Direct, real-time and sensitive plasma density diagnostic by quadriwave lateral shearing interferometry

21 April 2015

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loa

Outline

I. Challenges of ion acceleration on gas

II. Overdense Target development

III. 4-waves shearing interferometry

IV. Gas target with 30µm gradient

V. Preliminary overdense interaction results

Challenges of ions acceleration in gas

1. Saphir laser at LOA

SAPHIR
Ti:Sa Ultra-Intense laser

- 3 J on target
- 25 fs
- 1 x 10^{20} W/cm^2
- 1:10^8 contrast

SAPHIR

Feasability of medical ions sources per laser ?

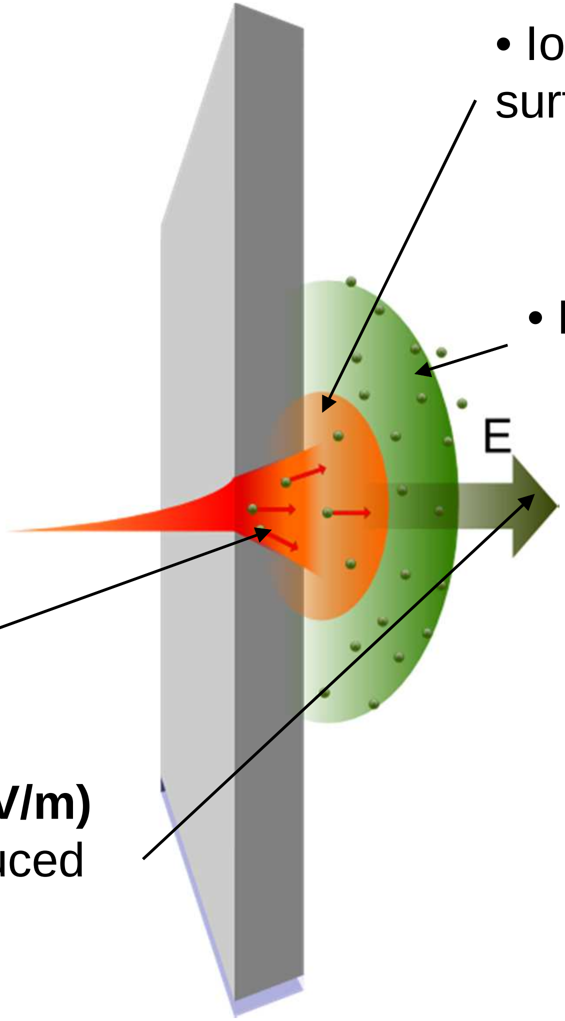
New targets exploration

Unknown Radiobiology domain
(peak dose of 10^9Gy/s vs. 1Gy/s in current medical application)

Challenges of ions acceleration in gas

1. Motivations

Back to TNSA



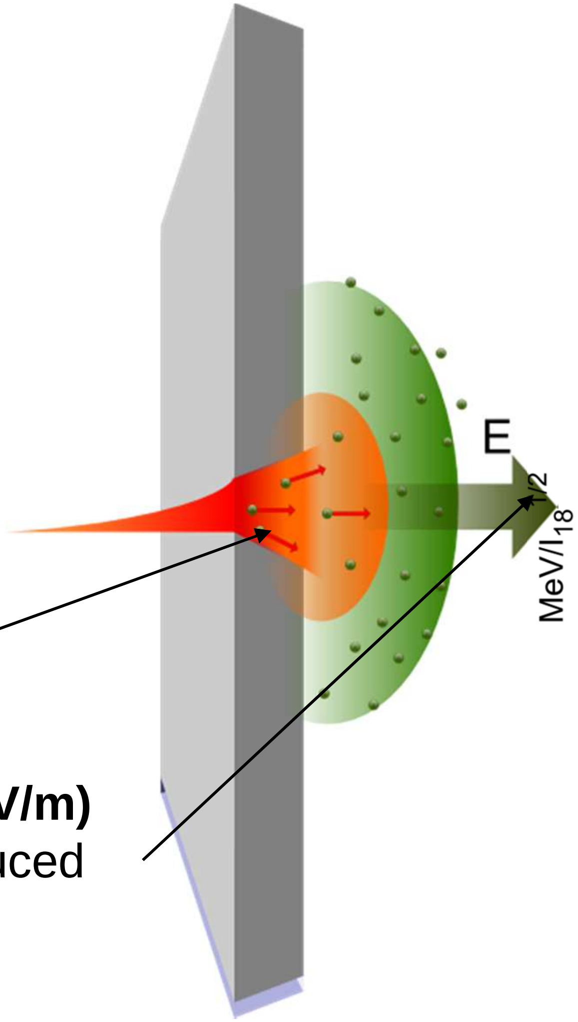
- Ionization of the rear surface by the hot e-
- Debye sheath
- Propagation of hot electrons and plasma expansion
- Strong E-Field **(10^{12} V/m)** from the thermally induced charge separation

Challenges of ions acceleration in gas

1. Motivations

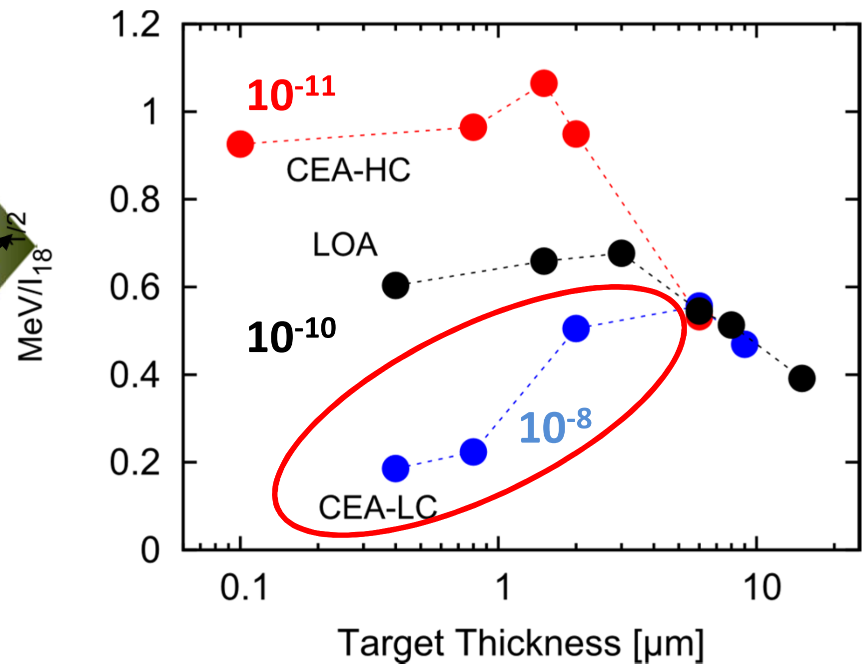
• Propagation of hot electrons and plasma expansion

• Strong E-Field **(10^{12} V/m)** from the thermally induced charge separation



Contrast is critical

CEA-LC : Saturable absorber : 10^{-8} at -50ps
LOA SJ: XPW :10^{-10} at -50 ps
CEA-HC : DPM 10^{-11} at -15ps



Credits : Flacco et al. **NIM A, 620**, *1, 18-22 (2010)*

Challenges of ions acceleration in gas

1. Motivations

Solid target for ion acceleration :

- Contrast dependant
- Acceleration of adsorbed particules
- Repetition rate difficulties

Challenges of ions acceleration in gas

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→ **Gaseous target can relieve the constraints depicted above**

Challenges of ions acceleration in gas

1. Motivations

Solid target for ion acceleration :

- Contrast dependant
- Acceleration of adsorbed particules
- Repetition rate difficulties

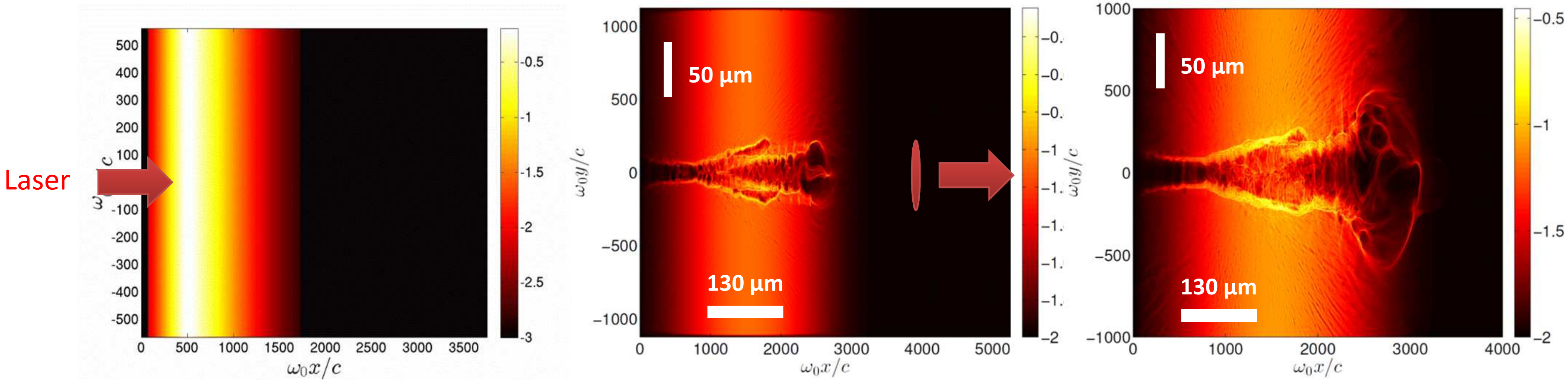
→ **Gaseous target can relieve the constraints depicted above**

Which mechanism ?

