Report

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IDLWhamp: A GUI to WHAMP

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Abstract

Solving the dispersion equation in linearized kinetic theory for plasma waves is an omnipresent problem in plasma physics. The computer code WHAMP published by **?** is capable of solving the full linearized electromagnetic dispersion equation for up to six different plasma species. The code approximates the dispersion function and therefore is very fast. The archaic command line in- and output of the original code urgently required a modern interface. A graphical user interface (GUI) to WHAMP was realized in an IDL® programming environment and has been named IDLWhamp. As the WHAMP code, it is open source and freely available on the Internet. It includes plotting routines for ready to print graphics and allows easy data handling and organization of datasets.

1 Introduction

The WHAMP computer program solves the dispersion relation for waves in a magnetized plasma. The original WHAMP code was developed and written by Kjell **?**, but the program that is used by IDLWhamp is a modified version by **?**. In the following, WHAMP always refers to the new version of the program. Although the program has been greatly improved and debugged, it still provides the user only with a command line interface for data input and output. Hence, while working with WHAMP the user always needs additional software for extracting data from raw output files and for visualization of the obtained data. In order to facilitate the working with the WHAMP code it is reasonable to combine the additional software and the WHAMP core program in a single software package. There were several attempts towards this goal, such as 'xwaves' (**?**) or 'xwhamp' (**?**), x-windows wrappers for WHAMP, available on the Internet. Both did not meet the needs of the author while working with WHAMP. It therefore was decided to program another package called IDLWhamp. The GUI is based on IDL® for it is widely used in the plasmaphysics and astrophysics community and delivers a suitable programming environment for GUIs. The user still can use the binary of WHAMP in the command line mode in the same version as distributed by **?** besides a slight change in the data output file.

The version of IDLWhamp described herein is Version 2.2 released in November 2001.

A short description of the physics of WHAMP follows in the next Section. The GUI is described in Section **??**. Section **??** describes the working with IDLWhamp and gives some hints for finding solutions and a short summary concludes this work.

2 Physics of WHAMP

The WHAMP code solves for the real and imaginary angular frequencies of the wave mode (the solution of the plasma dispersion relation) as a function of $k_\perp$ and $k_\parallel$, the components of the wave vector perpendicular and parallel to a background magnetic field. There may be multiple solutions (branches) of the dispersion relation at a given value of $k_\perp$ and $k_\parallel$. In that case, the particular solution that WHAMP finds will be determined by the initial guess for the real part of the angular frequency, which causes the code to lock onto a par-

ticular solution (branch).

The plasma may be composed of a variable number of up to six plasma species. The total distribution function will be the sum of the distribution functions for all the individual species. The distribution function for each species is considered to be uniform (or homogeneous) in space, but to vary not only with the magnitude of the velocity but also with its direction (see Eq.4). Thus each distribution function is a function of $v_\perp$ and $v_\parallel$, the components of the particle velocity perpendicular and parallel to the background magnetic field.

Each species is described by its density, temperature, particle mass, anisotropy and drift velocity along the magnetic field. The following is a short summary of the original report by **?**.

The plasma dispersion function can be written as

$$\det\left((\mathbf{1}k^2 - \vec{k}\vec{k})\frac{c^2}{\omega^2} - \vec{\vec{\epsilon}}(\omega,\vec{k})\right) = 0, \qquad (1)$$

where, according to linearized kinetic theory, the dielectric tensor $\vec{\vec{\epsilon}}(\omega,\vec{k})$ is given by

$$\vec{\vec{\epsilon}}(\omega,\vec{k}) = \mathbf{1} - \frac{\omega_\mathrm{p}^2}{\omega^2}\left\{\mathbf{1} - \sum_j \sum_{n=-\infty}^{\infty} \int \vec{v}\vec{\vec{\prod}} \times \frac{\frac{n\Omega_j}{v_\perp}\frac{\partial}{\partial v_\perp} + k_\parallel \frac{\partial}{\partial v_\parallel}}{\omega - k_\parallel v_\parallel - n\Omega_j} f_j^0\right\}. \qquad (2)$$

