IRAF LAB – 3

Aim:

To understand the principles of photometry and to do photometry of 2MASS J-band image around star FS13 using the ‘imexamine’ and ‘qphot’ tasks of IRAF.

Introduction:

Photometry involves measuring the flux emitted by sources of interest in specific wavelength bands. When it comes to optical and infrared photometry, the luminosity of stars is commonly denoted in magnitudes.

There are two major difficulties in conducting photometry below,

1. Atmospheric Extinction:
   The atmospheric extinction coefficient is determined by conducting observations in filters aligned with the wavelength passbands of interest. These observations entail measuring the flux of a standard star relative to its zenith angle (linked to the airmass). The slope of this curve provides the atmospheric extinction coefficient, which is subsequently utilized to adjust the observed magnitudes of targets. The corrected values yield the flux above the atmosphere.
2. Sky Background:
   The flux values of objects of interest are challenging to determine due to the overlay of their signals on the sky's background flux. This background light originates from diverse sources, such as unresolved stars and galaxies, sunlight scattered into the beam, stray reflections from the telescope, artificial light, airglow, zodiacal light, and more. A straightforward model for this sky background assumes its constancy in the proximity of each object of interest. The sky brightness is quantified in magnitudes per square arcsecond and varies based on the observation wavelength, the moon's phase, and other factors. The sky background can introduce significant errors, especially in crowded stellar regions. Hence, subtracting the background flux is a crucial step in accurate photometric analysis.

   A frequently used method for assessing the background flux near an object of interest involves selecting pixels within an annulus centred around it and calculating either the median or mode of their pixel values. This provides the background flux per pixel, which should be multiplied by the number of pixels considered in determining the source flux. The resulting value is then subtracted from the initially calculated, potentially erroneous, source flux.

In this context, the measured flux **f** is expressed in A/D converter units (ADUs) per second. Consequently, the zero-point magnitude corresponds to the magnitude of a source with a flux of 1 ADU/s.

Depending on the nature of the target, one of the following two photometric techniques is employed:

1. Aperture Photometry:
   This method involves using a circular aperture with a diameter larger than the Full Width at Half Maximum (FWHM) corresponding to the point spread function (PSF) of the instrument. The sum of pixel values within this aperture, centred around a star, provides the total signal from both the star and the background. An annulus, with an inner diameter greater than the aperture diameter and an outer diameter, is used to sample the background. The median or mode of the pixel values inside the aperture serves as the background per signal in the vicinity of the star. Multiplying this background per pixel by the number of pixels in the aperture and subtracting it from the sum of pixel values yields the source signal for the star in ADU. This technique is typically employed in sparse star fields.

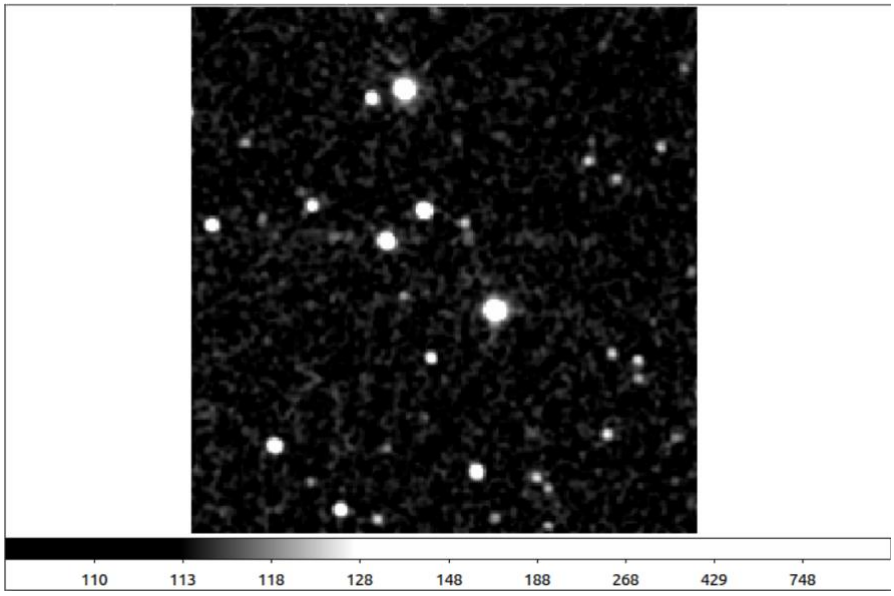
2. PSF Photometry:
   In PSF photometry, the image of a star is fitted with a PSF template to determine both the flux from the star and the background flux in its vicinity (Heasley et al., 1999). Given the star's location on the image (x, y), a region slightly larger than the FWHM of the PSF of the instrument, centred at (x, y), is selected. This region is then fitted into a template of the PSF on top of some background. The parameters obtained from the best fit of the model provide information about the source flux and the background, eliminating the need for a separate step for background subtraction. This technique is particularly useful in crowded star fields.

