NAnoPlasmonic Laser Ignited Fusion Experiment

– a status report –

T.S. Biró[1, 2, 3] for the NAPLIFE collaboration

[1]NKFIH NAPLIFE research project
Wigner Research Centre for Physics, Budapest

[2]Complex Science Hub, Vienna

[3]Universitatea Babeş-Bolyai, Cluj

Wigner 121, Budapest, September 18-20, 2023

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

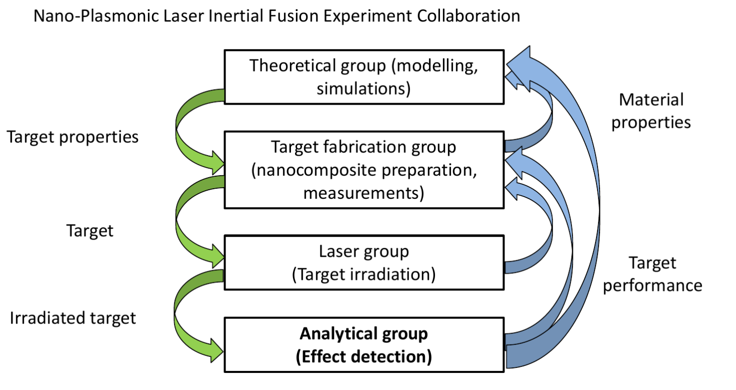
AZ NKFI ALAPBÓL
MEGVALÓSULÓ
PROJEKT

Lab Structure

organogram

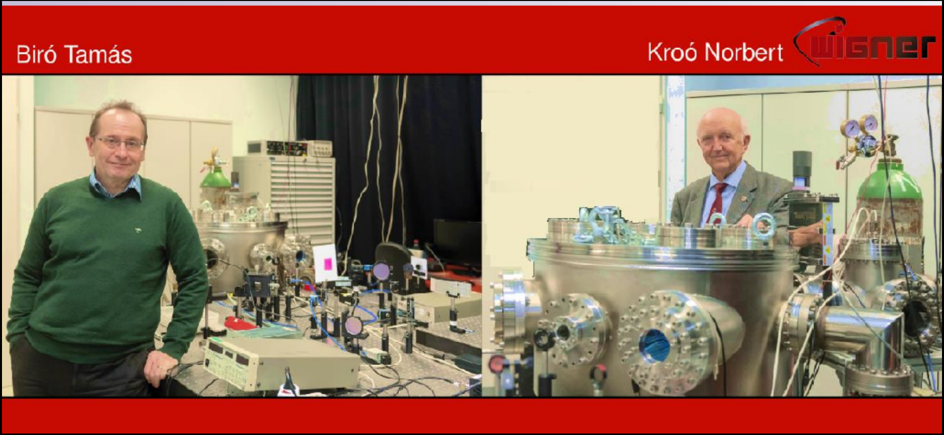
Group Structure

cooperation



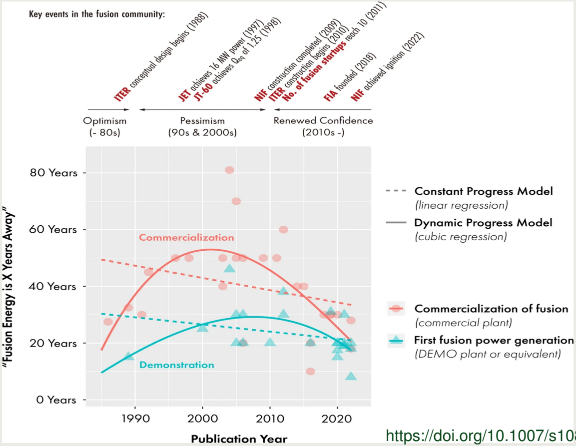
NAPLIFE devices

laser table, vacuum chamber



When will be there fusion?

answers in years



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

Specific energy content

J/mg = MJ/kg

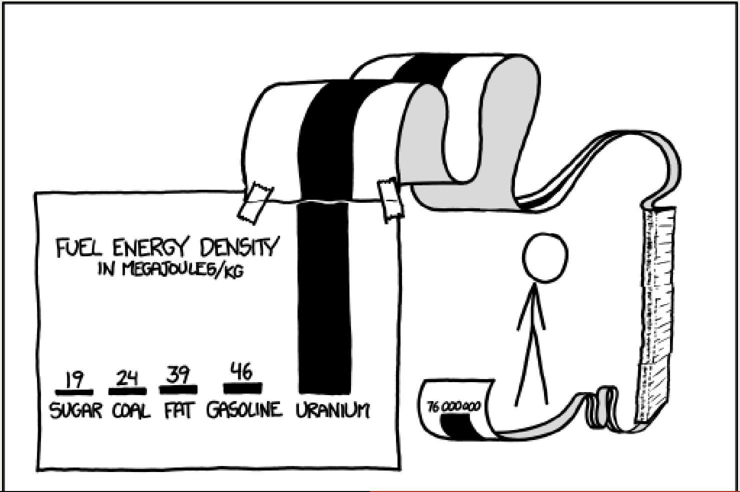
https://afdc.energy.gov/fuels/properties; https://en.wikipedia.org/wiki/energy_density

