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

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[2]New Jersey Institute of Technology
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[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

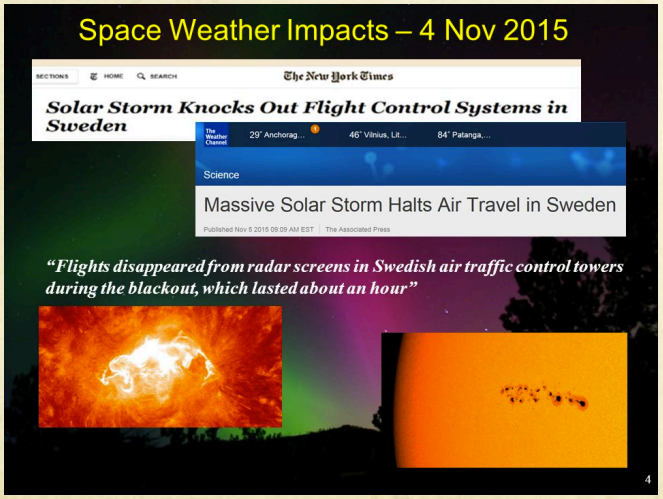
The interaction of solar activity with Earth's upper atmosphere occurs through a complex series of events - Space Weather

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)

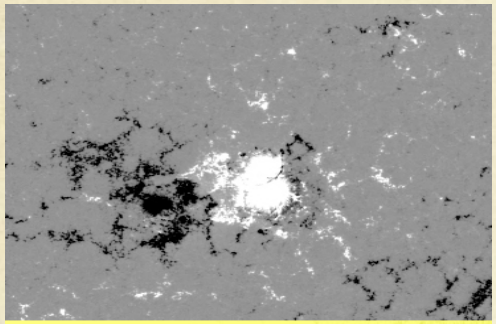


A major impact on life and modern technology-based society in Space or on Earth.

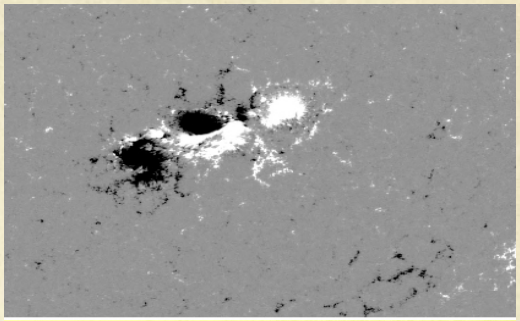
The Science: Flares/CME & photospheric field configuration

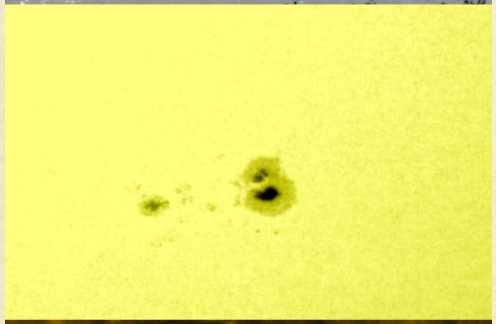
Bipolar: AR 11734

Delta-type: AR11158

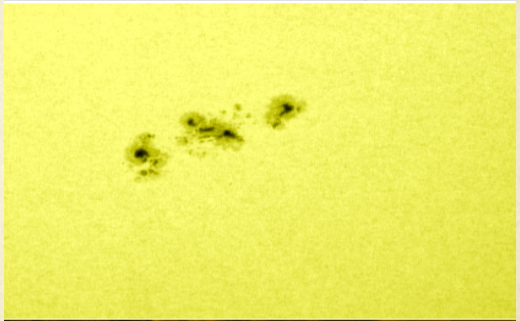


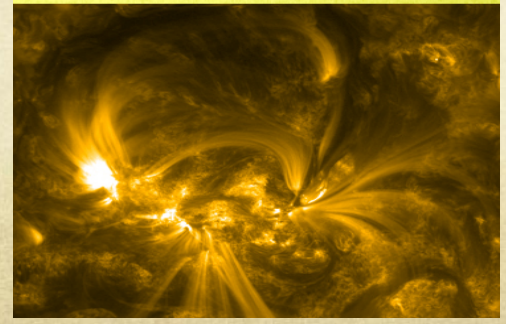
Magnetogram



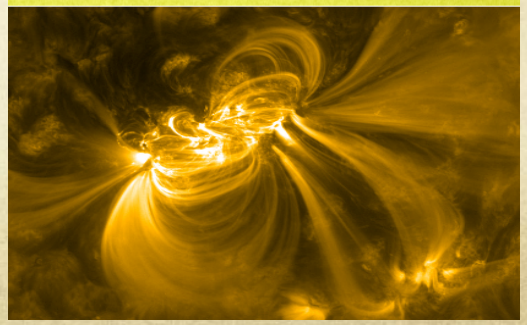


Photosphere White light continuum



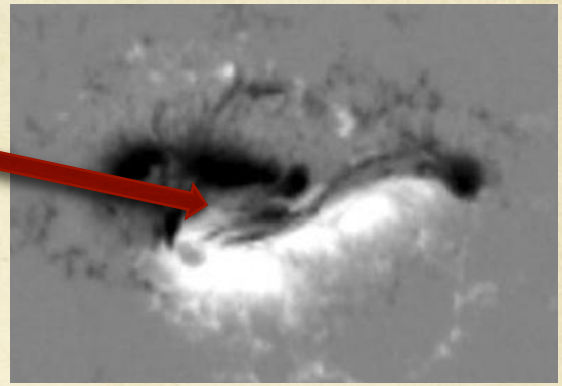


Upper Transition Region



The Science: Introduction

Inversion line of high magnetic gradient
(Schrijver, ApJ, 655, L117, 2007)

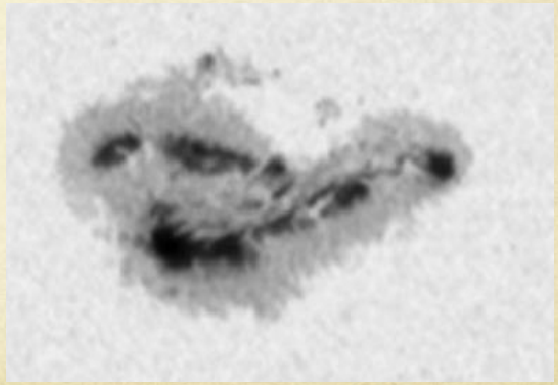


Present method:

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:

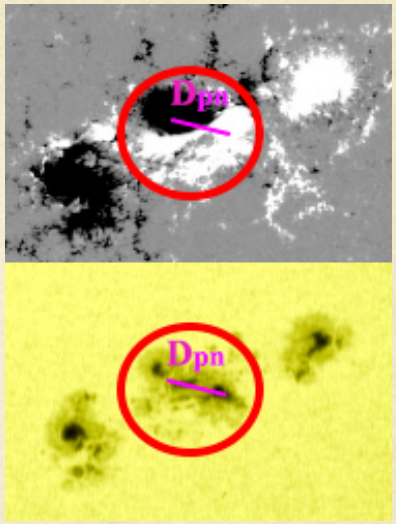
SOHO/MDI
SDO/HMI
Magnetic field extrapolation
Artificial data by Pencil MHD Code

WG_M method

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

Positive Magnetic flux — Negative Magnetic flux

$$WG_M = \left| \frac{\sum_i B_{p,i} \cdot A_{p,i} - \sum_j B_{n,j} \cdot A_{n,j}}{D_{pn}} \right|$$

