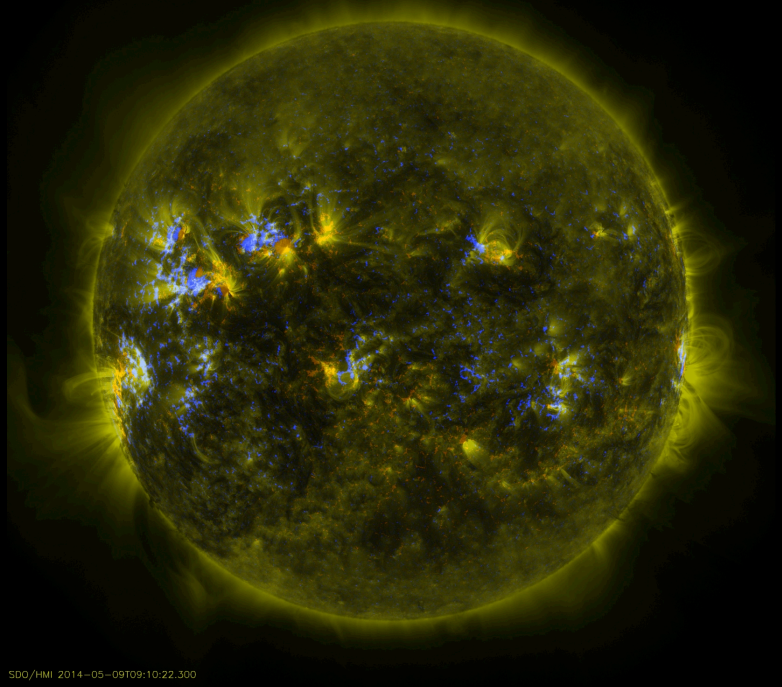
Atmospheric seismology of solar active regions



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Freiburg, Germany

STOCKHOLM, SUNSPOT FORMATION, 09-13 March 2015

Outline

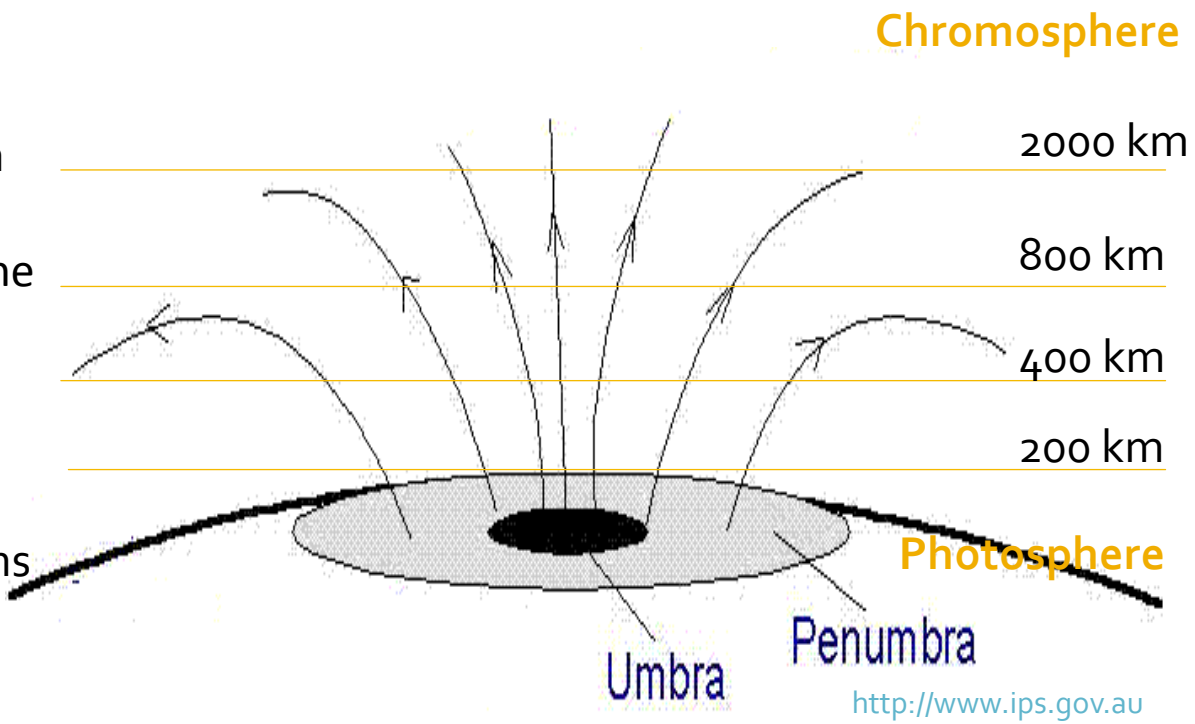
- Motivation for research
- Observational challenge(MULTI-HEIGHT observation) instrument & measurement
- Helioseismic analysis

Quiet Sun area as a context to the active region and sunspot results

- Summary

Motivation

- Provide MULTI-wave length observations
- Investigating the propagation of acoustic waves to understand the structure of the quiet and magnetized atmosphere
- Propagation of an acoustic waves above the active regions and the sunspots



Motivation

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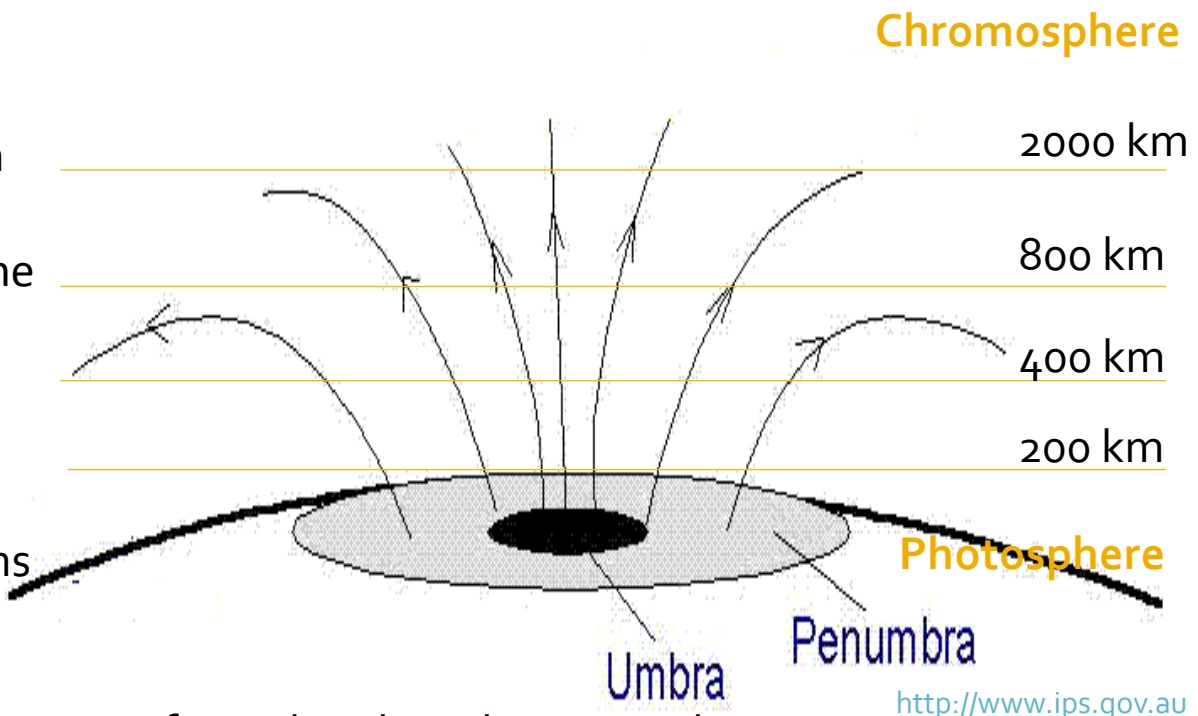


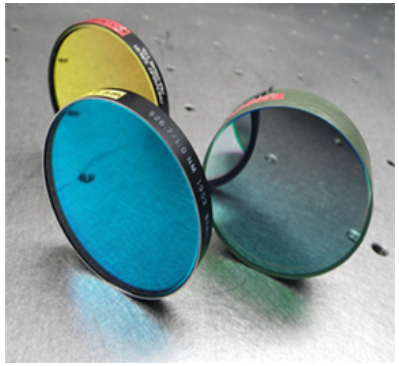
http://www.ips.gov.au

- Analysis of the kinematic energy transfer within the solar atmosphere at high temporal and spatial resolution.
- Estimating the deposit of acoustic energy with height.
- Confirmation of formation heights for the spectral lines

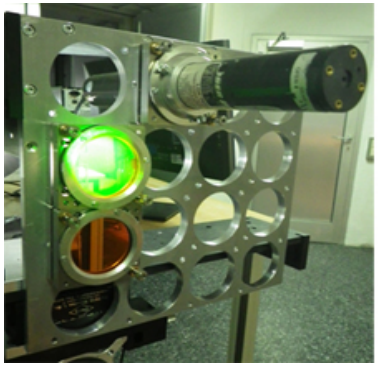
The instrument : HELLRIDE @ VTT

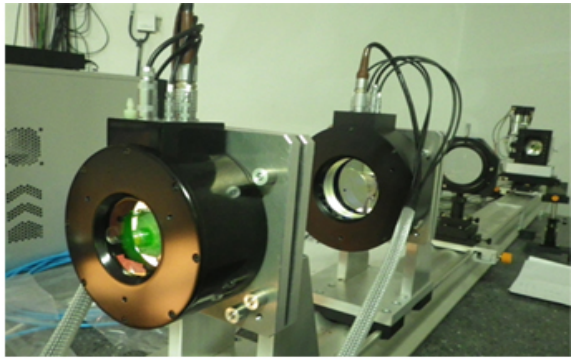
- We carry out the observation with the new Fabry-Pérot based spectrometer HELLRIDE (Helioseismologic Large Regions Interfeometric Device) @ the Vacuum Tower Telescope, Tenerife.

