First Observation of a Transverse Vertical Oscillation During the Formation of a Hot Post Flare Loop

Rebecca White, Erwin Verwichte & Claire Foullon
r.s.white@warwick.ac.uk

Centre for Fusion, Space and Astrophysics,
University of Warwick, UK

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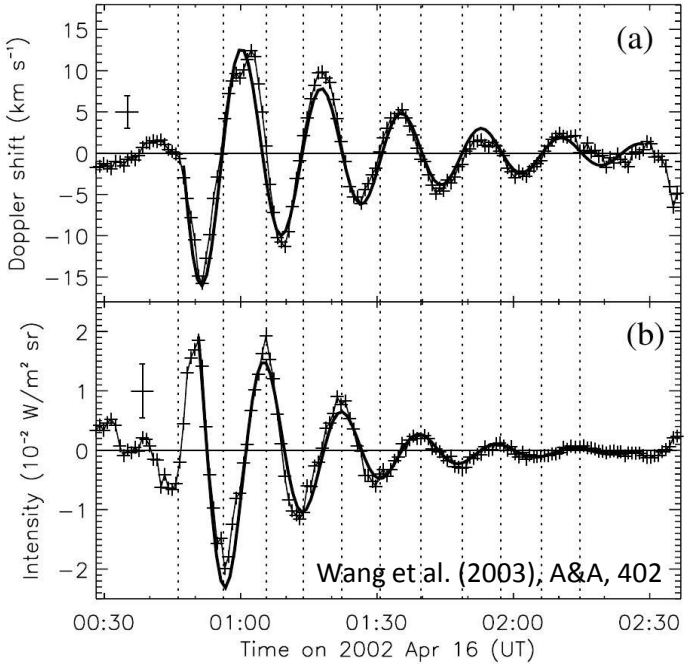
Introduction

- Oscillations in hot flare lines have been detected e.g. SUMER oscillations. *Kliem et al. (2002), ApJ, 568; Wang (2011), Space Sci. Rev., 158*

- SUMER oscillations are interpreted as slow magneto-acoustic standing waves. *Wang et al. (2003), A&A, 406*
  - Phase speed close to sound speed.
  - Intensity variations lagging the Doppler shift by quarter period in a few cases.
  - Average oscillation periods significantly bigger than transverse oscillations seen by TRACE.



- Spatial observations of transverse loop oscillations have so far been limited to the cooler bandpasses (1-2 MK). *E.g. Nakariakov et al. (1999), Science, 285; Aschwanden et al. (2002), Sol. Phys., 206; White & Verwichte (2012), A&A, 537*

Introduction

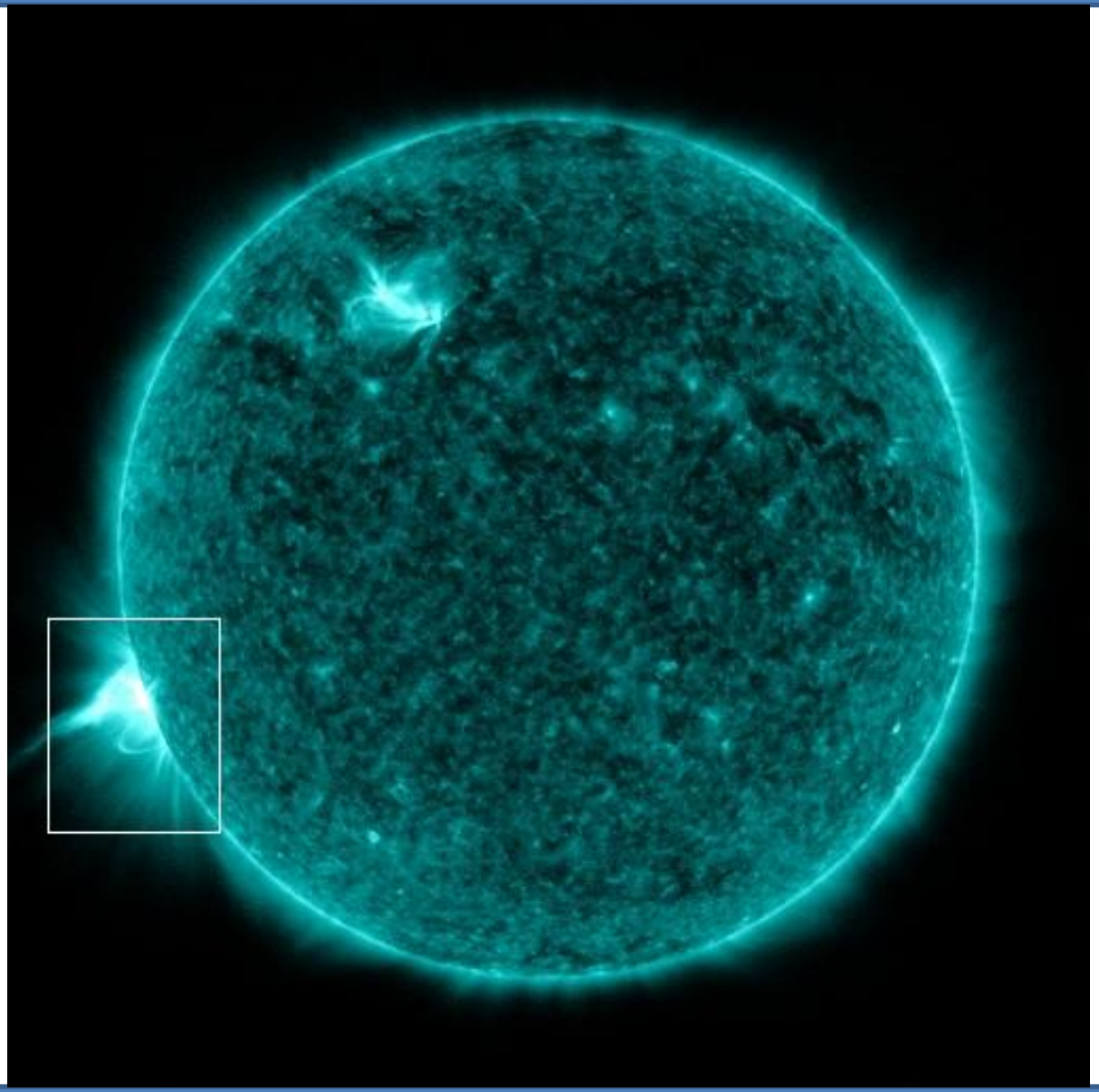
- Higher order harmonics in coronal loop oscillations are rare. *Verwichte et al. (2004) Sol. Phys., 223; De Moortel & Brady (2007), ApJ, 732; Van Doorsselaere et al. (2009), A&A, 508*