Procedure and Observation:

- ## Aperture Photometry using Imexamine

The **2MASS J-band** image of the area surrounding the standard star **AS 13 (FS 13)** with coordinates **05 57 7.5**, **+00 01 11** was obtained by utilizing the **2MASS** Interactive Image Service. The image dimensions were set at a fixed size of **240** arcseconds.

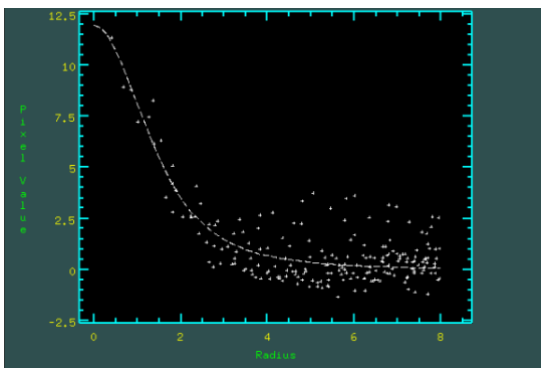
Below is the image which is downloaded.



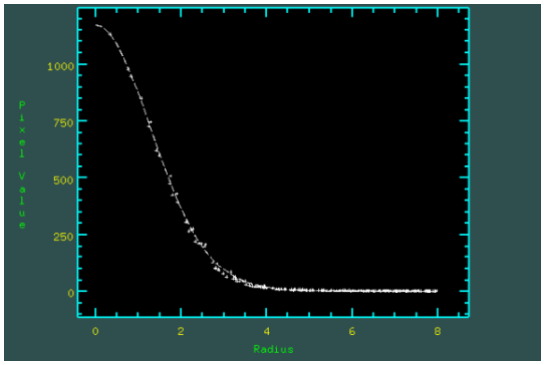
Question: Is it a crowded Field?
Answer: No, the field is not crowded.

Question: What is the zero-point magnitude for this image?
Answer: The header file of the image tells us that its zero-point magnitude is 20.9376

The '**imexamine**' tool's radial profile plot feature was employed to generate radial plots for several stars, and two of them are presented below.



Radial profile of faint star



Radial profile of a bright star

As observed, the noise becomes comparable to the signal emitted by faint stars, potentially causing inaccuracies in the radial profile fit. Consequently, for determining the Full Width at Half Maximum (FWHM) of the Point Spread Function (PSF), radial profiles of 10 bright stars were analysed. The resulting FWHM of the PSF was approximately 3 pixels. Subsequently, the aperture radius was set to 12 pixels (4 times the FWHM of the PSF). This value was then utilized in the '**imexamine**' task through the **'epar rimexam**' command.

As instructed to use an **inner radius of 15** and a **sky annulus width of 10**, the background **buffer width**—defined as the separation between the aperture and the inner edge of the annulus—was configured to 3.

The background width, determining the extent of the sky annulus, was established at 10. The number of iterations for radius adjustment was specified as 1, as there was no intention to modify the aperture radius.

```
                                  I R A F
                Image Reduction and Analysis Facility
PACKAGE = tv
   TASK = rimexam

(banner =                     yes) Standard banner
(title  =                        ) Title
(xlabel =                  Radius) X-axis label
(ylabel =             Pixel Value) Y-axis label
(fitplot=                     yes) Overplot profile fit?
(fittype=                  moffat) Profile type to fit
(center =                     yes) Center object in aperture?
(backgro=                     yes) Fit and subtract background?
(radius =                     12.) Object radius
(buffer =                      3.) Background buffer width
(width  =                     10.) Background width
(iterati=                        1) Number of radius adjustment iterations
(xorder =                        0) Background x order
(yorder =                        0) Background y order
(magzero=                 20.9376) Magnitude zero point
(beta   =                   INDEF) Moffat beta parameter
(rplot  =                      8.) Plotting radius
More                                                    ESC-? for HELP
```

