extra_solar_lab

October 31, 2022

0.1 Extra Solar Planets Lab record

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Start by importing all the relevant packages.

[209]:
```
import numpy as np      # Used for mathematical operations
import scipy as sp      # Used for manipulating data and functions
import matplotlib.pyplot as plt     # Used for plotting
import extra_solar_functions as es      # A script supplied from the a2 folder␣
 ↪defining a complex function
import os      # Used for operations on directories
```

The aims for the first method of this experiment (The Doppler Wobble Method) are

To understand the effect of Doppler Shifts on the intensity of stellar spectra and use the sp.optimize library to determine best-fits for radial velocities from high resolution observed on different dates

Derive radial velocity Curves for each star and use sp.optimize.curve_fit to estimate the amplitude of each curve

Estimate the mass and semi-major axis of each planet

Useful Equations for the First method given in the labscript

You need a background section which gives some context to the lab. This should explain the background science to lab, ie what the doppler wobble method is and how it works.

It doesn't have to be as in depth as the lab script, but should explain the basic processes.

$$v_s = (\frac{2\pi G}{T})^{1/3} M_S^{-2/3} m_p$$

(Equation 1)

$$v_{pred} = v_{mean} + v_s \cos[2\pi(\phi_{obs} - \phi_{max})]$$

(Equation 2)

$$G(M_S + m_p) = \frac{4\pi^2 a^3}{T^2}$$

(Equation 3) Where the symbols take there usual values and ϕ is the phase

you need to explain all symbols and what they mean.

1 Method 1 The Dobbler Wobble Technique

2 1.1 Task 1

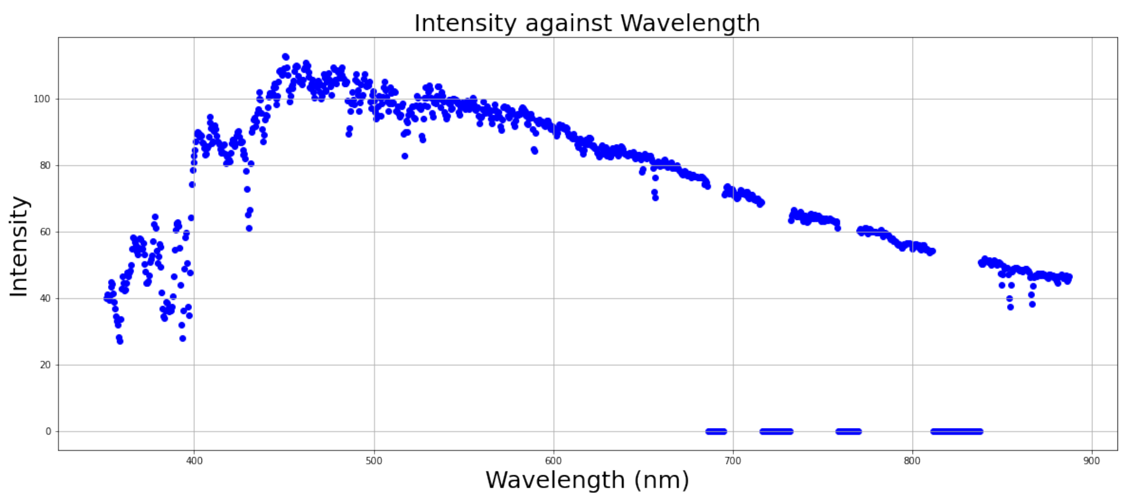
In this task we are expected to import the template data set and do an initial plot of this ideal data to obtain a graph of the intensity with respect to the wavelength

[210]:
```
data = np.loadtxt('G5V_template.txt') # Import data for the G5V star
```

[211]:
```
wavelength = data[:,0]      # Split data into respective columns and define them
intensity = data[:,1]
```

[212]:
```
text_size_plots = 25    # sets a base text size for all plots and enable them to change all at once
```

[159]:
```
plt.figure(figsize=(44,8))    # plot the reference data fom above to graphical show the data and its relation

plt.subplot(121)
plt.scatter(wavelength,intensity,marker="o",color="b",)
plt.grid(True)
plt.title("Intensity against Wavelength", size=text_size_plots)
plt.xlabel("Wavelength (nm)", size=text_size_plots)
plt.ylabel("Intensity", size=text_size_plots)

plt.show()
```



fonts too small

3 1.1 Task 2

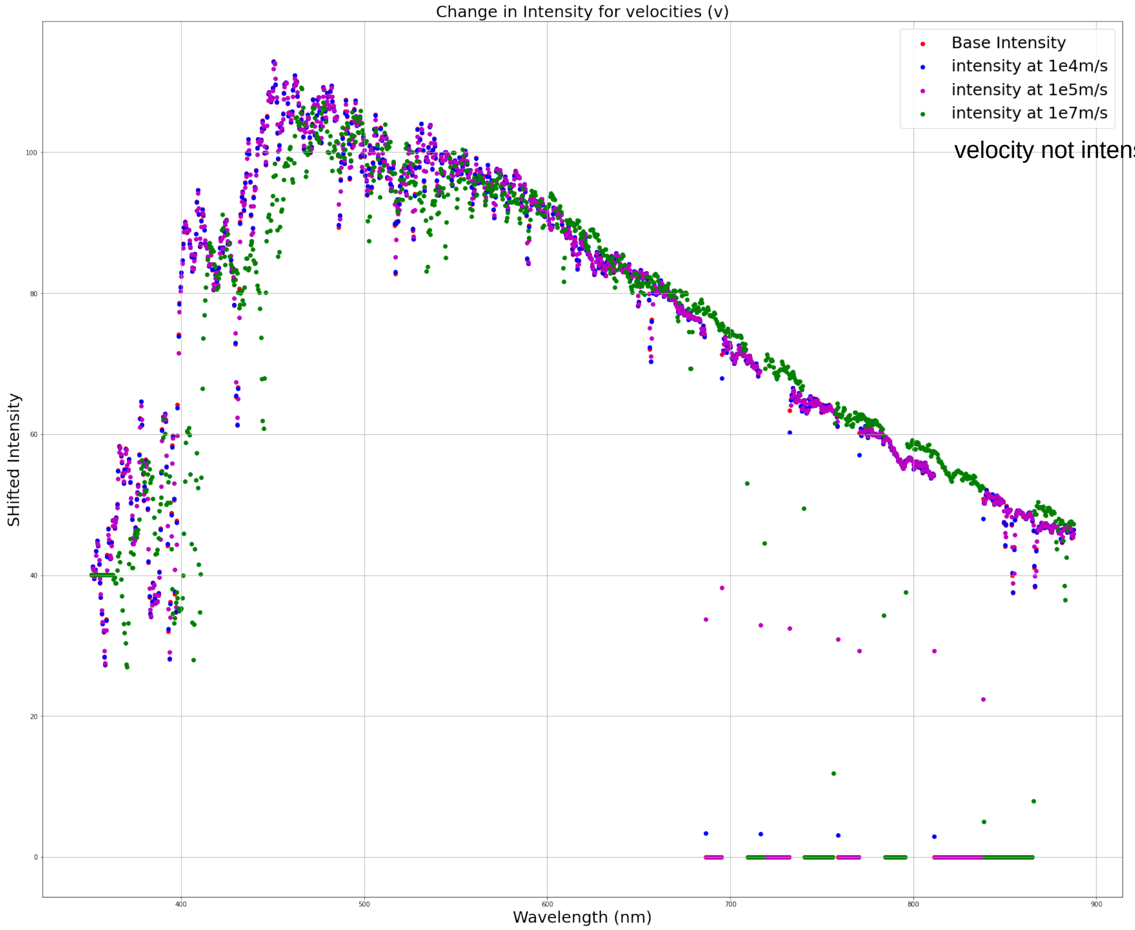
In this task we are expected to calculate shifted spectra using the function labelled ‘es’ provided at some different radial velocities and determine graphically when there is a noticable difference in the shifted spectrum   you can go into more detail about shift spectrum does

