Cosmic fishermen: in search of ferromagnetic spherules

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Abstract

Our Milky Way is kind of a soup made out of star dust and other elements. Each day, approximately 60 tonnes of particles coming from asteroids, comets and other celestial bodies fall to the ground. These small treasures, mostly metallic and presenting different shapes, textures and colours, are called micrometeorites and they constitute the eldest matter in our Solar system.

Although these particles cover planet Earth, they are particularly abundant in areas with no human activity, for example the bottom of the ocean, the deserts or the poles. The probability of finding them in urban areas is also high; however, they can be mistaken for metallic debris originated by industries.

Amongst all the different types of micrometeorites found on Earth, we have based our project on the so called ferromagnetic cosmic spherules, simply because they are quite accessible to study without having to perform complex experiments. Our project consists of learning how to locate and differentiate these cosmic particles.

In order to study the spherical shape that some micrometeorites adopt in crossing the atmosphere, we have performed several physics simulations.
Furthermore, we have searched for micrometeorites in natural environments where water is likely to be retained, such as gutters and water chests but also ponds and river mouths located in the vicinity of our homes. The samples retrieved, consisting of mud, water and sand, were subsequently taken to be analysed using simple instruments: a neodymium magnet, a stove, a sieve and a microscope.

This is an interdisciplinary project which has been developed with primary school children. The project is linked to the science curriculum from this stage of education and uses instruments and methodologies in accordance with their age.

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Development

1. Introduction

Fred L. Whipple[1] first coined the term micrometeorites to describe micrometeoroid objects that have survived through the atmosphere and fall to Earth.

These particles have the size of dust (hence they are also called cosmic dust) and vary between 50 µm to 2 mm and with an individual mass of between 10 -9 and 10 -4 g. Micrometeorites travel through the atmosphere at high speeds (about 11 km / s), heating up due to atmospheric friction and compression.

[1] American astronomer, who proposed the "dirty snowball" model for comets, and whose contribution to the knowledge of the minor bodies of the Solar System (comets, asteroids and meteoroids) was very remarkable. (Source: Wikipedia)

The different textures of micrometeorites are due to the different structural and mineral compositions they present and to the degree of heating they experience when they pass through the atmosphere, directly related to the initial velocity and the angle of entry.

It is estimated that 40,000 ± 20,000 tons of cosmic dust enter the upper atmosphere each year, although less than 10% (2,700 ± 1,400 Tm / year) reach the surface as particles. Therefore, the mass of micrometeorites deposited on the earth's surface is approximately 50 times greater than that estimated for other meteorites, approximately 50 Tm / year. This large number of particles comes from all dust-producing objects in the Solar System, including asteroids, comets, fragments of our Moon and Mars.

2. Curricular aspects of the project

Main Objectives

- To awaken in primary school students the interest, curiosity and the capacity for wonder by phenomena such as meteor showers and by astronomical bodies, specifically micrometeorites.
- Study the existence of micrometeorites on the earth's surface.
- Acquire scientific skills through an attractive approach during field work.
- Present simulation in physics as a very useful element for the understanding of astronomical concepts and phenomena.

Secondary Objectives

- Understand and value the structure and protective function of our atmosphere.
- Make the natural environment of Campo de Gibraltar known among students and generate in them a high level of appreciation about the region where they live.

Thematic units in primary education linked to the project

In the graph that follows, we have listed the links between our project and the teaching units in our national curriculum of Natural Science (in green) and Social Studies (in blue).

