Classification of fireballs: upgrading the PE criterion

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The visual observation of meteors has gathered over the last century the interest of scientists and the fascination of public. As the meteor observational techniques were spread worldwide, the meteor research community was avid of reliable mathematical relationships to derive further clues on these events: their orbital origin, their hazardous potential, etc. For such purpose, the combination of the meteor event observed flight parameters seemed to comply with these goals. Moreover, this approach was little by little more feasible given the technology growth that gradually improved the accuracy of the observations. Amongst all the suggested flight parameter relationships available in the literature, the one introduced by Ceplecha and McCrosky [1] in the mid 70's became timely and used in many studies as a 'ground truth'. The empirical work of Ceplecha and McCrosky [1] was also mathematically supported by the single body Newtonian formulation that is still widely used to model the meteor trajectory [2]. Moreover, Ceplecha and McCrosky [1] expanded the use of this relationship to elaborate a meteor classification. The classification relies on the value of a criterion, called PE, which ranks the value of the correlation given by the parameters included in the relationship. Although the authors did not expect the classification to be extremely accurate, it allows quick interpretation of the event under study. Consequently, both the criterion and the classification have played a relevant role in the scientific publication over the decades.

The PE criterion relates the meteor observed end height to its atmospheric entry velocity, mass and flight trajectory angle. To keep the PE calculation straightforward, and because it originally was used for decelerating events, the influence of the meteoroid mass loss (ablation and shape coefficient) was simplified and a mean value for all the meteors registered in the same database was assumed. In the recent years, several alternative formulations for the meteoroid atmospheric flight modelling have been proposed in order to reduce the required analysis-related assumptions and consequent results' inaccuracies. Amongst them, a formulation based on scaling laws and dimensionless variables has obtained significant results when tackling with different common meteor related studies (see e.g. [3-9]). The main advantage of this methodology is that it provides relevant clues on the event under study removing the necessity of stating initial assumptions on the meteor

parameters. Additionally, the accuracy of the outcome is, in most cases, directly linked to the quality of the observations. Interestingly, this new methodology quantifies the meteoroid mass loss in a unique and straightforward way by matching the meteor trajectory (observed height and velocity values) with two dimensionless parameters that are physically meaningful. On one hand, the ballistic coefficient, α , expresses the drag intensity suffered by the meteor body during its flight and it is proportional to the mass of the atmospheric column with the initial meteoroid cross section area along the trajectory divided by the meteoroid's pre-atmospheric mass. On the other, the mass loss parameter, β , characterizes the mass loss rate of the meteoroid; it can be expressed as the fraction of the kinetic energy per mass unit of the body that is transferred to the body in the form of heat divided by the effective destruction enthalpy.

Since these two parameters comprise all the meteoroid flight variables earlier included in the PE criterion, but avoid artificial assumptions, we have proposed and studied the hypothesis that there should exist a mathematical expression involving these two parameters which offers an improved classification criterion [2]. In this work, we verify this hypothesis. The results of our study show that: i) under the same original assumptions [1] the derived $\log(2\alpha\beta)$ which we advocate using leads to the exactly same PE formula obtained by Ceplecha and McCrosky [1]; ii) the newly offered possibility to include the individual event mass-loss effects in the criterion allows an accurate formulation that still remains simple to implement; iii) the improved criterion is scalable – it is suitable for expanding the classification beyond fully disintegrating fireballs to larger impactors, including meteorite-dropping fireballs. We use the Prairie Network meteor observations for comparative analysis, which demonstrates the effectiveness and reliability of the new formulation.

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