Flare forecasting in 3D solar ARs: From theory to facility – SAMNET

[1]Robertus Erdélyi

[1]M. B. Korsós, [1]N. Gyenge, [2]S. Yu, [3]S. Bios, [4]P. Chatterjee, [5]S. Poedts, [6]M. K. Georgoulis, [3]Y. Yan, [1]M. S. Ruderman, [7]M Stangalini et al.

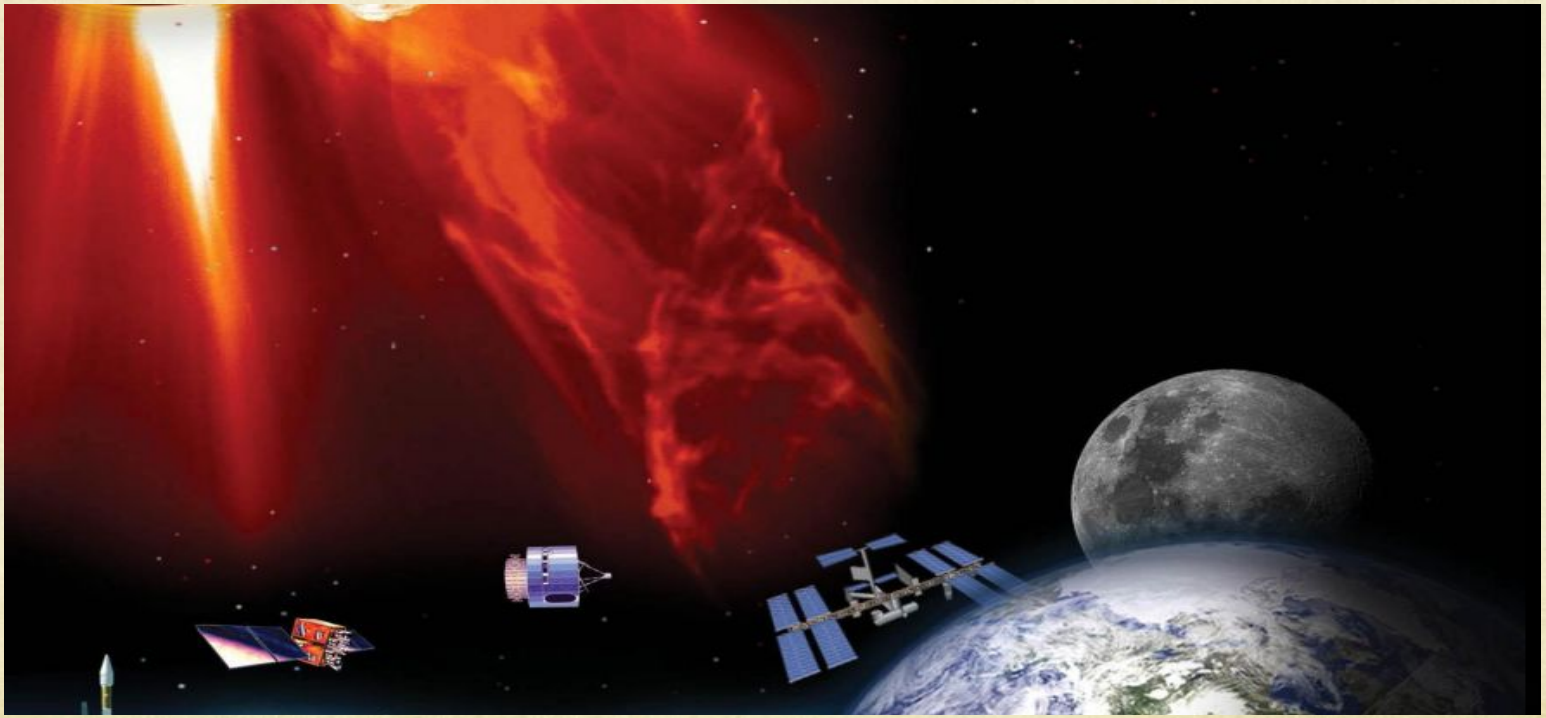
[1]SP2RC, University of Sheffield, UK
[2]New Jersey Institute of Technology
[3]NAOC, Chinese Academy of Sciences, Beijing
[4]Indian Institute of Astrophysics, Bangalore
[5]Center for Mathematical Plasma Astrophysics, KU Leuven,
[6]Research Center for Astronomy and Applied Mathematics of the Academy of Athens
[7]INAF Team at Rome Observatory, Italy

The University Of Sheffield.

Research Centre

Introduction: Why Bother

The interaction of solar activity with Earth's upper atmosphere occurs through a complex series of events - Space Weather

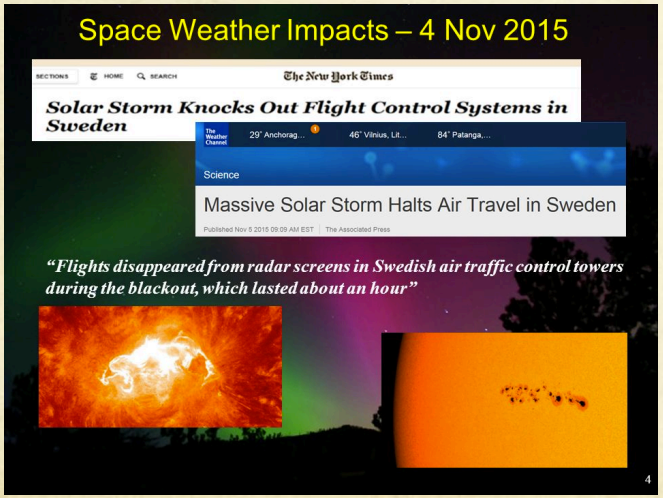


A major impact on life and modern technology-based society in Space or on Earth.

Introduction: Why Bother

The interaction of solar activity with Earth's upper atmosphere occurs through a complex series of events - Space Weather

Solar storm shuts down air space (4 Nov 2015)

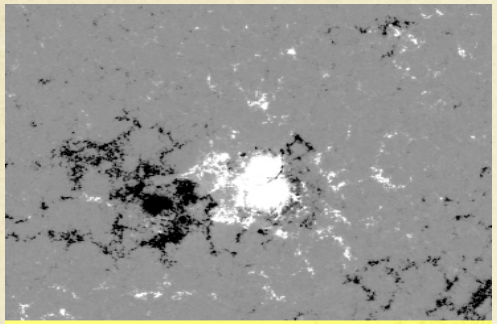


A major impact on life and modern technology-based society in Space or on Earth.

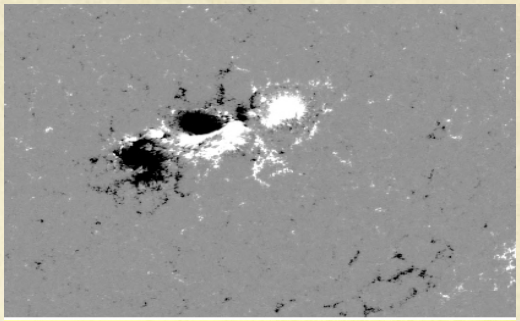
The Science: Flares/CME & photospheric field configuration

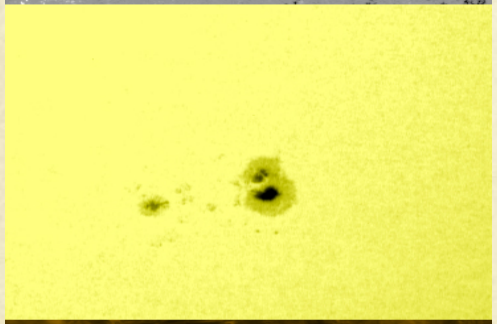
Bipolar: AR 11734

Delta-type: AR11158

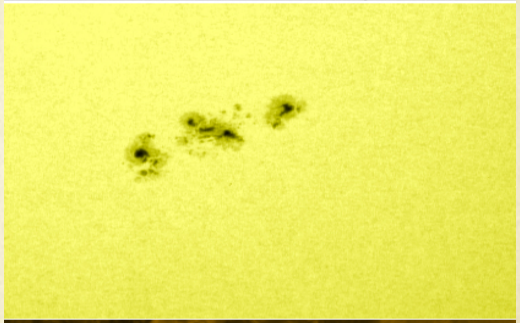


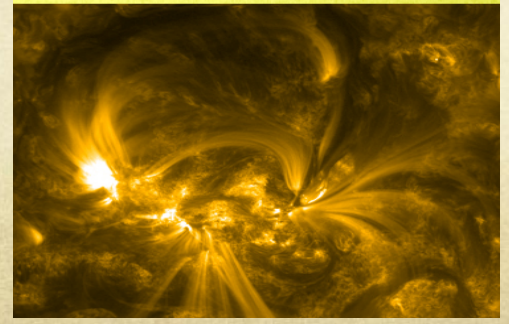
Magnetogram



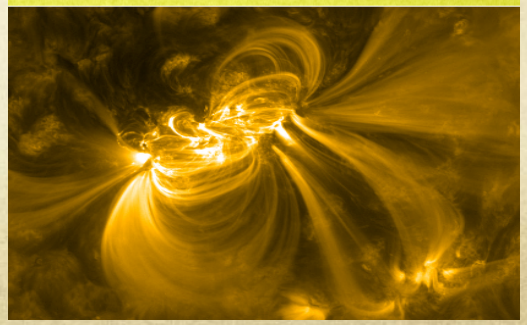


Photosphere White light continuum





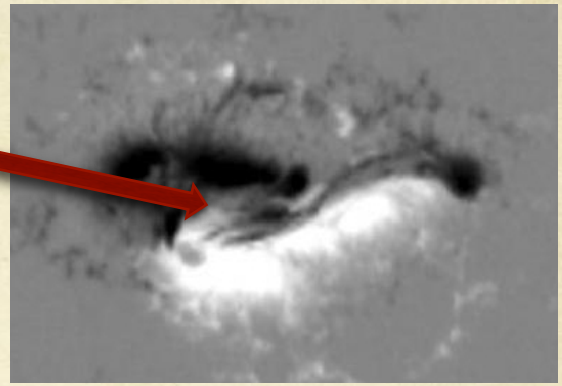
Upper Transition Region



The Science: Introduction

Inversion line of high magnetic gradient

(Schrijver, ApJ, 655, L117, 2007)

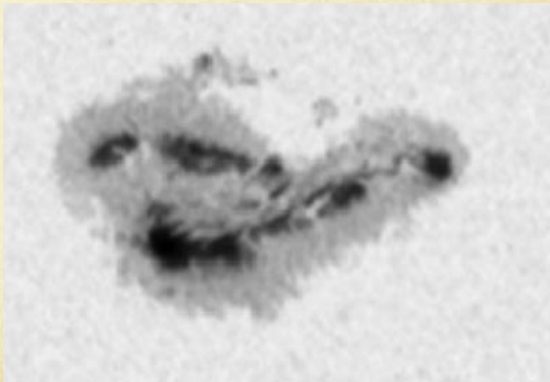


Present method:

Tracking the dynamics of sunspots

Input data of the photosphere study: Korsos et al. ApJ, 802, L21, 2015

SDD-(SOHO/MDI - Debrecen Data)
HMIDD-(SDO/HMI - Debrecen Data)



