Getting Data from .fits

Data was imported into python console using astropy package.
The logged intensity of each point was then plotted as shown measured in counts

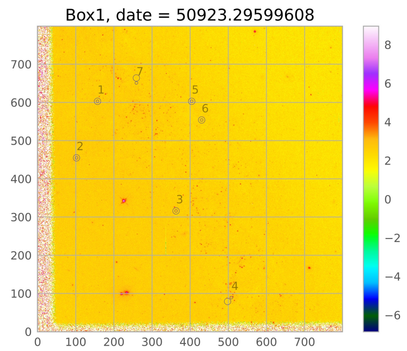
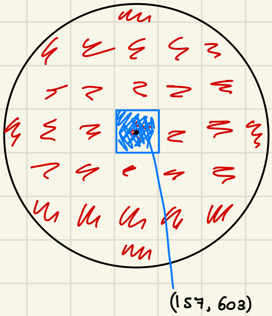


Fig 1

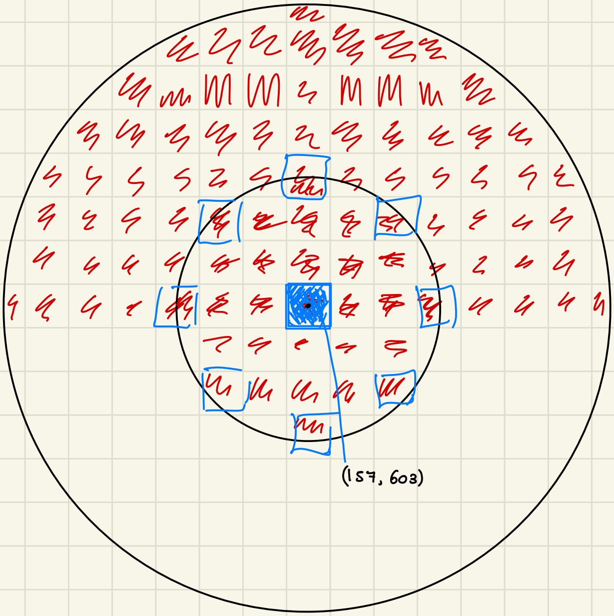
the Coordinates of each cepheid was taken from the refence [Newman, J.A et al, 2001 Astrophysical Journal Vol. 533 p 562]
Circular regions were drawn around the Cepheids as shown in the figure.
The intensity of these regions were found by summing the individual intensities of each point in the Circle as shown:



C+3	1
C+2	5
C+1	5
C	7
C-1	5
C-2	5
C-3	1
	29

The blue Square is the point with the cepheid. As the Circle was drawn with radius 3. So including the Center Square the row is 7 points (3 either side) so the points 3 either side of the Center Coordinate were summed.
This was repeated for each row above and below the Centre for the right amount of points as shown above.

A background region of radius 7 was drawn around each region The intensity was summed as before.



C+7	1
C+6	7
C+5	9
C+4	11
C+3	13
C+2	13
C+1	13
C	15
C-1	13
C-2	13
C-3	13
C-4	11
C-5	9
C-6	7
C-7	1
	151

Note that the coordinates of Cepheid 7 from the reference were wrong so were moved to [259, 651]
Also the background region around Cepheid 4+7 was populated by stars so was moved to a different place as shown in Fig 1.

These 2 Cepheids were different so were run seperately.

Errors

Error for a Poisson Distribution is $\sigma = \sqrt{\frac{\lambda}{n}}$ where λ is the Poisson mean
n is sample size.

here λ = measurement as only 1 measurement is taken
thus $n=1$

So this reduces to $\sigma = \sqrt{N}$ this is error for all regions.

Moving background region for 4+7 increases n so decreases error.

Cepheid 7:

The background region was drawn above the Cepheid.

Intensity of the cepheid was calculated by $\left(\frac{I_{,c}}{n_{pix,c}} - \frac{I_{,b}}{n_{pix,b}}\right) \times n_{pix,c}$ to eliminate Intensity from the background.

The error on $I_{,c}$ is $\sqrt{N}$

Therefore as $\left(\frac{\sigma_f}{f}\right)^2 = \left(\frac{\sigma_a}{a}\right)^2 + \left(\frac{\sigma_b}{b}\right)^2$ $\quad f = \frac{a}{b}$

Error on Intensity Per Pixel: $\frac{N}{n_{pix,c}} \quad \frac{\sqrt{N_c}}{N} = \frac{\sqrt{N_c}}{n_{pix,c}}$

Therefore as $\sigma_f^2 = \sigma_a^2 + \sigma_b^2$ for $f = a+b$

Error on $\underbrace{IPP_c - IPP_b}_{y}$: $\underbrace{\sqrt{\left(\frac{\sqrt{N_c}}{n_{pix,c}}\right)^2 + \left(\frac{\sqrt{N_b}}{n_{pix,b}}\right)^2}}_{\sigma_y}$

So error on final intensity is: $\left(\frac{\sigma_f}{f}\right)^2 = \left(\frac{\sigma_y}{y}\right)^2$

$$\sigma_f = f\,\frac{\sigma_y}{y}$$

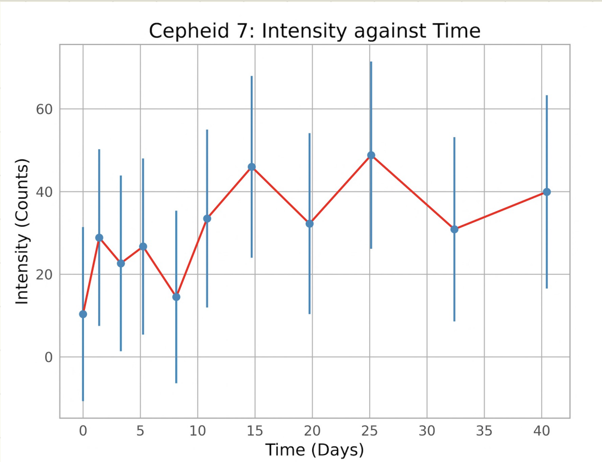
$$= \left[\left(\frac{I_{,c}}{n_{pix,c}} - \frac{I_{,b}}{n_{pix,b}}\right) \times n_{pix,c}\right] \times \frac{\sqrt{\left(\frac{\sqrt{N_c}}{n_{pix,c}}\right)^2 + \left(\frac{\sqrt{N_b}}{n_{pix,b}}\right)^2}}{\left(\frac{I_{,c}}{n_{pix,c}} - \frac{I_{,b}}{n_{pix,b}}\right)}$$

This was repeated for each day and values are shown:

Cepheid7

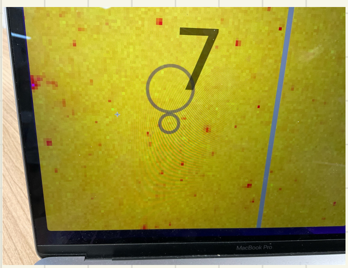
# Intensity for Cepheid 7 in Counts	Errors
10.352	21.062
28.865	21.361
22.640	21.250
26.707	21.290
14.502	20.878
33.484	21.515
45.978	21.978
32.234	21.890
48.817	22.654
30.885	22.277
39.919	23.378
68.767	22.192

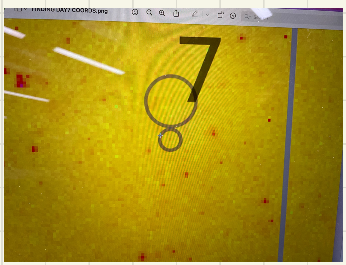
Plotting data

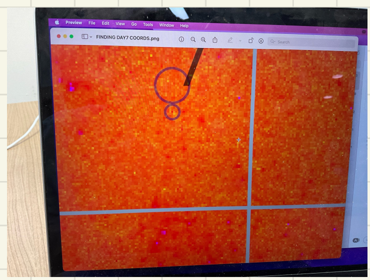


Initially the 12th data point was removed as it was 318 days in advance.
This gave the following graph

No period could be deduced from this graph.
Therefore we removed some data points. These were chosen by amiguous intensity plots:

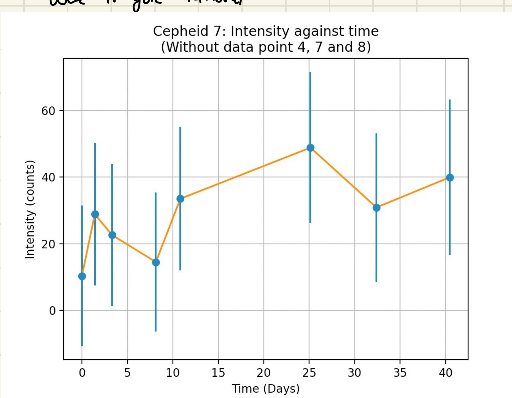






These corresponded to data point 4, 7, 8.

These were therefore removed

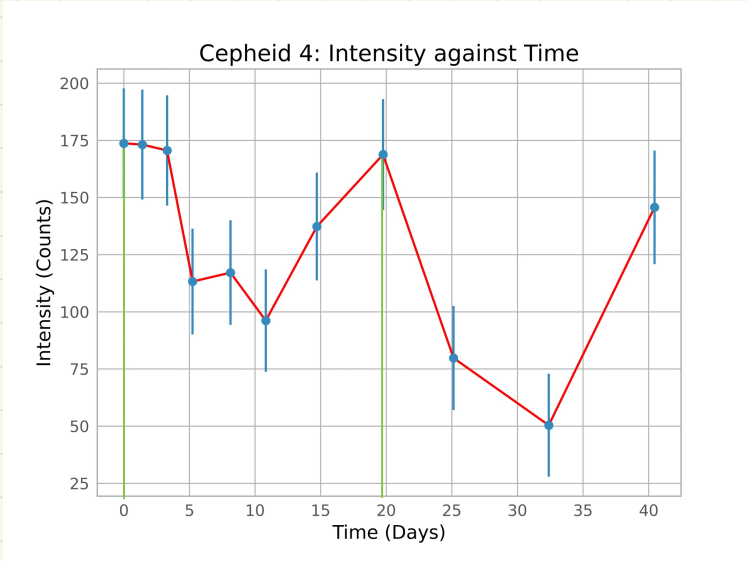


Cepheid 4

The same method was repeated for Cepheid 4 but the coordinates moved on each time point

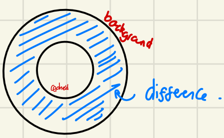
these coordinates are listed:

```
c41 = [508, 89]
c42 = [509, 87]
c43 = [508, 89]
c44 = [509, 87]
c45 = [509, 88]
c46 = [509, 88]
c47 = [509, 95]
c48 = [508, 89]
c49 = [508, 89]
c410 = [508, 89]
c411 = [508, 89]
c412 = [508, 89]
```



Cepheids 1, 2, 3, 5, 6

The method for removing background intensity was different for these cepheids as the background region was drawn around the cepheid region



$$\text{Inner} = I_{in} \pm \sqrt{I_{in}}$$

$$\text{Outer} = I_{out} \pm \sqrt{I_{out}}$$

$$\text{Diff} = (I_{out} - I_{in}) \pm \sqrt{I_{out} + I_{in}}$$

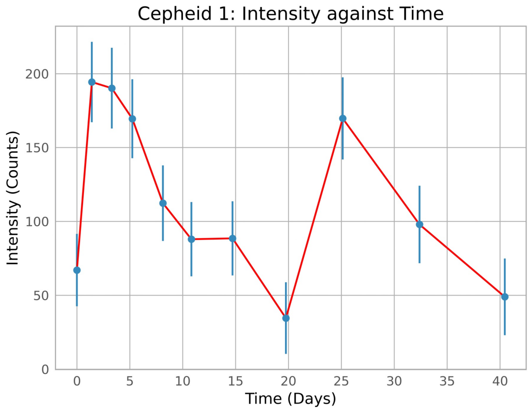
$$\text{Diff PP} = \frac{(I_{out} - I_{in})}{n_{out} - n_{in}} \pm \frac{1}{n_{out} - n_{in}} \sqrt{I_{in} + I_{out}}$$

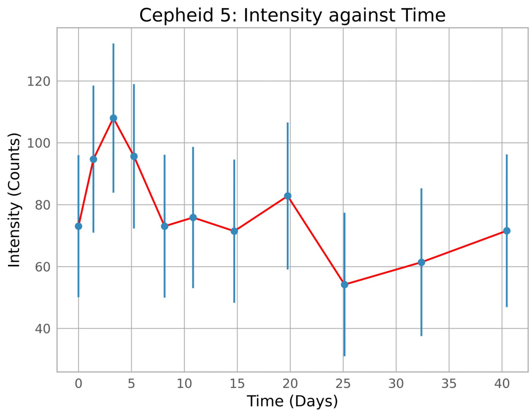
$$\text{Intensity PP of difference} = \frac{I_{diff}}{n_{pix,diff}}$$

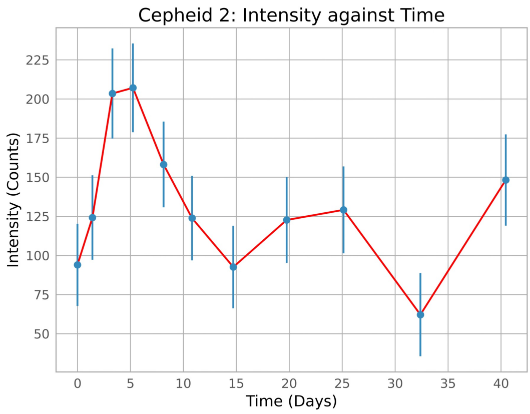
$$\text{Inner PP} = \frac{I_{in}}{n_{in}} \pm \frac{\sqrt{I_{in}}}{n_{in}}$$

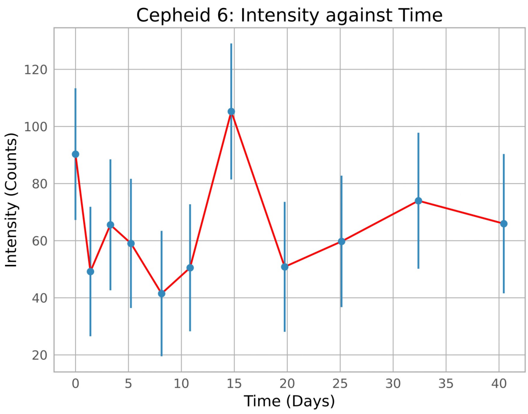
$$\text{final PP} = n_{in} \times \left(\frac{I_{in}}{n_{in}} - \frac{(I_{out} - I_{in})}{n_{out} - n_{in}} \right) \pm (n_{in}) \times \sqrt{\frac{I_{in}}{n_{in}^2} + \frac{(I_{in} + I_{out})}{(n_{out} - n_{in})^2}}$$

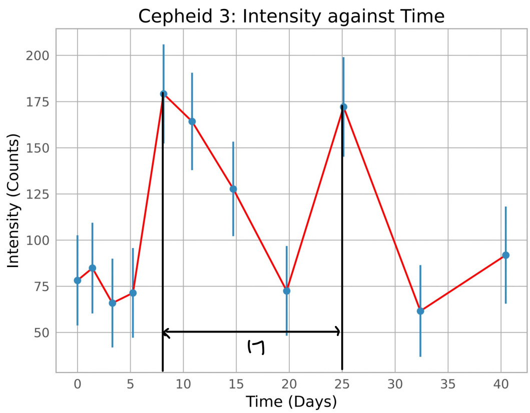
graphs are shown on next page


Cepheid 1: Intensity against Time
Intensity (Counts)
Time (Days)


Cepheid 5: Intensity against Time
Intensity (Counts)
Time (Days)


Cepheid 2: Intensity against Time
Intensity (Counts)
Time (Days)


Cepheid 6: Intensity against Time
Intensity (Counts)
Time (Days)


Cepheid 3: Intensity against Time
Intensity (Counts)
Time (Days)

For Cepheids 8-15, Coordinates all match up, however outer regions were moved for 8, 14 and 15. Cepheid region for 15 (down 1)

Day 7, all coords moved to the right by 6

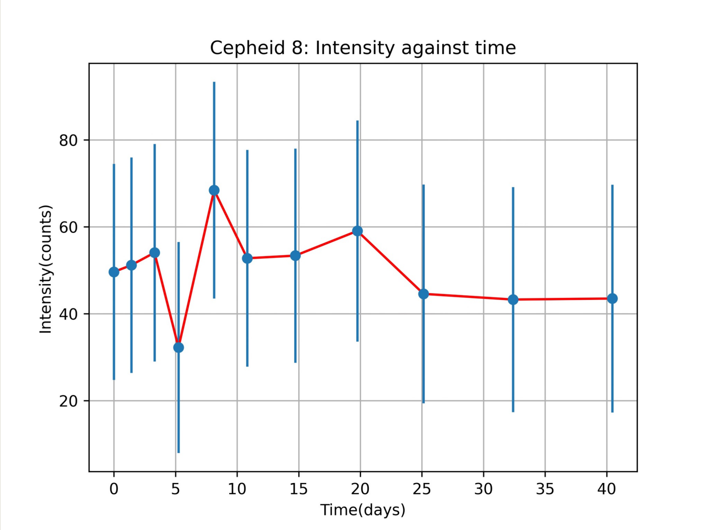
Cepheid 14 outer region moved up 4
Cepheid 15 outer region moved left 6
Cepheid 8 outer moved right 3

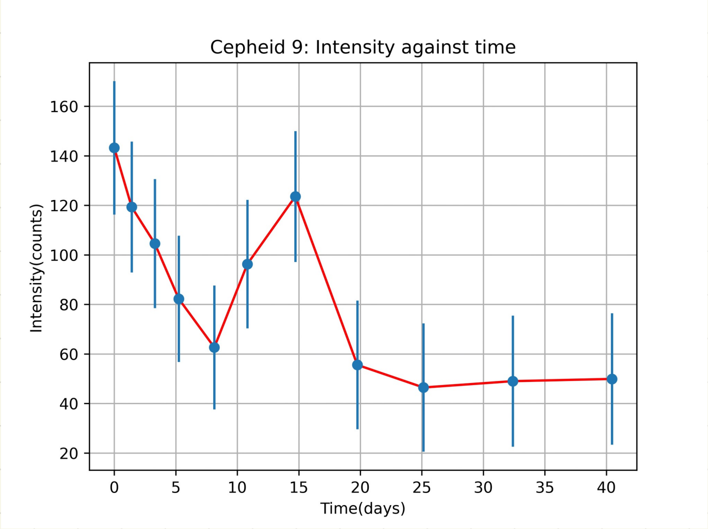
need to input into if, elif, elif...

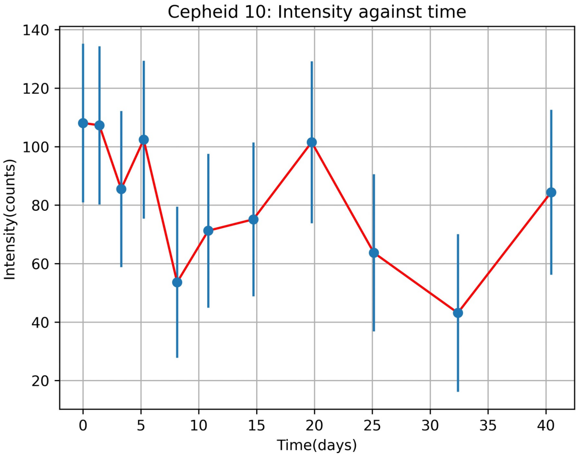
These graphs were plotted using the same method. These are shown below

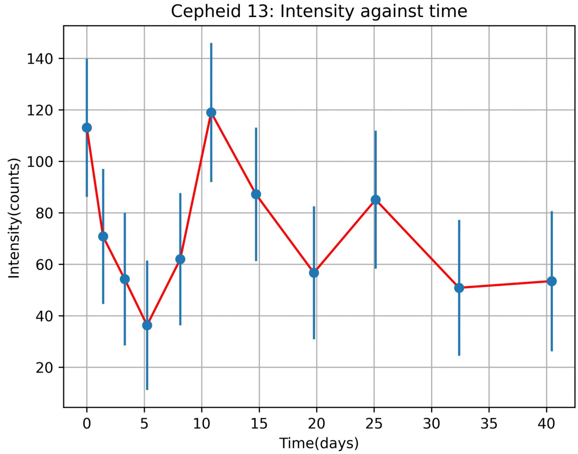
Cepheid 15 was calculated with the same method as Cepheid 4.

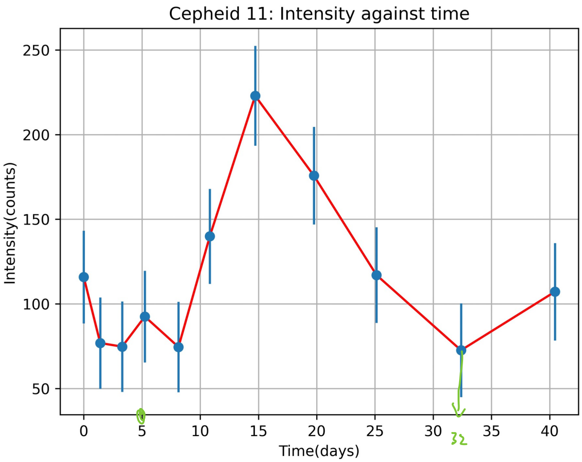
others were calculated normally.

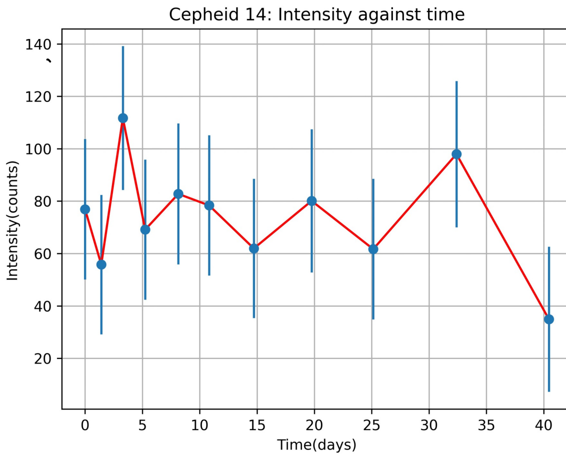


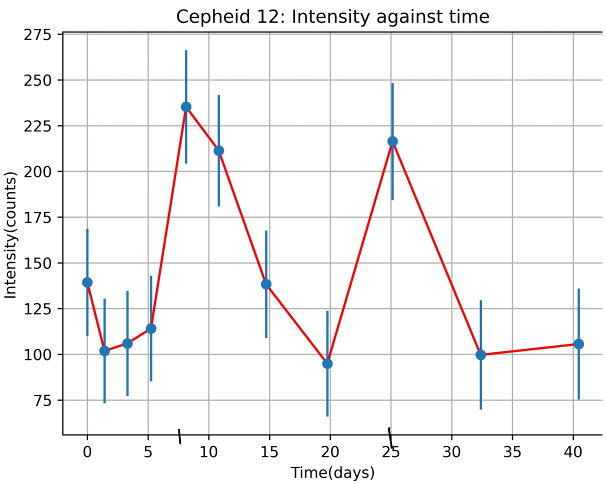


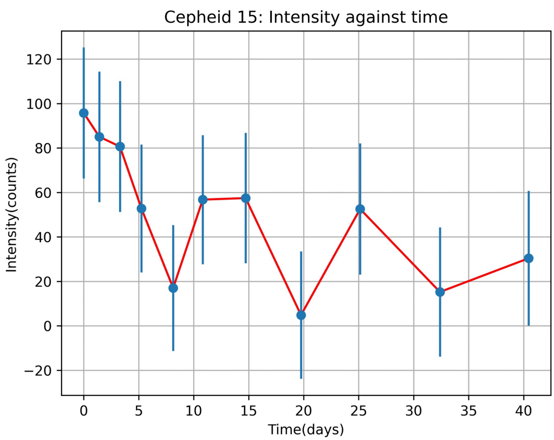

Cepheid 10: Intensity against time
Intensity(counts)
Time(days)


Cepheid 13: Intensity against time
Intensity(counts)
Time(days)


Cepheid 11: Intensity against time
Intensity(counts)
Time(days)
32


Cepheid 14: Intensity against time
Intensity(counts)
Time(days)


Cepheid 12: Intensity against time
Intensity(counts)
Time(days)


Cepheid 15: Intensity against time
Intensity(counts)
Time(days)

Phase Folding (shortest String)

- First the periods of the rotation of the cepheids were estimated by eye.

for cepheid 1 this was first estimated to be 23 days.

the time data was divided by the period estimate to give phase values.

Values greater than 1 were folded back.

All values were doubled to give 2 periods.

Intensity values were scaled from 0 → 1.

The length of the distance between each point was calculated. ← Shortest String method.

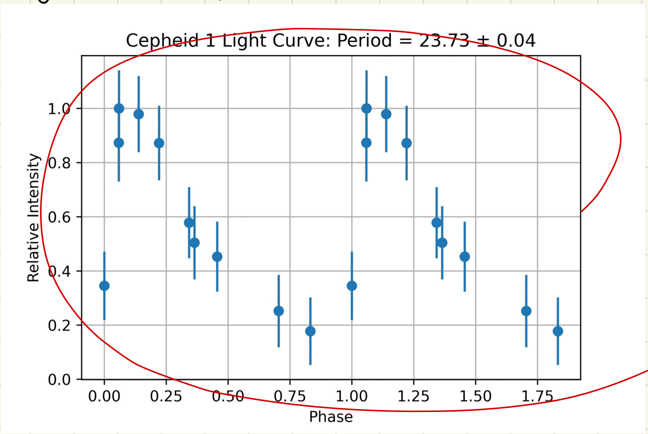
This was then minimised w.r.t phase values.