- They can be used as a seismological tool, e.g. to determine the density stratification in coronal loops. *Andries et al. (2005), A&A, 430; Dymova & Ruderman (2006), A&A, 457*

- There are few observations of vertically polarised modes. *Wang and Solanki (2004), A&A, 421*

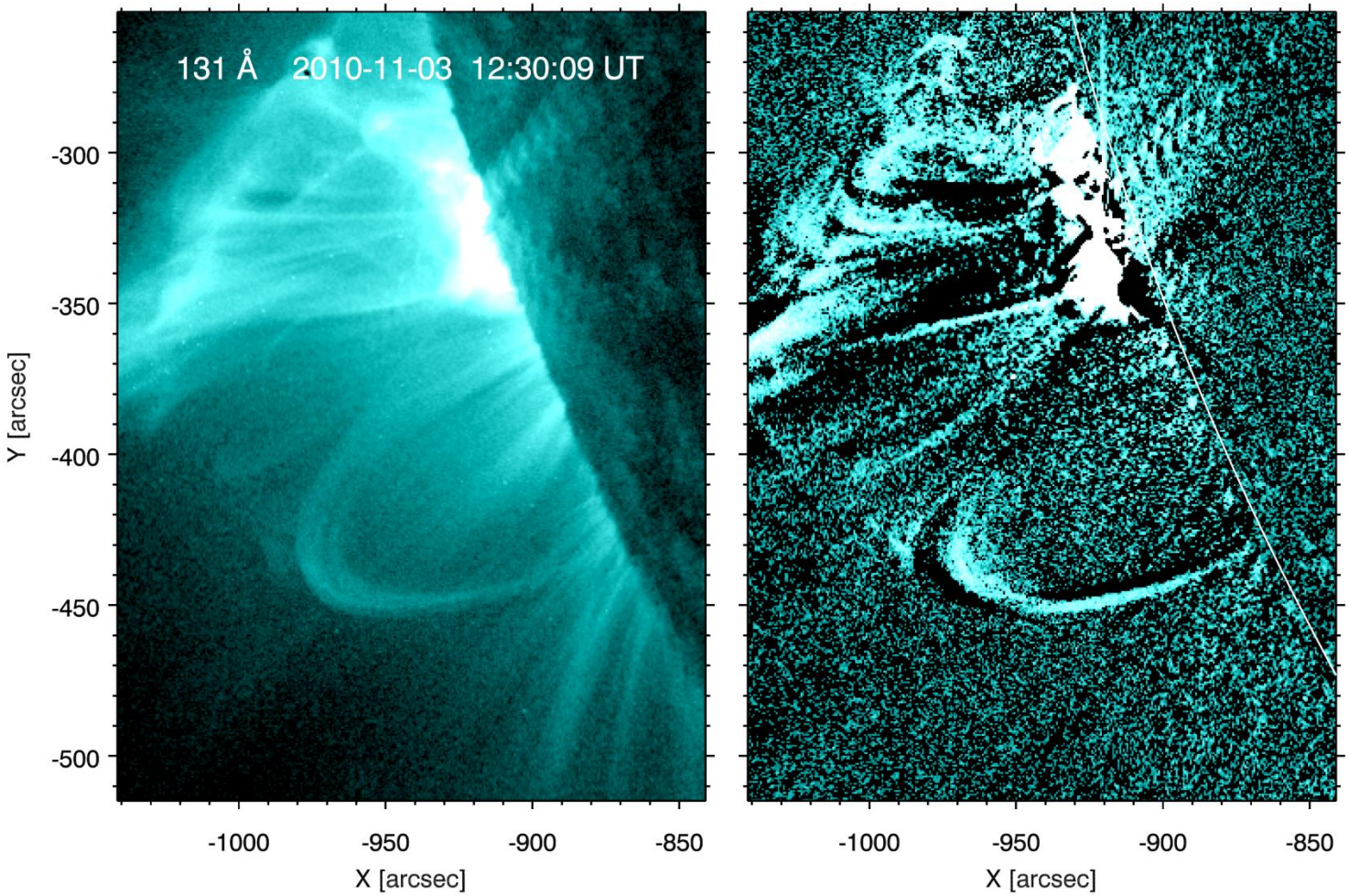
Here we present the first analysis of a higher harmonic vertical transverse loop oscillation seen in a hot loop with AIA/SDO.