- HELLRIDE was designed and developed in KIS for helioseismic measurements



Interference filters





the filter-matrix , double etalon system.

Staiger, A&A (2009)
Staiger A&A (2011)

measurements

Prefilters: 8
Spectral lines: 10

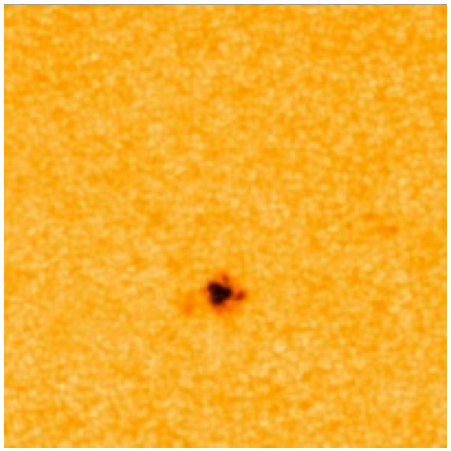
Height difference: about 1400 *km*
(middle photosphere – lower chromosphere)

FoV**: 100 arc sec**
Image size: 512 x 512 pixels
Resolution => 0,2 arcsec / pixel
Cadence : 60 sec
Total time of measurement: 8,5 hours

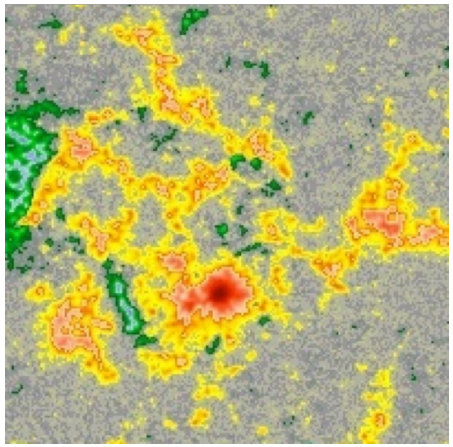
QS [nm]	AR [nm]	SS [nm]
Fe I 543.4	Fe I 543.4	Fe I 543.4
Na I D 2	Fe I 543.3	Fe I 543.3
589.0	Na I D2	Na I D2
Na I D 1	589.0	589.0
589.6	Ni 589.3	Ni 589.3
H alpha	Na I D1	Na I D1
656.2	589.6	589.6
Fe I 557.6	H alpha	H alpha
Fe I 630.2	656.2	656.2
Fe I 630.1	Fe I 557.6	Fe I 557.6
Fe I 630.2	Fe I 630.2	Fe I 630.2
Mg I 517.2	Mg I 517.2	Mg I 517.2
Fe I 617.3	Fe I 617.3	Fe I 617.3
(HMI line)		

Absorption line	Lande g	Pre-filter width [Å]	Formation height [km]
Mg b2 5172	1.75	10	583±100
Fe I 5434	0	4.0	687 ±250
Fe I 5576	0	3.0	402±105
Na D2 5890	0	3.2	961±200
Na D1 5896	0	3.0	580±600
Fe I 6173	0	3.0	332±230
Fe I 6301	1.6	3.0	304±120
Fe I 6302	2.5	3.0	337±100
Hα 6563	0	6.0	1986(*)±150
			(*) intensity contribution function

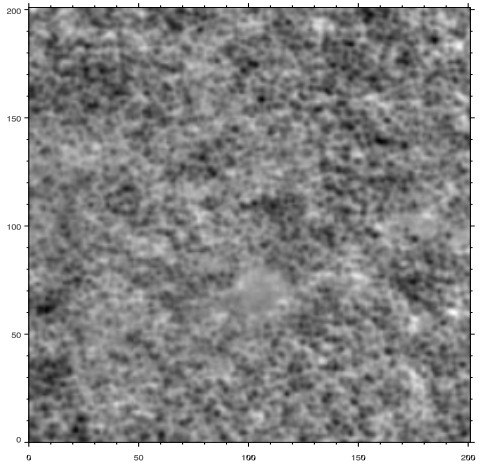
Pore [AR 12053]



a) the Intensity map from HMI instrument (450.0 nm)

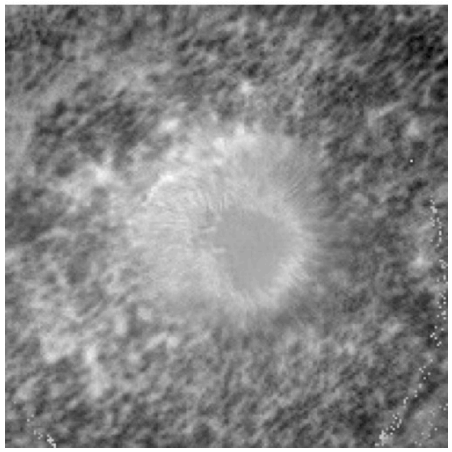


b) Colorized magnetogram from HMI instrument

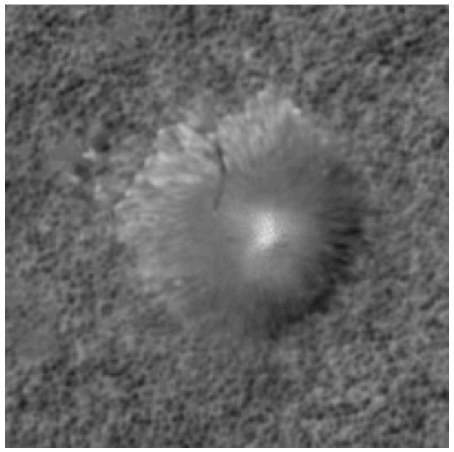


c) the Dopplergram from HMI instrument for the same region

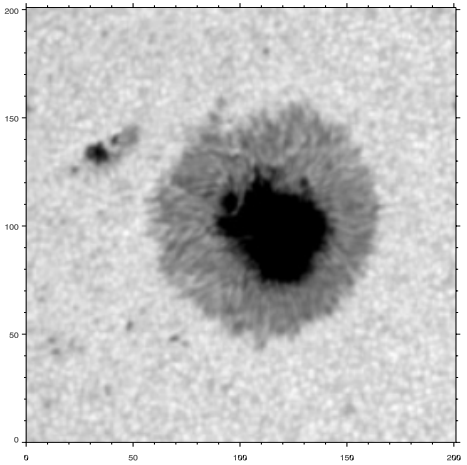
Active Region [AR 12055]



