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Automated Spectral Reduction in the IRAF Fabry-Perot Package

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Abstract. As introduced at ADASS I and II (Bland-Hawthorn, Shopbell, & Cecil 1992), a Fabry-Perot analysis package for IRAF[1] is under development as a joint effort of ourselves and the IRAF group. In this paper, we describe an important component of the Fabry-Perot package, the **fpplot** task for spectral plotting and fitting. While this task has many similarities with the familiar **splot** and **specplot** tasks in the **onedspec** package, **fpplot** has been optimized and extended specifically for use with imaging Fabry-Perot data. The task provides for the display and analysis of grids of spectra, including functions for binning, scaling, masking, and overplotting spectra. The most important features of **fpplot** use the IRAF `nlfit` and `inlfit` nonlinear fitting libraries to perform both interactive and background fitting of Fabry-Perot spectra. Automated techniques are essential for quantifying the thousands of spectra in a Fabry-Perot data cube for velocity and photometric studies. An example is given from current work involving the starburst galaxy M82.

1. Motivation

Since their inception, the complexity of imaging Fabry-Perot interferometers has made the reduction of their data a daunting task. Large data sets and complex instrumental profiles have caused the majority of Fabry-Perot observations to be interpreted simply as velocity maps, ignoring the enormous amount of photometric information also present. A primary goal of the IRAF Fabry-Perot package is to enable the *photometric* reduction of imaging Fabry-Perot data.

Once the characteristic Airy instrumental profile of the Fabry-Perot etalon is removed from the data, by a process we call "phase calibration" (Shopbell, Bland-Hawthorn, & Cecil 1992), data visualization can take two forms:

[1]IRAF is distributed by the National Optical Astronomy Observatories, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation.

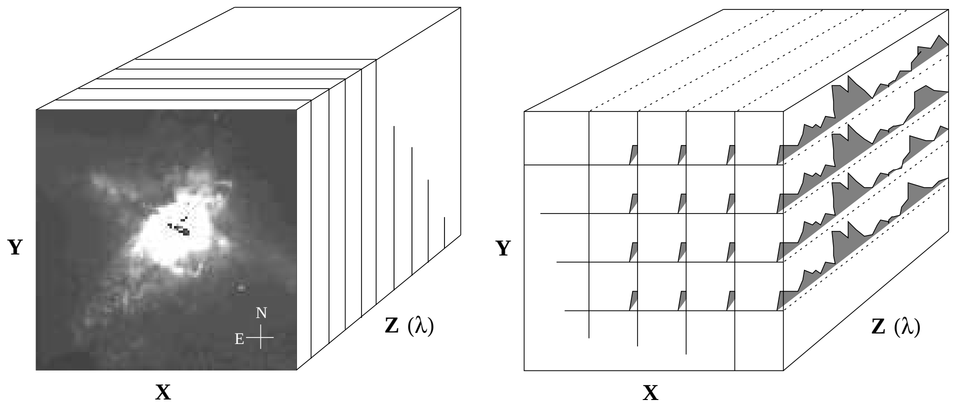

Figure 1. Two forms of imaging Fabry-Perot data visualization. The left cube depicts a series of monochromatic spatial frames sampled regularly in wavelength. The right cube depicts a grid of spectra sampled regularly in the spatial dimensions.

1. A sequence of spatial monochromatic images, each separated by a small increment in wavelength (~ 1 Å).

2. A spatial grid of spectra, sampled at the pixel resolution of the CCD ($\sim 0\farcs5$).

These forms are illustrated in Figure 1.

Early stages of the reduction of Fabry-Perot data, including cosmetic cleaning, flat-fielding, and alignment, employ the first visualization model. The later stages of reduction, such as phase correction, sky subtraction, and spectral fitting, employ primarily the second visualization model. While there are clearly tools available for the manipulation and display of images and image mosaics, there is currently a lack of useful visualization tools for application to the spectral domain of Fabry-Perot data. **fpplot** has been designed to assist the user in the advanced analysis stages of imaging Fabry-Perot data.

2. Features

The **fpplot** task in the IRAF Fabry-Perot package has many features found in the **splot** and **specplot** tasks in the **onedspec** and **twodspec** packages, as well as many options added specifically for Fabry-Perot data analysis. First there is the display of spectra. The displayed spectral grid merely represents a "window" onto the full spectral cube. The limits of the view may therefore be shifted and zoomed to view large-scale trends or details of individual spectra. Next, the spectra may be arbitrarily binned in the spatial dimensions, allowing the user to view large spatial variations. Binning in the spectral dimension is also possible. Additionally, one can scale the spectra. The spectra may be scaled to a variety of limits, including the extremes of the entire data set or each spectrum's extremes (i.e., autoscaling). In addition to the above, many overplotting options are provided for the comparison of data with other data or

