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Quasi-Periodic Pulsations in Solar Flares

RHESSI 15 Meeting

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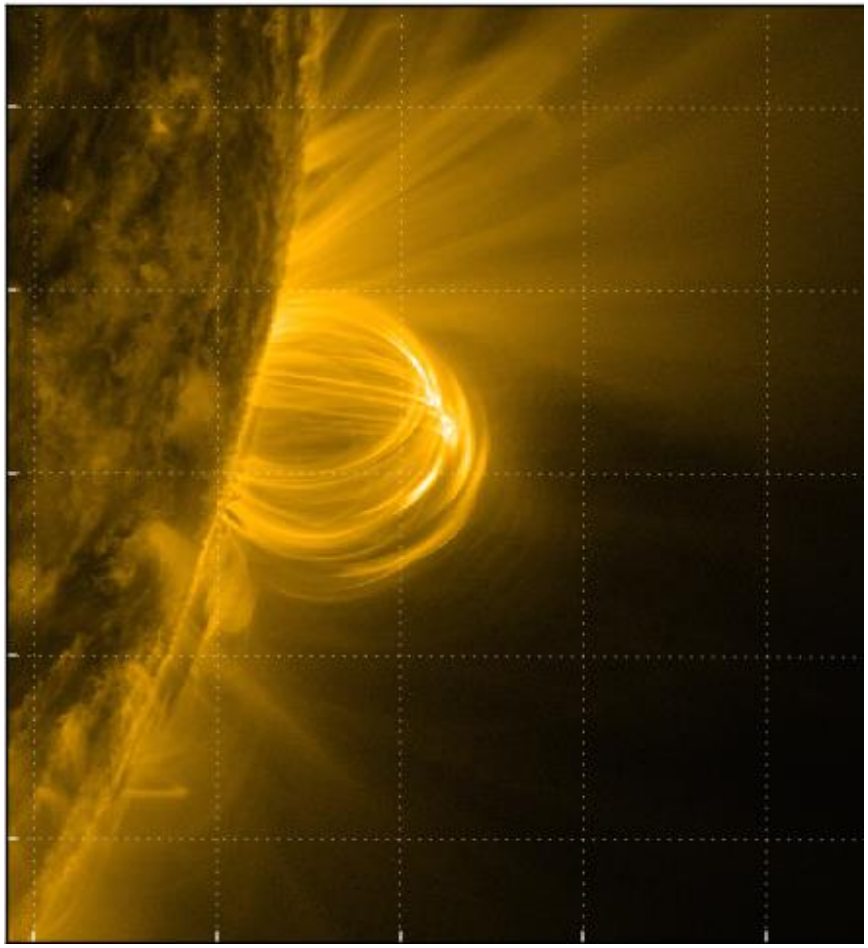
29 July 2016

Quasi-Periodic Pulsations (QPP) in Solar Flares

Outline

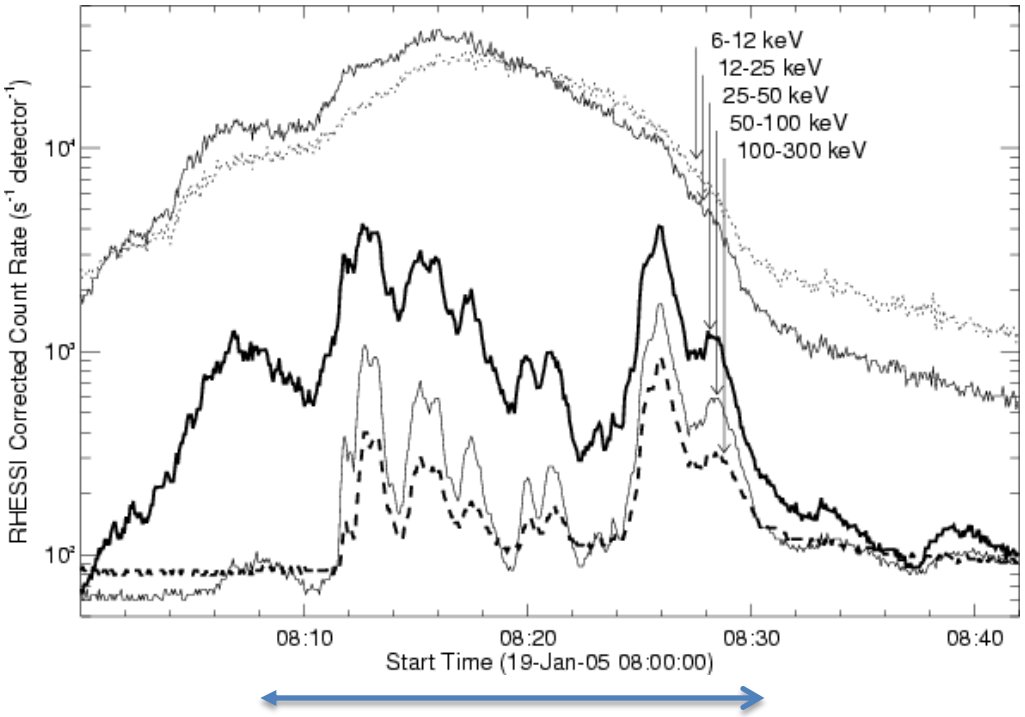
- Observational Introduction to QPP & Why Interesting
- Possible Mechanisms for QPP
- Multi-wavelength analysis of QPP;
  - X1.0 Flare Impulsive and decay phase pulsations
  - M7.7 Long duration soft X-ray pulsations



Quasi-Periodic Pulsations in Solar Flares

Introduction

Nakariakov et al. 2006



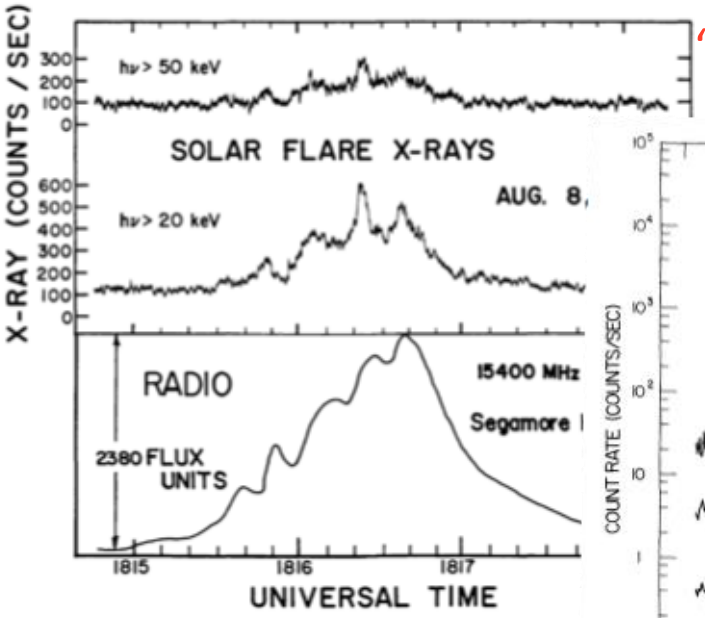
Period of ~2-4 min

- Oscillatory signatures in emission
- Characteristic periods of 1s - several mins
- Majority of investigations focus on **non-thermal emissions**
- **Why interesting?**
  1. Fundamental physical processes in flares
  2. Coronal seismology
  3. Stellar flares

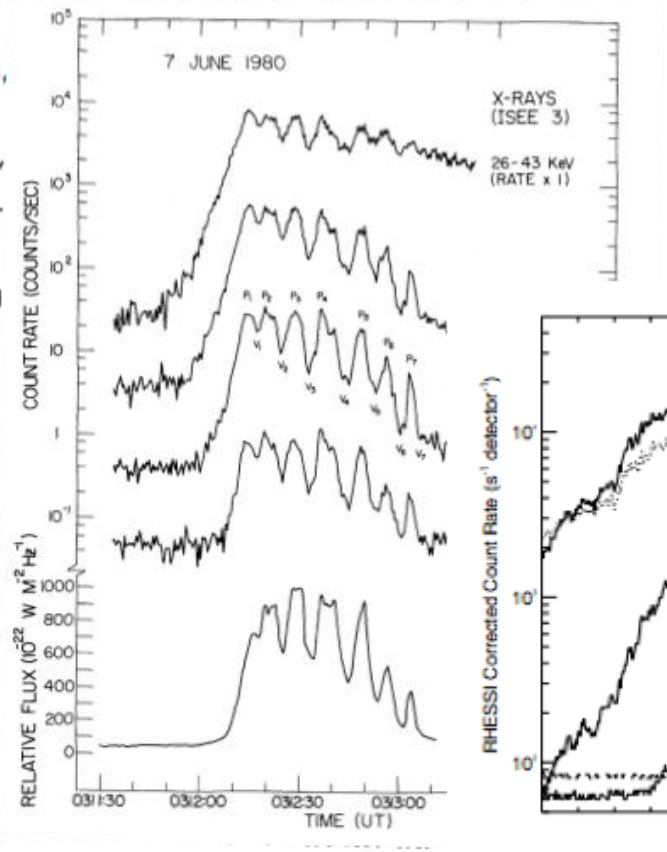
Quasi-Periodic Pulsations in Solar Flares

Previous Studies

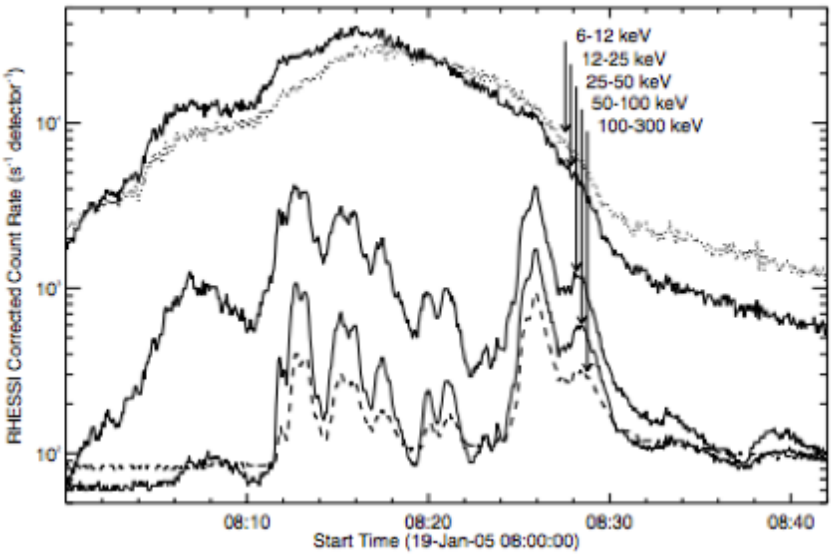
Parks and Winkler 1969



'Seven Sisters Flare'
Kane et al. 1983



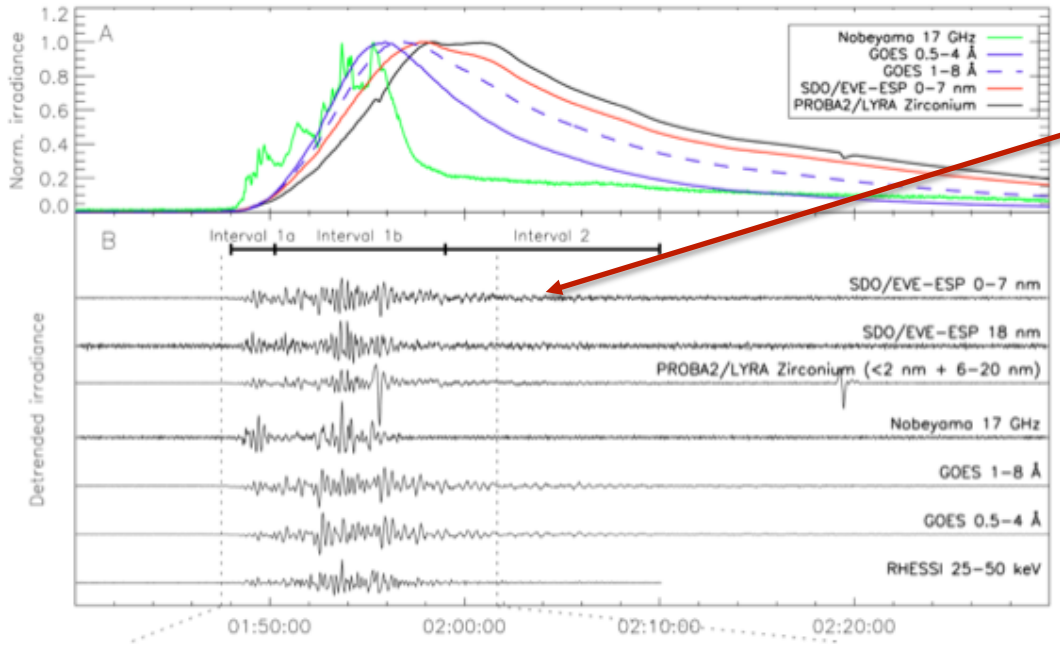
Nakariakov et al. 2006



Quasi-Periodic Pulsations in Solar Flares

Previous Studies: Soft X-ray Contributions

Dolla et al. 2012



- Gradual trend removed highlights pulsations
- Pulsations observed across soft X-ray emissions from GOES, LYRA, EVE/ESP

