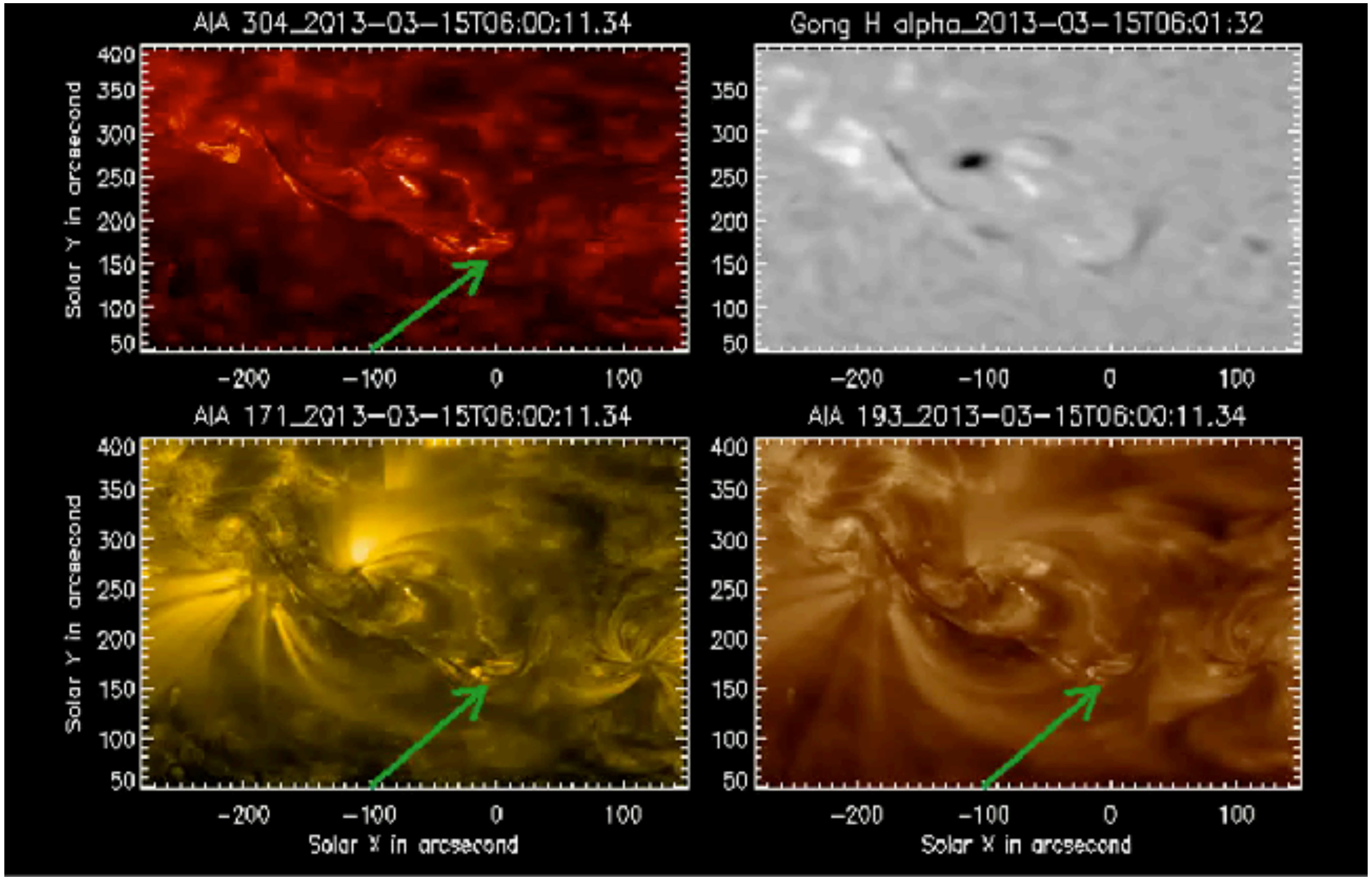
Simultaneous longitudinal and transverse oscillations in active region filament

Dipankar Banerjee, V. Pant, Ding Yuan, Rakesh Mazumder, Y Shen, Abhishek Srivastava

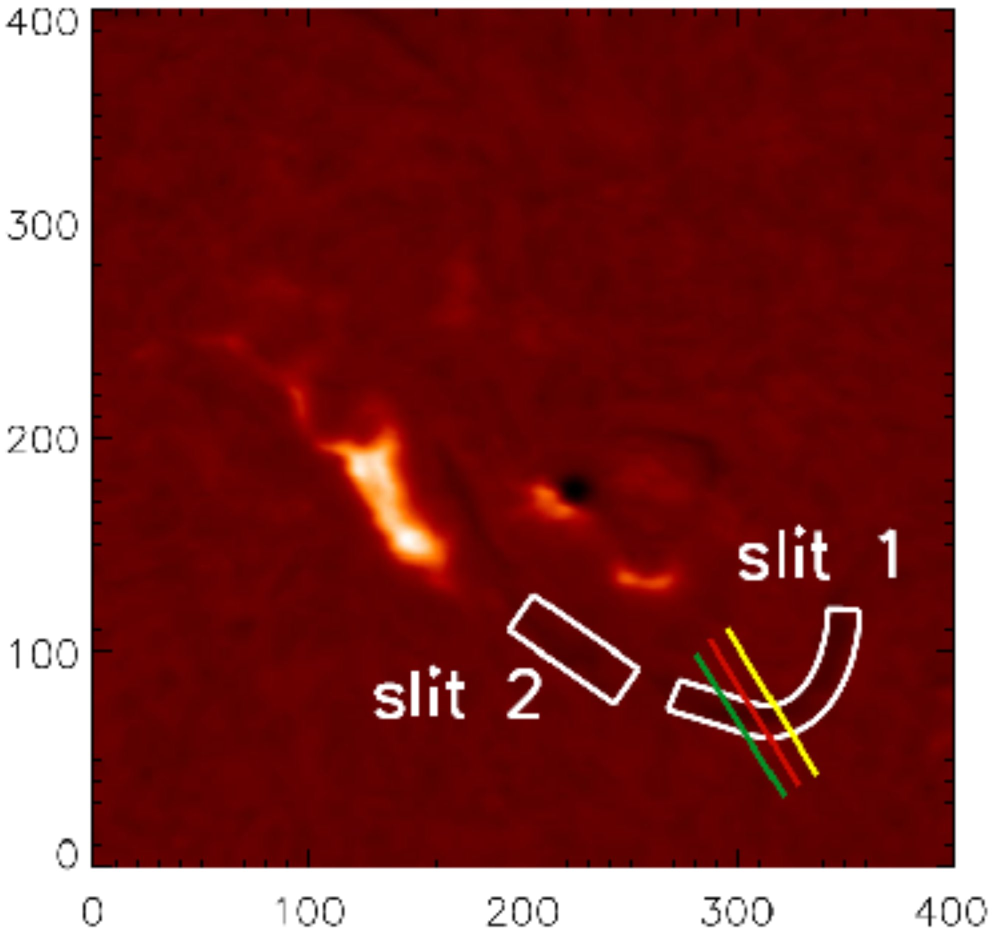
Observations



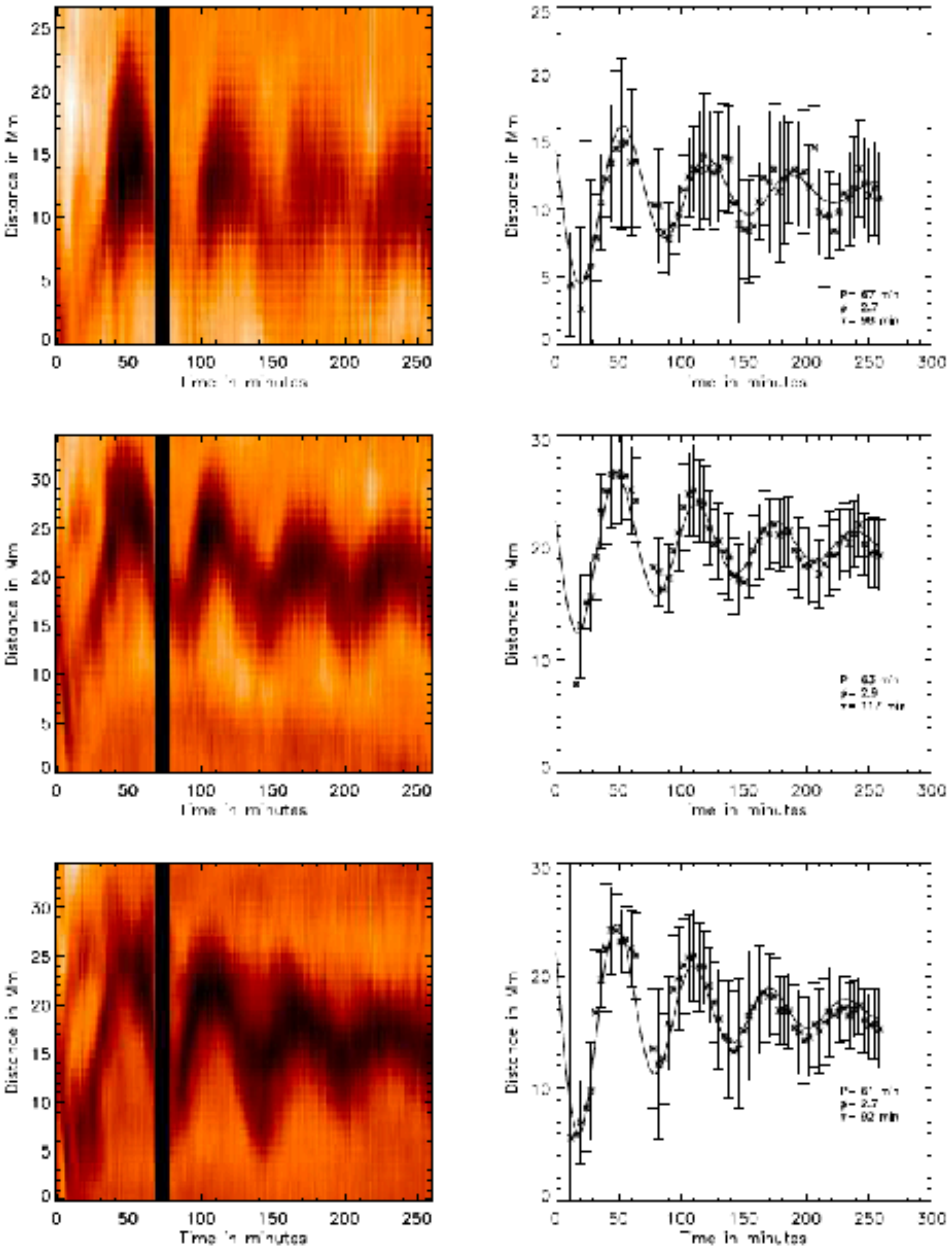
- An Active filament was seen in GONG H-alpha images
- Oscillations happened after a flare happened in a nearby active region
- Filament is also seen in AIA EUV channels
- Shock from a nearby flare or CME triggered oscillations in filament
- One hour data gap in AIA thus initial phase of oscillation is not captured

Filament in AIA channels is marked with arrow in green

Time-distance maps

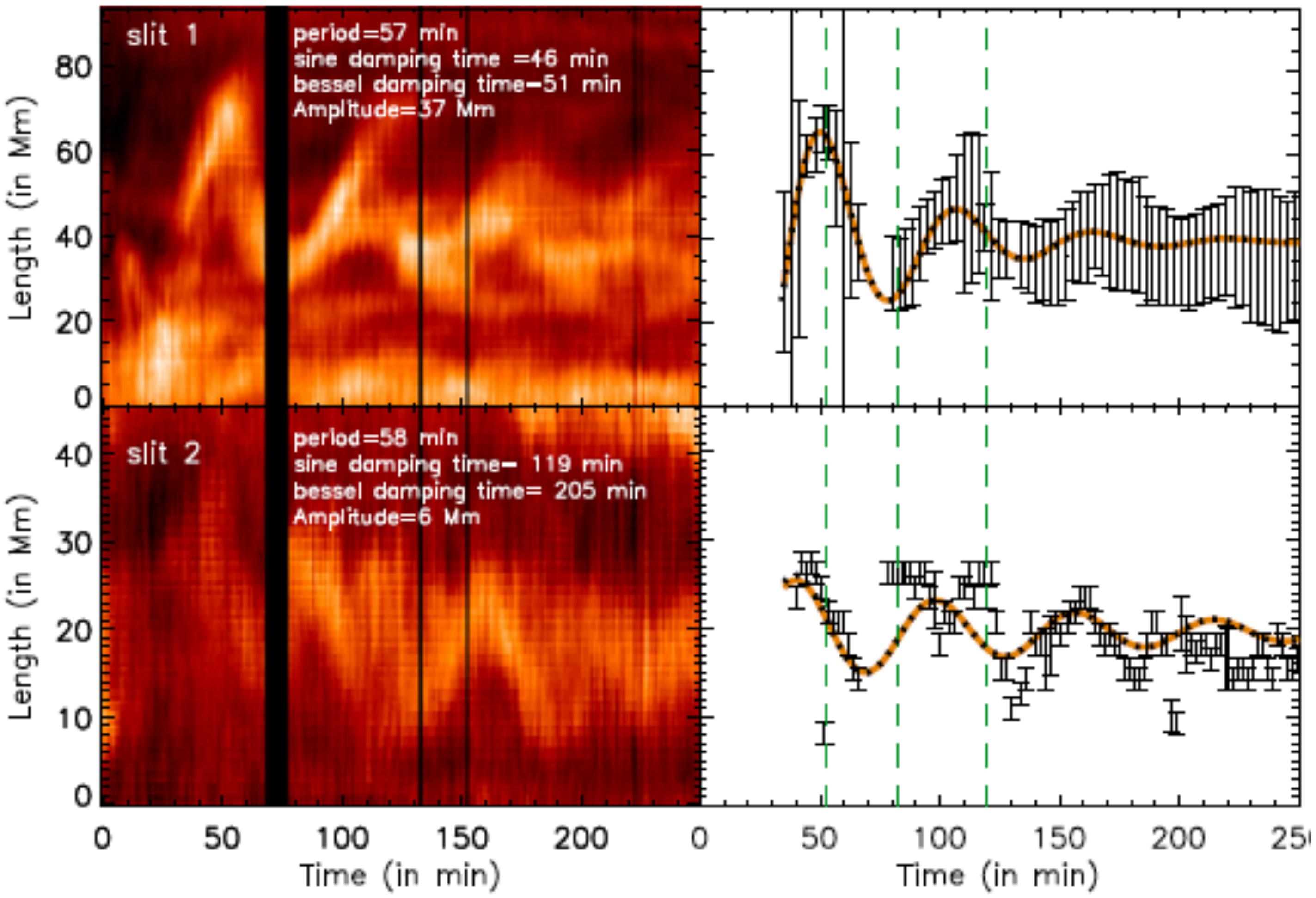


- Both longitudinal and transverse artificial slices are placed on the filament
- To characterise transverse and longitudinal oscillations
- Time-distance maps for 3 transverse slits are shown
- Oscillations are damped -> Resonant absorption
- Period of oscillation ~ 63 min
- Damping time ~ 95 min

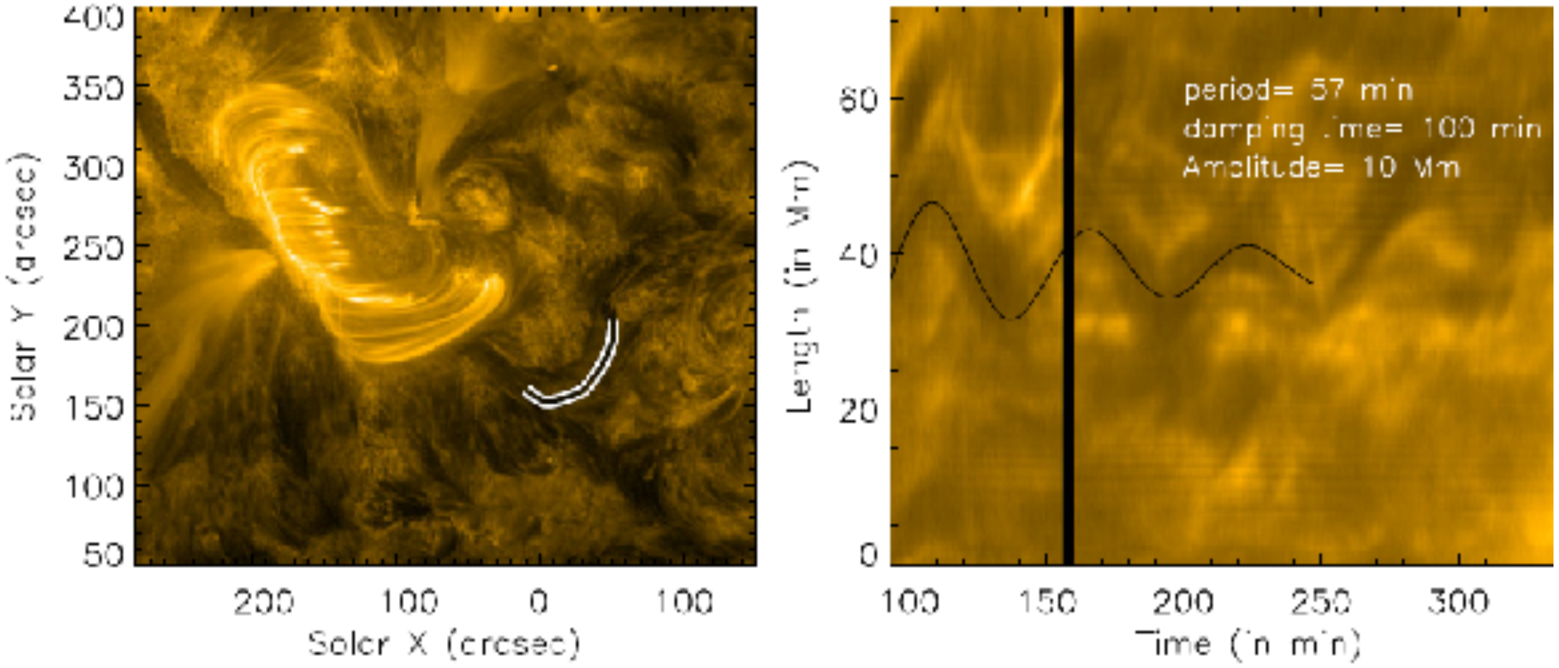


Pant et al, 2015

- Time distance map for longitudinal slit using GONG images
- Damp sinusoidal (dashed curve) and Bessel functions (curve in orange)are fitted
- Bessel fitted curve gives an estimate of mass accretion parameter (Luna et al, 2012)
- Period of oscillation ~ 58 min
- Sine damping time ~ 46 min for slice1 and 119 min for slice 2
- Bessel damping time is 51 min for slice1 and 205 min for slice2



