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Towards a MHD instability tool for space weather forecasting

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AXA Research Fund

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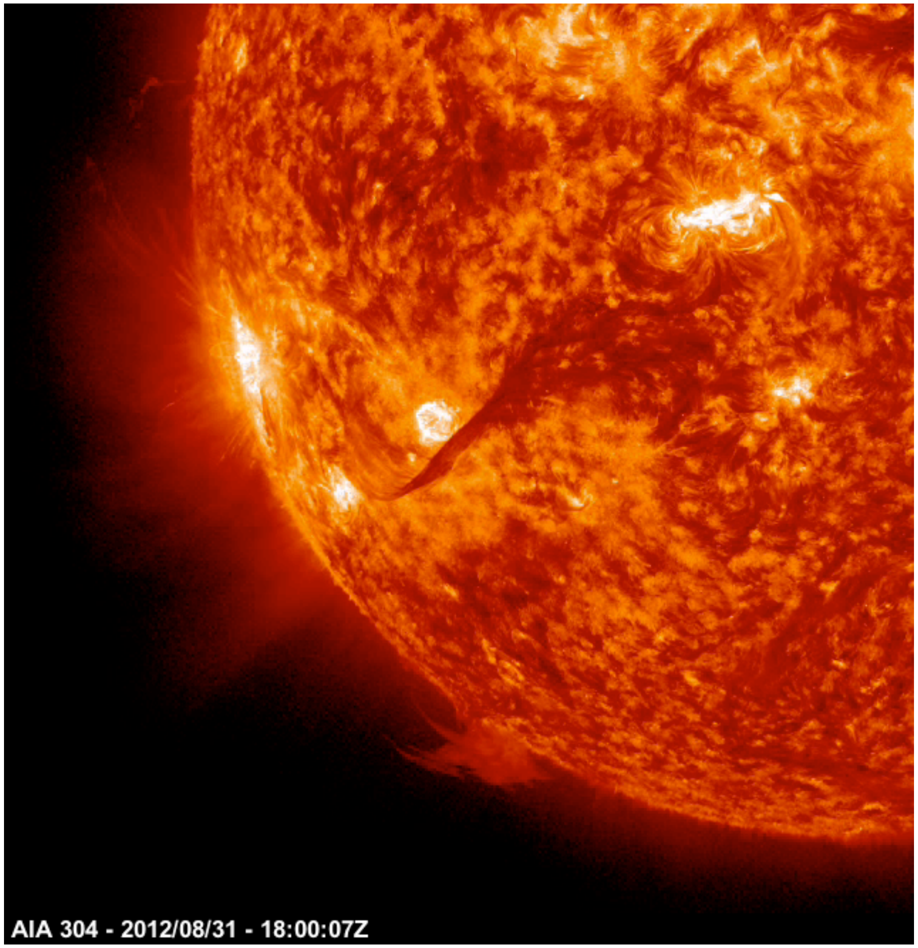
Introduction



Quite often eruptive filaments display a two phases evolution:

1. Initial slow rise/evolution

2. Fast eruption

Rupture of equilibrium

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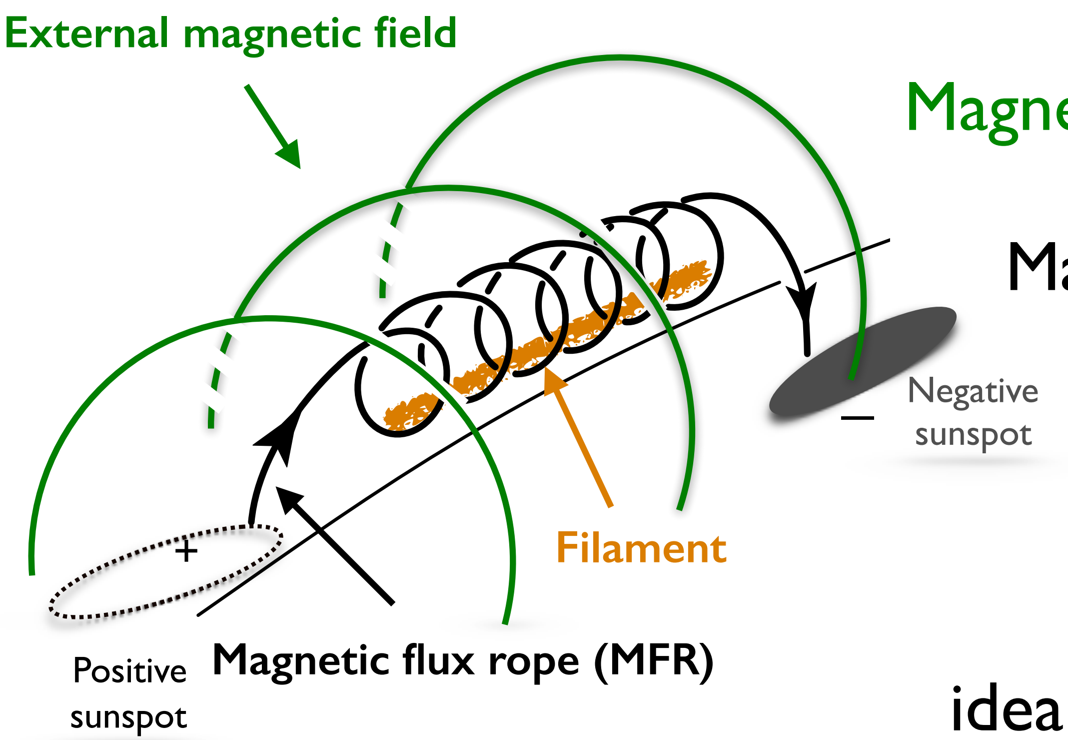


Rupture of equilibrium

Magnetic tension of the external field

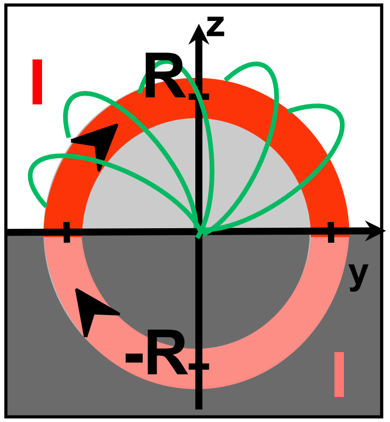
VS

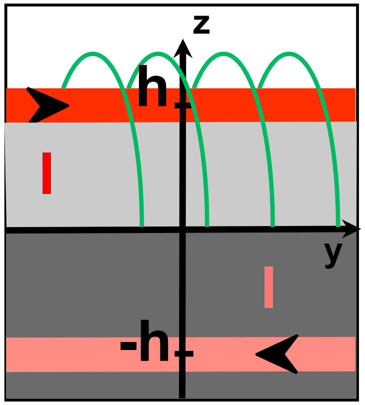
Magnetic pressure of the MFR

resistive instability

ideal-MHD instability

Introduction





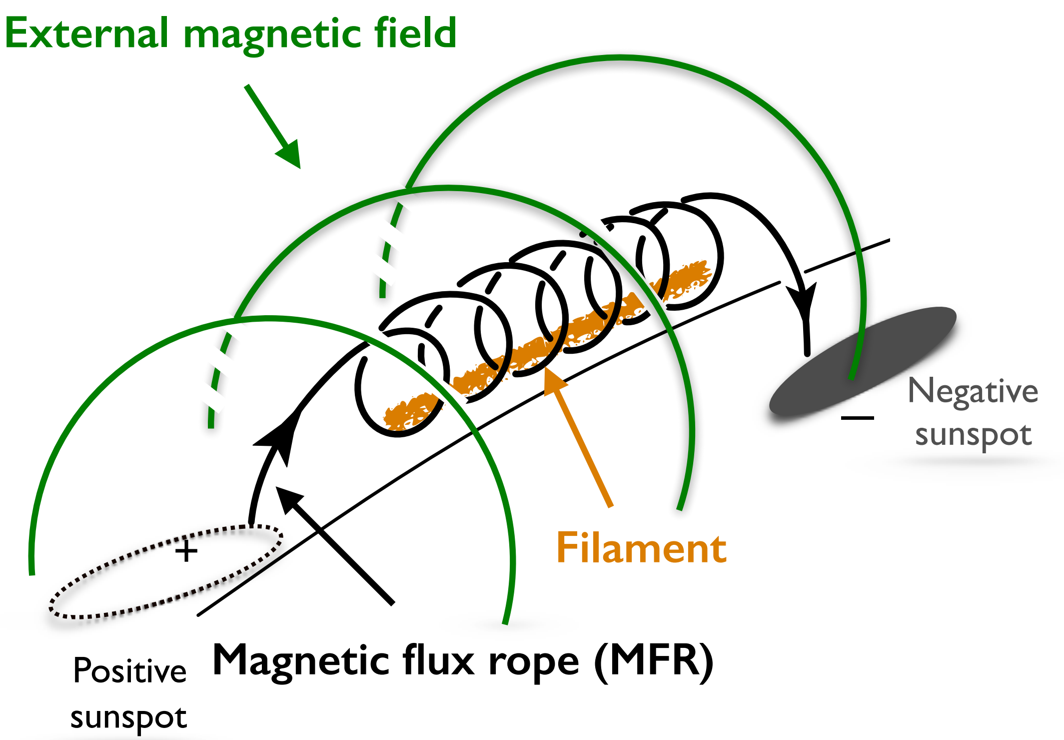
Current-wire models

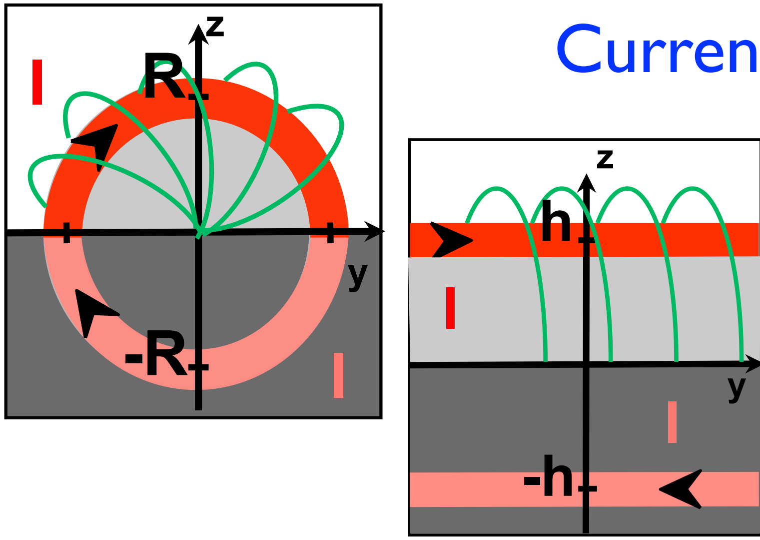
coronal B_{ex}
coronal current
image current

