Conferences

Luminous efficiency determination and its challenges

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The luminous efficiency τ describes the fraction of lost kinetic energy of an entering object converted into brightness. This parameter is used to calculate a meteoroid's mass from its observed brightness. Presently, the luminous efficiency is part of current research and its determination based on several assumptions. Amongst others, different meteor parameters have to be assumed. They range from the shape of the meteoroid, which changes during the flight through the atmosphere, possible fragmentation, to the composition of the meteoroid as well as of the atmosphere, and aspects of the detection themselves. The data of FRIPON, the Fireball Recovery and InterPlanetary Observation Network, was used to calculate the luminous efficiencies of their recorded meteors. First, deceleration-based formulas for the mass computation of the corresponding meteoroids were used. Then, the recorded light curves were investigated to determine the luminous efficiencies. We found τ-values in the range of $10^{-4}\%$ – 100%, whereas most are in the order of 0.1%–10%. In this work we will briefly introduce the process of obtaining these values and point out its difficulties.

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1 Introduction

Meteors and fireballs are of large public and scientific interest. Especially the brighter ones can cause a lot of attention in the general public. The AMS/IMO (American Meteor Society/International Meteor Organisation) collects and analyses witness reports of meteor sightings, see e.g. Hankey and Perlerin (2014). On social media there is a large interest on bright events, which is the reason why these platforms are used as an information source for NEMO, the NEar real-time MOnitoringsystem, which is operated by ESA's Near-Earth Object Coordination Centre (NEOCC), see e.g. Ott et al. (2020).

The initial meteoroids or asteroids are of special scientific interest since they are expected to be originated from larger asteroids or comets. These parent bodies are thought to be almost unchanged since the formation of our solar system. Hence, by studying meteors, we can learn about our Solar System's formation.

The luminous efficiency τ is a parameter which is frequently used in meteor physics. It describes the fraction of kinetic energy loss that is converted to the luminosity of the entering object along its path through the atmosphere. Although the parameter is needed to calculate the pre-entry mass of the observed body from its brightness, τ is only established relatively inaccurately. Values in the literature vary by orders of magnitude, compare e.g. Verniani (1965) who found values down to 0.02 % in the course of an analysis of meteors recorded with the Harvard photographic meteor project, and Svetsov and Shuvalov (2018) who found values as large as almost 20% based on simulations for entering asteroids and comets. These differences could be caused by different assumptions that have to be made to calculate the parameter τ.

We will show how the comparably robust method introduced by Gritsevich (2008) to determine the mass of the entering object from height and velocity observations with fewer assumptions needed than those usually used for the computations, can be utilized to compute the luminous efficiency as presented in Gritsevich and Koschny (2011).

In Section 2 the utilized method is briefly described. Section 3 presents some values of the luminous efficiency that can be found in literature. The utilized data is introduced in Section 4 and first results in Section 5. A short conclusion is given in Section 6.

2 Method

To derive the pre-entry meteoroid mass that corresponds to a detected meteor different methods can be carried out. A lot of them use the recorded brightness of the meteor as a starting point. As introduced by Verniani (1965), the relation between the emitted light intensity I, the meteoroid's mass loss dM/dt, and its pre-entry velocity v_e can be described by

$$I = \frac{-\tau v_e^2}{2} \frac{dM}{dt} \quad (1)$$

It includes the luminous efficiency τ describing the portion of the kinetic energy of the entering body that is emitted as visible radiation. Hence, the relation to compute the pre-entry meteoroid mass M_e can be described

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by

$$M_e = \frac{2}{\tau v_e^2} \int I_s ds \tag{2}$$

The term $\int I_s ds$ describes the light I that is emitted during the flight through the atmosphere in Watts and integrated over the flight path s. As is can be seen an assumption for τ has to be made affecting the resulting mass. A different way to compute the pre-entry meteoroid mass is to use the observed velocity and height information of the meteor. Based on the rate of deceleration of the entering object its pre-entry mass can be computed. This was done e.g. by Gritsevich (2008). Gritsevich and Koschny (2011) use the information found with this method to determine τ using the brightness data. As explained in the just mentioned work in detail, the proper value of τ, as well as of the shape change coefficient μ, can be found with a least-squares fit with equation (3) to the observed light curve.