[160]:
```
shift_i1 = es.shiftSpectrum(wavelength,intensity,1)
shift_i2 = es.shiftSpectrum(wavelength,intensity,10000)
shift_i3 = es.shiftSpectrum(wavelength,intensity,100000)
shift_i4 = es.shiftSpectrum(wavelength,intensity,10000000)
```

```
# Uses the given function to shift the intensity of the star by some reference␣
 ↪velocity which is given by the third term
```

These comments are good, but we don't mark them. you need to make them in the text section

[161]:
```
# Plot the reference wavelength against the new shifted intensity 4 times for␣
 ↪different velocities on the same graph

plt.figure(figsize=(30,25))
plt.scatter(wavelength,shift_i1,marker="o",color="r", label='Base Intensity')
plt.scatter(wavelength,shift_i2,marker="o",color="b", label='intensity at 1e4m/
 ↪s')
plt.scatter(wavelength,shift_i3,marker="o",color="m",label='intensity at 1e5m/
 ↪s')
plt.scatter(wavelength,shift_i4,marker="o",color="g",label='intensity at 1e7m/
 ↪s')

plt.grid(True)
plt.title("Change in Intensity for velocities (v)", size=text_size_plots)
plt.xlabel("Wavelength (nm)", size=text_size_plots)
plt.ylabel("SHifted Intensity", size=text_size_plots)
plt.legend(fontsize=text_size_plots)
plt.show()
```



velocity not intensity

Difference in Spectra due to different Radial Velocities
For velocities v < 1e5m/s there is negligible difference in shifted spectra, as shown by the blue data set in reference to the red data

For velocities 1e5m/s < v < 1e7m/s there is noticeable but not huge difference in shifted spectra, the magenta data is slightly different from the red data

For velocities v > 1e7m/s there is a large difference in shifted spectra from the base value as seen by the green data being significantly different from the red data good

4 1.2 Task 1

For this task we are expected to open a file containing the template data for the G5V star as well as a column of the actual observed intensity of the star, this data can then be used in an optimize.curve_fit function to obtain the expected radial velocity of the star on the julian date specified in the filename in this case Julian date 2451460 and add the error to it that is given in the lab script

ideally you have few more words here explaining your function and importantly what guess you used in the curve fit and the motivation behind the guess.

[162]:
```
# Load new data into the notebook and format it so that the third column is
↪defined as the actual intensity of the star

JD51460_data = np.loadtxt('JD51460.txt')
JD51460Inten = JD51460_data[:600,2]
```

[163]:
```
#Limiting the reference data to be for all values less than wavelengths of
↪650nm, as there are inconsistencies above this

wavelength_600 = data[:600,0]
intensity_600 = data[:600,1]
```

[164]:
```
# Using the given function es.shiftspectrum we define a function that will vary
↪the velocity and use the sp.optimize.curve_fit function to
# find the optimal line of best fit for the actual data when using the
↪theorectical data as a reference

def shiftedintensity(wavelength_600,velocity):
    return es.shiftSpectrum(wavelength_600,intensity_600,velocity)
popt,_ = sp.optimize.curve_fit(shiftedintensity,wavelength_600,JD51460Inten,
↪p0=(20000))
```

[165]:
```
print('The radial velocity of the star that provides the best curve fit is {0:.
↪2f}m/s ± 15m/s'.format(popt[0]))
# best fit solution for shifted data
```

```
The radial velocity of the star that provides the best curve fit is 21821.23m/s
± 15m/s
```
good

5 1.2 Task 2

This task is a repeat of the task above but for all the data sets on different julian dates and for both the stars this uses the python techniques of 'for loops' and 'def' to increase efficiency as it means we do not need to write the same code 60 times.

[166]:
```
# Import the directory of data containing all the data for the first star and
↪extract this data into the relevant columns
# Carry out the curve_fit optimisation for this array of data and print each
↪optimal velocity next to the corresponding julian date along with the error
↪that was given in the lab script


path = "/home/2663452m/examples/a2/extra_solar_data/HD-28185/"
file_list = sorted(os.listdir(path))

datesG5 = [0]
radvel_5 = [0]
```

```
for file in file_list:
    filename = path + file
    data_wavelength,data_intensity=np.
 ↪loadtxt(filename,unpack=True,usecols=[0,2])
    data_wavelength600 = data_wavelength[:600]
    data_intensity600 = data_intensity[:600]



    def shiftedintensity(data_wavelength600,velocity):
        return es.shiftSpectrum(data_wavelength600,intensity_600,velocity)
    popt,_ = sp.optimize.
 ↪curve_fit(shiftedintensity,data_wavelength600,data_intensity600, p0=(20000)␣
 ↪, absolute_sigma=True)
    date = (file[2:7])

    datesG5.append(date)
    radvel_5.append(popt[0])

    print(f'On Julian date 24{date} the best fit radial velocity is {popt[0]:.
 ↪2f}m/s with a radial velocity uncertainty of ±15m/s')
```

```
On Julian date 2451460 the best fit radial velocity is 21821.23m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451475 the best fit radial velocity is 21821.05m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451490 the best fit radial velocity is 21855.97m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451500 the best fit radial velocity is 21851.69m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451520 the best fit radial velocity is 21859.15m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451548 the best fit radial velocity is 21821.05m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451575 the best fit radial velocity is 21786.18m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451580 the best fit radial velocity is 21788.01m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451627 the best fit radial velocity is 21753.69m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451780 the best fit radial velocity is 21788.05m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451785 the best fit radial velocity is 21788.05m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451790 the best fit radial velocity is 21788.05m/s with a radial
velocity uncertainty of ±15m/s
```

```
On Julian date 2451800 the best fit radial velocity is 21818.97m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451840 the best fit radial velocity is 21835.86m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451842 the best fit radial velocity is 21838.48m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451846 the best fit radial velocity is 21840.77m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451850 the best fit radial velocity is 21851.69m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451870 the best fit radial velocity is 21846.74m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451875 the best fit radial velocity is 21854.00m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451910 the best fit radial velocity is 21846.74m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451925 the best fit radial velocity is 21821.05m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451930 the best fit radial velocity is 21838.81m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451970 the best fit radial velocity is 21793.49m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451975 the best fit radial velocity is 21778.48m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451978 the best fit radial velocity is 21771.07m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451980 the best fit radial velocity is 21777.40m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451982 the best fit radial velocity is 21760.64m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451985 the best fit radial velocity is 21758.93m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2451986 the best fit radial velocity is 21757.21m/s with a radial
velocity uncertainty of ±15m/s
On Julian date 2452175 the best fit radial velocity is 21789.58m/s with a radial
velocity uncertainty of ±15m/s
```