Parameter Values set for the '**imexamine**' task using '**repar rimexam**'

Zero point magnitude set to the required value of 20.9376

There was no provision to specify the size of the centering box in '**imexamine**' since it automatically utilizes a square with a side length twice the aperture radius for centering. This posed a challenge, as, for certain stars, the centering box encompassed additional stars, resulting in the fit being centered on the brighter star instead.

Hence, the center of gravity (COG) was determined prior to obtaining the magnitudes of 15 stars. This approach allowed us to assess the effectiveness of a smaller aperture, ensuring that no stars in its vicinity fell within the aperture or the associated centering box.

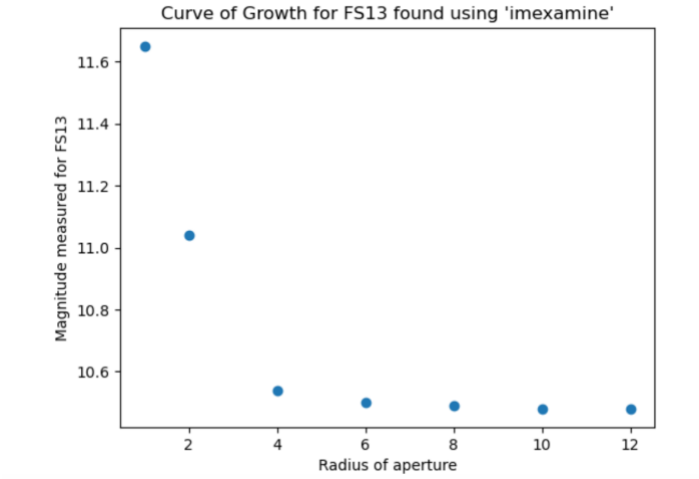
The star FS13 at coordinates **121.07**, **89.10** served as the reference for the curve of growth. Using the '**imexamine**' task with the image displayed in DS9, the log file was accessed by pressing 'w' to save all outputs. Circular aperture photometry was conducted by centering the cursor on the star and pressing 'a'.

After closing the log file with 'w', the radius and buffer width parameters were adjusted using '**epar rimexam**'.

This process was iterated for various aperture values, and the results are tabulated below.

Radius of Aperture	Magnitude	Flux
1.00	11.55	5174.
2.00	11.01	9123
4.00	10.44	14455
6.00	10.50	14955
8.00	10.48	15107
10.00	10.48	15177
12.00	10.48	15233

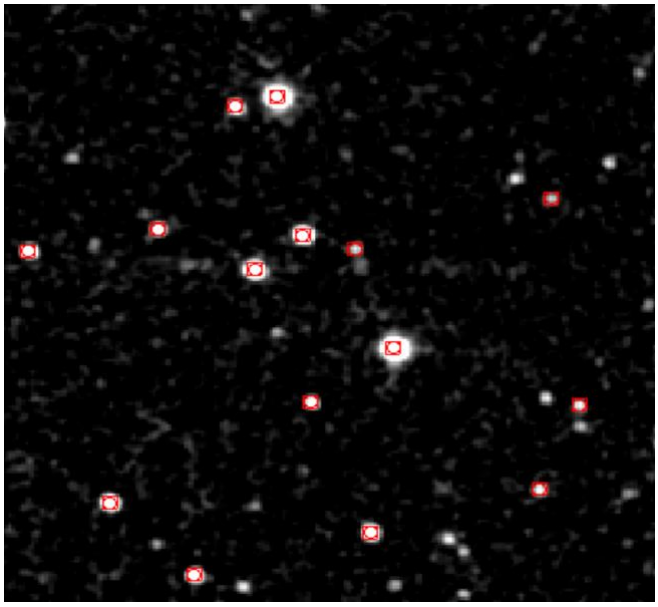
Below is a plot in python which is drawn for Magnitude vs Radius of Aperture.



