POSTER 18-SO-88

5th EUVL Symposium
Barcelona, 15-18 October 2006

Characterization of ionic debris interaction with a buffer gas in the frame of debris mitigation issues.

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Introduction

Various methods, and their combination, have been proposed for controlling the debris production by plasmas :

- application of electric and/or magnetic fields for deflection or velocity reduction
- use of appropriate ambient gas for speed reduction
- use of foil traps for particle capture
- use of mass-limited (e.g. porous) targets for reducing debris emission without affecting the conversion efficiency

In order to devise techniques and tools for debris emission control and/or debris suppression, it is important to know the characteristics of the emitted debris and to understand the debris-production mechanism.

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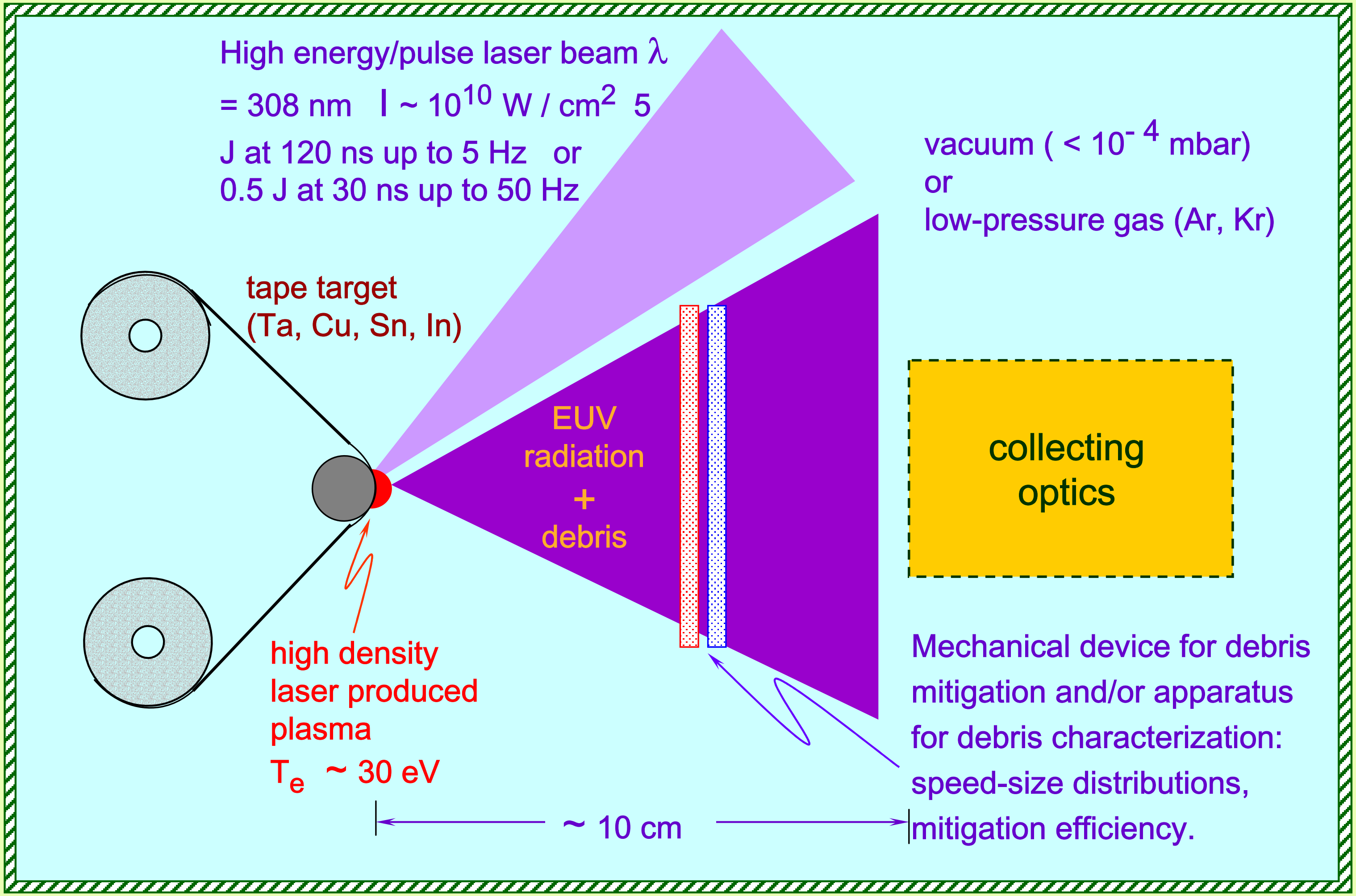
ENEA LASER-PLASMA SOURCE



High energy/pulse laser beam λ = 308 nm I ~ 10^{10} W / cm^2 5 J at 120 ns up to 5 Hz or 0.5 J at 30 ns up to 50 Hz

vacuum (< 10^{-4} mbar)
or
low-pressure gas (Ar, Kr)

tape target
(Ta, Cu, Sn, In)

EUV
radiation
+
debris

collecting
optics

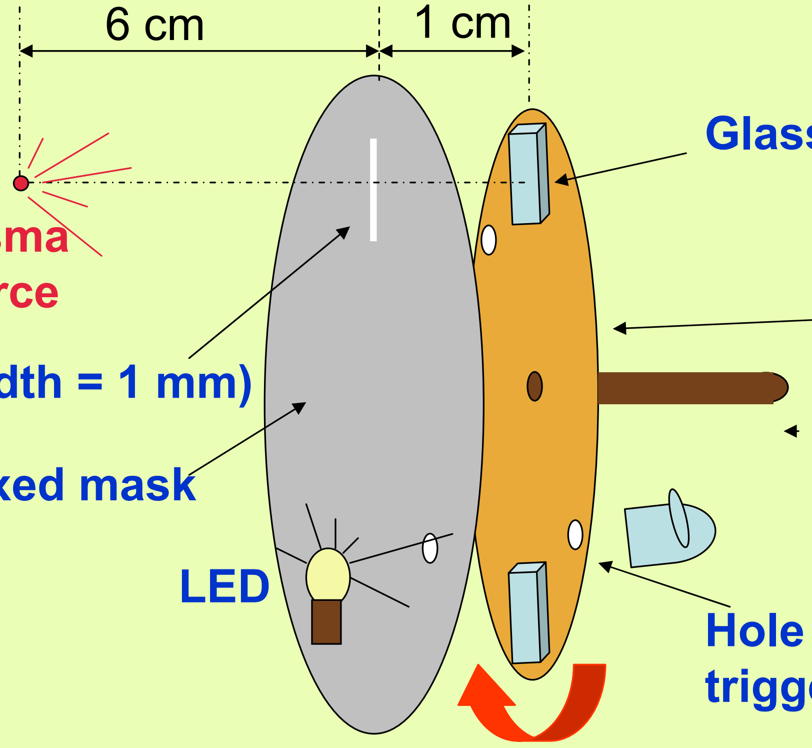
high density
laser produced
plasma
T_e ~ 30 eV

Mechanical device for debris mitigation and/or apparatus for debris characterization: speed-size distributions, mitigation efficiency.

~ 10 cm

Primary elements of an LPP EUV lithographic device, basically inspired by the experimental setup implemented at the Frascati ENEA Laboratory for EUV lithography and DMS related investigations.

Characterization of Cu debris by turning glass plates



Plasma source

Slit (width = 1 mm)

Fixed mask

LED

Glass plate for debris collection

Turning disk:
f = 20 Hz (1800 r.p.m.)

