Mike's Spextool Manual

First of all, this is NOT meant to replace the Spextool help files that you can access using the Menu button at the bottom of each module's IDL window. (You can also read these text files directly – look in Spextool/helpfiles – they are plain text). My intention was to provide an annotated visual record of what a Spextool session is like, and also describe some things I have come to learn about the details of the process. Here I summarize each module and what it does, in the order that they are to be done.

Xspextool – Here you construct your calibration frames (master flat and wavelength calibration), determine extraction apertures, extract the data (after background subtraction and flat-fielding), and merge the A and B beam observations. The result is a number of spectra representing each original observation file, properly calibrated. SXD and LXD are done separately.

Xcombspec – Here you merge the various observations together, SXD and LXD dome separately.

Xtellcor - (and **xtellcor_finish**) Generally the most time-consuming part of the process, at least for SXD (again SXD and LXD are done separately). Here you use your observations of an A0V star and telluric model absorption spectrum to determine the telluric corrections for your target star data. It is based on doing a flux calibration of your A0V star based on Vega. This requires determining how to alter the Vega spectrum to match the H line shapes and strengths of your A0V star, and apply it to the entire spectrum. This is then used to "remove" the H lines from your A0V star data so that it should resemble the telluric data. Since no two A0V stars are exactly identical (and Vega is peculiar, being a rapidly rotating star viewed pole-on) you need to go in and "tweak" them into submission. You can then construct the telluric correction data and apply it to your science target spectrum. You then adjust the wavelength scales of the telluric spectrum and your science target data by aligning their telluric features. The divine the two to get a (hopefully) telluric-corrected spectrum. If you have an A0V calibration star that is a good match in airmass & telescope position for more than one science target, **xtellcor_finish** allows you to skip most of the first part, which would simply be repeating what you have done, and go right to the spectra alignment.

Xmergeorders – This allows you to merge the various orders together within SXD and LXD separately.

Xcleanspec – For trimming out data that is noisy, or where you want to remove wavelength regions with systematic distortions due to poor matching of airmass between the A0V star and the science targets.

Xmergexd – Here you can merge SXD and LXD together.

At any stage of the process you can examining the spectra using **xvspec**. Note that at each stage of file writing, information of what you just did is added onto the FITS file header. I find it useful to look at these using a suitable FITS viewer, like the SAOIMAGE DS9 utility. Note that **Xcleanspec** can be used after **Xmergexd** if you need to go back and do some more cleaning.

For more info, see: *Vacca et al. 2003, PASP, 115,389 – Telluric Corrections* and *Cushing et al. 2004, PASP, 116, 362 – Xspextool Package*

TABLE OF CONTENTS

XSPEXTOOL 3

XCOMBSPEC 16

XTELLCOR 22

XMERGEORDERS 56

XCLEANSPEC 72

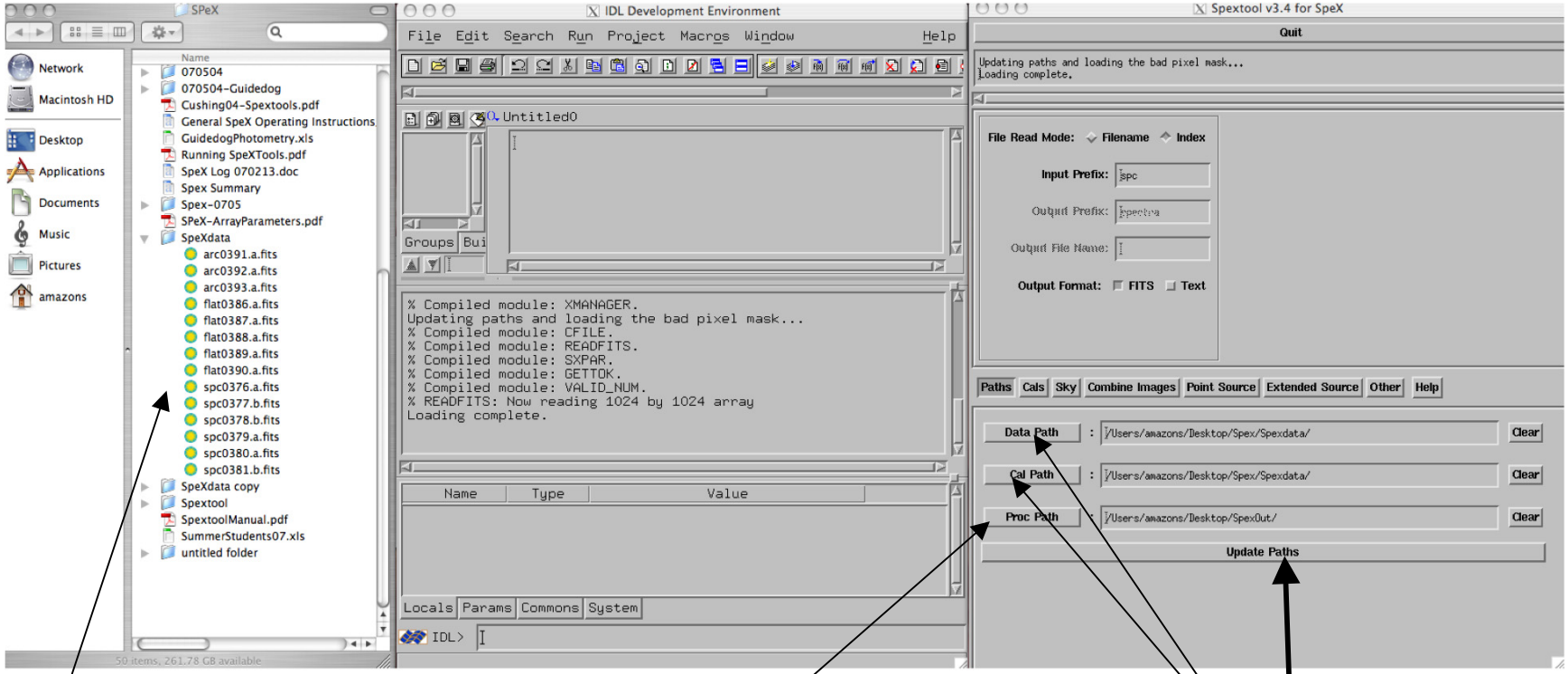
XMERGEXD 77

PRISM DATA 84

APPENDIX - PMS STAR LINE IDENTIFICATIONS

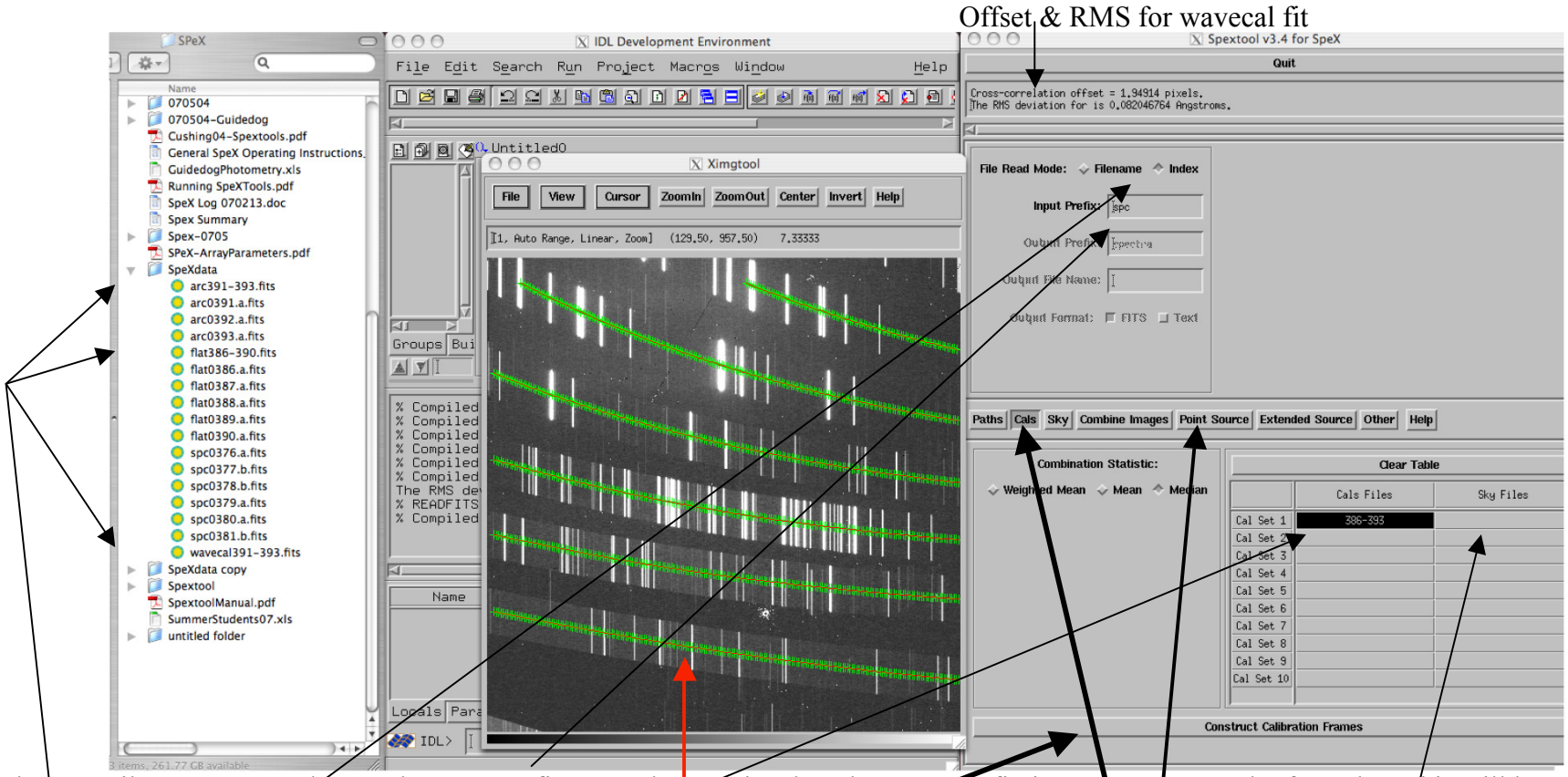
XSPEXTOOL

IDL Window Spextool "Main Base"



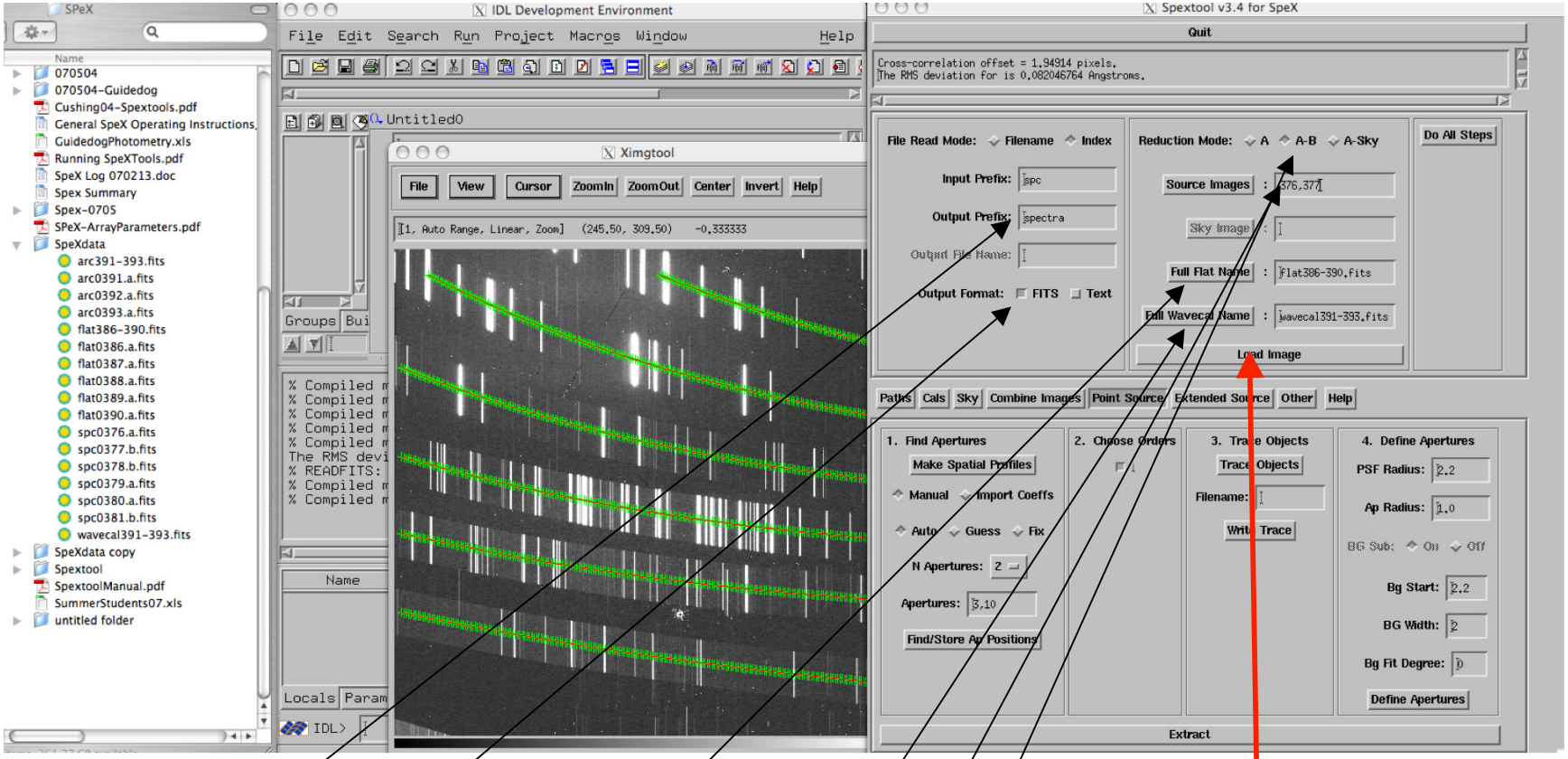
Original Spex data files Windows open after entering "xspextool" in IDL window & hitting *return*

Your first order of business is to set the paths of your input files for stellar data and calibration files by clicking here and navigating through your directory tree. You also need to select where you write your output files. Then remember to click on **Update Paths** so ***xspextool*** will *remember* them.

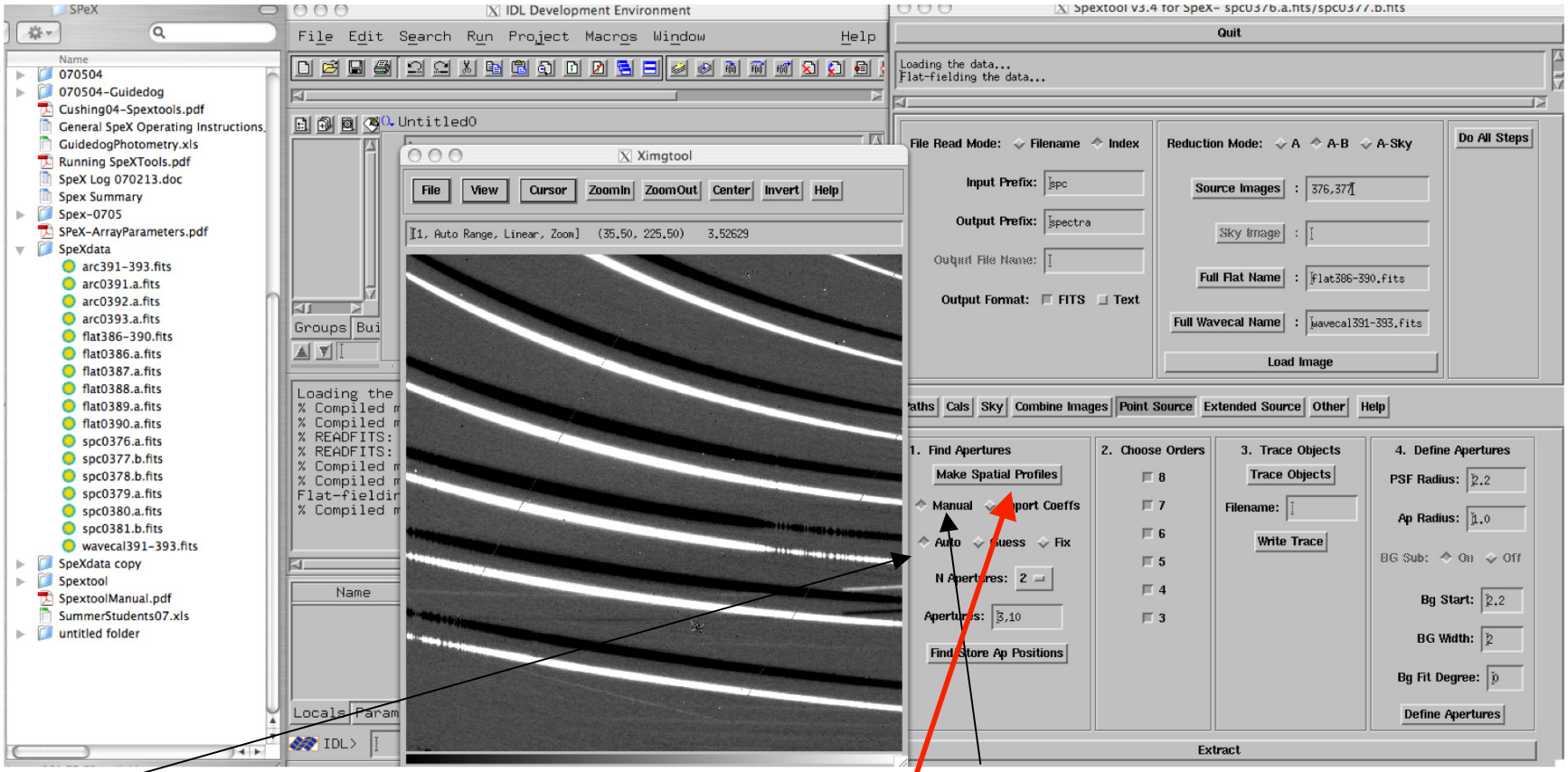


Choose "Filename" or "Index" and "Input Prefix". For the practice data the Input Prefix is "spec". For much of our data, this will have a star name designation (especially when using star files for adding lines in LXD mode). Click on **Cals**.

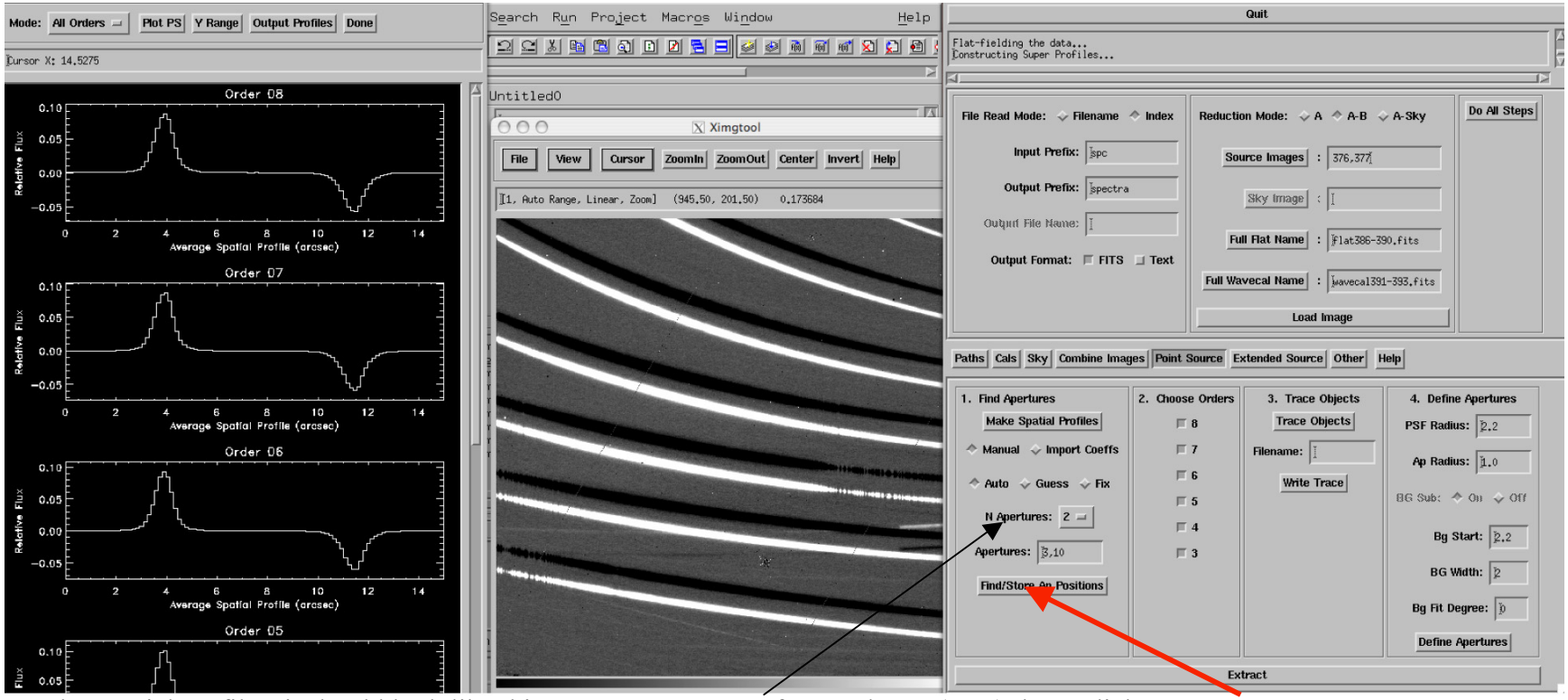
Then you put in the range of the file numbers of the SXD or LXD Cal Macro here and hit *return*. (without the return, nothing will happen in the next step…). Click on **Construct Calibration Frames**. The Ximgtool window should appear, and after the arcs & flats are loaded and processed by Spextool, it should look like this. Also note that a file of merged arcs, flats, and wavecal files have appeared in your input data file. When you are done constructing the cal files, click on **Point Source** to proceed with *stellar* sources.
For LXD you also need to enter an AB pair of stellar files so that telluric emission lines can be added for the longer wavelengths.



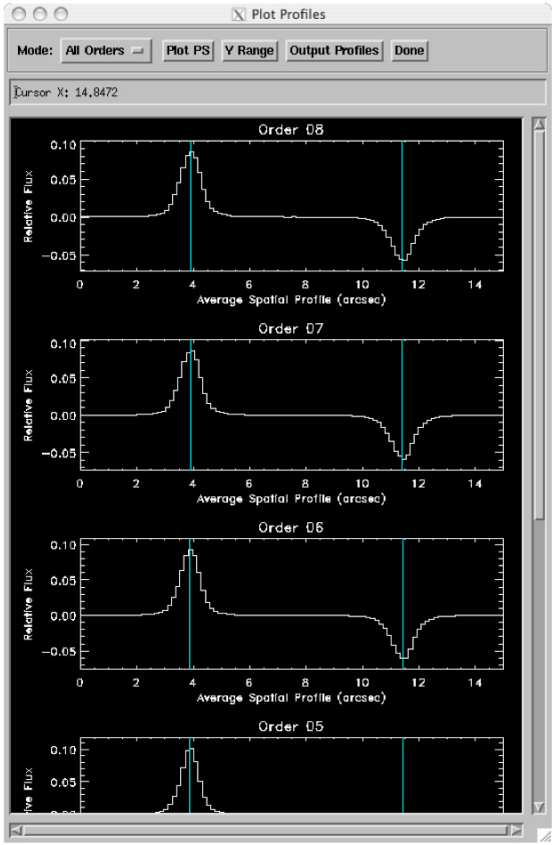
Pick your output file prefix, select FITS as the output format. Select the first 2 star data files to work on (generally the A and B beam files in the nodded observations). Click on Full Flat Name and Full Wavecal Name (not Arc!). These will load the last ones created. If you need others instead, fill in the boxes appropriately. For A-B beam subtraction, click on the A-B box. Click on **Load Image**.



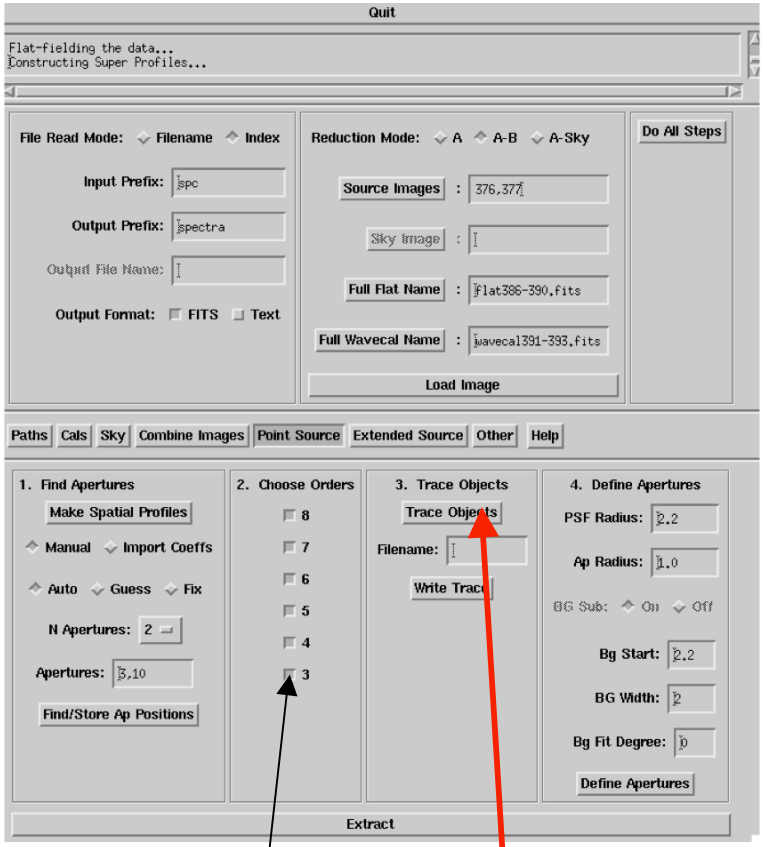
After **Load Image** it should look like this. For finding apertures, we will generally use Manual (manually determined from the data and Auto (to automatically fit the actual observations). Click on **Make Spatial Profiles**.



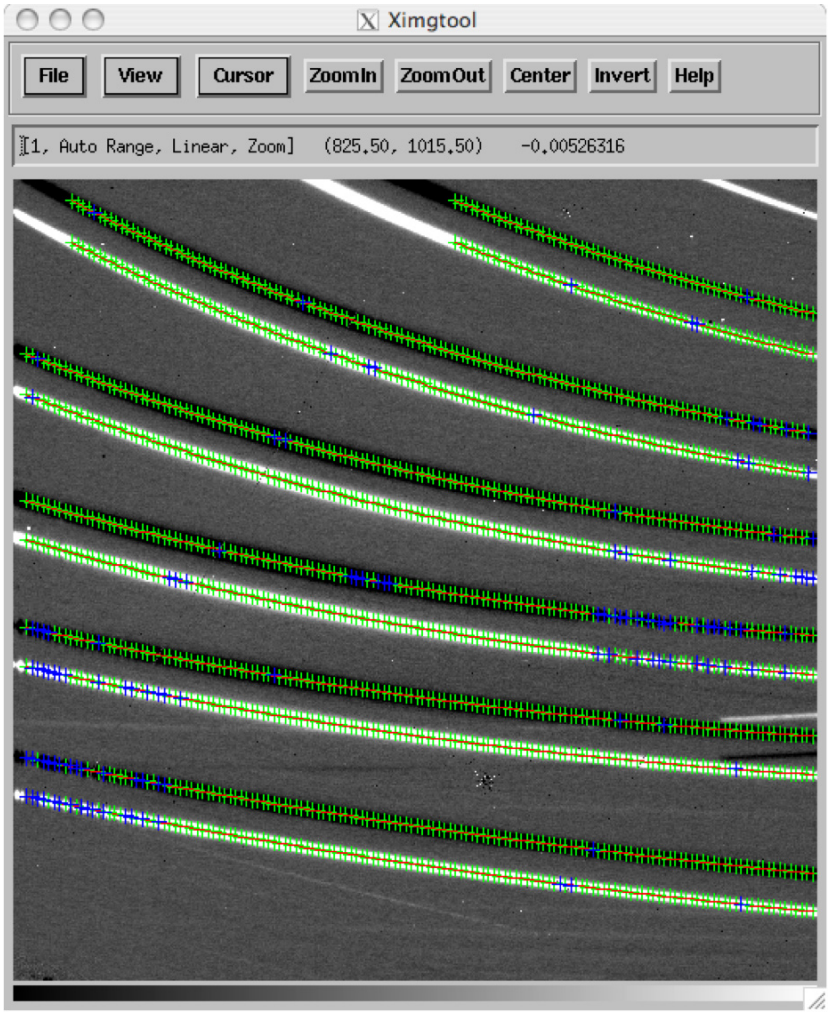
After Make Spatial profiles, it should look like this. Set Apertures to 2 for two-beam (A-B) data. Click on **Find/Store Ap Positions**.



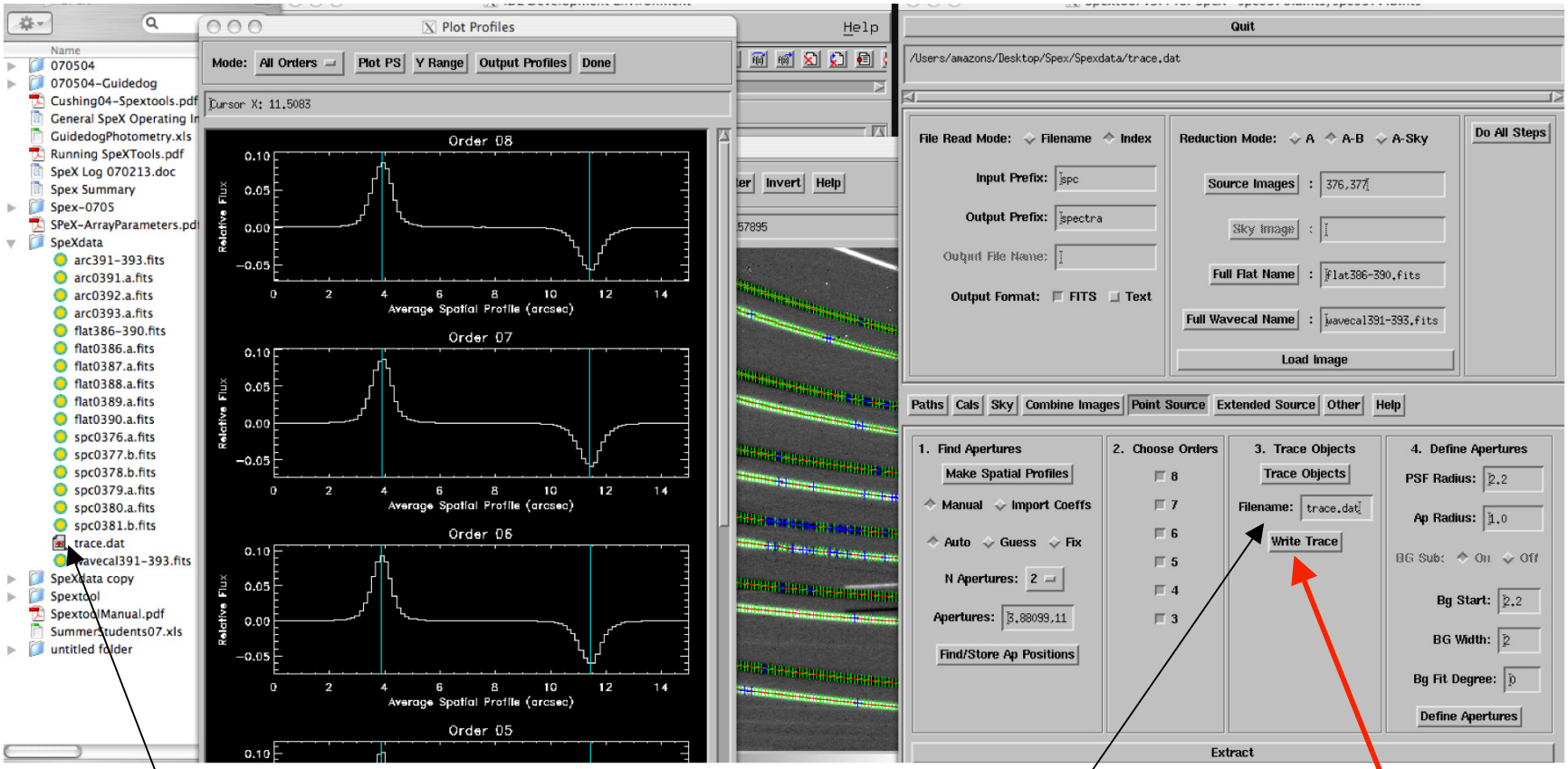
Here Spextools has located the centers of the apertures over all spectral orders. The centers of the A and B beams are indicted by the blue lines.



Select the spectral orders to be processed (usually all of them) by selecting the boxes shown. Hit **Trace Objects**.

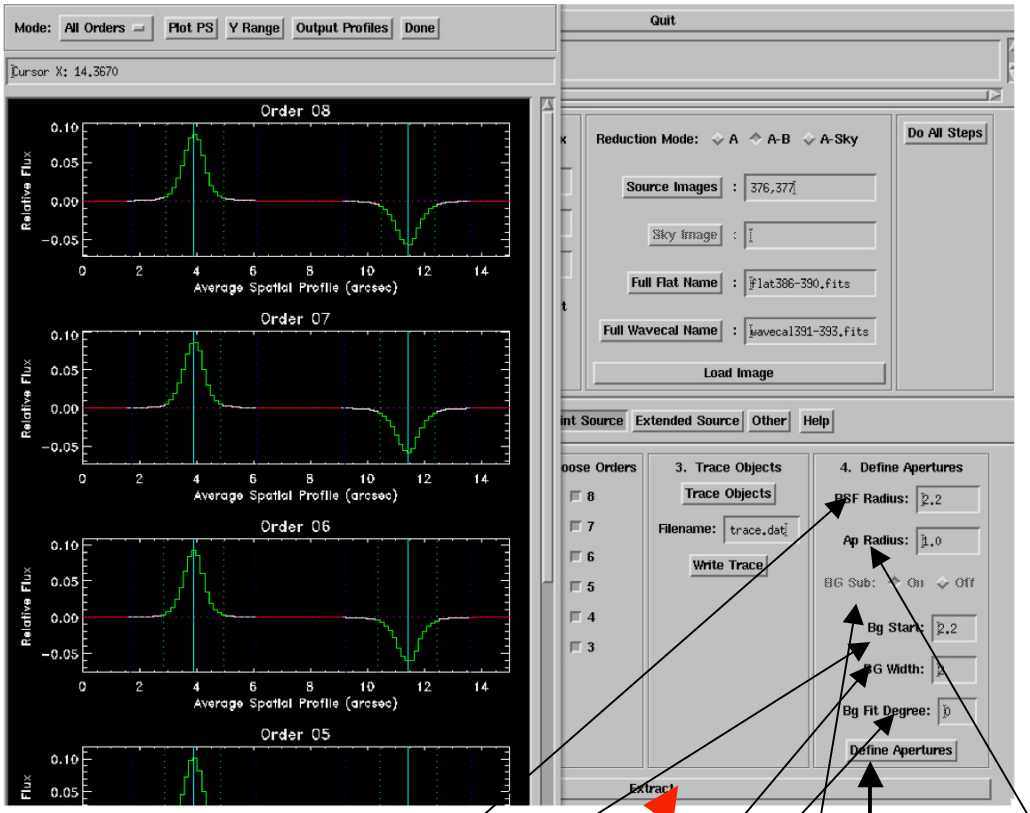


After hitting trace objects, you should see this. Spextools has trace the peaks of the spectral orders for both A and B beams.



This will write the file into your folder/directory.

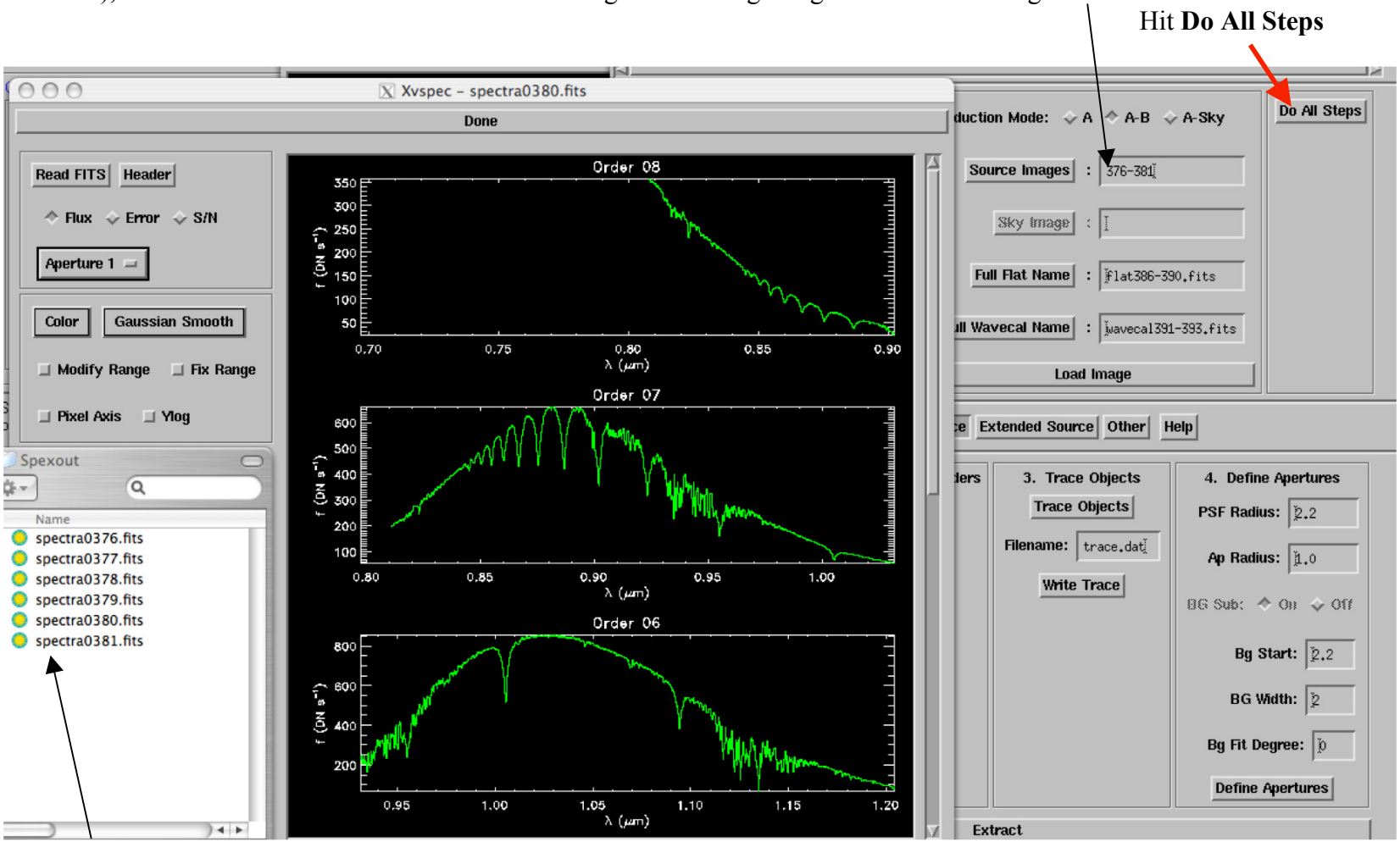
Now, pick a file name for your result, and hit **WriteTrace**.



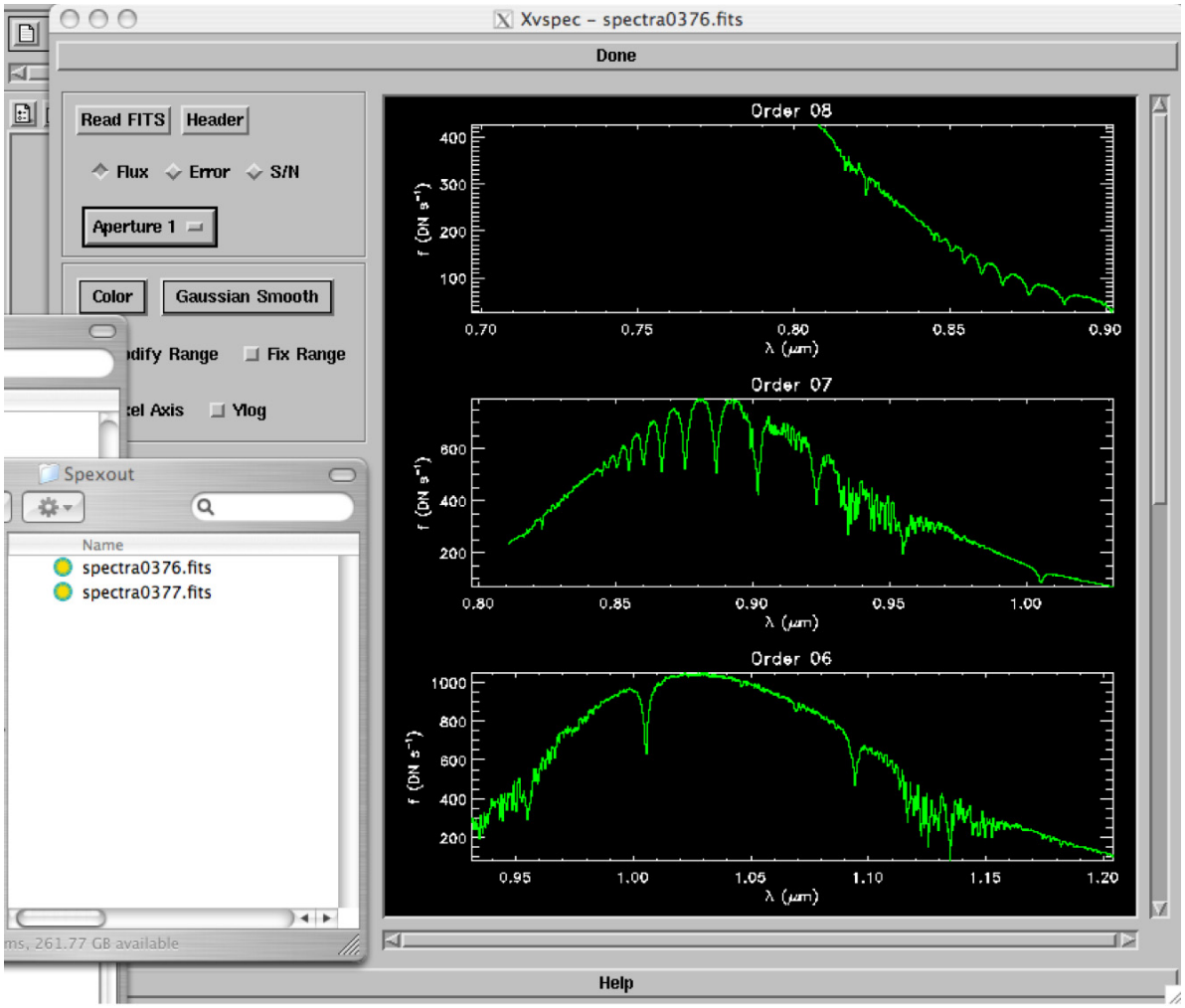
You will need to define the PSF radius in arcsec (usually about 2.0-2.5 for the IRTF, supposedly) and the Aperture Radius, which must be no larger than the PSF. For most of the data you will use, we will perform the background subtraction (the background outside the A and B apertures. Stars the BG outside the PSF aperture, and give it a width wide enough to get a lot of data, but not to encroach on the other aperture! You must pick a polynomial order number for the fitting, which will usually be zero (i.e.flat).

Hit **Define Apertures.** This will place the background subtraction locations on the plot. If these are okay, hit **Extract**. If not, go back & modify your parameters.

We are almost done with the first phase of the extraction process. Once you are satisfied with what you did on these two data files (A and B beams of one set), do the same to the rest of the data on that target with that grating. Put the whole range of file numbers in.



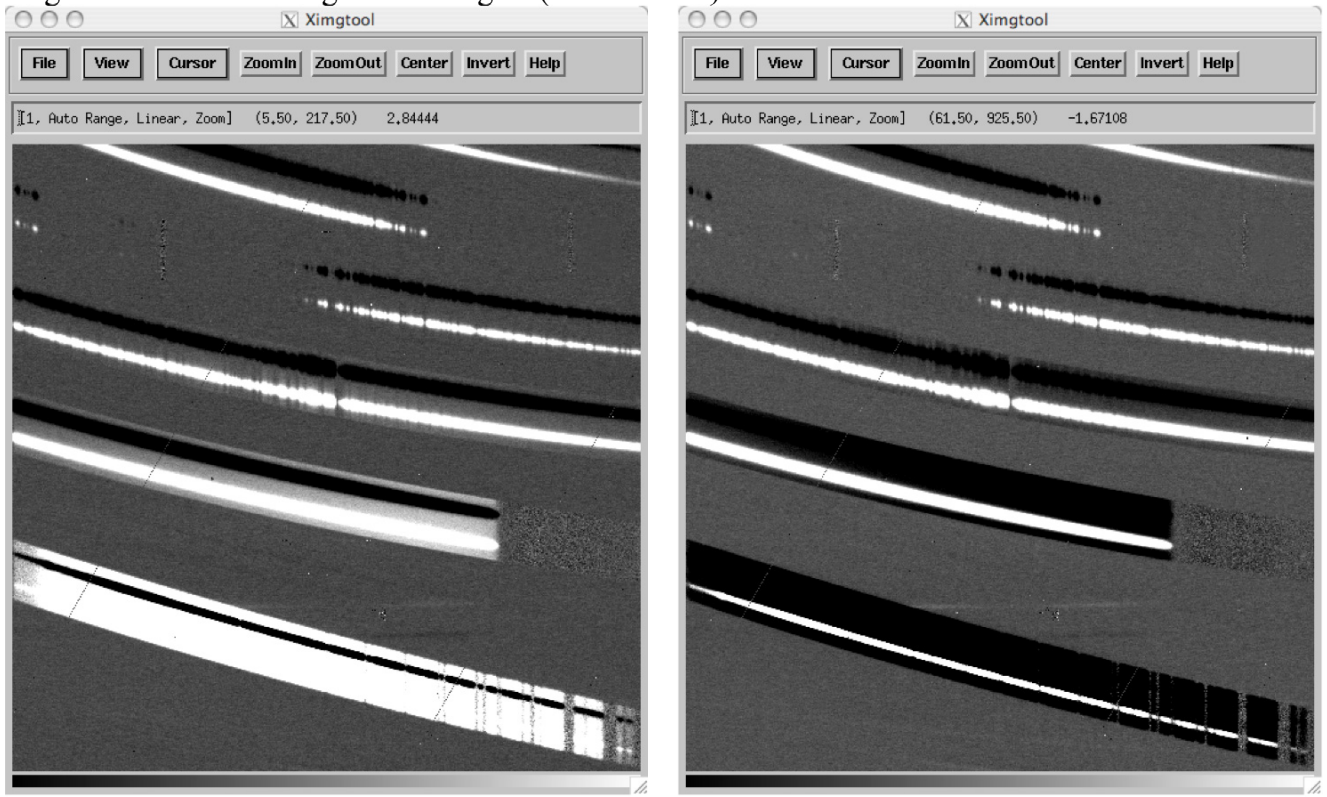
This will extract the rest of the files
And write them in your folder/directory.



