NAPLIFE: NAnoPlasmonic Laser Ignited Fusion Experiment

– nanofusion progress in 2023/2024 –

T.S. Biró[1, 2,] for the NAPLIFE collaboration

[1]NKFIH NAPLIFE research project

HUN REN | Wigner Research Centre for Physics, Budapest

[2]Complex Science Hub, Vienna

PP2024 invited talk, Budapest, June 11, 2024

project sponsoring

2022 Oct 1 - 2026 Feb 28

WIGNER FIZIKAI
KUTATÓKÖZPONT

2022-2.1.1-NL-2022-00002
NANOPLAZMONIKUS LÉZERES FÚZIÓ
KUTATÓLABORATÓRIUM

A TÁMOGATÁS ÖSSZEGE:
1 127 964 898 FORINT

NEMZETI KUTATÁSI, FEJLESZTÉSI ÉS INNOVÁCIÓS HIVATAL

AZ NKFI ALAPBÓL
MEGVALÓSULÓ
PROJEKT

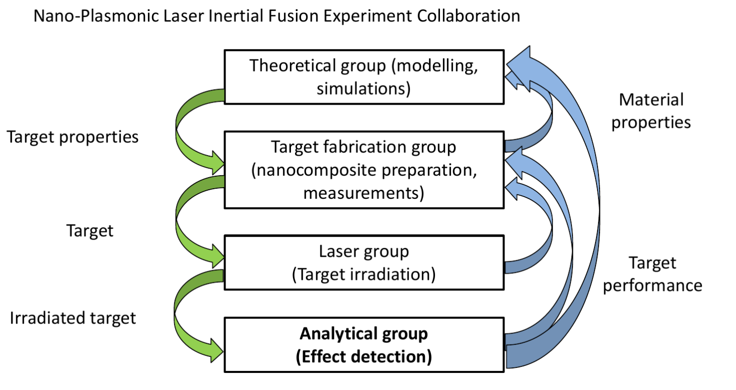
IDEAS

the project is based on

1. N.Kroó: Plasmonics $\rightarrow$ NFE, Coulomb threshold lowering, p - acceleration
2. L.P.Csernai: 2-sided laser shots $\rightarrow$ no RT instability, ultrafast non-eq. ignition
3. T.S.Biró: make and detect 1) energetic ions, 2) fusion reaction products

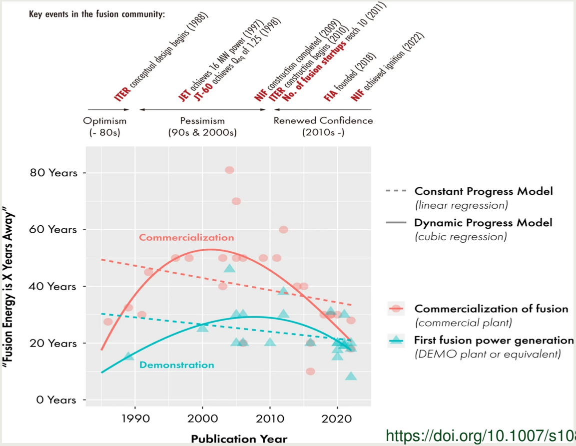
Project Group Structure

cooperation



When will be there fusion?

answers in years



https://doi.org/10.1007/s10894-023-00361-z

Specific energy content

J/mg = MJ/kg

https://afdc.energy.gov/fuels/properties; https://en.wikipedia.org/wiki/energy_density

- coal 23; lignit 18; torf 7; wood 11; biomass 10; fallout 9; oil pala 20
- petrol, PB gas 40; bio-fuel 30; liquid fallout 25
- natural gas 47; H 40; biogas 20; rest gas 15
- uranium 460.000; fusion 640.000.000

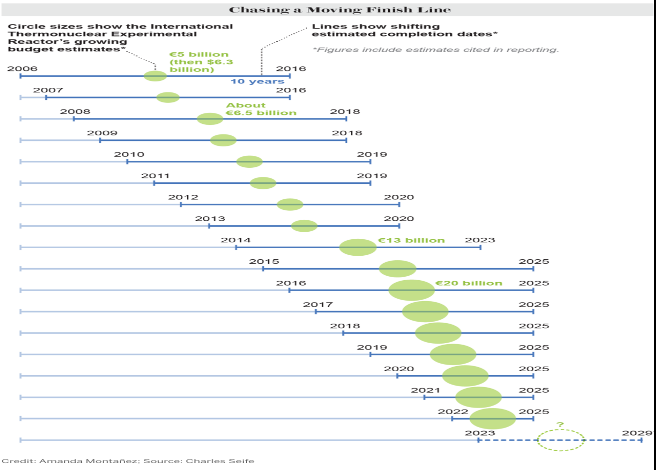
20 tons of coal $\approx$ 1 kg uranium $\approx$ 1 g fusion fuel