Instability if

$$n = -\,d(\ln B^{ex}) / d(\ln z) \geq 1\text{-}1.5$$

based on morphology





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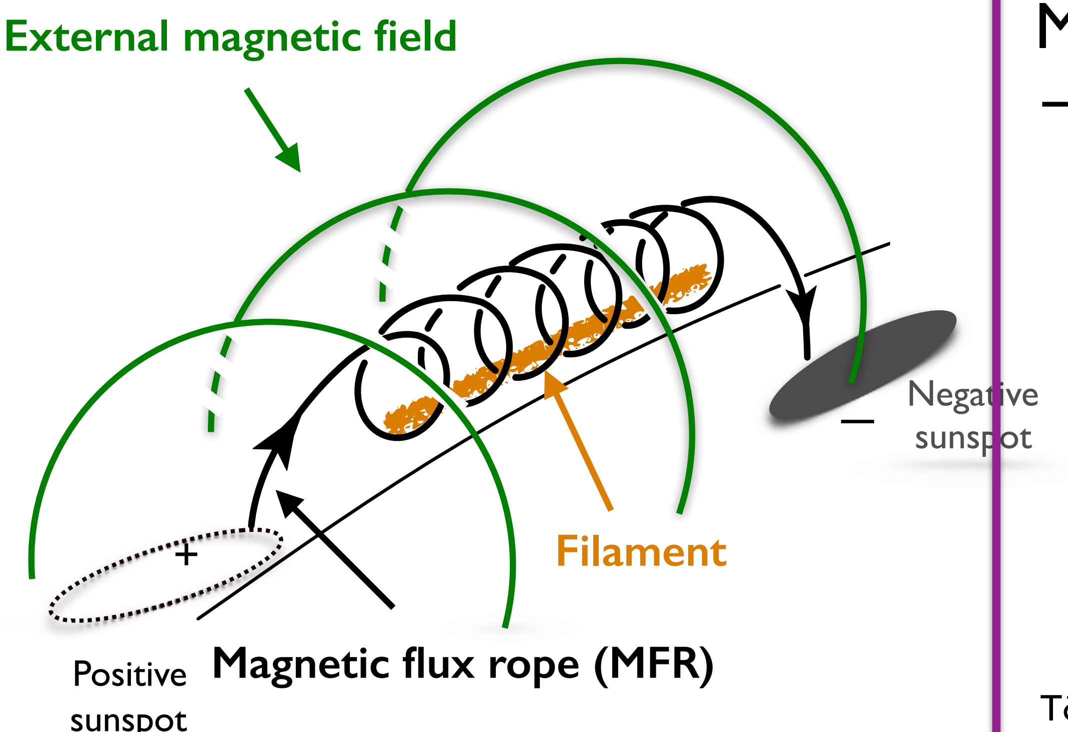
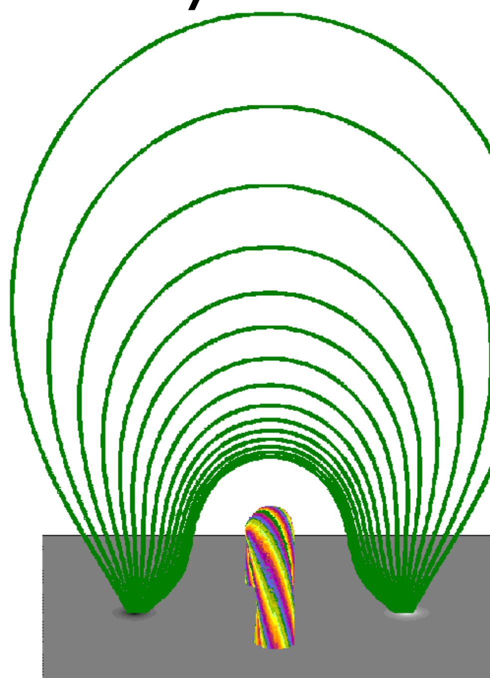


MHD relaxation of analytical MFR
→ $n_{crit} = 1.5$



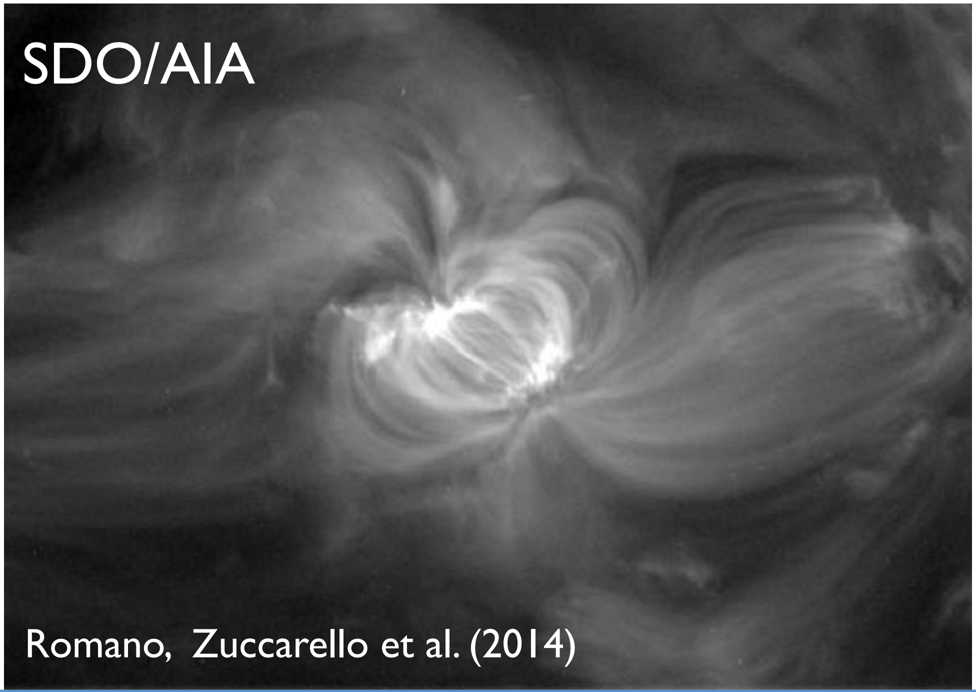
Török & Kliem (2005, 2007)

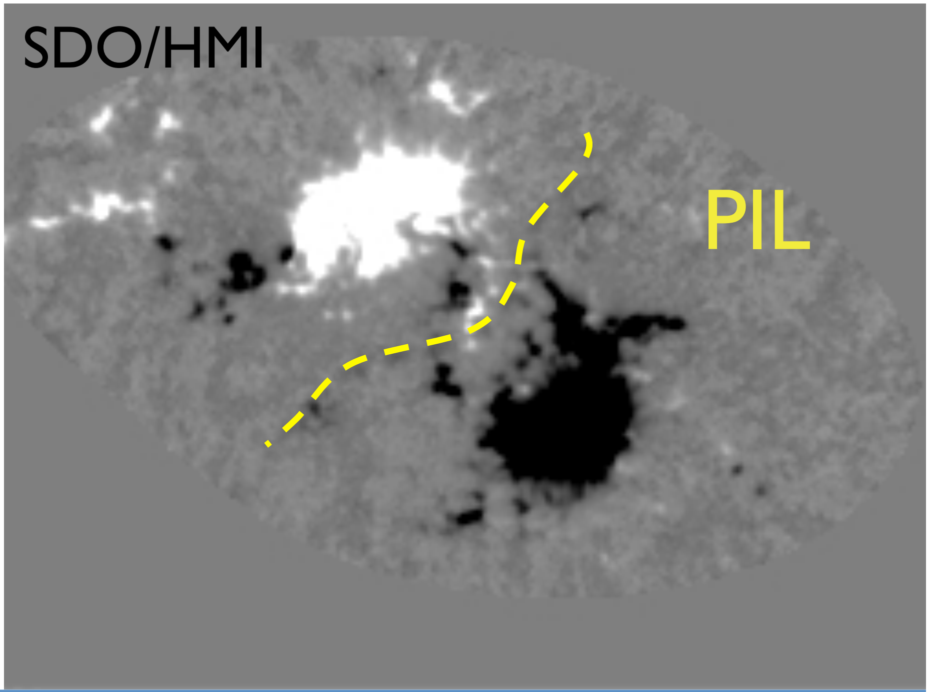
Towards observation inspired MHD simulations

… filaments are seen to form over days,

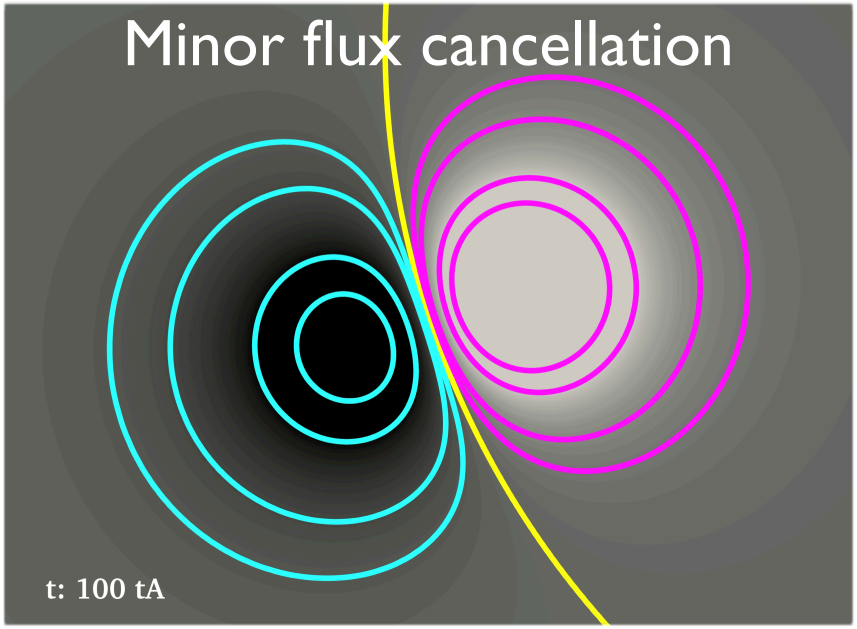
does this affect the eruption's onset ?
how to define the shape of a (non-analytical) MFR ?

