Reduction of Spectroscopic data: Spectrophotometric calibration of Gaia

Abstract

The goal of this bachelorproject is to determine the absolute fluxes of stars for use as calibrators in the photometric reduction of data from the GAIA (Global Astrometric Interferometer for Astrophysics) astrometric satellite, which will fly in at the end of 2011. [1] This project involves observing candidate flux standard stars using the spectrograph on the Calar Alto 2.2m telescope in Sierra de Los Filabres (Andaluca, Southern Spain) north of Almeria. I reduced this data using the GAIA project protocols to provide the reduced data to the GAIA Photometric Reductions Coordination Unit. I conclude with a discussion of the reliability of the data.

Key words: spectroscopy, astrometry, calibration, GAIA, reduction, IRAF.

1 Introduction

In the 19^{th} century Friedrich Bessel was the first astronomer who calculated the distance to a star using the stellar parallax method. Knowing those enormous distances, astronomers of that time believed stars will always remain a mystery. [15]
Determining distances of stars using the stellar parallax method was time consuming and therefore it was at the end of the 19^{th} century that parallaxes has been measured for only 60 stars, with errors of circa 20 mas.
Using automatic plate measuring machines, that accurately scan photographic plates, led to more accurate measurements in the 1960s but they were replaced in the 1980s by charge-coupled devices (CCD's) which can lead to uncertainties of 1 mas. [2] [18]
The need to be able to observe the entire sky and to achieve more accurate results led to build a satellite. In 1980 ESA accepted to build an astrometric satellite, a satellite that provides us information about the distances, movements and positions of more than one million stars, giving us a kinematic view of our Galaxy. Hipparcos was launched in 1989 to observe large parts of the sky. Hipparcos was able to observe hundreds of thousands of stars in 30 months and each direction was at least observed twice. Reduction of all the obtained data led to the Hipparcos Catalogue. The catalogue generated great international interest because the Hipparcos mission was the first space astrometry mission.

Hipparcos measured the distances of 118 218 stars with a very high accuracy and the mission ended on 15th of August in 1993 when it fell to Earth and burned up in the atmosphere. After the publication of the Hipparcos Catalogue, the results of the catalogue was criticized, because multiple accurate measurements previously made did not match with the Hipparcos results and therefore the conclusion was made that they had to apply a new reduction procedure, to improve the results. [2] Even before the publication of the catalogue there were plans of a new improved mission. One of the improvements were the replacement of photomultipliers, used in Hipparcos, with electronic detectors. This modification led to the proposal of RØMER. RØMER would have been 20 times more accurate than Hipparcos and would have been able to observe more faint stars. Eventually ESA approved the GAIA mission in 2000.
(See Figure 1). [3]
The enormous amount of scientific data we will receive from the astrometric scanning satellite GAIA is due to the combination of 3 main features of the GAIA satellite:

1. Performance of accurate astrometric measurements
2. Ability to observe large parts of the sky
3. Performance of spectroscopic measurements

This data will enlarge our view in different branches of astronomy like in astrophycis, in the solar system and in the general relativity. [19]
GAIA will carry 2 telescopes which will scan the sky at a rate of 60 arcsec/s. [4] These telescopes will measure positions, distances, space motions of one billion stars up to V=20 of which 150 million stars have a distance accuracy of more than 10 percent and 10 million stars will have a distance accuracy of even more than 1 percent. This is 100 times more accurate than Hipparcos. The high accuracy of the determination of distances of celestial objects will allow us to map the Galaxy in three dimensions. [5]

Figure 1: An artistic impression of GAIA: ESA's astrometric satellite

Spectroscopy is important to determine not only the composition of stars but also to determine the radial velocity due to doppler shift of the spectral lines. Nowadays almost every large ground-based optical telescope has a spectrometer, GAIA will also travel with a spectrometer on board. The Radial Velocity Spectrometer (RVS) will provide measurements of radial velocities of about 100 million stars with an accuracy for stars with V=17 of 2 - 10 km/s. [3]
The powerful combination of spectroscopy and astrometry, which will have a measurement precision of a few millionths of an arcsecond, will give us a new view of the six-dimensional phase space of the Milky Way, which provide us a relation between the distribution of stars and their kinematics.[5]
Just like Hipparcos, GAIA will observe binaries but in contrast with Hipparcos the RVS on board of GAIA will detect circa 60 million spectroscopic binaries and 10^5 eclipsing binaries, from which the mass can be determined what leads to a relation between mass and luminosity. Other differences between Hipparcos and GAIA are listed in table 1.[6]
Besides observing stars and collecting astrometric measurements of 1 billion stars, GAIA will also survey the solar system for objects like major planets, comets and asteroids, including several thousand near-Earth objects, and extragalactic objects like quasars and supernovas. GAIA is able to observe a specific asteroid 15 times per year with an accuracy 500 times better than previous observations.[7] Determination of the diameter of 1000 asteroids provide us information about the shape and density of asteroids. By observing the bending of star light, GAIA will be able to observe the structure of space-time and will therefore test Einsteins theory of general relativity.[8]
After launch, GAIA will send 50 GB raw data each day, for a total of 100 TB of data after the completion of the mission, these data represents photon counts which are recorded on CCD's.[9] However, these data will be calibrated only with themselves. To use them for other projects, we have the need to calibrate these data onto an external system. The GAIA project is therefore establishing a large network of spectrophotometric standard stars that will be used to make this calibration and use them in the photometric reduction of the GAIA data.

	HIPPARCOS	GAIA	
Magnitude limit	12	20-21	
Completeness limit	7.3 - 9	20	
Number of objects	120000	35x10^6	V<15
		350x10^6	V<18
		1.3x10^9	V<20
Astrometric accuracy	1 mas(V<9)	7 μas	V<12
	1 - 3 mas(V>9)	25 μas	V=15
		300 μas	V=20
σ_π/π<1%	150 stars	11x10^6 stars	
σ_π/π<5%	6,200 stars	77x10^6 stars	
σ_π/π<10%	21,000 stars	150x10^6 stars	
Radial velocity	-	2 -10 km/s	V<17
Spectro-photometry	-	R $\simeq$ 20-100*	V<20
Low resolution spectroscopy	-	R = 11,500	V<16-17

Table 1: Astrometric performaces of GAIA compared to Hipparcos [3]
*range $3300\mathring{A}-10500\mathring{A}$

2 Data

The spectroscopic data were obtained with the Calar Alto 2.2m telescope with the Calar Alto Faint Object Spectrograph (CAFOS) taken in March/April 2007. The spectrograph has an 2048 x 2048 pixel blue sensitive CCD with 24 μm pixels (Site1d), which has an imaging scale of 45.3 μm/" or 0.53"/pix, a readnoise of 6.6 e- and a gain of 2.33 e-/ADU.[10] The B-200 (blue) and the R-200 (red) grisms were used which yield respectively dispersions of 4.70 $\AA$ and 4.35 $\AA$ per pixel. The spectra was obtained with the B-200 and R-200 grating through a 2" slit, which corresponds to a wavelength coverage from 3200 $\AA$ to 7000 $\AA$ and from 6300 $\AA$ to 11000 $\AA$ respectively, at a spectral resolution of approximately 10 $\AA$.

3 Data Reduction

One has to reduce and analyse the images observed to get the desired information. Before the reduction can begin one has to download the program IRAF, the *Image Reduction and Analysis Facility*, a general purpose software system for the reduction and analysis of astronomical data. There are also a lot of introductory papers and other manuals for reduction that can be downloaded at the IRAF website (www.iraf.net).

3.1 CCD reduction

The first step in the reduction process is to study the data we got. Because of the enormous amount of data, I had to copy the data to:
/net/halley/data/users/ankone.
After studying the images there was confusion, because the images were already trimmed to 1201 x 1650. After email contact the answer was that the spectroscopic images were acquired with a rectangular window [1201, 1650], while the imaging was acquired with a square window [1131, 1131]. This was done because of the slow readout. There was also vignetting: the field of view is a circle on the CCD, smaller than CCD. For this reason the overscan section was not available. This means that the raw images were trimmed during the reading phase directly at the telescope by the control system. To start I had to make a list with all the spectroscopic data. For each night I made a list: the list for the first night I called spectro, for the second night I called spectro1, etcetera. After making the lists, the biassec, datasec and the ccdsec had to be changed, because they were not given in the standard iraf format.
I changed the biassec, datasec and the ccdsec with the following commands:

```
cl> hedit @spectro.lst biassec "[0:0,1:1650]"
(cl> hedit *.fits biassec "[0:0,1:1650]")

cl> hedit @spectro.lst datasec "[400:1600,1:1650]"
(cl> hedit *.fits datasec "[400:1600,1:1650]")

cl> hedit @spectro.lst ccdsec "[400:1600,1:1650]"
(cl> hedit *.fits ccdsec "[400:1600,1:1650]")
```

To see the results, I used the following command:

```
cl> hselect *.fits $I,biassec, datasec, ccdsec yes
```

