KINKS AND CHARGED EXCITATIONS IN MICA

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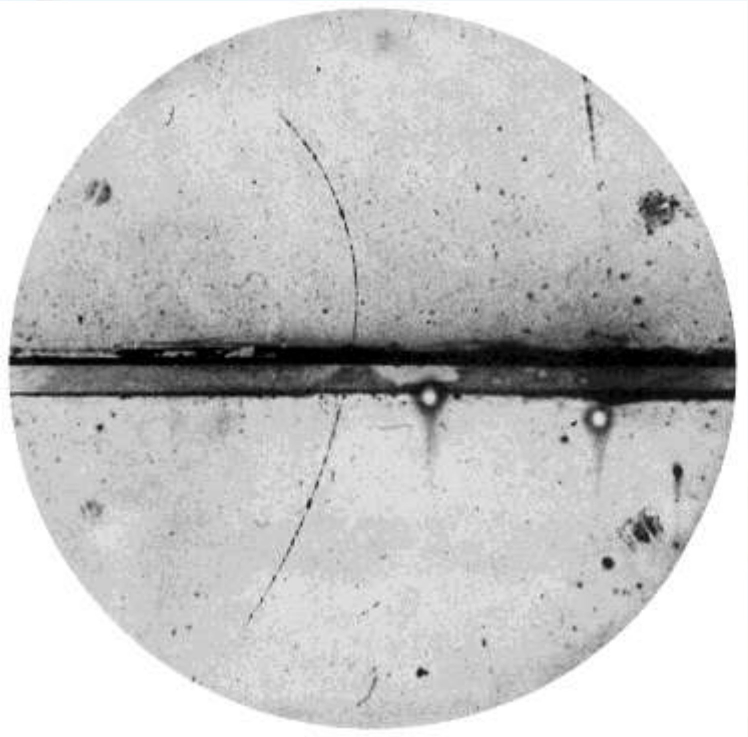
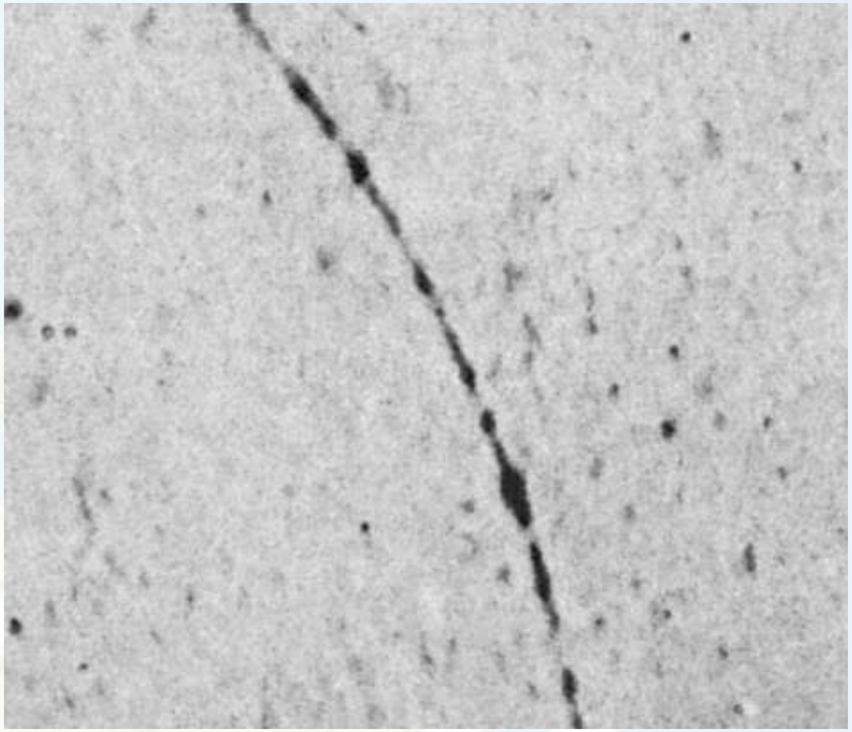
Moscow, September 17, 2015.

Nuclear particle in a diffusion cloud

- **45x45cm** Image taken in the Pic du Midi at 2877m in a Phywe PJ45, (2014)

First positron identified, Anderson 1932





Positron passing across 6mm lead plate
Diameter 26 cm
Cloud chamber, 63 MeV

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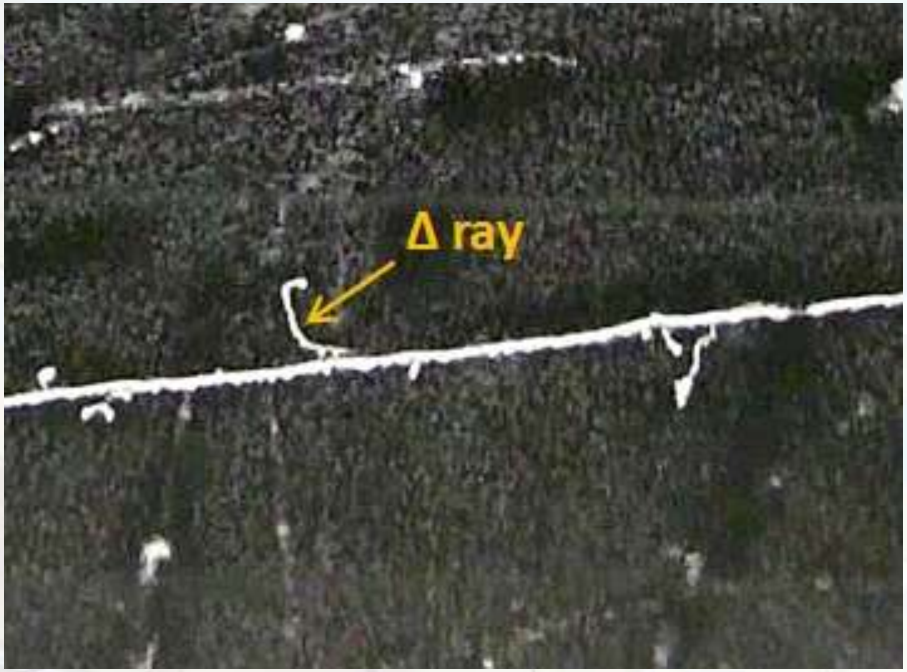
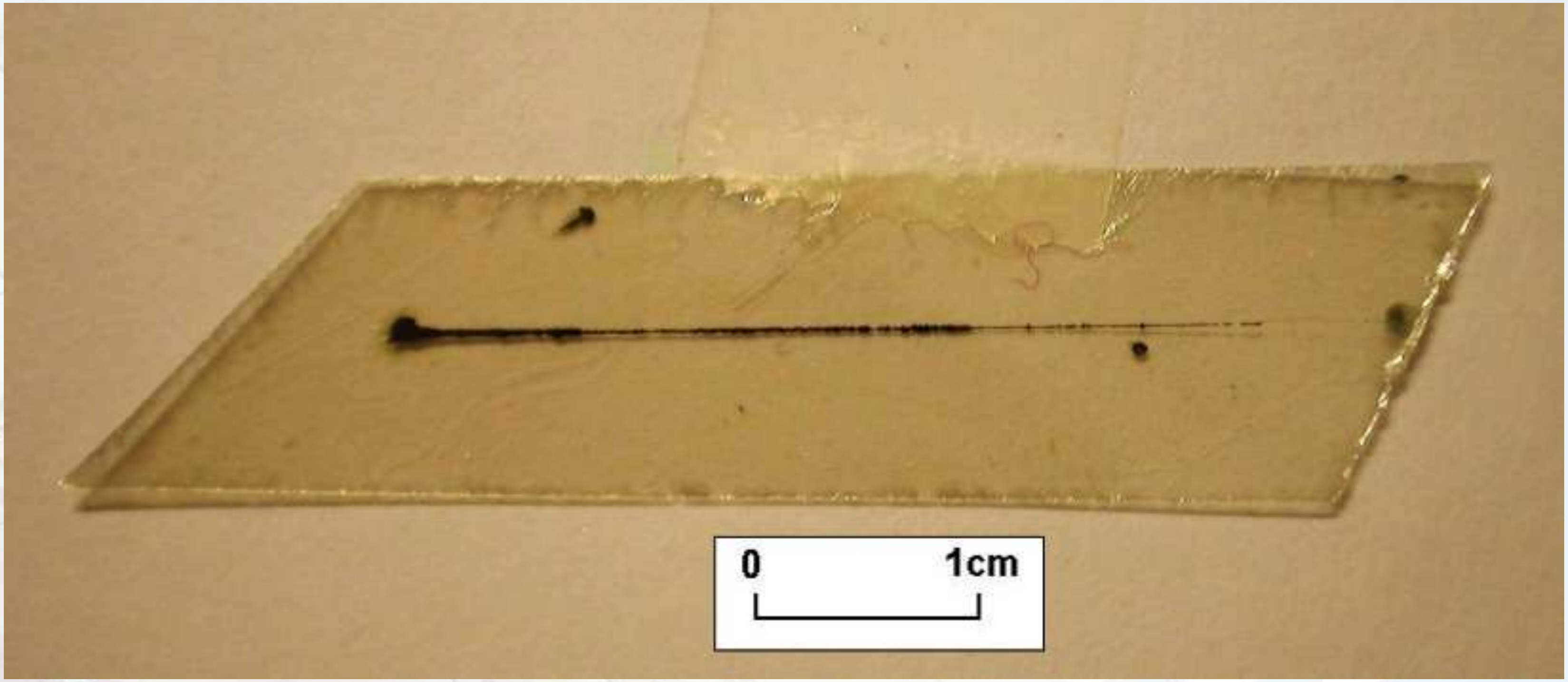
CD Anderson, The positive electron, Phys. Rev. 43 (1933) 491

Nuclear particle in a diffusion cloud chamber



- Supersaturated water (or methanol) vapor
- Charged swift particles act as centers for water droplet formation
- The alcohol vapor condenses around ion trails

Tracks in mica



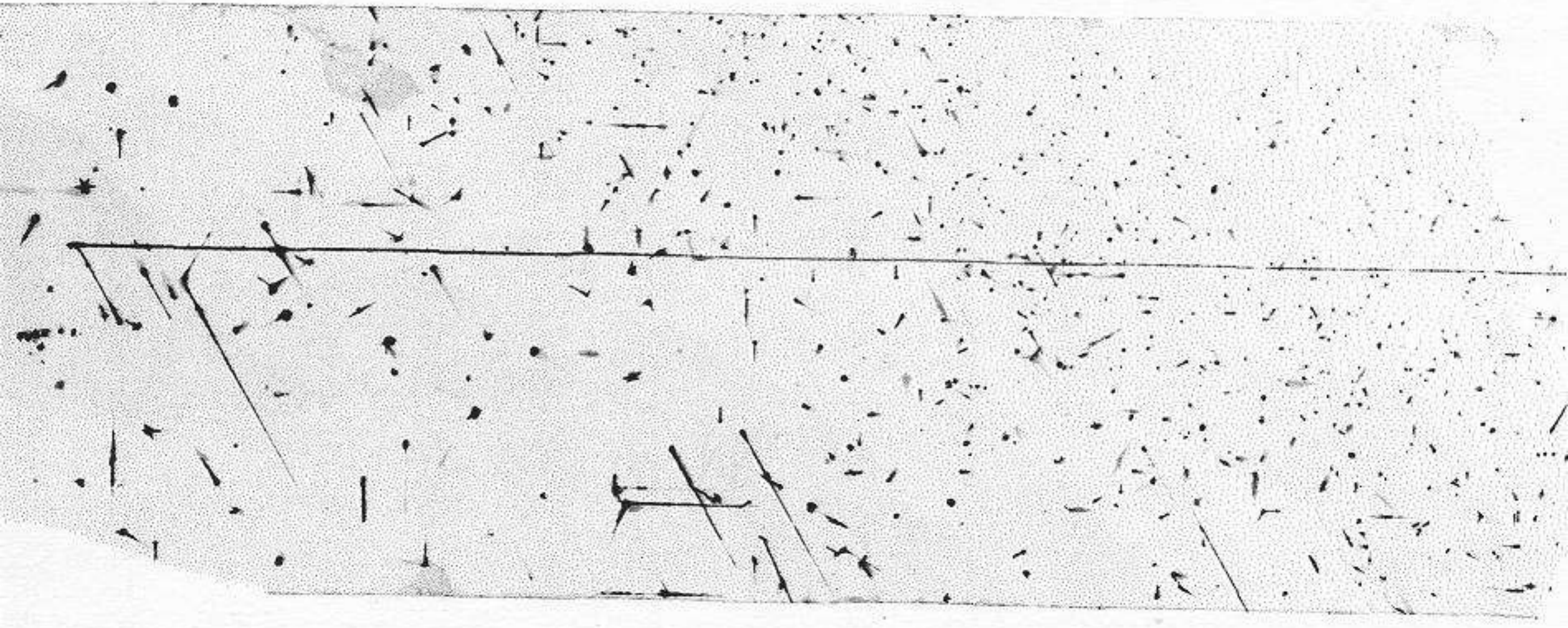
- Positron track produced in the decay of K^{40} with 0.5 MeV.
- 3 per second per cm^3
- Tracks are Fe oxides, magnetite