- Time-distance maps using AIA
- Note that oscillations starts after 100 min because of data gap in AIA
- First cycle of oscillation is missed
- Damping time and amplitude estimation is not correct
- Thus Bessel function is not fitted



Pant et al, 2016

Estimated Parameters using longitudinal oscillations

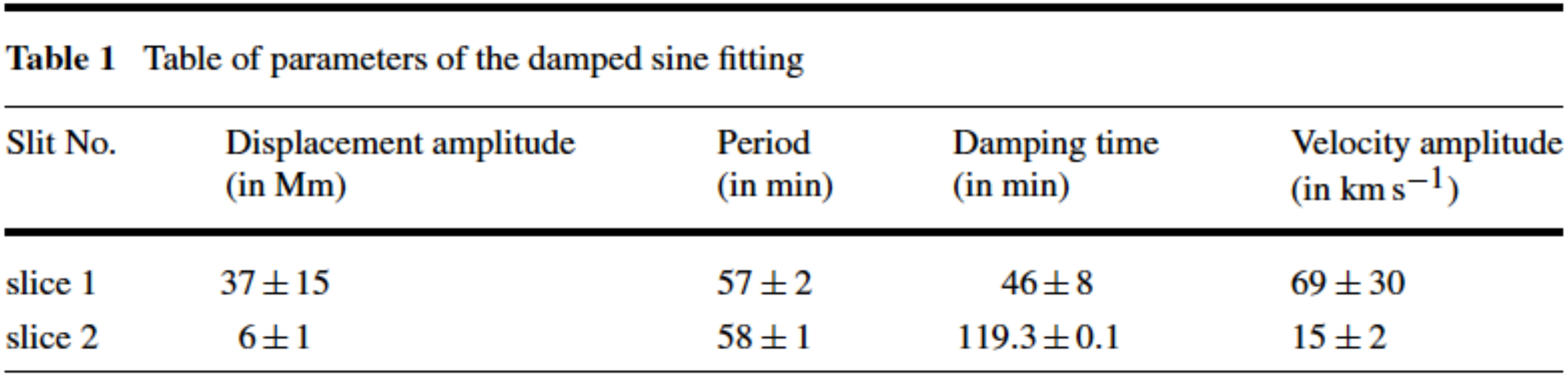


Table 1 Table of parameters of the damped sine fitting

Slit No.	Displacement amplitude (in Mm)	Period (in min)	Damping time (in min)	Velocity amplitude (in $\mathrm{km\,s^{-1}}$)
slice 1	37 ± 15	57 ± 2	46 ± 8	69 ± 30
slice 2	6 ± 1	58 ± 1	119.3 ± 0.1	15 ± 2

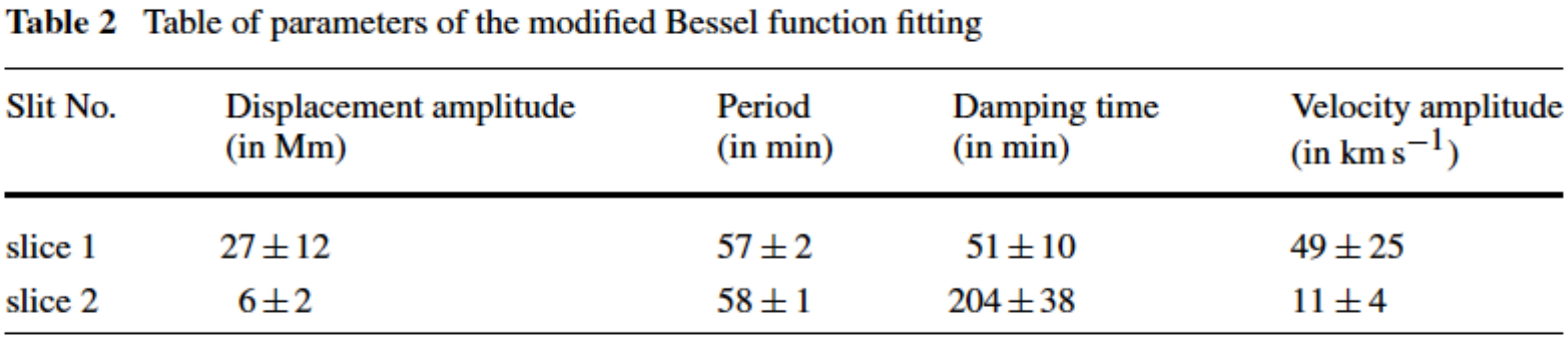


Table 2 Table of parameters of the modified Bessel function fitting

Slit No.	Displacement amplitude (in Mm)	Period (in min)	Damping time (in min)	Velocity amplitude (in $\mathrm{km\,s^{-1}}$)
slice 1	27 ± 12	57 ± 2	51 ± 10	49 ± 25
slice 2	6 ± 2	58 ± 1	204 ± 38	11 ± 4

- Filament material is supported by magnetic field against gravity
- Simple pendulum model can be used to estimate radius of curvature of magnetic dip

$$\omega = \frac{2\pi}{P} = \sqrt{\frac{g_0}{R}}$$

Luna and Karpen, 2012

- Radius of curvature, R is estimated to be 80 Mm and 85 Mm at the position of slice 1 and slice 2

Estimation of magnetic field and mass accretion rate

- Magnetic stress is balanced by the weight of filament material -> lower limit of magnetic field can be estimated using

$$B(G) \geq 26\left(\frac{n_e}{10^{11}}\right)^{\frac{1}{2}} P$$

- Assuming electron density to be 10^11 we estimate magnetic field density to be 25 G at the location of slice1 and slice2
- Damping of longitudinal oscillations -> Accretion of mass in the dip of filament (Luna and Karpen, 2012)
- Mass accretion rate is given by $\alpha = \frac{\omega m_0}{\phi_{\rm bes}}$
- Where alpha is the mass accretion rate, m is the initial mass of filament plasma along the dip and phi is the phase of Bessel function fitted. Mass can be derived by estimating the length of the cool (dark) plasma at the dip, radius and density of the filament.
- The extent of brightness in each column of the x-t map gives an estimate of the length of the cool plasma along the dip and mass of the plasma is estimated
- Mass accretion rate is found to be ~ 51 X 10^6 kg/hr at the location of slice1

Does longitudinal oscillations are driven by kink oscillations

- To explore this, we use the expression derived in Yuan and Van Doorsselaere, 2016

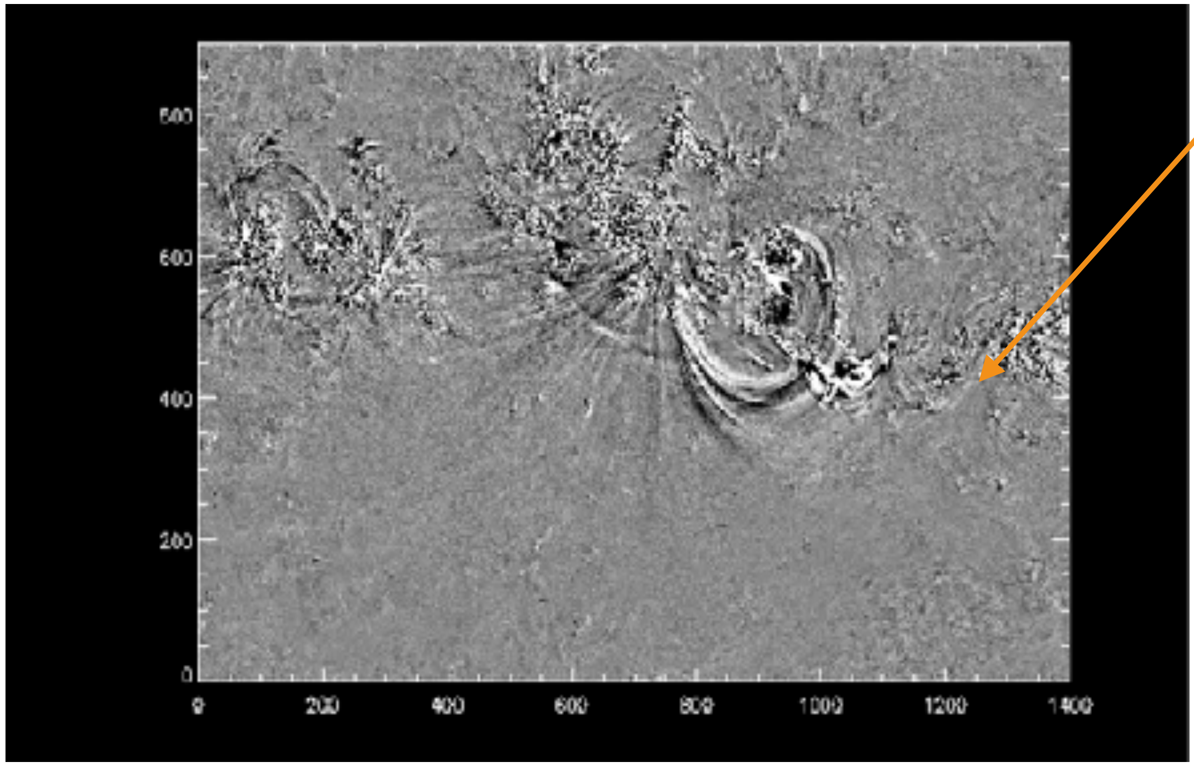
$$\frac{v_z}{v_r} = k\frac{C_T^2}{C_A^2}\frac{R}{\frac{\mathrm{d}R}{\mathrm{d}r}}\frac{\omega^2-\omega_A^2}{\omega^2-\omega_T^2}\cot(kz)$$

  - Where v_z is the longitudinal velocity amplitude and v_r is the transverse velocity amplitude
  - z is the distance at which transverse slits are placed over filament
  - For simplicity we take length of slit 2 as the length of filament in these calculations
  - First we calculate the axial-to-radial velocity amplitude from observations. We find them to be 3.92, 3.26 and 2.22 at the location of three transverse slits respectively
  - Then we used the right hand expression of the above equation to estimate the axial-to-radial velocity amplitude
  - We estimate the ratio to be 4 X 10^-4, 2 X 10^-2 and 1 X 10^-5 at the location of three slices respectively
  - We find that the theoretical estimates <<<< observed values
  - Thus longitudinal oscillations can not be driven by kink oscillations
  - There could be kink driven longitudinal oscillations but their amplitudes are too less to be detected by current imaging capabilities

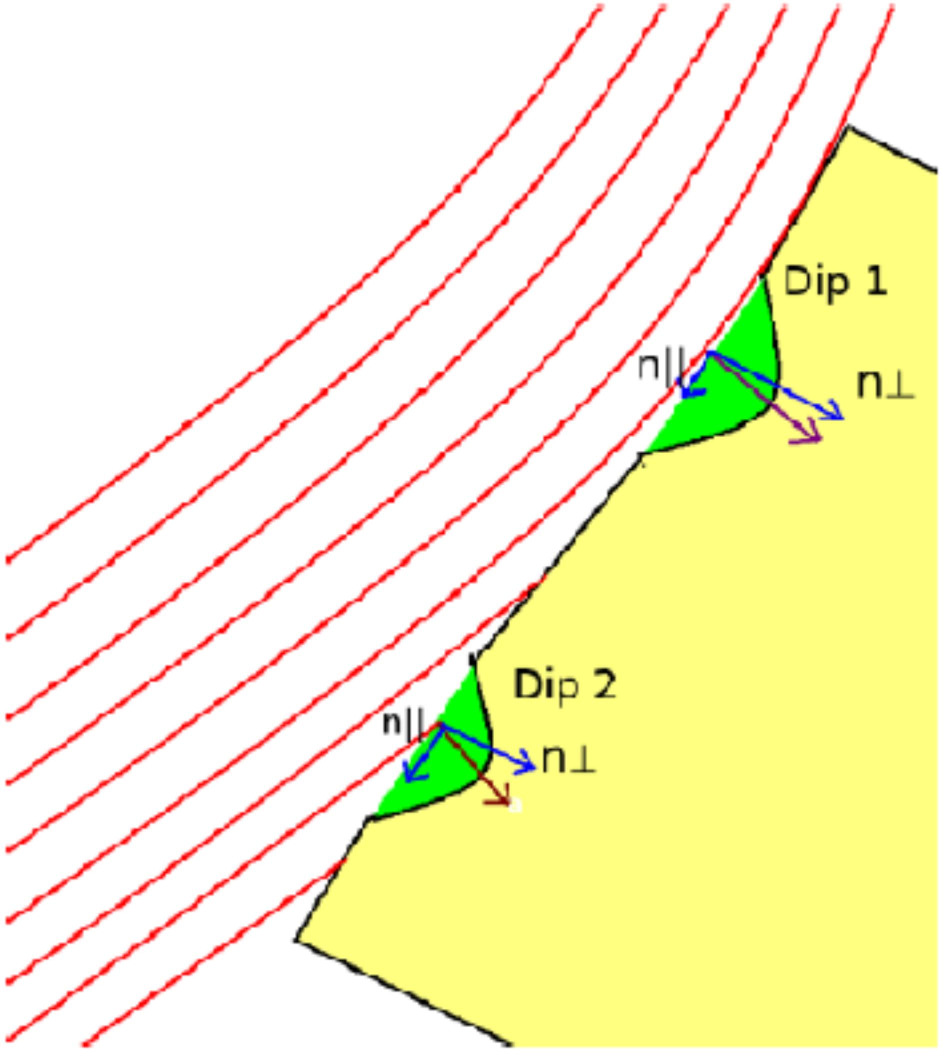
Above expression is applied to optically thin lines but H alpha is optically thick. Yet it gives an order of estimate of axial-to-radial velocity amplitude

How the oscillations are triggered?

- Shock waves can interact with filaments in two possible geometries (Shen et al, 2014)
- Orientation of shock wave with filament axis give rise to longitudinal and transverse oscillations
- We conjecture that if shock wave interacts obliquely then it can trigger both transverse and longitudinal oscillations in a filament
- Shock front is marked with arrow in red



filament



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WAVES IN THE SOLAR CORONA

Simultaneous Longitudinal and Transverse Oscillations in an Active-Region Filament

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Standing Oscillations in coronal plume and fan loops