[167]:
```
# Import the directory of data containing all the data for the second star and
 ↪extract this data into the relevant columns
# Carry out the curve_fit optimisation for this array of data and print each
 ↪optimal velocity next to the corresponding julian date along with the error
 ↪that was given in the lab script



G8_data = np.loadtxt('G8V_template.txt')
G8_wavelength = G8_data[:,0]
```

```python
G8_intensity = G8_data[:,1]
G8_wavelength600 = G8_wavelength[:600]
G8_intensity600 = G8_intensity[:600]

datesG8 = [0]
radvel_8 = [0]

path = "/home/2663452m/examples/a2/extra_solar_data/HD-73256/"
file_list = sorted(os.listdir(path))
for file in file_list:
    filename = path + file
    data_wavelength,data_intensity=np.
 ↪loadtxt(filename,unpack=True,usecols=[0,2])
    data_wavelength600 = data_wavelength[:600]
    data_intensity600 = data_intensity[:600]



    def shiftedintensity(data_wavelength600,velocity):
        return es.shiftSpectrum(data_wavelength600,G8_intensity600,velocity)
    popt,_ = sp.optimize.
 ↪curve_fit(shiftedintensity,data_wavelength600,data_intensity600, p0=(20000)␣
 ↪, absolute_sigma=True)
    date = (file[2:12])

    datesG8.append(date)
    radvel_8.append(popt[0])

    print(f'On julian date 24{date} the best fit radial velocity is {popt[0]:.
 ↪2f}m/s with a radial velocity uncertainty of ±15m/s')
```

```
On julian date 2452640.0300 the best fit radial velocity is 13593.84m/s with a
radial velocity uncertainty of ±15m/s
On julian date 2452641.5800 the best fit radial velocity is 13363.37m/s with a
radial velocity uncertainty of ±15m/s
On julian date 2452646.7772 the best fit radial velocity is 13375.04m/s with a
radial velocity uncertainty of ±15m/s
On julian date 2452648.1557 the best fit radial velocity is 13562.99m/s with a
radial velocity uncertainty of ±15m/s
On julian date 2452653.8929 the best fit radial velocity is 13392.28m/s with a
radial velocity uncertainty of ±15m/s
On julian date 2452655.3315 the best fit radial velocity is 13598.76m/s with a
radial velocity uncertainty of ±15m/s
On julian date 2452656.0715 the best fit radial velocity is 13484.73m/s with a
radial velocity uncertainty of ±15m/s
On julian date 2452658.0901 the best fit radial velocity is 13598.76m/s with a
radial velocity uncertainty of ±15m/s
```

On julian date 2452659.6501 the best fit radial velocity is 13399.27m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452667.3758 the best fit radial velocity is 13411.26m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452669.1344 the best fit radial velocity is 13402.90m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452670.7630 the best fit radial velocity is 13601.90m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452674.6715 the best fit radial velocity is 13371.57m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452676.5601 the best fit radial velocity is 13445.90m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452678.8987 the best fit radial velocity is 13511.48m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452688.8730 the best fit radial velocity is 13569.91m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452695.0502 the best fit radial velocity is 13362.75m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452696.0502 the best fit radial velocity is 13593.84m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452699.9573 the best fit radial velocity is 13363.37m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452703.0259 the best fit radial velocity is 13428.13m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452706.8531 the best fit radial velocity is 13539.27m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452712.9302 the best fit radial velocity is 13368.86m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452730.2803 the best fit radial velocity is 13402.90m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452735.6275 the best fit radial velocity is 13363.37m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452738.8260 the best fit radial velocity is 13432.90m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452744.0732 the best fit radial velocity is 13484.73m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452748.2204 the best fit radial velocity is 13383.79m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452777.2147 the best fit radial velocity is 13493.43m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452789.8576 the best fit radial velocity is 13459.19m/s with a radial velocity uncertainty of ±15m/s
On julian date 2452817.9320 the best fit radial velocity is 13468.27m/s with a radial velocity uncertainty of ±15m/s

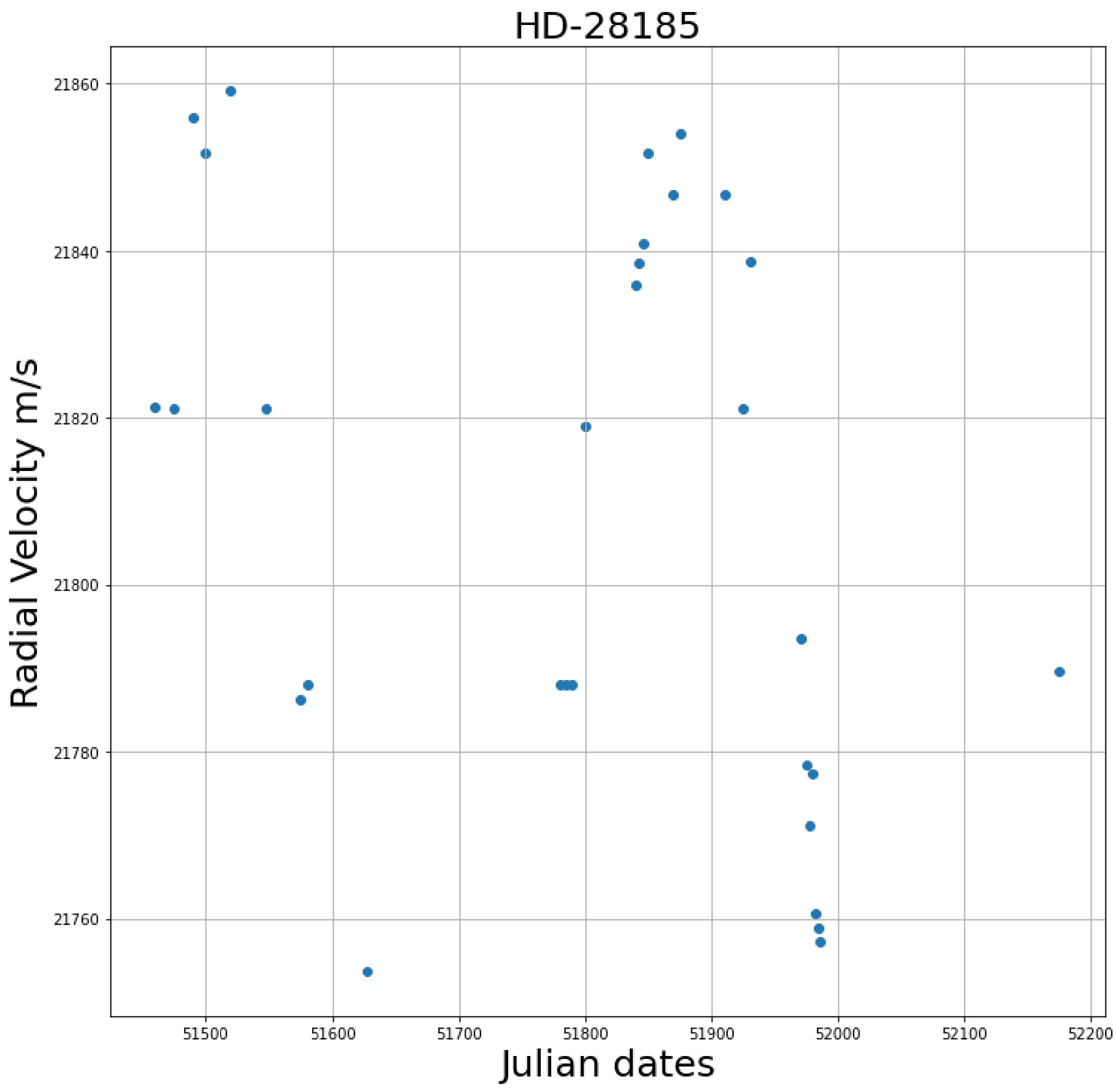
good

6 1.3 Task 1

In this task we take the array of the radial velocities on the different dates for the two stars and plot two seperate graphs of this data against the Julian dates to obtain an estimated graph of the radial velocity as a function of time for both stars