Challenges of ions acceleration in gas

2. Simulation PIC-CALDER 2D

He ionic density [n_c] $t=t_0$ | He density at t_0 + 1.7 ps | He density at t_0 + 2.9 ps



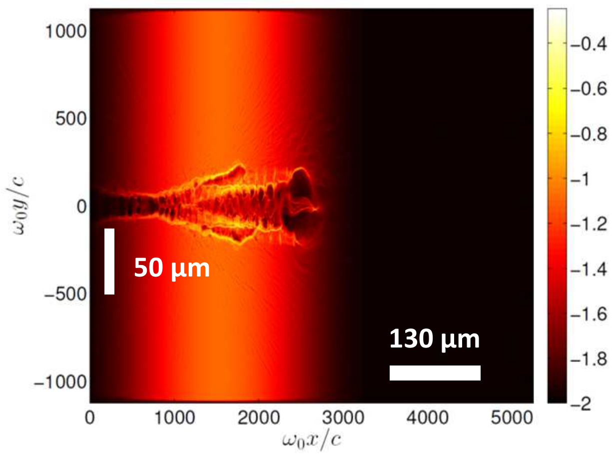
- E_{laser} ~ 7J
- Real profile from 100µm nozzle.
- $n_e = 0.16\ n_c$

Courtesy : A. Debayle & L. Gremillet CEA/DAM

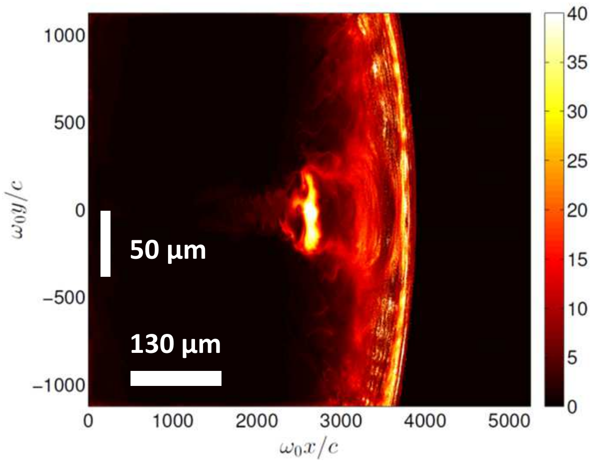
Challenges of ions acceleration in gas

2. Simulation PIC-CALDER 2D

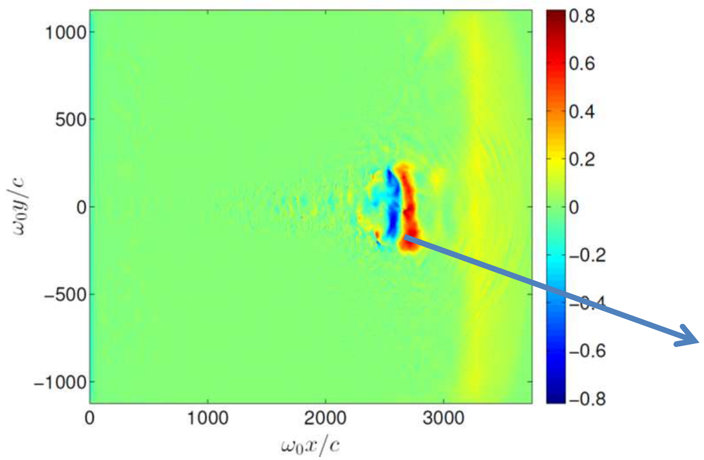
He density [n_c] at $\omega_0 t$=4000 ; t_0 + 1.7 ps



<γ_e-1> at t_0 +1.7 ps



E_x [$m\omega_0 c/e$] at t_0 + 1.7 ps



E_x = 3 x 10^{12} V/m

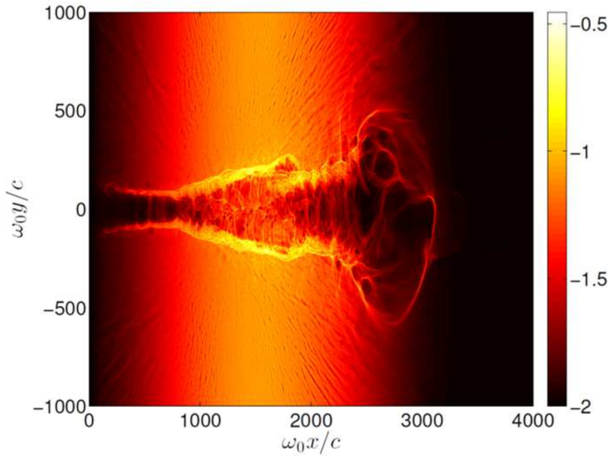
- Shock formation
- Electron heating
- Strong charge separation E-field in the rear gradient

Courtesy : A. Debayle & L. Gremillet CEA/DAM

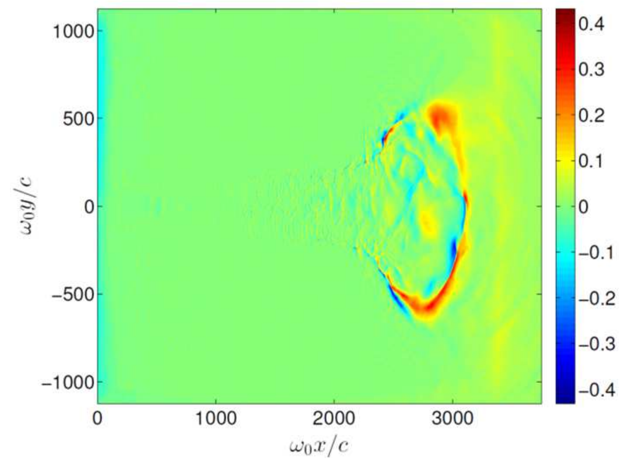
Challenges of ions acceleration in gas

2. Simulation PIC-CALDER 2D

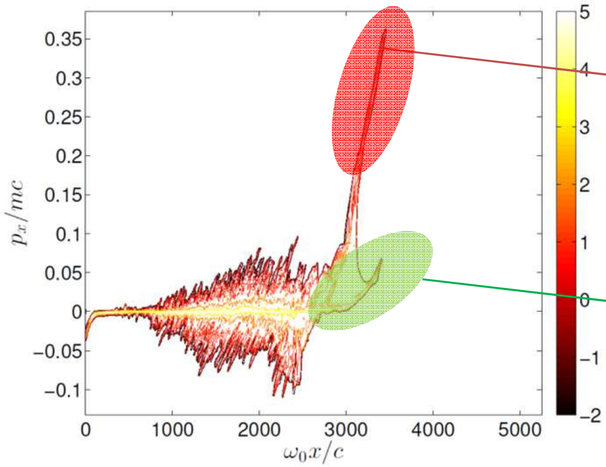
He density at $\omega_0 t$=6750 ; t_0 + 2.9 ps



E_x [$m\omega_0 c/e$] at t_0 + 2.9 ps



Distribution function He, f(p_x,x,t)



