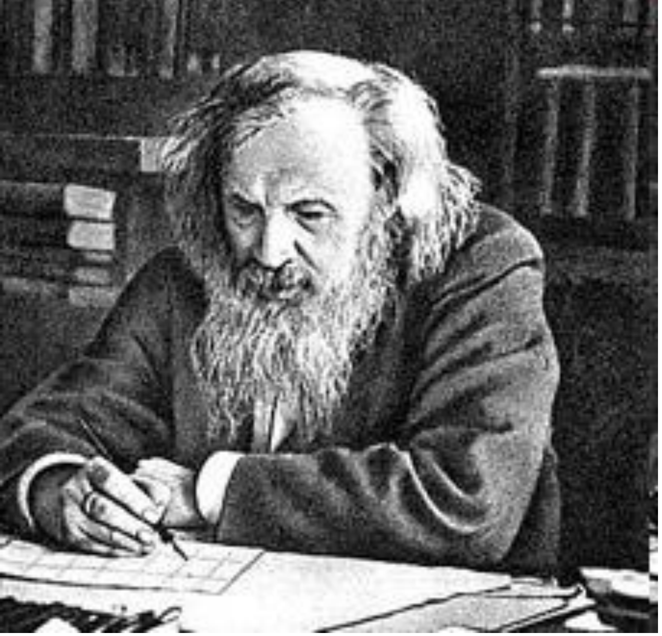
Image recognitions during automated scanning as method for investigations of the tracks of galactic cosmic ray nuclei in olivines from meteorites

N.G.Polukhina

OLIMPIYA

(the Russian acronym of **OLI**viny iz **M**eteoritov – **P**oisk tyazholykh **I** sverkhtyazholykh **YA**der / Olivines from meteorites: Search for heavy and superheavy nuclei)



1869 - Periodic system of D.I. Mendeleev

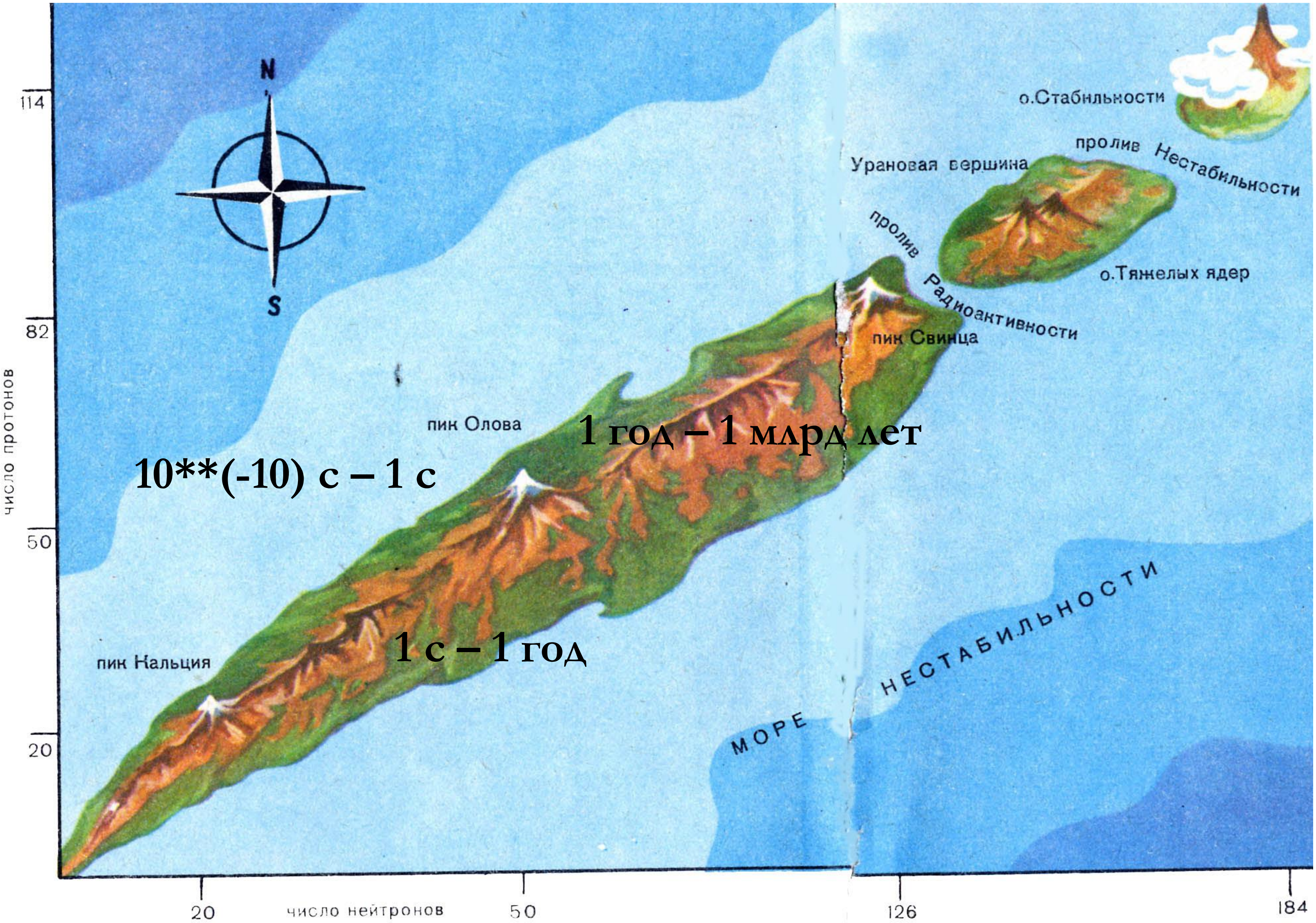
1875 - gallium
1879 - scandium
1886 – germanium

The greater the charge of the nucleus, the stronger the attraction of the internal electrons, the first calculations - the nuclei with A <170-180

However, the development of physics has shown that the table boundary is determined not by the instability of the electron shell of an atom, but by the instability of the nucleus.

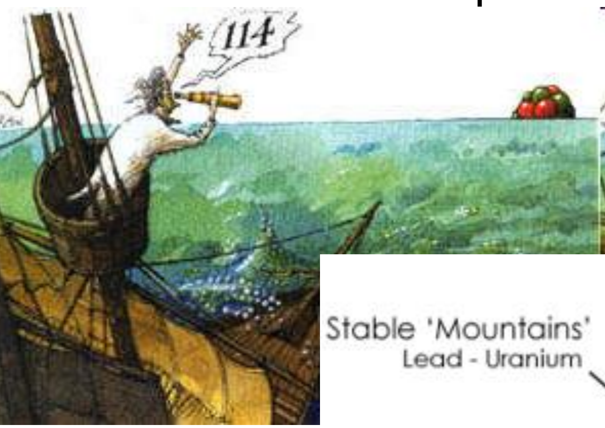
Very stable isotopes with an even number of p and n.

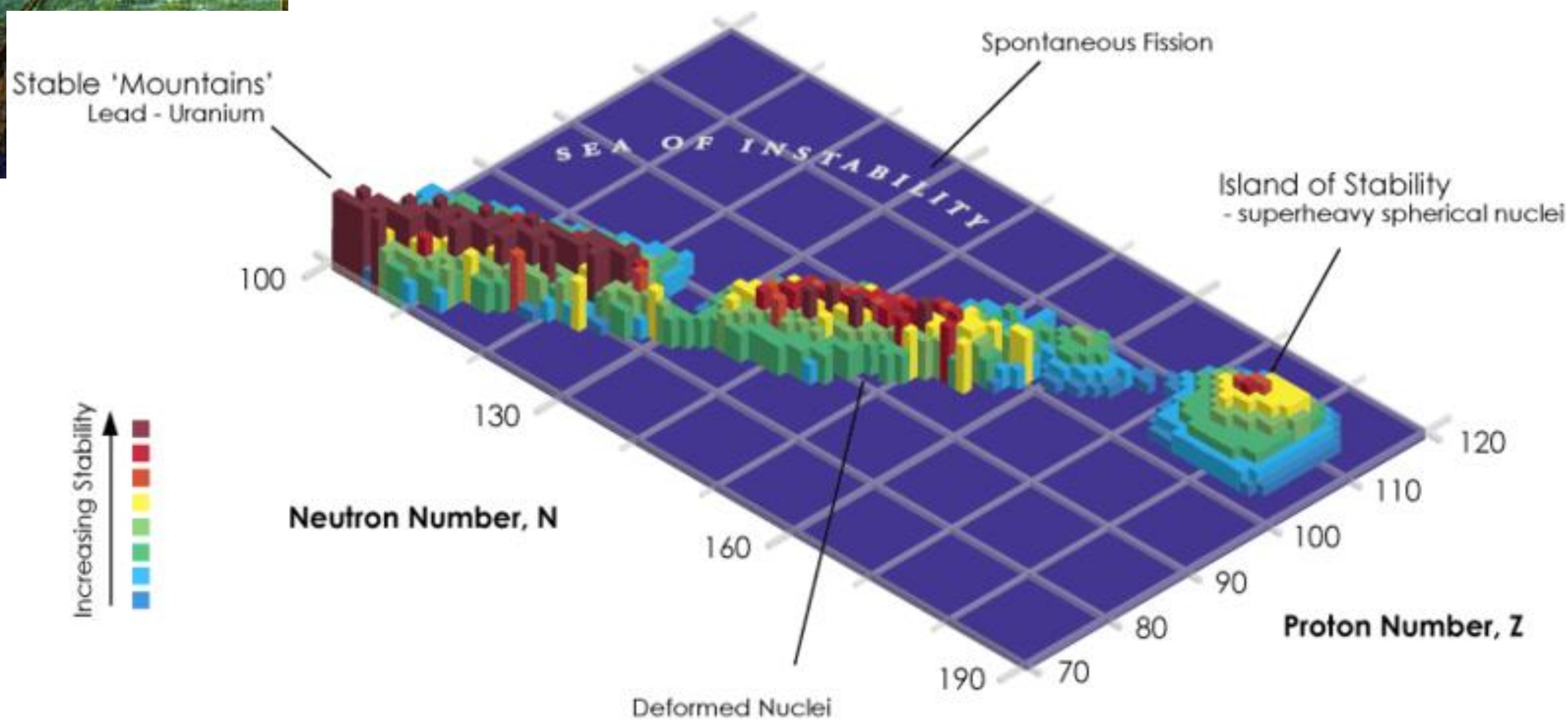
The most stable are nuclei containing the magic number of neutrons or protons (2, 8, 20, 50, 82, 126) - neutron and proton shells (calcium, tin, lead) are completely built up.


N
S
114
82
50
20
число протонов
о.Стабнльности
пролив Нестабильности
Урановая вершина
пролив Радиоактивности
о.Тяжелых ядер
пик Свинца
пик Олова
1 год – 1 млрд лет
10**(-10) с – 1 с
1 с – 1 год
пик Кальция
МОРЕ НЕСТАБИЛЬНОСТИ
20
число нейтронов
50
126
184

Superheavy elements were synthesized by neutron synthesis (reactor method; one neutron was added, the nucleus is supersaturated with neutrons, beta decay occurred, a proton was formed and the nuclear charge increased by one).
The possibilities of this method of artificial synthesis ended on a fermii (99 elements of Einstein-253 and 100 elements of Fermi-255).

In this way, transfermium elements are synthesized during supernova explosions or in the bowels of pulsars.





In 1869 г. – 63 elements, 2019- 118

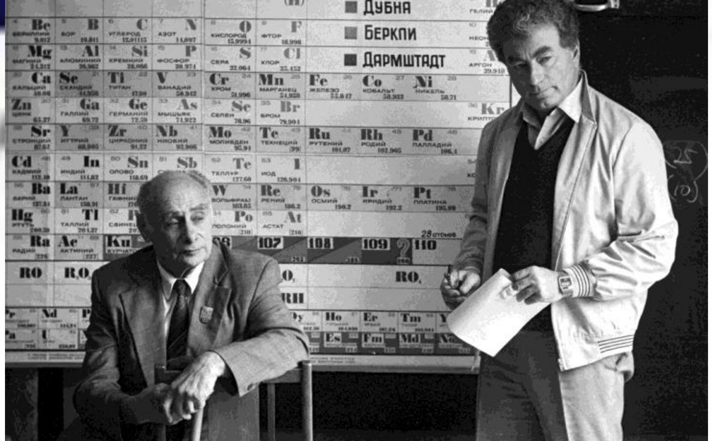
The most used artificial element is Pu-239.

The production of synthetic elements in the world has grown from billions of grams to many kilograms and even tons.

ПЕРИОДИЧЕСКАЯ СИСТЕМА ЭЛЕМЕНТОВ Д. И. МЕНДЕЛЕЕВА

ПЕРИОДЫ	РЯДЫ	ГРУППЫ ЭЛЕМЕНТОВ: A I B	A II B	A III B	A IV B	A V B	A VI B	A VII B	B VIII	A
1	1	H 1 1,01 ВОДОРОД						(H)	МЕНДЕЛЕЕВ Дмитрий Иванович (08.02.1834–02.02.1907) Русский ученый-энциклопедист. В 1869-1871 гг. изложил основы учения о периодичности, открыл периодический закон и разработал периодическую систему химических элементов. На основе системы впервые предсказал (1870) существование и свойства нескольких ещё не открытых элементов.	He 2 4,00 ГЕЛИЙ
2	2	Li 3 6,94 ЛИТИЙ	Be 4 9,01 БЕРИЛЛИЙ	B 5 10,81 БОР	C 6 12,01 УГЛЕРОД	N 7 14,01 АЗОТ	O 8 16,00 КИСЛОРОД	F 9 19,00 ФТОР		Ne 10 20,18 НЕОН
3	3	Na 11 22,99 НАТРИЙ	Mg 12 24,31 МАГНИЙ	Al 13 26,98 АЛЮМИНИЙ	Si 14 28,09 КРЕМНИЙ	P 15 30,97 ФОСФОР	S 16 32,06 СЕРА	Cl 17 35,45 ХЛОР		Ar 18 39,95 АРГОН
4	4	K 19 39,10 КАЛИЙ	Ca 20 40,08 КАЛЬЦИЙ	21 44,96 Sc СКАНДИЙ	22 47,90 Ti ТИТАН	23 50,94 V ВАНАДИЙ	24 52,00 Cr ХРОМ	25 54,94 Mn МАРГАНЕЦ	26 55,85 Fe ЖЕЛЕЗО; 27 58,93 Co КОБАЛЬТ; 28 58,69 NI НИКЕЛЬ	
	5	29 63,55 Cu МЕДЬ	30 65,39 Zn ЦИНК	Ga 31 69,72 ГАЛЛИЙ	Ge 32 72,59 ГЕРМАНИЙ	As 33 74,92 МЫШЬЯК	Se 34 78,96 СЕЛЕН	Br 35 79,90 БРОМ		Kr 36 83,80 КРИПТОН
5	6	Rb 37 85,47 РУБИДИЙ	Sr 38 87,62 СТРОНЦИЙ	39 88,91 Y ИТТРИЙ	40 91,22 Zr ЦИРКОНИЙ	41 92,91 Nb НИОБИЙ	42 95,96 Mo МОЛИБДЕН	43 97,91 Tc ТЕХНЕЦИЙ	44 101,07 Ru РУТЕНИЙ; 45 102,91 Rh РОДИЙ; 46 106,42 Pd ПАЛЛАДИЙ	
	7	47 107,87 Ag СЕРЕБРО	48 112,41 Cd КАДМИЙ	In 49 114,82 ИНДИЙ	Sn 50 118,71 ОЛОВО	Sb 51 121,76 СУРЬМА	Te 52 127,60 ТЕЛЛУР	I 53 126,90 ЙОД		Xe 54 131,30 КСЕНОН
6	8	Cs 55 132,91 ЦЕЗИЙ	Ba 56 137,33 БАРИЙ	57 138,91 La* ЛАНТАН	72 178,49 Hf ГАФНИЙ	73 180,95 Ta ТАНТАЛ	74 183,84 W ВОЛЬФРАМ	75 186,21 Re РЕНИЙ	76 190,2 Os ОСМИЙ; 77 192,22 Ir ИРИДИЙ; 78 195,08 Pt ПЛАТИНА	
	9	79 196,97 Au ЗОЛОТО	80 200,59 Hg РТУТЬ	Tl 81 204,38 ТАЛЛИЙ	Pb 82 207,20 СВИНЕЦ	Bi 83 208,98 ВИСМУТ	Po 84 [209] ПОЛОНИЙ	At 85 [210] АСТАТ		Rn 86 [222] РАДОН
7	10	Fr 87 [223] ФРАНЦИЙ	Ra 88 [226] РАДИЙ	89 [227] Ac** АКТИНИЙ	104 [261] Rf РЕЗЕРФОРДИЙ	105 [262] Db ДУБНИЙ	106 [263] Sg СИБОРГИЙ	107 [262] Bh БОРИЙ	108 [265] Hs ХАССИЙ; 109 [266] Mt МЕЙТНЕРИЙ; 110 [271] Ds ДАРМШТАДТИЙ	
	11	111 [272] Rg РЕНТГЕНИЙ	112 [285] Cn КОПЕРНИЦИЙ	Nh 113 [284] НИХОНИЙ	Fl 114 [289] ФЛЕРОВИЙ	Mc 115 [288] МОСКОВИЙ	Lv 116 [292] ЛИВЕРМОРИЙ	Ts 117 [294] ТЕННЕССИН		Og 118 [294] ОГАНЕСОН
ВЫСШИЕ ОКСИДЫ		R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4	
ЛЕТУЧИЕ ВОДОРОДНЫЕ СОЕДИНЕНИЯ					RH_4	RH_3	H_2R	HR		

Ce 58 | Pr 59 | Nd 60 | Pm 61 | Sm 62 | Eu 63 | Gd 64 | Tb 65 | Dy 66 | Ho 67 | Er 68 | Tm 69 | Yb 70 | Lu 71



G.N.Flerov:

102, 103, 104, 105 (dubnii), 106

Yu.Ts.Oganessian:

112, 113, 114 (flerovii), 115, 116 (livermorii), 117, 118.