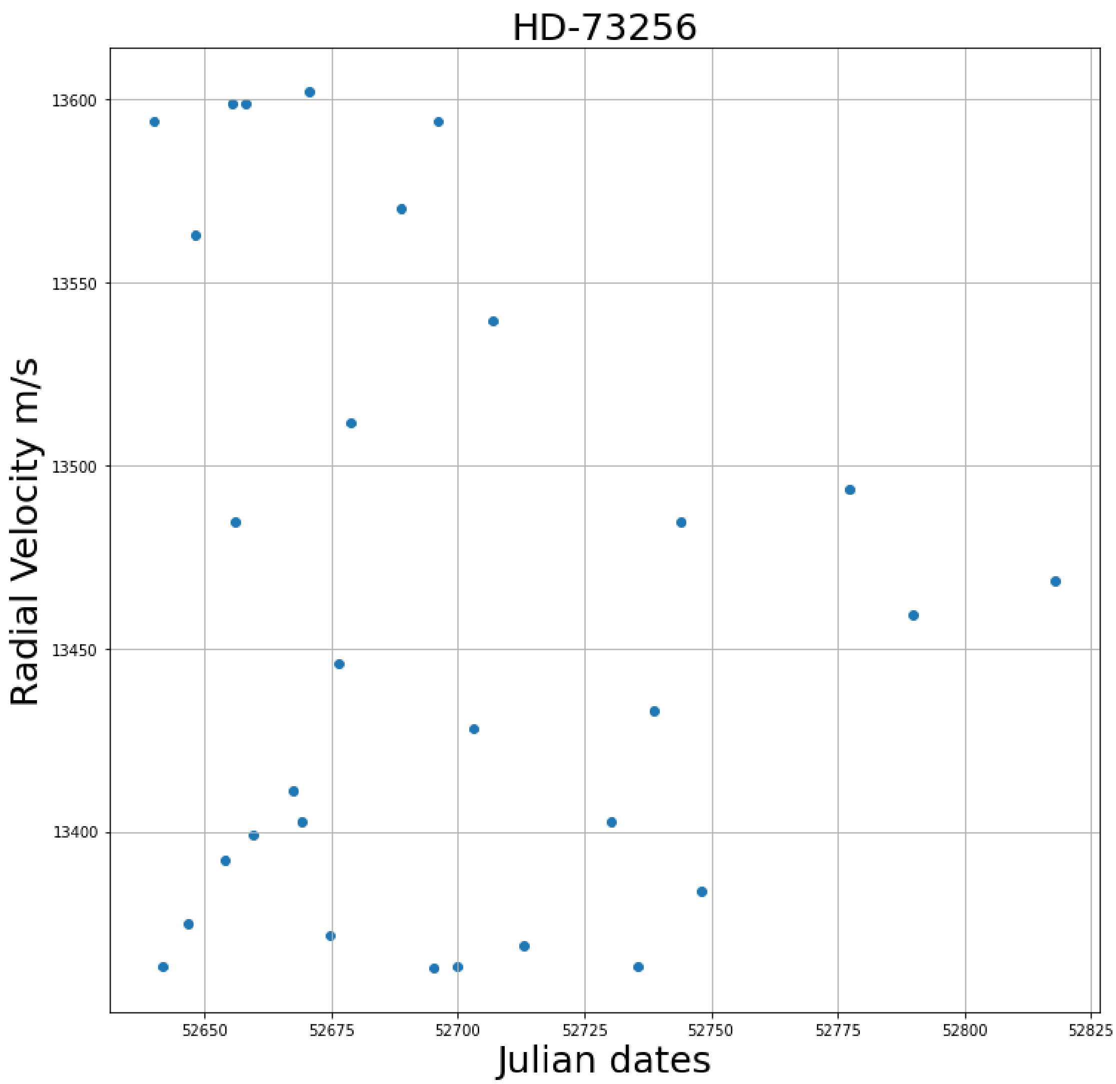
[168]:
```
# This is some number and array manipulation that was necessary
#for plotting the graphs below but has no significant value to the experiment␣
 ↪itself


dates_G5 = np.fromiter(datesG5, dtype=float)
dates_G8 = np.fromiter(datesG8, dtype=float)
dates5 = dates_G5[1:31]
dates8 = dates_G8[1:31]
radvel5 = radvel_5[1:31]
radvel8 = radvel_8[1:31]
```

[169]:
```
# This plots the Radial velocity against the Julian Dates for the first star␣
 ↪which obtains a
#roughly sinusoidal graph of the stars radial velocity with time

plt.figure(figsize=(12,12))

plt.scatter(dates5,radvel5)

plt.grid(True)
plt.title("HD-28185", size=text_size_plots)
plt.xlabel("Julian dates", size=text_size_plots)
plt.ylabel("Radial Velocity m/s", size=text_size_plots)

plt.show()
```



[170]:
```
# This plots the Radial velocity against the Julian Dates for the second star
↪which obtains a roughly
#sinusoidal graph of the stars radial velocity with time


plt.figure(figsize=(12,12))

plt.scatter(dates8,radvel8)

plt.grid(True)
plt.title("HD-73256", size=text_size_plots)
plt.xlabel("Julian dates", size=text_size_plots)
plt.ylabel("Radial Velocity m/s", size=text_size_plots)
```

```
plt.show()
```



at this stage you should make a comment about these graphs in particular do they match with what you expect.

7 1.3 Task 2

In this task we are expected to calculate the phase of the two stars on their specified julian dates and project some estimated error onto them.