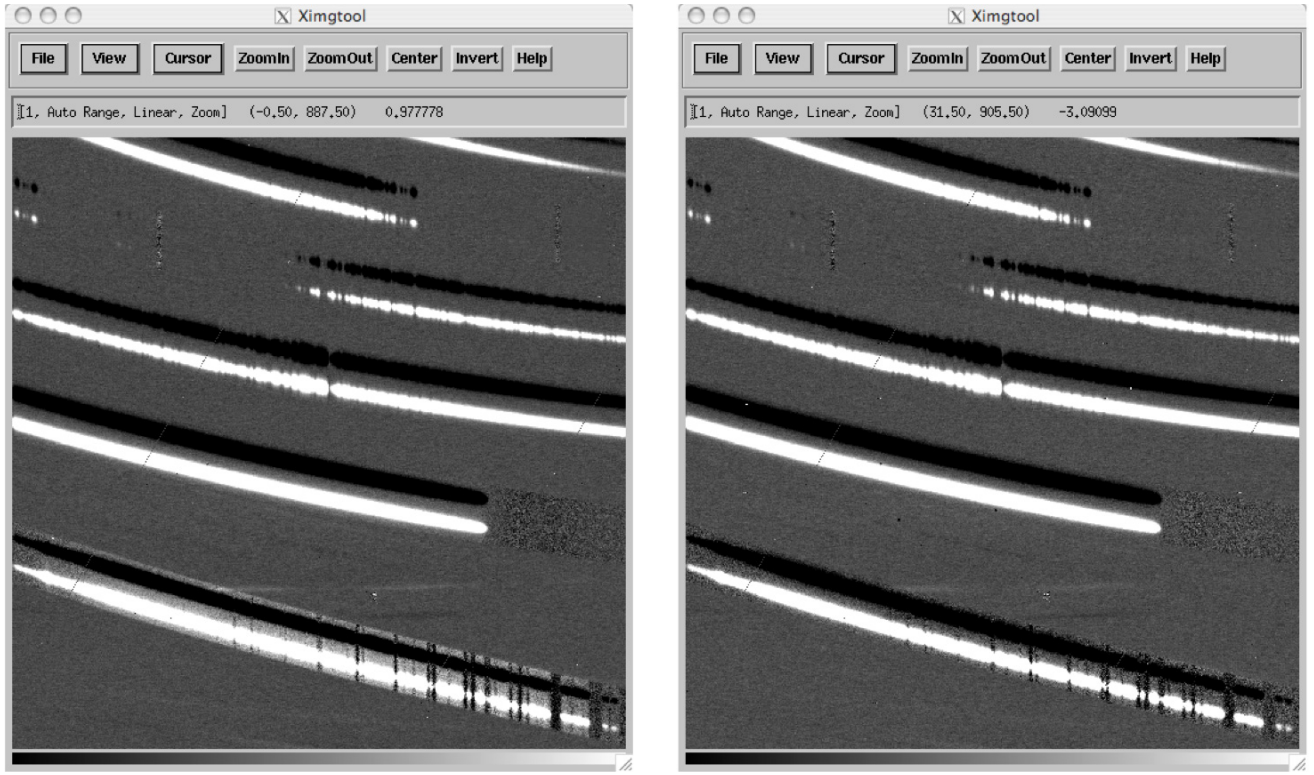
After the extraction, you will see the background-subtracted A-B beam data merged

LXD-Cloudy Skies

Sometimes you will have spectra taken through thin clouds (cirrus). These not only cause the sky transmission to be low and variable, but cause the background to be high and variable at longer wavelengths (lower orders) in LXD.



The clouds might be more prevalent in either the a-beam (left) or the b-beam (right).



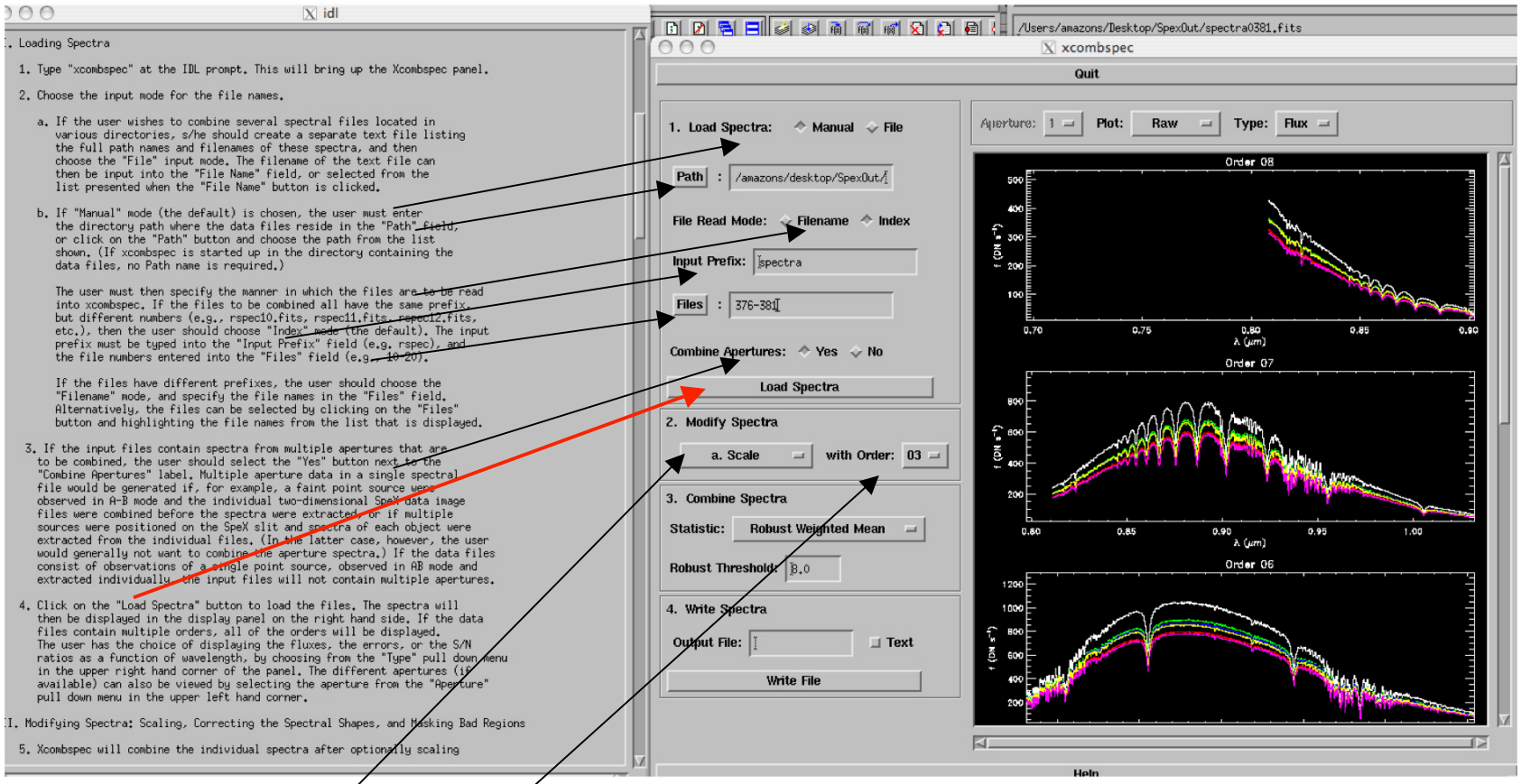
Sometimes there is only a little bit more cloud in one beam than another (left), while the next set might be essentially cloud-free (right).

Here I had to "hand-pick" individual pairs by examining them using the **Source Images** and **Load Image** buttons in xspextool prior to making the spatial profiles.

XCOMBSPEC

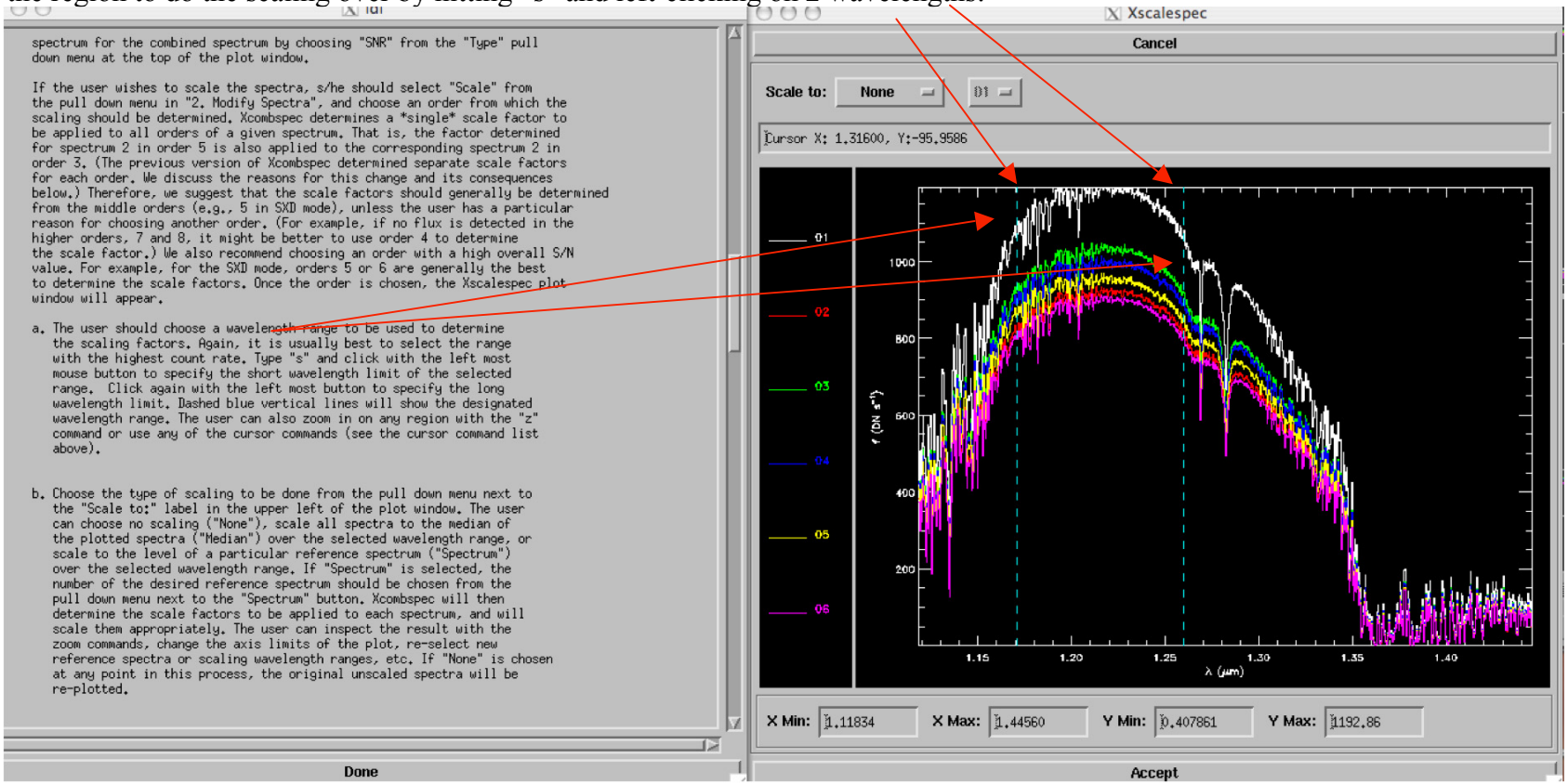
The next phase is to merge the spectra you have just extracted for a specific target stars and grating setting. To do this, go back into the IDL window, type in *xcombspec* and hit *return*.

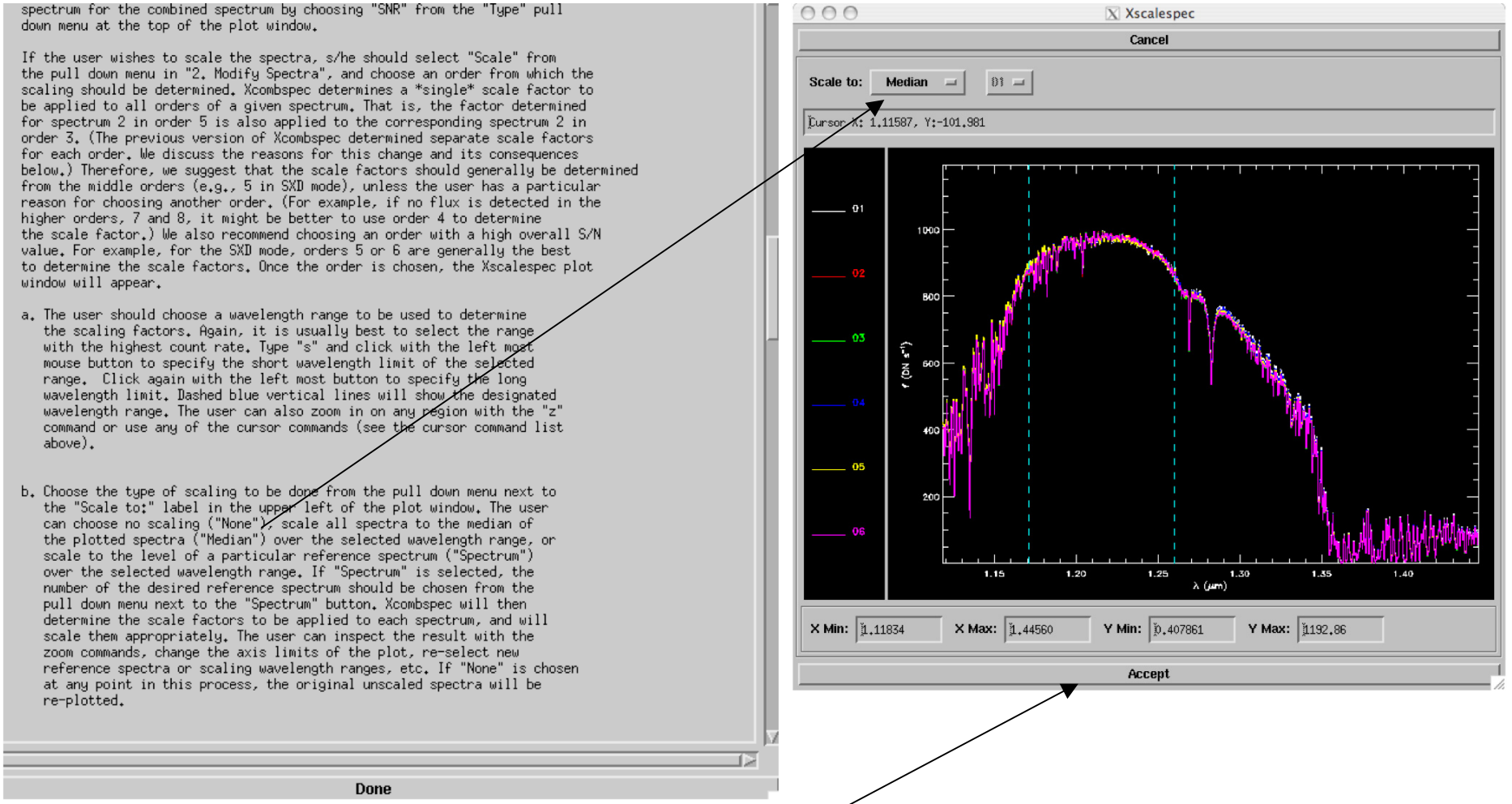
Then open up the Help window and follow along the instructions.



Under 2.Modify Spectra, chose Scale and an order (generally a middle one, like 6; for LXD use 5).

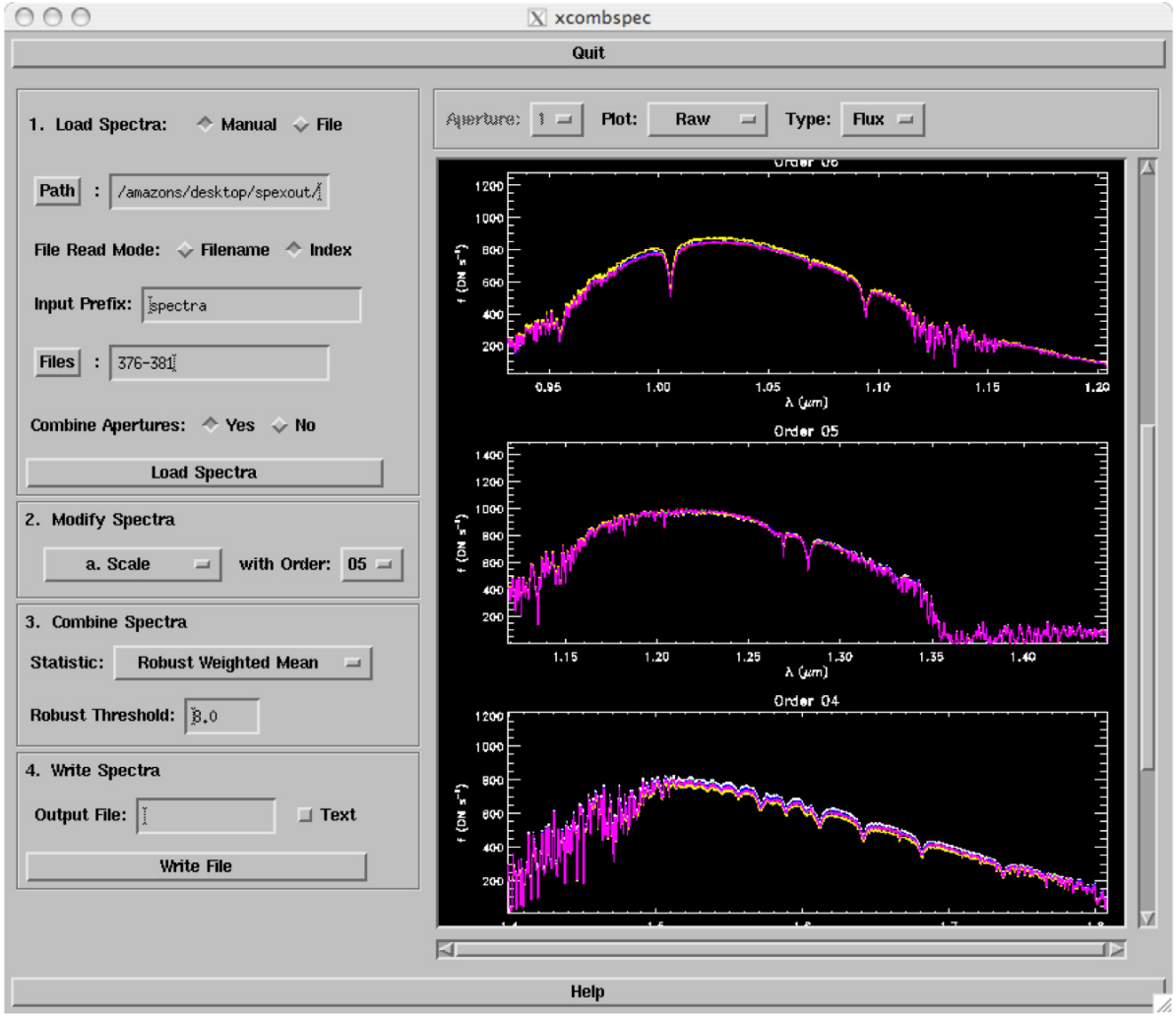
Select the region to do the scaling over by hitting “s” and left-clicking on 2 wavelengths:



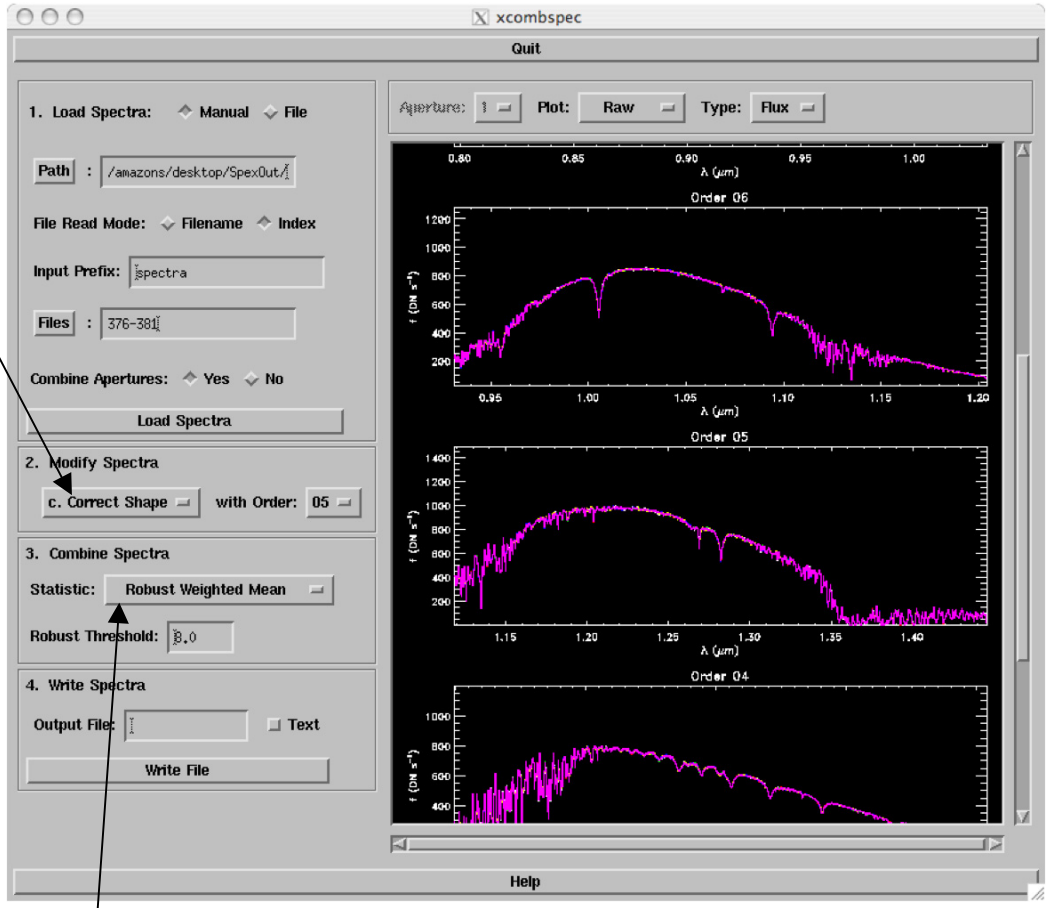


This will apply the same scaling to all orders. If satisfied, hit **Accept.** Note: if you want to try to get close to the real absolute flux level, you can use Spectrum instead of Median. For LXD only Order 5 is clean enough.

Often those orders far from the order chosen will be off:

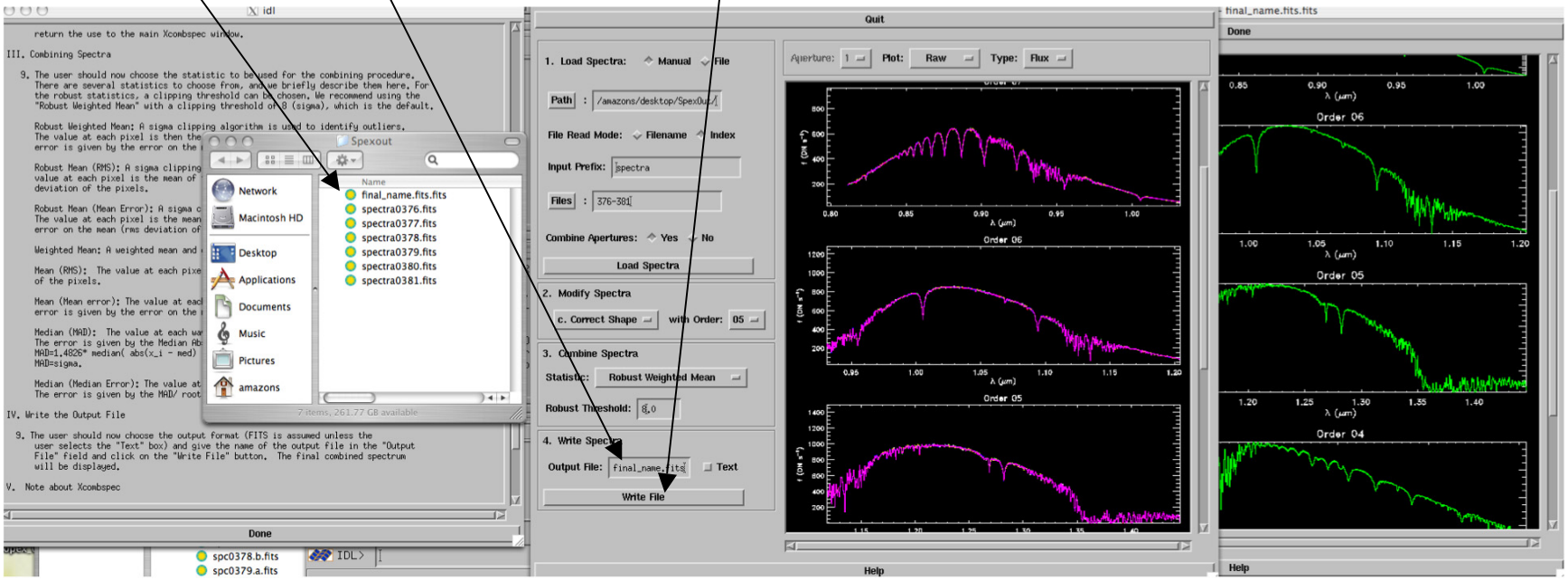


To fix that do Correct Shape. This will make the spectra within each order match better.



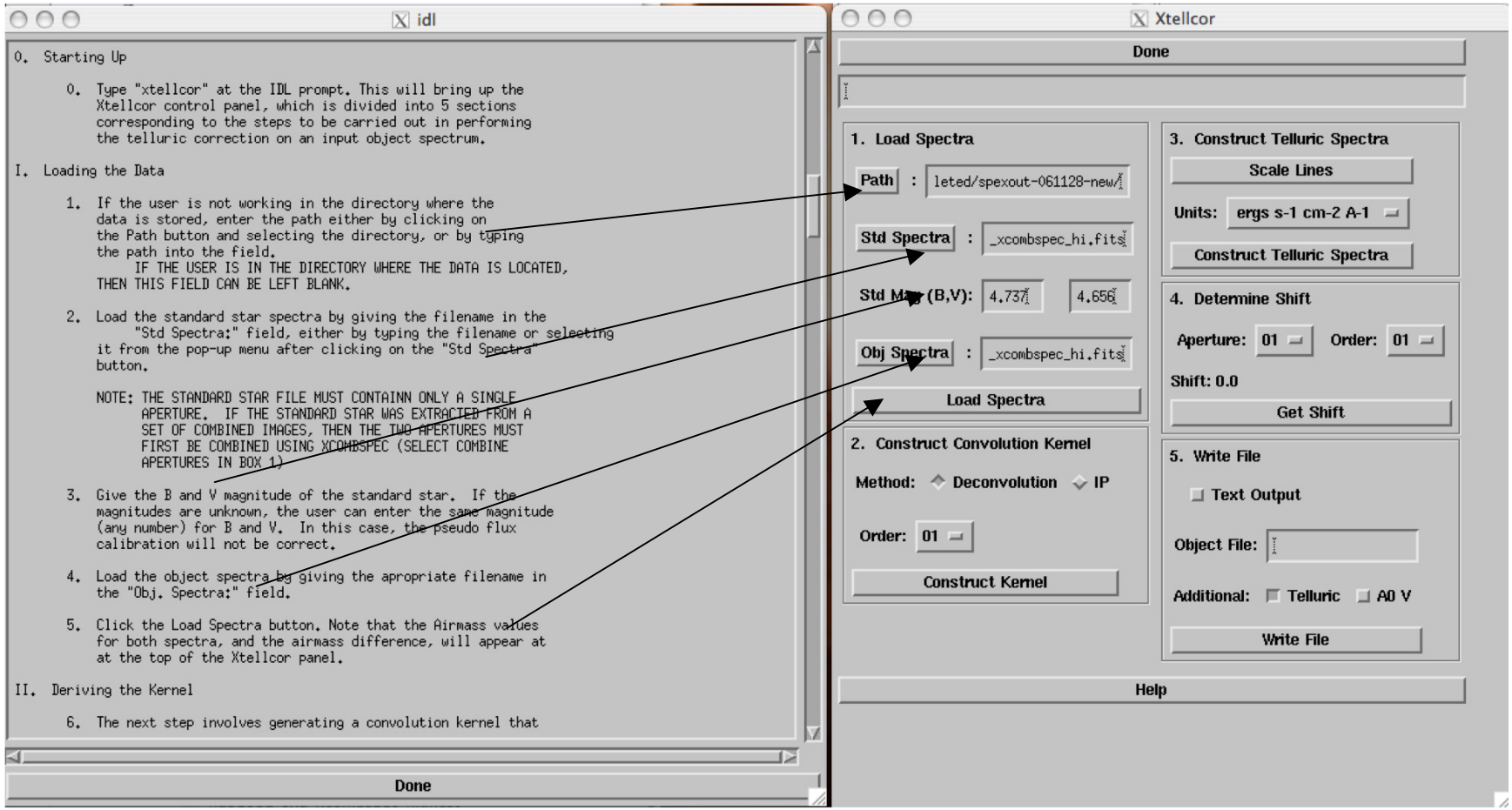
Then choose a method for doing the statistics of the merger. Usually Robust Weighted Mean is preferred.

Finally…….Choose a file name for the grand result an hit **Write File**.
It will write the final file.



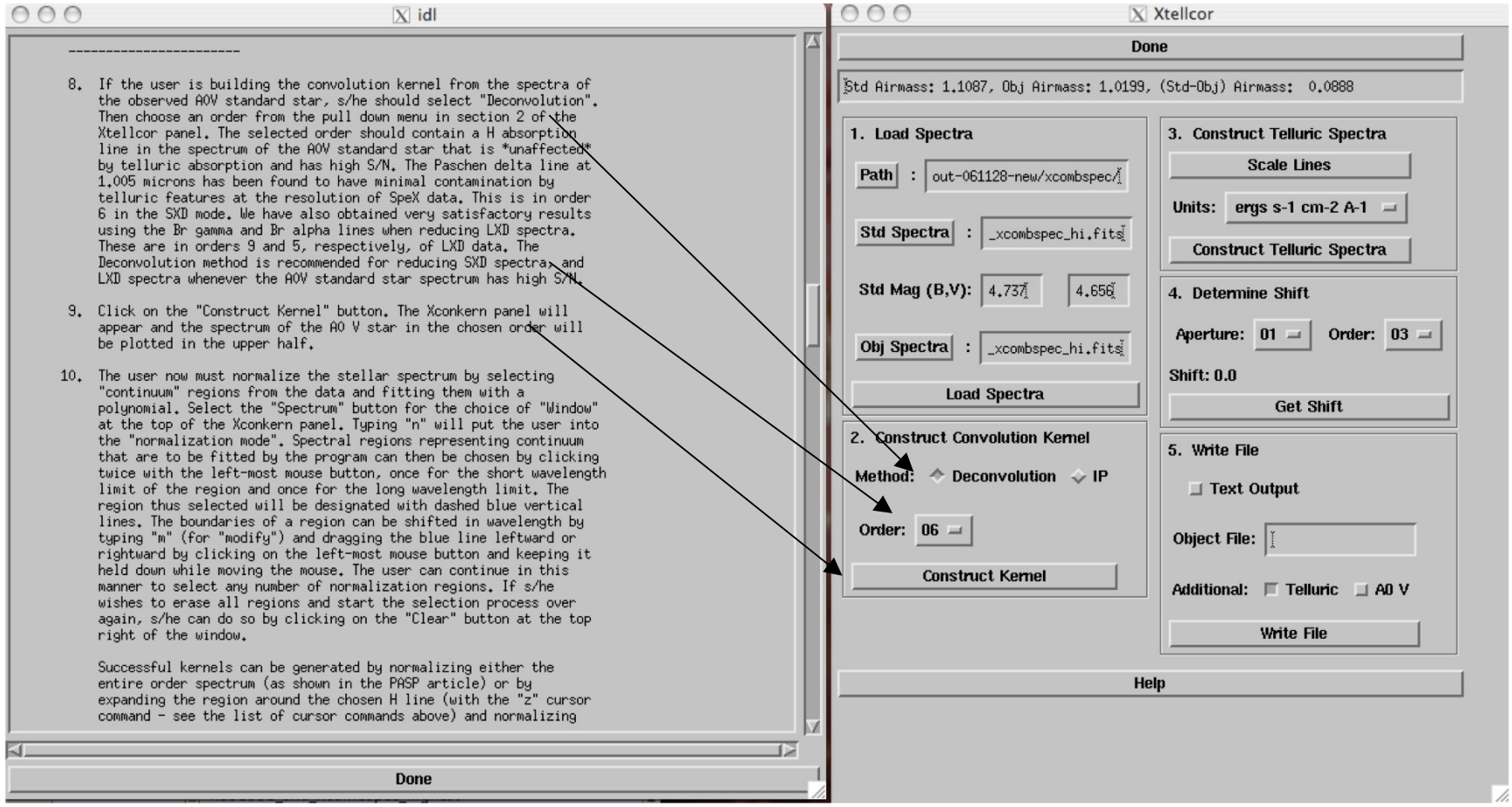
USING XTELLCOR

First you need to set your paths, indicate you A0 STD star input files, the B & V mags of the A0 STD star (from SIMBAD), and the science target star's files:

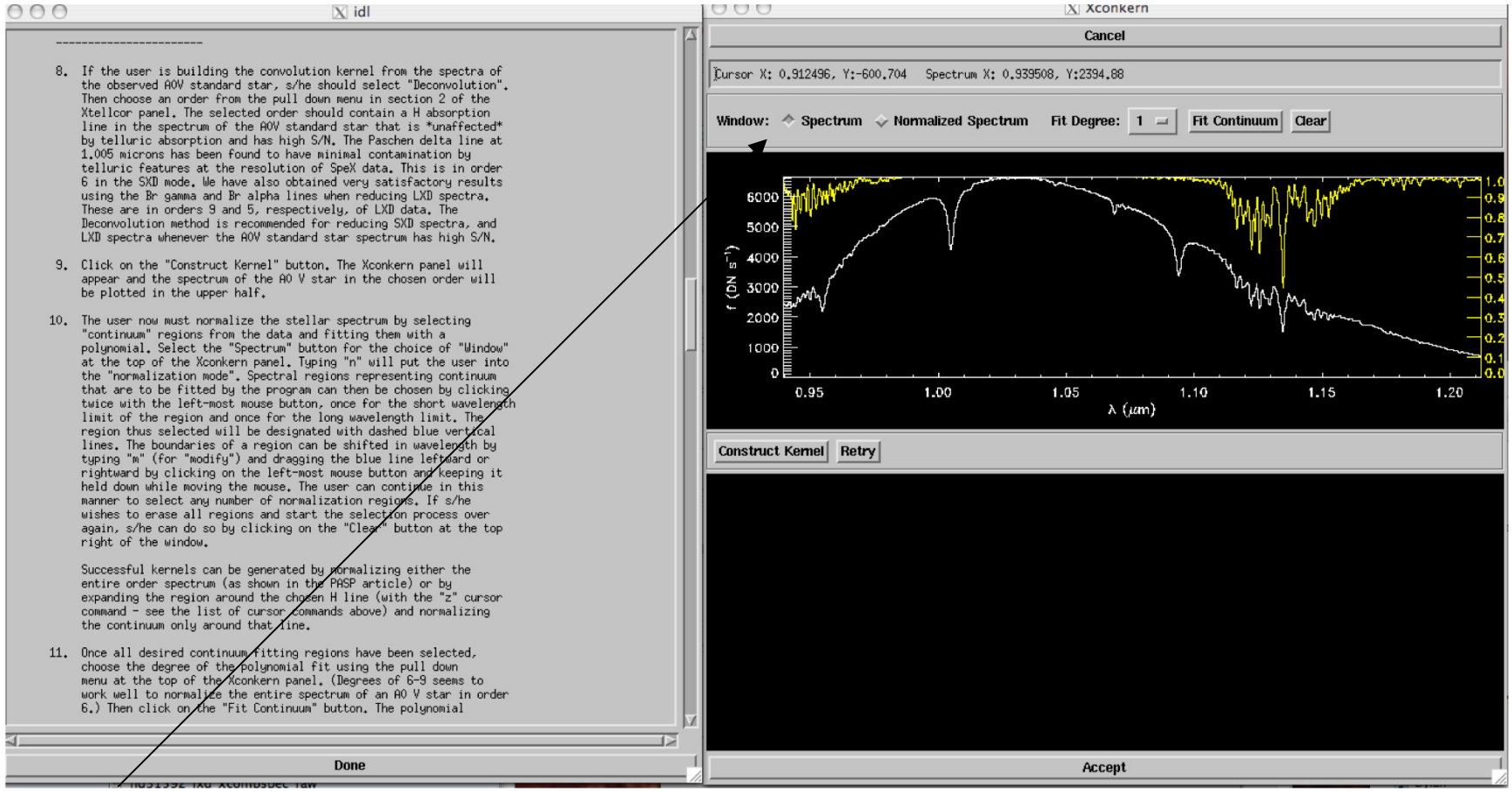


Here, the input files are those created in the "xcombspec" routine, and I labeled them as such when I created them.

The instrumental profile then needs to be constructed. For SXD, this should be done via "Deconvolution", since you can use actual stellar lines in regions free of telluric contamination to do this. For LXD, you are not so fortunate (although it is claimed that it can be done if the data is VERY high SNR). For LXD, choose IP. We will look at LXD later. Right now, we will concentrate on SXD.

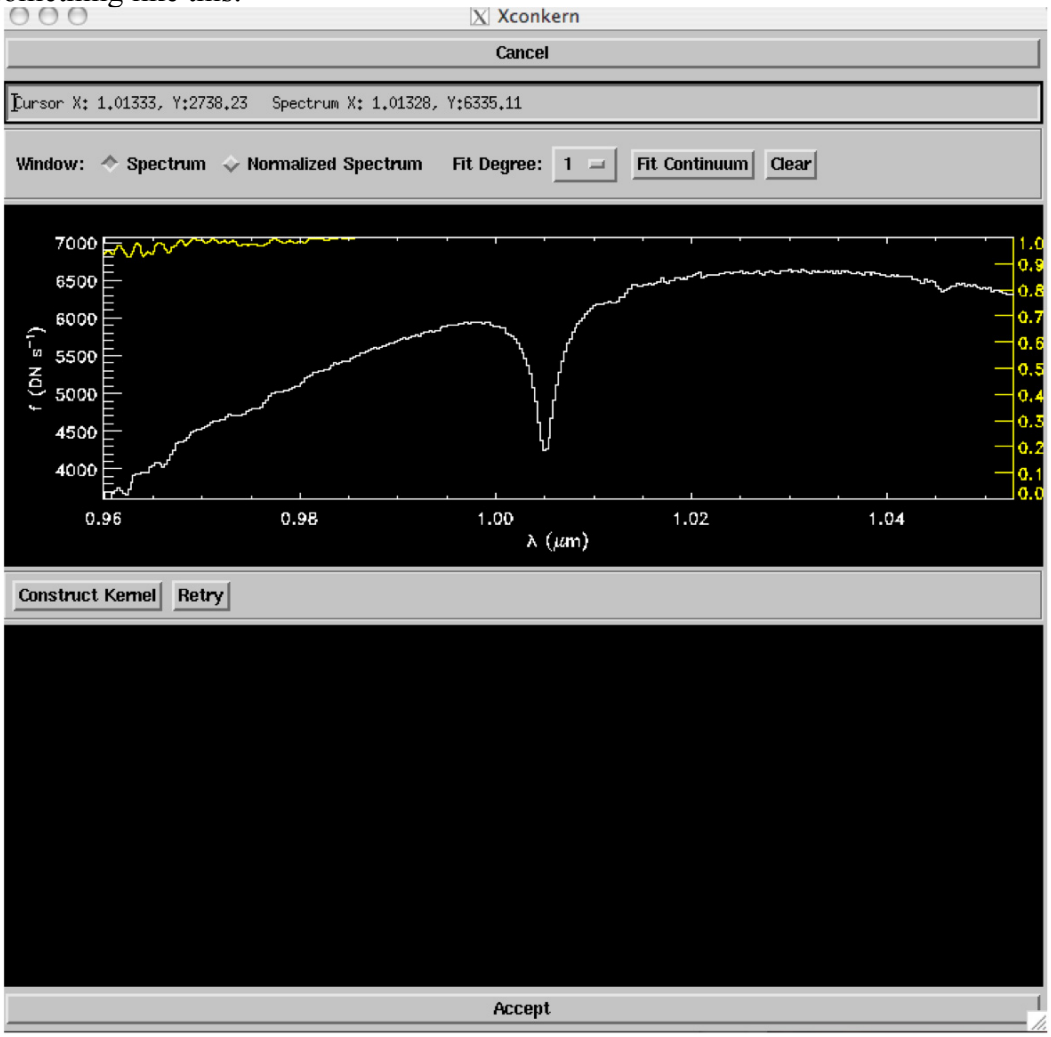


For SXD, Pa δ seems to be the best line to use, and it is located on Order 6. For LXD, Br α (4.052 μm) is in Order 5, while Br γ (2.166 μm) is in order 9. But Order 9 will NOT be accessible in LXD_2.3 mode! Note also that LXD is so cluttered with telluric lines that you may be better off using the IP ("instrumental profile") mode. I usually do.
This will bring up the Xconkern (X construct kernel) window.

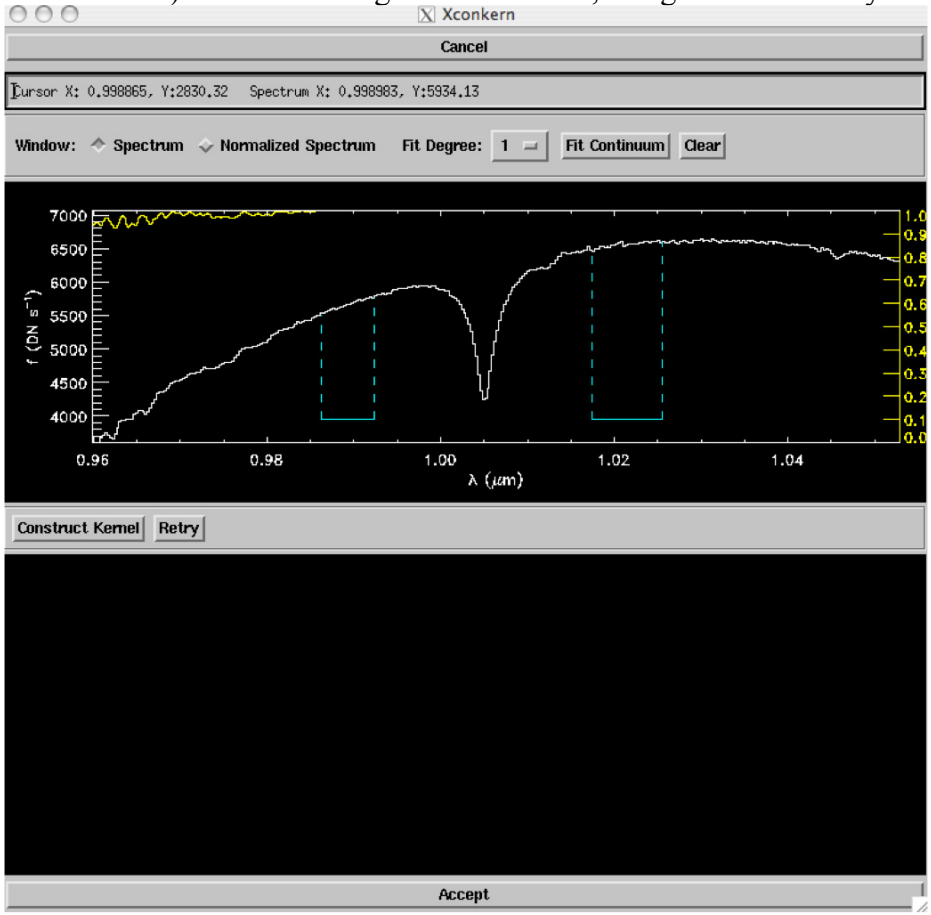


Select Spectrum. Then it's a good idea to hit "z" for zoom, to see the region around Paδ more easily. To zoom, hit "z" and then define a zoomed box by clicking on the image with your mouse, say upper left corner and lower right corner of the region you want zoomed.

When zoomed, it should look something like this.

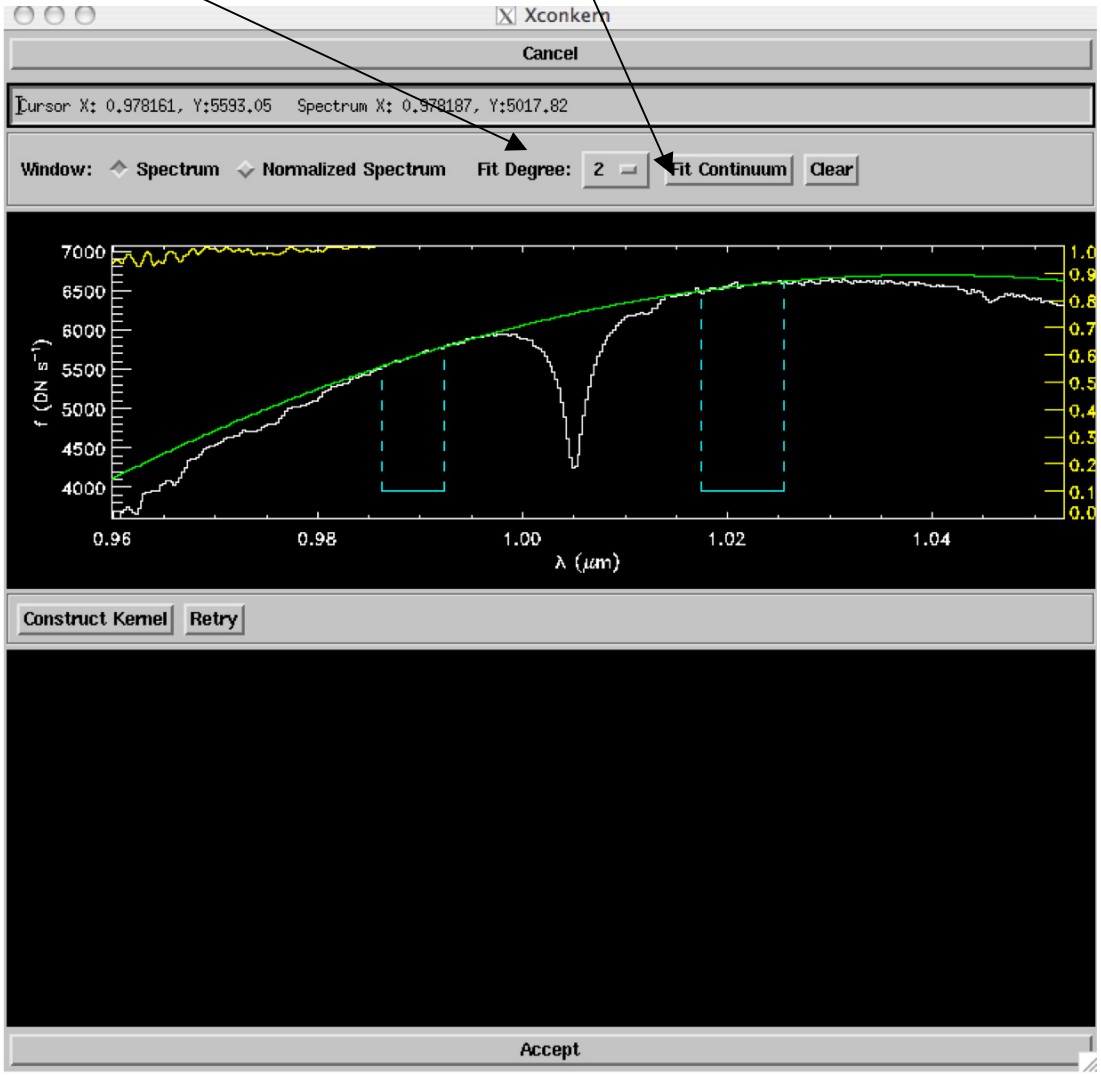


Then hit **"n"** ("normalize", NOT "s" for "select") to select the region to do this in, using a left-click of your mouse:

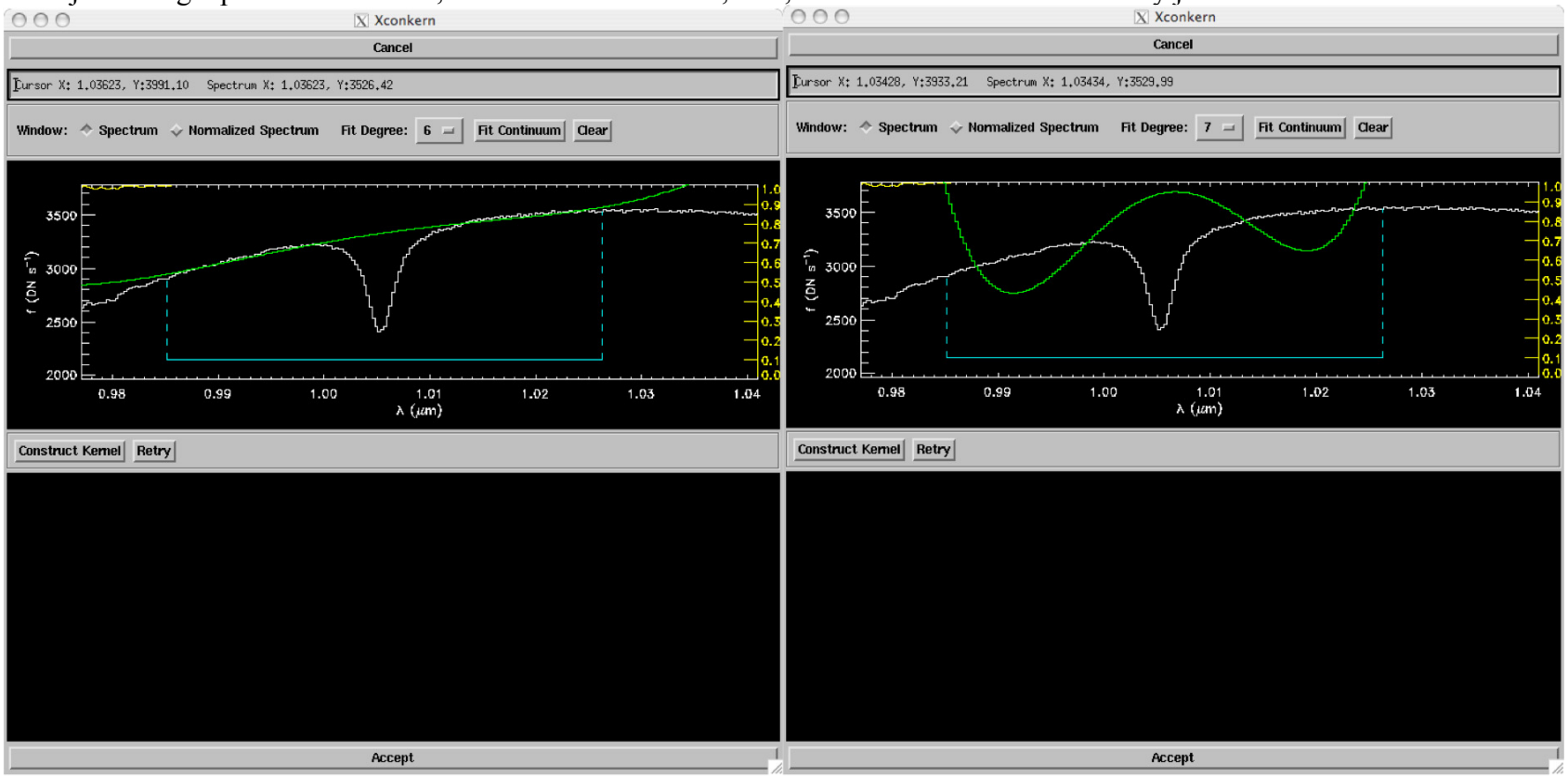


It seems to work better of you pick TWO points on either side, instead of just ONE. The goal is to find a smooth curve that fits the continuum, from which the spectrum can be normalized to get a level continuum. This is done using a polynomial fit of order 0-24. This can be tricky. You may need to iterate on a "best choice" wavelength region and polynomial fit order, and go back between the two in order to find something reasonable. The experts tell us 6-9 works well. Let's find out, but sometimes even 2 give acceptable results.

