Nanoflare vs footpoint heating : Observational signatures

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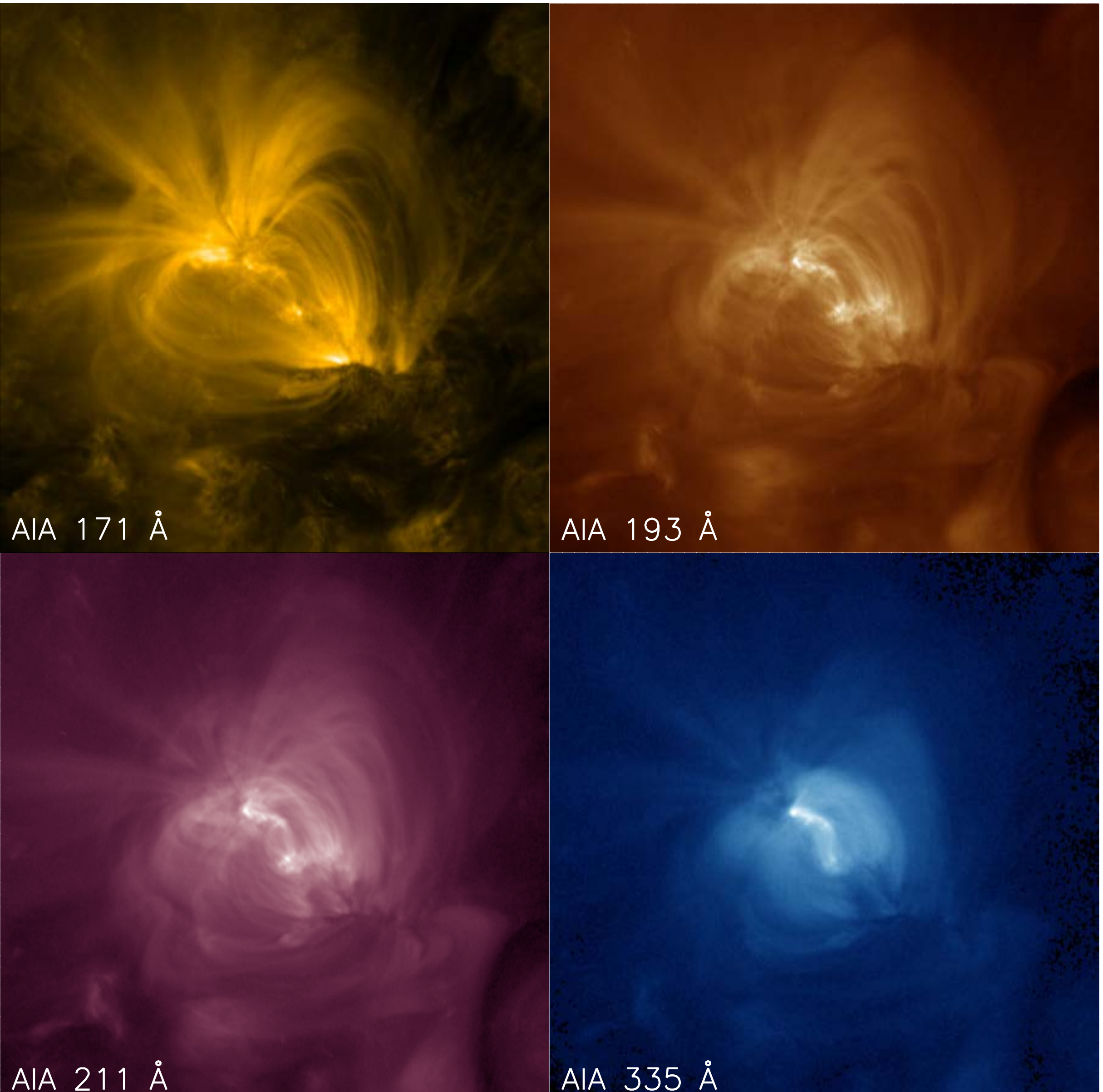
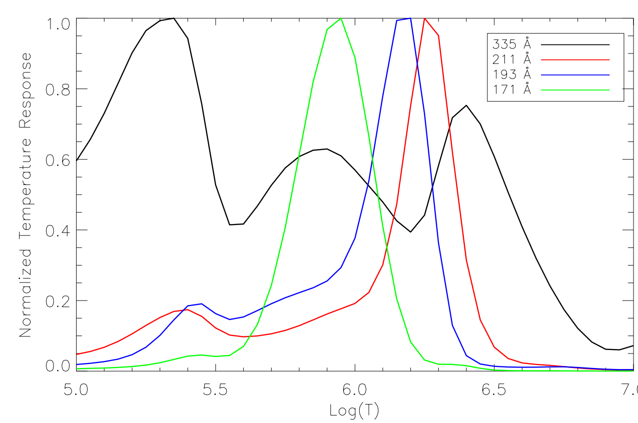
Time Lag Analysis of AR 11082



Active Region 11082 was observed on 2010 June 19 and originally studied by Viall and Klimchuk (2012).

We only consider 4 EUV AIA channels.

171, 193, and 211 are narrow and sharply peaked. 335 is broad with multiple peaks.



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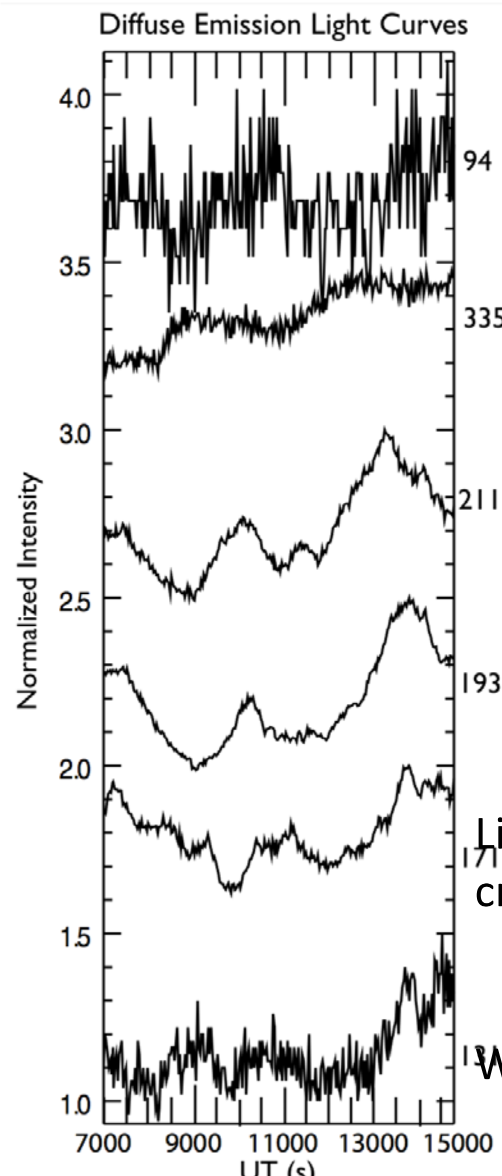
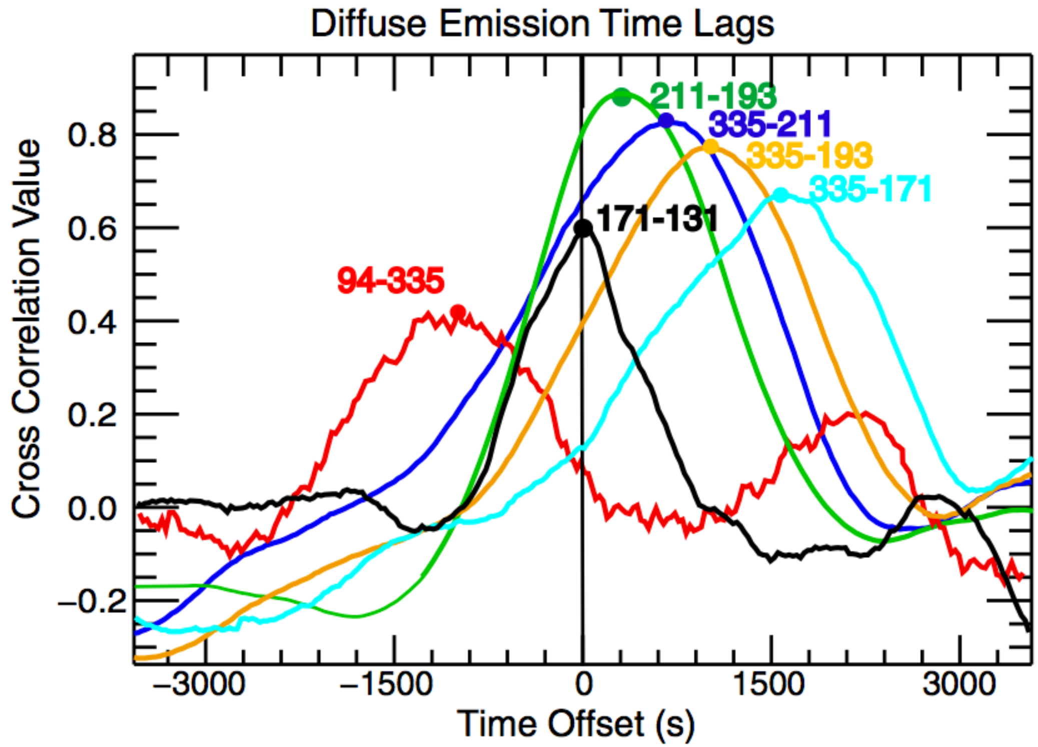