115 – Moskovii, 118 – Oganesson

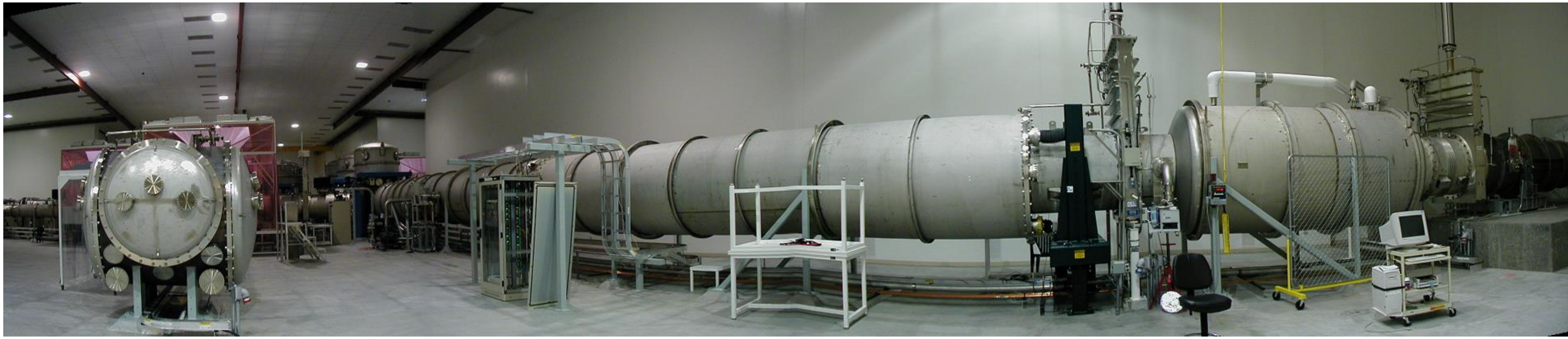
In astrophysical processes, in a medium with a high density of free neutrons, heavy nuclei are known to be formed due to two types of neutron capture reactions:

1. s-process (s-slow), when the atomic nucleus manages to experience beta decay before it captures a neutron.

2. r-process (r-rapid) - nucleosynthesis that occurs near the border of neutron stability, when the rate of neutron capture by nuclei is much higher than the rate of beta decay.

It is now generally accepted that many nuclei are heavier than iron, including all nuclei heavier than ^{209}Bi, are formed in the r-process by quickly sequentially capturing a large number of neutrons.

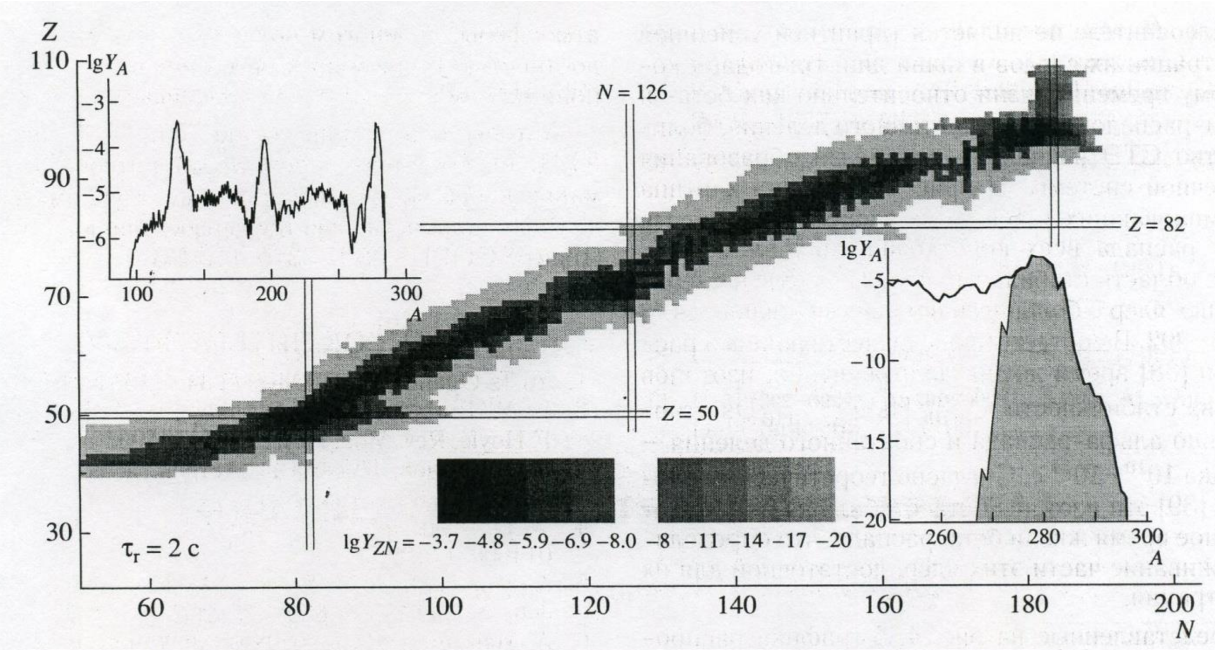
Although neutron star mergers (manifesting itself as macronova or kilonova) occur by a factor of 100 to 1000 rarer than regular core-collapse supernovae, they could potentially be the dominant mode of r-process production of the heavy elements, the prevalence of which is often left unexplained by models of supernova processes.



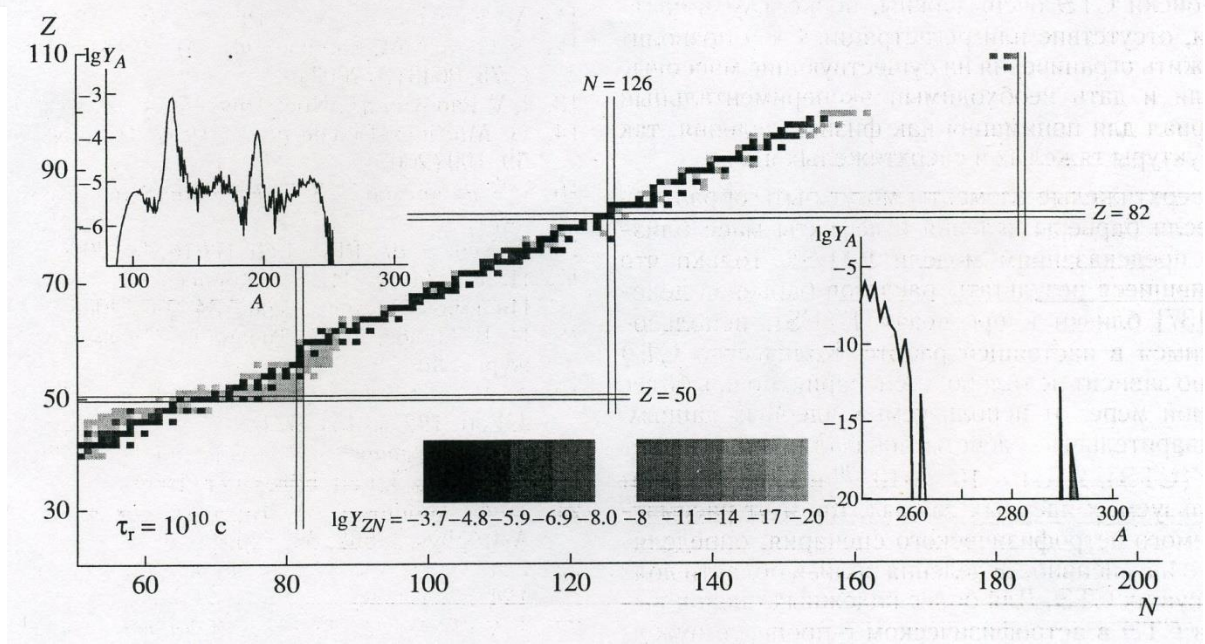
Synthesis of superheavy elements in kilonovae is confirmed by recent data on the electromagnetic spectrum of the event GW170817. These observations became available through the discovery of gravitational waves from inspiralling neutron stars in the LIGO–Virgo experiments, confirming and significantly improving the sky localization of this event.

The theory predicts that the element Z = 110, A = 294 should live for more than 100 million years. However, if you change the number of neutrons or protons by 2-3 units (only 1%), then the lifetime of an element will decrease by 10 million times.
The same example of Pb-208 (Z = 82, N = 126), no one observed its decay. Pb with 127 neutrons decays in 3.3 hours.

The results of the calculation



In fig. - the prevalence of elements at the time of the highest neutron flux density. It can be seen that the region of prevalence also covers superheavy elements with Z≈110.



After the neutron density decreases below 10^{19} cm^{-3}, when the β- and α-decay rate exceeds the neutron capture process, many radioactive nuclei decay and after 10^{10} c a narrow band of stable nuclei remains, including in the region Z = 110

The results obtained using multilayer plastic track detectors (PTD) showed the promise of their use in studying the charge composition of the GCR nuclear component up to (Th, U) group elements. In order to register several nuclei of a (Th, U) GCR group, an assembly consisting of many dozen PTD plates with an area of about 0.25 m2 each should be irradiated in open space (300-400 km above the Earth's surface) on the satellite for several years.

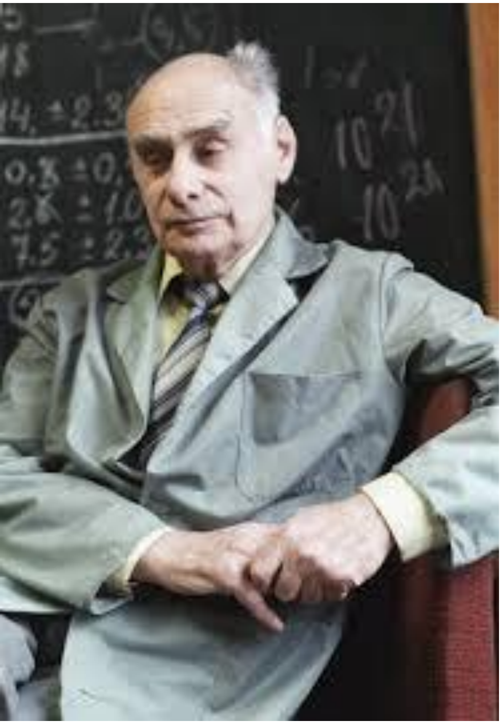
For example, a track detector located on the Skylab space station included 36 cameras, each of which consisted of 32 layers of the Lexan PTD, was exhibited at an altitude of 430 km for 253 days. Identification of the charge of the nuclei forming the tracks was carried out according to the magnitude of the rate of their etching in plastic.

PTD assemblies, also made up of lexan plates, with lead plates located between them (UHCRE — Ultra Heavy Cosmic Ray Experiment experiment) were exposed at an altitude of 450 km for 69 months on the LDEF space station. In total, about 2500 tracks related to nuclei with Z> 65 were recorded in this experiment.

The TREK experiment was conducted on the Mir space station at an altitude of 450 km and lasted more than 40 months. The detector included 150 stacks, each of which consisted of 16 sheets of barium phosphate glass (BP-1). After etching, several hundreds of tracks belonging to heavy nuclei with Z> 70 were found.

In the field of nuclei with Z> 86, there are only a few dozen events and very uncertain data on their energy distribution, due to small fluxes ~ **1-2 nucl./m²/year**

Conclusion: very large area detectors and long exposures are required.



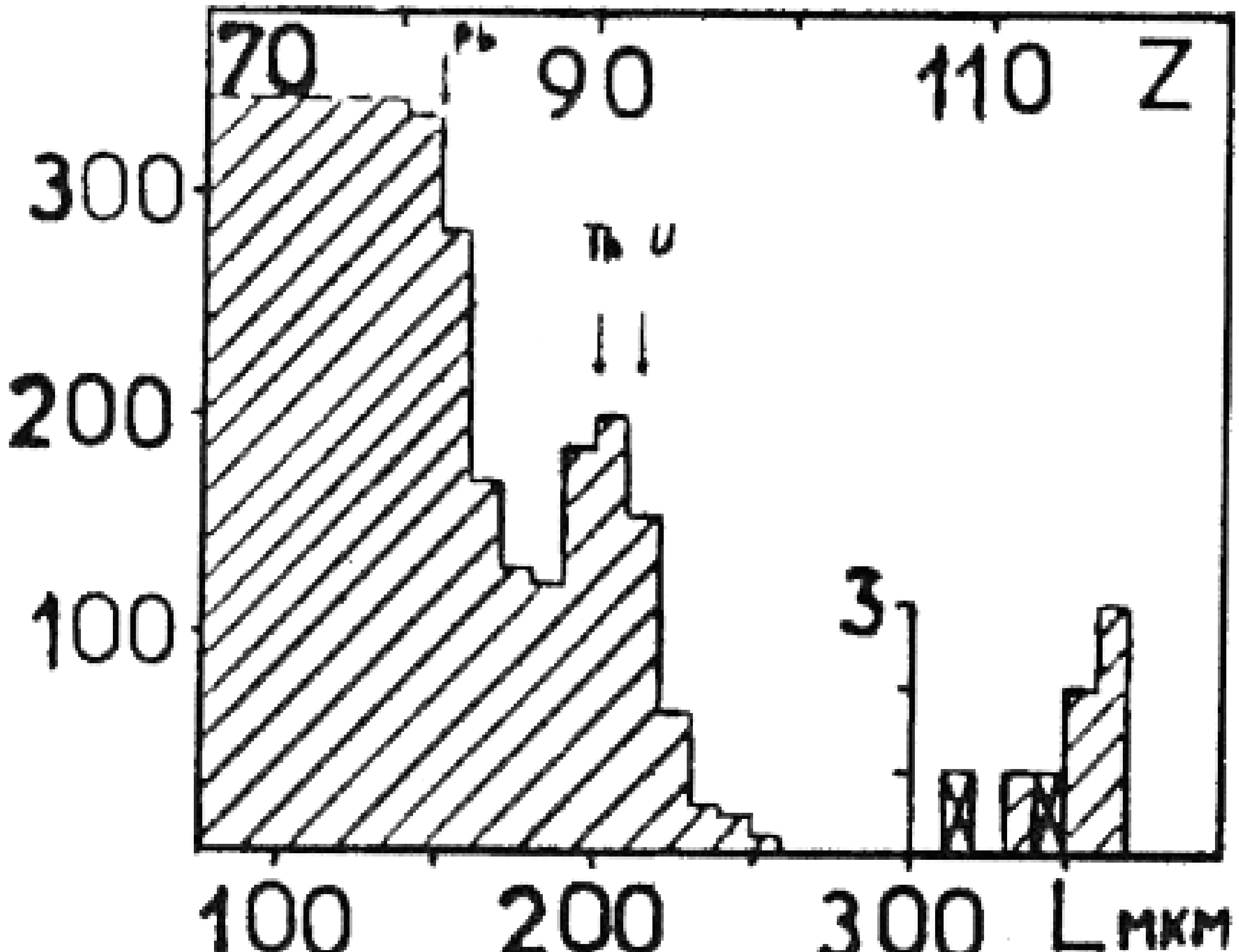
G.N. Flerov: when the meteorite is millions hundreds years old, a studing of 1 cubic cm is equivalent to conducting an experiment with 1-2 tons of photo emulsion in space for 1 year.

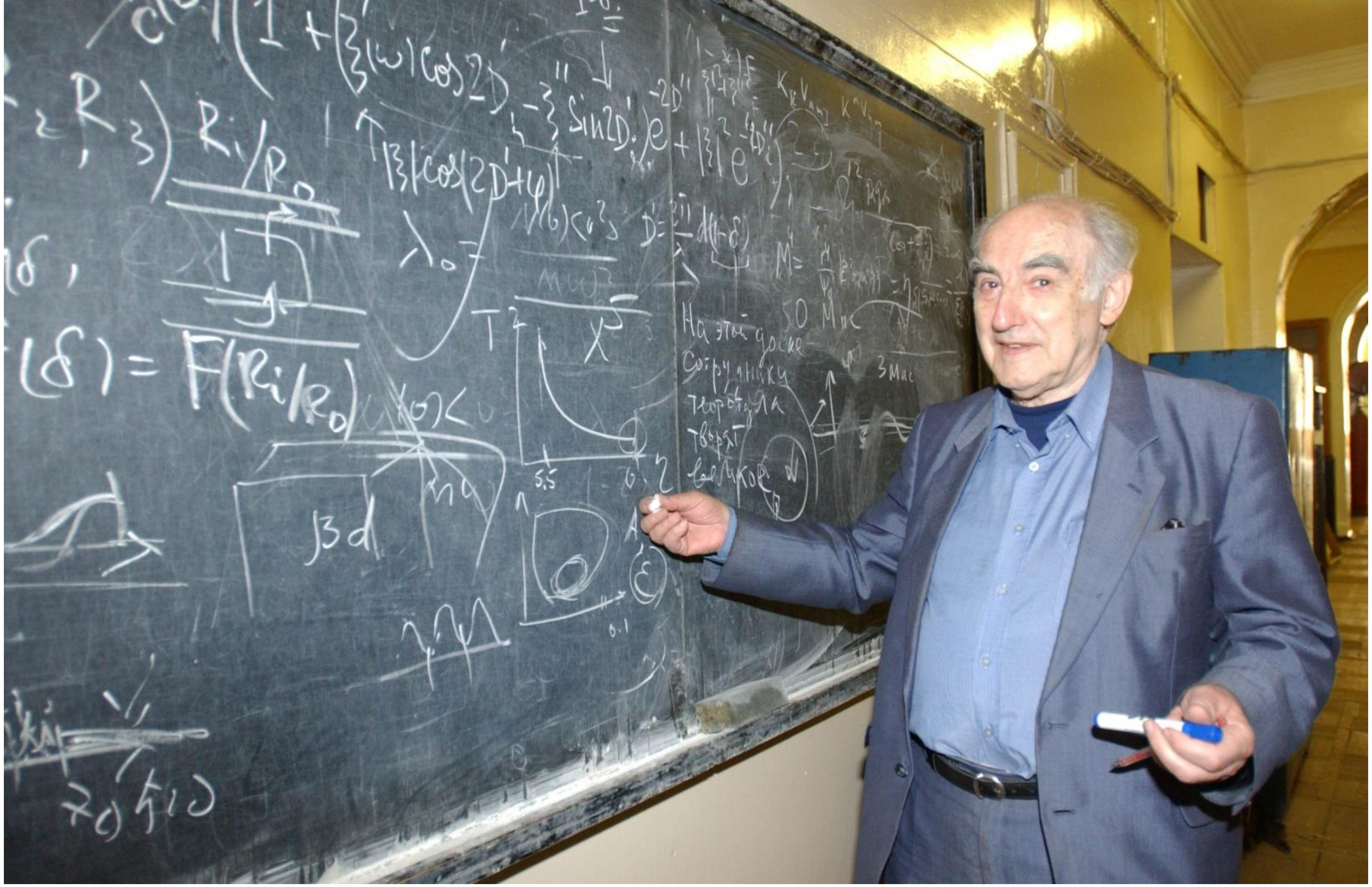
For the first time, heavy nuclei (Z ~ 26) were found in meteorites in 1964 (Maurette et al.).

Heavier nuclei in 1967 (Fleischer et al.)

The cores of the group of thorium and uranium - 1980 (Perelygin and others.)

V.P. Perelygin, S.G. Stetsenko, G.N. Flerov; 1985.





VL Ginzburg considered the problem of searching for superheavy nuclei in nature and the possibility of the existence of the "island of stability" one of the most important for physics of the 21st century.

VL has included it in his famous list of priorities.

Doklady Physics, Vol. 50, No. 6, 2005, pp. 283–285. Translated from Doklady Akademii Nauk, Vol. 402, No. 4, 2005, pp. 472–474.

