

# Coronal loop dynamics as seen from combined Imaging & Spectroscopic observations

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# Overview

- Introduction
- Observations I
  - TRACE & CDS
  - Results
- Observations II
  - AIA & EIS
  - Results
- Conclusions

# Introduction

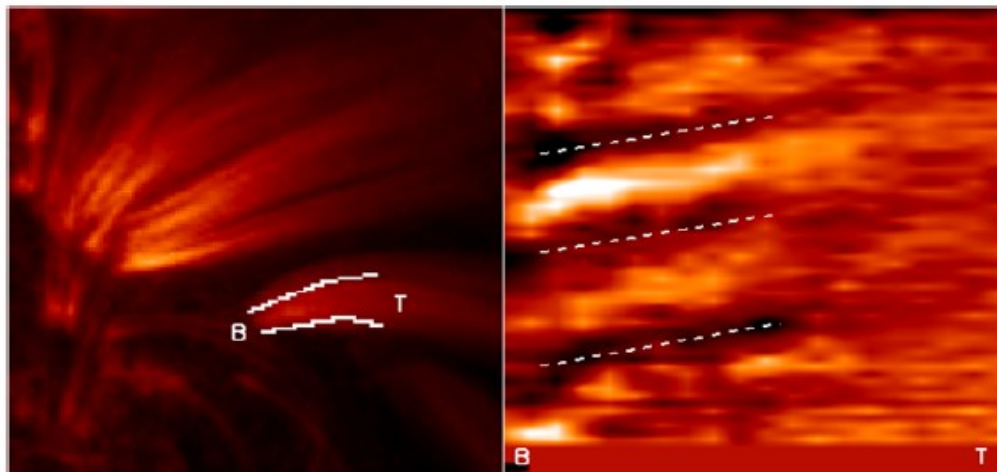
- Berghmans et al. 1999, first observed the quasi-periodic propagating intensity disturbances in fan like loop structures using EIT/SoHO in 195 Å channel.
- These were later confirmed using TRACE 171 Å data. (De Moortel et al. (2000) and were interpreted as slow magneto-acoustic modes (Nakariakov et al. 2000).
- These waves were thought to be important for understanding the energy balance and coronal seismology (Nakariakov et al. 2005).
- There were many observations of 3 min and 5 min oscillations propagating supporting their origin in photospheric p-mode wave leakage (De Pontieu et al. 2005).
- Slightly longer periods (10-15 min) were also observed by some of the authors, using EIT, TRACE & EUVI/STEREO but their origin is not clear. (Berghmans et al. 1999; McIntosh et al. 2008; Marsh et al. 2009)
- There were some attempts to study these oscillations using spectroscopy. (for e.g., Marsh et al. 2006; Wang et al. 2009)

**Table 1** Statistical overview of the averages and ranges of the physical properties of the 63 oscillations in coronal loop footpoints analysed by De Moortel et al. (2002a) and McEwan and De Moortel (2006). Note that the uncertainty in the parameters is taken to be the standard error in the mean,  $\sigma_M$ . (Taken from McEwan and De Moortel 2006)

Parameter	Average	Range
Oscillation Period, $P$	$284.0 \pm 10.4$ s	145–550 s
Propagation Speed, $v$	$99.7 \pm 3.9$ km s <sup>-1</sup>	$O(45)–O(205)$ km s <sup>-1</sup>
Relative Amplitude, $A$	$3.7\% \pm 0.2\%$	0.7–14.6%
Detection Length, $L_d$	$8.3 \pm 0.6$ Mm	2.9–23.2 Mm
Energy Flux, $F$	$313 \pm 26$ erg cm <sup>-2</sup> s <sup>-1</sup>	68–1560 erg cm <sup>-2</sup> s <sup>-1</sup>

**Table 2** Overview of the propagation speeds of propagating slow MHD waves detected in coronal loop (adapted from De Moortel 2006)

	Speed (km/s)	Wavelength
Nightingale et al. (1999)	130–190	171 & 195
Schrijver et al. (1999)	70–100	195
Berghmans and Clette (1999)	75–200	195
De Moortel et al. (2000)	70–165	171
Robbrecht et al. (2001)	65–150	171 & 195
Berghmans et al. (2001)	~300	SXT
De Moortel et al. (2002a)	$122 \pm 43$	171
King et al. (2003)	25–40	171 & 195
McEwan and De Moortel (2006)	$98 \pm 6$	171



# Observations I : TRACE & CDS

Details of the 11<sup>th</sup> September 2003 JOP165 data.

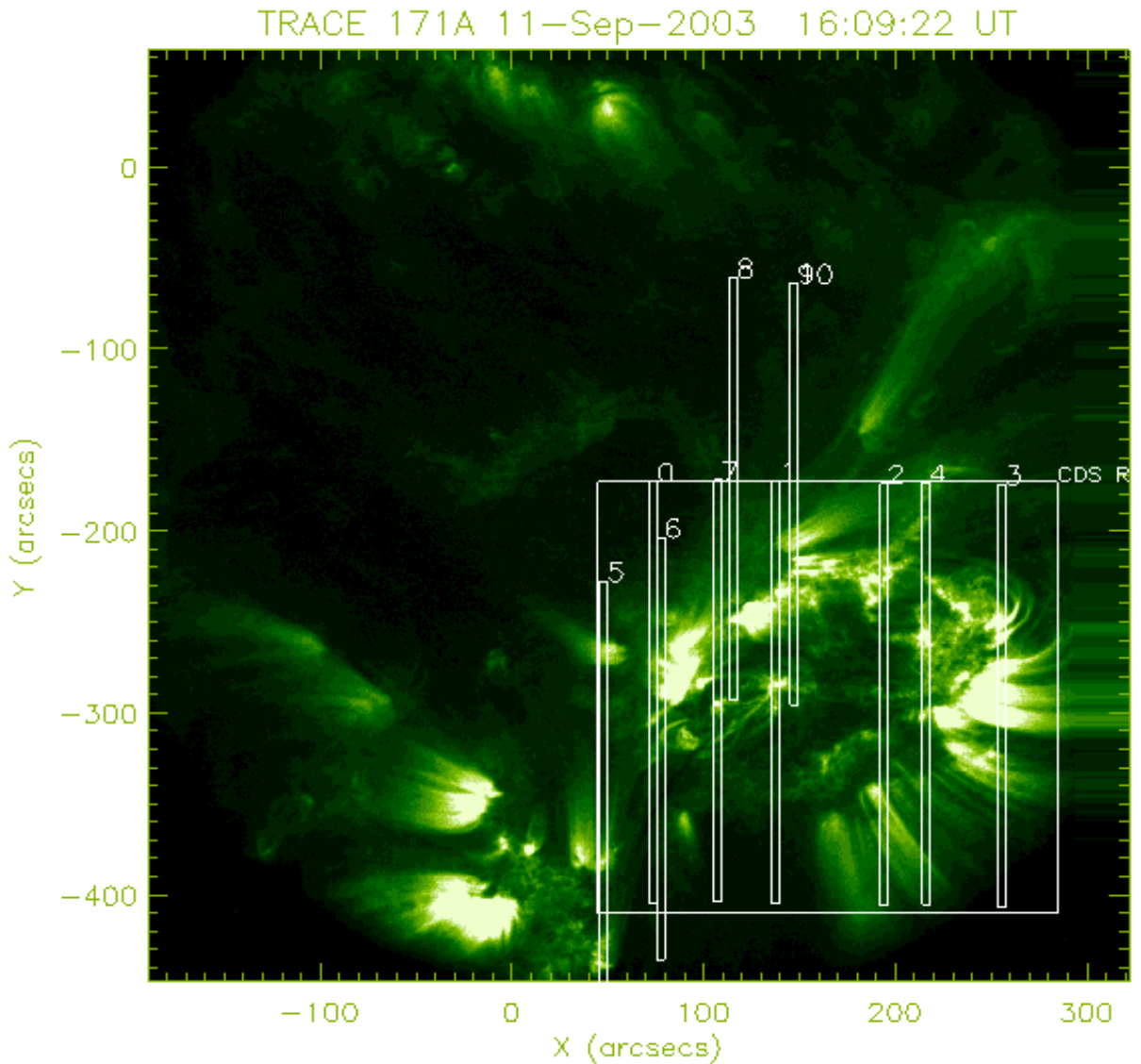
Data	Start & End time	Total duration (approx.)	Cadence	Exp. time	Spatial resolution
TRACE Images	13:00:17.000 - 20:59:32.000	8 Hours	1 min.	46.34 sec.	0.5" x 0.5"
CDS Raster	13:45:34.712 - 14:07:15.715	22 min.	21 sec	15 sec	4" x 3.3"
CDS Slits [Sit & Stare] (Total 11 slits 0-10, each of duration 30min.)	14:07:51.199 - 19:37:26.081	5 ½ Hours	21 sec.	15 sec.	4" x 3.3"
CDS Raster	19:38:10.087 - 19:59:49.583	22 min.	21 sec	15 sec	4" x 3.3"

