AIPS Memo 120 Revised

Exploring Image Cubes in AIPS

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Abstract

AIPS has recently acquired powerful tasks to fit models to the spectral axis of image cubes. These tasks are easier to run if the user is already familiar with the general structure of the data cube. A new task TVSPC has been written to assist in acquiring this familiarity. This task provides an exploration tool within the AIPS environment, rather than requiring users to export their cubes to one or more of the many excellent visualization tools now available. In the 31DEC17 version an additional data cube may be displayed one plane at a time. [1]

1 Introduction

A completely re-written XGAUS, plus new tasks ZEMAN and RMFIT first appeared in the 31DEC13 release of AIPS and have been improved in subsequent releases. XGAUS fits Gaussians to the first axis of an image cube, normally the spectral axis of a transposed cube. ZEMAN fits a gain and one or more parameters proportional to magnetic field to matching cubes of total (Stokes I) polarization and circular (Stokes V) polarization. RMFIT fits Faraday rotation and thickness models to matching cubes of linear polarization (Stokes Q and U). These tasks, along with display and modeling tasks, are described in an AIPS Memo[2] which includes descriptions of the mathematics, the input adverbs, and the flow of each program. Similar tasks geared for use with absorption-line spectral cubes have appeared in the 31DEC17 release of AIPS. AGAUS and ZAMAN are also described in an AIPS Memo[3]

One can use the above tasks without being familiar with the contents of the image cubes. However, users who are familiar with the contents of their data cubes will find the modeling tasks simpler to use. The author has watched AIPS users export their cubes (with FITTP) to the various external image viewers now available. While AIPS cannot attempt to duplicate the full functionality of these excellent tools, it can offer, within the AIPS environment, some tools to acquaint the user with the contents of the image cube(s). In addition to the task TVSPC described herein, there is another new task TVIEW described in another AIPSMemo.[4] It displays image cubes in all three transpositions with a reference image and a spectral plot.

2 Spectral exploration: TVSPC

A new task, called TVSPC, has now appeared in the 31DEC16 version of AIPS, with added options in later versions. It presumes that the user has a "spectral" image cube which has been transposed to make the spectral axis first and the two spatial coordinates as the second and third axes. Optionally, the user may

[1] The color red has been used for changes made to this memo in April 2025; all other coloring for earlier revisions has been removed.

[2] Greisen, E.W. 2015, AIPS Memo 118 revised, "Modeling Spectral Cubes in AIPS," May 2020 revision.

[3] Greisen, E.W. 2017, AIPS Memo 122, "Modeling Absorption-line Cubes in AIPS," May 2020 revision.

[4] Greisen, E. W. 2019, AIPS Memo 124, "Further Exploration of Image Cubes in AIPS", April 2025 (revised).

also have a second transposed spectral cube which matches the first in its dimensions and coordinates. XGAUS requires a transposed cube, while transposed-cube pairs are required by ZEMAN (Stokes I and V) and by RMFIT (Stokes Q and U) already. TVSPC also assumes that the user has some "reference image," namely an image plane (in the spatial axes) that represents the emission region as a whole. This reference image may be a moment-zero image from a normal spectral-line cube, the Stokes I image from a region of polarized emission, or any other two-dimensional image meaningful to the user. The reference image does not need to have the same dimensionality or coordinates as the cube(s) so long as they all overlap in the spatial coordinates. The 31DEC17 version of TVSPC introduces an optional "spatial" cube in the transposition having the spatial axes first followed by the spectral axis. This cube may be displayed interactively, one plane at a time, and also used to select spectra from the transposed cube(s). This cube must have the same spectral coordinate type and similar spatial coordinate types as the transposed cube(s), but is not required to have the same reference values, increments, or pixels as those cubes.

2.1 Inputs

The usual INNAME *et al.* adverbs define the two-dimensional reference image to be loaded as a gray-scale image on the *AIPS* TV (assumed to be the XAS program). Adverbs TBLC and TTRC select the portion of the image to appear on the TV including the plane if INNAME points at an image cube. TVCHAN selects the TV channel used for the gray-scale display. PIXRANGE selects the image intensity range while FUNCTYPE selects the transfer function used to load the image to the TV. IN2NAME *et al.* adverbs define the primary transposed spectral cube to be examined. Optionally, the IN3NAME *et al.* adverbs define the secondary spectral cube to be explored along with the first. Two spectra are displayed if IN3NAME is specified, otherwise only one spectrum is shown. If IN4NAME *et al.* adverbs are also specified, then the menu includes options to display the spatial cube. Adverb CBPLOT controls the plotting of the Clean beam on position-position images when labeling is enabled.

Adverbs APARM and SAMPTYPE control the plotting of the spectra and may be changed interactively. APARM(1) and APARM(2) control the plotted range of the spectra, with APARM(2) $>$ APARM(1) setting a fixed scale, APARM(2) $<$ APARM(1) selecting the full image range, and APARM(2) $=$ APARM(1) having each plot be self-scaling. The spectra plotted are the average of the cube over a circular aperture (in the $y - z$ axes) of radius APARM(3) pixels with zero meaning a single pixel. The gray-scale image(s) and the spectra may appear in the right and left halves of the screen (APARM(4) > 0), they may appear in the upper and lower halves of the screen (APARM(4) < 0), or they may appear on top of each other (APARM(4) $= 0$) using the full screen area. When the screen is split, APARM(5) controls the fraction used by the spectra. If IN3NAME is specified, the two spectral plots may appear on top of each in separate colors but the same intensity range (APARM(6) ≤ 0) or be separated into two, potentially differently-scaled plots. If the spectra are in the lower half of the screen, this separation is horizontal. Otherwise it is vertical. Spectra are labeled in channels if APARM(8) > 0, otherwise they are labeled in the units of the first axis of the transposed cube. When doing Gaussian fits, APARM(9) controls the fitting of a spectral baseline. A value of zero means no baseline, one fits a constant, two fits a constant and a slope, and three fits a constant, a slope and a second-order term.