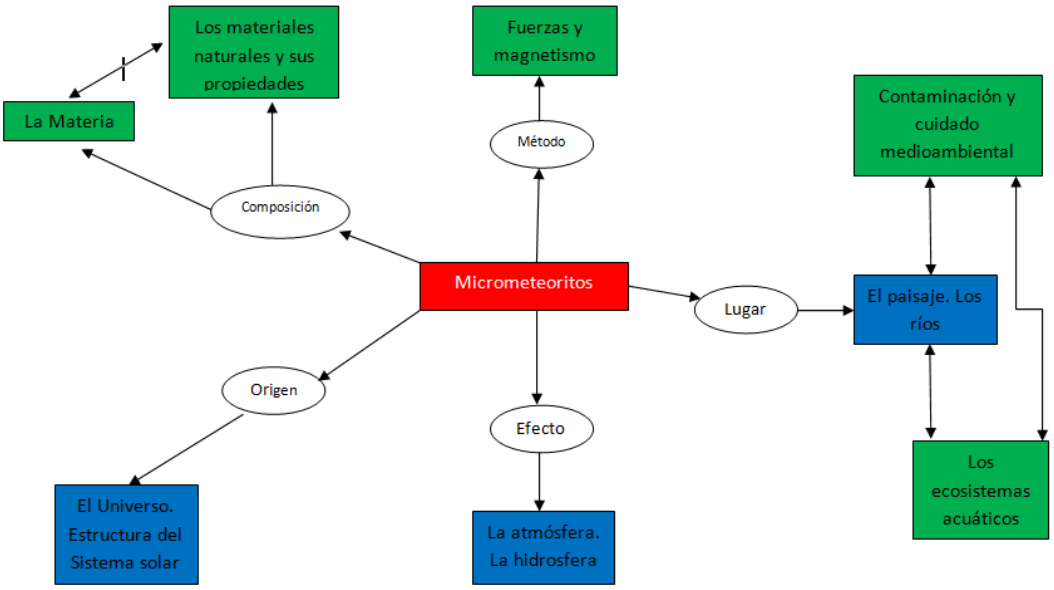


Image 1. Contribution of the Primary Curriculum to the project.

In red: Micrometeorites
In white: Composition. Method. Place. Effect. Origin.
In green: Matter. Natural materials and their properties. Forces and magnetism. Pollution and environmental care. Aquatic ecosystems
In blue: The landscape, the rivers. The atmosphere, the hydrosphere. The Universe. Solar System Structure.

3. Historical context

The existence of interplanetary dust was discovered in the late 18th and early 19th centuries. The father of acoustic science, E. Chladni, defended the extraterrestrial origin of meteors, fireballs and meteorites in 1794. The spectacular Leonid meteor storm in 1833 and the observation that meteors seemed to emerge from a stationary point in the Constellation Leo led many scientists at the time to independently conclude that these meteors had an extraterrestrial origin.

In the latter part of the 19th century, small spherical particles were collected from deep places on the ocean floor, and they were determined to be chemically similar to meteorites, which is why they were called "cosmic spherules". Analysis by E. J. Öpik of deep ocean samples collected in the 1930s suggested that the Earth was accumulating 8x109 Kg of meteorite material per year (about 1.5 grams of material per square centimeter per year).

Similarly, in the first half of the 20th century, dust collection experiments were carried out, placing containers in the open air, generally in the patios and roofs of the scientists themselves. Likewise, rain and snow were studied, using magnetic separation methods for the dust grains present in them. This provided iron-nickel particles, which were assumed to have a meteorite origin. As a consequence, the estimates made about the amount of material accumulated by the Earth over a year varied by several orders of magnitude, ranging between 104 and 108 kg. The estimation methods depended on meteor observations and falls of meteorites as well as dust collection experiments. However, it was recognized that these estimates were necessarily incomplete.

In the early 1950s, Warren Thomsen placed several plastic-lined cans outdoors for six months on a farm several kilometers from Iowa City, United States, and examined the collected dust under a microscope. He estimated that spherical magnetic meteorite dust particles fell at a rate of 2.0x109 kg / year across the Earth. This result (which is two to four times higher than the currently agreed value) sparked criticism that focused on concerns about the high potential for contamination of dust samples collected on the Earth's surface.