# Field of view

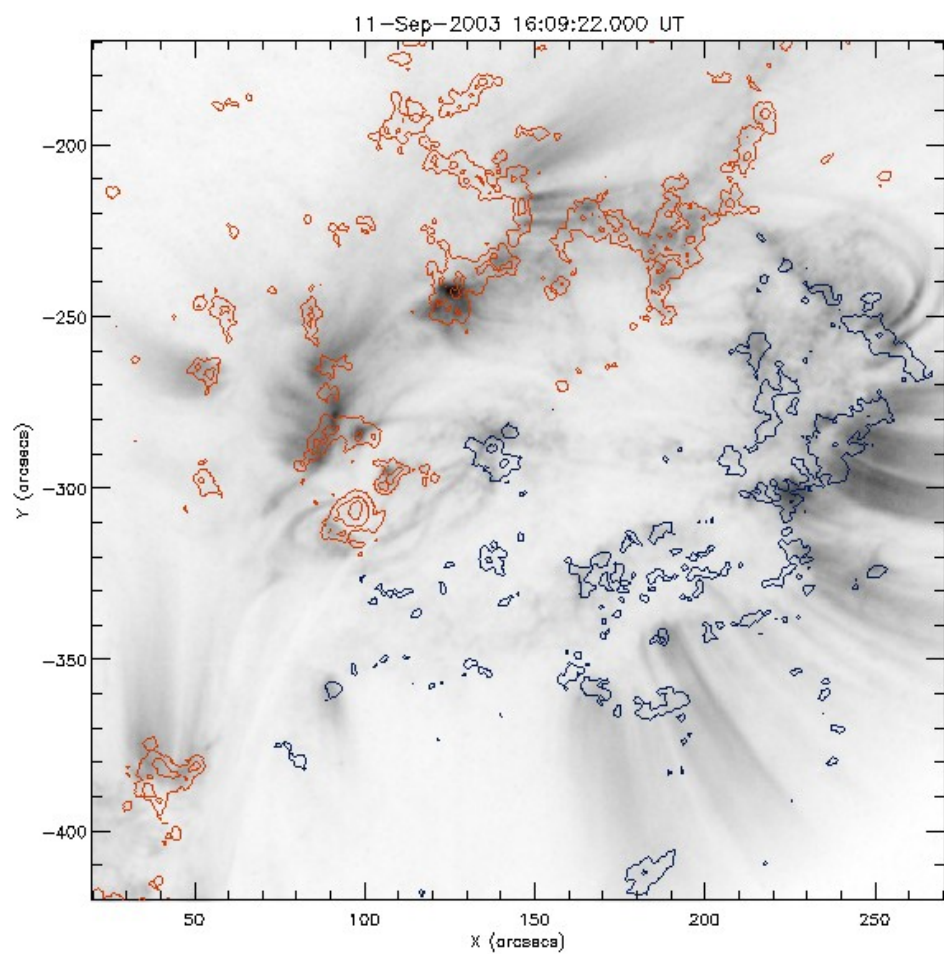
NOAA no. : AR 10457

TRACE FOV: 512" X 512"

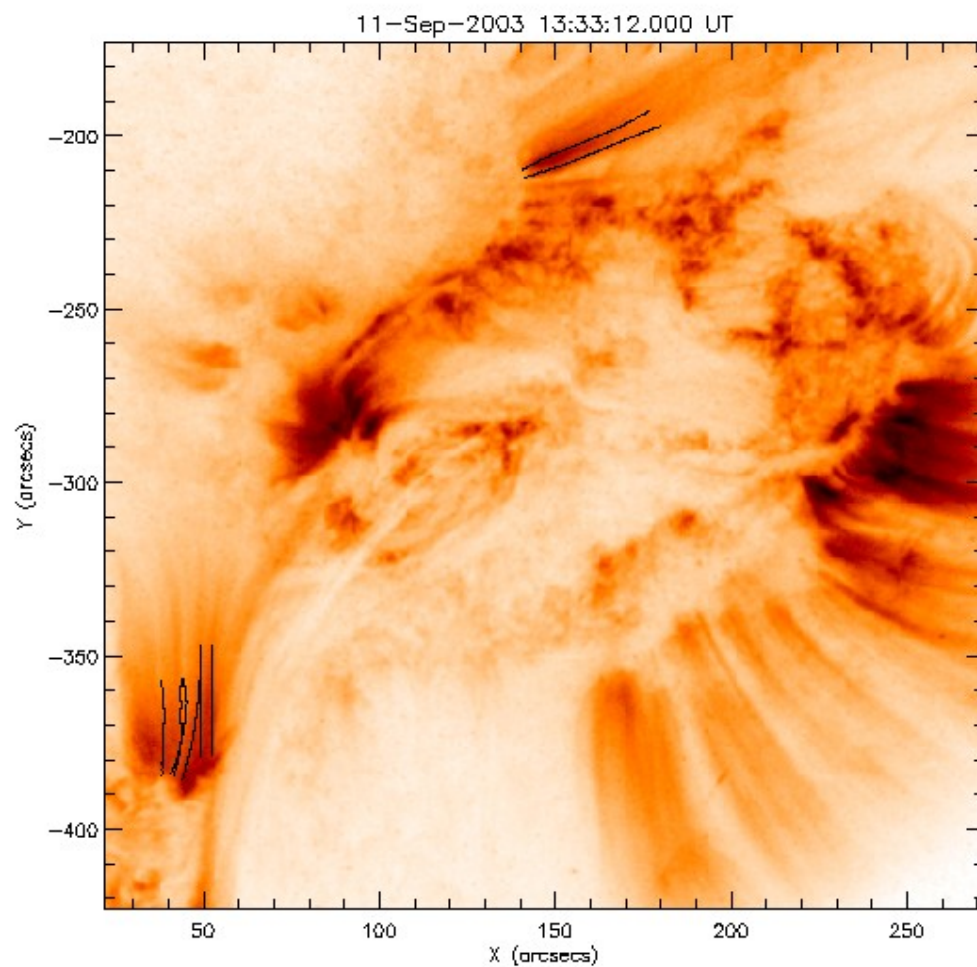
CDS FOV: 240" X 231"



MDI magnetogram over plotted on TRACE



Location of fan loops chosen from TRACE

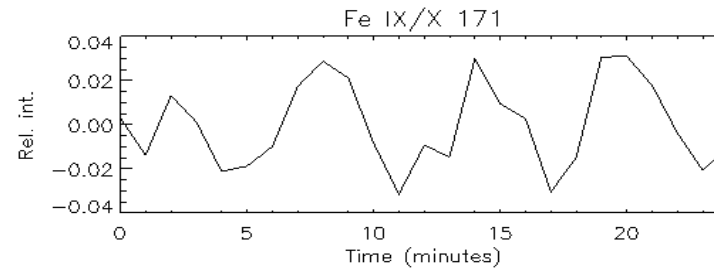
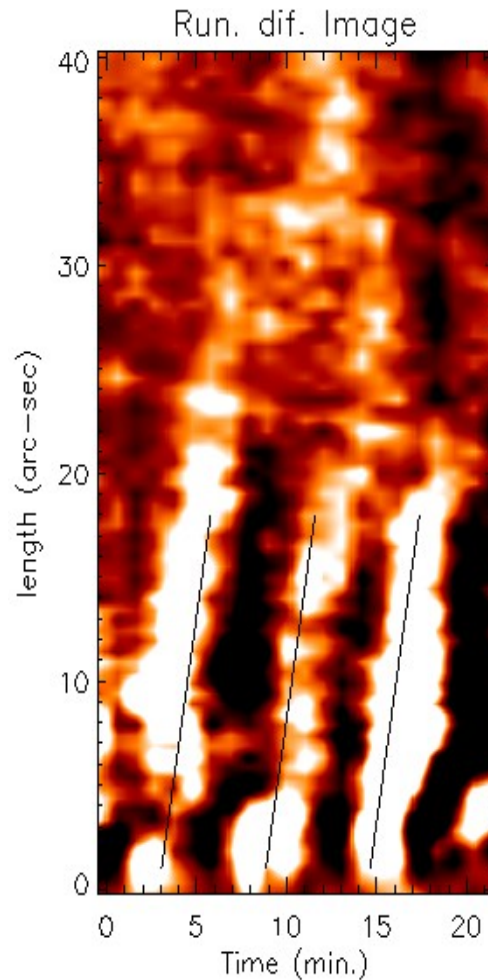


# Results and discussion

At Pos 11 : Running difference image and wavelet diagram.

Projected propagation speed: 74.46 km/s  
Periodicity: 5.8 min.

