Department of Physics and Mathematics

Seminar in Physics Engineering II

"Splinters of the Universe: Search, Study, and Chemical Characterization of Micrometeorites"

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Fall 2024

As always,

everything I do in my life,

I do thinking of you.

Even though you're my little brother,

I will always look up to you.

And even if we are apart,

I always have you present.

I love you and I miss you, cawn...

In recent years, I've dreamt of finding micrometeorites,

perhaps out of ego, or maybe my love for the vast cosmos.

I've imagined telling others that I hold the universe in the palm of my hand,

not realizing that I already do when I hold yours.

So I guess this work, this passion, and this dream

is also dedicated to you.

Abstract

"Splinters of the Universe: Search, Study, and Chemical Characterization of Micrometeorites" focuses on the analysis of extraterrestrial particles that pass through the Earth's atmosphere, known as micrometeorites (MMs). This project combines advanced techniques such as Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) to identify and characterize MMs collected in urban areas of Mexico City. Using a methodology inspired by Jon Larsen's work, various samples were evaluated to understand the influence of the urban environment on the composition and preservation of these objects. Despite methodological and logistical challenges, the results highlight the importance of using detailed analyses to distinguish between terrestrial materials and true MMs.

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1 Introduction

1.1 Context and Justification

Every year, between 20,000 and 40,000 tons of cosmic dust fall on Earth. Most of this is cosmic dust. The particles that make up this cosmic dust are generally disintegrated (about 10% survive) [10] when they enter Earth due to friction with the atmosphere [2]. The 'particles' that survive the hypervelocity and high temperatures settle on the Earth's surface in the form of micrometeorites (MMs) [7].

Micrometeorites usually vary in size, ranging from 2000 micrometers to smaller sizes of less than 10 micrometers [10].

Despite their small size, micrometeorites can represent an important part of the material used for the empirical study of the formation of the Solar System [7]. These micrometeorites are also fundamental in the study of the composition of comets in outer space, the formation of the early stages of the protoplanetary disk, as well as the composition of interplanetary space [7].

Thus, the continuous flux of micrometeorites represents a great opportunity for studies in the fields of astronomy, astrogeology, and astromineralogy.

1.2 Objectives

The objectives of this project are as follows:

- Define, in a methodical way, areas for the collection of urban micrometeorites.
- Test Jon Larsen's methodology (see Section 3) regarding urban micrometeorites.
- Identify and characterize urban micrometeorites in Mexico City.
- Contrast the results obtained to analyze the influence of urban conditions on the micrometeorites found in Mexico City and those found in rural areas in different regions of the world.

1.3 Research Questions

- How does the urban environment influence the preservation and composition of micrometeorites compared to rural areas?
- Is it possible to effectively apply the micrometeorite collection methodology proposed by Jon Larsen in a megacity like Mexico City?
- What compositional and morphological patterns can be identified in micrometeorites collected in urban areas, and how do these patterns contribute to our

understanding of the formation of the Solar System?

2 Theoretical Framework

2.1 Literature Review

The study of micrometeorites is relatively new, with the term being coined by Fred Lawrence Whipple in 1949 [1]. Micrometeorites are characterized by having a size not exceeding 2mm in diameter and being spherical. Their spherical geometry is due to the hypervelocity they experience when they come into contact with our atmosphere and the friction exerted by it, reaching speeds of up to 11 km/s. Micrometeorites have gained popularity in various fields of study as they represent an important source of extraterrestrial matter. The study of micrometeorites is important for understanding the composition of cosmic dust and other celestial bodies. Their study has opened many opportunities for the study of interplanetary space, astrobiology, astronomy, astromineralogy, among other fields.

The formation of micrometeorites is usually due to various celestial bodies such as comets and asteroids $> 98\%$ [9]. They typically form from collisions or disintegration of matter when it approaches the Sun, generating cosmic dust that eventually reaches Earth [6].

