Evidence of Excitation Sources of oscillations in solar coronal loops

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IRIS 10 meeting (Bengaluru)
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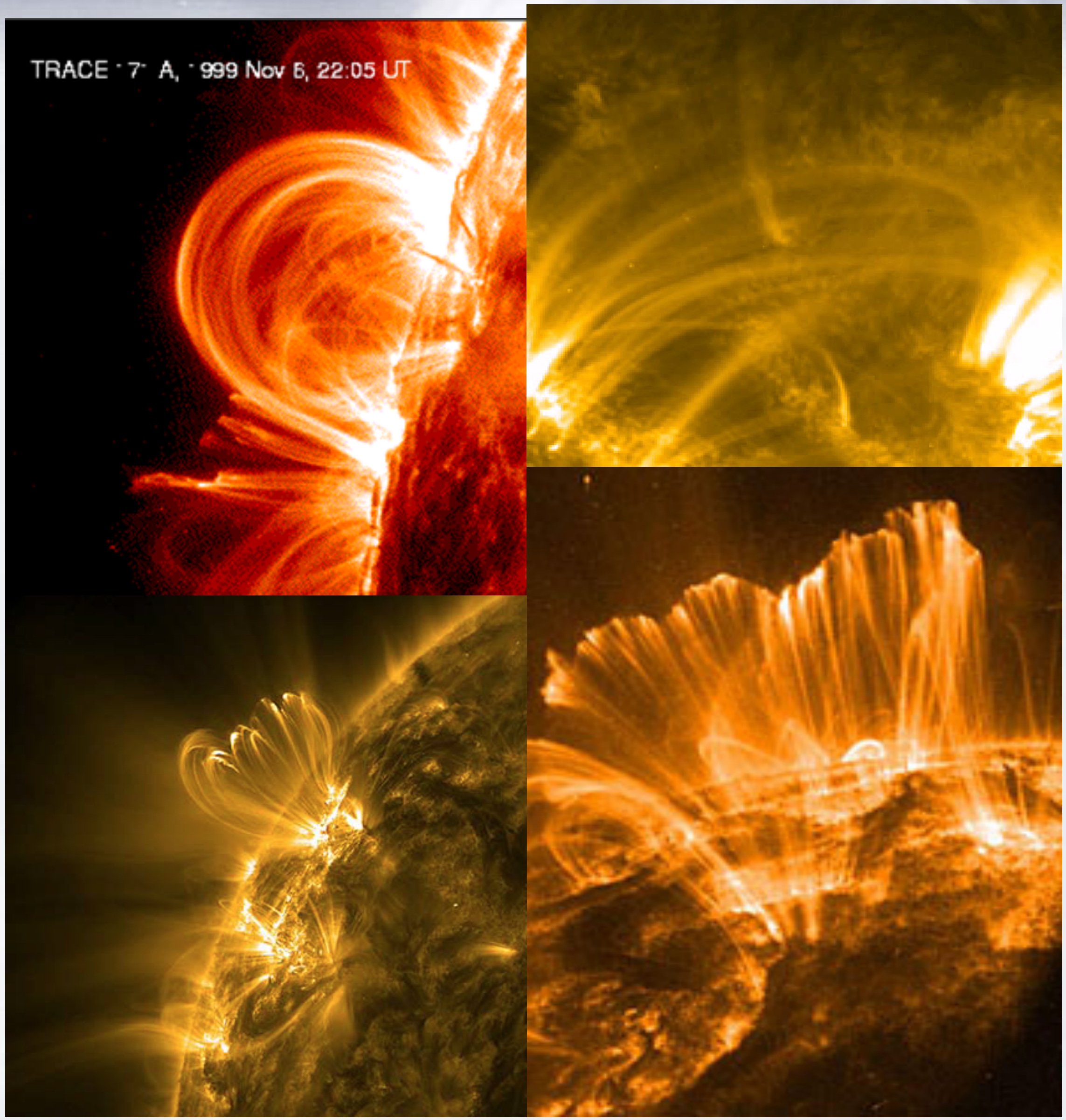
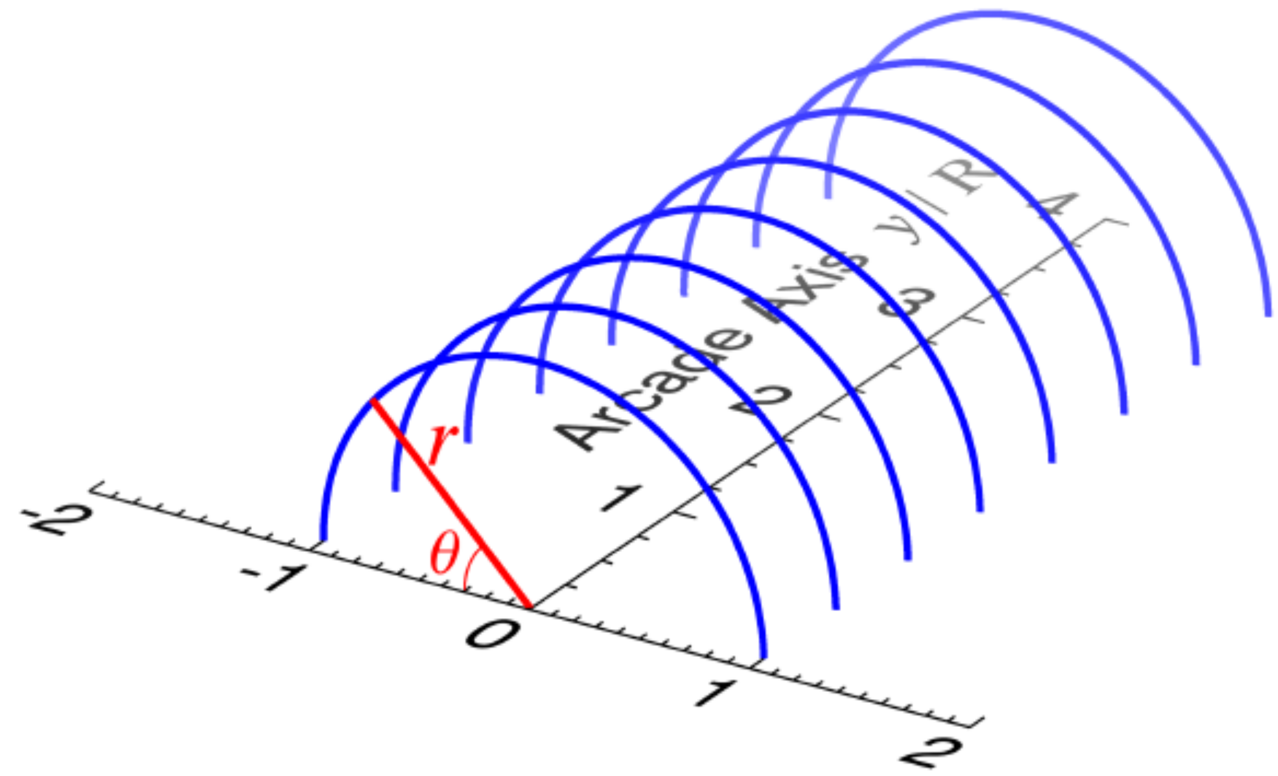
Coronal Arcades



Large amplitude decaying
and
Small amplitude decayless
oscillations

Source: NASA: TRACE, SDO/AIA

A three-dimensional cylindrical waveguide



Hindman and Jain (2015).

Investigated fast MHD wave propagation

Two-component signal

$$S(s,y,t) = S_{bg}(s,y,t) + S_{imp}(s)\delta(t-t')\delta(y-y')$$

Low amplitude, continuous, broad-band driver (could be due to random movement of the footpoints by convective motions or buffeting from ambient waves in corona outside the waveguide)

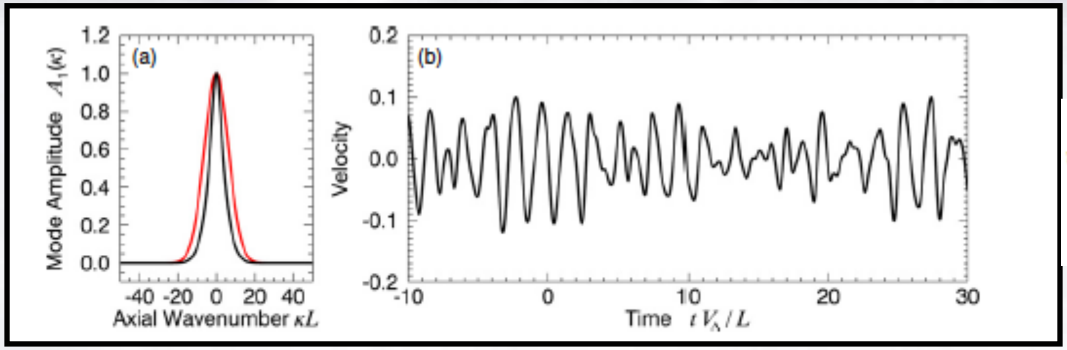
Energetic impulsive which has a large initial pulse with subsequent ringing (e.g. flare!)