Wavelet at pixel 30 from the foot point



Global Period at max.  
power (< 8.8 min.)  
= 5.8 min.  
Prob. level: 99–100%

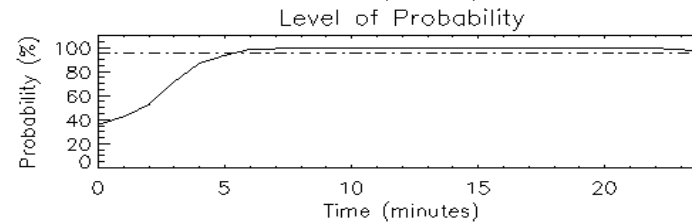
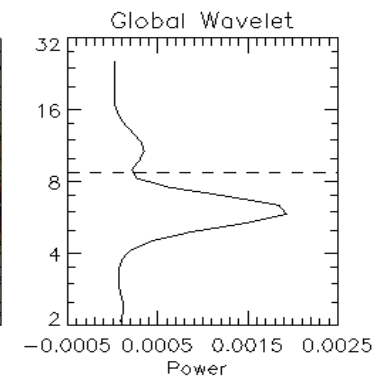
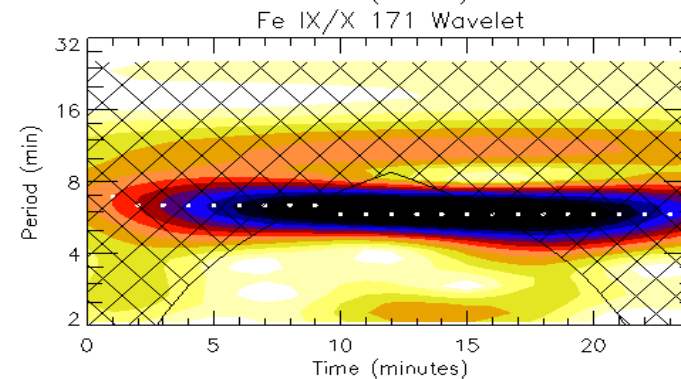
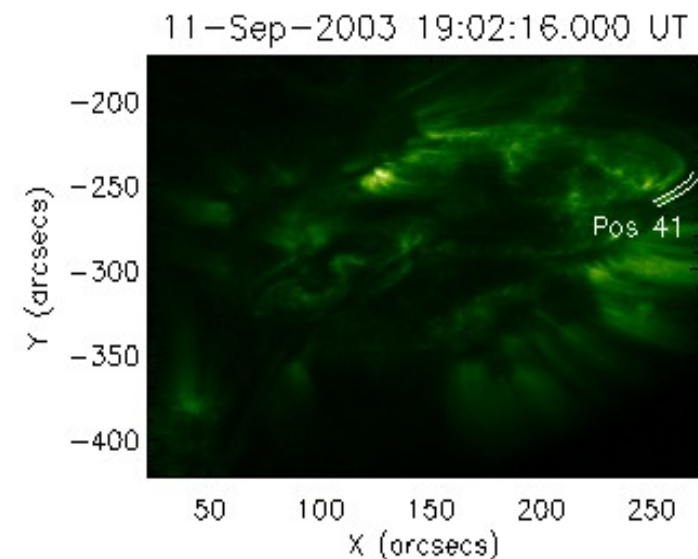
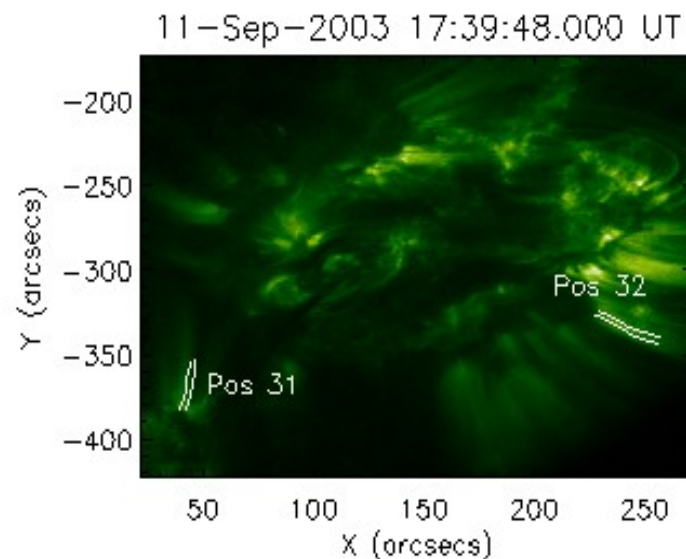
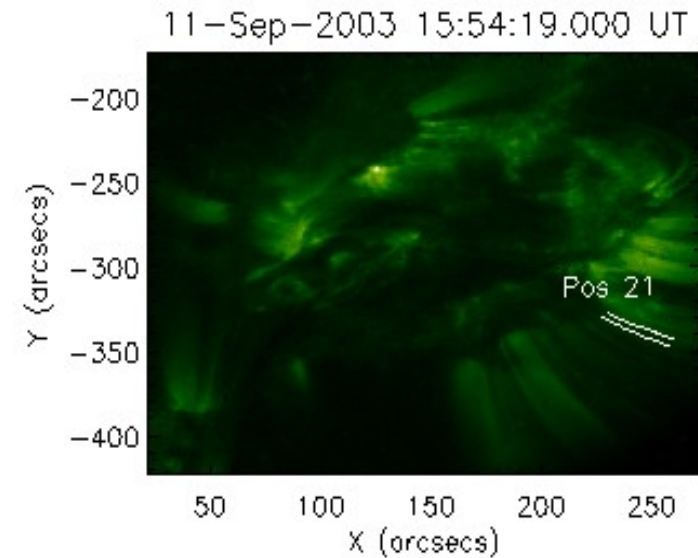
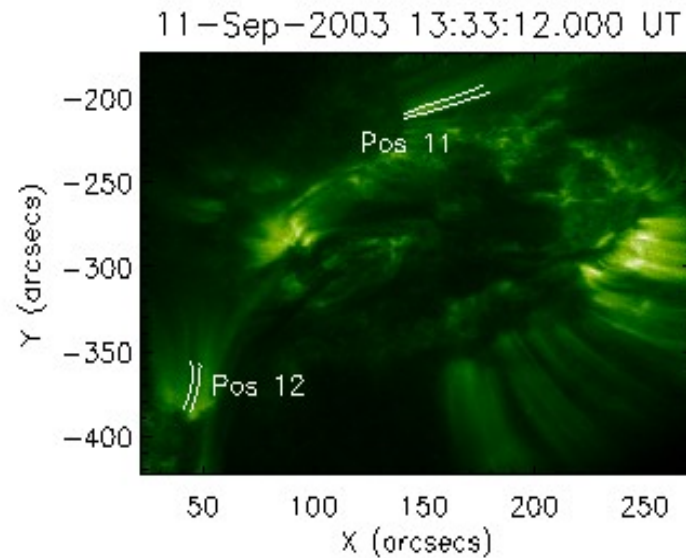
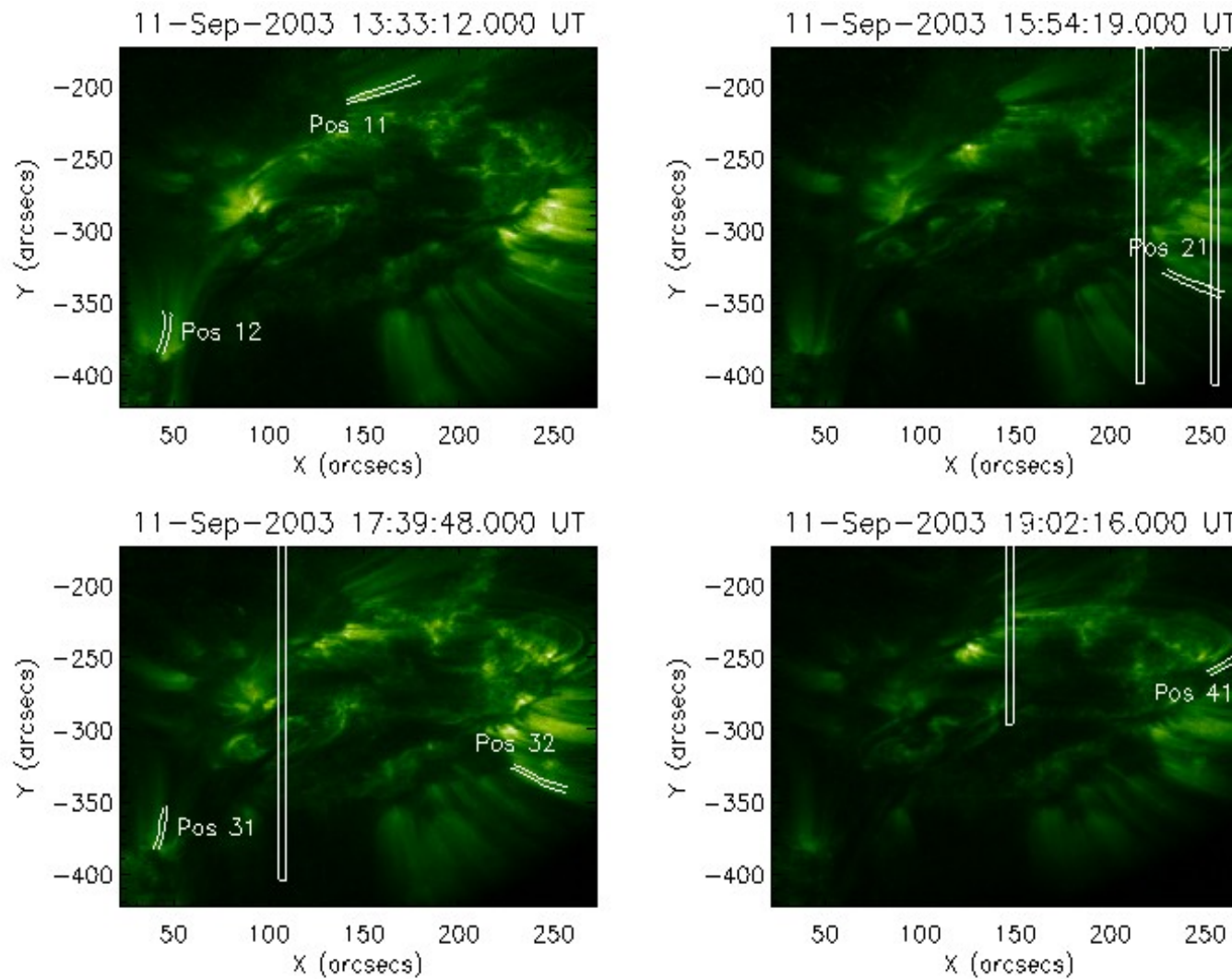