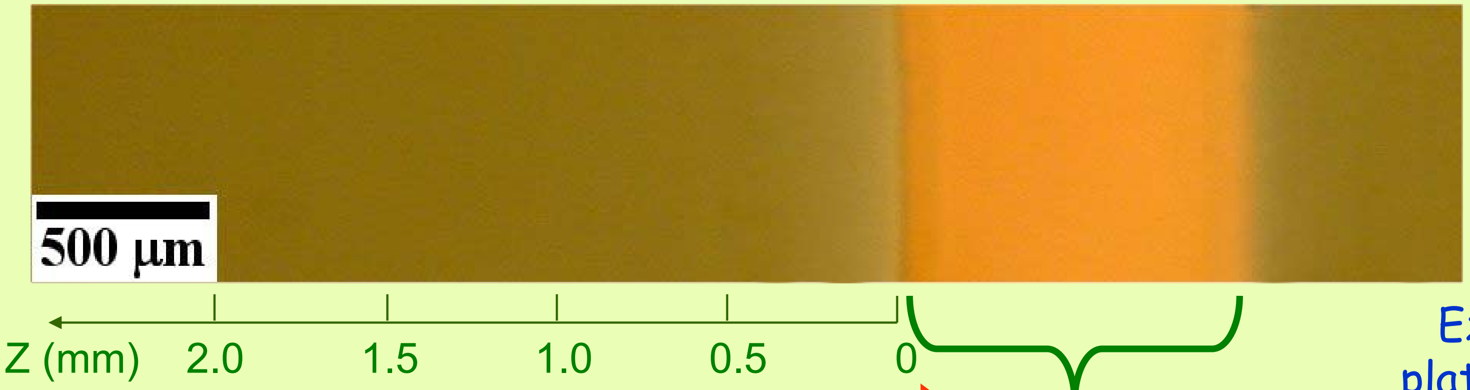
Hole for triggering

V_{glass}=1.1 cm/ms

$1/ V_{glass}$=90 µs/mm

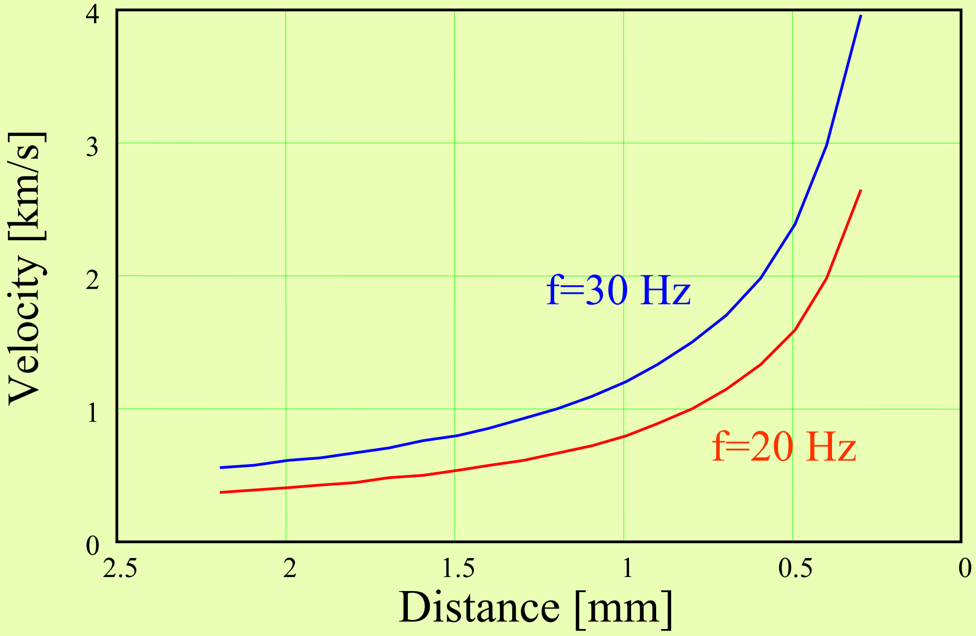
Glass plate exposed to $5{\cdot}10^4$ shots in vacuum

Direction of glass motion: →

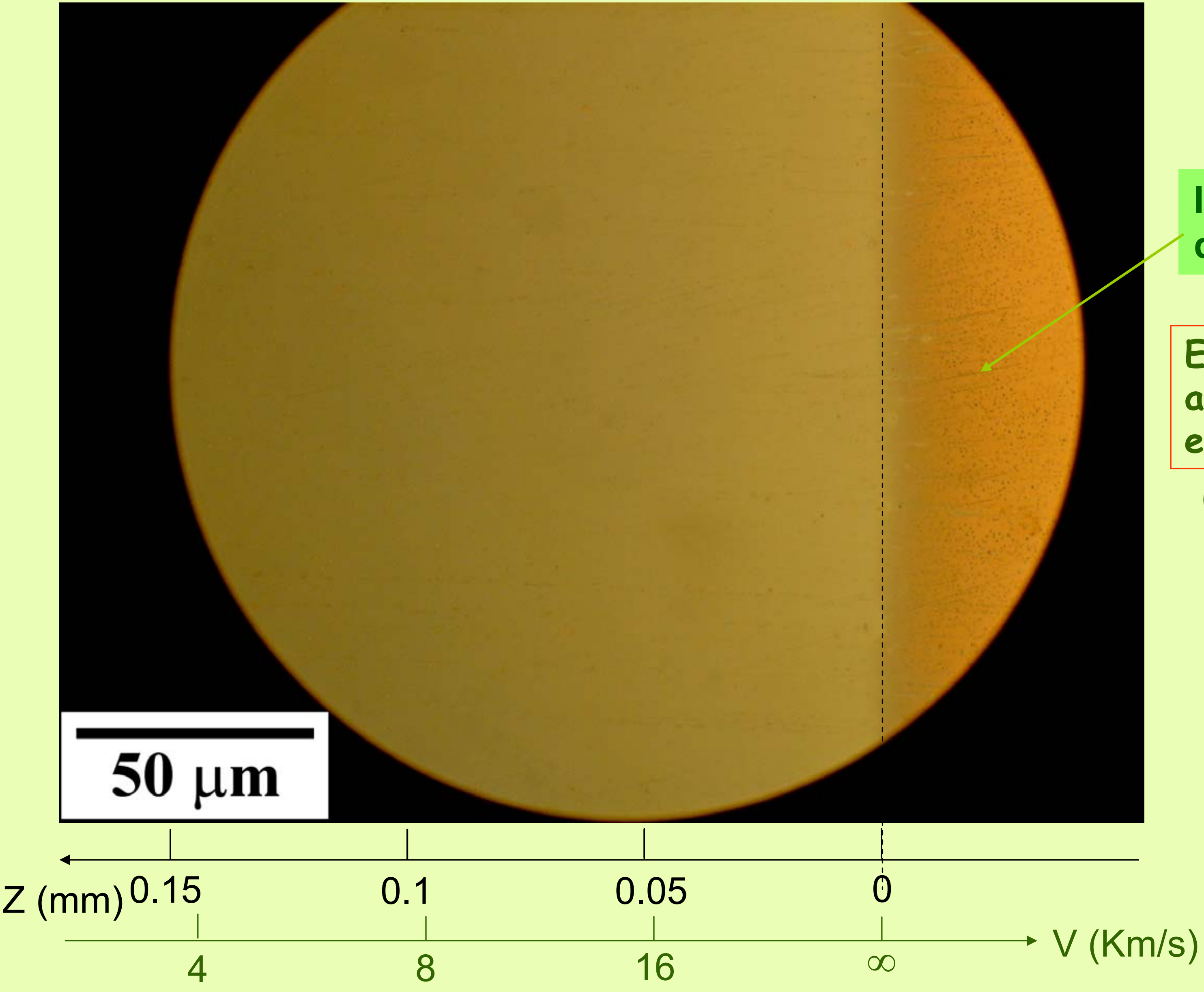


Slit width (=1 mm):
strong deposition
of atomic debris

Exposed glass
plate observed at
microscope in
reflection mode
(objective 2.5X)



Setting the zero at this point,
we are looking at the velocity
uncertainty upper limit



Ionic deposition

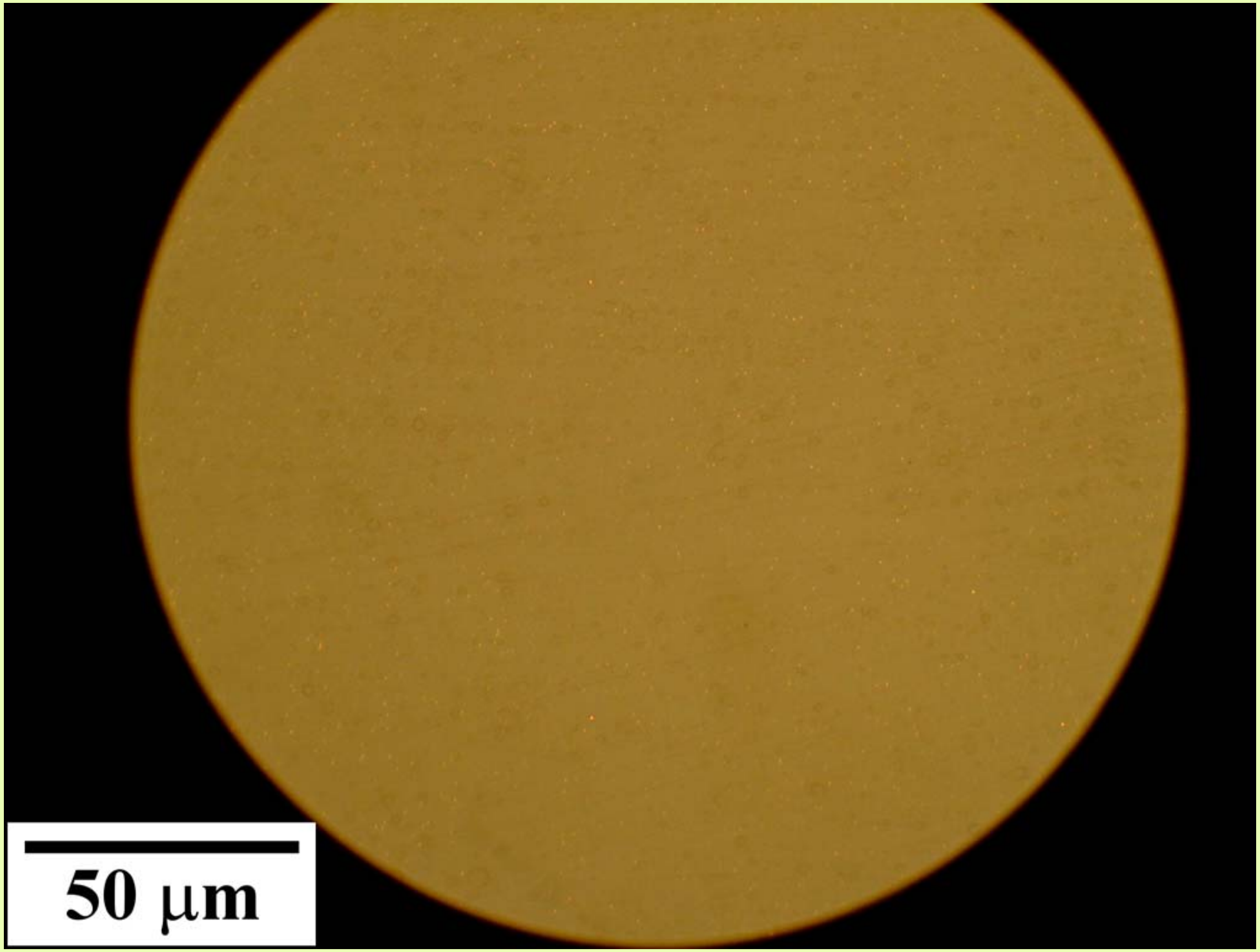
Estimated average ion energy ~ 2 keV

(SEE POSTER 15-SO-66)