Each source will independently produce a wave response

$$v(s,y,t) = v_{bg}(s,y,t) + v_{imp}(s,y,t)$$

Background oscillations: two examples

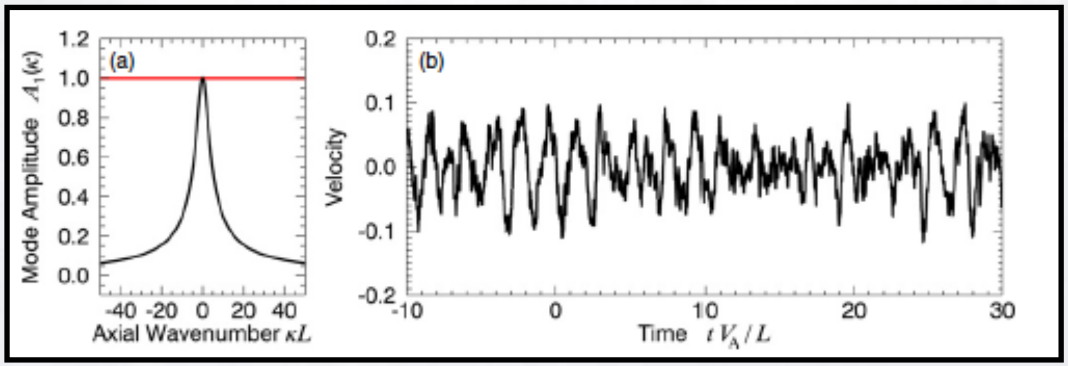
Source strength as a Gaussian function of wavenumber
Amplitude spectrum



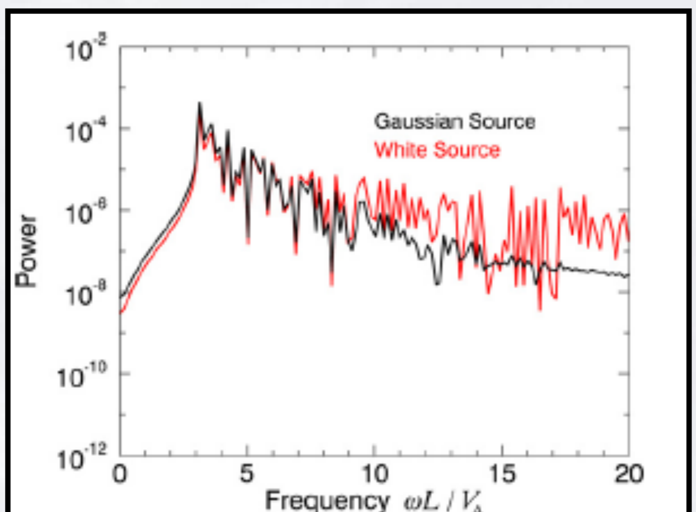
$$v_{bg}(s,y,t) = \frac{1}{2\pi}\sum_{n=1}^{\infty}\int_{-\infty}^{\infty} d\kappa \, \frac{|\hat{S}_n^{(bg)}(\kappa,\omega_n)|}{\omega_n(\kappa)} U_n(s) \times \sin[\kappa y - \omega_n(\kappa)t + \theta_n(\kappa)],$$

$$\theta_n(\kappa) \equiv \arg\{\hat{S}_n^{(bg)}(\kappa,\omega_n)\}.$$

Source strength independent of wavenumber (white source)
Amplitude spectrum



Temporal power spectra



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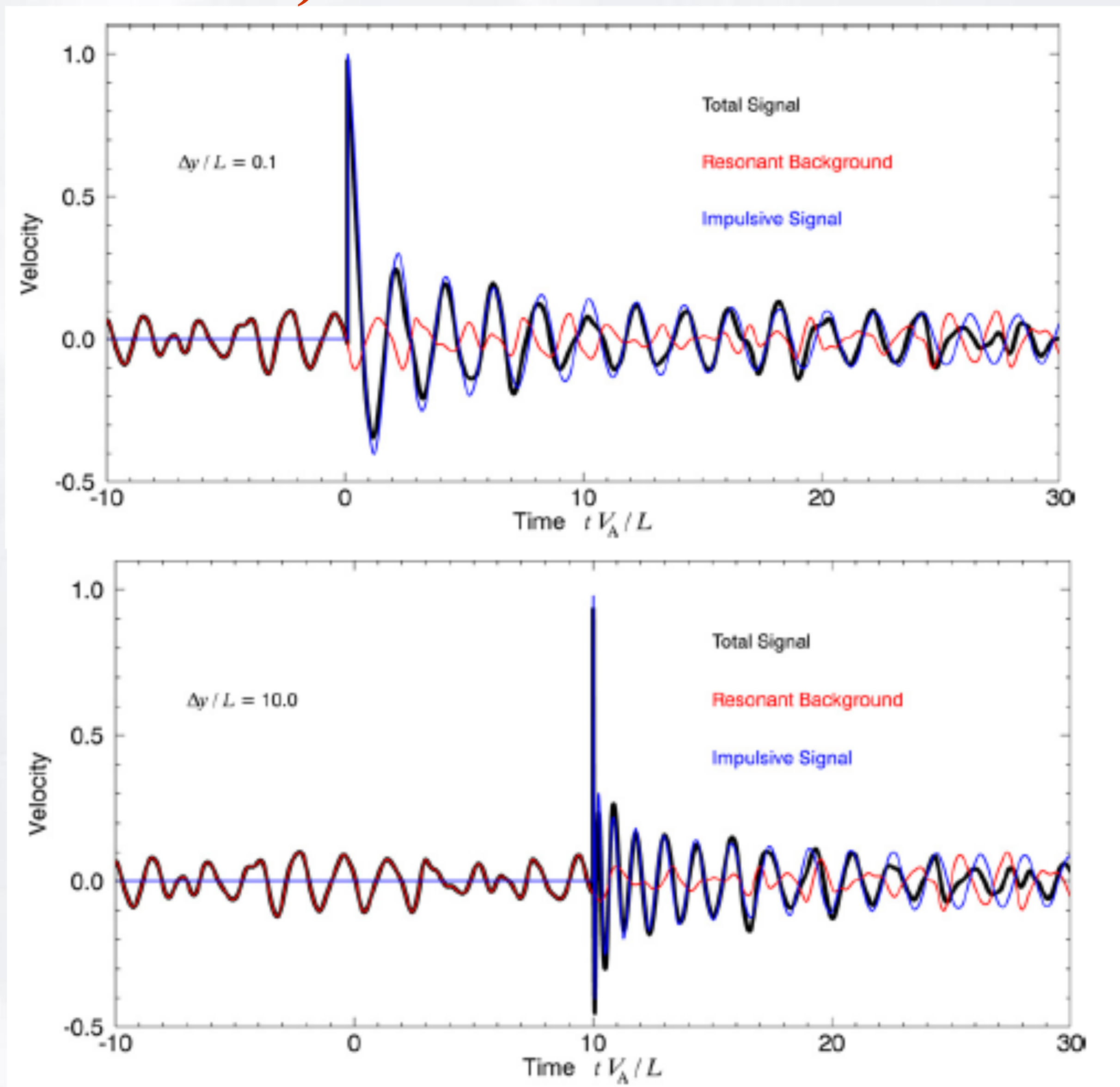
Signal from impulsive driver superimposed on background (Gaussian) oscillation

- Impulsive source at t = 0
- Waves observed at the apex but at different distance from the source

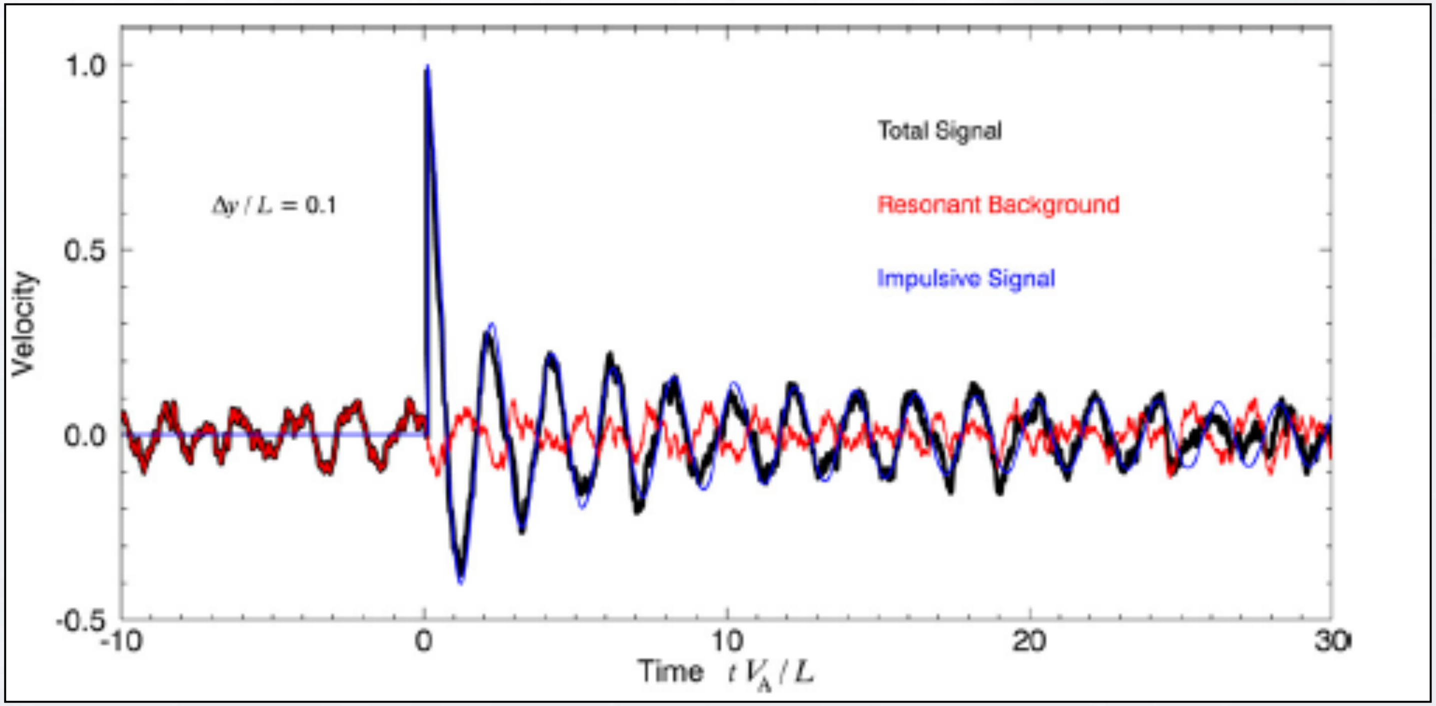


- Time delay at observation point.
- Fringe pattern is compressed near the time of first arrival.

