

# Time delays in quasi-periodic pulsations observed during the X2.2 solar flare on 2011 February 15

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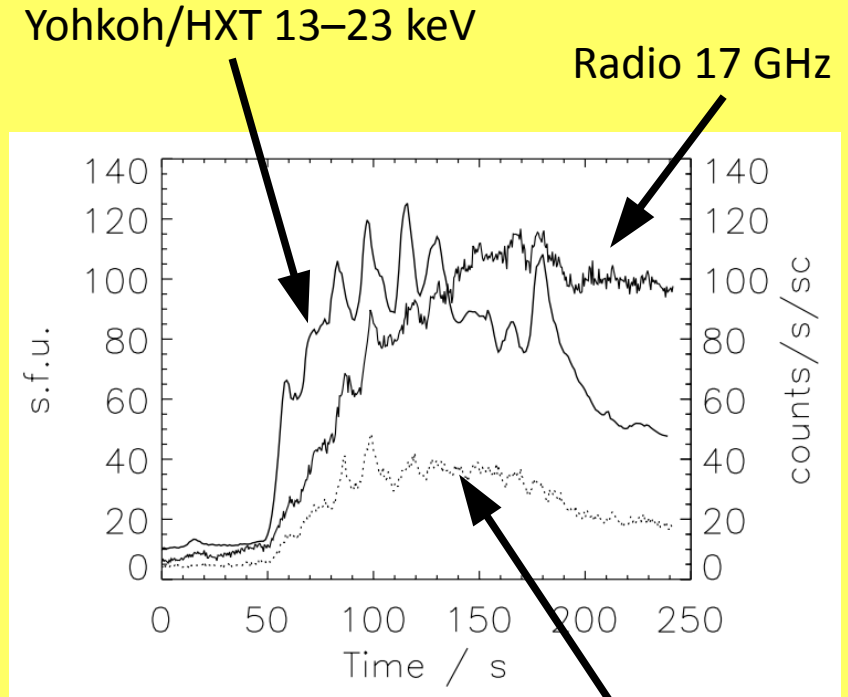
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# “QPP” (or “QPO”)

- Quasi-periodic pulsations (or oscillations) are a common feature during flares
- Review by Nakariakov and Melnikov 2009
- Observed in many different wavebands (from radio to gamma rays)
- What is the generation process?
  - “load/unload” mechanism for non-thermal electrons (reconnection) ?
  - Modulation by MHD waves?

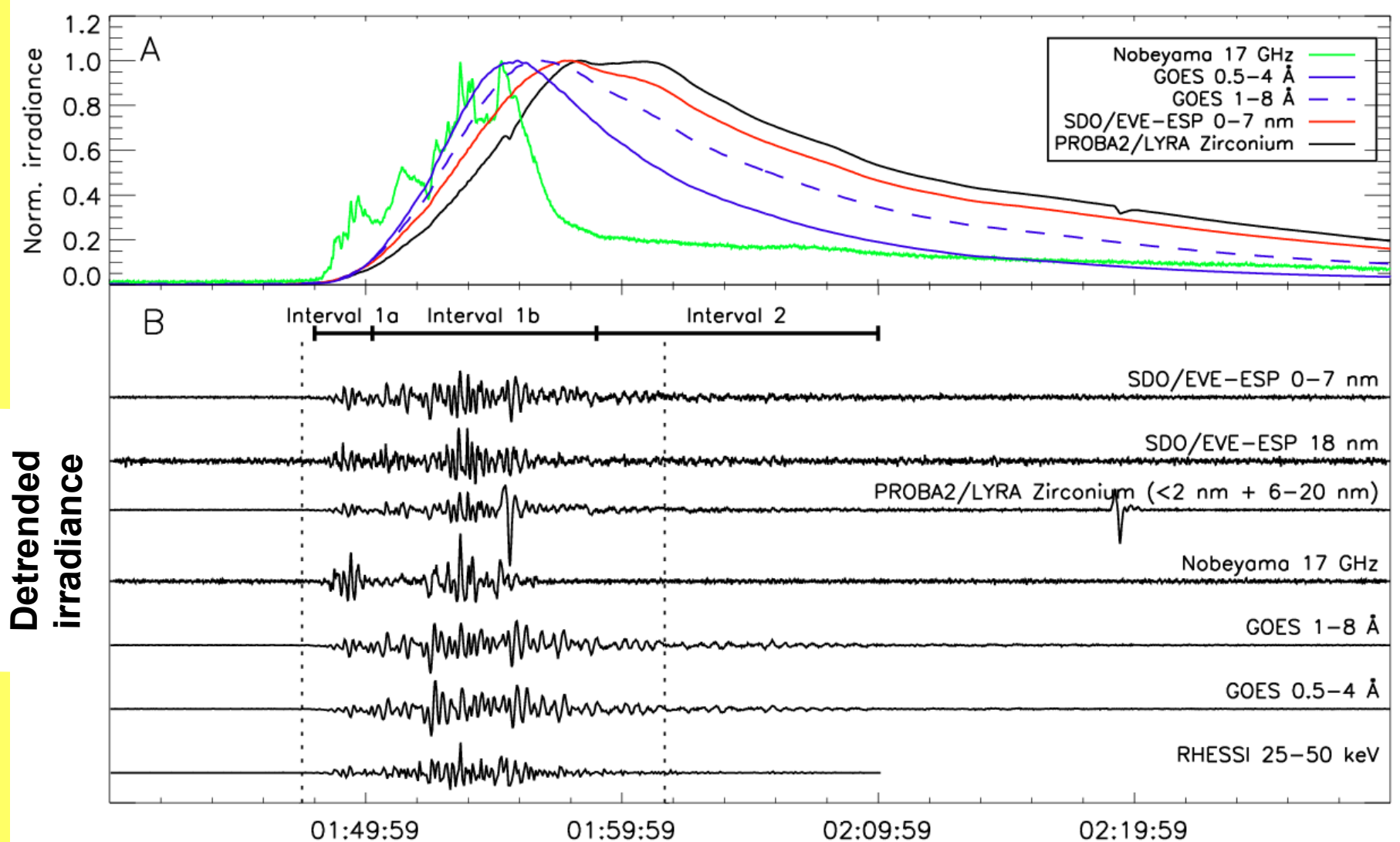


Yohkoh/HXT 23–33 keV

(Nakariakov and Melnikov 2009)