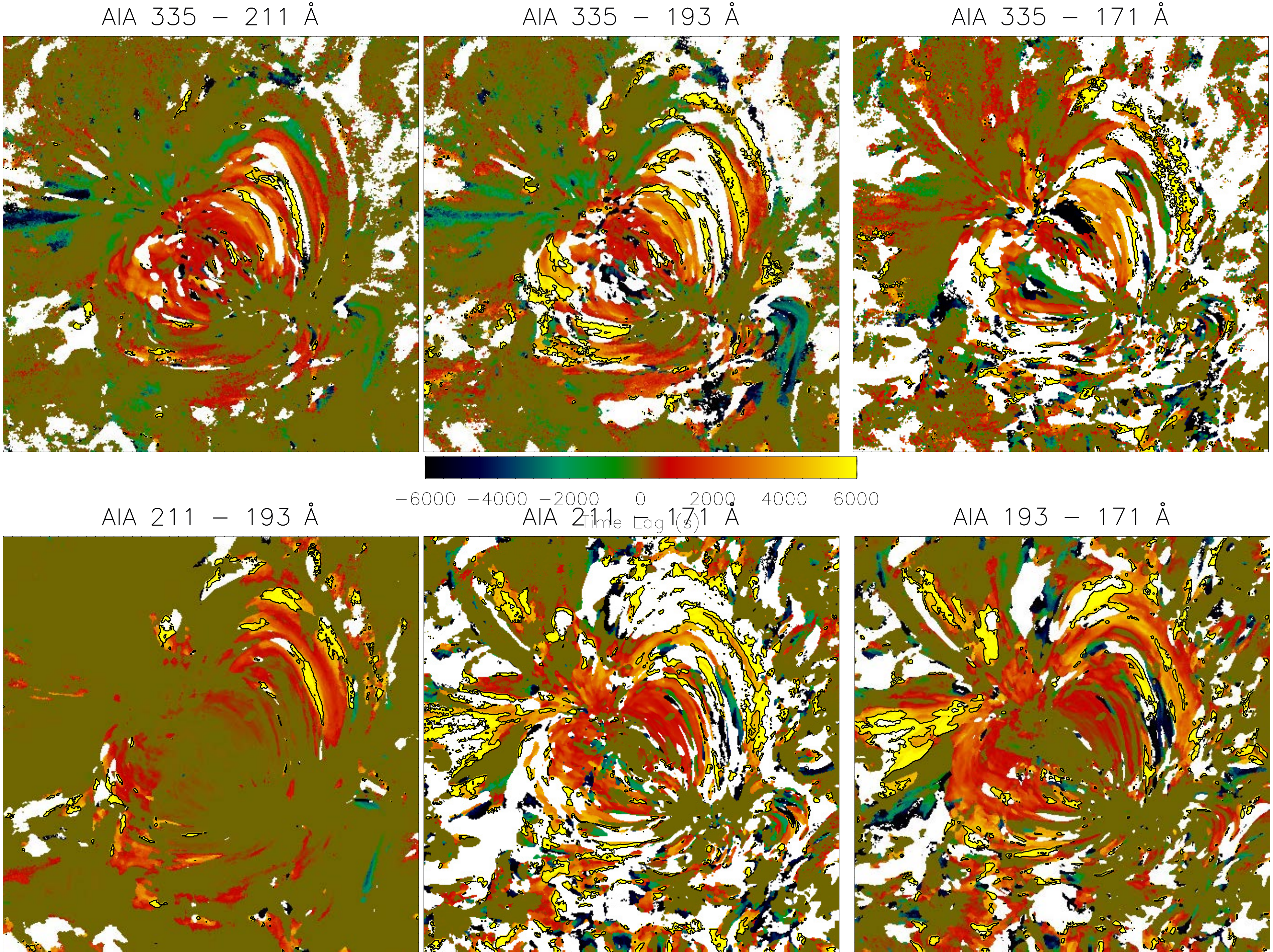


Lightcurve of each pixel is cross correlated to find time lag with highest cross correlation value in each channel pair.

(Viall & Klimchuk, 2012, ApJ, 753: 35)

We perform identical analysis with 2 exceptions:

- If CC value is < 0.2, we set timelag to WHITE
- If timelag saturates (is greater than 7,200s) we set timelag to WHITE



AIA 335 – 211 Å
AIA 335 – 193 Å
AIA 335 – 171 Å
−6000 −4000 −2000 0 2000 4000 6000
Time Lag (s)
AIA 211 – 193 Å
AIA 211 – 171 Å
AIA 193 – 171 Å

Statistics on TL maps

Channel Pair	Percentage pixels where CC > 0.2 and TL does not saturate	Percentage where TL measured and NEGATIVE	Percentage where TL measured and = 0	Percentage where TL measured and POSITIVE
335 - 211	85.9%	33.2%	25.8%	40.9%
335 - 193	79.7%	31.2%	24.8%	44.0%
335 - 171	72.1%	23.9%	23.0%	53.1%
211 - 193	96.4%	6.3%	60.5%	33.1%
211 - 171	78.1%	13.3%	40.9%	45.7%
193 - 171	86.0%	10.6%	38.8%	50.6%

↑

Next slide deals with only the subset of pixels where timelag is measured and positive.

Positive timelag pixels

Channel Pair	0-2500 s	2500-5000 s	> 5000 s
335 - 211	87.9%	8.7%	3.4%
335 - 193	66.4%	19.2%	14.4%
335 - 171	71.3%	16.7%	11.9%
211 - 193	81.7%	11.1%	7.2%
211 - 171	48.3%	25.3%	26.3%
193 - 171	61.4%	22.6%	15.9%

CAN LARGE TIME DELAYS OBSERVED IN LIGHT CURVES OF CORONAL LOOPS BE EXPLAINED BY IMPULSIVE HEATING?