Select the polynomial order using the pull-down menu and hit the Fit Continuum button. Here is an example of a 2nd order fit. Looks pretty decent.

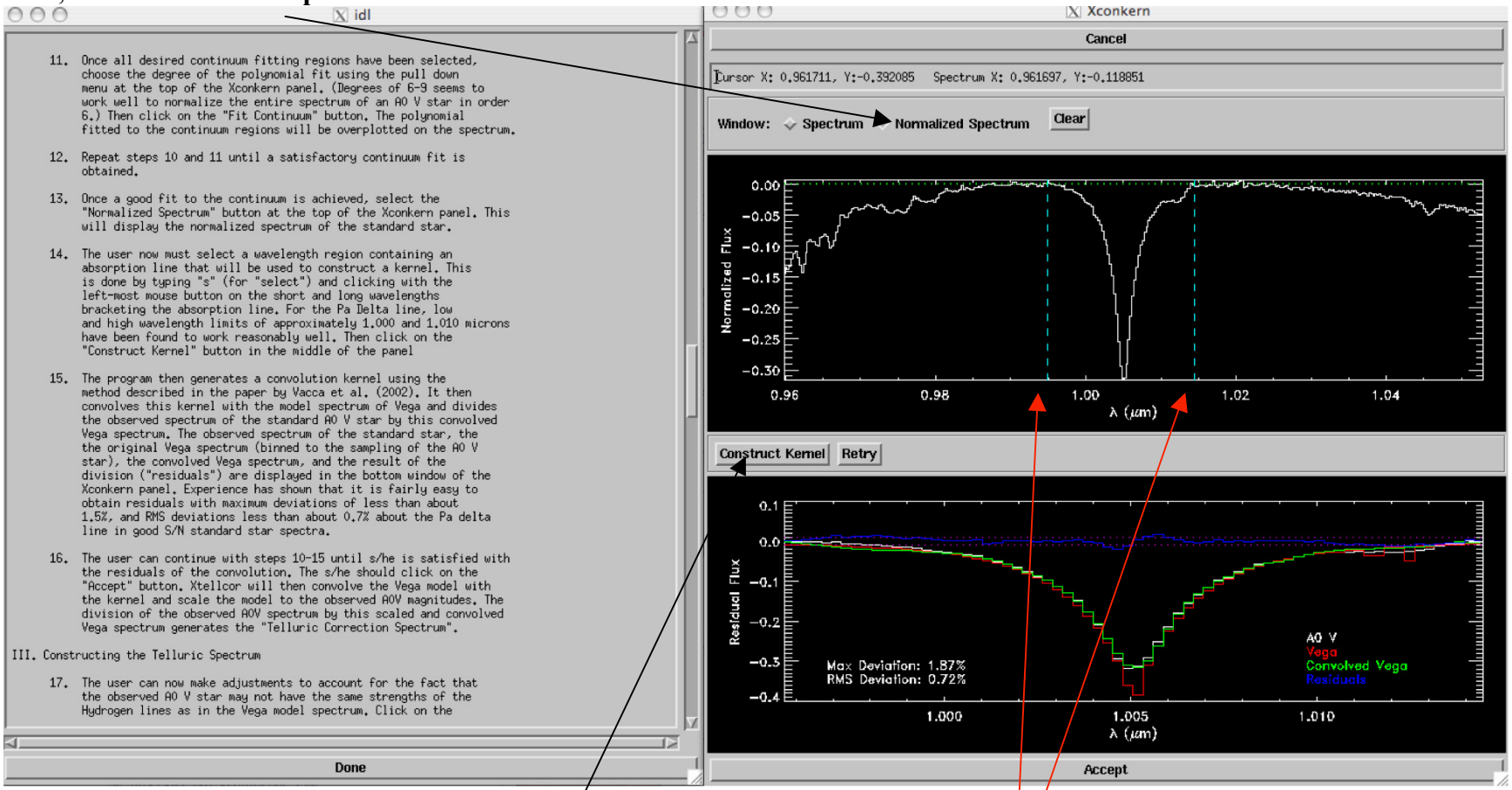


With just a single point on each side, a 6th order fit does fine, also, but a 7th order one is obviously junk.



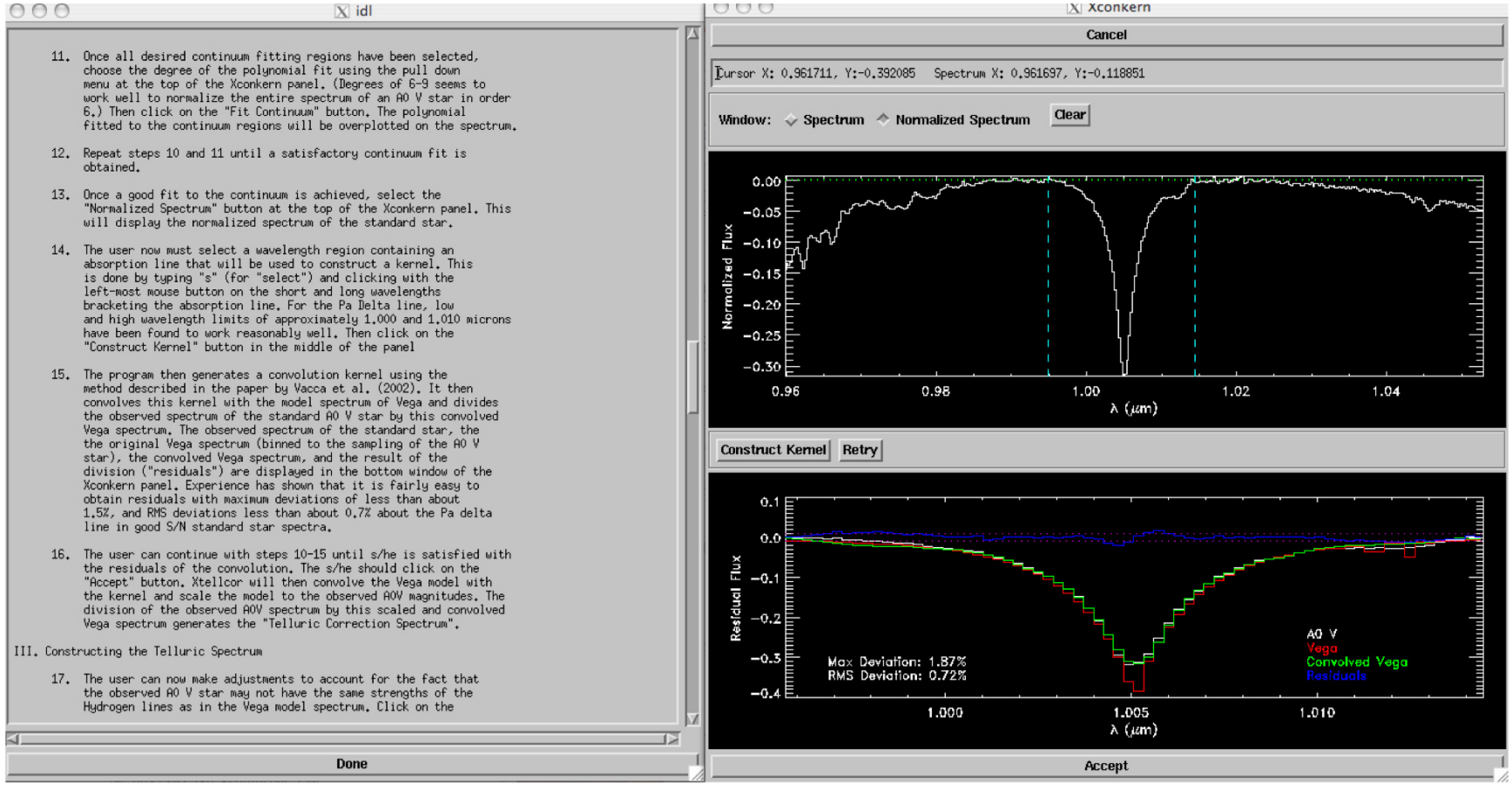
Let's stick to our original choice…..

Now, select **“Normalize Spectrum”.**



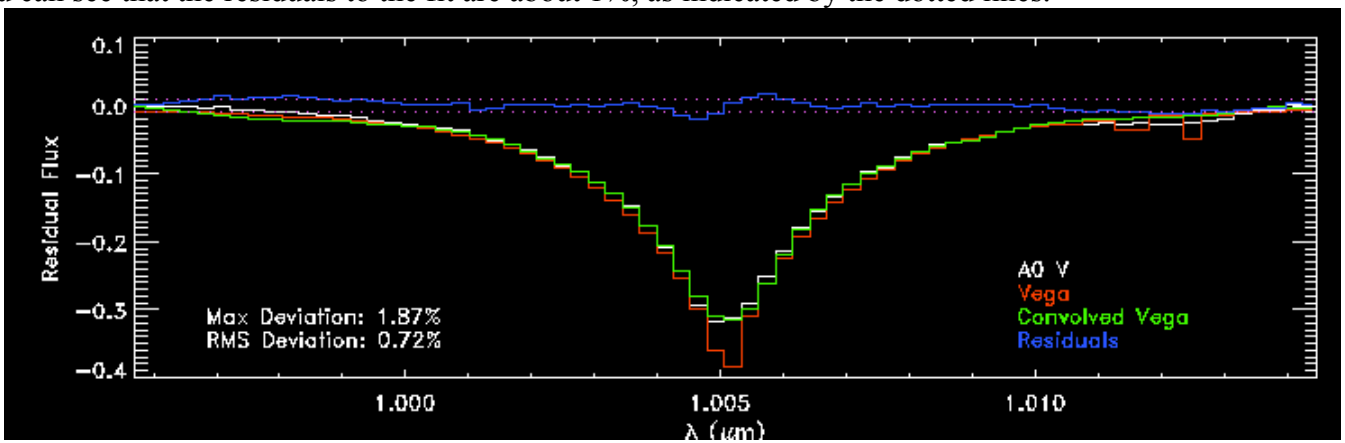
Hit **“s” (select)** and select the wavelength range over which you plan to do this with a left-click on the short wavelength side, and another left-click on the right. Be sure to get all of the line!

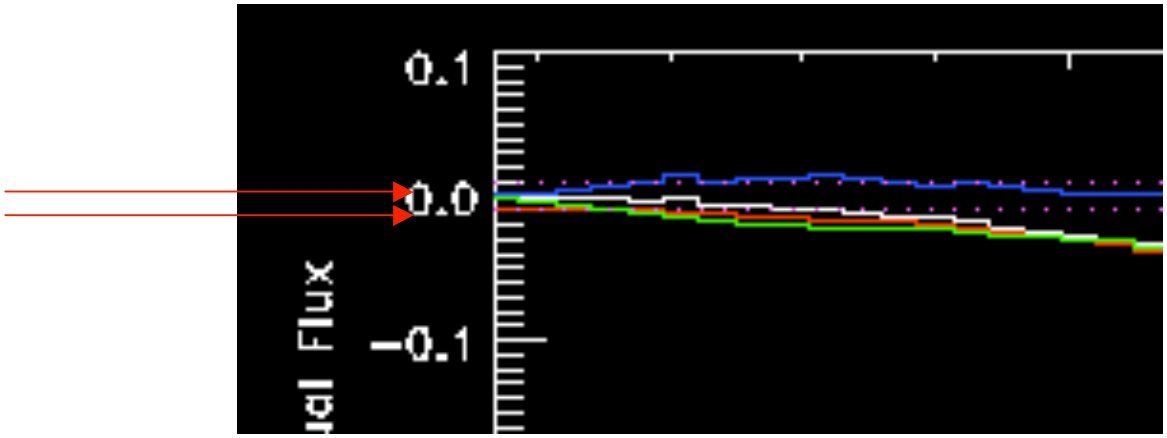
Then hit the **“Construct Kernel”** button.



Now, note that the lower panel shows 3 curves. One is your A0 STD (white), one is the spectrum of Vega (red), the third is Vega shifted in velocity to match your A0 STD and convolved with a broadening function to attempt to match your A0 star. The upper blue line is the difference.

In this example, you can see that the residuals to the fit are about 1%, as indicated by the dotted lines.

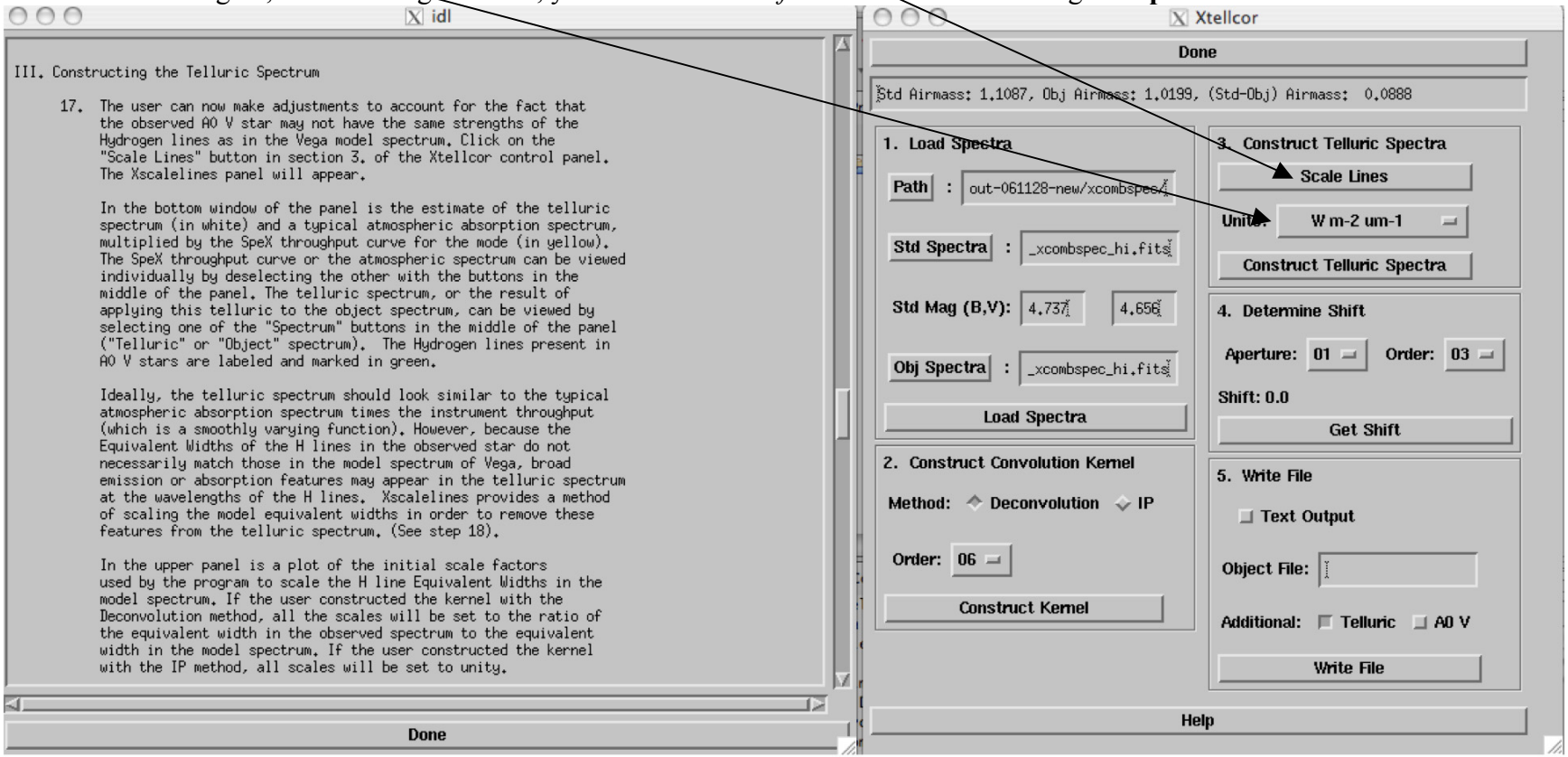




Usually the largest residuals will be near the line core. Vega is a rapid-rotator, but is seen pole-on, and the exact shape of the line depends on a lot of factors.

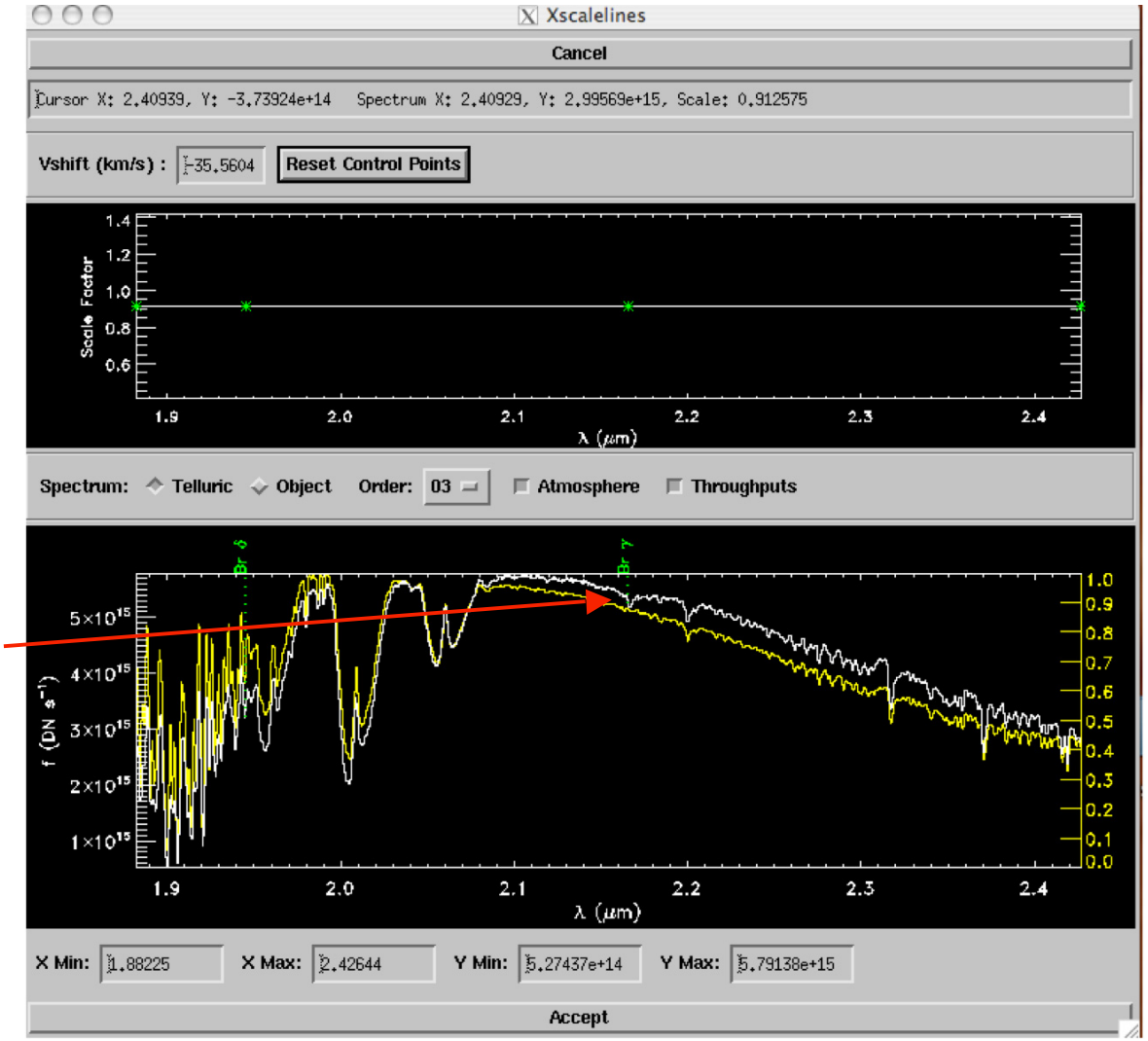
Now it's time to scale the lines in the Hydrogen likes using this profile. *One has to do this line by line, in all of the orders, before finally accepting the result by hitting the **Accept** bar at the bottom of the window*.

Next, I first choose the units I am going to use. THEN hit **Scale Lines,** and the Xscalelines window will open.
REMEMBER – Again, when scaling the lines, you need to do *all of the orders* **before** hitting **Accept**.

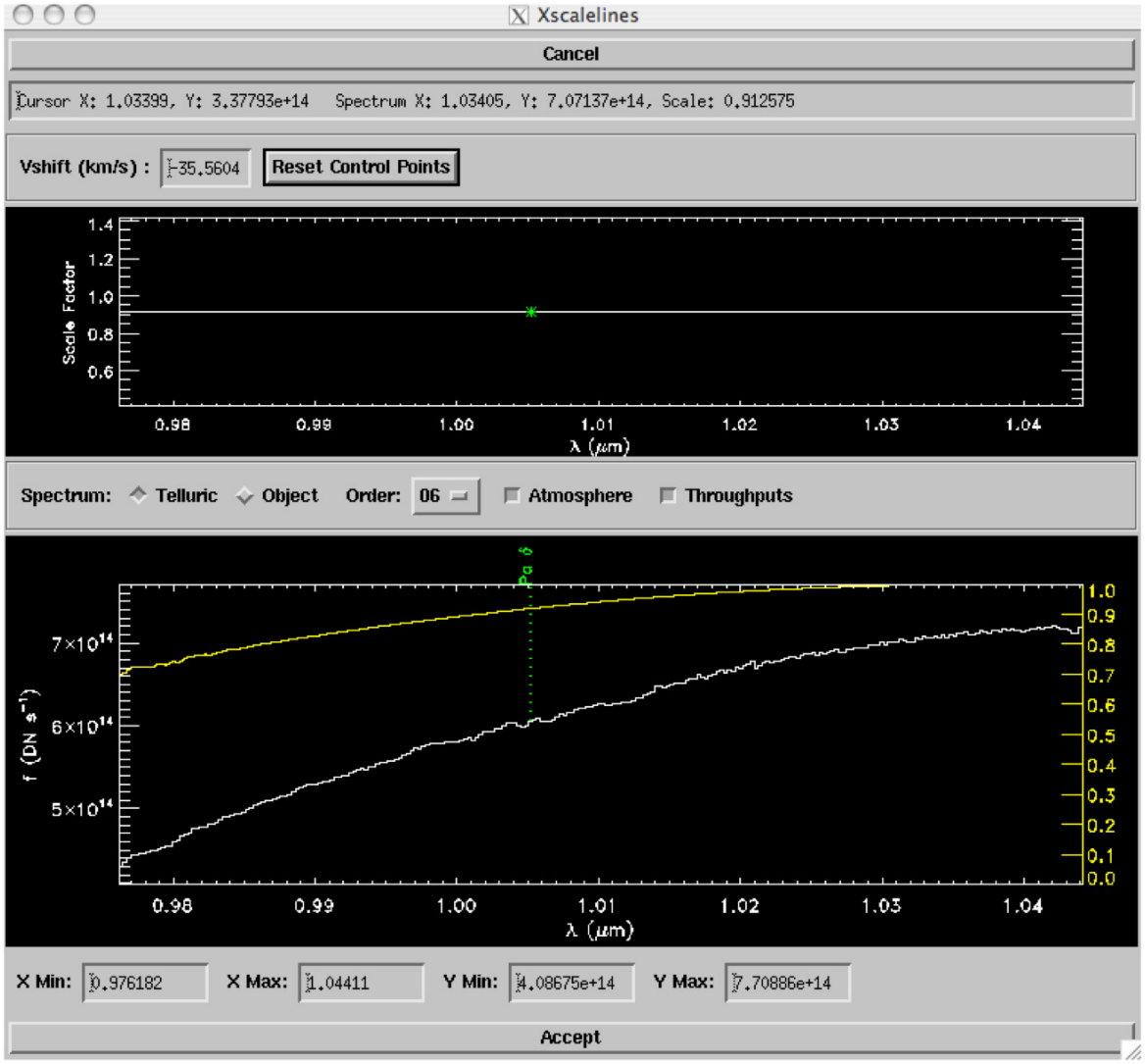


Now, if all A0V stars had spectra identical to that of Vega, then all would be effectively removed by constructing the kernel (in this case Pa δ). But since they do not all have the exact same effective temperature nor surface gravity, small residuals in either emission (over-corrected) or absorption (under-corrected) will remain. (Note: because Vega is a rapid rotator, these parameters will differ from its pole to its equator, so it is almost guaranteed that there will be residuals). Here, we see that the remaining residual for Br γ is present in absorption, but it is weak, only a few percent of the continuum level.

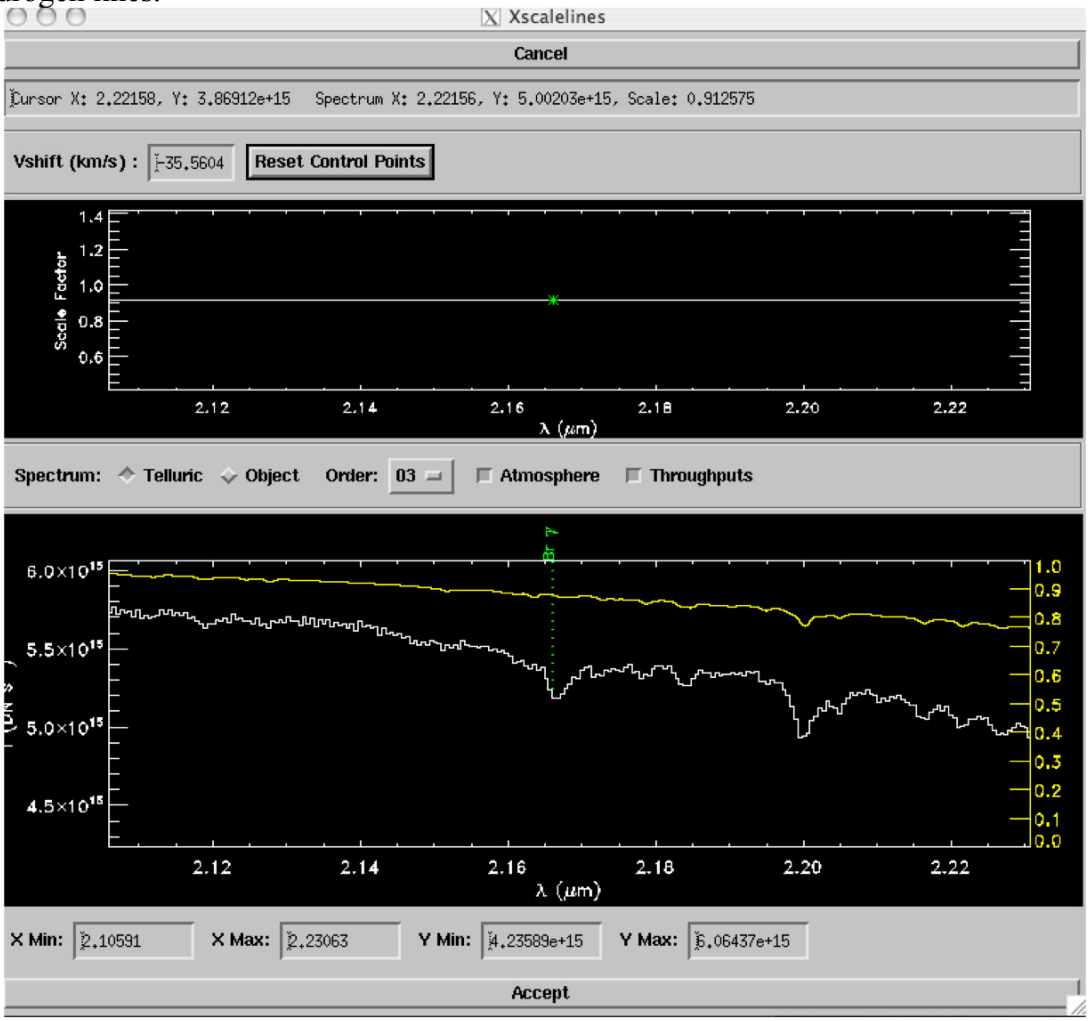
This is pretty typical of the lines in SXD Order 3.



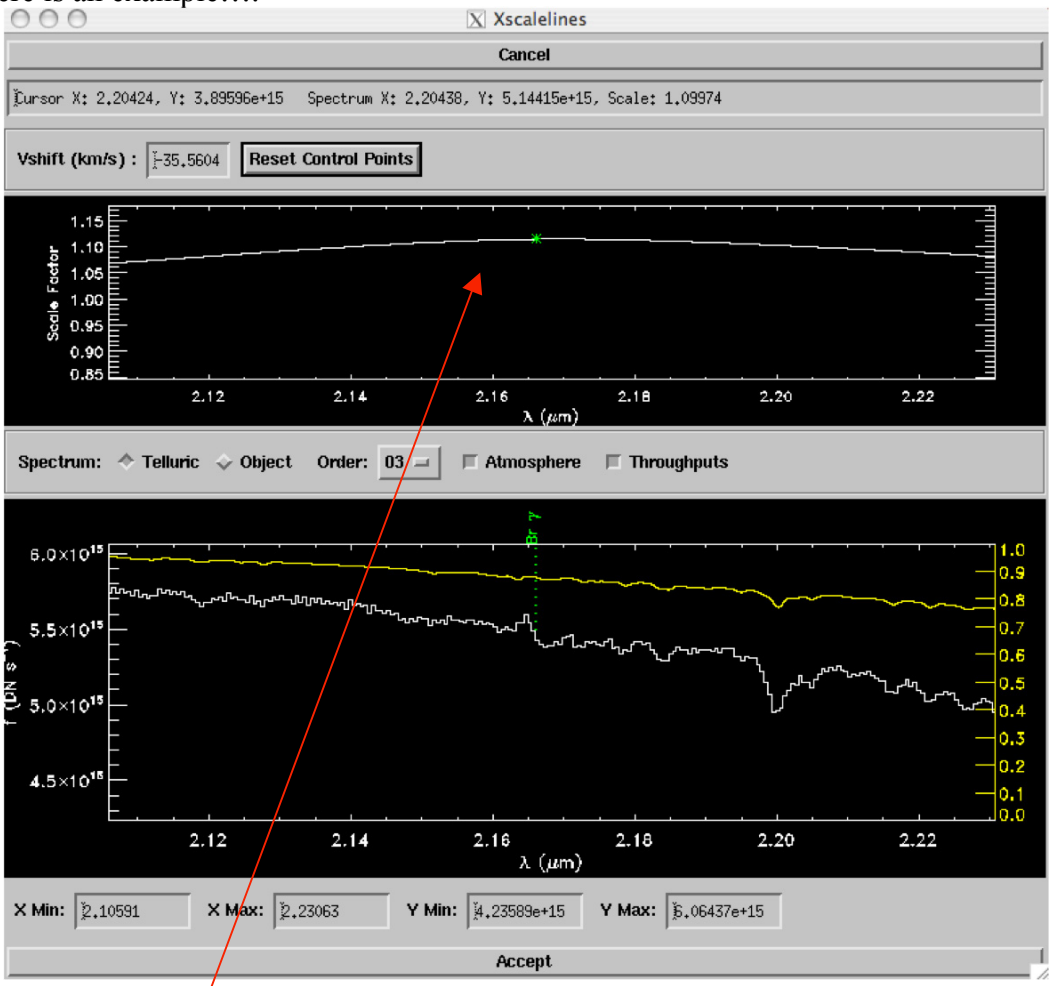
In Order 6 we see the Pa δ line that was used to construct the kernel, and the effect that the non-zero residuals had on the final product. Again, the structure is at the 1-2% level.



Now, the idea here is to try to make your “rectified” A0V star look like the “standard” telluric spectrum shown in yellow. Now one might want to smooth out the residual hydrogen lines.

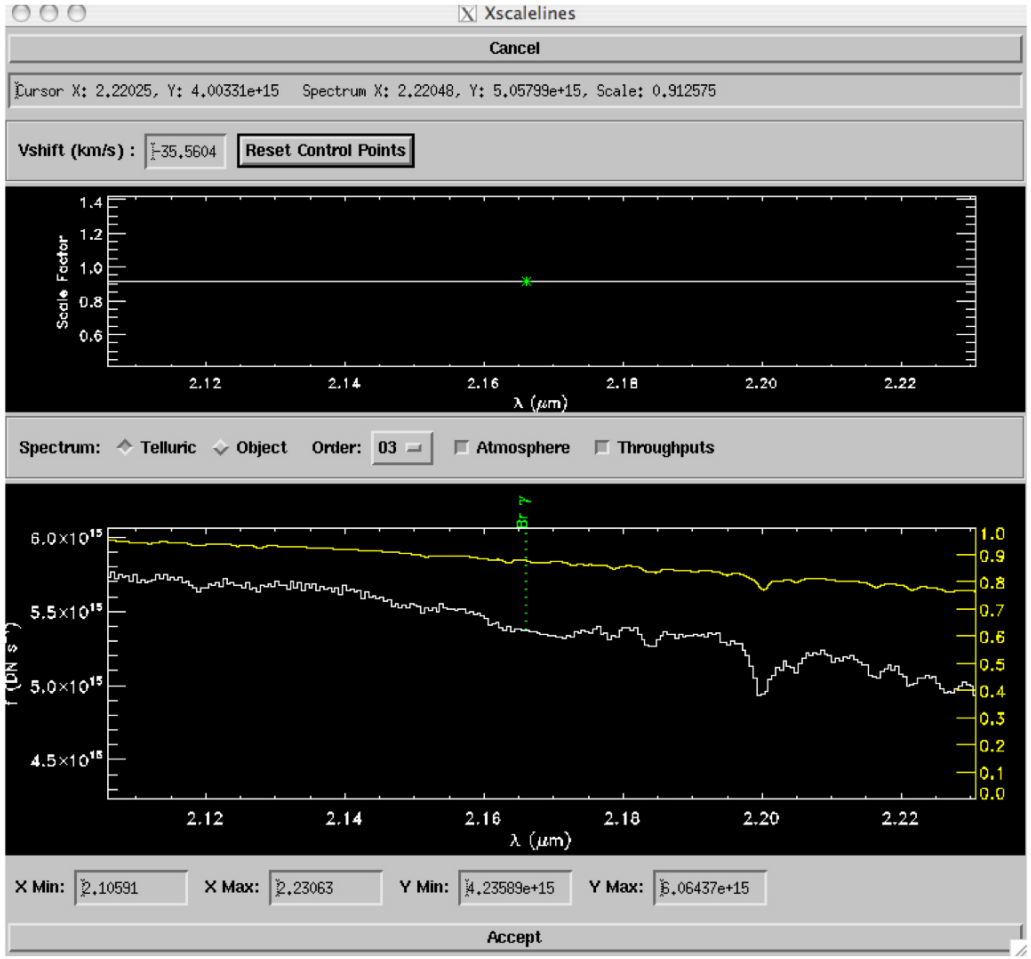


There are three ways to do this. One uses a program-generated estimate by hitting “e” and clicking on either side of the feature. I have personally found this tricky. Here is an example….

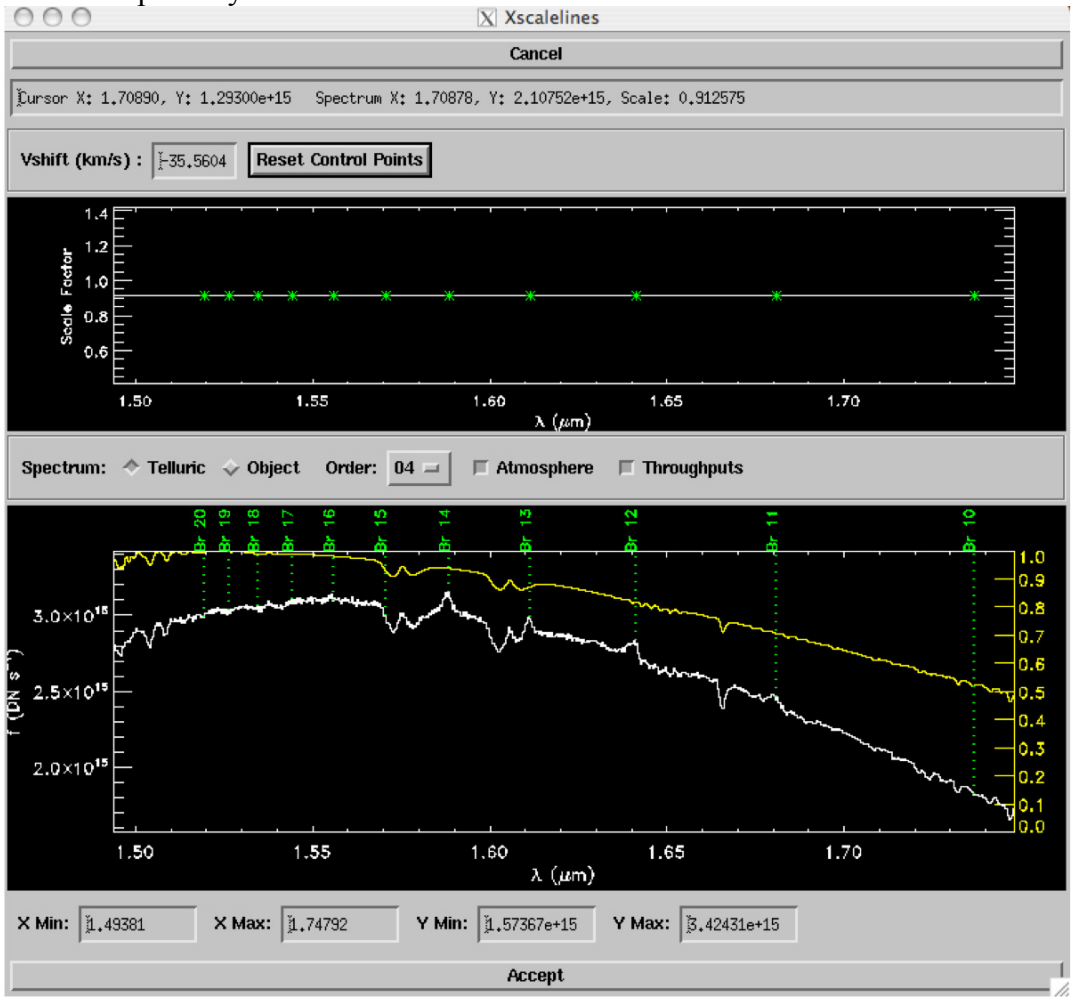


Note that the “set point” in the spline fit (the green asterisk in the upper panel) has now been raised. A second way to do this is to “grab” the set pint by dragging it with your mouse to the desired level. More on this later….

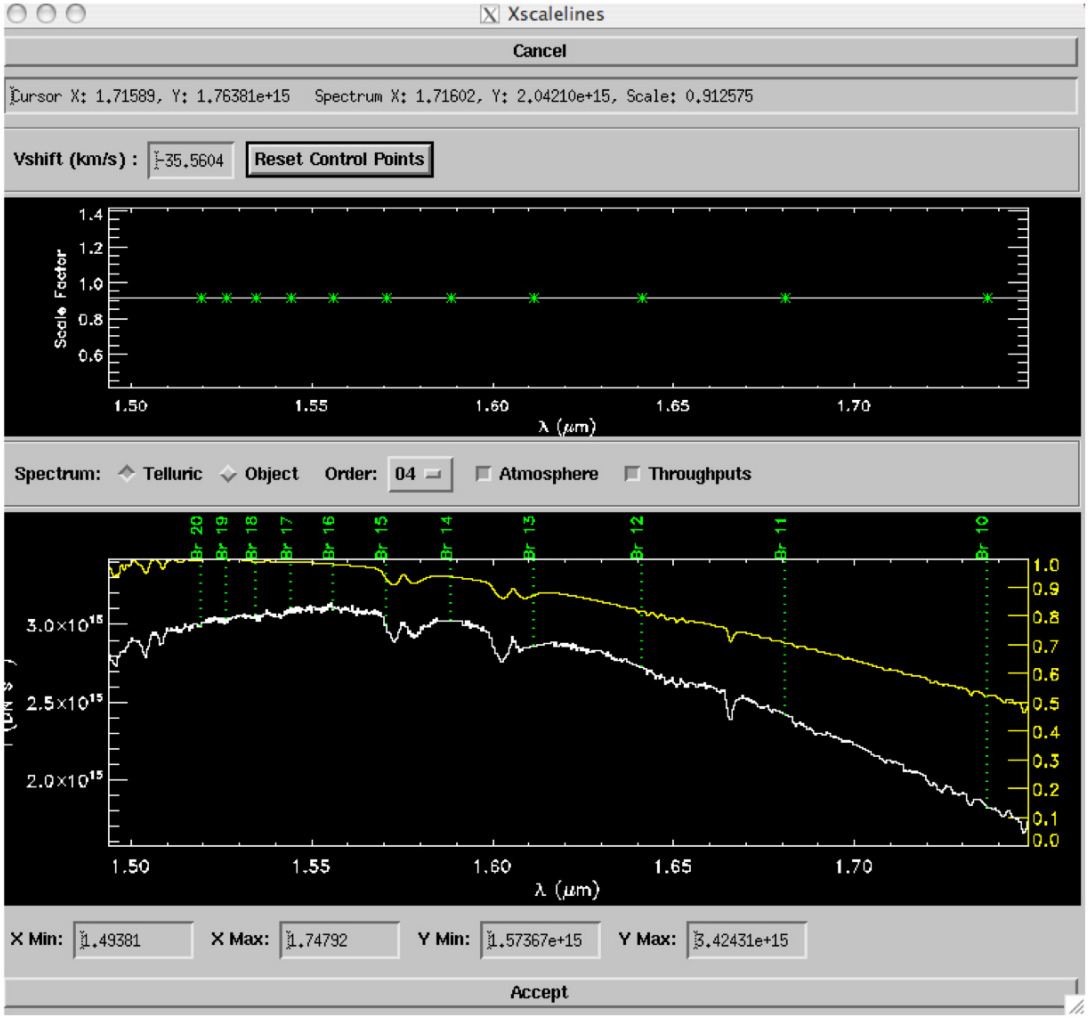
Finally one can use the “fix” routine by hitting the “f” key and then clicking on the spectrum on either side of the line. This produces a linear interpolation over the feature. In the case of lines with noise or blended with real telluric lines, you may want to (read “need to”) do this a few times. It will remember what you did before, since it has already replaced those data! But it also means that if you over-do it, you will have to go back and try again.



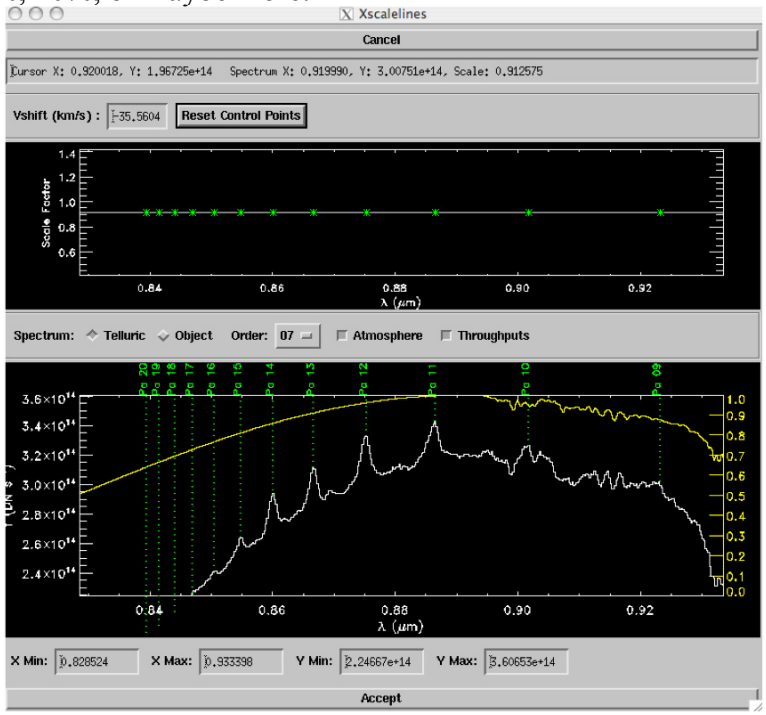
Here we see a case where the lower order Br lines have positive residuals ("emission") and should be corrected, but by Br 15, the residuals are tiny, and even switch over to weak absorption by Br 18. This is normal.