Signal from impulsive driver superimposed on background (white source) oscillation

- There is equal power in all wavenumbers
- Noticeable high frequency jitter.

The beating and slow modulation of the phase caused by interference between different nearby frequency components is easily seen.



Key findings

Hindman and Jain (2014, 2018: ApJ) showed that the observed **decaying** and **decayless** oscillations can be explained if there are two distinct wave sources of excitation: a continuous, distributed stochastic source and a large amplitude impulsive source which is localised spatially and temporally.

The decay in this model is a wave interference effect and the resulting fringe pattern is sensitive to the shape of the waveguide.

Where are the observations for the exciters?
Are the exciters below the corona?
Are they broadband or at specific frequencies?

} **Ongoing work**

Simultaneous Different wavelength observations are required of similar ROI
Good temporal and spatial cadence required

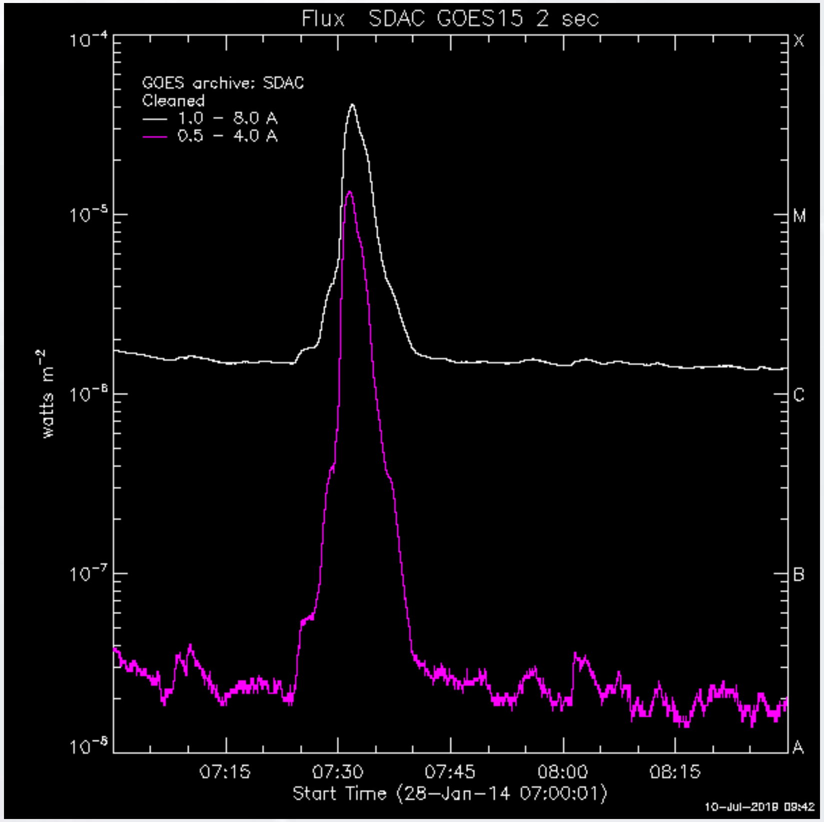
Data

Intensity variations seen in a coronal loop structure of the AR 11967

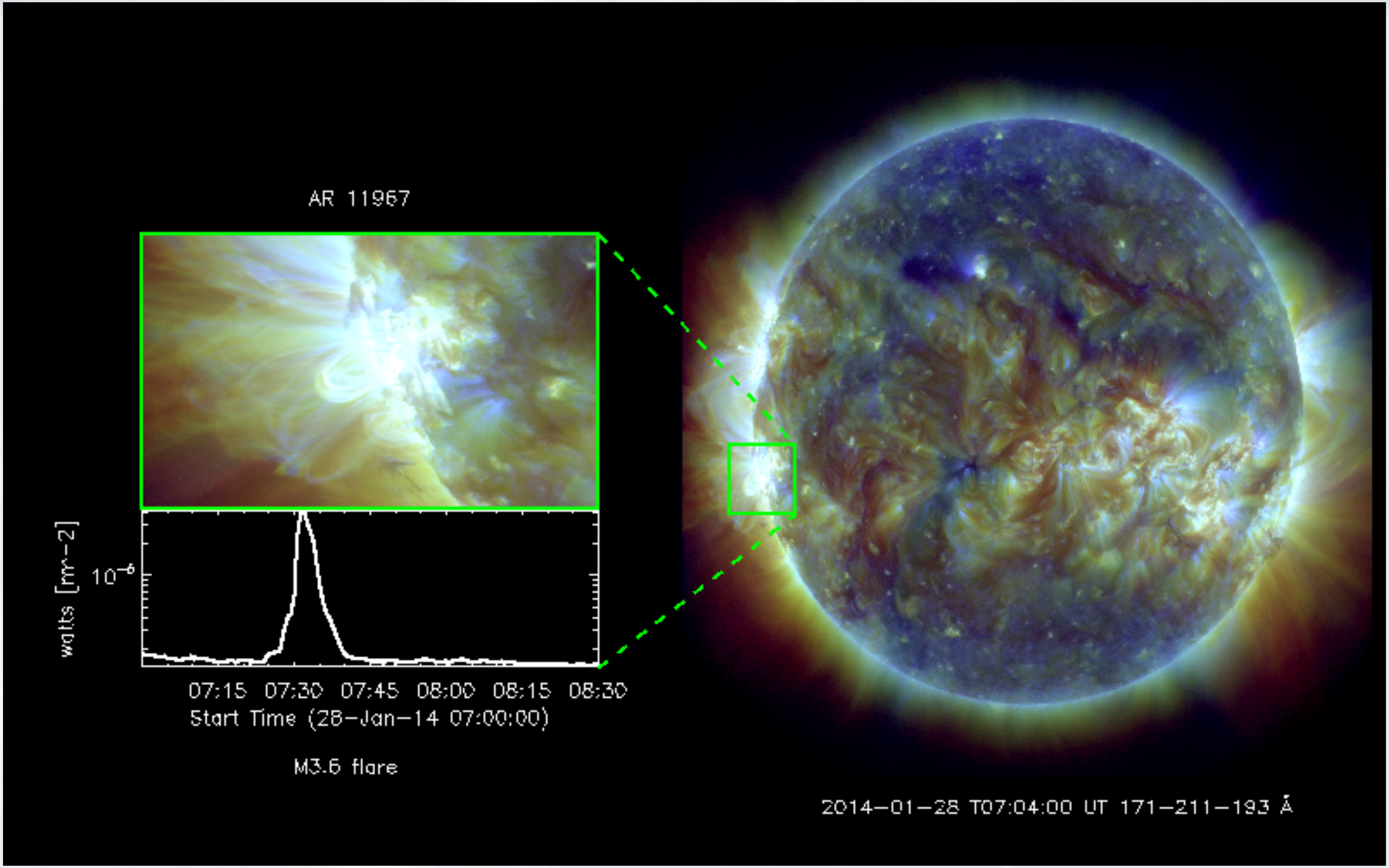
M3.6 flare: GOES instrument

Flaring duration: 07:30 – 08:07 (28/01/2014)

AIA images with cadence: 12 sec. and 0.6 arcsec.



Data


AR 11967
watts [m^-2]
10^-6
07:15 07:30 07:45 08:00 08:15 08:30
Start Time (28-Jan-14 07:00:00)
M3.6 flare
2014-01-28 T07:04:00 UT 171-211-193 Å

Data: images

M3.6 flare: GOES instrument

Flaring duration: 07:30 – 08:07 (28/01/2014)

AIA (07:00 – 08:07 UT)

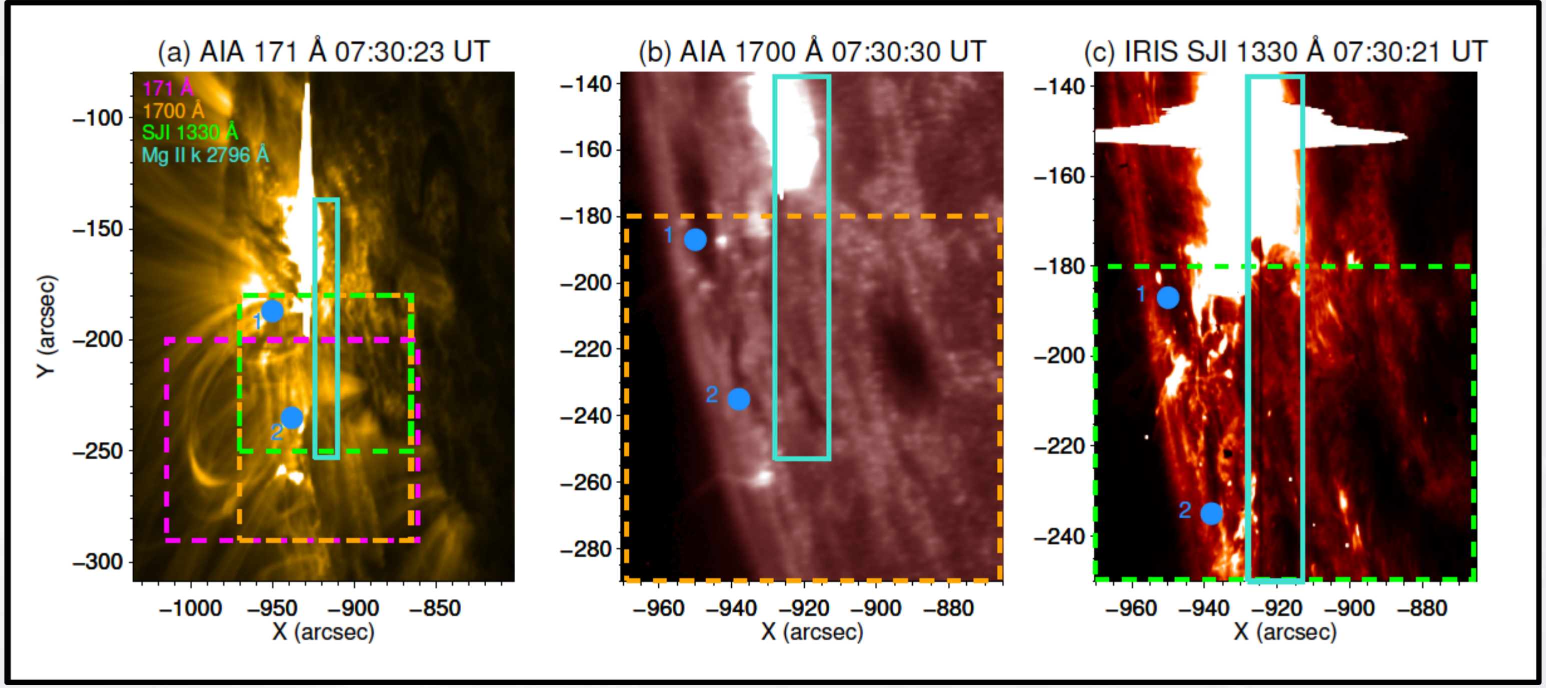
171 Å, **1700 Å** passband images of AR on the limb