Later, efforts were directed at relating the dust collected on Earth and that observed in space. In 1947, Van de Hulst estimated the mean mass density of interplanetary dust particles (Interplanetary Dust Particles, IDPs) that give rise to zodiacal light, taking into account their light scattering properties. Assuming that this dust was swept by the Earth at its orbital speed around the Sun, the annual dust fall would be 6x108 Kg.
As new technologies became available, they were applied to identify interplanetary dust falling on Earth and determine its properties. In the 1940s, radar began to be used to detect meteors even in broad daylight and determine their speeds. Retrofitted V2 rockets with sensors were also launched to detect the sound that the small particles made when they hit the surface of the rocket.

The lower part of the atmosphere has a large amount of suspended earth dust, which gives rise to problems of contamination of the samples collected in it. These inconveniences were avoided as of 1960, with the sampling of atmospheric dust at high altitude (more than twenty kilometers) carried out with collecting planes and probe balloons. In the 1960s, extraterrestrial particles were better collected in the upper part of the atmosphere and a consensus was reached about the amount of dust accreted by the Earth each year: about 109 kg (more than 2,700 tons per day).

In the last third of the 20th century, space probes and infrared telescopes in orbit around the Earth have increased our understanding of the complexity of the interplanetary dust cloud.

In the late 1960s, particles were directly sampled in space using impact detectors. In the 1980s, the Infrared Astronomical Satellite, an orbiting telescope sensitive to thermal emission, discovered numerous space structures within the zodiacal cloud in the inner Solar System. In the 1990s, crash detectors aboard the Galileo and Ulysses probes discovered dust streams originating from the Jupiter system. Finally, in 1993, using information from the Ulysses dust experiment, Eberhand Grün and his colleagues announced the first direct detection of interstellar dust grains within the Solar System. The direction from which they came indicated that their origin could not be found within the zodiacal cloud.

4. Classification of micrometeorites

With the "classical classification" of meteorites (rocky, mixed and metallic), it was believed that meteorites came from the same body: rocky (the surface), metallic (the core of the supposed body) and mixed (between the surface and the core). But around 1970, meteorites could be studied with better microscopes and deeper chemical analyzes, especially with isotopes, could be performed. This caused that the "classic classification" that had been used for decades began to be invalid, since many apparently the same meteorites were not from the same time or from the same body of origin.

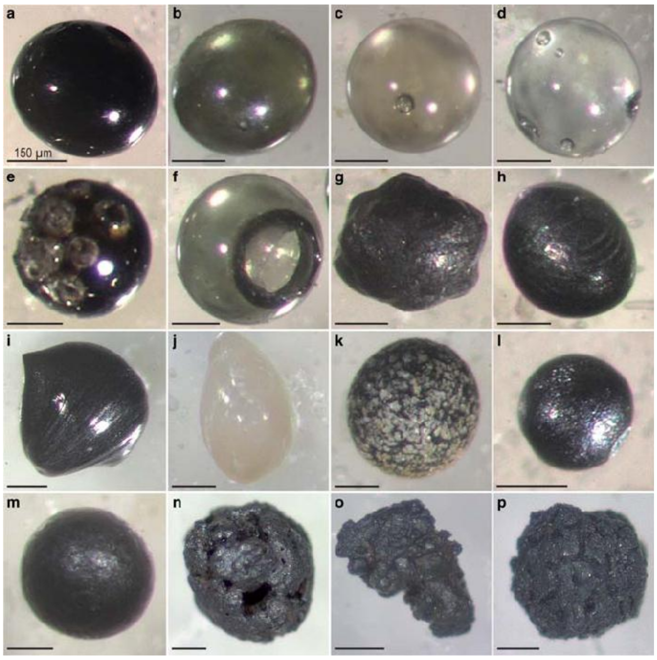
Of the various classifications that exist, we have seen fit to focus attention for our project on three of them: the classic, the one that refers to the origin and the one that refers to the degree of warming suffered when passing through the atmosphere.