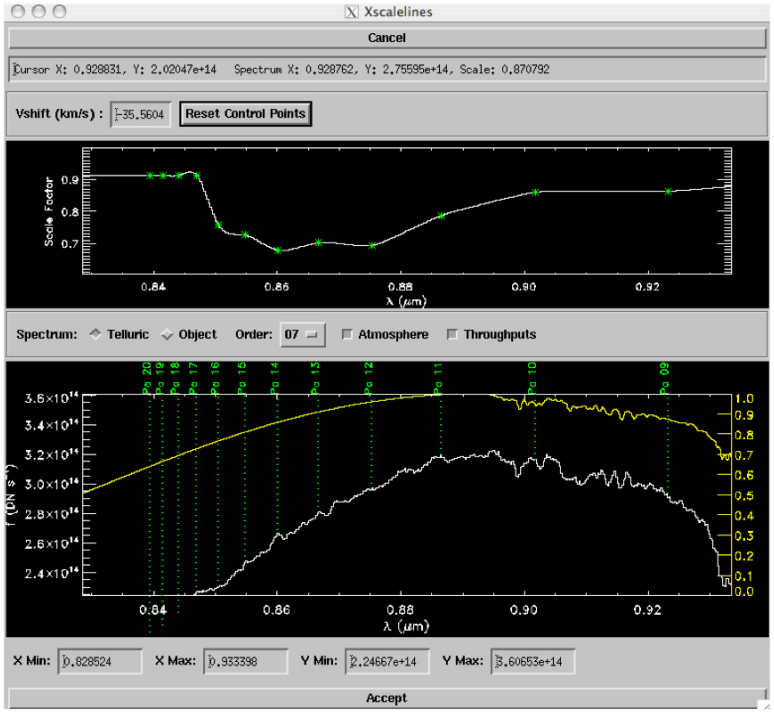


Here I used “f” to fix the Br 11-13 (Br 12 sits in a telluric feature, so this is a bit tricky). Granted, this is a bit “brute force” but it seems to work.



These residuals are more noticeable. The Pa lines often have strong residuals are closely packed. I have found that dragging the set points in this region is a bad way to go if you are interested in the *continuum shape* in this region. This is because dragging any one point also move the adjacent ones1 That's the nature of splines. So if you go back & forth dragging the set points around you will affect the continuum levels but 10%, 20%, or maybe more.

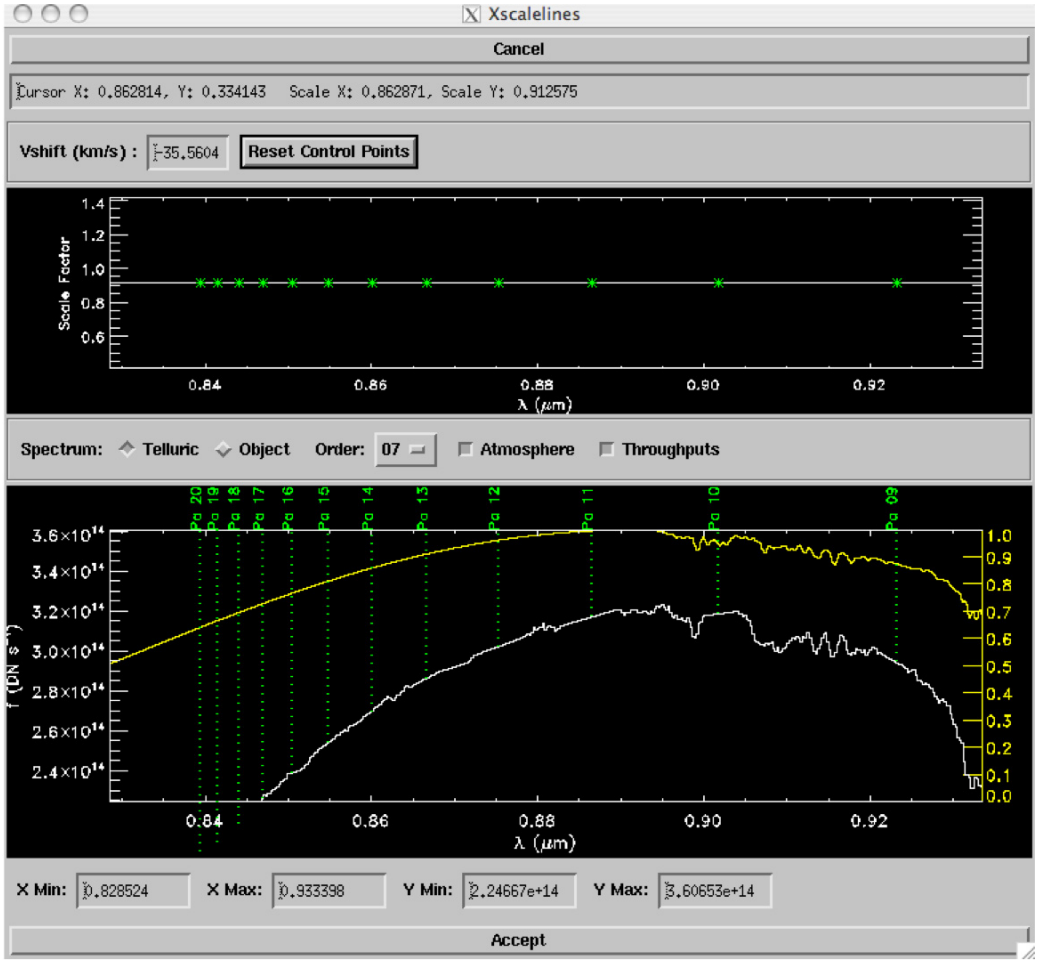




In the example shown here, the residuals were removed by moving the set points downward by about 20%. But the entire continuum in that region has been depressed by that amount. (The residuals from the Pa δ are still present).

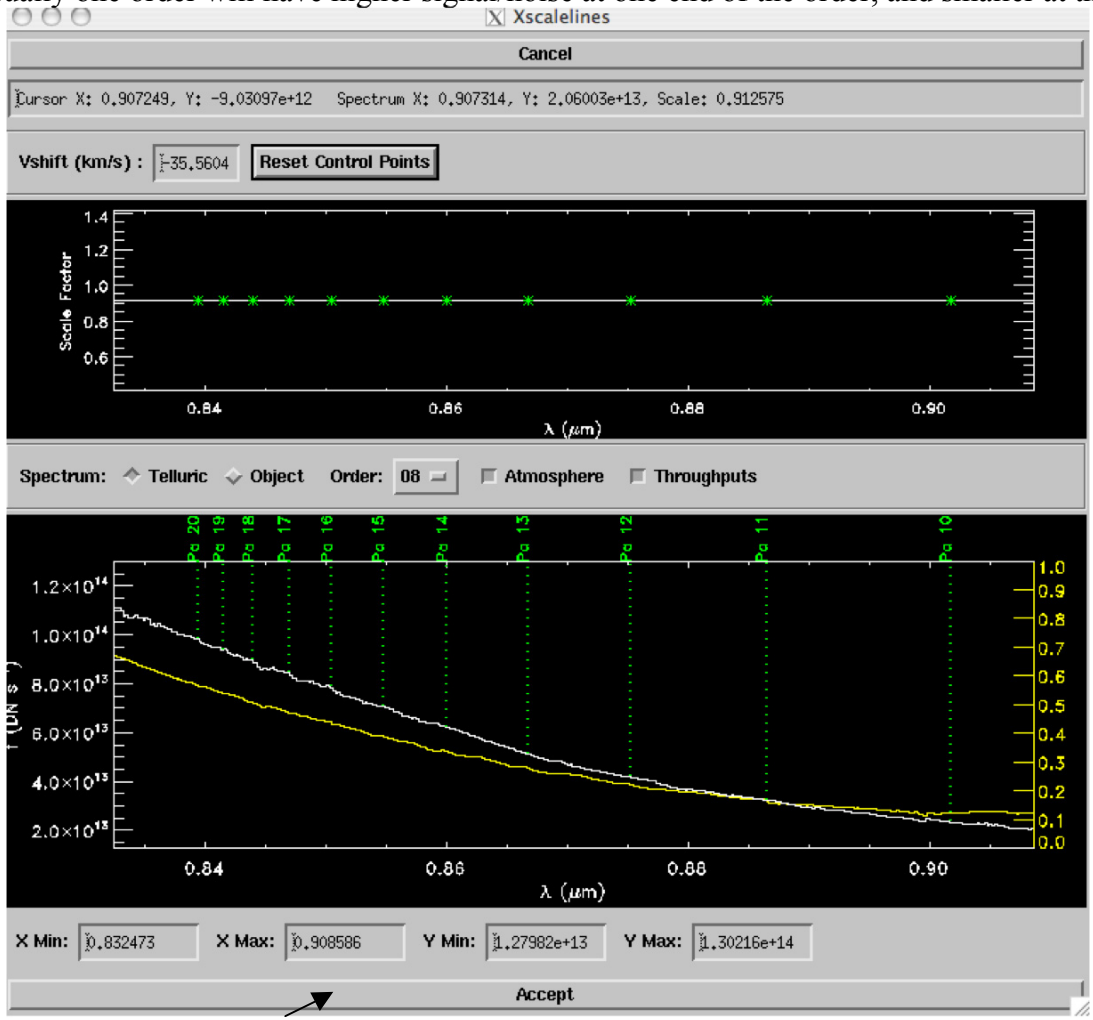
Note: I have seen where using the spline adjustment technique will produce a very noticeable "kink" in the spectra in Order 4 if the high order Br lines have strong residuals, for the same reason. ***Very bad of maintaining the integrity of the continuum shape.*** *However, if you are not concerned with overall spectral shape or photometric integrity, the method of moving the set point is fine. If you are interested in these, however, be sure that using this technique does not move the overall continuum more than your own tolerance level. Because I want to get close to 3% tolerance or better, I avoid this technique if it does anything to the continuum level.*

Now using “f”.



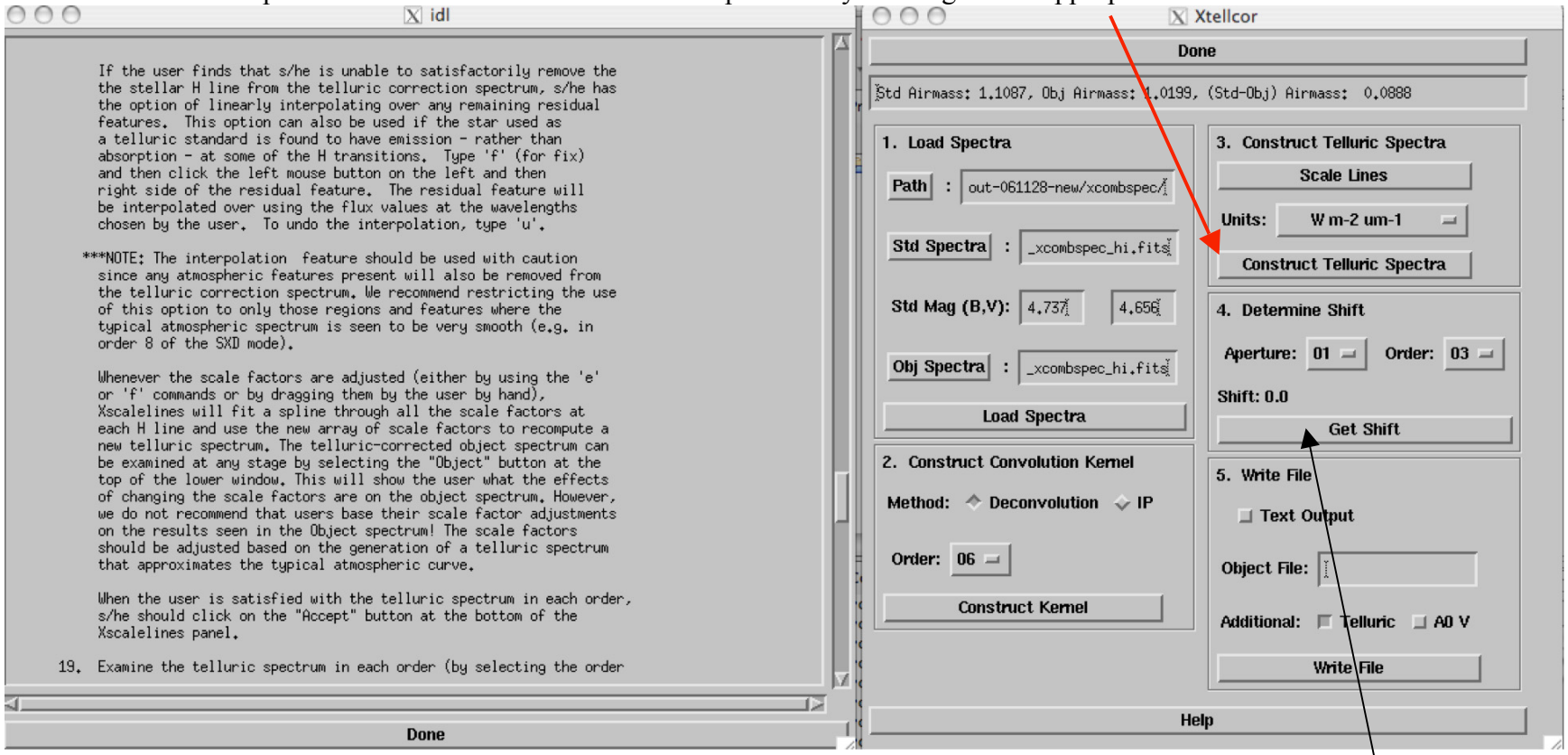
With that said, I have seen cases – late type PMS stars (i.e T Tauri stars) - which show a “hump” between 1.5 and 1.8 µm, even after using the “f” method. It may be intrinsic. I am still looking into this.

Now, in the LXD 2.3 mode of SpeX, many of the lines on Order 7 also appear in Order 8. They should still be adjusted, since you will later merge the various orders. Usually one order will have higher signal/noise at one end of the order, and smaller at the other end.



Once you have done ALL of the orders, hit the **Accept** button.

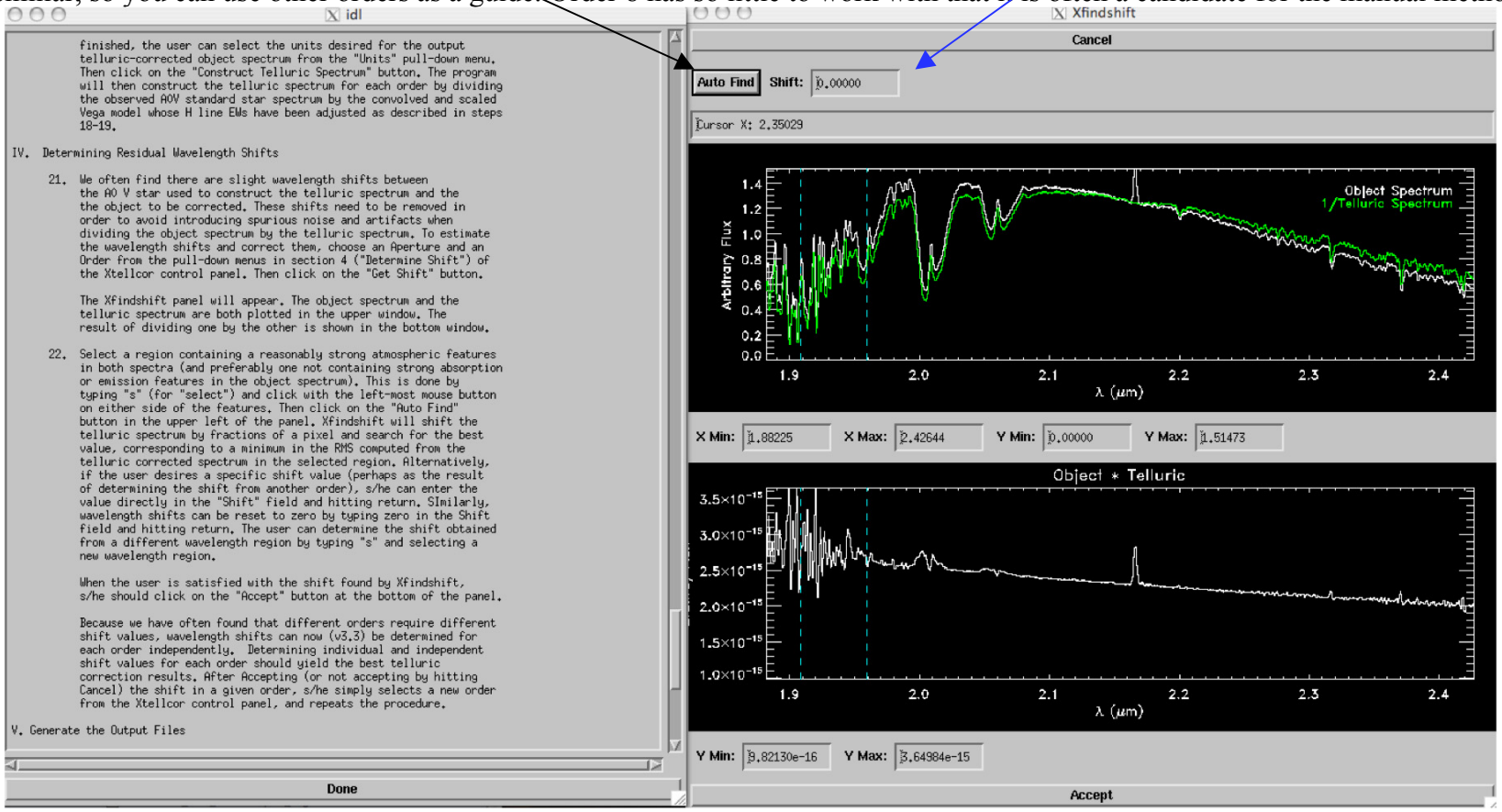
With all these “tweaks” in place it is time to construct the telluric spectrum by clicking on the appropriate button.



You won’t see anything happen, but you are ready to go to the next step, to line up your telluric spectrum with that of your science target and divide it out – hopefully removing the telluric features. If conditions are really good, and the airmass of your science target and A0V calibration star match well, some of the weaker features divide out well. Really strong ones, where both spectra hit close to zero, you get a result that you might expect by dividing zero by zero.

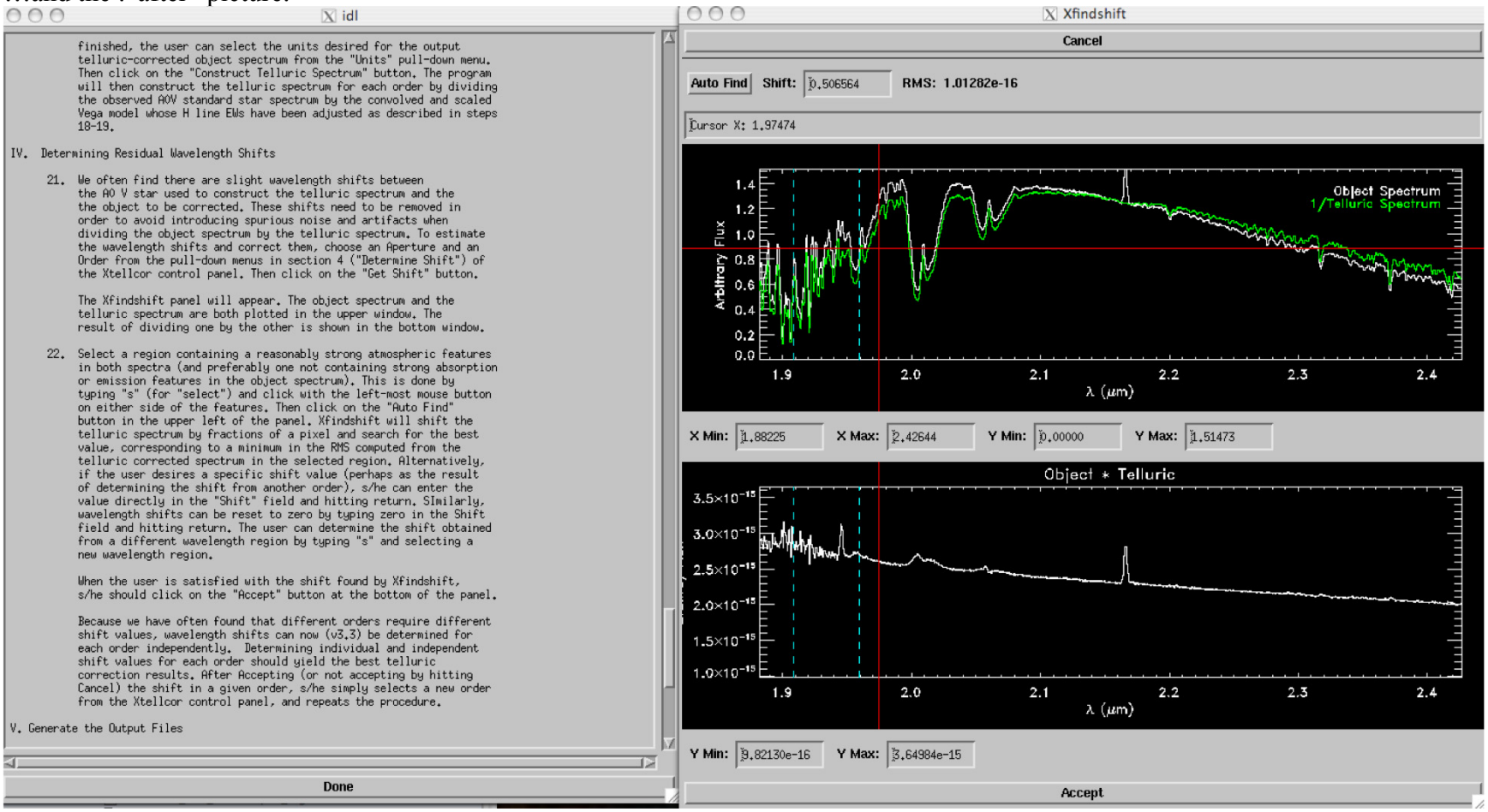
Now, your telluric spectrum and target star spectrum may not be precisely matched in wavelength, so select an order and **Get Shift**.

Here you need to select a region to shift. USUALLY, one with medium strength telluric features may be the best. The routine will shift the two back & forth until the Object*Telluric scatter is minimized. With really weak features, I suspect that this will be more highly affected by noise and other small features. Using the largest may give too much weight to fitting the 0/0 locations. LOOK at the results and use your own best judgment. So select your region, hit **Auto Find** and watch the fun. You may also enter this *manually* and hit *return*. Usually most of the shifts will be similar, so you can use other orders as a guide. Order 8 has so little to work with that it is often a candidate for the manual method.



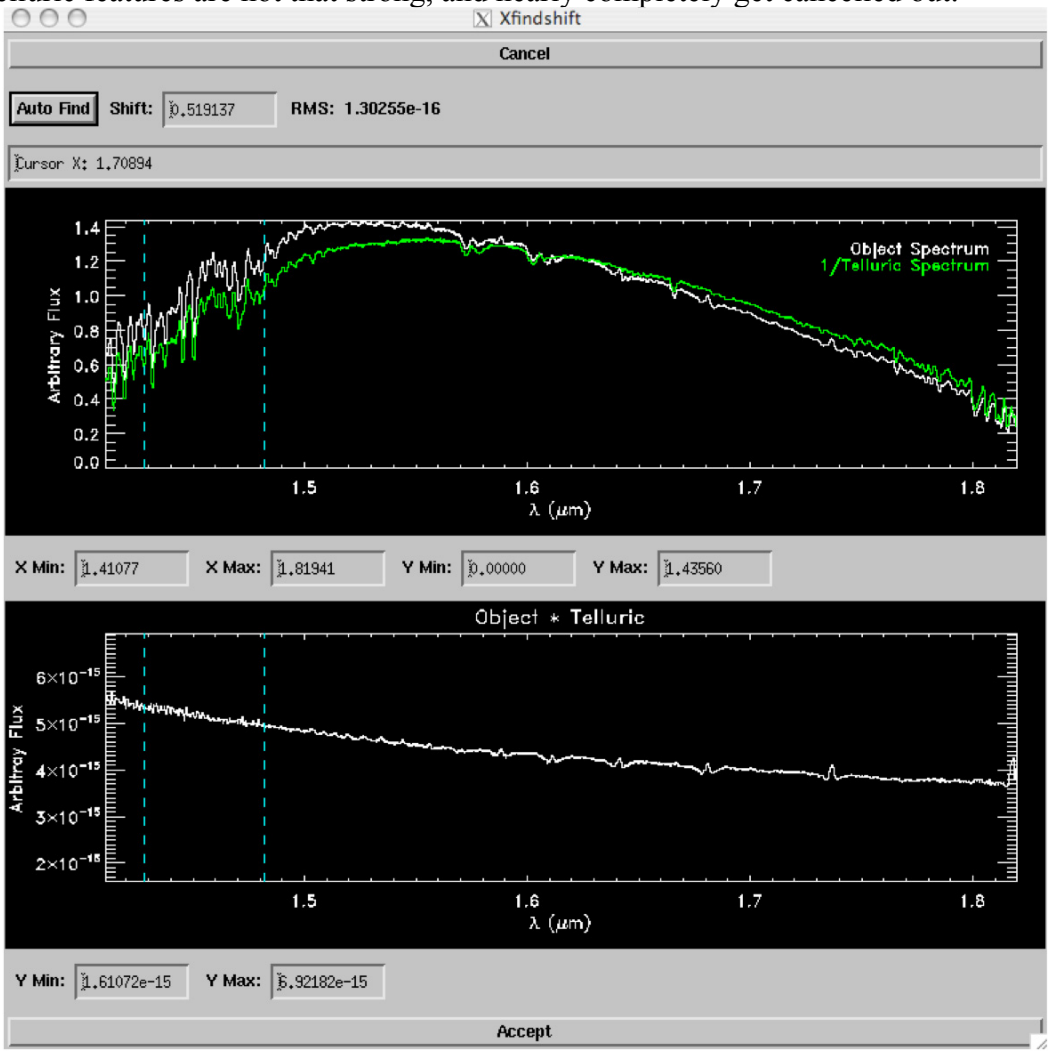
This is the “before” picture….

…and the :"after" picture.



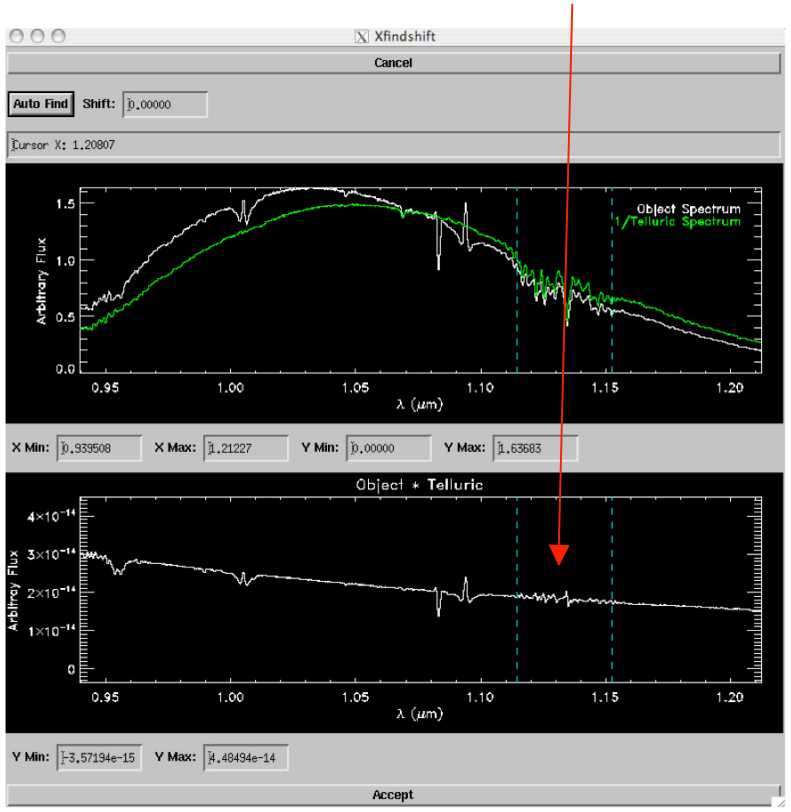
Unlike Scale Lines, ***here you need to hit Accept after every order is treated!*** Repeat this process for all orders.

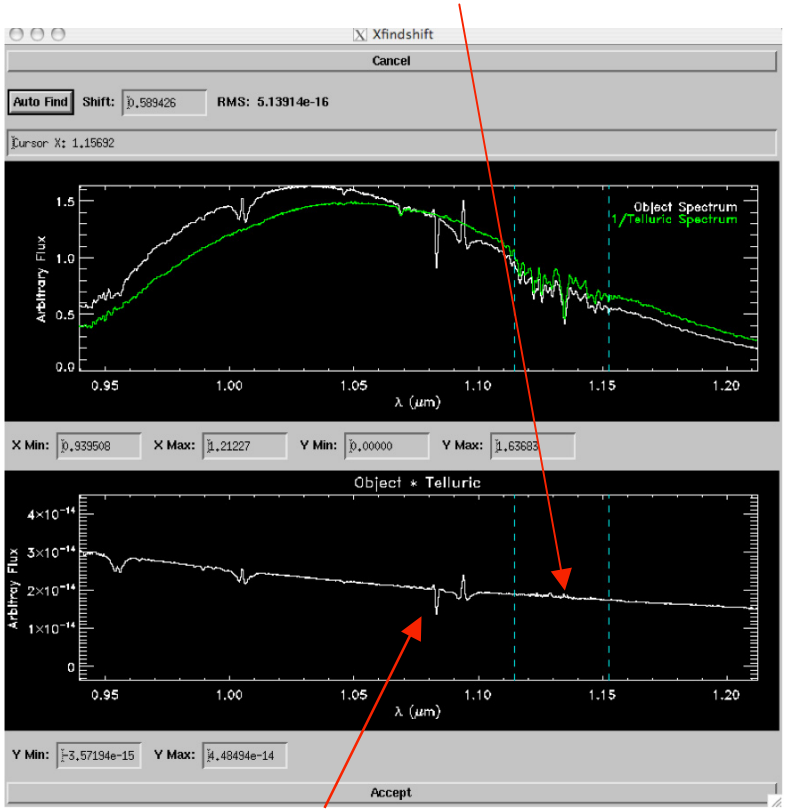
This is an example where the telluric features are not that strong, and nearly completely get cancelled out.



Note there the weak circumstellar emission lines are poking out of the photospheric absorption lines.

Another “before” and “after” pair. Not that even before shifting the telluric cancellation is pretty good. But after shifting it is even better!

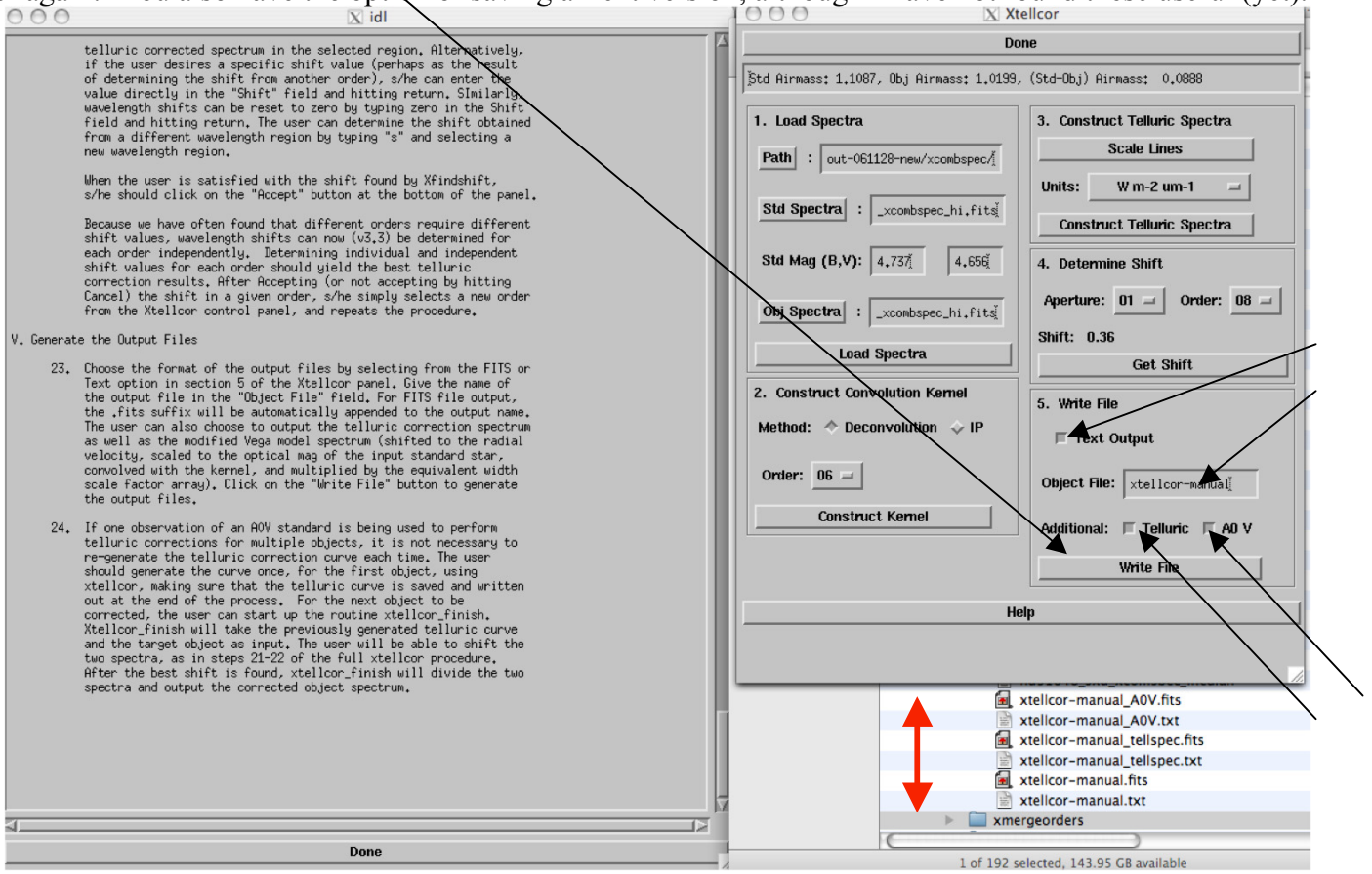




Here is an example where the circumstellar H lines are seen in emission, but the He I line at 1.083 μm is in absorption. In many PMS stars this will have a P Cygni line profile indicative of a wind (either from the star or from the disk). Here it looks like a very weak “inverse” P Cyg profile is present, possibly indicating infall.

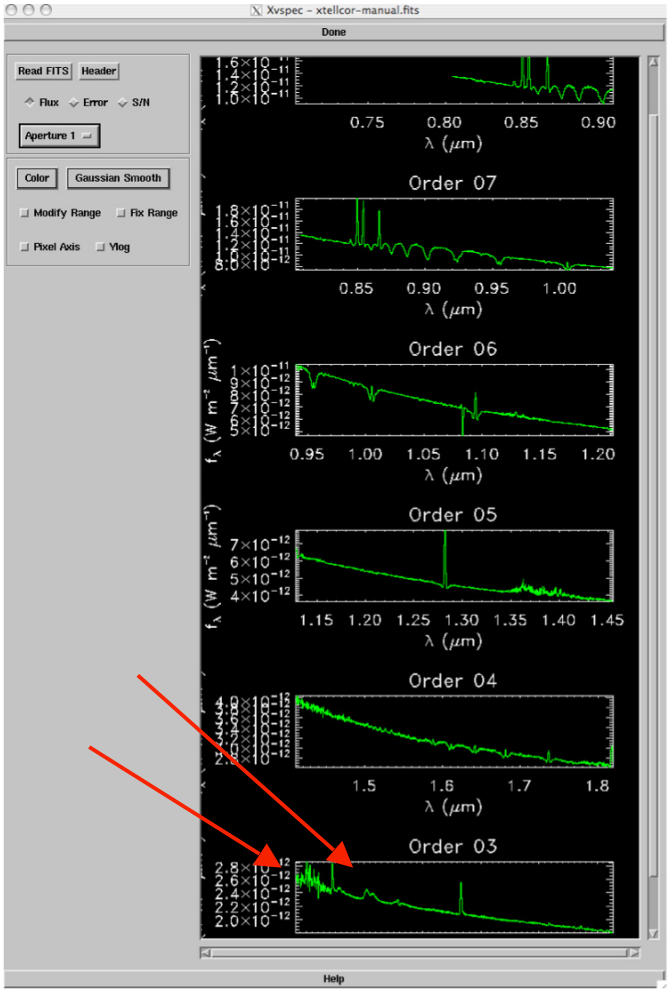
After you have **Accept**-ed all of the orders, it’s time to save your work.

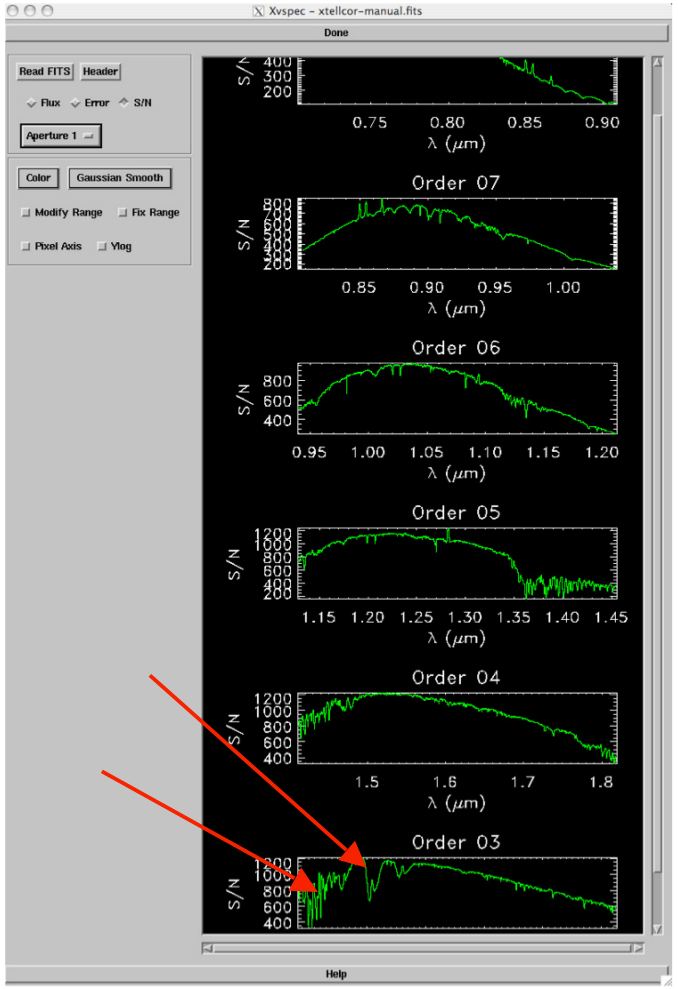
In general it is probably a good idea to **write** the telluric-corrected spectrum of the science target, but also the A0V star and especially the Telluric spectrum, which can be used again if you have another science target for which the A0V star you just used is appropriate (airmass, telescope pointing, etc.). For that you use the **xtellcor_finish.pro** routine. This allows you to skip having to construct the Kernel & Scale Lines from scratch all over again. You also have the option of saving a Text version, although I have not found these useful (yet).



When done, you will find **these** files written. Congratulations! You are done! (with xtellcor, at least…). I usually include the term "_xtellcor_" in the file name just so I tell what the file is later on.

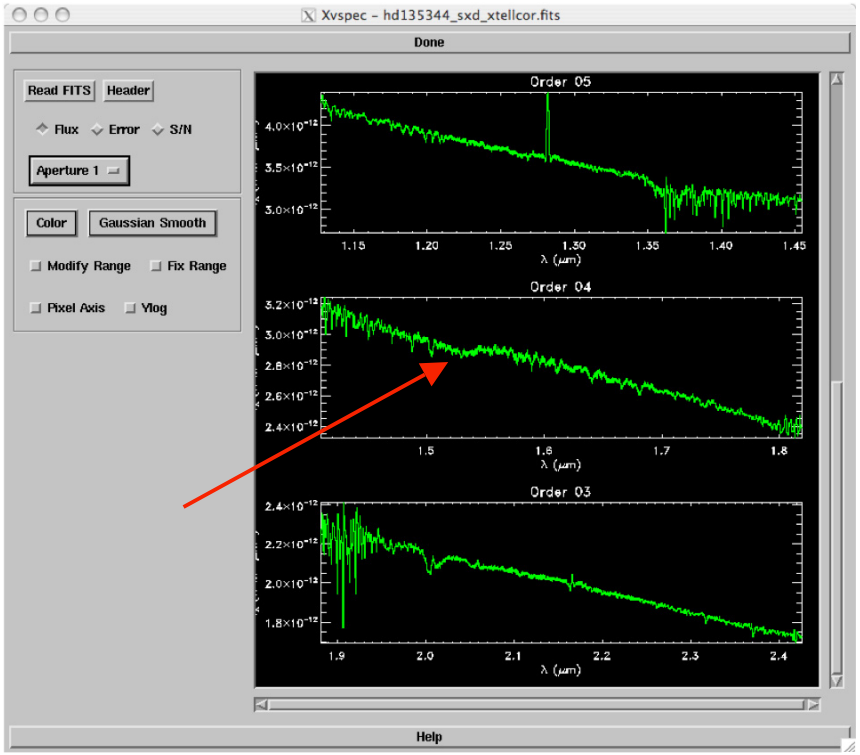
When you write the files, xtellcor will display your final spectra. You can display them as fluxes or signal-to-noise.

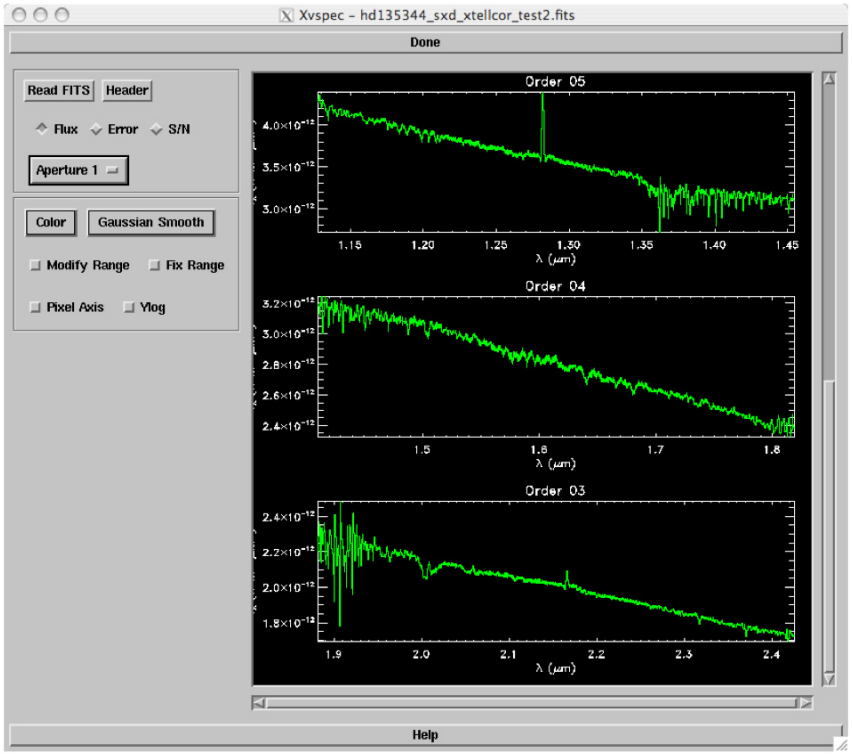




Note that some regions may have excellent S/N (in the hundreds) but can still have significant telluric features present of the airmass match was poor.

An example of when dragging the set points mangles your continuum. The left-hand version is victim to over-using this technique. The right-hand one shows what the continuum ought to look like at this stage.



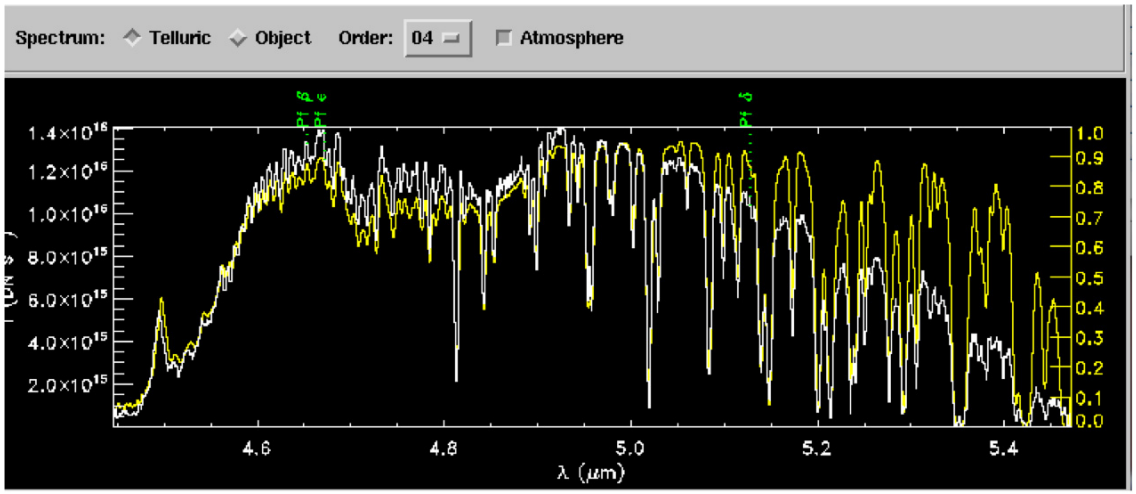


This is the “kink” that I described earlier.

Xtellcor in LXD

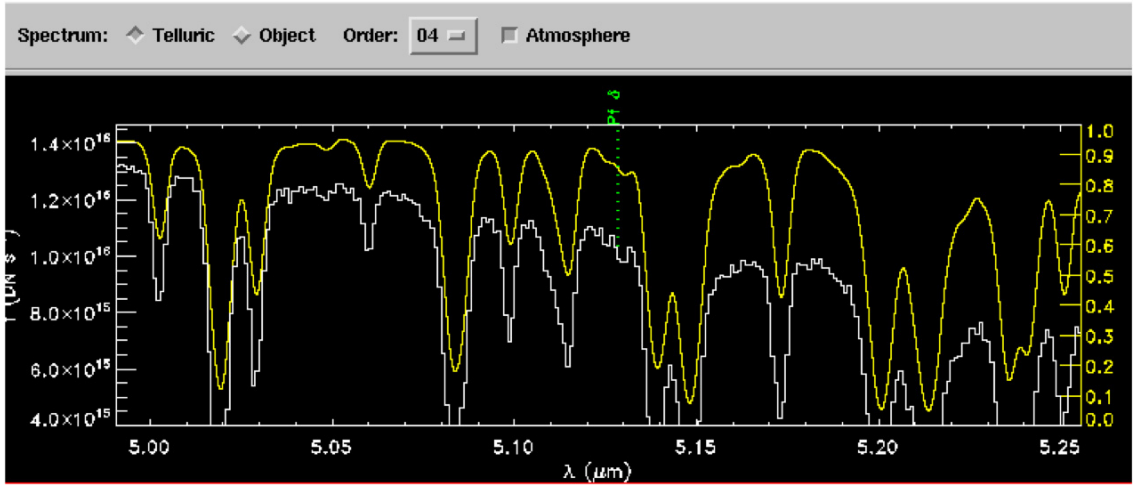
Now, for the LXD, I use the IP (Instrumental Profile) for construction of the Kernel. What about Scale Lines? Here we will examine each order. I will show the entire order and zoom in on one sample region.

Order 4:



This is by far the noisiest portion, at least in terms of strong telluric lines. Can you imagine trying to do the continuum fitting here?

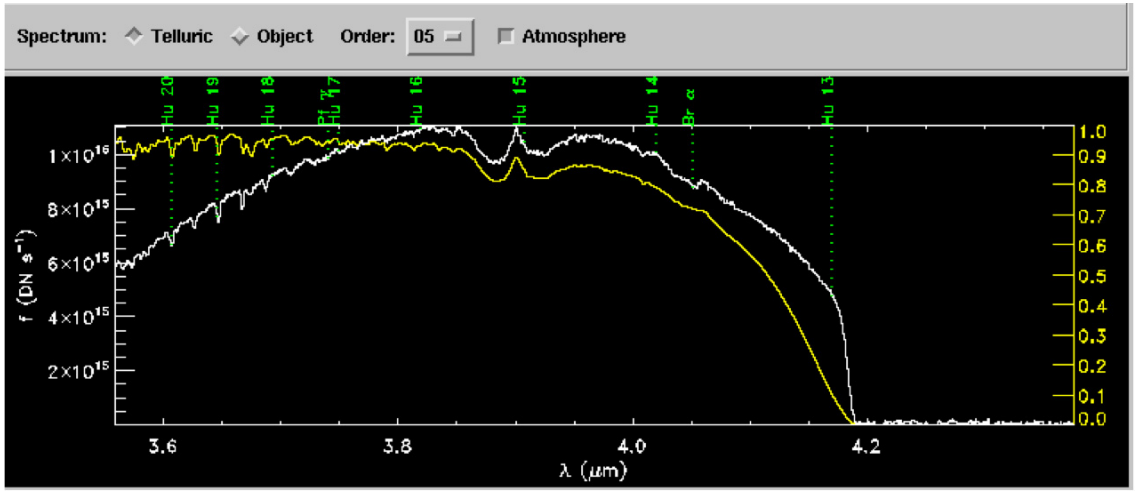
Now for the close-up.



