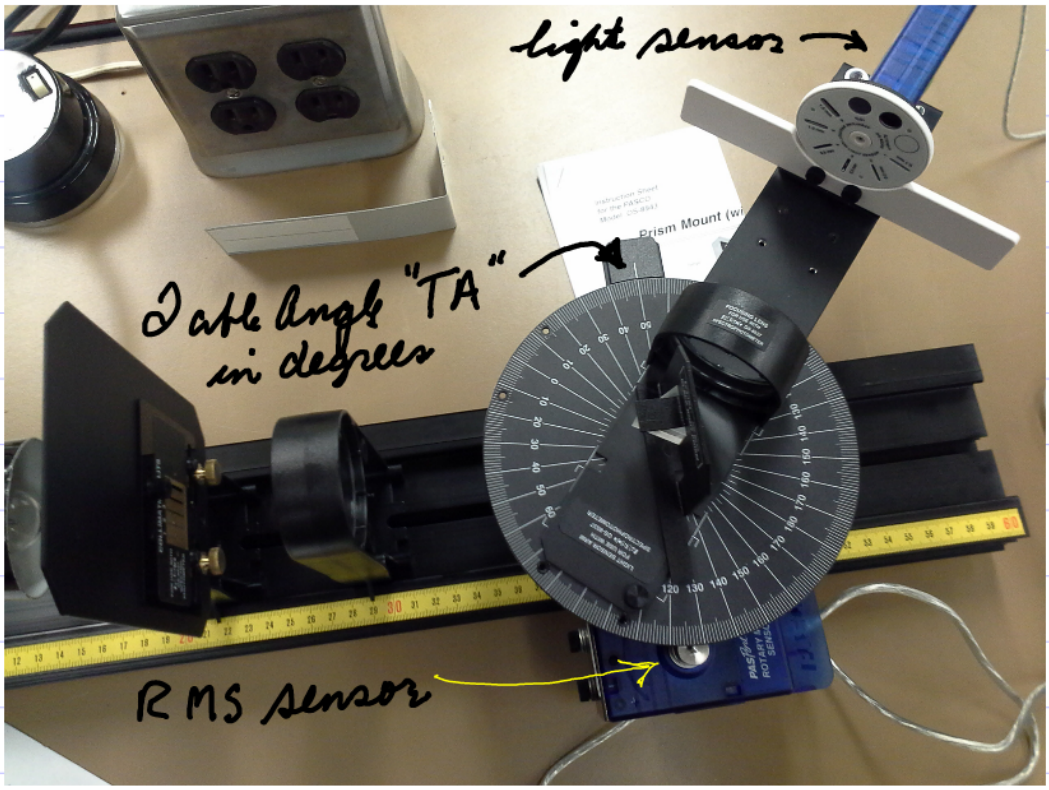
2020 Black Body Analysis

(file: pi/no tablet/275/2020 black body analysis)

Step # 1 is to use the data in the file table.angle.2020.txt file to determine how the rotary motion sensor's (RMS's) angle in radians relates to the real angle the refracted light travels through or over after leaving the prism.

This file was generated on the GLX by moving the arm (on which the light sensor is mounted) to the physical stop. That table angle (TA) is 75.0° as determined by using the scale drawn in white on the table. A photo is below showing the table at TA = 50.0°.



The file has the columns labeled and then the values. It is a three column table with col # 2 showing RMS values [radians], col # 3 has TA values [degrees]

This file will be available for download from the 275 page on hogan53.net. It can be imported into Fnspace using the instructions on the next page.

After saving the file to your linux vm/machine, open xmgrace. Usually the downloaded file is put into the /home/jst/Downloads directory. In xmgrace click on

Data, Import, Ascii

Use the Read sets dialog that opens to navigate to the Downloads directory. Then change the filter to show *.txt as xmgrace looks for *.dat by default. (Delete dat, type in txt, press enter.) The Files section will now show the downloaded file: table.angle.2020.txt. Select it. More defaults must be changed:

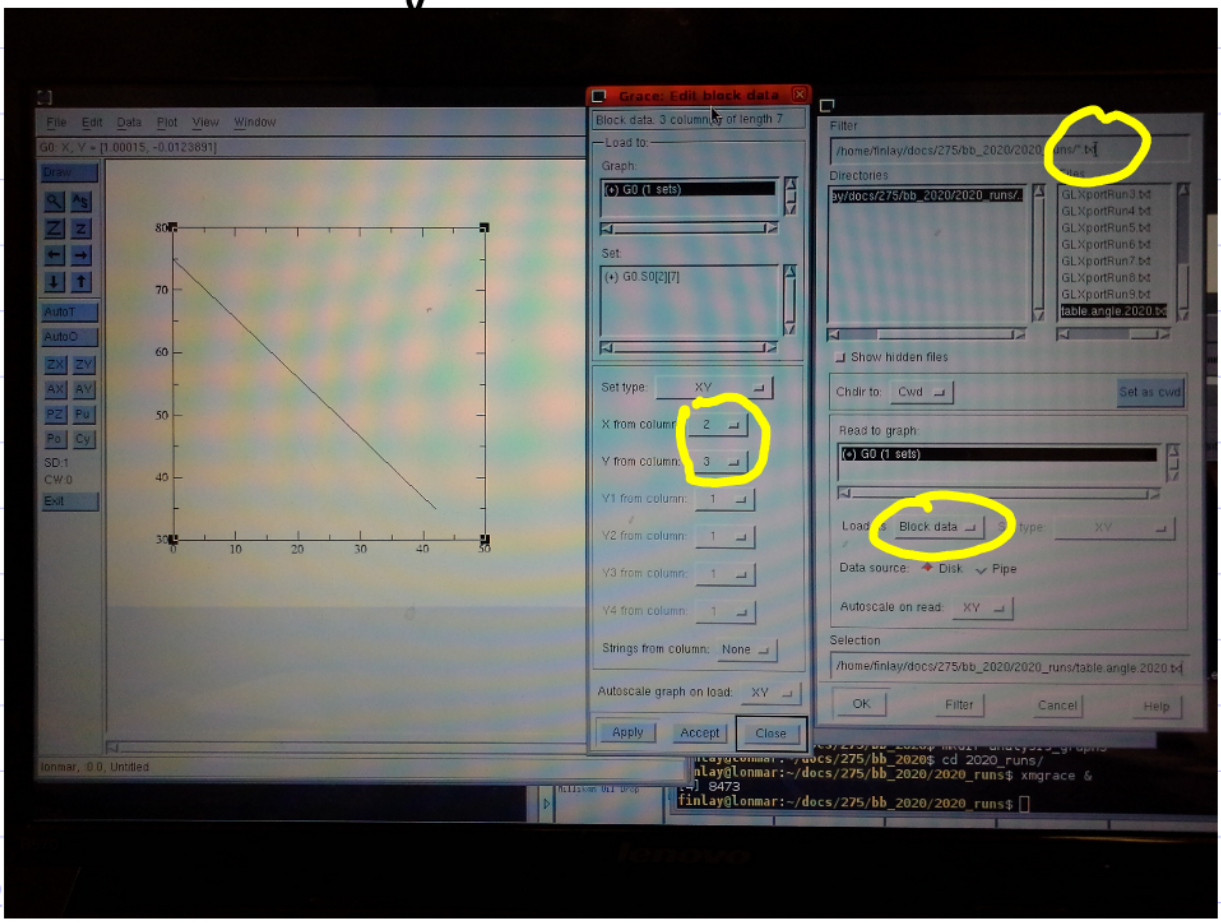
Load as Single Set → change to: Block data

Click ok: The Edit block data dialog opens. Change

X from column 1 → to 2

Y from column 1 → to 3

Click Accept. The photo below shows these changes but the directory locations won't match.



At this point, go ahead and fit the data, label the axis, put the fit equation + title and units on the plot as usual. You will now have the equation that converts RMS angle to Table Angle.

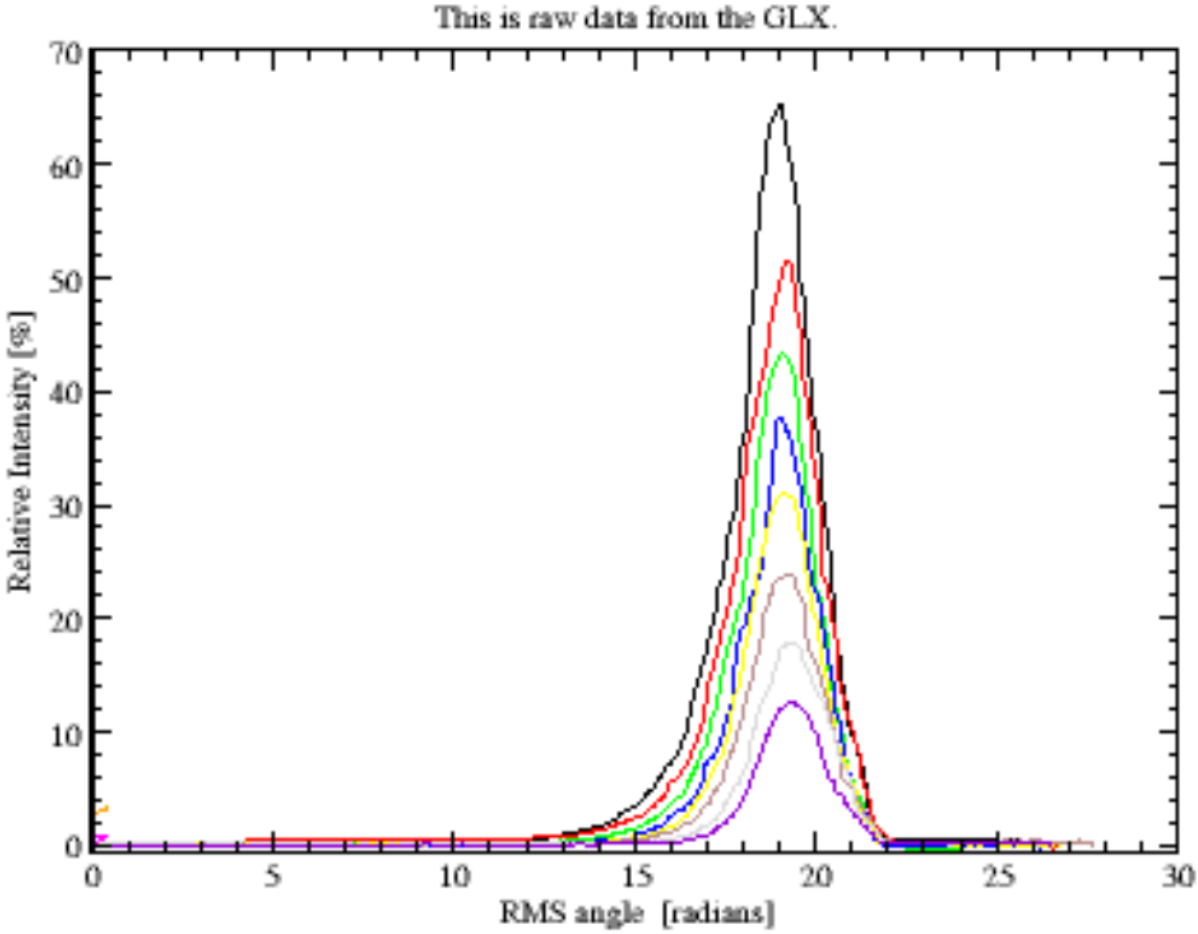
Save this graph as RMS_to_TA_angle-2020.agr.