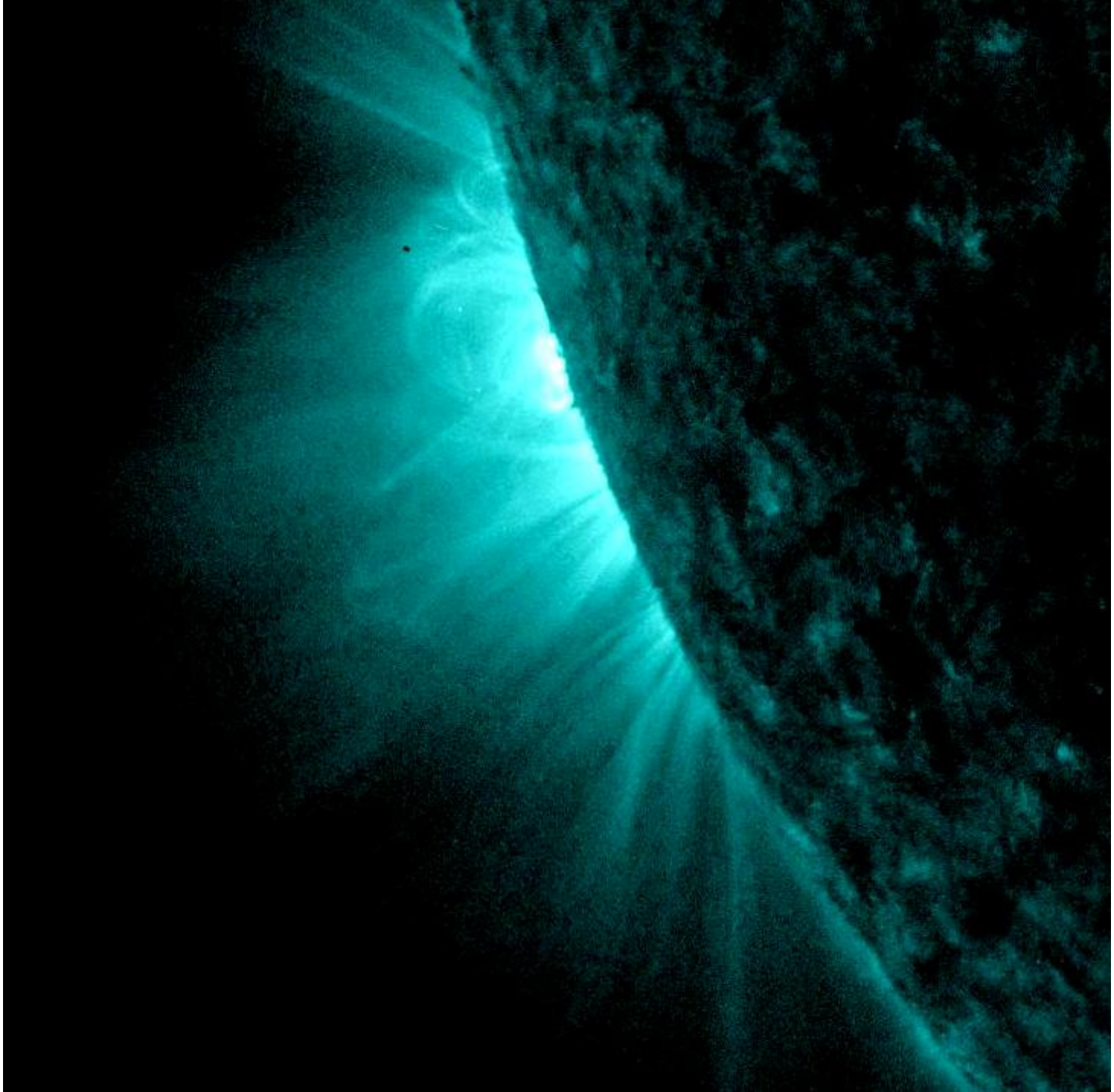
Event: 3 November 2010



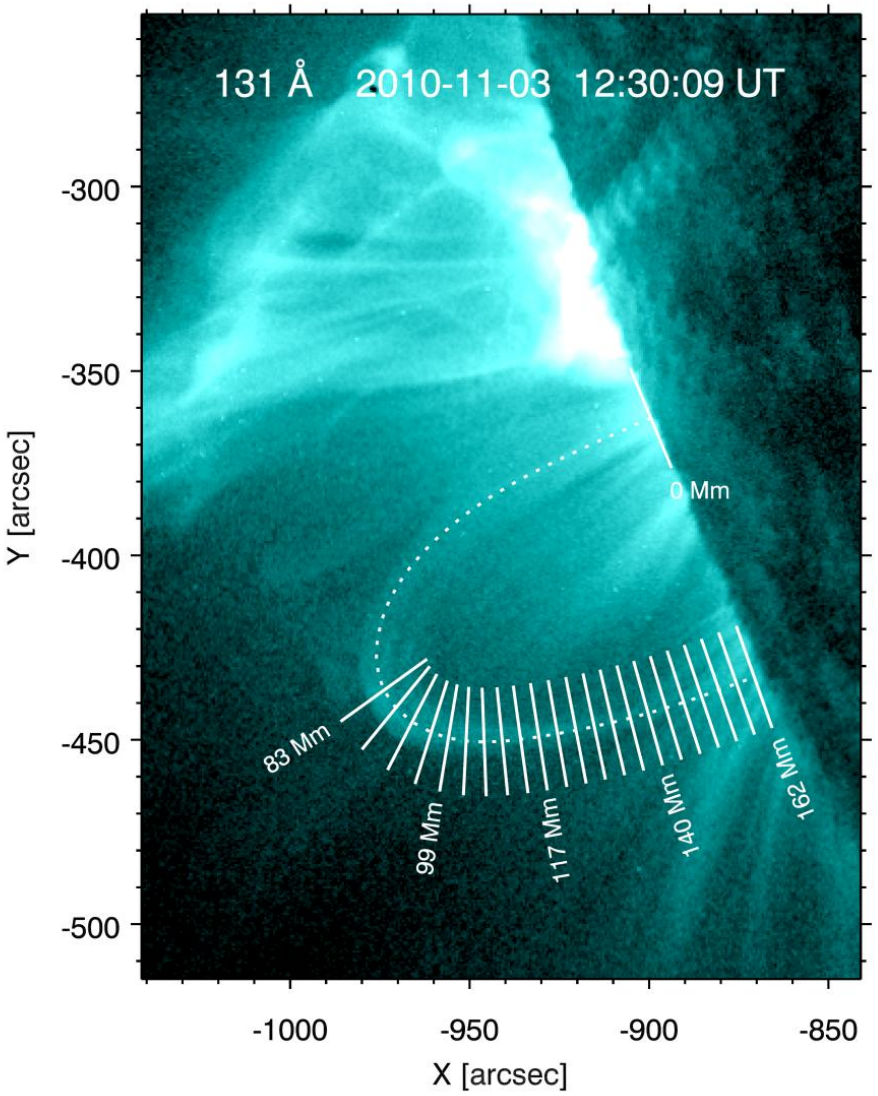
Event: 3 November 2010

