Planetary and Space Science xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Planetary and Space Science

journal homepage: www.elsevier.com/locate/pss

Determination of the meteor limiting magnitude

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ARTICLE INFO

Keywords:
Meteors
Optical detectors

ABSTRACT

We present our method to calculate the meteor limiting magnitude. The limiting meteor magnitude defines the faintest magnitude at which all meteors are still detected by a given system. An accurate measurement of the limiting magnitude is important in order to calculate the meteoroid flux from a meteor shower or sporadic source. Since meteor brightness is linked to meteor mass, the limiting magnitude is needed to calculate the limiting mass of the meteor flux measurement. The mass distribution of meteoroids is thought to follow a power law, thus being slightly off in the limiting magnitude can have a significant effect on the measured flux. Sky conditions can change on fairly short timescales; therefore one must monitor the meteor limiting magnitude at regular intervals throughout the night, rather than just measuring it once. We use the stellar limiting magnitude as a proxy of the meteor limiting magnitude. Our method for determining the stellar limiting magnitude and how we transform it into the meteor limiting magnitude is presented. These methods are currently applied to NASA's wide-field meteor camera network to determine nightly fluxes, but are applicable to other camera networks.

1. Introduction

The meteor limiting magnitude is the apparent magnitude at which all meteors brighter than are detected. This value depends on the camera hardware and software, sky conditions, and the angular speed of the meteors. These factors will change over the course of the night, as the meteor radiant moves across the sky and as the sky conditions change. Since the limiting meteor magnitude ultimately is used to calculate the limiting meteor mass, it is important to understand these factors and to monitor how they change throughout the night. A small magnitude uncertainty in limiting magnitude can translate to a significant uncertainty in the limiting mass.

Measuring the meteor limiting magnitude using the meteors themselves is a difficult problem since the sky conditions and radiant position will change before enough meteors have been detected to get a good statistical measurement of the limiting magnitude. A better approach consists of using the stars in the field of view of the camera as a proxy to determine the meteor limiting magnitude. This approach allows us to measure the signal from 100's of stars with known magnitude and color at any time throughout the night. After applying corrections for the meteor's moment, causing the light to be spread out over more pixels in a frame compared to the stationary stars, we can determine the meteor limiting magnitude.

2. NASA wide-field meteor camera network

This work was designed to help determine meteoroid fluxes on the wide-field meteor camera network at NASA's Marshall Space Flight Center (Blaauw et al., 2016). The system was established to automatically calculate the flux of mm-sized meteoroids from any active showers or sporadic sources daily. ASGARD (Brown et al., 2010) was used for the meteor detections and allows the system to run almost autonomously without human iteration and only minor upkeep. The camera network consists of two stations with four cameras each separated by 31.7 km. The pointing was setup to maximize the collecting volume of the system. The cameras consist of Watec 902H Ultimate with 17 mm f/0.95 lenses, giving a field of view of 22° × 16°. This work is specifically designed to be used on this system, but the methods will work with other optical systems.

3. Stellar limiting magnitude

In order to determine the limiting meteor magnitude we first determine the limiting stellar magnitude. The typical stellar limiting magnitude of a given camera system is determined by the camera hardware and lens combination as well as the sky conditions. The sky conditions can change on relativity short timescales as clouds and weather fronts move though the camera's field of view (FOV). Fig. 1 shows a plot of the limiting magnitude throughout a night. Calibration images are created by computing the median of 40 s, or 1200 frames, of

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http://dx.doi.org/10.1016/j.pss.2017.03.006
Received 13 September 2016; Received in revised form 22 February 2017; Accepted 10 March 2017

Please cite this article as: Kingery, A., Planetary and Space Science (2017), http://dx.doi.org/10.1016/j.pss.2017.03.006

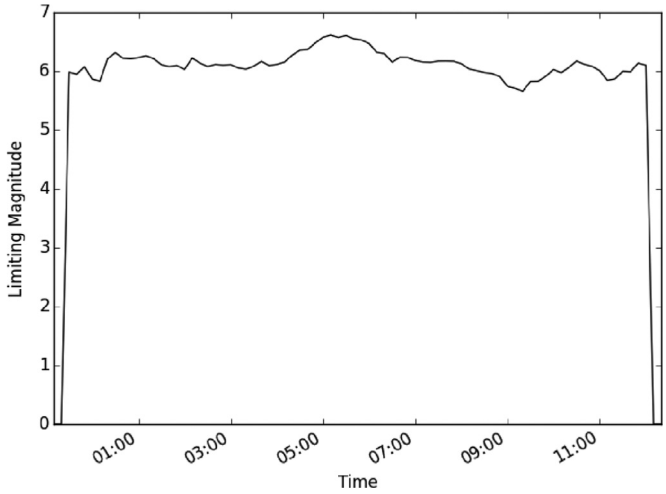

Fig. 1. Limiting stellar magnitude for a wide-field meteor camera throughout a night.