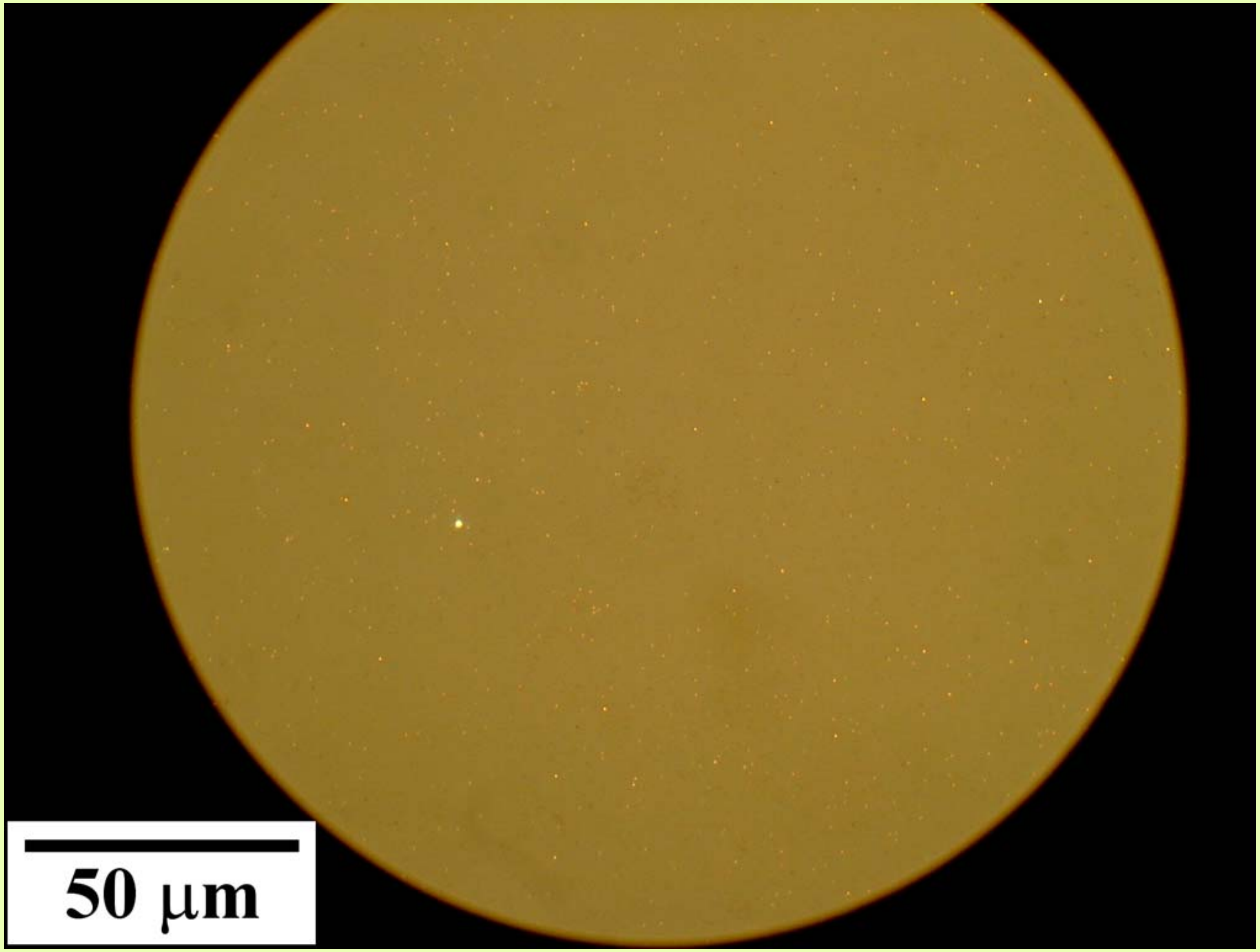
<Z> = 0.7 mm

BEGINNING OF SIGNIFICANT DEBRIS PRESENCE

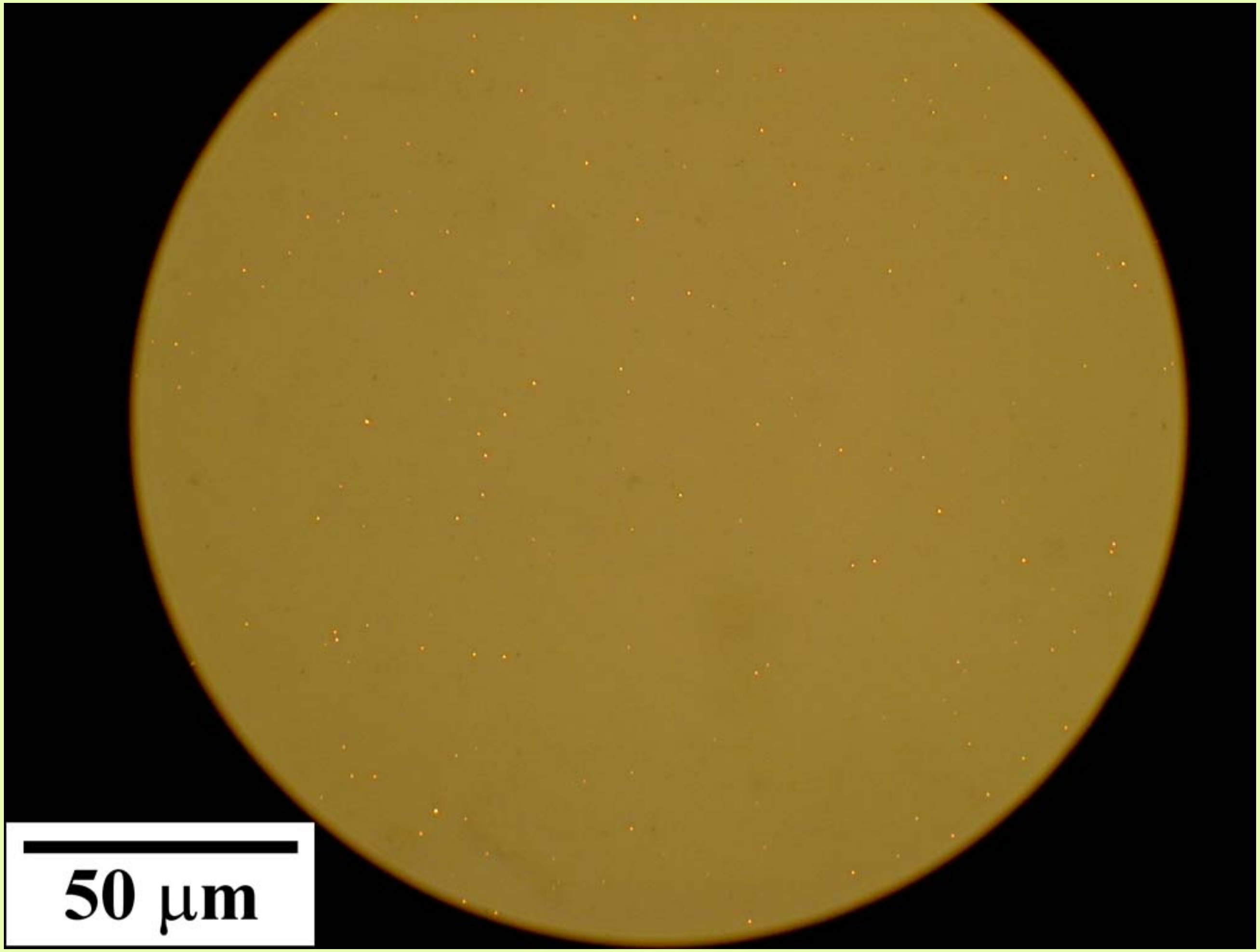
<t> =63 μs v=1.0÷1.3 km/s



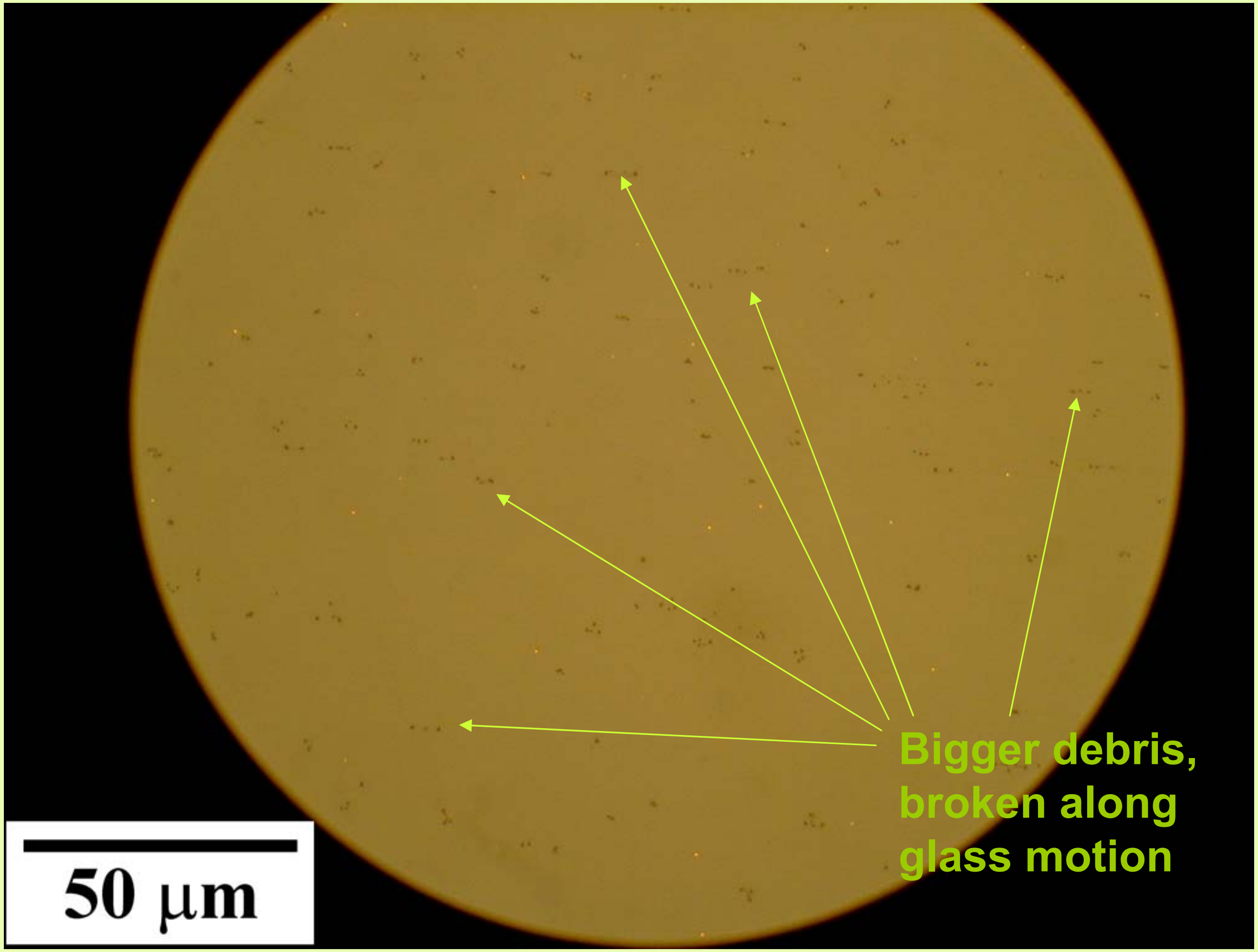
<Z> = 2 mm <t> =180 μs <v>=390 m/s



<Z> = 5 mm <t> =450 μs <v>=150 m/s

