Lecture 8

Nov 3, 2016
Data Analysis for Labs 4 and 5
News

• Lab 2 handed back

• Lab 4: Photometry of M31 and M32
  – NOT due today
  – Due Nov 10

• Lab 5: Measuring the Transit of an Exoplanet
  – Due November 17
Lab 4: Galaxy Surface Photometry

• Galaxies are not resolved into stars (certainly not in our telescope!)
  – So measure amount of light per area (mag/sq arcmin)

• Measure projected shape of light distribution.
  – Shape is elliptical to first order.
    • “Disky” and “boxy” departures from ellipses are seen.
  – Ellipticity and position angle of major axis can vary with radius.
    • Ellipticity: $\varepsilon = 1 - \frac{b}{a}$; $b=$minor axis, $a=$major axis
    • Position angle: angle from North to major axis (measured positive through east).
M32 V

Log Contour plot of [1175:1244,507:576]

Logarithmically spaced contours (select log scaling in RUPhAst)
Logarithmically spaced contours (select log scaling in RUPhAst)
Log Scaling
Logarithmically spaced contours (select log scaling in RUPhAst)
Logarithmically spaced contours (select log scaling in RUPhAst)
Lab 4: Galaxy Surface Photometry

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Lab 4: Galaxy Surface Photometry

• Galaxies are not resolved into stars (certainly not in our telescope!)
  – So measure amount of light per area (mag/sq arcmin)

• Measure radial profile of light distribution.
  – Ideally on ellipsoidal contours
    • Galsbmag_ru uses circular apertures.
  – Choosing a local “sky” level is critical since galaxy profiles quickly become fainter than it.
    • galsbmag_ru, img, xcen, ycen, rmax, sky, skyunc, img_scale, m1, title
Log Scaling
Lab 5 Image Calibration

What do you do with your raw images?
Stellar Photometry in Images

• Correct the image to a uniform, linear response.
  – Dark current and bias level subtraction done at the telescope with autodark subtraction.
  – Need to create an average image of a uniformly illuminated field (“flat field”) and divide by it.
    • The mkflatru command.

• Identify your target and comparison stars.

• Measure the brightness of each star in all of the images.
Lab 5 Image Calibration

The flatfield produced by the median of dome exposures - mkflatru.
Divide all of the images loaded into PhAst by a flatfield using *Pipeline -&gt; Batch calibrate*. Select the flatfield in the popup window. Push start and the flattened images are written in the output/images directory.
Raw image
Data Analysis

Stellar Photometry in Images

• Correct the image to a uniform, linear response.
• Identify your target and comparison stars.
  – Comparison stars should be bright, but not saturated.
• Measure the brightness of each star in all of the images.
  – Use the PhAst aperture photometry tool.
In ImExam mouse mode, left-click on your target star (TrES-3 b here) to bring up the aperture photometry window.
Note the FWHM of the stellar images. Decide on the aperture size.
Measuring Stellar Brightness

• Choosing an Aperture Size
  – Compromise on an intermediate size that contains a fixed fraction of the light.
    • This lab compares the brightness of stars in the same image (*differential photometry*), so a fixed fractional loss is OK as long as it is constant across the image.
  – Thus, the size needs to be bigger than the time- and spatially-variable core of the PSF.
  – Rule of thumb: aperture radius = 2 × FWHM of the stellar profile. In this lab, the stars are bright enough that noise from the sky is less important and can err on the side of even larger apertures.
    • Compensates for less-than-perfect guiding and variable PSF.
Measuring Stellar Brightness

• RUPhAst aperture photometry measures (x,y) position, “object counts” (c), “sky level” (s in counts/pixel), and exposure time (t in seconds, from the image header).

  – Can only measure *non-saturated* stars.

• Calculates instrumental magnitudes using

  – \( m_{\text{inst}} = 20.3 - 2.5 \log_{10}(c/t) \)
  
  – \( \sigma_m = 1.086 \left( \sigma_c / c \right) = 1.086((c \, g + N_p \, s \, g + N_p \, r^2)^{1/2} / (g \, c)) \)

  • \( g = \) gain = 0.80 electrons/ADU
  
  • \( r = \) read noise = 15.5 electrons/pixel
Can open a file to save the photometry in and then photometer the star in all of the loaded images with the “Do all” button.
Choose comparison stars with a brightness similar to or greater than the target star. This minimizes the uncertainty in the magnitude difference.
An even brighter comparison star.
But don’t use saturated stars.
## Photometry Output from RUPhAst

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Photometry Output in Excel

“Import” the text file from RUPhAst into Microsoft Excel or the OpenOffice Calc program.

A fixed-width input format works best.

Delete extra lines and rearrange blocks of photometry in Excel/Calc (or earlier with a text editor).
Calculate the difference between the magnitudes of the target and comparison stars at each time. Also the uncertainty.
HAT-P-10 and comparison stars
Taking magnitude differences reveals the transit.
Taking magnitude differences reveals the transit.

Note the non-default axis ranges and labeling. Choose ranges that best display your data.
Differencing comparison star magnitudes shows no (strong) trends. Maybe a change of 0.01 mag from beginning to end.
Averaging the results from the different comparison stars.

Note the too-large y-axis range. But note the error bars on the points --- obtained by supplying the uncertainty for each point using the “custom” option.
Lab 5 Analysis

• Once you have your transit light curve, how to quantitatively estimate the depth, duration, and central time?
  – One useful approach is to plot running mean of the data (say three points). The smoother curve can make it easier to see the features of the transit.
Transit seems shorter and later than predicted.
Lab 5 Analysis

• Once you have your transit light curve, how to quantitatively estimate the depth, duration, and central time?
  – One useful approach is to plot a running mean of the data (say three points). The smoother curve can make it easier to see the features of the transit.
  – Averaging the points in and out of transit and taking the difference yields an estimate of the depth.

\[
\begin{array}{|c|c|c|}
\hline
\text{3pt mean} & \text{out avg} & \text{in avg} & \text{diff} \\
\hline
-0.0883 & -0.0912 & 0.0011 \\
-0.0856 & -0.0689 & 0.0010 \\
-0.0852 & 0.0223 & 0.0015117 \\
-0.0889 & & \\
0.0087 & & \\
\hline
\end{array}
\]

(points 4-11 and 65-74)
(points 19-53)
The estimated depth of $0.0223 \pm 0.0015$ magnitude is shallower than the 0.025 tabulated, but agrees with the results shown above (taken from the results in the Exoplanet Transit Database). Note also the shorter durations and delayed transit times.
Lab 4 Analysis

- Once you have your transit light curve, how to quantitatively estimate the depth, duration, and central time?
  - Another approach is to adopt a simple model for the transit light curve and adjust $t_c$, $t_d$, $\Delta t$, $d$, and $m_0$ (by hand or by least-squares fit) to achieve a good match to the data.

![Diagram showing transit light curve parameters $t_c$, $t_d$, $\Delta t$, $d$, and $m_0$.]
Least-squares fit of model to the data
Lab 5 Analysis

• Once you have your transit light curve, how to quantitatively estimate the depth, duration, and central time?
  – Example: \( t_c = 2.814 \text{ UT} \ (2.792 \text{ predicted}) \pm 0.05 \text{ hr?} \)
  \[ t_d = 2.36 \text{ hours} \ (2.65 \text{ predicted}) \pm 0.1 \text{ hr?} \]
  \[ d = 0.0224 \text{ mag} \ (0.025 \text{ predicted}) \]
  \[ \Delta t = 0.275 \text{ hours} \]

A scientific least-squares fitter (as opposed to the excel solve function) would return uncertainties for the fitted parameters.