3.2 ZeroCombine

Bias frames, which are zero second integration exposures, are necessary because they provide information on the underlying signal level (bias level) and the readout noise within each frame. [11]. Each CCD chip has a bias voltage, which assures there will be no negative voltages on the chip. That would effectively decrease the incoming light and would not properly be subtracted.[12] A bias frame can be taken and will be subtracted from an image taken of the sky, which results in an image with count levels that designate the light received from the observing object. To combine all the bias-images to create a Master bias frame, I used the command in the shell:

```
find spectro* -name bias\*.fits> bias.lst
```

To check the mean I used:

```
 cl> imstat @bias.lst
```

This yields an average of circa 437 pixel counts for the first 5 nights and circa 108 pixel counts for the last night. Therefore I made two lists: bias.lst and bias1.lst, first four nights and last night respectively.
Having all the bias frames in a list, I combined the bias frames into an average master bias frame:

```
cl> zerocombine @bias.lst ccdtype="" output="Zero.fits"
cl> zerocombine @bias1.lst ccdtype ="" output="Zero1.fits"
```

The master bias frame, called Zero.fits for the first 5 observing nights and Zero1.fits for the last observing night, was copied in spectro, spectro1, spectro2, spectro3 and spectro4, while the Zero1.fits was copied into spectro5. Once I copied Zero1.fits into spectro5, I changed the name into Zero.fits.
By checking the pixel counts of all raw images, it revealed that subtracting the master bias frames, gave negativevalued spectra for some of the data of the 5^{th} night. After some considerations and email-contact with people who reduced the same images, it was decided that I had to subtract the master bias frame of the last night from the 5^{th} night spectra.

3.3 Flat fielding

Due to the differences in the pixel-to-pixel sensitivity of the detector it is necessary to take flat fields, because this will remove the artifacts from the observing images. By exposing the detector uniformly (during twilight or on the dome using internal lamps) the deviations become visible in an image. This is the flat field.[15] The procedure of making a list of all the flat-fields is the same as described above for the bias frames, with the difference that I created a separate list for each night and seperated those into 2 different kind of lists: blue and red (flatB.lst and flatR.lst).
The flat field is a multiplicative effect, which means that the variations in the amount of light received over the field of view are dependent on the exposure

level and therefore the images have to be divided by a normalized flat field.[14]
After adjusting the datasec to [1:1201, 1:1650] and having knowledge of the readnoise and gain, I used the following commands to combine all the flats for a specific night:

```
cl> flatcombine @flatB.lst ccdtype="" output="FlatB.fits" rdnoise=6,3 gain=2,3
cl> flatcombine @flatR.lst ccdtype="" output="FlatR.fits" rdnoise=6,3 gain=2,3
```

After changing dispaxis into 2, because the spectra were oriented along the y-axis, I had to normalize the master flat fields (FlatB and FlatR) for each night using the response task in the twodspec package:

```
lo> response, FlatB, FlatB, nFlatB, yes
```

The normalized flats were represented as nFlatB and nFlatR.
I normalized the twillight flats (specsky files), that I also divided those into 2 lists: specskyR and specskyB. The spectroscopic images (spss files) were also divided into blue-side and red-side and therefore I created two separate lists for the spectroscopic images: spssB and spssR. Finally I ran ccdproc on the four lists to do the bias subtraction and the flat field division of all the spectroscopic spss files.

3.4 Illumination Correction

For the correction of the data, which were now divided by the flat-fields, I had to do a final correction: an illumination correction. This correction is necessary, because by exposing the detector uniformly against the dome, which is at a finite distance, the image will look different than the real observation, which is at (effectively) an infinite distance. Ideally this correction would thus be the same throughout the whole length of the image. After combining the twilight images the illumination correction can be made with the twodspec.longslit.illum package. After examine the corrected twilight images, I divided all the images by the illumination correction; changing *illumco* in ccdproc to *'yes'*.
Now all the images are zero-, flat- and illumination corrected.

3.5 Spectrum extraction

Extraction is a part in the reduction process where you discard all the information you do not need. Because of our interest in the spectrum of the star, extraction can be done using the *twodspec.apextract.apall* package. Before changing the parameters in *apall*, I had to determine the center of each spectrum and the full width at half maximum (FWHM) to extract the spectra carefully. The table in Appendix A provides information of the center and the FWHM.

Knowing the center and the FWHM, one can extract the spectra adjusting some parameters. (See appendix B). Running the *apall* task a plot is shown which presents the aperture and background regions. If the aperture and the background regions are set right, the extraction can be completed by confirming that the extraction can be made.
The comparison spectra are not presented in Table 2 because they were extracted using the reference parameter in the apall task. Filling in the reference spectrum and changing *background="none"* and *weight="none"* the spectra can be extracted using:

```
ap> apall  ref="" \
    recen- trace- back- interac- find- extras-
```

3.6 Wavelength calibration

The wavelength calibration relates the spectral dimension in pixels to wavelengths. The first step is to identify which comparison lines have what wavelengths with the *onedspec.identify* task. Two parameters in the *identify* task had to be adjusted: *function="legendre"* and *coordlist="spectrolines.dat"*. For the latter parameter, I had to create a list containing the rest wavelength of the CAFOS calibration lamps. (See figure 2 and 3 for the comparison lines of the CAFOS calibration lamps).[10].
I identified the lines in a red-side extracted comparison spectrum and in a blue-side extracted comparison spectrum: spectro/spss0014.ms.fits and spectro/spss0038.ms.fits respectively. Using those two spectra as reference spectra provided me the identification of all the other comparison spectra with the *noao.onedspec.reidentify* task. After renaming the reference spectra to *spss0014ref.ms* and *spss0038ref.ms*, I copied the reference images into the directory of the other nights. After changing the information in the id-files of the reference spectrum, I could also copy them into the directories of the other nights. The final step is to adjust the parameter *refspec1* to specify the reference spectrum:

```
on> hedit spss0014ref.ms refspec1=spss0014ref.ms
```

Whereupon I could run the *reidentify* task:

```
on> reidentify spss0014ref.ms <name of the spectrum>
```

Knowing the dispersion solutions due to the identify-task, the link must be made for the corresponding object spectra. A list of all the object spectra of each night and a table refering to what comparison spectrum refers to which object spectrum must be made in order to relate the comparison spectra to the corresponding object spectra.

Finalizing the wavelength calibration by relating the dispersion solutions to the object spectra provides me the object spectra with the corresponding wavelength scale. Using the *noao.onedspec.dispcor* task:

```
on> dispcor @objectsB.lst
    List of output spectra (d//@objectsR.lst): d//@objectsB.lst
```

the actual object spectra with a correct wavelength scale are now present with a *d* in front of the objects' names.