Equilibrium and thermal fusion

ITER magnetic confinement

ITER schedule

construction dates and costs



Sudden and direct fusion

NIF laser shots

NIF

out/in factor Q = 1.5

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CONGRATULATIONS! | ITER APPLAUDS NIF FUSION BREAKTHROUGH

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ITER NEWSLINE -

12 DEC, 2022 — Print | Read the latest published articles

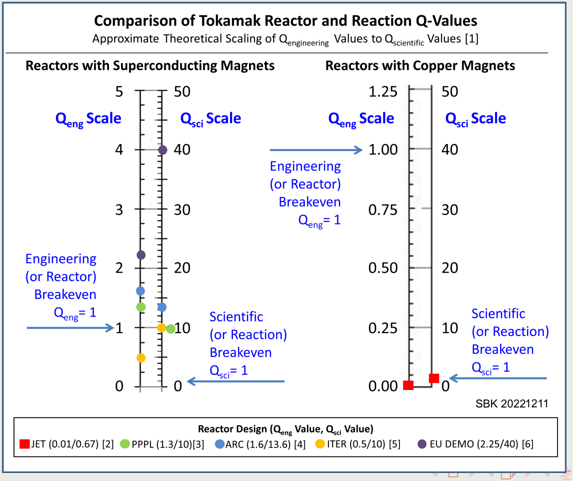
Congratulations!

ITER APPLAUDS NIF FUSION BREAKTHROUGH

ITER scientists hailed the latest experimental results at the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in California: the achievement of "breakeven" fusion energy. "When future generations look back on the evolution of fusion energy research, I believe this will be recognized as a historic milestone," said ITER Director-General Pietro Barabaschi. NIF's experiment used 2.05 megajoules of laser energy to produce 3.15 megajoules of fusion energy, reaching a Q value of 1.5.

Q values

scientific and engineering



HUN REN Wigner

Where is the fusion to date?

The Lawson contest

FUSION INDUSTRY ASSOCIATION

Fusion Is Close

Decades of advances in plasma physics

\+ Technology revolutions in materials, computing power, advanced manufacturing

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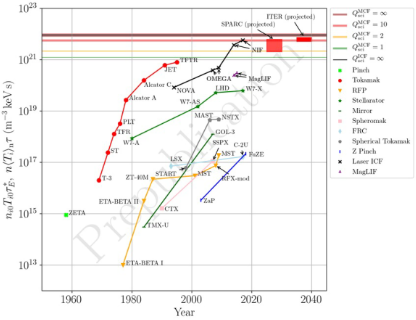
The cusp of net gain energy

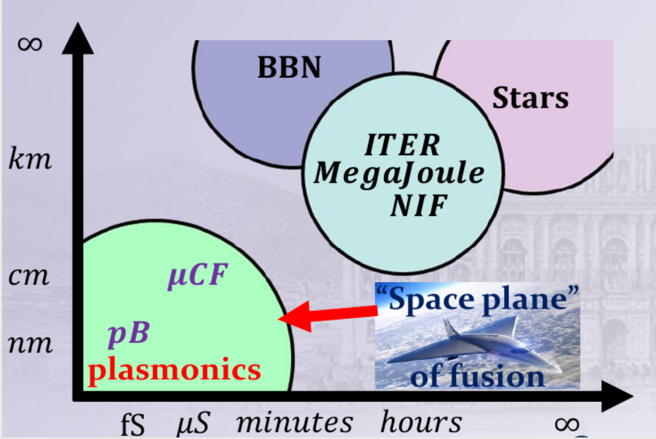
U.S. Government investment has enabled this moment: it is time to capitalize on it.



Wurzel, Samuel & Hsu, Scott. (2021). Progress toward Fusion Energy Breakeven and Gain as Measured against the Lawson Criterion.

Fusion time scales

Jan Rafelski's inauguration talk at MTA 2022.05.31.



Neutronfree fusion reactions

examples (wiki)

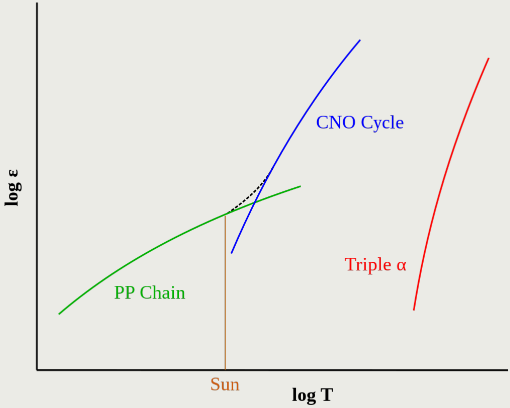
High nuclear cross section aneutronic reactions[1]