Image showing the locations where significant oscillation is found. Different images represent different time slots

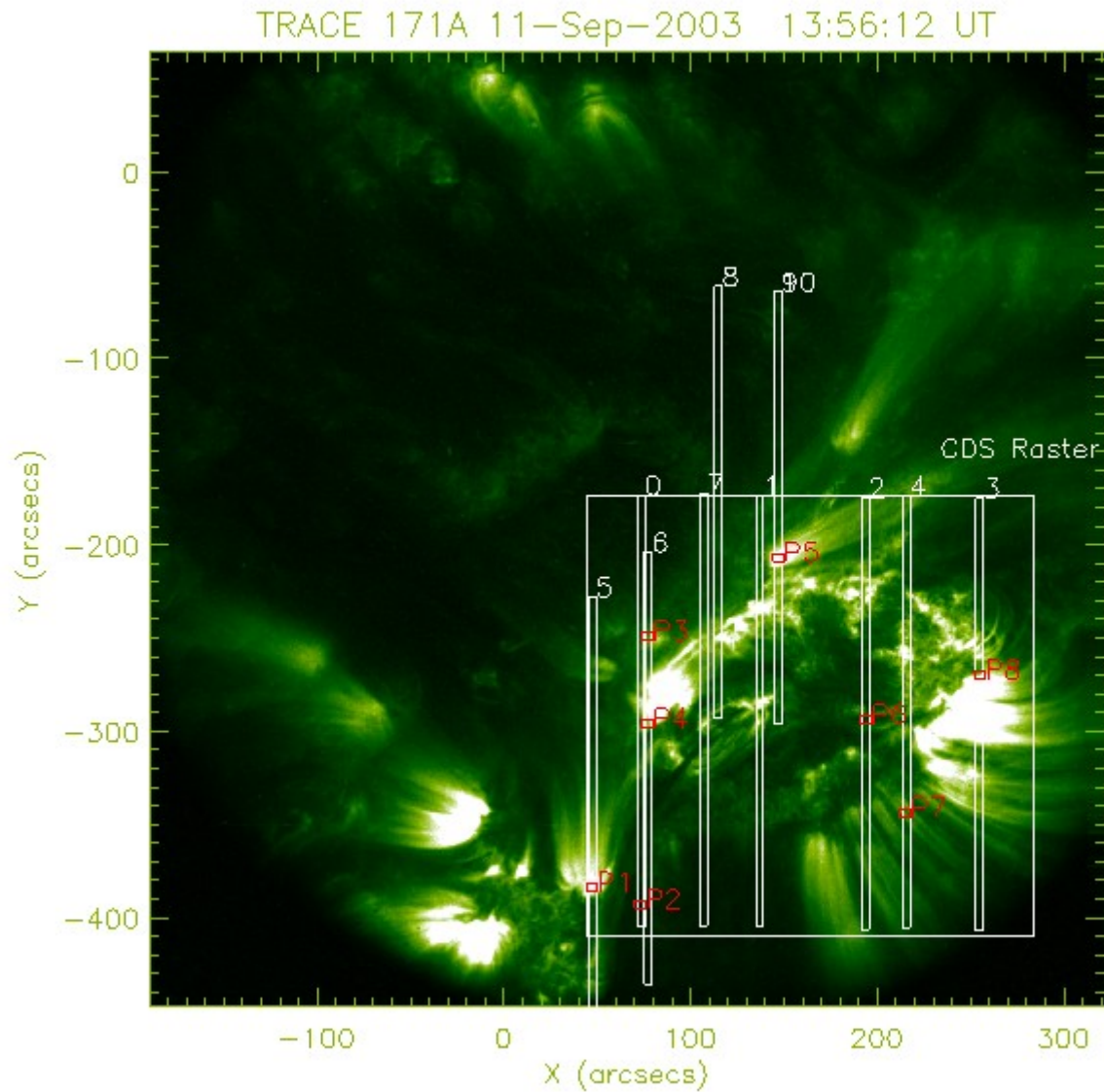


# Image showing CDS slit locations in the time slots chosen



No overlaps!!

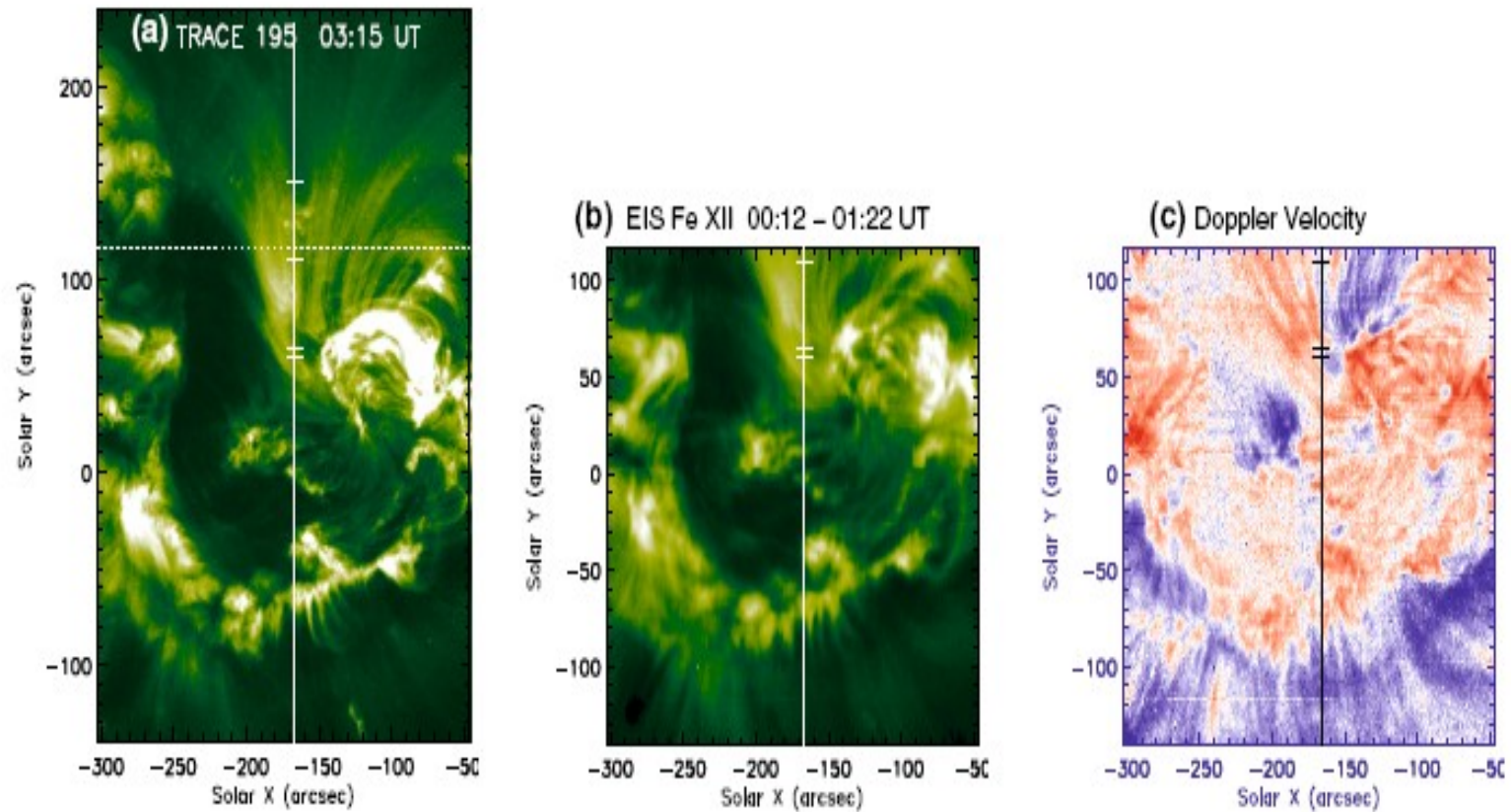
We studied CDS independently. Following plot shows the locations on CDS where significant oscillations are identified.



