Long-period oscillations of active region patterns: method of least-square mapping on second order curves

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In collaboration with

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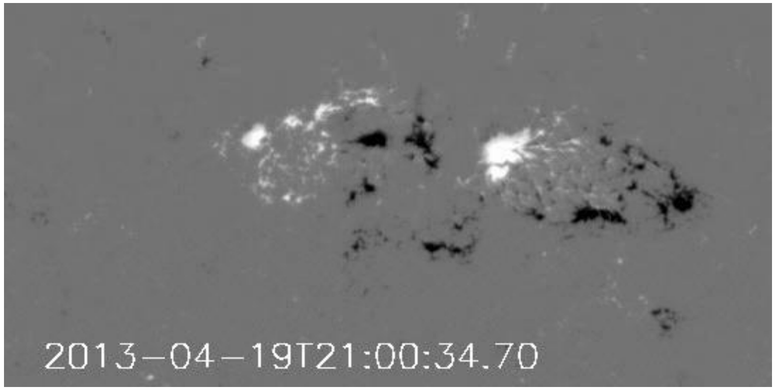
Active Regions

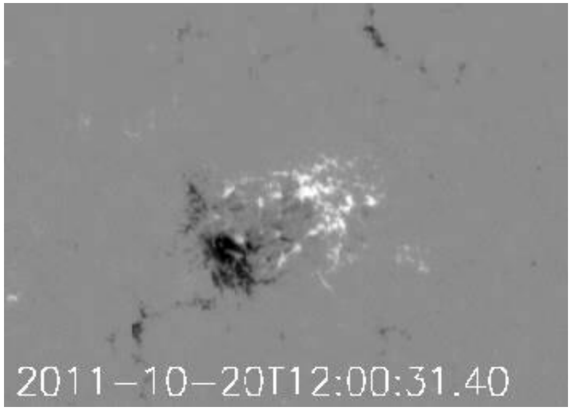
AR 11726

- The data set covers the observational time windows: 2013/20/04 at 00:00 am UT – 2013/22/04 at 3:12 am UT;
- Duretion of observation is 52 hours;
- In total 60 flares were detected: 1 - M, 49 – C, 10 B GOES class;



AR 11327

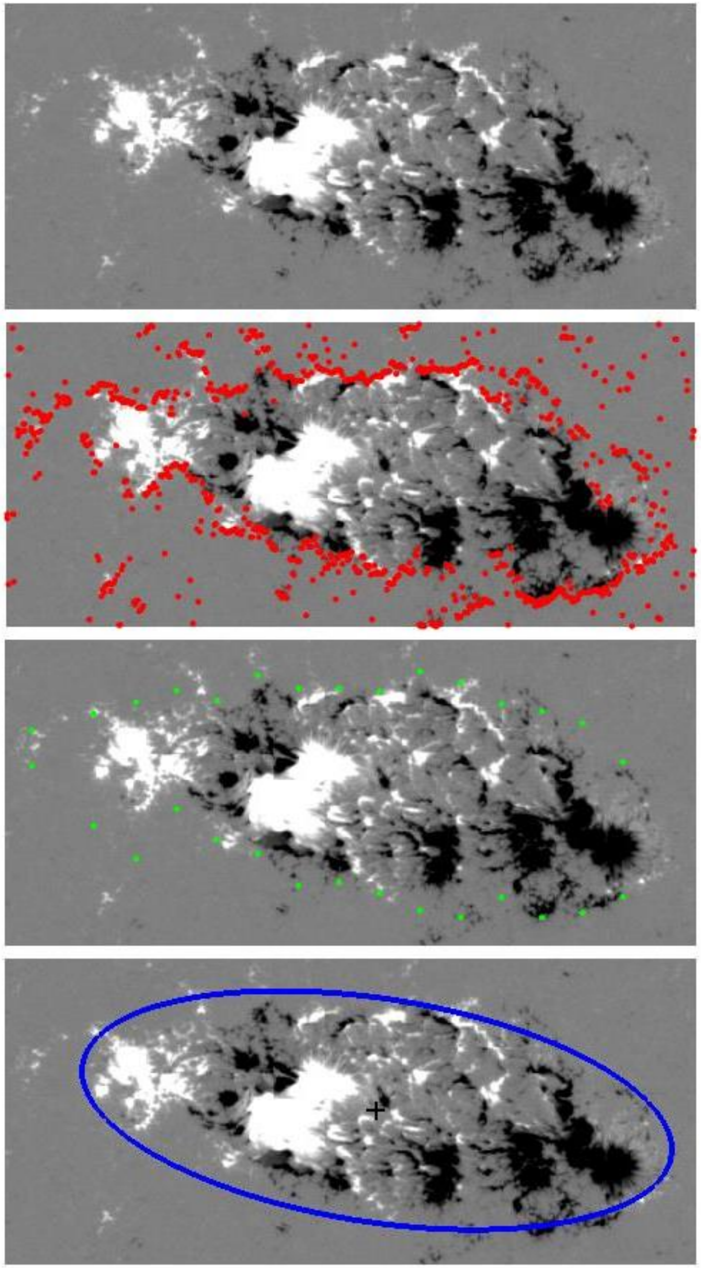
- The data set covers the observational time windows 2011/20/10 at 6:00 pm UT – 2011/22/10 at 9:12 pm UT;
- Duretion of observation is 52 hours;
- No flare was detected.