It is estimated that 2 MMs fall per year per square meter, although due to the regular maintenance of rooftops and drains, the collection efficiency in urban areas is about 0.1% [6].

2.1.1 Current Classification of MMs

The current classification of micrometeorites described in [4] helps us identify, in different phases, potential MM candidates.

This classification is divided into groups, classes, types, and subtypes. Initially, it is possible to identify the group to which a potential candidate belongs. This is done using optical microscopy, as this categorization is morphological.

Subsequently, a Scanning Electron Microscopy (SEM) study is necessary to perform the detailed categorization of the candidates. This technique allows for a detailed appreciation of the surface texture, which enables categorizing MMs into classes.

In reality, for this project, it is most likely that MMs belonging to the group of *Melted MMs* will be found. This is because most particles (70% - 90%) greater than $> 100\mu m$ belong to this group. [4]

This facilitates their identification as they are the ones that are "easier" to filter using the techniques described by Larsen.[4]

Groups	Class	Type	Subtype	Description
Melted MMs	Cosmic Spherules (CSs)	S	CAT	Spherules with Mg/Si >1.70 enriched in Ca, Ti, and Al. They have barred olivine textures.
		S	Glass	Spherules almost completely composed of glass.
		S	Cryptocrystalline	Spherules dominated by submicrometric crystals and magnetite. Some include multiple domains.
		S	Barred Olivine (BO)	Spherules dominated by olivine in parallel growth within glass.
		S	Porphyritic Olivine (Po)	Spherules dominated by equiaxed and skeletal olivine within glass. Varieties with relicts contain unfused minerals.
		S	Coarse Grained	These spherules contain more than 50% volume of relict minerals.
		G		Spherules dominated by dendrites of magnetite within silicate glass.
		I		Spherules dominated by magnetite and wüstite.

Table 1: Classification of Melted MMs [4]

Group	Class	Type	Subtype	Description
Partially Melted MMs	Scoriaceous Micrometeorites (ScMMs)	-	-	Vesicular particles dominated by a mesostasis of microphenocrysts of fayalitic olivine within glass. ScMMs often contain relict minerals and areas of relict matrix.

Table 2: Classification of Partially Melted MMs [4]

Group	Class	Type	Subtype	Description
Unmelted MMs	Fine-Grained Micrometeorites (FgMMs)	C1	-	Compact, chemically homogeneous. Often contain framboidal magnetite.
		C2	-	Compact, chemically heterogeneous. Often contain isolated silicates and/or tochilinites.
		C3	-	Highly porous. Often contain isolated silicates and framboidal magnetite.
	Coarse-Grained Micrometeorites (CgMMs)	Chondritic CgMMs	Porphyritic olivine and/or pyroxene	Igneous MMs dominated by olivine and/or pyroxene phenocrysts within glass.
			Granular olivine and/or pyroxene	Igneous MMs dominated by olivine and/or pyroxene without significant glass.
			Barred olivine	Igneous MMs dominated by parallel growth of olivine within glass.
			Radiating pyroxene	Igneous MMs dominated by radial dendrites of pyroxene within glass.
		Type I Type II	Type I Type II	Type I CgMMs are reduced particles containing Fs and/or Fa <10 mol%. Type II CgMMs are oxidized particles with Fs and/or Fa >10 mol%
		Achondritic CgMMs	–	Differentiated igneous micrometeorites.
	Refractory Micrometeorites	Porous	–	Porous particles dominated by refractory minerals.
		Compact	–	Compact particles dominated by refractory minerals.
		Hydrated	–	Particles dominated by refractory minerals surrounded by Fe-rich phyllosilicates or their dehydroxylation products.
	Ultra-Carbon Rich Micrometeorites	-	–	Particles dominated by carbon-rich materials with inclusions.