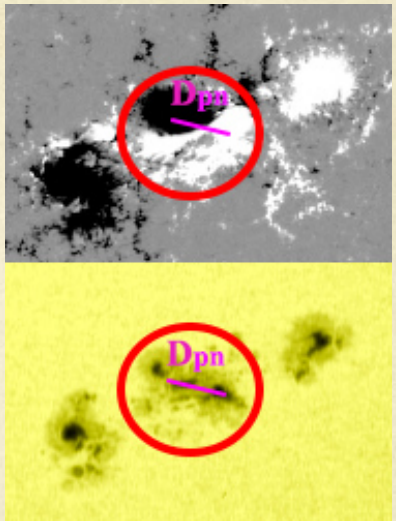
Input data of the 3D study:

SOHO/MDI
SDO/HMI
Magnetic field extrapolation
Artificial data by Pencil MHD Code

WG_M method

We define a **proxy quantity** for the **weighted horizontal magnetic gradient**:

$$WG_M = \left| \frac{\overbrace{\sum_i B_{p,i} \cdot A_{p,i}}^{\text{Positive Magnetic flux}} - \overbrace{\sum_j B_{n,j} \cdot A_{n,j}}^{\text{Negative Magnetic flux}}}{D_{pn}} \right|$$

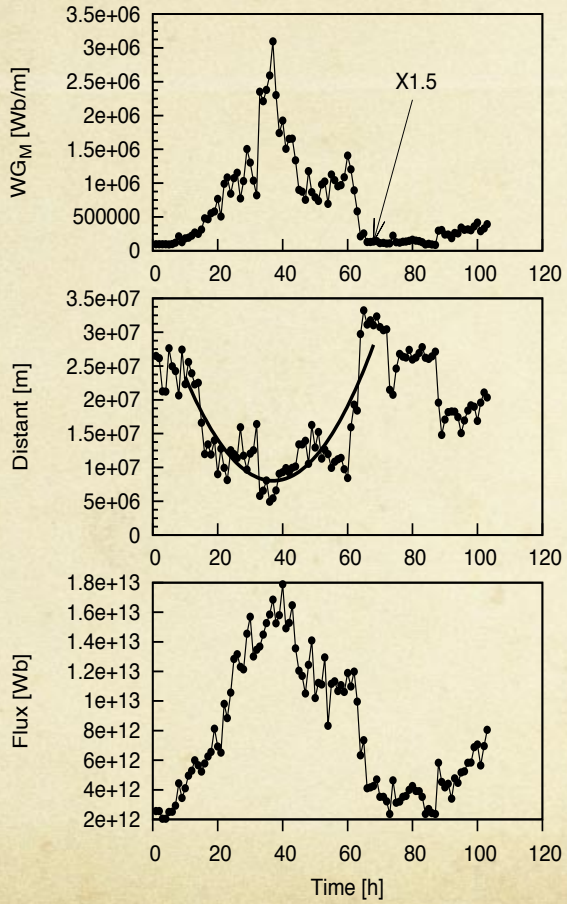


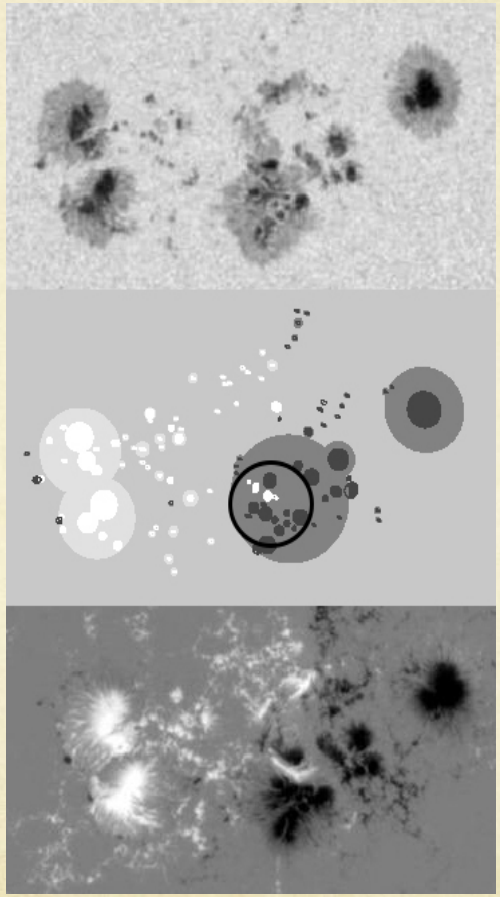
AR11158

We follow the variation of WG_M in the area of highest magnetic gradient.

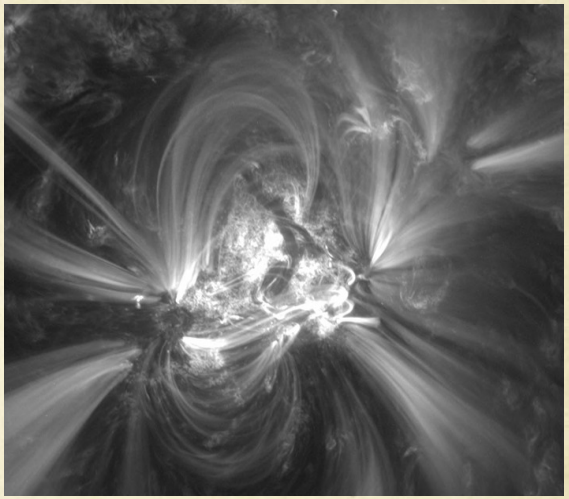
Korsos et al. ApJ, 802, L21, 2015

NOAA 11166



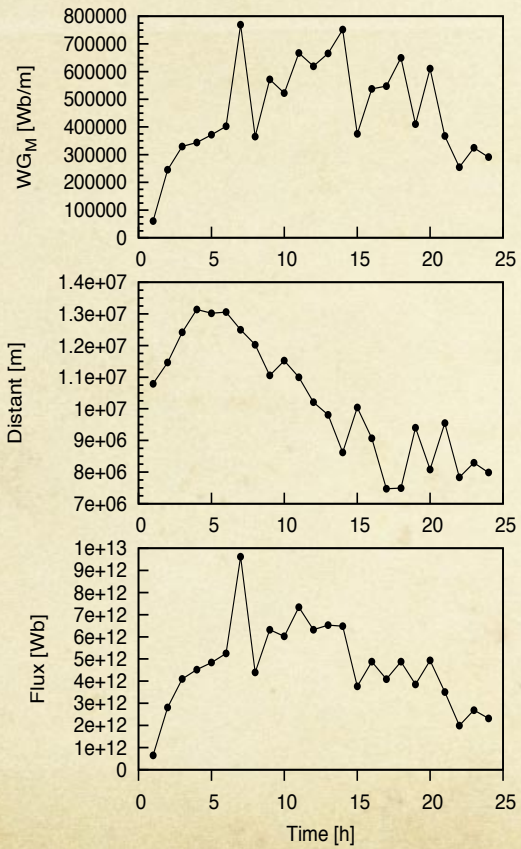


Large flare

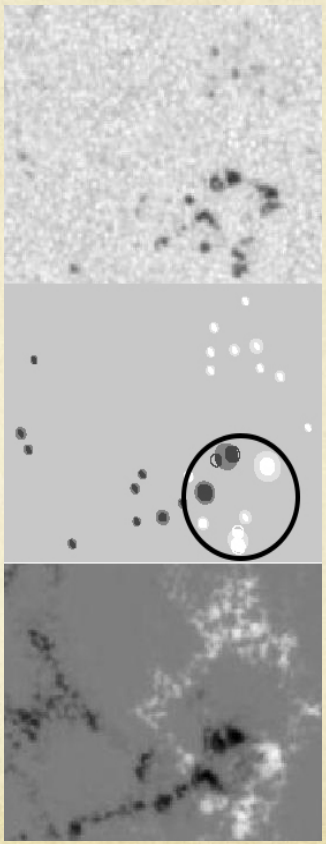


Korsos et al. ApJ, 802, L21, 2015

NOAA 11995

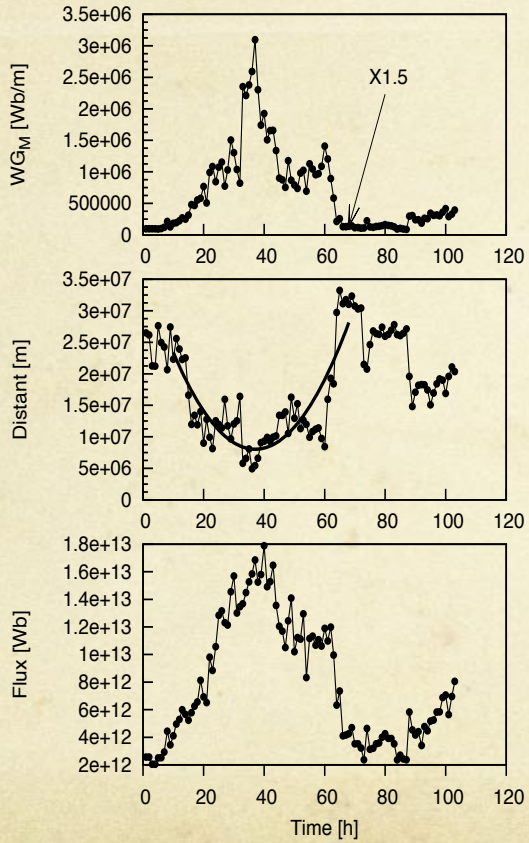


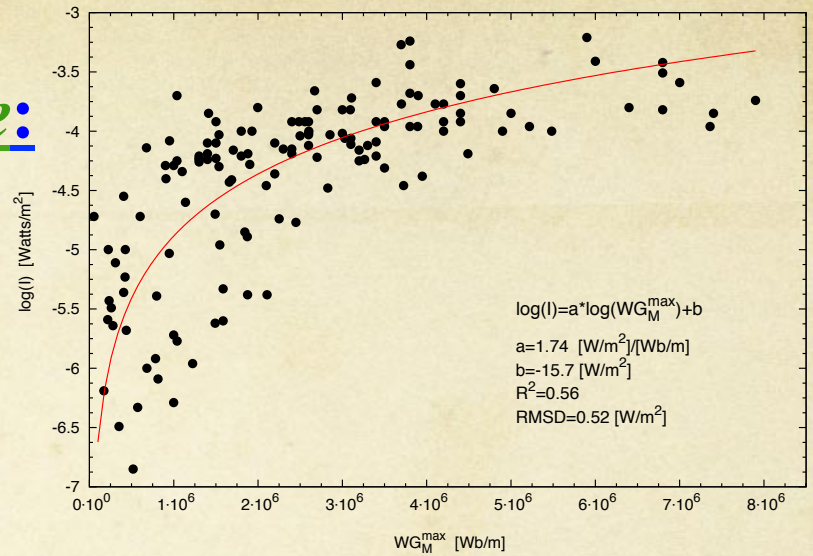
No Flare!