PHYSICS

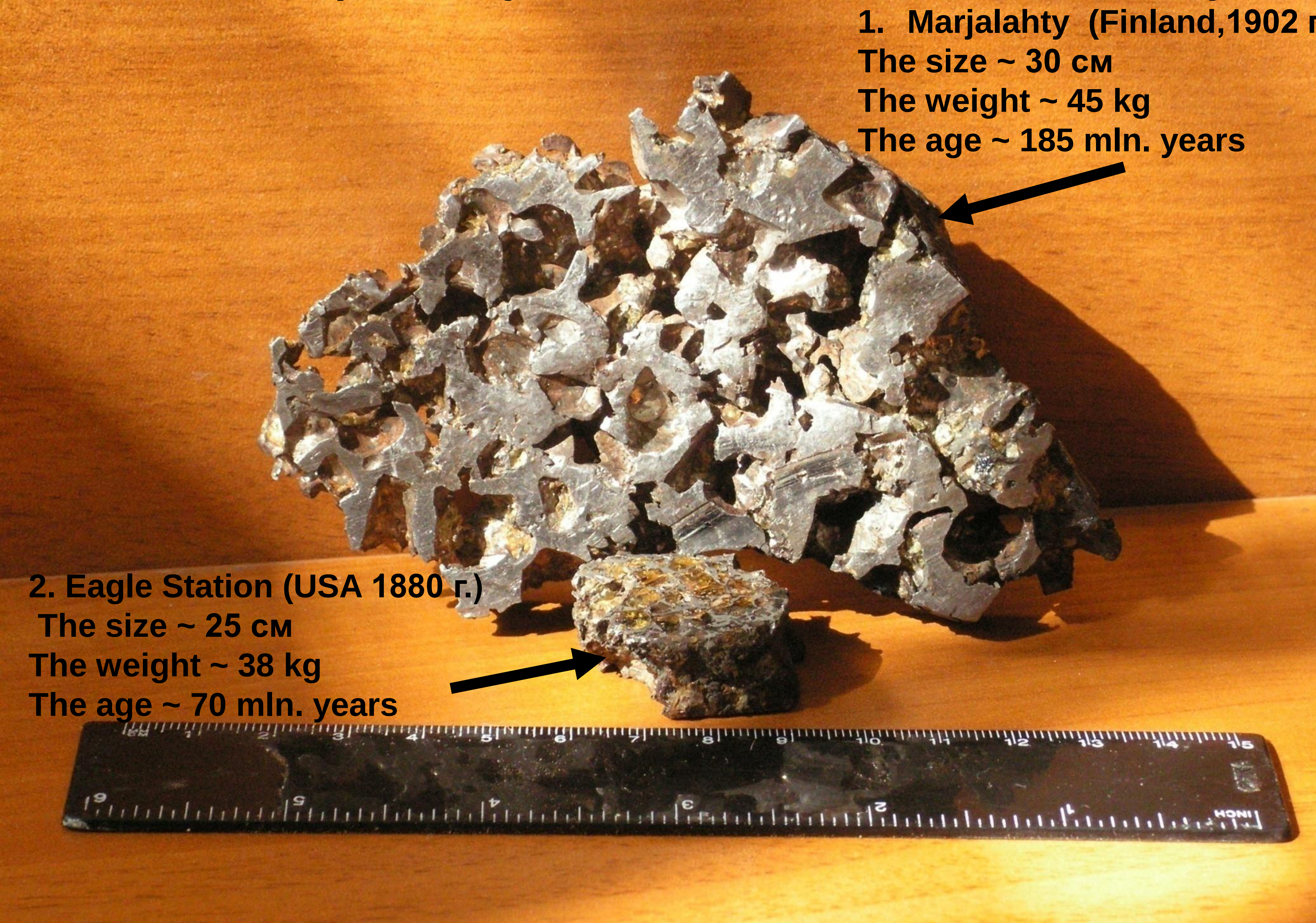
Problems and Horizons of the Search for Tracks of Heavy and Superheavy Nuclei in Olivine Crystals from Meteorites (OLIMPIYA Project)

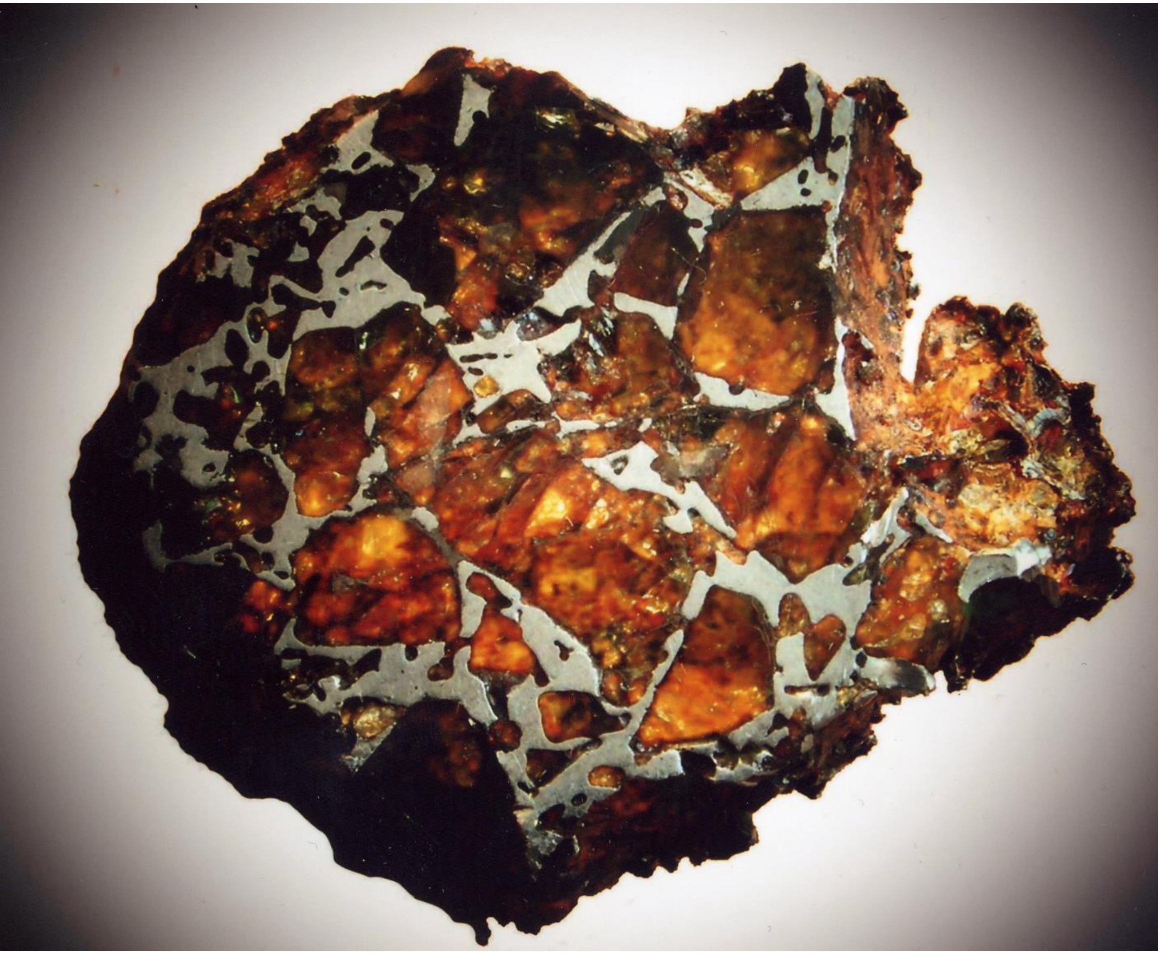
Academician V. L. Ginzburg, Academician E. L. Feĭnberg, N. G. Polukhina, N. I. Starkov, and V. A. Tsarev

Received February 1, 2005

In this paper, we consider the nucle
astrophysical aspects of investigations
the search for heavy and superheavy nu
position of cosmic rays. We also discuss
of searching for tracks of these nucle
crystals found in meteorites with the u
pletely automated PAVICOM setu
designed for the scanning and process
particles.

Search for Superheavy Elements in Galactic Cosmic Rays



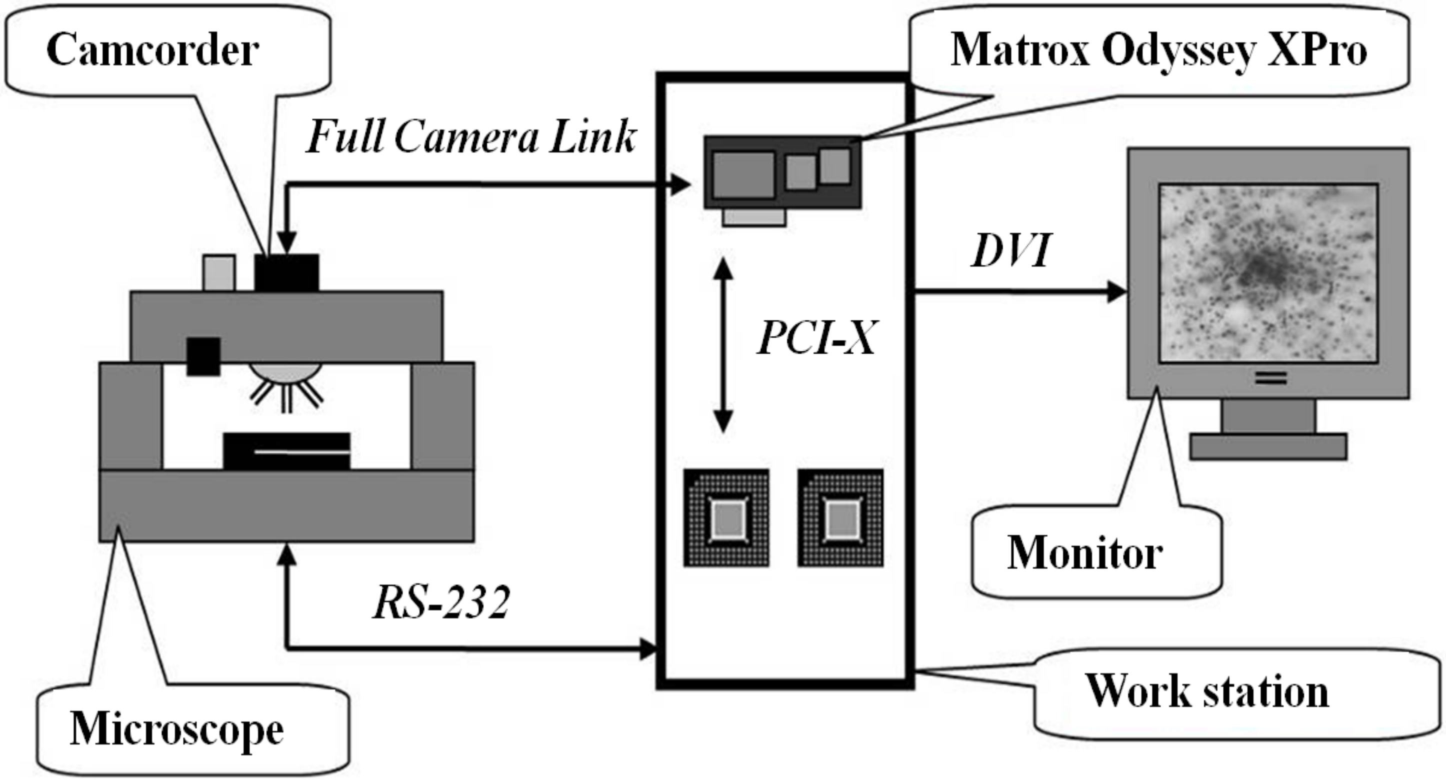


Meteorites of the class of pallasites consist of an iron-nickel "matrix", in the volume of which there are inclusions of olivine crystals, a translucent yellow mineral with a size of up to 1-2 cm.

The depth of olivine crystals in meteorites before entry into the atmosphere is 4–5 cm (Marjalahty) and 1.5–2 cm (Eagle Station), and their size is 0.5–2 mm.

Highly efficient measuring complex PAVICOM

PAVICOM used to search for and measure the parameters of tracks of superheavy GCR nuclei in olivine crystals

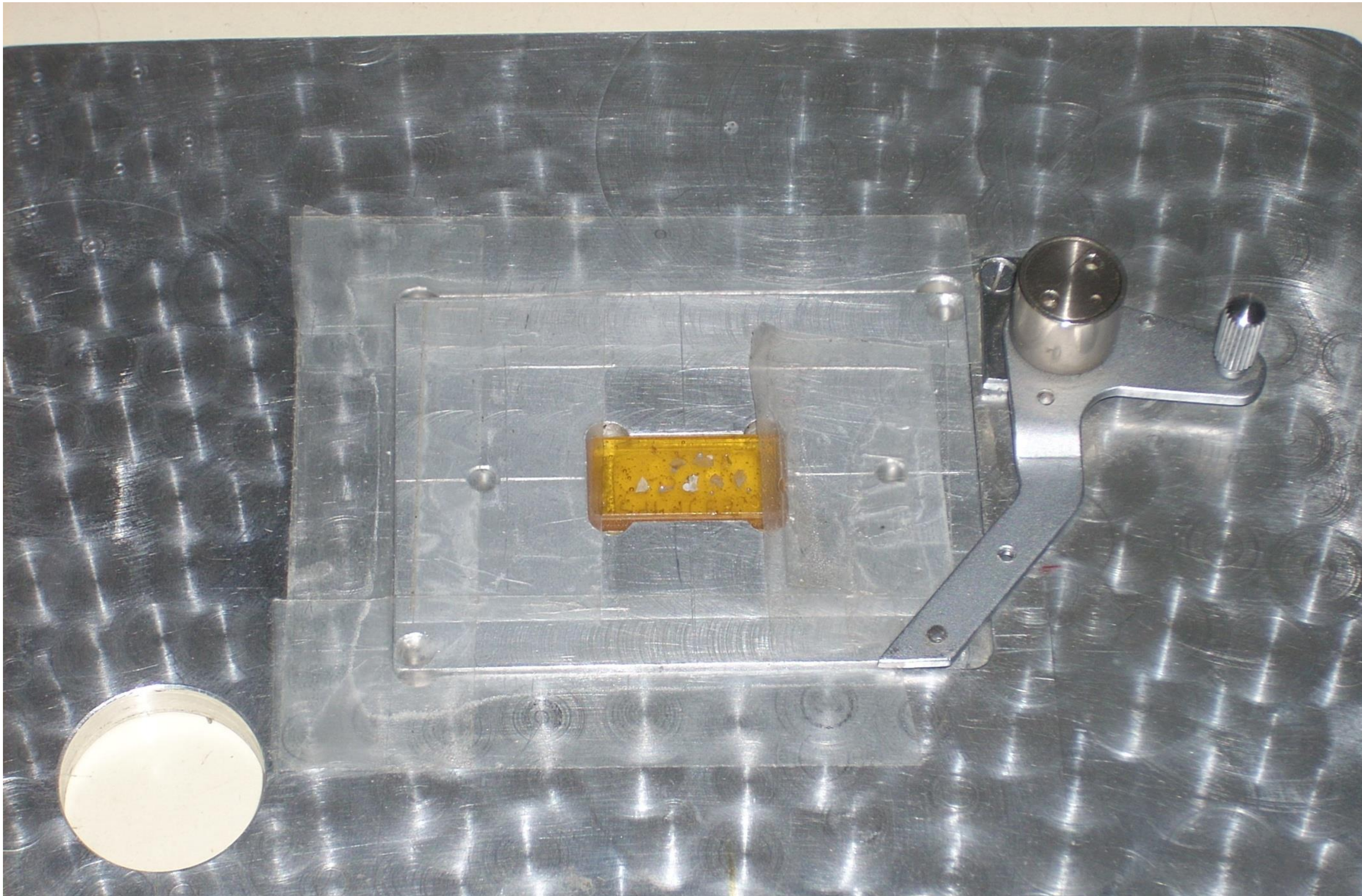


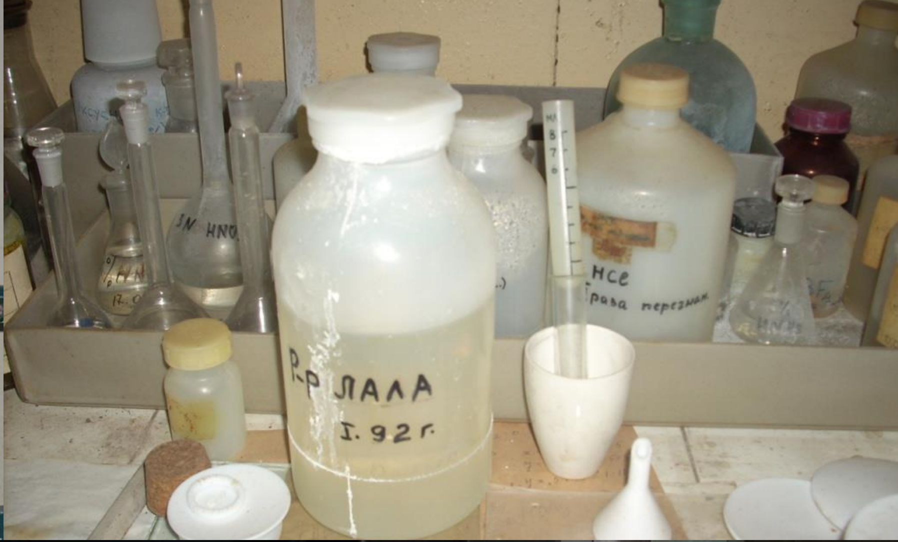
The complex is based on the use of CCD cameras to register and digitize images of heavy nuclear tracks in the microscope, and a original software package for recognition of track images and reconstitution of track positions in space

Completely Automated Measuring Complex-PAVICOM

Microscope Nikon;
the motorized movable stage MiCos;
range of motion: X = 200 mm, Y = 200 mm, Z = 45 mm;
accuracy of coordinate measurement: 0.25 mkm;
CMOS- video camera Mikrotron MC-1310 with 1024 grey levels;
Image size: 1280 x 1024 pixels, shooting speed up to 500 frames per second;
a dual-processor workstation based on Intel Pentium 4 Xeon 3.6 GHz;
digitizing board and the image processing Matrox Odyssey Xpro;
the microcontroller to operate the step motors National Instruments PCI 7344.

Several olivine crystals are packed in an epoxy resin tablet.