- 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 ≈ 1 kg uranium ≈ 1 g fusion fuel

Specific energy

comparing the uncomparables

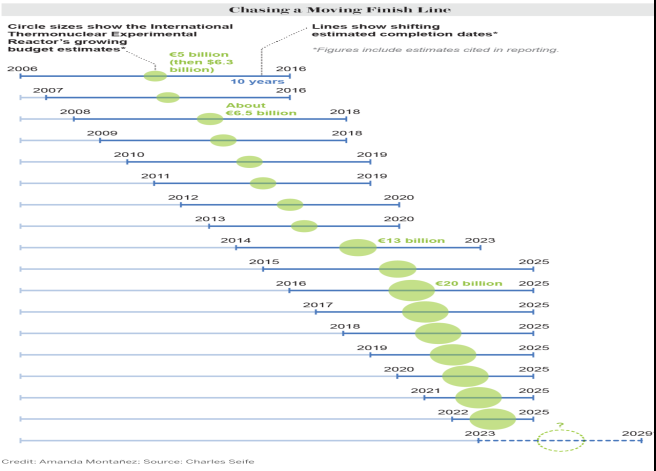


Equilibrium and thermal fusion

ITER magnetic confinement

ITER schedule

delays and costs

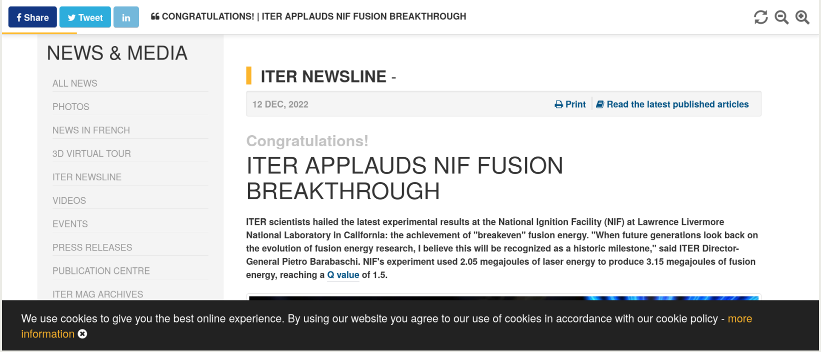


Sudden and direct fusion

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.

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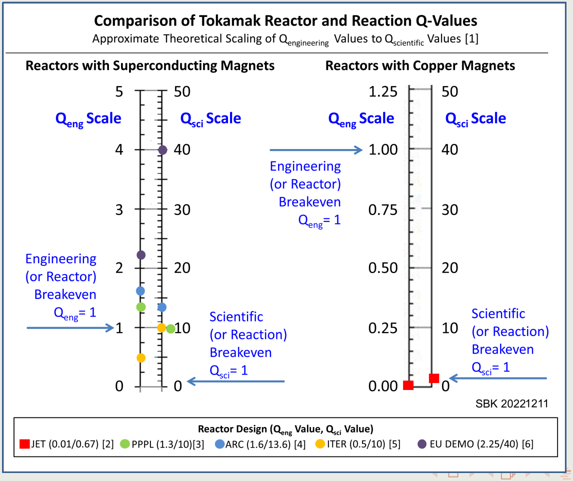
Q values

scientific and engineering



Where is the fusion to date?

The Lawson contest

FUSION INDUSTRY ASSOCIATION

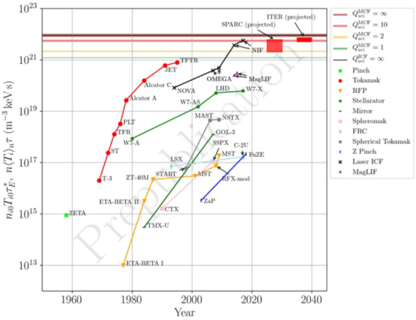
Fusion Is Close

Decades of advances in plasma physics

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

The cusp of net gain energy

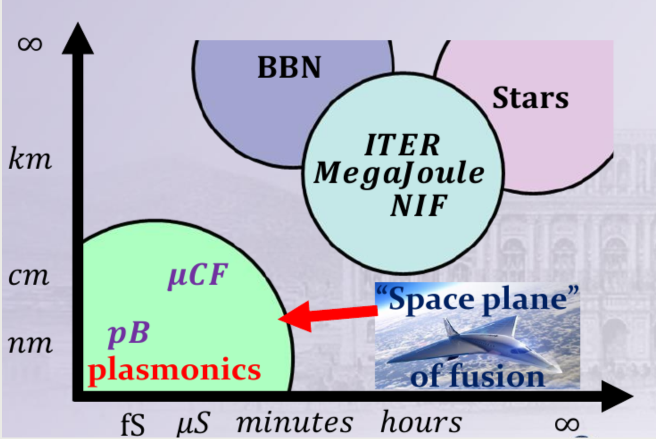
U.S. Government investment has enabled this moment: it is time to capitalize on it.