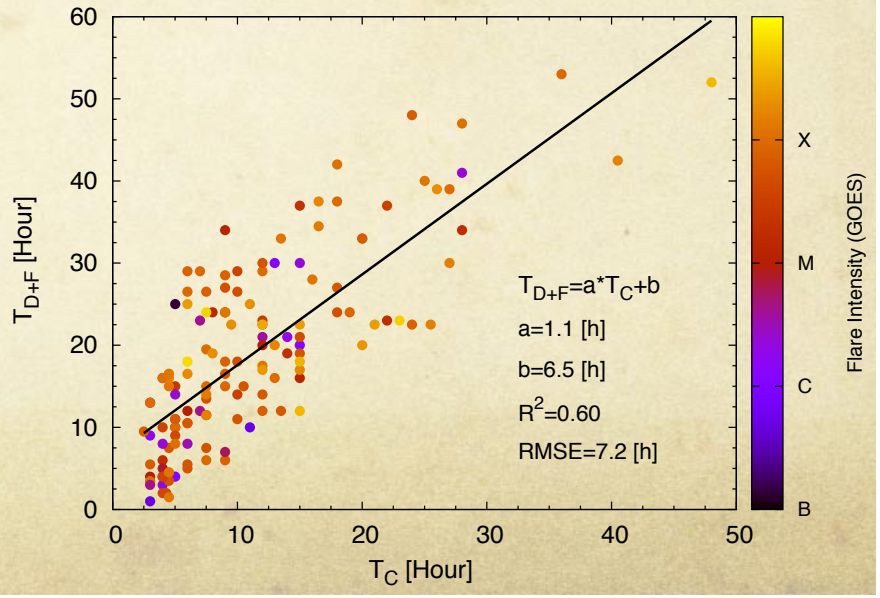


Korsos et al. ApJ, 802, L21, 2015

Estimation of the expected flare *intensity* and flare *onset time*:





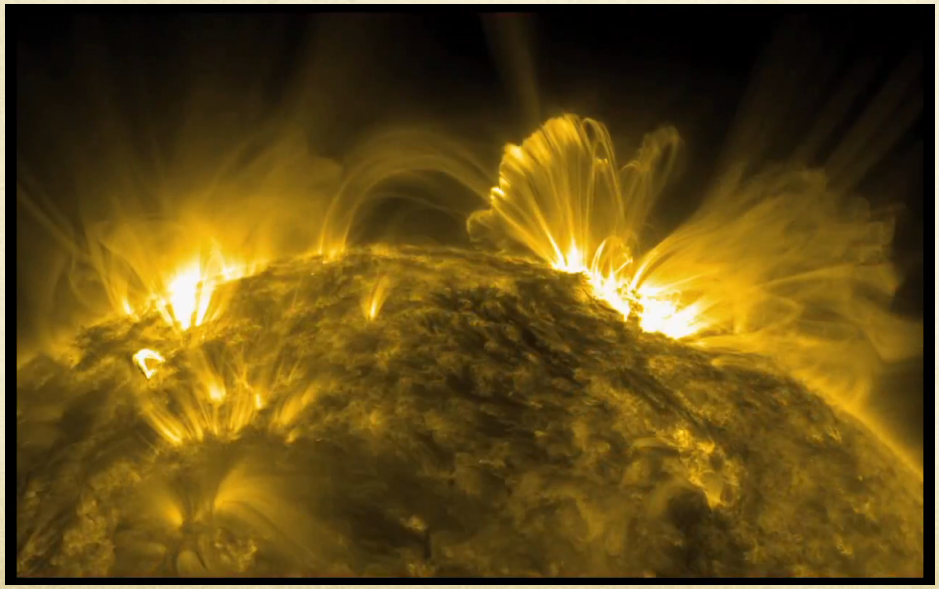


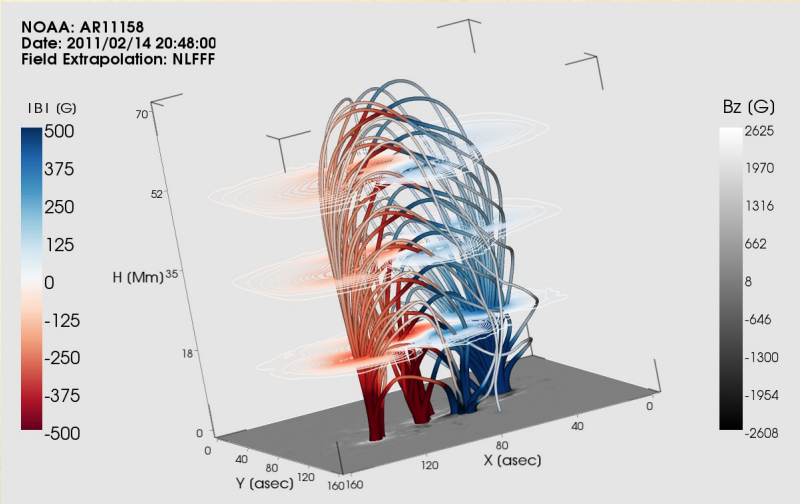
Statistics of **130 ARs** (within ±70º CMD)

WG_M method in the lower solar atmosphere

We propose: extend our investigations into the chromosphere and low corona in 3D.

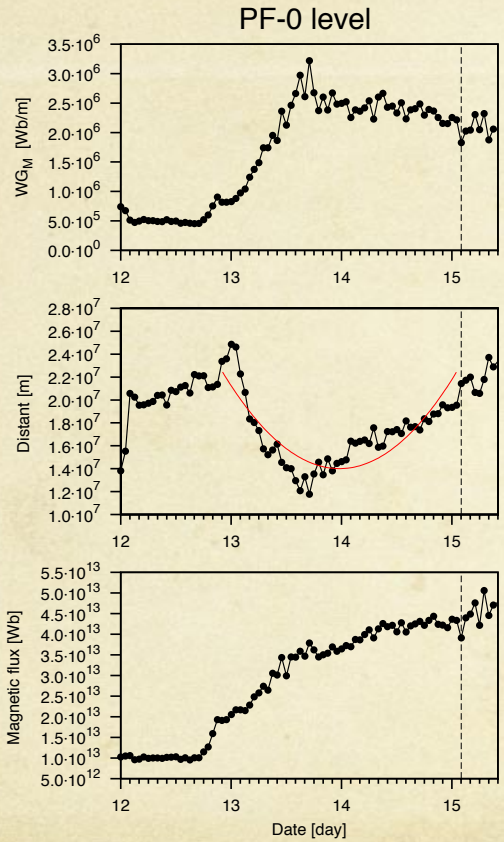
We develop a complex 3D tool that allows us to predict flare onsets based on magnetic field topology in the lower solar atmosphere.