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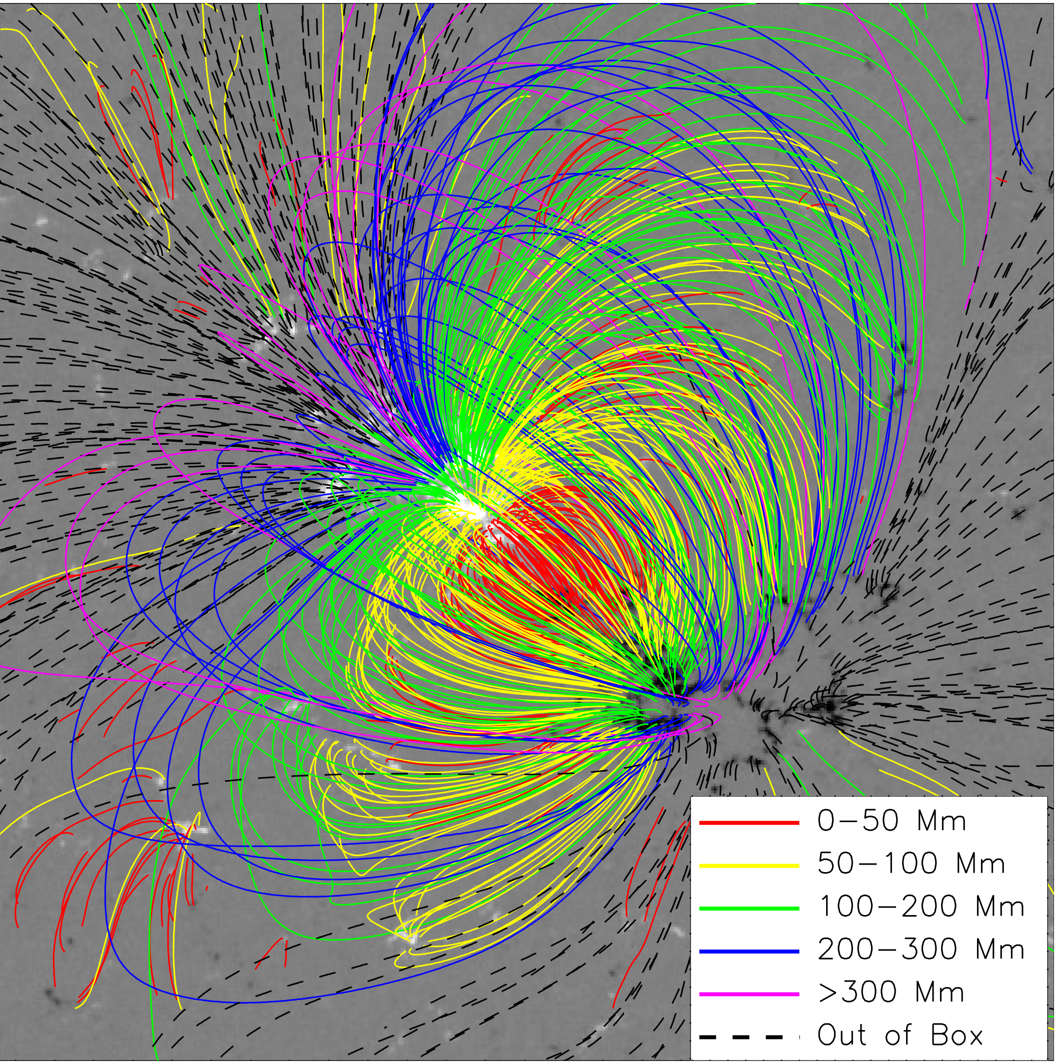
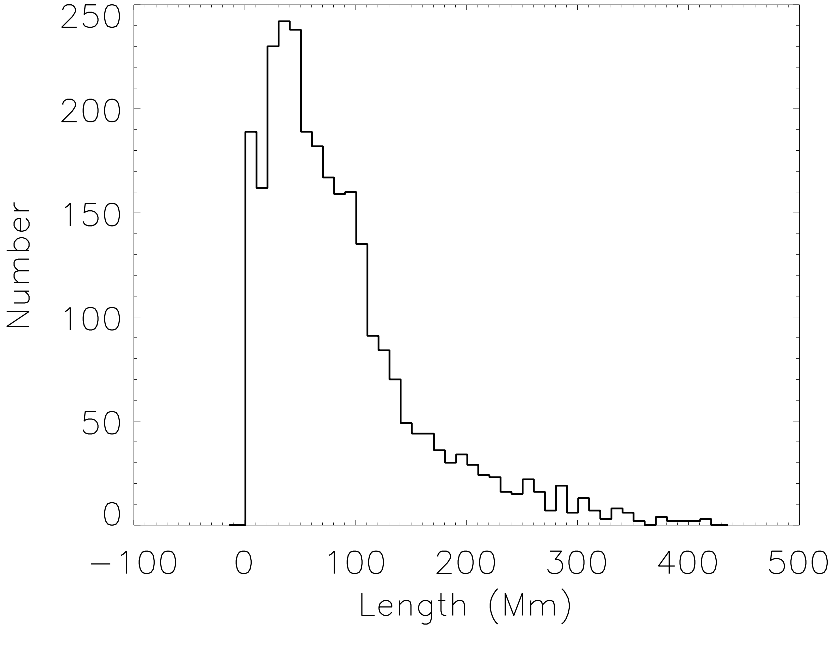
Loop length is important

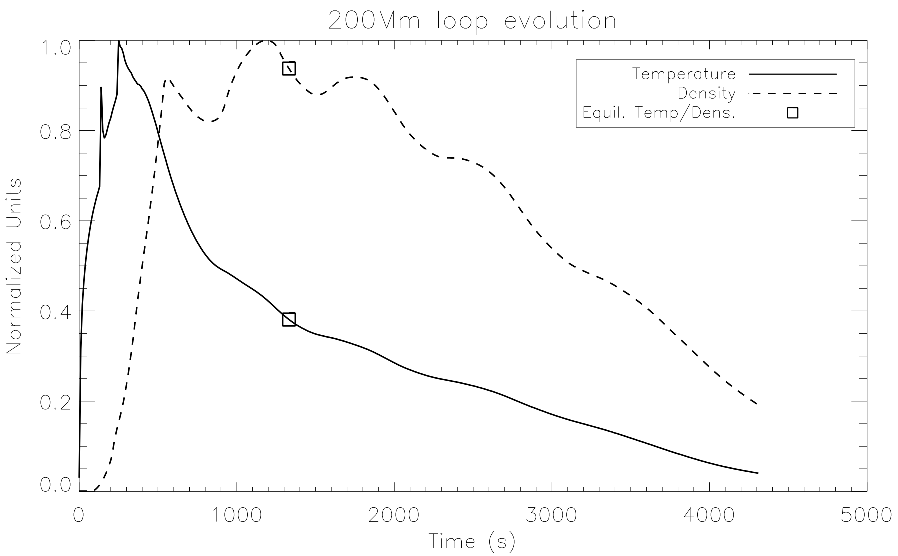


Performed potential field extrapolation of AR 11082.

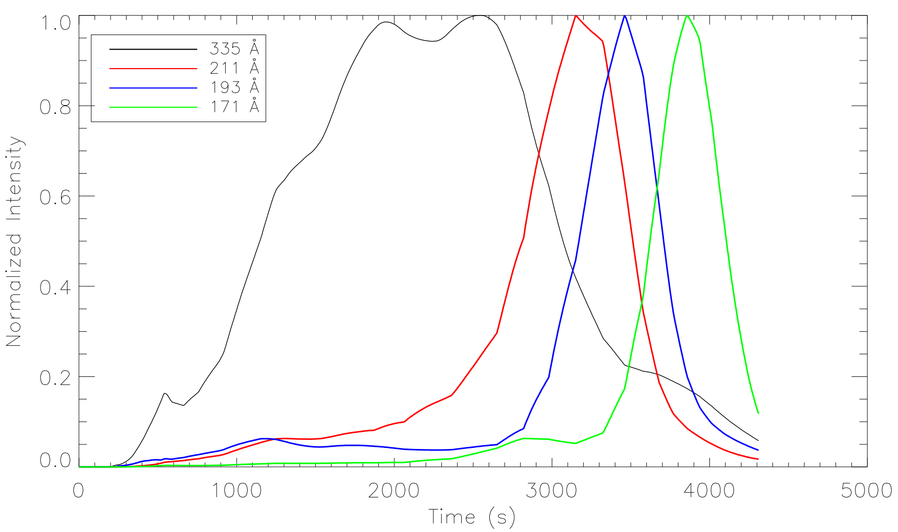
Maximum loop length is 400 Mm.