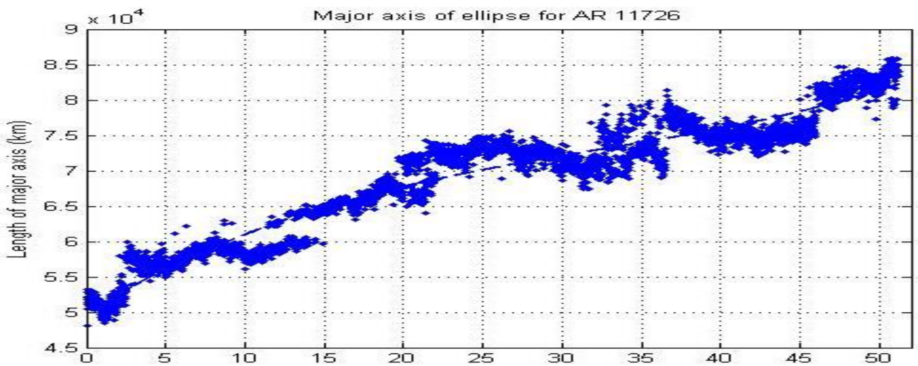
Method

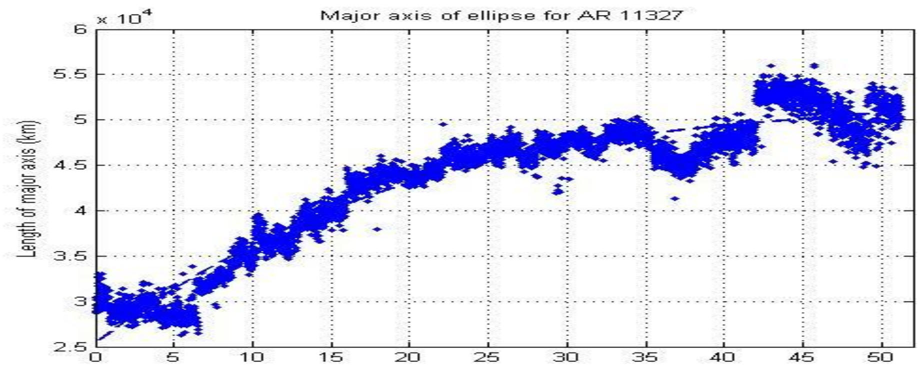
To study the dynamics of the ARs of interest, we set a certain procedure for the AR boundary recognition that we call the 'method of least-square mapping on an ellipse'. This procedure implies several stages following:

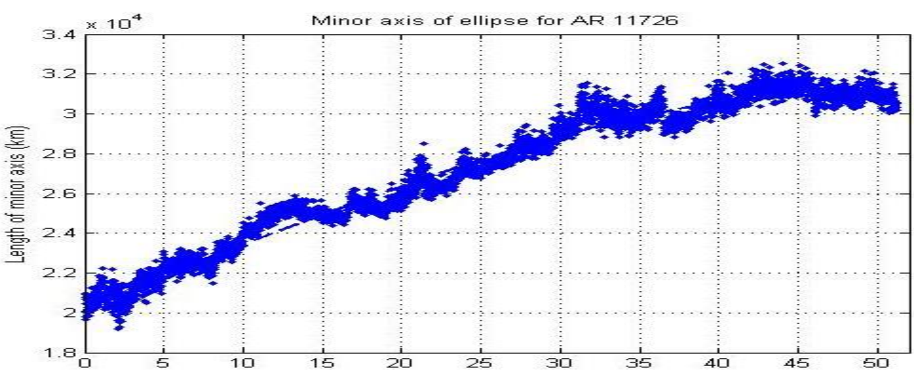
- We took cuts of the solar disk magnetograms that include the considered ARs completely.
- To select the boundary points we calculated the differences of the magnetic field intensities between neighboring pixels within each vertical slice of the AR image.
- We made vertical parallel slices of the AR image each representing a line intersecting the boundary of the AR in two points.
- We made an averaging of the coordinates of these points for 30 consecutive points.
- Using obtained boundary points we employed least-square fitting method to identify the shape of the envelop ellipse.