- FM Russell, From Nature 1967, Nature 216, 907 ; 217 , 51 (1967) and many more

More positrons tracks

FM Russell, From Nature 1967, Nature 216, 907 ; 217 , 51 (1967) and many more

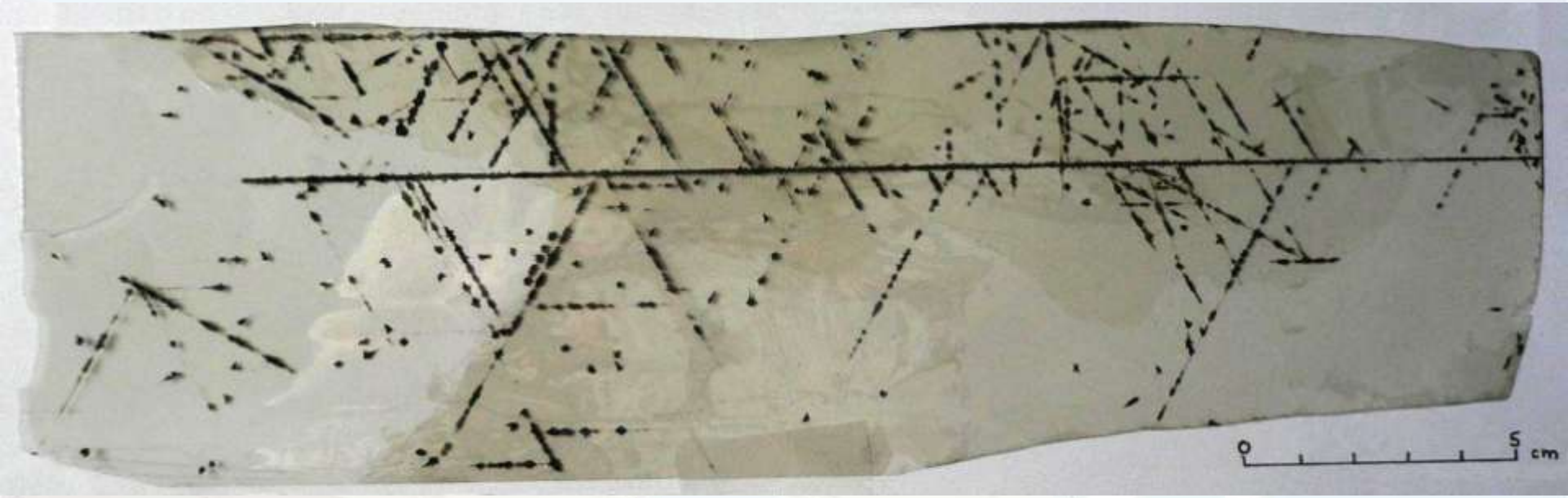
Poston tracks in mica muscovite



- Produced in the decay of K^{40} with 0.5 MeV.
- 3 per second per cm^3
- Tracks are Fe oxides, magnetite

. Review: Tracks in Mica, 50 years later. In Quodons in Mica, JFR Archilla et al, eds, Springer (2015)

Quodons: quasi one-dimensional excitations of the lattice in mica muscovite



Tracks: magnetite Fe_3O_4

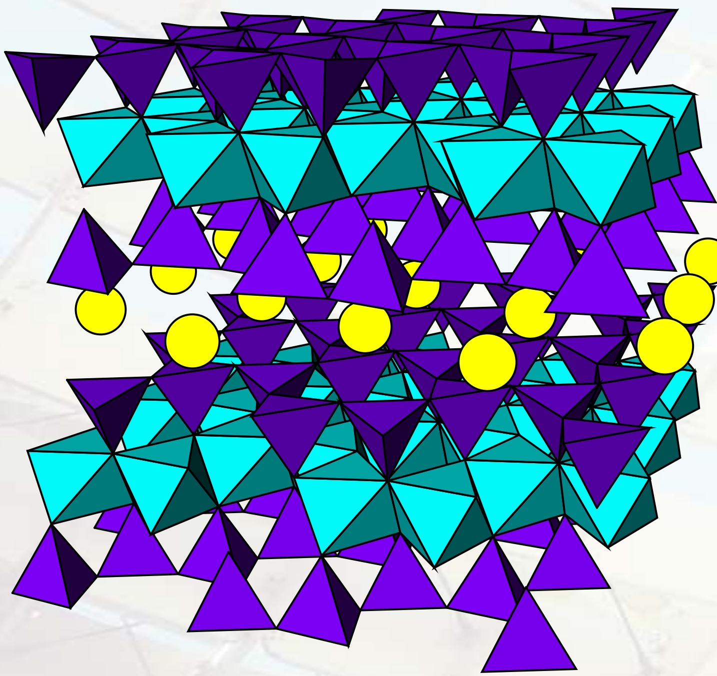
Causes

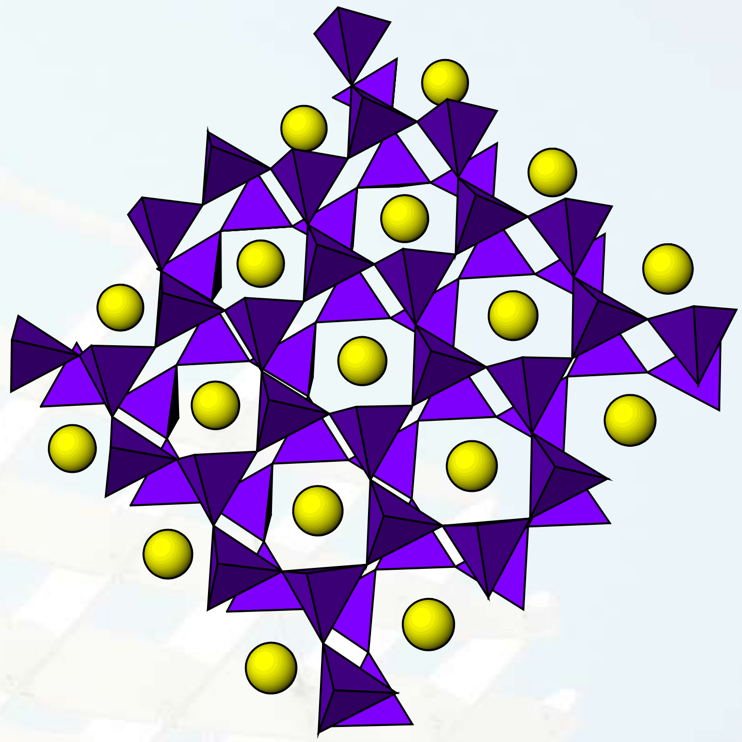
- 0.1% Swift particles
  - antimuons: after neutrino interaction
  - Positrons: decay of 40K
  - Protons
- 99.9% Most in lattice closed packed directions

Anharmonic lattice excitations?

Mica muscovite. Cation layers

$K_2[Si_6Al_2]^{IV}[Al_4]^{VI}O_{20}(OH)_4$



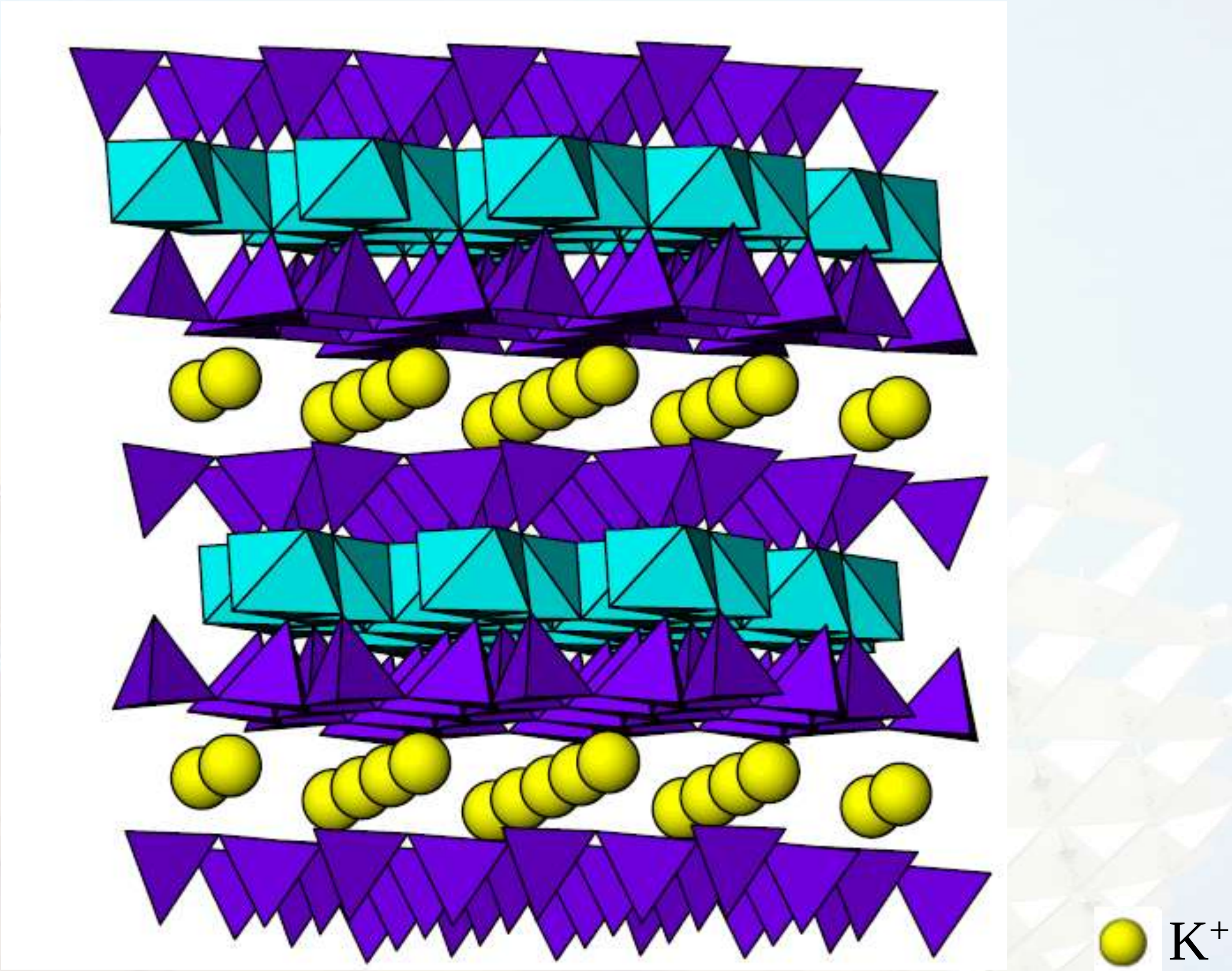


$K_2[Si_6Al_2]^{IV}[Al_4]^{VI}O_{20}(OH)_4$

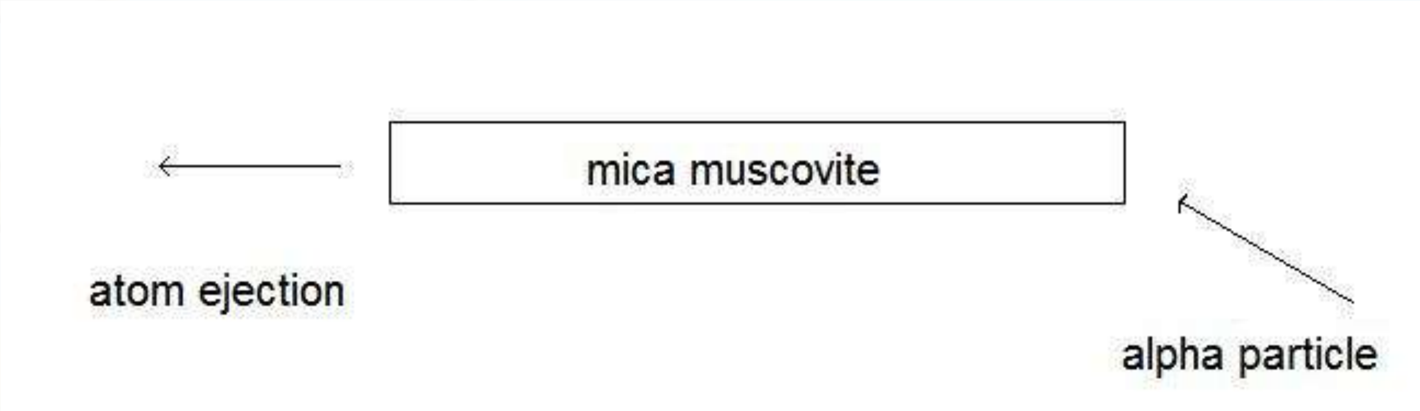
K^+

K^+ : 2D lattice of repulsive particles

Rows of ions within the K layers



Experimental evidence of travelling excitations in mica muscovite



Trajectories were along lattice directions within the K^+ layer .
Surface binding energy of ejected atoms unknown: typical values 3-8 eV

- Russell, F.M., Eilbeck, J.C. (2007). Evidence for moving breathers in a layered crystal insulator at 300K. *Europhysics Letters* 78, 1004, 1-5.

Quodons: what kind of lattice excitation?

-Not phonons:

-too low energy with respect to thermal one

-Spread because frequency is in the phonon band

-Breathers?

-Internal oscillation

-Higher energy

-Frequency outside the phonon bands

-Kinks?