• Classical classification (conforms to the classification of meteorites), according to their composition:

- Stony (also called: rocky): chondrite and achondrite.
- Metallic (also called: siderites, iron, ferrous, ferric): atxite, octahedrite and hexahedrites.
- Metalrocosos (also called: siderolites, mixed, ferric of rocky type, ferro-stone, stone-ferrous, rocky-metallic, lithodehyde, stone-metallic): pallasites and mesosiderites.

- Classification according to origin:
  - Micrometeorites originating from Comet Dust. Its size is only a few microns in diameter. When a comet approaches the Sun, its temperature increases enormously and some of its material sublimates, leaving behind a huge trail of dust. If the Earth orbits close to that trajectory, much of this dust enters our atmosphere. This cometary material, on many occasions, causes the known meteor showers, but much of it can remain in our stratosphere for days and days until it finally falls on Earth in a much more peaceful way. These particles are believed to have an aerosol function and act as small nuclei for the formation of water droplets, which causes large amounts of extraterrestrial material to be dragged to the surface of our planet when it rains. On a scientific level, micrometeorites that come from comet dust or interstellar dust are very interesting, since by not undergoing a fusion process, their structure and properties remain unchanged, so they can provide us with much more information about their origin and the formation of the Solar System.
  - Micrometeorites that come from Asteroids. They undergo fusion processes that limit their scientific usefulness somewhat, although the elements that compose it remain unchanged. Being much larger, it is much easier to locate them and also, why not say it, they turn out to be much more beautiful.
  - Micrometeorites called Planetary type, since their origin is in rocky planets, such as Mars. When the planet is hit by a meteorite, pieces are released, which then fall on the surface of the Earth. Other meteorites come from the Moon. But to search of this type, we will wait to be true scientists.

- Classification according to the degree of warming suffered in the transit of our atmosphere:
  If we look at the composition and the degree of heating, it could be classified into three large groups:
  - Particles that are not fused and retain their original mineralogy.
  - Particles that are partially fused.
  - Fused cosmic spherules (spherical shape) some of which have lost a large part of their mass due to vaporization.



Images 2. Luigi Folco Classification. (a – f) Cosmic glass spheres showing the most common color range and variable vesicularity. (g) Cryptocrystalline cosmic sphere with characteristic turtle-back morphology (polyhedral type). (h – i) Barred olivine cosmic spherules showing characteristic striations. (j) CAT cosmic spherule with its characteristic milky white colour. (k) Porphyritic cosmic spherule. (l) Type I cosmic spherule with its characteristic metallic luster. (m) Spherical cosmic type G. (n) Partially fused micrometeorite with characteristic scoriaceous structure. (o – p) Unmelted micrometeorites with characteristic angular to sub-angular shapes. Scale bars 150 mm.

As we carried out the present study with primary school students, we focused our attention on micrometeorites that could be identified with a certain ease and "reliability", without doing mineralogical or chemical studies, that is, cosmic spherules and especially those of metallic composition. On the one hand, the spherical shape, the dark colour, the opacity and the small size (around 0.05 mm or a little larger) will make it easier to recognize them with the microscope and on the other hand, being ferromagnetic, they will be strongly attracted by a magnet.

The students were informed at all times that these types of micrometeorites that we are looking for only constitute a small part of the total of those that reach the surface of the Earth and that the process that we will describe later, discriminates enough the possibility of finding many more with different characteristics.

