Probing Flux Rope Formation using Novel Techniques

E K Mottram, L M Green, H A S Reid, A W James

Mullard Space Science Laboratory, UCL, Holmbury Hill Rd, Dorking RH5 6NT

1 Introduction

Coronal Mass Ejections (CMEs) are the largest driver of space weather in the solar system. When they reach earth certain properties define how geo-effective the CME will be. Some of these properties are speed, density and magnetic field strength and orientation.
Preparations are needed to mitigate the risks posed by space weather as the geo-magnetic disturbance can cause millions of dollars worth of damage to global infrastructure **[1]**.

In CME models the core of the CME is thought to be a flux rope structure and where the bulk of the CME plasma is located, therefore the characteristics of the flux rope can help with preparations

To look at these characteristics EUV and radio emission can be used. EUV can be utilized to find temperature of the emission, and the radio can be utilized to calculate the density of accelerated electrons in the plasma or the magnetic field strength of the structure.

2 February 24th 2024

The event looked at in the case study is the formation and eruption of a flux rope on the 24th February 2024.

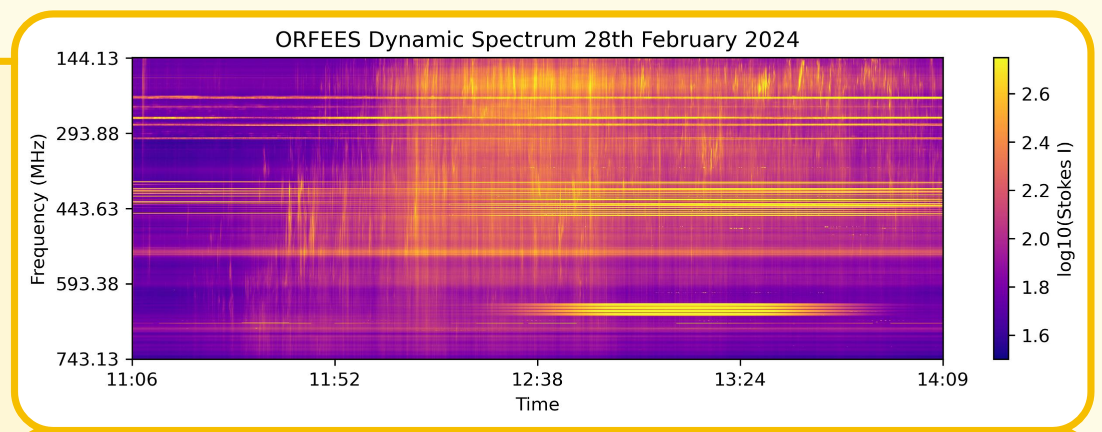
A confined C-class flare occurred at approx. 10:45 UTC. After the flare a hot channel appeared in AIA 94Å and 131Å