The gyro frequency of the jth species is given by $\Omega_j = q_j B/(cm_j)$ and ω_p denotes the plasma frequency defined as $\omega_\mathrm{p} = \sqrt{\sum_j \omega_{\mathrm{p}_j}^2} = \sqrt{\sum_j 4\pi n_j q_j^2/m_j}$. The tensor $\vec{\vec{\prod}}$ is given by the matrix

$$\vec{\vec{\prod}} = \begin{pmatrix} \left(\frac{n\Omega_j}{k_\perp}J_n\right)^2 & i\frac{n\Omega_j}{k_\perp}v_\perp J_n J_n' & \frac{n\Omega_j}{k_\perp}v_\parallel J_n^2 \\ -i\frac{n\Omega_j}{k_\perp}v_\perp J_n J_n' & (v_\perp J_n')^2 & -iv_\perp v_\parallel J_n J_n' \\ \frac{n\Omega_j}{k_\perp}v_\parallel J_n^2 & iv_\perp v_\parallel J_n J_n' & \left(v_\parallel J_n\right)^2 \end{pmatrix} \qquad (3)$$

where the argument of the Bessel function J_n is $k_\perp v_\perp/\Omega_j$. $f_j^0(v_\parallel, v_\perp)$ in equation (2) denotes the zero order distribution function in velocity space of the particle species j. The most general form a particle distribution function in the WHAMP code can have is given by

$$f_j^0(v_\parallel, v_\perp) = \frac{1}{(\sqrt{\pi}v_{\mathrm{th}}^j)^3}\exp\left(-\left(\frac{v_\parallel}{v_{\mathrm{th}}^j} - v_{\mathrm{D}}^j\right)^2\right) \times \left[\frac{\Delta_j}{\alpha_{1j}}\exp\left(-\frac{v_\perp^2}{\alpha_{1j}(v_{\mathrm{th}}^j)^2}\right) + \frac{1-\Delta_j}{\alpha_{1j}-\alpha_{2j}} \times \left\{\exp\left(-\frac{v_\perp^2}{\alpha_{1j}(v_{\mathrm{th}}^j)^2}\right) - \exp\left(-\frac{v_\perp^2}{\alpha_{2j}(v_{\mathrm{th}}^j)^2}\right)\right\}\right]. \qquad (4)$$

This is the original notation used in **?**. The α_{1j} parameter is the temperature anisotropy $\alpha_{1j} = T_\perp^j/T_\parallel^j$ of the j-th distribution function. Δ_j and α_{2j} define the depth and size of a possible loss-cone.

The integral over velocity space in Eq. 2 is evaluated by the following two relations

$$\Lambda(\lambda_j) = \int_0^\infty J_n\left(\frac{k_\perp v_\perp}{\Omega_j}\right)\exp\left(\frac{-v_\perp^2}{(v_{\mathrm{th}}^j)^2}\right)\frac{2v_\perp}{(v_{\mathrm{th}}^j)^2}\,dv_\perp \qquad (5)$$

where $\lambda_j = 1/2(k_\perp v_{\mathrm{th}}^j/\Omega_j)^2$, and

$$Z\left(\frac{\omega - n\Omega_j}{k_\parallel v_{\mathrm{th}}^j}\right) = \frac{1}{\sqrt{\pi}}\int_{-\infty}^{\infty}\frac{\exp\left(\frac{-v_\parallel^2}{(v_{\mathrm{th}}^j)^2}\right)}{v_\parallel - (\omega - n\Omega_j)\frac{1}{k_\parallel}}\,dv_\parallel \quad , \qquad (6)$$

where $\Lambda_n(\lambda_j) = e^{-\lambda_j} I_n(\lambda_j)$, I_n is a modified Bessel function of order n, and Z is the plasma dispersion function (**?**).

By introducing a Padé approximant for the plasma dispersion function the infinite sums of modified Bessel functions which appear in Eq. 2 may be reduced to a summable form. The resulting expression for $\vec{\vec{\epsilon}}(\omega,\vec{k})$ is valid for all real $\vec{k}$ and suited for numerical evaluation.

Additional information about the general theory underlying the program and the FORTRAN code comprising the WHAMP program are described in **?**.