Table 3: Classification of Unmelted MMs [4]

3 Methodology

3.1 Research Design

To search for micrometeorites, the methodology described by Jon Larsen in his book extitOn the Trail of Stardust: The Guide to Finding Micrometeorites [8] will be employed. His book is considered the best guide for the search for urban micrometeorites since its publication in 2019. In his book, Larsen emphasizes the importance of finding urban areas with low human activity. Therefore, public places such as streets, parking lots, and highways are ruled out, and areas that Larsen establishes as optimal will be used: rooftops. Rooftops and building roofs are generally less frequented by people, except on specific occasions when maintenance or installations are required. These places represent a good opportunity to find micrometeorites due to their continuous exposure to the sky.

For the project, it was decided to work on three main rooftops:

- Clavius Observatory, Universidad Iberoamericana
- Anahuac High School, Campus Cumbres
- Private residence in Cuajimalpa

These locations were chosen due to their accessibility and the extent of their roofs, which, although they may be frequented, represent a good option to start searching for micrometeorites.

3.2 Materials and Methods

The materials to be used in the research are as follows:

- Magnet with a 40 kg holding capacity
- Kitchen sieve for washing rice (2mm) or a graded sieve tower
- Optical Microscope
- Scanning Electron Microscope
- Energy Dispersive Spectroscopy (EDS)

3.3 Procedures

1. Sweep the selected areas (focusing on drains).
2. Collect the swept material and wash it.
3. Pass a magnet through the washed sample and collect what adheres to it.
4. Filter the sample by size using a sieve.
5. Search for potential candidates using an optical microscope.
6. Analyze the micrometeorites using Scanning Electron Microscopy (SEM).
7. Analyze the micrometeorites with Energy Dispersive Spectroscopy (EDS).
8. Characterize and classify the micrometeorites found.

3.3.1 Sample Collection

As of the date of this document, 9 field searches were conducted. These searches were carried out in the following locations:

1. Private Residence in Cuajimalpa, Mexico City
2. Private Residence in Cuajimalpa, Mexico City
3. Private Residence in Santa Fe, Mexico City
4. Terrace of the Chemical Engineering Laboratory, Universidad Iberoamericana
5. Terrace of the Chemical Engineering Laboratory, Universidad Iberoamericana
6. Clavius Observatory, Universidad Iberoamericana
7. Terrace of the Physics and Mathematics Department, Universidad Iberoamericana

Figure 1: Waterproofed roof at UIA

8. Private Residence in Chapultepec, Mexico City
9. Rooftop of the Physics and Mathematics Department, Universidad Iberoamericana

The samples were collected and labeled to maintain a record of potential MMs that could be found. The sample labeling system only indicated the field search number (or FS) and the collection date.

Some limitations were that the selection of locations, although meeting Larsen's requirements, were still very frequented, with a clear human presence. This is likely because most of the locations are within a university as popular as Universidad Iberoamericana.

Another limitation is the type of waterproofing used in Mexico City. A common waterproofing technique for roofs is the use of acrylic mixed with rubber.

This technique is characterized by being extremely lumpy, which significantly complicates sample collection. Additionally, with high temperatures, it can become gummy, further complicating the collection process.

3.3.2 Sample Cleaning

Once the samples were obtained, they were cleaned using hot water (50 degrees Celsius) and dishwashing soap.

Figure 2: Precipitation as a method to separate organic matter in the sample

The precipitation method was also used to remove most of the organic matter from the samples.

Both techniques are recommended by Larsen; however, starting with the eighth search, I chose another approach due to the inconvenience of working with moistened samples.

For the last two searches, which were the most efficient in terms of time and logistics, another route was taken.

By using various pharmaceutical-grade sieves, better control over the samples was achieved.