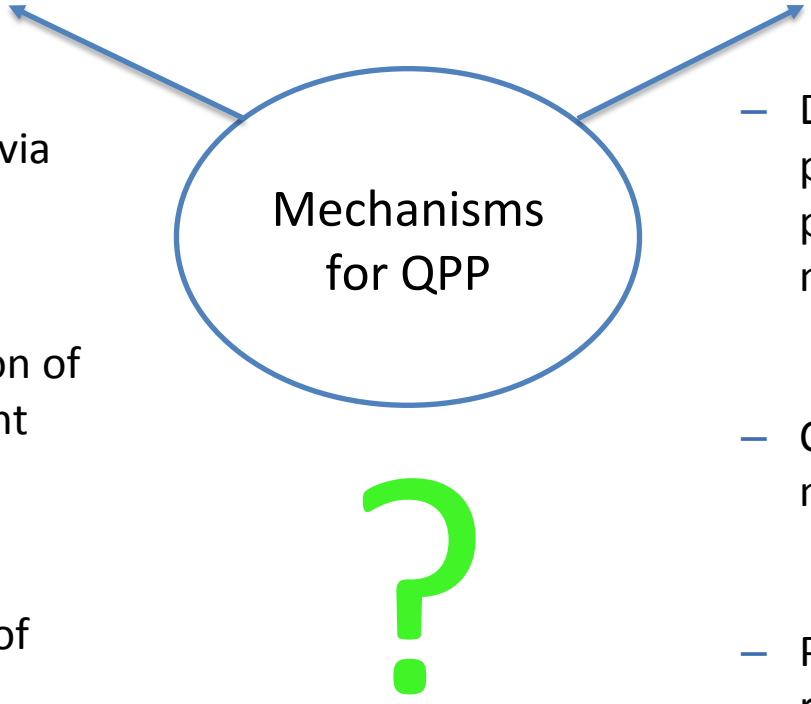
- SXR variability now seen to be a very common, if not intrinsic feature of flare emission.
- Also detected in IRIS in intensity and doppler shift of Fe lines.

Quasi-Periodic Pulsations in Solar Flares

Possible Mechanisms

‘Bursty’ Energy release mechanisms?

- Impulsive energy release via ‘Bursty’ Reconnection
- Generation and interaction of magnetic islands in current sheets
- Can explain simultaneity of pulsations in different observational bands



Magnetohydrodynamic Oscillations?

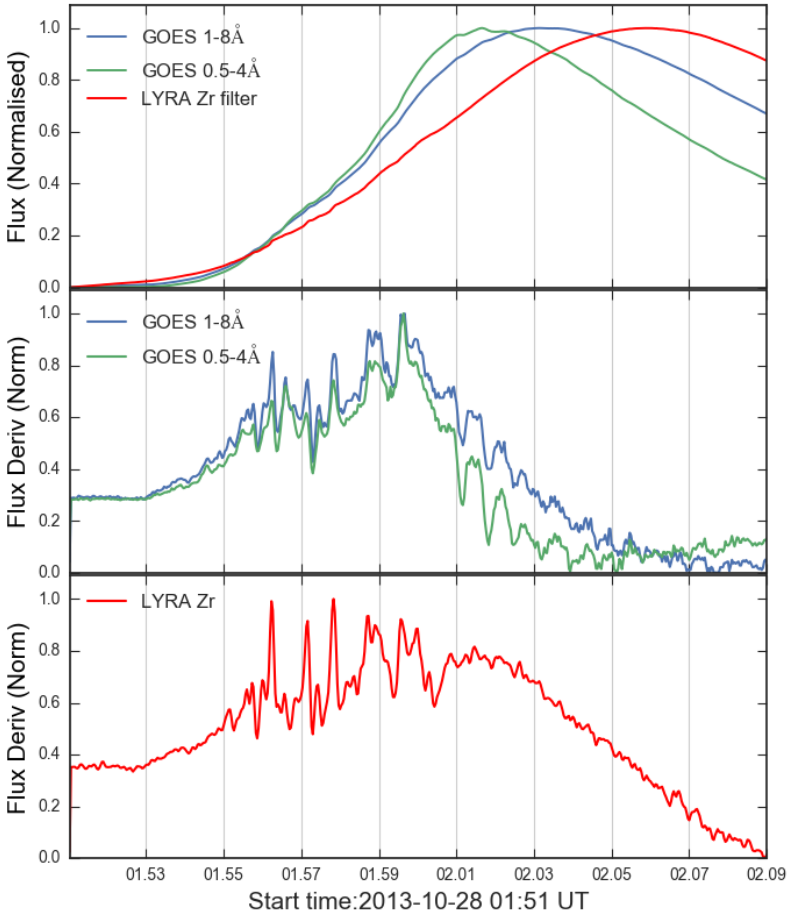
- Directly modulate physical parameters of emitting plasma (e.g. kink, sausage modes)
- Changing kinematics of of non-thermal electrons
- Periodically induce magnetic reconnection

Still no complete theory

Multi-wavelength detection of QPP

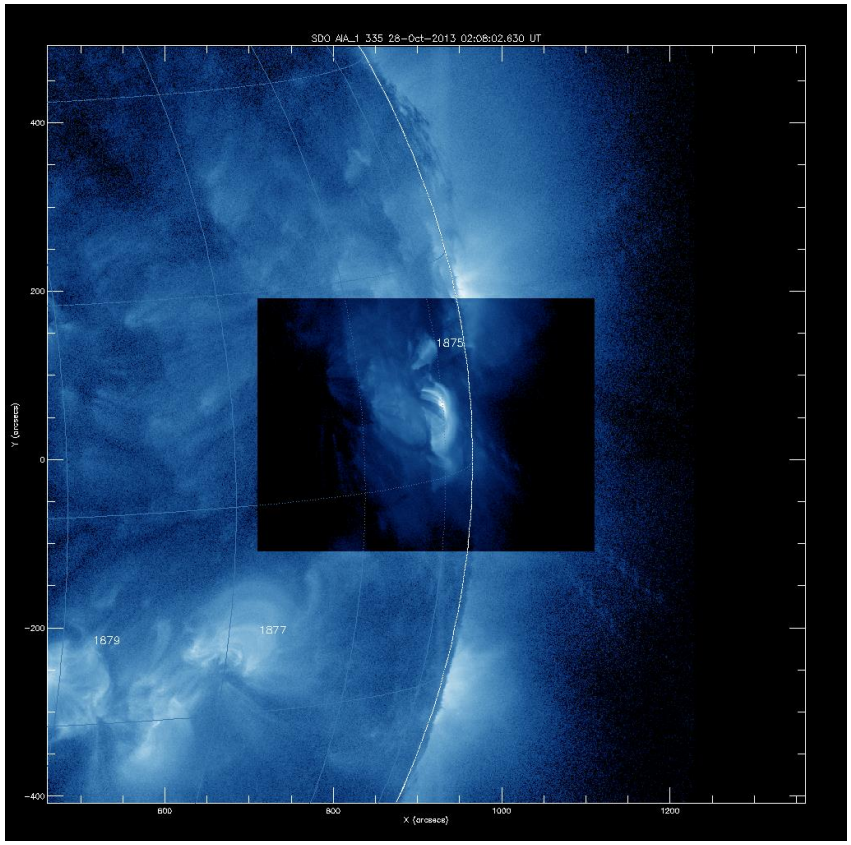
Key science goals X1.0 Flare

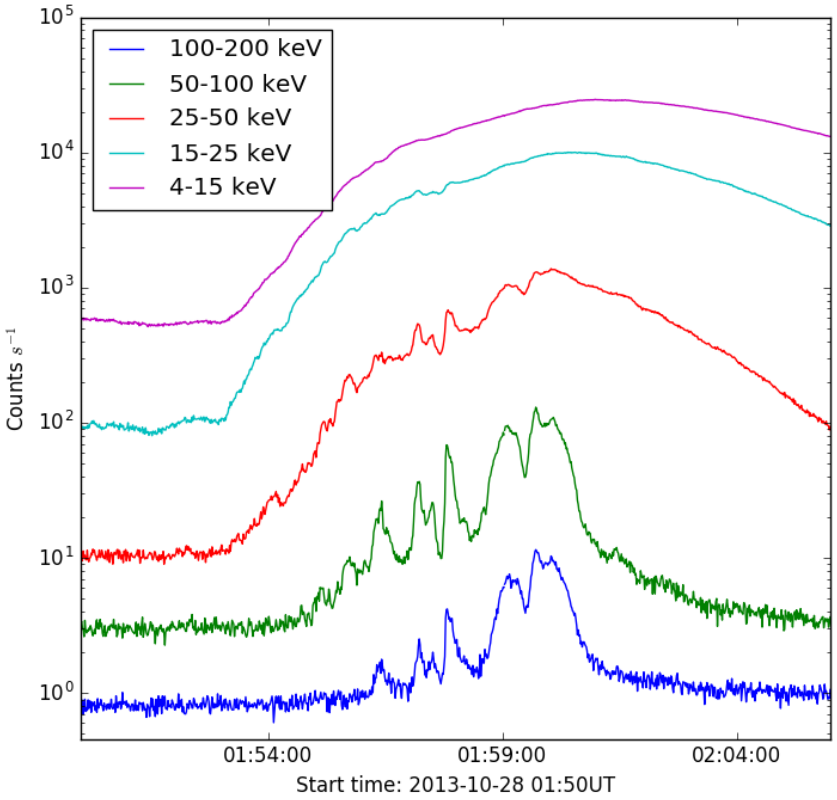
- **Perform a multi-instrument study focusing on fine structure recently identified in soft X-ray emissions.**
- Highlight pulsations using **time derivative** of soft X-ray time series
- Take advantage of **LYRA,** and **EVE/ESP** nominal cadence and use as a **GOES proxy** to highlight soft X-ray pulsations