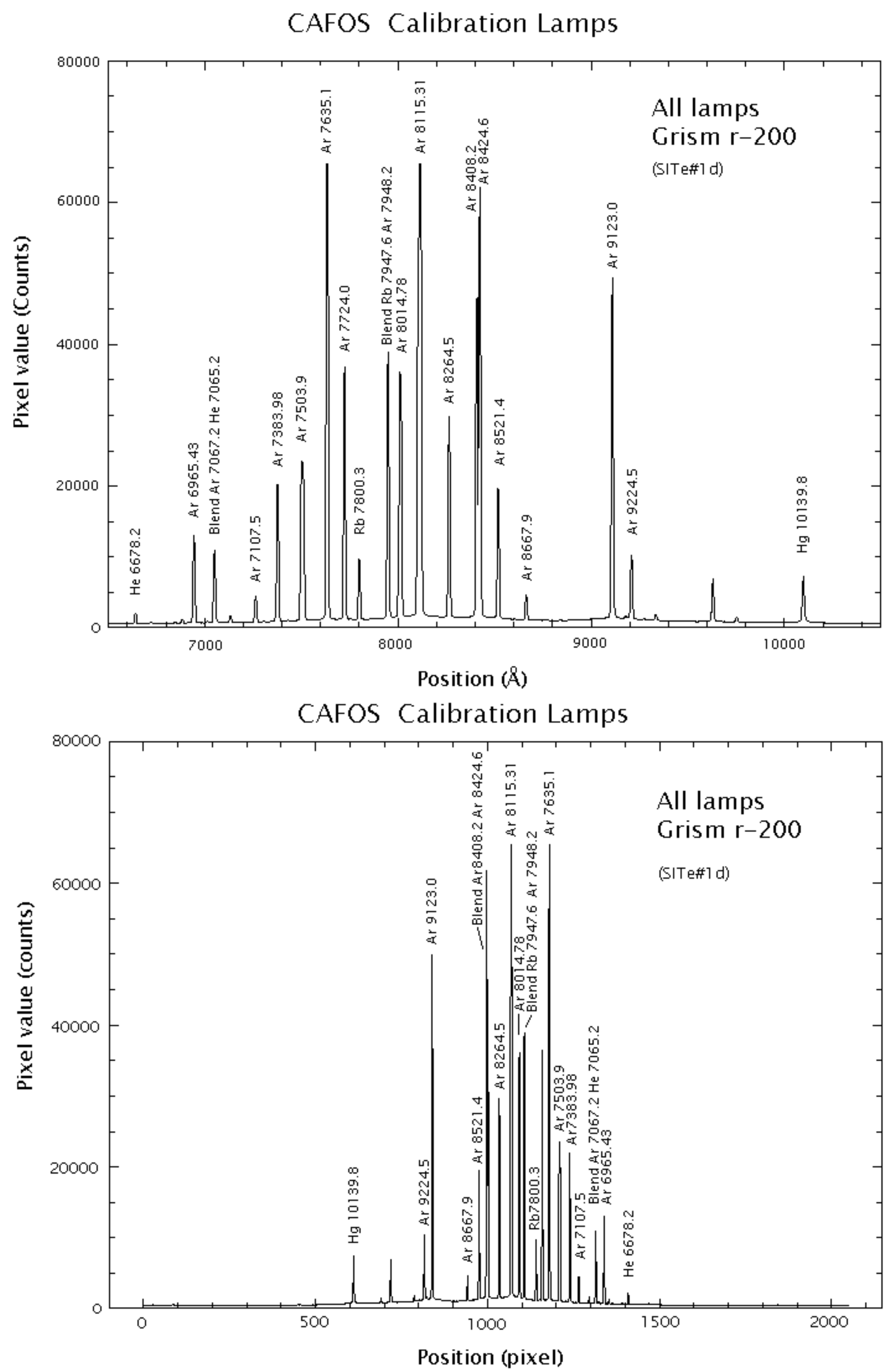
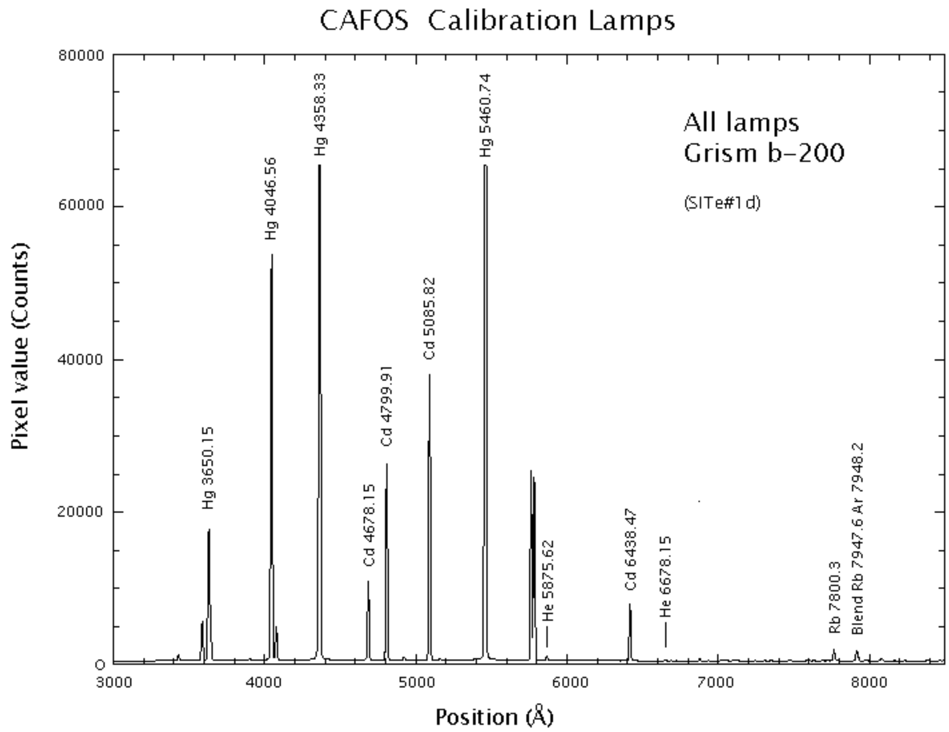


Figure 2: Comparison lines grism r-200



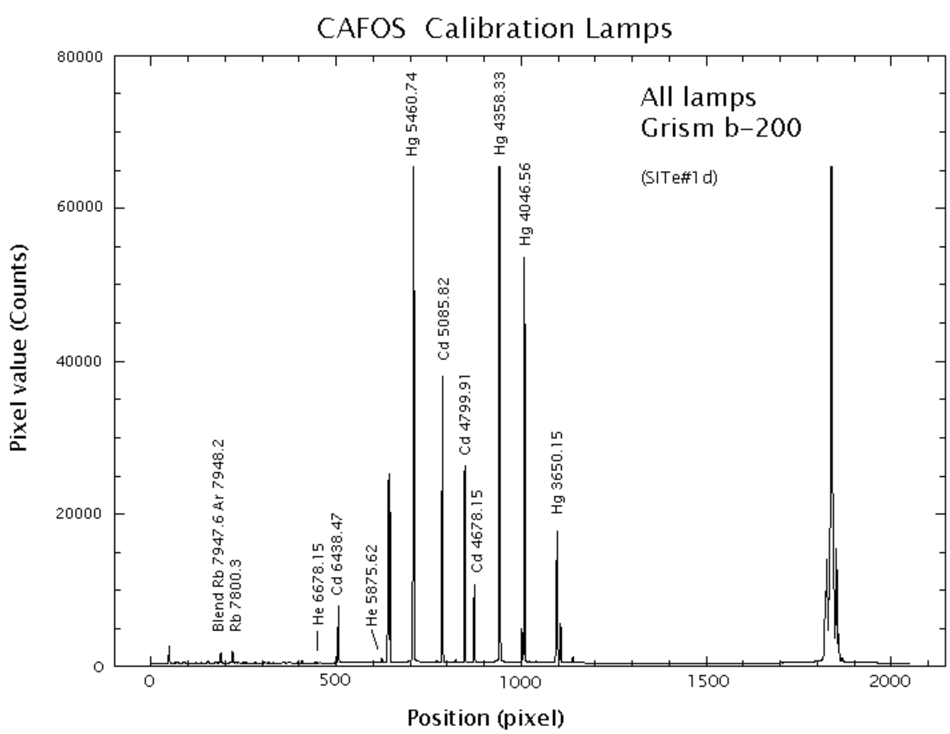


Figure 3: Comparison lines grism b-200

3.7 Flux calibration

Standard stars are a series of stars in which the fluxes are accurately known. Determination of the brightness of the observed object comes from the comparison of the standard star to the observed object. To scale the fluxes in the spectra, I used the standard star G191B2B. To get an acceptable fit of the sensitivity function, I divided the observed spectra of G191B2B into two parts; the first part reaches 3150 $\AA$ to 4500 $\AA$ and the second part has a range of 4000 $\AA$ to 6000 for the B-side. I made similar division of the observed spectra of G191B2B in the R-side: the first part has a range of 6100 $\AA$ to 6800 $\AA$ and the second part from 6600 $\AA$ to 10500 $\AA$. To calibrate the spectra I used the following commands:

```
on> standard @pillarB1.dat stdB1 g191b2bcalspec
```

The *standard* task integrates over the given wavelengths and gives me an output with the associated calibration fluxes, which I have to use in the *sensfunc* task:

```
on> sensfunc stdB1 newext=newextinctionB1.dat
```

This permits me to fit the sensitivity function as a function of wavelength and the determination of the extinction. The final step is to apply the sensitivity function to the data using the *calibrate*-task but first I had to combine the sensitivity function back together:

```
on> scombine sensB1.0001.fits,sensB2.0001.fits output=sensB
on> calibrate @dobjectsB.dat c//@dobjectsB.dat sensB
```

Where *dobjects* is a list containing all the wavelength calibrated observed spectra of objects. The resulting calibrated, wavelength and flux calibrated, spectra are represented by a *cd* in front of their name.

4 Results

Now that all the raw data are reduced and calibrated, I want to compare my spectra of standard stars with the spectra of fundamental flux standards that are used for the calibration of the Hubble Space Telescope (HST).[20]:
`http://stsci.edu/ftp/cdbs/current_calspec`
Figures 4 to 16 present the results, where the solid lines are my reduced and calibrated spectra and the dotted lines are the spectra from the HST. Below each comparison spectrum there is a plot that presents the ratio between the two lines. The ratio was obtained using the *onedspec.sarith* task:

```
on> sarith <observed standard star> / <CALSPEC spectrum>
```

The plots show high fluctuations at wavelengths ~6880 $\AA$ and ~7800 $\AA$, which are telluric lines due to the molecular oxygen in the earth's atmosphere.[15]. Ground based observations and therefore my observations are plagued with those absoption lines which I did not remove. However it is possible to remove them using HITRAN, which is a *hi*gh-resolution *tran*smission molecular absorption database that can simulate the earth's atmosphere.[16] Using HITRAN to simulate the spectrum of the earth's atmosphere as it was at the time of observation would produce telluric lines that could be matched to those in the observed spectrum. Division of the observed spectrum and the simulated atmospheric spectrum could therefore provide a spectrum where the telluric lines are removed.[17].
Examining the plots you are able to see that the RMS scatter is small and the relative accuracy, which is the RMS scatter divided by the average, is also small. (See Table 2). Note however that SA107-544 is not listed in Table 2, because there were no comparison spectra available and that there were no spectra taken in the red side of HZ43.

	blue			**red**		
Star	Ratio	RMS scatter	Relative RMS	Ratio	RMS scatter	Relative RMS
Feige34	0.9	0.014	0.002	2.5	0.014	0.006
G191B2B	0.870	0.008	0.009	0.725	0.007	0.009
Feige66	0.540	0.003	0.006	1.250	0.012	0.009
HZ44	0.910	0.010	0.010	3.750	0.051	0.011
Feige67	0.350	0.016	0.005	0.980	0.013	0.013
HZ43	0.450	0.004	0.008	-	-	-

Table 2: Comparison between ratio, RMS scatter and relative RMS between observed data and the HST data.