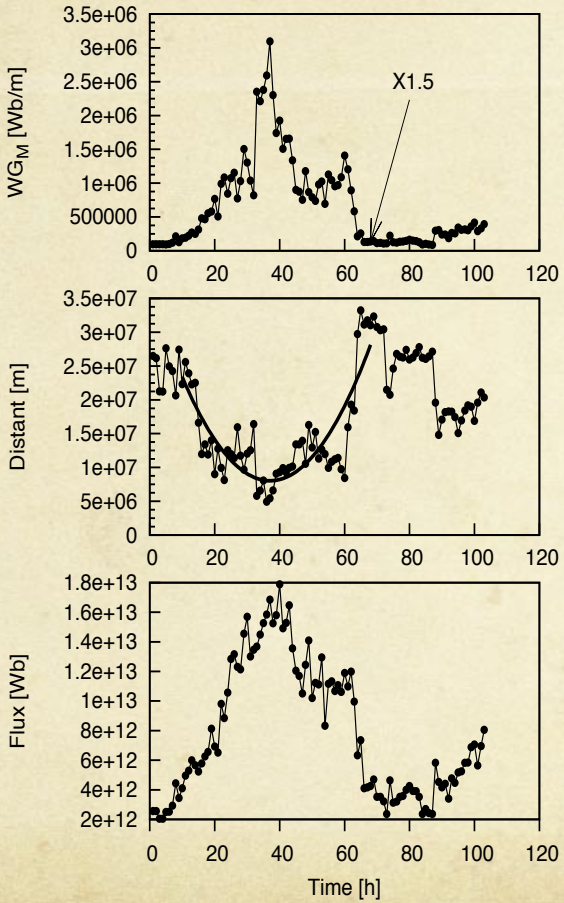


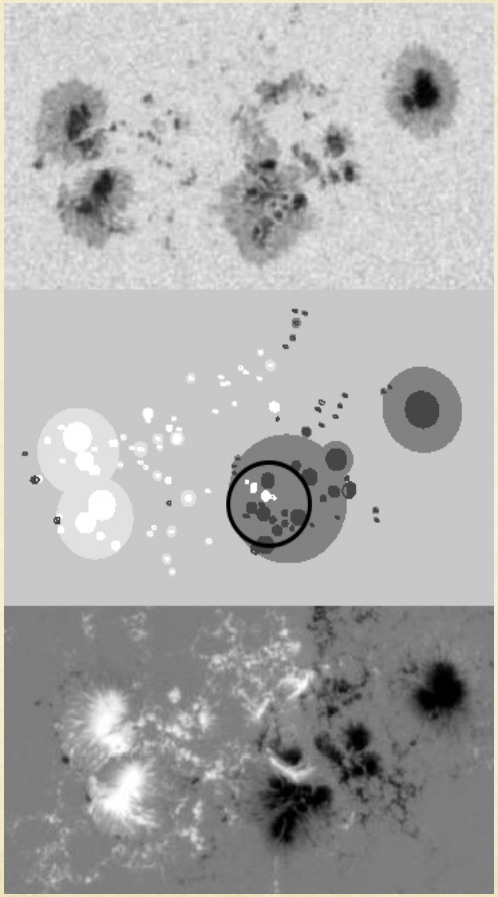
AR11158

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

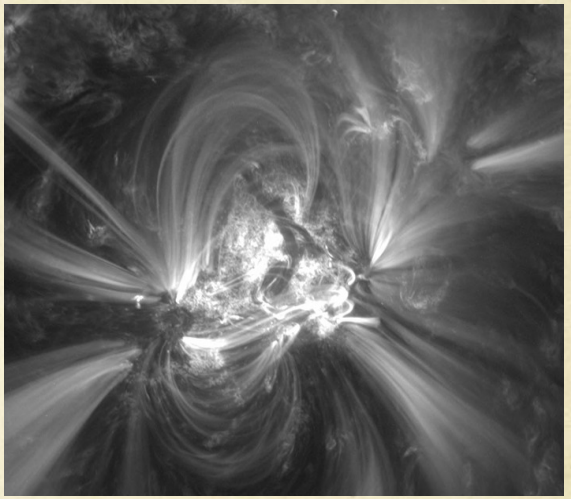
Korsos et al. ApJ, 802, L21, 2015

NOAA 11166



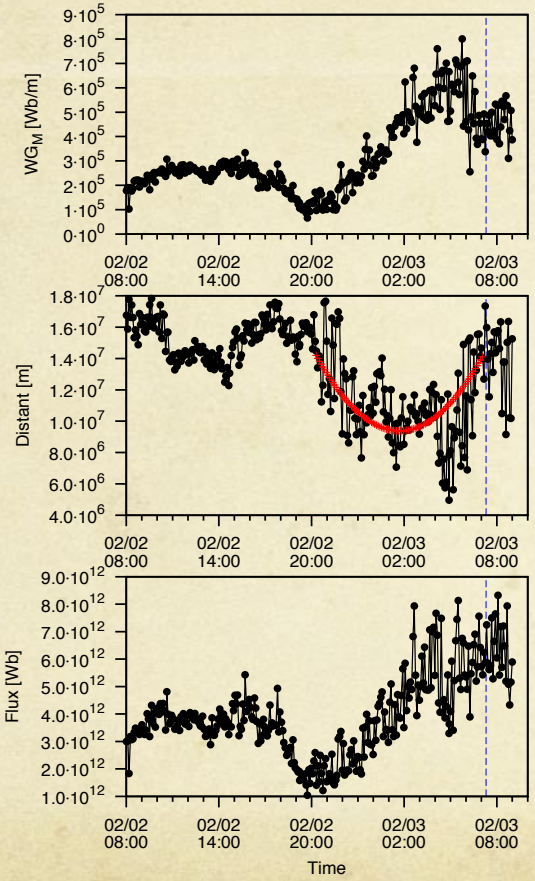


Large flare



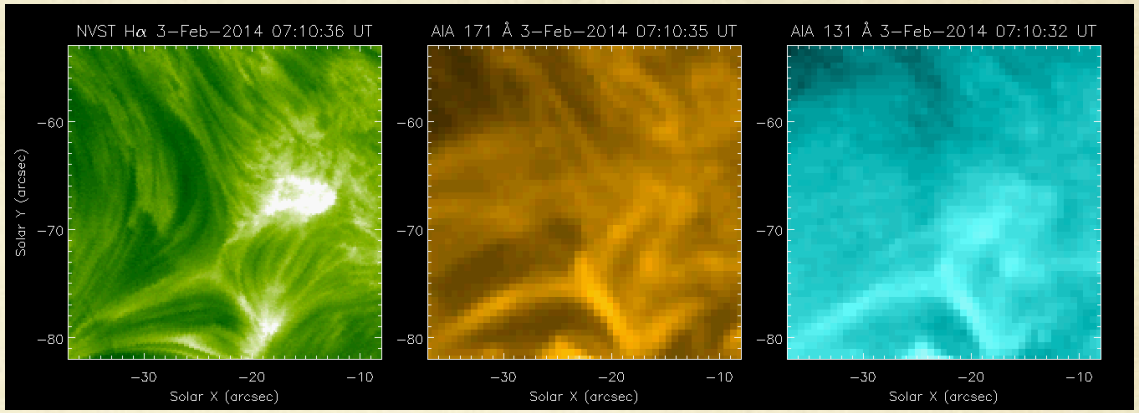
Korsos et al. ApJ, 802, L21, 2015

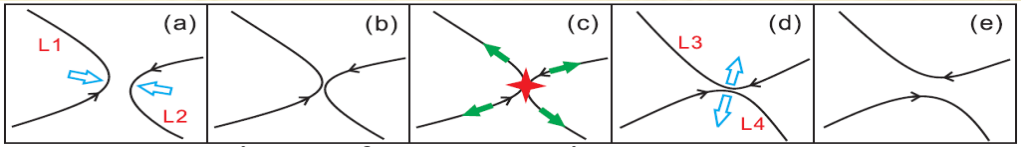
Tiny flare



Courtesy: **Shu-Hong Yang**

NVST H-alpha images, AIA 171 A and AIA 131 A images



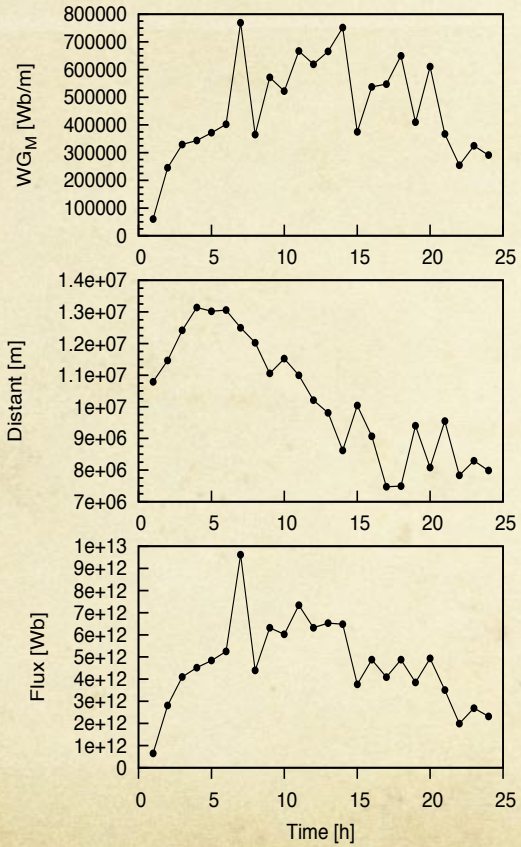


Drawings of reconnection process based on the NVST observations

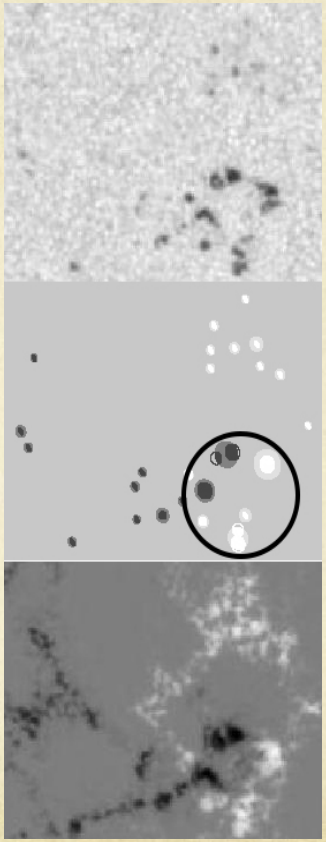
Magnetic reconnection between small-scale loops in the chromosphere

(Yang, Zhang & Xiang, 2015, ApJL, 798, L11)

NOAA 11995

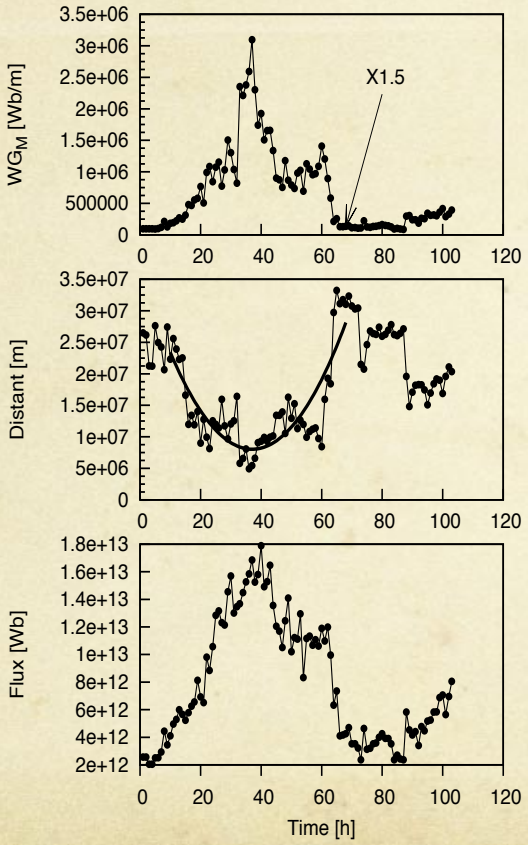


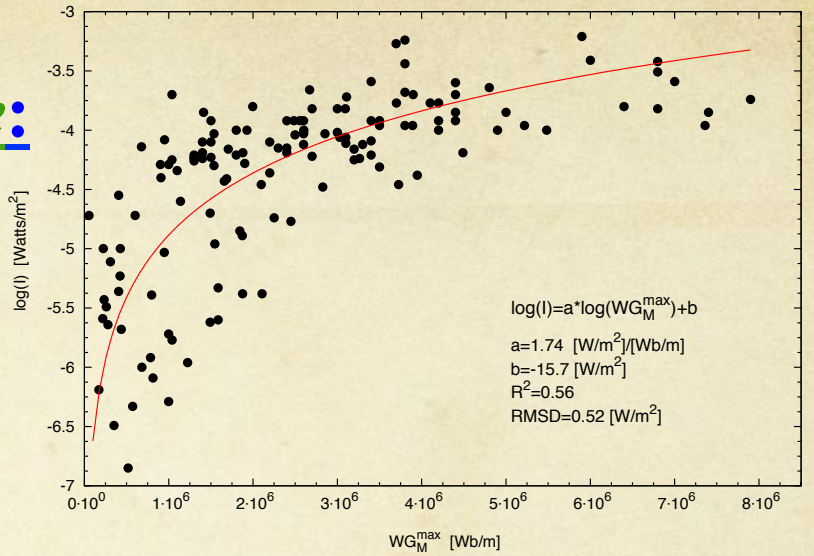
No Flare!