4. Physical recreation of cosmic spherules: Why are they so small and spherical?

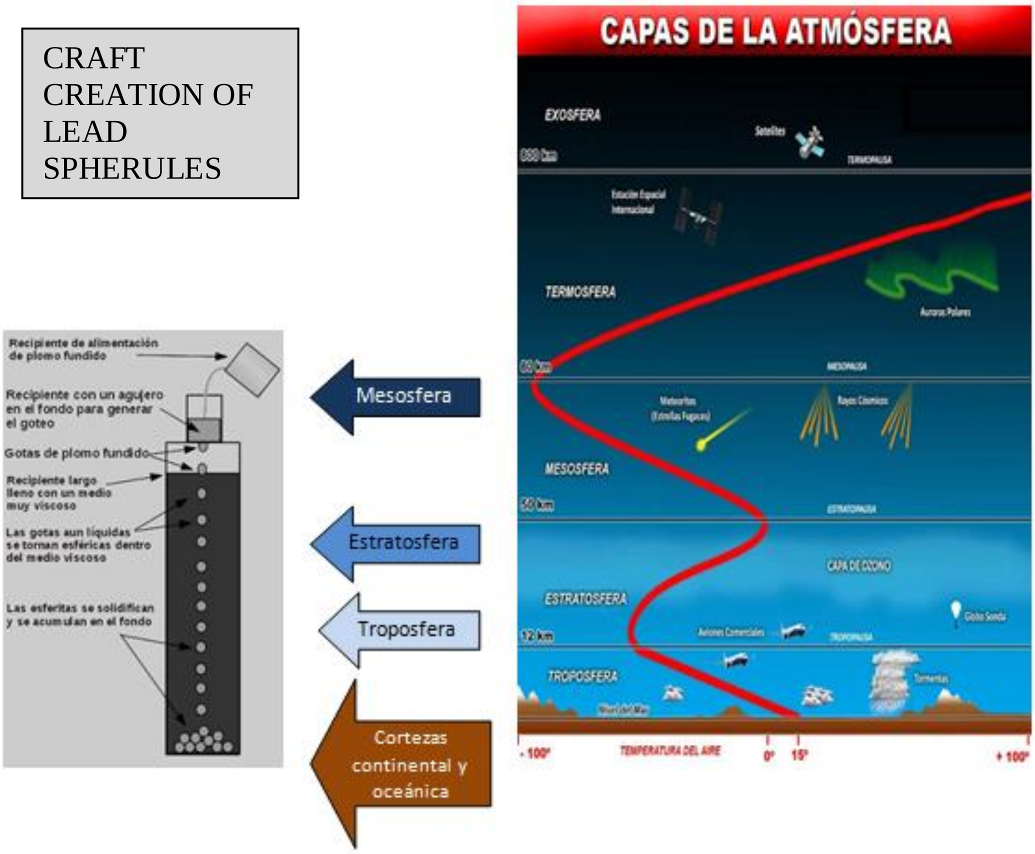
When a meteoroid enters our atmosphere, attracted by our gravitational field, it passes through it at incredible speeds. In many cases they can reach 60,000 km/h and when this happens, the body becomes incandescent, reaching temperatures of 2000º C, due to friction and pressure with our atmosphere. The body fragments and releases small particles that melt due to the high temperature. Subsequently, these particles cool, solidify and end up falling to the surface. In this process of melting and cooling the material acquires a typical crystalline structure and a rounded shape. The result is thousands and thousands of spherules of small size and enormous beauty that fall on our heads. A curious fact is that all of them have a size that is within a very narrow range, since all these micrometeorites have a diameter between 0.2 and 1.2 mm. Obviously those that meet certain qualities survive the fusion process.

In the world of physics, matter will always tend to rest in the way that consumes the least amount of energy. A minimum that is associated with an advantageous relationship between surface and volume. In other words, the shape it acquires is one that allows it to have the greatest volume of matter contained with the least possible surface area. As these molten meteoroids fall, their particles attract each other to establish a balance of forces close to zero until possible. As long as they do not have contact with any solid surface, they will tend to assume a spherical shape in this state due to surface tension. For all these reasons, the micrometeorites that can be located with the naked eye have spherical shapes.

Physical simulations: "Cosmic spherules of Pedro Ximenez"

The most appropriate experience to stage the process that leads the meteoroid to transform into spherules is the artisanal creation of lead shot.
This metal is easy to handle as it has a low melting temperature (just over 300ºC) and it can be melted in any steel container that can be put in a stove. It is recommended that this experience be done outdoors, due to the toxicity of the vapours that are given off throughout the process.

