Spectral Analysis of the Electron Density Fluctuation in the Solar Corona obtained by Radio Occultation Experiments using the Akatsuki Spacecraft

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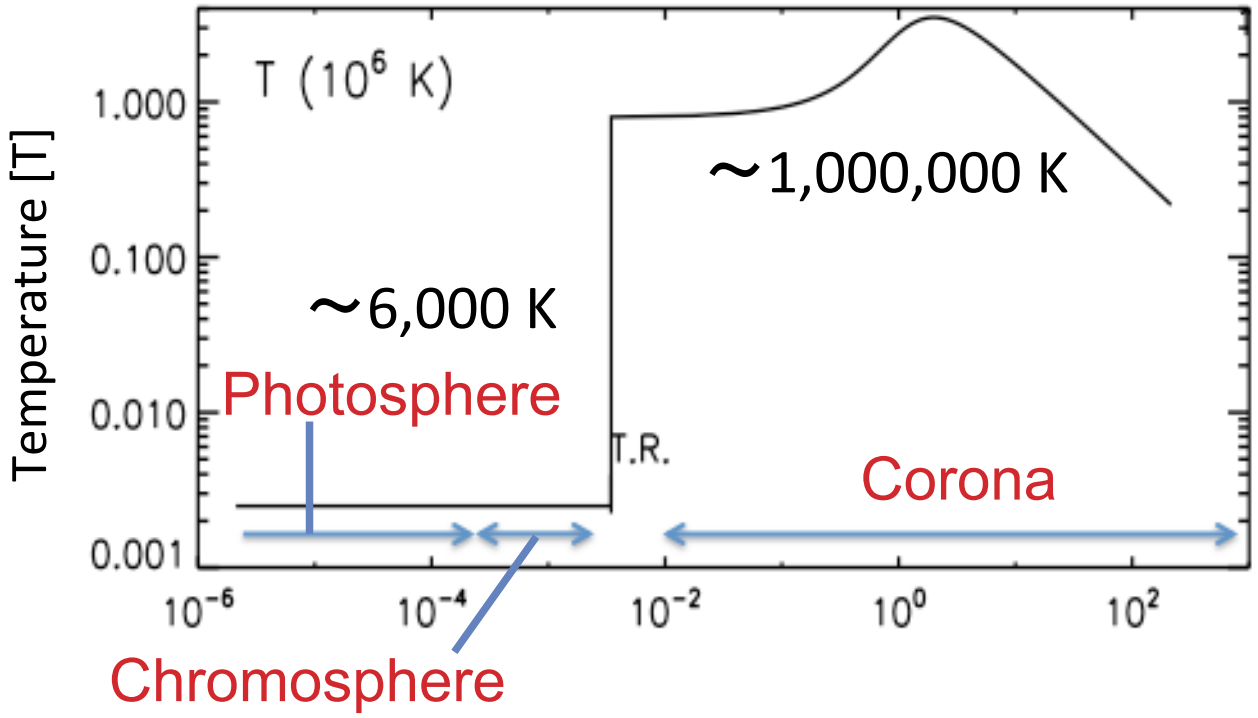
Coronal Heating

Temperature distribution with height



Distance from the surface of sun R-1 [Rs]

Rs: solar radius

Andrew and Marco (2006)

Coronal Heating by Waves

Alfven waves

- incompressible, transverse wave
- They are expected to transport energy to heat the corona.

Mode conversion

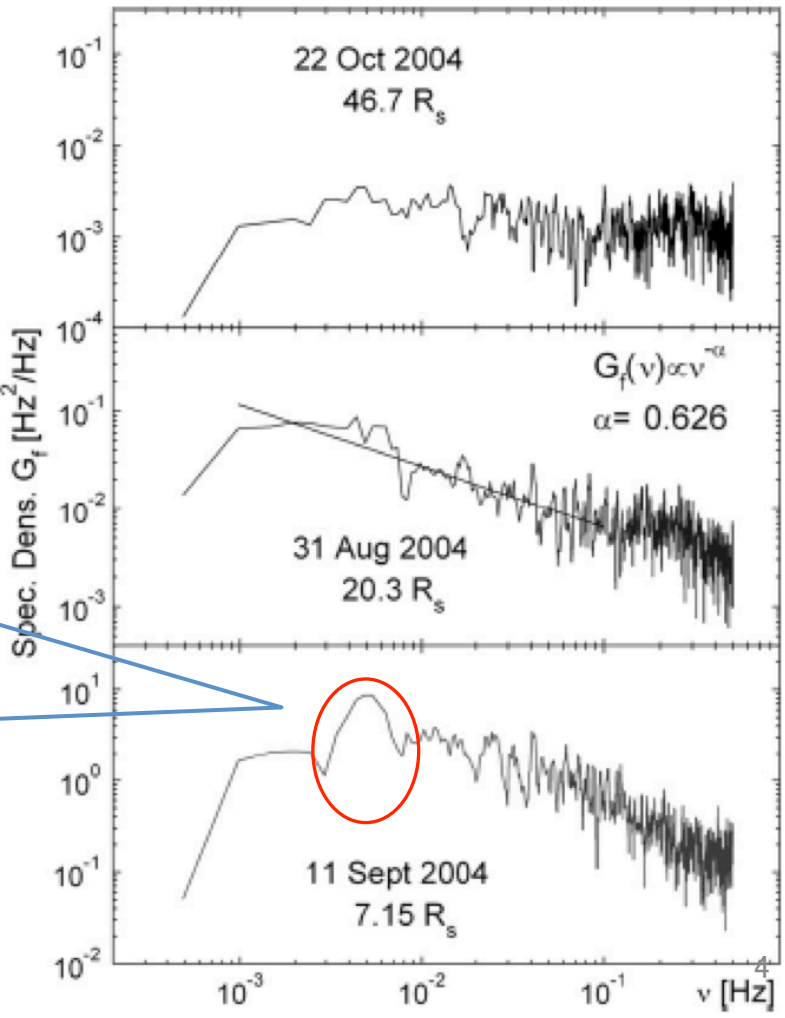
Magnetosonic waves

- compressible, longitudinal wave
- They cannot easily propagate to the corona, since they make shock waves and then dissipates energy rapidly. The cutoff period in transition region is about 150 s. (Erdelyi et al., 2007)

Sound wave in the Corona

Statistical analysis of quasi-periodic electron density fluctuations obtained by radio occultation experiments (Efimov et al., 2012)

Frequency fluctuation spectra



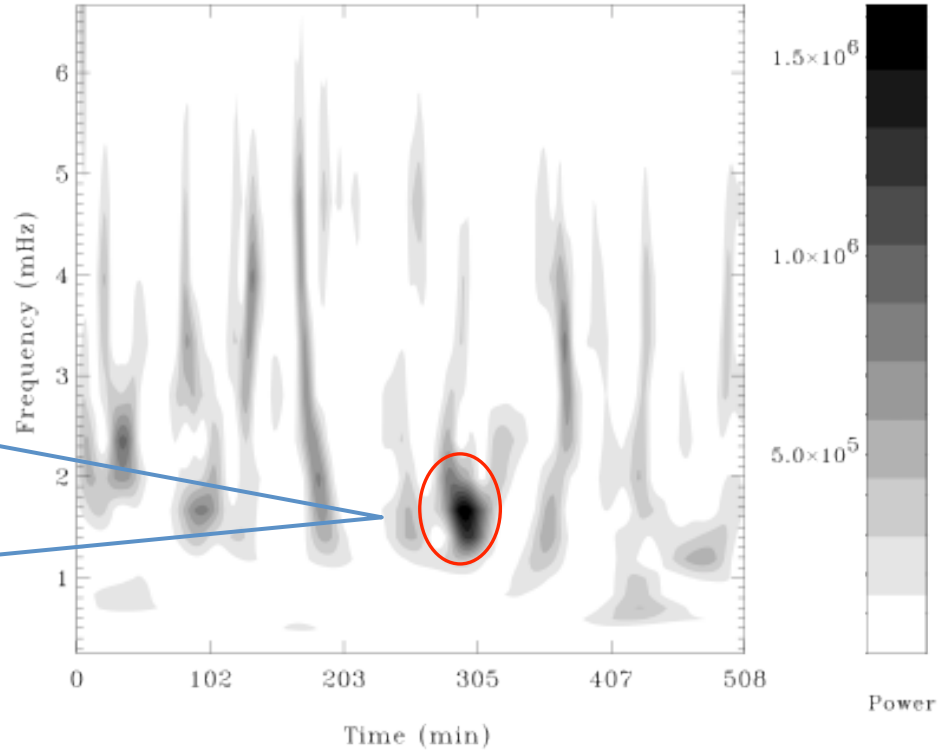
Period : ～4 minutes
(Frequency : ～4 mHz)
Distance : 3-40 Rs
Coherence time : ～30 minutes
Occurrence frequency : ～20%

Sound wave in the Corona

Compressional waves obtained by SOHO ultraviolet coronagraph spectrometer white light channel (Ofman et al., 2000)

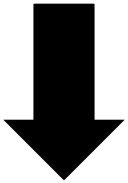
Wavelet analysis of the polarized brightness

Period : 6-10 minutes
(Frequency : 1.6-2.5 mHz)
Distance : 1.9 Rs
Coherence time : ～30 minutes