Following the curve of growth analysis and verifying the centering performance with different aperture radius values, an aperture size of 8 was

selected. Opting for a larger aperture size resulted in inadequate centering. The buffer width was set to 7 to ensure the inner radius of the sky annulus remained at 15.

Question: Select 15 stars in the field and get the magnitudes using the tasks within 'imexamine'.
Answer: Have a look at the following image which shows 15 stars whose magnitudes have been found.



Utilizing the '**imexamine**' task with the DS9-open image, the log file was accessed by pressing the 'w' key to save all outputs. The cursor was successively centred on individual stars, and the '**a**' key was pressed to conduct circular aperture photometry at those positions.

Pressing '**w**' again closed the log file, saving all the results.

The image below displays the logfile with the data with results of photometry done using 'imexamine'

```
# [1] fs13.fits -
#    COL     LINE  COORDINATES      R     MAG    FLUX     SKY    PEAK     E    PA BETA ENCLOSED   MOFFAT DIRECT
  85.27   176.78 85.27 176.78   8.00  10.65  13075.   112.5   1175. 0.06  -49 12.9      2.79     3.05   2.95
  72.36   173.33 72.36 173.33   8.00  13.87    674.   112.8   60.85 0.23   67 18.3      2.86     3.05   2.96
   8.85   122.95  8.85 122.95   8.00  13.78    730.   112.5   65.54 0.18   49 7.08      2.60     3.08   2.96
  48.51   130.62 48.51 130.62   8.00  14.35    430.   112.6   36.62 0.24  -55 12.6      2.97     3.00   2.94
  78.29   116.50 78.29 116.50   8.00  12.17   3206.   112.5   305.3 0.09  -39 10.2      2.73     2.92   2.85
  93.11   128.62 93.11 128.62   8.00  12.54   2284.   112.5   200.7 0.10   29 6.88      2.66     3.13   3.06
 109.57   122.68 109.57 122.68   8.00  15.25   188.7   112.6   7.463 0.66  -78 2.14      3.97     3.93   4.07
 169.63   140.91 169.63 140.91   8.00  15.32   176.8   112.3    8.93 0.04  -75 4.75      3.08     3.44   3.22
  95.63    70.34  95.63 70.34   8.00  14.96   246.9   112.5   26.84 50.9   29 5.89      2.57     2.96   3.02
 121.08    89.12 121.08 89.12   8.00  10.49  15107.   112.6   1283. 0.06  -26 6.64      2.69     3.18   3.11
  33.84    35.32  33.84 35.32   8.00  13.06   1419.   112.5   132.8 0.09    0 14.6      2.58     3.03   2.96
  59.82     9.86   59.82 9.86   8.00  13.82   704.9   112.5   65.06 0.23    6 6.13      2.58     3.07   3.01
 113.86    24.97 113.86 24.97   8.00  13.38   1058.   112.4   97.42 0.21  -55 5.81      2.60     3.05   2.98
 165.72    39.87 165.72 39.87   8.00  14.99   238.5   112.4   17.32 0.65   36 9.62      2.94     2.98   2.88
 177.98    65.81 177.98 65.81   8.00  15.01   234.6   112.6    1.98 0.62  -85 10.6      8.33    12.62   9.76
```

- ## Aperture Photometry using 'qphot':

Question: Take the same image and display.

Answer: After opening the image in ds9, iraf was opened for analysis.

The settings for **'qphot'** were modified by utilizing **'epar qphot'** to adjust parameters related to the aperture radius, inner radius, annulus width, centering box width, and zero-point magnitude. The specific values assigned to these parameters were **8**, **15**, **10**, **5**, and **20.9376** respectively.

Additionally, the interactive mode parameter was configured to 'no' to activate **'qphot'** in a passive mode.

The x and y coordinates of the selected 15 stars were extracted from the photometry table created in the concluding section and stored in a region file named '15stars.reg.' Subsequently, the **'coords'** parameter in **'qphot'** was configured to **'15stars.reg**' to ensure that the coordinates are sourced from this file.

The **'qphot'** operation was executed, and the results were saved in a file named 'fs13.fits.mag.1.'

Question: See the parameters and the help of this task and use it. Extract the image name, xcenter, ycenter,flux, mag, merr.