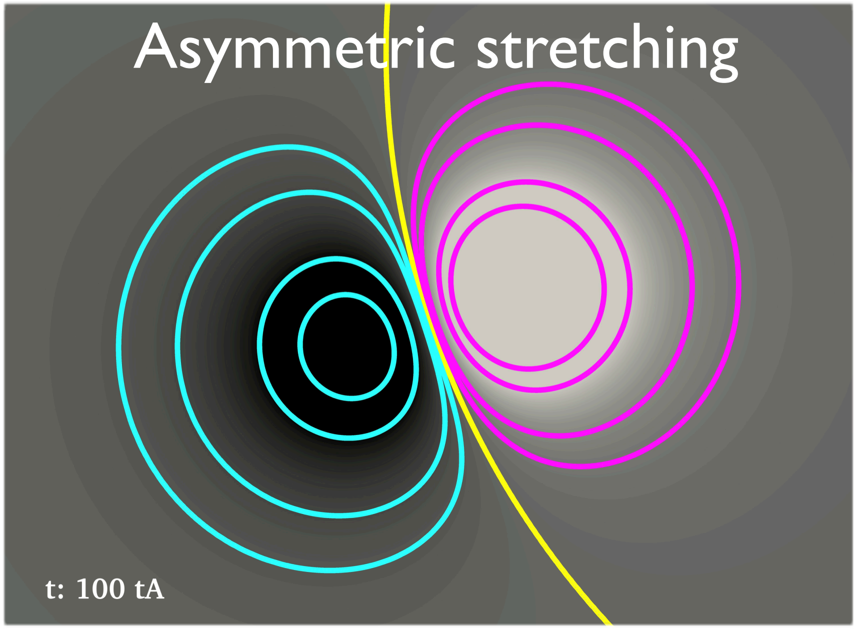
→ line-tied photospheric motions (shearing/twisting)
+ flux cancellation by diffusion or convergence motions

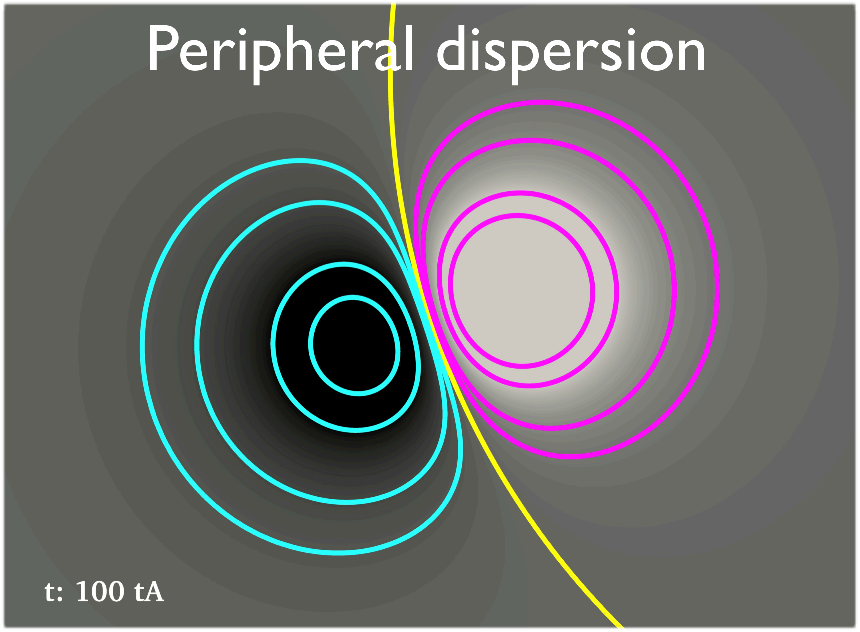


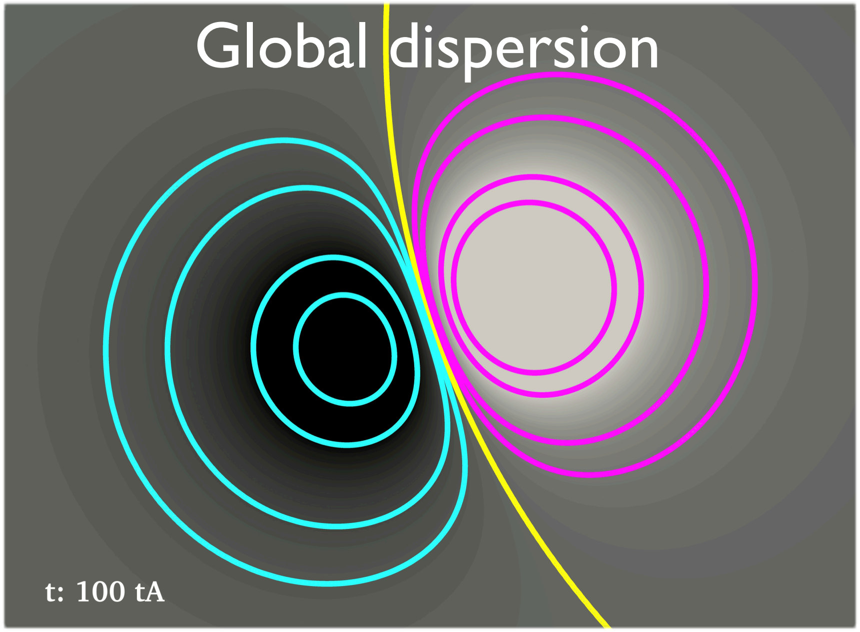


4 different photospheric flows





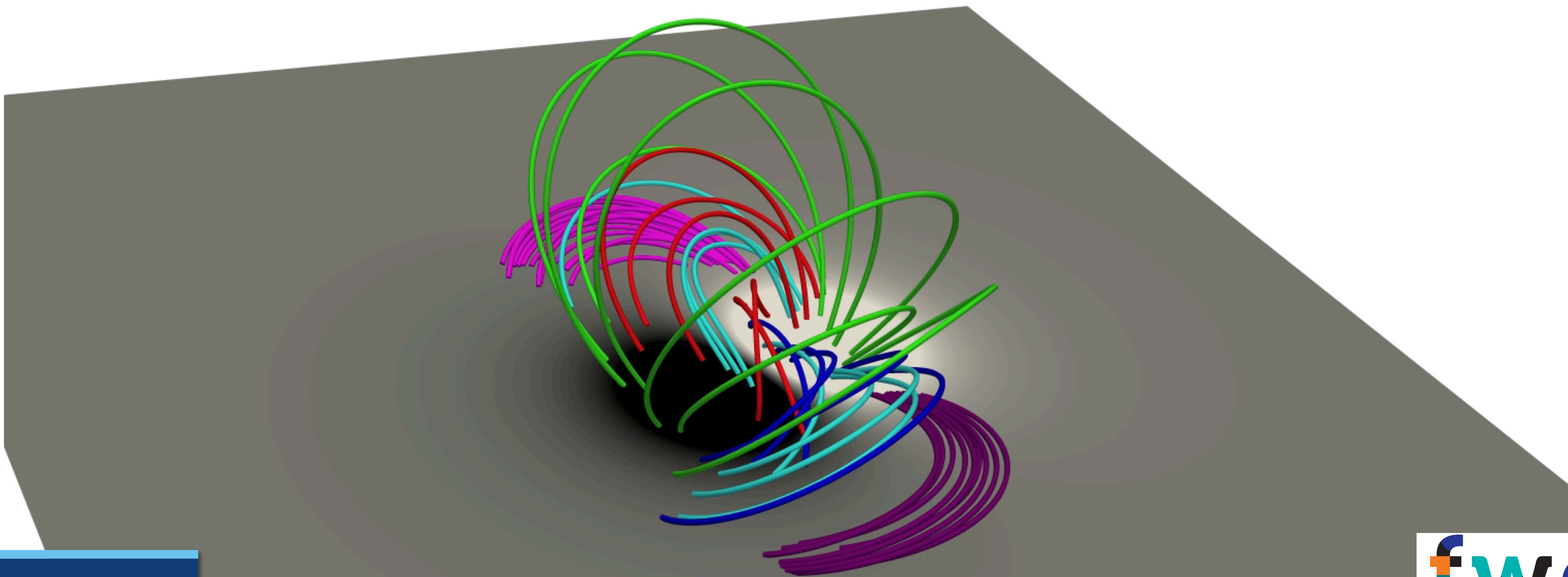




Zuccarello, Aulanier & Gilchrist (2015)

Coronal response

(tether-cutting) magnetic reconnection between highly sheared bald-patches field lines sets-in resulting in the formation of a magnetic flux rope and a sigmoid



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Zuccarello, Aulanier & Gilchrist (2015)

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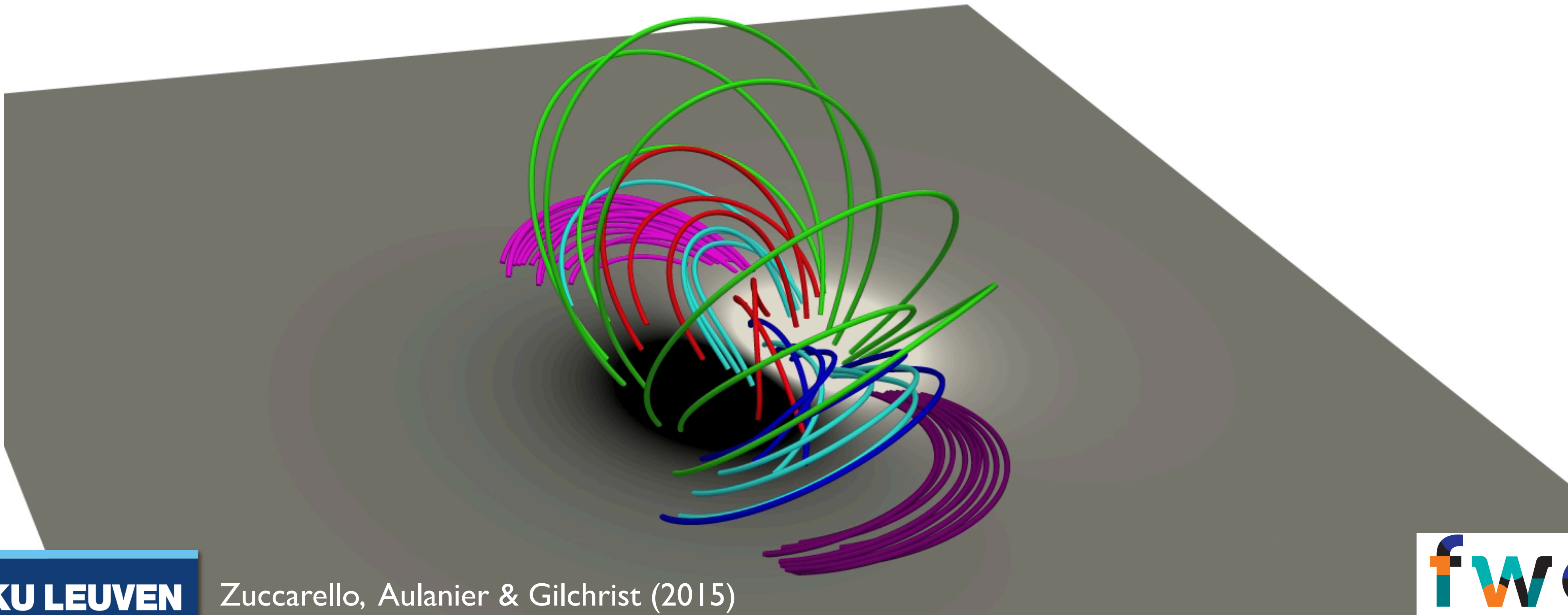
Coronal response

