QUEEN'S UNIVERSITY BELFAST

Chromospheric Signatures of Flare Induced Sunquakes

Sean Quinn,

Aaron Reid, Mihalis Mathioudakis, Christopher Nelson,

S. Krishna Prasad

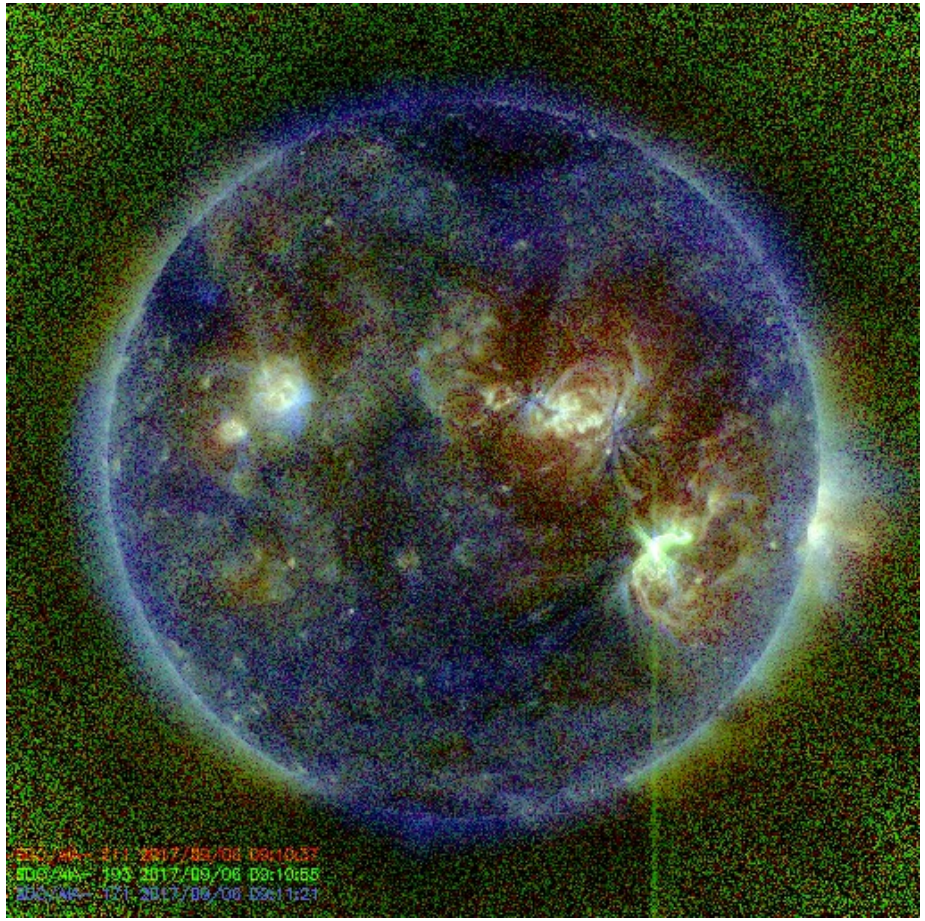
QUEEN'S UNIVERSITY BELFAST

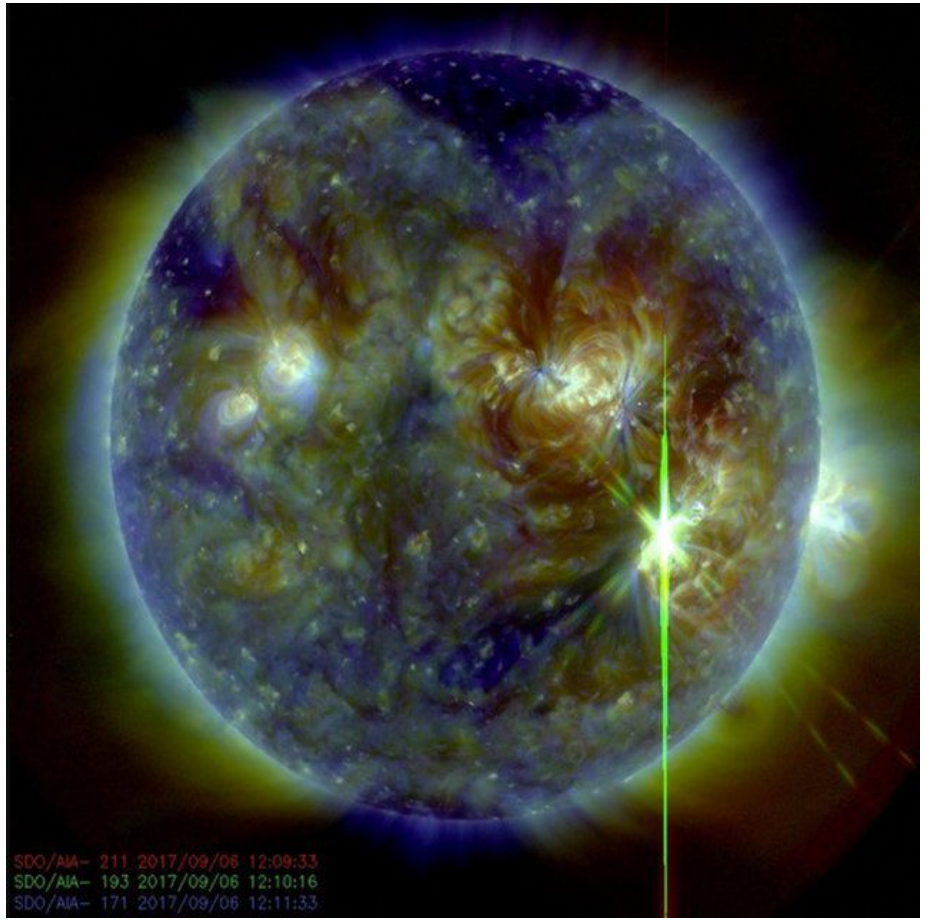
Talk Outline

- Display the SST observations of the X2.2 and X9.3 Solar Flares from 6th September 2017
- Explain the Sunquake model we use in our analysis
- Show the SDO/HMI LOS observations of the X-Class flares
- Discuss the different analysis techniques used in the investigation of the X9.3
- Our conclusions from this analysis
- Our future work

QUEEN'S UNIVERSITY BELFAST

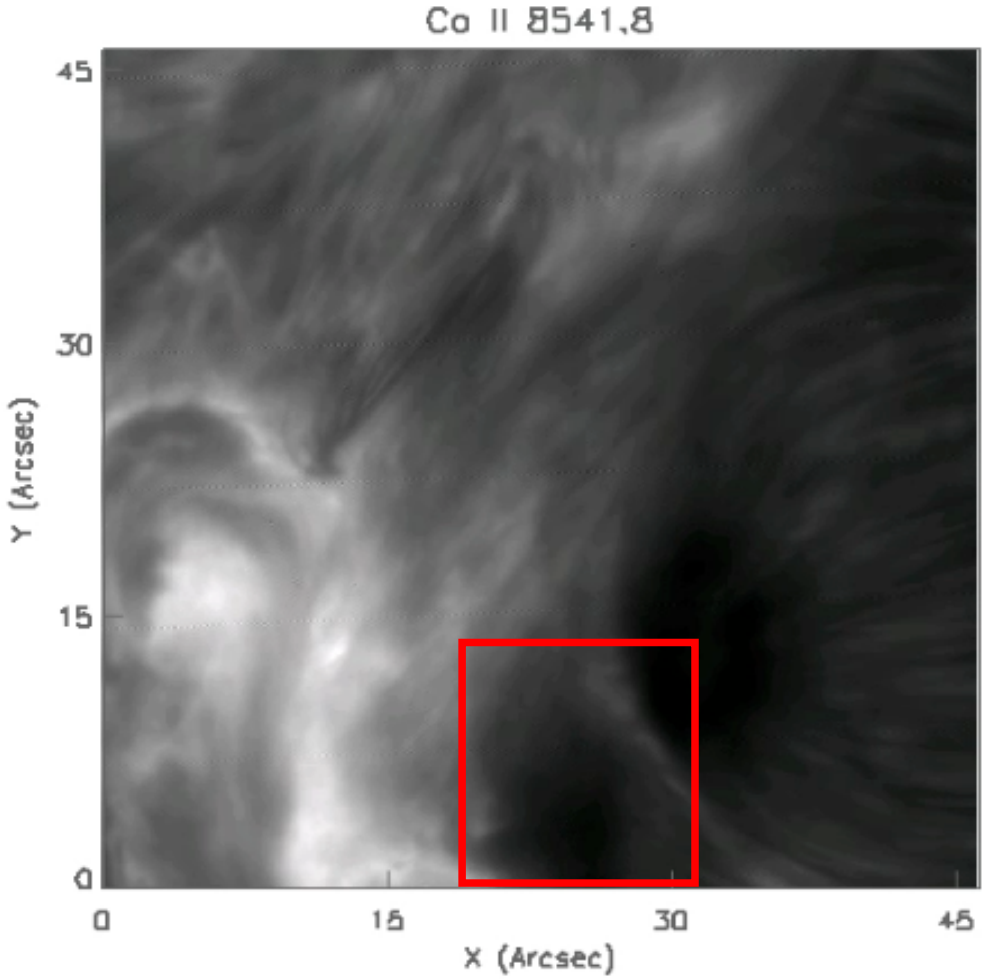
6th September 2017



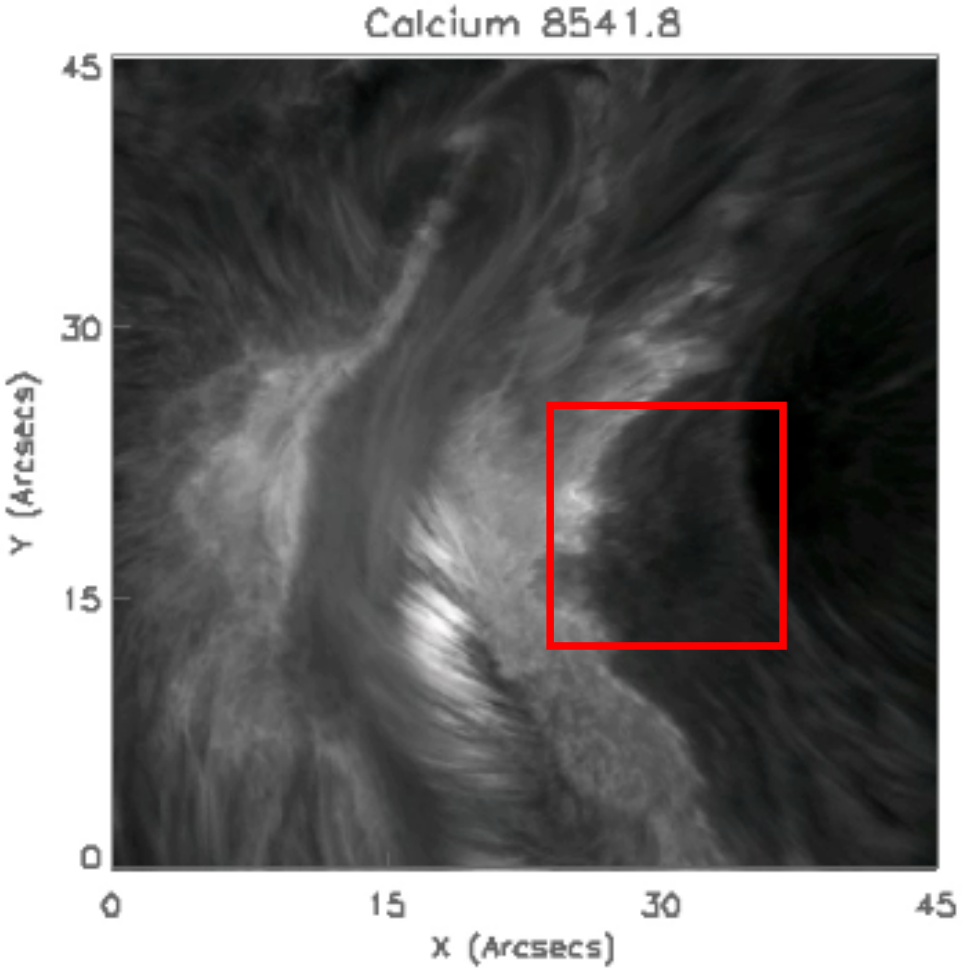


The Ca II 8542Å SST Observations

X2.2- Starts at



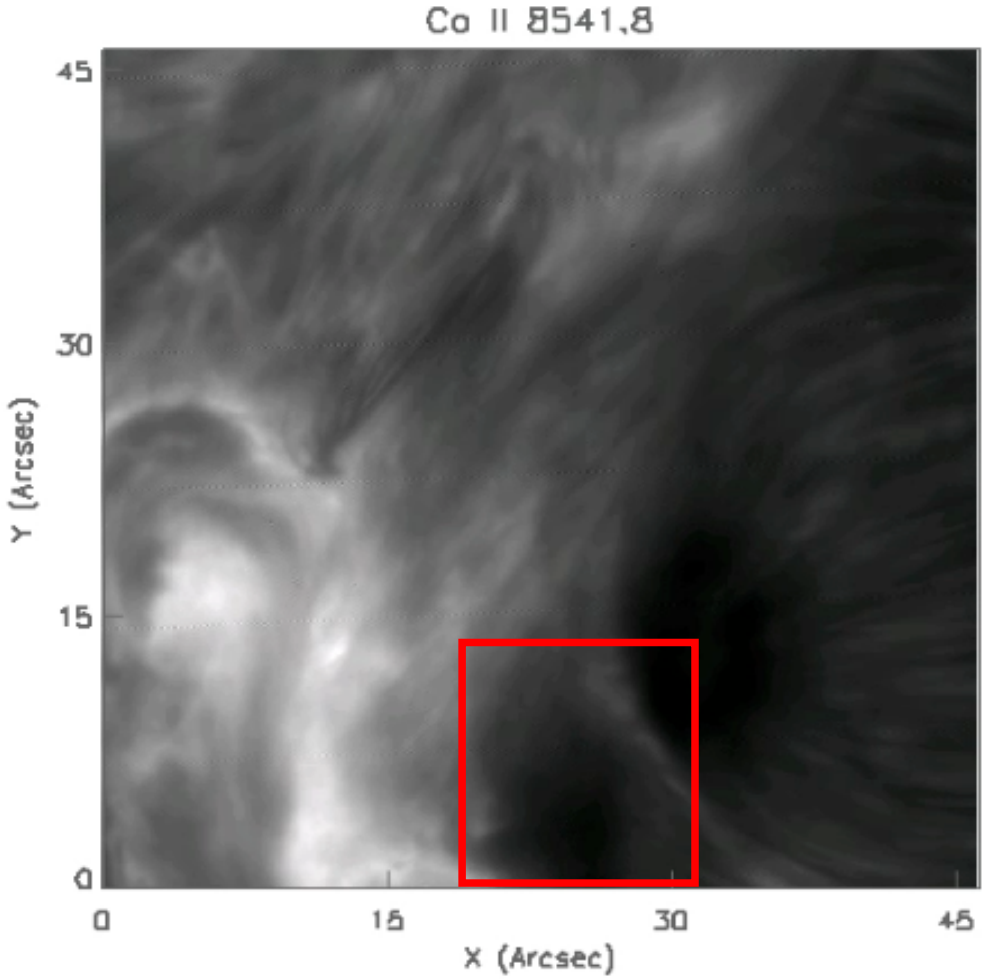
X9.3- Starts at 11:55:47



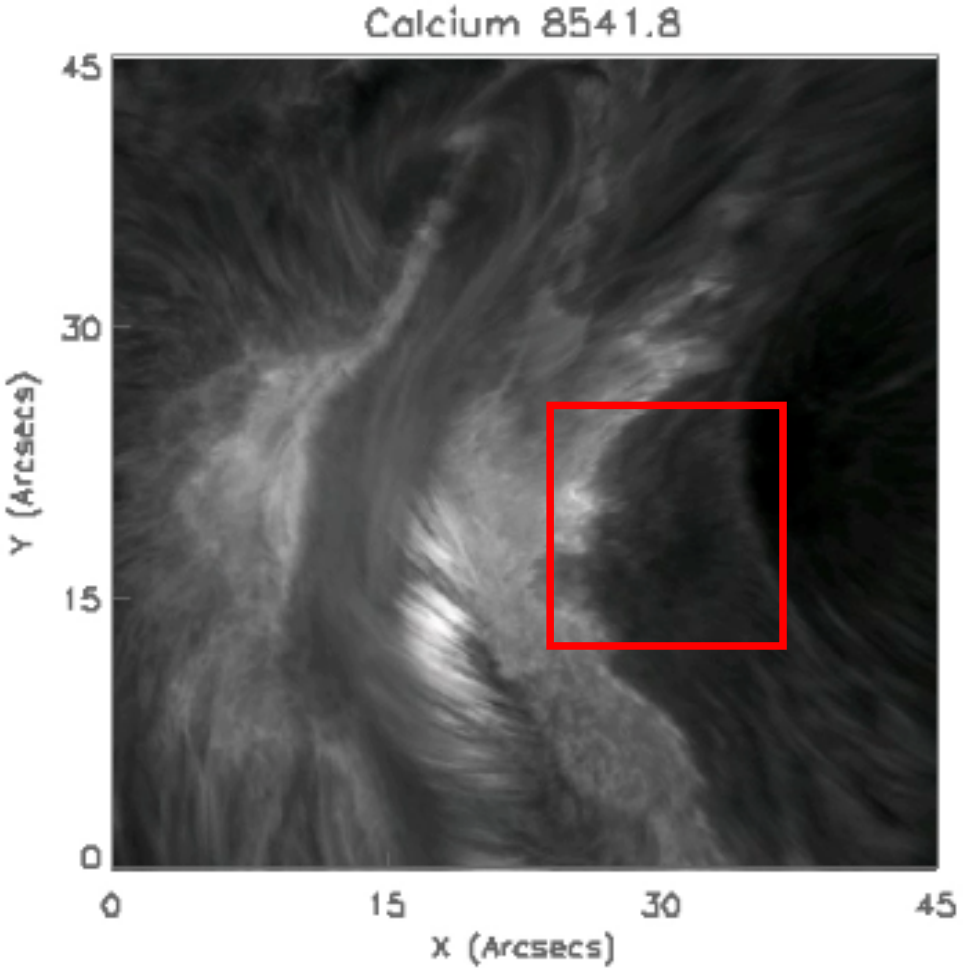
For the full analysis of this event see Quinn et al. 2019

