Brazilian Meteor Observation Network: History of creation and first developments

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One way to learn more about the space environment in the terrestrial neighborhood is studying the annual flow of meteors that reaches our planet. Long-lasting projects and surveys have been dedicated to observing the sky with the purpose of capturing meteors, and generating large databases that allow searching for patterns in the sporadic meteor background and the identification of meteors associated with large and minor meteor showers. Most of the projects, however, are located in the northern hemisphere, making it difficult to detect southern hemisphere meteor showers. Thus, in order to increase the representativeness of meteor observation in this area and to allow the search for new radiants, BRAMON—the Brazilian Meteor Observation Network—was created, aiming to be a meteor-monitoring network based in Brazil. This work presents the network and the development of its first data-mining tool, necessary for its operation and search for new meteor showers. Using algorithms dedicated to the search for, and validation of, new radiants, the developed software called Encontreitor was able to find at least 108 possible new radiators so far in open access databases. In conclusion, it was shown that there is a willingness among the public to develop a collaborative meteor-monitoring network in the molds of citizen science, even in a country with a tradition in scientific research that is still in development. In addition, the created software proved to be a robust tool to search for new radiants. In this way, the network is preparing to present the new meteor showers obtained by Encontreitor, validating the findings, to the Meteor Data Center. Meanwhile, there are plans in other research areas involving meteors and other atmospheric events like Transient Luminous Events.

1 Introduction

Meteors are common phenomena in which a meteoroid collides with the upper atmosphere of a planet. A meteoroid travels through the space following a path determined by its orbit and, at the moment it penetrates the atmosphere, the direction from where it seems to come from is called the radiant. Some events, like the passage of an active comet, can generate streams with a large number of particles that follow the same orbit. If Earth intercepts this stream, a high number of meteors can be detected seemingly radiating from a single area in the sky, in what is called a meteor shower. Any meteor detected that does not belong to any of the known meteor showers is called a sporadic meteor (Ceplecha et al., 1998).

Large and long-lasting radar surveys and optical observation projects have collected a great volume of data on both sporadic meteors and meteor showers. Using mathematical and statistical tools, it is possible to search through the databases of these projects, allowing the identification of minor showers not previously noted (e.g., Šegon et al., 2015). Most of these projects are located in the northern hemisphere, making infeasible the detection of a representative number of meteors in the higher latitudes of the southern hemisphere (Campbell-Brown and Jones, 2006). More recently, new projects dedicated to filling this gap have been proposed (Janches et al., 2015; Jenniskens et al., 2016).

To expand the coverage area of the meteor surveys and to provide more reliable meteor orbital data on the southern hemisphere, the authors of this paper and many other collaborators have created the first Brazilian optical meteor detection network based on recording stations, namely BRAMON—the Brazilian Meteor Observation Network. To support the search for new meteor shower radiants, it was necessary to develop a robust tool capable of finding patterns of new showers in this growing database. The development of this tool required constant testing of the underlying algorithms on real data, so, major open-access databases were investigated, namely the SonotaCo and EDMOND databases. This paper describes briefly the creation and implementation of BRAMON and the initial development of the ENCONTREITOR software, dedicated to finding and validating new minor meteor showers. Already 108 possible new radiants of meteor showers were identified with it.

2 BRAMON

2.1 The network

The Brazilian Meteor Observation Network or BRAMON is a scientific organization whose mission is to develop, promote and disseminate science and technology, especially the study of meteors, their origins and nature, and the characterization of their orbits. It is a nonprofit collaborative network maintained by volunteers, bringing together several meteor-monitoring operators with the prime purpose of producing scientific data and providing them to the community, and this by analyzing the records acquired by the monitoring stations. In addition to the traditional astrometric analyses performed for sporadic meteor and meteor shower research, other activities can be developed with the data acquired with the cameras: obtaining spectra of meteors and other atmospheric phenomena with the use of diffraction gratings coupled to the cameras; triangulation and calculation of the trajectory of bright meteors to estimate possible strewn fields of meteorites (Rendtel, 2017); detection of other interesting phenomena such as sprites, blue jets, and other TLEs—Transient Luminous Events (Campbell-Burns and Kacerek, 2014); and observation of satellites and other artificial objects' reentry or whose orbit determination is of interest.

