## HW 05 - Measure the brightness of J1614-1906

You will carry out measurements to determine if the object J1614-1906 (RA/Dec. 16h14m 20.3s -19d06m48.1s) is variable. You are being provided a set of images which are fully reduced observations in r’ from the LCOGT 1m telescope network. This HW will prepare you to be able to write a paper arguing whether there is sufficient evidence to further investigate this object.

### Email to Geoff by Oct. 17, noon:

A document containing the following:

* A draft **introduction** outlining:
  + possible reasons for variability in young stars
  + how one tries to determine if a particular star is variable
  + what is the evidence that J1614-1906 is a young star
  + in general, what do we know about J1614-1906? Be sure to include its R magnitude from the literature
* An **image** of a zoom-in on J1614-1906 showing it and nearby stars to identify it.
* Draft text for the **Observations** section of the paper, describing:
  + Total image size, in both pixels and angle on sky
  + Region and aperture size used for photometry,
  + Total number of counts in the aperture,
  + Region and aperture size used for the sky subtraction,
  + Mean and standard deviation of counts in the sky region,
  + X Y position of the star in the image.

### Use the following files:

Start with image file: coj1m011-kb05-20140607-0113-e90.fitsLiterature search

Retrieve PDFs of the following papers:

* Cody et al., 2014, Astronomical Journal, volume 147, p. 82
* Preibisch & Mamajek, 2008, from the book Handbook of Star Forming Regions, Volume II, ed. B. Reipurth (*hint: book chapters tend to end up in only in physical books and on Astro-PH*)

Use the Astrophysical Data System (<http://adsabs.harvard.edu/>). To search ADS by first author, use ‘^’. For example, to retrieve the first paper, search for:

^Cody 2014

You may also need to make use of the UH Manoa library journal server to find accessible journal websites (<http://sfxhosted.exlibrisgroup.com/uhmanoa/az/>), or Astro-PH to directly access pre-print versions of papers (<https://arxiv.org/>).

Use the introduction of Cody et al. to gain a basic understanding of:

* Variability in young stars and its potential causes
* How does one search for such variability

Use the Preibisch & Mamajek book chapter, in particular sections 3.2 - 3.5, to understand:

* What evidence do we have that J1614-1906 is a young star?

### Open python

ipython --pylab

### Loading and examining image data

There are specialized packages for working with astronomical .FITS files.

from astropy.io import fits as fits

hdulist = fits.open('coj1m011-kb05-20140607-0113-e90.fits')

# quick check of file basics, especially dimensions

hdulist.info()

# copy data and header into their own variables

image = hdulist[0].data

header = hdulist[0].header

# quick check that data is a 2 dimensional array

image

# quick check that header does contain header information

header

Now extract the key statistics of the data array:

import numpy as np

# get the number of rows

n\_imcols = np.shape(image)[0]

# get the number of columns

n\_imcols = np.shape(image)[1]

# get basic image stats: mean, median, standard deviation

np.mean(image)

np.median(image)

np.std(image)

Display the data as an image. This might take some experimentation with scaling.

import matplotlib.pyplot as plt

# display the image and experiment with scaling

plt.imshow(image)

np.min(image), np.mean(image), np.max(image)

showIm = np.log10(image)

plt.imshow(showIm,'gray')

np.min(showIm), np.mean(showIm), np.max(showIm)

np.nanmin(showIm), np.nanmean(showIm), np.nanmax(showIm)

showIm = np.log10(image - np.mean(image))

plt.imshow(showIm,'gray')

np.nanmin(showIm), np.nanmean(showIm), np.nanmax(showIm)

### Sky region

From the whole image, select a region that has no stars to use for estimating how much light each pixel is getting from the background and how that varies.

IMPORTANT: when specifying a subset of a 2D array, the first set of indices are rows, the second are columns (i.e., Y, X).

background = image[850:1000,1040:1100]

showIm = np.log10(background)

plt.imshow(showIm,'gray')

dims\_bk = np.shape(background)

n\_bk = dims\_bk[0] \* dims\_bk[1]

mean\_bk = np.mean(background)

sigma\_bk = np.std(background)

# always inspect important variables!

n\_bk, mean\_bk, sigma\_bk

Target region

From the whole image, select a region that has the target star, but no others. For this region, the key value is the total number of counts.

target = image[1030:1070, 945:985]

showIm = np.log10(target)

plt.imshow(showIm,'gray')

dims\_tg = np.shape(target)

n\_tg = dims\_tg[0] \* dims\_tg[1]

sum\_tg = np.sum(target)

Convert to the number of electrons (proxy for the number of photons)

The gain from the header tells you how to convert from counts to the number of electrons.

gain = header['GAIN']

sum\_gain = sum\_tg \* gain

back\_gain = mean\_bk \* gain

std\_gain = sigma\_bk \* gain

Aperture photometry

You must subtract the background from total number of counts. The sky region tells you the mean value of the background in each pixel. So, multiplying the number of pixels in the aperture by the mean sky value will let you estimate the background contribution to your total.

back = n\_tg \* back\_gain

nPhotons = sum\_gain - back

Uncertainty estimates

You must propagate the uncertainties to make an estimate for the final uncertainty in the number of photons detected from the target.

Remember, we are *counting* photons, which means Poisson statistics applies. So, where we have only the one chance at measuring the light from the target, the uncertainty is the square root of the number of photons.

The background, on the other hand, is something which we have many opportunities to measure (essentially, each pixel in empty sky). You could use the square root of the mean background value… but this will almost certainly be an under-estimate of the variability. The standard deviation of the background is almost alway larger than what the Poisson error of the mean would imply.

Centroid to determine the star’s position

You’ll need arrays with X and Y values to determine the position of the star in the image.

# centroid on your source

indices = np.indices((n\_imrows,n\_imcols))

xs = indices[1,:]

ys = indices[0,:]

target\_xs = xs[1030:1070, 945:985]

target\_ys = ys[1030:1070, 945:985]

target\_xs, target\_ys

target\_x = np.sum(target \* target\_xs) / np.sum(target)

target\_y = np.sum(target \* target\_ys) / np.sum(target)

Using information from the header, you can calculate what that location is in terms of RA and Declination.

# use Header to determine source position

# FITS headers number pixels from 1 onward. Python starts at 0

x0 = header['CRPIX1'] - 1

y0 = header['CRPIX2'] - 1

ra0 = header['CRVAL1']

dec0 = header['CRVAL2']

# these give how large is each pixel in degrees in Y and X direction

CD1\_1 = header['CD1\_1']

CD2\_2 = header['CD2\_2']

ra = CD1\_1 \* (target\_x - x0) + ra0

dec = CD2\_2 \* (target\_y - y0) + dec0

ra, dec

There are astropy packages for easily converting from degrees to sexagesimal.

from astropy import units as u

from astropy.coordinates import SkyCoord

c = SkyCoord(ra=ra\*u.degree, dec=dec\*u.degree, frame='icrs')

c.to\_string('hmsdms')

Use a standard star to determine the r-magnitude of J1614-1906

16 14 20.912 -19 06 04.70 has an r magnitude of 13.5. Carry out aperture photometry for it, and use the flux ratio with J1614-1906 to determine J1614-1906’s r band magnitude. When estimating the uncertainty, you may find this transformation useful:

log10X = ln X / ln 10

Useful Python code is:

np.log10(X)

np.log(X)