Using Proba2 for coronal seismology

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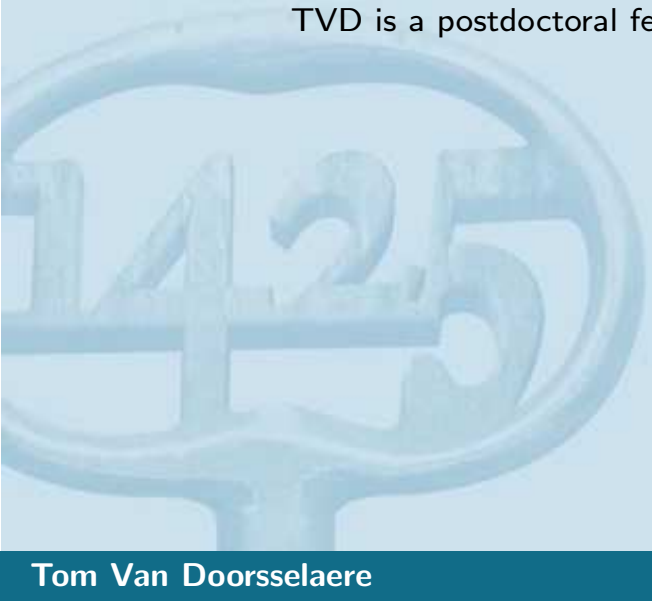
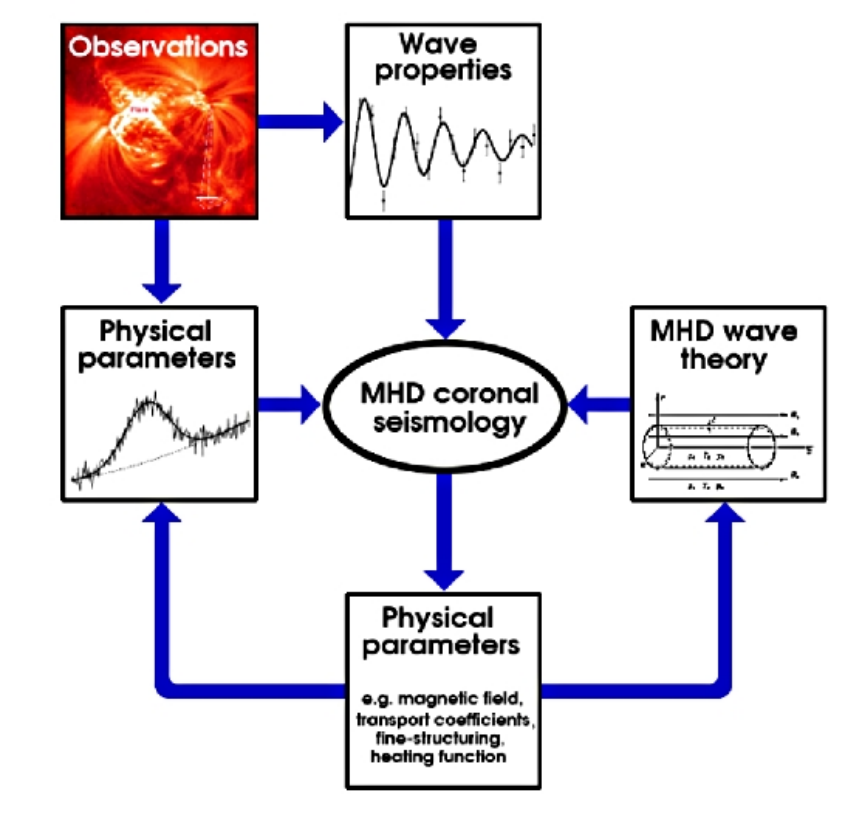
TVD is a postdoctoral fellow of the FWO - Vlaanderen and is also funded by an Odysseus grant.

May 4, 2012



Coronal seismology

Coronal seismology: measure quantities in corona by the use of waves



(Nakariakov & Verwichte, 2005)

Ubiquitous waves

Since 2007, waves are ubiquitously observed in the solar atmosphere:

- Running transverse waves in coronal loops: Tomczyk et al. (2007), McIntosh et al. (2011)
- Transverse waves in spicules: De Pontieu et al. (2007)
- Slow, longitudinal waves in active regions: Krishna Prasad et al. (2012)

Excellent opportunities for seismology!

How can Proba2 be used in such studies?

SWAP

EIT-like instrument: full sun imager with low cadence, low resolution

→ Not suitable for coronal seismology?

IT IS! Study oscillations in long loops (not visible in SDO), or slow waves in loop footpoints.