-No internal oscillation

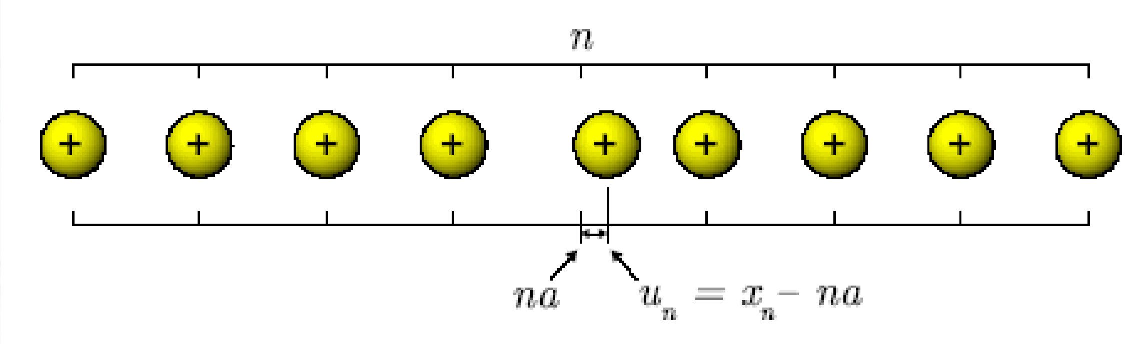
-Supersonic

-High energy

-Other?

Peakons, compactons, polarons, solelectrons…?

Minimal Model



- **Normalized movement equations:**

$$\frac{\partial^2 u_n}{\partial t^2} = -\frac{1}{(1+u_{n+1}-u_n)^2} + \frac{1}{(1+u_n-u_{n-1})^2}$$

- $$v_n = u_n - u_{n-1}$$

Ziegler Biersack Litmark (ZBL) potential for high energy collisions

$$U_{ZBL}(r) = \frac{Z_1 Z_2 e^2}{4\pi\varepsilon_0 r}\, f(\frac{r}{a})$$

$$a = \frac{0.98856\ \mathrm{a_B}}{Z_1^{0.23} + Z_2^{0.23}}$$

a_B Bohr radius

$$f(x) = \sum_{i=1}^{4} a_i \exp(-b_i x)$$

Ziegler JF, Biersack JP, Littmark U, The Stopping and Range of Ions in Matter (Pergamon, New York, 1985)

Simplification up to 200 KeV:

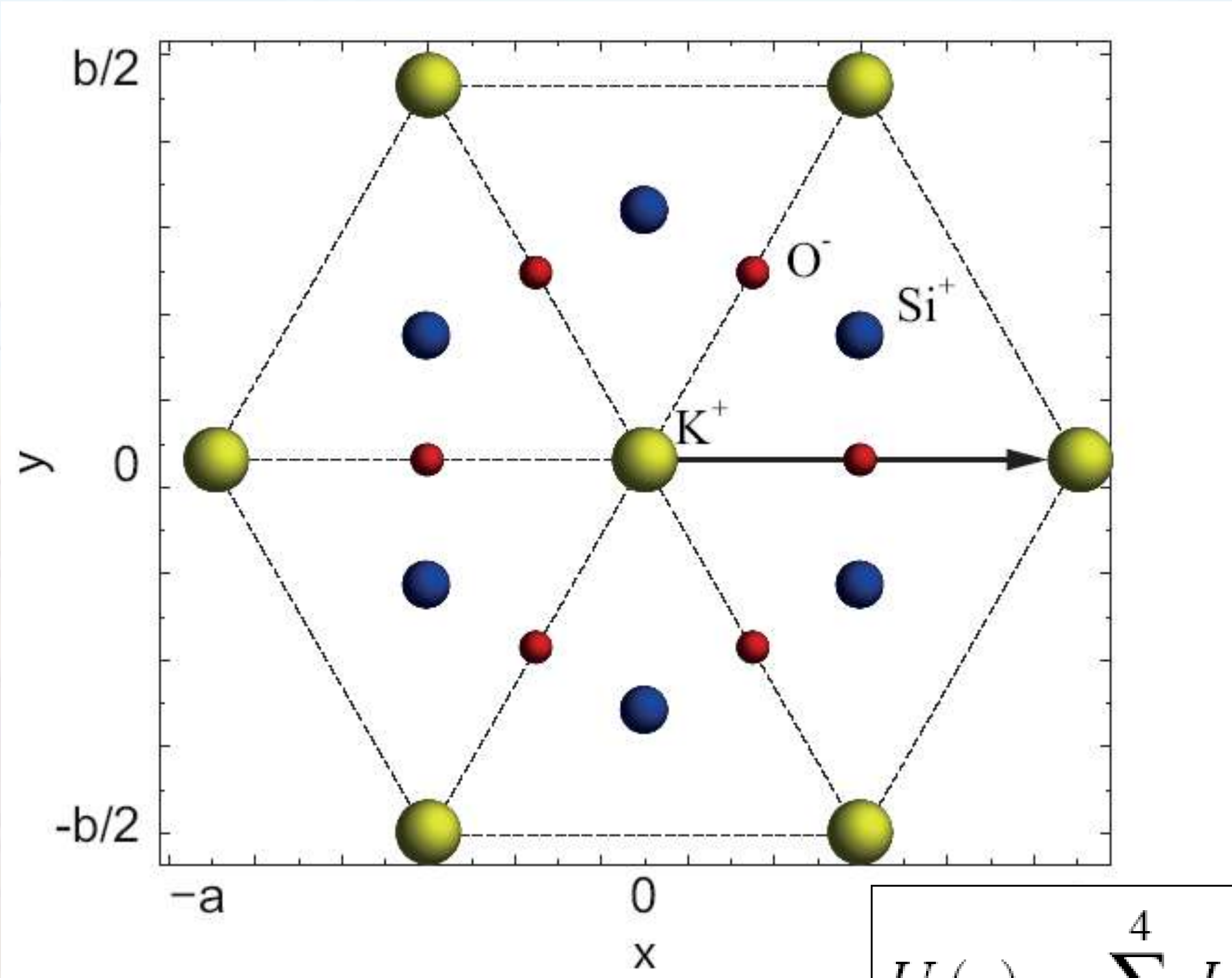
$$U_{ZBL}(r) = \frac{2650\,\mathrm{eVA}}{r}\exp(-\frac{\mathrm{r}}{0.3\mathrm{A}})$$

$$U_{ZBL}(x) = \frac{184}{x}\exp(-\frac{\mathrm{x}}{0.06})$$

Coupling potential:

$$U(r) = \frac{1}{r} + \frac{\alpha}{r}\exp(-\frac{\mathrm{r}}{\rho})$$

Substrate potential (1)



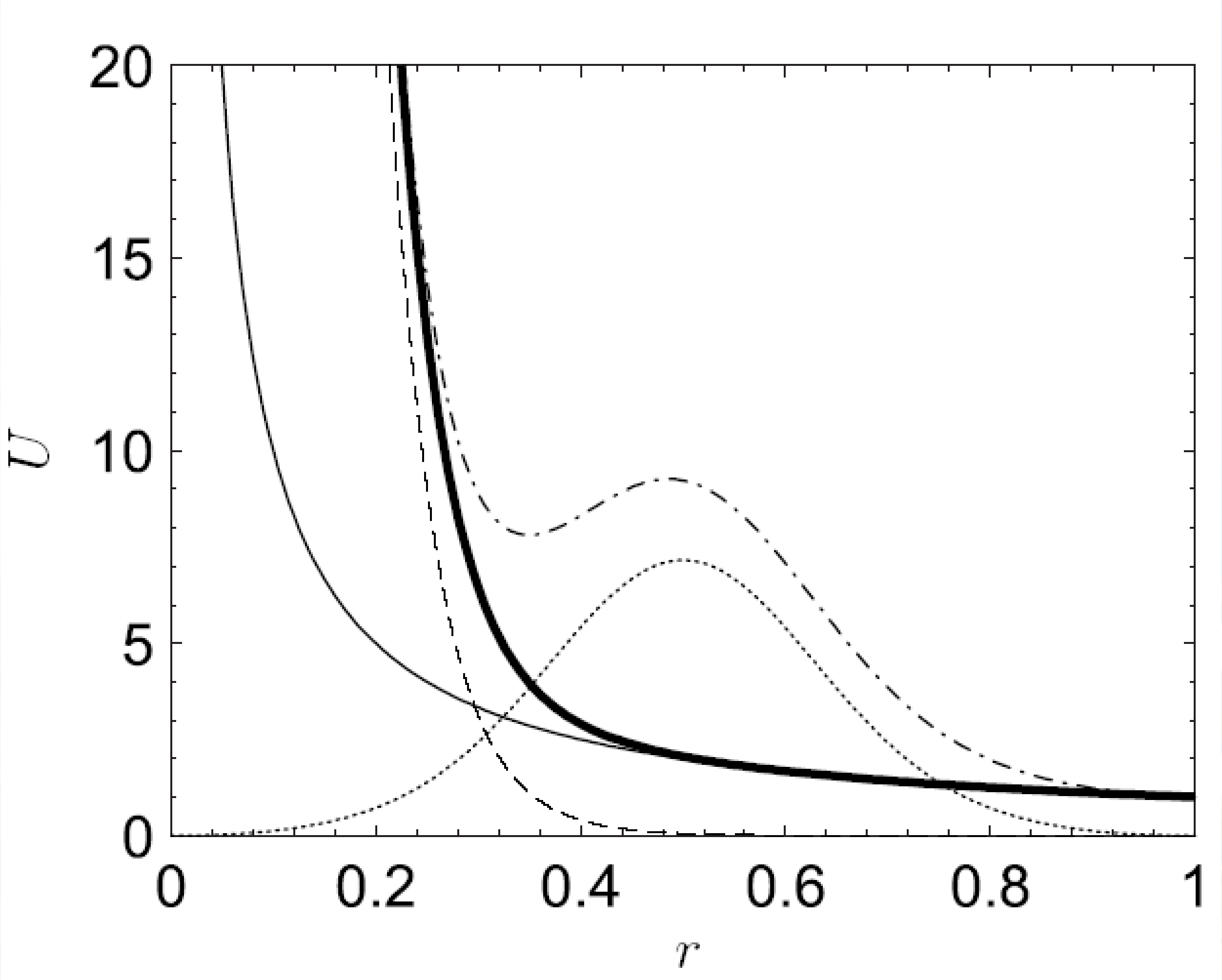
O and Si in planes above and below.

Coulomb and ZBL potentials.

Gives the right Frequency 110 cm-1

$$U_s(x) = \sum_{n=0}^{4} U_n \cos(2\pi\, n \frac{X}{a})$$

Comparison of potentials



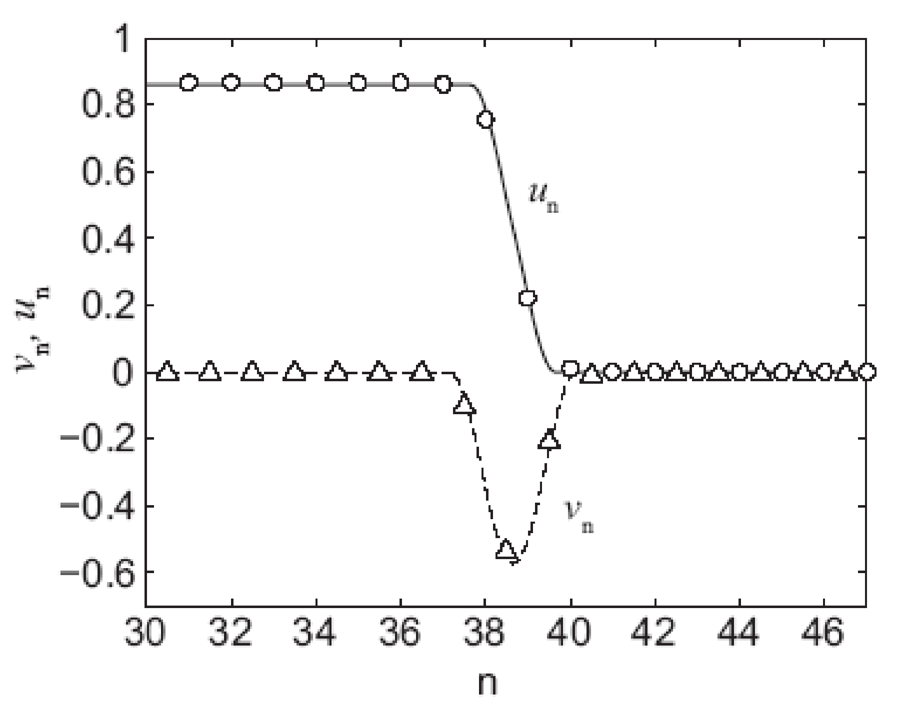
Units
U 2.77 eV
R 5.19 A

Coulomb (—); ZBL (– –); Coulomb+ZBL (thick –)
substrate potential (· · ·) **Sum of all (-.-)**