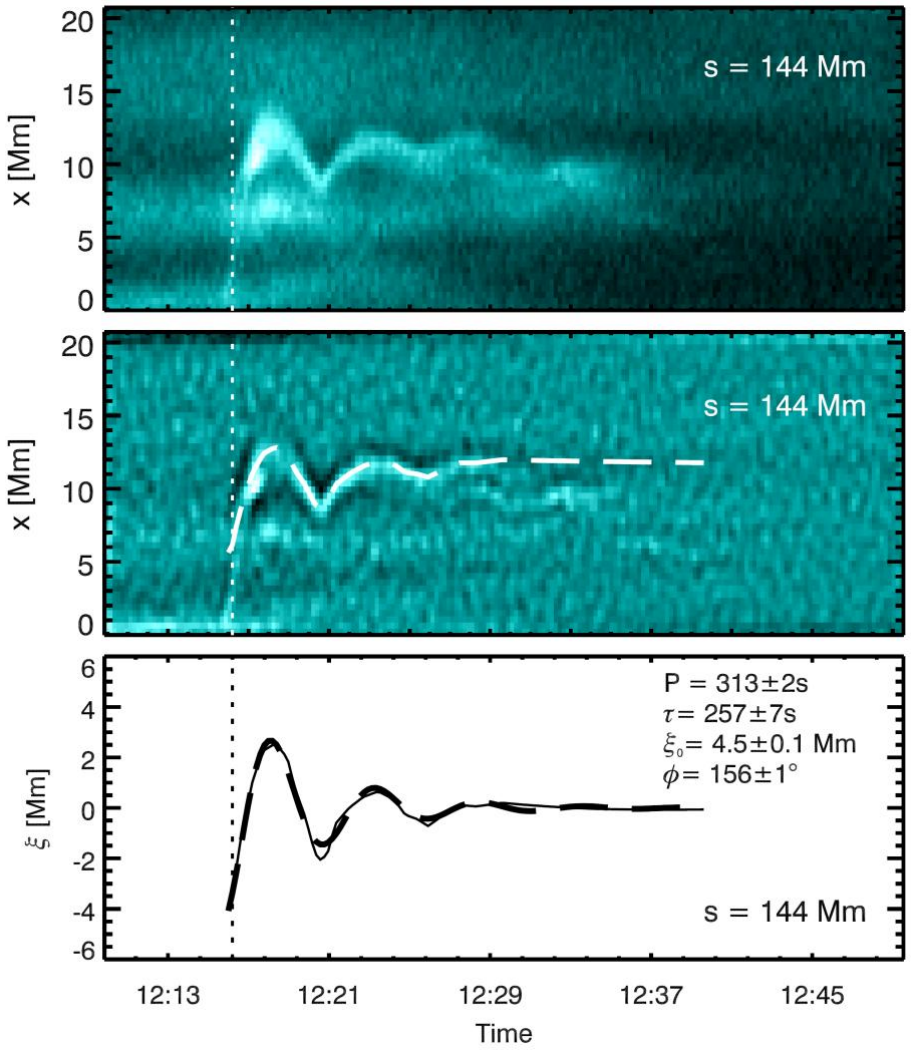
- CME/flare (C4.9 GOES) on south east solar limb.
- Seen exclusively in 131 Å and 94 Å (between 9-11 MK).