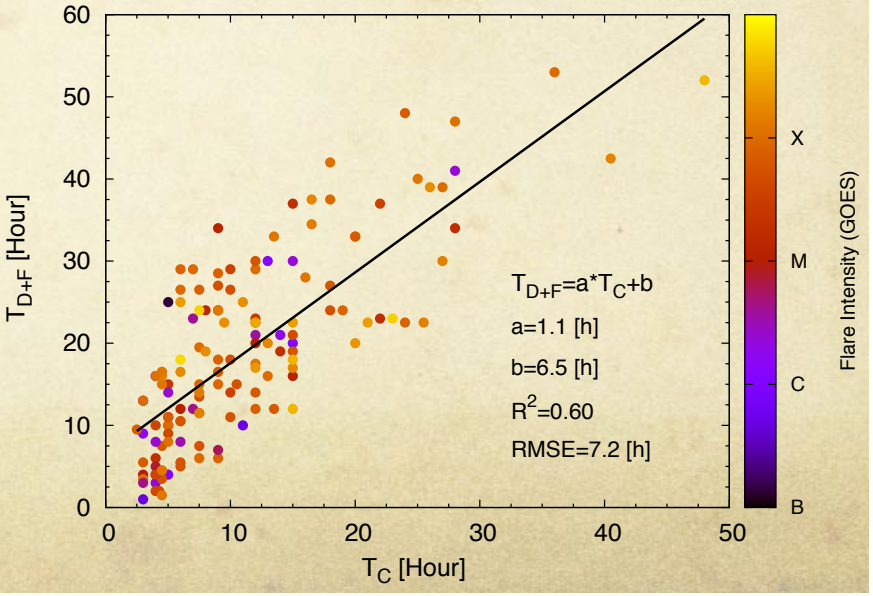


Korsos et al. ApJ, 802, L21, 2015

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

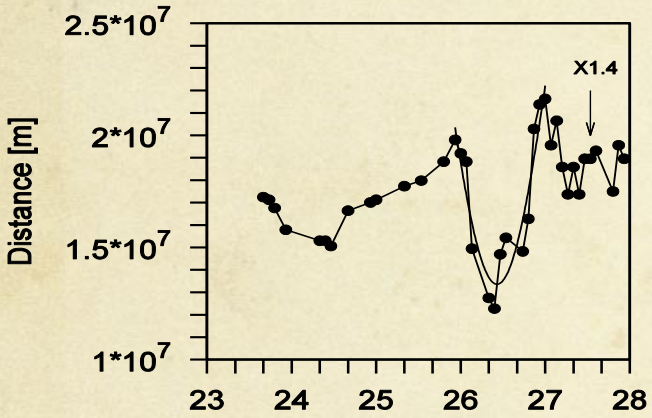


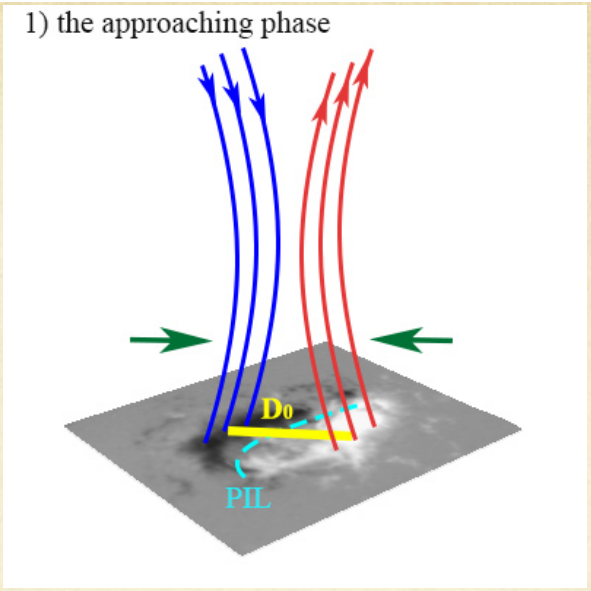


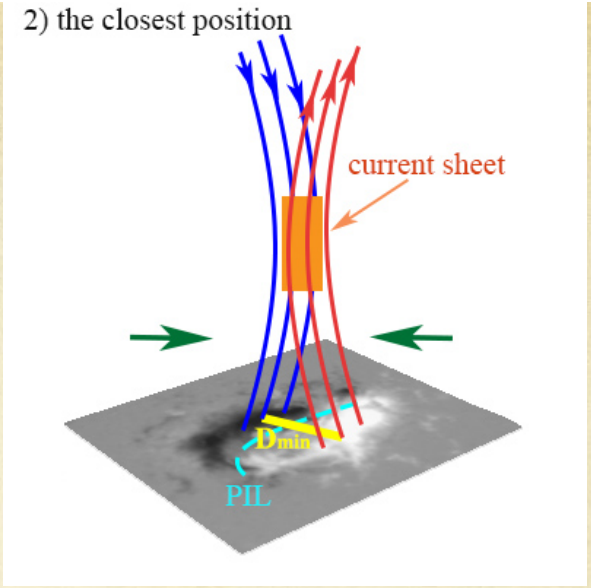


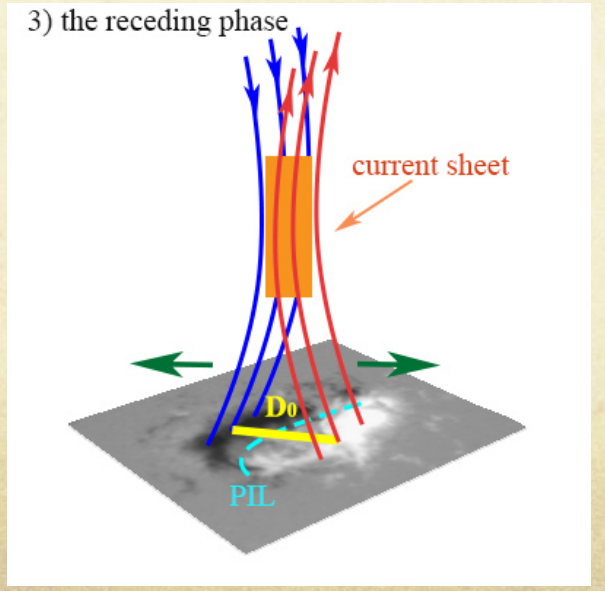
Statistics of **130 ARs** (within ±70º CMD)

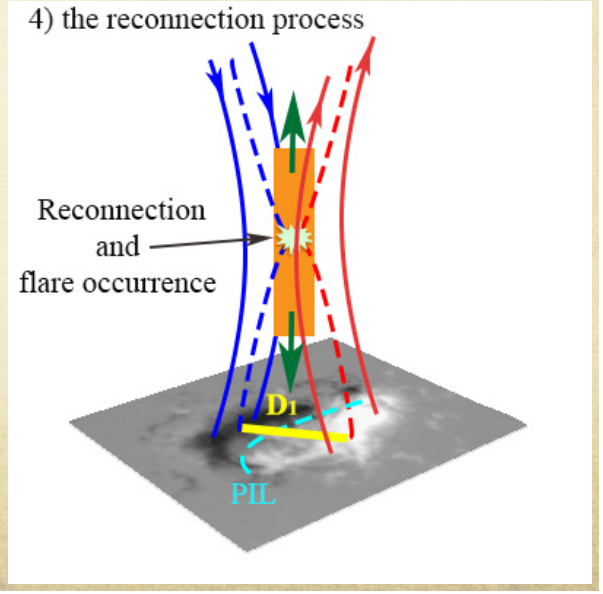
Our observational experience:







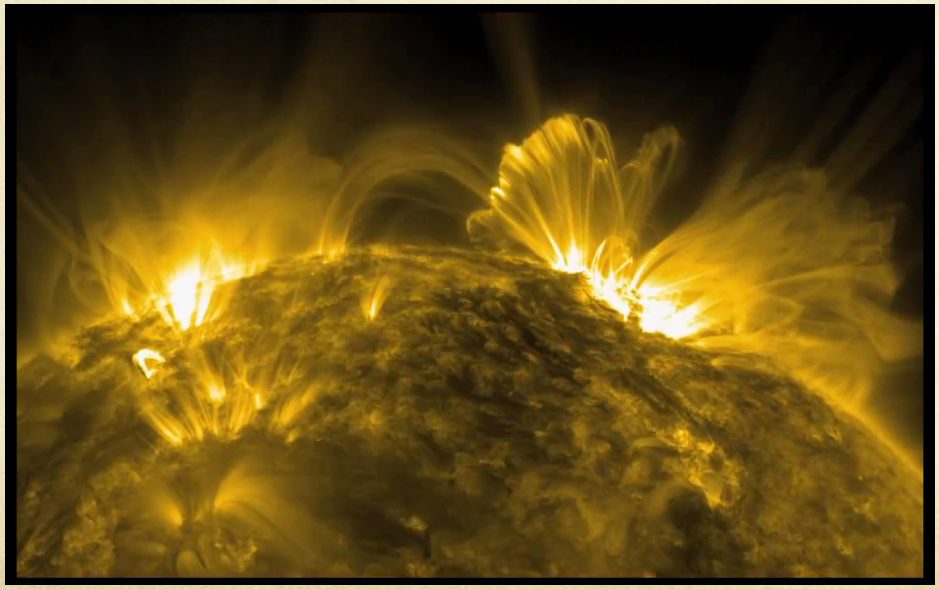


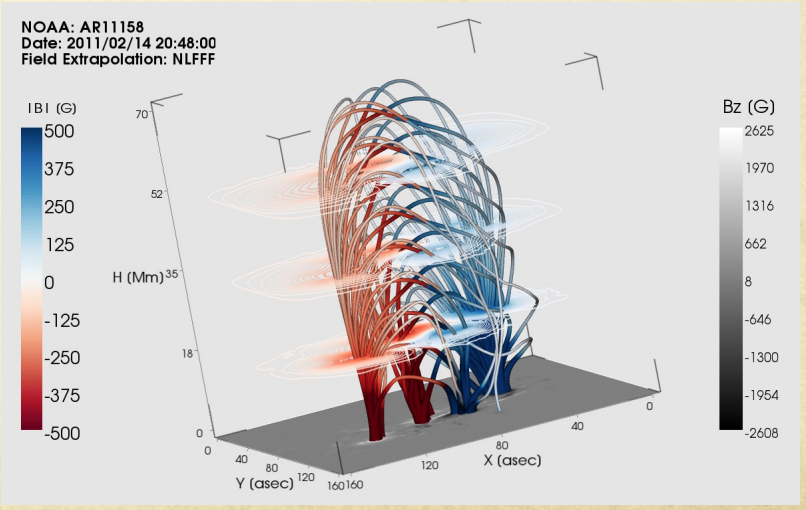


WG_M method in the lower solar atmosphere

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

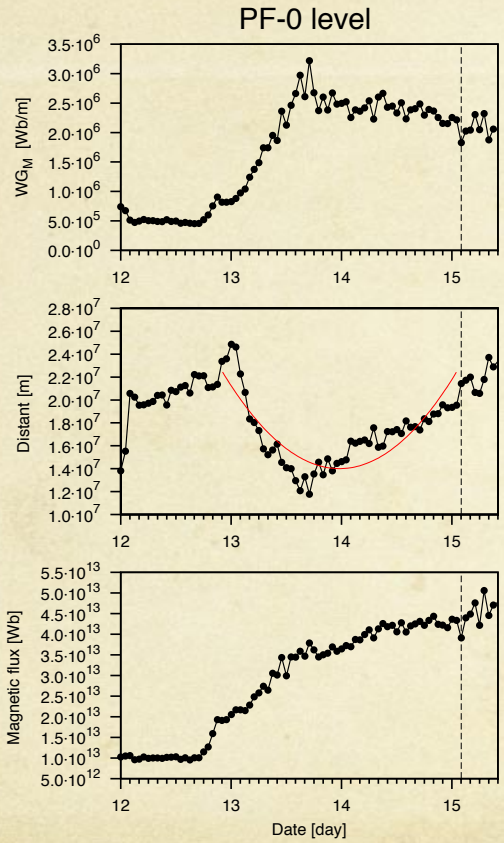
We develop a complex 3D tool that allows us to predict flare onsets based on magnetic field topology in the lower solar atmosphere.