Isotopes	Reaction
Deuterium - ^{3}He	$^2D + {}^3He \rightarrow {}^4He + {}^1p + 18.3$ MeV
Deuterium - ^{6}lithium	$^2D + {}^6Li \rightarrow 2\,{}^4He + 22.4$ MeV
Proton - ^{6}lithium	$^1p + {}^6Li \rightarrow {}^4He + {}^3He + 4.0$ MeV
^{3}He – ^{6}lithium	$^3He + {}^6Li \rightarrow 2\,{}^4He + {}^1p + 16.9$ MeV
^{3}He - ^{3}He	$^3He + {}^3He \rightarrow {}^4He + 2\,{}^1p + 12.86$ MeV
Proton – Lithium-7	$^1p + {}^7Li \rightarrow 2\,{}^4He + 17.2$ MeV
Proton – Boron-11	$^1p + {}^{11}B \rightarrow 3\,{}^4He + 8.7$ MeV
Proton – Nitrogen	$^1p + {}^{15}N \rightarrow {}^{12}C + {}^4He + 5.0$ MeV

Electrons in the fusion

PEP process (wiki)

$p + e^- \to n + \nu_e$ (-1.25 MeV), $p + n \to d + \gamma$ (+2.22 MeV)



NAPLIFE individual features

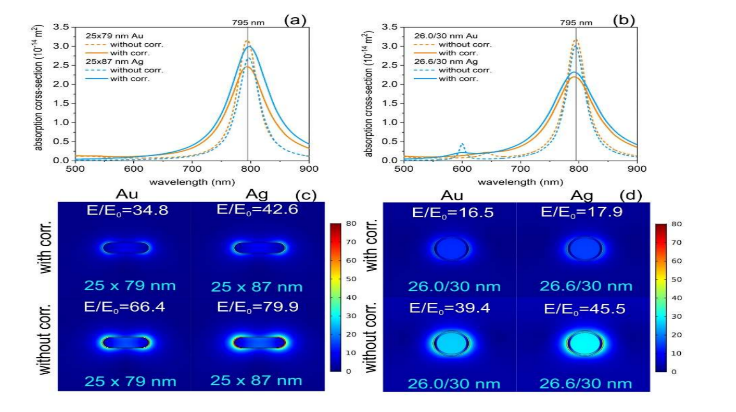
1. Plasmonic collectivity, energy concentration, threshold lowering, lifetime cca. $20 - 30$ fs
2. Non-equilibrium, simultaneous ignition with lightspeed
3. Nanoantennas in target, ultrashort, great contrast laser pulses (10^6, 40 fs @ Wigner, 10^{10}, 12 fs @ ELI)
4. Energy balance and products: microcraters, (Raman, LIBS, MS) CR39, Thomson parabola

Nanofusion

plasmons: barrier lowers, energy hot spots

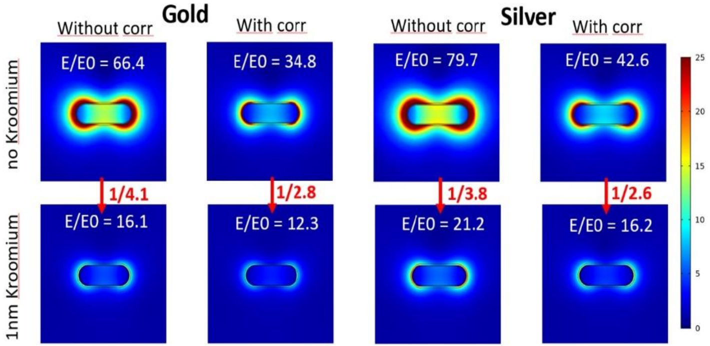
Plasmonics at work

simulations (M. Csete group)



Plasmonics at work

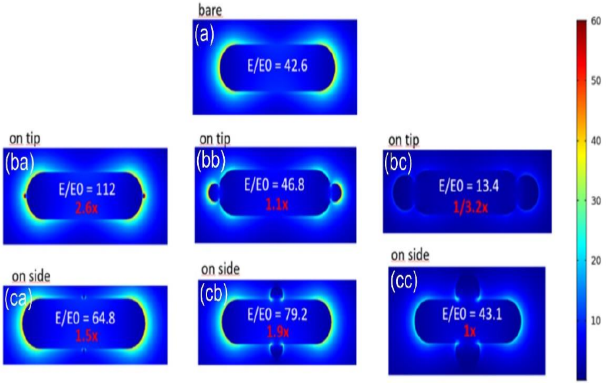
NFE (near field enhancement) (M. Csete group)



1.1.2. ábra A vizsgált rendszerek közeltér erősítés eloszlása ($|\mathbf{E}|/|\mathbf{E}_0|$).