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

Fusion time scales

in Nature and in experiments



Neutronfree fusion

examples (wiki)

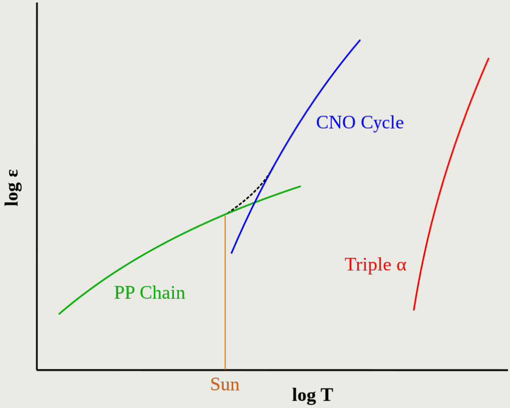
High nuclear cross section aneutronic reactions[1]

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

Electrons in the fusion

PEP process (wiki)

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



NAPLIFE individual features

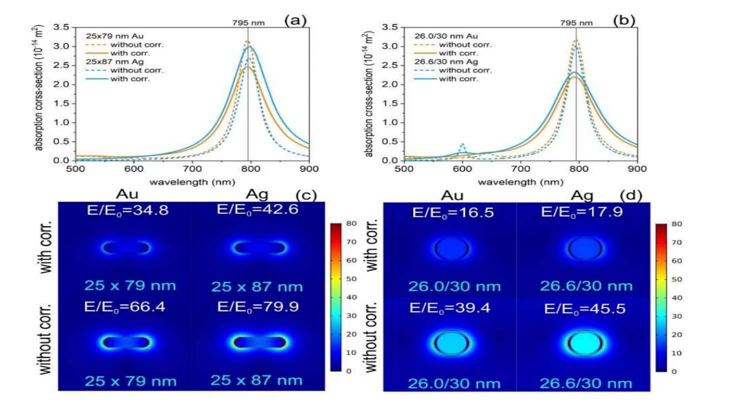
1. Plasmonic collectivity, energy concentration, threshold lowering, lifetime cca. $20 - 30$ fs
2. Non-equilibrium, simultaneous ignition with lightspeed
3. Nanoantennas in target, ultrashort, great contrast laser pulses (10^6, 40 fs @ Wigner, $--->$ ELI)
4. Energy balance and products: microcraters,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

Nanofusion

plasmons: barrier lowers, energy hot spots

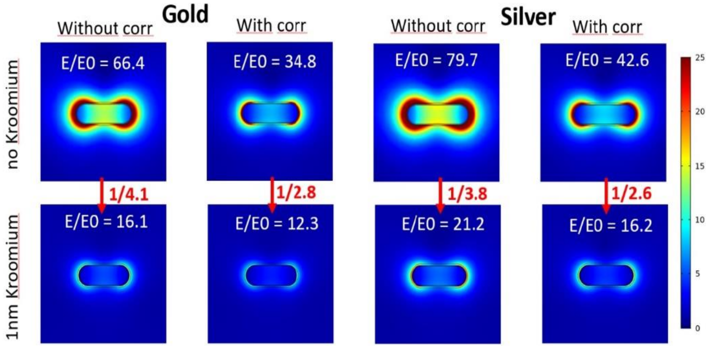
Plasmonics at work

simulations (M. Csete group)



Plasmonics at work

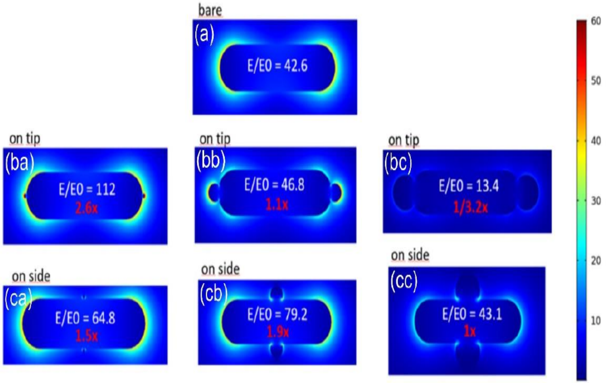
NFE (near field enhancement) (M. Csete group)



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

Plasmonics at work

doped nanoantennas (M. Csete group)

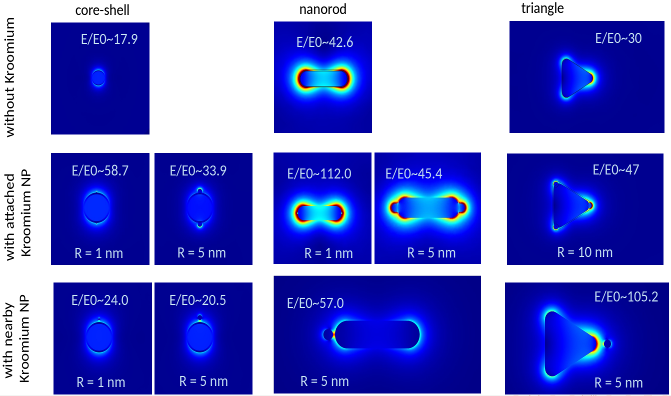


1.1.5. ábra A vizsgált ezüst (korrigált ε(ω) függvény) rendszerek közeltér erősítés eloszlása ($|\mathbf{E}|/|\mathbf{E}_0|$). (a) Kroómium nélküli eset, (ba-bc) on-apex és (ca-cc) on-side konfigurációk 1 nm – 10 nm KNP mérettel.

