Tracks of magnetic monopoles

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ABSTRACT. We review and discuss in some detail tracks recorded on X-ray films, following electric breakdowns in water, as initiated by L. Urustkoev et al. [1]. We suggest that they are the result of the production of light magnetic monopoles, theoretically predicted by G. Lochak [2].

1 Introduction

Almost fifteen years ago, L. Urustkoev et al. [1] published their findings about radiation emitted by high voltage pulse discharges in water, of the kind used in electroforming. Since then, many experiments have been performed, in several laboratories, using different devices, which led to similar results [3],[4].

The various properties of the emitted radiation, shown in these different experiments point towards the assumption that the associated particles carry a magnetic charge. The creation of such particles does not necessarily require high energy accelerators, as shown by the theory of leptonic magnetic monopoles due to G. Lochak who expressed this idea already in 1983 [2].

These monopoles (or associated secondary particles) leave characteristic tracks on several materials, such as X-ray or nuclear emulsions, metals [5] or silicium [6]. These tracks look very different from what is usually recorded in particle experiments ([1],[3]) and justify a closer analysis. In the following we want to give a detailed analysis of these tracks as registered on X-ray films in numerous experiments performed at the Ecole centrale de Nantes.

2 Experimental device

We briefly recall the principle of the apparatus, which has been described in detail elsewhere [4]. In a closed vessel (stainless steel or aluminum), the fusion of a titanium wire (0.3 g) initiates the discharge of a capacitor (360 μF, 4 kV) in a small chamber filled with water (22 cm^3), see figure 1. The duration of the electric pulse is around 70 μs for a peak current of 30-40 kA, the total energy dissipated amounts to 3 to 8 kJ.

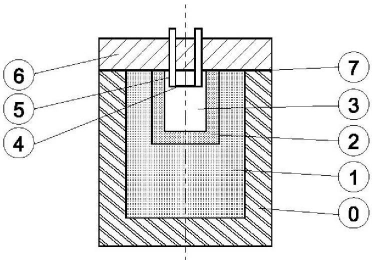

Fig. 1. (0) Containing vessel, (1) Insulating sheath made of polyurethane, (2) Removable container where the explosion of the wire takes place, (3) Active room filled with unmineralized water. (4) Wire connected to electrodes. (5) Insulated electrodes (6) Lid made of aluminum. (7) Leak proof gasket.

The films are exposed in two different ways. Firstly, they can be placed in the vicinity ($\approx$ 50cm) of the container, and thus exposed during a very short time, showing relatively few tracks. A second method (initiated by L. Urutskoev et al. [1]) consists in putting the content (water and powder resulting from the fusion of the wire) of the inside container (3) in a small glass cup (6cm diameter), placing the X-ray film on top of it (a few millimeters above the water surface) and waiting a score of hours; more tracks are recorded in that case. In some experiments an electric field (an idea of G. Lochak), perpendicular to the surface of the film is applied to the whole device by means of two copper plates (applied voltage $\approx$ 10V).

The film is then developed[1] in a standard developer, fixed, and observed with the help of different devices. The tracks obtained by both methods (instantaneous or delayed) share the same characteristics. In the following we shall comment mainly on tracks obtained by the second method.

[1]In some experiments the film was developed and fixed before being exposed. They give essentially the same results.

3 Low magnification observations

With an optical microscope at magnifications around 40 or 100 times, numerous point-like tracks (punctures in the emulsion as will be seen later) are always present on the films, as can be seen on figure 2. They are almost absent on films non exposed to the radiation.

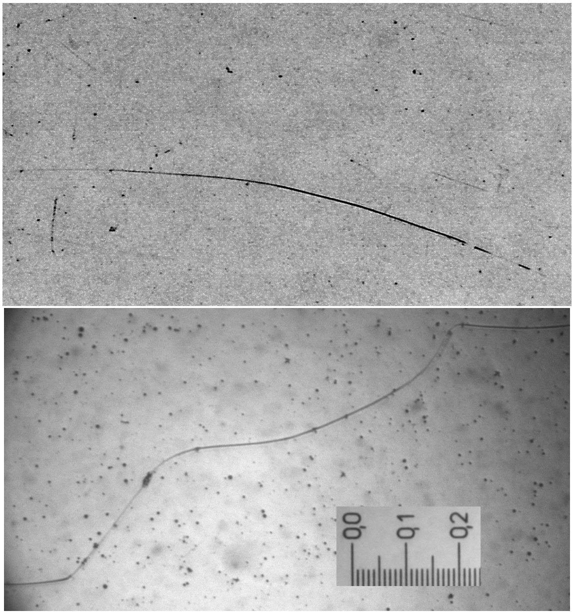

Fig. 2. above : 3200 dpi scan, picture 8.5 mm width ; below : track recorded in a North Pole expedition, scale in mm.