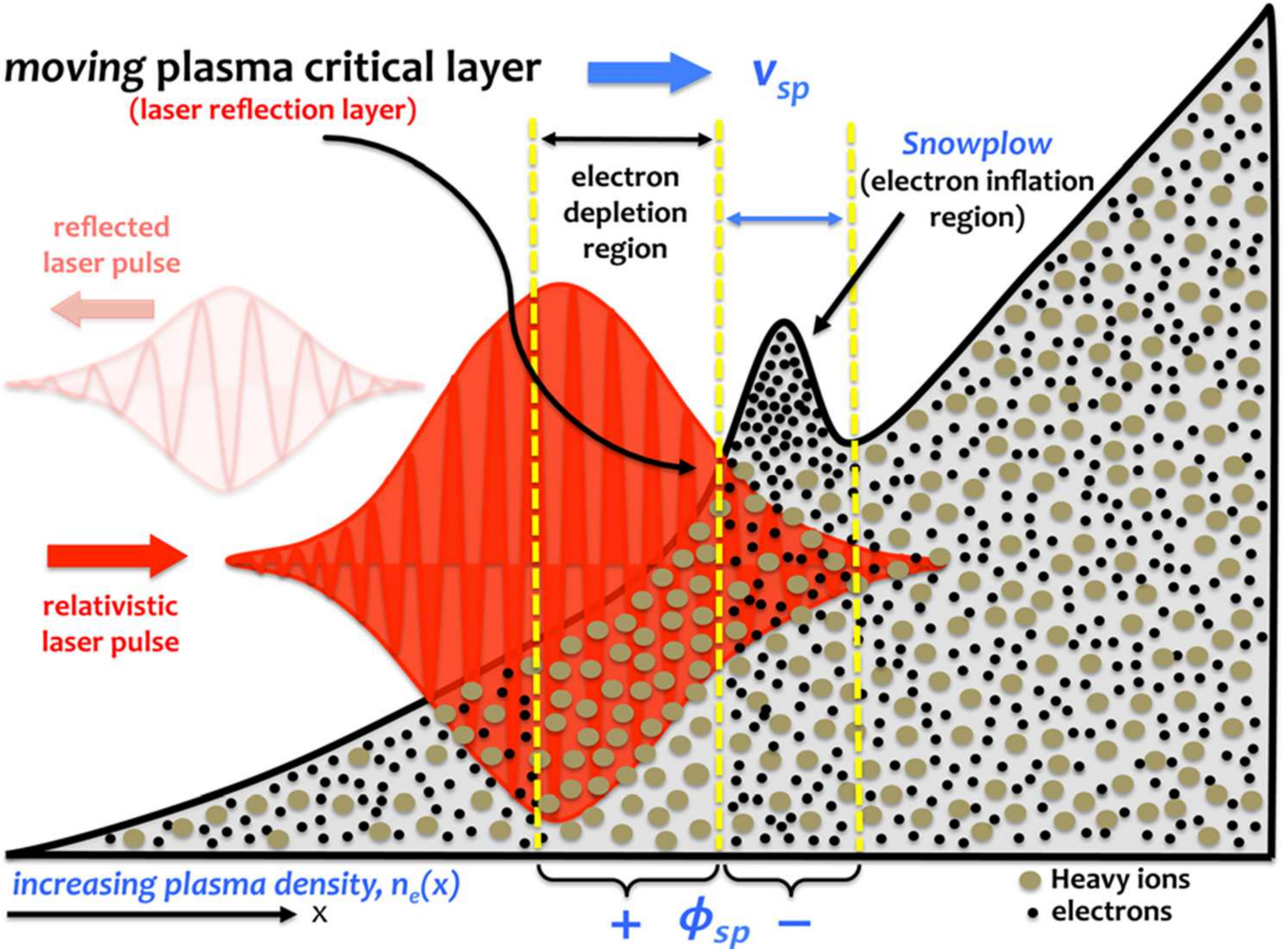
Reflected ions at 50MeV/u

« TNSA-like » ions

Courtesy : A. Debayle & L. Gremillet CEA/DAM

Challenges of ions acceleration in gas

3. Snoplow mechanism



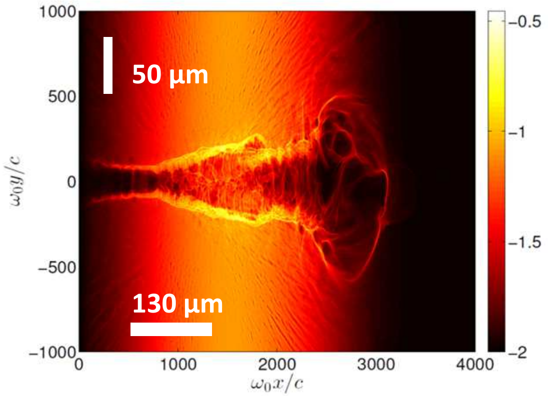
5 n_c in 30µm

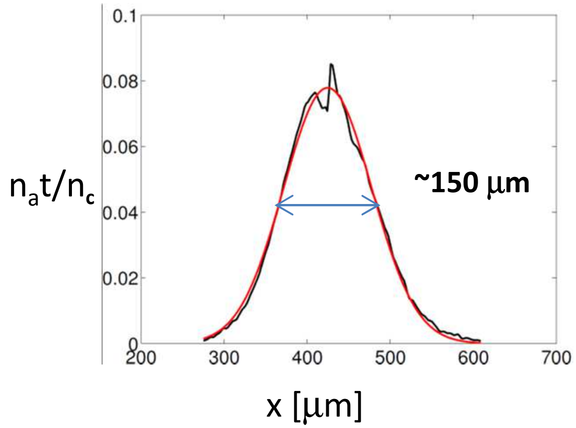
A. Sahai PoP **21, 056707 (2014)**

Challenges of ions acceleration in gas

4. Target summary

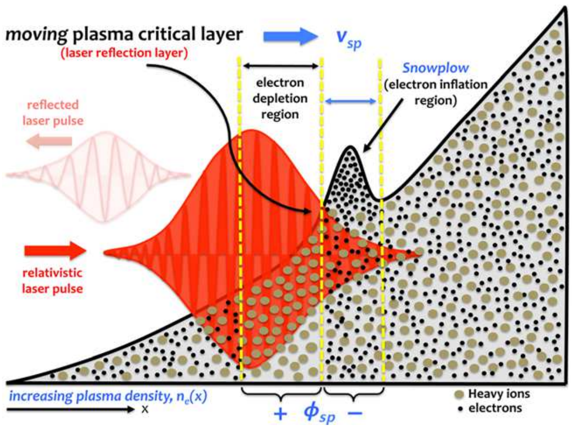
1. Shock in downramp

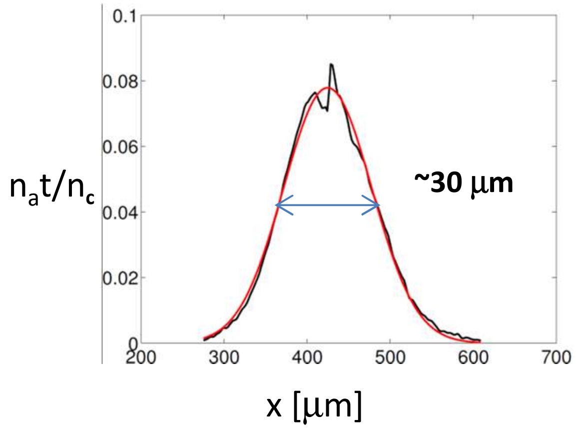




$n_e = 0.16\ n_c$
(140 bars H_e
in 100μm
sonic nozzle)

2. Snowplow



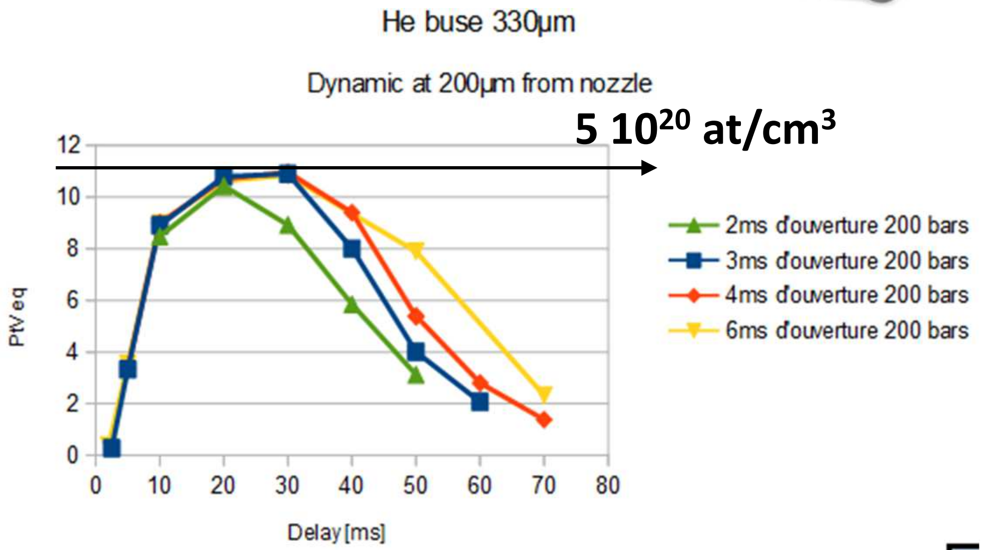


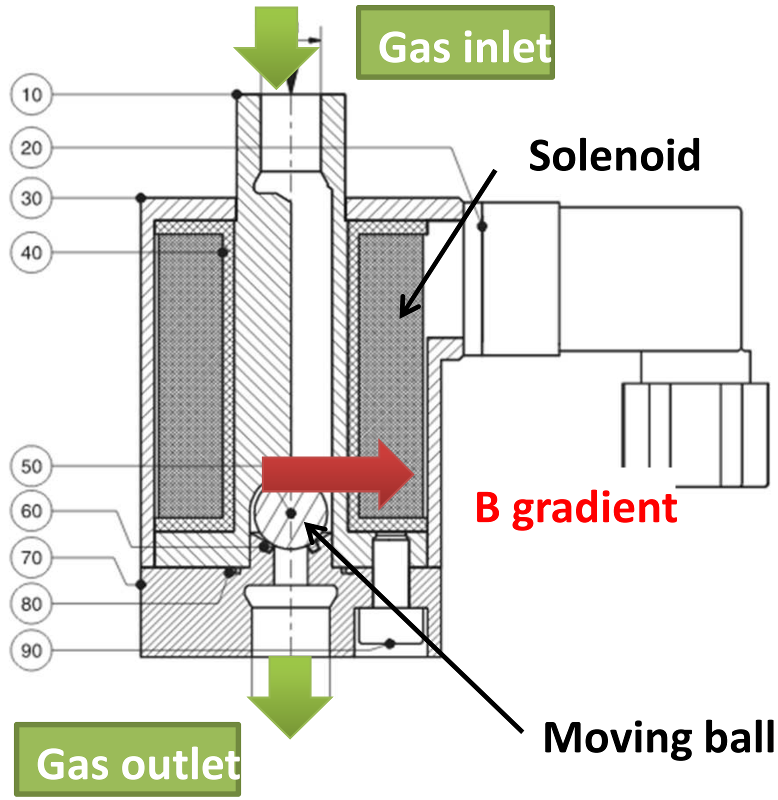
300 bars Ar/H(1%)
$n_e = 5n_c$

Shear wave interferometry

1. Target characterisation

- Fast solenoid electrovalve
- up to 400 bars
- ~20ms opening time





Sylla et al, Rev. Sci. Instr. 83, 033507 (2012)