The spectra, after they have been read from the transposed cube(s) and averaged, may also be smoothed spectrally. If SAMPTYPE is 'BOX' (boxcar) or 'MWF' (median-window), APARM(7) specifies the number of spectral pixels over which the boxcar or median-window is performed. If SAMPTYPE is 'HANN' (Hanning), 'GAUS' (Gaussian), or 'EXP' (exponential), APARM(8) is the full-width at half maximum of these functions in spectral pixels. All other values of SAMPTYPE produce no spectral smoothing. It has been found that 'MWF', while very useful for removing badly discrepant points from *e.g.*, RFI, produces less than desirable results when applied to well-behaved spectra.

Note that the values of APARM, CBPLOT, and SAMPTYPE may be changed interactively during the execution of TVSPC.

2.2 Execution: the image

When TVSPC begins, it loads the TV in gray-scale with the reference image from INNAME with the plane selected by TBLC and TTRC and the scaling selected by PIXRANGE and FUNCTYPE. If the spatial cube is not specified, the image is centered in the full screen, the left half of the screen, or the upper half of the screen, depending on APARM(4). Whenever the reference image is loaded to the screen, the pixel increment in x and y is made the same and is chosen to maximize the size of the displayed image. Thus every n^{th} pixel may be loaded, every pixel may be loaded, or an interpolated image may be loaded. A message telling the pixel increment or interpolation factor appears in the message window. If the spatial cube is specified (IN4NAME *et al.* set), then the reference image is shown in left half of the area used for grey-scale images or the lower half if APARM(4) > 0.

The following menu appears in yellow at the left of the screen whenever you need to select some operation.

OFF TRANS	Initialize black-and-white transfer function
OFF PSEUDO	Turn of any pseudo-coloring
TVTRANSF	Adjust black-and-white transfer function
TVPSEUDO	Color contours of a variety of types
TVPHLAME	Flame-like pseudo-coloring
OFMCOLOR	Pseudo-colorings from many OFM tables
SET APARM	Change the plot and smoothing parameters
LABEL IMAGES?	Cycle through image labeling options
SET WINDOW	Select a sub-image for more detailed viewing
RESET WINDOW	Return to viewing full image
SET CHANNELS	Interactively set channel range for spectra
RESET CHANNELS	Plot and fit spectra with all channels
CURVALUE	Display intensity and pixel under the cursor
PLOT SPECTRA	Plot spectra of cube(s) selected with reference image
FIT SPECTRUM	Gaussian fit the plotted spectrum
SAVE SPECTRUM	Save the plotted spectrum as a slice
LOAD PLANE	Display a plane selected from the spatial cube
PLOT PL SPECTRA	Plot spectra of cube(s) selected with plane from spatial cube
SET PL WINDOW	Select a sub-image from the spatial cube plane
RESET PL WIN	Return to viewing the full spatial cube plane
SET PL RANGE	Enter intensity range for spatial cube display
EXIT	Exit TVSPC

The gray-scale image(s) are displayed with a black-and-white enhancement function followed by pseudo coloring, all with familiar functions. TVTRANSF is an interactive alteration of the black-and-white enhancement in which the TV cursor x position controls the intercept and the y position controls the slope of a linear transfer function. Buttons A and B turn a plot of this function on and off, button C changes the sign of the slope, and button D exits. OFF TRANS resets the transfer function. TVPSEUDO is an interactive pseudo coloring. Button A selects triangles in the three colors with the cursor x position controlling the position separating the lowest color from the highest, the cursor y position controls the "gamma" correction affecting the intensity of the colors, and repeated hits of button A cycling between all 6 possible color orders. Button B selects circles in hue at maximum saturation and intensity, with the cursor x position controlling the number of circles and the cursor y position controlling the starting hue. Button C selects color contours with the cursor x position controlling the image intensity at which contours begin, the cursor y position sets the range of image intensities over which the contours extend, and repeated hits of button C select between five different contour designs. Button D exits, returning to read the next operation from the menu. TVPHLAME implements a flame-like pseudo-coloring ranging initially from red through orange and yellow to white. The cursor x position controls the intensity at which the color transitions take place, the y position controls the gamma correction and repeated hits of buttons A or B will cycle between the 6 color sequences possible. Buttons C and D return you to the main menu. OFMCOLOR, added in version 31DEC25, allows you to set the color transfer function using the TV cursor and a large number of the standard OFMs ("output function memory" tables). Hitting buttons A, B, or C causes the selected OFM to change working through 3 separate lists of 10. After an OFM has been selected it may be adjusted with the horizontal position of the cursor. Hit button D to exit, keeping whatever color scheme you have developed. OFF PSEUDO turns off all coloring.

SET WINDOW is used to select a section of the reference image to be blown up for more detailed pixel selection. It is similar to verb TVWINDOW and begins by setting the lower-left corner. Hit buttons A or B to switch to setting the upper right corner. Buttons A and B switch between the corners thereafter. Buttons C and D exit with the window set. At this point, TVSPC reloads the reference image with the selected corners, maximizing the size of the image on the TV while keeping the x and y pixel increments the same. RESET WINDOW sets the display corners back to the initial TBLC and TTRC and reloads the reference image with the pixel increment that maximizes the size of the image on the TV.

SET APARM carries out a dialog on the input terminal to change all of the APARM and SAMPTYPE adverb values. The task prompts with "Spectral plot range min and max." Enter 2 values: if the first is less than the second the spectral plots are done from the first value to the second, if the second is greater than the first the spectral plots are done over the full image range, and if the first equals the second the spectral plots are all self-scaling. The task then prompts "Spectral averaging radius in YZ pixels;" enter 1 value $>= 0$ to set the spatial averaging radius in IN2NAME $y - z$ pixels. Then the task prompts "Split screen: < 0 vertical, > 0 horizontal, 0 none" to set the split of the screen between the area for the INNAME (and IN4NAME) image(s) and the area for the spectral plot(s). If a split screen is selected, the prompt "Fraction of split screen for spectra" requests a number between 0.1 and 0.9 with a default of 0.5. If IN3NAME was specified, you are asked "Split spectra: $<= 0$ no, > 0 yes" to control whether the two spectra over-plot each other or plot in separate windows. Then the question "Baseline fit order: ¿ 0 -¿ yes" appears. Answer 0 for no baseline or 1, 2, or 3 for the number of polynomial parameters to be fit. Finally, the prompt "Spectral smoothing function type (4 characters)" requests a string to do spectral smoothing, with BOX, MWF, HANN, GAUS, and EXP as known values. Any other value means do not smooth spectra. If smoothing with BOX or MWF, you are prompted for "Spectral smoothing support in channels" or, if smoothing with HANN, GAUS, or EXP, you are prompted with "Spectral smoothing FWHM in channels.". Enter one number greater than zero for the full support or FWHM in channels. Finally, you are prompted for "Set CBPLOT to 0 to 4." Enter 0 for no Clean beam plot, 1 lower left corner, 2 lower right, 3, upper right, or 4 upper left.

