ASACUSA supersonic gas-jet target:
present status and future development

V.L. Varentsov[2, 3], N. Kuroda [2], Y. Nagata [1, 2], H. A. Torii [1],
M. Shibata[2], Y. Yamazaki[1, 2]

[1]Institute of Physics, University of Tokyo, Komaba, Meguro-ku, Tokyo 153-8902, Japan
[2]Atomic Physics Laboratory, RIKEN, Wako, Saitama 351-0198, Japan
[3]V.G. Khlopin Radium Institute, 2nd Murinskiy Ave. 28, 194021, St. Petersburg, Russia

Introduction

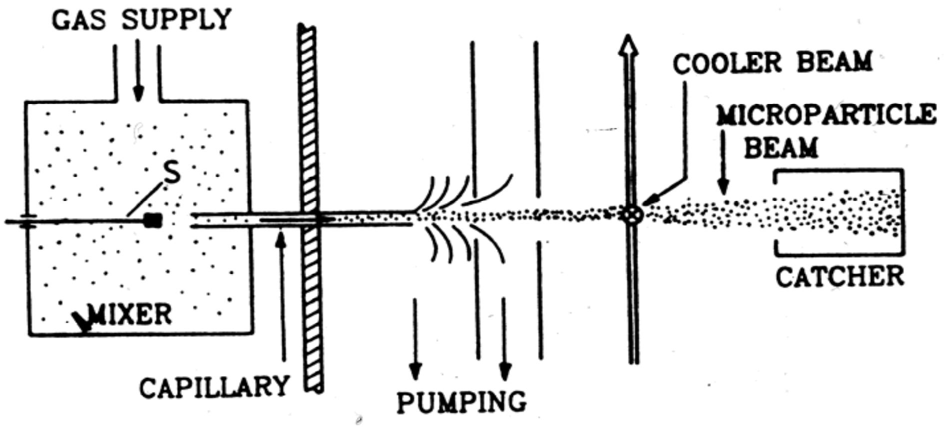
Types of internal targets

- **Solid targets:**
  - thin fibers
  - dust targets
  - pellet targets

- **Molecular beam targets:**
  - molecular effusion
  - gas-jets
  - cluster-jets
  - carrier gas cooling technique

Introduction

Microparticle beams – dust targets



T. Tanabe et al., Nucl. Instr. and Meth., A256 (1987) 439.

A. Berdoz et al., IUCF Scientific and Technical Report 1987/88, p.204

H.O. Meyer et al., Nucl. Instr. And Meth., A295 (1990) 53

F. Hinterberger et al., Topical Conf. on Electronuclear Physics with Internal Targets, SLAC, Stanford, 1989, p. 168.

B.B. Voitsekhovskii et al., Sov. J. Nucl. Phys., 48 (1988) 4.

particle size ~ (1-3) μm

Effective dust targets thickness ~ 10^{14} – 10^{16} atoms/cm^2

Introduction

Frozen hydrogen micro-droplets – pellet targets

Nozzle diameter 20 μm

Pellets diameter ~ 40 μm

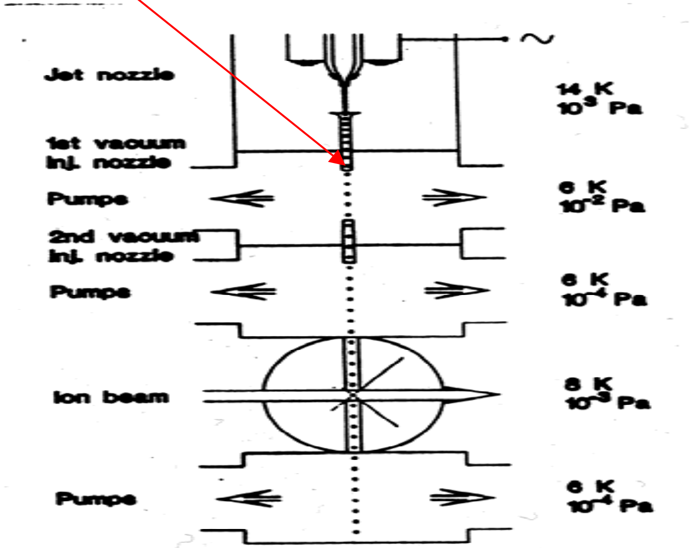


Fig. 1. The principles of operation for a conceptual hydrogen micro-sphere internal target facility.

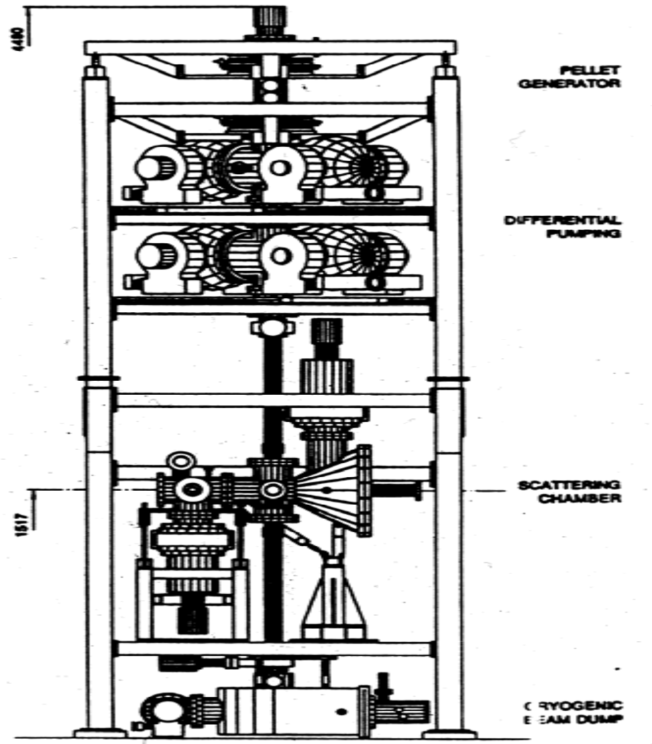


Fig. 7. Hydrogen pellet-target system installed at the CELSIUS storage ring to test the influence on the ring parameters like lifetime of stored beams and vacuum. The pellets, produced in the pellet generator, will pass a differentially pumped system to interact in the scattering chamber with the ions in the ring at a distance of about 2.5 m from the nozzle, and to be collected in the cryogenic beam dump about 1.4 m further down.

Droplets are produced by an acoustical excitation induced by a piezo-electric transducer of ~ 70 kHz frequency

Introduction

Types of internal targets

- **Solid targets:**
  - thin fibers
  - dust targets
  - pellet targets

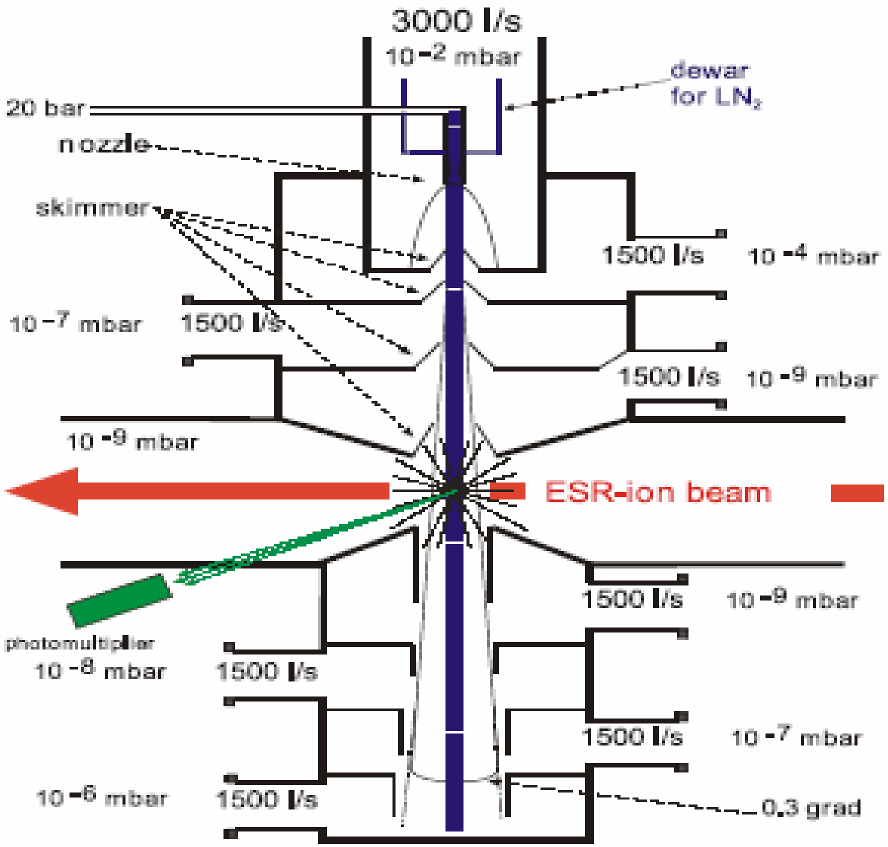
Solid targets are locally very thick (10^{17} – 10^{19} atoms/cm^2) and they are unsuitable for collision experiments with ultra slow pbar-beams

- **Molecular beam targets:**
  - molecular effusion
  - supersonic gas-jets
  - cluster-jets
  - carrier gas cooling technique

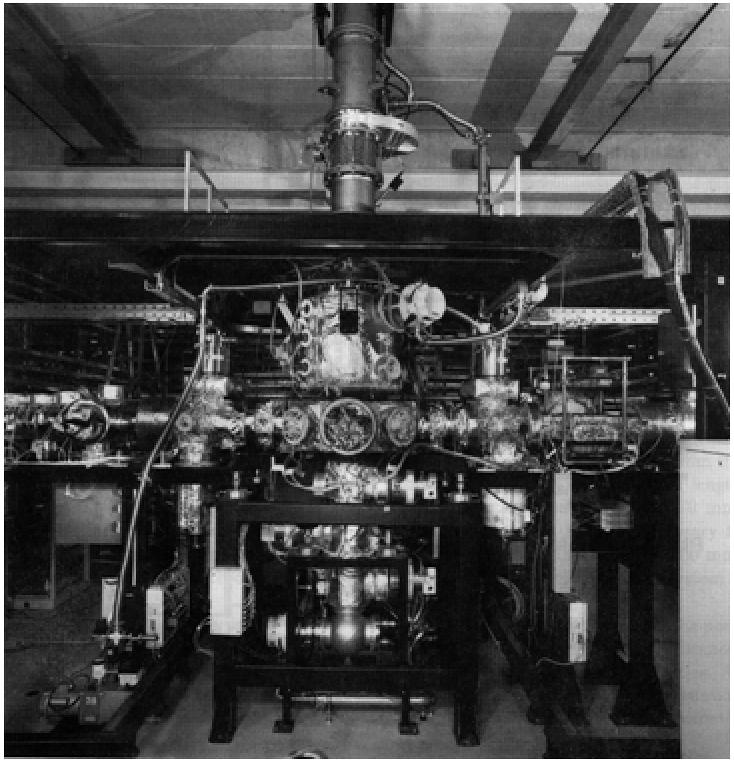
Supersonic gas-jet targets

The ESR internal target at GSI, Darmstadt

H. Reich, W. Bourgeois, B. Franzke, A. Kritzer, V. Varentsov, Nucl. Phys. A 626 (1997) 417



Trumpet-shaped nozzle with 0.1 mm throat diameter



Target densities

He (T= 300 K) – 5*10^{10} p/cm^3

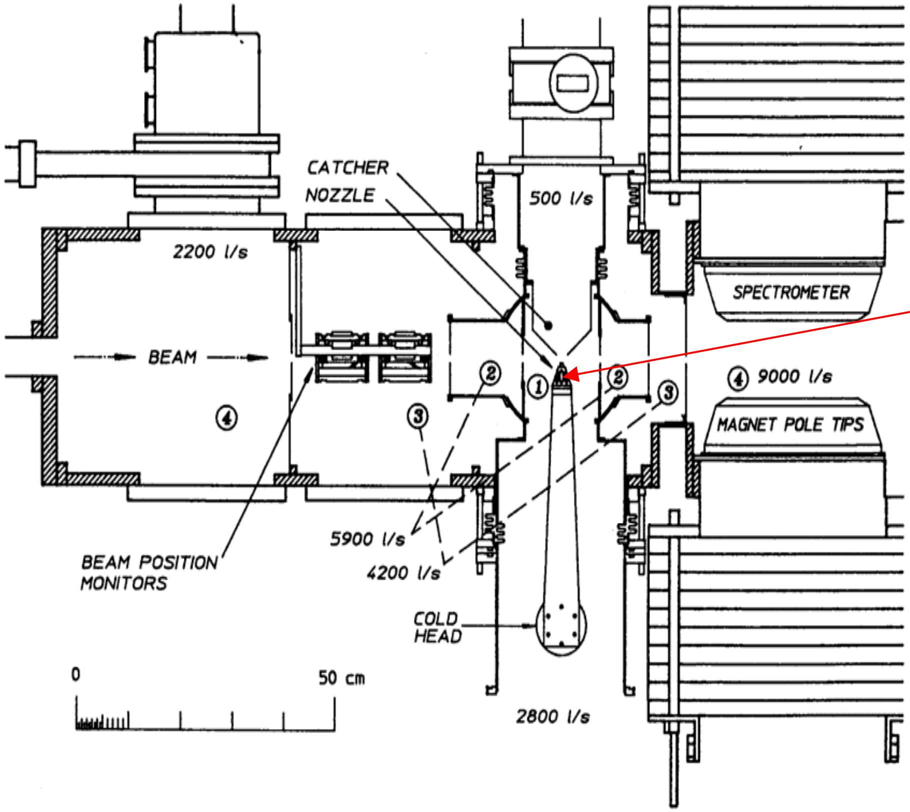
H_2 (T= 300 K) – 3*10^{10} p/cm^3

H_2 (T= 80 K) – 1*10^{13} p/cm^3 - clusters in the jet

Supersonic gas-jet targets

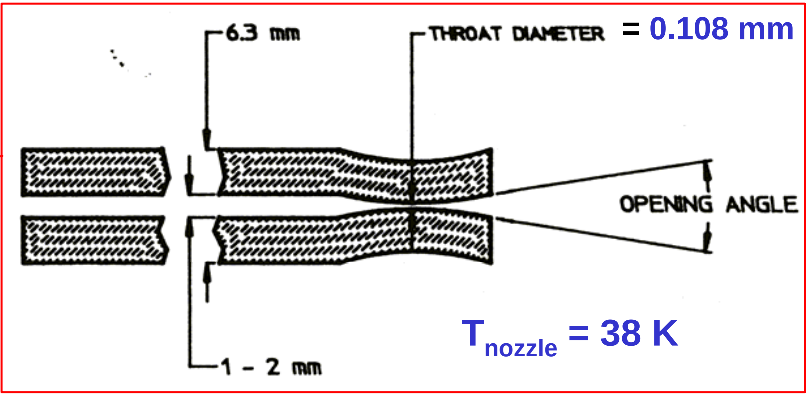
Indiana Cooler ring target at IUCF, Bloomington

J.E. Doskov, F. Sperisen, Nucl. Instr. and Meth., A362 (1995) 20



Nozzle – gas-catcher distance = 14 mm

Geometry of glass nozzle



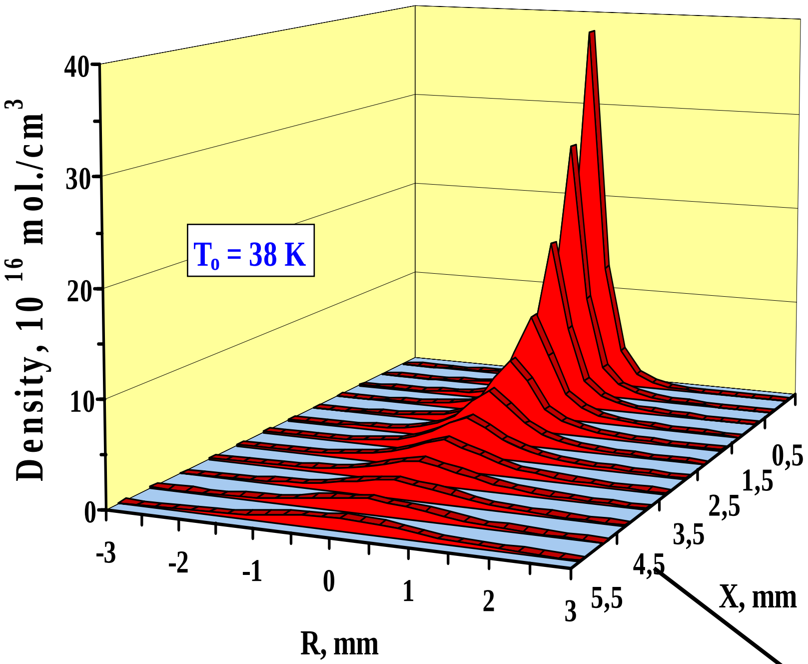
H_2 flow rate through the nozzle = $1*10^{20}$ mol./s
~ 4 mbar l/s

Background pressure in the scattering chamber **> $5*10^{-4}$ mbar**

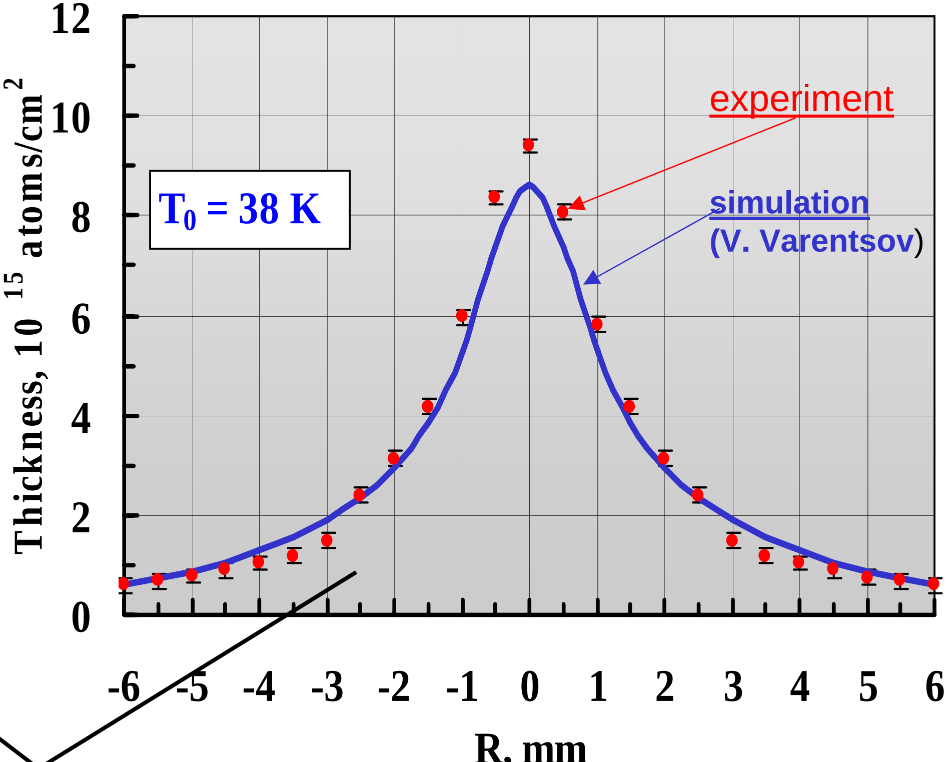
Supersonic gas-jet targets

Indiana Cooler ring target at IUCF, Bloomington

Computed density profile of H_2 supersonic jet (V. Varentsov)



Hydrogen target thickness profile at 5 mm downstream the nozzle exit



Simulation:

see V.L. Varentsov and A.A. Ignatiev, Nucl. Instr. and Meth., A413 (1998) 447

Introduction

Cluster-jet targets

C. Ekström / Nucl. Instr. and Meth. in Phys. Res. A 362 (1995) 1–15

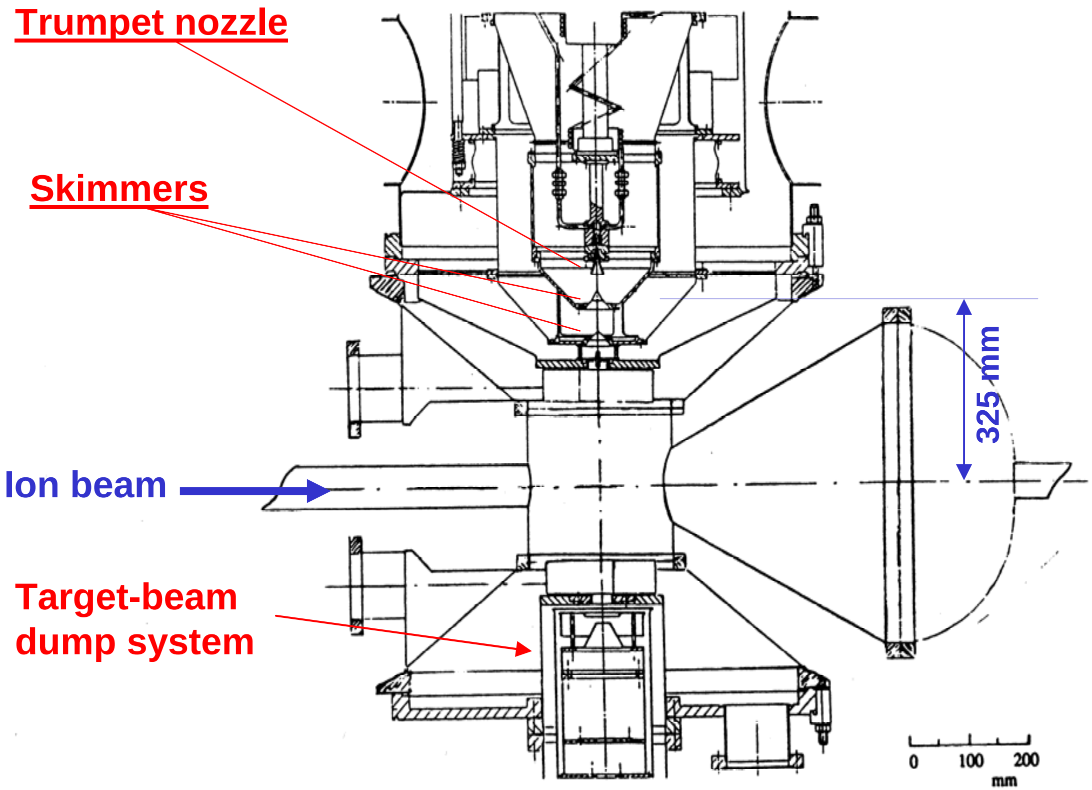


Fig. 2. Vertical cross section of the central part of the cluster-jet target at the CELSIUS ring, showing, in the upper part, the differentially pumped beam source with the cooled nozzle, skimmer and collimators, the wide-angle scattering chamber, and, in the lower part, the cryogenic target-beam dump.

Cluster-beams are formed by pressing a gas through a trumpet-shaped nozzle with temperature and pressure conditions close to the phase transition to liquid

Typical cluster size ~ 10^5 atoms

Effective target thickness (1-2)*10^{14} atoms/cm^2

Introduction

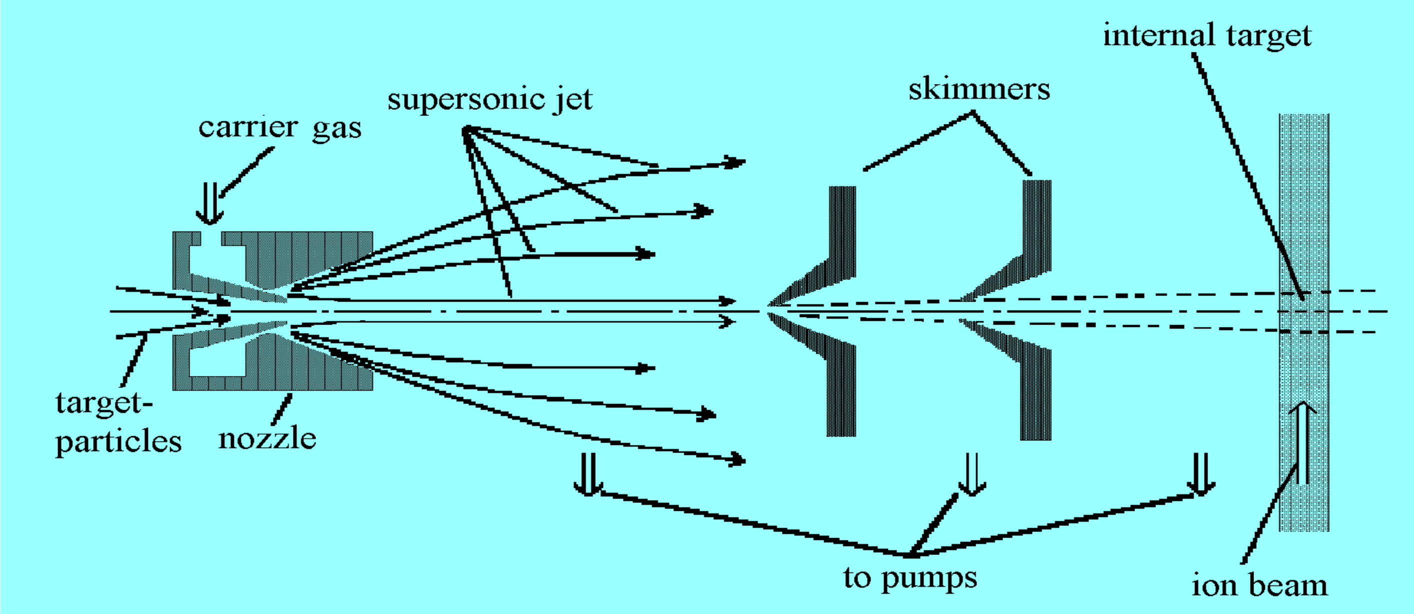
Carrier gas cooling technique

- **Only internal targets from gases (H$_2$, He, D$_2$, N$_2$, Ar, CO$_2$, CH$_4$, Kr, Xe) are now in operation at storage rings.**
- **Our novel method of gas dynamic cooling allows to considerably extend the range of elements are available for internal targets production**

  E.g. see: ***V.L. Varentsov et al., Nucl. Instr. and Meth., A317 (1992) 1***

  V.L. Varentsov et al., Nucl. Instr. and Meth., A352(1995) 542

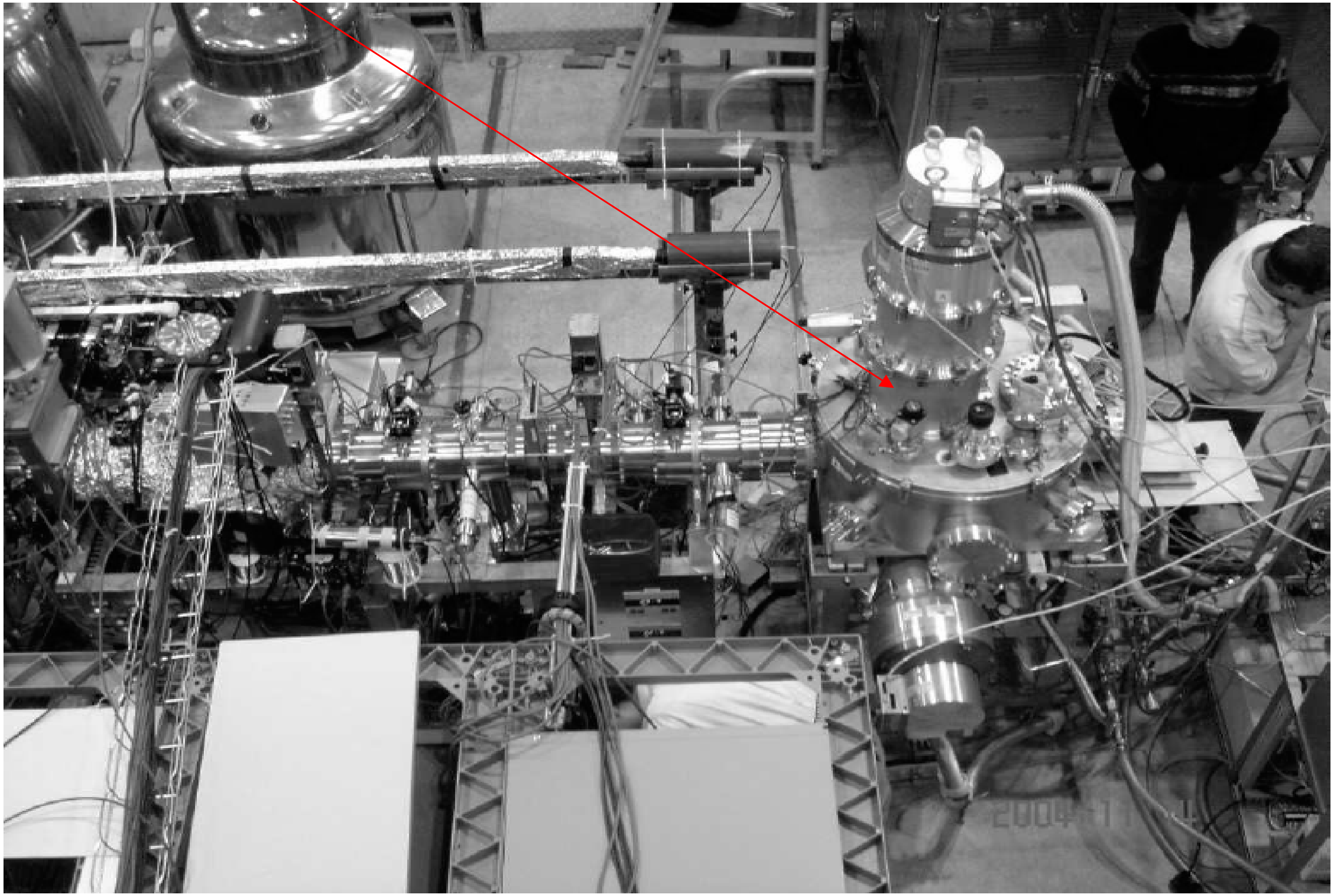
  V.L. Varentsov et al., AIP Conf. Proc., vol. 421,(1997) 381



- **Maybe, it will be reasonable to use this technique also for study pbar-nucleus cross sections at low pbar energies (up to 100KeV)**

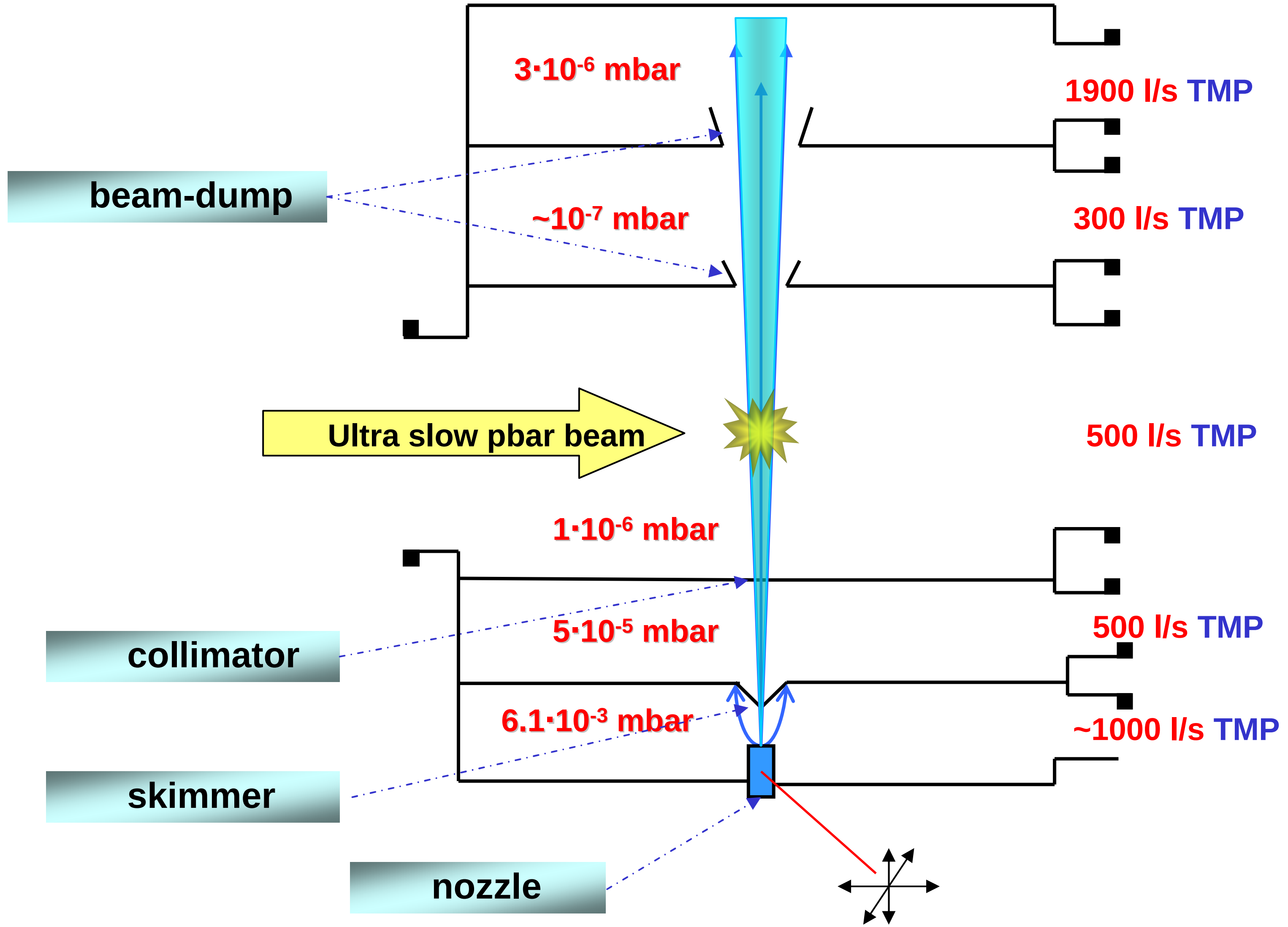
ASAKUSA gas-jet target: ***present status***

Gas-jet target setup connected to the MUSASHI beamline

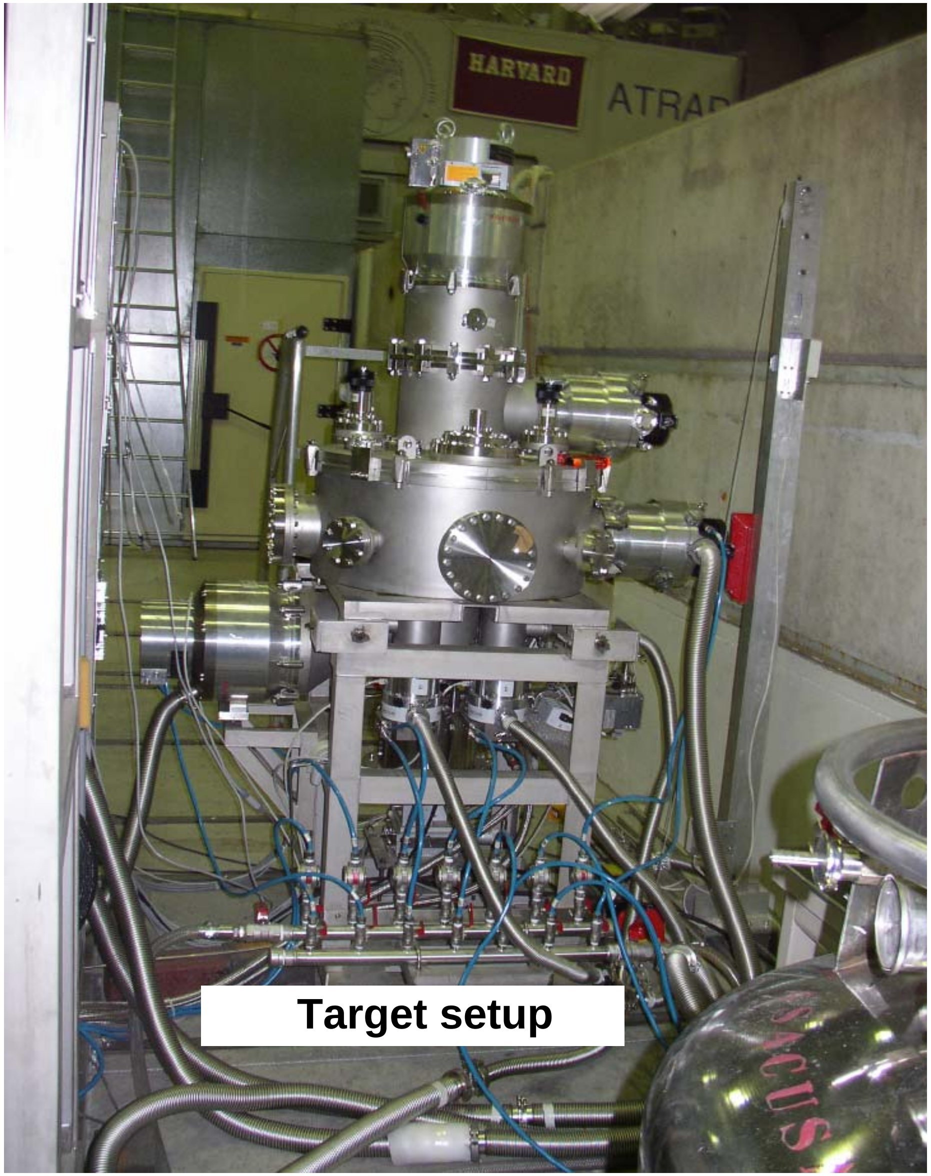


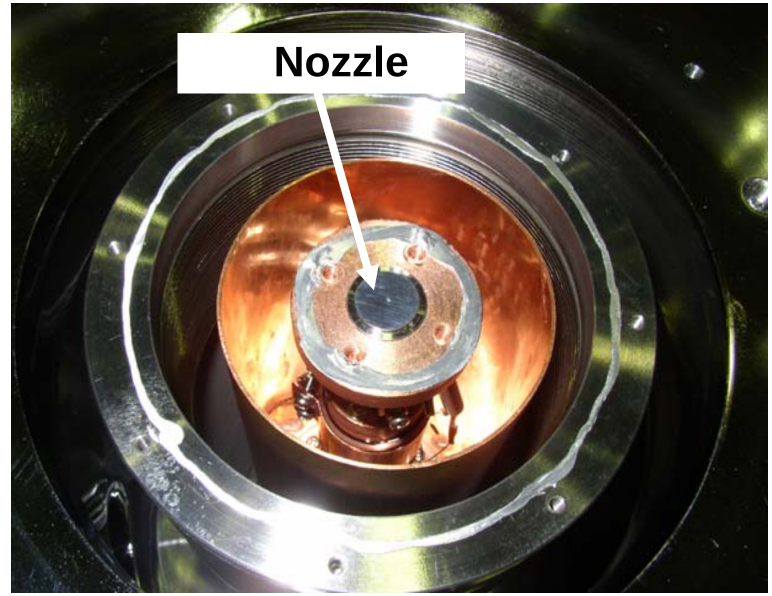
ASAKUSA gas-jet target: *present status*

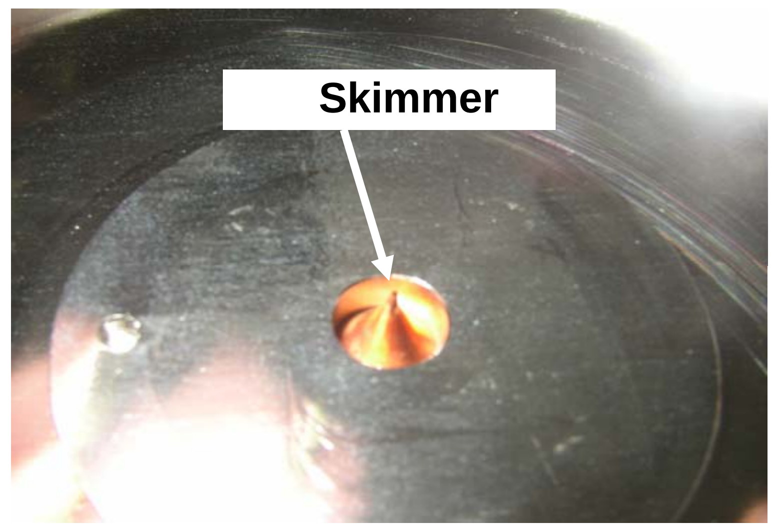
Schematic figure of the gas-jet target



ASACUSA gas-jet target: ***present status***



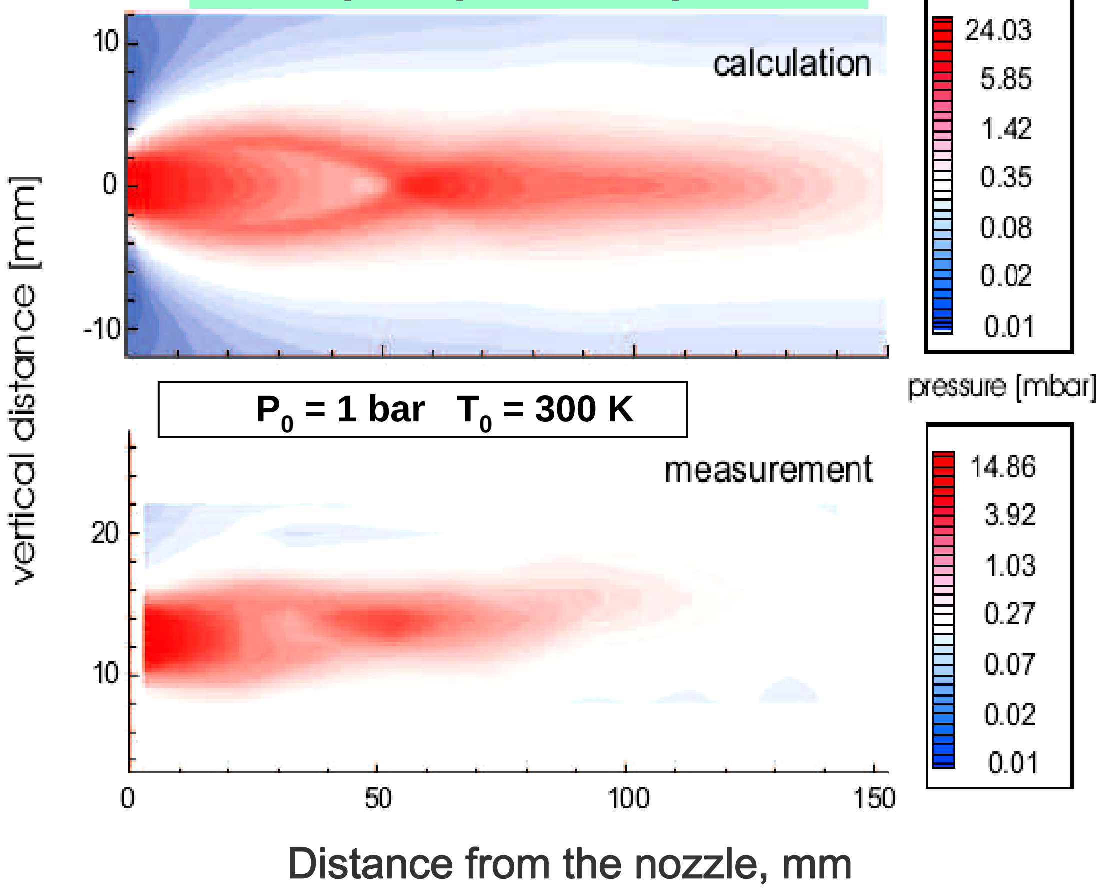




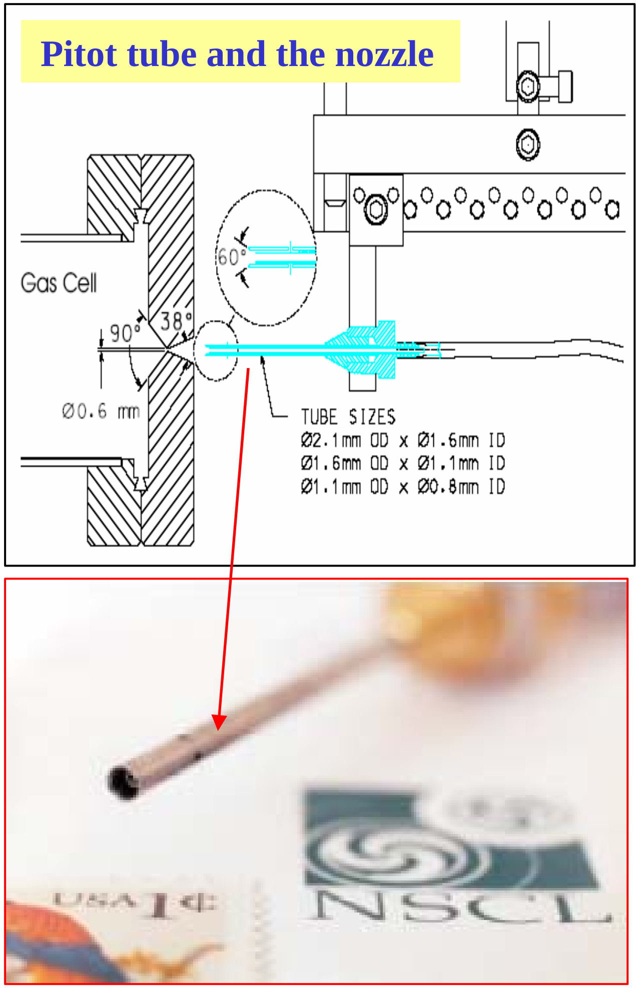
Supersonic Jet measurement and simulation

He supersonic jet from a conical converging-diverging nozzle of NSCL stopping gas cell, Michigan State University, 2001

Impact pressure profile



Pitot tube and the nozzle



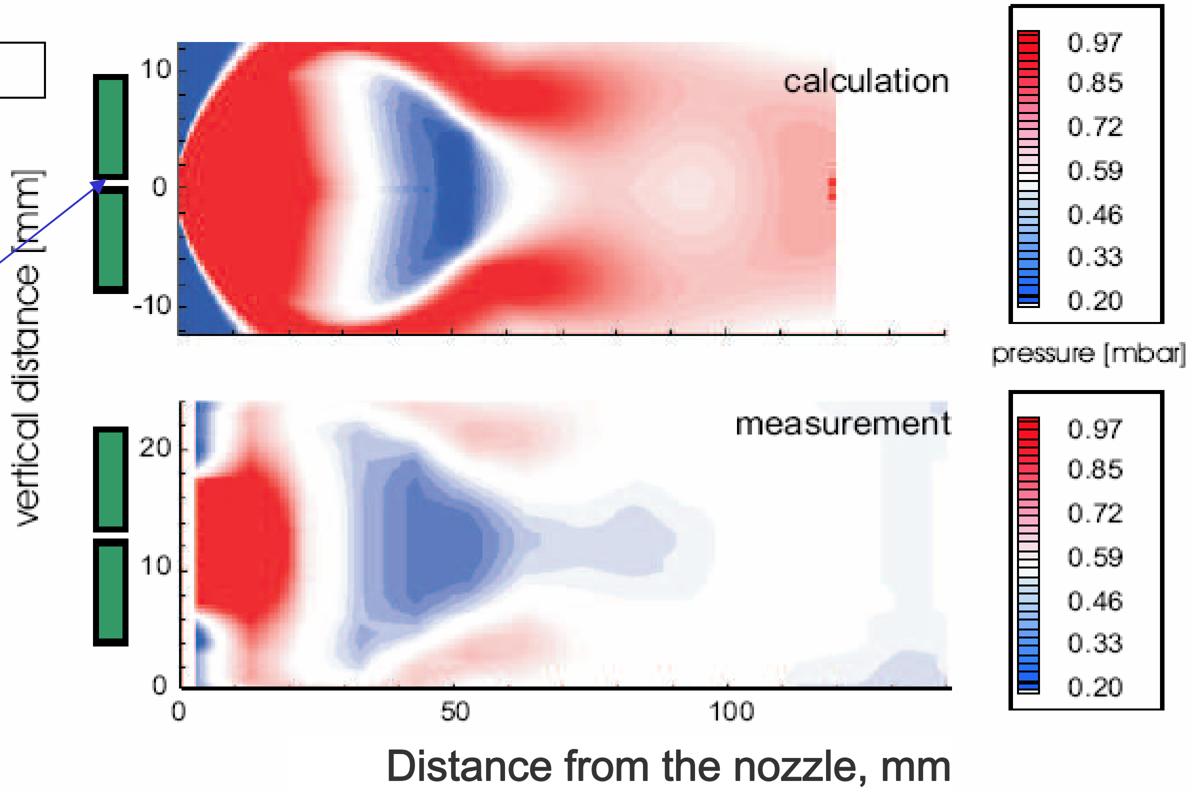
Supersonic Jet measurement and simulation

He supersonic jet from a cylindrical nozzle of NSCL stopping gas cell, Michigan State University, 2001

Impact pressure profile

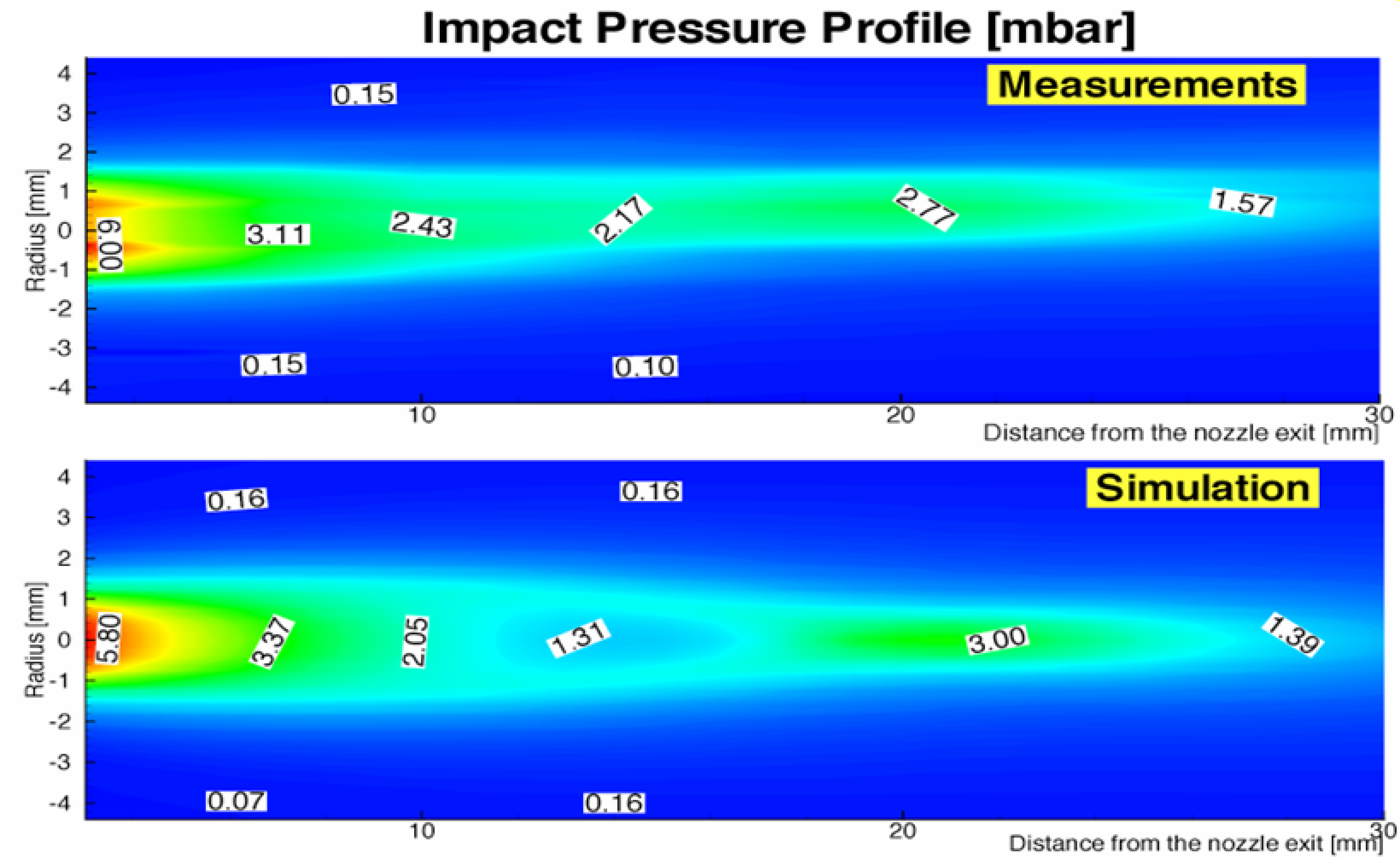
P_0 = 1 bar T_0 = 300 K

Nozzle diameter = 1 mm



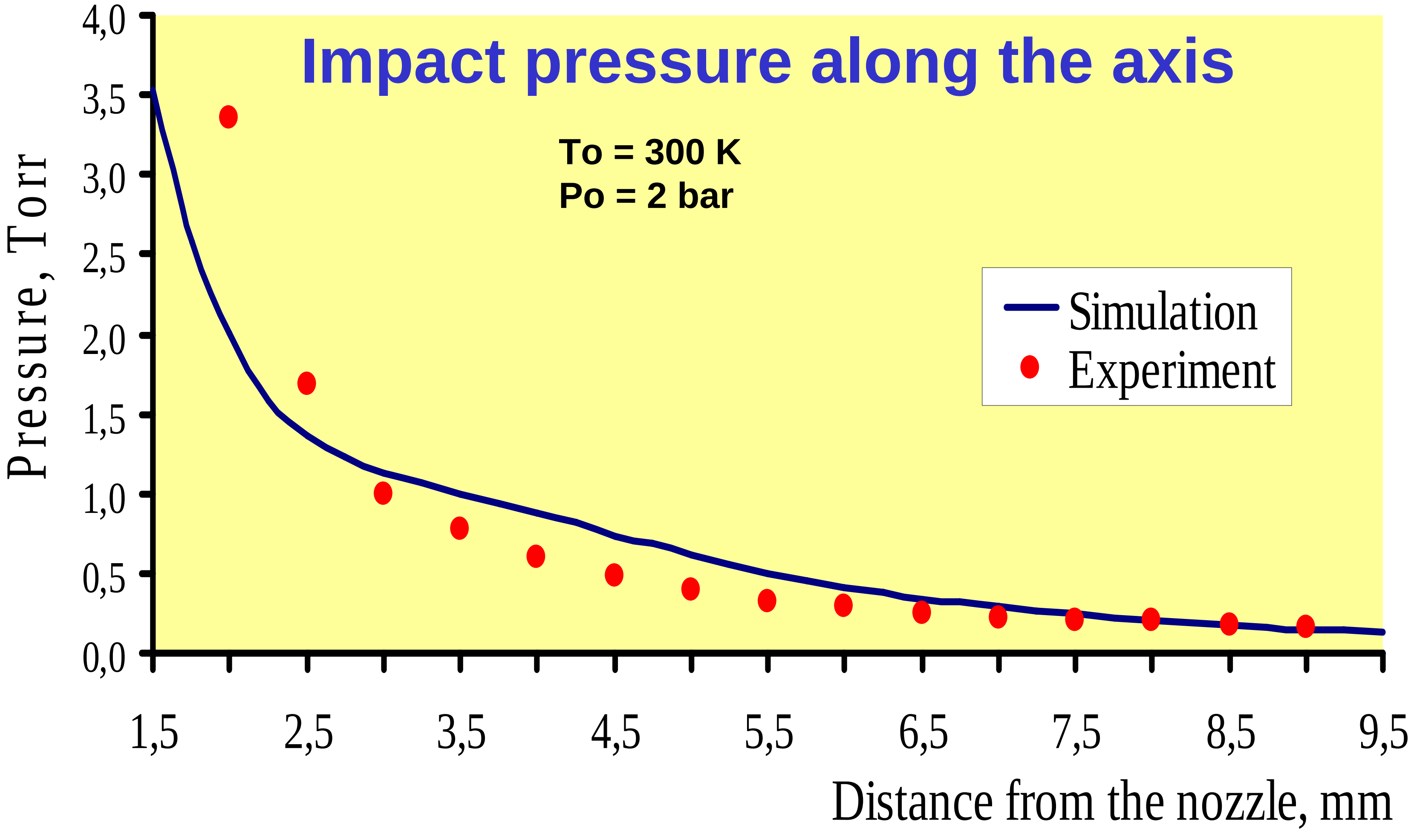
Supersonic Jet measurement and simulation

Supersonic jet from the nozzle of SHIPTRAP stopping gas cell, Munich University, 2000



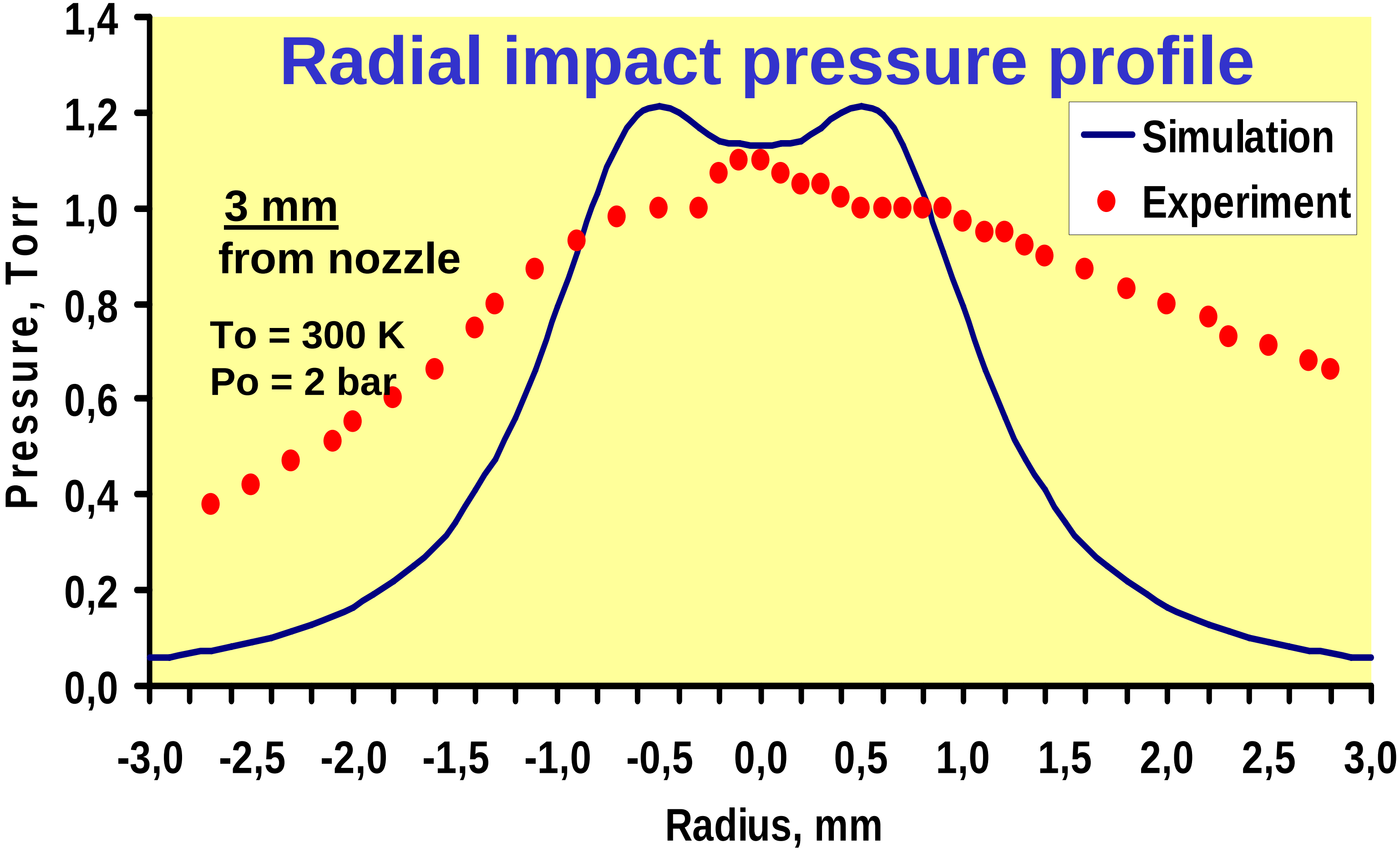
ASAKUSA gas-jet target: ***present status***

Supersonic jet profiles measurements with Pitot tube



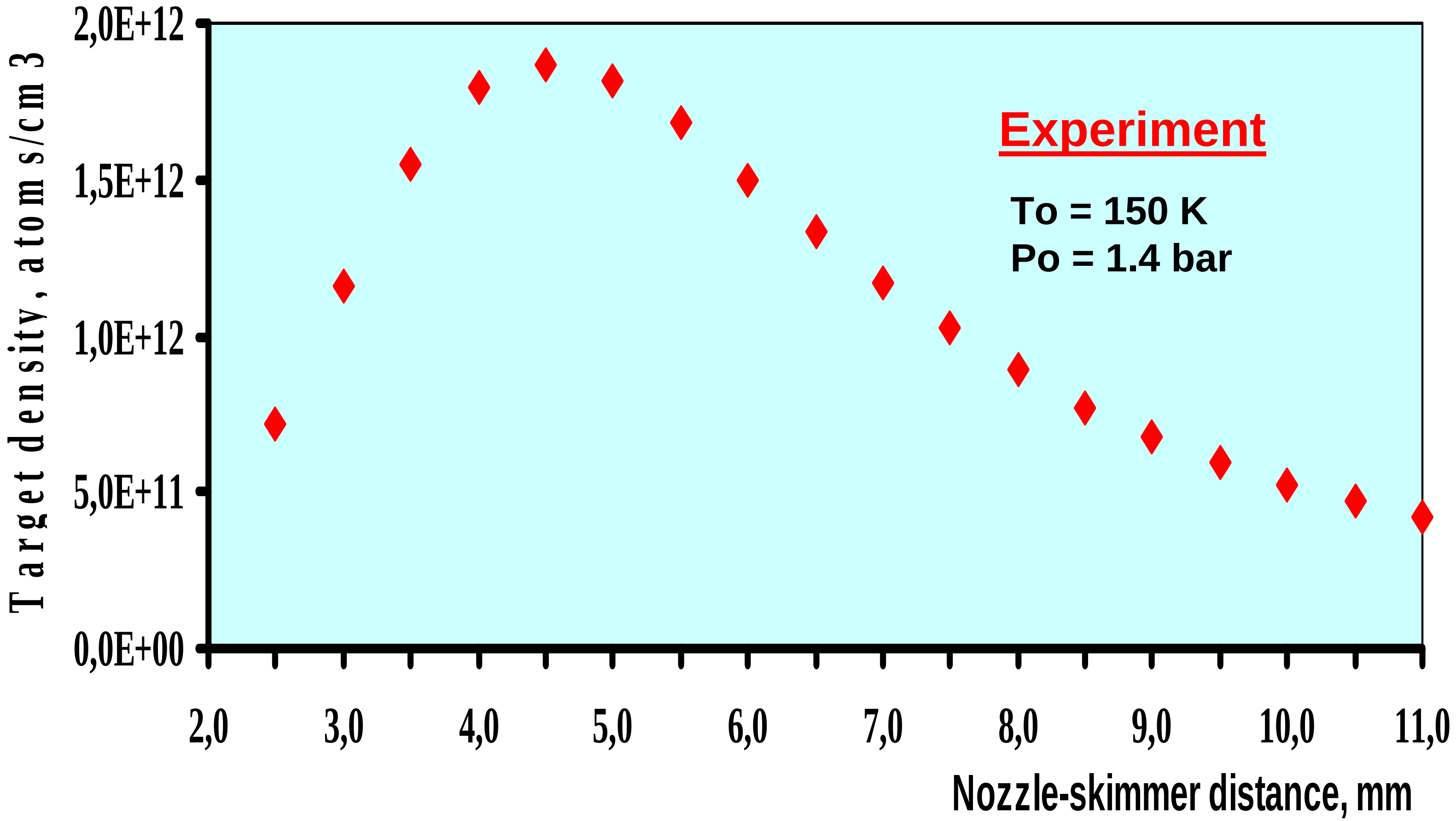
ASAKUSA gas-jet target: *present status*

Supersonic jet profiles measurements with Pitot tube



ASAKUSA gas-jet target: ***present status***

Helium target density as a function of nozzle-skimmer distance



ASAKUSA gas-jet target: ***present status***

Helium supersonic jet simulation

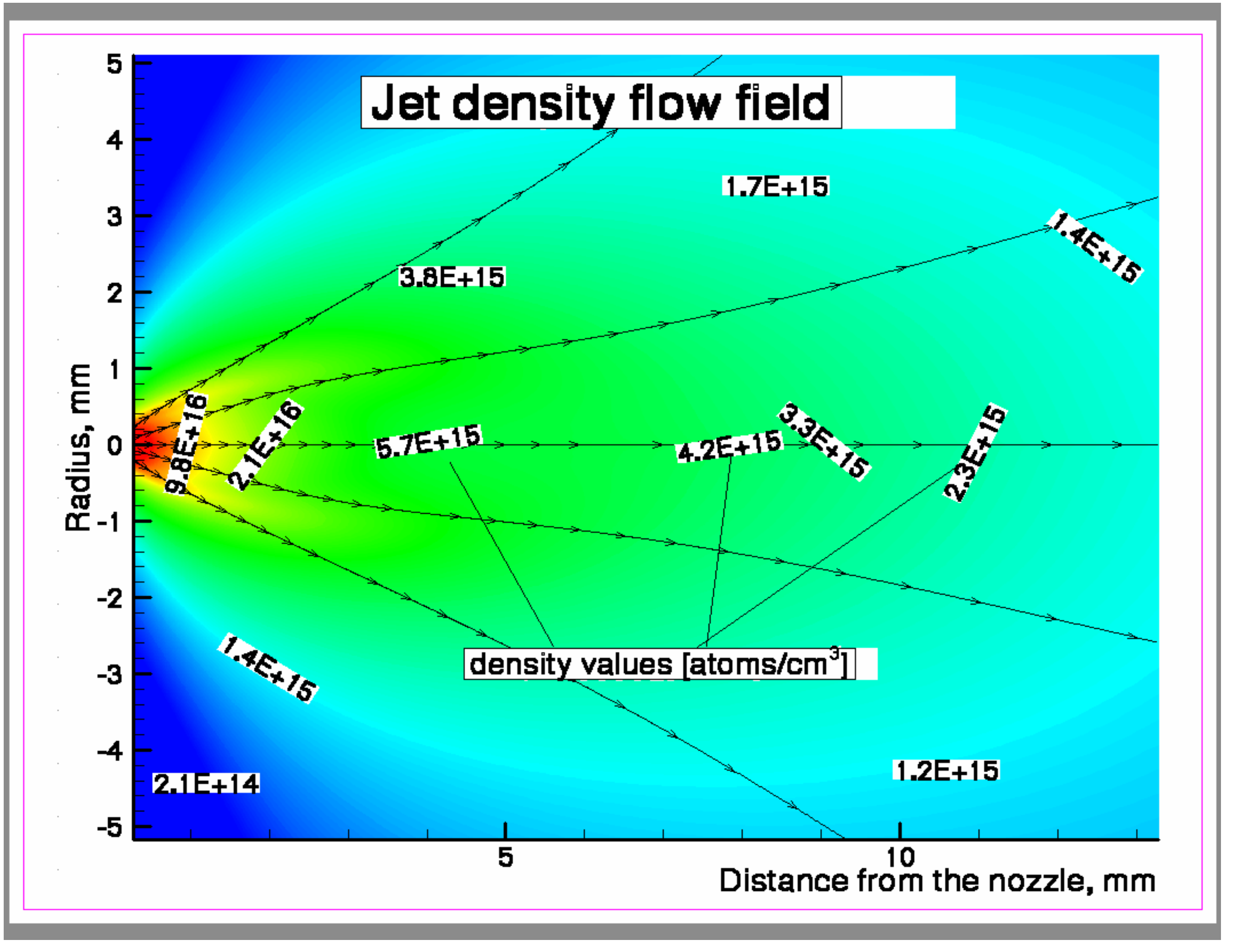
Nozzle diameter = 0.1 mm

Po = 1.41 bar
To = 150 K

Pumping speed
1076 l/s

Gas flow rate
6.6 mbar l/s

Ambient pressure
6.1∗10^{-3} mbar



ASAKUSA gas-jet target: *present status*

Main target design and operation parameters

Nozzle and skimmer geometry

Nozzle diameter	0.1 mm
Skimmer diameter	0.6 mm
Collimator	2.2x4.4 mm
Nozzle-skimmer distance	4 mm
Collimator-skimmer distance	35 mm

He gas flow and pumping conditions

Stagnation pressure	Po = 1.41 bar
Stagnation temperature	To = 150 K
Ambient pressure	$Pa = 6*10^{-3}$ mbar
Gas flow rate	6.6 mbar l/s
Effective pumping speed	1076 l/s

He gas-jet parameters at skimmer entrance

Velocity	1190 m/s
Temperature	13.1 K
Mach number	5.9
Density	$5.7*10^{15}$ atoms/cm^3

Calculated target density

$1.8*10^{12}$ atoms/cm^3

Target cross section 5x10 mm

⇓

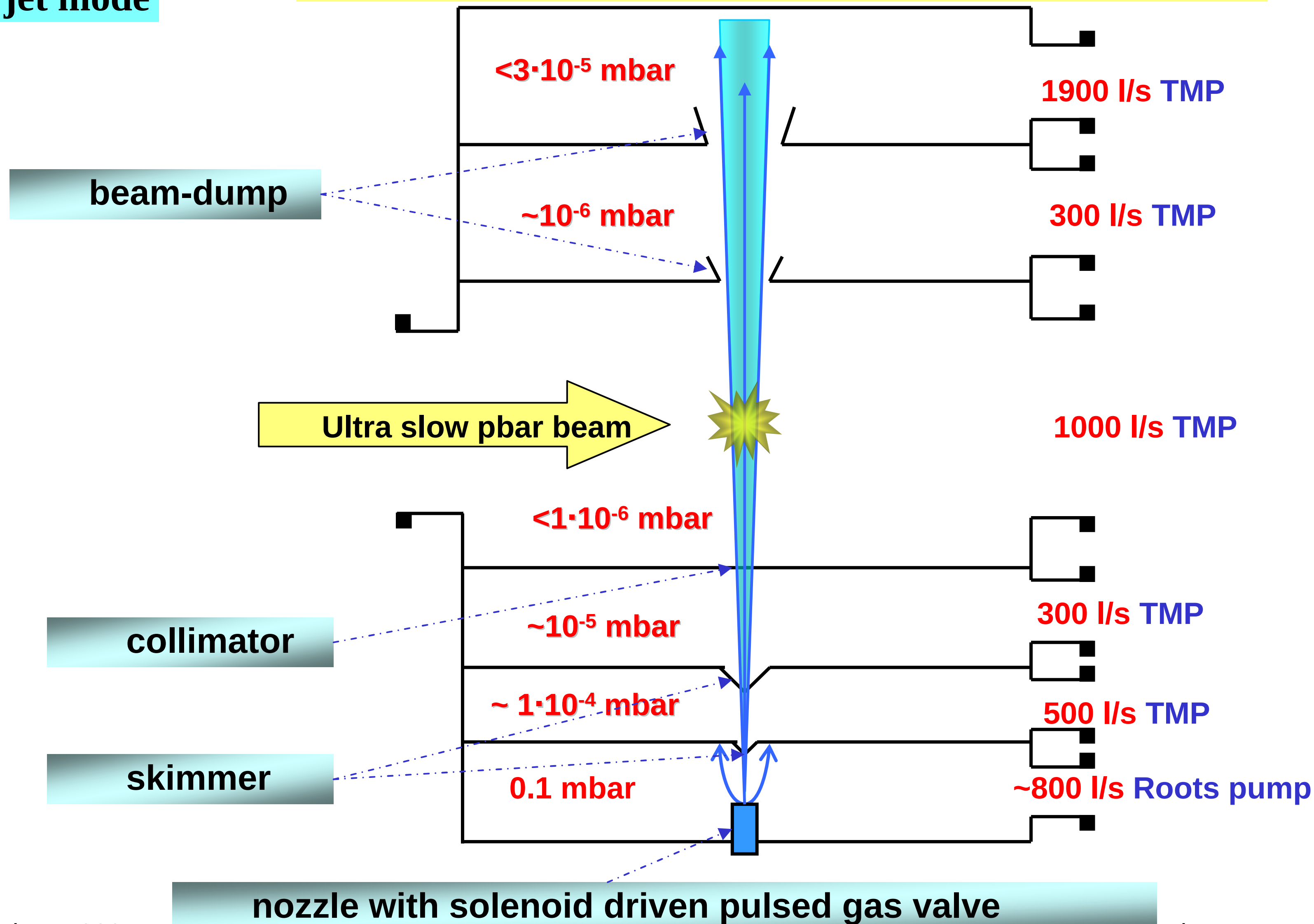
Target thickness

$1.8*10^{12}$ atoms/cm^2

ASAKUSA gas-jet target: ***future development***

Schematic figure of the gas-jet target

Pulsed jet mode



ASAKUSA gas-jet target: ***future development***

Helium supersonic jet simulation

Pulsed jet mode

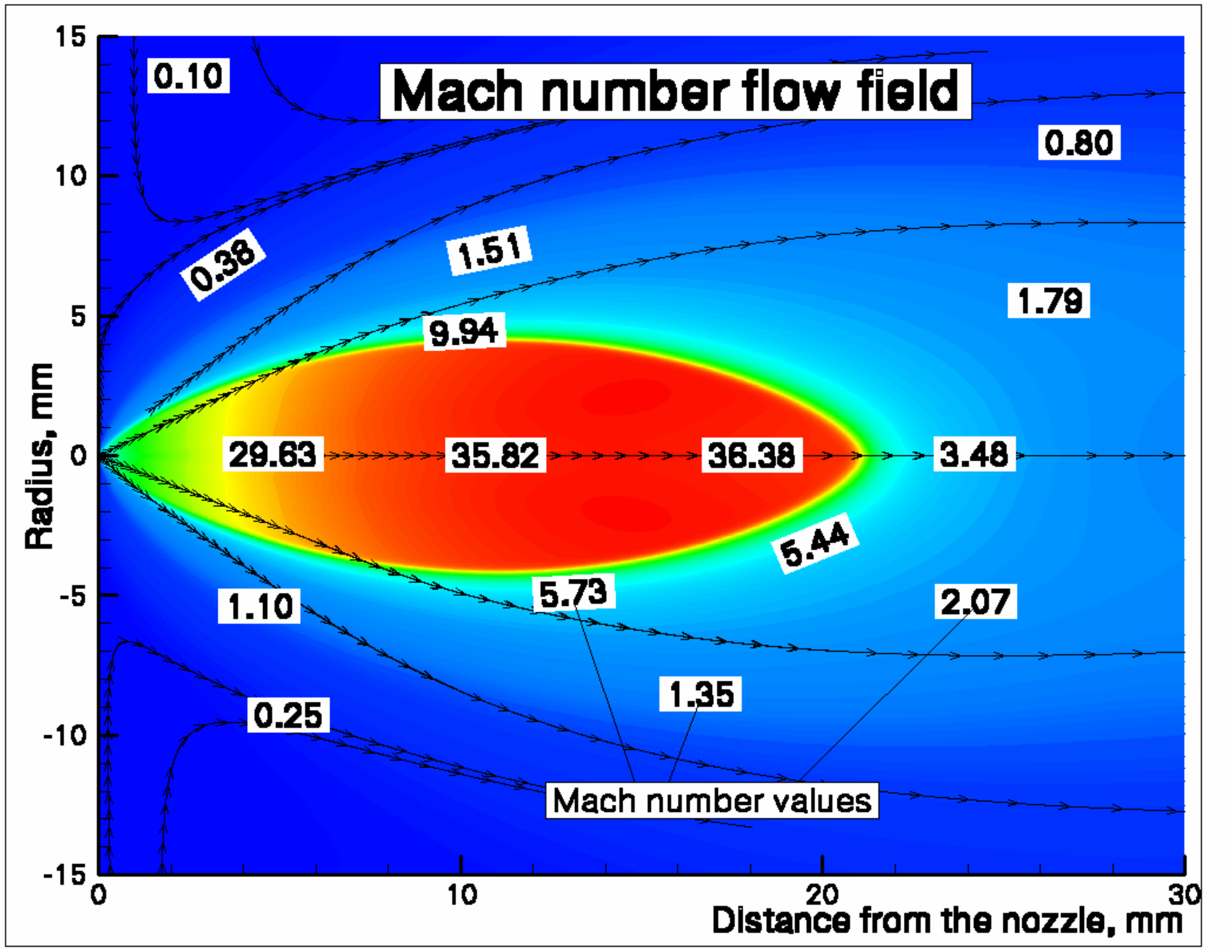
Nozzle diameter = 0.1 mm

Po = 22.6 bar
To = 300 K

Roots pump
875 l/s

Pulse gas flow rate
78.5 mbar l/s

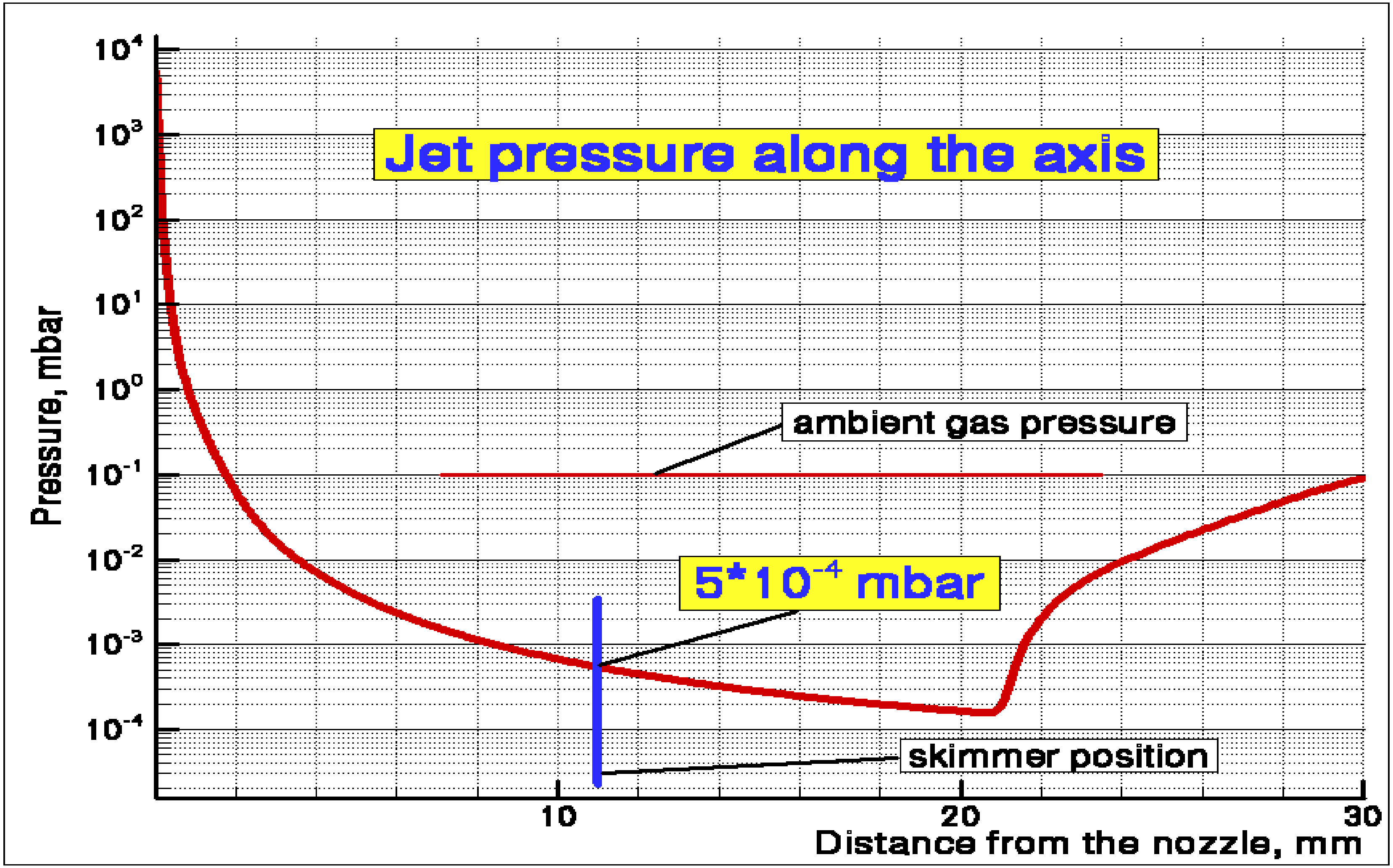
Ambient pressure
0.1 mbar



ASAKUSA gas-jet target: ***future development***

Pulsed jet mode

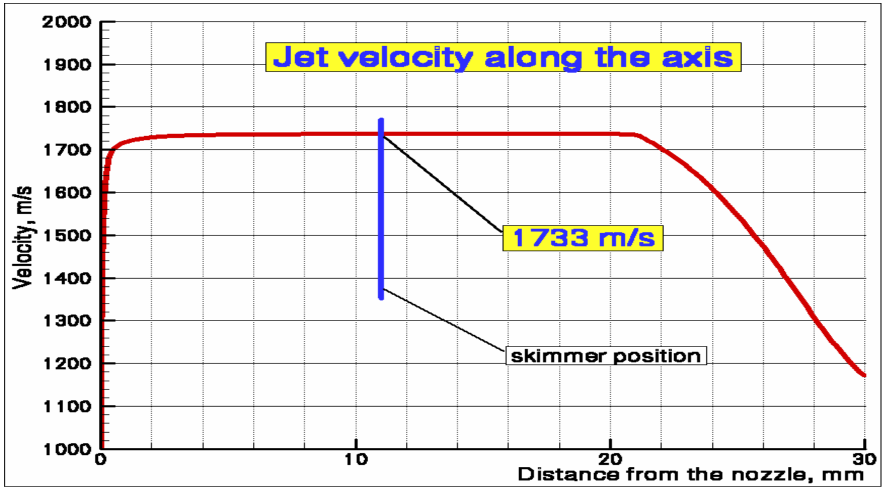
Helium supersonic jet simulation

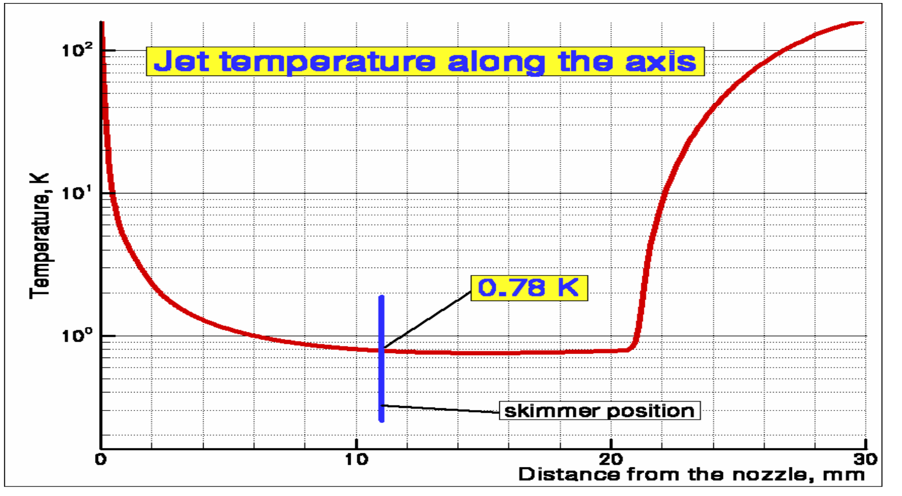


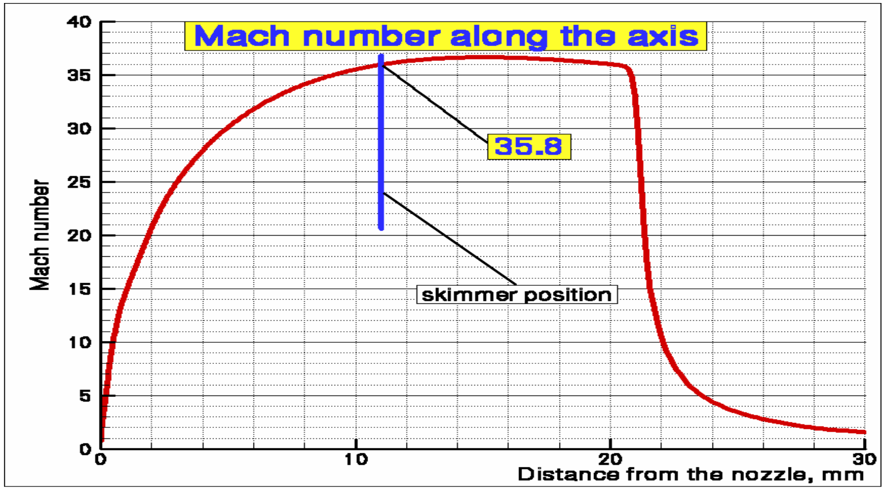
ASAKUSA gas-jet target: *future development*

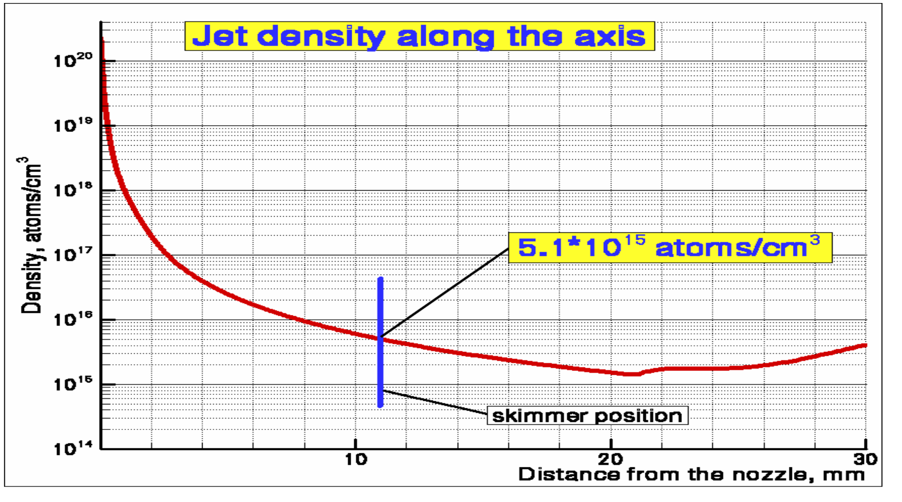
Pulsed jet mode

Helium supersonic jet simulation









ASAKUSA gas-jet target: *future development*

Main target design and operation parameters

Pulsed jet mode

Nozzle and skimmer geometry

Nozzle diameter	0.1 mm
1st skimmer diameter	0.6 mm
2nd skimmer diameter	2.2 mm
Collimator	2.2x4.4 mm
Nozzle-skimmer distance	11 mm
Skimmer-skimmer distance	25 mm
Collimator-skimmer distance	35 mm

He gas flow and pumping conditions

Stagnation pressure	Po = 22.6 bar
Stagnation temperature	To = 300 K
Ambient pressure	Pa = 0.1 mbar
Pulse gas flow rate	78.5 mbar l/s
Effective pumping speed	785 l/s

He gas-jet parameters at skimmer entrance

Velocity	1733 m/s
Temperature	0.78 K
Mach number	35.8
Density	$5.1 * 10^{15}$ atoms/cm^3

Calculated target density

$3.0 * 10^{13}$ atoms/cm^3

Target cross section 4x8 mm

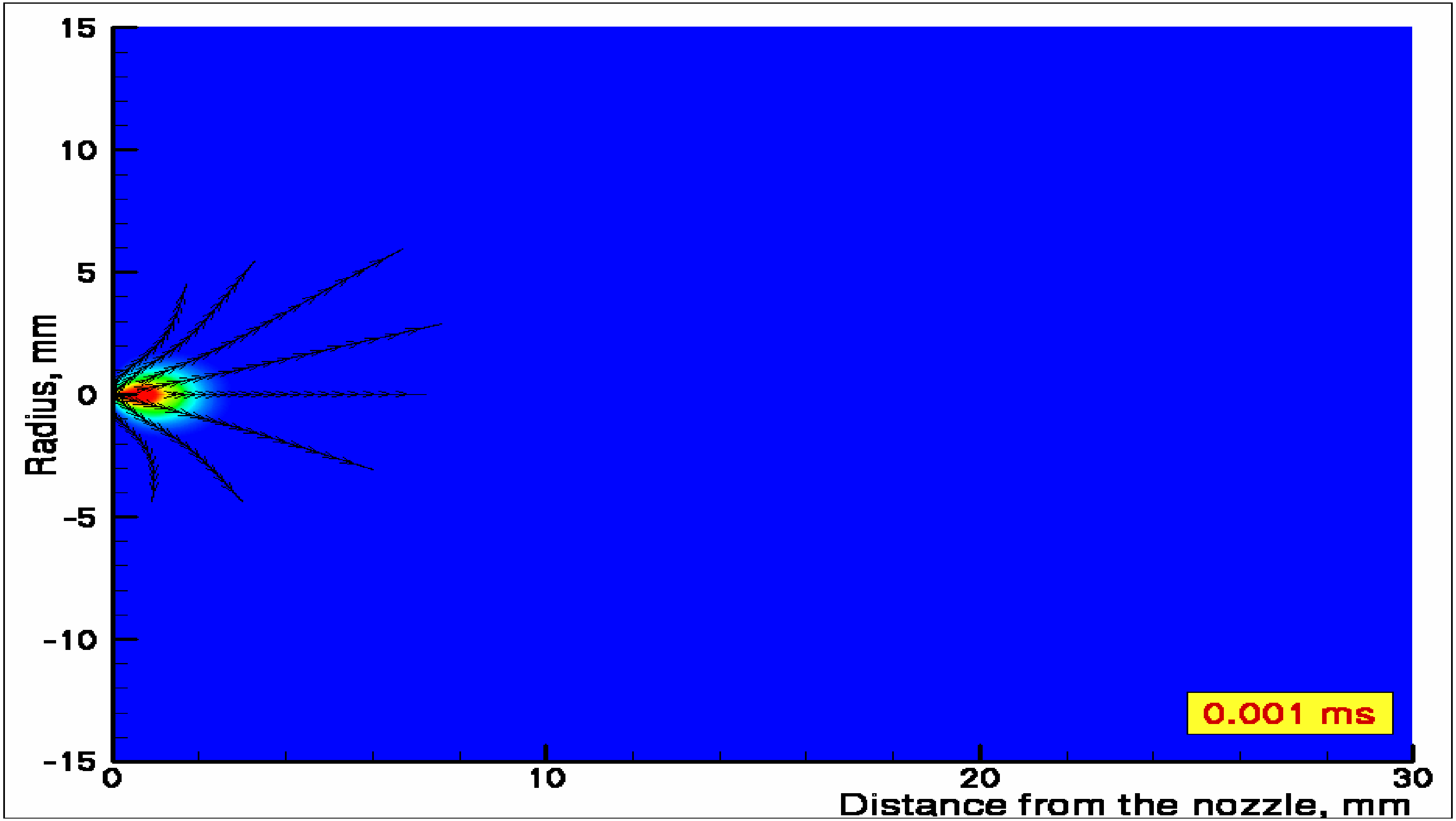
⇓

He target thickness

$2.4 * 10^{13}$ atoms/cm^2

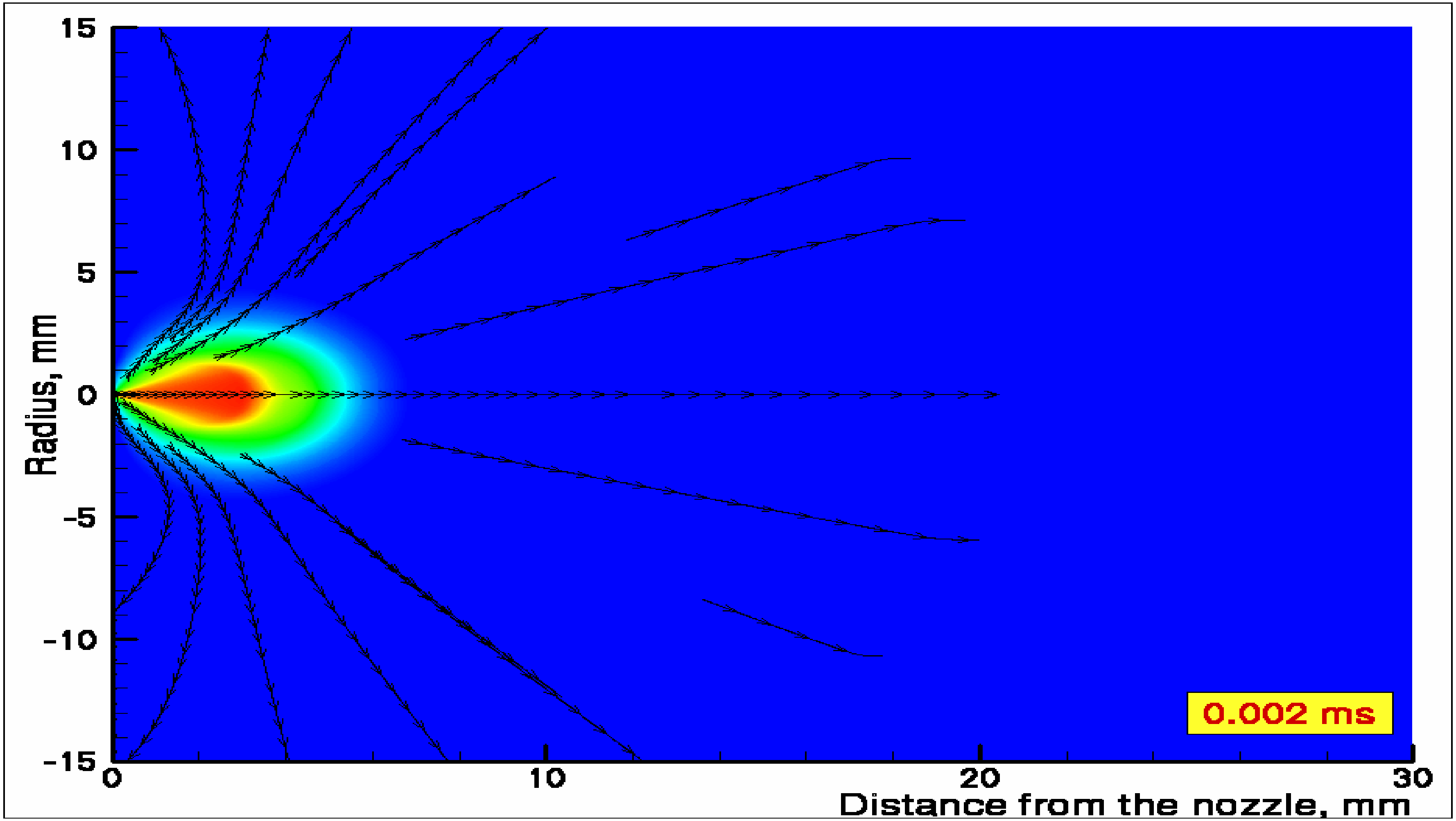
Gas-jet pulse development

Helium gas-jet velocity profile



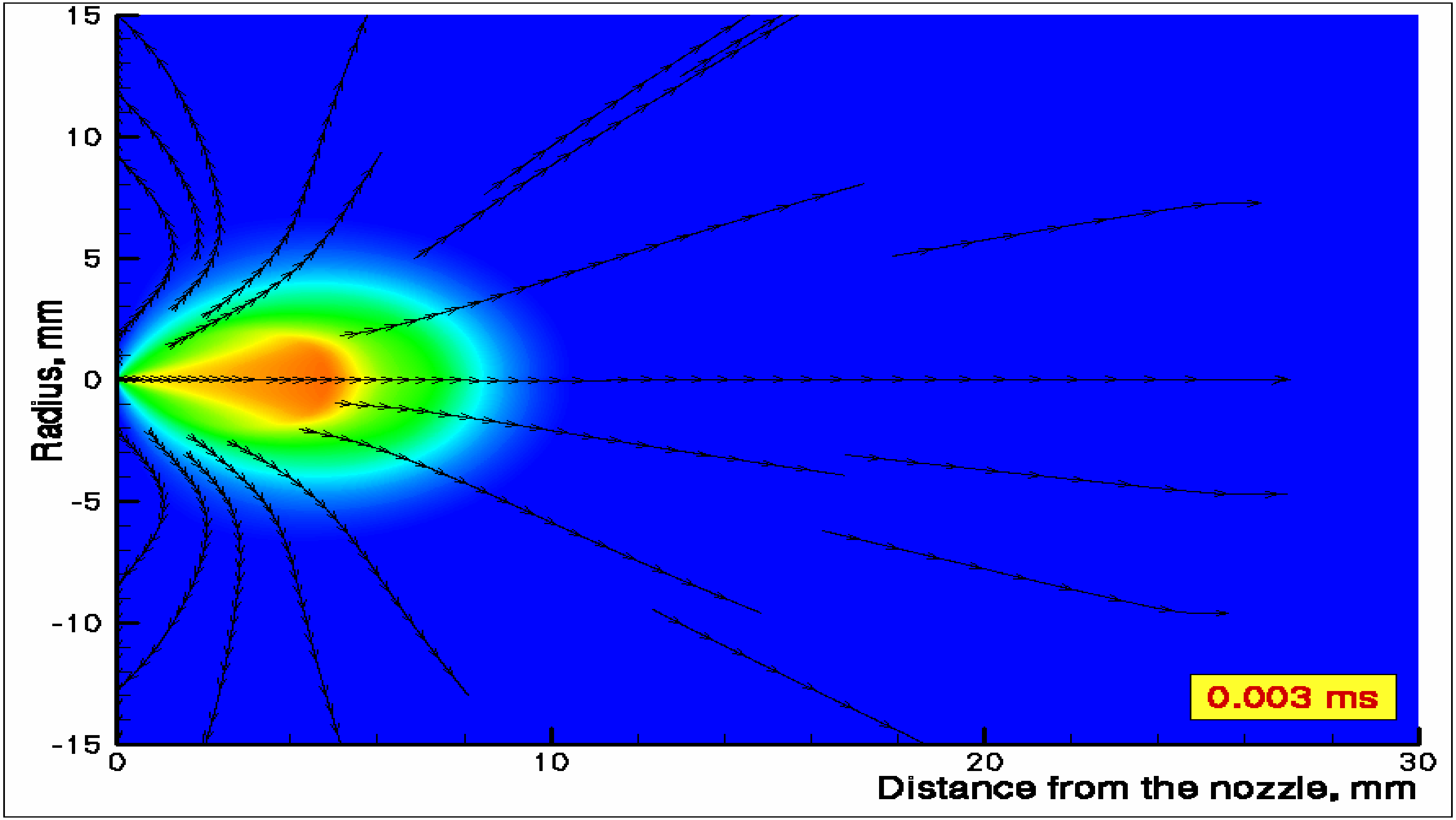
Gas-jet pulse development

Helium gas-jet velocity profile



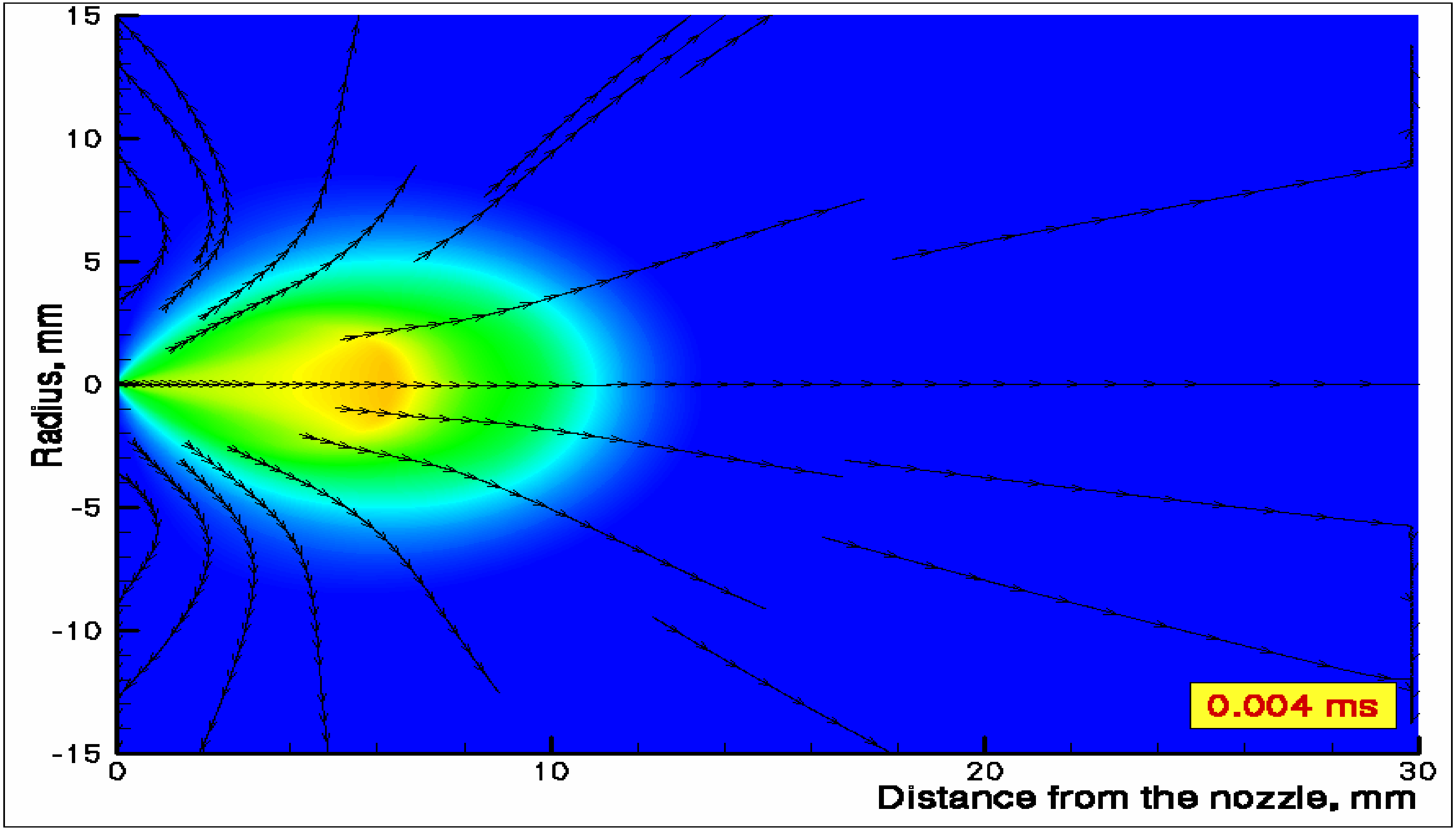
Gas-jet pulse development

Helium gas-jet velocity profile



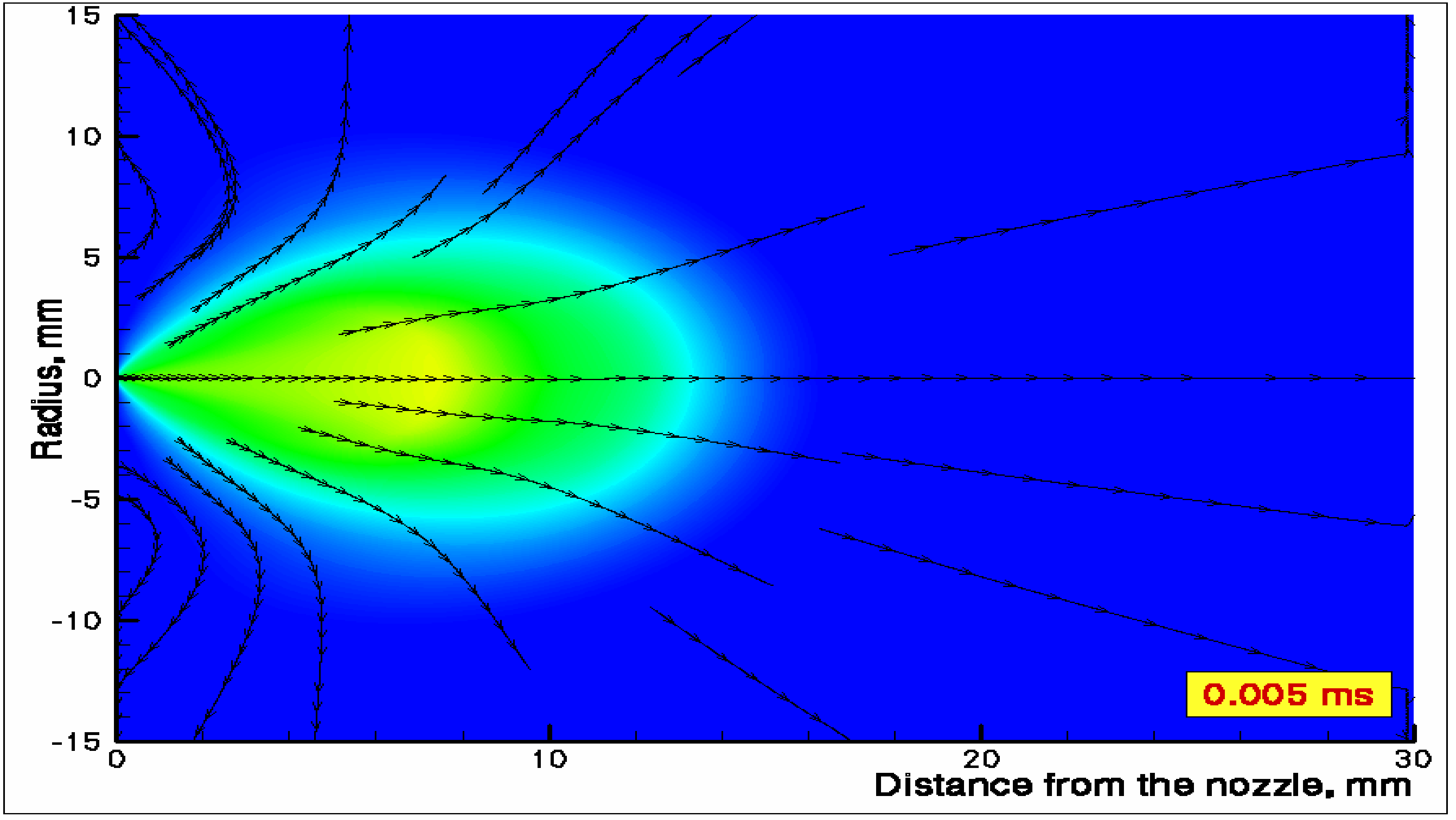
Gas-jet pulse development

Helium gas-jet velocity profile



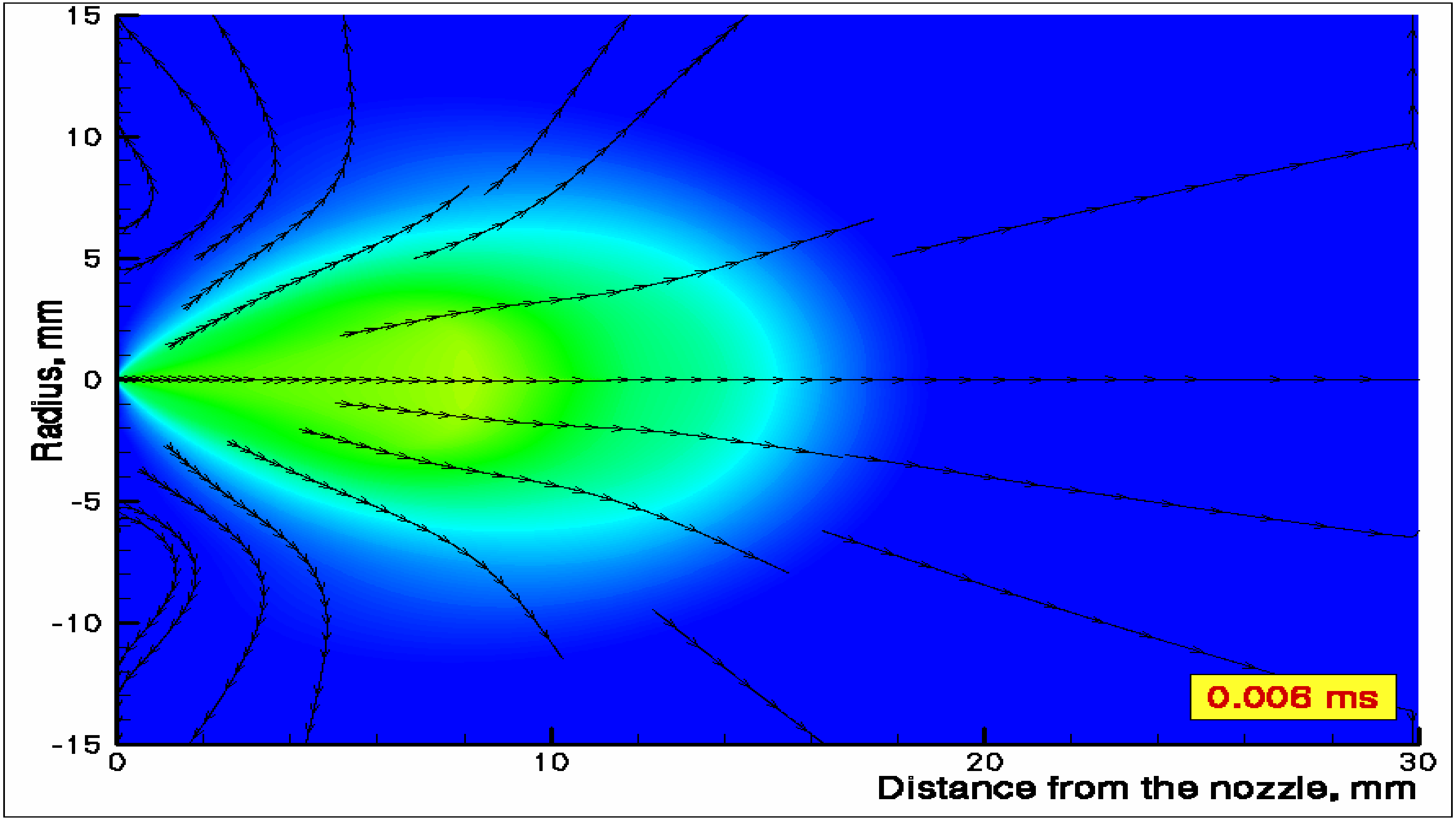
Gas-jet pulse development

Helium gas-jet velocity profile



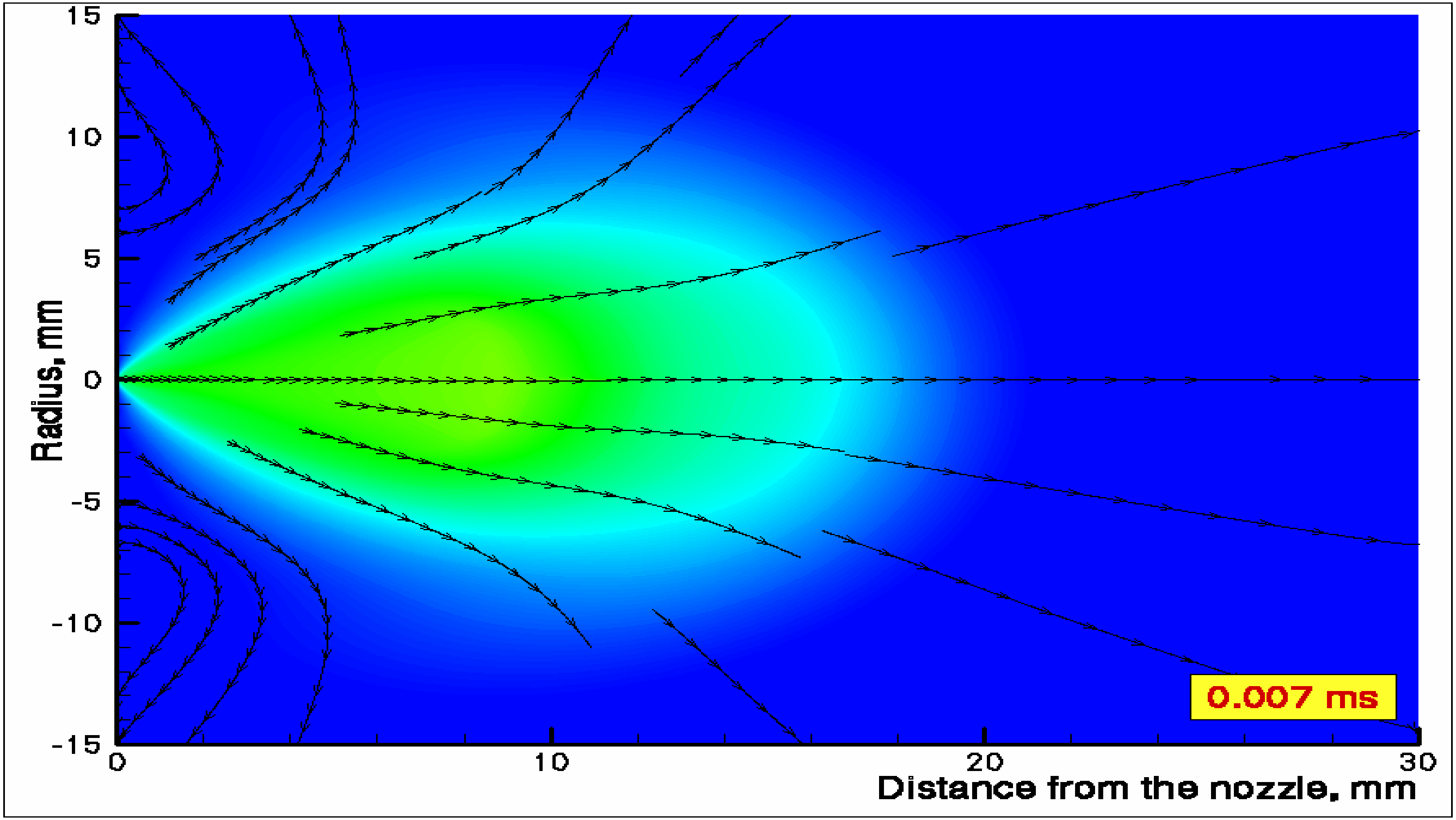
Gas-jet pulse development

Helium gas-jet velocity profile



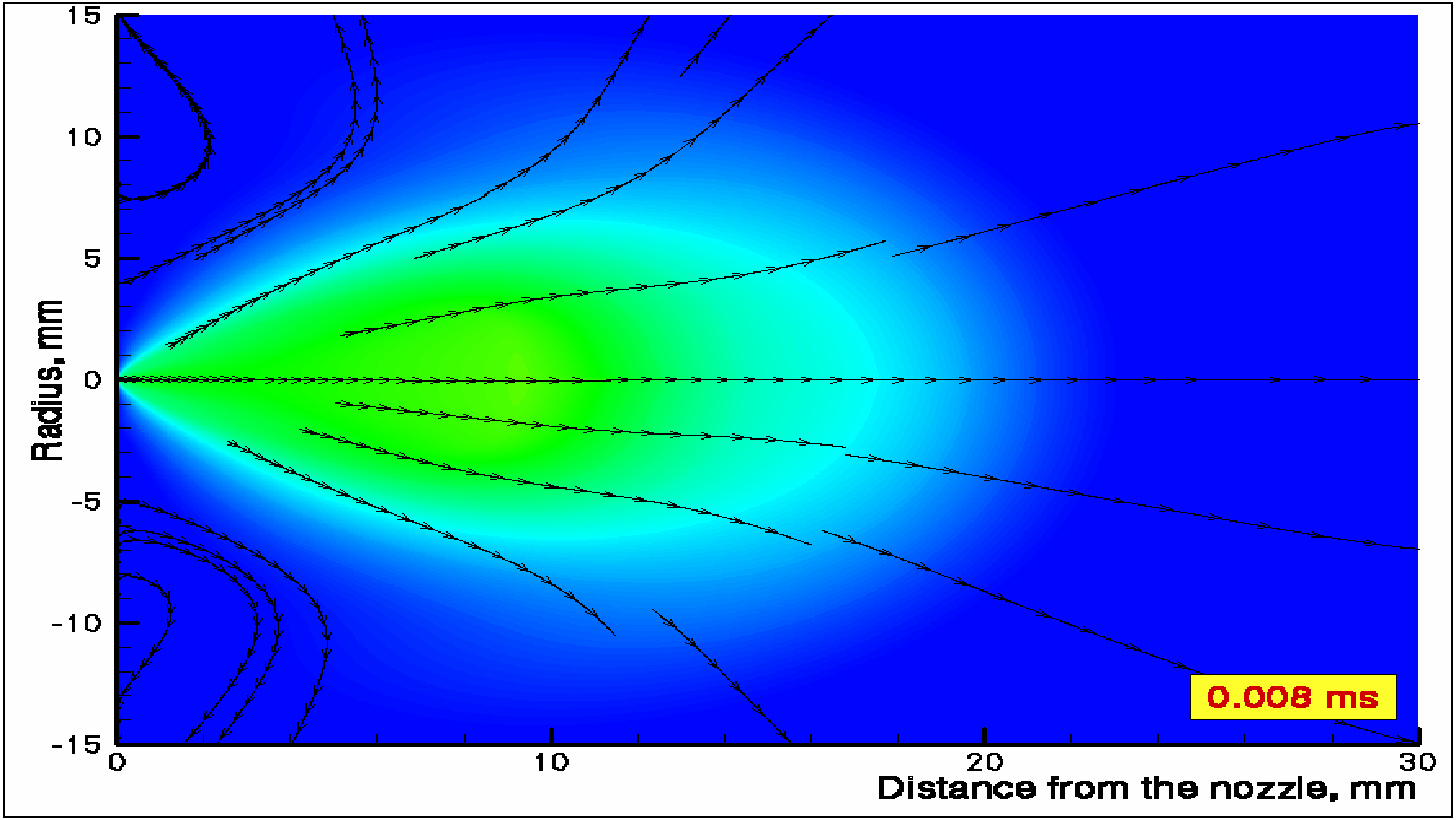
Gas-jet pulse development

Helium gas-jet velocity profile



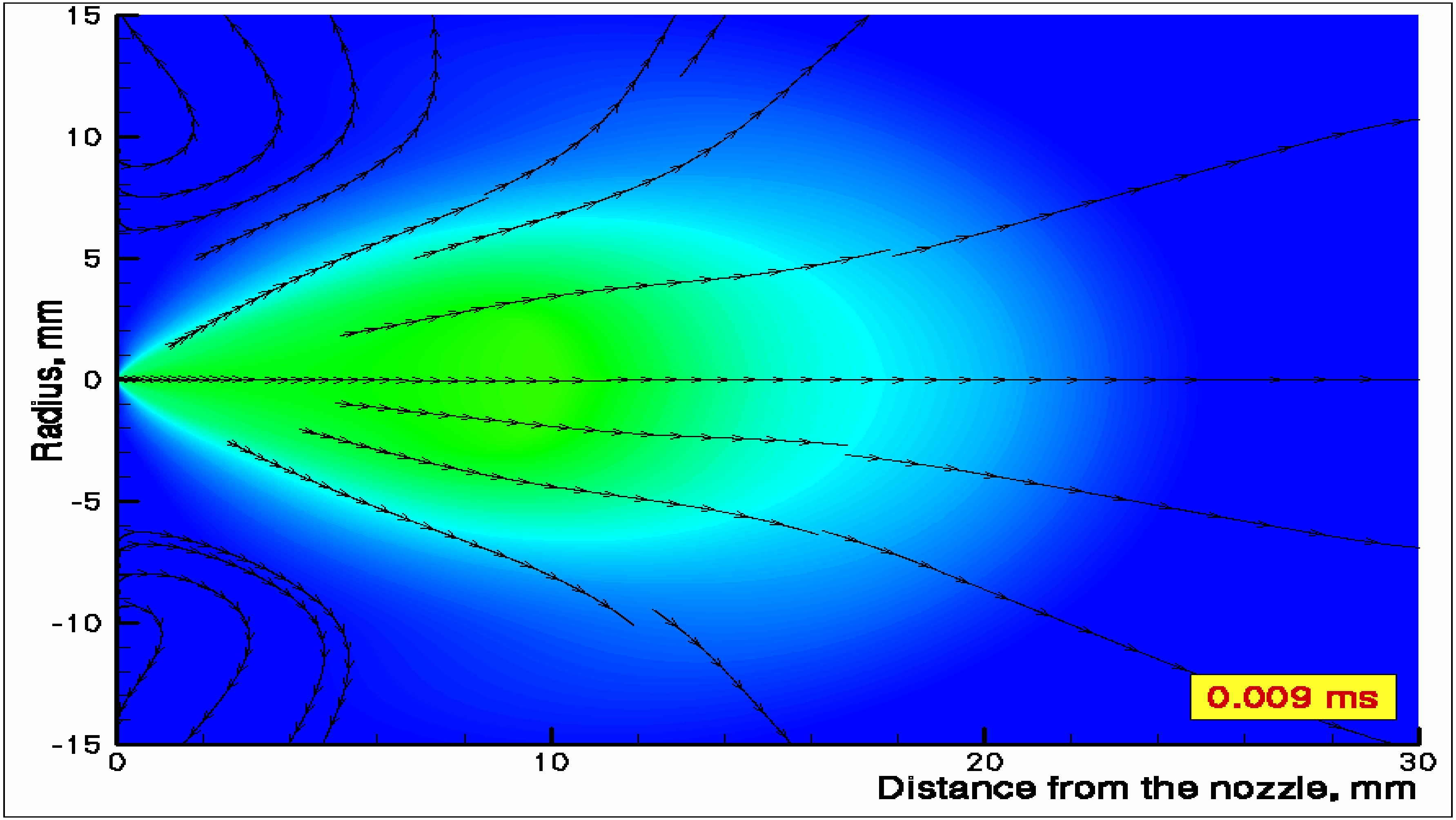
Gas-jet pulse development

Helium gas-jet velocity profile



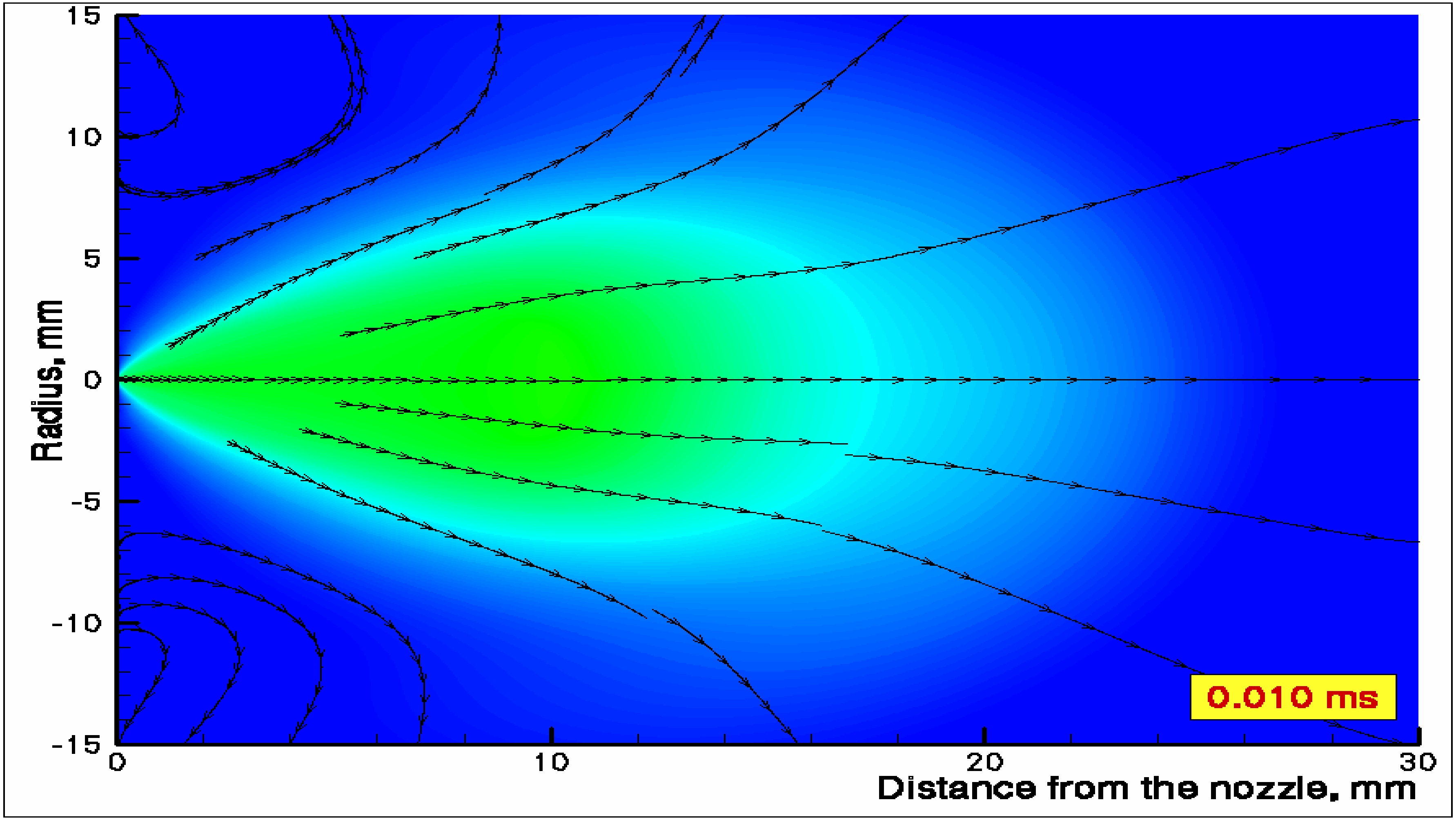
Gas-jet pulse development

Helium gas-jet velocity profile



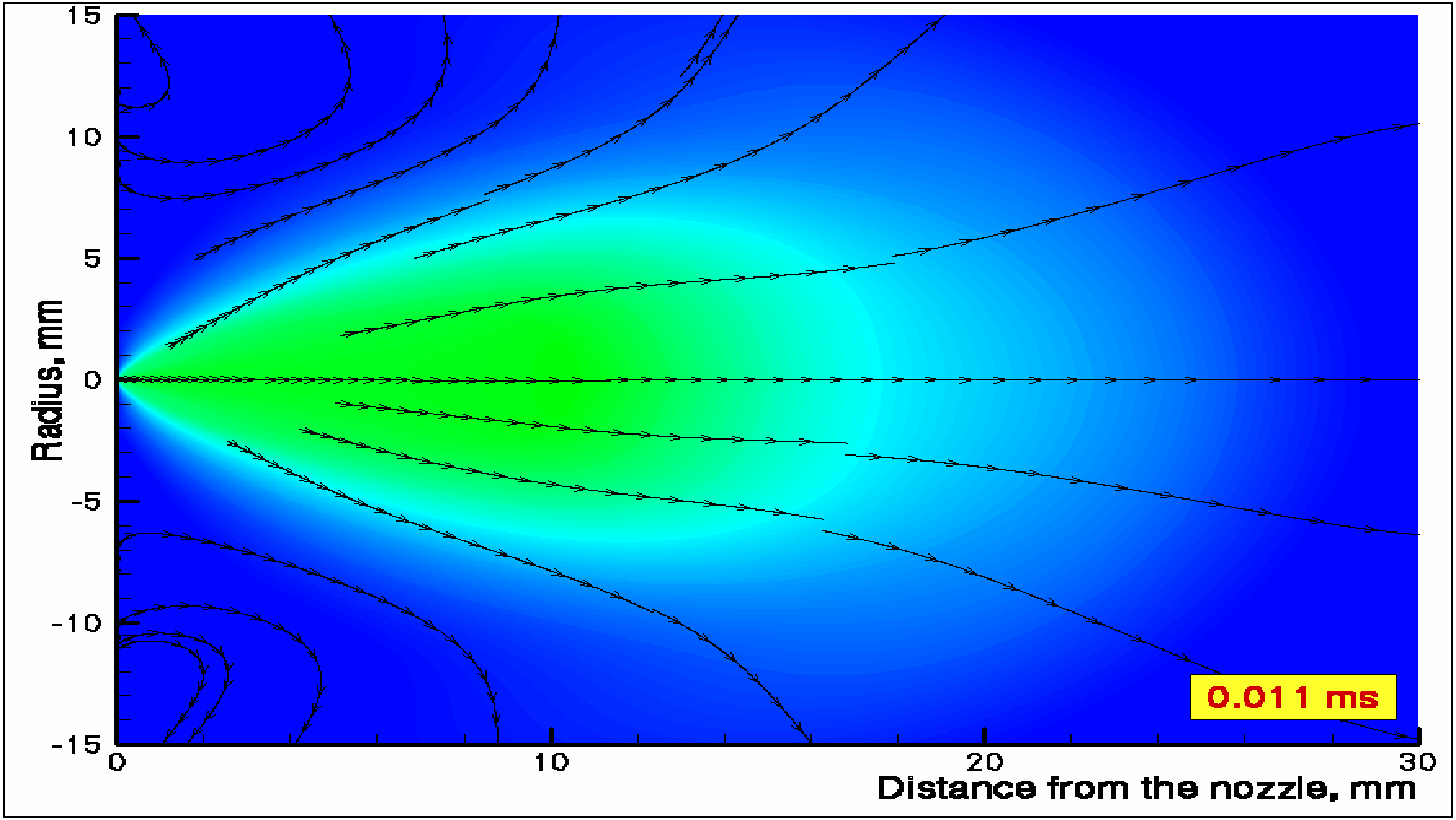
Gas-jet pulse development

Helium gas-jet velocity profile



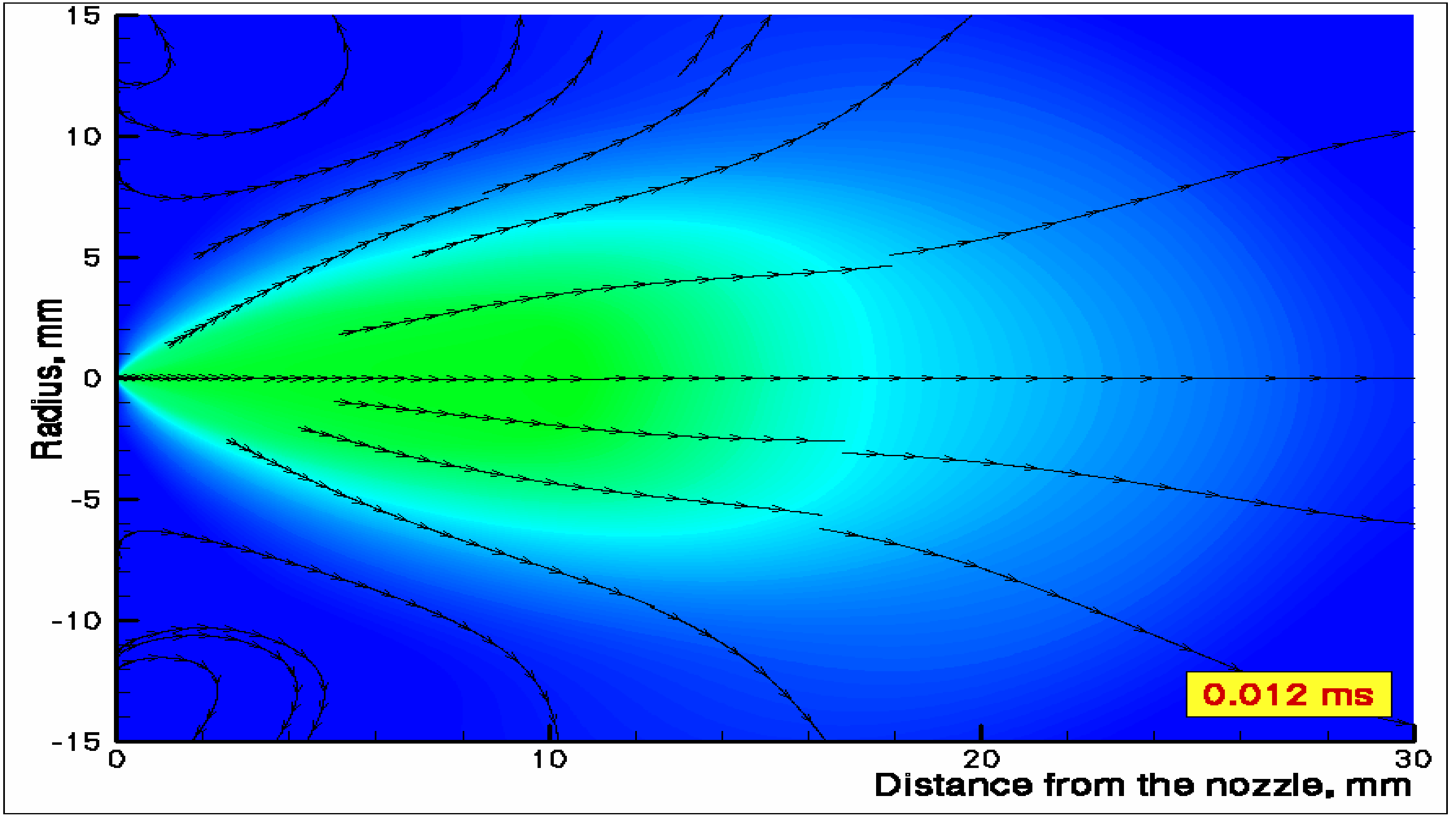
Gas-jet pulse development

Helium gas-jet velocity profile



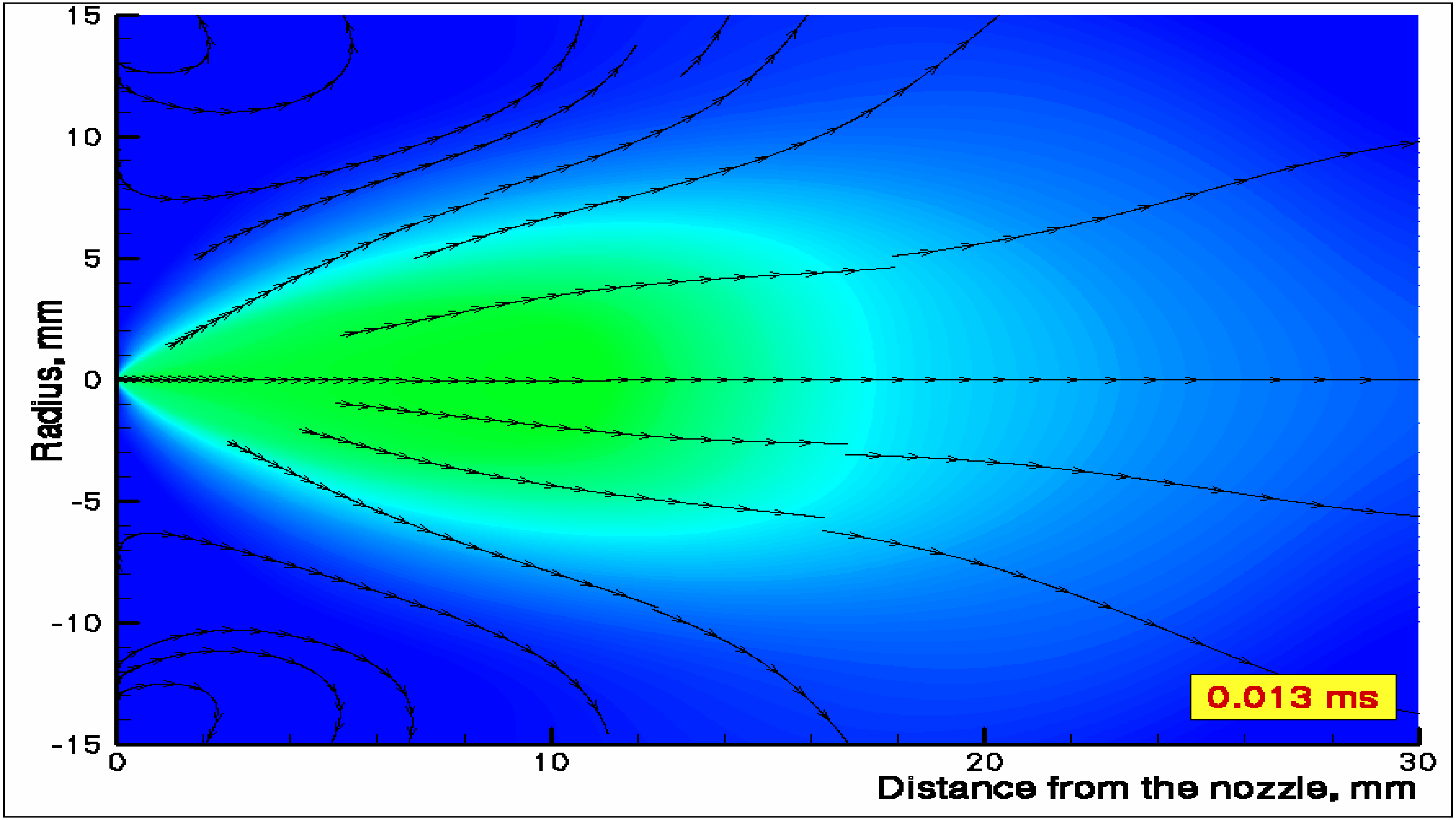
Gas-jet pulse development

Helium gas-jet velocity profile



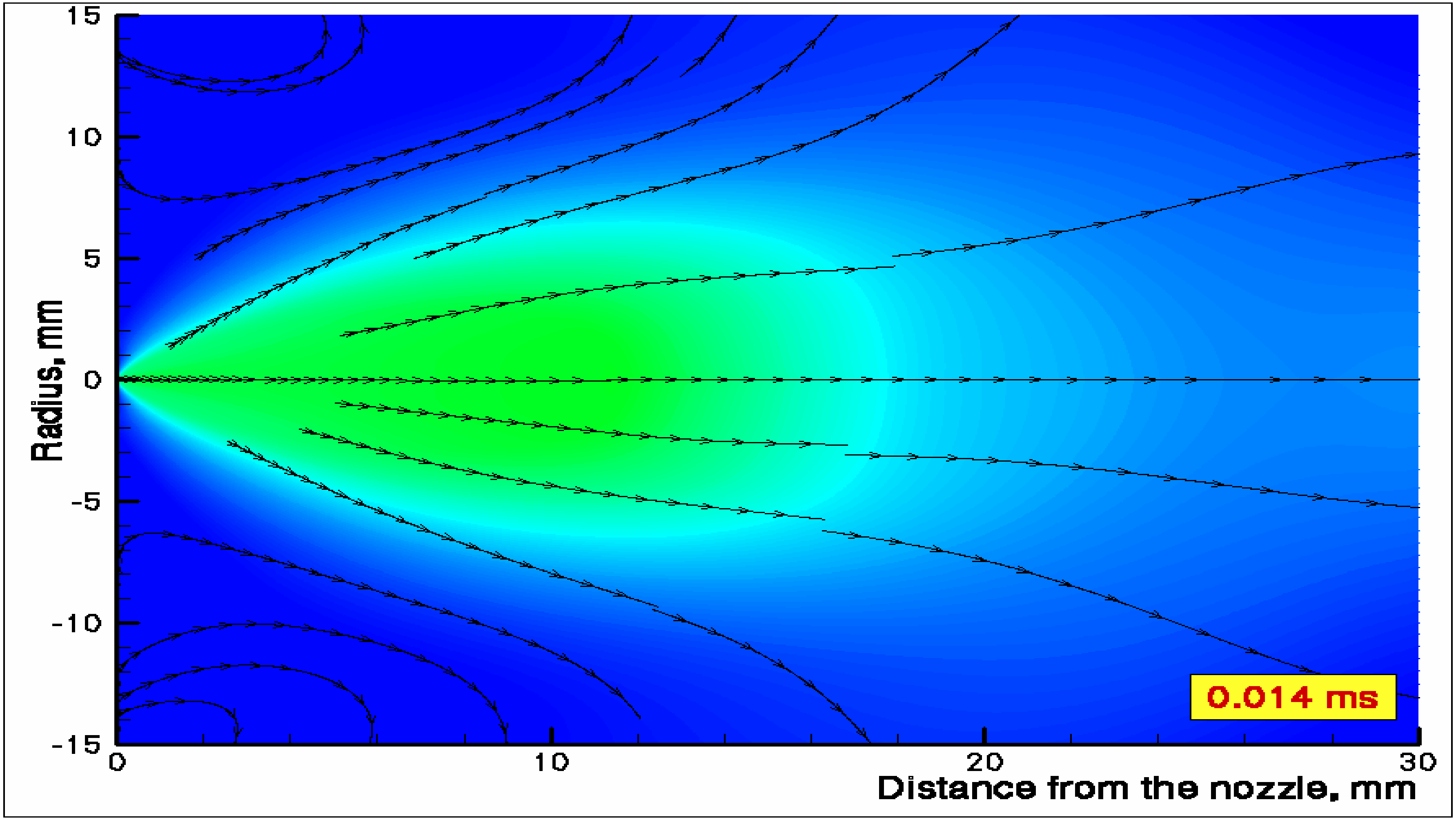
Gas-jet pulse development

Helium gas-jet velocity profile



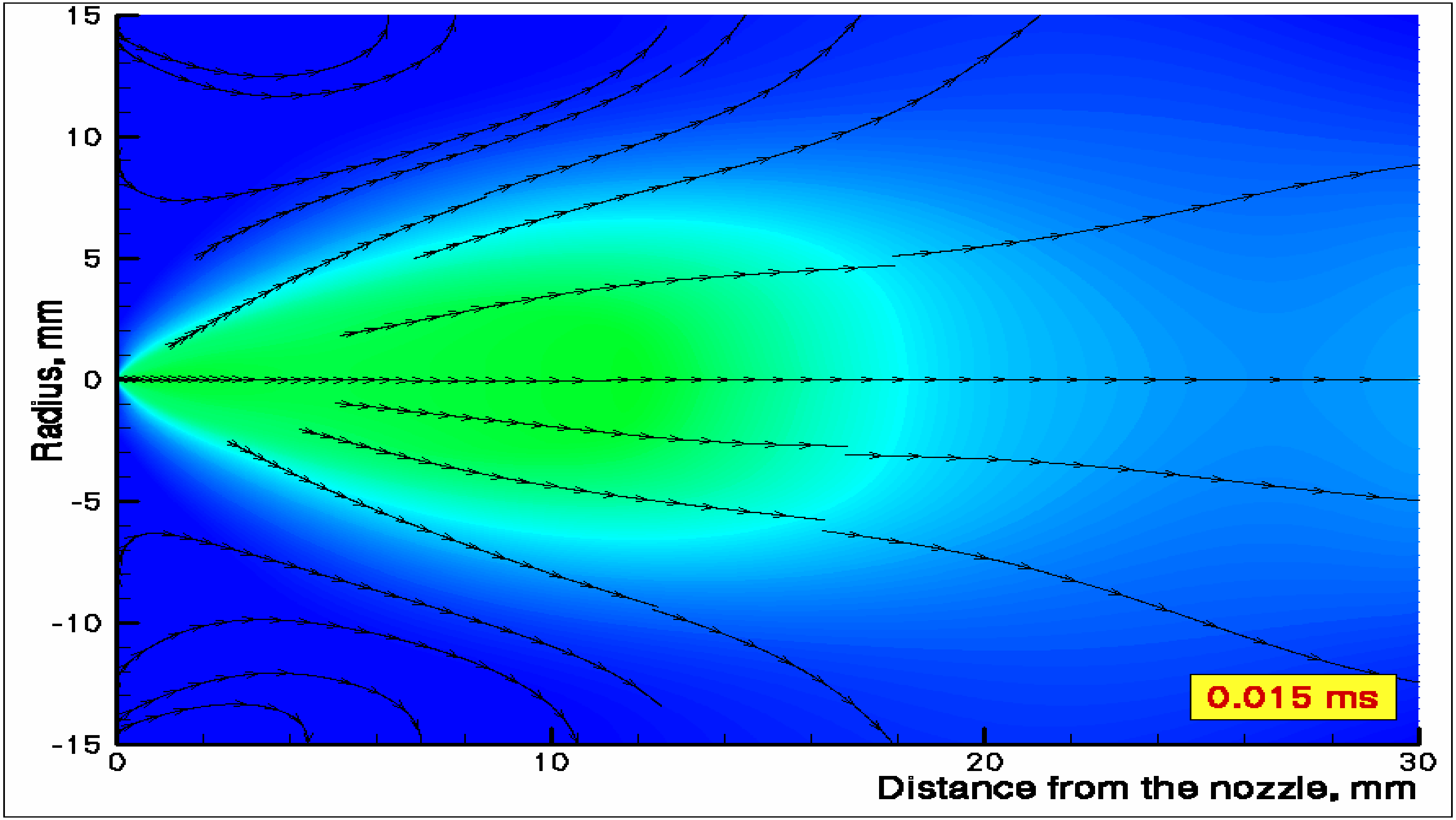
Gas-jet pulse development

Helium gas-jet velocity profile



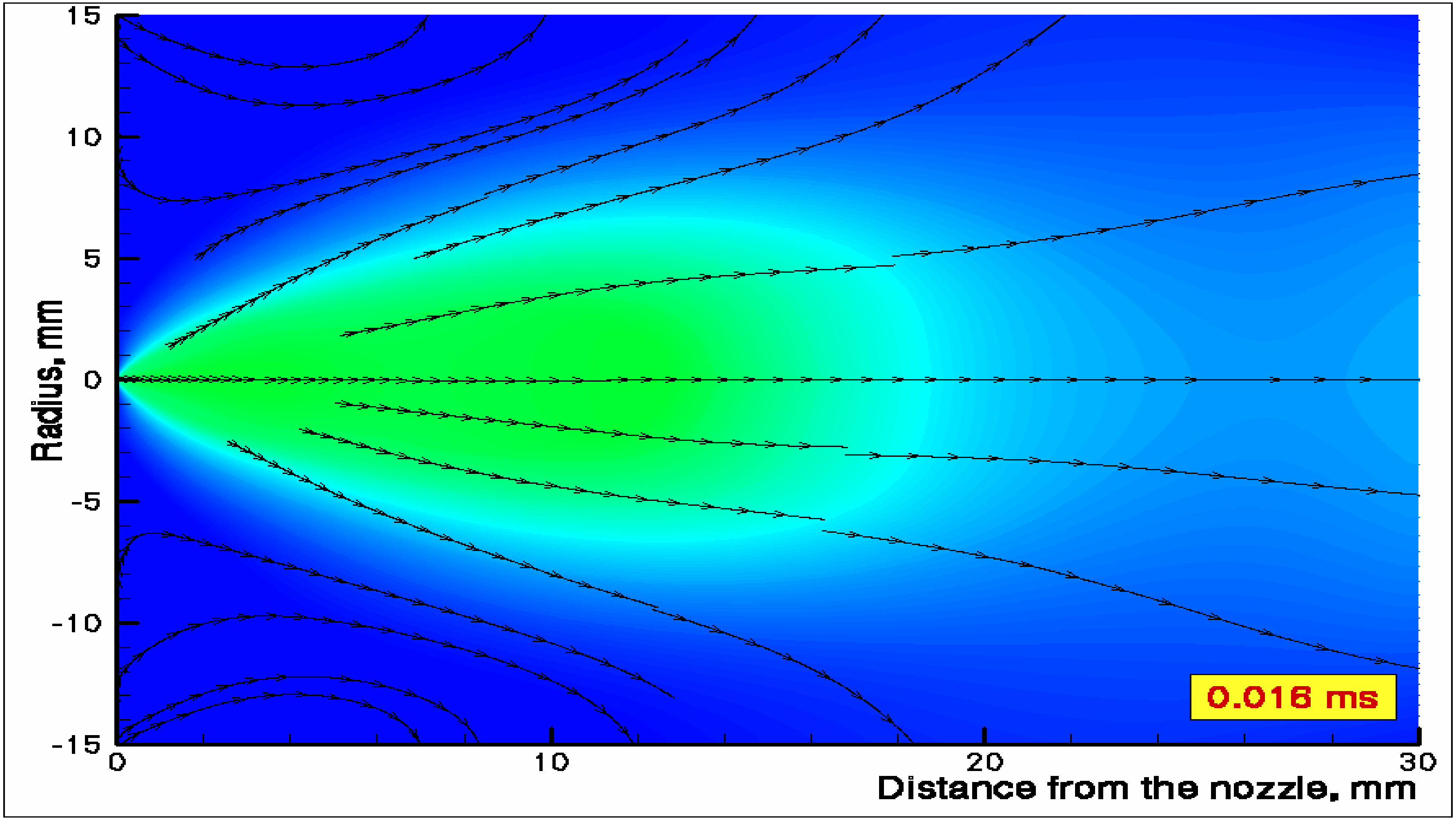
Gas-jet pulse development

Helium gas-jet velocity profile



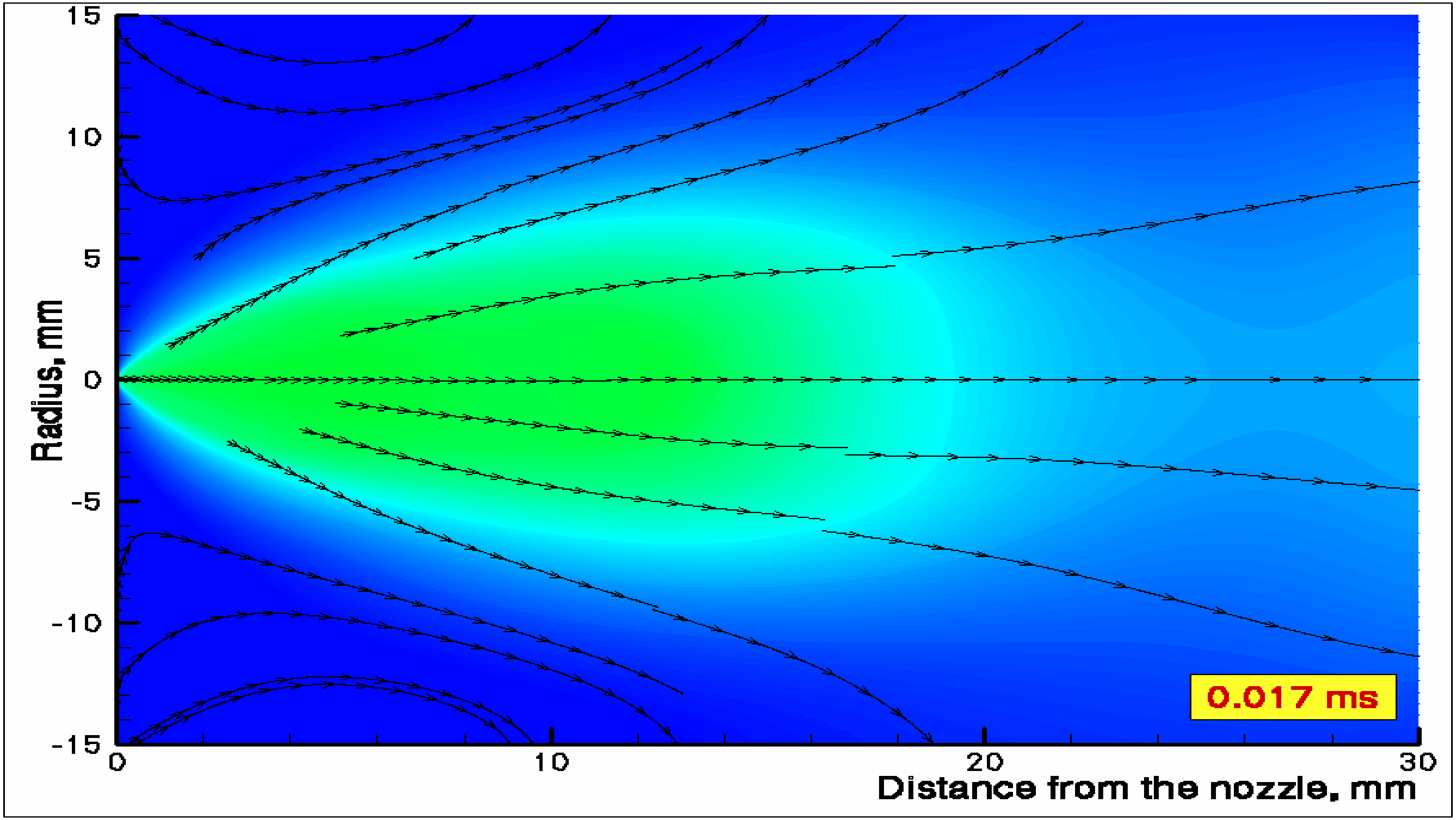
Gas-jet pulse development

Helium gas-jet velocity profile



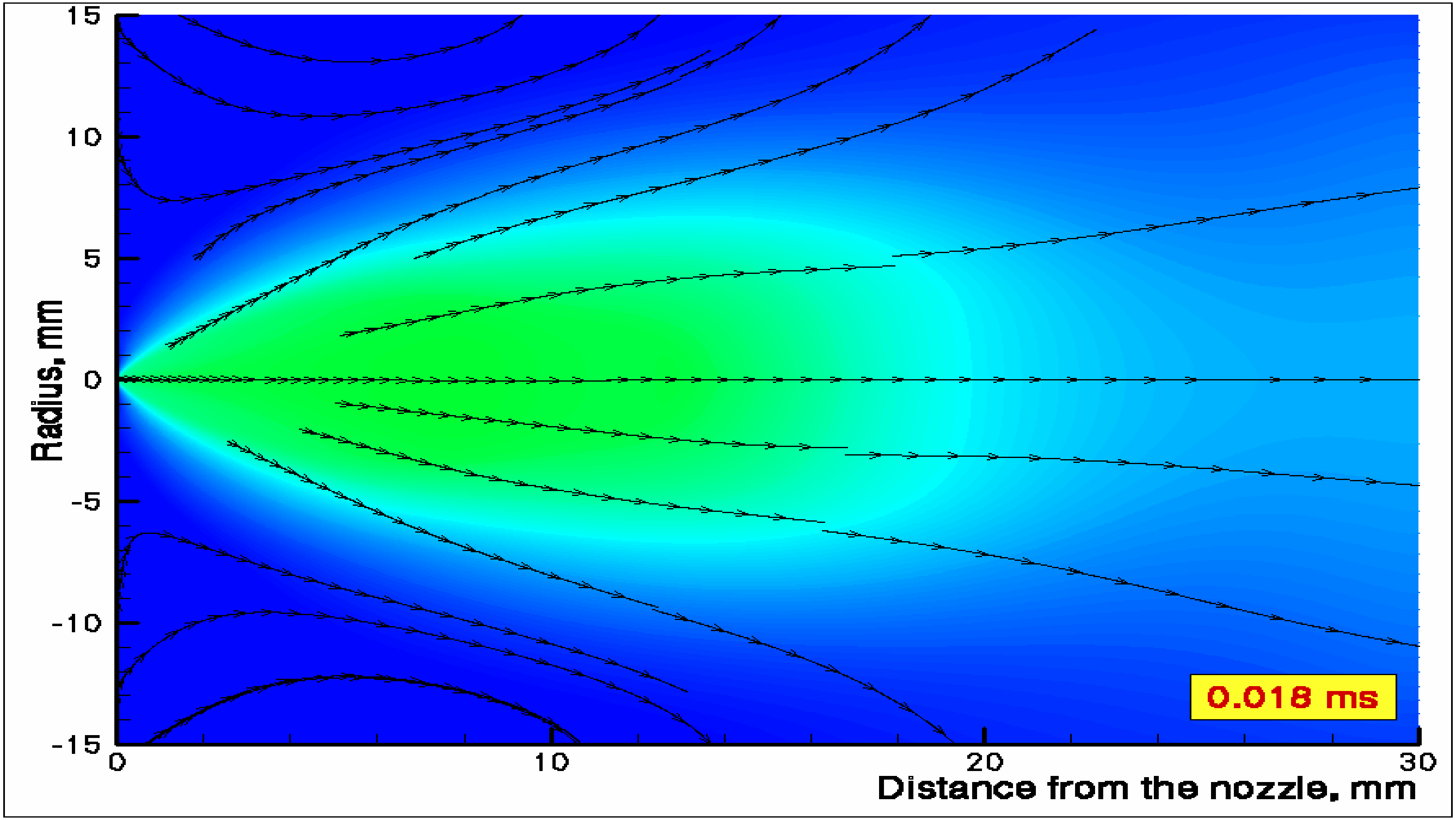
Gas-jet pulse development

Helium gas-jet velocity profile



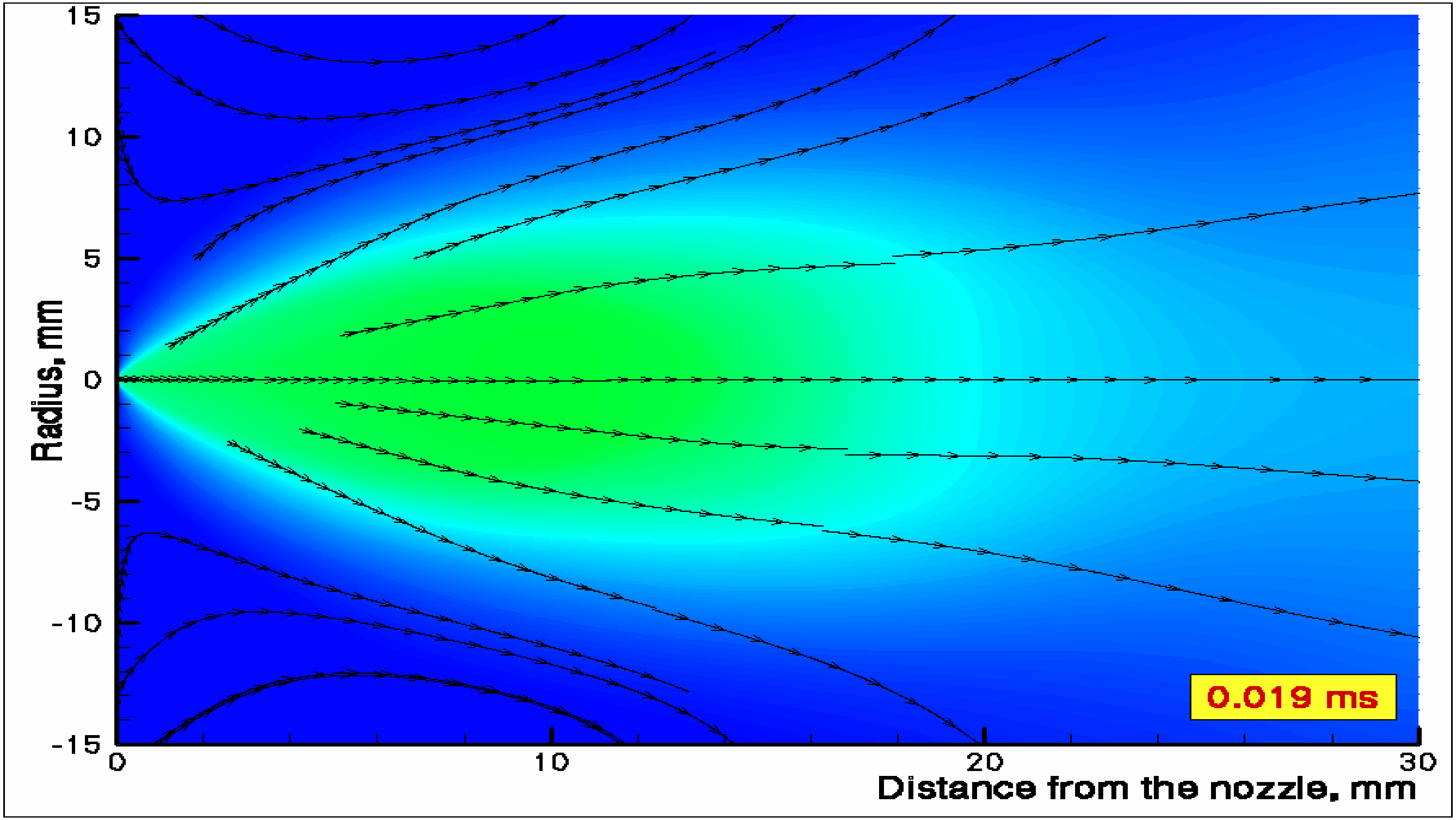
Gas-jet pulse development

Helium gas-jet velocity profile



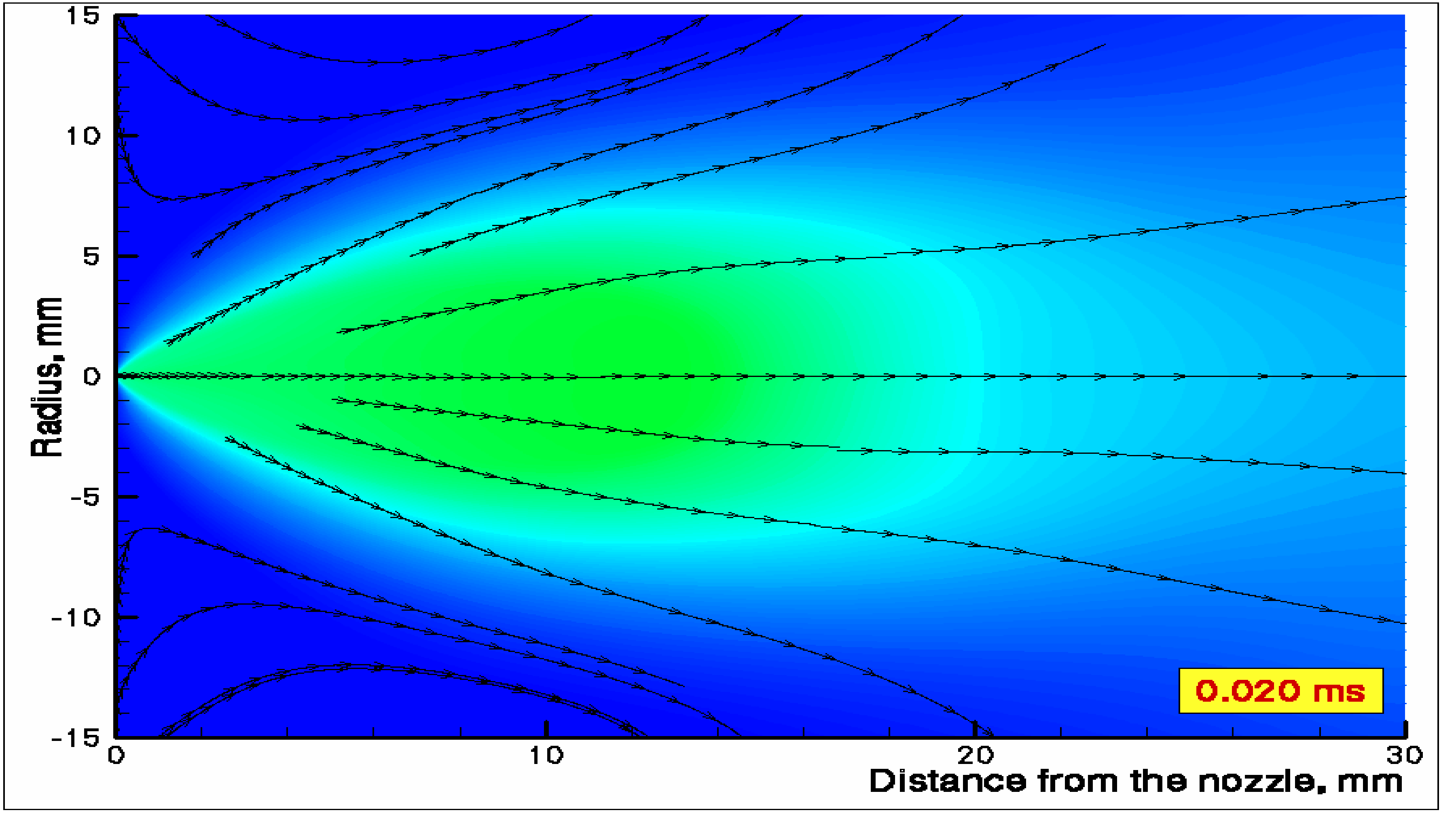
Gas-jet pulse development

Helium gas-jet velocity profile



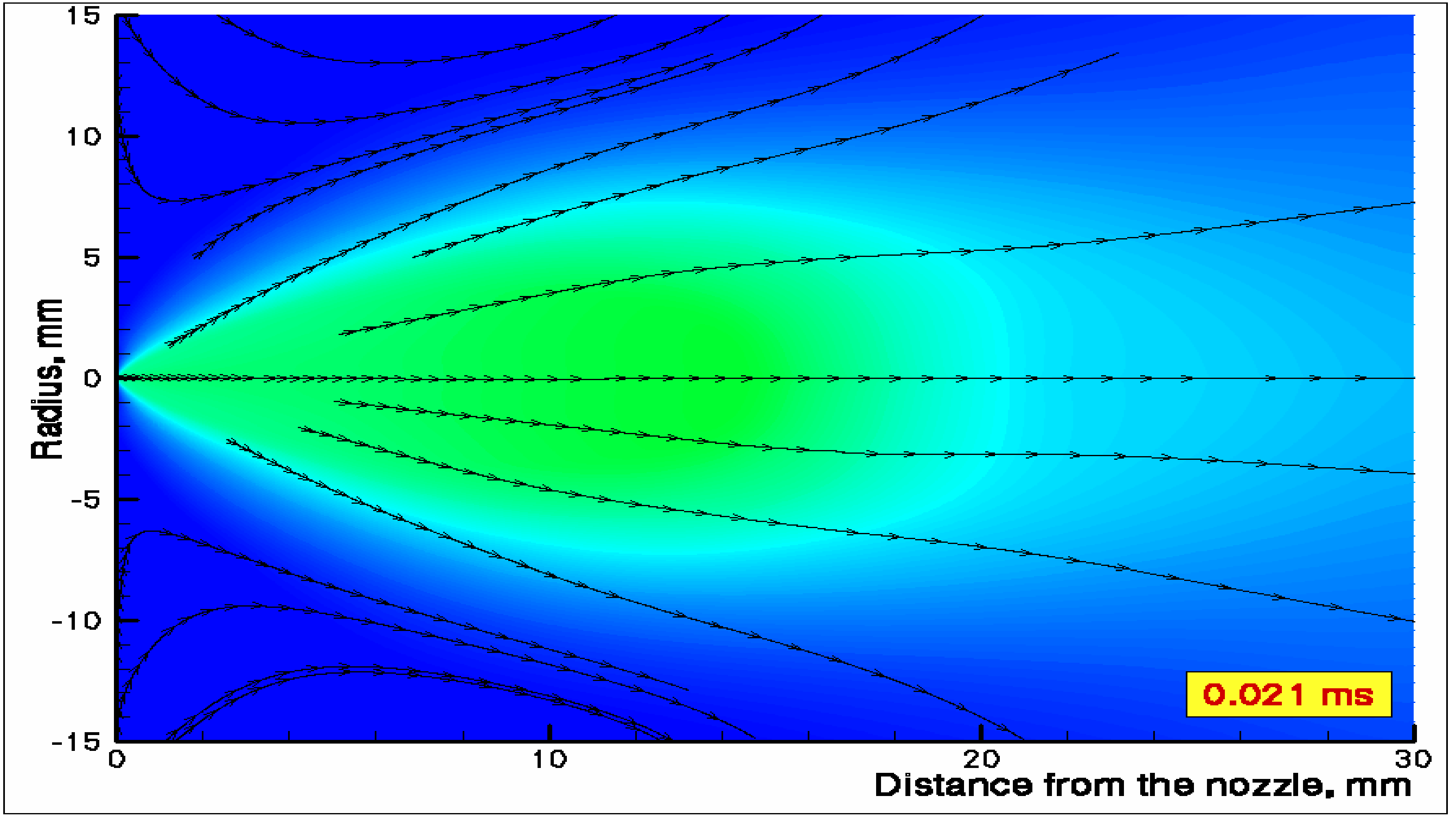
Gas-jet pulse development

Helium gas-jet velocity profile



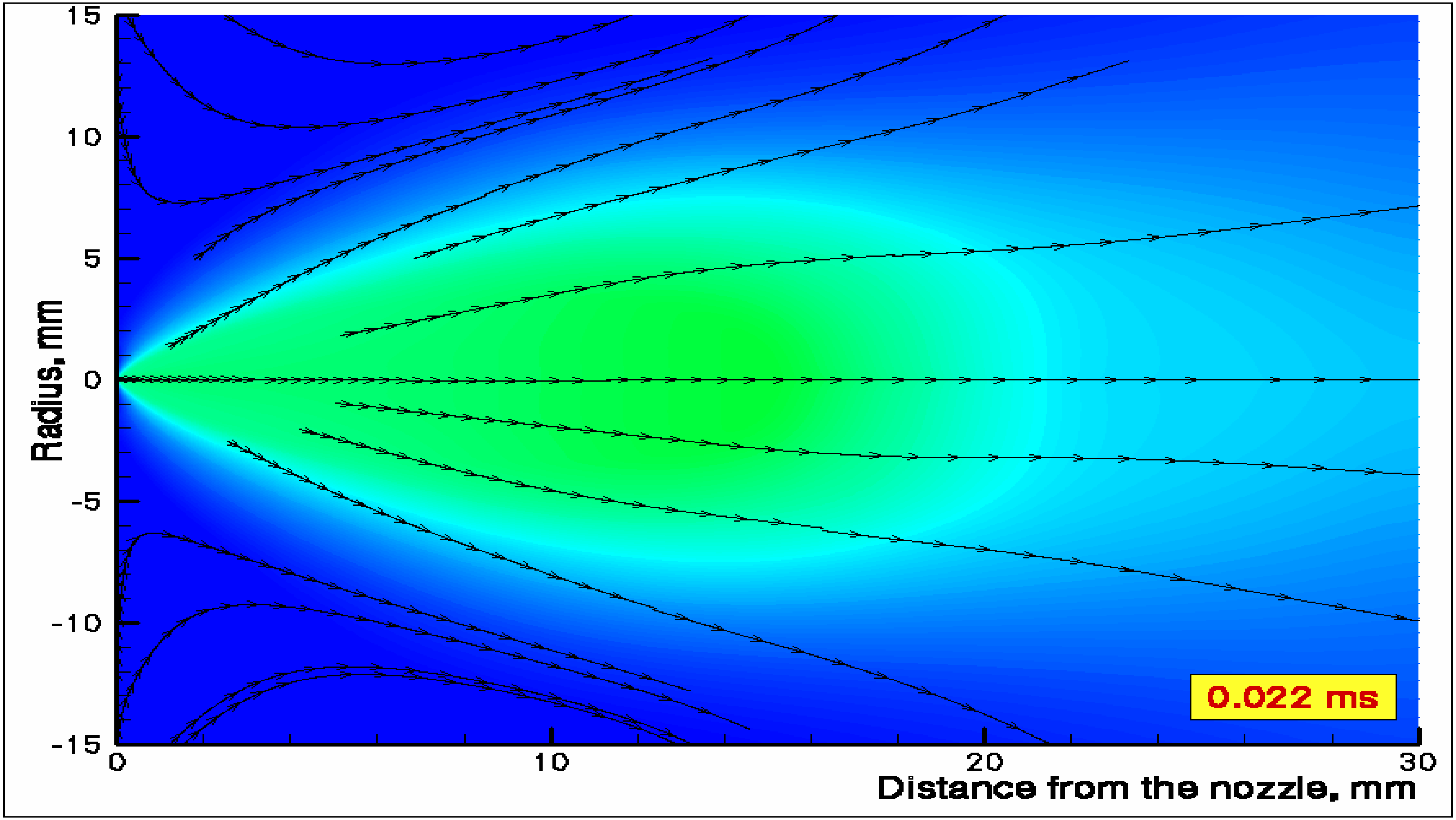
Gas-jet pulse development

Helium gas-jet velocity profile



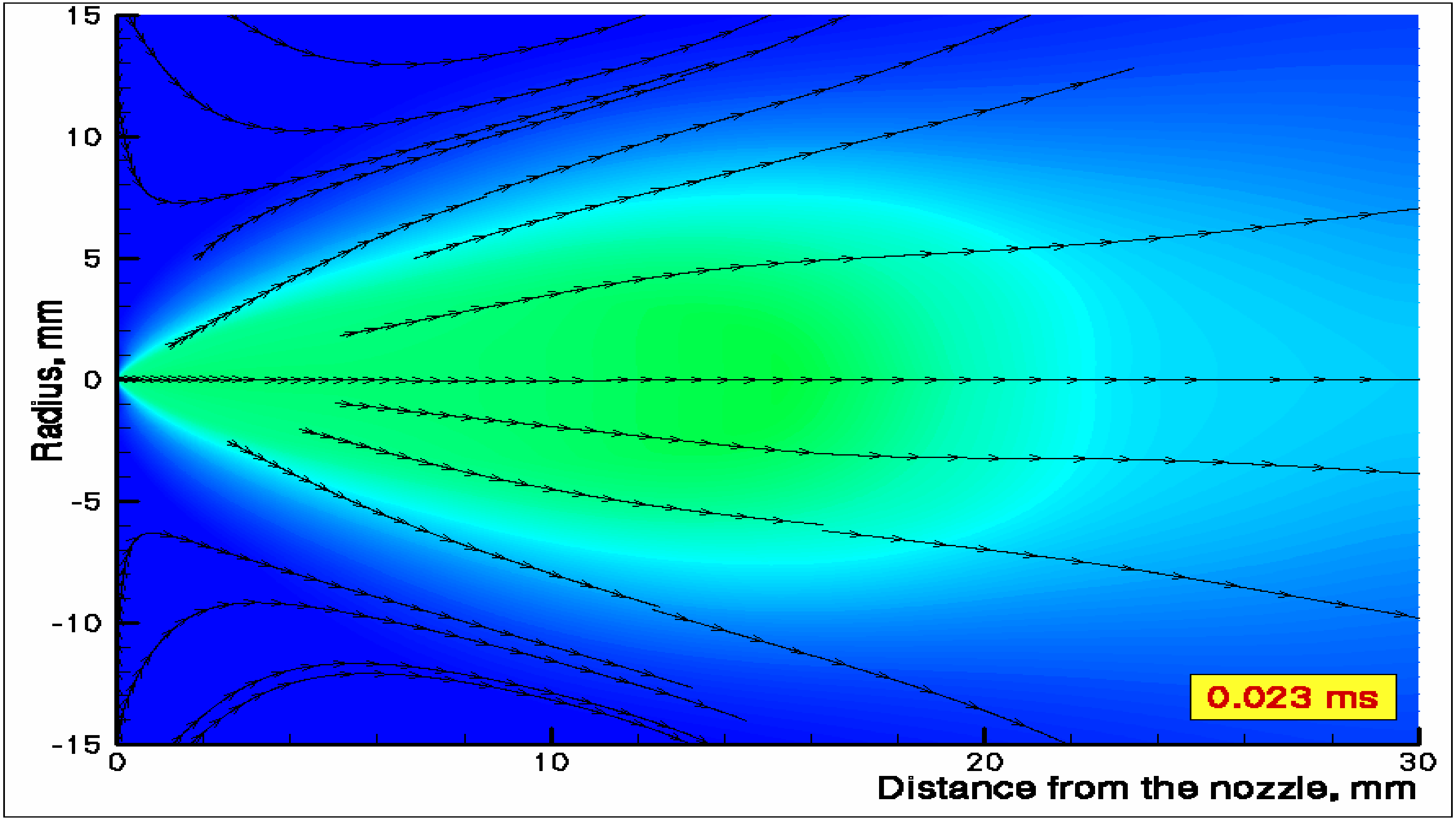
Gas-jet pulse development

Helium gas-jet velocity profile



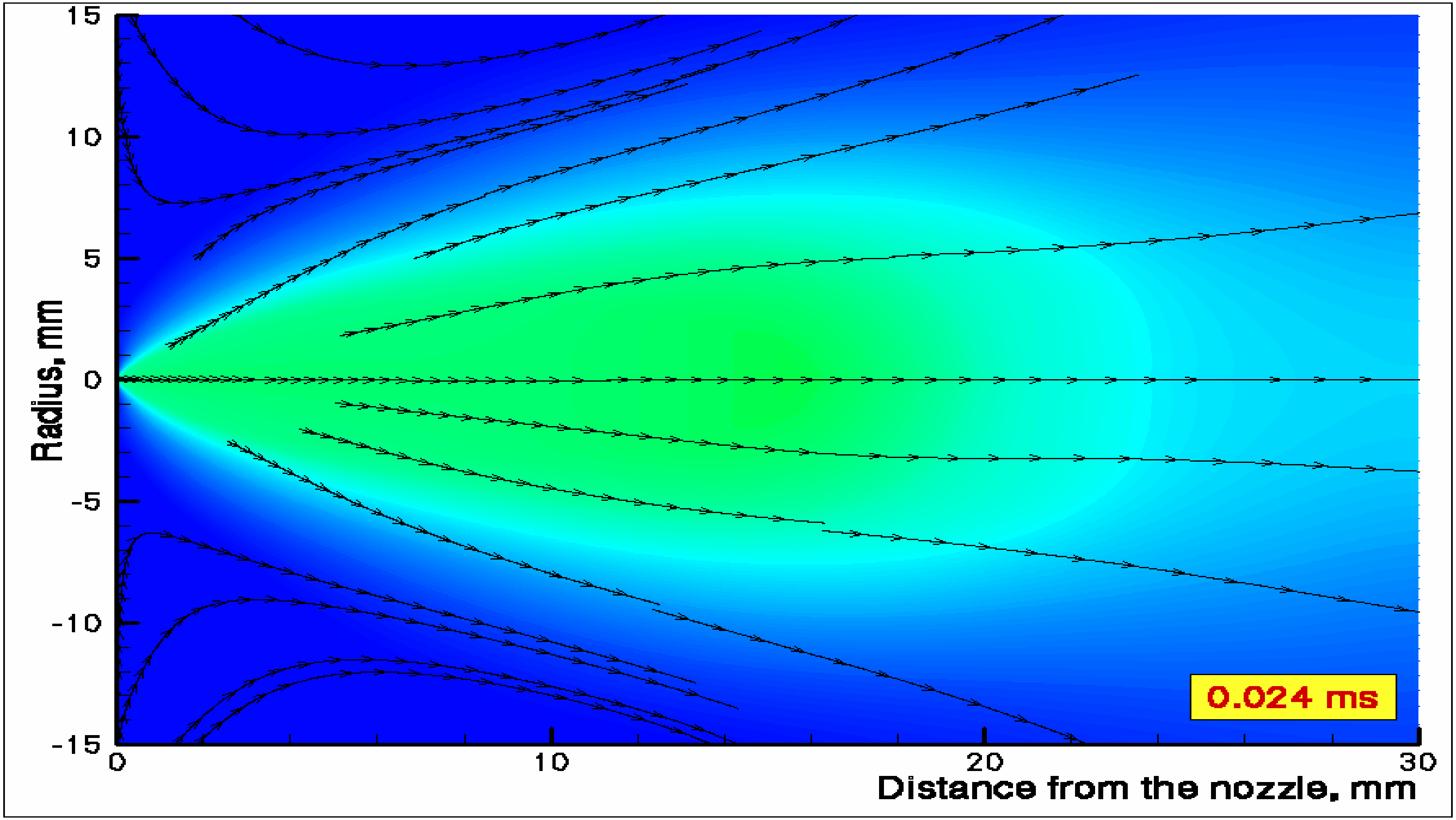
Gas-jet pulse development

Helium gas-jet velocity profile



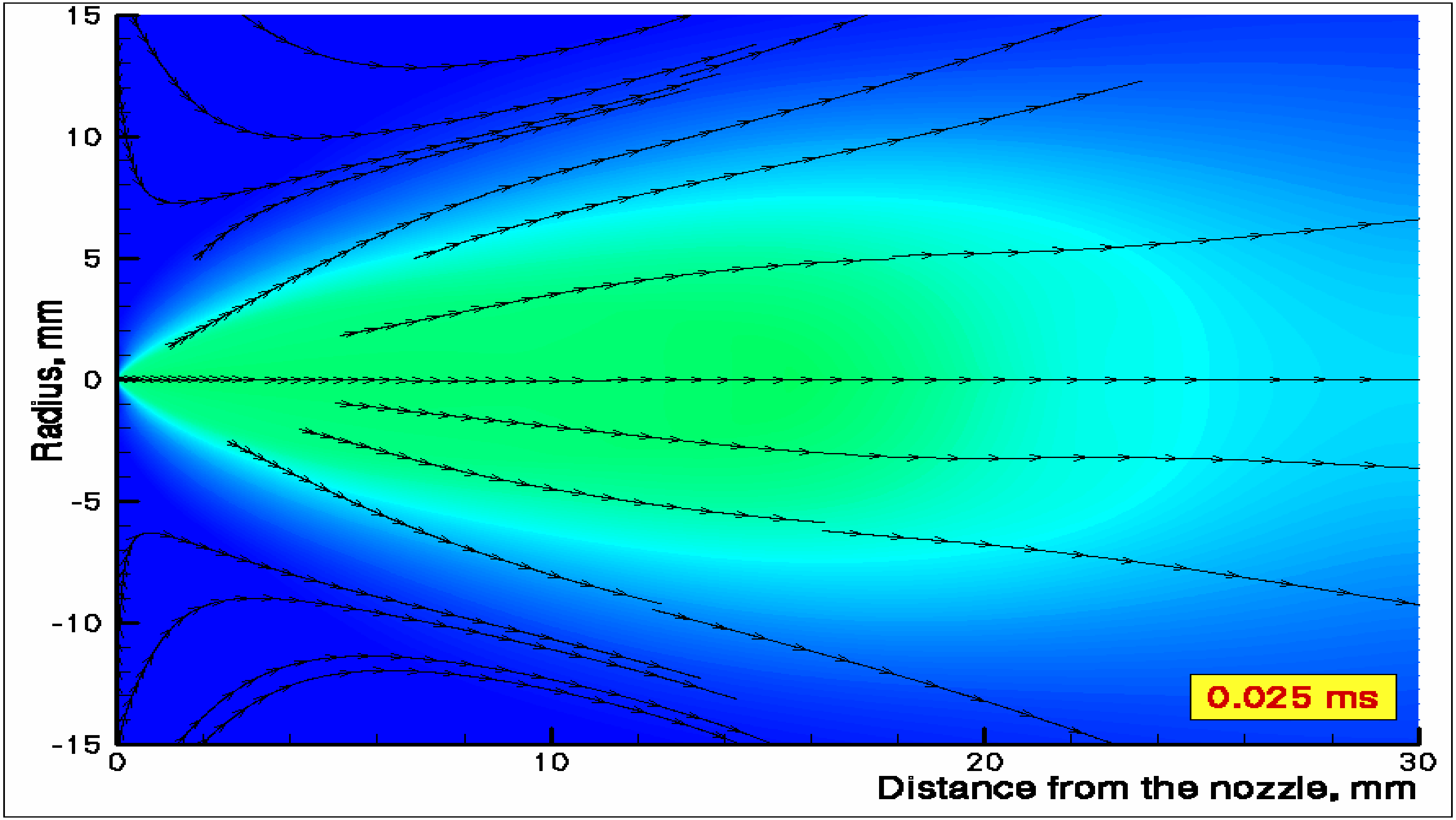