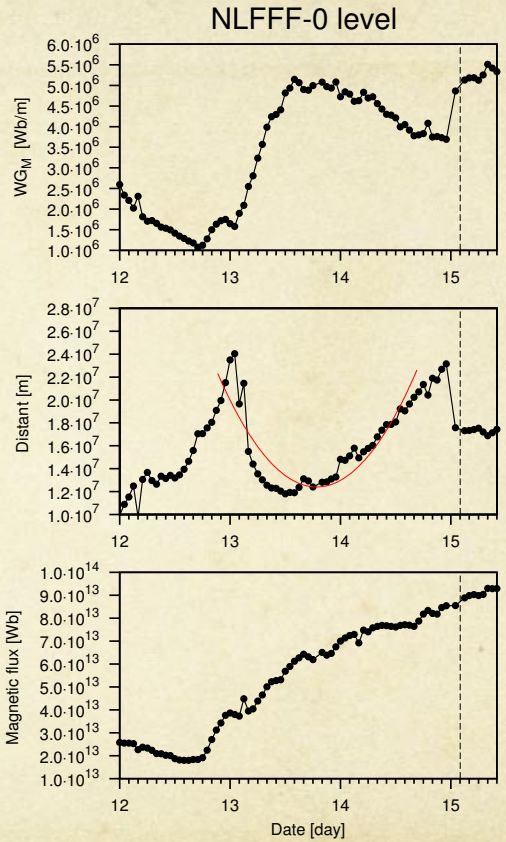




AR 11158

0 km level



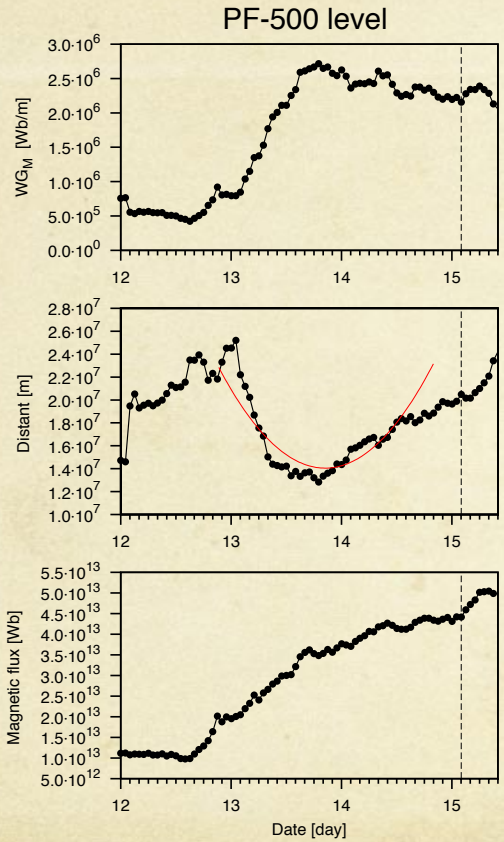


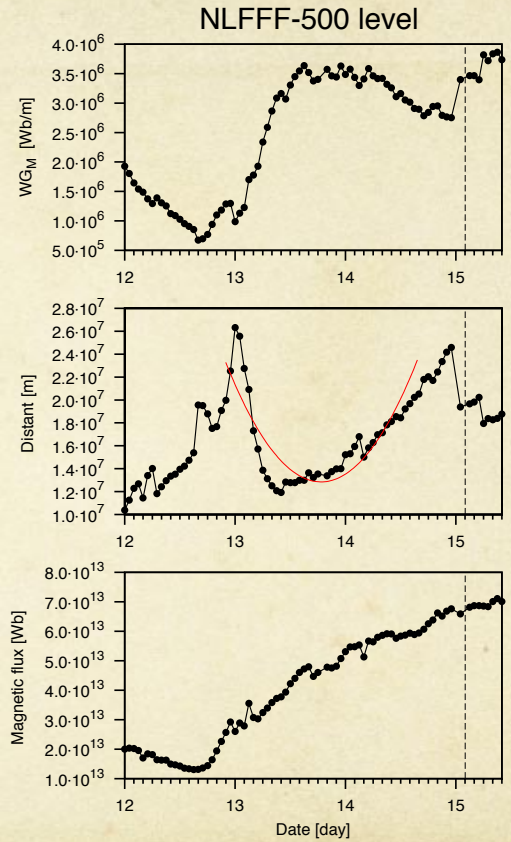
Potential field extrapolation

Nonlinear force-free extrapolation

AR 11158

500 km level



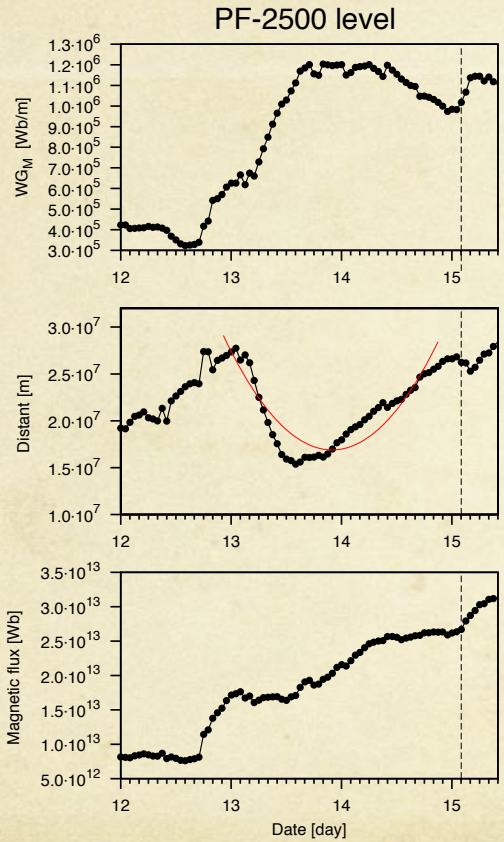


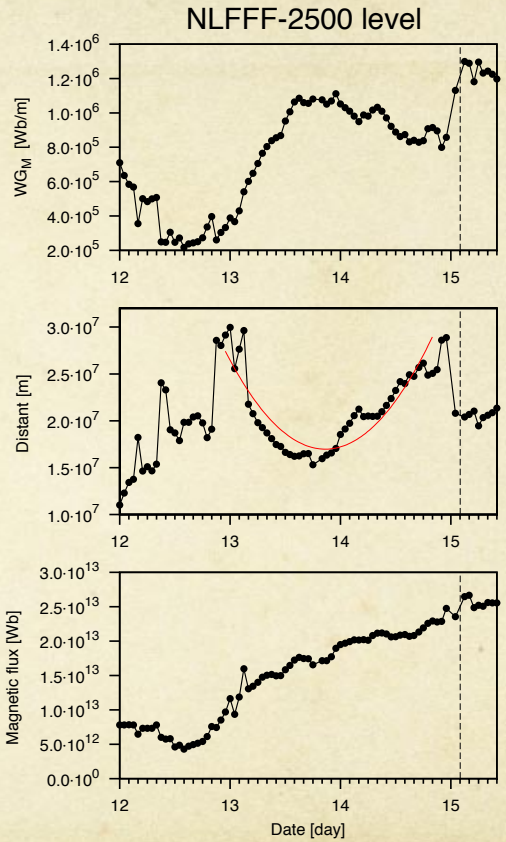
Potential field extrapolation

Nonlinear force-free extrapolation

AR 11158

2500 km level



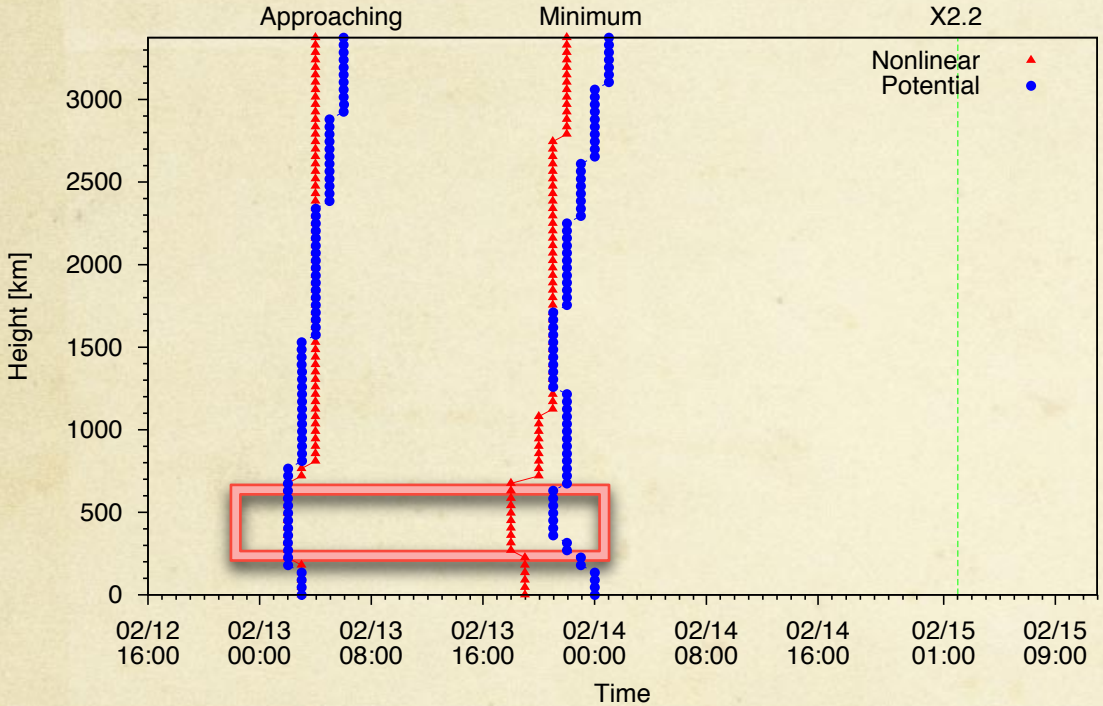


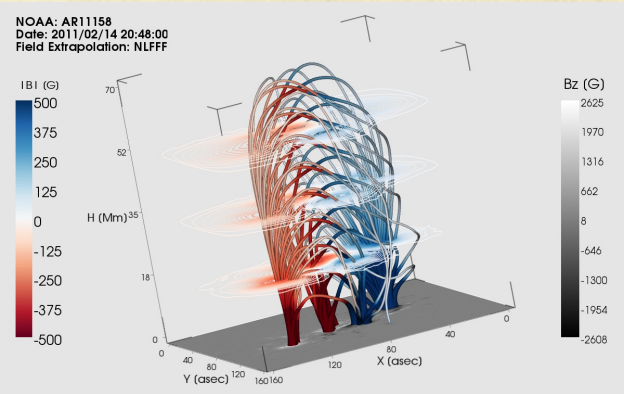
Potential field extrapolation

Nonlinear force-free extrapolation

The actual starting times of approaching, minimum point and flare onset as function of height