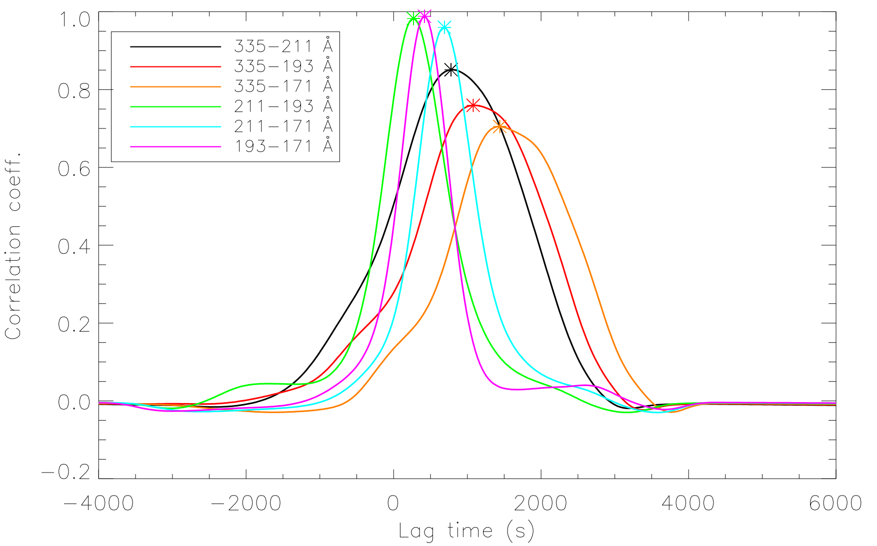


Example Simulation



Channel Pair	Time lag (s)	Correlation Coefficient
335-211 Å	780	0.85
335-193 Å	1080	0.76
335-171 Å	1440	0.71
211-193 Å	270	0.98
211-171 Å	690	0.96
193-171 Å	420	0.99





Parameter Space Considered

- Loop length – 50 Mm – 400 Mm
- Abundances – photospheric and coronal abundances.
- Heating magnitude – A wide range of heating magnitudes that results in loops with equilibrium temperatures from 2- 10 MK.
- Area expansion – constant and expanding cross section.

Resulted in over 100 simulations. For each one, we calculated time lags in all channel pairs.

Results from study

Loop Length [Mm]	Abundances	Area Expansion	Time lag 335-211 Å [s]	Time lag 335-193 Å [s]	Time lag 335-171 Å [s]	Time lag 211-193 Å [s]	Time lag 211-171 Å [s]	Time lag 193-171 Å [s]
50	C	no	150–210	180–330	270–570	30–120	60–390	60–270
100	C	no	270–420	390–600	510–1020	90–240	210–750	120–510
200	C	no	600-840	780–1230	1020–1890	180–420	420–1380	270–960
300	C	no	900–1230	1140–1590	1500–2700	240–540	570–1950	330–1350
400	C	no	1350–1680	1740–2370	2250–3420	390–660	960–2310	600–1650
50	P	no	180–360	390–570	540–990	90–240	240–780	150–540
100	P	no	360–750	720–1140	1170–1950	210–450	510–1500	300–1080
200	P	no	990–1500	1830–2220	2460–3630	390–840	1050–2610	690–1860
300	P	no	1740–2220	2640–3090	480–4740	570–1200	1440–3510	900–2460
400	P	no	780–2250	1740–3720	3900–5130	900–1440	2280–3780	630–2700
50	C	yes	150	270	510	120	390	240
100	C	yes	390	720	1350	330	930	600
200	C	yes	870	1590	2820	690	1890	1200
300	C	yes	1230	2250	3960	990	2700	1740
400	C	yes	1320	2340	4980	1260	3870	2640
50	P	yes	150	390	840	240	840	600
100	P	yes	480	1080	2520	690	2250	1530
200	P	yes	1170	2580	5700	1500	4710	3180
300	P	yes	1650	3570	7770	2040	6540	4470
400	P	yes	1470	3060	7200	2010	7860	5700

Positive timelag pixels

Channel Pair	Maximum timelag found	% of positive pixels with timelag > maximum timelag
335 - 211	2250 s	13.6%
335 - 193	3720 s	23.4%
335 - 171	7200 s	0 %
211 - 193	2040 s	22.2%
211 - 171	7860 s	0 %
193 - 171	5700 s	11.0%

Results from this study

- There is no combination of parameters that can account for longest time lags in four of the channel pairs.
- The time lags in the other channel pairs could originate from long, expanding loops with photospheric abundances.