In addition, some tracks are lines in the film plane, very long for elementary particles, straight (or slightly curved) a few millimeters long most often, but sometimes very tortuous as above on figure 2.

They can also be very short and ring-like (see figure 3), a property which could be due to the applied electric field, as the force acting on a magnetic monopole reads in Gaussian units

$$\vec{F} = g(\vec{H} - \frac{\vec{v}}{c} \times \vec{E}) \tag{1}$$

where g is the monopole charge. Thus a magnetically charged particle moving perpendicularly to the electric field must turn in the same way as an electron rotates in a magnetic field. The radius of curvature depends of course on the energy and the mass of the particle, both unfortunately unknown in our experiments. Many circular tracks are present on our films.

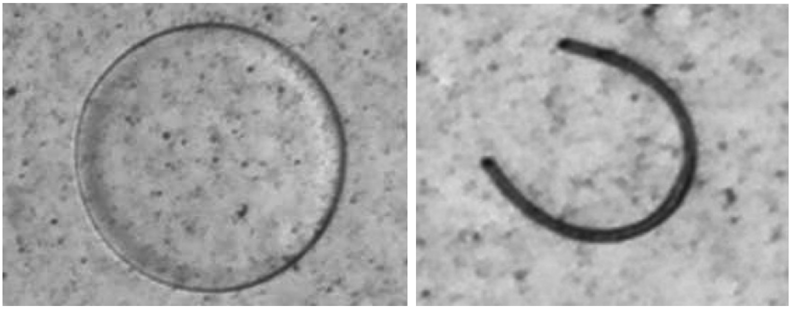

Fig. 3. left : diameter 0.2 mm ; right : width = 0.19 mm.

As the film has been developed in a liquid solution, one immediately thinks that these rings could be due to bubbles present before the drying process. But they have also been observed on metallic plates exposed close to electric discharges [5],[6] and this explanation seems unlikely.

These elongated tracks may also be discontinuous, as shown on figure 4 below :

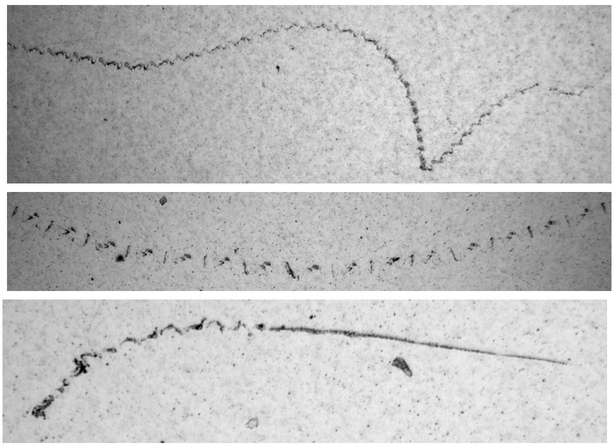

Fig. 4. Discontinuous tracks, length (mm) : above 2.4 , middle 2.6, below 1.5 mm.

This discontinuous character has been noted from the beginning by Urutskoev et al. [1] who called them "caterpillar" tracks, and has also been observed on solid Si-AL surfaces [6].

Sometimes the tracks show branching points (figure 5),

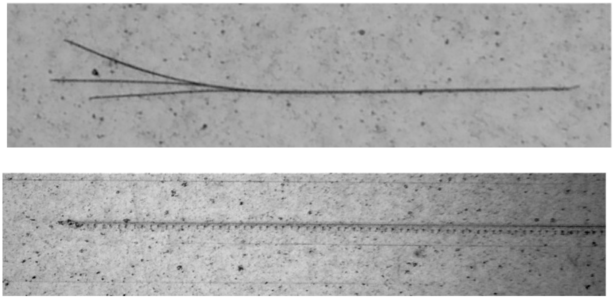

Fig. 5. Branching points (length : above 0.77mm, below 1.87mm).

sharp angular turns, or cusps as shown on figure 6.