The ratio of the spectrum of the standards in the blue side are less than 1. This is acceptable, because light falling in our atmosphere will decrease the amount of light falling in our telescope. Therefore it is logical that the flux of the spectra of the HST will be larger than that of my own. However the logic stops looking at the red side of the spectrum, where the ratio is mostly greater than 1. The conclusion that can be drawn on basis of the plots is that the sky was covered with thick clouds when the G191B2B red spectrum was taken, what leads to a 'too strong' response function, which is the extinction function multiplied with the sensitivity function. If the night during the observation of the red spectrum was indeed covered with thick clouds it would cause a 'too strong' response function compared to what it should have been if the same spectrum was taken at a cloudless night. Applying this response function to the other standards, which are taken with less or even no clouds, the obtained spectra would have more flux than they really should have.

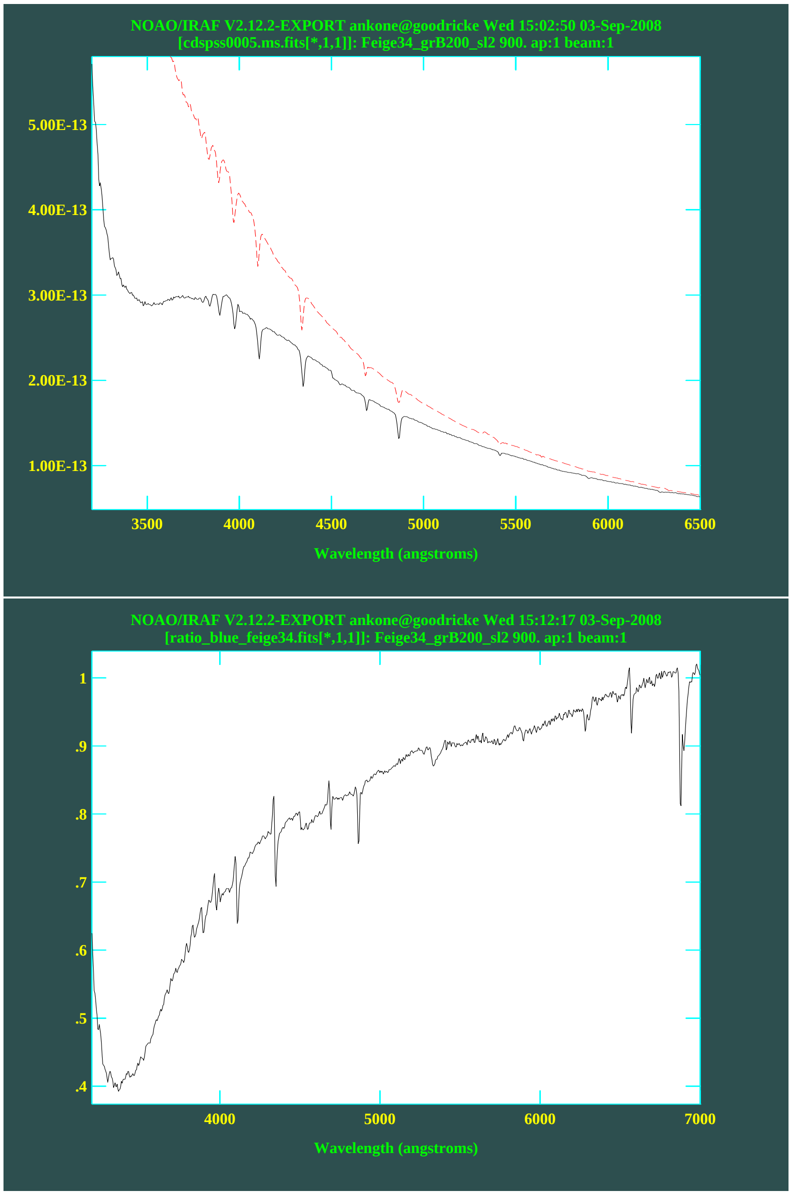


Figure 4: Comparison spectrum and the ratio between the obtained spectrum of Feige34 and from the HST, for the blue side.

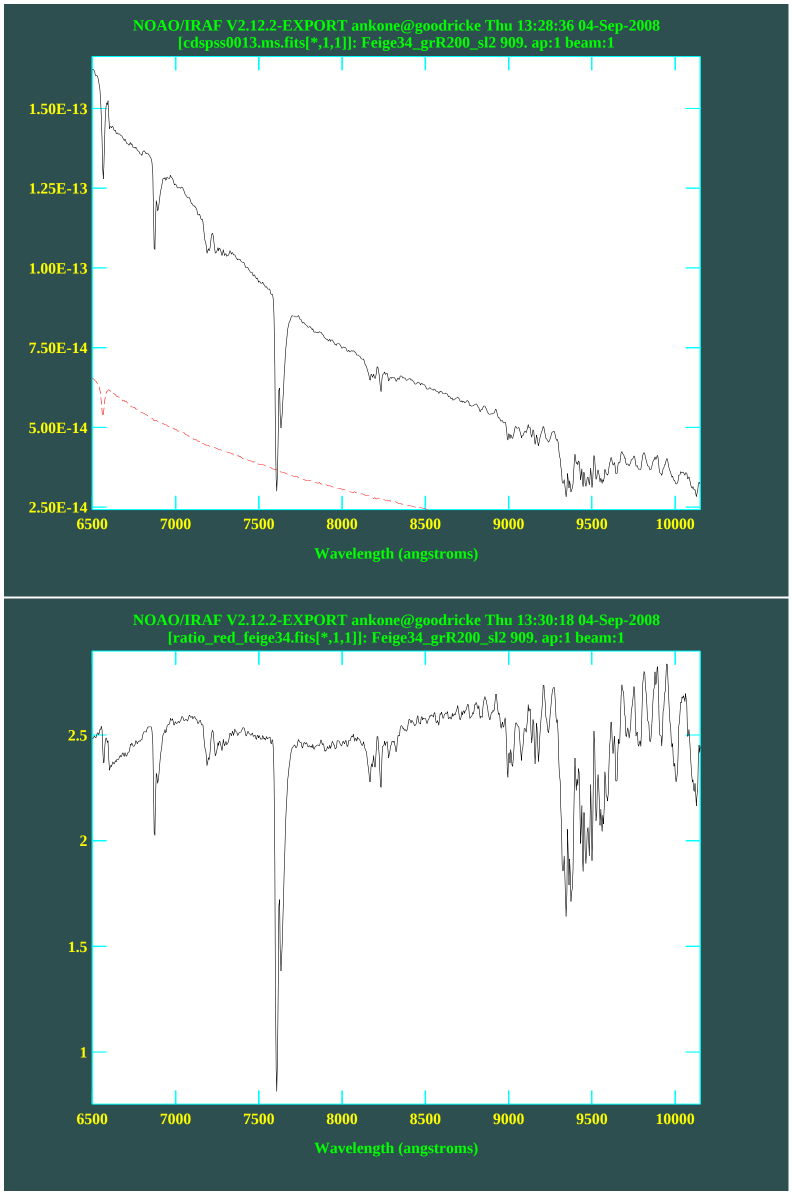


Figure 5: Comparison spectrum and the ratio between the obtained spectrum of Feige34 and from the HST, for the red side.

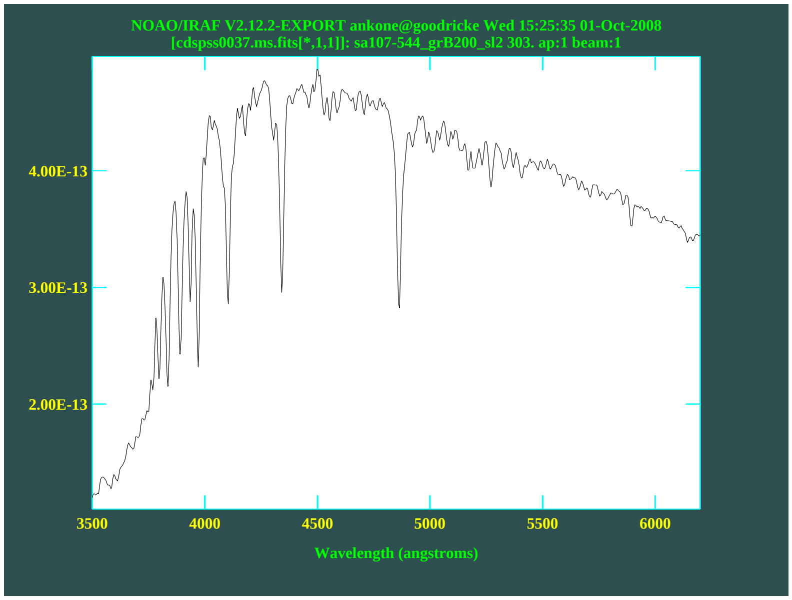


Figure 6: Spectrum of SA107-544, for the blue side (no comparison spectra available).