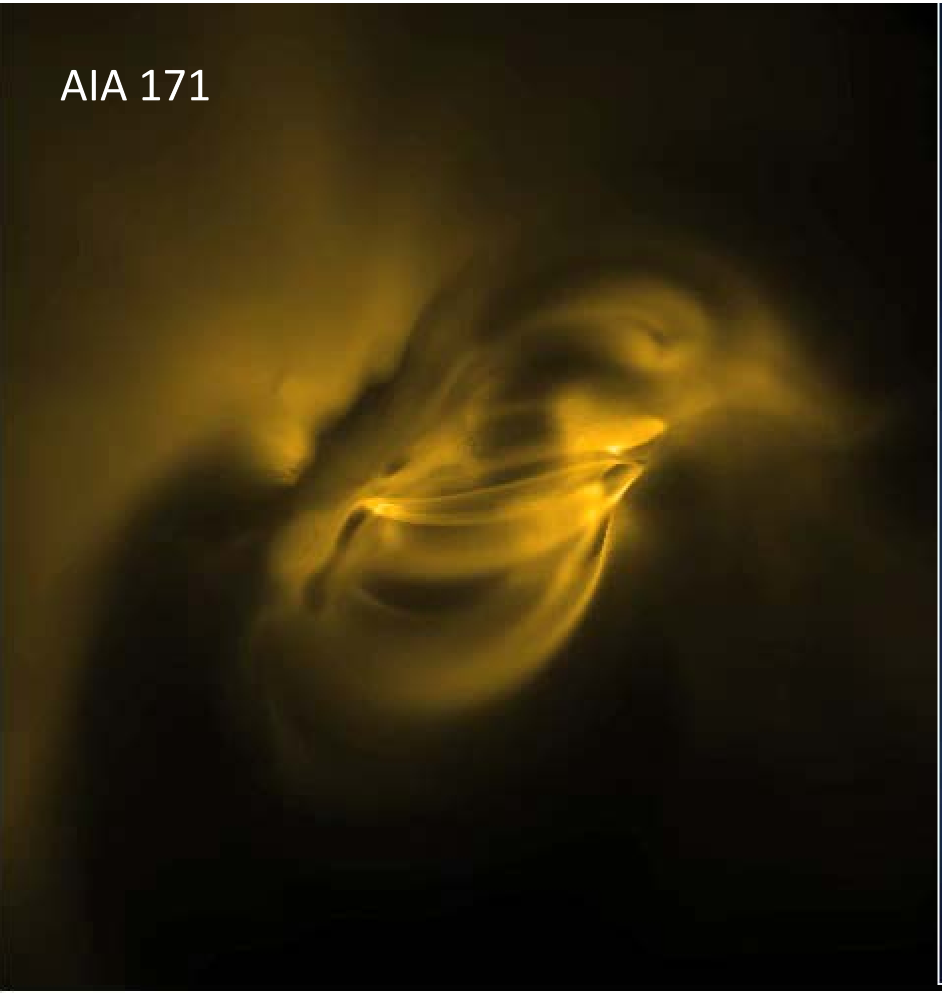
Possible Conclusions

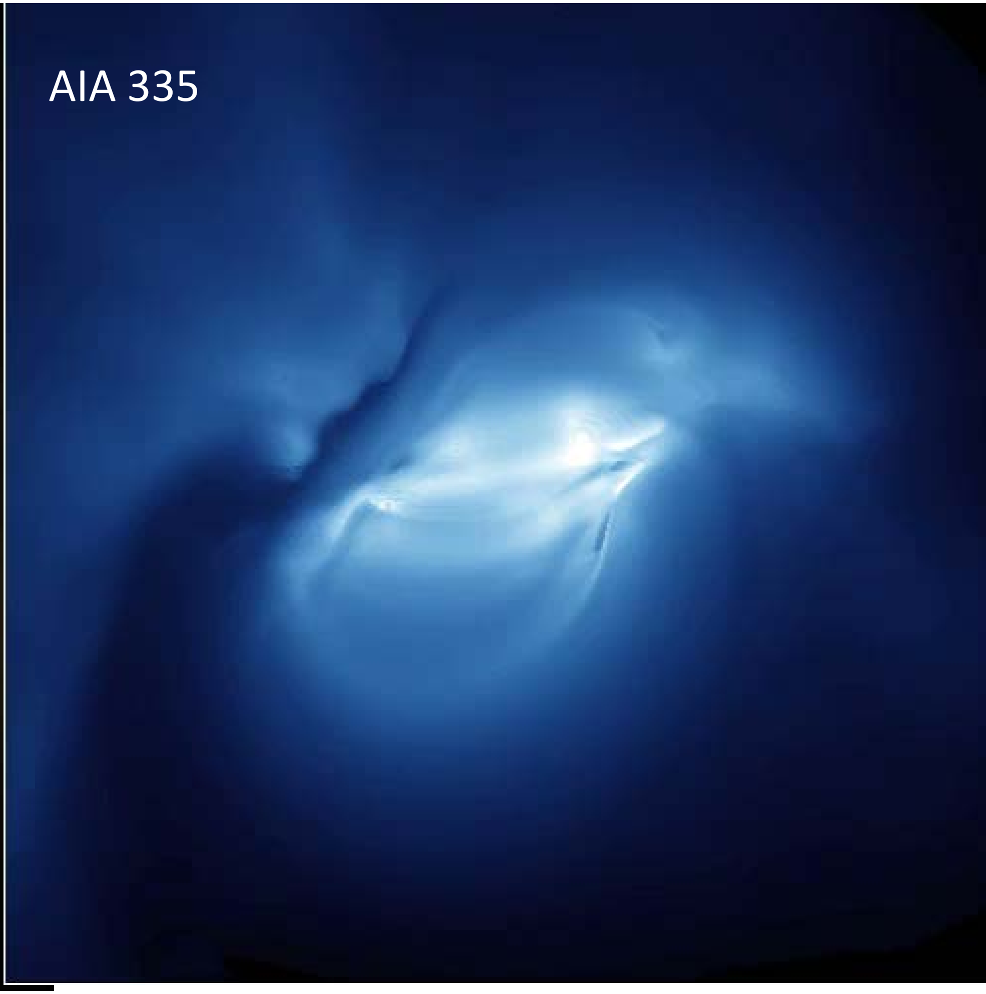
- Perhaps the timelag measured is not indicative of a real loop evolving.
- Perhaps another heating scenario is at work.

Highly-stratified, Footpoint heating

- Highly-stratified, quasi-steady heating can cause thermal non-equilibrium (TNE), meaning there is no steady-state solution.
- TNE occurs in corona confirmed by coronal rain.
- TNE can cause long term oscillations in data confirmed by Auchere et al. (2014)
- Mok et al. (2005, 2008, 2010) used this type of heating with magnetic field based on AR 7986 (Aug 30, 1996).

AIA movies of Mok's simulation





AN INVESTIGATION OF TIME LAG MAPS USING 3-DIMENSIONAL SIMULATIONS OF HIGHLY-STRATIFIED HEATING

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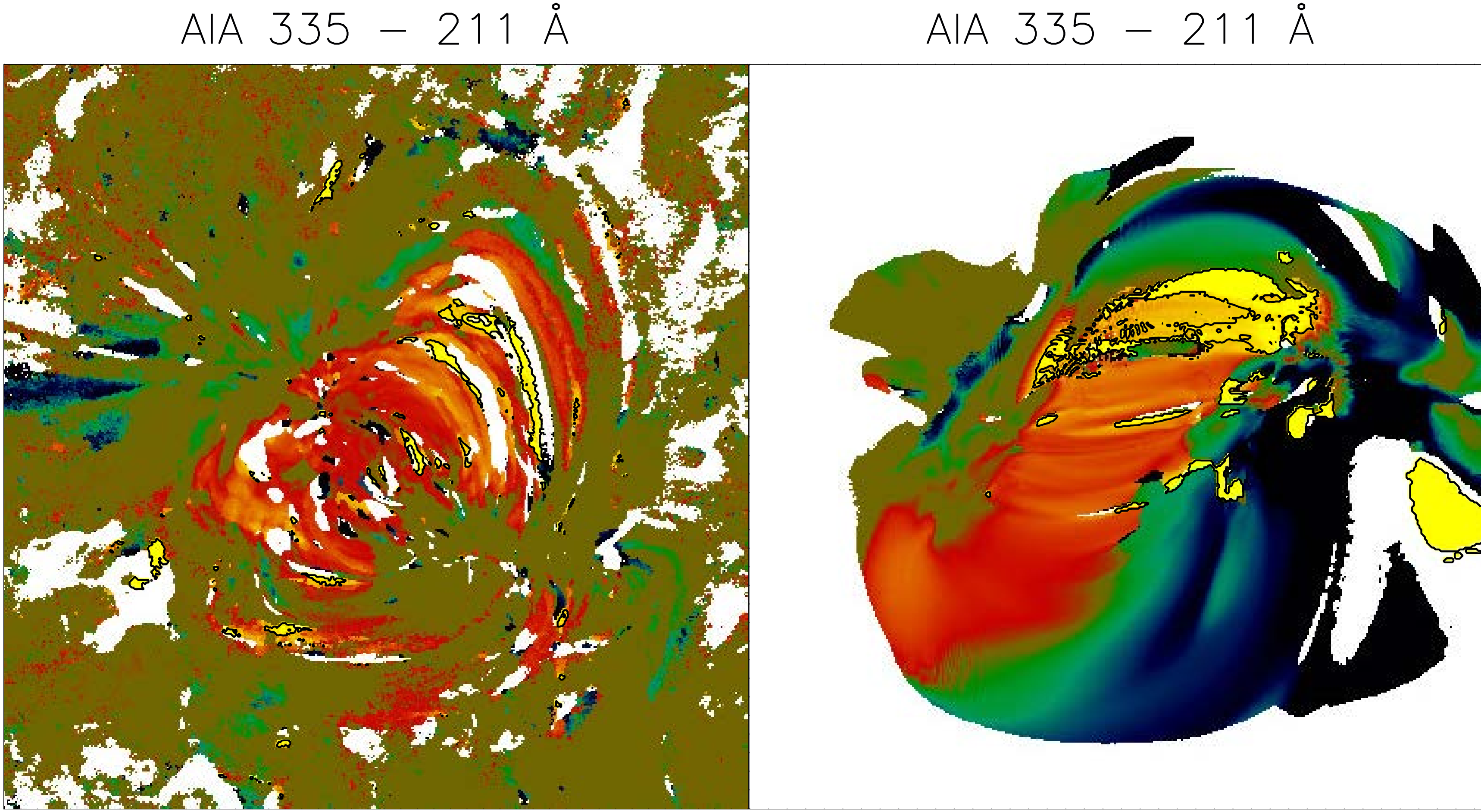
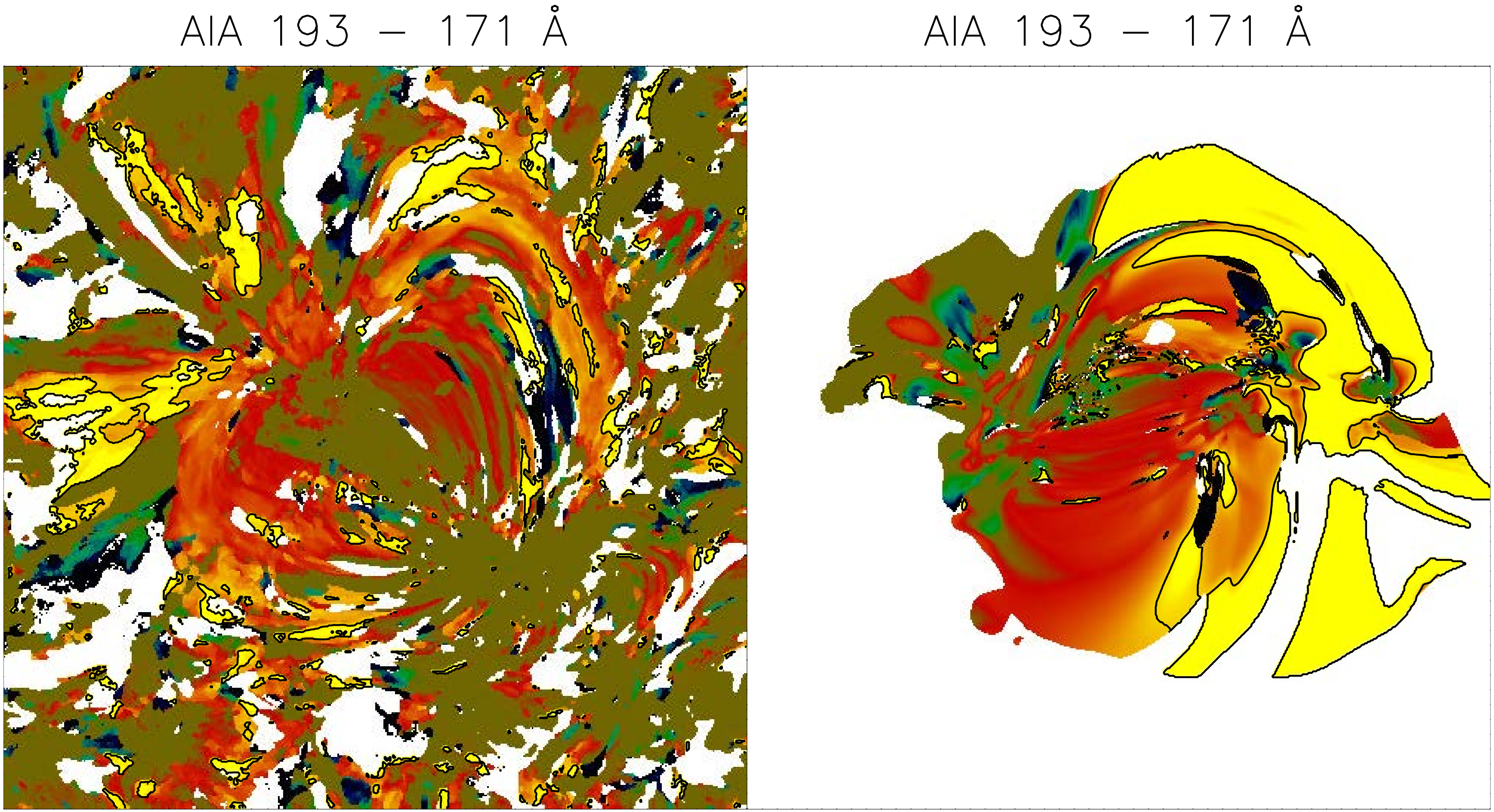
Time lag analysis of simulated data