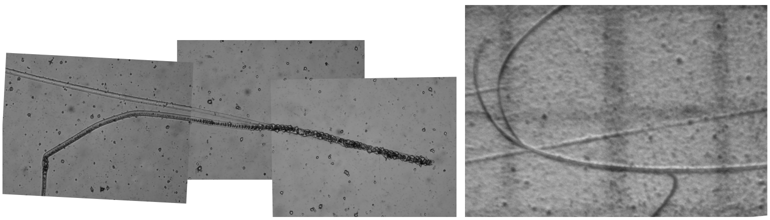

Fig. 6. Cusps and branching points.

Finally, the tracks are often double, as observed already by Urutskoev et al. [1], who considered this feature a characteristic of this novel radiation. One of the tracks has a much lower intensity as if it were a duplicate of the other, as shown on figure 7, or has the same origin (cf the lower track on figure 5).

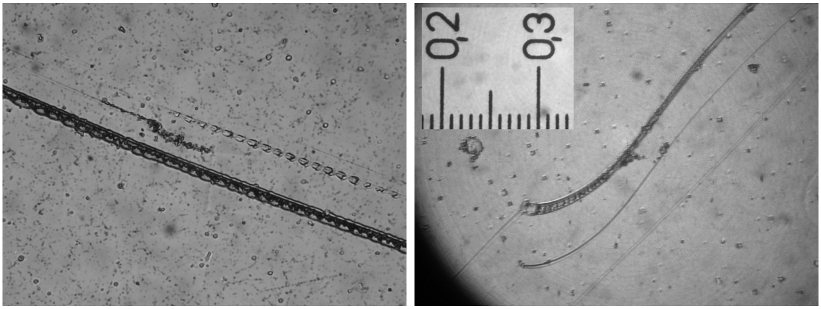

Fig. 7. Secondary tracks accompanying the main ones.

This latter feature is also a feature of (mechanical) scratches on the film surface, which are also present on our films (and sometimes difficult to distinguish from tracks), and have a similar appearance on these pictures taken with optical microscopes. This point is important, as it indicates that the tracks are not due to Ag grains as is usual with ionizing radiation, but are rather grooves dug in the film as will be seen in detail in the next section.

4 Detailed observation of the tracks

We have submitted some interesting tracks to a detailed investigation, by various means of observation. We have chosen the right end of the track on the top of figure 2. Images given by a confocal microscope are reproduced below (figure 8).

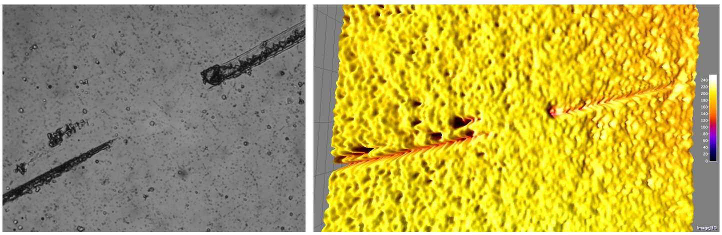

Fig. 8. The chosen track, left, with a standard optical microscope, right, surface view with a confocal microscope.

The confocal microscope gives a 3-dimensional image of the surface, with an estimate of the vertical depth of the track, as on figure 9.

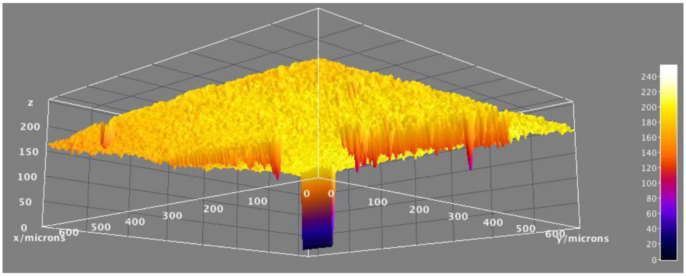

Fig. 9. The same track, surface viewed from below with a confocal microscope.

If we trust the reconstruction done by the confocal microscope, the order of magnitude of the depth is 40 micrometers ; the film is a Kodak Industrex MX125, which is composed of a substrate 180 μm thick, and two sensitive layers, each 18 μm thick. This means that the tracks reach (and even cut into) the much harder plastic substrate.