Location (sol_x,sol_y)	Slit No.	Spectral line	Int. Oscill. period Primary (secondary) ( in min.)	Prob. Level (%)	Vel. Oscill. period Primary (secondary) (in min.)	Prob. Level (%)
P1 (47,-384)	5	O_V	4.5 (6.9)	99-100	-	-
		He_I	6.3 (4.9)	99-100	4.9 (~10)	97.5
P2 (73,-393)	0	O_V	5.3(~10)	99-100	-	-
P3 (77,-249)	6	O_V	8.2(4.1)	99-100	8.2(2.9)	99-100
P4 (77,-296)	6	O_V	5.8(~10)	99-100	5.3 (~11)	99
P5 (147,-207)	10	O_V	9.0(4.9)	99-100	-	-
P6 (194,-294)	2	O_V	5.8(9.0)	99-100	-	-
P7 (215,-343)	4	O_V	6.3(9.8)	99-100	8.2(5.3)	99-100
		He_I	6.9(6.9)	99-100	5.3(~11)	99-100
P8 (255,-271)	3	O_V	9.8(4.9)	99-100	6.9(6.9)	99-100
		He_I	9.0(2.1)	99-100	9.0(9.0)	99-100

# Conclusions: part I

- We find around ~5 min oscillations from TRACE, exhibiting the properties like damping and filamentary nature.
- The propagation speeds, periodicities, and intensity amplitudes fall in the range given by De Moortel et. Al (2009)
- Although, we could not get the simultaneous spectroscopic information, independent analysis from CDS indicate that these are more likely to be slow magneto-acoustic waves.

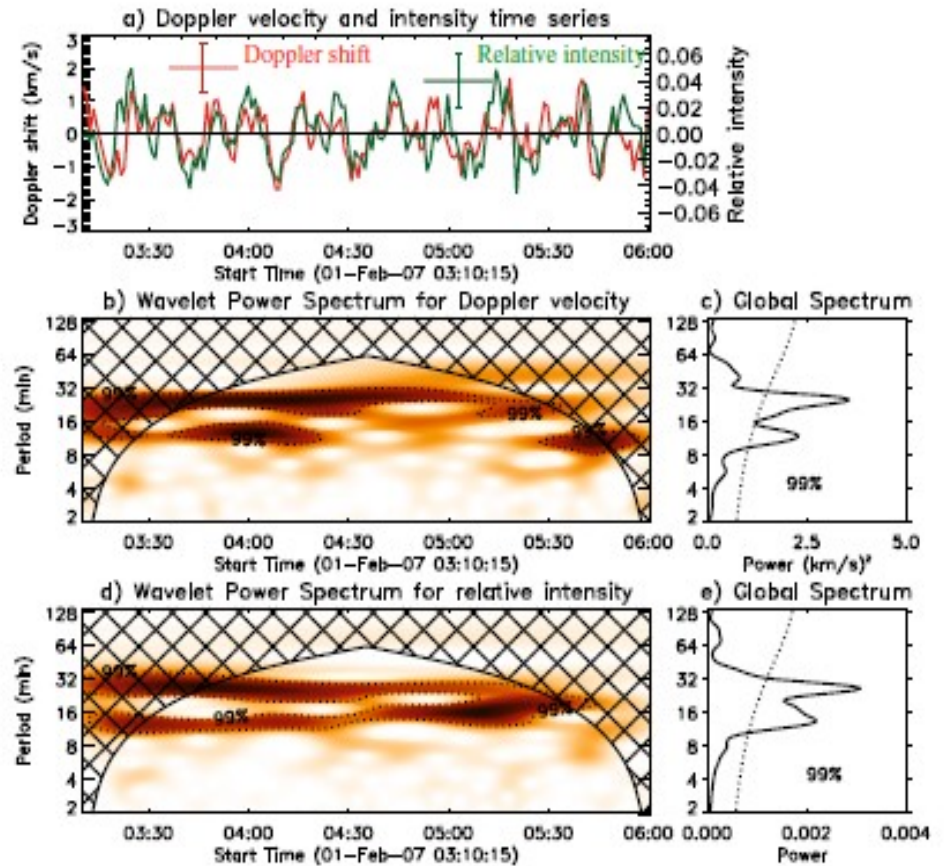
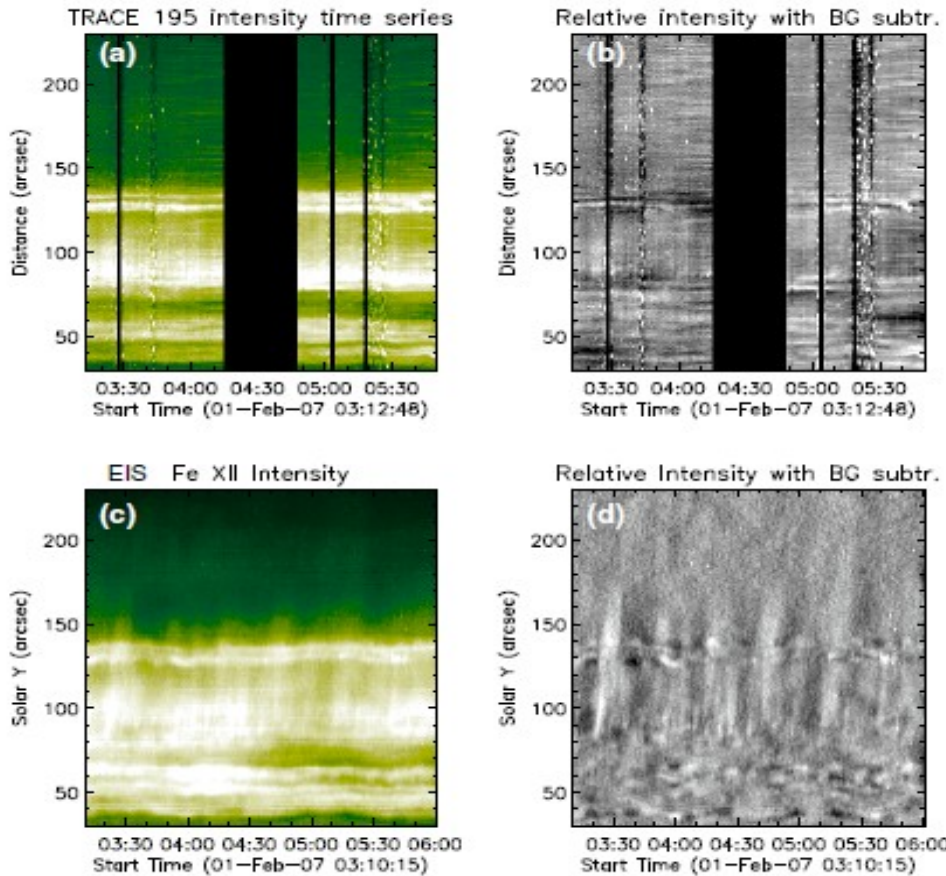


**Fig. 1.** a) The TRACE  $\lambda 195$  bandpass image. b) The intensity map in the Fe XII  $\lambda 195.12$  line from EIS. The raster observation was taken from 00:12 to 01:22 UT on 2007 February 1. c) The Doppler velocity measurements. The red color represents the redshift and the blue color the blueshift with a scale range from  $-20 \text{ km s}^{-1}$  to  $+20 \text{ km s}^{-1}$ . The vertical line in each plot shows the position of the EIS 1" slit for the sit-and-stare observation. The short horizontal lines on the slit mark the positions where the oscillations are analyzed.

Wang et. al (2009)

