

Meteor Photometry for All-Sky Cameras

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March 13, 2018

Overview

- Why photometry?
- Camera Considerations
- Prerequisites
- Stellar Photometry
- Calibration Models
- Meteor Photometry

I will describe the steps needed to develop your own analysis framework for meteor photometry, referring back to the MEO's tools as examples

Why photometry?

- How bright was that light in the sky? Answer can be of public interest
- How big was that object? Answer usually comes from photometry with luminous efficiency
- What flux of meteoroids are we measuring? To answer this, we need a selection function for which objects we expect to be observable

So how do we actually perform photometry on meteors?

Step 1: Know Your Camera

Getting to know your Camera

The process I will discuss, like any photometry process, has assumptions

- The signal in your image/video frame originates from photons on the sky
- The pixel values are directly proportional to the brightness of the object during the exposure time
- The scaling is the same for every pixel

These assumptions are generally not valid, but for All-sky data they are typically “close enough” given the other limitations of the data. This would be a very different talk if we all had scientific grade CCD imaging cameras...

Step 2:

Prerequisites

What do you need to do meteor photometry?

Fundamentally, what you need are the following

- A camera image with stars in it
- A catalog of reference stars with magnitudes in it
- A way of figuring out which stars in the image correspond to which stars in the catalog
- A way of measuring the values of pixels throughout the image

Ideally, this image comes from the data that includes the meteor to minimize time dependent variations in photometry

METAL

END

BEG

Step 3: The Stars

Raw Stellar Magnitudes:

Source Aperture

Stars are point sources on the sky, but that light gets spread out over several pixels due to atmosphere and camera. The simplest and most common photometric calculation is known as aperture photometry

- Choose a centroid position for your star. Can be determined manually, semi-automatically, or automatically
- Find all of the pixels within a radius of $\sim 3 - 4$ pixels of that centroid, and calculate the total number of pixels (N_*) in that region as well as the **summed** signal (S)
- Aperture size is a nominal value that should roughly optimize SNR (see three slides from now), but it is a good idea to confirm and adjust if necessary

Raw Stellar Magnitudes: Background Aperture

- Every pixel in the star aperture has signal from both the star and background (sum of noise and diffuse light from the sky). We need to estimate that background level.
- There are many ways to do this, but the simplest method is to use an annular region centered on the same position as our star aperture
- Find all of the pixels between radii of 6 and 9 pixels of that centroid, and calculate the total number of pixels (N_{BG}) and the **average** signal per pixel ($\bar{B}$)

Raw Stellar Magnitudes: The Final Calculation

- Net signal from the star is $S' = S - N_{\star} \times \bar{B}$
- If there is a potential for exposure time mis-match, normalize signal by time $S' \rightarrow S' / t_{\text{exp}}$
- The raw magnitude is then $m = -2.5 \log_{10} S'$
- The logarithm plus prefactor of -2.5 are there for traditional reasons tracing back to Ancient Greece, and smaller numbers corresponding to brighter sources

Repeat for many reference stars

Signal-to-Noise

Frequently we want to know uncertainties associated with our magnitudes. The signal-to-noise ratio provides the statistical uncertainties associated with the number of source counts as well as the background subtraction (do before exposure time normalization)

$$SNR = \frac{S'}{\sqrt{S' + N_{\star} \times \left(1 + \frac{N_{\star}}{N_{BG}}\right) \bar{B}}}$$

With the uncertainty (in magnitudes) equal to $\sigma_{mag} = 1.0857/SNR$, which can easily exceed ~ 0.5 mag for faint sources

Reference Catalogs

- Many reference catalogs available to use, all made for different purposes
- Ideally, your catalog has a large number of reference stars in field-of-view which are visible in your camera system
- For All-sky camera data, best catalog to use is probably Sky 2000 V5, which has 300,000 V-band magnitudes for the brightest stars and is publicly available