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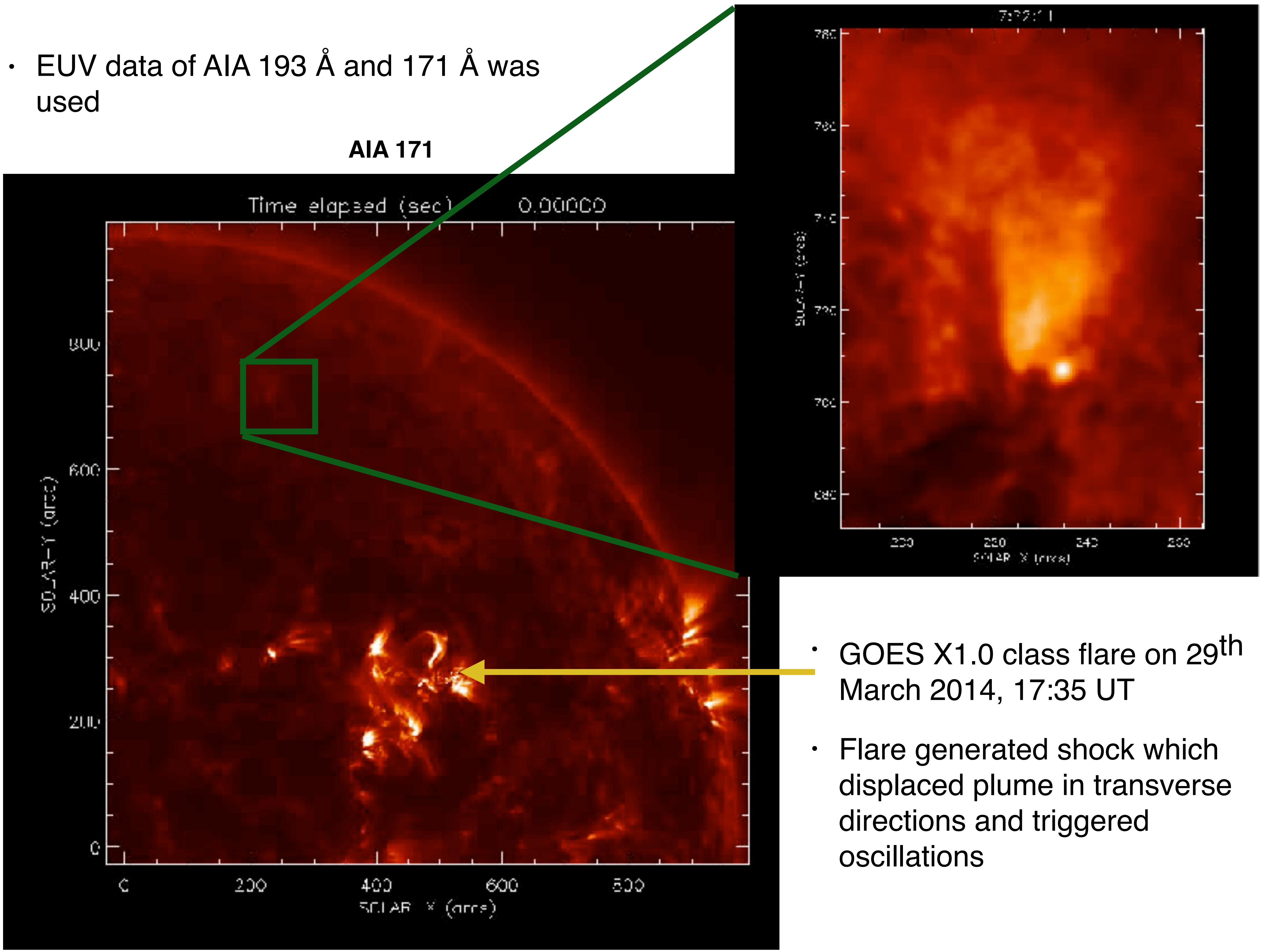
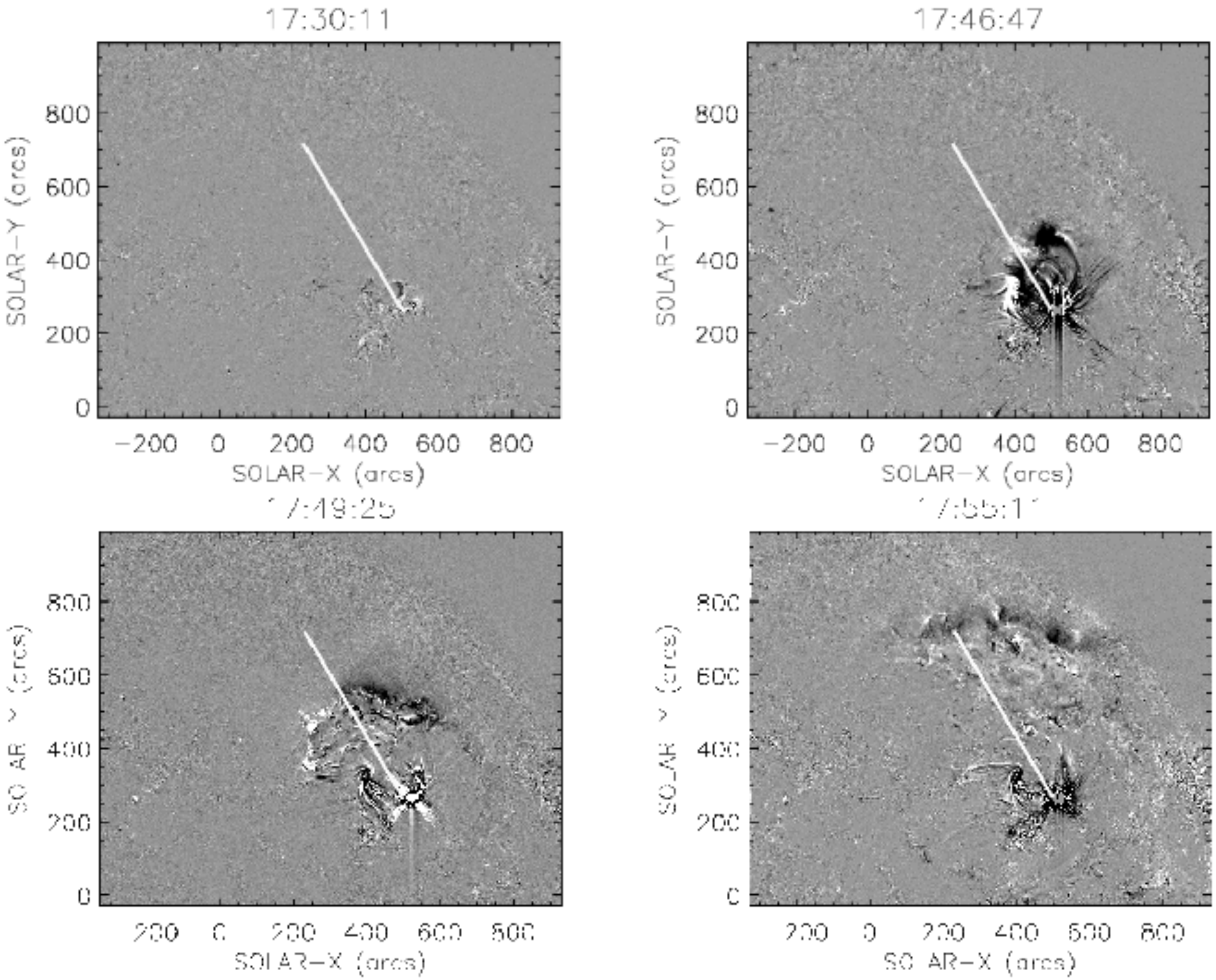
Oscillations in coronal plume

- EUV data of AIA 193 Å and 171 Å was used



- GOES X1.0 class flare on 29th March 2014, 17:35 UT
- Flare generated shock which displaced plume in transverse directions and triggered oscillations

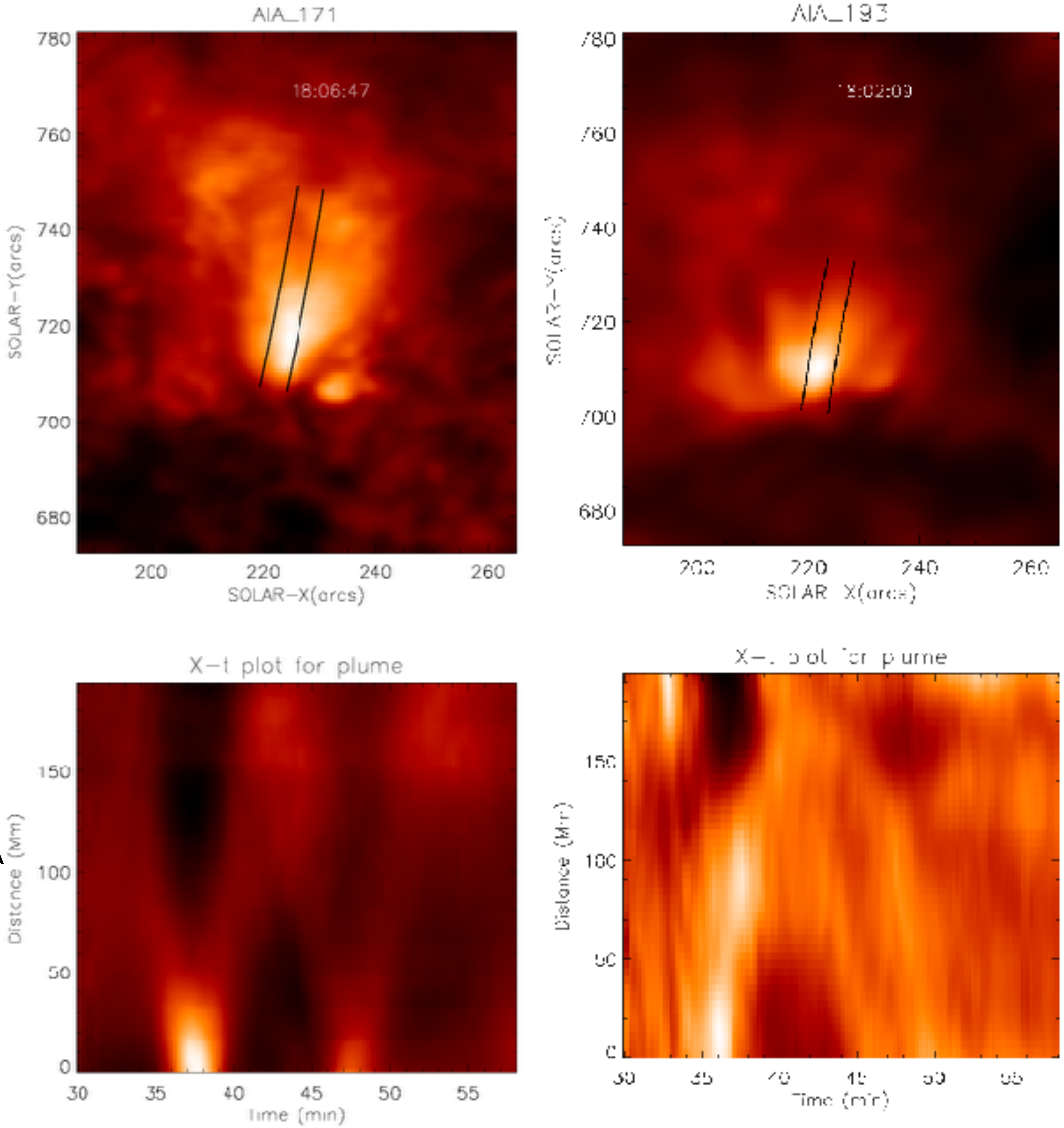
Estimating speed of shock wave



shock velocity = 450 km/s

Time-distance maps

- Broad slice is placed to increase signal to noise
- Oscillations are best seen in AIA 171 A
- AIA 193 has diffuse background
- Oscillations are not clear in AIA 193 A
- Alternate bright and dark ridges are present
- Intensity oscillations are out of phase at the footpoint and at the top of the plume
- Similar feature is seen in AIA 193 A but not very clear



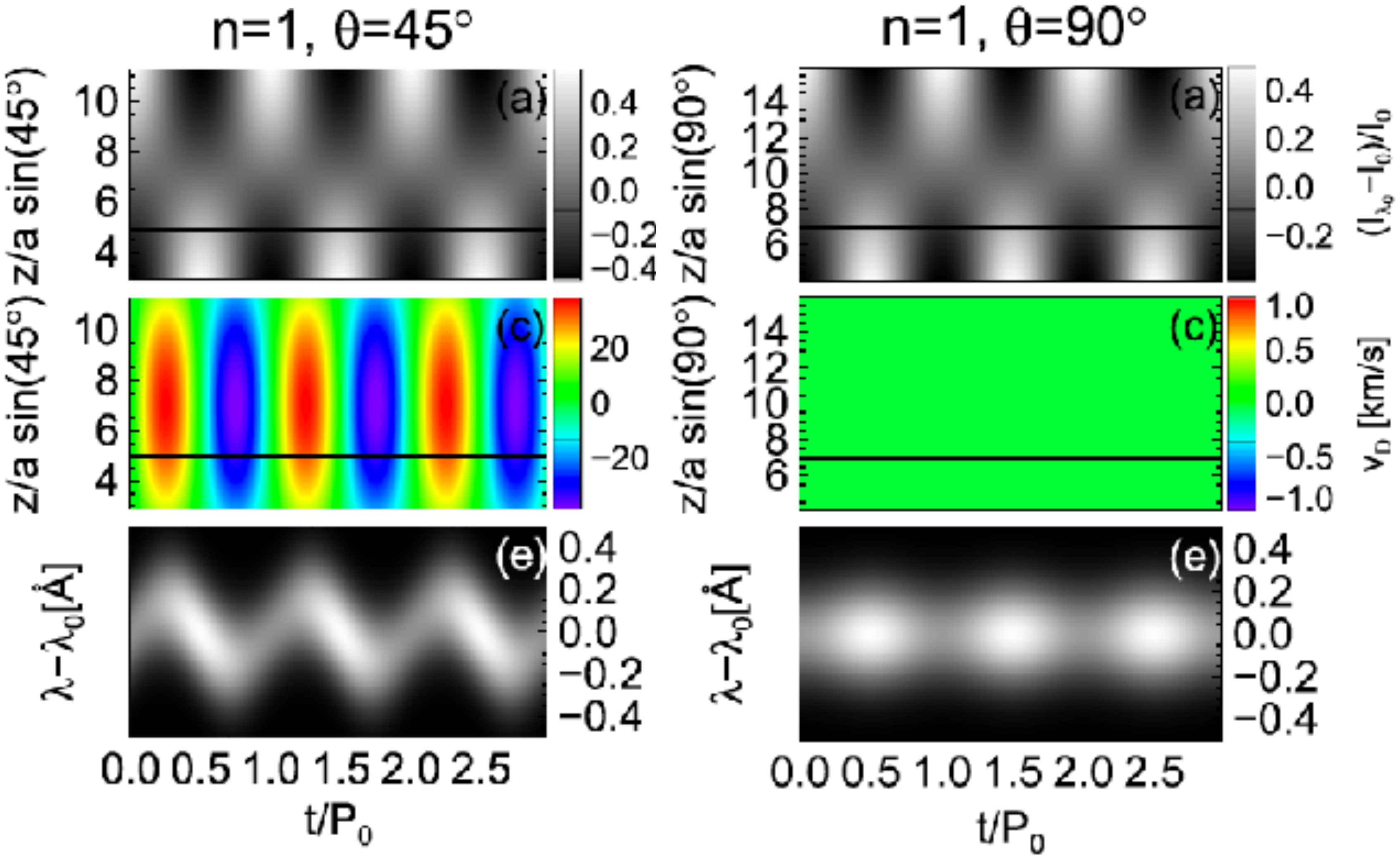
Standing modes in coronal loops

How they look?

Intensity, doppler velocity and line width maps for loop aligned at 45 and 90 degree to LOS

Forward modelling was performed for hot flaring loops

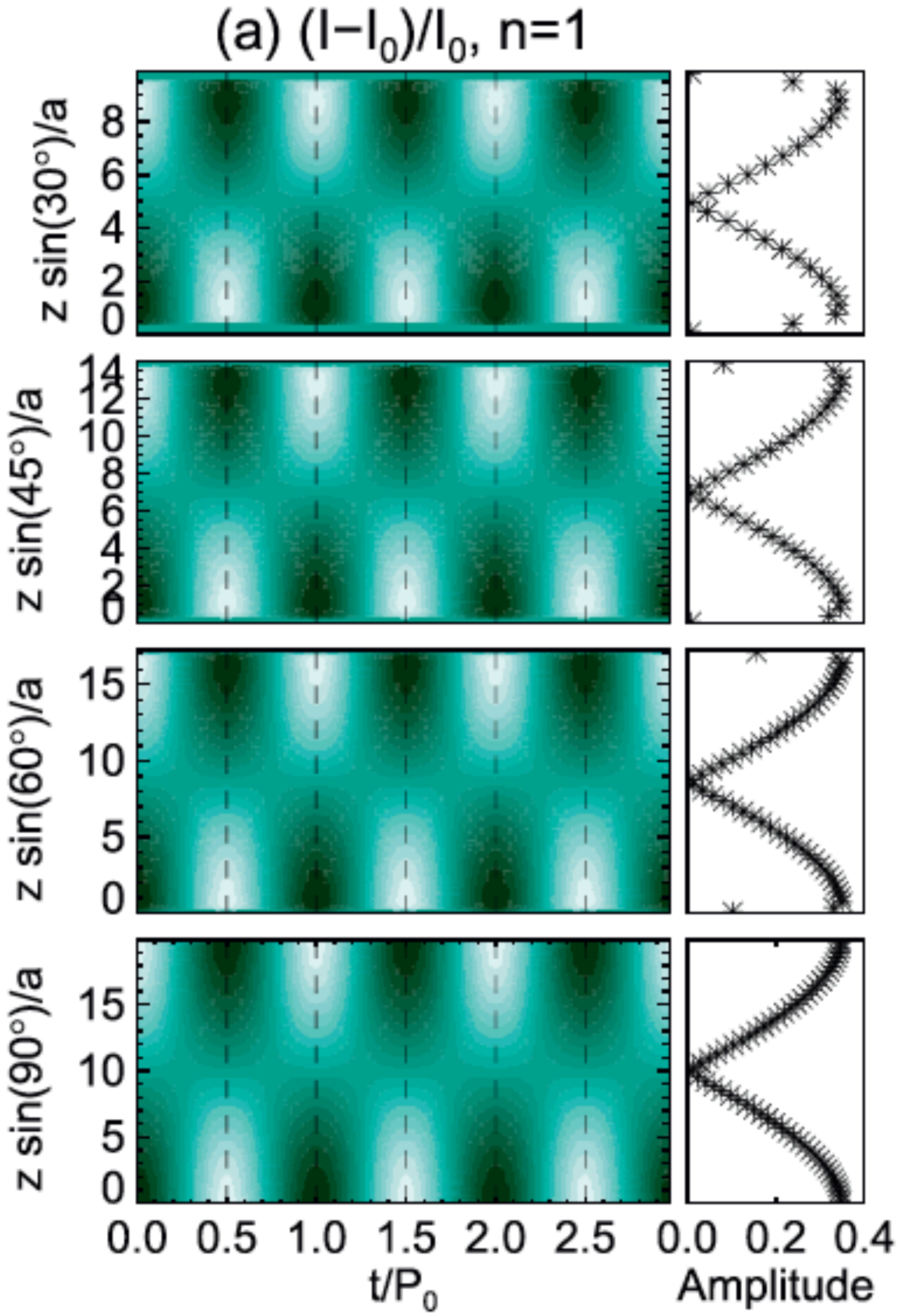
Note that intensity oscillations are out of phase at top and bottom of the plume



Yuan, D et al, 2015

Observables from AIA

- Only intensity variation along plume
- Amplitude of oscillations
- Period of oscillations
- Damping time