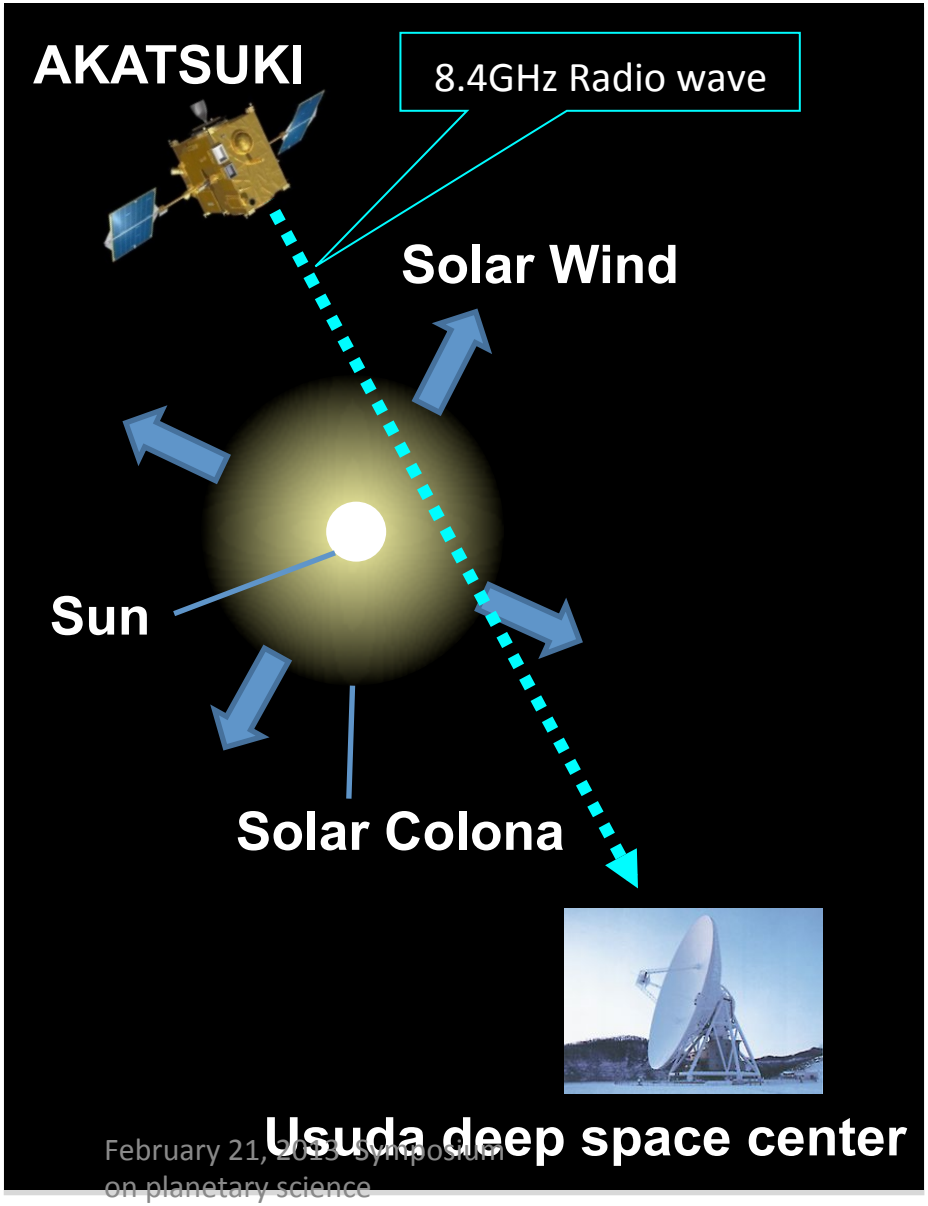
Purpose of this study

- Secondary generation of acoustic waves from Alfvan waves might play an important role in coronal heating.
- Observations of acoustic waves in corona have been limited.



The purpose of this study is to examine the radial dependence of acoustic wave characteristics, such as the period, the density amplitude and the energy flux, in the region from 1.5 to 20.5 Rs.

Radio Occultation



Signal frequency fluctuation (f')
∝ Rate of change of the electron column density (dN'/dt)

$$\phi' \propto N'$$

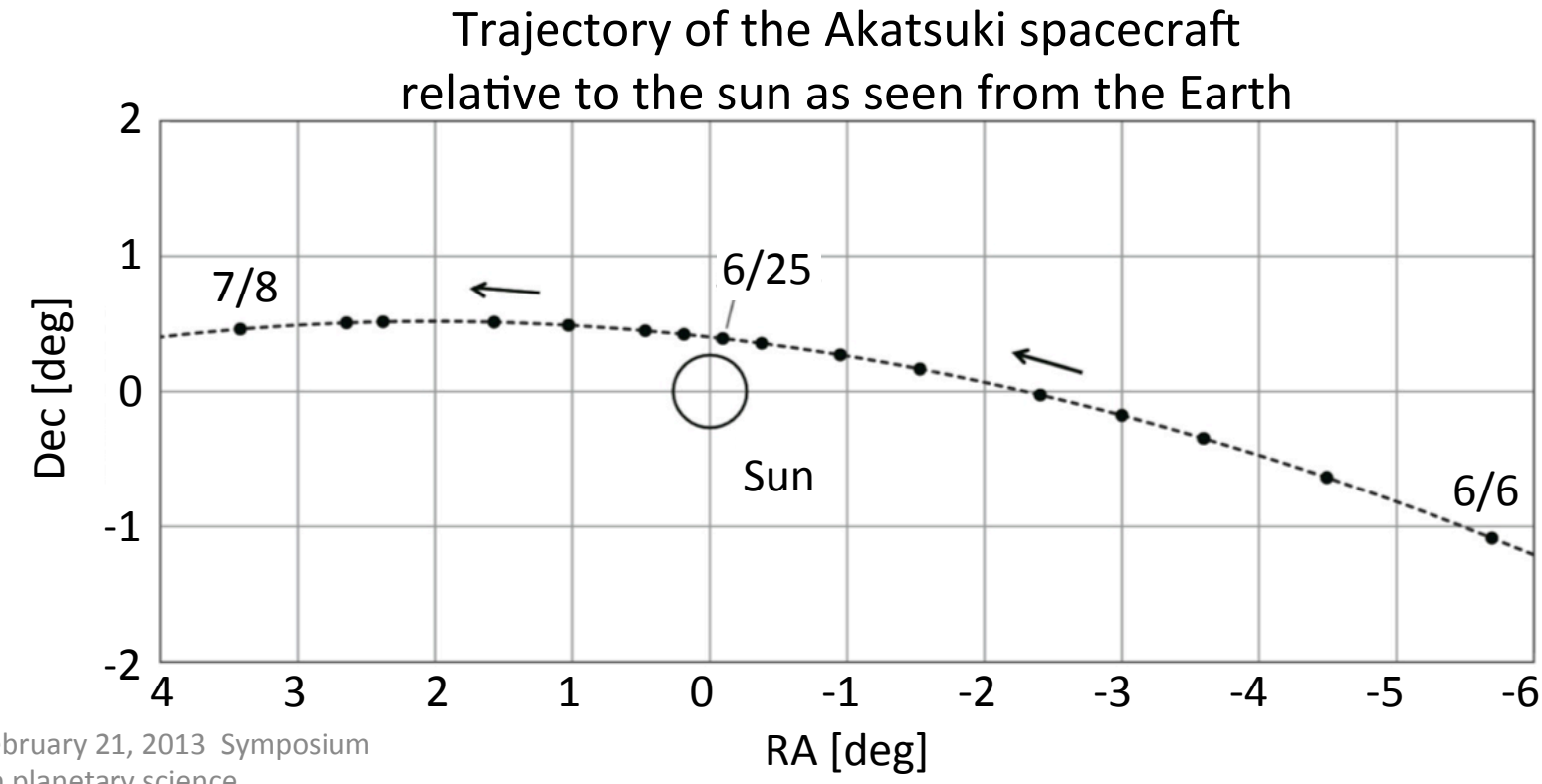
$$f' \propto \frac{dN'}{dt}$$

ϕ' : Phase fluctuation
N' : Electron column density fluctuation
f' : Frequency fluctuation