Shear wave interferometry

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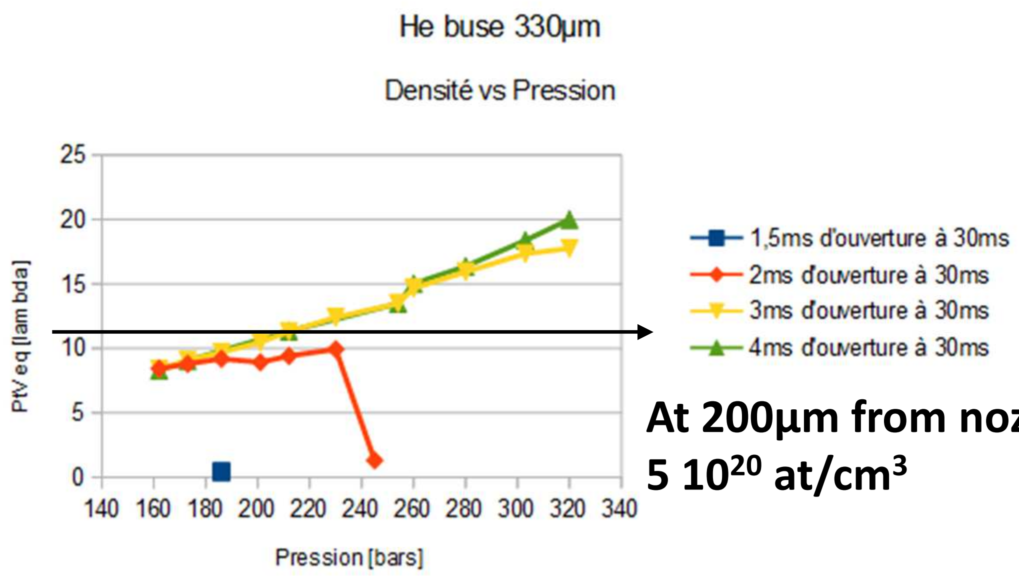
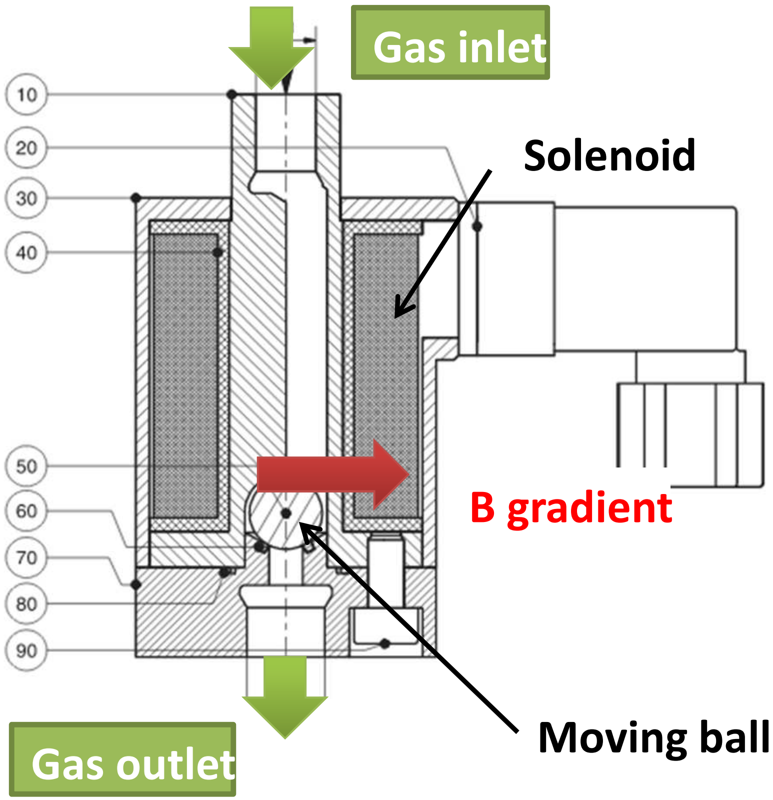


At 200µm from nozzle : $5\ 10^{20}$ at/cm^3

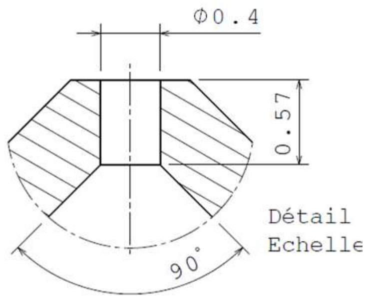


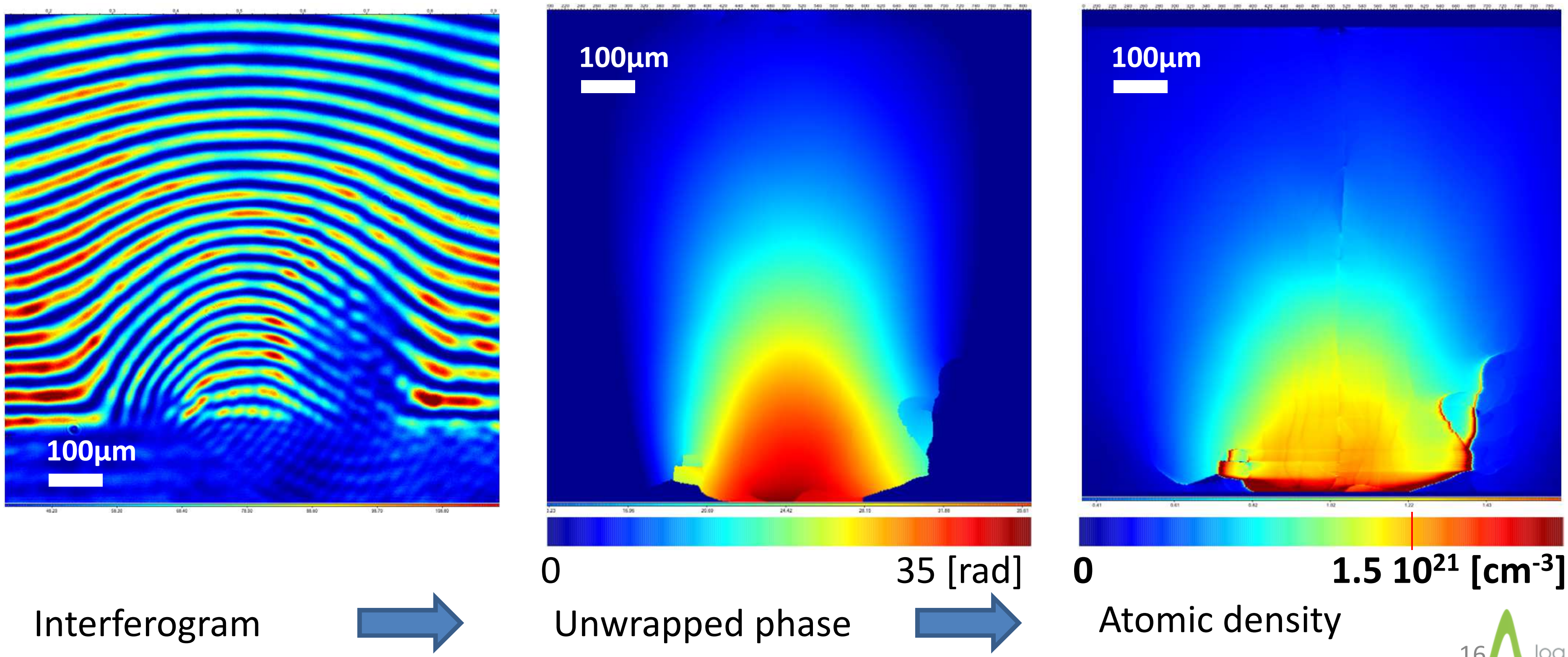
Sylla et al, Rev. Sci. Instr. 83, 033507 (2012)

Shear wave interferometry

2. Mach-Zehnder set-up

Sonic nozzle 400µm Ø 300bar of Argon





Shear wave interferometry

1. Principle

Two beams interferometry

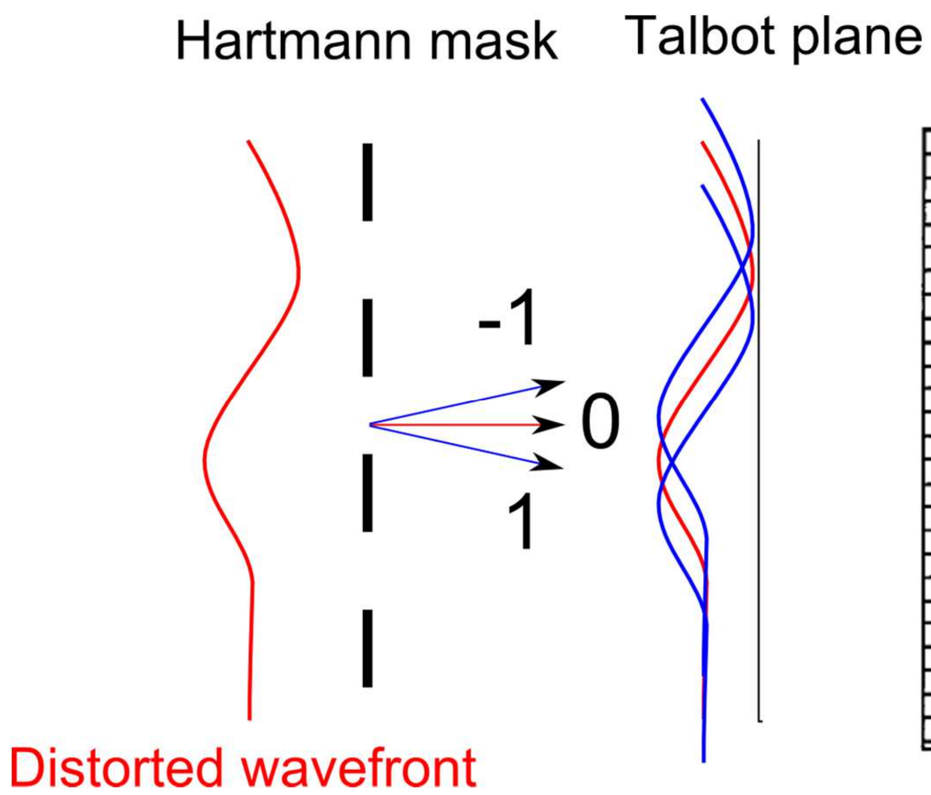
Phase difference between
Flat front vs **distorted front**

4-wave shearing interferometry

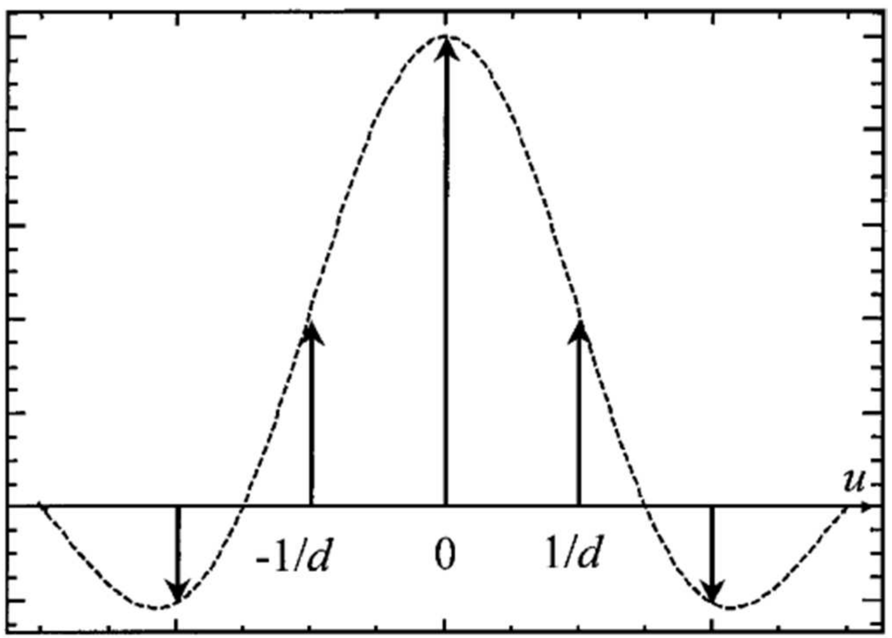
Phase difference between
distorted front (x) vs **distorted front (x + dx)**