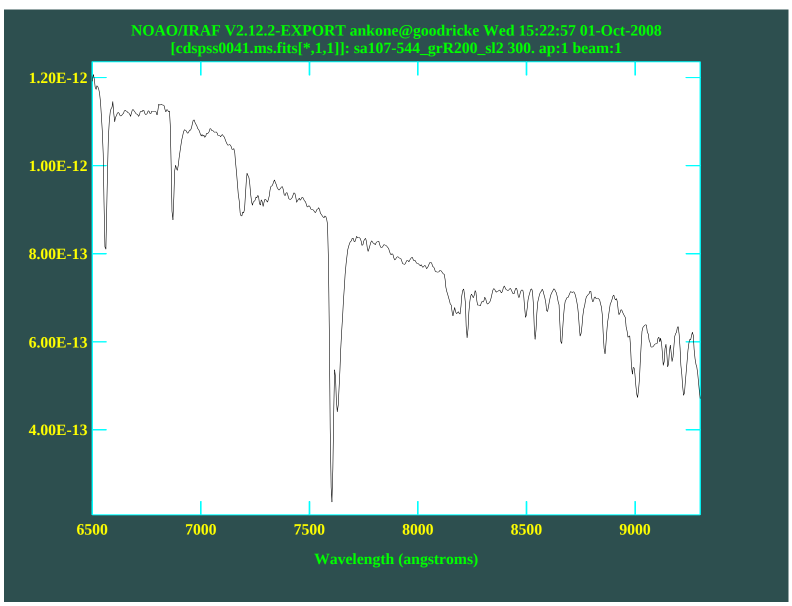


Figure 7: Spectrum of SA107-544, for the red side. (no comparison spectra available)

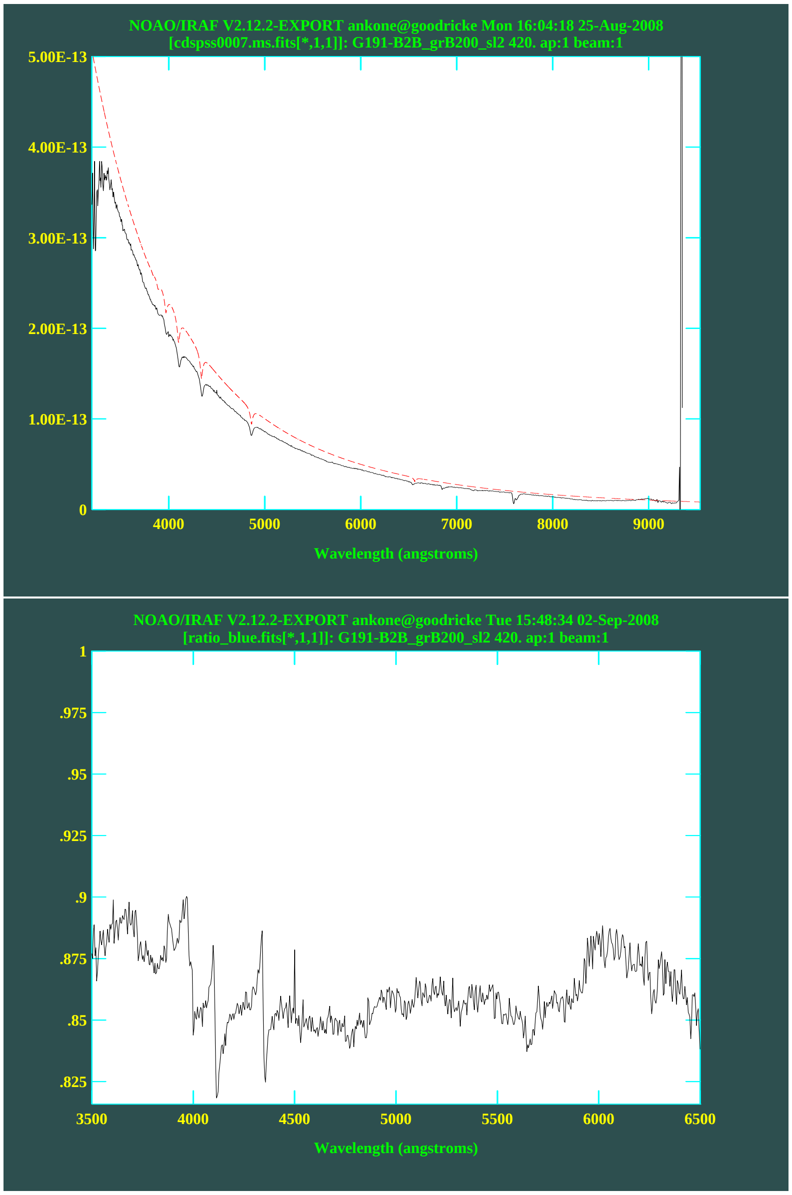


Figure 8: Comparison spectrum and the ratio between the obtained spectrum of G191B2B and from the HST, for the blue side.

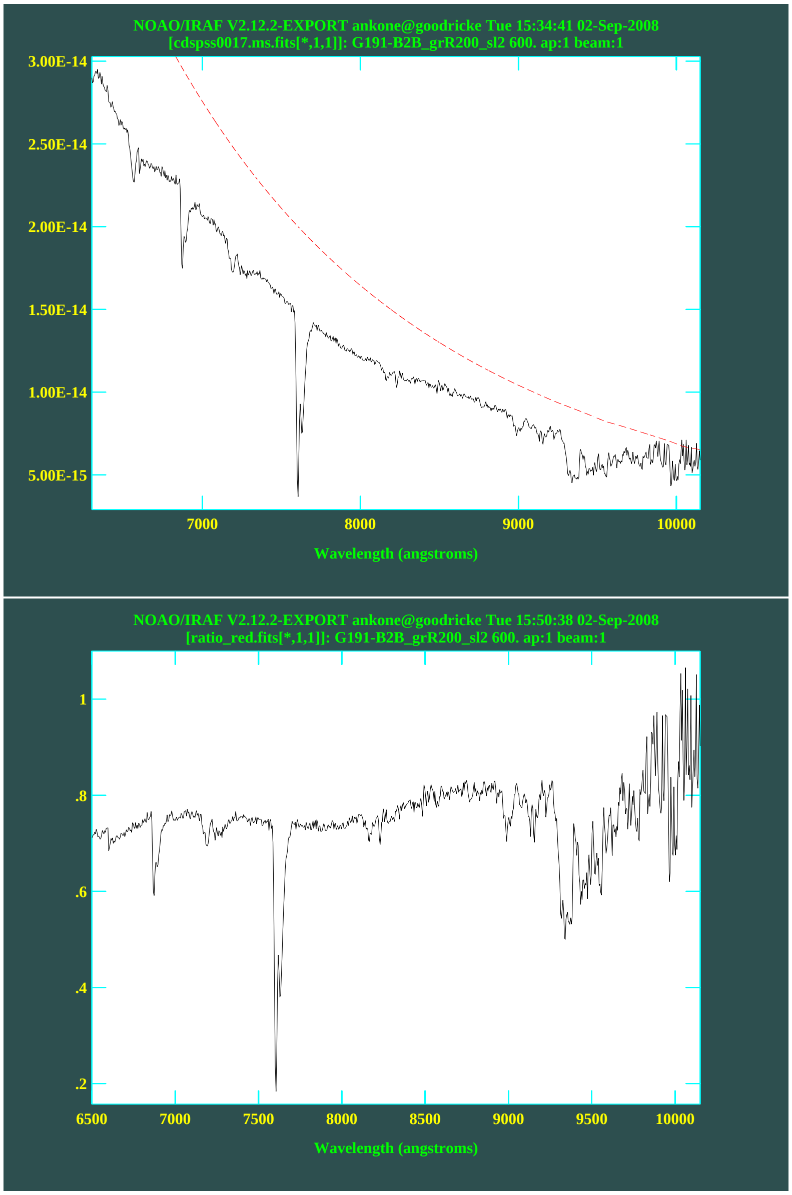


Figure 9: Comparison spectrum and the ratio between the obtained spectrum of G191B2B and from the HST, for the red side.