To carry out the simulation we have to build a column that acts as the atmosphere. First, we make a dripping container, which is nothing more than a steel can, like those used for preserved products, perforated at the base. The diameter of the hole should be of the order of 1 or 2 mm.
Next, we make the cooling column. We fill a 3-4 inch 75 cm PVC tube at 1m high with a very viscous substance, for example cane molasses has a fairly high cooling capacity. In this way, a sufficient travel time is achieved for the solidification of the ball within the medium.
Finally, the container is placed on the cooling column with the help of a metal support so that it is not necessary to manipulate it during the process, taking care that the bottom of the container is within the cooling medium.



LAYERS OF THE ATMOSPHERE

Image 3. Comparison of spherule recreation phases.[2].

[2] Meteors pass through the exosphere and thermosphere without much trouble because those layers don't have much air. Nevertheless, when they reach the mesosphere, there are enough gases to cause friction and create heat.

There is a second more suitable simulation to carry out with families. It is about recreating spherules Pedro Ximenez style.
To do this, we heat 75 ml of Pedro Ximenez in a saucepan and, before it comes to a boil, remove it from the heat and add 1 gram of agar-agar in the form of rain, thus preventing lumps from forming. We stir well with some rods and pass through a fine strainer. On the other hand, we will use very cold sunflower oil (freezer at least 30 minutes). We fill a container with that cold oil and proceed to solidify. With the help of a dropper or syringe, small amounts of Pedro Ximenez are dropped into the column. The contrast of temperature, quantity and initial physical state of Pedro Ximenez / Agar, cause small spheres (spherules) to form immediately. Now we just have to drain the spherules well into Pedro Ximenez before "using" them.

MESOSPHERE	STRASTOPHERE TROPOSPHERE	CONTINENTAL AND OCEANIC BARKS

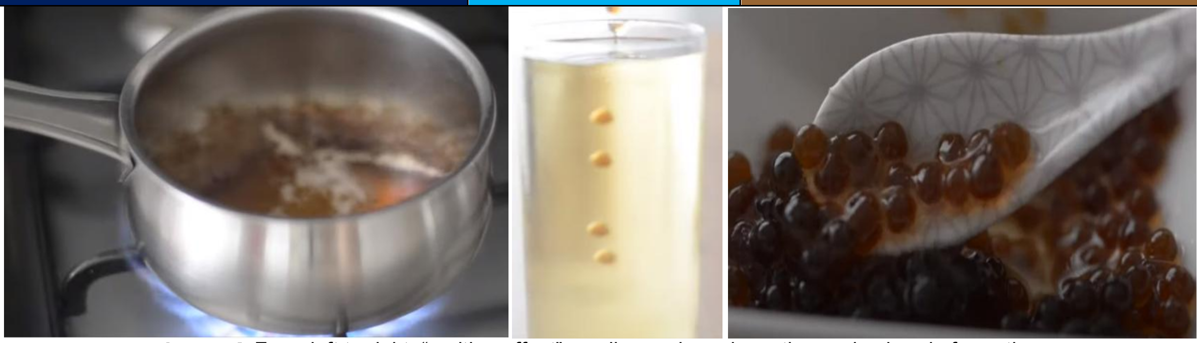


Image 4. From left to right, "melting effect", cooling and condensation and spherule formation.

And for the children, we did the simulations with chocolate shake[3].