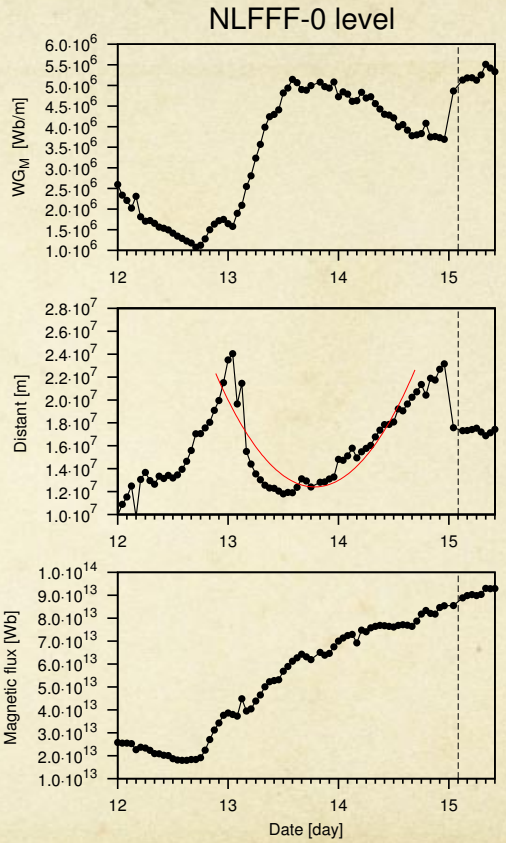




AR 11158

0 km level



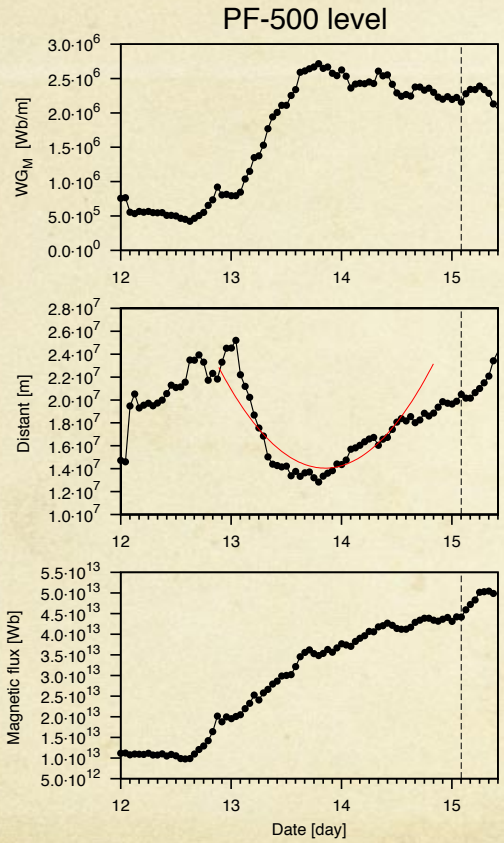


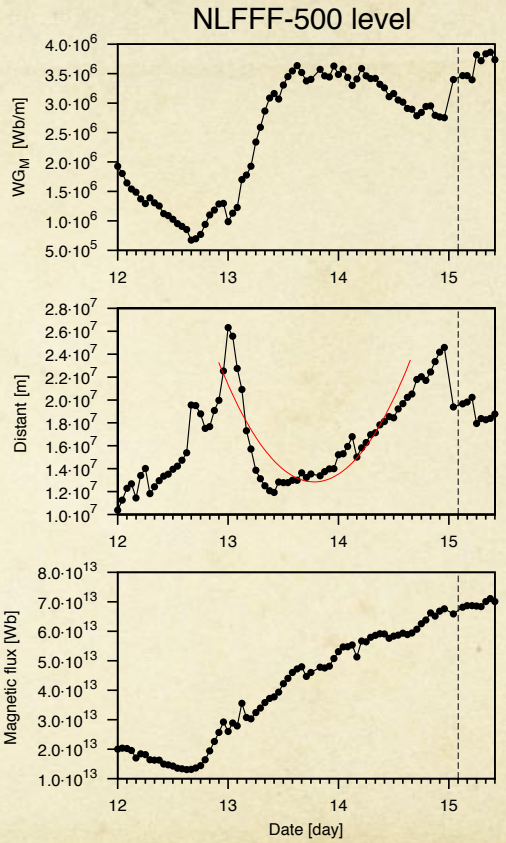
Potential field extrapolation

Nonlinear force-free extrapolation

AR 11158

500 km level



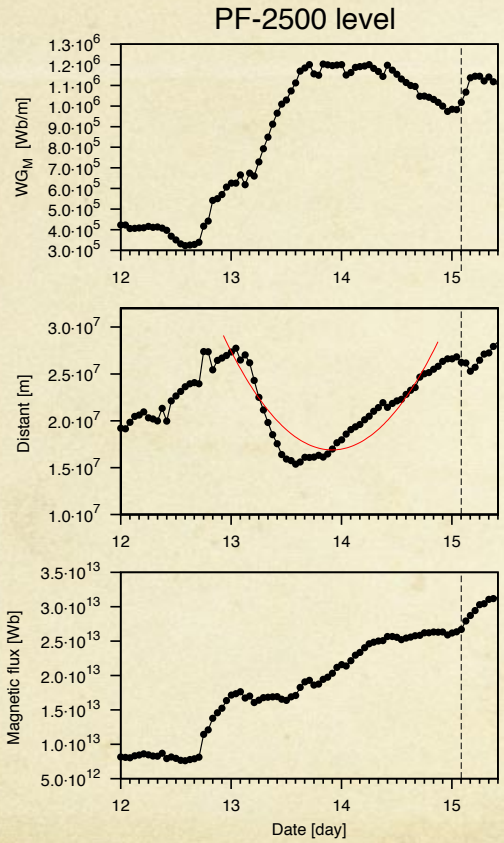


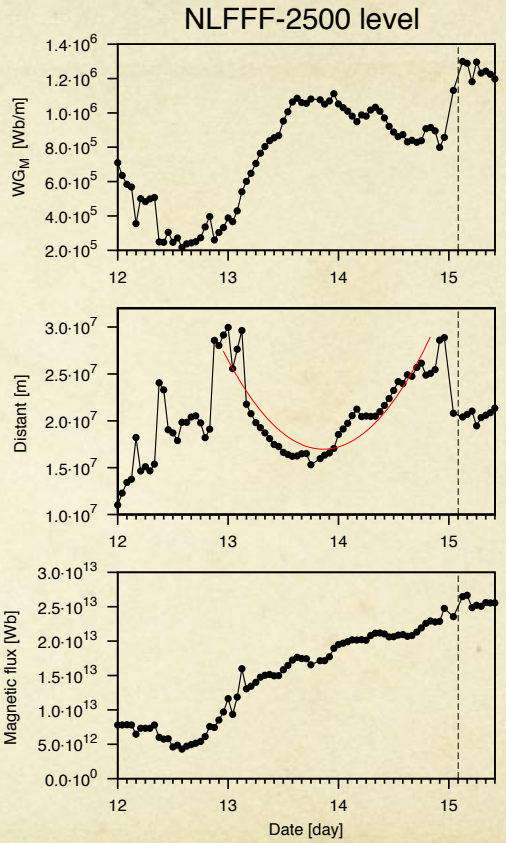
Potential field extrapolation

Nonlinear force-free extrapolation

AR 11158

2500 km level

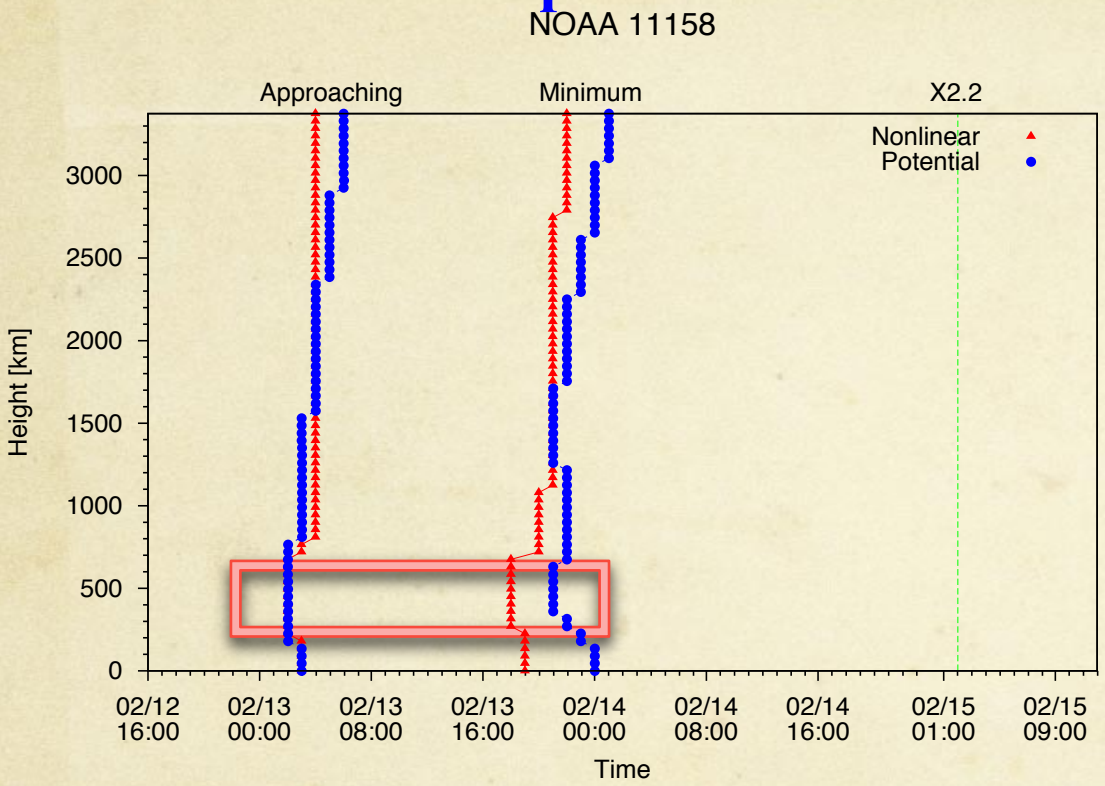


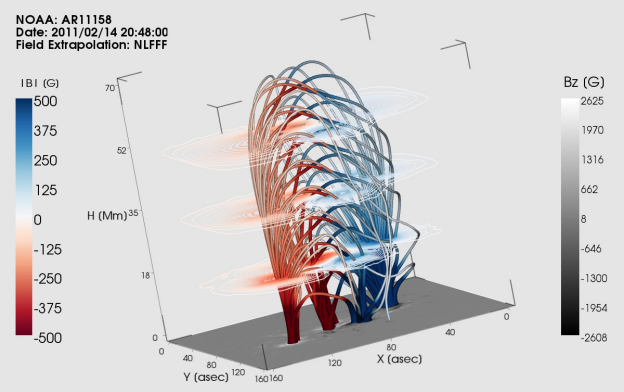


Potential field extrapolation

Nonlinear force-free extrapolation

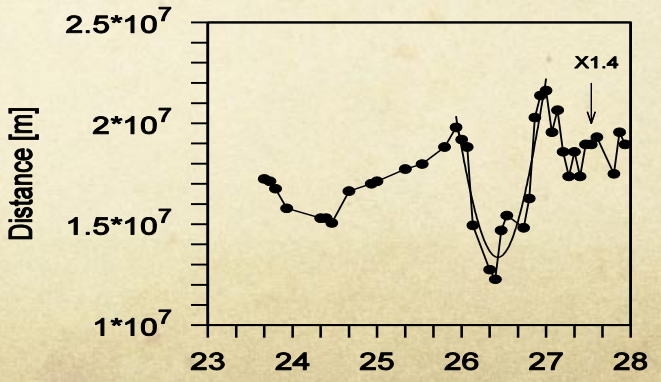
The actual starting times of approaching, minimum point and flare onset as function of height