Plasmonics at work

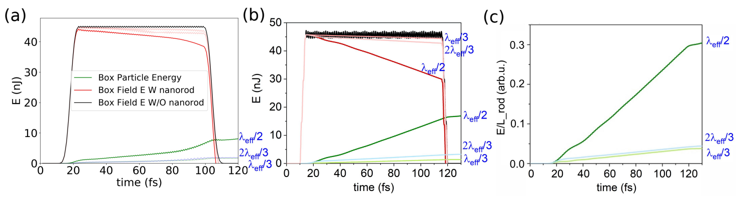
nanoantenna shape variations (M. Csete group)

Near-field enhancement with individual plasmonic nanoresonators & Kroomium nanoparticles



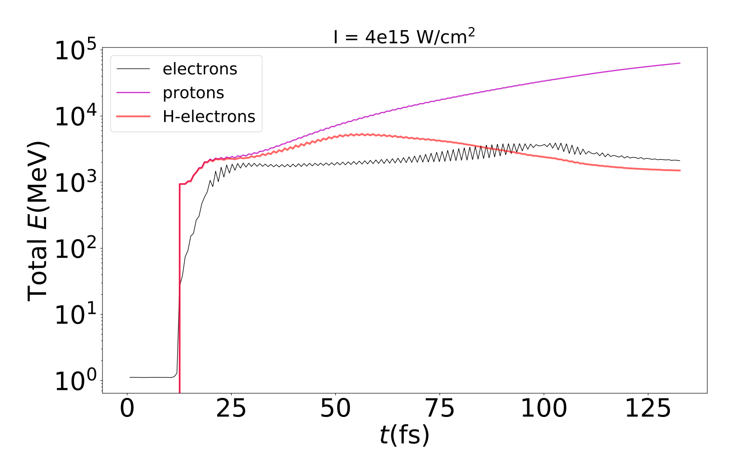
Kinetic model: PIC

Single nanorod resonating length (I. Papp)



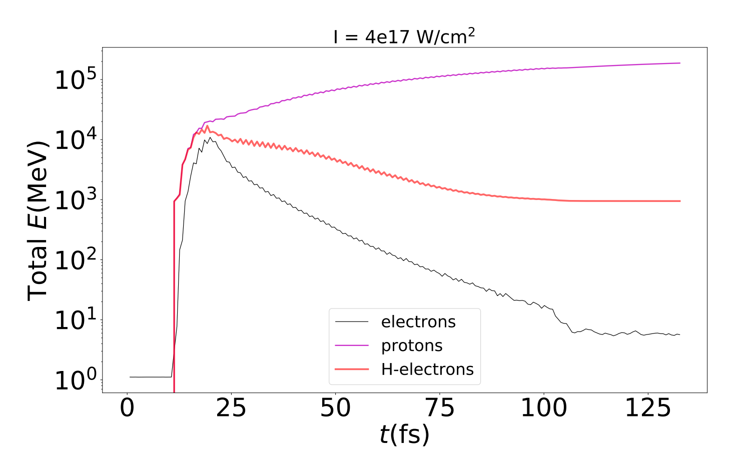
Kinetic model: PIC

Low intensity energy sharing (I. Papp)



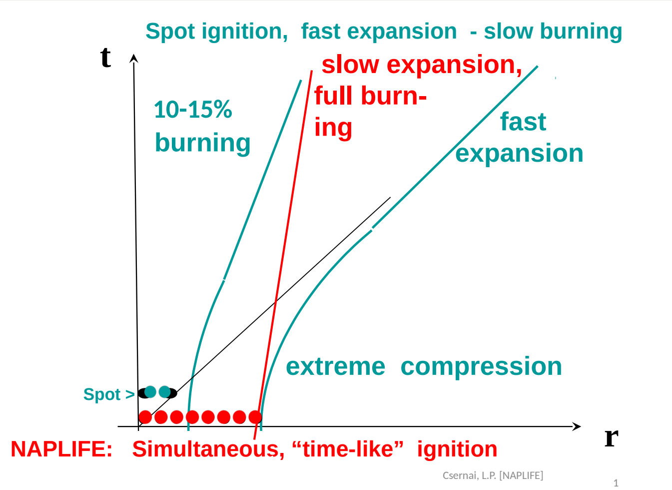
Kinetic model: PIC

Higher intensity energy sharing (I. Papp)



NAPLIFE (25 mJ, 40 fs) vs NIF (1 MJ, 10 ns)

Rapid vs slow ignition (L. Csernai)



NAPLIFE NANO

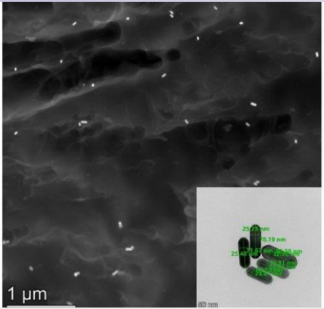
Au nanoparticles under microscope, absorption (Bonyár group)