The LABEL IMAGES? option has three states: labels off, labels on the gray-scale image(s), and labels on the image(s) with a full coordinate grid. Successive selection of this option cycles through the three states. The CURVALUE option lets you display the pixel numbers and intensity under the cursor when the cursor is placed in one of the grey-scale images and when the cursor is placed in one of the spectral plots. In the latter, the intensity displayed is that of the particular spectrum at the channel selected by the cursor rather than the value actually under the cursor.

2.3 Execution: spectra

The purpose of TVSPC is to examine spectra, but until PLOT SPECTRA is selected the portion of the screen reserved for spectral plots is blank. Selecting this option, position the TV cursor within the reference image and move it around. The TV cursor selects a celestial position, the spectra at that position are read from the transposed cube(s) and averaged over radius APARM(3) pixels, smoothed spectrally if requested, and then plotted. Note that, if two spectra are plotted, both have been averaged over the same area and smoothed spectrally in the same manner. The position and intensity of the reference (gray-scale) image are tracked in the upper left corner of the screen (much like verb CURVALUE) while the spectral plot(s) display the celestial coordinate and transposed-image pixel position along with the plot(s). Move the cursor around to select some particularly interesting spectrum. Then hit buttons C or D to terminate the plotting. Pixel positions not in the transposed image are reported whenever such errors begin.

Initially, the spectra are plotted with all spectral channels found in the transposed cubes. However, having exited from `PLOT SPECTRA`, you may select the `SET CHANNELS` option which will allow you to reduce the range of channels plotted and used in the fitting described below. `SET CHANNELS` is interactive. It plots a vertical line at each end of the plotted spectrum and then reads the cursor to adjust these end points. Buttons A and B allow you to switch between the lower and upper end points while the channels chosen are displayed in the upper left of the screen. When you hit buttons C or D, the channel range is set and will be used in future executions of `PLOT SPECTRA`. The `RESET CHANS` option is the only way to select a channel range outside the current range and it sets the channels to the full range. Thus to choose a restricted range outside the current range, you must `RESET CHANS`, then `PLOT SPECTRA`, and finally `SET CHANNELS`.

Having exited from `PLOT SPECTRA`, you may choose to fit up to four Gaussians to the spectrum from `IN2NAME`. Select `FIT SPECTRUM` and the task will prompt you to position the cursor at the peak of the first component and hit button A or B. This sets the initial guess for the peak and central channel of the first component. Then the task prompts you to point at the half-power point of the first component and hit button A or B. The x position of the cursor then sets the initial guess of the FWHM of the first component. The task then asks for the initial guesses for component 2, 3, and 4 in a similar fashion. If at any time you hit buttons C or D, the setting of the initial guesses is terminated and the number of Gaussians fit will be the number for which both positions were specified. The task then fits the Gaussians to the spectrum, including an optional polynomial baseline, using non-linear least squares (as in `SLFIT` and `XGAUS`). The results including uncertainties are displayed on the message terminal with the peaks being in image brightness units and the centers and widths being in channels. The task plots the model fit and the residuals (data minus model) in two additional colors on top of the spectrum. If the result is not satisfying, you may select `FIT SPECTRUM` and try a new initial guess. Note that selecting `PLOT SPECTRA` causes the Gaussian fit results to be discarded.

Having exited from `PLOT SPECTRA`, you may choose to save the displayed spectrum as a slice (`SL`) file attached to its transposed spectral cube (`IN2NAME`). The full spectrum is saved as a slice with the necessary additional information to match the action that could have been done by task `SLICE`, but with the addition of the optional spatial averaging and spectral smoothing. The latest Gaussian fit, if any, is also saved with the slice in a manner matching that of task `SLFIT`.

2.4 Execution: spatial cube

A third "spatial" cube may be specified with adverbs `IN4NAME` *et al.* If it has been specified, additional menu items appear. Having done a `PLOT SPECTRA`, you may now do a `LOAD PLANE`. This operation displays a vertical line in the spectrum plot which is used to select the spectral value of a plane from the spatial cube. This plane is then displayed in the right-hand or upper half of the area reserved for grey-scale displays. Moving the cursor horizontally in the spectral plot allows you to select planes quite interactively. When you have found a plane you wish to examine in more detail, hit any button to terminate the `LOAD PLANE` operation.

Having displayed a plane from the spatial cube, you may now `PLOT PL SPECTRA` which is the same operation as `PLOT SPECTRA` but using the displayed plane from the spatial cube. You may also `SET PL WINDOW` which is the same as `SET WINDOW` except that it sets a window into the spatial cube. That window will be used for the current display and any further `LOAD PLANE` operations until a `RESET PL WIN` resets the spatial cube window to the full dimensions of the cube. The intensity range used for the spatial cube grey-scale display may be changed with `SET PL RANGE`. Enter two numbers, the lower end of the range followed by the upper end of the range. If the second number entered is less than or equal the first, then the full intensity range of the spatial cube will be displayed. The prompt message shows that full range of intensities.

2.5 Examples

The first example is an HI spectral line cube of NGC 6503. The reference gray-scale image chosen is a moment-zero image giving a wide-angle view of the total HI in the galaxy. It covers a larger spatial area than the transposed cube which also has different spatial pixel size and other different coordinate parameters. Figure 1 illustrates the split screen option, with the top plot having `APARM(4) = -1` and the bottom plot having `APARM(4) = 1`. The gray-scale image is loaded over its full range in the top plot, but only every other pixel. In the bottom plot, `SET WINDOW` was used to allow every pixel in the sub-image to fit in the left 45% of the screen. In the bottom plot, the `PLOT SPECTRA` operation is being performed, giving the `CURVALUE`-like display in the upper left corner.