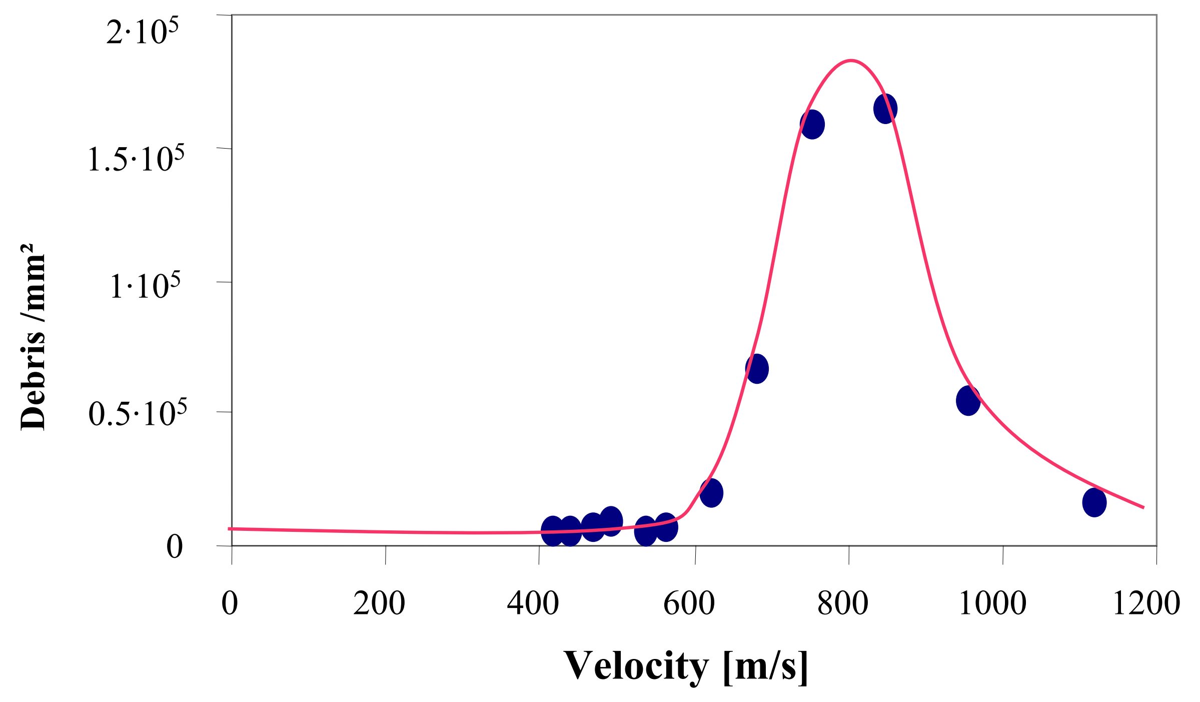


<Z> = 10 mm <t> =900 μs <v>=78 m/s



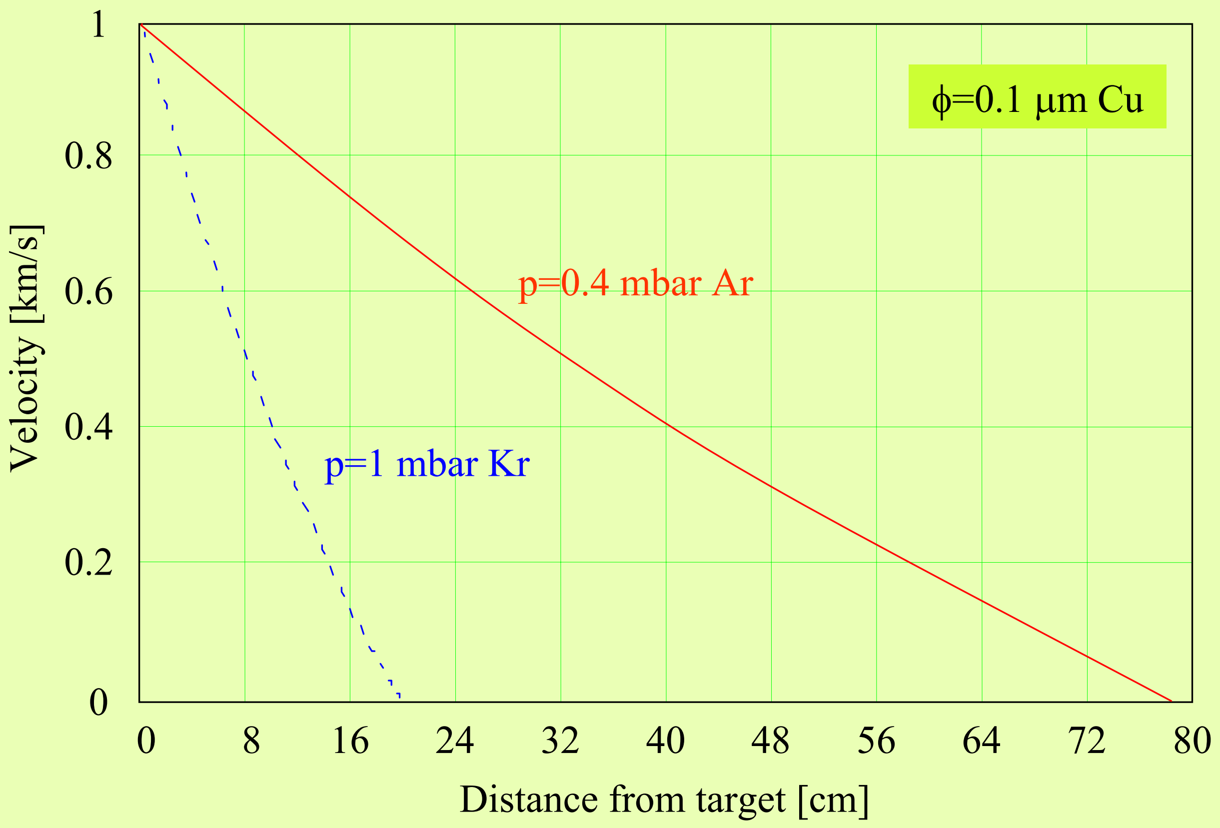
Bigger debris, broken along glass motion

Velocity distribution of “all-sizes” particulate debris in vacuum



The velocity distribution shows a peak at 800 m/s.