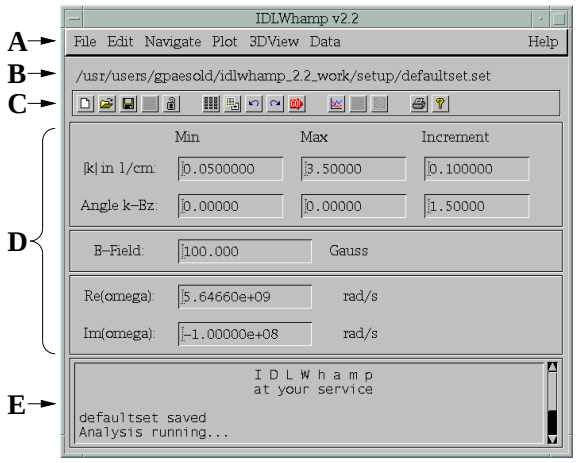

Figure 1: Image of the IDLWhamp main window. All the iteration parameters are changed via this window.

3 The GUI

When starting up IDLWhamp, IDL®forms a new window (see Fig. **??**) in the upper left corner of the screen. The window contains a menu bar on top (Fig. **??**, A) through which all features of IDLWhamp are accessible, the most often used actions in form of a tool bar (Fig. **??**, C), the first page of WHAMP inputs (Fig. **??**, D) and a dialog field (Fig. **??**, E) keeping the user informed of the current status of IDLWhamp. The inputs on the main window contain the parameters for the solving iteration: the range in $|\vec{k}|$, increment of $|\vec{k}|$, the range in angle Θ, the angle between $\vec{k}$ and the direction of the background magnetic field, increment in Θ and the initial guess for the complex angular frequency. For information on how to choose starting values for the iteration see Section **??**.

The top line of the IDLWhamp main window (Fig. **??**, B) always displays the path and name of the current dataset. The pull down menu is divided into seven categories named 'File', 'Edit', 'Navigate', 'Plot', '3DView', 'Data' and 'Help'. The 'File' and 'Edit' menus contain, besides the usual functions, some special items that are described below in the tool bar section. The 'Navigate' menu is a dynamic list of the ten last datasets loaded during a session. It allows the user to switch between dataset in an emacs-like style. The '3DView' menu contains buttons for the 3D plotting routines displaying the distribution functions of single plasma species. In order to use them, only one plasma species needs to be activated in the 'Enter Setup' window. The 'Data' menu contains the link to a plasma property calculator allowing quick information on the properties (plasma beta, gyro frequency, etc.) of a chosen species and another button for viewing the raw ASCII WHAMP data file. The functionality of the rest of the pull down menus is self describing and needs no explanation.

The tool bar mirrors several functions of the menu bar. Some of them are special to IDLWhamp and shall be explained here in detail. 'Lock Setup' is a function that prevents the user from accidentally altering a dataset. If a setup is locked, no inputs of any kind are possible anymore, only plotting routines and unlocking are allowed. 'Import Setup' allows the user to import an already existing setup into a newly created setup. 'Print Setup' prints out the whole setup (name, iteration parameters, plasma parameters). The rest of the tool bar items concerns setup handling and plotting and is straightforward.

Instead of typing in the iteration parameters IDLWhamp provides a graphical input interface (Fig. **??**) which allows the user to determine the starting values via mouse. A region in the $\omega, |\vec{k}|$ plane is displayed (Fig. **??**, C) and can be shifted to arbitrary values (Fig. **??**, D). By choosing one of the plasma species by pressing one of the buttons (Fig. **??**, A) the characteristic values for plasma frequency ω, gyro frequency Ω and several wave vectors (k_I inertial length, k_D Debye length, k_L Larmor radius) are displayed. Starting values now can be chosen by left clicking on some point in the plane. The range in $|k|$ is determined by a second left click which also starts the analysis. The number of points that should be computed is chosen via the check boxes in the window (Fig. **??**, B). Three dialog fields keep the user informed on the current status (Fig. **??**, E).

After launching the main window IDLWhamp loads a dataset called 'defaultset'. It is harcoded in the source of IDLWhamp and therefore cannot be changed permanently. In case of any changes, the next time IDLWhamp is started all values are

reset. For the input of the plasma parameters

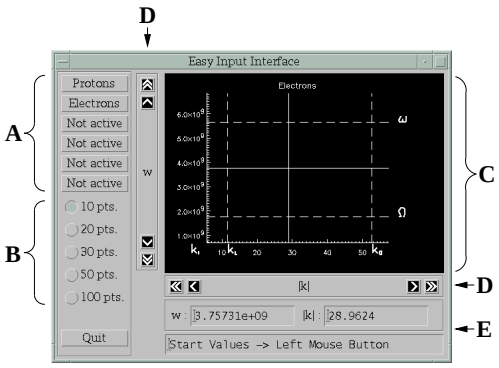

Figure 2: Image of the IDLWhamp main graphical input interface.

another window pops up, the so-called 'Enter Setup' window. Here the plasma distribution functions are defined by the input of name, charge, density, mass, parallel temperature, perpendicular temperature, drift velocity, loss cone depth and size for each of the plasma species. The setup can be saved manually by choosing the option from the 'File' menu. This creates a file in the setup/ subdirectory of the IDLWhamp tree containing all defining parameters of the current dataset. This file is only used by the GUI.