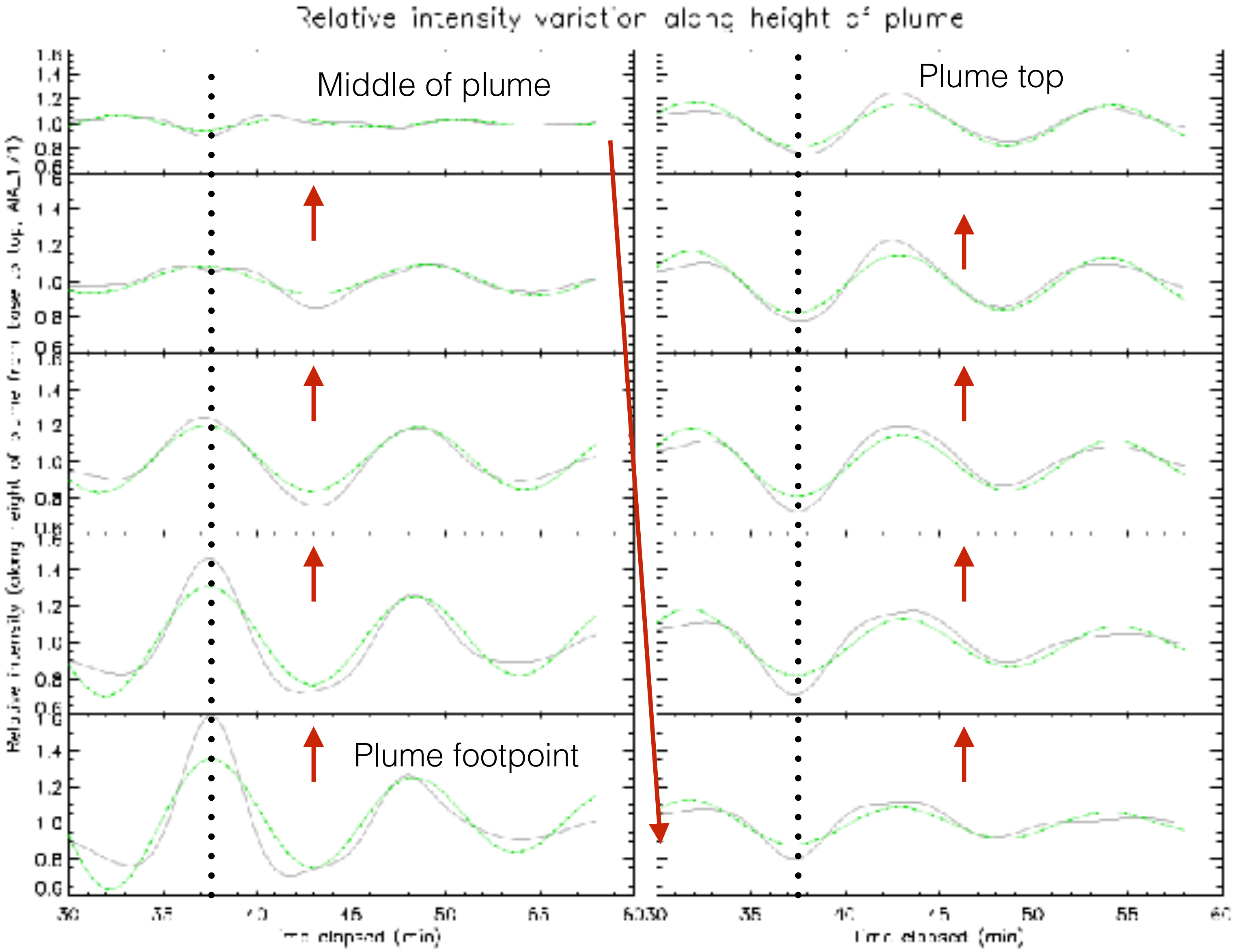


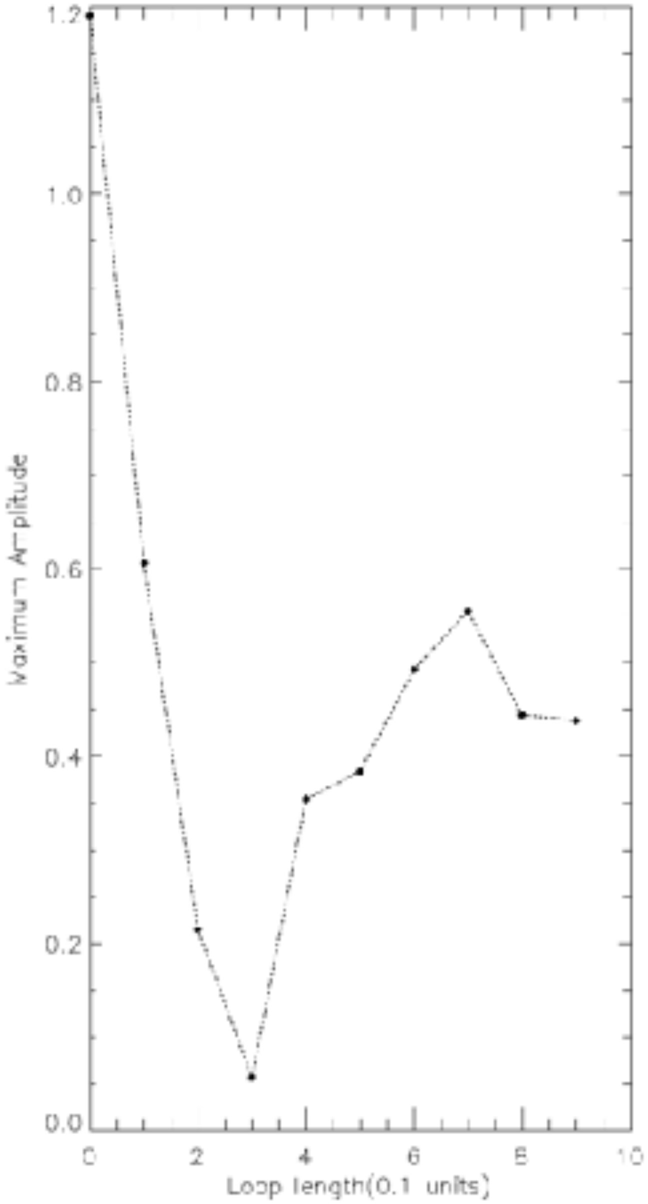
Yuan, D et al, 2015

- Simulated standing oscillations of hot flaring loop in AIA 94 A for fundamental mode
- Note that **the amplitude of intensity should be less at the middle of the loop for fundamental mode**
- Present for different orientation of loop with line of sight
- Out of phase nature of oscillations at top and bottom of loop together with the variation of intensity amplitude along the length of the loop is the observational signatures of standing oscillations

Do we get similar signatures in our study ?

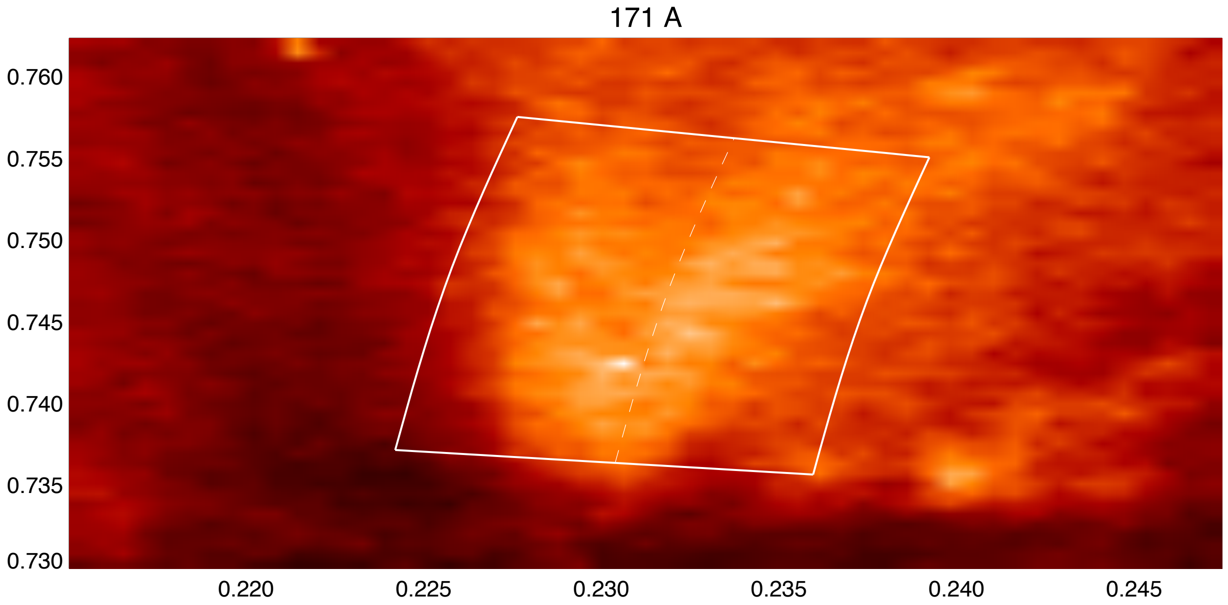
Intensity variation along the plume



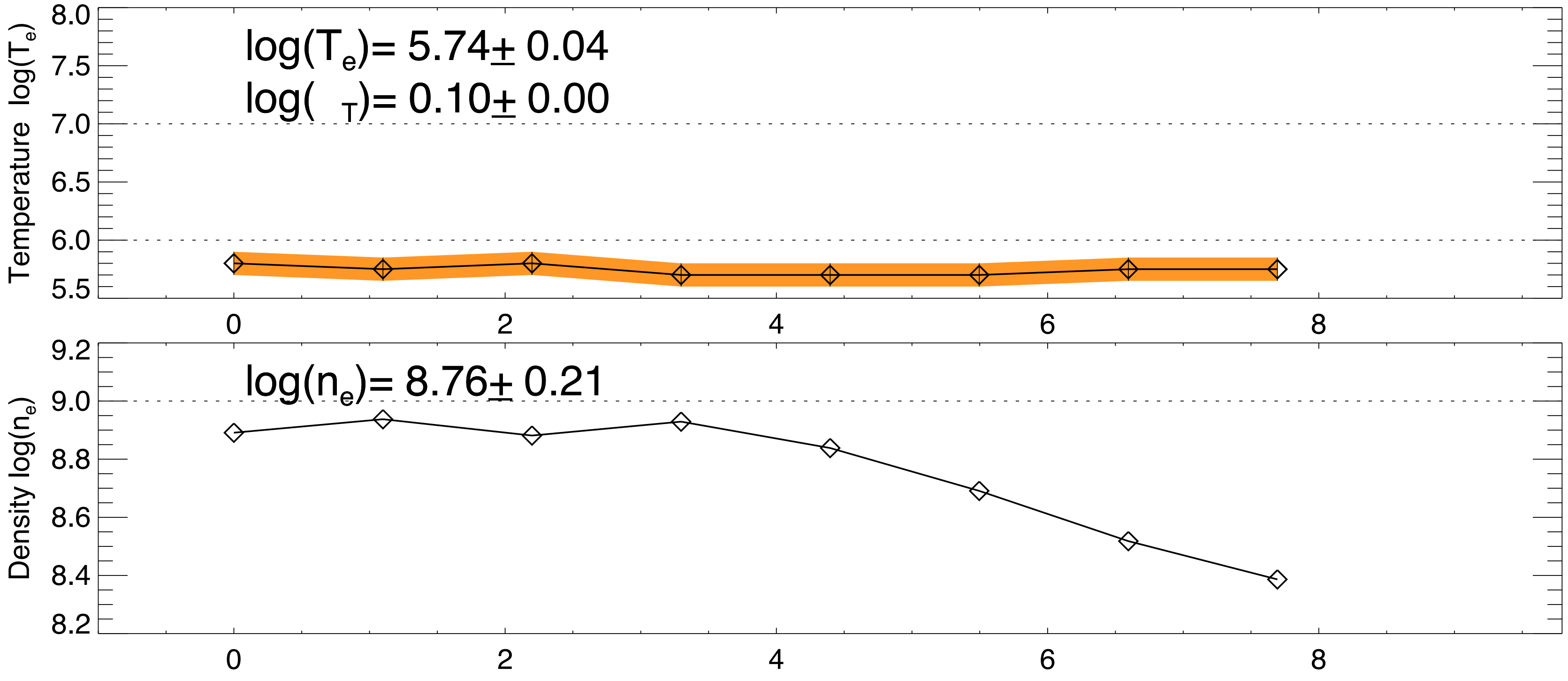


- Intensity variation with time along the plume for AIA 171 A
- Curve in black represent original data points while best fit damped sinusoidal curve is shown in green
- Dotted line represents the instant of time where the amplitude is measured
- Its clearly seen that oscillations are out of phase at plume base and top
- Intensity amplitude also varies along the length of plume as expected from simulations

Density estimates inside plume



- DEM and density estimates were obtained using automated DEM analysis developed by Aschwanden
- Not accurate since the plume is extended object and spread over a large area
- Beyond certain height, background emission dominates over plume
- It gives an order of estimate of density



- Temperature inside plume is ~0.6 MK
- Density is decreasing along the plume
- Contribution from background, thus density variation might be more sharp

Can a density front act like a reflecting surface ?

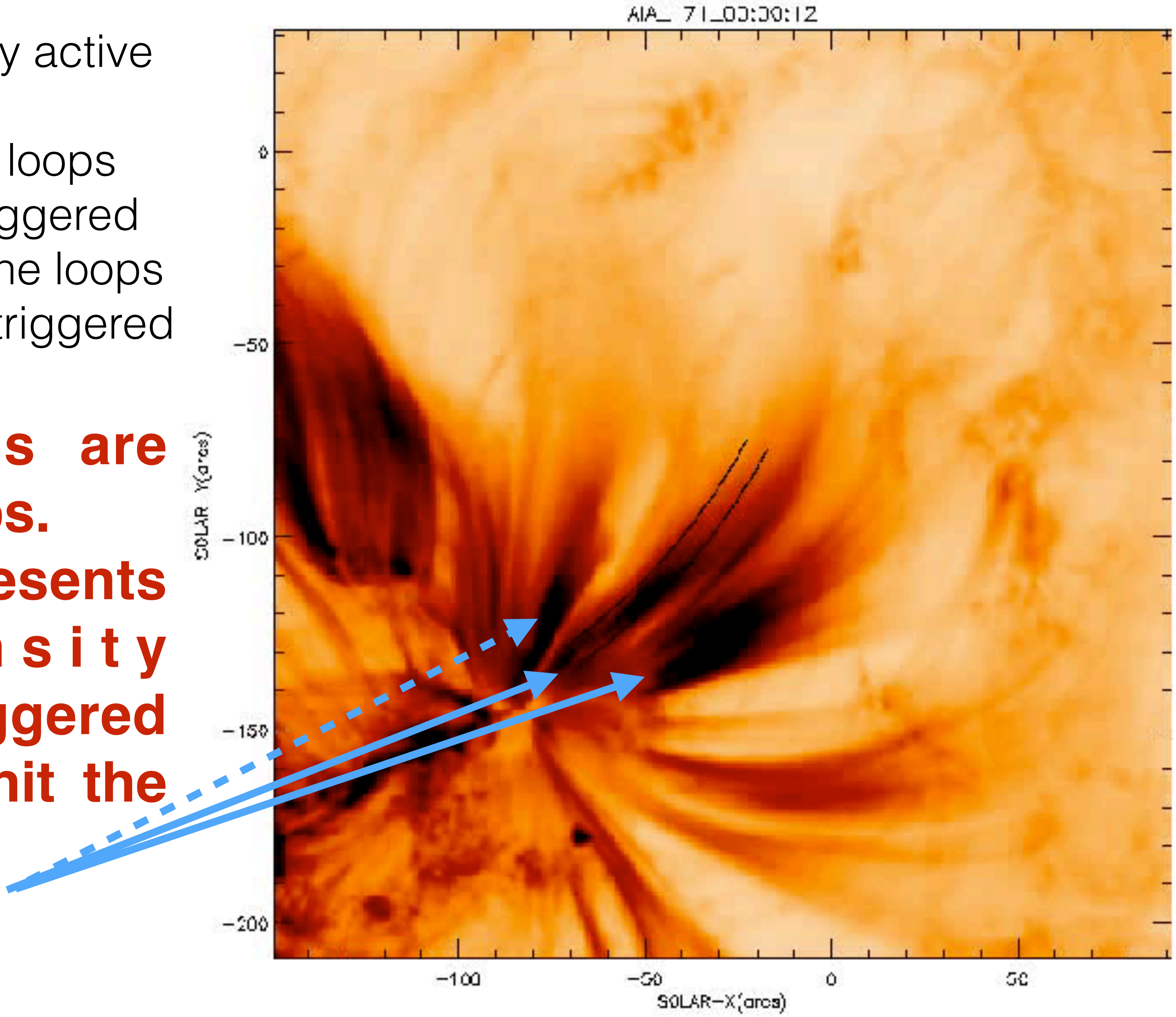
Conclusions

- Signature of standing oscillations in plume
- Period of oscillations is found to be ~11 min
- Damping time is found to be ~ 13 min
- Quality factor (damping time/ period) ~ 1.2
- Is thermal conduction responsible for damping ?
- Wave velocity ~ 107 km/s in AIA 171 A and ~ 138 km/s in AIA 193 A. Although signature was not very clear in AIA 193 A. Difference in velocity -> signature of waves
- Wave velocity ~ sound speed -> slow mode
- Trigger -> Shock wave from distant active region
- Density stratification is clearly seen
- Density stratification might be supporting the oscillations (acting as a reflective surface)
- Amplitude variation along the loop -> Unlikely to be a plasma motion