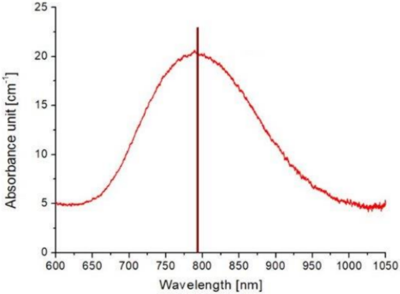
The NAPlife plasmonic fusion project

UDMA polymer with resonant gold nano-rods

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

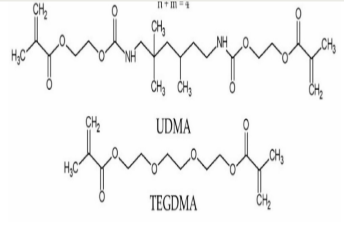
Actual absorption curve for nano composites measured by optical spectroscopy. The absorption peak is tuned to resonate with laser wavelength at 795 nm

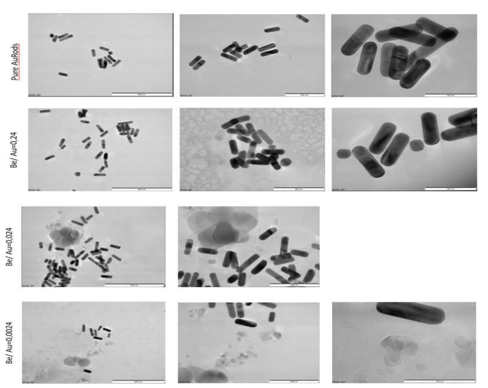




NAPLIFE NANO

Nanorod samples (Bonyár, Veres groups)



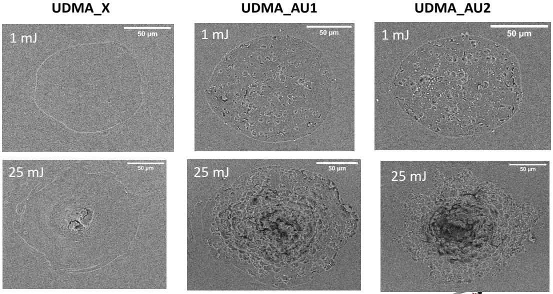


12. ábra. A különböző AuRods/ Be aránnyal rendelkező minták TEM felvételei

NAPLIFE CRATER

craters microscopic picture (J. Kámán)

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



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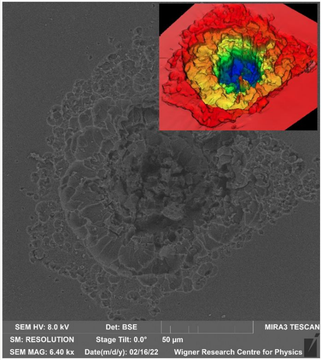
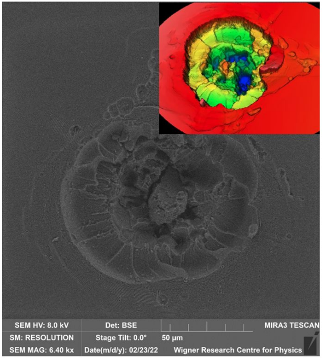
NAPLIFE CRATER

microcraters inside craters (J. Kámán)

SEM IMAGE OF UDMA WITH AU NANORODS



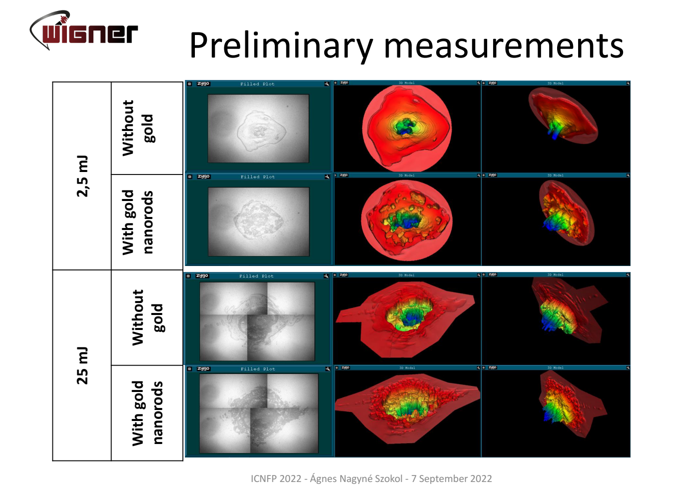
SEM IMAGE OF UDMA WITHOUT AU NANORODS



Images at 17.5mJ laser energy, $1{,}16.10^{17}$ W/cm^2 laser intensity.The volume of the crater of the sample with nanorods is 1.98 times that of the sample without rods.

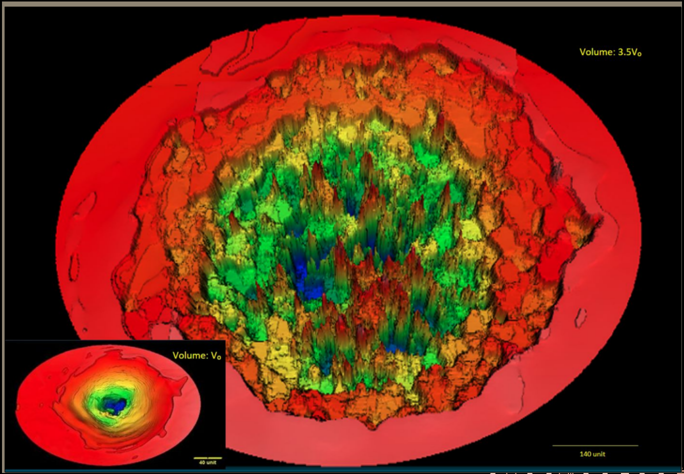
NAPLIFE CRATER

shot craters (Á. Nagyné Szokol)



