Towards a MHD instability tool for space weather forecasting

**Francesco P. Zuccarello**, Zakaria Meliani, Guillaume Aulanier

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Quite often eruptive filaments display a two phases evolution:

1. Initial slow rise/evolution

2. Fast eruption

Rupture of equilibrium
Quite often eruptive filaments display a two phases evolution:

1. Initial slow rise/evolution
2. Fast eruption

**Rupture of equilibrium**

Magnetic tension of the external field VS Magnetic pressure of the MFR

resistive instability
dead ideal-MHD instability
Introduction

Current-wire models

Instability if

\[ n = - \frac{d(\ln B^e_x)}{d(\ln z)} \geq 1 - 1.5 \]

based on morphology

coronal \( B^e_x \)
coronal current
image current

External magnetic field

Magnetic flux rope (MFR)

Positive sunspot

Negative sunspot

Filament
Introduction

Current-wire models

Instability if

\[ n = - \frac{d(\ln B_{\text{ex}})}{d(\ln z)} \geq 1 - 1.5 \]

based on morphology

MHD relaxation of analytical MFR

\[ \rightarrow n_{\text{crit}} = 1.5 \]

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

Romano, Zuccarello et al. (2014)
4 different photospheric flows

Minor flux cancellation

Asymmetric stretching

Peripheral dispersion

Global dispersion

Zuccarello, Aulanier & Gilchrist (2015)
(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
Perform relaxation runs to determine the time of the onset of the eruptions
Coronal response

From the different photospheric flows and coronal resistivities

\[ n_{\text{crit}} = 1.4 \pm 0.1 \]

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
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- 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 $n_{\text{crit}}=1.1 \pm 0.1$

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

After the M6 flare

Zuccarello, Seaton et al. (2014)
Application to observed filament eruptions

Decay index along the magenta plane

Yellow-green: region where $n \approx 1.1 \pm 0.1$

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 $n \approx 1 \pm 0.1$

Zuccarello, Seaton et al. (2014)
Towards an operational tool

Agreement between selected observational cases and MHD simulations

… but how to make it operational?

Essentially one 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
Stereoscopic observations

‘Hand-made’ (L3 student’s project) stereoscopic reconstructions

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<thead>
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<th>Coordinates (x,y) arcsec</th>
<th>SDO/AIA 171 Å</th>
<th>SDO/AIA 193 Å</th>
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### Stereoscopic observations

‘Hand-made’ (L3 student’s project) stereoscopic reconstructions

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Stereoscopic observations

‘Hand-made’ (L3 student’s project) stereoscopic reconstructions
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

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, maximum intensity, etc.), as well as tracking information to identify co-rotating feature on the solar disc.

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

API | Web Services | About HFC
---|---|---

l'Observatoire de l'Université de Liège (ULg) | Laboratoire d'Etudes Spatiales et d'Instrumentation en Astrophysique (LESIAS) | FWO, project No. 238969

KU LEUVEN | FWO
Ground based Hα observations

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

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

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 66 days: 15

Submit

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Ground based Hα observations to estimate the height of the filament.
Ground based Hα observations

Fuller, Aboudarham et al. (2005)
Conclusion

• Torus instability is a robust mechanism to trigger filament eruptions
• Consistent results with different approaches: analytical, observational & 3D MHD
• $n_{\text{crit}}$ 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 $n_{\text{crit}}$ values/MFR’s morphologies

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<td>Low</td>
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- An instability-likelihood approach that depends on different combinations of $n_{\text{crit}}$ values/MFR’s morphologies

- 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 …
Thank you!

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