In order to check this information, we used a profilometer, which is based on a different principle. The representation of the same track is given below (figure 10)

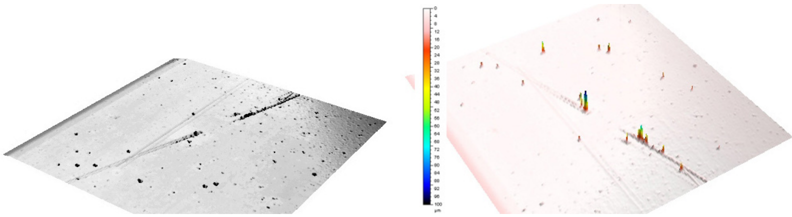

Fig. 10. Profilometer images of the film surface, same track as on figures 8,9 ; right, reversed image showing the underside of the film surface.

As the lateral resolution of this profilometer is 2 μm, it gives a rather accurate average depth information, confirming the confocal measurements, which were somewhat blurred by noise. This track consists in two deep (more than 50 μm) pits, seemingly at the origin of two (double) tracks starting in opposite directions, and confined to the sensitive layer of the film (less than 20 μm deep). One also sees other (also double) tracks, crossing the main one. With the two devices these tracks look like grooves, similar to scratches, but, in our opinion, impossible to confuse with scratches because they start in opposite directions.

As the next observations (figure 11) will show, this information is not always true, and the precise shape is rather a tunnel dug in the outer layer of the film.

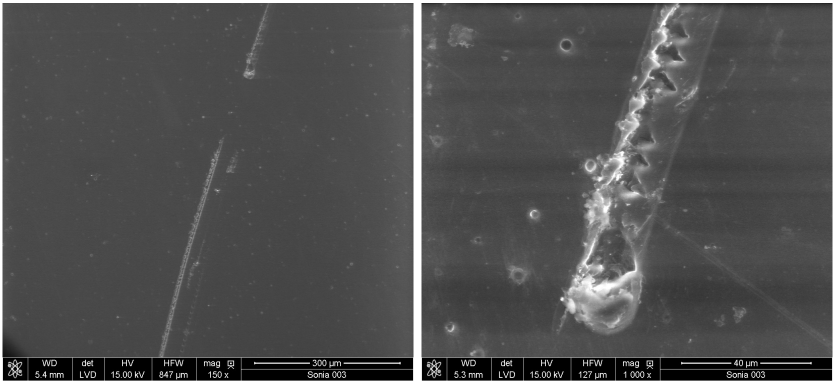

Fig. 11. SEM images of the film surface, same track as on figures 8,9 ; right, close-up showing the beginning of a track.

Other SEM images (figure 12) show clearly the complexity of the tracks, suggesting that different objects have traveled together, one under the surface (but above the substrate), the other above the film, leaving periodical imprints on the surface. This feature is also visible on figures 4,5. Similar tracks have also be observed on hard materials such as Al or Si by Adamenko S.V., Vysotskii V.I. [6].

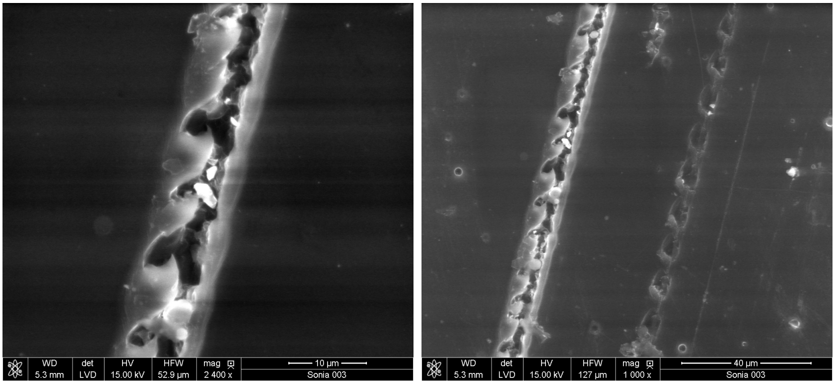

Fig. 12. SEM images of the film surface, same track as on figures 8,9 ; right, detail showing the main track and a secondary one.

A rather constant feature is the association of a impact (point-like track) with a line as seen above, and also clearly visible on the other example below (figure 13).