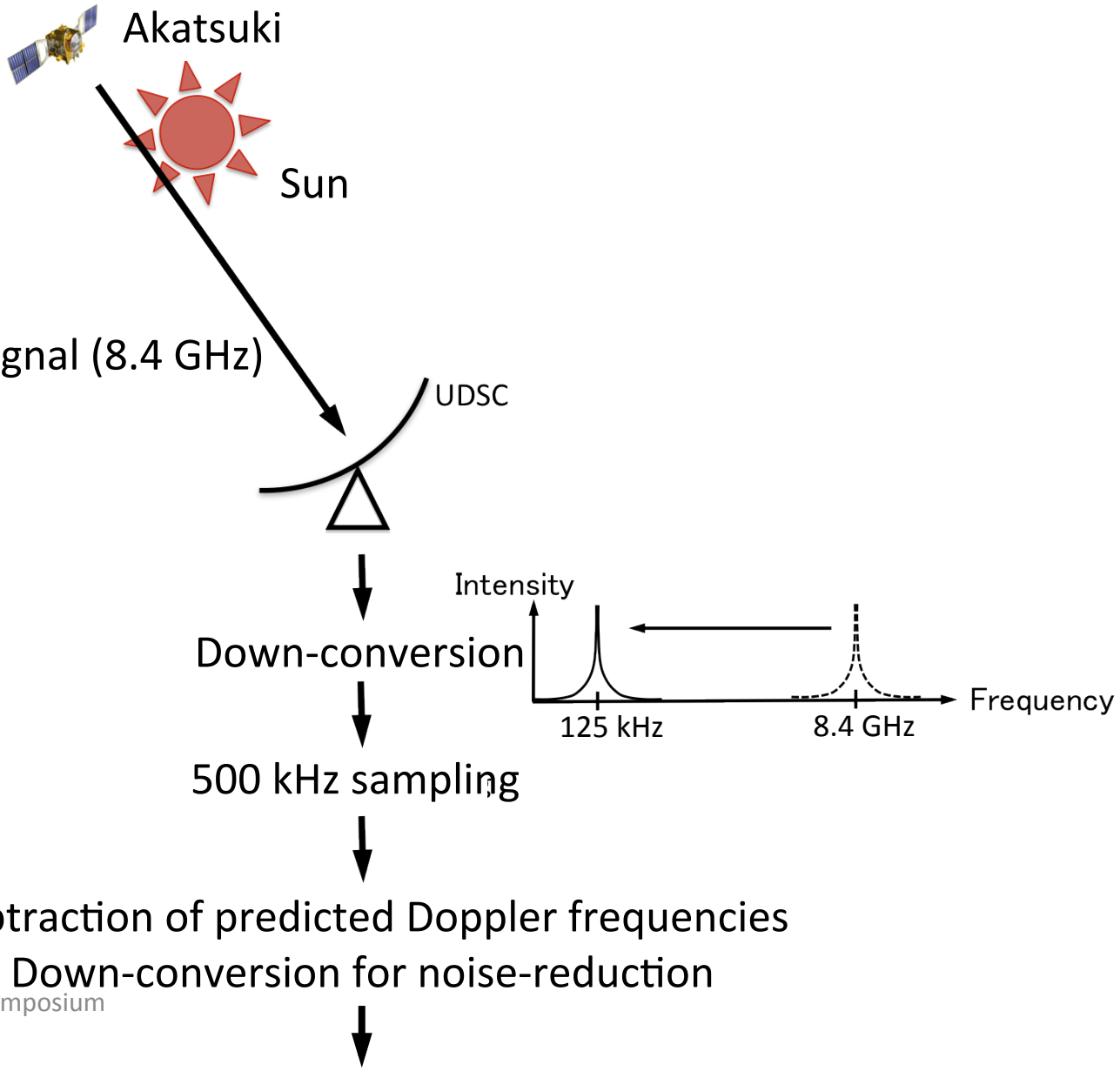
① Spectral analysis of frequency fluctuation(f')
② Column density(N') → Density amplitude → Energy flux

Observations

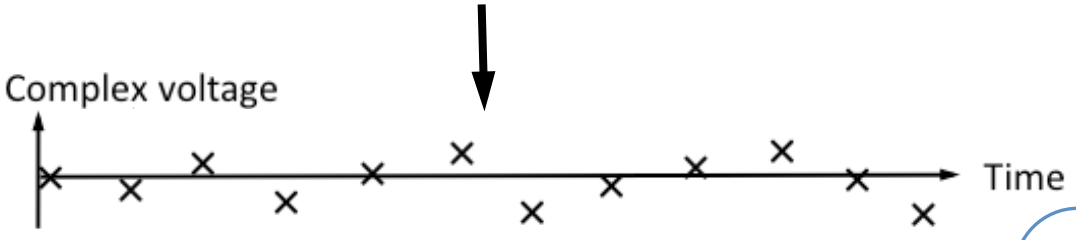
- Date : June 6, 2011-July 8, 2011 (16 days)
- Recording time : 3.0-7.5 hours
- Heliocentric distance : 1.5-20.5 Rs



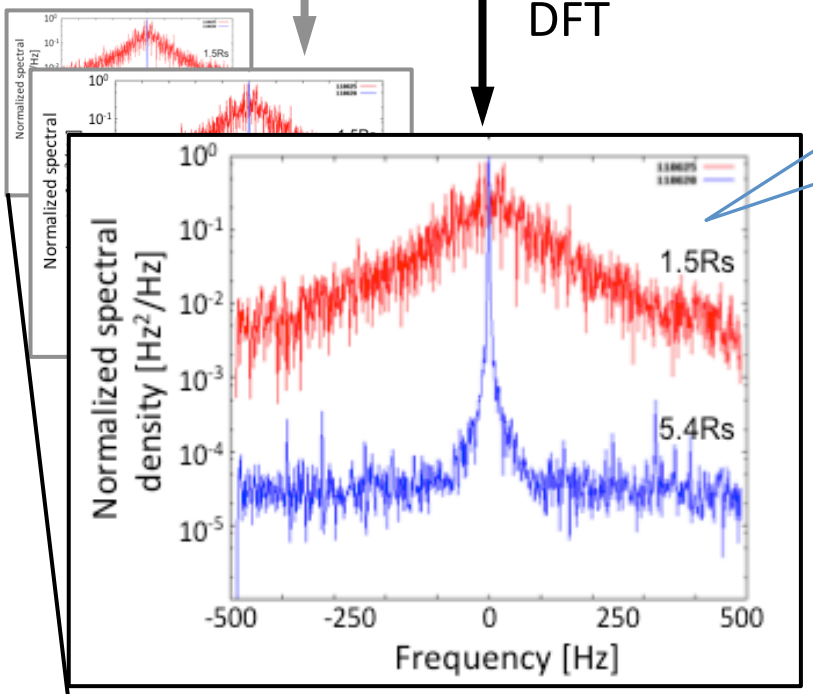
Data Processing



Data Processing



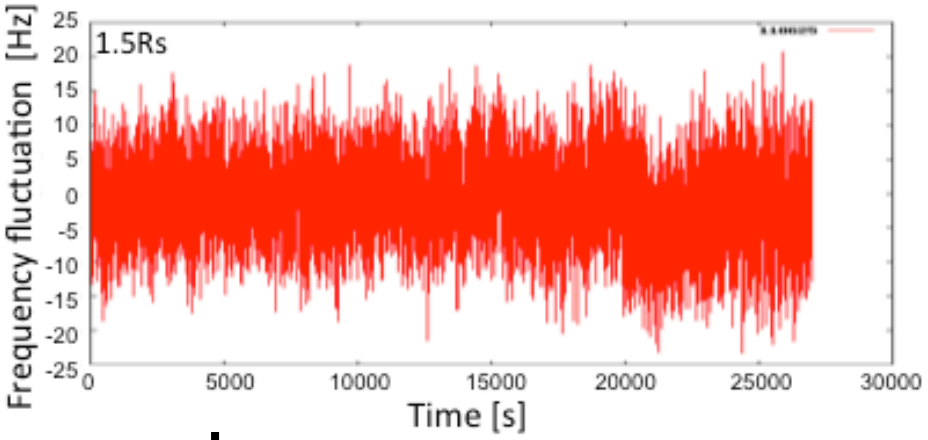
DFT



Determination of central frequency

- Spectral fitting method (4.1-20.5 Rs)
- Centroid method (1.5-3.6 Rs)

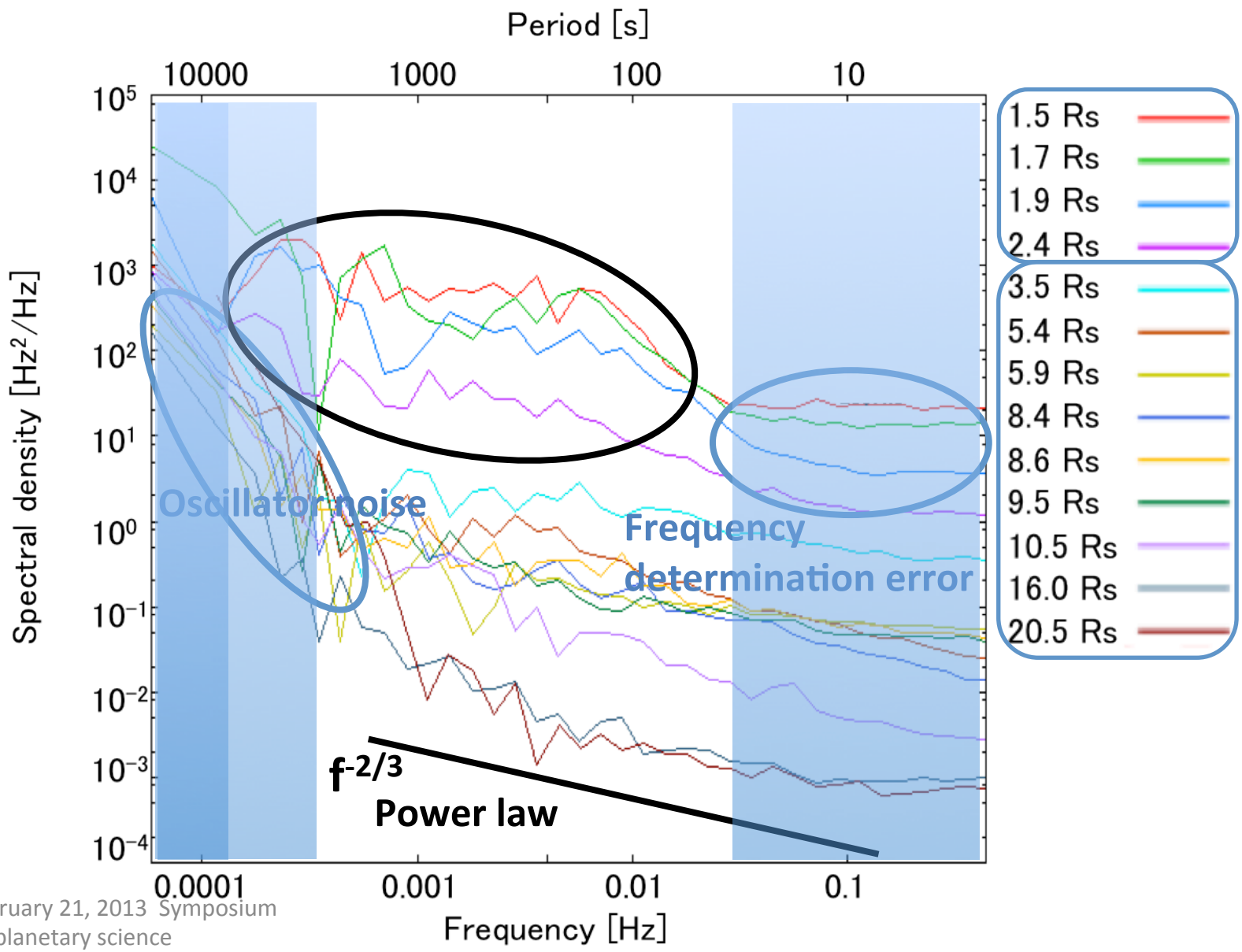
Time series of frequency fluctuation (f')