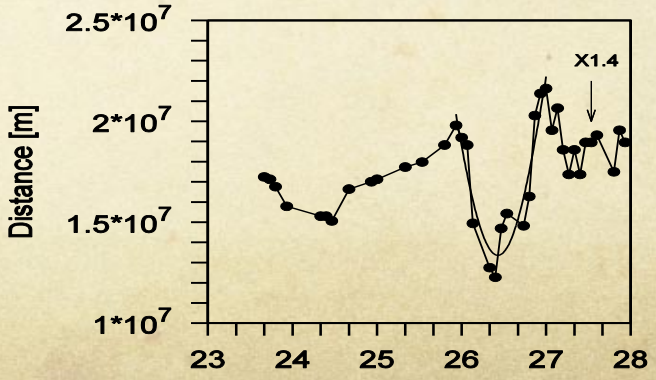
NOAA 11158





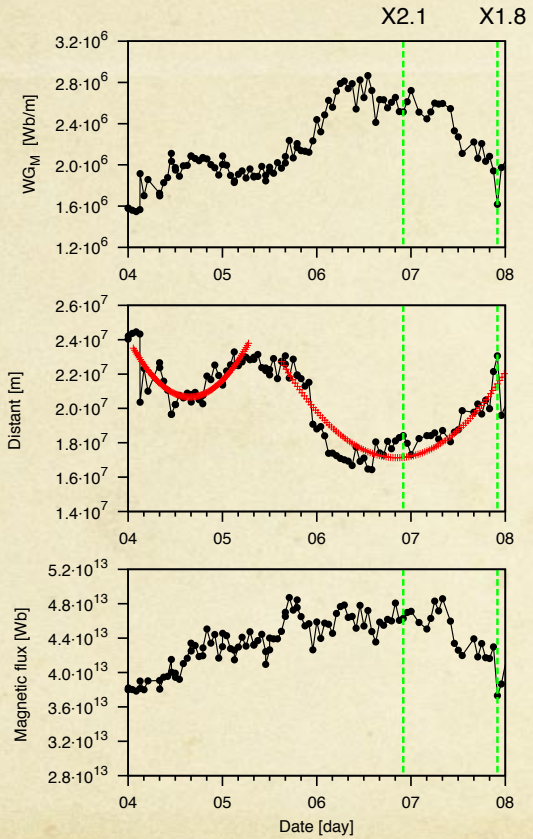
y=0 is the photosphere

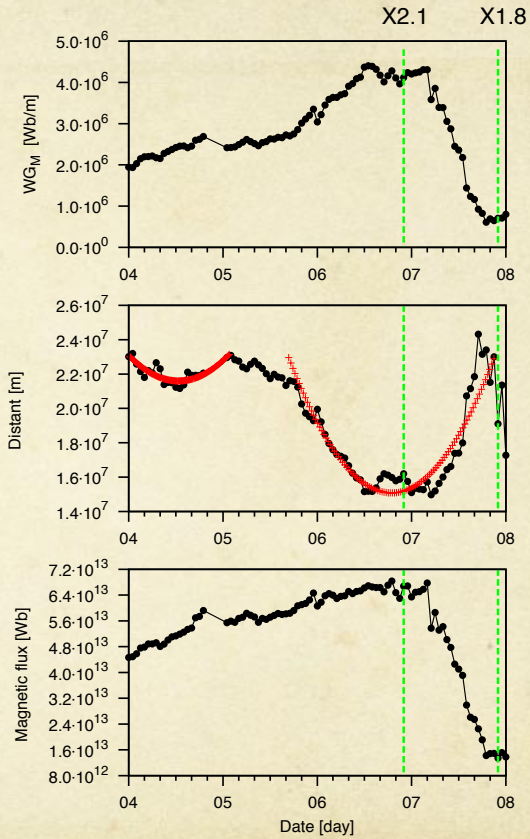
$$T_{predicted} = 0.85 * T_C + 12.8$$



AR 11283

0 km level



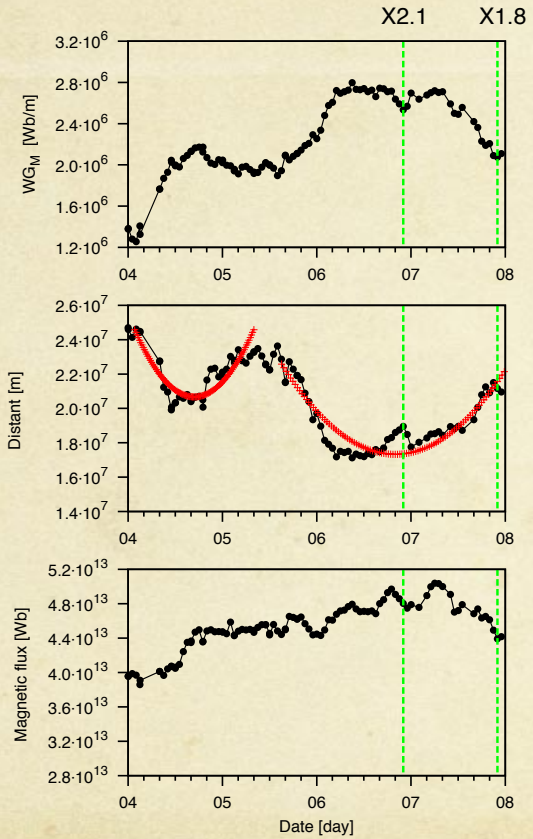


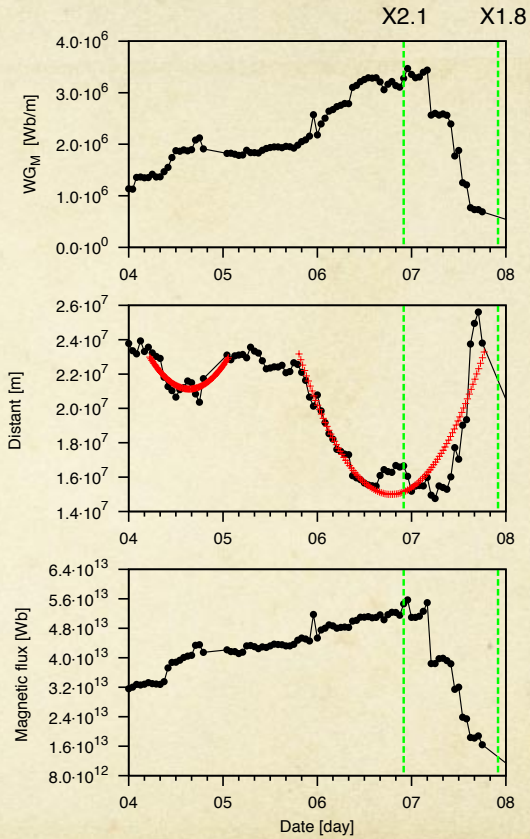
Potential field extrapolation

Nonlinear force-free extrapolation

AR 11283

500 km level



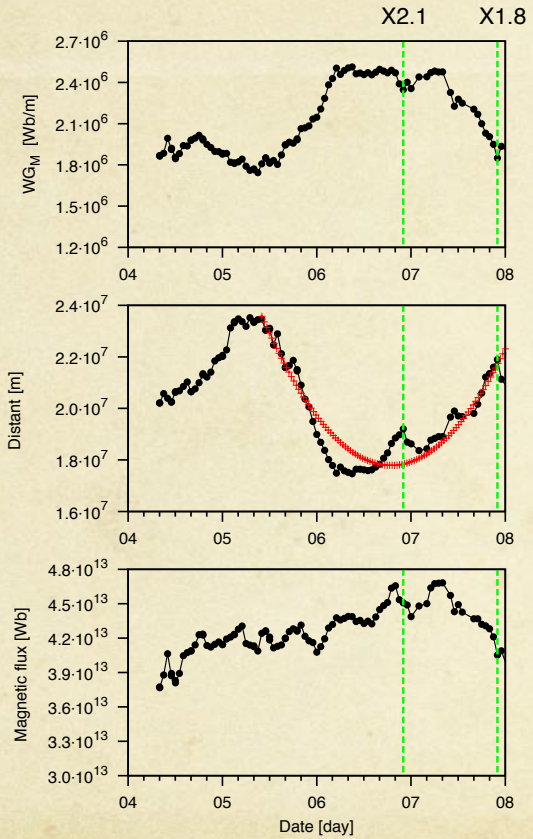


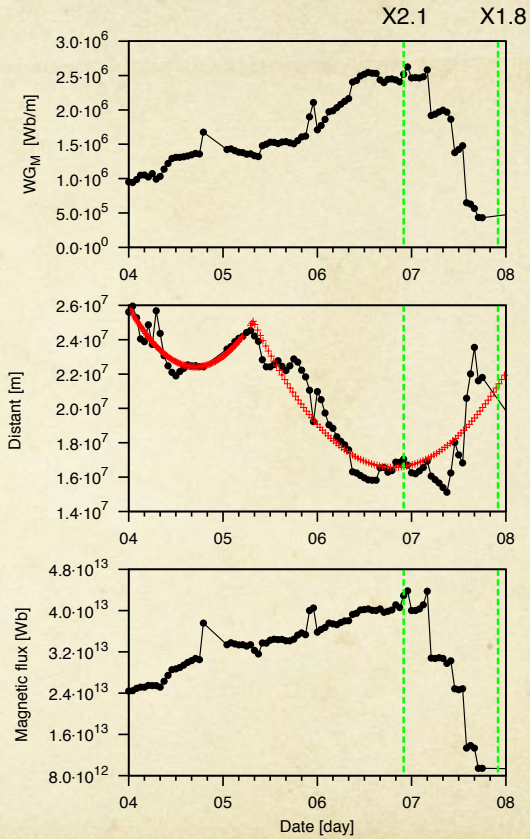
Potential field extrapolation

Nonlinear force-free extrapolation

AR 11283

1000 km level



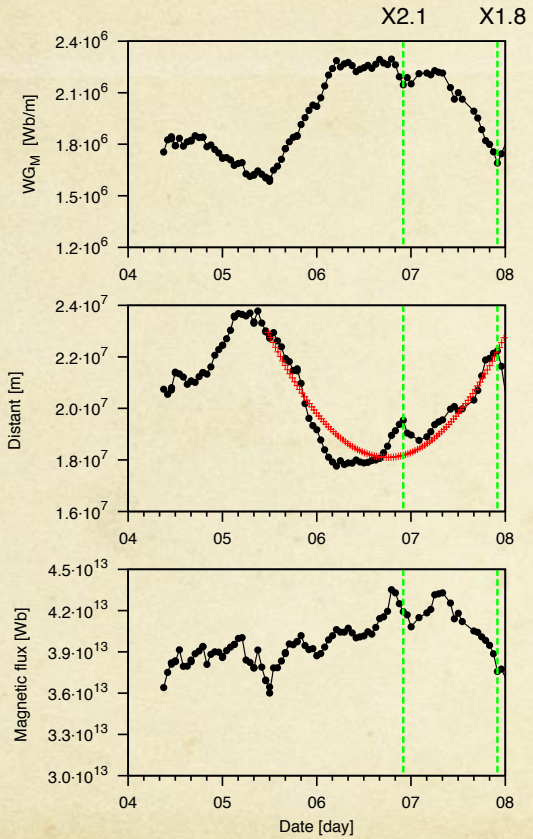


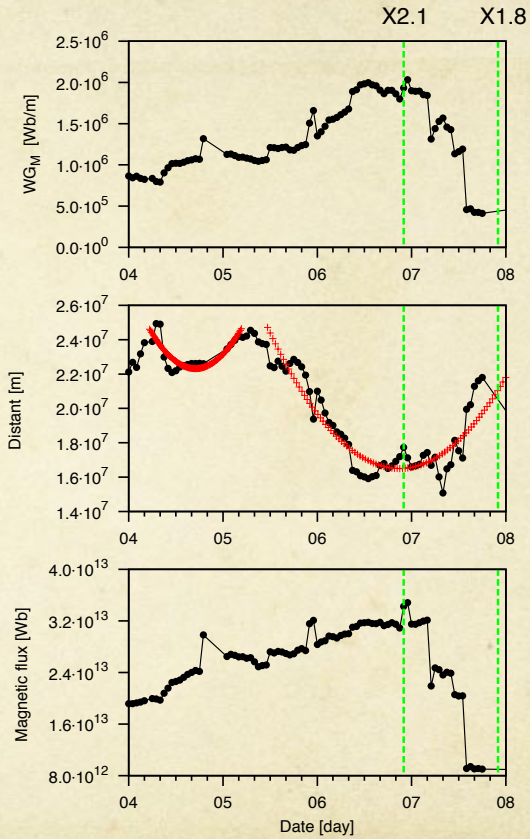
Potential field extrapolation

Nonlinear force-free extrapolation

AR 11283

1500 km level

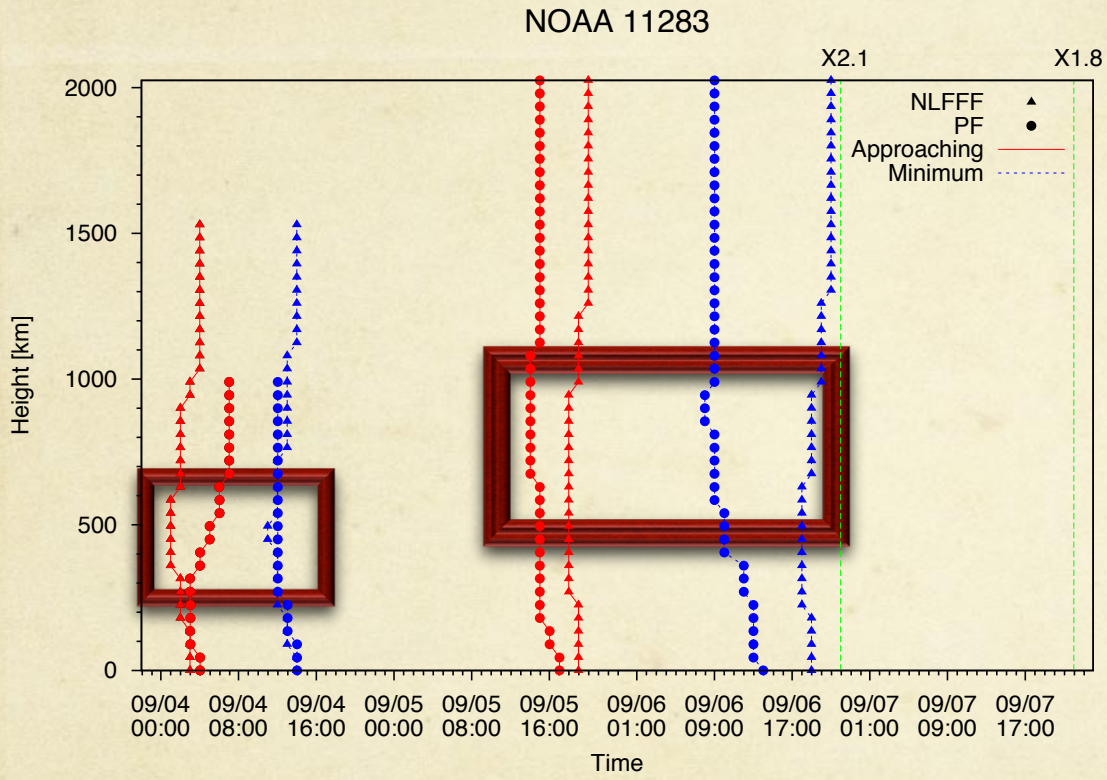


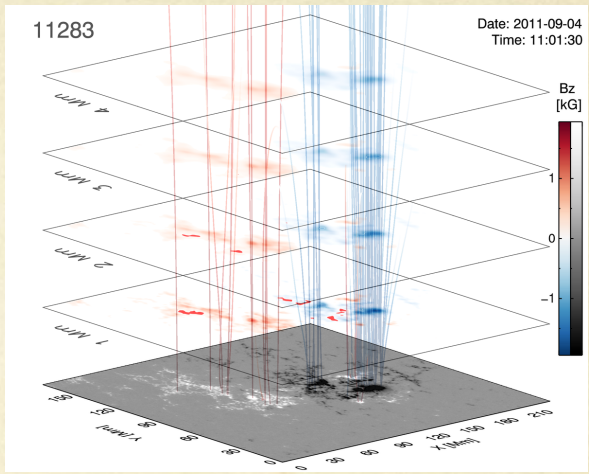


Potential field extrapolation

Nonlinear force-free extrapolation

The actual starting times of approaching, minimum point and flare onset as function of height