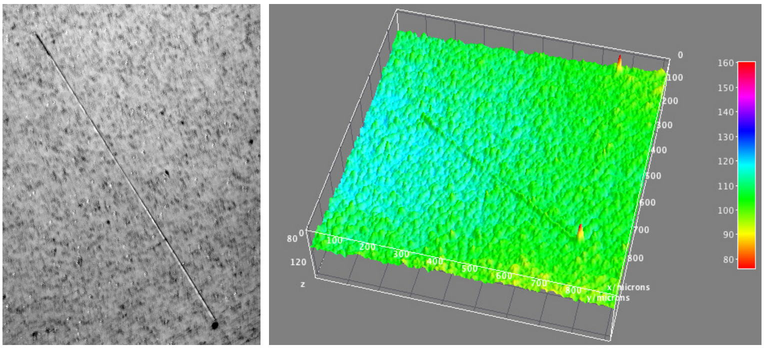

Fig. 13. Confocal images of the film surface, left, standard view, right, 3-D reconstruction of the underside.

5 Interpretation in terms of magnetic monopoles

We have unfortunately no definitive interpretation to offer for these tracks, just some remarks hinting towards possible explanations. A curvature of the track in a uniform fixed electric field seems the best indication of the presence of a magnetic charge.

5.1 Some properties of light magnetic monopoles

First of all, these tracks are always produced in association with an electric breakdown implying the production of an intense magnetic field. Several experiments performed by Urustkoev et al. [1] and Ivoilov [7] have shown that in this case magnetically charged particles appear, which are in agreement with the light magnetic monopoles whose equations have been found already in 1984 by G. Lochak [2]. In their simplest form they obey quantum dynamics equations corresponding to magnetically charged neutrinos with no mass. A second family of equations has also been given by G. Lochak [2], which contains a mass term.

The detailed properties of the interaction of these monopoles with matter is at present largely unknown, as well as their energy, but a few remarks can be made.

These magnetic monopoles possess states in electric fields, implying that the elementary magnetic charge satisfy the Dirac relation, $g = n\frac{\hbar c}{e}$ where e is the electron charge and n is an integer or half-integer [2]. But this has also the consequence that monopoles seem to be able to be trapped inside matter, creating heavy magnetically charged composite particles, or modifying the magnetic properties of crystals.

An analogous effect has been observed by Ivoilov N.G., Urutskoev L.I. [7], when they measured the Mössbauer spectrum of Fe57 in foils exposed to the radiation produced by electric breakdowns as mentioned above.

A second observation has been made twice in the experiments performed in Nantes. These rather exceptional (two out of a hundred) events are very suggestive. As we have said, the remains of the wire, a metallic powder dispersed in water, is placed in a shallow glass dish 10 cm in diameter (figure 14). Part of the metallic powder is composed of spongy particles which float on the surface ; as they contain some iron, they follow a magnet being moved near the surface, with a velocity not exceeding a few mm/s.

Fig. 14. The glass dish containing the remains of the titanium wire.

A completely different behavior has been observed twice. As the magnet was approaching, one of these particles (size $\approx$ 0.1 mm) crossed the dish so quickly that the magnet did not have time to be moved during that fraction of a second. Its estimated velocity was about 10 cm/s, i.e. a hundred times the usual velocity. The only explanation in accord with the laws of electromagnetism and fluid mechanics seems to be the presence of a magnetic charge on the particle (magnetic dipoles can not behave in this way).

5.2 Particle-like behavior

From equation (1) one easily deduces that a massless monopole accelerated in a constant magnetic field H on a length L, gains the energy

$$W = gHL \tag{2}$$

and that the radius R of its trajectory in a plane perpendicular to the electric field E is

$$R = W/gE \tag{3}$$

Firstly, it can be noted that the exposition of the films on top of the dish containing the remains of the discharge, suggests that the particles emitted are escaping the matter where they were stored, and, as there is no sign of any nuclear reaction, must possess only a low energy.

Many of the elongated tracks are curved, and this can be ascribed to the electric field which is applied perpendicularly to the film, as said before. As the electric field is approximately $E = 500\,\mathrm{V/m} \approx 17\,10^{-3}$ in Gaussian units, the radius on figure 3, 0.2 mm, and the elementary magnetic charge $g = 137e/2 = 3.3\,10^{-8}$ in Gaussian units, the energy should be $W = gER \approx 8$ eV. Even for the tracks shown on figures 4 or 6 this energy is less than 100 eV.

If we compare with similar tracks left by alpha-particles on films, for instance, the energy necessary to carve the grooves shown on figures 11 or 12 should be in the MeV range. Furthermore the curvature changes sign on some tracks (figures 4, 6). Thus it seems difficult to explain how the tracks are produced, even if we believe that they are associated with magnetic monopoles. Possible explanations have been given, but they imply local nuclear reactions [6], or even more exotic phenomena like small ball lightnings [8], and in our opinion the question remains open.