Perform relaxation runs to determine the time of the onset of the eruptions



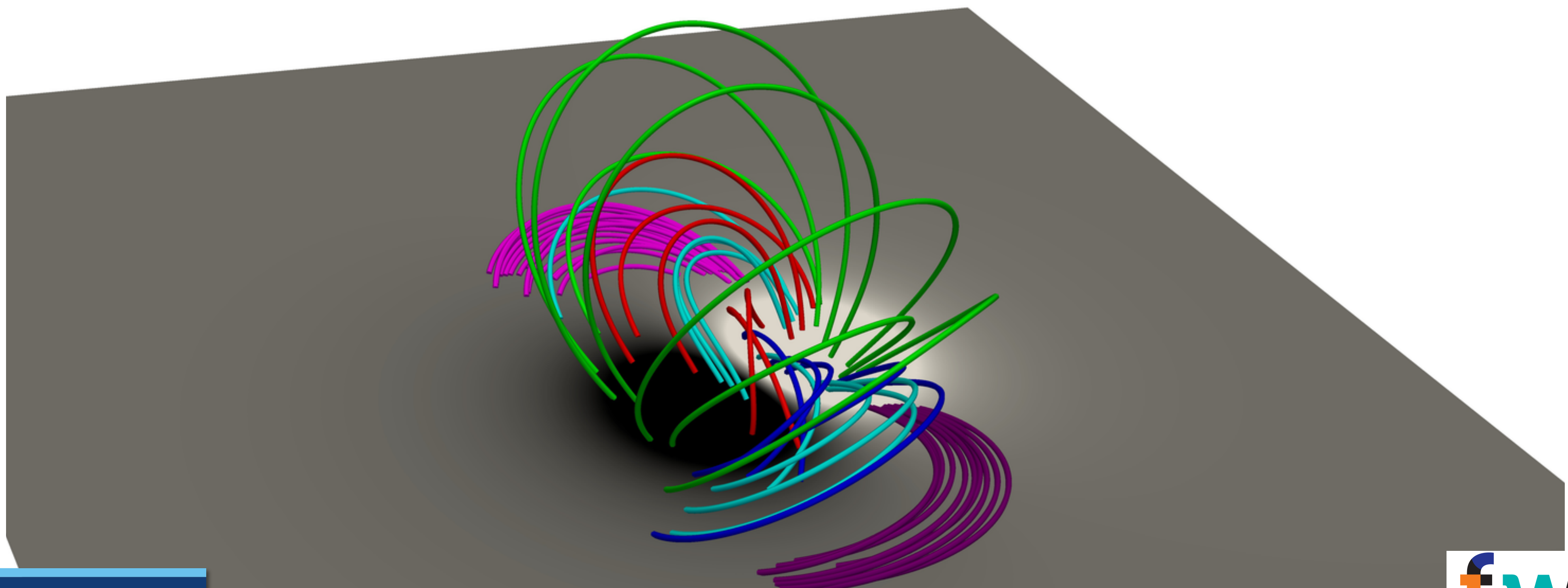
Zuccarello, Aulanier & Gilchrist (2015)

Coronal response

From the different photospheric flows and coronal resistivities

→ n_{crit}=1.4 ± 0.1

Zuccarello, Aulanier & Gilchrist (2015)

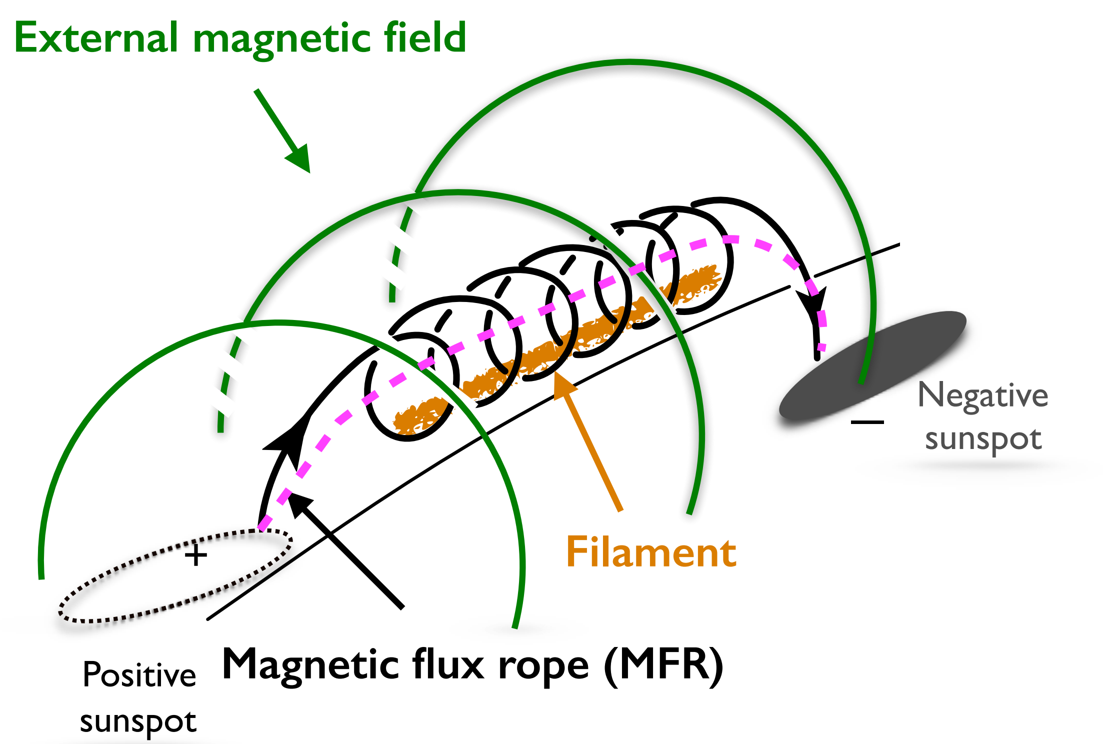


How to use this criterion in observations ?

… and for space weather tools … ?

Key ingredients:

- Potential field extrapolations to compute the decay index
- The height of the axis of the magnetic flux rope

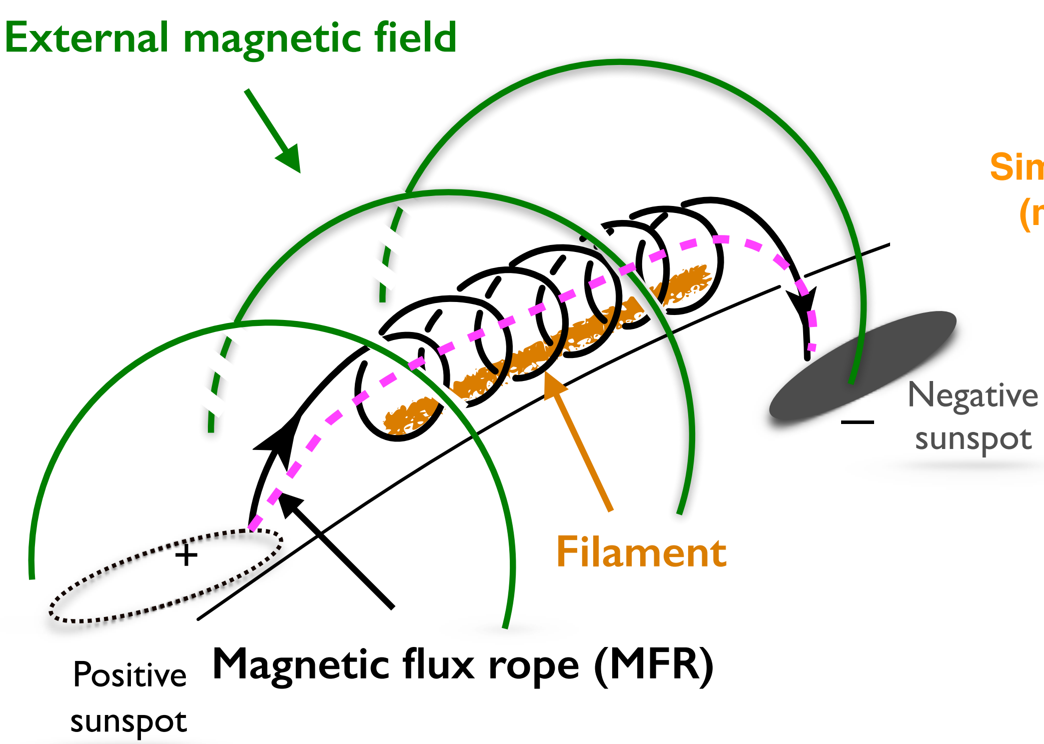


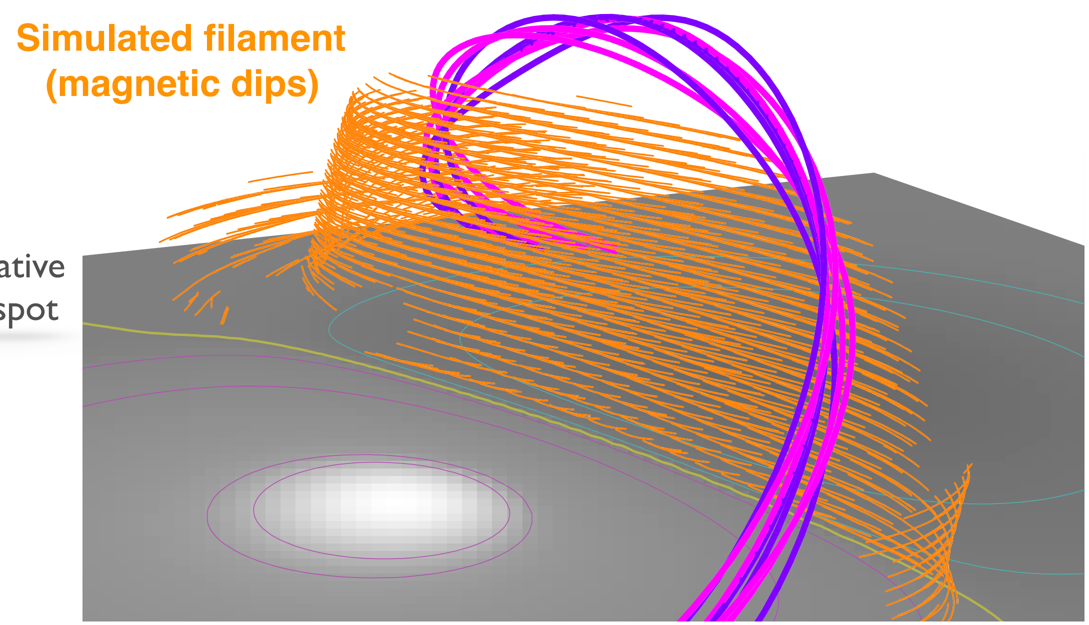
Key ingredients:

- Potential field extrapolations to compute the decay index
- The height of the axis of the magnetic flux rope

From observations we have info on the filament not on the MFR

→ do the same with the MHD simulation





Key ingredients:

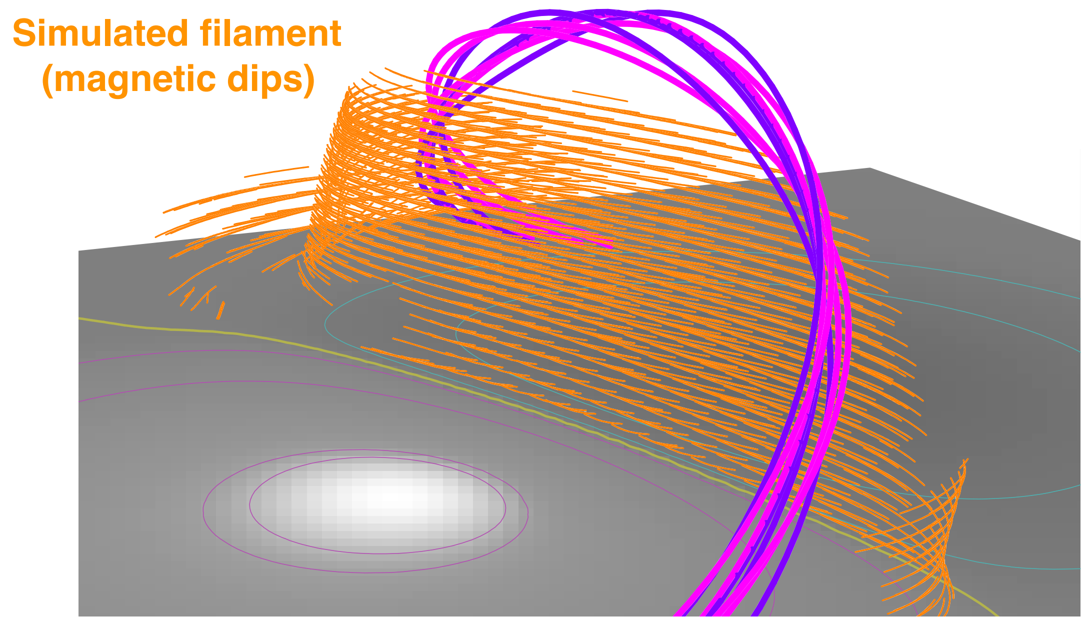
- Potential field extrapolations to compute the decay index
- The height of the axis of the magnetic flux rope

From observations we have info on the filament not on the MFR

→do the same with the MHD simulation

→ apparent n_{crit}=1.1± 0.1

Zuccarello, Aulanier & Gilchrist (2016)

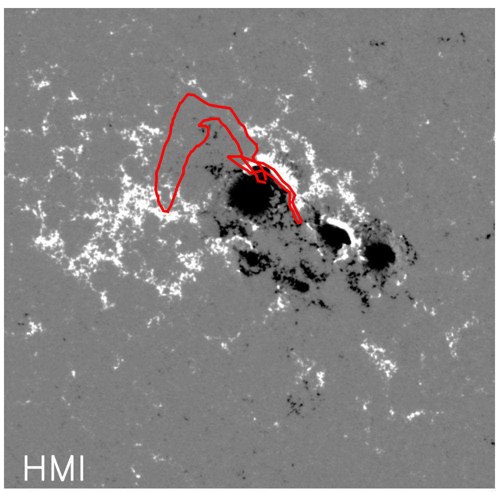


Application to observed filament eruptions

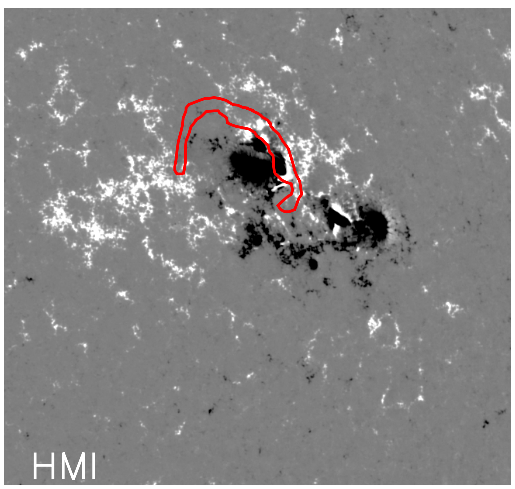
Torus instability criterion can be tested from observations

→ limb observations

→ stereoscopic observations



Before the M6 flare



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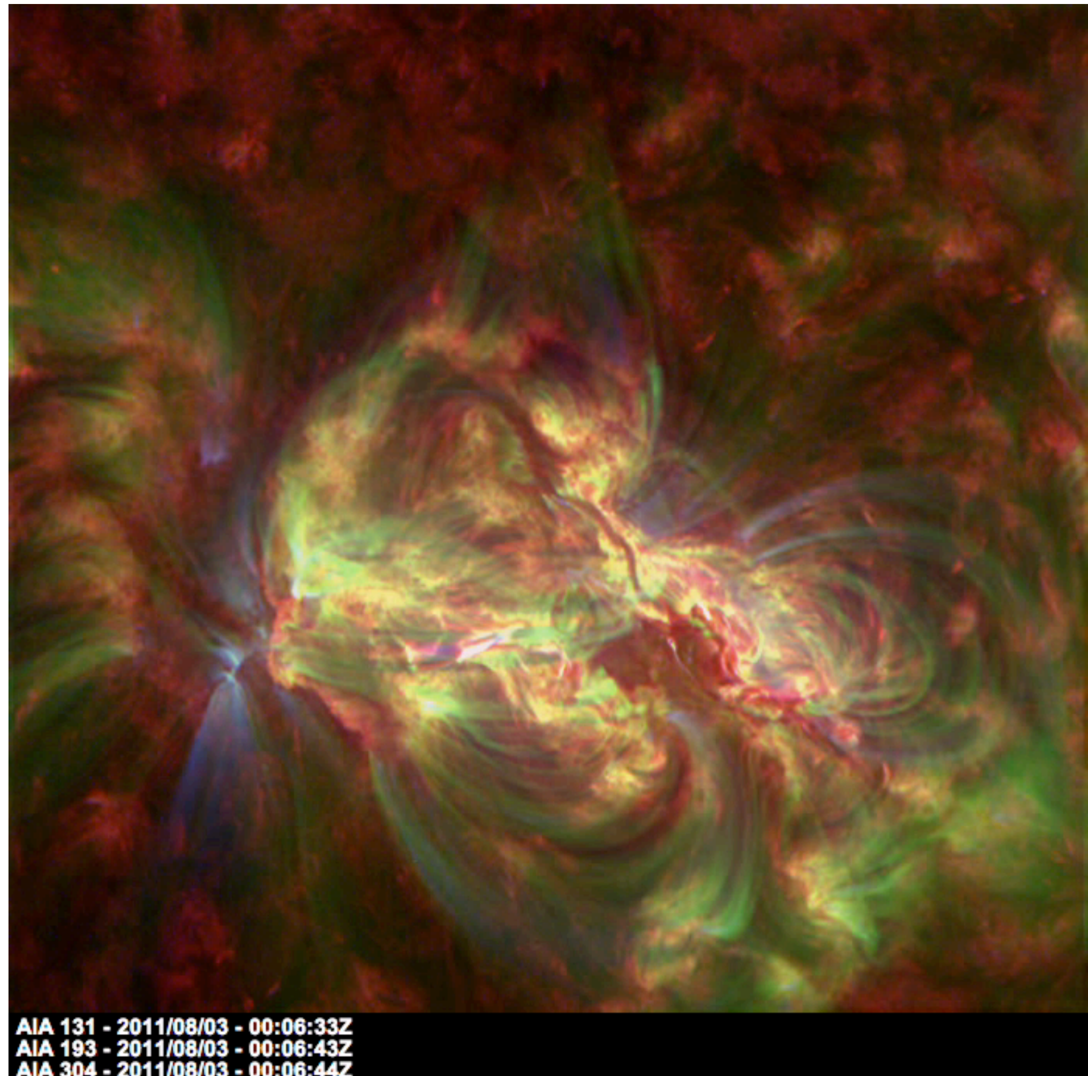

Zuccarello, Seaton et al. (2014)