[171]:
```
# This is calculating the phase for each of the data sets and extracting the
↪data where p is the phase and T is the period


p = [0]
```

```
T1 = [0]
for date in (dates5):
    t_elapsed5 = (date-51460)

    T = (t_elapsed5/383)

    T1.append(T)
    P = (T-int(T))
    p.append(P)

p2 = [0]
t2 = [0]
for date in (dates8):
    t_elapsed8 = (date-52640.0300)

    T2 = (t_elapsed8/2.54858)
    t2.append(T2)

    P2 = (T2-int(T2))

    p2.append(P2)
```

[172]:

```
# Calculating the error in the period which is the same as the error in the␣
↪phase

Terr = (np.array(T1)*0.00522)
Terr_30 = Terr[1:31]
# Some data manipulation so that the arrays are of a specified size

N_30 = p[1:31]

N2_30 = p2[1:31]

# print(Terr)
```

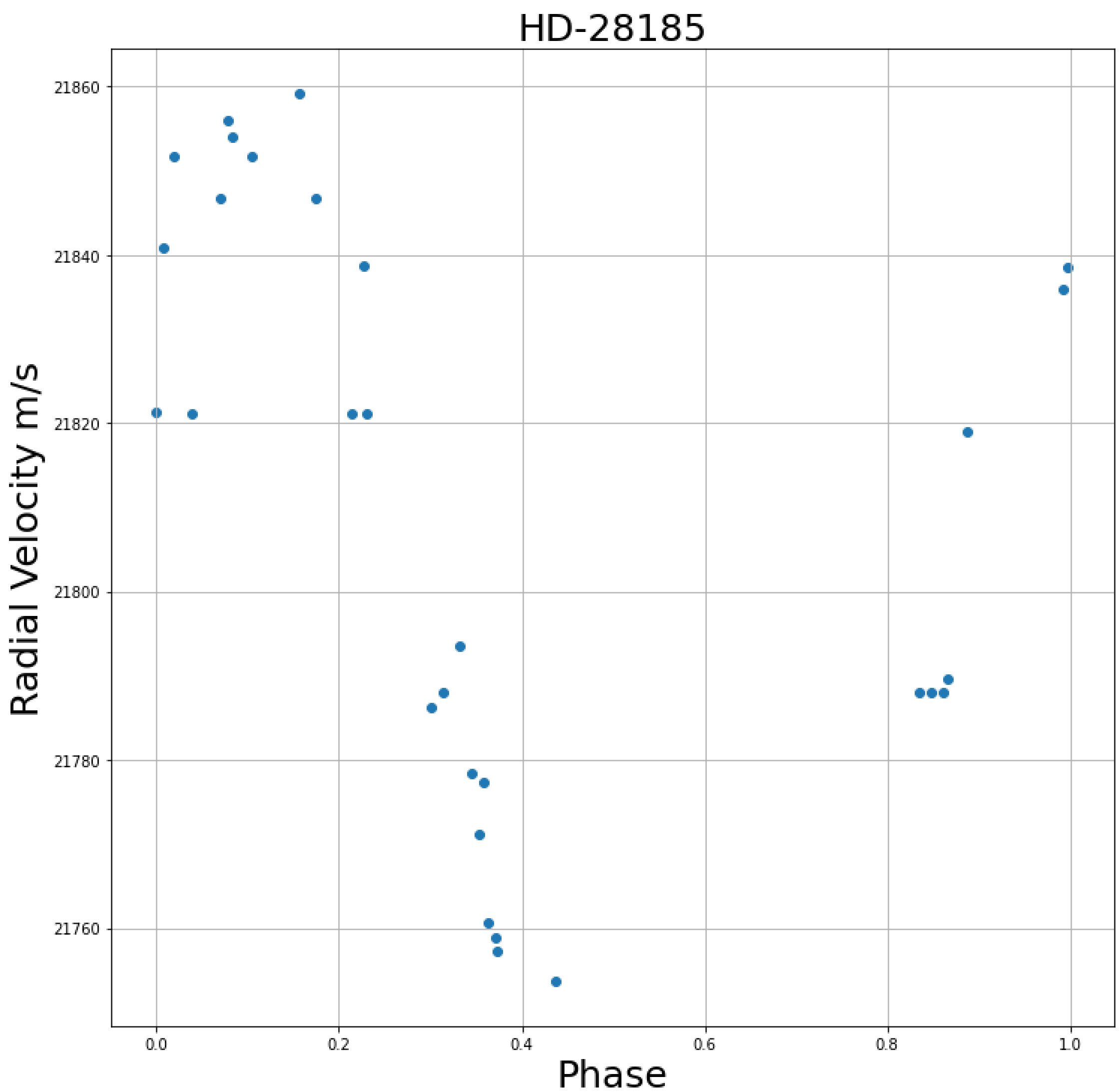
8 1.3 Task 3

In this task we are to plot the radial velocities against the phases for each star to find the sinusoidal approximation for the radial velocity as a function of time

[173]:

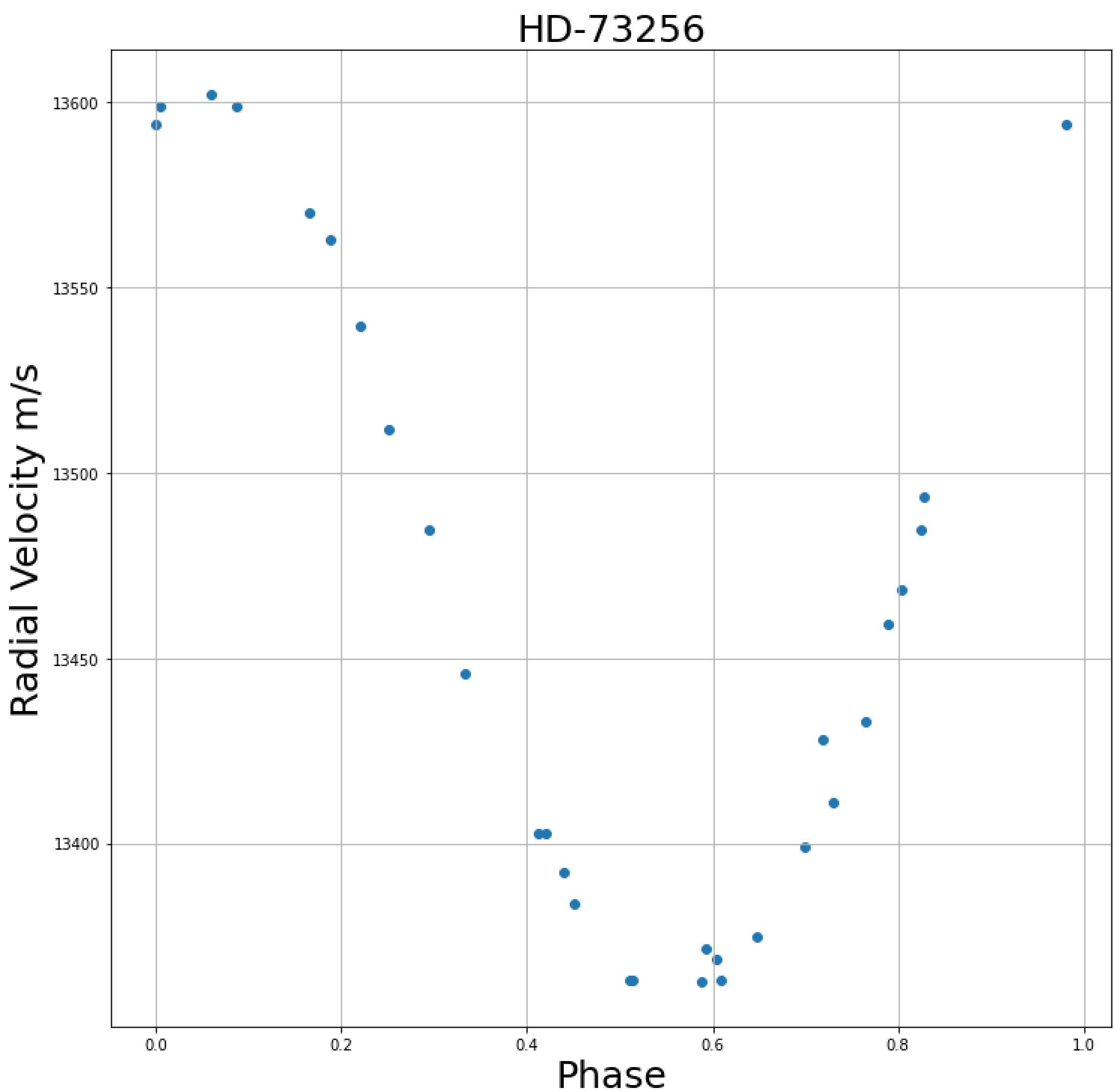
```
# This is plotting the radial velocity for the first star against the phase to␣
↪obtain the true graph for the radial velocity
#with respect to time



plt.figure(figsize=(12,12))
```

```python
plt.scatter(N_30,radvel5)

plt.grid(True)
plt.title("HD-28185", size=text_size_plots)
plt.xlabel("Phase", size=text_size_plots)
plt.ylabel("Radial Velocity m/s", size=text_size_plots)

plt.show()
```