&

IRIS (07:30 – 08:07 UT)

SJI 1330 Å images

corona



Lower chromosphere and transition region

12 second

19 second

24 second

Temperature minimum to the photosphere

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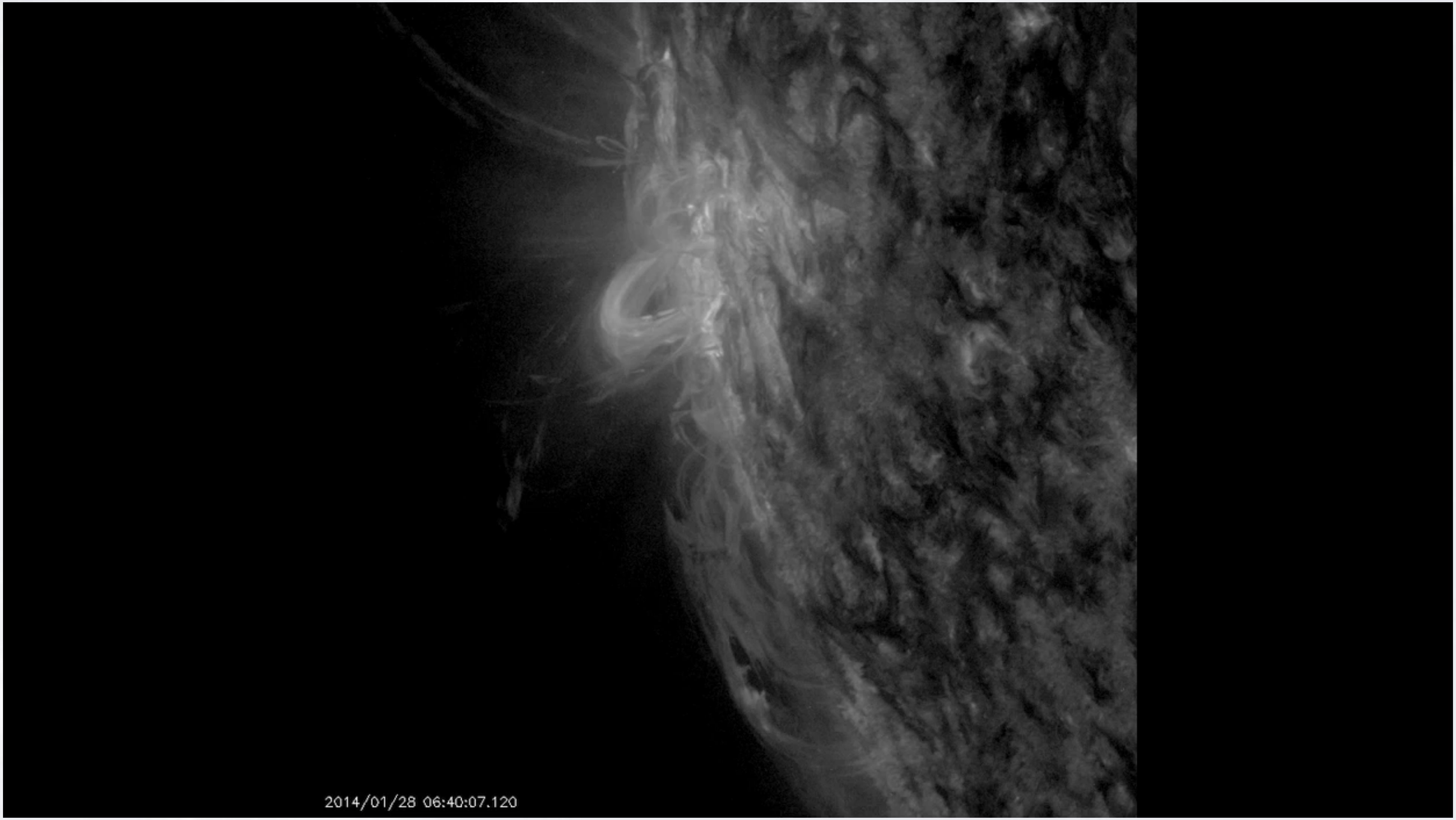
AIA 304 Å



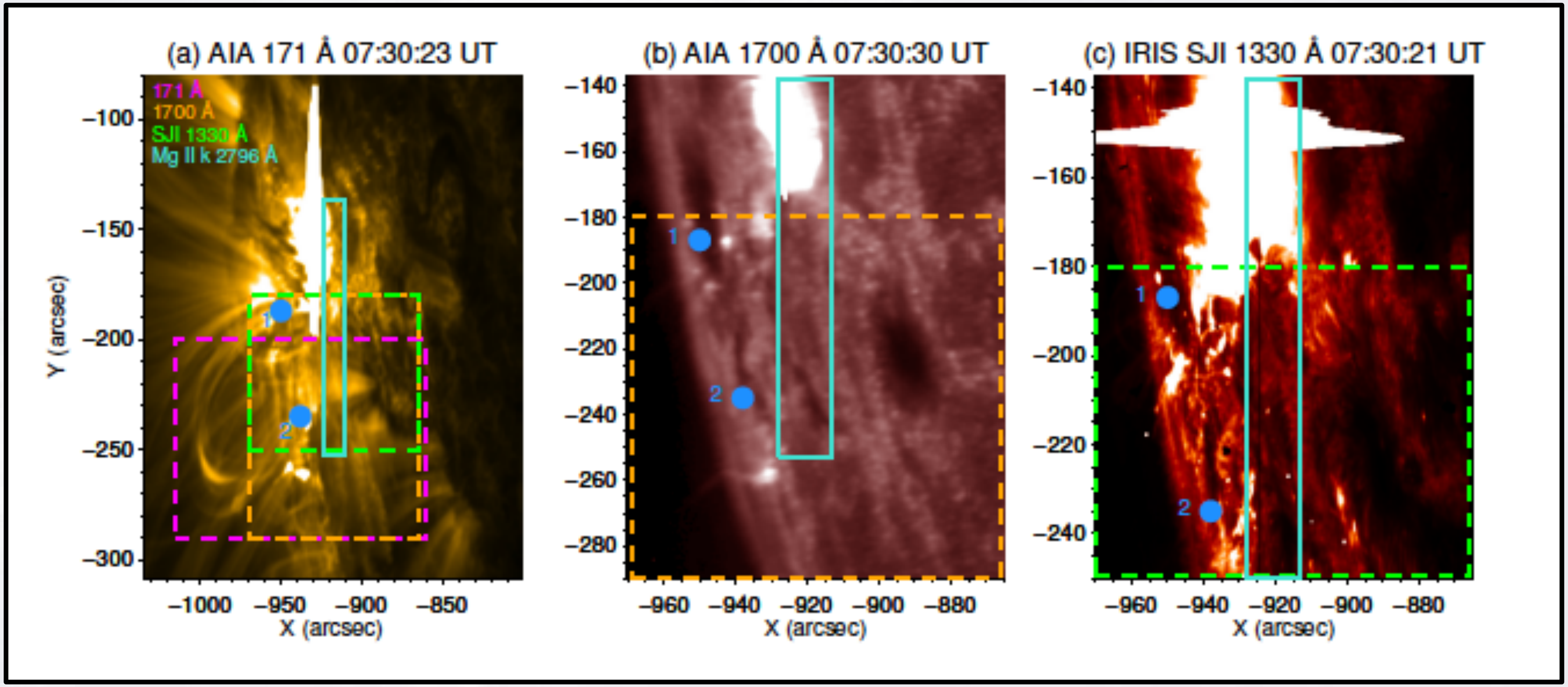
ar304.mov

Data: spectral

Raster files from IRIS Spectrograph channels

Mg IIk 2796 Å, C II 1336 Å, Si IV 1403 Å

multiple-repeat raster with FOV of 14″ X 19″ in steps of 8″X2″ & cadence: ~10 second