(1)

Importing the Blackbody spectra/runs.

Similar to the above imported file, the runs at each voltage the bulb was set to can be imported. Some data values, in terms of Table Angle, λ, RMS angle (all are x-axis parameters) must be removed as the prism does not function or refract light to these λ, TA, RMS angles. Data gets collected here on the blue end because the physical stop the arm is moving to provides a reliable start point for all runs. The red side may also have data outside the valid range depending on the angle the run was stopped at.

The raw data was imported the same as the previous angle-angle data was: Data, Import, Ascii, change filter to txt, locate file + select, columns X = 2, Y = 3, apply.



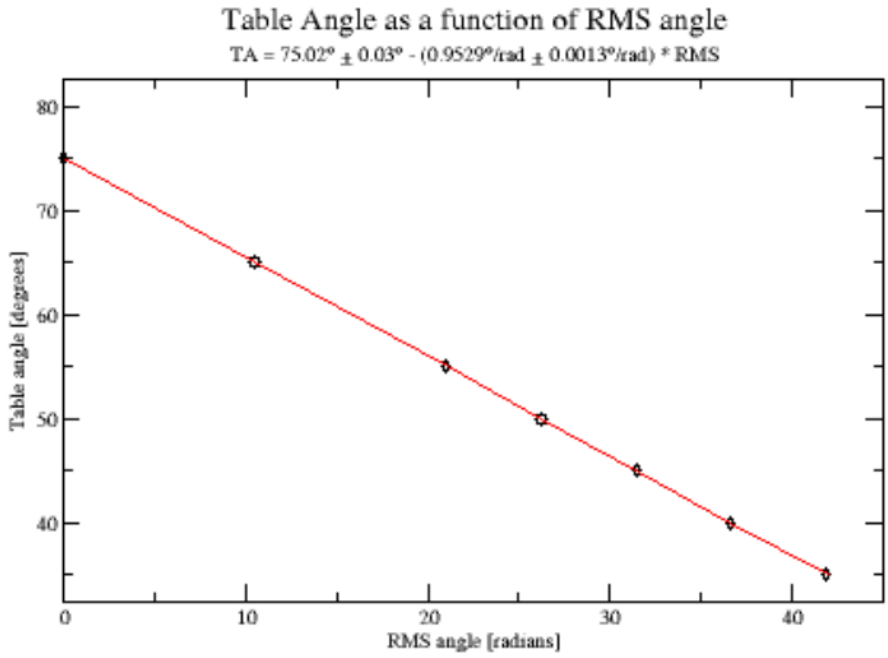
Your data will look like the figure above. Save this file and make a copy of it using the file manager or within xmgrace by saving as another name. This will provide a backup. It is advisable to continue this practice: Create the next graph, then copy the file as a backup.

②

Changing the x-axis: RMS angle → Table angle

The x-axis in the image above has RMS angle in radians and we need the actual table angle: This angle is the angle used in the prism formulas to get λ on the x-axis.

The conversion formula will come from the plot of Table Angle versus RMS angle. An image of this plot is below. The fit gives the conversion formula.



Error bars were not included. The error on the TA would be ± 0.2 degrees. The error in the RMS angle depends on the RMS resolution and if there is evidence of slippage.

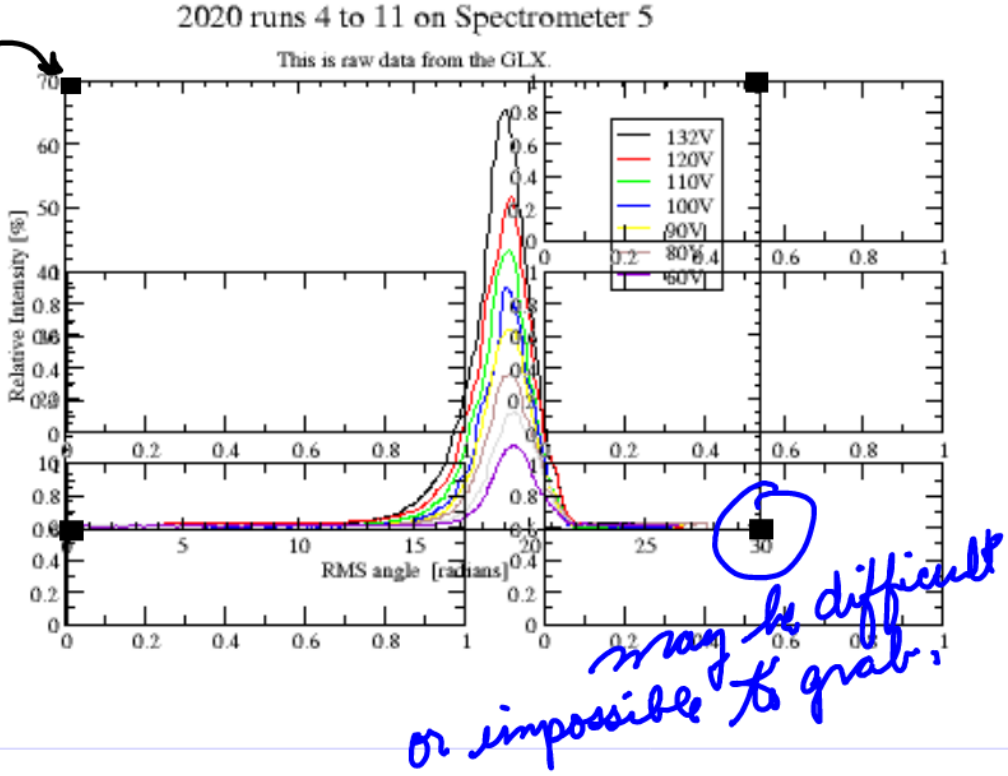
In order to create multiple graphs (G0, G1 ... G6) click on Edit, Arrange graphs. Set Cols (in Matrix) to 2 and Rows to ~~3~~ 2 and click Accept. just need G0 → G3 = 4 graphs