The Ca II 8542Å SST Observations

X2.2- Starts at



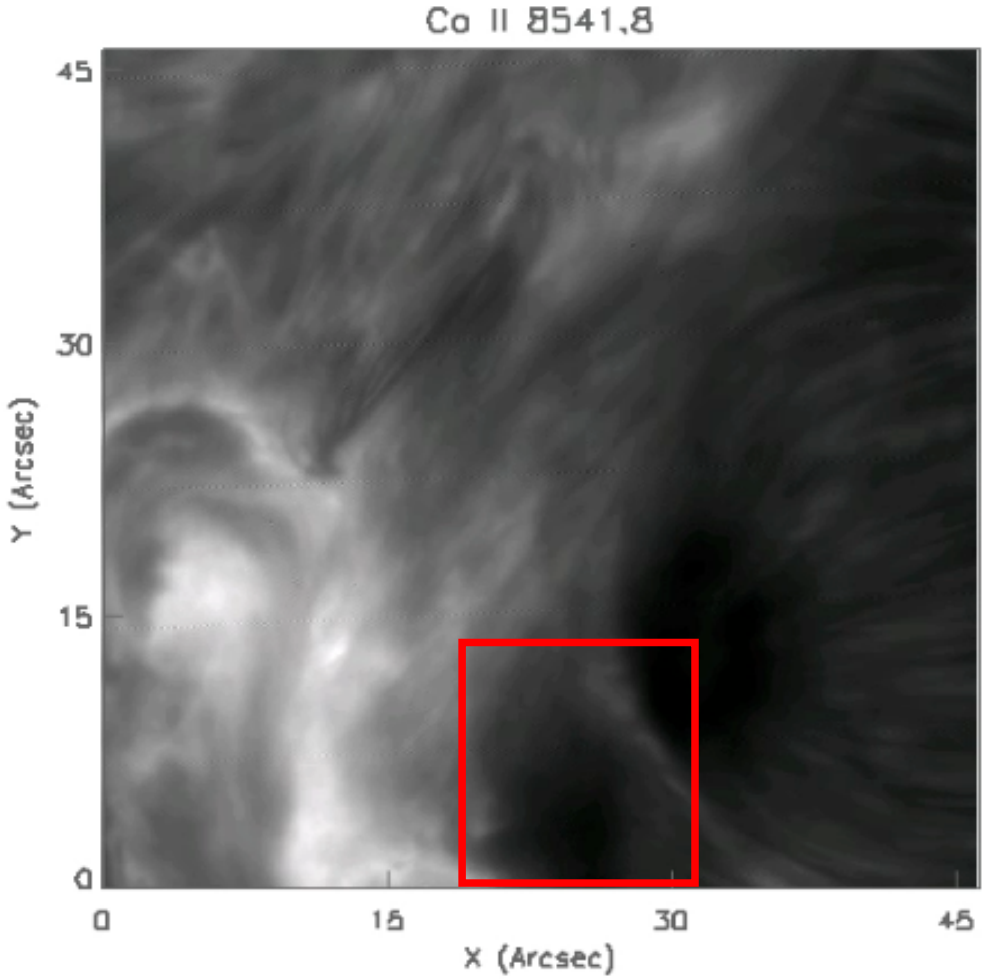
X9.3- Starts at 11:55:47



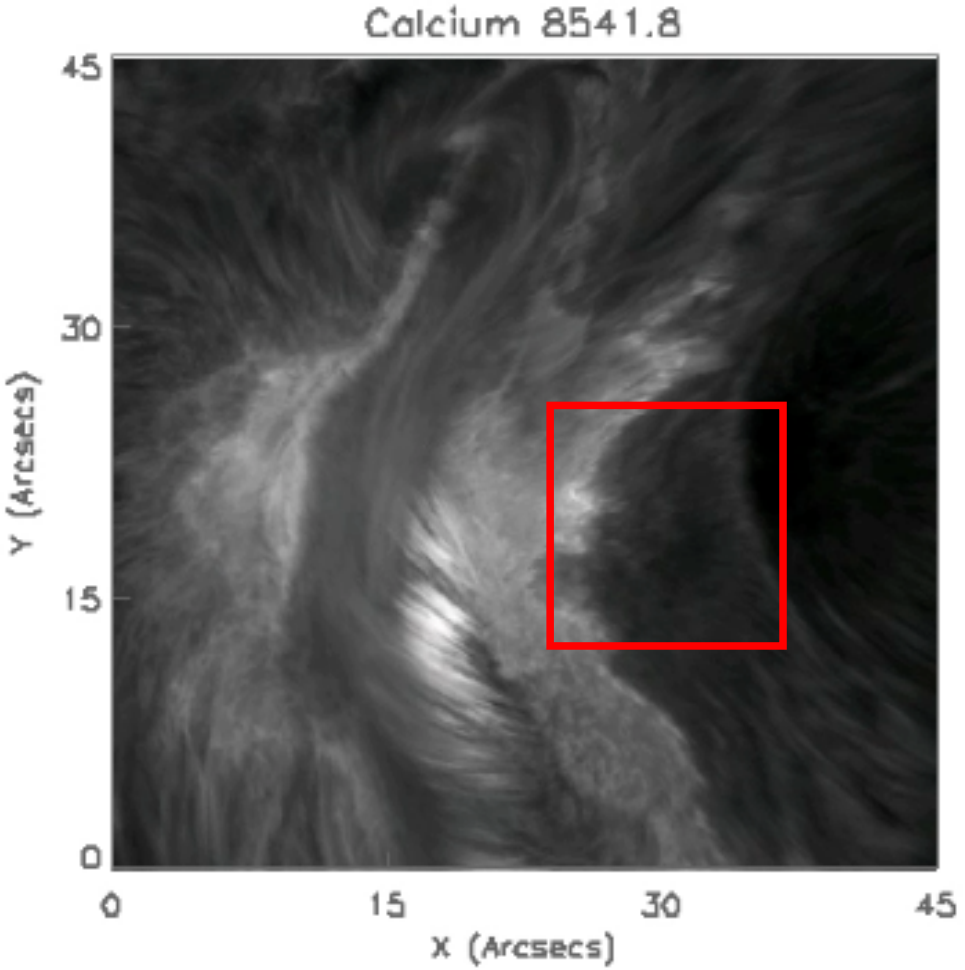
For the full analysis of this event see Quinn et al. 2019

The Ca II 8542Å SST Observations

X2.2- Starts at



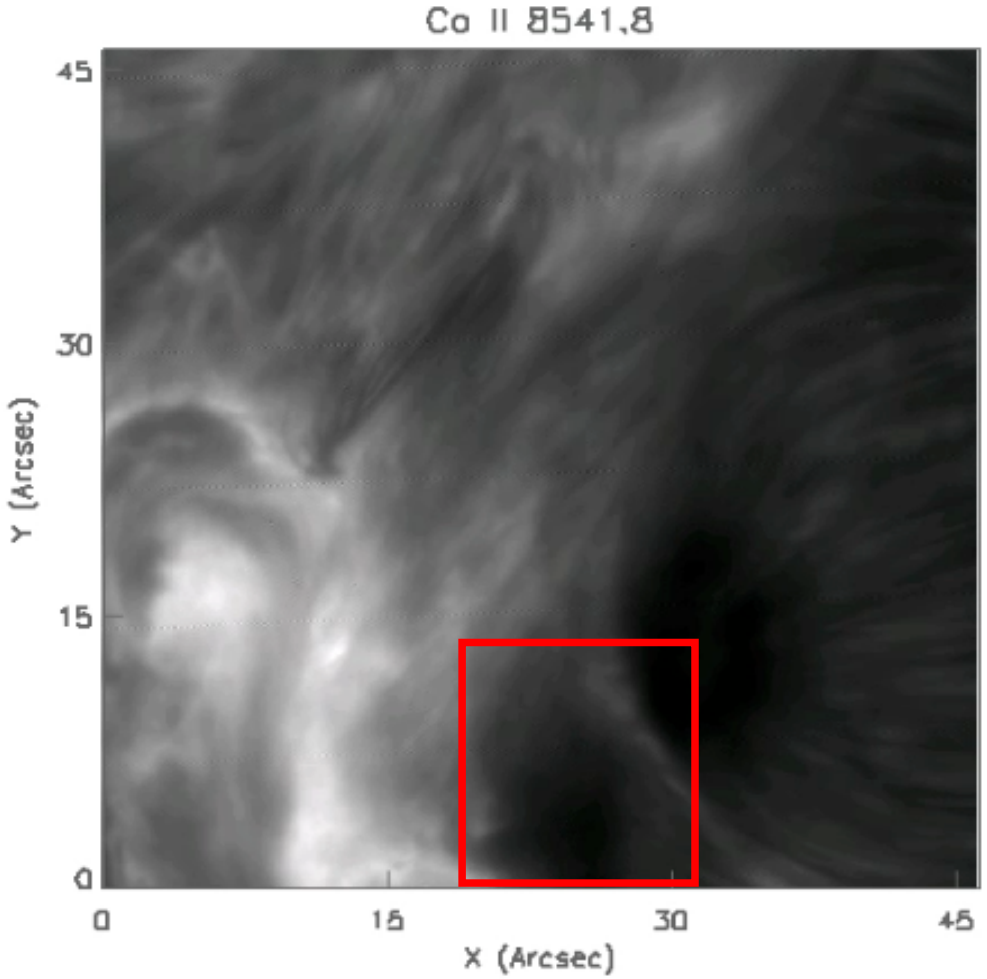
X9.3- Starts at 11:55:47



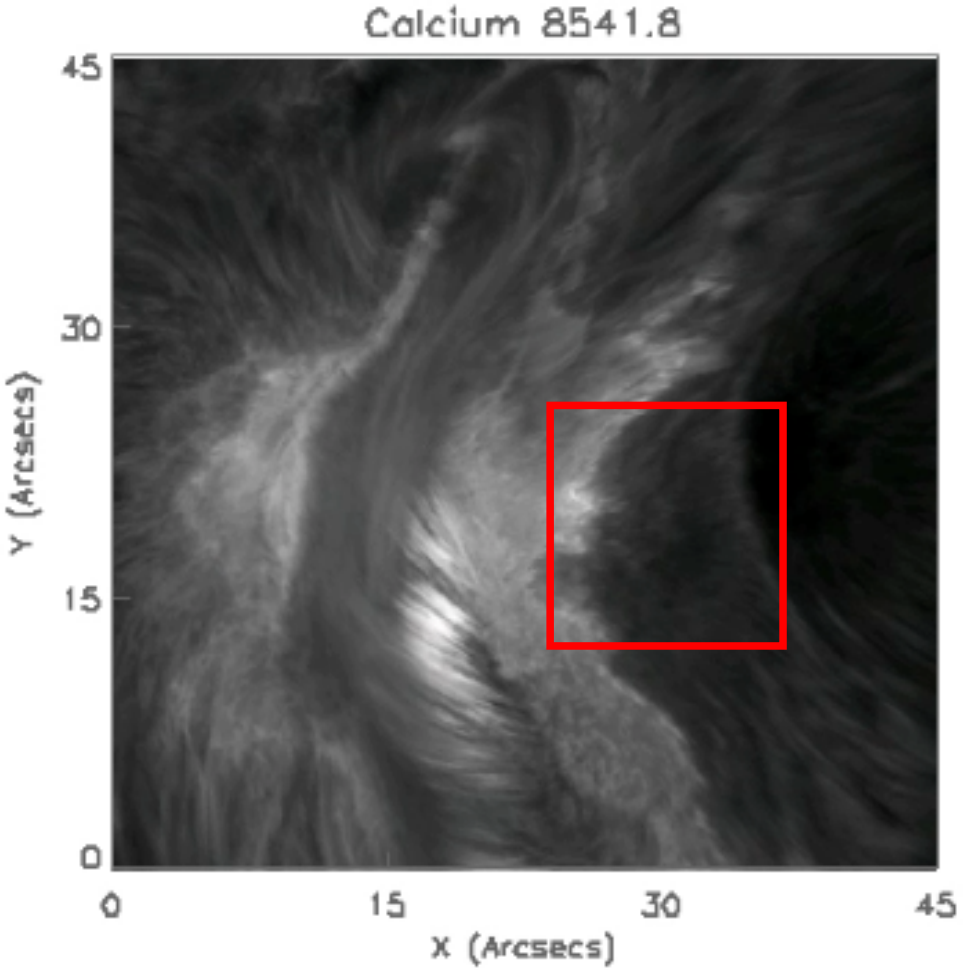
For the full analysis of this event see Quinn et al. 2019