Figure 2 also illustrates the split screen option, with the top plot having `APARM(4) = 1` and the bottom plot having `APARM(4) = 0`. Every pixel of a large sub-image of the moment zero image is loaded in the top plot, while a smaller sub-image allows the loading "interpolated by 4" (meaning 3 values interpolated between every actual image pixel). In both, a Gaussian fit has been performed.

Figure 3 illustrates the `31DEC19` and later versions with a spatial cube specified. Note the presence of 5 additional menu items. The reference image is the moment-zero (total HI) image while the spatial cube is the spectral cube before transposition. The top plot shows the screen after a `PLOT SPECTRA` but before any `LOAD PLANE`. The bottom shows the screen after a `LOAD PLANE` operation was performed. The vertical pink line in the spectrum plot shows the plane chosen.

The second example is of a small OH maser region with spectral cubes in both Stokes I and Stokes V. In these data, the two maser lines were not spatially resolved, although `ZEMAN` following `XGAUS` was able to determine separate magnetic field strengths for the two components. Lacking a moment-zero image, we use one of the output images from `ZEMAN` (the "field1" image). Figure 4 shows screens split vertically (`APARM(4) = -1`) with the top image not separating the I and V spectra (`APARM(6) = 0`) and the bottom plot separating them (`APARM(6) = 1`). In the top plot, the `PLOT SPECTRA` operation is being performed, leading to the `CURVALUE`-like display in the upper left corner. Note the units of the field1 image. In the bottom plot, the Stokes I spectrum has been fit with two Gaussians and a small sub-image was selected in order to see some detail in the field1 image. Both plots used `APARM(5)=0.6` to increase the size of the spectral plots.

Figure 5 illustrates screen splitting with the full screen split horizontally and the spectra vertically (`APARM(4) = 1` and `APARM(6) = 1`). in the top plot. In the bottom plot, both splits have been turned off (`APARM(4) = 0` and `APARM(6) = 0`). In each plot, the Stokes I spectrum has been fit with two Gaussians.

Figure 6 illustrates the use of `TVSPC` with full polarization cubes. The total intensity image is shown with spectra from Stokes Q and U.

The HI data have been described in the literature by Greisen, E. W., Spekkens, K., van Moorsel, G. A., 2009, "Aperture Synthesis Observations of the Nearby Spiral NGC 6503: Modeling the Thin and Thick Disks," AJ, 137, 4718-4733. The OH data were provided by Emmanuel Momjian from EVLA commissioning observations of sources known to show Zeeman splitting. The polarization data were produced by an *AIPS* simulation task to test rotation-measure modeling in `RMFIT`.

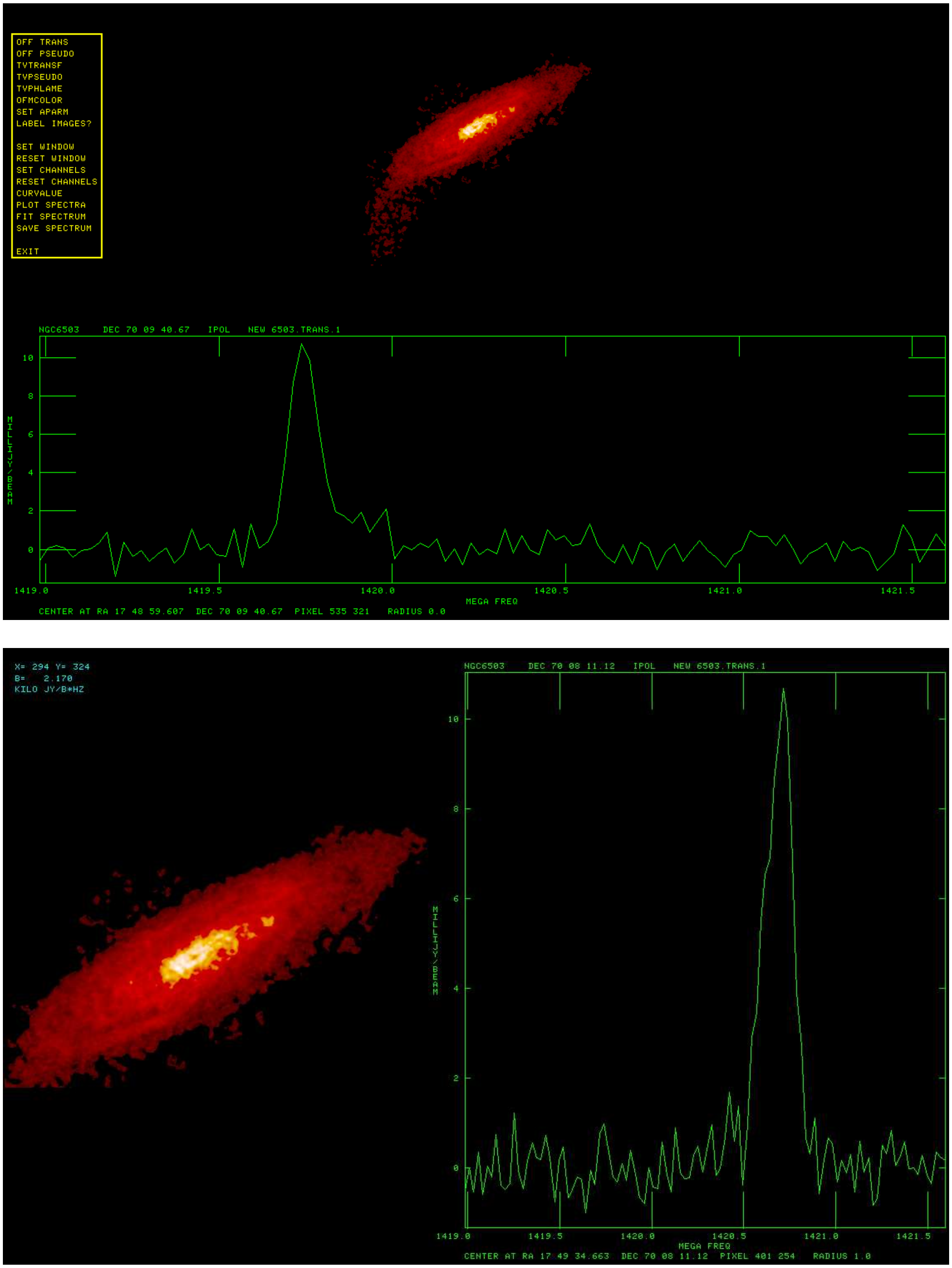


Figure 1: HI moment-zero reference image with spectrum. Top: split vertically, every other pixel of reference image loaded, shown with flame coloring at the menu prompt. Bottom: split horizontally, every pixel of sub-image loaded, shown during `PLOT SPECTRA` operation.