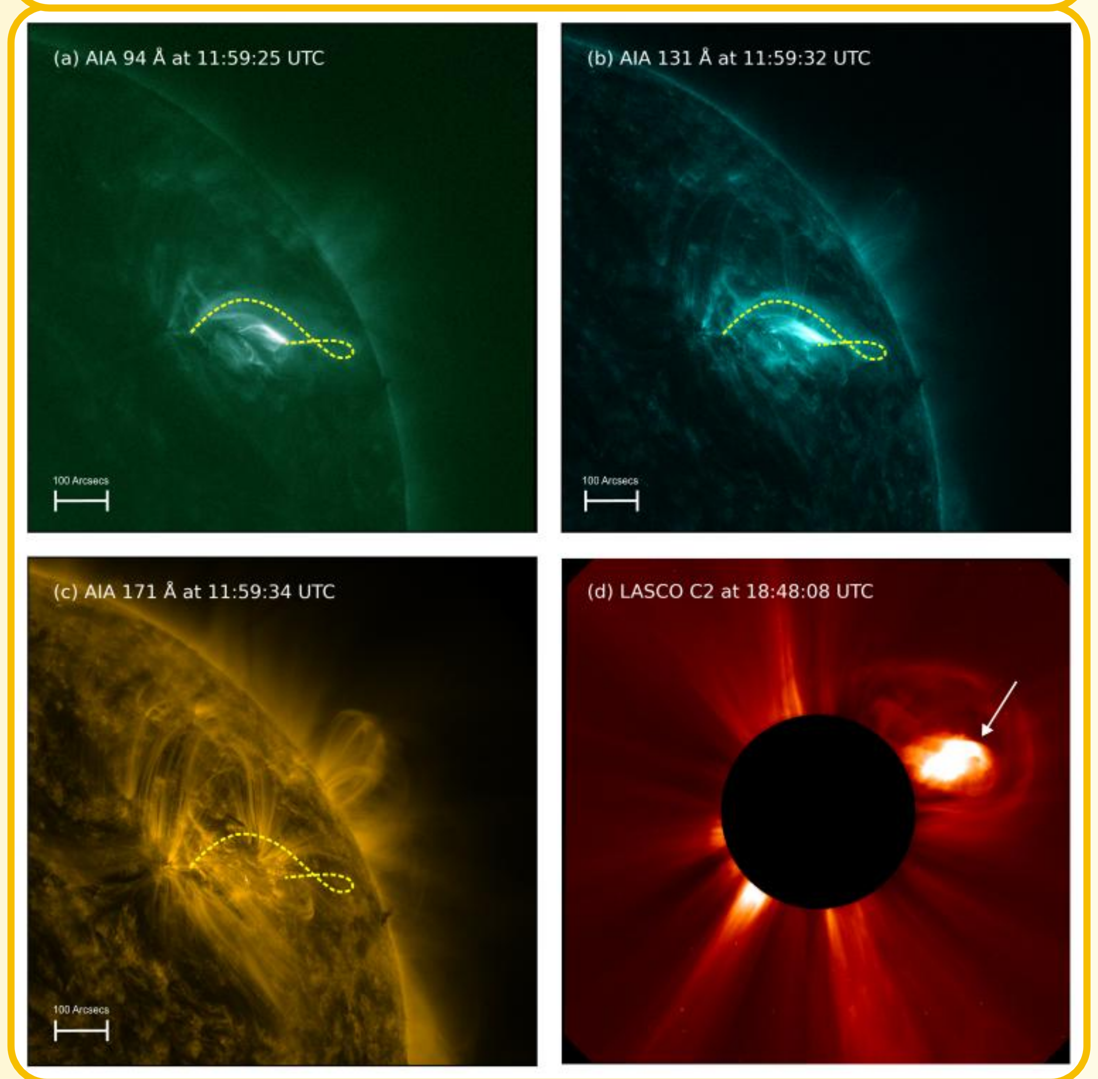
The region where the flux rope formed showed significant sunspot rotation leading up to and possibly assisting with the formation of the flux rope **[2]**.

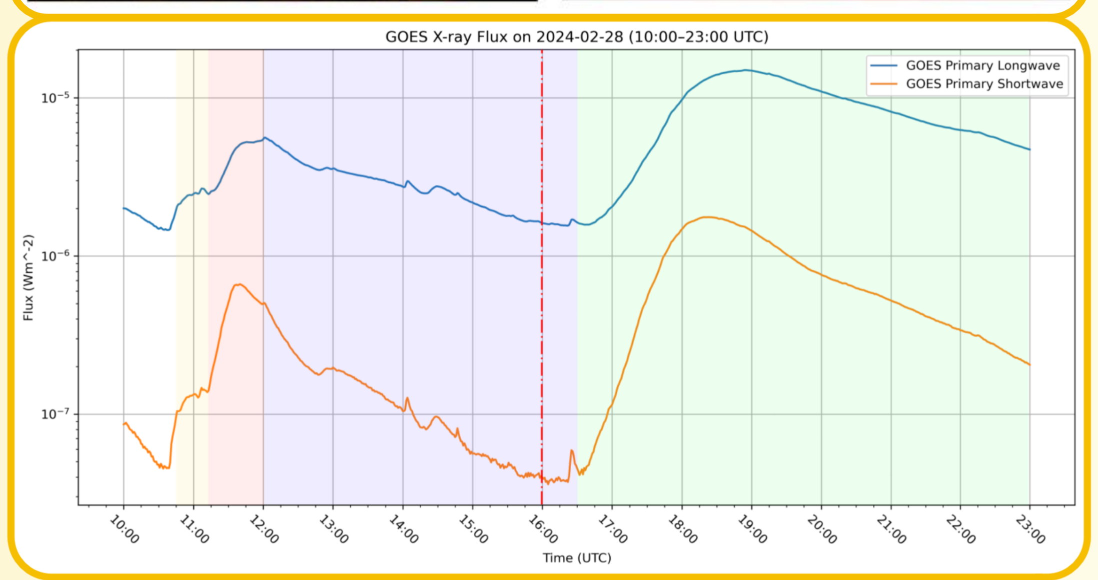
Alongside the flux rope a Stationary Type IV radio burst was observed by the Nançay Radioheliograph (NRH) beginning at approx. 11:30 UTC