The Ca II 8542Å SST Observations

X2.2- Starts at



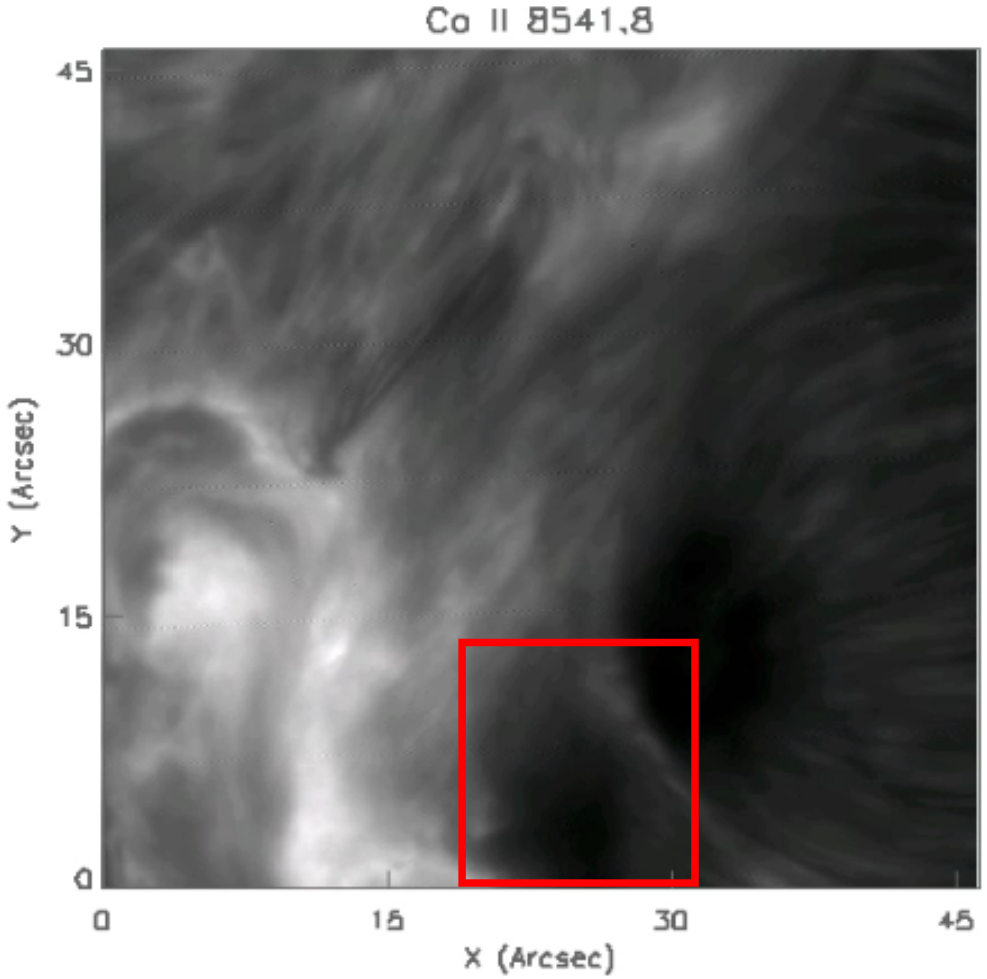
X9.3- Starts at 11:55:47



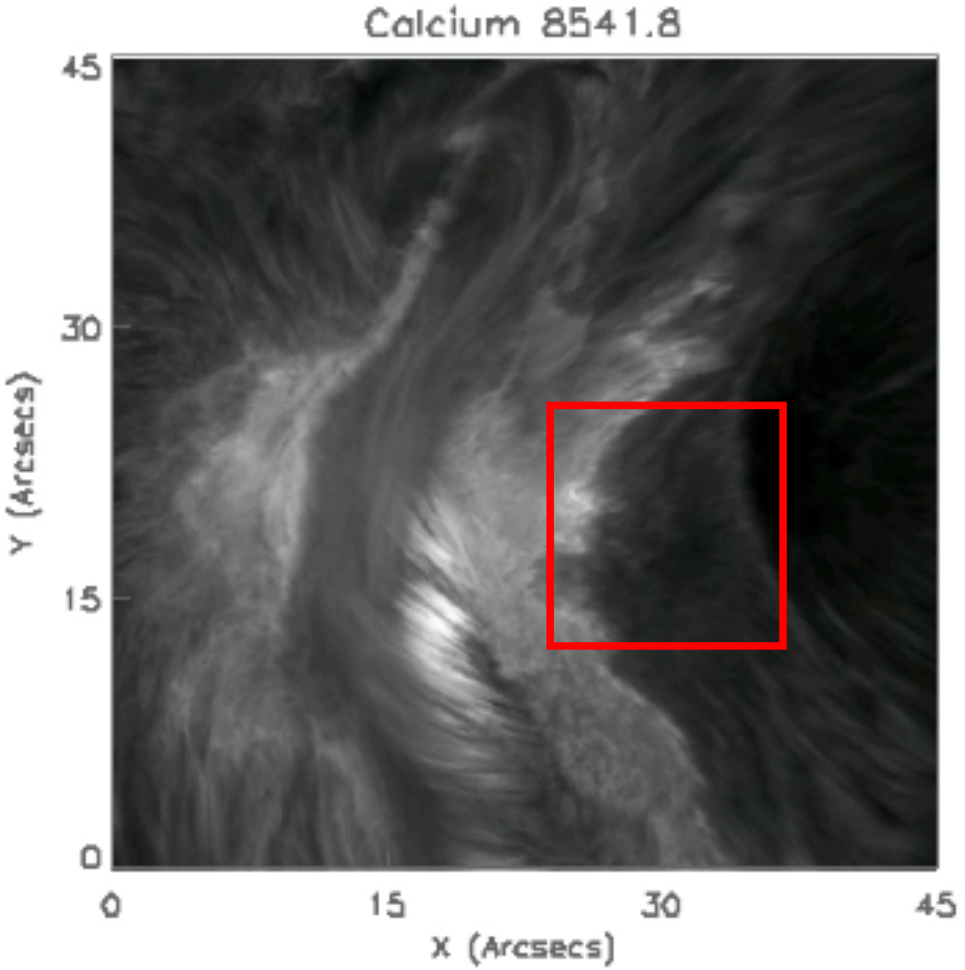
For the full analysis of this event see Quinn et al. 2019

The Ca II 8542Å SST Observations

X2.2- Starts at



X9.3- Starts at 11:55:47

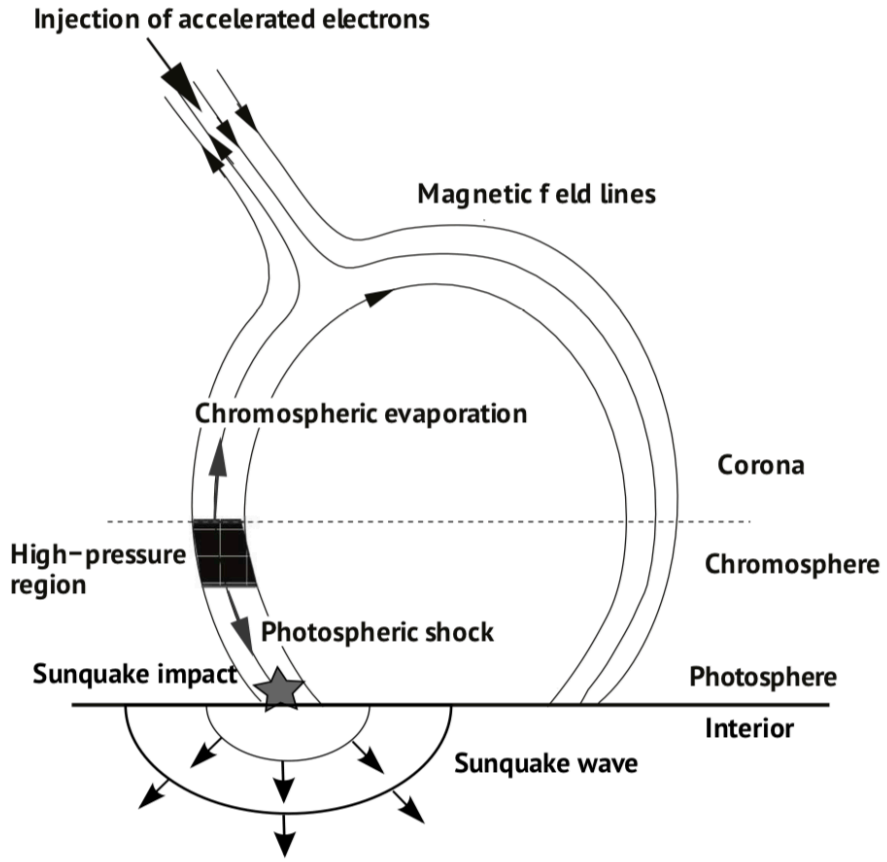


For the full analysis of this event see Quinn et al. 2019

QUEEN'S UNIVERSITY BELFAST

What is a Sunquake?

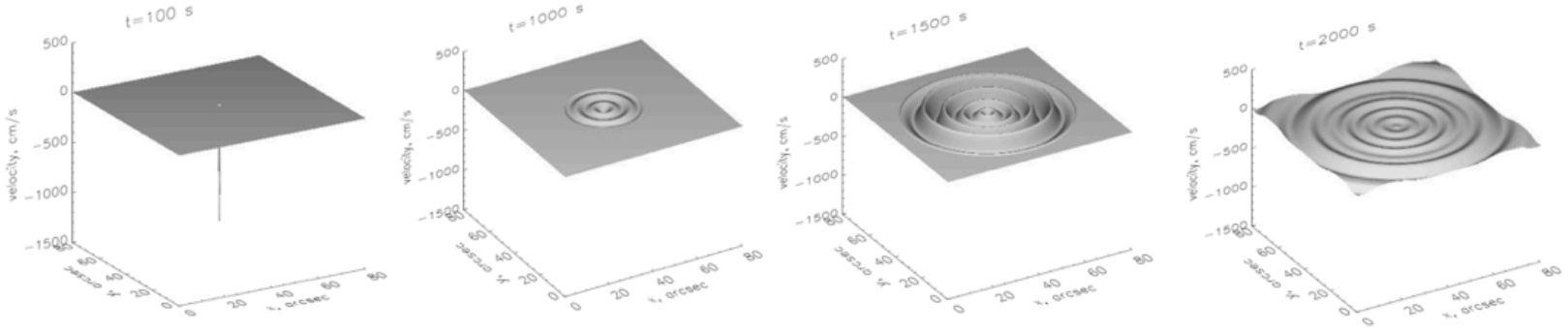
- The model we are using occurs after reconnection
- Particles accelerate down from reconnection site, where they collide with the chromosphere
- Chromospheric plasma expands, pushing plasma
  below the impact site deeper
- Plasma 'bubble' collides with the denser photosphere
- Imparts a shock front into the photosphere
- Eventually restored as a ripple pattern



(Kosovichev, 2006)

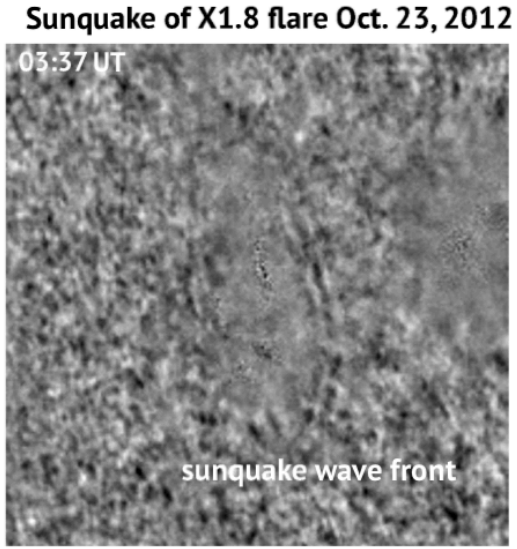
QUEEN'S UNIVERSITY BELFAST

What is a Sunquake?



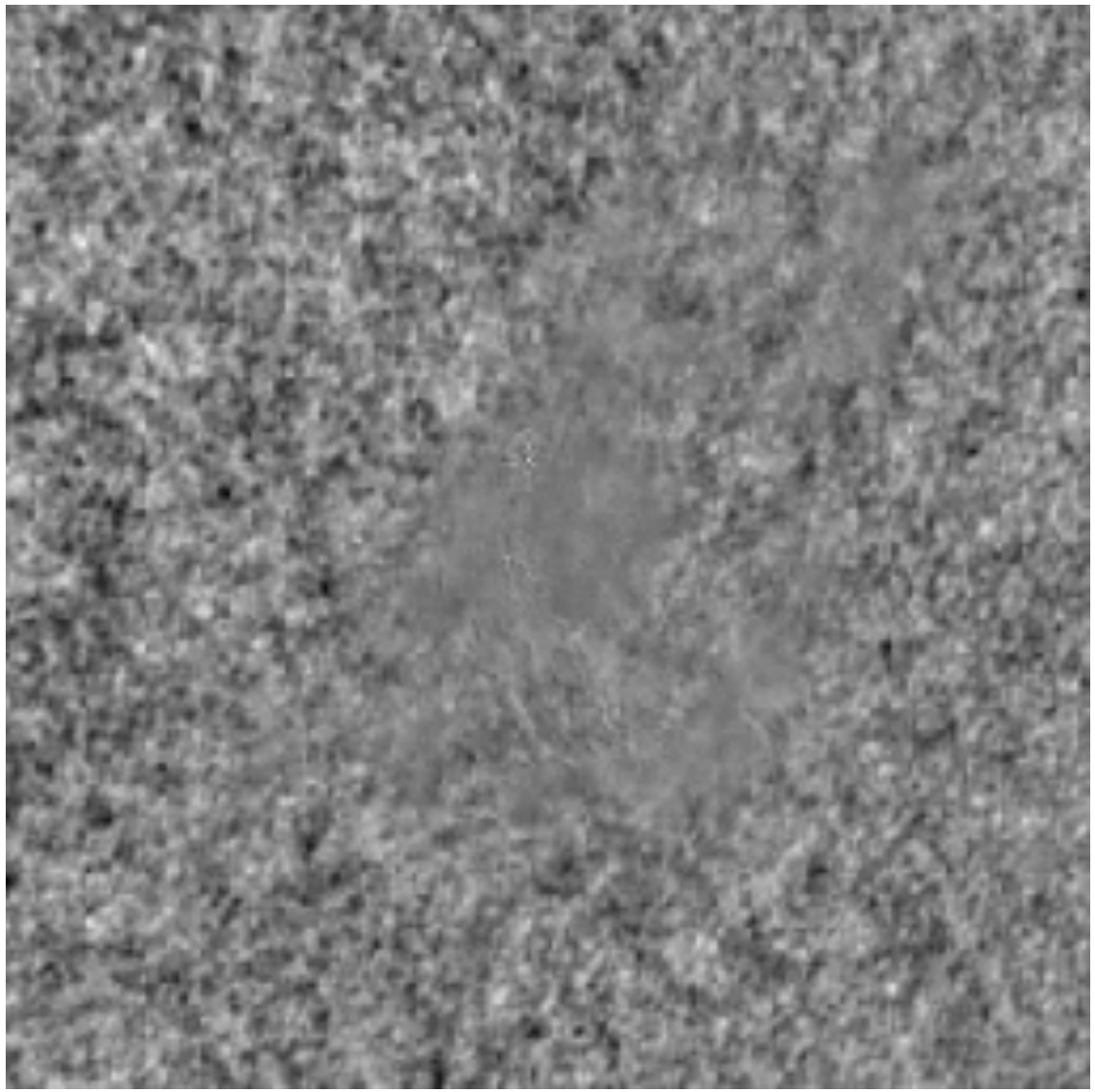
(Kosovichev and Zharakoa, 1996)

- Simulations were conducted before the first SQ detection
- A momentum impact was allowed to evolve in a simulated quiet photosphere
- Similar to a pebble in a pond
- Not the actual pebble that creates the ripples, but the surface restoring
- Can have global impact
- Our explanation of the Chromospheric response is the restoration force was so strong that it was able to propagate plasma upwards into the Chromosphere, creating the ripples



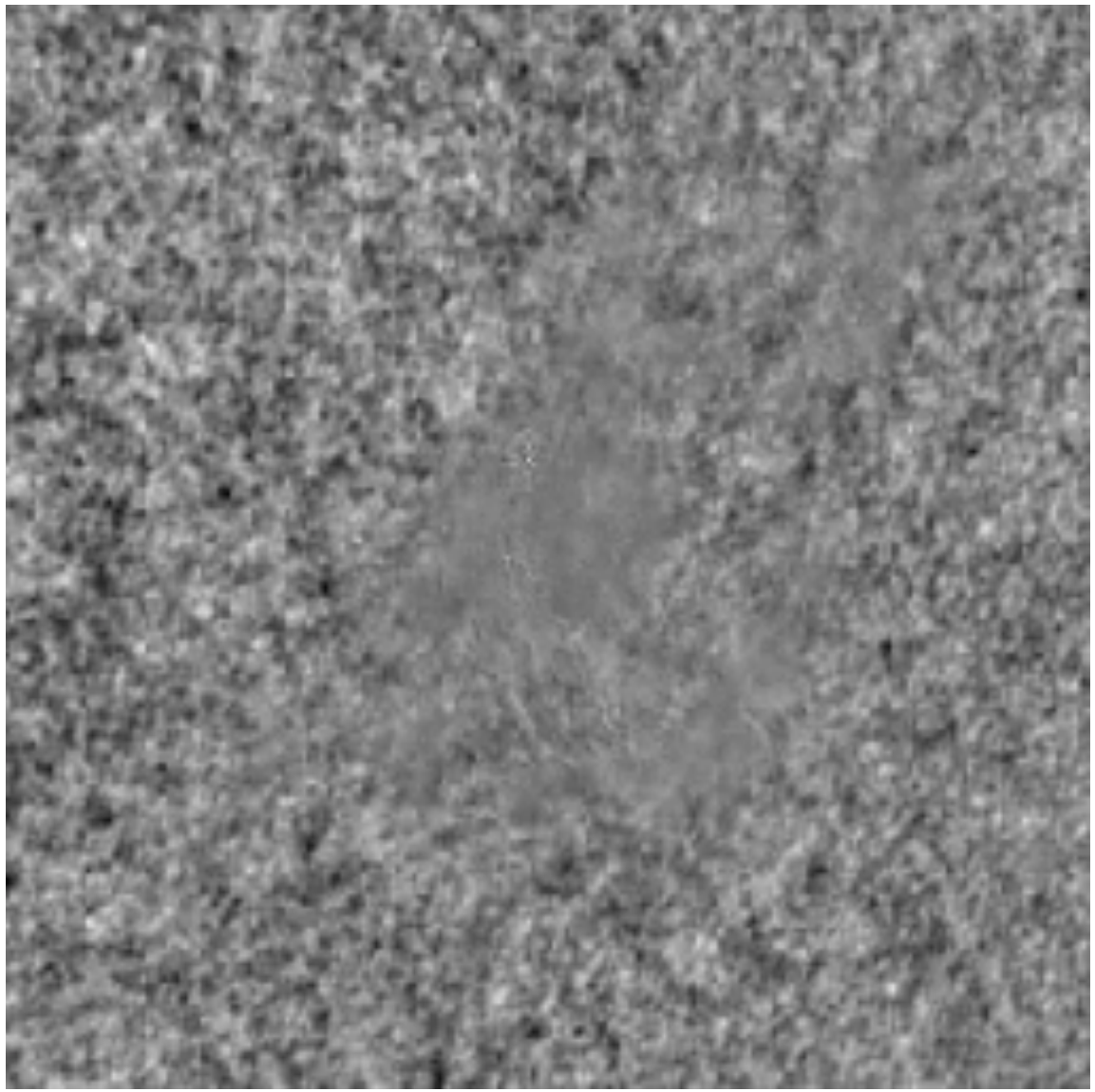
(Kosovichev, 2014)

