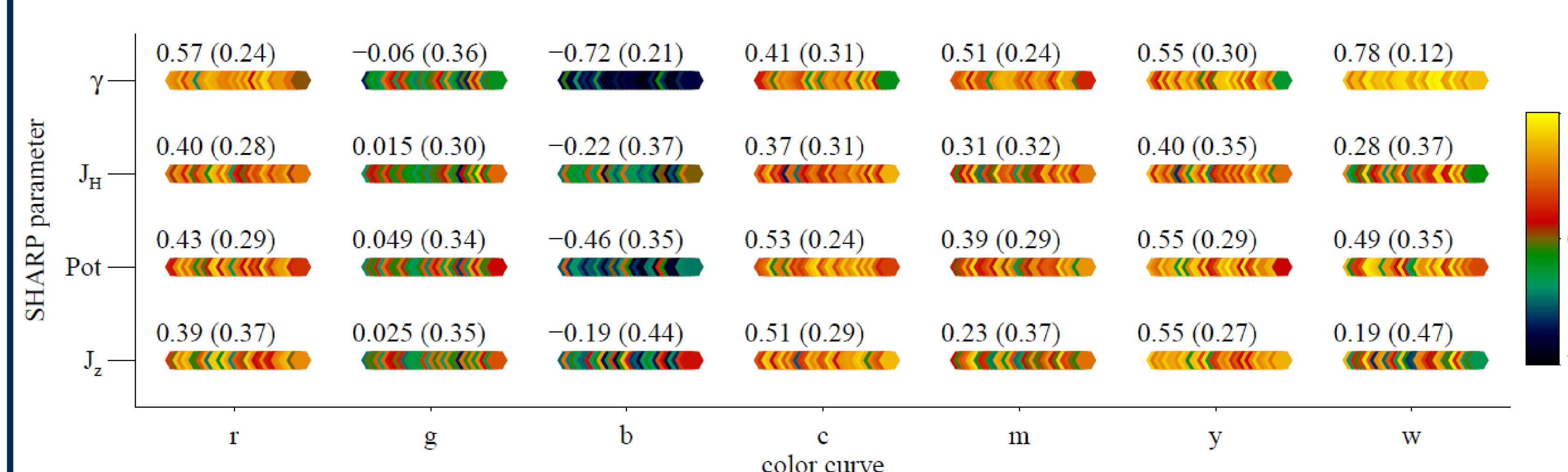

Fig. 4*. Correlations between the six color curves and four non-potentiality parameters, calculated for 33 active regions. Each hexagon represents the individual correlation coefficient between parameter and color curve. The average and standard deviation correlations are also included.*

COCOMAGs as flaring activity predictors

- Flaring probabilities for red, magenta, yellow and white color curves are comparable/higher than those for the total unsigned magnetic flux.
- COCOMAGs could be used for feature extraction and image-based prediction schemes.

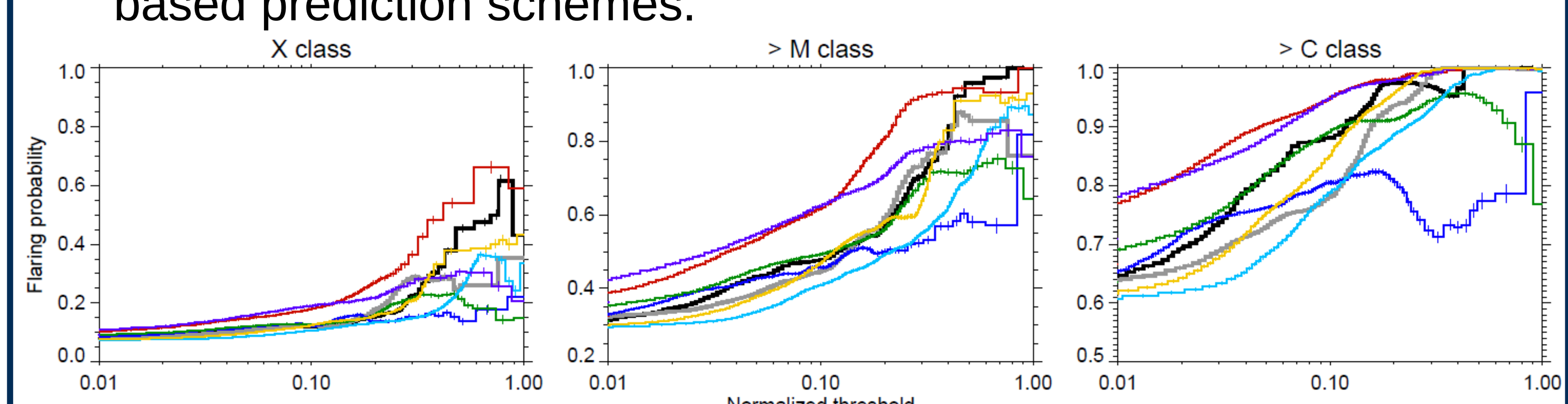

Fig. 5*. Bayesian flaring probabilities (time window = 24 h) calculated for the color curves of 33 active regions of Solar Cycle 24. Each color represents flaring probabilities for the corresponding color curve while black stands for probabilities calculated for the total unsigned magnetic flux of the region.*

More info: Kontogiannis et al. 2024 A&A in press arXiv:2408.07047

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