Answer: To capture essential data such as image name, x-center, y-center, flux, magnitude, and magnitude error, the following command was issued-

'txdump fs13.fits.mag.1 IMAGE, XCENTER,YCENTER,FLUX,MAG,MERR yes > phot_qphot.txt.'

Subsequently, this information was stored in a new file called **'phot_qphot.txt**.'

#N IMAGE	XCENTER	YCENTER	FLUX	MAG	MERR
#U imagename	pixels	pixels	counts	mag	mag
#F %-26s	%-14.3f	%-11.3f	%-14.7g	%-7.3f	%-6.3f
#					
fs13.fits	85.353	176.701	13080.48	10.646	0.010
fs13.fits	72.452	173.455	692.1606	13.837	0.045
fs13.fits	121.073	89.174	15106.71	10.490	0.009
fs13.fits	95.780	70.372	244.0345	14.969	0.086
fs13.fits	78.390	116.496	3218.455	12.168	0.019
fs13.fits	93.146	128.550	2299.87	12.533	0.023
fs13.fits	113.903	24.978	1063.417	13.371	0.035
fs13.fits	59.755	9.891	708.4754	13.812	0.044
fs13.fits	33.849	35.397	1416.387	13.060	0.030
fs13.fits	8.706	122.876	728.9192	13.781	0.043
fs13.fits	48.508	130.549	427.6524	14.360	0.061
fs13.fits	165.611	39.752	236.1981	15.004	0.087
fs13.fits	177.902	69.394	145.1972	15.533	0.118
fs13.fits	169.345	141.340	175.6349	15.326	0.103
fs13.fits	109.248	123.783	195.4715	15.210	0.100

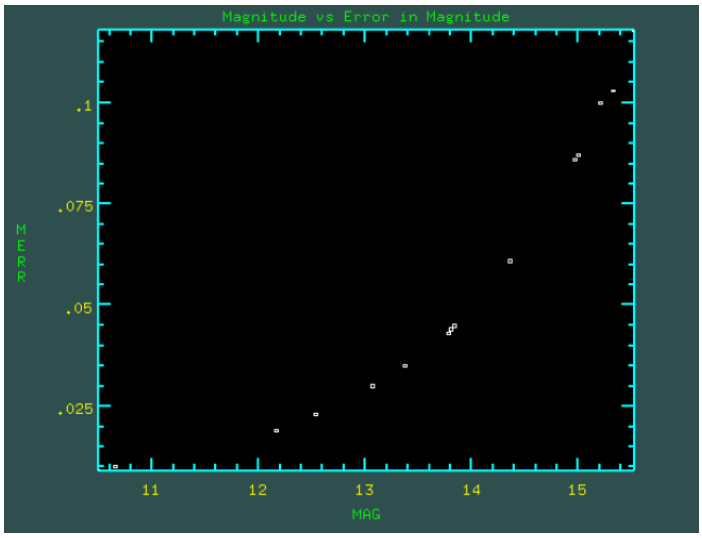
Table with results for photometry using qphot

By employing the command **'txdump fs13.fits.mag.1 MAG,MERR | graph po+,'** a plot illustrating the relationship between magnitude error and the magnitude of the 15 stars was generated.

Subsequently, the **'xlabel**,' **'ylabel**,' and 'title' parameters were adjusted using the **'epar graph**' command to modify the labels and title of the plot.

The resulting plot is displayed below.

Question: What does this plot imply?



Plot of Magnitude vs Error in Magnitude for chosen 15 stars

Answer: The plot s more pronounced for sta gns with expectations, as stars with higher magnitudes are typically fainter, resulting in lower signal-to-noise ratios (SNR).

Consequently, the estimates of magnitude for these fainter stars exhibit larger error bars.

Through 'epar qphot,' the 'aperture' parameter was configured with values '1,2,4,6,8,10,12,' and the 'coords' parameter was defined as 'FS13.reg.' This region file exclusively contained the x and y coordinates of FS13.