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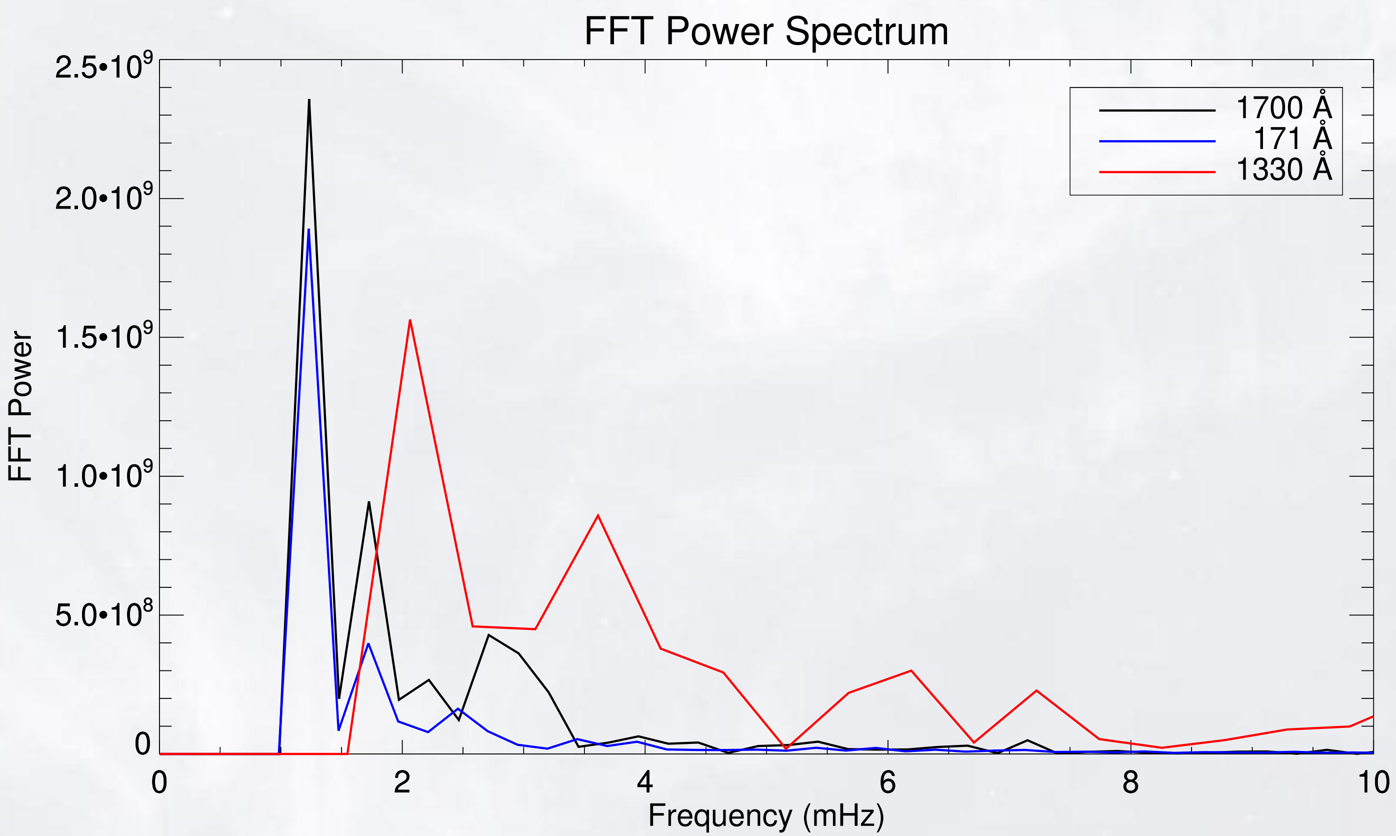
FFT power spectrum



Nyquist Frequency:

1700 Å: 0.5/24 s^{-1} = 20.5 mHz

171 Å: 0.5/12 s^{-1} = 41.5 mHz

1330 Å: 0.5/19 s^{-1} = 26 mHz

Frequency Resolution:

1700 Å: 1/(24*150) = 0.27 mHz

171 Å: 1/(12*300) = 0.27 mHz

1330 Å: 1/(19*150) = 0.35 mHz

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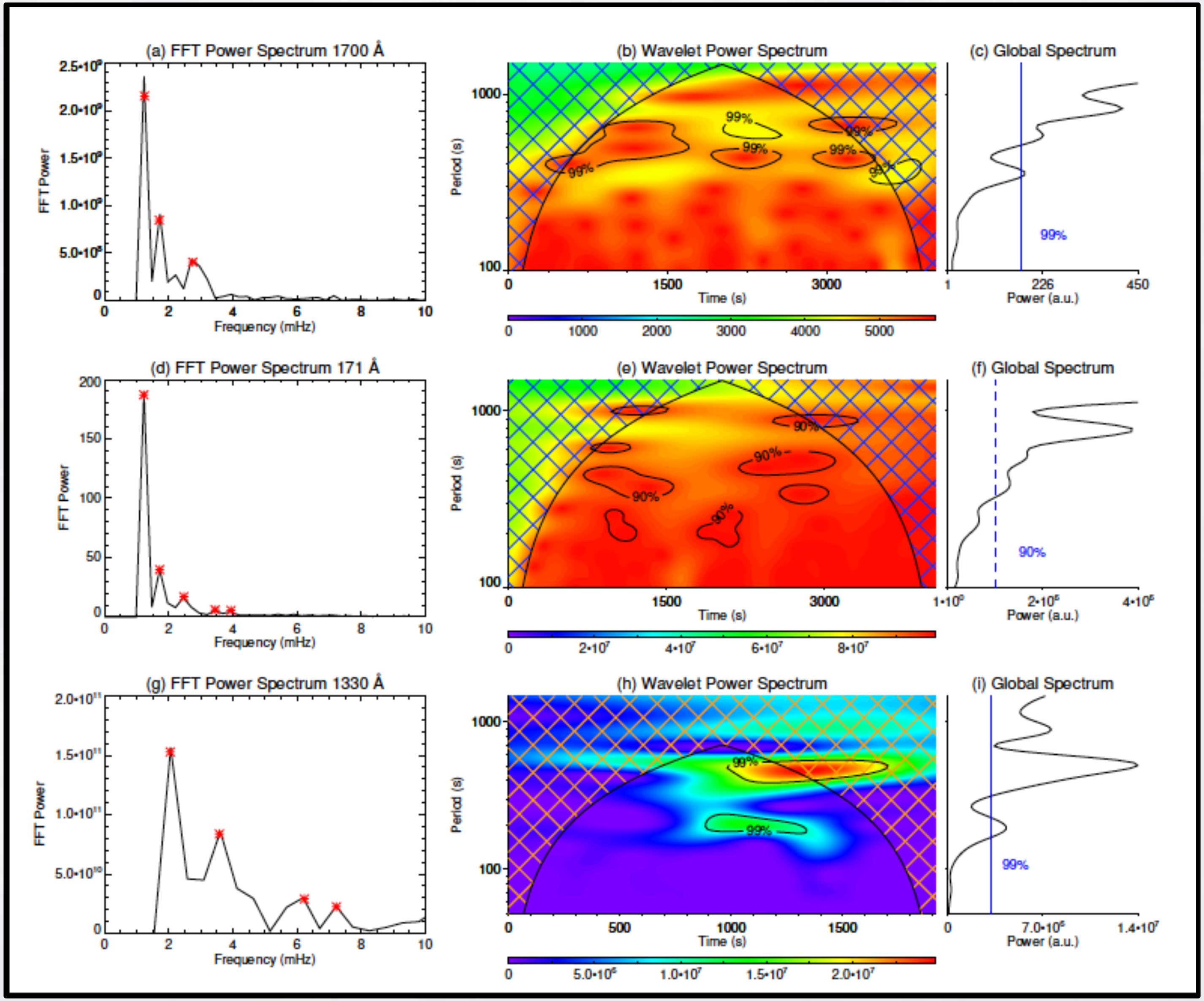
FFT & Wavelet power spectrum

AIA 1700 Å

AIA 171 Å

IRIS 1330 Å



Peak ν : 6, 9, 13 min.

Peak ν :6, 9, 13 min.

Peak ν : 3, 4, 8 min.

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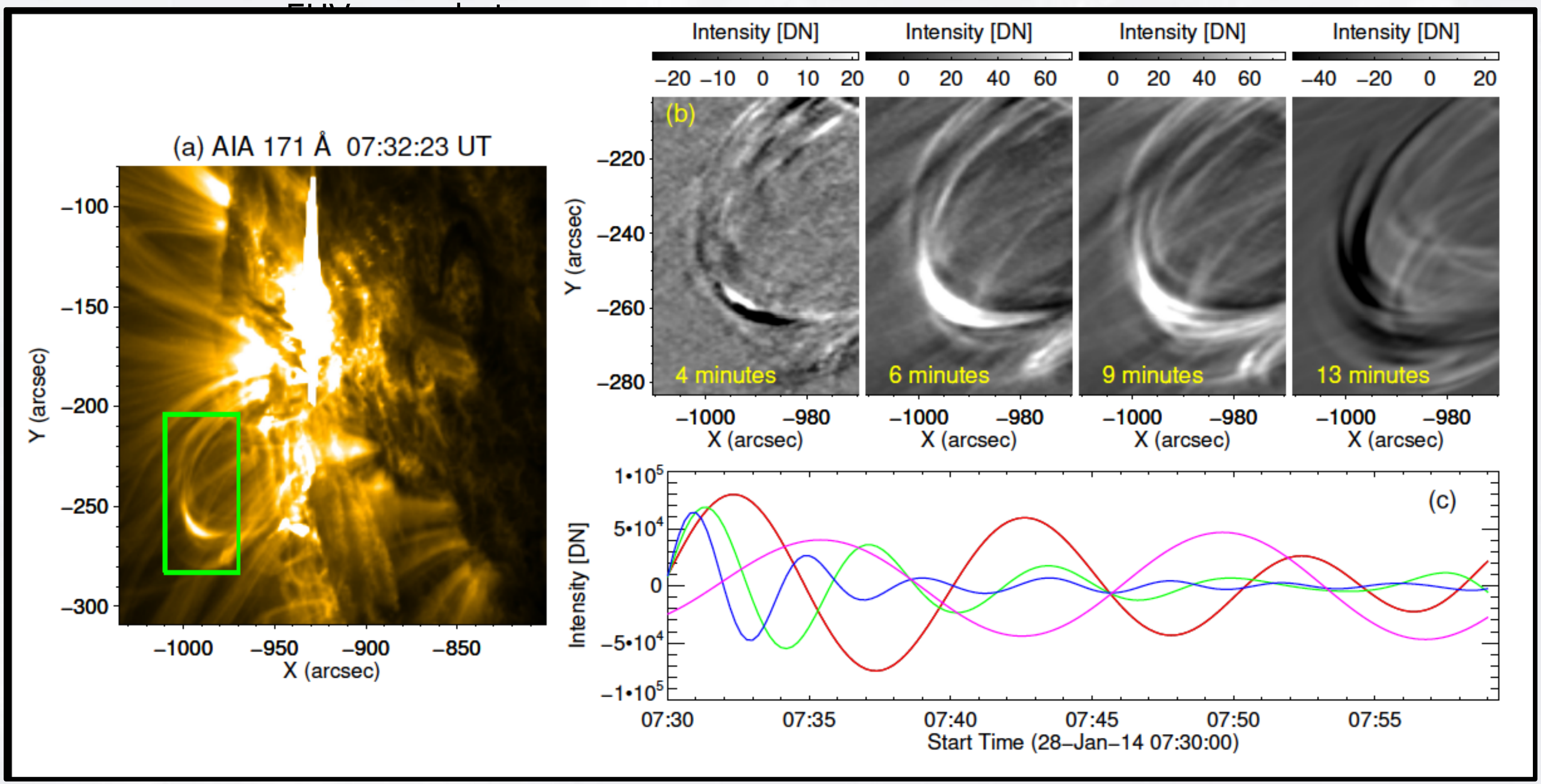
Pixelised Wavelet filtering