[174]:
```python
# This is plotting the radial velocity for the second star against the phase to
 ↪obtain the true graph for the radial velocity
#with respect to time
```

```
plt.figure(figsize=(12,12))

plt.scatter(N2_30,radvel8)

plt.grid(True)
plt.title("HD-73256", size=text_size_plots)
plt.xlabel("Phase", size=text_size_plots)
plt.ylabel("Radial Velocity m/s", size=text_size_plots)

plt.show()
```



9 1.4 Task 1

its best to restate the equation here so its fresh on people mind, rather then having to scroll to top of the document.

For this task we are to calculate the unknown parameters in Equation 2, v_{mean}, v_s and ϕ_{max} using and optimize.curve_fit function as well as the parameter covariance output of this function to determine the errors in these values

Again, when you use curve fit its important to mention what inital guess you used and why you selected those values

This is then repeated for the second star

[175]:
```
# Use sp.optimize.curve_fit to find the unknown values in equation 2 and using␣
↪the covariance matrix to find the associated errors



v_pred=radvel5
phi_obs = np.sort(N)
b = np.ones(30)*15

def eqn2(phi_obs,v_mean,v_s,phi_max):
    return (v_mean+(v_s*np.cos(2*np.pi*(phi_obs-phi_max))))

params,pcov = sp.optimize.curve_fit(eqn2,N_30,radvel5, p0=(21000,50,0.2) ,sigma␣
↪= b, absolute_sigma=True)
# print(params)
perr = np.sqrt(np.diag(pcov))
# print(perr)

print('The mean velocity of the star is {0:.2e}m/s ± {3:.2f}m/s, the amplitude␣
↪of the radial velocity graph is {1:.2e} ± {4:.2f} and the phi_max value is␣
↪{2:.2e} ± {5:.2f}'.
↪format(params[0],params[1],params[2],perr[0],perr[1],perr[2]))
```

```
The mean velocity of the star is 2.18e+04m/s ± 4.00m/s, the amplitude of the
radial velocity graph is 6.76e+01 ± 6.16 and the phi_max value is 8.59e-02 ±
0.01
```

[176]:
```
v_pred2=radvel8
phi_obs2 = np.sort(N2)


def eqn3(phi_obs2,v_mean2,v_s2,phi_max2):
    return (v_mean2+(v_s2*np.cos(2*np.pi*(phi_obs2-phi_max2))))

params2,pcov2 = sp.optimize.curve_fit(eqn3,N2_30,radvel8, p0=(13000,120,0.2) ,␣
↪sigma = b,absolute_sigma=True)
# print(params2)
perr2 = np.sqrt(np.diag(pcov2))
# print(perr2)
```

```
print('The mean velocity of the star is {0:.2e}m/s ± {3:.2f}m/s, the amplitude␣
 ↪of the radial velocity graph is {1:.2e} ± {4:.2f} and the phi_max value is␣
 ↪{2:.2e} ± {5:.2f}'.
 ↪format(params2[0],params2[1],params2[2],perr2[0],perr2[1],perr2[2]))
```

```
The mean velocity of the star is 1.35e+04m/s ± 2.80m/s, the amplitude of the
radial velocity graph is 1.20e+02 ± 3.92 and the phi_max value is 5.73e-02 ±
0.01
```

state a conclusion. ie explain if these results are good not based your errors and how they compare to what you might expect to find.

10 1.5 Task 1

In this task we used Equation 1 to find the mass of the planetary companions of the two stars and then proceeded to use Equation 3 to estimate the semi-major axis of the planets orbit, while still propagating errors onto our new values.

[208]:
```
# Calculating the mass of the planetary companions for the stars when assuming␣
 ↪the mass if the star to be an average main
#sequence star in this case I assumed the mass of the star to be approximately␣
 ↪the mass of the sun

import scipy.constants as consts
v_s5 = params[1]
m_s = (2*10**30)



m_p = (v_s5/(((((2*np.pi*consts.G)/T))**(1/3))*(m_s**(-2/3))))
# print(m_p)




v_s8 = params2[1]
m_s2 = (2*10**30)

m_p2 = (v_s8/(((((2*np.pi*consts.G)/T2))**(1/3))*(m_s2**(-2/3))))
# print(m_p2)
```

[178]:
```
#Error analysis
Terr = (np.array(T1)*0.00522)
# m_perr**2 is going to be (Terr**1/3)**2 + perr[1]**2

m_perrarray = (((Terr**(1/3))**2) + (perr[1]**2))**(1/2)



m_perr = np.mean(m_perrarray)
# print(m_perr)

Terr2 = (np.array(t2)*0.000063)
```

```
m_perrarray2 = (((Terr2**(1/3))**2) + (perr2[1]**2))**(1/2)

m_perr2 = np.mean(m_perrarray2)

# print(m_perr2)
```

[179]:
```
print('The mass of the planetary companion around the star HD-28185 is␣
 ↪estimated to be {0:.4e}kg ± {1:.2f}%'.format(m_p,m_perr))
print('The mass of the planetary companion around the star HD-73256 is␣
 ↪estimated to be {0:.4e}kg ± {1:.2f}%'.format(m_p2,m_perr2))
```

```
The mass of the planetary companion around the star HD-28185 is estimated to be
1.7654e+25kg ± 6.17%
The mass of the planetary companion around the star HD-73256 is estimated to be
1.0517e+26kg ± 3.93%
```

[180]:
```
a1 = ((((T**2)*consts.G*(m_s+m_p))/(4*(np.pi**2)))**(1/3))
# print(a1)
a2 = ((((T2**2)*consts.G*(m_s2+m_p2))/(4*(np.pi**2)))**(1/3))
# print(a2)

print('The semi-major axis of the planetary companions orbit around the star␣
 ↪HD-28185 is estimated to be {0:.4e}m'.format(a1))
print('The semi-major axis of the planetary companions orbit around the star␣
 ↪HD-73256 is estimated to be {0:.4e}m'.format(a2))
```

```
The semi-major axis of the planetary companions orbit around the star HD-28185
is estimated to be 2.2756e+06m
The semi-major axis of the planetary companions orbit around the star HD-73256
is estimated to be 2.5446e+07m
```

need conclusion

[181]:
```
Terr = (np.array(T1)*0.00522)
```

11 Task 2 The Planetary Transits Method

The aims of the second method of the experiment are

To obtain a Phase-folded photometric light curve for a star with a transiting planetary companion and use this to estimate the radius and semi-major axis of the planet