$$I(v^*) = \frac{\tau M_e \; v_e^3 \; \sin(\gamma) \; f(v^*)}{2 \; h_0} \tag{3}$$

with

$$f(v^*) = v^{*3}\left(\overline{Ei}(\beta) - \overline{Ei}(\beta v^{*2})\right) \cdot \left(\frac{\beta \; v^{*2}}{1-\mu} + 1\right) \cdot \exp\left(\frac{\beta \; (\mu v^{*2} - 1)}{1-\mu}\right) \tag{4}$$

with the meteor brightness I, the angle between horizon and trajectory γ, the scale height of the Earth's atmosphere h_0, the mass loss parameter β, which is derived during the process of pre-entry mass determination as explained in Gritsevich (2008), the exponential integral $\overline{Ei}(x)$:

$$\overline{Ei}(x) = \int_{\infty}^{x} \frac{e^z \; dz}{z} \; , \tag{5}$$

and the dimensionless velocity

$$v^* = \frac{v}{v_e} \; . \tag{6}$$

Figure 1 – The fireball from 6 January 2020 recorded with the FRIPON station at Bedonia, Italy.

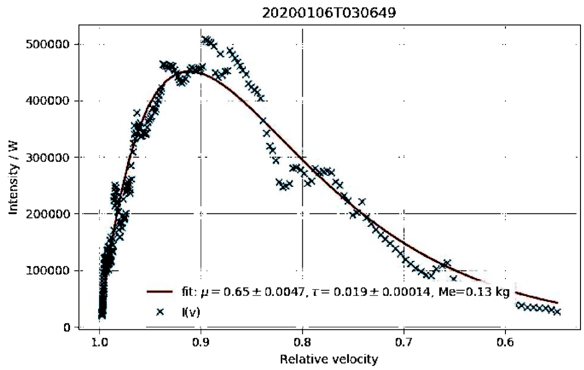

Figure 2 – The computed light curve of the fireball from 6 January 2020 with applied fit. The x-axis displays the relative velocity v^* the meteor for which each velocity value is divided by the meteor's initial velocity. The computed brightness values in Watts are shown as blue '×'. The applied fit is displayed as a solid red line.

To give an example, in Figure 1 a fireball that occurred above Italy on 6 January 2020 at 03:06:49 UTC is shown. It was detected with four stations of the FRIPON network and its absolute magnitude reached a peak brightness of about −6.3 mag. In Figure 1 the image of the fireball taken with the FRIPON station at Bedonia, Italy, can be seen. The computed light curve of this fireball with applied fit, according to Equation (3), is presented in Figure 2. For this fireball, a value of τ around 1.9% was derived.

3 Literature values

Various studies were done to compute the luminous efficiency of meteors. They include diverse types of data from analysis of optically recorded data (e.g. Verniani, 1965) and radar data (e.g. Weryk and Brown, 2013), to laboratory measurements (e.g. Friichtenicht et al., 1968) or simulations (e.g. Svetsov and Shuvalov, 2018). The obtained results differ by orders of magnitudes. As shown e.g. by Koschny et al. (2017) or Subasinghe et al. (2017) even small variations in τ can yield large differences in the computed mass of the entering object.

One main difficulty in computing the luminous efficiency or even in meteor physics in general is the large number of unknown parameters with a big impact on the result for which values have to be assumed. These include, amongst others, the shape and mass of the entering object. Additionally, the change of the shape and mass during the flight through the atmosphere are usually not known. The process of fragmentation has to be kept in mind also. Furthermore, the composition of not only the meteoroid itself but also of the atmosphere are uncertain. Uncertainties of the detection method do also affect the results, as well as the uncertainties of the observed parameters like the velocity, height, and brightness of the meteor.

