ISOCHORIC BEAM DEPOSITION FOR ASTEROID DEFLECTION

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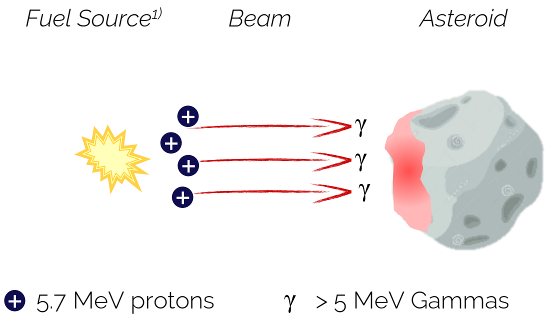
AGENDA

ASTEROID DEFLECTION WITH ISOCHORIC BEAM DEPOSITION

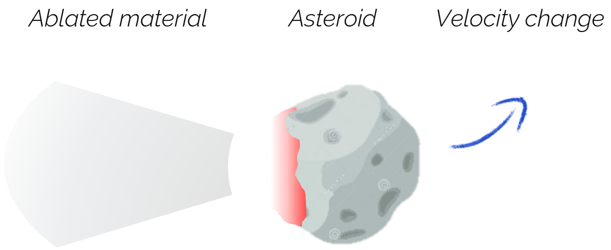
The deflection maneuver takes advantage of a proprietary method to generate a particle beam in space

Step 1 | Irradiate asteroid surface



- Incident particle beam directed towards asteroid, penetrates asteroid surface material
- Energy deposited and asteroid material gets ablated due to incident particle beam

Step 2 | "Rocket exhaust" with ablated material

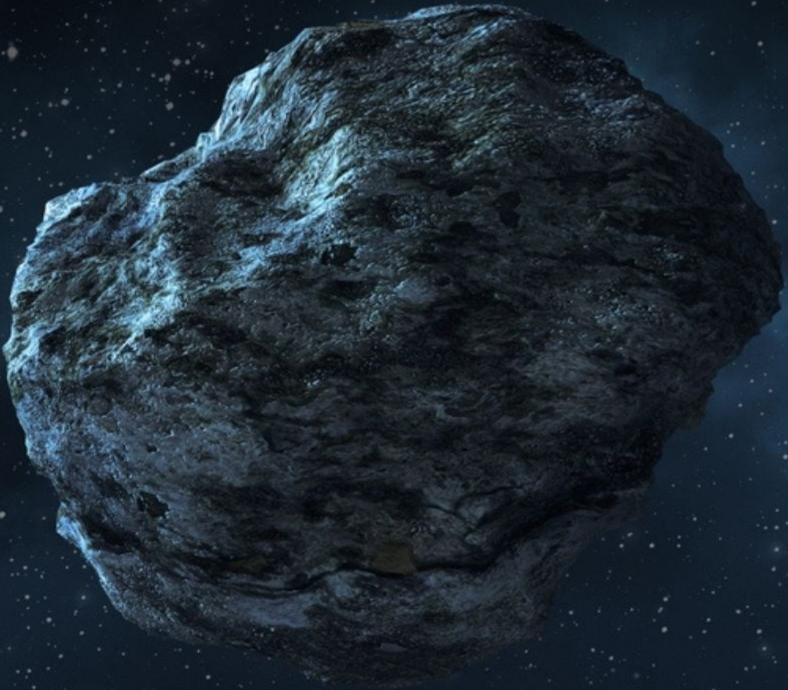


- Ablated material works similar like "rocket exhaust" and leads to change of velocity
- Deflection performance determined by penetration and ablation behavior

1) Based on specific nuclear fusion reaction, only possible in space; not in scope (given time restrictions)

BENEFITS COMPARED TO OTHER ASTEROID DEFLECTION METHODS

- Higher level of prediction accuracy for orbital maneuver
- Several orders of magnitude higher efficiency



HIGH LEVEL OF PUBLIC INTEREST

Recent missions create public awareness and provide valuable data for benchmarking

