Visualization of Oscillations Data via Spirals

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Abstract. This paper presents some ideas about the visualization of stellar oscillations data by means of spiral maps. The application area (Asteroseismology) is introduced before the problem itself is presented. Part of this problem is the identification of the fundamental frequencies, and some of their combinations, because this involves analysis of huge Intensity vs. Frequency graphs. The idea explored in this paper is the construction of images which encode this information in hierarchical fashion, enabling the user to easily browse the data set. The main geometry is a spiral, but color and other shapes are also used to enhance data understanding.

Keywords: Scientific Visualization, Asteroseismology, Spectrum Analysis.

1 Overview

This paper presents the basic ideas behind S-Browser, a software tool designed to help scientists identify stellar oscillation modes. It is part of the "Visualization of Stellar Oscillations Data" project, under development at the UFRGS National Supercomputing Center, in Porto Alegre. Main aspects of the application are briefly presented to provide a broad overview and understanding of where the data come from and what they are used for. Then it presents one of the problems that scientists face in this area and how this project intends to minimize it. The idea's backbone is the construction of spiral maps to show the dataset, which could be directly manipulated in a "point-and-click" fashion. The first prototype implemented is described and some results commented.

2 Visualization of Stellar Oscillations Data: the project

The project began in August 1992 as a collaborative effort of two professors from the Informatics Institute and the Physics Institute of the Federal University of Rio Grande do Sul (UFRGS) in Porto Alegre, Brazil. In short, the problem presented by Prof. Kepler de Oliveira Filho consisted of an 82 million-points graph which was hard to analyze with the regular software tools at hand. These data came from his asteroseismologic studies of the "G117-B15A" white dwarf star, also called "RY LMi."

2.1 Asteroseismology

In this area of Astronomy researchers try to deduce the internal structure of stars from vibrations on their surfaces [Powell et at. (1992)]; it's like monitoring earthquake waves to understand the inner structure of the Earth. Most experiences have been done with the Sun ("Helioseismology)" and with white dwarf stars, which are the remnants of sunlike stars (those that are progressively cooling and contracting).

Instabilities in the outer layers of white dwarf stars can generate waves that make the whole star shake, causing certain regions of the surface to compress, get hotter and thus radiate more intensely. Changes in brightness can therefore show stellar oscillations, and these reveal the star's basic parameters, such as mass, rotation rates, rate of revolution, and so on (please see [Kepler et al. (1991)] for some examples.)

The starting point of asteroseismologic studies is the star light curve, which is obtained by photometric observation. In this process the star brightness is measured with a photometer at regular intervals (seconds) during hours, days or years. This measurement can be taken only at night during certain days of the year, due to daylight, the star's position, weather and sky conditions. This means the light curve is not continuous, what becomes a source of further concern.

The next step in the process aims at identifying frequencies contained in this "light curve." To be understood, it must be converted into a frequency-series basis, which makes more sense to allow "oscillation" mode interpretation.

At this point, a Fourier Transform (FT) is applied to the light curve, yielding an Intensity vs. Frequency graph. The FT is a math calculation that allows the identification of periodic variations in a signal; in Asteroseismology, it helps the scientist to identify the star light's normal frequencies.

If the input signal is steady (if it's repeated over and over to infinity), the FT output clearly shows "peaks" that represent the signal's main frequencies. In real life, however, the signal is very seldom actually steady; it is sometimes "assumed" as steady after a finite observation. In this case the output curve shows the real peaks AND other smaller peaks, called "sidelobes." This is exactly the case of a signal such as the star light curve: it is considered steady for a certain observation period, which can be one night, one week, or years long. The FT then results in a few significant peaks and a lot of sidelobes combined, as well as a lot of noise, because these white dwarfs are faint and the sky is not completely dark.

This output curve is called the star's "power spectra" and describes the star light emission oscillations (see Figure 1).