Shear wave interferometry

1. Principle



APPLIED OPTICS / Vol. 39, No. 31 / 1 November 2000



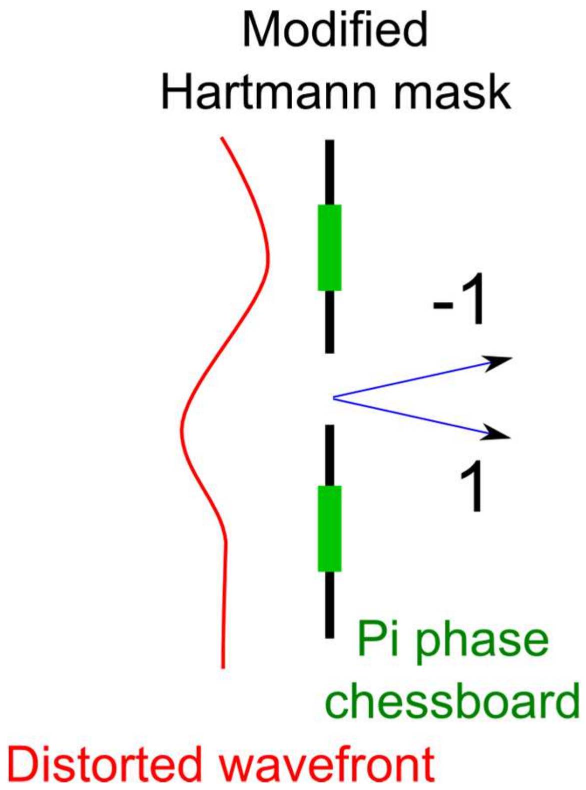
d : pitch of the grid (29µm)

a : open square size (2d/3)

- Strong chromatic dependance
- Contrast of interference ~ cos ($\pi\lambda z/d^2$)

Shear wave interferometry

1. Principle



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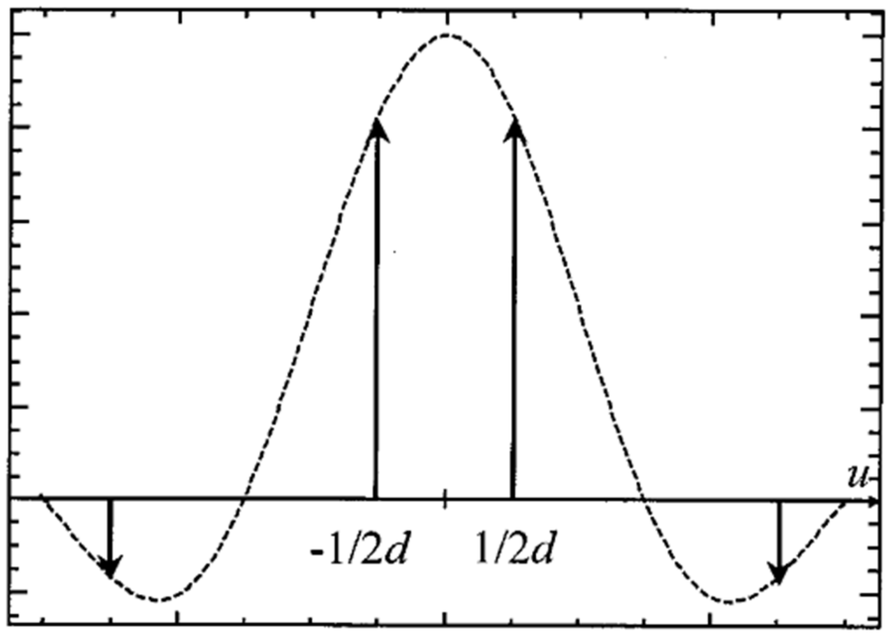


d : pitch of the grid (29µm)

a : open square size (2d/3)

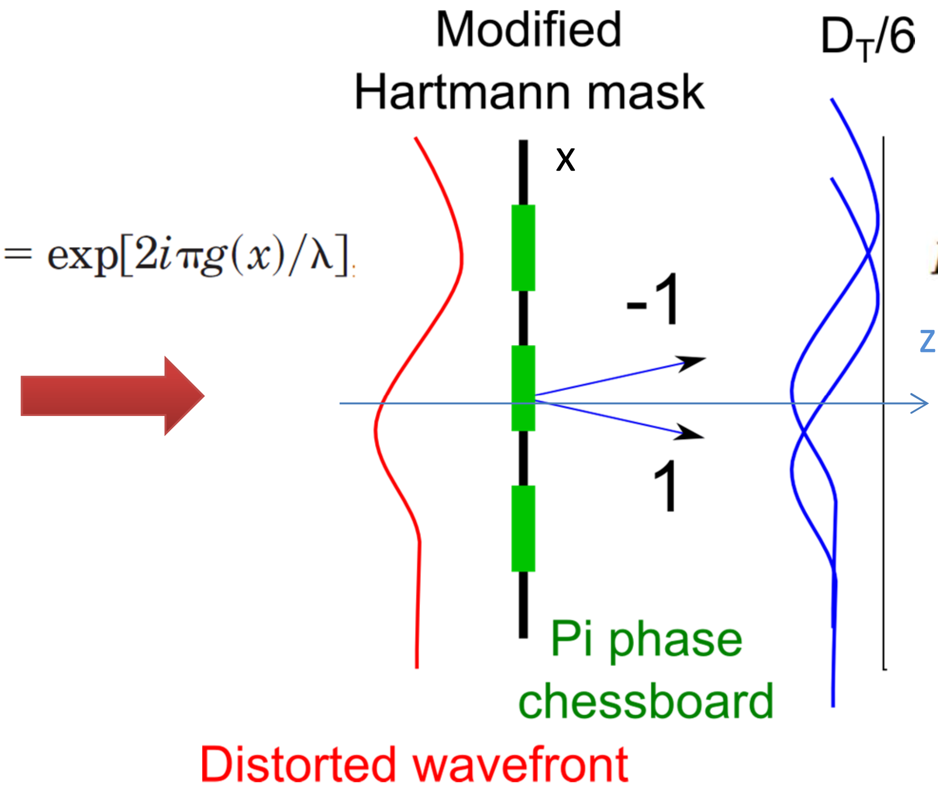
Same phase delay :

- Contrast invariant by propagation
- Achromatic
- Self imaging at $D_T/6$

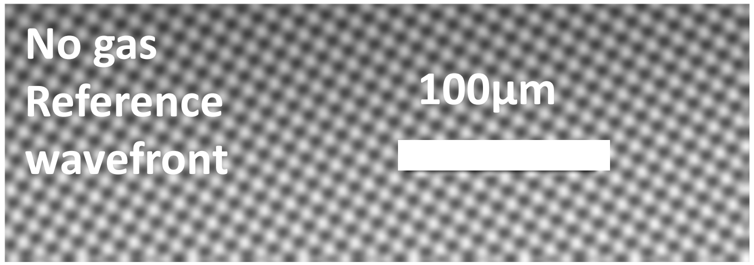
Shear wave interferometry

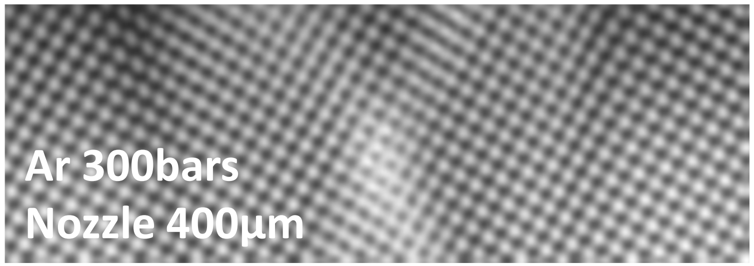
1. Principle

$$E_i(x) = \exp[2i\pi g(x)/\lambda]$$



$$Ip(x,z) = 2C_{1/2}{}^2\left\{1+\cos\left[\frac{2\pi}{d}\left(x - z\frac{dg}{dx}\right)\right]\right\}.$$





Shear wave interferometry

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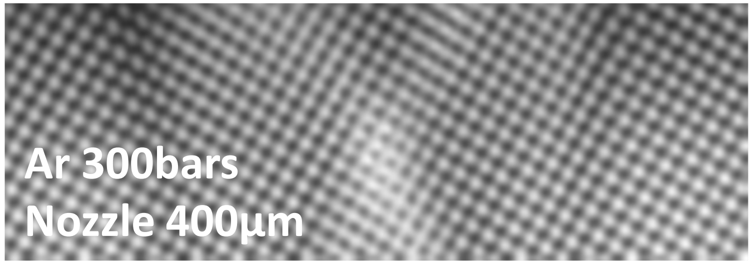
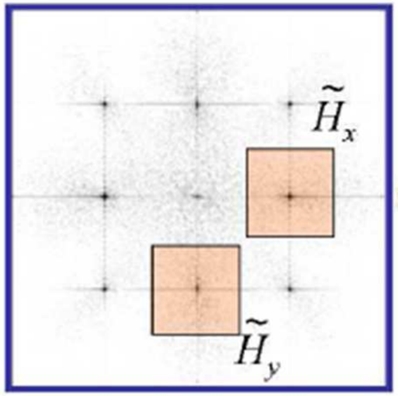
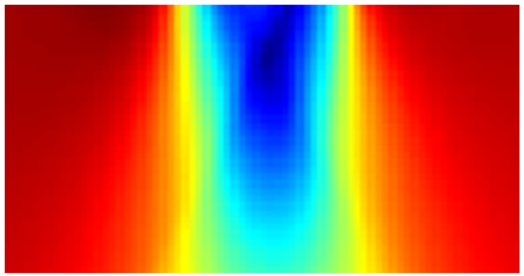