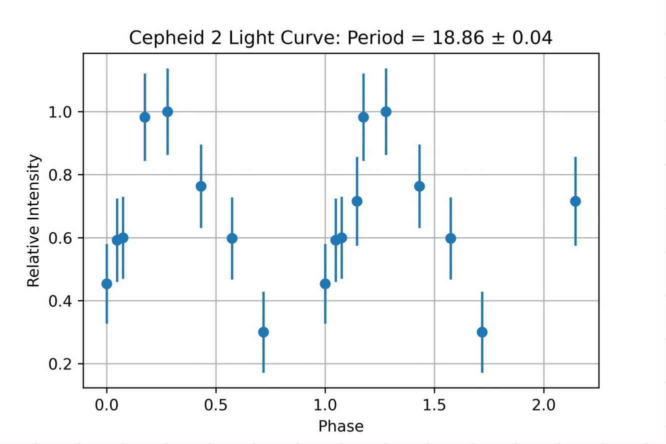
The minimum value of length corresponded to the phase value.

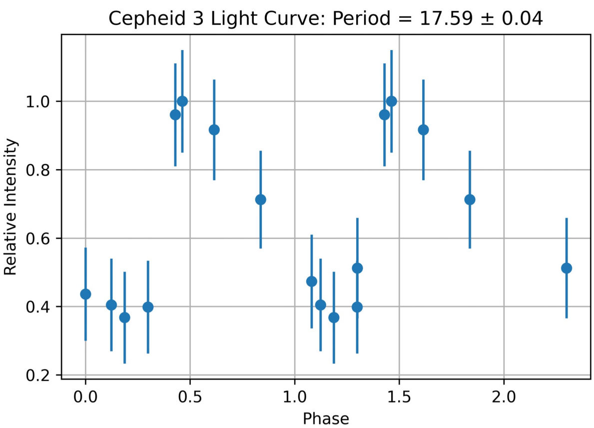
The error on phase corresponded to the spacing of phase values tested.

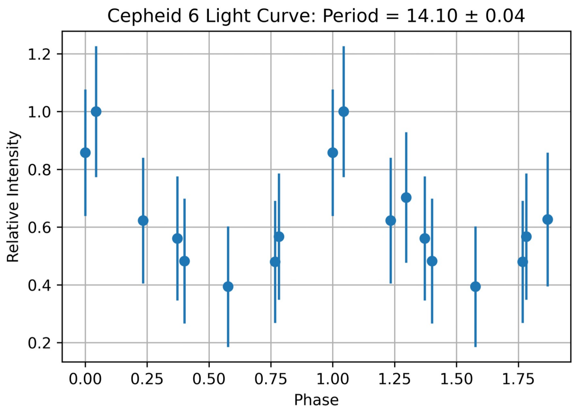
Anomalous data points were removed.

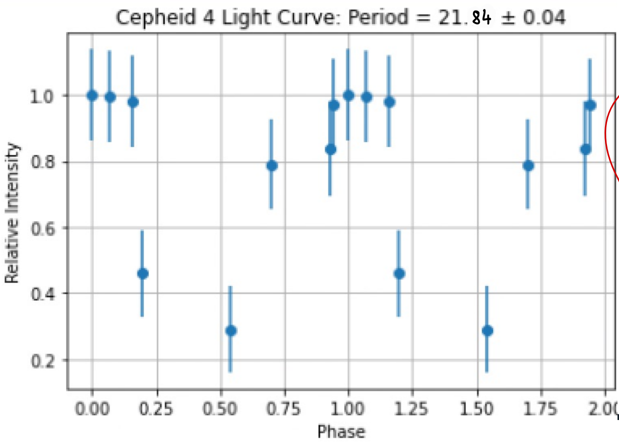
This graph is shown for each Cepheid with calculated values of period.