Fourier analysis

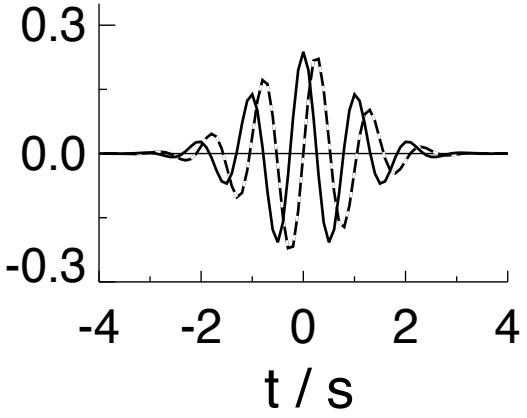
Wavelet analysis

Power Spectra



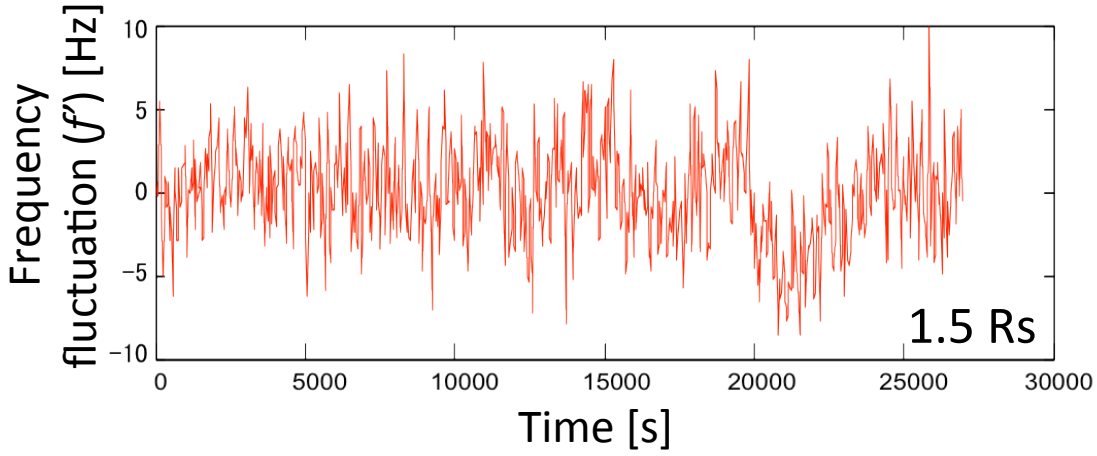
Wavelet Analysis

Morlet function ψ (t / s)

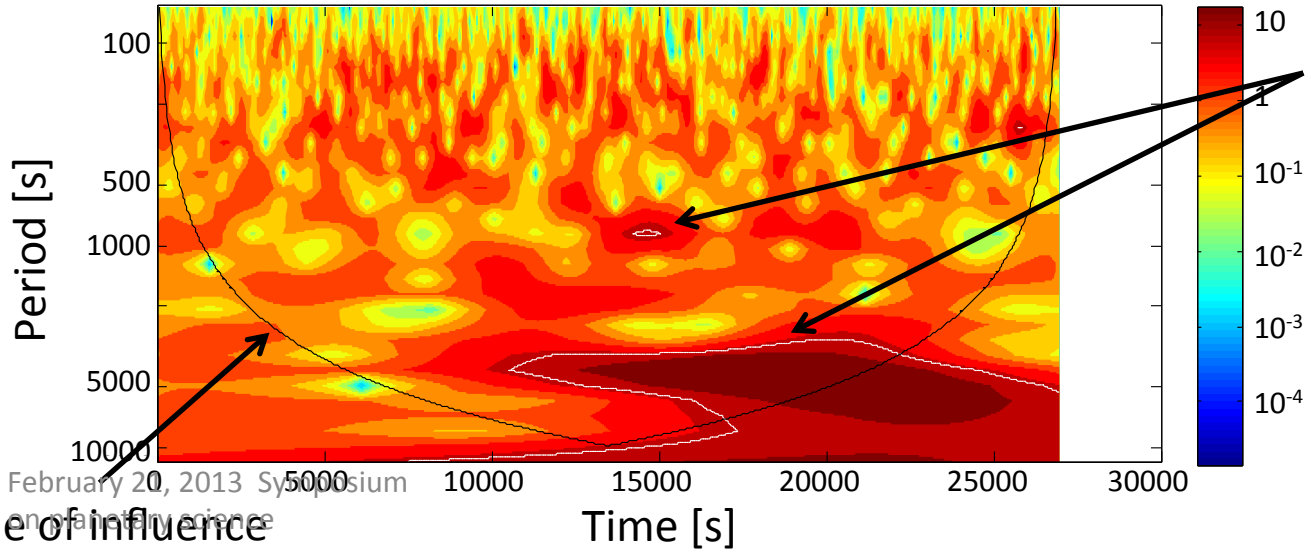


Torrence & Compo (1998)

Convolution integral



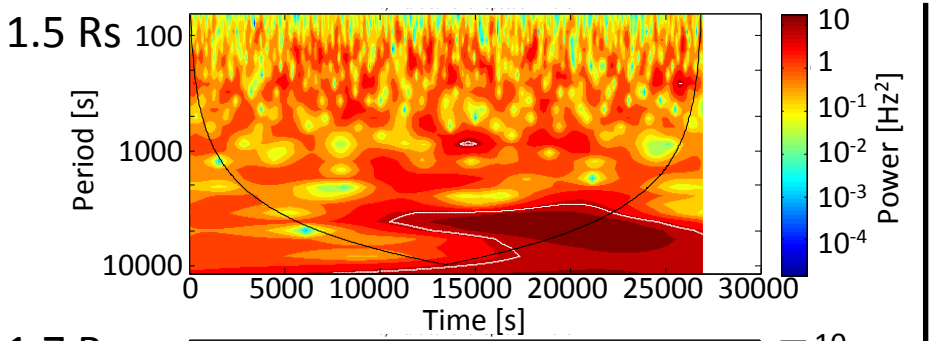
Wavelet transform

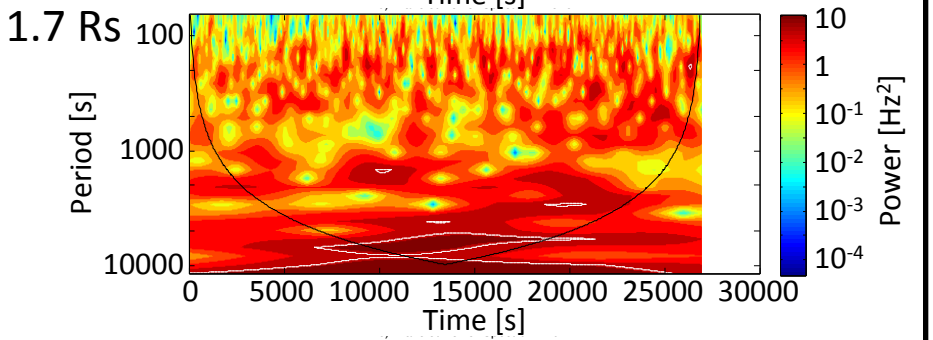


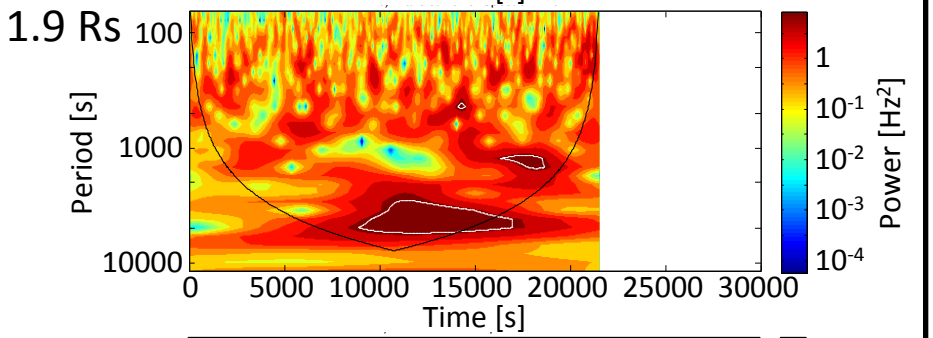
95% significance level evaluated by randomization method (Nemec & Nemec, 1985)