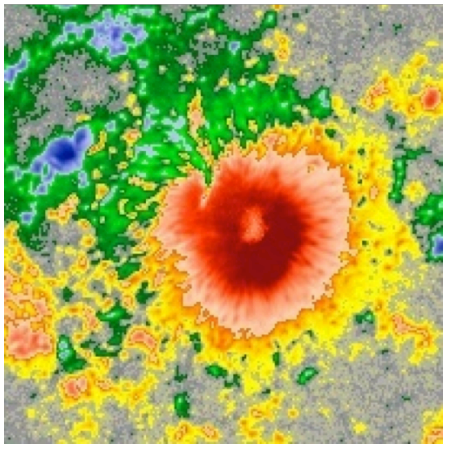
a) velocity field calculated from HELLRIDE in the Sun Spot (AR 12055) in a wavelength 617.3 nm



b) the Dopplergram from HMI instrument
for the same sunspot

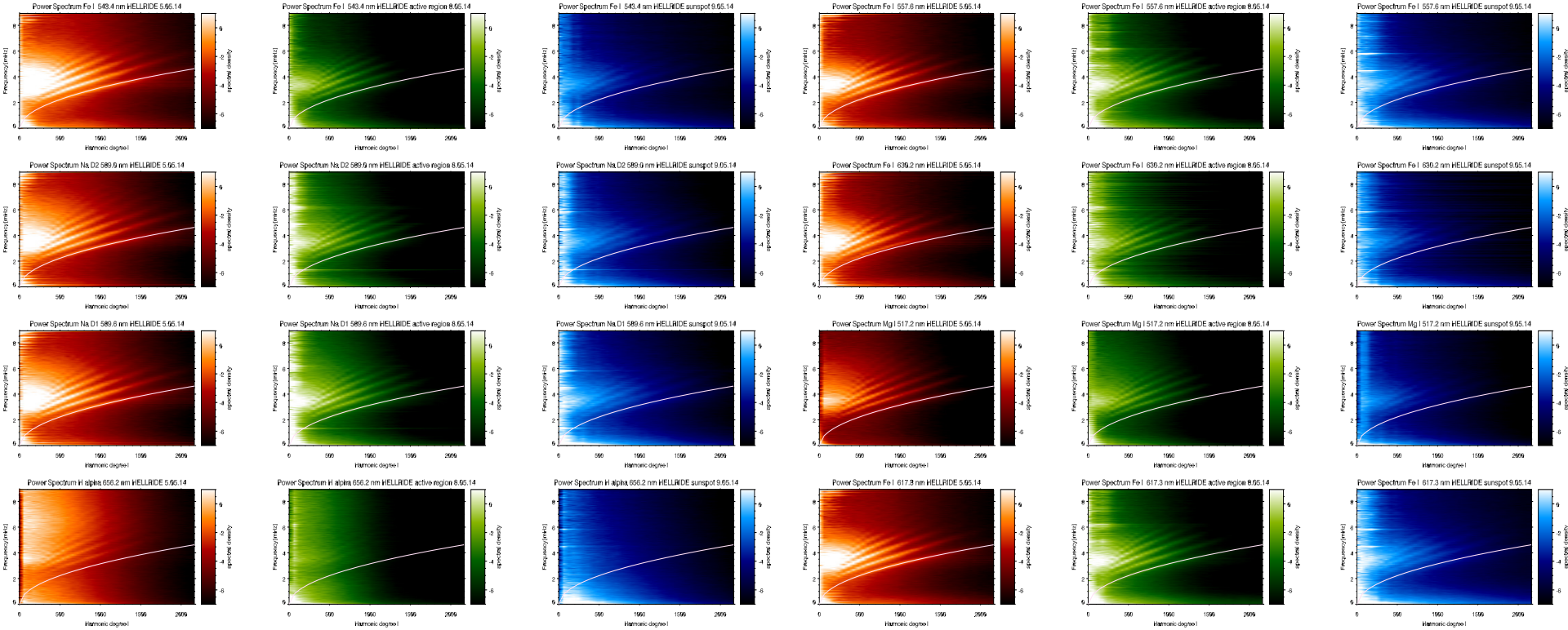


c) the Intensity map from HMI instrument (450.0 nm)



d) Colorized magnetogram from HMI instrument

Results from Mai 2014
Quiet Sun, Active Region, Sunspot



Wisniewska, Roth, Staiger 2015 in prep.

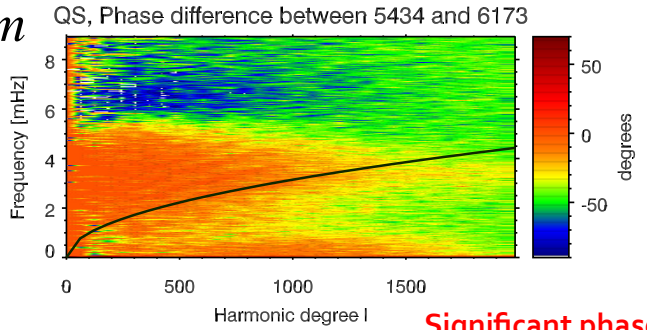
The cut off frequency in the QS

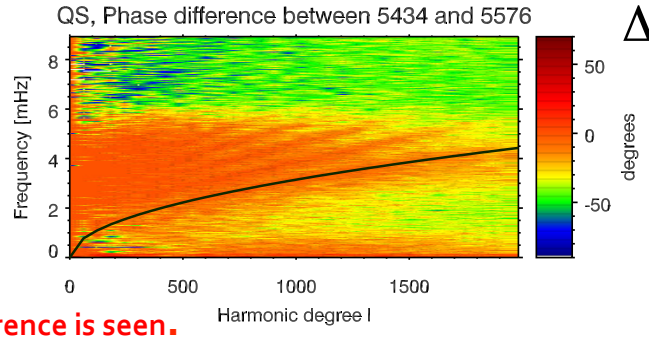
- The cut-off frequency represents highest frequency for acoustic solar eigenmodes. Is an important parameter of the solar atmosphere as it determines the upper boundary of the p-mode resonant cavities.

- In solar case: $\omega_c / 2\pi = 5.3 mHz$

Phase differences for spectral lines 5434 and 6173, 5576

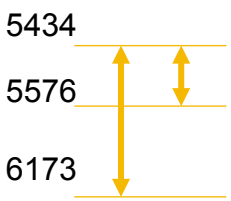
$\Delta z \approx 360 km$

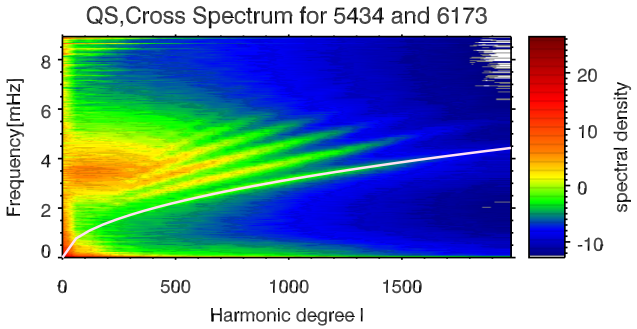


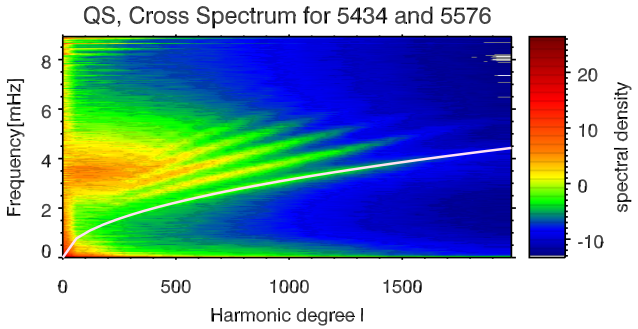


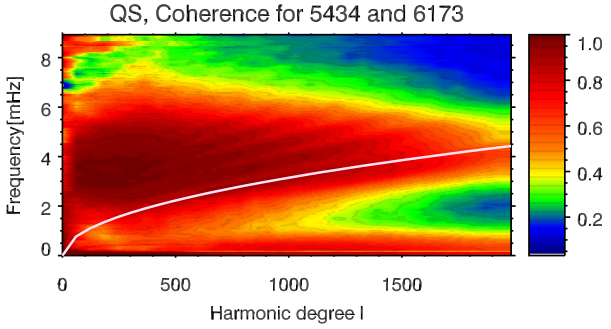
$\Delta z \approx 160 km$

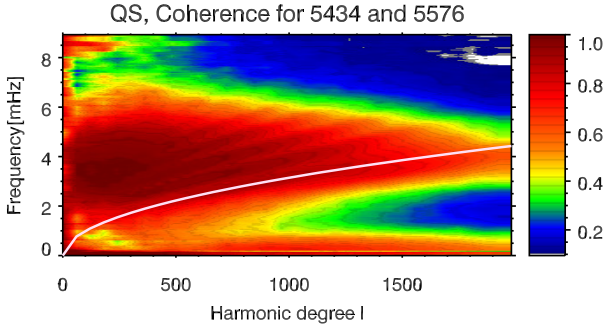
Significant phase difference is seen.