# X2.2 flare on February 15<sup>th</sup> 2011

## Short time-scale fluctuations in several wavebands

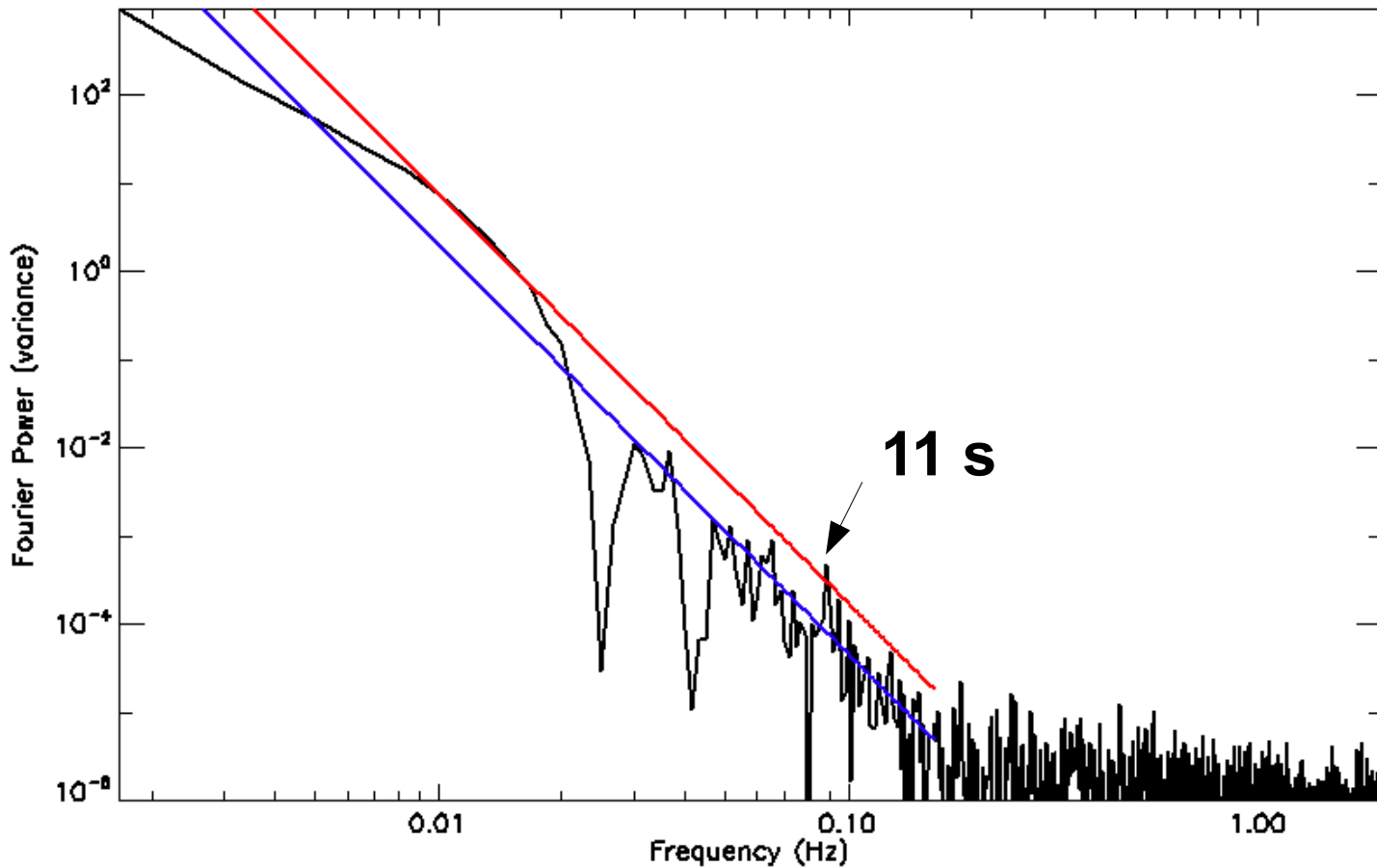


Cadences : from 50 ms to 4 s

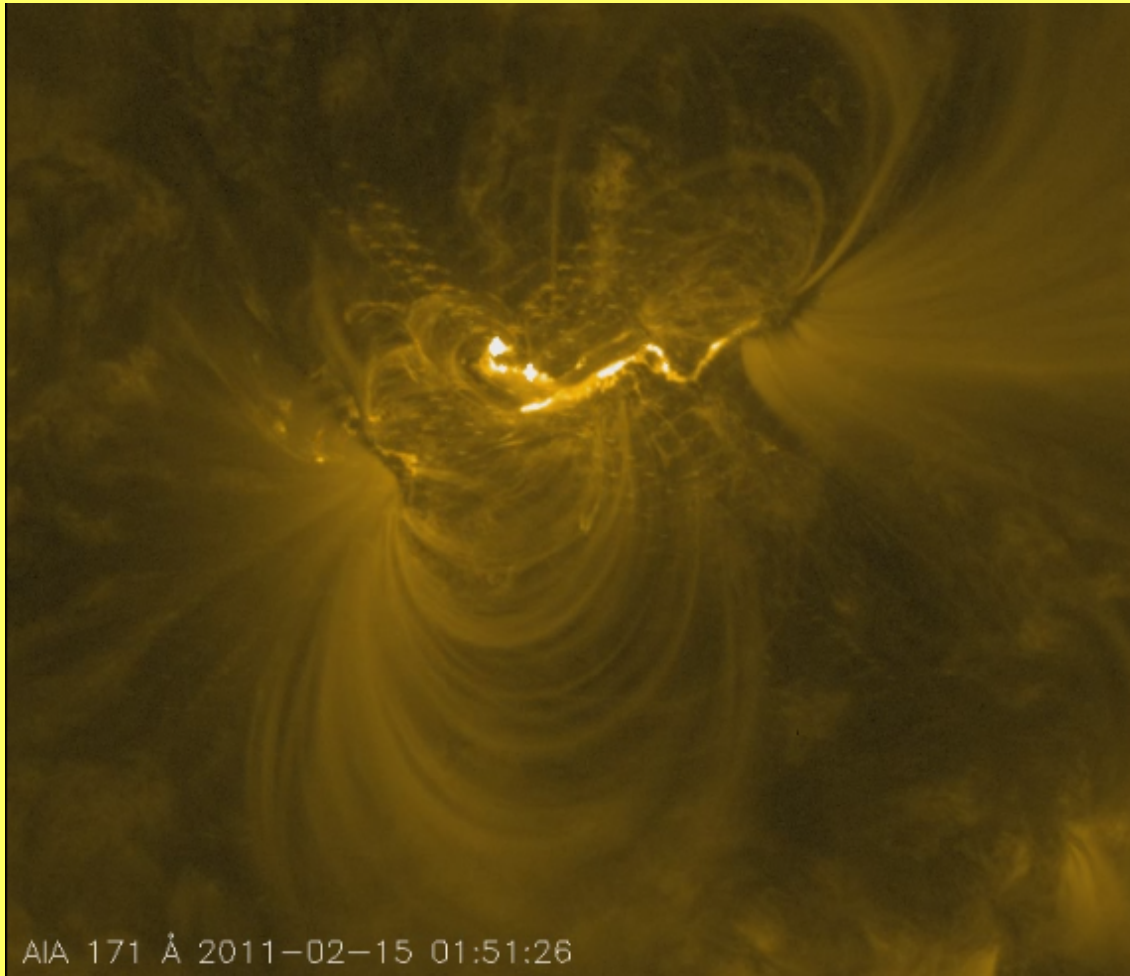