The existing plot can be resized by double-clicking on the black squares in the corner of that graph.

The title and subtitle may have to be removed and redone as a comment that can be moved. The axes fonts will need to be reduced.

The legend is positioned and font sized in the "Graph Appearance" dialog.

double-click on here to drag/resize.

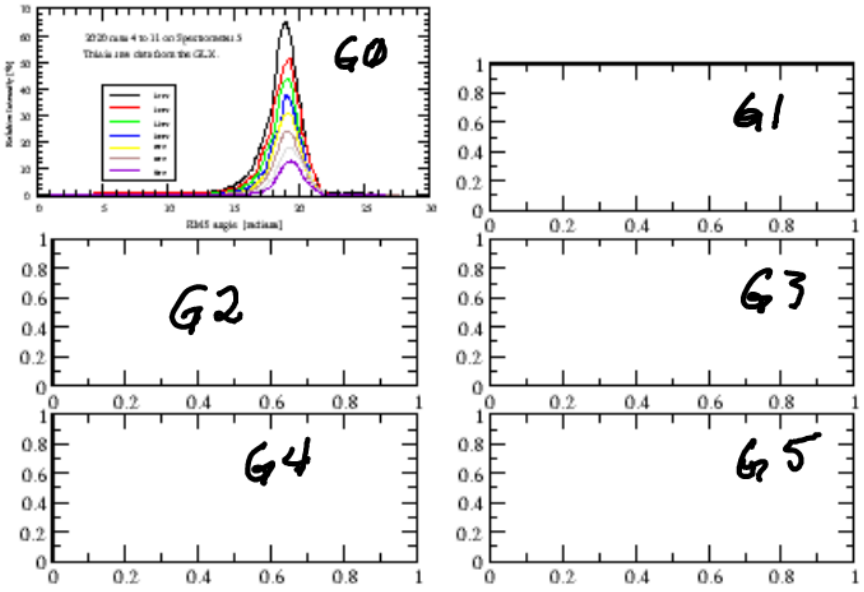


We can choose G2 to put the intensity as a function of Table angle into - It does not matter though, just a habit of your author.

may be difficult or impossible to grab.

G2 will receive the translated x-axis for all 8 sets.
The relationship is:

TA = 75.02° ± 0.03° - (0.9529°/rad ± 0.0013°/rad) * RMS



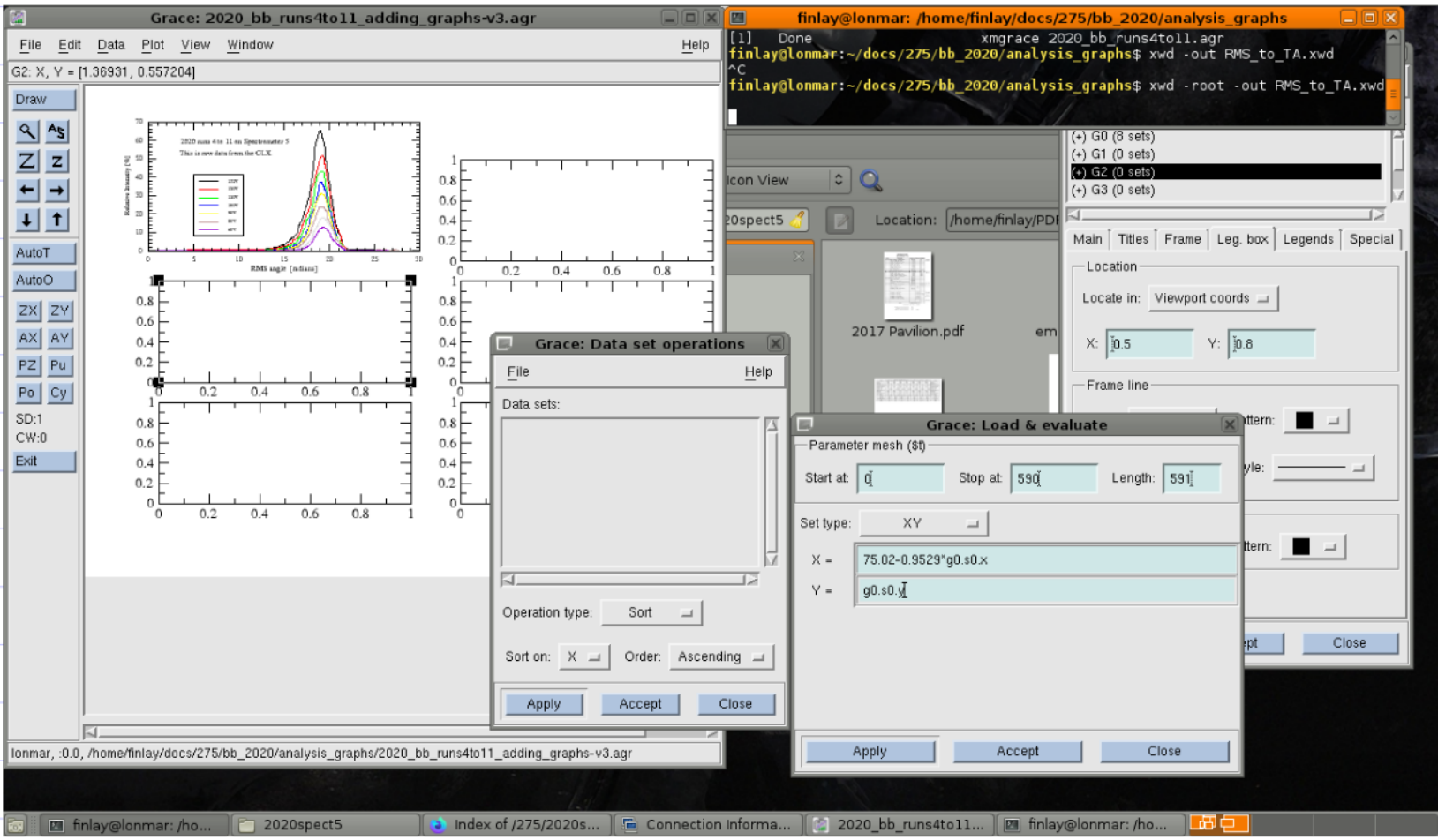
∴ G2.S0 will have a translated set from G0.S0 ... G2.S1 from G0.S1 etc. Copy down the # of data points in each set of G0. S0 has 591 points: 0 to 590.

With G2 as the active graph (click on it), Click on Data, Data set operations. Right click + hold on the empty space, Create new, By formula. See the image on the next page -

We will run over the full set: Start at: 0, Stop at: 590, Length: 591

X = 75.02 - 0.9529 * g0.s0.x ← x is T.A [degrees].

Y = g0.s0.y ← brings over Intensity % values



Press As (autoscale) to see the result.

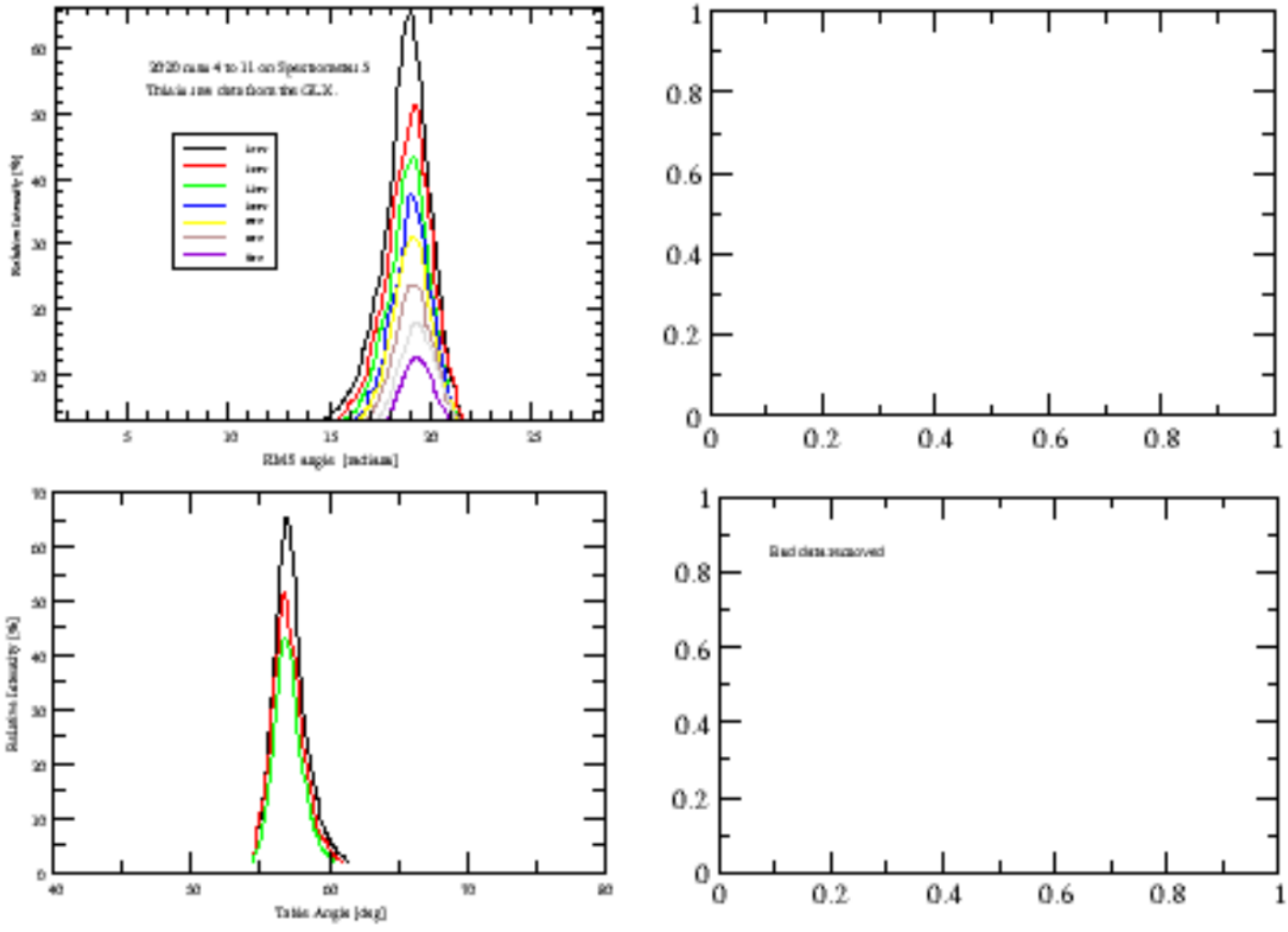
Now repeat Create new, By formula + simply increment s0 to s1, s2, s3 for all sets. Remember to adjust the stop at values + both X = + Y = must have matching set members. Use Apply to keep the dialog up.