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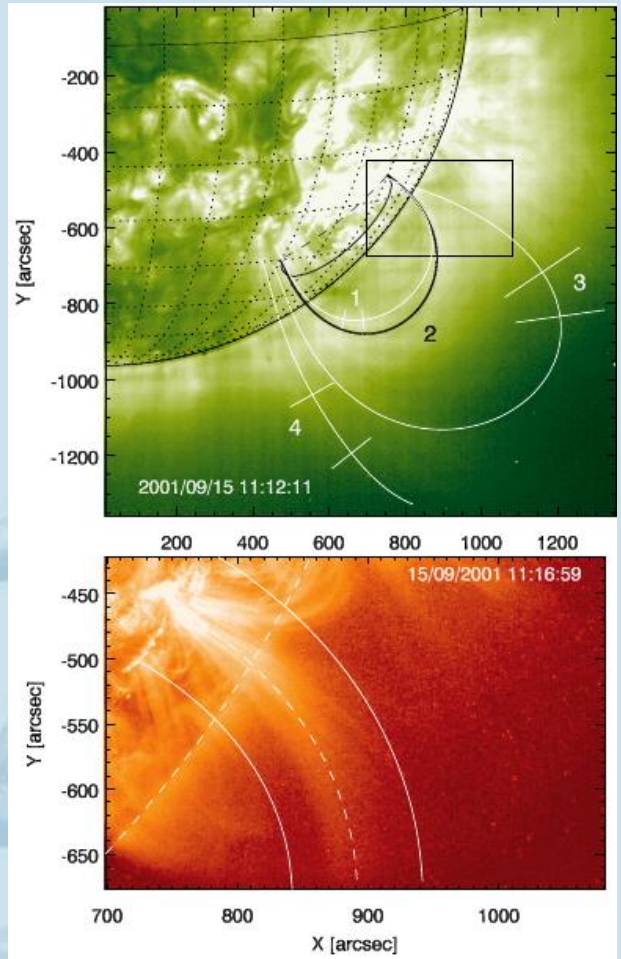
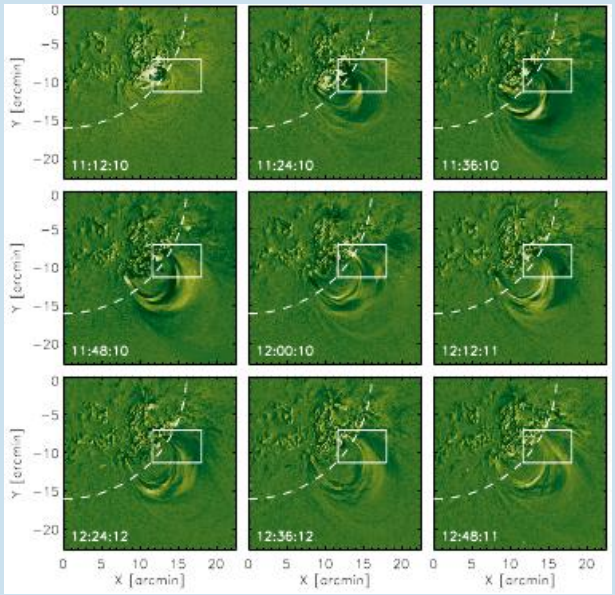
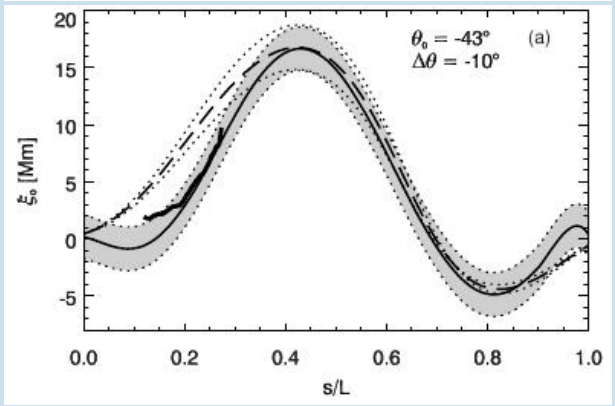
Verwichte et al. 2010

Study of transverse oscillation with TRACE & EIT.







LYRA

View Sun-as-a-star: very high cadence with no spatial resolution

→ Not suitable for coronal seismology?

IT IS! Study oscillations in flares, or oscillations in a spatially averaged sense.

