Lecture 12

November 19, 2015
Lab 6 and Lab 7
News

• Next Tuesday is....
News

• Next Tuesday is…. Tuesday!
  – So no class next week.
  – Next class is Thursday, December 3rd.
News

• Lab 6: Stellar Photometry and the Color-Magnitude Diagram
  – Observing done. I will make data available to those who were not able to observe.
  – Instrumental CMD due *Wednesday, November 25*.
  – Lab due *Thursday, December 3*.

• Lab 7: Nebular Spectroscopy
  – No observing; we will use pre-existing data.
  – Lab due *Thursday, December 10*.
Lab 6: Color-Magnitude Diagram

• Target is the open cluster M34.
  – CMD can determine the cluster distance and age.

• Will again perform differential photometry by using stars in the field with known standard magnitudes.
  – So the observations can be taken through thin scattered clouds.

• Will observe in both the V and I filter to get stellar colors, V–I.
  – Color measures stellar surface temperature.
DAOPHOT/ALLSTAR Package

• Finds stars in images and does both aperture and psf-fitting photometry.
• Command line driven programs (i.e., you type in commands), so are less intuitive to use.
• Start-up files initialize parameters.
  – daophot.opt: sets the gain, read noise, and typical FWHM of stars (plus other more esoteric things)
  – photo.opt: sets the aperture and sky annulus radii
  – allstar.opt: sets some parameters for the psf-fitting photometry
DAOPHOT – the *attach* command specifies the image to measure.

```
Command: attach m34v7-010.fits
m34v7-010...
```

```
READ NOISE (ADU; 1 frame) = 11.14   GAIN (e-/ADU; 1 frame) = 0.87
LOW GOOD DATUM (in sigmas) = 7.00    HIGH GOOD DATUM (in ADU) = 60000.00
FWHM OF OBJECT = 7.50     THRESHOLD (in sigmas) = 4.00
LS (LOW SHARPNESS CUTOFF) = 0.30   HS (HIGH SHARPNESS CUTOFF) = 1.40
LR (LOW ROUNDNESS CUTOFF) = -1.00  HR (HIGH ROUNDNESS CUTOFF) = 1.00
WATCH PROGRESS = 1.00     FITTING RADIUS = 8.00
PSF RADIUS = 25.00     VARIABLE PSF = 0.00
SKY ESTIMATOR = 0.00    ANALYTIC MODEL PSF = -6.00
EXTRA PSF CLEANING PASSES = 1.00  USE SATURATED PSF STARS = 0.00
PERCENT ERROR (in %) = 0.75     PROFILE ERROR (in %) = 5.00
```

```
Command: find
```

```
Sky mode and standard deviation = 27.310 17.212
Clipped mean and median = 27.525 27.453
Number of pixels used (after clip) = 9.962
Relative error = 0.46
```

```
Number of frames averaged, summed: 1.1
File for positions (default m34v7-010.coo):
```

Use the default name.
Many stars found, some of which will turn out to be noise.

Are you happy with this? [y]

Command: phot

File with aperture radii (default photo.opt):

| A1 | RADIUS OF APERTURE 1 = 8.00 | A2 | RADIUS OF APERTURE 2 = 0.00 |
| A3 | RADIUS OF APERTURE 3 = 0.00 | A4 | RADIUS OF APERTURE 4 = 0.00 |
| A5 | RADIUS OF APERTURE 5 = 0.00 | A6 | RADIUS OF APERTURE 6 = 0.00 |
| A7 | RADIUS OF APERTURE 7 = 0.00 | A8 | RADIUS OF APERTURE 8 = 0.00 |
| A9 | RADIUS OF APERTURE 9 = 0.00 | AC | RADIUS OF APERTURE 10 = 0.00 |
| AB | RADIUS OF APERTURE 11 = 0.00 | OS | OUTER SKY RADIUS = 60.00 |

Are given the option to alter the radii here, but you do not need to.

Use default names

DAOPHOT – the phot command performs aperture photometry
DAOPHOT – *pick* chooses bright, unsaturated stars to determine the psf.
DAOPHOT – \textit{psf} uses the picked stars to determine the psf. It shows a simple plot of each star and you decide whether to use it or not.

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<th>X-Coord</th>
<th>Y-Coord</th>
<th>Mag</th>
<th>Error 1</th>
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<td>28.3</td>
<td></td>
</tr>
</tbody>
</table>

Estimated magnitude limit (Aperture 1): 16.9 \pm 0.4 per star.

Command: pick

Input file name (default m34v7-010.ap):
Desired number of stars, faintest magnitude: 30.99

Output file name (default m34v7-010.lst):

30 suitable candidates were found.

Command: psf

File with aperture results (default m34v7-010.ap):
File with PSF stars (default m34v7-010.lst):
File for the PSF (default m34v7-010.psf):
Want bright, isolated stars. These are OK.
These stars should not be used to determine the psf.
Tries six different functional forms for the psf and chooses the one that fits best. Differences from the functional form are handled with a look-up table (so any psf shape can be accommodated).