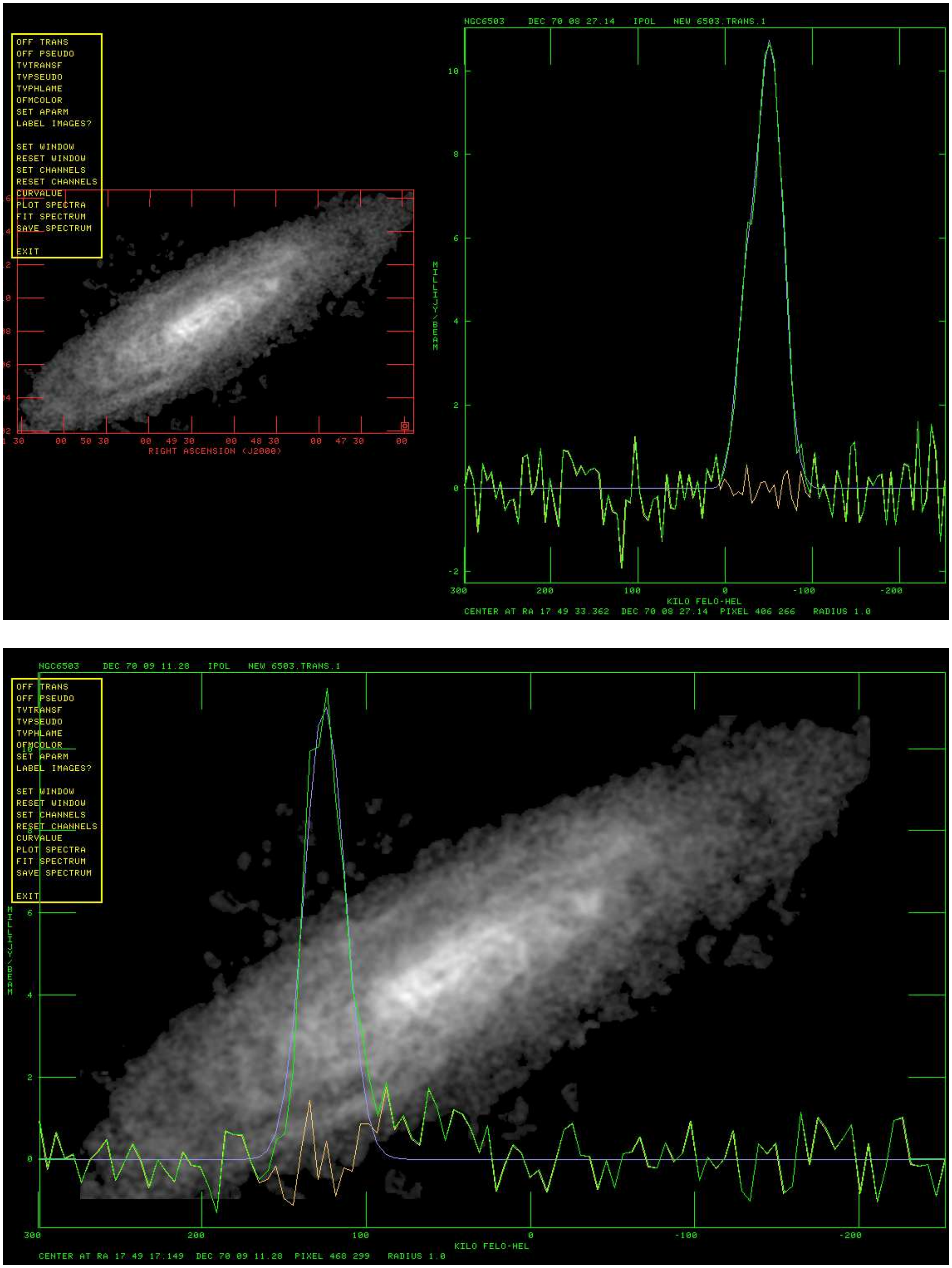


Figure 2: HI moment-zero reference image with spectrum. Top: split horizontally, every pixel of reference sub-image loaded, shown at menu prompt after `FIT SPECTRUM` and `LABEL IMAGES?`. Bottom: not split, smaller sub-image interpolated by 4, shown at menu prompt after `FIT SPECTRUM` operation.