Fundamental ansatz

$$v_n = -\frac{A}{2}(1+\cos(q(na-Vt))) \quad \text{with} \quad -\pi \le q(na-Vt) < \pi$$

and $v_n = 0$ otherwise



$\lambda = 2\pi/q$ is the wavelength

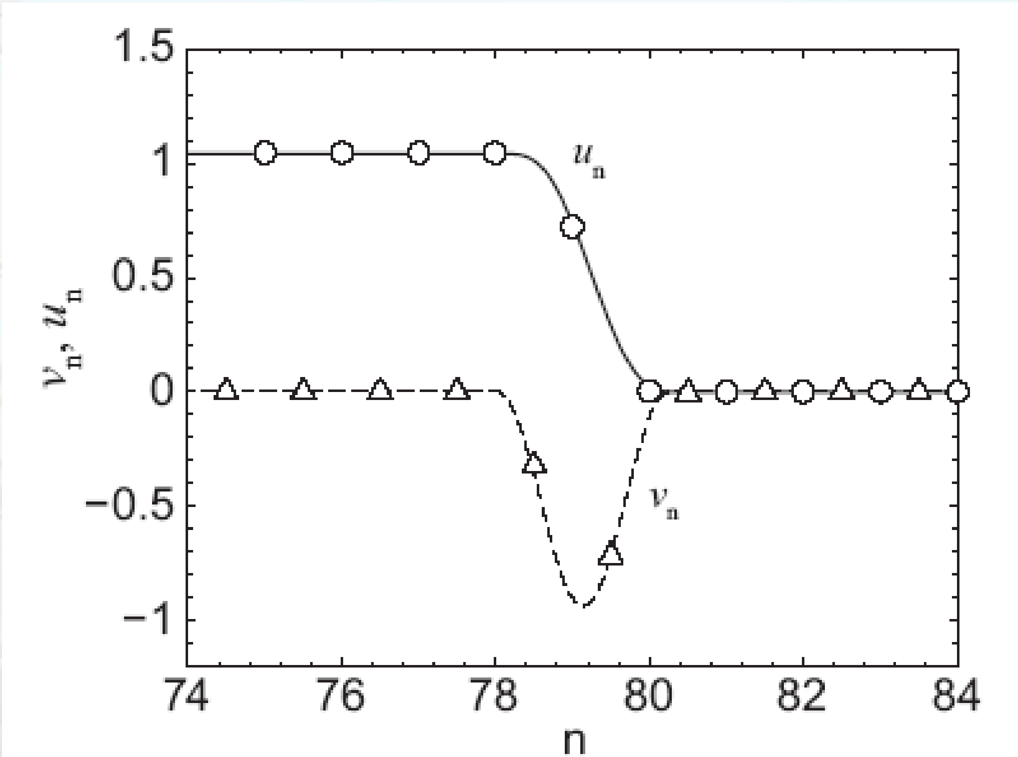
magic wave number $q \simeq 2\pi/3$

Wavelength ~ 3

They are exact solutions for intermediate amplitudes for the system without substrate

Kosevich, Yu.A., Khomeriki, R., Ruffo, S.:.
Europhys. Lett. ***66, 21–27 (2004)***

Mode π



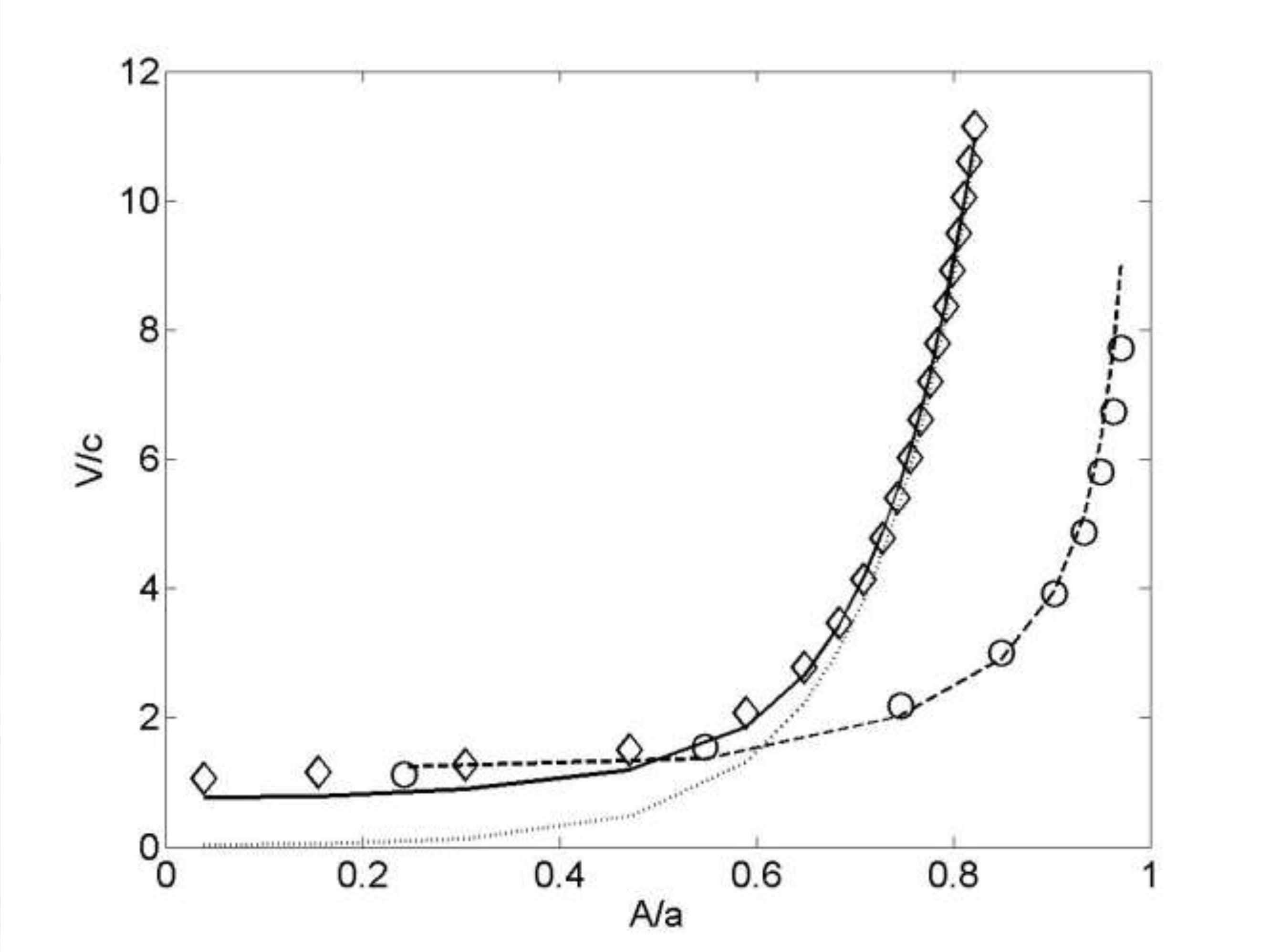
$$q \simeq \pi$$

$$\lambda = 2$$

Equivalent to a hard sphere model

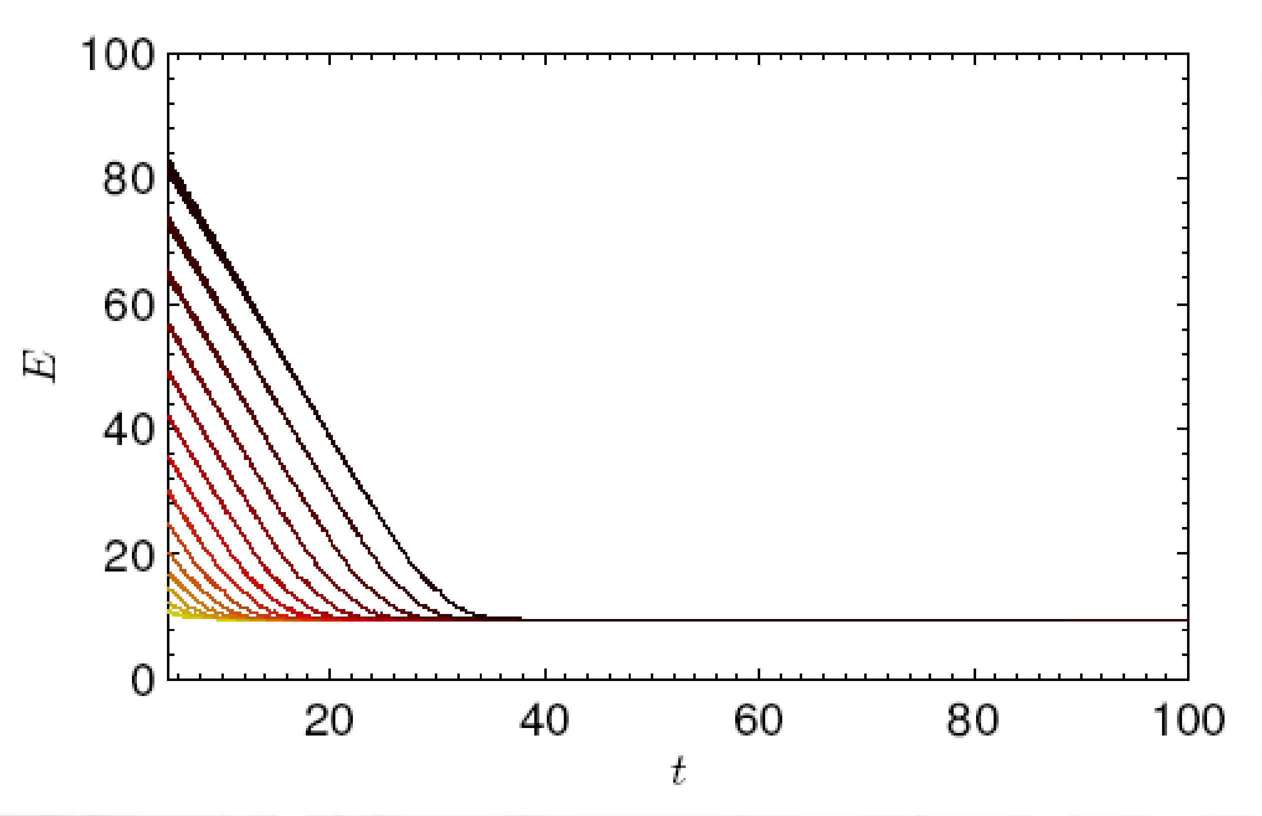
Friesecke, G., Matthies, K.: Atomic-scale localization of high-energy solitary waves on lattices. Physica D 171(4), 211 – 220 (2002**)**
Moleron, M., Leonard, A., Daraio, C.: Solitary waves in a chain of repelling magnets. J. Appl.
Phys. 115(18), 184,901 (2014)

Kink velocities in FPU (no substrate)



Archilla, J.F.R., Kosevich, Yu.A., Jiménez, N., Sánchez-Morcillo, V.J., García-Raffi, L.M.: Moving excitations in cation lattices. Ukr. J. Phys. 58(7), 646–656 (2013)

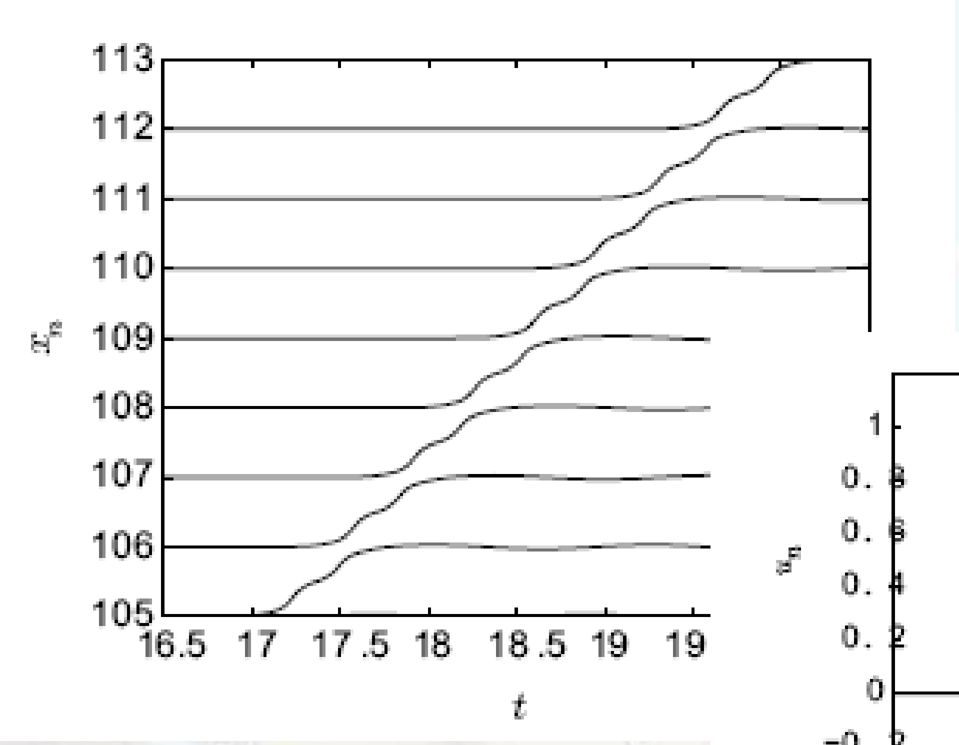
System with substrate (Klein-Gordon) Supersonic crowdions