# Fourier spectrum

## SDO/EVE/ESP 0-7 nm (SXR)

(90% confidence level with red noise, Vaughan 2005)



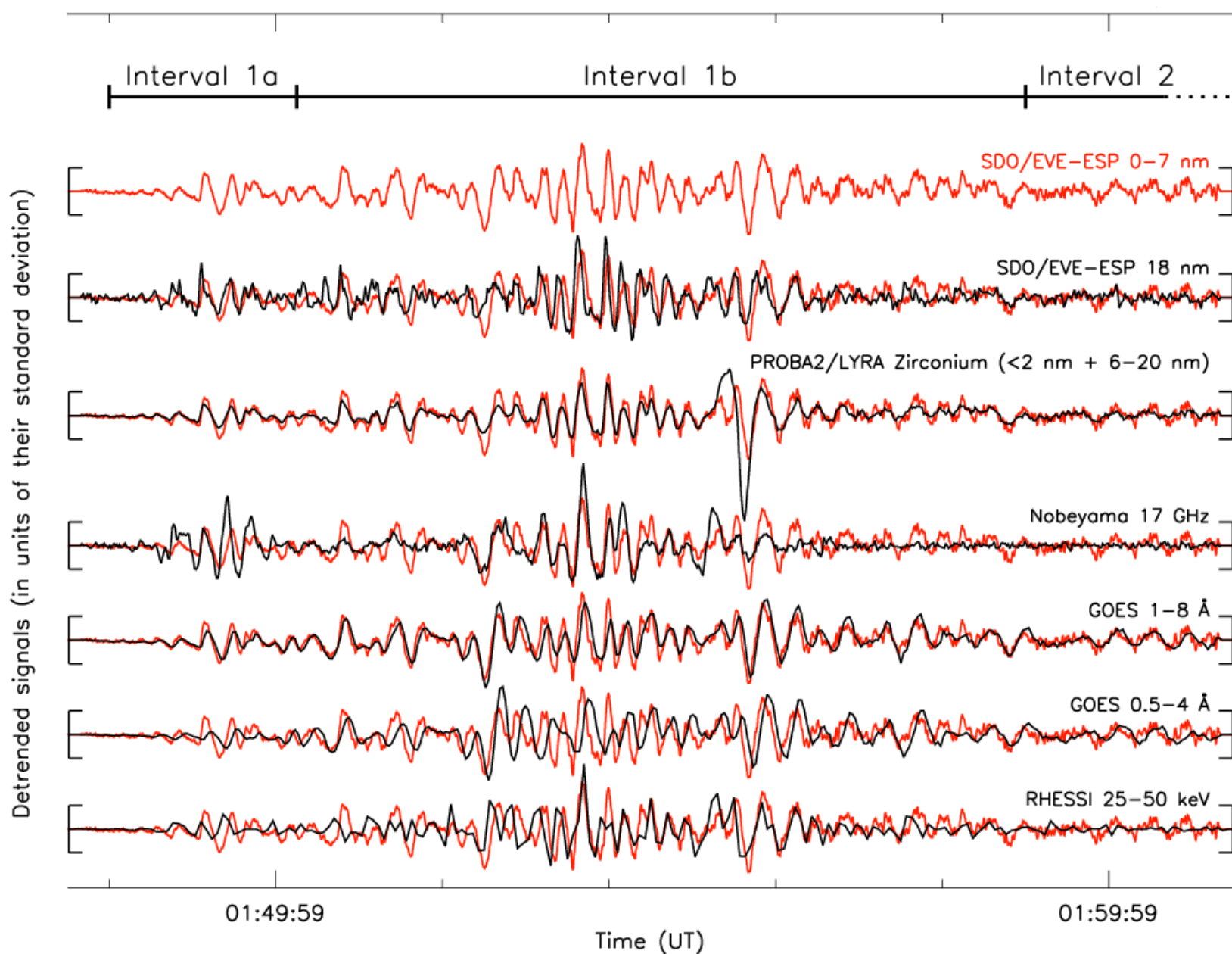
# Spatial localisation of the QPP ?