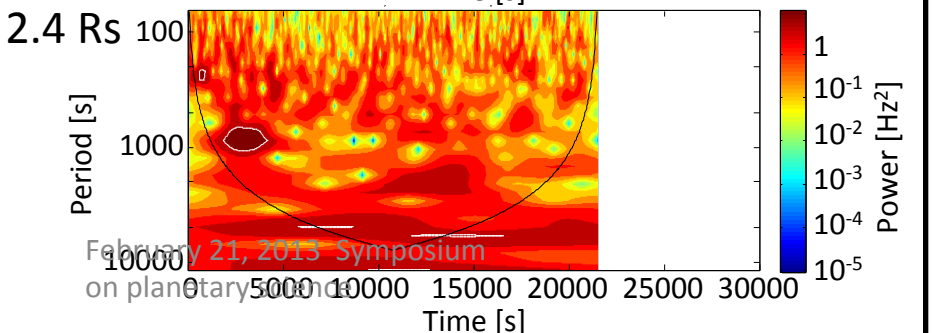
Cone of influence

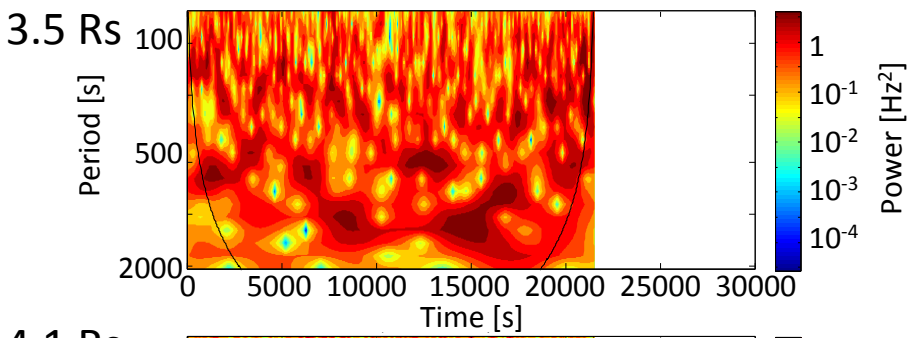
Wavelet Spectra 1.5-5.9 Rs

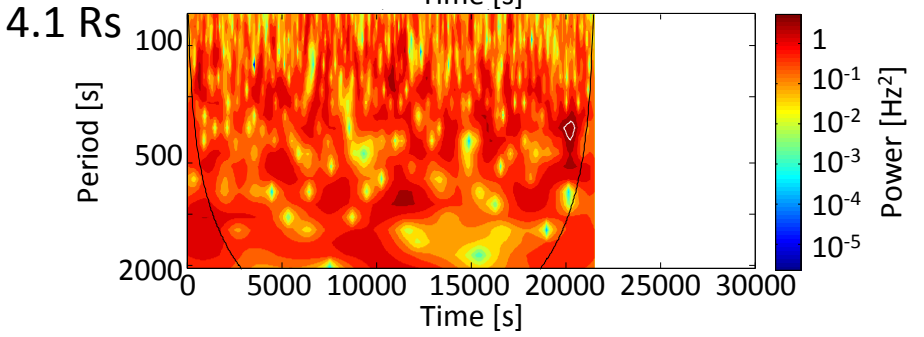


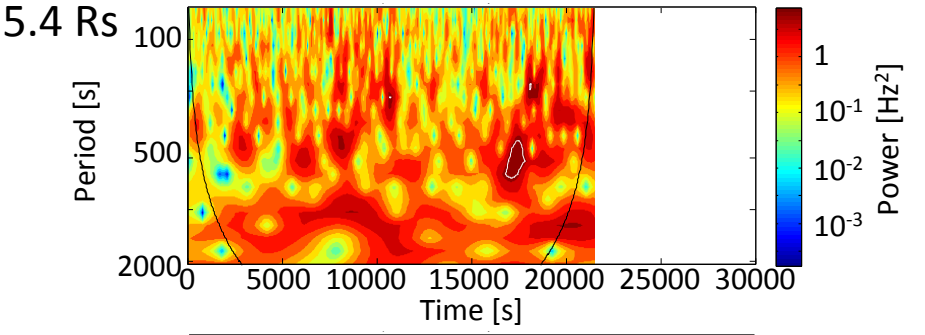


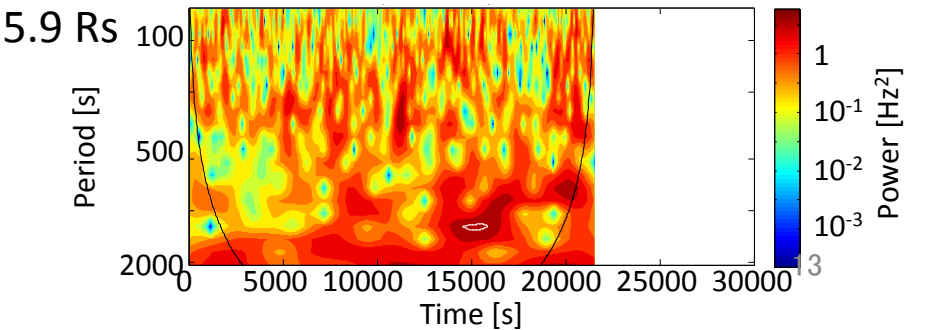




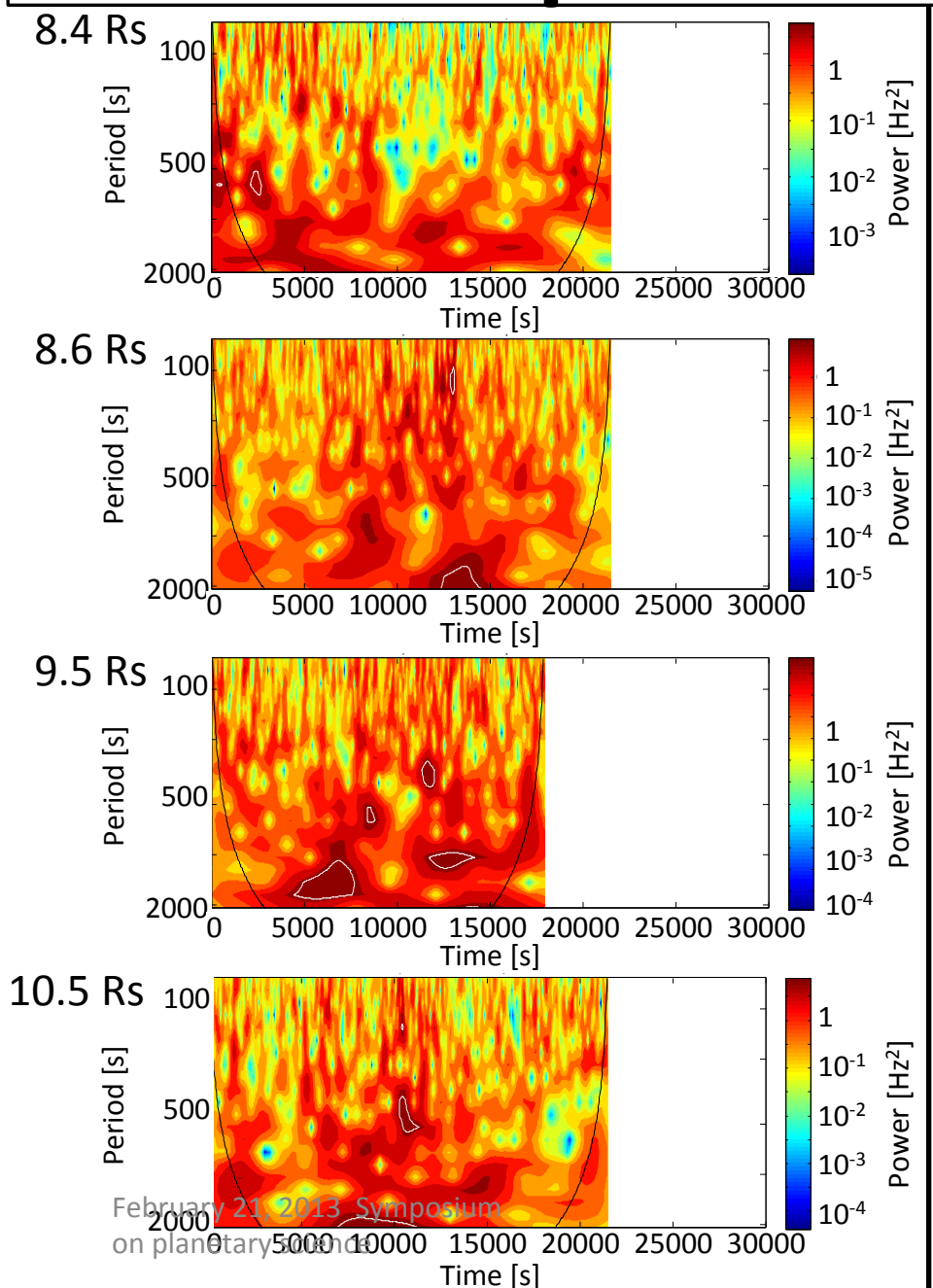


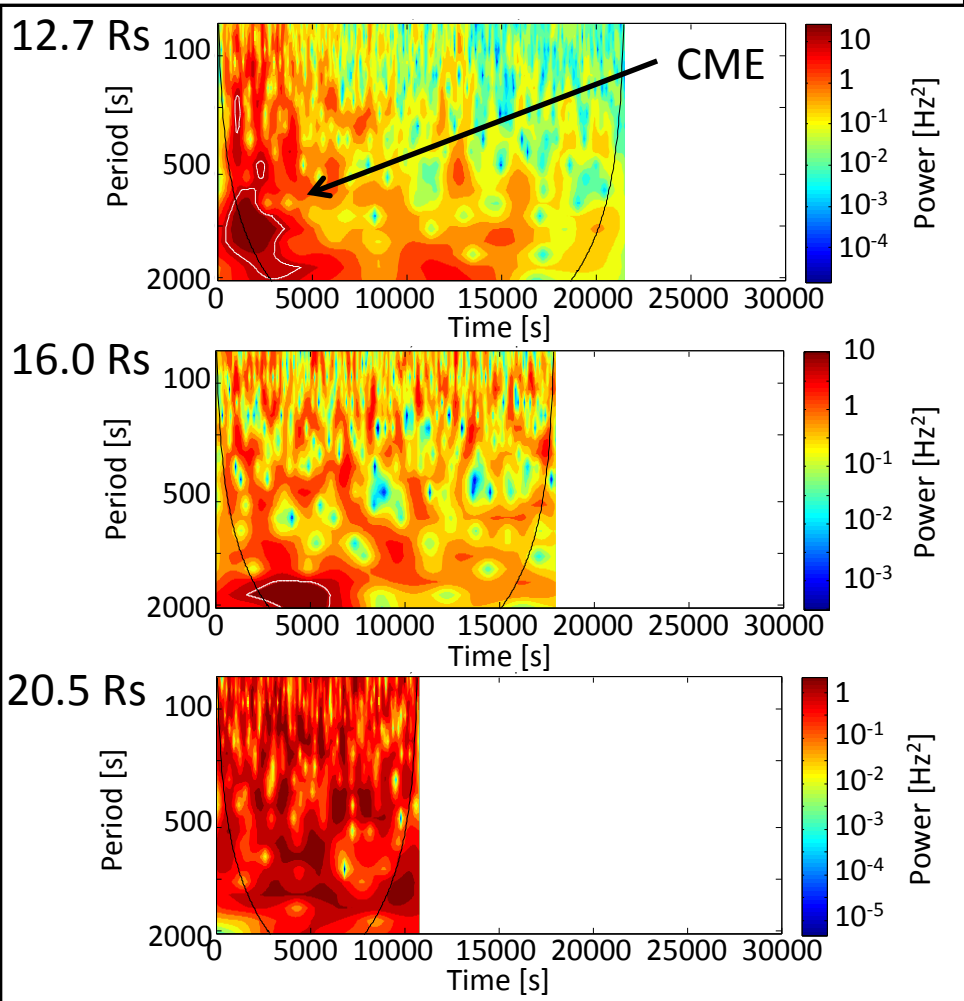




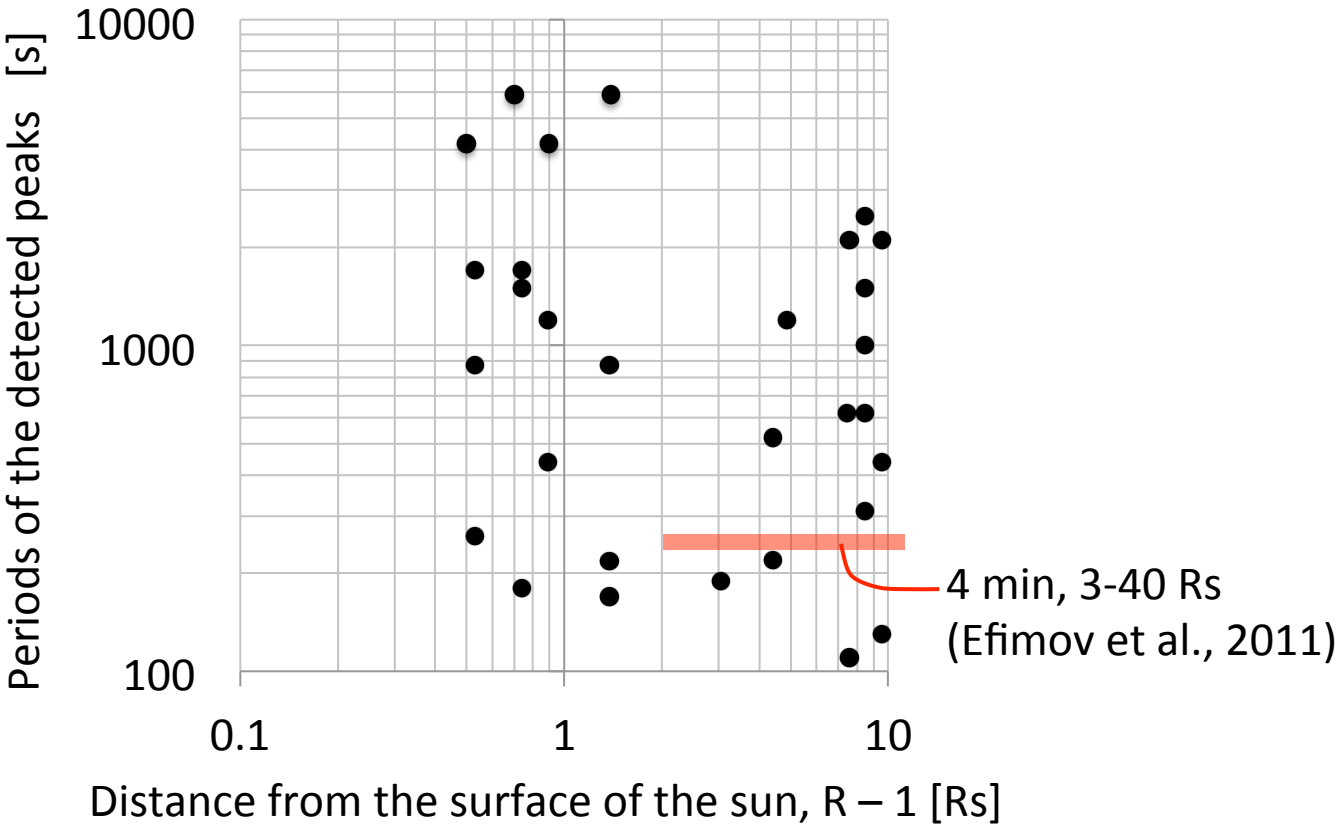


Wavelet Spectra 1.5-5.9 Rs





Periods of the density fluctuations



➡ Density fluctuations having various periods from a few hundred to a few thousand seconds were detected.