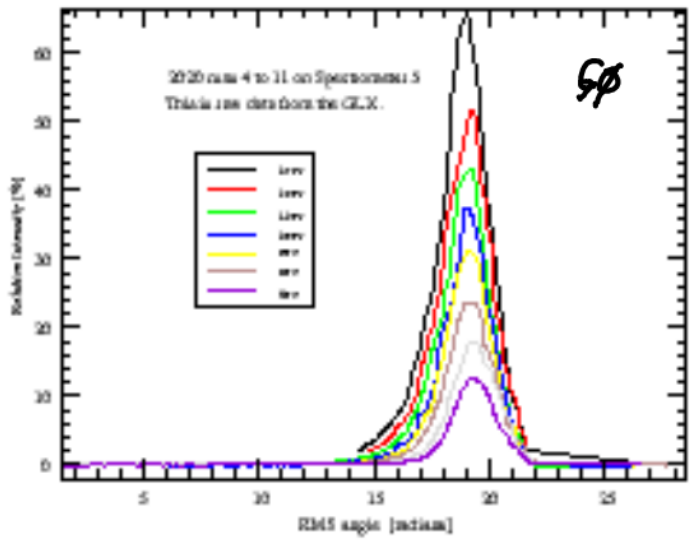
If you make an error, the Console window will likely pop up with a description of the issue.

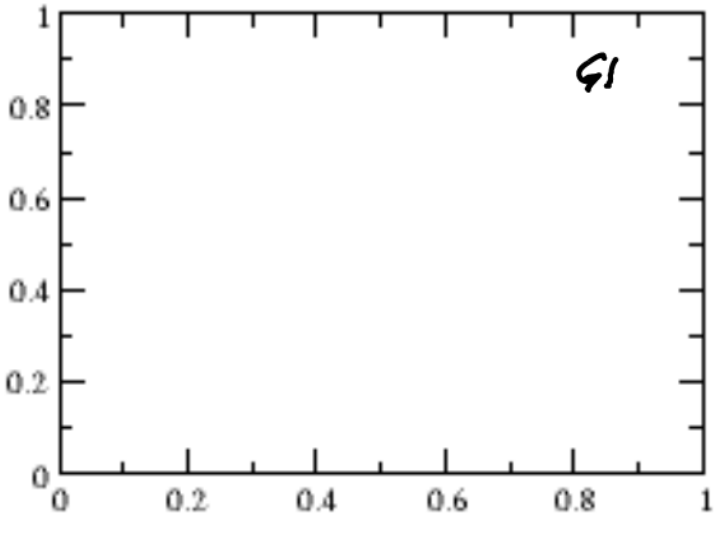
file 2020_bb_runs4to11_RMS_to_TA_into_G2-V1.agr

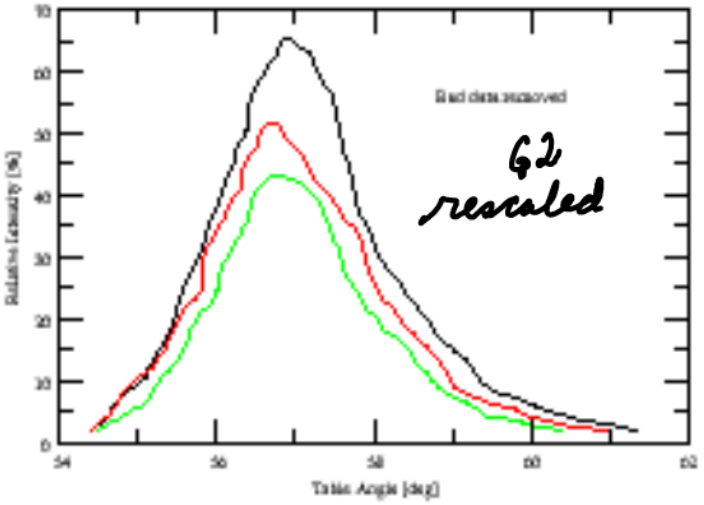
As you proceed continue to save and rename your file so that if something goes very wrong, you can open the previous file & start there rather than having to go back to the very start.