4 Data

Several networks are spread all over the world which were designed for meteor and fireball monitoring. Examples are the Australian Desert Fireball Network (Howie et al., 2017), or the Canadian Automated Meteor Observatory (Weryk et al., 2013). One European network is the French FRIPON (Fireball Recovery and InterPlanetary Observation Network). The network covers the sky over France, as well as large areas of the sky above the neighbouring countries. It consists of all-sky cameras which are operated completely autonomous during night time. For more information about the FRIPON network see e.g. Colas et al. (2014) or Colas et al. (2020). Data collected and analyzed by the network as explained in Jeanne et al. (2019) is used for this study. The pipeline uses a similar approach within the data analysis of the FRIPON network as presented in Gritsevich (2008) to compute the pre-entry meteoroid mass based on the recorded deceleration data, see Jeanne et al. (2019) for details.

5 Results

Applying the method summarized in Section 2 and explained in the publications mentioned therein, we analysed data collected with FRIPON cameras. 3871 confirmed events were in the database and have been investigated (status as of 2020 July 4). Of these, a subset of 294 fireballs and their luminous efficiencies has been investigated and will be presented in this work. These fireballs were chosen based on different aspects. A very important point is that enough and good quality observation data is available for the event. A fireball that was not recorded simultaneously by at least two cameras does not have sufficient data available to apply our method to. The reason is that the brightness values derived from the recording all-sky cameras include relatively large uncertainties which are in the order of half a magnitude. Furthermore, some events did produce non-physical viable results or results with very large errors. Those were also excluded. For the 294 events the luminous efficiencies were computed and the distribution is presented in Figure 3. As it can be seen, the τ-values span a wide range of values from 10^{-4}% to 100%. Most of the calculated luminous efficiencies are in the range 0.1%–10%.

In Figure 3 it can be seen that derived values for the luminous efficiency can be as high as 100%. That is of course physically unrealistic as it would imply that all kinetic energy of the meteoroid would be transformed into (visible) light. No energy would be left for e.g. ablation and deceleration. Such high values for τ are obtained mainly for the smallest masses. They could result from a combination of observational bias, fragmentation, or break down of the analysis method for these cases. Further investigations are ongoing. As already stated in the title: it is rather difficult to derive the luminous efficiency of entering meteoroids.

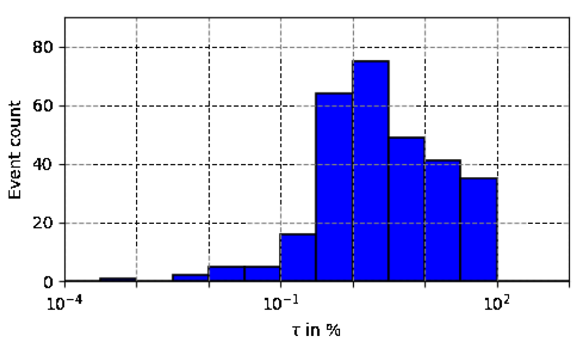

Figure 3 – Distribution of luminous efficiencies τ of 294 analyzed FRIPON fireballs in percent.

6 Conclusion

The luminous efficiency of meteors is still only poorly understood. Values that can be found in literature derived with various methods vary by orders of magnitudes. Nonetheless, this parameter is frequently used since it is needed to compute the pre-entry mass of the entering meteoroid or asteroid, respectively, from an observed meteor's recorded brightness. The lack of certainty is mainly due to the large amount of unknown or uncertain parameters that have to be assumed to determine the proper value of the luminous efficiency. These parameters include, amongst others, the mass and shape of the entering body which do change during the flight of the entering object along its way through the Earth's atmosphere. Its composition and behavior of fragmentation have to be taken into account too, as well as numerous further aspects. The method used in this work does use the deceleration data of the observed meteor to compute its mass and by comparing the shape of the observed light curve the luminous efficiency can be determined. This way fewer assumptions have to be made to calculate the luminous efficiency. Data of FRIPON, the Fireball Recovery and InterPlanetary Observation Network, was utilized since the recorded fireballs are in a promising size range and have good quality deceleration data. A subset of 294 fireball events was analyzed and the computed luminous efficiencies presented. They range from 10^{-4}% to 100%, whereas most found luminous efficiencies are in the order of 0.1% to 10%. Still, a lot of possible uncertainties have been found. Analyzing these sources of errors in more detail is the next step and part of our future work.

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