The 'Enter Setup' windows also displays the resulting charge when the 'Update charge' button is pressed or the window is closed. In case of the resulting charge not being equal to zero a window pops up notifying the user of a problem with charge neutrality. This does not necessarily mean, that charge neutrality is violated. Due to numerical accuracy problems in IDL® it sometimes is not possible to correctly compute the resulting charge. In this case it is recommended to check the plasma parameters 'Density' and 'Charge'.

By choosing the 'Run Analysis' action, IDLWhamp first saves the current setup and creates a parameter file in the subdirectory par/ which is used as an input file for the WHAMP code. The WHAMP code is started by IDLWhamp spawning a call to the executable. The output of the WHAMP code is copied to a file in the data/ subdirectory.

Three files are therefore needed for a full dataset. After having run an analysis, the data can directly be plotted by choosing one of the options from the 'Plot' menu. The options are grouped in four different subsections and a general plot window: 'Wave Dispersion', 'Electric Polarization', 'Magnetic Polarization', 'Resonance Factors' and 'General 2D Plots'. The last one offers the opportunity to choose from a list containing all possible output data from WHAMP for x-axis and y-axis. The former ones offer nicely formatted plots for the most important and frequently used data and derived quantities. There are slight differences in the plot windows but in the following we only want to describe the specialized plot window in detail.

The plot window (see Fig. **??**) offers a wide

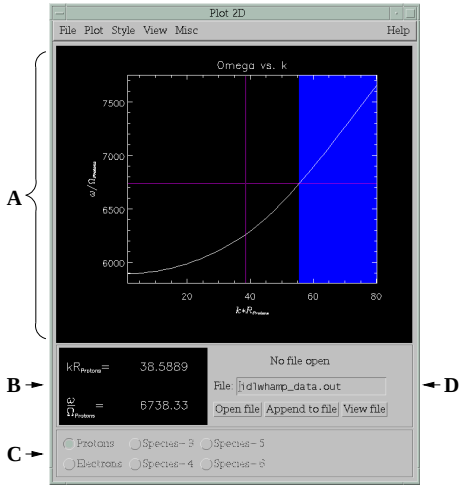

Figure 3: Image of the IDLWhamp plot window.

diversity of interactive data analysis. Interactively obtained data points can be written to an ASCII file in two column format by pressing the right mouse button (Fig. **??**, D). Information on electro magnetic field strengths and other wave parameters are obtained by pressing the middle mouse button. The cross hair can be fixed in x-direction by pressing the left mouse button in order to make an accurate readout of data points easier. In a field at the bottom left of the plot window the current position of the cross hair is continuous displayed in data coordinates (Fig. **??**, B). At the bottom of the 'Plot' window there is a menu of check boxes that allows the choice of a plasma species for the 'Resonance Factor' plots (Fig. **??**, C).

During the solving process the accuracy of the iteration can drop below a certain tolerance value.

IDLWhamp therefore sometimes underlays the plot with blue and/or red color in uncertain regions (dark gray shade in Fig. **??**). A detailed description of the color coding follows in the next Section (Note: color coding is not present in the 'General 2D Plots' window!).

4 Hints for using IDLWhamp

If an analysis is run with IDLWhamp (by choosing 'Run Analysis' from the pull down menu 'File' or by pressing the 'GO!' button in the tool bar of the main window) it might happen, that no data is displayed in the plot window when opened and the message 'Analysis running...' was not followed by 'Analysis finished' in the dialog field. In this case the WHAMP code did not produce any output (the WHAMP output file can be checked by choosing 'View Raw Data' from the 'Data' menu). This means that some of the input parameters are not accepted by the WHAMP code: charge neutrality etc. have to be checked to be correct. Most possible wrong inputs should be intercepted by IDLWhamp but there still can be some gaps.