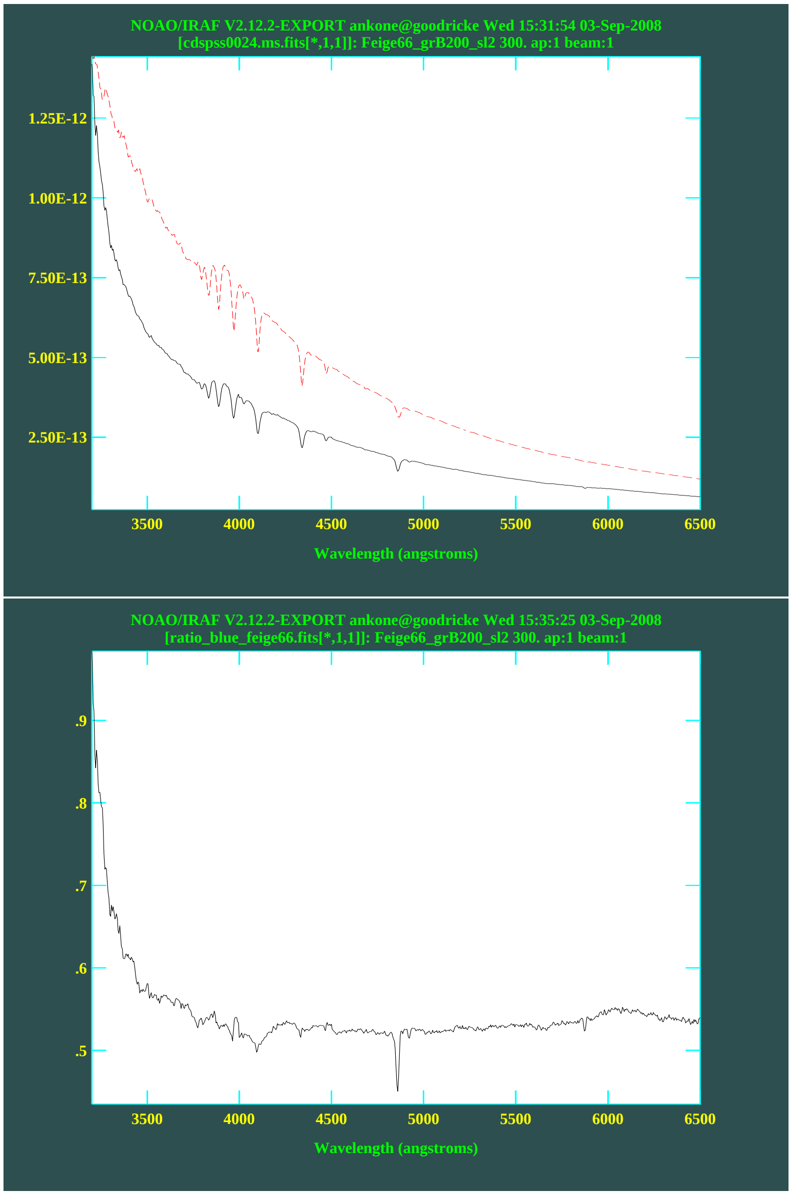


Figure 10: Comparison spectrum and the ratio between the obtained spectrum of Feige66 and from the HST, for the blue side.

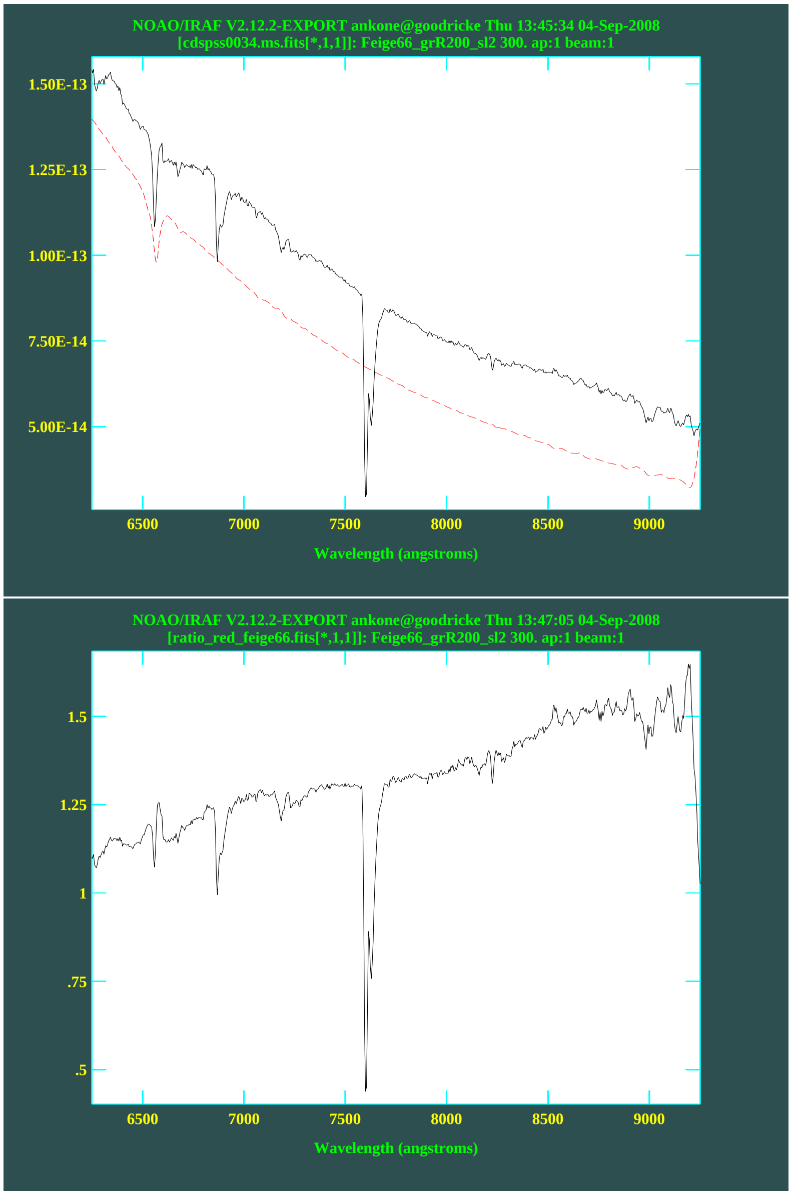


Figure 11: Comparison spectrum and the ratio between the obtained spectrum of Feige66 and from the HST, for the red side.

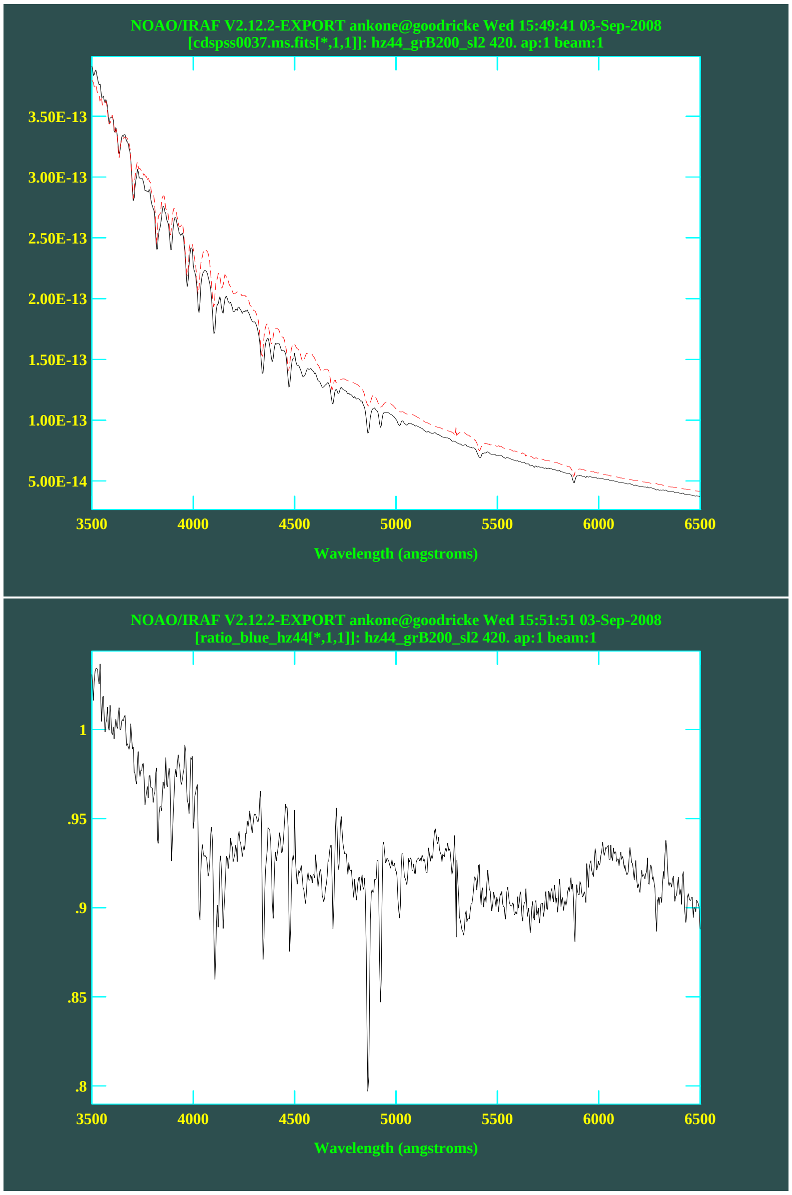


Figure 12: Comparison spectrum and the ratio between the obtained spectrum of HZ44 and from the HST, for the blue side.