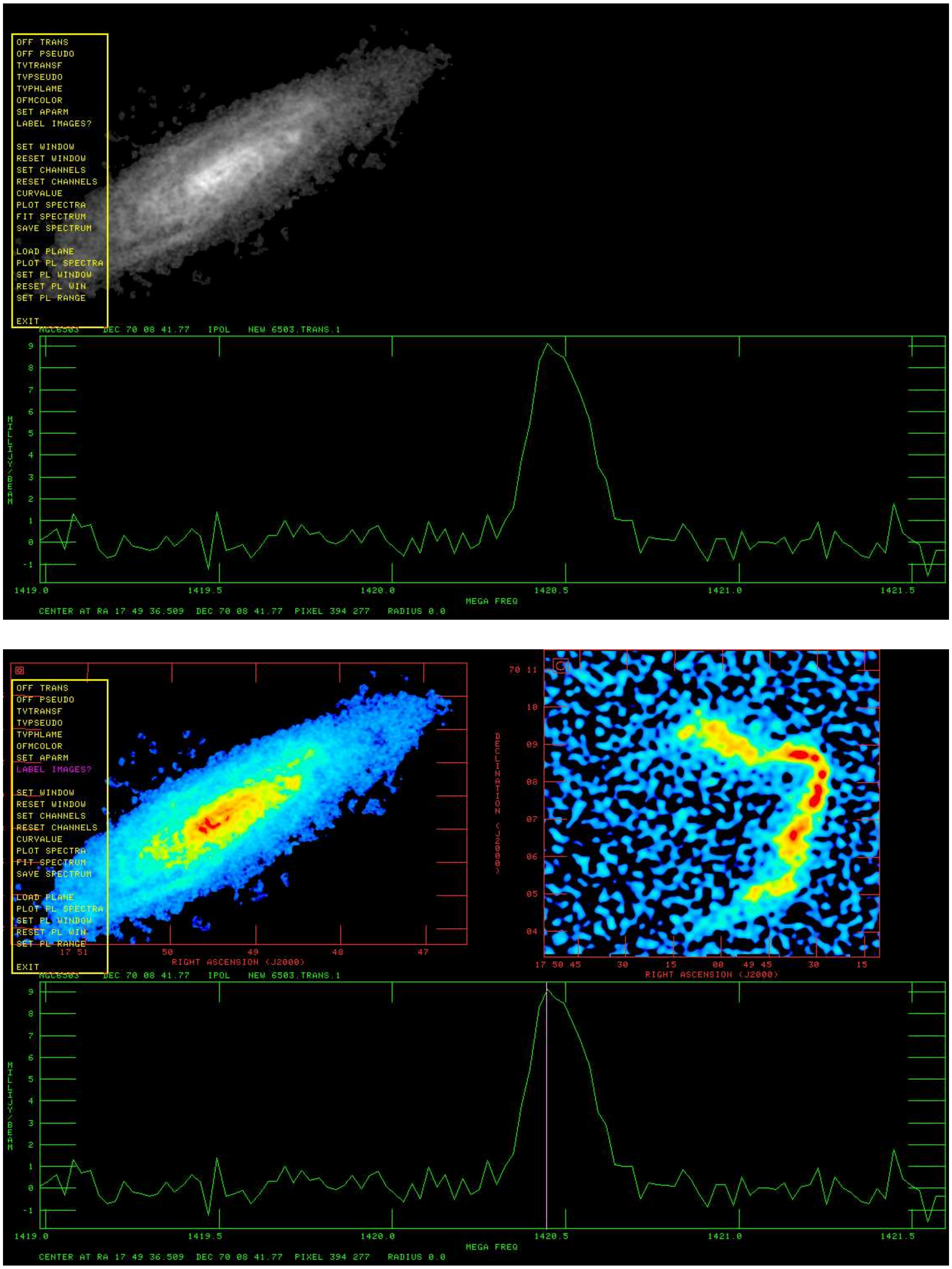


Figure 3: HI moment-zero reference image with spectrum and spatial cube. Top: split vertically, every pixel of reference sub-image loaded, shown at the menu prompt before `LOAD PLANE`. Bottom: same image, shown after `LOAD PLANE` and `TVPSEUDO` with every pixel loaded from a sub-image of a plane of the spatial cube. The intensity range of the plane has been set to 0 to 0.01 Jy/beam from the default -0.003 to 0.017 Jy/beam. Image axes are labeled. Sub-images are shown so that the Clean beam (`CBPLOT=4`) will be visible.