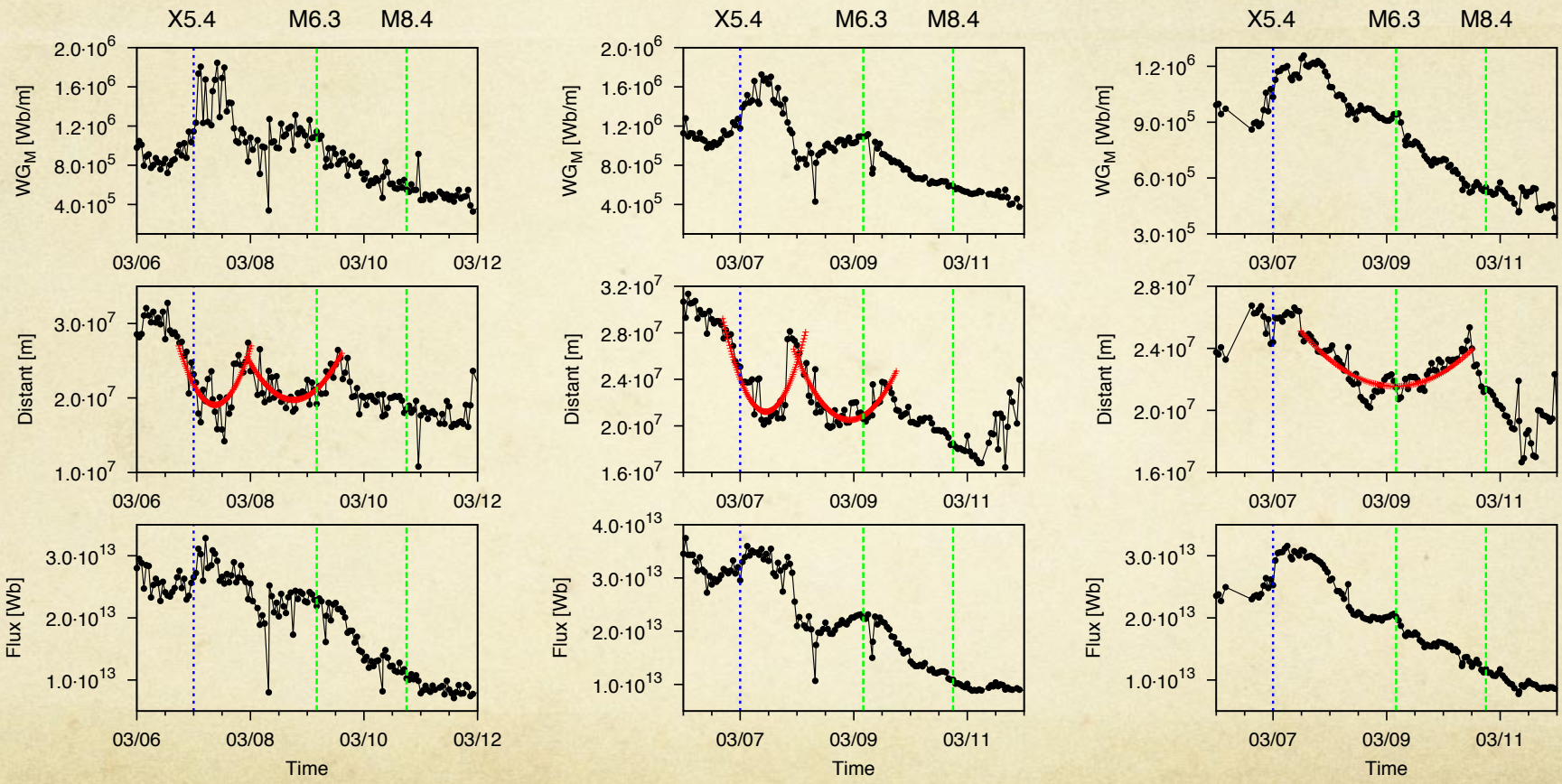


y=0 is the photosphere

$$T_{predicted} = 0.85 * T_C + 12.8$$

AR 11429

Potential force-free extrapolation

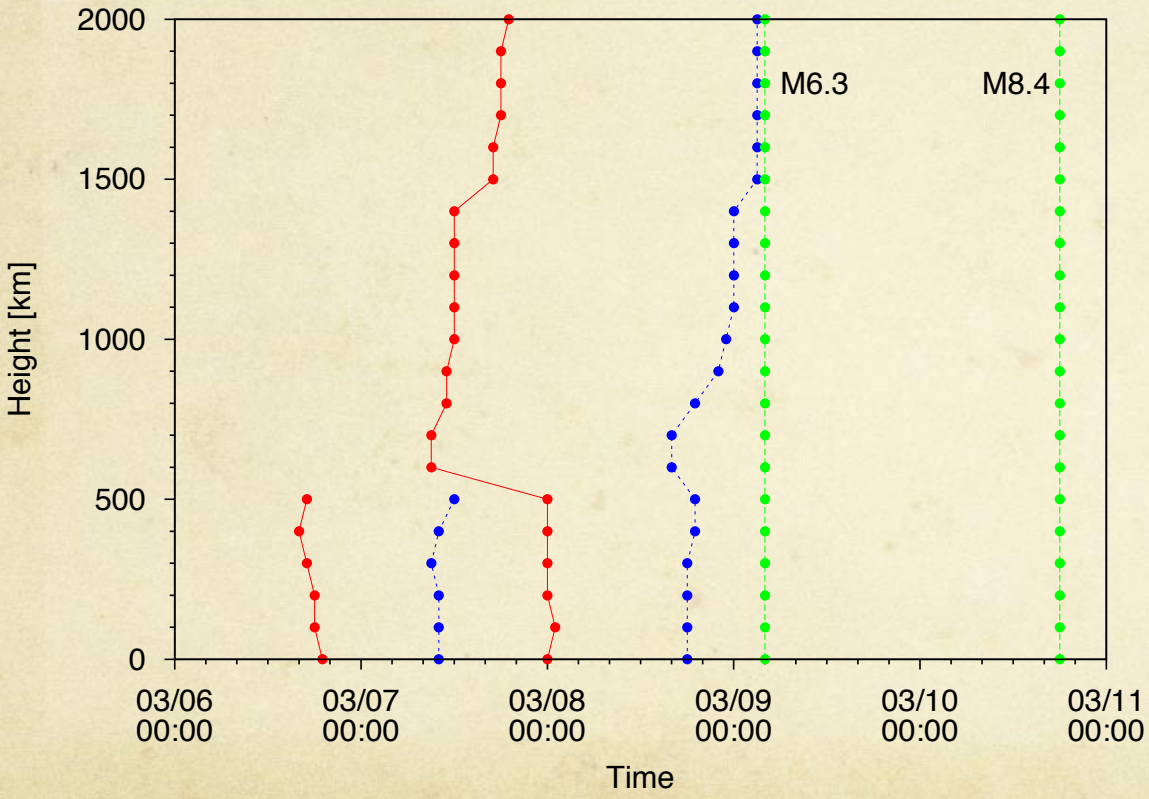


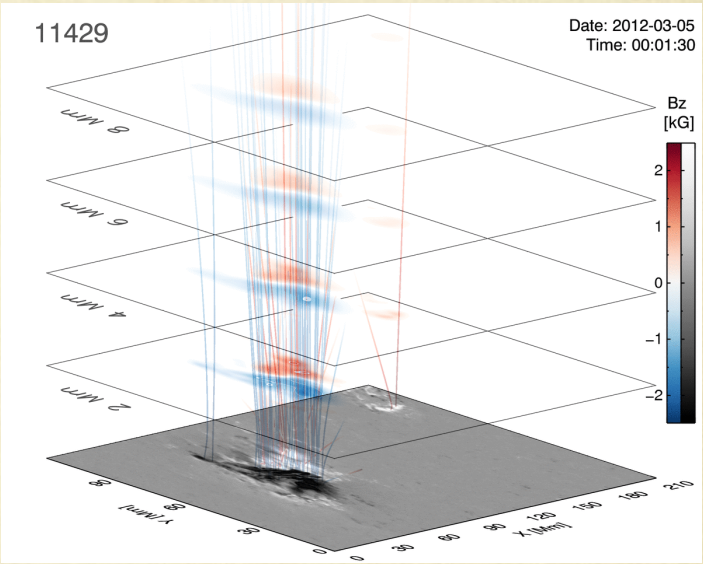
0 km level

500 km level

1000 km level

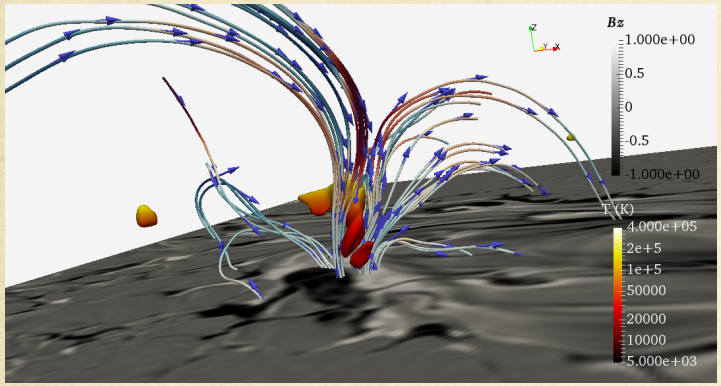
Starting times of approaching, minimum point and flare onset as function of height