Column density variation (N')

Signal frequency fluctuation (f')

$\propto$ Rate of change of the electron column density (dN'/dt)

$$f' = \frac{cf}{\alpha}\frac{dN'}{dt}$$

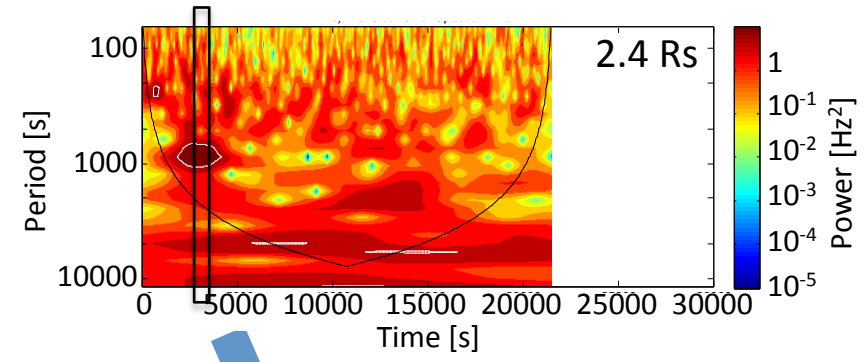
where

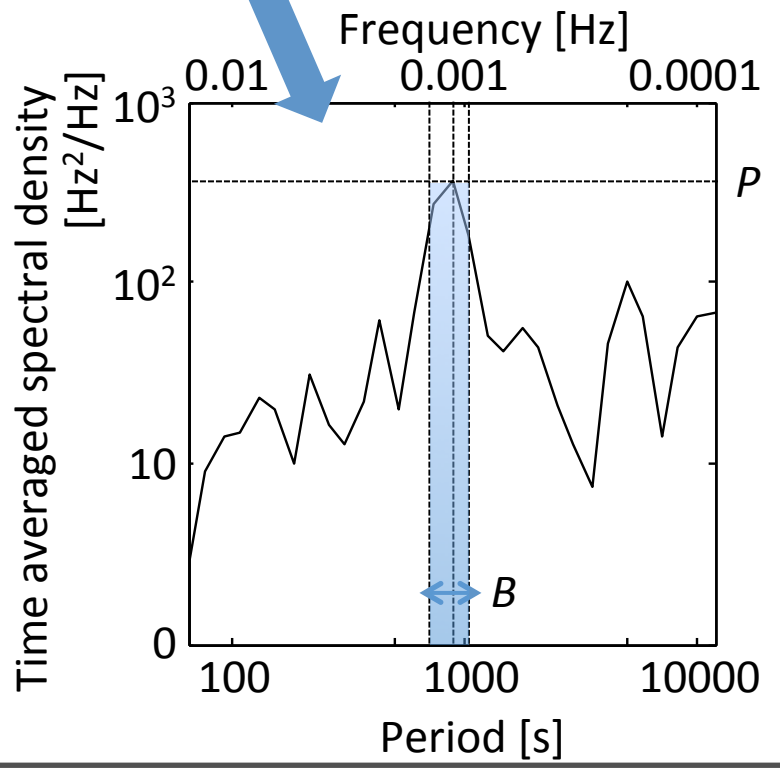
$$f' = \sqrt{PB}$$

Column density variation

$$|N'| = \frac{1}{\omega}\left|\frac{dN'}{dt}\right|$$

$c = 3\times10^8$ m s^{-1} : Light speed
$f = 8.4\times10^9$ Hz : Signal frequency
$\alpha \sim 40.3$ m^3 s^{-2}
P : Peak spectral density
B : Full width at half maximum
ω : angular frequency