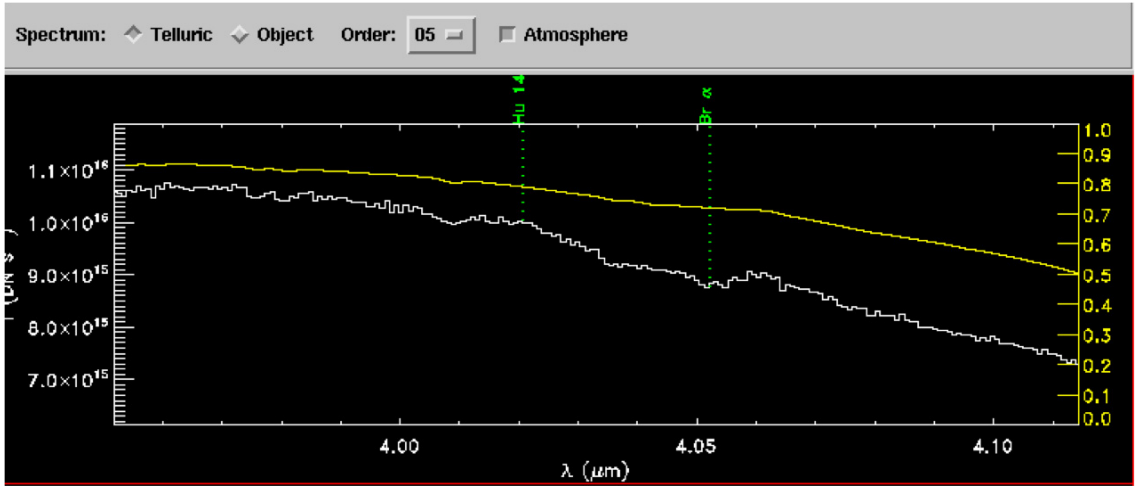
Here we see the results of applying the Kernel to the A0V spectrum. If Pf δ is present at all, it has apparently been corrected for pretty well.

Order 5:

It appears that the Hu lines at the short wavelength end might need correcting, but if you look closely you will see twice that many lines there, and they don't look like others (i.e. Hu 16), suggesting that they are telluric lines that coincide with the Hu lines. The fact that the A0V spectrum here matches the telluric one means these should be left alone.



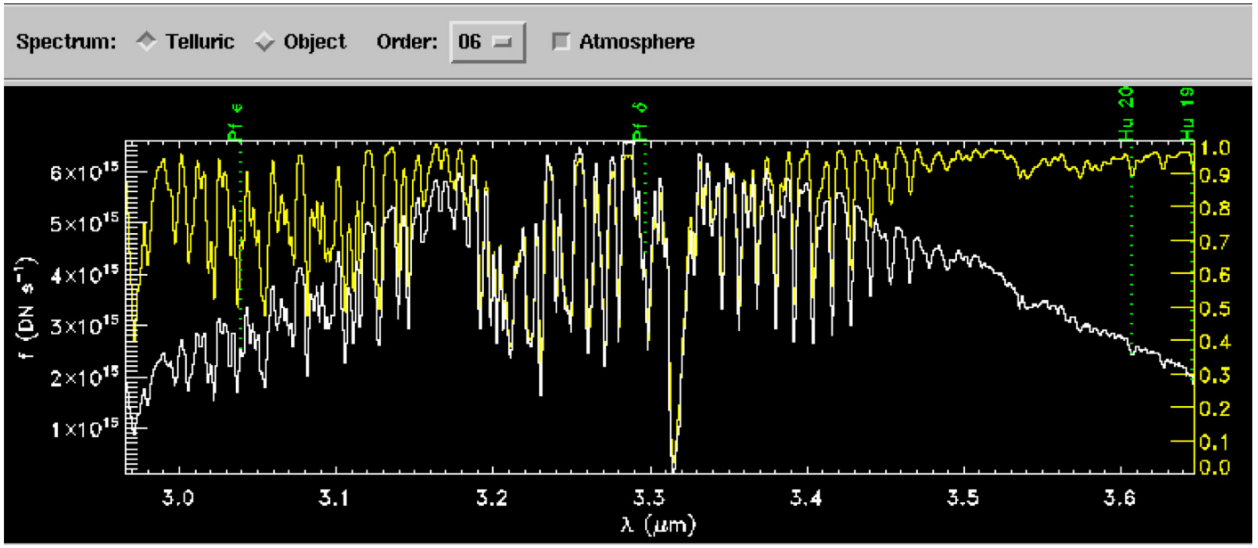
Here we see perhaps the only lines in this order that you might want to correct. Br α looks real at about the few % level, and you might want to use the "fix" routine here. Perhaps also on Hu 14, but I don't. You might even skip Br α if you don't need high precision in this line (like measuring its strength when it is weak compared to the continuum level).



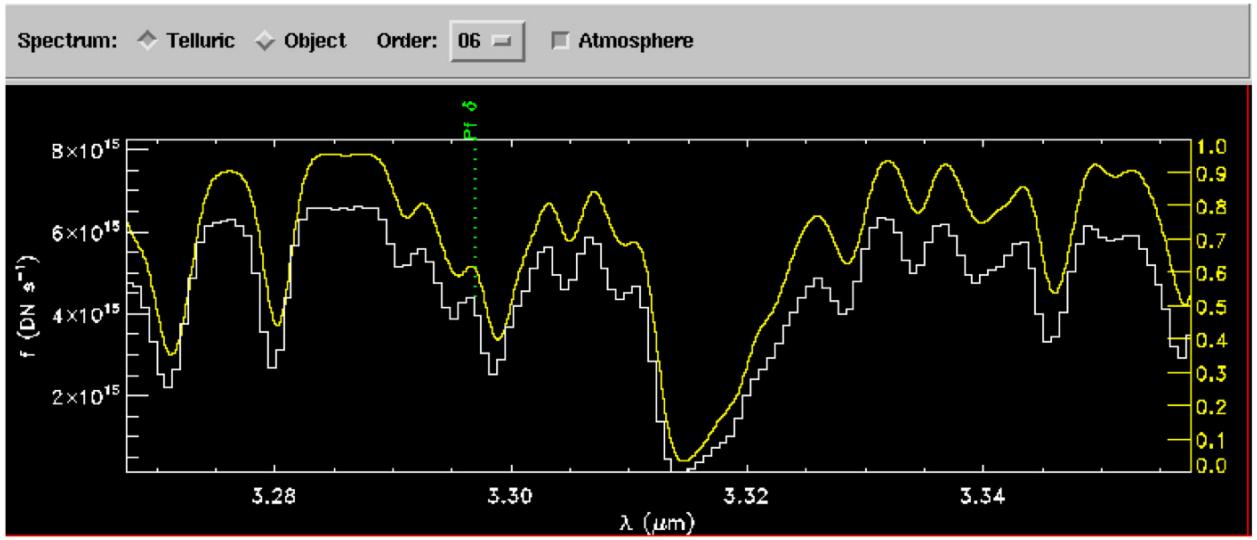
This is the only order in LXD with any hope of fitting the continuum for constructing the Kernel, and the only line present is too weak to do this for.

Order 6:

This region can be a mess if the water vapor level is anything but tiny. This is where one finds the 3.3 μm organic band, but Pf δ is also present there. Note that including the strong feature in the middle when doing the wavelength shifts may place too much weight on the 0/0 issue. The lines just longward are probably a good choice for that.

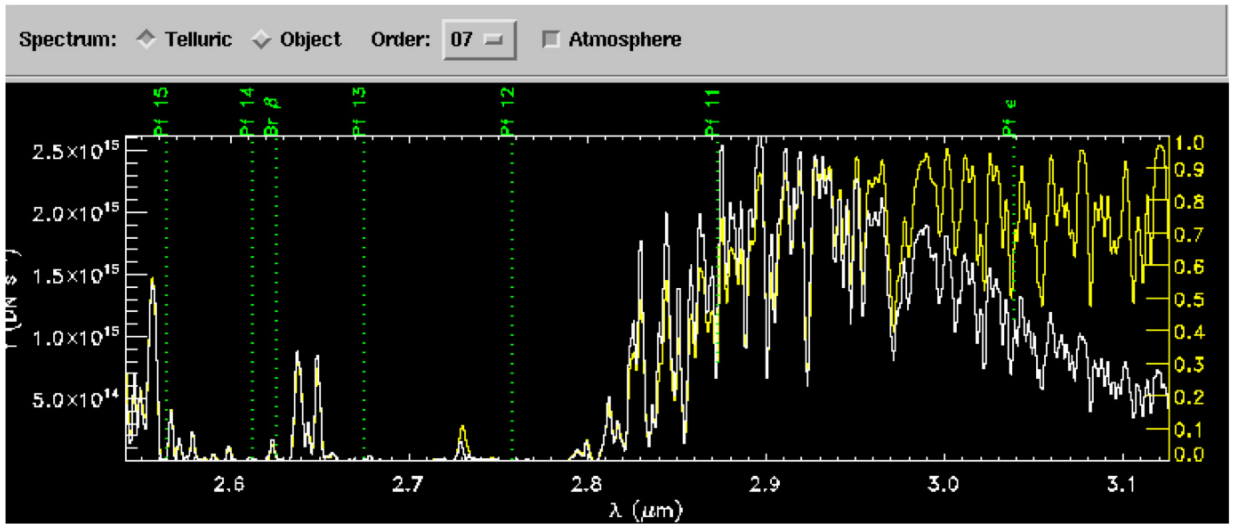


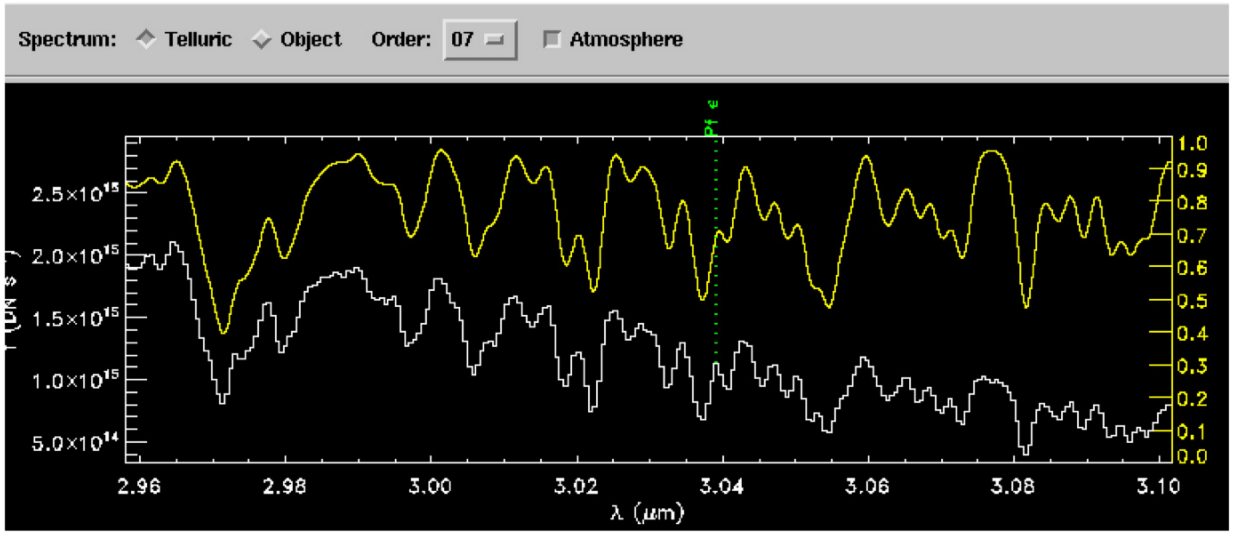
Here we can see that the A0V and Telluric spectra are very similar, and the effect of Pf δ seems to me minimal (in other words the IP Kernel seems to have done its job).



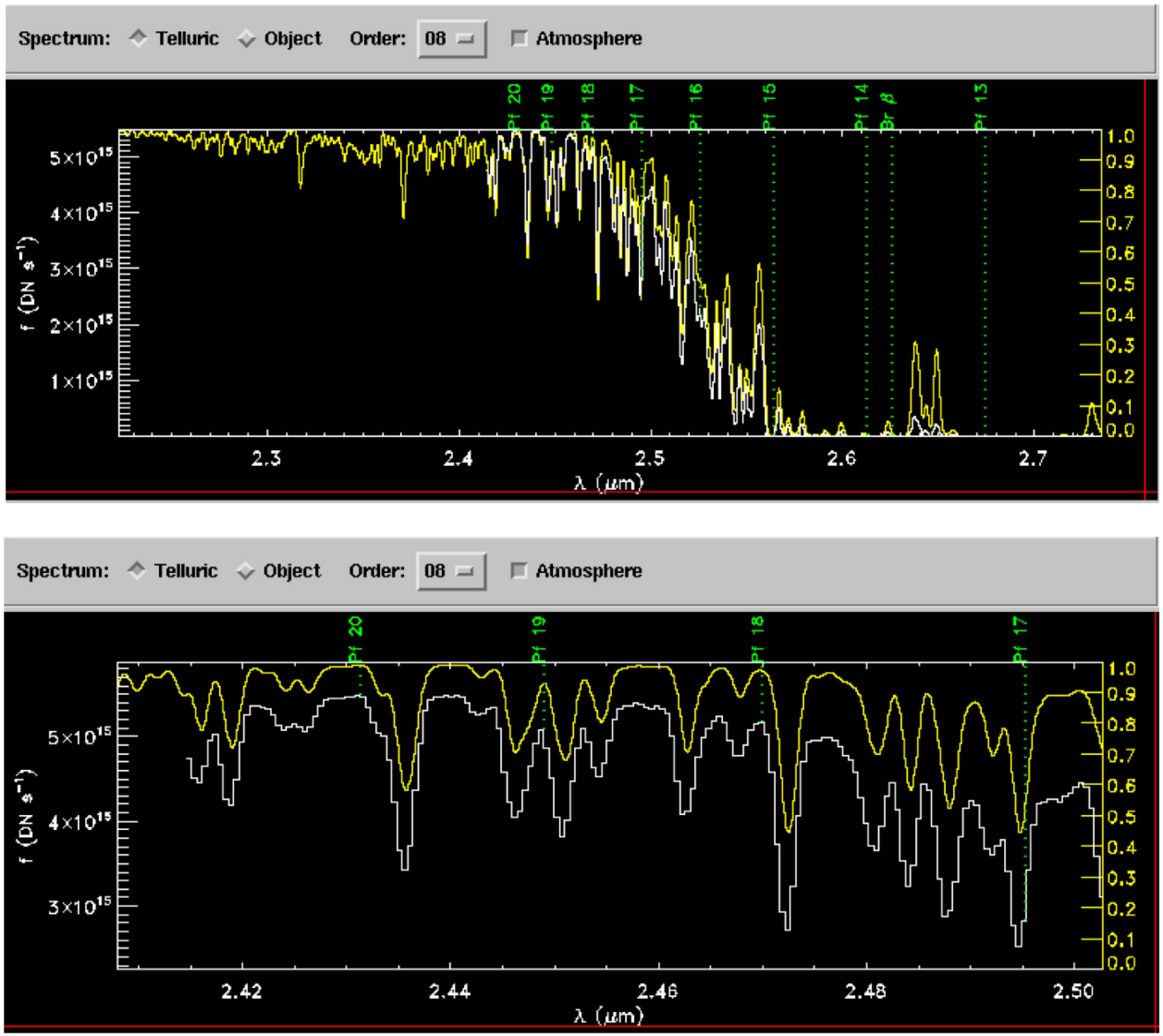
Order 7:

Another nasty order.





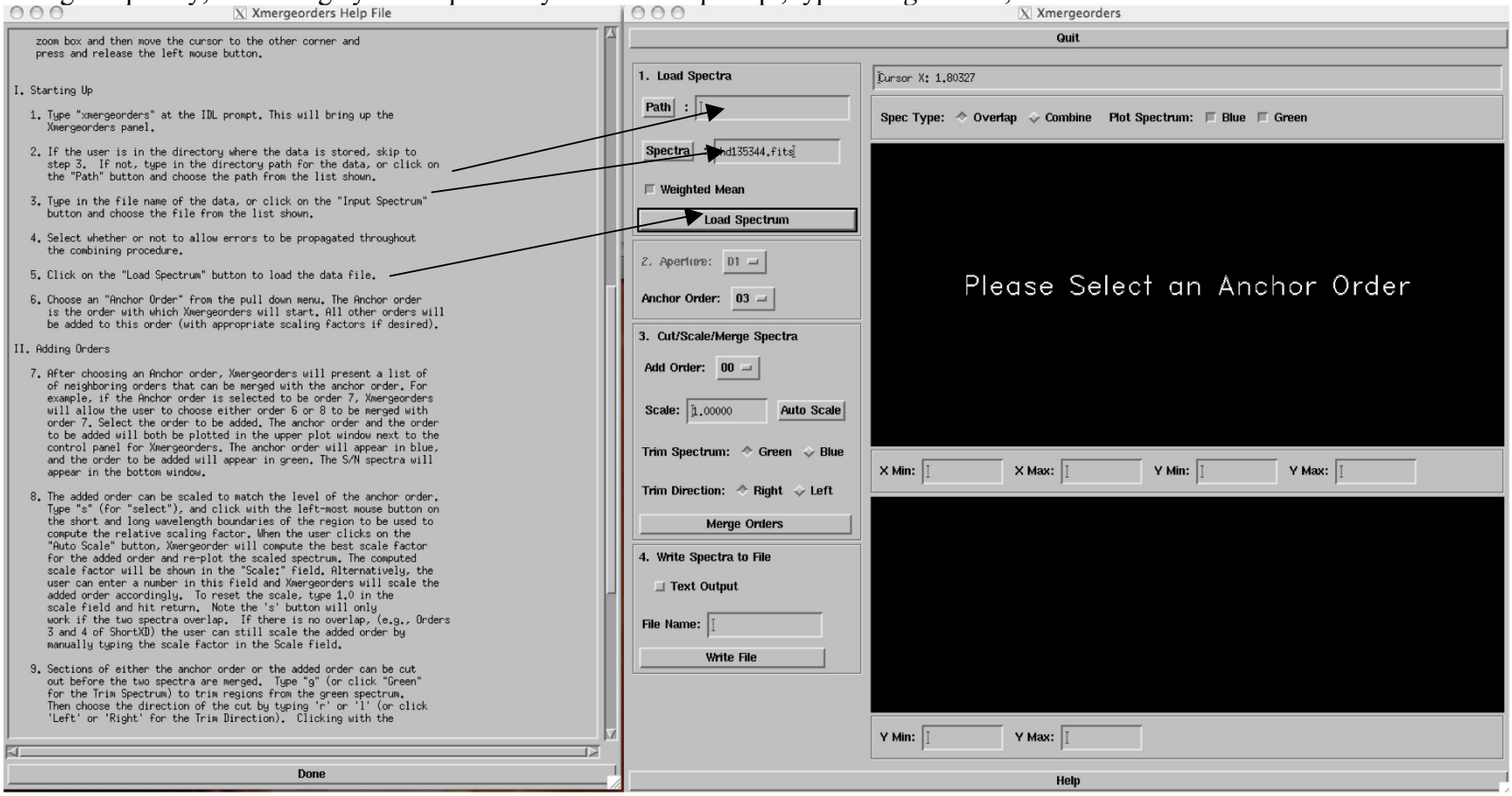
Order 8:



Enough said? Basically there does not seem much hope (point) is doing major corrections in LXD. Maybe Br α in Order 5, but not much else. As a consequence, running **xtellcor** on the LD data actually takes less time than on SXD.

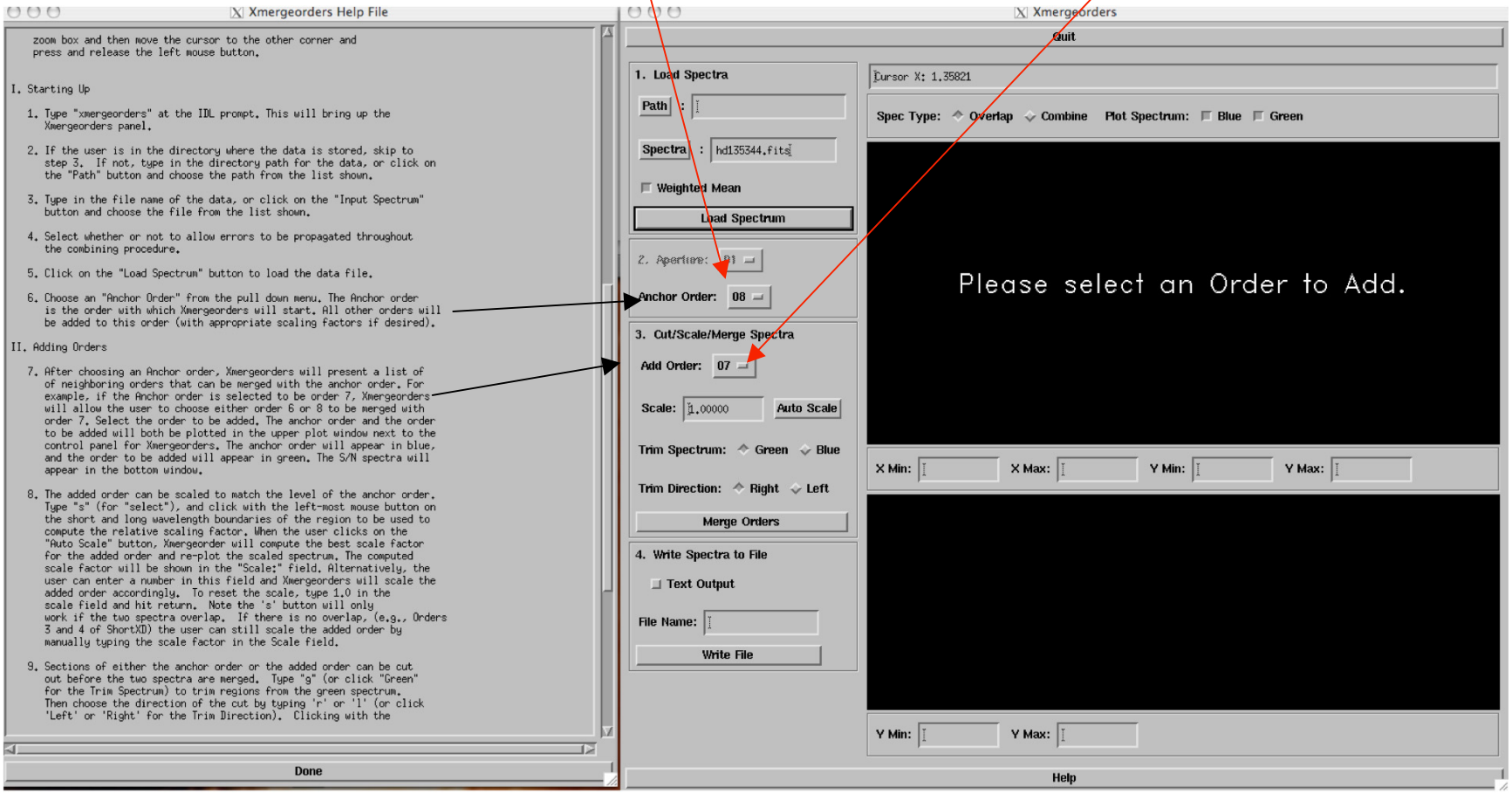
XMERGEORDERS

This goes quickly, and is largely self-explanatory. In the IDL prompt, type *xmergeorders*, and hit return.



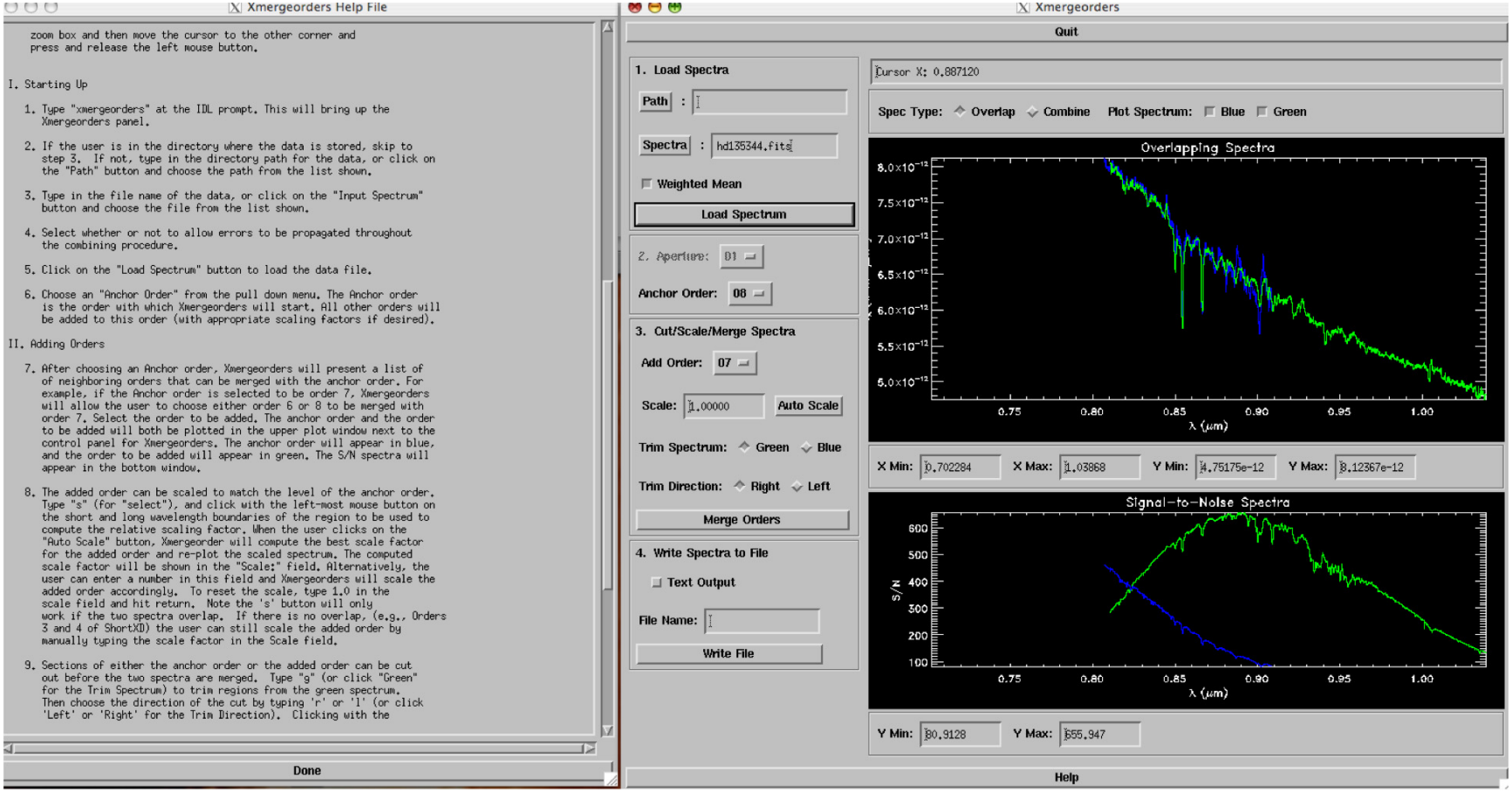
Set the path and load your spectrum.

You will then be asked to choose an order from which to successively scale & merge the other orders to. This is the *anchor order*. For the sake of illustration, I am going to start with Order 8, and build from there, starting with Order 7.

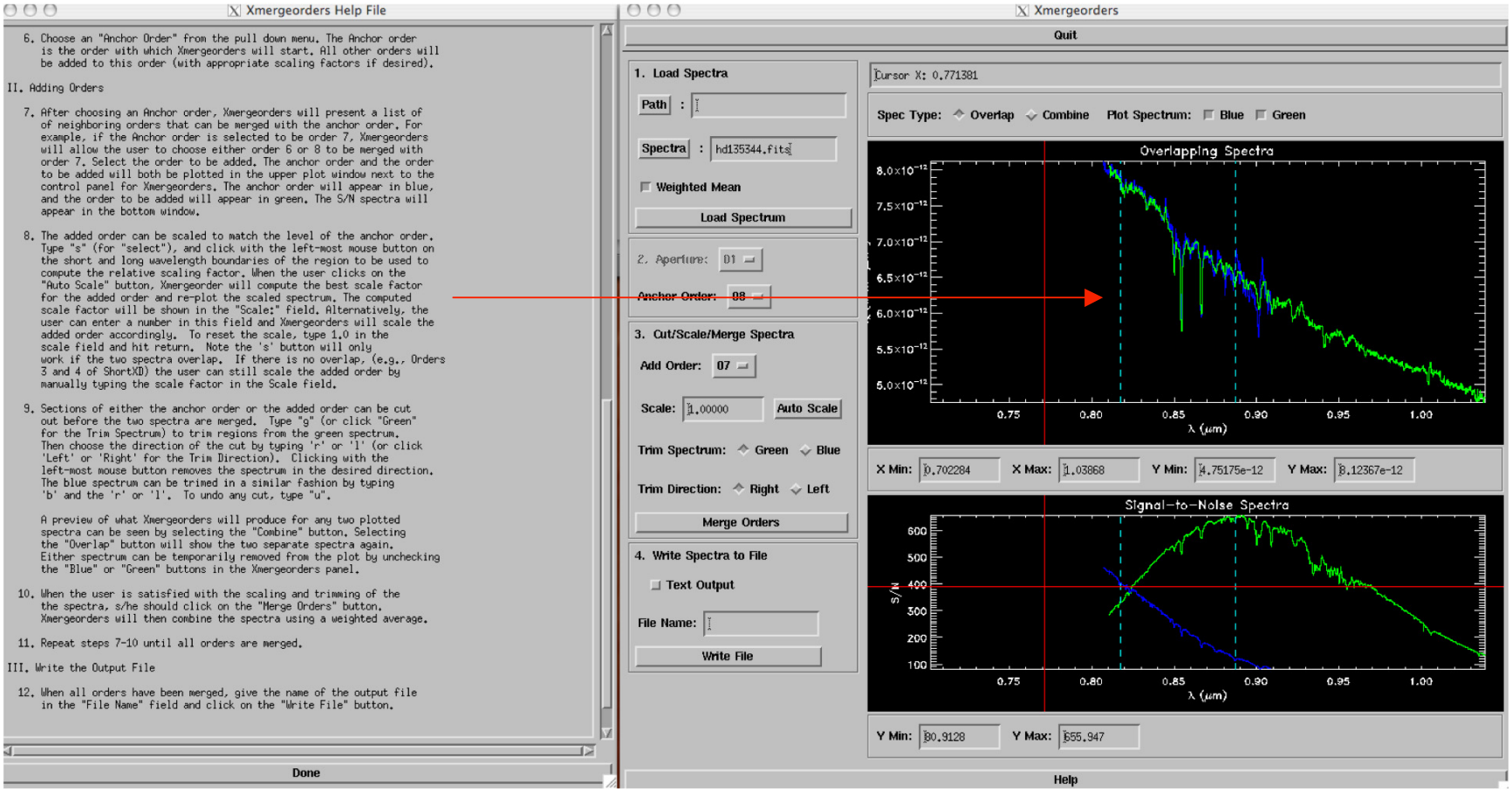


While you can use the "pull down menu" for selecting the order to be added, I found that on my machine I had to actually "click" on it to load the spectra for these orders (sometimes double-click, slowly or press-hold). If not, the next step produces an "index out of range" error!

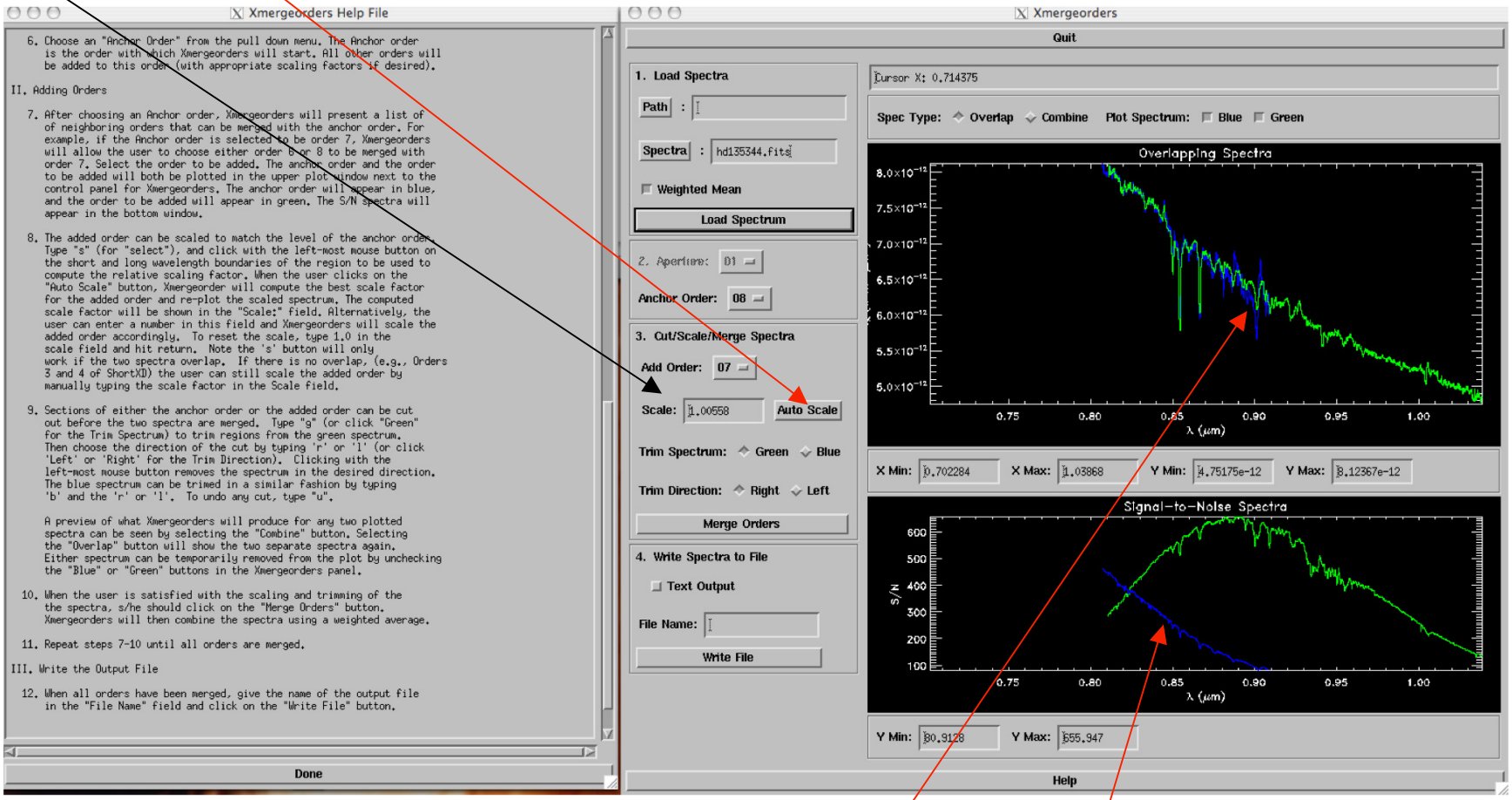
This is what it should look like. Here Order 8 is in blue, and Order 7 is in green.



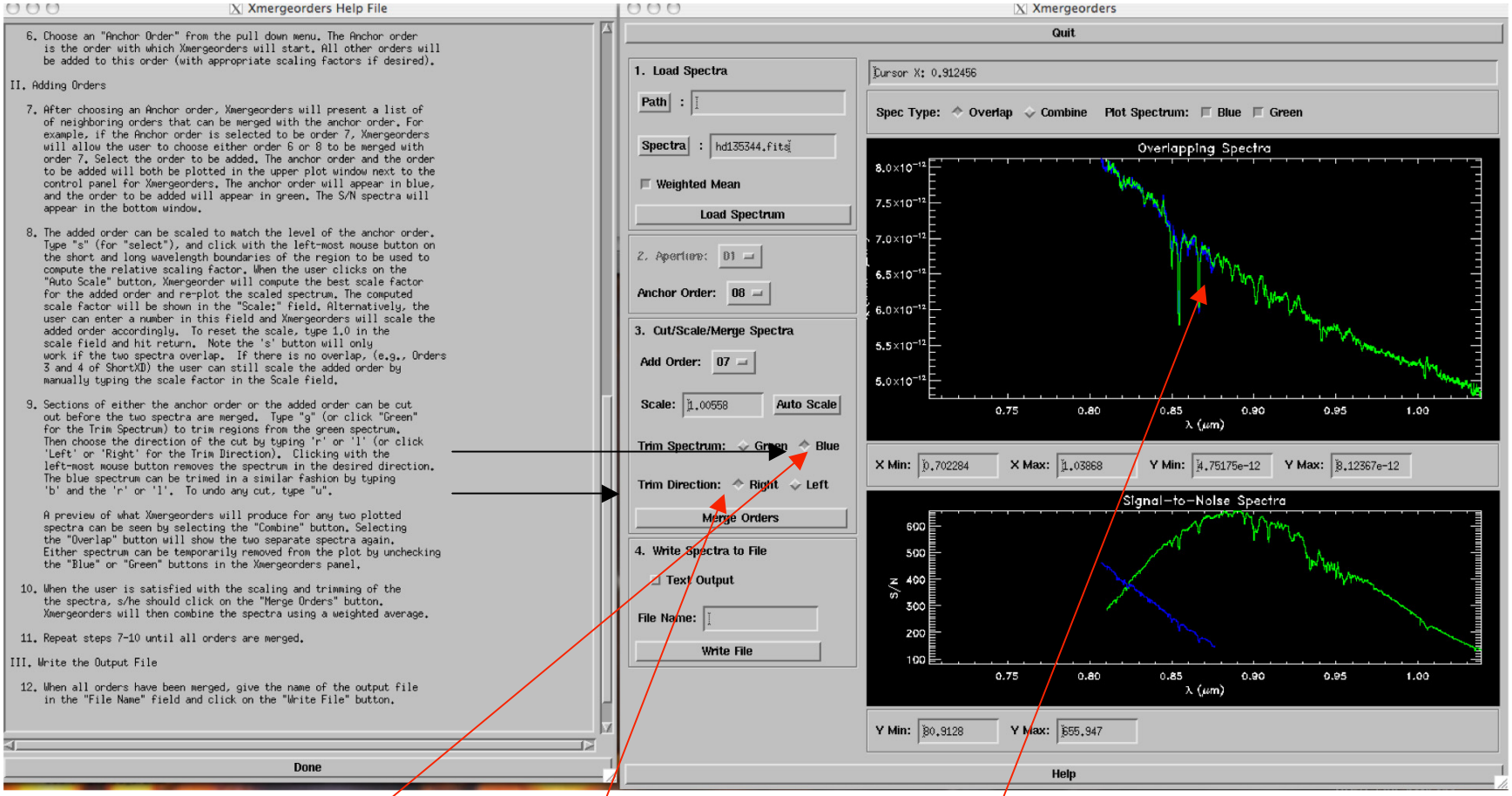
For the next step, you need to select ("s") over what wavelength range you will use to re-scale order 7 to the flux level of Order 8, using the left mouse button. So hit "s" and then left-click over the desired range.



Then hit **Auto Scale** and you get Order 7 re-scaled to Order 8. If you need to you can also do this manually by entering a scale factor on the box *and hitting return.*

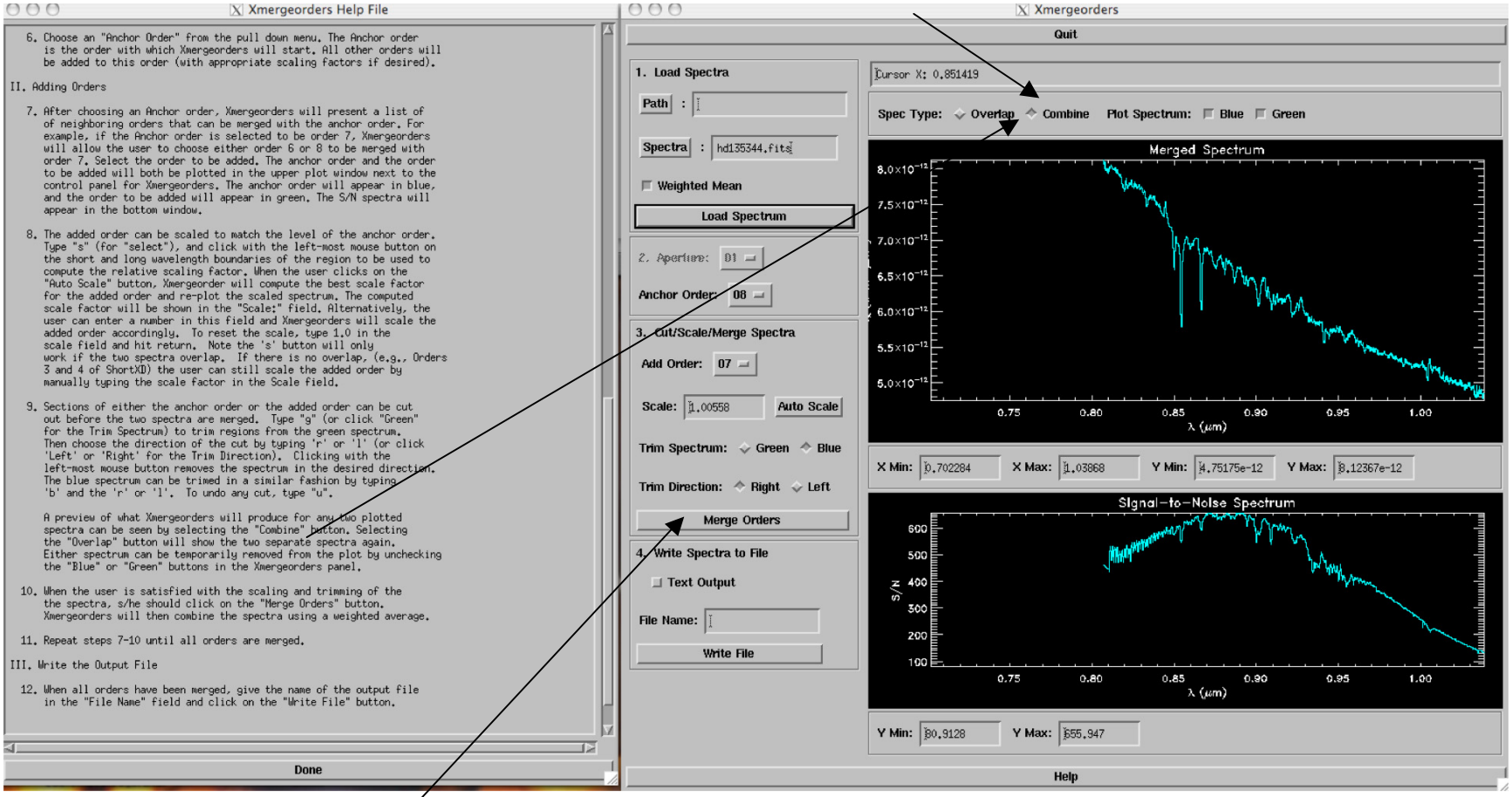


It's hard to see, but the green spectrum (Order 7) has moved just a little bit.
It is also apparent that the noise in Order 8 is a bit more than in 7 in the wavelength range where they overlap. You can see this in the spectra, and in the S/N plots. So we will trim off the noisy part before merging.



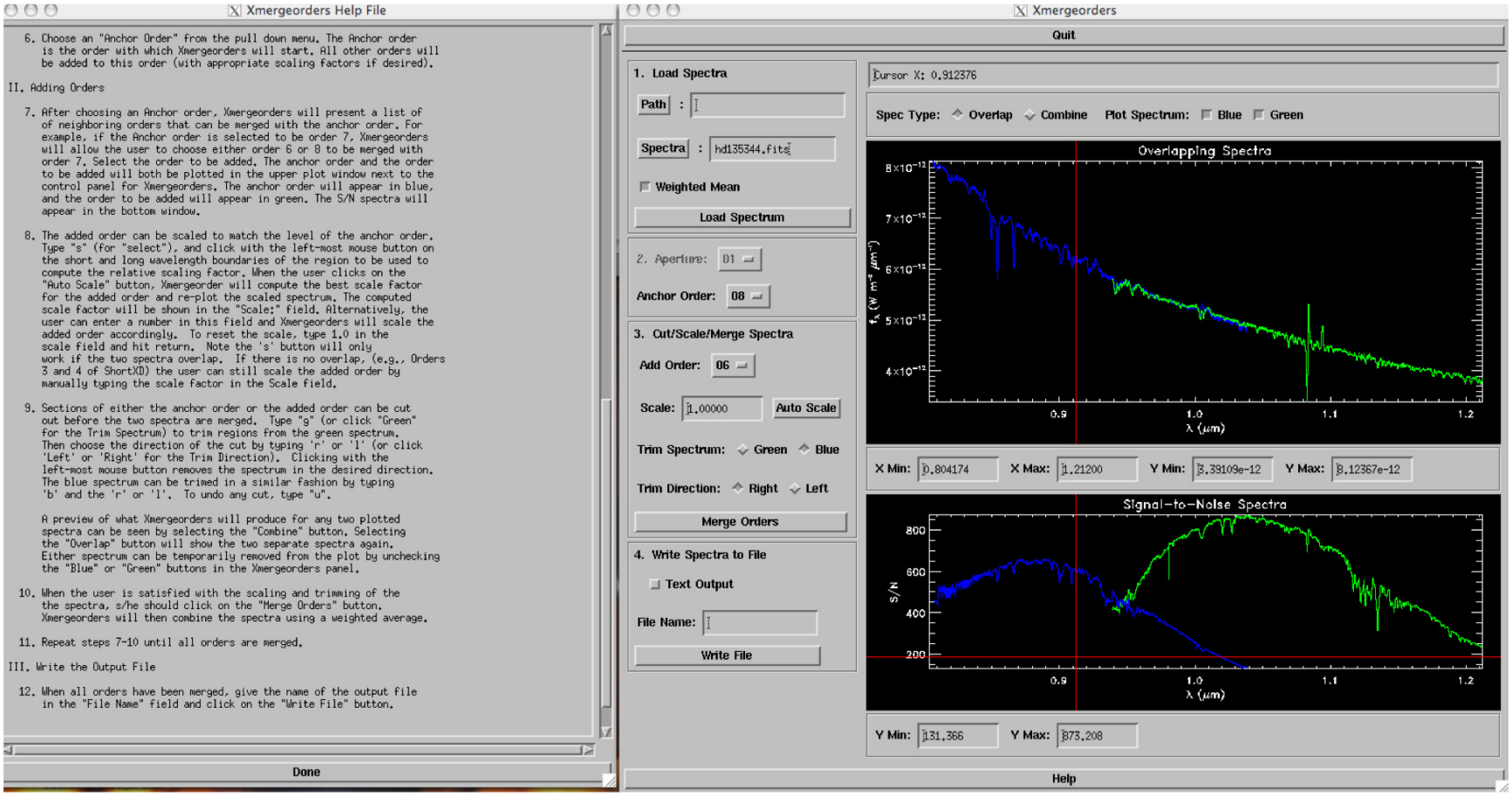
Here, I selected trimming the blue spectrum to the right of wherever I left-clicked on the spectrum.