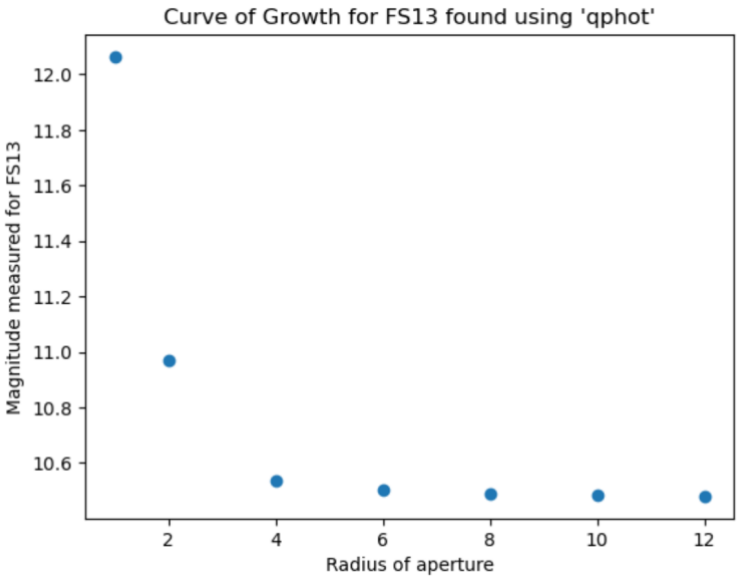
Subsequently, employing the qphot task in passive mode, the Center of Gravity (COG) data was obtained and is presented in the tabulated form below.

Radius of Aperture	Magnitude	Flux
1.00	12.064	3543.317
2.00	10.971	9697.675
4.00	10.535	14486.23
6.00	10.501	14952.93
8.00	10.490	15106.71
10.00	10.485	15177.69

12.00	10.480	15238.2

Question:By setting a number of apertures get the COG and plot it (same as you have done for the 'imexamine' photometry'.

Answer:



As I encountered difficulty obtaining celestial coordinates from the IRAF output, I turned to DS9's region options to retrieve them. I saved the x, y coordinates of the stars in a **.reg** file, opened it, selected '**XY**' and 'Physical' format, and then saved it again, this time with **'XY'** and '**fk5**' formatting.

This process provided me with a list of celestial coordinates for the stars, maintaining the same order as the x, y coordinates in the initial .reg file. Subsequently, I used this information to generate a table, which was cross-matched with the **2MASS** All Sky Survey table obtained through a cone search with a radius of **120 arcseconds** around **FS13**.

The resulting compiled table is presented in the results section.

Results:

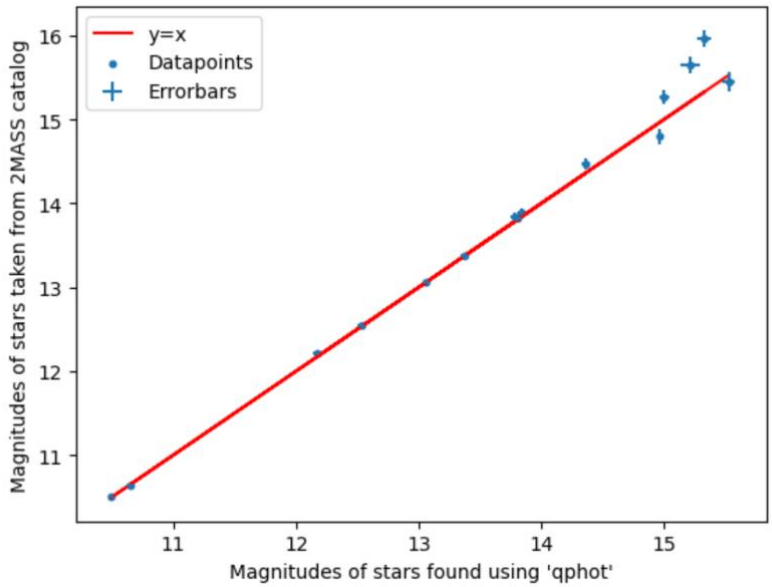
Question: Make a table with the following columns for the 15 selected stars.

Answer: Kindly find the table containing photometric results and the plot depicting 'qphot' magnitude values against the corresponding values from 2MASS below.