Gas-jet pulse development

Helium gas-jet velocity profile



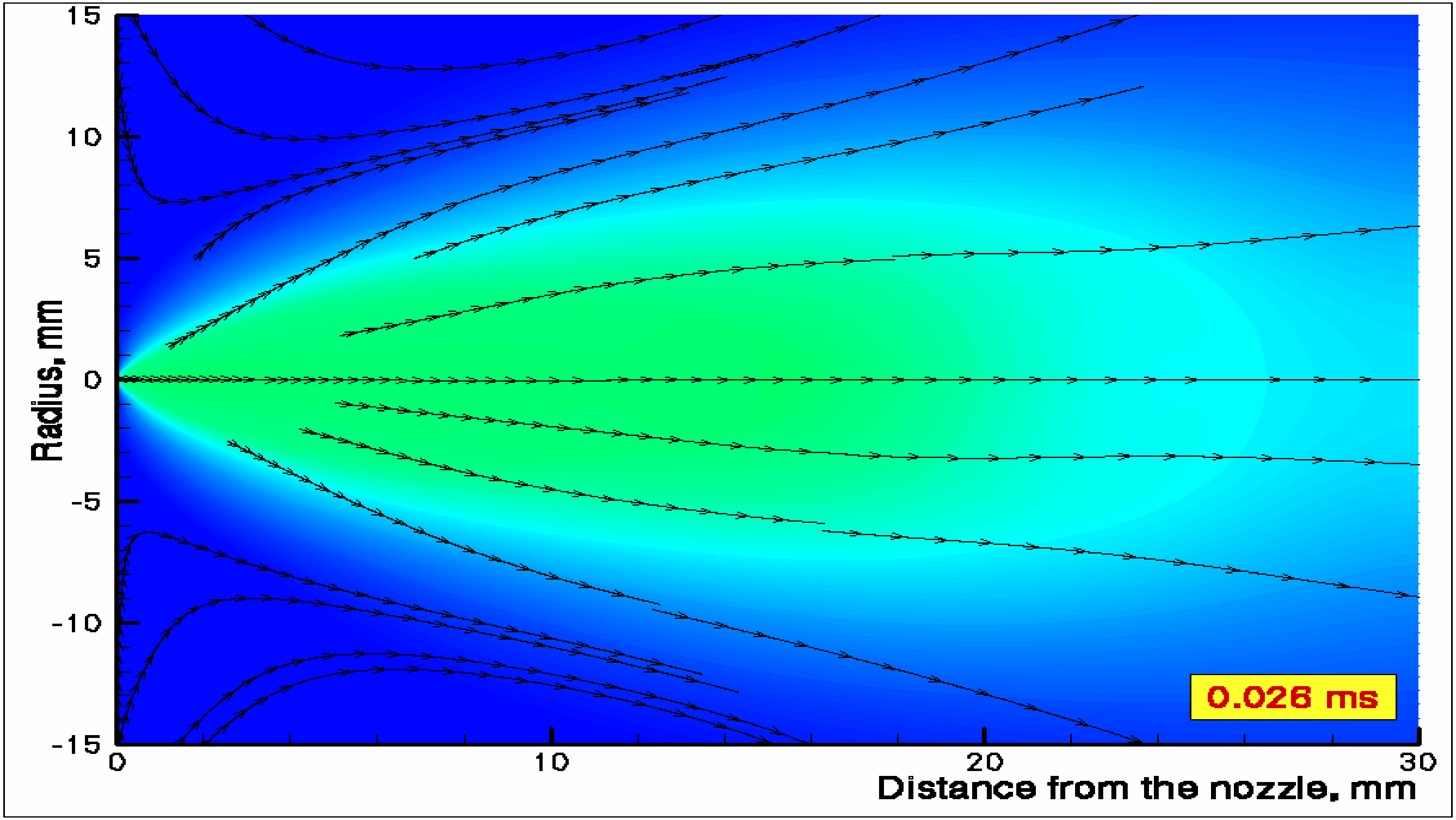
Gas-jet pulse development

Helium gas-jet velocity profile



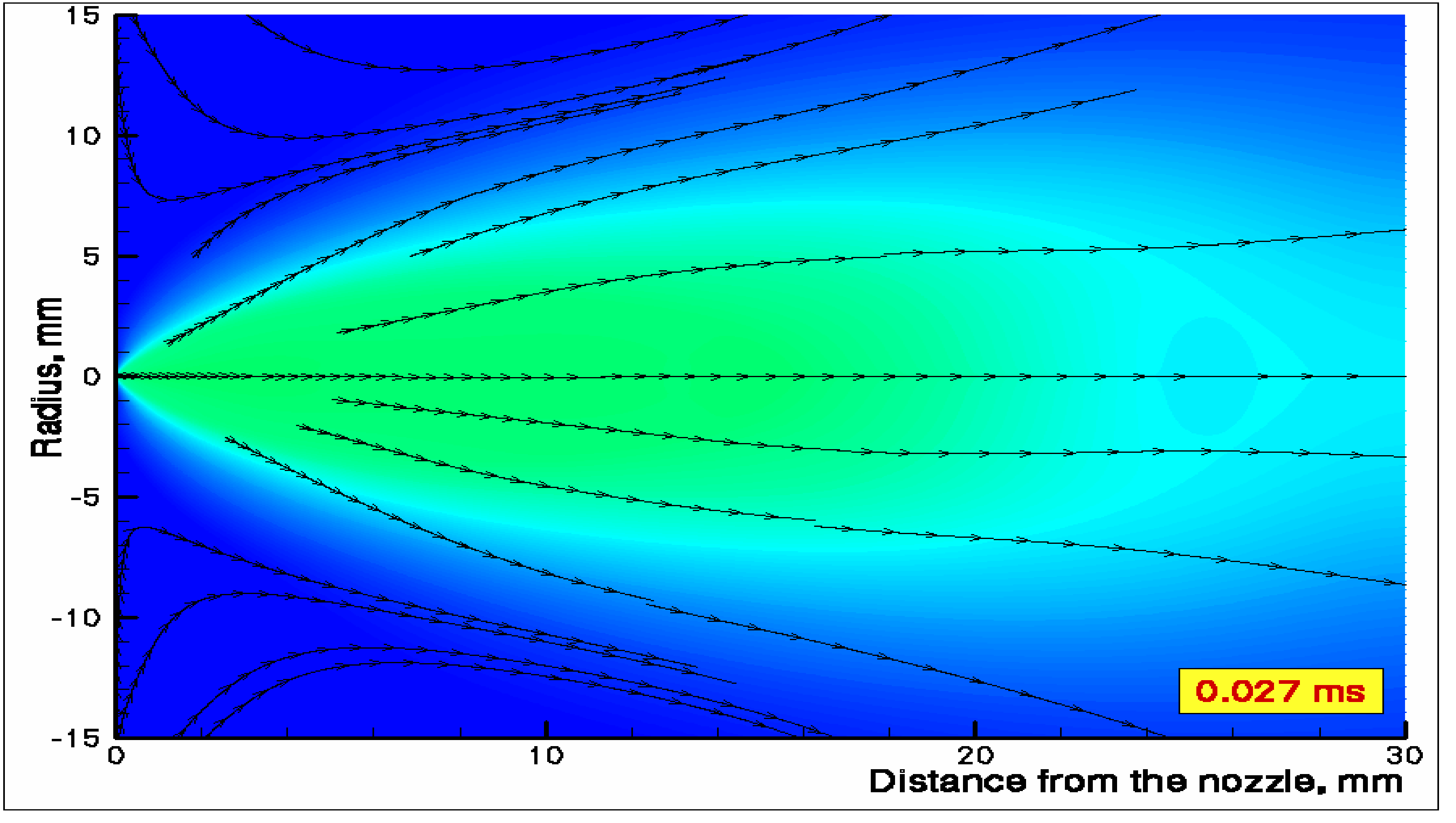
Gas-jet pulse development

Helium gas-jet velocity profile



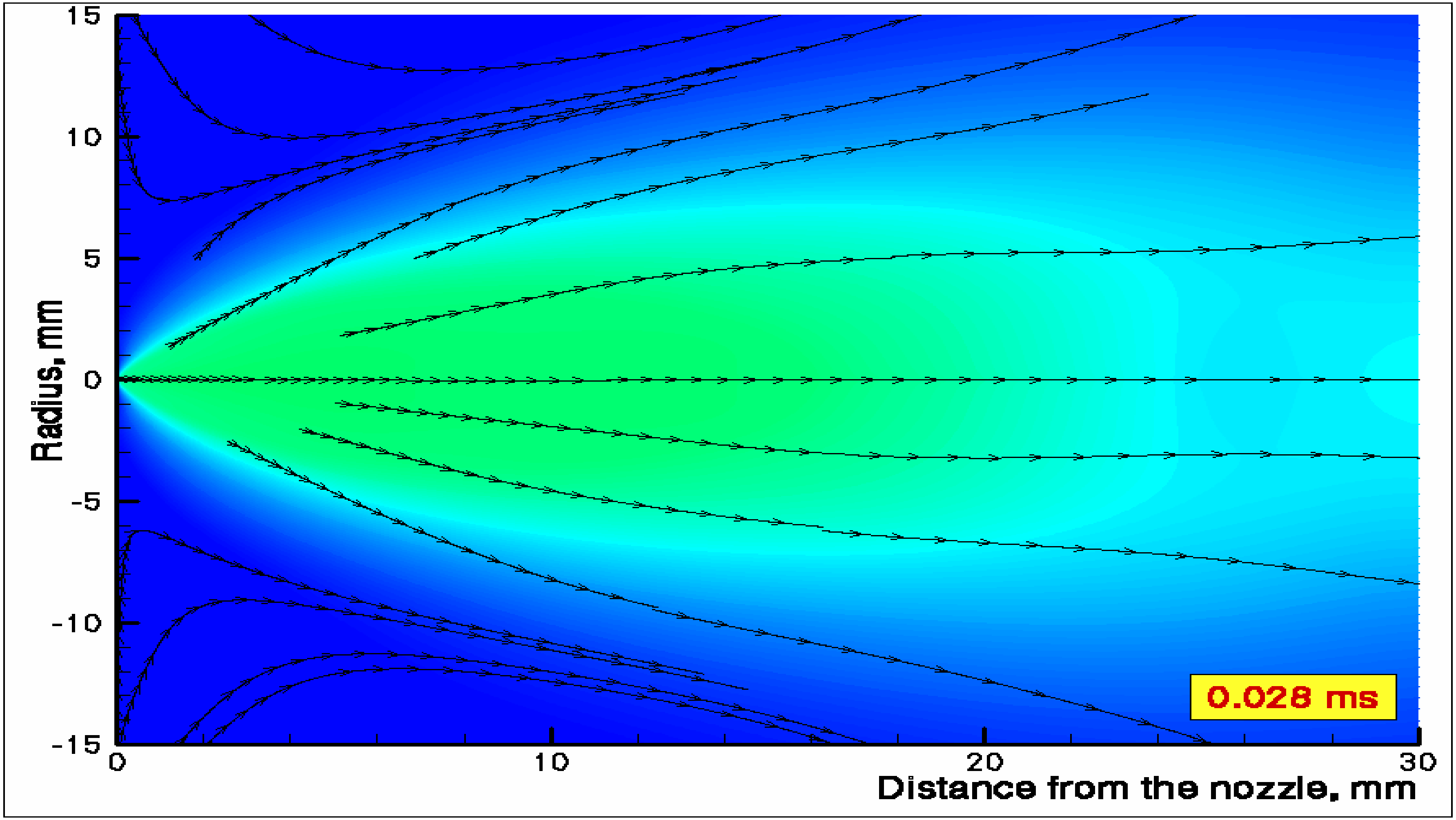
Gas-jet pulse development

Helium gas-jet velocity profile



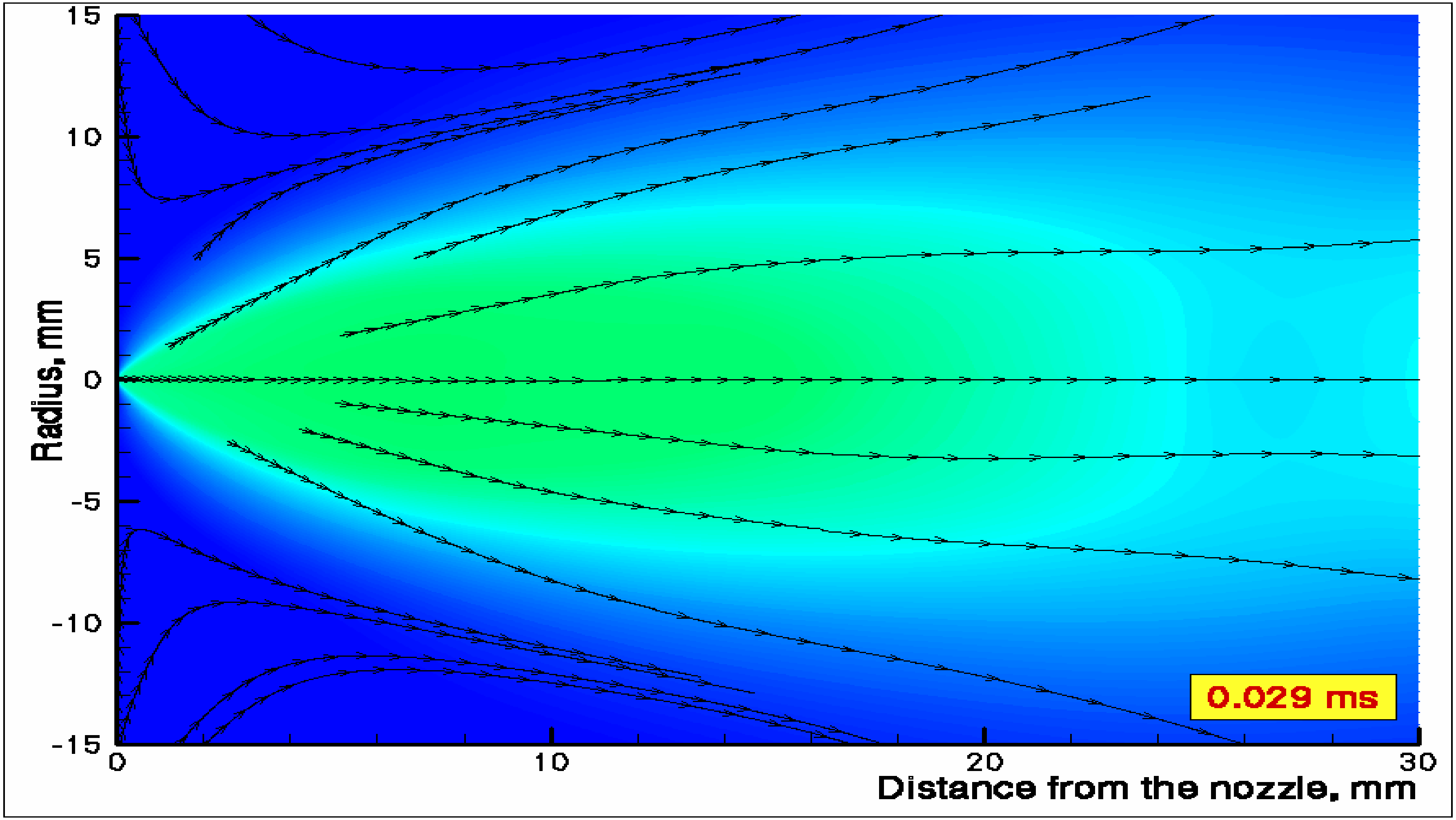
Gas-jet pulse development

Helium gas-jet velocity profile



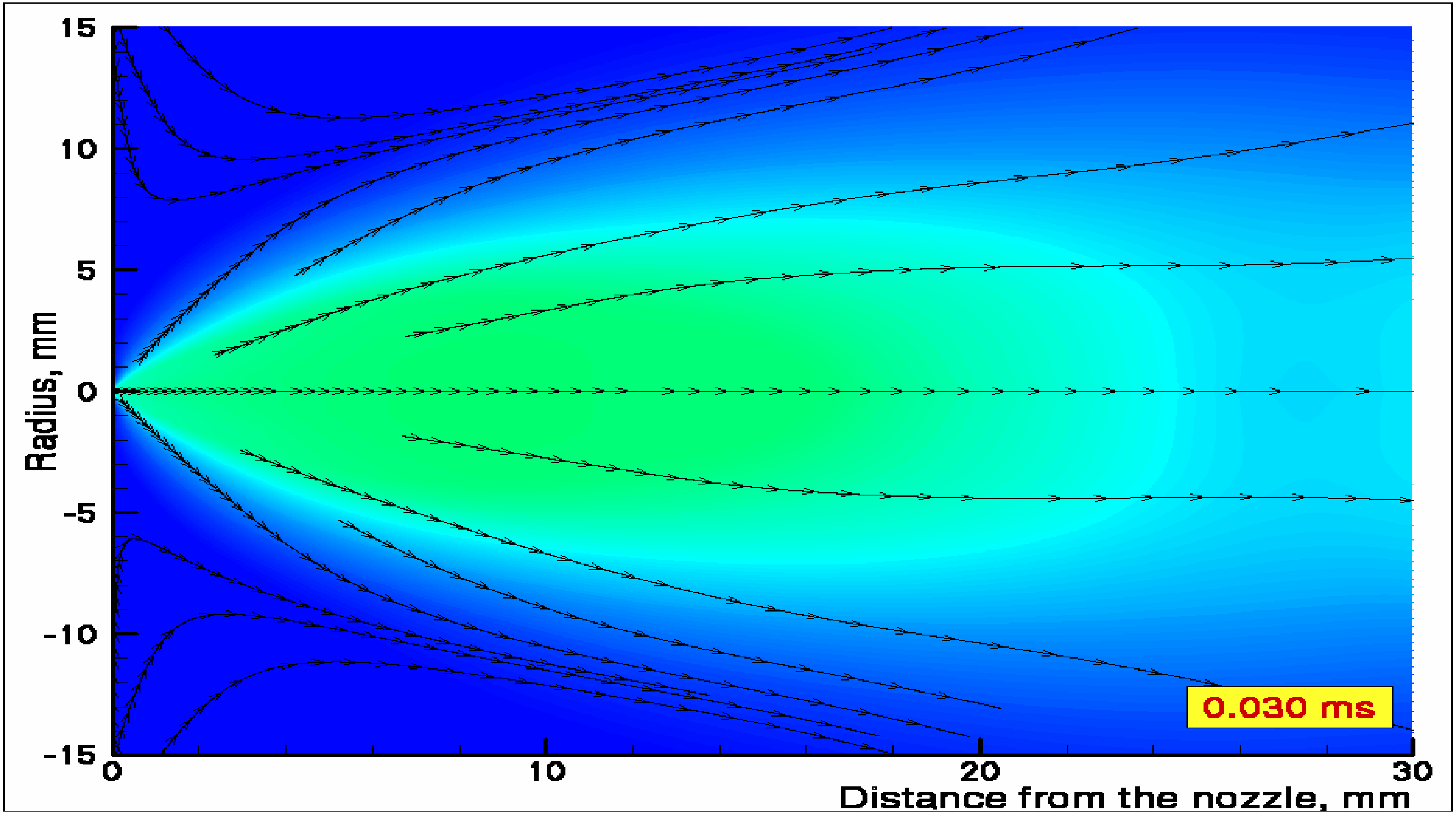
Gas-jet pulse development

Helium gas-jet velocity profile



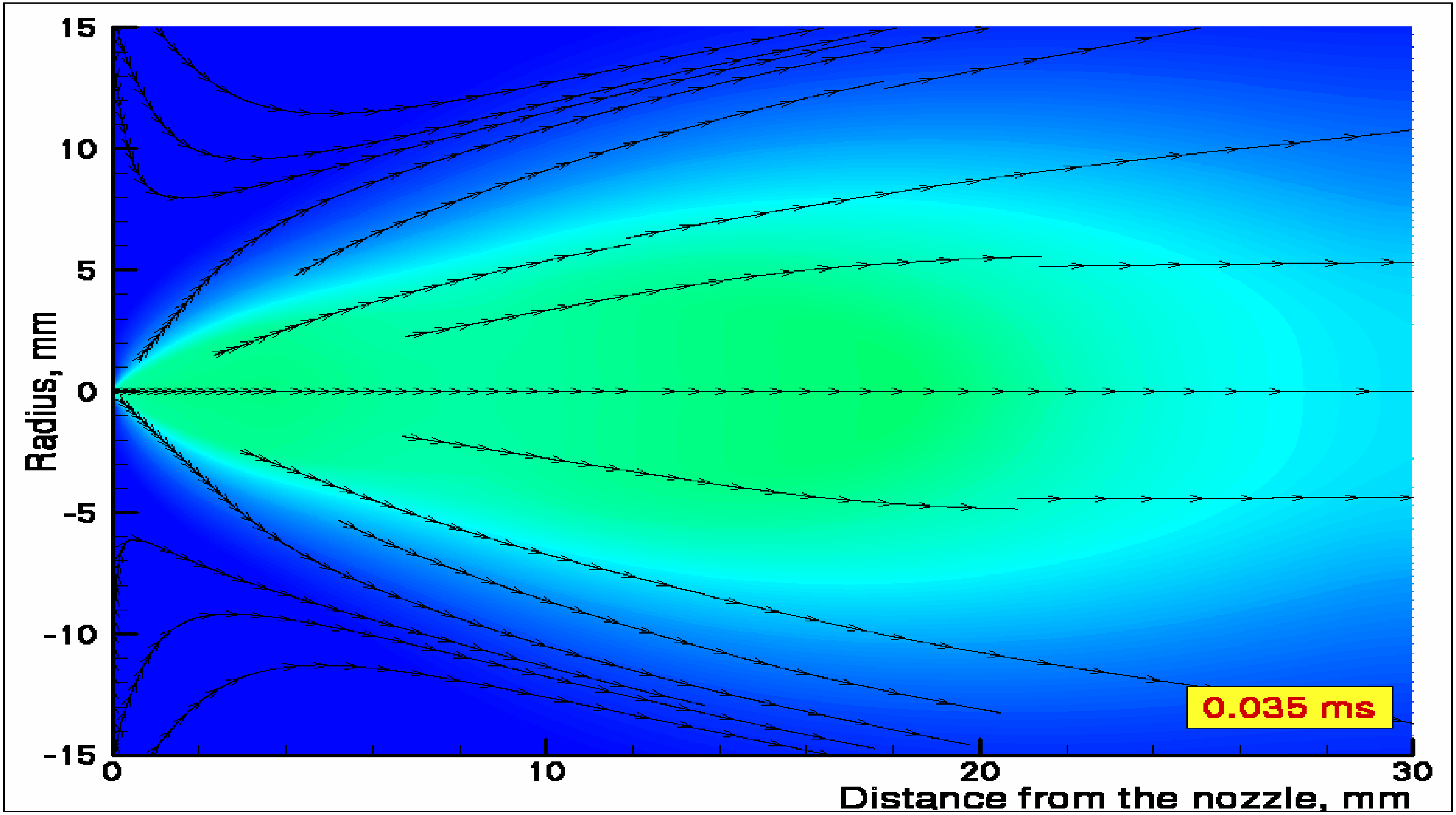
Gas-jet pulse development

Helium gas-jet velocity profile



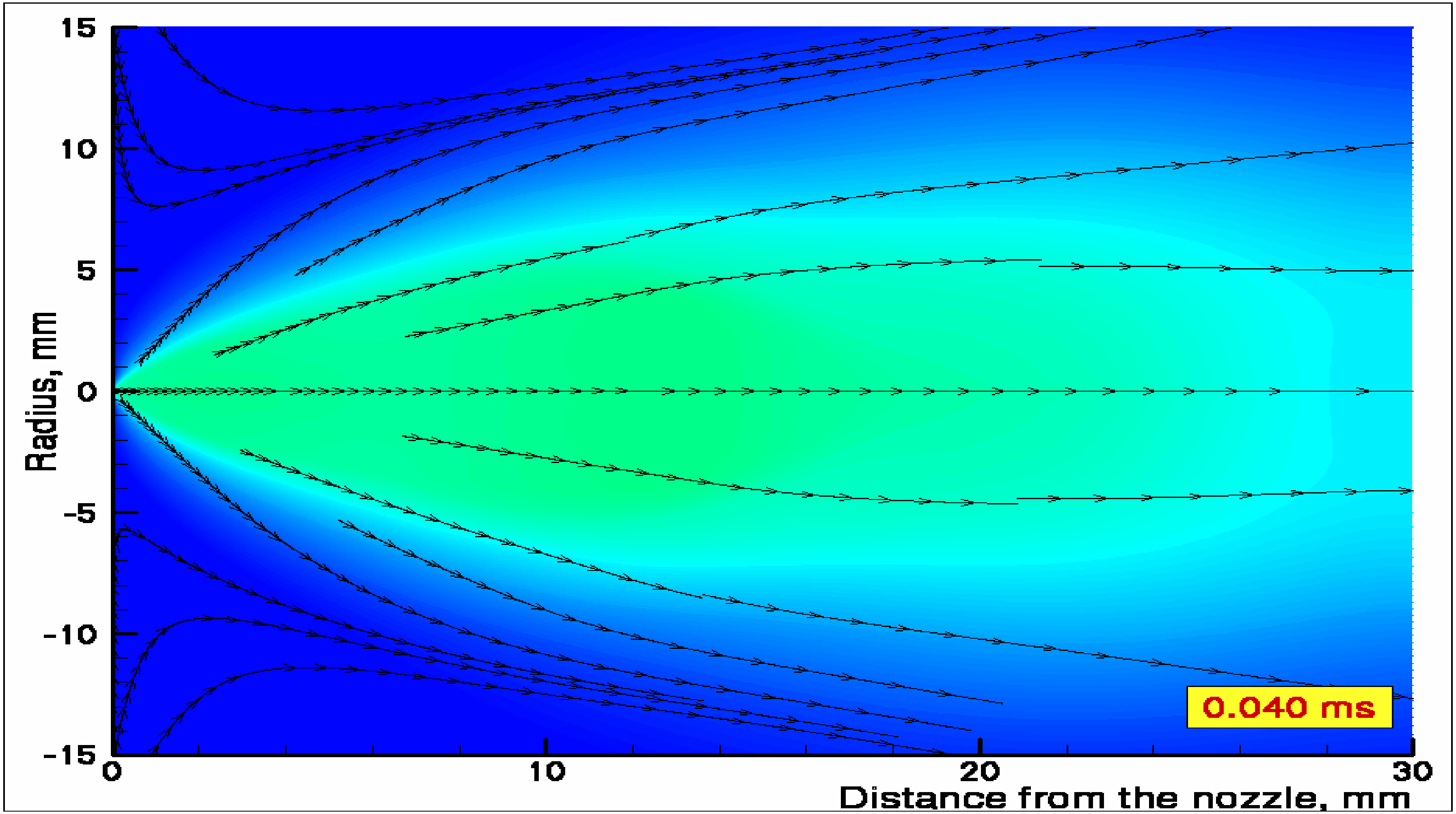
Gas-jet pulse development

Helium gas-jet velocity profile



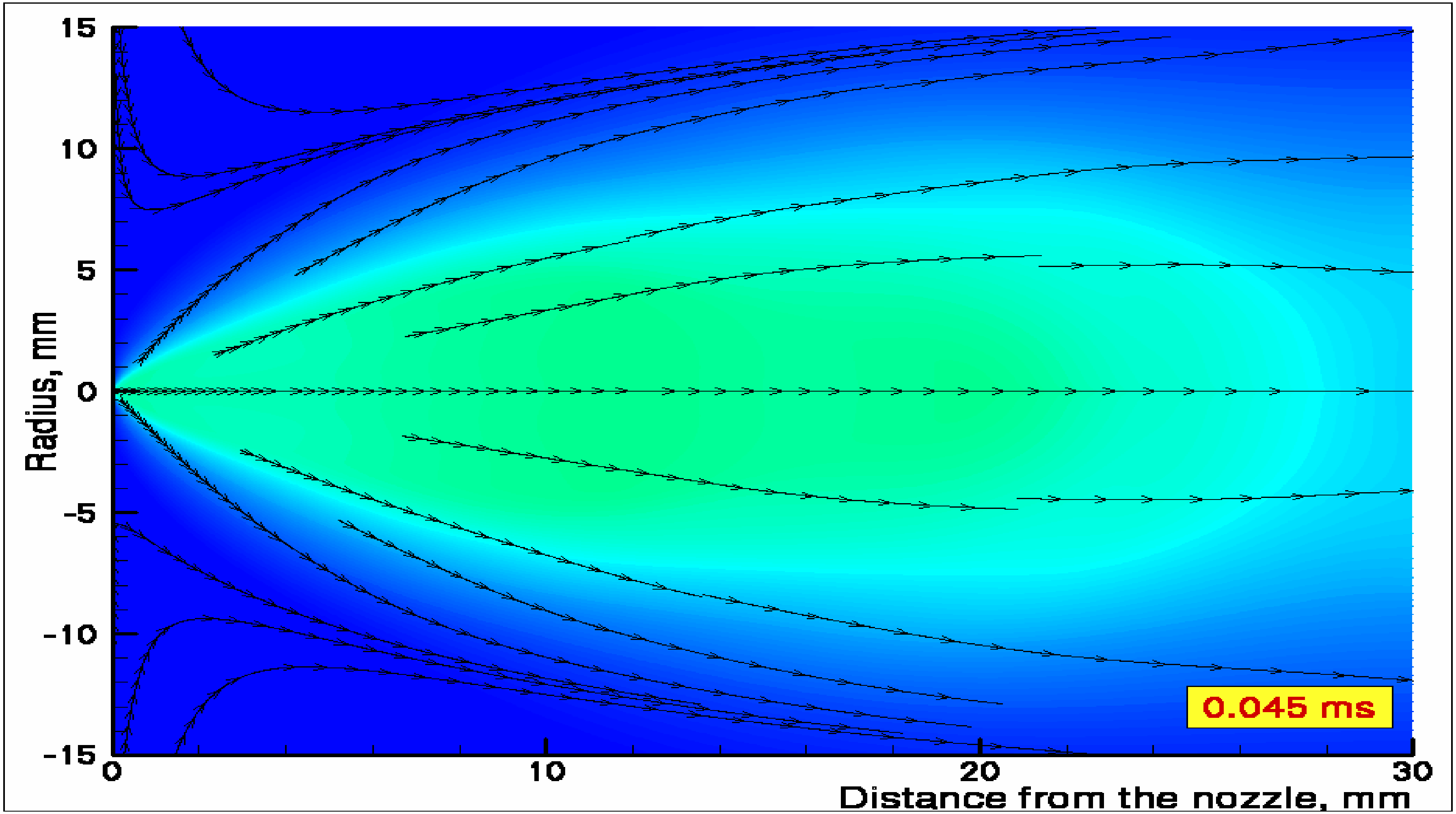
Gas-jet pulse development

Helium gas-jet velocity profile



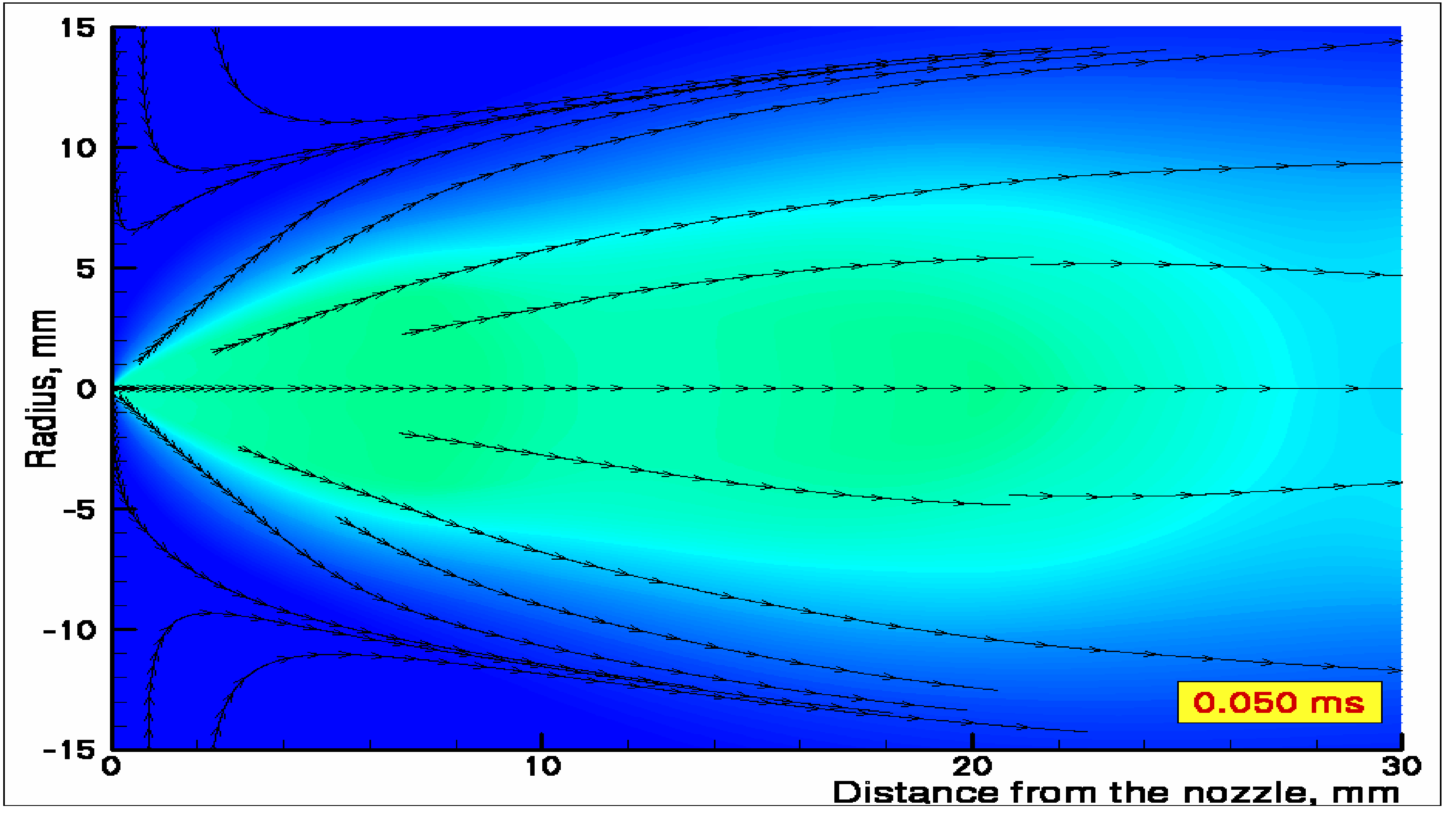
Gas-jet pulse development

Helium gas-jet velocity profile



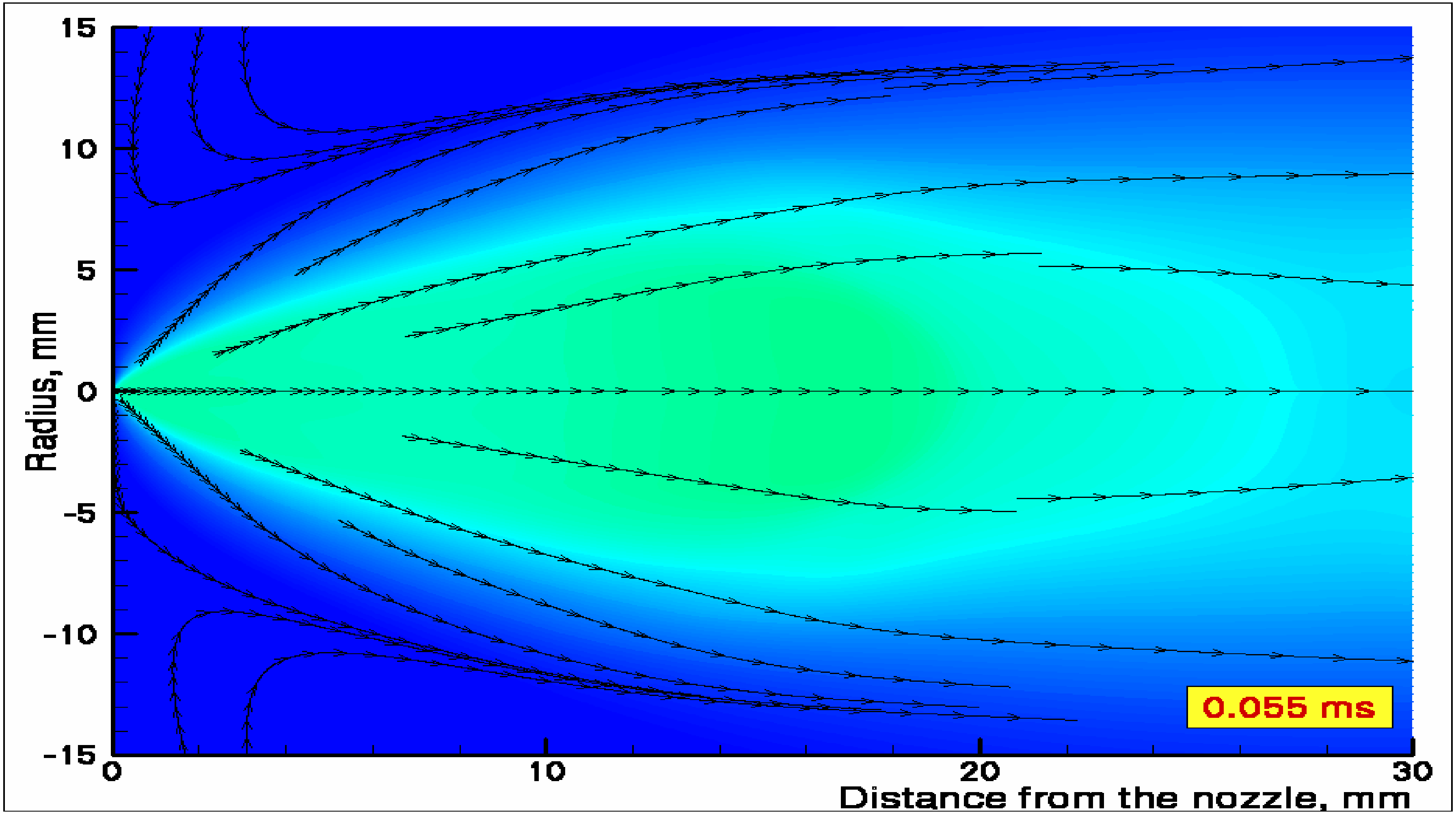
Gas-jet pulse development

Helium gas-jet velocity profile



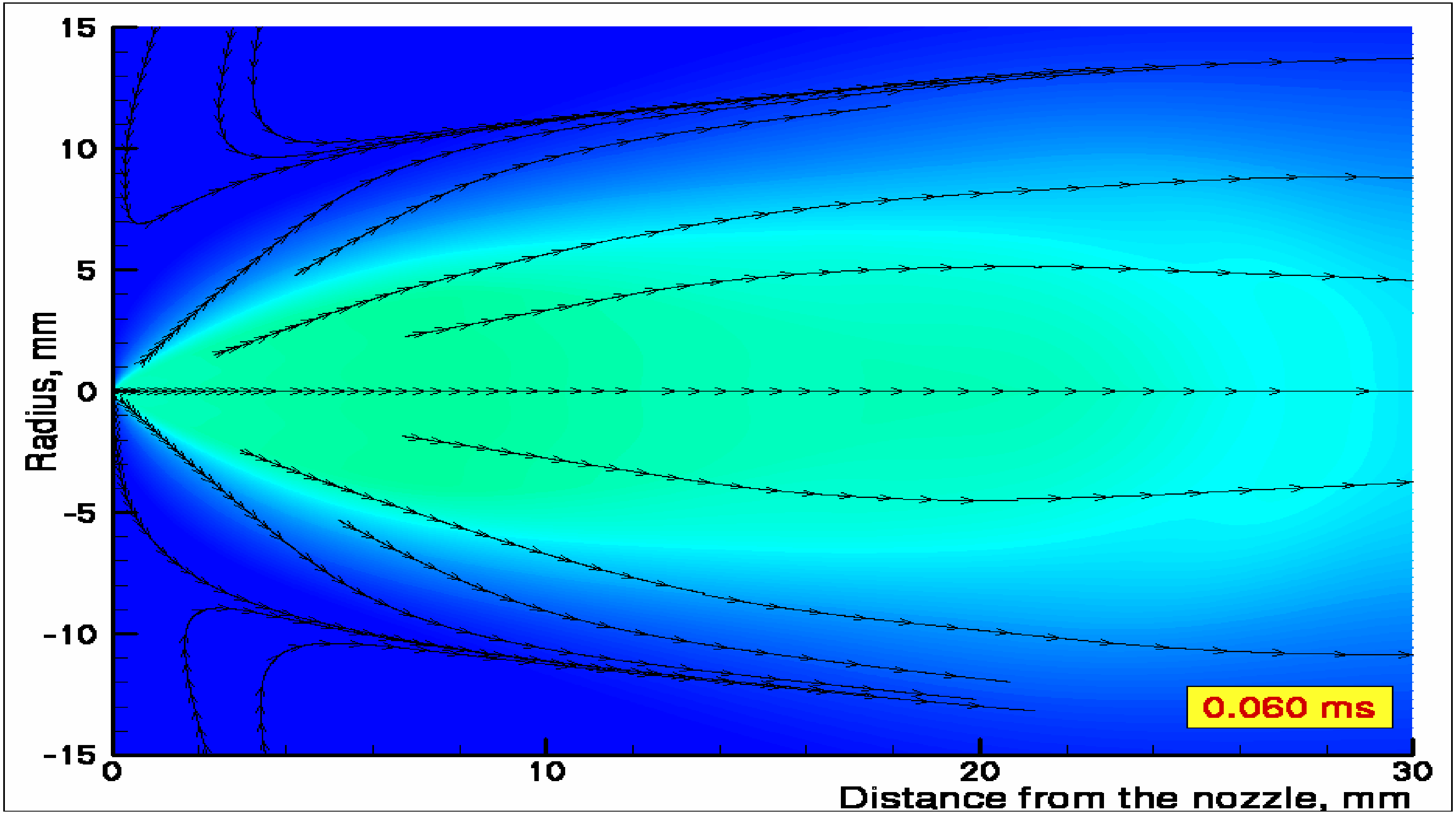
Gas-jet pulse development

Helium gas-jet velocity profile



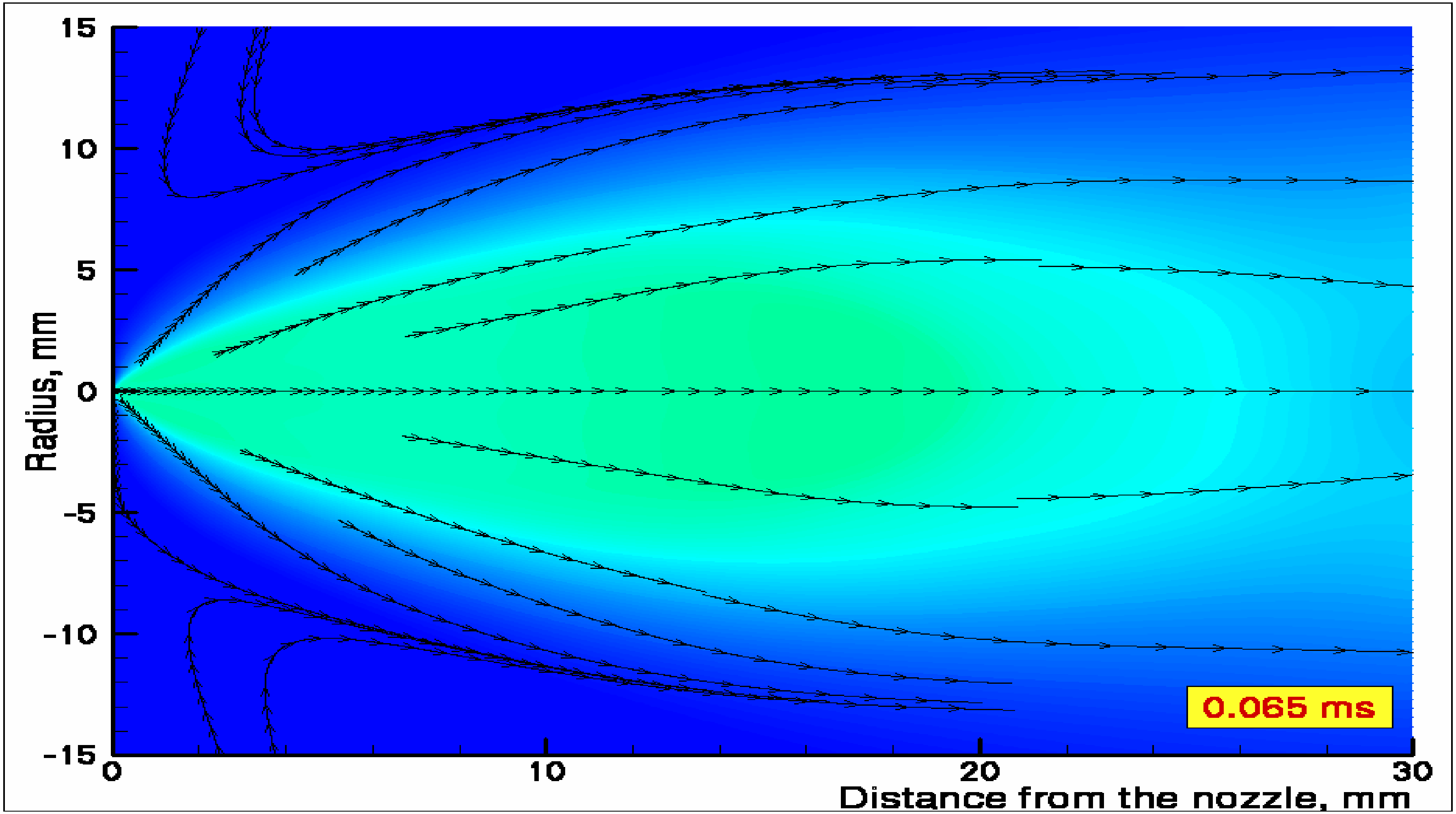
Gas-jet pulse development

Helium gas-jet velocity profile



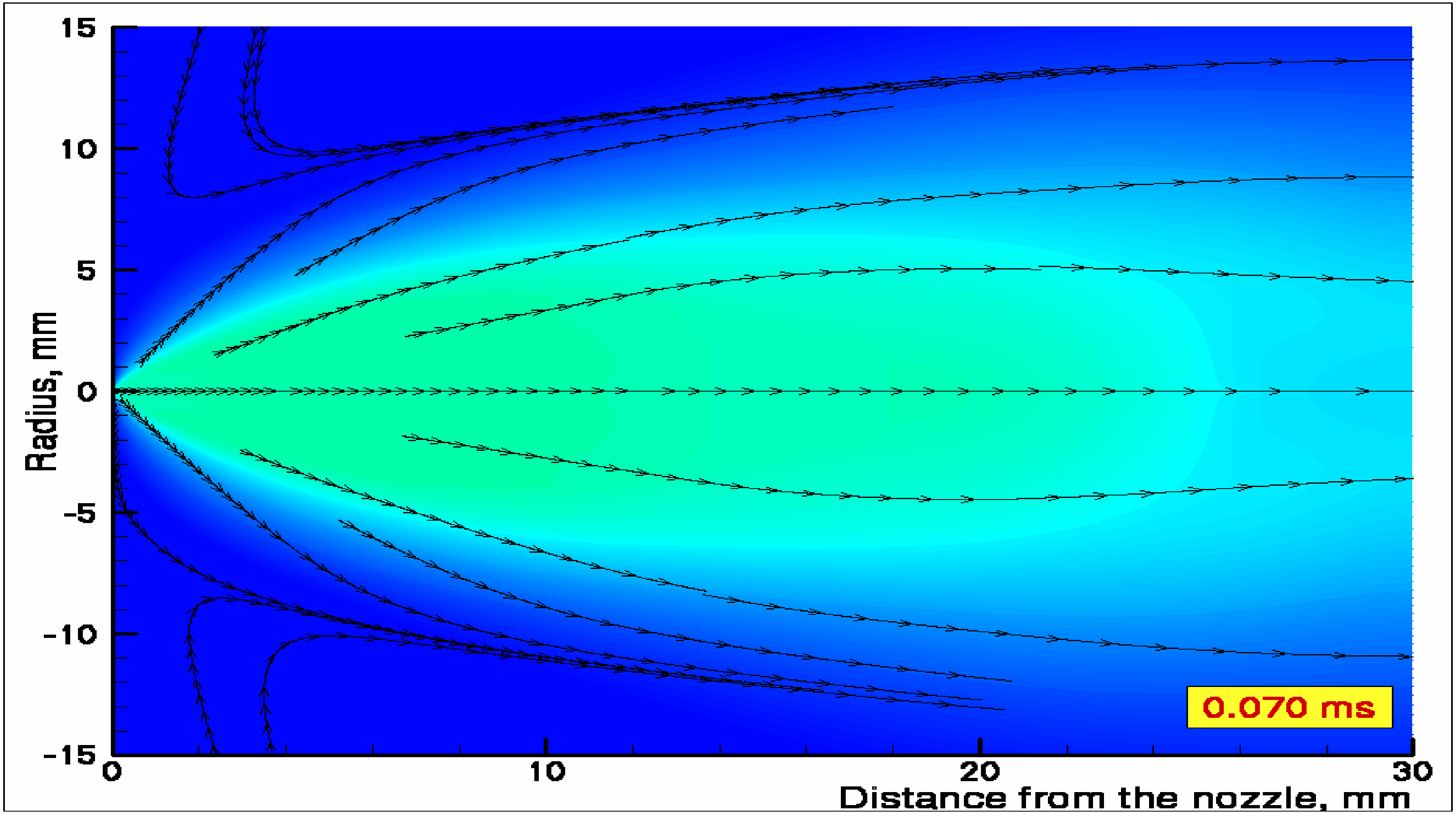
Gas-jet pulse development

Helium gas-jet velocity profile



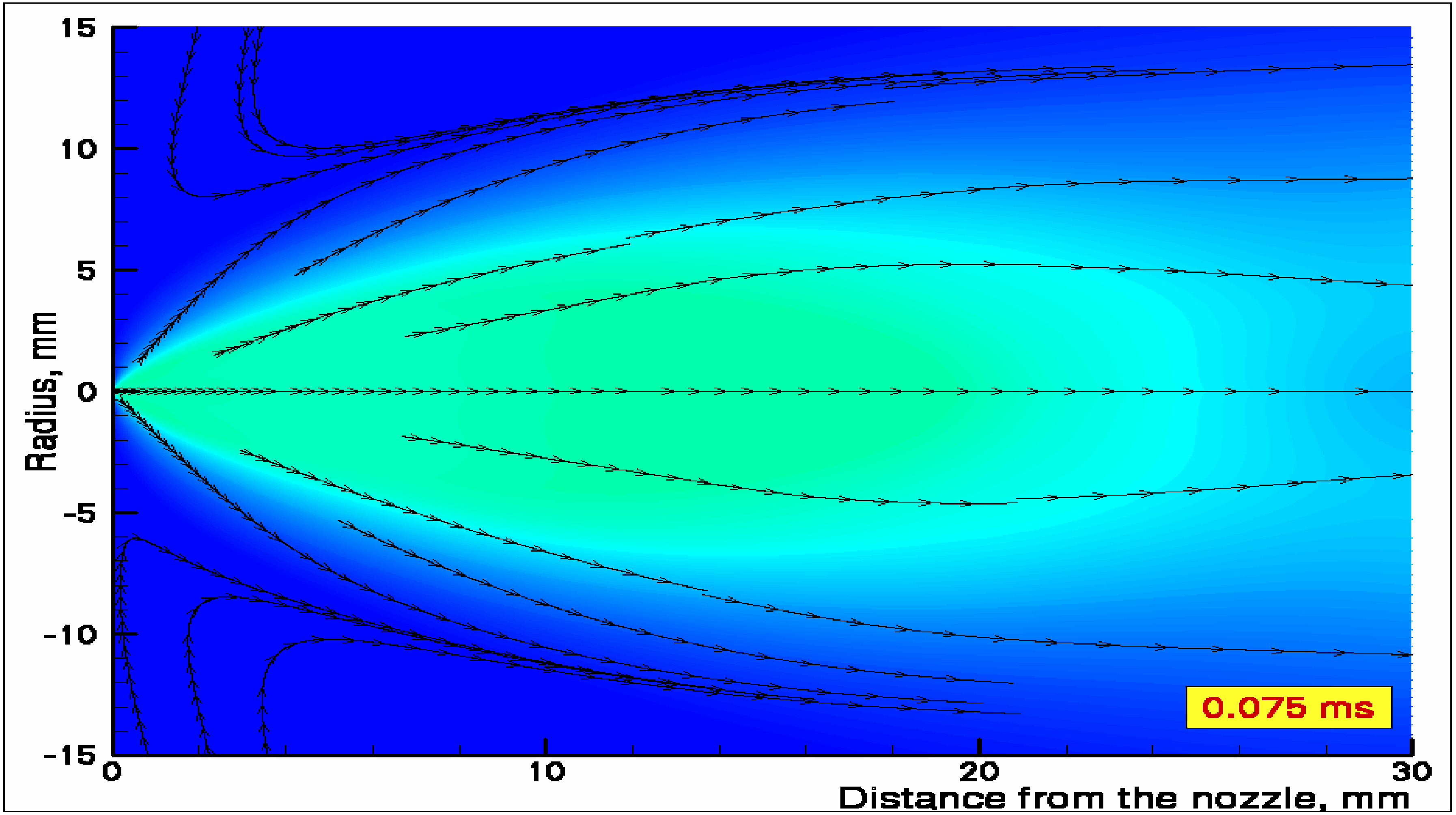
Gas-jet pulse development

Helium gas-jet velocity profile



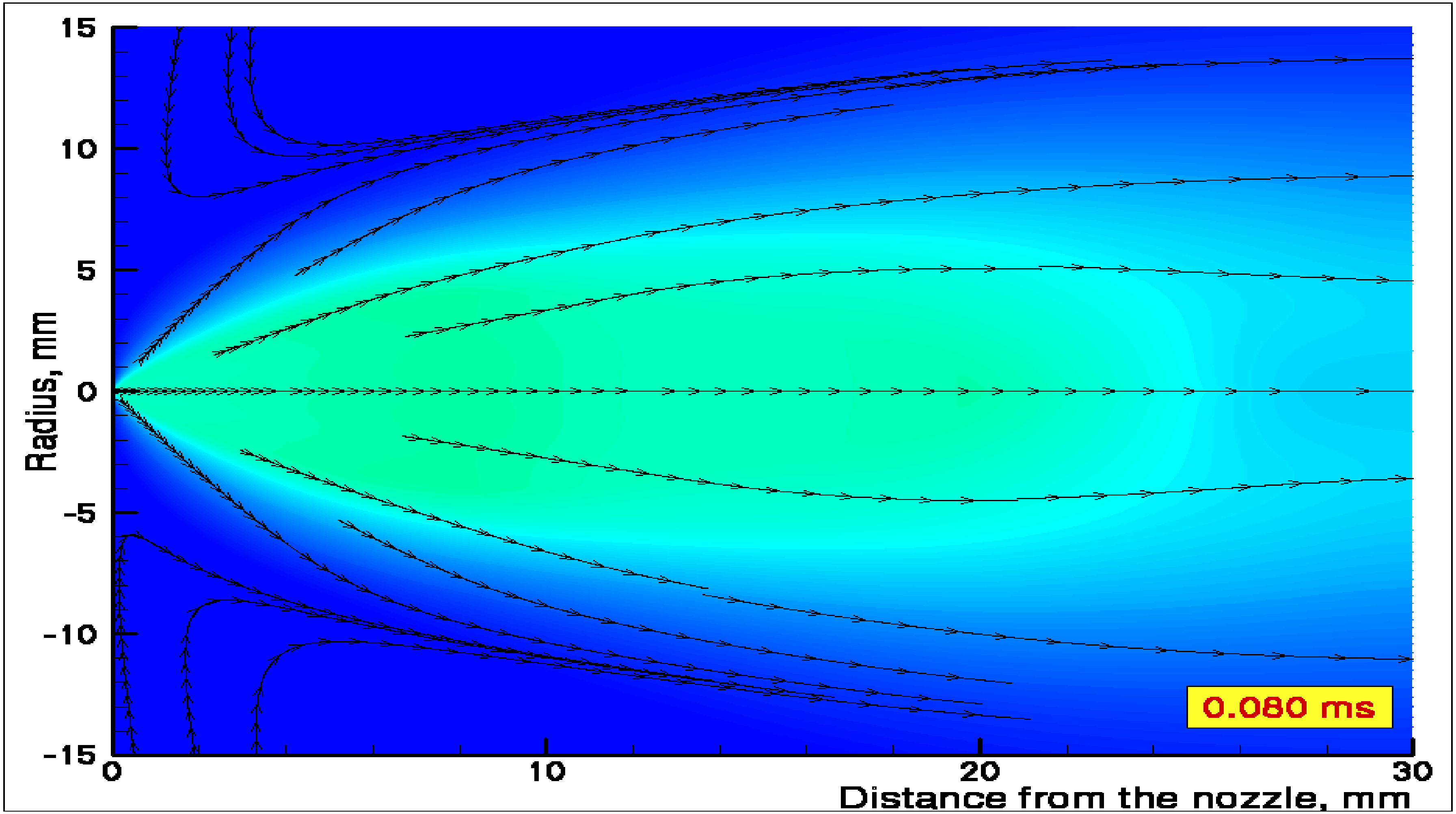
Gas-jet pulse development

Helium gas-jet velocity profile



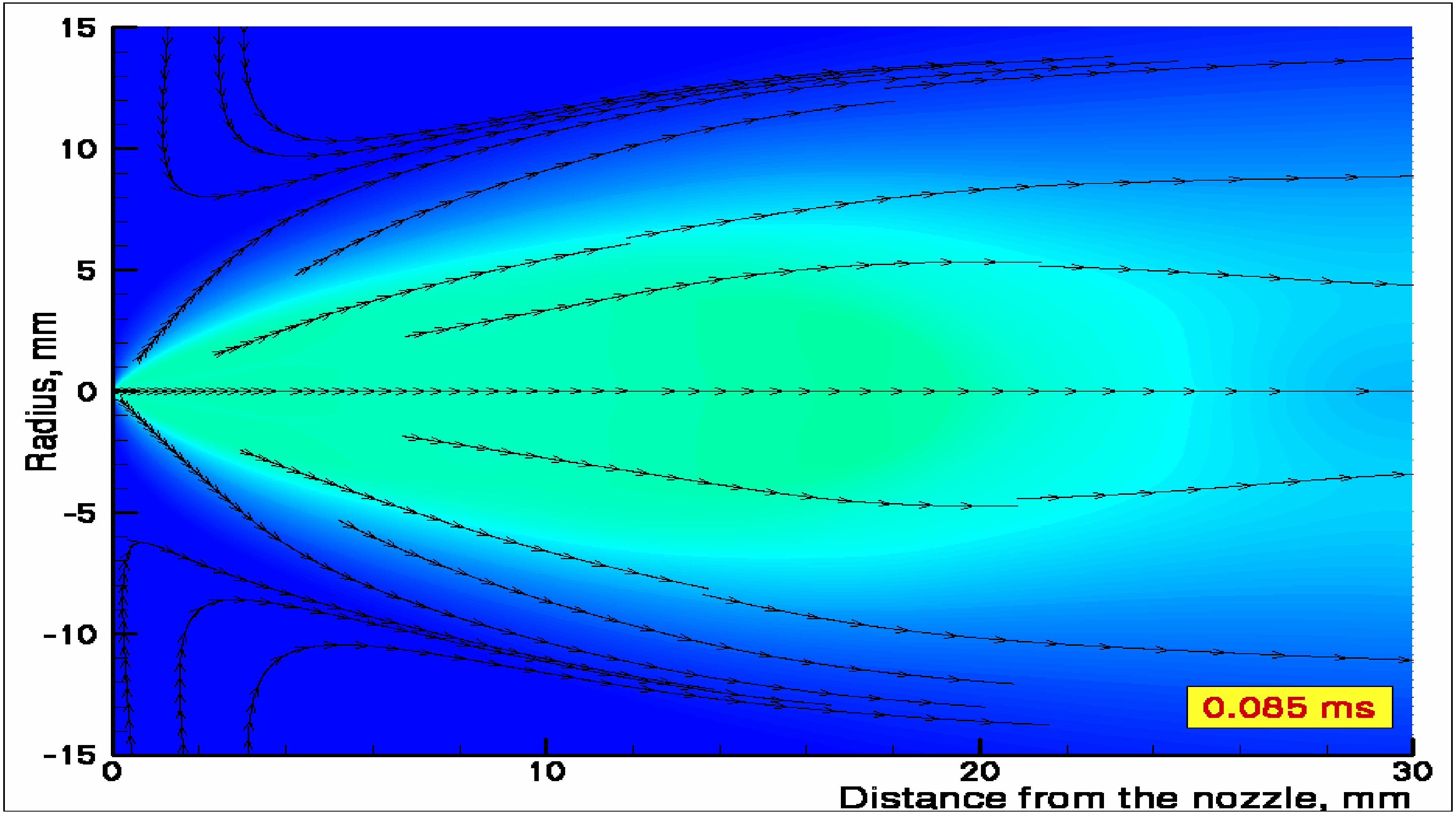
Gas-jet pulse development

Helium gas-jet velocity profile



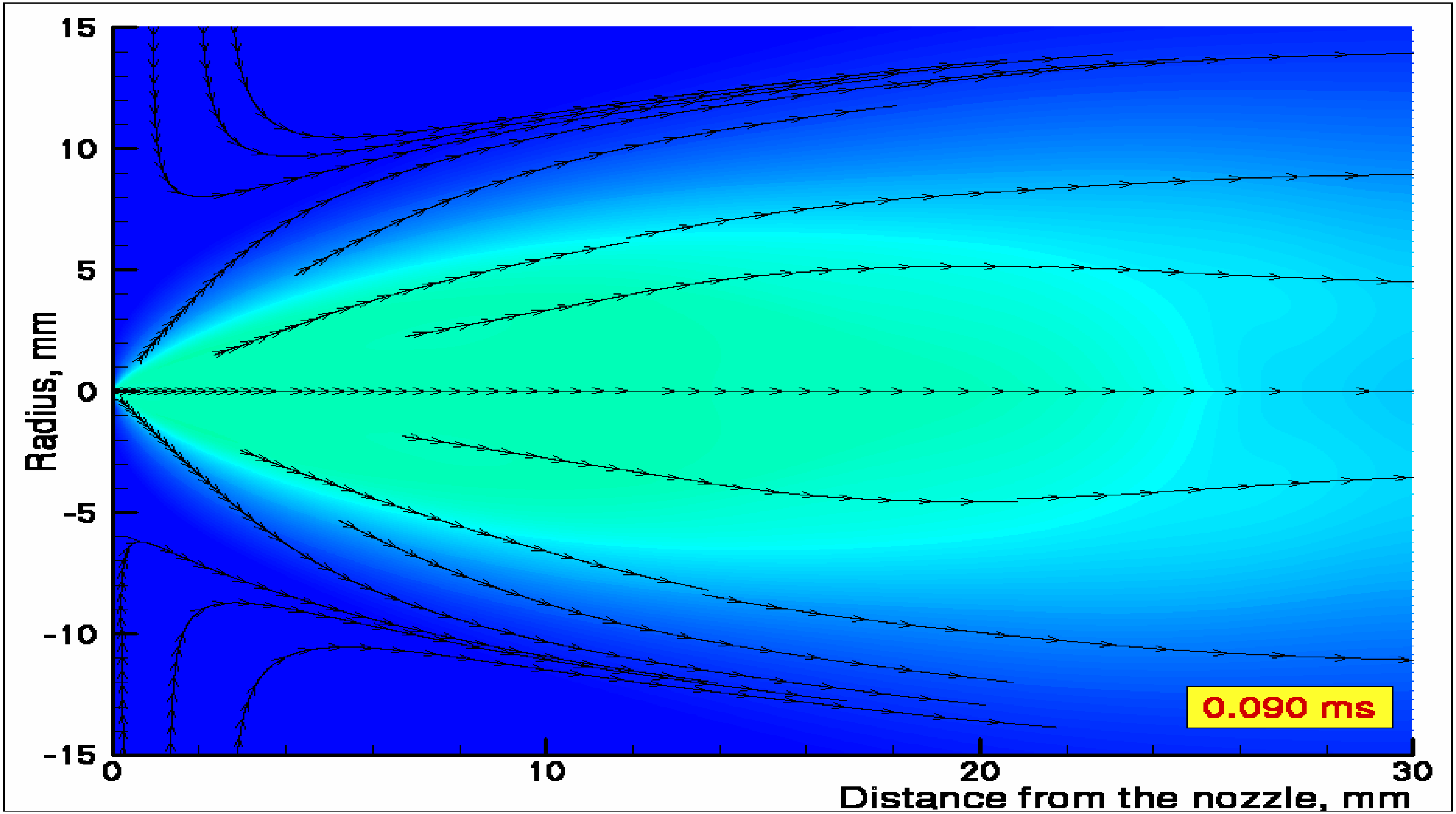
Gas-jet pulse development

Helium gas-jet velocity profile



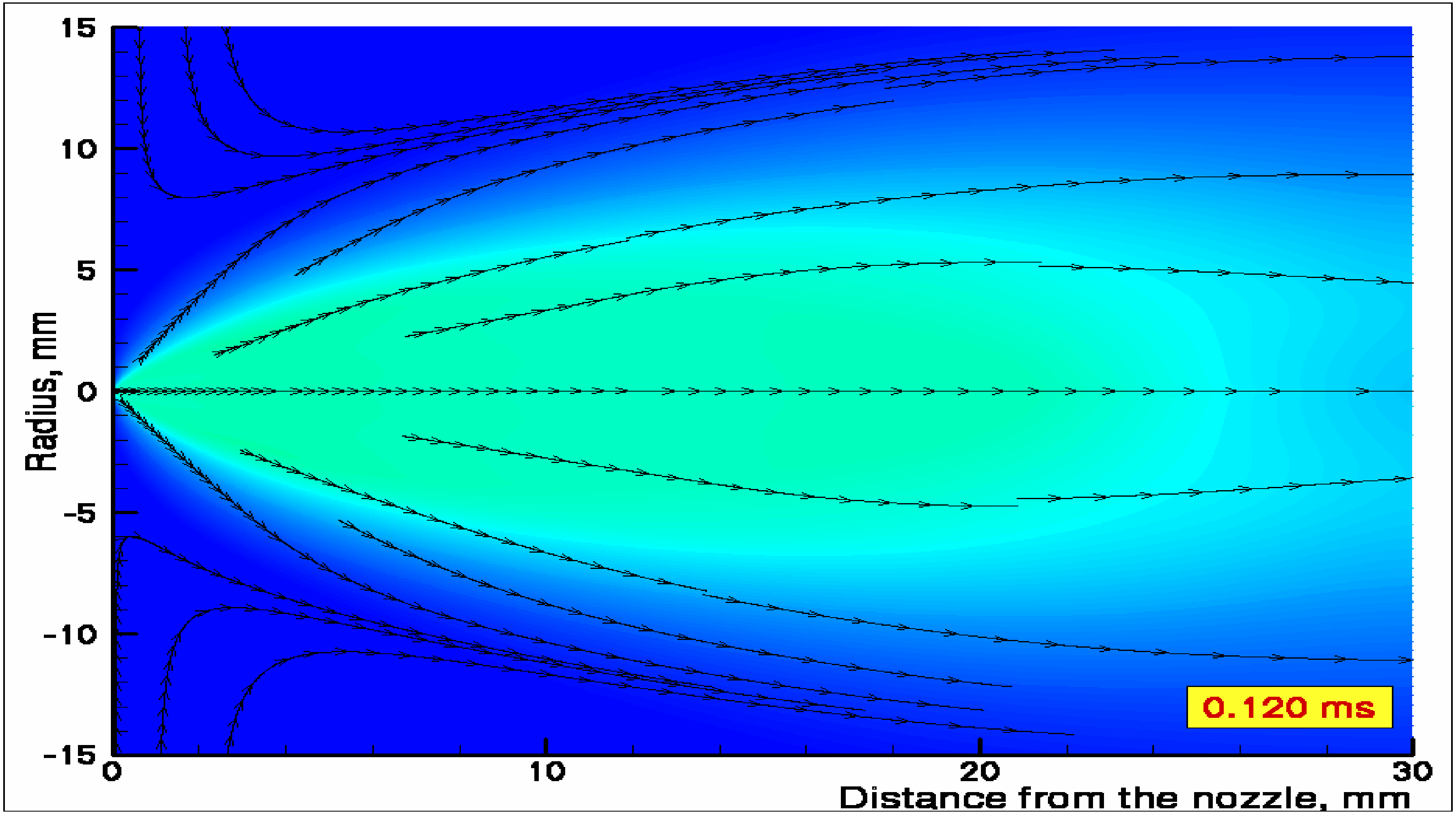
Gas-jet pulse development

Helium gas-jet velocity profile



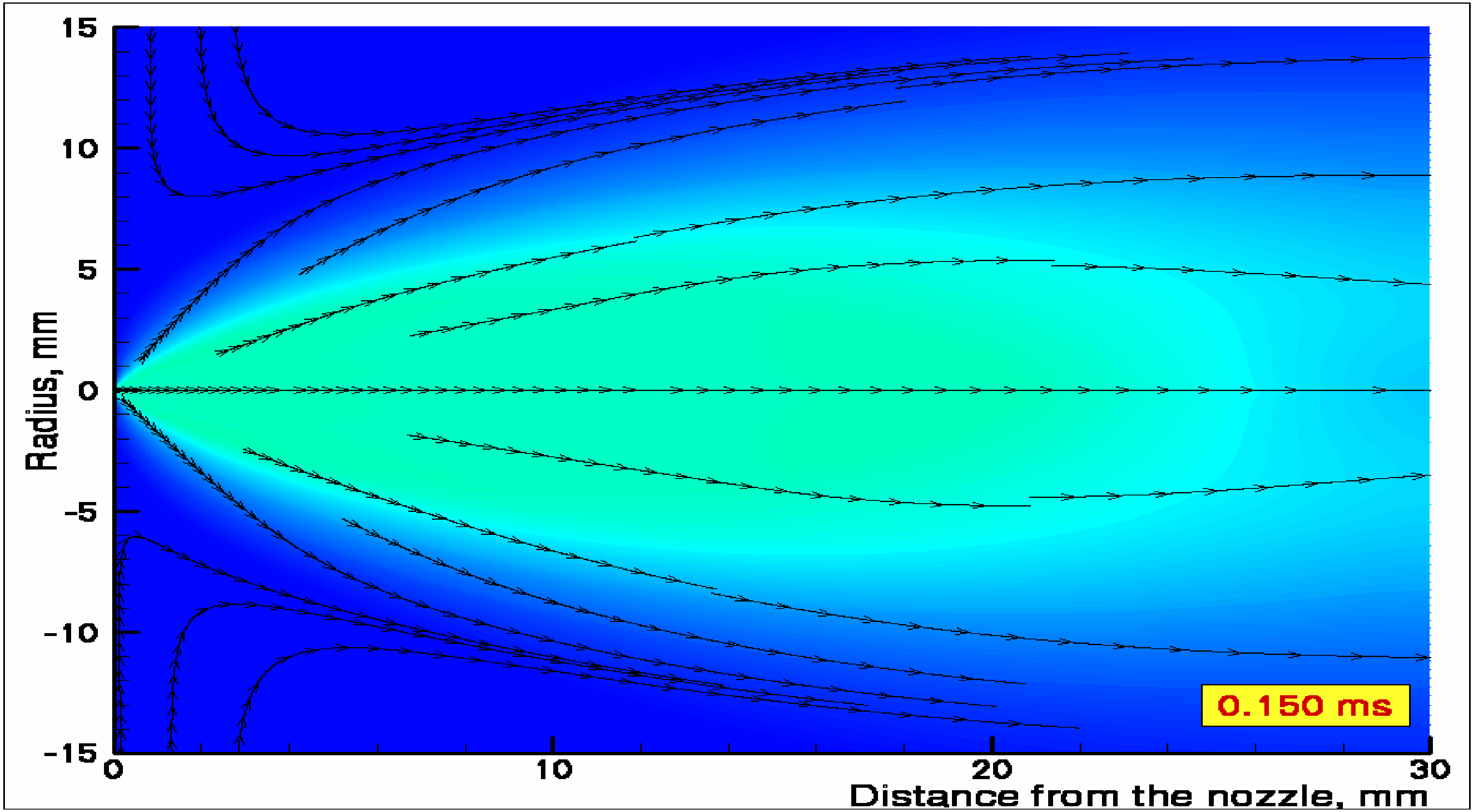
Gas-jet pulse development

Helium gas-jet velocity profile



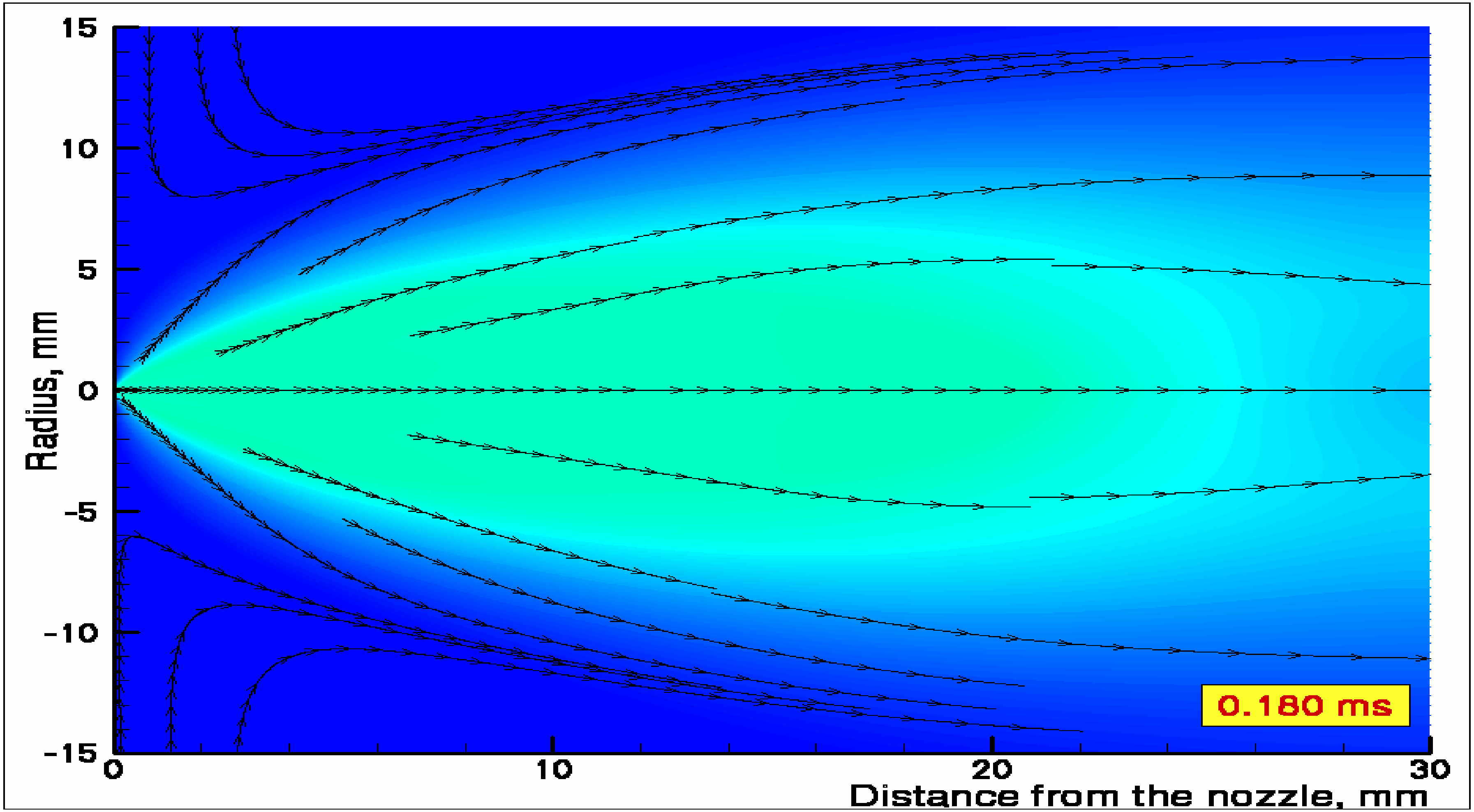
Gas-jet pulse development

Helium gas-jet velocity profile



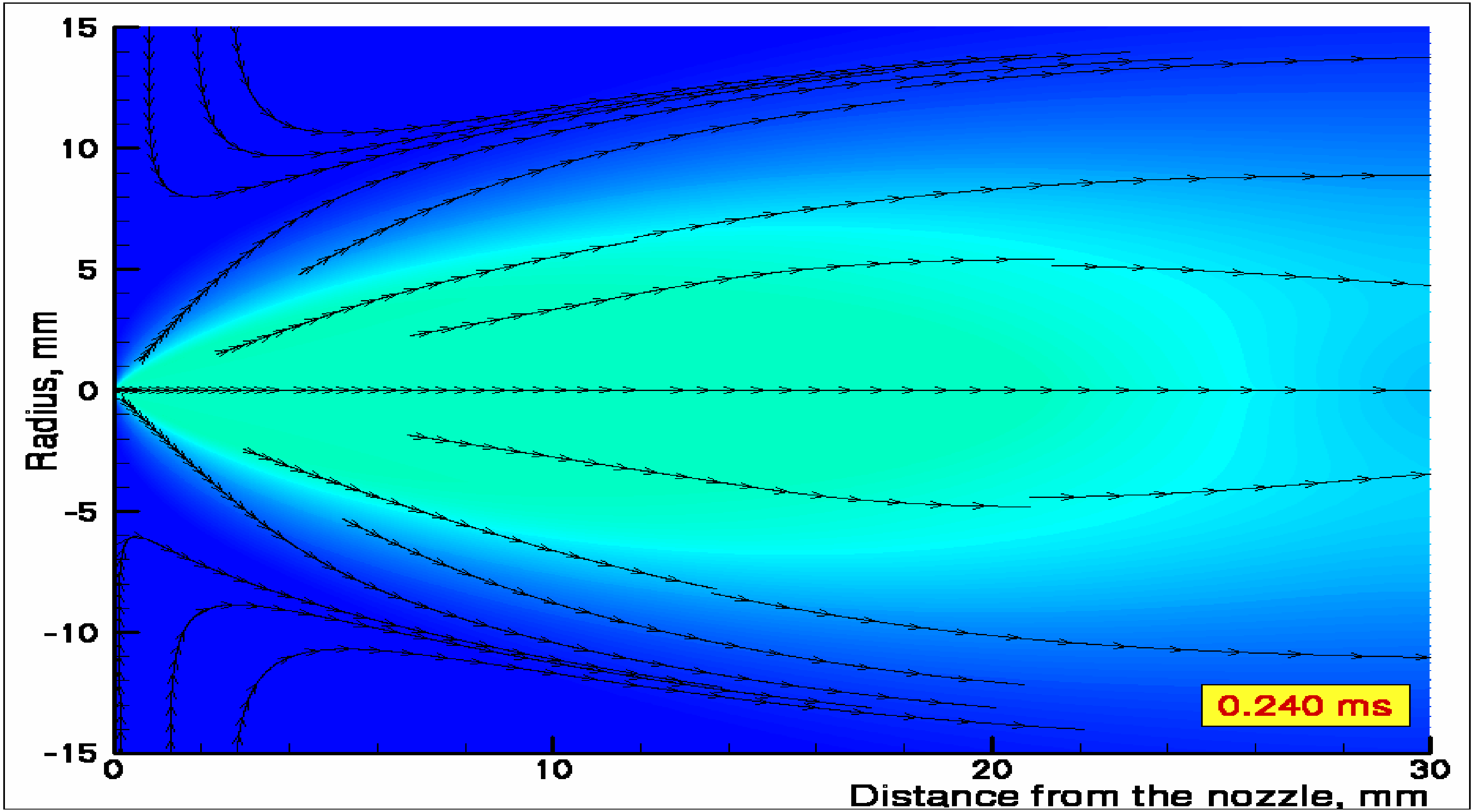
Gas-jet pulse development

Helium gas-jet velocity profile



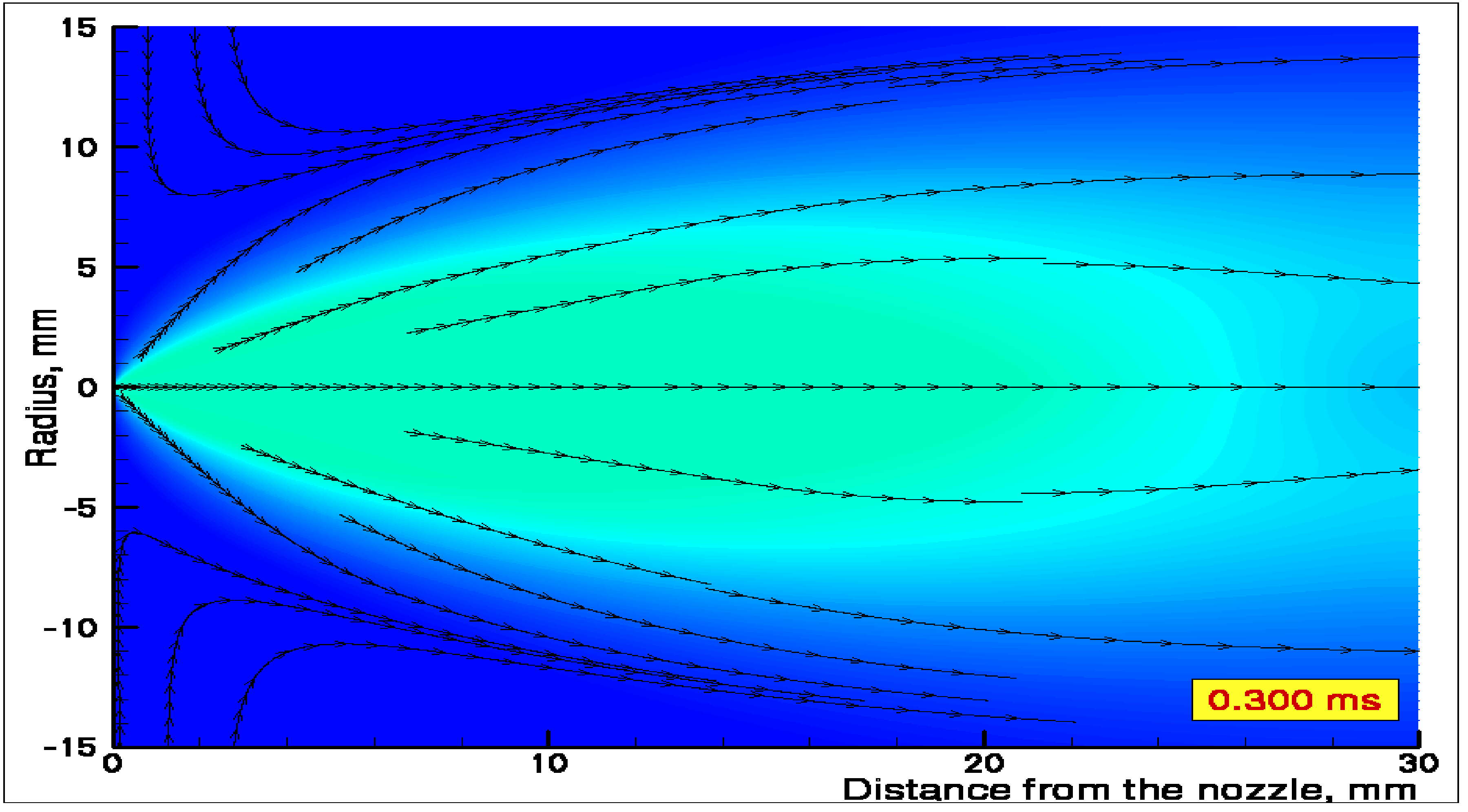
Gas-jet pulse development

Helium gas-jet velocity profile



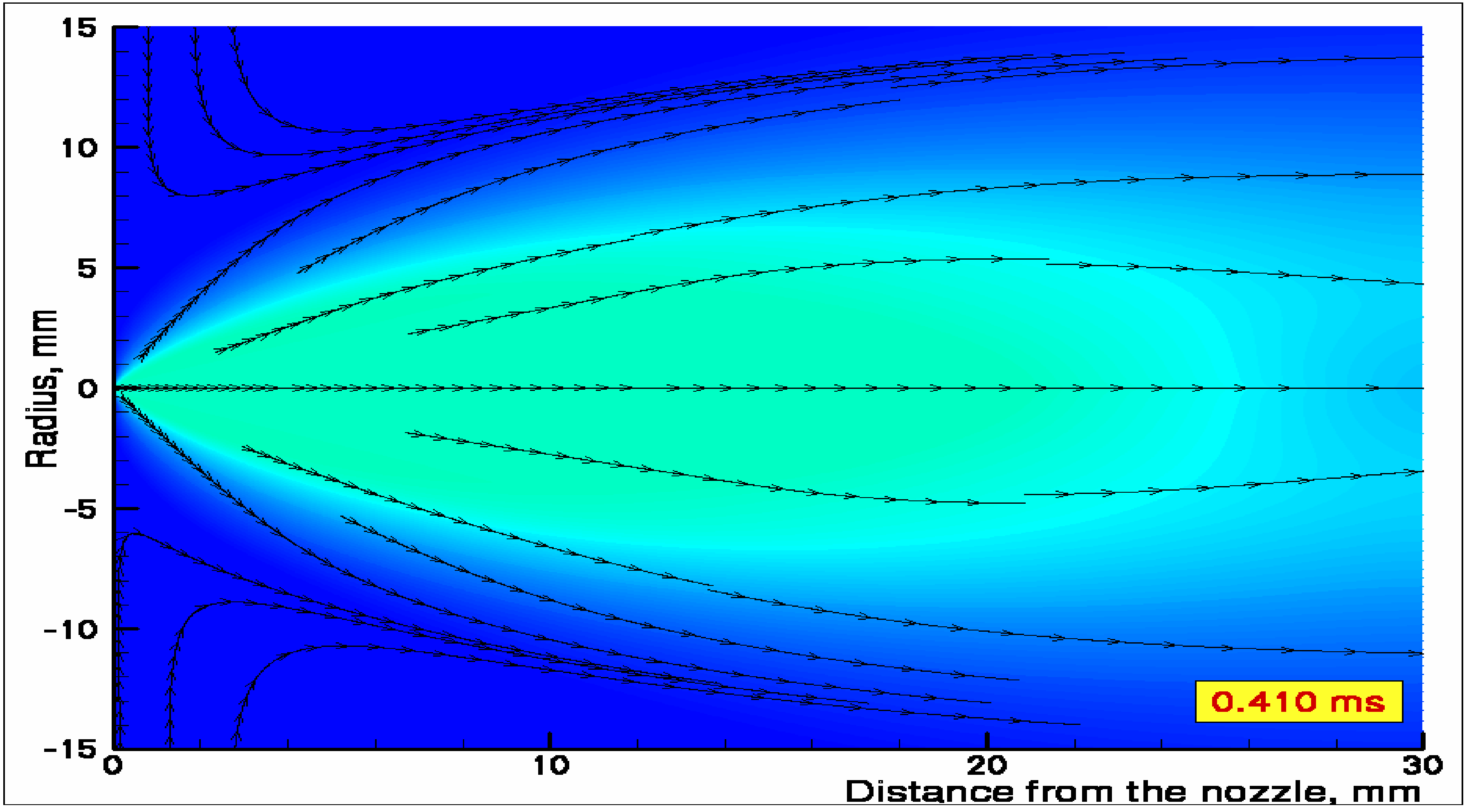
Gas-jet pulse development

Helium gas-jet velocity profile



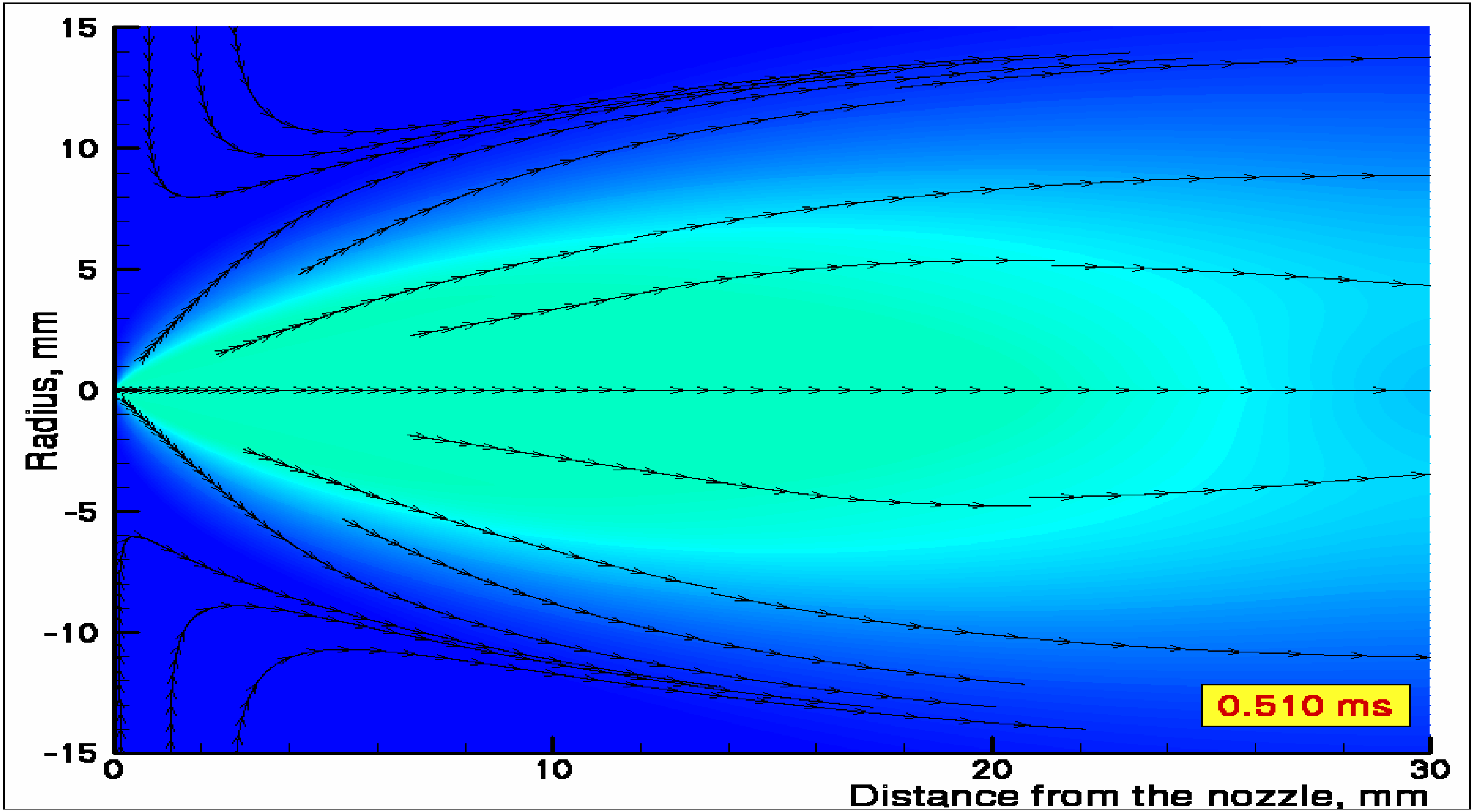
Gas-jet pulse development

Helium gas-jet velocity profile



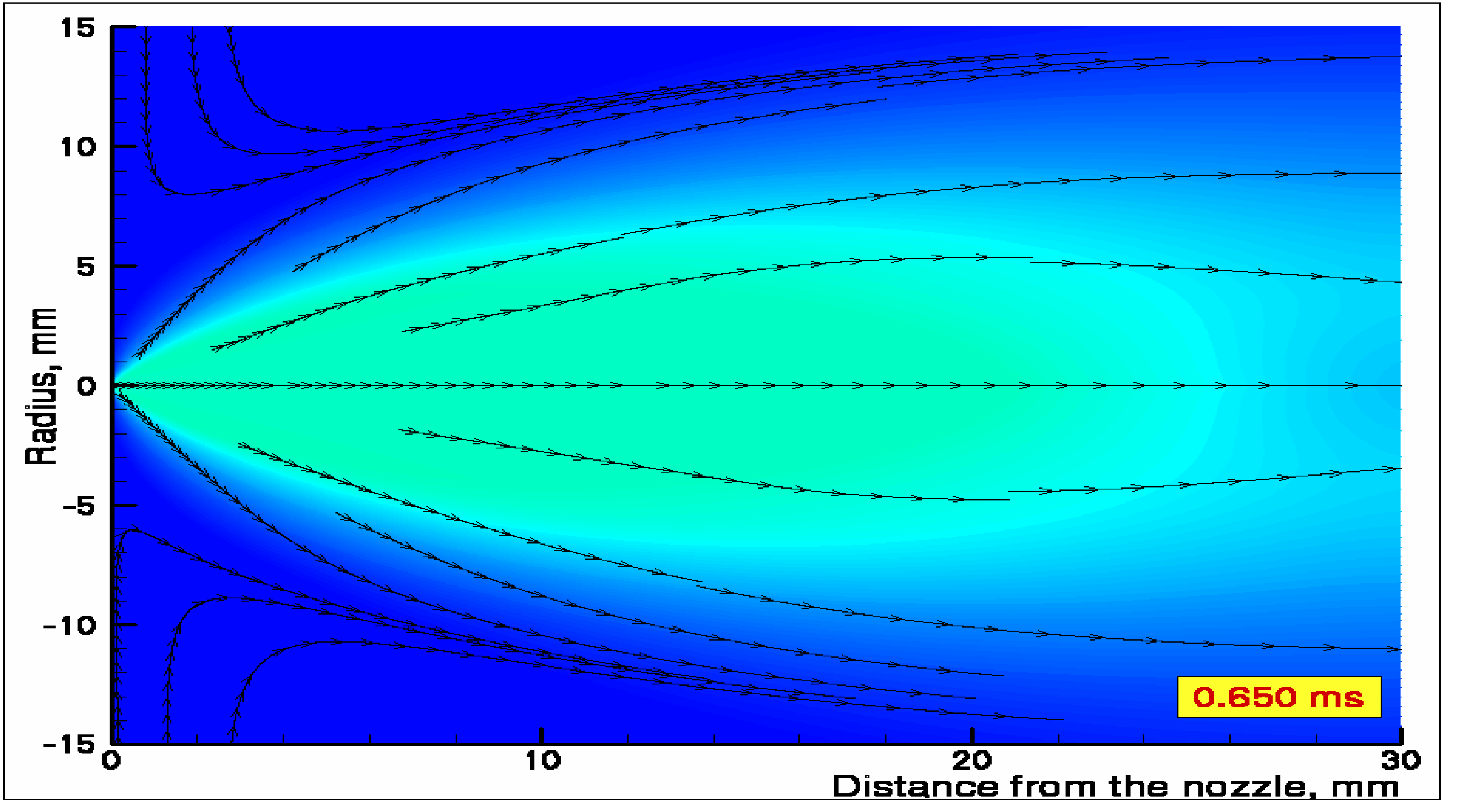
Gas-jet pulse development