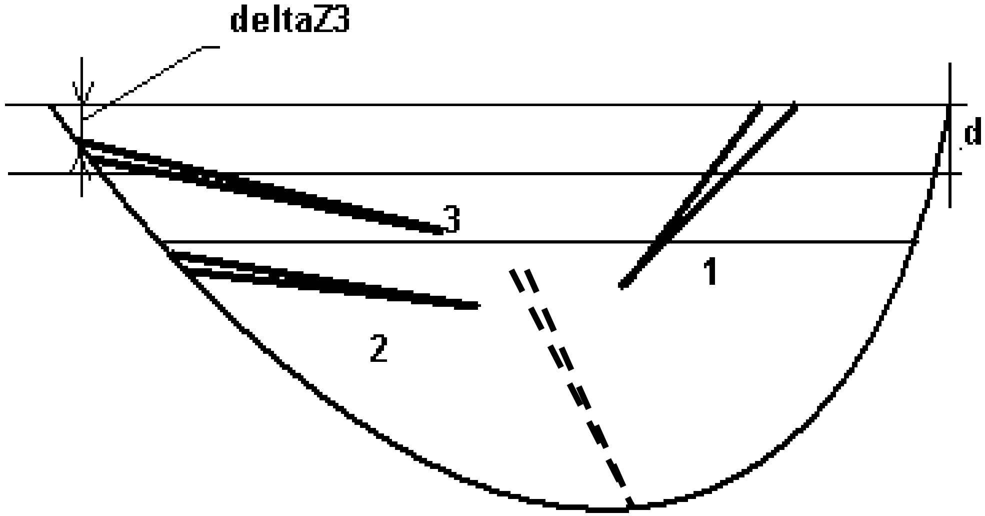




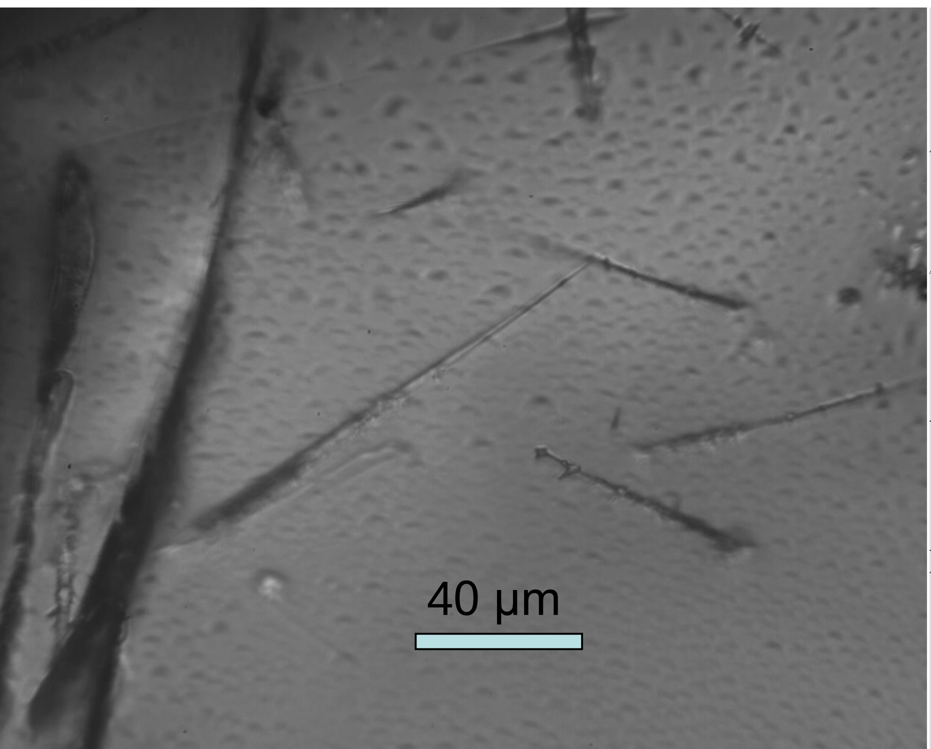
Источник Cf-252,

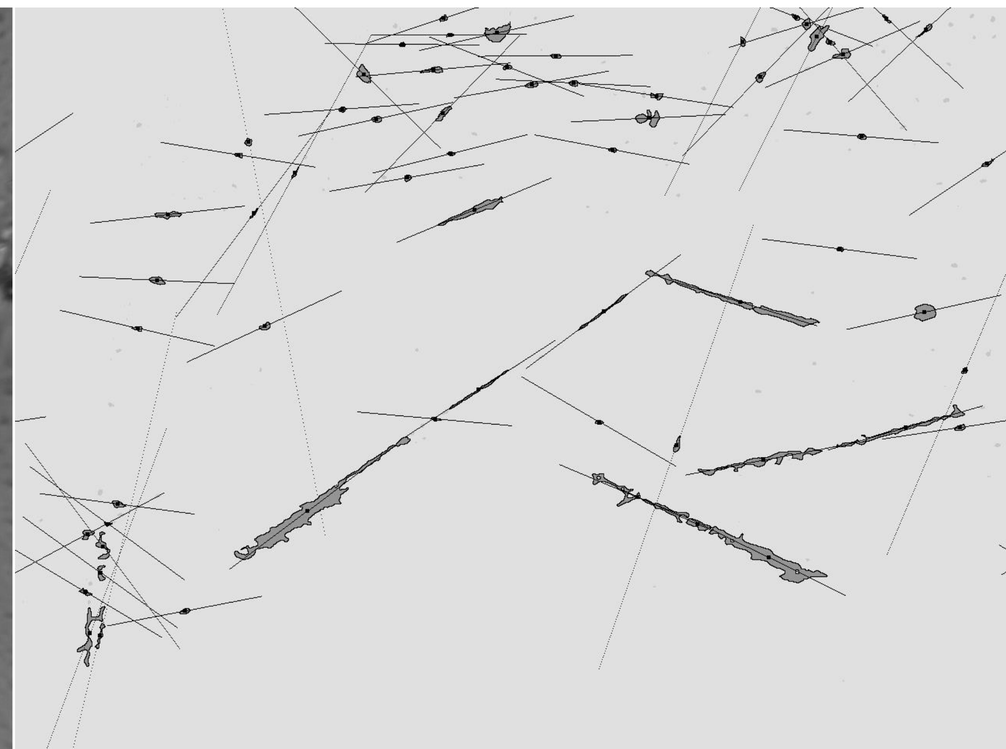
за 10 мин дает 10**5 осколков ядра

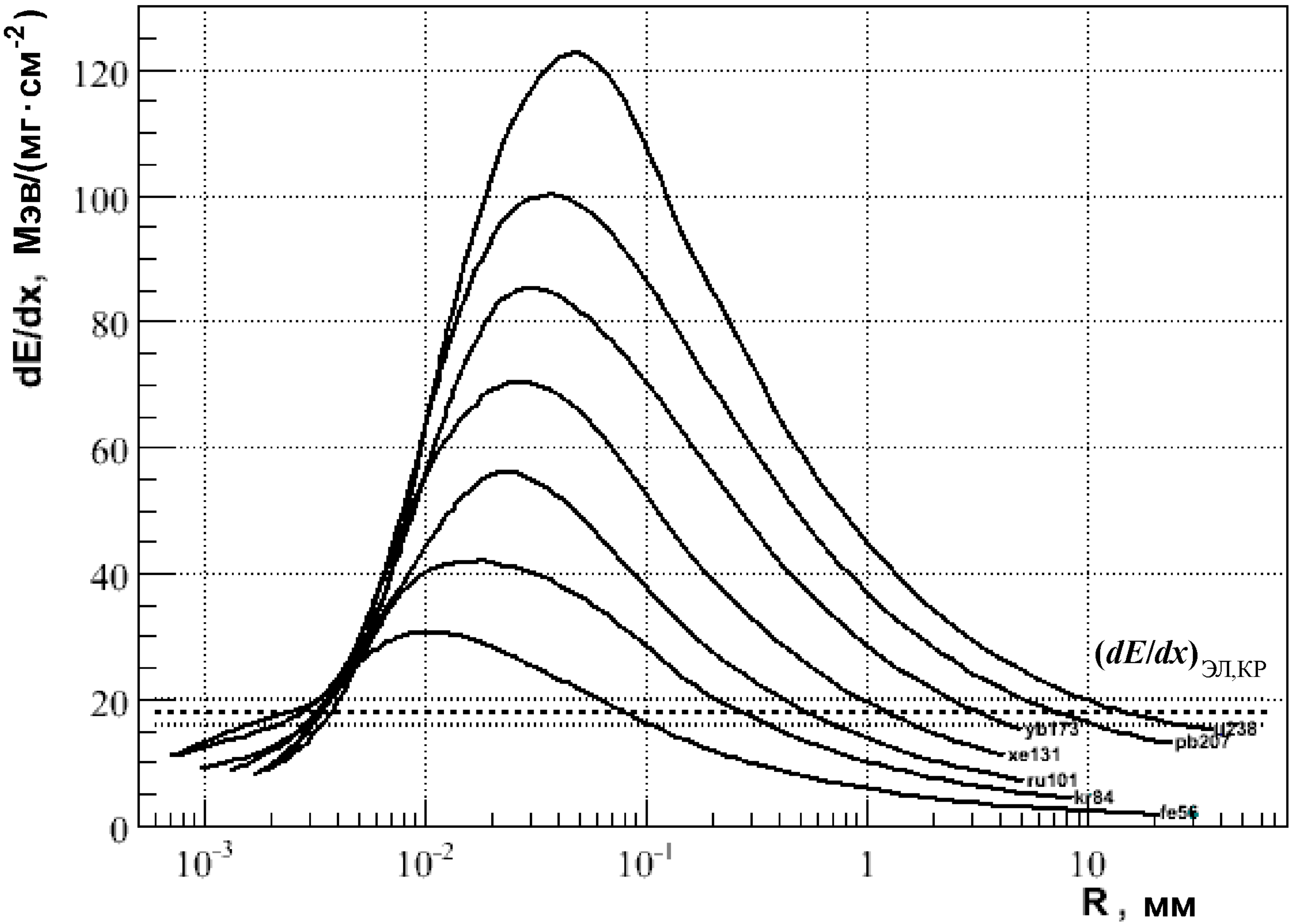
The method of layer-by-layer etching and cutting



Cutting layer thickness
d = 30 - 100 µm

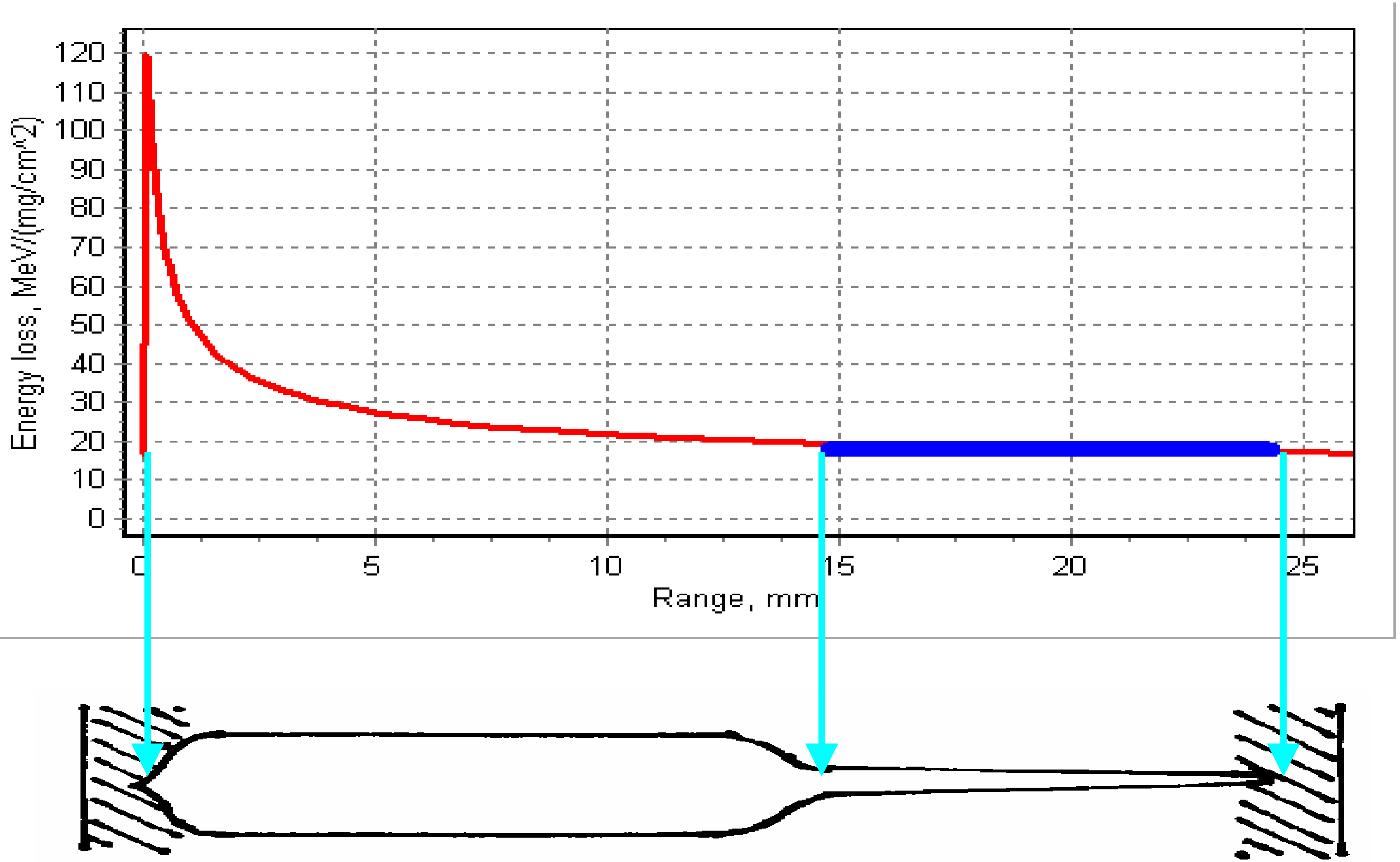


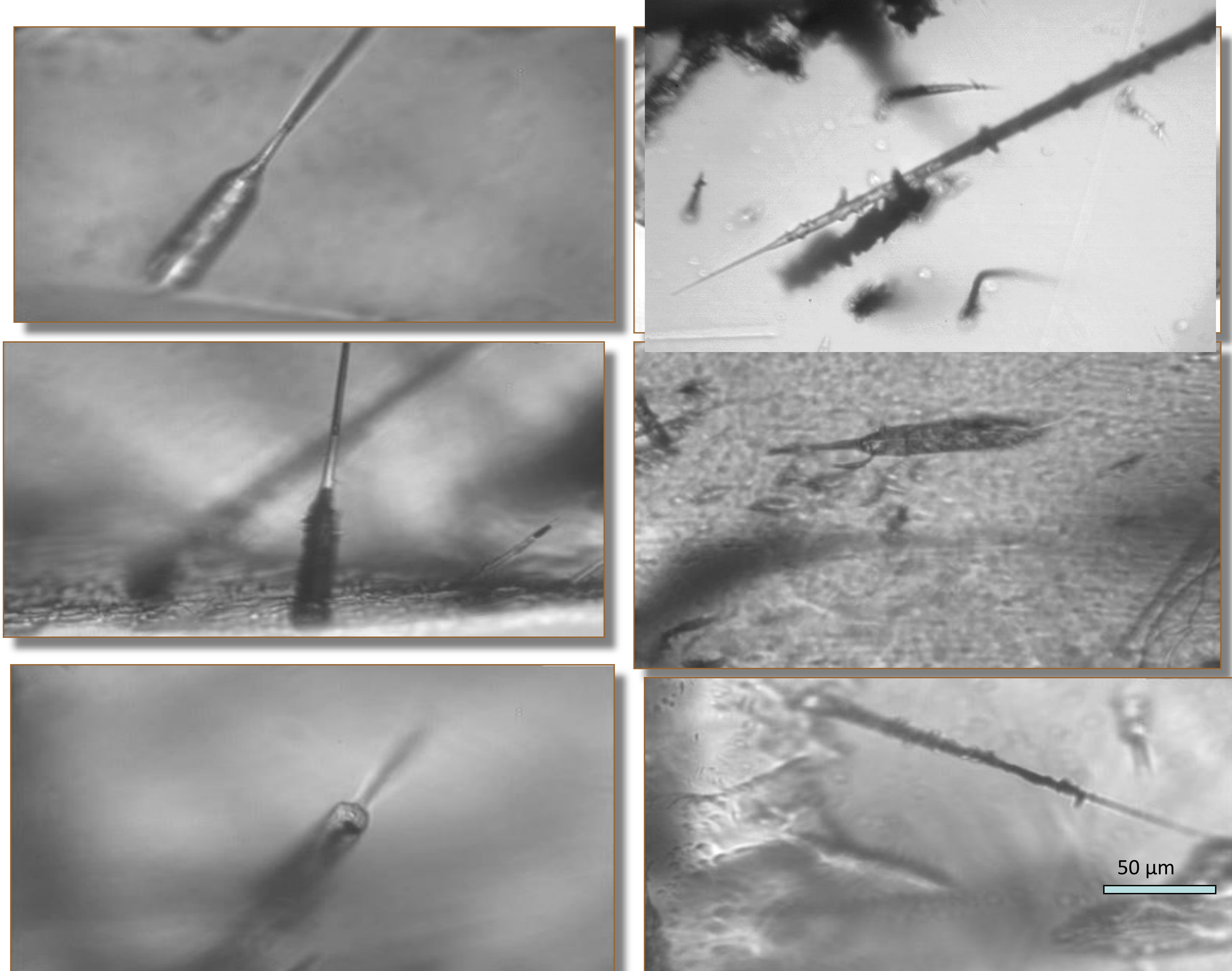


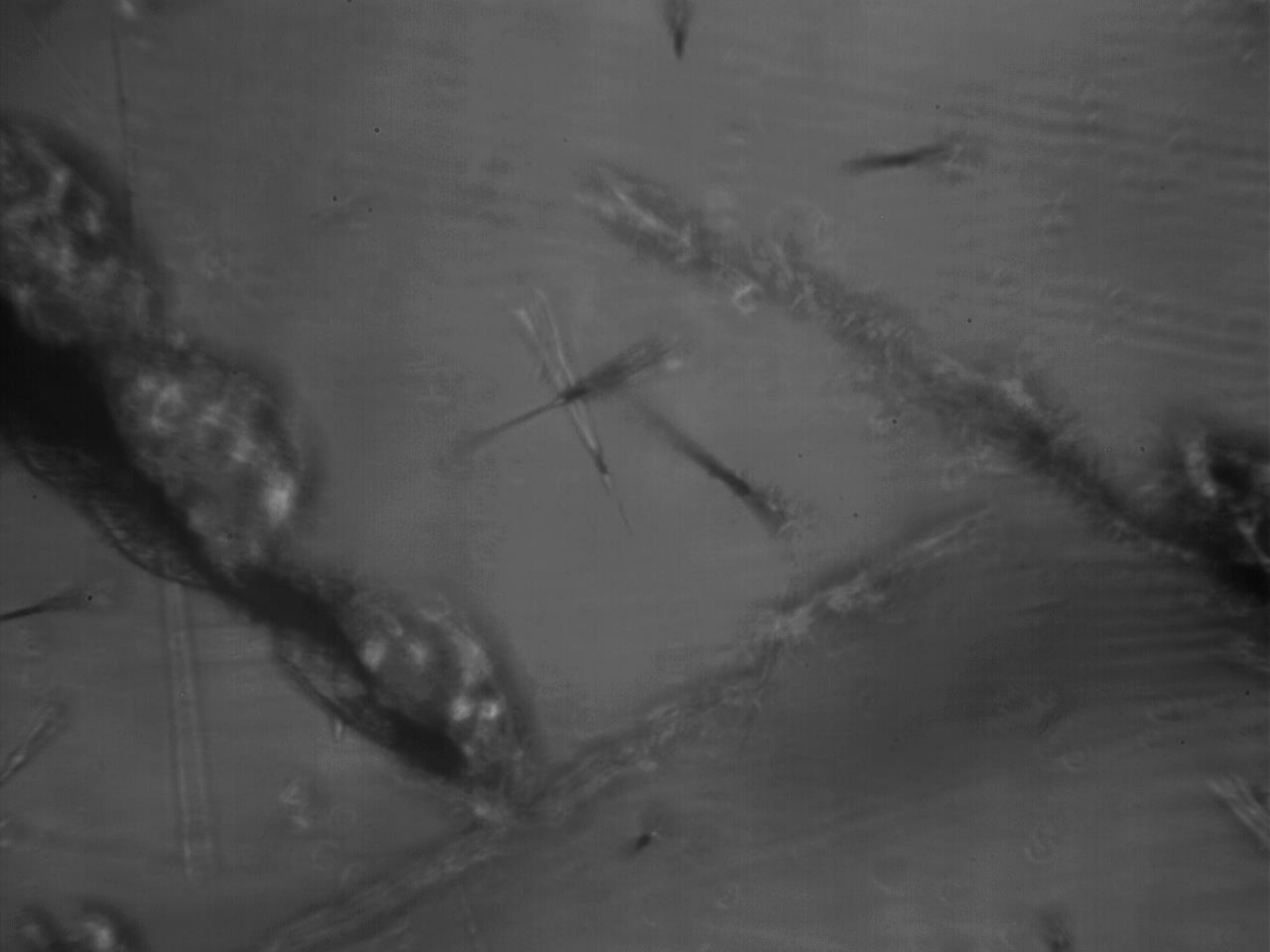


Curves illustrating the method of determining the total etching track length in olivine, for several nuclei from $^{56}_{26}Fe$ **up to** $^{238}_{92}U$