The difference in HMI LOS observations for the 2 X-Class Flares



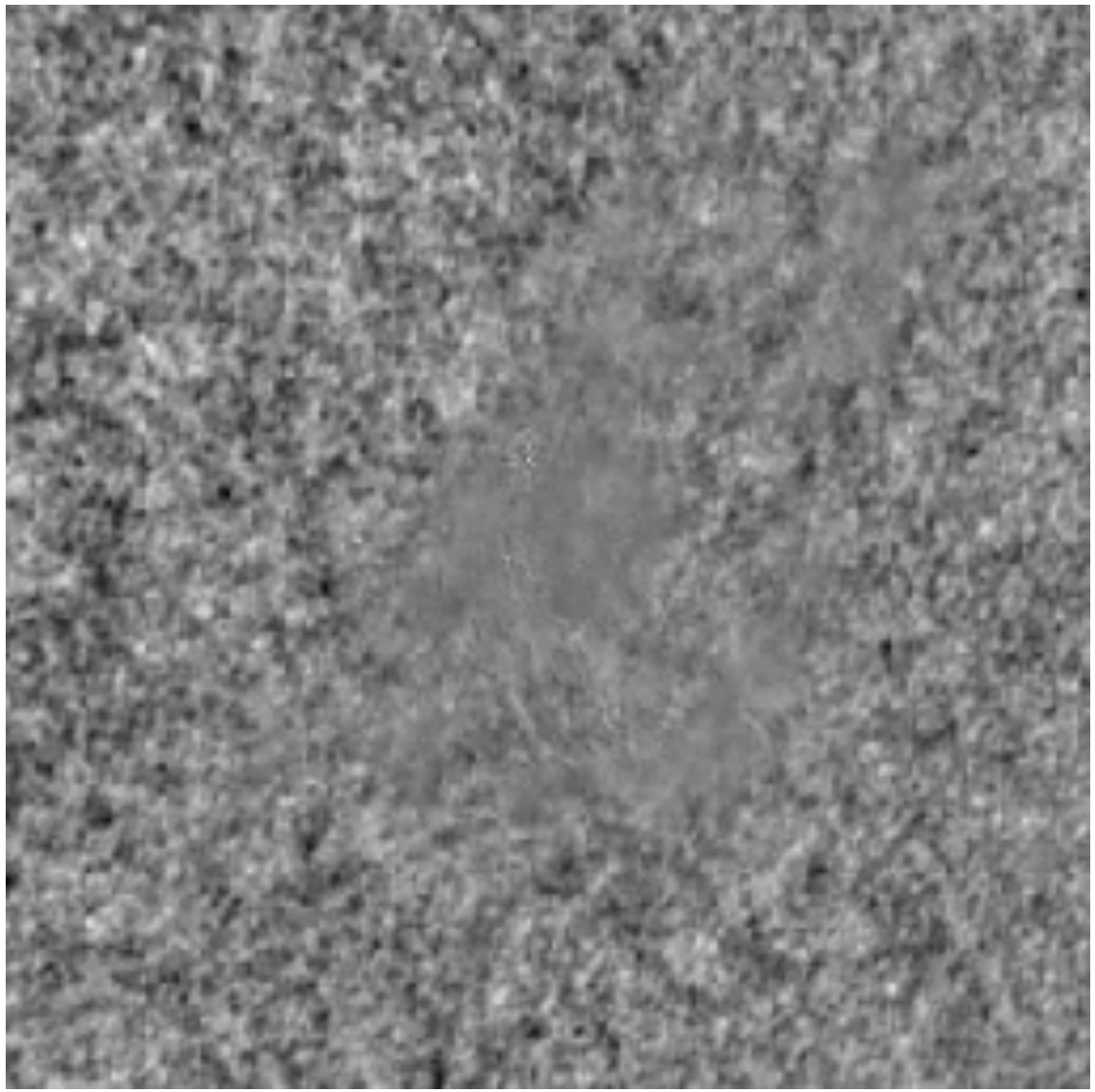
- The X9.3 flare had already had a photospheric Sunquake reported when the SST analysis was being undertaken (Sharykin & Kosovichev, 2018)
- This flare has a much stronger and noticeable response

The difference in HMI LOS observations for the 2 X-Class Flares



- The X9.3 flare had already had a photospheric Sunquake reported when the SST analysis was being undertaken (Sharykin & Kosovichev, 2018)
- This flare has a much stronger and noticeable response

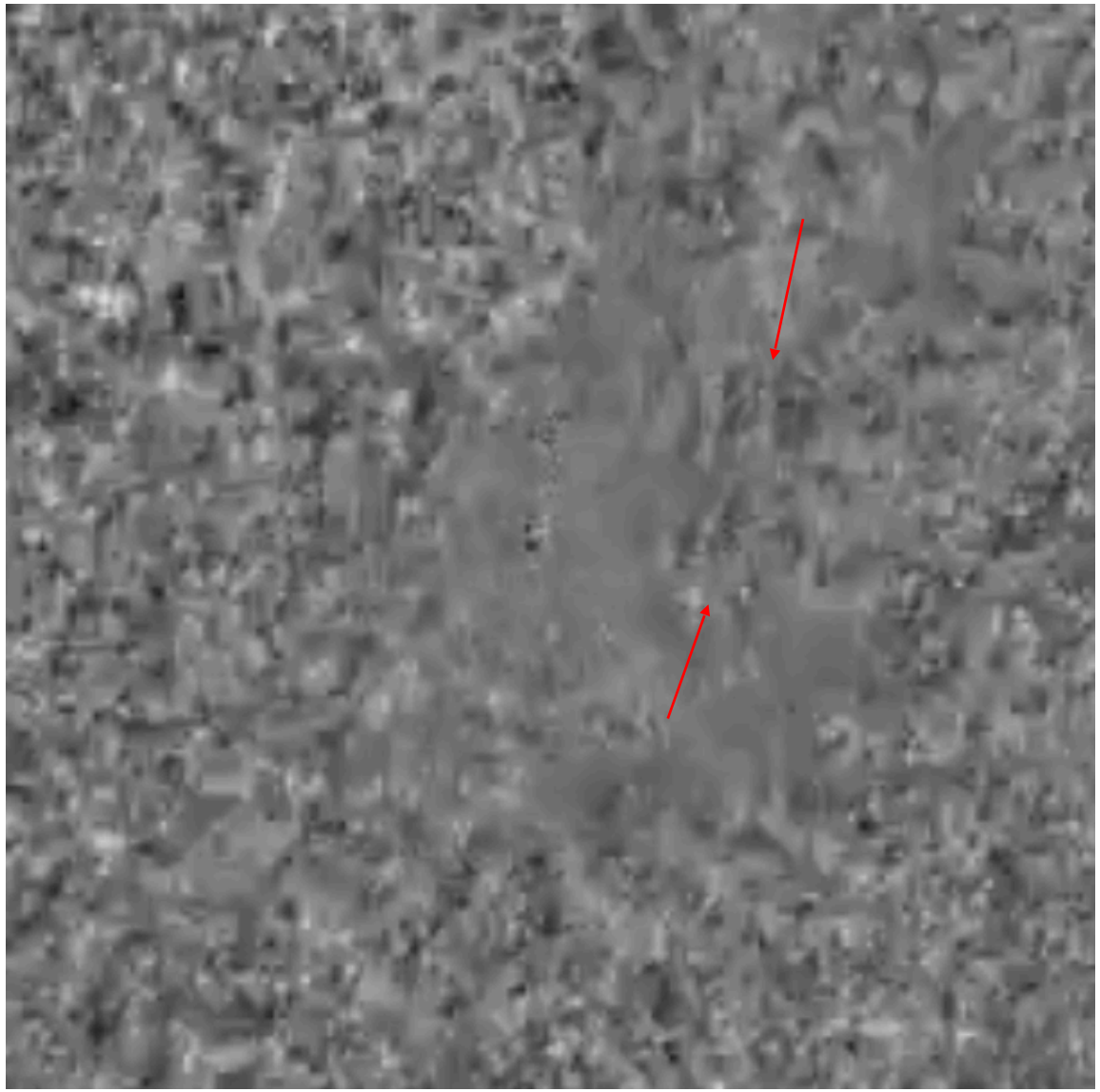
The difference in HMI LOS observations for the 2 X-Class Flares



- The X9.3 flare had already had a photospheric Sunquake reported when the SST analysis was being undertaken (Sharykin & Kosovichev, 2018)
- This flare has a much stronger and noticeable response

The difference in HMI LOS observations for the 2 X-Class Flares

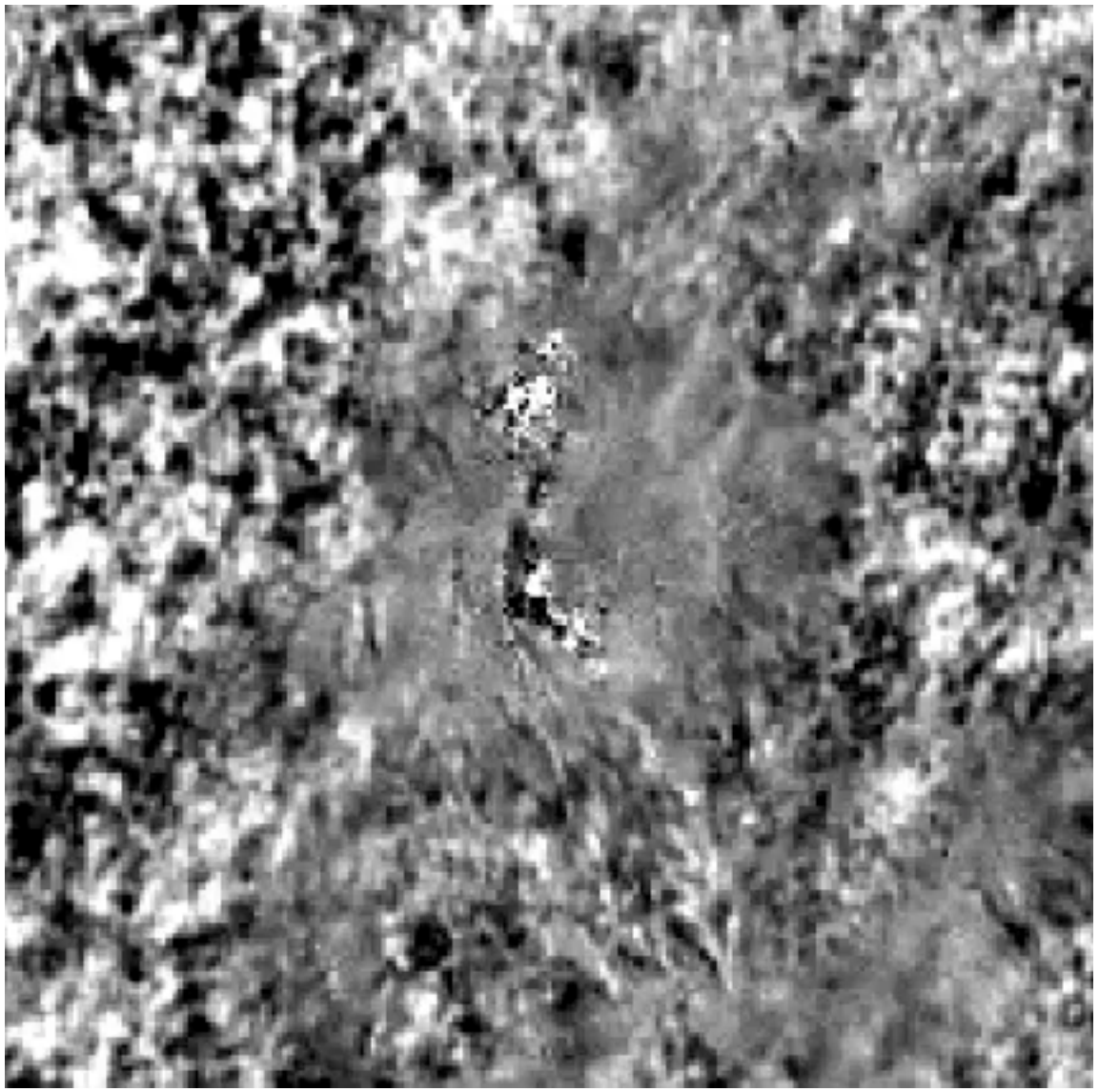
QUEEN'S UNIVERSITY BELFAST



- The X9.3 flare had already had a photospheric Sunquake reported when the SST analysis was being undertaken (Sharykin & Kosovichev, 2018)
- This flare has a much stronger and noticeable response

The difference in HMI LOS observations for the 2 X-Class Flares

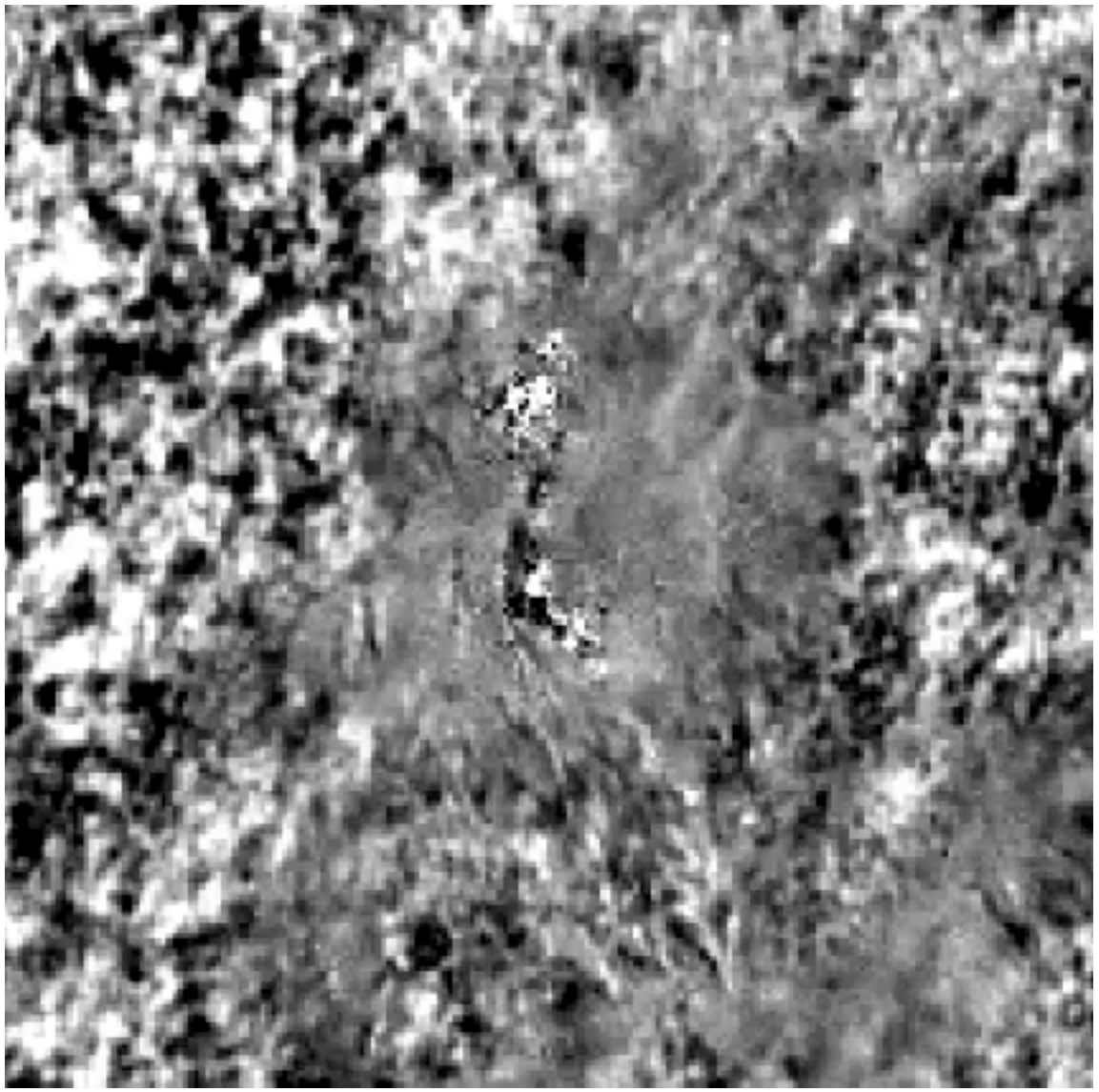
QUEEN'S UNIVERSITY BELFAST



- The X2.2 flare has had no photospheric response reported, which is understandable considering the extremely short life of the response
- Due to the better observations of the X9.3 it will be the case used in the rest of this talk