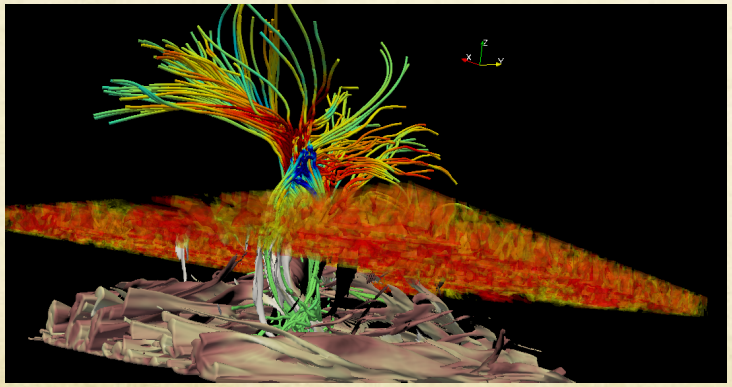




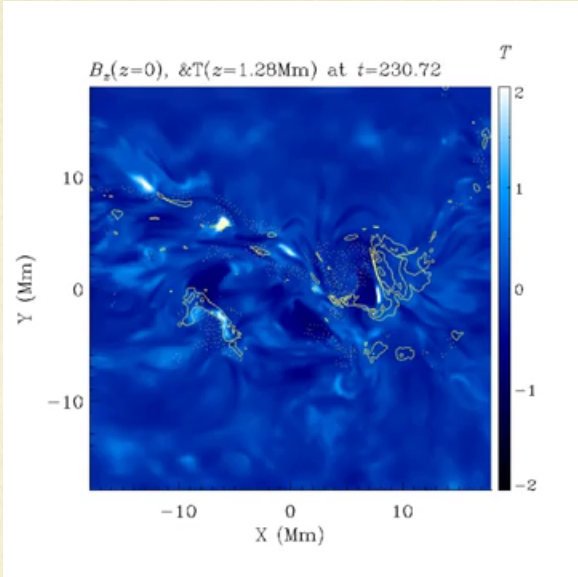
y=0 is the photosphere

Test of the WGM method on the *artificial AR* by the Pencil MHD Code





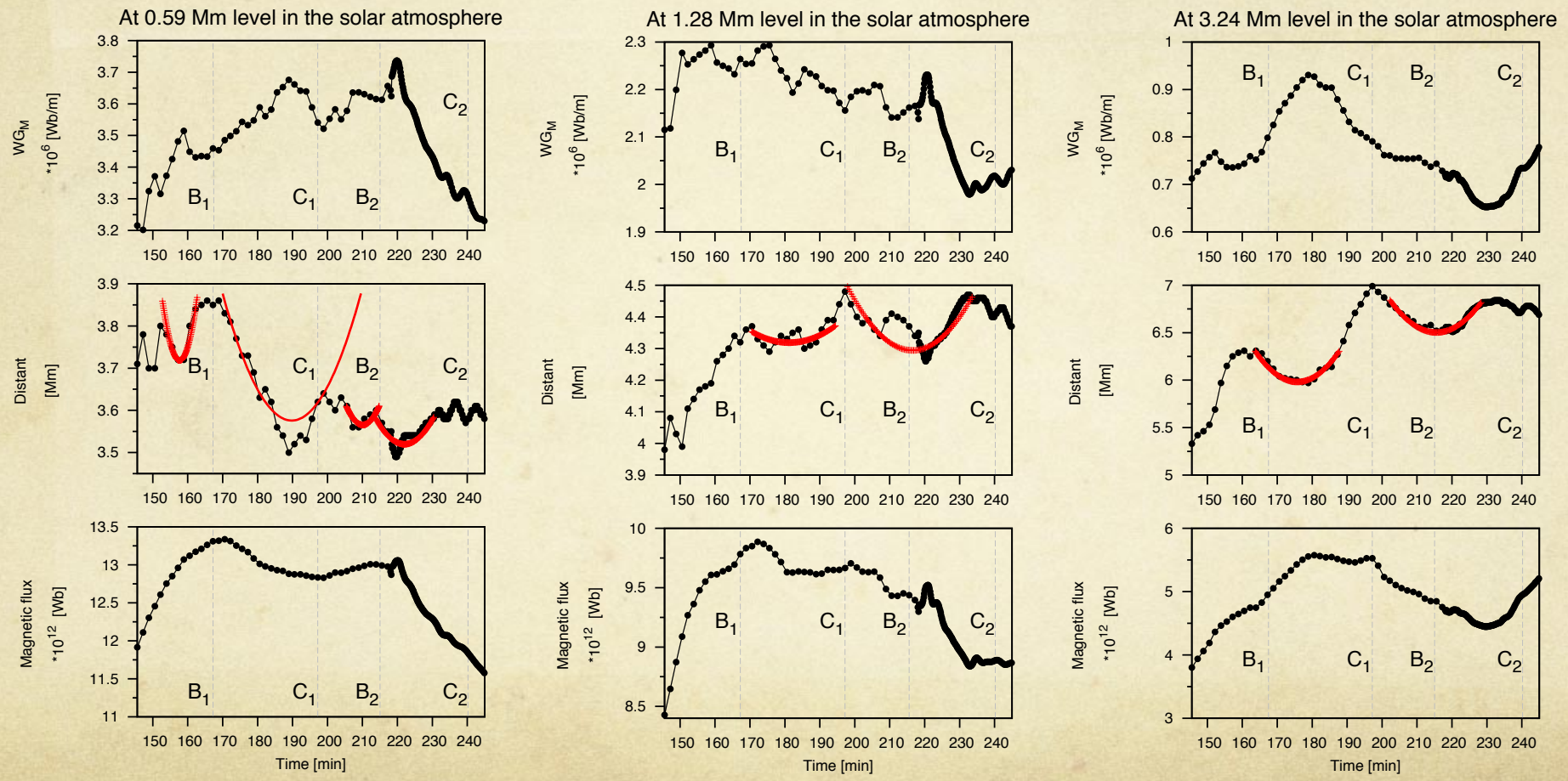
Snapshots of simulation



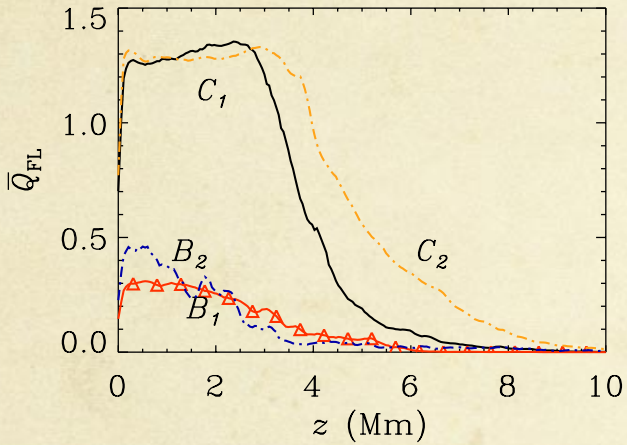
Local temperature map

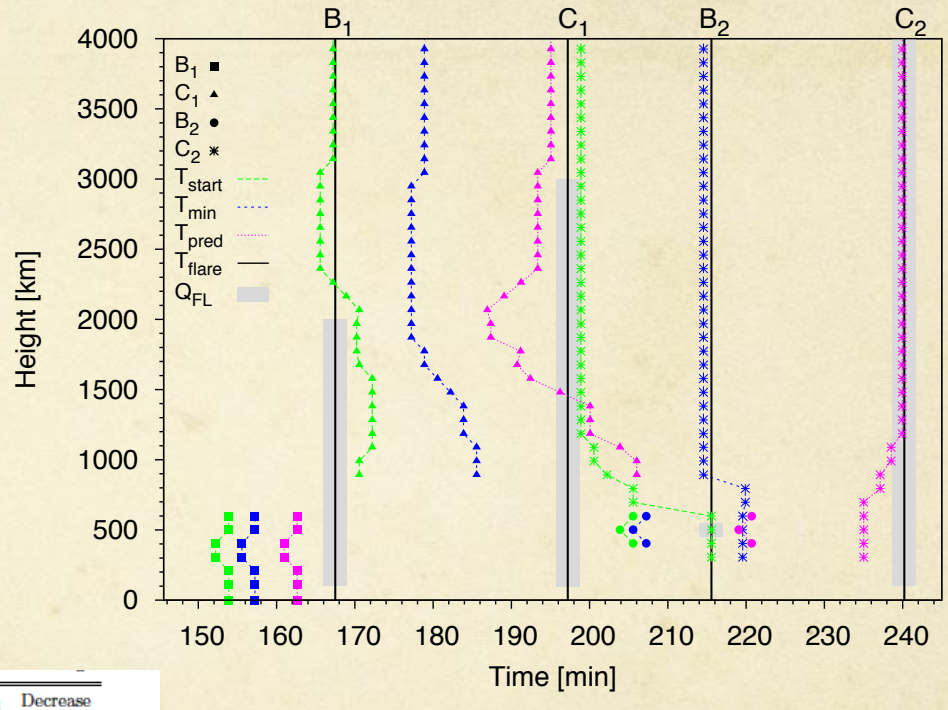
Chatterjee et al. Physical Rev. L, 116, 10, 1011012016.

The *artificial AR* by the Pencil MHD Code



The actual starting times of approaching, minimum point and flare onset as function of height





Flare	Interval	Optimum height [Mm]	$\overline{Q}_{FL}$ [Mm]	Maximum WG_M $\cdot 10^6$ [Wb/m]	Onset WG_M $\cdot 10^6$[Wb/m]	T_C [min]	T_{D+F} [min]	T_{pred} [min]	Decrease [%]
B_1	Min	0.3	0.1	3.995858	3.935404	3.34	11.94	5.40	1.5%
	Max	0.4	2	3.875480	3.806449	3.34	11.94	5.40	2%
C_1	Min	2.3	0.2	1.423277	1.241406	11.60	19.98	16.20	12.7%
	Max	2.7	3	1.191264	1.010575	11.60	19.98	16.20	18.2%
B_2		0.5	0.5	3.928899	3.927835	1.66	10	13.50	0%
C_2	Min	1.3	0.1	2.231090	2.017166	15.70	25.70	25.40	9.5%
	Max	4	4	0.797131	0.666601	15.70	25.70	25.40	16.3%

Time estimation:

$$T_{predicted} = 0.85 * T_C + 12.8$$

Science conclusions

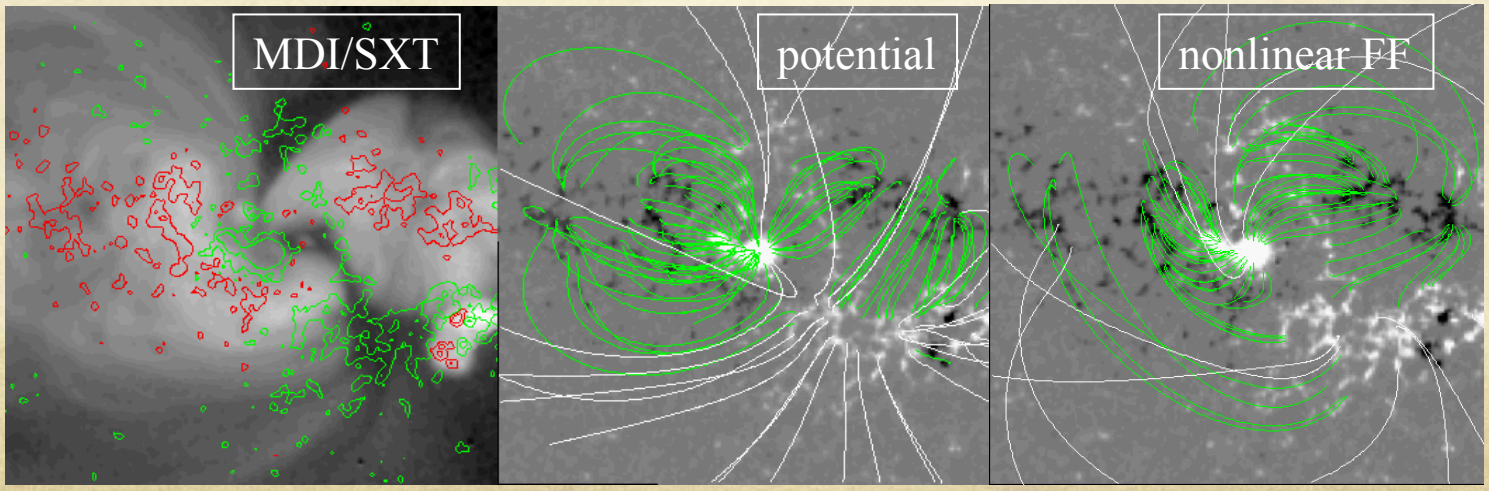
Tracking of the following quantities may be promising for flare forecast.

- Weighted horizontal gradient of magnetic field (WG_M),
- Steep increase of WG_M → for warning,
- High maximum of WG_M → for the assessment of flare intensity,
- Decrease of WG_M after maximum → for warning,
- Time of approaching and receding phases → onset time of flare
- The *3D method* is capable of *increasing* the *forecast time.*

Major Issue: Magnetic field extrapolation

Potential field , Linear force-free and Nonlinear force-free extrapolation

From the same photospheric field distributions, one can extrapolate the coronal magnetic field (by solving $\nabla.B=0$ and $\nabla\times B=\alpha B$, with appropriate upper boundary conditions)



What's next?

Science conclusions

- **...**
- **...**
- The *3D method* is capable of *increasing* the *forecast time.*

Facility development!