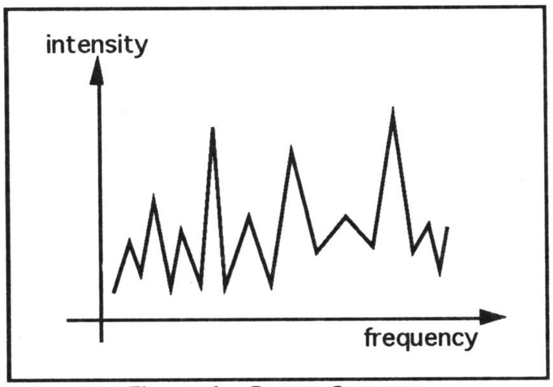

Figure 1 - Power Spectra

Some frequencies in the power spectra (called "real peaks") are important to the understanding of stellar oscillation, because they represent the real normal frequencies of the star. The determination of such peaks are not an easy task, though; due to the huge amount of noise and sidelobes, the criteria to determine if a peak is "real" or "false" varies a lot: it depends on the local noise.

This cycle - detect a potential peak, analyze the surroundings, confirm if it is real or not - is repeated until the scientist identifies all the significant peaks, or the star's normal frequencies. Then he/she starts to look for some important harmonics and combined peaks, as well as for groups of peaks that form special patterns - the multiplets. This analysis nowadays is still done with very little help of graphics tools, usually consisting of simple 2D-graph plots and much visual inspection.

2.2 The problem

In the current case of study (the "RY LMi" white dwarf star), the power spectra curve has 82 million points. This curve is the result of the FT for a 120-day light curve sampled over 15 years.

Because of its size, the information contained in this dataset can't be readily understood. Besides, only very few points are really meaningful because of noise and sidelobes, but there's no absolute or simple criteria for data selection or elimination. This means the physicist constantly needs to "browse" this huge dataset with almost no computer help, and this task obviously requires more sophisticated software tools.

The project's goal then is build a visualization tool able to help the scientist identify important oscillation information present in the FT output - the power spectra. This tool was called S-Browser - "Spectrum Browser" - because it should allow the user to "browse" the curve in an easier way.

2.3 Initial ideas

The main idea is simple: the program should show graph points in a "map" and allow the user to select different views (zoom/pan operations). The difficulty is to decide a way of building such a map, which was supposed to show marks corresponding to points over a huge one-dimensional curve using color and other graphic attributes.

The first idea was to split this curve into many small pieces and encode each point in a pixel, showing the intensity information by means of a color scale. Every piece could be displayed in one screen line, and many of them could be combined into the same image. A monitor resolution of roughly 1,000 X 1,000 pixels would allow the representation of one million curve points per image - a total amount of 82 images for the complete spectra. This solution presents two main problems, and in fact never was adopted.

One problem was the amount of information (too many images and too many points per image as well); data culling was necessary [Springmeyer et al. (1992)]. Because most of the points on the curve are noise, it seemed obvious to previously process the input data set to select only the "potential peaks" for display. This can be done by means of statistics tools explained in [Olabarriaga-Kepler (1992)].

The other problem was the division of contiguous data in two screen lines. Because the user is also interested in detecting sequences of peaks (the multiplets), this division was considered a problem. It was necessary to find another way of filling the space with this one-dimensional curve so that the resulting image visually preserved continuity of frequency values.

The idea developed next tried to solve these problems: it's the spiral map, which in fact has some extra interesting properties not only for this particular application, but to the visualization of any kind of oscillations data as well.

3 Spiral maps

An example of spiral map is shown on Figure 5. The image was generated S-Browser version 0.0, using test data for demonstration purposes.

Only potential peaks are shown by markers on the map, according to user chosen selection criteria. Markers are sequentially placed on a spiral and their colors indicate peak intensity. On Figure 5, peak height grows from blue to cyan, green, yellow and red. Areas where no peaks were detected are marked with white lines.

In a spiral map, continuity is achieved by twisting the power spectra curve into a two-dimensional spiral; frequency values grow from the center into image edges. Peaks which are contiguous in frequency domain then remain close on the image as well. Although apparently exotic, this way of filling a 2D surface with an 1D curve is very natural from the user's point of view and presents some other interesting properties described in section 3.1.

Twisting that huge curve into a spiral doesn't solve all the problems, though. There is a resolution question: the resulting spiral still needs many points to show the complete spectra. An approximate calculation shows that it would be possible to distinguish about 400,000 markers on an 1,000 X 1,000 screen, not enough for the current dataset. It was necessary first to build images indicating the regions of interest, and then to allow the user to zoom-in whenever necessary.