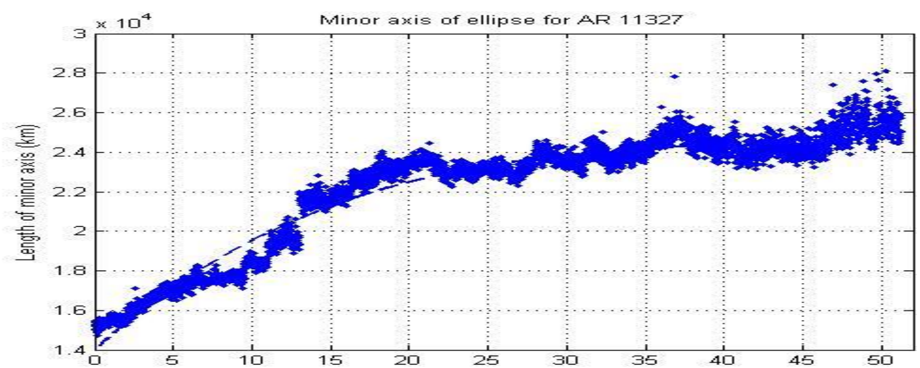


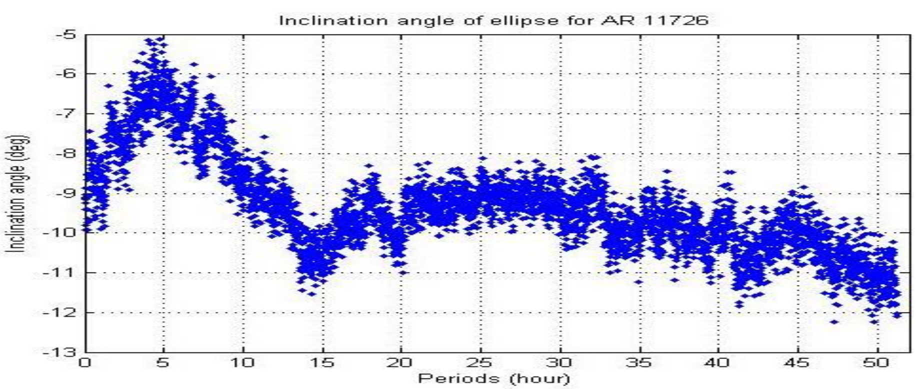
Obtained data series

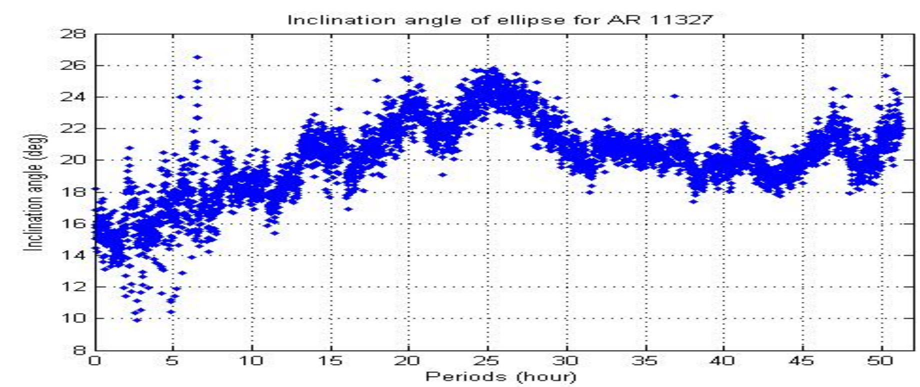






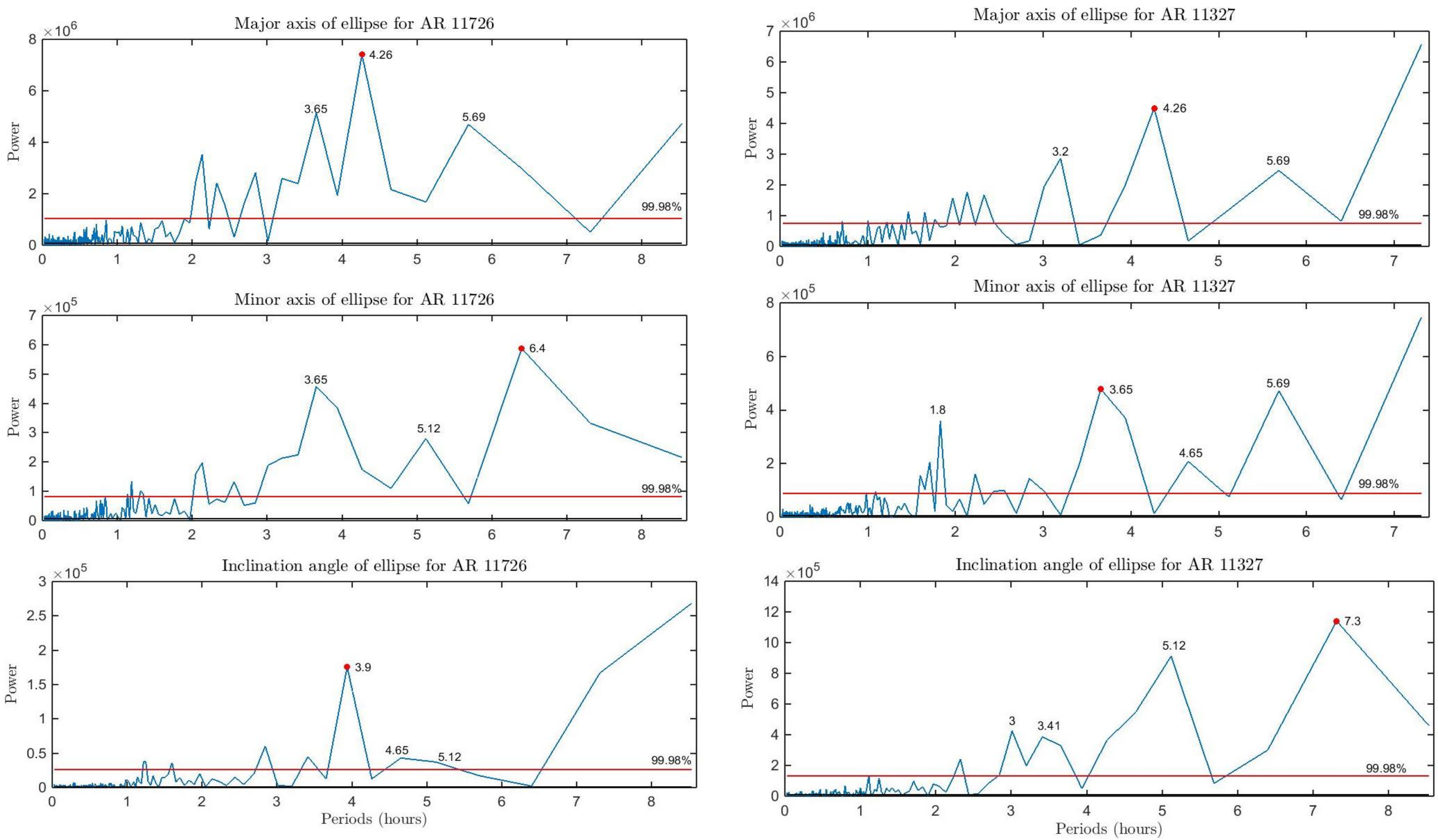






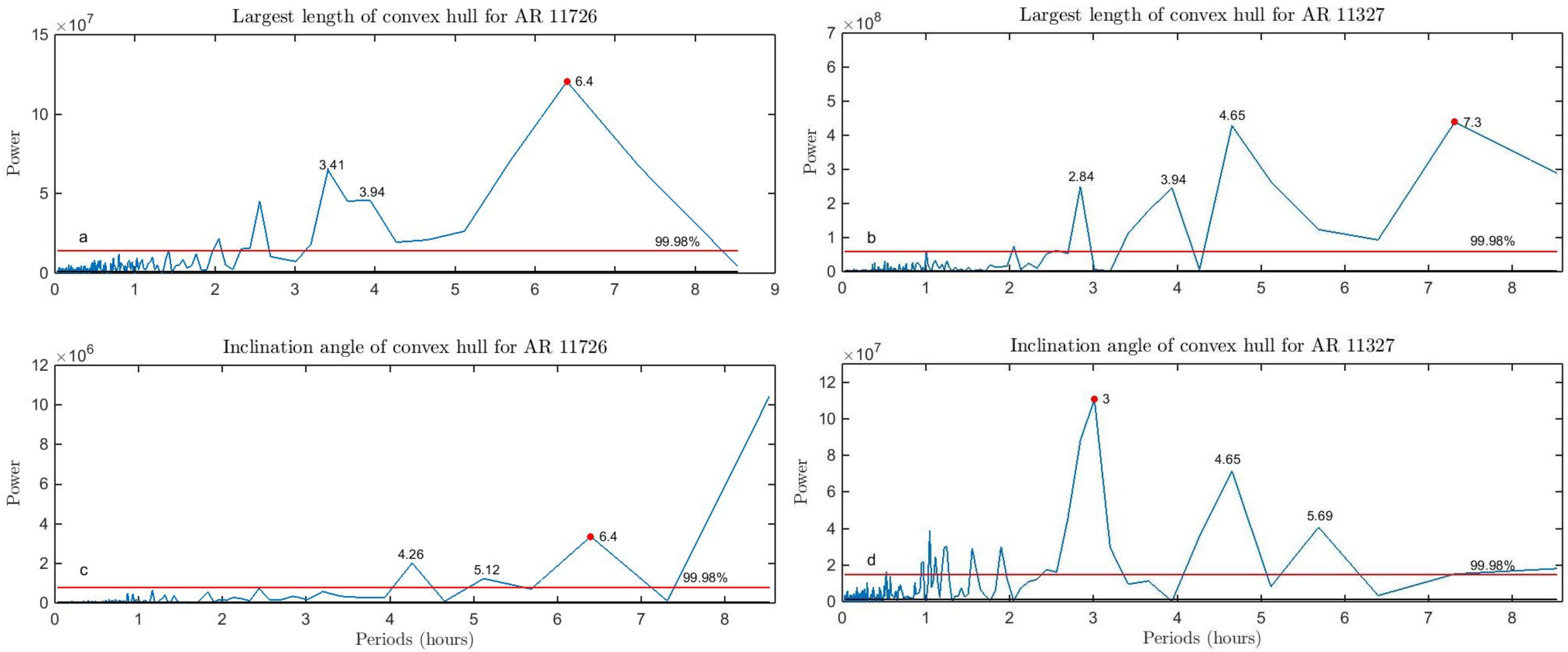