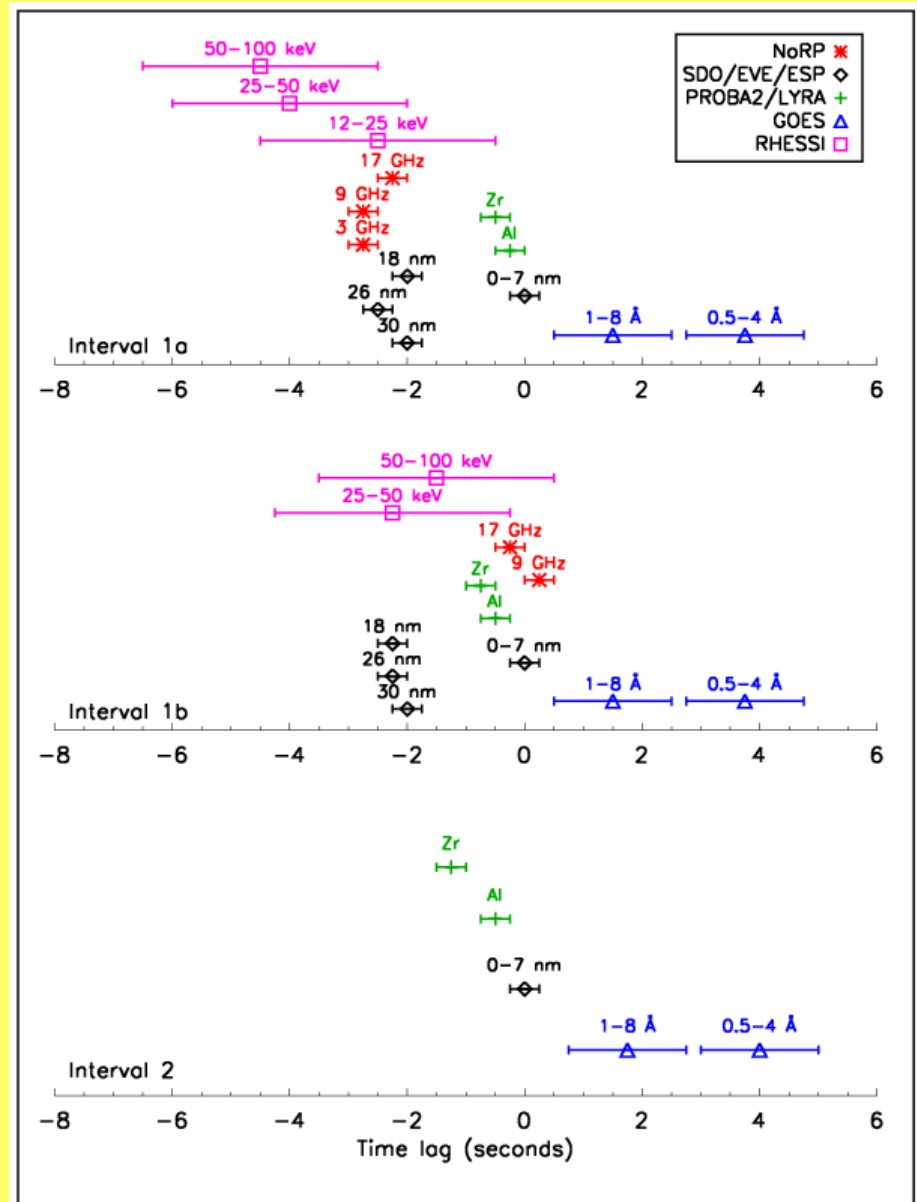
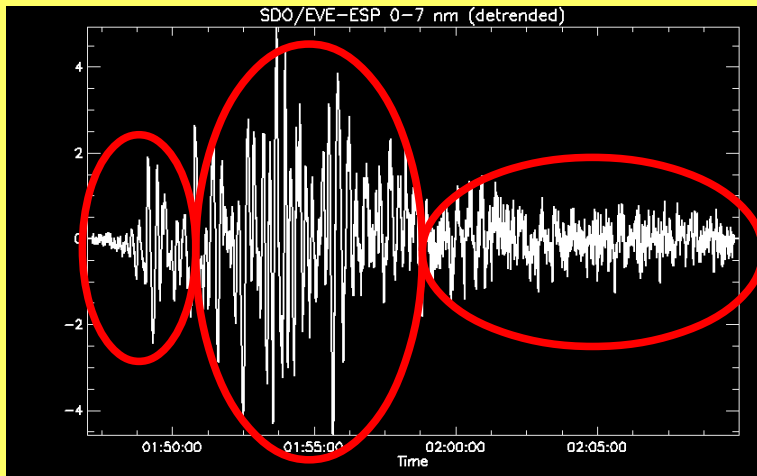
- Only the NoRH radio data (17 GHz) have sufficient time cadence (2 s) to clearly identify the spatial localisation of the QPP.
- But bad spatial resolution
- Apparently correlated with some of the bright spots in EUV (SDO/AIA 171 Å)
- (movie)