Plasmonics at work

doped nanoantennas (M. Csete group)

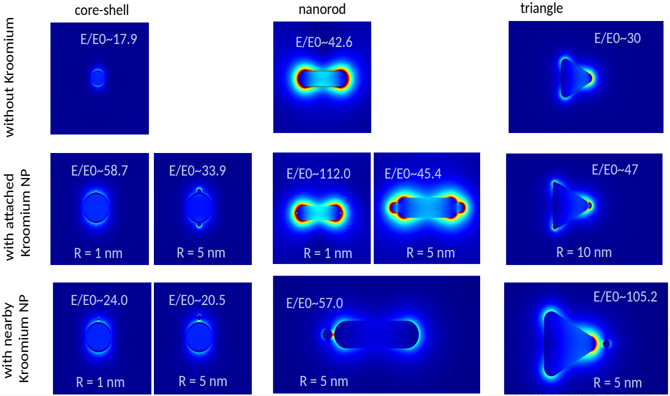


1.1.5. ábra A vizsgált ezüst (korrigált ε(ω) függvény) rendszerek közeltér erősítés eloszlása ($|\mathbf{E}|/|\mathbf{E}_0|$). (a) Kroómium nélküli eset, (ba-bc) on-apex és (ca-cc) on-side konfigurációk 1 nm – 10 nm KNP mérettel.

Plasmonics at work

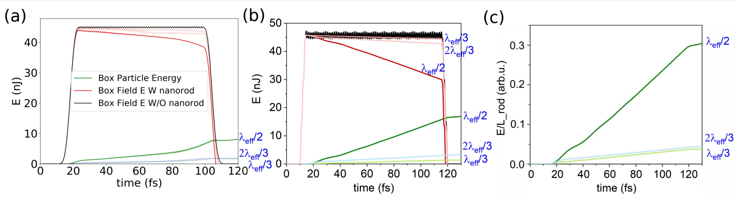
nanoantenna shape variations (M. Csete group)

Near-field enhancement with individual plasmonic nanoresonators & Kroomium nanoparticles



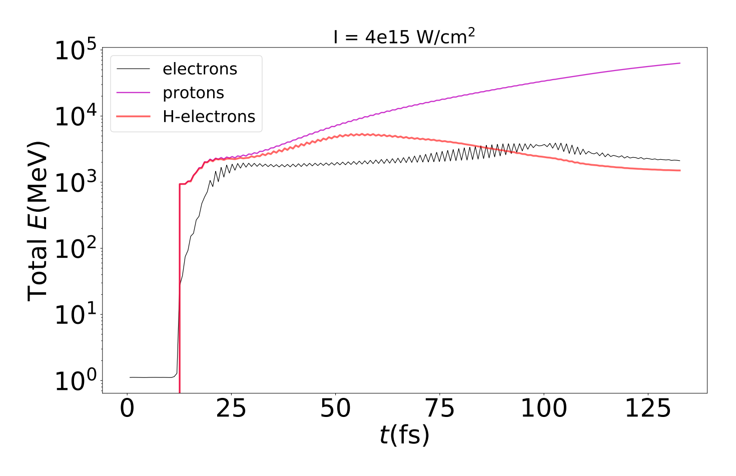
Kinetic model: PIC

Single nanorod resonating length (I. Papp)



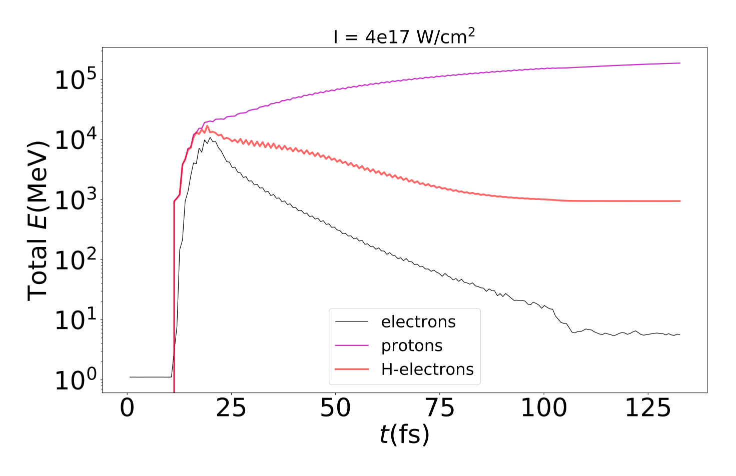
Kinetic model: PIC

Low intensity energy sharing (I. Papp)



Kinetic model: PIC

Higher intensity energy sharing (I. Papp)



NAPLIFE NANO

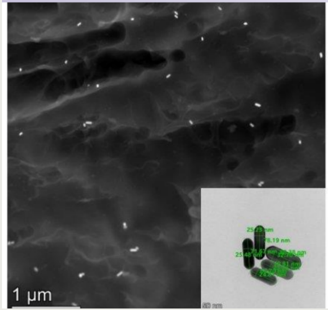
Au nanoparticles under microscope, absorption (Bonyár group)

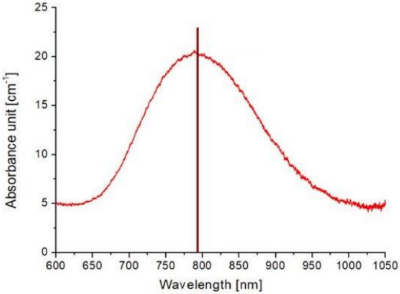
The NAPlife plasmonic fusion project

UDMA polymer with resonant gold nano-rods

Gold nano-rods embedded in polymer matrix: Transmission electron microscope image; insert shows actual nano-rods