Helium gas-jet velocity profile



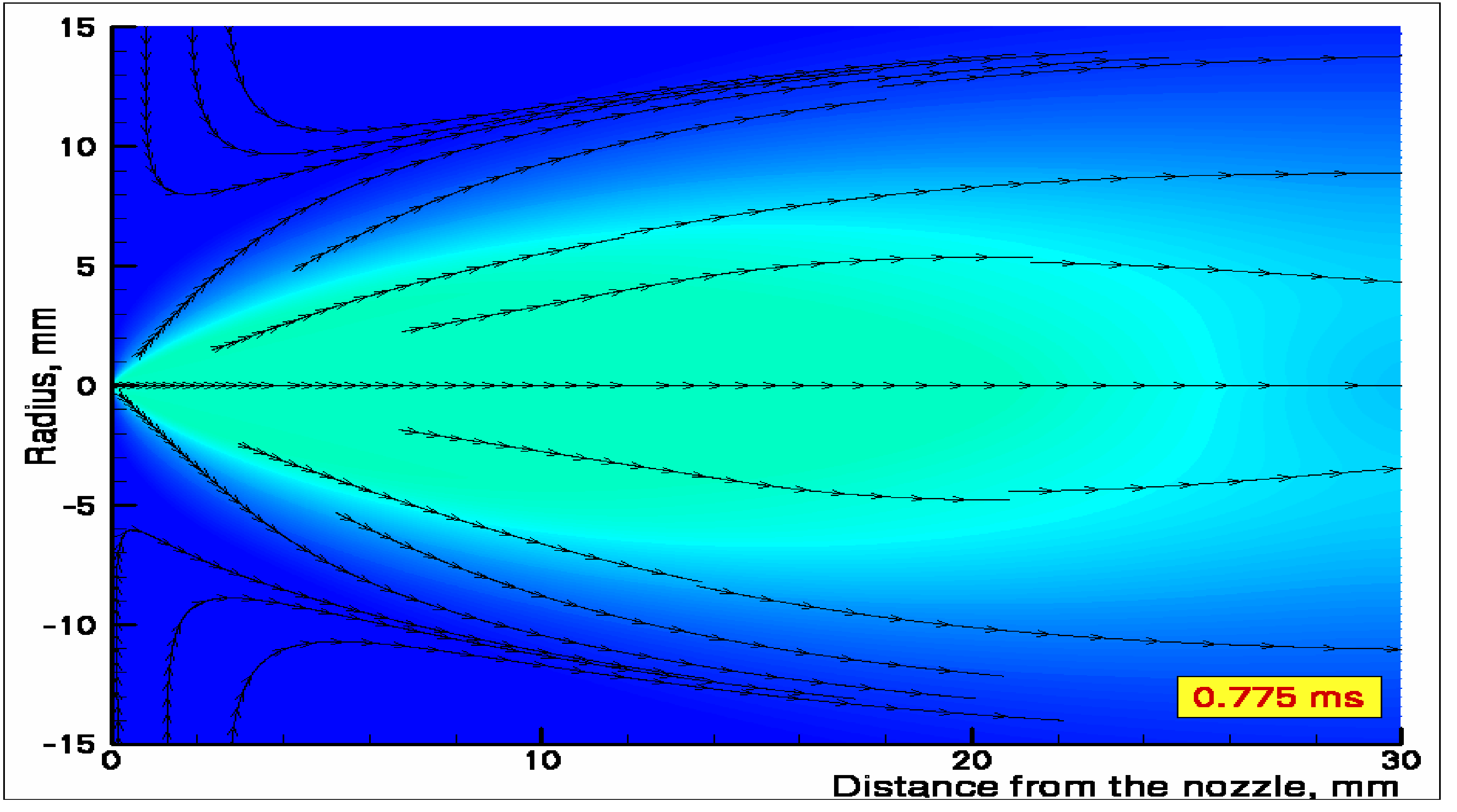
Gas-jet pulse development

Helium gas-jet velocity profile



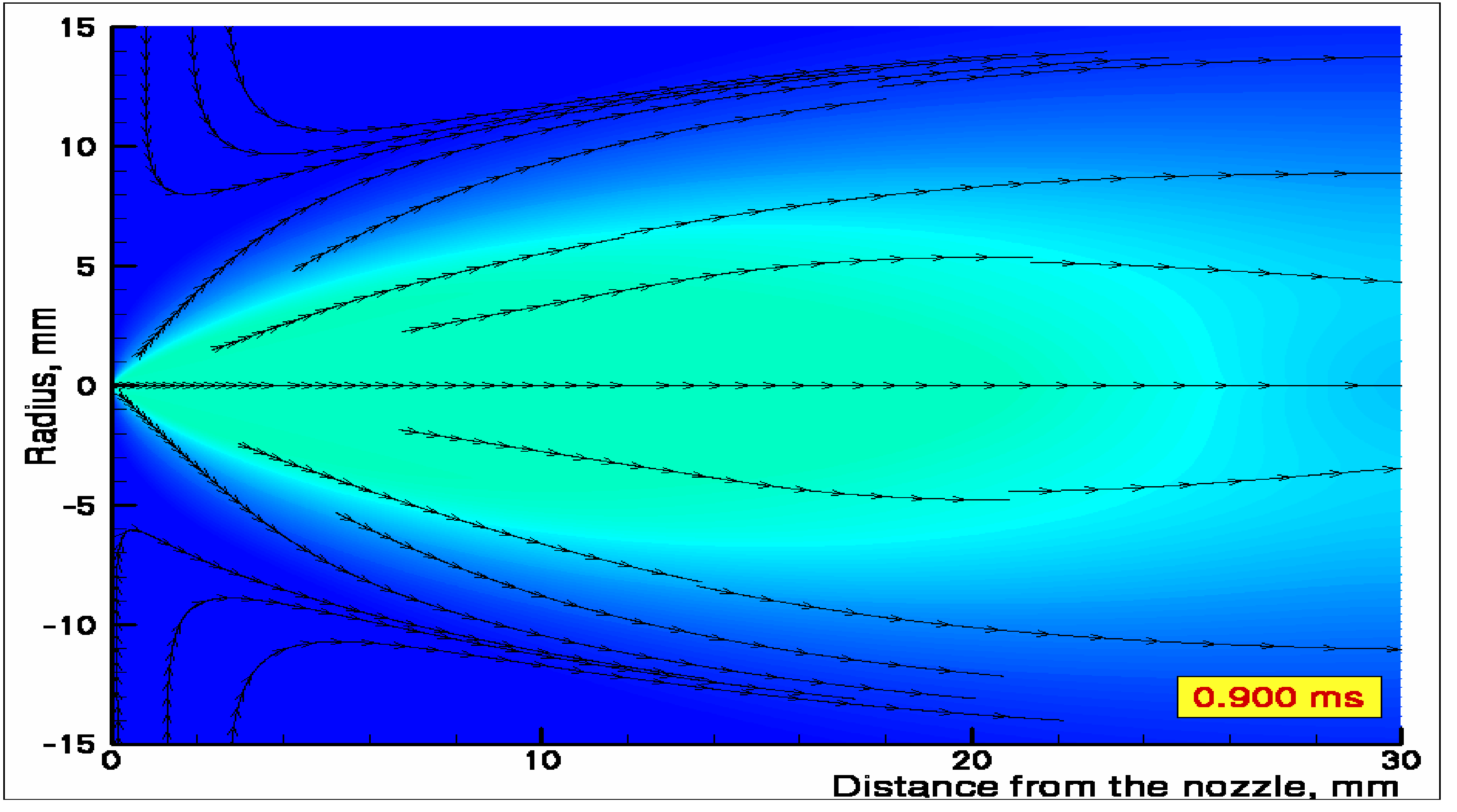
Gas-jet pulse development

Helium gas-jet velocity profile



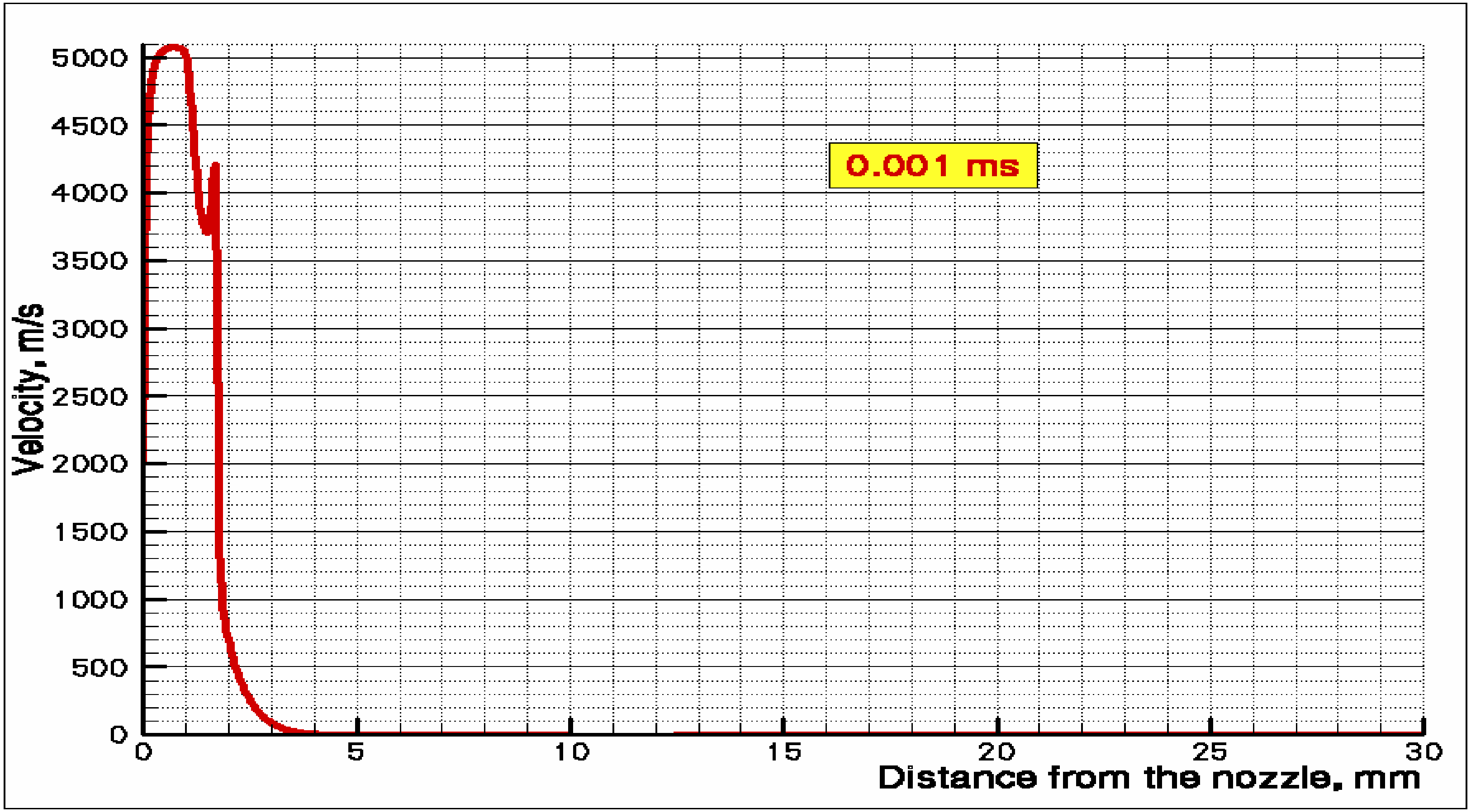
Gas-jet pulse development

Helium gas-jet velocity profile



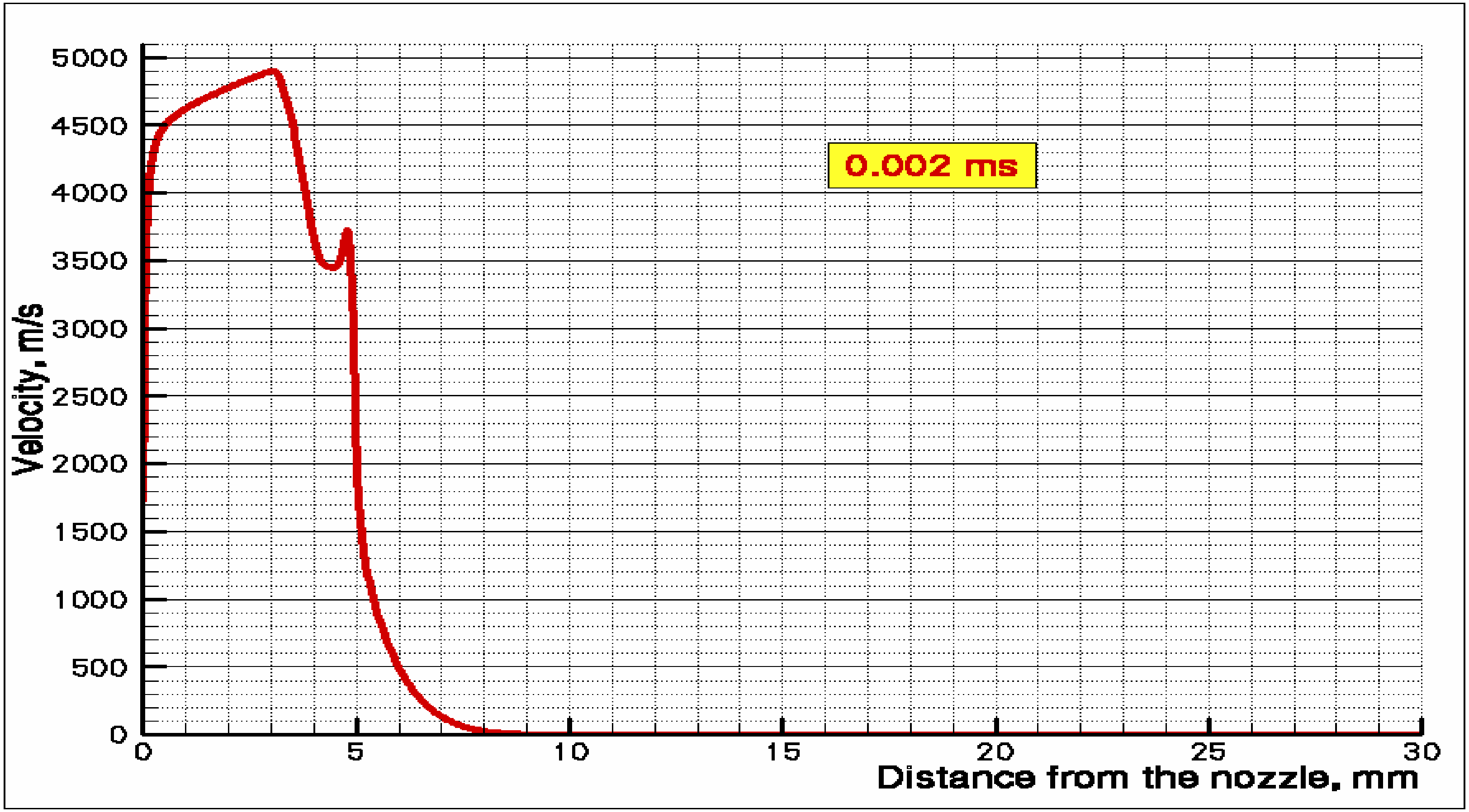
Gas-jet pulse development

Helium gas-jet velocity along the axis



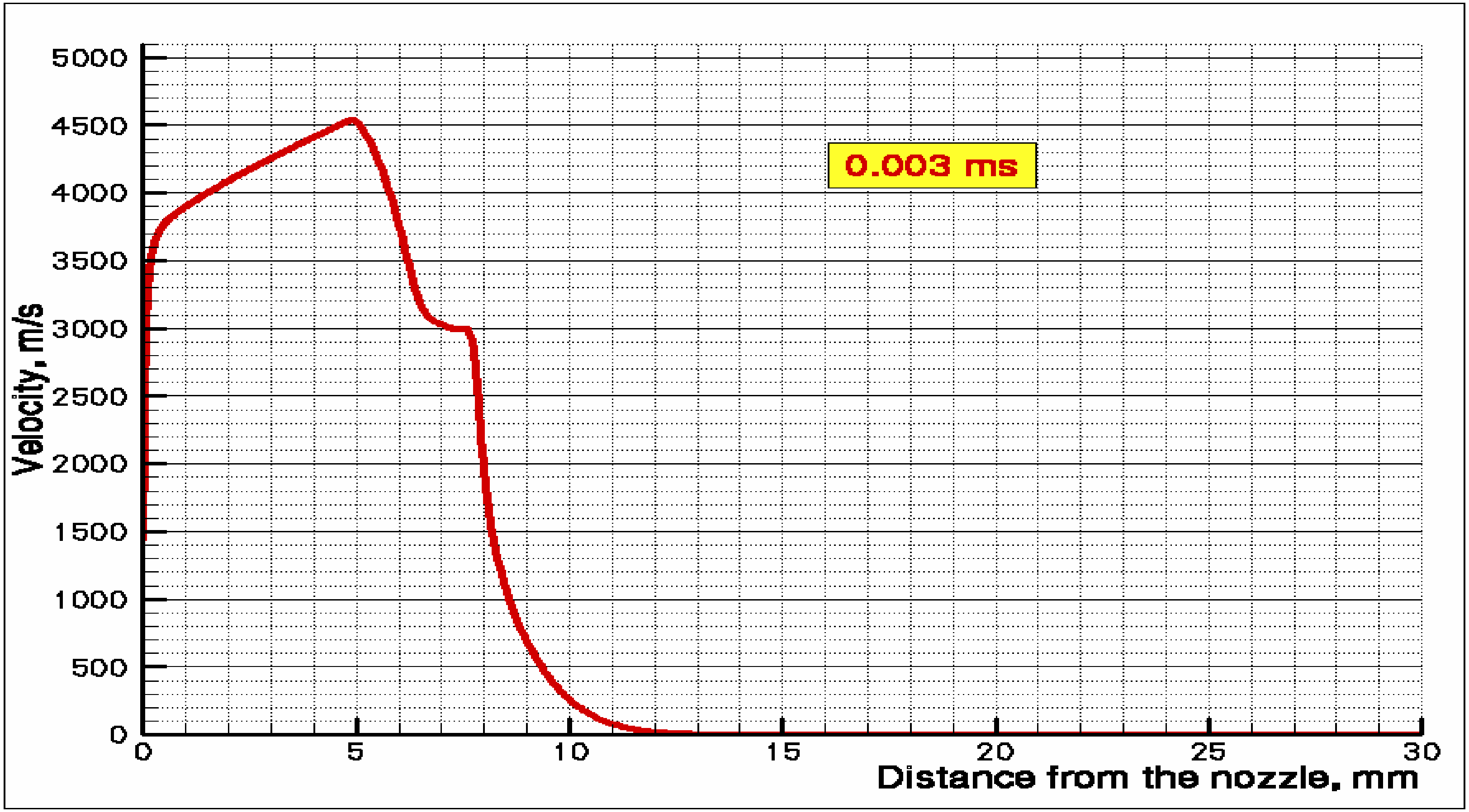
Gas-jet pulse development

Helium gas-jet velocity along the axis



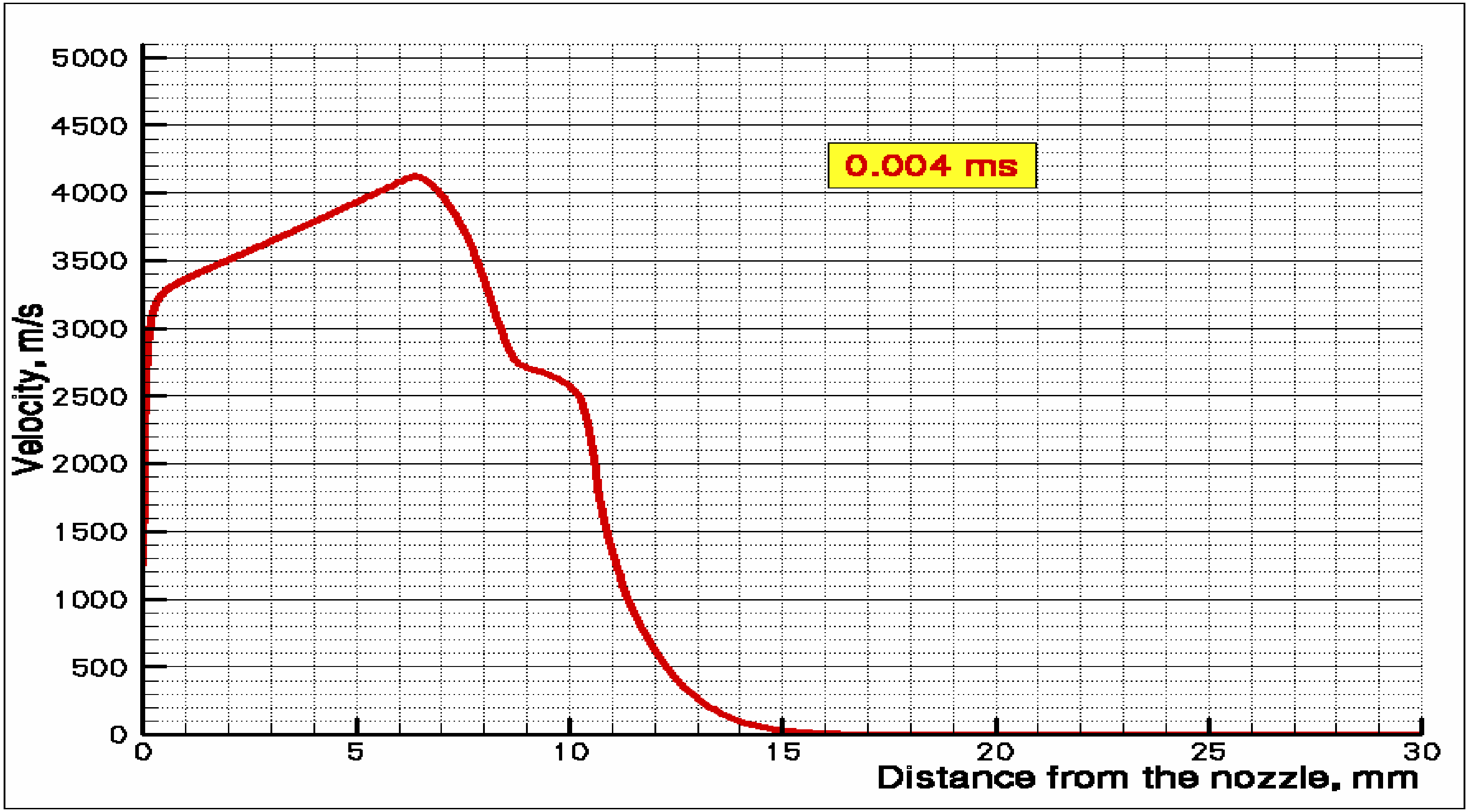
Gas-jet pulse development

Helium gas-jet velocity along the axis



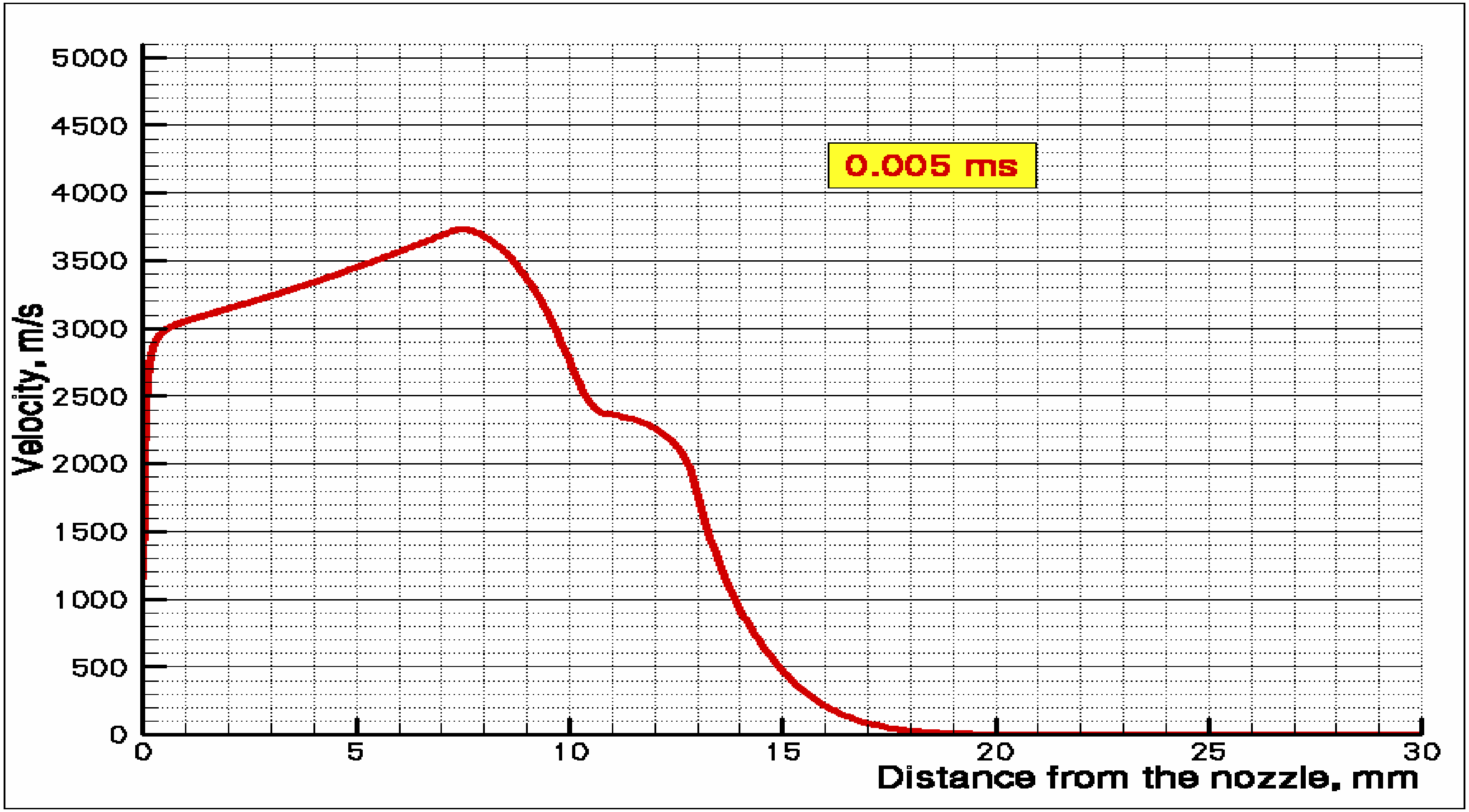
Gas-jet pulse development

Helium gas-jet velocity along the axis



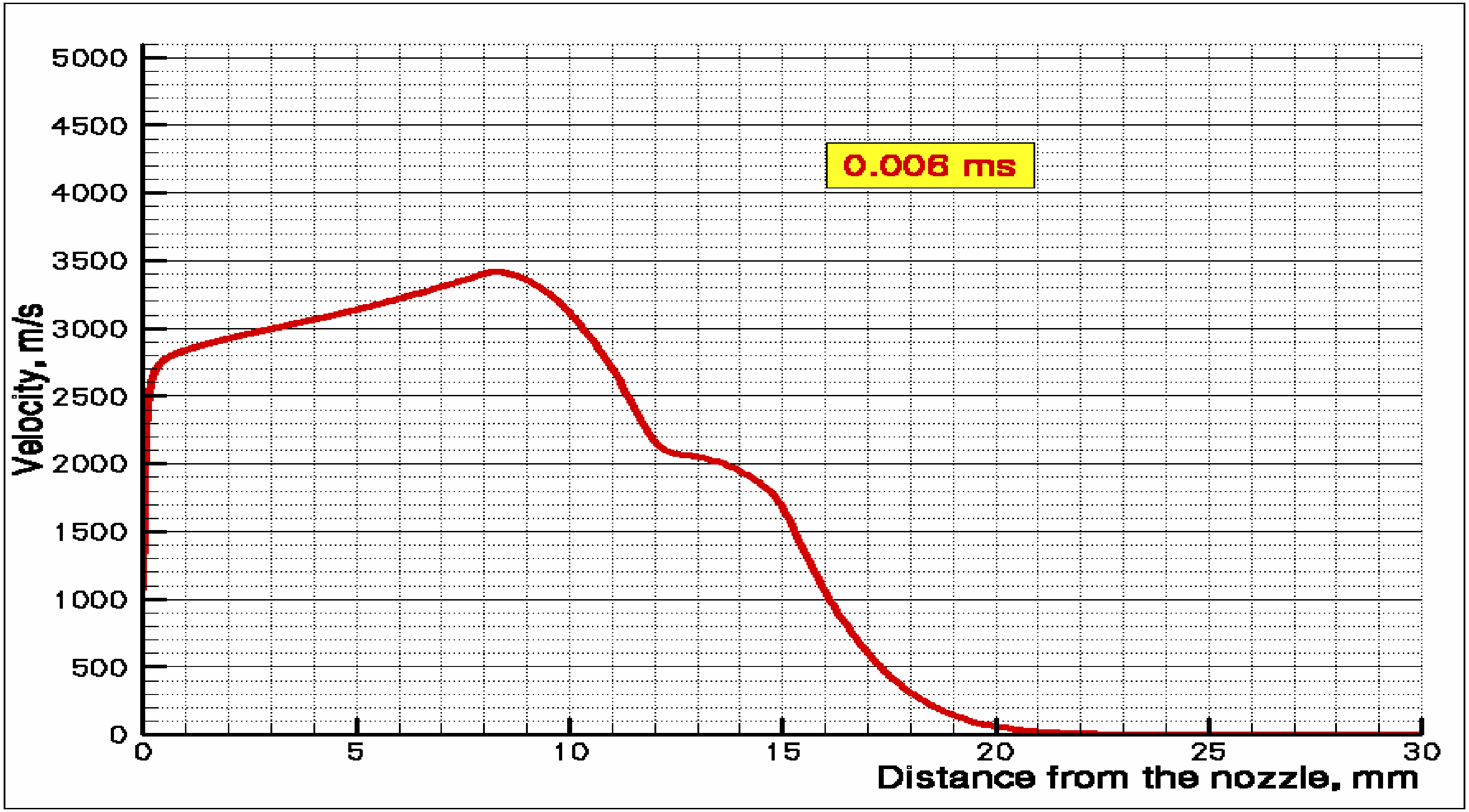
Gas-jet pulse development

Helium gas-jet velocity along the axis



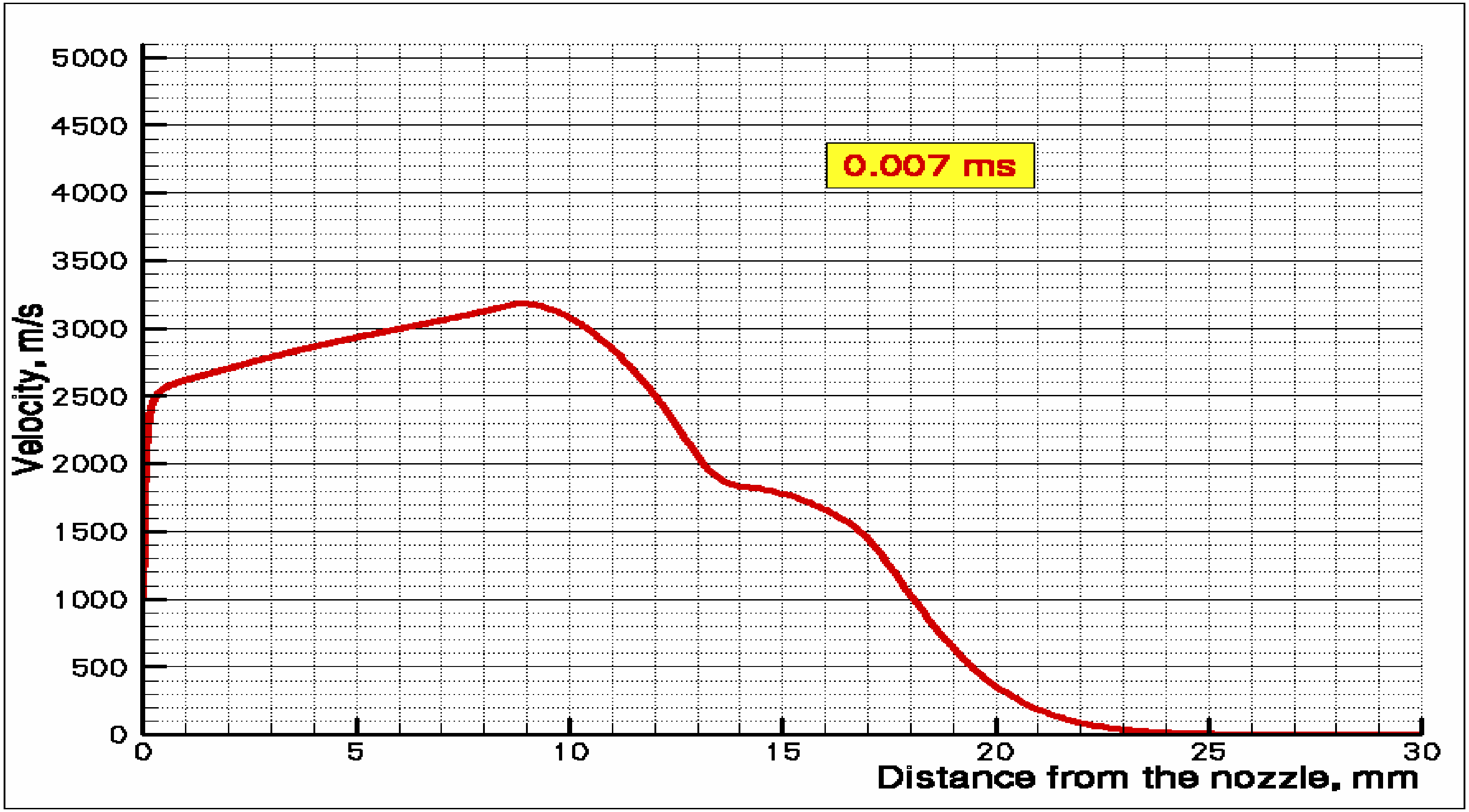
Gas-jet pulse development

Helium gas-jet velocity along the axis



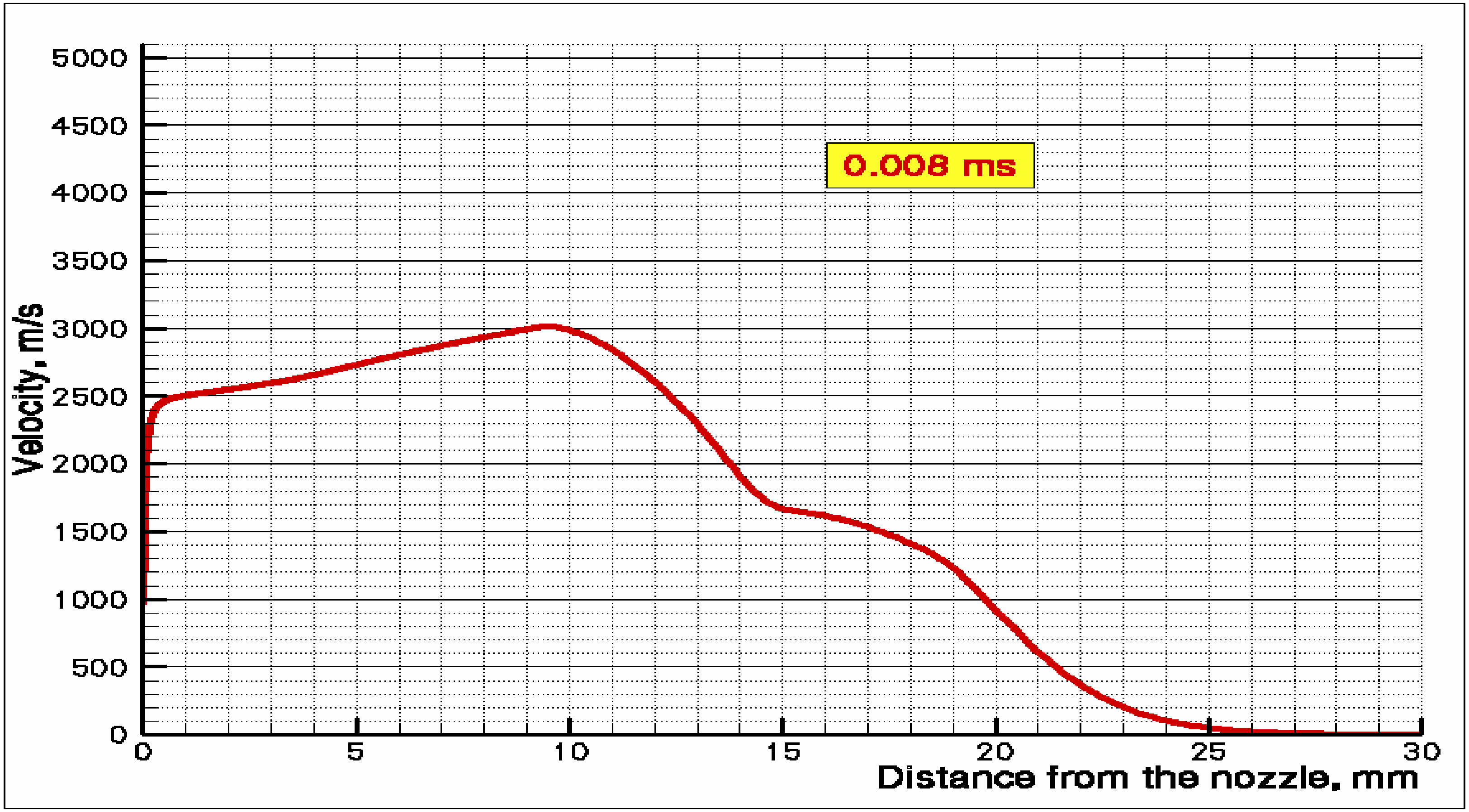
Gas-jet pulse development

Helium gas-jet velocity along the axis



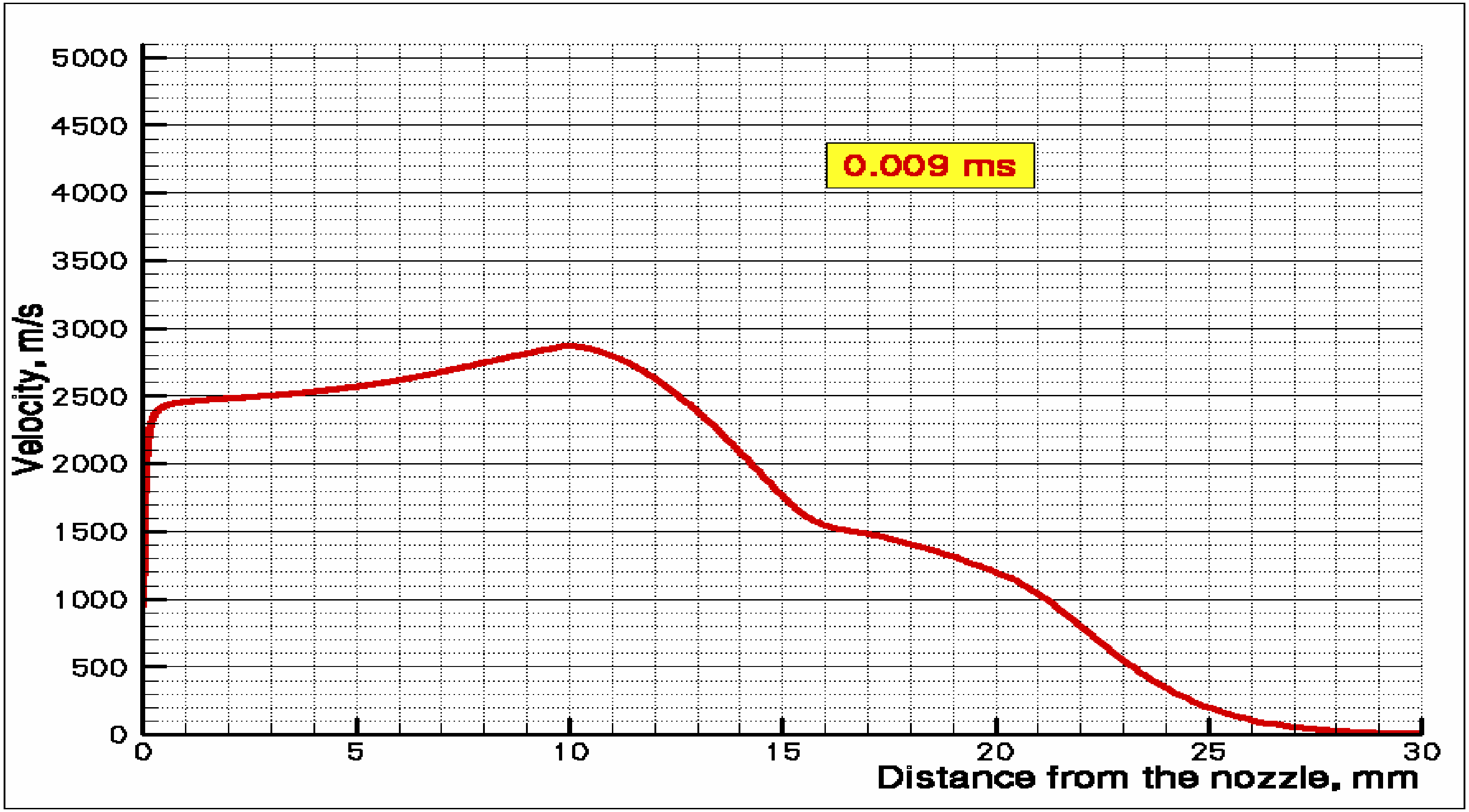
Gas-jet pulse development

Helium gas-jet velocity along the axis



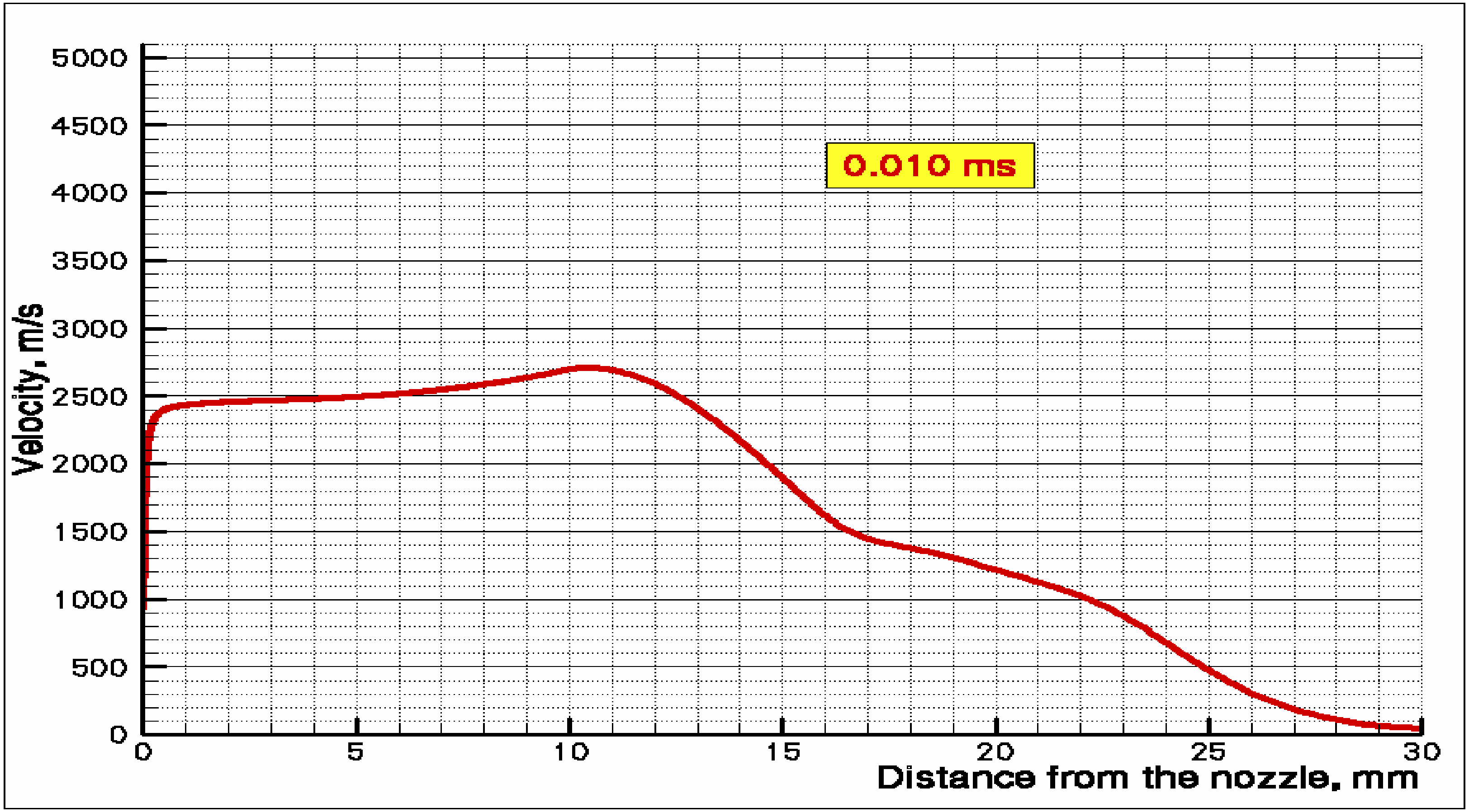
Gas-jet pulse development

Helium gas-jet velocity along the axis



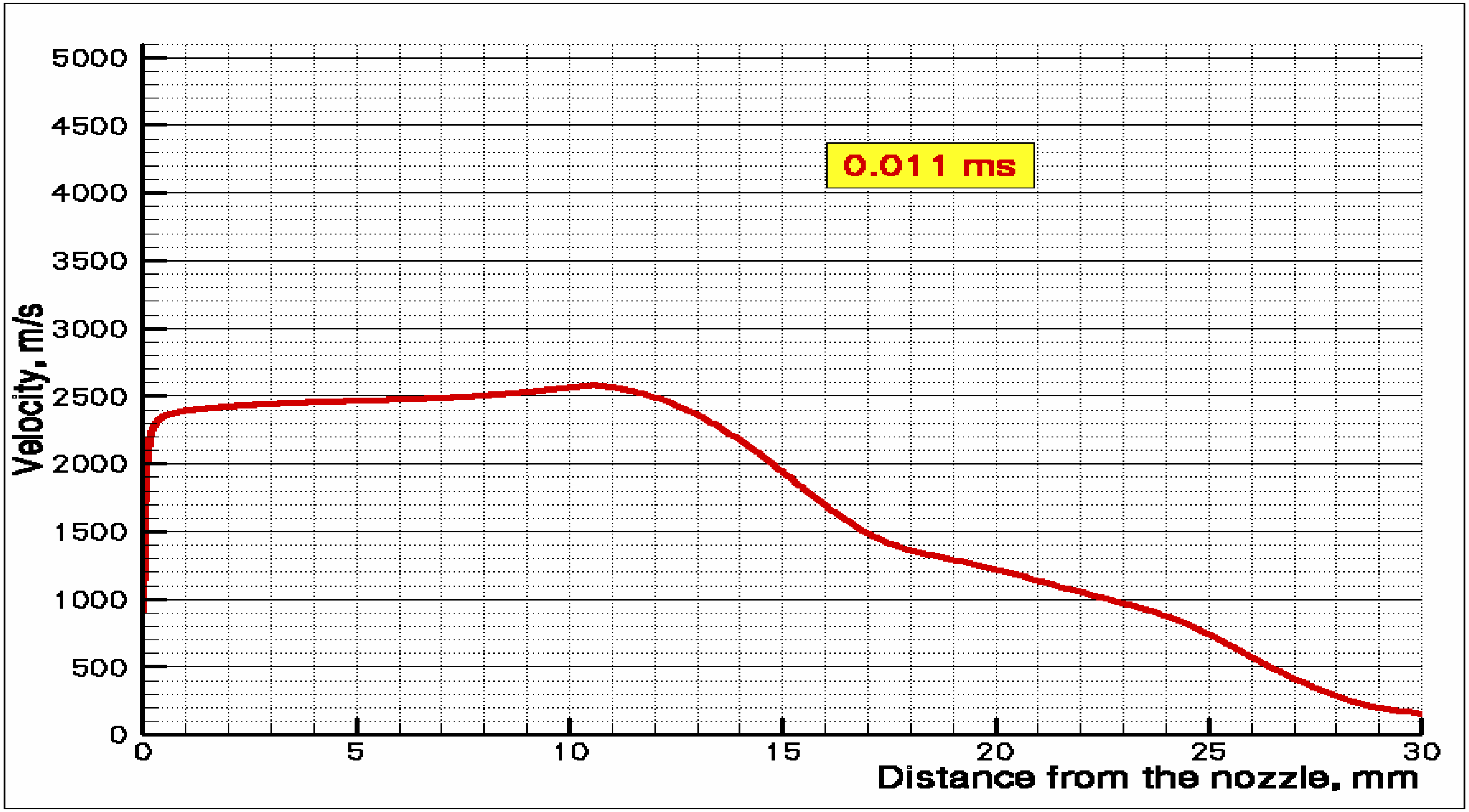
Gas-jet pulse development

Helium gas-jet velocity along the axis



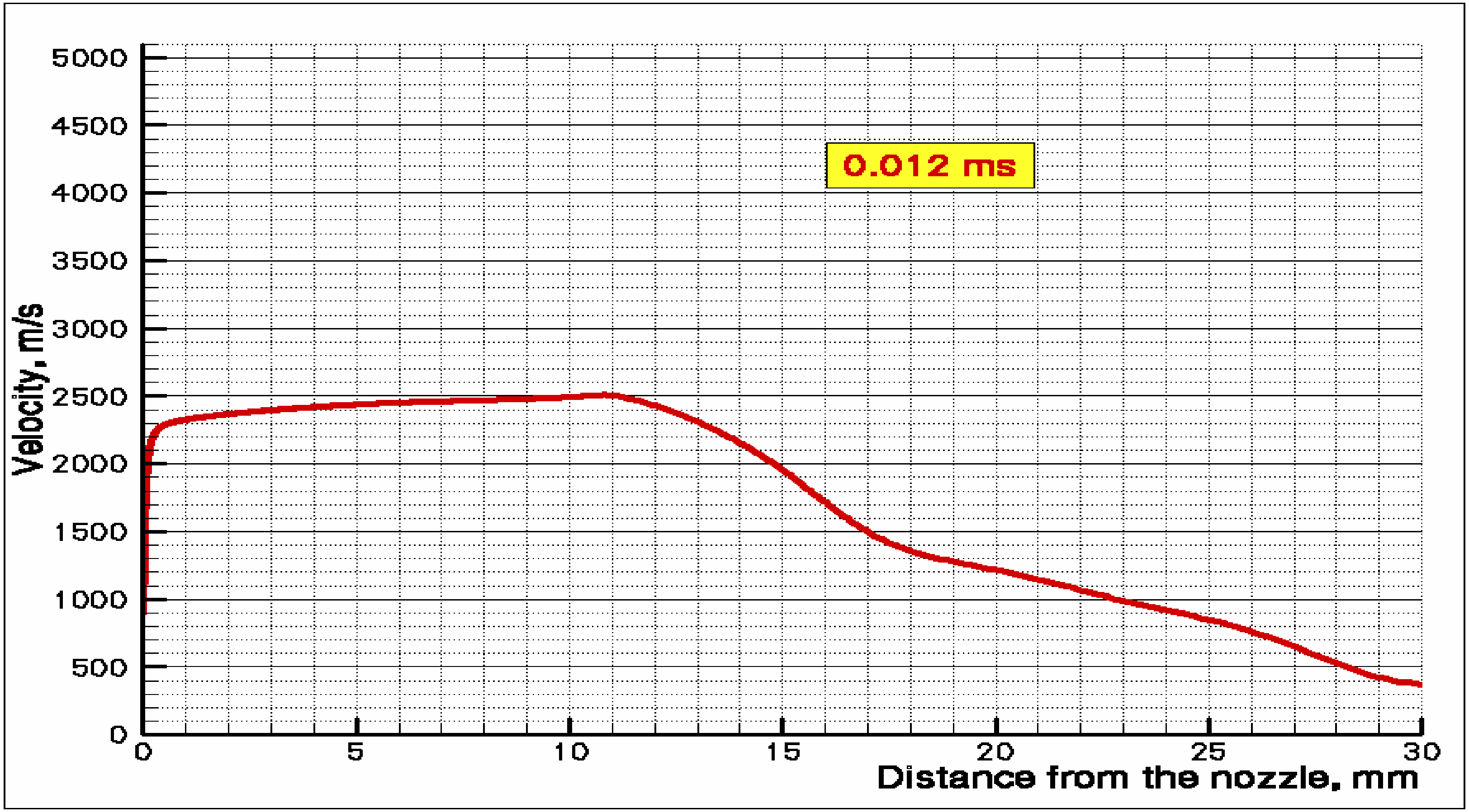
Gas-jet pulse development

Helium gas-jet velocity along the axis



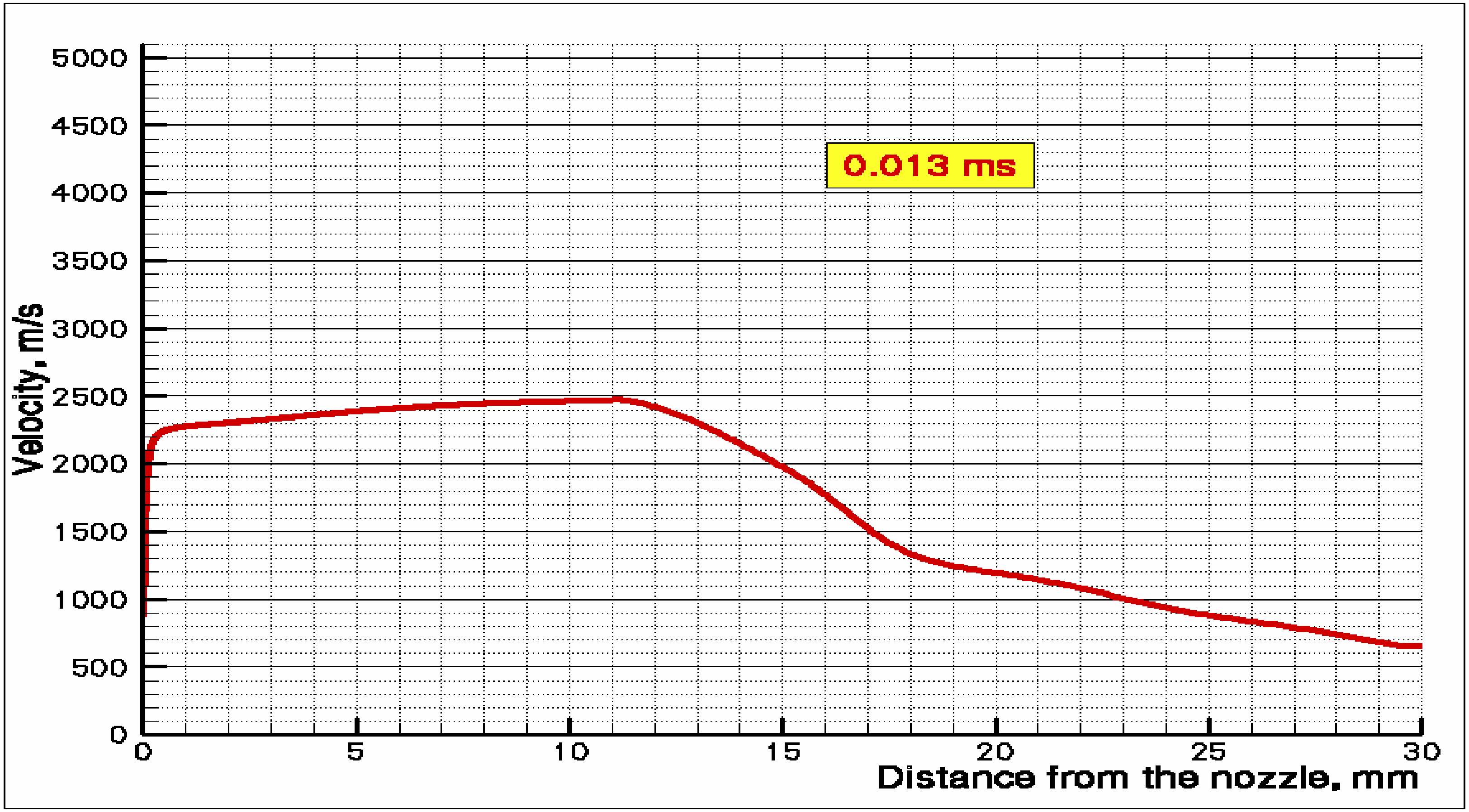
Gas-jet pulse development

Helium gas-jet velocity along the axis



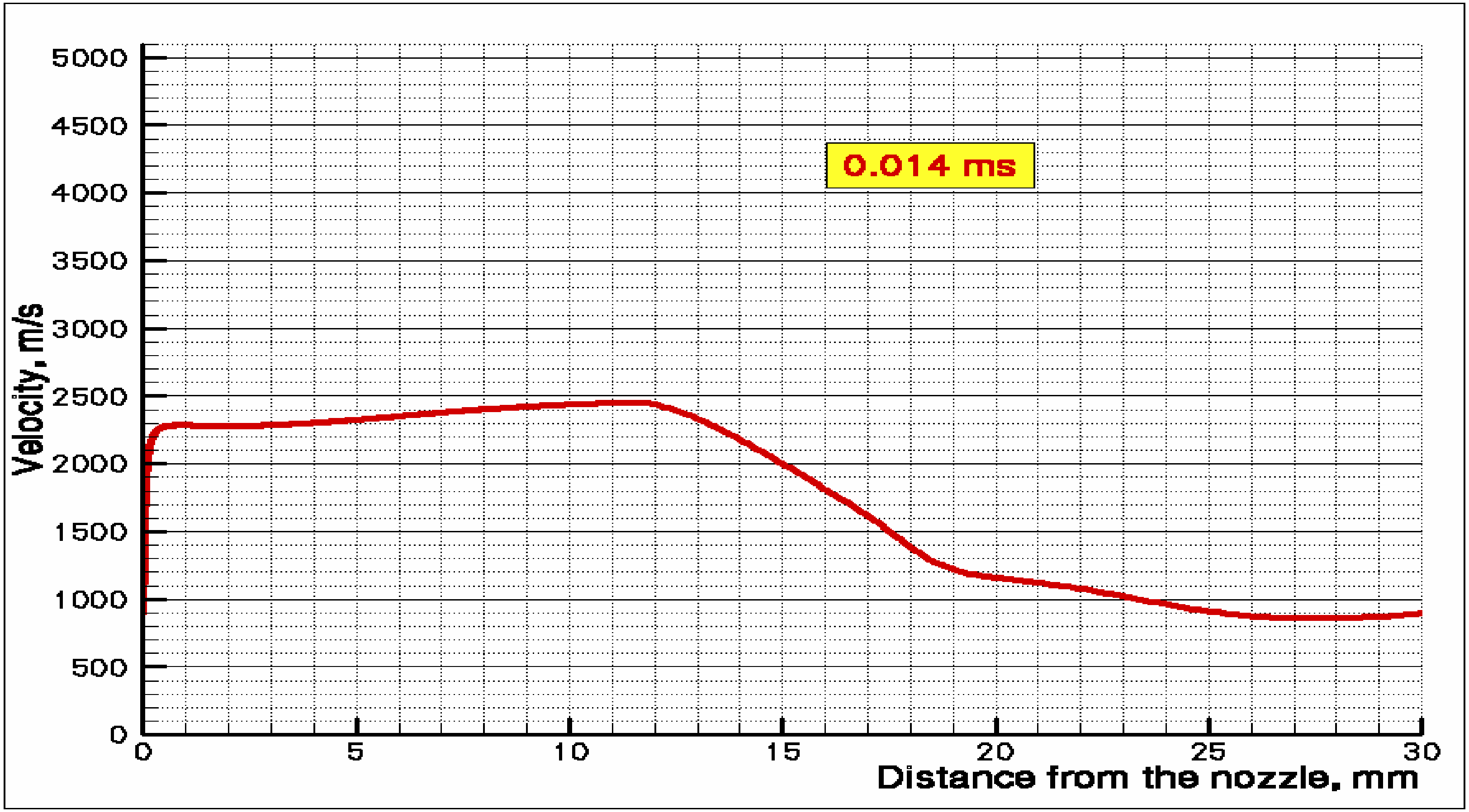
Gas-jet pulse development

Helium gas-jet velocity along the axis



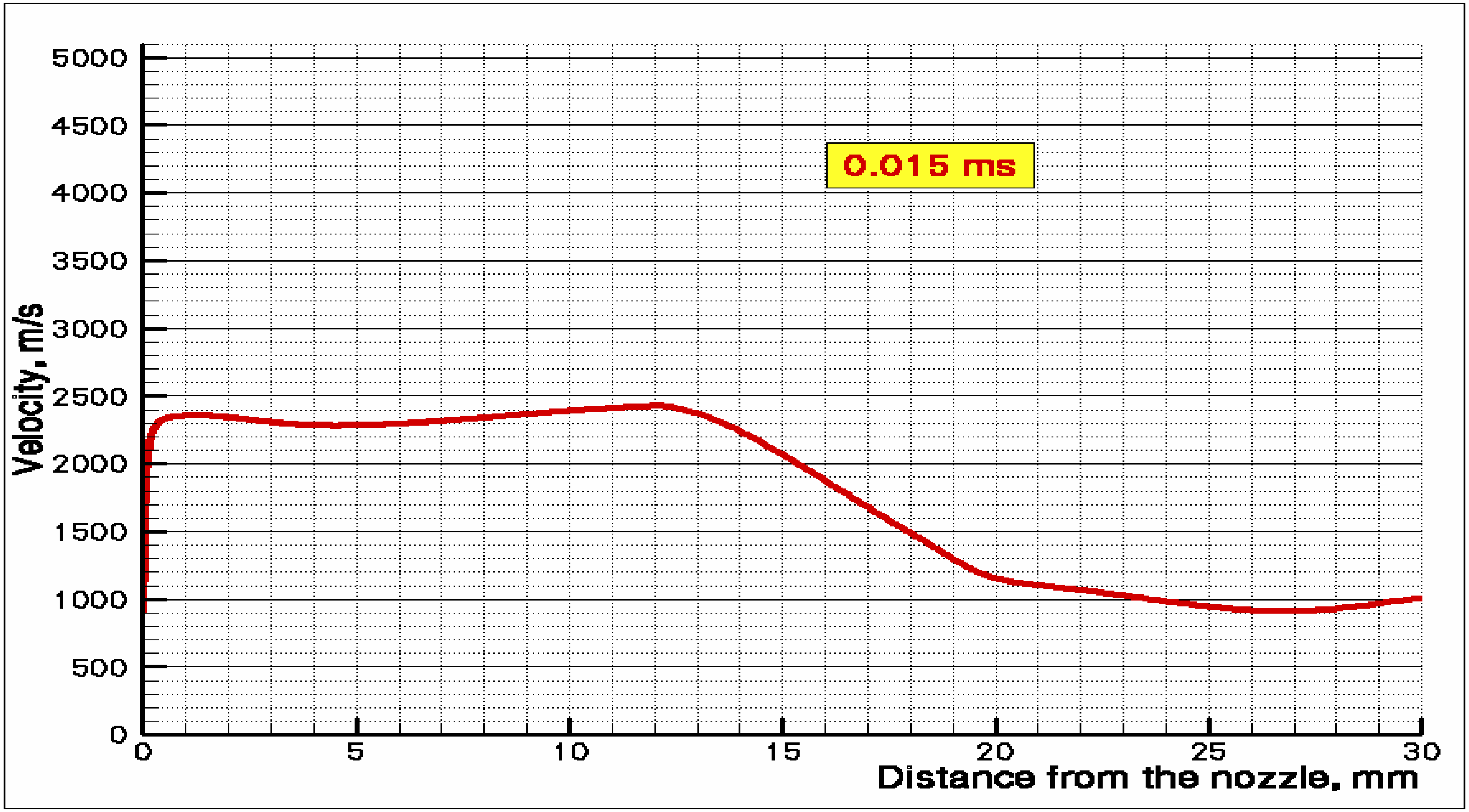
Gas-jet pulse development

Helium gas-jet velocity along the axis



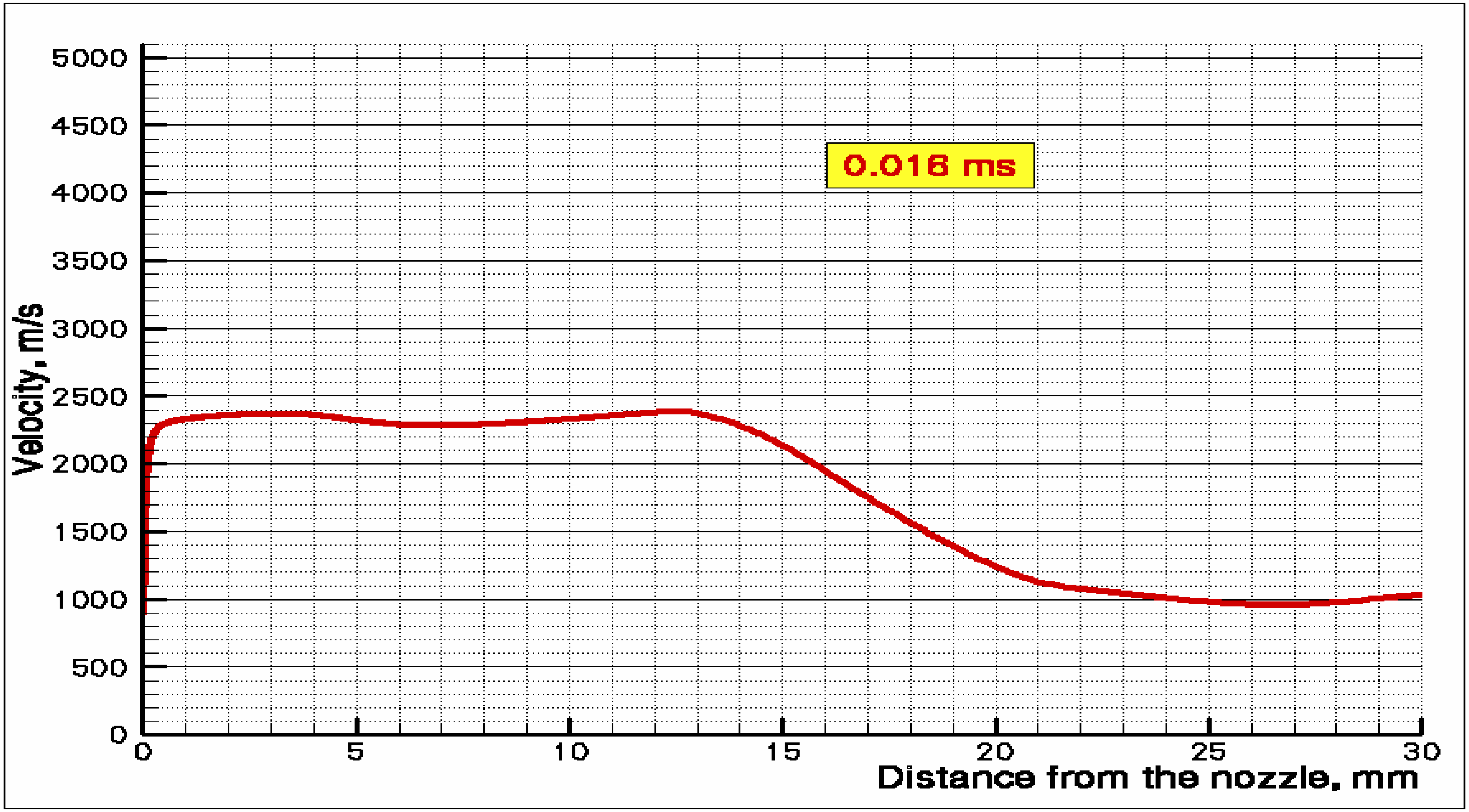
Gas-jet pulse development

Helium gas-jet velocity along the axis



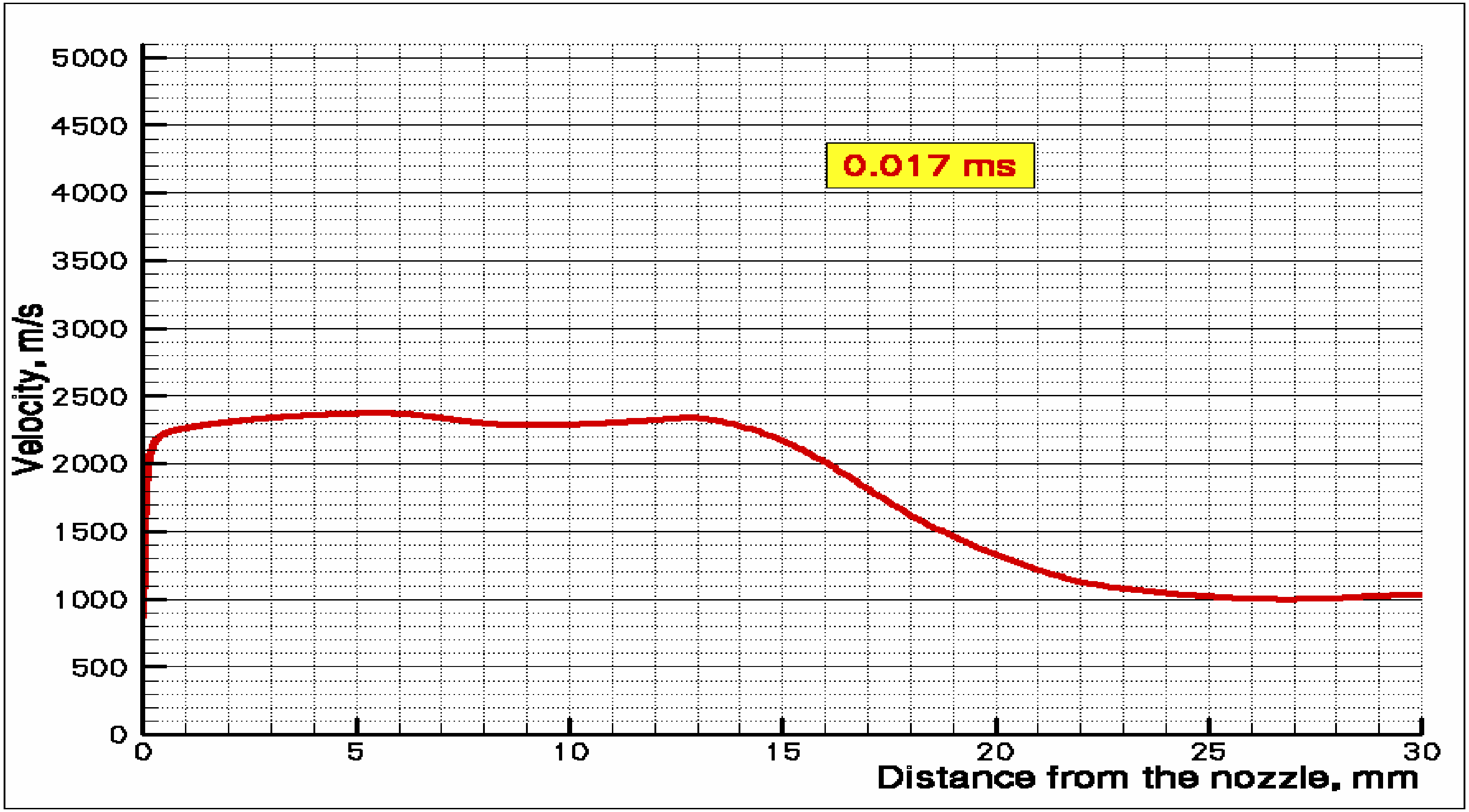
Gas-jet pulse development

Helium gas-jet velocity along the axis



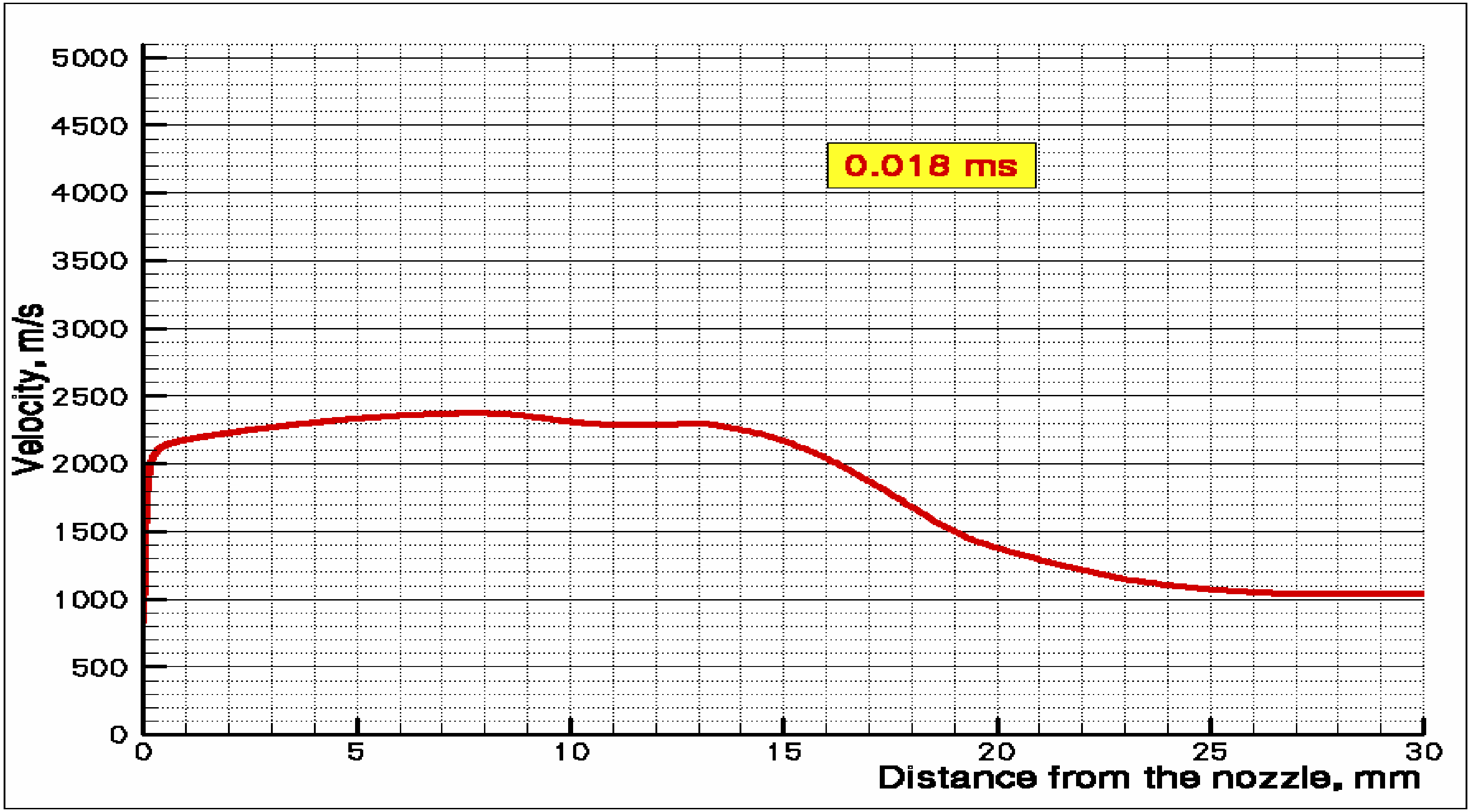
Gas-jet pulse development

Helium gas-jet velocity along the axis



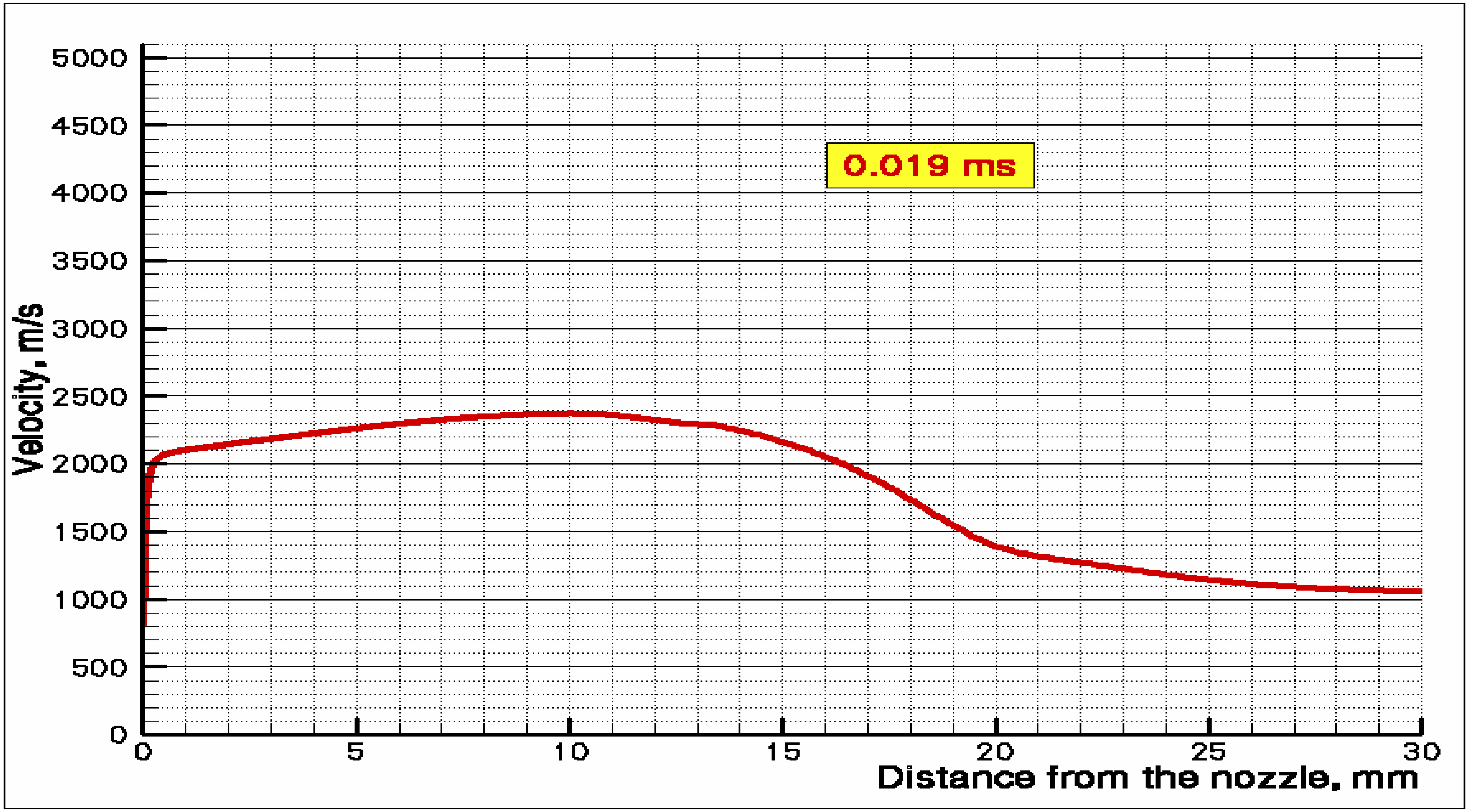
Gas-jet pulse development

Helium gas-jet velocity along the axis



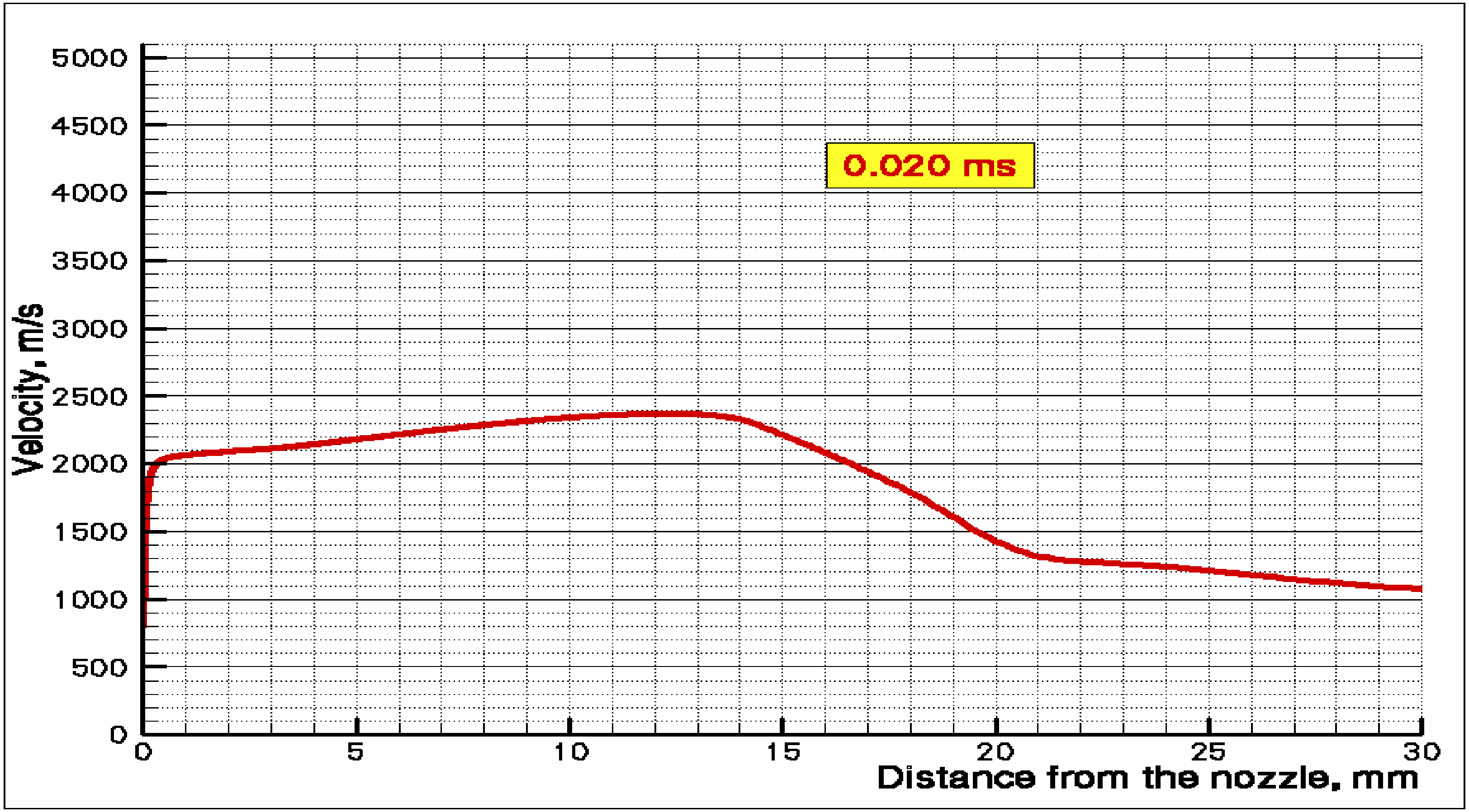
Gas-jet pulse development

Helium gas-jet velocity along the axis



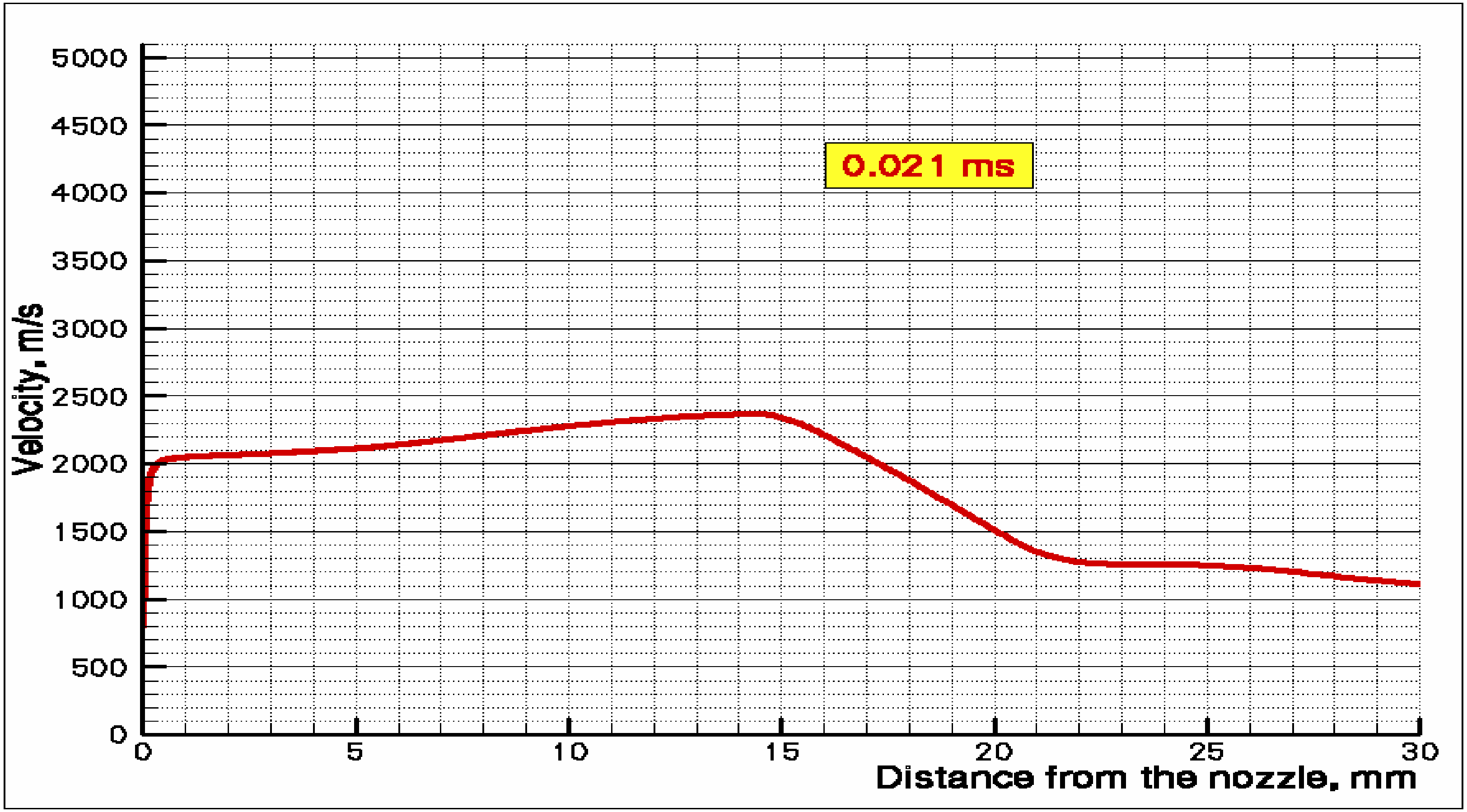
Gas-jet pulse development

Helium gas-jet velocity along the axis



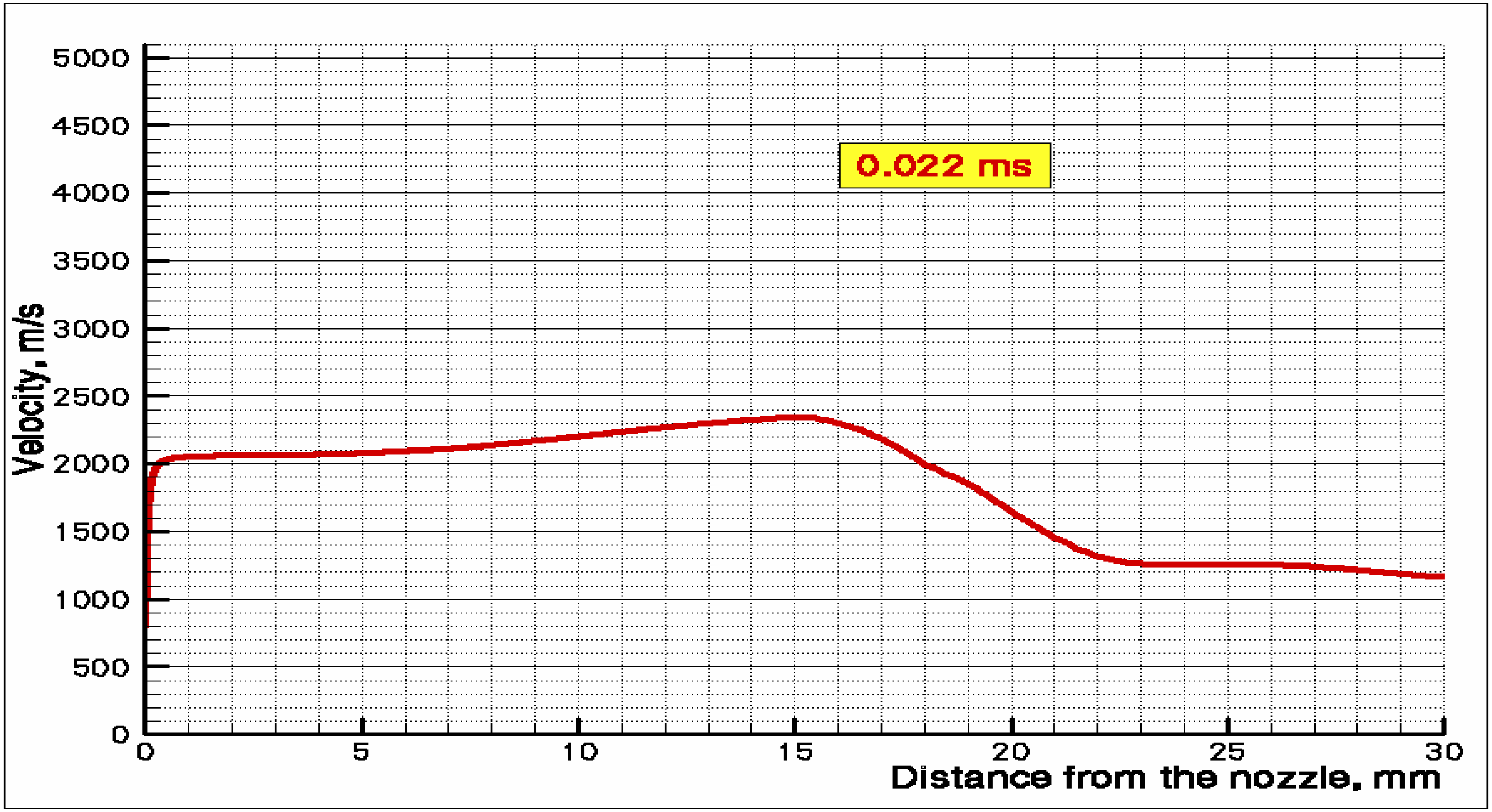
Gas-jet pulse development