SAMM - **S**olar **A**ctivity **MOF M**onitor (single mount, dual axis 2xMOF)
SAMM+ - Upgrade of SAMM to 4xMOFs
SAMNet – Network of SAMM+ stations

Synoptic solar telescope based on Magneto Optical Filter (MOF) technology: SAMM

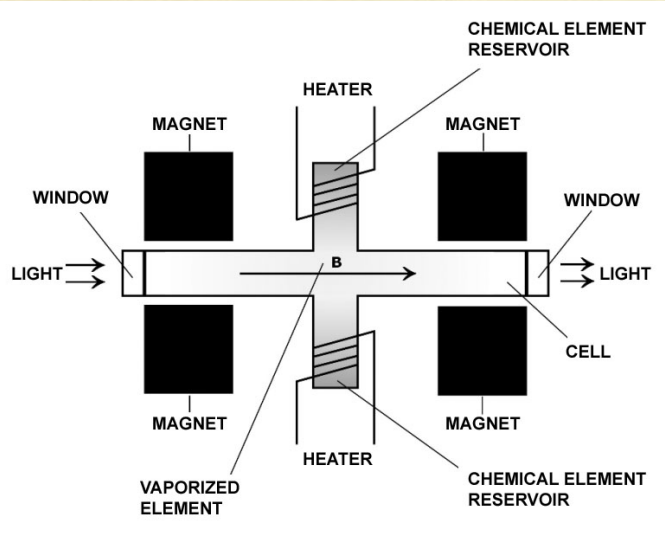
MOF technology →

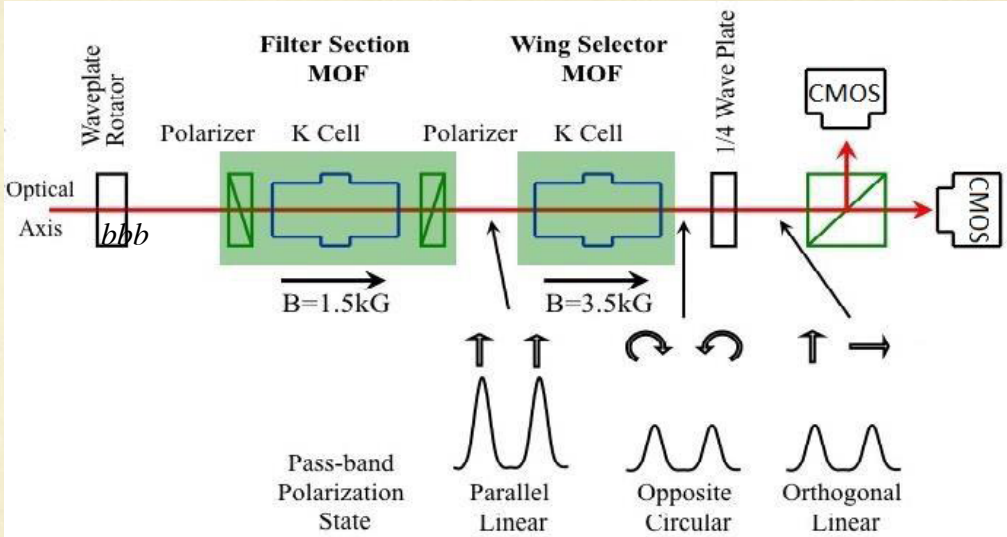
- Dopplergrams
  Magnetograms
- Fixed wavelength but high stability and sensitivity

Synoptic →

- 2 observation lines at 2 altitudes in the solar atmosphere:
  Na D2 (600-700 km)
  K I (300-400 km)
  Future: Ca I (1000 km), He 1083
- Full-disk or near-full-disk monitoring of solar activity

Synoptic solar telescope based on Magneto Optical Filter (MOF) technologies: SAMM





$$B_{LOS} \propto (R^{+}-B^{+})/(R^{+}+B^{+})-(R^{-}-B^{-})/(R^{-}+B^{-})$$

Cacciani et al. 1990

$$v_{LOS} \propto (R^{+}-B^{+})/(R^{+}+B^{+})+(R^{-}-B^{-})/(R^{-}+B^{-})$$

Heritage: Jeffries et al, **MOTH I**, **MOTH II**

SAMM: Putting the numbers into perspective...

Magnetograms

- MOF ground-based telescope
  - 2-5 G sensitivity
- HMI on SDO satellite
  - 8-15 G official sensitivity

Dopplegrams

- MOF ground-based telescope
  - Worst case: 1 m/s sensitivity
- Scientific requirements
  - 10 m/s sensitivity

Atmospheric seeing → Optical design provides for future implementation of Active/Adaptive Optics

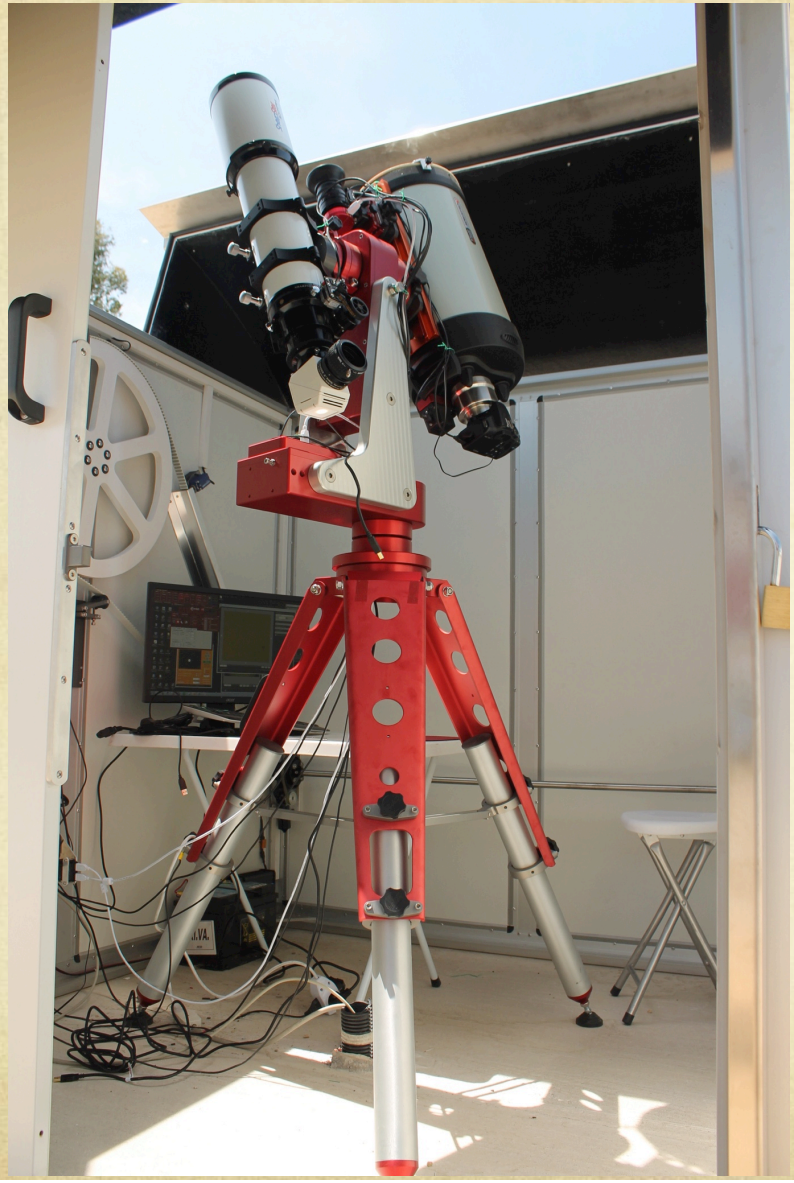
Image and data quality / atmospheric seeing →

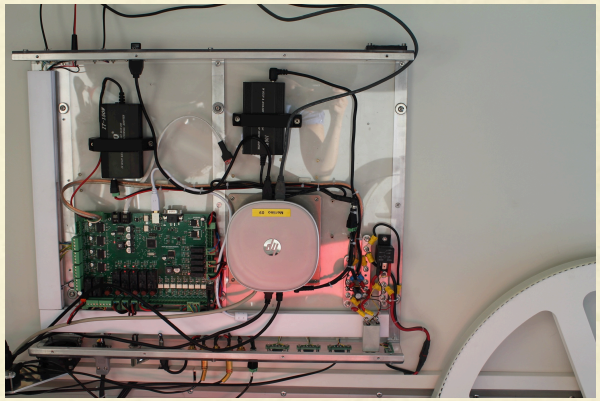
- High quality cameras.
- Collaboration with INAF and Andor Zyla cameras
- High frame-rate, extremely low electron noise, 1 ms exposures, possibility of "freezing" atmospheric seeing

Protected, simple, remotely operated, compact setup → Development of an extra-large version of the Merlino Portable Remote Observatory

SAMM: Realisation

Hungarian Solar Physics Foundation
www.hspf.eu





SAMM: Realisation – Gyula SO

Hungarian Solar Physics Foundation
www.hspf.eu

SAMM: Realisation – Gyula SO

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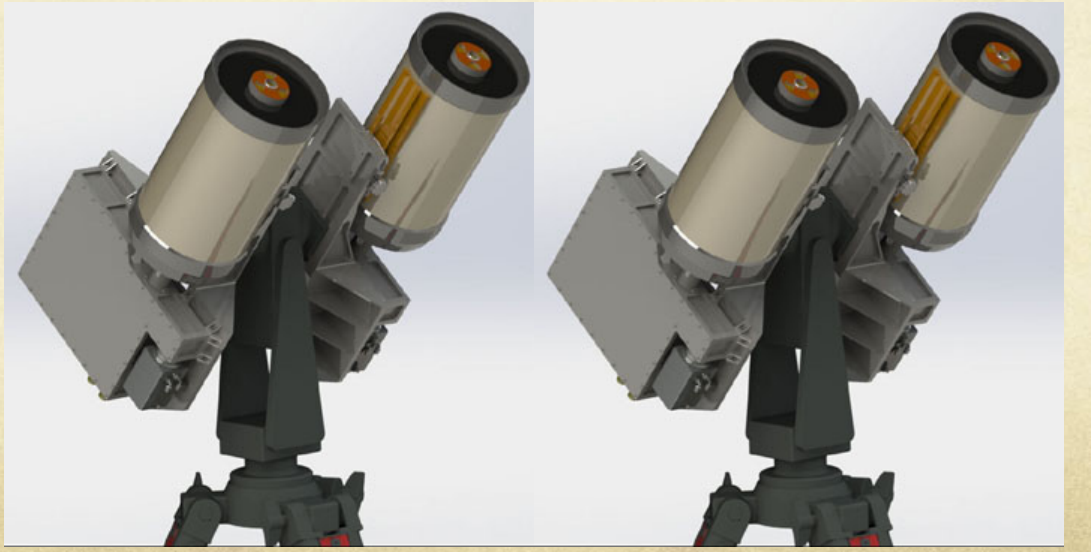
Near Future

- **SAMM+:**

4x observation lines at 4 altitudes in the solar atmosphere:
Na D2 (589 nm, 600-700 km)
K I (770 nm, 300-400 km)
Ca I (422 nm, 1000 km)
He 1083 nm (1900 km)



Future

- SAMNet:

Thank you for your attention!