The difference in HMI LOS observations for the 2 X-Class Flares

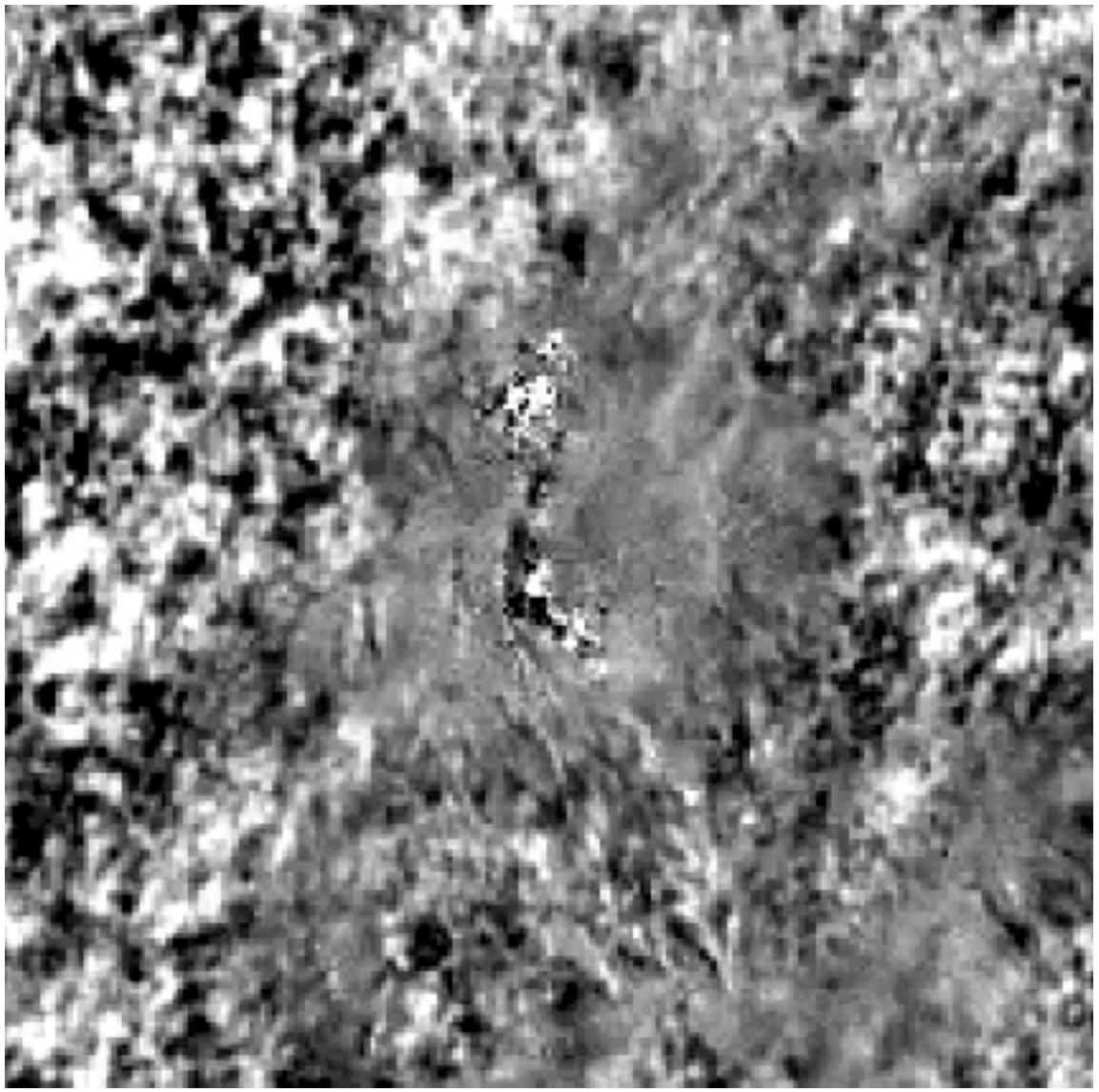
QUEEN'S UNIVERSITY BELFAST



- The X2.2 flare has had no photospheric response reported, which is understandable considering the extremely short life of the response
- Due to the better observations of the X9.3 it will be the case used in the rest of this talk

The difference in HMI LOS observations for the 2 X-Class Flares

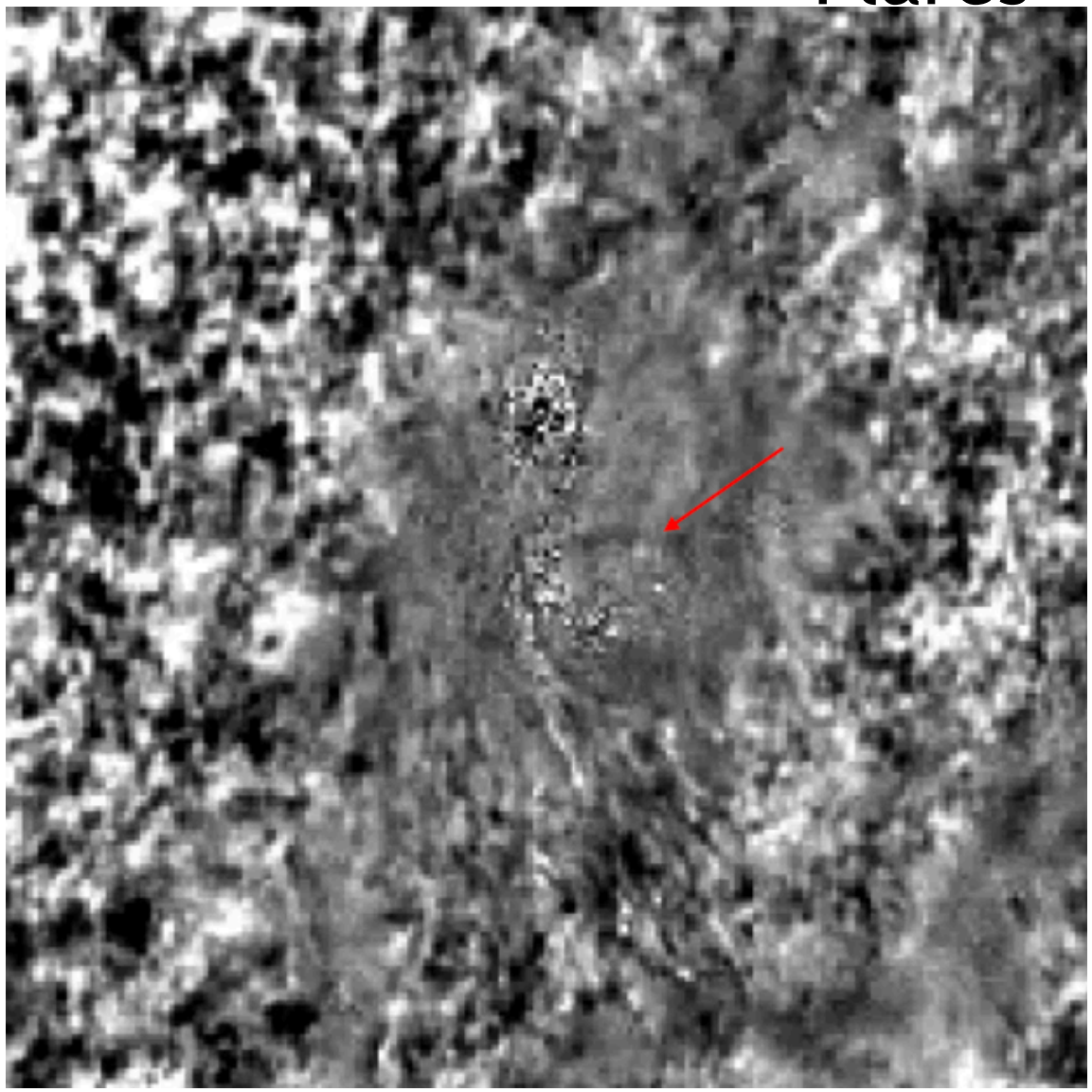
QUEEN'S UNIVERSITY BELFAST



- The X2.2 flare has had no photospheric response reported, which is understandable considering the extremely short life of the response
- Due to the better observations of the X9.3 it will be the case used in the rest of this talk

The difference in HMI LOS observations for the 2 X-Class Flares

QUEEN'S UNIVERSITY BELFAST



- The X2.2 flare has had no photospheric response reported, which is understandable considering the extremely short life of the response
- Due to the better observations of the X9.3 it will be the case used in the rest of this talk

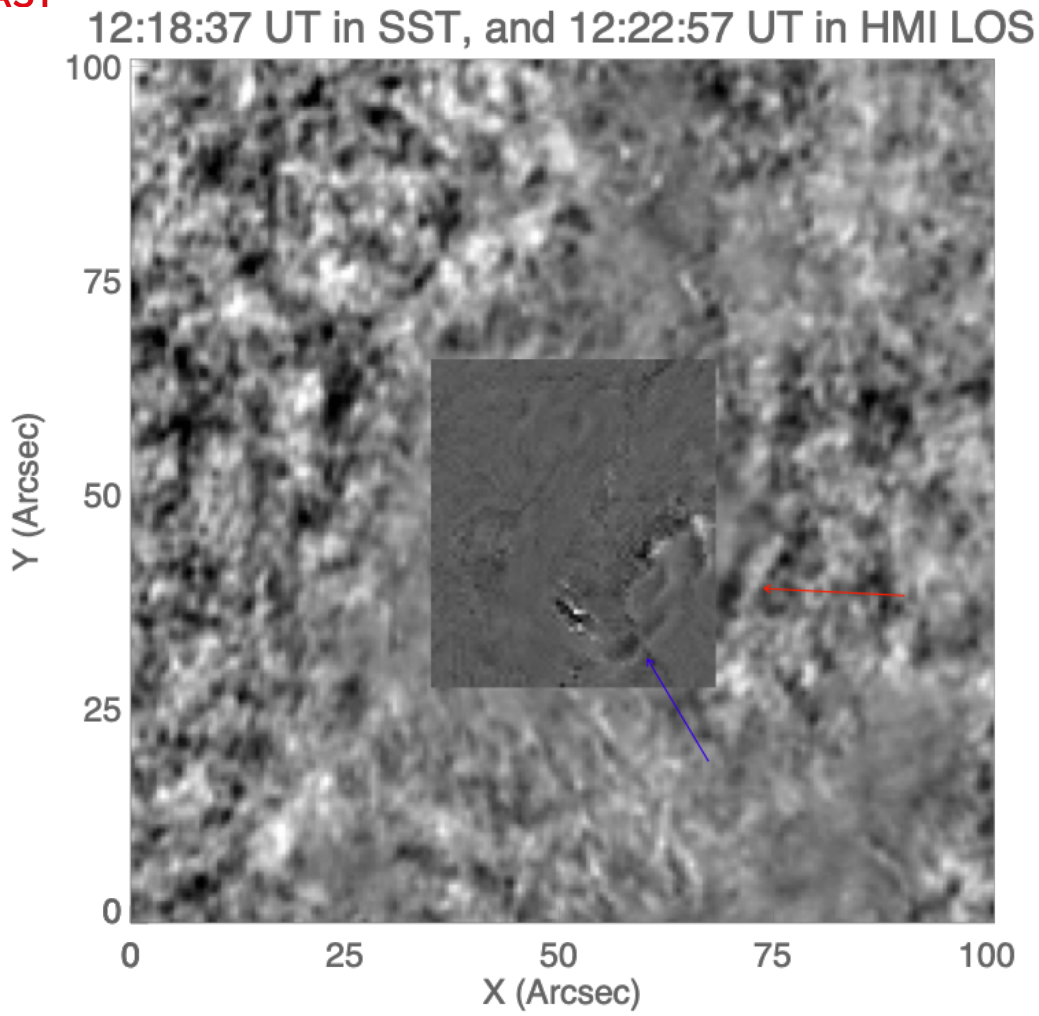
QUEEN'S UNIVERSITY BELFAST

‘Overplotted’ Time-Distance

- The SST running difference was ‘overplotted’ on the HMI LOS running difference
- Using this entire dataset, an ‘overplotted’ time-distance diagram was created
- Red crosses used in Chi-Squared analysis
- Testing regression trend, polynomial and straight line
- Blue trend is best fit for both observations
- Velocity = 4.5 km s^{-1} – 29.5 km s^{-1}

QUEEN'S UNIVERSITY BELFAST

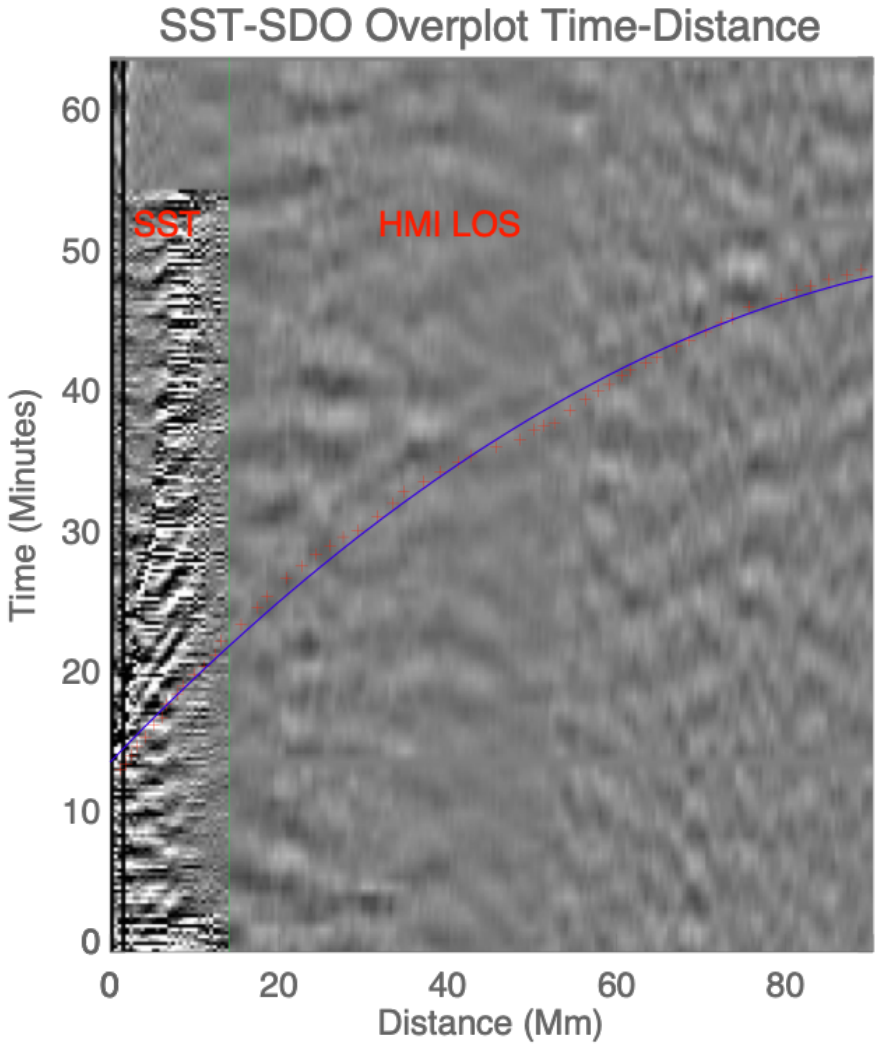
'Overplotted' Time-Distance



- The SST running difference was 'overplotted' on the HMI LOS running difference
- Using this entire dataset, an 'overplotted' time-distance diagram was created
- Red crosses used in Chi-Squared analysis
- Testing regression trend, polynomial and straight line
- Blue trend is best fit for both observations
- Velocity = 4.5 km s^{-1} – 29.5 km s^{-1}