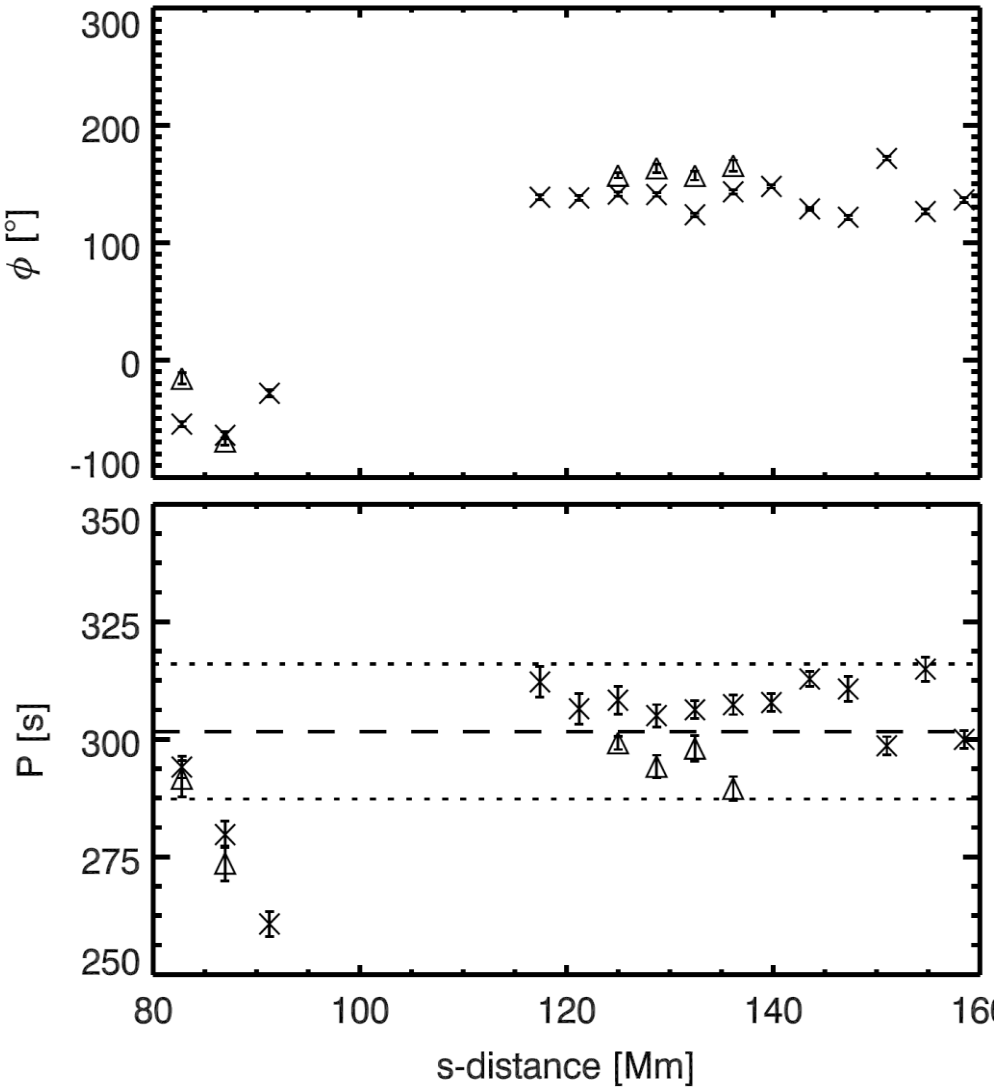


Displacement Time Series Analysis



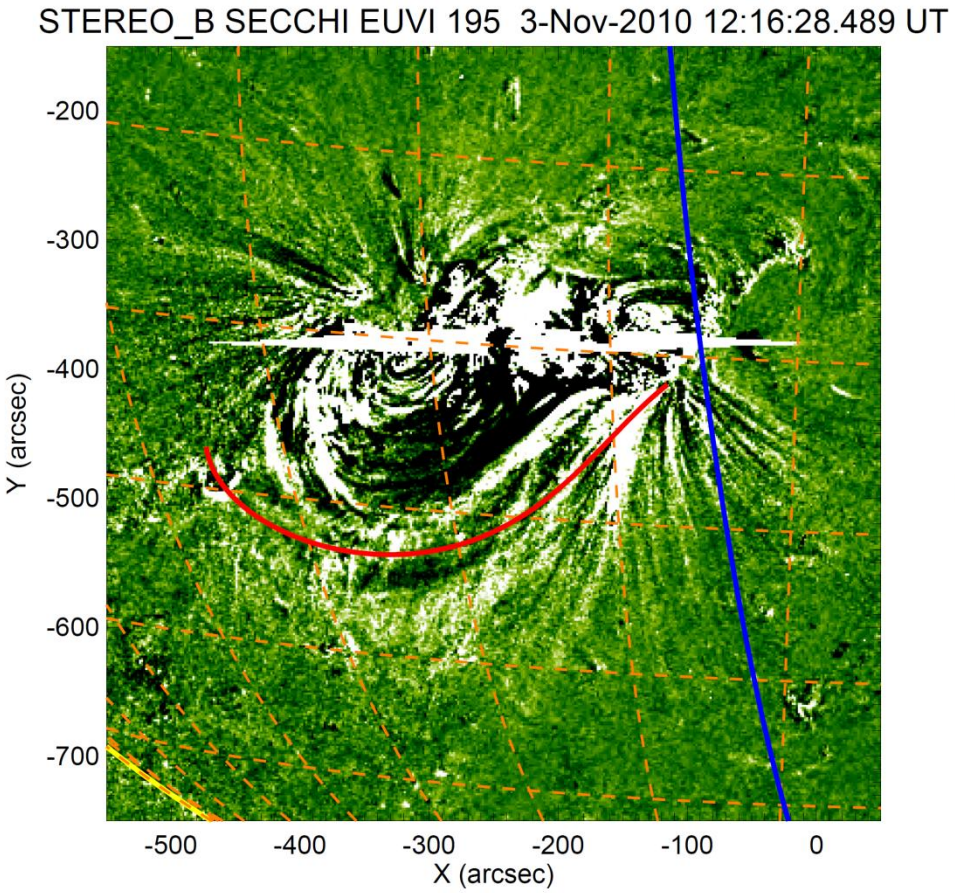


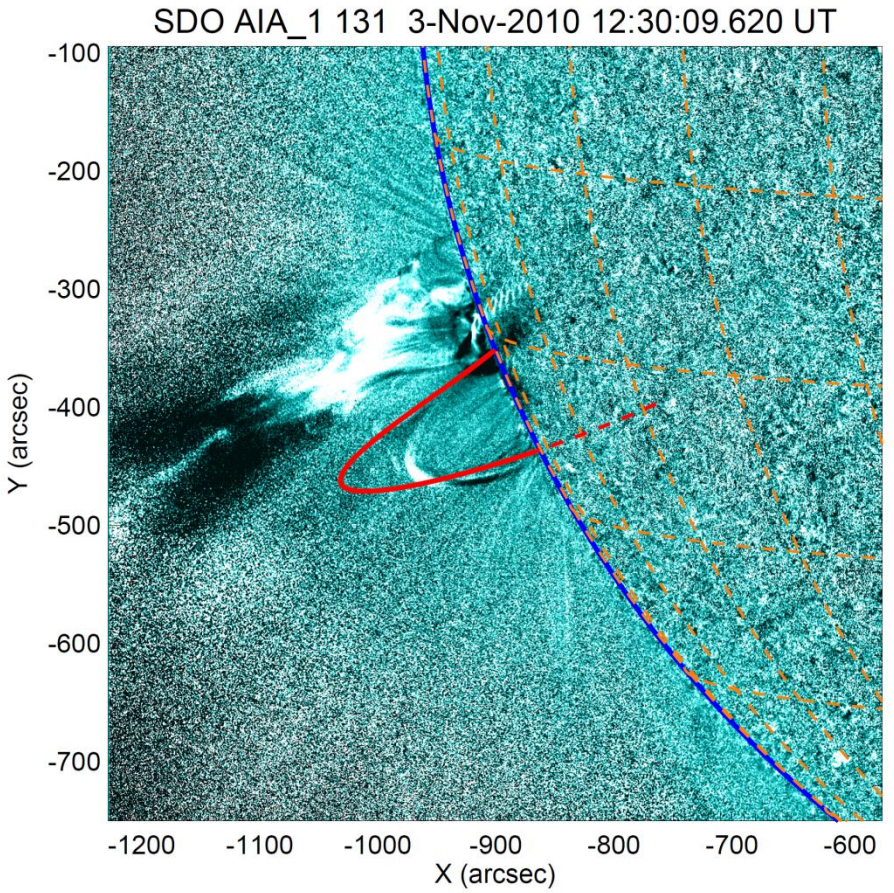
Displacement Time Series Analysis



- Two strands observed in six of the cuts.
- P = 302 ± 14 s (5 min)
- $\tau/P \sim 1$
- Northern loop leg is hidden by the poor contrast with the background plasma – no time series analysis.
- 180° phase shift suggests we observe a higher order harmonic.