FFT analysis

Ellipse Oscillations Results



FFT analysis

Convex Hull Oscillations Results



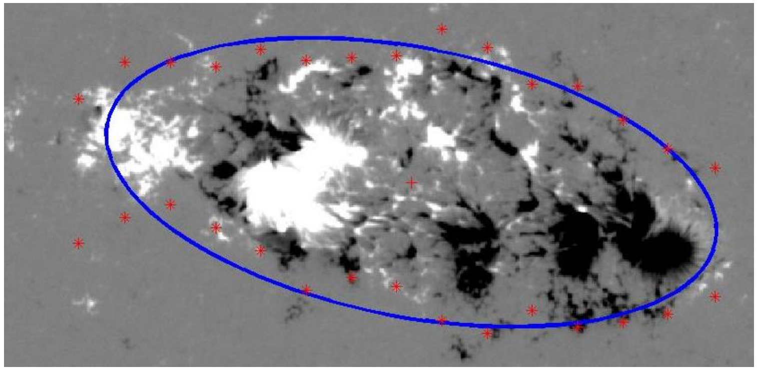
Oscillation periods

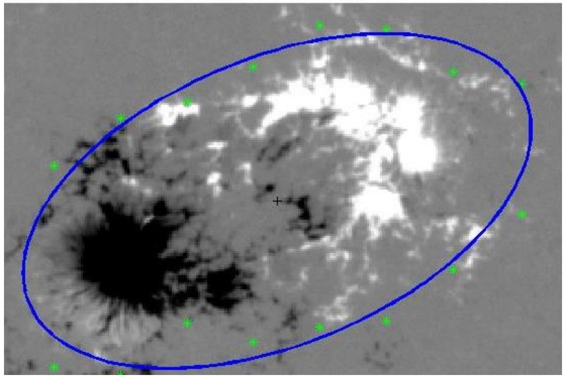
Error calculations by method 1: the half width of the corresponding power peaks and then taking their mean values.

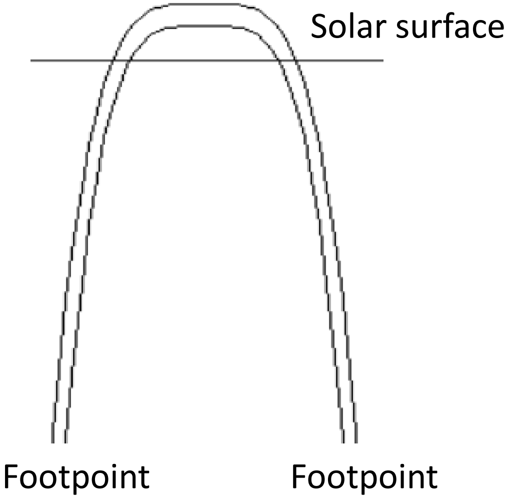
Error calculations by method 2 is based on finding the standard error of the peaks ($\nabla P_{error} = \frac{\sigma}{\sqrt{n}}$).