Star no.	X	Y	RA	DEC	MAG(imexamine)	MAG(qphot)	MAG(2MASS)	
1	85.353	176.701	89.29146	0.044231	10.65	10.646	10.644	
2	72.452	173.455	89.295045	0.04325	13.87	13.837	13.896	
3	8.706	122.876	89.312642	0.029267	13.78	13.781	13.842	
4	48.508	130.549	89.301618	0.031418	14.35	14.36	14.473	
5	78.39	116.496	89.293387	0.027486	12.17	12.168	12.223	
6	93.146	128.55	89.289284	0.030856	12.54	12.533	12.539	
7	109.248	123.783	89.284862	0.029481	15.25	15.21	15.652	
8	169.345	141.34	89.26815	0.034418	15.32	15.326	15.965	
9	95.78	70.372	89.288556	0.014637	14.96	14.969	14.799	
10	121.073	89.174	89.281508	0.019864	10.49	10.49	10.499	
11	33.849	35.397	89.305719	0.004895	13.06	13.06	13.067	
12	59.755	9.891	89.298521	-0.00212	13.82	13.812	13.83	
13	113.903	24.978	89.283511	0.002038	13.38	13.371	13.383	
14	165.611	39.752	89.269161	0.006177	14.99	15.004	15.267	
15	177.902	69.394	89.265764	0.014349	15.01	15.533	15.45	

Question: Generate a plot which will has the ‘qphot’ mags on the x- axis and the 2MASS values on the y- axis.

Answer:



Observing the data, a satisfactory agreement is evident between the **'qphot'** magnitude values and **2MASS** values for brighter stars (lower magnitude). However, a noticeable discrepancy is observed for fainter stars (higher magnitude). This divergence may be attributed to instances where more than one star falls within the aperture centred on one of them, potentially influenced by the larger aperture radius chosen.

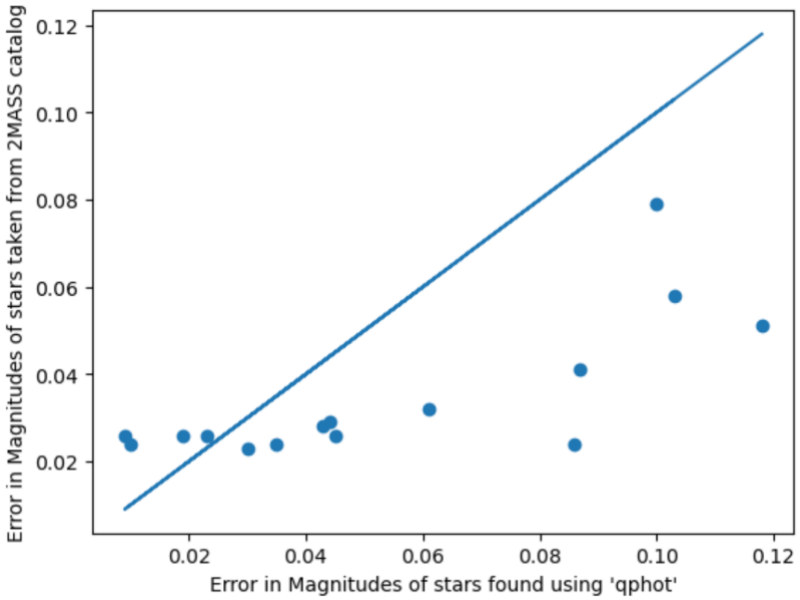
Question: Try to find out about the photometric accuracies of the 2MASS catalogued values from documentation available on the net. Are they consistent with your results?

Answer: The table below presents a comparison of the magnitude errors obtained through 'qphot' with those provided in the 2MASS catalog. The accompanying plot facilitates a more detailed comparison of these values.

It's evident that these error values are not uniformly aligned. Generally, the error values for magnitudes derived from 'qphot' are smaller compared to those specified in the 2MASS catalog.

MERR(qphot)	MERR(2MASS)
0.01	0.024
0.045	0.026
0.043	0.028
0.061	0.032
0.019	0.026
0.023	0.026
0.1	0.079
0.103	0.058
0.086	0.024
0.009	0.026
0.03	0.023
0.044	0.029
0.035	0.024
0.087	0.041
0.118	0.051

This table is from the catalog available on the net.



The above plot shows the comparison from the ‘qphot’ we found to those in the 2MASS catalog

Conclusion:

I have learnt more about IRAF through this lab.