We find similar magnitude/distributions of timelags to Viall & Klimchuk (2012).

Note this AR is larger than Viall & Klimchuk's AR.

Time lag analysis of simulated data



We find similar magnitude/distributions of timelags to Viall & Klimchuk (2012).

Note this AR is larger than Viall & Klimchuk's AR.

Statistics on TL maps of simulation

Channel Pair	Percentage pixels where CC > 0.2 and TL does not saturate	Percentage where TL measured and NEGATIVE	Percentage where TL measured and = 0	Percentage where TL measured and POSITIVE
335 - 211	55.2%	54.0%	16.3%	29.6%
335 - 193	61.9%	45.7%	20.4%	33.8%
335 - 171	61.8%	23.3%	30.8%	45.8%
211 - 193	61.6%	42.2%	18.5%	39.2%
211 - 171	49.8%	24.1%	21.2%	54.7%
193 - 171	60.5%	10.8%	19.4%	69.8%

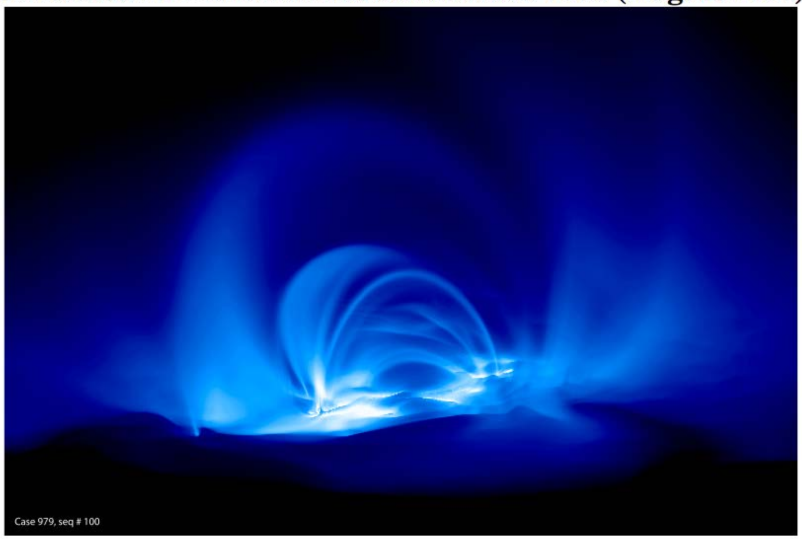
Next slide deals with only the subset of pixels where timelag is measured and positive.

Positive timelag pixels from simulations

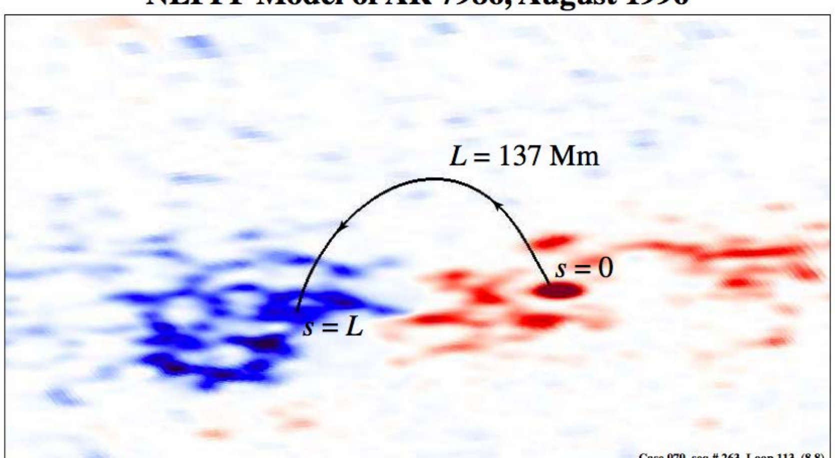
Channel Pair	0-2500 s	2500-5000 s	> 5000 s
335 - 211	58.9%	21.4%	19.6%
335 - 193	21.8%	42.8%	35.4%
335 - 171	62.8%	29.4%	7.8%
211 - 193	24.7%	40.8%	34.4%
211 - 171	61.0%	30.9%	8.1%
193 - 171	38.9%	17.5%	43.5%

How can we differentiate between sporadic and footpoint heating?

Simulated EIT 171 Å Emission from AR 7986 (August 1996)



Field Line from a 3D Active Region Simulation
NLFFF Model of AR 7986, August 1996



Selected a single field line geomtry from Mok simulation (previously studied by Mikic et al 2014).

Investigate how heating magnitude and stratification effect timelags and intensity ratios.

Compare the TNE solutions with sporadic impulsive heating solutions with same average heating rate.

CAN TIME LAGS DIFFERENTIATE BETWEEN SPORADIC AND FOOTPOINT HEATING?