EXEMPLARY ASTEROID MISSIONS

RYUGU

BENNU

DART

16PSYCHE

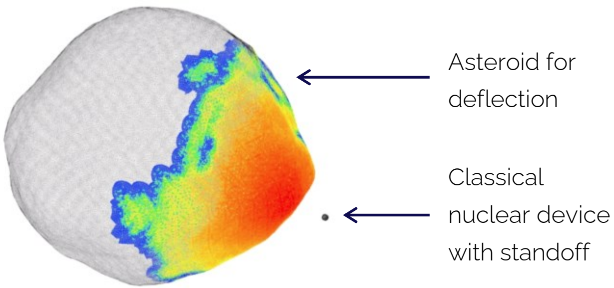
RELEASE IN APRIL 2023

NATIONAL PREPAREDNESS STRATEGY & ACTION PLAN FOR NEAR-EARTH OBJECT HAZARDS AND PLANETARY DEFENSE

BENCHMARKING AGAINST CLASSICAL NUCLEAR DEVICES

Nuclear explosives are still considered the most efficient asteroid deflection mechanism

EXEMPLARY SIMULATIONS RESULTS ON NUCLEAR DEVICES



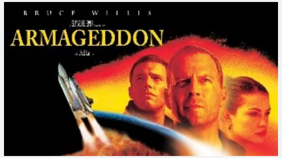
Horan IV, Holland, Bruck Syal, Bevins, Wasem. "Impact of neutron energy on asteroid deflection performance." *Acta Astronautica (183)*, 2021: 29 - 42.

POSSIBLE CONCLUSIONS FOR PLANETARY DEFENSE

The New York Times

How a Nuclear Bomb Could Save Earth From a Stealthy Asteroid

An atomic blast is not the preferred solution for planetary defense, but 3-D models are helping scientists prepare for a worst-case scenario.



The Government Says We Should Use Nukes to Deflect Asteroids

That's better than just blowing up the space rocks, according to tests.

TECHNOLOGY

The Plans to Use Nuclear Weapons to Blow Up Incoming Asteroids

For real.

DOUGLAS BIRCH OCTOBER 16, 2013

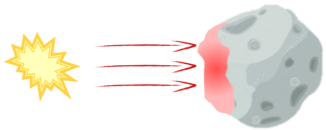
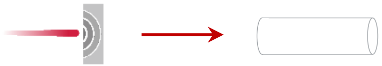
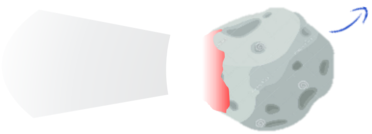
UNIQUE FEATURES OF OUSOCO'S DEFLECTION SCHEME

The concept can be clearly distinguished from a weapons technology

- ✓ More efficient than classical nuclear devices
- ✓ Safe mechanism and NOT a weapons technology
- ✓ Legally compliant with international treaties
- ✓ Allows for lab-based testing

EXPERIMENTAL SETUP

The particle beam conditions can be tested at CERN HiRadMat and results benchmarked against other deflection schemes

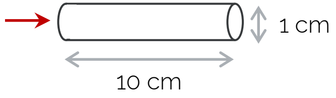
STEPS	MISSION SETUP	EXPERIMENTAL SETUP
Material irrad-iation	Fusion reaction / Particle beam / Asteroid target 	Research facility / Hadron beam / Meteorite sample 
Energy depo-sition	Ablated material / Velocity change 	Material behavior / Transfer of momentum 

EXPERIMENTAL APPROACH

- **Similar** pressure and incident beam intensity **conditions** in both setups
- Use of **different beam parameters** with well-characterized meteorite target sample

Dimensions

Cylindrical-shaped meteorite



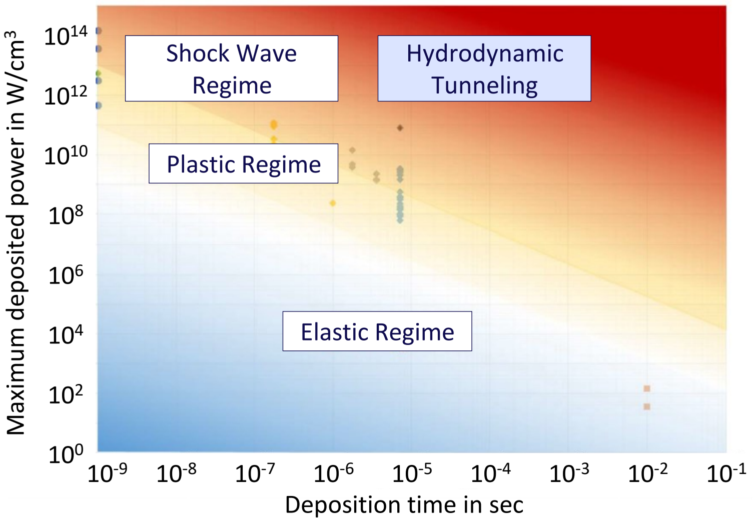
- Metal-mix containing
  - mainly Iron and Nickel
  - other precious metals
- Material density ~ 7 to 8 g/cm^3