Fig. 2. Example image from one of our meteor cameras.

video data. These images contain over 100 stars with a typical limiting stellar magnitude of around 6th magnitude. A sample image is shown in Fig. 2. This calibration image is created to improve the signal to noise for astrometric and photometric calibration.

The stars used to determine the limiting magnitude consists of any star in the Sky2000 catalog (Myers et al., 2001) which is brighter than 7th magnitude. Anywhere from 80 to 300 stars exist on a clear image depending on which part of the night sky is the in cameras FOV. R band magnitudes are used since for the spectral response of the Watec 902H Ultimate's CCD, a Sony ICX249 Exview HAD CCD, most closely follows the R band filter compared to all other widely used astronomical filters. Future work includes switching to using a ‘Watec’ band magnitude. See Elhert et al. (2017) for information on how these ‘Watec’ band magnitudes are determined.

The images are first gamma corrected. This is done by performing the reverse gamma seen in Eq. (1) where F is the measured counts on the video camera CCD, F' is the corrected linear counts, and γ is the cameras gamma setting, 0.45 in this case. The cameras have a nonlinear gamma setting to improve sensitivity and contrast at low light levels:

$$F' = 255 \times F^{\frac{1}{\gamma}} \tag{1}$$

The other standard astronomical image corrections, bias, darks and flats, are not applied due to the difficulty of obtaining them on a remote video system with a large FOV. In order to take a bias or a dark image physical access to the cameras would be required to change the exposure to be very short to take a bias image and to cover up the aperture to take a dark. Since as the cameras age they develop new hot pixels and other defects this would need to be done regularly. Instead of using a bias and dark images a median combination of images on a clear night is used as the dark and bias. This image will be subtracted from the data image and will have the median background of the image along with all the CCD defects the dark would normally correct. Flat field images are very difficult on cameras with such a large field of view. In order to take a flat field image one needs to image something that is uniform in intensity. For most telescope systems a twilight flat or a flat field screen can be used since they can be very uniform on fields of view less than 1°, but on 20° it is very difficult to get a uniform image. With the difficulties of obtaining a flat field image we currently apply no flat field correction.

Aperture photometry is then performed on the stars in the image. A circular aperture is used to measure the counts from the stars with an annulus used to perform background subtraction. The circle around the star has a radius of two pixels and the annulus has a inner and outer radius of four and seven pixels respectively. The FWHM of the images is around three pixels. The signal to noise ratio is then calculated using the methods found in Howell (2006). If the signal to noise ratio is greater than three the star is considered detected and is considered a non detection if below the cutoff.

The catalog magnitudes of the detected stars were then fit to a Gumbel distribution, which has an exponential rise and an exponential cutoff (see Fig. 3). This distribution closely matches what is expected; an exponential rise as more faint stars are detected with a sudden drop as the detection threshold is reached. The peak of the fit distribution is used as the limiting stellar magnitude. Using a statistical distribution fit to the data reduces the possibility for a few bad stars to throw off the fit to the data; which could occur if we did a simple fit to the SNR vs magnitude points. This will also limit the effect caused by hot pixels or double stars. If a star is artificially brightened by a nearby star or being next to a hot pixel that was not accounted for with median background image, it will only effect the limiting magnitude if it is able to move over or below the SNR threshold. Since this will not happen for a large number of stars in an image this will have little impact on the limiting magnitude. This method will not work well if there is a significant gradient in the limiting magnitude across the image, like in an all-sky camera or an intensified camera. Our initial attempts at splitting an image into regions with approximately constant limiting magnitude show promise, but needs to be developed further. For our flux calculations we consider any image with clouds in it cloudy and it is not used in flux calculations. It may be possible to create a masking algorithm and use that to calculate the limiting magnitude on part an image when the rest of the image is cloudy.

We then accounted for the effect of using the median of 1200 frames to find the stellar limiting magnitude when the limiting magnitude in a single frame was actually required. To measure this effect, the limiting stellar magnitude was measured on images of a different number of stacked frames from the same time period (see Fig. 4). Using this technique allowed us to determine the offset between the limiting magnitude of a single frame versus the median combination of 1200 frames.

4. Meteor limiting magnitude

In order to determine the meteor limiting magnitude from the stellar limiting magnitude, some corrections need to be applied. These corrections account for the fact that the meteor can move a significant distance within a video frame. This motion will cause the light to be more spread out when compared to the stationary stars. This effect then causes the pixel counts for a meteor to be lowered when compared to a star of the same brightness and makes the meteor limiting magnitude fainter than the stellar limiting magnitude.

The relationship between these two expressions adapted from Hawkes (1993) and Brown et al. (2002) is