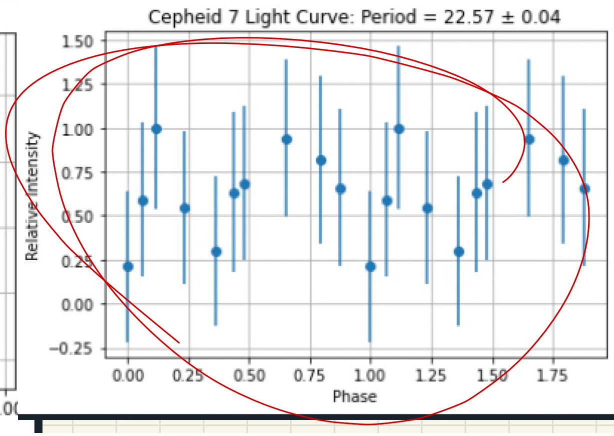


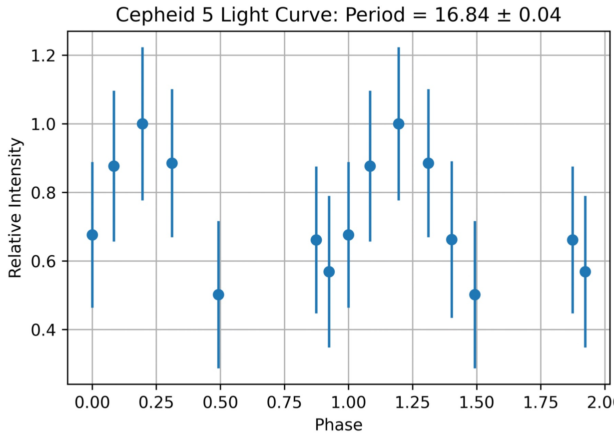


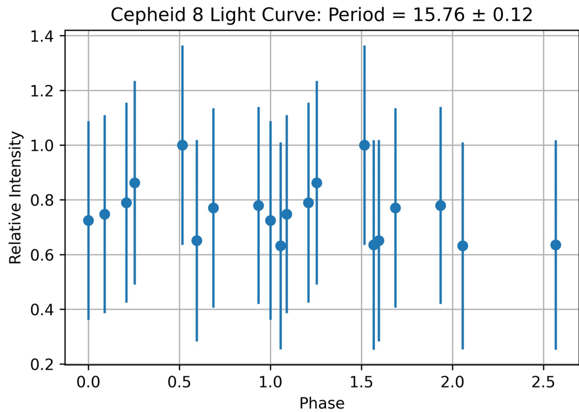

Cepheid 3 Light Curve: Period = 17.59 ± 0.04
Relative Intensity
Phase


Cepheid 6 Light Curve: Period = 14.10 ± 0.04
Relative Intensity
Phase


Cepheid 4 Light Curve: Period = 21.84 ± 0.04
Relative Intensity
Phase

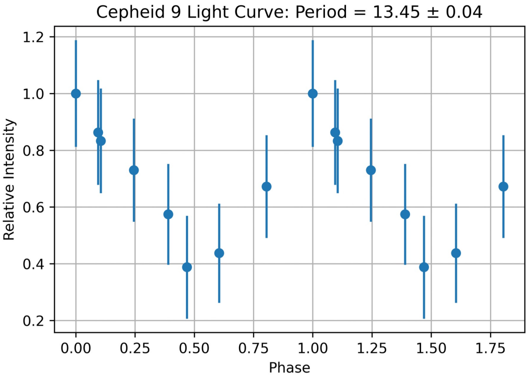

Cepheid 7 Light Curve: Period = 22.57 ± 0.04
Relative Intensity
Phase

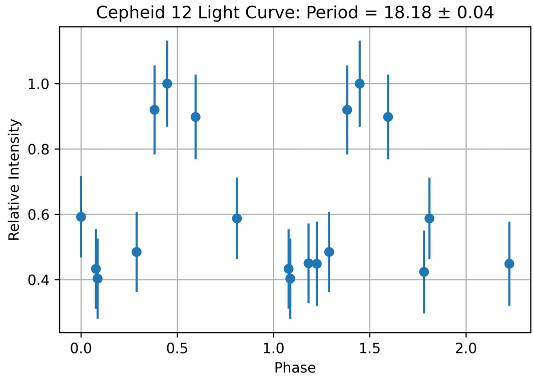

Cepheid 5 Light Curve: Period = 16.84 ± 0.04
Relative Intensity
Phase

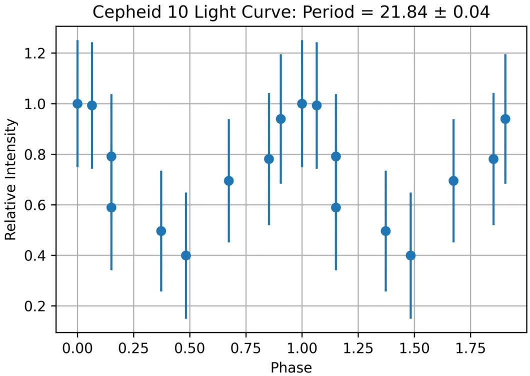

Cepheid 8 Light Curve: Period = 15.76 ± 0.12
Relative Intensity
Phase

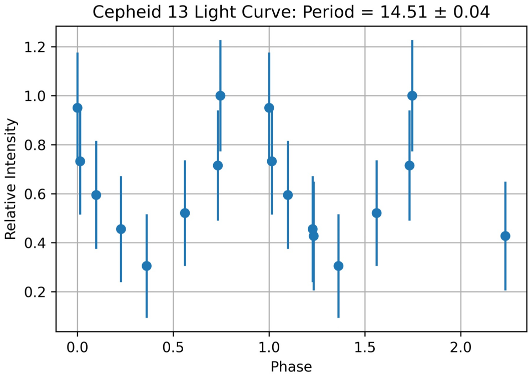
68.46

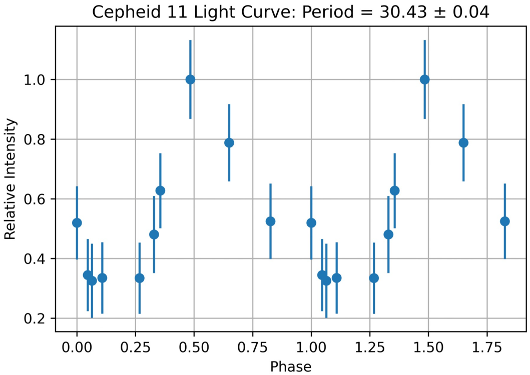
15.76

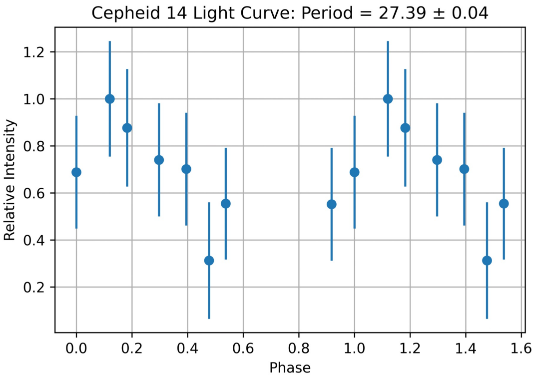

Cepheid 9 Light Curve: Period = 13.45 ± 0.04
Relative Intensity
Phase

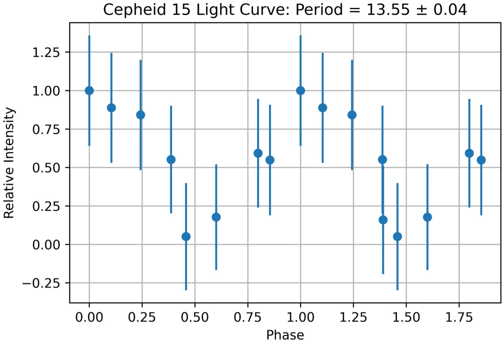

Cepheid 12 Light Curve: Period = 18.18 ± 0.04
Relative Intensity
Phase


Cepheid 10 Light Curve: Period = 21.84 ± 0.04
Relative Intensity
Phase


Cepheid 13 Light Curve: Period = 14.51 ± 0.04
Relative Intensity
Phase

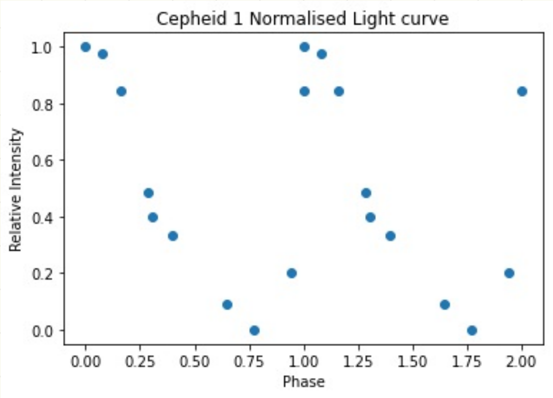

Cepheid 11 Light Curve: Period = 30.43 ± 0.04
Relative Intensity
Phase


Cepheid 14 Light Curve: Period = 27.39 ± 0.04
Relative Intensity
Phase

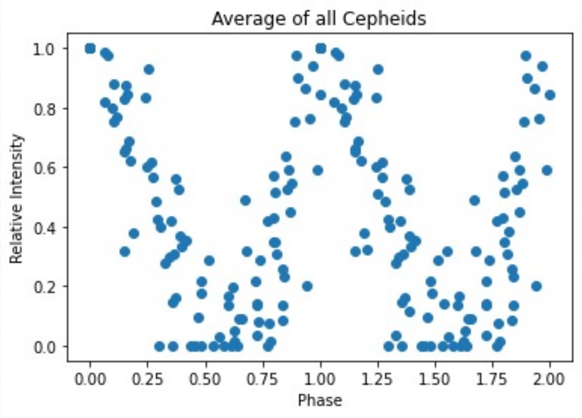

Cepheid 15 Light Curve: Period = 13.55 ± 0.04
Relative Intensity
Phase

Fit Function + χ^2

These curves were normalised so they all started at a maximum. This is shown for Cepheid 1



From this, a collection of all of the Cepheids was plotted:



The aim was to then perform a fourier transform to obtain fourier coefficients.