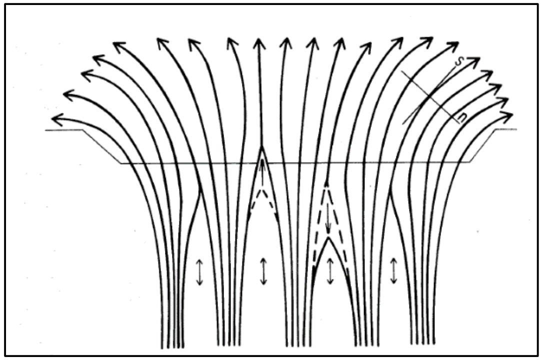
	AR 11726			AR 11327		
	Periods (hours)	Errors (hours) Method 1	Errors (hours) Method 2	Periods (hours)	Errors (hours) Method 1	Errors (hours) Method 2
Major axis	4.53	0.39	0.49	4.38	0.32	0.59
Minor axis	5.05	0.54	0.65	4.66	0.32	0.6
Inclination angle	4.56	0.47	0.29	4.7	0.55	0.85
Largest length (convex hull)	4.58	0.62	0.75	4.68	0.51	0.82
Inclination angle (convex hull)	5.26	0.6	0.51	4.45	0.3	0.63

Analysis of oscillations









Parker, 1979

Analysis of oscillations

The kink speed: $c_{T0} = \frac{c_{s0} v_{A0}}{(c_{s0}^2 + v_{A0}^2)^{1/2}}$, $T = {}^3/_5 T_e$, $T_e = 5700\ K$

The tube speed: $c_k = \left(\frac{\rho_0}{\rho_0 + \rho_e}\right)^{1/2} v_{A0}$

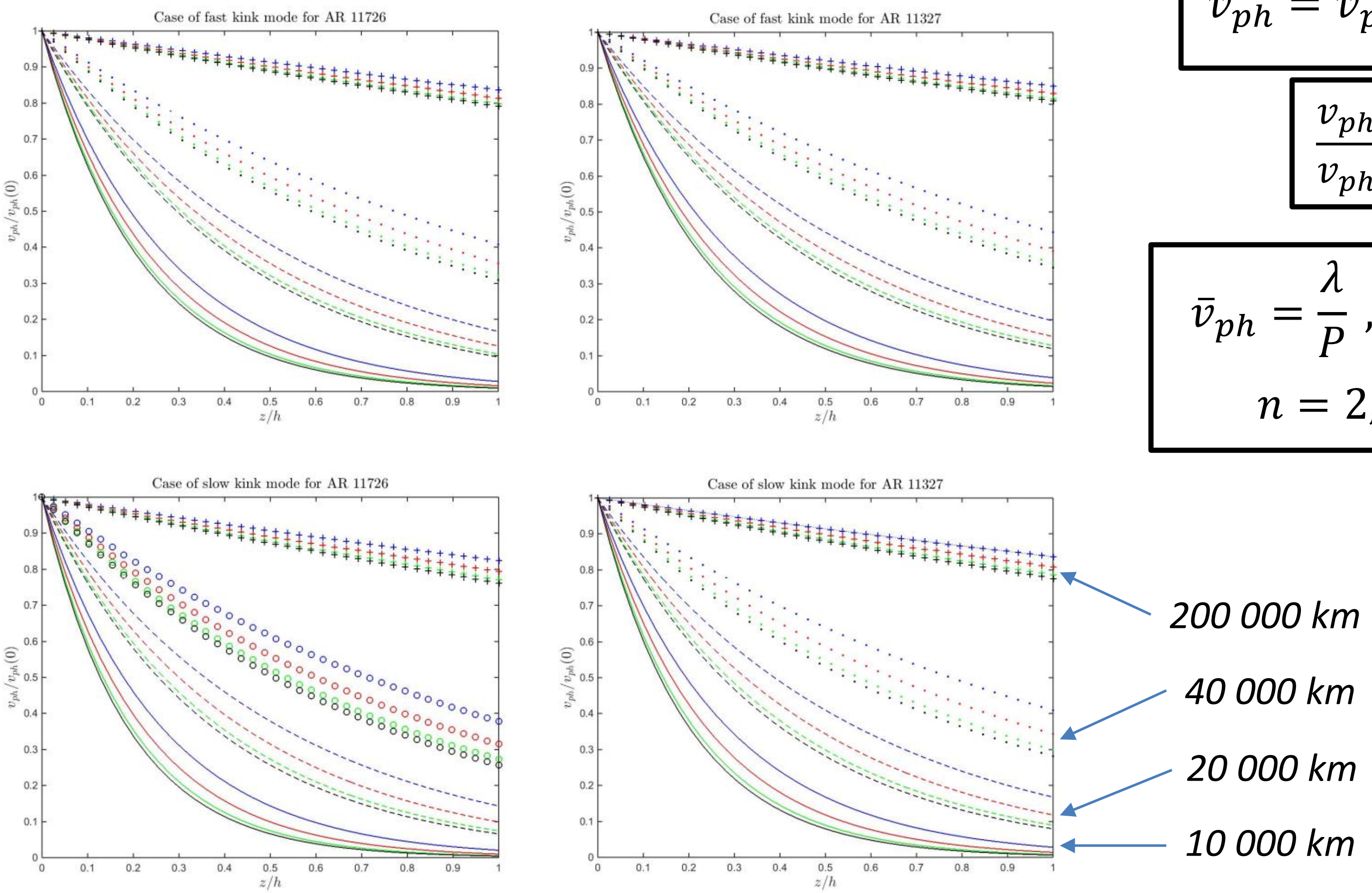
The boundary value: $v_{A0} = \frac{B_0}{\sqrt{4\pi\rho_0}}$

