Boletim da Sociedade Astronômica Brasileira, **36**, no. 1, 183-185

Spectral analysis of the meteor over Mato Grosso, Brazil, on June 22, 2023

Matheus A. G. Costa[1], Gabriel G. Silva[2], Vandson P. Guedes[3], & Rodolfo Langhi[1]

[1] Universidade Estadual Paulista e-mail: matheus.agenor@unesp.br
[2] Universidade de São Paulo
[3] BRAMON

Abstract. In this study, we analyzed the spectrum of a meteor recorded by the ROO1/MT monitoring station, located in Rondonópolis, MT, affiliated with BRAMON. For acquisition, we used an IMX-291 surveillance camera, together with a 500 line/mm diffraction grating. On June 22, 2023, the ROO1/MT station recorded a meteor of remarkable brightness. Through this capture and the use of the RSpec software, we performed an analysis of the spectrum resulting from the ablation of the meteor. The exploration of the intensity peaks allowed us to identify the chemical composition of the generated plasma, revealing the presence of elements such as Fe, Ca, Mg, Na, N and O, the latter two originating from the atmosphere. Based on the intensity of the peaks of Na I (1), Mg I (2) and Fe I (15), it was classified as a group of Mainstream meteoroids, a subgroup of Normal meteoroids.

Resumo. Neste estudo, analisamos o espectro de um meteoro registrado pela estação de monitoramento ROO1/MT, localizada em Rondonópolis, MT, afiliada à BRAMON. Para aquisição, utilizamos uma câmera de vigilância IMX-291, juntamente com uma rede de difração com 500 linhas/mm. Em 22 de junho de 2023, a estação ROO1/MT registrou um meteoro de brilho notável. Por meio desta captura e do uso do software RSpec, realizamos uma análise do espectro resultante da ablação do meteoro. A exploração dos picos de intensidade permitiu identificar a composição química do plasma gerado, revelando a presença de elementos como Fe, Ca, Mg, Na, N e O, estes dois últimos originários da atmosfera. Com base na intensidade dos picos de Na I (1), Mg I (2) e Fe I (15), ele foi classificado como um grupo de meteoroides Mainstream, subgrupo de meteoroides Normal.

Keywords. first keyword – second keyword – third keyword

1. Introduction

Meteor spectroscopy is a technique that dates back to the 19th century (Millman, 1980), but it has significant potential to explore the chemical composition and other characteristics of meteoroids and their parent bodies. The fully exploit of this method requires further theoretical research and observational work (Borovicka , 1998).

Studies like this can still be employed to conduct fundamental qualitative and semi-quantitative analyses of the Solar System's evolution, as well as to characterize meteoroids and their parent bodies, such as asteroids and comets, both within and beyond the Solar System.

With regard to interplanetary dust particles, there are several ways to study them and obtain valuable information about their composition and origin. They can be studied in situ by dust detectors on spacecraft, by collecting material in the stratosphere, or by examining what falls to Earth.

It is important to emphasize that, while the above approaches are extremely useful for studying interplanetary dust particles in general, when it comes to individual meteoroids with dimensions not much larger than a few centimeters, observing their interaction with the Earth's atmosphere is the only viable way to study them in detail (Borovicka et al. , 1999). The analysis of meteor spectra during their atmospheric interaction is a powerful tool to investigate their composition and chemical abundance (Borovicka et al. , 2005).

In the present work, we present a brief study on the chemical composition of a bolide observed over the state of Mato Grosso in June 2023.

2. Methodology

Data were collected by the ROO1/MT monitoring station, belonging to Vandson P. Guedes, from the Brazilian Meteor Observation Network (BRAMON), located in Rondonópolis, state of Mato Grosso.

The station is equipped with an IMX-291 camera, with a resolution of 1280 x 720 pixels, operating at 25 fps, with a FOV of 53.6. The camera has a diffraction grating of 500 lines/mm attached to its optical system, so that, when capturing a meteor, the grating could reveal the spectrum of the light trail. In this configuration, the calculated dispersion is approximately 14.5 Å/pixel.