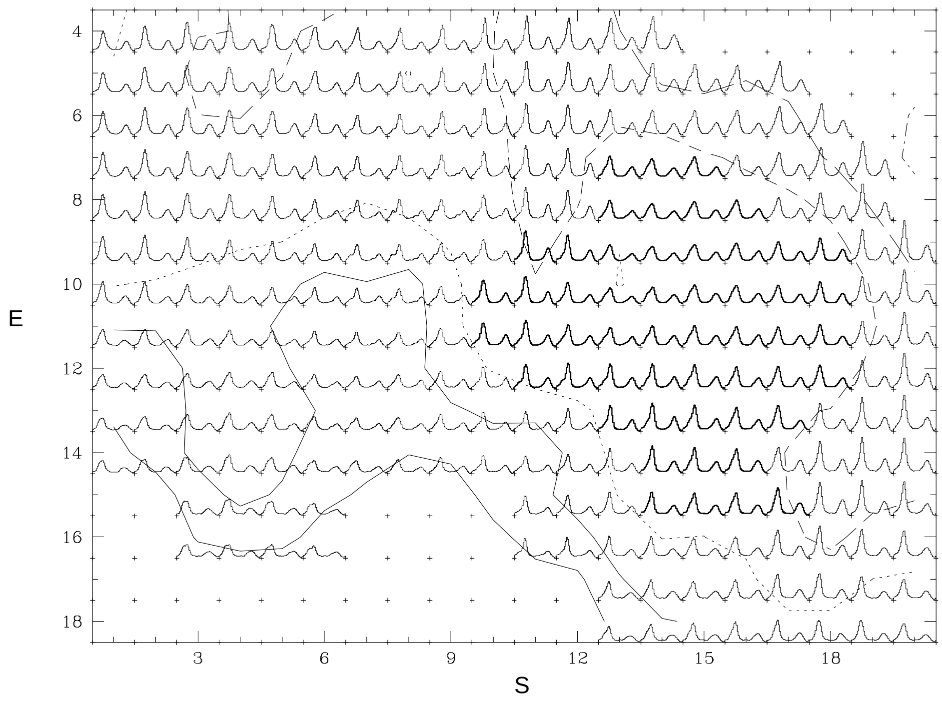

Figure 2. A spectral grid from Fabry-Perot data of the starburst galaxy M82 (Hα/[N II]), illustrating an overlaid contour map, two irregular areas of masked spectra, and a large area of spectra fitted automatically with a four-component Gaussian model.

models. Additional Fabry-Perot spectral cubes, spectral fits, and image contour maps may be overplotted. Also included is the sophisticated spectral fitting module **fpplot** which allows for both interactive and background fitting of spectra with multiple-component Gaussian functions. The interactive form is very similar to that provided by the **splot** task, including point rejection, residual plotting, etc. The automatic form uses spectra that have already been fitted to determine initial conditions for fitting additional spectra. Currently Gaussian functions and a linear continuum are used; Lorentzian and Voigt line fitting, as well as non-linear continuum fitting are under development. Lastly, to enable efficient automated fitting, full support is provided for spatial masking, via the IRAF PLIO routines (Tody 1988). Using masks, the user can remove bad pixels, sky regions, etc. from the fitting process. Figure 2 demonstrates several of these features using Fabry-Perot data from a central region of the starburst galaxy M82 (Shopbell 1995).

3. Fitting

The most significant capability of the **fpplot** task is that of fitting spectra. A small (512×512) CCD, assuming a useful data coverage of 50%, yields over 125,000 distinct Fabry-Perot spectra. If the instrument characteristics are well understood, these spectra can be fit to yield not only radial velocities, but emission line fluxes and dispersions as well. However, such a study clearly requires an automated means of fitting the emission line spectra.

The fitting portions of **fpplot** are modeled after those found in the **splot** task (in particular, those activated by the 'd' and 'k' keys). Single Gaussian functions can be fit; multiple Gaussians can be deblended. As with **splot**, **fpplot** employs IRAF's `nlfit` and `inlfit` nonlinear least squares fitting routines (Davis 1991) to fit the Gaussian profiles and, optionally, a linear continuum.

Major additions to **fpplot** enable it to fit large numbers of spectra in an almost entirely automated fashion. The user need only fit a few "characteristic" spectra interactively. **fpplot** will then propagate these fits across the desired region, using the fits of spatially nearby spectra as initial guesses for the current spectrum's fit. This propagation method is similar to that used in the FIGARO **longslit** package (Wilkins & Axon 1992). Because Fabry-Perot spectra are typically of low spectral resolution and encompass small wavelength ranges, this method of fitting works especially well. The typical problems of incomplete spectral coverage and inadequate continuum are still present however, as well as difficulties arising from multiple spectral components and rapidly varying spatial features. The use of an iterative procedure involving interactive verification of selective fits appears to solve these problems adequately.

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