Apply The method of least squares to estimate mean apparent magnitudes during the transit and non-transit phase, hence estimate the radius of the planet

Useful Equations for the Second Method of the Experiment

$$G(M_S + m_p) = \frac{4\pi^2 a^3}{T^2}$$

good

(Equation 3)

12 2.1 Task 1

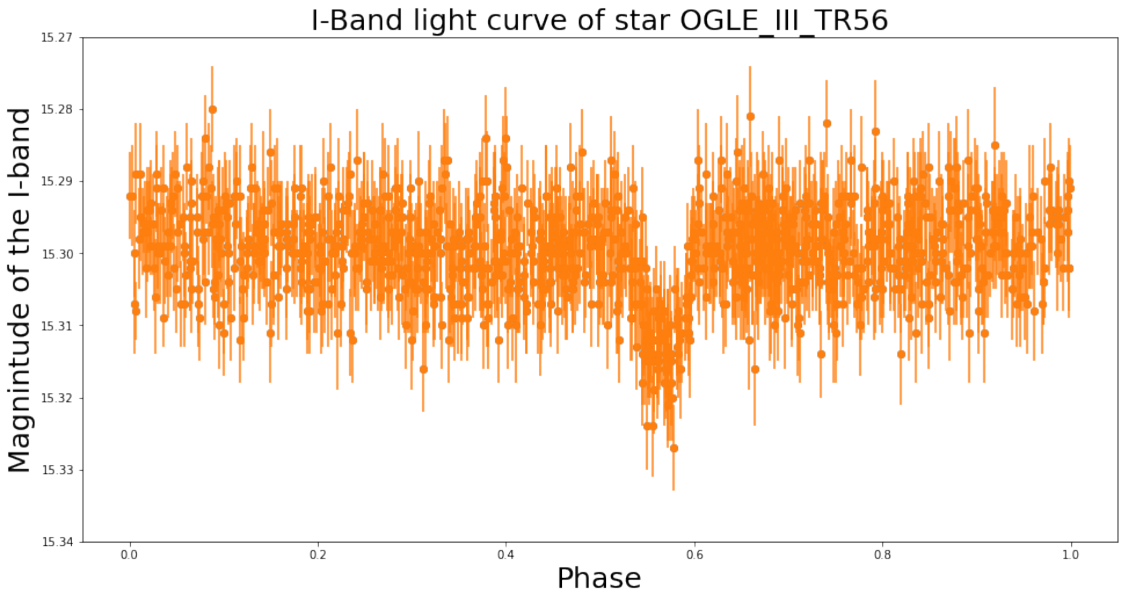
For this task we are to obtain a Phase-folded Light Curve for the star OGLE-III-TR56 this is done by first loading data and seperating it into the useful arrays and then using a for loop to calculate the period and then the phase for all the values, this phase was then plotted against the I-band magnitude of the star to visualize the dip in magnitude due to a star transiting the stars surface in the plane facing Earth.

And then using limits to zoom in on the area of data that contains the dip in magnitude as this is the useful data

good

[200]:
```
data = np.loadtxt('OGLE_III_TR56.txt')
```

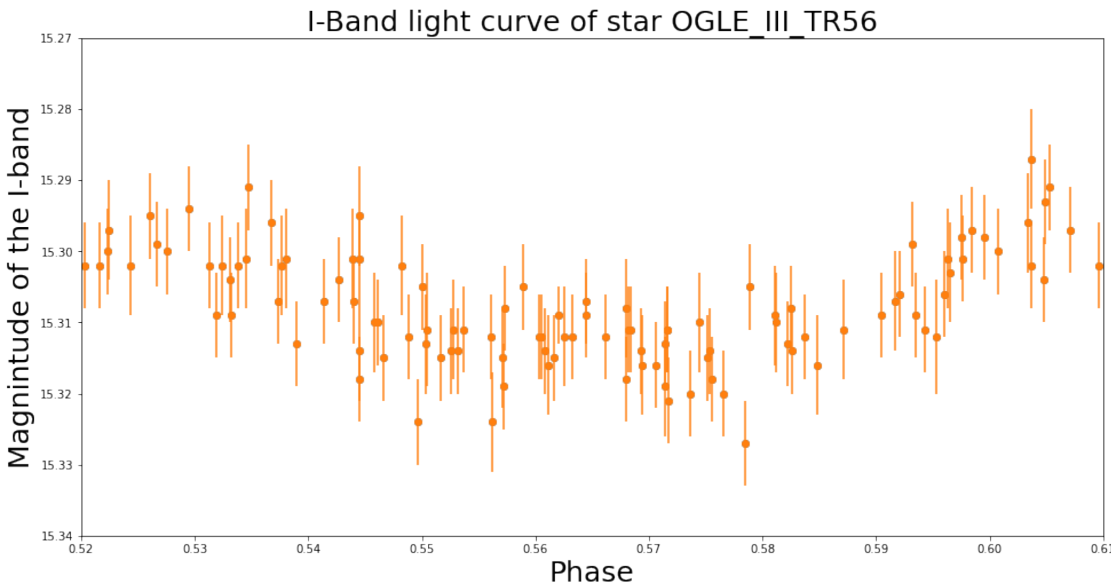
[201]:
```
P = 1.21190
JulianDate_TR = data[:,0]
I_b = data[:,1]
m_err = data[:,2]

Phase_TR = np.array([])
for a in JulianDate_TR:
    t_ela = float(a) - 2452075.6312
    T_orbit = t_ela/P
    calc = T_orbit//1
    Phase_21 = T_orbit-calc
    Phase_TR = np.append(Phase_TR,Phase_21)


plt.figure(figsize = (16,8))
plt.scatter(Phase_TR,I_b)
plt.title('I-Band light curve of star OGLE_III_TR56', size=text_size_plots)
plt.xlabel('Phase', size=text_size_plots)
plt.ylabel('Magnintude of the I-band', size=text_size_plots)
plt.errorbar(Phase_TR,I_b,yerr=m_err, fmt='oC1')
plt.ylim(15.34,15.27)
plt.show()
```



you should add a comment here explaining what the figure shows and highlight the important elements, eg the dip between 0.5 and 0.6. This ensures the reader does not take away a different conclusion then what you want to communicate to them

[202]:

```
plt.figure(figsize = (16,8))
plt.scatter(Phase_TR,I_b)
plt.title('I-Band light curve of star OGLE_III_TR56', size=text_size_plots)
plt.xlabel('Phase', size=text_size_plots)
plt.ylabel('Magnintude of the I-band', size=text_size_plots)
plt.errorbar(Phase_TR,I_b,yerr=m_err, fmt='oC1')
plt.ylim(15.34,15.27)
plt.xlim(0.52,0.61)
plt.show()
```