The UFOCaptureV2 software was used for data capture, while the UFOAnalyzerV2 software was used to analyze and interpret the data obtained. For spectral analysis, the Real-time Spectroscopy software (RSpec) was employed. The camera has a focal ratio of 1.0, ideal for low-light conditions, allowing the detection of low-luminosity meteors by the camera sensor. The camera was also modified by removing the infrared (IR) filter from its sensor to broaden the spectrum of light captured by the device, thus increasing its sensitivity.

Although there are methods and equations to estimate the mass of a meteor based on its observed characteristics, these estimates are often approximate and require a series of assumptions. A mathematical model allows the estimation of the mass of a meteor with satisfactory accuracy; however, specific conditions must be met for the validity of the equation presented. Equation 1 has a validity limit for $V > 25$ km/s and $M < 1$ kg, and describes a direct relationship between luminosity and the kinetic energy of the meteor, based on an assumption about the

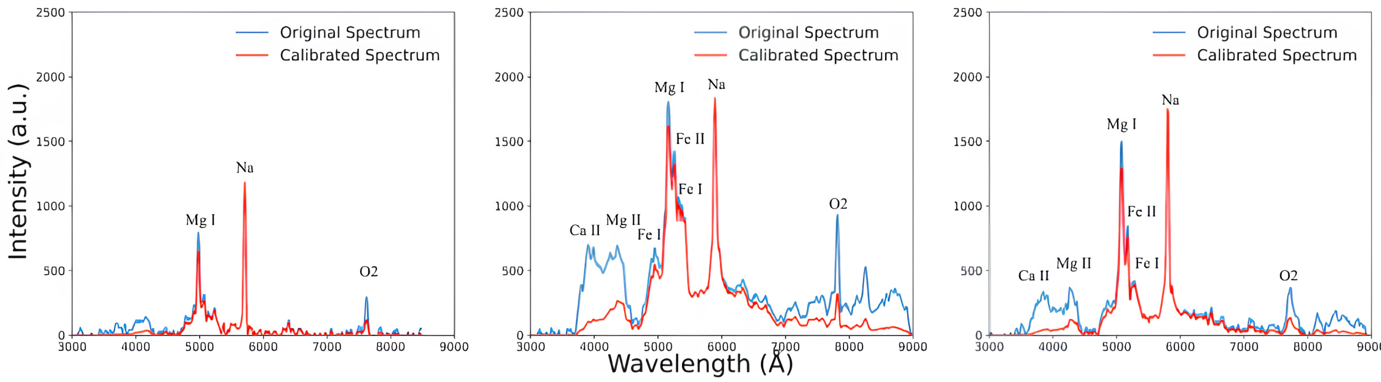

Figure 1. Spectrum of meteors, in frames 54 on the right, 55 in the center and 56 on the left. The blue curve represents the uncalibrated spectrum, in red the calibrated spectrum, and in green the calibration curve for the instrument.

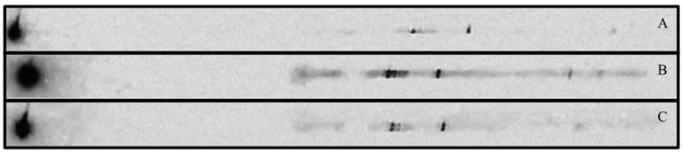

Figure 2. Figures A, B, and C represent frames 54, 55, and 56, respectively. The magnitudes obtained for each frame by the UFOAnalyzerV2 software were: 54 = -1.43; 55 = -3.49; 56 = -2.06.

way luminous efficiency varies with velocity and the definition of magnitude (Jenniskens , 2006).

$$\log M = 6.31 - 0.40\,\mathrm{m} - 3.92 \log V - 0.41 \log(\sin(h)), \quad (1)$$

where M is the mass, in grams, m is the apparent magnitude, V is the velocity in km/s, and h is the entry angle into the atmosphere.