To identify the spatial distribution of periodicities present in the ROI
(In this method, wavelet transform is done at each pixel and then the temporal signal is filtered by predominant period bands).



Filtered intensity maps for oscillations of 4, 6, 9 & 13 min. periods

Filtered integrated Intensity variation With time
4, **6**, **9** & **13** min.

Oscillations found in the loop-top using AIA 171 Å images

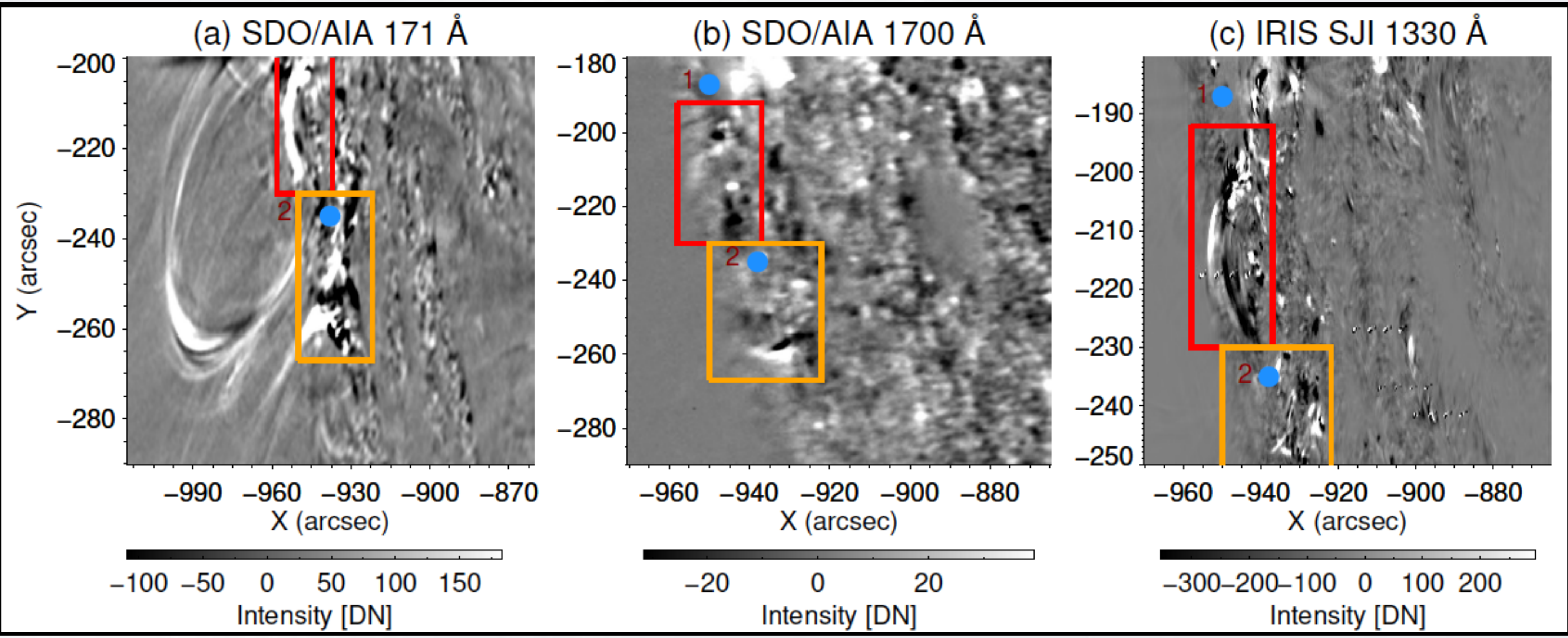
Temporal signal filtered in period bands

W171.avi
M6m.1.avi

Temporal signal filtered in period bands: phase

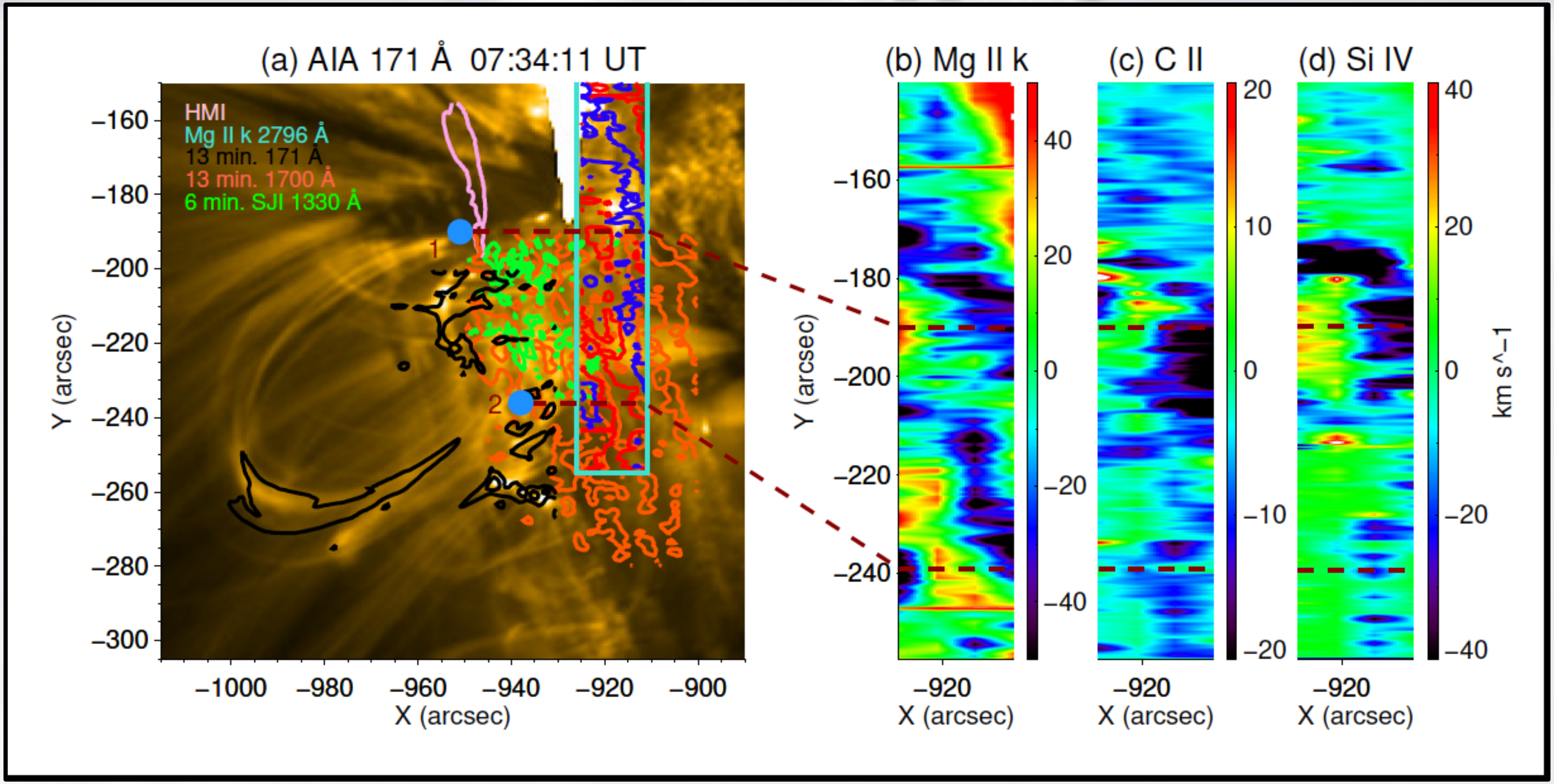
phase6m(2).mov

Filtered intensity narrowband map centered at 6 min.