Multi-wavelength detection of QPP

X1.0 GOES event



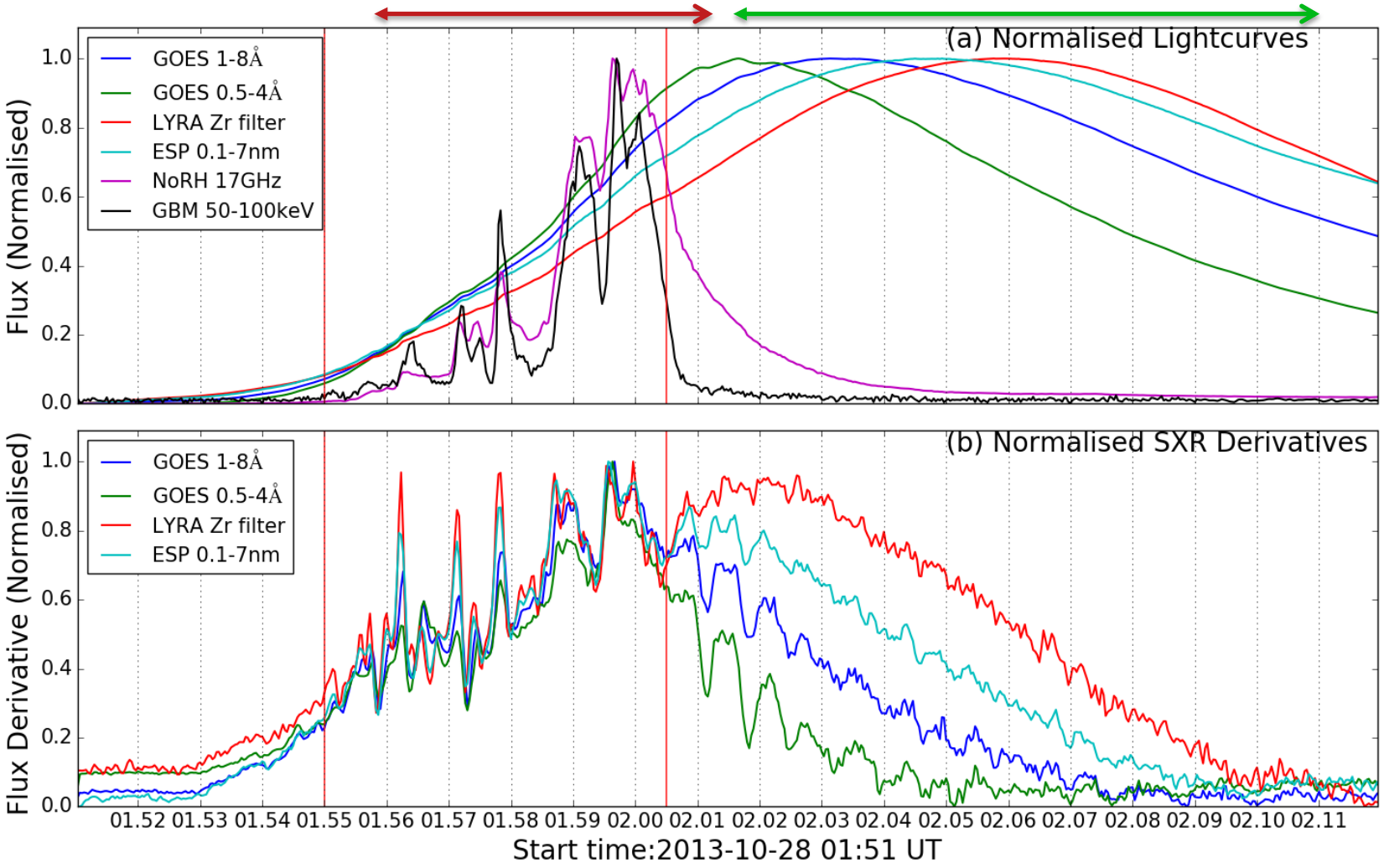


Multi-wavelength detection of QPP

X1.0 GOES event

Impulsive

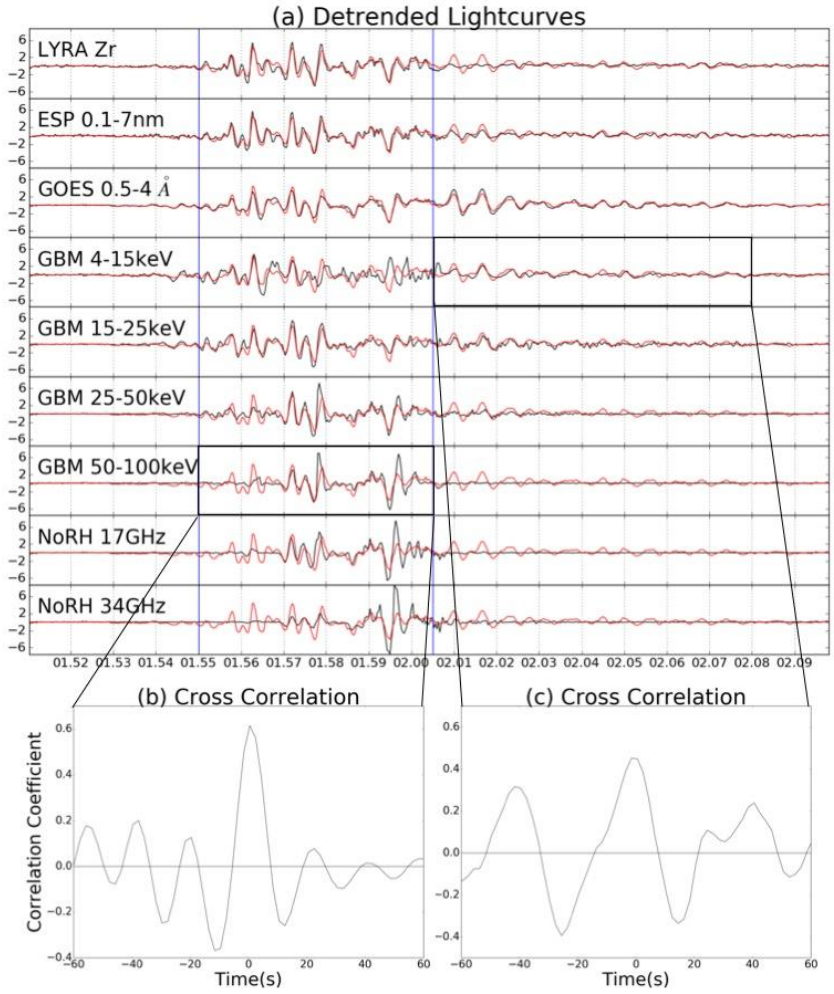
Gradual



Multi-wavelength detection of QPP

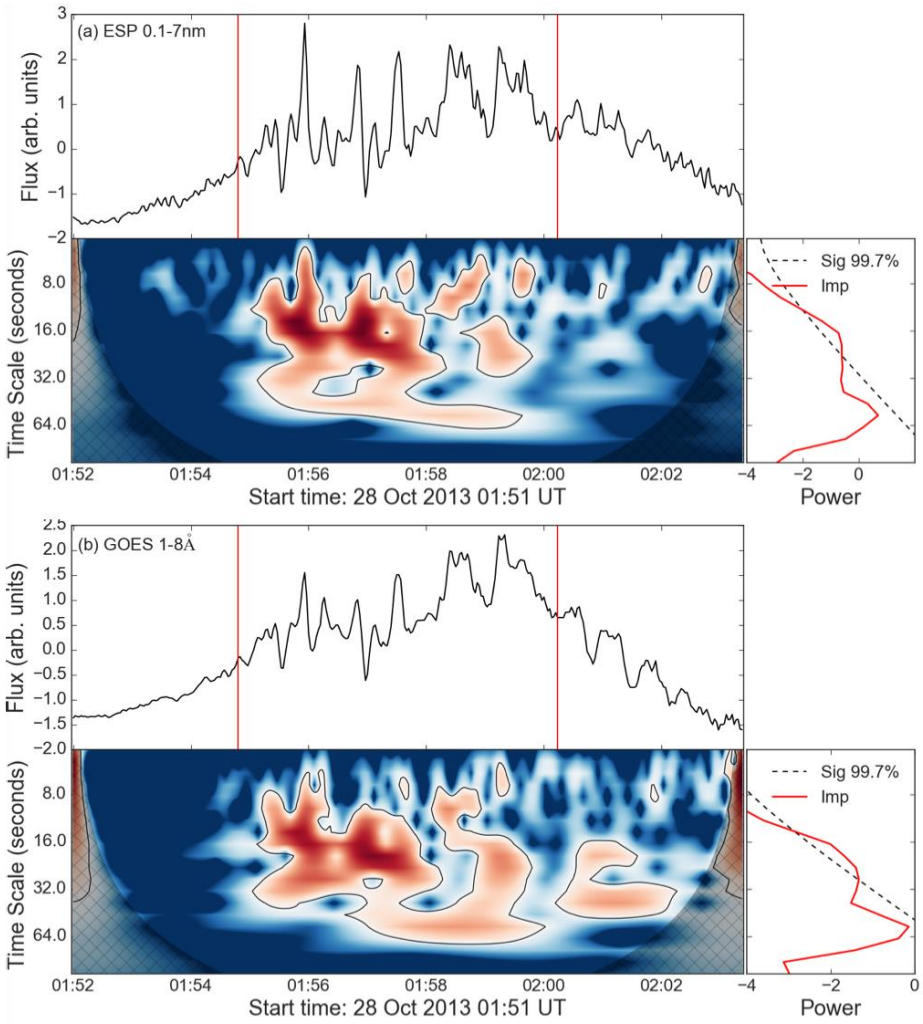
X1.0 GOES event

- Short time-scale fluctuations correlated across multiple energies
- Minimal time delay between peaks (<=2s)
- Pulsations persist in thermal channels



Multi-wavelength detection of QPP

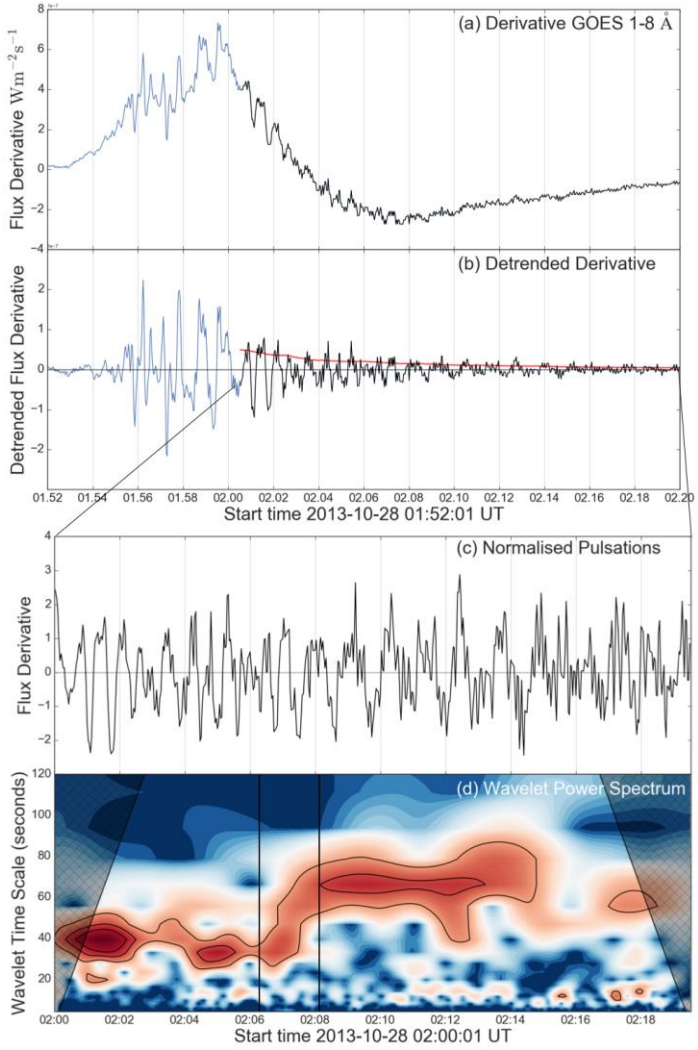
X1.0 GOES event GOES wavelet Analysis



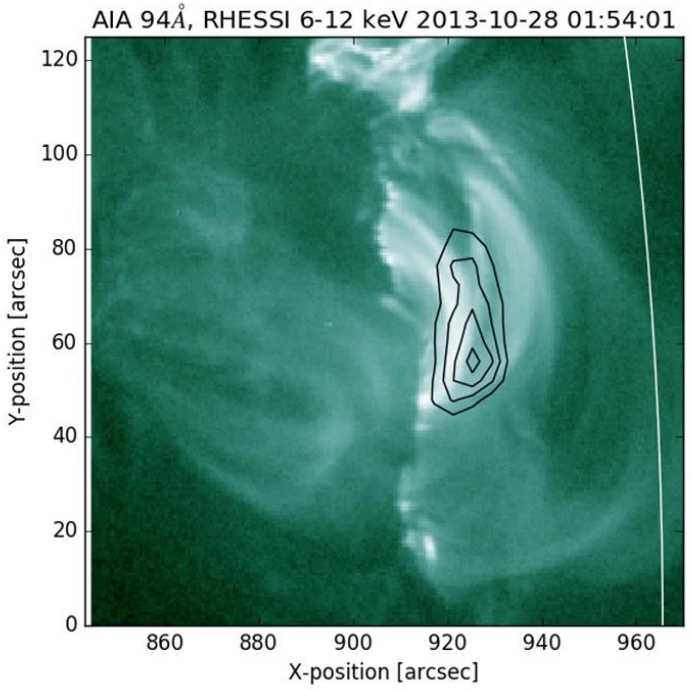
- Wavelet analysis taking into consideration power-law distribution
- Characteristic timescales ~20s across all channels
- In non-thermal emission, find second characteristic timescale of ~55s

Multi-wavelength detection of QPP

X1.0 GOES event (persistent thermal pulsations)



- Thermal pulsations persist 20 mins after non-thermal emission cease
- Increase in timescale ~39s to ~70s



Multi-wavelength detection of QPP

Conclusions of Single Study: Mechanisms?