# Analysis from TRACE & EIS

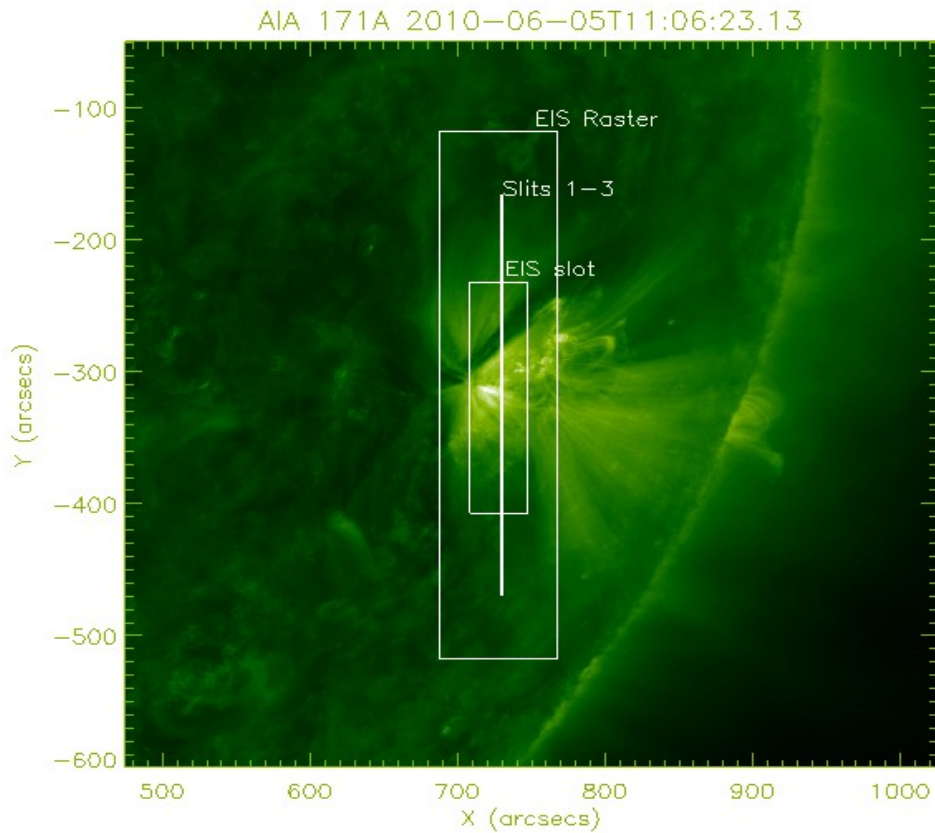
# Wavelet at $y=110''$



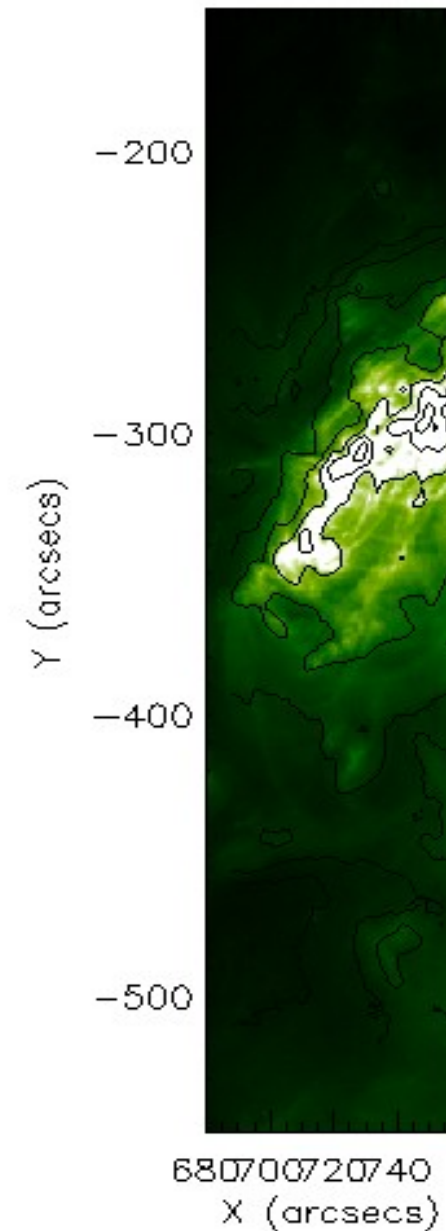
Periodicities observed : 12 & 25 min ; Propagation speeds : 100 -120 km/s;  
 Temperature: 0.7 +/- 0.3 MK; Magnetic field inclination: 59 +/- 8 degrees.

- De Pontieu & McIntosh (2010) repeated Wang's analysis using their R-B asymmetry technique. They find significant blue shifts 75 km/s to 125 km/s in the line profiles.
- They also found line width oscillations in addition to the observed intensity and velocity oscillations and showed from simulations that this can be possible by quasi-periodic high speed upflows
- McIntosh et al (2010) using STEREO observations in polar plumes, suggested that these could be more likely quasi-periodic high speed upflows rather than waves.
- Verwichte et al (2010) showed theoretically that the slow modes can produce the line asymmetries when the emission line is averaged over an oscillation period.

# Data



5-Jun-2010 11:06:18.620 UT



## HOP 156 observations:

EIS raster for context

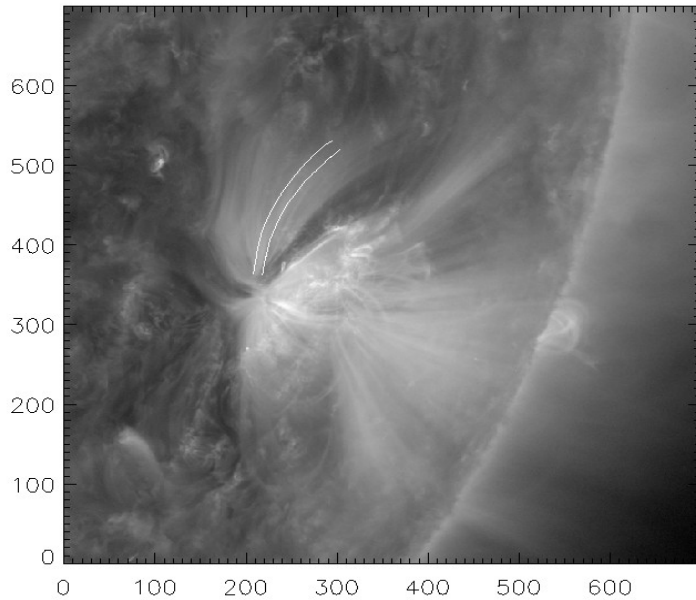
EIS slot of cadence: ~6s

EIS slit of cadence: ~6s

Spatial pixel: 1 arcsec

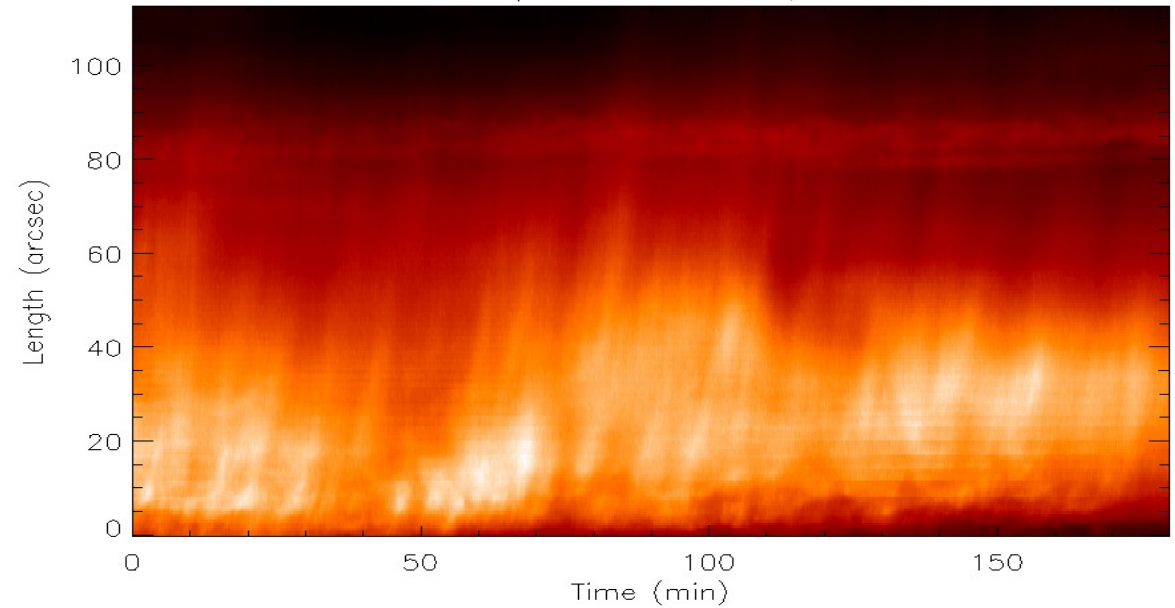
Total duration of observation: 1hr (11:00 - 12:00 UT)