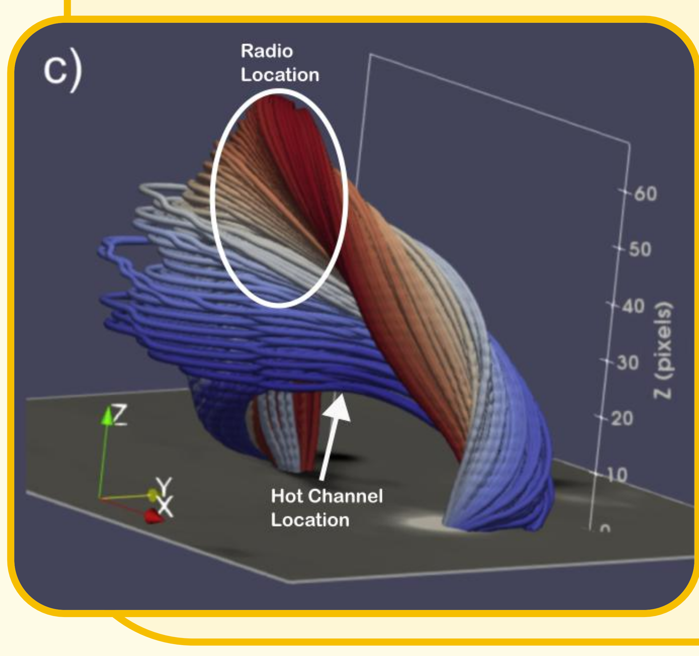
The flux rope formed and expanded to a state of equilibrium where it remained for ~6 hours before becoming unstable and erupting at approx. 17:30 UTC.

The CME had a very bright core in LASCO and showed a clear 3-part structure.









Left: Schematic of where the different emission is located within the flux rope. Imaged adapted from **[3]**.
Right Top: Dynamic spectrum showing the Type IV radio burst associated with the flux rope.
Right Middle: GOES X-ray flux over the 28th Feb indicating different phases in the formation and eruption of the flux rope.
Right Bottom: Images from SDO AIA (a-c) showing the hot channel that indicates the presence of a flux rope. The hot channel meets the criteria in **[4]** for identifying hot flux ropes. (d) SOHO LASCO image of the CME that was seen once the structure erupted