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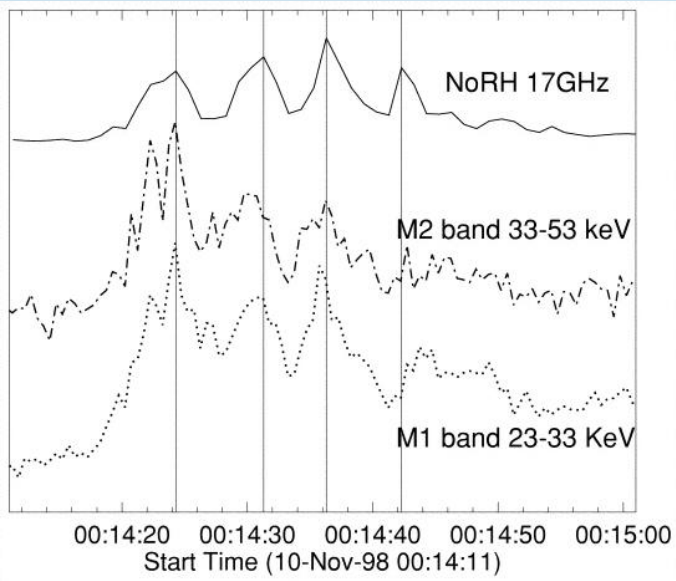
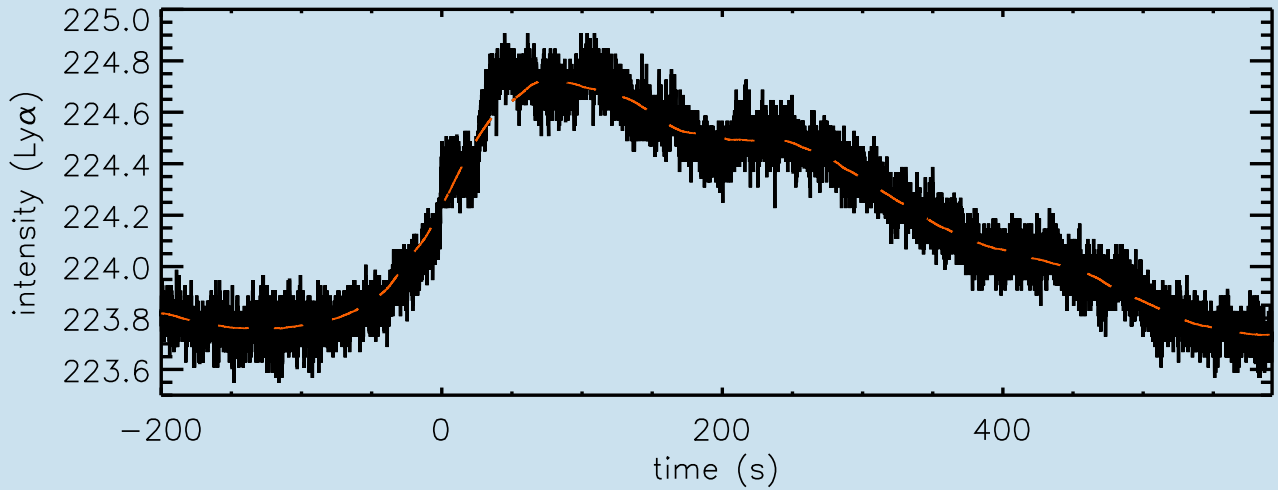
QPPs in flares

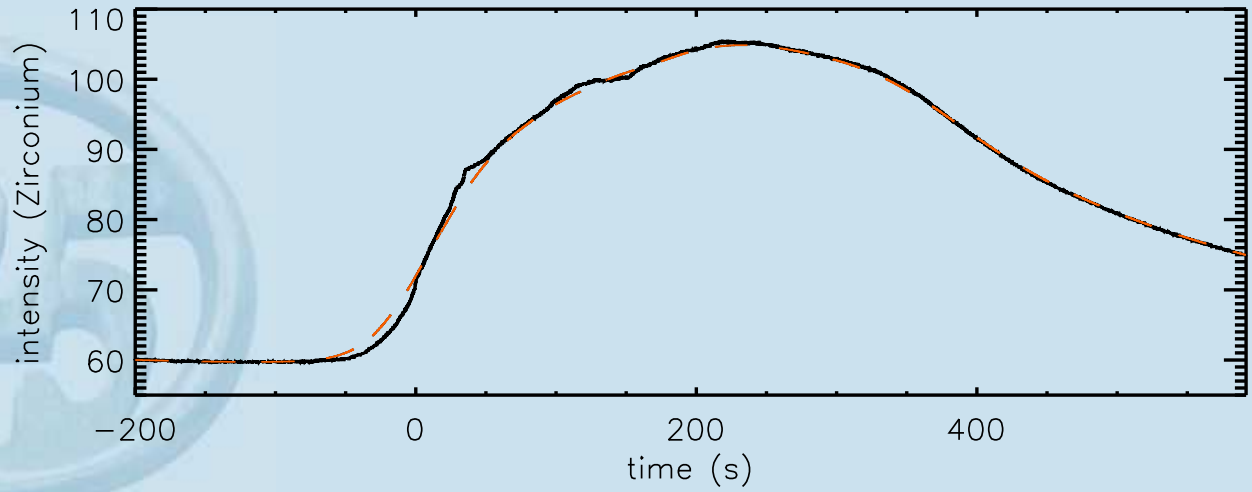


Taken from Asai et al. (2001)

- Quasi-periodic pulsations are intensity variations in flares.
- They have been observed in radio, X-rays, visible light.
- Periods of a few seconds (i.e. MHD regime).
- Multi-periodicity has been observed (Inglis et al. 2009).
- Physical mechanism?
- See talk by Laurent Dolla.