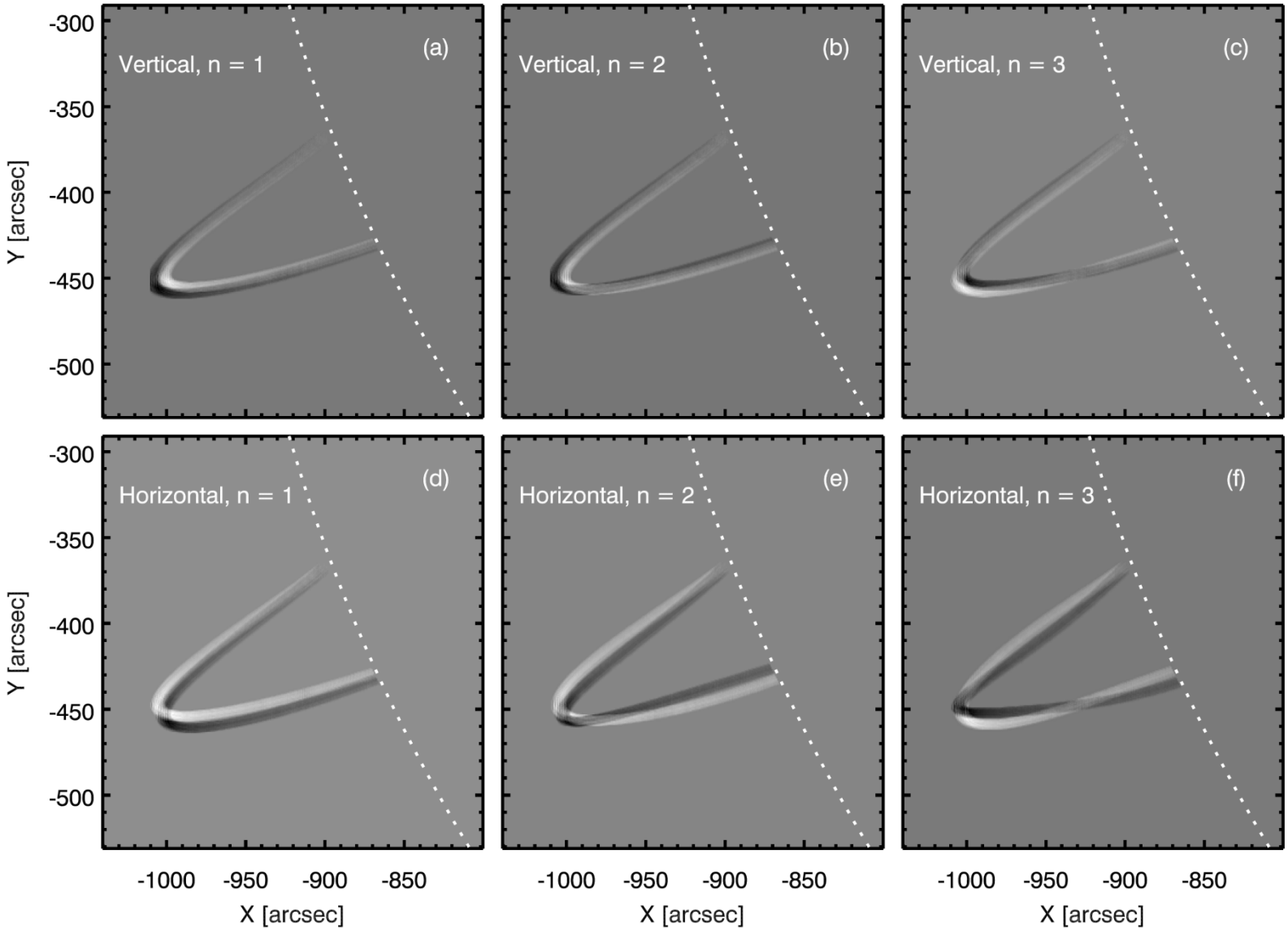
3D Loop Geometry





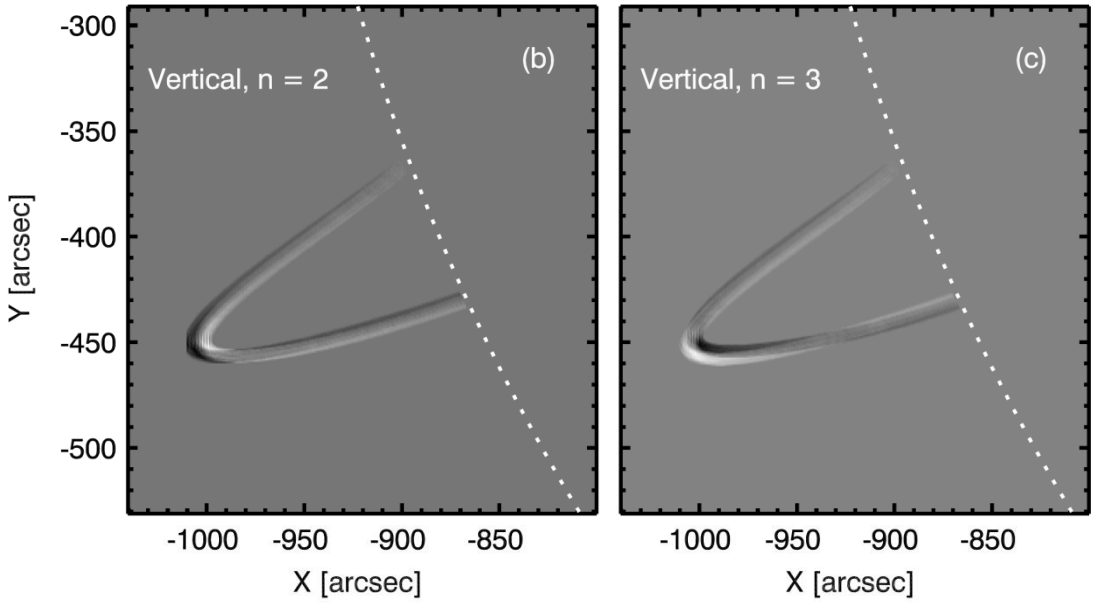
Comparison of STEREO-B and SDO viewpoints.
Loop length = 466 Mm and inclination angle = -6°.

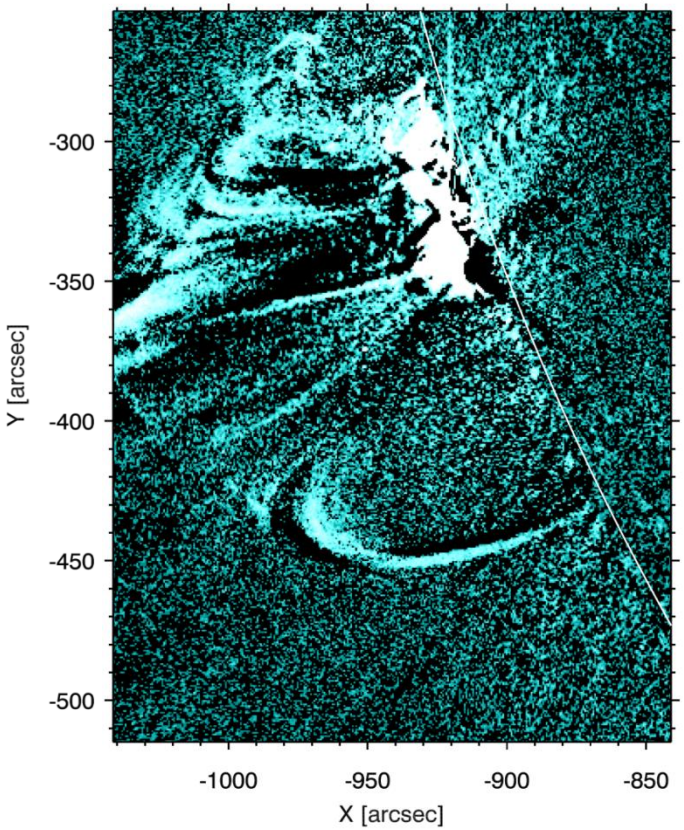
Forward Mode Modelling