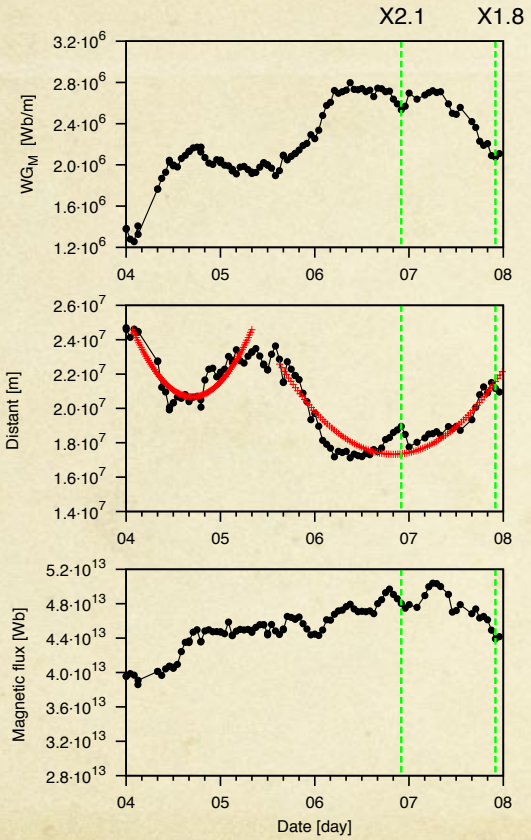
y=0 is the photosphere

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

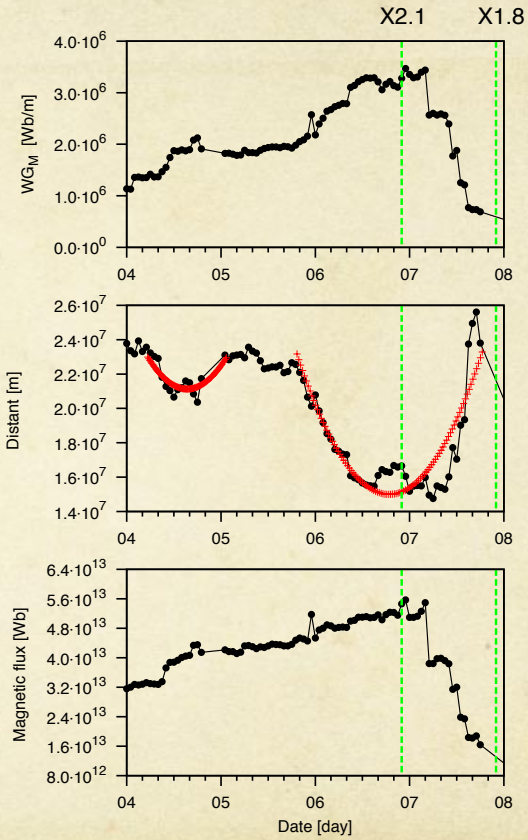


AR 11283

500 km level

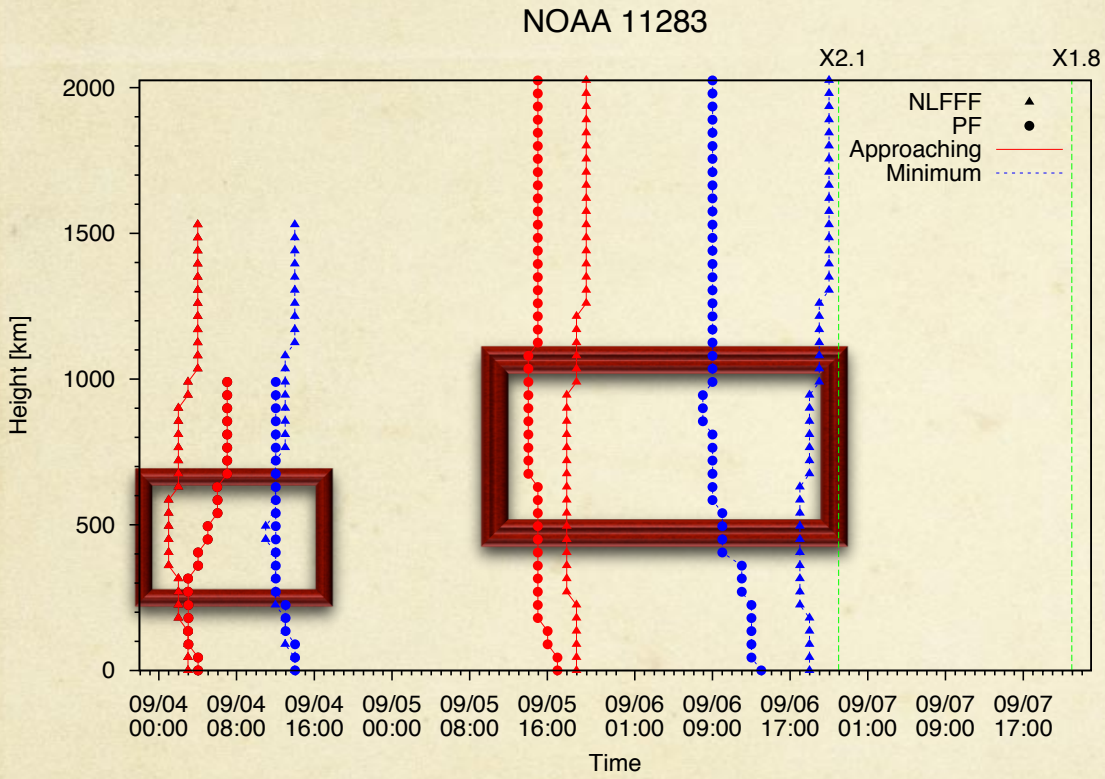


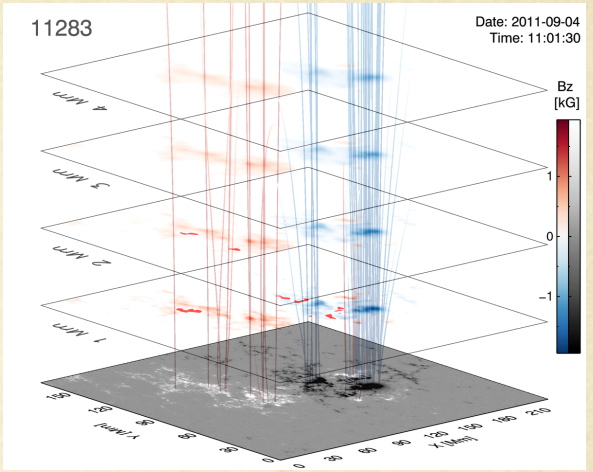
Potential field extrapolation



Nonlinear force-free extrapolation

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