Therefore an average Cepheid fit function could be compared to each Cepheid with a χ^2.

However, the fourier series obtained did not resemble the data due to the randomness.

Also, the χ^2 would not have any meaning as the error bars were so large the χ^2 would be ~ 0.

Distances

The P-I relation for visible light from the Key Project on Extragalactic Distance Scale is:

$$\bar{M}_V = -2.760(\pm 0.03)(\log_{10} P - 1) - 4.218(\pm 0.02)$$

$$\sigma \log_{10} P = \frac{\sigma_P}{P} \frac{1}{\ln 10}$$

$$\sigma_2 = 2.760(\log P - 1)\sqrt{\left(\frac{\frac{\sigma_P}{P}\frac{1}{\ln 10}}{\log_{10} P}\right)^2 + \left(\frac{0.03}{2.760}\right)^2}$$

$$\sigma = \sqrt{\sigma_2^2 + (0.02)^2}$$

This calculates the average absolute magnitude.

The average apparent magnitude is calculated from:

$$m_1 - m_2 = -2.5 \log_{10} \frac{I_1}{I_2}$$

$$m_1 = m_2 - \underbrace{2.5 \log_{10} \frac{I_1}{I_2}}$$

$$\sigma = \frac{1}{\ln 10}\left(\frac{\sigma_{I_1}}{I_1}\right)$$

$$\sigma_{m_1} = 2.5 \times \frac{1}{\ln 10} \frac{\sigma_{I_1}}{I_1}$$

Using a reference of $m_2 = 22.57$ when $I_2 = 1000$ and the intensity of the Cepheid is the mean average.

Then

$$m - M = 5\log_{10}(d) - 5$$

So

$$d = 10^{\frac{5 + (m-M)}{5}}$$

$$\sigma_d = \ln(10)\, d\, \sigma\left(\frac{5 + m - M}{5}\right)$$

$$d = 10^x$$

$$\sigma_d = \frac{\partial d}{\partial x} \sigma_x$$

$$\sigma_d = \ln(10) 10^x \sigma_x$$

$$d = 10^x$$

$$\ln d = x \ln 10$$

$$\frac{d \ln d}{dx} = \frac{d \ln d}{dd} \frac{dd}{dx} = \ln 10$$

$$\frac{1}{d} \frac{dd}{dx} = \ln 10$$

$$\frac{dd}{dx} = d \ln 10 = 10^x \ln 10$$

Results

# Absolute Magnitude	Error
-5.254	0.023
-4.978	0.022
-4.895	0.021
-5.154	0.022
-4.843	0.021
-4.630	0.020
-5.194	0.023
-4.763	0.021
-4.573	0.020
-5.154	0.022
-5.552	0.025
-4.934	0.021
-4.664	0.021
-5.426	0.024
-4.582	0.020

# Apparent Magnitude	Error
24.922	0.246
24.759	0.224
25.004	0.259
24.788	0.197
25.335	0.326
25.543	0.387
26.363	0.778
25.818	0.543
25.249	0.334
25.293	0.359
24.914	0.262
24.689	0.228
25.431	0.398
25.400	0.398
26.057	0.741

# Distance (Mpc)	Error (MPc)
10.842	1.235
8.859	0.918
9.544	1.141
9.739	0.889
10.853	1.633
10.828	1.930
20.480	7.342
13.072	3.273
9.213	1.420
12.285	2.034
12.392	1.499
8.406	0.885
10.450	1.917
14.630	2.688
13.421	4.579

The average distance value is: $d = 11.67 \pm 2.79$ MPc when $\sigma_d = \sqrt{\frac{\sum \sigma_i^2}{N}}$

Using Newman J,A, et al. Astrophysical Journal, Vol 553, P562.

The distance is $d_{true} = 7.8 \pm 0.8$ MPc

As $H_0 = \frac{v}{d} = \frac{440}{11.67} = 37.7 \pm 9.0$ kms^{-1}MPc^{-1}

$$\left(\frac{\sigma_{H_0}}{H_0}\right)^2 = \left(\frac{\sigma_d}{d}\right)^2$$

$$\sigma_{H_0} = 37.7 \times \frac{\sigma_d}{d}$$

True value of H_0 is

$H_{0,true} = 72.86^{+0.94}_{-1.06}$ kms^{-1}MPc^{-1}

from Brout, Dillon et al

'The pantheon+ Analysis: Cosmological Constraints'

↳ under true value. Intensity values should be higher (explained with CCD)

Table 2
Parameters of Cepheids Found

ID	Chip	X[1]	Y[1]	DoPHOT $<V>^2$	DoPHOT $<I>^2$	DoPHOT Period (d)	DoPHOT Amplitude[3]	ALLFRAME $<V>^2$	ALLFRAME $<I>^2$	ALLFRAME Period (d)
C1	2	158.18	603.73	24.55 ± 0.03	23.84 ± 0.03	20.5 ± 0.2	1.08	24.77	23.94	21.3
C2	2	102.72	455.97	24.70 ± 0.03	23.84 ± 0.02	17.6 ± 0.2	0.99	24.77	23.84	17.2
C3	2	364.28	317.39	24.86 ± 0.03	24.07 ± 0.03	17.0 ± 0.1	1.14	24.86	24.07	17.0
C4	2	509.26	90.23	25.22 ± 0.04	24.16 ± 0.03	21.4 ± 0.4	1.00	25.50	24.26	20.5
C5	2	405.30	604.14	25.15 ± 0.03	24.33 ± 0.03	16.0 ± 0.3	0.68	25.27	24.40	14.0
C6	2	431.21	554.94	25.59 ± 0.04	24.35 ± 0.04	15.2 ± 0.3	0.74	25.68	24.42	13.9
C7	2	447.29	566.43	25.55 ± 0.04	24.66 ± 0.05	10.4 ± 0.1	0.79	25.61	24.62	10.1
C8	3	627.67	365.75	25.58 ± 0.04	24.65 ± 0.05	11.7 ± 0.2	0.60	25.71	24.80	11.2
C9	3	276.75	618.19	25.10 ± 0.03	24.24 ± 0.03	15.2 ± 0.3	0.95	25.12	24.36	15.2
C10	3	535.47	636.44	25.13 ± 0.03	24.20 ± 0.04	17.3 ± 0.3	0.81	25.26	24.42	17.6
C11	3	566.89	659.25	24.61 ± 0.03	23.53 ± 0.02	31.4 ± 0.5	0.82	24.59	23.64	30.7
C12	3	597.51	717.16	24.57 ± 0.02	23.75 ± 0.03	18.2 ± 0.2	0.93	24.60	23.85	17.6
C13	3	780.74	236.12	25.27 ± 0.04	24.44 ± 0.04	12.3 ± 0.3	0.97	25.33	24.57	12.4
C14	3	495.77	645.99	25.26 ± 0.03	24.19 ± 0.03	13.6 ± 0.2	0.74	25.37	24.32	13.7
C15	3	599.59	740.72	25.44 ± 0.04	24.59 ± 0.06	13.7 ± 1.3	0.82	25.57	24.73	13.0