Impulsive phase:

- **Co-existing QPP across 10 wavebands** on 5 different instruments (both thermal and non-thermal) with **characteristic timescales of ~20s** in all channels and additional 55s in non-thermal emissions
- MHD modes doesn't make sense during impulsive phase due to complex evolution of geometrical structures
- Episodic or intermittent reconnection resulting in impulsive energy release - timescale connected to characteristic timescale of dynamic reconnection processes - possibly multi-island?

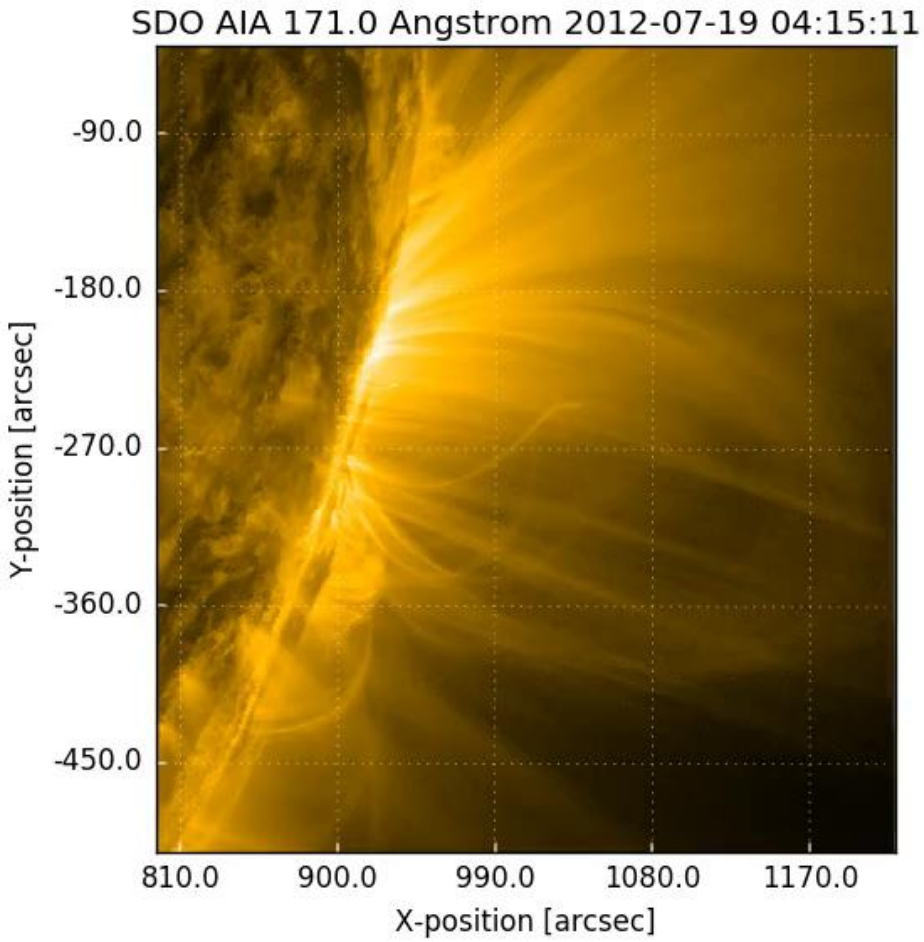
Decay phase:

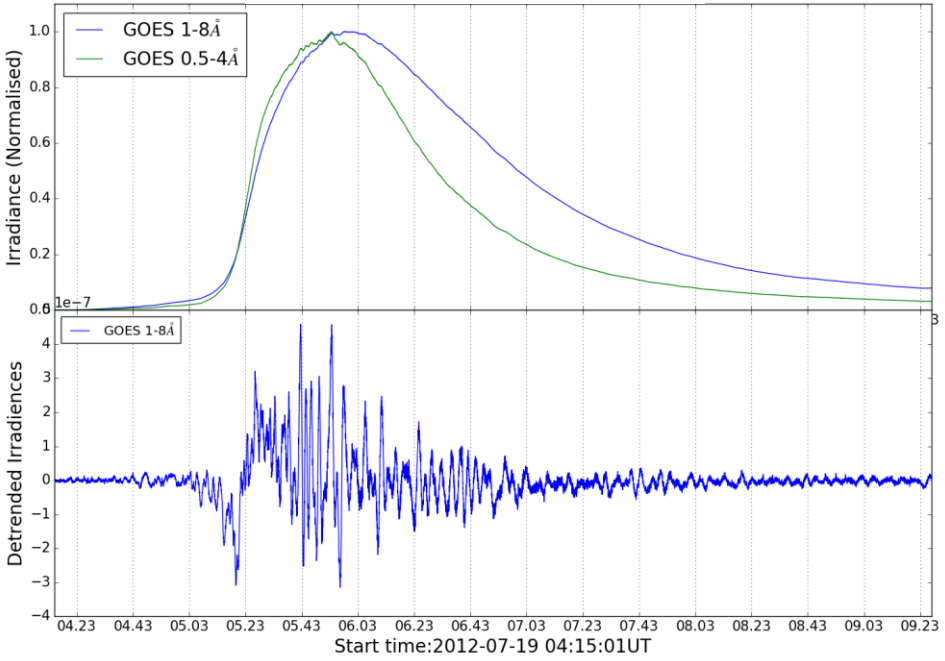
- Distinct **pulsations in the high temperature plasma persist** into decay phase with timescales increasing from ~40s to ~70s.
- Small amplitude and increasing timescale most likely connected with MHD processes within post-flare loops.
- Possibly fast sausage or vertical kink mode oscillation