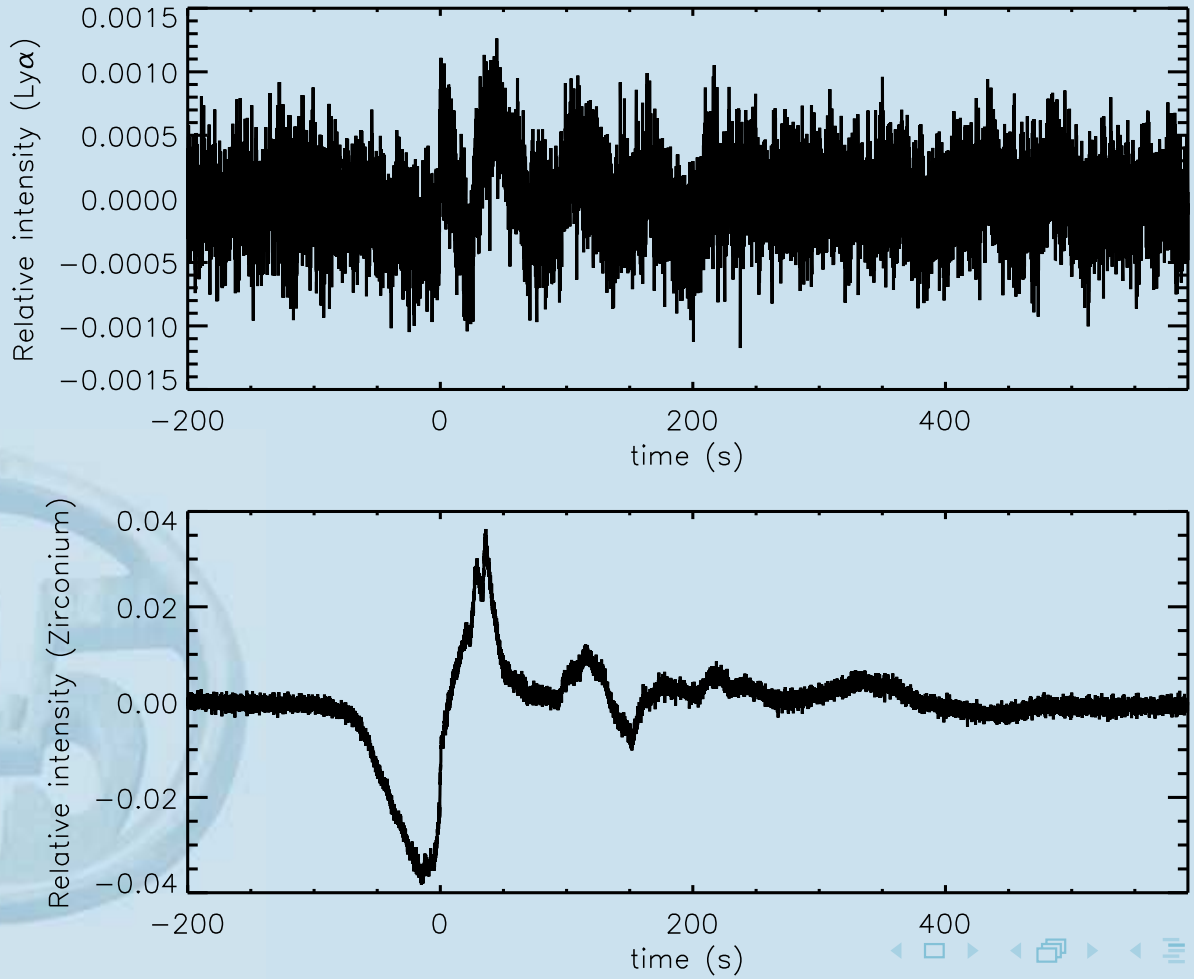
LYRA intensity data from 08 Feb 2010





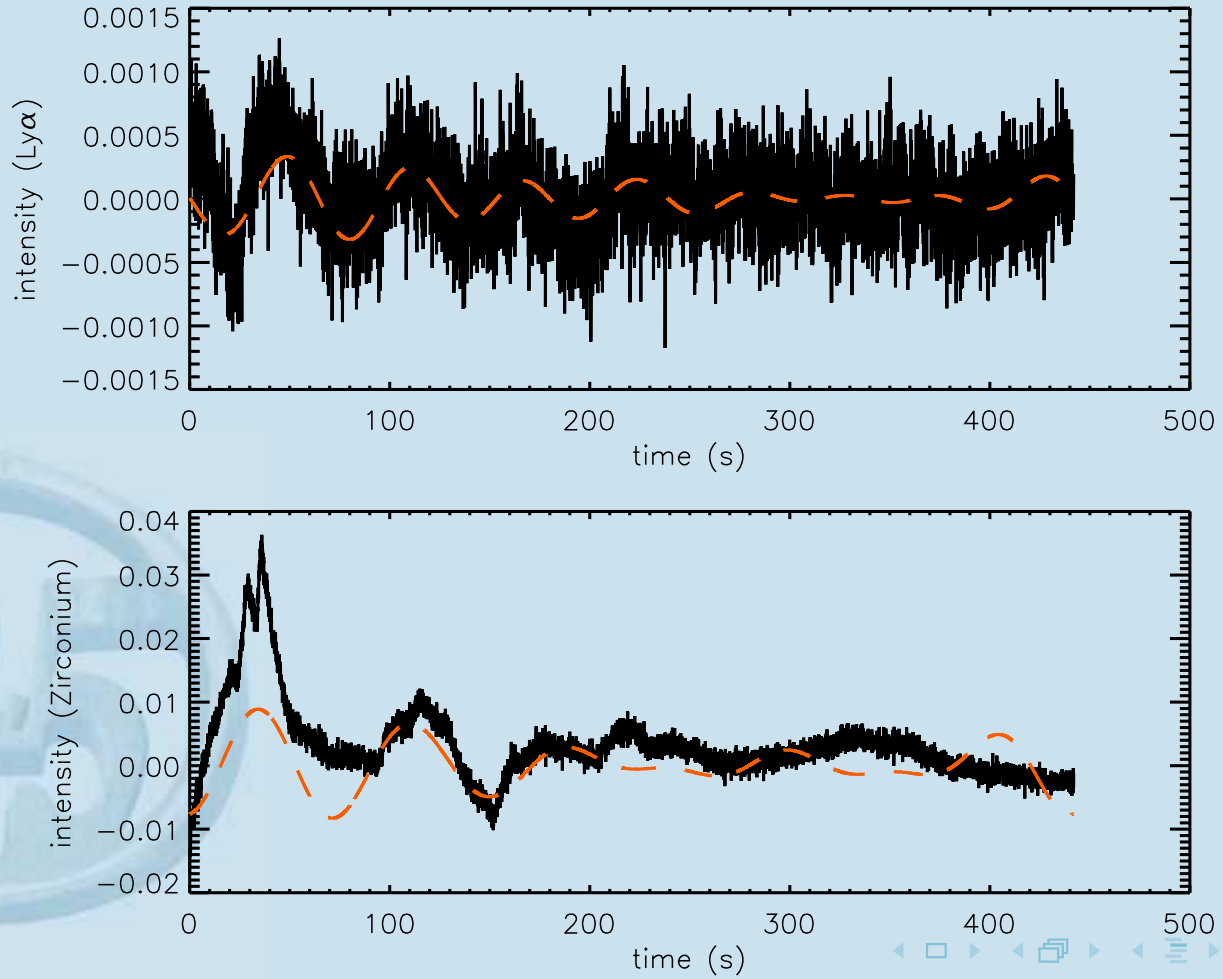
Relative intensity

After background subtraction (dashed line in previous graph), i.e. time signal smoothed by 1500 data points (75s).