Intensity variations seen near the endpoints in all three wavelengths

Oscillations and Dopplergram



Pink contour : sunspot position seen in HMI
Black contour : 6 min. oscillations in 171 Å
Green contour : 6 min. oscillations in SJI 1330 Å

Aquamarine Box
Blue contour : negative velocity showing up-flows
Red contour : positive velocity showing down-flows
Red dashed line: endpoint position

Opposite flows in the vicinity of endpoints 1 and 2 in Mg II k

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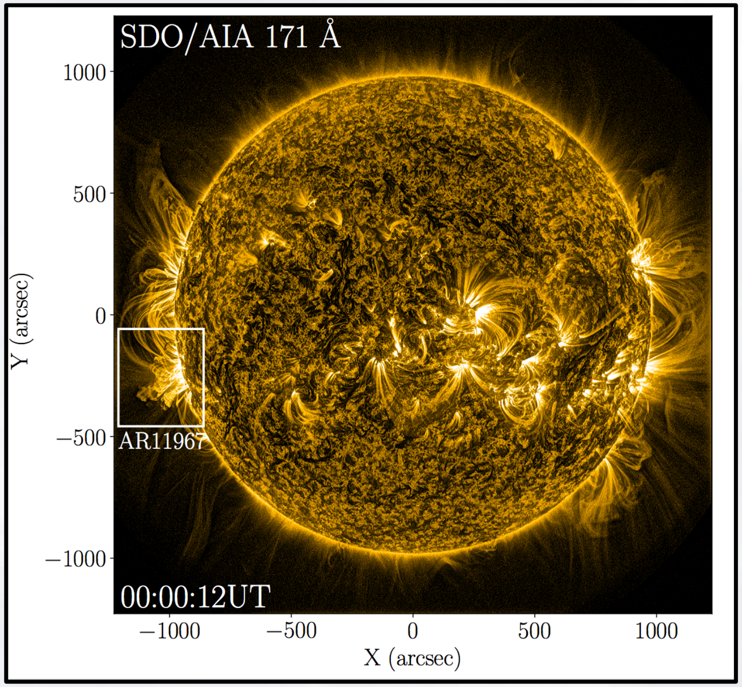
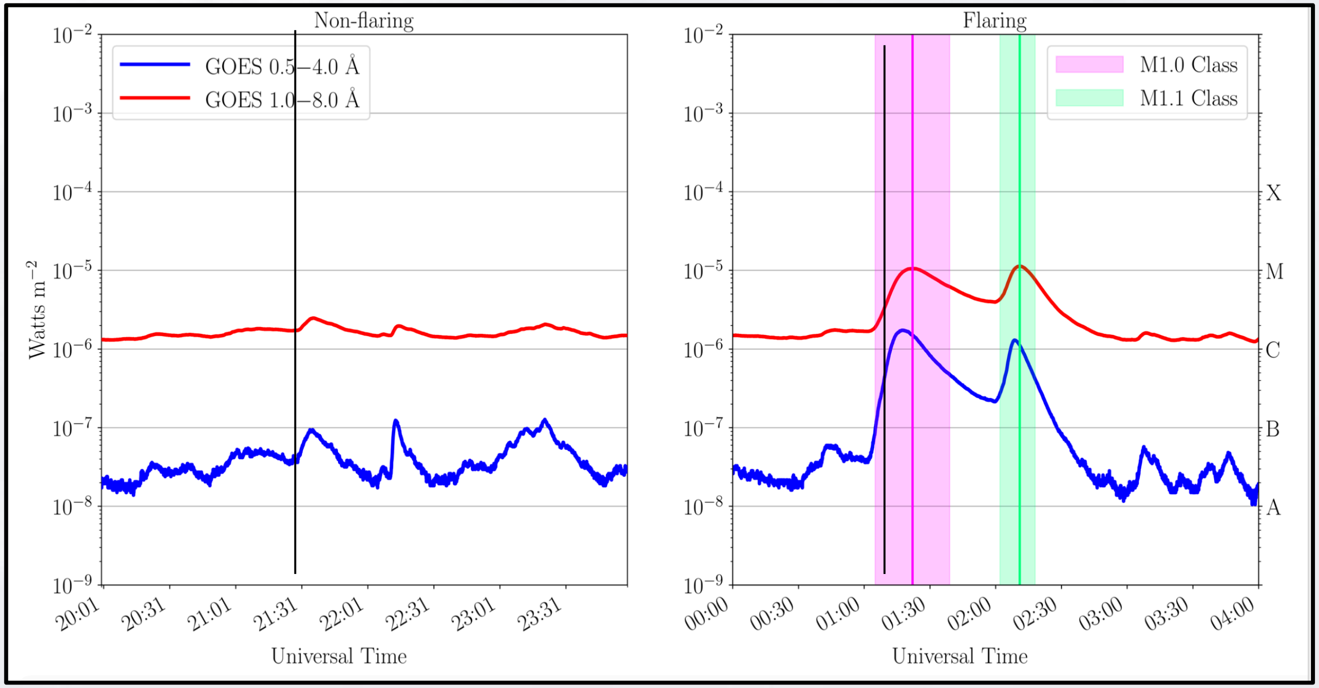
Data

AIA 171 Å passband on the limb

Non-flaring duration: 21:00-00:00 (26/01/2014)

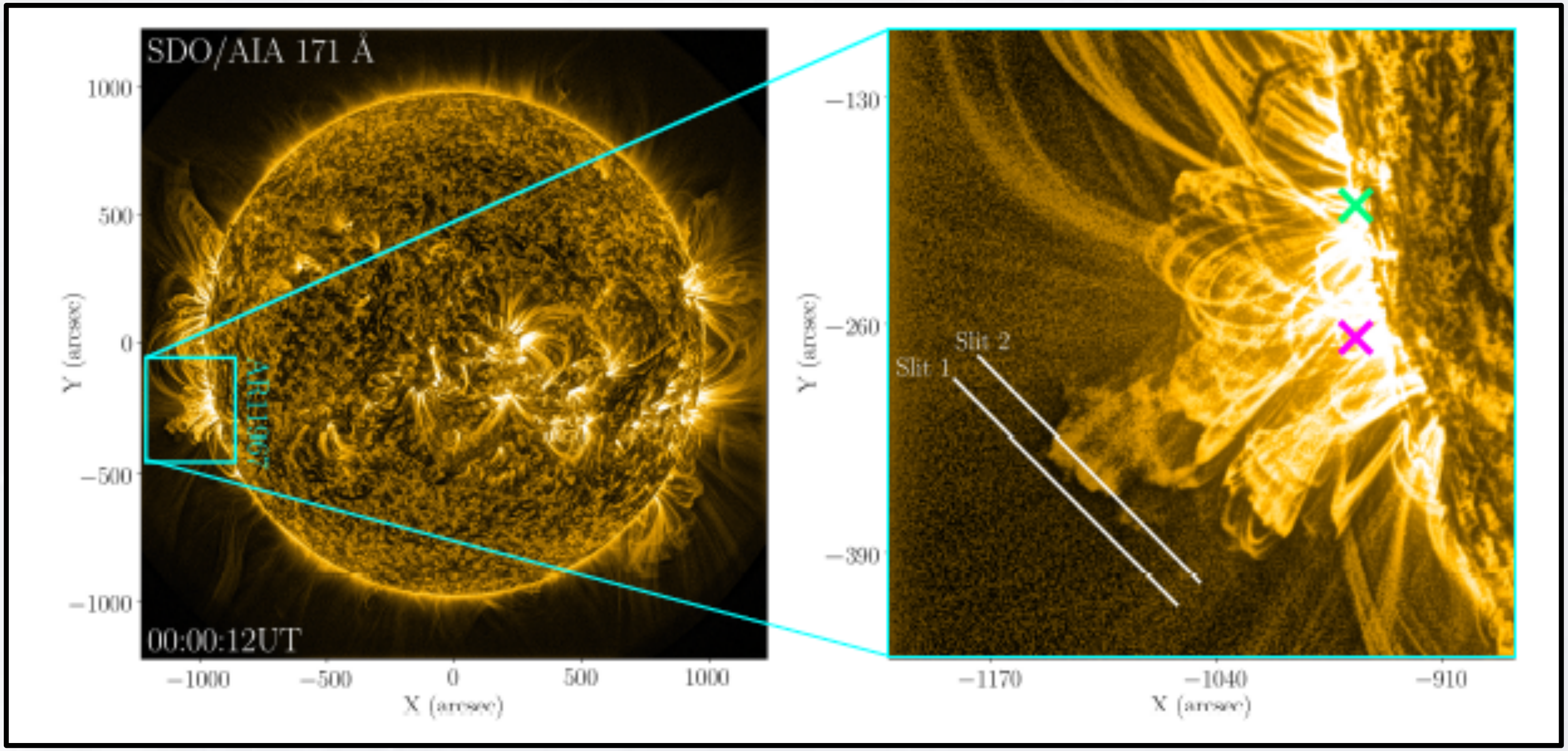
Flaring duration: 01:00 am – 04:00 (27/01/2014)





From Allian , Jain and Hindman (ApJ, 2019)

Coronal Arcade in 171 Å

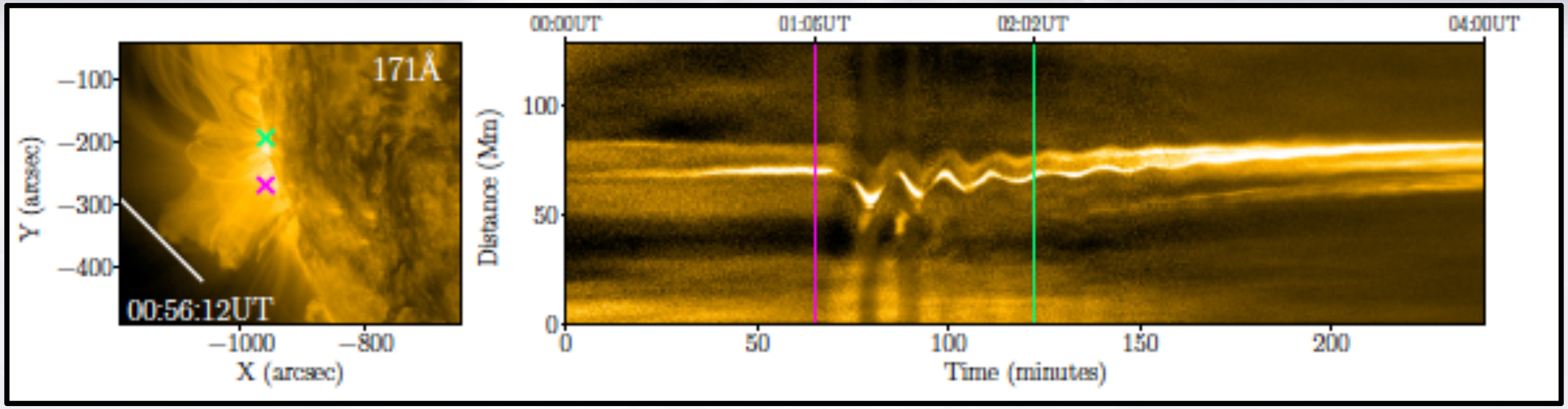


From Allian, Jain and Hindman (ApJ, 2019)