Theoretical particulate debris interaction with a buffer gas

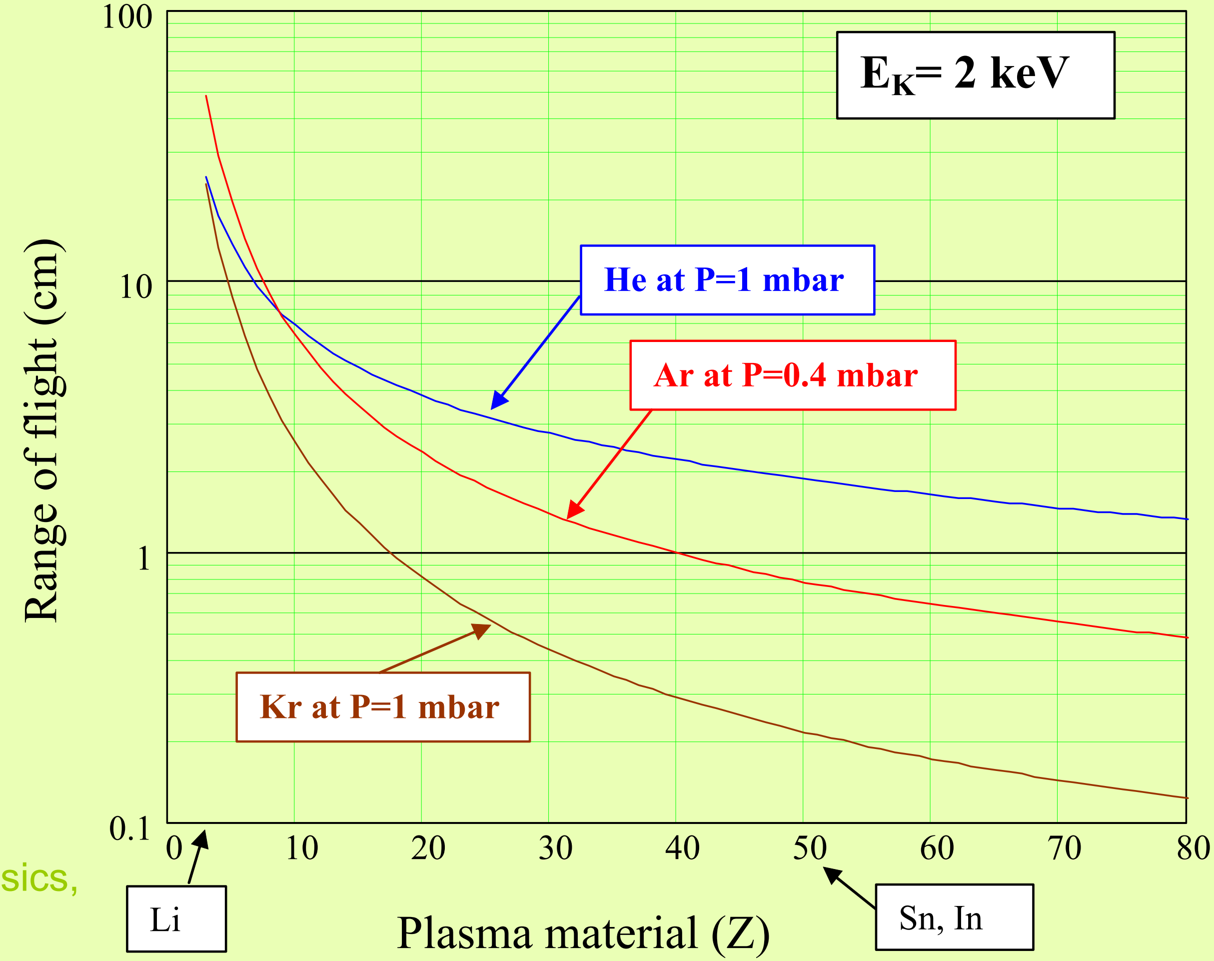


Theoretically, fast and small particulate-debris cannot be stopped in few cm by Ar nor even by the heavier Kr at gas pressures which guarantee a good transparency

See: S. Bollanti, T. Letardi, C.E. Zheng: "Flight range of the particulate in a laser-plasma generated soft X-ray chamber", Appl. Phys. A, Vol. **71**, pp. 255-260, (2000).

Theoretical ionic debris interaction with a buffer gas

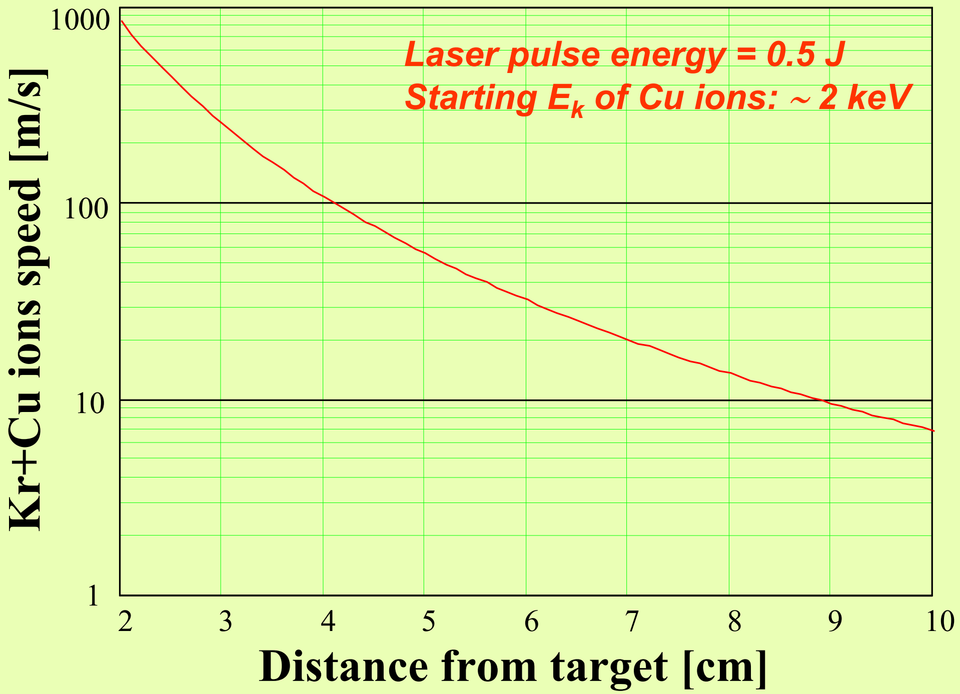
Theoretically, ionic debris should reach a thermalization after few mm of flight in Kr or in Ar



See: O. B. Firsov, Soviet Physics, JETP, **36**, 1076 (1959)

… BUT …

Because of the momentum originally contained in the ionic stream, after the interaction with gas and thermalization, the "dirty" gas cloud starts to move and goes to lower velocities only after that a big amount of gas is included into the stream.

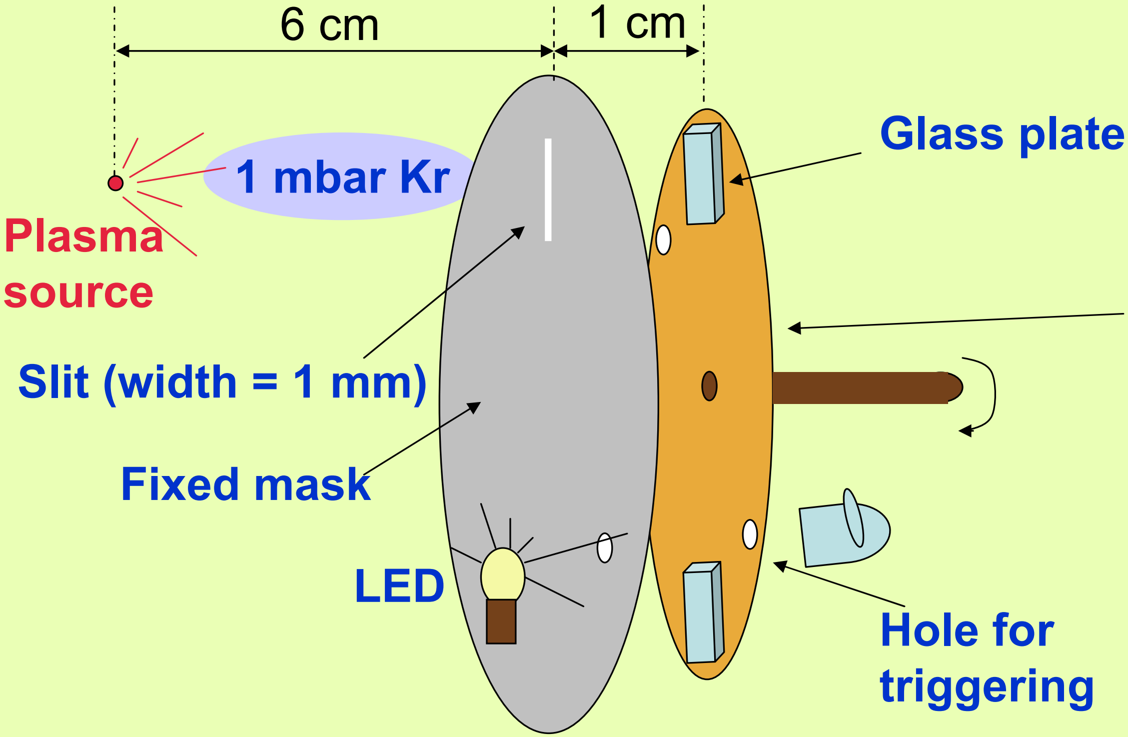


Estimated speed of the dirty cloud of Kr gas and Cu ionic debris, for a gas pressure of 1 mbar and a stream diverging solid angle of 1 sr.

It seems that at 10 cm the cloud should be easily stopped by a mechanical device or by transverse gas puffing like those of foil traps.