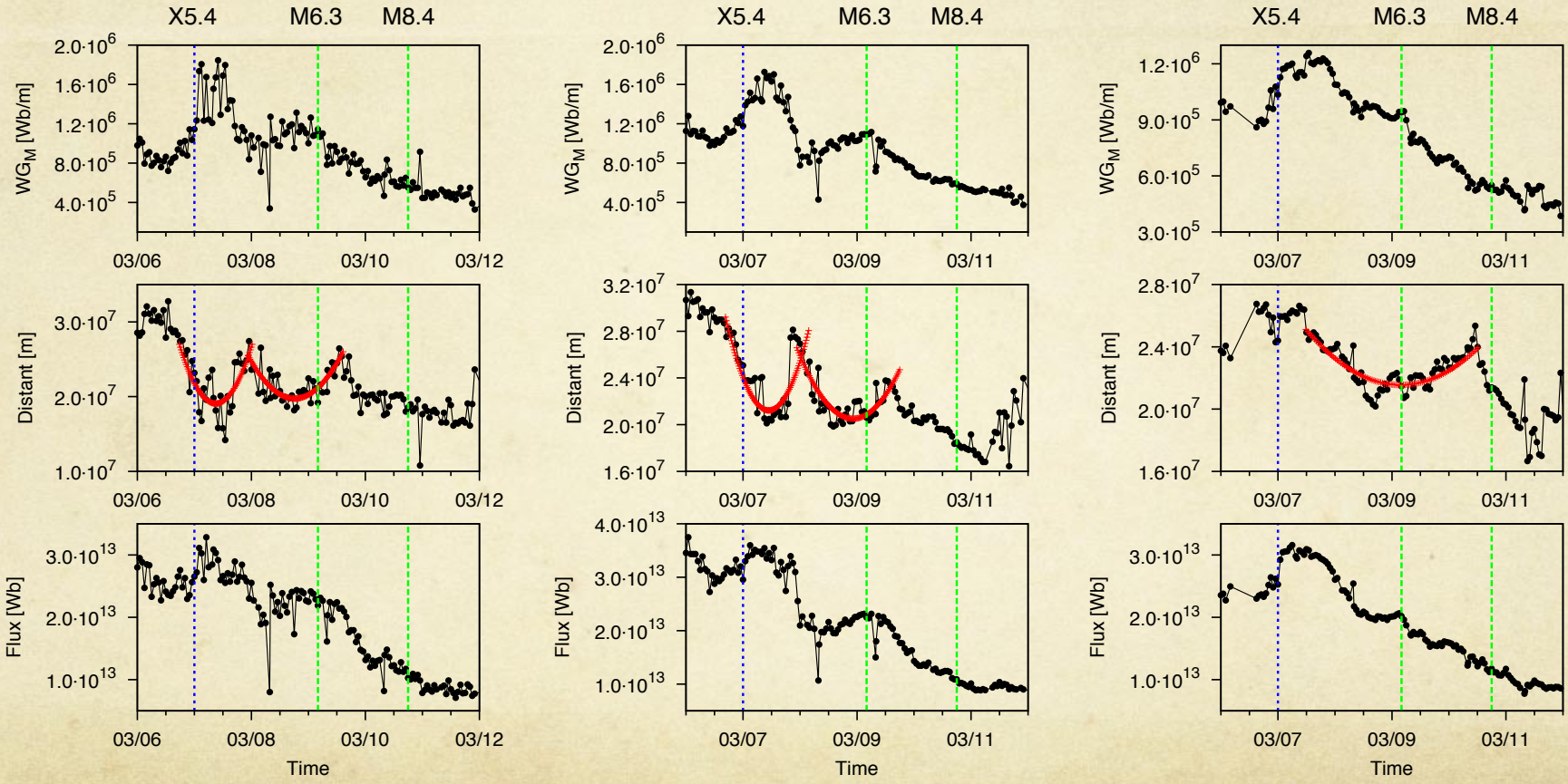


y=0 is the photosphere

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

AR 11429

Potential force-free extrapolation

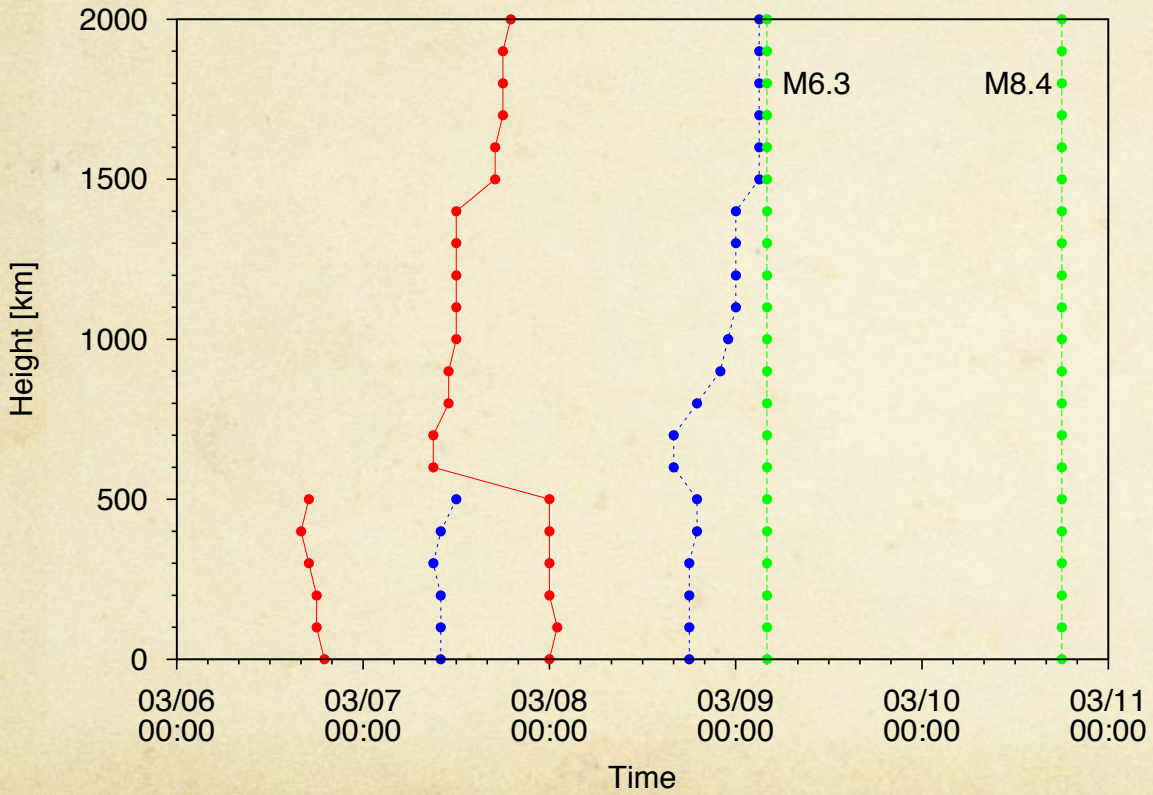


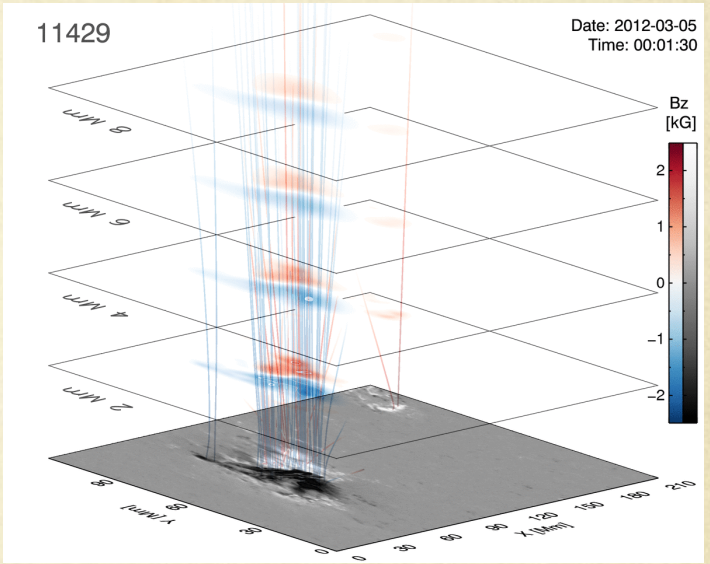
0 km level

500 km level

1000 km level

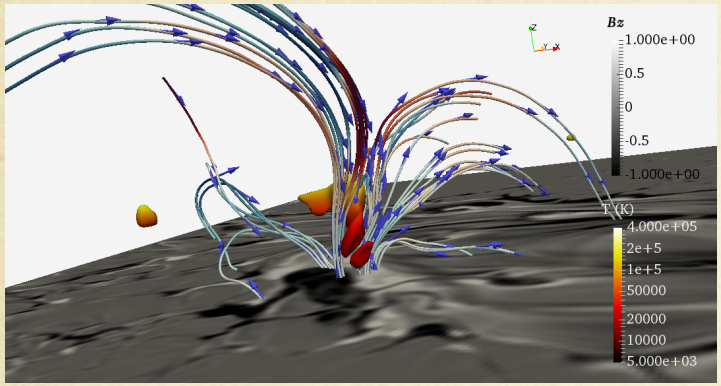
Starting times of approaching, minimum point and flare onset as function of height