Hayes et al. *Accepted,* ApJ Letters. http://arxiv.org/pdf/1607.06957.pdf

M7.7 Limb Flare

Long Duration Pulsations

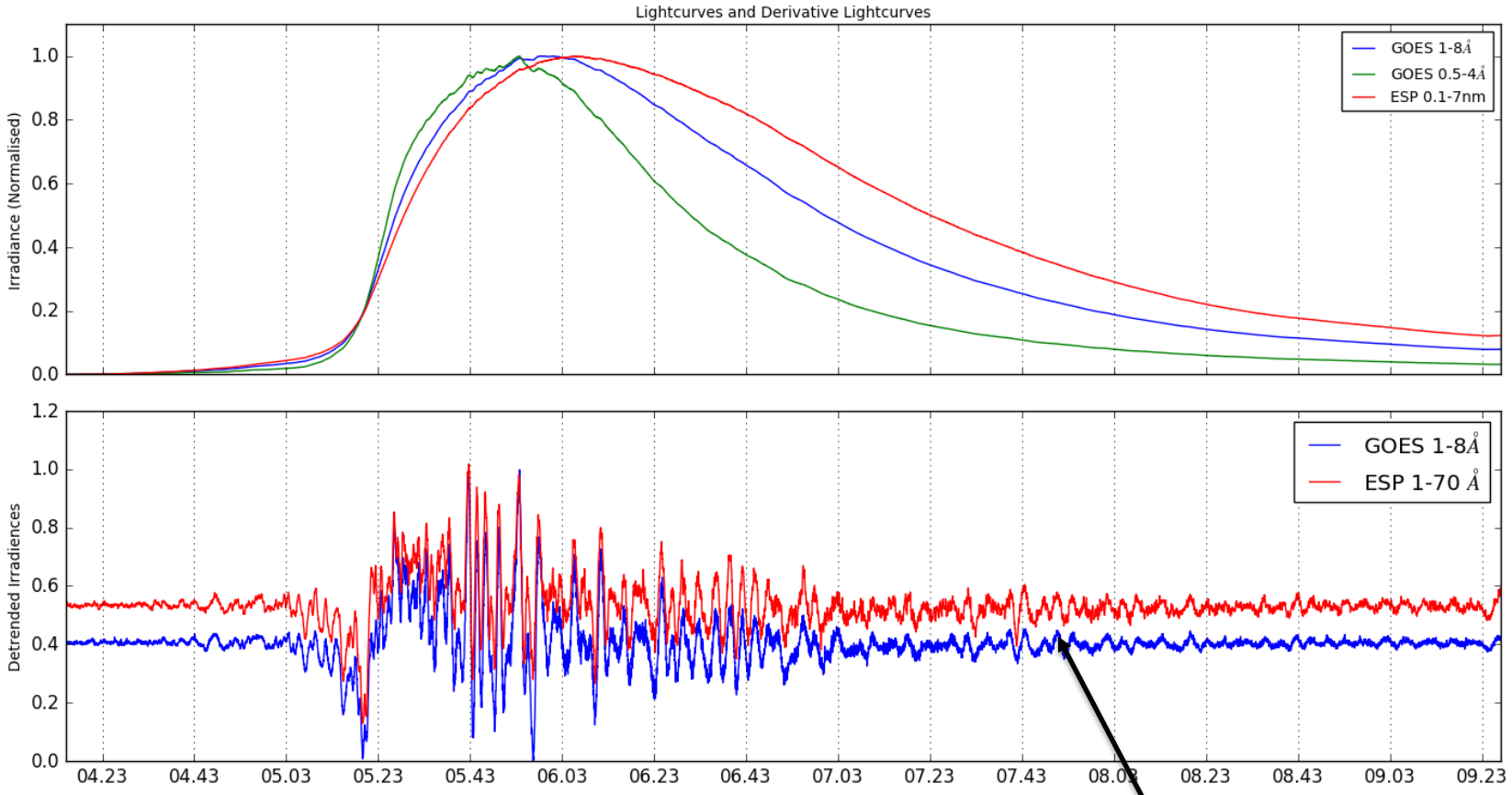




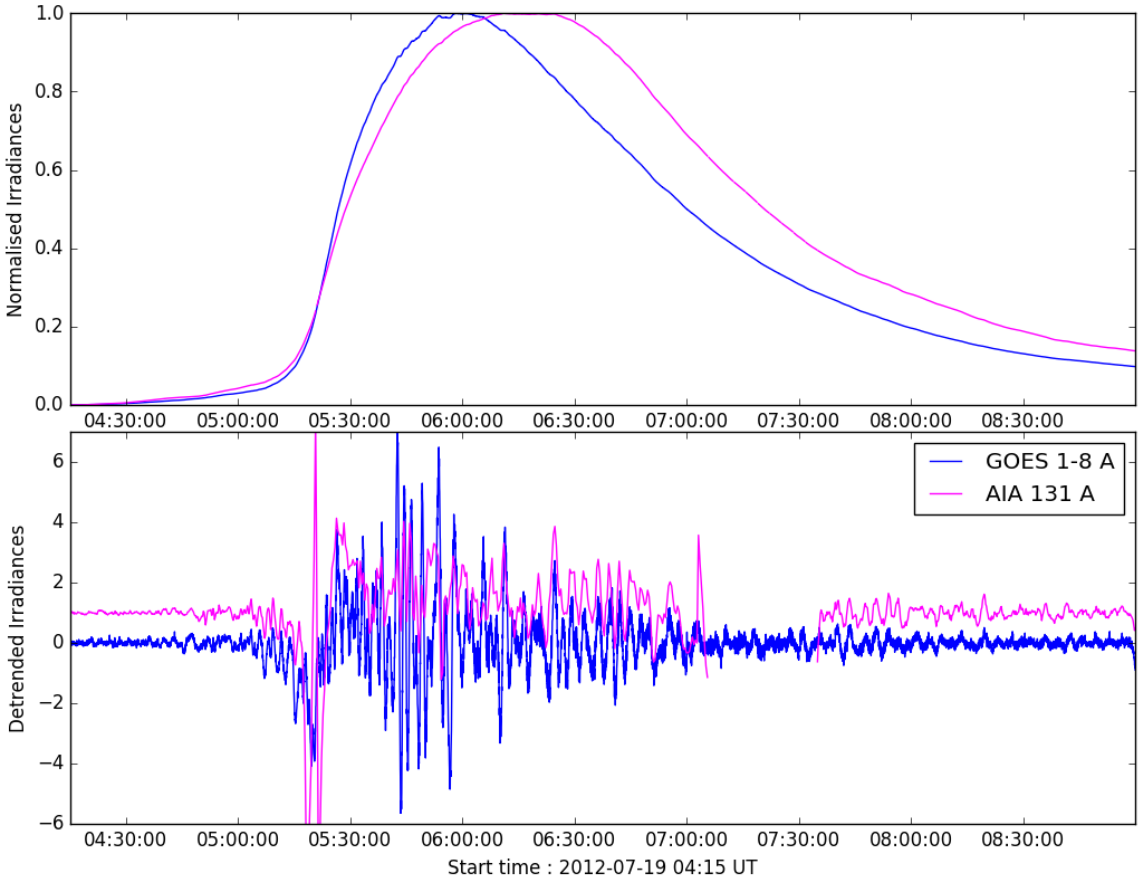
Event has been studied by many previous authors e.g. Liu, W et al. 2013 Krucker & Battaglia 2014, ect ..

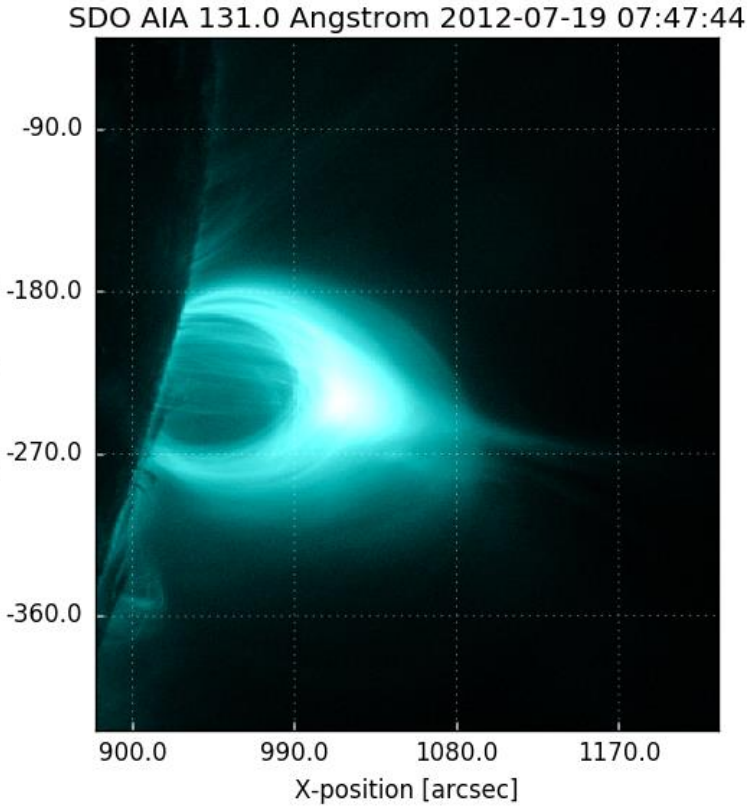
M7.7 Limb Flare

Long Duration Pulsations



M7.7 Flare Extra Slides





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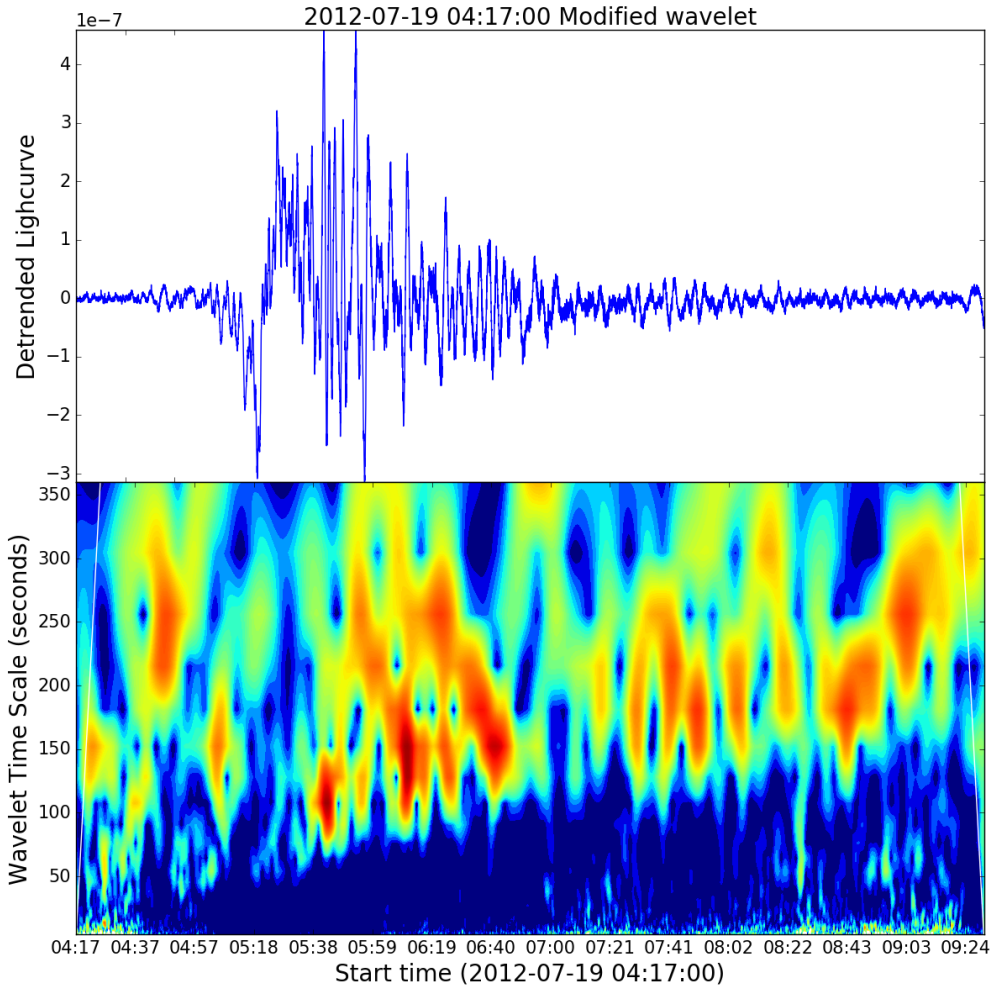
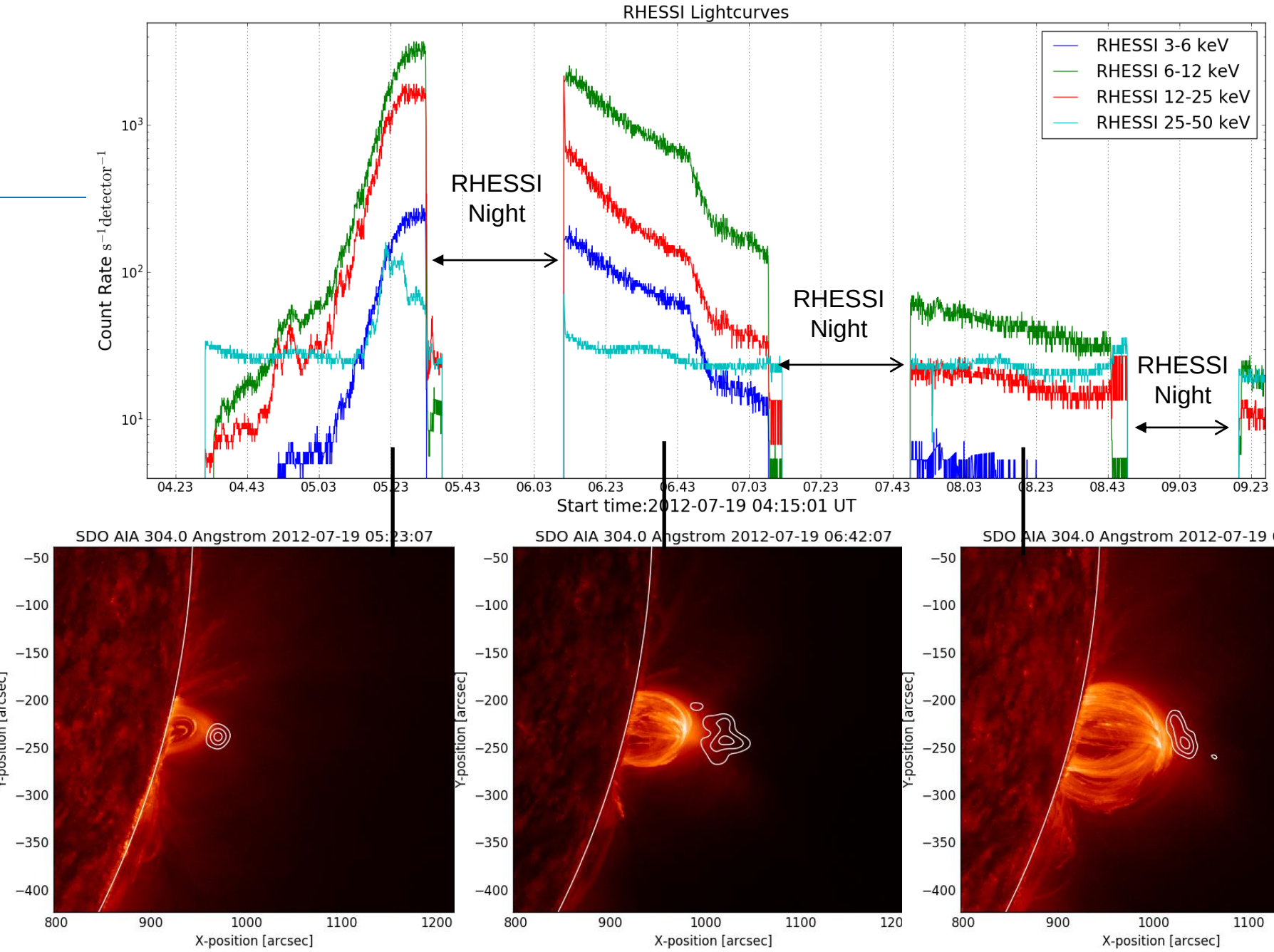
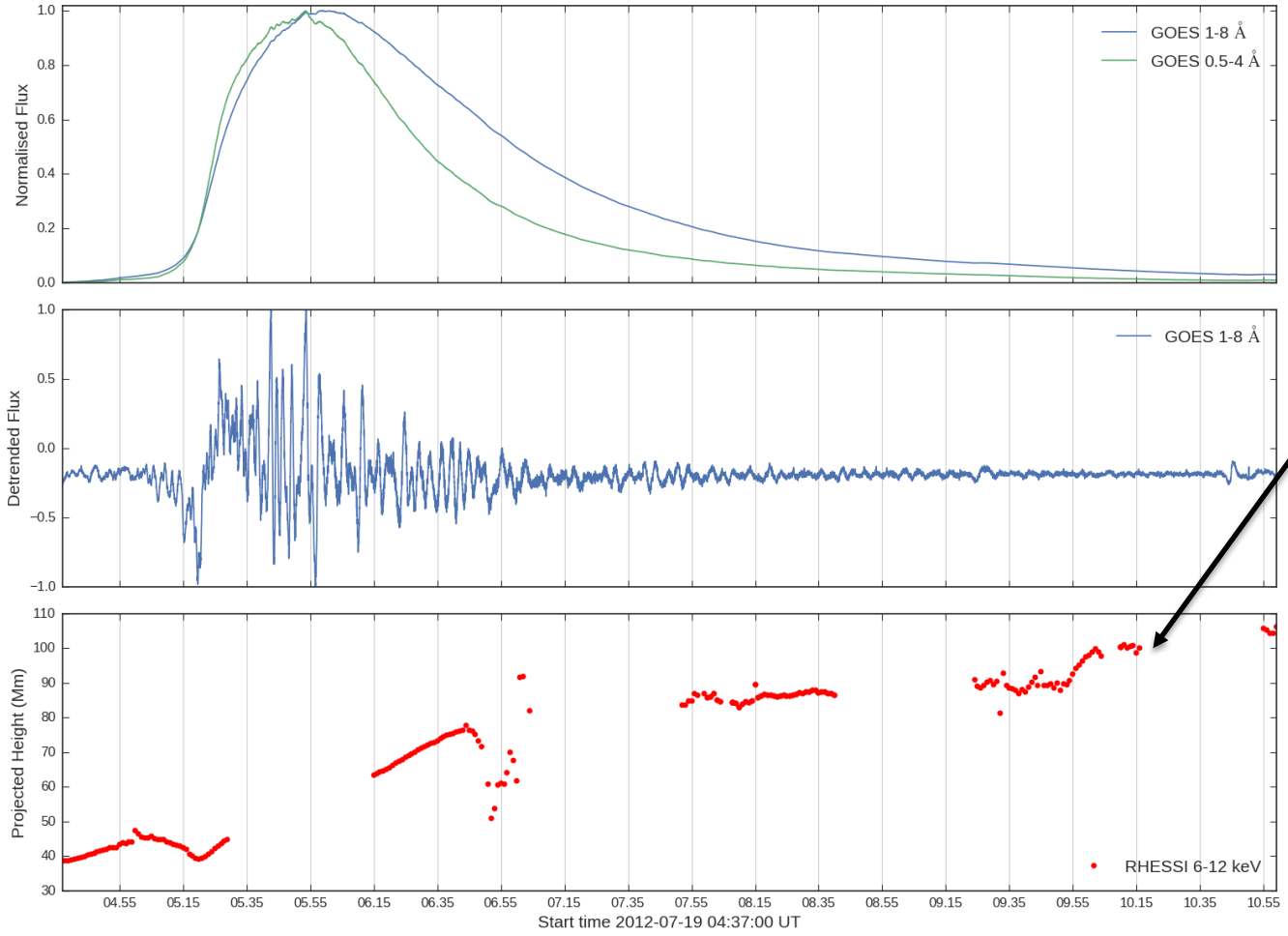