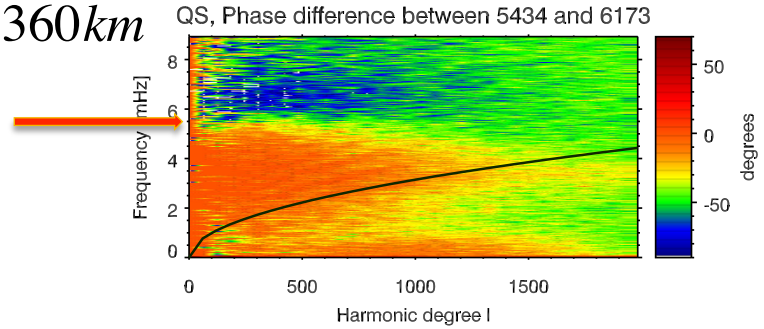


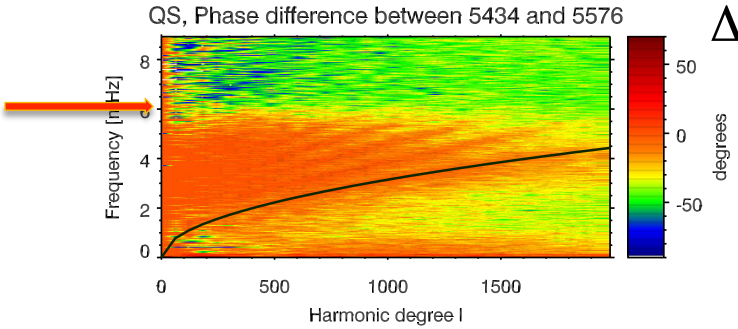




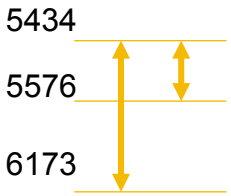
Phase differences for spectral lines 5434 and 6173, 5576

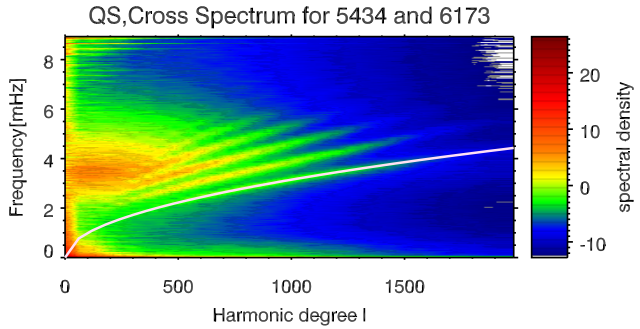
$\Delta z \approx 360 km$

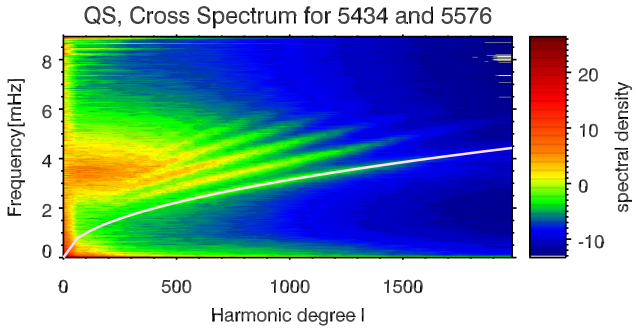


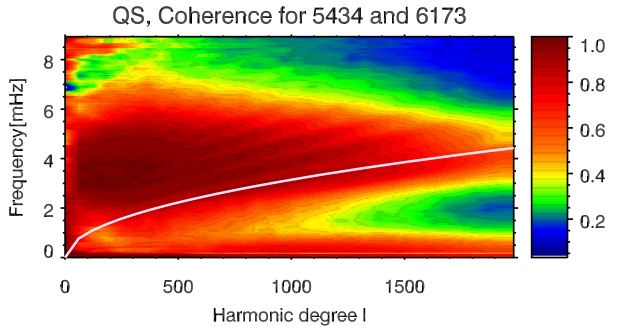


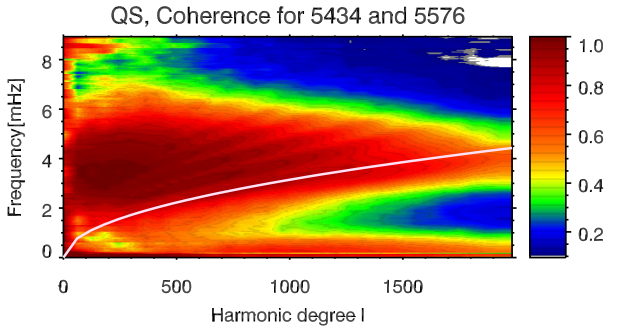
$\Delta z \approx 160 km$







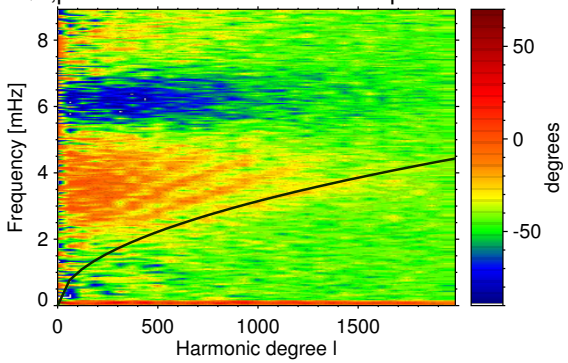




Phase diagrams QS for H alpha with other 6 spectral lines

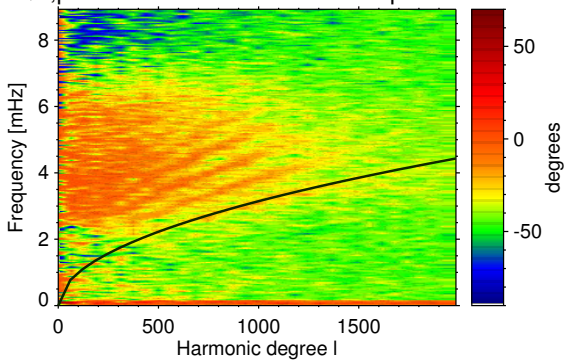
$\Delta z \approx 1400 km$

a) QS,phase difference between H alpha and 6173



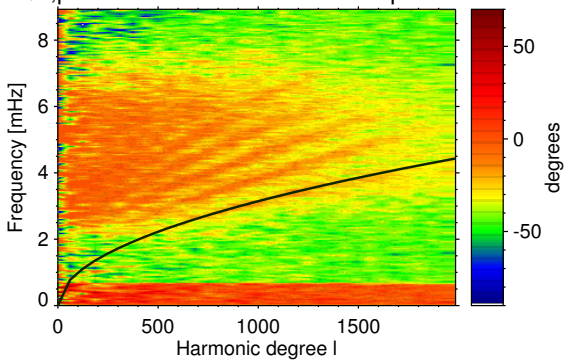
$\Delta z \approx 1100 km$

c) QS,phase difference between H alpha and 5172

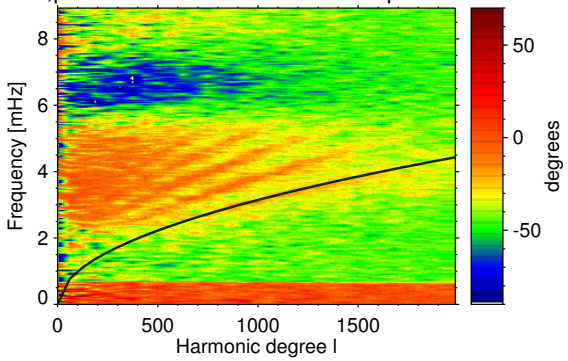


$\Delta z \approx 900 km$

e) QS,phase difference between H alpha and 5896

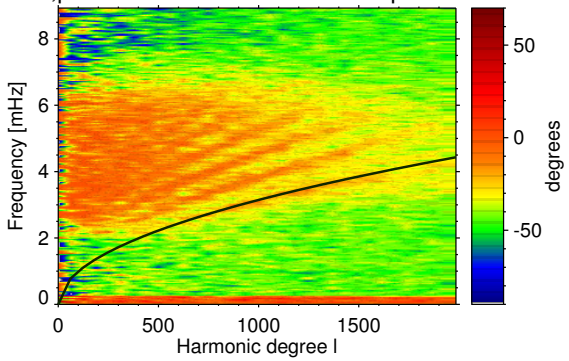


b) QS,phase difference between H alpha and 5576



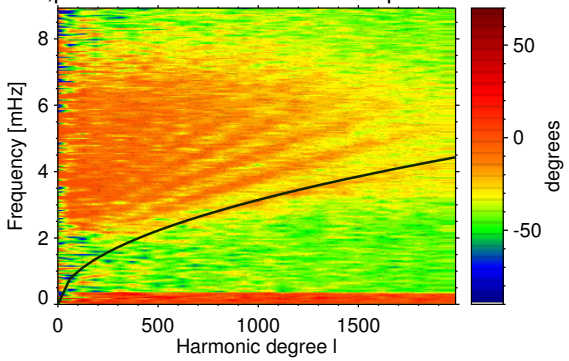
$\Delta z \approx 1300 km$

d) QS,phase difference between H alpha and 5434



$\Delta z \approx 1000 km$

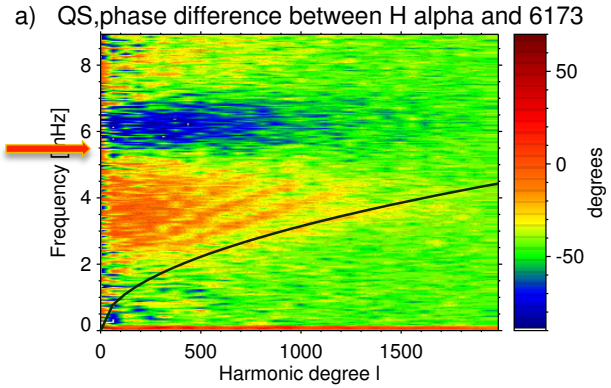
f) QS,phase difference between H alpha and 5890