NAPLIFE CRATER

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

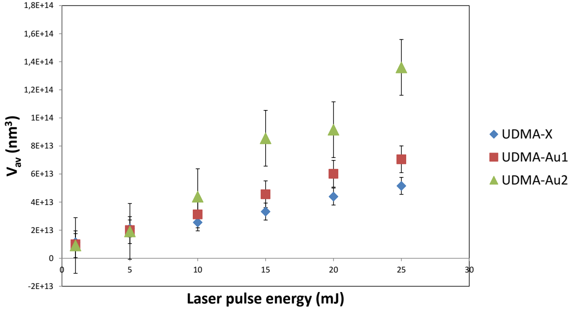


NAPLIFE CRATER

crater volume vs laser energy (Á. Nagyné Szokol)

Crater volume

The analysis of the crater volumes – in 5 different points for every energy and target



ICNFP 2022 - Ágnes Nagyné Szokol - 7 September 2022

NAPLIFE RAMAN

UDMA - TEGDMA copolymer (Veres group)

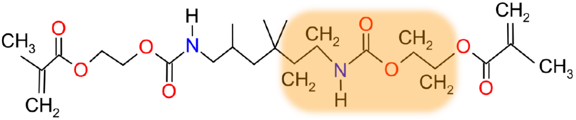


Figure 1. Chemical structure of UDMA monomer together with the selected part used for further modeling and calculations.

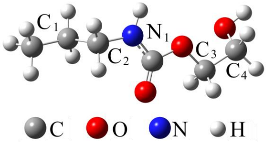
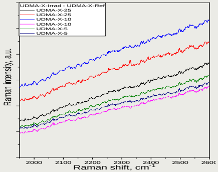
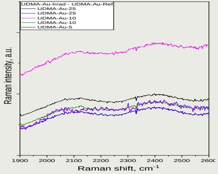


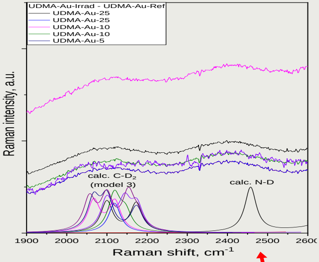
Figure 2. Optimized (B3LYP/6-311++G(d,p)) geometry of UDMA model (C_1H_2-C_2H_2 and C_3H_2-C_4H_2 groups are in anti and gauche conformational states, respectively).

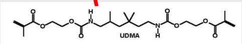
NAPLIFE RAMAN

Raman signs: molecular vibrations (Veres group)





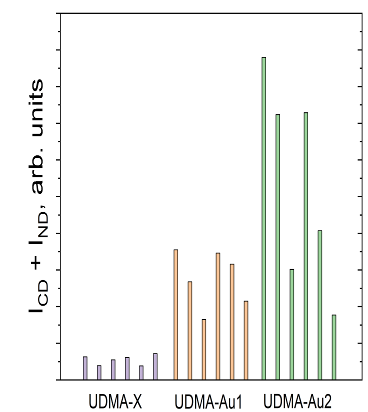


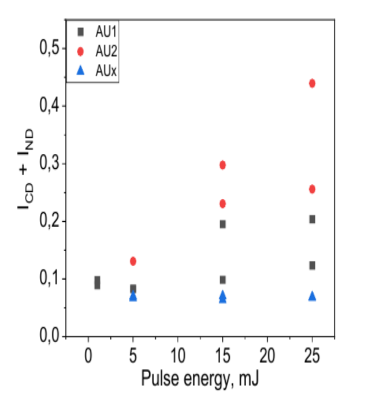


$I_{laser} > 10^{16}$

NAPLIFE RAMAN

SERS from several points in a crater





NAPLIFE LIBS

LIBS: plasma plum (Aladi group)

− + Automatic Zoom

DIAGNOSIS No3: LIBS analysis of the laser plume plasma

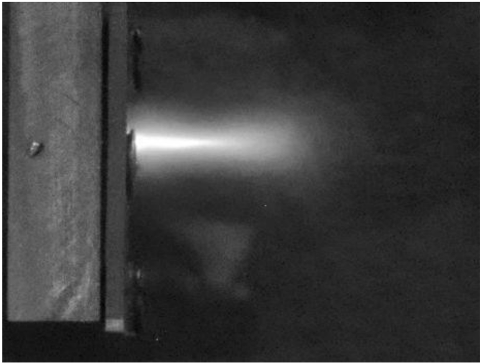
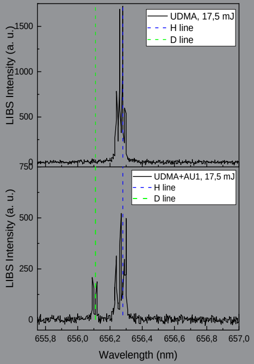
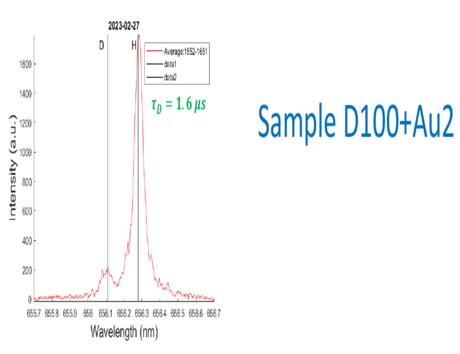