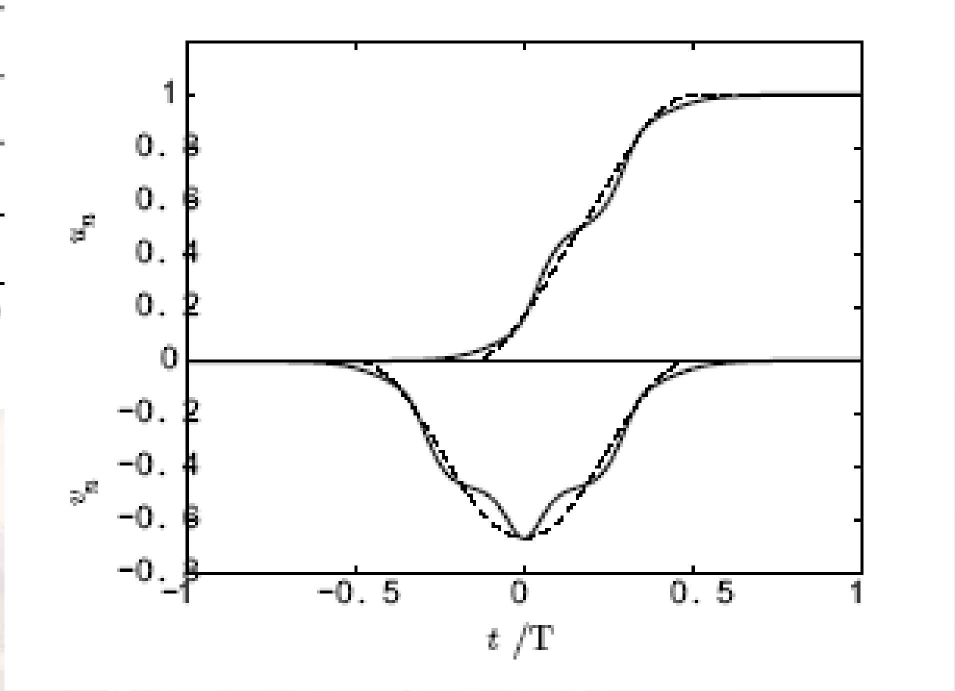
$$V_c = 2.7387 \ (7.2 \, \text{km/s}) \qquad E_k = 9.5 \ (26.2 \, \text{eV})$$

Kosevich, A.M., Kovalev, A.S.: The supersonic motion of a crowdion... Solid State Commun. **12**, 763–764 (1973);

System with substrate: supersonic crowdions



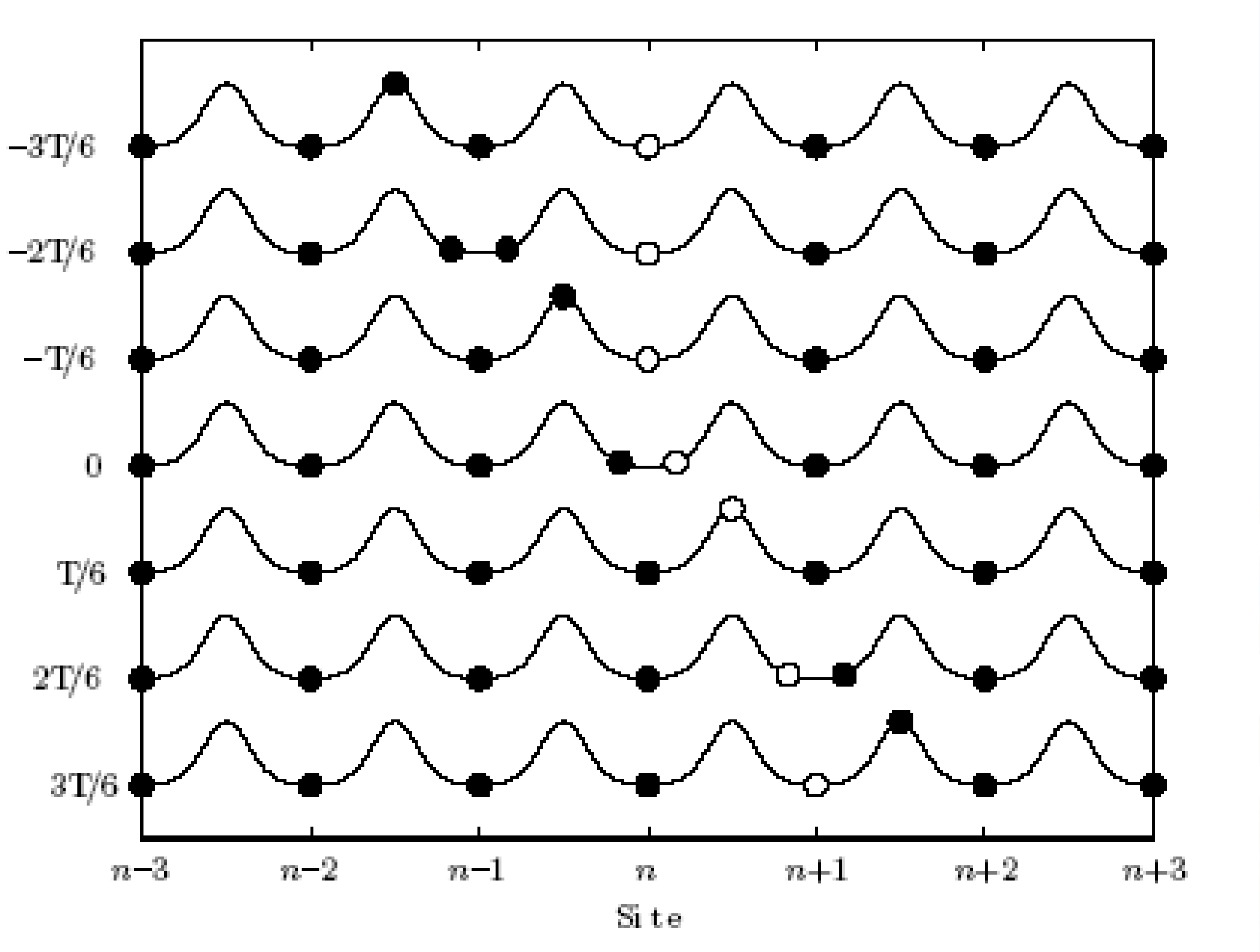
Double kink:
Easy to explain



Savin, A.V.: Supersonic regimes of motion of a topological soliton. Sov. Phys. JETP **81(3)**, 608–613 (1995)

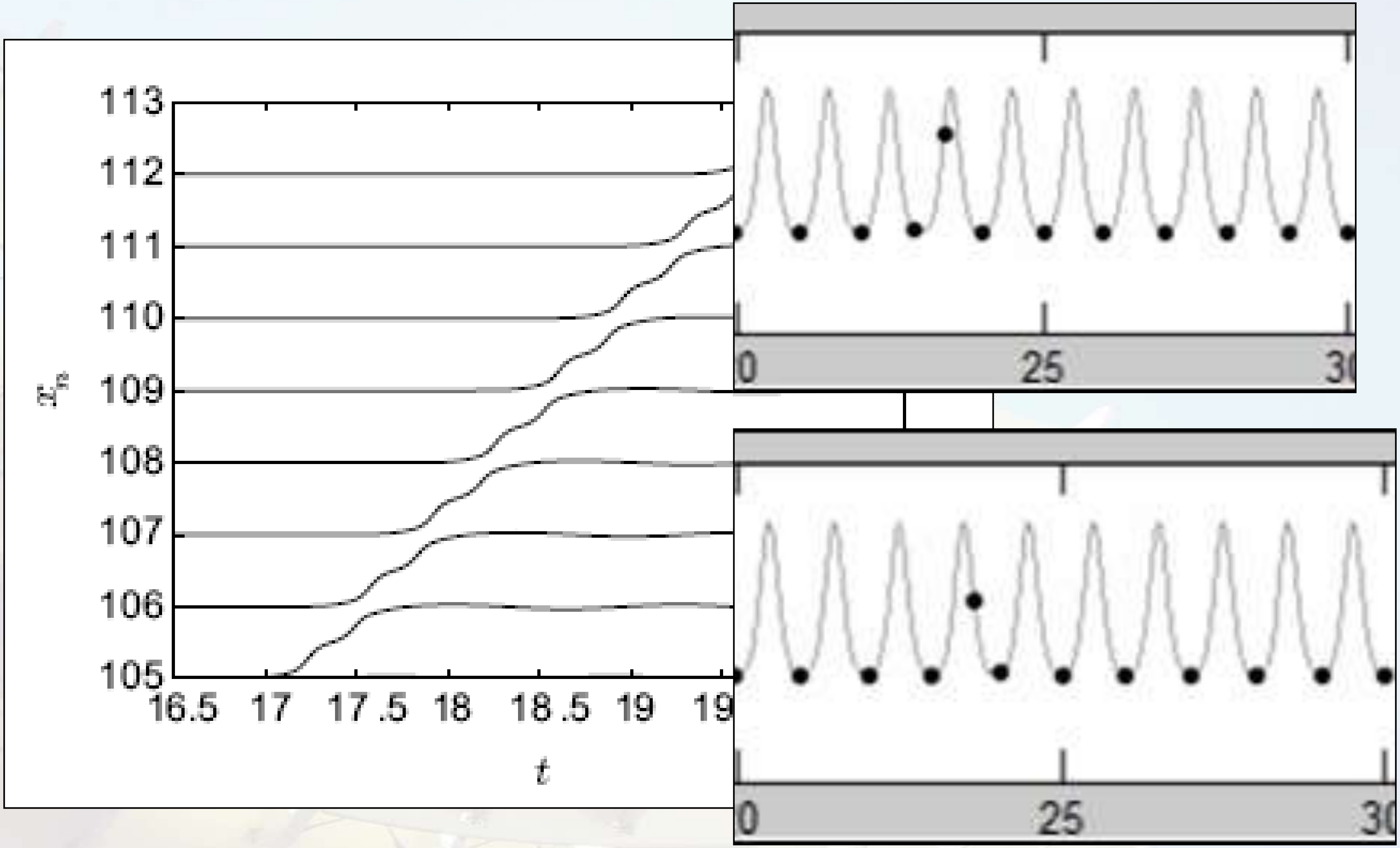
Zolotaryuk, Y., Eilbeck, J.C., Savin, A.V.: Bound states of lattice solitons and their bifurcations. Physica D 108, 81–91 (1997)