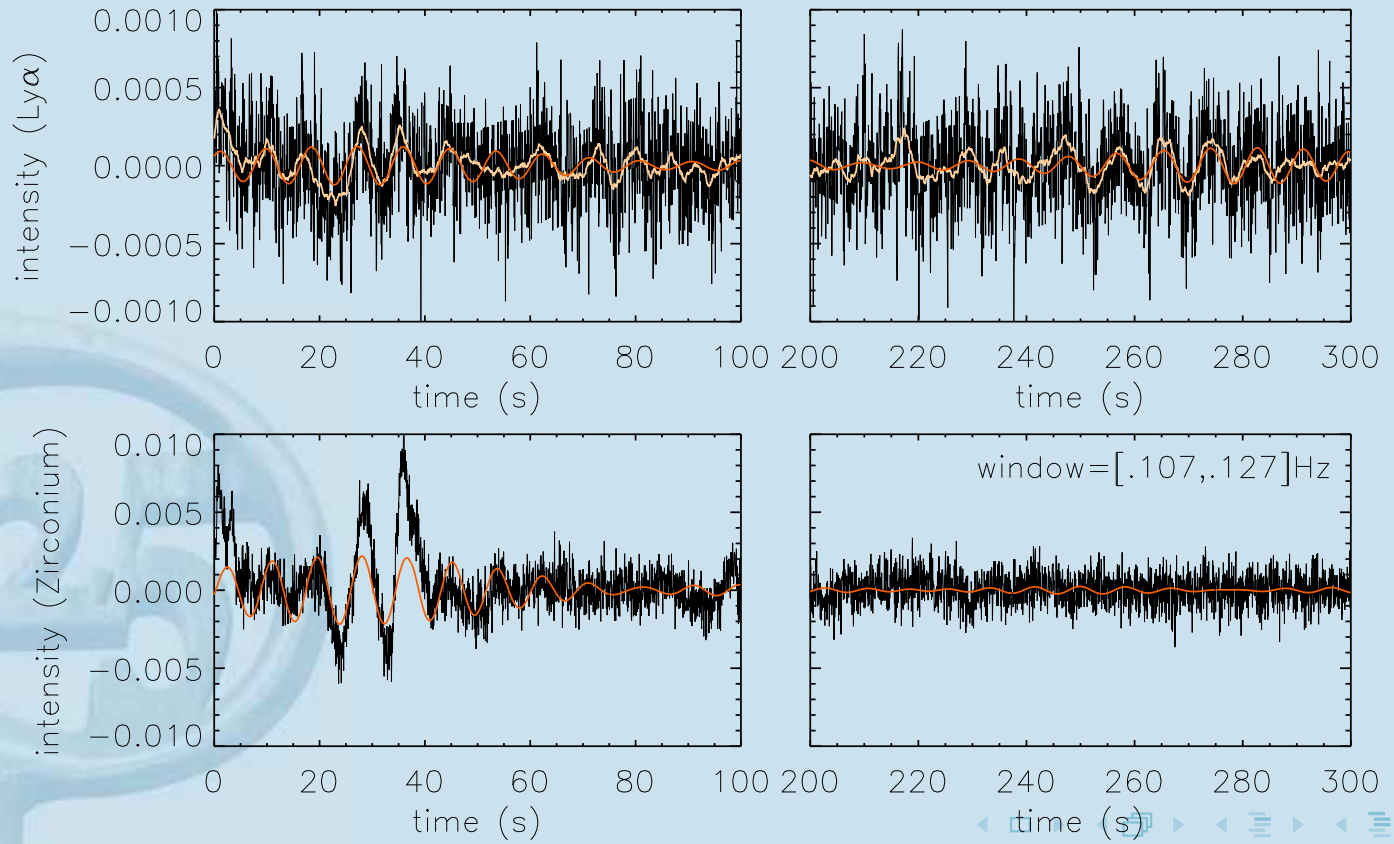
Filtered signals

Spectral peak at $P = 75$s. Overplot filtered signal (top hat filter between 10 and 19mHz) in orange.



Fast(er) oscillations

Smooth with 12.5s (250 data points). Oscillations with period 8.5s are found. Filter signal (top hat filter between 107 and 127mHz). Obvious match with oscillations in