### Loop location



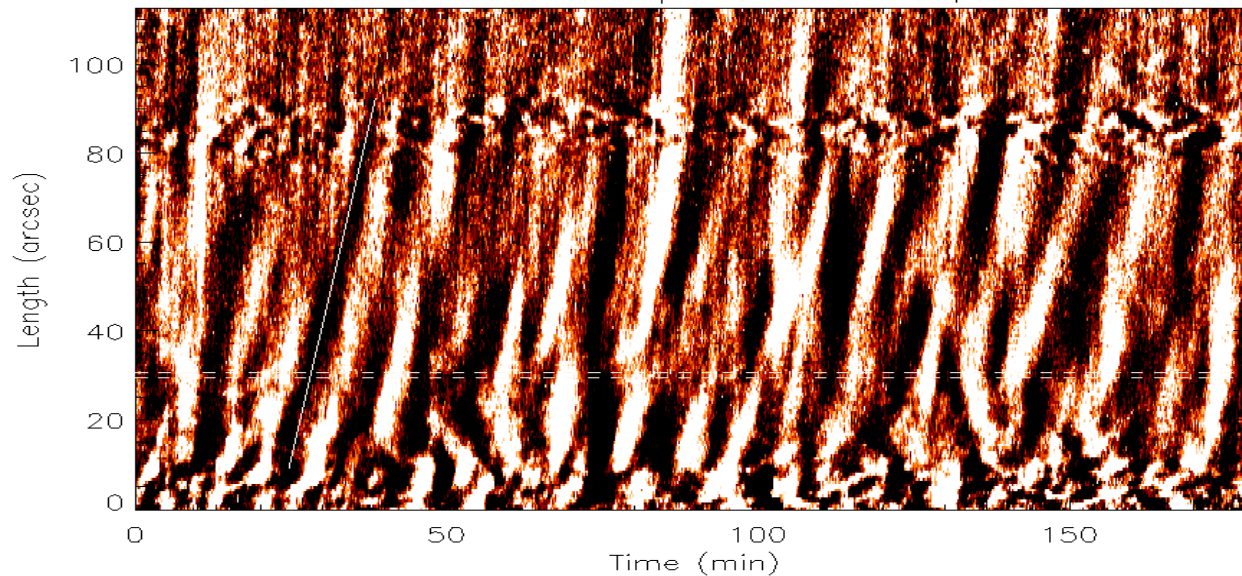
### Space-Time map

Space-Time map



### Processed Space-Time map

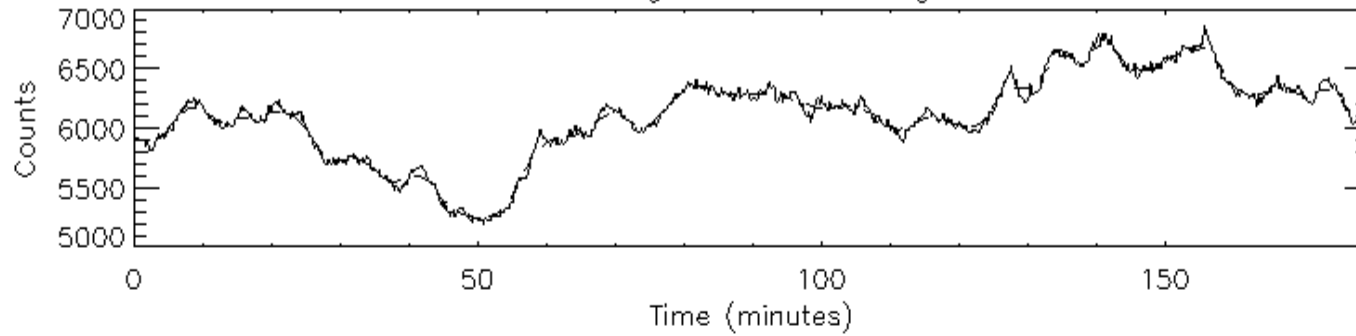
Processed Space-Time map



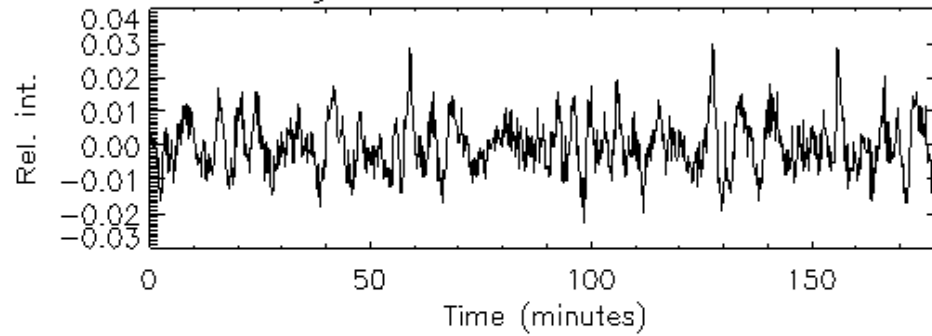
Observed periodicity  
from the map:  $\sim 8$  min

Projected propagation  
Speed: 72 km/s

Fe\_IX Light curve – Original

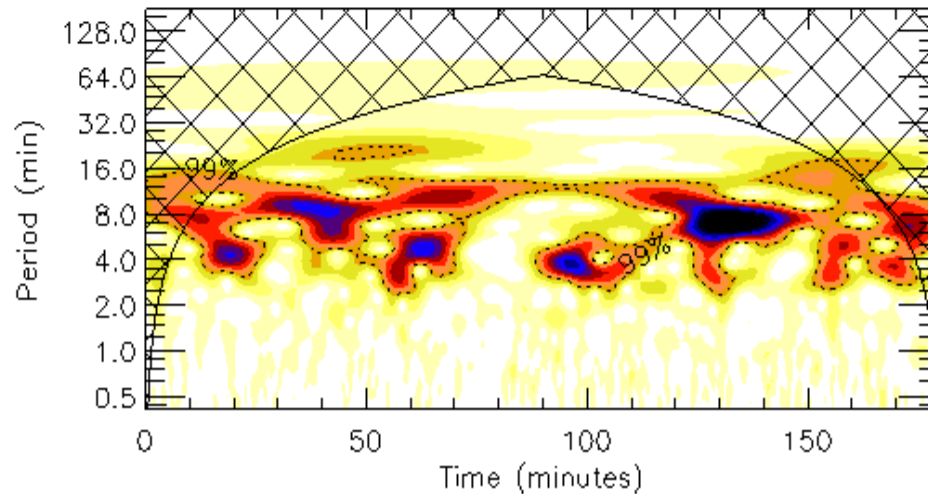


Fe\_IX Light curve – After trend subtraction

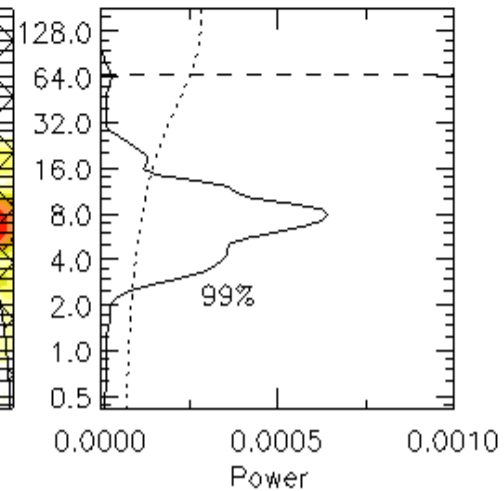


Global Period at max.  
power (< 65.6 min.)  
P1= 7.9 min.  
Second highest Peak  
P2= 4.3 min.

Fe\_IX Wavelet



Global Wavelet



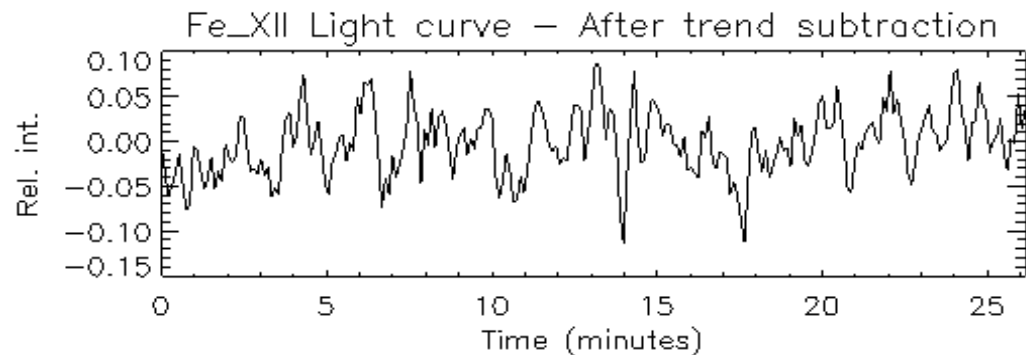
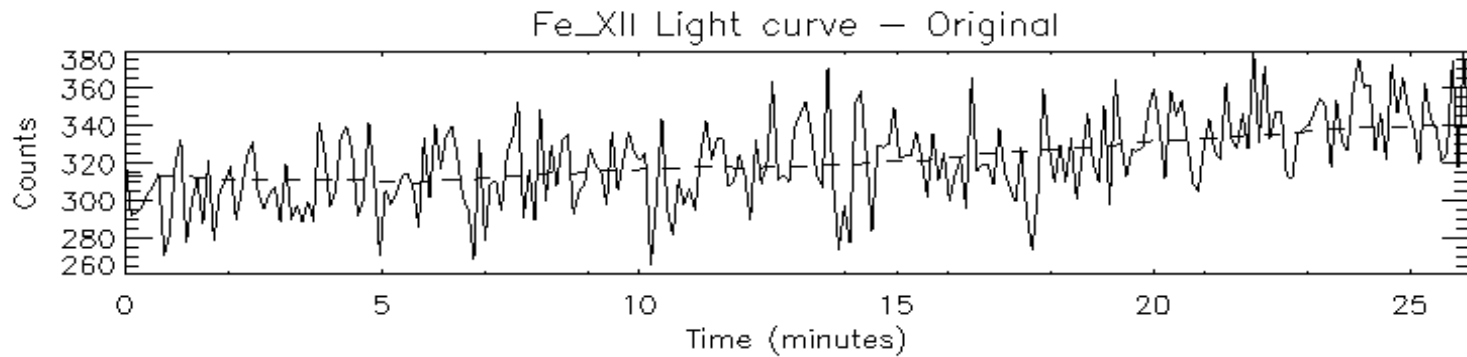
## Comparison of results from 171 A and 193 channels

	171 A channel	193 A channel
Observed periodicities (min)	37.4	31.4
	20.4	18.7
	12.1	12.1
	<b>7.9</b>	<b>8.6</b>
	4.3	4.3
Projected propagation speeds (km/s)	72	65
Theoretical acoustic speeds (km/s)	136	170