To encourage the participation of all members, BRAMON is constantly updating its database of good and low-cost materials and equipment. This allows the constant construction of new stations and guarantees the quality of the data obtained by the group. In the same way, the team is dedicated to keep operators well informed and oriented so that the best pointing and triangulation solutions are achieved. In addition, through the ideal of citizen science (Socientize, 2013), we seek the commitment of the public in the activities promoted by the network, allowing everyone to be able to contribute actively to the accomplishment of scientific research. In this context, the network not only conducts meteor-monitoring activities, but also promotes public observations and transmissions of meteor showers with the help of social networks. It also disseminates

Figure 1 – Coverage of the BRAMON camera network as of end 2016.

meteoritics in schools, colleges, universities, astronomy clubs, and official entities of study within the country.

2.2 Brief history

The first meteor monitoring station was set up by Professor Alberto Silva Betzler, in the state of Bahia, in 2005. In 2006, a station was put in operation by Professor Maria Elizabeth Zucolotto, curator of the meteorite collection at the Museu Nacional (National Museum) in Rio de Janeiro. The goal was to develop a national network solely to watch for bright meteors with the potential of meteorite dropping, in order to allow the determination of a more precise trajectory for the bolide, improving and simplifying the processes of finding and recovering the fragments. The idea was presented during the 10^{th} ENAST—Encontro Nacional de Astronomia (National Astronomy Meeting)—in 2007, and caught attention of people who wanted to create a national meteor observation network. In the following years, some new stations became active, but the all-sky project could not flourish as planned mainly because of technical difficulties and the high cost of equipment.

In 2013, there was a new attempt to create a meteor-monitoring network, this time led by the amateur astronomers André Moutinho, Carlos Augusto di Pietro Bella, Eduardo Plácido Santiago, and Renato Cássio Poltronieri. At the end of that year, Eduardo Santiago started to dialogue with meteor-monitoring networks in Europe, like UKMON and CEMeNt/EDMOND. Particularly valuable was the continuous support of Jakub Koukal to create a project better adapted to the situation of amateur astronomy in Brazil. This time, the stations were designed using primarily old security cameras equipped with common lenses, instead of the too expensive all-sky design. With this setup we were able to obtain a narrower field of view, allowing the detection of fainter meteors and retrieving more precise data. The first meteor image captured by this network was acquired by the station of Renato Poltronieri on January 9, 2014.

Shortly after the success of capturing the first meteors, the station owners created a group in a social media website aiming to gather people interested in joining the network. The growing number of stations allowed some regions to be covered by more than one camera, making possible the first meteor triangulation of the network (and probably the first ever over Brazil). The simplicity and the low cost of the components selected for the BRAMON stations enabled the network to grow rapidly and to aspire national coverage, as planned since the beginning.

BRAMON begun operation in 2014 with 9 stations, and grew to 23 in 2015. At the end of 2016, the network of cameras covered 50% of the Brazilian territory, with 39 stations spread across 16 states, as can be seen in Figure 1. Most of the stations are located in the southeastern region of Brazil, the most populated area of the country. In the northeastern region, the stations are concentrated near the coast, as the interior of this area has a semi-arid climate and low population density. The number of stations in the southern region is growing, with the potential of an even greater contribution to the detection of southern hemisphere meteor showers. During this period of operation, the stations recorded 76 568 individual meteors, of which 15 381 were double- or multi-station observations, which allowed for the calculation of 8041 orbits.

3 Encontreitor software

A meteor detection network is formed by gathering a group of single or multiple stations that operate to register meteors via video or radio recording. Later, the set of registrations, also known as captures, is used to extract useful data like the orbital parameters of the meteors. All the information collected is then sent to a database and becomes available for public or private research. The ENCONTREITOR software was developed to meet a primary need of an automated search process for new radiants in the emerging open-access meteor orbit database of BRAMON. The software can receive as input a set of orbits extracted from software like UFOORBIT, and it returns a list of possible new radiants. Other meteor detection networks such as EDMOND and SonotaCo also have a policy of keeping their databases open-access, allowing anyone interested in meteor research to search through the data. To validate the ENCONTREITOR software, a large number of tests was executed using the information stored in these databases leading to the preliminary discovery of 108 meteor showers (23 already approved by the Meteor Data Center as *pro tempore*, 75 under current analysis, and 10 to be submitted). The software can perform a series of tasks to find the new radiants as described below.