For instrumental response calibration, we used the spectrum of the Vega star as a reference and performed comparisons between the recorded spectrum intensity and the intensity values provided in the RSpec software catalog for A0V-type stars.

The main composition of a meteor spectrum is usually represented by three major lines: Na I (multiplet 1), Mg I (multiplet 2) and Fe I (multiplet 15). The difference in the intensities of these lines can reveal the different composition of individual meteoroids. Based on this, we inferred the type of meteor based on its spectrum (for more details on this, see Borovicka et al. (2005)).

3. Results

The phenomenon was recorded in the early morning of June 22, 2023, at 02:03:53 UTC (Coordinated Universal Time). In the brightest frame, the luminous event reached a m -3.49. The capture occurred at the coordinates: 282.16º of Azimuth and 29.07º of Elevation. The event lasted around 2.70 s, with its peak intensity at 2.22 s. The spectra of the three main frames can be seen in Figure 1.

The estimated initial height and geocentric velocity are 111 km and 60 km/s, respectively. This is a relatively high velocity, considering that the typical speeds of meteors during entry into the atmosphere are 11 to 72 km/s (Bronshten 1983; Varella 1985; Ceplecha et al 1998). However, such velocity could explain the high brightness of the body. As the meteor was recorded by a single station (ROO1/MT), it was not possible to calculate its trajectory and orbit with precision. To obtain the orbital parameters of a meteor, an event must be recorded by, at least, two stations with different points of view, with a minimum parallax required. The algorithm used to automatically estimate the height and geocentric velocity of the meteor by a single-station capture is not provided by the software UFOAnalyzerV2 and these values must be taken with caution. The estimated mass of approximately 7 grams, despite being subject to significant uncertainty.

The capture consisted of a total of 69 frames, of which the 3 most intense frames were analyzed, which were frames 54, 55, and 56, in which the captured object reached m of -1.43, -3.49, and -2.06, respectively. Each separated frame can be seen in Figure 2.

The analysis of the spectra (Figure 1), reveals several important points regarding the presence and behavior of various elements, particularly Fe, Ca, Mg, Na, N, and O. The identification of forbidden lines of Nitrogen (N) and Oxygen (O) is noteworthy. These lines are typically expected to form in low-density environments due to the selection rules responsible for the quadrupole transitions. Forbidden lines, as the name suggests, are suppressed in high-density environments, which is consistent with their presence being attributed to the atmosphere. The fact that both Nitrogen and Oxygen are abundant in the atmosphere of the Earth strengthens this hypothesis, aligning with prior studies that have identified atmospheric contributions to such spectral features (e.g. Millman 1980;Agenor & Langhi 2023).

Furthermore, the analysis of the near-infrared region after removing the IR filter from the CCD camera reveals uncharacterized peaks between 8000-9000 Å. Based on previously published spectra (Vojáček et al. , 2015), these peaks are likely indicative of emissions of Nitrogen and Oxygen species from the atmosphere, although this interpretation should still be made with some caution. The parallel between the spectra present here and other spectra of meteors studied before further supports the atmospheric origin of these lines, aligning with the characteristics of meteors from the Geminid meteor shower (Vojáček et al. , 2015).

The main composition of a meteor spectrum is usually represented by three major lines: Na I (multiplet 1), Mg I (multiplet 2) and Fe I (multiplet 15). The difference in the intensities of these lines can reveal the different composition of individual meteoroids (Borovicka et al. , 2005). The relative intensi-