To accomplish this, groups of contiguous points, are mapped into the spiral instead of individual ones. In this case, the color and/or shape chosen for the marker represents the corresponding spectrum region in terms of the number and peak amplitudes detected there. The user may then "pick-and-click" any region to obtain a closer look, to ask quantitative information or even to see the original curve (graph plot). The zoom factor must be flexible enough to avoid the problem of separating peaks that lay on the regions boundaries.

An example of this idea is presented on Figure 6, which shows a map with squares and triangles. The shape selection is made according to the number of peaks detected in the region: a triangle means that only one peak was identified there, while a box indicates more than one.

3.1 Spiral types and properties

There are basically two ways of distributing frequencies on the spiral map: "linear" and "polar" mapping.

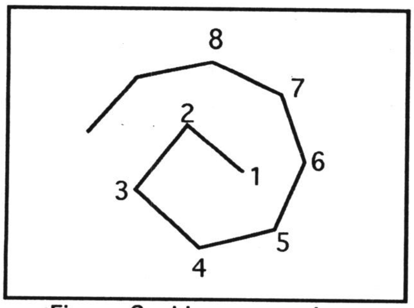

Figure 2 - Linear mapping

In linear mapping, the spiral is divided in pieces with the same length and the frequency value is used as a "distance" measured over this one-dimensional line (see Figure 2). In this case, frequencies are equally spaced from its neighbors all along the spiral. The maps generated using this distribution are specially adequate to show patterns, which indicate repeated sequences of peaks in the spectra. The spiral on Figure 5 was built with this type of mapping and it clearly shows patterns such as "yellow, yellow, greenish-yellow, green." This property is very useful in Asteroseismology for multiplets analysis.

In the polar mapping, the frequency value is used to calculate an angle and a distance from the spiral center. Only a fixed frequency interval is mapped into each lap; in Figure 3 the interval is 4. This kind of map has two interesting properties: increasing resolution along the spiral and harmonics alignment.

Figure 3a shows a polar spiral with fixed number of points per lap. As it can be observed in Figure 3b, however, it's possible to map more frequencies per lap as the distance from center grows. Because polar mapping implies a fixed frequency interval per lap, there are more points available for the same interval, or better resolution, on the outer laps. The user can take advantage of this feature by shifting the most interesting region to the outermost laps, which can be achieved by changing the map's frequency boundaries. The visual effect of sliding these boundaries would be a "zoom" on the regions closer to the upper limit, an interesting tool for spectra browsing and analysis.

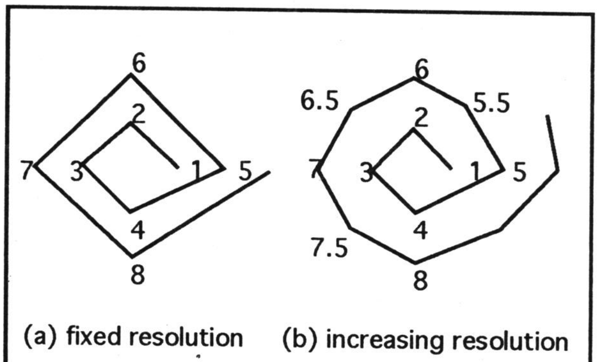

Figure 3 - Polar mapping

The most important property of polar mapping, however, is the alignment of frequency multiplets: peak markers lie on a diagonal line if the frequency interval per lap is correctly set. This is shown in Figure 7: the peaks align when the interval per lap is 9, indicating that they are spaced by 9 frequency units in the spectra curve. In the power spectra analysis context this could indicate the star's fundamental frequency and harmonics in the signal, which are very important information for asteroseismologic research.

Searching for the alignment point may be done interactively by changing the interval per lap value until diagonal lines are present on the map. As it is modified, different patterns can be identified in the map, as shown in Figure 8. When the interval per lap is smaller then the fundamental frequency, the markers are placed along clockwise twisted curves (Figure 8a); increasing this value makes them align and twist again (Figure 8b). It's straightforward to apply animation tools to improve the analysis process: the user could specify the interval per lap "key values", the number of steps, and the program would generate the sequence of corresponding maps.

Both properties enhance oscillation data understanding, being very useful for spectra analysis in general.

4 S-Browser version 0.0

S-BROWSER is an interactive program designed to offer basically three services: peak search in the raw dataset under user-given conditions; peaks map display using the spiral approach, and pointing&clicking of image portions to show different levels of information.