Lyα, but the oscillations in Zr do not persist past the maximum of the flare.



Interpretation

Our interpretation of the observed periodicities:

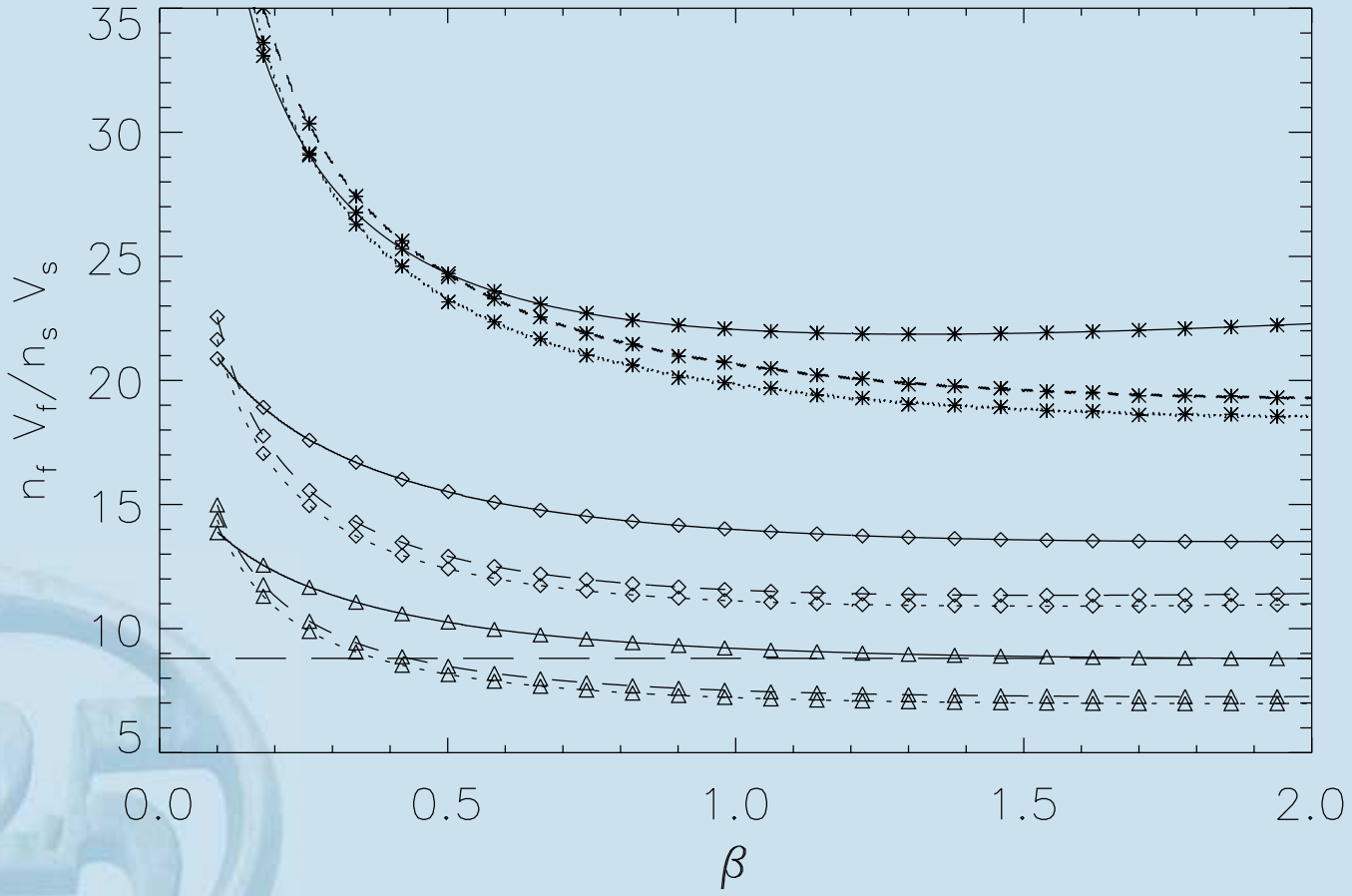
- Periods are from standing oscillations in a single post-flare loop (scenario 3 from introduction).
- Short period = fast sausage mode
- Long period = slow sausage mode