- Wavelet analysis shows increase in timescale of pulsations throughout flare
- Timescale increases up to ~ 4minutes
- Similar results found via peak to peak analysis by eye.
- Related to source height of energy release or length of loops?


RHESSI Lightcurves
RHESSI 3-6 keV
RHESSI 6-12 keV
RHESSI 12-25 keV
RHESSI 25-50 keV
Count Rate s^{-1}detector^{-1}
RHESSI Night
RHESSI Night
RHESSI Night
Start time:2012-07-19 04:15:01 UT
SDO AIA 304.0 Angstrom 2012-07-19 05:23:07
SDO AIA 304.0 Angstrom 2012-07-19 06:42:07
SDO AIA 304.0 Angstrom 2012-07-19 08:22:07
Y-position [arcsec]
X-position [arcsec]

M7.7 Limb Flare

Long Duration Pulsations SXR source height



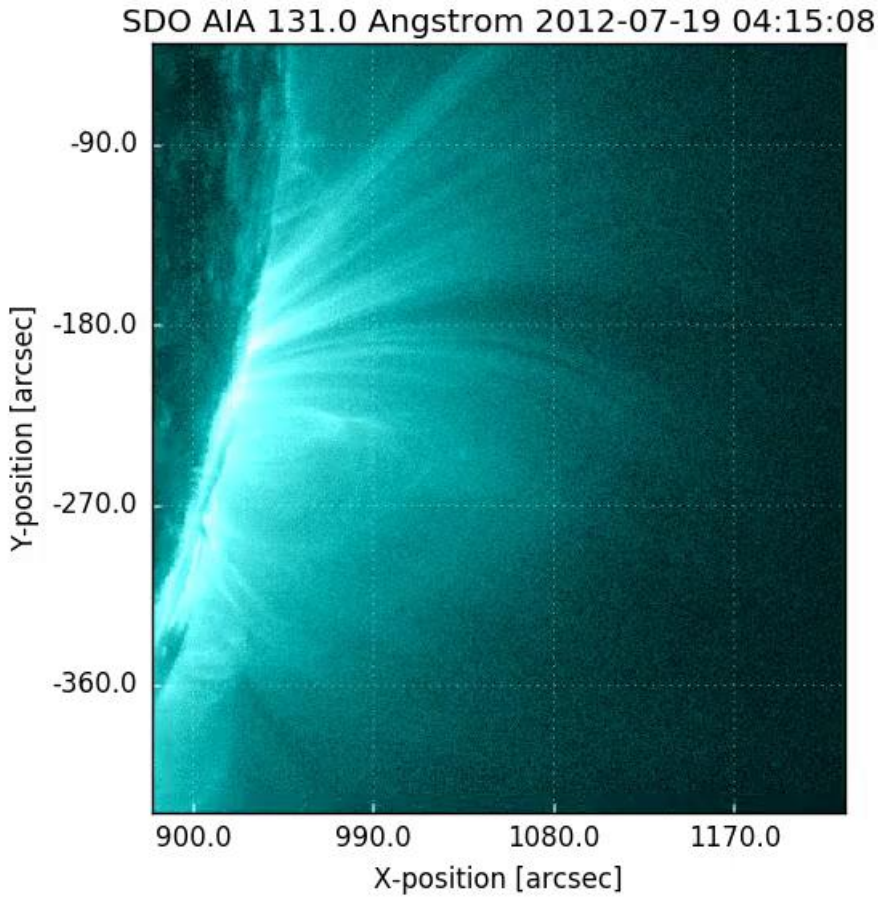
6-12 keV RHESSI centroid from limb

Systematic increase in timescale = increase in source height (loop length)?

M7.7 Limb Flare

Long Duration Pulsations SXR source height

- What causes prolonged pulsations in soft X-ray? Signature of continued heating and reconnection at higher altitudes?
- Source height increase - longer loop lengths, possibly kink modes triggered in loops of longer length?
- Liu, W et al. 2013 find plasmoid ejections and downward contractions of reconnected loops late into this event - possibly resulting in these observed pulsations



Conclusions and Future Work

QPP

Conclusions

- Soft X-ray pulsations are a common, if not intrinsic feature of solar flares
- Different characteristics in impulsive and decay phase, probably related to different mechanisms
- Can last late into decay phase of some solar flares

Proposed future work

- **L**arge scale multi-wavelength analysis of QPP with particular attention of soft X-ray thermal emissions with GOES/XRS & LYRA Zr throughout impulsive and decay phases of flares
- Relate characteristic time scales to some physical parameters:
    - Higher altitude of energy release site or related to length of loops?
    - Length scales of reconnection?
    - Distinguish between impulsive and gradual processes

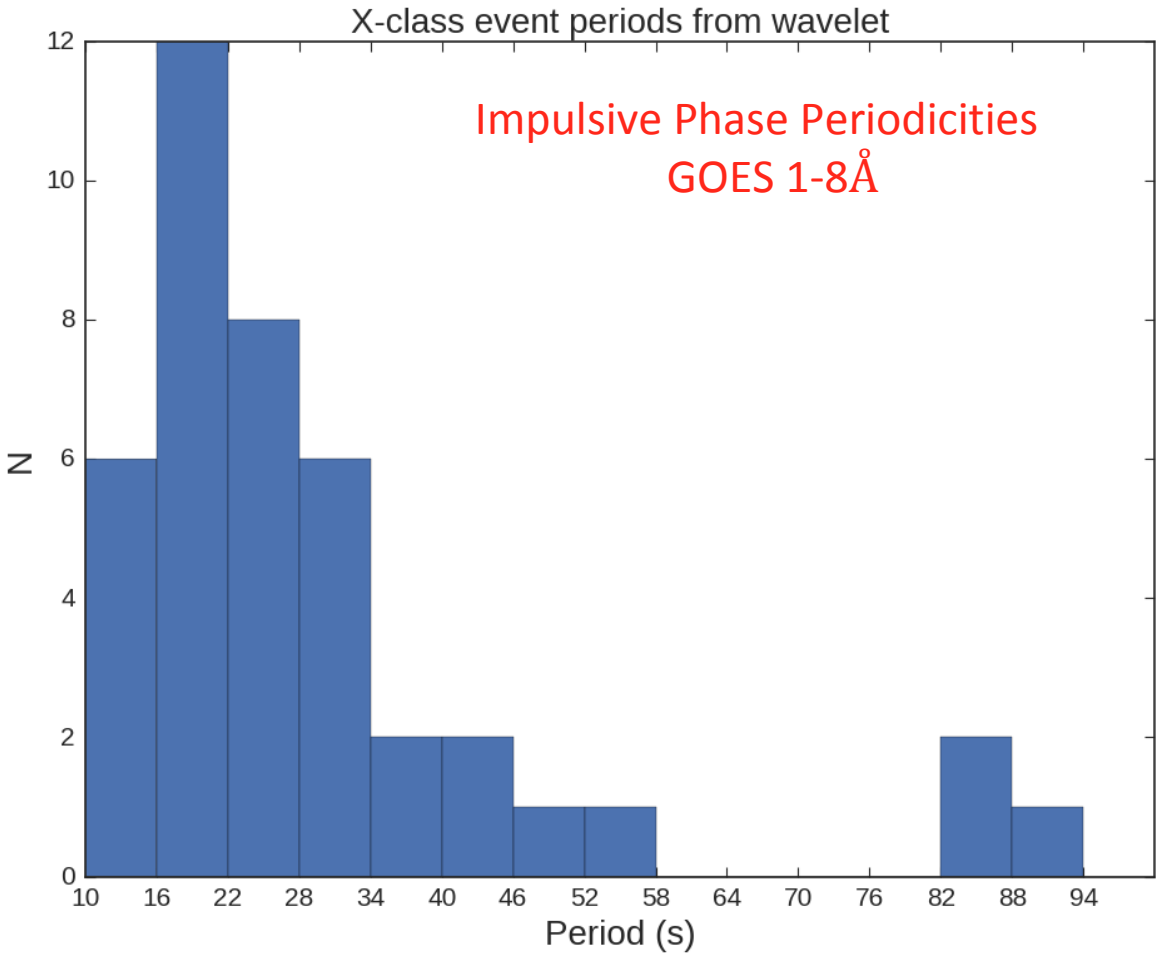
FOXSI

- Improved imaging and spectroscopic observations with the proposed FOXSI mission will be key in our understanding of the QPP phenomena.
- We can take advantage of its sub second cadence and energy resolution to determine locations of pulsating structures and their evolution throughout flare.