The main requisites considered in the S-BROWSER design were: dealing with huge amounts of data, considering noise in computations, handling quantitative information, supporting exploration recording, and providing a comfortable user interface. These requisites were based on user demands and recommendations in [Springmeyer et al. (1992)] and [Hubbold (1992)]; they're deeply explained in [Olabarriaga-Kepler(1992)].

The first version of S-Browser was developed in February 1992. The main goal of version 0.0 was to test the spiral map idea as well as performance issues. The commands responsible for session recording and display of quantitative information were left aside due to time constraints.

Silicon Graphics workstations and Iris Explorer environment were chosen for this implementation. Iris Explorer is a scientific visualization tool for Silicon Graphics workstations which enables the user to interactively build dataflows by selecting modules and connecting their input and output ports [Silicon Graphics (1991)]. Each module performs a certain action (function) on the input and produces output data; the system takes care of detecting changes in input data, executing the right function and sending the information to the next module on the flow. This platform enables fast prototyping, because many generic modules are available, and it's easy to build new ones as well. It's possible to create new modules within the "module builder" environment, which generates user interface code so that the programmer can concentrate on the function to be performed on the data itself.

S-Browser is in fact a dataflow that combines some Explorer's modules with new developed ones (see Figure 4). The round-cornered boxes indicate Explorer modules.

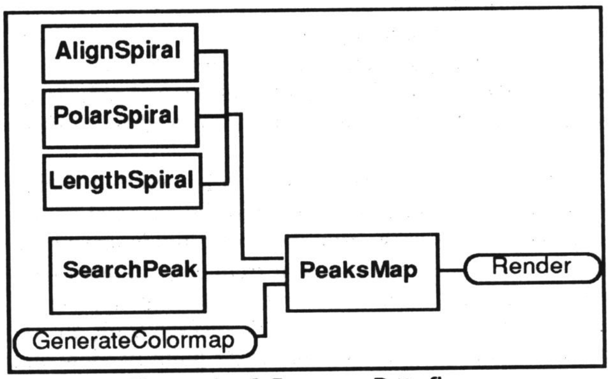

Figure 4 - S-Browser Dataflow

The modules *AlignSpiral*, *PolarSpiral* and *LengthSpiral* generate a list of discrete points on a spiral; the (x,y) coordinates are organized from the center outwards. The user can control parameters such as the number of points and spacing through a dialog box. AlignSpiral and PolarSpiral both generate points to be used in polar mapping with increasing resolution. The first module increases the resolution exponentially and the second linearly. PolarSpiral results in less points with worse alignment if compared to AlignSpiral, but it allows faster image generation. The module LengthSpiral generates points on a spiral by keeping a fixed distance between them, for linear mapping.

SearchPeak is the module that looks for peaks in the raw dataset, eliminating noise according to user specified parameters. The user can also indicate the search interval and the minimum peak level in a dialog box. This module generates a list of potential peaks which are mapped into the spiral by *PeaksMap*. Each peak is described by its frequency, absolute height and the height relative to local noise.

The map construction itself is based on the information generated by the previous modules. PeaksMap chooses peaks from the list generated by SearchPeaks and calculates the map position according to user-chosen mapping type. It determines the frequency's relative position on the spiral and uses the pre-calculated (x,y) coordinates to place a marker. The shape is chosen as described in section 3: the current version uses triangles and boxes to indicate that the region contains only one peak or more. Color for triangles is chosen depending on the peak's height, and boxes are colored according to the average peak height. This criteria is still under study and must be improved to avoid masking important information. The colors used are specified in the palette created by the *GenerateColorMap*. module.

GenerateColorMap allows the user to interactively associate colors and scalars and create a look-up table. This is achieved by specifying "key colors" and "key values" which are interpolated using bi-cubic curves. The result is a scale of scalars and related (R,G,B) colors used to indicate the desired encoding colors for peak heights.

The image is drawn by *Render*, another Explorer module. It allows the display of three-dimensional objects, camera manipulation, picking and lights control, exploring SGI Graphics Library capabilities. Because this module offers more services than needed on this project, it is slower than necessary, specially considering image complexity vs. graphics hardware features. Due to performance reasons, therefore, it will be replaced on the next implementation by a new module better suited to this application.