Anyway, an unexpected phenomenon occurs which changes the debris nature during the interaction with the ambient gas

Characterization of Cu debris interaction with Kr gas by turning glass plates

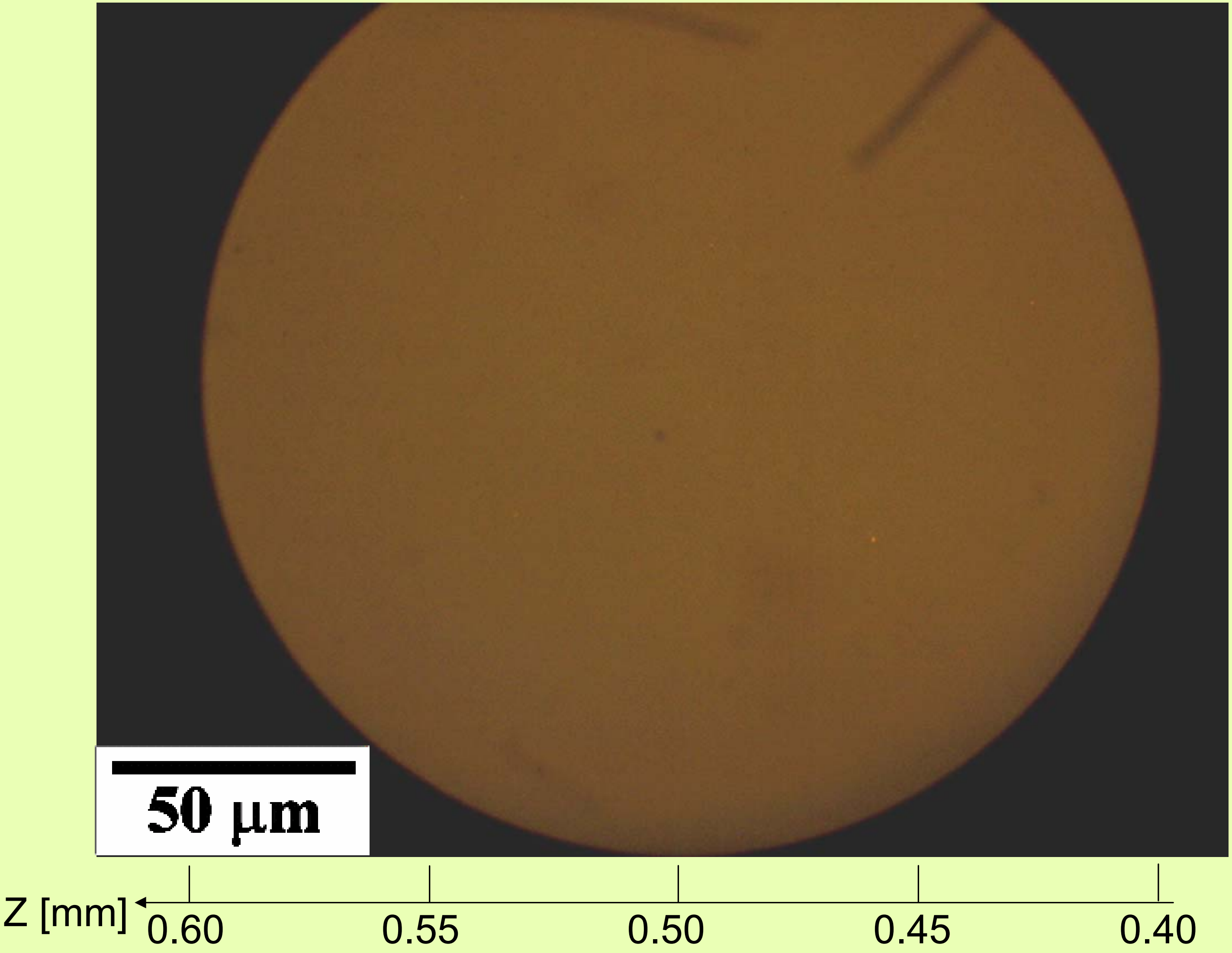


V_{glass}= 1.6 cm/ms

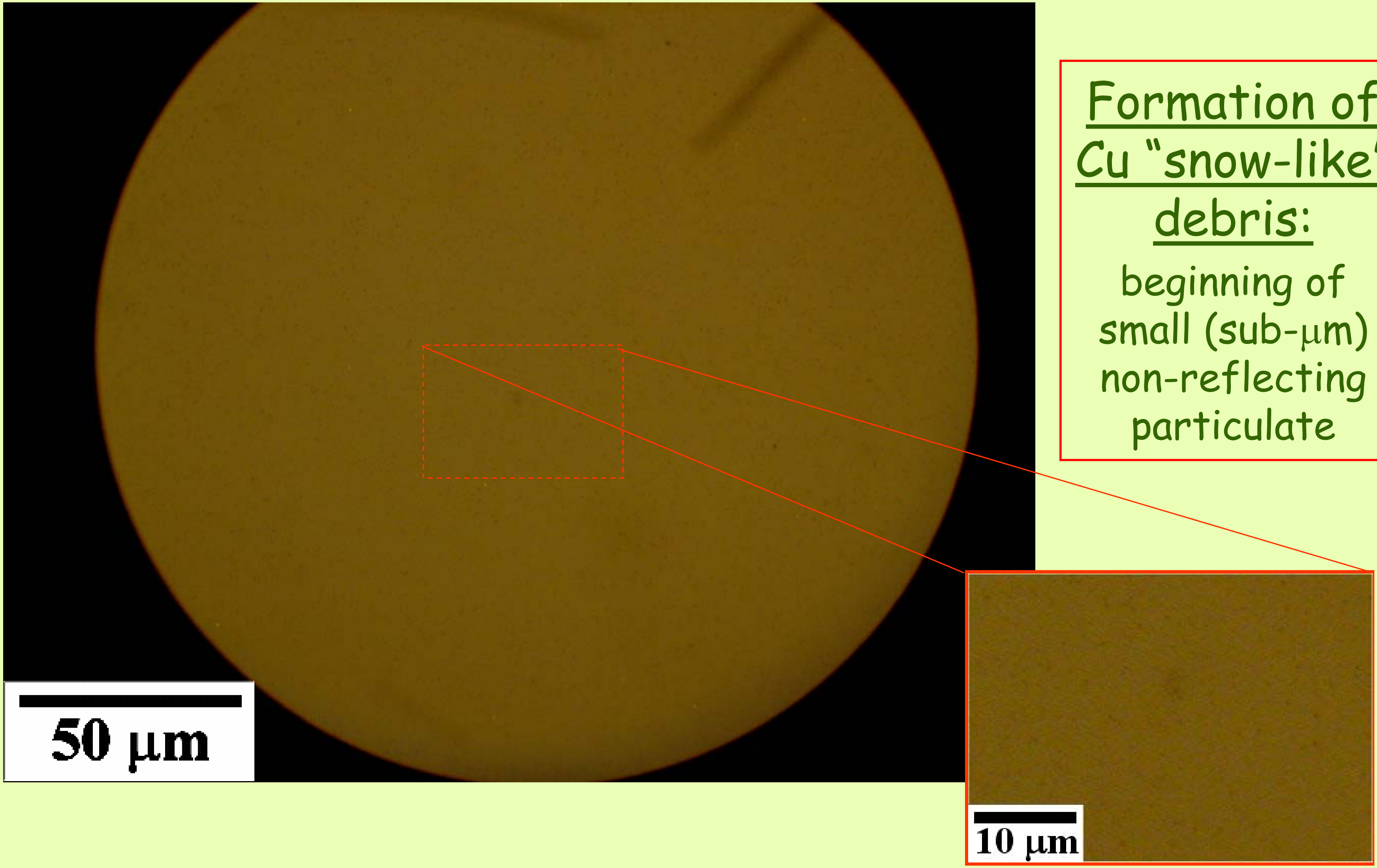
1/ V_{glass}= 62 μs/mm

Debris exposure conditions for glass plate:
$2 \cdot 10^3$ shots in vacuum + 10^4 shots in Kr @ 1 mbar

<Z> = 0.5 mm <t> = 31 µs <v>=2.3 km/s



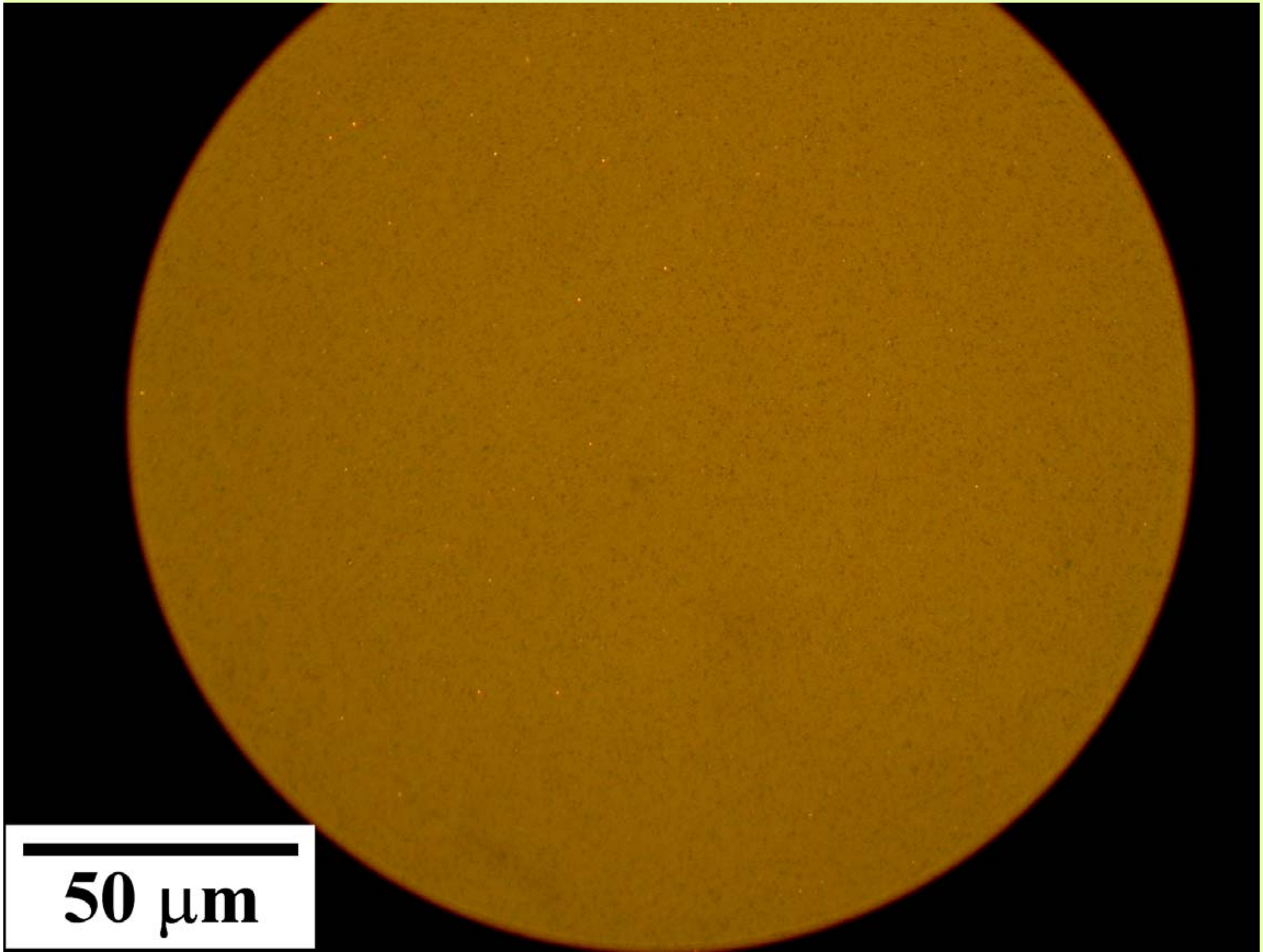
$\langle Z\rangle = 1.5$ mm $\langle t\rangle = 93$ μs $\langle v\rangle=750$ m/s