When viewing data plots it sometimes happens that regions of the plotting area are under laid with blue or red color. The color coding mirrors to kinds of 'error' messages from WHAMP. Blue stands for the message 'too damped' and red stands for 'no convergence'.

The latter means that WHAMP could not lock-on to a solution of the dispersion relation. The process of finding a solution involves an iterative calculation, and the process is producing a diverging result. This could mean that the initial frequency and/or the starting value for $|k|$ is bad. Dispersion codes tend to be rather sensitive to good initial guesses in order to converge. Knowing a good frequency guess will require either a previous successful run (like the run which results from the default parameters) from which you can gradually change the parameters, or some knowledge of the physics (i.e. results obtained from cold plasma physics or warm plasma solutions). Also the units used should be checked. Information on the requested units for each plasma parameter can be found by pressing the according button in the 'Enter Setup' window (i.e. by pressing the button 'Drift Vel.' a small window pops up saying 'The drift velocity in units of the actual thermal velocity', see also the Appendix).

Blue color indicates that the damping rate (imaginary part of the angular frequency) is too large (WHAMP recognizes that in such a case the results are not good – the results may still be correct, but they cannot be trusted anymore) In that case, WHAMP did lock-on a solution of the dispersion relation, but the results are not good. Different starting values for $|k|$ and/or Θ should therefore be used. It might be possible to lock-on to a region of the dispersion surface which leads to good result.

If only parts of the plotting region are under laid with blue (red), WHAMP successfully has found the angular frequency for several combinations of $|k|$ and Θ. But sometimes, the code will be unable to solve for certain combinations of $|k|$ and Θ. As described above the two reasons why this can occur are either that the damping rate was too large (sometimes because the angular frequency is approaching a gyro frequency), or that the code was simply unable to converge on a result (sometimes because the angular frequency is increasing too steeply – changing the $|k|$ and/or Θ increment can sometimes help with this problem). When WHAMP does not give a result for a value of $|k|$ and Θ, it continues to run, but it skips to the next value of whichever is varied, resulting in red regions in the plot. Transitions over blue(red) regions should not occur in data that should be trusted because it never is ensured that the solver stays on the same branch of solution. Nevertheless it is allright for quick viewing dispersion relations and the search for good initial guesses.

5 Summary

WHAMP is a well known linear dispersion code which has been publicly available for about twenty years now. It has been debugged by many users and the results are very reliable. It therefore is, also due to its public availability, a very helpful tool for all communities involving plasma physics. An extension to the WHAMP code is presented here that does not concern the mathematics and physics of WHAMP, but it provides the potential user with an easy to use and straight forward graphical user interface called IDLWhamp. The greatly improved speed of input and output combined with enhanced computer power of modern platforms allow to ex-

plore vast regions of (ω, k) space in a new way. It has been used also as an efficient tool for planning and interpretation of numerical simulation at the particle level (**?**). It also allows a concise handling of datasets and includes plotting routines for the most important results of WHAMP. Every possible output parameter of WHAMP can easily be accessed, plotted and analyzed directly from within the program. Obtaining solutions with WHAMP therefore became easier and much faster.

Acknowledgments

The author wants to thank Kjell Rönnmark for providing him with the WHAMP code and a copy of the KGI report describing the program. The author also wants to acknowledge Gérard Belmont and Laurence Rezeau for giving him free access to their improved version of WHAMP, which has become the mathematical core of IDLWhamp.

A Appendix

The following table displays the units used in IDLWhamp. They differ from the original normalizations used in WHAMP, described in **?**.

Name	Symbol	Units
Modulus of wave vector	$\lvert\vec{k}\rvert$	cm^{-1}
Angle $\vec{k}, \vec{B_0}$	Θ	deg
Frequency, Growth rate	ω, γ	rad/s
Background magnetic field	$\lvert\vec{B_0}\rvert$	Gauss
Plasma Parameters of Species j		
Charge	q_j	e
Density	n_j	cm^{-3}
Mass	m_j	m_P
Temperatures	$T^j_\parallel, T^j_\perp$	K
Drift velocity	v^j_{D}	v^j_{th}
Loss cone depth,size	Δ_j, α_{2j}	

B Appendix

Directory structure of IDLWhamp:

idlwhamp_2.2/
- data/
- help/
- lib/
- par/
- pics/
- sessions/
- setup/ tmp/
- user/
- WHAMP/ whampmaster/ common/ Linux/ DEC_alpha/

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