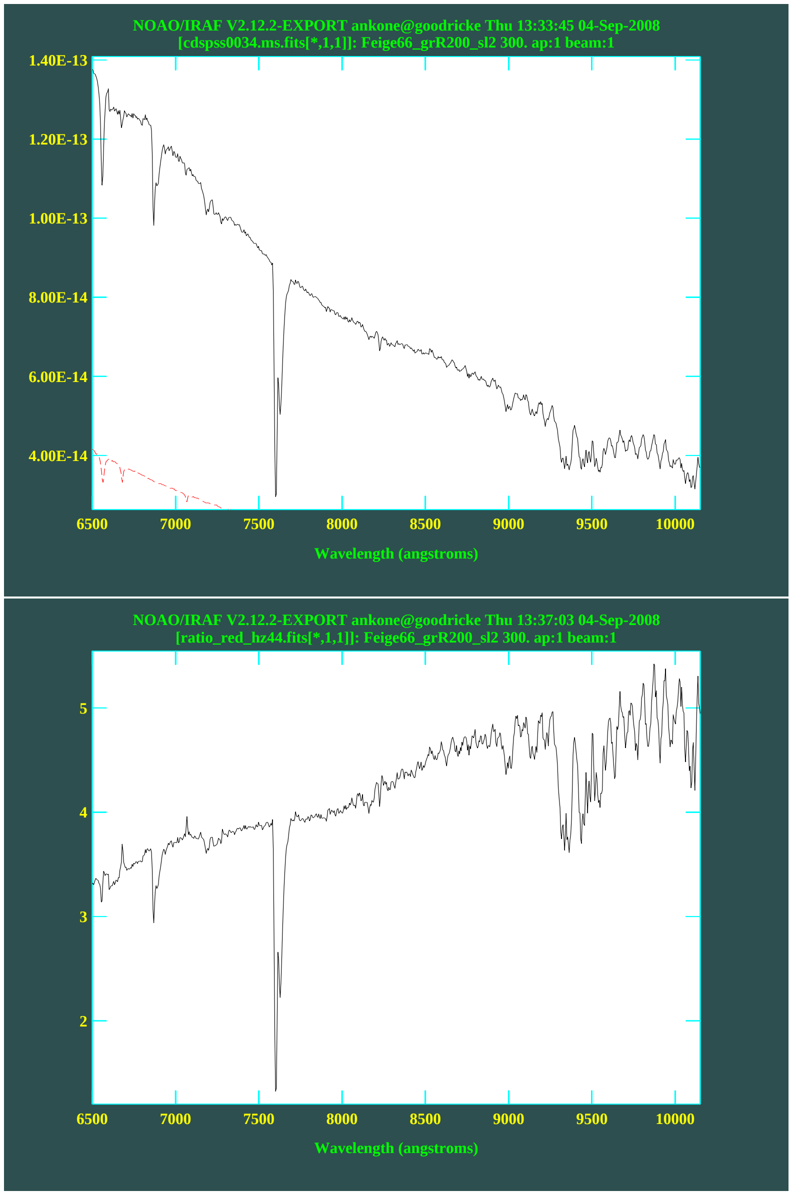


Figure 13: Comparison spectrum and the ratio between the obtained spectrum of HZ44 and from the HST, for the red side.

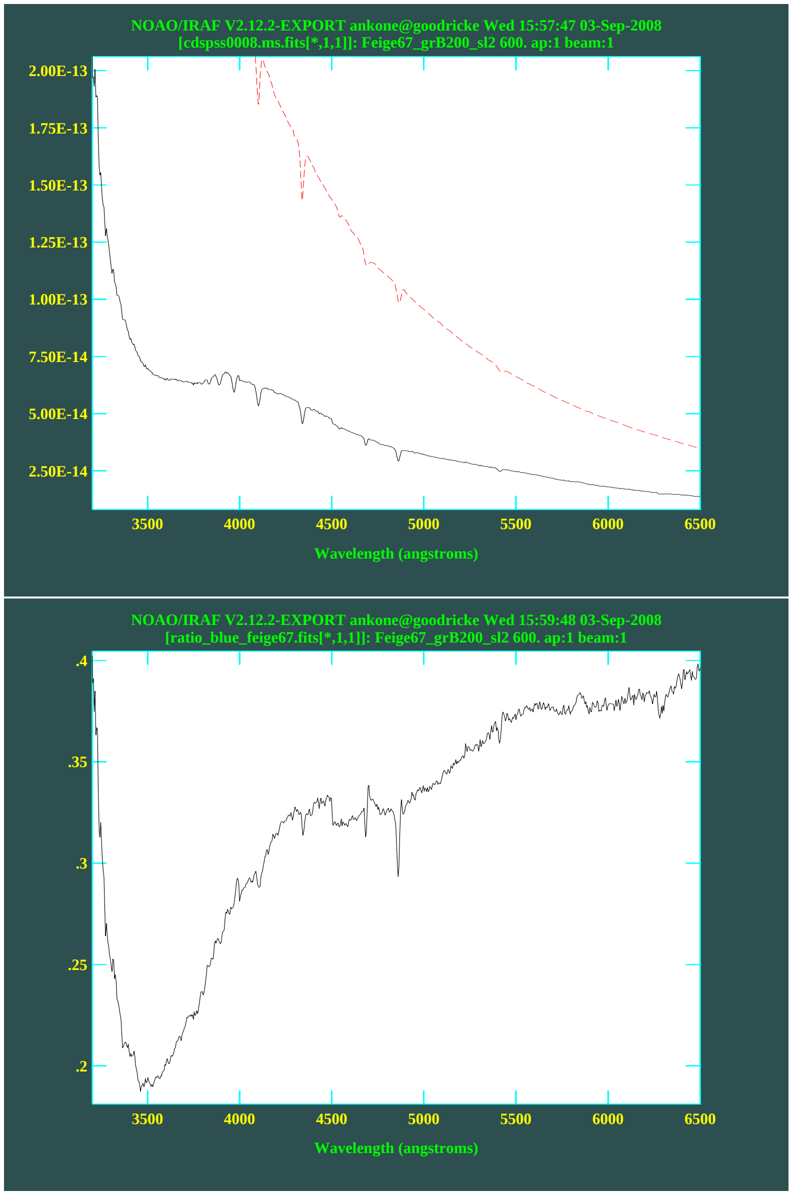


Figure 14: Comparison spectrum between the obtained spectrum of Feige67 and from the HST, for the blue side.

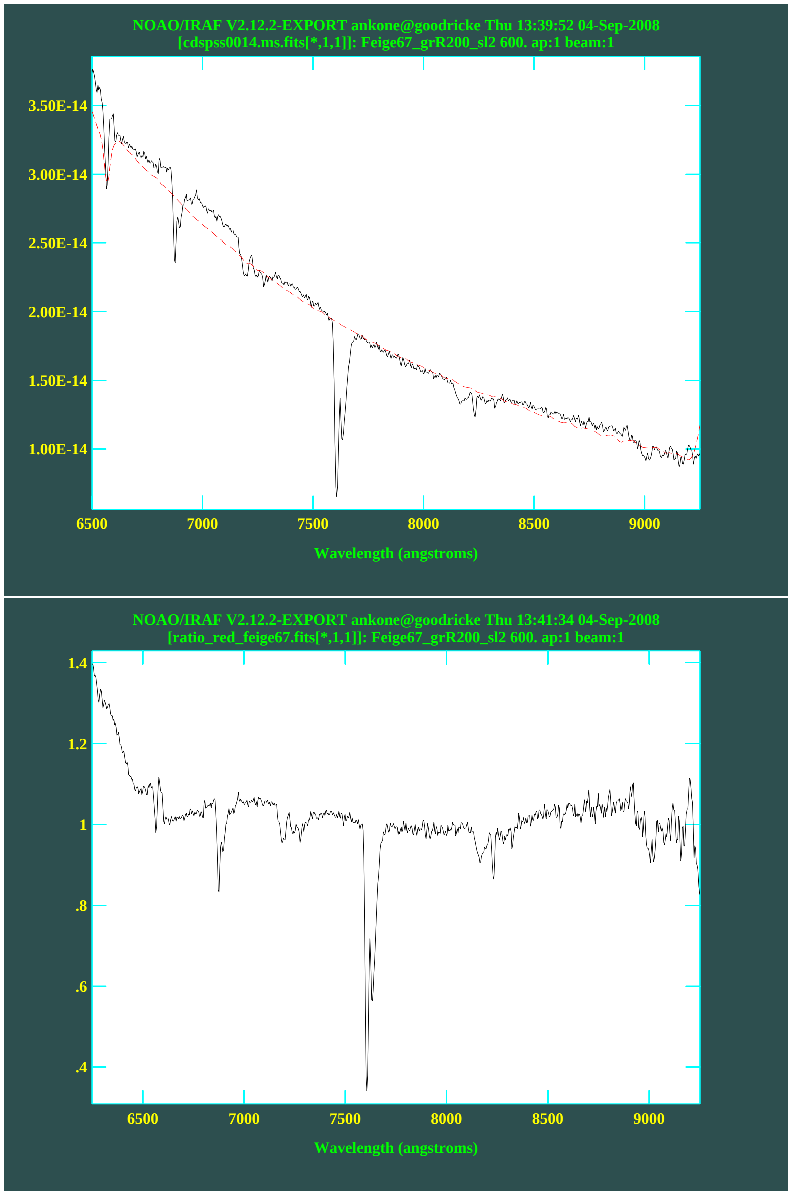


Figure 15: Comparison spectrum between the obtained spectrum of Feige67 and from the HST, for the red side.