Movement of the particles in a crowdion with the magic mode

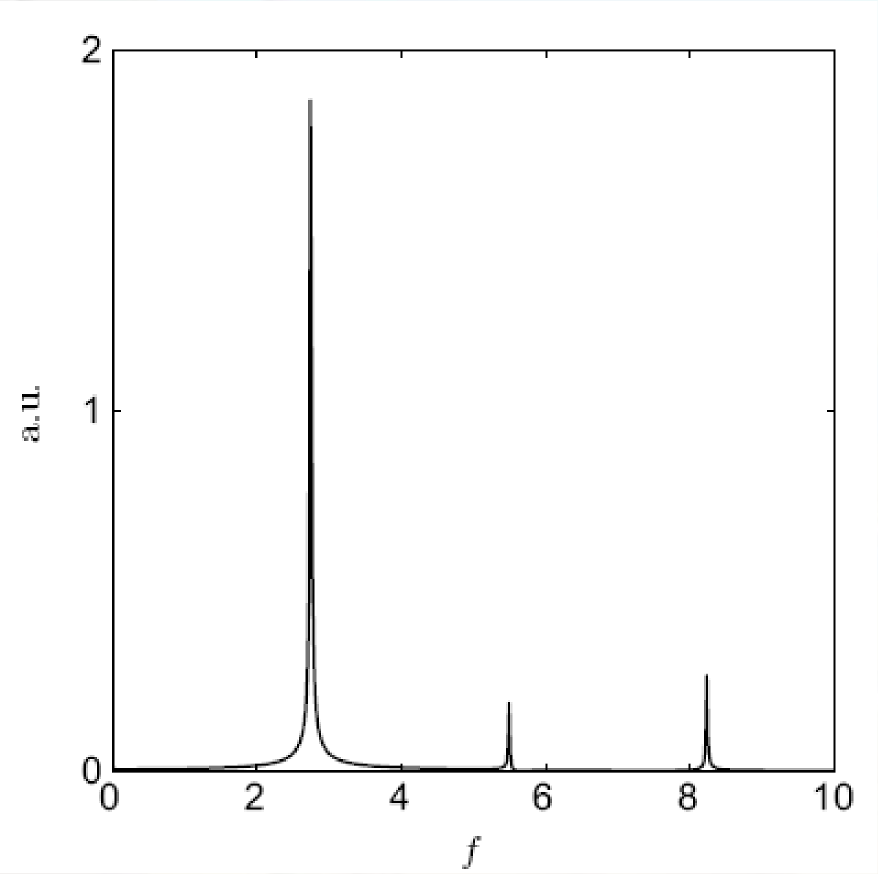


$$\langle V_p \rangle = 1/T = V_c/3$$

Origin of the double kink



Fourier spectrum of the crowdion

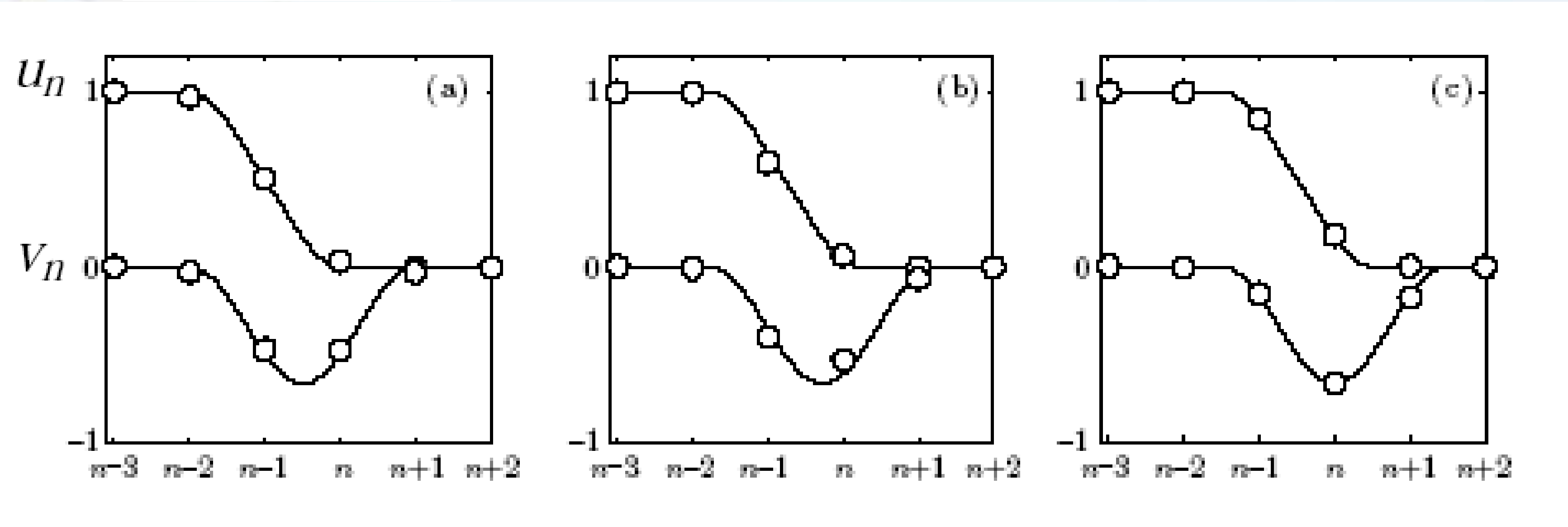


Kinetic energy in a moving frame

$$\bar{\nu} = V_c / a$$

Profile of the crowdion

(a) $t \simeq -T/6$ (b) $t \simeq -0.5T/6$ (c) $t \simeq 0$



$$V_n = u_n - u_{n-1}$$

It corresponds very closely to the magic mode but not exactly

Phonons and crowdions

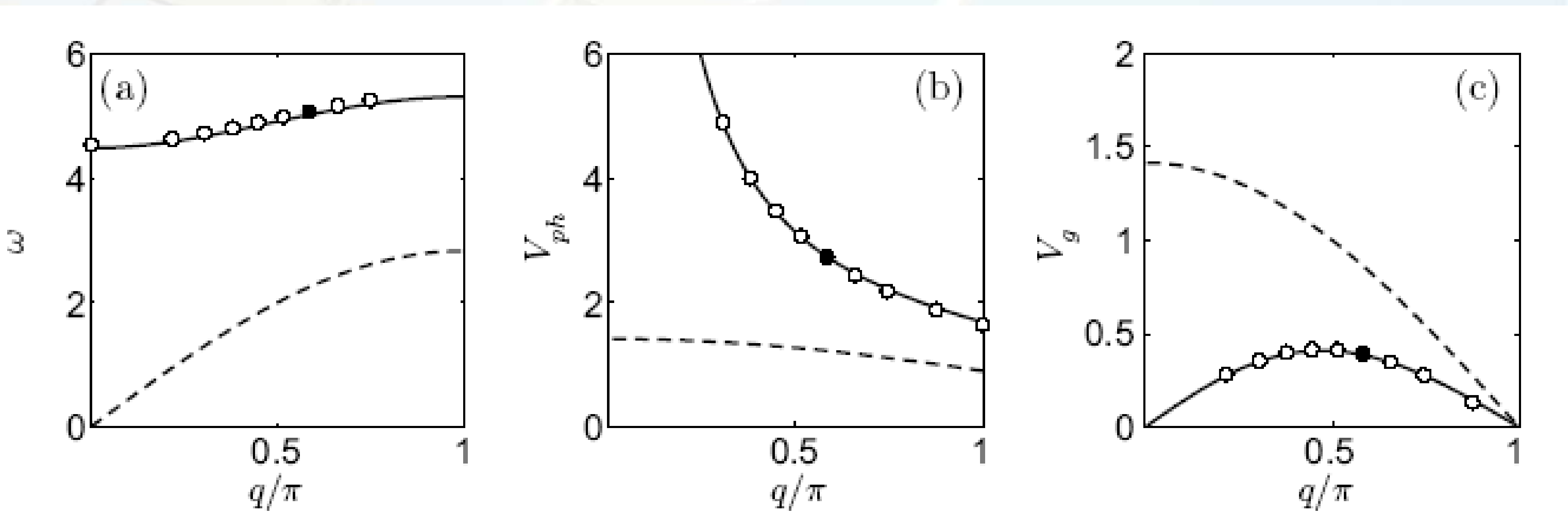
$$\ddot{u}_n = -\omega_0^2 u_n + c_s^2 (u_{n+1} + u_{n-1} - 2\,u_n)$$

$$c_s = \sqrt{2} \text{ or } 3.7\,\text{km/s}$$

$$u_n = \exp(\mathrm{i}(qn - \omega t))$$

$$\omega^2 = \omega_0^2 + 4\,c_s^2 \sin^2\left(\frac{q}{2}\right) \quad ; \quad V_{\text{phase}} = \frac{\omega}{q}$$

(a) Dispersion relation (b) phase velocity (c) group velocity



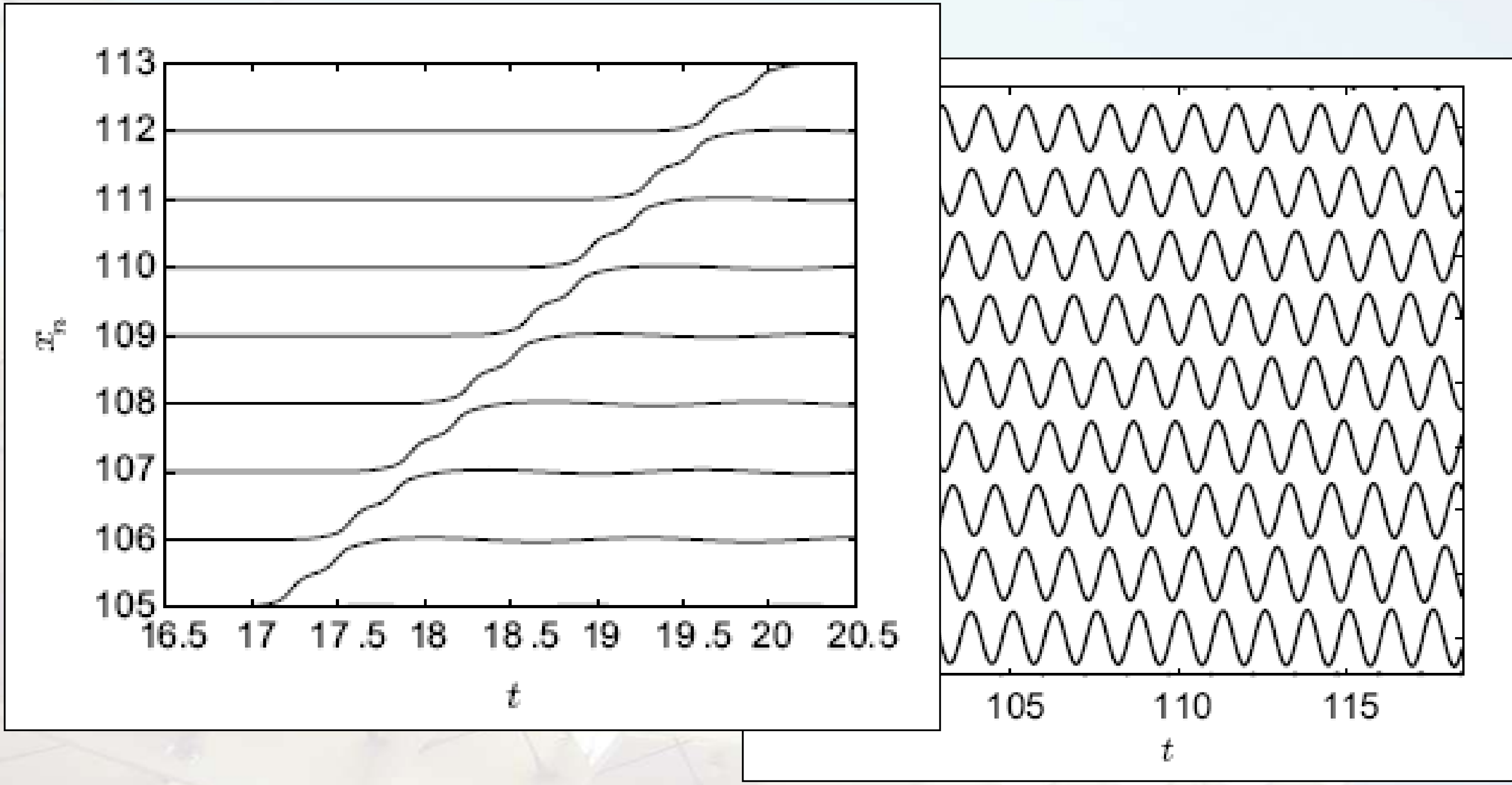
Without substrate (----)

With substrate (___)

Black dot: crowdion

Crowdion phonon tail

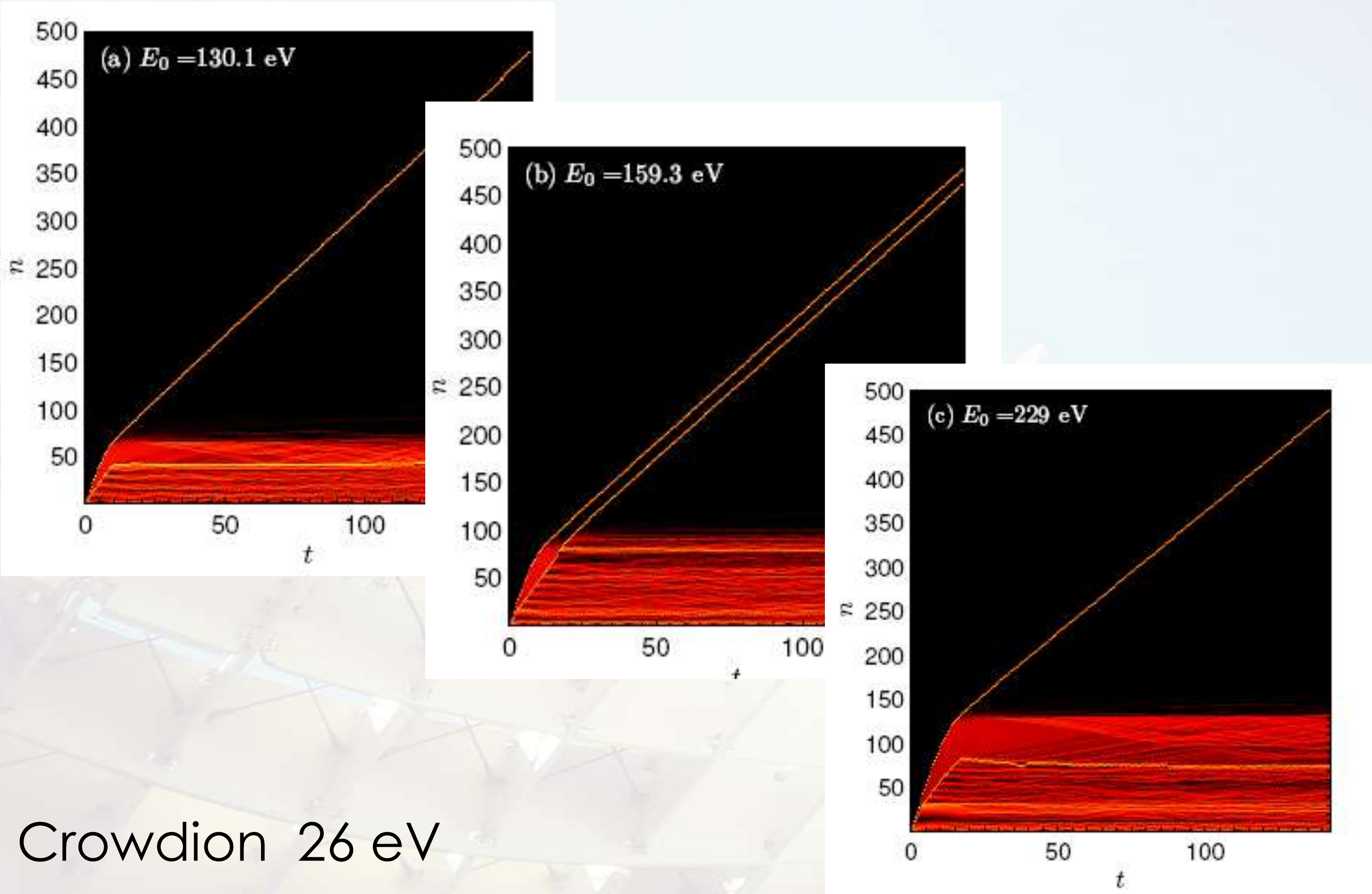
Kink velocity aproaches asympticaly to the crowdion’s one