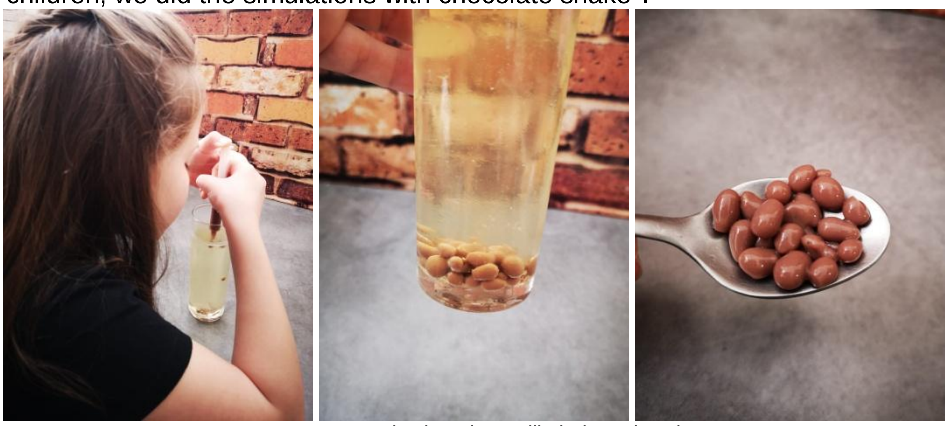


Image 5. Cosmic chocolate milkshake spherules.

5. Traditional search method

As we said in previous sections, spherical micrometeorites with a metallic composition can be identified with some ease using a magnet and observation under a microscope.

The Stardust Project is an international collaboration promoted by J.Larsen from Norway with the aim of collecting micrometeorites from rooftops in urban areas. The first results of such a search have recently been presented in an article by M.J. Genge (Imperial College, London), Larsen and two collaborators in Geology magazine. Although these authors now show that city roofs can serve as very useful micrometeorite collectors, this is not a new idea, since some groups of amateur astronomers have been promoting it for many years. In fact, as early as 1941 a study of numerous magnetic spherules collected in urban areas was published. However, Genge and colleagues argue that such particles were of artificial origin.

[3] We experimented with Cola-Cao but the spherules fell apart when drained, we thought they lacked sugar to help maintain the spherical shape. We also did it with orange juice.

In the first part of our sampling, we collected wind dust by taking samples of accumulated materials on roofs, at the outlet of downspouts and in their manholes.

Images 6. Collection of samples in manholes after a rainy day.

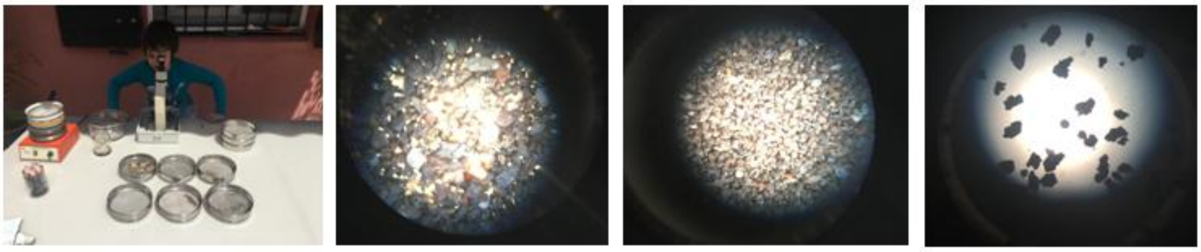
We must avoid sampling near urban areas and all types of facilities where coal is used as fuel (chimneys, thermal power plants, industries ...). When coal is burnt, the metallic minerals present in it can melt and generate small spherules similar to those of extraterrestrial origin, which are later transported as part of the smoke emitted in the combustion process.

Images 7. Collection of samples in roof gutters after a rainy day.

To collect the samples, it is recommended to use a jar with a metal lid. The treatment of the samples begins by placing a magnet (we used a neodymium one) on the lid of the jar, so in addition to cleaning the samples, we select the ferromagnetic material. Later we heat everything that the magnet has attracted and dry it in a stove to release all the moisture. Finally, we will carry out a sieve with the help of a sieve with which the samples will be categorized by size.

Image 8. Selection, drying and screening process.

Once classified, the materials are observed under a microscope. We place the chosen sample on a slide with the help of a fine awl or a pin mounted on a handle. If the particle has the characteristics indicated above, it is very likely that we are observing a sample of interplanetary dust.