Cepheid Number	Period/Days	Error/Days
1	23.73	0.04
2	18.86	0.04
3	17.59	0.04
4	21.84	0.04
5	16.84	0.04
6	14.10	0.04
7	22.57	0.04
8	15.76	0.12
9	13.45	0.04
10	21.84	0.04
11	30.43	0.04
12	18.18	0.04
13	14.51	0.04
14	27.51	0.04
15	13.55	0.04

'60101R

; for ALLFRAME, intensity-weighted means based

only value for Cepheid 7 overlaps with Newman's value.
Cepheid 7, 8 and 14 were very far away.

By omitting these 3 distances from the average distance calculation:

$$d = 10.57 \pm 1.99 \text{ MPc}$$

This does overlap with Newman's value of

$$d_{true} = 7.80 \pm 0.80$$

This gives a Hubble Constant of:

$$H_0 = 41.6 \pm 7.8 \text{ kms}^{-1} \text{ MPc}^{-1}$$

Which still doesn't overlap.

Improvements

- Account for Extinction:

Dust Particles in Interstellar medium roughly the same size as the wavelength of Blue light. Thus Blue light is strongly Scattered and absorbed by the dust removing it from the light we see making it more red.

This can be accounted for:

got this (V-I)

didn't have this

$$E(B-V) = (B-V) - (B-V)_0$$

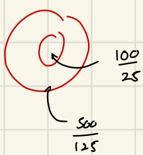
Reddening factor

measured Colour index

true Colour index

true distance is thus: $d = 10^{\left(\frac{5+m-M-3.2E(B-V)}{5}\right)}$ decreasing the average d close to true value

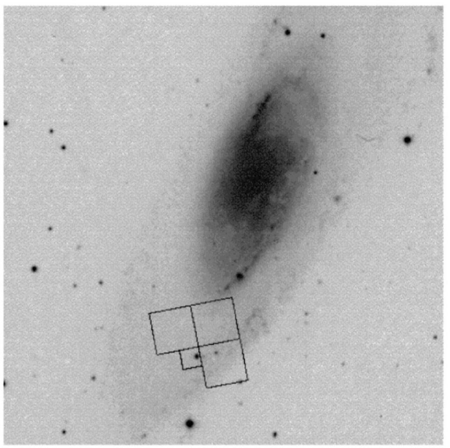
CCD chip underestimated I values. If the efficiency of the CCD was accounted for, I would be higher, decreasing m, decreasing d.



$\frac{500-100}{100} = 4$; $\frac{500}{125} - \frac{100}{25} = \frac{500}{125} - \frac{400}{125} = \frac{100}{125}$

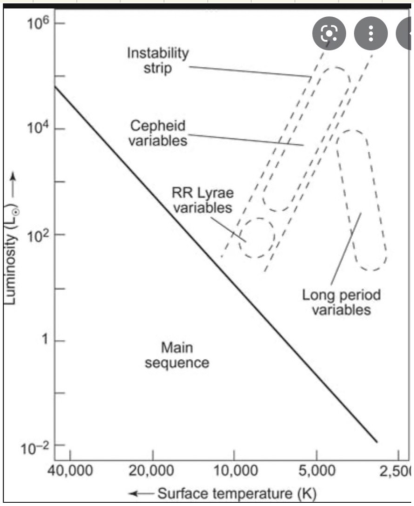
Questions

- CCD doesn't measure counts < 7 photons So true Intensity is greater than measured intensity   QE of $\frac{100}{7}$ % ?



← readings taken far out as less density of stars so less background Intensity.

- Measurements can be done on the ground but approximations need to be made for how the atmosphere interacts with light.
- More accurate to use space telescope.



Cepheids

He^{2+} → high temp → more opaque (absorbs light)

when a CV is dim, lots of He^{2+} in star → gets hotter (absorbs light) → expands.

As it expands it cools, so less He^{2+}, more transparent (Bright) → photons no longer trapped, doesn't heat as much → Cools → Collapses back in.

when it collapses

Certain Combinations of T and R lead to pulsation.

When a Star enters a phase in its lifecycle with the Correct T and R it will pulsate as a Cepheid.

All files in: /Desktop/Uni/UniYear2/Labs/Cepheid

CCD

$I_{avg} = 114$

$\div 0.14$

$I_{avg} = 814$; $\bar{m} = 22.57 - 2.5 \log_{10} \frac{814}{1000}$

$\bar{m} = 22.79$

$\bar{M} = -5.234$

$d = 4062561$ Pc

$= 4$ MPC

$d_{avg} = 3.95 \pm 0.11$

Report

- Equation part of theory needs beefing up.
- Remove H-R diagram? Doesn't add much to the report.

Bin avg graph
+
fit
+
Chi square

to beef up?

Take 4 out of loop and move background

Took 1 from each coordinate to account for python counting from zero

Account for extinction / reddening.

Do Max's method for all Cepheids. Average function.

How? → Average shape requires PCA

Tells us how well each Cepheid fits an average Cepheid curve.

avg graph from Sara?

this is what it should fit to.

↳ fit should be independent from data.

$\boxed{\text{or avg from all data ?}}$

- Use maxs FT method → use graph with smallest χ^2

just highest order. $\chi^2 = 0$. Exactly data points

- Absolute magnitude (M) from $M = -2.760 (\log_{10} P - 1)' - 4.218$
- apparent magnitude from $m_1 - m_2 = -2.5 \log_{10} \frac{I_1}{I_2}$ ← Ref 1000 Counts ⇒ $m = 22.57$

use avg I ?

- $m - M = 5 \log \frac{d}{10}$

$d = 10 \times 10^{\frac{m-M}{5}}$