FT



FT^{-1}

Phase front : loss of resolution of 4

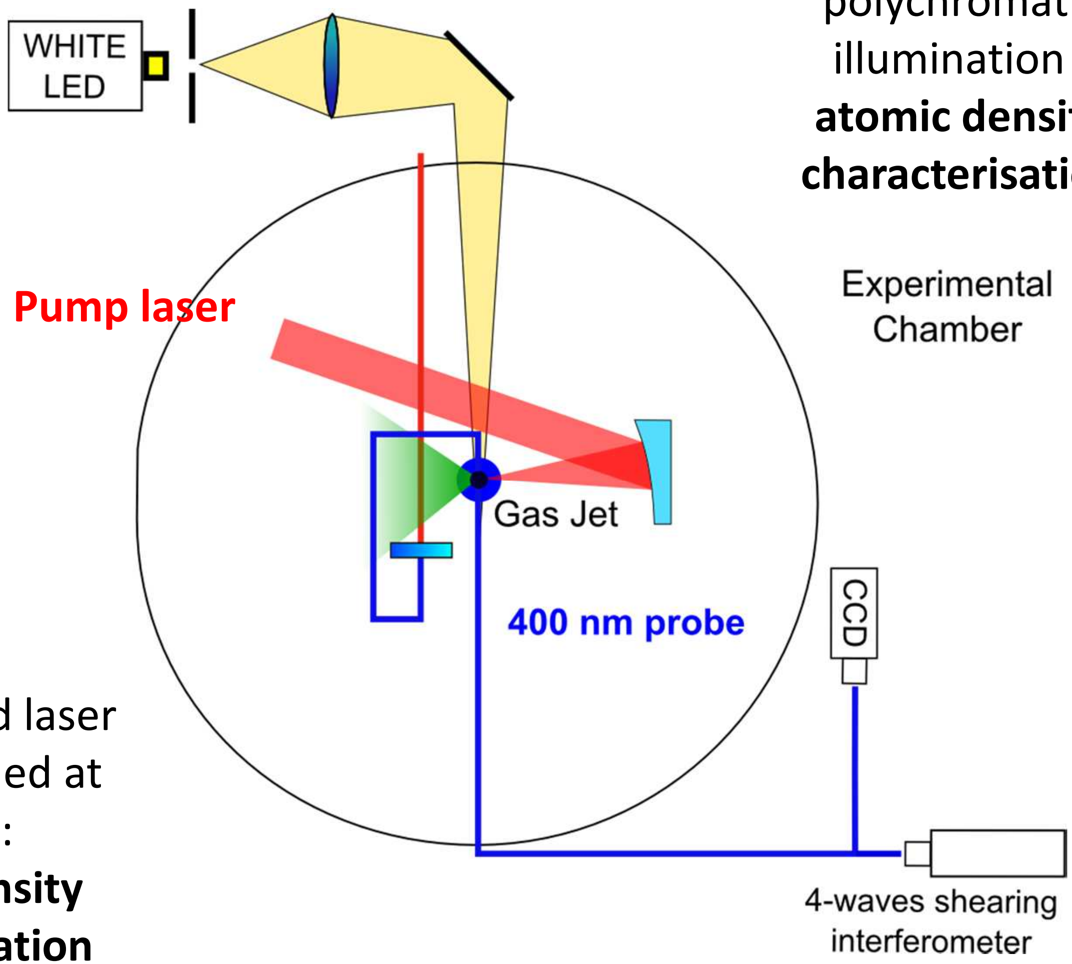


Bon et al Vol. 17, No. 15 / OPTICS EXPRESS 13082

Shear wave interferometry

2. Set-up

Pulsed (100µs) polychromatic illumination : **atomic density characterisation**

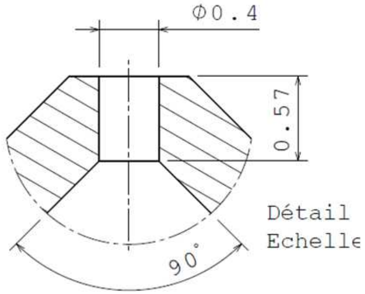


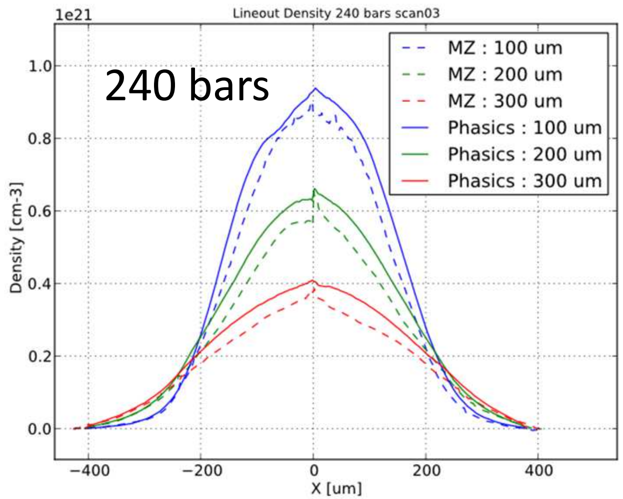
Femtosecond laser probe doubled at 400nm : **plasma density characterisation**