Helium gas-jet velocity along the axis



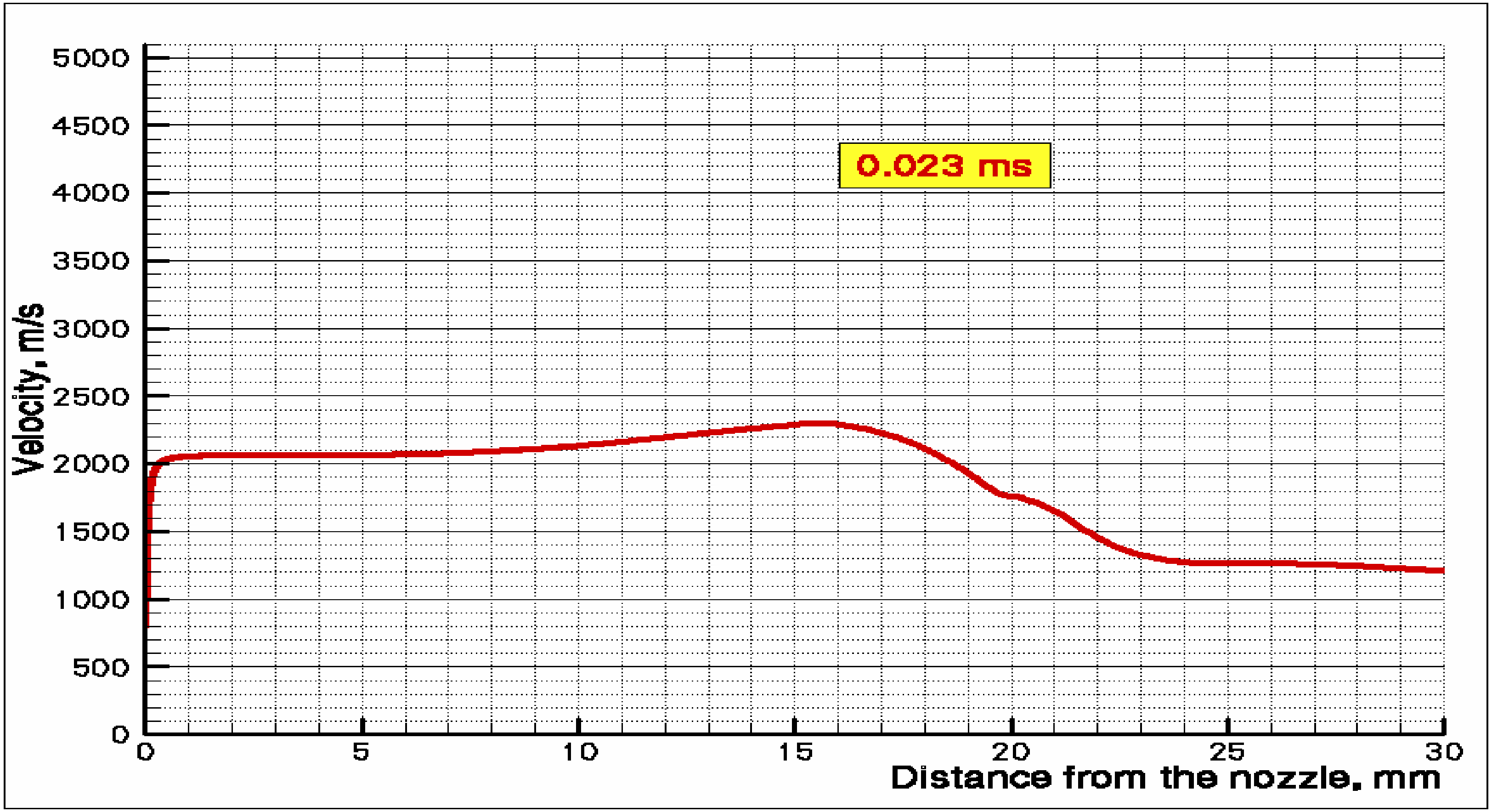
Gas-jet pulse development

Helium gas-jet velocity along the axis



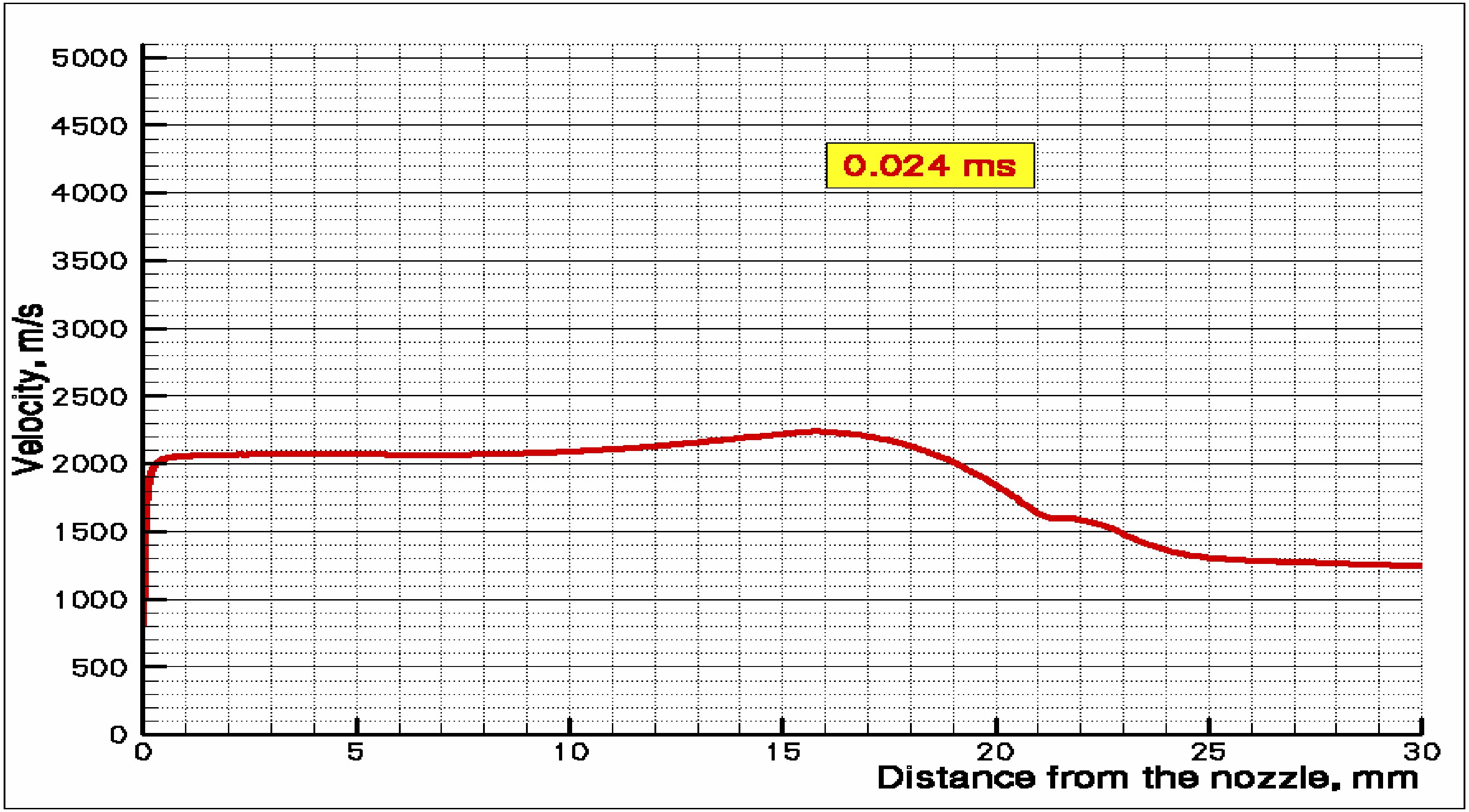
Gas-jet pulse development

Helium gas-jet velocity along the axis



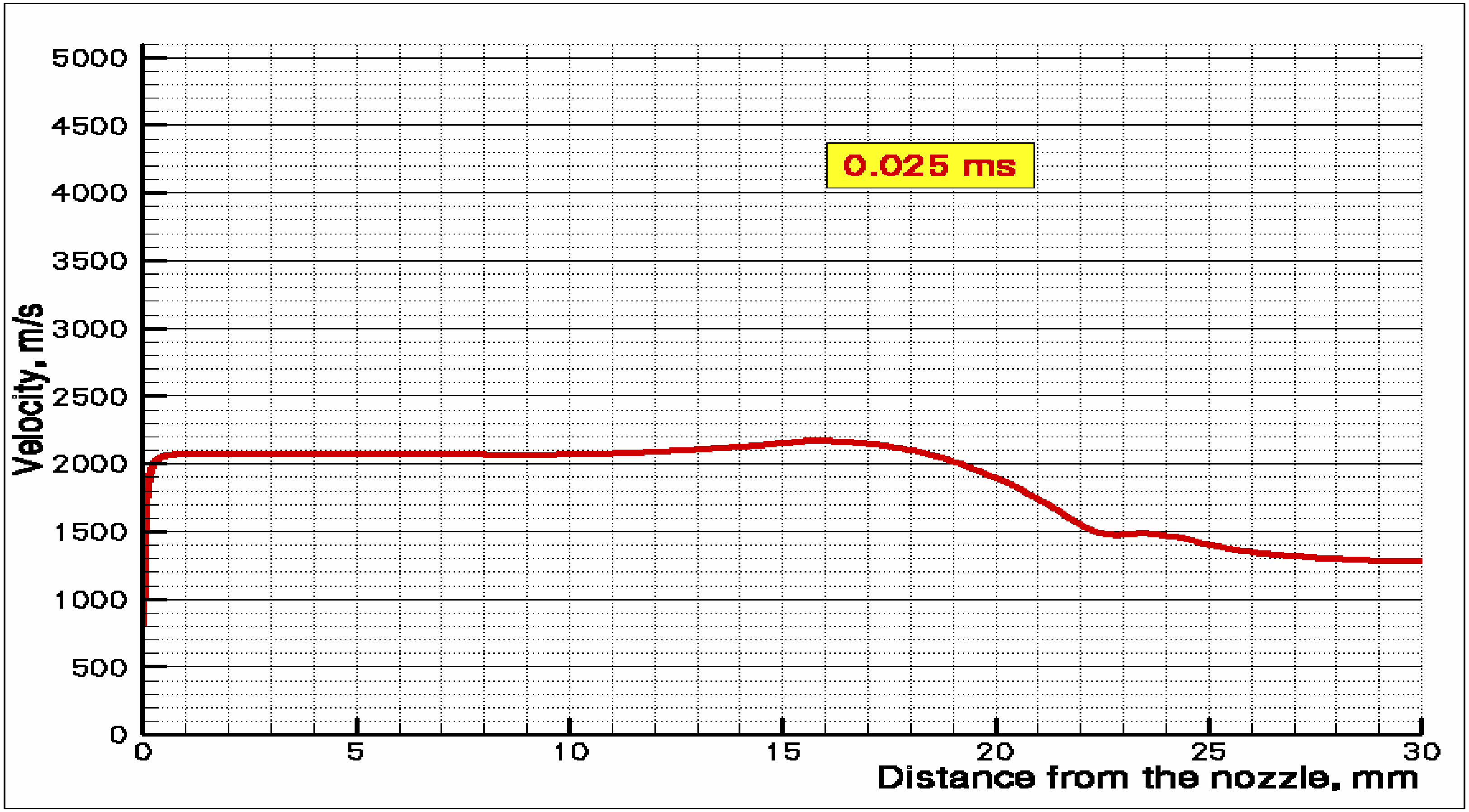
Gas-jet pulse development

Helium gas-jet velocity along the axis



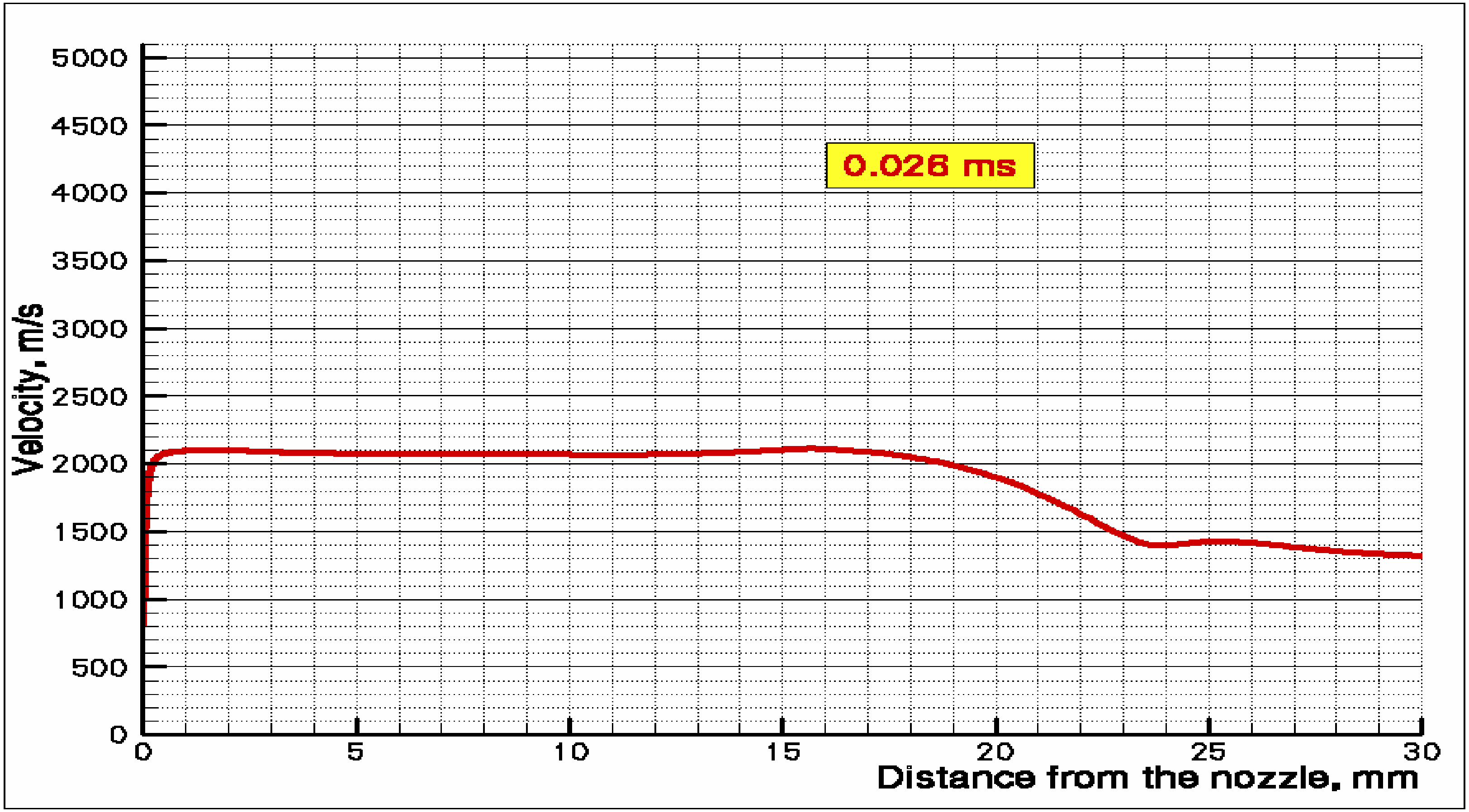
Gas-jet pulse development

Helium gas-jet velocity along the axis



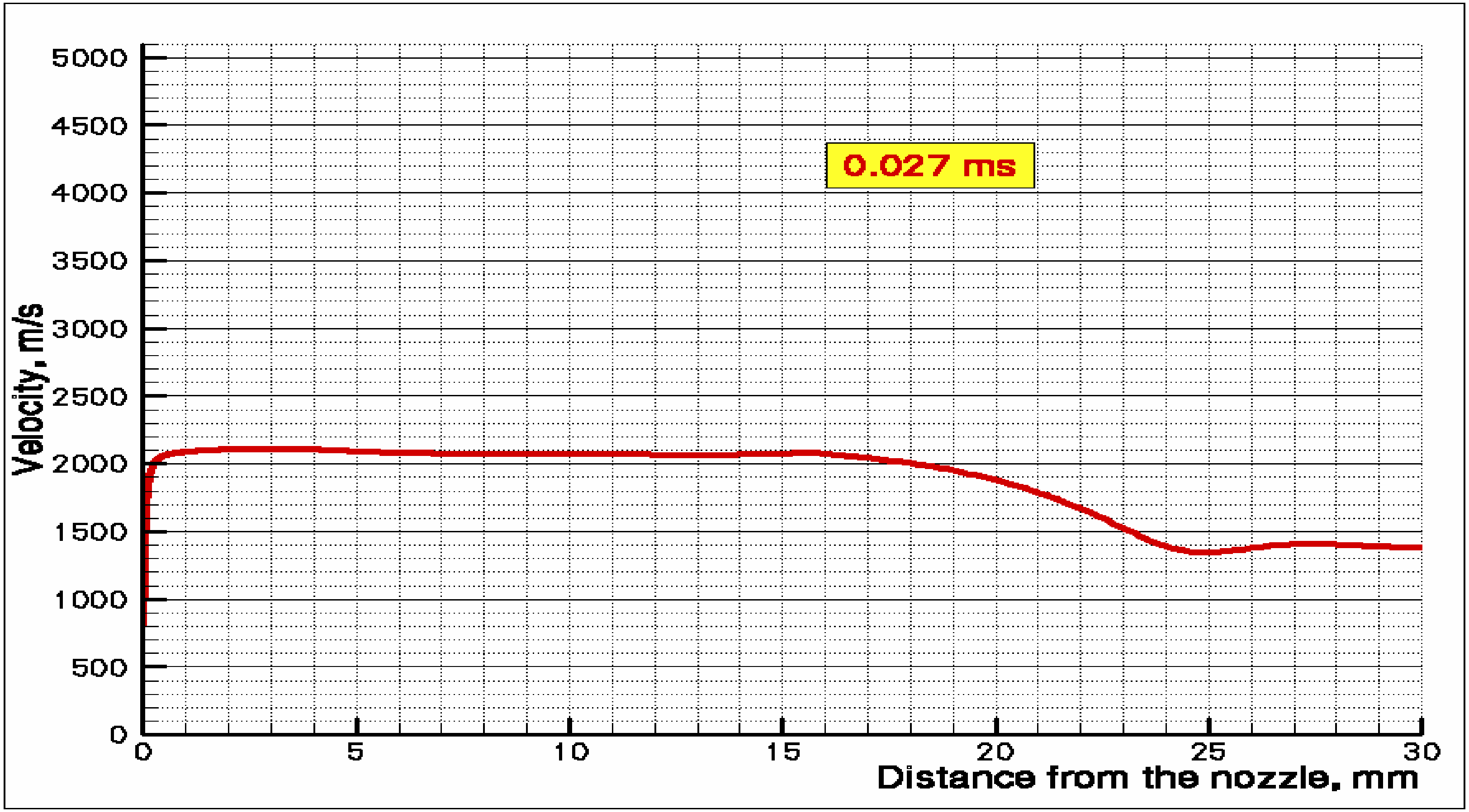
Gas-jet pulse development

Helium gas-jet velocity along the axis



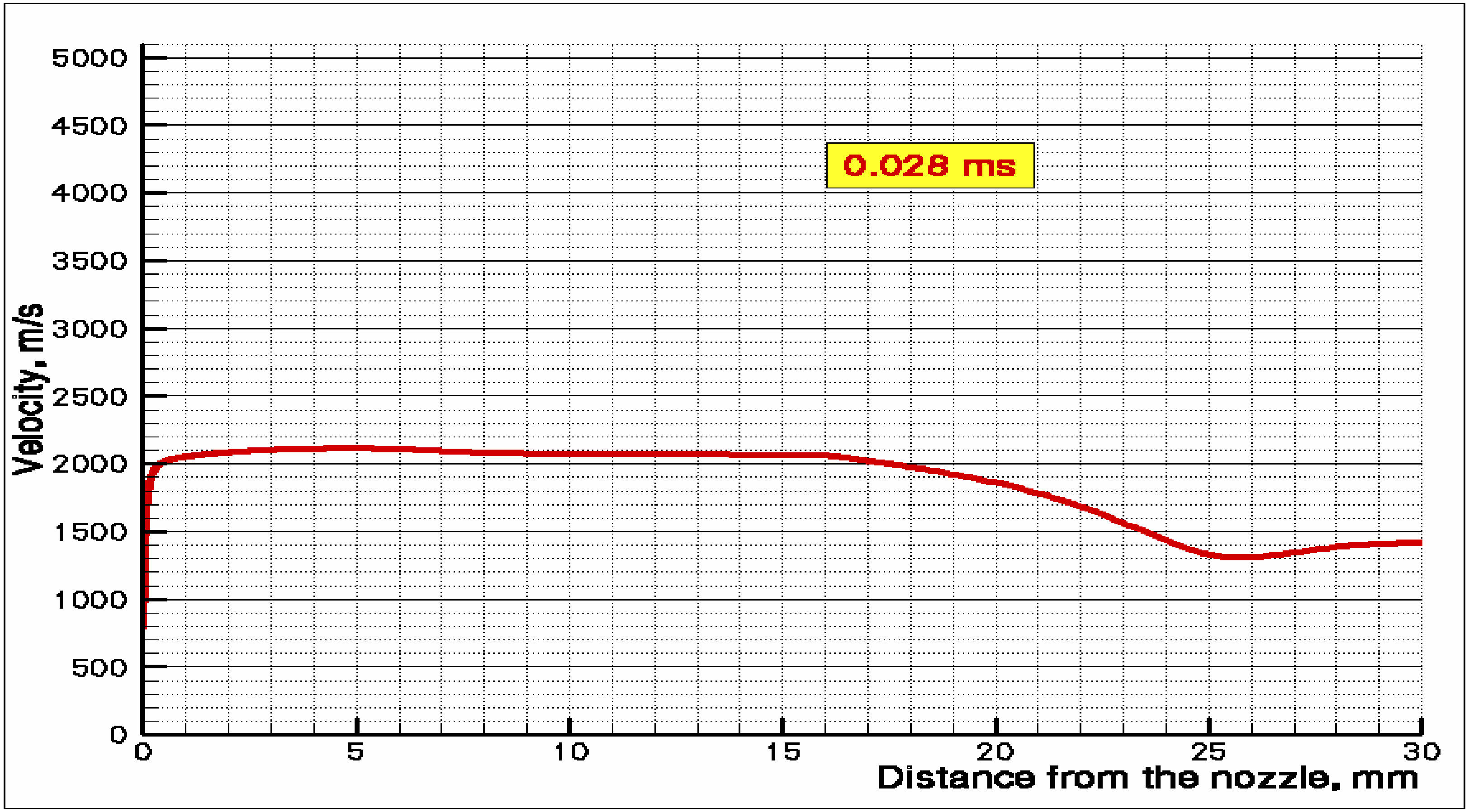
Gas-jet pulse development

Helium gas-jet velocity along the axis



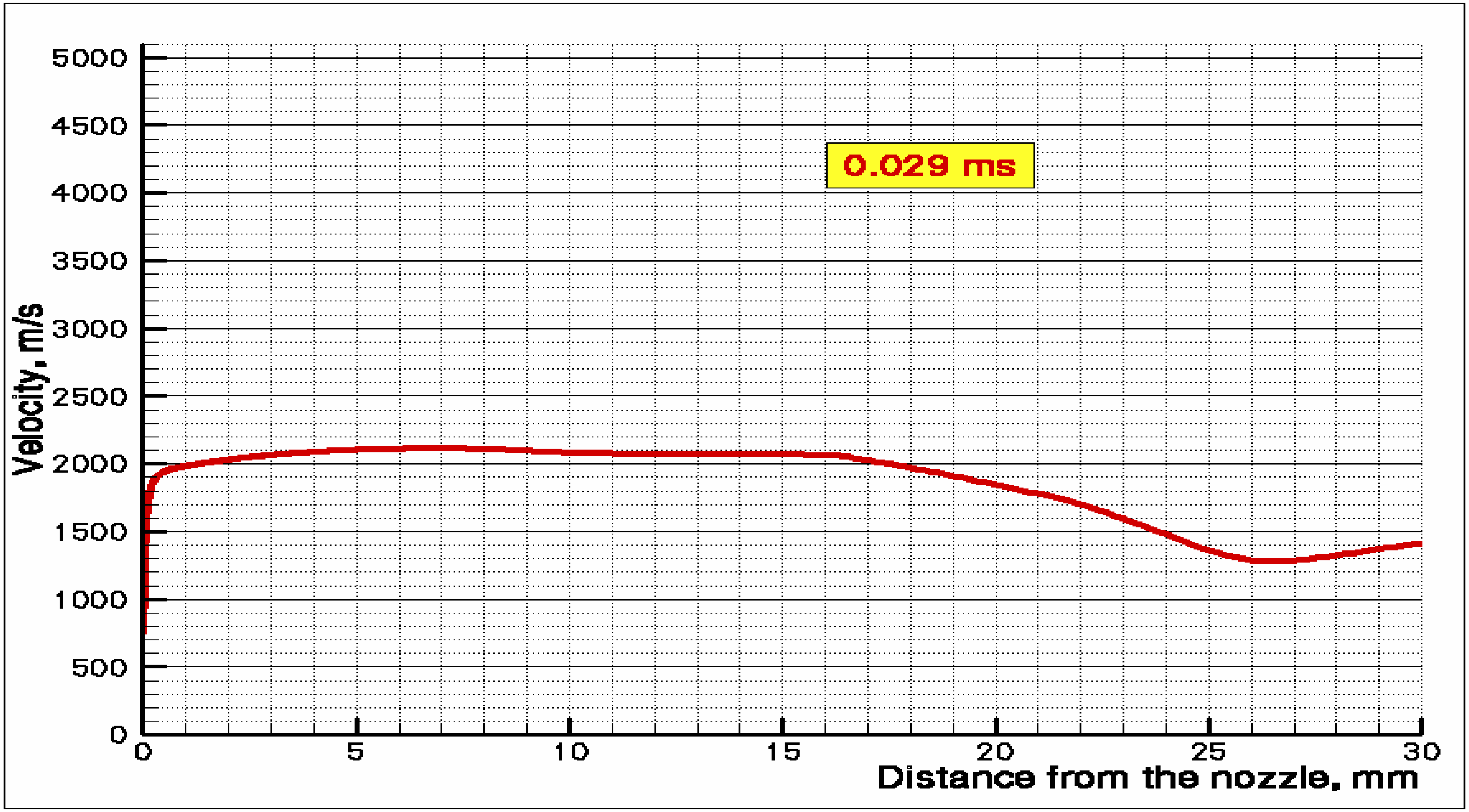
Gas-jet pulse development

Helium gas-jet velocity along the axis



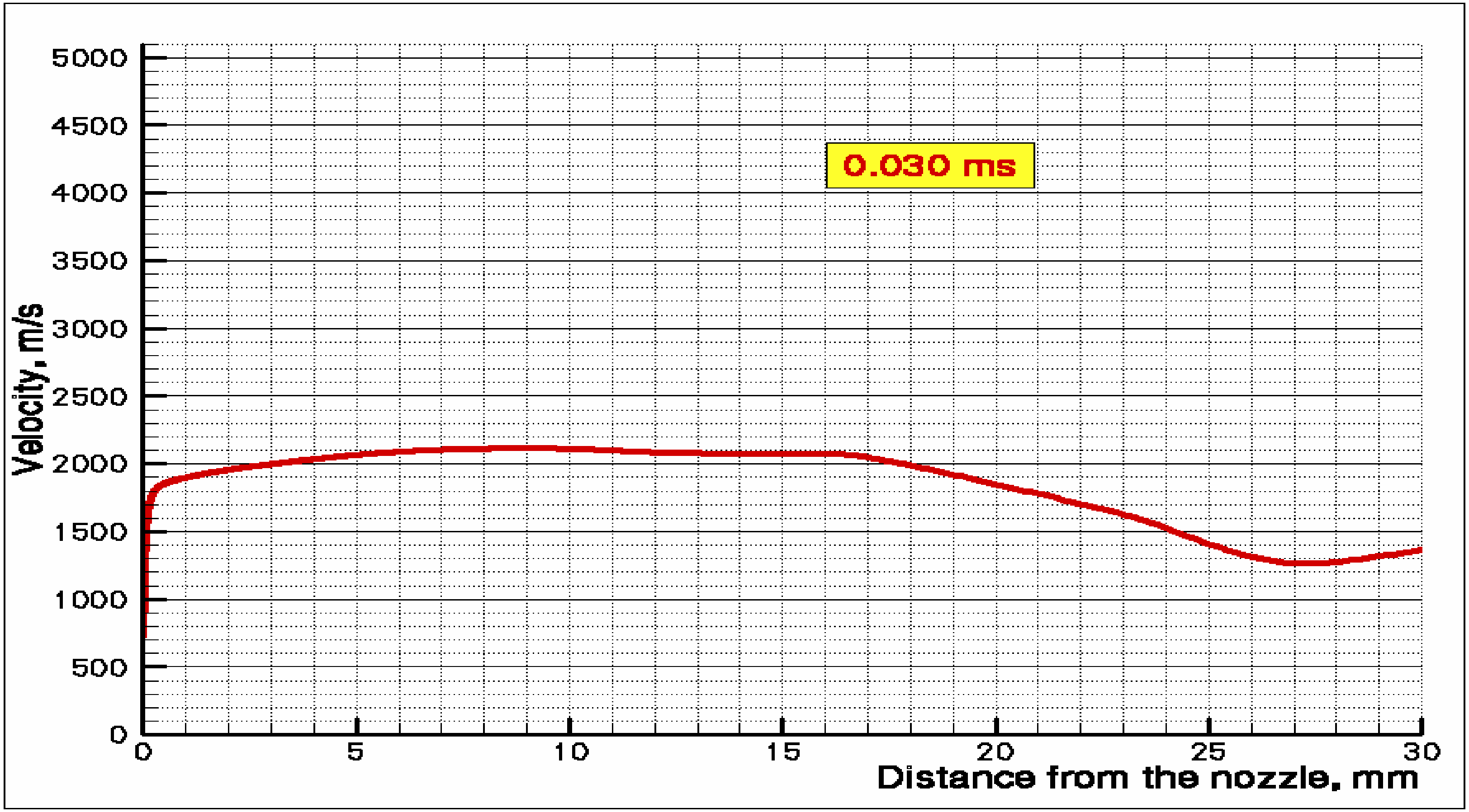
Gas-jet pulse development

Helium gas-jet velocity along the axis



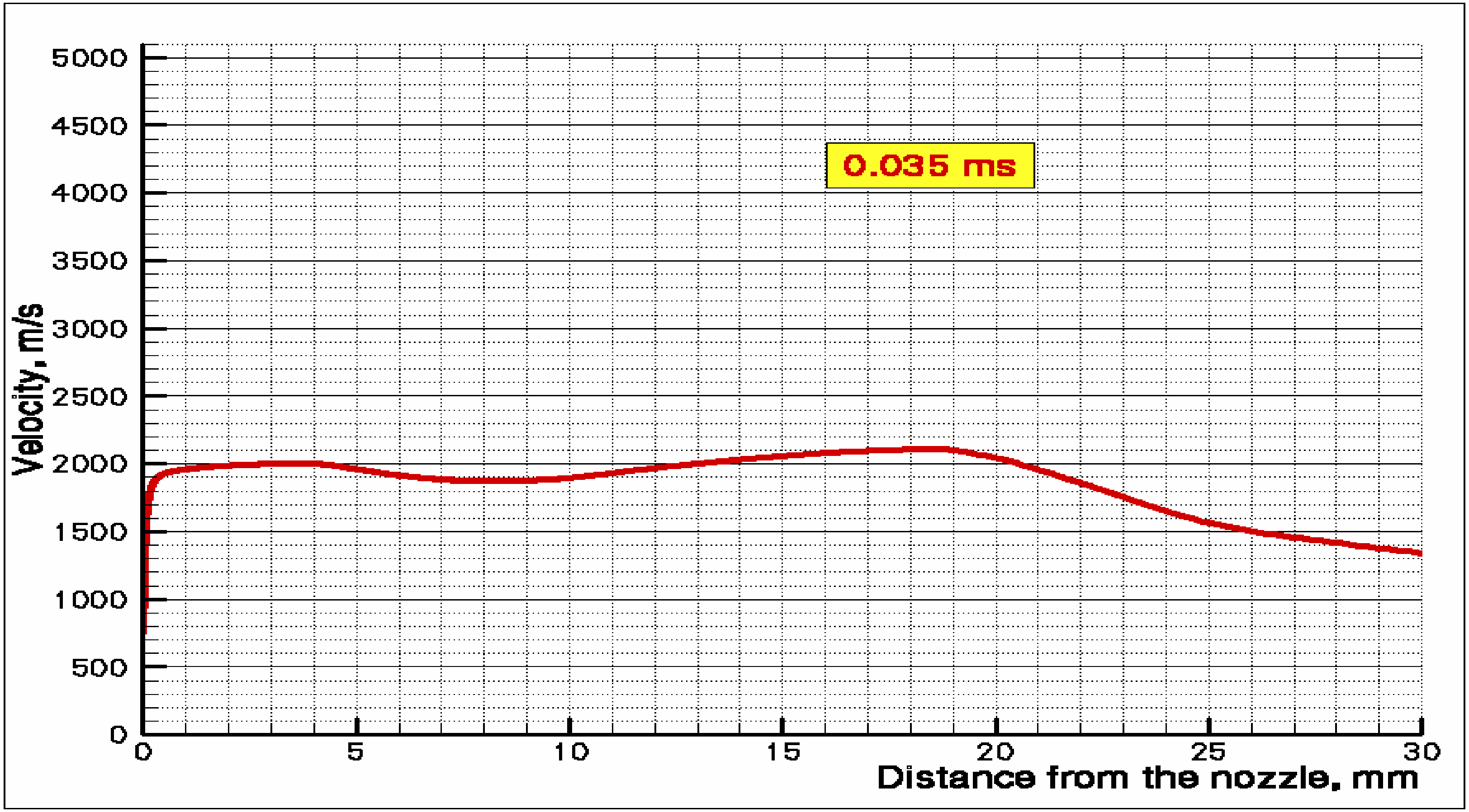
Gas-jet pulse development

Helium gas-jet velocity along the axis



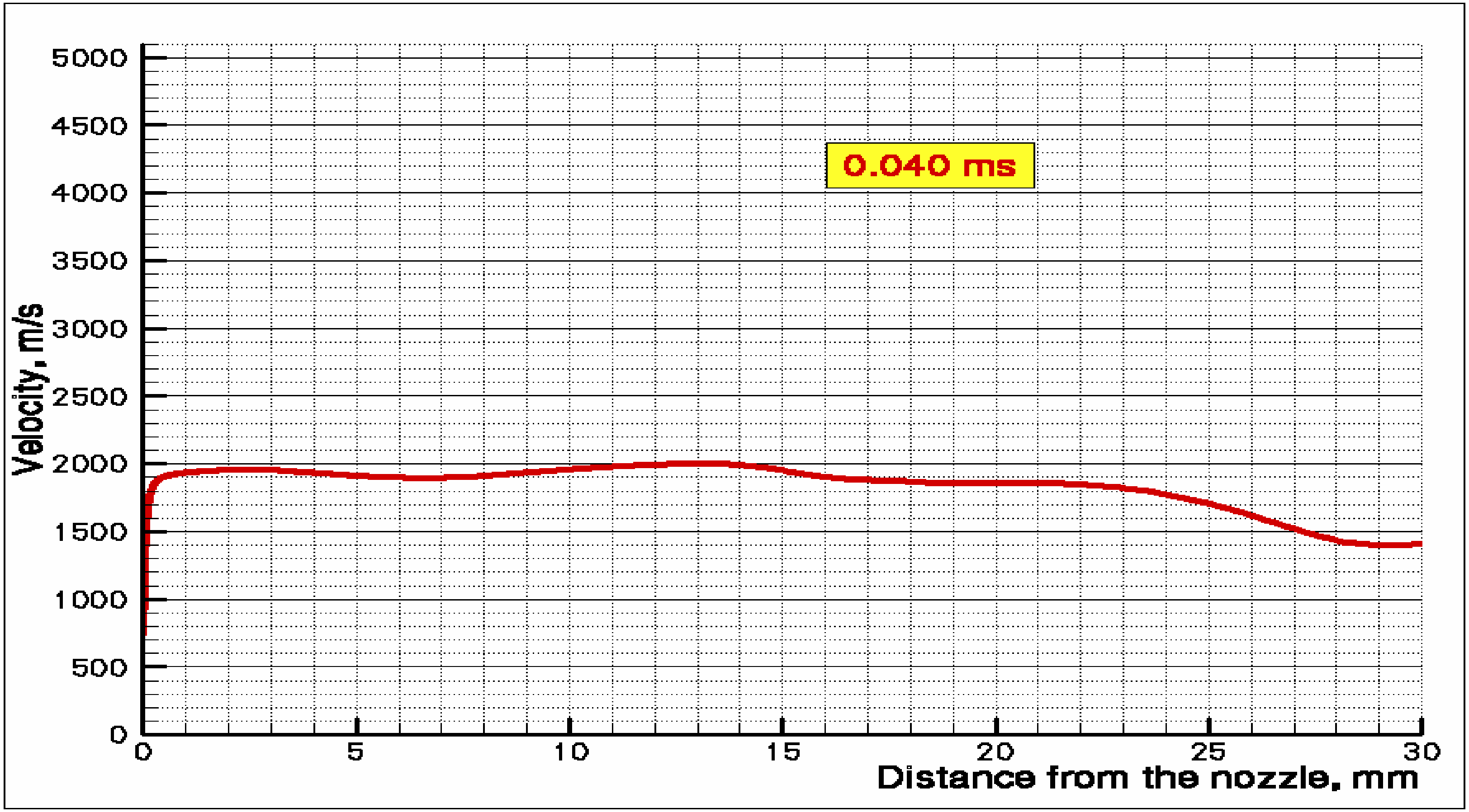
Gas-jet pulse development

Helium gas-jet velocity along the axis



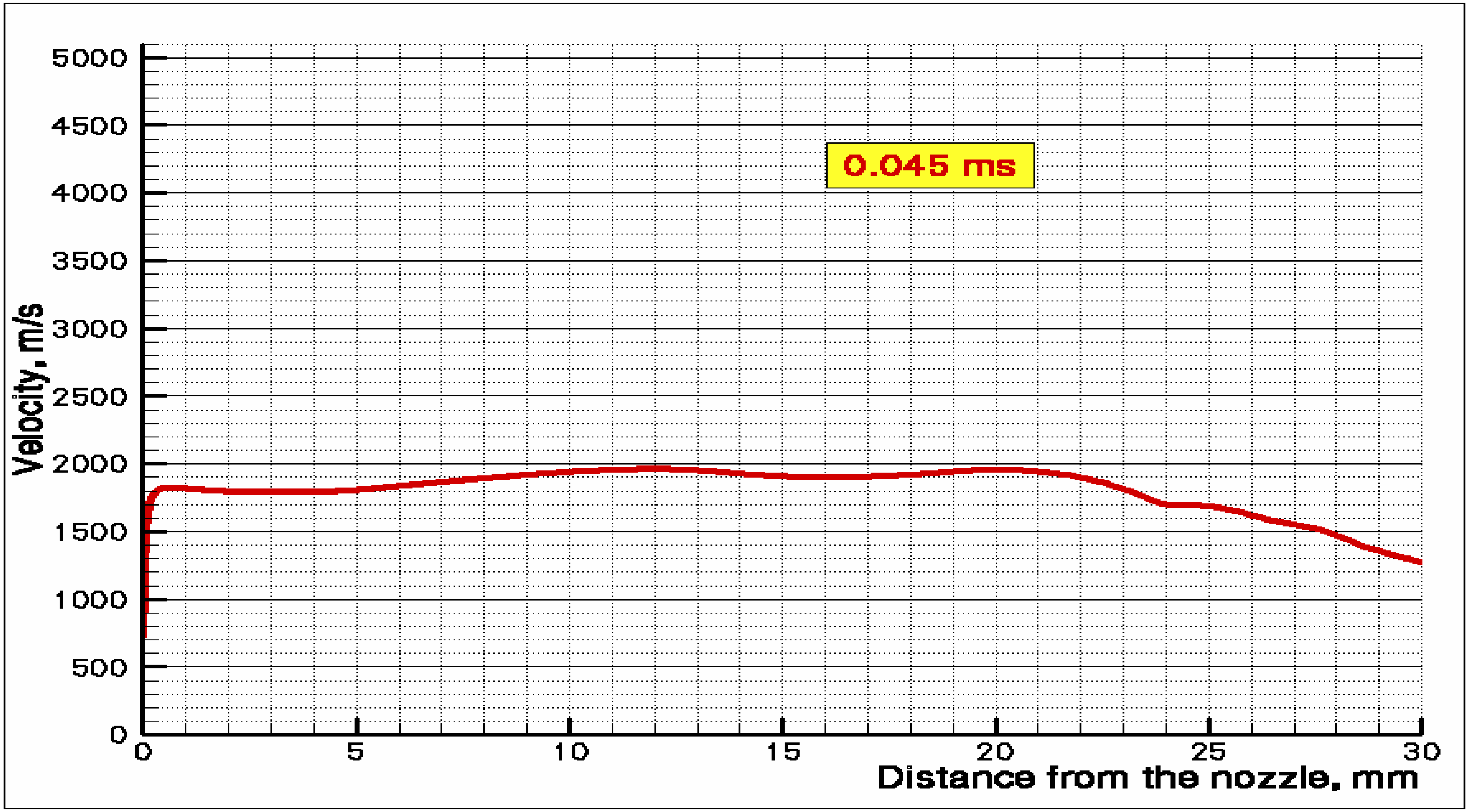
Gas-jet pulse development

Helium gas-jet velocity along the axis



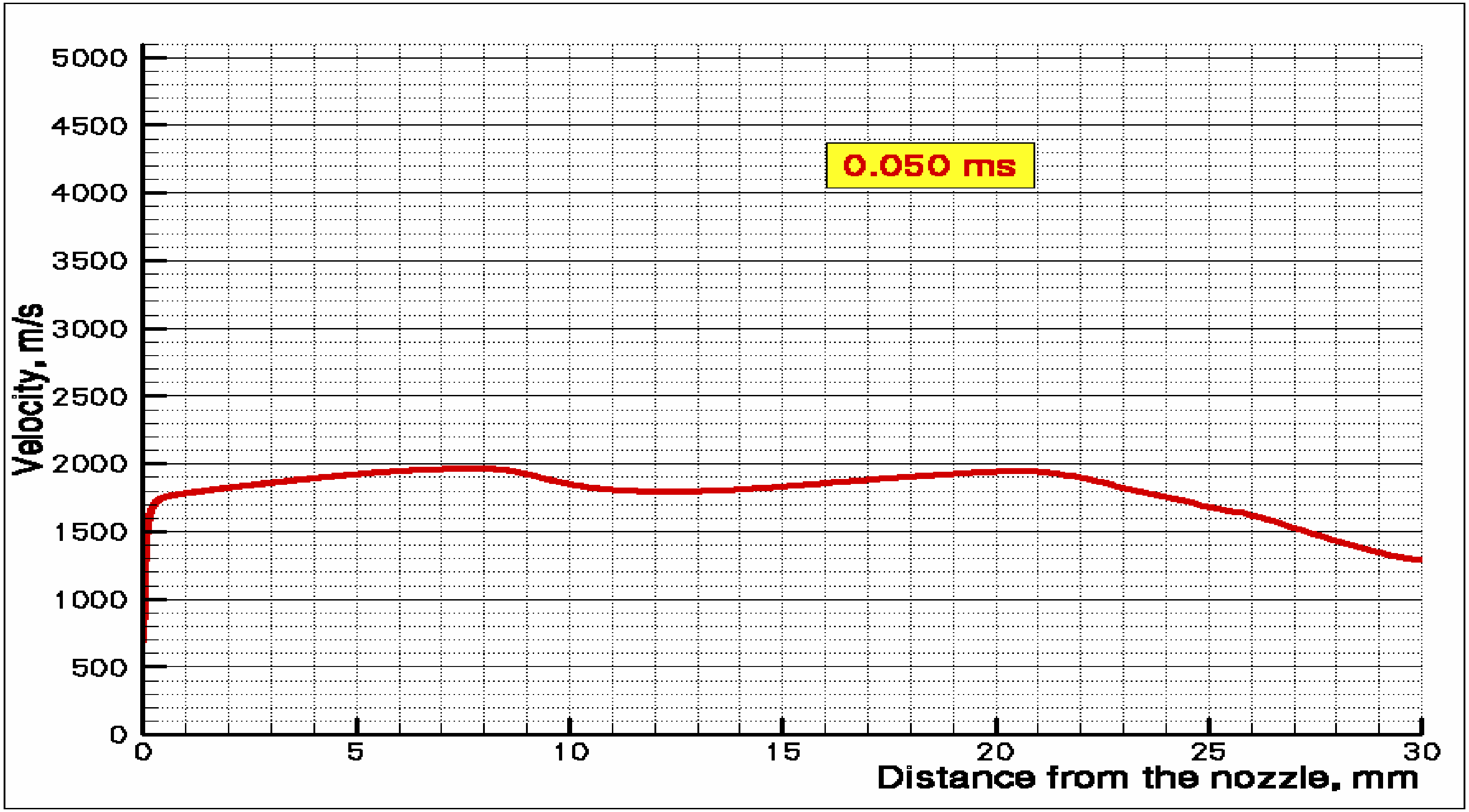
Gas-jet pulse development

Helium gas-jet velocity along the axis



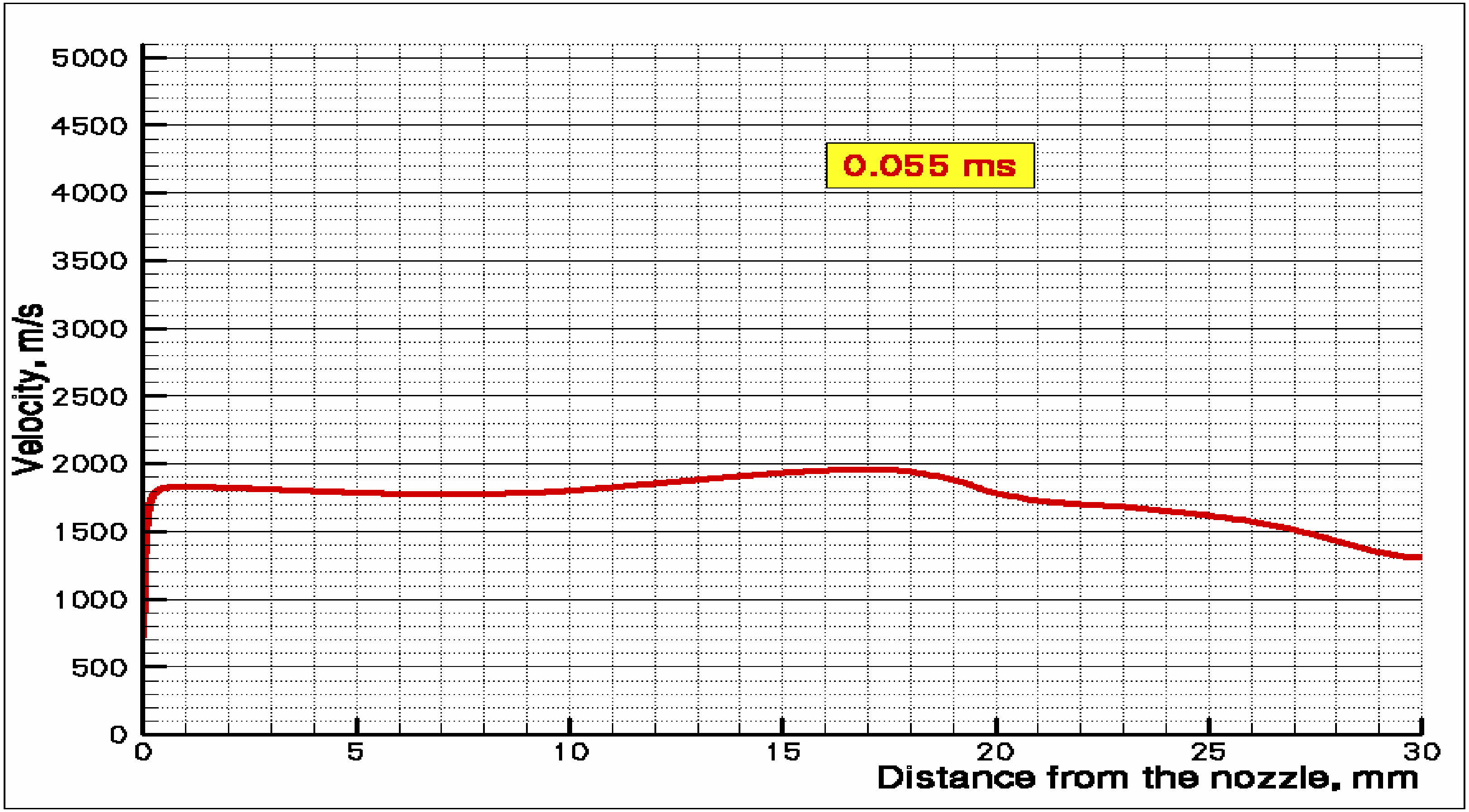
Gas-jet pulse development

Helium gas-jet velocity along the axis



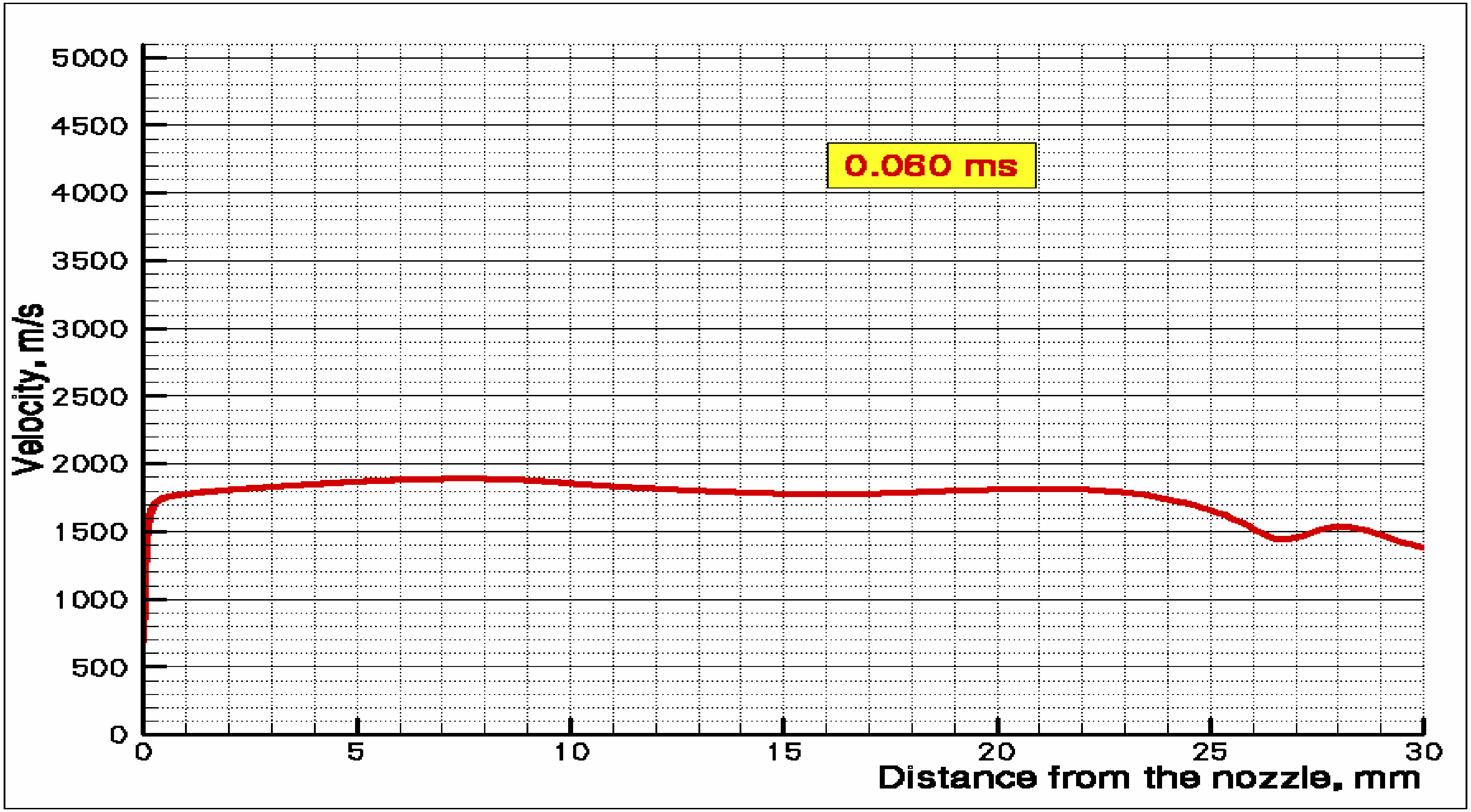
Gas-jet pulse development

Helium gas-jet velocity along the axis



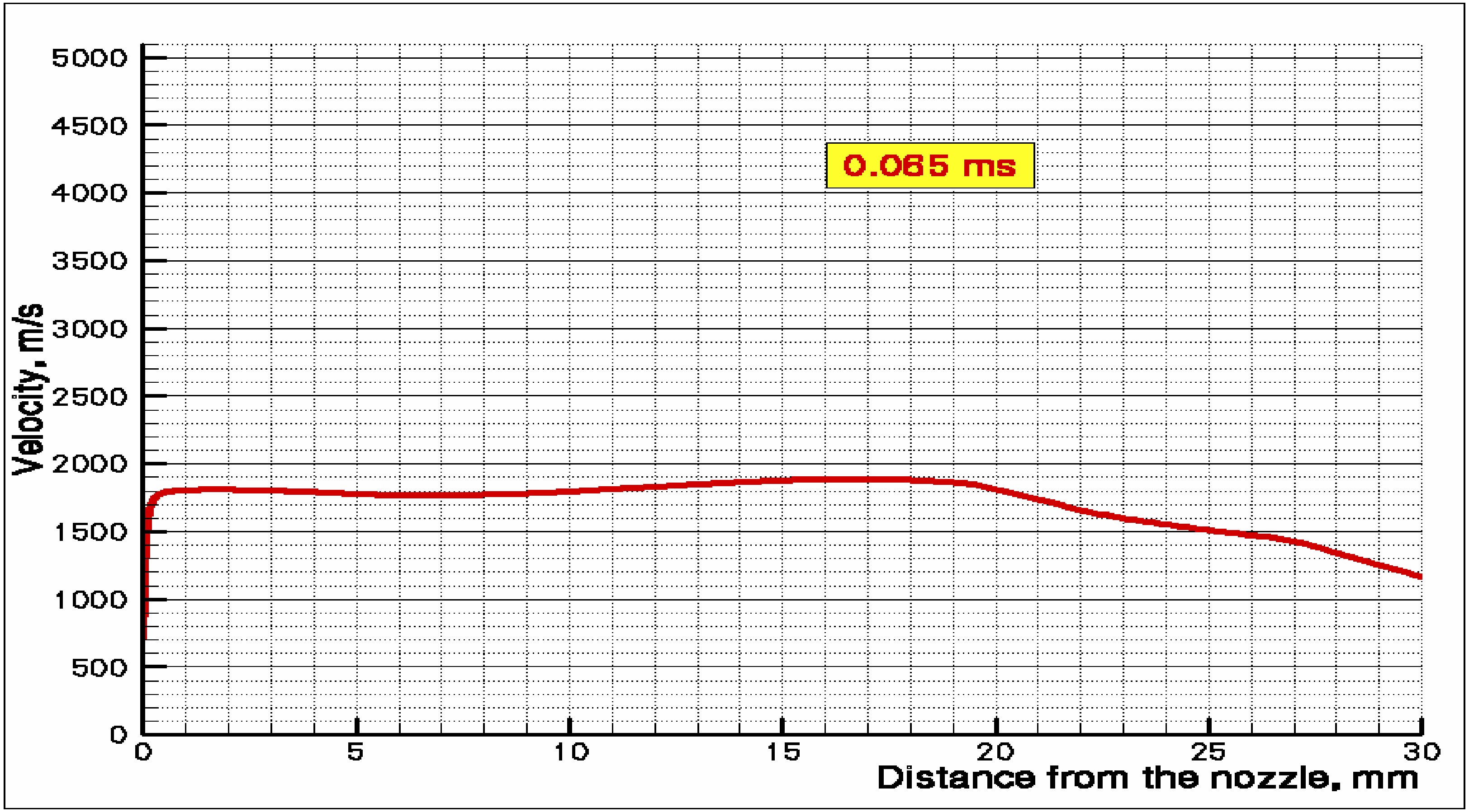
Gas-jet pulse development

Helium gas-jet velocity along the axis



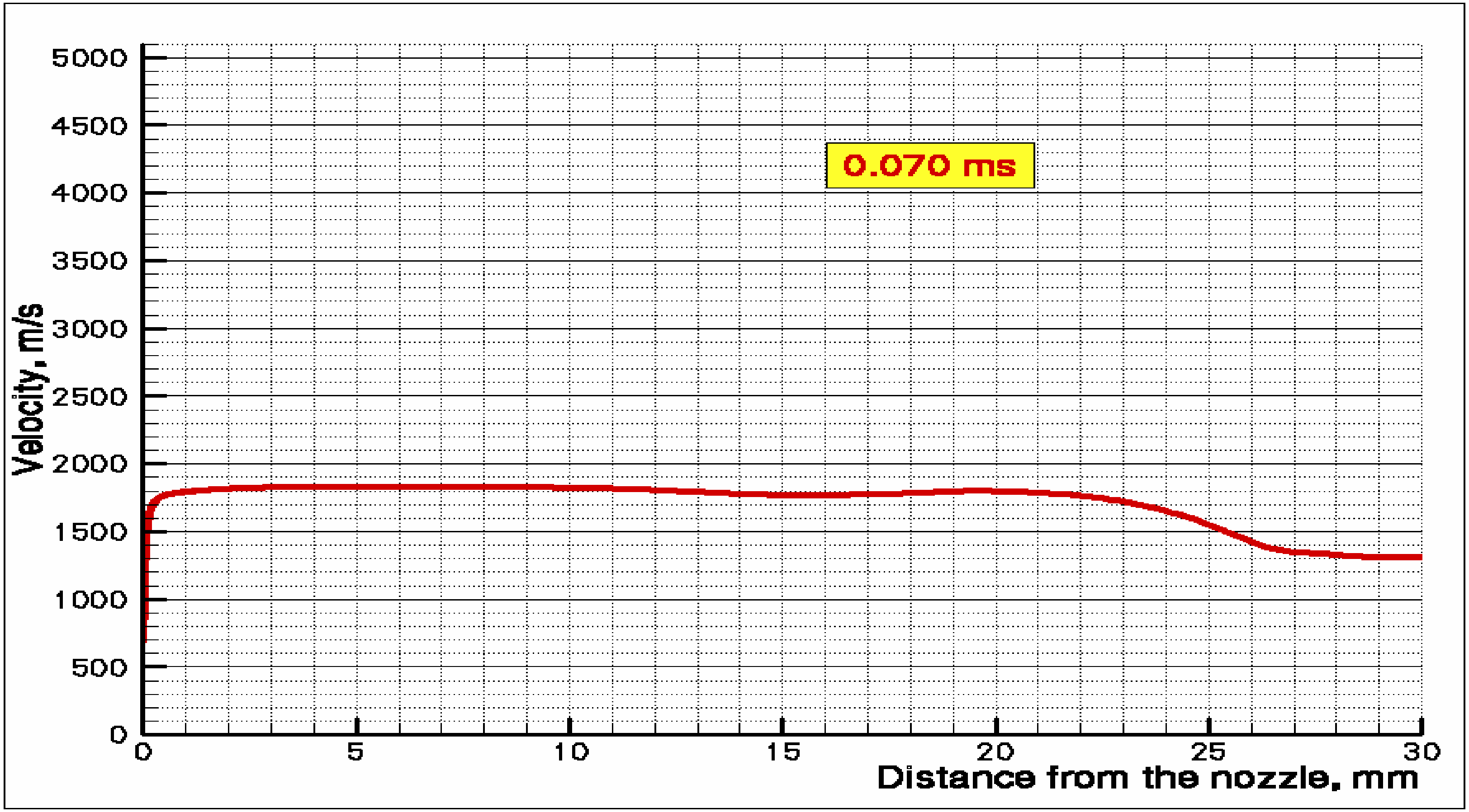
Gas-jet pulse development

Helium gas-jet velocity along the axis



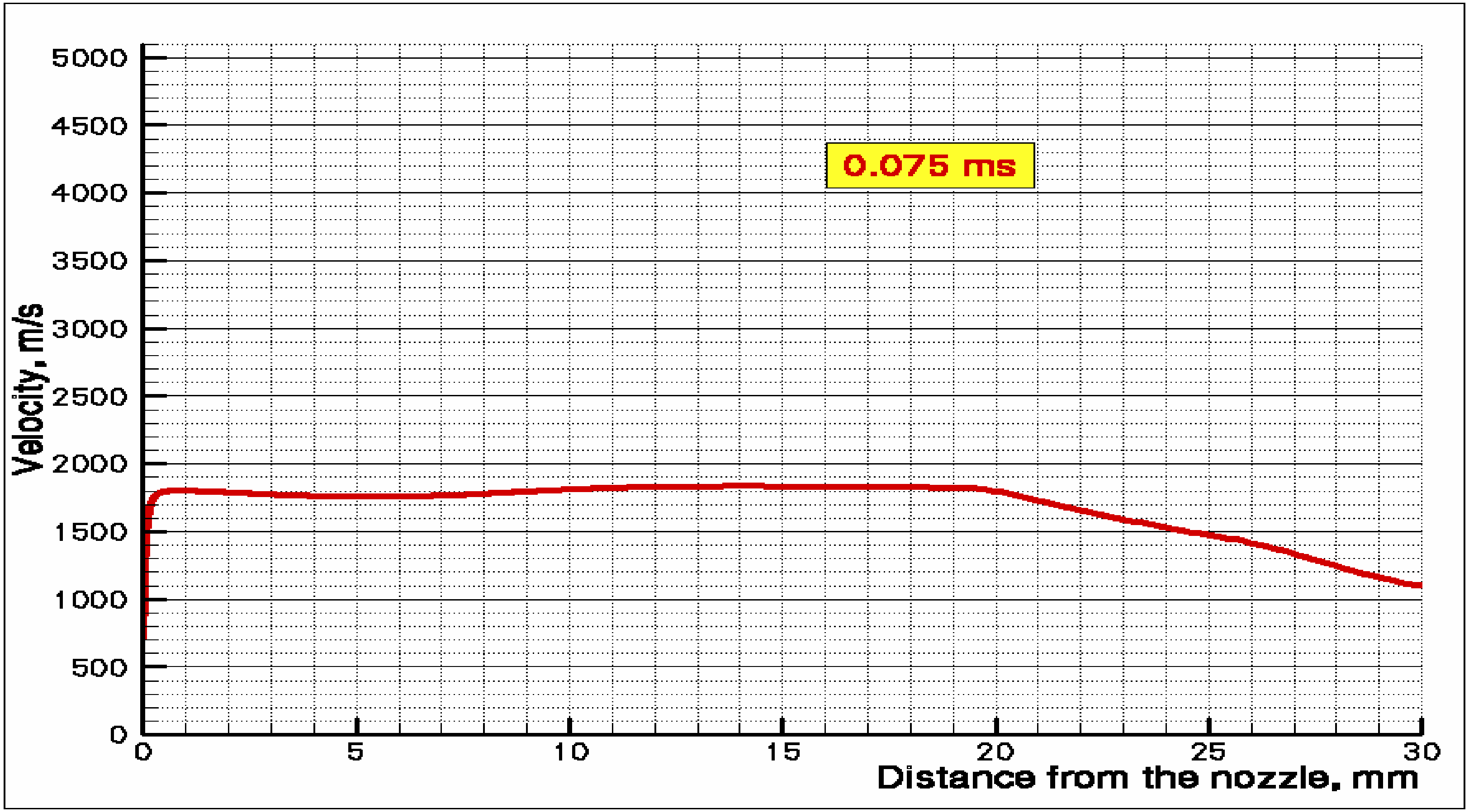
Gas-jet pulse development

Helium gas-jet velocity along the axis



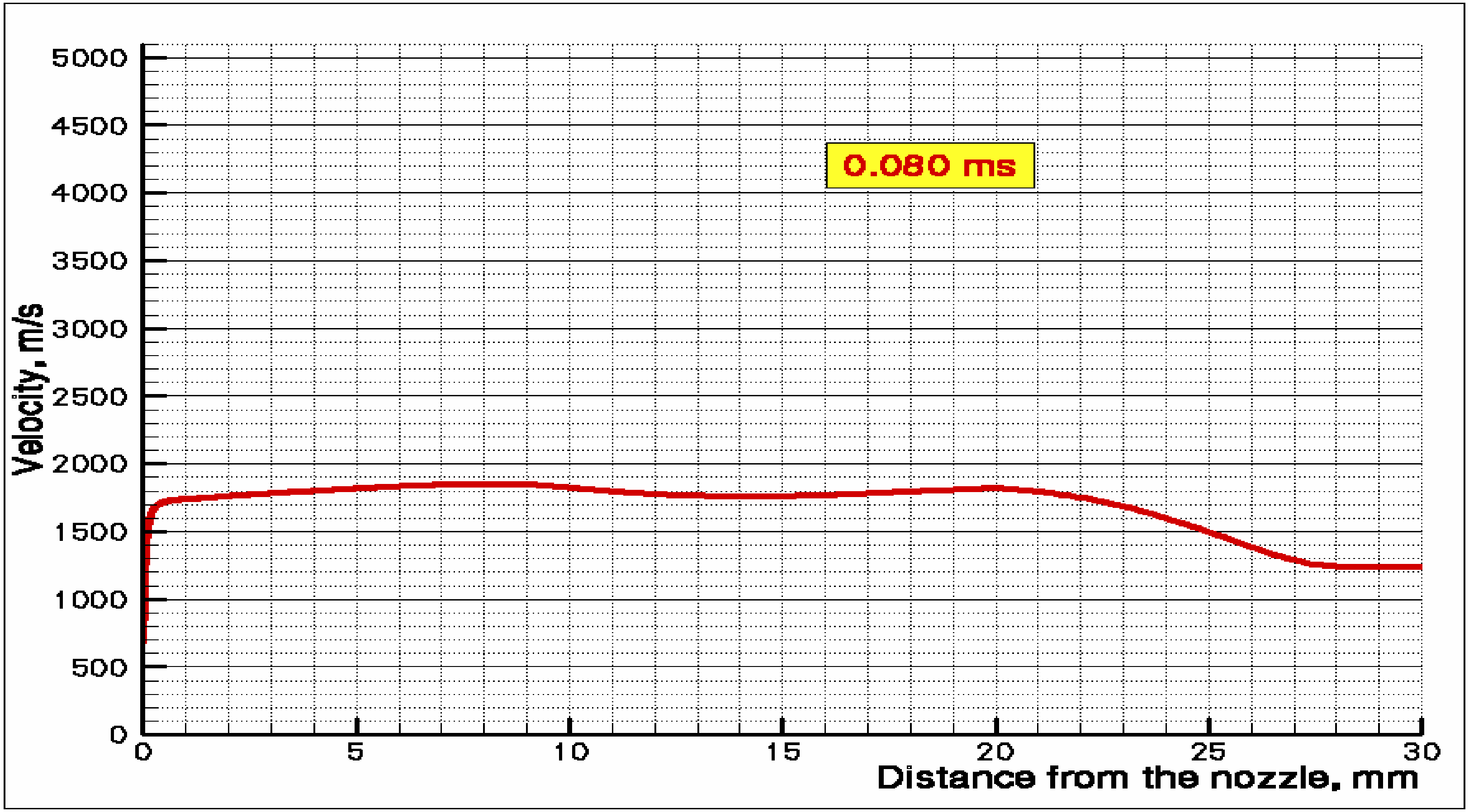
Gas-jet pulse development

Helium gas-jet velocity along the axis



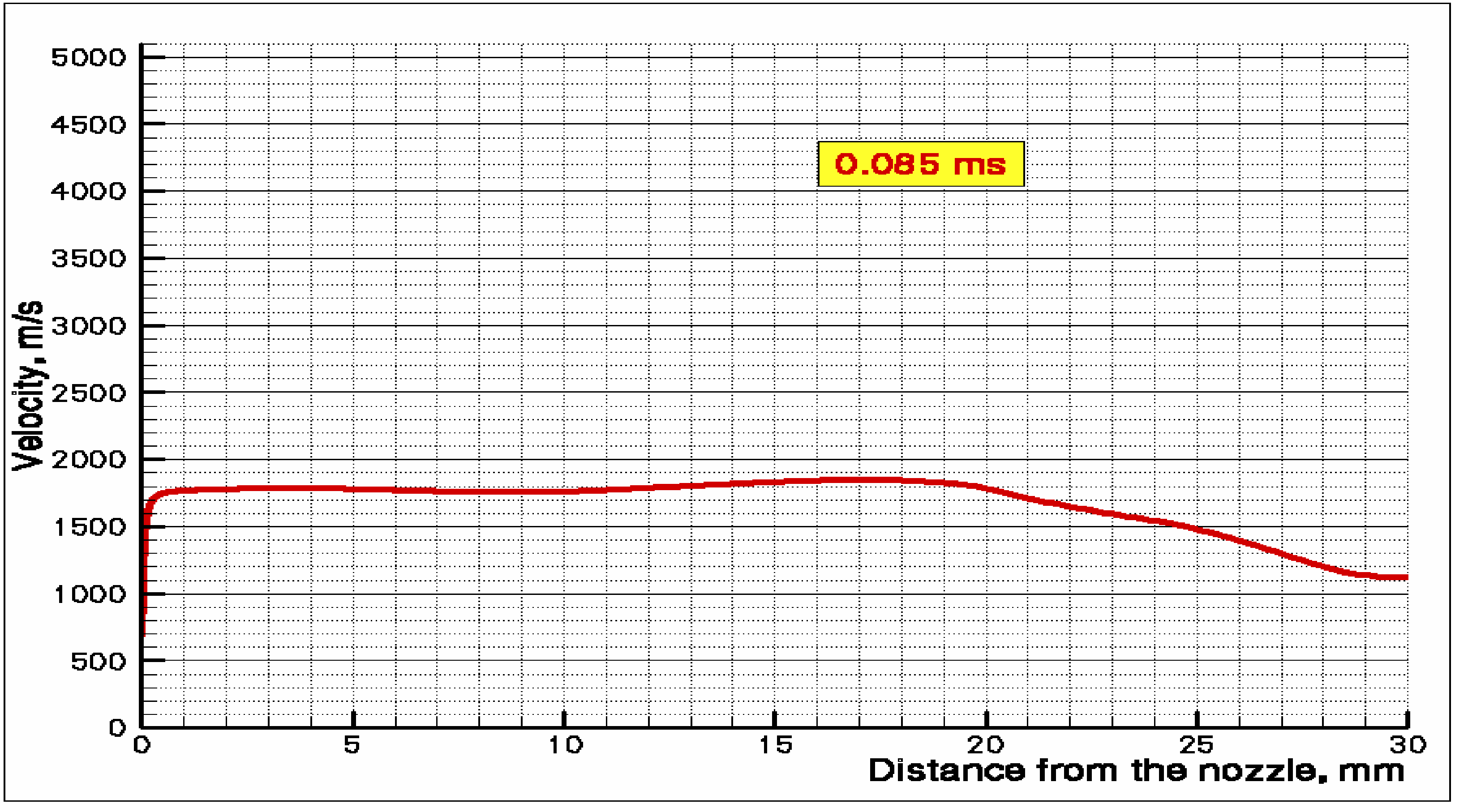
Gas-jet pulse development

Helium gas-jet velocity along the axis



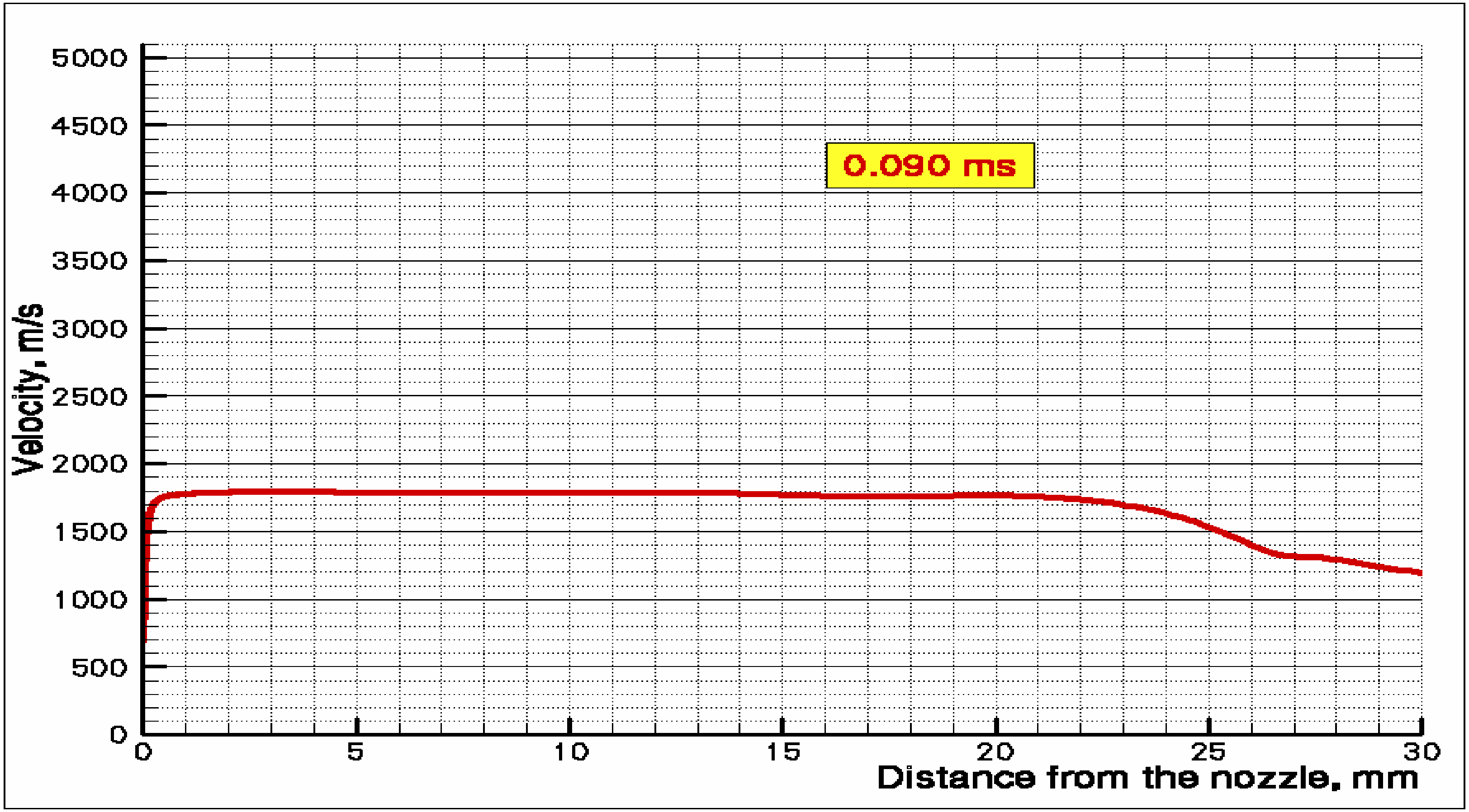
Gas-jet pulse development

Helium gas-jet velocity along the axis



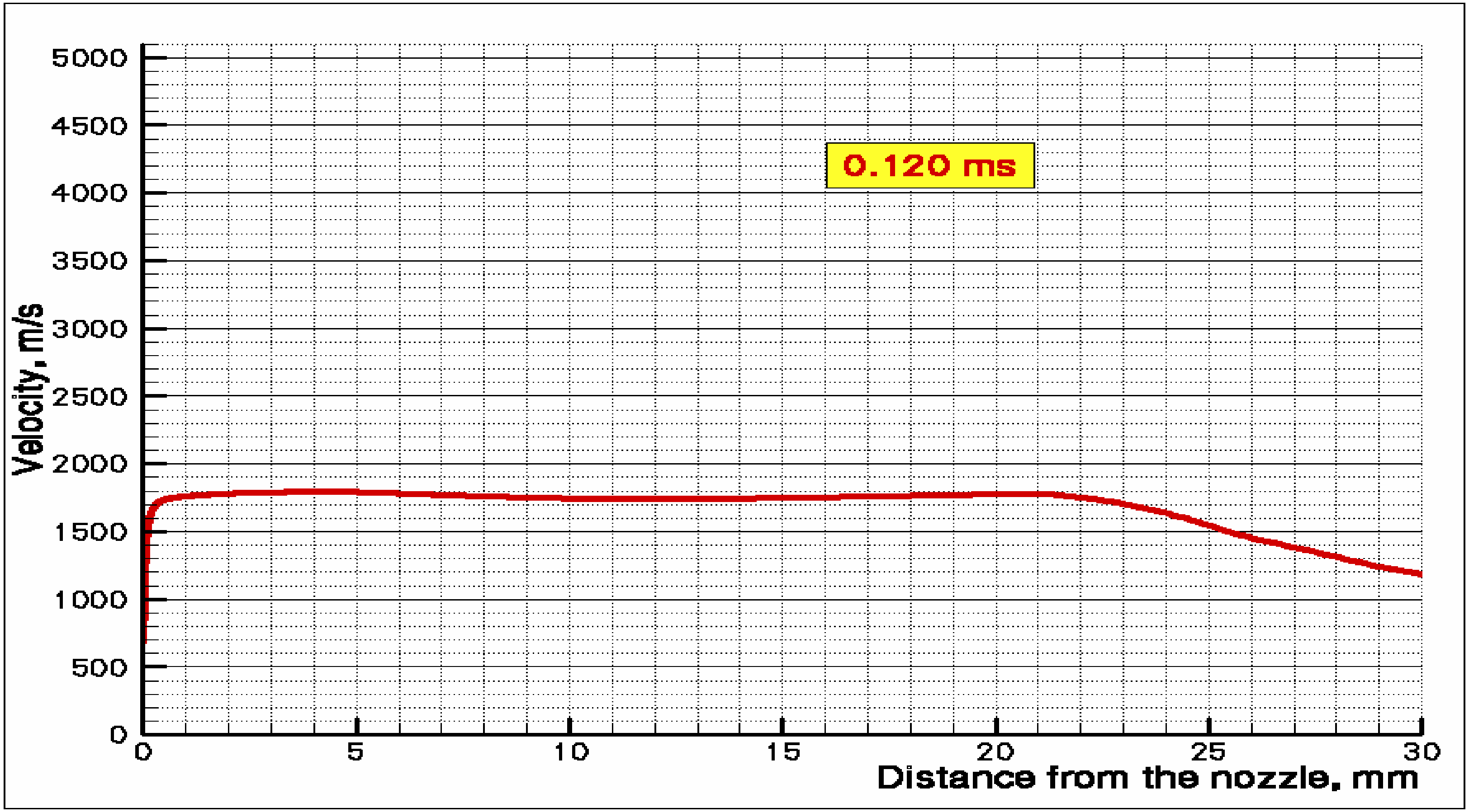
Gas-jet pulse development

Helium gas-jet velocity along the axis



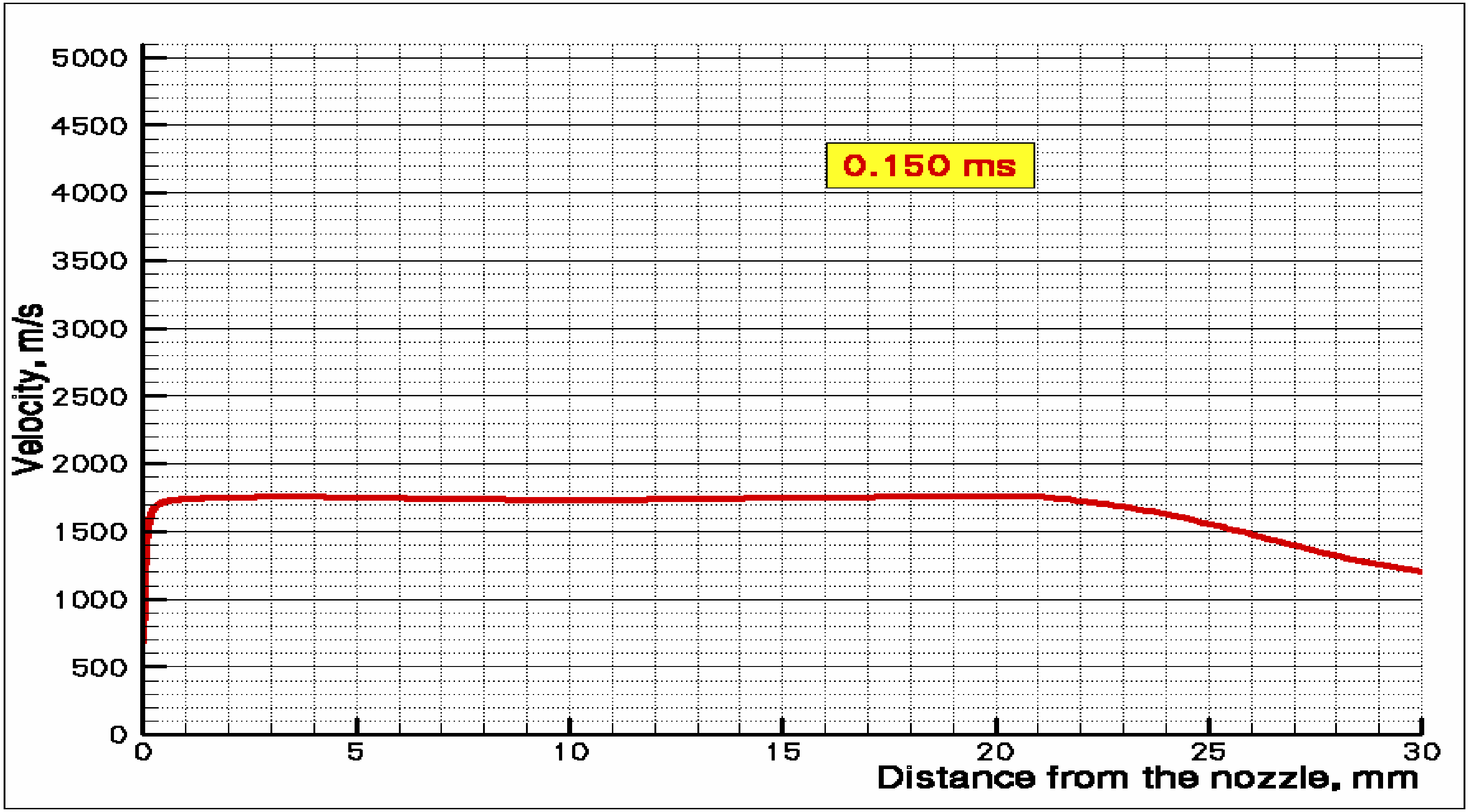
Gas-jet pulse development

Helium gas-jet velocity along the axis



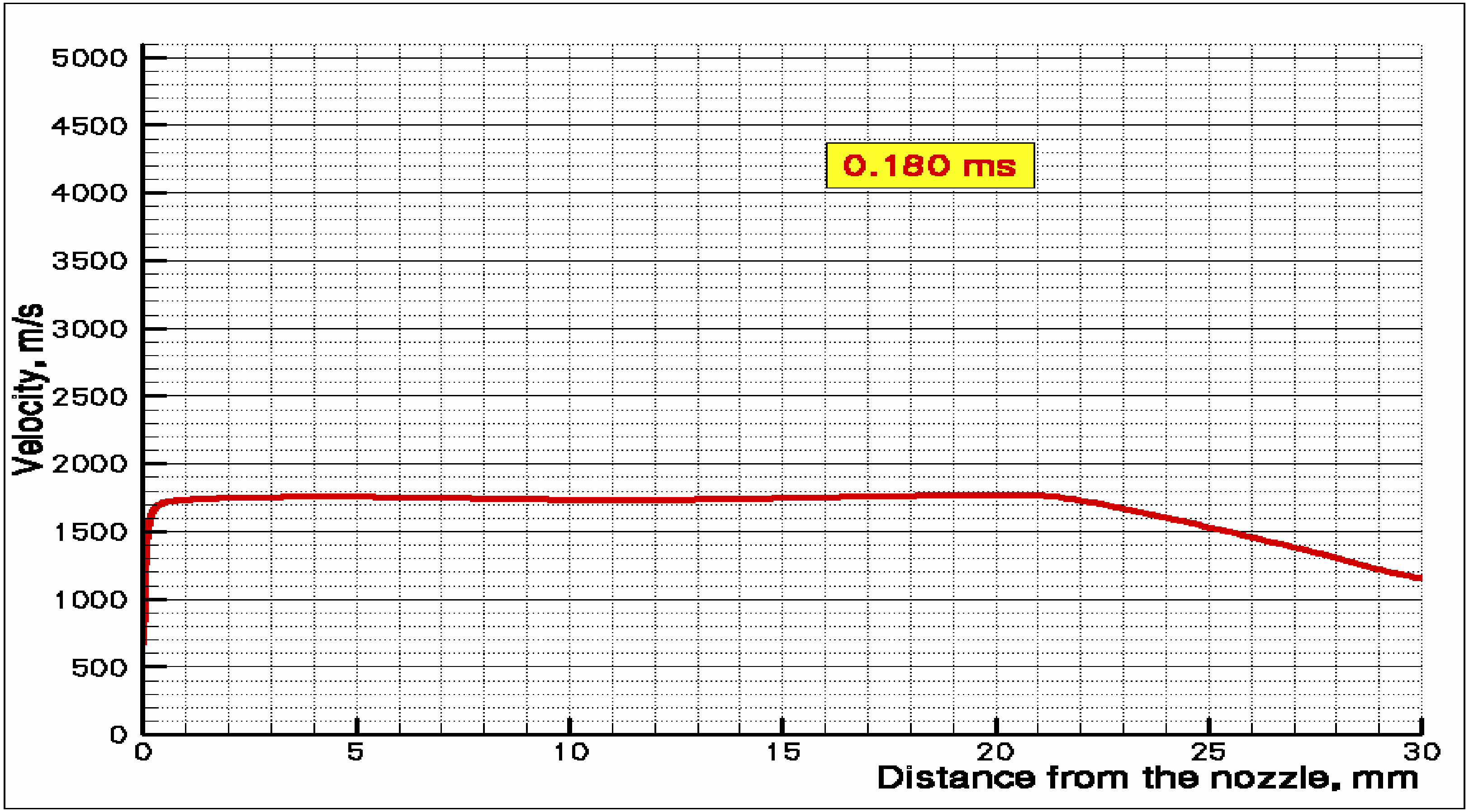
Gas-jet pulse development

Helium gas-jet velocity along the axis