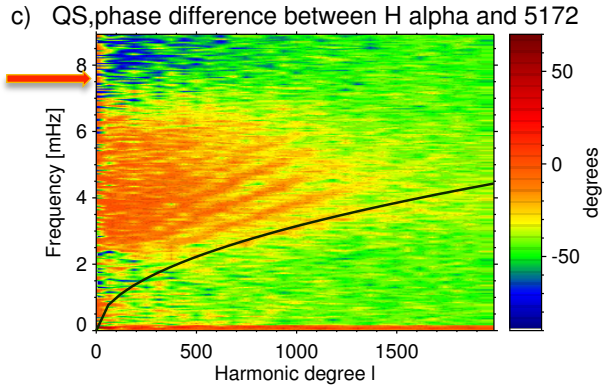
$\Delta z \approx 800 km$

Phase diagrams QS for H alpha with other 6 spectral lines

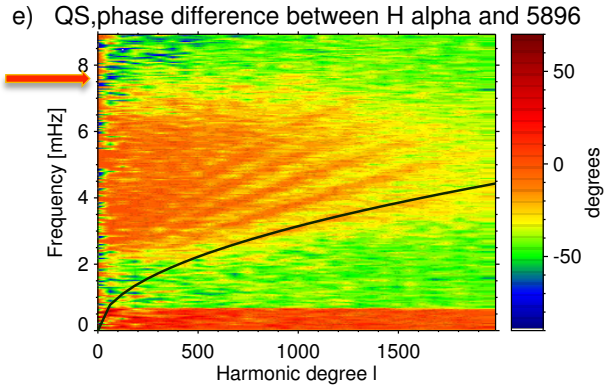
$\Delta z \approx 1400 km$

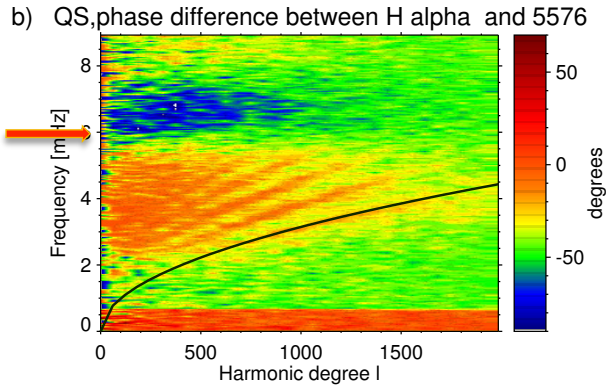


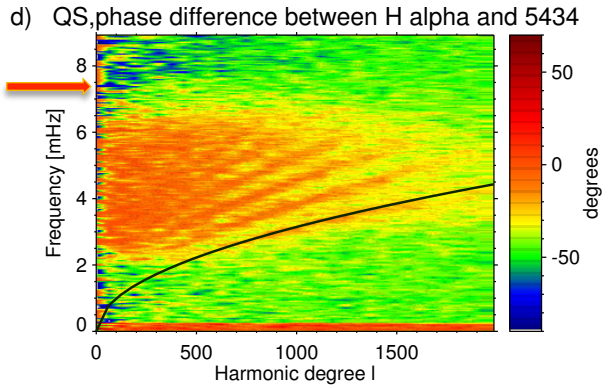
$\Delta z \approx 1100 km$

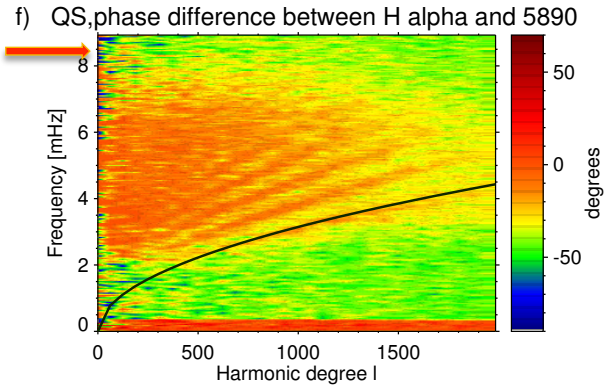


$\Delta z \approx 900 km$









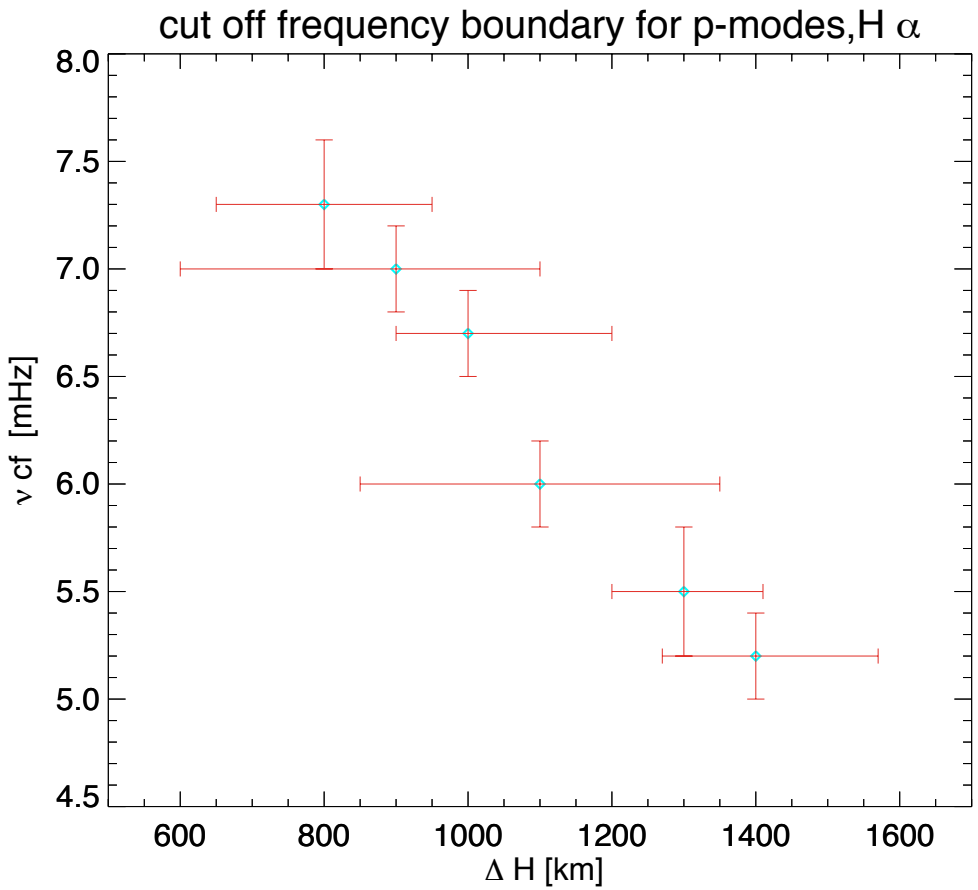
$\Delta z \approx 1300 km$

$\Delta z \approx 1000 km$

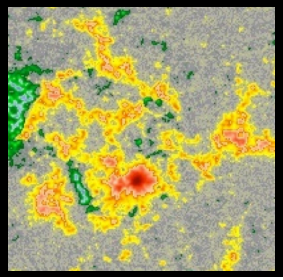
$\Delta z \approx 800 km$

Cut-off frequency is shifted towards higher frequencies

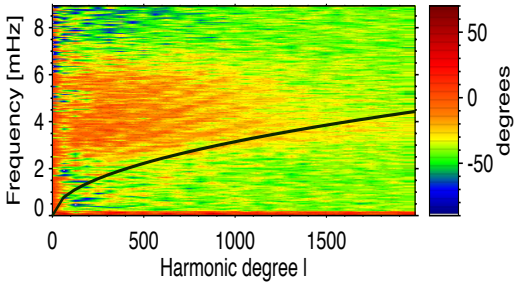
Cut off frequency as a function of height in the solar atmosphere