# Short time-scale fluctuations in several wavebands

**Detrended  
irradiance**



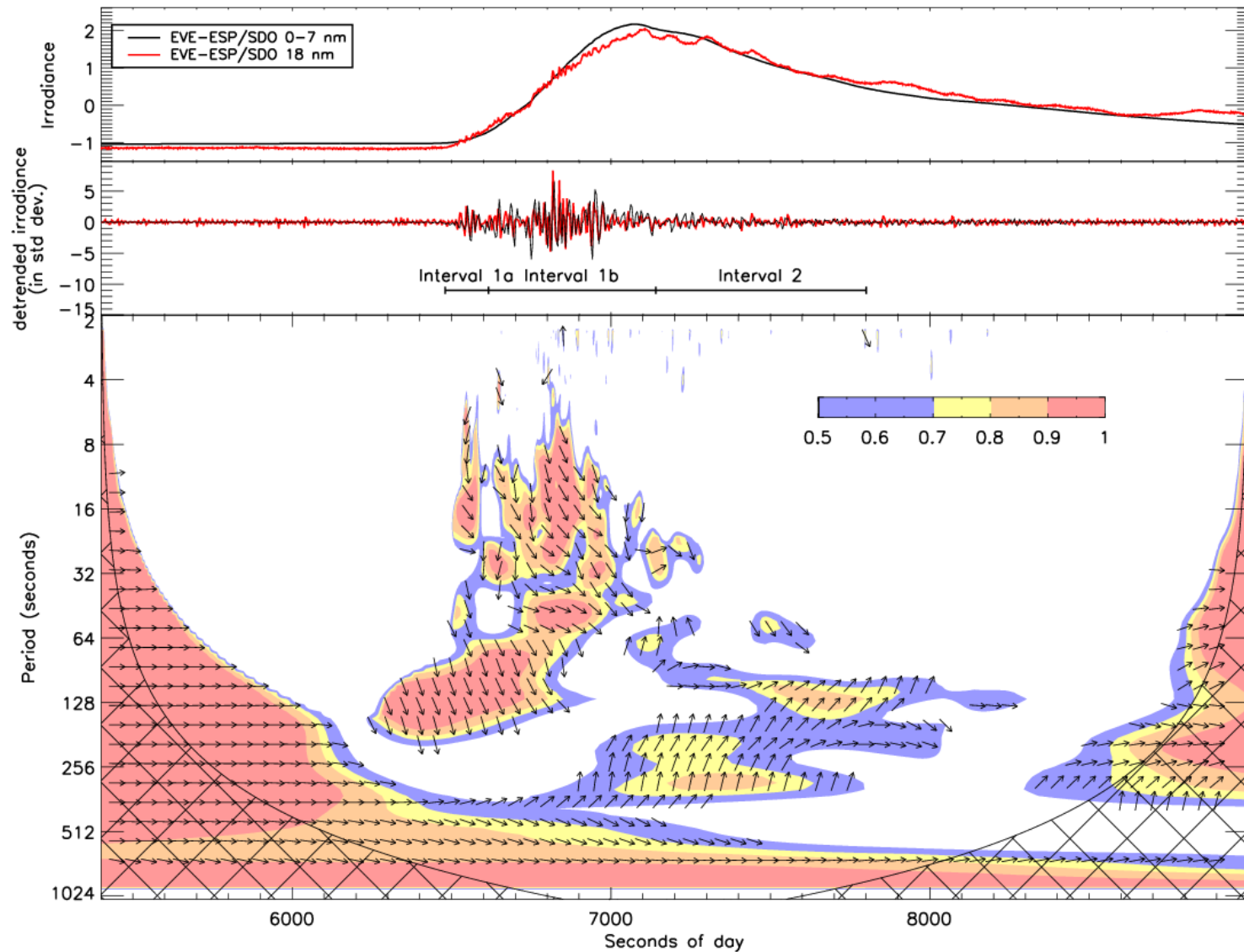
# Time lags



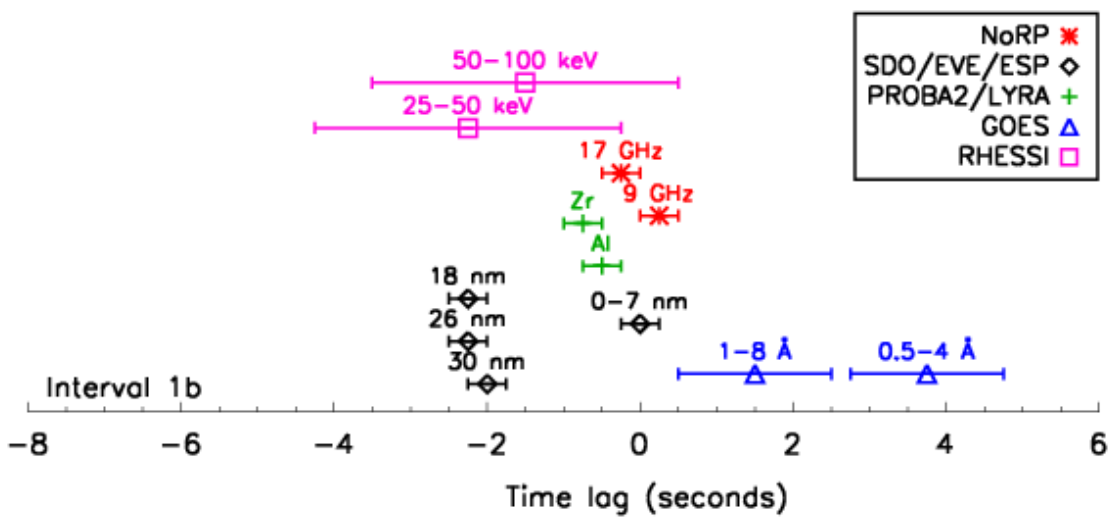
Dolla et al. (2012)

# Wavelet cross-coherence

(cf Torrence & Webster 1999)