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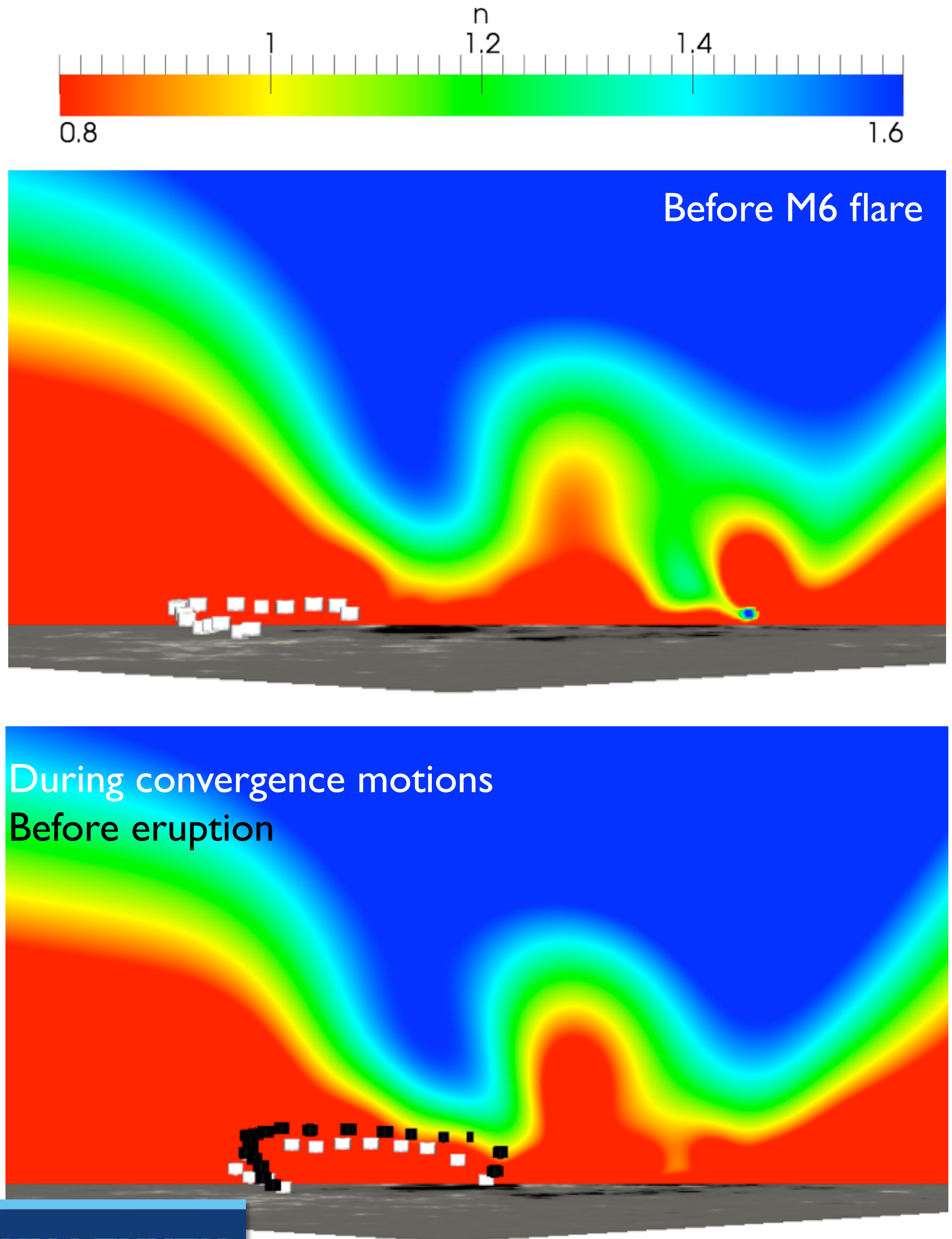

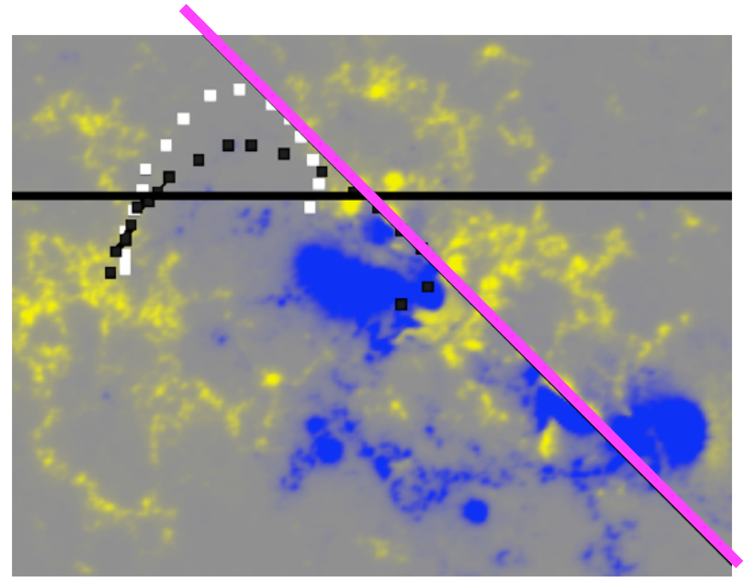

Decay index along the magenta plane

Yellow-green: region where n ≃ 1.1 ± 0.1

When the M6.0 flare occurred the filament was in a torus stable region and did not erupt

The filament erupts when reaches the height where n ≃ 1 ± 0.1

Zuccarello, Seaton et al. (2014)

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Towards an operational tool

Agreement between selected observational cases and MHD simulations

Zuccarello et al. (2012, 2014, 2015, 2016)

… but how to make it operational ?

Essentially ones needs:

- Potential field extrapolations to compute the decay index at different heights

→ LOS magnetograms (lat ± 30°/35°)

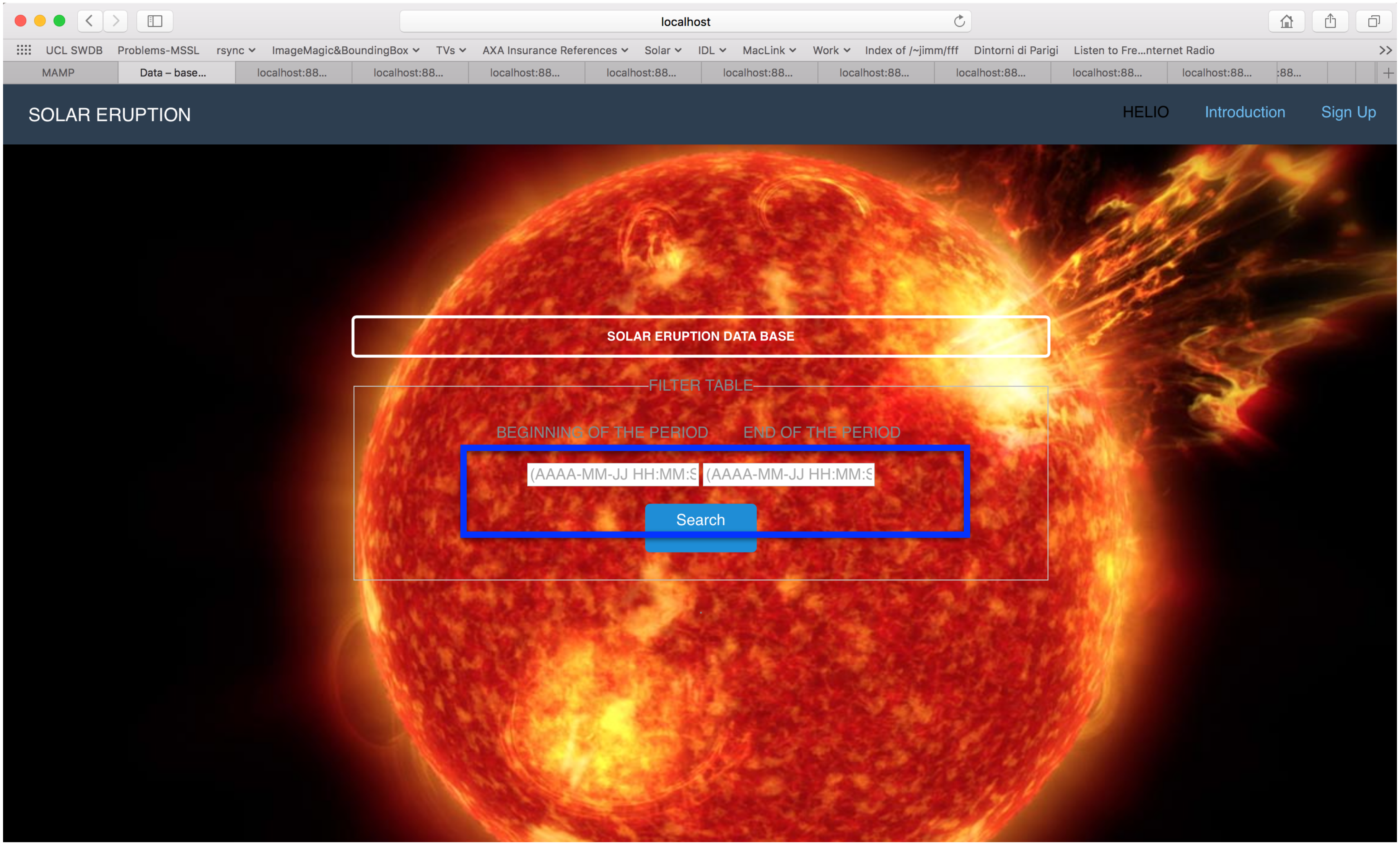
- A way to estimate/track the height of the axis of the magnetic flux rope

→ Stereoscopic observations (L5 mission)

→ Ground based Hα observations

Stereoscopic observations

'Hand-made' (L3 student's project) stereoscopic reconstructions



Date	Coordinates (x,y) arcsec	SDO/AIA 171 Å	SDO/AIA 193 Å	SDO/AIA 304 Å	Potential field extrapolation	Filament reconstruction

Stereoscopic observations

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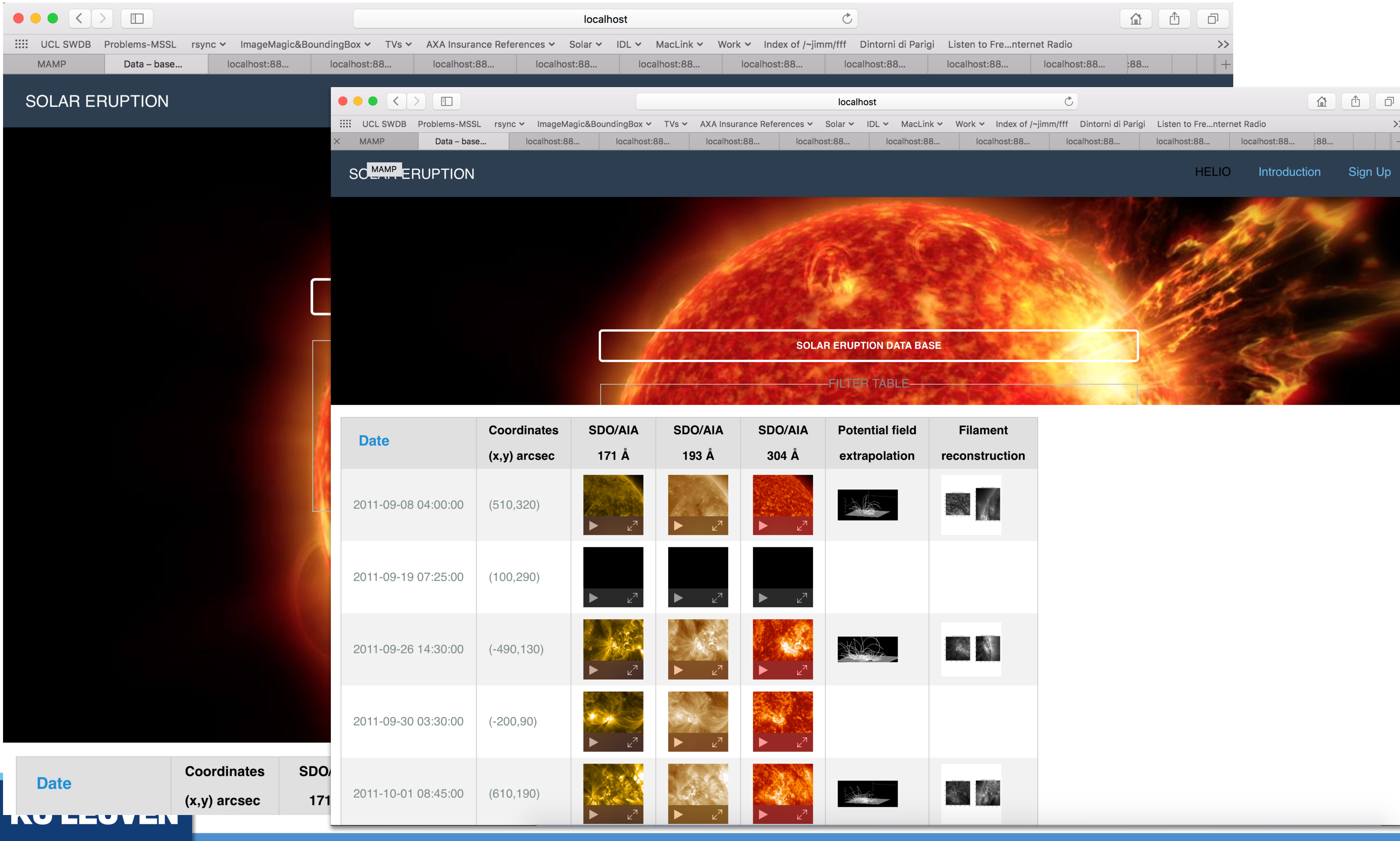