The sinusoidal phonon tail phase velocity equal to the crowdion’s one

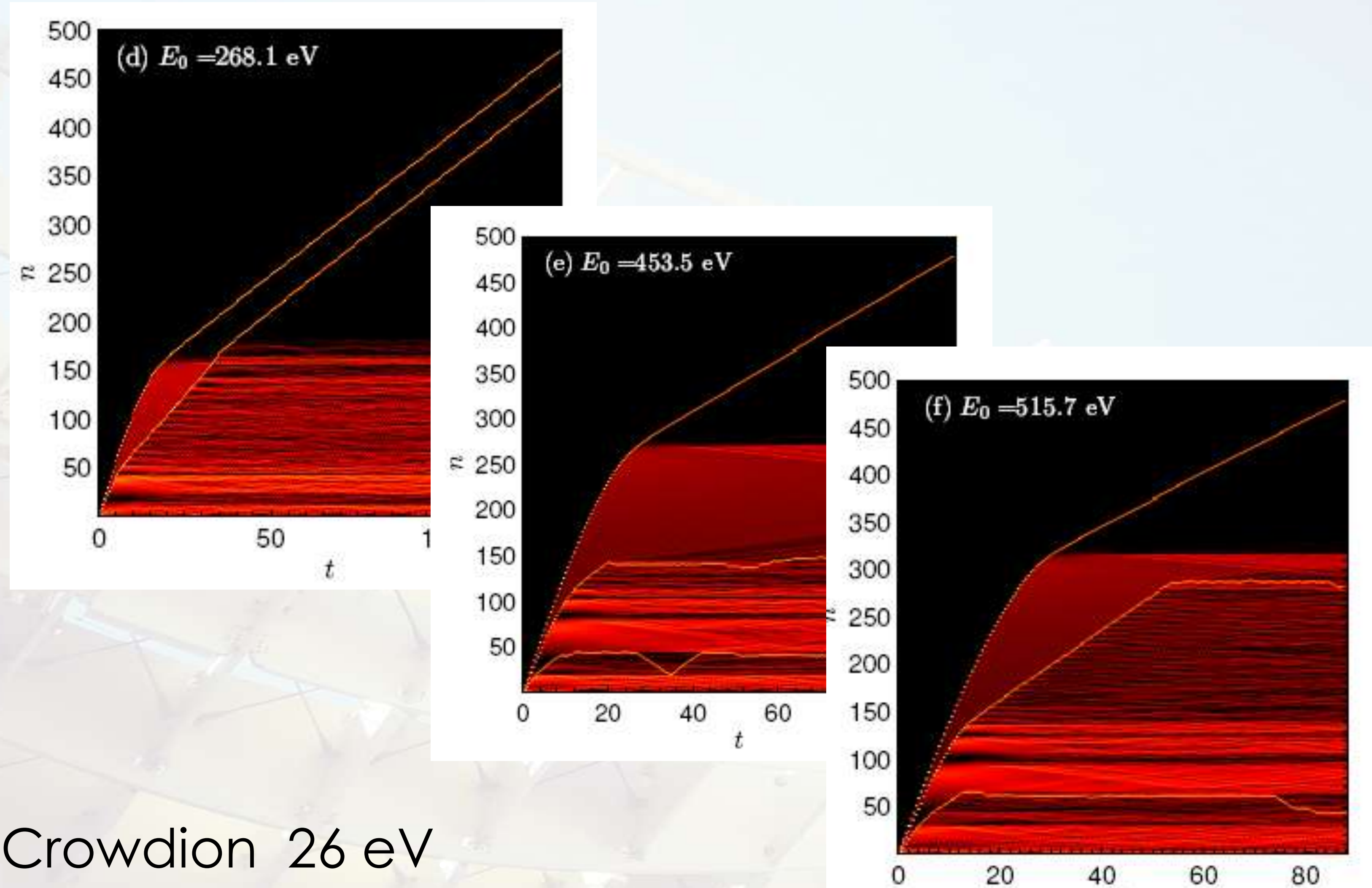
Zolotaryuk, Y., Eilbeck, J.C., Savin, A.V.: Bound states of lattice solitons and their bifurcations. Physica D 108, 81–91 (1997)

Excess energy (1)



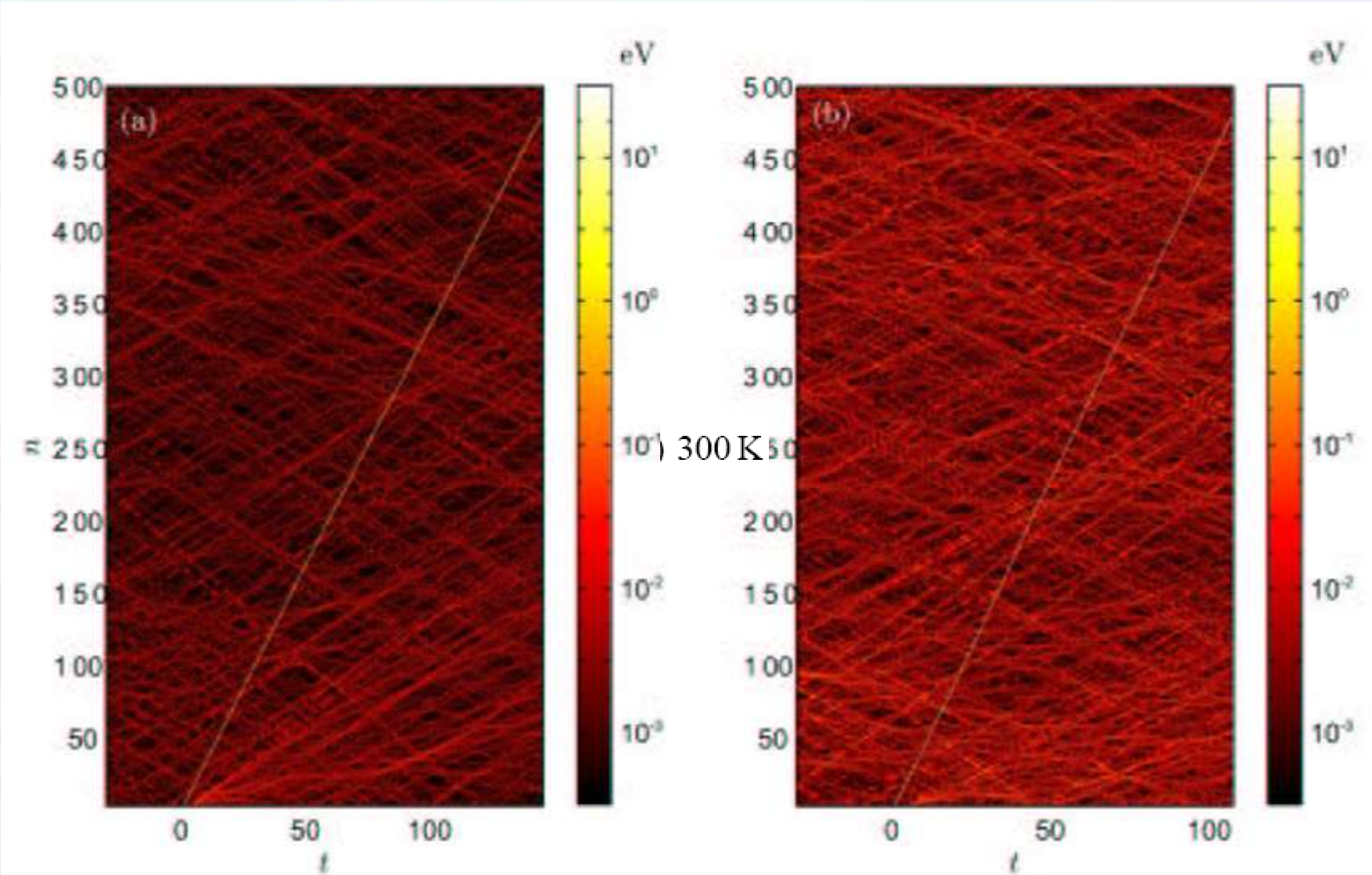
Crowdion 26 eV

Excess energy (2)



Crowdion 26 eV

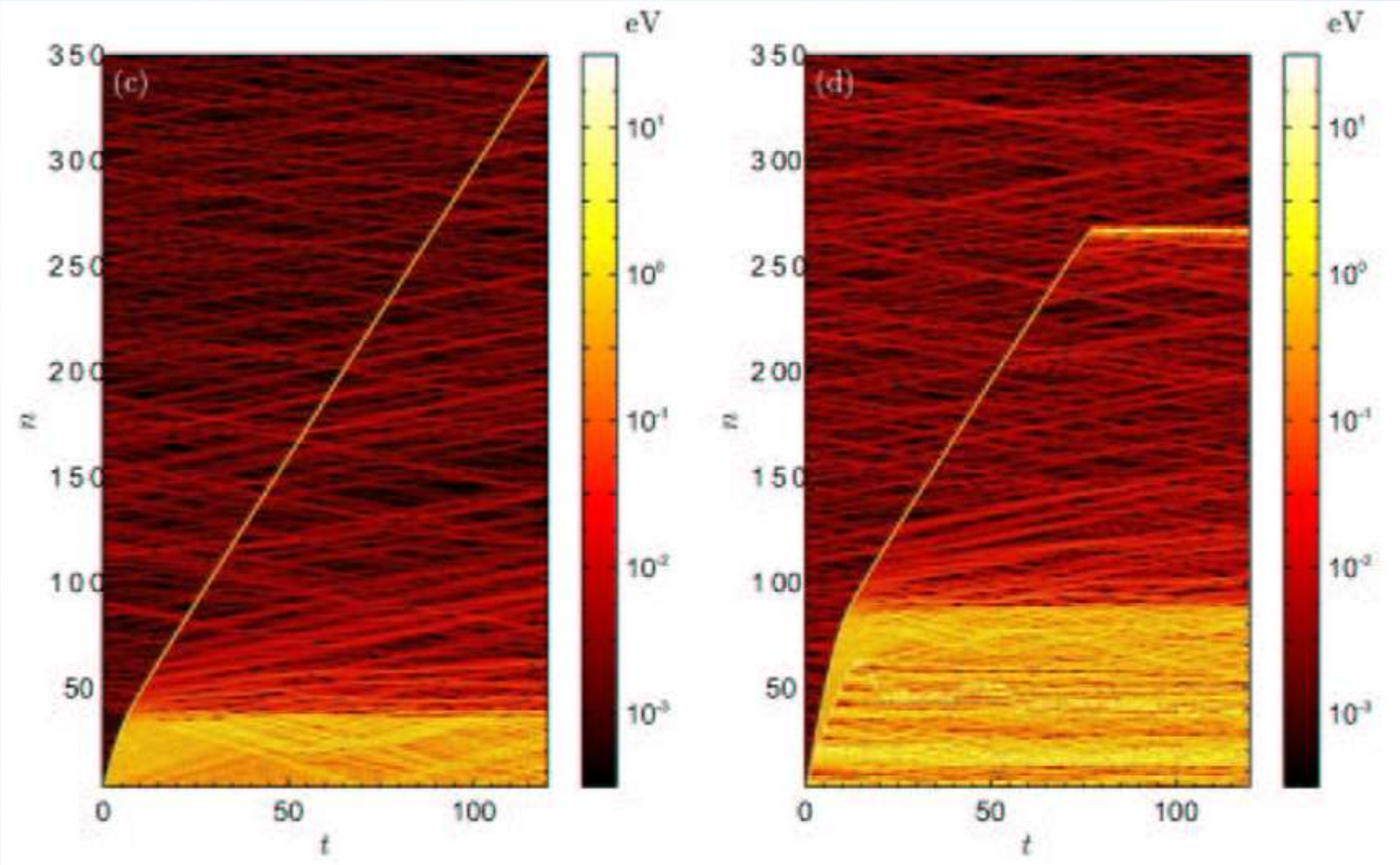
Thermalized medium FPU (without substrate)



300 K

1000 K

Thermalized medium KG (With substrate)



300 K

1000 K

Properties of crowdions in mica

-Crowdions travel long distances

-Energy of the crowdion 26 eV can be provided by K40 decay (0-50 eV)

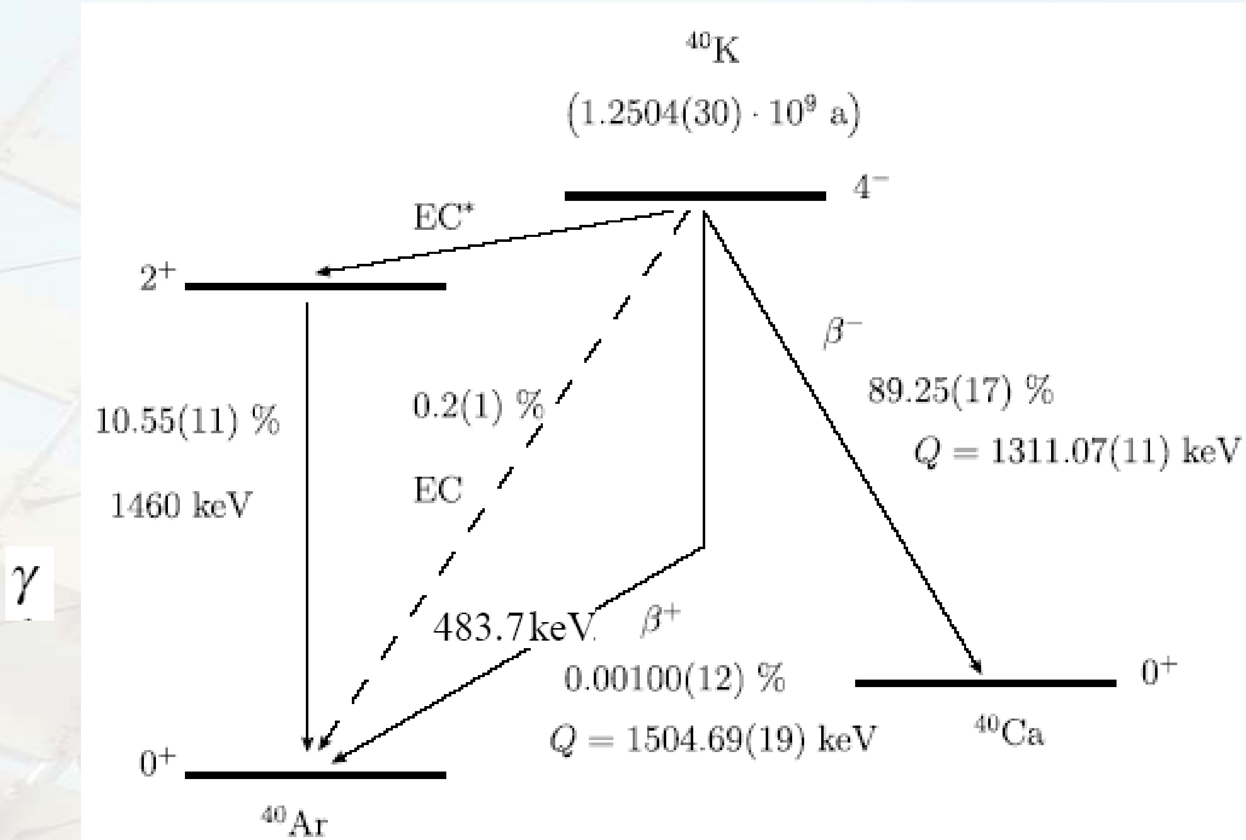
-Energy of the crowdion is enough to expel an atom (4-8 eV)

-Crowdions have large energy with respect to thermal one ~1000

-Crowdions survive to high temperatures 300 K, even 1000 K
- Crowdions transport positive charge

.