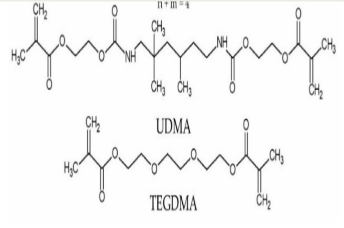
Actual absorption curve for nano composites measured by optical spectroscopy. The absorption peak is tuned to resonate with laser wavelength at 795 nm

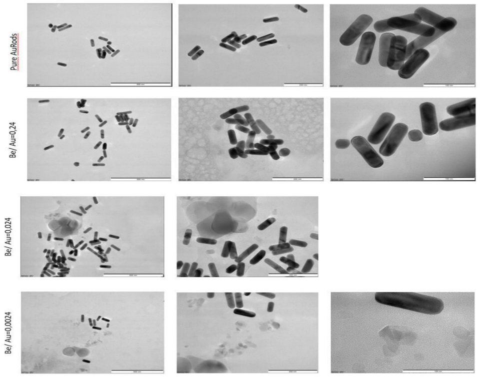




NAPLIFE NANO

Nanorod samples (Bonyár, Veres groups)



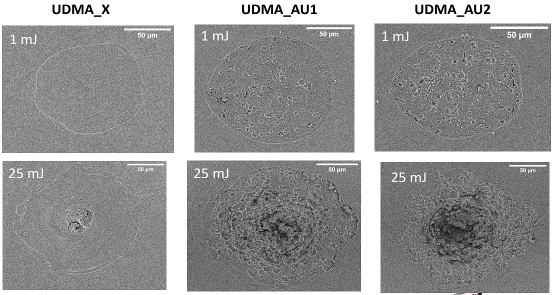


12. ábra. A különböző AuRods/ Be aránnyal rendelkező minták TEM felvételei

NAPLIFE CRATER

craters microscopic picture (J. Kámán)

7. Surface structure of the laser ablated area, investigated by SEM



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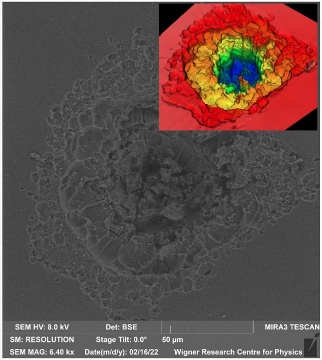
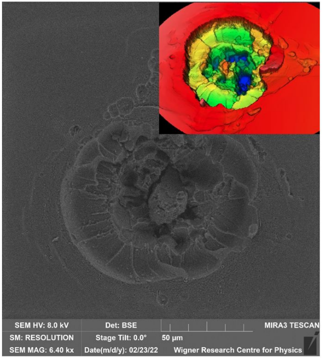
NAPLIFE CRATER

microcraters inside craters (J. Kámán)

SEM IMAGE OF UDMA WITH AU NANORODS



SEM IMAGE OF UDMA WITHOUT AU NANORODS



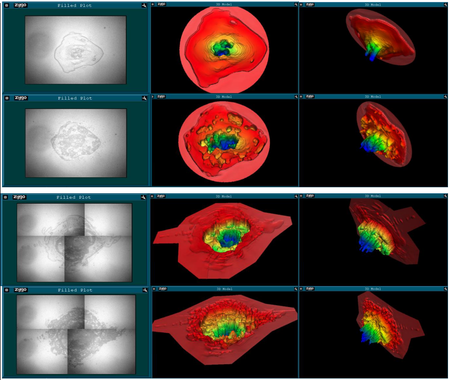
Images at 17.5mJ laser energy, $1{,}16.10^{17}$ W/cm² laser intensity.The volume of the crater of the sample with nanorods is 1.98 times that of the sample without rods.

NAPLIFE CRATER

shot craters (Á. Nagyné Szokol)

Preliminary measurements

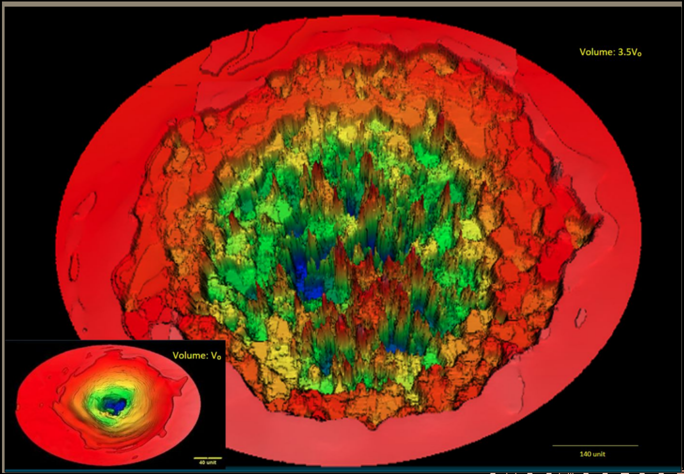
2,5 mJ	Without gold
	With gold nanorods
25 mJ	Without gold
	With gold nanorods