Four sieves were used with the following mesh openings:

1. 2.38 mm
2. 0.84 mm
3. 0.59 mm
4. 0.25 mm

Figure 3: Sieves used to separate samples

Figure 4: Aerial view

Figure 5: Sieved sample separated by size

(a) Figure A

(b) Figure B

Figure 6: Sieved sample separated by size

With these sieves, it was easier to separate the samples initially. This is because we are only interested in particles between 200μm to 400μm [8]. Most MMs are found in this range. Moreover, handling more homogeneous particle sizes allows for a more efficient optical microscopy phase, as frequent field adjustments are not needed.

With the sample separated by particle size, it is easier to conduct the magnetic test before proceeding to optical microscopy.

3.4 Data Analysis

3.4.1 Optical Microscopy

For the project, the acquisition of a USB-connected optical microscope was very useful. This microscope made obtaining images and videos that clearly demonstrate what is sought in this phase of the work much easier.

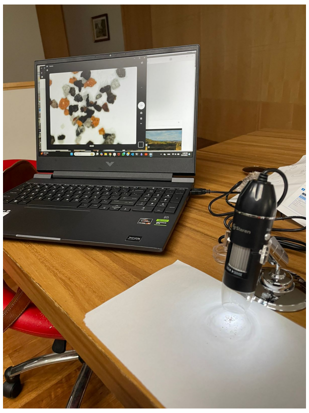
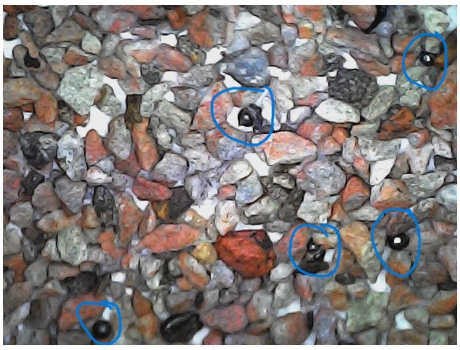


Figure 7: Initial optical microscopy analysis

Figure 8: Sample analysis using an optical microscope with USB connection

One of the main issues when working with these types of samples in high-traffic areas is that there are many particles that may seem like good candidates at first, but their sheer number should be interpreted as an indication that they are not MMs.

(a) Figure A



(b) Figure B

Figure 9: Comparison of potential candidates during initial identification

In an urban area with less human activity, it would be very easy to mistake each of these particles for MMs.

The best candidates were individually separated into containers using a sharpened stick and labeled for the next phase of the project.

Figure 10: A sharpened stick is used to manipulate the sample and separate candidates

Figure 11: Candidates separated individually

3.4.2 Scanning Electron Microscopy (SEM)

This is the part of the project that is crucial in identifying and classifying micrometeorites. Due to the nature of the study, it is possible to observe the candidate's morphology in great detail, from its size to its shape and surface texture.

This is where particles that appear to be MMs under an optical microscope no longer seem like it upon closer inspection.

For this stage, four candidates were selected, one of which seemed very promising: candidate 9 from field search 9, labeled as C9 FS9.

It is important to note that it is easy to determine that the other candidates are not MMs since they do not meet the morphological requirements. Nevertheless, the study itself had an important aesthetic value, providing a detailed view of the types of particles that can be found on urban rooftops in a megacity like Mexico City.