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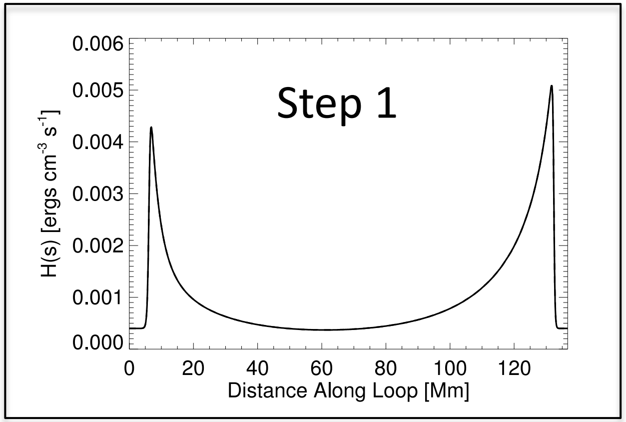
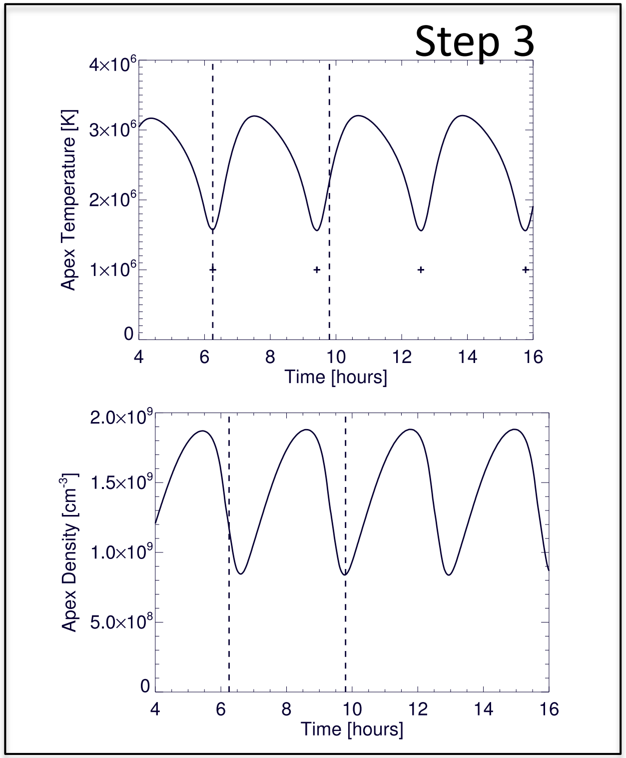
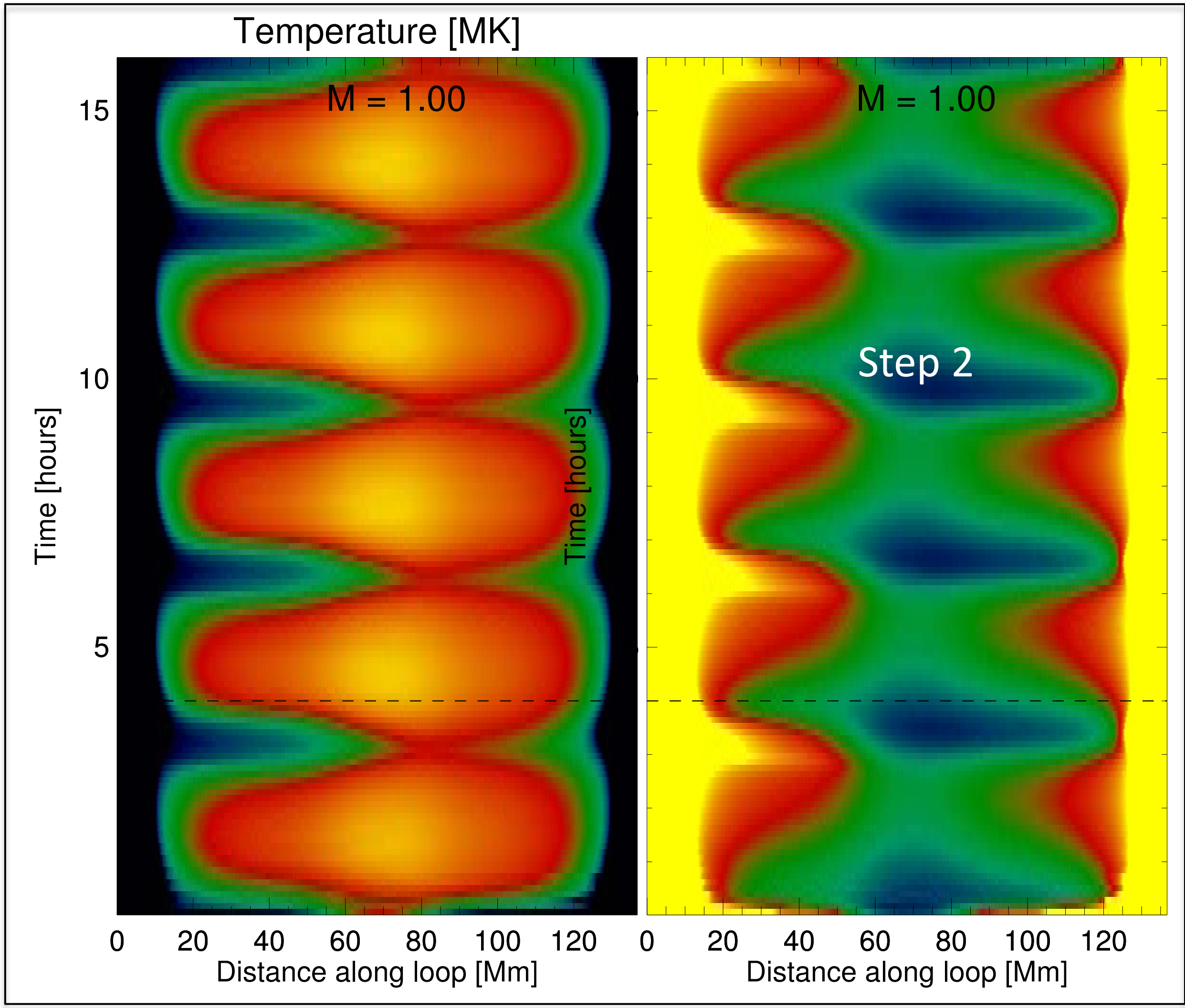
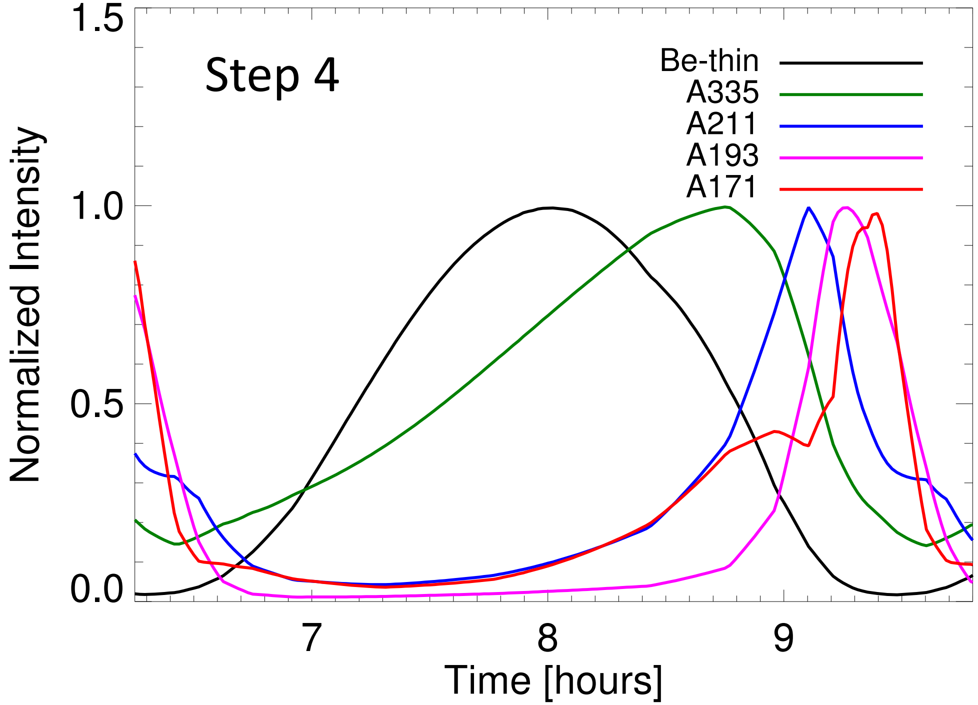
Example Simulation