QUEEN'S UNIVERSITY BELFAST

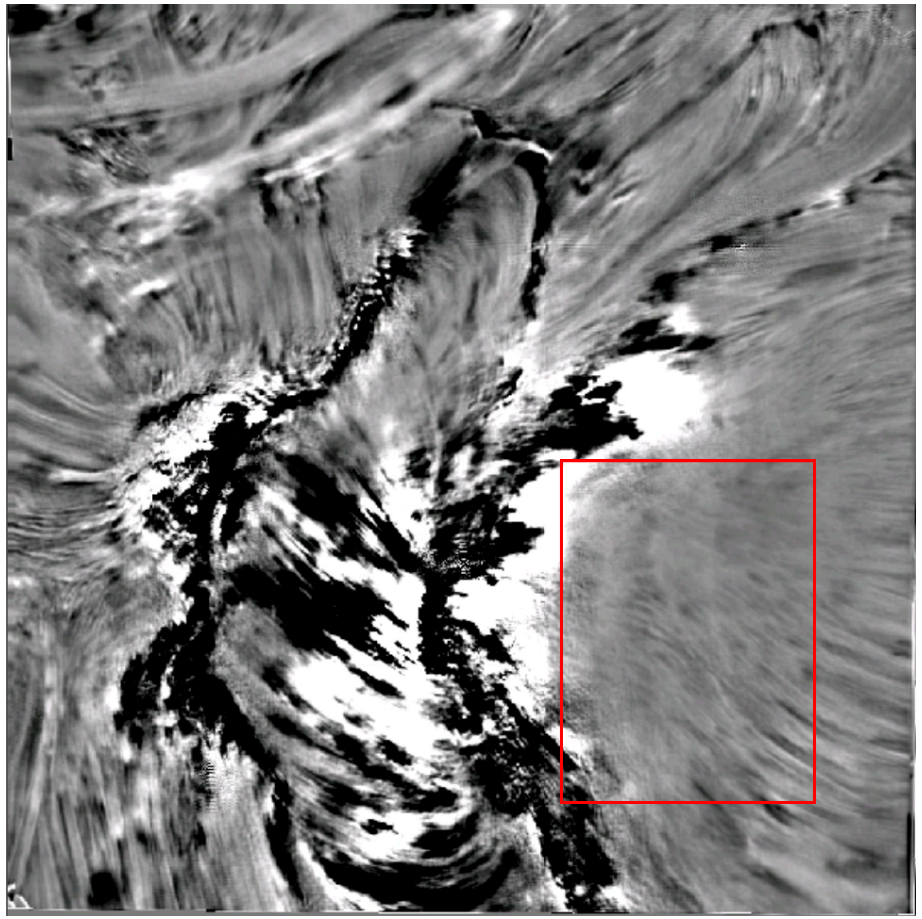
'Overplotted' Time-Distance

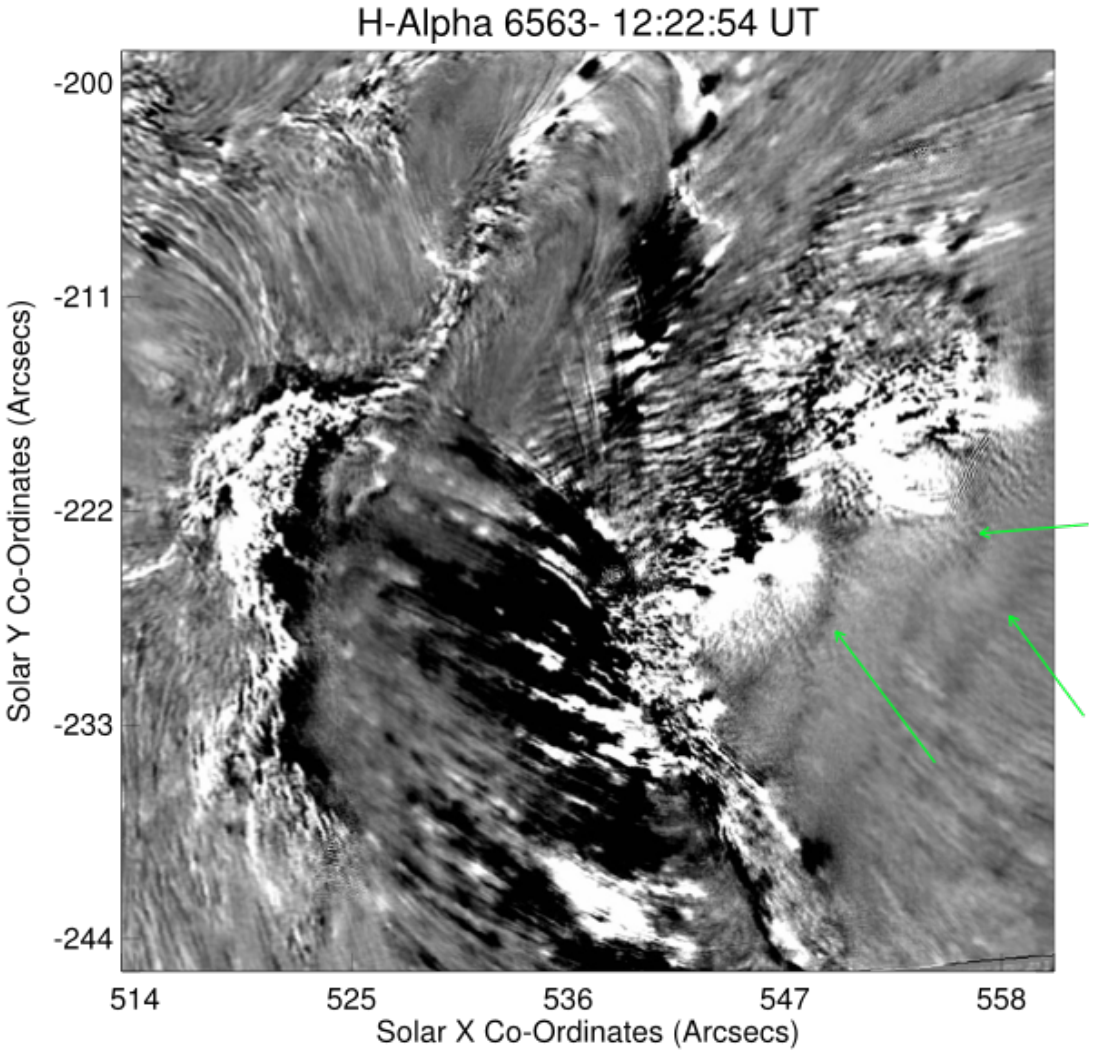


- The SST running difference was 'overplotted' on the HMI LOS running difference
- Using this entire dataset, an 'overplotted' time-distance diagram was created
- Red crosses used in Chi-Squared analysis
- Testing regression trend, polynomial and straight line
- Blue trend is best fit for both observations
- Velocity = 4.5 km s^{-1} – 29.5 km s^{-1}