MATERIAL RESPONSE REGIMES

The goal of the experimental setup is to implement a fully dynamical scale model of the asteroid deflection maneuver

EXPERIMENTAL OBJECTIVE	• Measure transfer of momentum • Gather underlying data across different material response regimes
EXPERIMENTAL TUNING PARAMETER	• Deposited energy density • Variation through number of bunches (i.e. #protons per beam)
SELECTED SUPPORTING REFERENCE	Pasquali, M., et al. "Dynamic response of advanced materials impacted by particle beams: the MultiMat experiment." *Journal of Dynamic Behavior of Materials 5 (2019): 266-295.*

REGIMES OF MATERIAL RESPONSE



LAYERS OF MATERIAL RESPONSE

The peak of energy deposition density – with hydrodynamic tunneling – is at the irradiated frontend of the object

MATERIAL RESPONSE REGIMES

From irradiated frontend … DECREASING ENERGY DEPOSITION DENSITY …to averted backend

B Hydrodynamic tunneling layer

Separate experiments

A Elastic material response

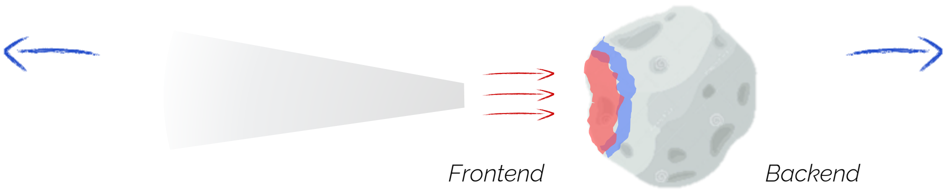
Large "cold" material block

Time after irradiation through particle beam →

SYSTEM DETERMINED BY CONSERVATION OF ENERGY AND MOMENTUM

Schematic illustration

Propellant stream



Forward propulsion

A ELASTIC REGIME (1/2)

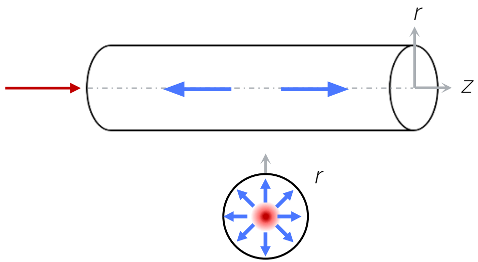
One part of the experimental campaign aims at further understanding the elastic material response regime

EXPERIMENTAL SETUP

p^+ beam

#p^+/ bunch[1)]
1.5 x 10^{11}

E/p^+
440 GeV

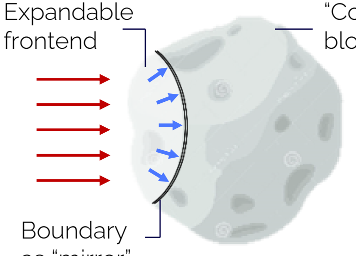


ASTEROID DEFLECTION SETUP

p^+ beam

#p^+/ output
~ 3 x 10^{31}

E/p^+
5.7 MeV



	Experimental setup	Asteroid deflection setup
Beam irradiation	Longitudinal and radial propagation of deposited energy from frontend along central axis	Irradiation of full front surface area through directed particle beam in space
Boundary conditions	Expandable surface area of cylinder as boundary condition for elastic wave	Boundary of cold block acts as "mirror" Irradiated frontend as the only expandable surface
Conclusion	Longitudinal and radial oscillations of target	Rocket-like exhaust at front end leading to Δv

Recalculate (experimental) oscillations into asteroid's Δv

1) Up to 288 bunches per train within the beam

A ELASTIC REGIME (2/2)

The Δv contribution from the elastic regime alone is comparable to the full effect of a classical nuclear device

PRELIMINARY VALUES FOR TARGET SAMPLE

- Assumption: “cold” material temperatures
- Changes expected for experimental setting

Material	Density	Young's Modulus	Frequency (longitudinal)
Iron	7.9 g/cm^3	200 GPa	150 kHz
Nickel	8.9 g/cm^3	200 Gpa	150 kHz
Gold	19.3 g/cm^3	70 Gpa	50 kHz
Titanium	4.5 g/cm^3	170 Gpa	180 kHz

FIRST ASSESSEMENT

Experimental target sample

Surface oscillations: m/s

Asteroid deflection maneuver

$\Delta v_{elastic}$: cm/s

Δv contribution purely from elastic regime

Further simulations needed

Detailed target characterization before/after experiments

SELECTED REFERENCES

Torregosa, et al.
"Experiment exposing refractory metals to impacts of 440 GeV/c proton beams for the future design of the CERN antiproton production target: Experiment design and online results."
Physical Review Accelerators and Beams 22 (2019): 013401.