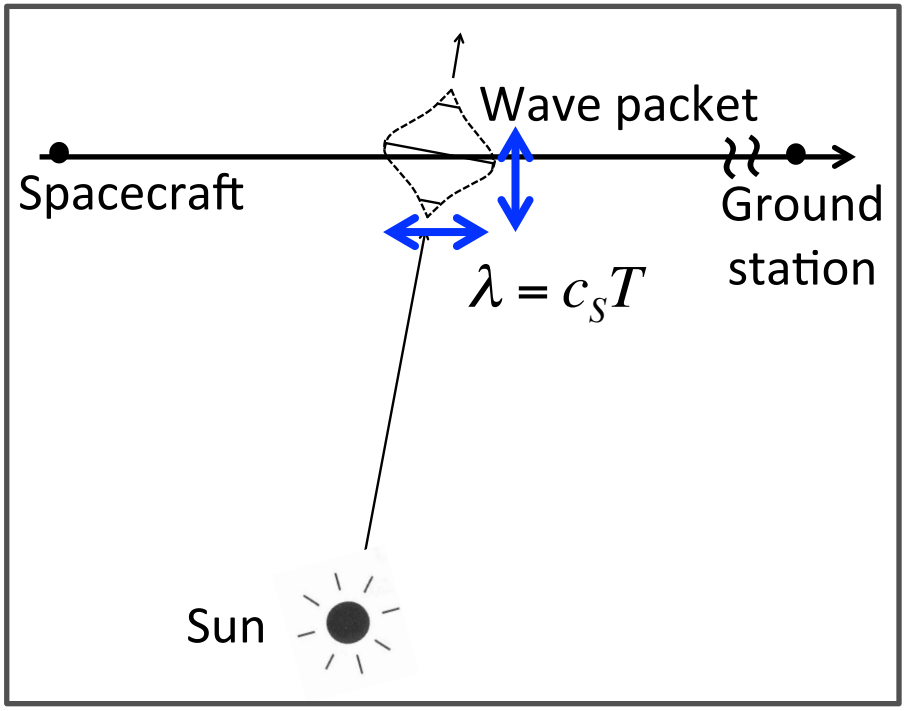




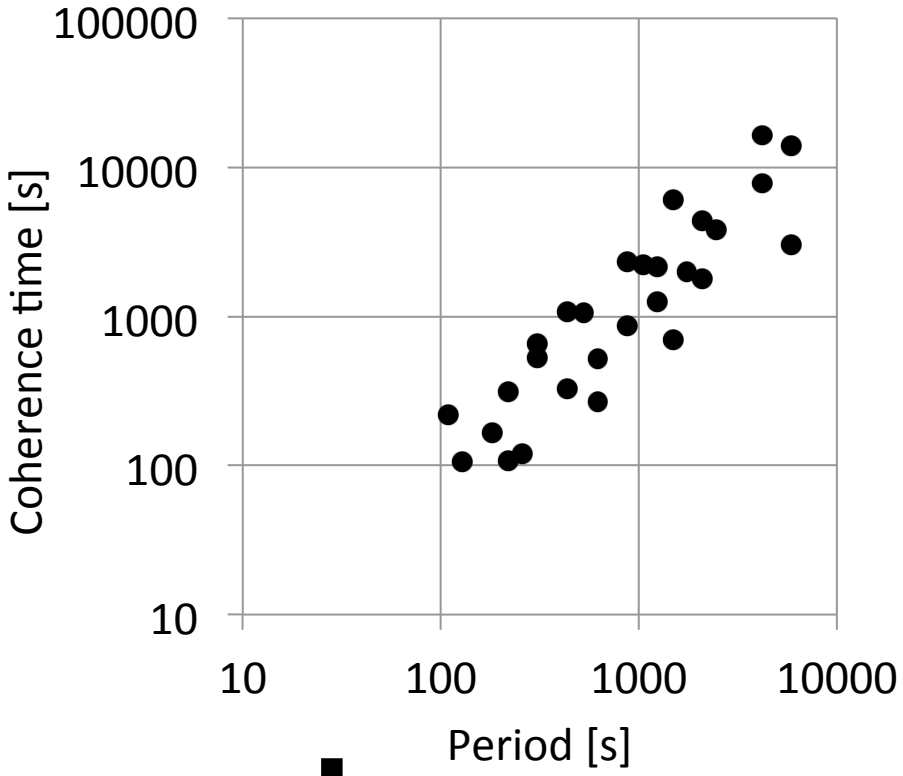
Estimate of density amplitude (n')

The spatial scale of the density fluctuation needs to be assumed.

The density fluctuation is assumed to occurs in a wave packet having a spatial scale comparable to the wavelength.



Periods and coherence time of each events



Density

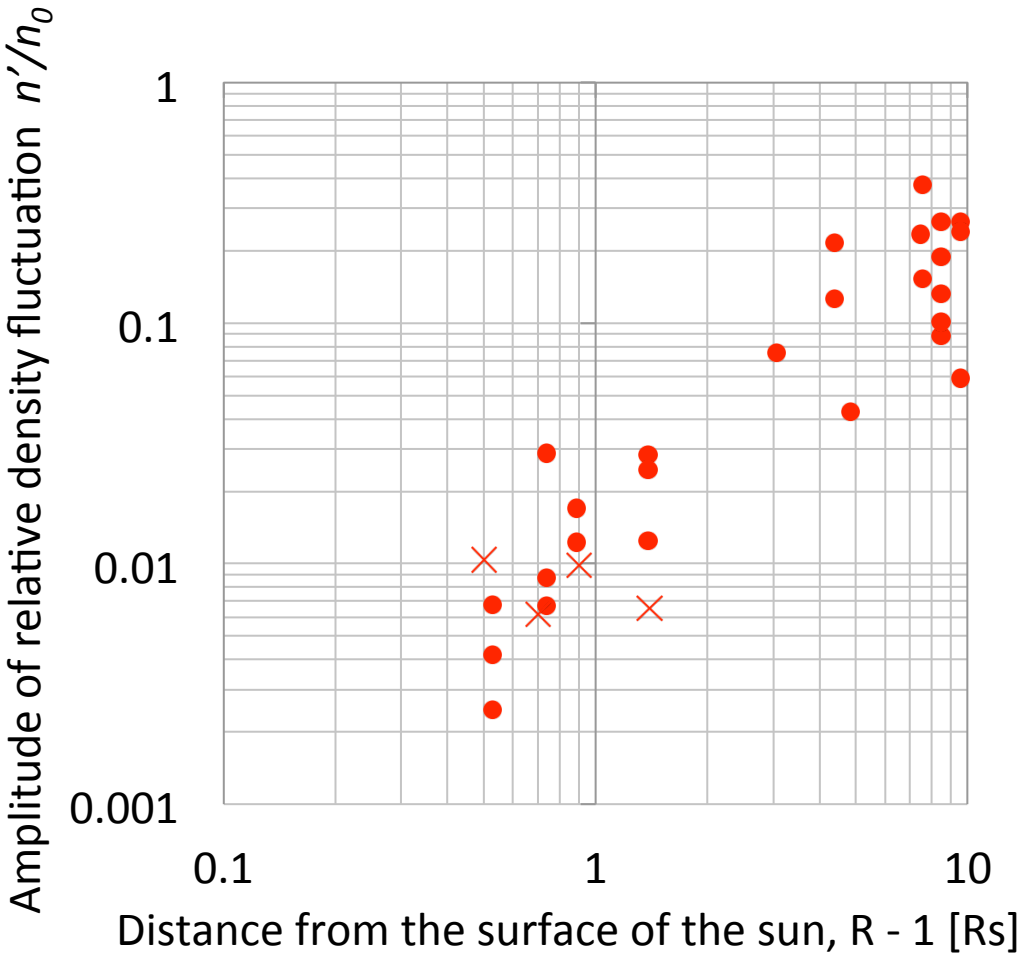
$$n' = \frac{N'}{c_S T}$$

T : Period

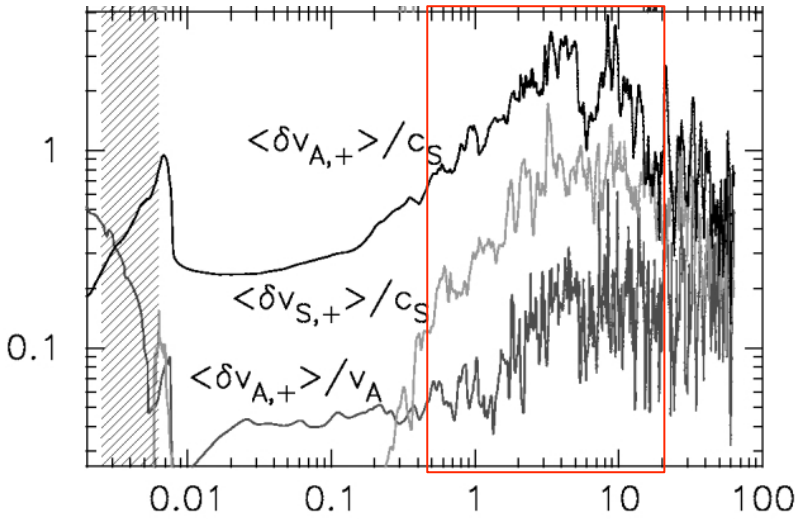
$c_S \sim 150$ km s^{-1} : Light speed

The spatial scale of a wave packet is typically around one wavelength.