Profile errors:

<p>| | | | | | |</p>
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</table>

Computation: 103 rows of 103 in the PSF.

File with PSF stars and neighbors = m34v7-010.nei

Command: exit

Good bye.
ALLSTAR – does the psf-fitting photometry

Use the default input and output filenames.

Input image name: m34v7-010.fits

File with the PSF (default m34v7-010.psf):
Input file (default m34v7-010.ap):
File for results (default m34v7-010.als):
Name for subtracted image (default m34v7-010s):

4963 stars. <<

I = iteration number
R = number of stars that remain
D = number of stars that disappeared
ALLSTAR fits all of the stars in the image simultaneously, so overlapping stars are handled correctly (assuming that both stars are in the input list). The solution is done iteratively.

<table>
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<th>C</th>
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</table>
Original 7-second, V-band image
Image with the fitted psf’s subtracted
daomatch begins the process of matching stars in the ALLSTAR output files for each image
Keep entering files until have done all of them for a given filter (V or B)
daomaster finishes the job of matching the stars in the “als” files.

File with list of input files: m34va.mch

6 input files

Maximum permitted number of stars in the master list: 500,000

Minimum number, minimum fraction, enough frames: 1.0.16.1
Maximum sigma: 0.2

Desired degrees of freedom ---

2: Translations only
4: Translations, rotation, and scale
6: Six-constant linear transformation
12: Quadratic transformation
20: Cubic transformation

Your choice: 2
Critical match-up radius: 3.0

0.32 0.72 -121 500 0.02 0.011 117 2 m34av7-045.als
0.11 0.14 0 0 1.74 0.023 186 2 m34v35-034.als
0.32 0.67 -120 501 1.75 0.021 116 2 m34av35-042.als
0.12 0.16 0 0 4.07 0.037 158 2 m34v300-035.als
0.33 0.78 -120 501 4.07 0.043 98 2 m34av300-039.als

1.235 stars within radius 3.000

New match-up radius (0 to exit): }
1,235 stars within radius 3.000

New match-up radius (0 to exit): 0

Transformations are in the sense  \text{STANDARD} = fn(\text{OBSERVED}).

Assign new star IDs? n

Now, do you want...

A file with mean magnitudes and scatter? y
Output file name (default m34va.mag):

A file with corrected magnitudes and errors? n
A file with raw magnitudes and errors? n
A file with the new transformations? y
Output file name (default m34va.mch):

This file already exists: m34va.mch

New output file name (default OVERWRITE):
A file with the transfer table? n
Individual .COO files? n
Simply transfer star IDs? n

Good bye.
M34 instrumental \((v, v-i)\) color-magnitude diagram. 1,235 stars
Stellar Photometry in Images

• Steps
  – Correction of image to a uniform, linear response.
  – Identify and determine positions of stars.
  – Measure the brightness of each star.
  – Correct for absorption by the Earth’s atmosphere.
  – Calibrate telescope + camera (determine the transformation of measured brightness to standard magnitudes).

• We will use stars with known standard magnitudes within our field, which greatly simplifies the process.

• “All sky” photometry using “standard stars” in separate fields is much harder since there cannot be any clouds and must measure atmospheric extinction.
Use the finding charts to identify the stars in the M34 fields with standard magnitudes given in the lab.
Transformation to Standard Magnitudes

• The simplest transformation would be a simple additive correction, like that for atmospheric extinction, to account for the efficiency of the telescope and detector.

• However, the passbands defined by our filters and the spectral response of the CCD do not exactly match that of the standard system (which was defined by a 1P21 photomultiplier tube that is no longer made).

  – As the following figures illustrate, the shift in the passband causes the correction to depend on the temperature of the star.
The effect of passband shifts on SN photometry

Vega, an ordinary star
The effect of a shifted passband will be different for hot and cool stars.
Transformation to Standard Magnitudes

• Thus, the standard transformation equations are:
  
  – \( V - I = \phi_{vi} + \mu_{bv} (v - i) \)
  
  – \( V - v = \phi_{v} + \epsilon (V - I) \)
  
  – Here, \( V \) and \( I \) are the standard magnitudes and \( v \) and \( i \) are the instrumental magnitudes.
  
  – These can be considered first-order Taylor expansions. We will ignore higher order terms (they are usually unimportant).
  
  – The \( \mu_{vi} \) coefficient would be 1.0 and \( \epsilon \) would be 0 if our system matched the standard one.
  
• Actually differ from these values by 0.1 – 0.2.
The quantum efficiency of the CCD is varying significantly across the V and I bands.
Fitting the Transformations

• V–I equation:
  – Calculate a column of
    \[ \Delta_{V-I} = (V-I) - (\phi_{vi} + \mu_{vi} (v - i)) \]
  – Make another column of \((\Delta_{V-I})^2\) and sum to form
    \[ \chi^2 = \Sigma_i (\Delta_{V-I,i})^2. \]
  – Minimize \(\chi^2\) by varying \(\phi_{vi}\) and \(\mu_{vi}\) using solver in excel.