QUEEN'S UNIVERSITY BELFAST

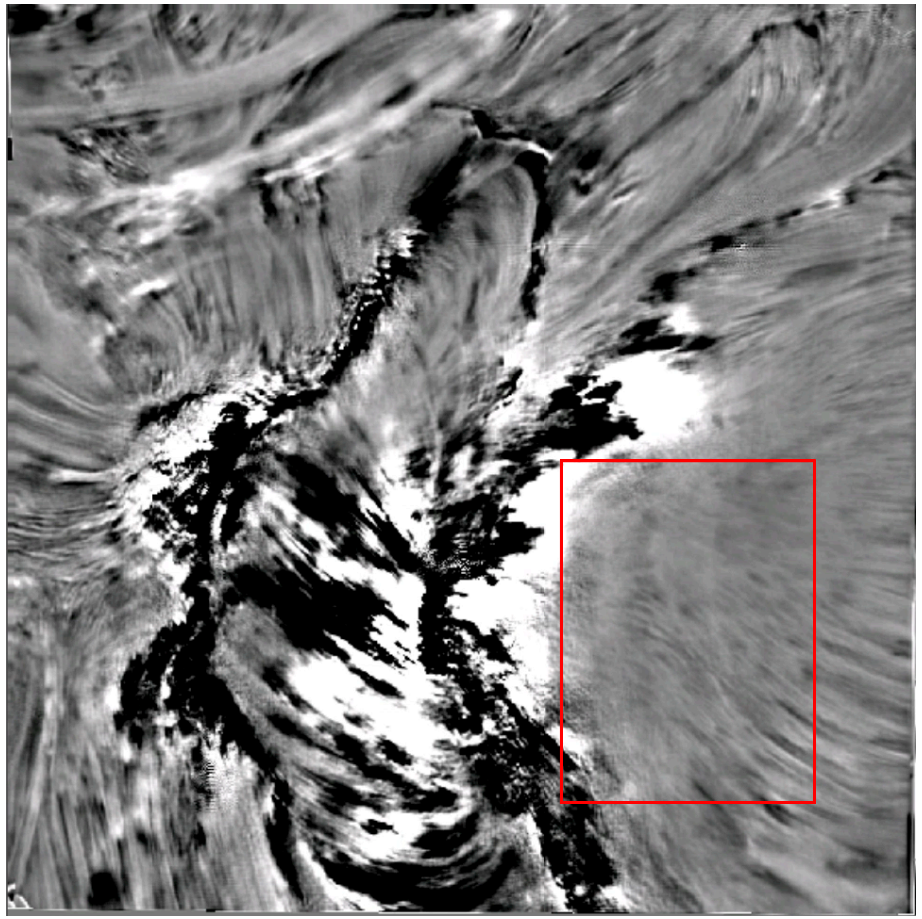
SST Hα data

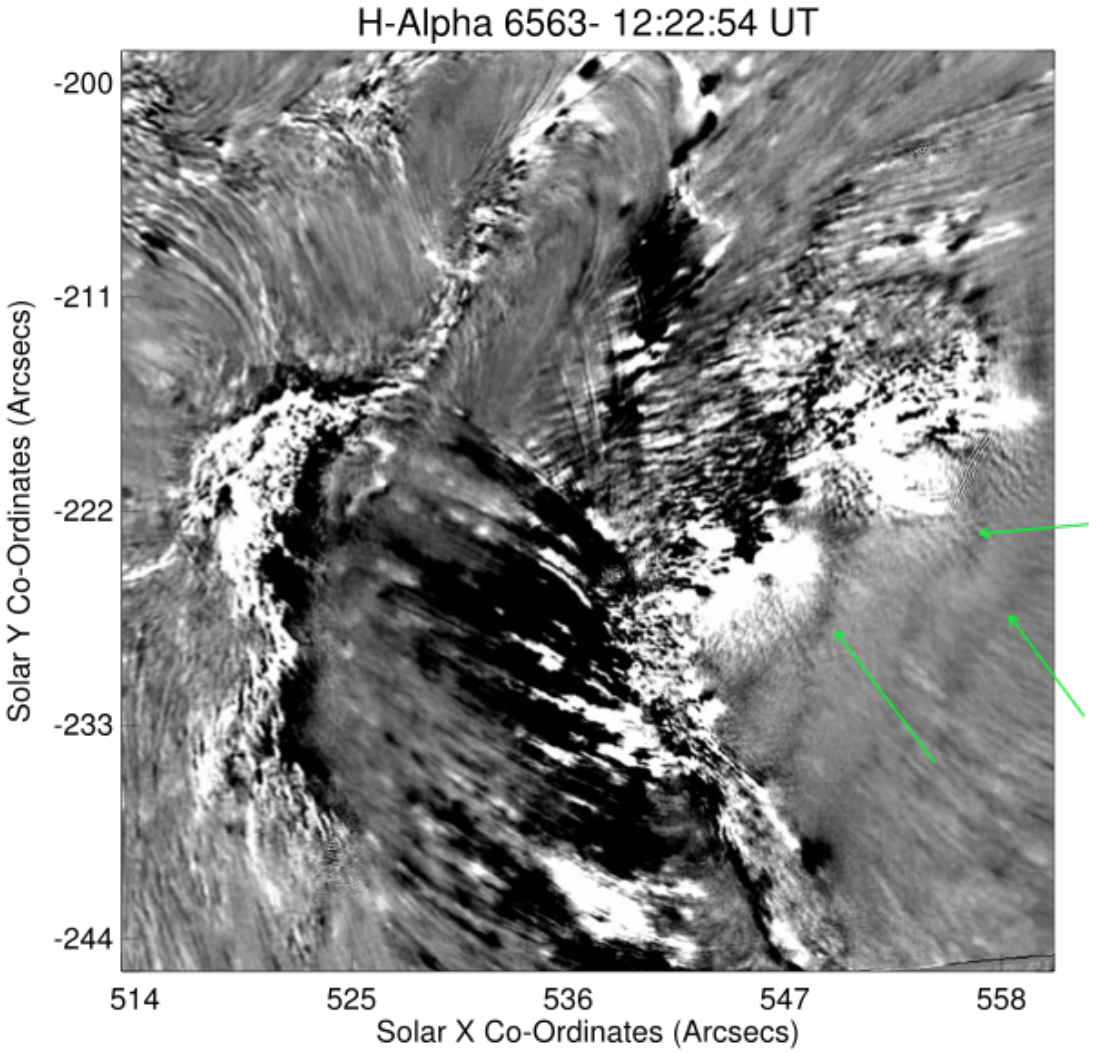




QUEEN'S UNIVERSITY BELFAST

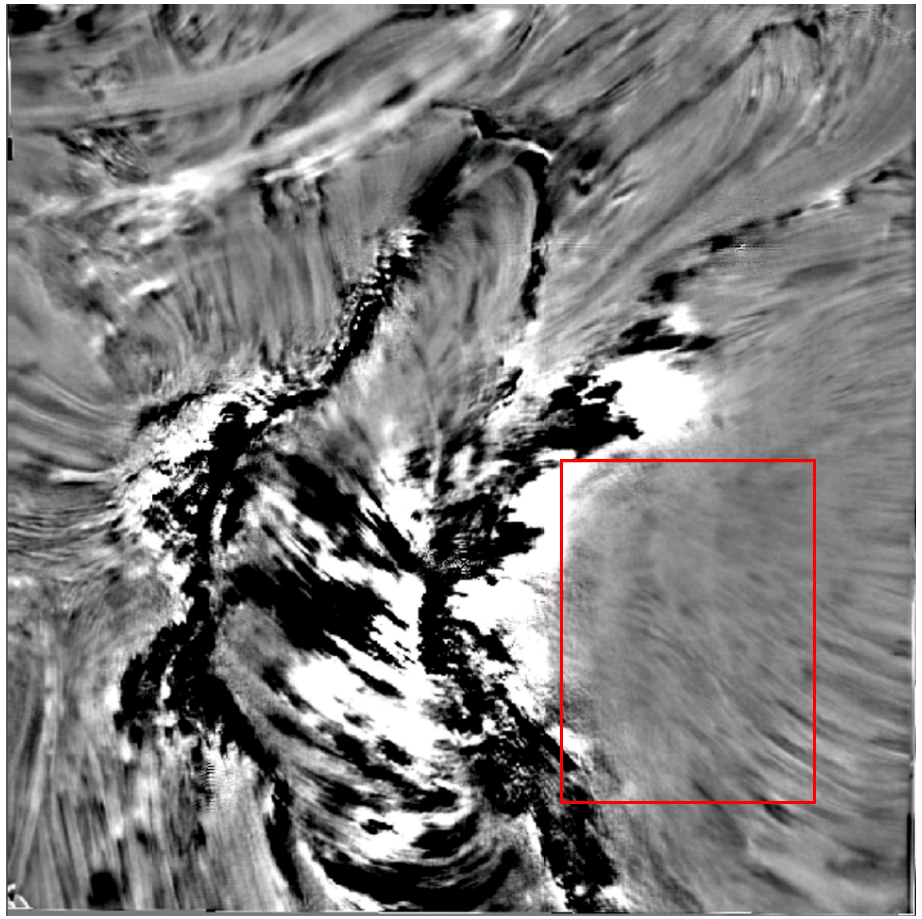
SST Hα data

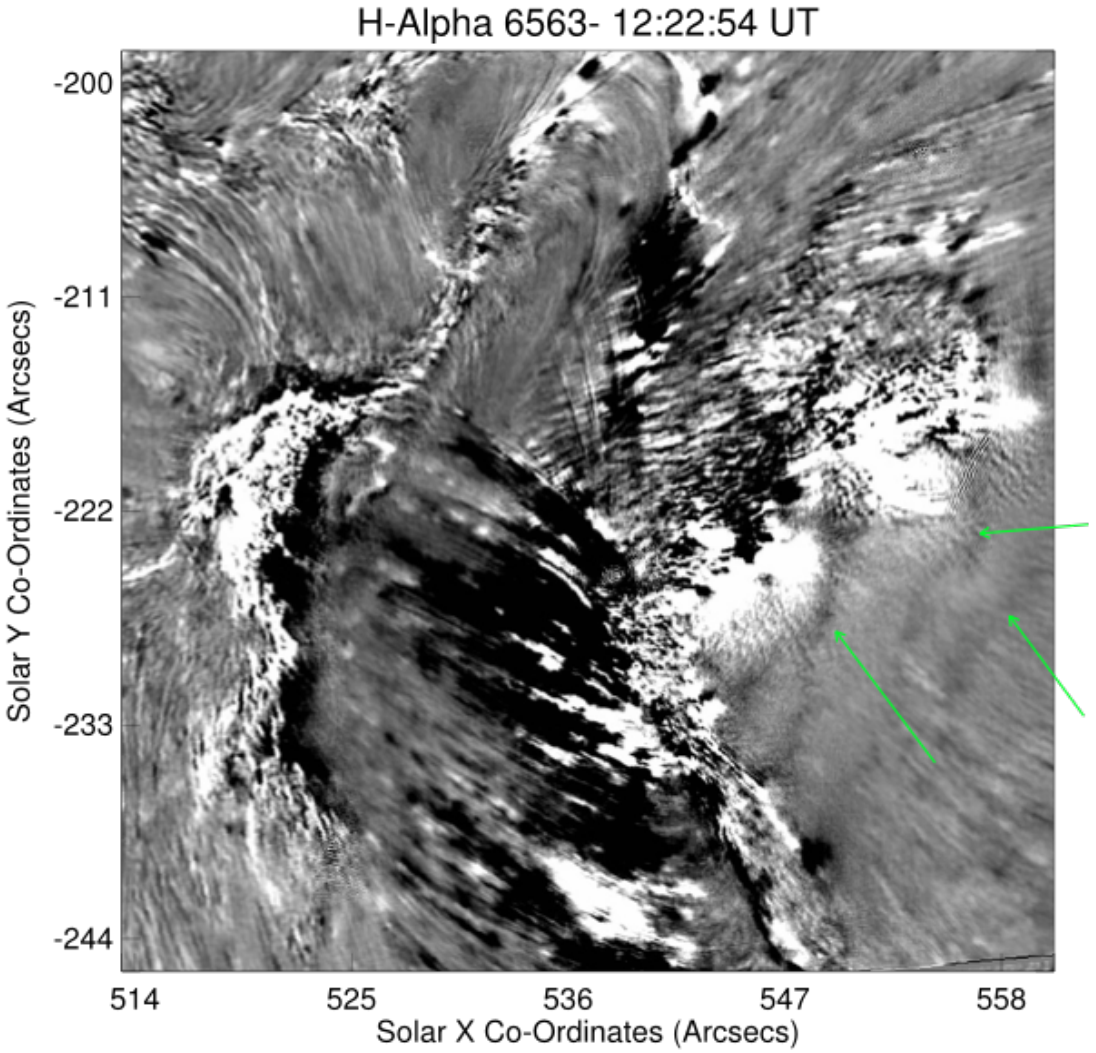




QUEEN'S UNIVERSITY BELFAST

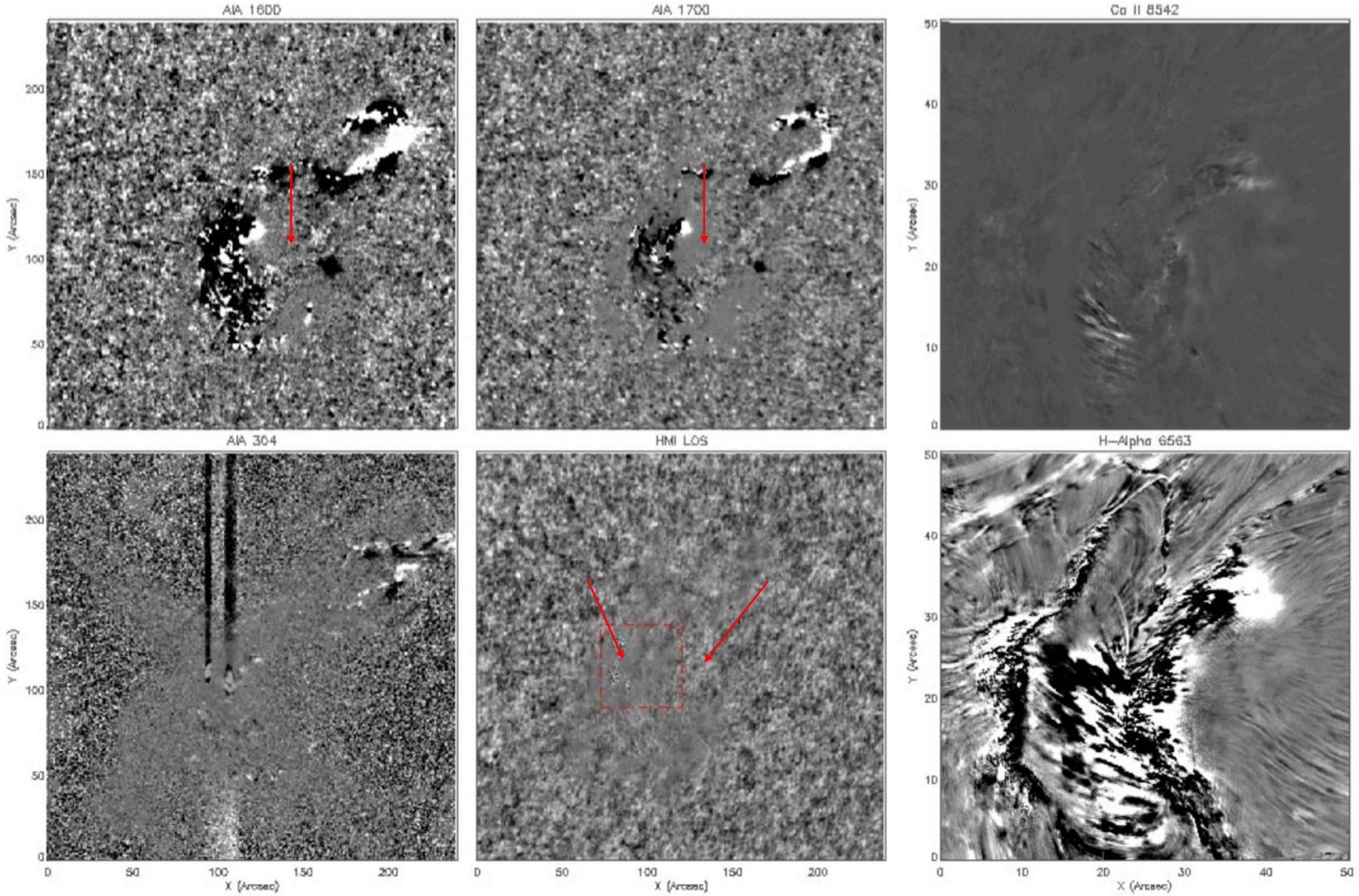
SST Hα data





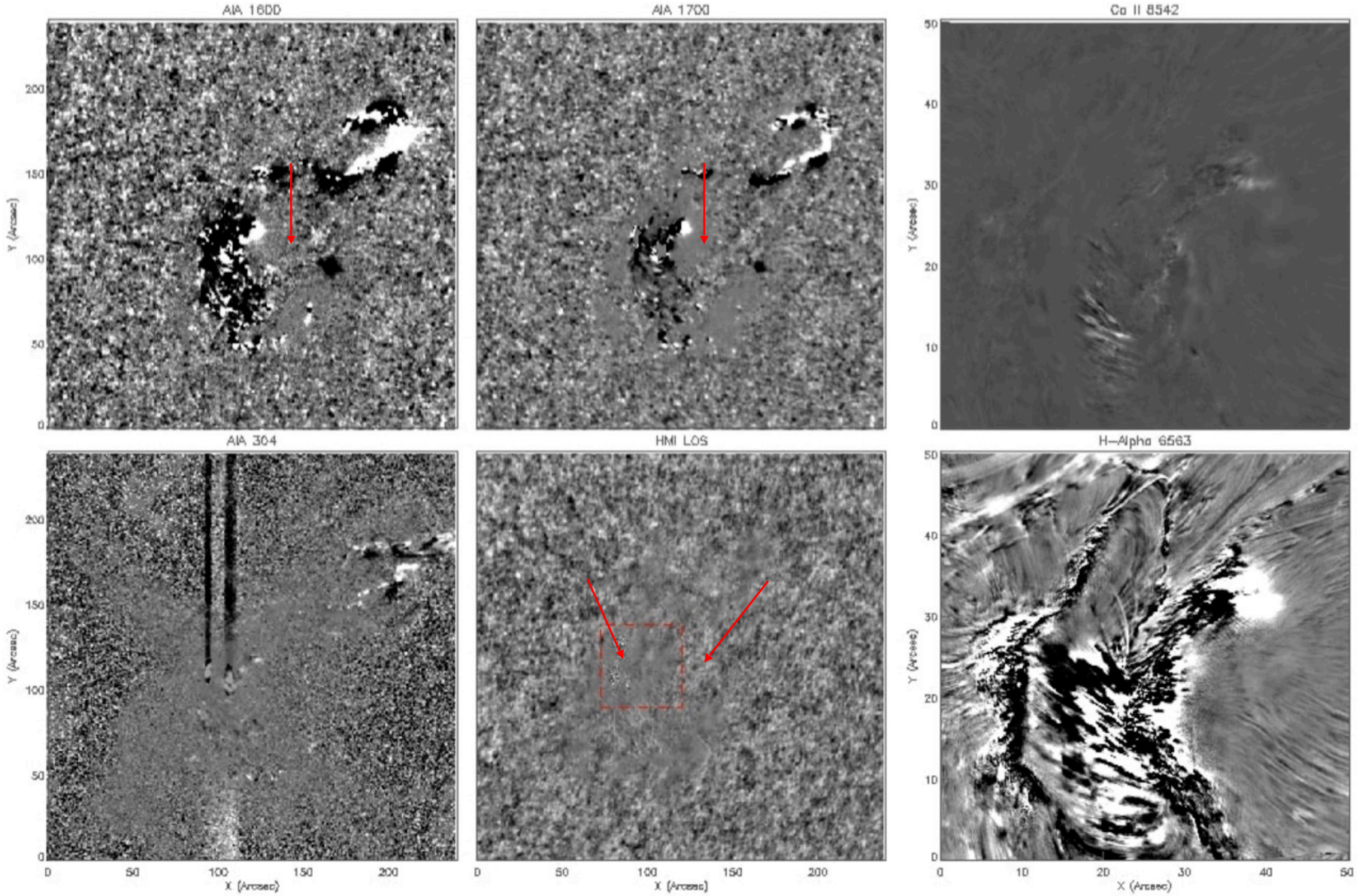
QUEEN'S UNIVERSITY BELFAST

Complete Observations of X9.3



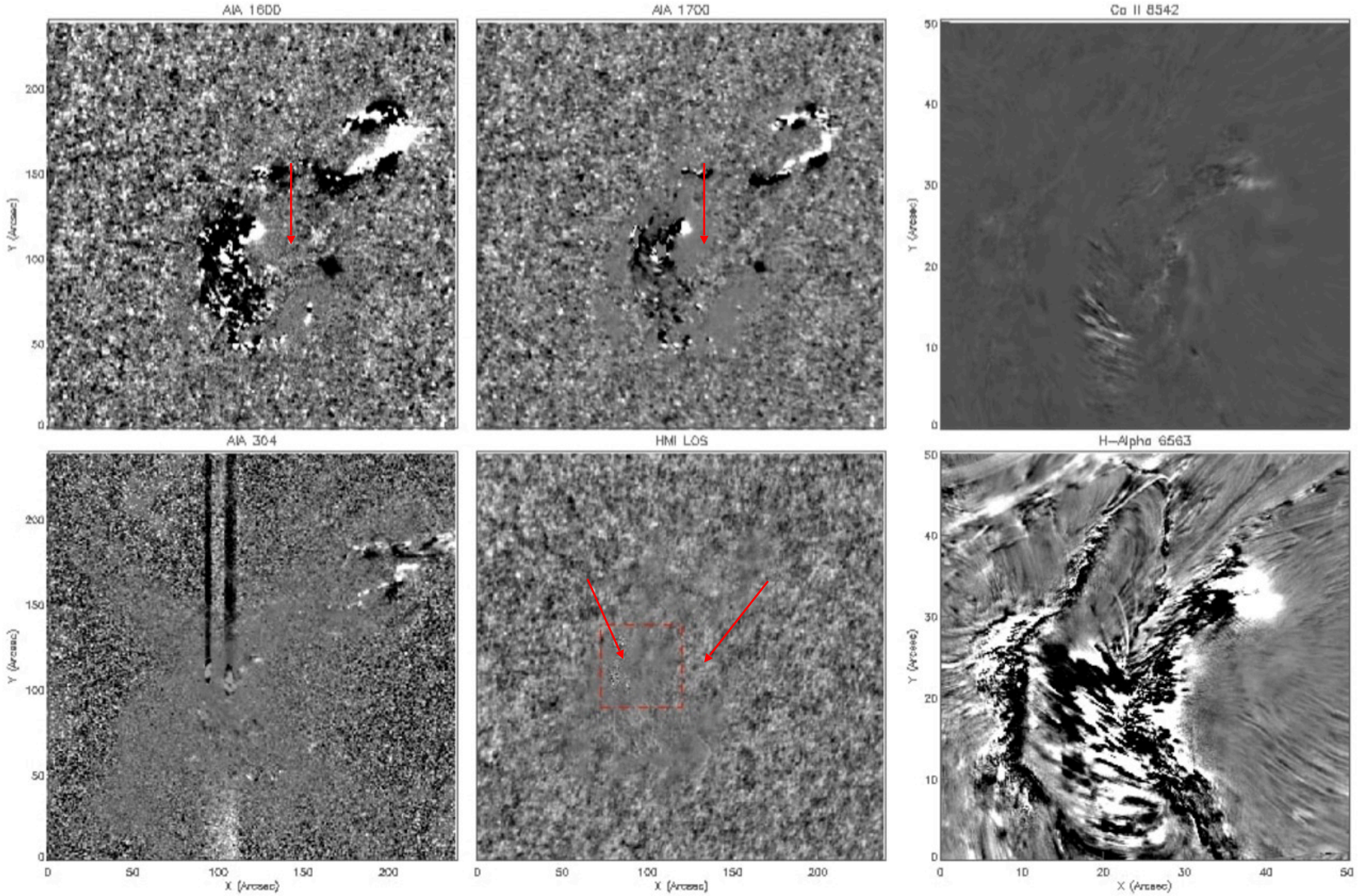
QUEEN'S UNIVERSITY BELFAST

Complete Observations of X9.3



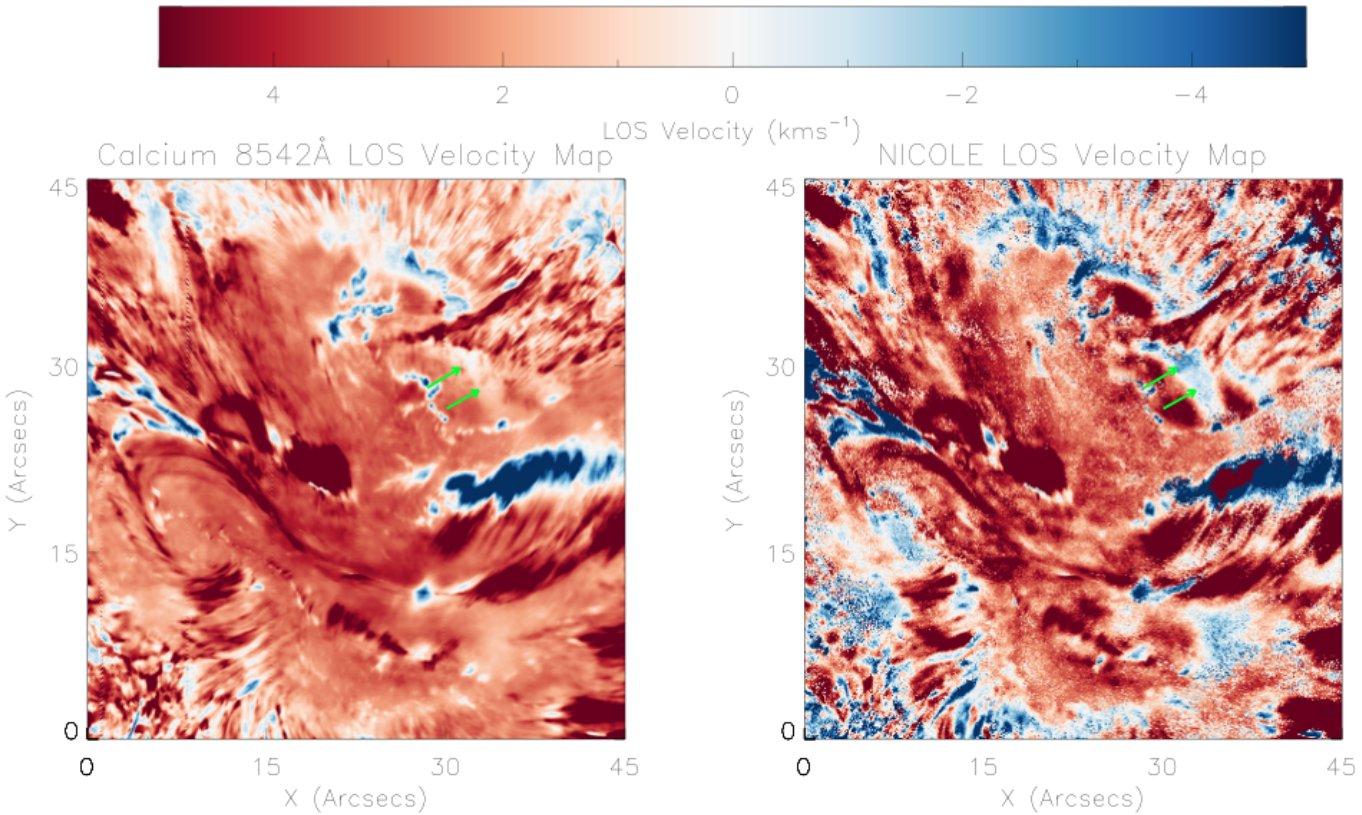
QUEEN'S UNIVERSITY BELFAST

Complete Observations of X9.3



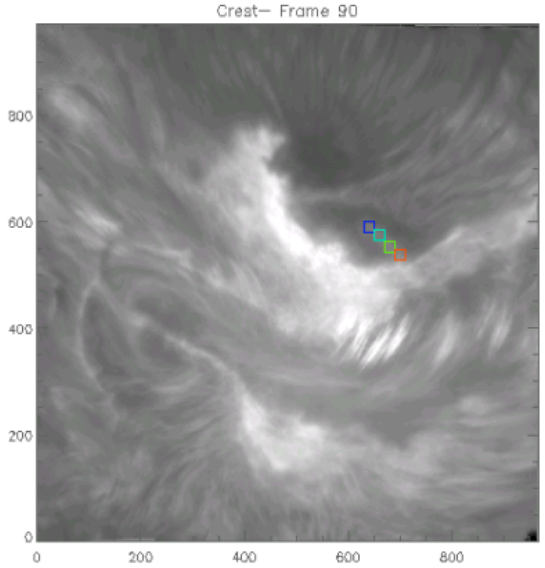
QUEEN'S UNIVERSITY BELFAST

NICOLE

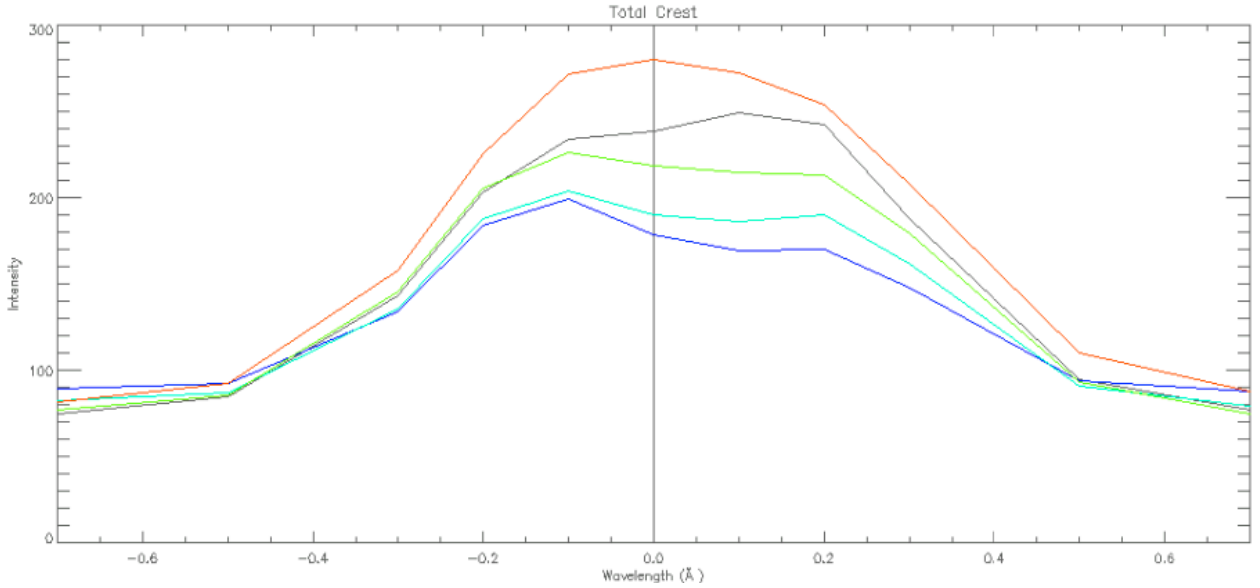


- Takes an observed data set, and finds certain constraints that can give these observations.
- Gives a number of output; LOS velocity, temperature, optical depth
- Creating a velocity map using the Centre of Gravity method allows the LOS map to be investigated
- Depending on optical depth, we can look at different heights in the atmosphere
- SQs themselves are velocity perturbations, and this Chromospheric response is also
- COG = 2.4 km s^{-1}
- NICOLE = 3.2 km s^{-1}