Additional assumptions necessary for seismology:

- Oscillations live in *the same post-flare loop*.
- Consider a cylindrical model for the post-flare loop, where density, pressure and magnetic field are constant in the internal and external region (*Edwin & Roberts, 1983*).
- Post-flare loop is in *pressure balance*.

Numerically calculate period ratio for different plasma-β.

Numerical results



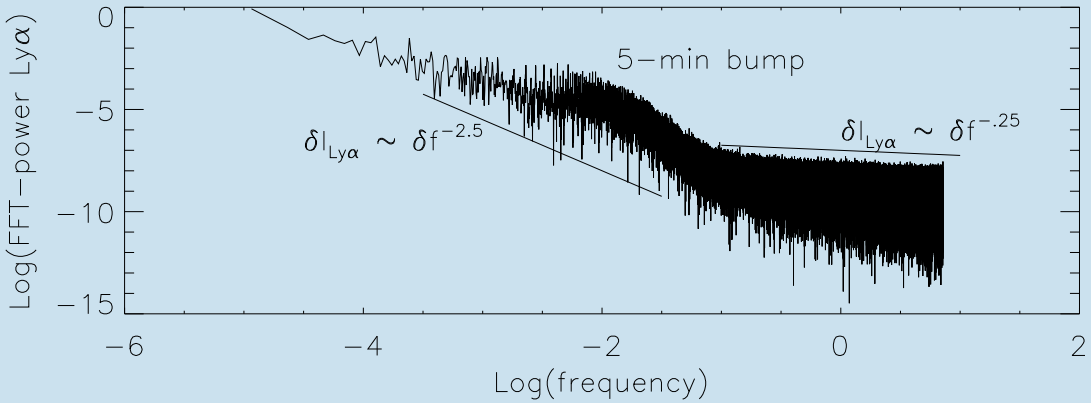
Solid lines are for $n_f = 1$, dotted for $n_f = 2$, and dashed for $n_f = 3$. Stars are for $n_s = 1$, diamonds for $n_s = 2$, and triangles for $n_s = 3$.

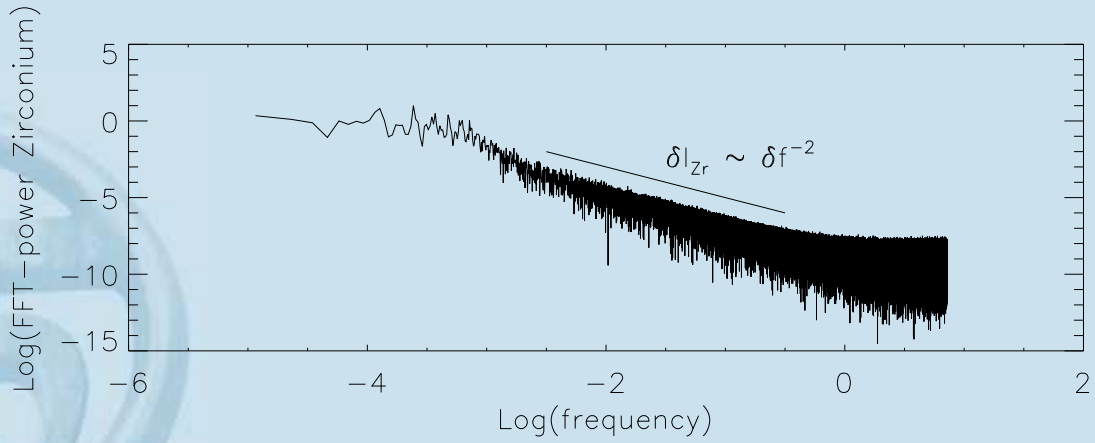
Seismological results

- Observed value of the period ratio only reached for 3rd overtone of slow mode $n_{\rm s} \geq 3$.
- In that case, $\beta = .4$ for $n_{\rm f} = 2, 3$. $\beta = 1.5$ for $n_{\rm f} = 1$.
- Should we exclude the $n_{\rm f} = 1$ case?

Power spectral density (PSD) of LYRA data

Take Fourier transform of LYRA data.

