Ion Heating due to Alfvén Waves in a Helicon Plasma

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Motivation/Objectives

Recent models for ion heating in the fast solar wind region of the Sun predicts the heating is due to MHD turbulence driven by counter propagating, low- frequency Alfvén waves [1]. Experiments to test this theory will be conducted in the West Virginia University HELIX (Hot hELIcon eXperiment) device in helium plasma. Densities in HELIX are on the order of 1013 cm-3 with ion temperatures of about 0.3 eV. To create counter propagating Alfvén waves one of two techniques will be employed. We will first attempt to launch the Alfvén waves from the helicon source region and generate a reflection due to an Alfvén speed gradient. The HELIX device has an Alfvén speed profile similar to the solar corona, a short region of increased Alfvén speed followed by a rapid decrease in speed as the magnetic field expands. Should the first method prove to be unsuccessful, two waves will be launched at each other from different antennas. This method has the added advantage of allowing the relative intensities of the counter-propagating waves to be varied. Temperatures of helium ions will be measured using a RF compensated energy analyzer. We will present information on the experimental apparatus as well as preliminary data.

1. Matthaeus, W.H., G.P. Zank, S. Oughton, D.J. Mullan, and P. Dmitruk, Coronal Heating by Magnetohydrodynamic turbulence driven by reflected low frequency waves, Astrophys. J., 523, L93, 1999a.

Experimental Apparatus

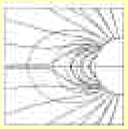
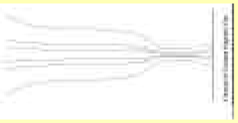


Illustration of the magnetic field lines of the Sun.



Magnetic field geometry of HELIX/LEIA

Of particular interest for this experiment is the similarity of the magnetic field gradient between the sun and HELIX/LEIA resulting in a gradient in Alfvén speed. The reflection of the Alfvén waves is expected to occur at this gradient. Note that the magnitudes are identical and the negative sign is as a result of coordinate selection.

Suitability of HELIX for coronal simulation (in He)

Parameter	LAPD	ALESPI	HELIX	Coronal Holes
n (x 10^{12} cm^{-3})	~ 2.2	~ 10	~10	~ 5 x 10^{-4}
B (G)	1700	800	800	1
$W/2p$	646 kHz	304 kHz	304 kHz	180 Hz
T_e (eV)	5.7	8	~ 8	~ 200
T_i (eV)	~ 1.0	?	~ 0.3	~ 400
V_{Te} (x 10^8 cm/s)	1.4	1.7	1.7	7.3
V_A (x 10^8 cm/s)	1.3	0.27	0.27	0.1
V_A' (x 10^8 cm/s)	0.61	--	0.05	0.6 (at $3R_S$)
$V_A' - V_A$ (x 10^8 cm/s)	0.69	--	0.22	-0.5
$\Delta V_A/V_{Amax}$	0.53	--	0.81	-0.83
w/W_i	0.5 – 1.0	0.33	0.4	0.0001
$l_{\|\|}$ (cm)	~ 175 cm	~ 250 cm	~ 200 cm	556 m
n_{ei}/w	1.60	13	< 10.7	6 x 10^{-4}
c/w_{pe} (cm)	0.36	0.17	0.17	24
r_i (cm)	0.12	--	0.14	~ 1500
r_s (cm)	0.28	0.72	0.58	~ 1500
ß	3 x 10^{-5}	--	5 x 10^{-3}	10^{-2}
$S = m_o V_A L/h$	2,223L	7,677L	7,677L	24,000L

Alfvén waves in HELIX

The dispersion relation for shear Alfvén waves in the kinetic regime ($V_A < V_{Te}$) is given by

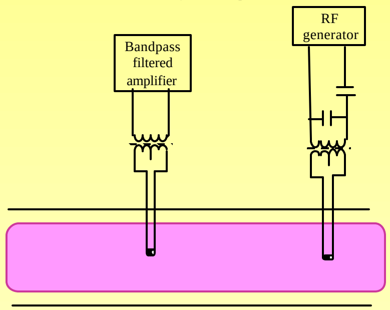
$$\left(w/k_{||}\right)^2 = V_A^2\left(1 - w^2/\Omega_i^2 - k_\perp^2 r_s^2\right)$$

To efficiently launch and detect electromagnetic waves at such low frequencies (~ 30 kHz) requires an efficient coupling of the rf source to an antenna and a high gain receiver.

Wave launching apparatus

Following the approach of *Hanna and Watts* [2001], a small coil wound on a ferrite coil is inserted into the plasma via a passively water cooled probe. Currently, the probe housing is bare stainless steel. Future versions will be coated with a layer of insulating alumina.

The 0.25" diameter, 1.025 mH coil is coupled to a 1 kW, 25-125 kHz generator through a capacitive matching network and a 1:1 center tapped high bandwidth transformer. Wave detection is accomplished by an identical probe located approximately 30 cm downstream and a three-axis coil set located 1m away in the expansion chamber.