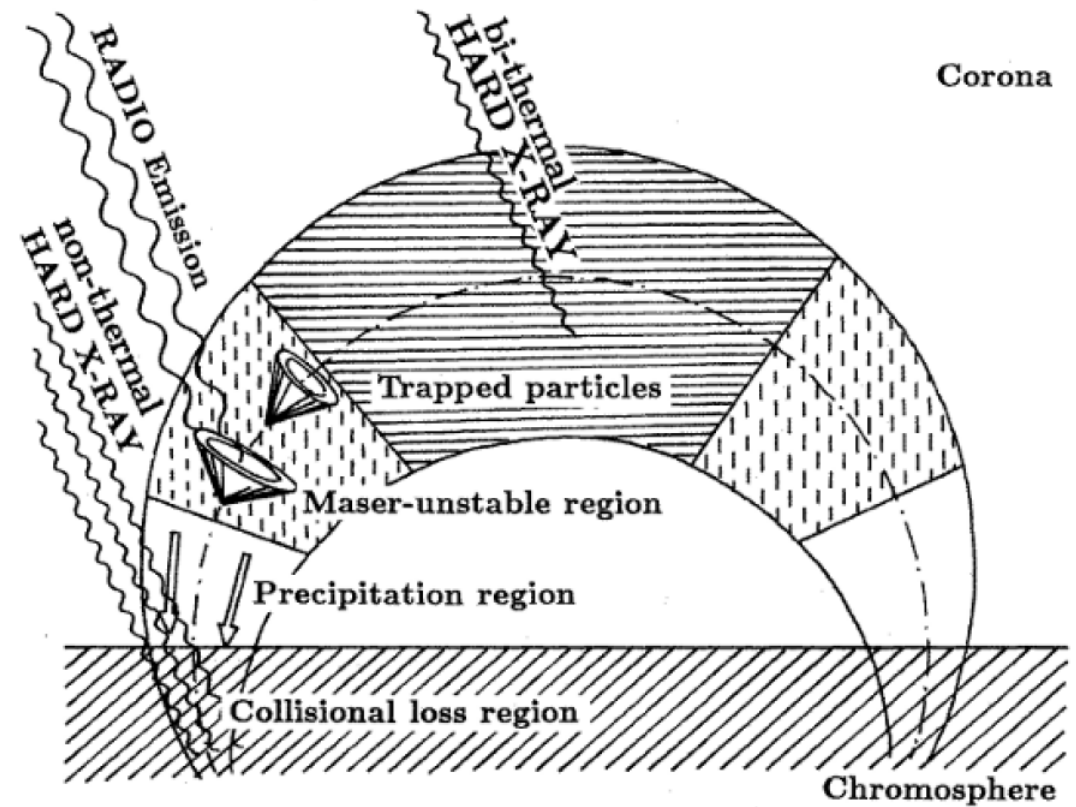






# Interpretation of the time delays

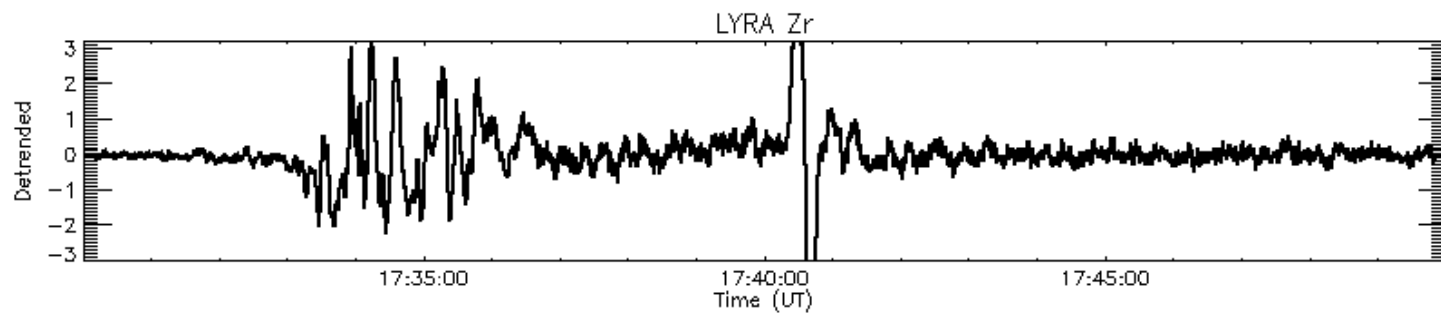
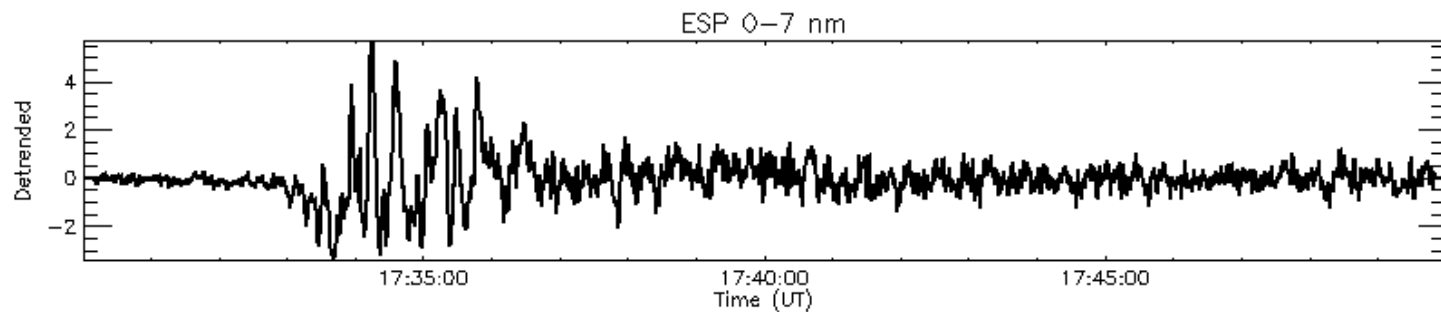
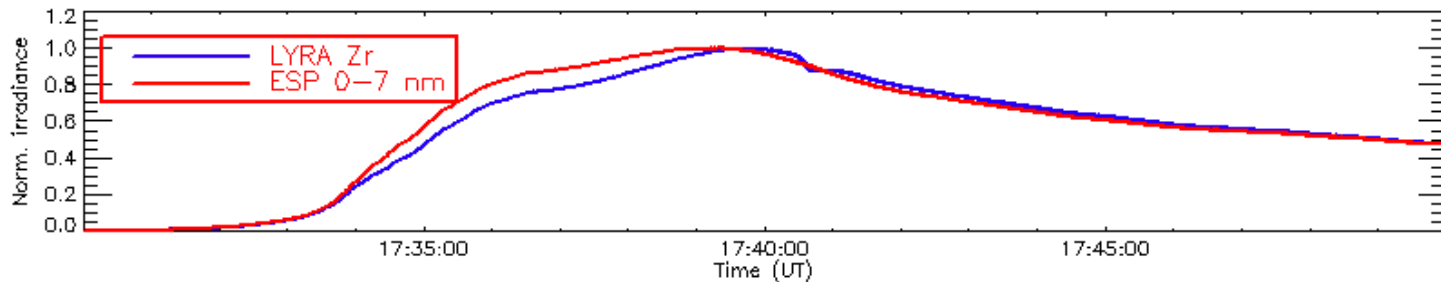
- **Trapping time** of energetic electrons
- **Cooling time** (~Neupert effect)
- Problem : SXR channels (ESP 0-7 nm, GOES, LYRA Zr) are in the reverse order as expected for cooling effects.