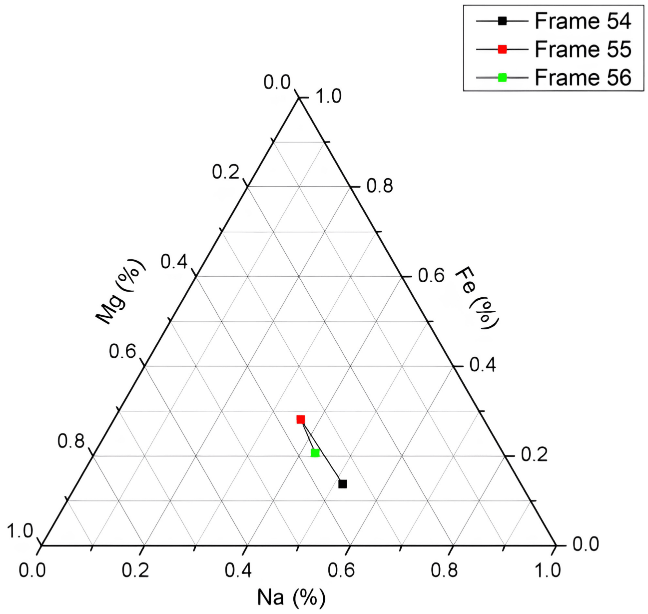

Figure 3. Ternary diagram of the relative multiplet intensities of Mg I (2), Na I (1) and Fe I (15). Each symbol represents the spectrum of each image analyzed.

ties observed for each of the three studied frames of the meteor are shown in Figure 3. The comparison of the spectra with the classification system proposed (Borovicka et al. , 2005), places the meteor in the Mainstream meteoroid group, with a particular classification in the Normal meteoroid subgroup. However, both the first and last frames in the study are near the transition area to the Na-enhanced and Fe-poor subgroups, which is expected for a chondritic composition, considering the velocity and temperature of the meteor.

4. Conclusions

The study of the spectrum of the meteor demonstrated the presence of Iron, Calcium, Magnesium, Sodium, Nitrogen and Oxygen, as identified in previous studies. It was also deduced that the presence of nitrogen and oxygen in the plasma is caused by atmospheric gases (Vojáček et al. , 2015).

Using the ternary diagram, it was also possible to classify the observed meteor as a body belonging to the Normal group (Borovicka et al. , 2005). In line with this, the observed elements are very common in chondritic rocks, which constitute approximately 85% of the meteorites found (Mason 1963; Norton & Chitwood 2008; Jenniskens 2006; Kepler & Saraiva 2017), providing a convincing argument to suggest that the studied meteoroid was a fragment of a chondritic body.

The mass of the meteor was calculated at the moment of maximum brightness (i.e., in magnitude -3.49), and it was estimated that the rock weighted about 7 g right before its entry into the atmosphere of the Earth. However, it is important to reiterate that this value may contain significant estimation errors, since it is not known exactly how the UFO performs the speed and height calculations.

References

Agenor, M., & Langhi, R. 2023, CdA., 4, 144
Borovicka, J. 1998, in Meteoroids 1998, 355
Borovicka, J., Stork, R., & Bocek, J. 1999, Meteorit. Planet. Sci., 34, 987
Borovicka, J., et al. 2005, Icarus, 174, 15
Bronshten, V. A. 1983, *Physics of Meteoric Phenomena* (Netherlands: Springer)
Ceplecha, Z., et al. 1998, Space Sci. Rev., 84, 327
Jenniskens, P. M. M. 2006, *Meteor Showers and Their Parent Comets* (Cambridge: Cambridge Univ. Press)
Kepler, S. O., & Saraiva, M. F. O. 2017, *Astronomia e Astrofísica* (4th ed.; São Paulo: Editora Livraria da Física)
Mason, B. 1963, Space Sci. Rev., 1, 621
Millman, P. M. 1980, IAU Symp., 90
Norton, O. R., & Chitwood, L. A. 2008, *Field Guide to Meteors and Meteoites* (New York: Springer)
Varella, P. G. 1985, *Meteoróides, meteoros e meteoritos* (São Paulo: Planetário/Escola Municipal de Astrofísica)
Vojáček, V., et al. 2015, A&A, 580, A67