3.1 Clusters of similar orbits

The ENCONTREITOR software is based in the Density-Based Spatial Clustering of Applications with Noise or DBSCAN algorithm (Sugar et al., 2017) to search the orbits in the database. As output, it returns clusters of similar orbits. The criterion for similarity used to compare the orbits is the D-criterion proposed by Drummond (Galligan, 2001; Jopek et al., 2002). This criterion compares the orbits giving a value of dissimilarity, that is, the smaller the number, the more similar are the orbits. The D-criterion uses the following orbital elements: eccentricity, distance of perihelion, longitude of perihelion, longitude of ascending node, and inclination. During the execution of the DBSCAN algorithm, a maximum value for the D-criterion must be given, along with the number of minimum neighboring orbits of a specific orbit for it to become considered as a core point, and the minimum number of orbits that defines a cluster, i.e., core orbits plus reachable orbits. A visual explanation is provided in Figure 2.

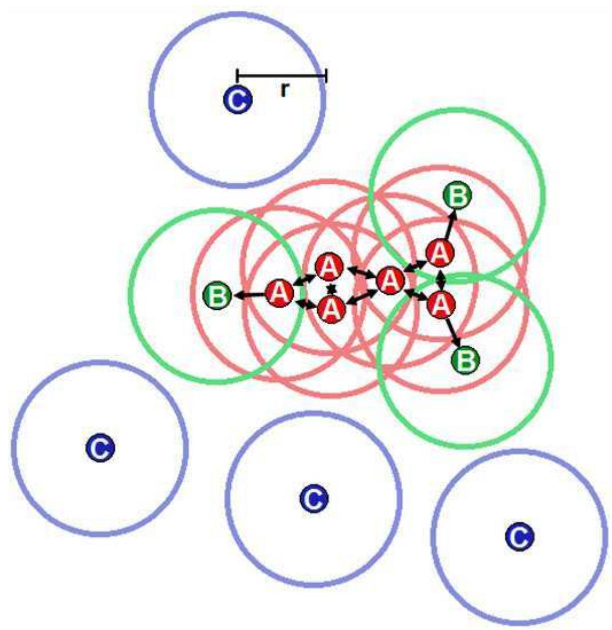

Figure 2 – Visualization of how the DBSCAN algorithm works. The minimum number of neighboring orbits for a point to be considered in the core is set to 4 in this illustration. The points A are core points, because the areas with radius r surrounding these points contain at least 4 points (including the central points themselves). The points B are reachable points, because the areas with radius r surrounding these points contain core points but less than four of them. The points C are noise, because they are neither core points nor reachable points.

A cluster may not define a new meteor shower as it can contain zero, one, or many radiants. Clusters with more orbits than the parameter of maximum size of the cluster are divided into smaller ones and clusters with less orbits than minimum orbits for a radiant (usually 6 orbits) are discarded. The groups formed after this stage are tested to confirm if they may represent new radiants through a combinatorial analysis algorithm that tests the similarity of the orbital elements. An average orbit is calculated for each group, and the D-criterion is applied between each orbit of the group and its average orbit. If all the orbits in the group are similar to the average orbit, respecting the maximum value of the D-criterion accepted for this step, the group is regarded

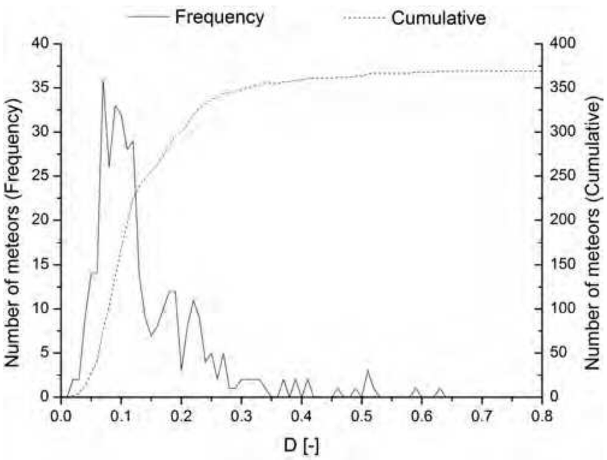

Figure 3 – Break-point method for the proposed September ε-Orionids radiant, showing the frequency and the cumulative series of meteors distributed per value of the similarity *D*-criterion (EDMOND and SonotaCo databases).