5.3 Wave-like behavior and chirality

If the observed monopoles are the massless "magnetically excited" neutrinos of G. Lochak, they are described by a spinorial equation which differs from Dirac's by its $e^{i\gamma_5}\psi$ gauge instead of Dirac's one $e^{i\varphi}\psi$. This equation has been split by G. Lochak [2] into two separate uncoupled equations by means of Weyl's transformation and give rise to two spinors, right- and left-handed. The question could be raised of a possible link between this feature and the double tracks observed very often.

This chirality is also suggested by the shape of the dots in dotted lines like those on figures 6, 7 or 15 below where the tracks look like imprints of screws on the film.

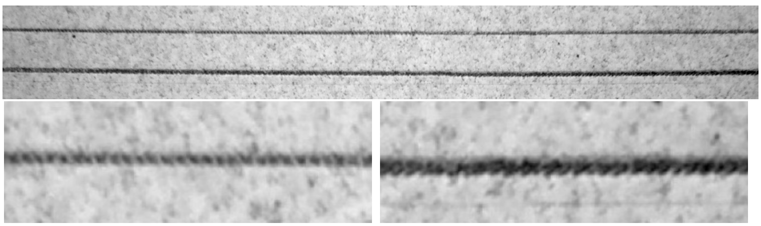

Fig. 15. Double track and two enlargements, one of the upper track, one of the lower one, looking like left and right spirals.

A second characteristic of the tracks is their spatial periodicity, as seen on most of the pictures shown above. This could be due to some relaxation phenomenon appearing in the interaction of the particle (whatever it could be) and the emulsion.

6 Conclusion

The results given in this paper are certainly incomplete, tentative and able to be much improved. But these tracks have been observed so many times in different laboratories and show enough original features to justify this detailed presentation, even if we have no precise explanation for their appearance. A few remarks can still be done.

It must be stressed that the elongated tracks are rare events, when compared with the numerous punctures appearing on the films, which we consider as primary impacts of monopoles. This is particularly clear on figures 8-11 where a pair of monopoles (or was it some cosmic ray ?) hit the film and gave birth to two double elongated tracks presenting all the characteristics commented above. Figure 13 above shows another case of this association of a puncture and an elongated track.

This raises the question of the nature of the particles travelling in the emulsion layer of the film. Are they also monopoles or some other secondary chunk of matter torn by the impact ? The calculations done in paragraph 5 assume that they are monopoles but this is not necessarily true.

We must also mention that we have analyzed above "regular" tracks, which are smooth lines. But we have also recorded very irregular tracks, presenting many sharp turns, almost like some Brownian motion. An example is given below.

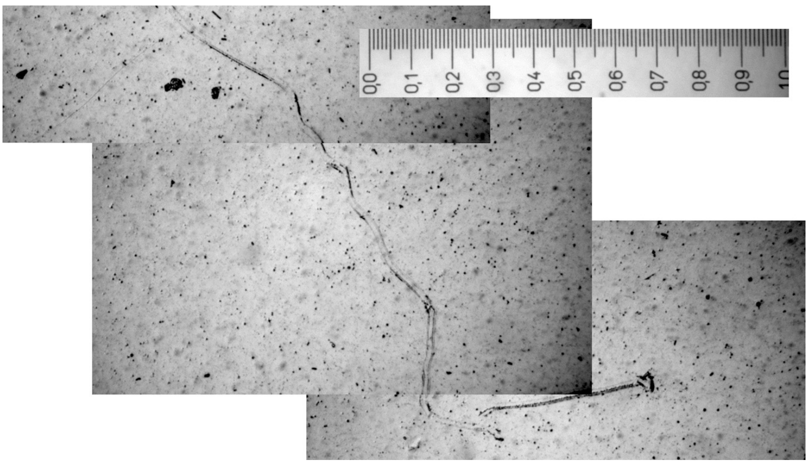

Fig. 16. Part of a long (1cm) and irregular track ; scale in mm .

One obvious explanation is that the energy of the particle is lower, but then why is the track so long ?

Acknowledgements

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We are also deeply indebted to Sonia Fargue (UCL, London) for the confocal observations, the first to show convincingly the groove character of the tracks.

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