ICNFP 2022 - Ágnes Nagyné Szokol - 7 September 2022

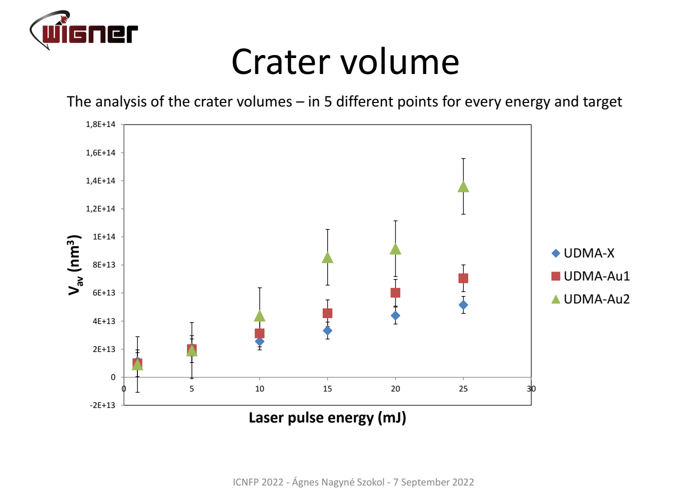
NAPLIFE CRATER

craters w/o Au nanorods (A. Nagyné Szokol)



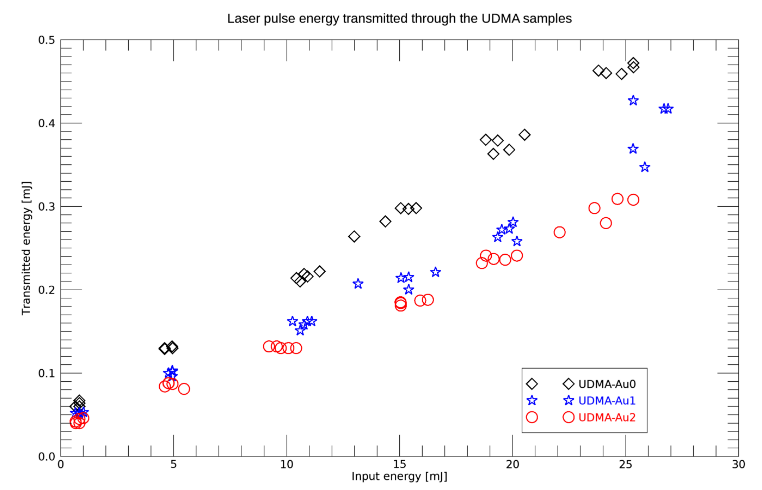
NAPLIFE CRATER

crater volume vs laser energy (Á. Nagyné Szokol)



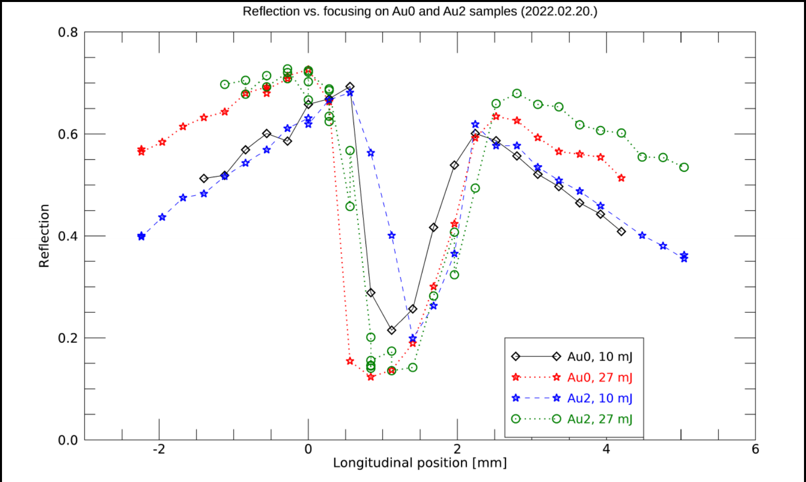
Transmitted energy < 2 %

M. Kedves



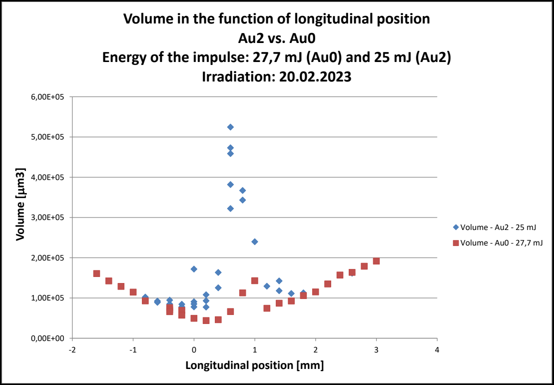
Plasma mirror: reflected energy vs focus