Aschwanden (2004)

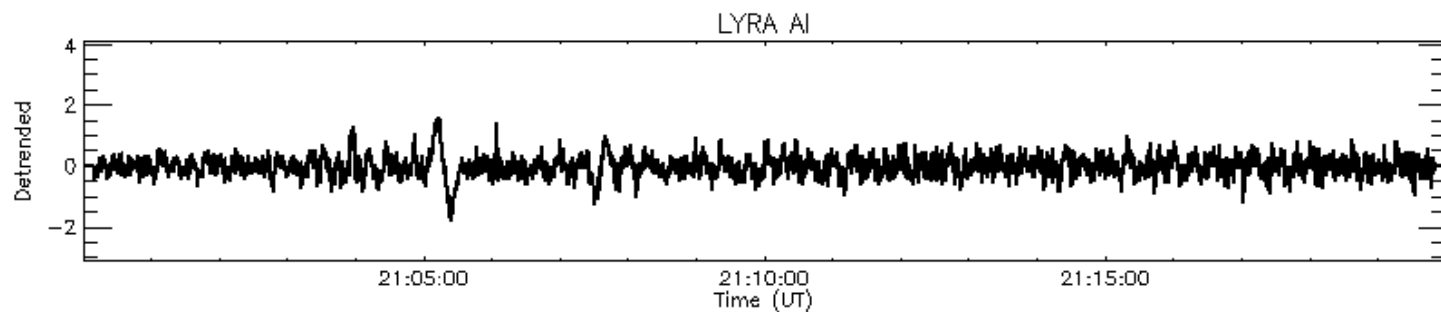
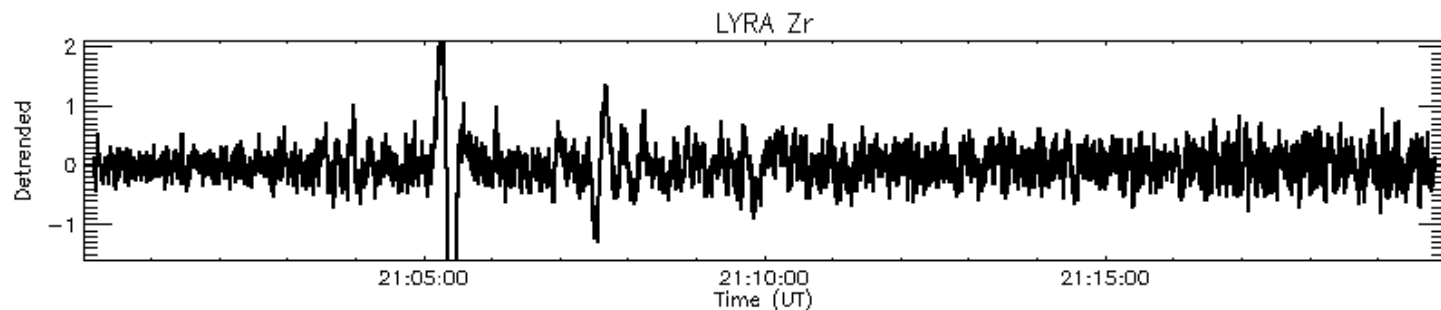
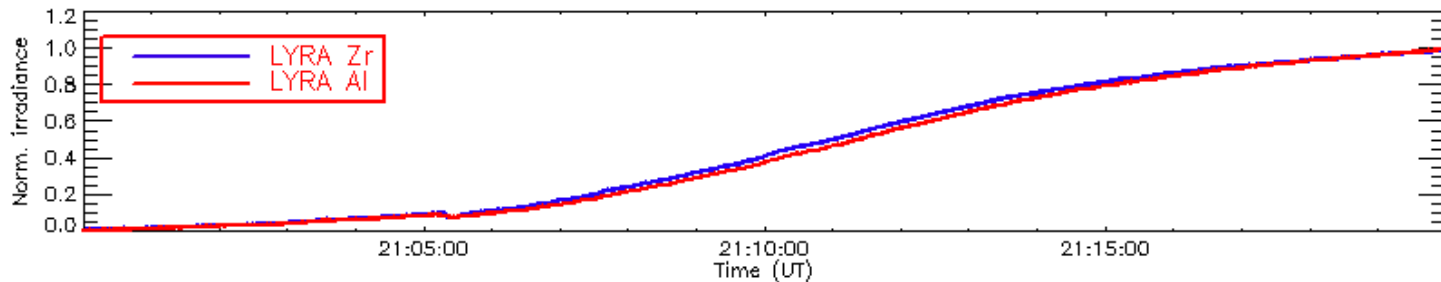
# More examples (1)