Then, take a look at what the merged spectrum will look like by hitting the combine button:

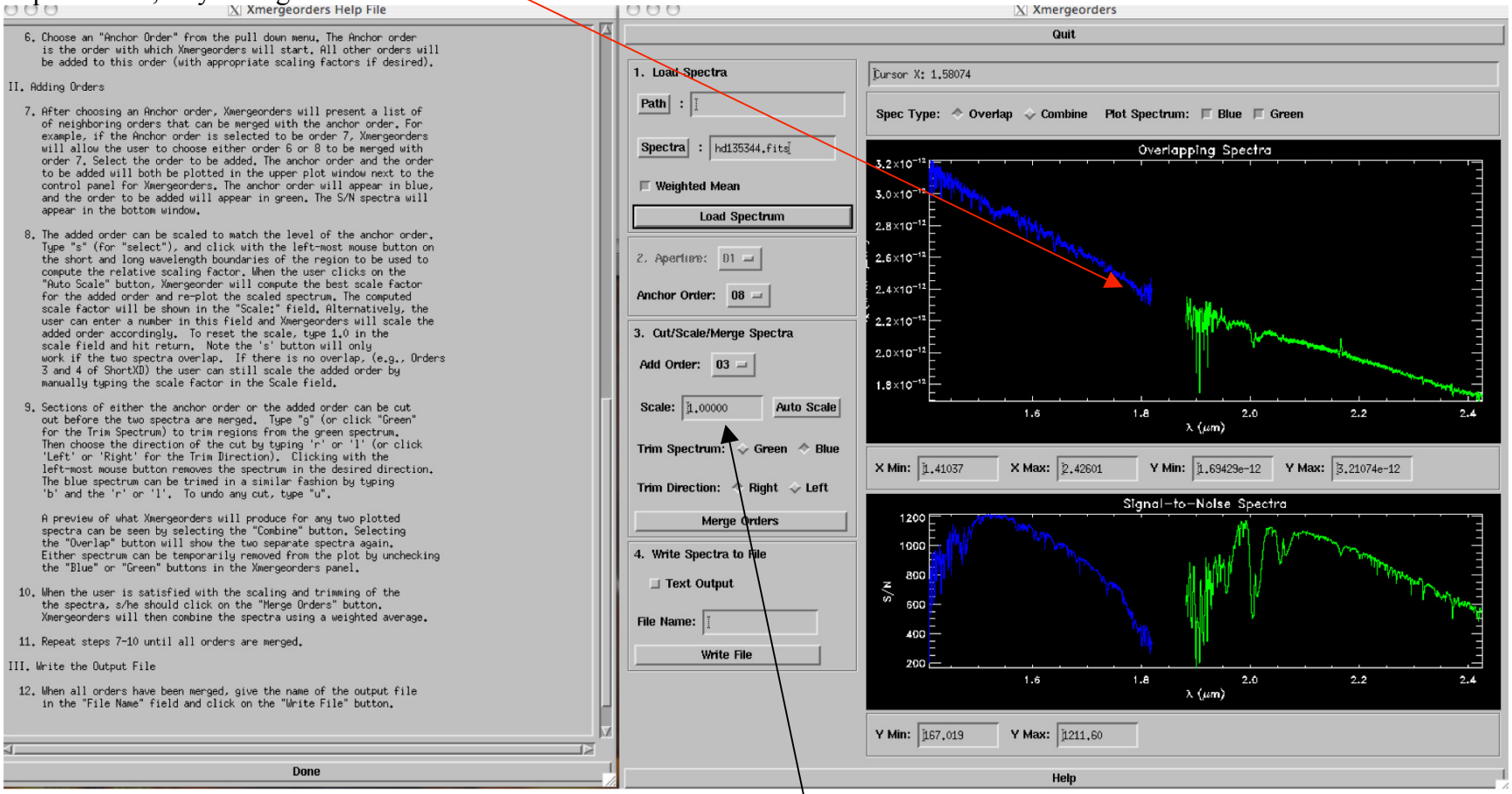


When you are satisfied, hit **Merge Orders**.

Repeat this process for the rest of the orders, but ***do not change the Anchor Order***, just the Add Order. Otherwise, the program thinks you are starting all over, and will forget what you have done up to this point!



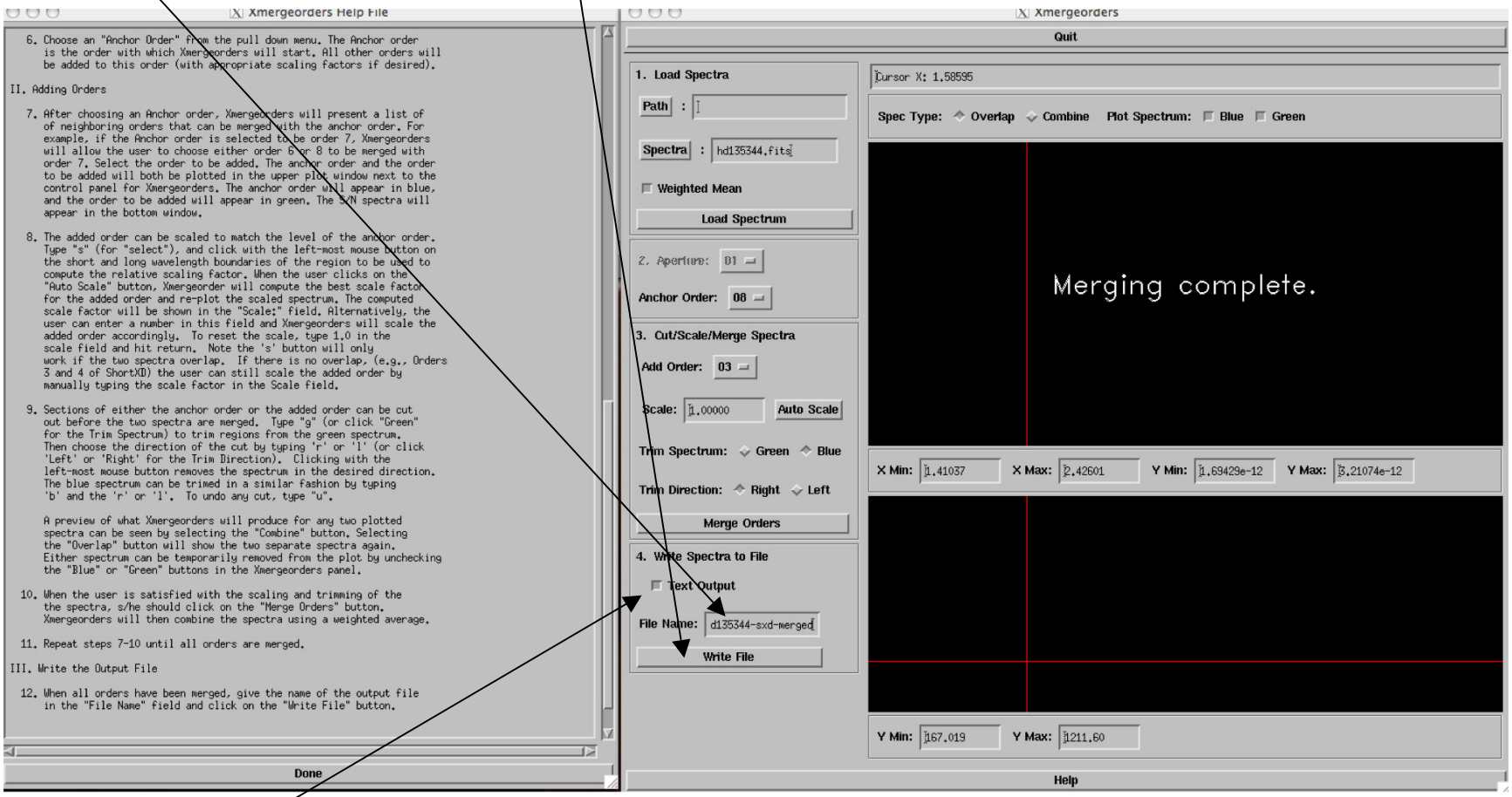
Now, orders 3 and 4 do not actually overlap, so it will require a bit of guesswork as to how much adjusting is needed. Most of the orders don't require much, so you might even leave this one alone.



Remember that you can also do the adjusting by typing in a scale factor manually, and hitting return.

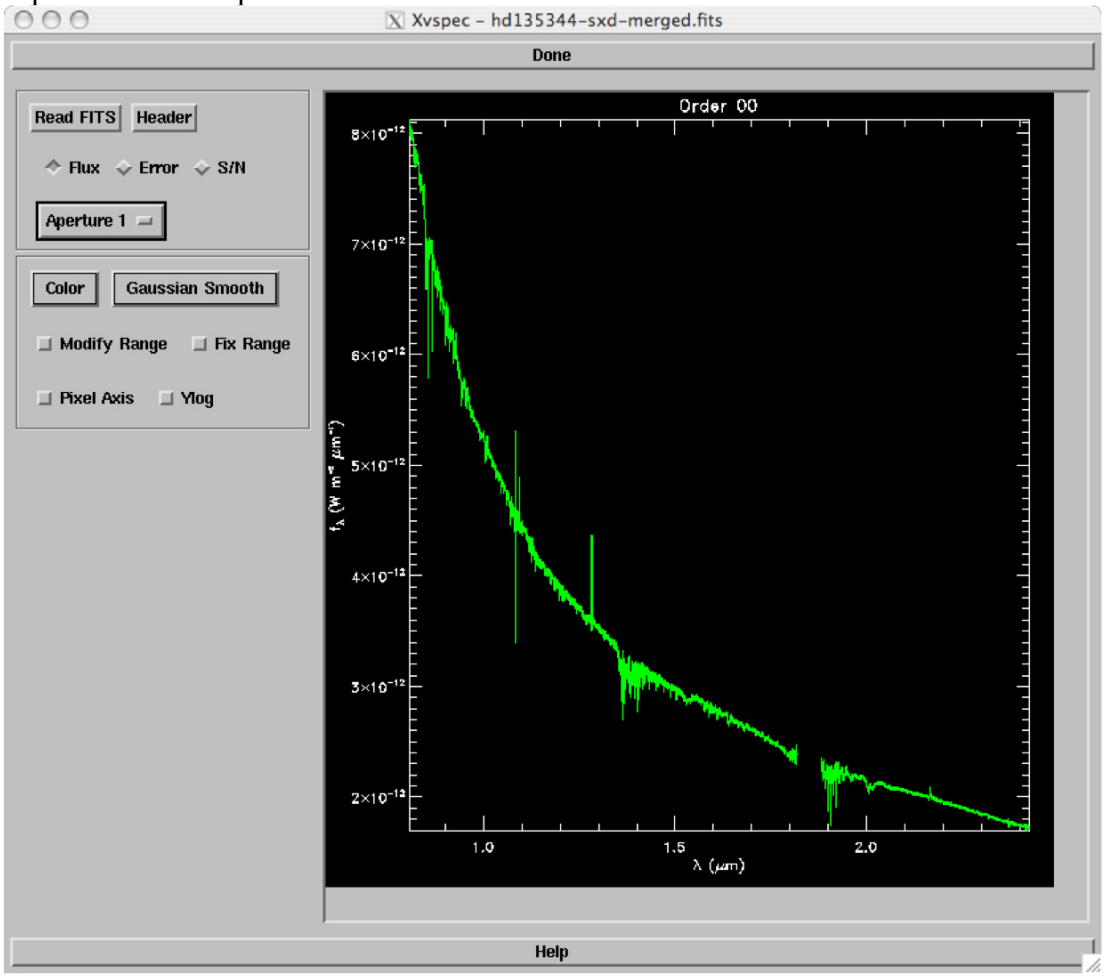
When all orders have been merged, you will be told that the merging is complete:

Pick a file name to write the result to and hit Write File.



You can select Text Output and get a text file as well as a FITS file (if you want).

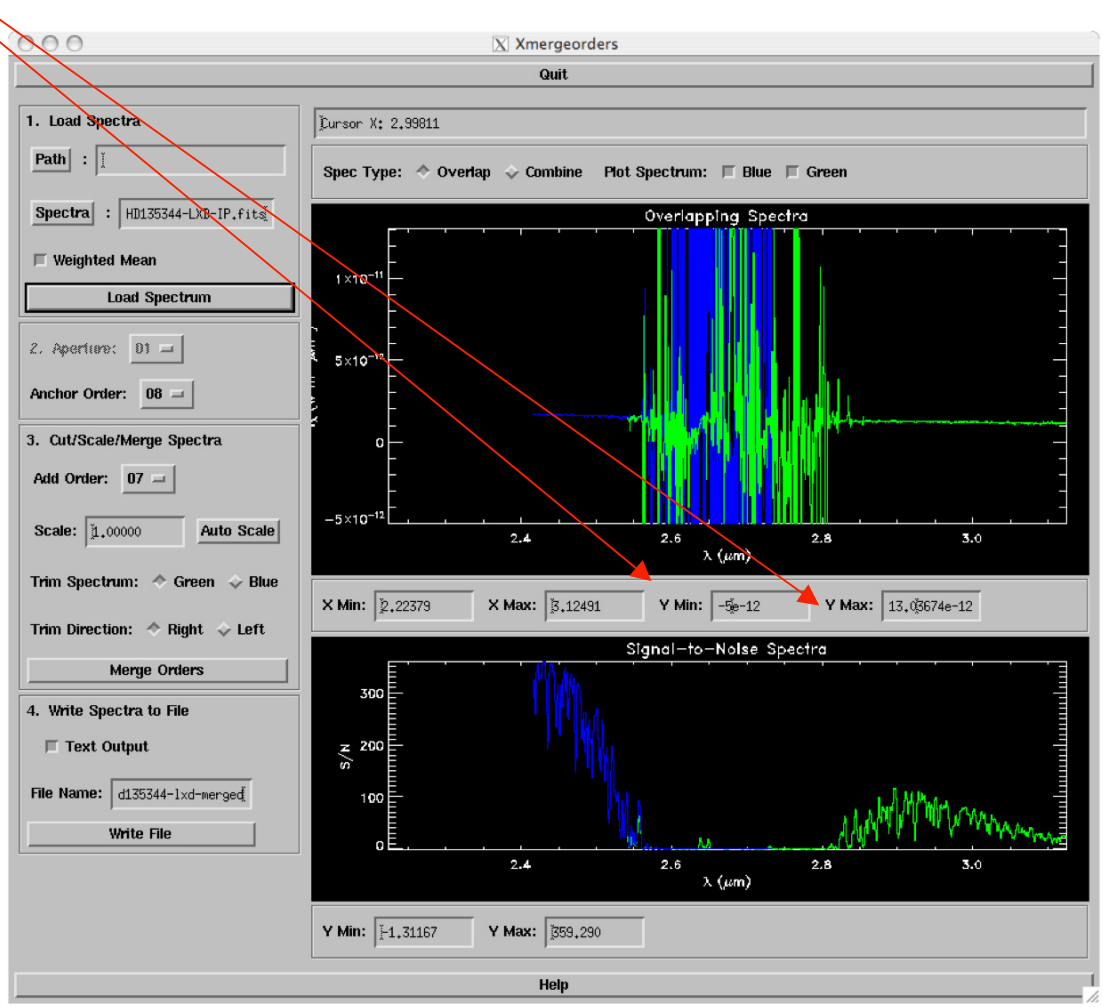
The program also shows you a plot of the final product:



Hopefully all of your spectra will look wonderful!

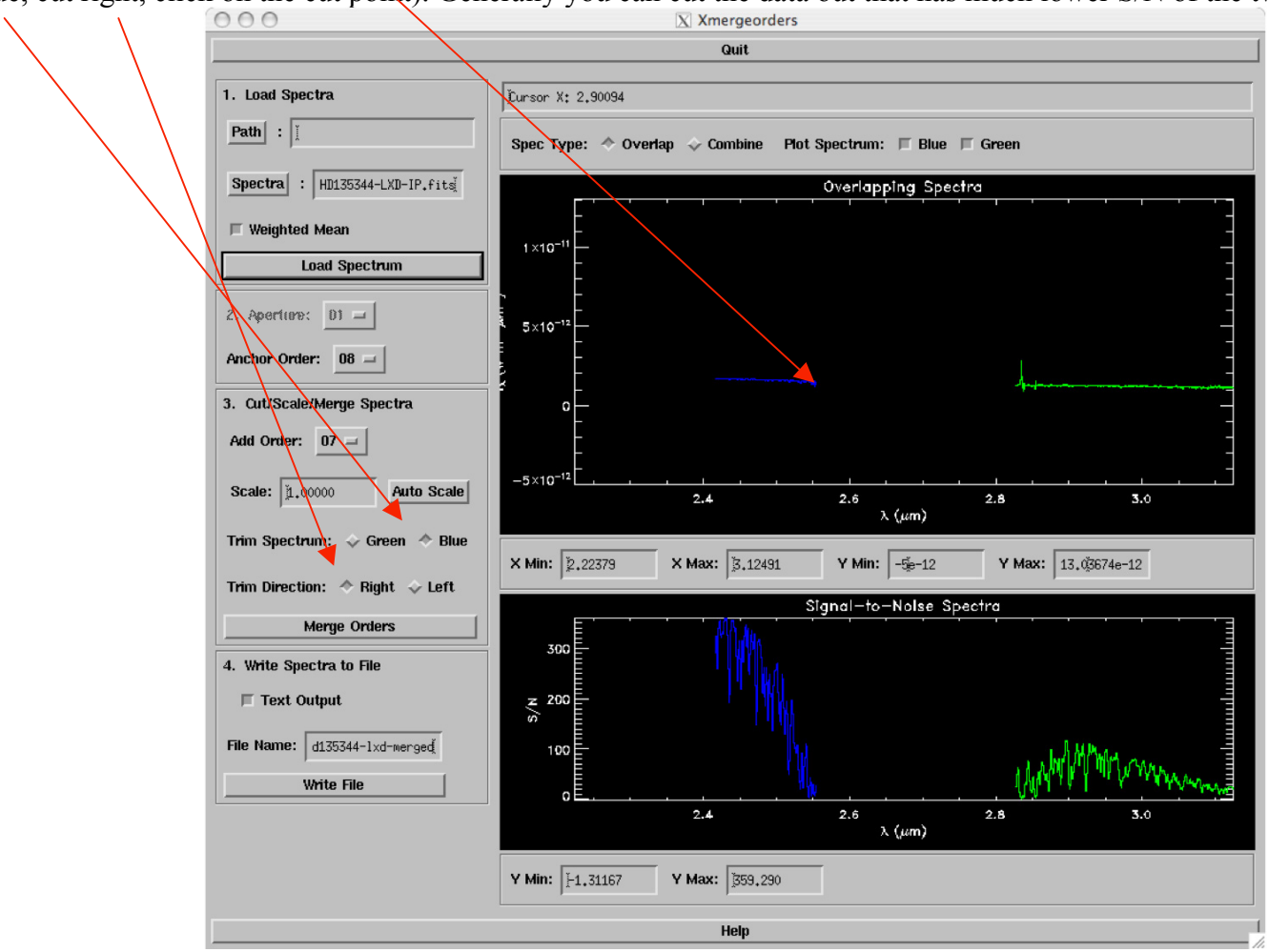
Merging Noisy LXD:

First, re-scale the plots manually (fill in & hit return for BOTH entries):

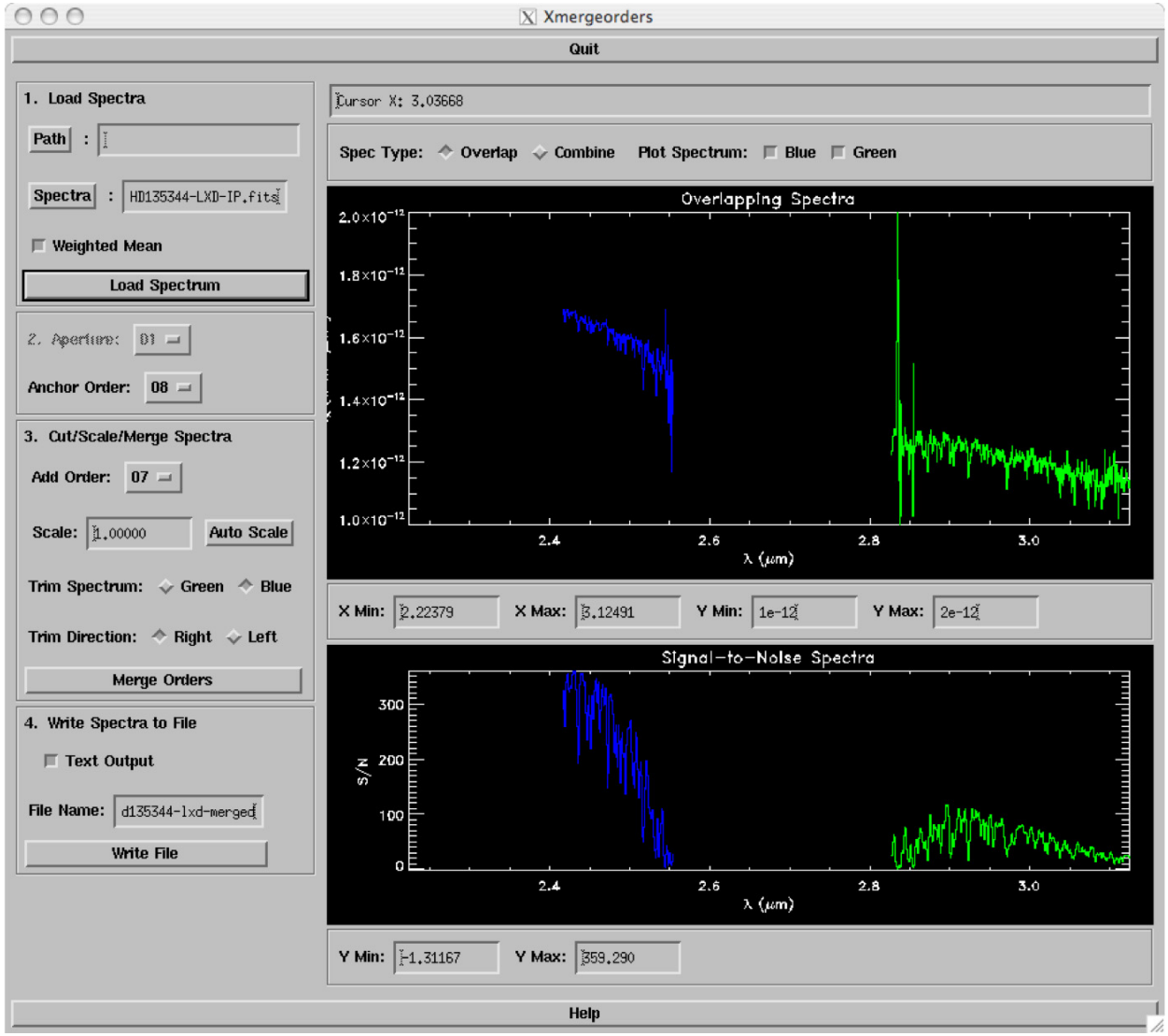


Using the Auto Scale here is pointless – it will be trying to normalize noise to noise, so you will have to use the Manual scaling here (when in doubt, use 1.0).

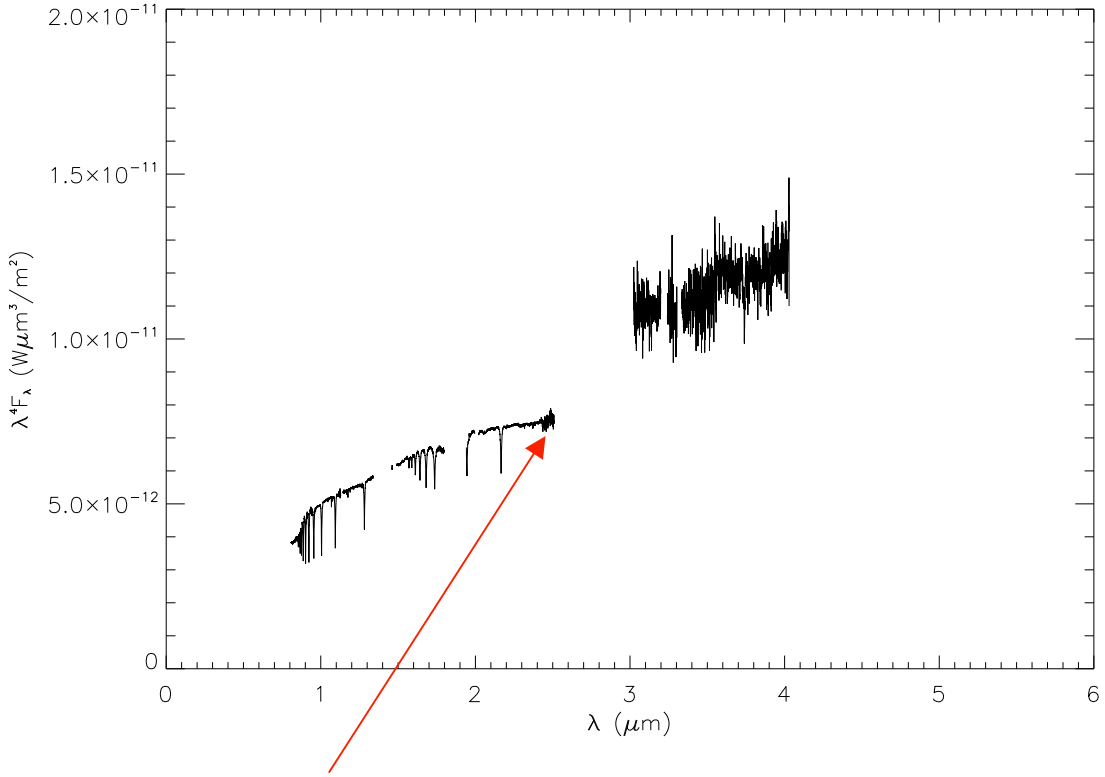
Then cut out the bad spots for the blue and the green (set green, cut right, then click on the cut point with the mouse;
Then set blue, cut right, click on the cut point). Generally you can cut the data out that has much lower S/N of the two sets.



Then expand in Y direction to see what need to be done.



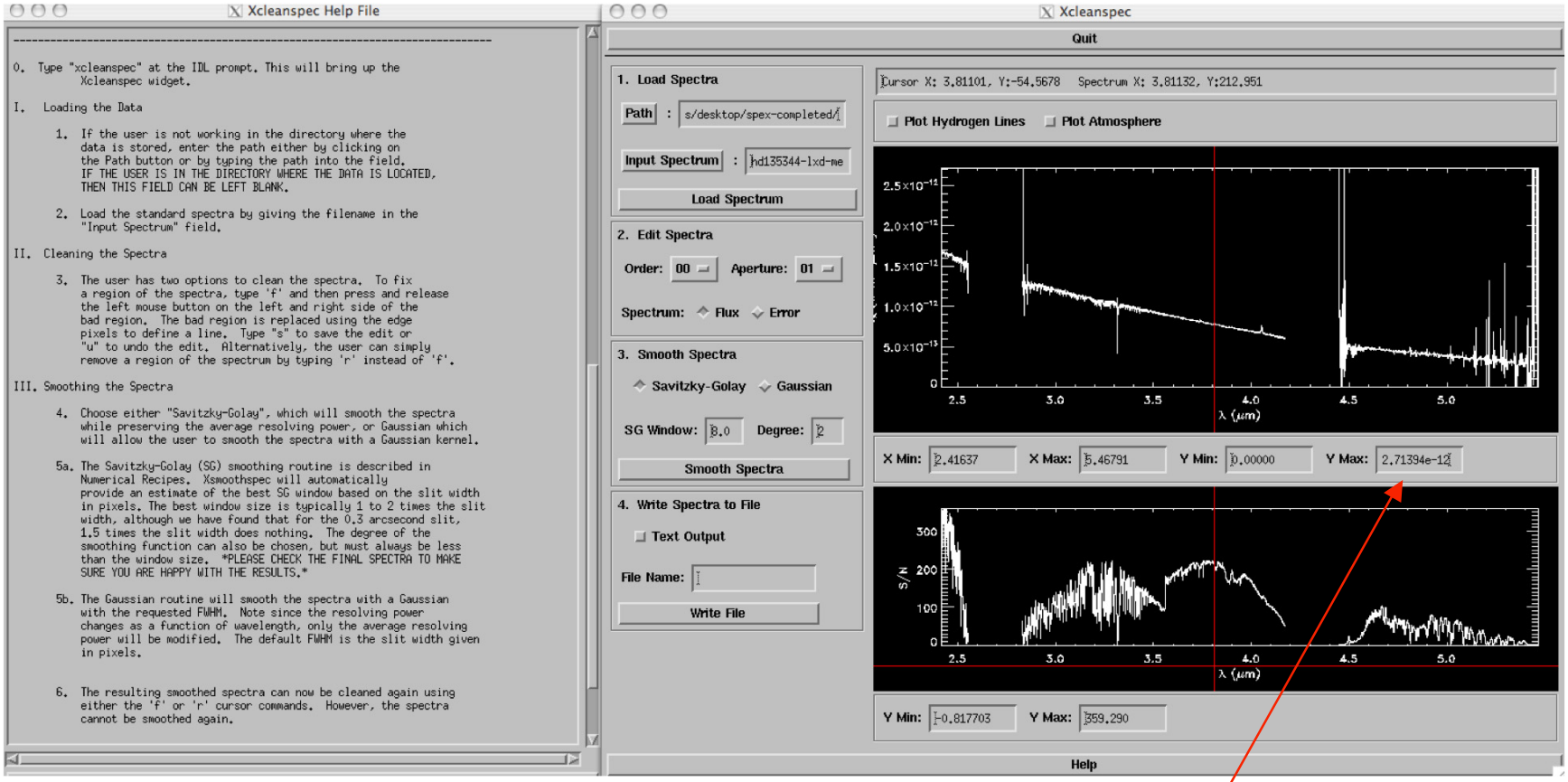
Now, as a "reality check", it is useful to read the FITS file and make a plot of λ versus $F(\lambda)*\lambda^4$ or something close to that. Because at these wavelengths most stars are close to being blackbodies in the Rayleigh-Jeans tail (where $B(\lambda) \propto \lambda^{-4}$), this "flattens" the data out, making scaling errors much easier to see. Here is an example of an A0V star after the joining of LXD to SXD in **xmergexd** (a later step):



The jump between the tiny portion of LXD data near 2.4 μm and the longward of 3 μm would have been very tough to see without doing this exercise. I show this at the **xmergeorders** stage because you may need to fix you data ***here*** **before** proceeding to **xcleanspec** and **xmergexd**. This is the difficulty in merging data (which may have a spectral slope) when the area use to do the scaling is nothing but noise.

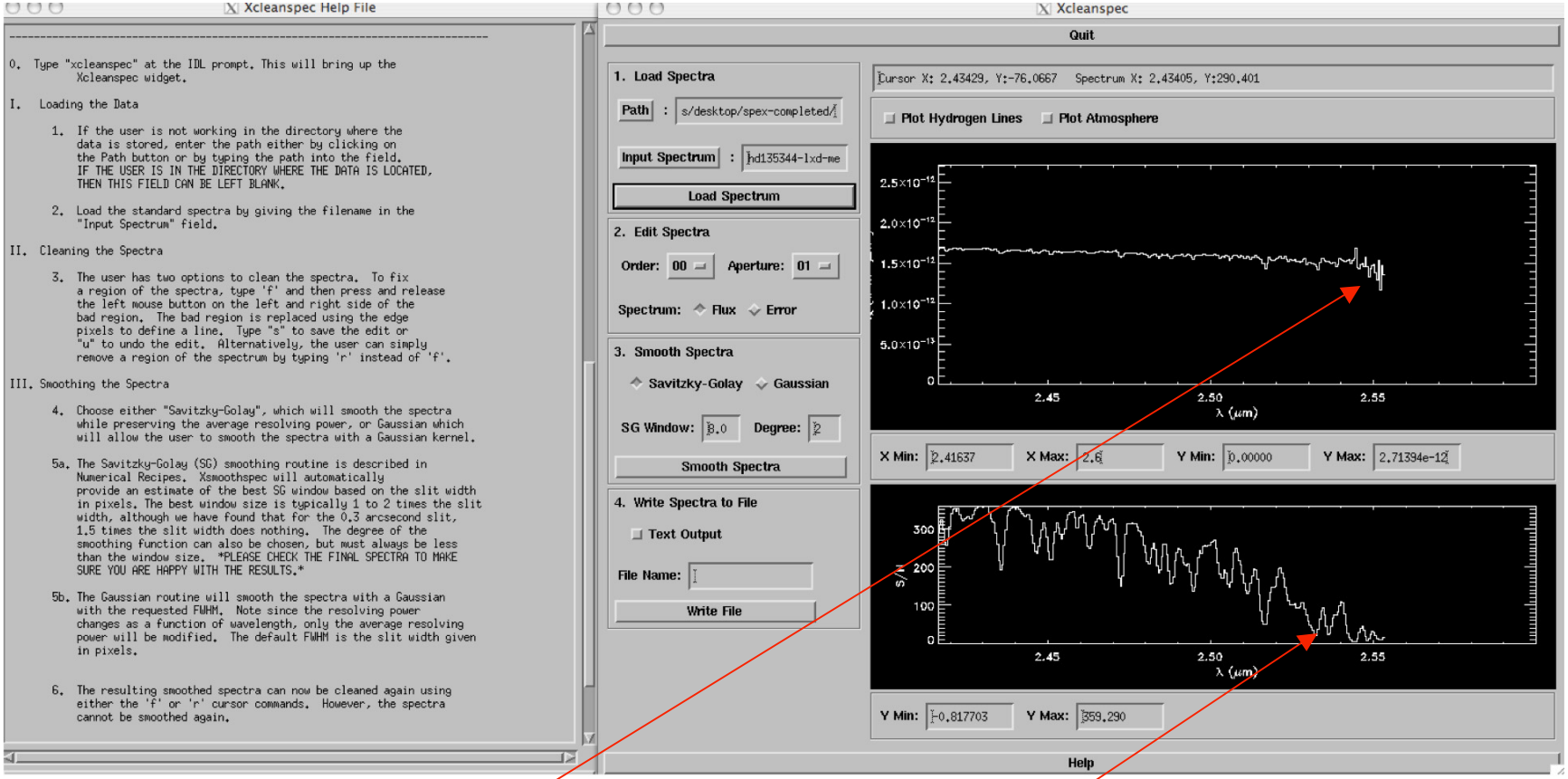
XCLEANSPEC

Many spectra, especially LXDs, will be noisy, especially in regions where telluric features are strong. One can snip out bad parts, fudge in straight line, and smooth them.



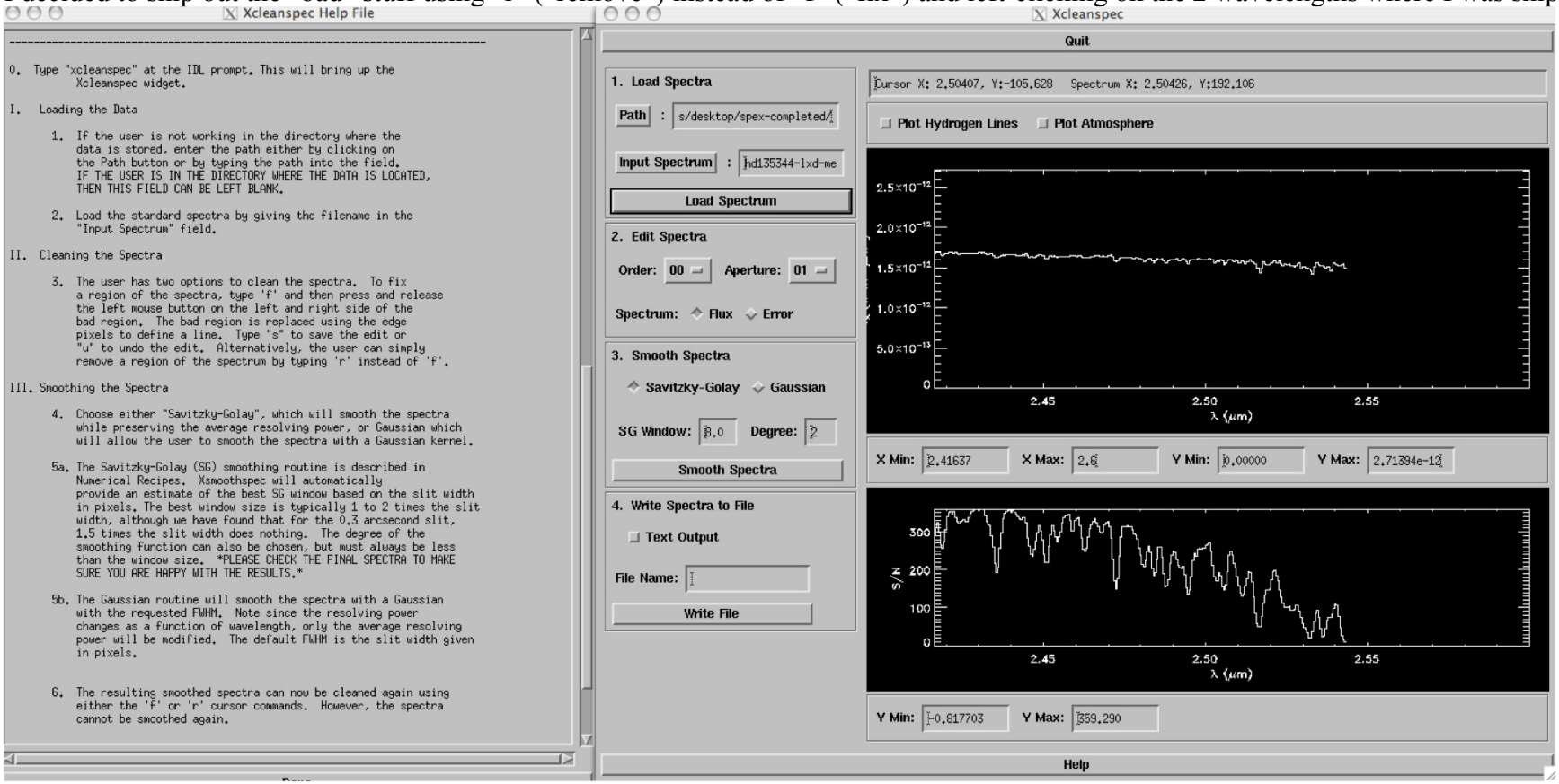
Here I loaded an LXD, but the autoscaling used the noise to set the y-range, so I manually adjusted it here to increase the scale by 10x – so I could SEE what I was doing!

In order to see things up close, I decided to expand the wavelength range around the region of interest:



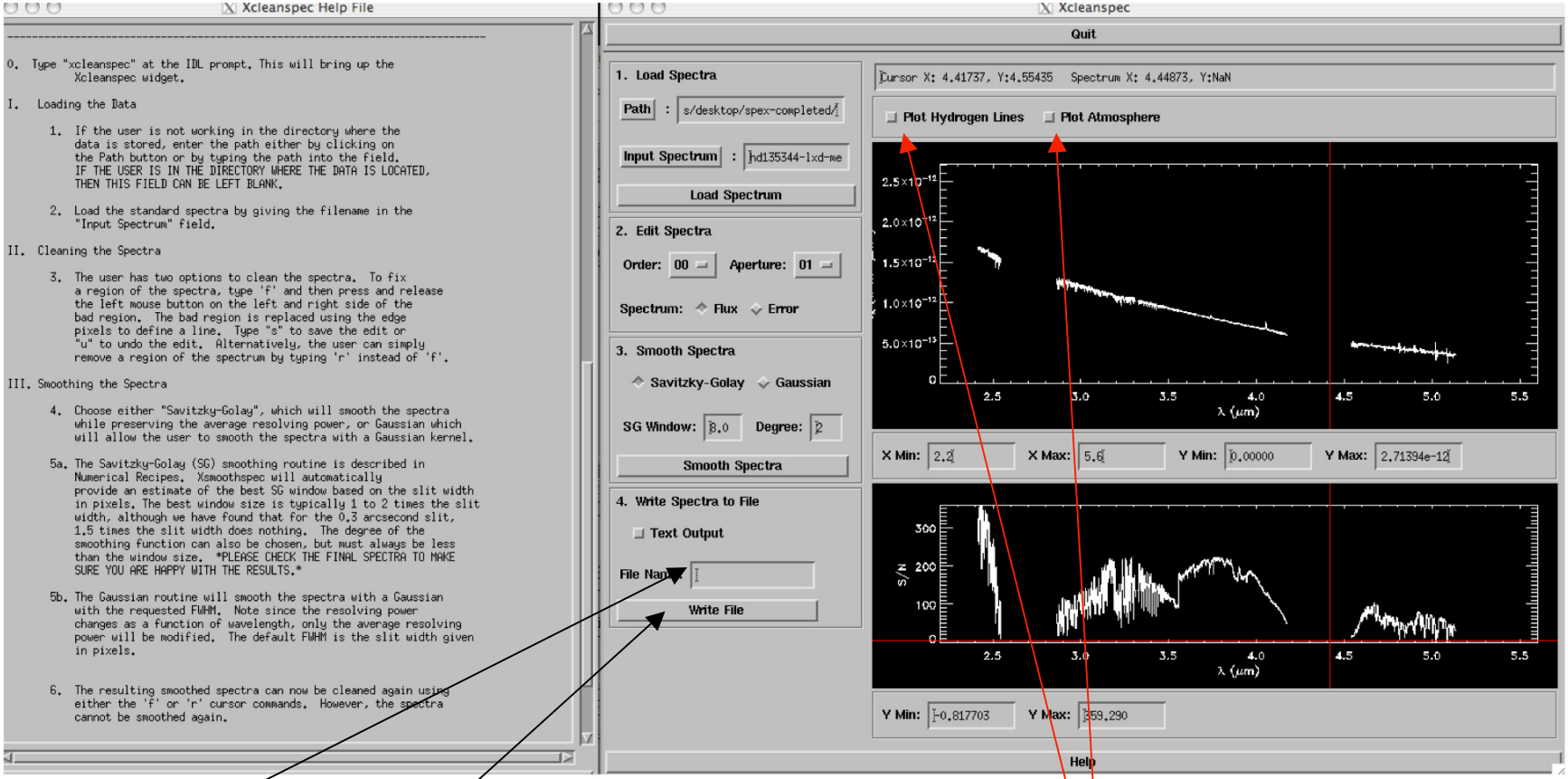
Here, it is apparent that the increased noise in the spectrum is accompanied by a drop in S/N.

I decided to snip out the “bad” stuff using “r” (“remove”) instead of “f” (“fix”) and left-clicking on the 2 wavelengths where I was snipping:



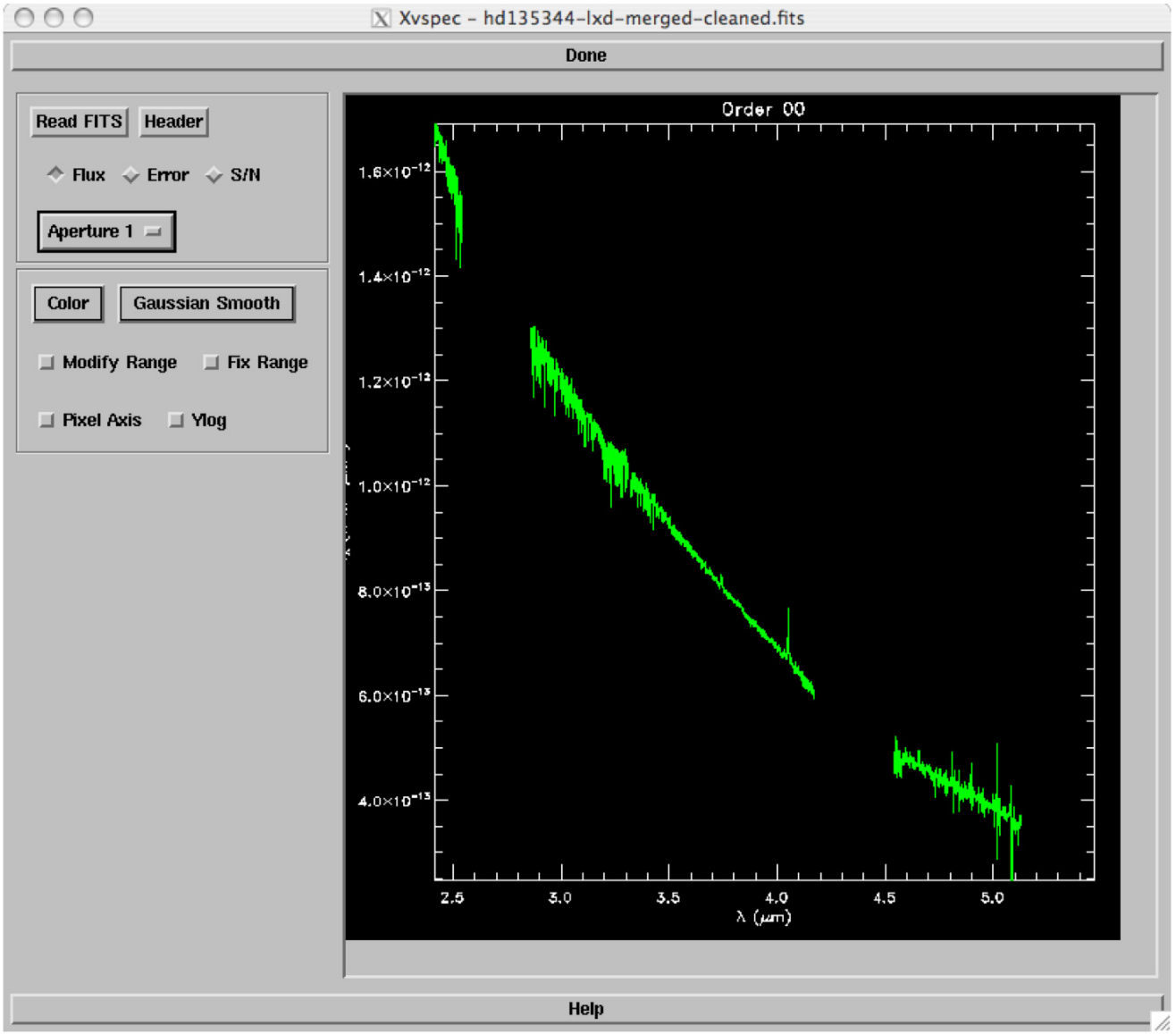
This neatly clipped the bad stuff out. I liked the result, so I hit “s” for “save”. ***NOTE: You MUST do a save after every individual edit, or they will be lost!*** Also note that the “meaning” of “s”: has changed from earlier routines of Spextools, where “s” meant “select”.

Okay, I went along snipping away, until I saw

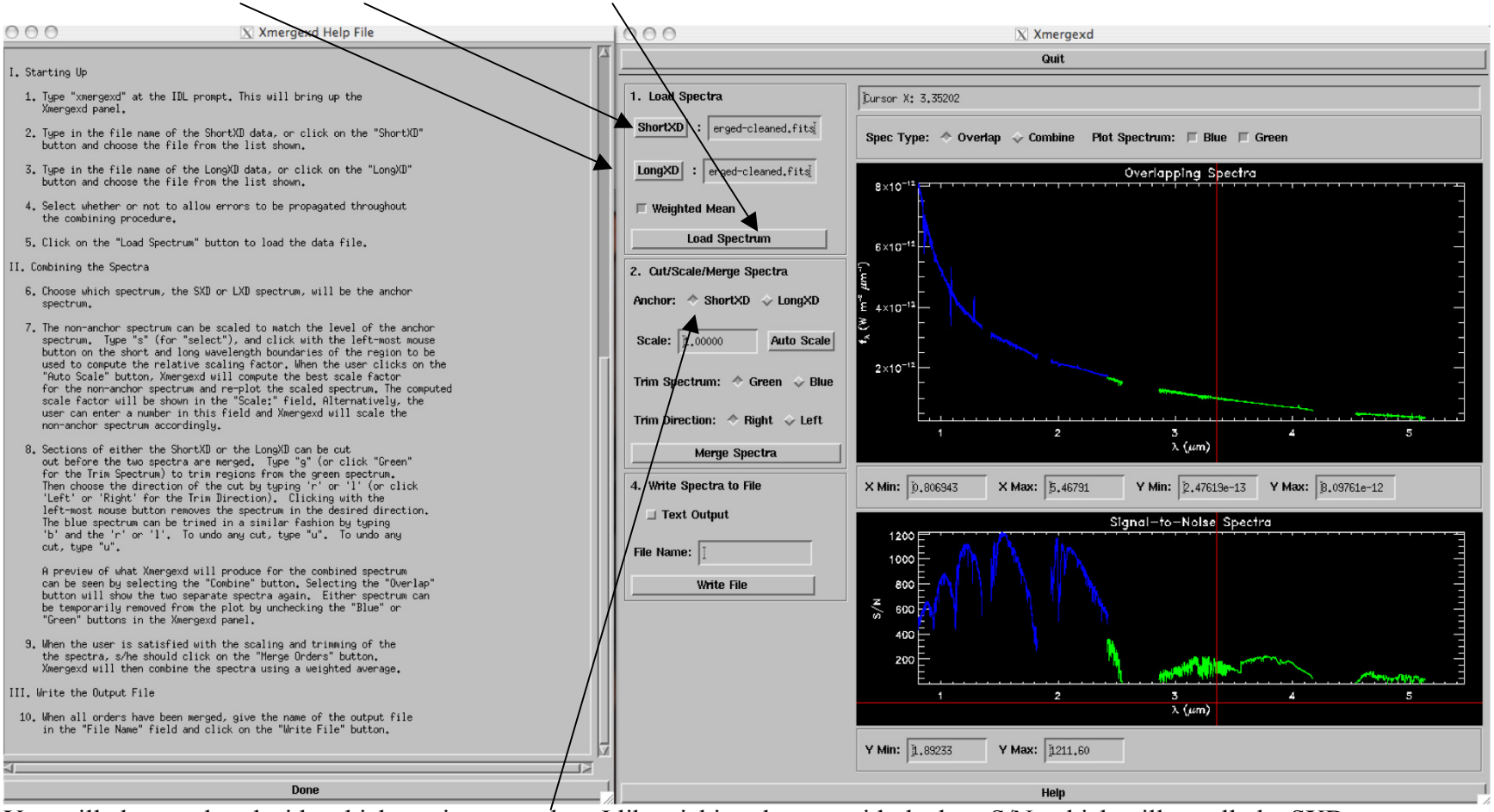


Now, at this point, one can smooth the spectra (follow along the Help File shown at left). But I thought this was pretty good, so I decided on a file name, and just saved the result.