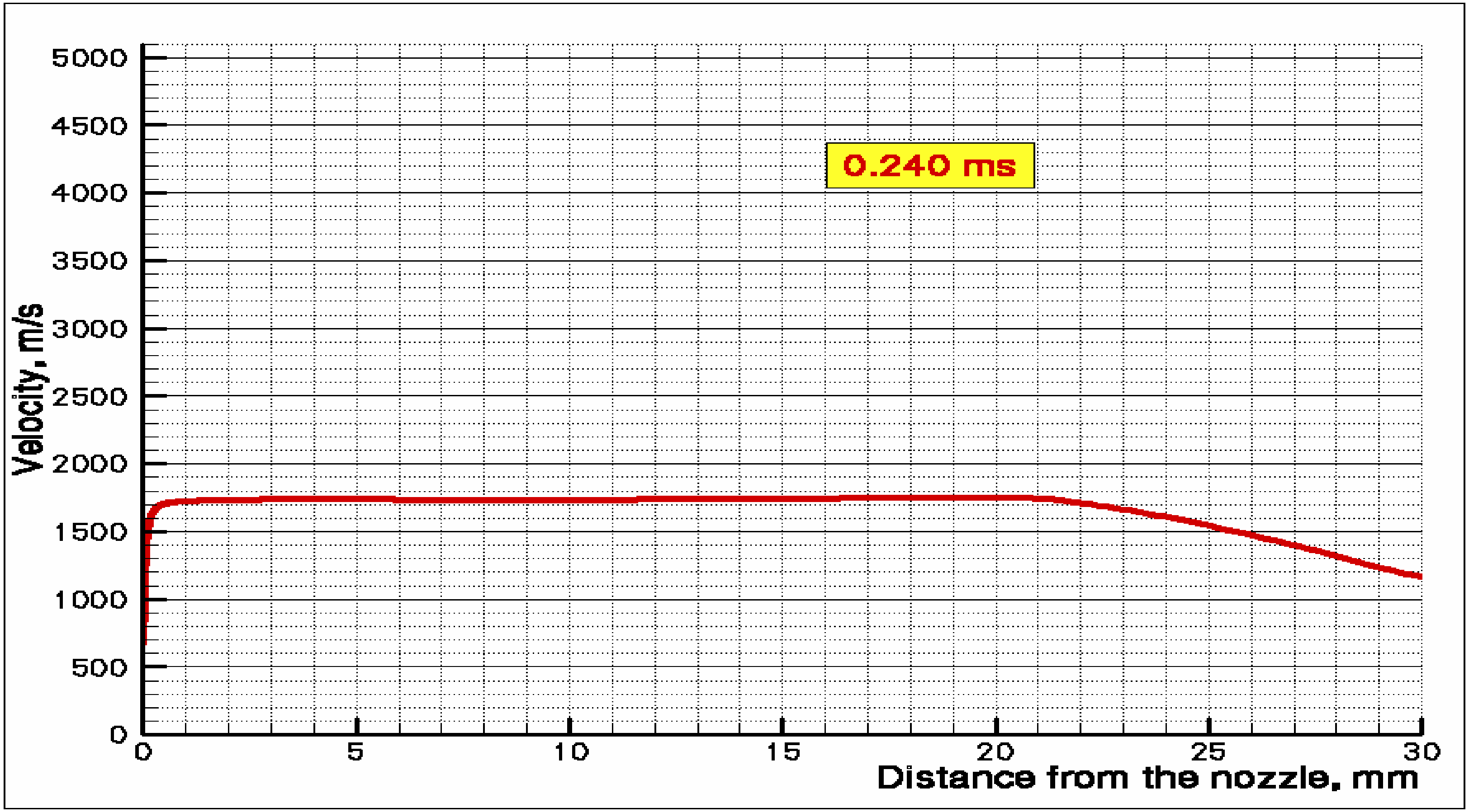
Gas-jet pulse development

Helium gas-jet velocity along the axis



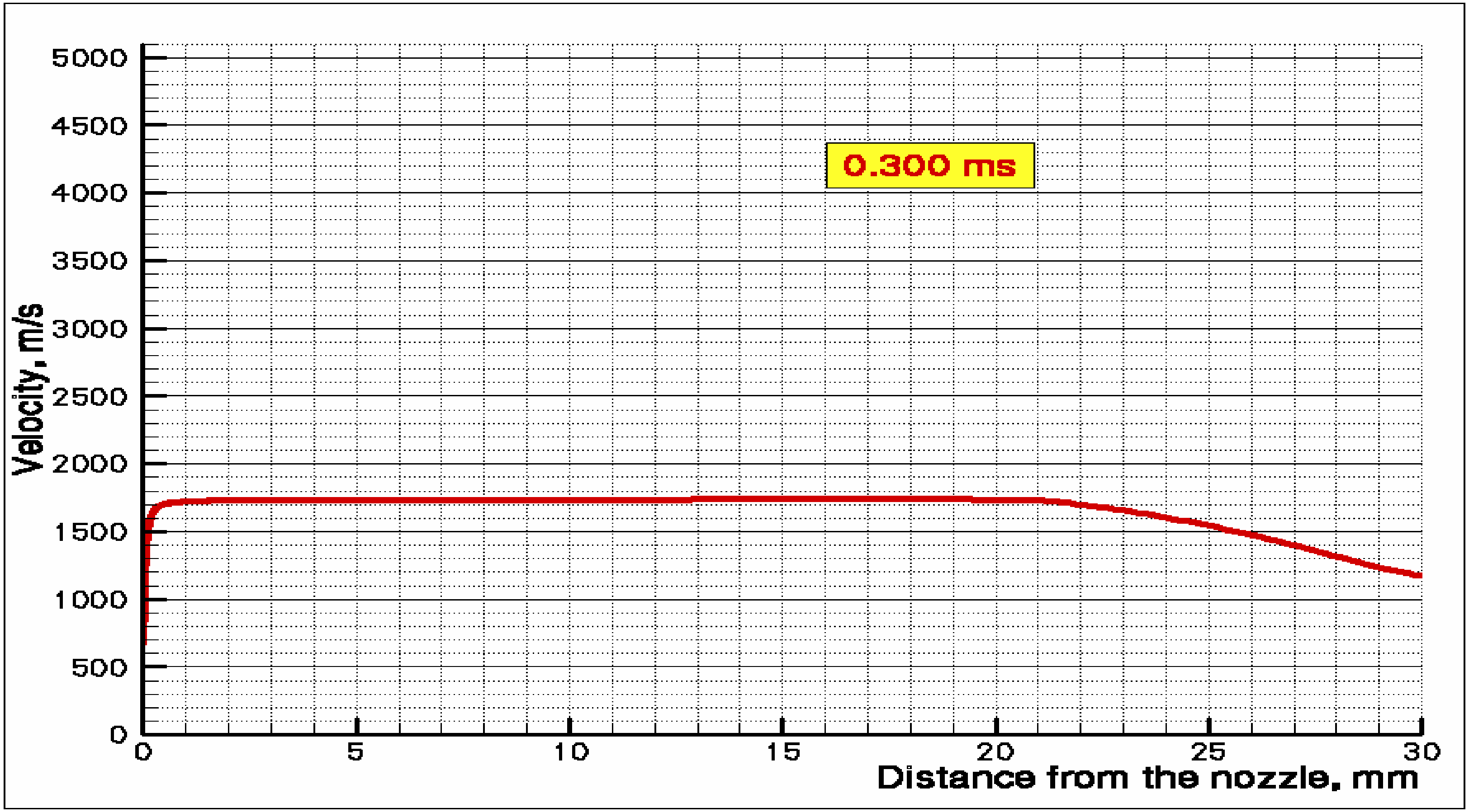
Gas-jet pulse development

Helium gas-jet velocity along the axis



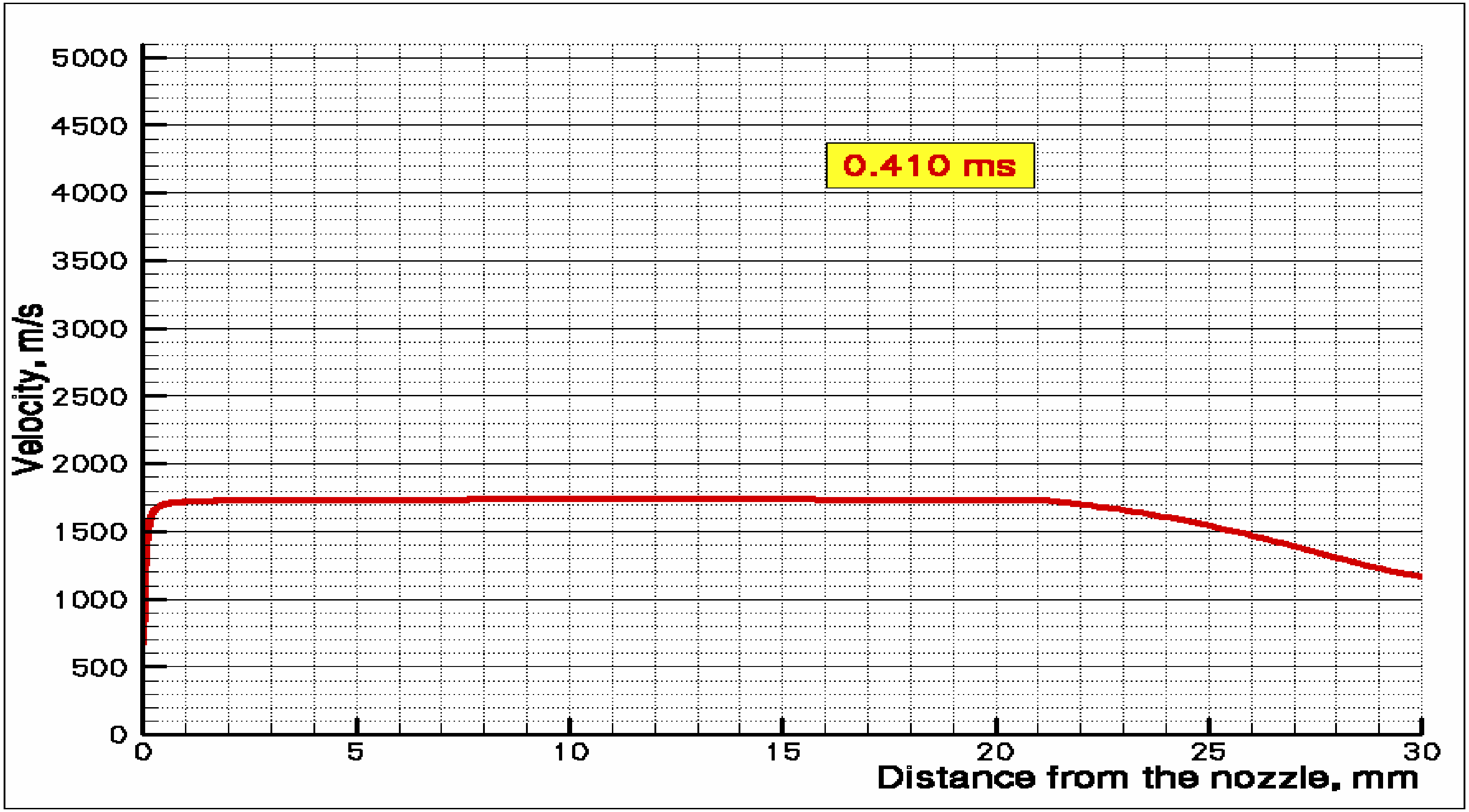
Gas-jet pulse development

Helium gas-jet velocity along the axis



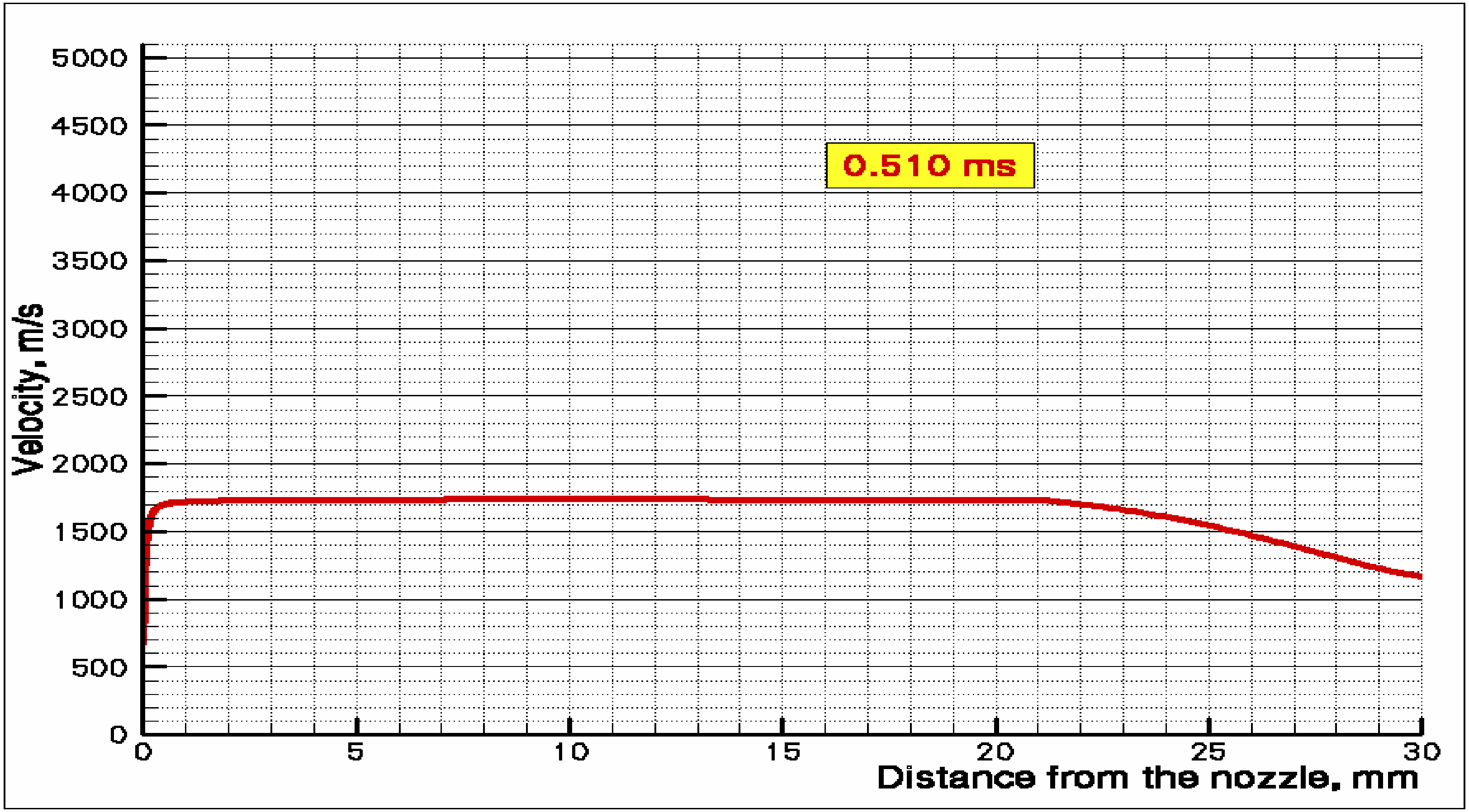
Gas-jet pulse development

Helium gas-jet velocity along the axis



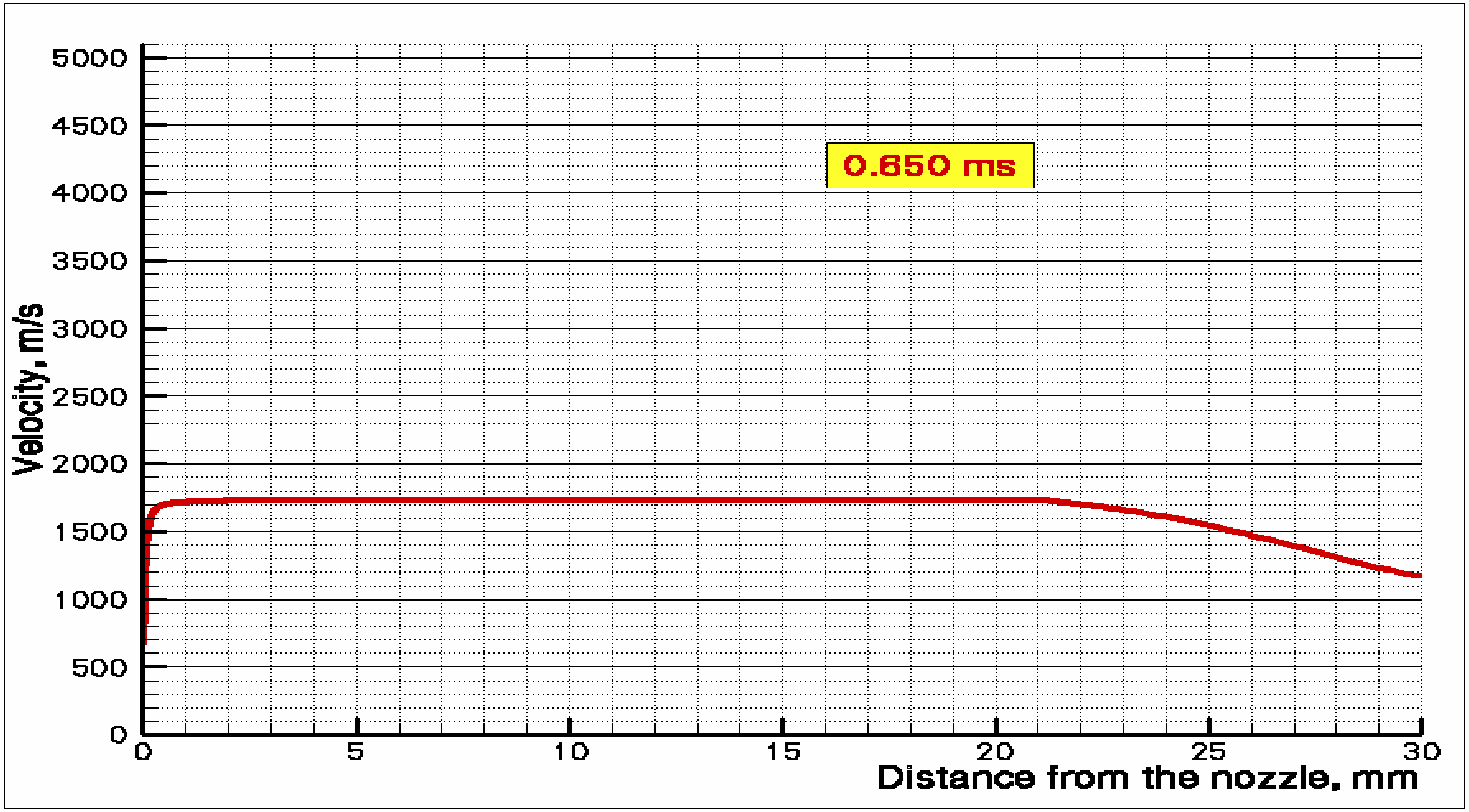
Gas-jet pulse development

Helium gas-jet velocity along the axis



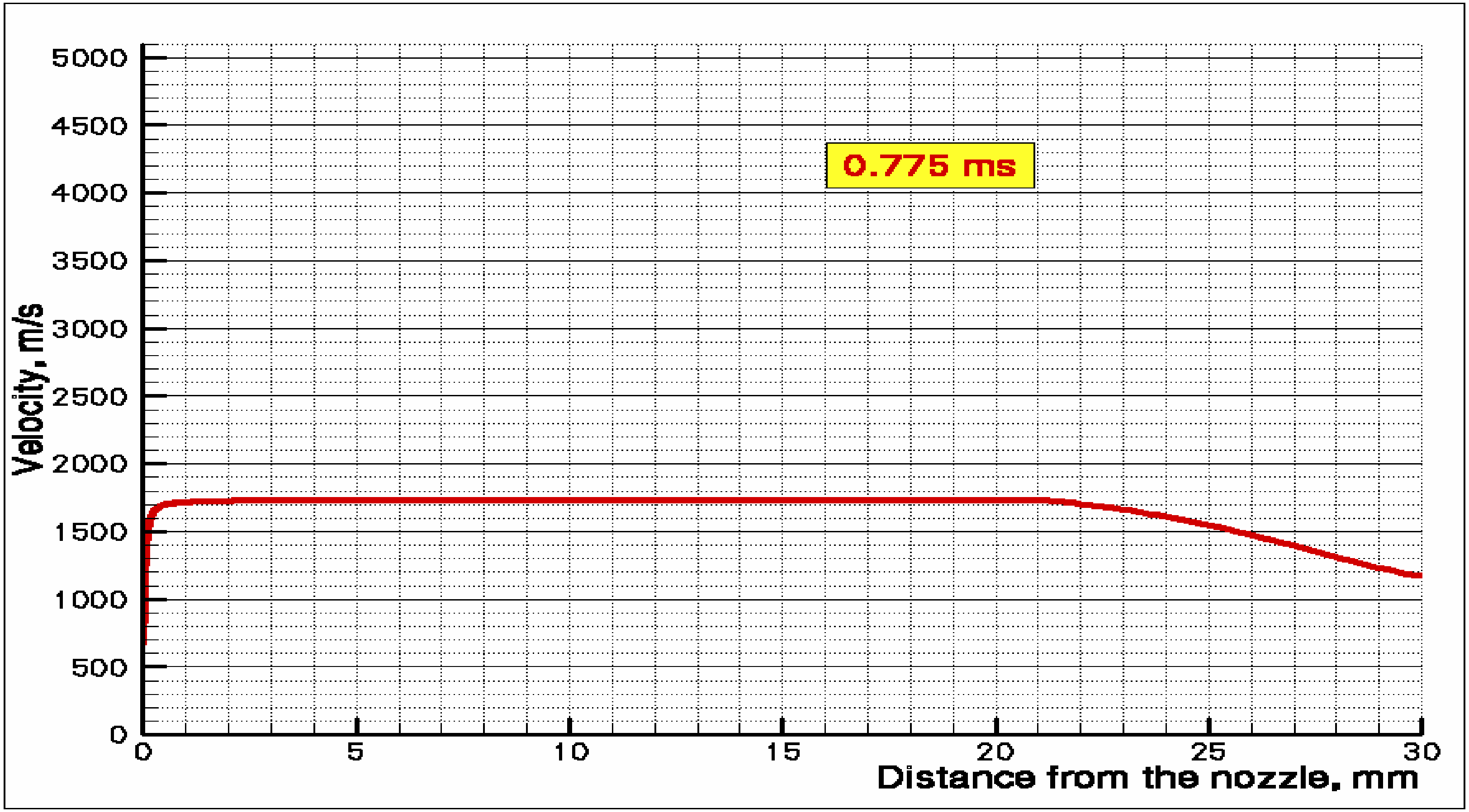
Gas-jet pulse development

Helium gas-jet velocity along the axis



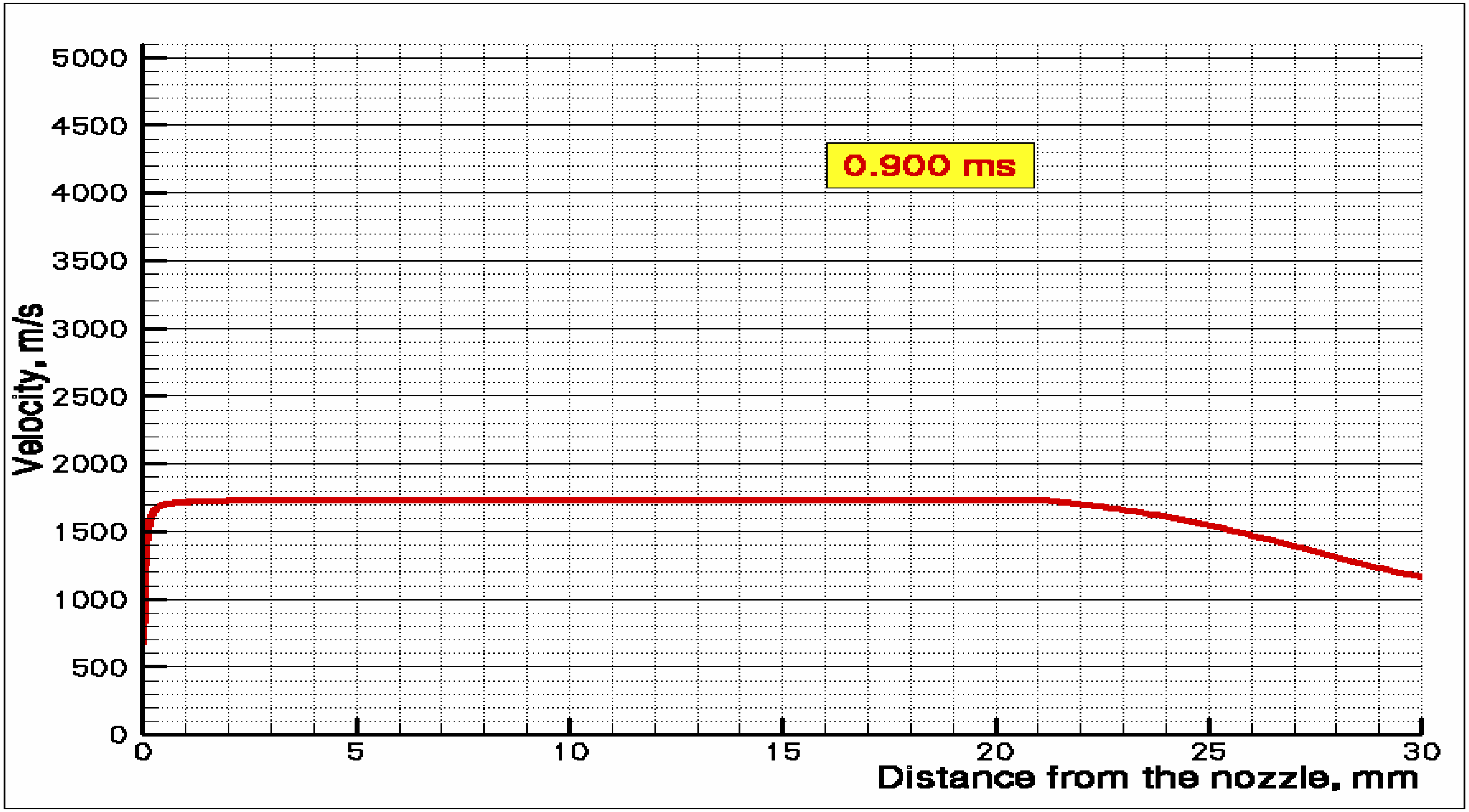
Gas-jet pulse development

Helium gas-jet velocity along the axis



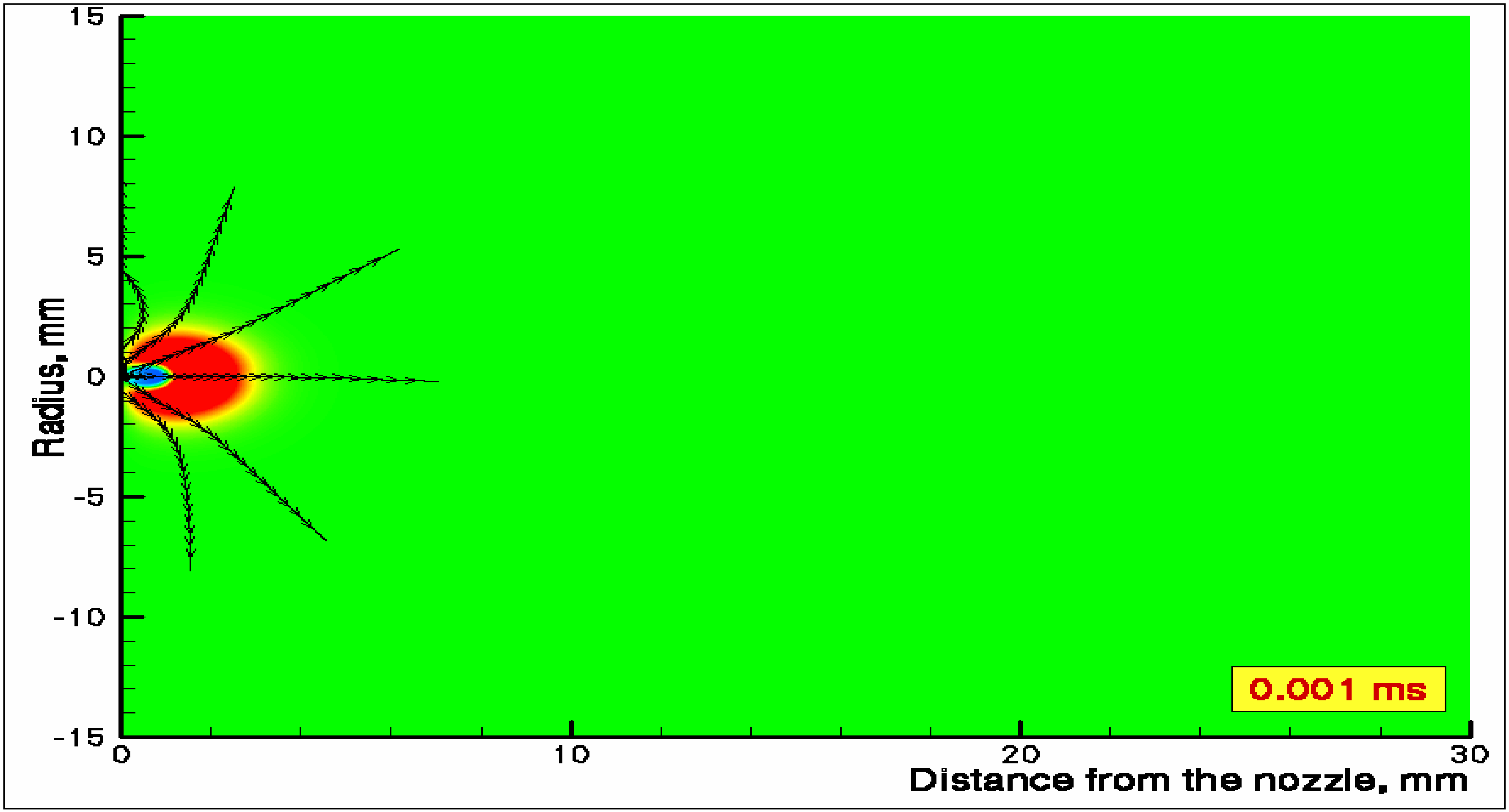
Gas-jet pulse development

Helium gas-jet velocity along the axis



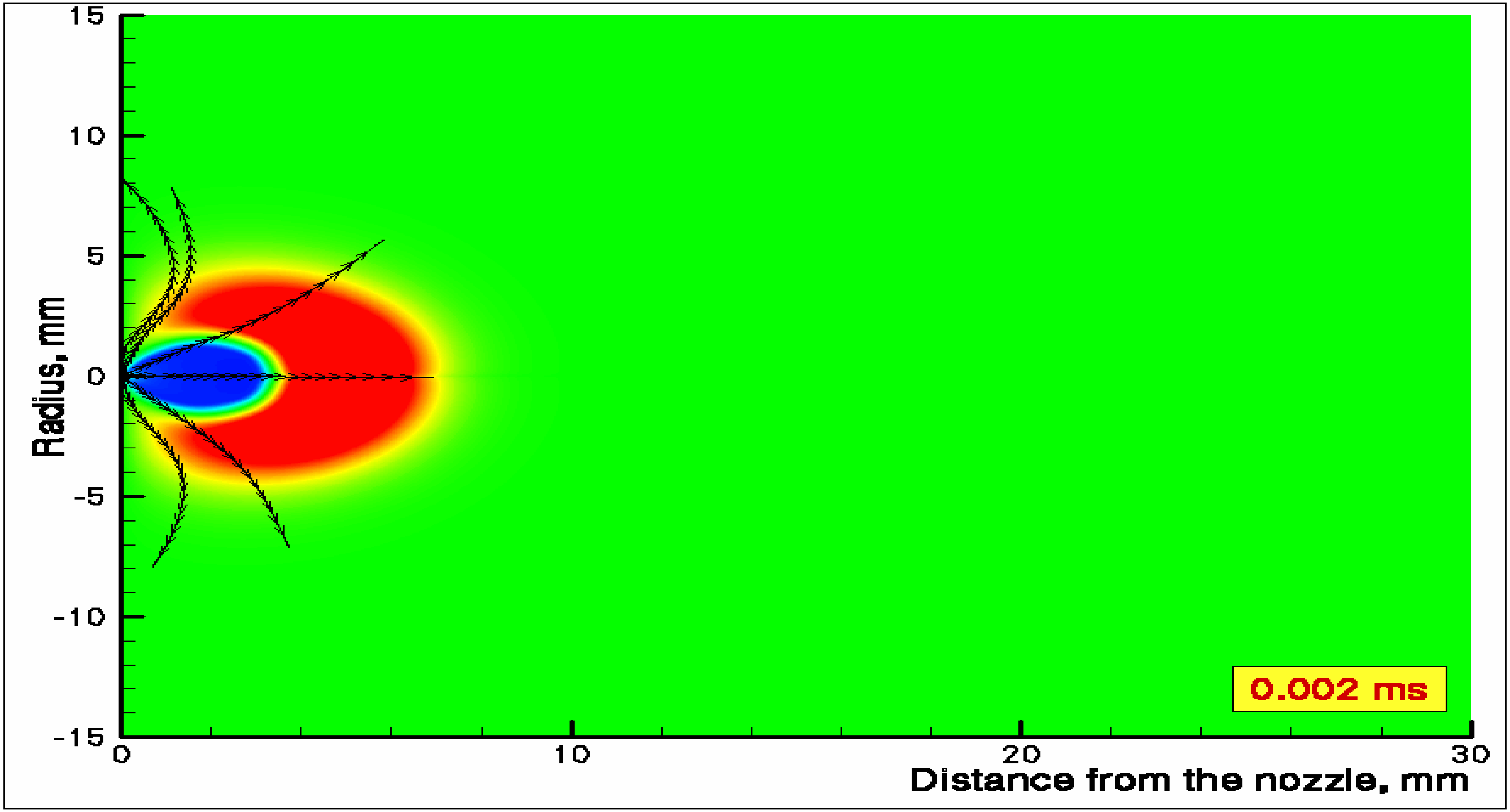
Gas-jet pulse development

Helium gas-jet temperature profile



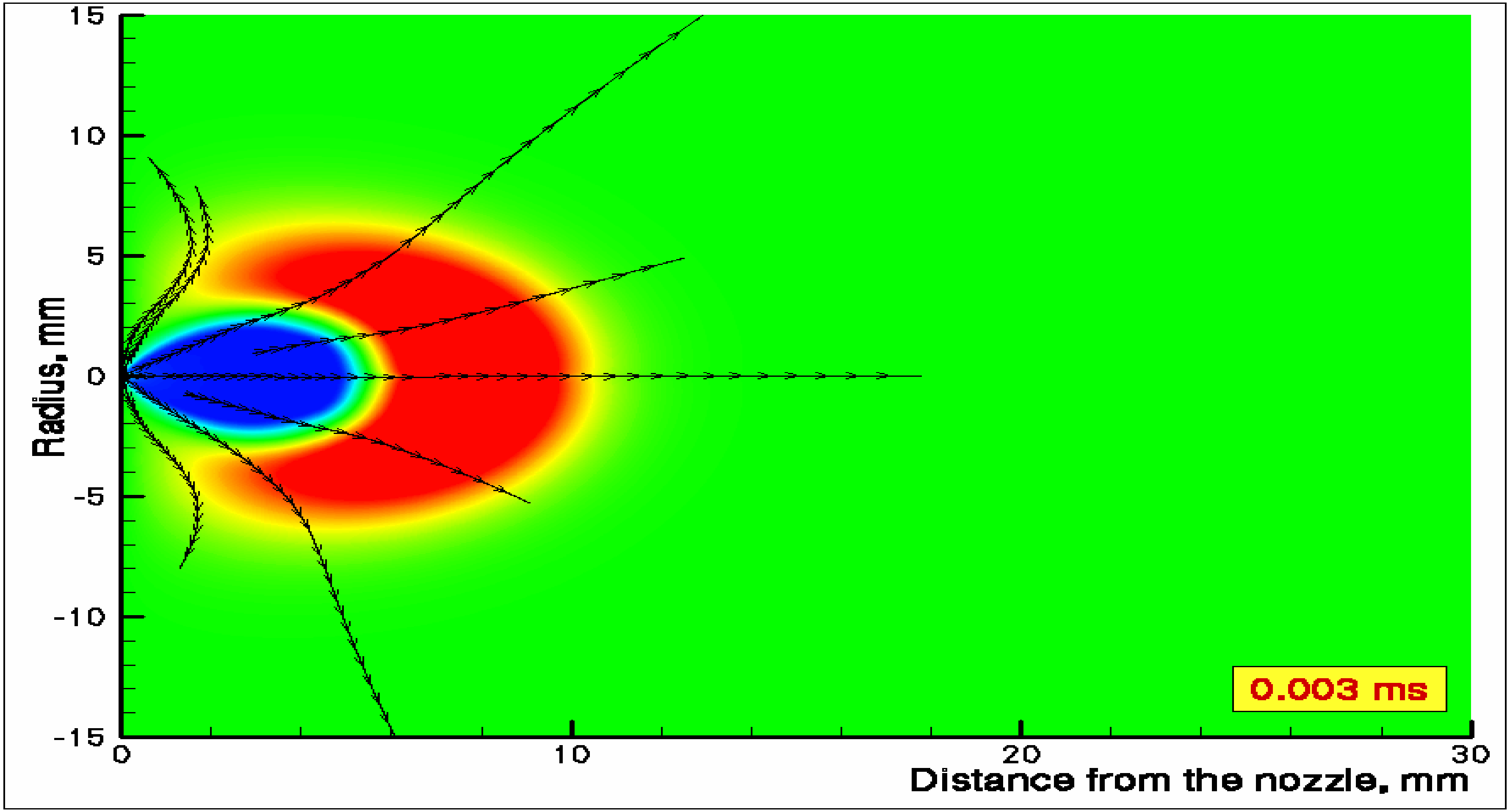
Gas-jet pulse development

Helium gas-jet temperature profile



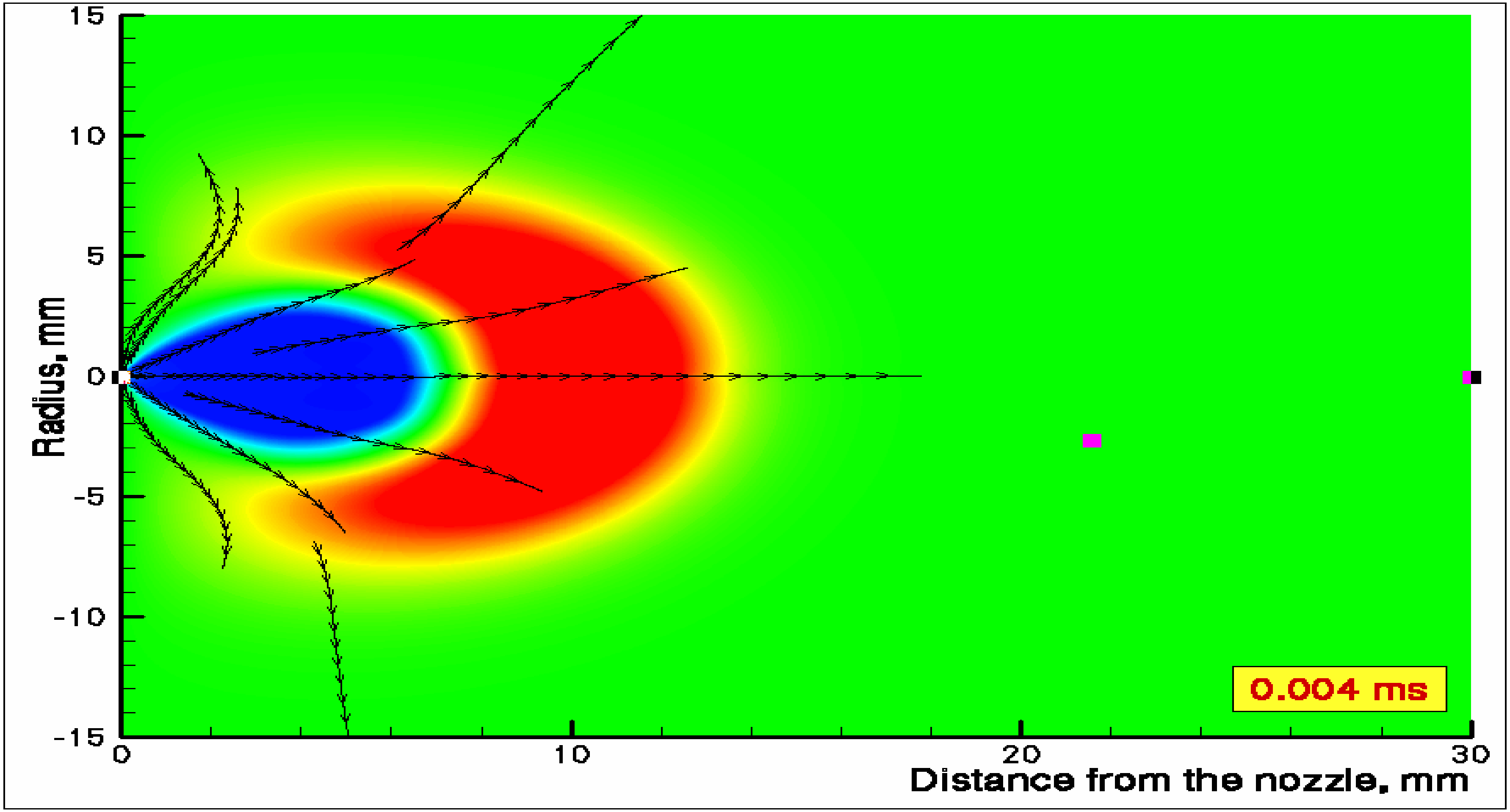
Gas-jet pulse development

Helium gas-jet temperature profile



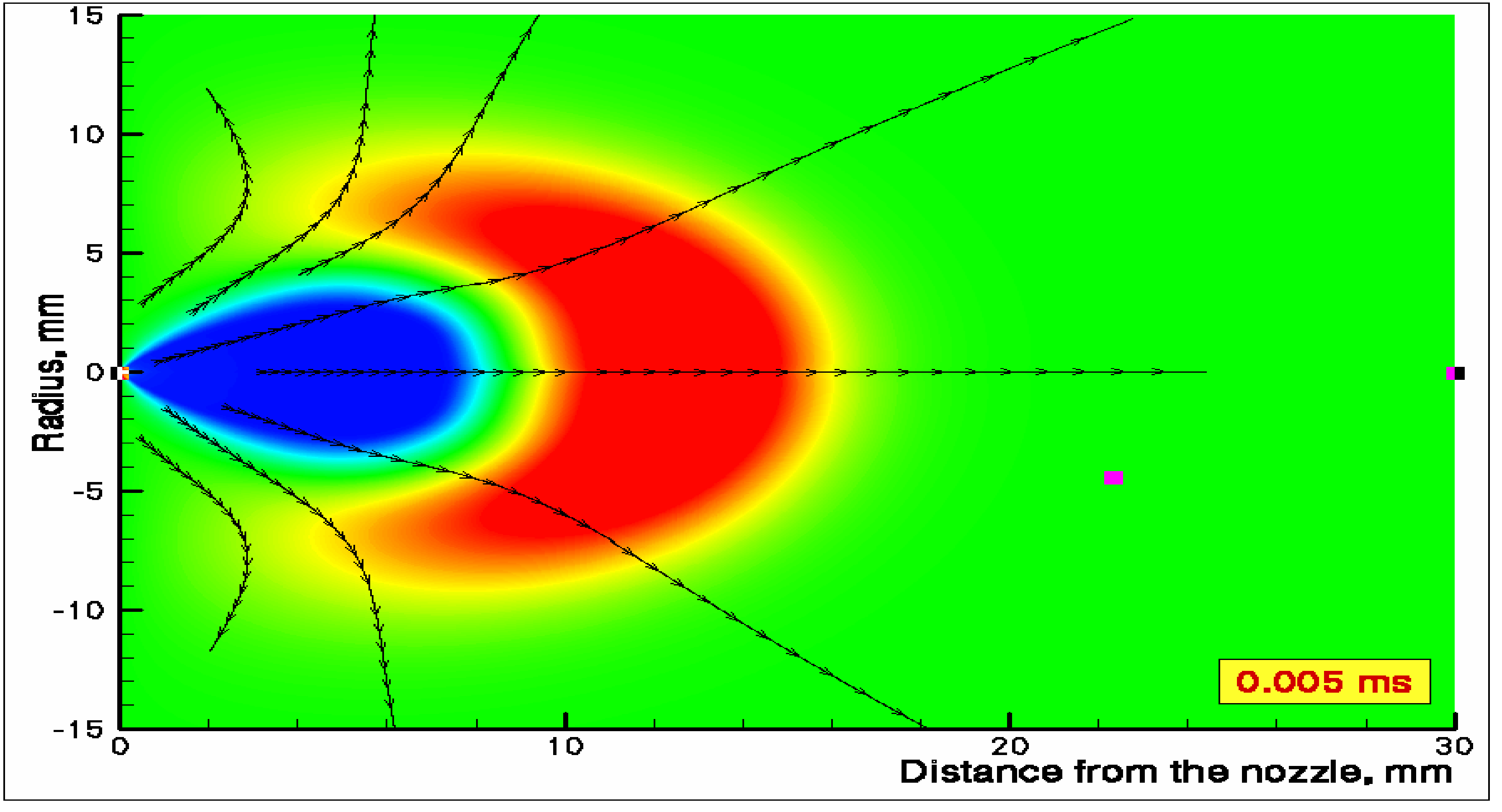
Gas-jet pulse development

Helium gas-jet temperature profile



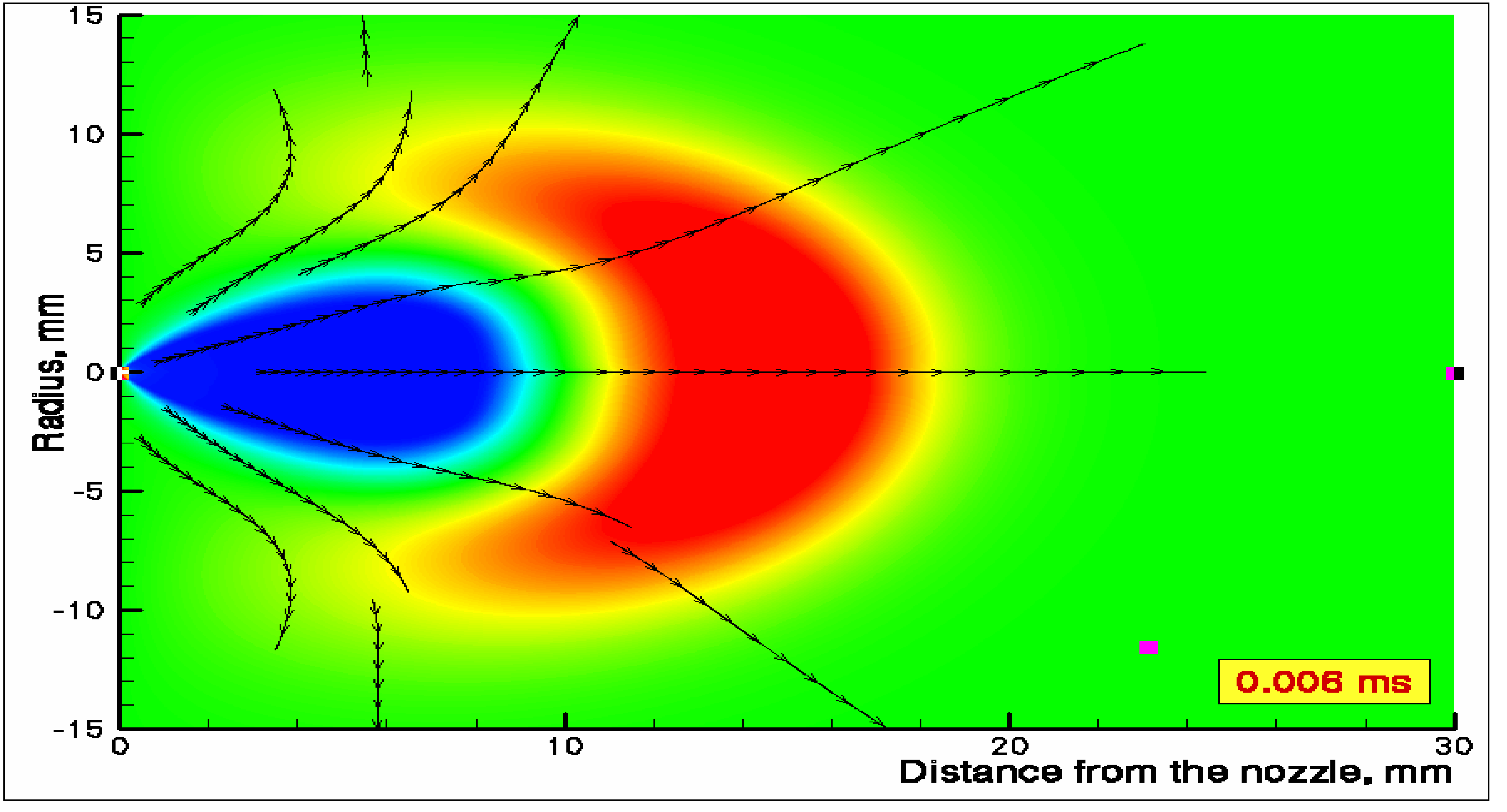
Gas-jet pulse development

Helium gas-jet temperature profile



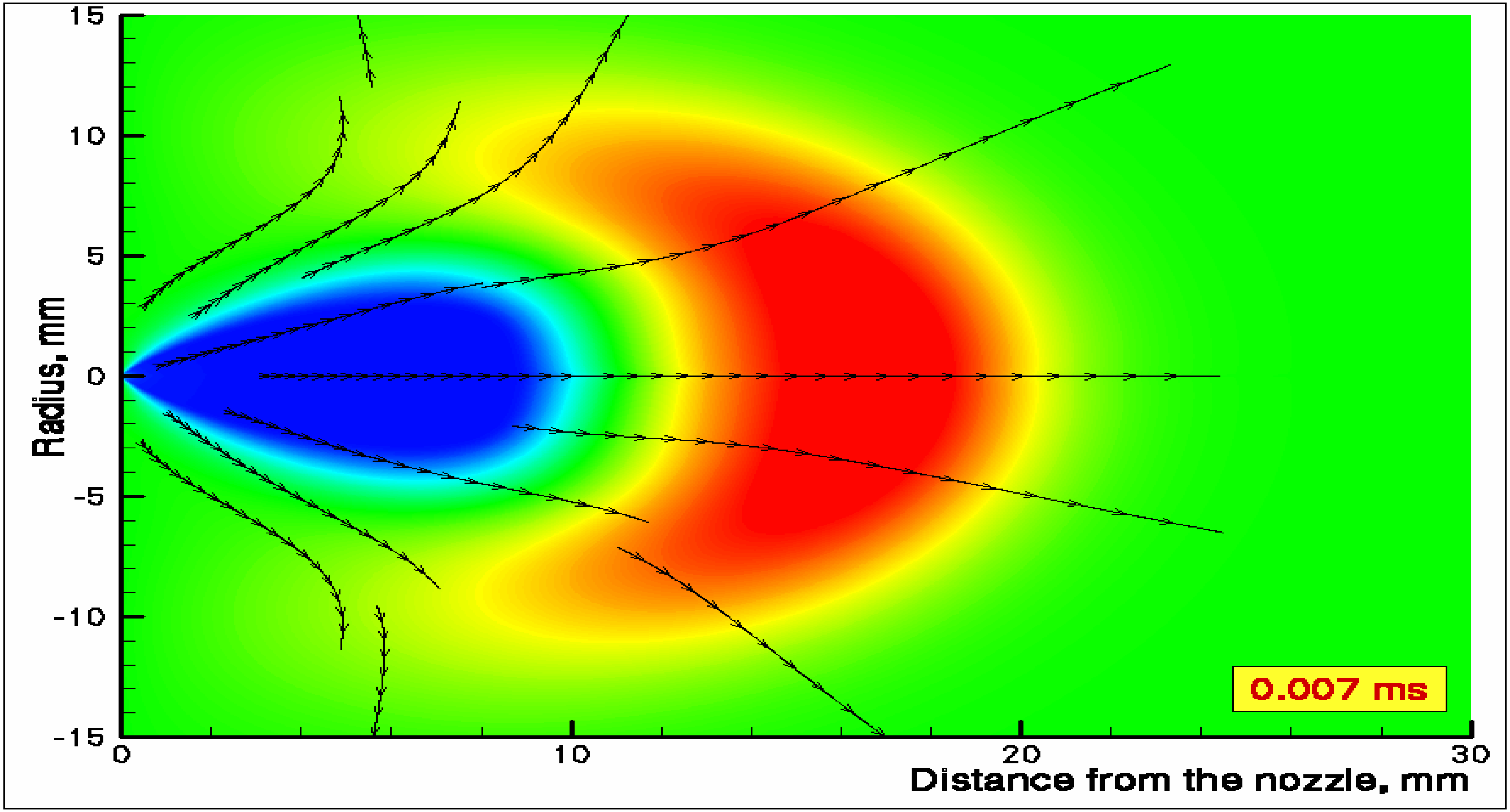
Gas-jet pulse development

Helium gas-jet temperature profile



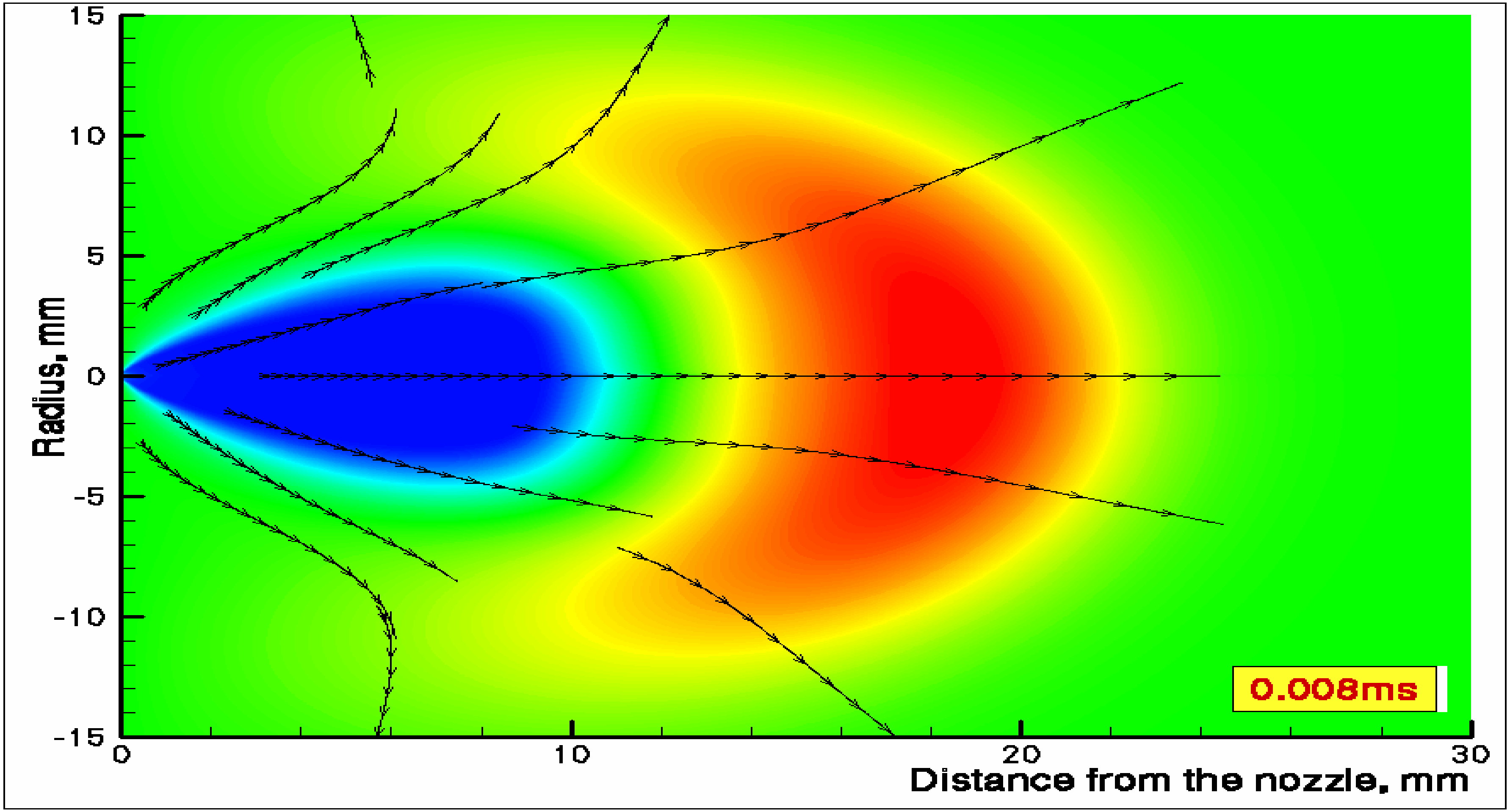
Gas-jet pulse development

Helium gas-jet temperature profile



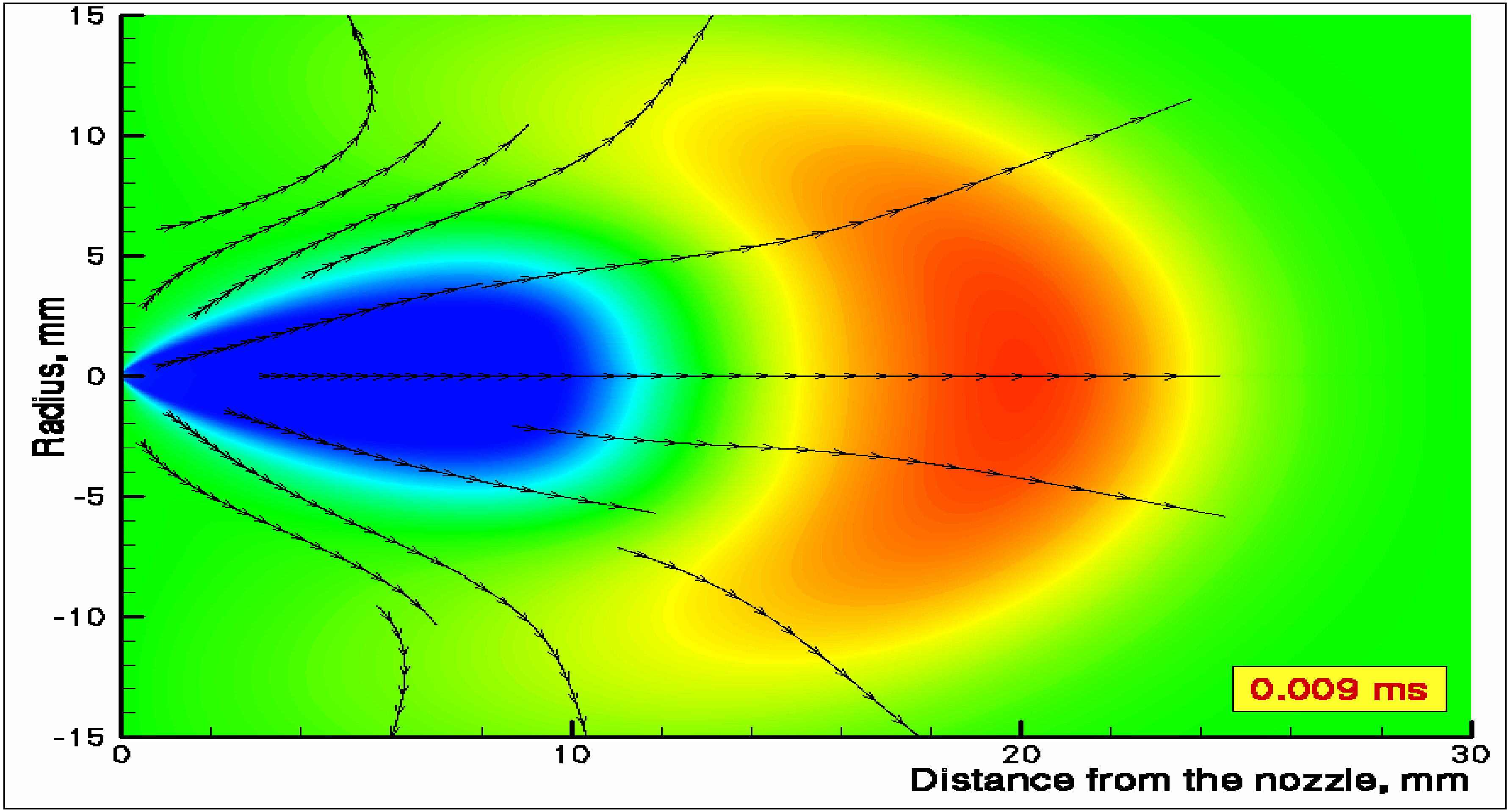
Gas-jet pulse development

Helium gas-jet temperature profile



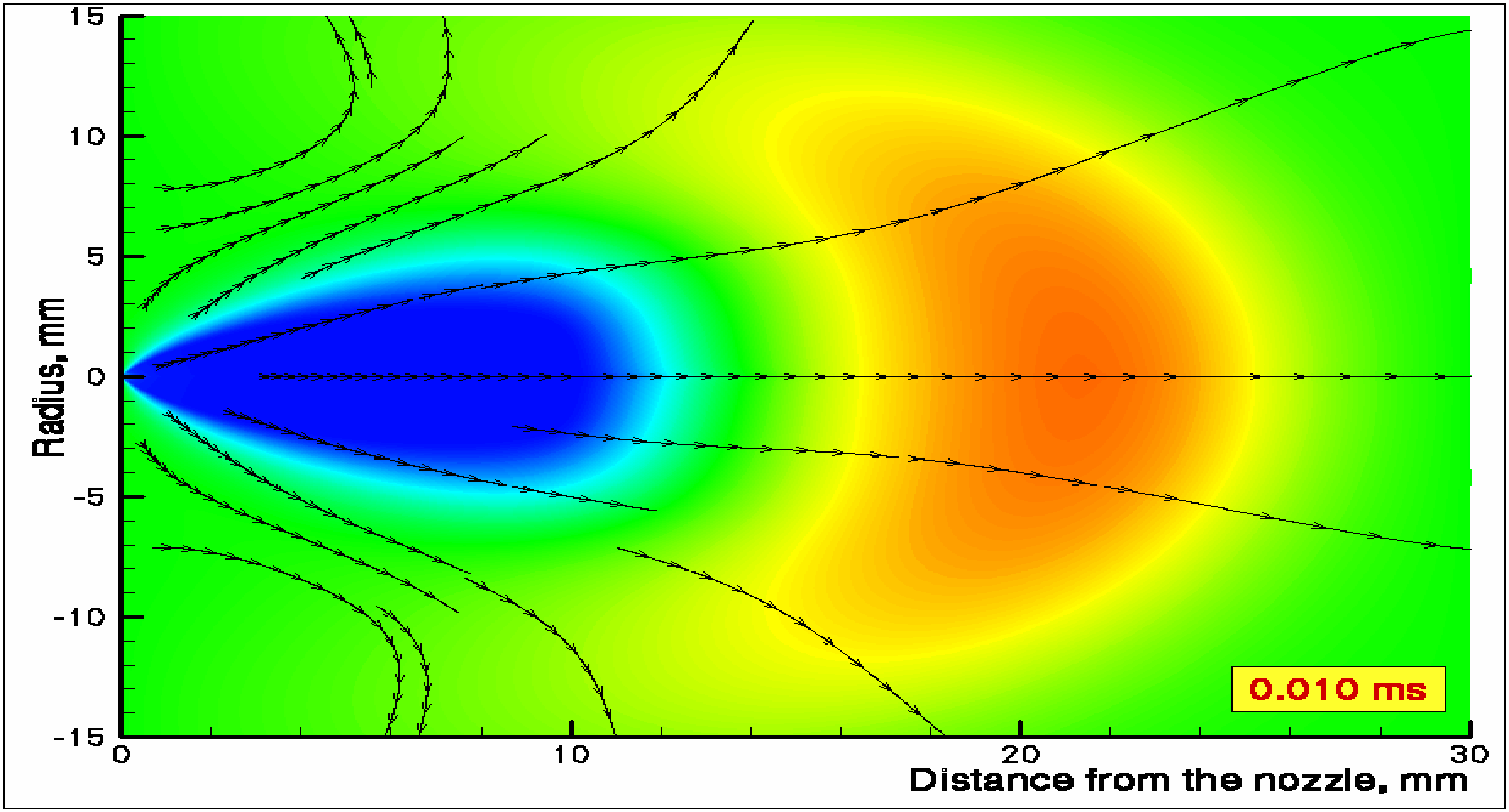
Gas-jet pulse development

Helium gas-jet temperature profile



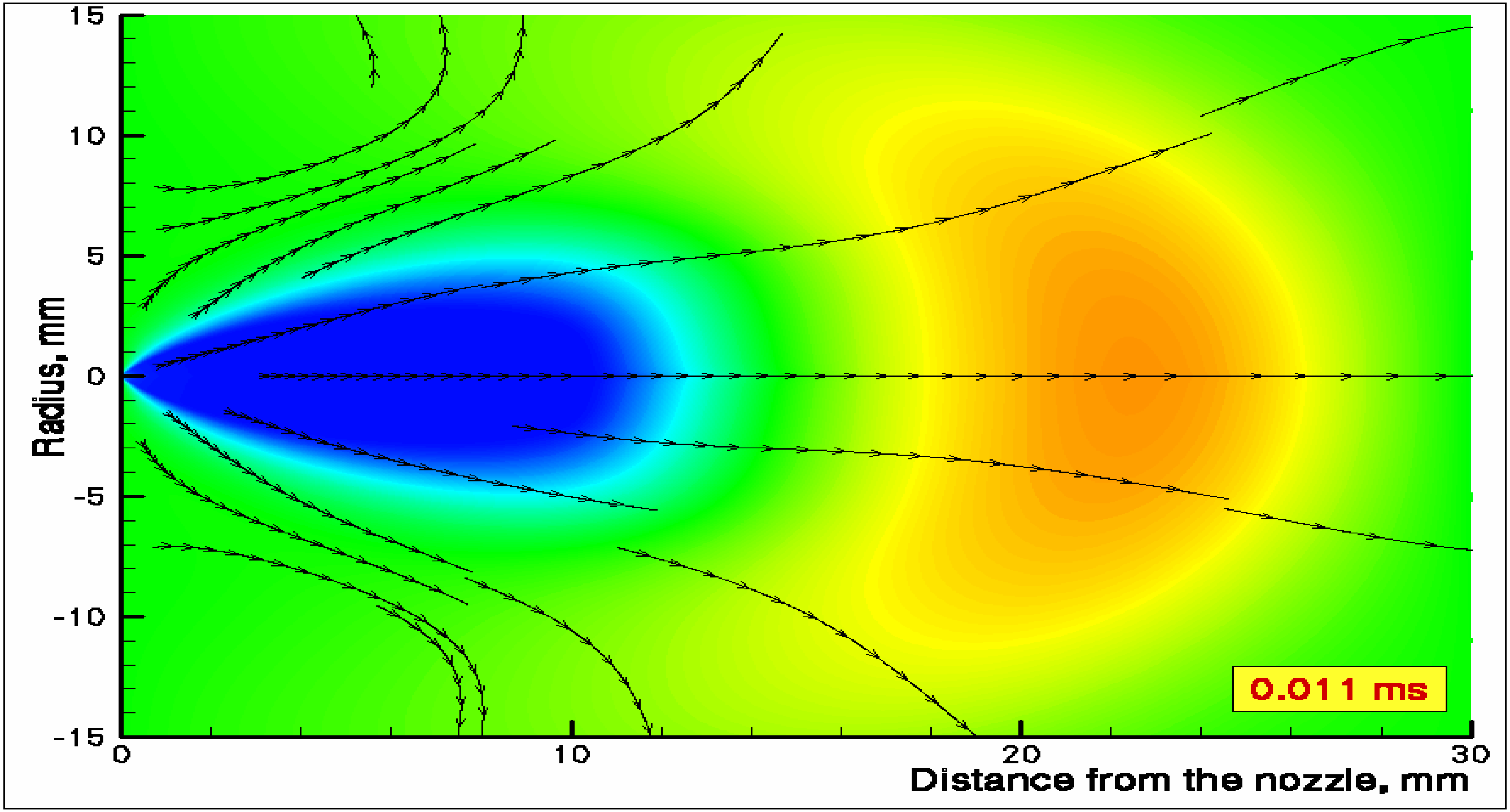
Gas-jet pulse development

Helium gas-jet temperature profile



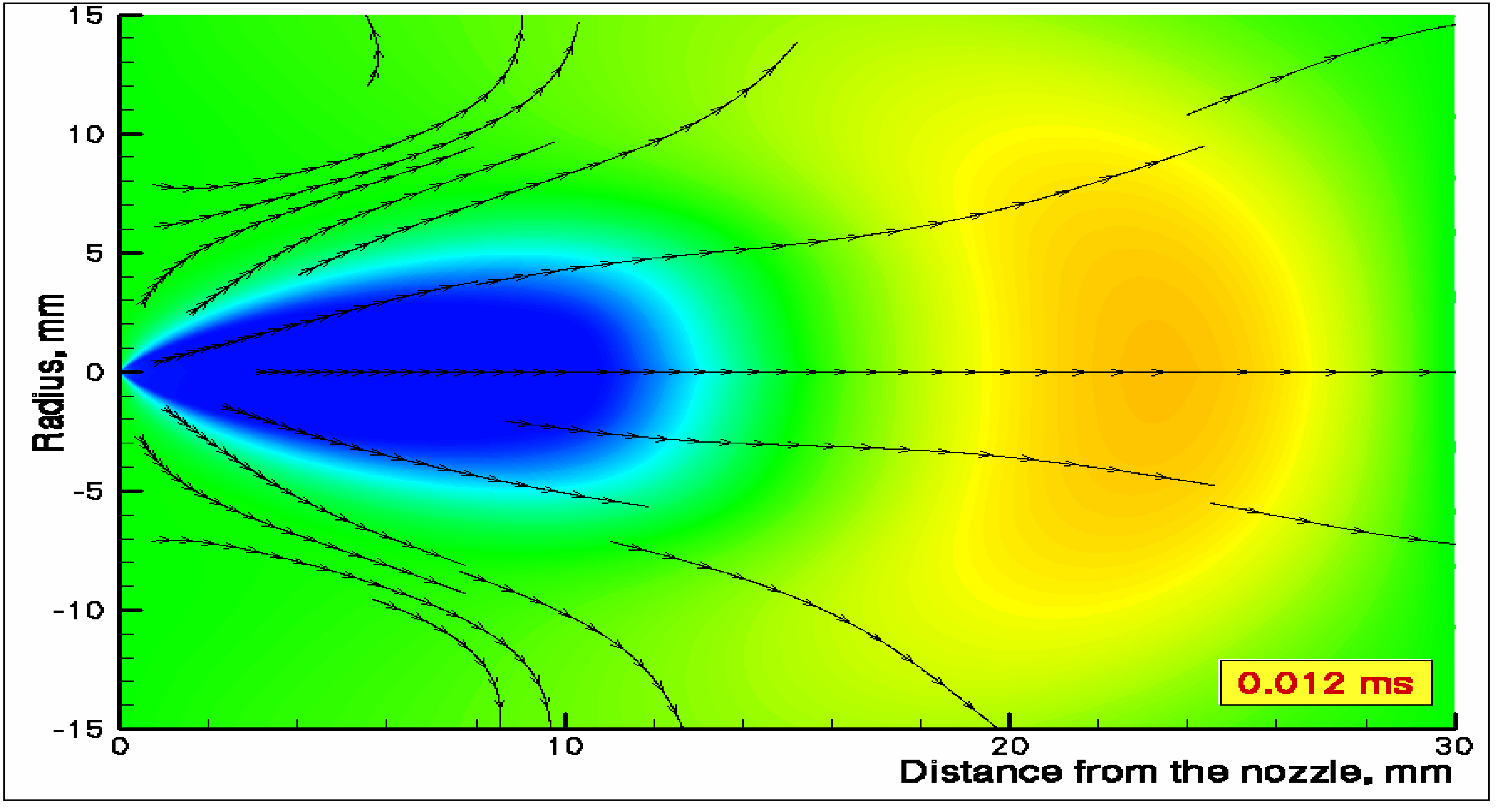
Gas-jet pulse development

Helium gas-jet temperature profile



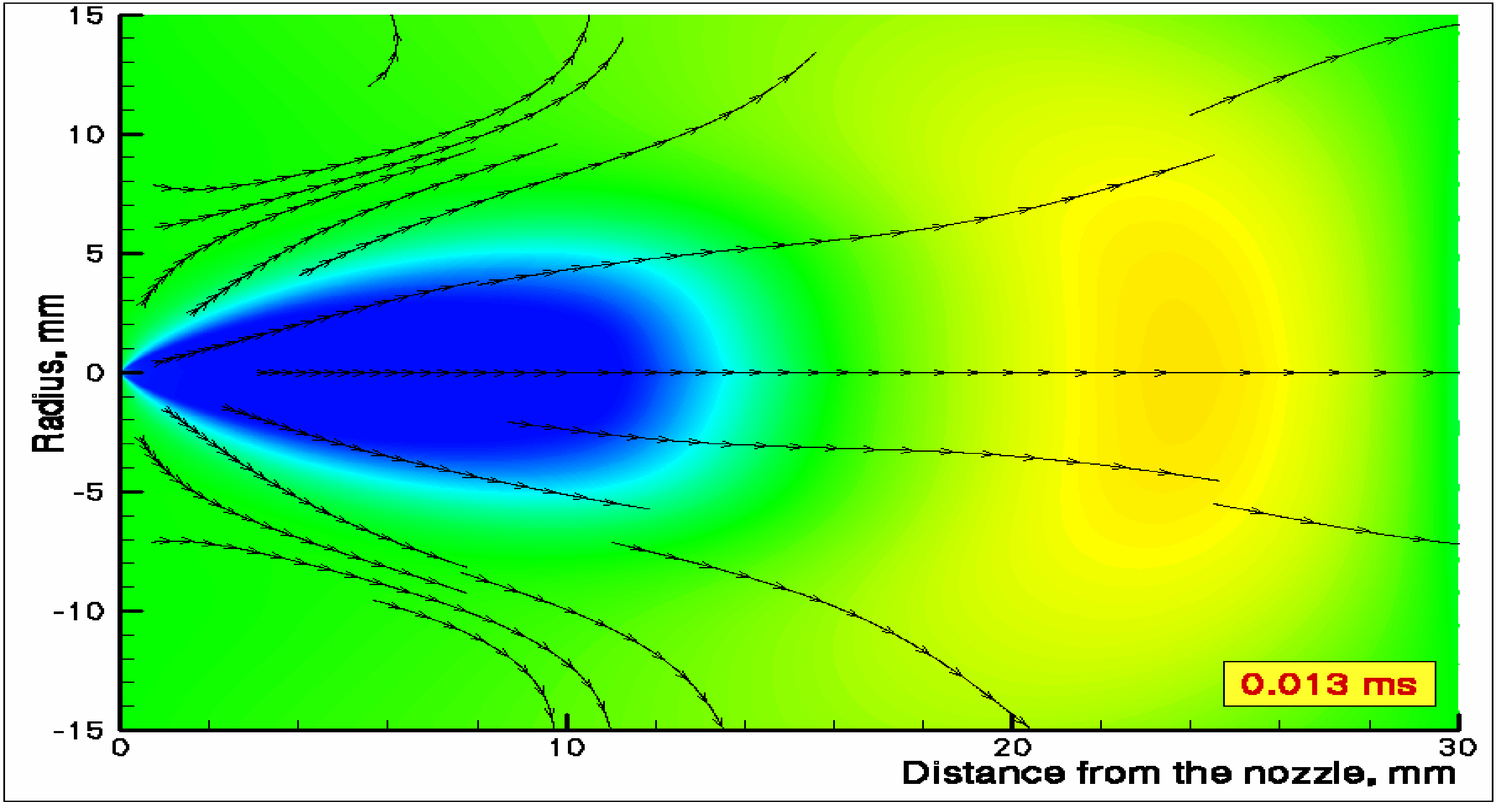
Gas-jet pulse development

Helium gas-jet temperature profile



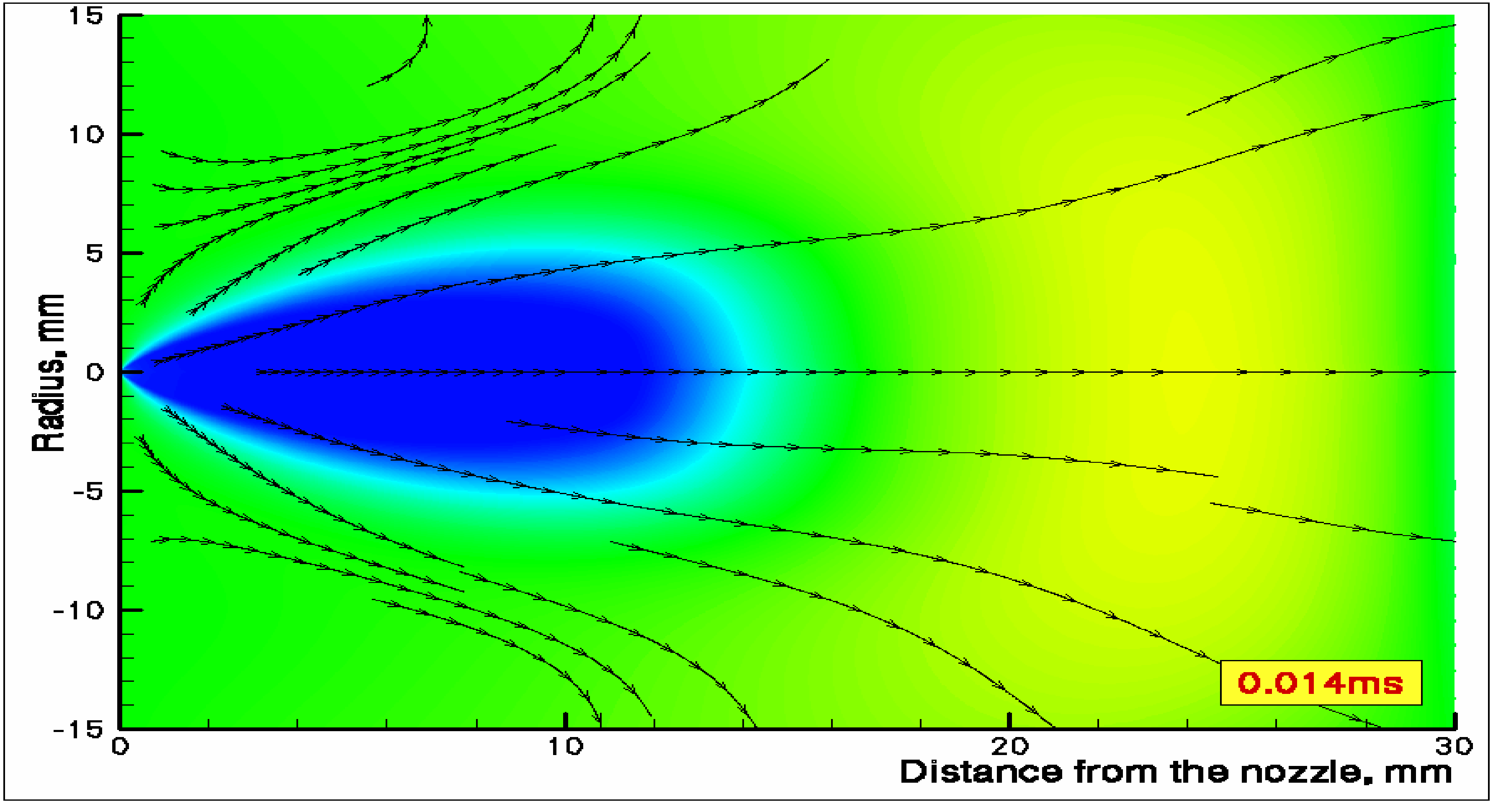
Gas-jet pulse development

Helium gas-jet temperature profile



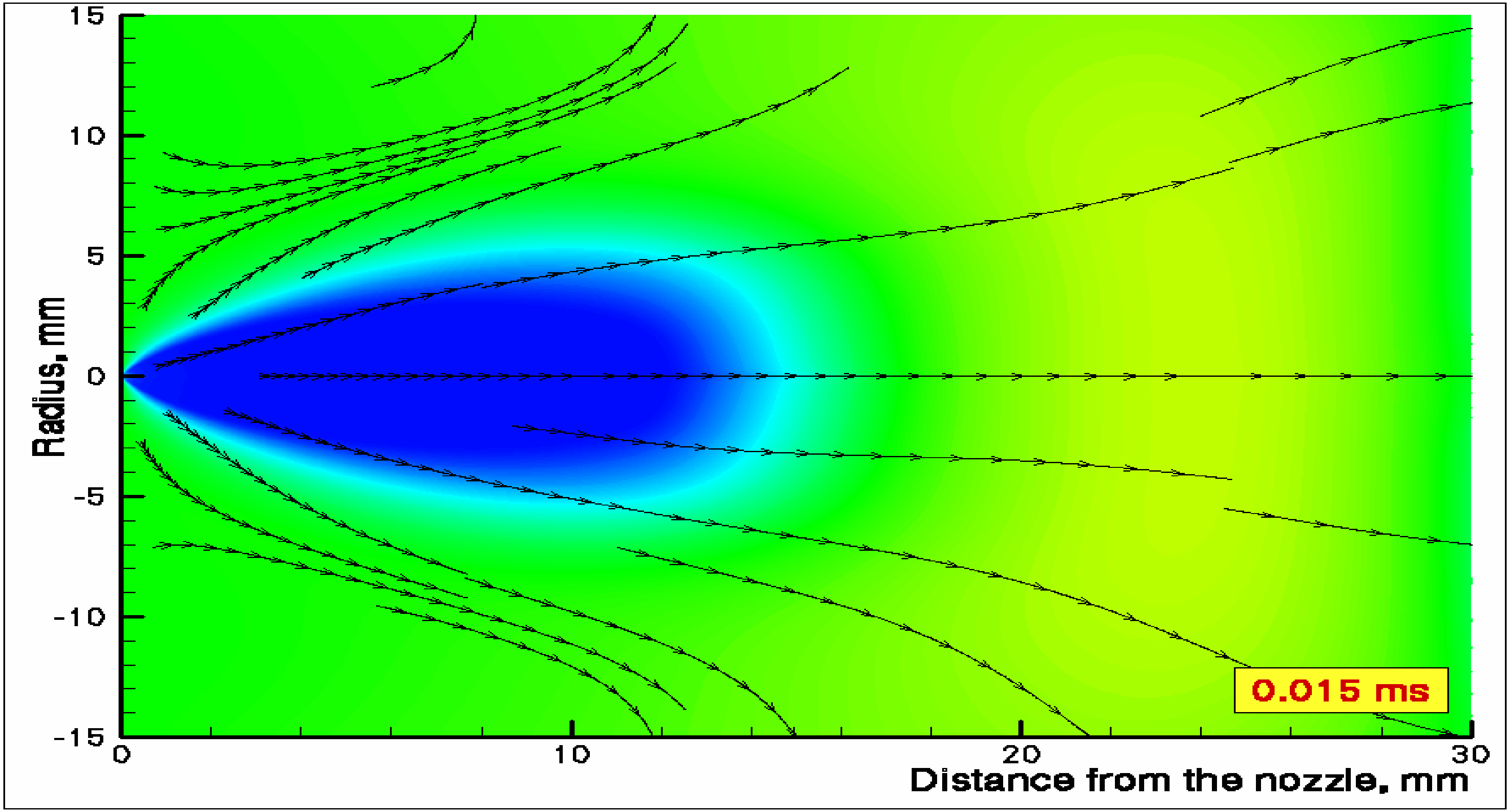
Gas-jet pulse development

Helium gas-jet temperature profile



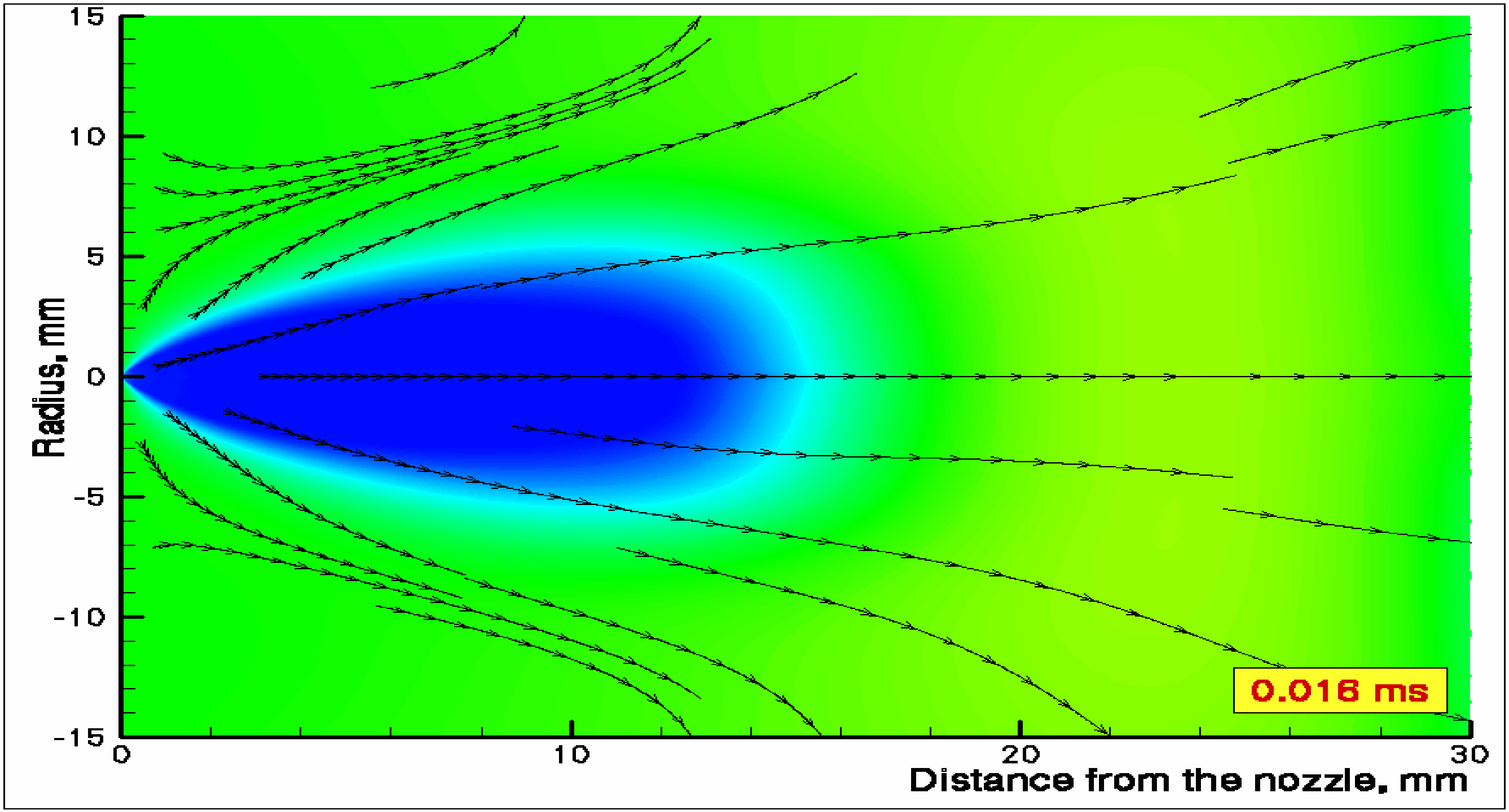
Gas-jet pulse development

Helium gas-jet temperature profile



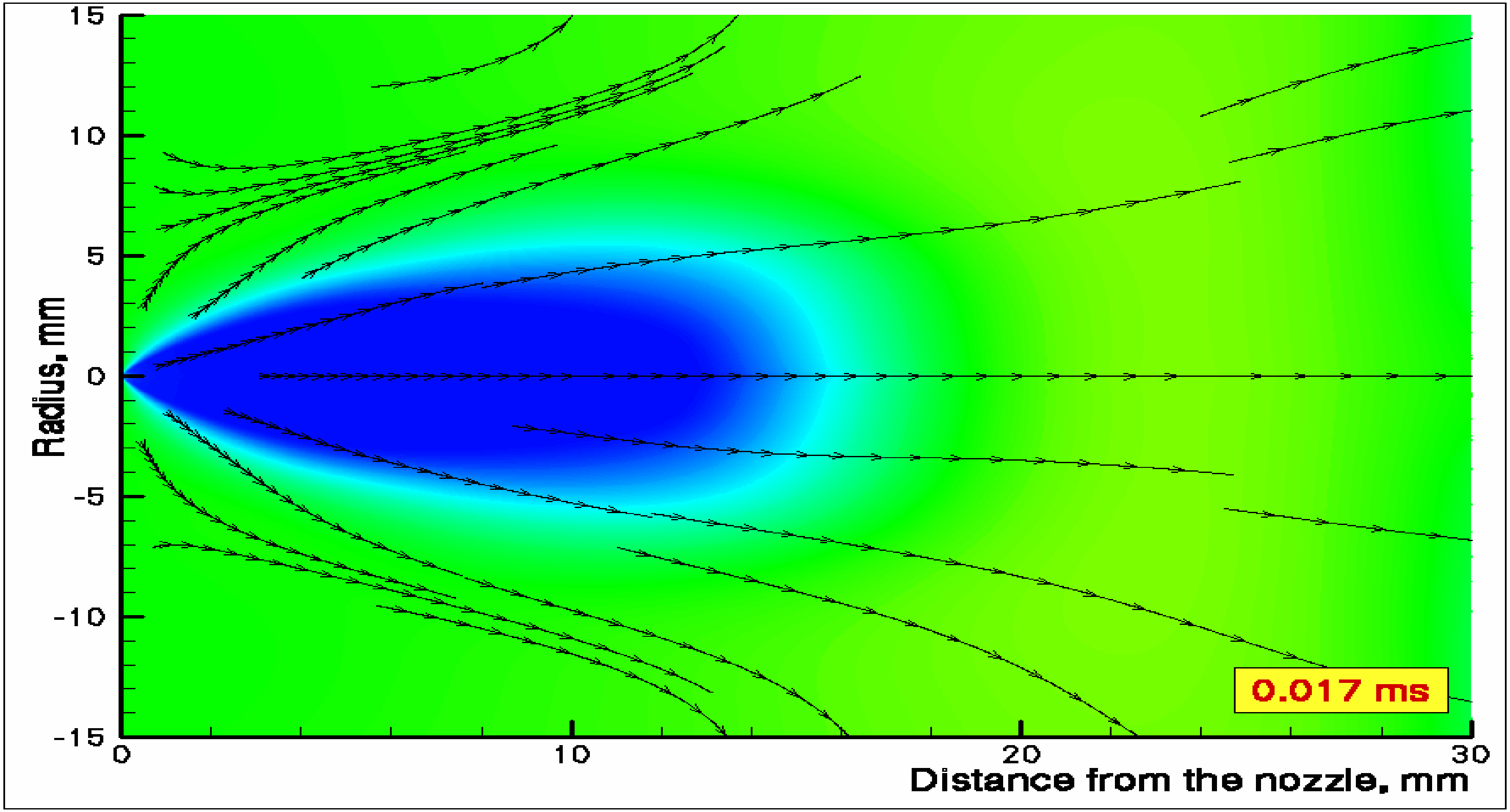
Gas-jet pulse development

Helium gas-jet temperature profile



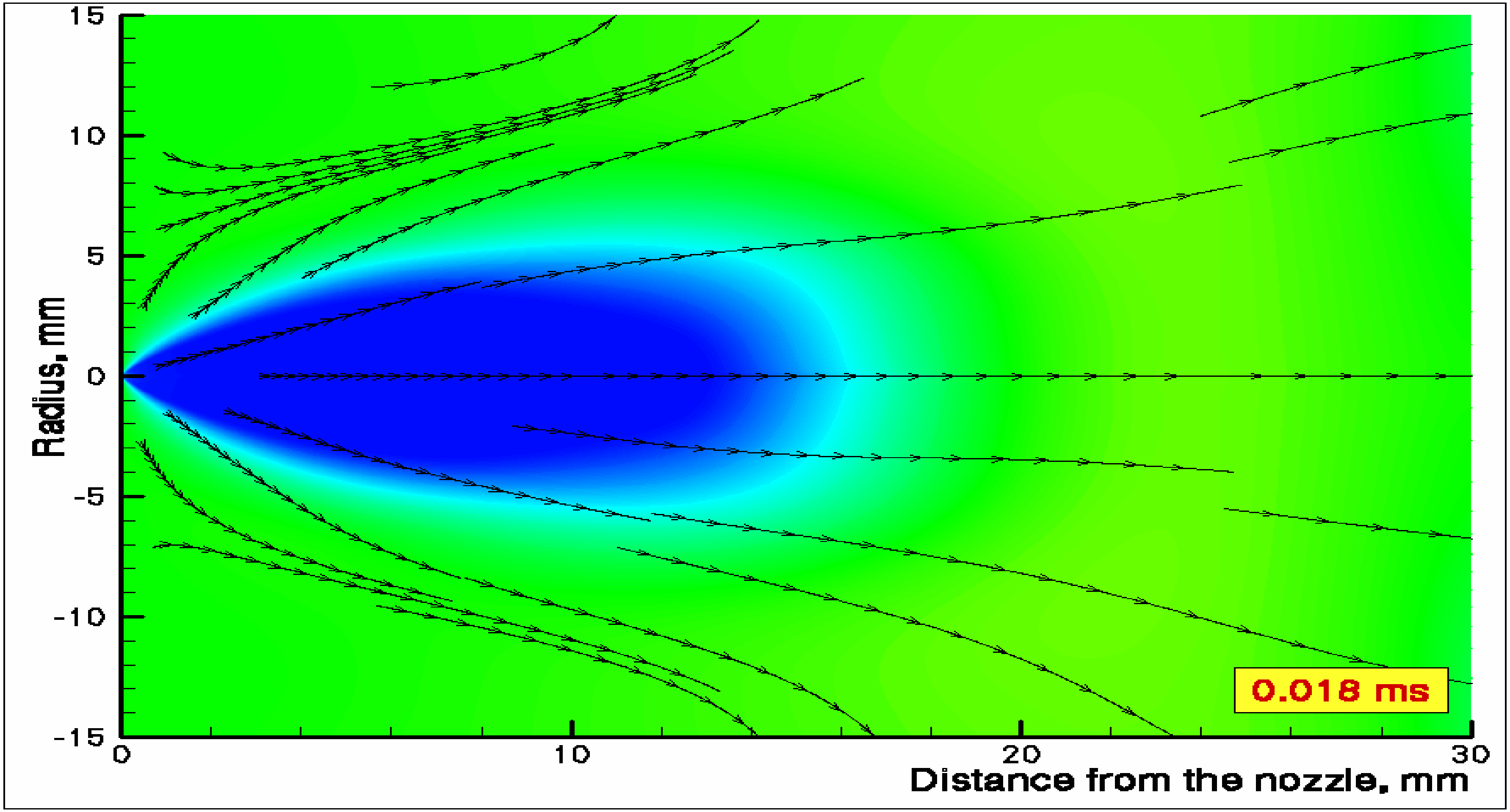