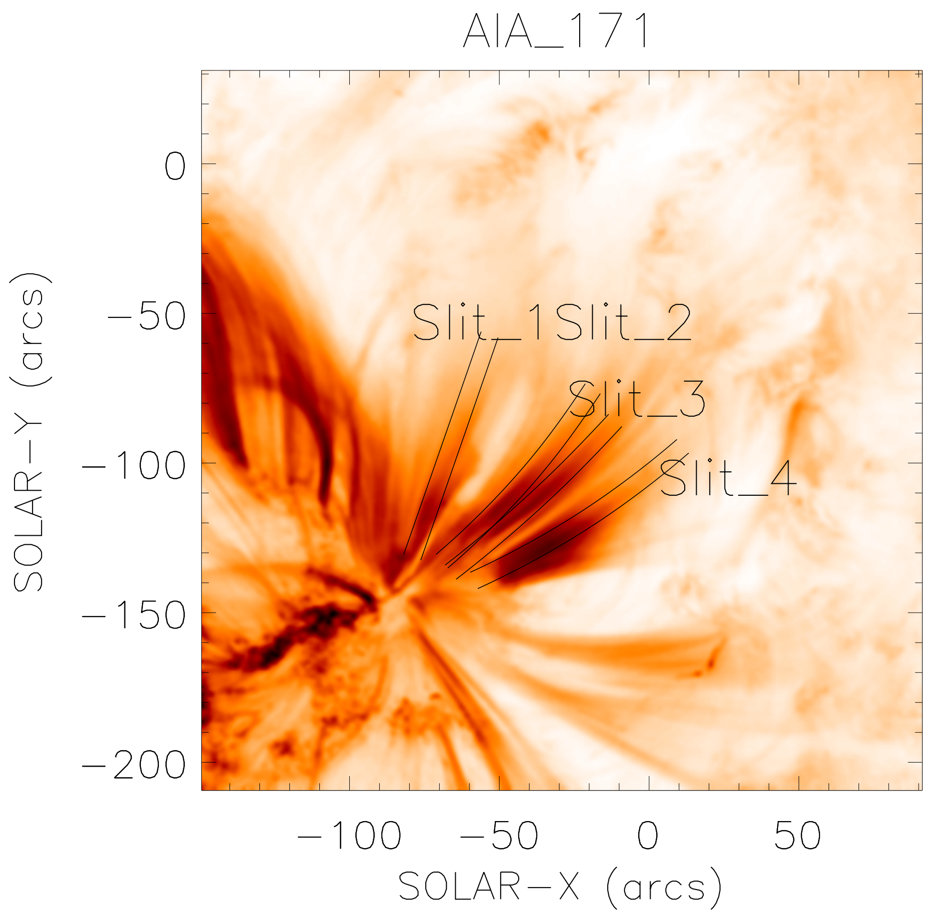
Oscillations in active region fan loops

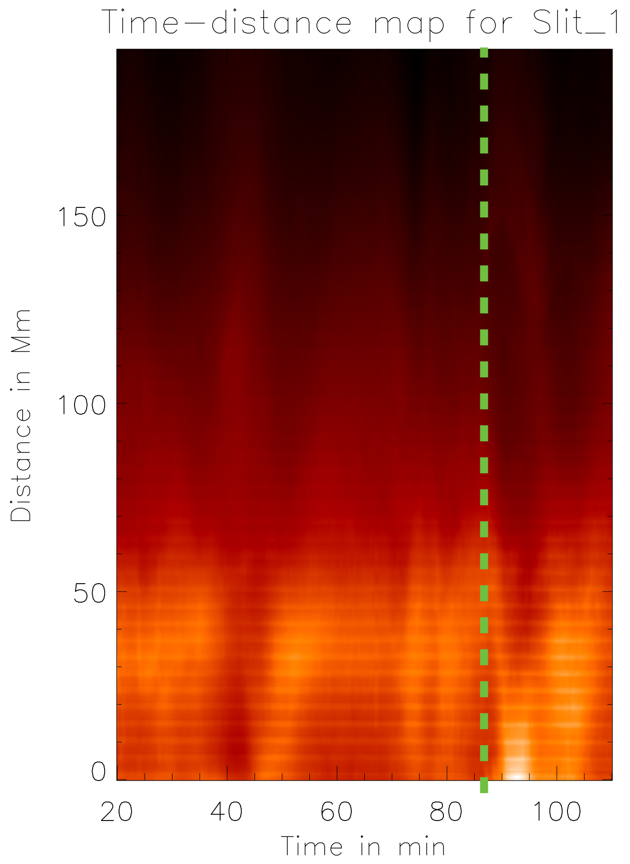
- Flare happened in a nearby active region
- Shock wave displaced the loops
- Intensity oscillations are triggered
- A second shock wave hit the loops again and oscillations are triggered

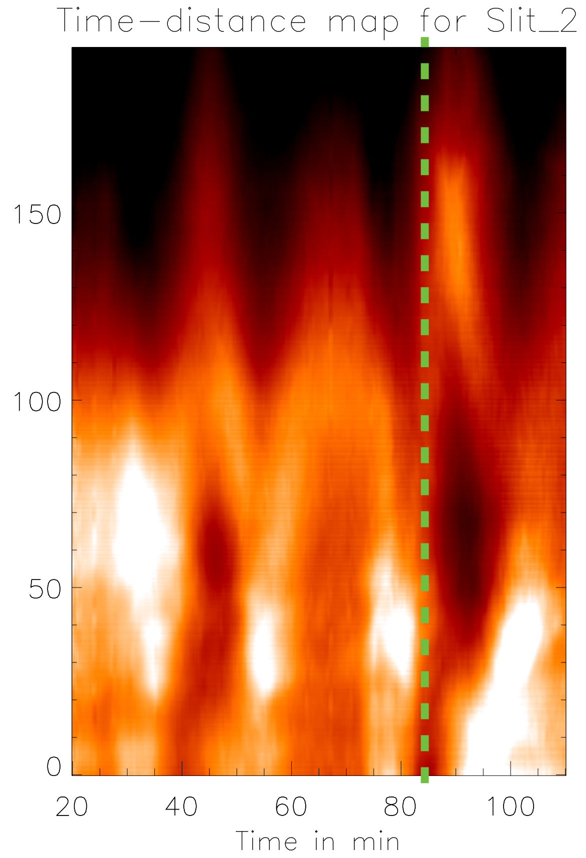
Intensity oscillations are seen in three fan loops. Dashed arrow represents that the intensity oscillations are triggered after second shock hit the loops

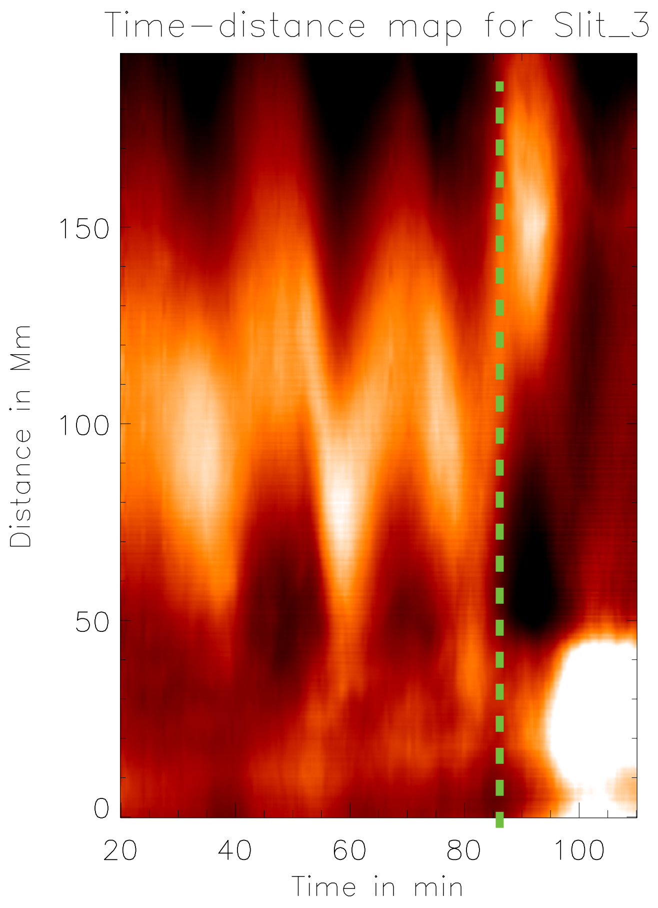


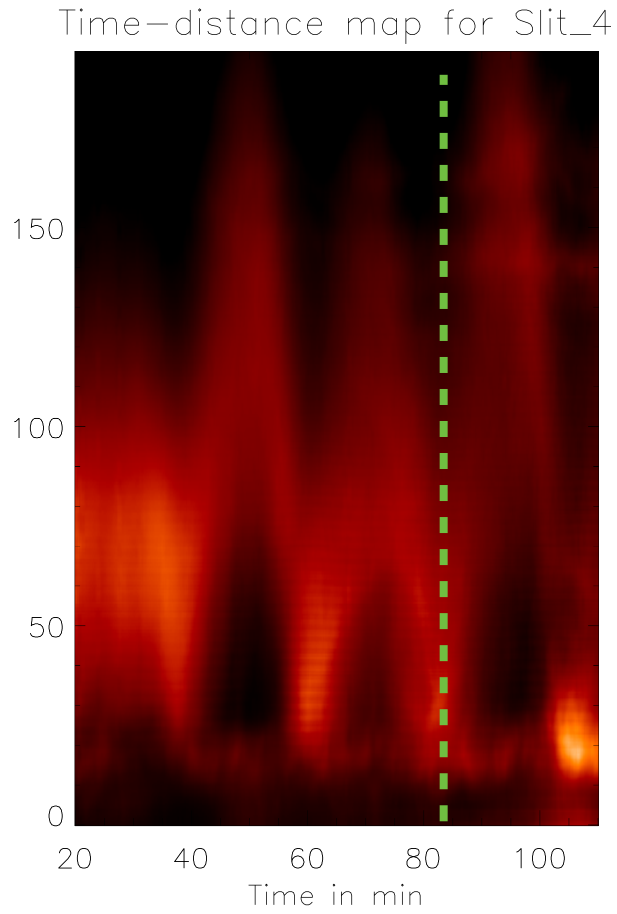
Time -distance maps





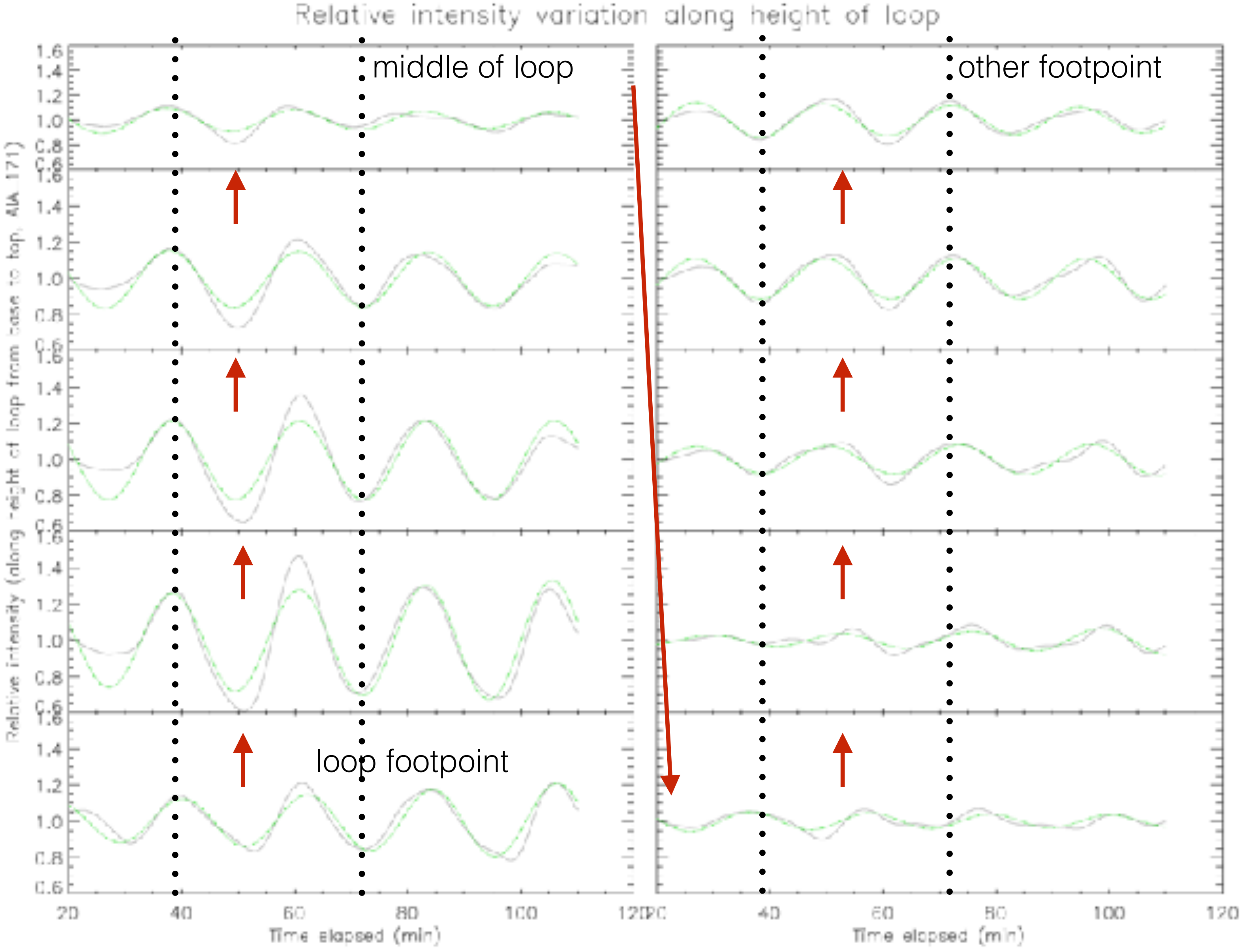


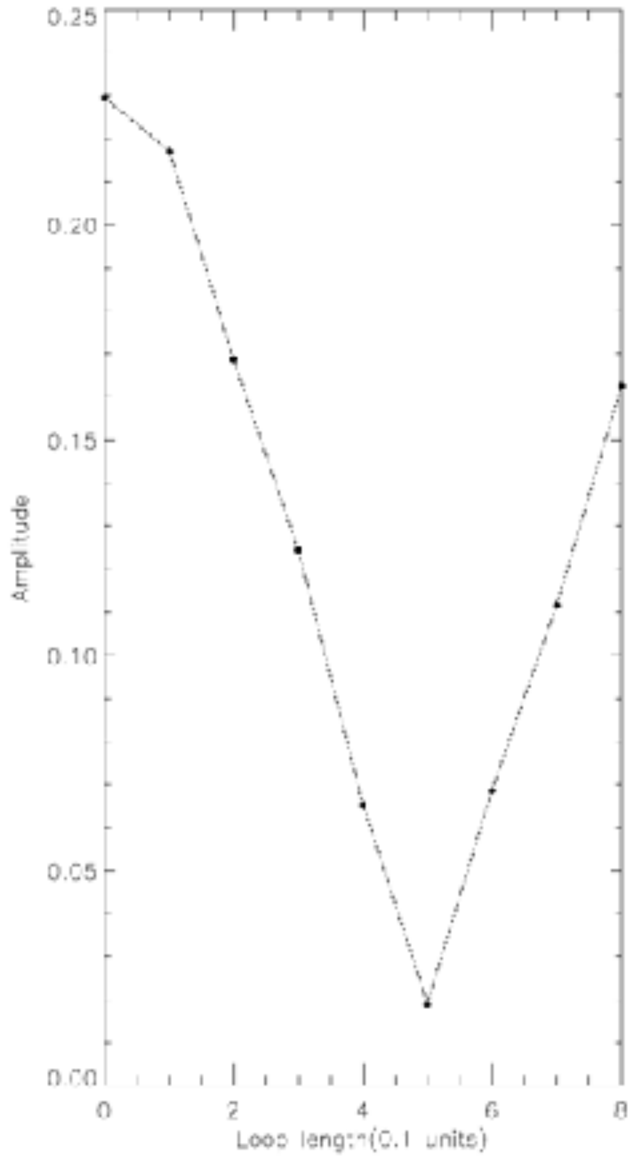




- Dashed green line -> time of arrival of second shock
- Intensity oscillations are not very prominent in slit 1 but present after second flare
- Intensity out of phase at two ends of fan loop
- Similar plots were generated for AIA 193 A

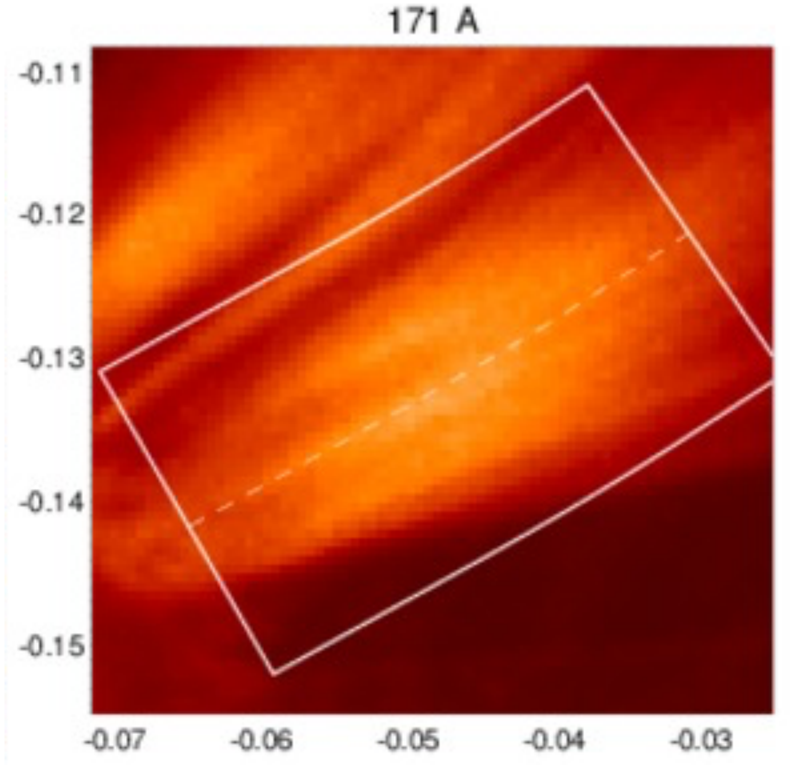
Intensity variation along loop

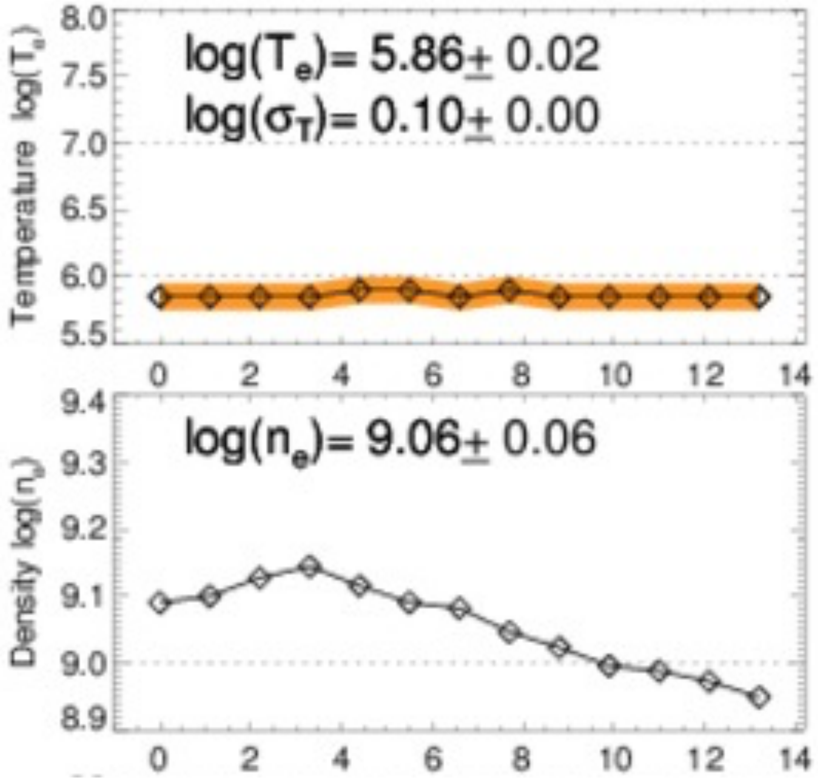




- At two foot points of loop oscillations are out of phase
- Amplitude decreases at the middle of fan loop and then increases
- Similar signature as in plumes
- Period of oscillation -> **22 min**
- Speed of wave is ~**109 km/s** in AIA 171 A and **148 km/s** in AIA 193 A