Example Simulation



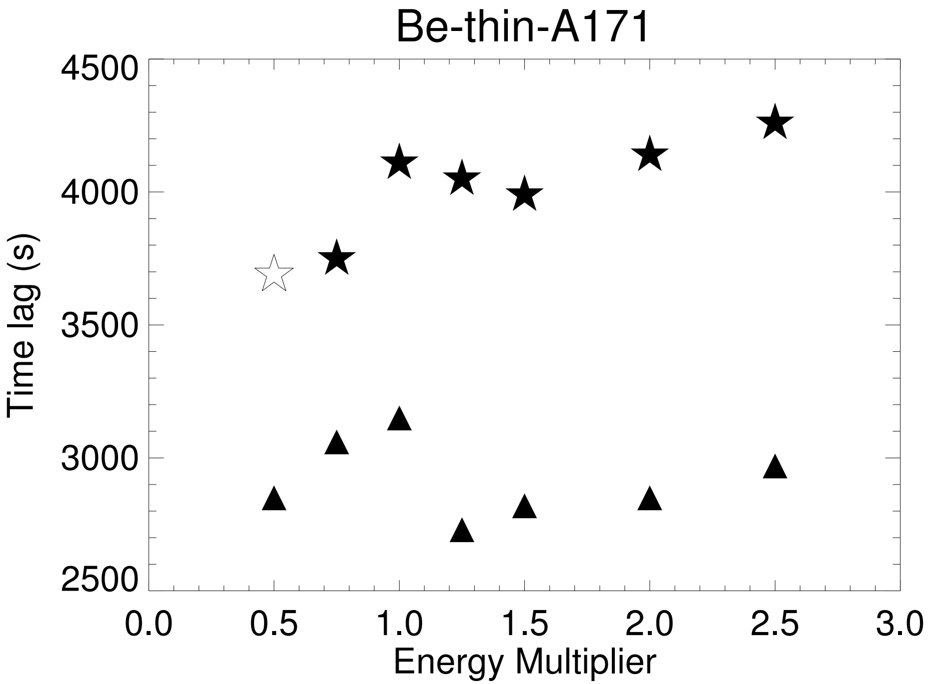
Step 5:
Calculate time lags and relative peak intensities between all channel pairs

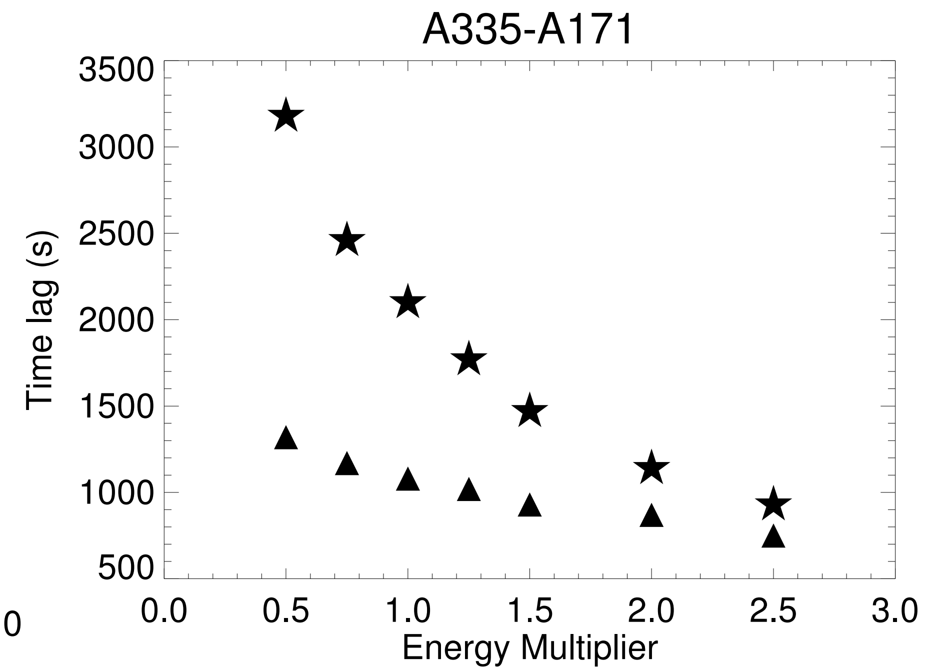
Repeat for different heating magnitude and stratification levels.

Repeat for sporadic impulsive heating with the same average volumetric heating rate.

Note we have added Hinode/XRT Be-thin for true hot channel.

Results



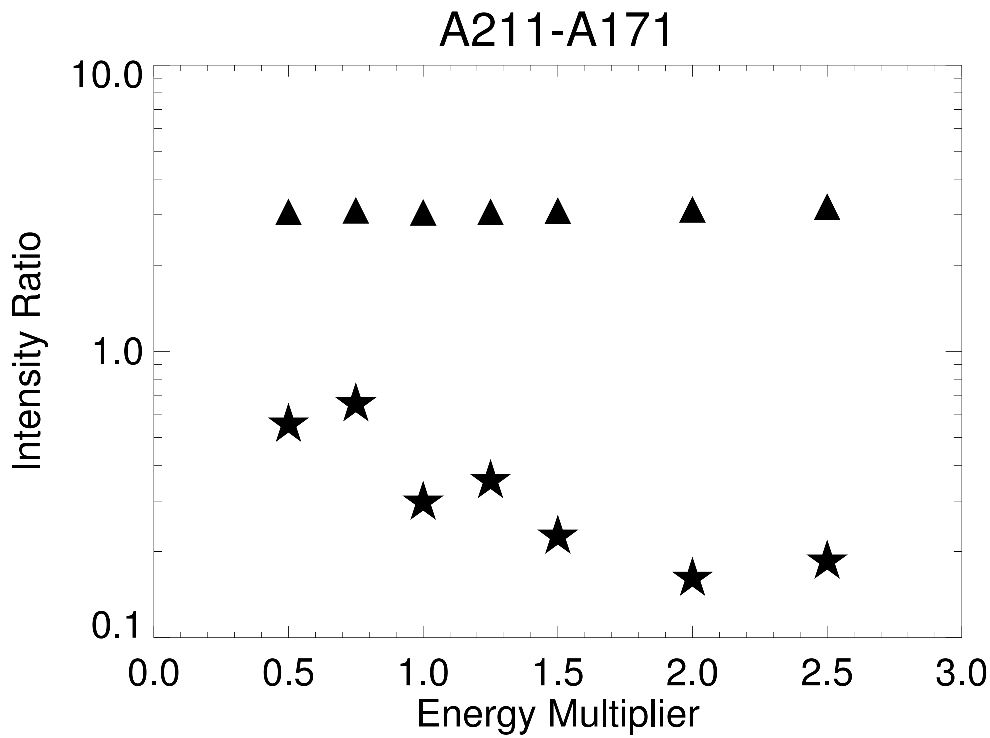


Time lags from the TNE solutions can look a lot like impulsive heating solutions.

Time lags from TNE solutions can be larger than time lags from impulsive heating solutions.

Using a true high temperature channel, like Be-thin, gives better discrimination.

Results



The ratio of the peak intensities in different lightcurves could be a clear discriminator between TNE and impulsive heating solutions.

Conclusions

- Time lag analysis shows very long time lags between all channel pairs.
- Impulsive heating cannot address these long time lags.
- 3D Simulations of footpoint heating shows a similar pattern of time lags (magnitude and distribution) to observations.

Conclusions (continued)

- Time lags and relative peak intensities may be able to differentiate between TNE and impulsive heating solutions.
- Adding a high temperature channel (like XRT Be-thin) may improve diagnostics.