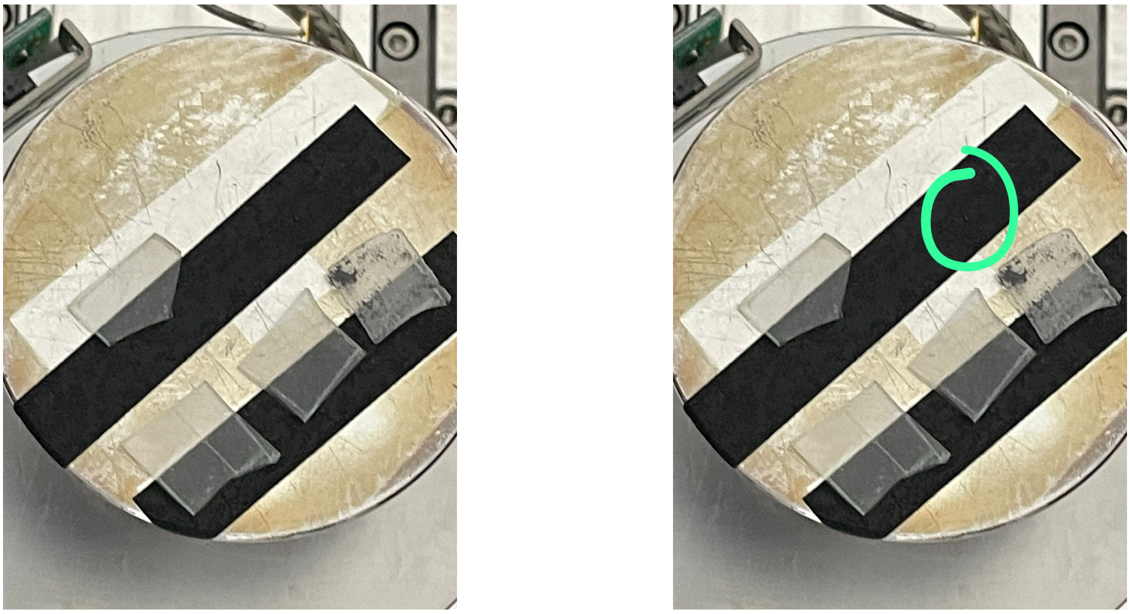
3.5 EDS

(a) Figure A

(b) Figure B

Figure 12: Sample preparation for SEM and EDS analysis

A compositional study of the candidates was also carried out, which was key in determining that C9 FS9 was not an MM. The sample was prepared and placed on double-sided carbon tape for analysis.



(a) Figure A

(b) Figure B

Figure 13: Sample preparation on double-sided carbon tape (possible MM indicated)

4 Results

Four potential candidates were studied using SEM, and detailed images were obtained that confirm the intrinsic aesthetic of a work of this kind.

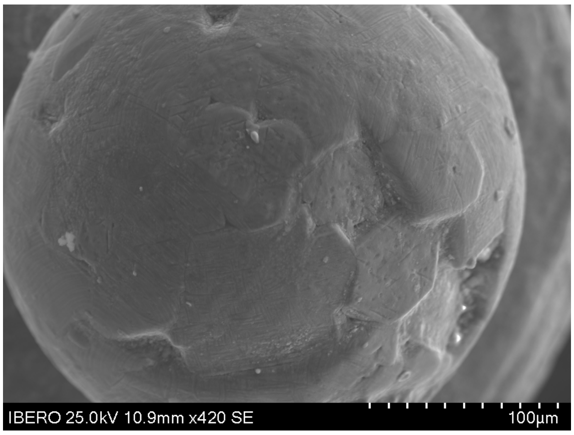
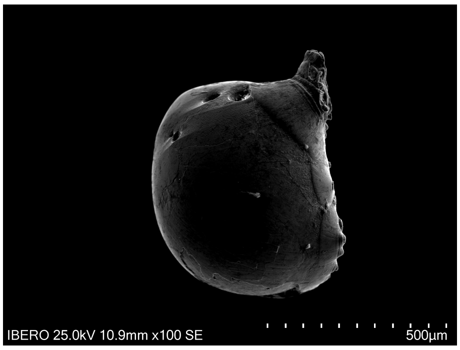


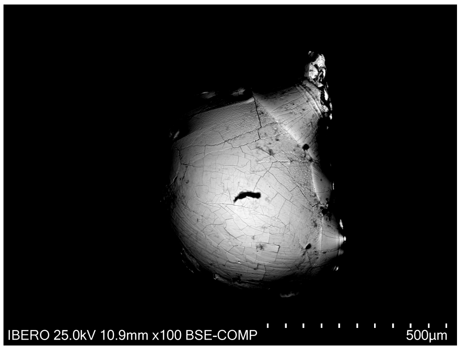
Figure 14: Candidate 2 as seen under SEM

This candidate was discarded due to its morphology, which did not exhibit sufficient sphericity.