3 EUV Observations

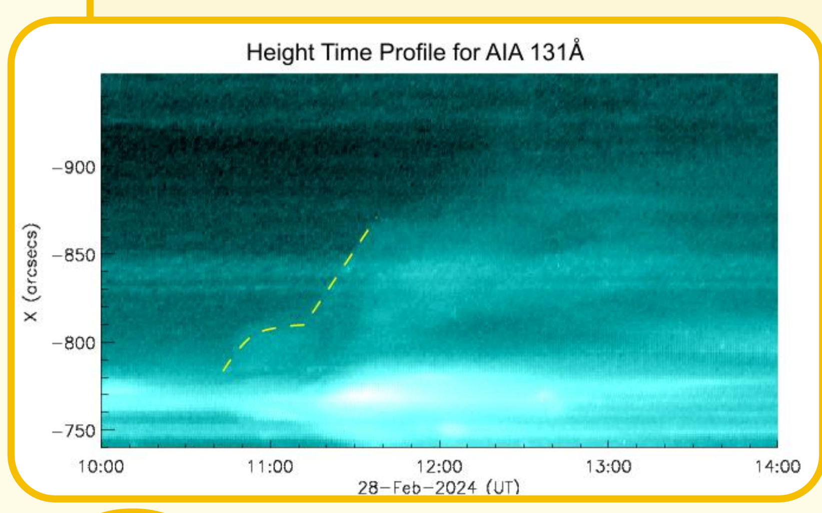
In Extreme Ultraviolet (EUV) the flux rope appears as hot channel, with 'fuzzy' edges that sits above an underlying flare arcade.

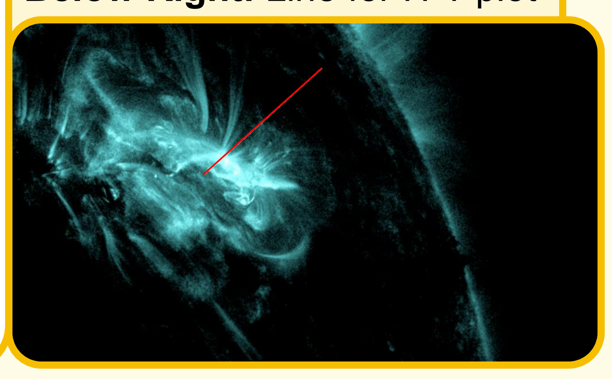
A Height-Time profile was plotted using AIA 131Å for the formation and subsequent expansion of the flux rope.

There is clear expansion seen in EUV that shows two phases a quick initial rise and a 'balloon' like expansion.

Both the rise phases correspond to a brightening of the underlying flare arcade

Below Left: EUV Height-Time plot showing expansion (yellow dashed line)
Below Right: Line for H-T plot





4 Radio Observations

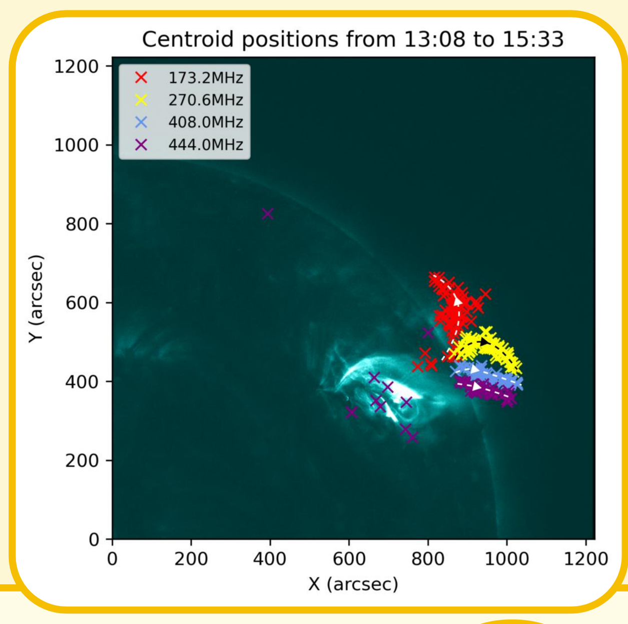
The NRH Radio data was fitted with a gaussian and the centroids of the emission were plotted.