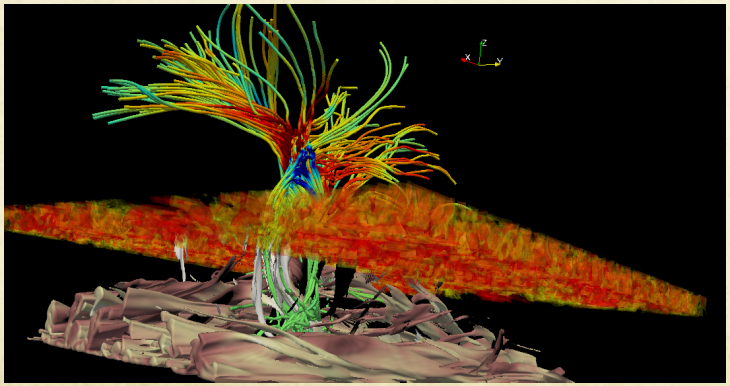




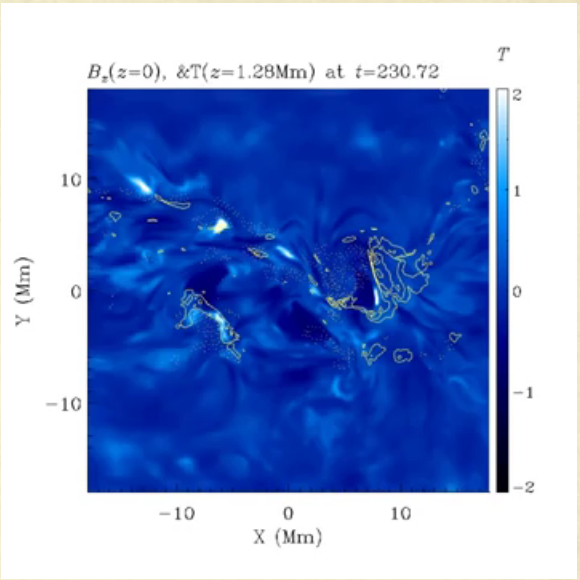
y=0 is the photosphere

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





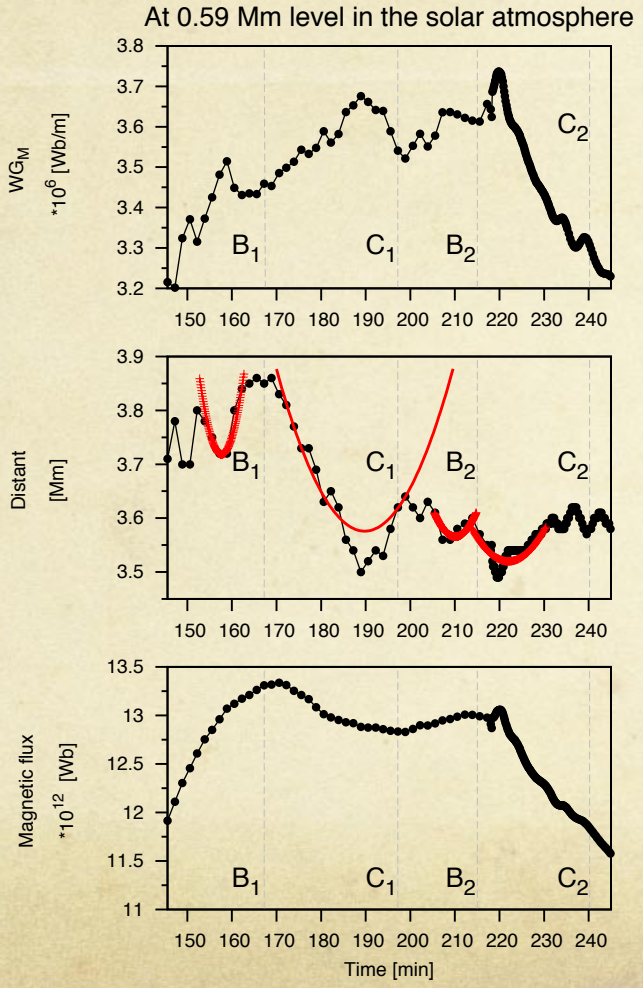
Snapshots of simulation

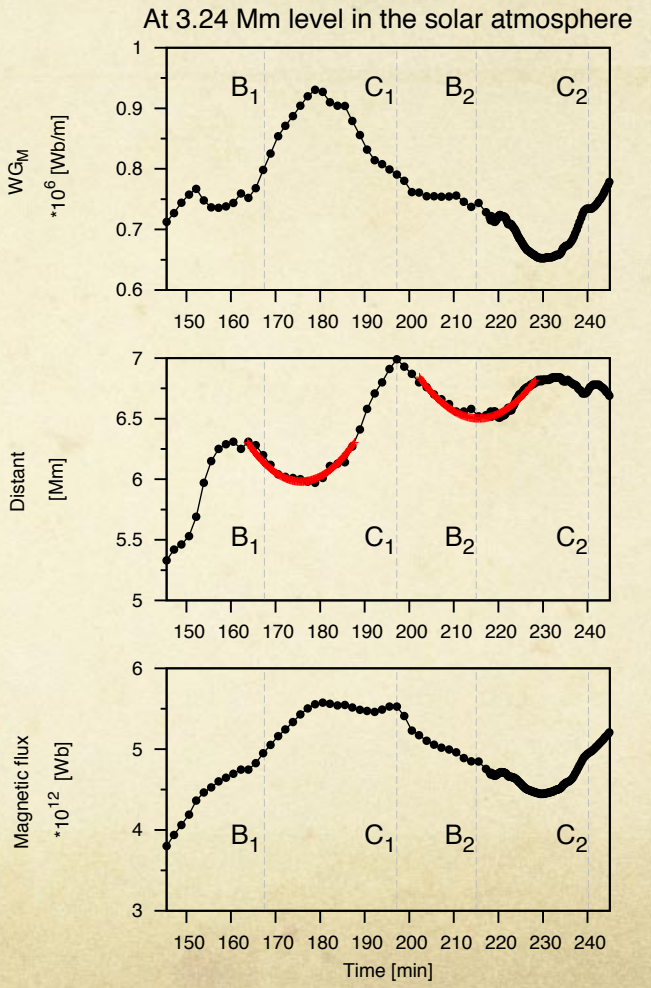


Local temperature map

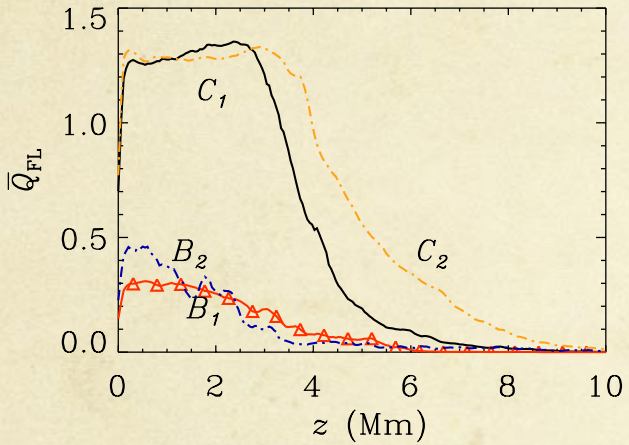
Chatterjee et al. Physical Rev. L, 116, 10, 1011012016.

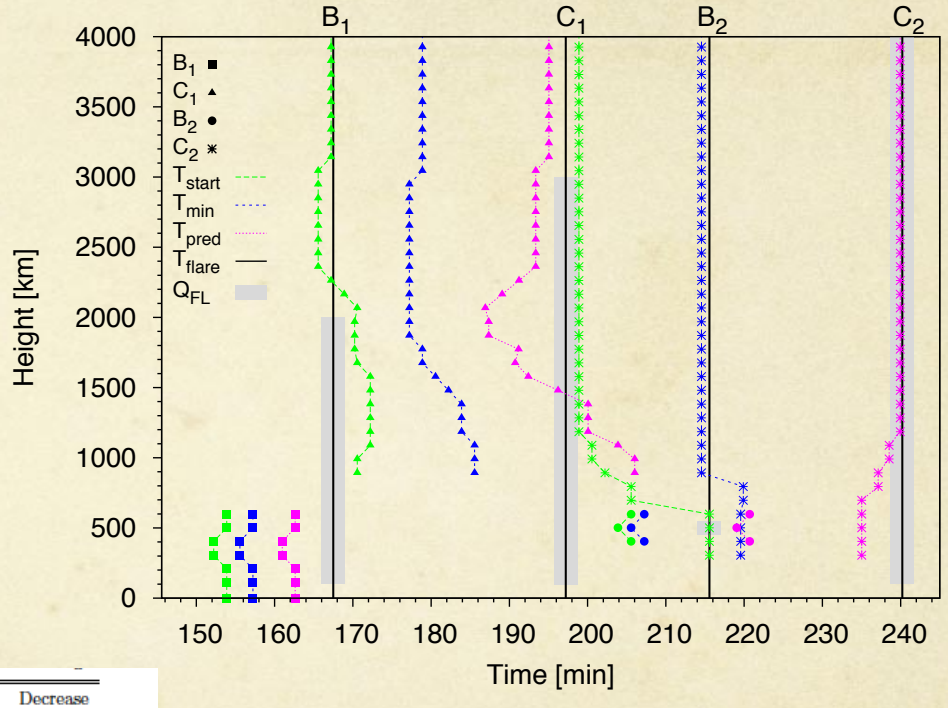
The *artificial AR* by the Pencil MHD Code





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

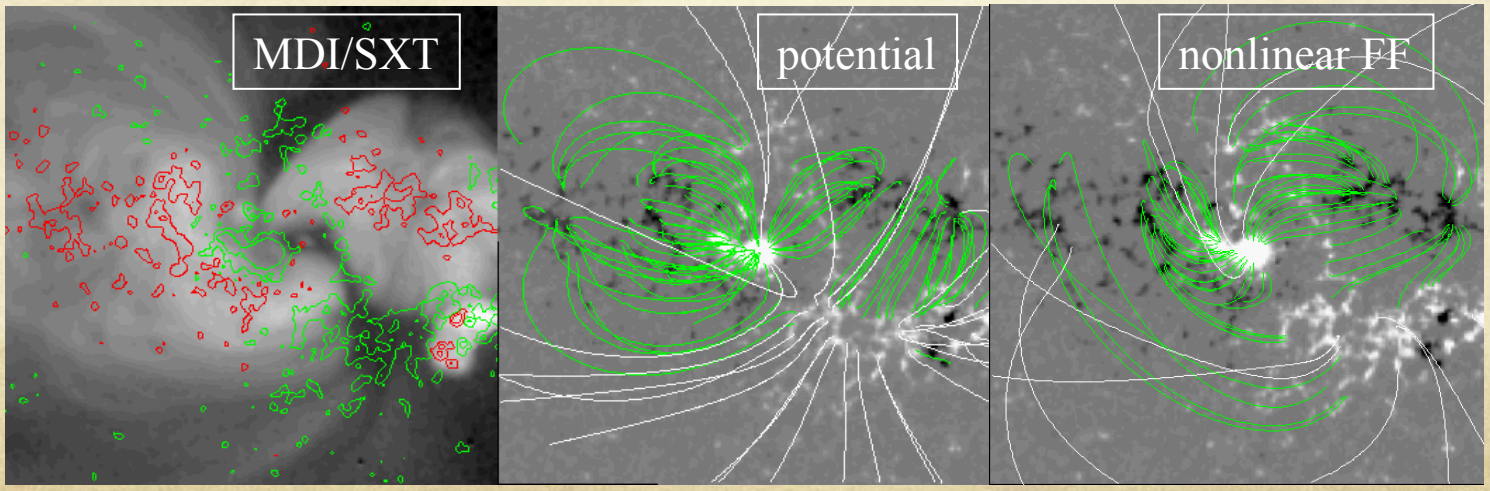
Tracking of the following quantities may be promising for flare forecast.

- 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

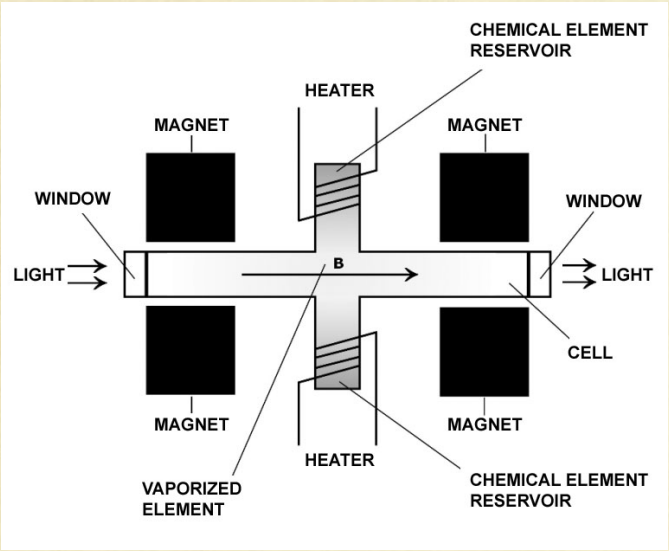
MOF technology →

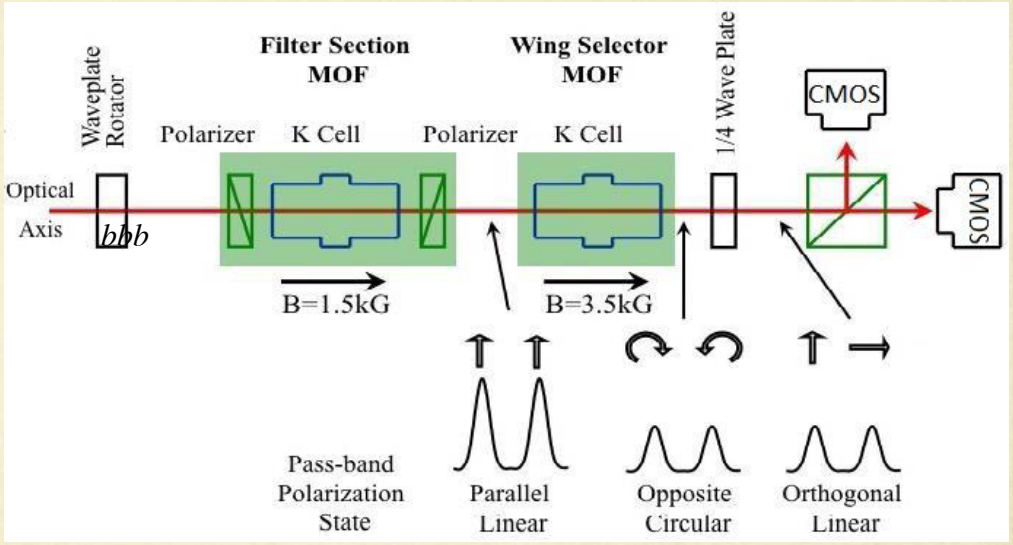
- Dopplergrams
  Magnetograms
- Fixed wavelength but high stability and sensitivity