Future Work

QPP Statistical Analysis

- Preliminarily statistical analysis of periods observed with GOES
- Characteristic periods ~15-30s
- Similar to Inglis et al.2016
- What about **gradual phase**?
- Thermal distribution of pulsating plasma possibly with LYRA?

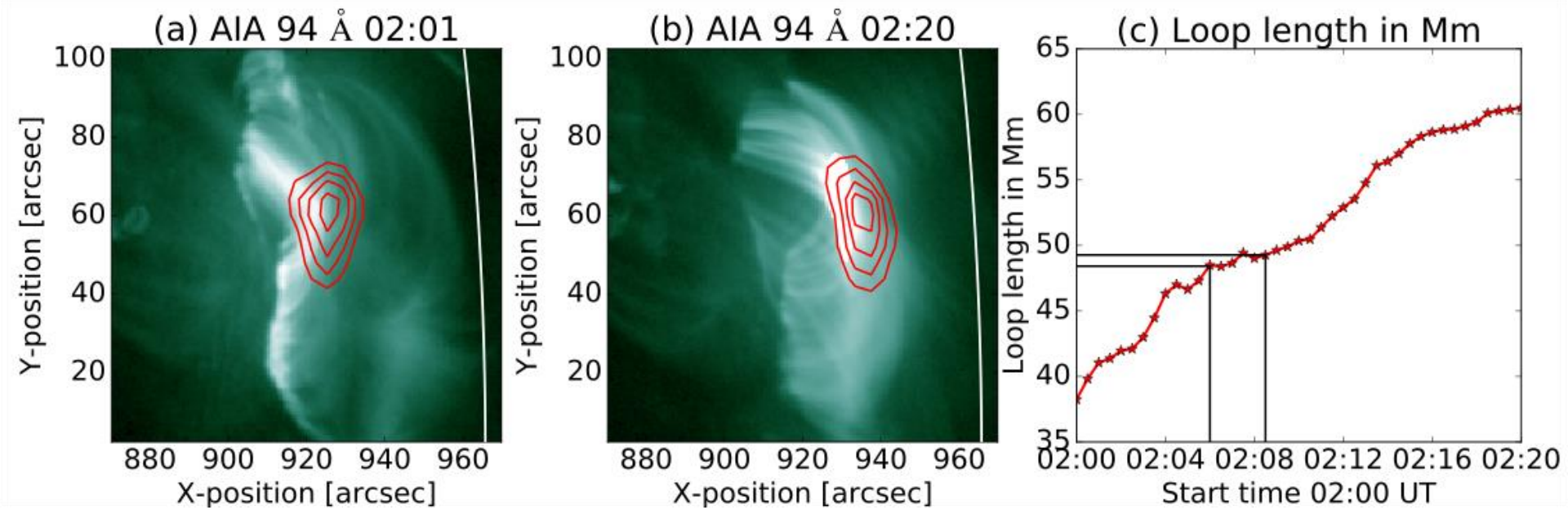


X1.0 Flare

Extra Slides

X1.0 Flare

QPP



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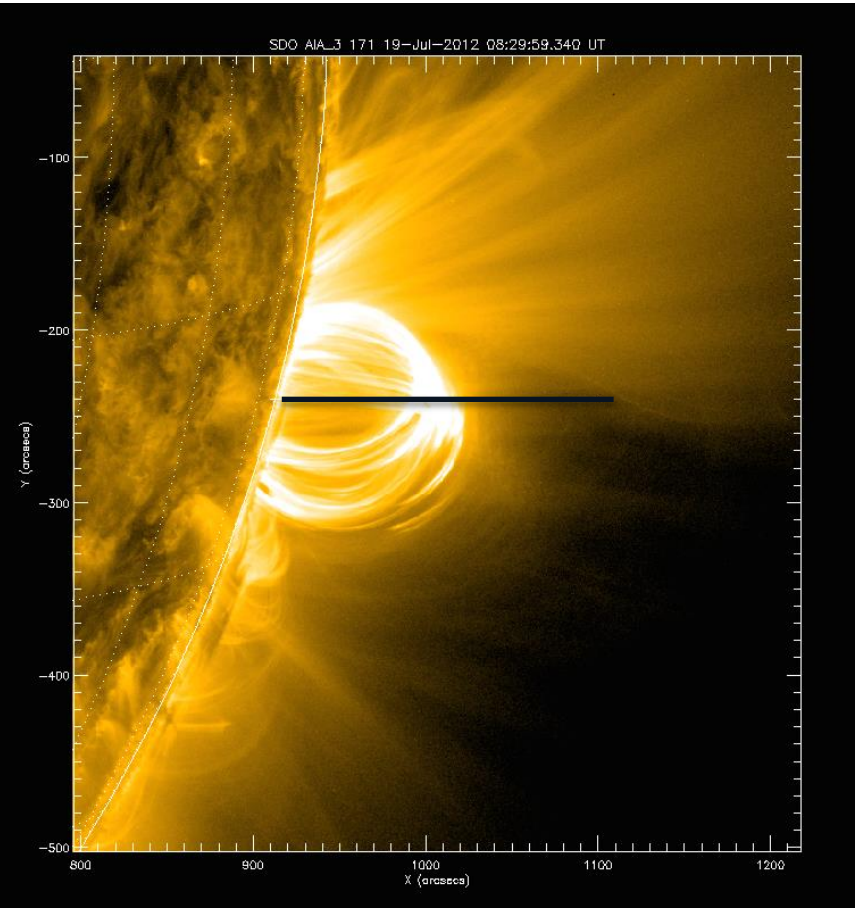
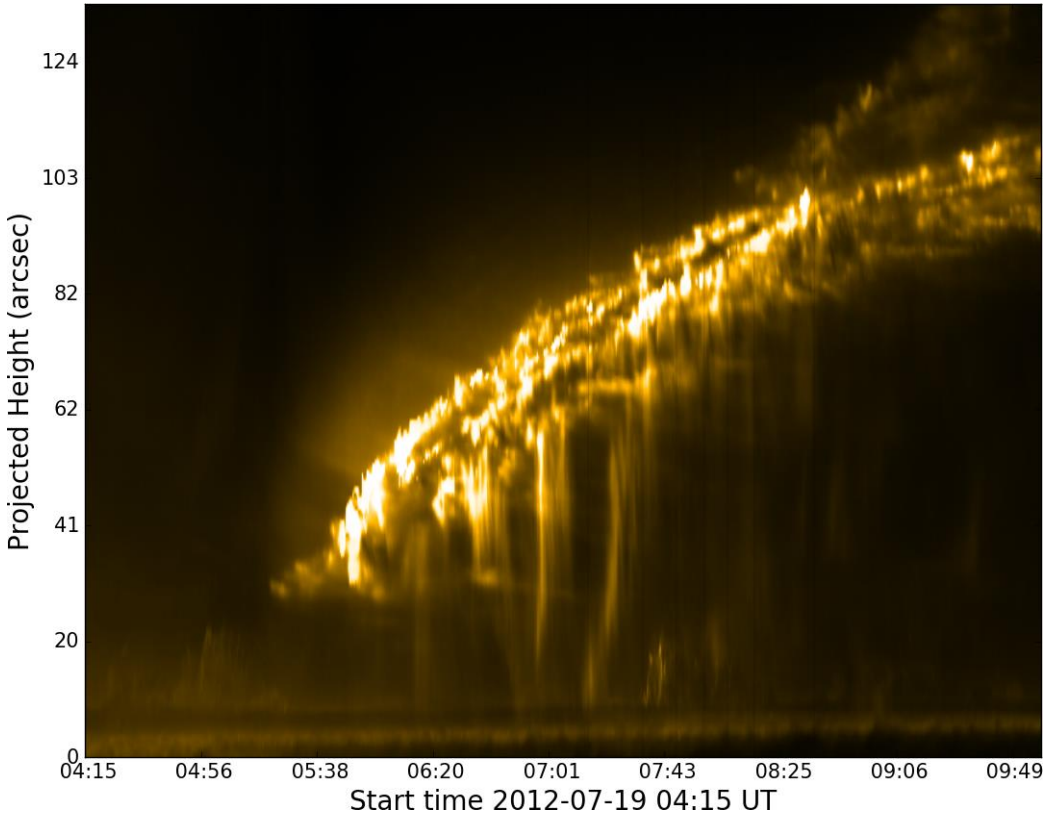
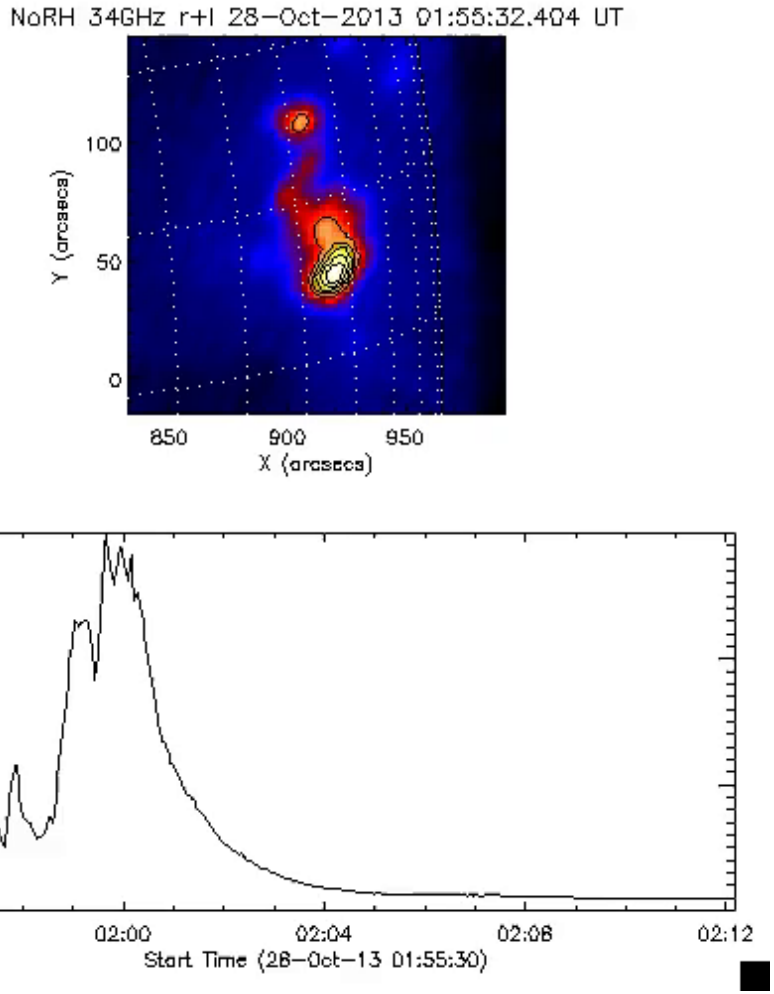