Density Estimation





- The average temperature of fan loop is ~ 0.6 MK which is similar to plume
- Density stratification is clearly seen
- Density profile is similar to plume

Possible that density front acts like a reflecting surface

Similarities between two observations

	Plume	Fan loop
Trigger	Shock wave	Shock wave
Temperature	0.6 Mk	0.6 MK
Density	Decreasing	Decreasing
Magnetic field topology	Diverging	Diverging

Conclusions

- Slow standing oscillations are seen in diverging magnetic field structures like plumes and fan loops
- Oscillations are triggered by displacement from shock wave unlike the disturbance (flare) happening at one foot point
- Unlike the standing oscillations reported in hot loops, these oscillations are sustained in cool loops
- Steep fall in density may cause reflection of wave at the open end
- There are not propagating waves because amplitude of oscillation decreases at the loop/plume mid point and then again increases at other end

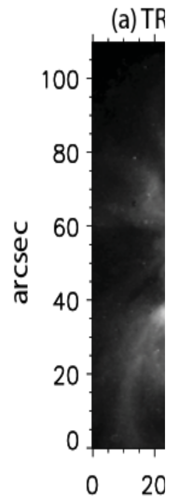
My team

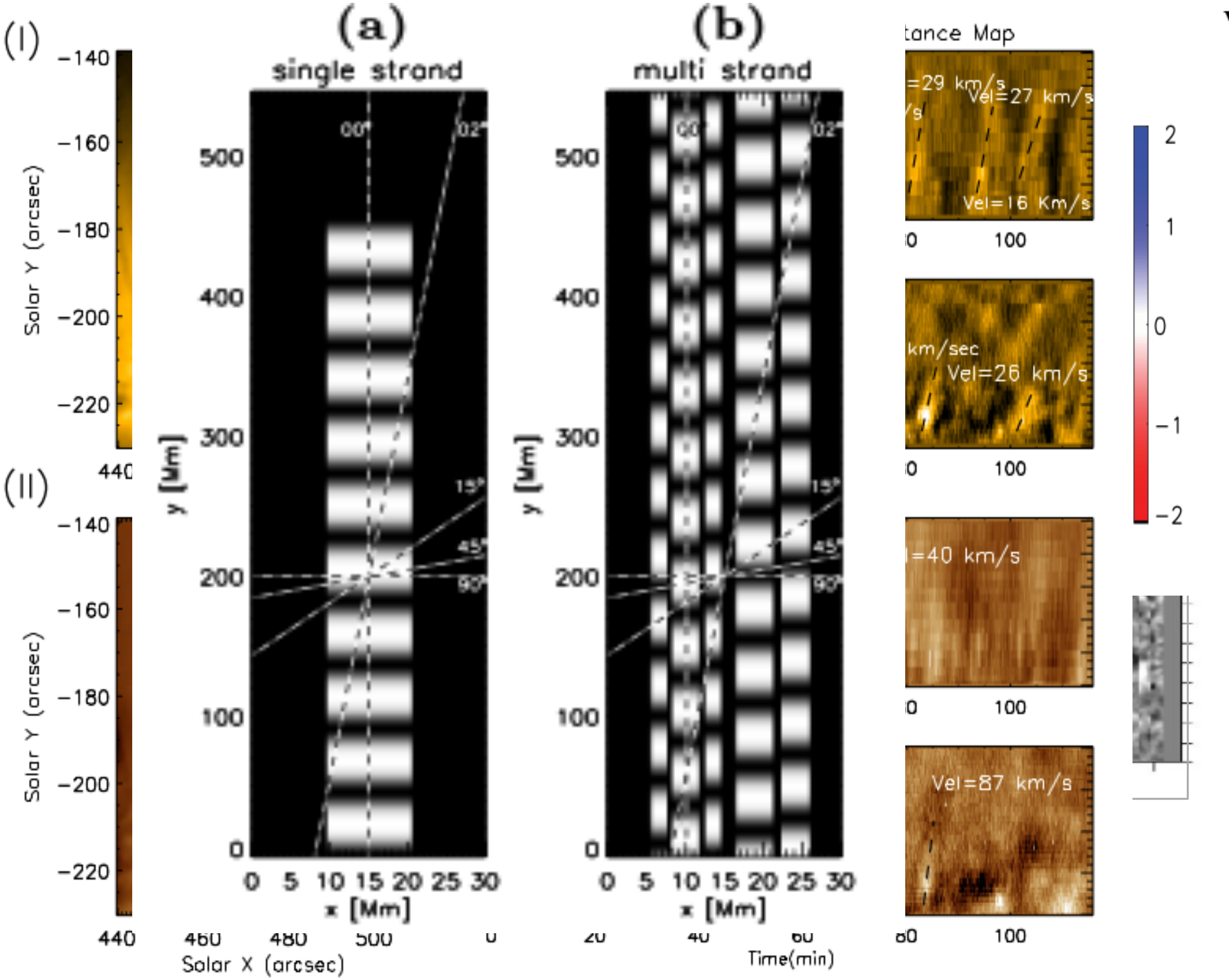
Reflection of Slow Magneto-acoustic Waves in Hot Coronal Loop

Sudip Mandal
With
D. Yuan, X. Fang, D. Banerjee, V. Pant, T.V.D

(Indian Institute Of Astrophysics, India)

Slow waves...Sure?





<u>Early detections</u>

DeForest & Gurman 1998
Berghmans & Clette 1999
De Moortel et al. 2000
And Many more....

<u>Upward Flows:</u>

De Pontieu et al. (2009)
De Pontieu & McIntosh 2010;
Tian et al. 2011a, 2011b

<u>Still the slow waves:</u>

Verwichte et al. (2010)

<u>May be both:</u>

Nishizuka & Hara (2011)
Mandal et al. 2015

<u>Not that easy:</u>

De Moortel et al. (2015)

General Properties:

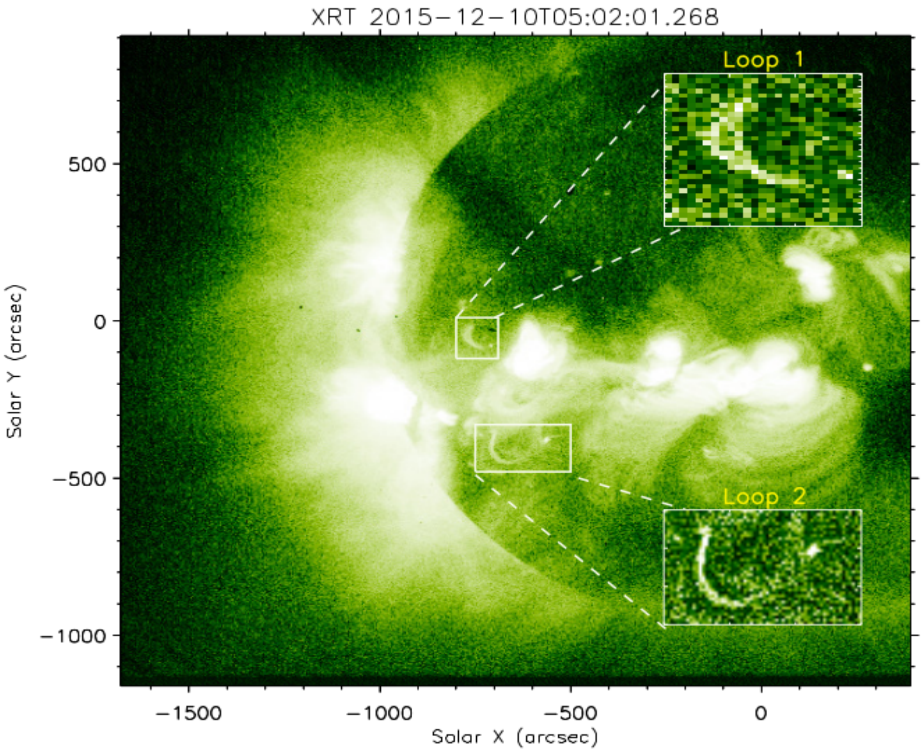
1. They are everywhere--Krishna Prasad et al. 2012B
2. Propagation speed between 50-150 km/s.--Marsh et al. 2009
3. Subject to damping --Ofman & Wang 2002 and Gupta 2014
4. Frequency dependent damping – Krishna Prasad et al. 2014 and Mandal et al 2016

Previous studies:

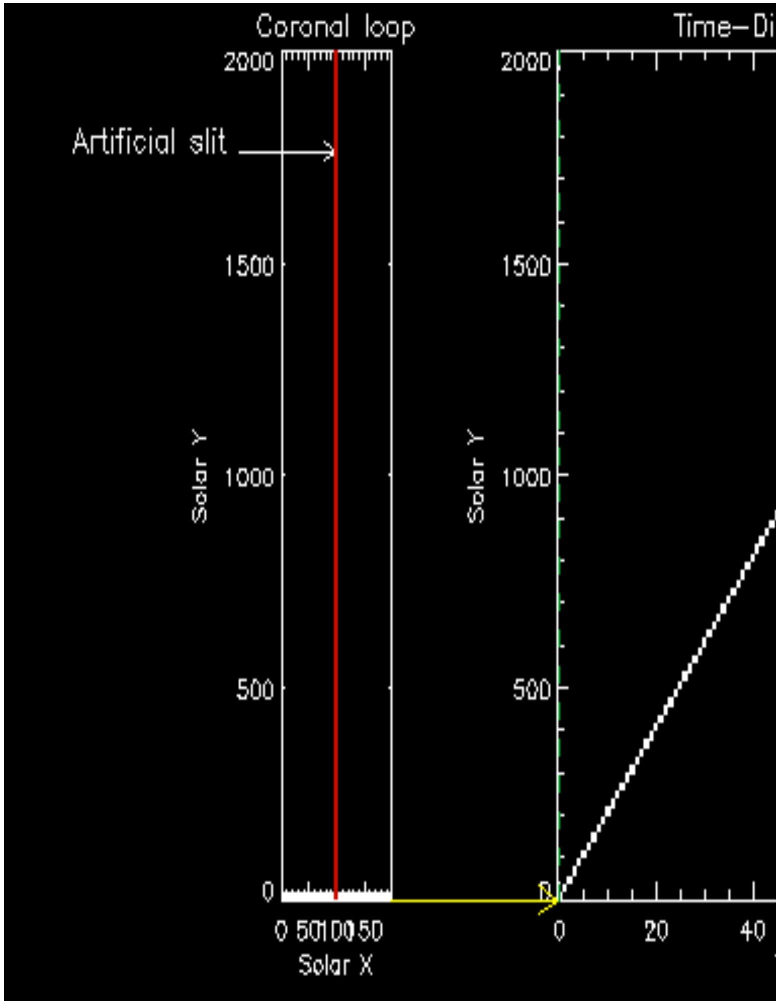
1.Kumar et al. (2013) found such an event using AIA 171 and 193 channel.

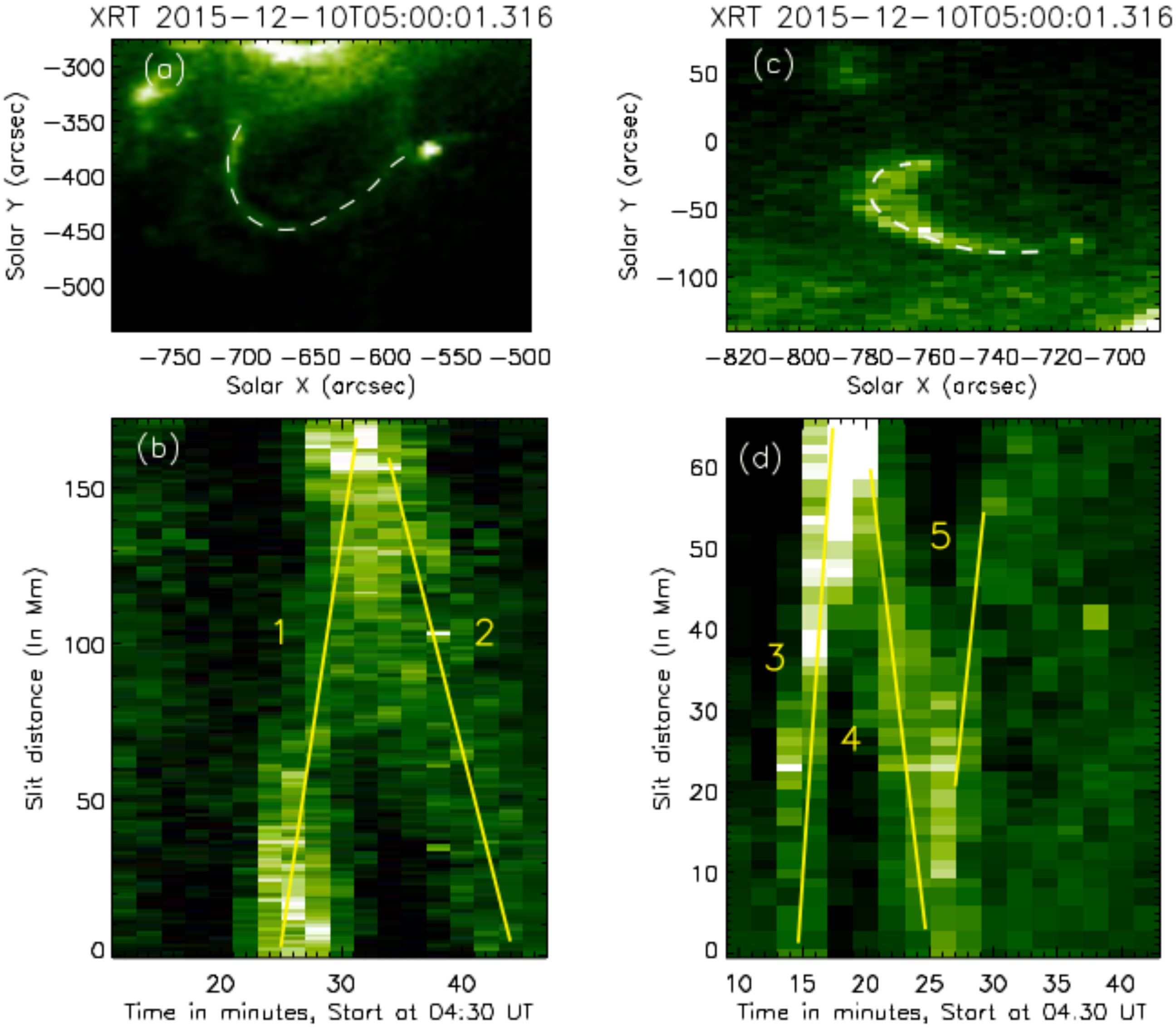
- 2. Fang et al. (2015), using a 2.5D MHD simulation reproduced the event.