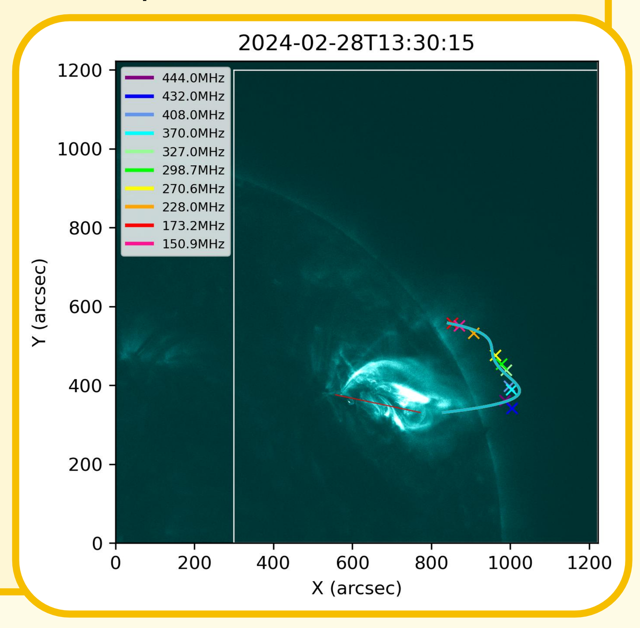
Through the observed period the centroids show movement similar to the hot channel in EUV

These centroids were fitted with a 4th order polynomial to represent the part of the structure they are in.

Below Left: Movement of the radio centroids over time

Bottom Right: Centroids at 13:30 UTC with a 4th Order polynomial fitted to indicate the loop





5 Results & Next Steps

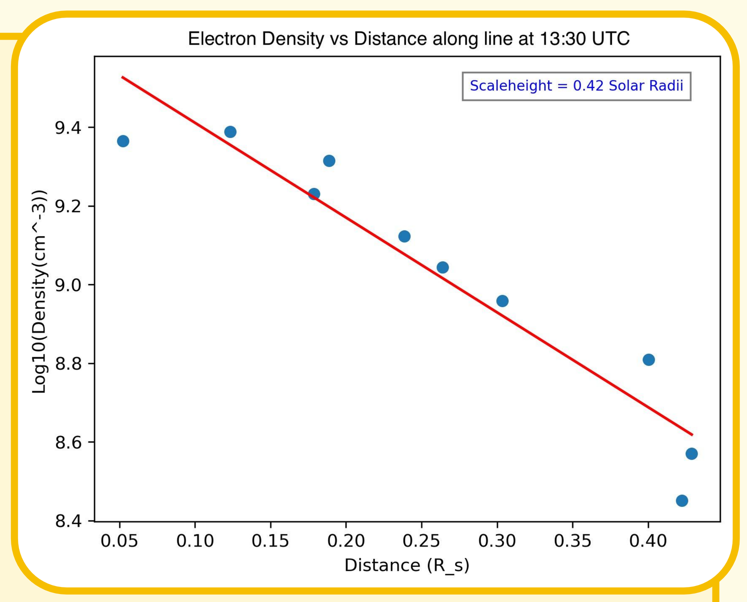
The radio emission was identified as being generated by the fundamental plasma emission mechanism.

Electron densities can then be calculated from the NRH frequencies.

From these densities the next step is to find the density structure of flux rope using the electron densities and the altitudes of the centroids above the surface. Then calculating a temperature estimate using the scale height calculated from the density fit.

$$f_{pe} = \sqrt{\left(\frac{n_e e^2}{\pi m_e}\right)} \approx 9000\sqrt{(n_e)}\ [Hz]$$

Above: Eq. for Plasma emission
Top Right: Electron density vs distance along fitted loop (preliminary work)
Bottom Right: Relation between electron density and altitude



$$n_e(h) = n_0 exp\left(\frac{-h}{\lambda}\right) \text{ where } \lambda = \left(\frac{k_b T}{mg(h)}\right)$$

6 References

[1] Eastwood, J.P. et al (2017). The Economic Impact of Space Weather: Where Do We Stand?

[2] James, A.W. et al. (2020). A new trigger mechanism for coronal mass ejections: The role of confined flares and photospheric motions in the formation of hot flux ropes.

[3] Nindos, A. (2015). How common are hot magnetic flux ropes in the low solar corona? a statistical study of EUV observations.

[4] James, A.W. et al. (2018). An Observationally Constrained Model of a Flux Rope that Formed in the Solar Corona

Emily K Mottram – emily.mottram.22@ucl.ac.uk

MSSL, Holmbury Hill Rd, Dorking RH5 6NT

Science and Technology Facilities Council