Amplitude of relative density fluctuation



1D MHD simulation

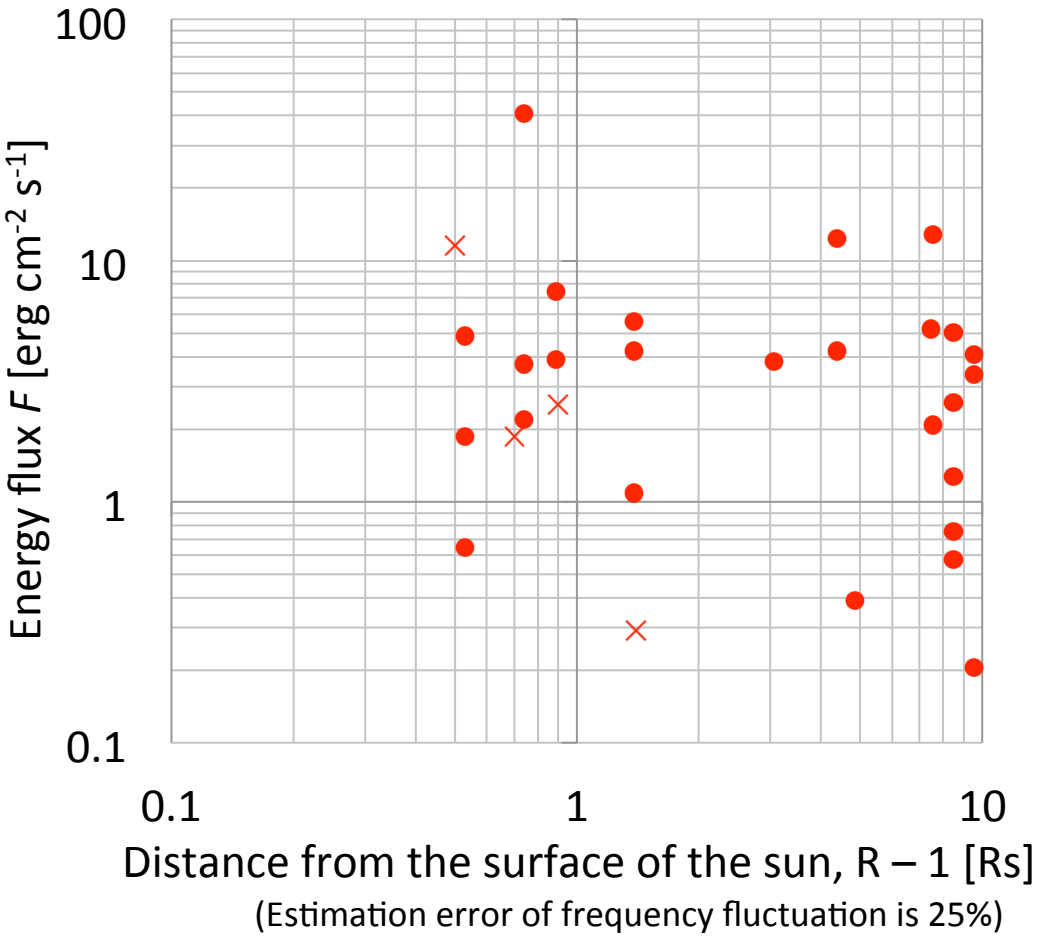


Distance from the surface of the sun
R - 1 [Rs]

Suzuki and Inutsuka (2005)

- The positive correlation between the amplitude of relative density fluctuation and the heliocentric distance is qualitatively similar to that in the simulation.
- The absolute values are smaller than those in the simulation.

Energy flux of acoustic wave (F')



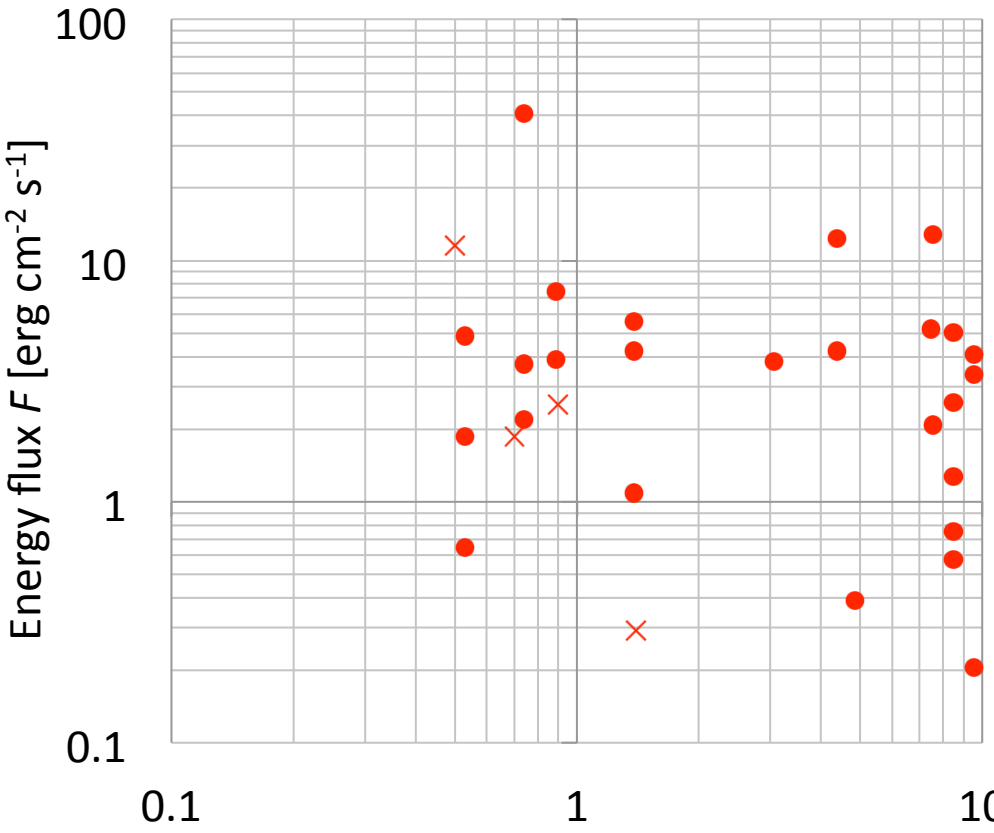
Energy flux of acoustic wave

$$F = \varepsilon c_S = c_S^3 \frac{a n'^2}{n_0}$$

ε : Energy density
a : Atomic mass unit

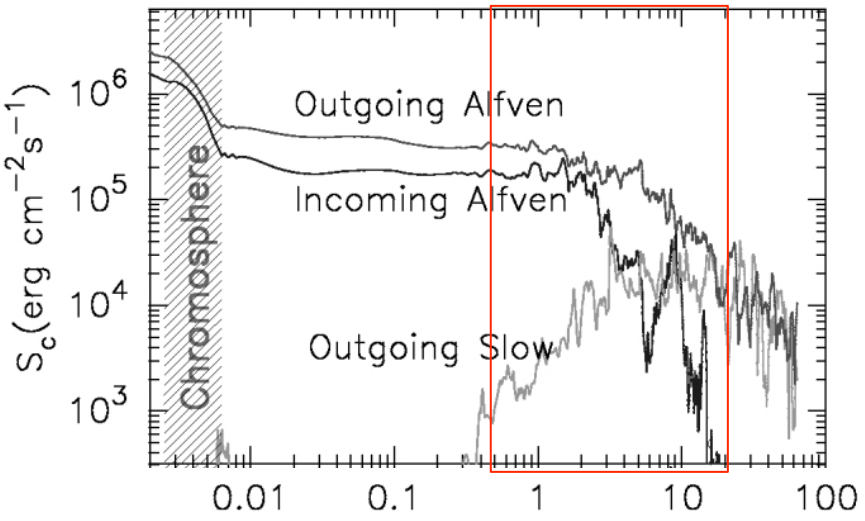
- The estimated energy fluxes are smaller than those in the simulation.

Energy flux of acoustic wave (F')



(Estimation error of frequency fluctuation is 25%)

1D MHD simulation



Distance from the surface of the sun
R - 1 [Rs]

Suzuki and Inutsuka (2005)

- The estimated energy fluxes are smaller than those in the simulation.

Summary

To examine the radial dependence of the characteristics of acoustic waves, we analyzed the radio occultation data near the sun and detected density fluctuations which can be interpreted as acoustic waves.

- The overall spectral feature is near power-law at large heliocentric distances.
- Density fluctuations having various periods from a few hundred to a few thousand seconds were detected near the sun.
- The positive correlation between the amplitude of relative density fluctuation and the heliocentric distance is qualitatively similar to that in the simulation, but the absolute values are smaller than those in the simulation.
- The estimated energy fluxes are also smaller than those in the simulation.
- We should note that only quasi-monochromatic fluctuations were considered as waves in this study.