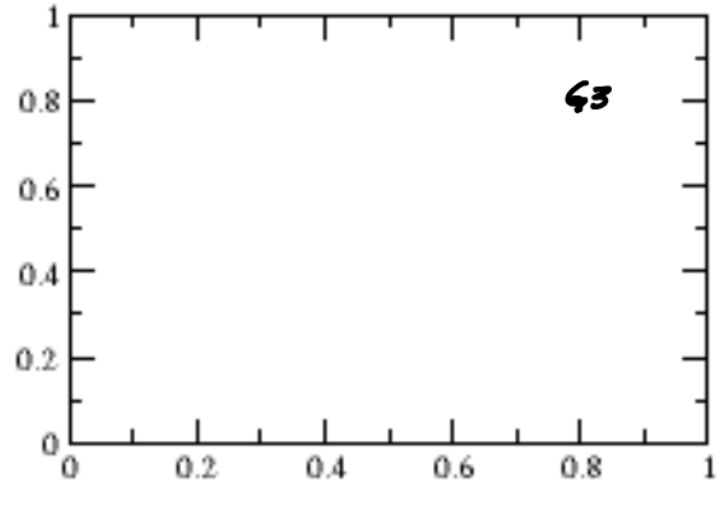
The image below has had data removed where it is not possible for the prism equation to make sense. A rescaled plot of 62 is on the next page.











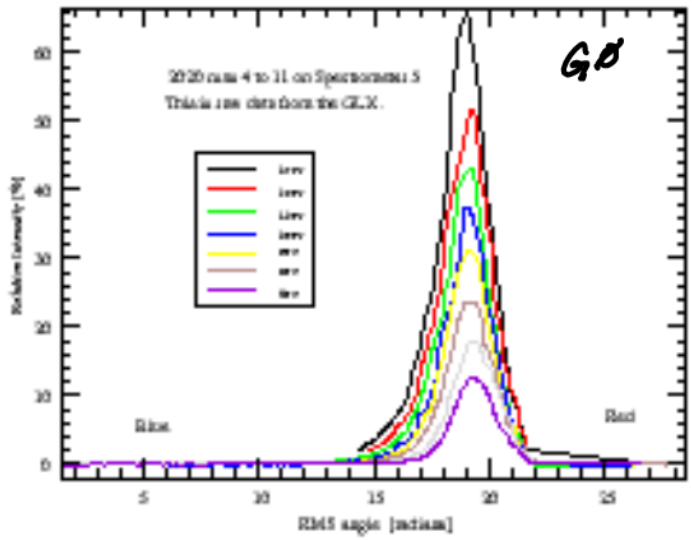
All datapoints with a relative intensity < 2% were removed from the xmgrace file. One must know what graph # / sets to modify. Use a text editor such as "pluma" to open the .agr file after saving it. Then save the modified .agr file as a new file. It can be re-opened in xmgrace. Record the new # of each set's points for future use/conversion. eg. S0 has 148 points now.

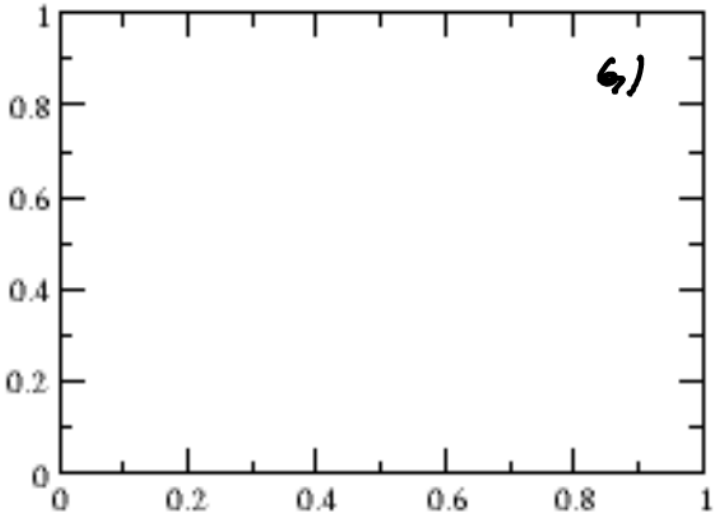
We now have to get λ on the x-axis. Although the curves in G2 look like blackbody curves, they are not as λ is not on the x-axis. Also it looks like the peak λ may be moving the wrong way. The left & right side slopes appear to be consistent with the BB curve shape.

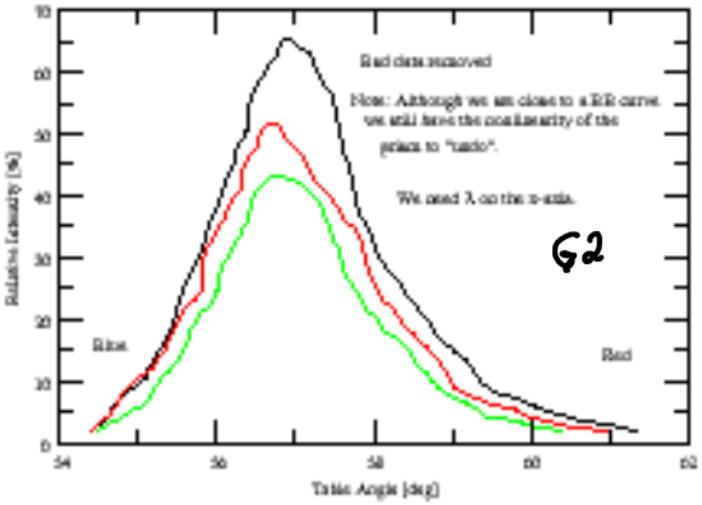
Q: Can the TA [degrees] to λ [nm] fix this? What could that translation do to hopefully reverse the peak λ order?
Ans. The prism eq'n is non-linear.