Diagram of the formation of the etched channel and determination of the total etched length of the track (needle, syringe)




50 µm



The example of very long track (L>700 μм; Z>80)

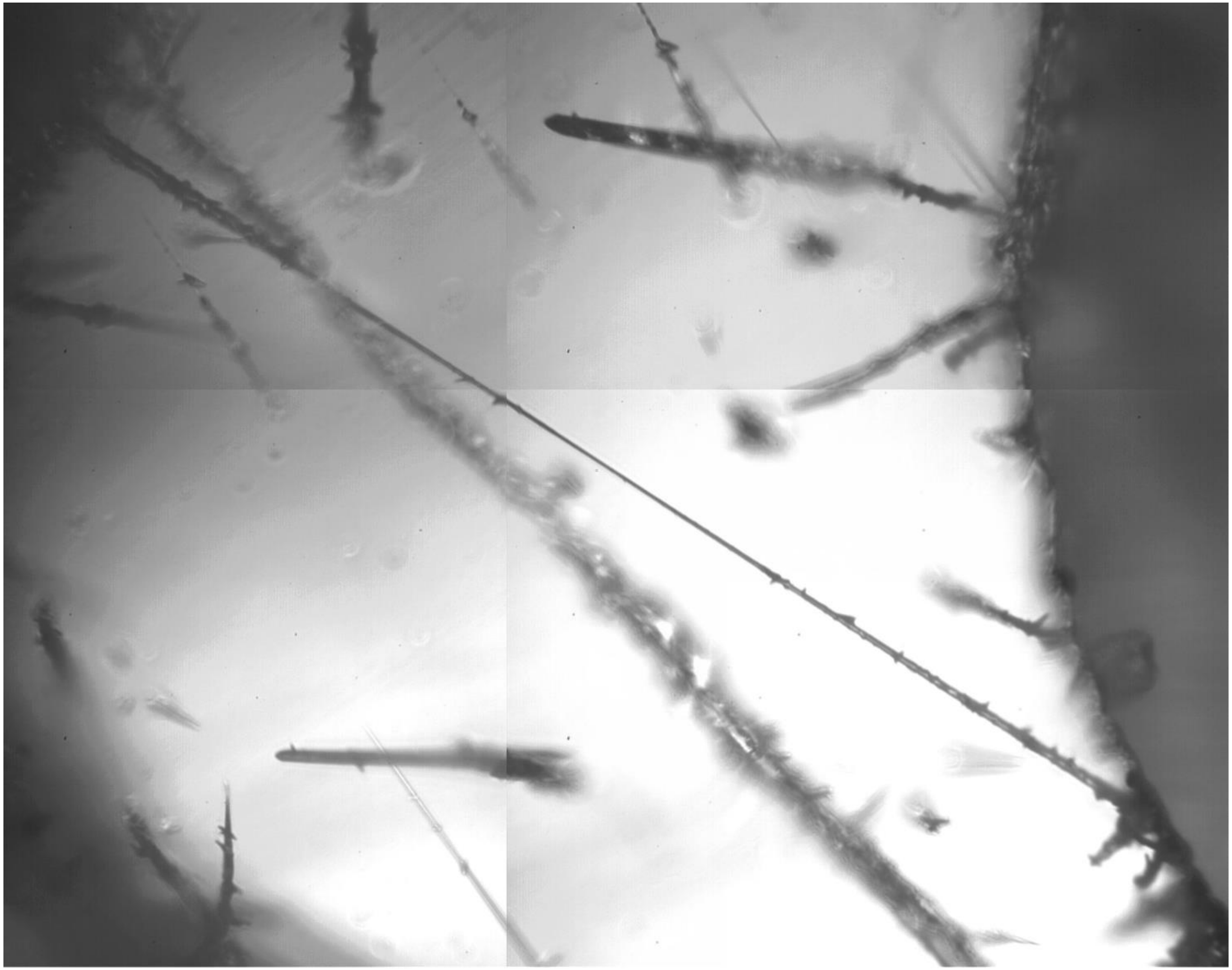
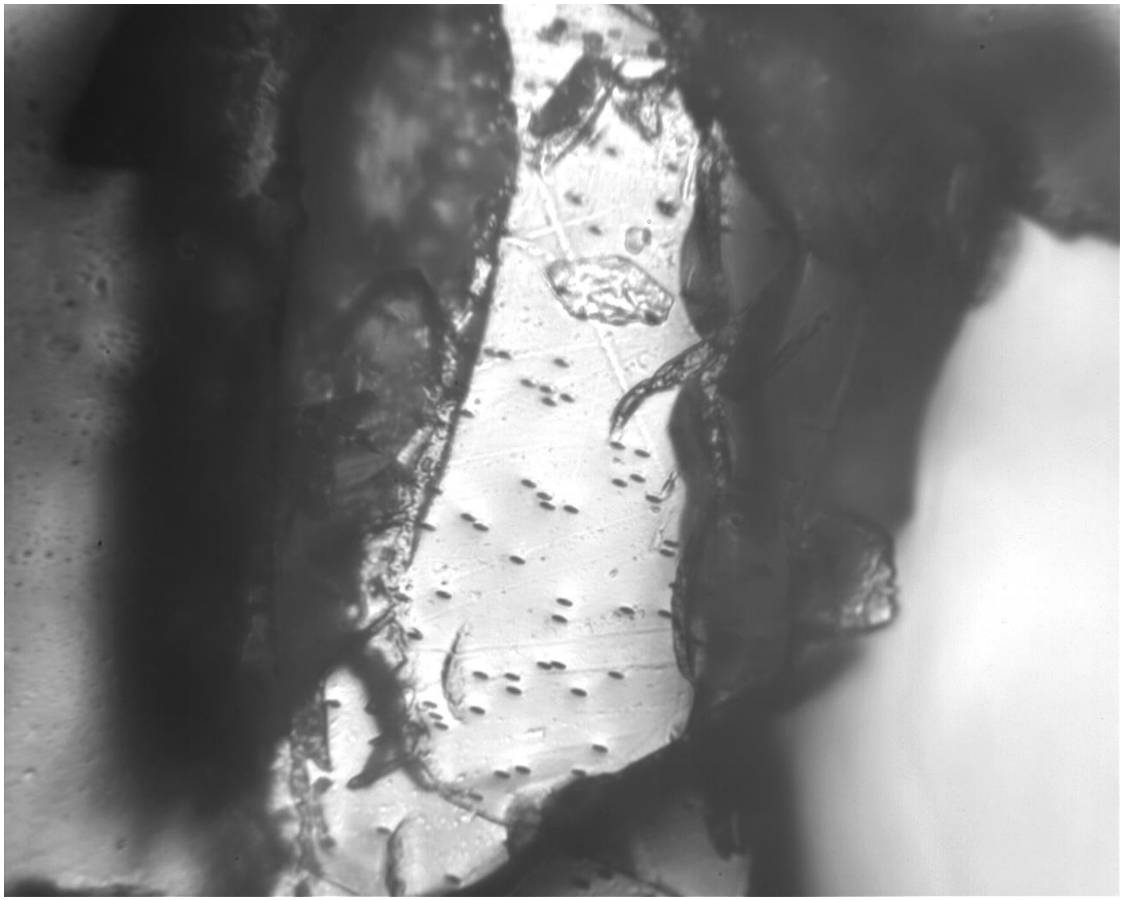
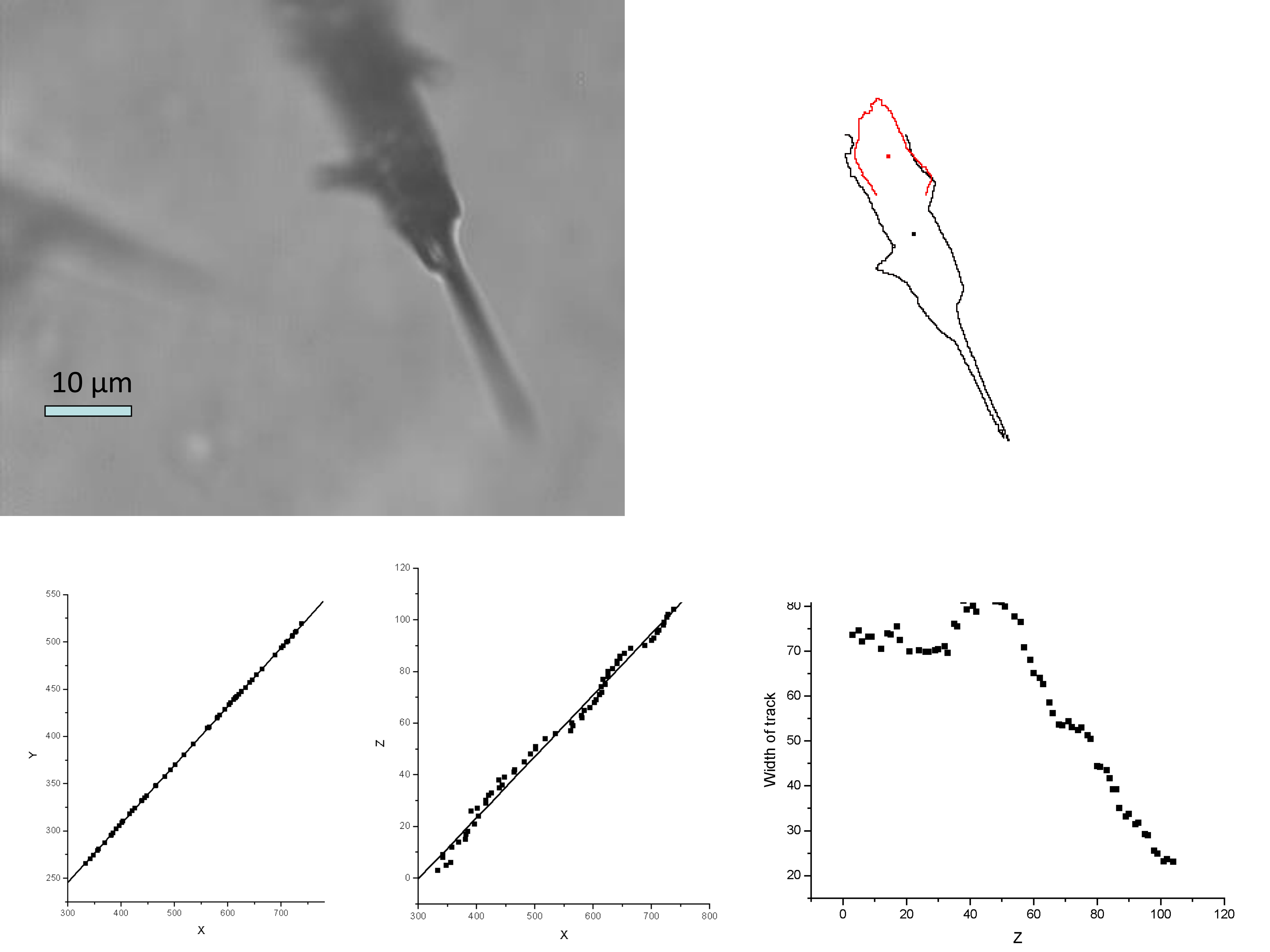


Image processing tracks in olivine

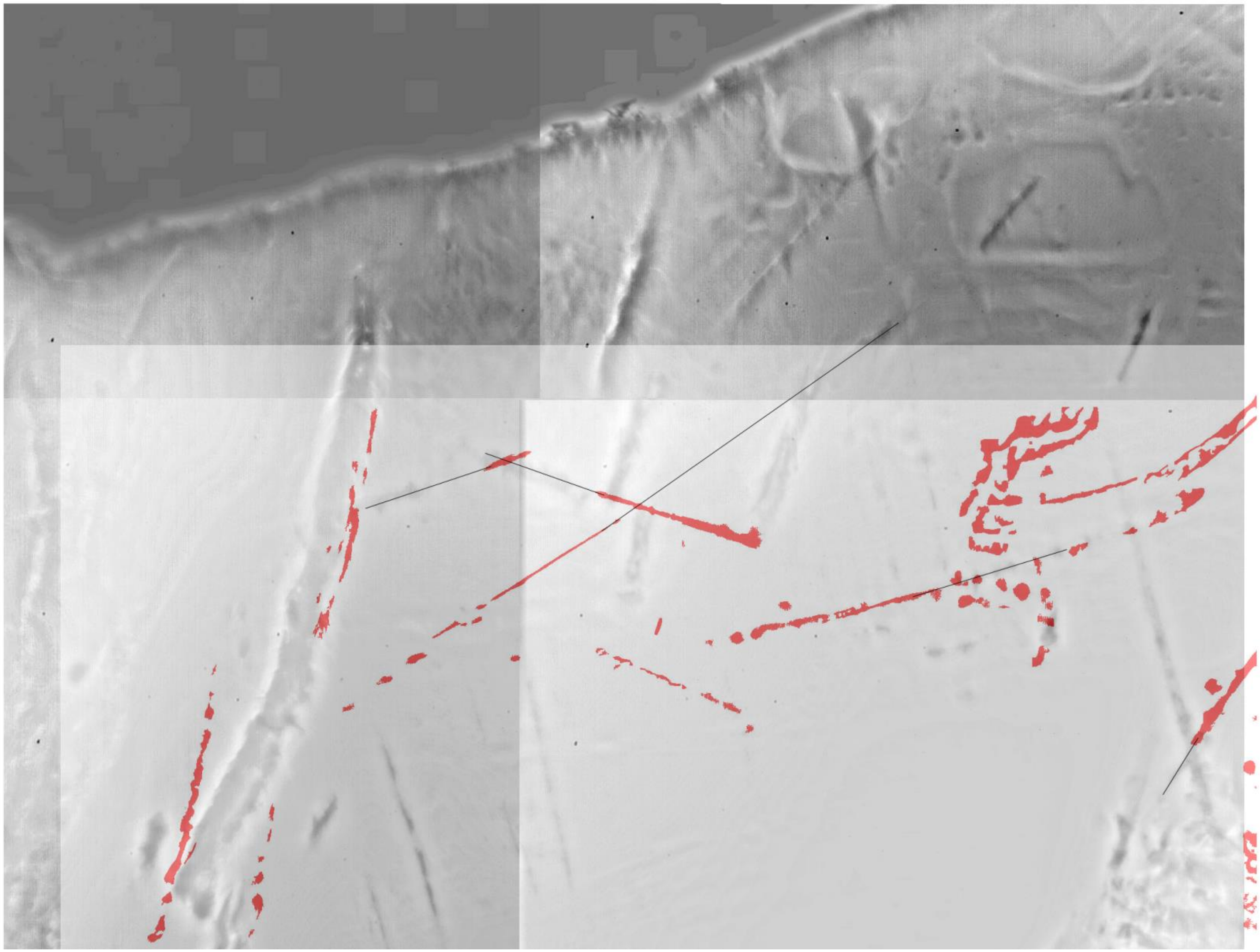


Selection of the treatment area in the case of large contamination of the field of view



10 µm
Y
X
Z
X
Width of track
Z

Search for the continuation of tracks in the following layers



Method of charge determination

The main problem: the size of the available olivine crystals is much smaller than the total etch length of the core track.

=> Therefore, it is not enough to measure the length of the track.

Identification parameters of the nuclear charge:

1. The length of the etched track.
2. The etching rate.
3. The diameter of the etched channel.

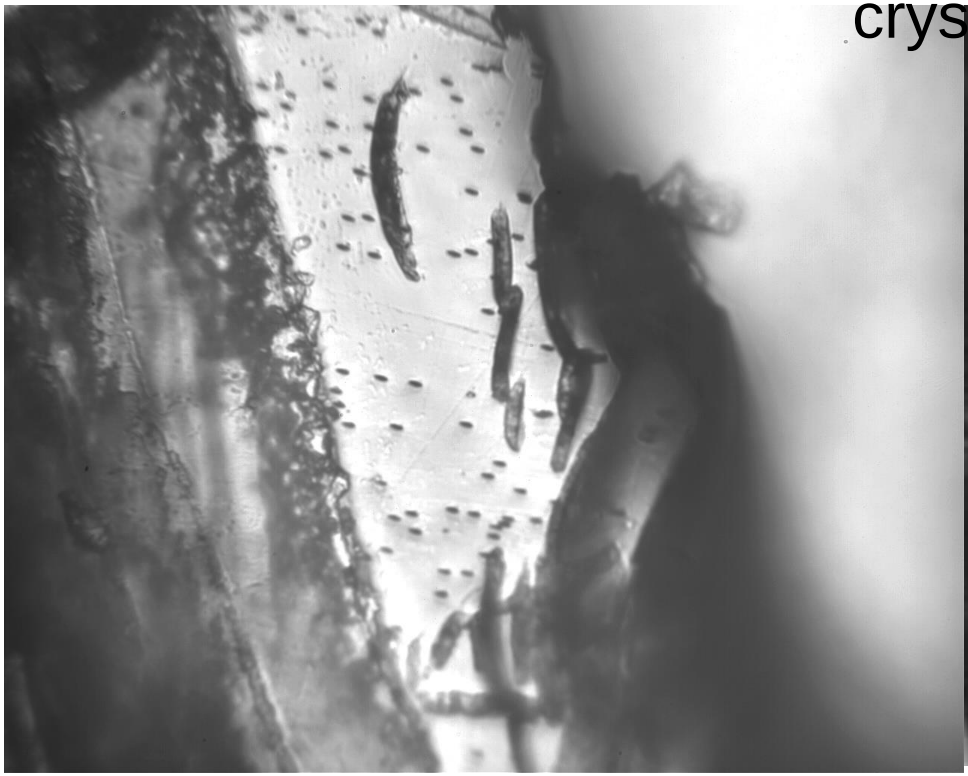
=> Calibration experiments required

Darmschtadt, GSI

Tracks of Xe nuclei (E = 11.4 MeV / nucleon)

The size of the field of view in photos ~ 500-700 microns

With a flux density of (4-10) 10 ** 5 particles / cm ** 2 - 30-80 tracks / crystal



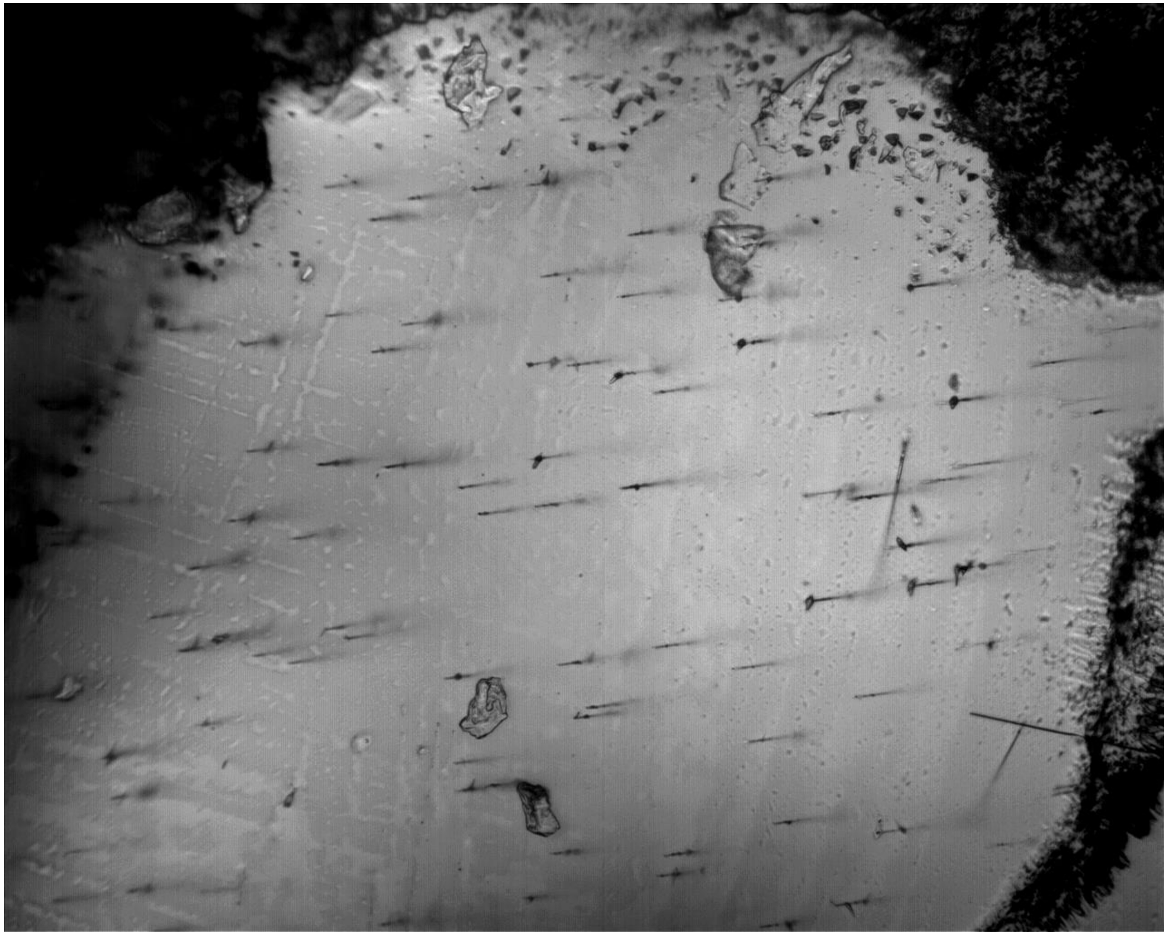
Track length = 57 ± 6 μm (estimated ~ 65 μm)

The etching rate (E = 11.4 MeV / nucl) ≈ 10-14 μm / hour

Darmschtadt, GSI, 2010 г., U, E= 150 MeV/n

Measured length for U (91 ± 5 μm)

Good agreement with the SRIM and GEANT4 U calculation data (89 ± 5 μm)



Results of the calibration experiments
* irradiations in GSI, Darmstadt
** irradiations in IMP, Lanzhou

Projectile	Beam energy, MeV nucleon^{-1}	Etching rate, μm h^{-1}	Measured track length, μm	Calculated track length, μm (SRIM-2008)
Kr	11.1*	0.5-1	71±5	75
Xe	11.1*	3–4	67±6	≈75
Au	11.1*	18±3	69±6	≈67
Bi	2.5**	19.4±4	26.6±2.9	≈25
	4.3**	19.2±4	47.5±1.1	≈40
	9.5 **	19.0±4	56±1.8	≈60
	11.1*	18.8±4	81±4.8	≈80

В.К.Егоров

X-ray diffractometer at the Institute of Problems of the Technology of Microelectronics and High-Purity Materials of the Russian Academy of Sciences, Chernogolovka

Measurement conditions: used Кα,β - Mo lines emitted by the molybdenum anode;

X-ray energy E = 25 keV; current I = 15 mA.

The crystals, the areas of flat polished surfaces of which were (0.2-0.5) 10 ** - 2 cm ** 2 tracks, were mounted on a diffractometric prefix of the goniometer. An X-ray beam passing through diaphragm slots 0.1 mm wide was directed at an angle to the analyzed crystal surface rotating around an axis perpendicular to the plane of the irradiated surface.

By measuring and recording the intensity of X-rays reflected at different angles, the observed set of peaks characteristic of a given texture of the crystals under study is established.

Образец	Сечение, мм^2	Излучение	Ориентация	Угол отклонения $\psi = \lvert\omega - \theta\rvert$	Наблюдаемые рефлексы	Относительная интенсивность, %	$\left(\frac{\Delta\theta}{\theta}\right)$	Оценка состава оливина	Степень монокристаллизации
1		$Mok_{\alpha\beta}$	(020)	~0,7°	(020) (040) (080) (0.10.0)	100 2 0,8 1,5	$3\cdot10^{-2}$	1.68:0.32 $(Mg_{0,84}Fe_{0,16})_2SiO_4$	Низкая
2		$Mok_{\alpha\beta}$	(134)	~0,13°	(134)	100	$8\cdot10^{-3}$	1.76:0.24 $(Mg_{0,88}Fe_{0,12})_2SiO_4$	Средняя
3		$Mok_{\alpha\beta}$	(020)	~0,2°	(020) (040) (080) (0.10.0) (0.12.0)	100 5 6 17 11	$4\cdot10^{-3}$	1.68:0.32 $(Mg_{0,84}Fe_{0,16})_2SiO_4$	Высокая
4		$Cuk_{\alpha\beta}$	(131)	<0,1°	(131) (262)	100 2,5	$1\cdot10^{-3}$	1.82:0.18 $(Mg_{0,91}Fe_{0,09})_2SiO_4$	Высокая
5		$Cuk_{\alpha\beta}$	(101)	~3,6°	(101)	100	$1\cdot10^{-3}$	1.76:0.24	Высокая
6									Средняя
7									…зможна текстура …сокого качества
8									Высокая
9									Средняя
10									…морфность или …елкодисперсия

О НЕКОТОРЫХ СТРУКТУРНЫХ ОСОБЕННОСТЯХ КРИСТАЛЛОВ ОЛИВИНА ИЗ МЕТЕОРИТА МАРЬЯЛАХТИ

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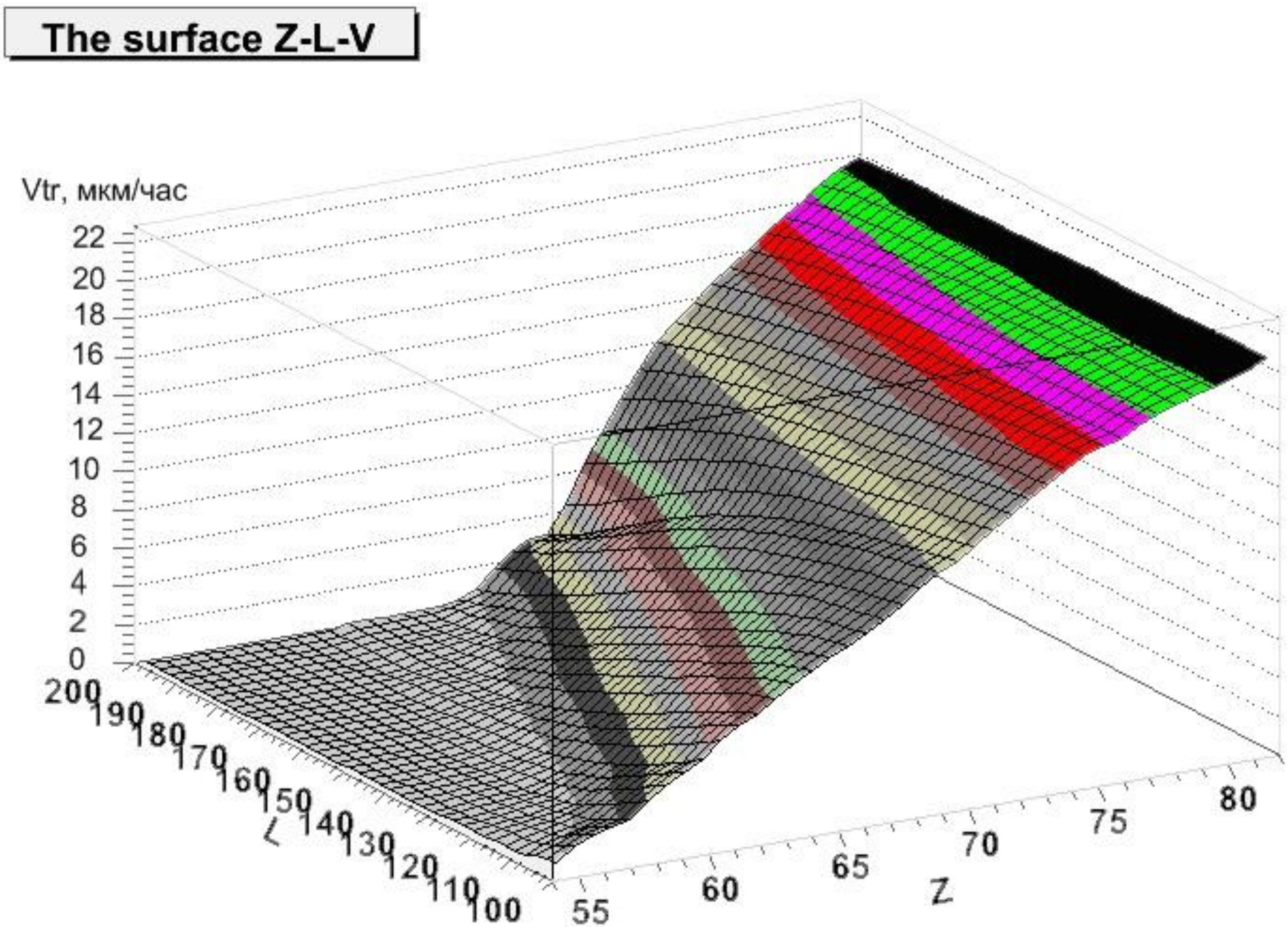
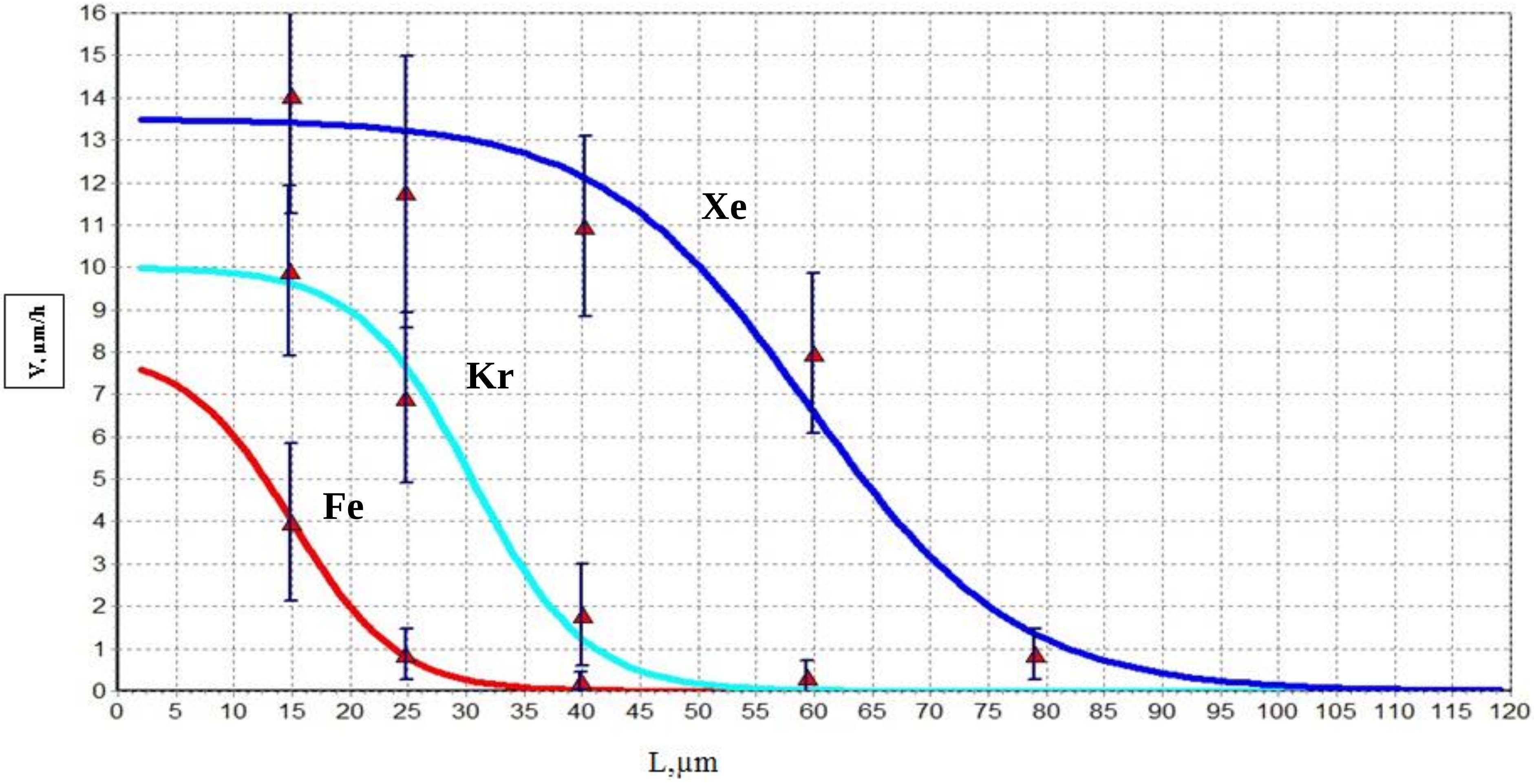
Введение. Оливин, представляющий собой силикатную фракцию метеоритов — палласитов [1], является высоко эффективным природным детектором ядер тяжелых элементов космических лучей [2]. Определение заряда этих ядер осуществляется на основа-

Задача диагностики степени совершенства структуры оливина осложнена специфическим фактором, свойственным его структуре. Ее главным структурным мотивом является наличие гексагональной плотнейшей упаковки (ГПУ) атомов кислорода. При кристал-

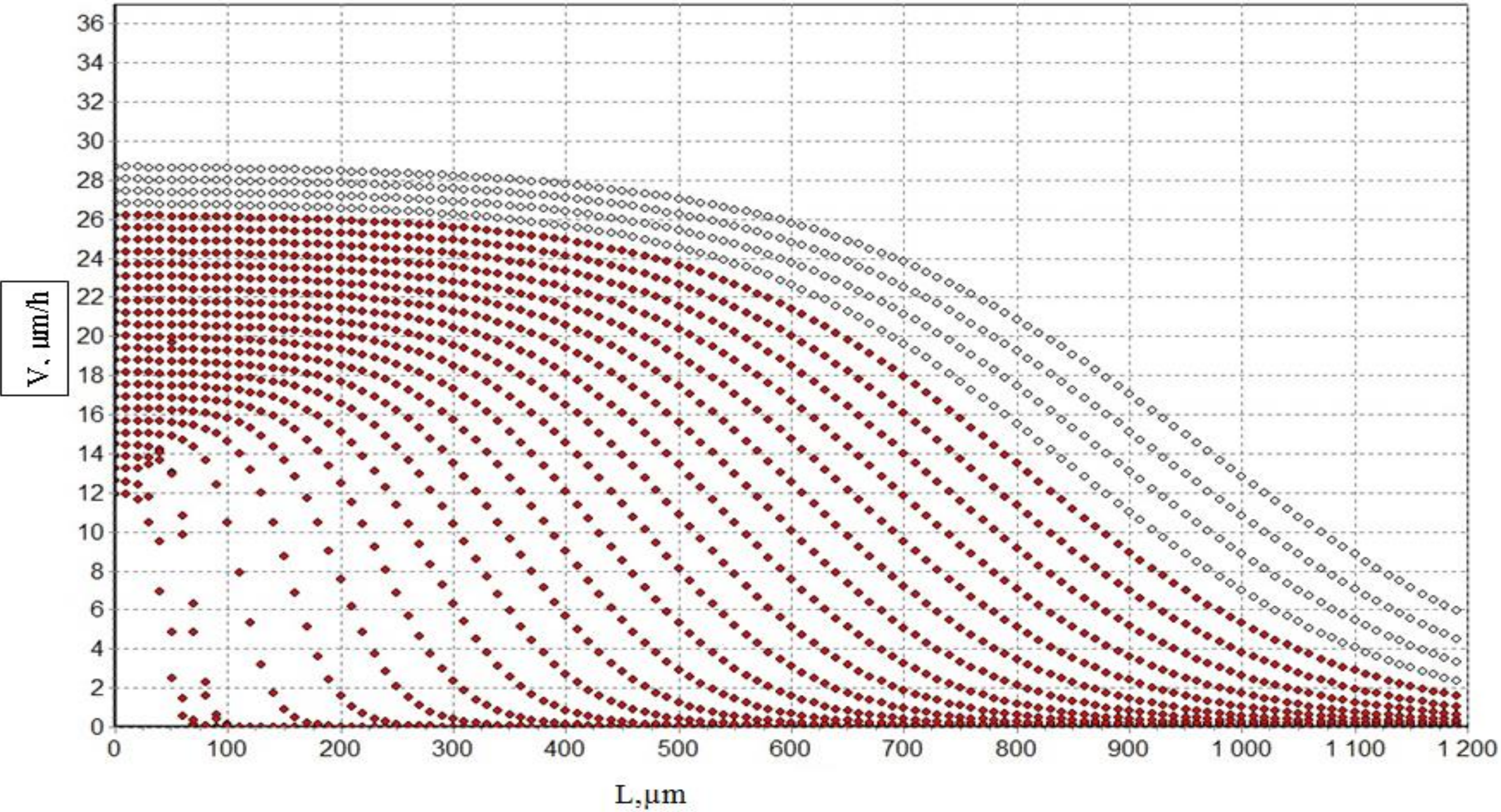
The relationship between charge, etching length and etching rate (UFN, Vol. 180, No. 8, p. 839-842, 2010).



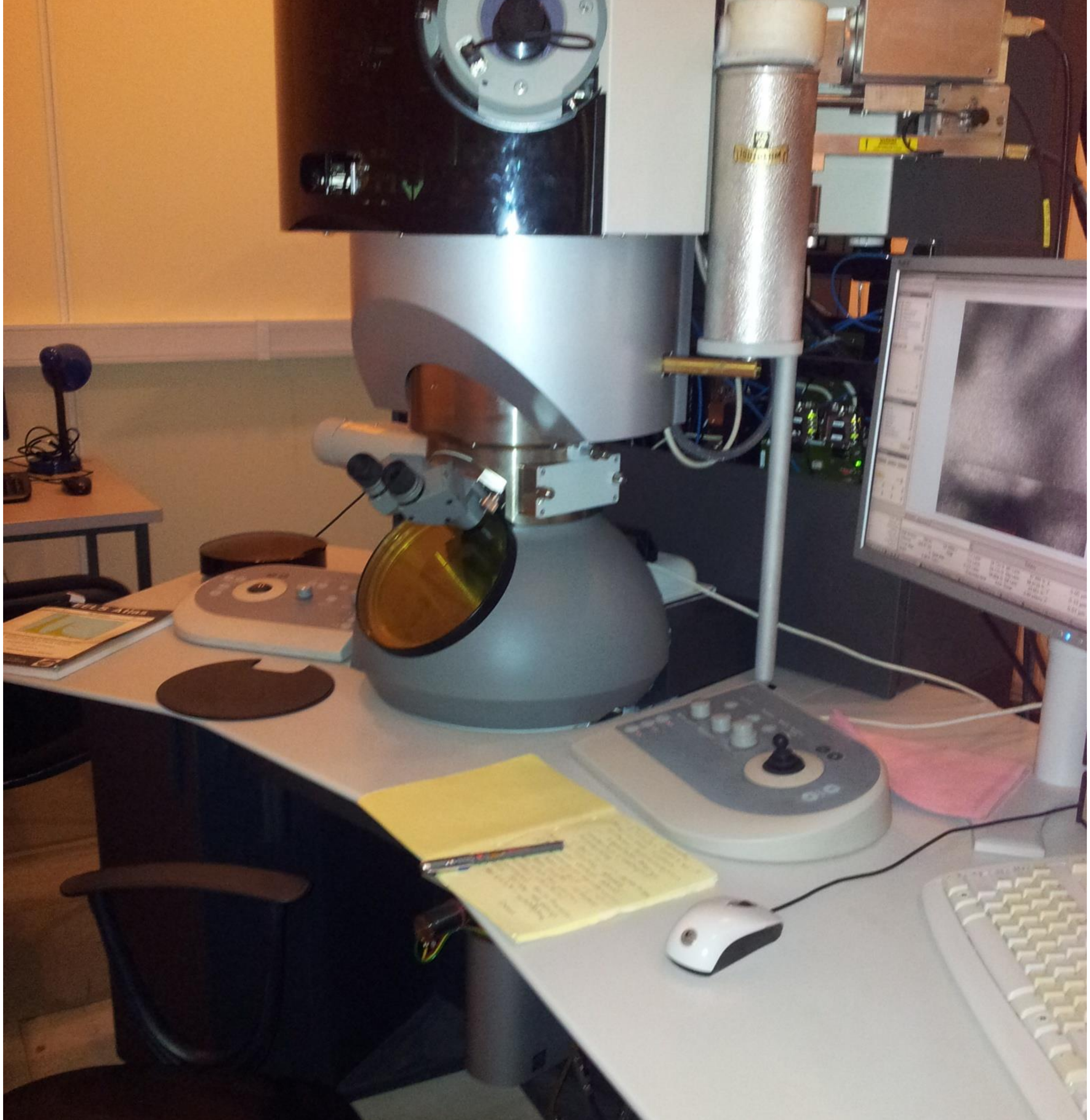
$$V(Z, L) = \frac{A(Z) \cdot (1 + E(Z) \cdot L^2)}{1 + B(Z) \cdot \exp[(L - C(Z)) / D(Z)]} \quad (1)$$

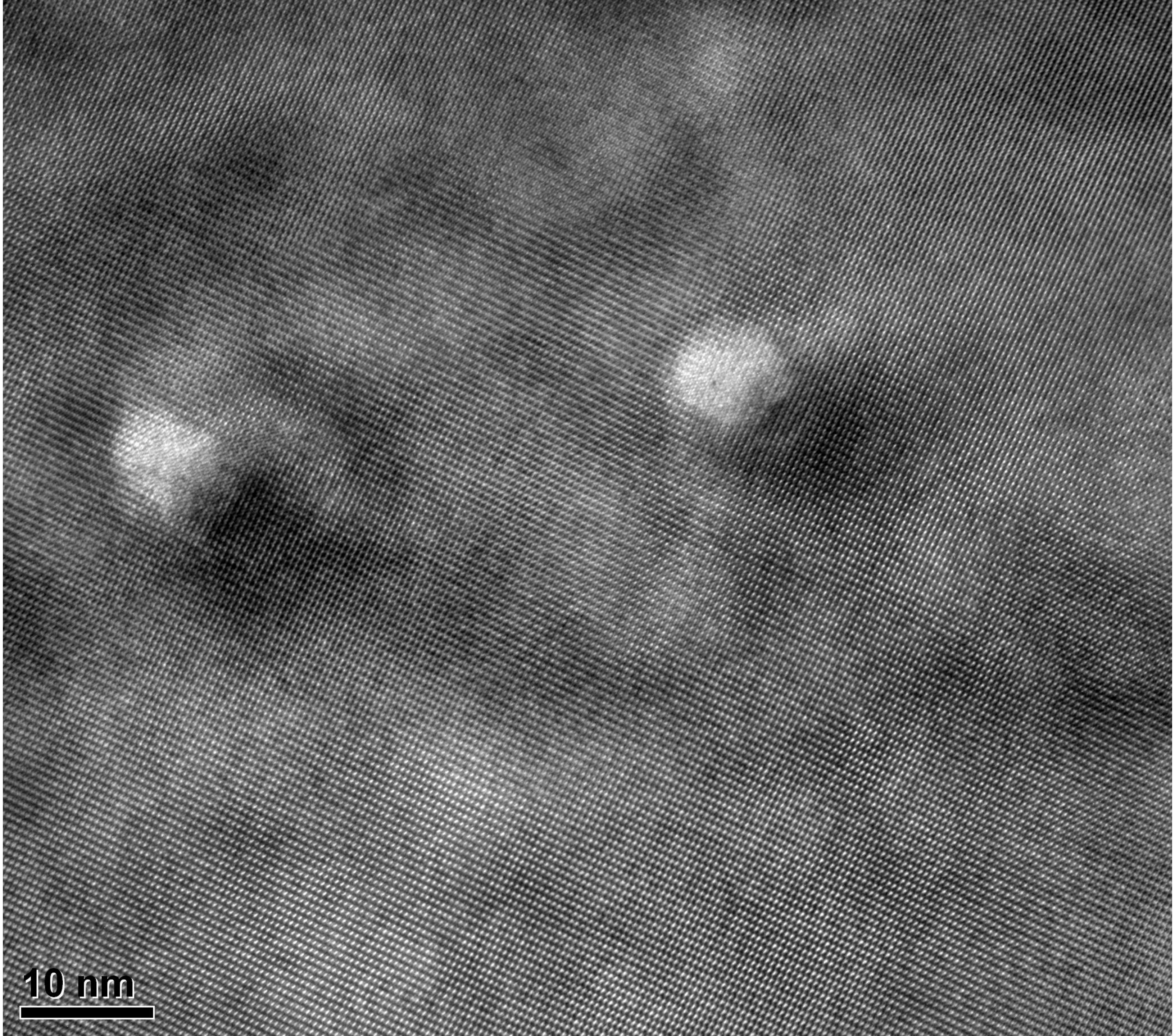


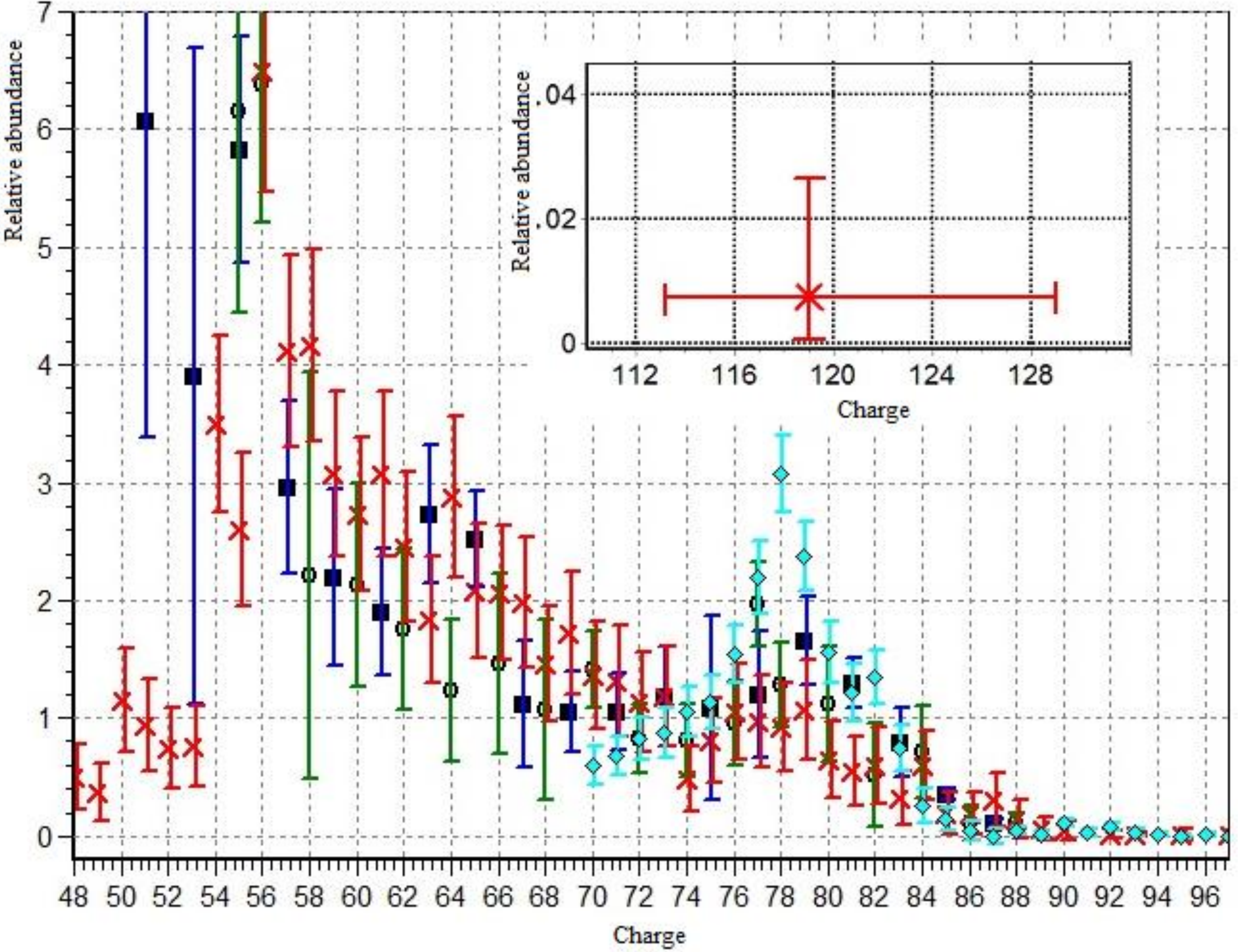
Using a five-parameter formula to describe the etching rate dependence of the residual length and charge for Fe, Kr и Xe.



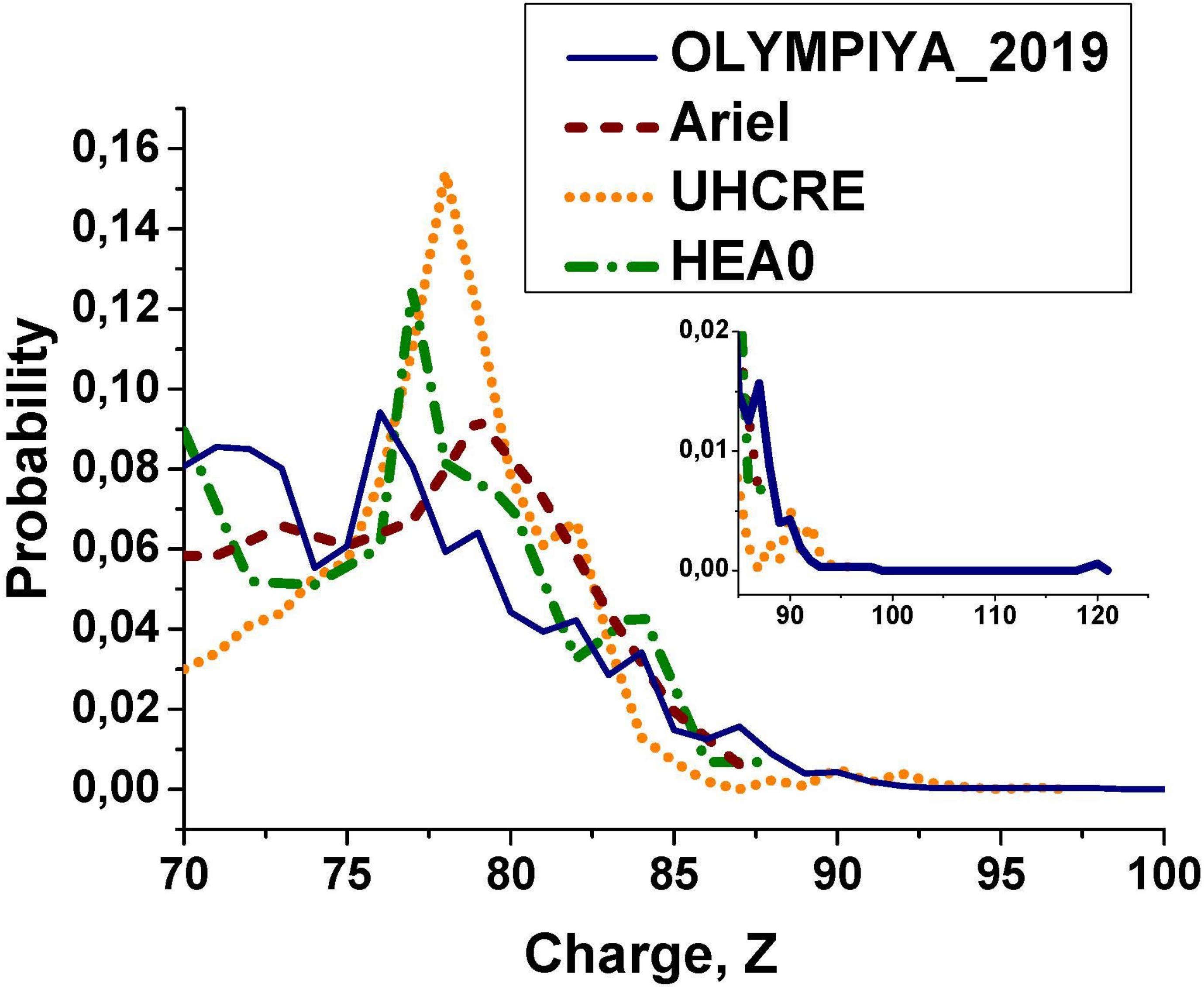
The family of $V_{etch}(Z, L)$ curves obtained by fitting the experimental data from calibration experiments by Eq. (1) and extrapolating the fitted values to all charges from Z = 54 up to Z = 92 (filled circles) and for larger charges from Z = 94 up to Z = 100 (empty circles) (the intervals between curves are two charge units).




10 nm

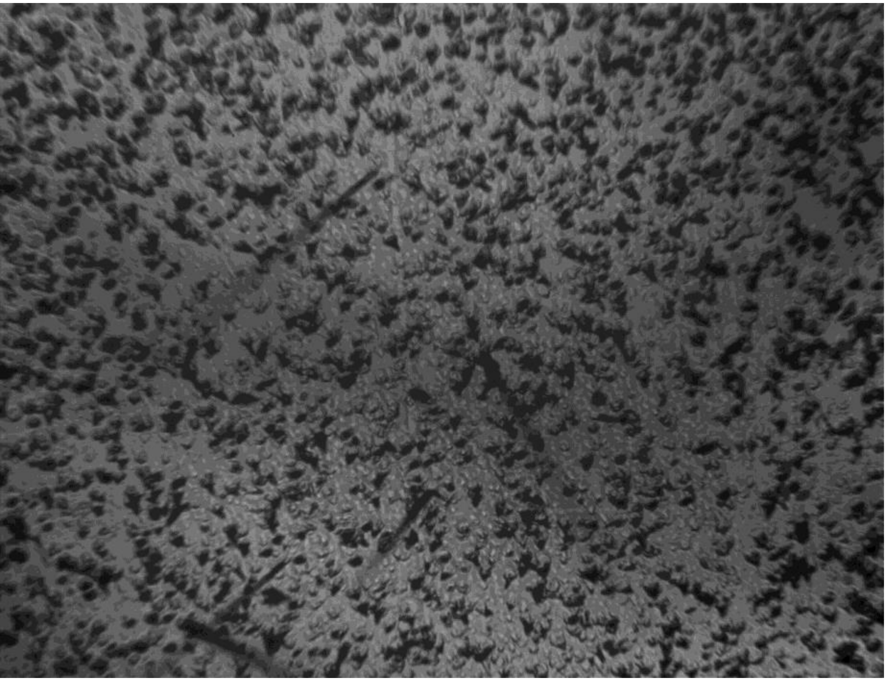


Relative abundance: OLIMPIYA (crosses), HEAO-3 (squares), ARIEL-6 (rombhuses) и UHCRE (circles). The inset shows three transfermium nuclei registered in OLIMPIYA. The abundance evaluation of these 3 nuclei is $A=0.015^{+0.042}_{-0.003}$ with level of confidence 95% on base of rare event processing method Gehrels (1986).



Relative abundance (the data were normalized by the content of iron nuclei $A({}_{26}Fe) = 10^6$, the data are normalized so that the sum of all probabilities over all integer charges gives unity) of GCR heavy nuclei registered in the OLIMPIYA experiment as compared with the results of other experiments: ARIEL-6, HEAO-3, and UHCRE. The inset shows three transfermium nuclei registered in this work.

Micrograph of a fragment of olivine crystal surface (the Marjalahti pallasite)



In the field of view of 284×226 μm in olivine; density of tracks, $1.5 \cdot 10^6$ cm^{-2}.

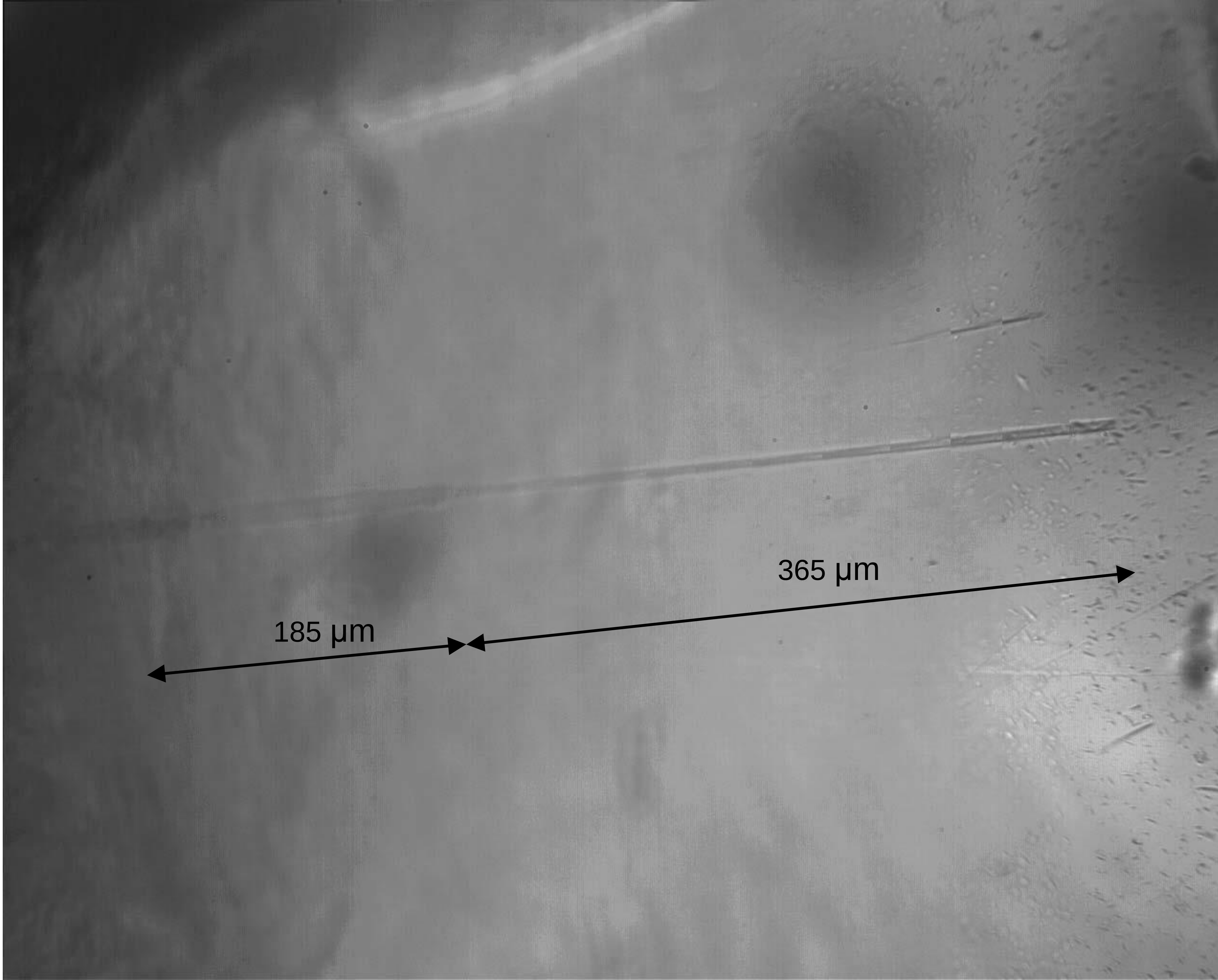
Micrograph of a fragment of olivine crystal surface with a large change of track density. Image size, 284×226 μm
the density of tracks within a distance of 800 μm changes by two orders of magnitude, from $3 \cdot 10^6$ up to $4 \cdot 10^4$ cm^{-2}.

Superheavy nuclei

In addition to this distribution of galactic nuclei, we found 3 nuclei with a charge of Z> 105.

Not only the length of these tracks is large (up to 800 microns), their minimum etching rate is more than 35 microns / hour.

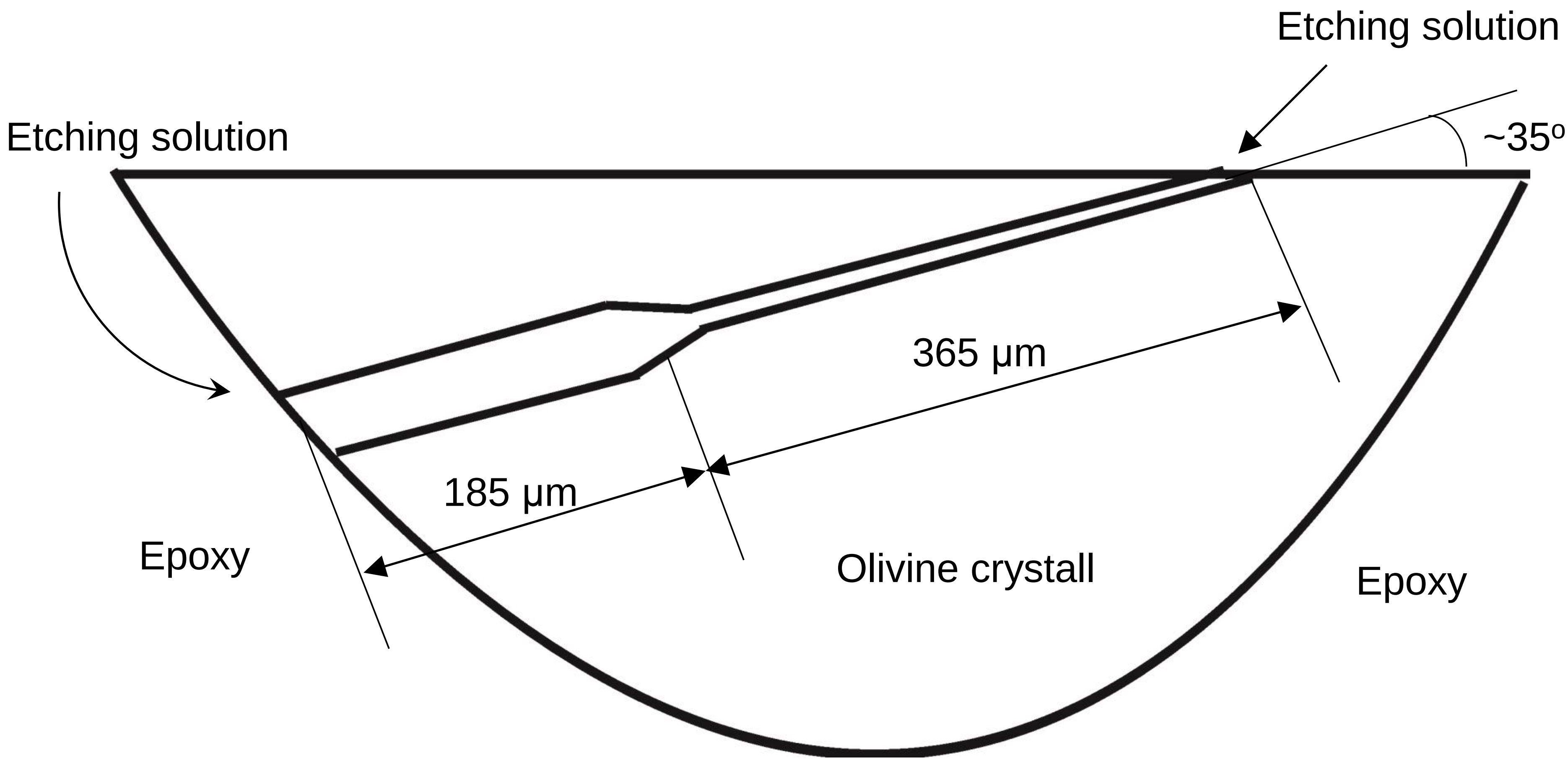
This value significantly exceeds the maximum etching rate for uranium nuclei (25 μm / h).

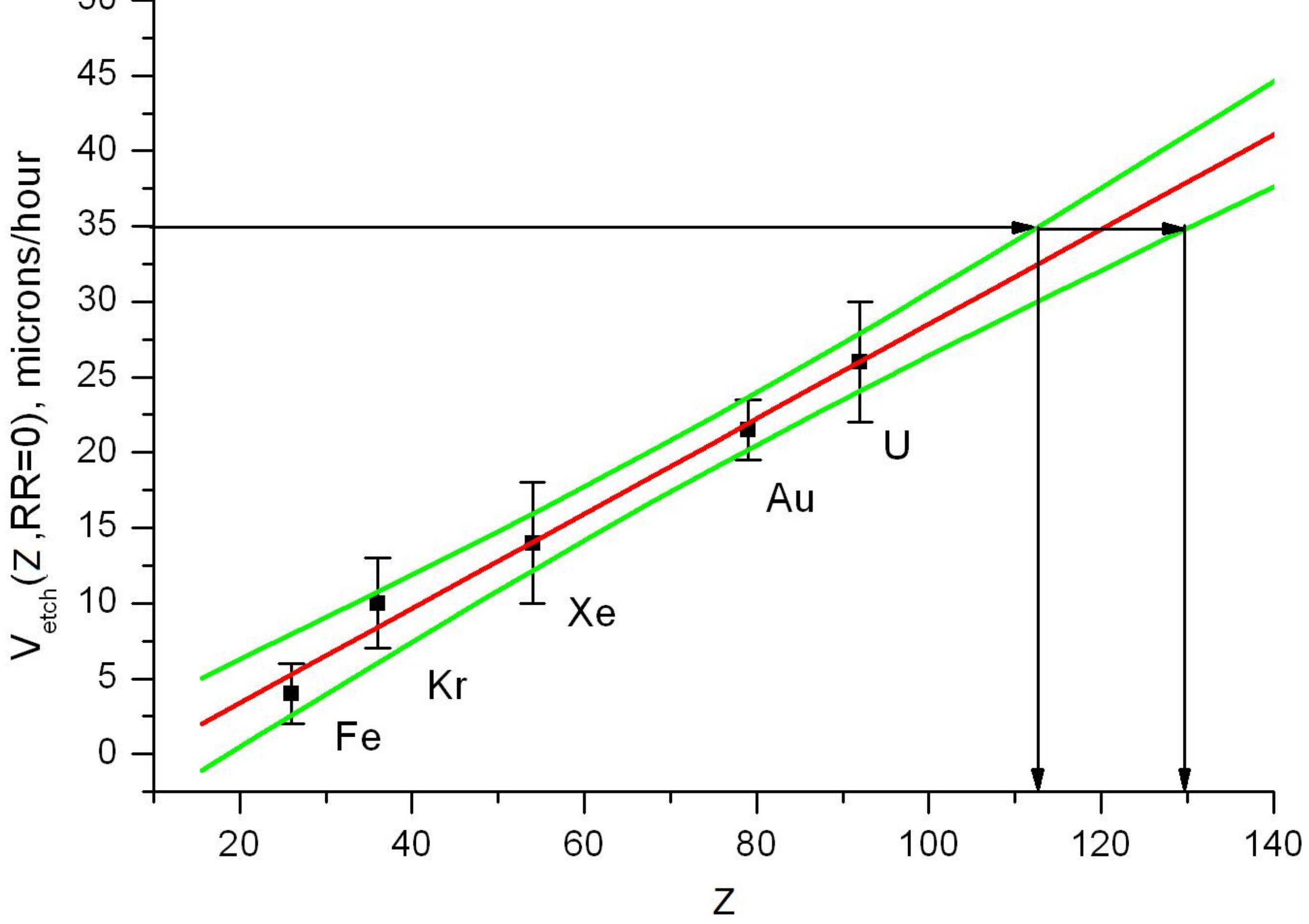

365 µm
185 µm

The length of this track in olivine is ~ 550 µm. Etching time - 8 hours.

But the etching solution could penetrate into the crystal in two directions.

=> Therefore, we use a minimum etching rate of 35 µm / h.





Regression analysis: at the 95% confidence level, the charge of a nucleus that forms a track with an etching rate near a breakpoint of 35 microns per hour is equal to Z = 119 (+ 10, -6).

On the graph, the red line is the description of the experimental points of the straight line, the green lines are the error corridor at the 95% confidence level. Vertical lines allocate a possible charge interval at a 95% confidence level at an etching rate near a stopping point of 35 microns per hour.

Lifetime?

Their average lifetimes should, as a minimum, be equal to the time they need for their flight from the place where they have been created to the Solar System asteroid belt, from where a predominant number of meteorites come. The minimum estimate of the lifetimes of the nuclei registered in pallasites can be determined as the time of their flight from a closest supernova (SN) to the Solar System, which depends on the velocity *V* to which a nucleus could accelerate after being formed and on the distance to the Solar System.

$$V_N = \frac{P}{E_{tot}} \qquad T = D / V_N' \cdot \sqrt{1 - V_N^2}$$

D - the distance from the nucleus place of birth to the solar system,

c = 3 * 10**5 km / sec

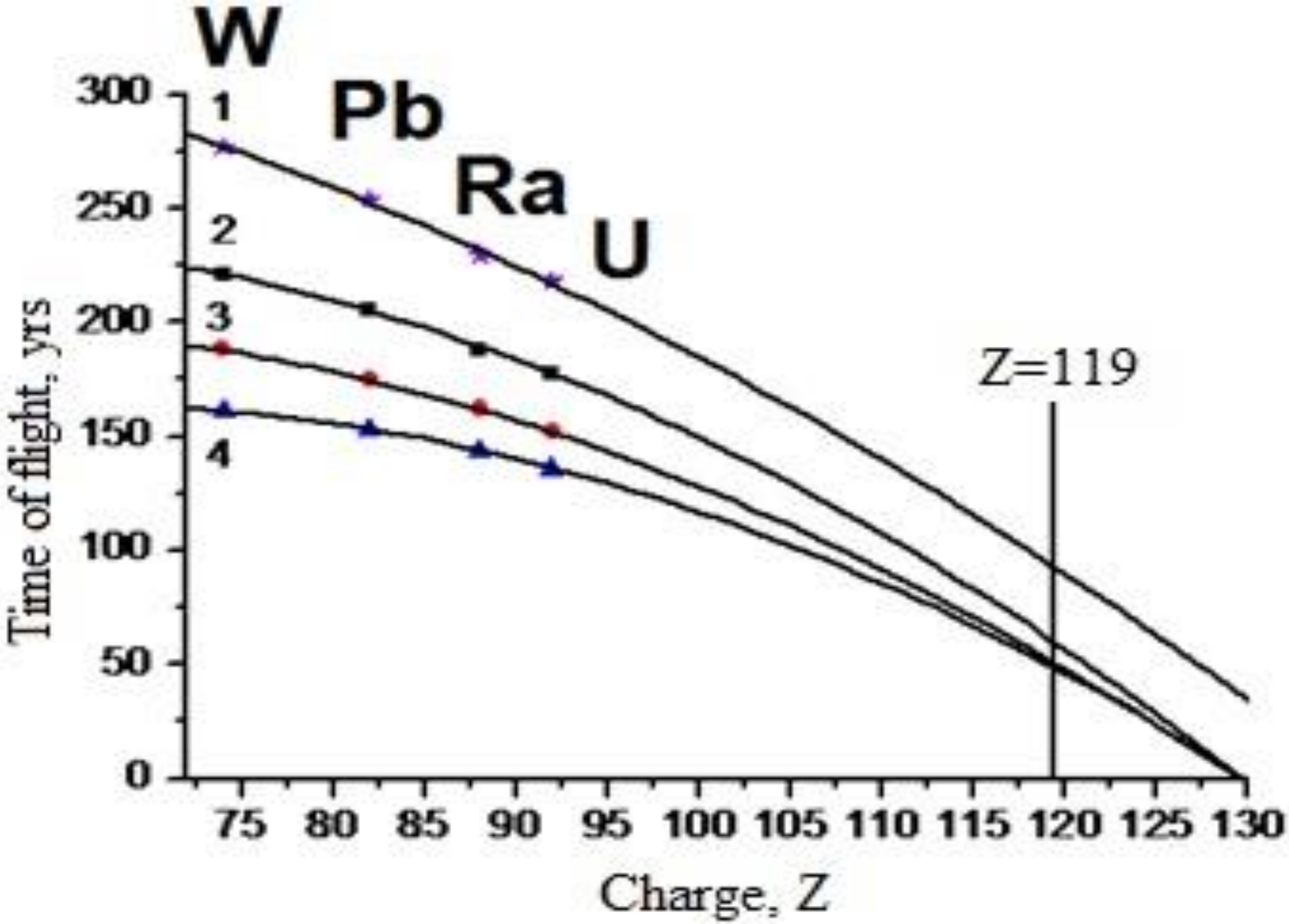
V_N in units speed of light; V_N' - in absolute units.

So, it is possible to find the time of flight and recalculate it taking into account the effect of slowing down time T

$$T = D/v \cdot \sqrt{1-(v/c)^2}$$

U

L, mm	10	20	30	40
Ekin./A, GeV/n	0,84	1,15	1,47	1,79
V_N	0,84	0,88	0,91	0,93
T, years (D=100 pc)	217	175	148	128



Dependence of the times of flights of different nuclei for various olivine crystal depths at *DD* =100 pc extrapolated by regression analysis into the region of large charges. *PD* = 10 mm (1), 20 mm (2), 30 mm (3) and 40 mm (4).

RESULTS:

1. We derived the charge distribution more then 21700 galactic nuclei whose charges are more 40.

2. We observed three events whose charges are estimated as Z=119(+10,-6).

3. Their estimated lifetimes are by many orders of magnitude larger than those of transfermium nuclei produced artificially at accelerators – at least, decades.

4. This gives reason to say that the obtained data supply arguments supporting the existence of the theoretically predicted Island of Stability for long-lived transfermium nuclei of natural origin.