Note that the previous loop structure was in a low-lying coronal arcade

Oscillations in 171 Å

Slit 1



~ 13 minute

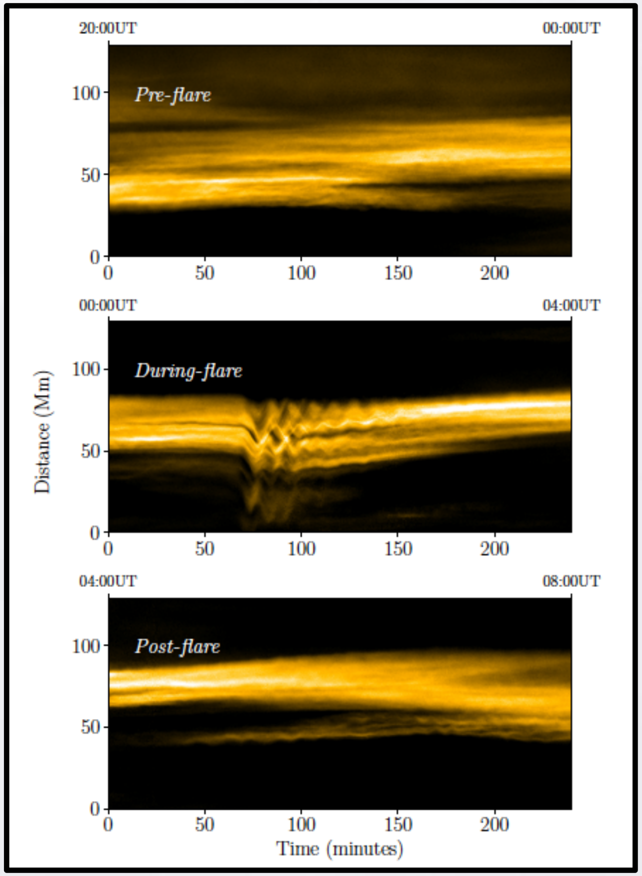
Allian, Jain and Hindman (ApJ, 2019)

Before

Slit 2

During

After



~ 9 minute

~ 13 minute

~ 9 minute

13 minute oscillations during the flaring activity!

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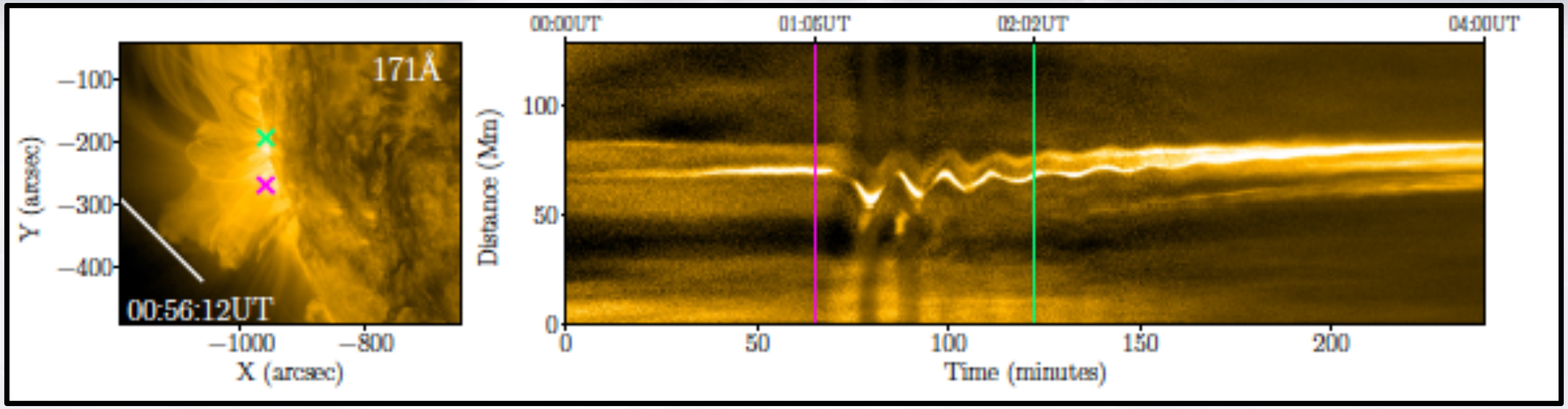
Oscillations in 171 Å

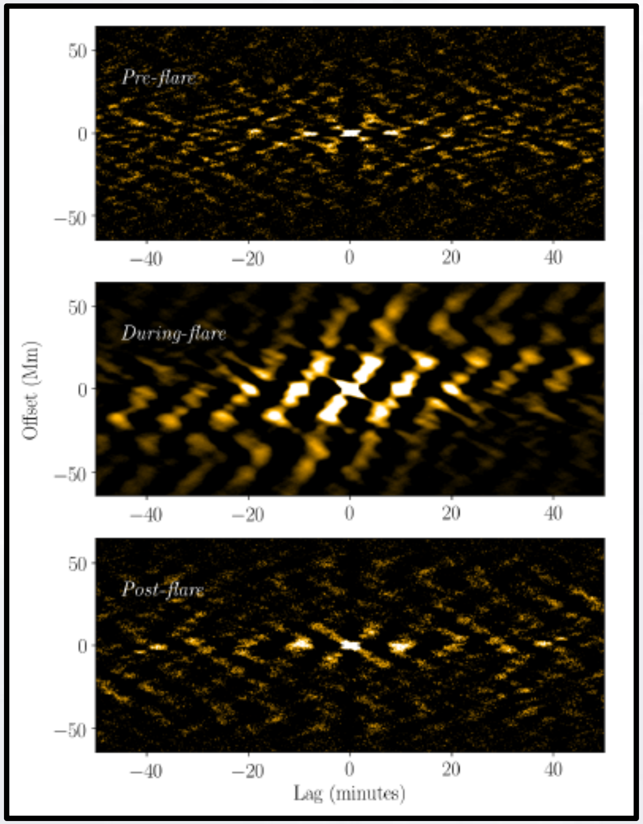
Slit 1



~ 13 minute

Slit 2

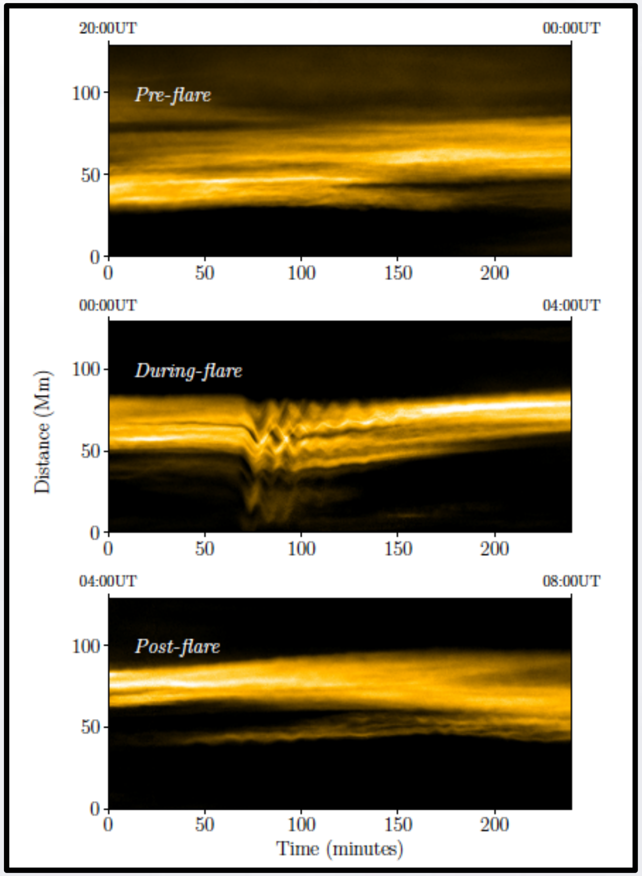
Allian, Jain and Hindman (ApJ, 2019)



Before

During

After



~ 9 minute

~ 13 minute

~ 9 minute

Conclusion

- Solar coronal arcades show complicated nature of oscillations.
- Multiple locations oscillate – sometimes with multiple periods
- Periodicities in 171 and 1700 Å images: 9 min. and 13 min. (dominant). However, the 13 minute oscillation is absent in IRIS SJI 1330 Å.
- The excitation sources appear to be broadband drivers in the lower atmosphere. The perturbations are close to the endpoints, as estimated from the 171 Å images, of the loop structure in the lower atmosphere. Filtered intensity narrowband maps show that the periodicities except for 13 min. are present in the lower atmosphere.
- The fact that 13 minute oscillations were also the dominant oscillations seen in 171 Å one day earlier in response to another flare suggest that at least in this particular case, the role of flares is to provide the right conditions in the active region arcade for detection of oscillations in a particular wavelength.