Forward Mode Modelling

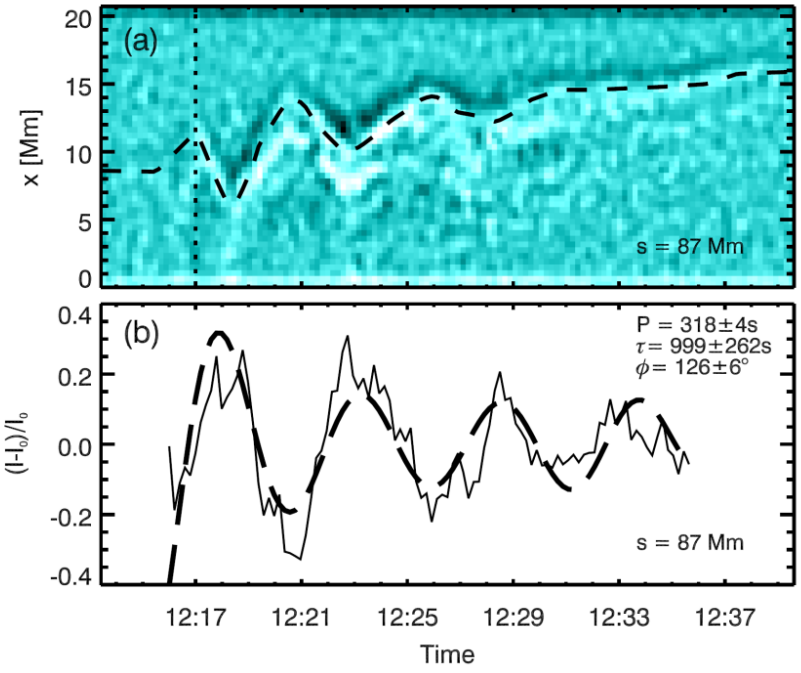
- The modelled loop is uniformly filled, has a contrast of 10 and a radius of 3 Mm.
- The forward mode modelling combined with the observation suggests a vertically polarised mode with either n=2 or n=3.