Formation of Cu "snow-like" debris:

beginning of
small (sub-μm)
non-reflecting
particulate

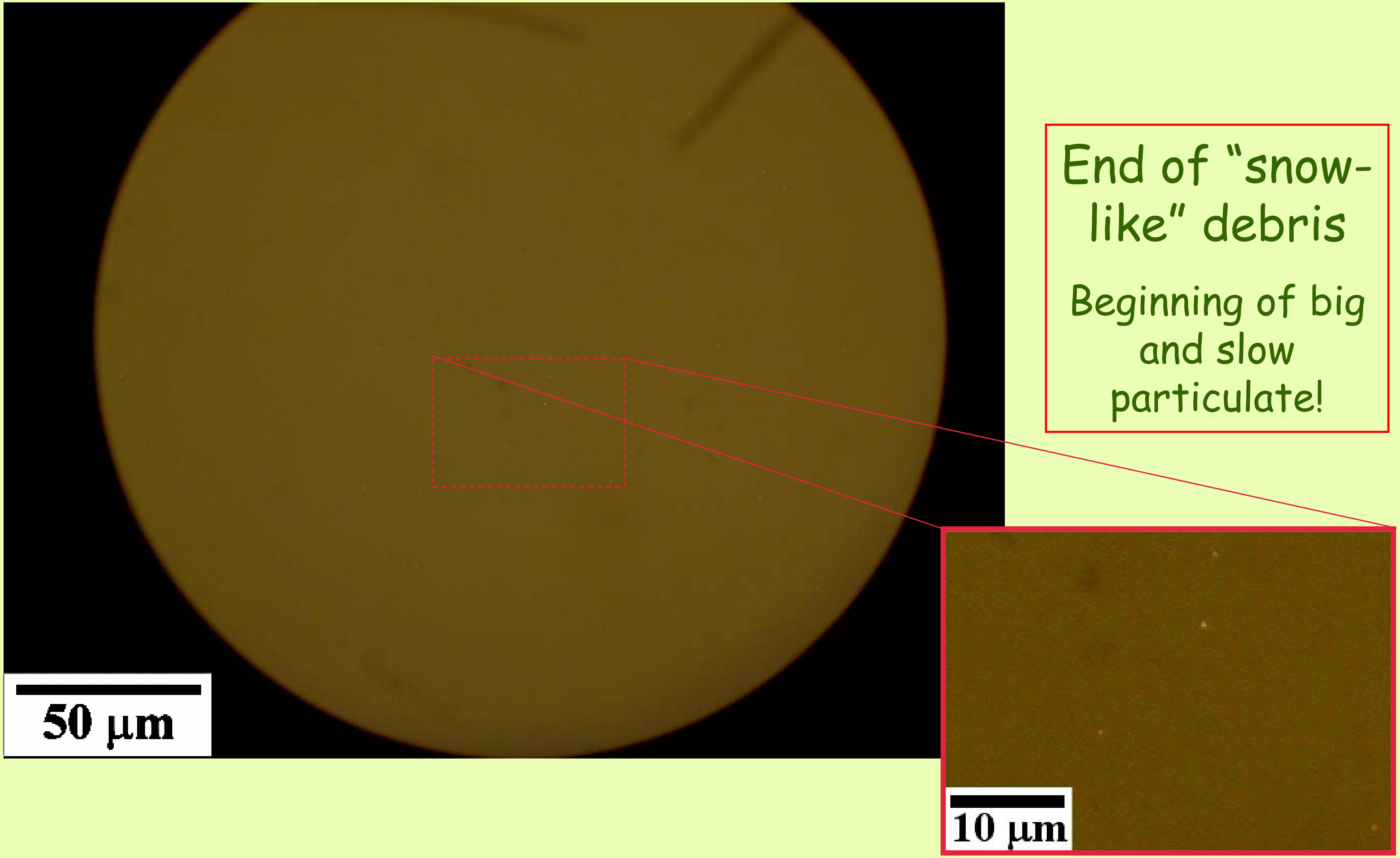
HERE THE "SNOW-LIKE" PARTICULATE IS MORE EVIDENT



<Z>= 2 mm

<v>=565 m/s

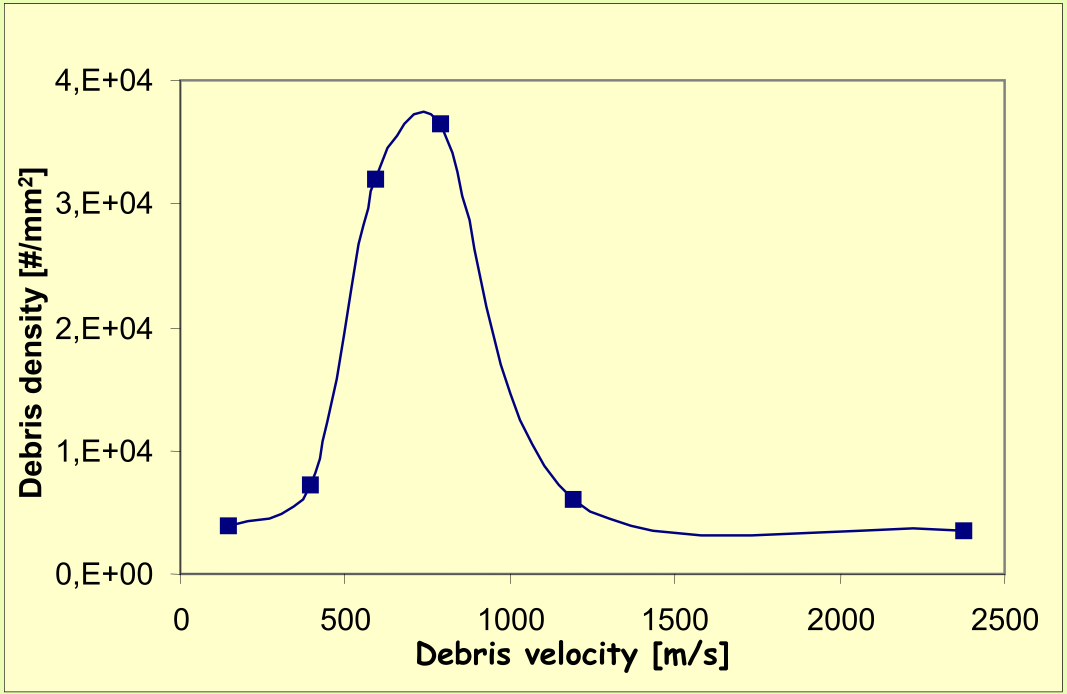
<Z> = 8 mm <t> =500 μs <v>=140 m/s



End of "snow-like" debris

Beginning of big and slow particulate!

Velocity distribution of “all-sizes” particulate debris in 1 mbar Kr



(Absolute values are referred to 10000 shots)

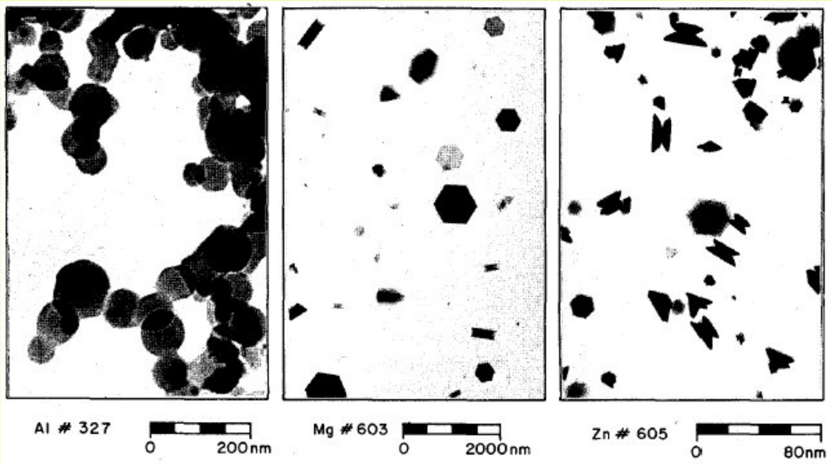
- The distribution peak has moved at 700 m/s, where most particles are “snow-like”

- The mechanical device should cut debris with a velocity up to 2.4 km/s !!