Images 9. Recognition process.

6. Field study: Palmones River, Guadacorte Lake and La Alcaidesa Beach

But perhaps at these ages the most interesting way of working is the collection of samples through “magnet fishing”. We locate places where water currents flow, possible river tunnels, small meanders, lakes ... and we cast the magnet as a hook. The collected material is kept in a jar for later treatment and observation under a microscope.

Images 10. Collection of samples from the Palmones River (Cádiz).

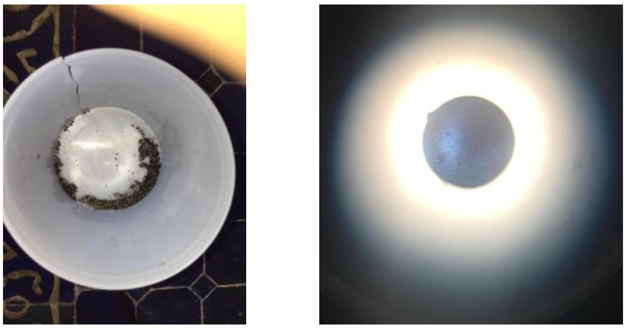
Images 11. Collection of samples from the mouth of the stream in La Alcaidesa (Cádiz).

Images 12. Collection of samples from Lake Guadacorte - Los Barrios (Cádiz).

The subsequent procedure is the same.

Images 13. Drying, sieving and recognition.

The results we have obtained, when we carry out the samplings in open spaces, are more spectacular than those obtained when collecting materials from roofs and manholes.



Images 14. Cosmic spherules.

But we could also observe that there was a lot of metal waste that we had to discard.

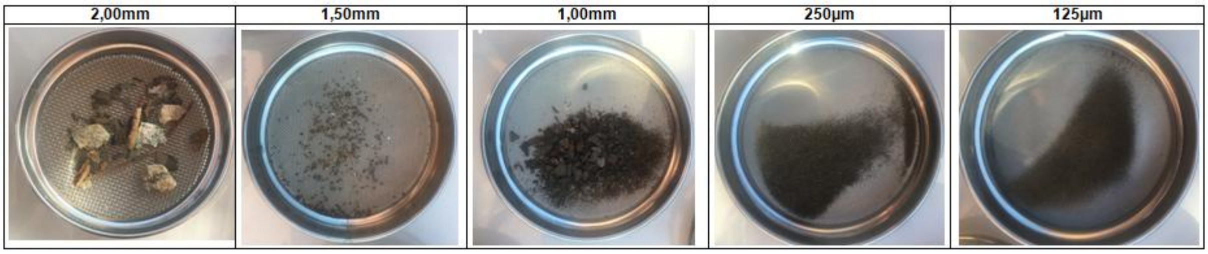


Image 15. Classification of metallic waste by size[4] in a single collection.

Conclusions

The study of micrometeorites, their origin, location and identification is a subject that offers infinite didactic possibilities. This gives us a greater didactic contribution than the ones we initially established (figure 1).

Through the scientific method, children have the possibility of verifying that science is a whole, it is the sum of different knowledge, supporting each other in order to complement each other: The sum of the parts is greater than the whole.

It is also surprising to realize the amount of micrometeorites that can be found around us. In reality, we are constantly surrounded by them: they are in the air that we breathe, on the ground that we step on, and in the dust that we sweep into our homes. They fall on the order of one per square meter per day.

Secondary, but not least, the search in flooded areas has given us information on the contamination present in rivers, lakes and therefore in our environment. As we can see in image 15, a large amount of metal waste accumulates in natural channels as a result of human activity. Although we have not dealt with this part in this project, undoubtedly the effects on the river flora and fauna should not be very positive.

Therefore, we encourage not only teachers and students but also families involved in citizen science to begin or continue in the study of micrometeorites.

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Traditional way of searching for them

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Collection procedure. Sifting. Analysis.

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