Observed phase speeds at solar surface (km/s)

	Fast kink mode		Slow kink mode	
	#11726	#11327	#11726	#11327
$\rho_0 = \rho_e$	4.1 ± 0.042	3.9 ± 0.042	4.4 ± 0.044	4.3 ± 0.044
$\rho_0 = \rho_e/2$	4.7 ± 0.049	4.5 ± 0.049	5.2 ± 0.053	5.2 ± 0.053
$\rho_0 = \rho_e/4$	5.1 ± 0.054	4.9 ± 0.054	5.9 ± 0.06	5.8 ± 0.06
$\rho_0 = \rho_e/6$	5.3 ± 0.056	5.1 ± 0.056	6.2 ± 0.063	6.1 ± 0.063

Analysis of oscillations

Distribution throughout of the tube



$$v_{ph} = v_{ph}(0)e^{\frac{v_{ph}(0)}{\bar{v}_{ph}}\frac{z}{h}}$$

$$\frac{v_{ph}(h)}{v_{ph}(0)} \ll 1$$

$$\bar{v}_{ph} = \frac{\lambda}{P}, \qquad \lambda = {}^{2L}/_{n},$$

$$n = 2, \qquad L \approx 2h.$$

Analysis of oscillations

We interpret the oscillations of the ellipse and convex hull axes lengths as the standing first harmonic of the flute modes.

$$v_{ph} = \frac{L}{P} \qquad L = 2h\,, \quad P \text{ is the observed period of oscillation.}$$

	Mean phase speeds (km/s) for AR 11726			
Turning point depth (km)	10 000	20 000	40 000	200 000
Kink mode	1.1 ± 0.12	2.3 ± 0.24	4.5 ± 0.49	22.7 ± 2.45
flute (ballooning) mode	1.2 ± 0.13	2.35 ± 0.26	4.75 ± 0.52	23.7 ± 2.62

	Mean phase speeds (km/s) for AR 11327			
Turning point depth (km)	10 000	20 000	40 000	200 000
Kink mode	1.2 ± 0.11	2.4 ± 0.22	4.8 ± 0.44	24.2 ± 2.21
flute (ballooning) mode	1.2 ± 0.09	2.4 ± 0.2	4.85 ± 0.4	24.2 ± 1.99

Conclusion

- ✓ The mean velocity values corresponding to the entire depth of the convection zone *h*=200 000 km are inconsistent with this assumption as the obtained mean phase velocity values are larger than their surface values. Therefore, our analysis shows that under our set up the modes propagating to that depth are practically ruled out.
- ✓ The characteristic depths of the turning point of waves, that might satisfy the requirements of the current preliminary modeling, must be at about 40 000 km, which is in agreement with helioseismic detection of sunspot depth.
- ✓ Our modeling might become a bases for further development of a seismoligical tool for the determination of the structure of active regions.