Intensity Analysis

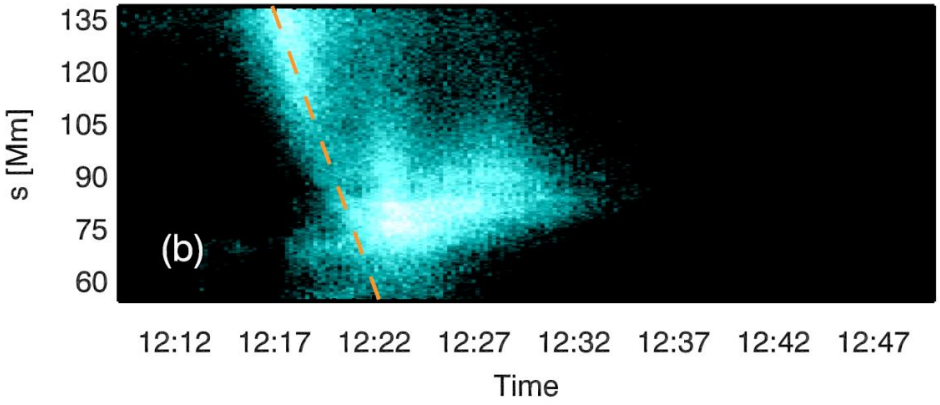
Intensity at loop location as a function of time



- Oscillations reliably extracted from two cuts.
- Periods are broadly consistent with the displacement time-series.

Intensity along the loop axis

- The Intensity front has a projected speed of about 210 kms^{-1}.



- The upflow is consistent with explosive chromospheric evaporation. *Fisher et al. (1985), ApJ, 289; Milligan et al. (2006), ApJ, 642.*
- There is some evidence of cool downflows in 304 Å.

Intensity Analysis

Can we explain the Intensity oscillations?

- **Line of sight effects?** *Cooper et al. (2003), A&A, 397*

Cannot be ruled out.

- **Linear coupling with a slow mode of the same period?**
  Terradas et al. (2011), A&A, 527

We would expect a slow mode with λ = 160 Mm but we do not detect spatial variations on this length scale.

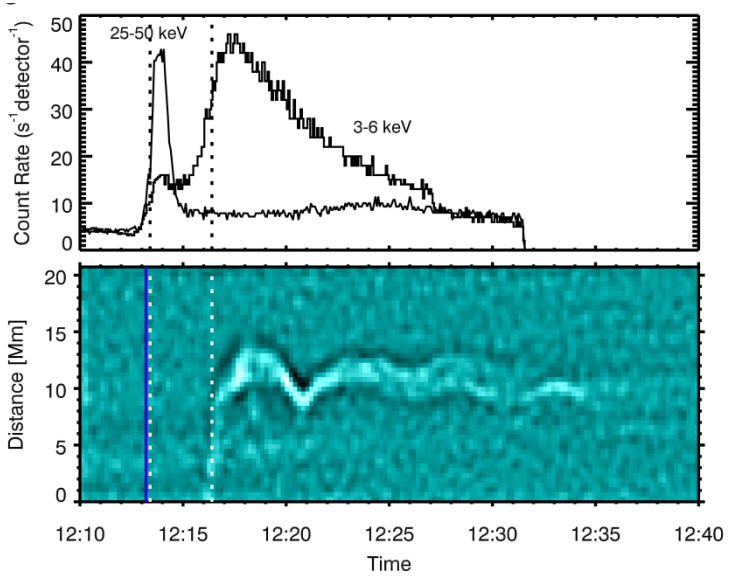
- **Intensity variations due to a vertically polarised mode?**
  Verwichte et al. (2006), A&A, 446

The relative intensity variation is given by $\delta I / I_0 \approx -4\xi / R$

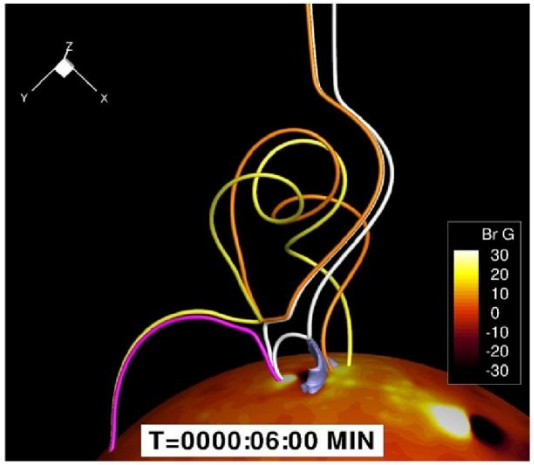
For an amplitude of 4-6 Mm and R = 150 Mm we predict a relative intensity variation of -0.1-03. This is consistent with the observation.

Loop Excitation

What are the conditions/mechanisms behind the excitation of this oscillation in a hot post flare loop?



- Excitation different to cool loops where a blast wave is often the trigger.
- Numerical simulations of vertical modes have been performed, often with a pulse located directly beneath the loop top. *Selwa et al. (2006), A&A, 454; Gruszecki et al. (2006), A&A, 460; Wasilijew & Murawski (2009), A&A, 498*



- The loop may be formed from the flare reconnection processes that excite the loop from above the loop top. 3D simulations from an active region show the formation of post flare loops. *Lugaz et al. (2011), ApJ, 738*

Conclusions

- First observation of a transverse loop oscillation in hot coronal lines.
- The loop oscillation is vertically polarised. This is supported by the detected intensity variations and the forward mode modelling.
- The loop is oscillating exclusively as a harmonic overtone (either n=2 or n=3) and the fundamental mode is suppressed.
  - For n=3: V_{ph} = 1030 kms^{-1}, V_{A0} = 730 kms^{-1} for the first strand. These are both above the sound speed (500kms^{-1}) for an 11 MK plasma.
- The excitation mechanism of this loop is different to that for the loops observed in the cooler bandpasses. We suggest that the formation and excitation is directly linked to the flare/CME reconnection processes.

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