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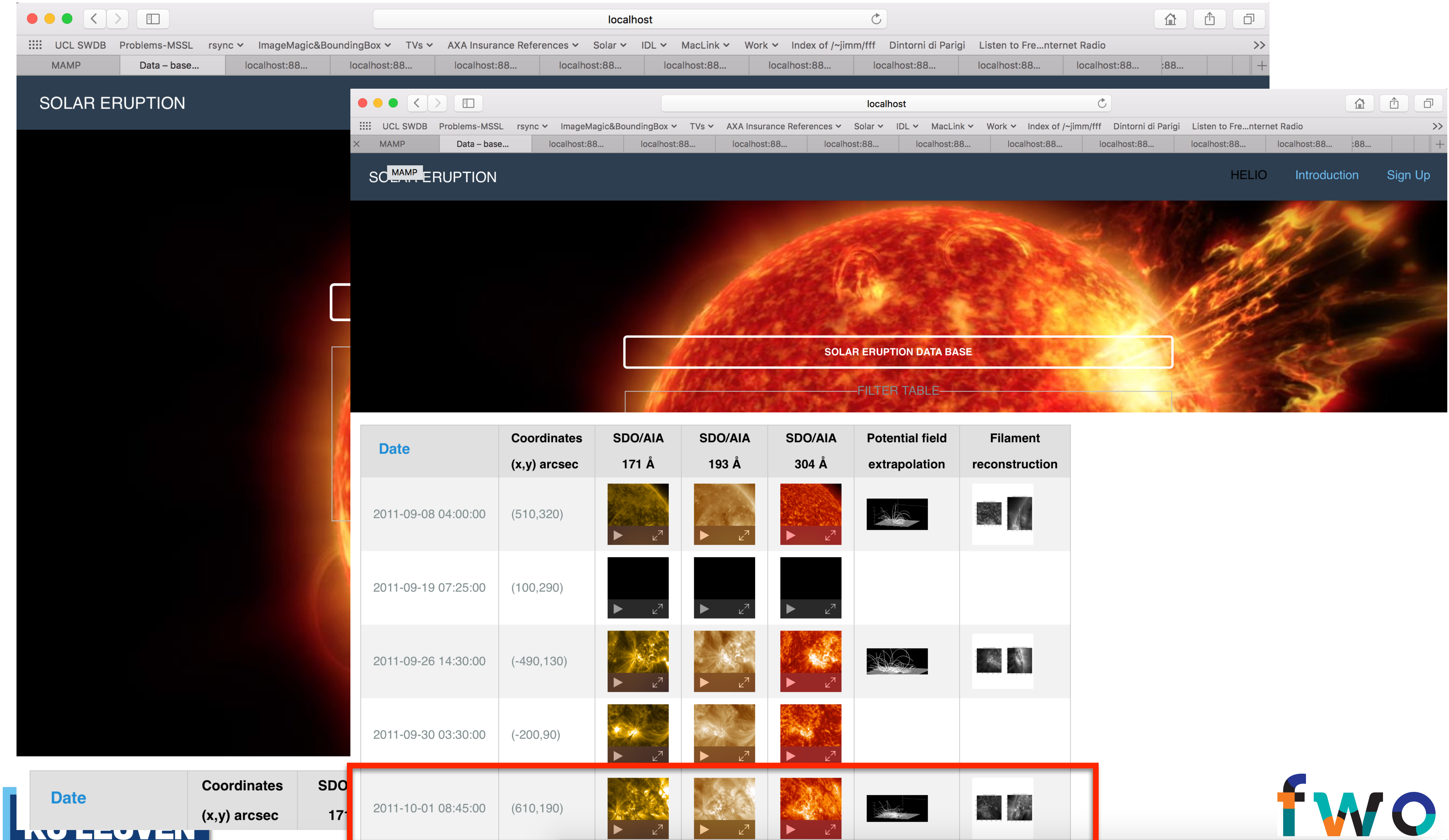

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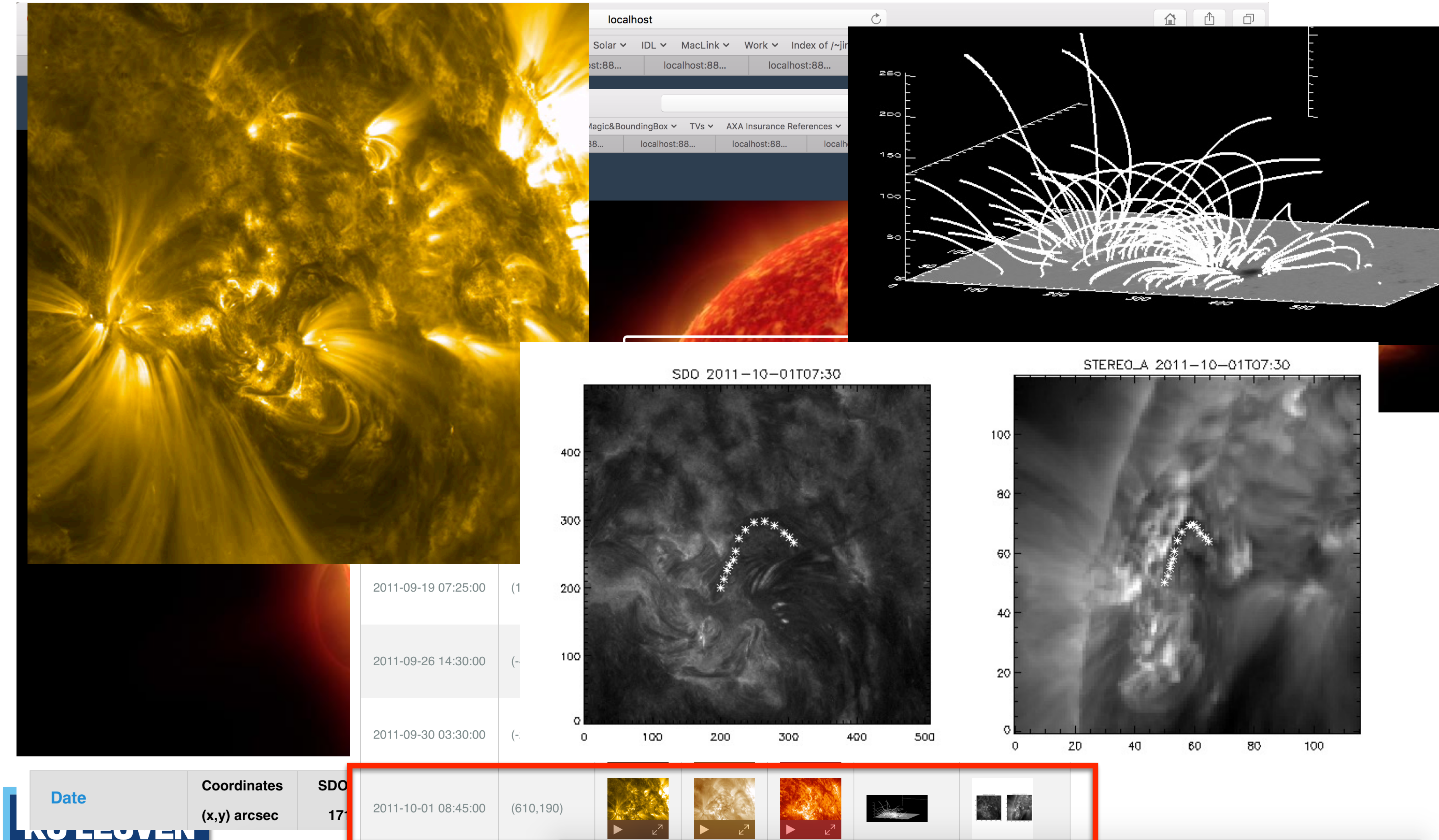
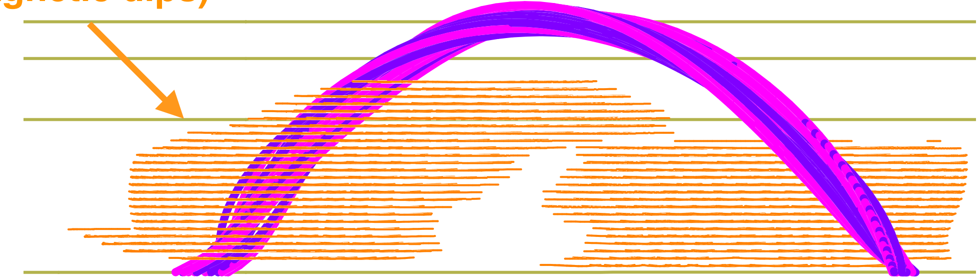


Ground based Hα observations

Ground based Hα observations to estimate the height of the filament

Filament extent to estimate foot point location + a shape model for the MFR's the height of its axis



Ground based Hα observations

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Assunzione ricercatori | Università degli Studi di Catania | Timetable – AstroFIt2 | Resorting Query Results | Heliophysics Feature Catalogue

HELIO **Heliophysics Feature Catalogue** 7 CAPACITIES

The **Heliophysics Feature Catalogue** (HFC) provides access to existing solar and heliophysics feature data, extracted from images by automated recognition codes.

The catalogue contains geometrical (e.g., gravity center coordinates, contours, area, etc.) and photometric feature parameters (e.g., average, minimum, and maximum intensity, etc.) , but also tracking information to identify co-rotating feature on the solar disc.