Something similar happened with candidate 4.



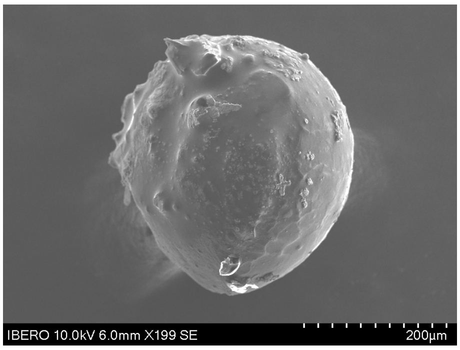
(a) Figure A



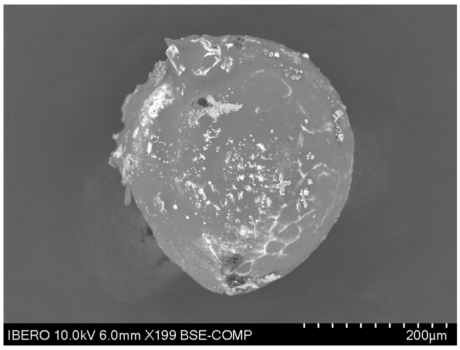
(b) Figure B

Figure 15: Detailed visualization of candidate 4 using SE and BSE

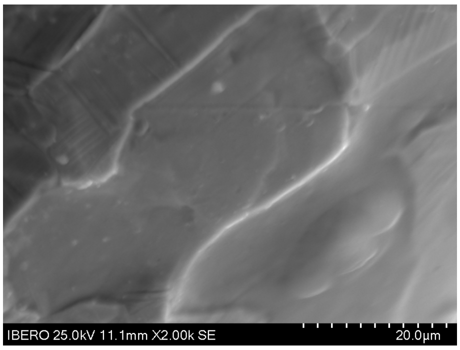
The same applies to candidate 5.



(a) Figure A



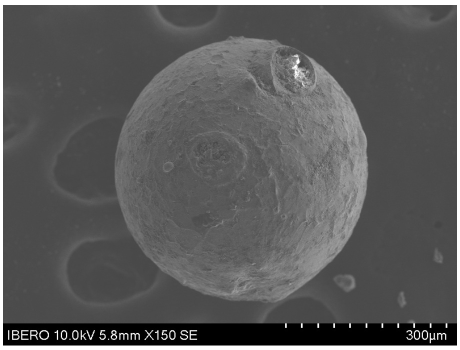
(b) Figure B



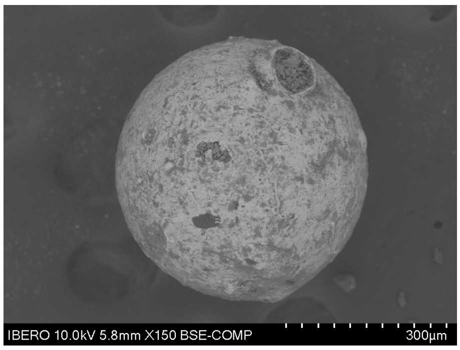
(c) Figure C

Figure 16: Detailed visualization of candidate 5 using SE and BSE and viewing its texture in detail

However, it should be noted that one of the candidates presented good morphology under SEM. This was the case for candidate 9, which exhibited significant sphericity, suggesting that it might be an MM. An EDS study was conducted to determine its composition and to confirm whether or not it was an MM.



(a) Figure A



(b) Figure B

Figure 17: Detailed visualization of candidate 9 using SE and BSE

4.1 Data Presentation

The EDS results indicated that the candidate was not an MM. This was due to the low iron (Fe) content. A peak corresponding to aluminum (Al) was also observed, which is largely attributed to the vacuum chamber in which the sample was analyzed.