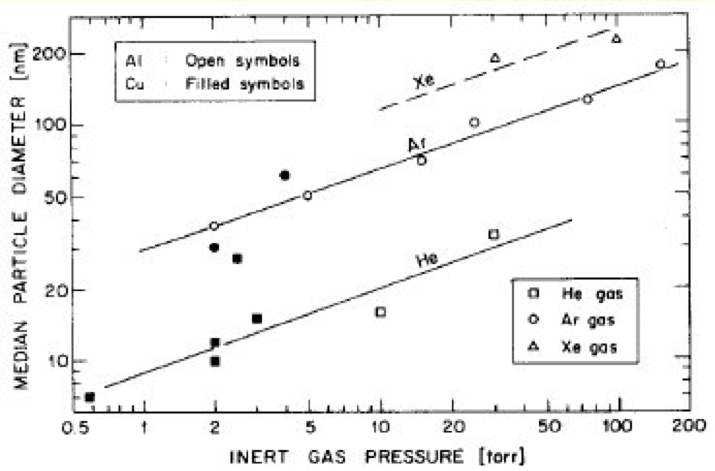
"Snow-like" Particles Formation

It is known since the 70's that the cooling process of metal atoms in low pressure rare gases (0.1÷10 mbar) leads to the formation of crystalline nanometric particles

(C.G. Granqvist & R.A. Burhman, "Ultrafine metal particles", J. Appl. Phys. 47, 2200, 1976).



Al, in 15 mbar Ar	Mg, in 3.5 mbar Ar	Zn, in 3.5 mbar Ar



Anyway, it has to be taken into account that in EUV plasma sources the relative ions/gas speed is much bigger than in past experiments based on thermal evaporation

Snow-like Debris Considerations

- The snow-like particles formation breaks the theoretical range of flight of ions: these sub-μm particles are still fast and much heavier than ions
- This effect increases the need of coupling the buffer gas to a mechanical device in order to achieve efficient DMS. In our experimental conditions (LPP with 0.5 J laser pulses, $I_L=5\cdot10^{10}$ W/cm^2, $T_e \sim 30$ eV) the mechanical device should catch particles as fast as 2.4 km/s
- The ionic debris velocity can be reduced by a small area magnetic field : **SEE POSTER 15-SO-66**: "Analysis of the Effects of a Small Area Magnetic Field for the Mitigation of the Debris Emitted by a Laser Plasma Source", L. Mezi et al., ENEA.
- The aim of this local magnetic field is not to stop ionic debris, but to make other DMS more efficient and, hopefully, to reduce the snow-like particle formation

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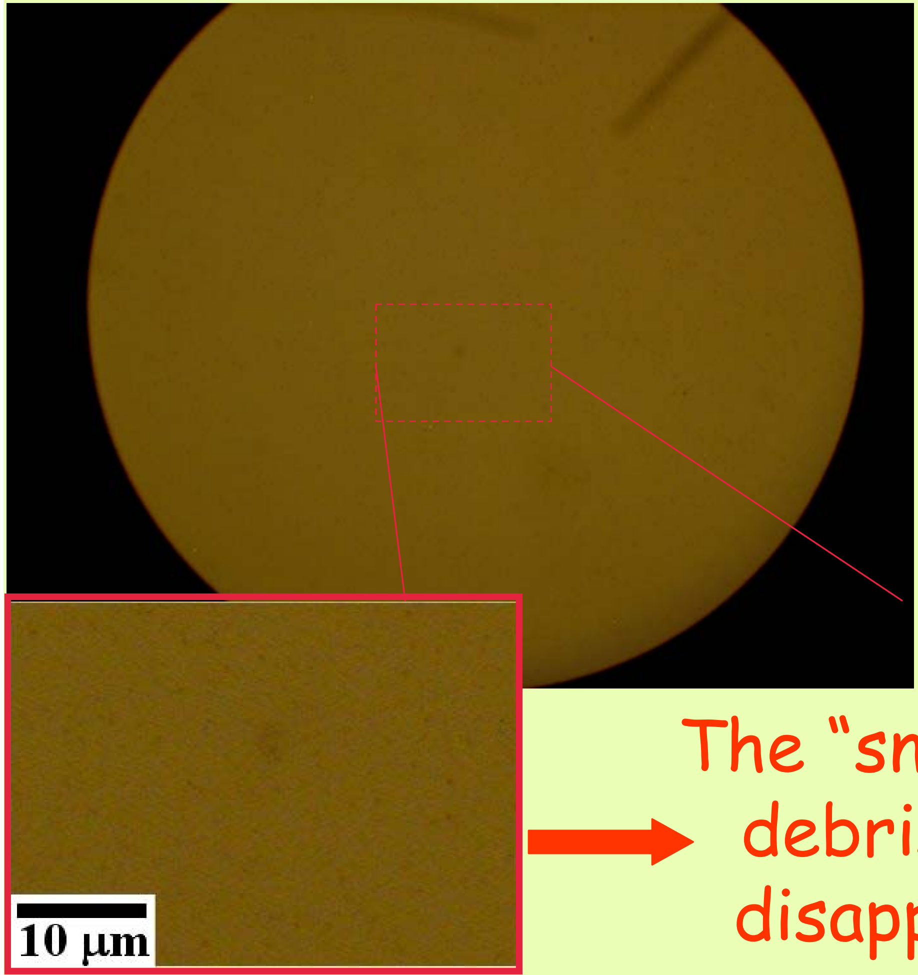
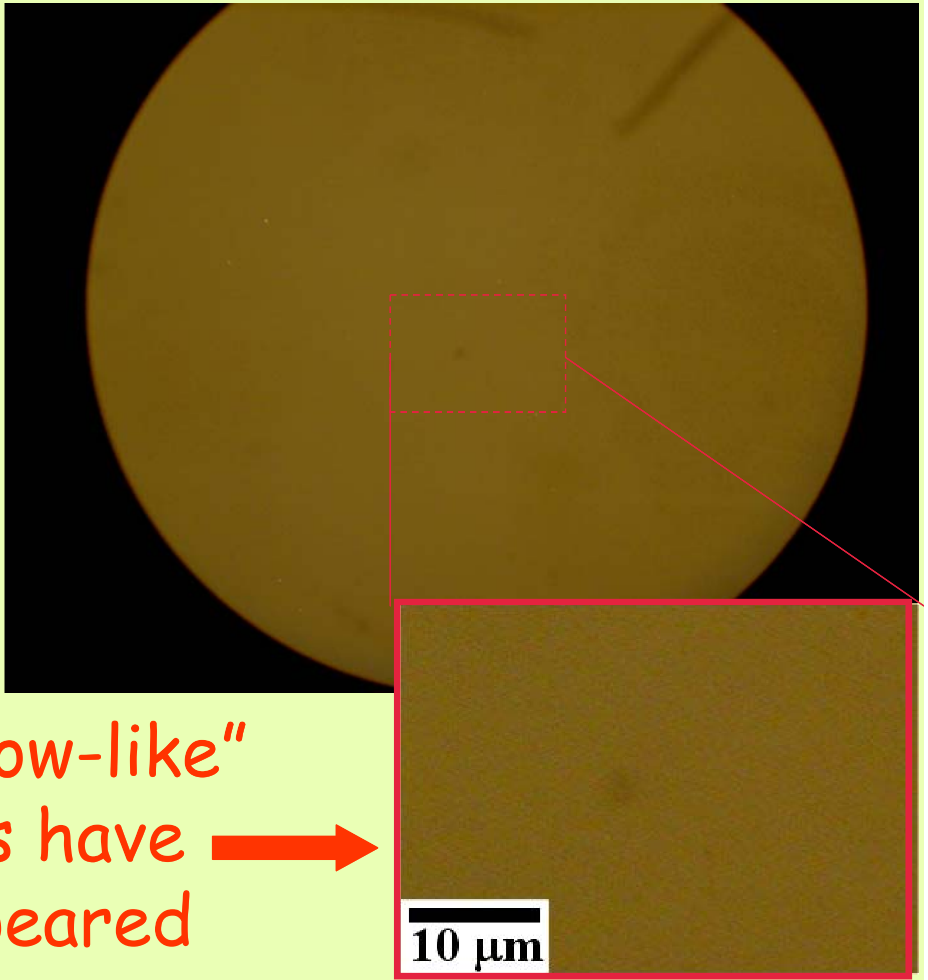
Pictures of exposed glasses corresponding to <v>=750 m/s, average velocity of the observed "snow-like" particles in krypton

1 mbar Kr



1 mbar Kr + B=0.4 T



→ The "snow-like" debris have disappeared →

Conclusions

- The physics of the interaction of debris with a buffer gas is better understood
- The formation of sub-μm particles (called "snow-like" debris) has been observed in presence of a buffer gas
- The application of a local magnetic field deeply influences the interaction between metal atoms and buffer gas.

Future work

- The design of an appropriate DMS is going on based on the results of the presented measurements
- A higher local magnetic field and a proper mechanical device should significantly improve the ENEA DMS
- Both the "snow-like" debris and the particulate accumulate into the gas: an efficient gas cleaning system is also needed.