• V equation:
  – Calculate a column of \(\Delta_V = V - (v + \phi_v + \epsilon (V - I))\)
  – Proceed as above to determine \(\phi_v\) and \(\epsilon\).
<table>
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<th>unc v0</th>
<th>i0</th>
<th>unc i0</th>
<th>v0-i0</th>
<th>unc v0-i0</th>
<th>V</th>
<th>B-V</th>
<th>V-I</th>
<th>V-v0</th>
<th>V-v0-phi'_v-eps**(V-I)</th>
<th>V-v0-phi'_v</th>
<th>V-I phi_v-eps*(V-I)0</th>
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| phi_v  | 0.412 | epsilon | -0.115 |
| phi'_v | 0.429 | epsilon' | -0.117 |
| phi_vi | 1.913 | mu_vi   | 0.919  |
Transformations

The smaller range of v-i compared to V-I may arise because the CCD quantum efficiency weights our I band towards short \( \lambda \)'s, thus reducing our wavelength baseline (hence, sensitivity to T).
Interstellar Extinction & Reddening

• Caused by scattering from “dust” grains in the interstellar medium.
  – About 1 magnitude of dimming per kiloparsec of distance in the plane of the Galaxy.
  – A major headache.

• Scattering cross-section is larger at shorter wavelengths (Rayleigh scattering), so light is reddened.
Interstellar Extinction & Reddening

• Dust grains properties uniform, so there is a (nearly) universal relation between reddening and extinction.
  
  – Reddening: $E(B-V) = (B-V) - (B-V)_0$
    
    $$(V-I)_0 = (V-I) - 1.6 \ E(B-V)$$
  
  – Extinction: $A_V = V - V_0 = 3.1 \ E(B-V)$

• Reddening is not easy to determine.
  
  – Measure spectral type of stars and use relation between color and type for very nearby stars.

• For Lab 6 you are given $E(B-V)$ and use it to correct your photometry to $V_0$ and $(V-I)_0$. 
Cluster Distance

• Slide a theoretical “zero-age” main sequence isochrone vertically until it matches the cluster main sequence.

\[ m - M = 5 \log(d/10 \text{ pc}) + A_V \]

\[ m = M_V + 5 \log(d/10 \text{ pc}) + A_V \]

• \( M_V \) = isochrone absolute magnitudes
• \( m \) = shifted isochrone apparent magnitudes
• \( d \) = cluster distance
• \( A_V \) = extinction due to interstellar dust.
Increasing the m–M adopted for the isochrone in steps of 0.1.
Increasing the m−M adopted for the isochrone in steps of 0.1.
Increasing the m−M adopted for the isochrone in steps of 0.1.
Cluster Age

• Match the main-sequence turnoff.

Isochrones

- Log Age (yr) = 3.00
- Log Age (yr) = 5.00
- Log Age (yr) = 6.00
- Log Age (yr) = 6.50
- Log Age (yr) = 7.00
- Log Age (yr) = 7.25
- Log Age (yr) = 7.50
- Log Age (yr) = 7.75
- Log Age (yr) = 8.00
- Log Age (yr) = 8.25
- Log Age (yr) = 8.50
- Log Age (yr) = 8.75
- Log Age (yr) = 9.00
Isochrones with different ages and best $(m-M)$
Spectroscopy of the Emission Nebulae

• Spectroscopy is a very powerful tool for determining physical properties of astronomical objects.
  – Temperature, density, composition, …

• Orion Nebula (M42)
  – Nearest site of active star formation. (~430 pc)
  – A dense cloud of (mostly) hydrogen gas illuminated and ionized by (ultraviolet) light emitted by partially embedded hot, young (newly-formed) stars.
Orion region in The Sky. The Orion Nebula (M42) is the middle “star” in the “sword” of Orion (below the three stars in the belt).
Near-IR (0.8 – 2.5 µm) view of the nebula taken with VISTA (Visible-IR Survey Telescope for Astronomy) at the European Southern Observ. (4.1 m aperture, 1.6 degree field of view). See deeper into the opaque regions.
The four bright stars in the middle of the cluster, the Trapezium, provide most of the UV light that formed the nebula.
Ionized Hydrogen (HII) Regions

- Created by: $\text{HI} + \gamma_{uv} \rightarrow \text{HII} + e^{-}$ (ionization)

- Emission (cooling) processes:
  - Recombination: $\text{HII} + e^{-} \rightarrow \text{HI} + \gamma$’s (Balmer series)
  - Collisional excitation + radiative de-excitation:
    $X + e^{-} \rightarrow X^* + e^{-} \rightarrow X + \gamma + e^{-}$ (emission lines)
  - Free-free emission (continuum radio emission)

- Physical conditions:
  - $T \approx 10^3 - 10^4$ K
  - $n_e \approx 100$’s – 1000’s cm$^{-3}$ (depending on the nebula)