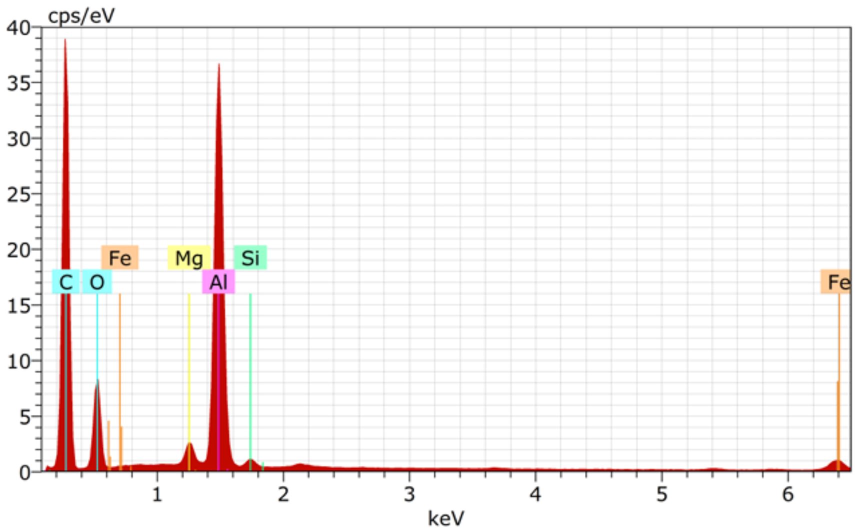


Figure 18: EDS results for candidate 9

Although magnesium and silicon content were favorable, the low iron content and the absence of nickel in the candidate helped determine that candidate 9 was not an MM.

5 Discussion

5.1 Interpretation of Results

Unfortunately, as of the date of this writing, no particle that can be indisputably confirmed as extraterrestrial, a micrometeorite, has been found. Although we have the tools and knowledge to eventually find one, at this point, the study has not yielded the expected results.

The samples, although they seemed to be MMs and good candidates under optical microscopy, and having passed the sieving and magnetic tests, and an initial identification, did not present a composition consistent with MMs. In particular, candidate 9 was determined not to be an MM after the EDS study. The other three candidates, candidate 2, candidate 4, and candidate 5, were discarded for lacking sufficiently spherical morphology under SEM.

6 Conclusions

The main conclusion of this work concerns Jon Larsen's methodology. Although his work is of great value and has inspired many people to do science, it can be misleading. I am one of those people who have been inspired by his work and have dreamed of finding micrometeorites. However, it is important to be cautious when claiming something without being 100% sure.

Throughout this project, I have seen many people on social media claiming to have found an MM based on Larsen's methodology and using his books [8] as their main guides. The problem with this is that, as can be seen in some images I presented, optical microscopy cannot be determinative for classifying and/or identifying an MM. Spherical and magnetic objects, such as residues from human activity, are very abundant, even at the small scale studied for MMs.

It is vital not to forgo a more detailed morphological study, such as that obtained with Scanning Electron Microscopy, to not only make a correct identification but also to classify MMs specifically.

More importantly, I believe it is impossible to determine if a candidate is an MM without an EDS study to analyze the candidate's composition. Only with these two studies is it possible to reach a conclusion for a particular candidate.

Larsen's work, although inspiring and noble, is ultimately an introductory work to the field of geology and astrogeology. It is a tool that attracts people's attention, which is of great value, but as can be seen in a more in-depth study, it is an incomplete methodology for identifying MMs initially.

6.1 Summary of Findings

Although good candidates can be observed in the samples with optical microscopy, in some cases, the abundance of a type of particle, no matter how spherical it may seem, is an indication that it is not. As seen in figure 16b.

The study was definitely impacted by the typical waterproofing techniques in Mexico City, which limit the collection of potential MMs. Additionally, the high level of human activity also complicates this process due to contamination of the chosen areas.