October X1.0 Flare Extra Slides

NoRH Movie



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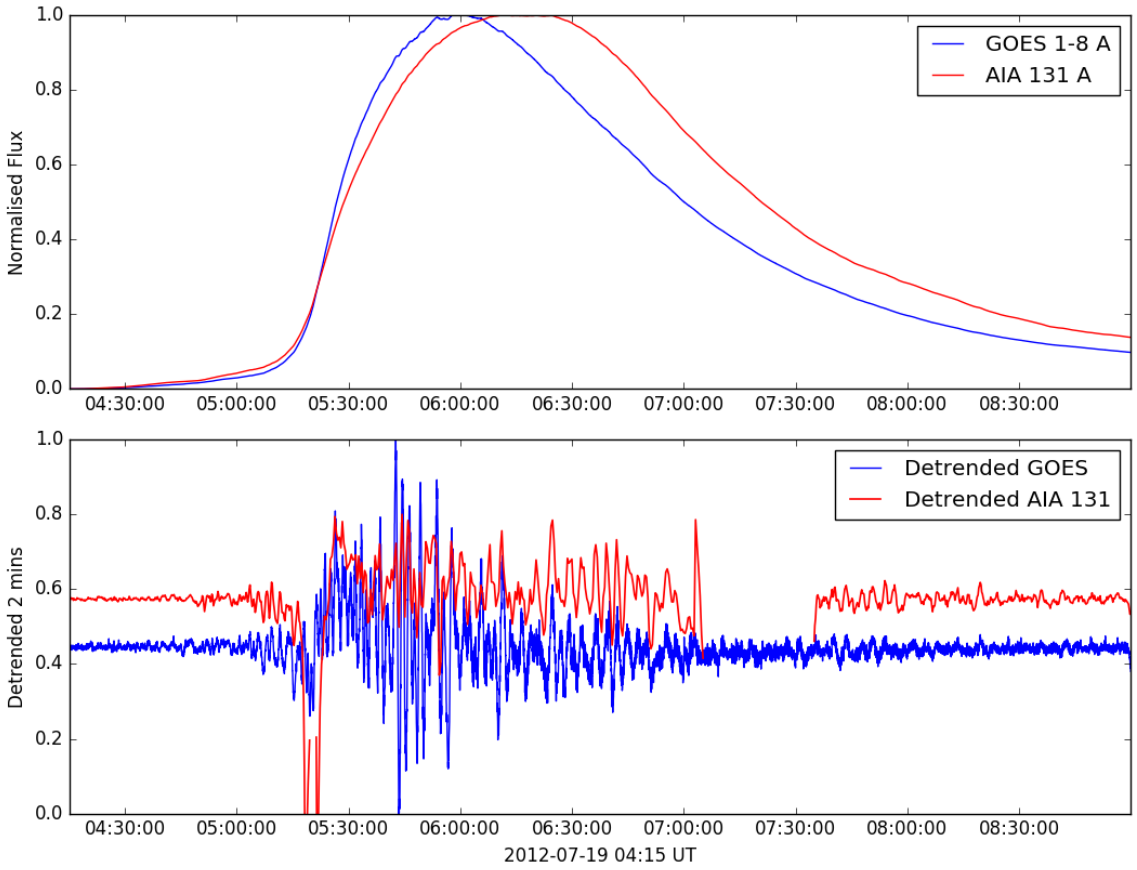
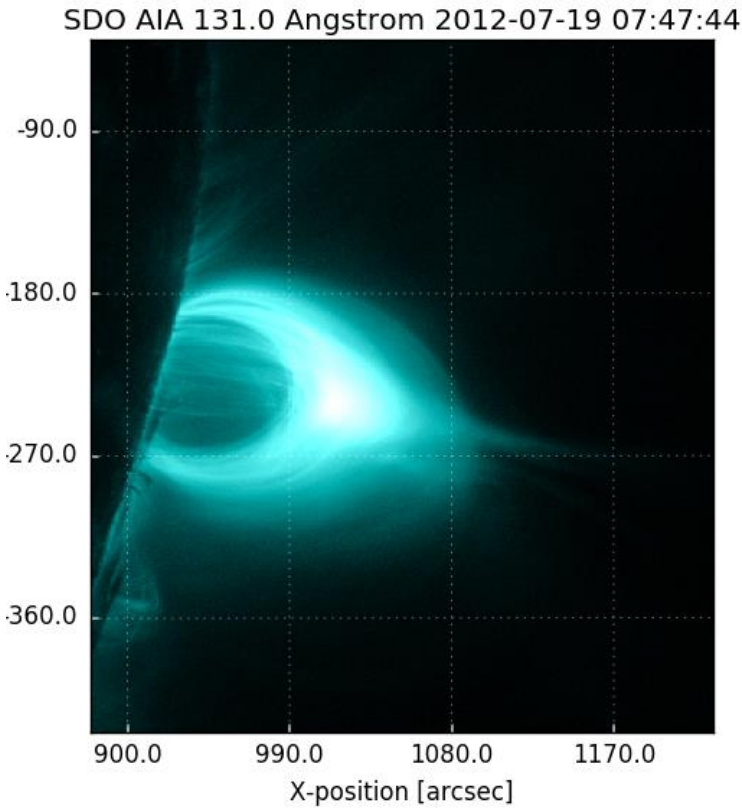
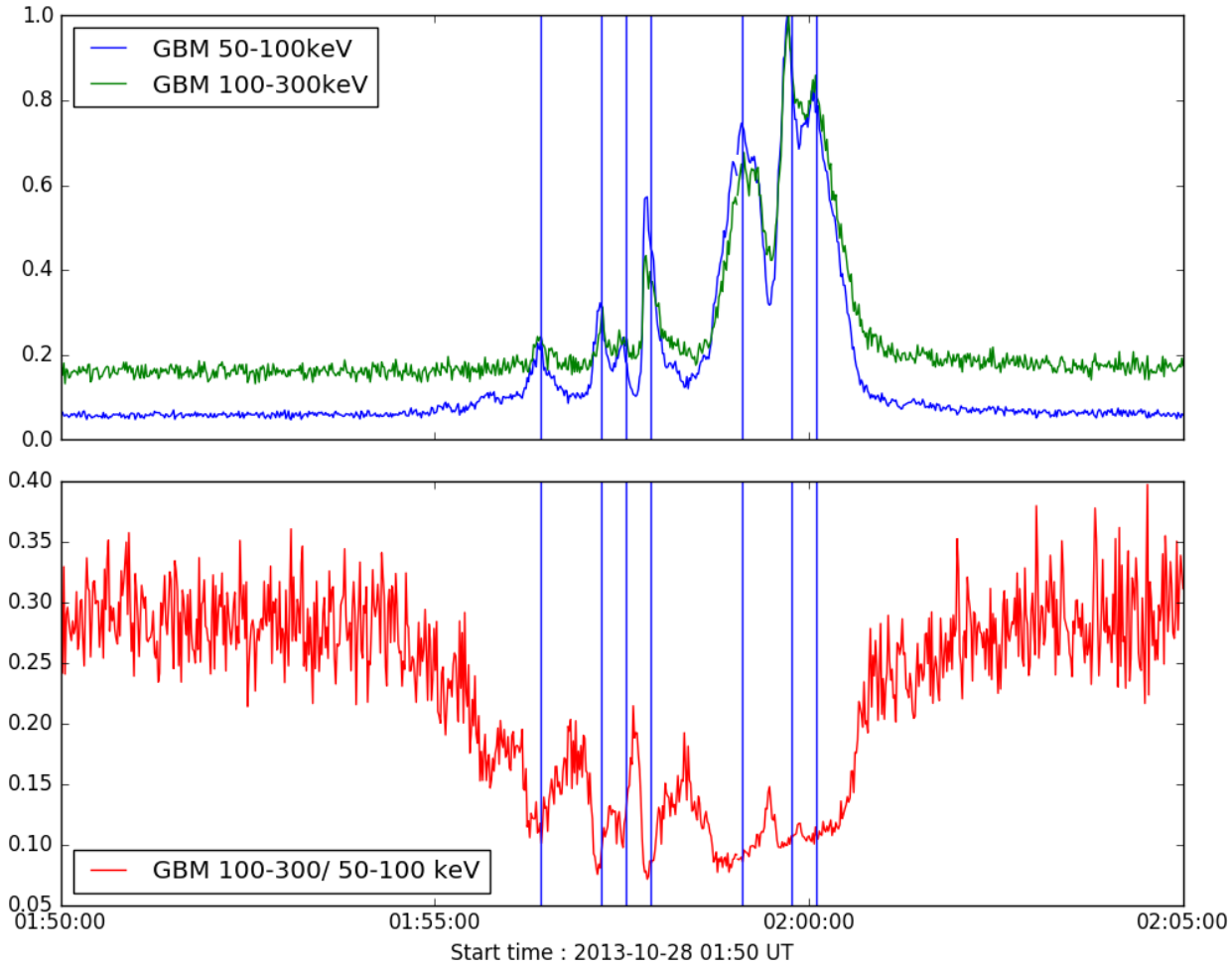




X1.0 Flare

QPP



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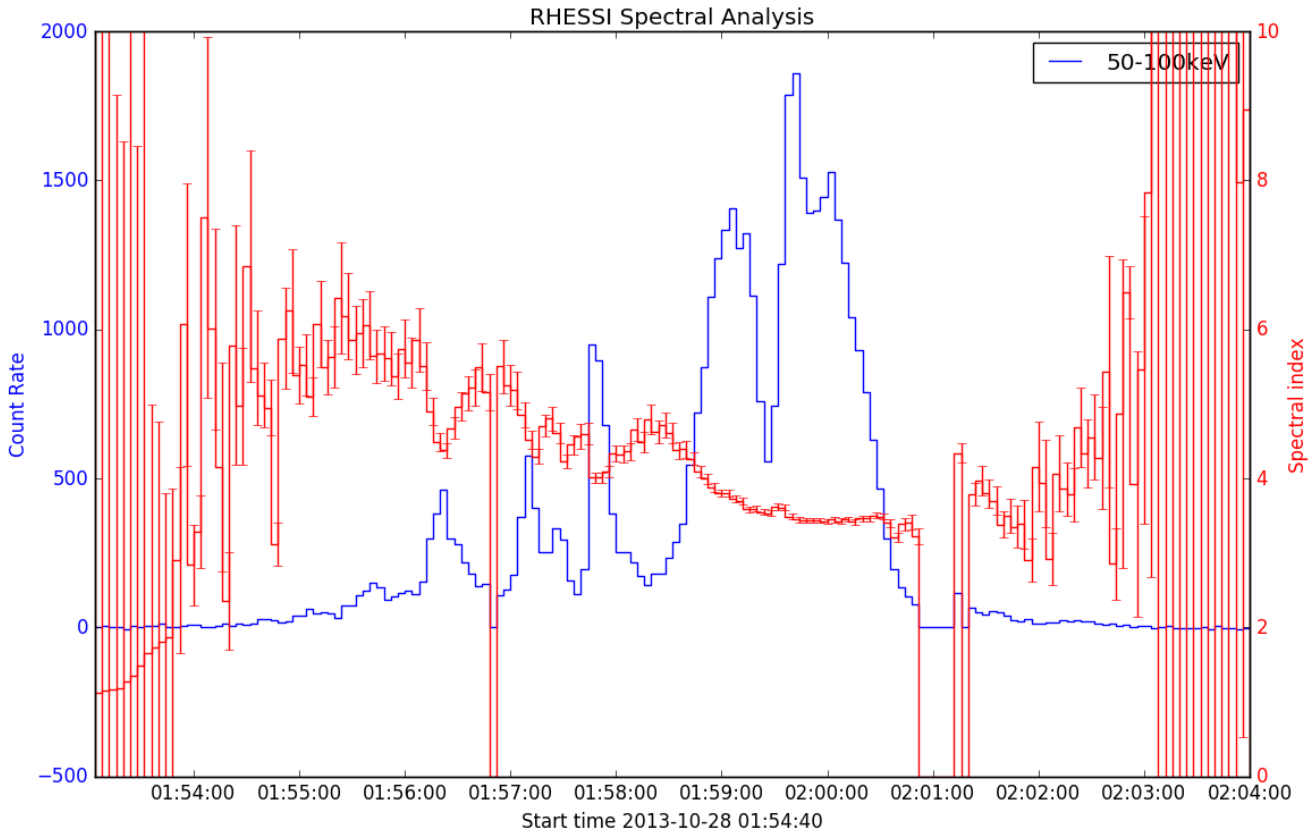

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