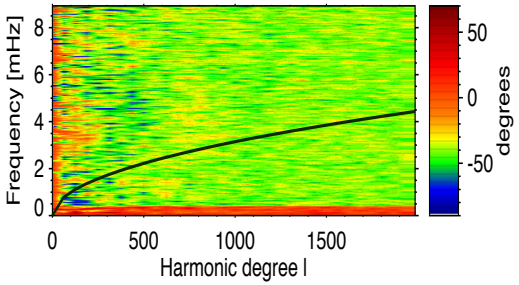
Active Region – pore
Phase diagrams



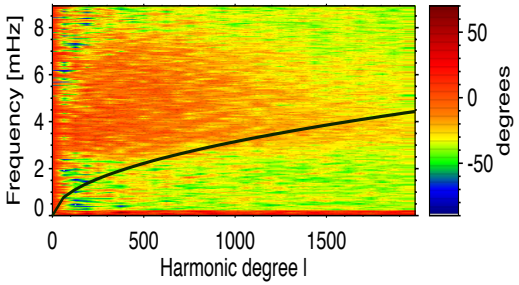
a) AR,phase difference between H alpha and 5433



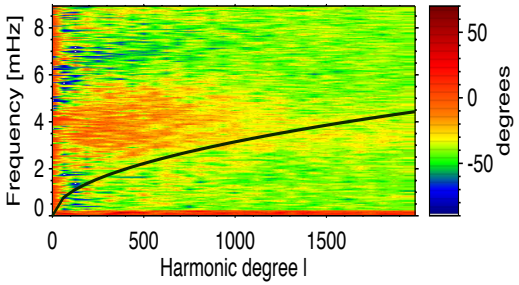
d) AR,phase difference between H alpha and 6302



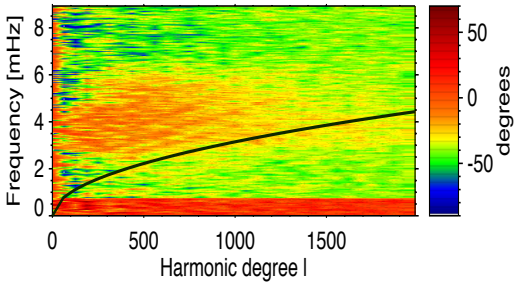
g) AR,phase difference between H alpha and 5434



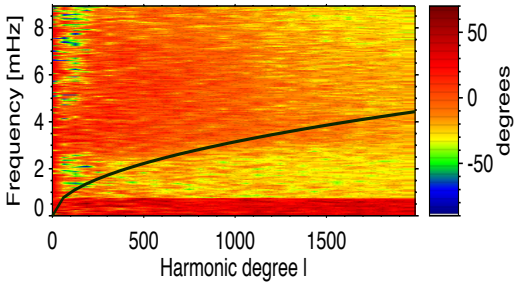
b) AR,phase difference between H alpha and 6173



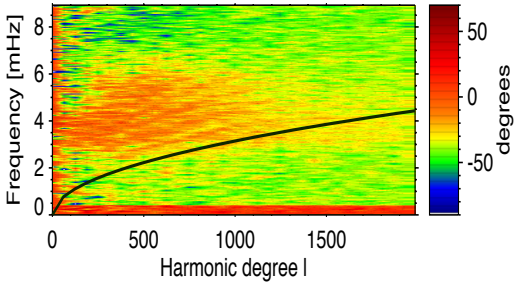
e) AR,phase difference between H alpha and 5576



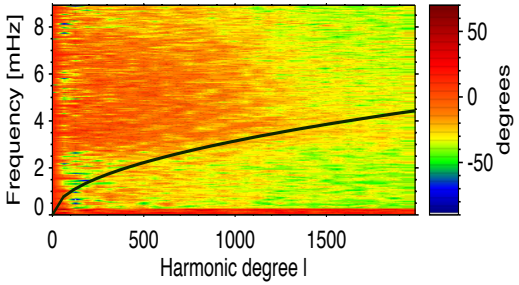
h) AR,phase difference between H alpha and 5896



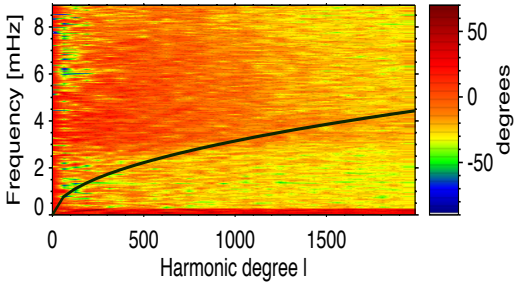
c) AR,phase difference between H alpha and 5893



f) AR,phase difference between H alpha and 5172

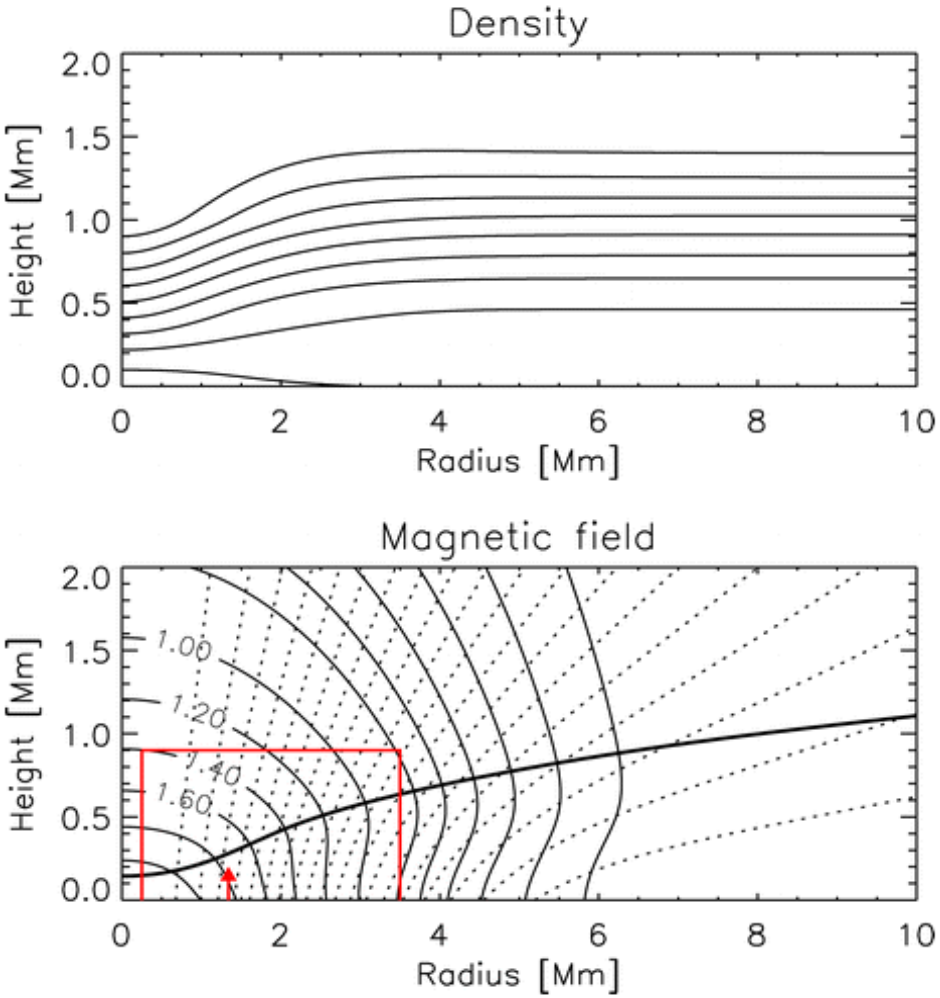


i) AR,phase difference between H alpha and 5890



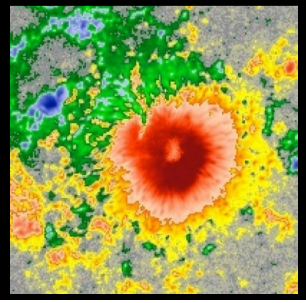
Sunspot model

Magnetohydrostatic Sunspot model from deep **subphotospheric** to **chromospheric** layers, up to 2000km

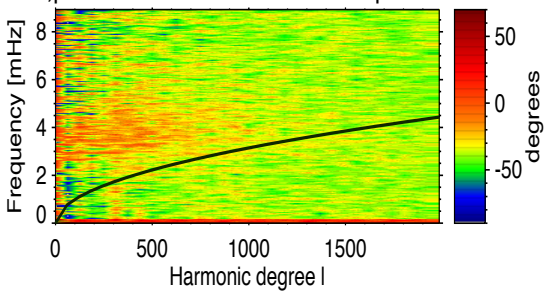


Khomenko & Collados, ApJ, (2008)