(M flare 2011/02/13)



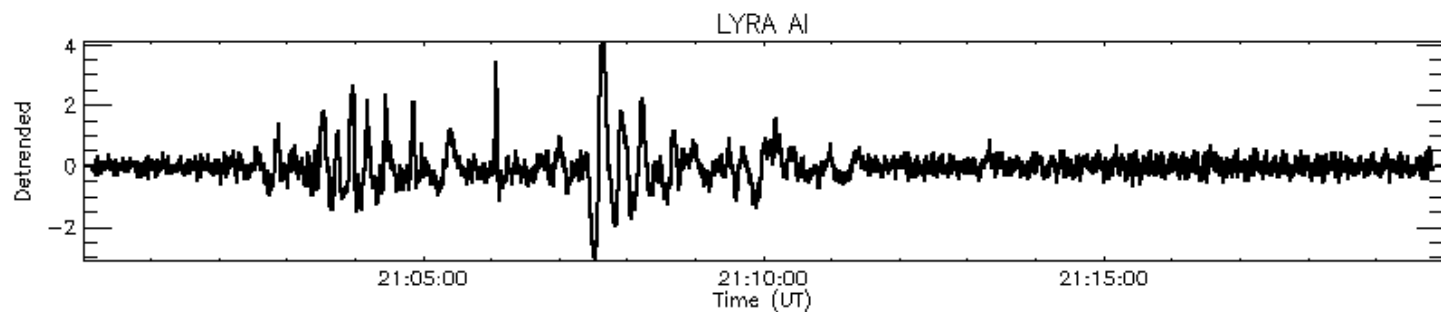
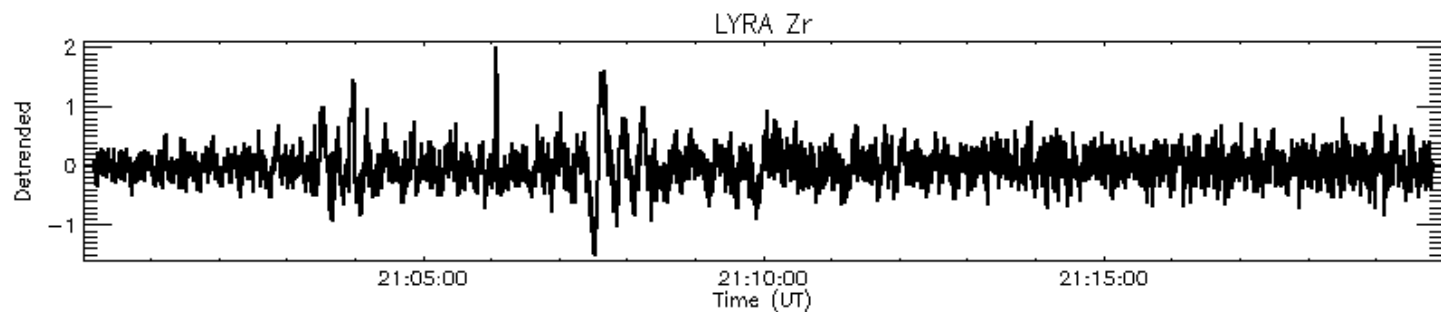
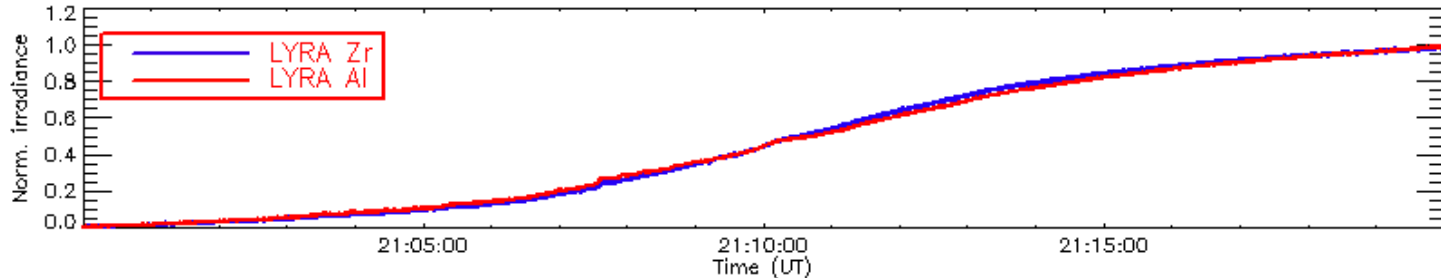
# More examples (2)

(2011/05/29)



# More examples (2)

(2011/05/29 → back up unit !)



# Conclusions

- Quasi-periodic oscillations observed simultaneously in several different instruments during the flare rising phase, with period similar to Van Doorselaere et al. (2011):
  - **11 s (2-32 sec)** → standing fast sausage mode ?
  - (1-3 min) → standing slow sausage mode ?
- For the first time: time delays between **EUUV** and **soft X-ray** fluctuations in the time scale range 2-30 s during flares, **for several events**.
- Why is it interesting ?
  - Part of the flare phenomenon, still not well understood
  - **Can provide diagnostics:**
    - with periods and MHD wave interpretation: loop density contrast, plasma  $\beta$ ...
    - With time delays: trapping and cooling effects (influence of magnetic field, density, heating processes, ...)
- Dolla et al. 2012, ApJ, 749, L16