Note: you can also see the location of Hydrogen lines or the telluric features by clucking on these boxes. This is often very useful (especially in the LXD data) to know when features are real, and when they are telluric – both noise and systematics (airmass….)

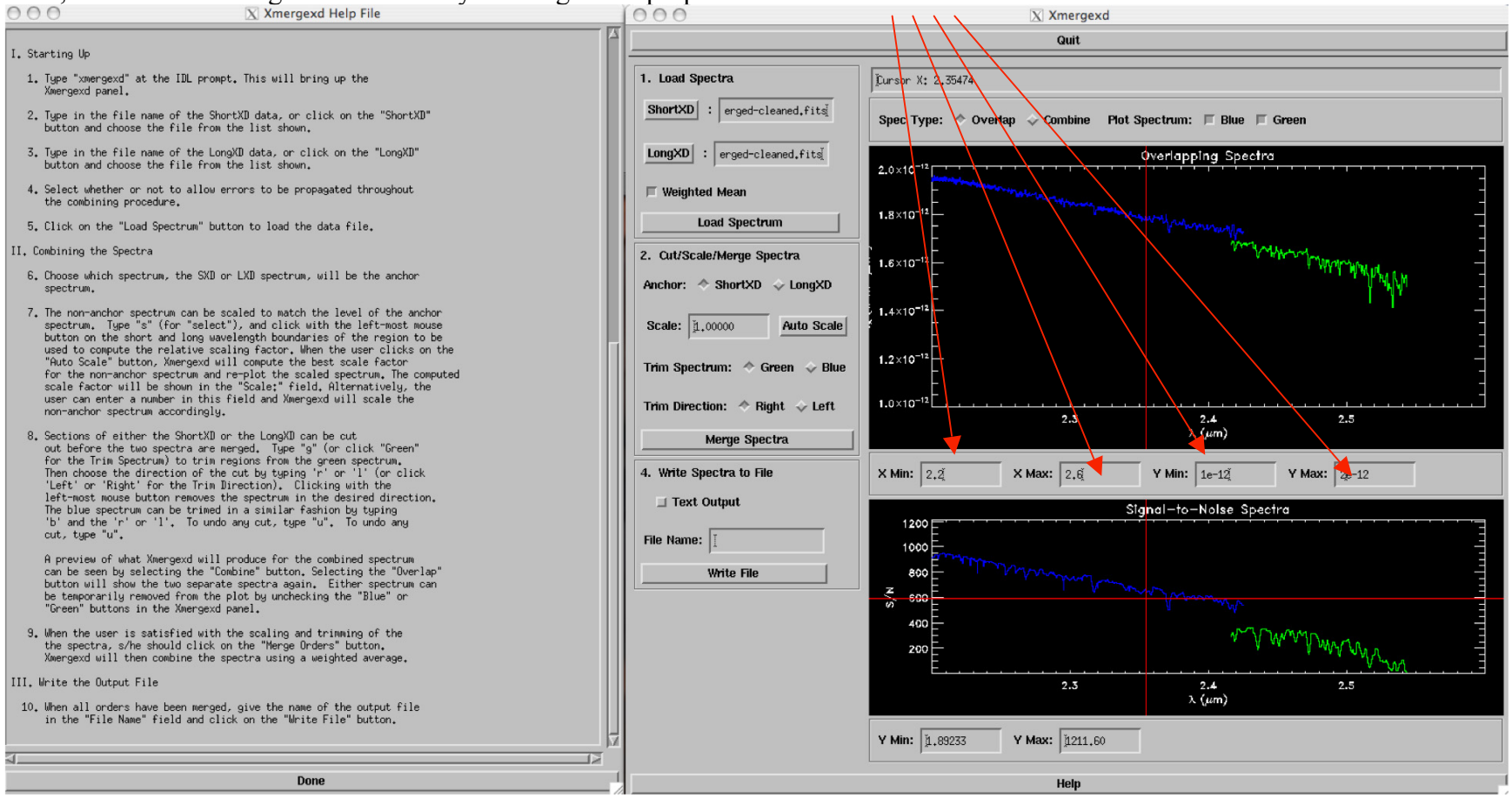

Xvspec - hd135344-lxd-merged-cleaned.fits
Done
Read FITS
Header
Flux
Error
S/N
Aperture 1
Color
Gaussian Smooth
Modify Range
Fix Range
Pixel Axis
Ylog
Order 00
1.6×10⁻¹²
1.4×10⁻¹²
1.2×10⁻¹²
1.0×10⁻¹²
8.0×10⁻¹³
6.0×10⁻¹³
4.0×10⁻¹³
2.5
3.0
3.5
4.0
4.5
5.0
λ (μm)
Help

Load your cleaned LXD and SXD spectra and hit **Load Spectrum**.

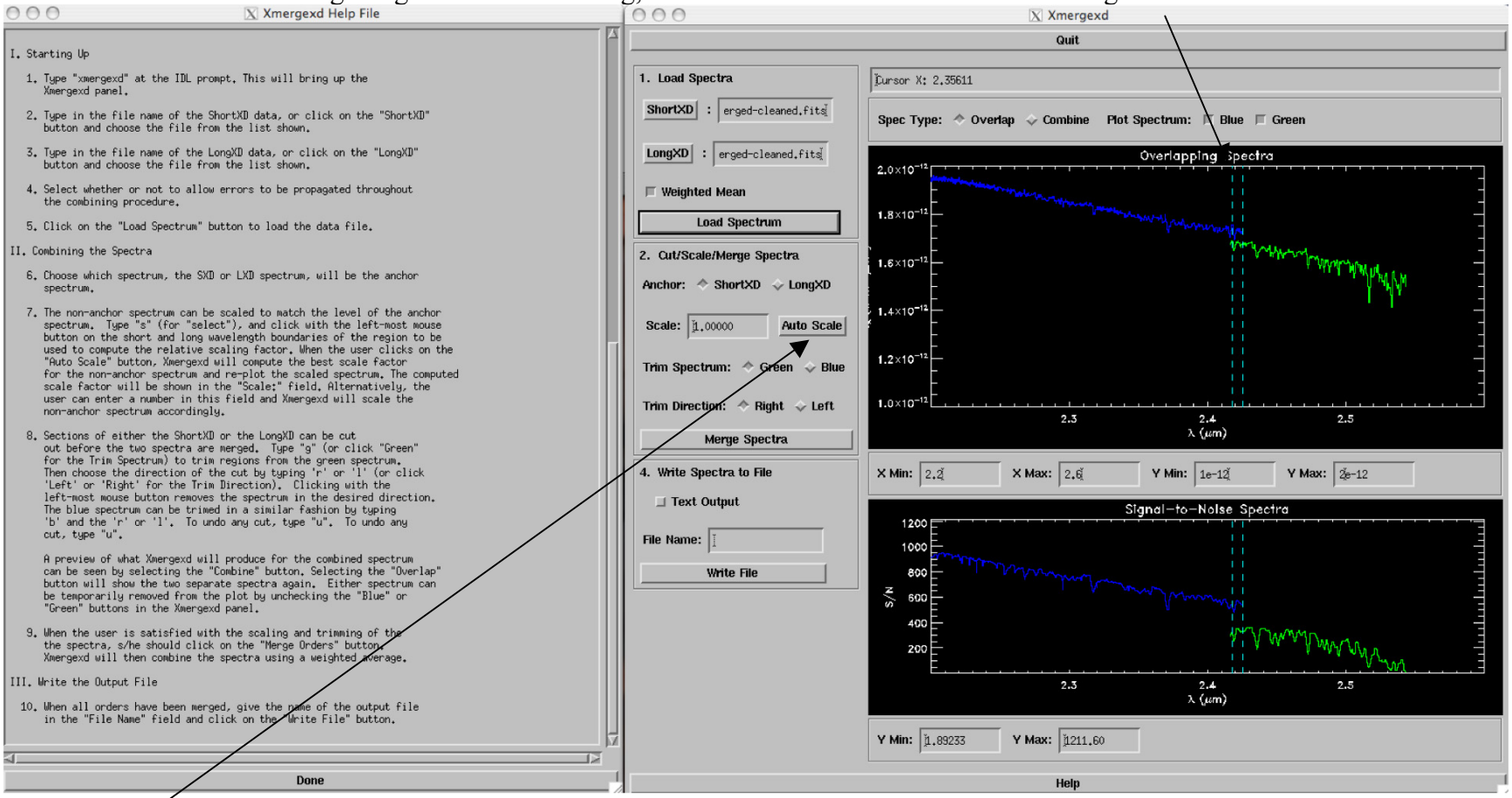


You will also need to decide which section to anchor. I like picking the one with the best S/N, which will usually be SXD.

Here, zoom in on the region of interest by entering in the proper values in the boxes.

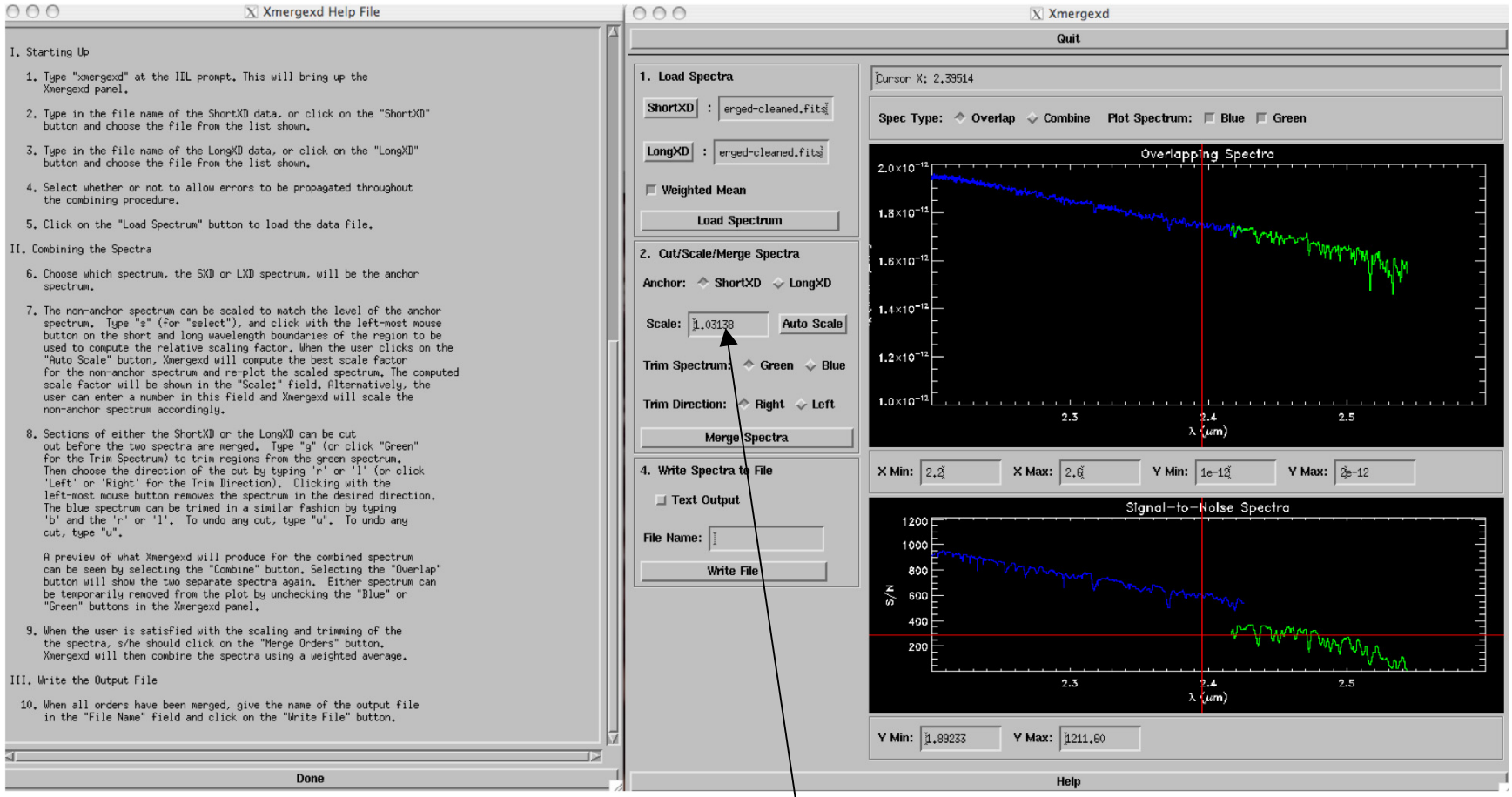


Use “s” to select the wavelength region to do the scaling, and lest-click on the ends of the wavelength interval over which to normalize.



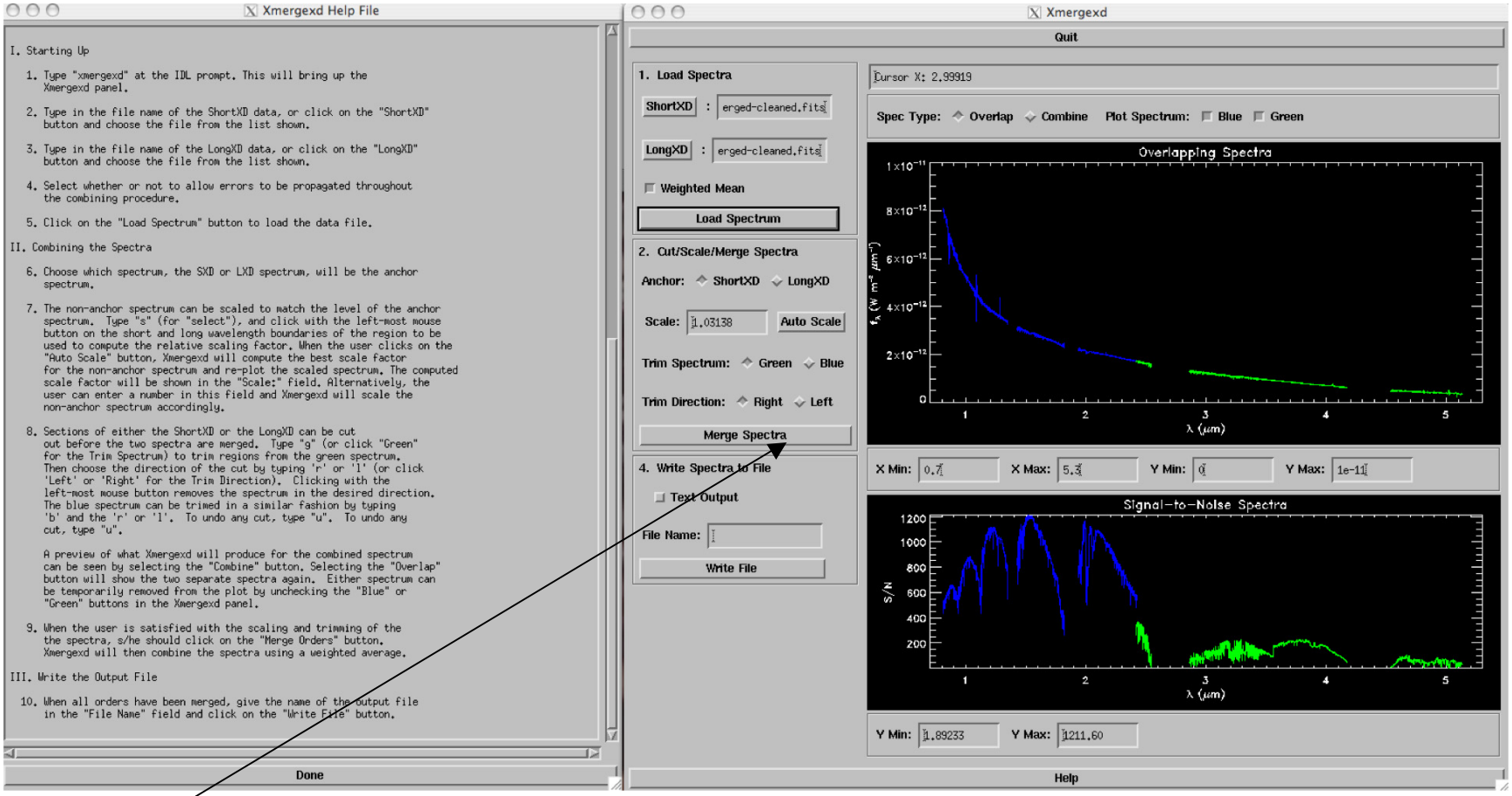
Hit **Auto Scale**.

Auto scaling will bring the LXD into agreement with the anchored SXD.



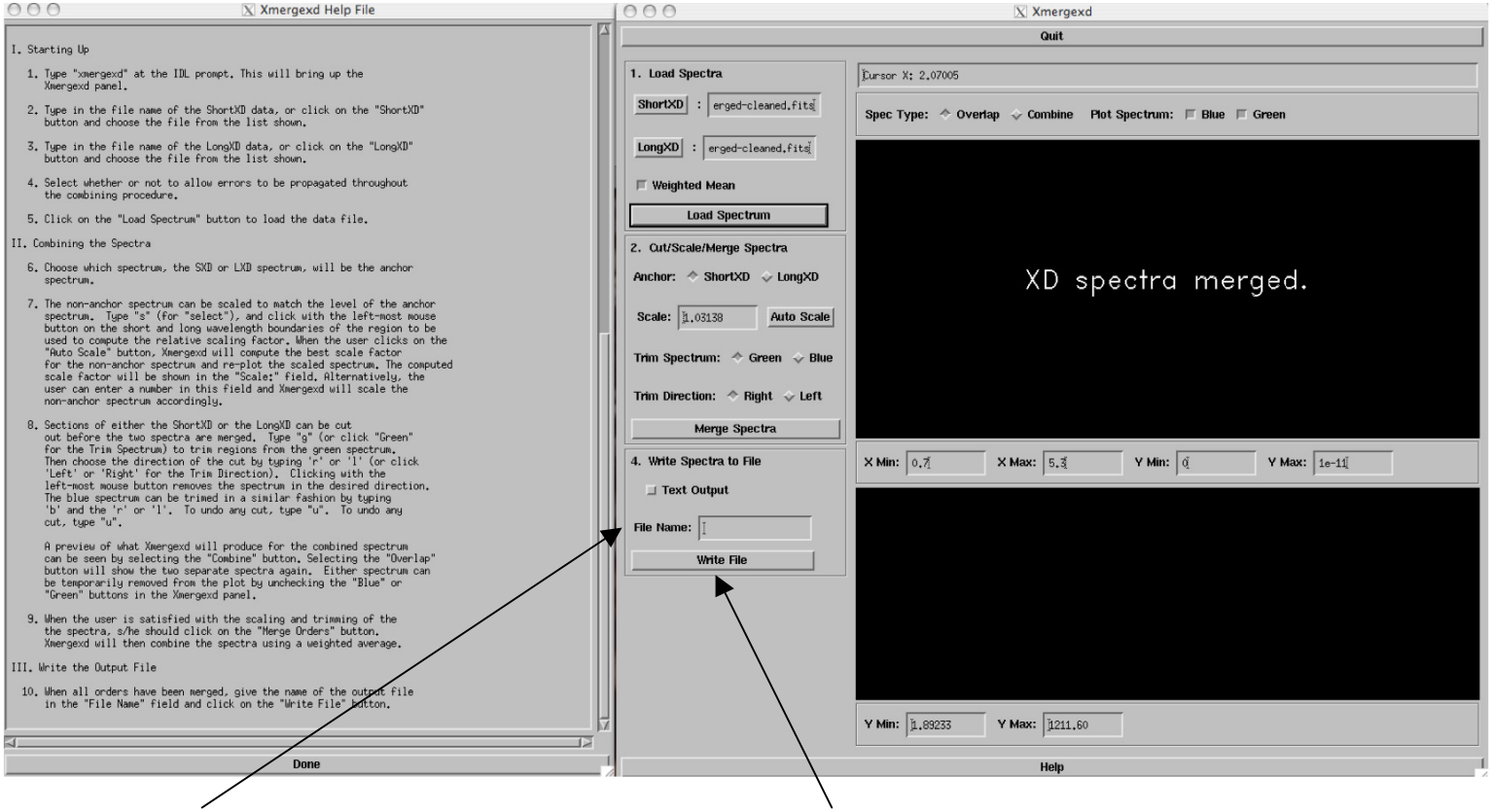
If you don't have any overlap between the two sets of data, **Autoscale** will fail. You must select a portion of one of the data sets, and manually rescale by filling in the value you deem appropriate in the box, and hitting return.

Now, back to look at the whole spectrum.



Hit **Merge Spectra**.

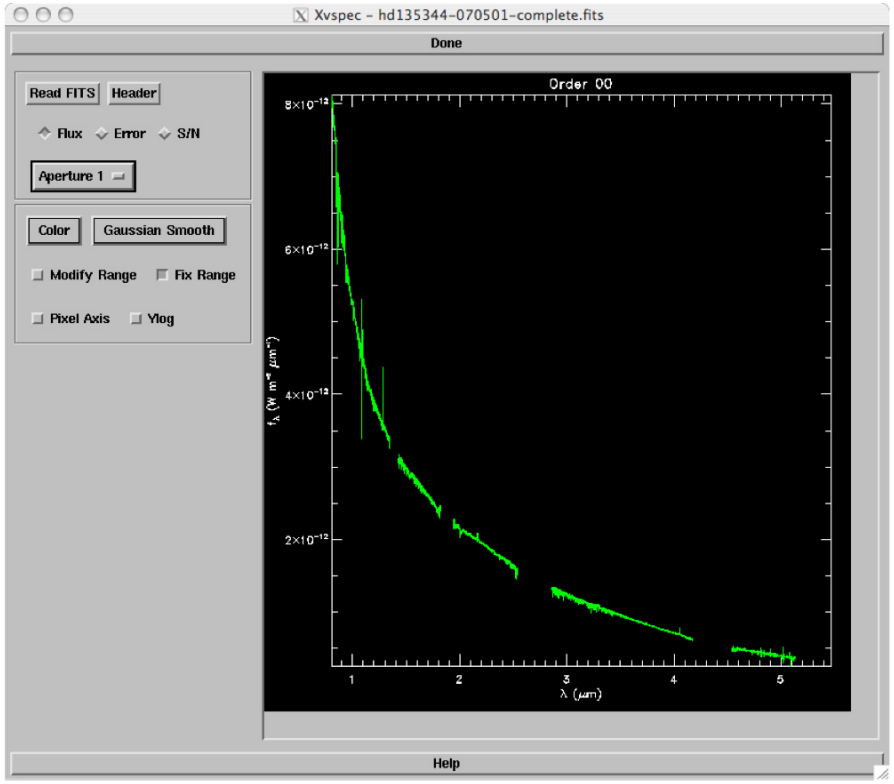
Unfortunately, nothing exciting appears…



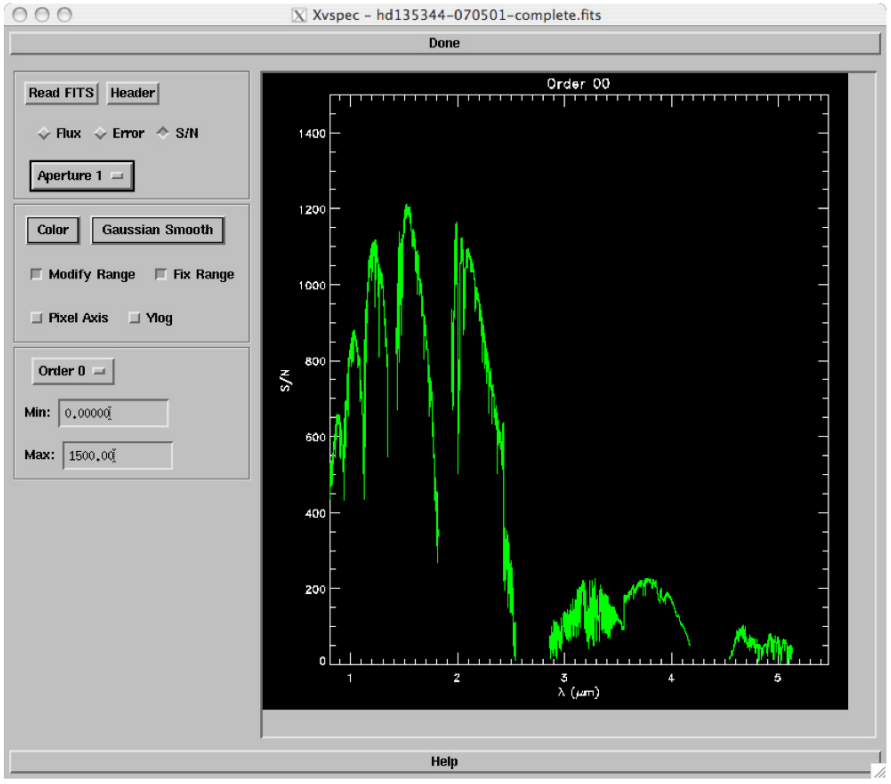
Enter the file name you want your final product to have, and hit **Write File**.

Note: because no path name is entered in **xmergexd**, the files get written to your home directory (wherever that may be).

Look at the final spectral flux…



…. and the S/N.

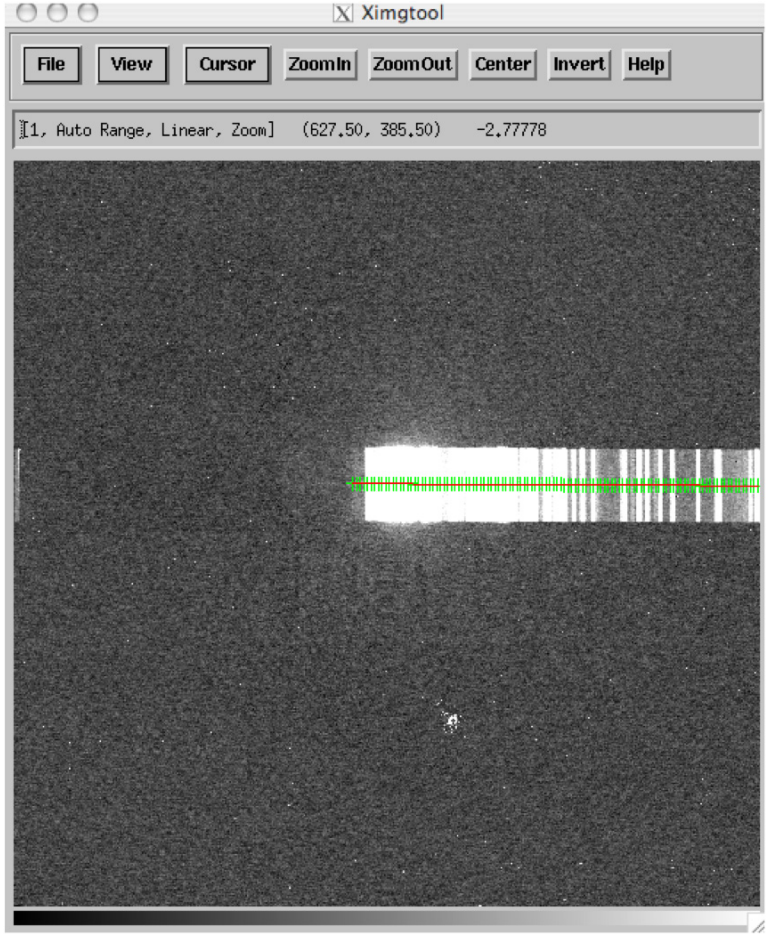


CONGRATULATIONS! YOU ARE DONE!!

Handling Prism Data

Most of procedures used to reduce the echelle data apply to data obtained with the prism. However, some differences in appearance (if not procedure) exist, and these will be described here.

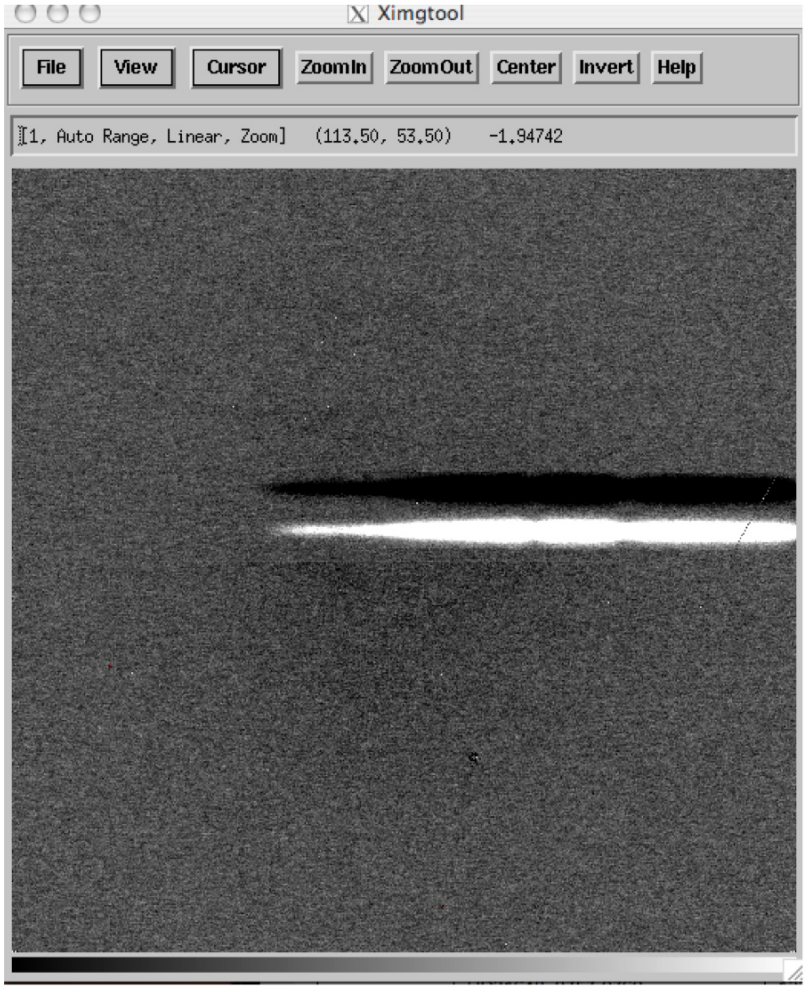
XSPEXTOOL

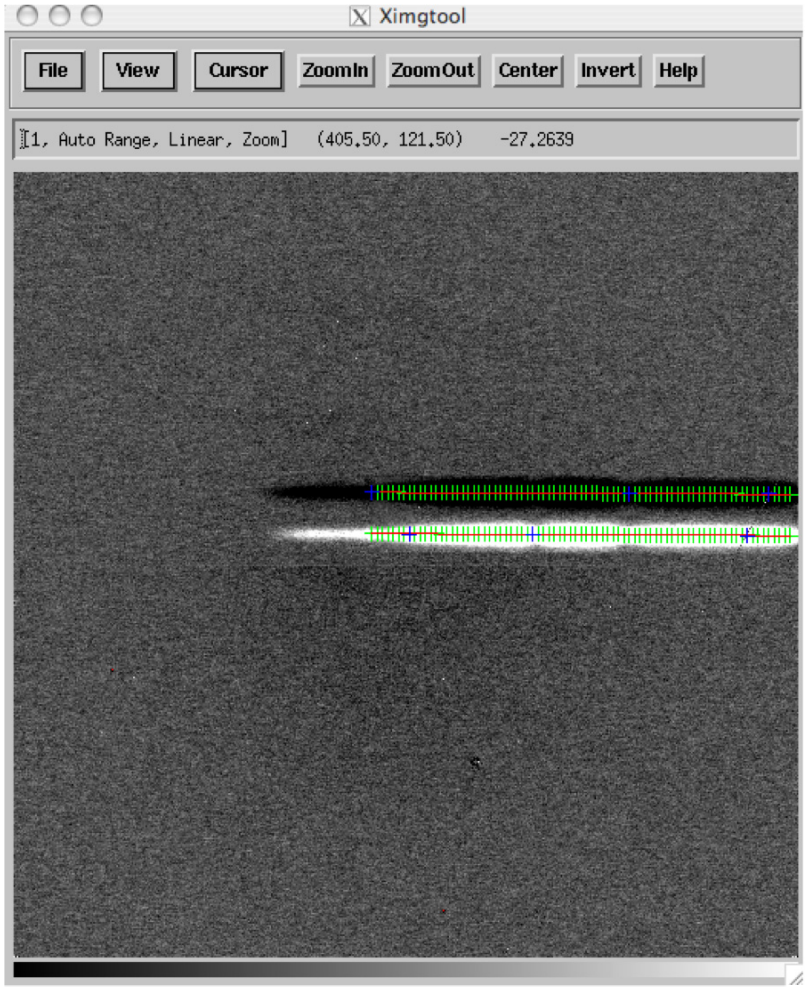


The first thing is obvious – there is only one "order"! Now, I have used the prism with a very wide - 3.0 arcsec – slit in an attempt to get something closer to "absolute flux levels" that one might get with a significantly narrower one. However, flats obtained through such a wide slit saturate, making them useless. Arcs are also rendered useless, because the lines are to wide and blended for a proper wavelength

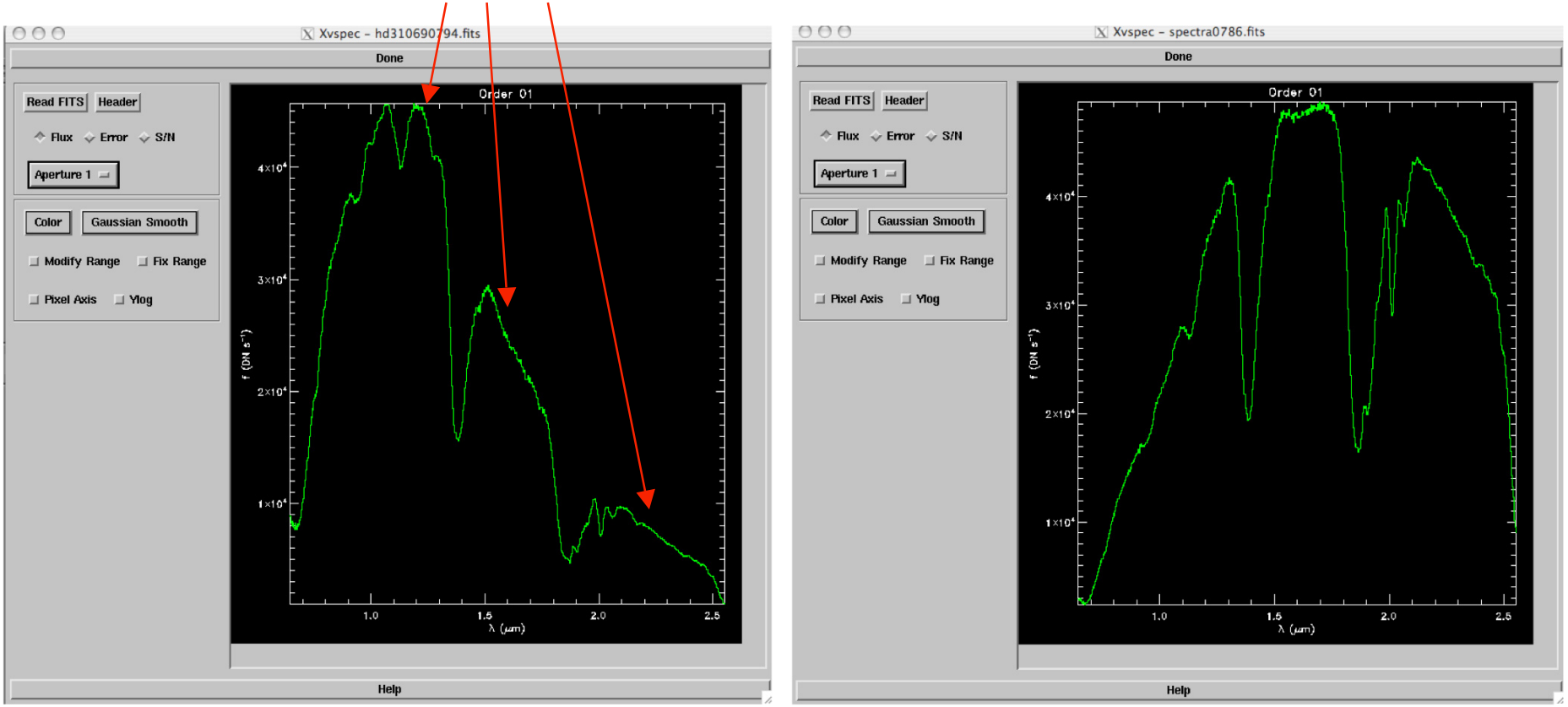
calibration. So I have done the cal macros with a narrower slit (say 0.8 arcsec) than the star observations. This is sort of a cheat, but it does seem to work.

Xspextool does a fine job in locating the spectra and tracing them.



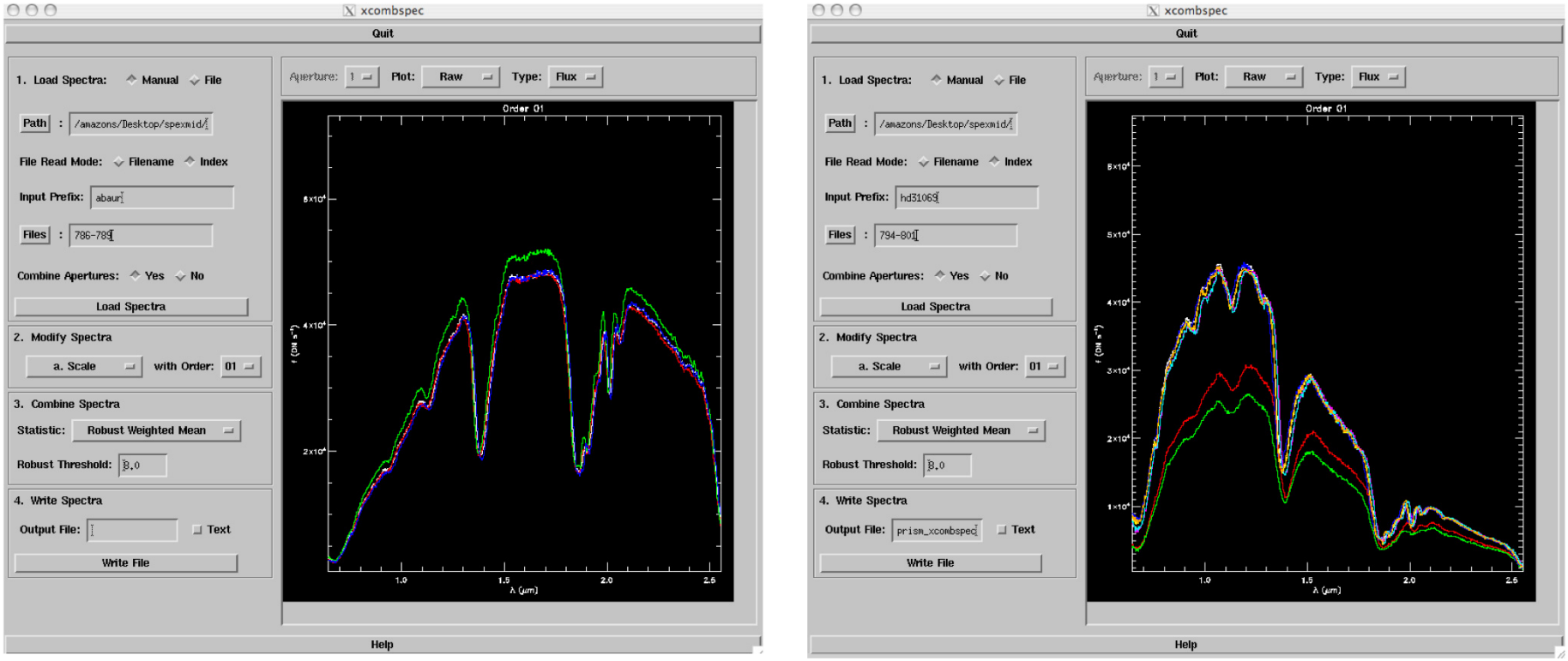


After doing the extraction you can see the low-resolution spectra, and simultaneously see all of the main telluric features. Here you can also see why the wavelengths of the photometric J, H, and K filters were defined the way they were – to avoid telluric features as much as possible.



Here you can also see a significant difference between the spectra of the two stars shown here. The one on the left is HD 31069, an A0V calibrator use for this set of observations. On the right is AB Aur, an A0V pre-main sequence star with a disk of warm dust surrounding it. This leads to a significant "infrared excess" that causes it to be systematically brighter at longer wavelengths than a "normal" A0V star.

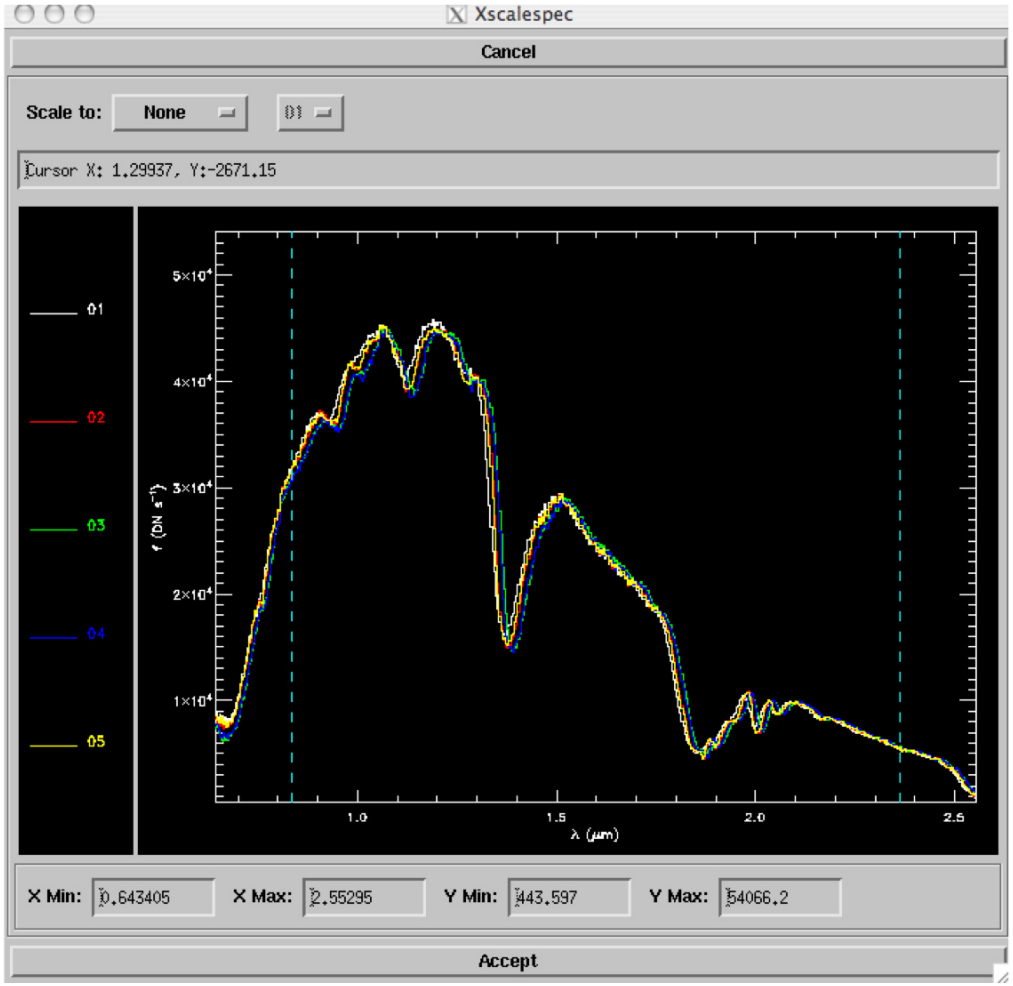
XCOMBSPEC



Left: 4 observations of AB Aur obtained with the 3.0 arcsec slit. Three reproduce each other nicely, with one a bit higher, perhaps during a moment of improved seeing and better light throughput.

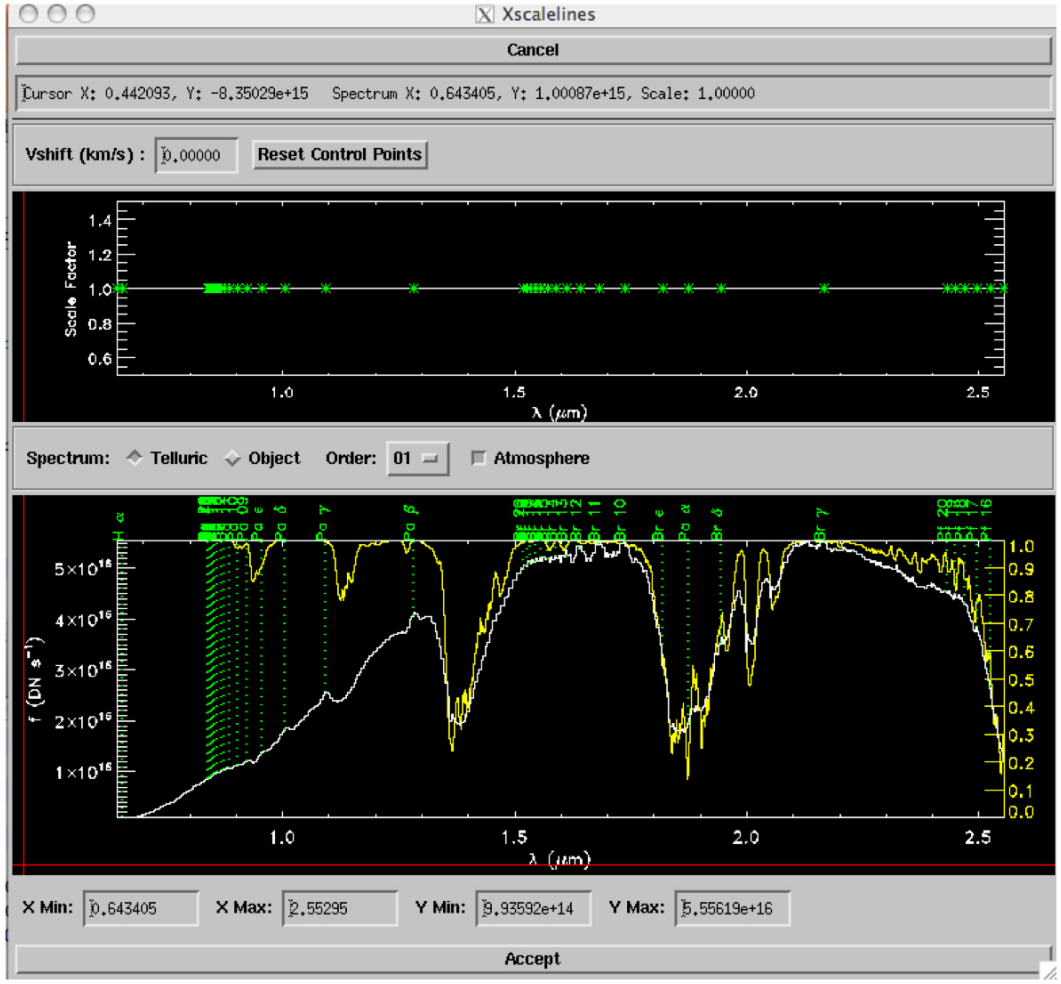
Right: The observations of HD 31069 were not as good. Two are obviously lower, most likely due to poor tracking, allowing half (or more) of the light to fail to make it through the slit. If you look carefully, you can see a slight shift in wavelength of the two low spectra. Remember that the spectrum is actually an image of the star occulted by the slit jaws, dispersed in wavelength.