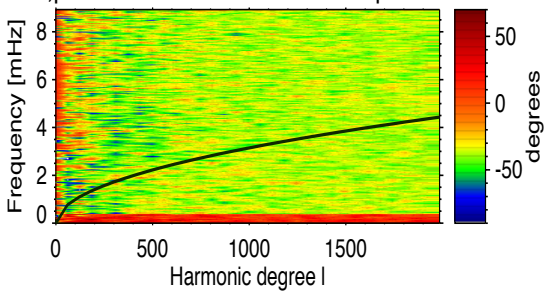
Sunspot Phase diagrams



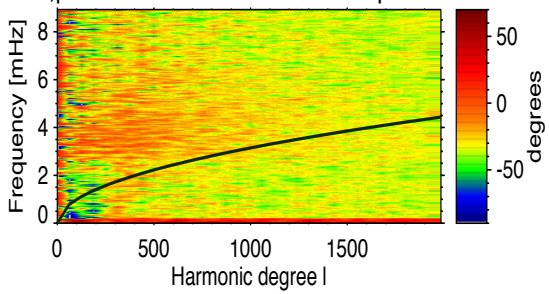
a) SP,phase difference between H alpha and 5433



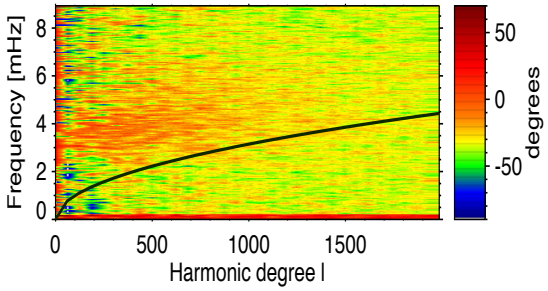
d) SP,phase difference between H alpha and 6302



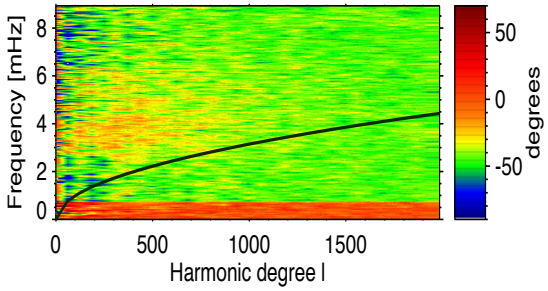
g) AR,phase difference between H alpha and 5434



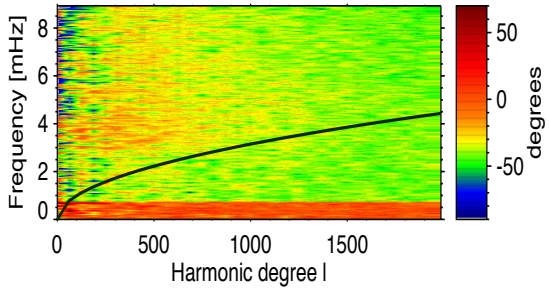
b) SP,phase difference between H alpha and 6173



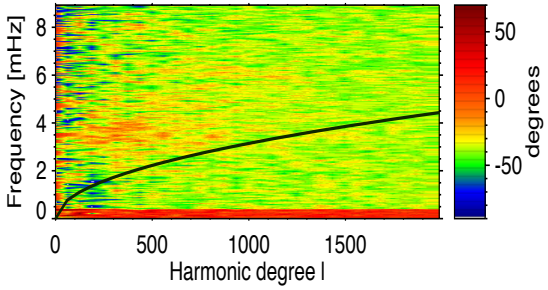
e) SP,phase difference between H alpha and 5576



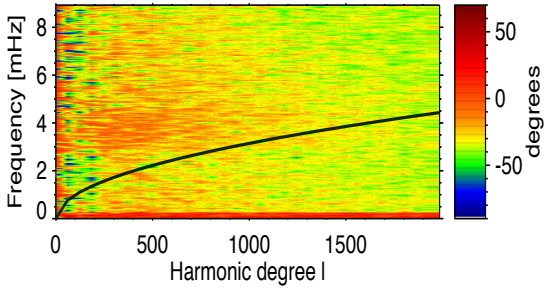
h) SP,phase difference between H alpha and 5896



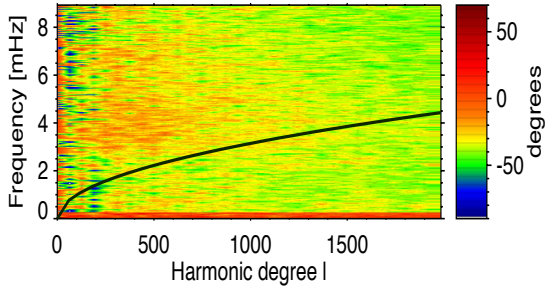
c) SP,phase difference between H alpha and 5893