5 Conclusions

This text didn't present a thorough description of S-Browser itself, but basically emphasized the main features and advantages of the spiral map approach. This idea has proven to be an adequate tool to spectra analysis, and the user is very enthusiastic about its properties, although no map has been generated with complete dataset yet. There's a long way to go before S-Browser will be able to interactively generate spiral maps based on the 82 million-points dataset, mainly due to performance problems. Some improvements can be obtained by re-writing some modules (like the Render) or running them on the Cray supercomputer, and these are the next steps in this project.

6 Acknowledgments

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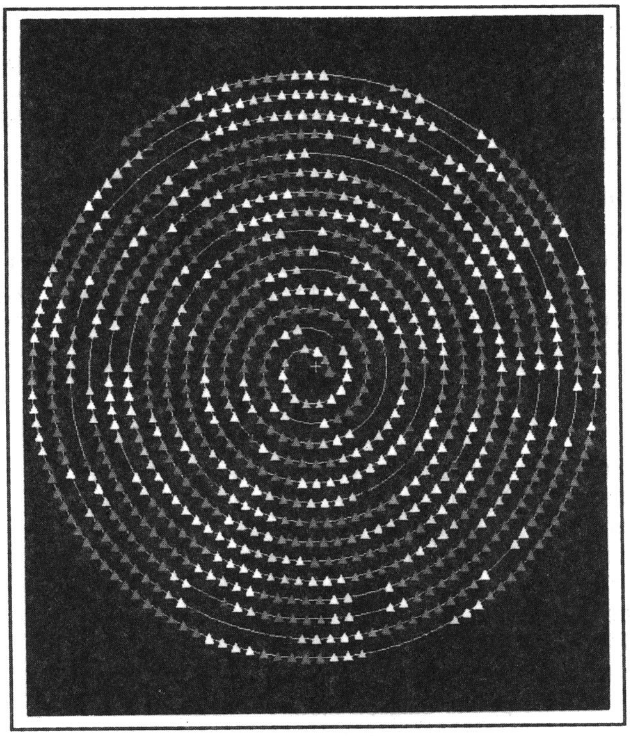

Figure 5 - Linear Mapping Spiral

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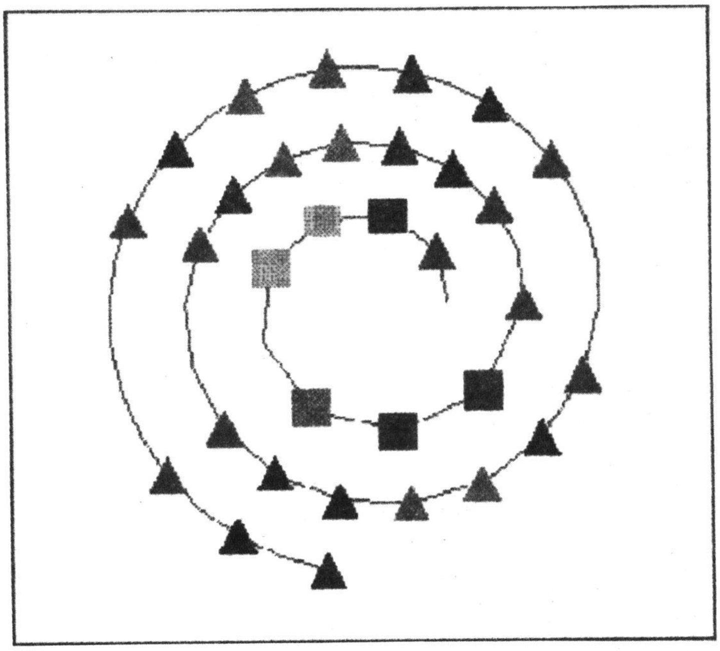