Creating Line Profiles

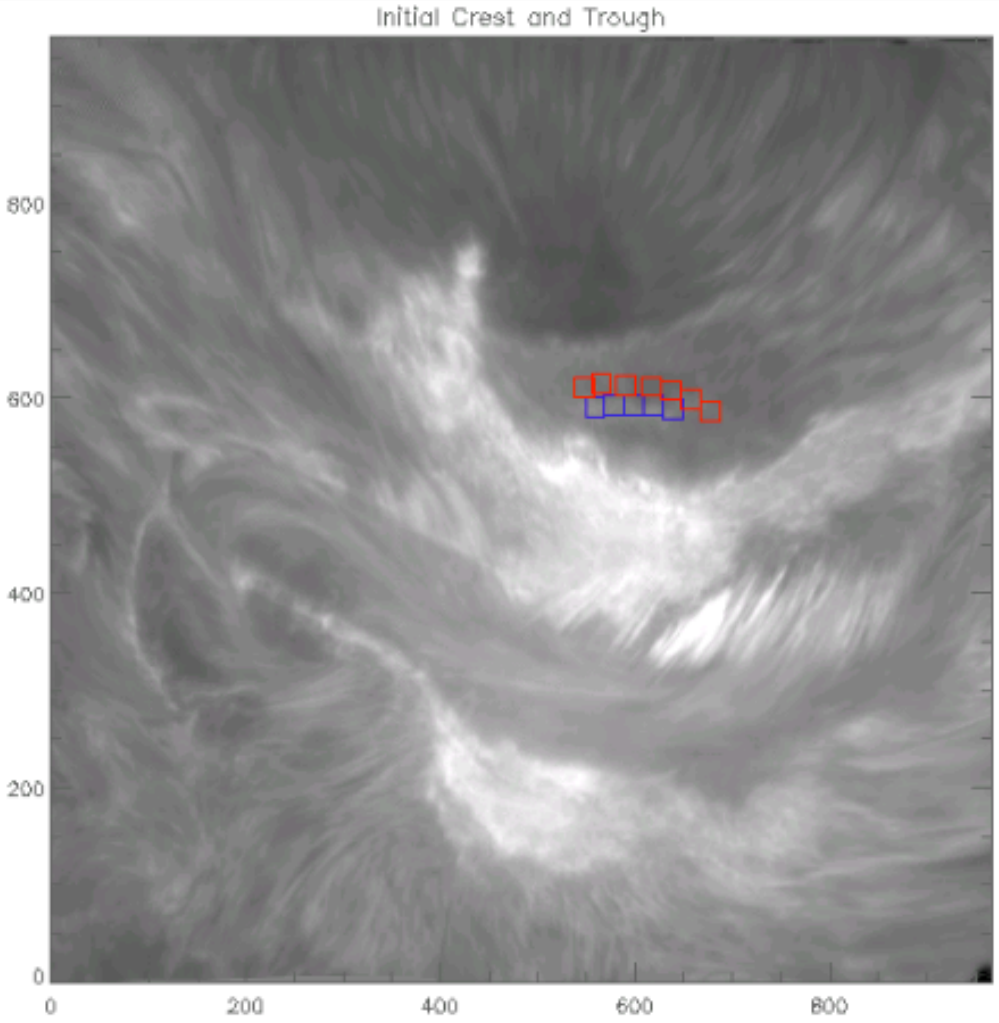


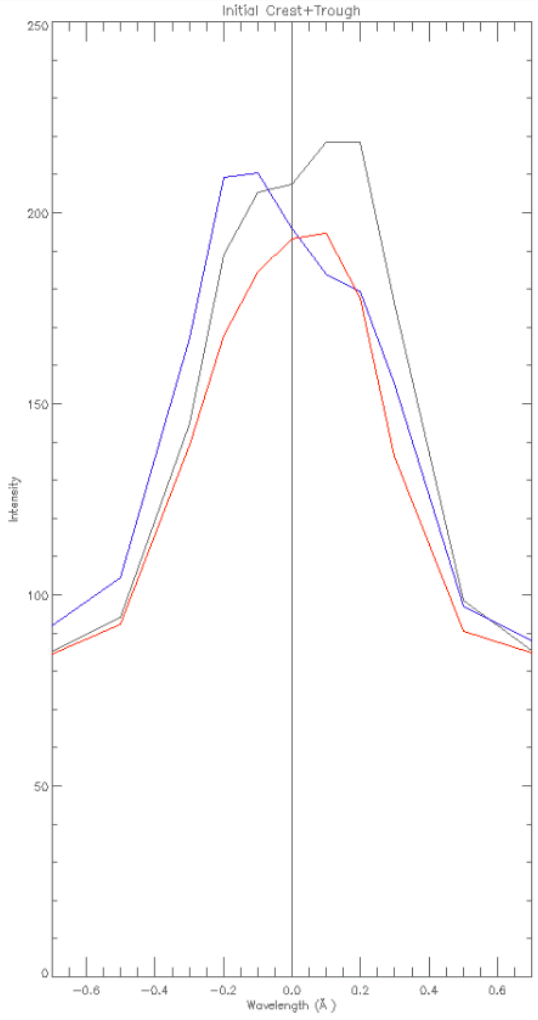
- Is this response only a velocity perturbation?
- By creating line profiles, we can see if there is any thermal broadening
- A number of 20 pixel by 20 pixel boxes contained in a ‘crest’ or ‘trough’
- The intensities of each were recorded at each observational position
- An average intensity for each box, for each observational position was created

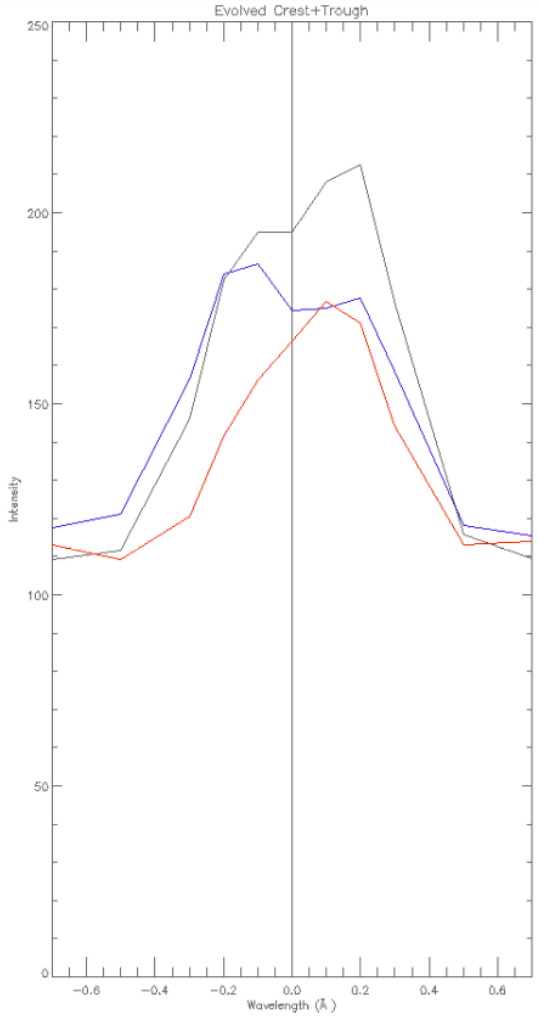


QUEEN'S UNIVERSITY BELFAST

Crests and Troughs

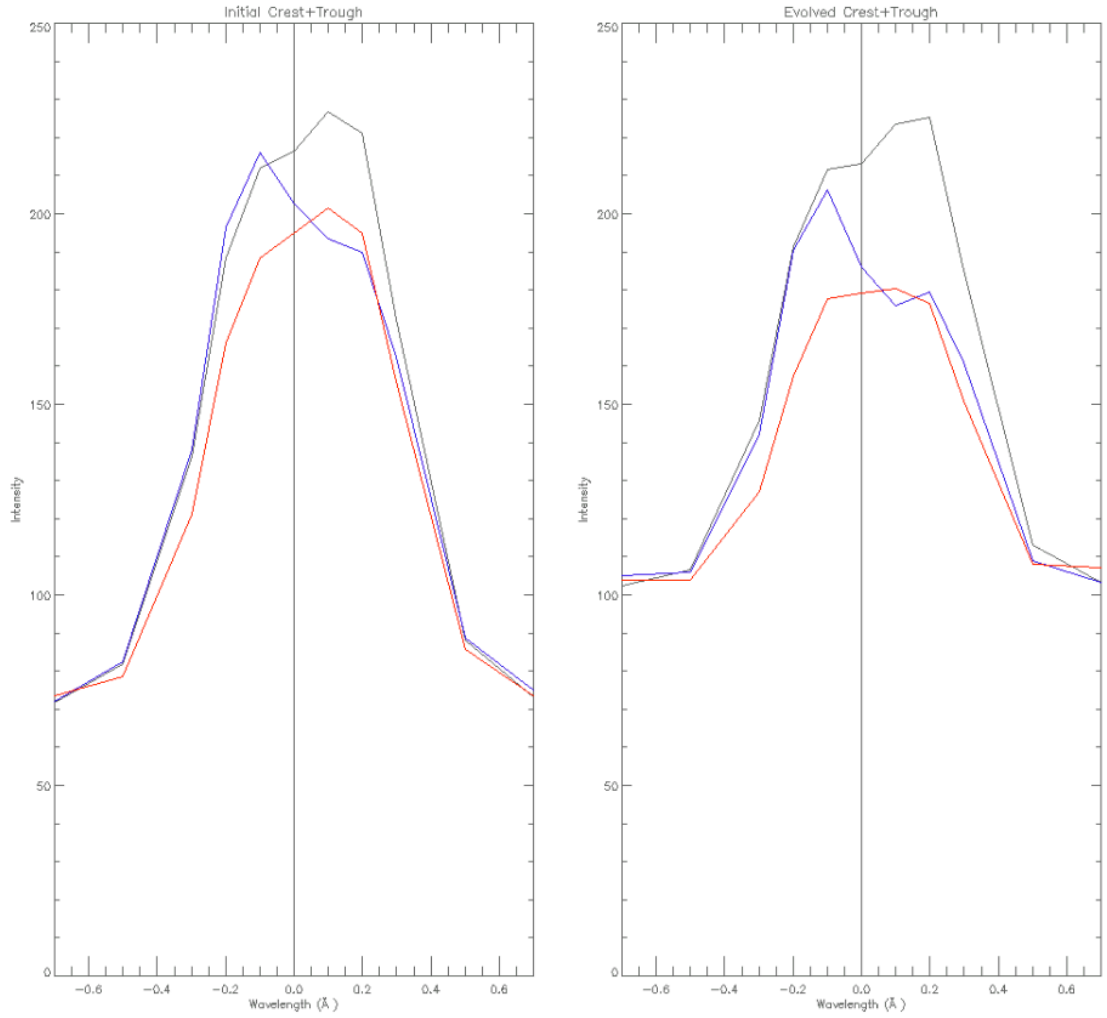






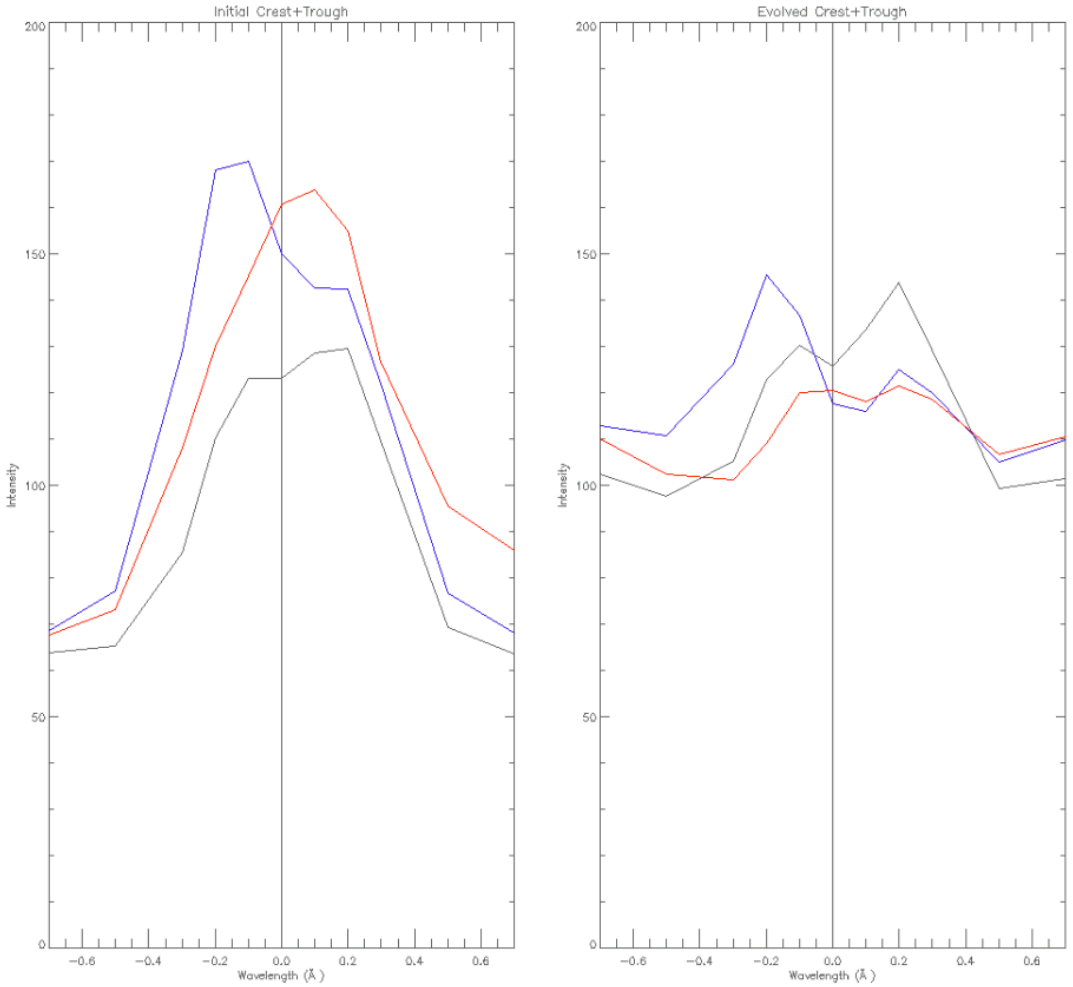
QUEEN'S UNIVERSITY BELFAST

Crests and Troughs



QUEEN'S UNIVERSITY BELFAST

Crests and Troughs



QUEEN'S UNIVERSITY BELFAST

Other Chromospheric responses?

- The SST also observed a number of other solar flares on the 6th September 2017

Time	Solar Flare Class
09:04:20	X2.2
11:08:59	M1.0
11:55:47	X9.3
14:36:03	M4.0
15:55:55	M2.5

- Only the X-Class flares created a photospheric SQ which possessed a chromospheric response

QUEEN'S UNIVERSITY BELFAST

Do only X-Class flares create a Chromospheric Response?

- We don't know, the Sun has been quiet since these X-Class flares, with no large class flares being produced since mid-September 2017
- To investigate this, I am currently looking at older SQs which do not have a reported, associated AIA 1600Å and 1700Å response
- If one is present, this could give us a candidate for a upper atmosphere response
- I also hope to use IRIS observations of solar flares with associated SQs, to determine if any responses have been observed with the SJI
- Once I have a good sample size, I would like to use RHESSI to establish any correlation between upper atmosphere responses to a SQ, and the energetics of the initiating flare

QUEEN'S UNIVERSITY BELFAST

Conclusions

- The X9.3 flare is the first observation of the Chromosphere responding to a flare-initiated Sunquake
- The lack of previous detections is likely due to the low resolution of previous observational setups
- These responses are created purely by velocity perturbations
- Can they form without a photospheric SQ?
- They can help us detect photospheric SQs
- For more details on the X9.3 event, please refer to Quinn et al. 2019