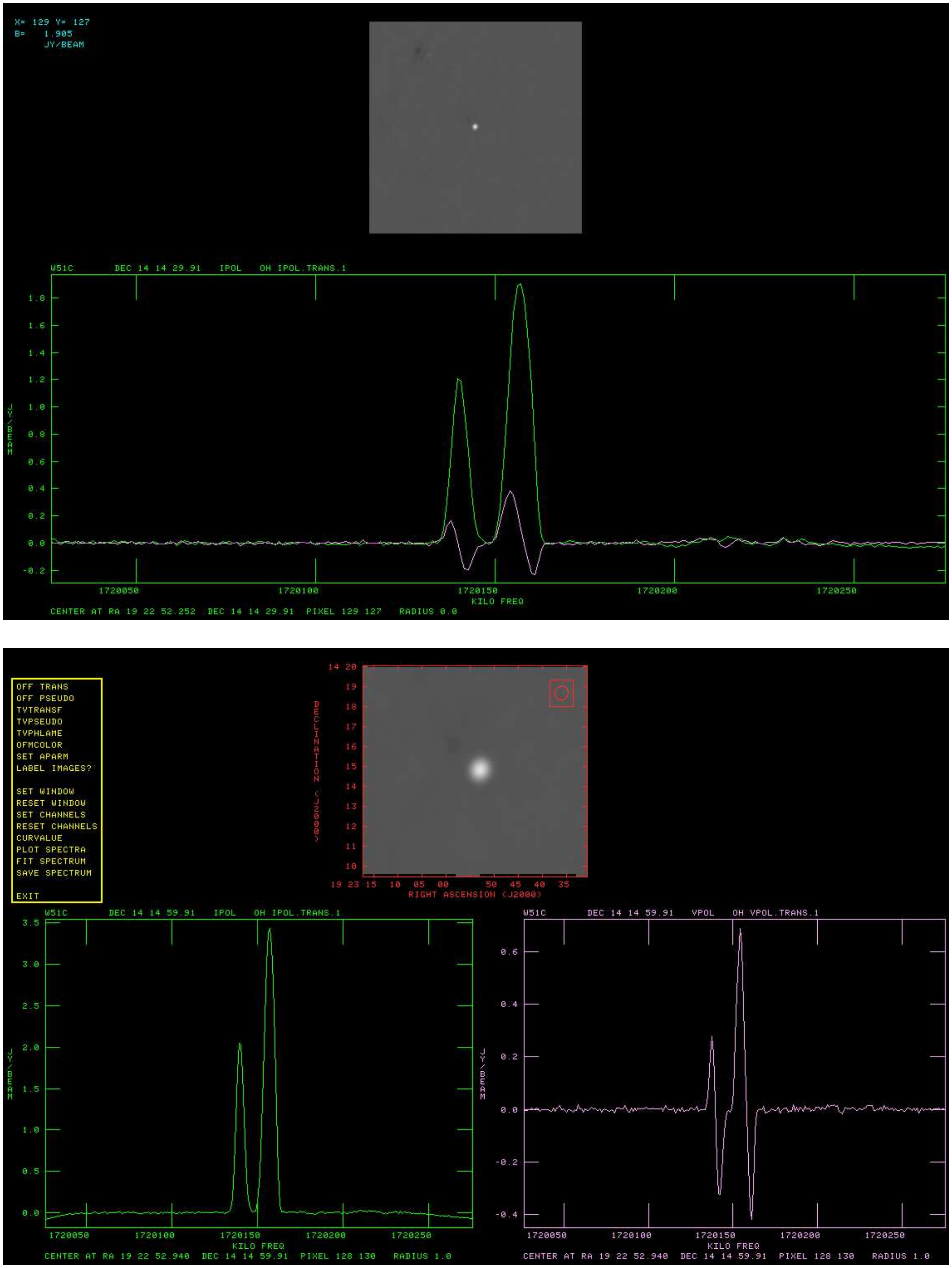
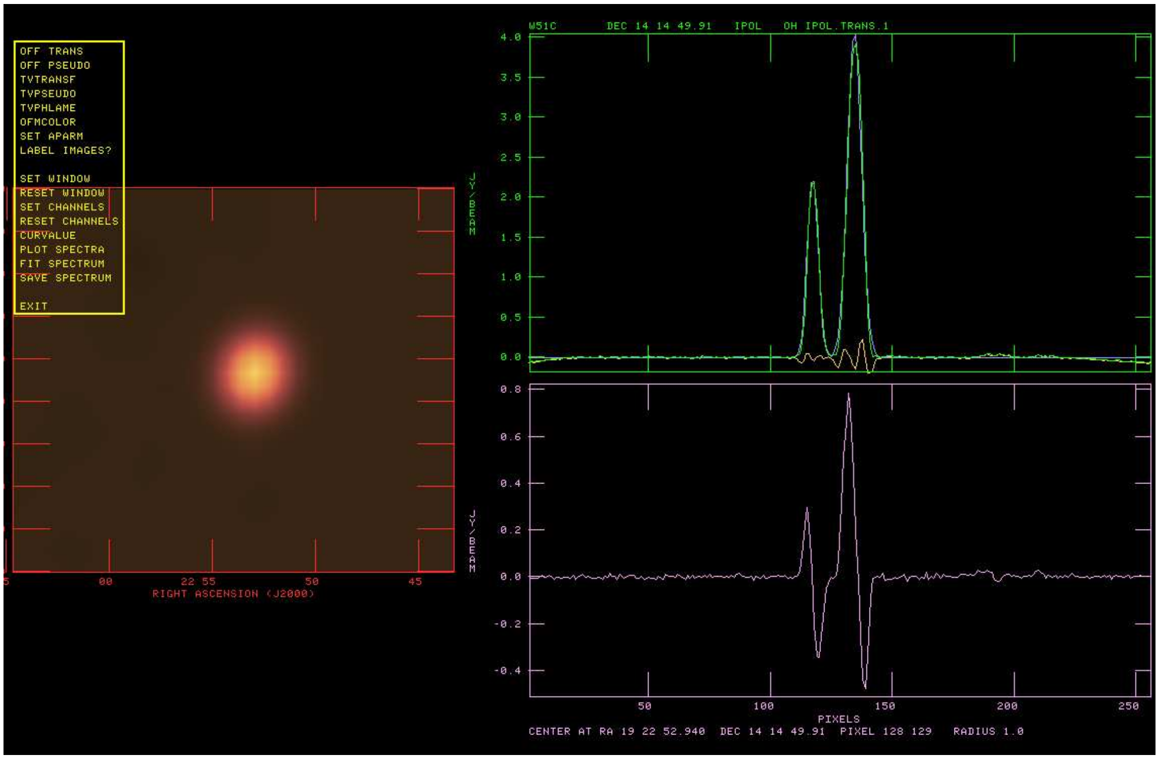


Figure 4: OH "field1" reference image with I and V spectra, screen split vertically. Top: every pixel of image loaded, shown during `PLOT SPECTRA` operation with I and V spectra overlapped. Bottom: sub-image interpolated by 7 loaded, spectra averaged over radius of 1 pixel, shown at menu prompt with I and V spectra separated and image labeled.