Query form | Database and fields description | Database content | Free SQL query | Helio Front End

Query form

1 - Date and time selection | 2 - Features selection | 3 - Output options

If 'From' and 'to' are empty, date selection is ignored and query applies to the whole database!

From 2011-10-01T00:00 to 2011-10-16T00:00 Or Duration between 0 and 60 days 15

Or Upload dates sample from VOTable

Submit ?

The following table provides the list of the features for which data are currently available in the HFC.

Feature	Instrument	Recognition code	Bibliography	Tracking information
Active Region	SOHO/MDI SOHO/EIT (171/195 A) SDO/AIA (171/193 A)	SMART SPOCA-AR SPOCA-AR	Higgins et al., 2010 Barra et al., 2009 Barra et al., 2009	No Yes Yes
Coronal Hole	SOHO/MDI + SOHO/EIT (195 A) SOHO/EIT (171/195 A) SDO/AIA (193 A)	CHARM SPOCA-CH SPOCA-CH	Krista and Gallagher, 2009 Barra et al., 2009 Barra et al., 2009	No Yes Yes
Filament	Meudon H Alpha Spectroheliograph	SoSoft & TrackFil	Fuller et al., 2005 - Bonnin et al., 2013	Yes
Prominence	Meudon CAII K3 Spectroheliograph	SoSoPro	N. Fuller	No
Sunspot	SOHO/MDI SDO/HMI	MDISS SDOSS	Zharkov et al., 2005 Zharkov et al., 2005	No Yes
Type III	Wind/Waves, STEREO/Swaves	RABAT3	X. Bonnin	No
Coronal radio emission	Nancay Radio Heliograph	NRH2D	C. Renié, X. Bonnin	Yes

Query form | Database and fields description | Database content | Free SQL query | Helio Front End

API | Web Services | About HFC

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FP7, project No. 238969

Ground based Hα observations

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l'Observatoire de Paris — LESIA

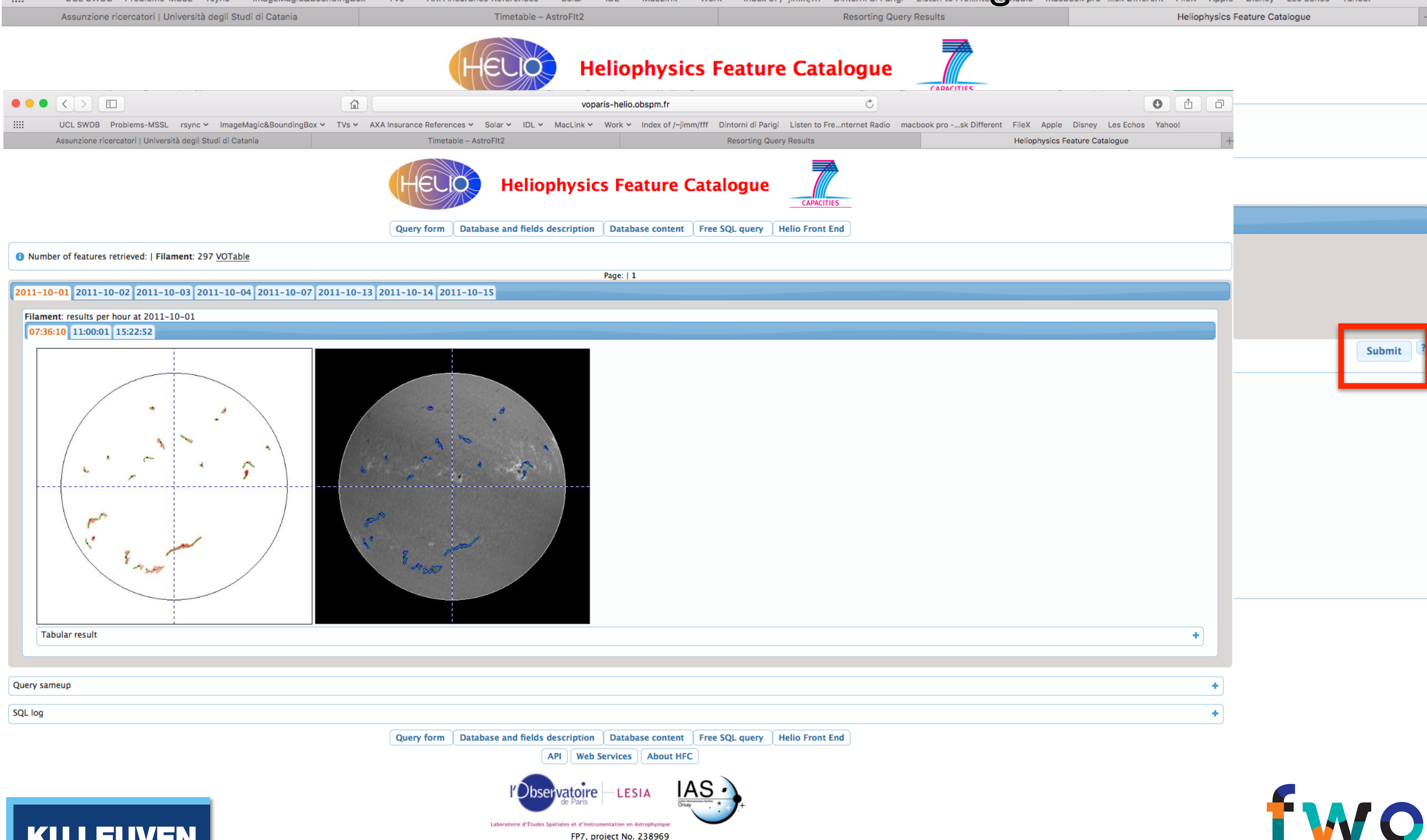
Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

IAS

FP7, project No. 238969

Ground based Hα observations

Ground based Hα observations to estimate the height of the filament



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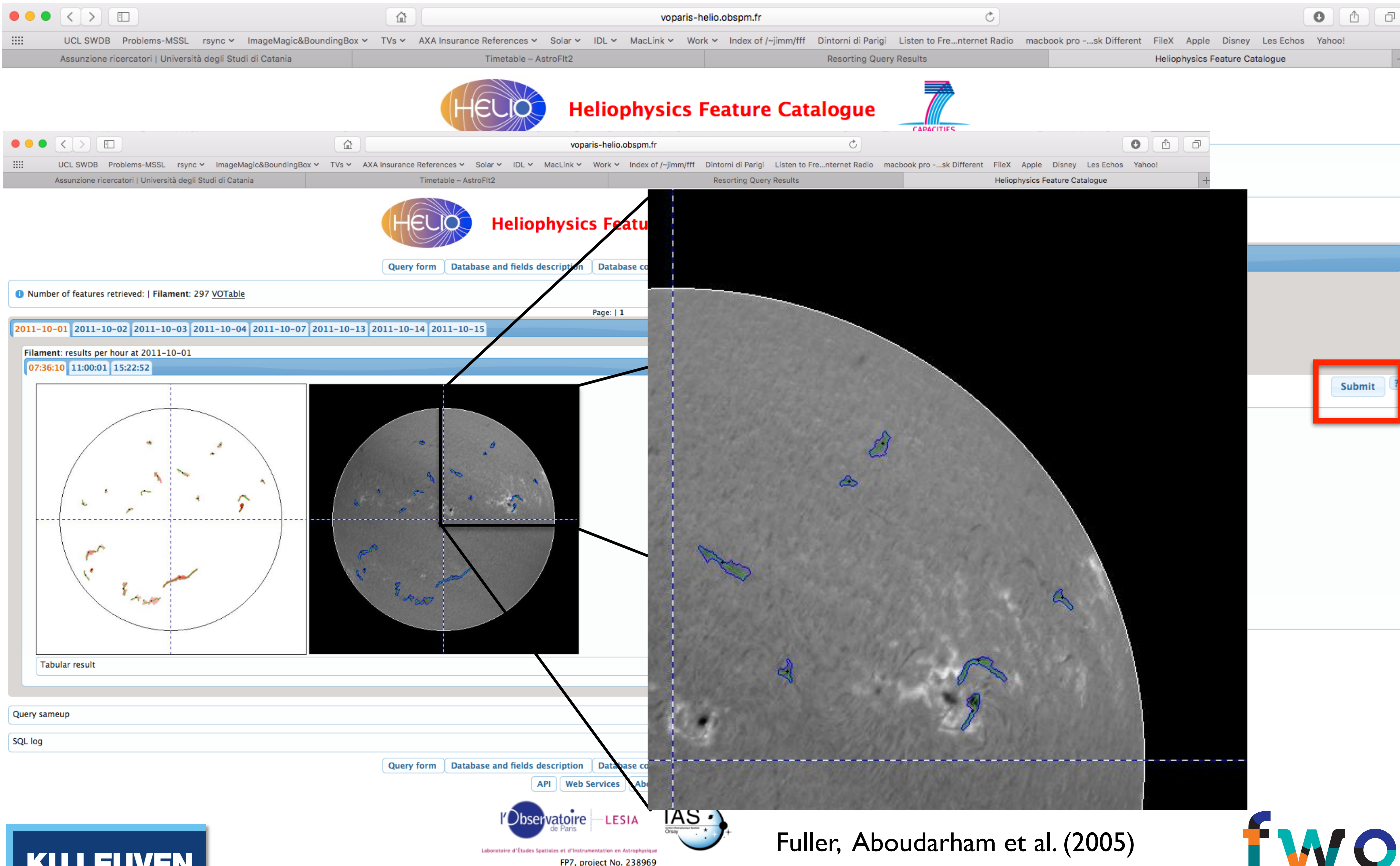
Ground based Hα observations



Fuller, Aboudarham et al. (2005)

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Conclusion

- Torus instability is a robust mechanism to trigger filament eruptions
- Consistent results with different approaches: analytical, observational & 3D MHD
- n_{crit} depends on MFR's morphology, photospheric flows and coronal diffusion,

  → for *usable* onset criterion a *critical decay index range* [1.1-1.5 ?] should be used

- An instability-likelihood approach that depends on different combinations of n_{crit} values/MFR's morphologies

	FR1	FR2
n1	Medium	Low
n2	High	Medium

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n1	Medium	Low
n2	High	Medium

- Key ingredients:
  - LOS (or vector) magnetic field for potential field extrapolations
    → already available
  - Height of the MFR's axis
    - Automatic filament recognition + different MFRs shapes
      → already available + easy to implement
    - Automatic prominence recognition for, not yet existing, L5 mission data
      → promising, but …

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Thank you !

Francesco P. Zuccarello, Zakaria Meliani, Guillaume Aulanier

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LESIA, LUTH Observatoire de Paris, CNRS, PSL, UPMC, Univ. Paris Diderot

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