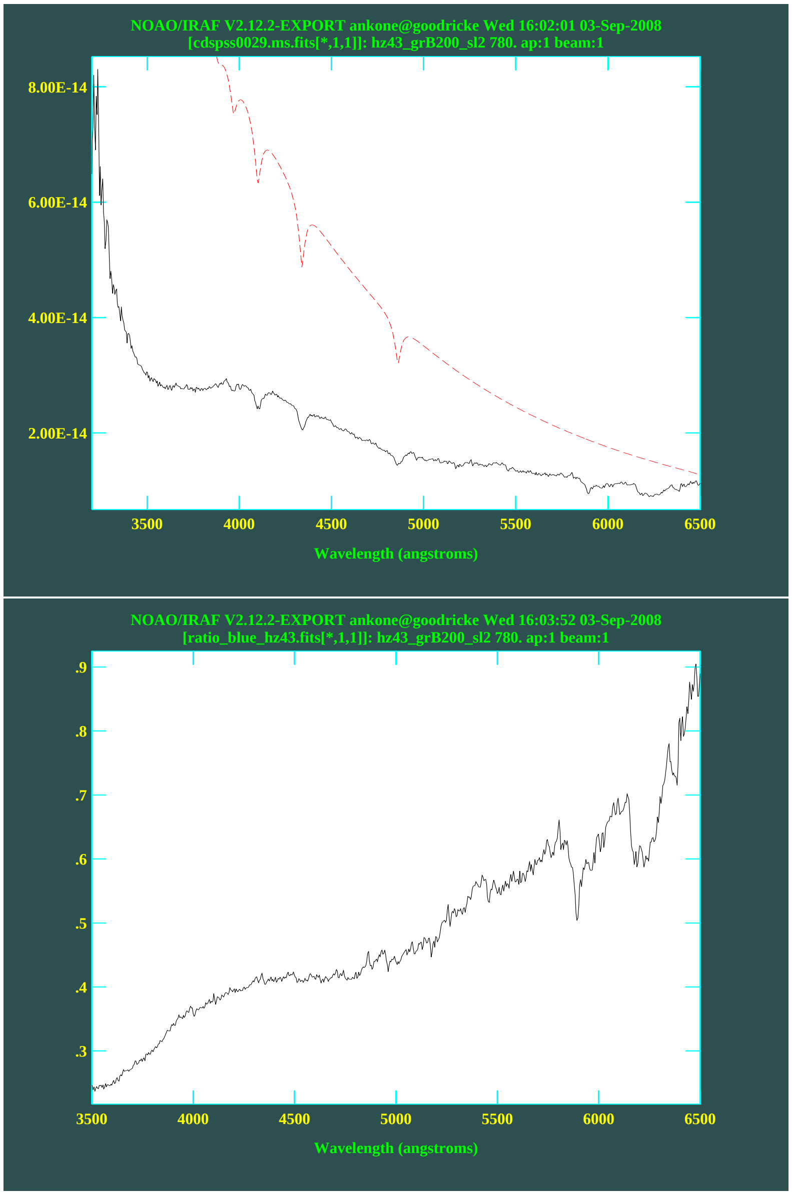


Figure 16: Comparison spectrum and the ratio between the obtained spectrum of HZ43 and from the HST, for the blue side.

5 Conclusion

The aim of the project was to determine the absolute fluxes of stars for use as calibrators in the photometric reduction of data from GAIA.
I reduced and calibrated the observed data using IRAF, where the wavelength calibration was done using arc lamps available at CAFOS: HgCdAr, He and Rb [10] while the wavelength calibration was done using the standard star G191B2B. To scale the flux a sensitivity function is created and applying this function to the other observed standard stars provides me the observed data to be reduced and calibrated. Comparison between the obtained data and the data of the HST indicate a cloudy night during the observations of the red spectrum of G191B2B. The relative accuracy is about 1% which enables spectrophotometry with very high accuracy.
Future observations should therefore be done during a cloudless night to obtain a different response function, which should lead to even more accurate results.

Appendix A

Center and FWHM of the comparison spectra		
	Center	FWHM
Spectro:		
spss0005.fits	605	2.87
spss0006.fits	605	2.70
spss0010.fits	605	2.69
spss0013.fits	611	2.67
spss0017.fits	611	3,16
spss0019.fits	611	3,49
spss0037.fits	604	6.34
spss0041.fits	610	4.37
spss0043.fits	610	4.72
spss0044.fits	610	4.73
spss0047.fits	606	5.05
Spectro3:		
spss0006.fits	535	4.60
spss0007.fits	602	5.56
spss0010.fits	602	5.15
spss0011.fits	602	6.34
spss0012.fits	602	5.54
spss0016.fits	613	5.88
spss0017.fits	613	5.33
spss0024.fits	604	4.20
spss0034.fits	614	3.90
spss0037.fits	604	4.10
spss0039.fits	604	3.87
spss0042.fits	611	3.00
spss0044.fits	610	3.16
spss0045.fits	610	3.84
spss0047.fits	606	3.76
Spectro4		
spss0008.fits	606	6.60
spss0010.fits	606	5.93
spss0011.fits	605	5.41
spss0014.fits	611	4.50
spss0016.fits	612	4.07
spss0017.fits	611	4.54
spss0020.fits	606	6.30
spss0021.fits	606	4.90
spss0023.fits	606	5.02
spss0024.fits	612	4.50
spss0025.fits	611	3.70
spss0027.fits	611	4.80
spss0029.fits	606	4.90
spss0032.fits	602	5.40
spss0033.fits	603	6.40

Appendix B

I R A F noao.onedspec.apextract.apall

PACKAGE = apextract	
Task = apall	
input =	<filename>
(output =	)
(apertur =	)
(format =	multispec)
(reference =	)
(profile =	)
(interac =	yes)
(find =	yes)
(recente =	yes)
(resize =	no)
(edit =	yes)
(trace =	yes)
(fittrac =	yes)
(extract =	yes)
(review =	yes)
(line =	<center>)
(nsum =	10)
#DEFAULT APERTURE PARAMETERS	-2.5*FWHM)
(lower =	2.5*FWHM)
(upper =	)
(apidtab =	
#DEFAULT BACKGROUND PARAMETERS	
(b_funct =	chebyschev)
(b_order =	3)
(b_sample =	-30:-15,15:300
(b_naver =	-3)
(b_niter =	0)
(b_low_r =	3.)
(b_high_r =	3.)
(b_grow =	0.)
#APERTURE CENTERING PARAMETERS	
(width =	5.)
(radius =	10.)
(thresho =	0.)
#AUTOMATIC FINDING ORDERING PARAMETERS	
nfind =	1
(minsep =	5.)
maxsep =	1000.)
order =	increasing)
#RECENTER PARAMETERS	
(aprecen =	)
(npeaks =	INDEF)
(shift =	yes)
#RESIZING PARAMETERS	
(llimit =	INDEF)
(ulimit =	INDEF)
(ylevel =	0.1)
(peak =	yes)
(bkg =	yes)
(r_grow =	0.)
(avglimi =	no)
#TRACING PARAMETERS	
(t_sum =	10)
(t_step =	10)
(t_lost =	3)
quitting =	
(t_funct =	legendre)
(t_order =	2)
(t_sample =	500:1500)
(t_naver =	1)
(t_niter =	0)
(t_low_r =	3.)
(t_high_r =	3.)
(t_grow =	0.)
#EXTRACTION PARAMETERS	
(backgro =	median)
(skybox =	10)
(weights =	variance)
(pfit =	fit1d)
(clean =	yes)
(saturat =	INDEF)
(readnoi =	6.3)
(gain =	2.3)
(lsigma =	4.)
(usigma =	4.)
(nsubaps =	1)
(mode =	q1)

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- A User's Guide to CCD Reductions with IRAF, Phil Massey, February 1997
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For the Images in the report I used the following websites:

- http://blogs.warwick.ac.uk/janedouglas/gallery/esa_estec_and_gaia/
- http://www.astro.rug.nl/