13 2.2 Task 1

In this task we used Equation 3 to estimate the semi-major axis of the planets orbit around the star when approximating the parent stars mass to be 1 solar mass and assigning an error to the value of the semi-major axis, we thought a reasonable error would be 5% of the stars mass good

[203]:
```
m_s = 1.989*10**30
m_p = 6.39*10**23

m_serr = 0.05*1.989*10**30


semimaj = ((((T_orbit**2)*consts.G*(m_s))/(4*(np.pi**2)))**(1/3))


semimaj_max = ((((T_orbit**2)*consts.G*(m_s+m_serr))/(4*(np.pi**2)))**(1/3))
semimaj_min = ((((T_orbit**2)*consts.G*(m_s-m_serr))/(4*(np.pi**2)))**(1/3))

errsemmaj = (semimaj_max-semimaj_min)/2
print(f' The semi-major axis of the planets orbit is {semimaj:.4e}m ±␣
 ↪{errsemmaj:.4e}m Mass of the planet is negligle in calculating the␣
 ↪semi-major axis')
```

```
 The semi-major axis of the planets orbit is 1.0737e+08m ± 1.7903e+06m Mass of
the planet is negligle in calculating the semi-major axis
```

Assumptions For the diameter of the planet being equal to the distance of the transit, the orbit needs to be circular, on a flat plane as observed from earth. good

14 2.2 Task 2

In this task we are asked to determine the circumference of the planets orbit which can be done easily if assuming the planets orbit to be circular as we can use πD to find this where D is the major axis of the planets orbit, while still carrying errors through from the semi-major axis.

From this we can estimate the diameter of the parent star and its uncertainty as we know the phase in which the magnitude is dipped is some fraction of the total circumference of the planets orbit, this fraction can be found by taking the difference in the pahse between the start and end of the dip in magnitude.

[204]:
```
# circumference of the planets orbit assuming it to be circular = pi*r*2
circ = np.pi*(semimaj*2)
circmax = np.pi*(semimaj_max*2)
circmin = np.pi*(semimaj_min*2)
circerr = (circmax-circmin)/2
```

```
print(f' The circumference of the orbit is {circ:.4e}m ± {circerr:.4e}')
```

```
The circumference of the orbit is 6.7460e+08m ± 1.1249e+07 unit
```

[205]:
```
#end of phase dip due to planet minus start of phase dip due to planet = 0.071␣
↪phase
#phase change multiplied by circ
d_star = 0.071*circ

d_starmax = 0.071*circmax
d_starmin = 0.071*circmin
d_starerr = (d_starmax-d_starmin)/2

print(f'The diameter of the parent star is {d_star:.4e}m ± {d_starerr:.4e}m')
```

```
The diameter of the parent star is 4.7897e+07m ± 7.9865e+05m
```

15 2.2 Task 3

For this task we use a similar method to the last one in which we use the fraction of the circumference of the planets orbit to estimate a radius for the planet, this is done in using the phase difference between when the magnitude of the star is at its base level (when the planet is not eclipsing) to when the magnitude of the star is first at its lowest magnitude (when the planet is first fully eclipsing the star)

[206]:
```
r_planet = 0.008*circ

r_planetmax = 0.008*circmax
r_planetmin = 0.008*circmin
r_planeterr = (r_planetmax-r_planetmin)/2

print(f'The diameter of the planet is {r_planet:.4e}m ± {r_planeterr:.4e}m')
```

```
The diameter of the planet is 5.3968e+06m ± 8.9989e+04m
```

16 2.2 Task 4

In this task we are expected to use the optimize.curve_fit function again to determine the mean I-band Apparent Magnitude during eclipse and non-eclipse and the associated errors#

I was unable to complete this task due to time constraint, this is touched upon in more detail in the summary below.

[207]:
```
# def func(t,amp,end,depth):
#     width = end - start
#     mid = start + 0.5*width
```

```
#     y1 = lambda t: amp
#     y2 = lambda t: amp - 2*depth*(t-start)/width
#     y3 = lambda t: amp - 2*depth*(end-t)/width
#     y4 = lambda t: amp
#     y = np.piecewise(t,[(t<start), (t>=start)*(t<mid), (t>=mid)*(t<end),␣
↪(t>=end)], [y1,y2,y3,y4])
#     return y



# plt.figure(figsize = (16,8))
# plt.scatter(Phase_TR,I_b)
# plt.plot(func)
# plt.title('I-Band light curve of star OGLE_III_TR56', size=text_size_plots)
# plt.xlabel('Phase', size=text_size_plots)
# plt.ylabel('Magnintude of the I-band', size=text_size_plots)
# plt.errorbar(Phase_TR,I_b,yerr=m_err, fmt='oC1')
# plt.ylim(15.34,15.27)
# plt.xlim(0.52,0.61)
# plt.show()
```

[ ]:

```

```

17 Summary of the Experiment

From Method 1 in this experiment we were able to determine a mass for the planetary companion of the two stars and the semi-major axis of this planets orbit, along with associated error which are within a reasonable range for these values.

We believe these values obtained are good as the planet and star systems are similar to that of the earth and the sun and we have obtained values close to that that we would expect for a star and planet of these sizes.

However I believe we couldve improved upon our errors had we had more knowledge on how to do these in python as well as more understanding of how to correctly propagate errors through functions especially those with awkward indices, this could've been resolved through more time to spend on the lab as this seemed to be a big limiter for this experiment.

From Method 2 we were able to obtain a good phase-folded photometric light curve for the star with a transiting magnitude, as from this we were then able to calculate reasonable values (in the correct order of magnitude as expected) for the diameter of the star, the radius of the planet and the orbital semi-major axis of the planet

The errors for this method were easier to calculate as it was mainly the difference in the maximum and minimum values divided by two, so I believe these error are more accurate and can be be considered more experimently sound than those found in method 1

However these values could've been improved upon had more care been taken when extracting values for the change in phase from the graph, and had we finished Task 4 in section 2.2 as this also allowed us to estimate the radius of the planet through a more mathematical approach using least-squares functions.

all good, would be nice to see these conclusions dotted through the lab as well. You can easily copy and paste stuff in these records (you can't for the report) as these are meant to be a rough outline of what you did, how did it and why you did it. This then would give you enough background to convert this work into a report.

```
[ ]:
```

Overall Feedback.

Your coding was good and got some good results with good errors analysis, well done.

As mentioned it would be good to see a few more intermediate conclusions. In particular this is so we can try and see your thought process (which is more what we are marking on then the actual results) so i would recommend that after every code cell you do a text cell where you explain the output of the code cell and give a comment about it, is it a good results, what does it mean moving forward with the lab (ie having to cut all data above 650nm after you first plot the spectrum), how does it compare with what you might expect.

secondly, would be great to see a little more science in your writing. Explain the background science in a little more detail, this will help you to understand your results better and hopefully give you a better indication of if a result is good or not, but also gives the reader more context so that they can understand what you did, why you did and then finally how you did it.

Remember the aim of this lab record is to be a document you can either give to somebody, or read back over in a year or two, and they (or yourself) should be able to understand, what you did (which is all about the background science, ie trying to determine properties of extra solar planets from stellar emissions), why you did it (this is why YOU in particular did something) and then how did it (which is how your coding relates to the science, eg explaining how you used curve fit to fit a function and what parameters you used, or how you did the error analysis)