A. Márk, M. Kedves



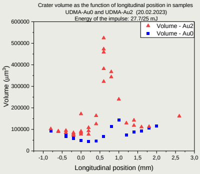
Crater volume vs focus position

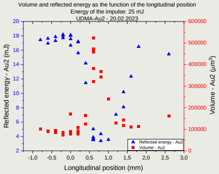
A. Márk, M. Kedves; Á. Szokol, N. Kroó

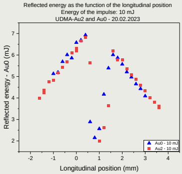


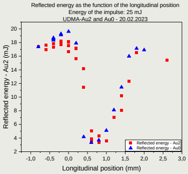
Volume and Reflection vs Focus Position

A. Márk, M. Kedves, B. Ráczkevi, Á. Szokol





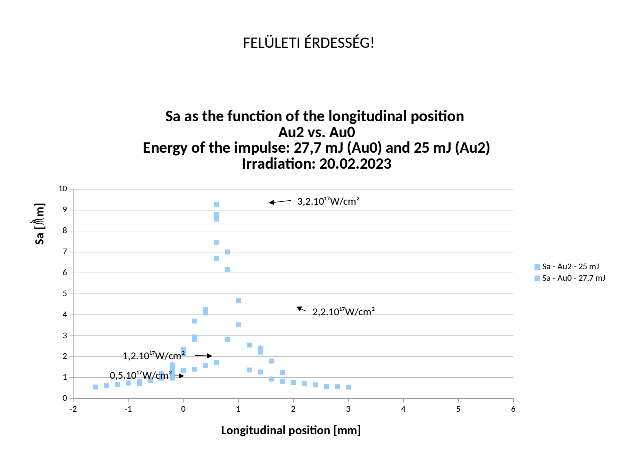




- With Au: larger volumes
- W/o Au: same reflection
- Plasmonic effect → larger volume

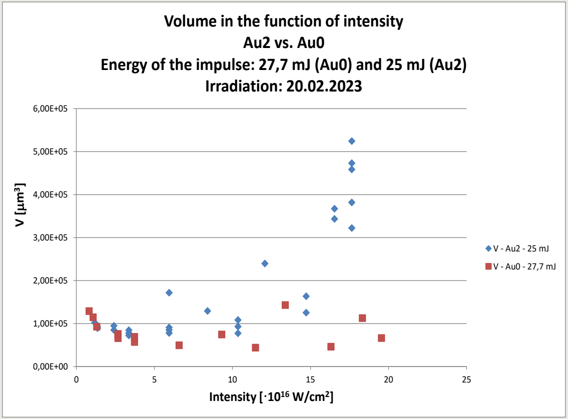
Crater roughness: Intensity counts!

A. Márk, M. Kedves; Á. Szokol, N. Kroó



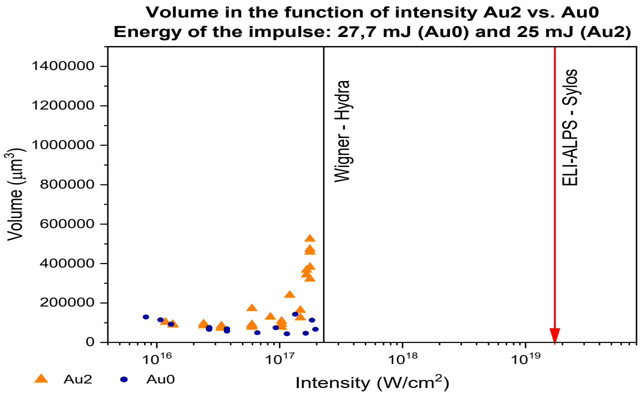
Crater volume vs intensity: Au counts!

Á. N. Szokol



Crater volume vs intensity: the laser counts!

Á. N. Szokol, N. J. Abdulameer



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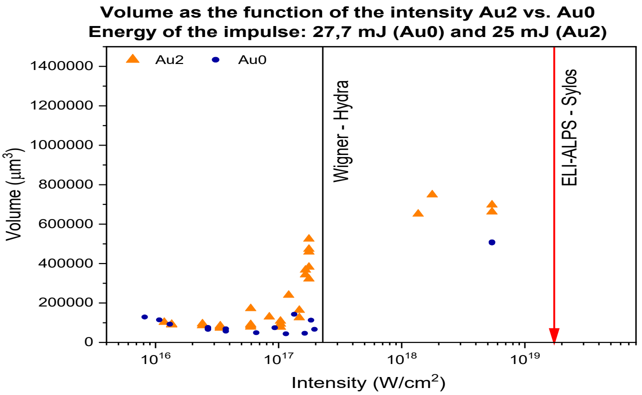