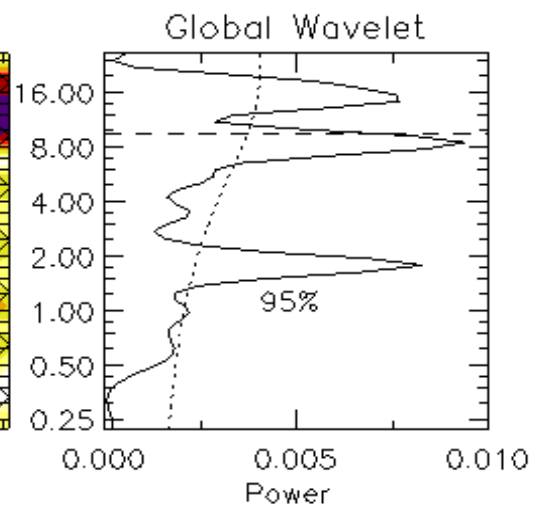
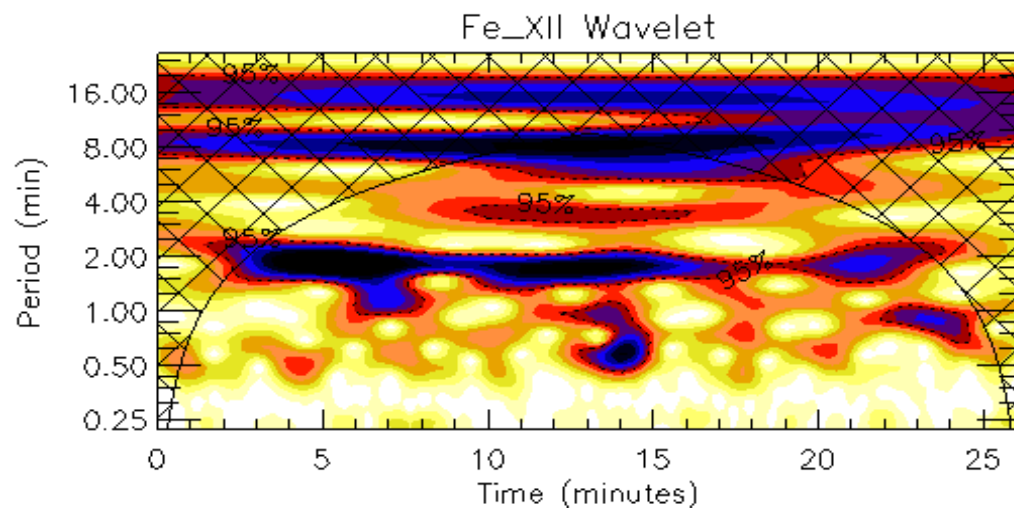
Theoretical speeds are calculated from  $C_s = 152 T^{(1/2)} \text{ m/s} \cdot T \text{ (K)}$   
Ref: Priest (1984)

Peak temperatures: 171 channel - 0.8 MK  
193 channel - 1.25 MK

# Results from EIS - Intensity oscillations

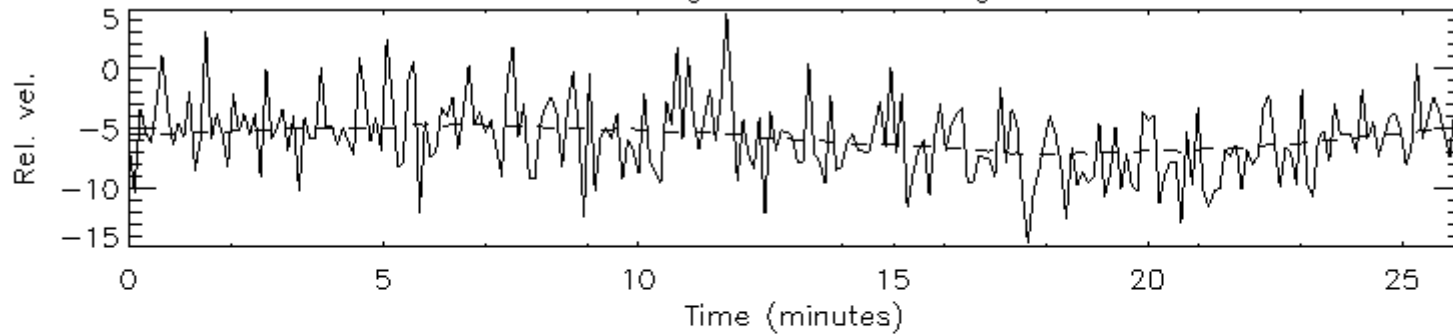


Global Period at max.  
power (< 9.5 min.)  
P1= 8.5 min.  
Second highest Peak  
P2= 1.8 min.

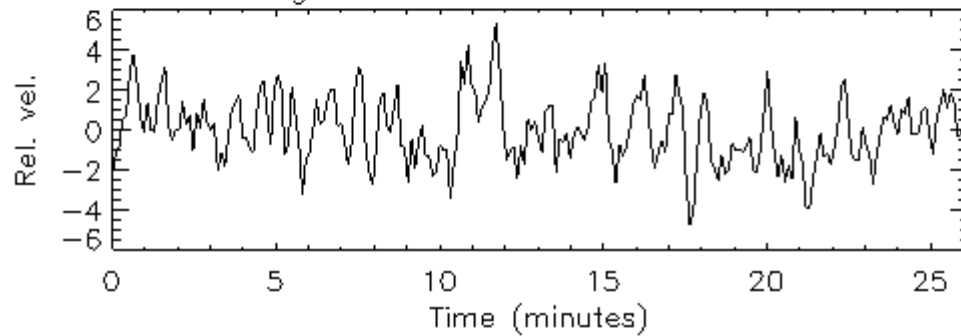


# Velocity oscillations

Fe\_XII Light curve – Original

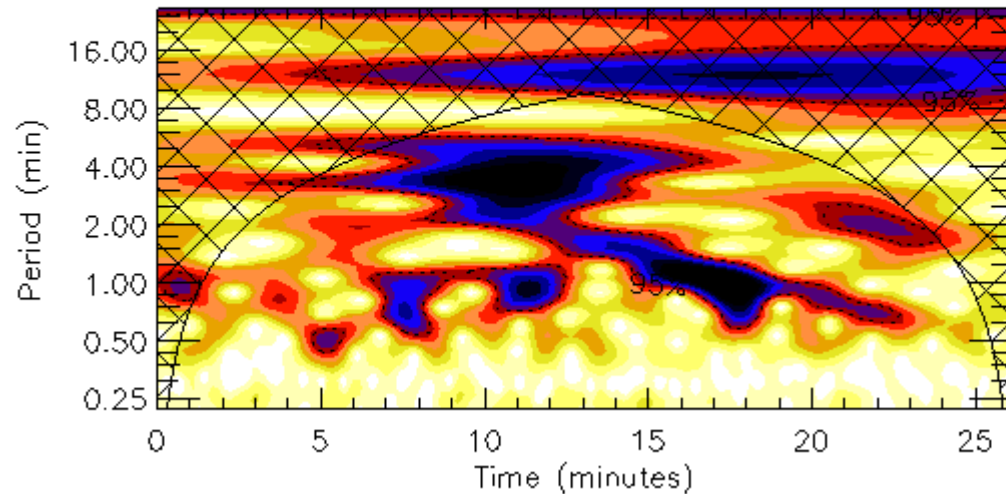


Fe\_XII Light curve – After trend subtraction

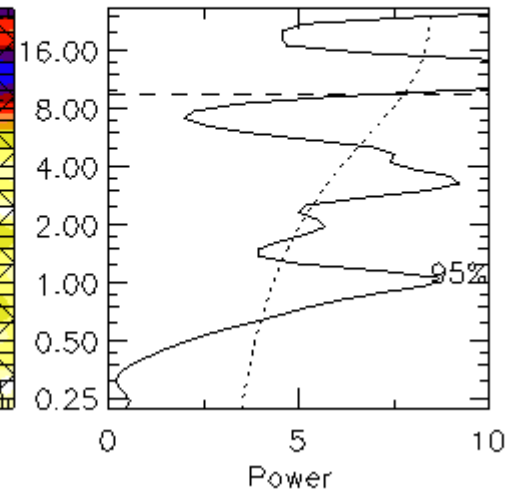


Global Period at max.  
power (< 9.5 min.)  
P1= 3.3 min.  
Second highest Peak  
P2= 1.1 min.

Fe\_XII Wavelet



Global Wavelet



## Conclusions : part II

- Multiple periodicities observed ranging from 4 min to 38 min. in both 171 A and 193 A – Periodicities comparable to that observed in polar regions?
- Projected propagation speeds are almost same in both the channels of AIA. Flows?
- The dominant  $\sim 8$  min periodicity is observed with confidence only from EIS intensity oscillations.
- This could be probably due to the low signal to noise of EIS observations.
- The exact nature of these oscillations cannot be predicted from the current analysis.

**Thank you for your attention!**

# Backup

Fig. 3 Running Difference in TRACE 171 Å (top) and 195 Å (bottom), adapted from King et al. (2003)