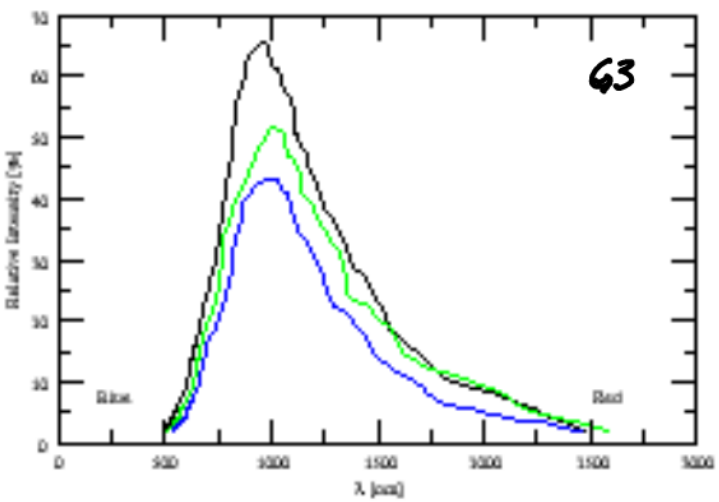
The prism eq'n relate λ as a function of angle θ on the spectrometer table. It is on pg 5 of the 2019 instructions pdf called "Blackbody Radiation Instructions". That graph is shown on the next page. Note the range of λ for which there are data.

Once the long equations in the 2019 file has been used to the Intensity as a function of Table Angle sets, the Intensity as a function of λ plots will be as in G3 below:









Note the graph below has a range of λ from 400nm to ~2500 nm. The equation developed (A5) applies to this range of λ and not much outside it. This also means the range of Table angle is similarly limited in range ⇒ the data acquired will need truncation.

Table III: Prism Data

	Index of Refraction	Lambda (nm)
1	1.68	2325.4
2	1.69	1970.1
3	1.69	1529.6
4	1.70	1060.0
5	1.70	1014.0
6	1.71	852.1
7	1.72	706.5
8	1.72	656.3

We need an equation based on the data in the table to use i our calculations. We use a polynomial and choose the valu of the constants to fit the prism data. The results are not unique but fit the data within the uncertainty in the index implicit in the data table of at least 0.005. The equation is

$$\lambda = A + B(n-E)^1 + C(n-E)^2 + D(n-E)^3 \qquad (A5)$$

where λ is the wavelength in nm, and the constants have values: A = 320 nm, B = 1 nm, C = 0.2 nm, D = 0.19 nm, and E = 1.635. On the graph, the circles represent the prism supplier's data with the size of the circles showing th uncertainty, and the curved line is from the above equation

now put $n = \sqrt{\left(\frac{2}{\sqrt{3}}\sin\theta + \frac{1}{2}\right)^2 + \frac{3}{4}}$ (A4)

into equation A5

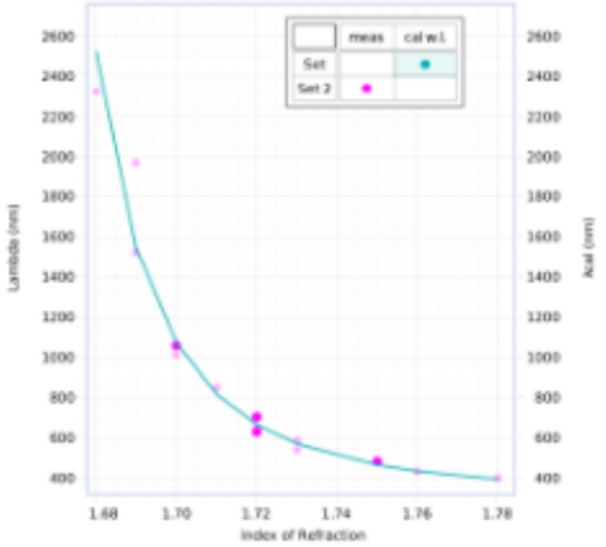


Figure 11: Prism Wavelength vs. Index of Refraction

So we have finally λ as a function of angle (or $\sin\theta$):

λ = 320 nm +

tells xmgrace angle is in degrees not radians

```
1nm*(sqrt(((1.1547*sin(g0.s#.x deg)+0.5)^2+0.75)
                                    -1.635)^-1

+0.2nm*(sqrt(((1.1547*sin(g0.s#.x deg)+0.5)^2+0.75)
                                    -1.635)^-2

+0.19nm*(sqrt(((1.1547*sin(g0.s#.x deg)+0.5)^2+0.75)
                                    -1.635)^-3
```

This is entered into xmgrace to convert the x-axis to λ [nm] from Table Angle in degrees. So we move from ② to ③

Finally we are ready to fit the data using the blackbody radiation formula. This requires some patience and can be tricky. Bounding is used to push the S/W to a solution when it cannot automagically find one. It is best if this is demonstrated as each case can provide unique challenges. Below is a fit to the data and it reveals that too much data was removed at the blue end of the spectrum.