PHOTO OF A LASER SHOT INDUCED PLASMA PLUME

NAPLIFE LIBS

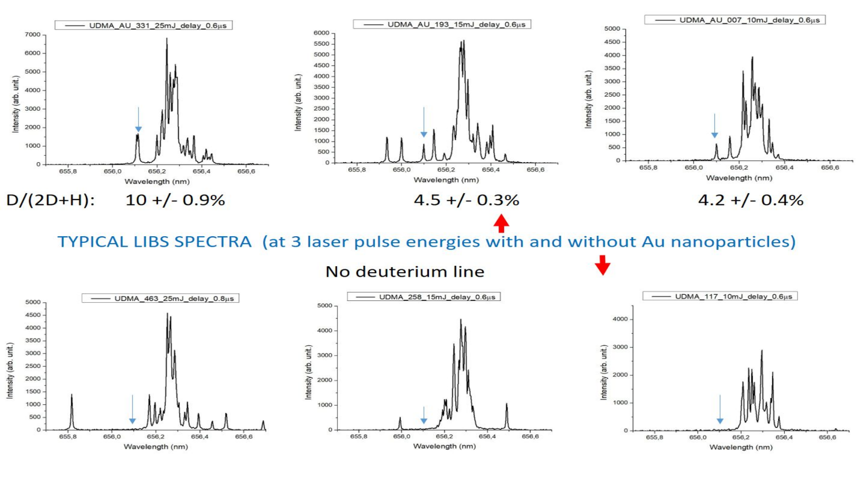
LIBS: atomic lines → D/H (Aladi + Galbács group)





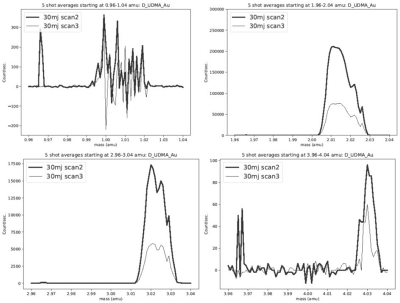
LIBS: selected spectra

Compare w/o Au, 10, 15, 20 mJ



NAPLIFE MASS SPECTRO

peaks: amu1 300, amu2 230.000, amu3 17.500, amu4 100 (Aladi group)



amu=1: H
amu=2: H_2 + D
amu=3: HD + He_3
amu=4: D_2+ He_4

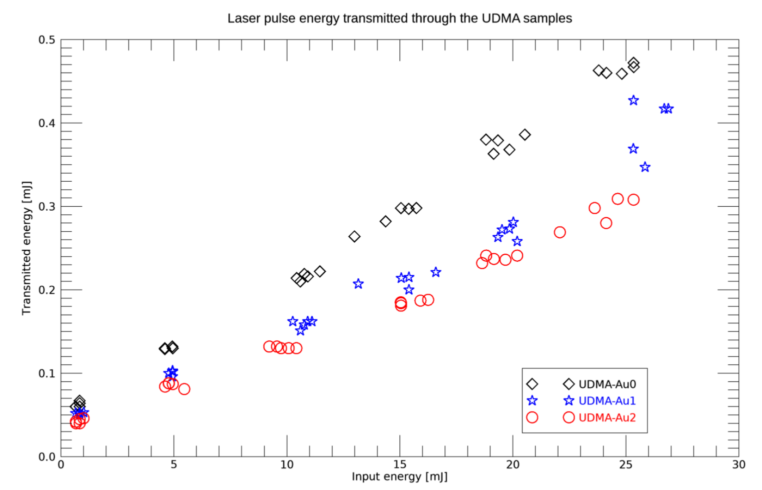
Minták:
- UDMA
- UDMA+Au2
- UDMA(30%D)
- UDMA(30%D+Au2)

Fenti mintaspektrumok az UDMA(30%D+Au2) minta amu=1, amu=2, amu=3 és amu=4 tömegszámú csúcsait mutatják

amu=2 tömegszám terület arányok:
- UDMA/UDMA = 1
- (UDMA+Au2)/UDMA = 1.17
- UDMA(30%D)/UDMA = 0.68
- (UDMA(30%D+Au2)/UDMA = 0.89