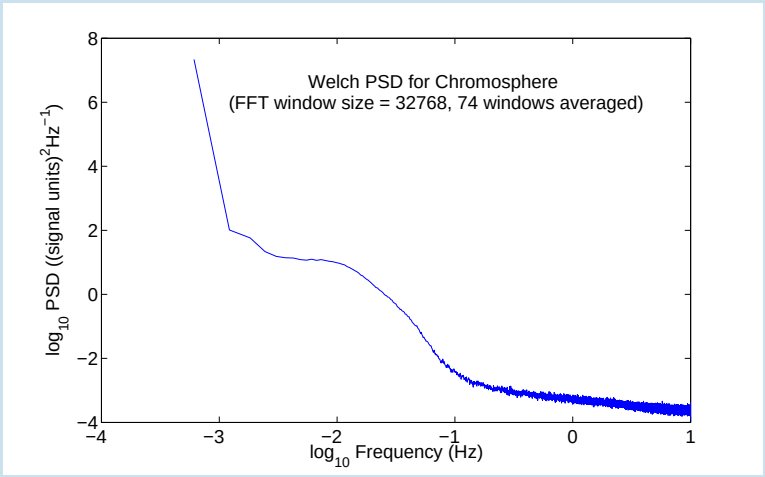


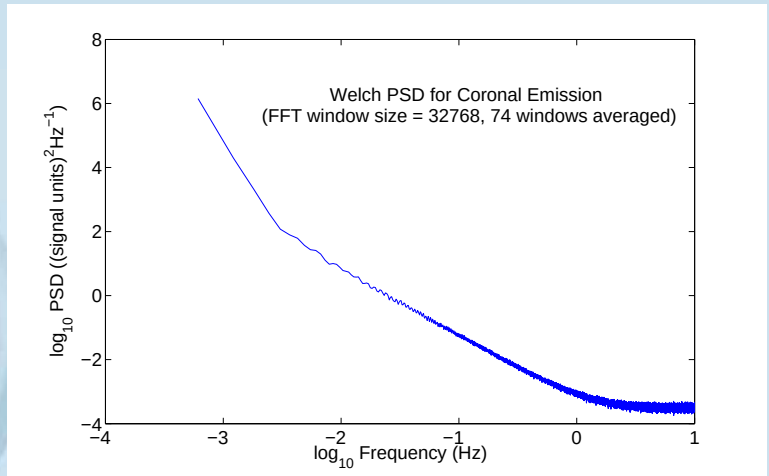


What physics is there in all the power slopes? Can these be used to do seismology?

Proper analysis

Ask a specialist in time series analysis:

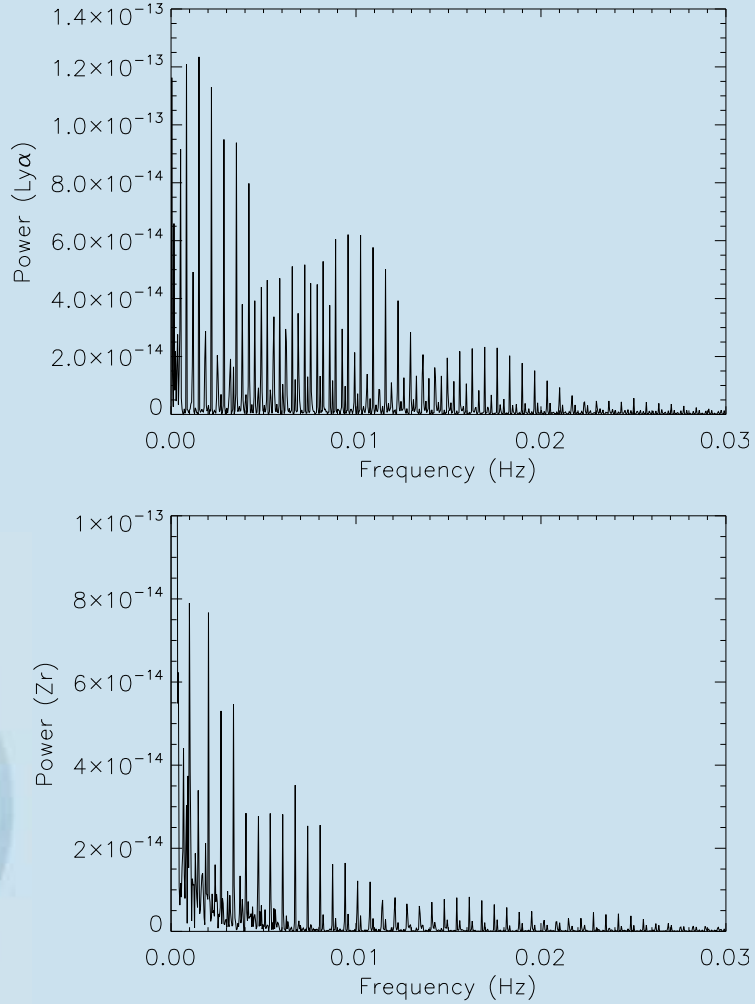




Courtesy Khurom Kiyani

But LAR...

FFT of day long data:



LAR introduce many spurious oscillations.

Conclusions

- How to use Proba2 for coronal seismology?
- SWAP: can be used for seismology of transverse oscillations of long loops.
- SWAP: seismology of slow waves?
- SWAP: unused so far!
- LYRA: seismology of quasi-periodic pulsations (QPP) in flares.
- LYRA: earlier result (VD2011) measures the flare plasma-β to be .4.
- LYRA: statistical study of disk-averaged oscillations?
- LYRA: huge potential due to high cadence.