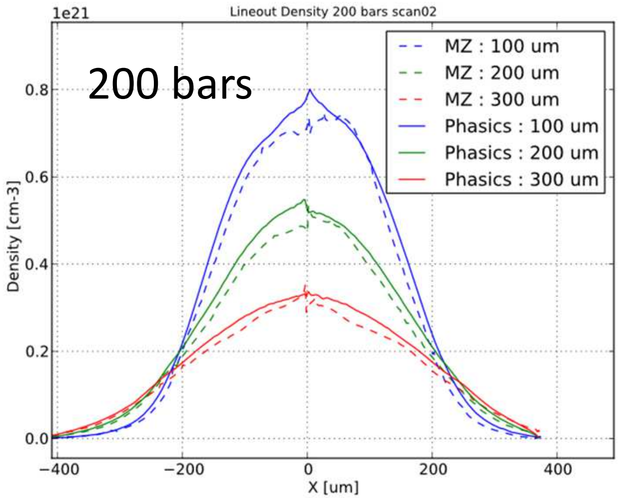
Shear waves interferometry

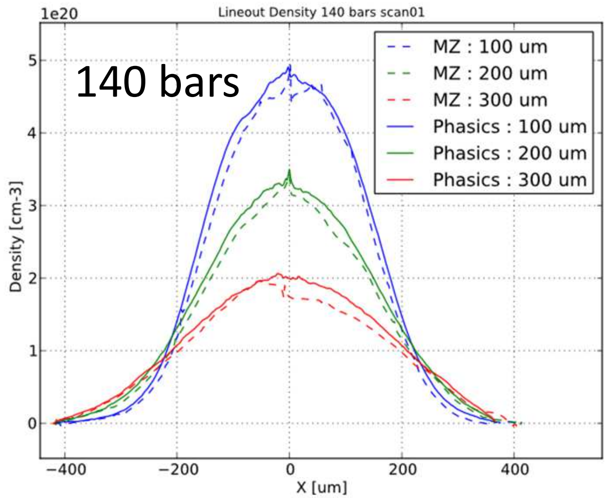
2. Shear waves vs Mach-Zehnder

Sonic nozzle 400µm Ø ; Argon





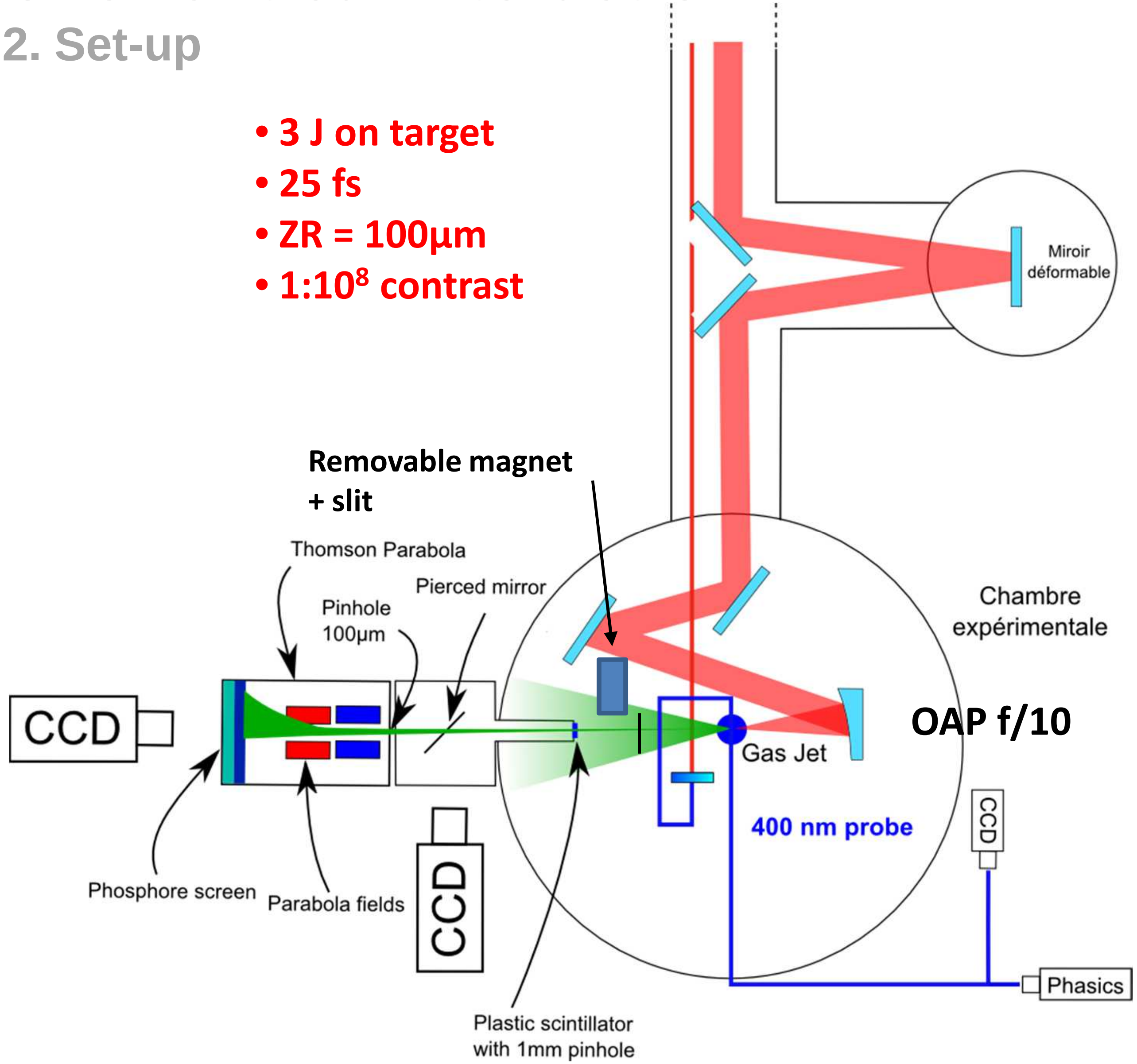




Over-critical interaction

2. Set-up

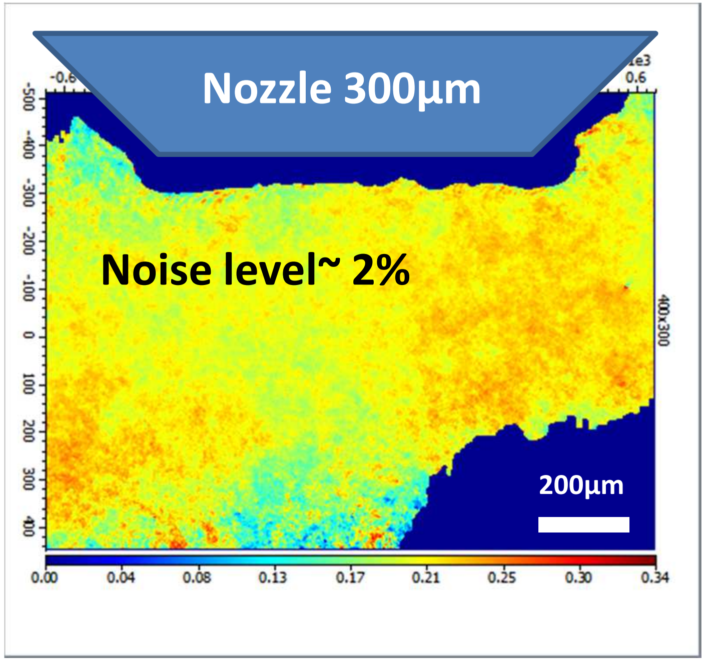
- 3 J on target
- 25 fs
- ZR = 100µm
- 1:10^8 contrast

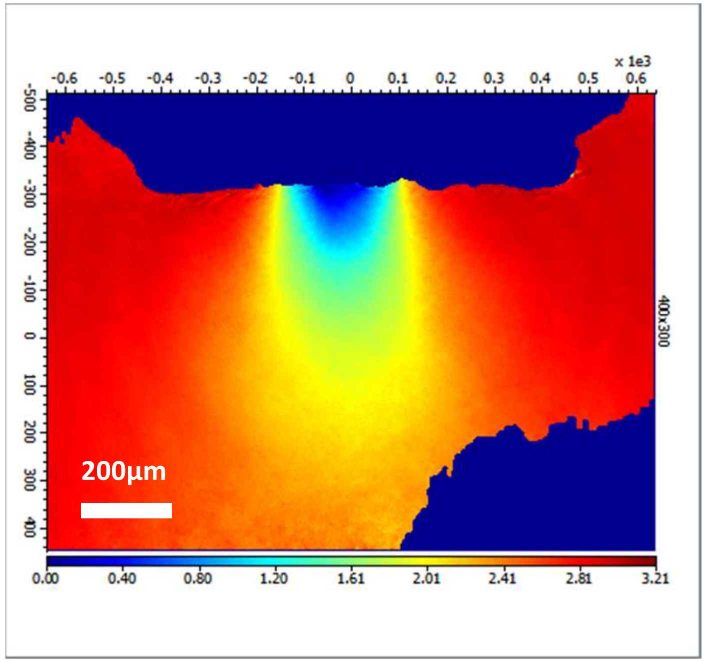


Shear waves interferometry

2. Quick Abel inversion

In line direct diagnostic : Images with 400nm probe



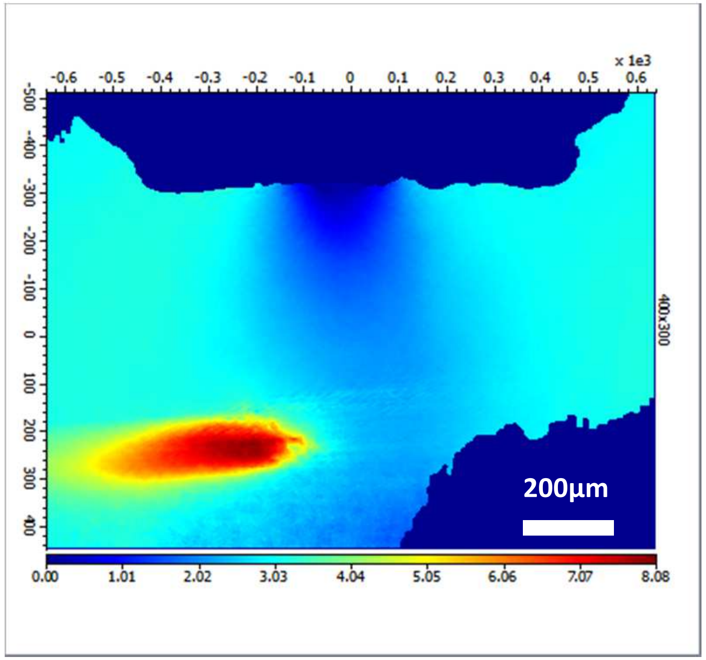


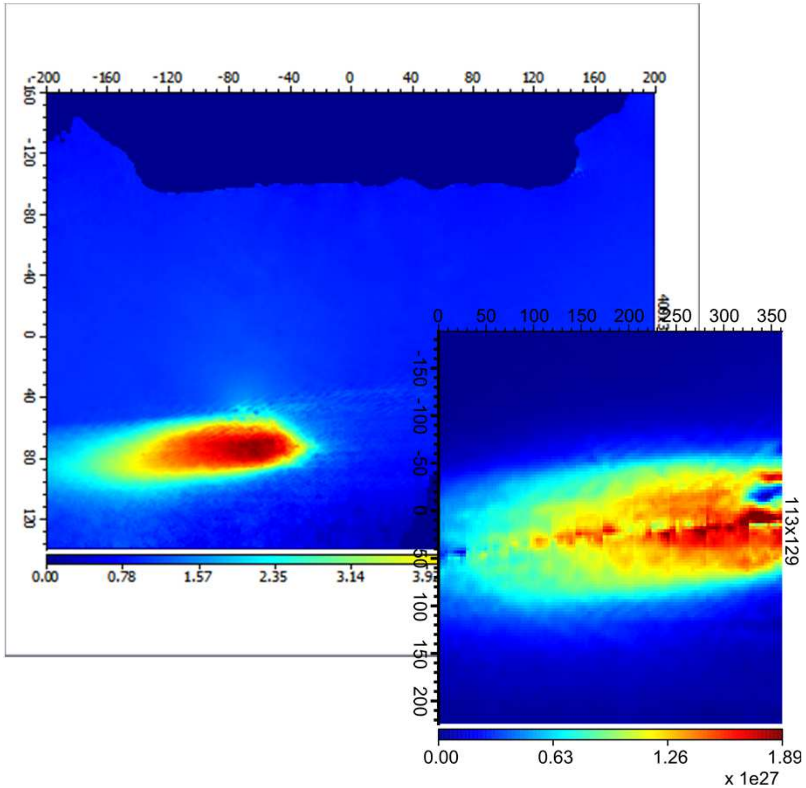
Plasma canal ionized by 200mJ / 35fs Ti:Sa laser
ZR = 100µm
Incoming on 300µmØ argon gas target at **10^{20} atom/cm^3**