Tullahoma

NO FLAT

Reference Stars

BEGND

beg end

BASE HALF FULL OVERSCAN REDSKY

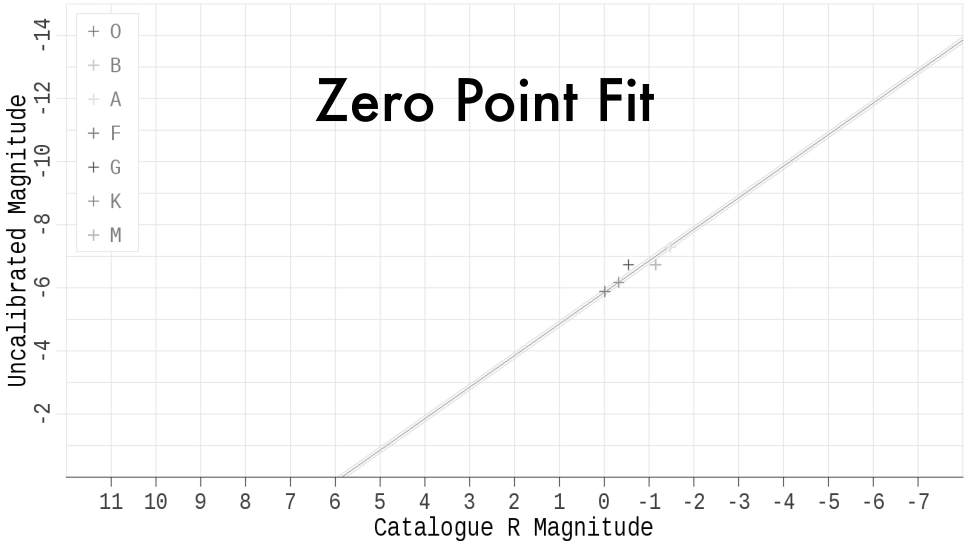


Zero Point

Once we have raw magnitudes (m) and catalog magnitudes (m_{ref}) for N reference stars, we can then calculate a zero-point as

$$zp = \frac{1}{N} \sum_i m_{\text{ref},i} - m_i$$

which is the number that gets added to each raw magnitude to determine its catalog magnitude. The more stars the merrier, but the zero-point only requires 1 reference star to work.



Step 4: The Meteor

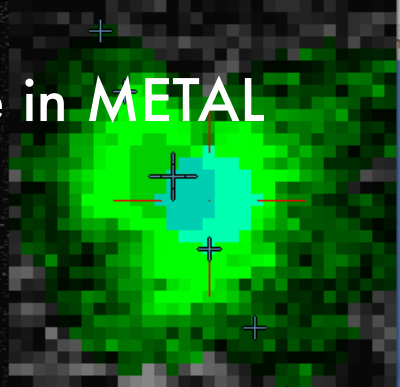
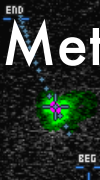
Meteor Photometry

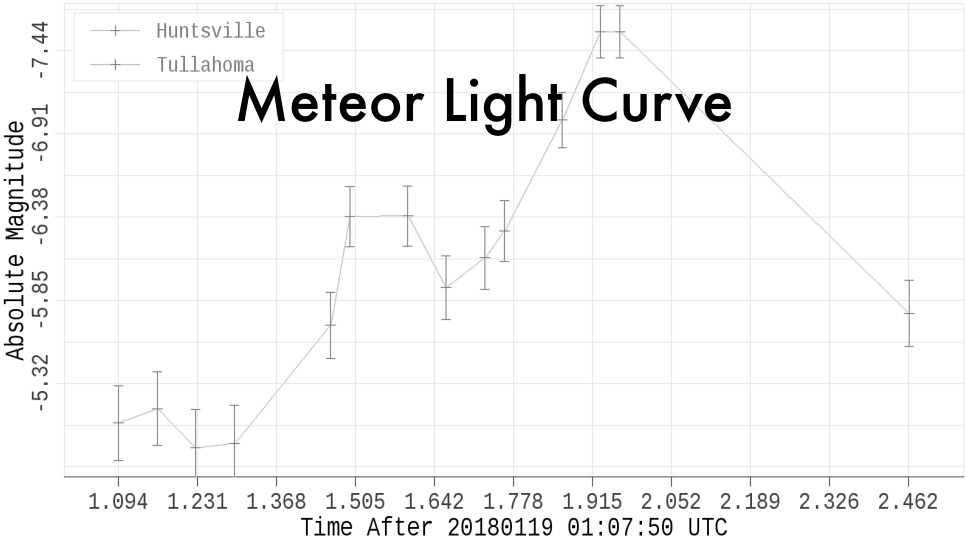
With a zero-point in place, how do we use it to measure meteor magnitudes? The process is very similar

- Decide on which pixels are “source” and “background”
- These regions may be circles, ellipses, or “free-painted” based on the shape of the meteor in your image and your software capabilities
- Calculate the raw magnitude of the source in the same fashion as before
- Add the zero-point to the raw magnitude to get the calibrated magnitude

Repeat this frame-by-frame (video) or section-by-section (still image) to get the meteor’s magnitude as a function of time

Meteor Aperture in METAL





Additional Sophistications

Pre-processing

Try to address sources of errors in raw image/video data prior to doing photometry

- Noise subtraction
- Flat-fielding
- Gamma correction

Calibration Model

Reference catalog usually has magnitudes in a particular filter, whereas most All-sky cameras don't. Calibration models can get far more sophisticated than a zero-point

- Extinction correction (differential between zenith and horizon)
- Color term (differential between detector and reference mag bandpasses)
- Saturation correction for very bright sources

Further Steps

Magnitudes in the camera are useful, but more physically motivated numbers are even more useful

- Absolute magnitude: $M_{\text{abs}} = m_{\text{app}} - 5 \log_{10} \left(\frac{R}{100 \text{ km}} \right)$
- Mass from peak absolute magnitude plus luminous efficiency
- Comparison to Quarter Moon (−9), Full Moon (−12), or Sun (−27)

Conclusions

- Photometry is a powerful capability to have, because meteor magnitudes are very useful information to measure
- Before you embark, make sure you know your camera well
- Simplest preprocessing and calibration models are frequently “good enough”
- Many of the pieces required to fully automate the process of measuring meteor magnitudes are freely available