Gas-jet pulse development

Helium gas-jet temperature profile



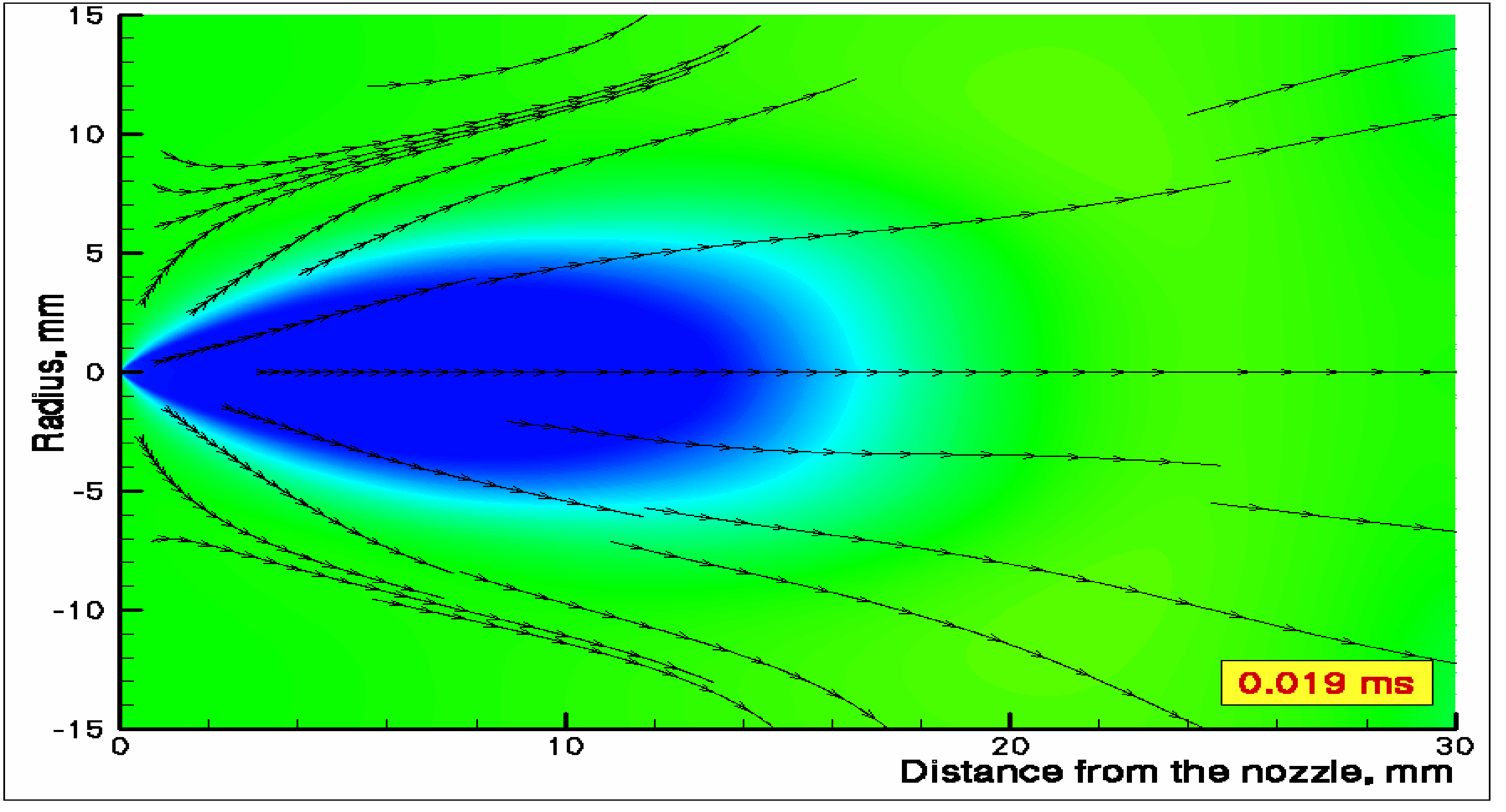
Gas-jet pulse development

Helium gas-jet temperature profile



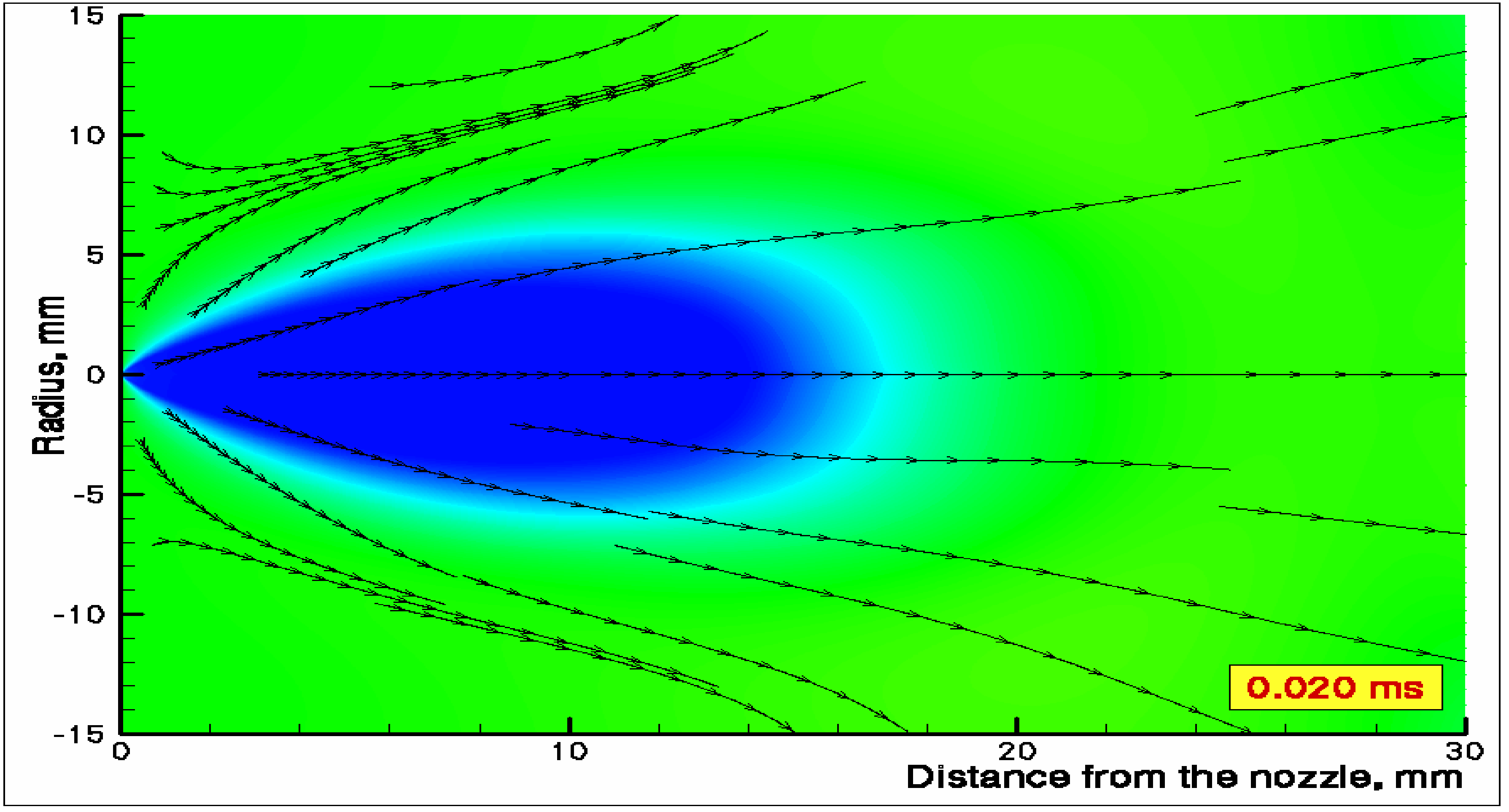
Gas-jet pulse development

Helium gas-jet temperature profile



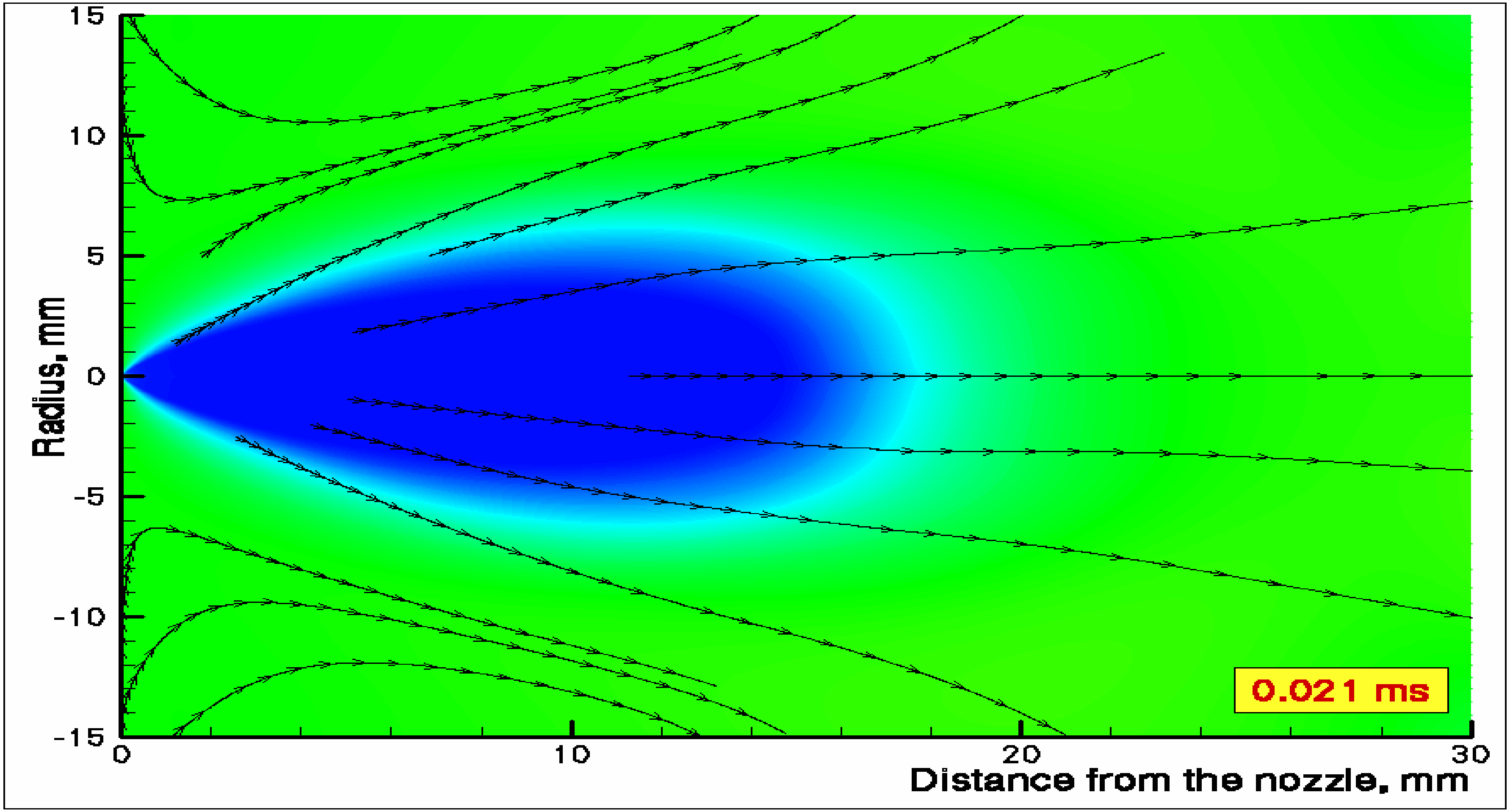
Gas-jet pulse development

Helium gas-jet temperature profile



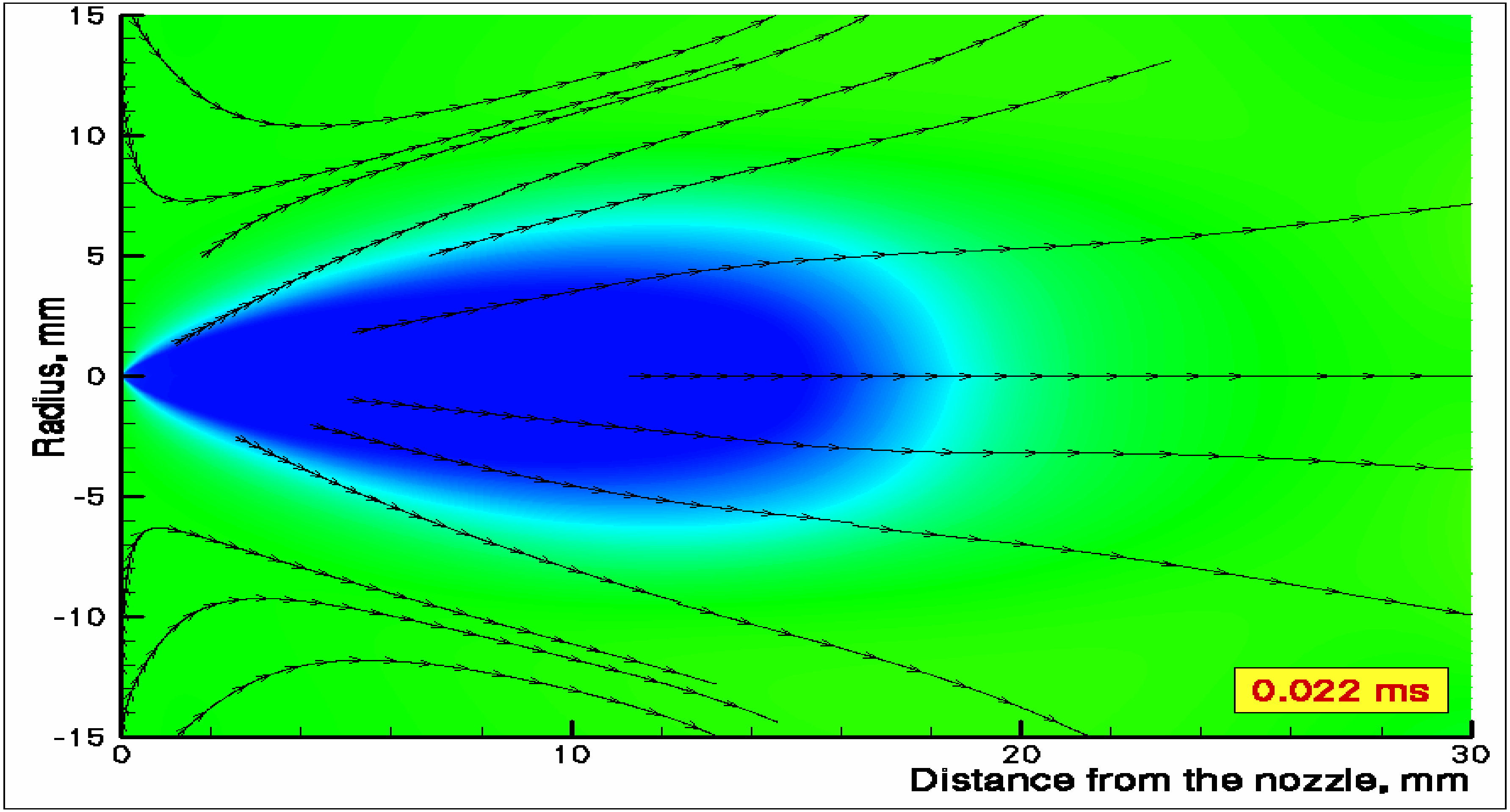
Gas-jet pulse development

Helium gas-jet temperature profile



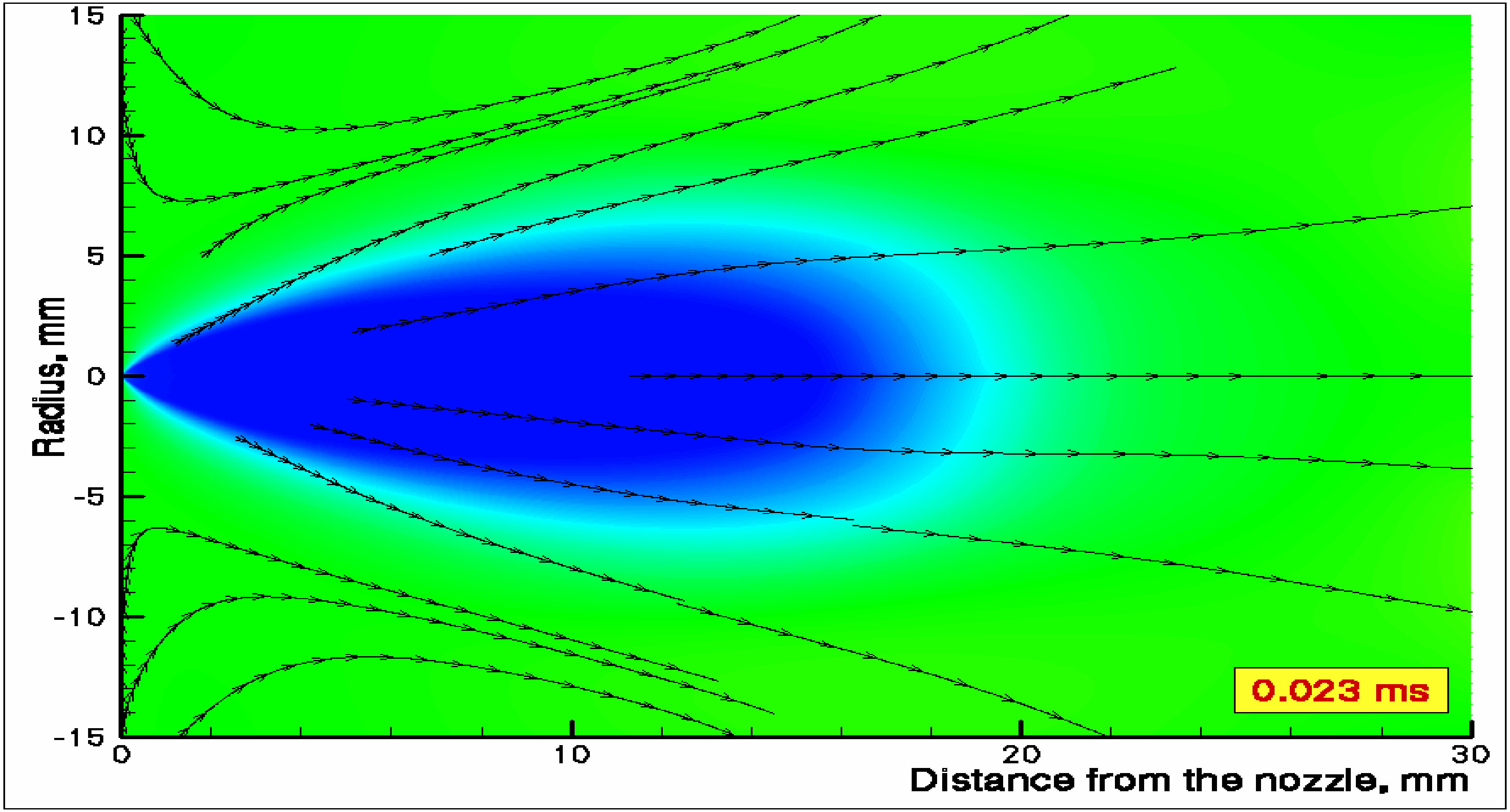
Gas-jet pulse development

Helium gas-jet temperature profile



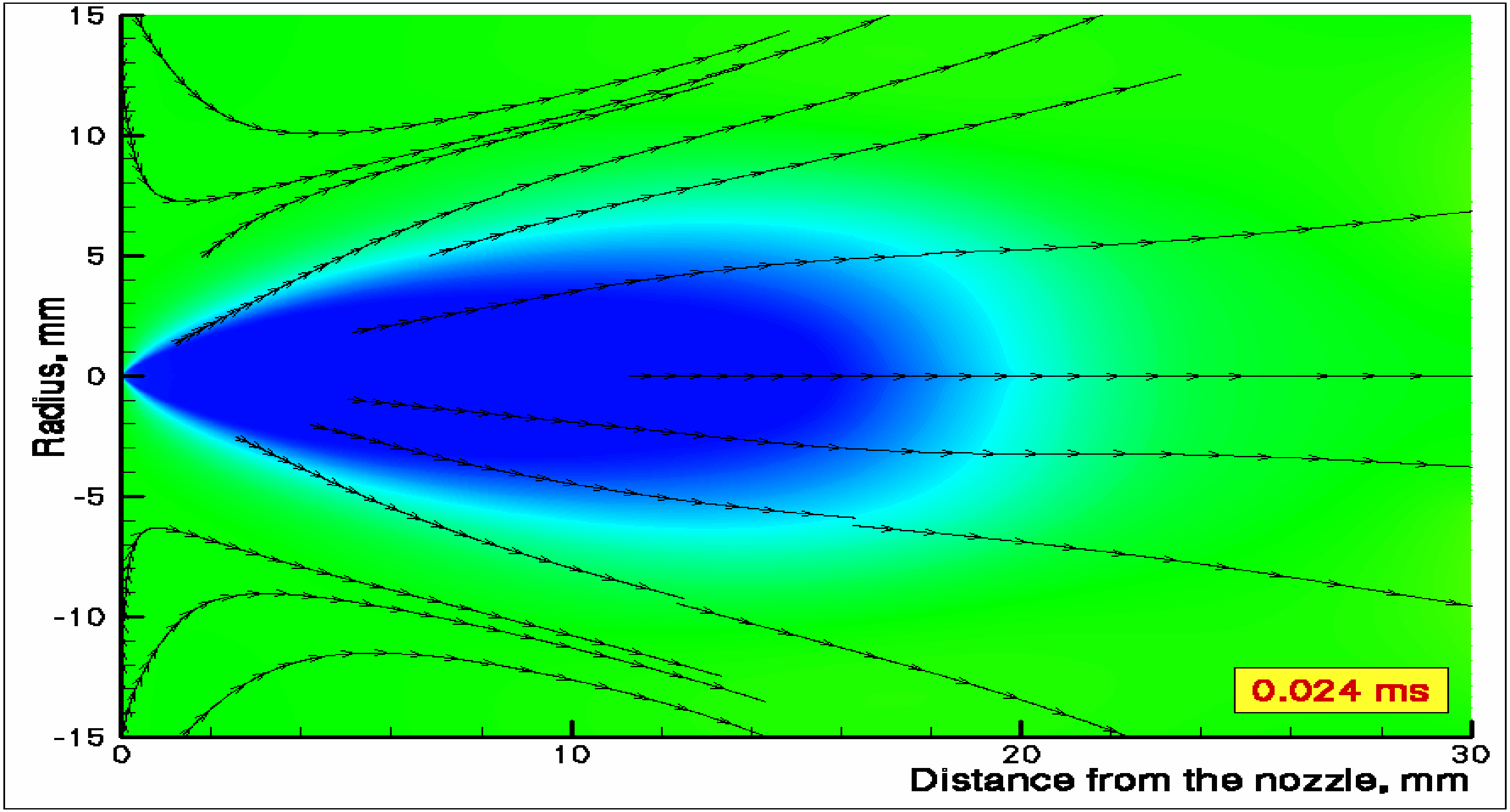
Gas-jet pulse development

Helium gas-jet temperature profile



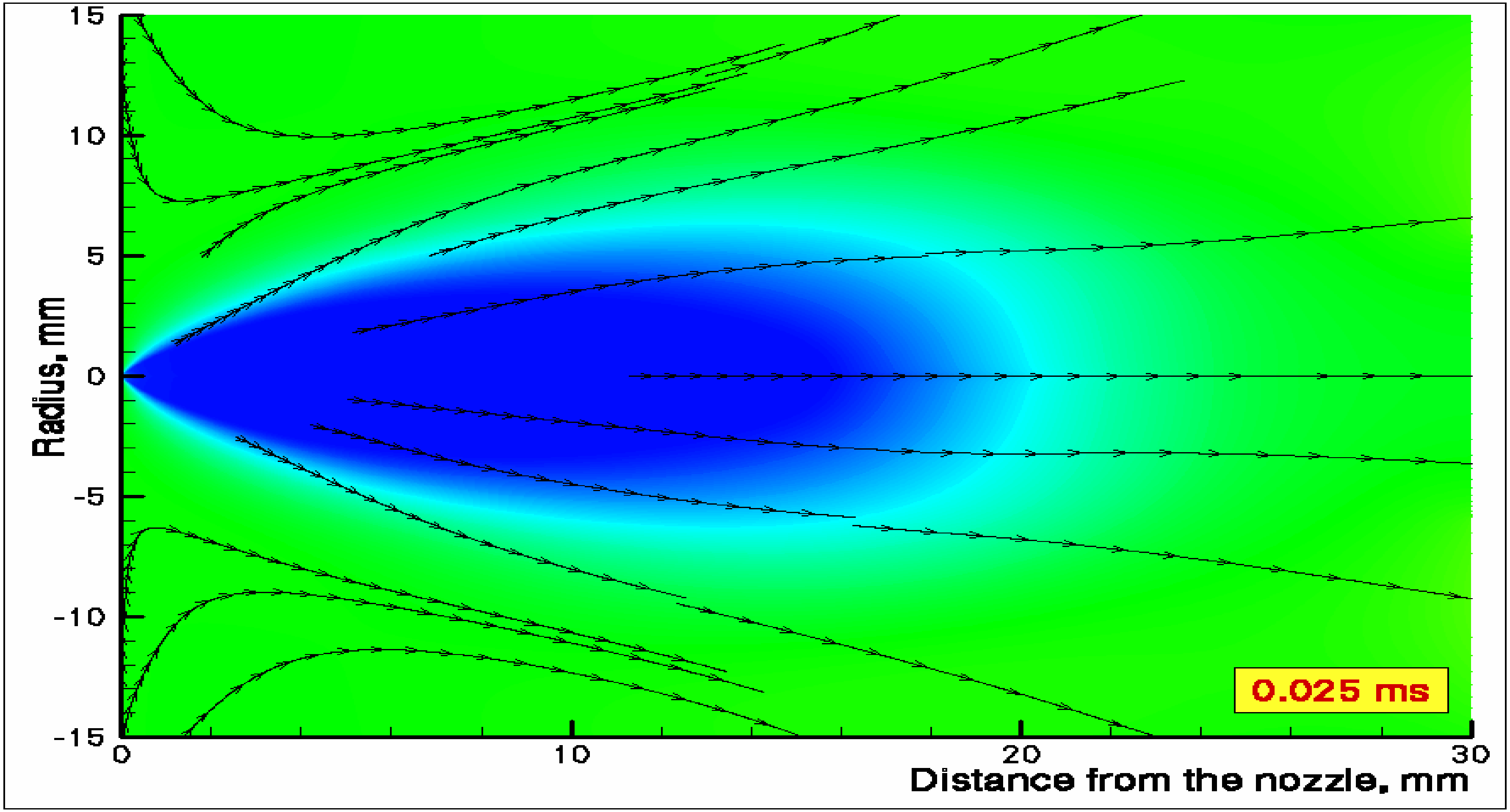
Gas-jet pulse development

Helium gas-jet temperature profile



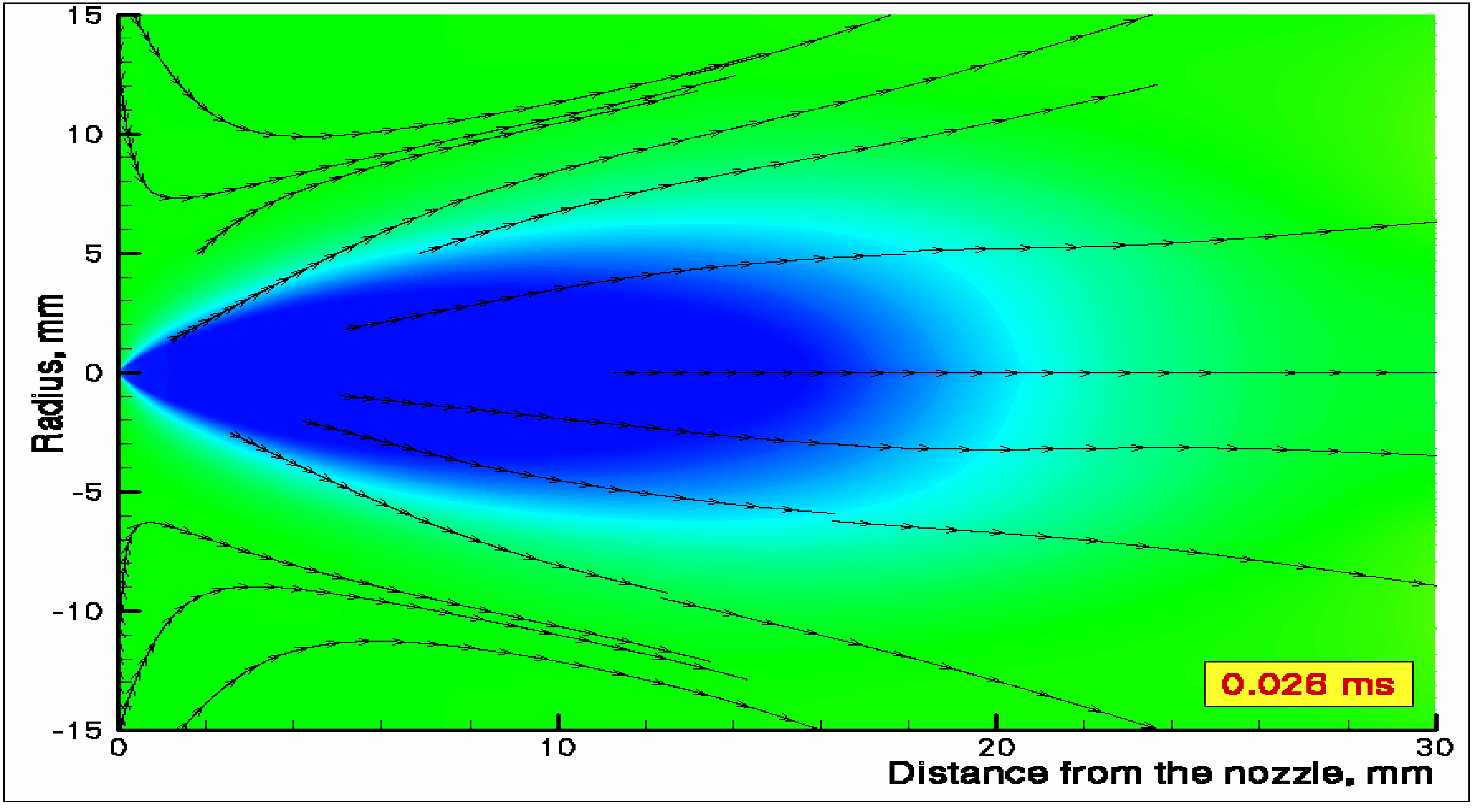
Gas-jet pulse development

Helium gas-jet temperature profile



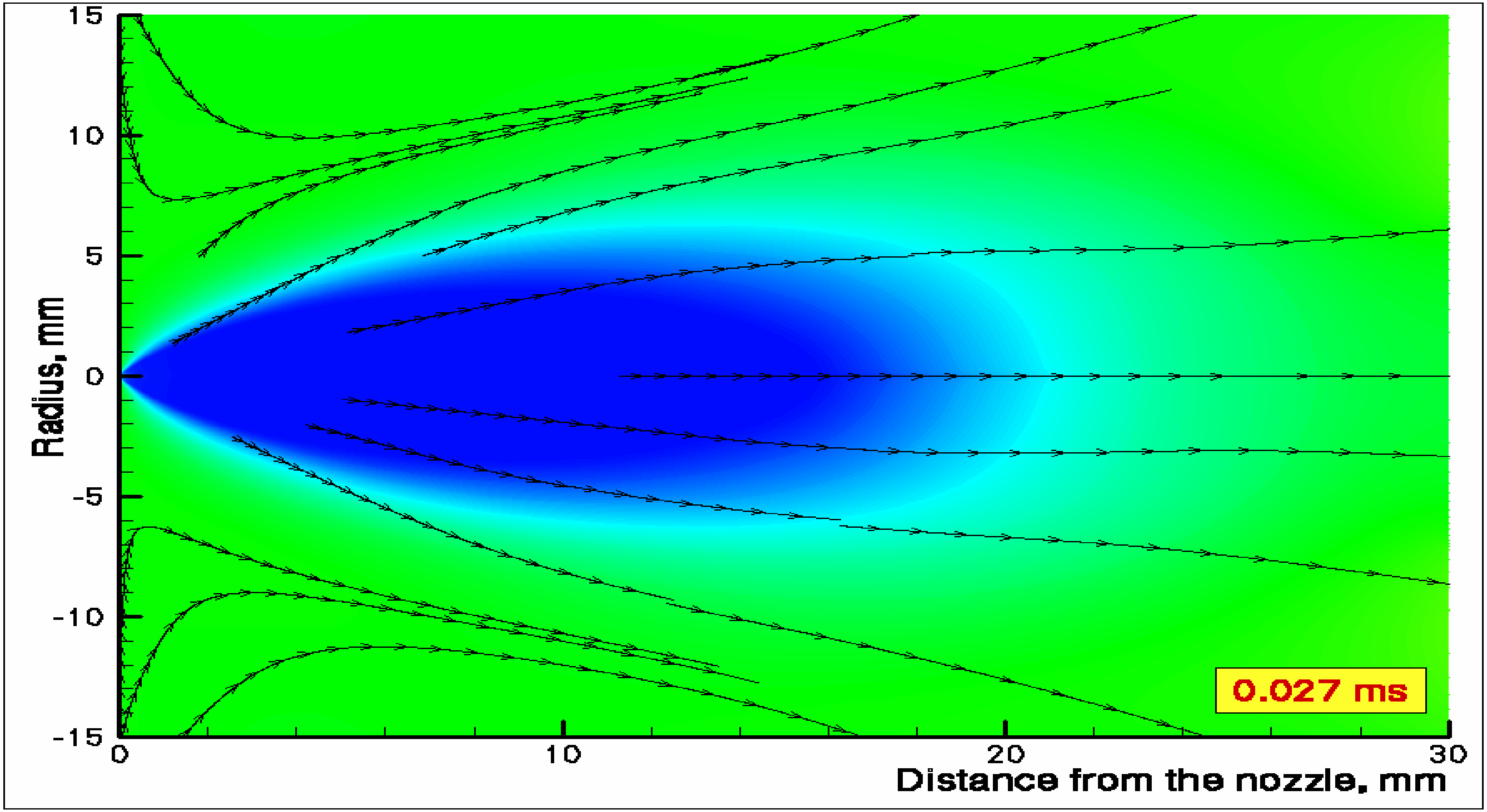
Gas-jet pulse development

Helium gas-jet temperature profile



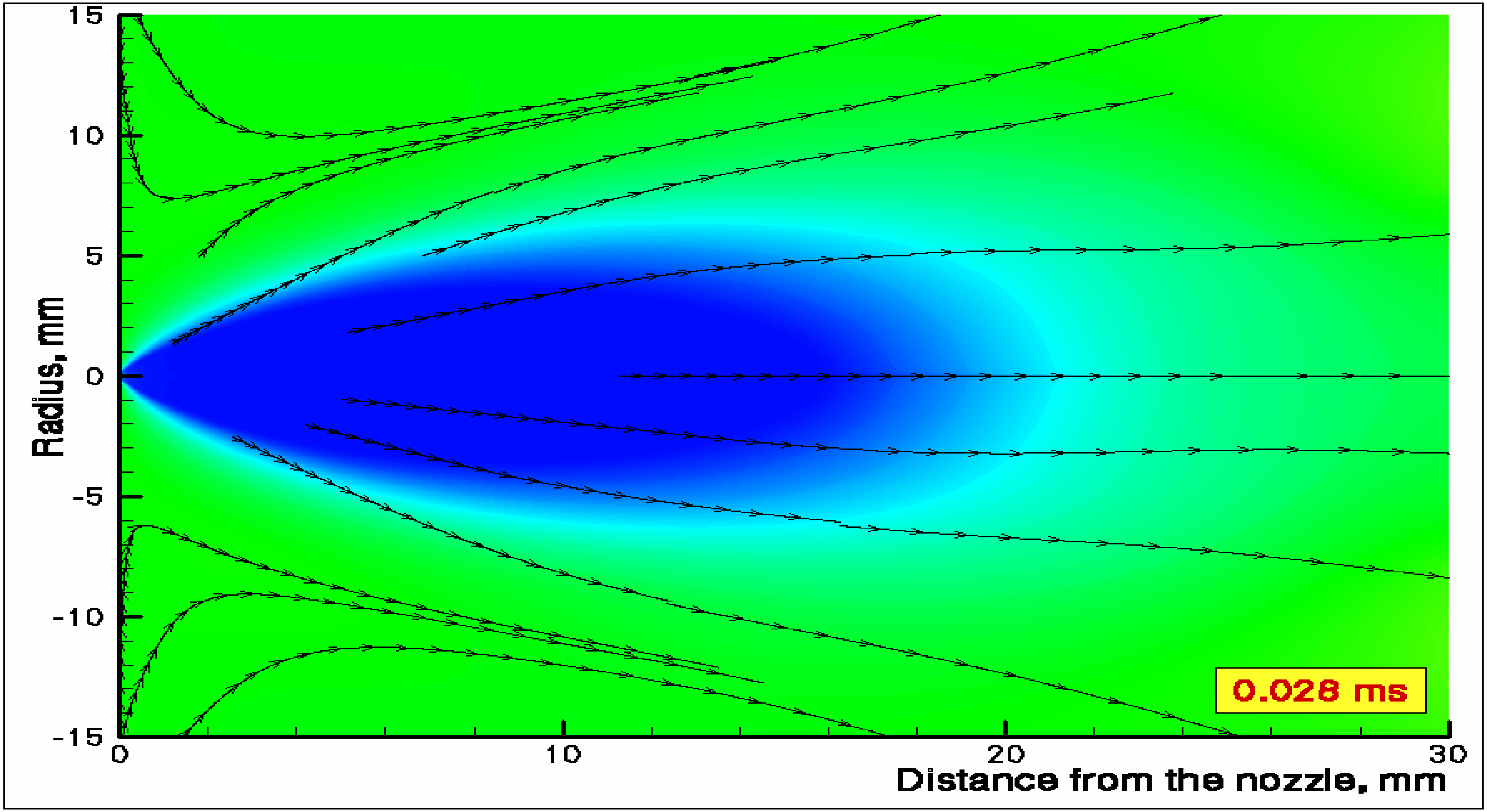
Gas-jet pulse development

Helium gas-jet temperature profile



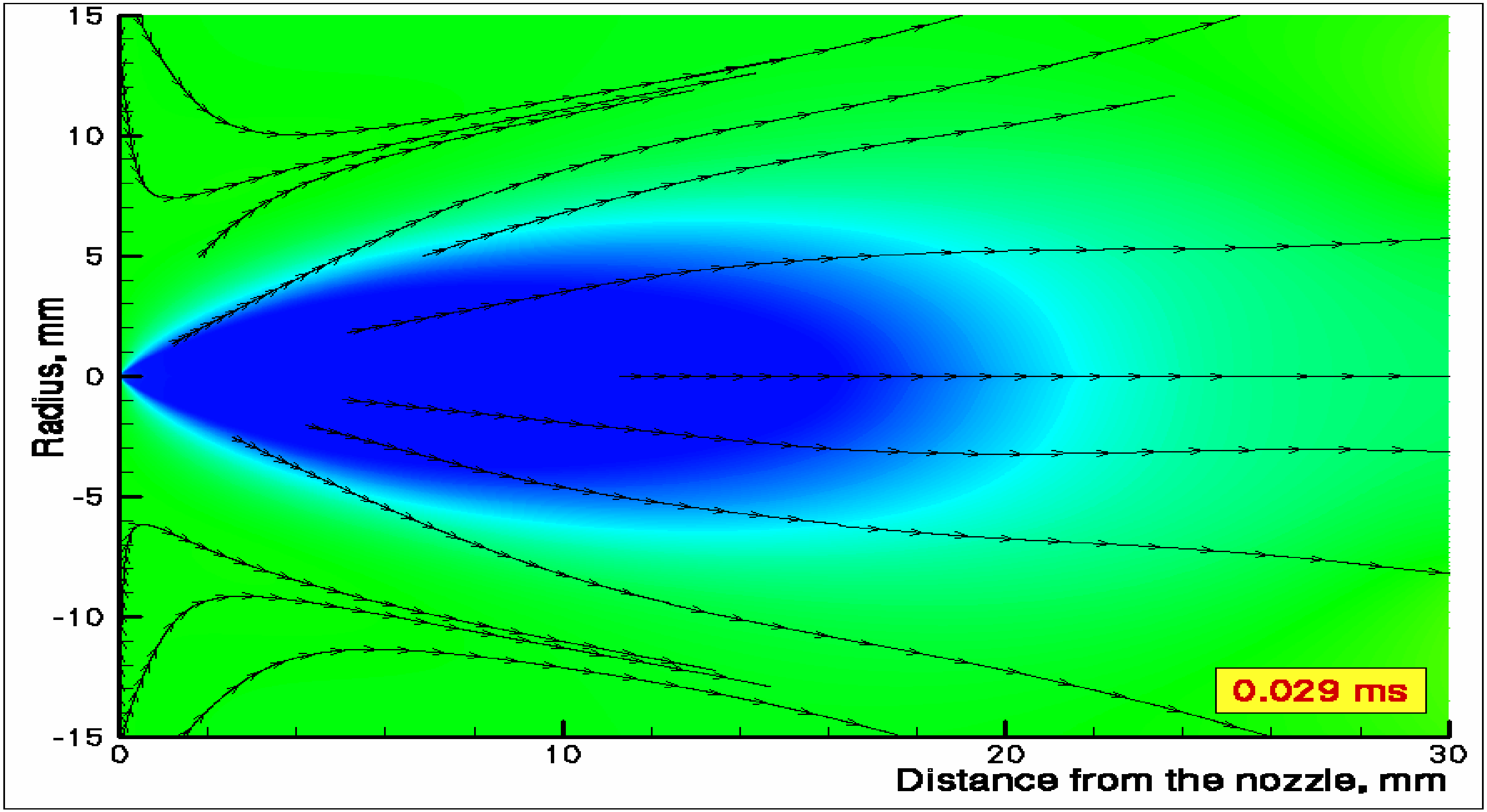
Gas-jet pulse development

Helium gas-jet temperature profile



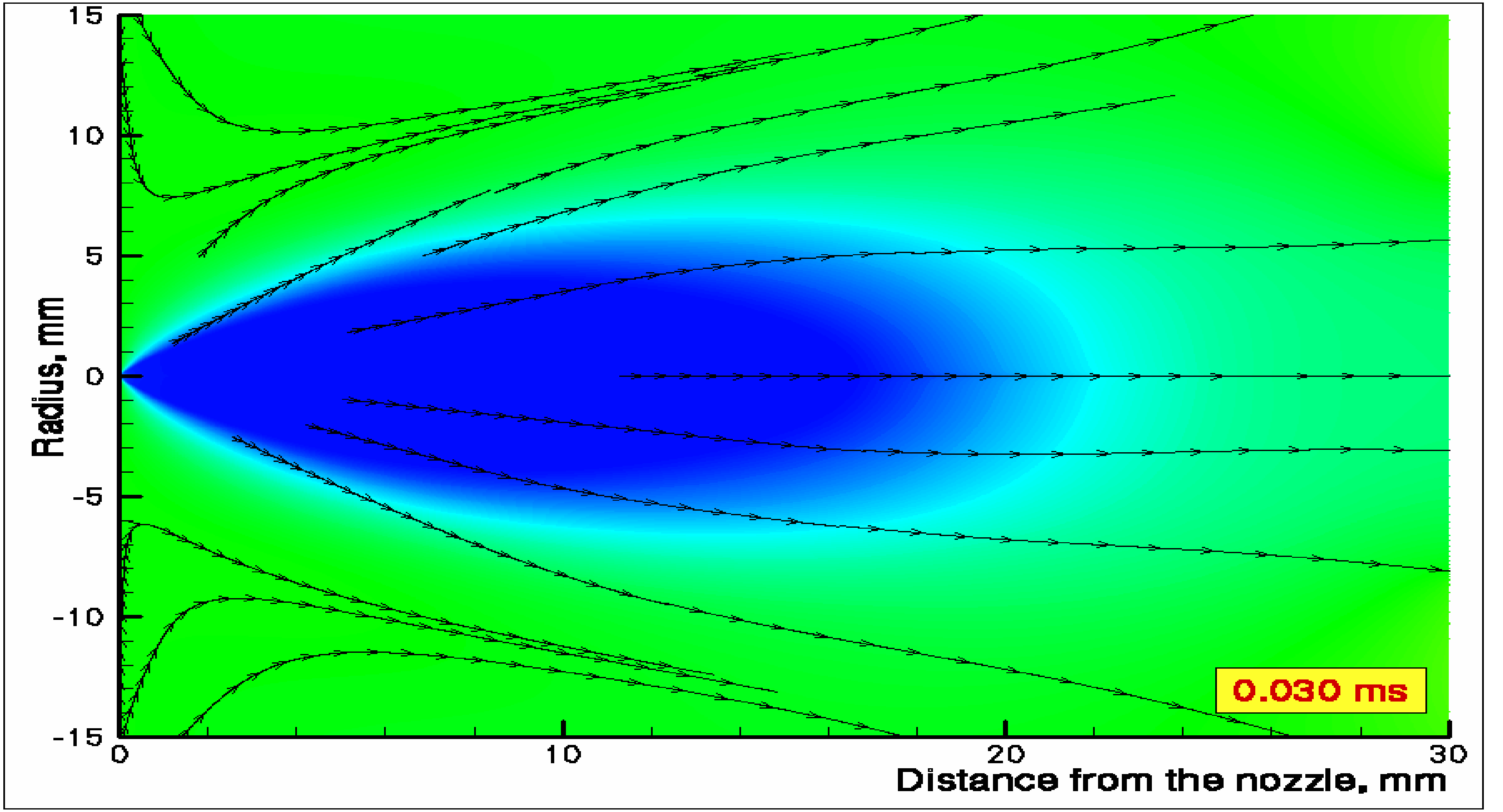
Gas-jet pulse development

Helium gas-jet temperature profile



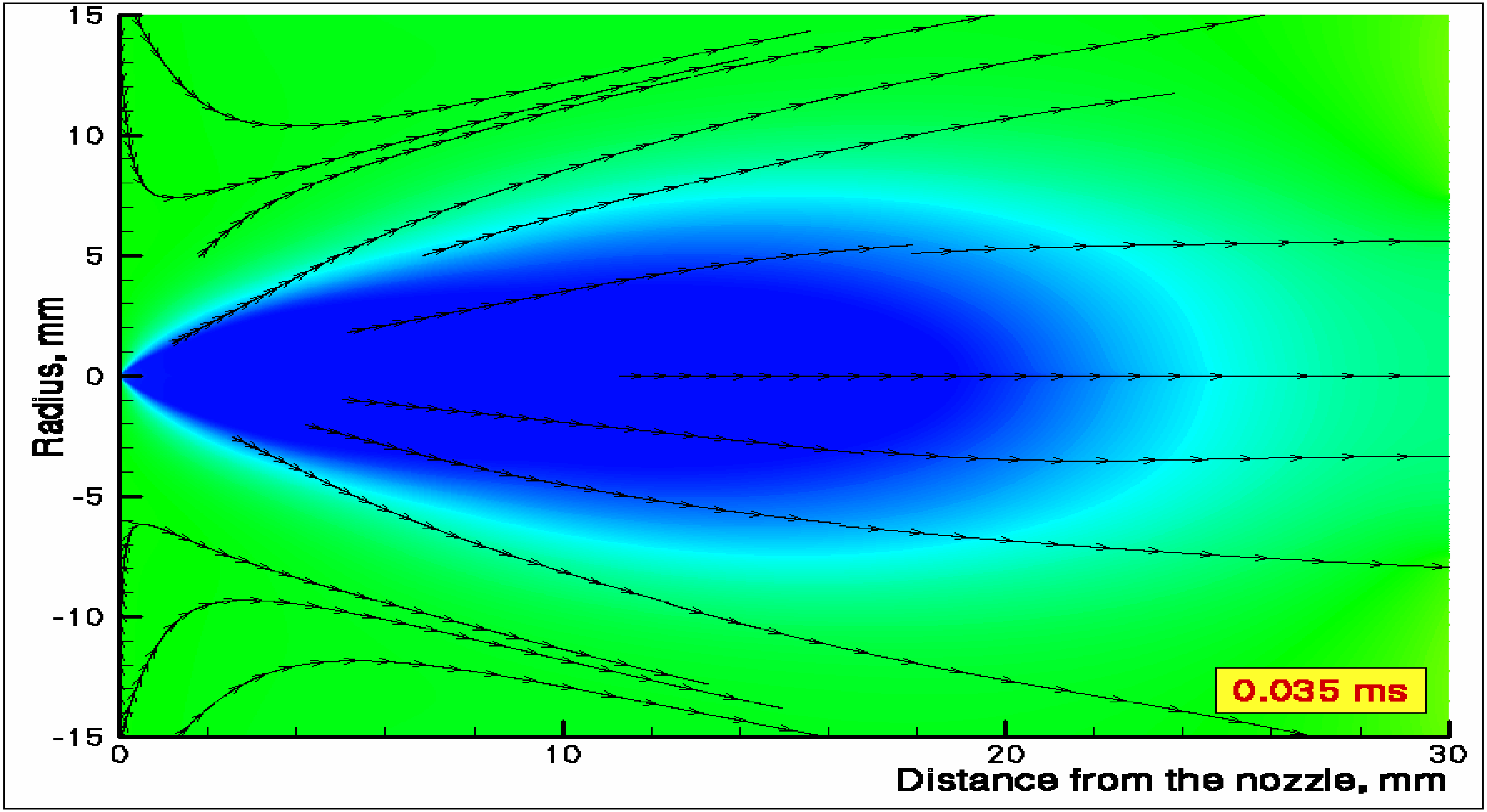
Gas-jet pulse development

Helium gas-jet temperature profile



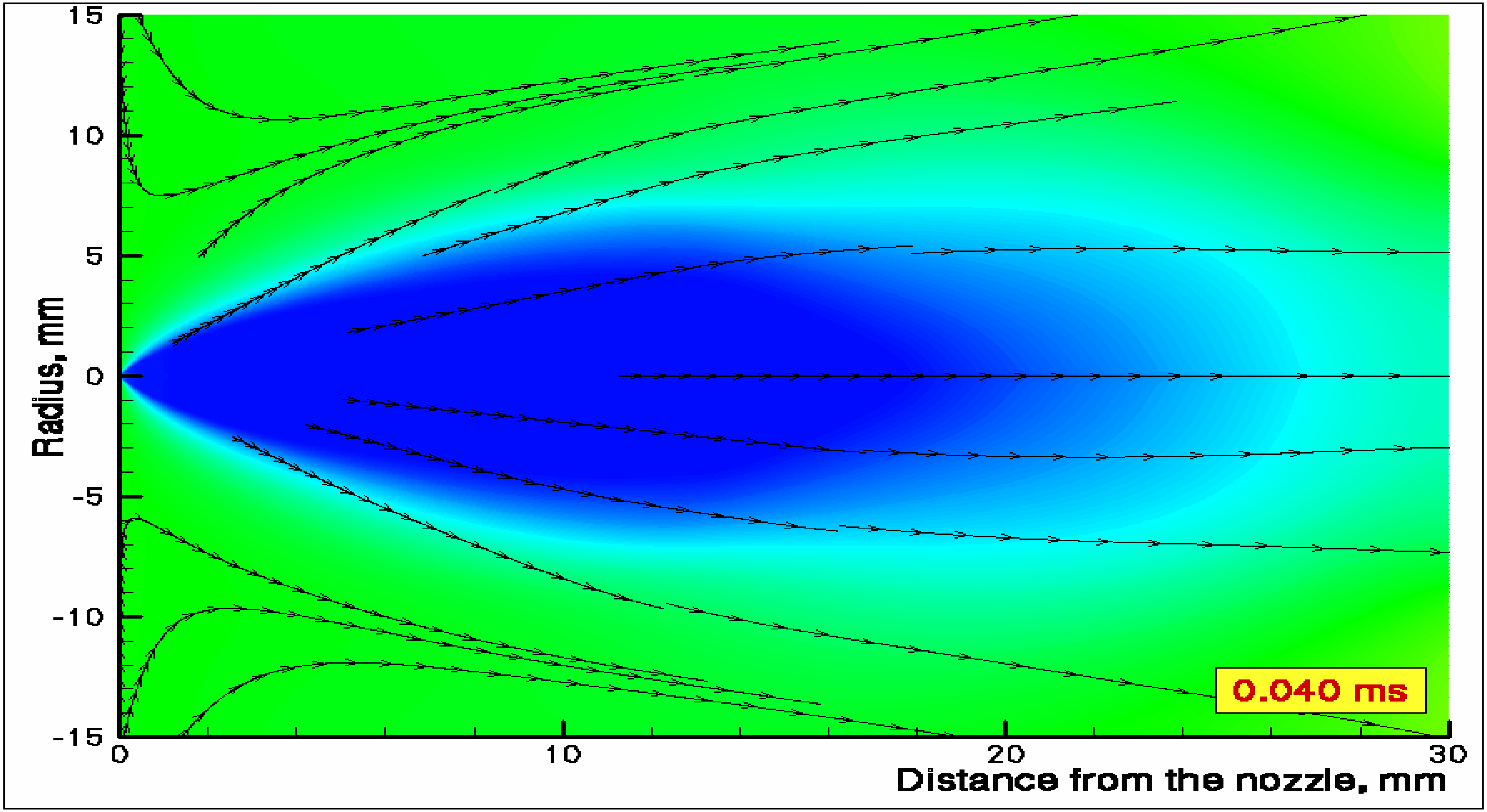
Gas-jet pulse development

Helium gas-jet temperature profile



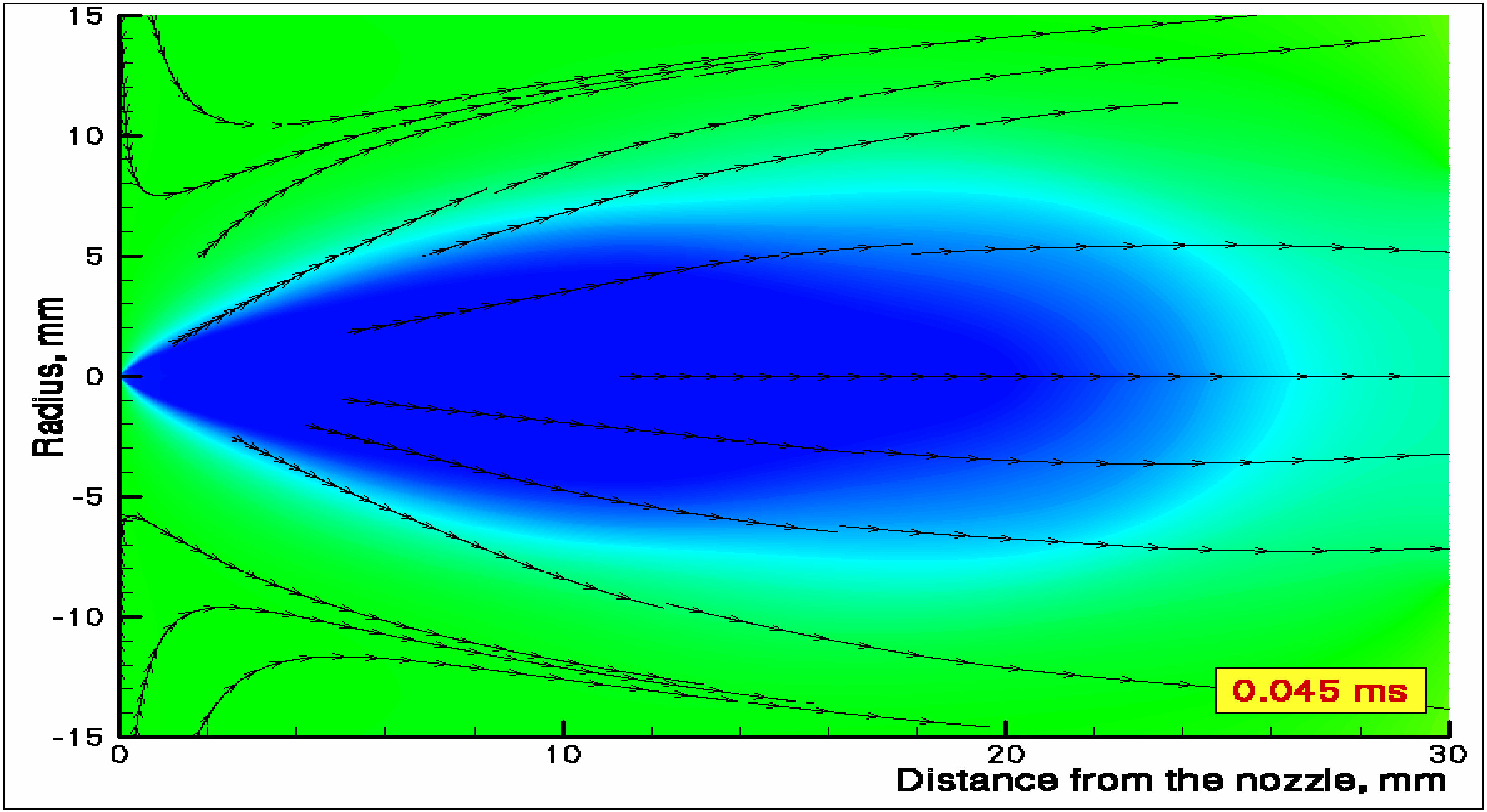
Gas-jet pulse development

Helium gas-jet temperature profile



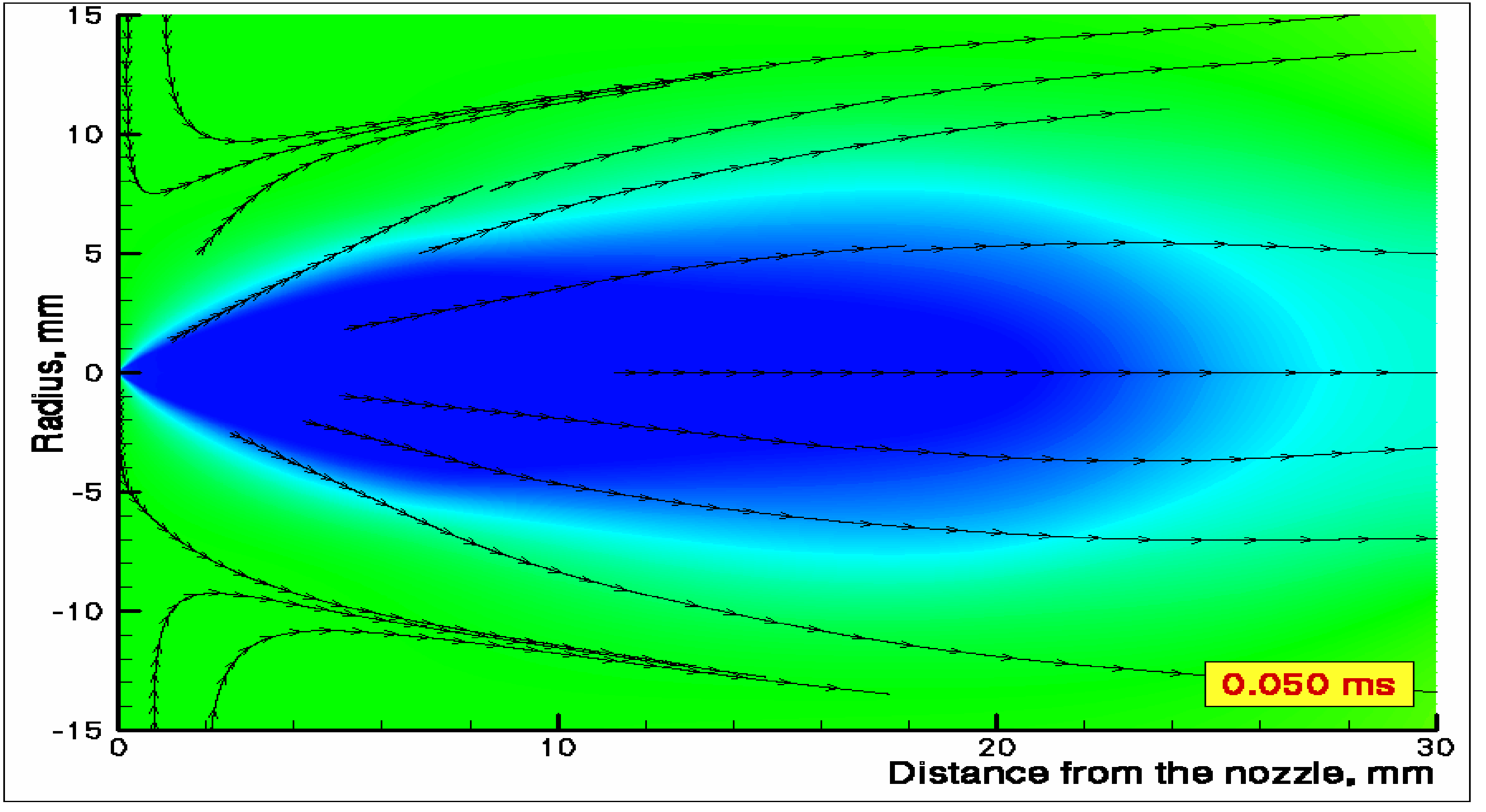
Gas-jet pulse development

Helium gas-jet temperature profile



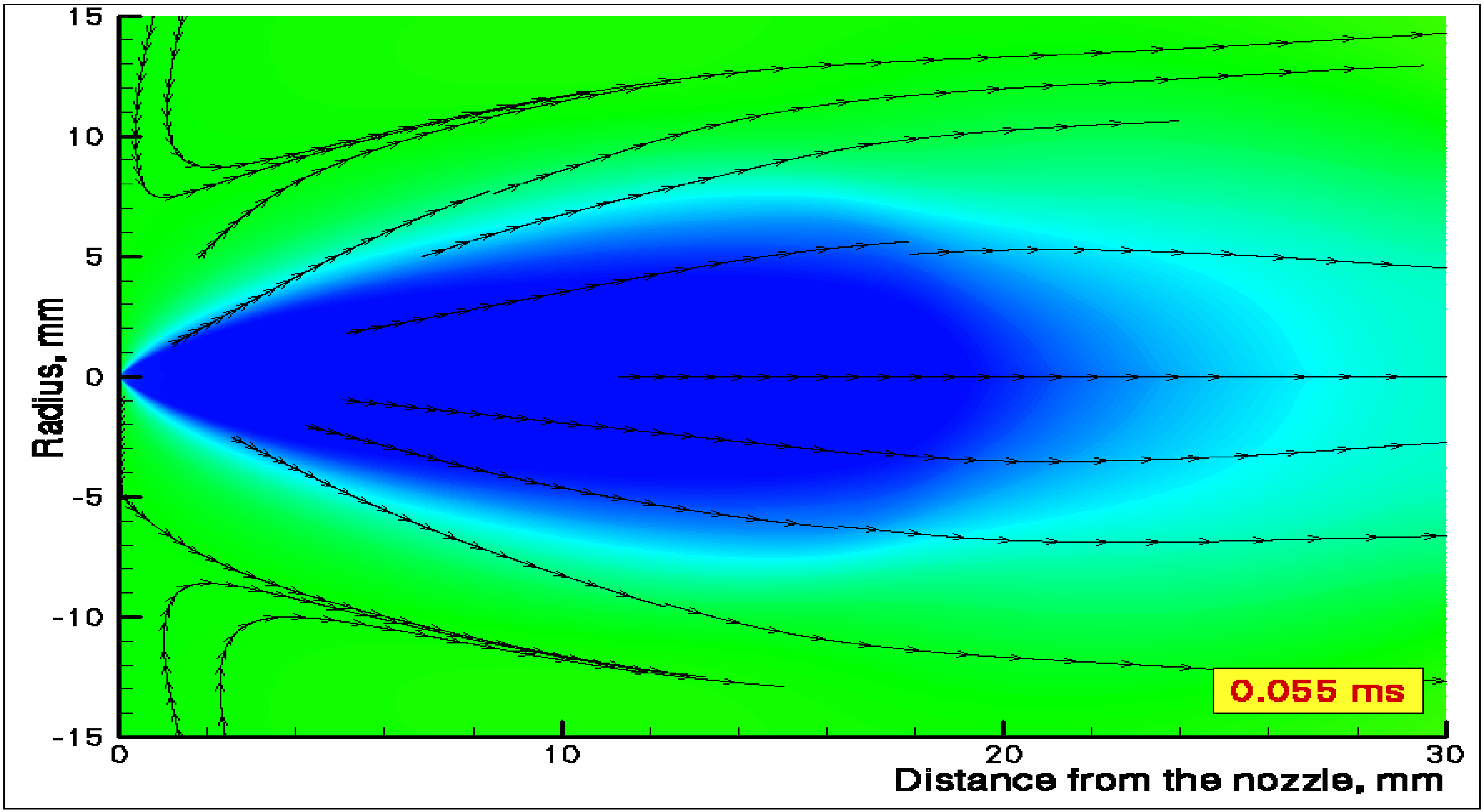
Gas-jet pulse development

Helium gas-jet temperature profile



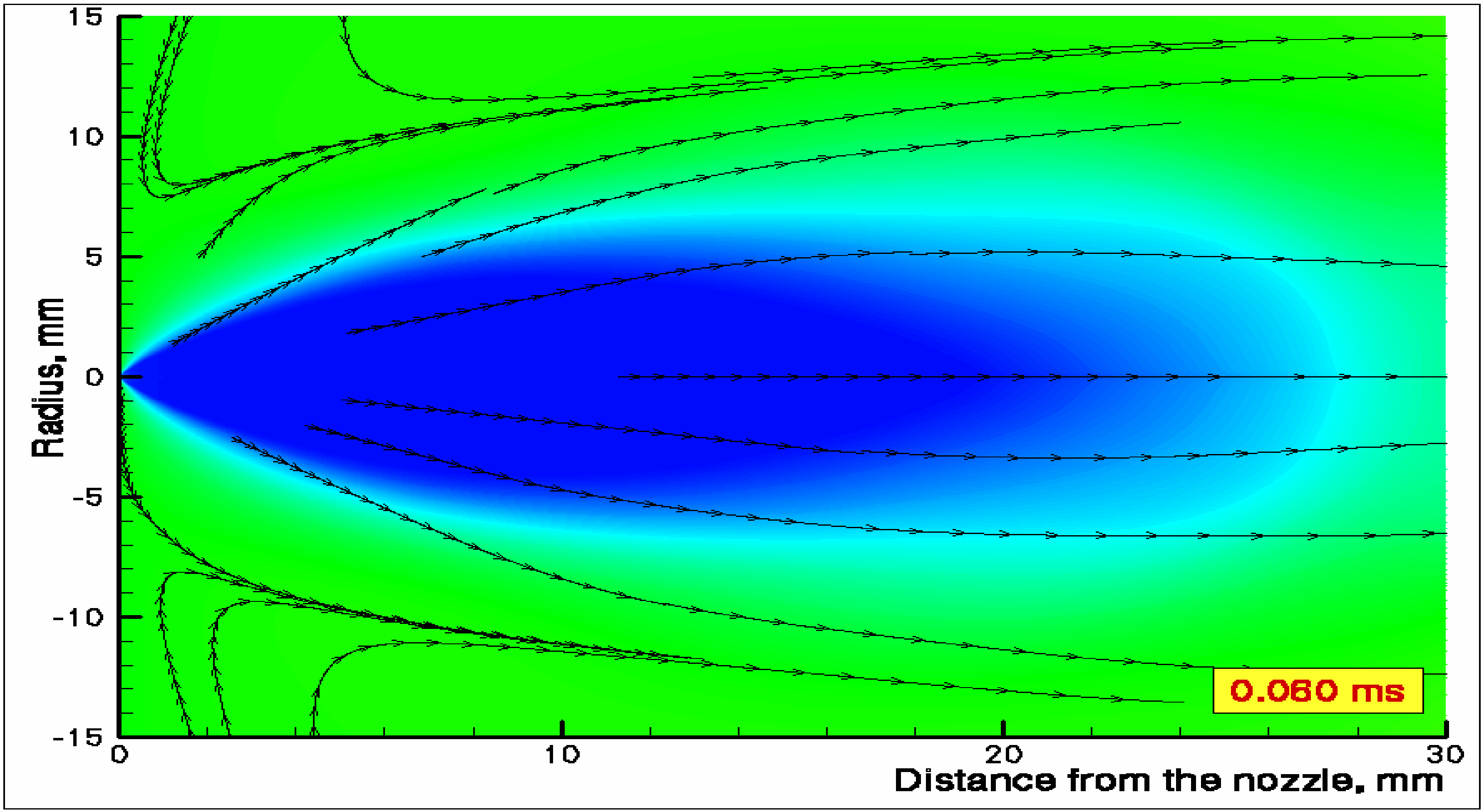
Gas-jet pulse development

Helium gas-jet temperature profile



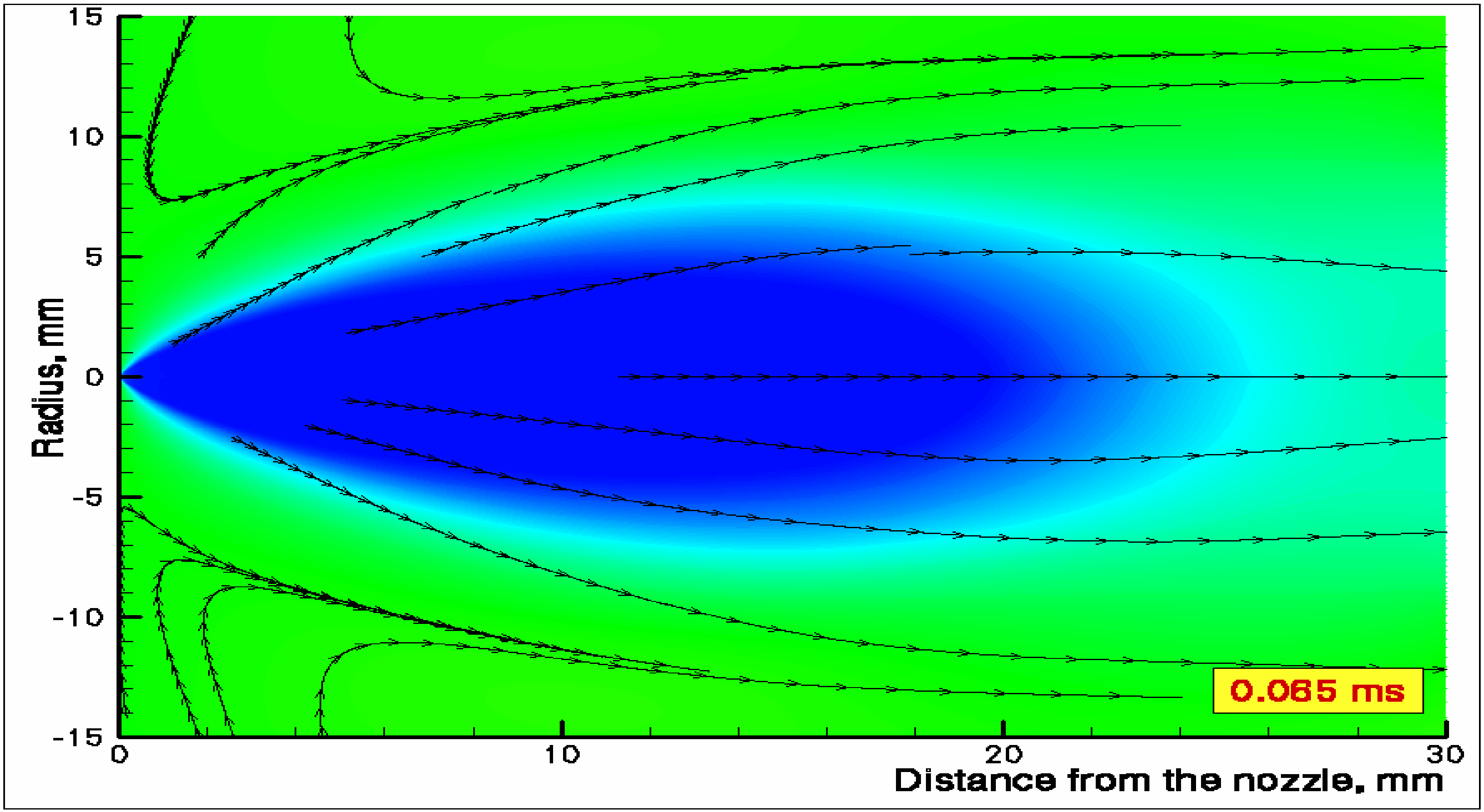
Gas-jet pulse development

Helium gas-jet temperature profile



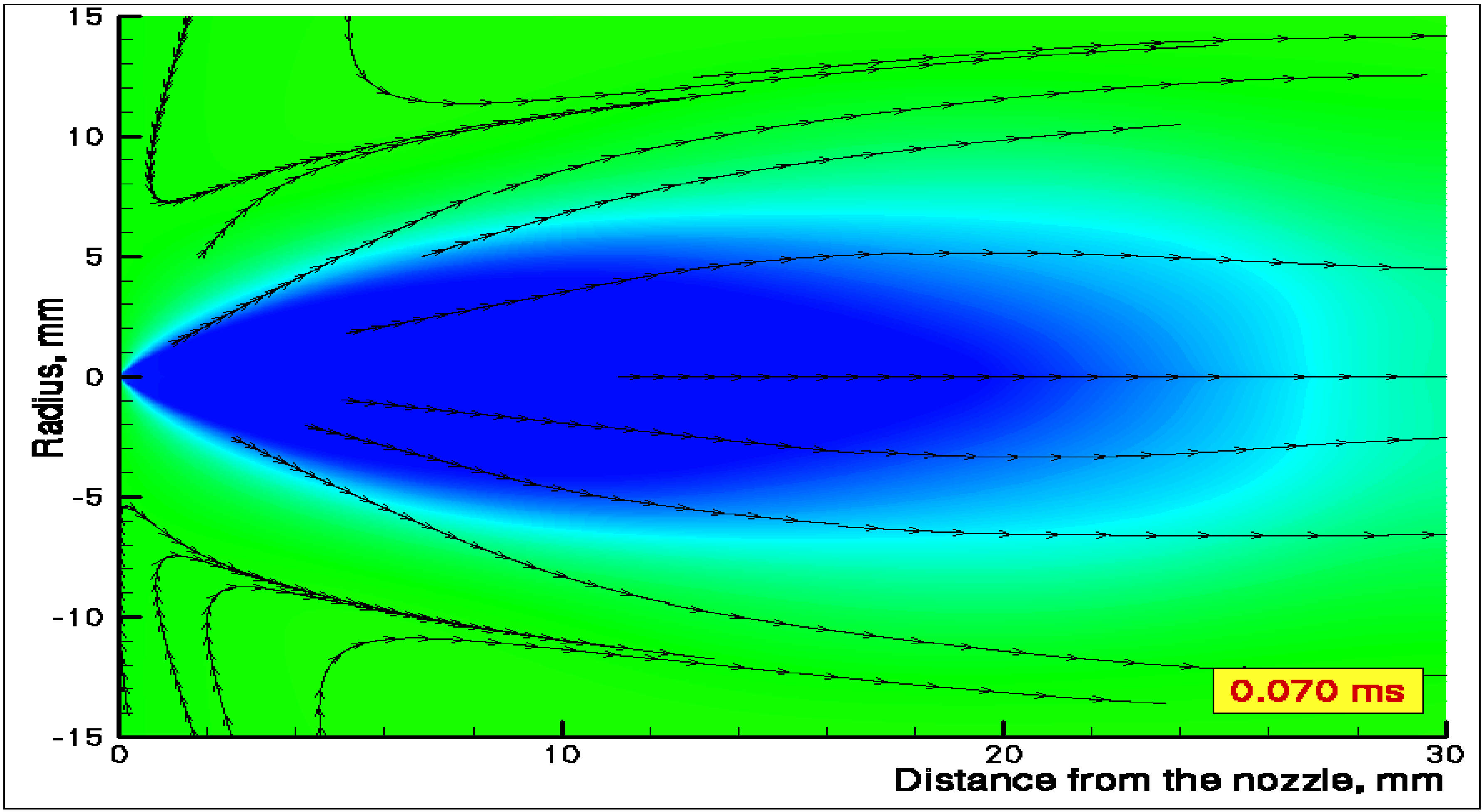
Gas-jet pulse development

Helium gas-jet temperature profile



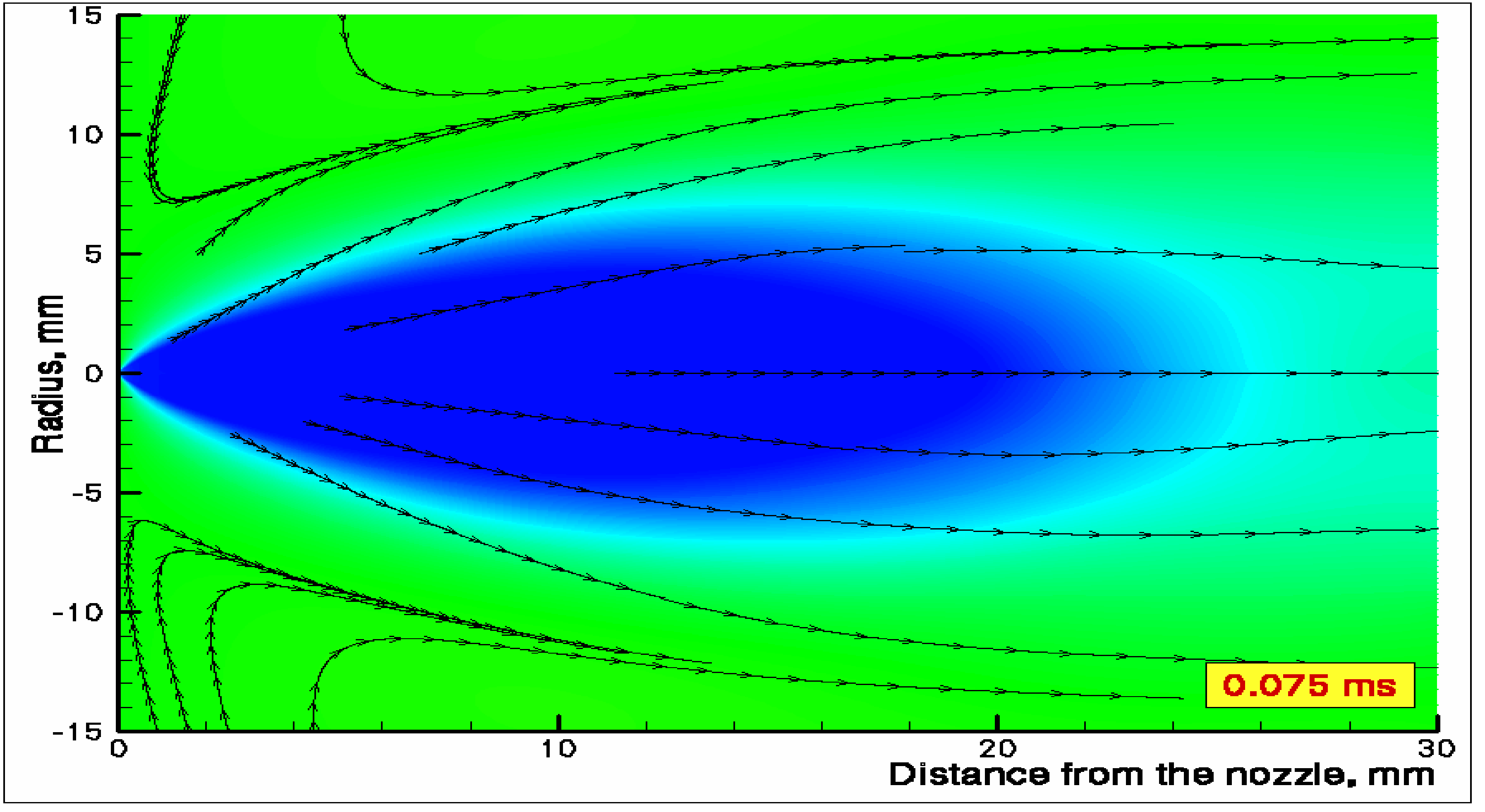
Gas-jet pulse development

Helium gas-jet temperature profile



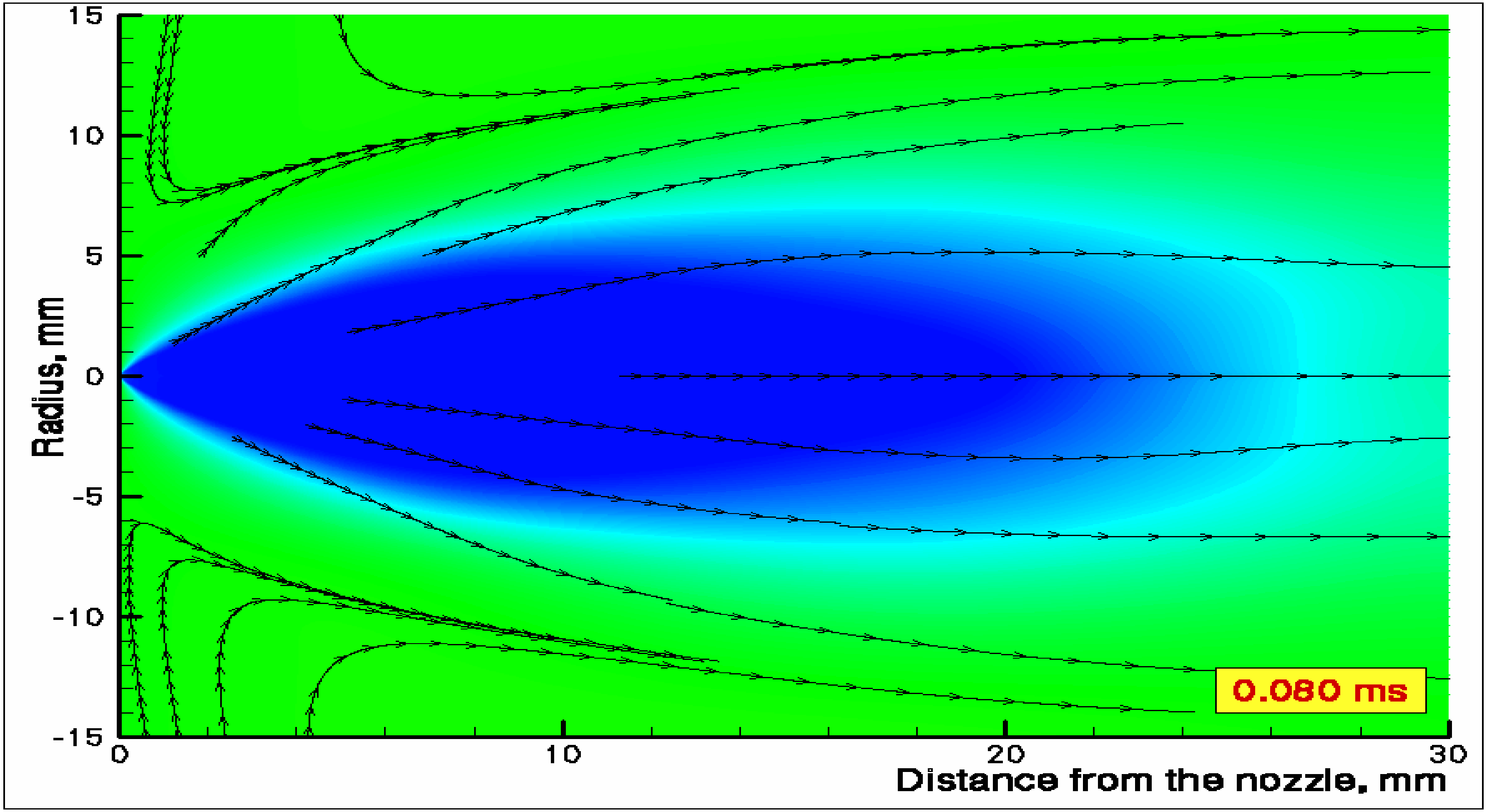
Gas-jet pulse development

Helium gas-jet temperature profile



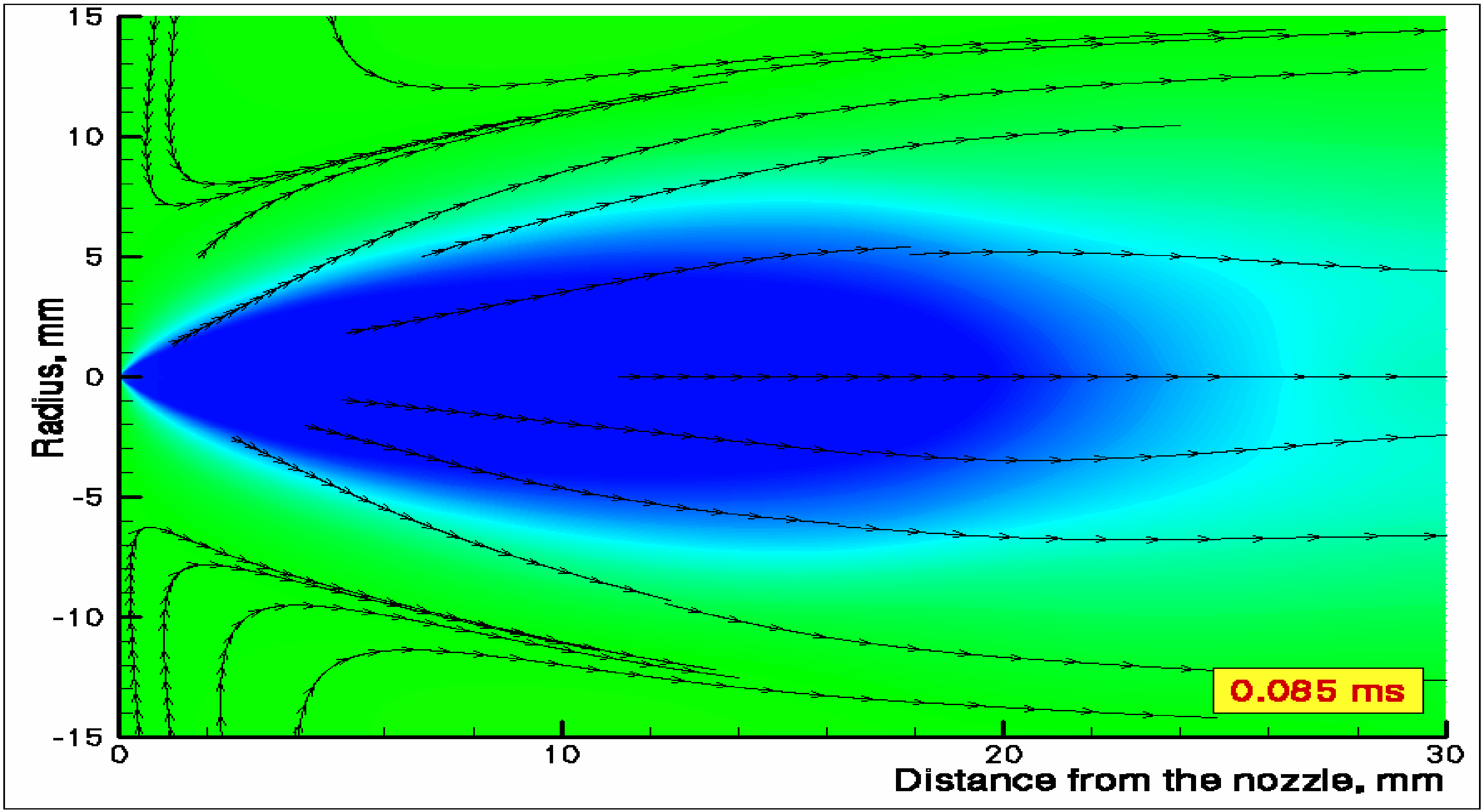
Gas-jet pulse development

Helium gas-jet temperature profile



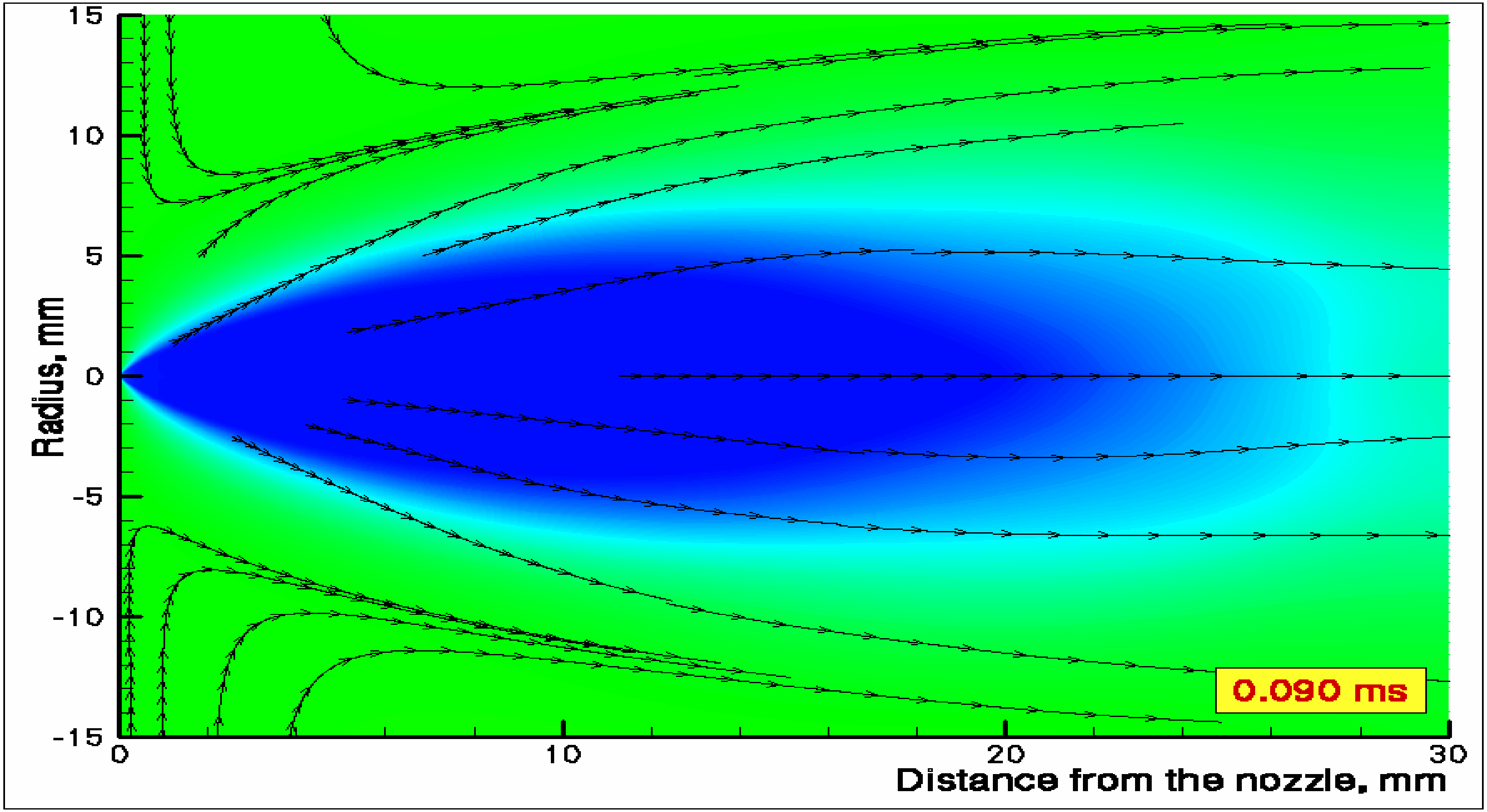
Gas-jet pulse development

Helium gas-jet temperature profile