Torregosa et al.
"Scaled prototype of a tantalum target embedded in expanded graphite for antiproton production: Design, manufacturing, and testing under proton beam impacts."
Physical Review Accelerators and Beams 21 (2018): 073001.

B HYDRODYNAMIC TUNNELING (1/2)

Hydrodynamic tunneling involves phases transitions and significant density depletion

FEATURES

Energy deposition density	$10^4 – 10^5$ J/cm³
Occurrence of phase transitions	e.g. to liquid or gas

Substantial density depletion, exemplary from solid metal to gas[1)]

Decrease of density[1)] — 1000x — Deeper penetration

EXEMPLARY SIMULATIONS RESULTS

Target material: copper

Beam size: 0.2 mm

p^+ energy	δ_p	#Bunch	Accelerator
440 GeV	0.8 m	108	SPS
7 TeV	35 m	2808	LHC
50 TeV	350 m	10600	FCC

SELECTED REFERENCES

Nie, Y., et al. "Numerical simulations of energy deposition caused by 50 MeV—50 TeV proton beams in copper and graphite targets." *Physical Review Accelerators and Beams 20.8 (2017): 081001.*

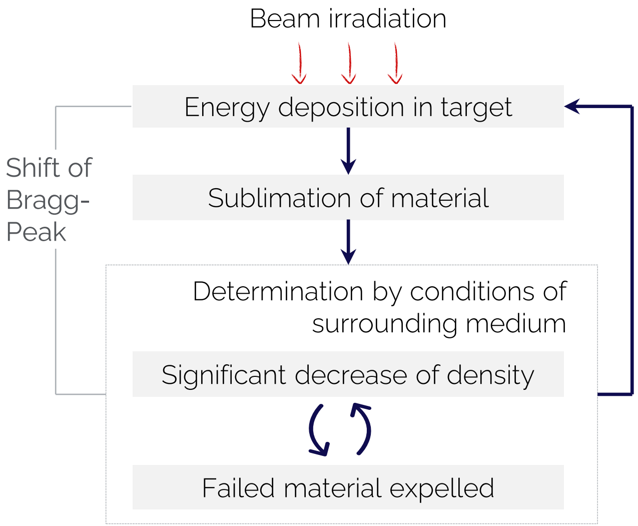
Tahir, Naeem Ahmad, et al. "Beam induced hydrodynamic tunneling in the future circular collider components." *Physical Review Accelerators and Beams 19.8 (2016): 081002.*

1) Under atmospheric pressure conditions at the ground

B HYDRODYNAMIC TUNNELING (2/2)

Hydrodynamic tunneling is expected due to the beam parameters and conditions of the surrounding medium

ITERATIVE STEPS



SIMULATIONS CODE

Montecarlo, e.g. FLUKA

Hydrocode, e.g. ALE

Hydrocode, e.g. ALE

SPH Code

SELECTED REFERENCES

Han, Pengfei, et al. "Numerical Study on Asteroid Deflection by Penetrating Explosion Based on Single-Material ALE Method and FE-SPH Adaptive Method." *Aerospace 10.5 (2023): 479.*

Bertarelli, Alessandro. "Beam-induced damage mechanisms and their calculation." *arXiv preprint arXiv:1608.03056* (2016).

B HYDRODYNAMIC TUNNELING - DIAGNOSTICS

Requirements on the diagnostics are derived from the beam structure

REQUIREMENTS DETERMINED BY BEAM STRUCTURE

Bunch with
Δt = 1 ns

> 1 image per bunch intended

...

Spacing = 25 ns

Requirements

Multiple images per bunch intended

Technical implications

- < 1 ns time resolution
- GHz repetition rate for new images

PREFERED DIAGNOSTICS SETUP

- ICCD camera system combined with ultra-short pulse Laser system
- GHz, IR sensitive Laser for density profile

König, Nolte, Tünnermann. "Plasma evolution during metal ablation with ultrashort laser pulses."
Optics Express 13.26 (2005): 10597-10607.