Combining Images

We can digitally combine N individual images into one master image of much better quality.

**Advantage #1:** Increase exposure time and signal-to-noise.

**Advantage #2:** Correct for image contaminants (cosmic rays, satellite trails, scattered light)

**Advantage #3:** Correct for detector problems (bad columns, flat fielding variations, etc)

**Advantage #4:** Reduce observing risk.
Combining Images

Problem #1: Different Sky values

Sky brightness can change over the course of a night, and also depends on airmass and direction you are observing. So the images all have different sky levels and we have to subtract off this sky level before combining.

Method #1: Measure sky at many spots across the image, work out an average value, subtract it off.

SKY = average sky
Combining Images

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\[ SKY = \langle I_{sky} \rangle \]

Method #2: Measure sky at many spots across the image, fit a plane to the sky level as a function of X,Y position on the image.

\[ SKY = X \nabla_{SKY,X} + Y \nabla_{SKY,Y} + SKY_0 \]

where \( \nabla_{SKY,X} \) and \( \nabla_{SKY,Y} \) are the sky gradients in the X and Y direction, respectively.
Combining Images

Problem #2: Different Photometric Zeropoints

Images were taken at different airmasses (and sometimes on different nights) so they have different photometric zeropoints. The same star will produce fewer counts when observed at greater airmass. We can’t just average all the images together, we have to scale them to correct for the different zeropoints.

Method #1: Observe standard stars, work out overall photometric solution, then apply to individual images:

\[ m_{\text{inst}} - m_V = C_V (B - V) + K_V \sec(z) + ZP_V \]

Method #2: Measure stars of known brightness on the image, calibrate zeropoints directly for each image:

\[ m_{\text{inst}} - m_V = C_V (B - V) + ZP_{V,\text{IMAGE}} \]

Each star on the image gives a value for \( m_{\text{inst}} - m_V \) and \( (B - V) \), so plot those values and fit to solve for \( C_V \) and \( ZP_{V,\text{IMAGE}} \).
Applying Zeropoints: Photometric Scaling

The same star will have different numbers of counts in each image due to the different zeropoints. We can define a “final zeropoint” and scale each image up or down in intensity to match this final zeropoint.

Since zeropoints are in magnitudes, we can say

$$ZP_{final} - ZP_{image} = -2.5 \log\left(I_{final}/I_{image}\right)$$

Then we scale each image in intensity by a factor of

$$I_{final} = I_{image} \times 10^{-0.4(ZP_{final} - ZP)}$$

That $10^\wedge$ term is the photometric scaling we multiply each image by to get them on the master zeropoint.

What do we chose for the final zeropoint? $ZP_{FINAL} = \text{np.average}(ZP)$
Our Approach

On each images, there are a hundred or so stars that have well-calibrated true magnitudes from the Sloan Digital Sky Survey.

Aperture photometry will give us instrumental magnitudes, from which we can calibrate the photometric zeropoints and color terms.

We will also use the sky estimate for each star as a function of X and Y to fit and subtract a sky plane from each image.
For each image, we calculate an instrumental magnitude for SDSS stars on the field:

\[ m_{inst} = -2.5 \log \left( \frac{I_{ADU}}{t_{exp}} \right) + 25 \]

the calibrate a photometric solution

\[ m_{inst} - m_B = C_B (B - V) + ZP_{B,IMAGE} \]
For each image, we also measure sky levels around stars. Again, for the B-band image obj0419029.fits:

\[
SKY = X \nabla_{SKY,x} + Y \nabla_{SKY,y} + SKY_0
\]

\[
\nabla_{SKY,x} = 1.468 \pm 0.082 \times 10^{-3} \text{ ADU/pix}
\]

\[
\nabla_{SKY,y} = 0.440 \pm 0.084 \times 10^{-3} \text{ ADU/pix}
\]

\[
SKY_0 = 606.50 \pm 0.27 \text{ ADU}
\]
Now we do this for all images, in both the B and V datasets.

In the M101 lab description, pick up with Step 3, number 5: run CalibrateImages.ipynb

This calculates photometric solutions for all images and write out new versions of each image with the sky levels subtracted off.

Look at photometric solutions for the B images: