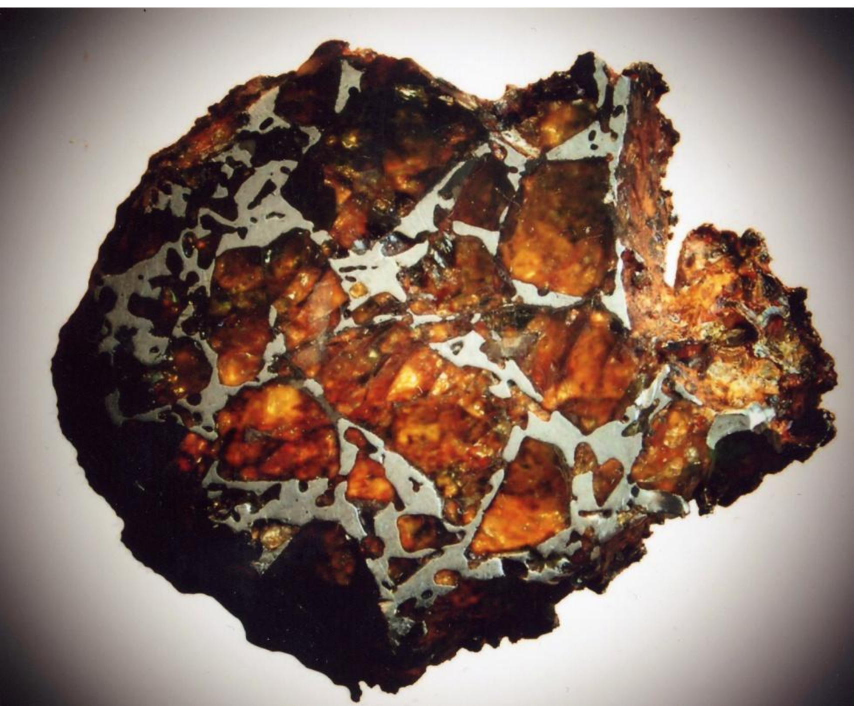
QUARKS-2014

18th International Seminar on High Energy Physics

Search for Superheavy Elements in Galactic Cosmic Rays

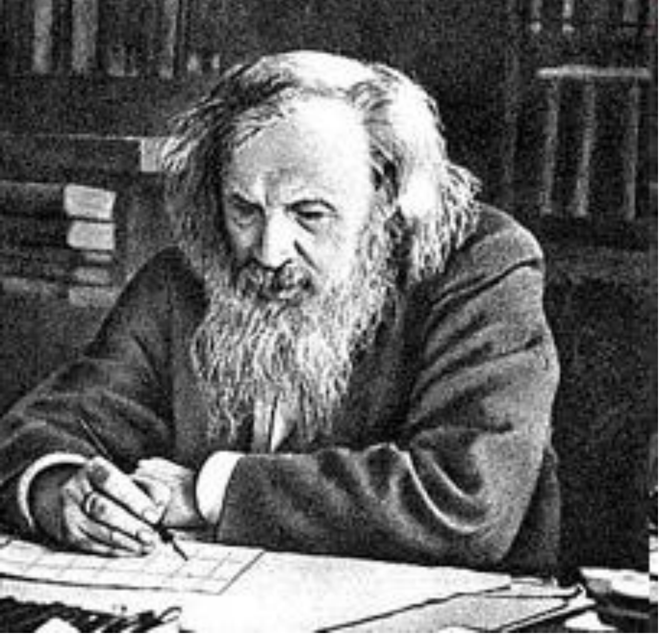


Lebedev Physical Institute of RAS

Vernadsky Institute of Geochemistry and Analytical Chemistry of RAS

N.Polukhina

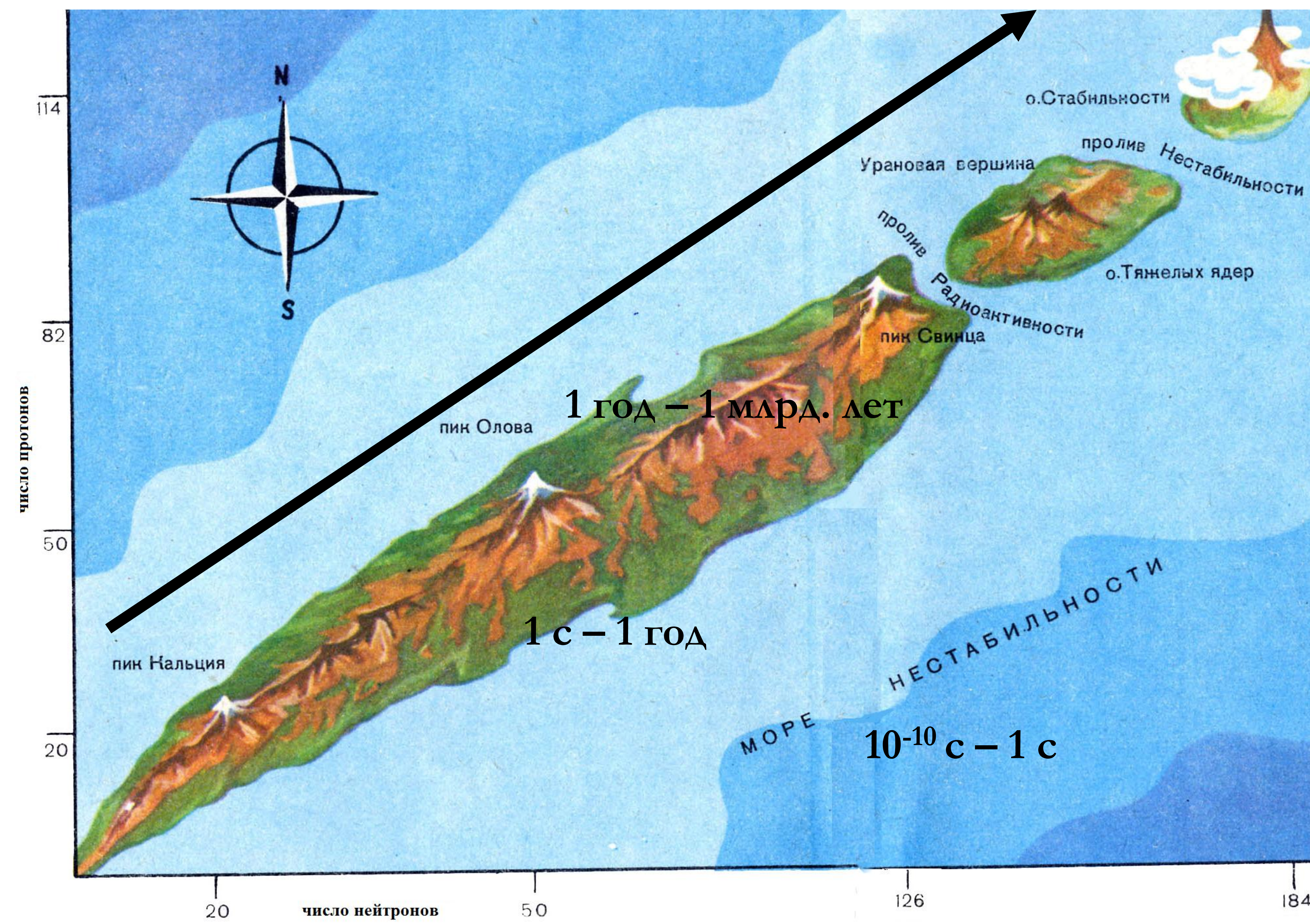
June 2-8, 2014



D.I.Mendeleev, Periodical System of Elements included: in 1869 г. – 63 elements, in 2014 - 118

(238)	(239)	(239)	(243)	(247)	(247)	(252)	(251)	(257)	(258)	(259)	(260)
92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr
$5f^3 6d^1 7s^2$	$5f^4 6d^1 7s^2$	$5f^6 7s^2$	$5f^7 7s^2$	$5f^7 6d^1 7s^2$	$5f^9 7s^2$	$5f^{10} 7s^2$	$5f^{11} 7s^2$	$5f^{12} 7s^2$	$5f^{13} 7s^2$	$5f^{14} 7s^2$	$5f^{14} 6d^1 7s^2$
1132	639	641	996	1340	1050	900	860	-	-	-	-
3818	3902	3340	2607	3110	2630	1227	-	-	-	-	-
~1.2/1.2	1.22/1.2	1.2/1.2	~1.1/1.2	1.2/1.2	~1.1/1.2	1.2/1.2	1.3/-	1.3/1.2	1.2/1.2	1.3/-	1.3/-
Uranium Уран	Neptunium Нептуний	Plutonium Плутоний	Americium Америций	Curium Кюрий	Berkelium Берклий	Californium Калифорний	Einsteinium Эйнштейний	Fermium Фермий	Mendelevium Менделевий	Nobelium Нобелий	Lawrencium Лоуренсий

(261)	(262)	(263)	(264)	(265)	(268)	(269)	( )	(277)	( )	(289
104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Uun	111 Uuu	112 Uub	113 Unt	114 Uuq
$5f^{14} 6d^2 7s^2$	$5f^{14} 6d^3 7s^2$	$5f^{14} 6d^4 7s^2$	$5f^{14} 6d^5 7s^2$	$5f^{14} 6d^6 7s^2$	$5f^{14} 6d^7 7s^2$	$5f^{14} 6d^8 7s^2$	$5f^{14} 6d^9 7s^2$	$5f^{14} 6d^{10} 7s^2$	$5f^{14} 6d^{10} 7s^2 7p^1$	$5f^{14} 6d^{10} 7s^2 7p$
Rutherfordium Резерфордий	Dubnium Дубний	Seaborgium Сиборгий	Bohrium Борий	Hassium Хассий	Meitnerium Мейтнерий	Ununnilium Унуннилий	Unununium Унуннуний	Ununbium Унунбий	Ununtrium Унунтрий	Ununquadiu Унунквади


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

It is known that at high density of free neutrons heavy nuclei are formed due to reactions of nuclear capture of two types:

1.s-process (s-slow) when a nucleus is beta-decayed before the capture of a neutron.

At neutron density of 10**10 cm**-3 the exposition time needed to completely transform iron into lead is about 10**3 years. S-process can be held responsible for formation of all the elements up to Z= 83.

2. r-process (r-rapid) – nuclear synthesis which takes place close to the boundary of neutron stability when the rate of neutron capture by nuclei is much higher than that of beta-decay.

Now it is generally accepted that many nuclei heavier that iron, including all nuclei heavier than ^{209}Bi are formed due to r-process by rapid consequential capture of large number of neutrons.

The formation of superheavy nuclei in nature can only be related to r-process.

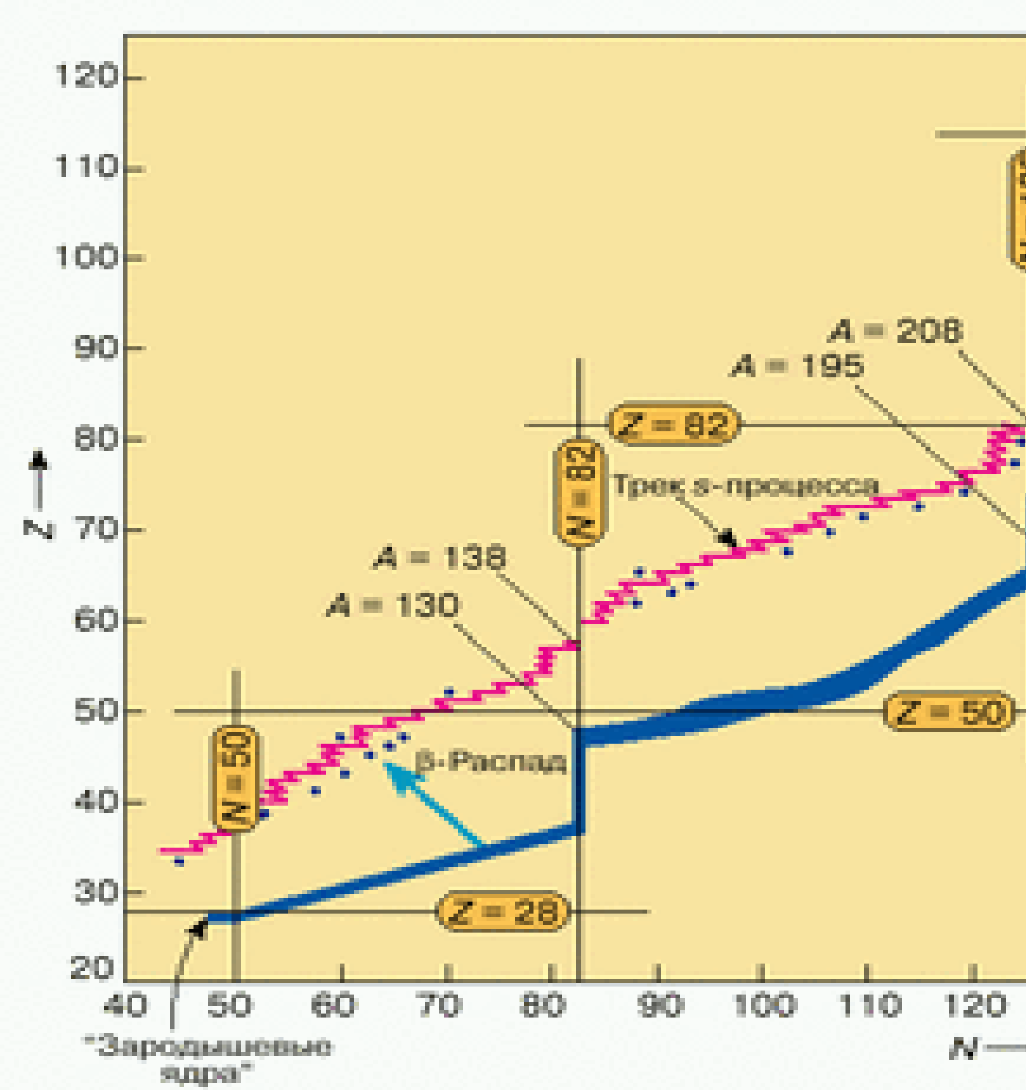
At present time are two conventional basic scenarios of evolution of astrophysical objects implying the realization of powerful r-processes with formation of superheavy elements.

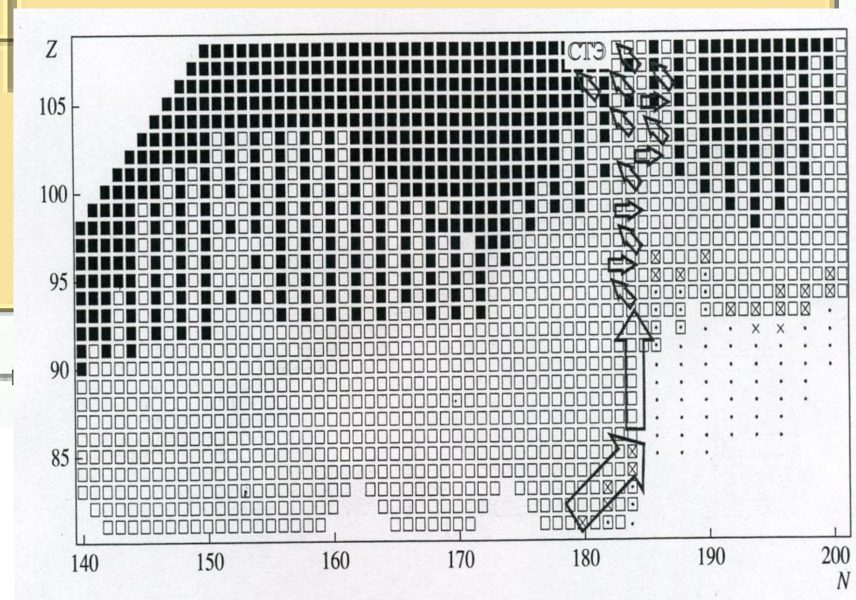
1. Ejection into interstellar space of strong neutronezed matter accompanying the merger of neutron stars (Frayburghaus et al 1999; Lattimer and Shramm, 1974; Simbalisty et al., 1982; Imshennik 2008).

2.High neutron density in the released envelope of type II supernova behind the shock wave front in neutrino heated internal part of the helium layer (Wysli et al, 1994; Witti et al, 1993).

The detailes of the mechanism are not yet clear, however both the relative concentration of elements calculated using these schemes (Frayburghaus, 1999) and observations of old stars (Sneden et al, 2000; Faruki et al 2009), allow to suggest that these scenarios might be realized in nature (Wasserburg et al, 1996; Kian and Wasserburg, 2000).

The models of formation of superheavy nuclei in astrophysical processes.





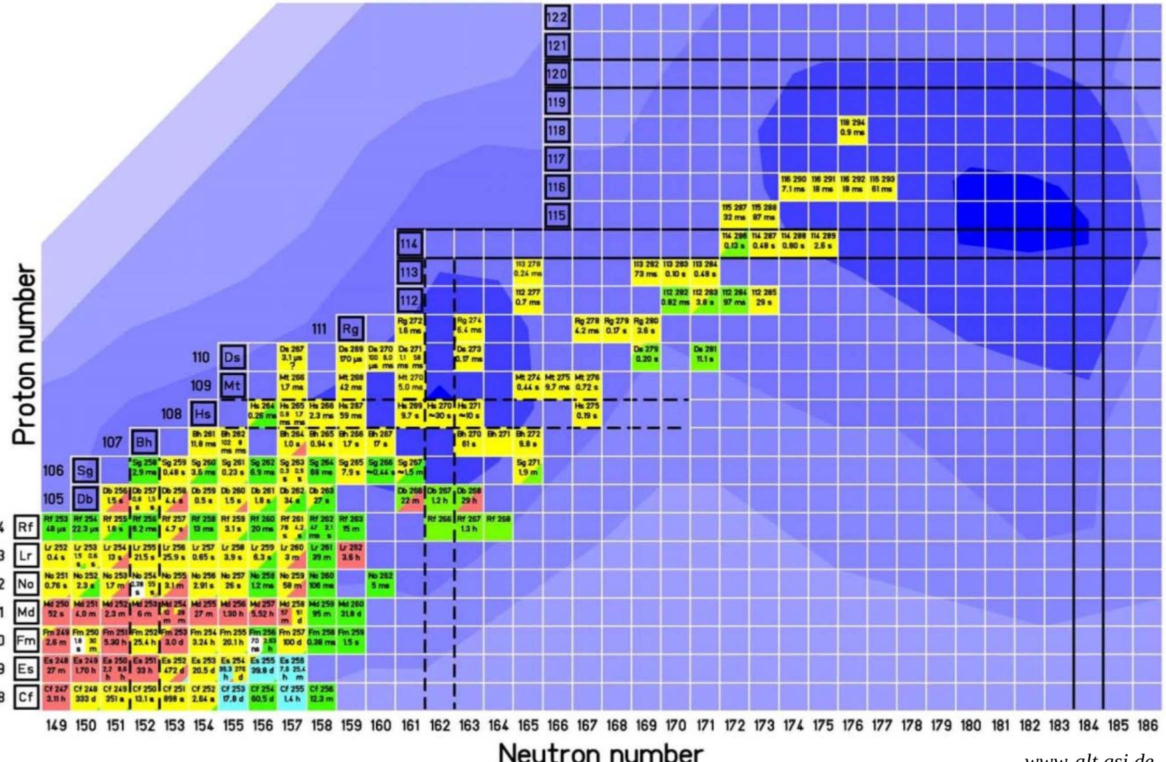
Ю.С. Лютостанский, Известия АН СССР, сер. физ., 1986, т. 50, с. 834.

И.В. Панов, И.Ю. Корнеев, Ф.-К. Тилеман, Ядерная физика, 2009, т. 72, № 6, с. 1070.

According to the theory the lifetime of element Z=110, A=294 should be more 100 million years. However, if the number of neutrons or protons in the nucleus are changed by 2-3 units (just by 1%), then the lifetime of the element is decreased by a factor 10 millions.
Another example in Pb-208 (Z=82, N=126), which is stable. However the lifetime of Pb with 127 neutrons is only 3.3 hours.

JINR synthetic elements production:

Flerov:
102, 103, 104, 105 (dubnii), 106
Oganessyan:
112, 113, 114 (flerovii), 115, 116 (livermorii), 117, 118.



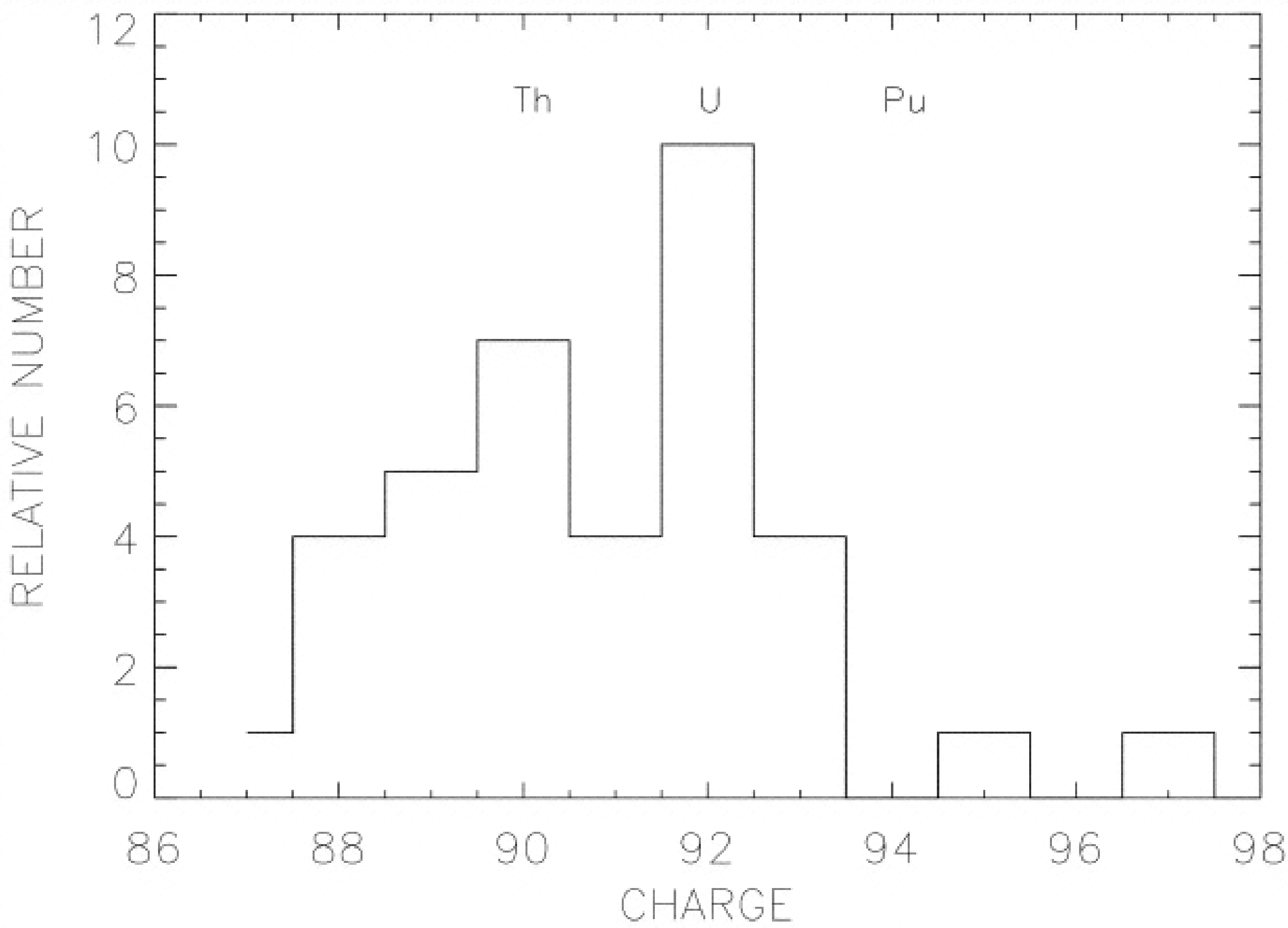
www-alt.gsi.de

Pu-239
Production of synthetic elements in the world growed from billion part of gramme up to many kilograms, even tones.

First investigation of very heavy nuclei (Z~26) were carried out by Maurette et al. (1964)
More heavy: Fleischer et al. (1967)

H. Tsao, et al., Astrophysical Journal, 549, 320-324, 2001

Domingo et al. (1995), Westphal et al. (1998), Donelli et al. (1999)



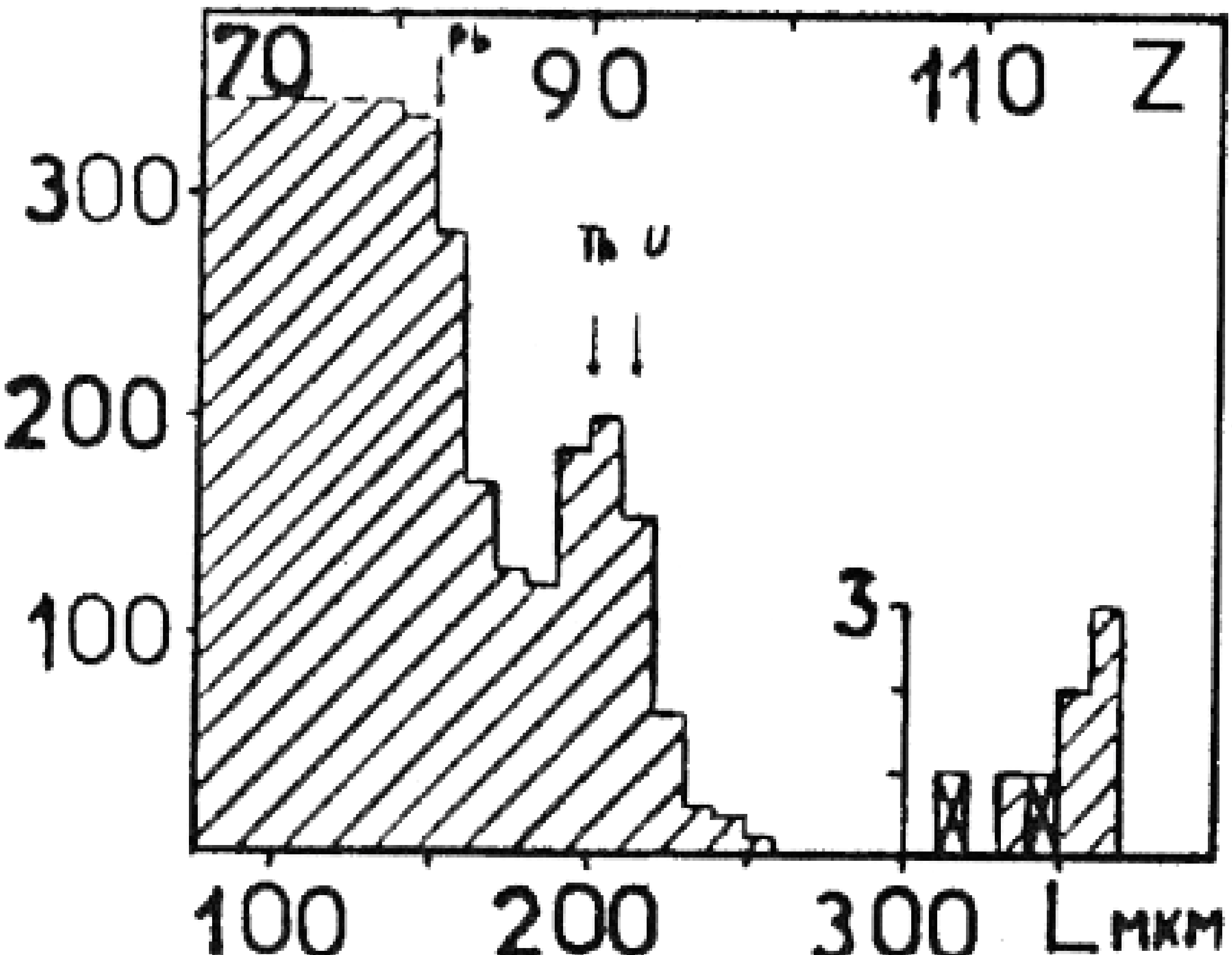
Полученные с помощью многослойных пластиковых трековых детекторов (ПТД) результаты показали перспективность их применения для изучения зарядового состава ядерной компоненты ГКЛ вплоть до элементов (Th, U)-группы. Для того, чтобы зарегистрировать несколько ядер (Th, U)-группы ГКЛ необходимо сборку, составленную из многих десятков пластин ПТД площадью сечения каждой около 0,25 м2, облучать в условиях открытого космоса (высота 300-400 км над поверхностью Земли) на ИСЗ в течение нескольких лет.

Так, например, трековый детектор, размещенный на космической станции Skylab, включал 36 камер, каждая из которых состояла из 32 слоёв ПТД лексана, экспонировался на высоте 430 км в течение 253 дней. Идентификация заряда ядер, образующих треки, осуществлялась по величине скорости их травления в пластике.

ПТД сборки, составленные также из пластин лексана, с расположенными между ними пластинами свинца (эксперимент UHCRE - Ultra Heavy Cosmic Ray Experiment) экспонировались на высоте 450 км в течение 69 месяцев на космической станции LDEF. Всего в этом эксперименте было зарегистрировано около 2500 треков, относящихся к ядрам с Z>65.

Эксперимент TREK проводился на космической станции Мир на высоте 450 км и продолжался более 40 месяцев. Детектор включал 150 стопок, каждая из которых состояла из 16 листов барий-фосфатного стекла (BP-1). После травления было найдено несколько сотен следов, принадлежащих тяжёлым ядрам с $Z > 70$.

The most detailed – Perelygin V. et al. (1985)



For nuclei with Z>86 there are just several scores of events with very uncertain data on their energy distribution, (*Binns et al., HEAO 3; Fowler et al., Ariel 6; Shirk et al., Skylab)*) - flux of such particles is about 1-2 nucl./m^2/year

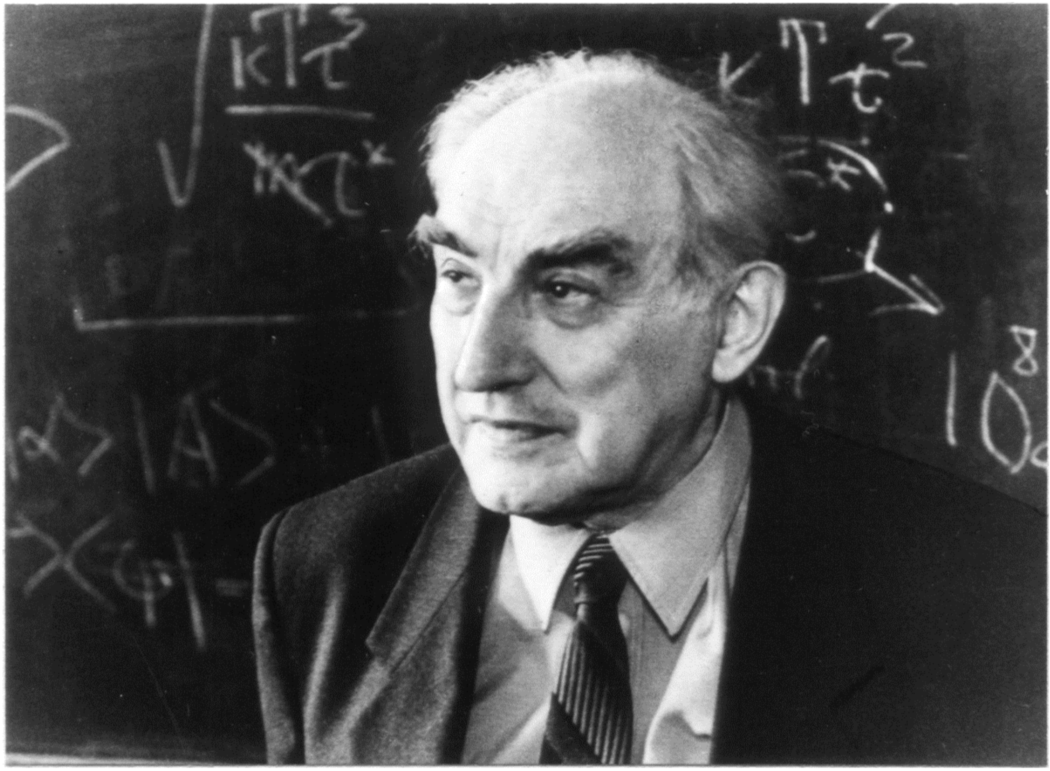
Conclusion: large area detectors and long expositions are needed.

The meteorites are natural “detectors” which have many millions years of exposition time.

The use of the factor of long-time exposure of meteorites in space leads to a great advantage of the method for the search of superheavy elements in crystals of olivine from meteorites as compared with methods based on the use of various satellite and aerostat detectors.

G.Flerov evaluated that in consideration of great meteorite ages investigation of 1 cubic centimetre olivine from meteorites is equal to results of space experiment with 1 ton of emulsion during 1 year.

Prof. V.L.Ginzburg (Nobel prize of 2003) considered problem of superheavy nuclei search (investigation of existence of stability element islands) as one of the most important problems in the modern physics.



Prof. V.L.Ginzburg included it to his famous list of first priority physical tasks.

Starting 2005 the investigations of galactic cosmic ray nuclei are carried out at Lebedev Physical Institute of RAS.

ady 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 nuclear-physical and rophysical aspects of investigations associated with search for heavy and superheavy nuclei in the comsition of cosmic rays. We also discuss the potentiality searching for tracks of these nuclei in the olivine stals found in meteorites with the use of the comtely automated PAVICOM setup, which was signed for the scanning and processing of tracks of ticles.

tinue to hold for very large values of N and Z, the existence of stability islands for even heavier nuclei must not be ruled out.

Verification of the existence of unusual stable forms of nuclear matter containing, for example, strange [4] or other even heavier quarks [5] would also be of obvious interest.

2. The measurement of fluxes and of the spectra of heavy and superheavy nuclei composing cosmic rays is

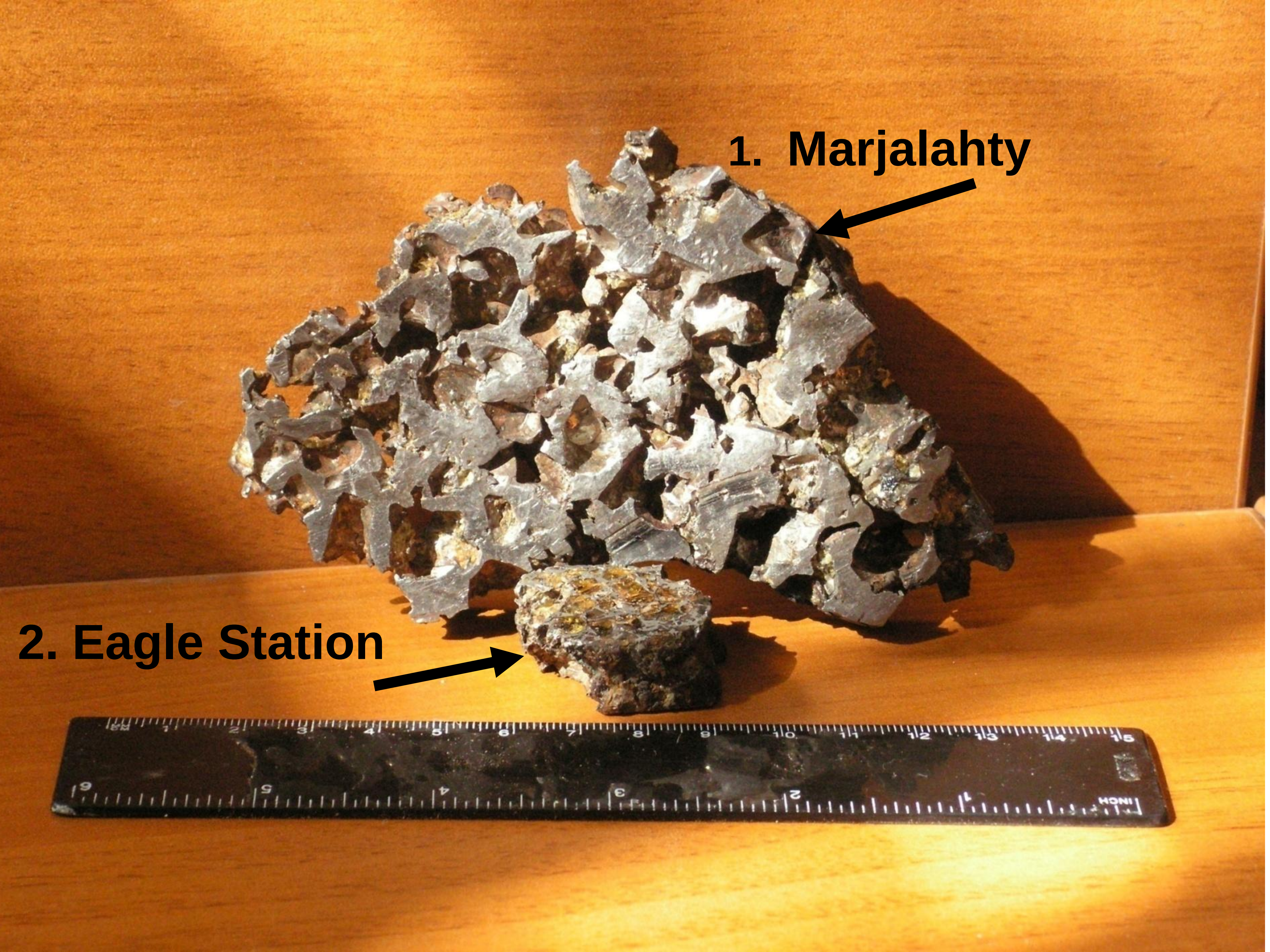
1.Marjalahty
(Finland, 1902 г.).

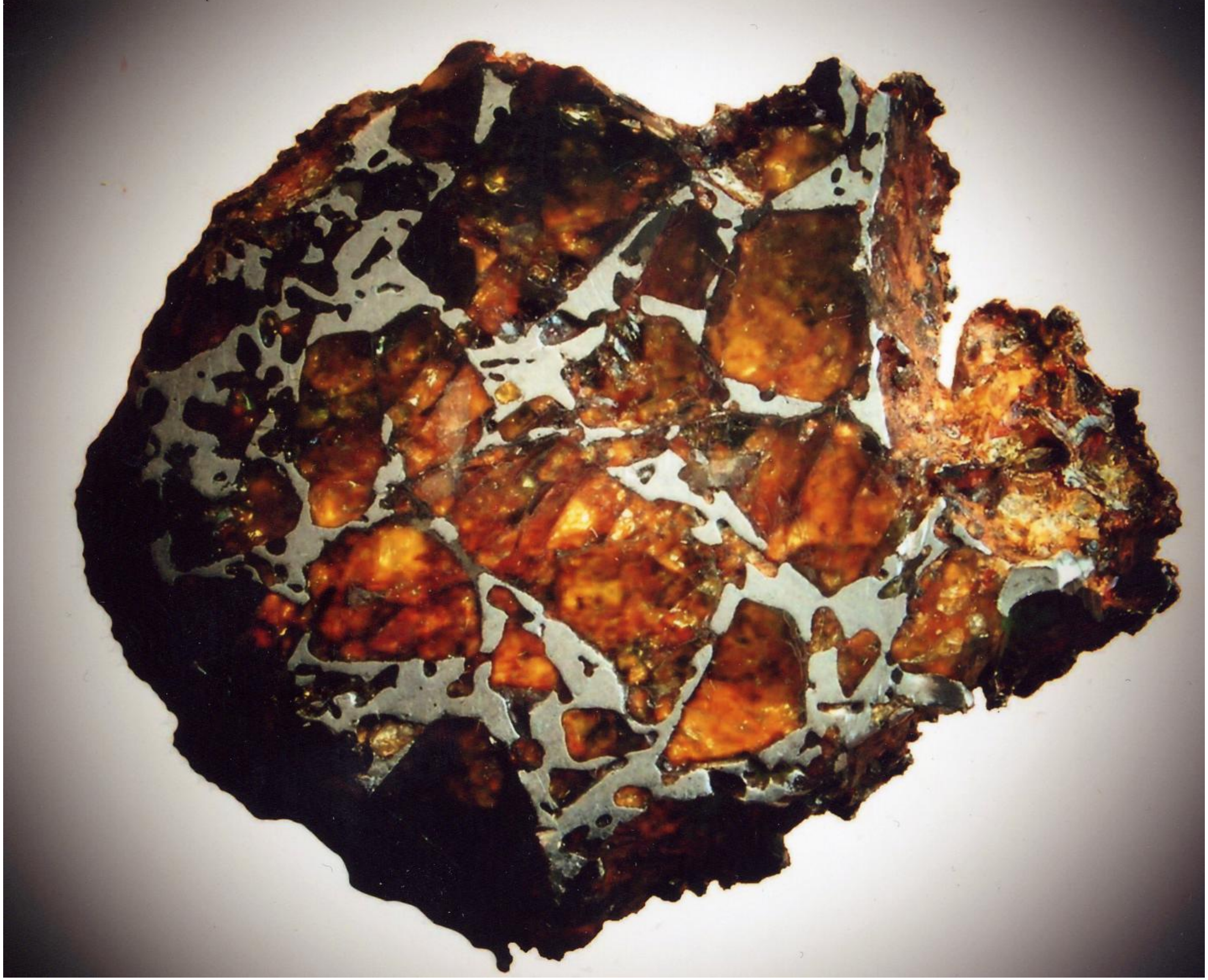
The size ~ 30 см.
The weight ~ 45 kg.
The age ~ 185 ml. years.

2. Eagle Station
(USA 1880 г.).

The size ~ 25 см.
The weight ~ 38 kg.
The age ~ 300 ml. years.

(C) Chinellato Matteo - Natural History Museum Milan


1. Marjalahty
2. Eagle Station

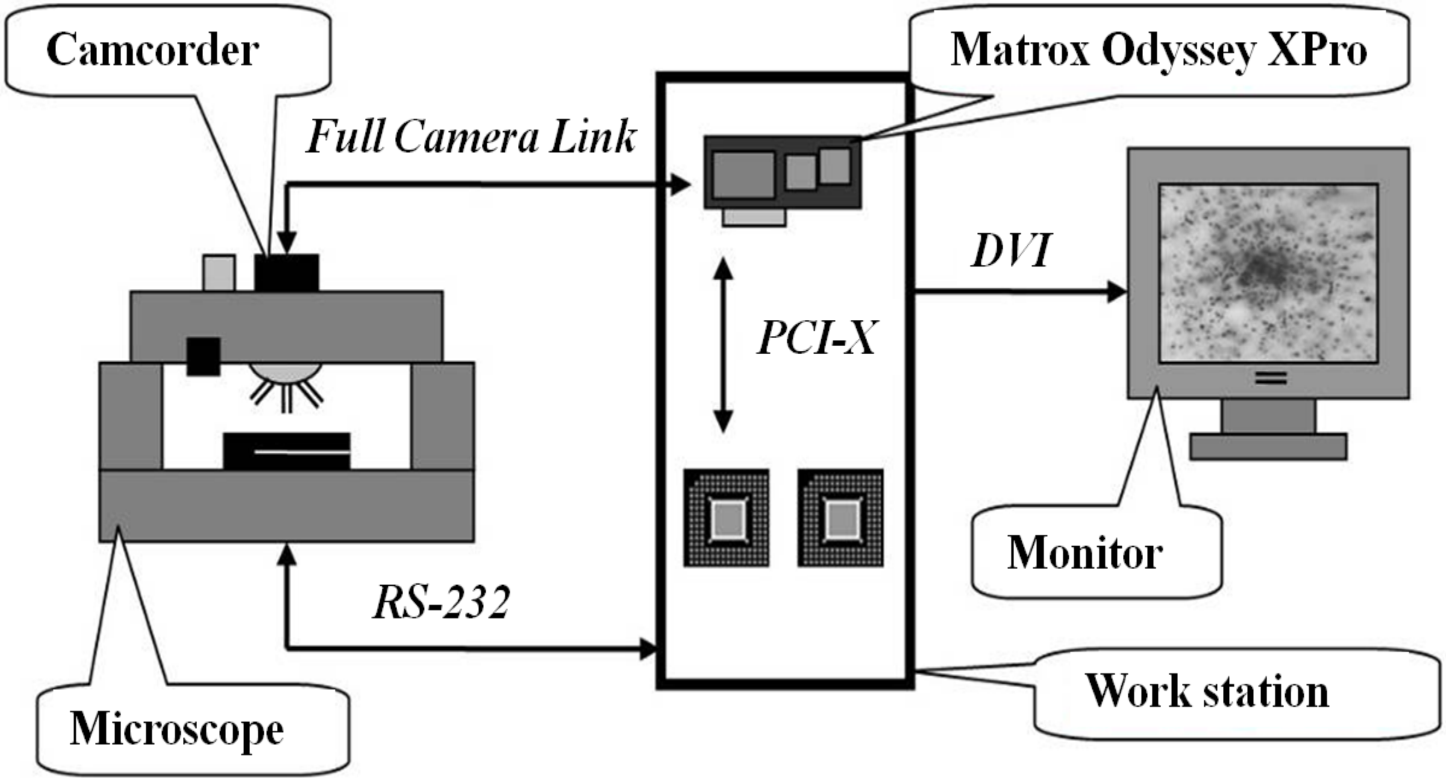


Pallasite meteorites consist of an iron–nickel matrix with inclusions of olivine crystals, a yellow semi-transparent mineral of up to 1–2 cm in size

Completely Automated Measuring Facility PAVICOM

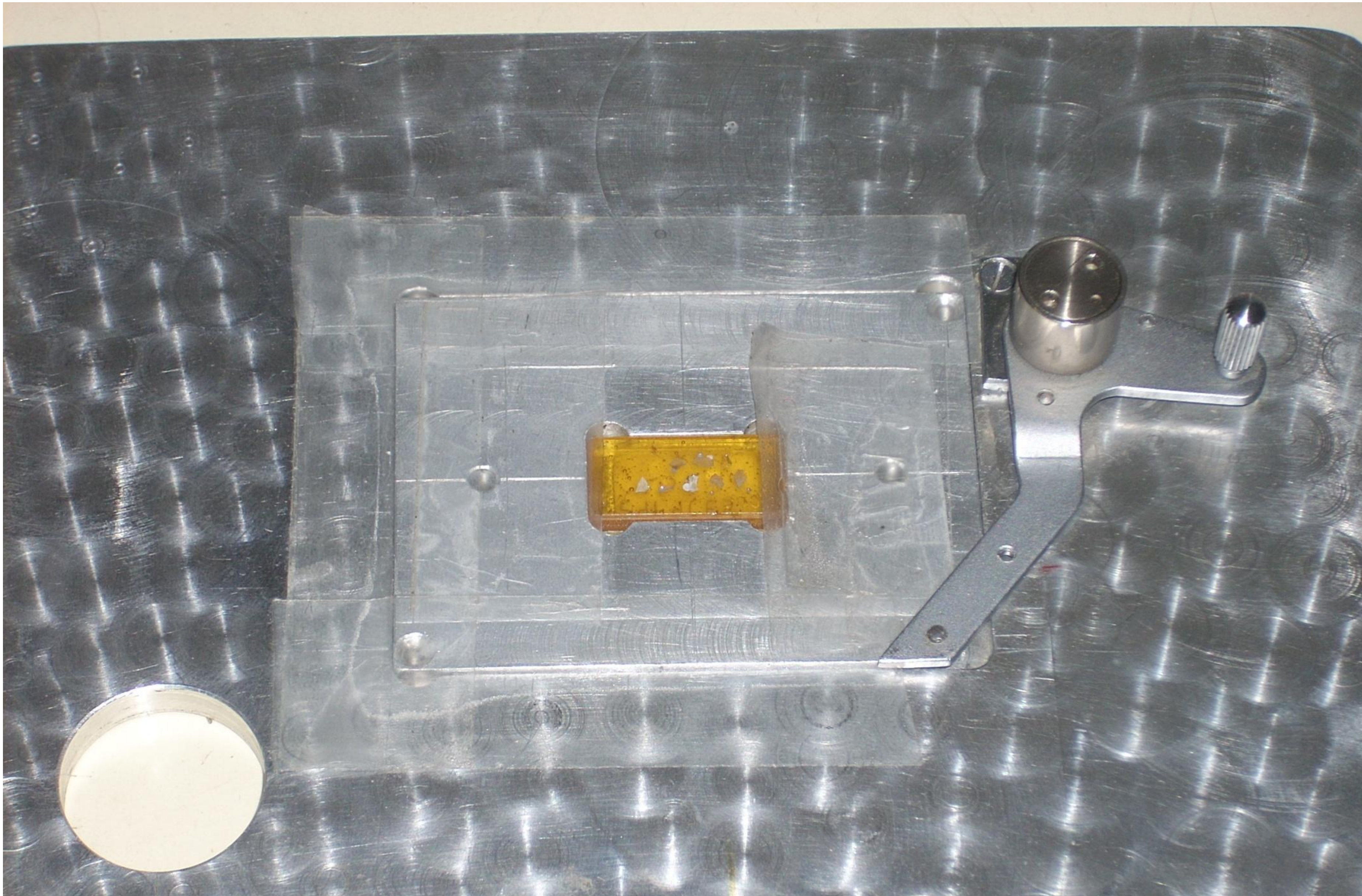
Highly efficient measuring complex PAVICOM

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

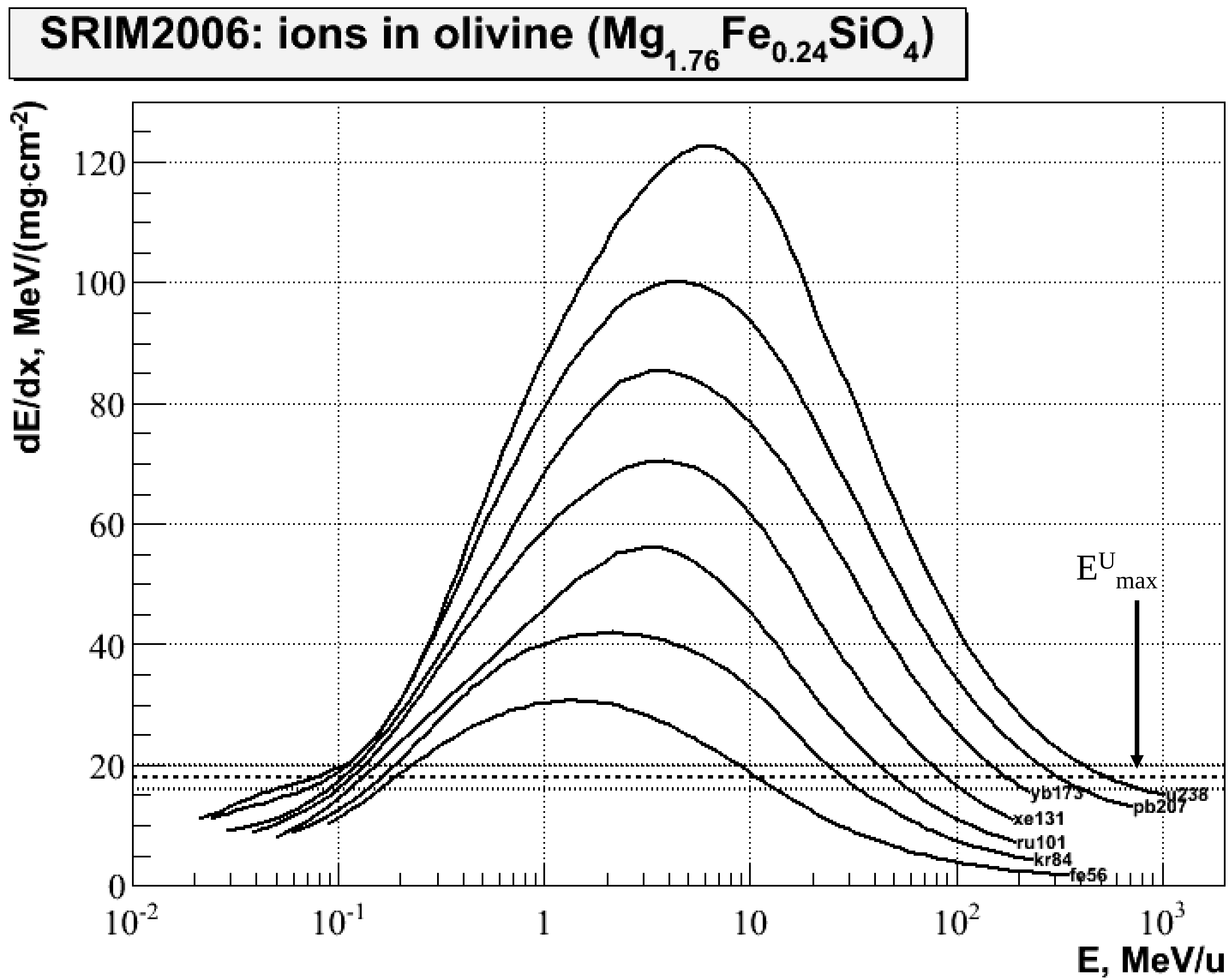


The complex is based on the use of CCD cameras to register and digitize images of heavy nuclear tracks in the microscope, and a original software package for recognition of track images and reconstitution of track positions in space

Few crystals mounted in epoxy tablet for investigation on microscope.

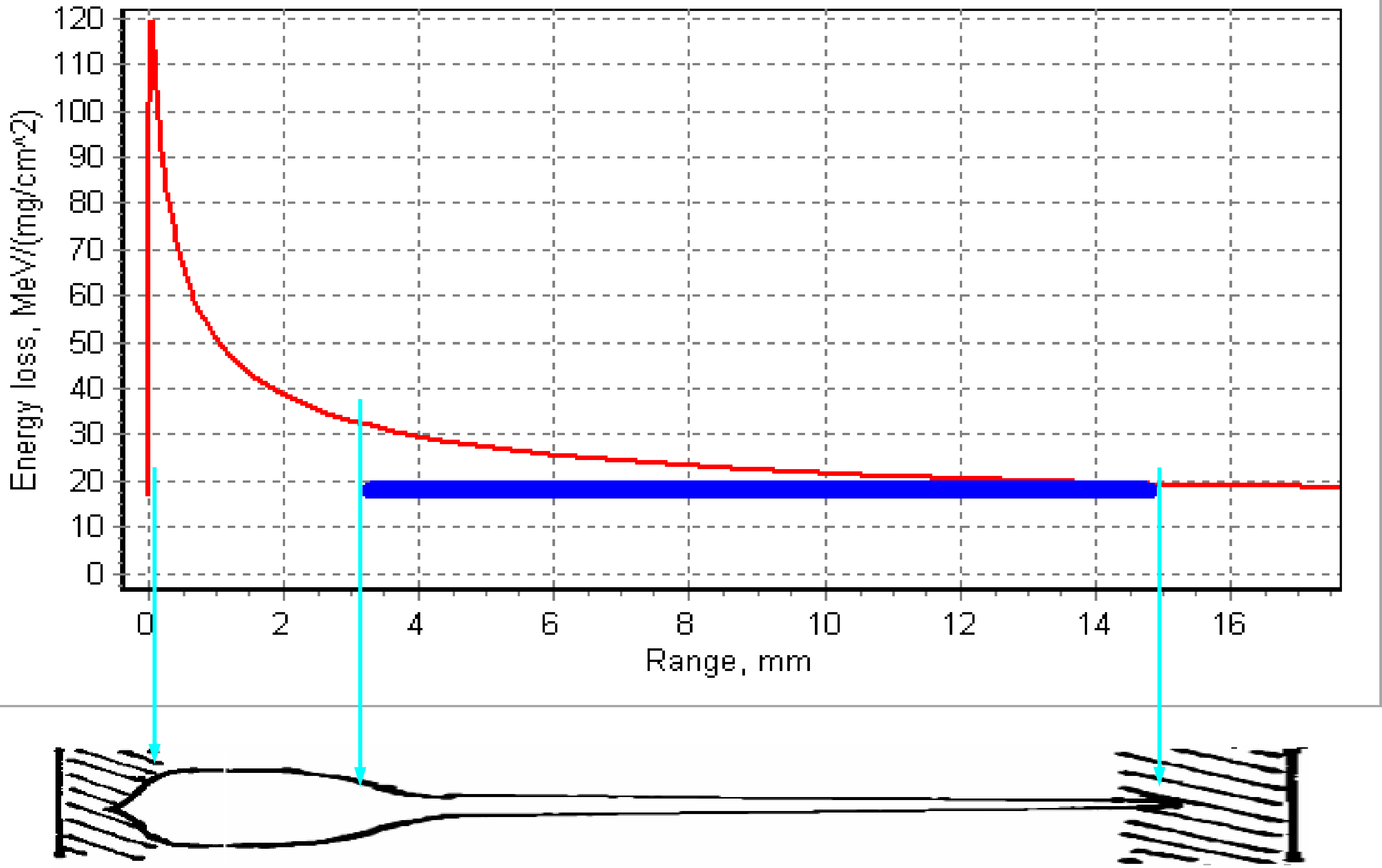


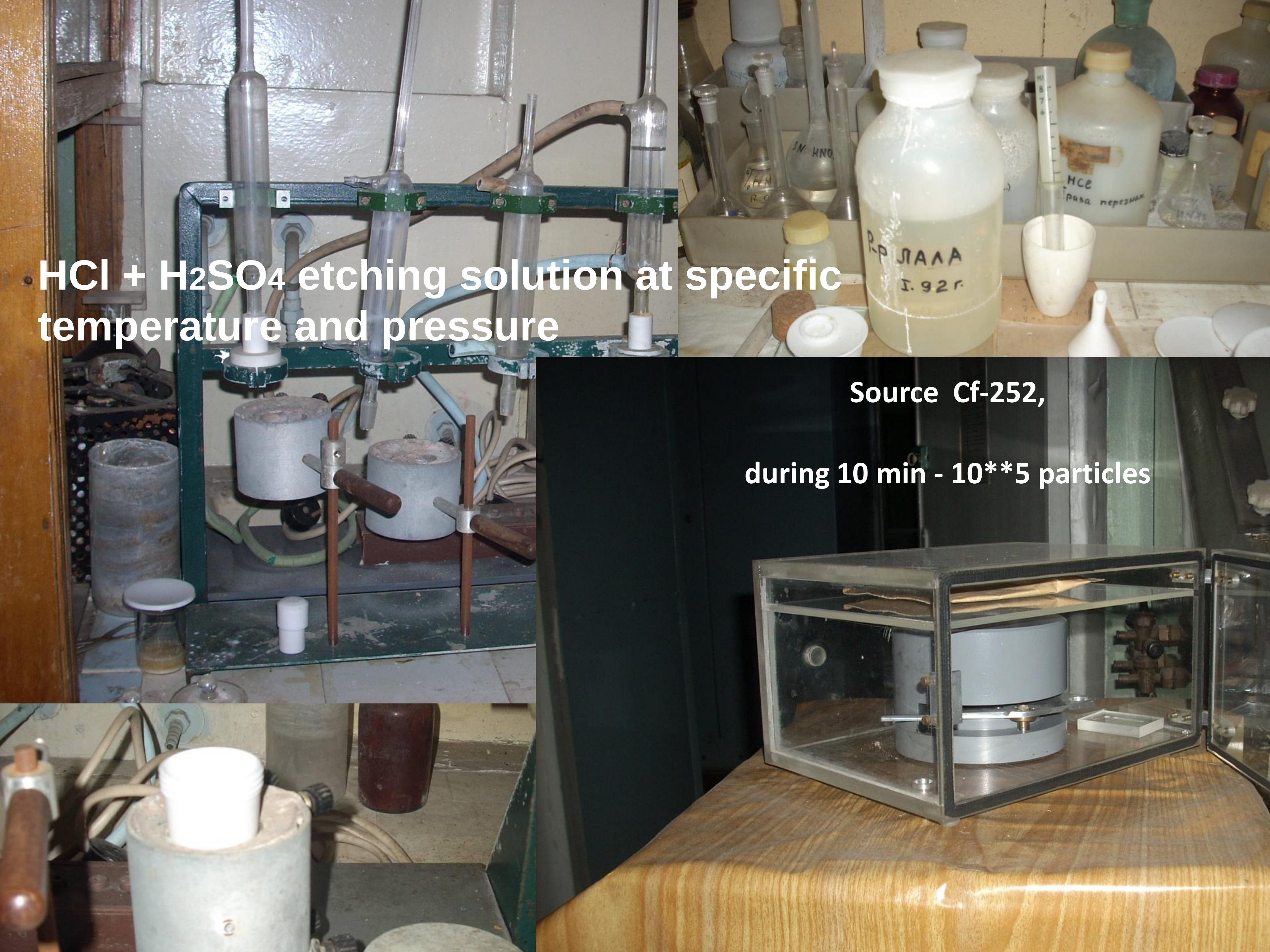
The curves illustrate the method of the full etching track length determination in olivine for a number of nuclei from $^{56}_{26}Fe$ up to $^{238}_{92}U$



The scheme of etching track formation in olivine

Heavy nuclei produce etchable structure transformations in solid-state detector

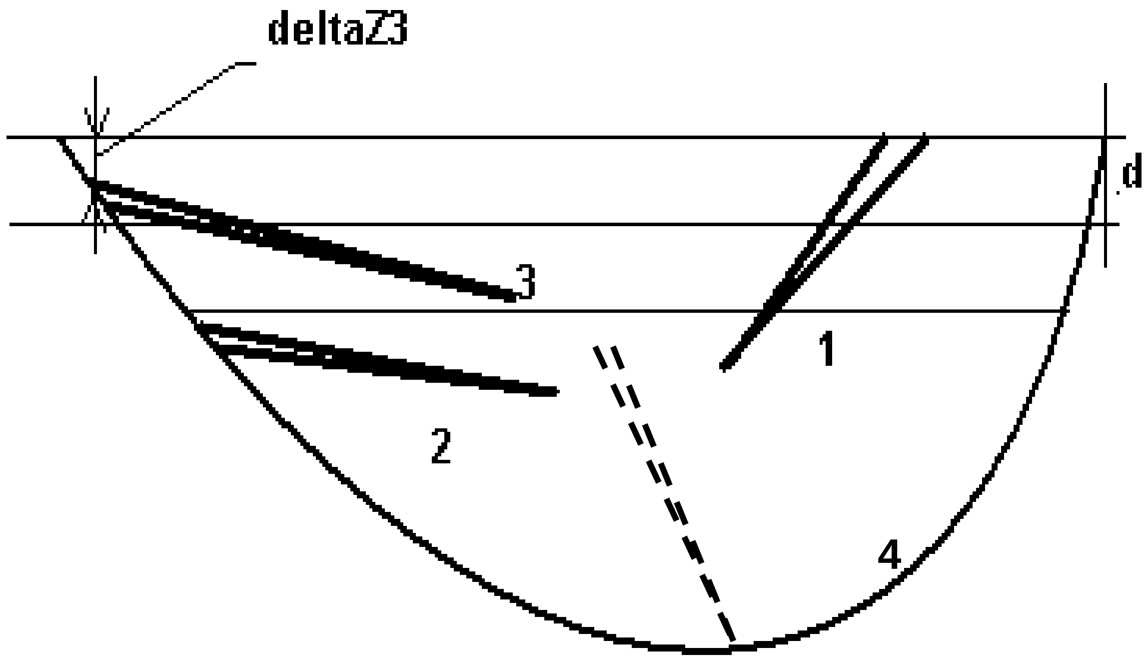




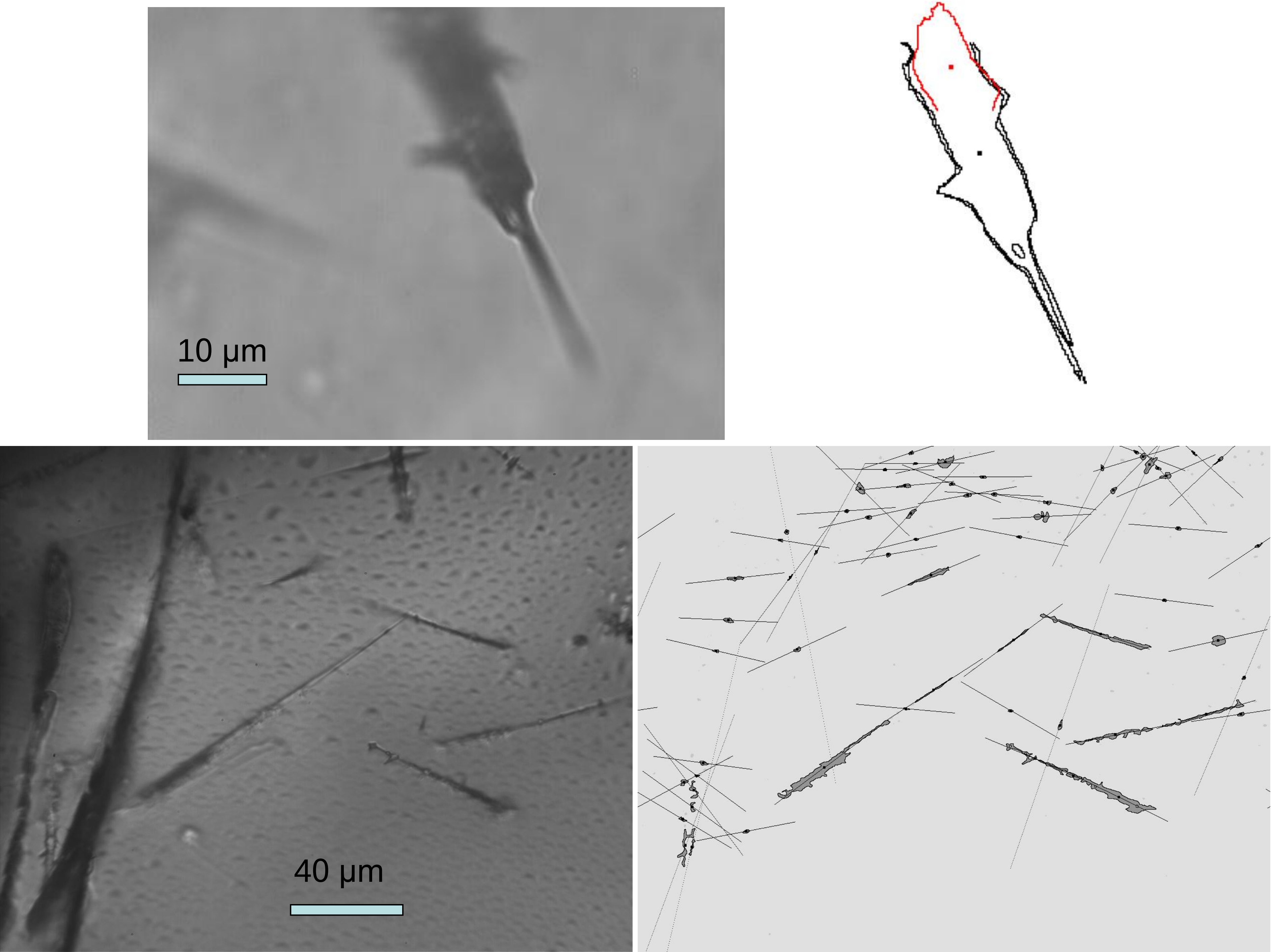
HCl + H_2SO_4 etching solution at specific temperature and pressure
Source Cf-252,
during 10 min - 10**5 particles


50 µm

The method of stepwise cut and etching is used



The thickness of cut layer is ***d*** = 30 – 100 μm


10 µm
40 µm

The charge identification method

The main problem:

the size of the using olivine pieces is less as compared with total etched length.

=> The measurement only track length is not enough

Characteristics :

1. **The length of etched track.**
2. **The etching rate.**
3. **The etched channel width.**

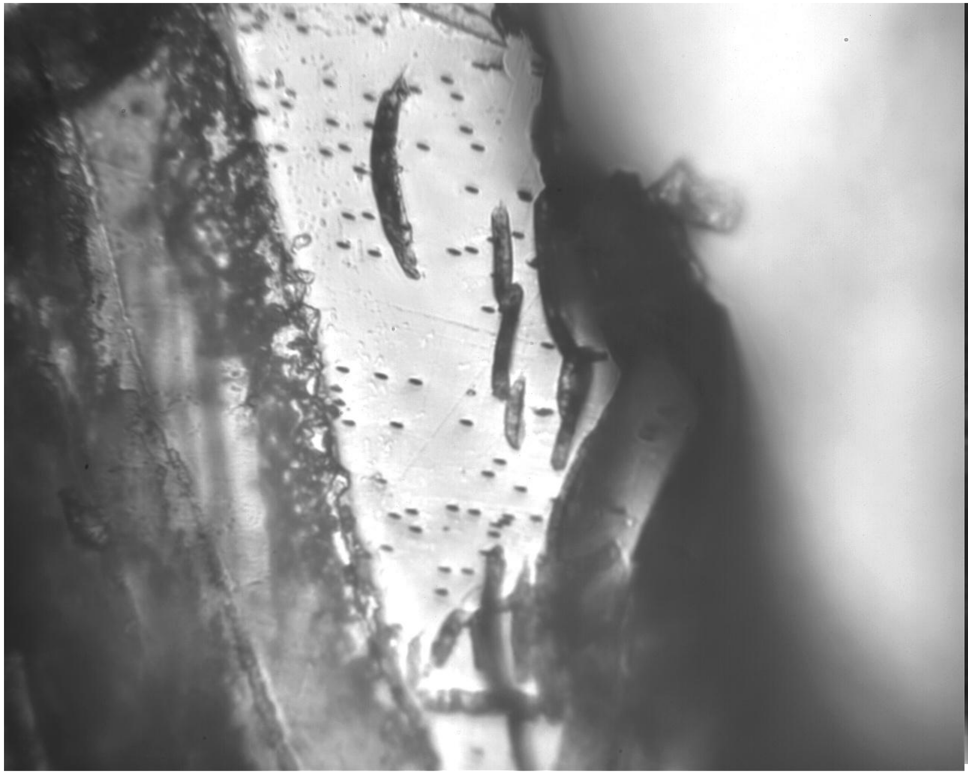
=> It is necessary to have calibration experiments

Darmschtadt, GSI

Xe nuclei tracks (E=11,4 MeV/n)

Size field of view ~ 500×700 microns

Flux density (4-10)105 nuclei/cm**2 - 30-80 tracks/crystal**

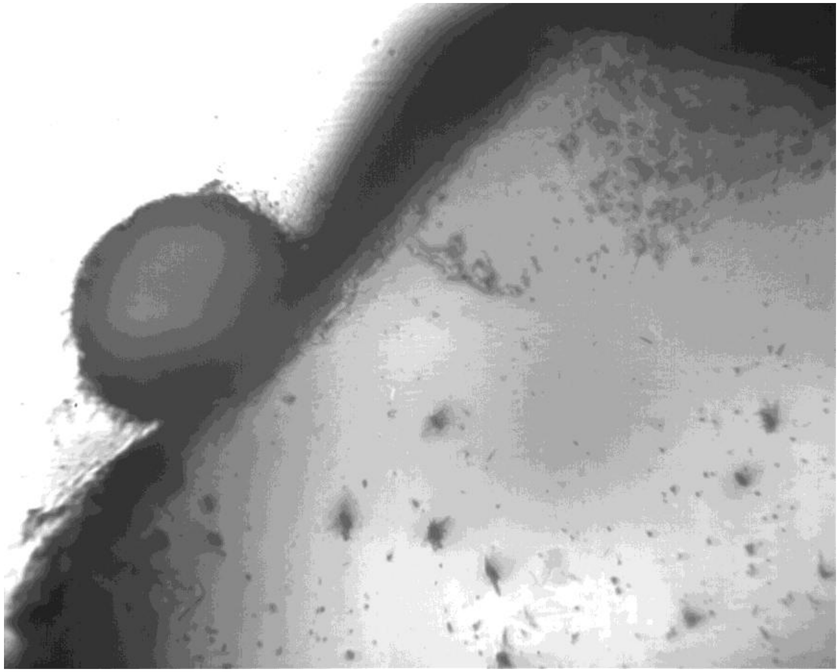


Length of tracks 57±6 мкм (by the calculation ~ 65 мкм)

Etch rate (E=11.4 MeV/nucl) ≈ 10-14 micron/hour

Darmschtadt, GSI, 2009 г.,

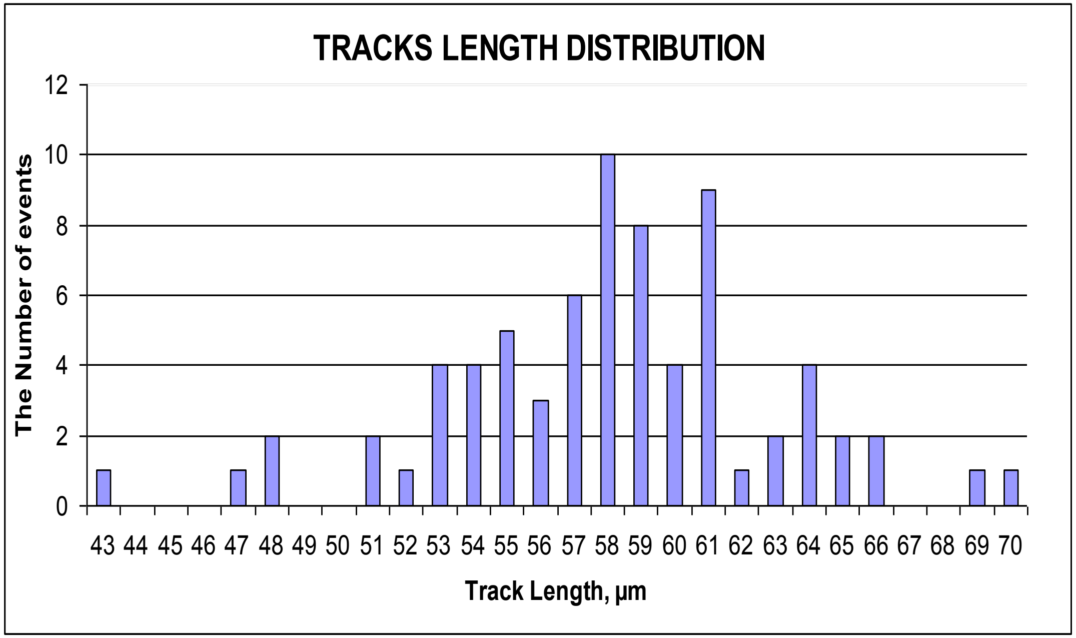
Au, 11.4 MeV/n



Calculation: (77 ± 5) microns

Experiment: (69 ± 6) microns

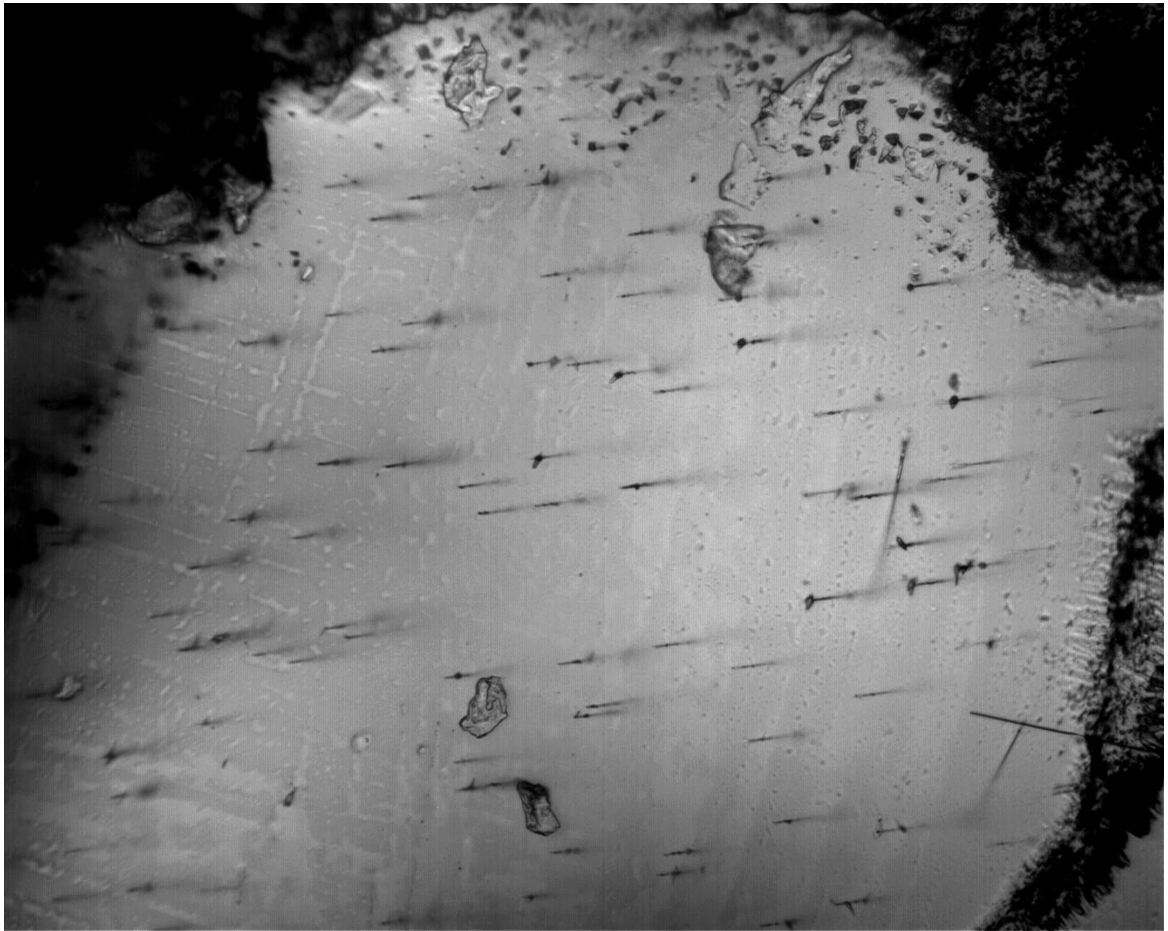
Etch rate 16 micron/hour

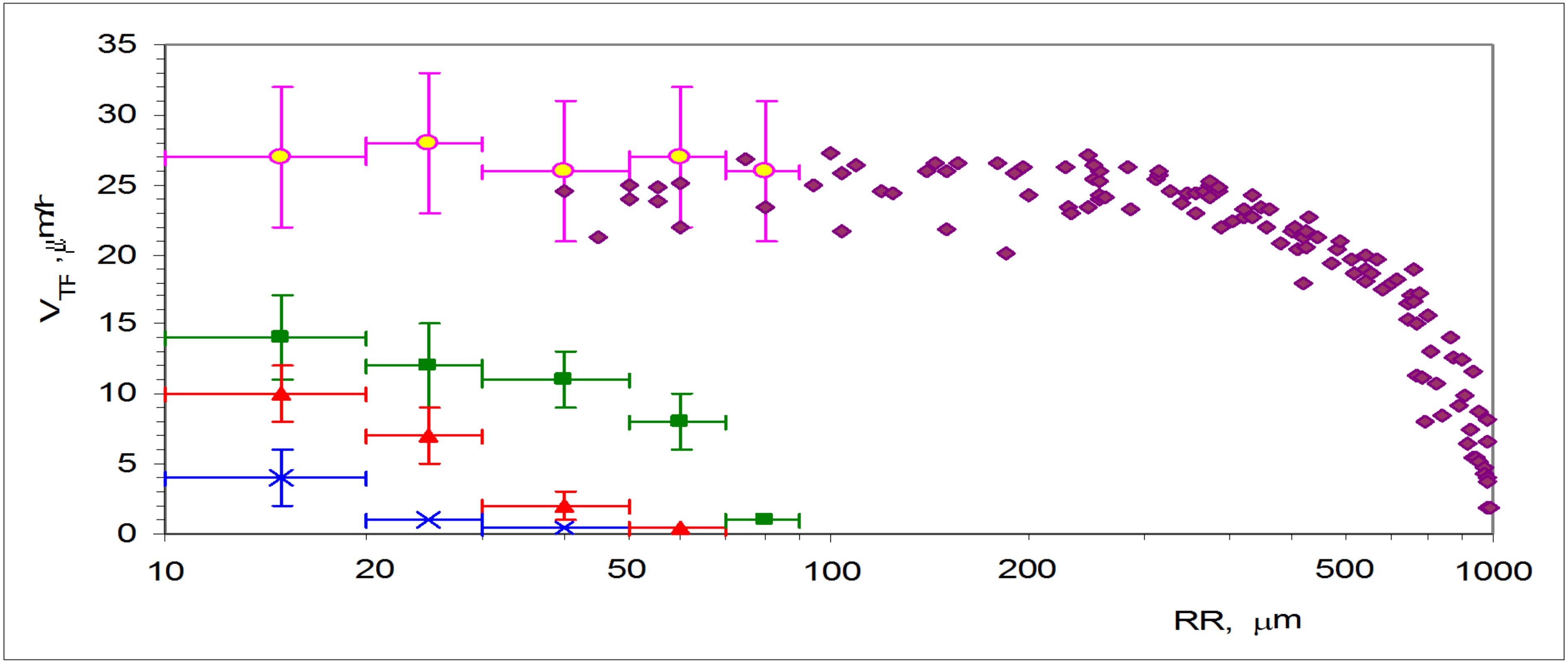


Darmschtadt, GSI, 2010 г., U, E= 150 МэВ/н

Obtained lengths U (91±5 μm)

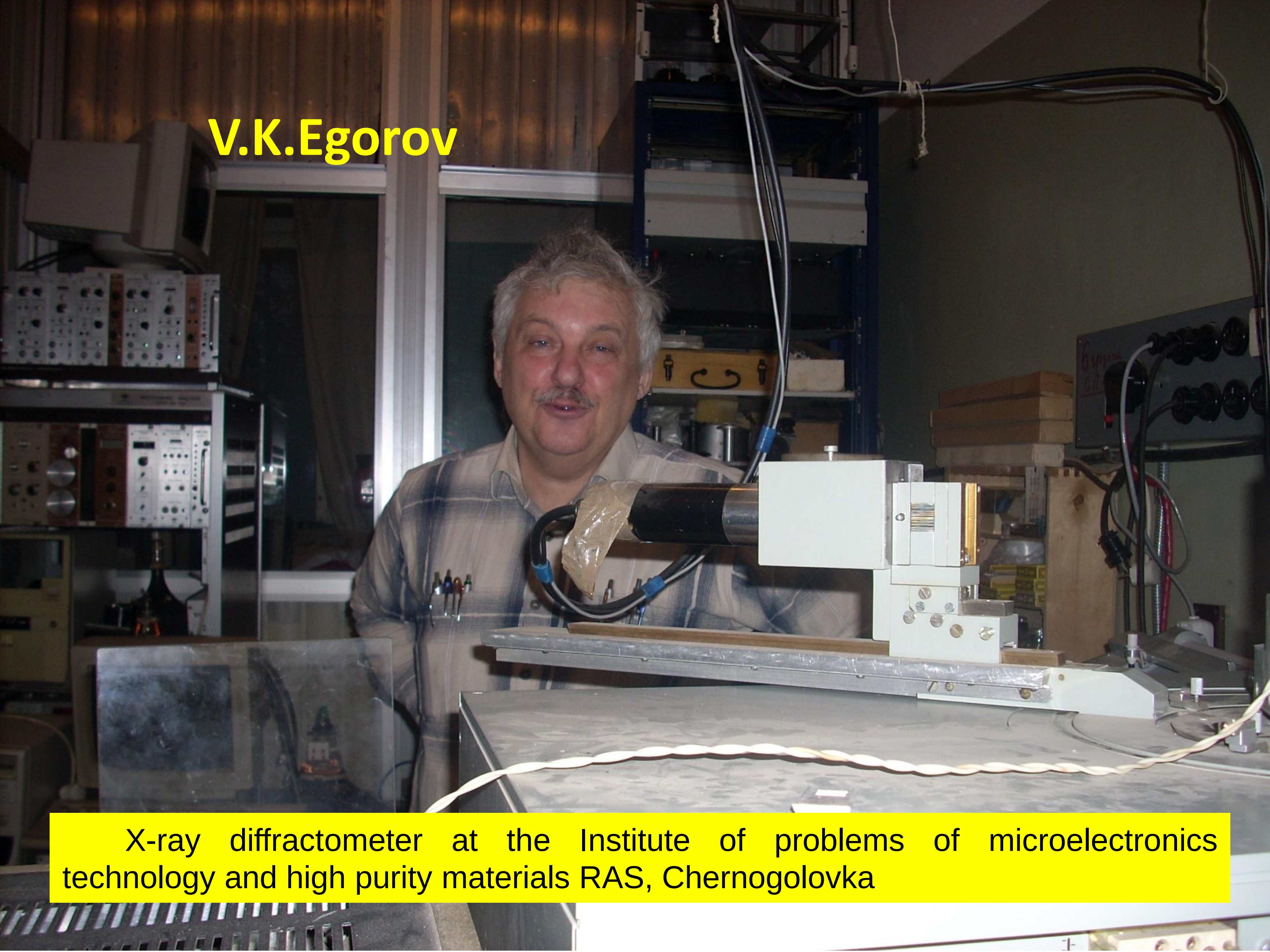
Good agreement with SRIM and GEANT4 programs U (89±5 μm)





Measured VTR values at the certain residual range (RR) of accelerated Kr, Xe and U ions and Fe nuclei in olivine crystals from the Marjalahti pallasite.

V.K.Egorov



X-ray diffractometer at the Institute of problems of microelectronics technology and high purity materials RAS, Chernogolovka

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									можна текстура сокого качества
8									Высокая
9									Средняя
10									морфность или елкодисперсия

О НЕКОТОРЫХ СТРУКТУРНЫХ ОСОБЕННОСТЯХ КРИСТАЛЛОВ ОЛИВИНА ИЗ МЕТЕОРИТА МАРЬЯЛАХТИ

В. К. Егоров[1], Л. Л. Кашкаров[2], Н. Г. Полухина[3], В. А. Царев[3]

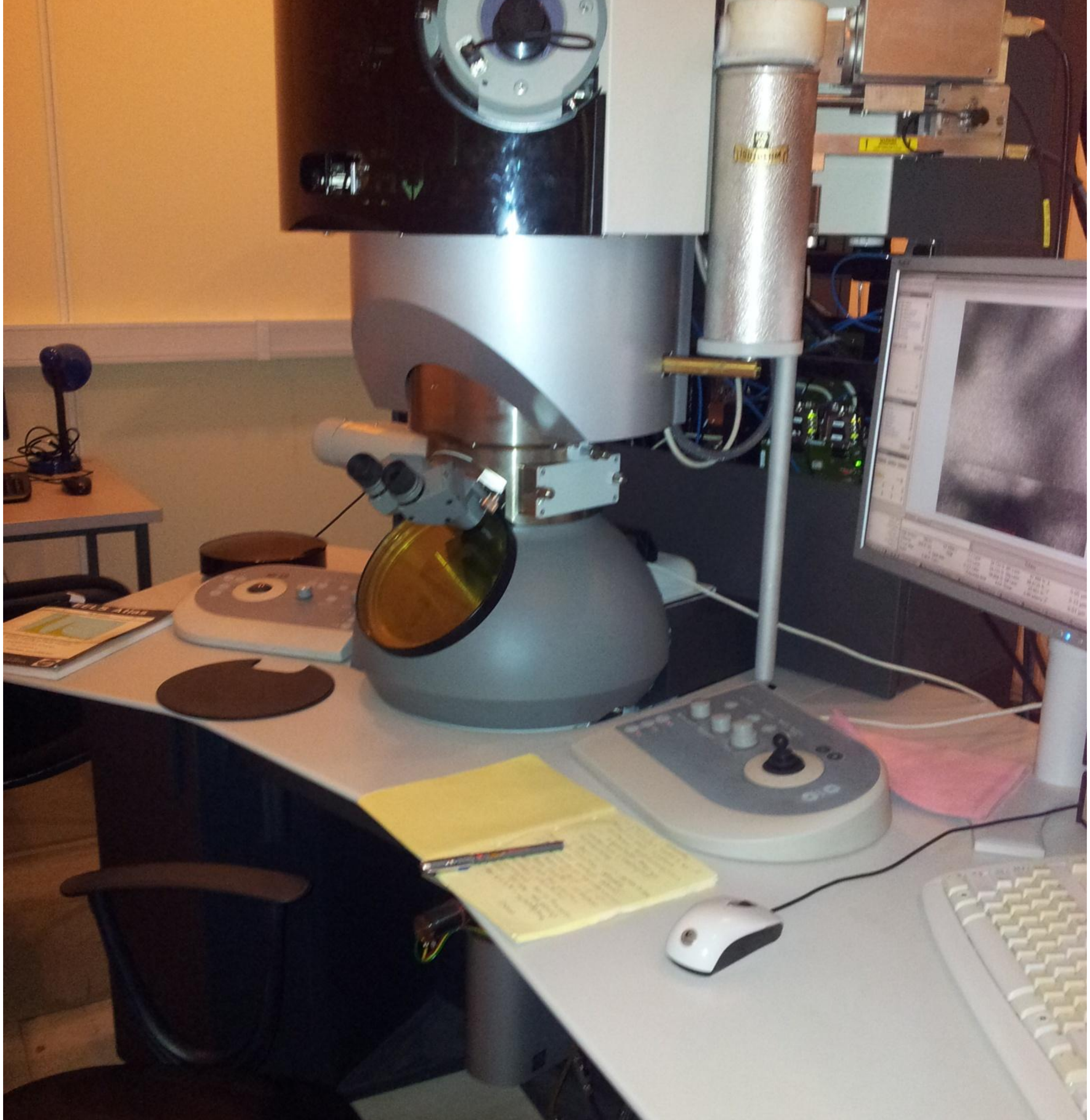
[1] Институт проблем технологии микроэлектроники и особочистых материалов РАН, Черноголовка, *egorov@ipmt-hpm.ac.ru*

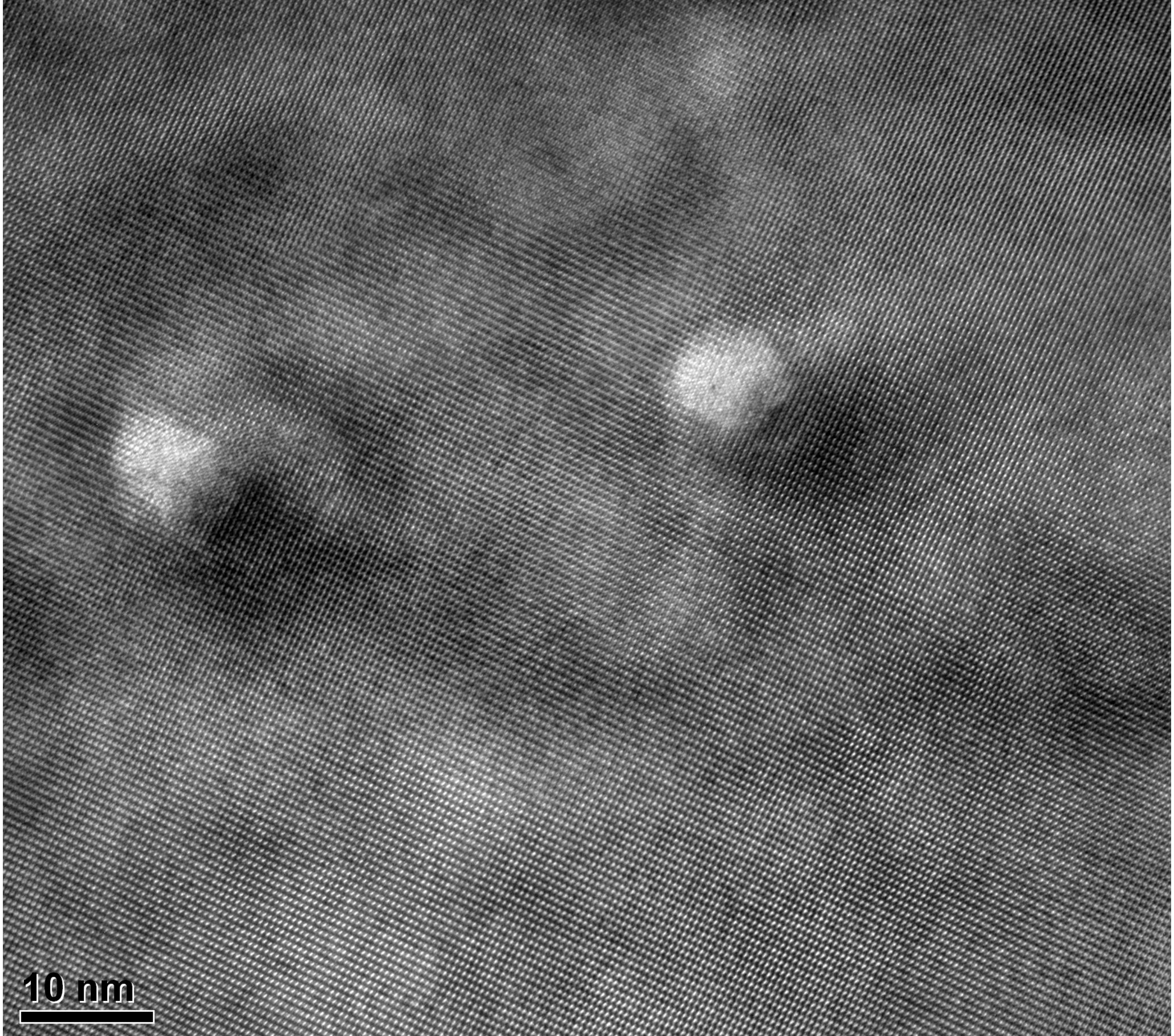
[2] Институт геохимии и аналитической химии им. В. И. Вернадского РАН, *ugeochem@geochem.home.chg.ru*

[3] Физический институт им. П. Н. Лебедева РАН, Москва, Россия, *poluhina@sci.lebedev.ru*

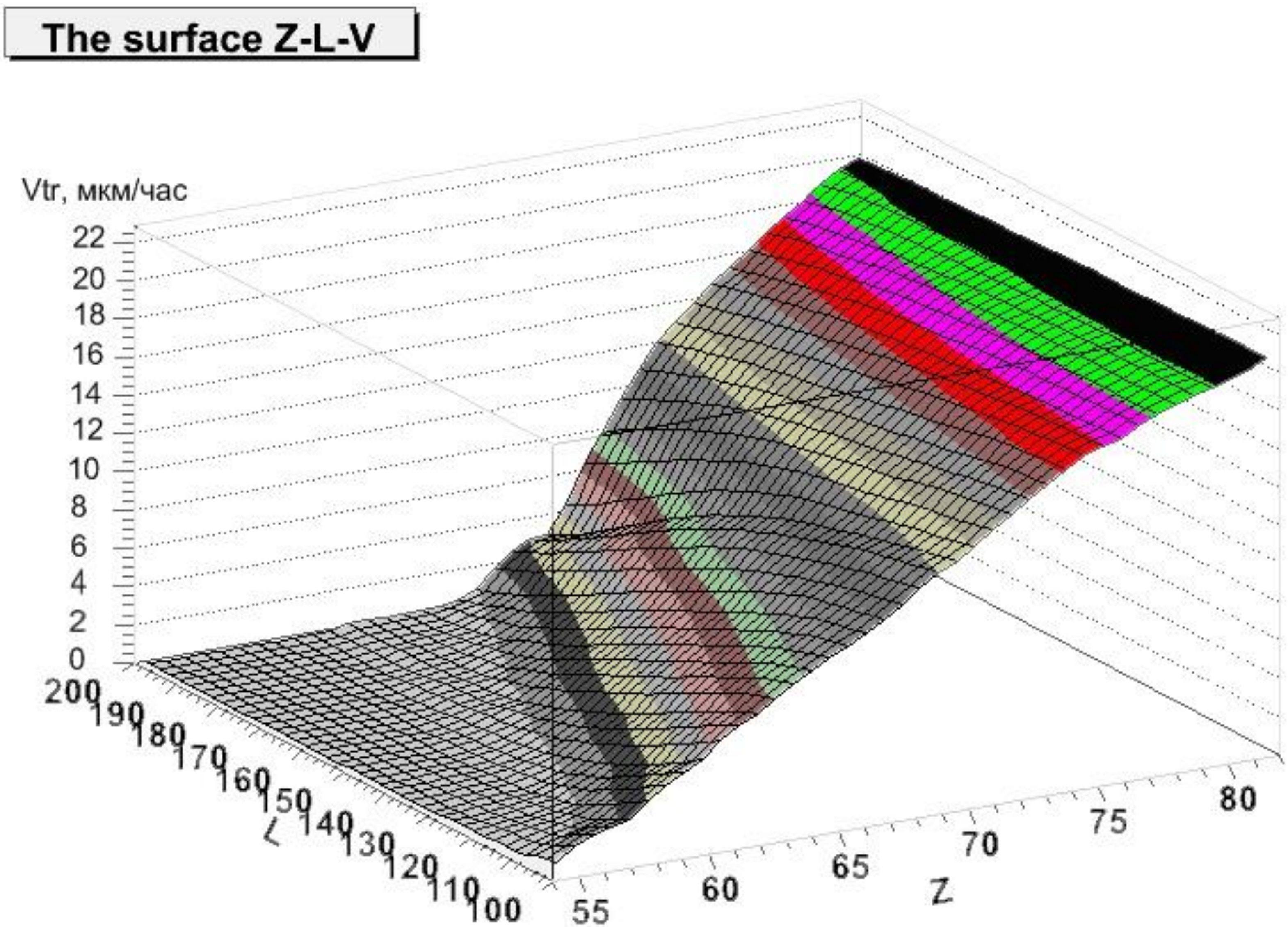
Введение. Оливин, представляющий собой силикатную фракцию метеоритов — палласитов [1], является высоко эффективным природным детектором ядер тяжелых элементов космических лучей [2]. Определение заряда этих ядер осуществляется на основа-

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-



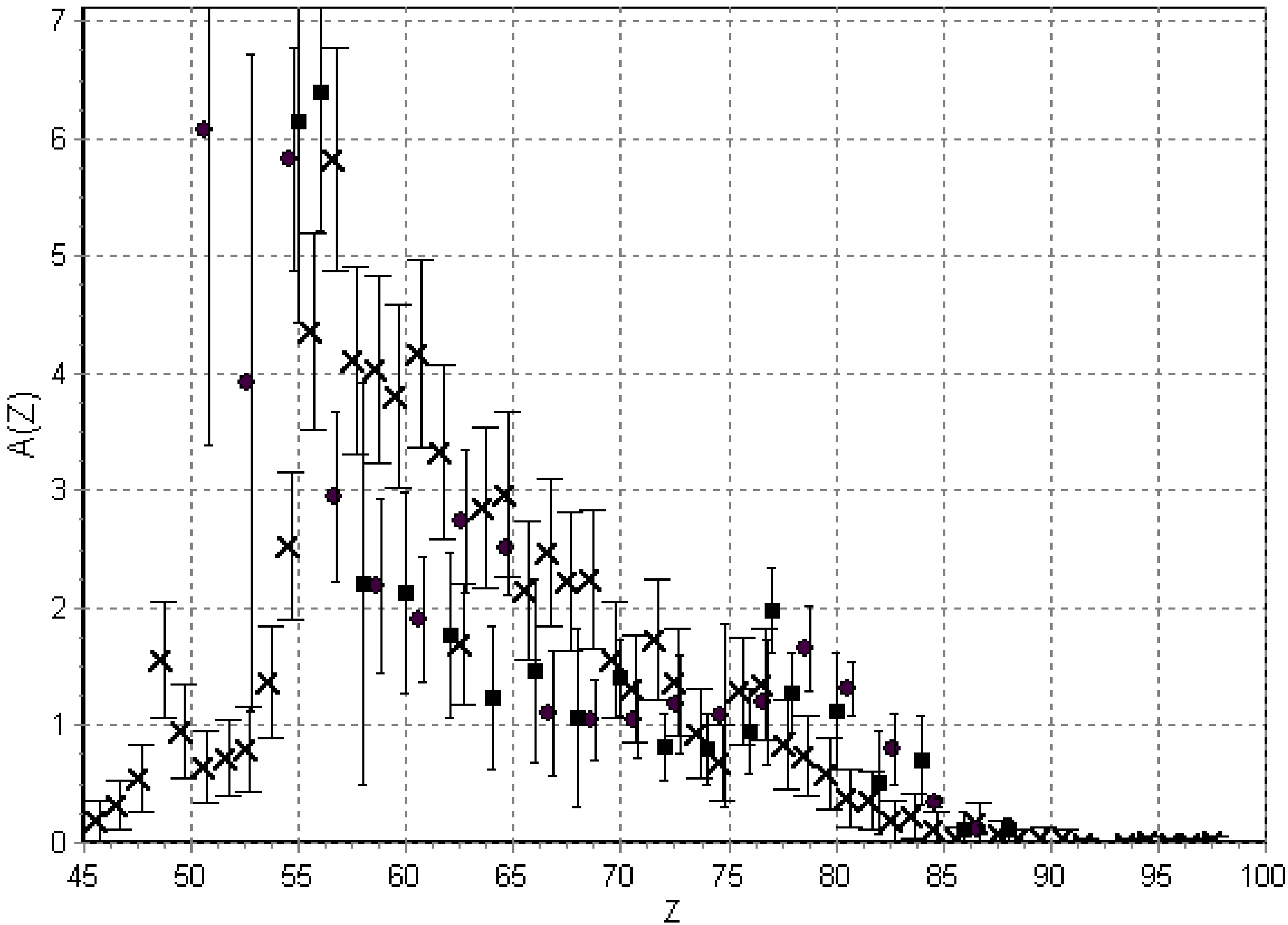

10 nm

Charge – Length – Etching Rate dependence
(UFN, v. 180, № 8, p.839-842, 2010).



The galactic nuclei abundance A (A_{Fe}= 10^6)

(■ - HEAO; o – Ariel; x – our results 9173 nuclei; Maryalakhty - 5654, Eagle Station – 3519)

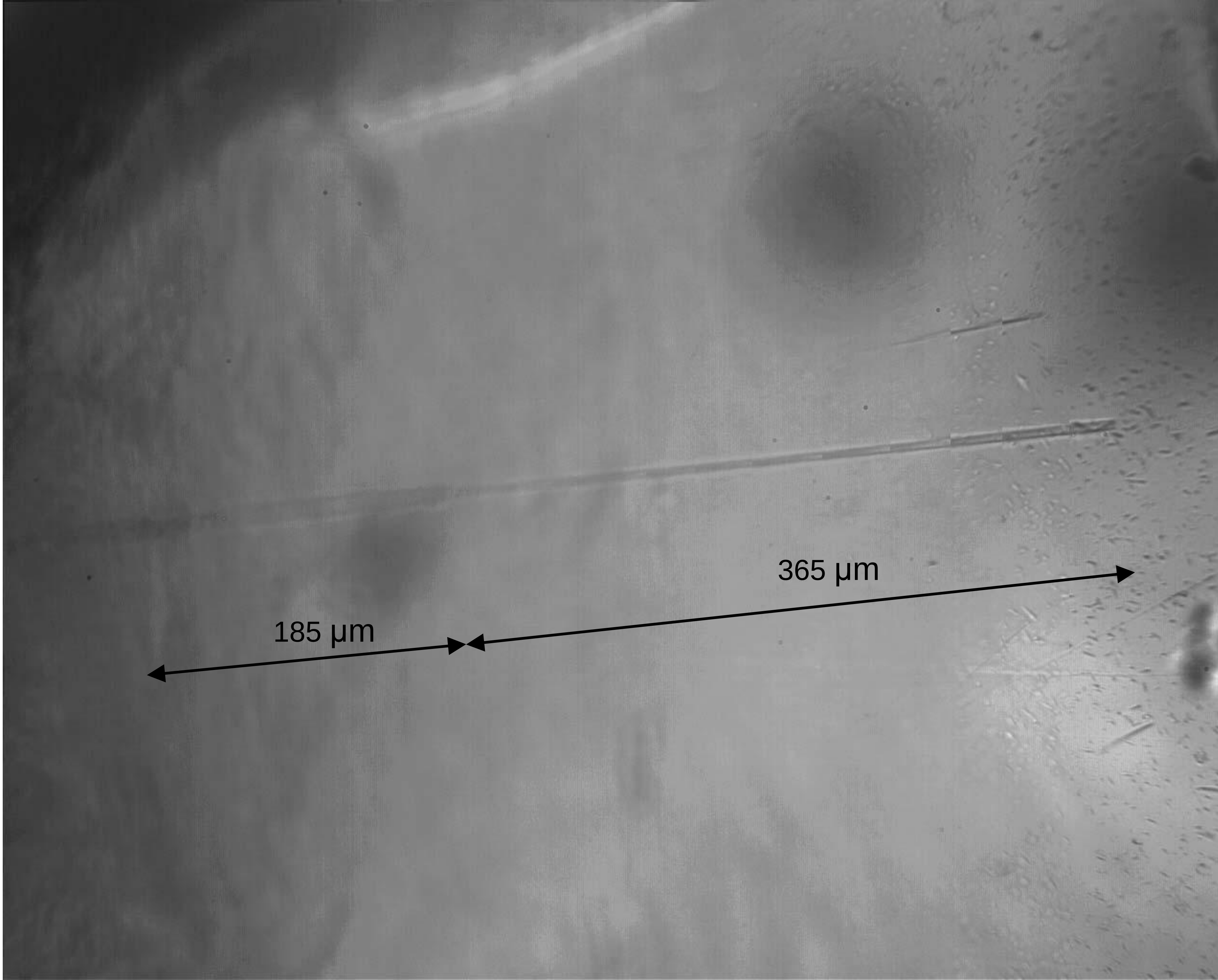


Superheavy nuclei

Besides the distributions of galactic nuclei we observed three events having very large charges (our estimations are Z>105).

Their lengths are large (700-900 μm) but their minimal etching rates are more then 35 μm/h.

It is very large as compared with the uranium maximum etching rate (25 μm/h).



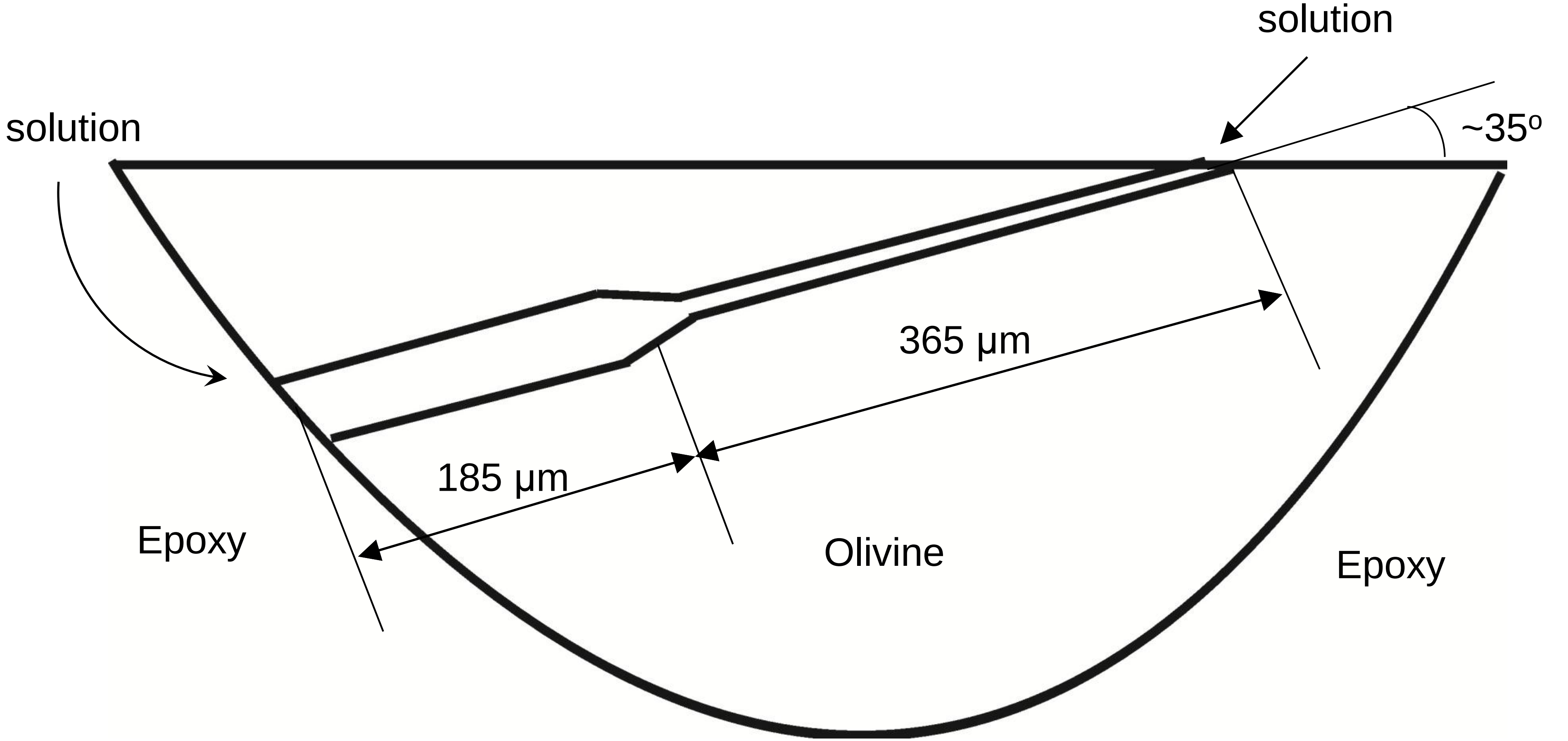
185 μm
365 μm

The total track length in olivine is ~550 μm.

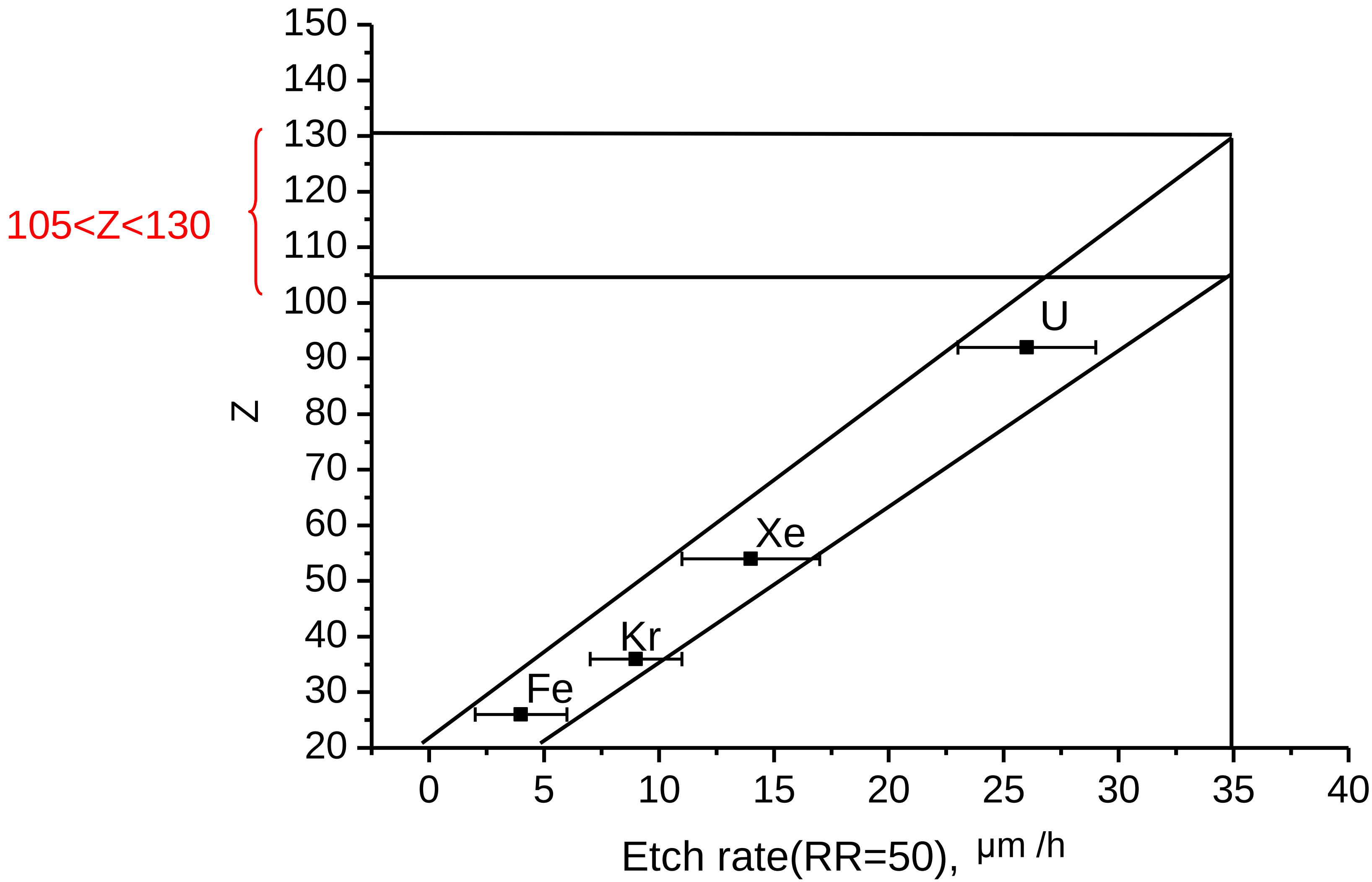
The etching time is 8 hours,

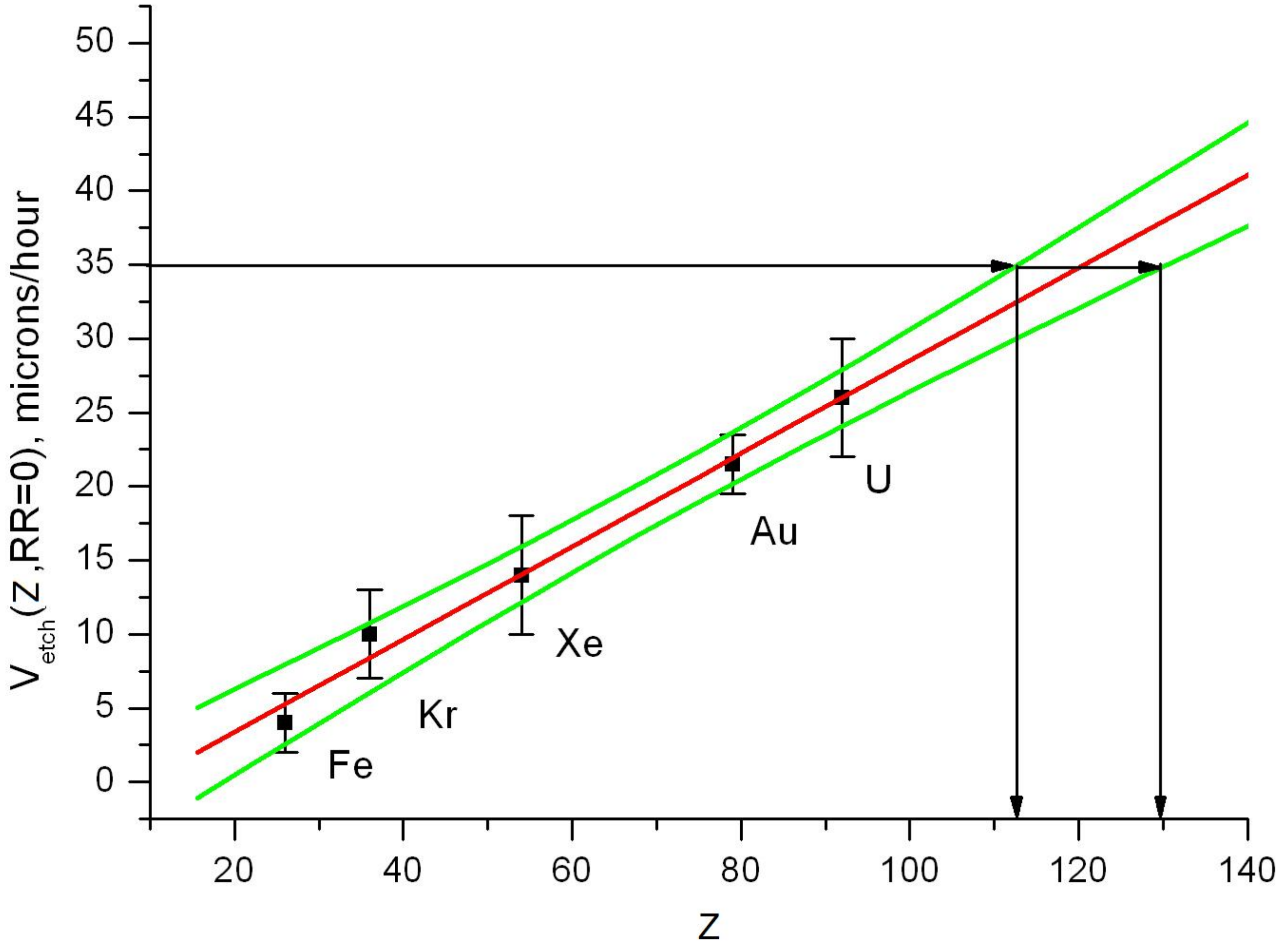
but the etch solution can reach to track from both sides.

=> The minimum etching rate is about 35 μm/h.



The extrapolation of the residual range dependence $Z(RR,V_{etch})$ to superheavy nuclei.





Regression analysis: at the confidence level 95% nucleus charge with etching rate about 35 micron/hour is **Z=119(+10,-6).**

On the plot: red line – approximation for experimental data by straight line, green lines – error corridor at the confidence level 95%. Vertical lines mark out possible charge interval at the confidence level 95% at etching rate near stopping point 35 micron/hour.

The superheavy nuclei in olivine crystals evidently lived long enough to fly from the place of their origin to the meteorite. At present, it is believed that the main source of the nuclear component of GCRs are supernovae, in which the nuclei of superheavy and transuranium elements are generated and accelerated.

To reach the solar system and form the tracks registered in our meteorites, the average lifetime of these nuclei must be equal to at least the time of their propagation from the source to our solar system's asteroid belt.

In estimating the lifetime of superheavy nuclei, we must consider that
(a) in order to form tracks in olivine crystal the nuclei must have an input energy in the meteorite of several gigaelectron volts per nucleon, and
(b) supernovae in our Galaxy can occur at distances of ~1–8 kiloparsecs from the solar system.

A rough estimate of the minimum lifetime of such GCR nuclei thus yields a value of 3000 to 25000 years.

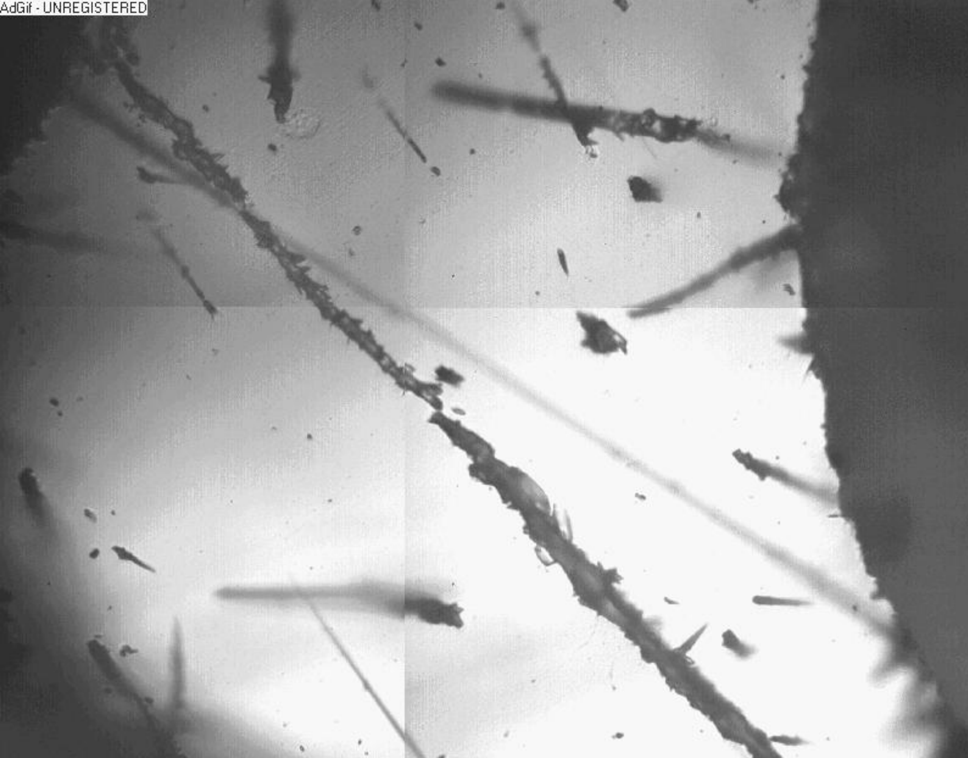
Conclusions.

1. **We derived the charge distribution more then 9000 galactic nuclei whose charges are more 55.**

2. **We observed three events whose charges are estimated $105<Z<130$; one of them $Z=119(+10,-6)$.**

3. **Our evaluation of minimum lifetime of GCR nuclei is equal about 3000 up to 25000 years.**

4. **So we derived additional indication of existence in nature (galactic cosmic ray) of the stability island elements.**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THANK YOU!