Figure 6 - Spiral Map with Group Markers

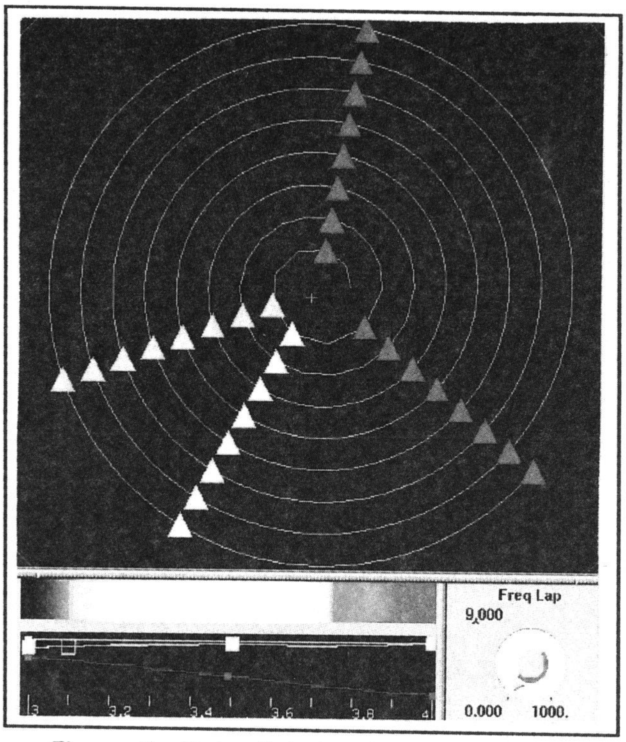

Figure 7 - Polar Spiral with aligned peaks

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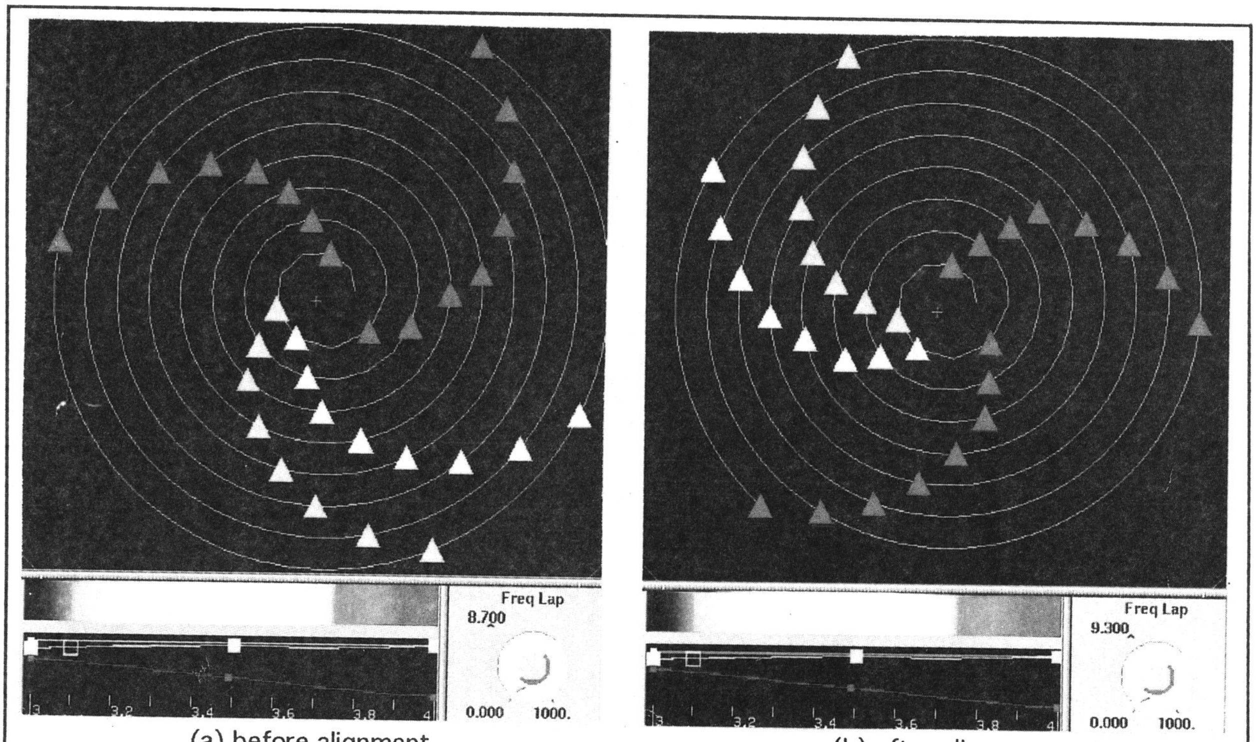

(a) before alignment (b) after alignment

Figure 8 - Non-aligned Polar Spirals