Event1:

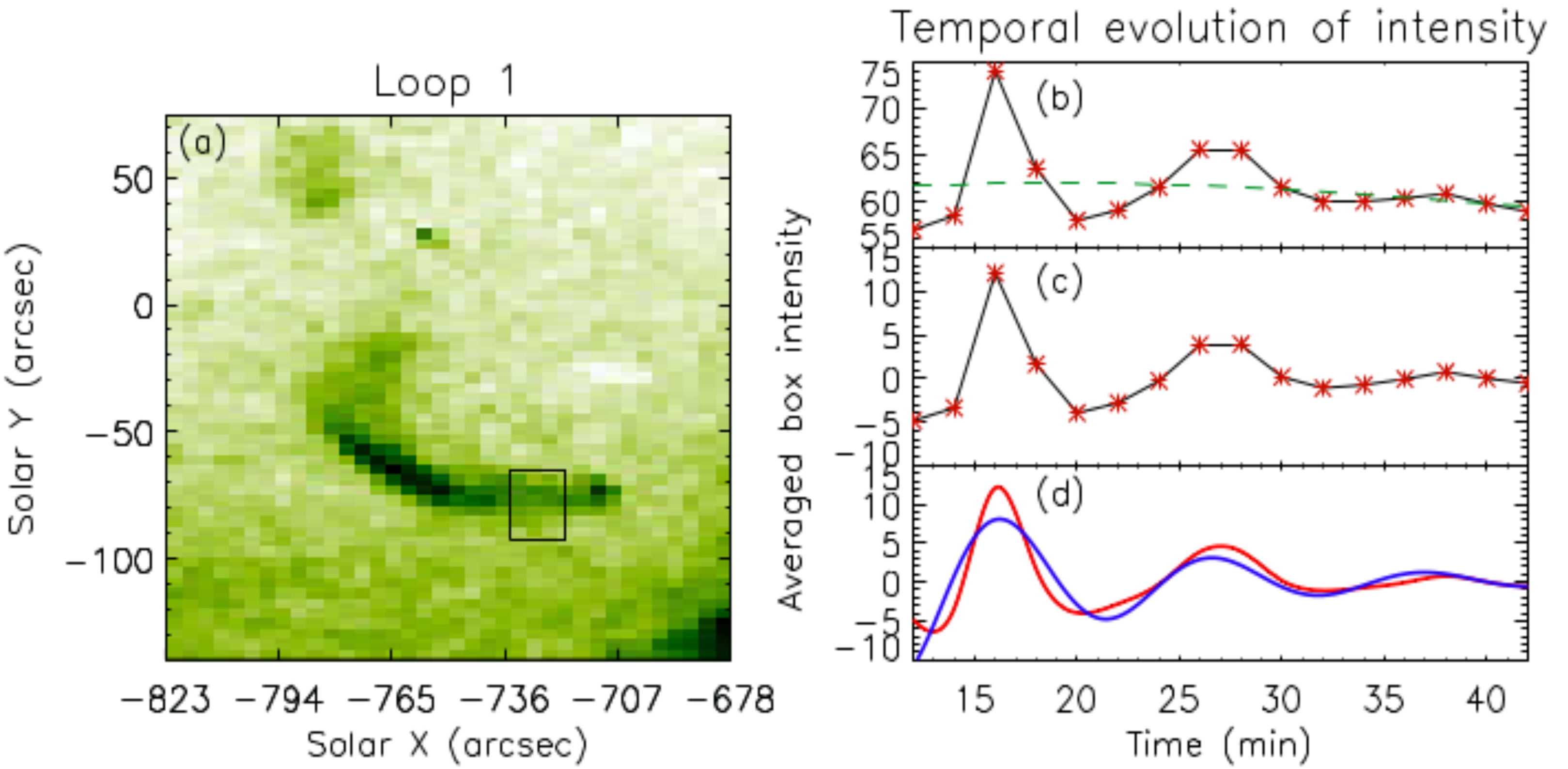

XRT 2015−12−10T05:02:01.268
Loop 1
Loop 2
500
0
−500
−1000
Solar Y (arcsec)
−1500
−1000
−500
0
Solar X (arcsec)

Time-Distance Map:





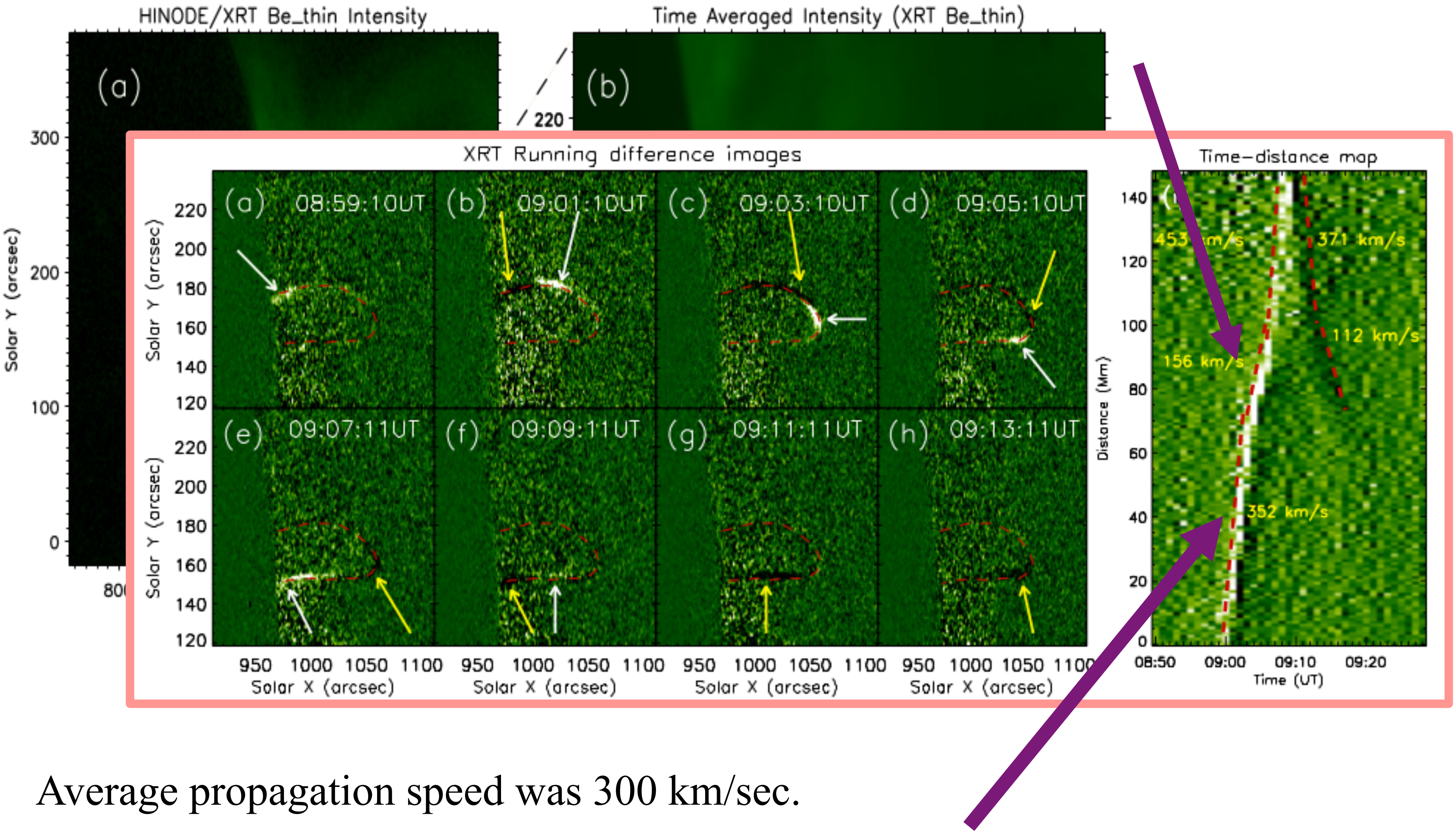
Damping of these waves:



$$I(t) = \mathrm{A}\sin\left(\frac{2\pi t}{\mathrm{P}} + \phi\right)\exp\left(\frac{-t}{\tau}\right)$$

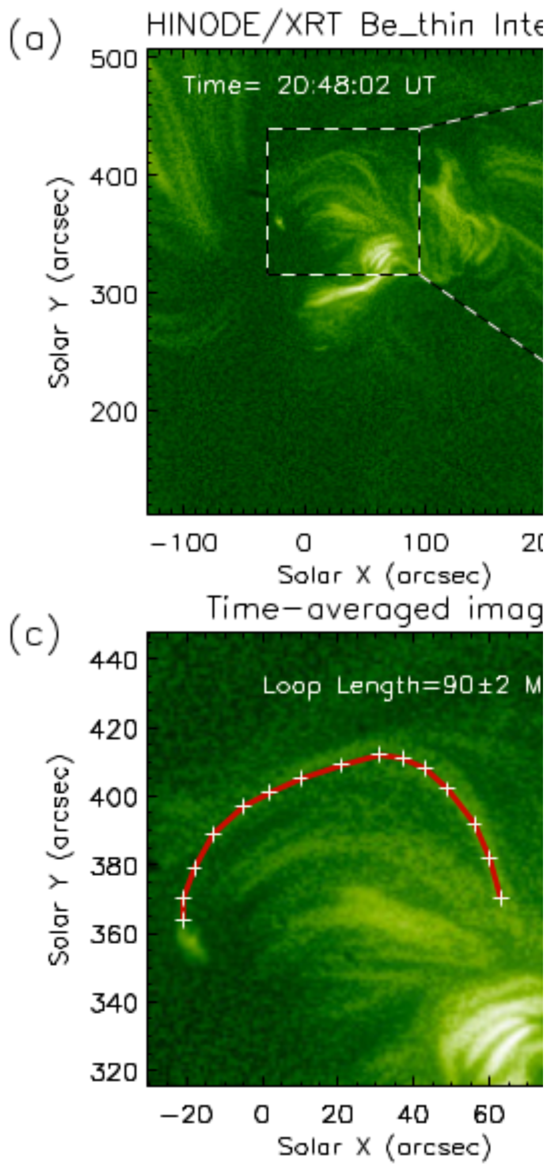
Estimates time period is 10.1 minutes whereas the damping time is 10.6

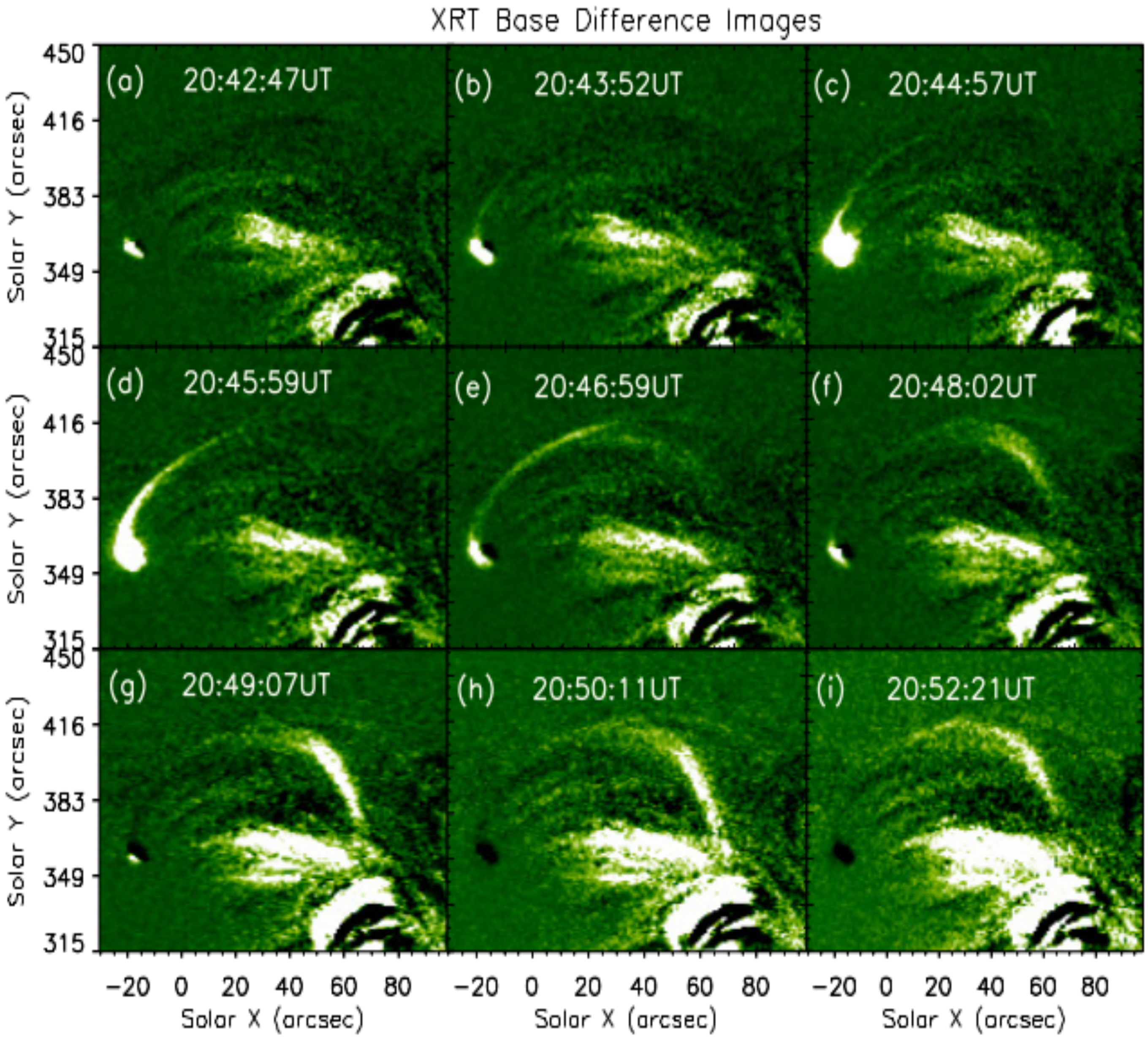
Event 2 and Event 3:



Average propagation speed was 300 km/sec.

Contd.....

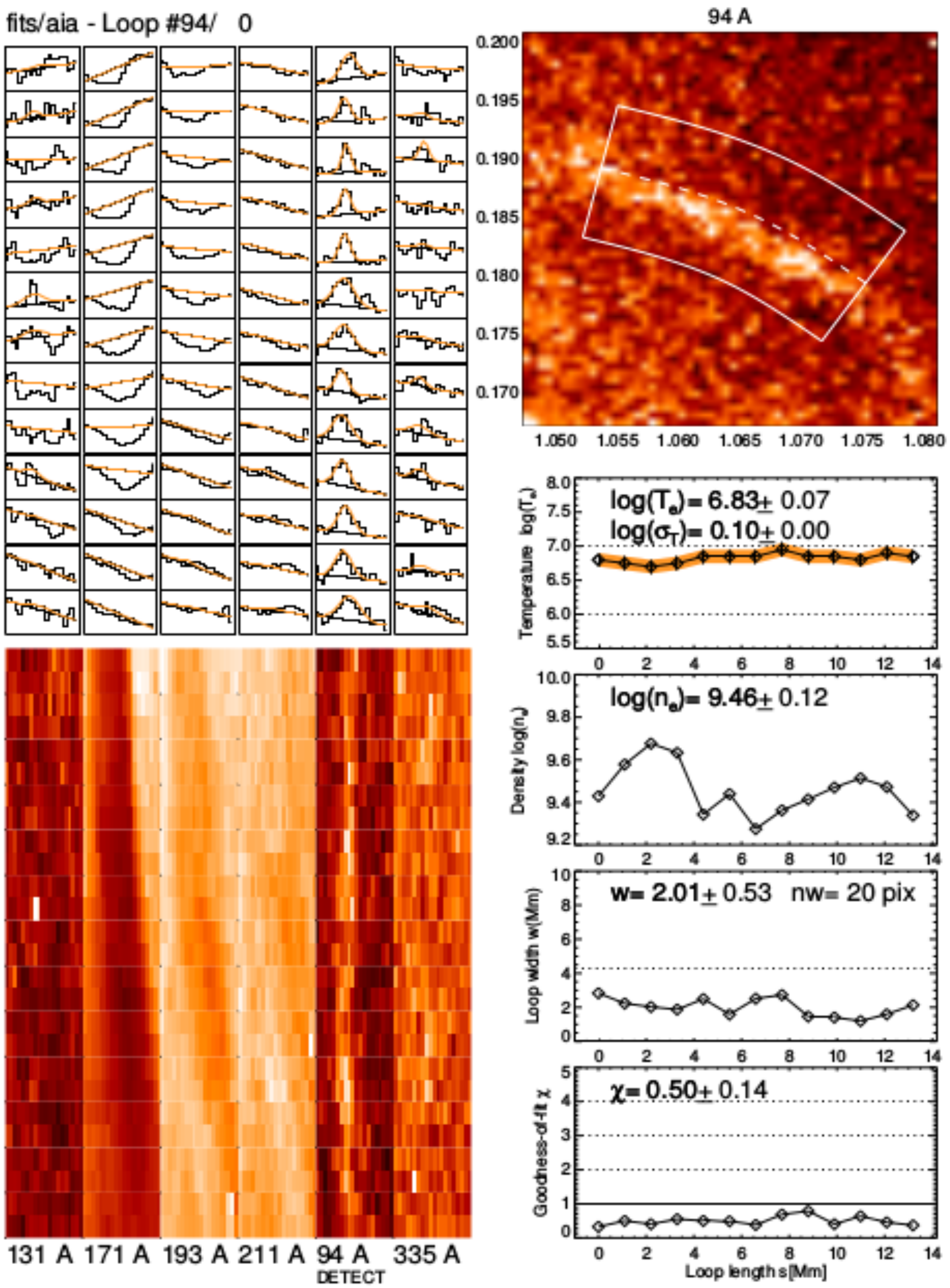

(a)
HINODE/XRT Be_thin Inte
Time= 20:48:02 UT
500
400
300
200
Solar Y (arcsec)
-100
0
100
20
Solar X (arcsec)
(c)
Time-averaged imag
Loop Length=90±2 M
440
420
400
380
360
340
320
Solar Y (arcsec)
-20
0
20
40
60
Solar X (arcsec)


XRT Base Difference Images
(a) 20:42:47UT
(b) 20:43:52UT
(c) 20:44:57UT
(d) 20:45:59UT
(e) 20:46:59UT
(f) 20:48:02UT
(g) 20:49:07UT
(h) 20:50:11UT
(i) 20:52:21UT
450
416
383
349
315
Solar Y (arcsec)
-20
0
20
40
60
80
Solar X (arcsec)

Got that in AIA too....

We looked at the hotter channels of AI
only visible in channel 94.