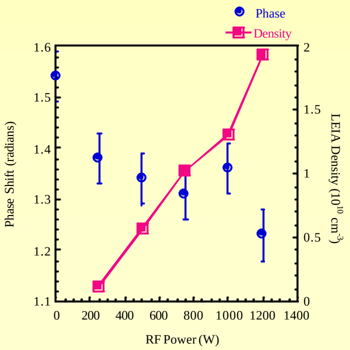


High frequency waves successfully launched and detected with transmitter/receiver coil pair

To test the transmitting and receiving coils, 200 kHz waves were launched and detected 30.5 downstream. For source parameters yielding an ion cyclotron frequency of 14.5 kHz, the most likely electromagnetic wave to be launched is a whistler wave governed by the dispersion relation:

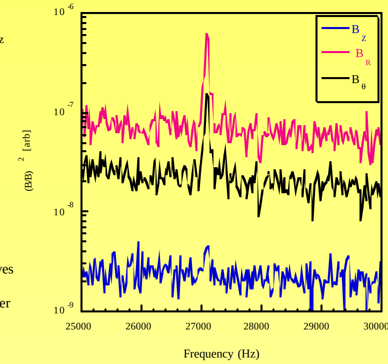
$$k = \sqrt{\frac{ww_p^2}{c^2\Omega_e}}$$

Phase shift as a function of increasing plasma density inconsistent with whistler wave propagation.



Sub-cyclotronic, transverse waves observed 1 m downstream of in-situ antenna in argon plasmas

RF power = 750 W
RF Freq = 9.50 MHz
B = 770 G
P = 8.7 mT
Ω_{ci} = 29.4kHz
? $_{launched}$ = 27 kHz



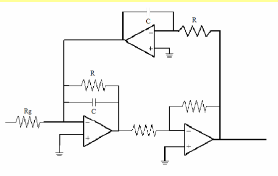
Observed wave polarization consistent with shear Alfvén waves propagating into expansion chamber from source.

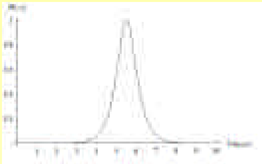
Project Status

- **Bandpass filtered amplifiers built and tested.**
- **Wave launching circuitry built and tested – preliminary data indicates sub-cyclotronic, transverse waves can be launched in argon plasmas (observed with 200 kHz differential digitizer – not filtered amplifiers).**
- **High frequency waves launched and density dependent phase shift observed using transmitting and receiving coil pair. Wavelength dependence on plasma density inconsistent with whistler wave dispersion relation.**
- **Custom electronics being constructed for reliable, ground-loop free phase comparison measurements between wave launching circuit and detection circuit.**

Bandpass filtered amplifier design

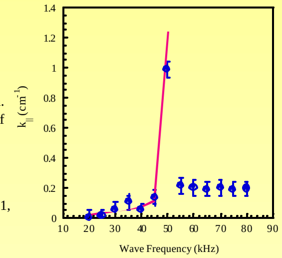
5 narrow bandpass, single input, three stage, active filters built for wave frequencies of 20, 40, 60, 80, and 100 kHz. Filters will be used for detection of heavily damped shear Alfvén waves in both helium and argon plasmas.





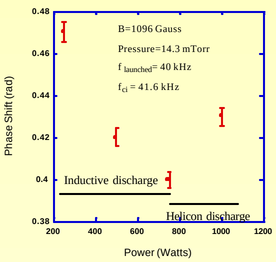
Wave dispersion consistent with Alfvén wave excitation

Measured phase shift versus wave frequency consistent with Alfvén wave dispersion relation. Solid line is a fit of the dispersion relation to the measured parallel wavenumber assuming $k_\perp r_s << 1$, i.e., $l_\perp >> 4.5$ cm.

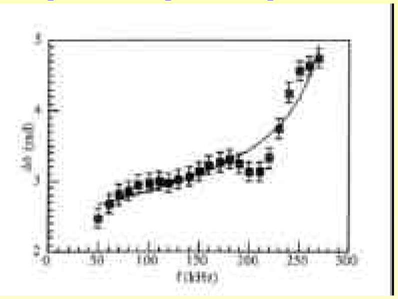


Sub-cyclotronic wavenumber versus RF power (plasma density)

One would expect to see the phase shift increase with increasing RF power (density). The observed phase shift dependence on RF power is yet to be understood and may indicate some change in the characteristics of the excited wave for different plasma parameters, e.g. variations in excited k .



Comparison with previous experiments



The ion cyclotron resonance in the shear Alfven wave dispersion has been observed in previous helicon plasma experiments [figure from Watts and Hanna, Phys Plasmas, **11**, 1358 (2004)]. In this helium plasma case, the ion cyclotron frequency is 293 kHz and a similar increase in phases difference (wavenumber) is seen near cyclotron resonance.

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