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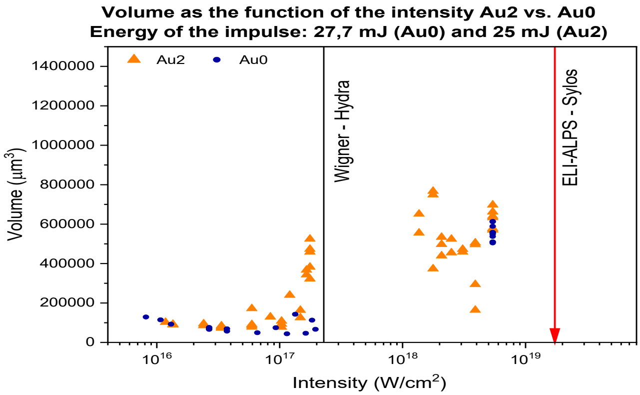


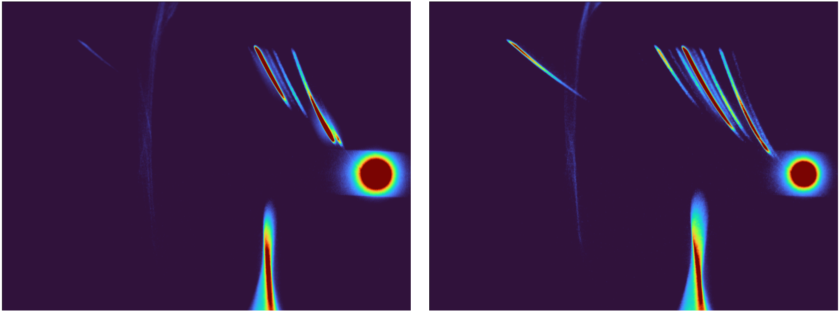
Interpretation

of crater volume results

1. Reflection is down to 10% at best focus = high intensity
2. Transmission is about $1 - 2\%$
3. Crater volume is prop. to *deposited* energy
4. Energy efficiency with Au2 is at a factor of $2 - 3$ (30-50 mJ extra) in some cases 7 (Q=6 180 mJ extra)!

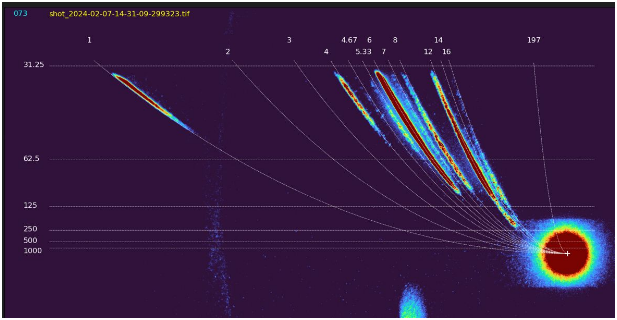
Thomson parabola

backward ions from thick target: left Au0, right Au2



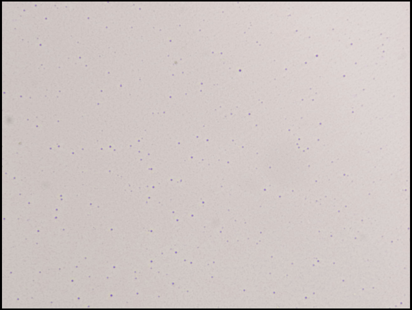
Backward plasma

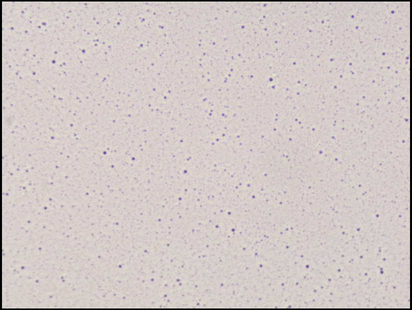
on energies



CR39 traces

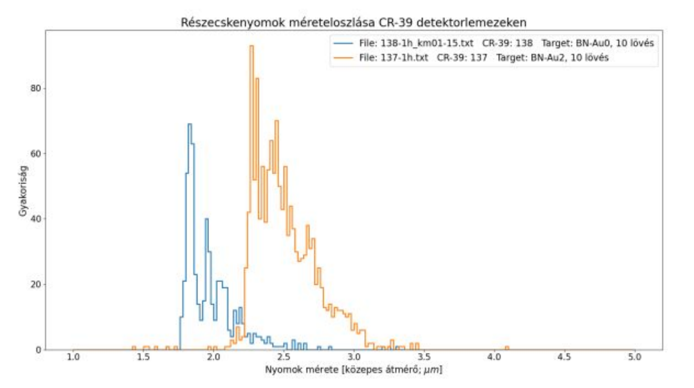
Au0 vs Au2





CR39 traces

Au0 vs Au2 size distribution



NAPLIFE FUTURE

plans

Contracted with NKFIH until February 28-th, 2026.

Plans:

- TP and CR39 evaluation (about 3.000 shootings were done in our ELI-campaign No 1)
- 2-nd ELI campaign (thinner - foil - targets, better detectors, more energetic ions) – user beamtime was applied in April 29th, 2024
- Use of doped targets, shape variations, reflectivity vs. intensity
- Measuring neutrons and alphas by TOF detectors