Shear waves interferometry

2. Quick Abel inversion

In line direct diagnostic



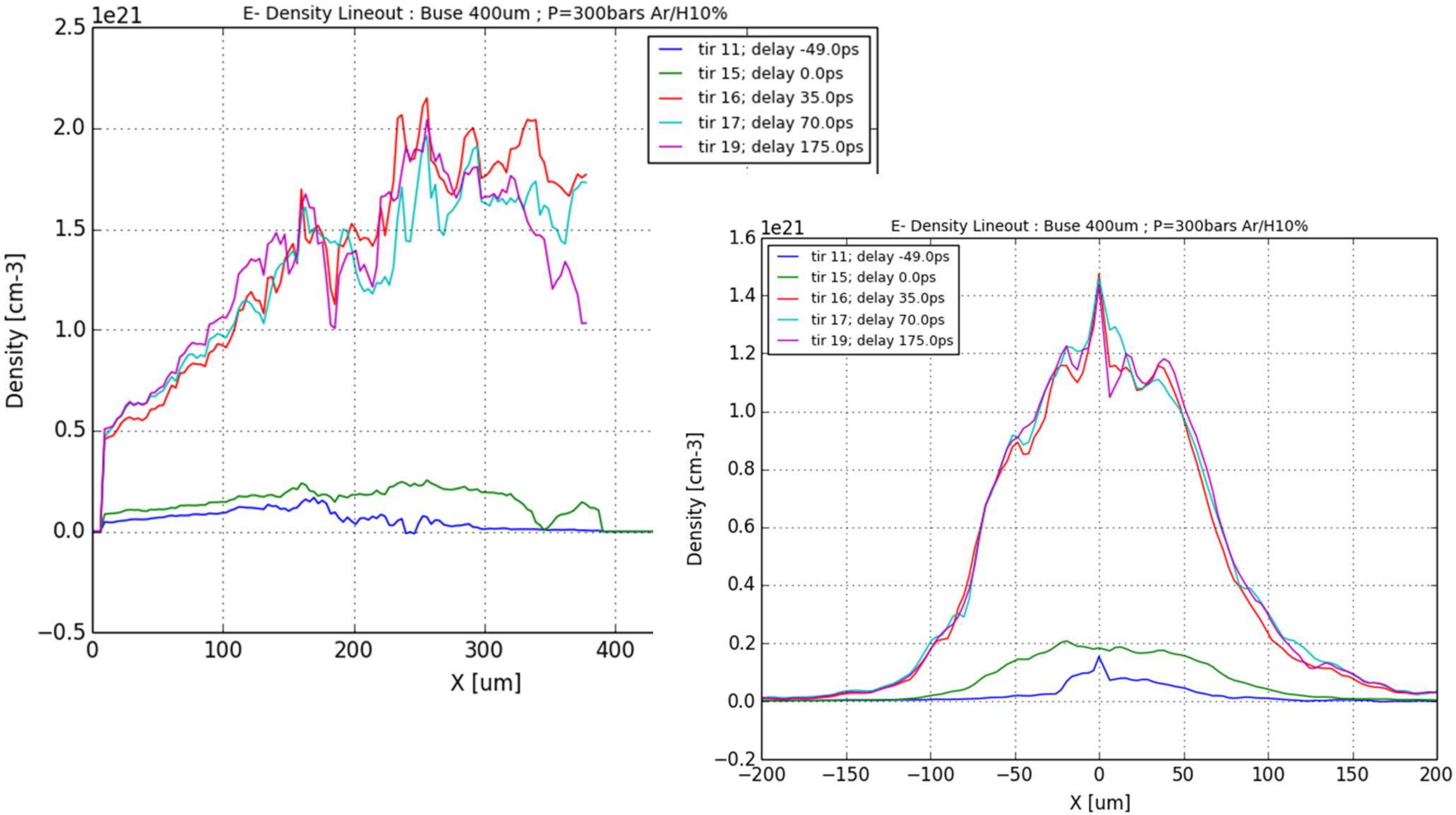


Plasma canal ionized by **200mJ / 35fs** Ti:Sa laser
ZR = 100µm
Incoming on 300µmØ argon gas target at **1e20 atom/cm-3**

Electronic density **[1e21 cm^{-3}]**

Shear waves interferometry

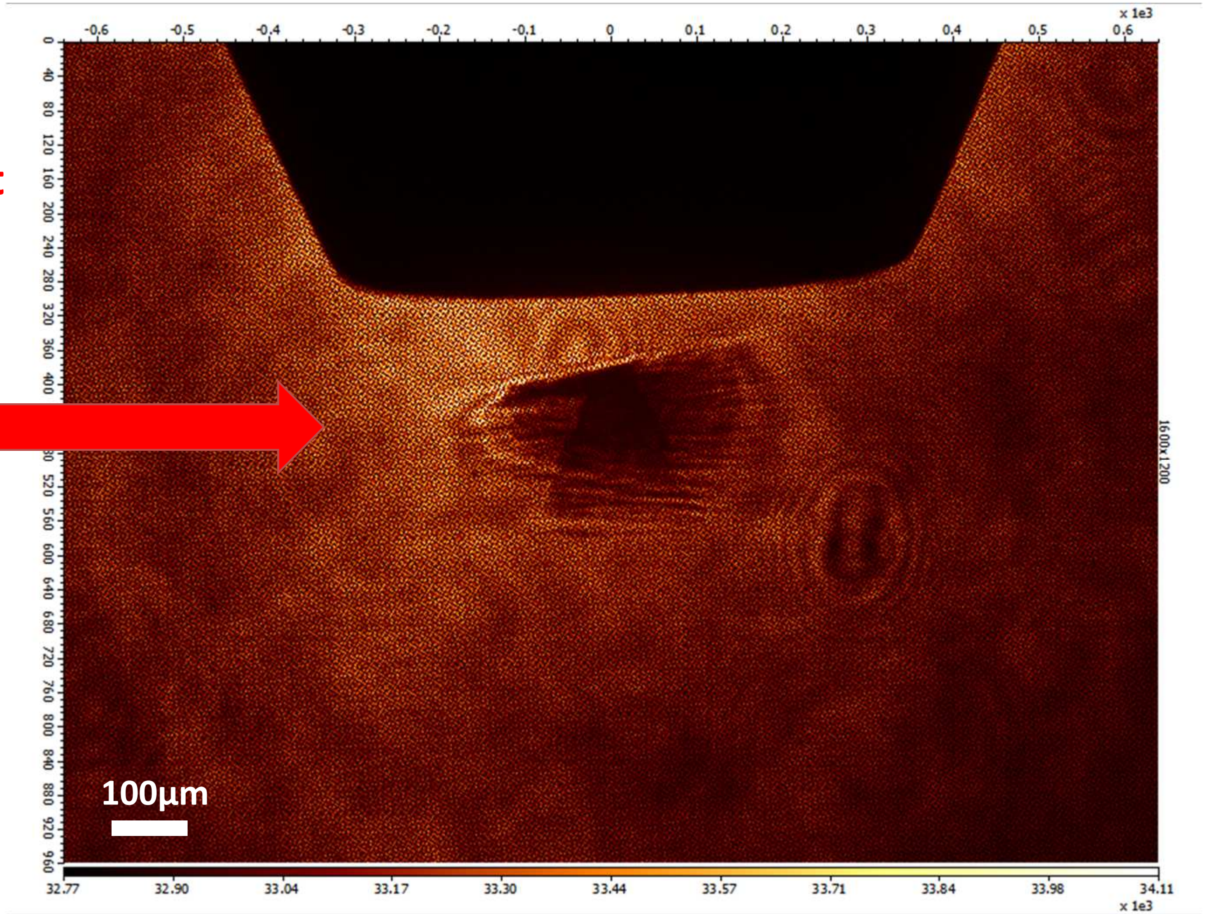
2. Plasma evolution



Thin gas layer

1. Shock Nozzle

- 30 mJ on target
- 25 fs
- ZR = 100µm
- $1{:}10^8$ contrast



Thin gas layer

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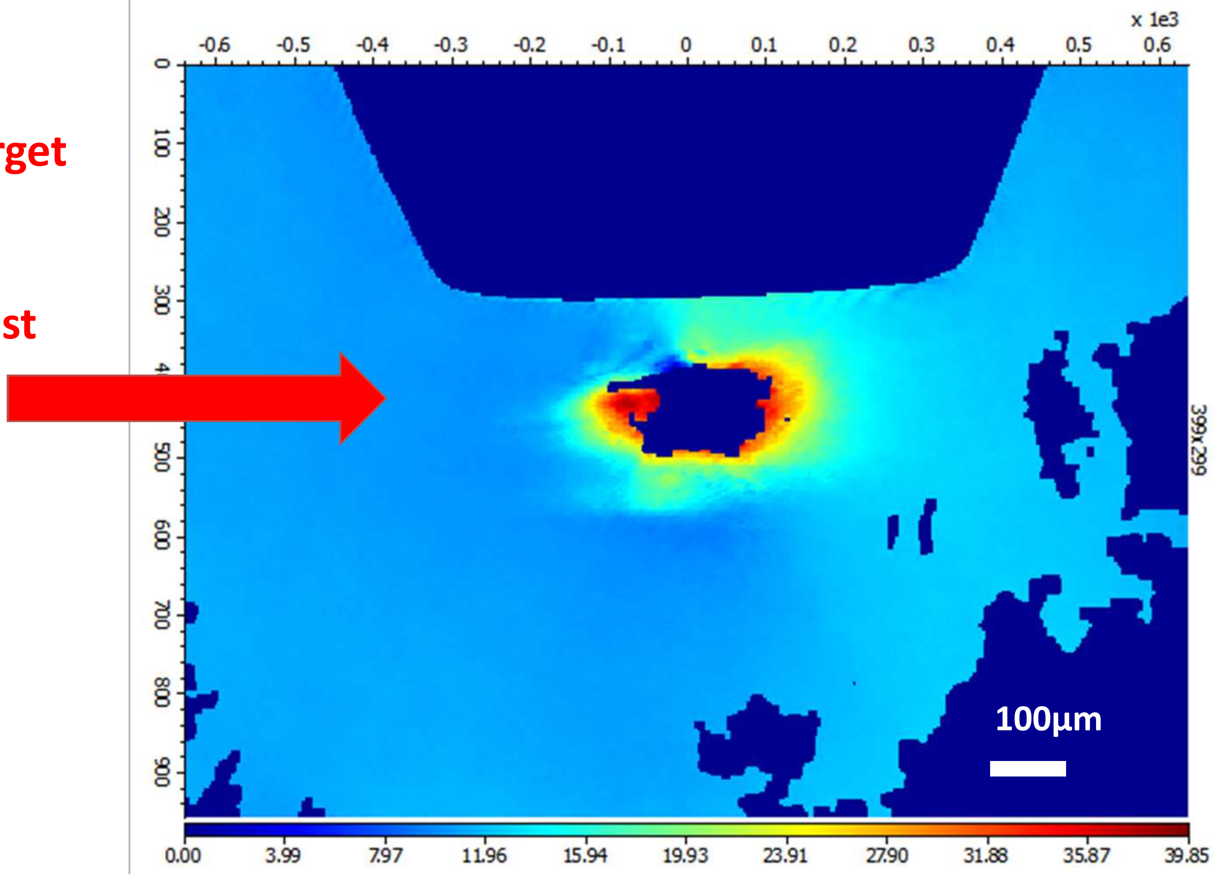

Thank you

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Antoine Doche

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