f) SP,phase difference between H alpha and 5172



i) SP,phase difference between H alpha and 5890

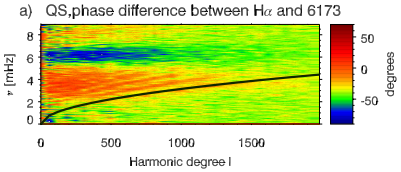


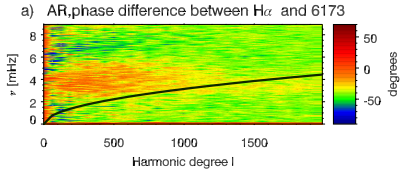
Phase diagrams for 3 regions

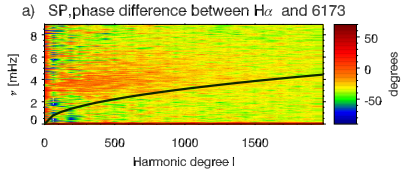
QS AR SP

Photosphere

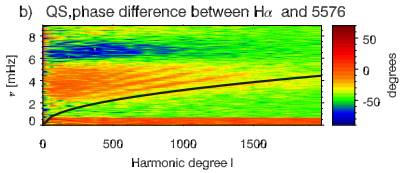
$\Delta z \approx 1400 km$

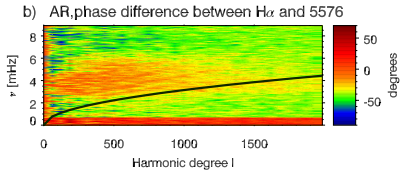


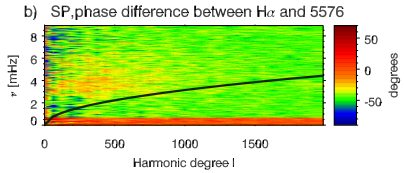




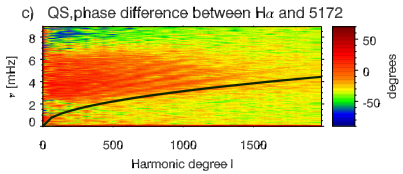
$\Delta z \approx 1300 km$

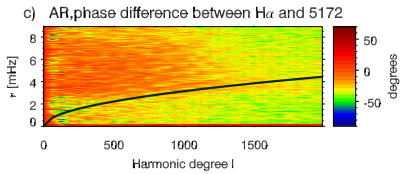


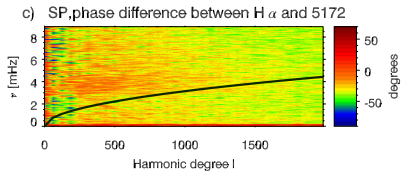




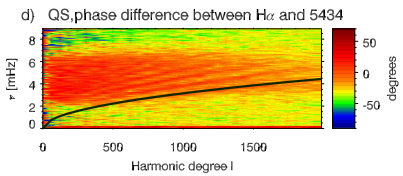
$\Delta z \approx 1100 km$

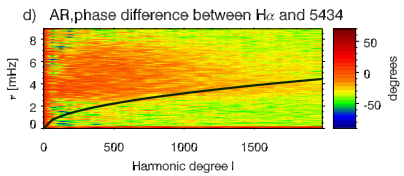


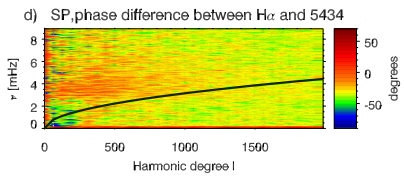




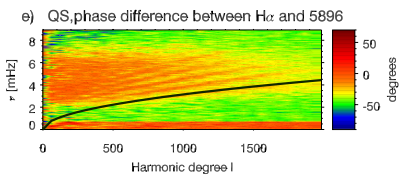
$\Delta z \approx 1000 km$

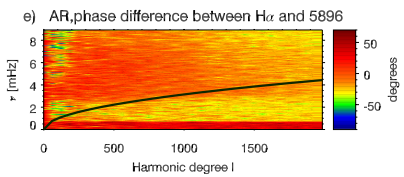


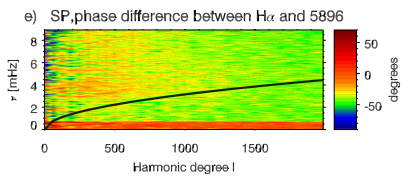




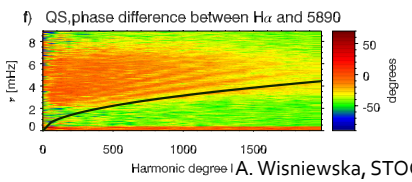
$\Delta z \approx 900 km$

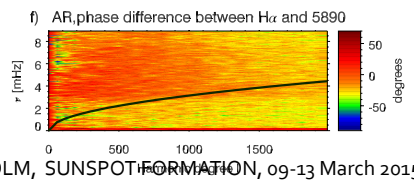


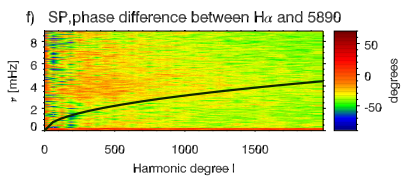




$\Delta z \approx 800 km$







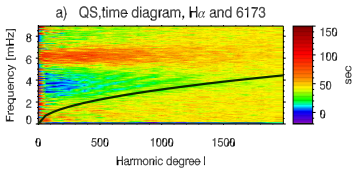
Chromosphere

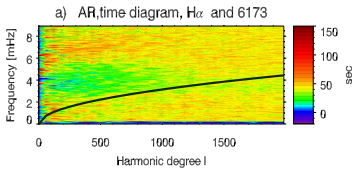
Waves travel times diagrams for 3 regions

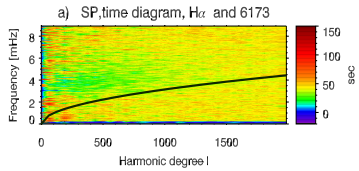
QS AR SP

Photosphere

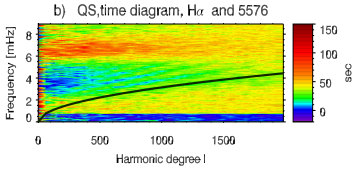
$\Delta z \approx 1400 km$

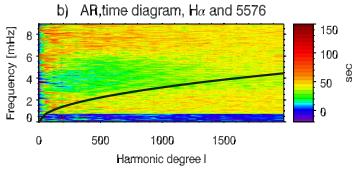


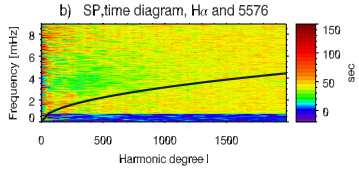




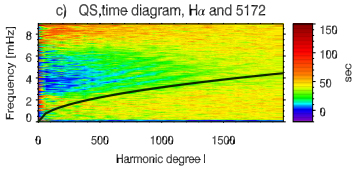
$\Delta z \approx 1300 km$

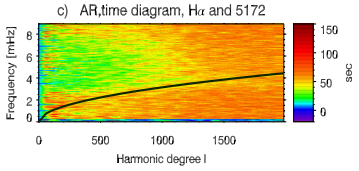


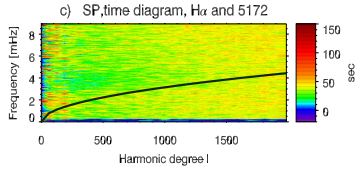




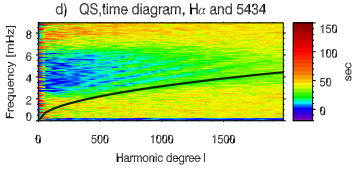
$\Delta z \approx 1100 km$

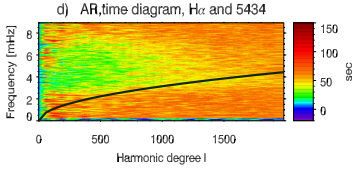


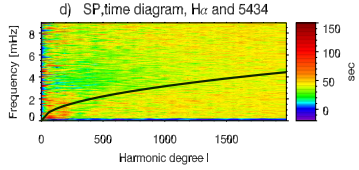




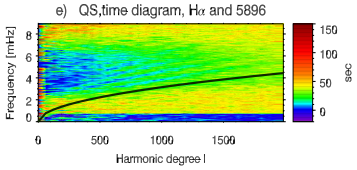
$\Delta z \approx 1000 km$

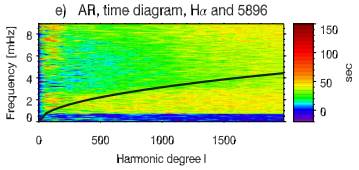


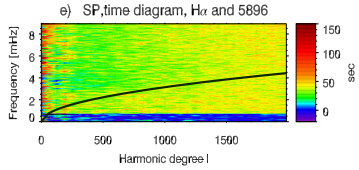




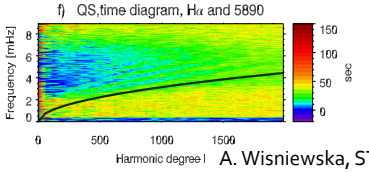
$\Delta z \approx 900 km$

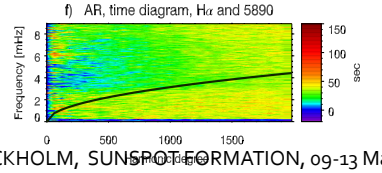


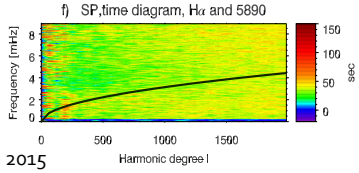




$\Delta z \approx 800 km$





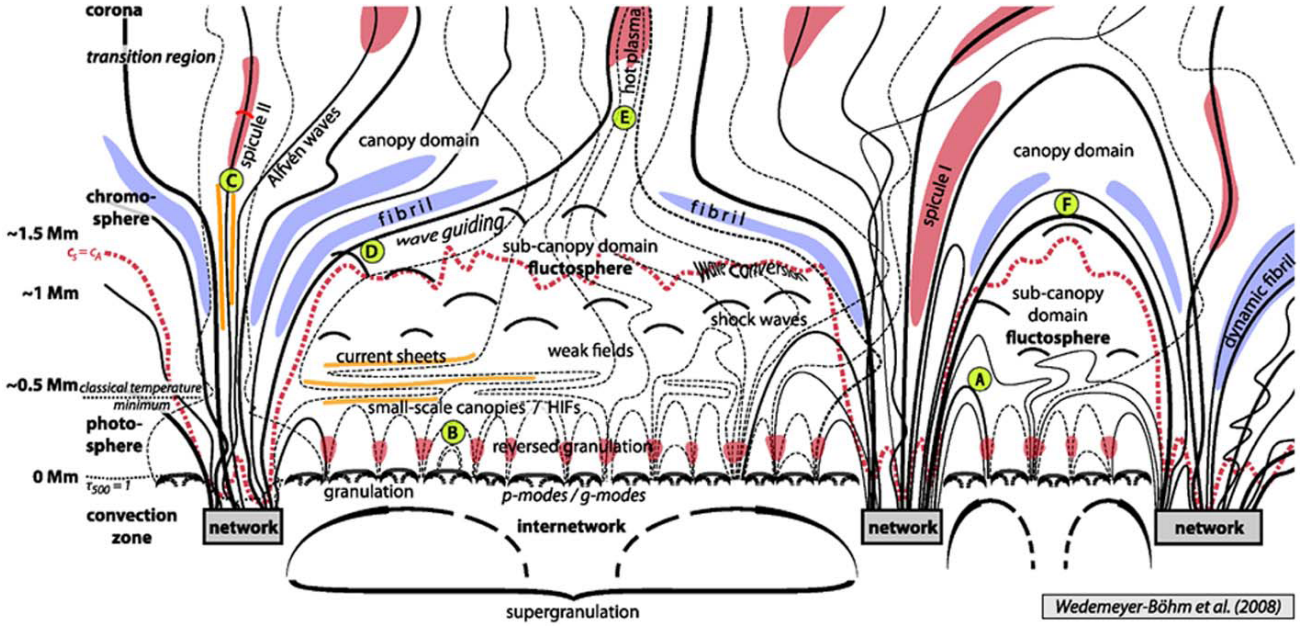


Chromosphere

SUMMARY

- MULTI- height observations allows to study structure of the solar atmosphere & together helioseismic analyze we can track the propagation of the waves through the solar atmospheric layers.

- The shift of the cut off frequency towards higher frequencies for the p-modes is a function of the height in the solar atmosphere



Thank You!