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

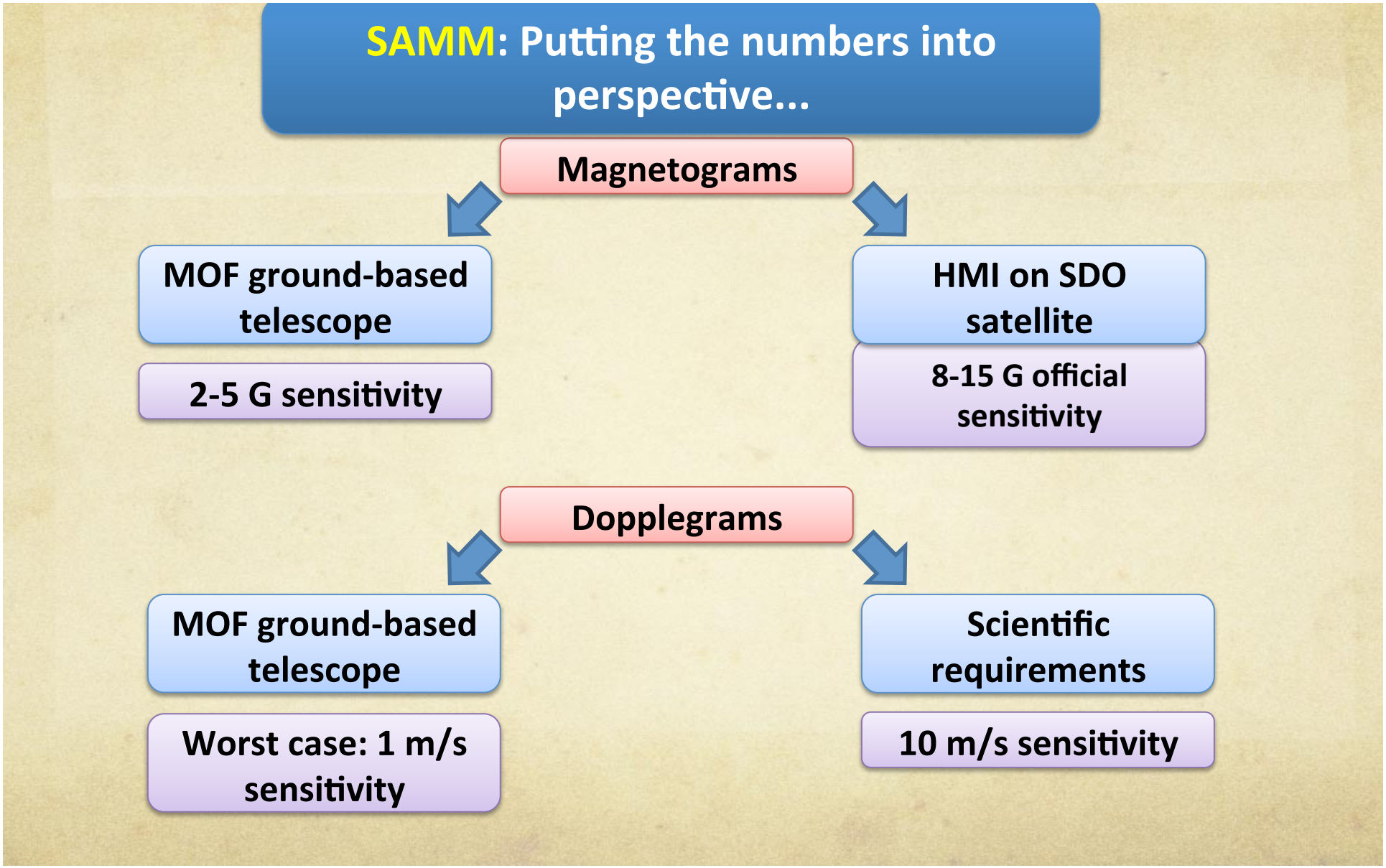




$$B_{LOS} \propto (R^{+}-B^{+})/(R^{+}+B^{+})-(R^{-}-B^{-})/(R^{-}+B^{-})$$ **Cacciani** et al. 1990

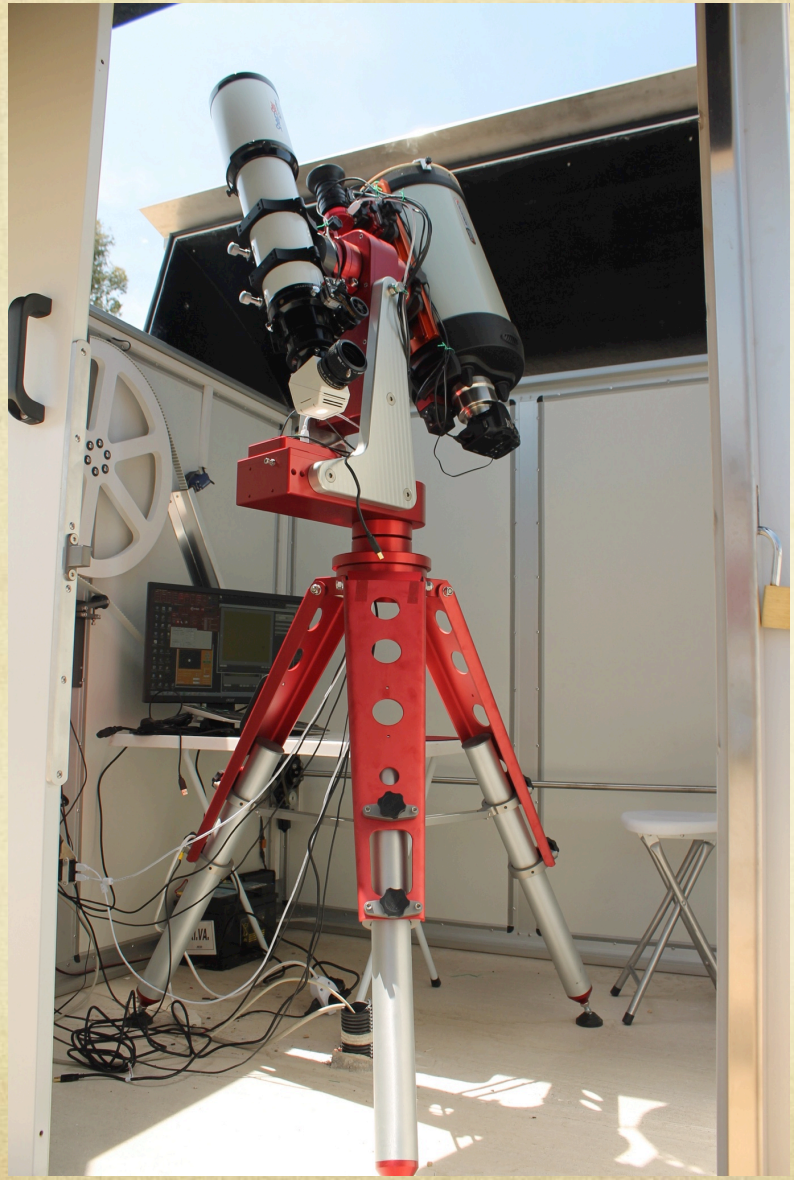
$$v_{LOS} \propto (R^{+}-B^{+})/(R^{+}+B^{+})+(R^{-}-B^{-})/(R^{-}+B^{-})$$

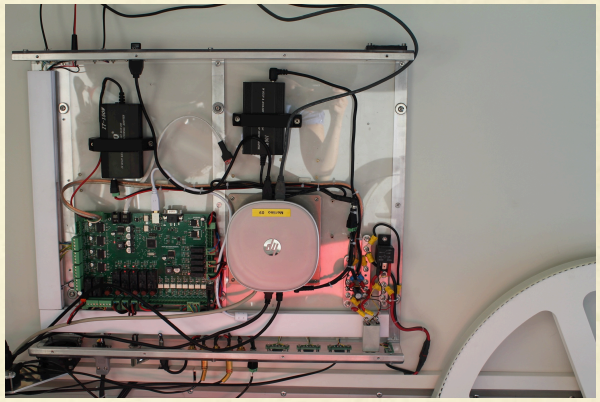
Heritage: Jeffries et al, **MOTH I**, **MOTH II**


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

SAMM: Realisation

Hungarian Solar Physics Foundation
www.hspf.eu





SAMM: Realisation – Gyula SO

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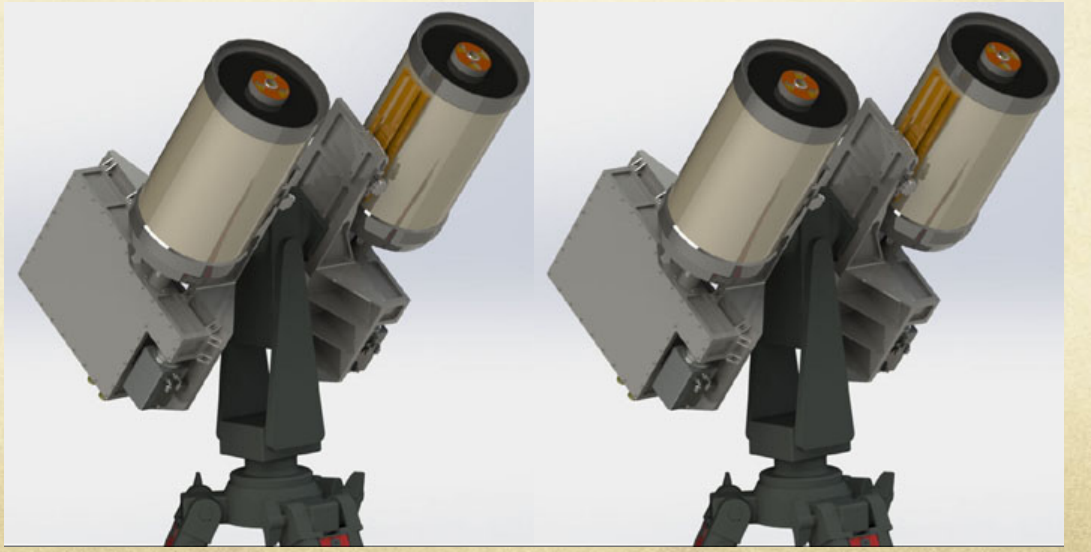
Near Future

- **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!