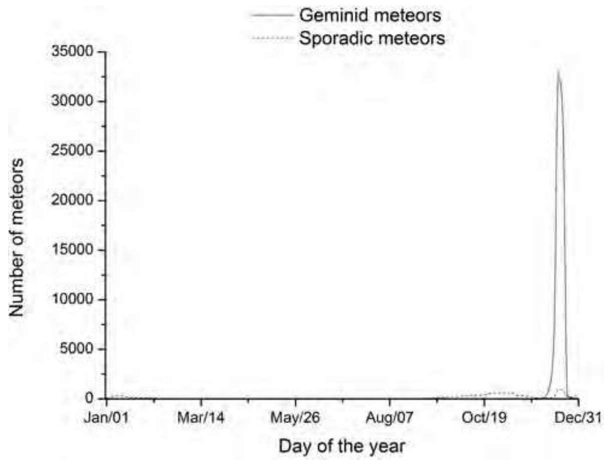

Figure 4 – Valideitor method of the Geminid radiant showing the number of meteors that are/are not associated to the shower inside a spherical area of radius 10° around the radiant center (EDMOND and SonotaCo databases).

as a possible new radiant. Some of the approved groups may represent the same shower and share repeated orbits, so these groups are gathered in a single group and the repeated orbits are eliminated. The similarity of the average orbit of the possible new radiants is tested against the orbital elements of valid meteor showers in the IAU database. At this stage, the solar longitude is also taken into account to differentiate meteor showers whose orbits intersect the orbit of Earth at more than one point.

3.2 Validation mechanisms

After finishing the initial analysis of a given database, a list of possible new radiants is produced, which is then subjected to further validation using the break-point method and the Valideitor method. The break-point method (Welch, 2001; Neslušan et al., 2013) is a graphical analysis in which all the orbits of a possible new radiant are plotted according to their value of the *D*-criterion of similarity. In addition, in the same graph, the orbits are presented cumulatively with increasing value of D. The method requires the input of the values of the initial D, the final D, and the integration delta. An example of the method can be seen in Figure 4. In this example, the orbits plotted show a distribution that resembles a Gaussian at the left side of the graph (between $D = 0$and $D = 0.2$), meaning that the orbits are concentrated near the orbital parameters of the radiant. In the cumulative series, the same region of the graph shows a fast growth, reaching an inflection point near $D = 0.2$.

To complement the break-point analysis, a method called Valideitor was proposed, in which the orbits of a possible new radiant are analyzed not only in function of *D*-criterion, but also as a function of time. It is expected that the temporal distribution of the meteors of a shower is Gaussian in the days near its peak. Using the method, it is possible to visualize the distribution of the orbits over time and how these orbits fit into the radiant. The method also makes it possible to understand how the orbits are distributed close to the radiant, providing a much greater understanding of the characteristics of the radiant and of its neighborhood. An example of an application of this method can be seen in Figure 4.

4 Conclusions

The implantation of a meteor-monitoring network like BRAMON in Brazil, a country with a still developing tradition in research in the meteor field, has shown that a good share of the population is interested in science. The number of people that appreciate astronomy has proved to be considerably high and, with the constant supply of information on good and cheap equipment, it is possible to bring these people together to contribute to a better understanding of the space environment in the terrestrial neighborhood, in a classical effort of citizen science. This endeavor has stimulated and encouraged the development of other useful solutions like the software ENCONTREITOR for the search of new meteor showers. The software facilitated the search through already established large databases, basing the analysis on the use of the *D*-criterion. It has also provided robust tools to validate the results using the break-point and the new Valideitor methods, increasing the confidence of the findings. The capacity of the algorithms was put to the test and they proved to be able to locate many new probable radiants. This development along with other ones made by BRAMON paves the way to a fully functional network with a high potential for discoveries in the field of meteor research in the southern hemisphere.

5 Future work

As a recently created meteor-monitoring network, BRAMON is still poorly known by the majority of the scientific community dedicated to meteor studies. To increase its visibility, a presentation paper is already being written, in parallel with a more complete paper focusing on the creation and the development of the algorithms behind of the ENCONTREITOR software. With the aim of seeing the tentative new showers found by the software approved in the List of Established Showers of the Meteor Data Center, their analyzed data will also be published within the mandatory deadline. Meanwhile, the search for more radiants within the open access databases (including the new BRAMON database, now part of the EDMOND database) will continue. Lastly, a new research effort on Transient Luminous Event will be developed in partnership with the Institute of Astronomy, Geophysics, and Atmospheric Sciences of the São Paulo University (IAG/USP).

Acknowledgements

The authors thank all the operators of the 39 BRAMON stations operational by 2016, all the new operators of the stations that started running since then, and all people who helped in the writing of this paper. They also thank the colleagues from the other meteor-monitoring networks that helped with the creation and development of BRAMON, making the dream become a reality, especially Roman Piffl from EDMOND and Richard Kacerek from UKMON.

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