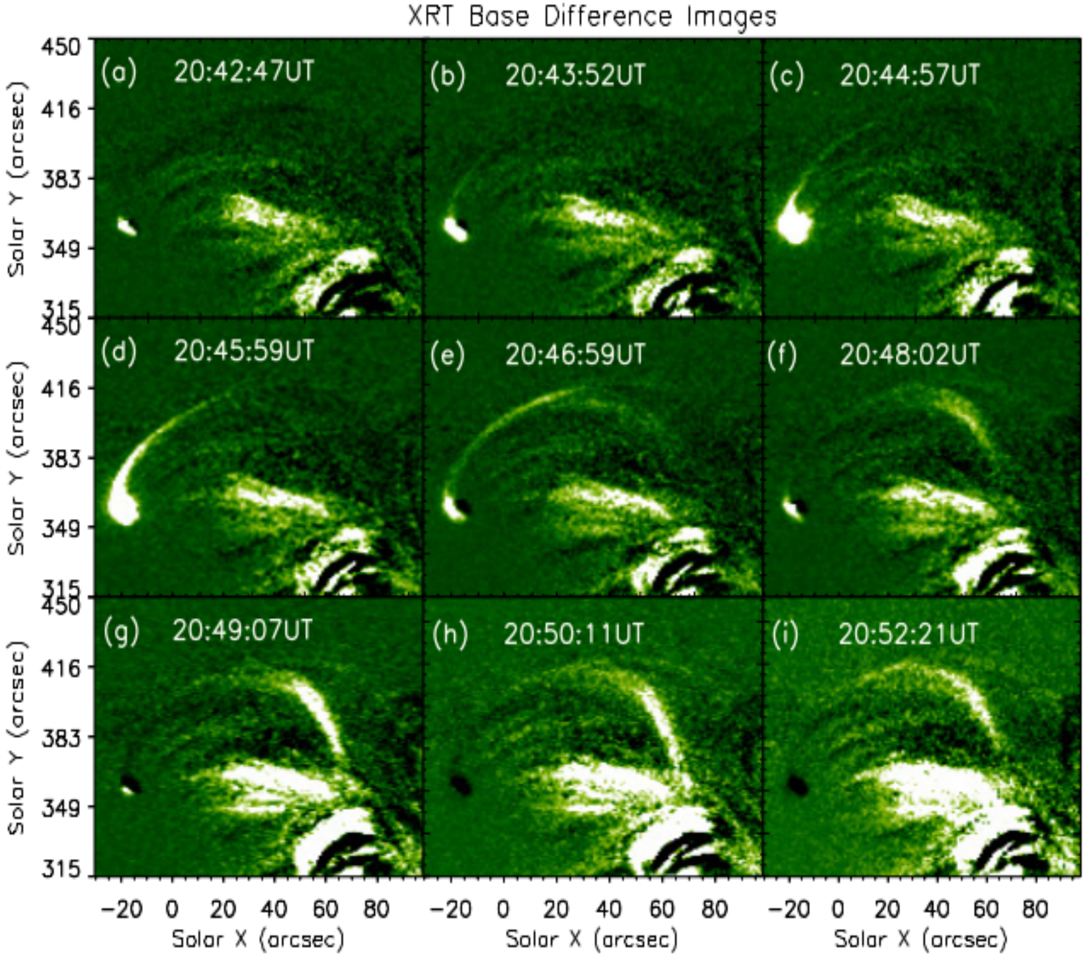
220
200
180
160
140
120
Solar Y (arcsec)



What about the source?

1. None of the loops are visible in any of the AIA channels except the one event.
2. The source footpoint for that case was on the far side of the sun (What a luck!)

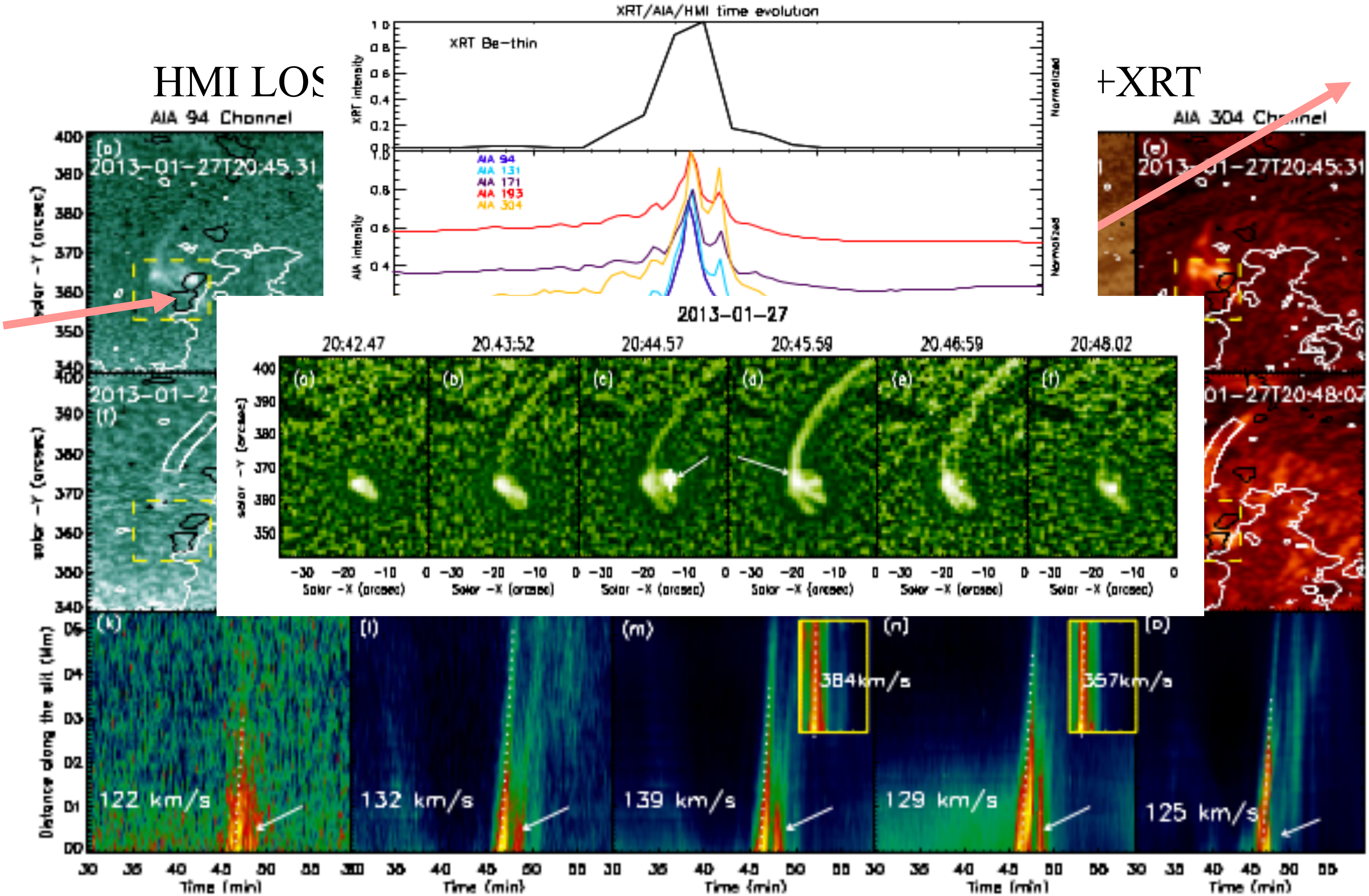
Let's look at the best event:



In detail:

HMI LOS

+XRT



Numerical Experiment:

From Event1: We got loop length, speed of propagation, temperature and density
From Event2: We got loop length and speed and information about the generation mechanism.

Our numerical setup includes gravity, anisotropic thermal conduction and radiative cooling and parametrized heating terms, in a domain of -60 Mm $\leq x \leq 60$ Mm and $0 \leq y \leq 80$ Mm. We inject heat at the one of the loop footpoints to mimic the flare situation. AIA 94 channel emission has been synthesized using FoMo forward modelling code.

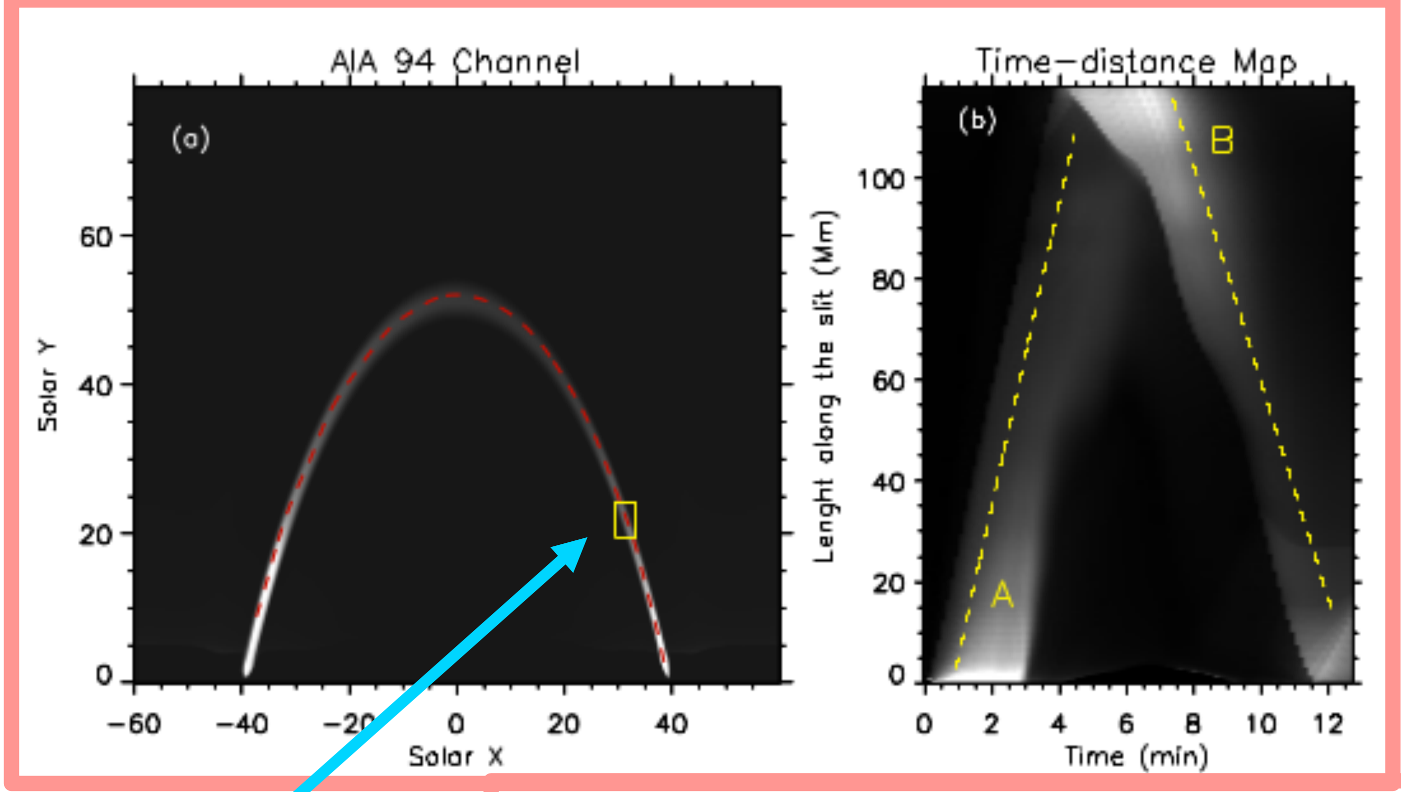
Numerical Experiment:

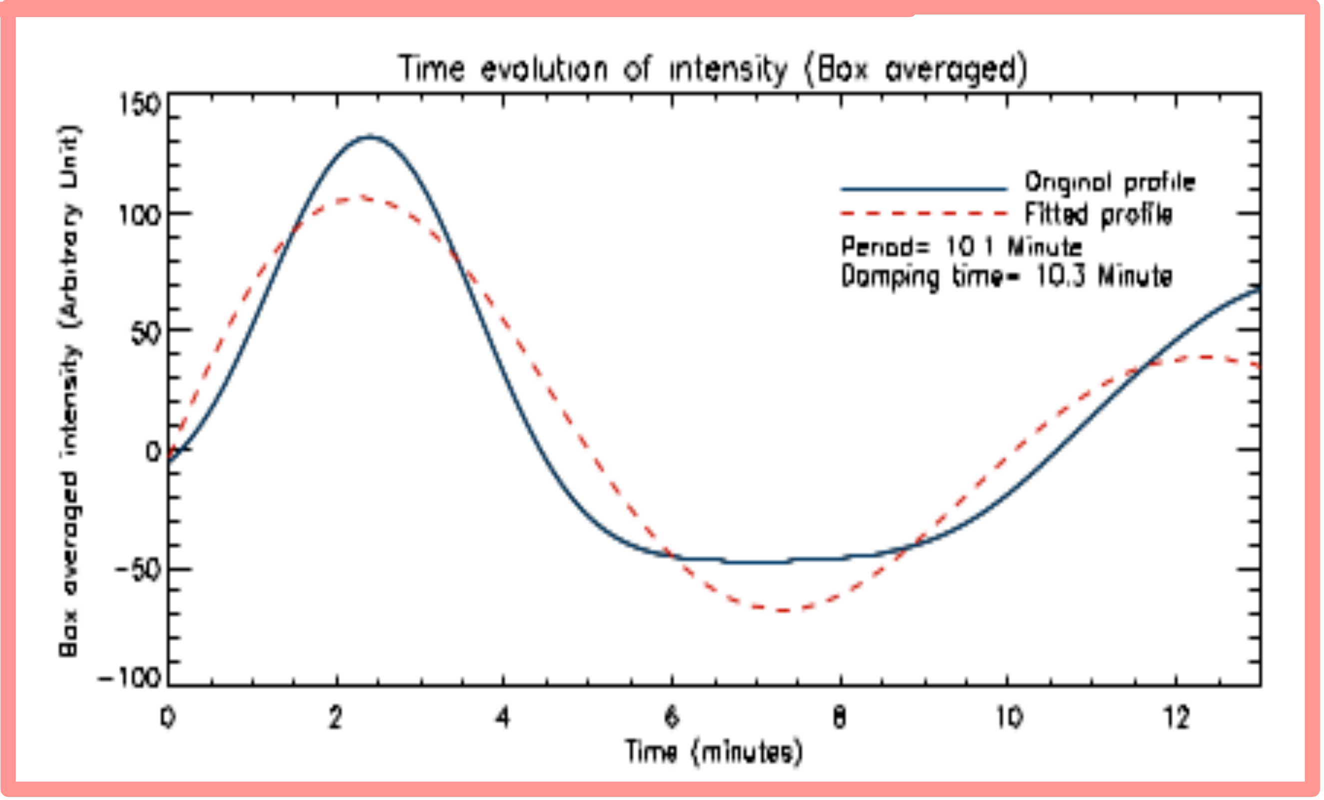
From the observations we obtained an estimate about the speed of the wave propagating through the loop. The the density and temperature values of the loop plasma are also calculated using DEM analysis using the AIA data.

Specs:Gravity, anisotropic thermal conduction and radiative cooling.

2. AMRVAC
3. $-60\text{ Mm} \leq x \leq 60\text{ Mm}$ and $0 \leq y \leq 80\text{ Mm}$
4. $H_1 = c_1 \exp(-(y - y_c)^2/\lambda^2) f(t)$

$$f(t) = \begin{cases} t/30 & 0 \leq t < 30 \quad \text{s} \\ 1 & 30 \leq t < 150 \quad \text{s} \\ (180 - t)/30 & 150 \leq t < 180 \quad \text{s} \end{cases}$$





Yellow Box used to get the intensity profile and the dotted re line is used to create the XT map

$$I(t) = \mathrm{A}\sin(\frac{2\pi t}{\mathrm{P}} + \phi)\exp(\frac{-t}{\tau})$$

Summary:

1. We report, for the first time, simultaneous observation of an intensity oscillations in a hot coronal loop as seen with HINODE/XRT and SDO/AIA.

2. Observed wave appears after a flare occurs at one of the loop footpoints and propagates with lower than the sound speed.

3. The DEM analysis performed on the AIA data revealed the loop temperature and density to be ~10MK and ~10^9 cm^{-3} respectively.

4. Analyzing the synthesized data, we have obtained the propagation speeds which matches well with the observed speeds from XRT and AIA.

5. Simultaneous imaging and spectroscopic data will greatly improve our understanding about such phenomena

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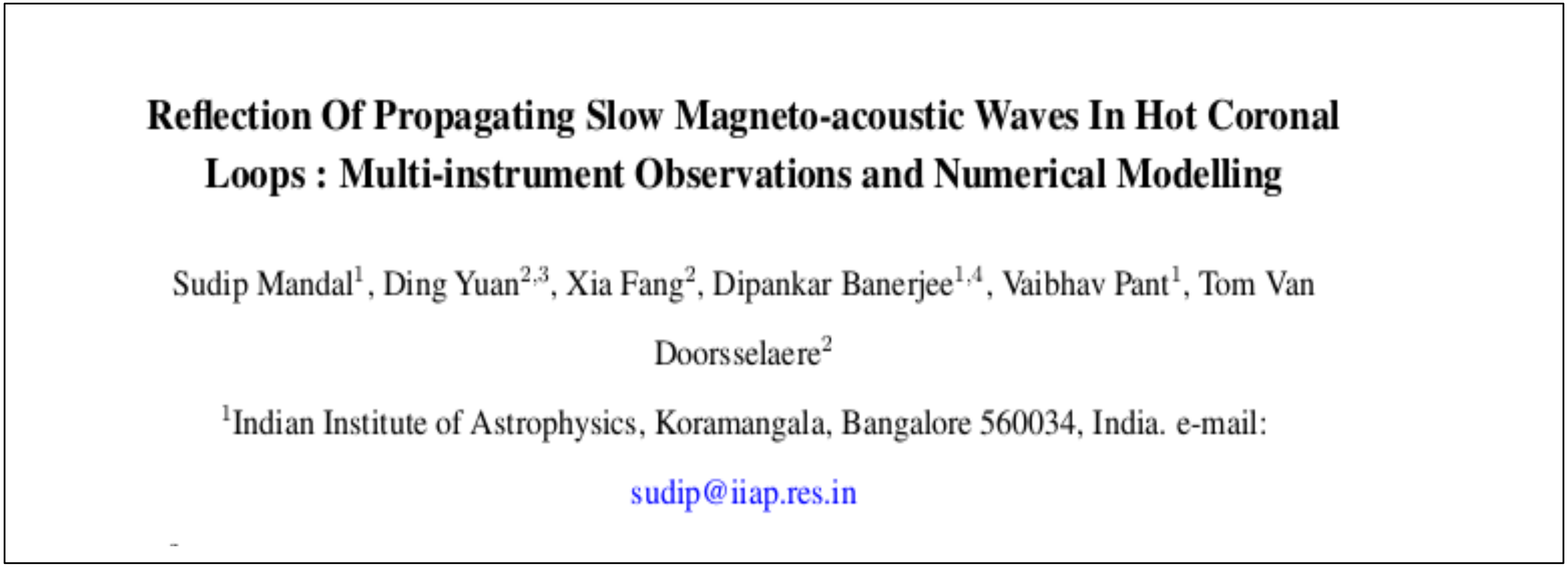
http://arxiv.org/abs/1604.08133



Reflection Of Propagating Slow Magneto-acoustic Waves In Hot Coronal Loops : Multi-instrument Observations and Numerical Modelling

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Thank you