More about charge: K-40 decay modes



Final ion: Ar^+ Ar Ca^{++}

Ar^{++} (CE 0.001%)

EC: electron capture from the shell. CE: conversion electron.

From: Pradler, J., Singh, B., Yavin, I.: Phys. Lett. B 720(2013) 399

K-40 decay modes (energy and charge)

Decay	β^-	EC1	EC1+CE[1]	EC2[2]	β^+
Intensity	89.25%	10.55%	0.001%	0.2%	0.001%
T (keV)	1311.07	1460	1460	1504.69	483.7
Emitted charged particle	e^-		e^-	e^-	e^+
Recoil from	$\nu+e^-$	γ	e^-	ν	$\nu+e^+$
Max Recoil (eV)	42	29.2^M	49.7^M	31.1^M	10
Daugther ion (A=40)	Ca^{++}	Ar^+	Ar^{++}	Ar^{++}	Ar
Max V (Km/s)	14.4	12^M	15.7^M	12.2^M	7
Ionization of daughter (eV)	50.6	27.7	40.8	40.8	15.8
Δq (e)	+1	0	+1	+1	-1

[1] Subset of EC1 when the gamma is delivered to a shell electron; ^{M} Monocromatic

[2] Direct decay to Ar ground state, recoil from neutrino emission; 3 KeV Auger e^-

EC: electron capture; CE: conversion electron; T: energy available excluding rest masses

Ionization energy of K^+ 31.6 eV

K-40 decay modes (energy and charge)

-Not only recoil energy is delivered but in most cases charge

-Charge is

~90% positive with very different energies,

~10% neutral,

~ 0.001% negative

-Some decays are monochromatic but other have a wide range of recoil energies

beta – from 0 to 50.6 eV(+)

beta + from 0 to 15.8 eV(-)

JFR Archilla, YuA Kosevich et al,
A supersonic crowdion in mica, in Quodons in mica, JFR Archilla et al, eds, Springer (2015) p. 69

Some facts about dark tracks (magnetite)

- Swift particles recorded: positrons, antimuons, protons
- All with positive charge

-Quodon tracks are dark (magnetite)

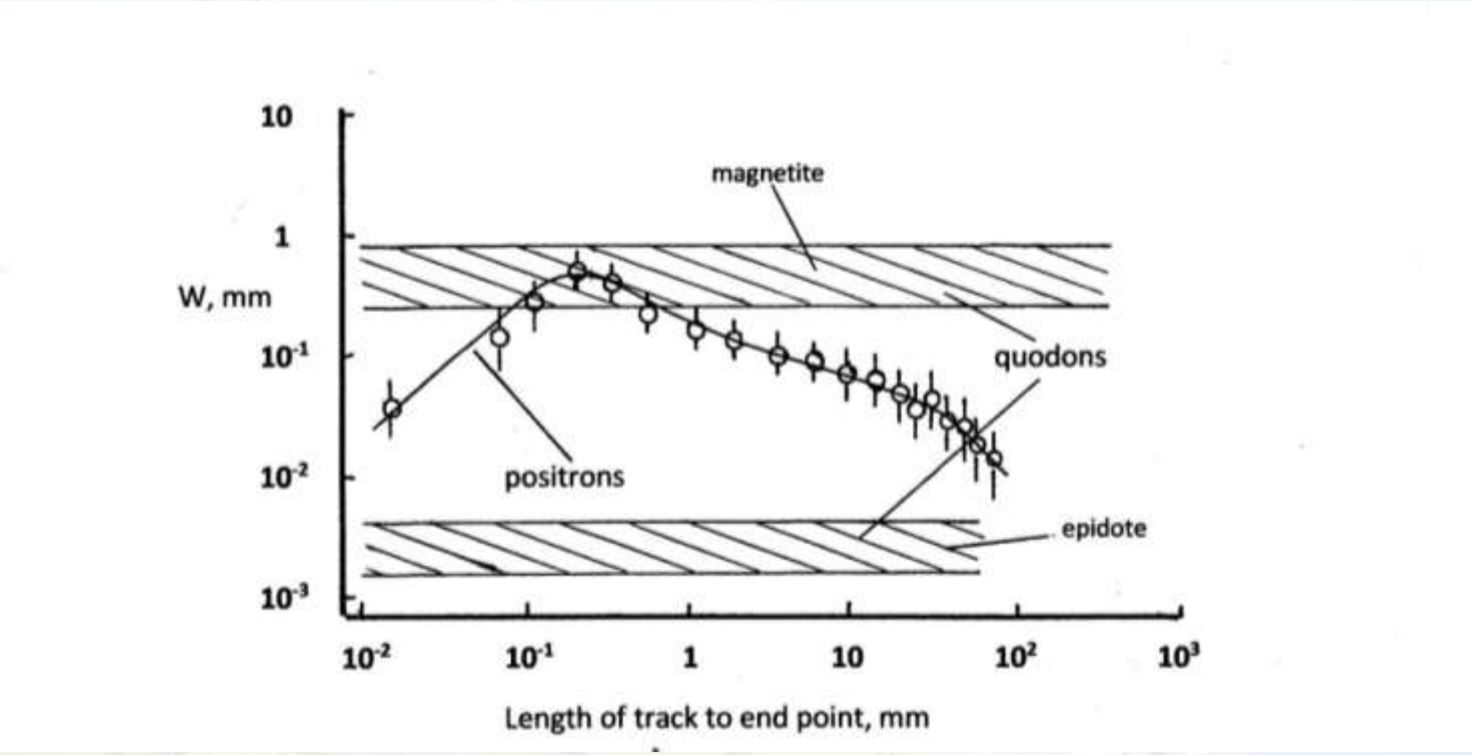
- 90% of the K-40 decay leave behind a positive charge

- There are also many black dots

- Swift particles and positrons tracks have similar thickness

Tracks of positrons and quodons

- Positrons tracks have similar thickness when the positron is about to stop a near sonic speed



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FM Russell (2015), arXiv:1505.03185

Epidote tracks

-There are some faint tracks of a semitransparente material often associated of positron tracks

A positron and the negative quodon produced by the recoil?

FM Russell (2015)

Hypothesis about quodons

1.-Quodons are localized anharmonic lattice excitations that transport charge.

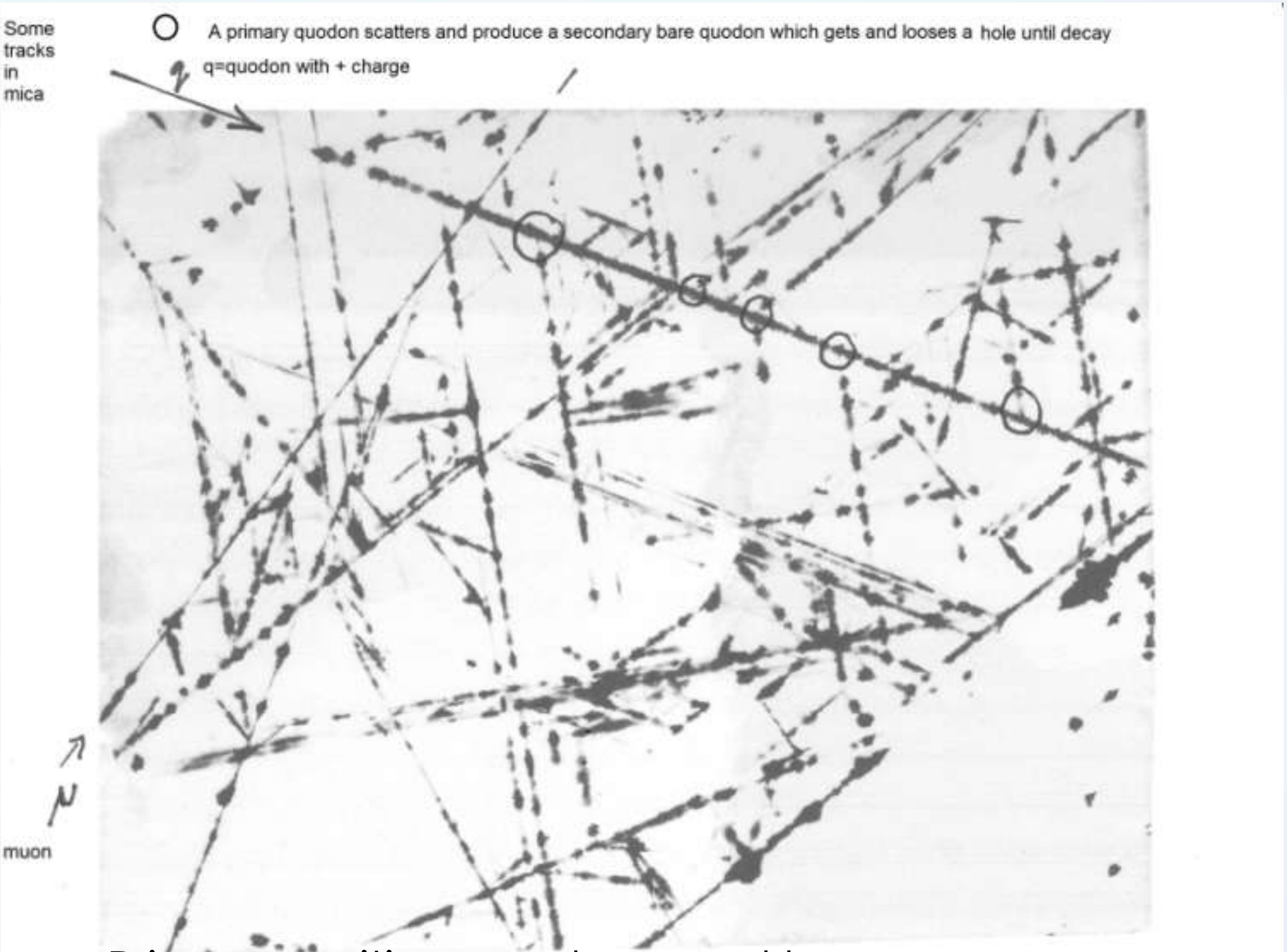
2.-Positive quodons cause the dark tracks of magnetite seen in mica muscovite

3.-Negative quodons are also produced and they may leave semi-transparent epidote tracks

Crowdions are positive: they should leave a dark track is stable in 2D

.

Many new interpretations of tracks



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Primary positive quodons, and bare ones

Some bibliography

Ultra-discrete kinks with supersonic speed in a layered crystal with realistic potentials, JFR Archilla, Yu A Kosevich, N Jiménez, VJ Sánchez-Morcillo and LM García-Raffi
Phys. Rev. E 91 (2015) 022912

JFR Archilla, Yu A Kosevich, N Jiménez, VJ Sánchez-Morcillo, LM García-Raffi , *A Supersonic Crowdion in Mica: Ultradiscrete kinks with energy between 40K recoil and transmission sputtering,* In Quodons in Mica: Nonlinear Localized Travelling Excitations in Crystals, J.F.R. Archilla et al, eds, Springer (2015) pp. 69-96

FM Russell, *Tracks in Mica, 50 Years Later: Review of Evidence for Recording the Tracks of Charged Particles and Mobile Lattice Excitations in Muscovite Mica*, In Quodons in Mica, Nonlinear Localized Travelling Excitations in Crystals , J.F.R. Archilla et al, eds, Springer (2015) pp. 3-33

FM Russell, JC Eilbeck, Evidence for moving breathers in a layered crystal insulator at 300 K. Europhys. Lett. **78**, 10004 (2007)

FM Russell, Charge coupling to anharmonic lattice excitations in a layered crystal at 800K, arXiv:1505.03185