Here one can see a wavelength shift even in the “best” exposures:

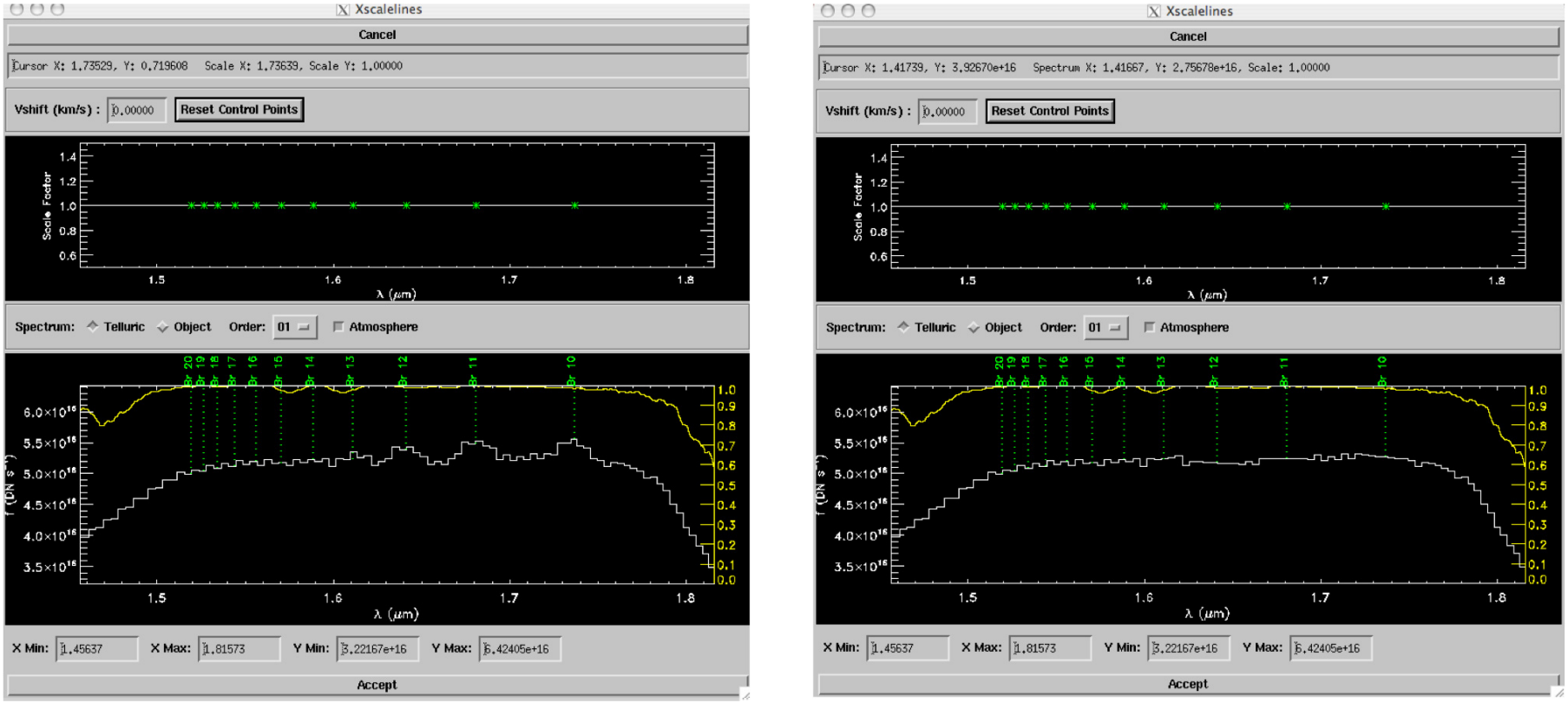


This will tend to smear out the features used in the telluric correction and introduce some distortion in the resulting spectrum of the science target.

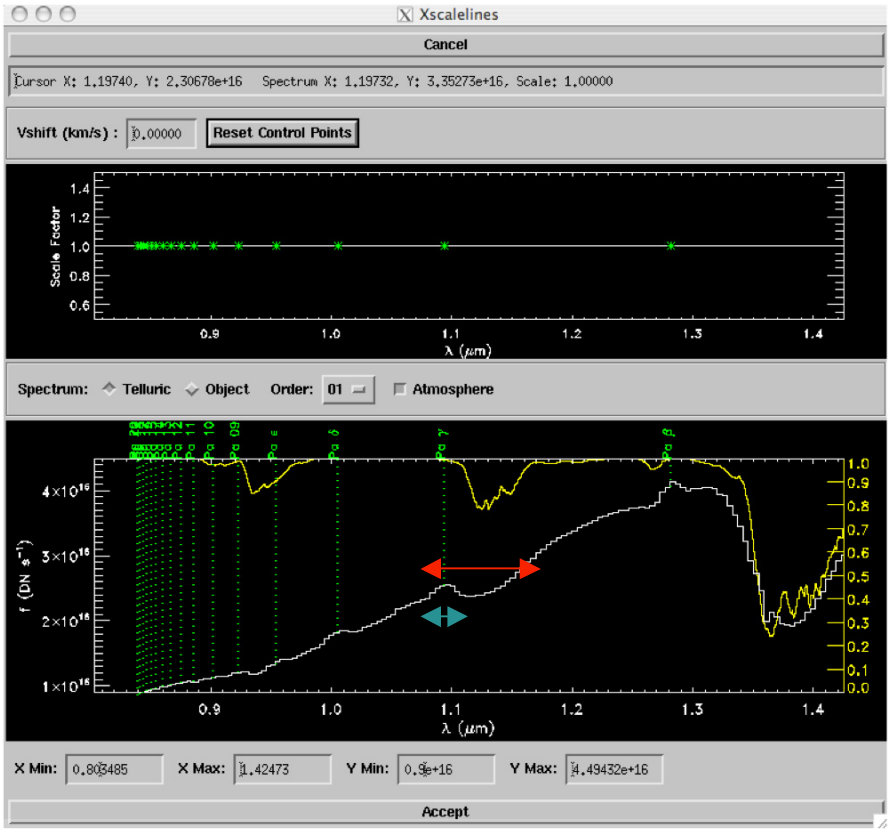
For this situation, especially where the stellar observations are so smeared out, only the “IP” option seems reasonable in Xtellcor. Using this option and going on to Construct Telluric Spectra and Scale Lines:



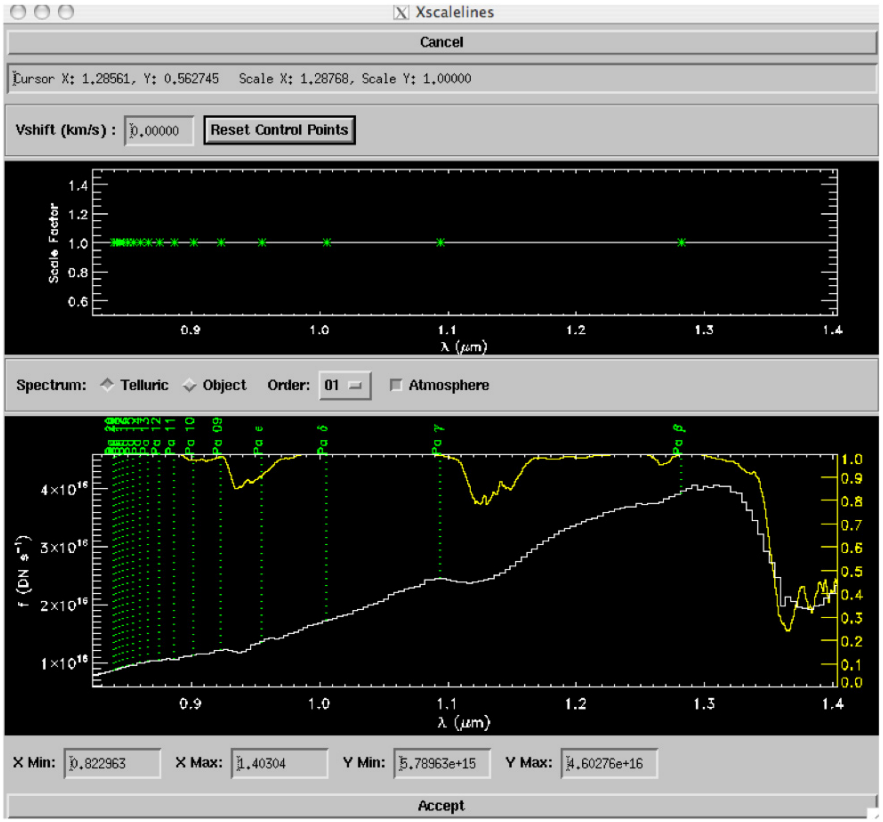
There are still some residuals to deal with.



Here we see the region in the H-band before (left) and after (right) using the "f" technique to correct the residuals.

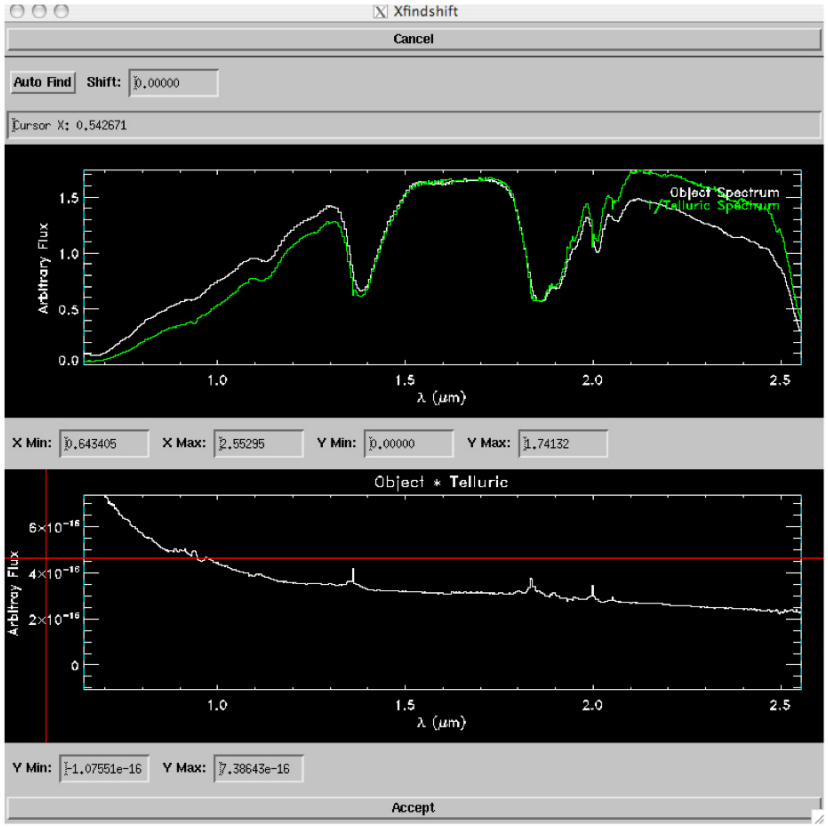


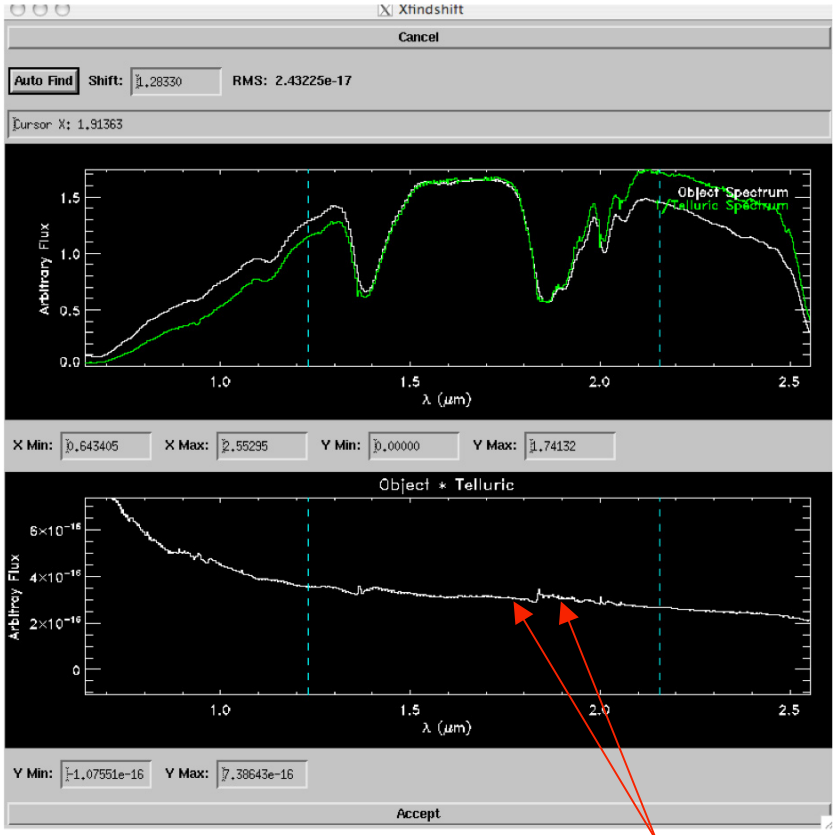
BEFORE



AFTER

In this wavelength region, one has to be very careful as the Paschen lines may border on the telluric features. The ides is to remove the Paschen lines with the least effect on the telluric lines. You don't want to remove those! Here I show in blue the extent of the Pa γ line that you could smooth over. Do NOT correct over the wavelength range of the red arrow, or you will remove the telluric band. Remember, the goal is to make the A0V spectrum resemble the telluric one as much as possible.





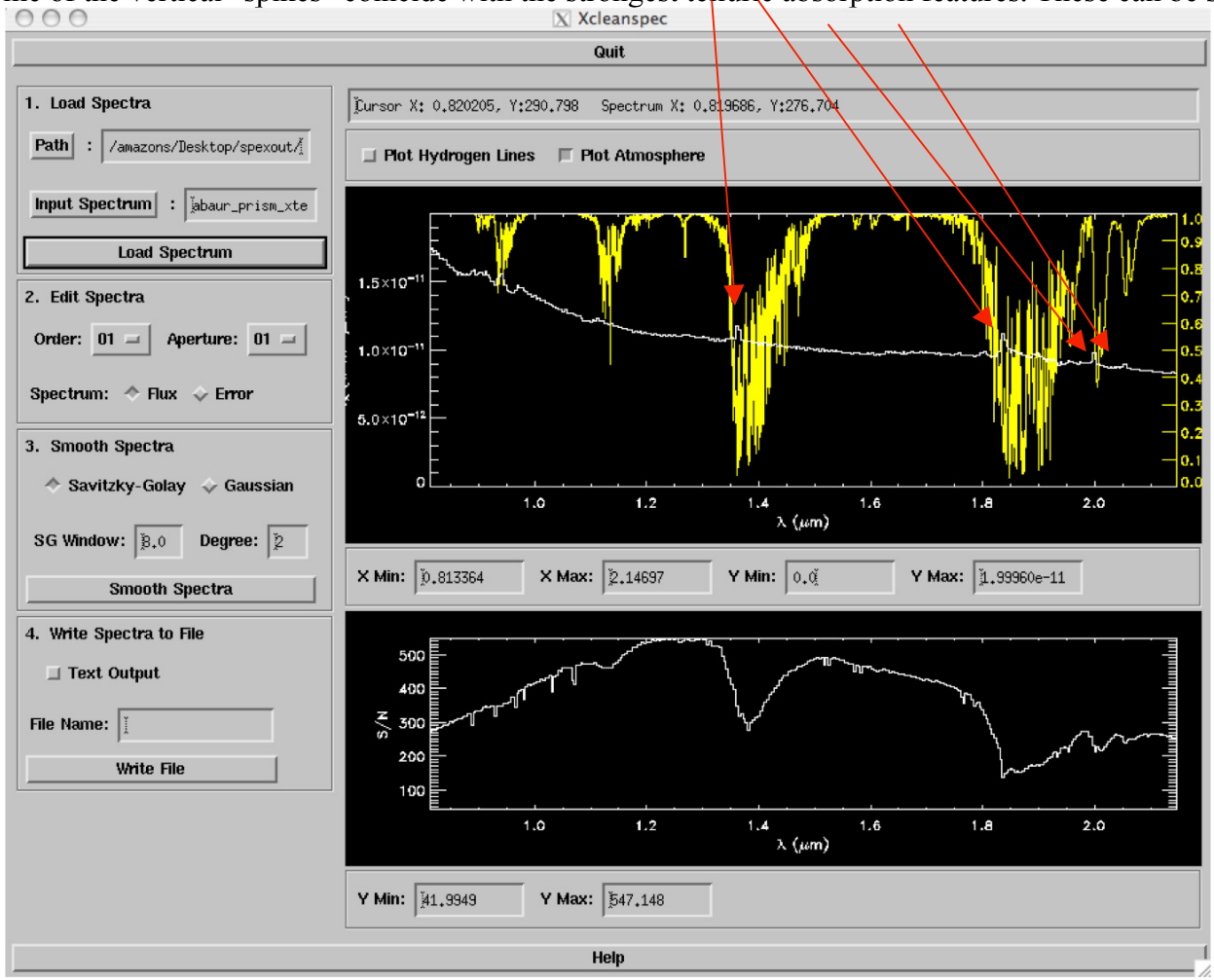
At the left is zero wavelength shift. At right is applying the Auto Find to the region between the dashed lines. Note the slight offset in height near 1.54 microns. This offset can actually be improved by doing the shift manually. Enter a value in the box, hit return, and see if it improves or gets worse. Iterate until you get the best result for the entire spectrum.

XMERGEORDERS

Skip because there are no orders to merge! Likewise, after **XCLEANSPEC**, **XMERGEXD** is irrelevant for the same reason.

XCLEANSPEC

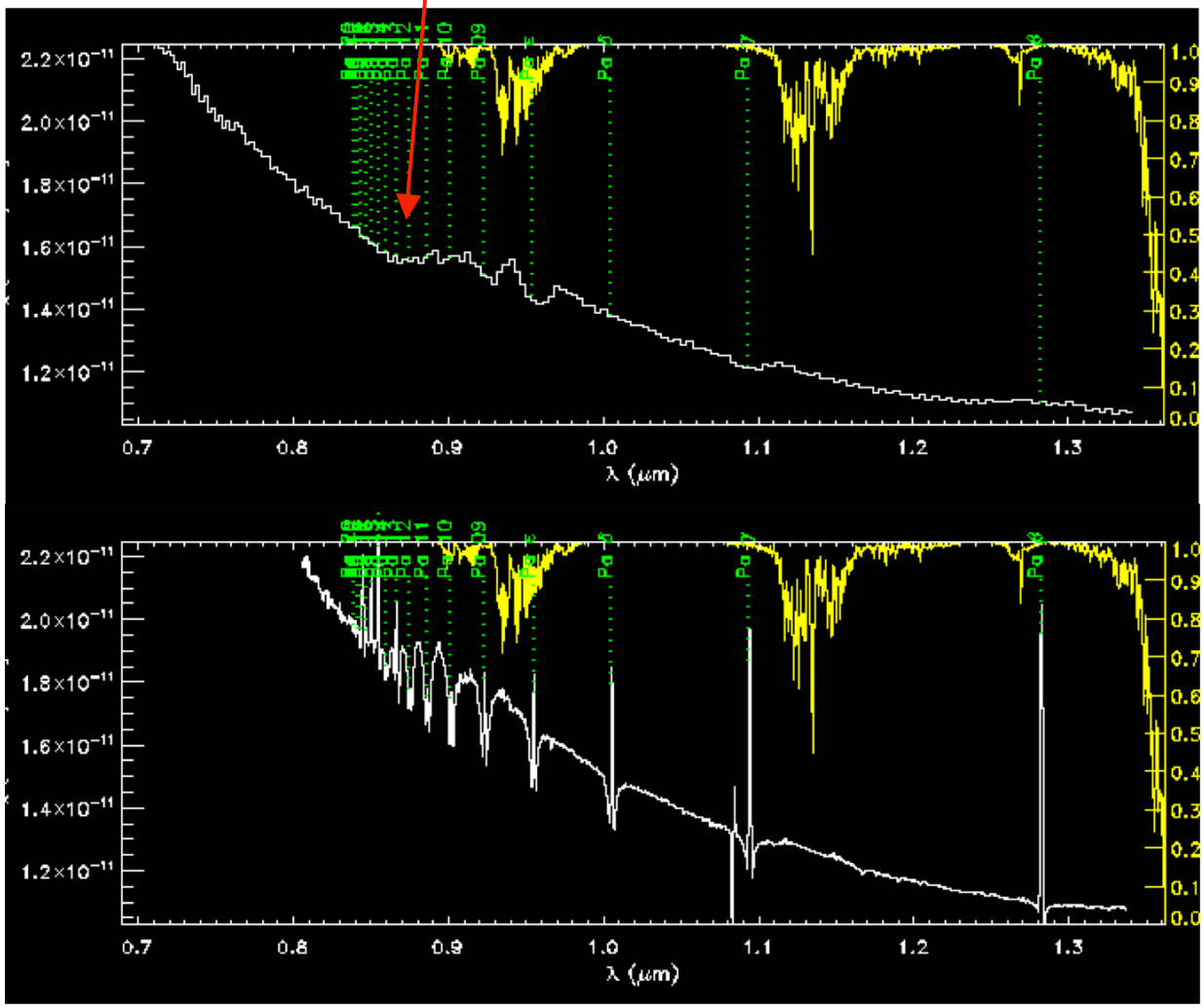
Here we can see that some of the vertical "spikes" coincide with the strongest telluric absorption features. These can be snipped.



The region between 0.85 and 1.0 µm is sort of a mess. Here we have a confluence of photospheric absorption bands, Paschen and the Ca II triplet both in emission, as well as one of the weaker telluric bands. The “kink” here is real!

Compare the Prism spectrum (above) with the

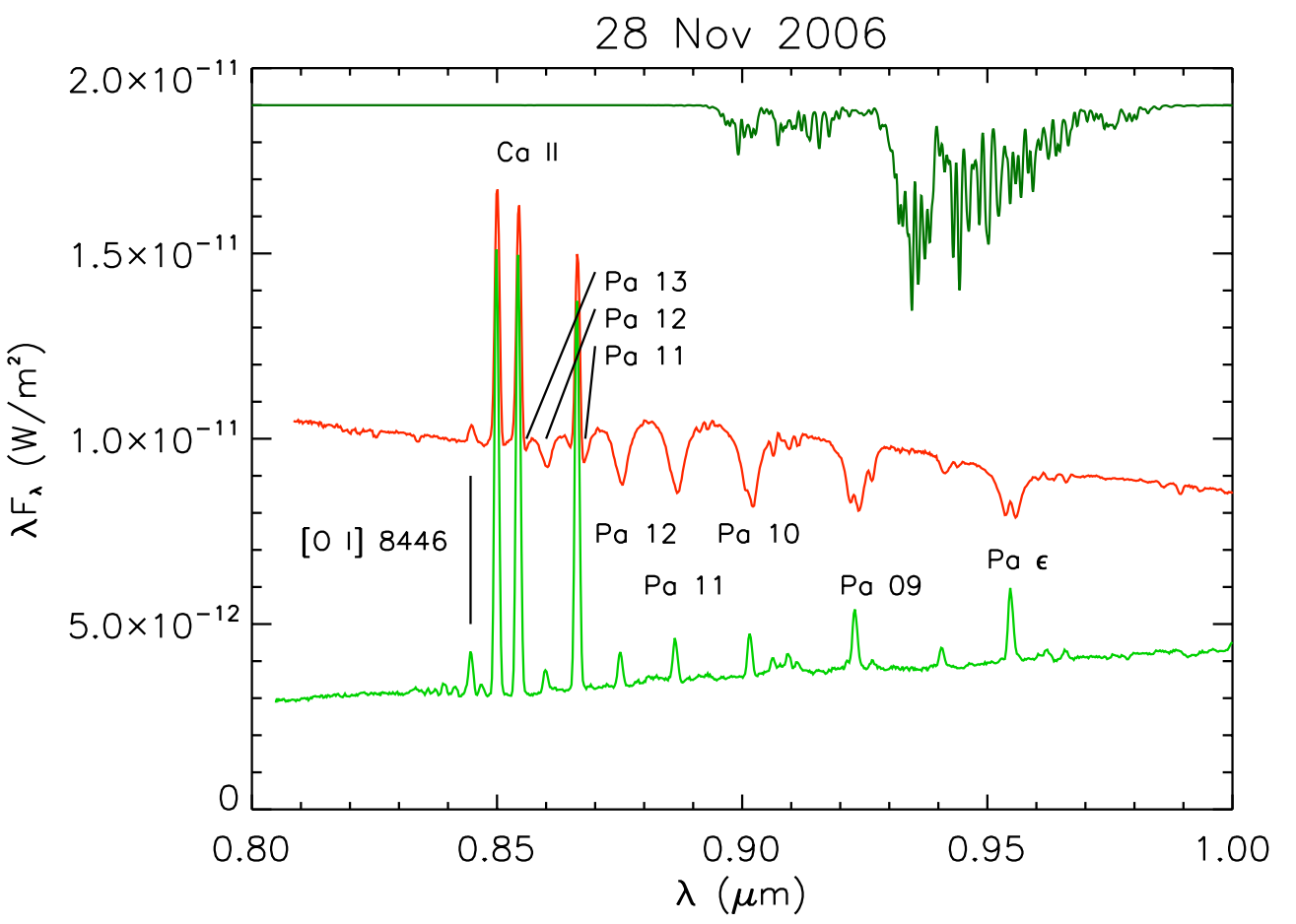
SXD spectrum (below).

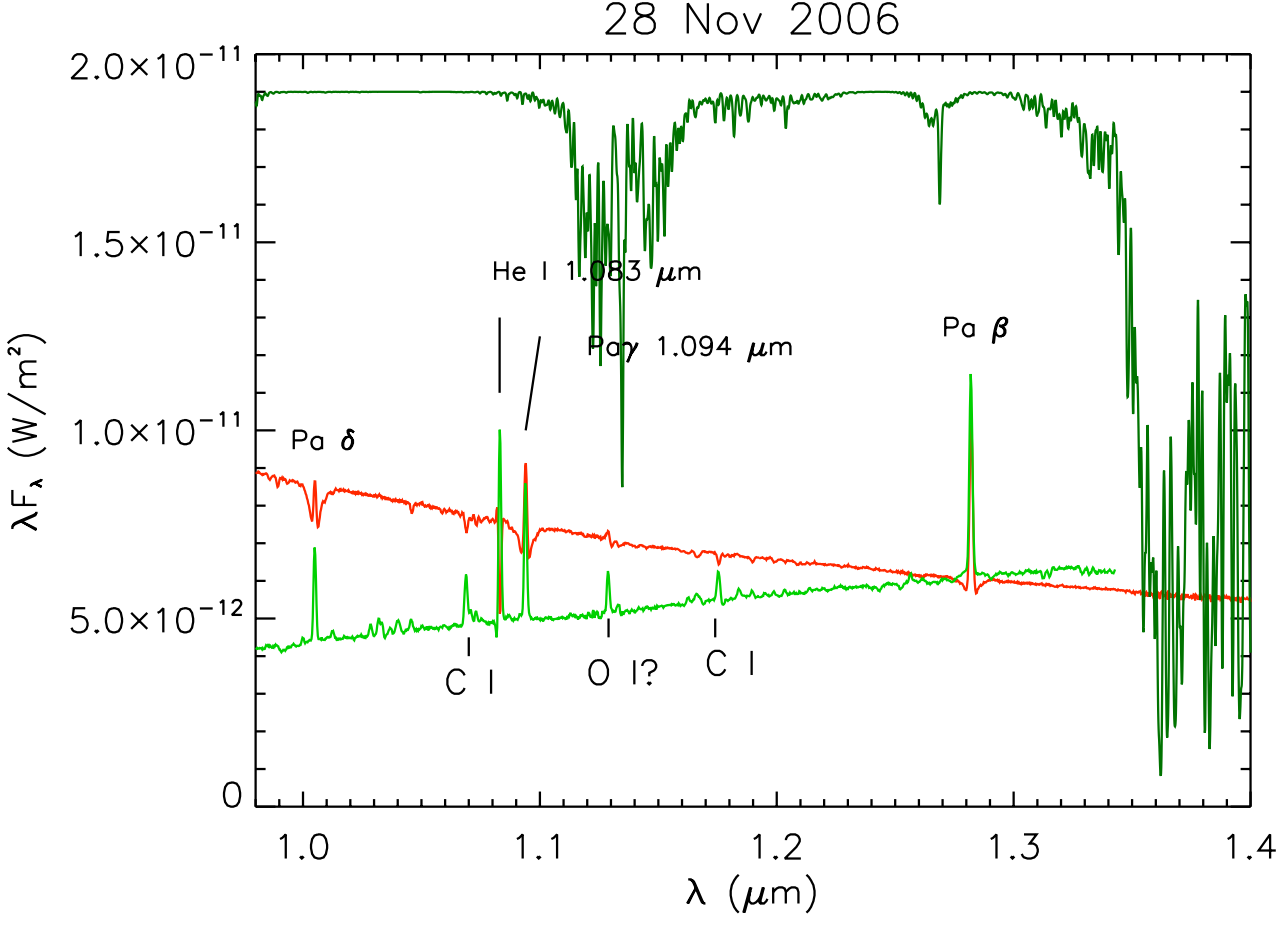


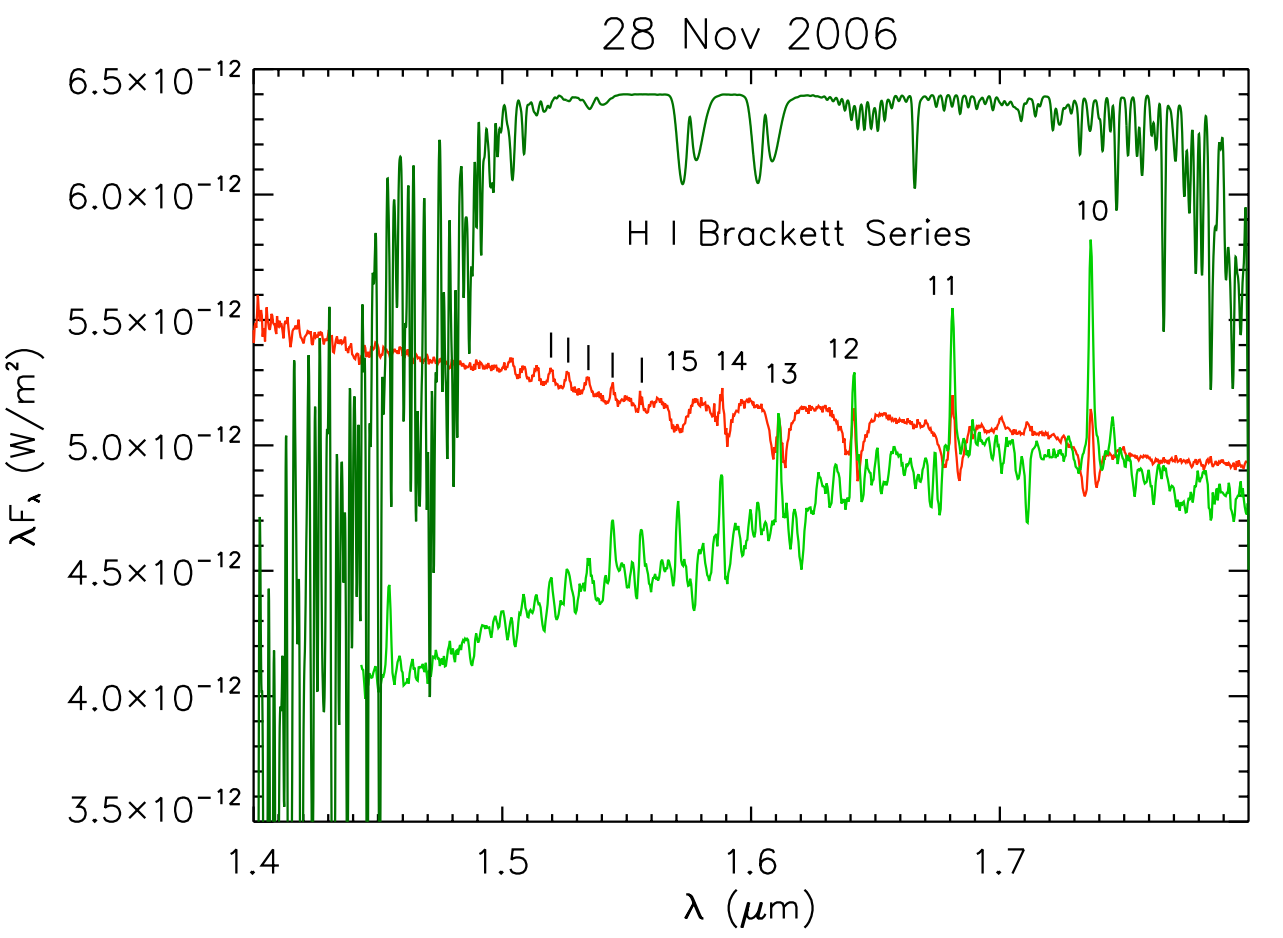
In my case, I am looking for the overall spectral shape and level; I am not trying to measure line properties! So at this point I would probably just ignore things and not remove any more data.

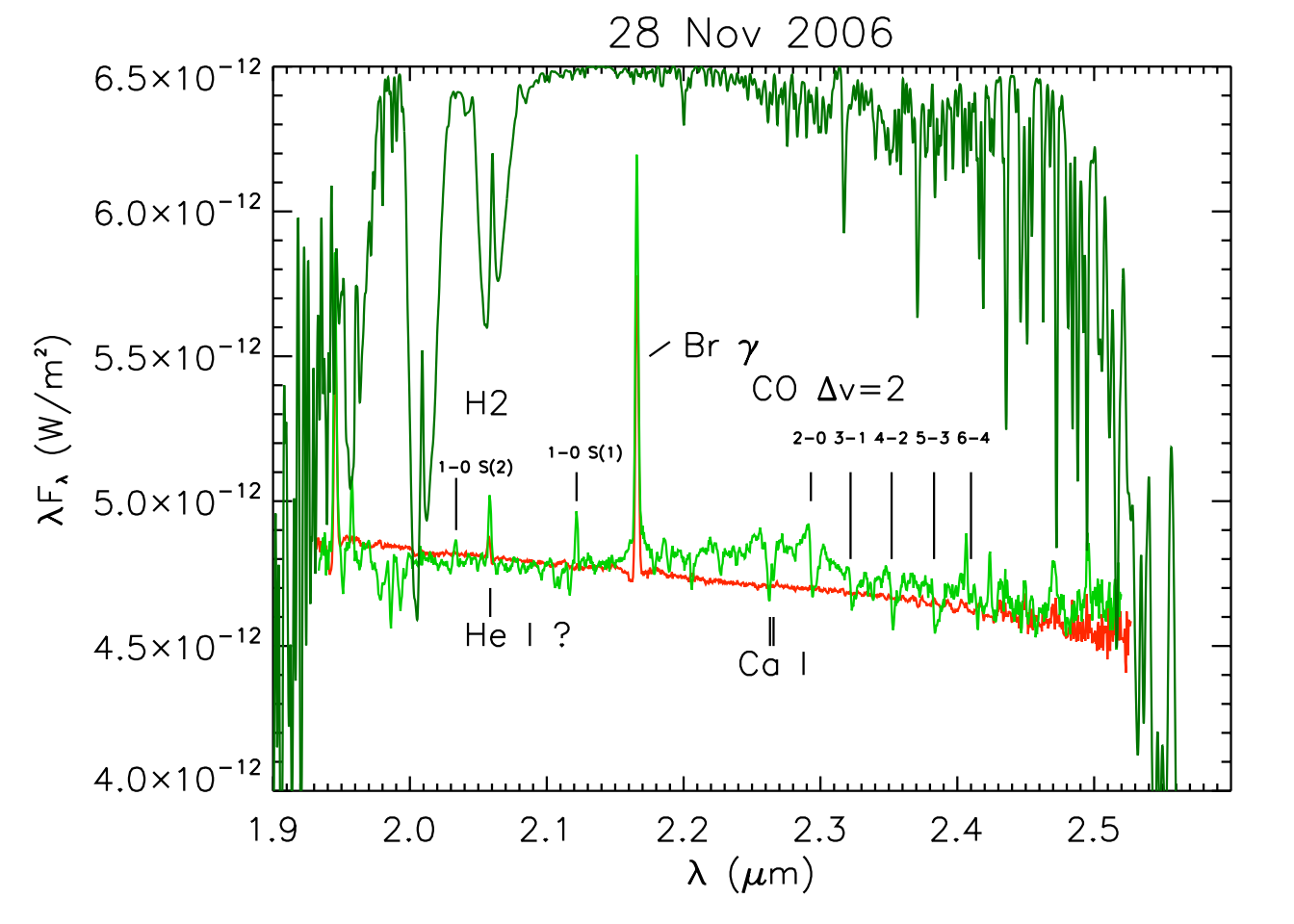
APPENDIX – LINE IDENTIFICATIONS

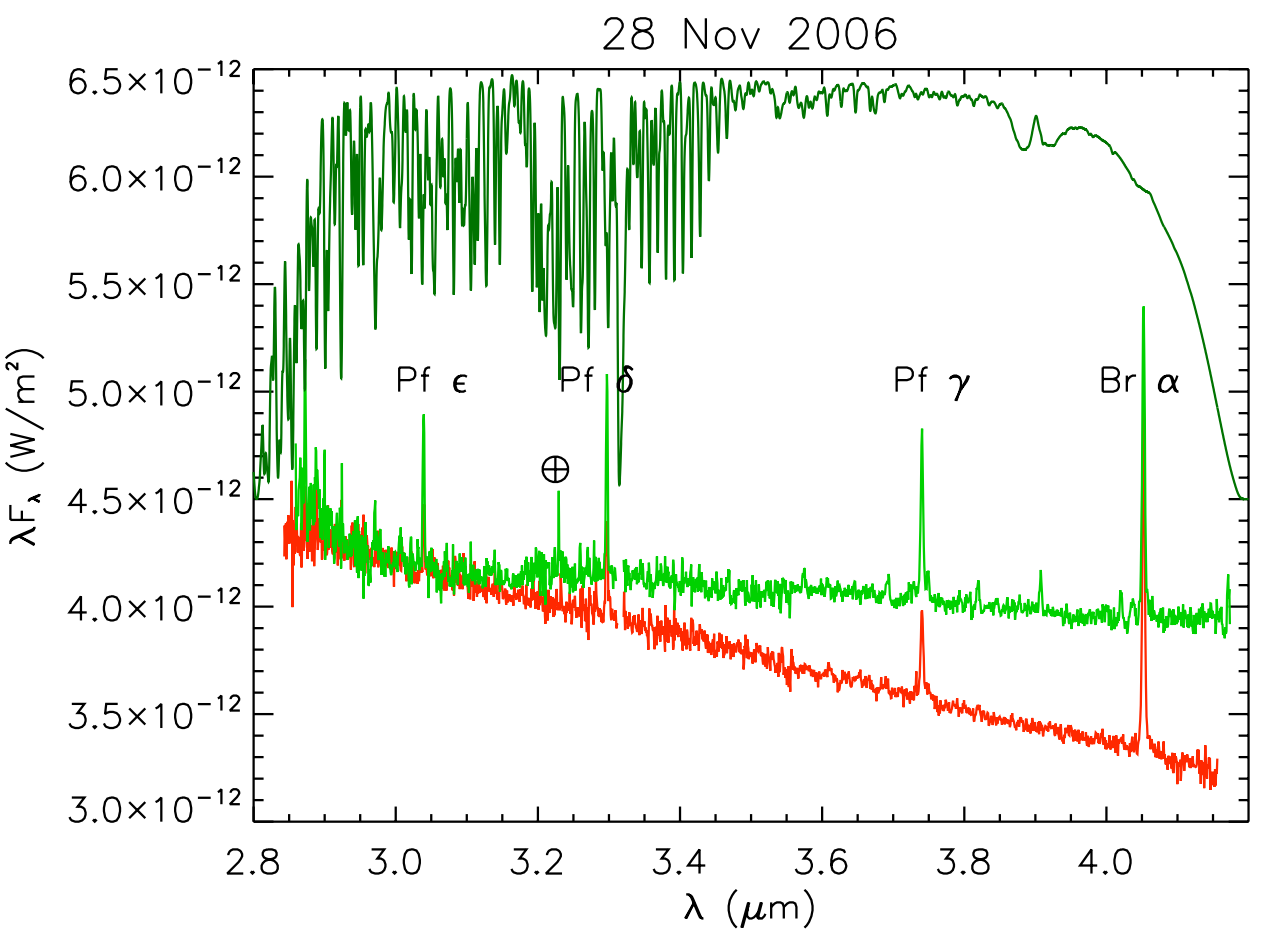
The Following pages are an attempt at line identification in PMS stars. In each panel I show a section of SpeX data for two stars, along with the telluric spectrum that Spextool uses. This is meant to be an aid to knowing what features are real or not, but it pre-supposes that no weal stellar lines are included in the latter.

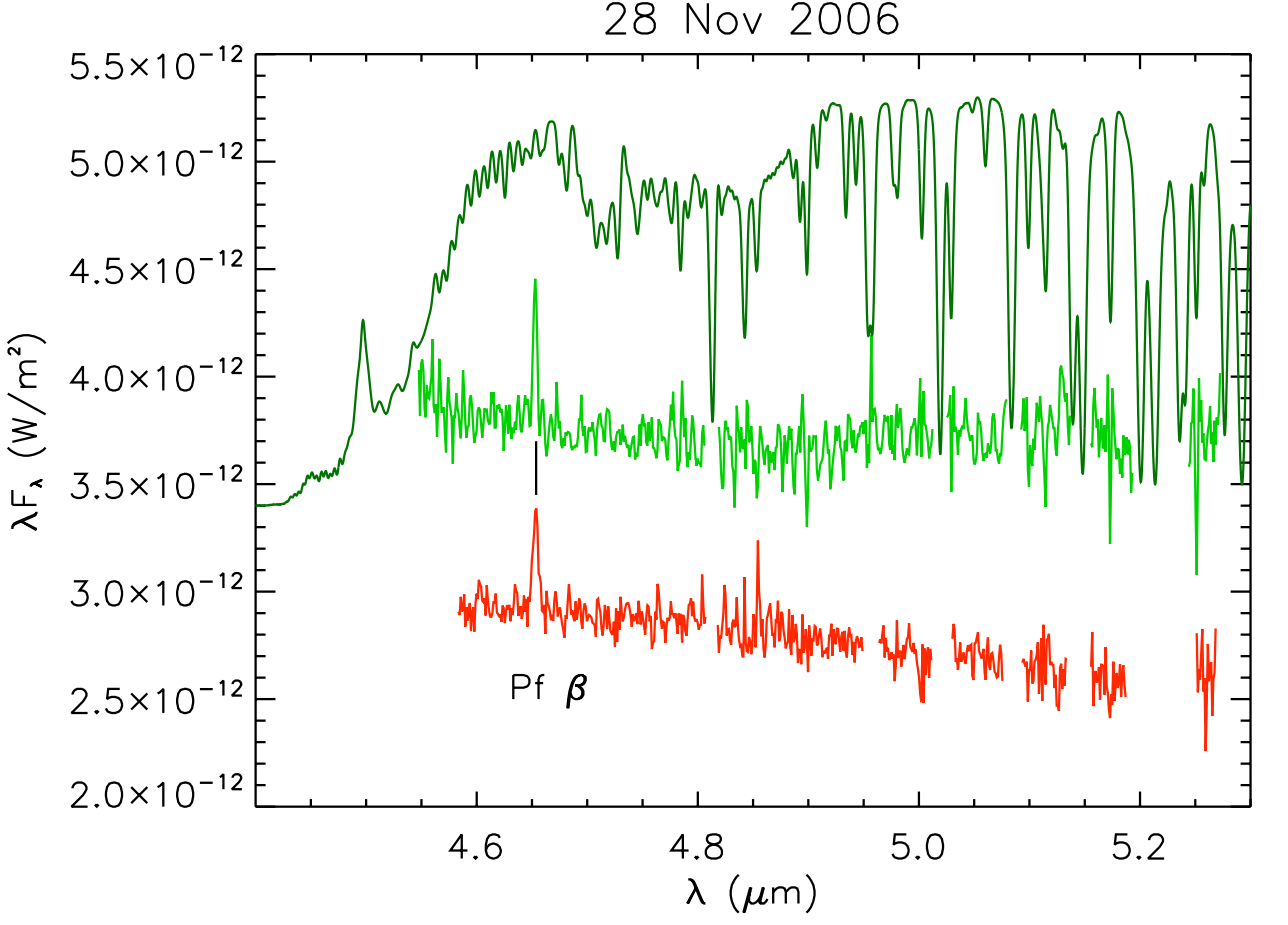

28 Nov 2006
2.0×10⁻¹¹
1.5×10⁻¹¹
1.0×10⁻¹¹
5.0×10⁻¹²
0
λF_λ (W/m²)
Ca II
Pa 13
Pa 12
Pa 11
[O I] 8446
Pa 12
Pa 10
Pa 11
Pa 09
Pa ϵ
0.80
0.85
0.90
0.95
1.00
λ (μm)


28 Nov 2006
2.0×10⁻¹¹
1.5×10⁻¹¹
1.0×10⁻¹¹
5.0×10⁻¹²
0
λF_λ (W/m²)
He I 1.083 μm
Paγ 1.094 μm
Pa β
Pa δ
C I
O I?
C I
1.0
1.1
1.2
1.3
1.4
λ (μm)


28 Nov 2006
H I Brackett Series
11
10
15
14
13
12
6.5×10⁻¹²
6.0×10⁻¹²
5.5×10⁻¹²
5.0×10⁻¹²
4.5×10⁻¹²
4.0×10⁻¹²
3.5×10⁻¹²
λF_λ (W/m²)
1.4
1.5
1.6
1.7
λ (μm)


28 Nov 2006
6.5×10⁻¹²
6.0×10⁻¹²
5.5×10⁻¹²
5.0×10⁻¹²
4.5×10⁻¹²
4.0×10⁻¹²
λF_λ (W/m²)
H2
1-0 S(2)
1-0 S(1)
Br γ
CO Δv=2
2-0 3-1 4-2 5-3 6-4
He I ?
Ca I
1.9
2.0
2.1
2.2
2.3
2.4
2.5
λ (μm)


28 Nov 2006
6.5×10⁻¹²
6.0×10⁻¹²
5.5×10⁻¹²
5.0×10⁻¹²
4.5×10⁻¹²
4.0×10⁻¹²
3.5×10⁻¹²
3.0×10⁻¹²
λF_λ (W/m²)
Pf ϵ
Pf δ
⊕
Pf γ
Br α
2.8
3.0
3.2
3.4
3.6
3.8
4.0
λ (μm)


28 Nov 2006
5.5×10⁻¹²
5.0×10⁻¹²
4.5×10⁻¹²
4.0×10⁻¹²
3.5×10⁻¹²
3.0×10⁻¹²
2.5×10⁻¹²
2.0×10⁻¹²
λF_λ (W/m²)
4.6
4.8
5.0
5.2
λ (μm)
Pf β