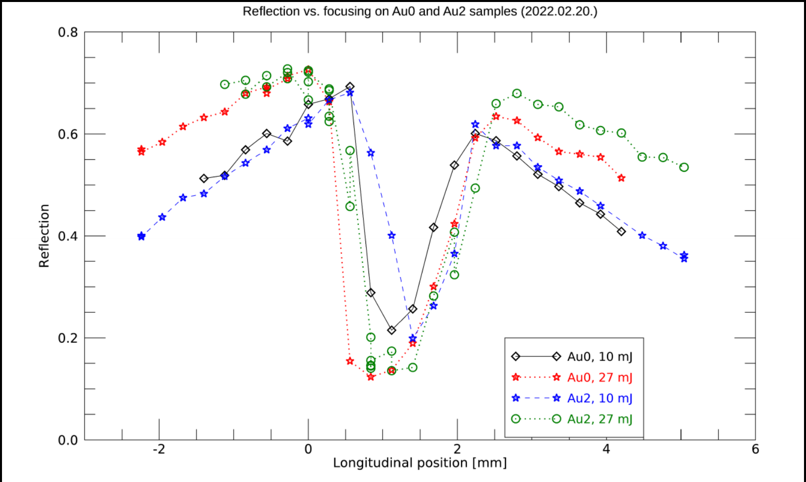
Transmitted energy < 2 %

M. Kedves



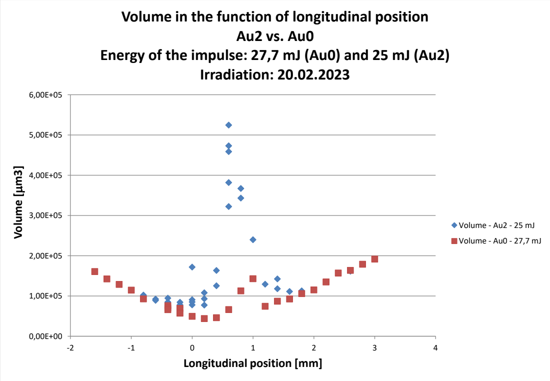
Plasma mirror: reflected energy vs focus

A. Márk, M. Kedves



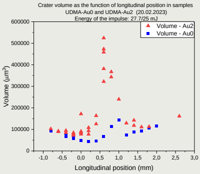
Crater volume vs focus position

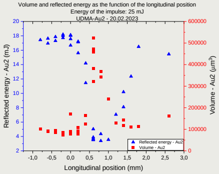
A. Márk, M. Kedves; Á. Szokol, N. Kroó

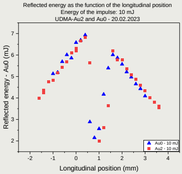


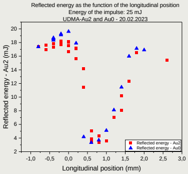
Volume and Reflection vs Focus Position

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







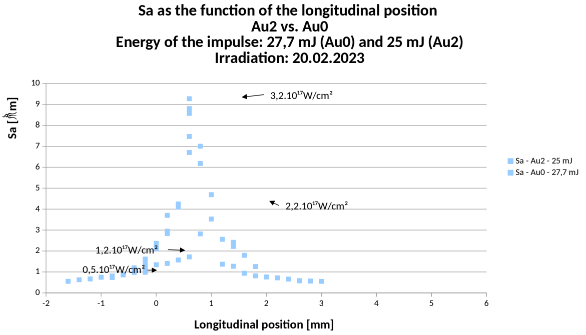


- With Au: larger volumes
- W/o Au: same reflection
- Plasmonic effect → larger volume

Crater roughness: Intensity counts!

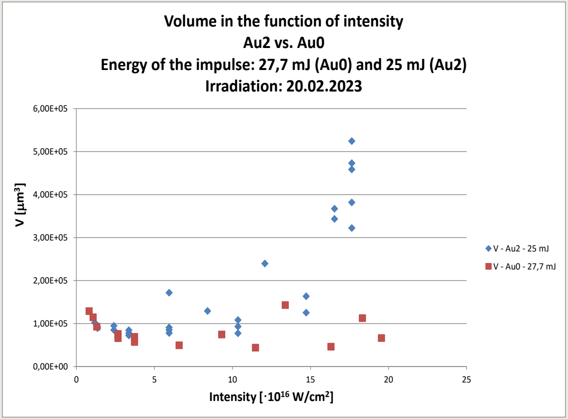
A. Márk, M. Kedves; Á. Szokol, N. Kroó

FELÜLETI ÉRDESSÉG!



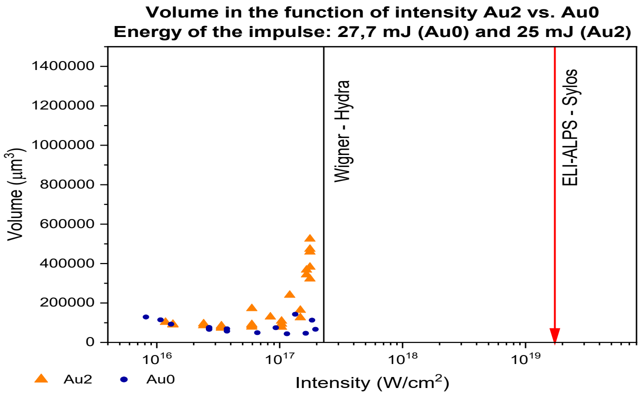
Crater volume vs intensity: Au counts!

Á. N. Szokol



Crater volume vs intensity: the laser counts!

Á. N. Szokol



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) !

NAPLIFE FUTURE

plans

Contracted with NKFIH until February 28-th, 2026.

Plans:

- Nuclear alpha detection (CR39), incl. p, d
- ELI shootings (shorter pulse, better contrast, similar energy, 100x intensity) – January 2024
- Use of doped targets, shape variations, reflectivity vs. intensity
- Buying gamma detector for few MeV range