6.2 Limitations

- Waterproofing techniques
- High human activity
- Limited access to viable areas due to safety concerns
- Luck?

6.3 Recommendations

It is advised that, if a sieve tower or pharmaceutical-grade sieves, as used in this process, are available, the methodology described here should be used. This is because it facilitates the work and allows for more samples to be analyzed in less time.

It is also important to have a microscope that offers a good field of view. Traditional optical microscopes are not very effective in this regard. Furthermore, it is crucial to look for a microscope that provides a good flat image to more efficiently identify potential candidates.

7 Future Work

For future work, it is considered of utmost importance to have a database that facilitates the identification of MMs. This database cannot be purely morphological. Identification should include a classification based on the composition of the candidates. This is to identify MMs more specifically and reduce identification error once microscopy and EDS data are available. Although a good database already exists, it is only based on morphology and is not very accessible to the general public.

Furthermore, the idea of developing a computer program based on a neural network capable of identifying and classifying MM candidates has been proposed. This neural network could theoretically be a fusion of a recurrent neural network and a convolutional neural network to train based on quantitative composition and size data of the candidates, as well as microscopy images.

8 Appendix A

8.1 Outreach Work

- **Clavius Observatory Talk:** On November 27th, a talk about the work will be given in an interactive presentation format for the community of the Clavius Observatory at Universidad Iberoamericana.
- **Night of the Stars:** On November 9th, a poster with general information about micrometeorites was presented at the *Night of the Stars* at the National Autonomous University of Mexico (UNAM). **Figure** 19
- **Publication in *¿Cómo ves?* magazine:** After the conclusion of the project, an article will be prepared for publication in *¿Cómo ves?*, a science outreach magazine by UNAM.

- **Nano Ibero:** Possible publication of results and images obtained using Scanning Electron Microscopy along with some explanatory text about the images.

Figure 19: *Night of the Stars* Poster

9 Appendix B

9.1 Definition of Key Concepts

1. **Micrometeorite**
   A *micrometeorite* is a microscopic-sized particle, generally smaller than 2mm and larger than 10 μm, that has passed through Earth's atmosphere and reached the planet's surface. They are fragments of comets, asteroids, or interplanetary particles that originated in space and have undergone modifications due to friction and heating during entry into Earth's atmosphere. [4] [9]

2. **Cosmic Dust**
   Cosmic dust refers to extremely small particles (submicrometric to micrometric) present in interplanetary, interstellar, or intergalactic space. It is crucial in the formation of celestial bodies. [11]

3. **Fusion Crust**
   The *fusion crust* is the outer layer of micrometeorites that forms due to extreme heating and surface melting during their entry into Earth's atmosphere [3]. This crust may exhibit a glassy texture and is a key feature for identifying micrometeorites [8].

4. **Chemical Composition**
   The *chemical composition* of micrometeorites describes the elements and compounds present in these particles.

5. **Optical Microscopy**
A conventional optical microscope consists of a system of lenses that allow an image to be magnified [5]. It is used for the initial identification of micrometeorites [8].

6. **Scanning Electron Microscopy (SEM)**
Scanning Electron Microscopy (SEM) is a technique used to obtain high-resolution images of the surface of micrometeorites. This technique allows observation of morphological details at the micrometric level and is essential for studying the texture and surface structure of these particles.

7. **Energy Dispersive Spectroscopy (EDS)**
Energy Dispersive Spectroscopy (EDS) is an analytical technique used to determine the elemental composition of a sample. It is based on the interaction of a high-energy electron beam, such as those generated in a scanning electron microscope (SEM), with the atoms of the sample. This interaction causes the emission of characteristic X-rays of the elements present in the material, allowing their identification and quantification.

8. **Micrometeorite Fall Rate**
The *micrometeorite fall rate* refers to the estimated number of micrometeorites that reach Earth's surface per unit of time and area. [10]

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