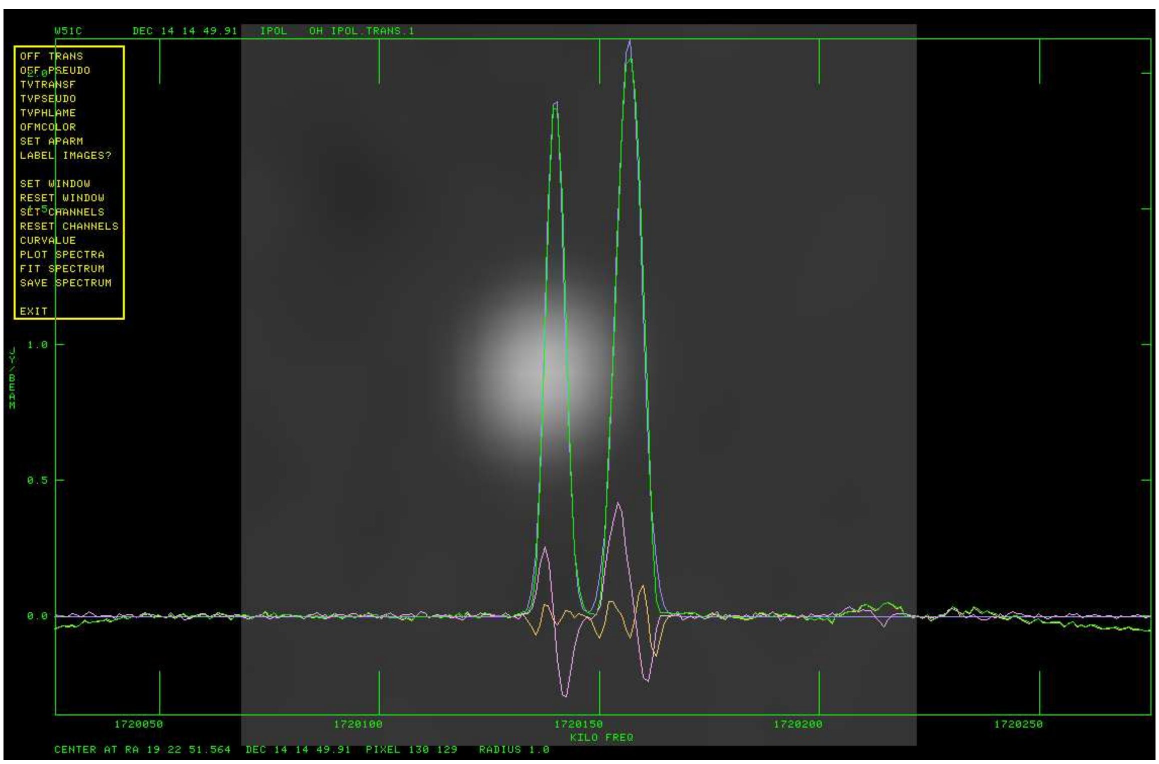


Figure 5: OH "field1" reference image with I and V spectra shown after `FIT SPECTRUM` operation. Top: split horizontally with `APARM(5)=0.6`, sub-image loaded interpolated by 14, could now save spectrum as a slice. One of the `OFMCOLOR`s was chosen. Bottom: not split, sub-image interpolated by 23, spectra averaged over radius of 1 pixel, shown at menu prompt with a fit at a point off center.

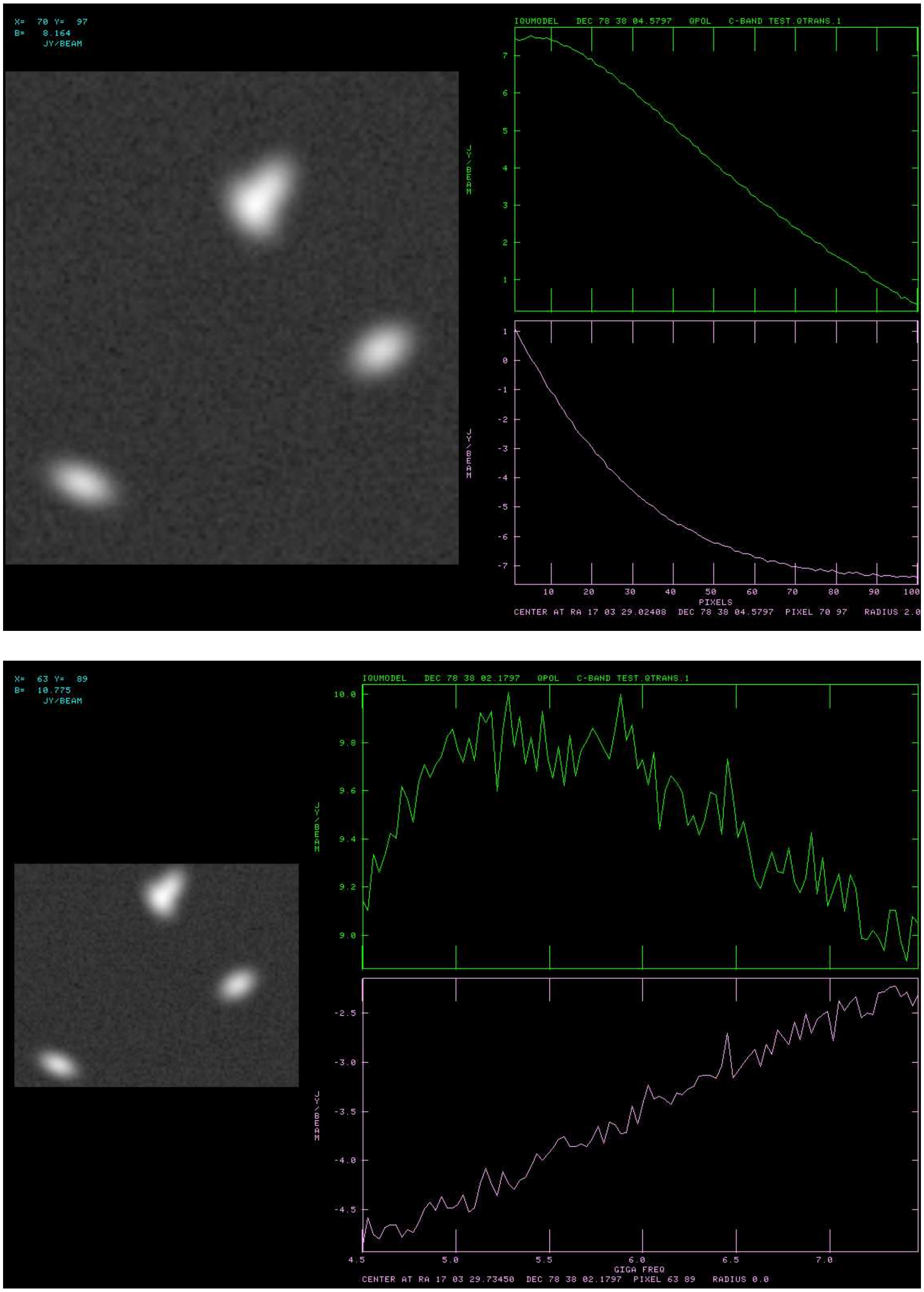


Figure 6: The third example is a model reference image made to test `RMFIT`. The gray-scale is the Stokes I image and the transposed cubes are the Stokes Q (green) and U (pink) images. The screen is split horizontally with different values of `APARM(5)` and the polarized spectra are split vertically. The screen shots were taken during a `PLOT SPECTRA` operation at different pixels in the upper model object. The gray-scale image was interpolated by 5 in the upper plot and by 3 in the lower plot. The spectra were averaged over a radius of 2 in the upper plot and not averaged in the lower plot.