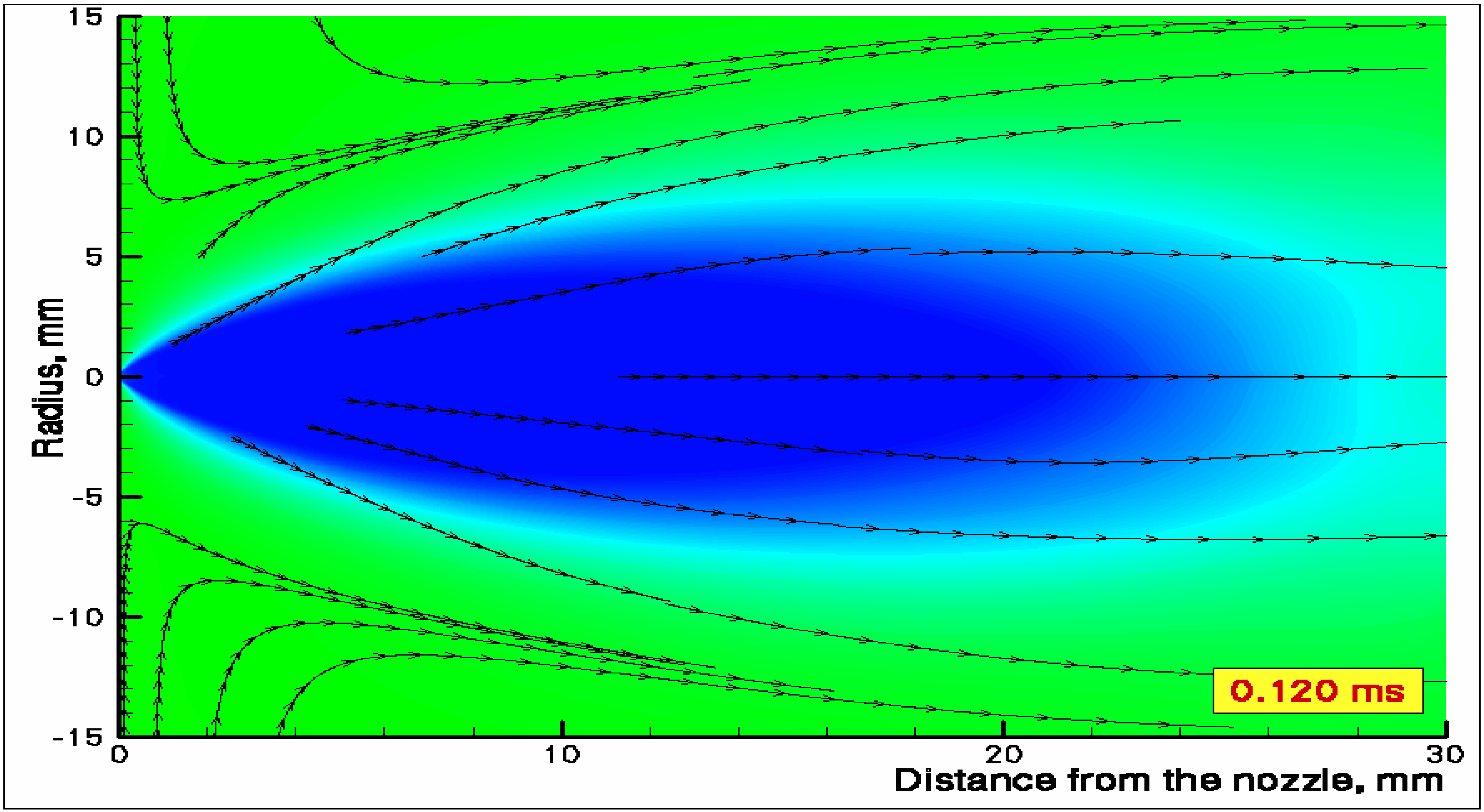
Gas-jet pulse development

Helium gas-jet temperature profile



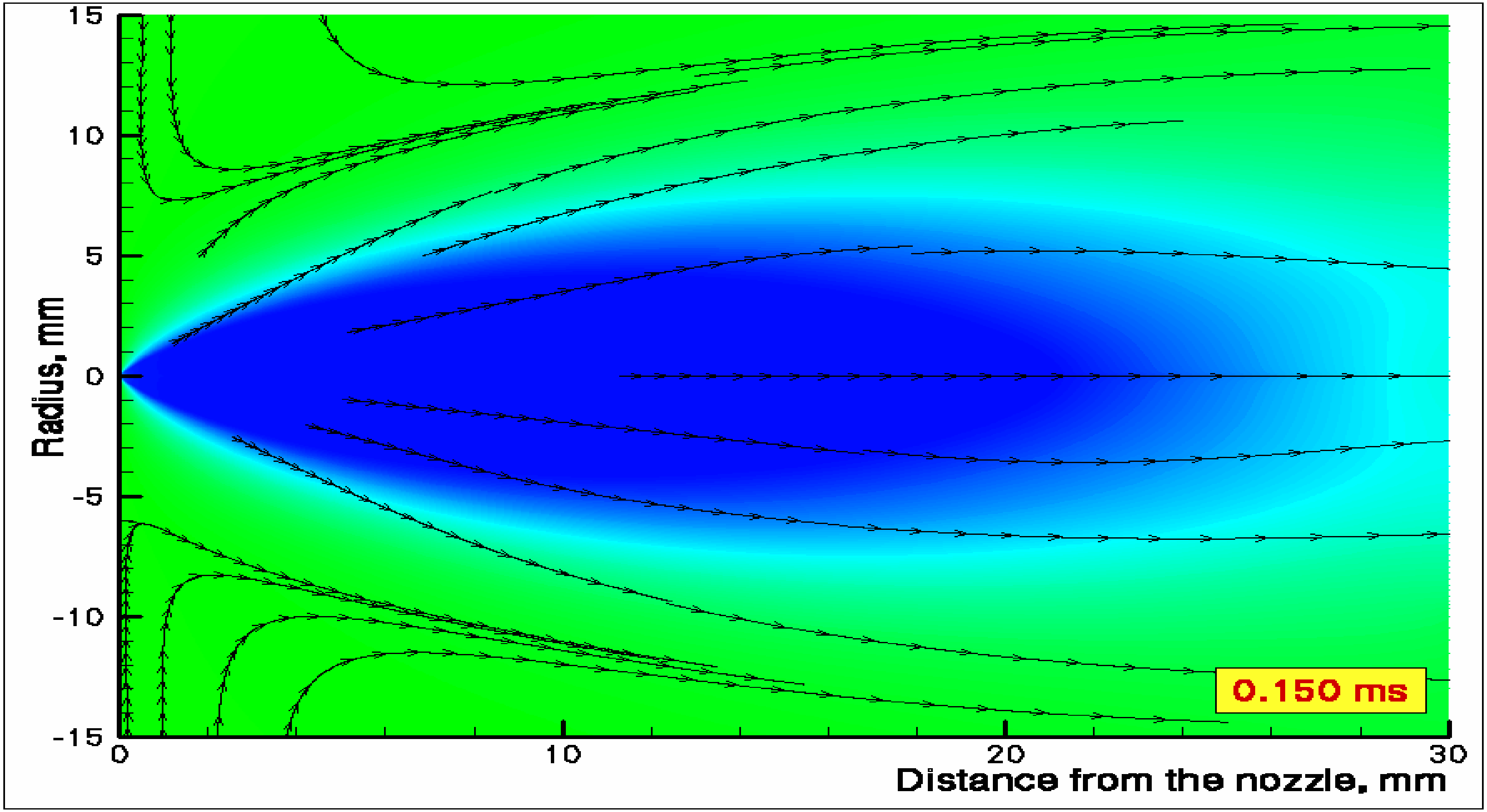
Gas-jet pulse development

Helium gas-jet temperature profile



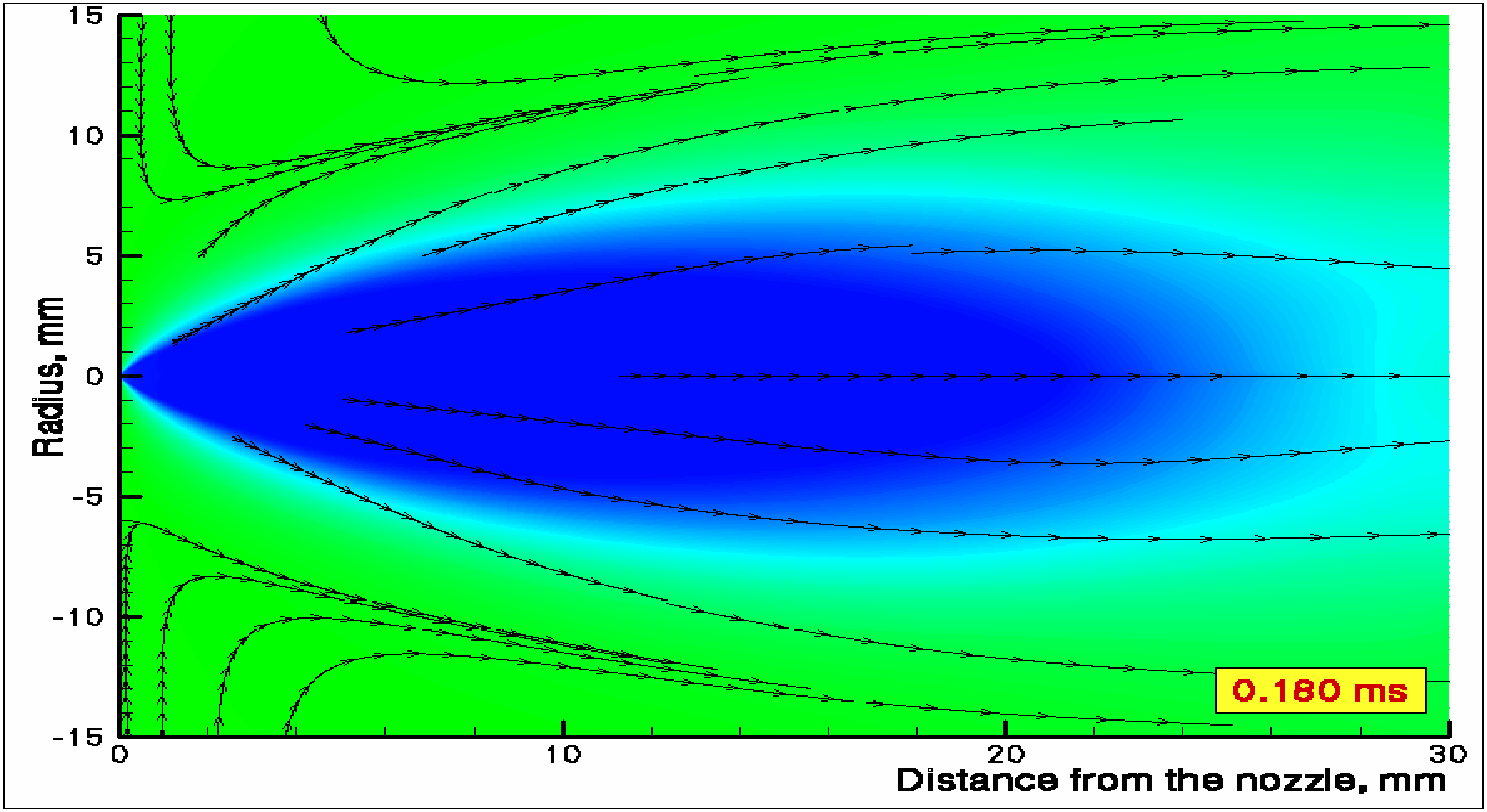
Gas-jet pulse development

Helium gas-jet temperature profile



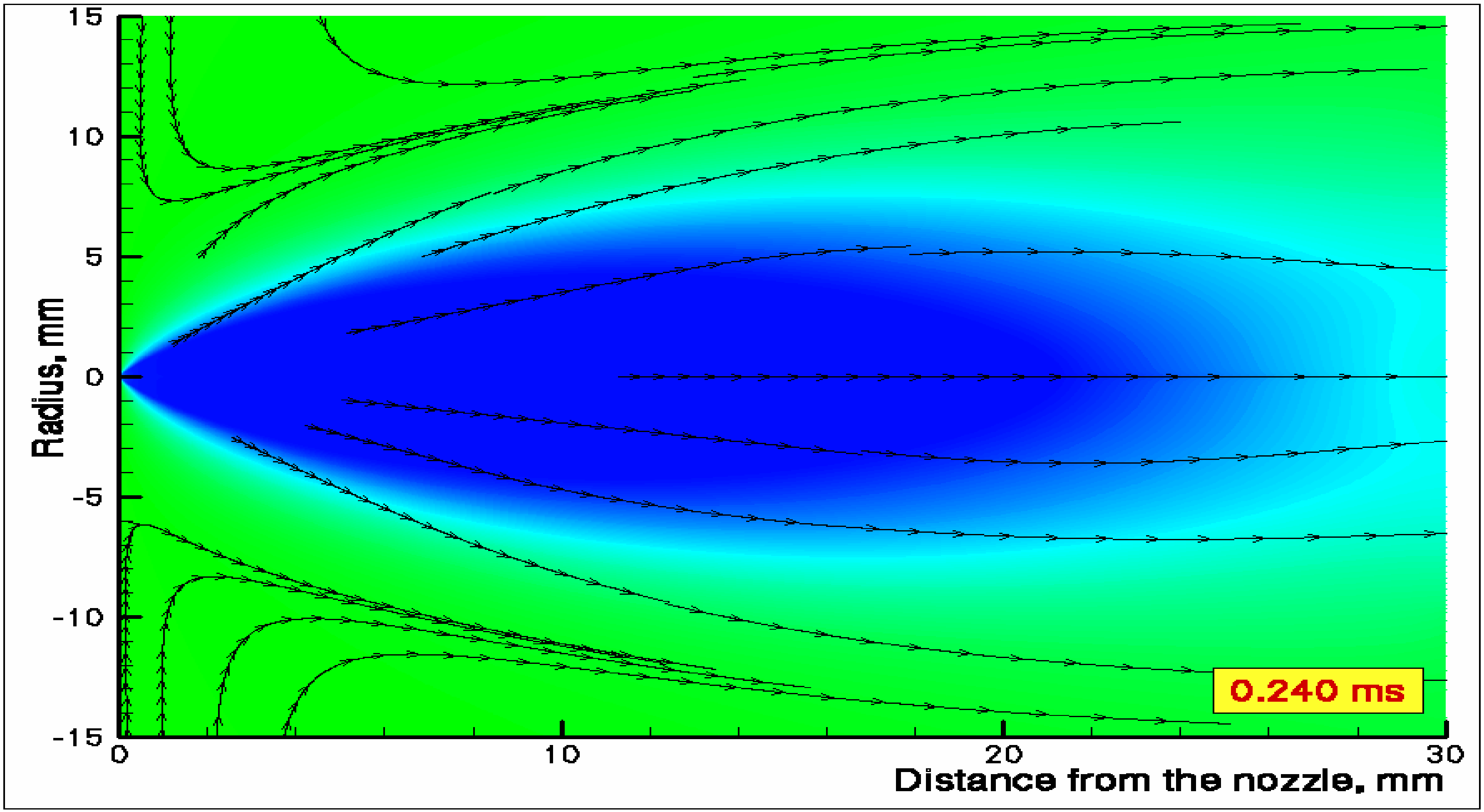
Gas-jet pulse development

Helium gas-jet temperature profile



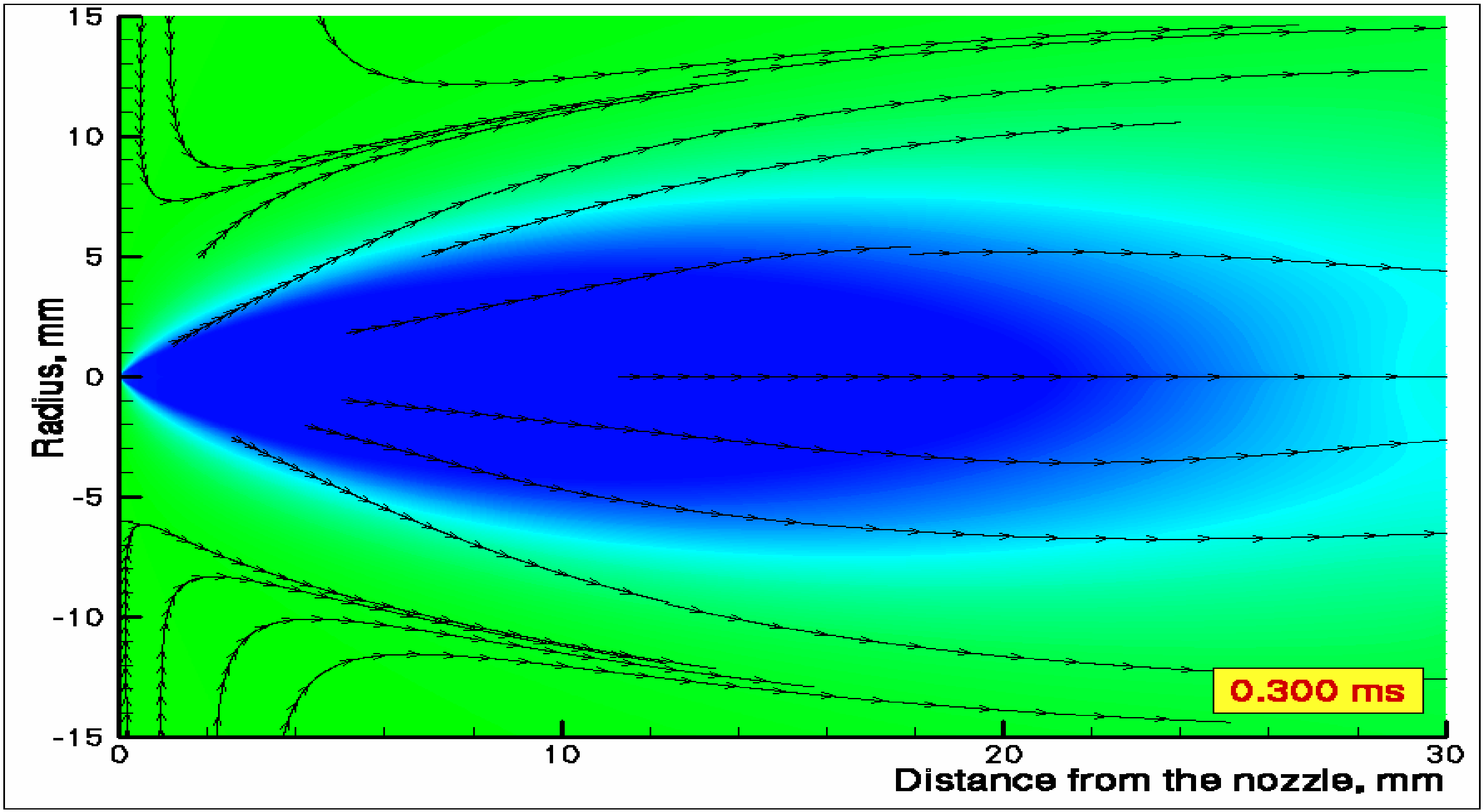
Gas-jet pulse development

Helium gas-jet temperature profile



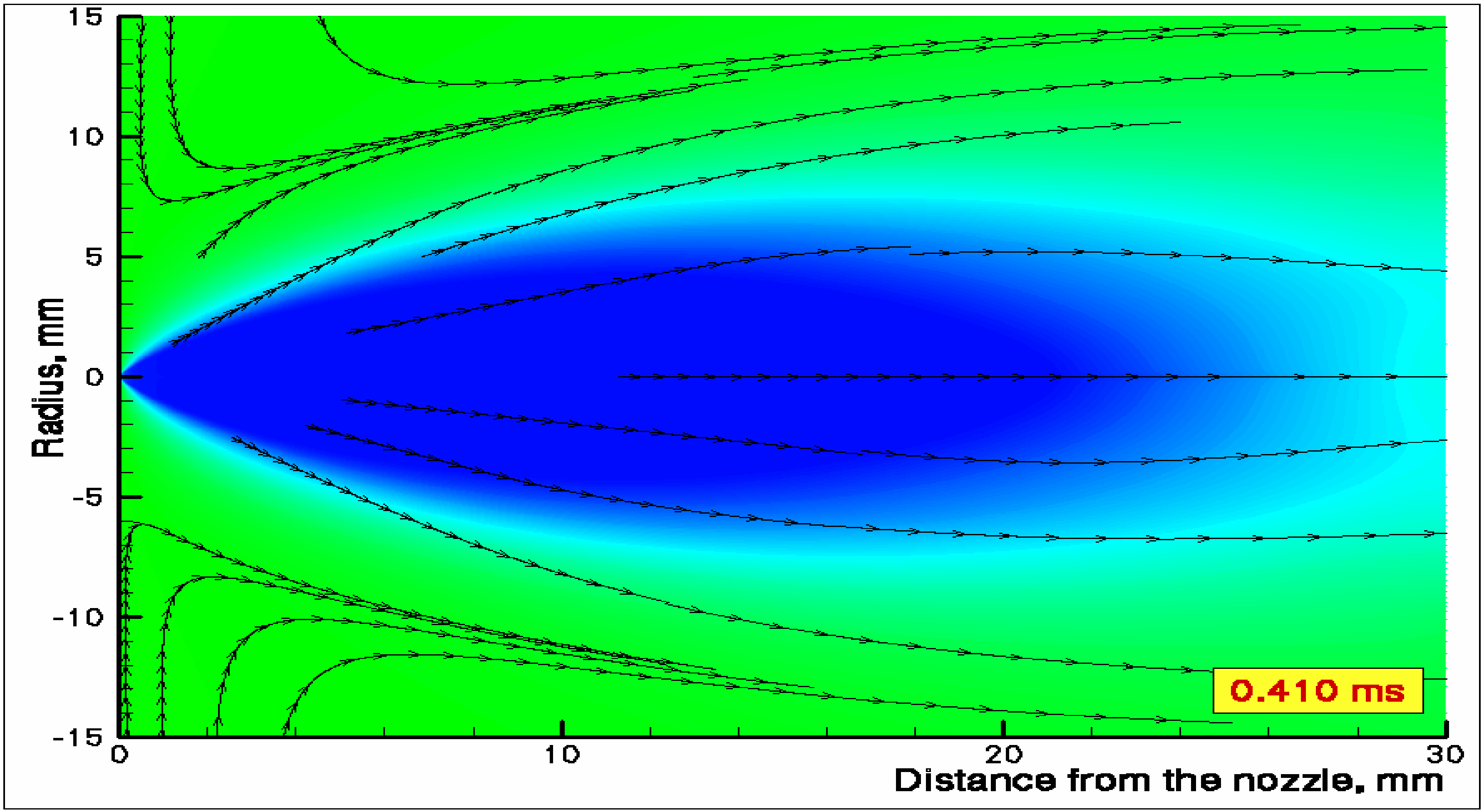
Gas-jet pulse development

Helium gas-jet temperature profile



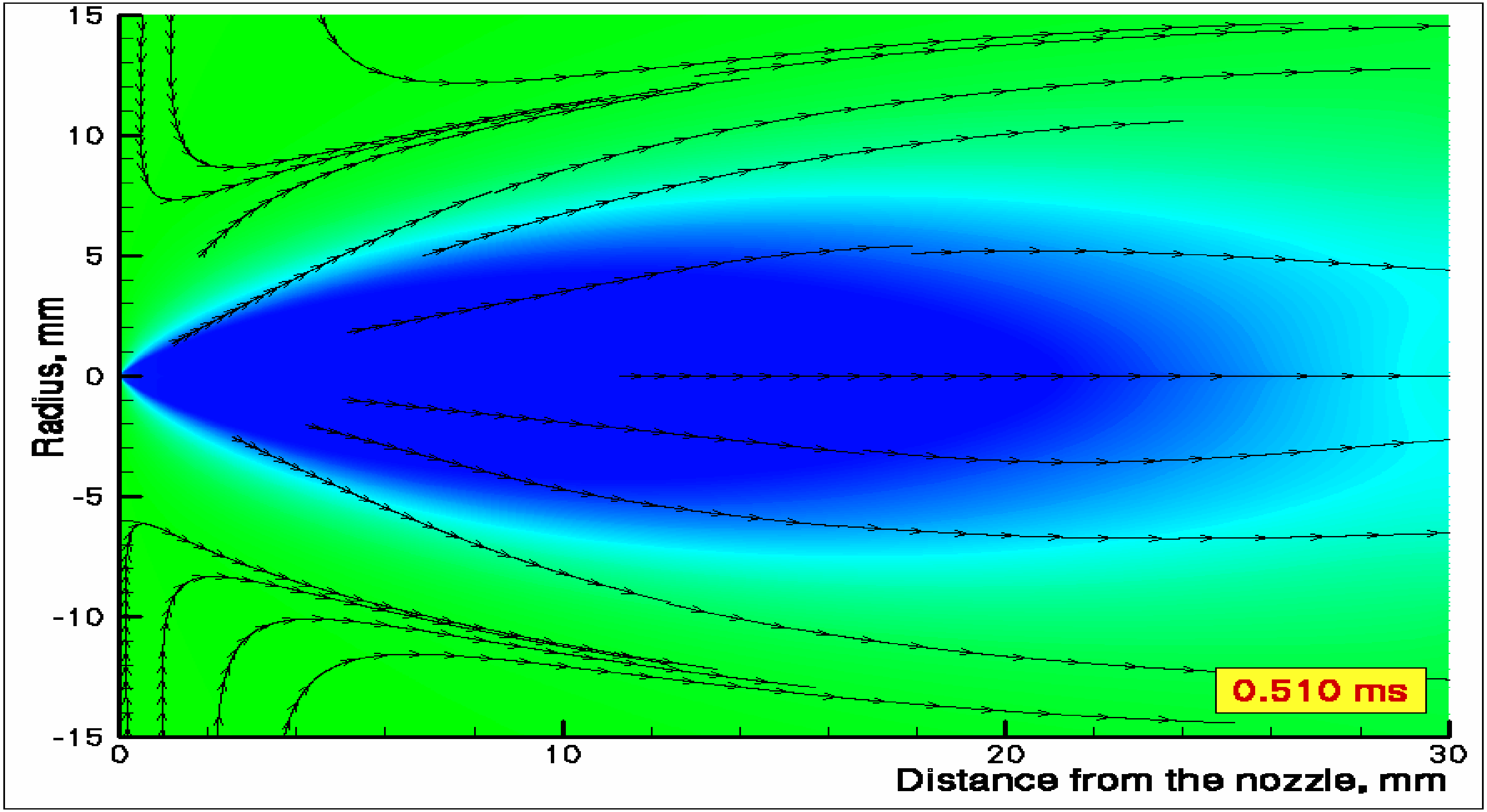
Gas-jet pulse development

Helium gas-jet temperature profile



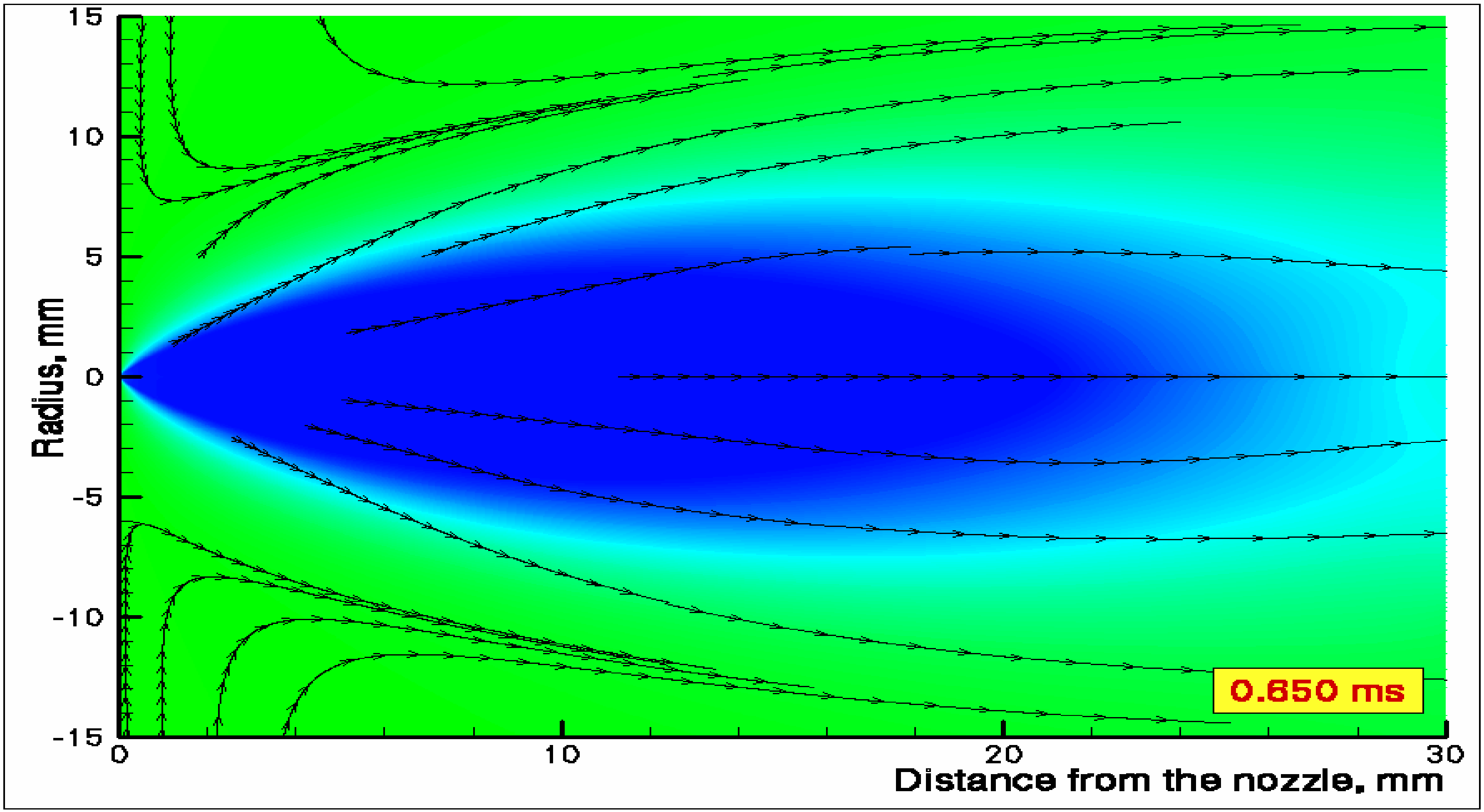
Gas-jet pulse development

Helium gas-jet temperature profile



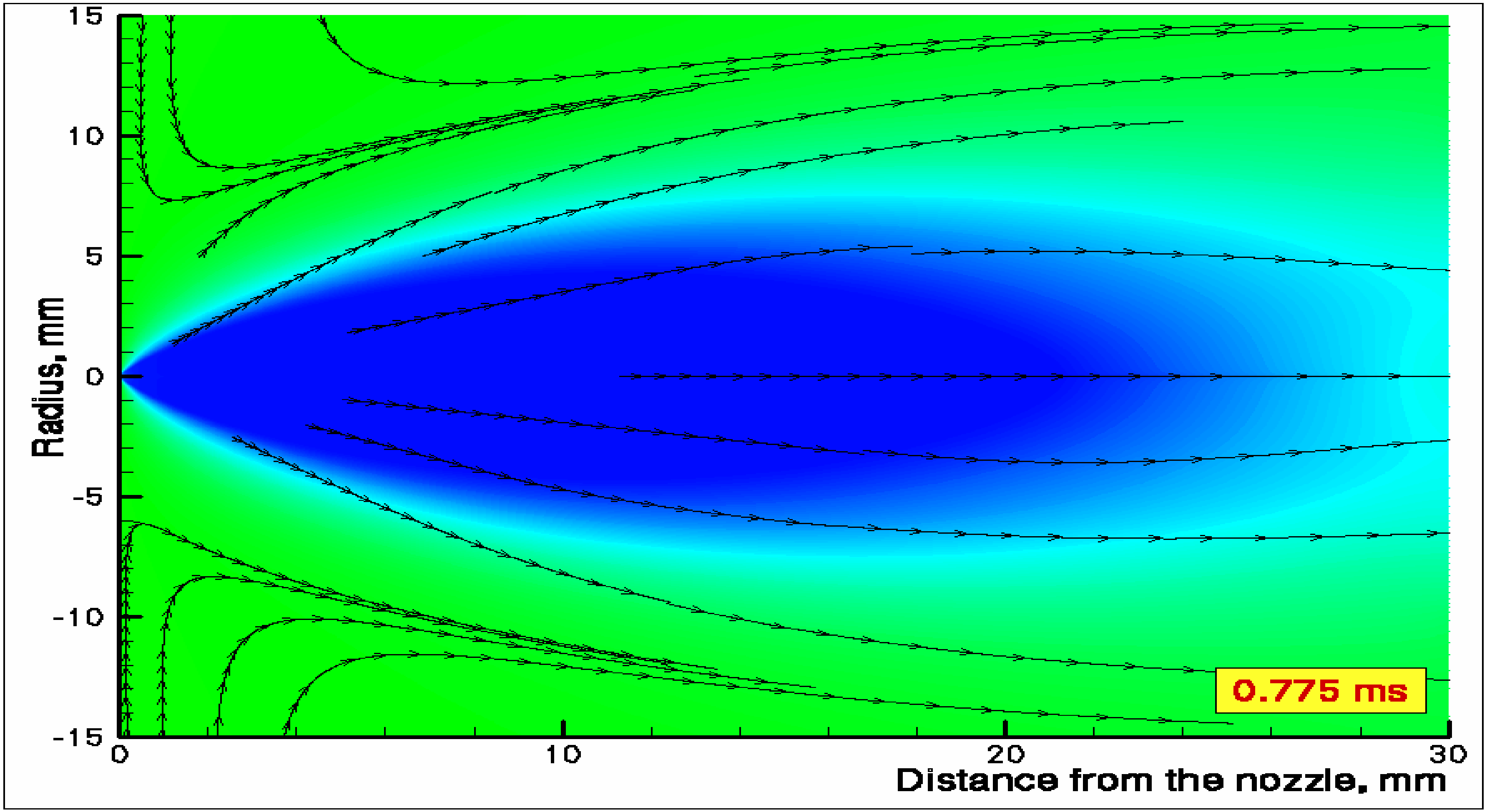
Gas-jet pulse development

Helium gas-jet temperature profile



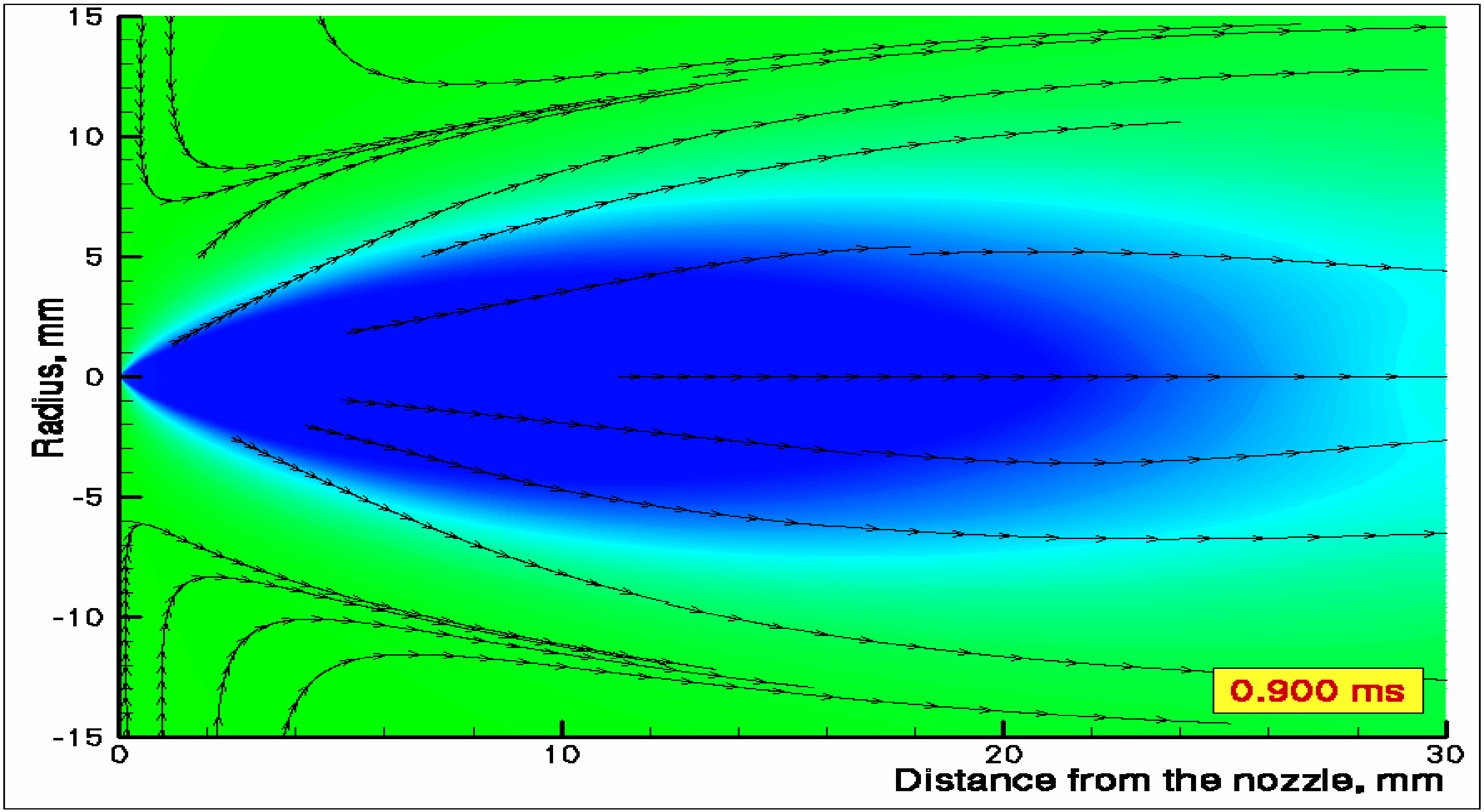
Gas-jet pulse development

Helium gas-jet temperature profile



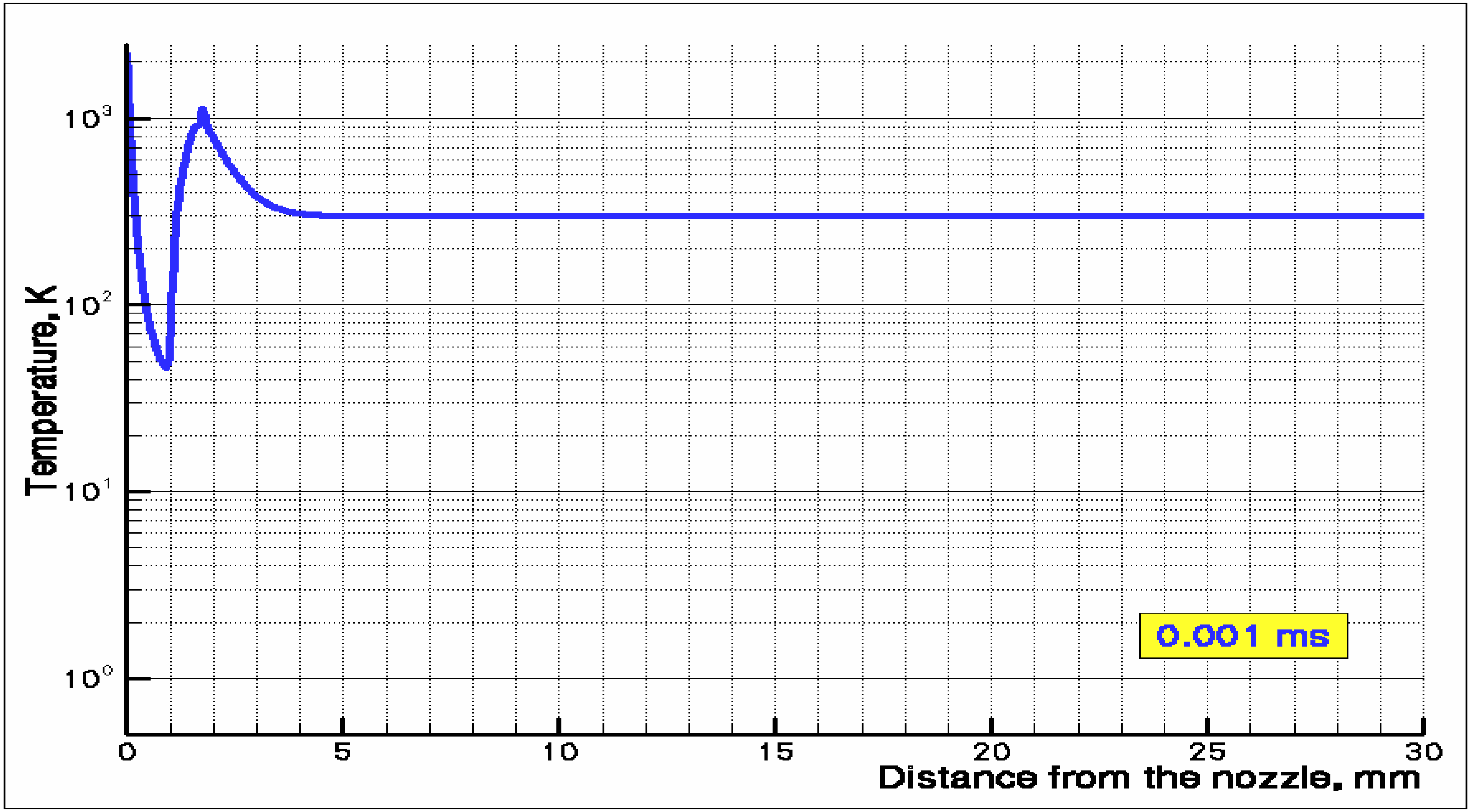
Gas-jet pulse development

Helium gas-jet temperature profile



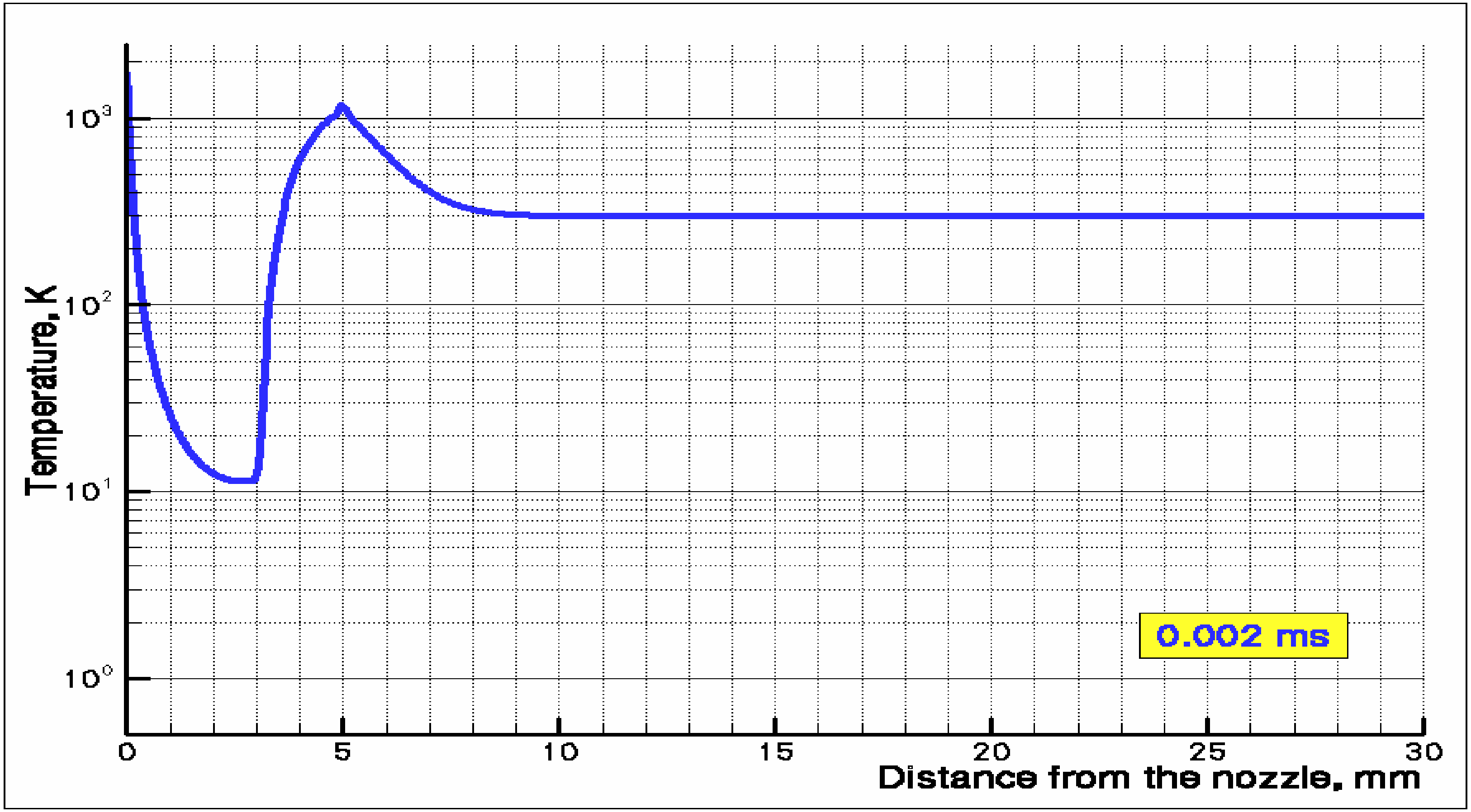
Gas-jet pulse development

Helium gas-jet temperature along the axis



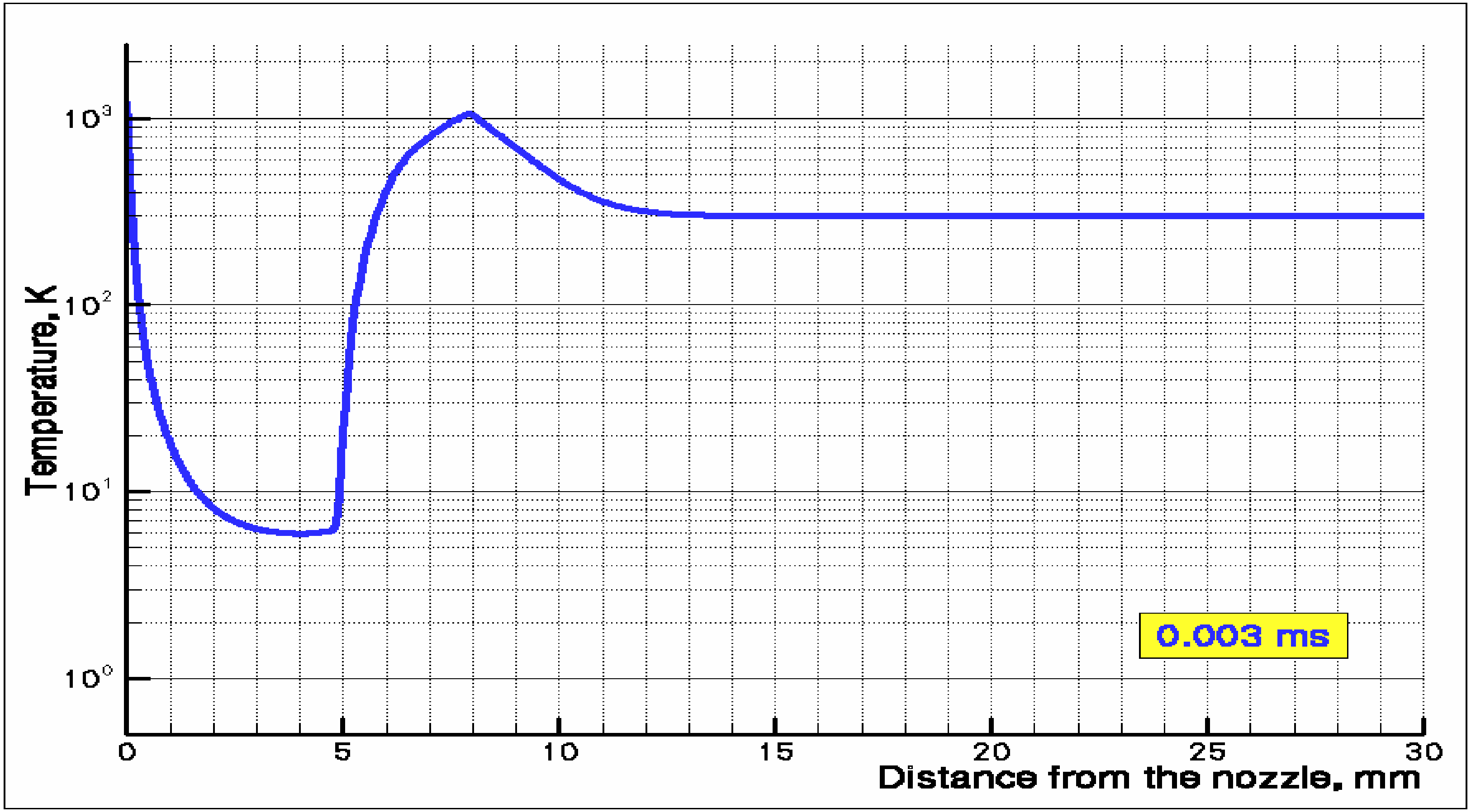
Gas-jet pulse development

Helium gas-jet temperature along the axis



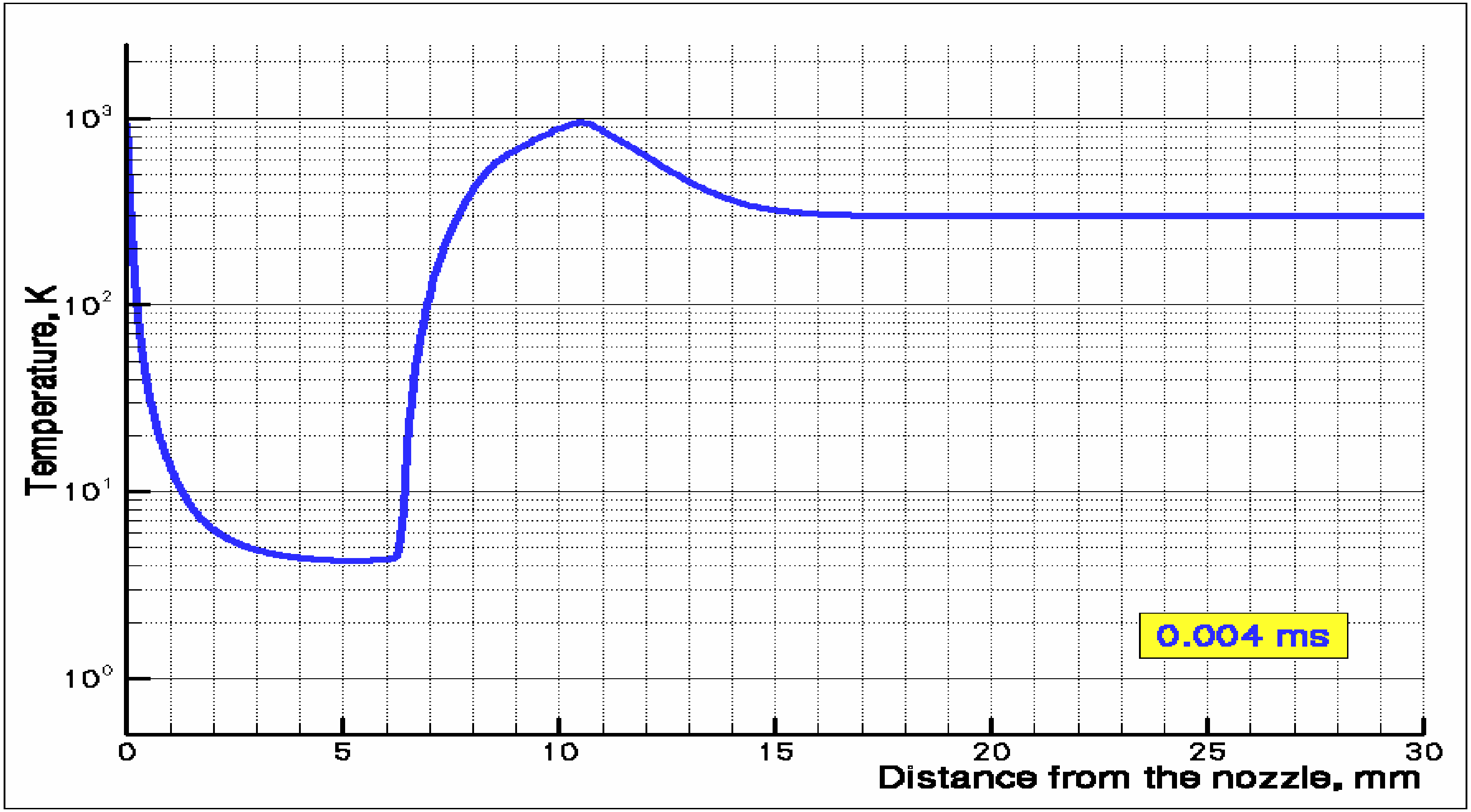
Gas-jet pulse development

Helium gas-jet temperature along the axis



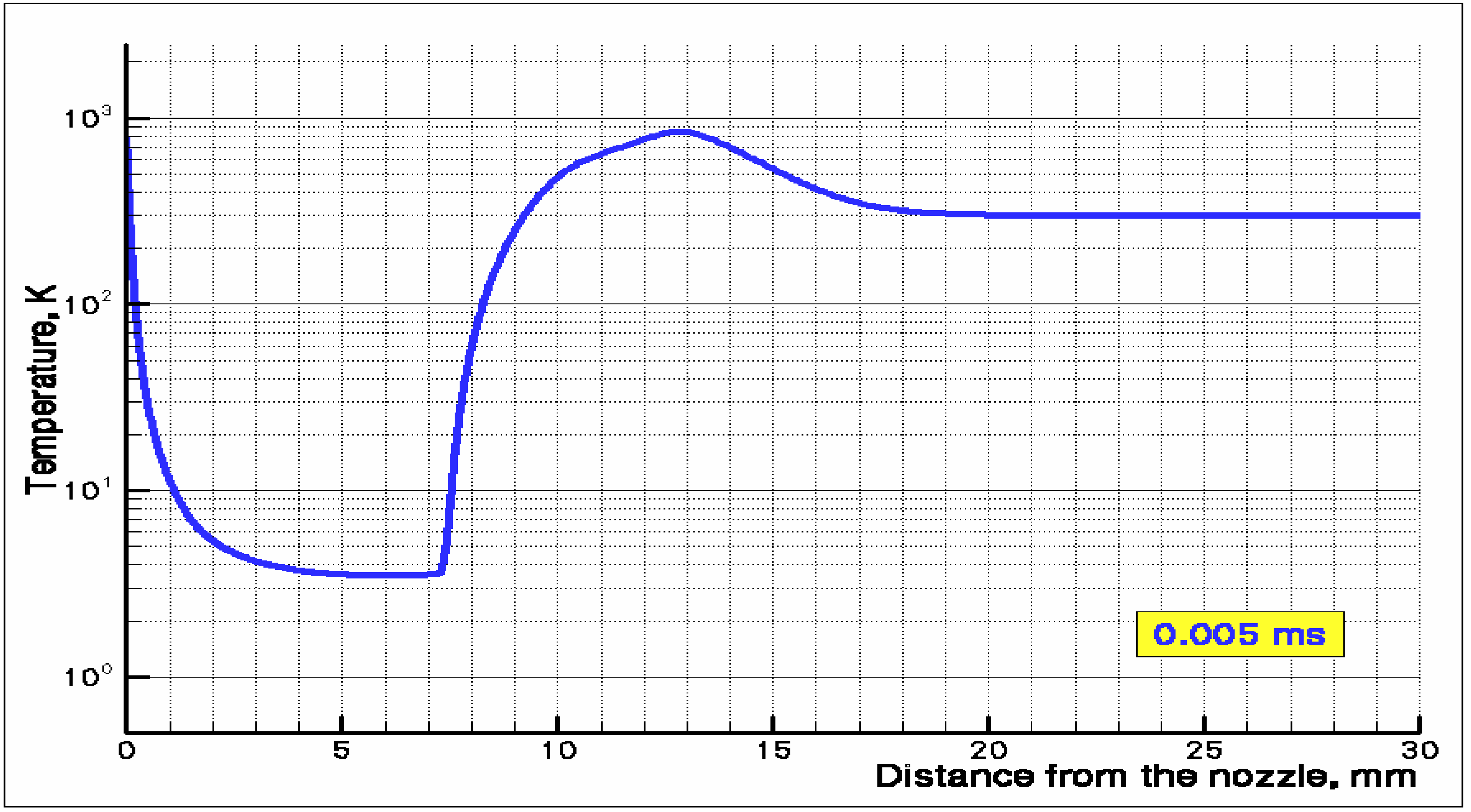
Gas-jet pulse development

Helium gas-jet temperature along the axis



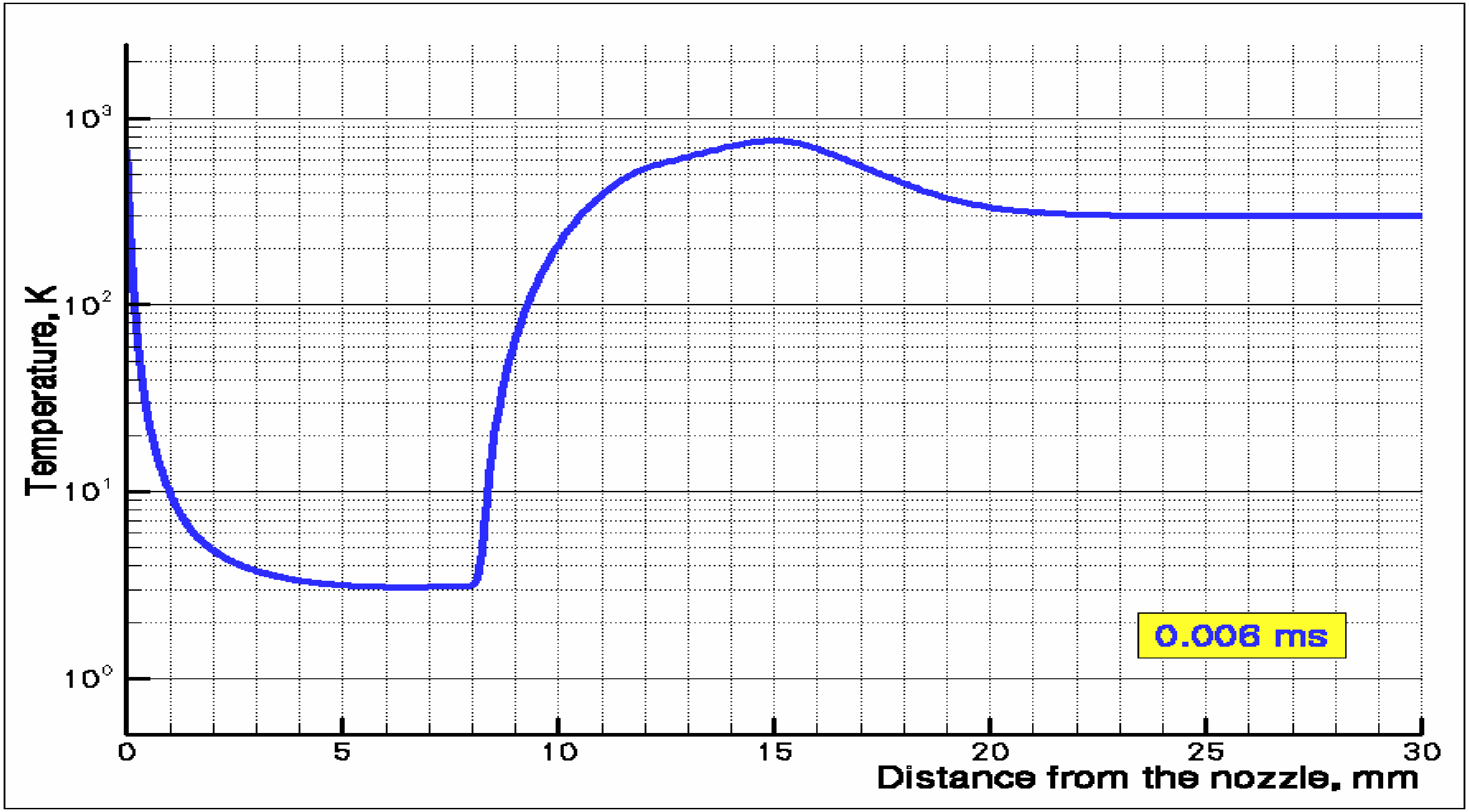
Gas-jet pulse development

Helium gas-jet temperature along the axis



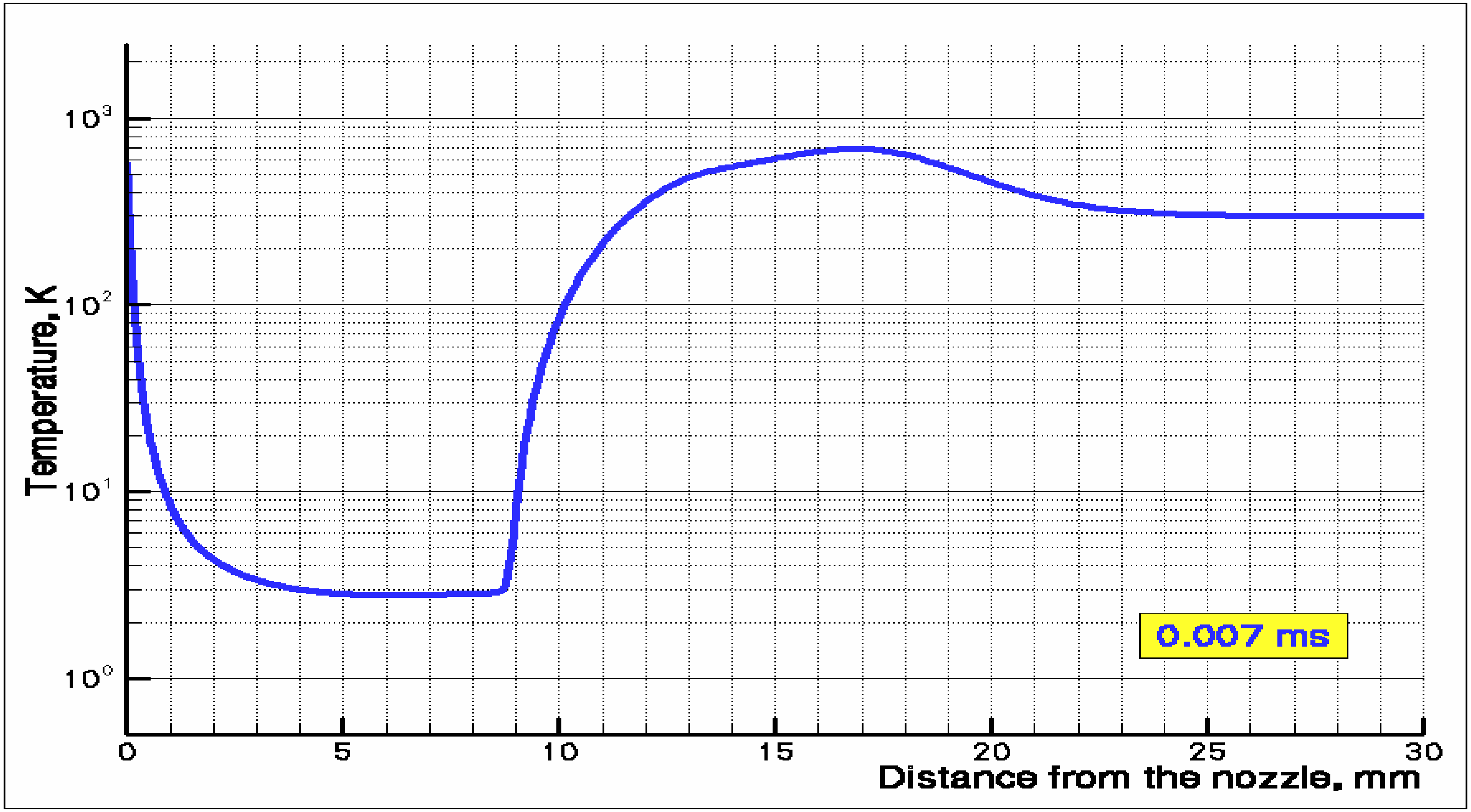
Gas-jet pulse development

Helium gas-jet temperature along the axis



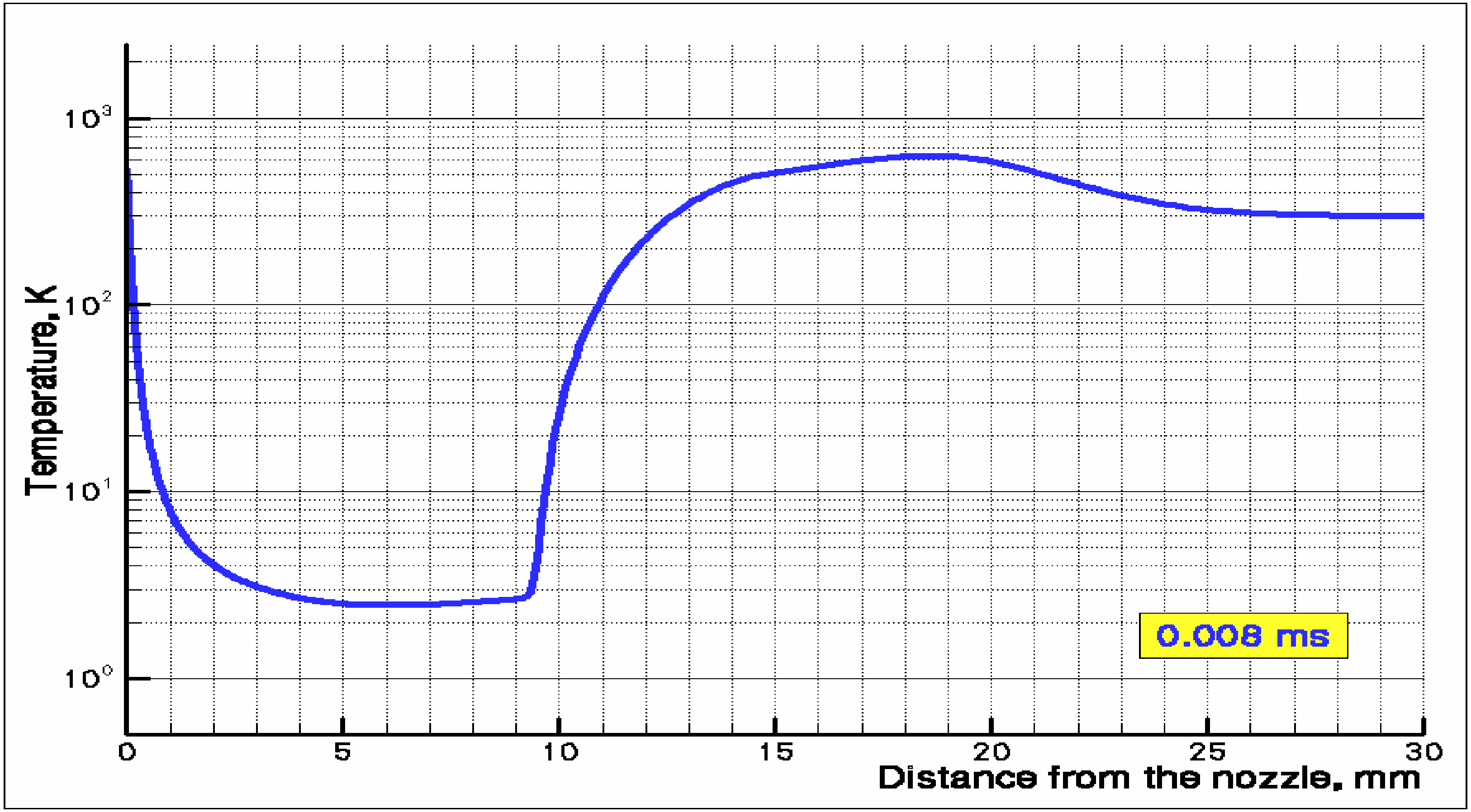
Gas-jet pulse development

Helium gas-jet temperature along the axis



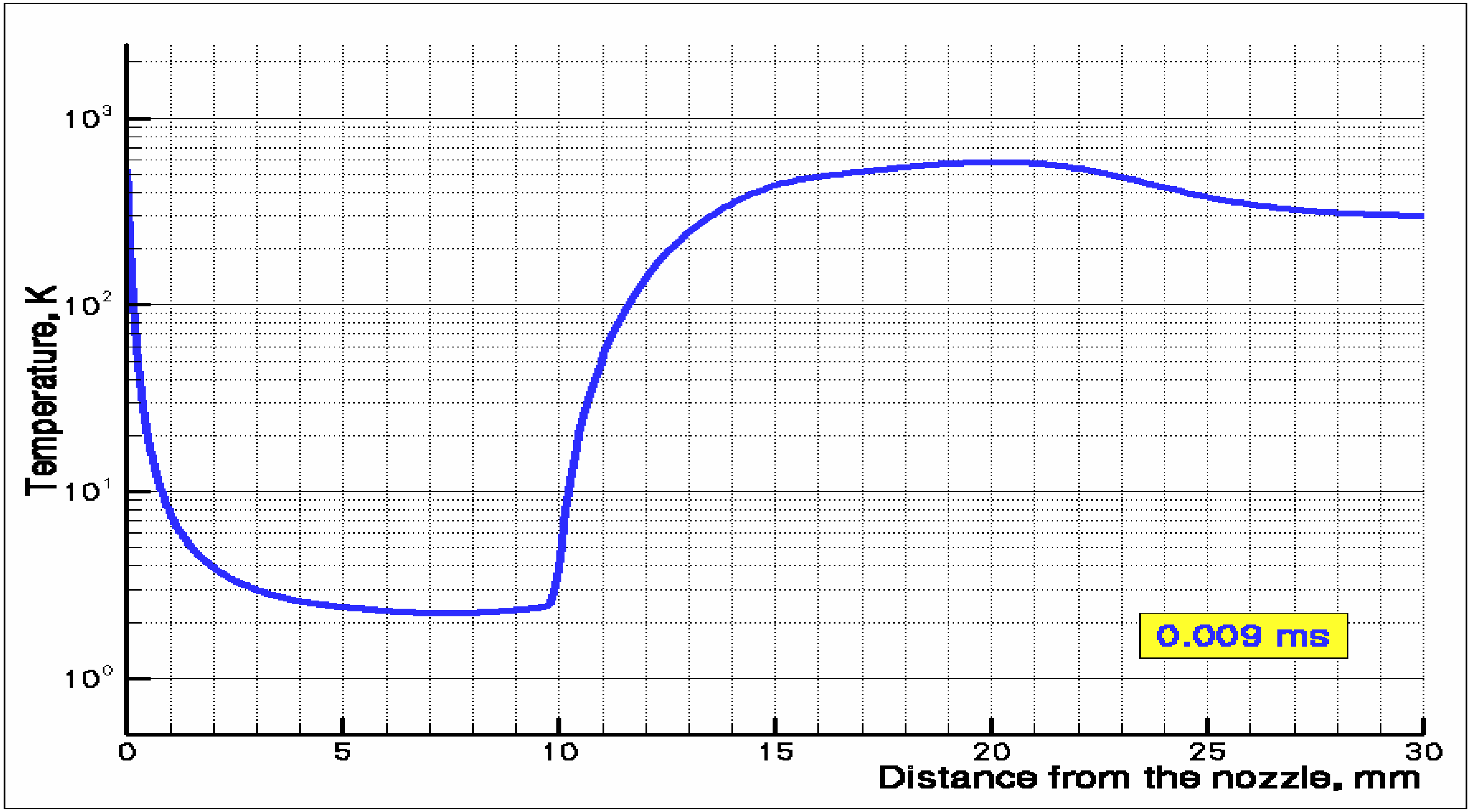
Gas-jet pulse development

Helium gas-jet temperature along the axis



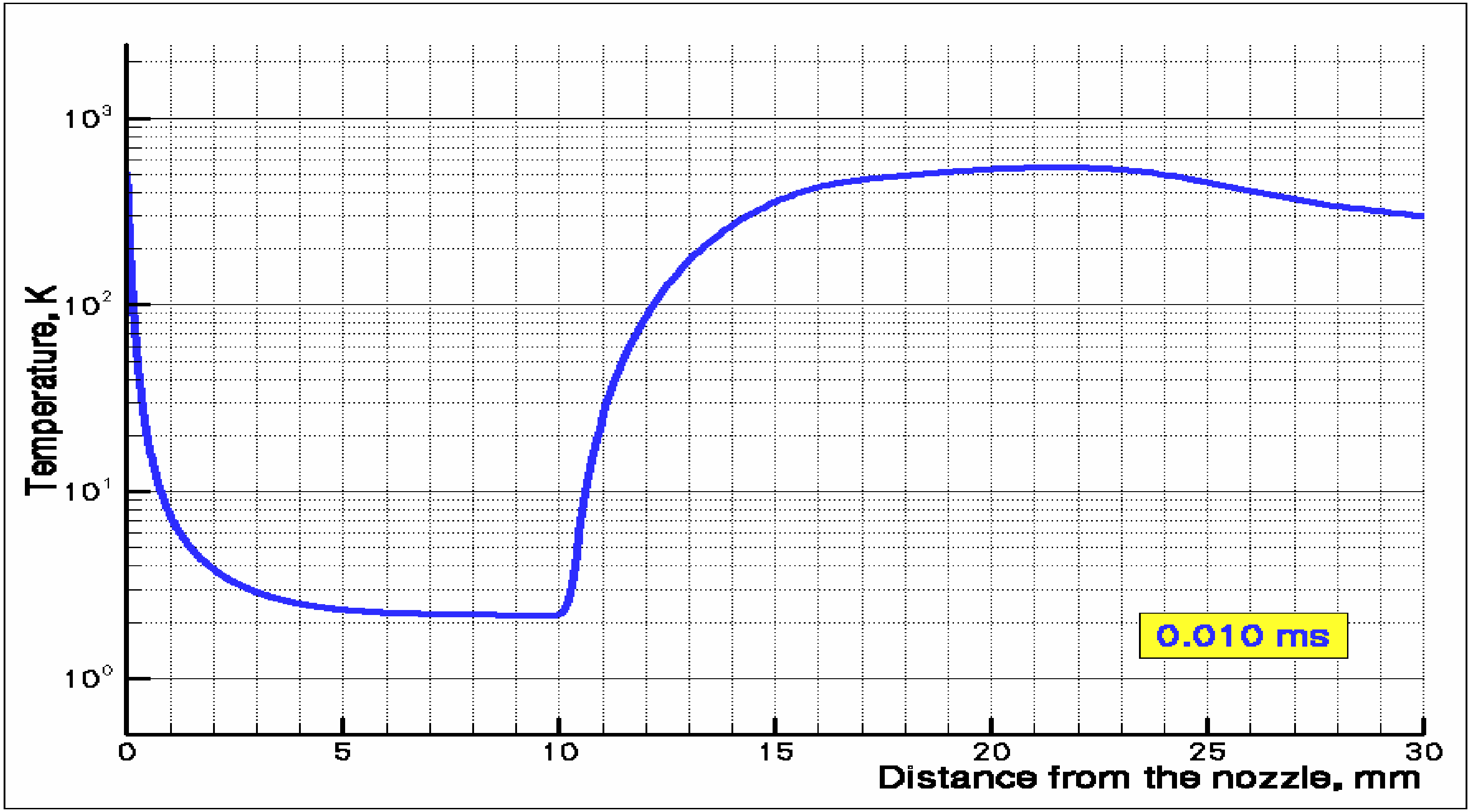
Gas-jet pulse development

Helium gas-jet temperature along the axis



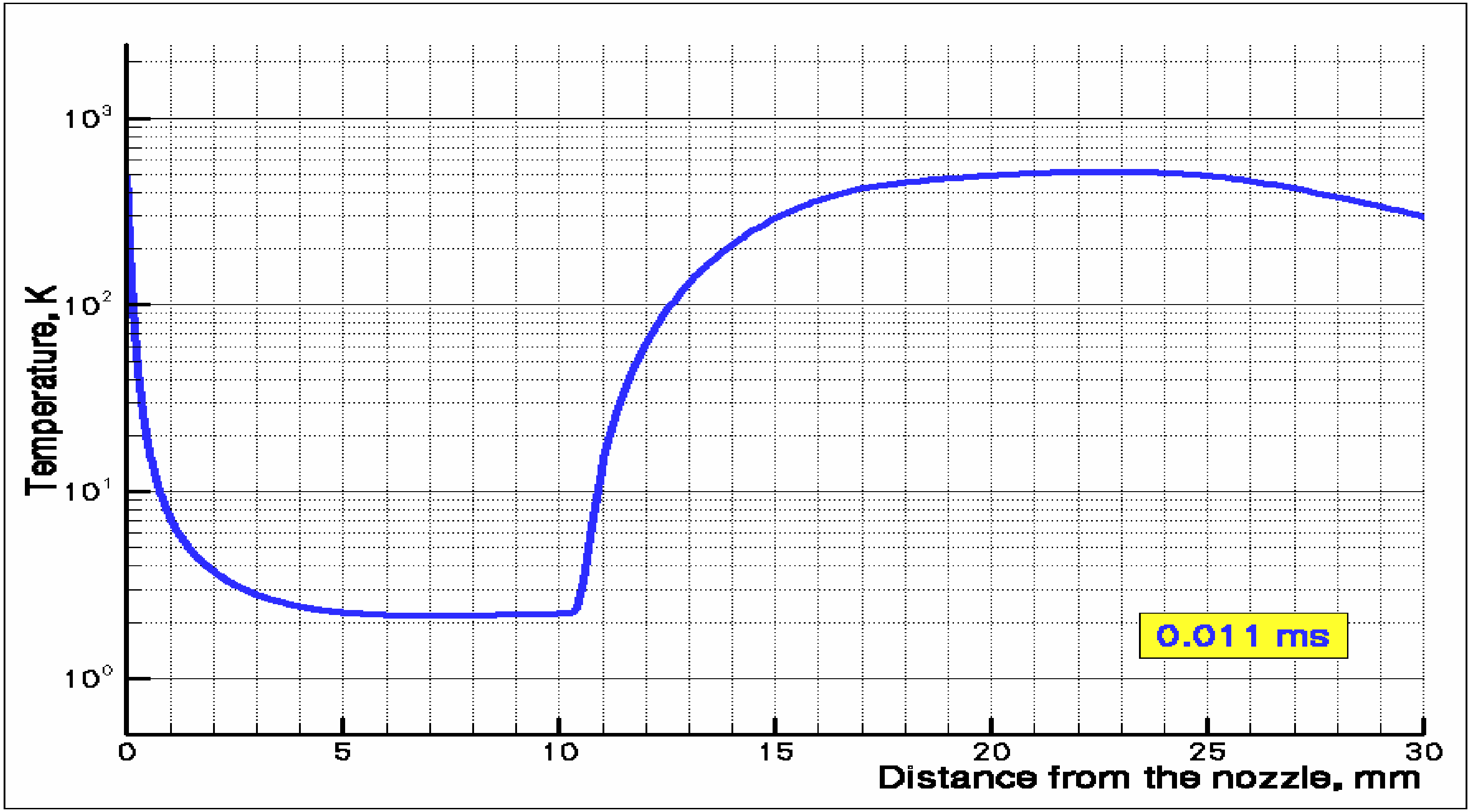
Gas-jet pulse development

Helium gas-jet temperature along the axis



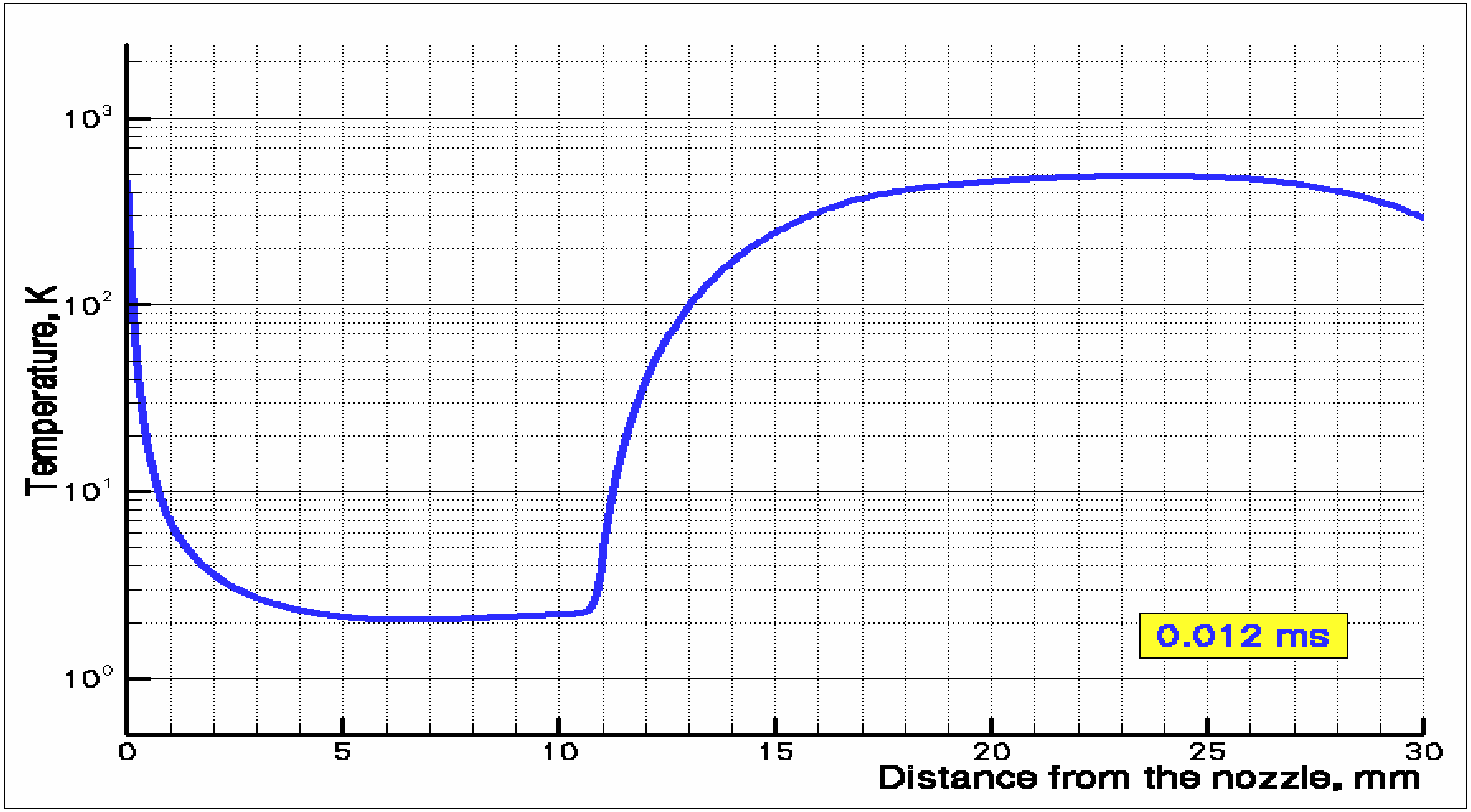
Gas-jet pulse development

Helium gas-jet temperature along the axis



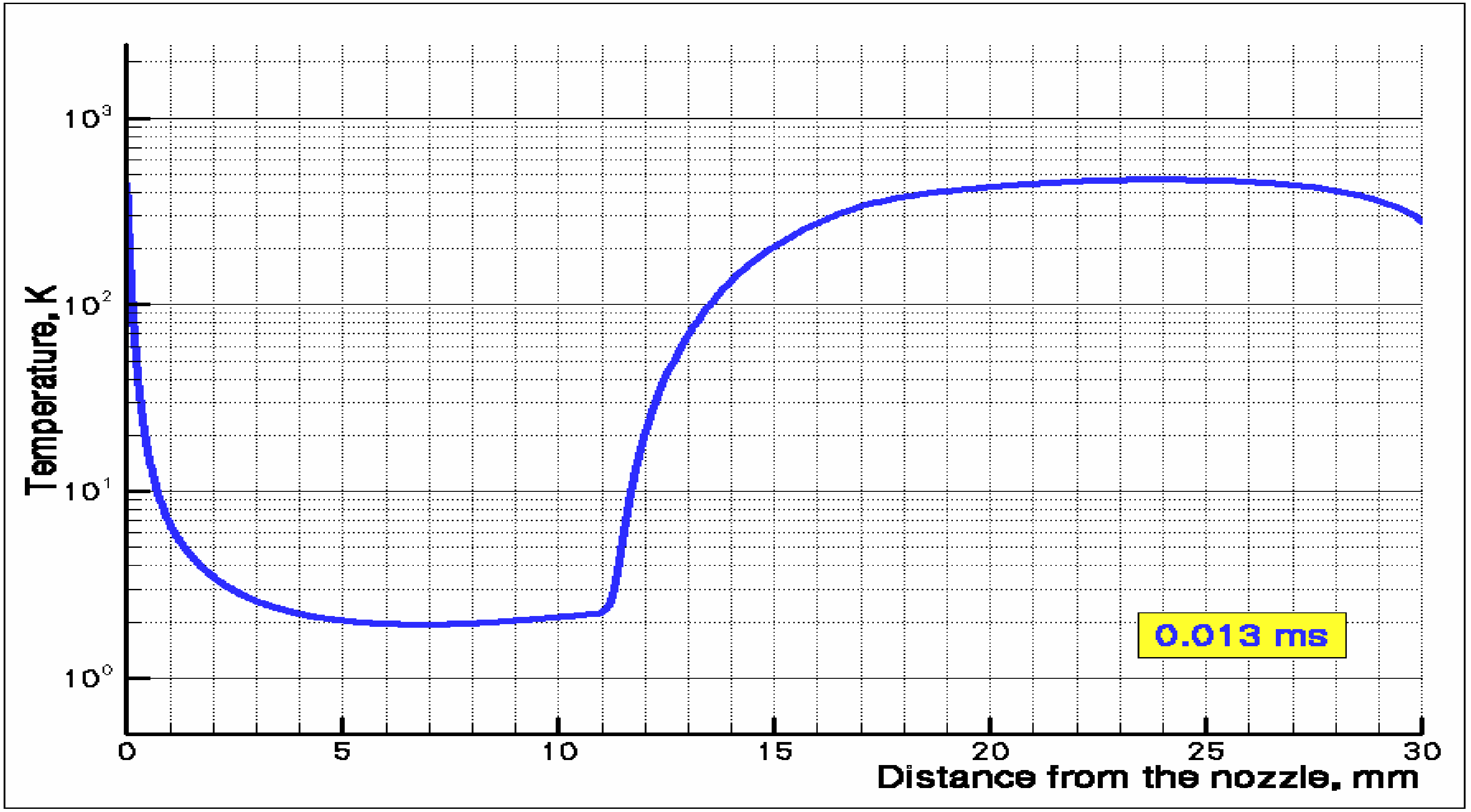
Gas-jet pulse development

Helium gas-jet temperature along the axis



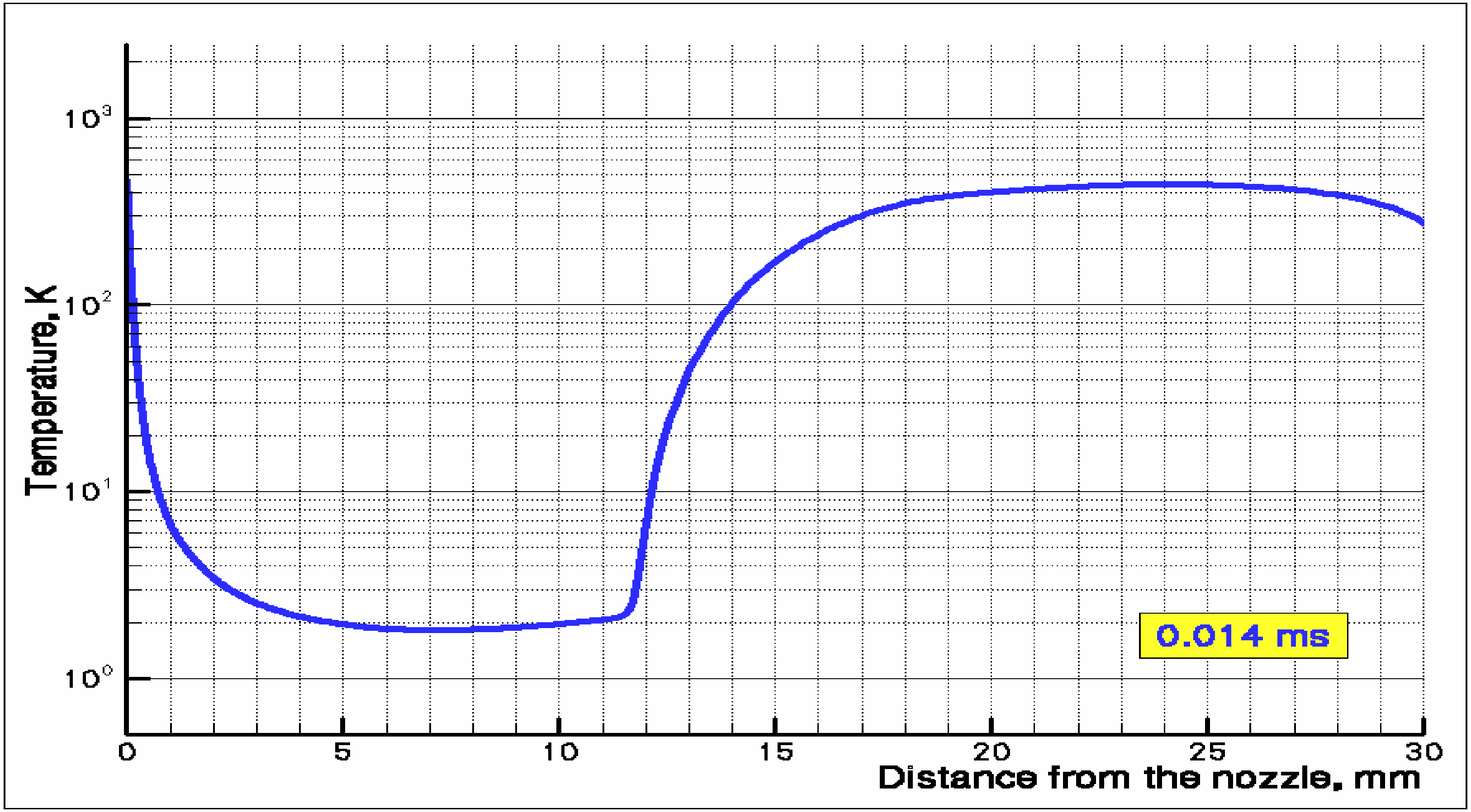
Gas-jet pulse development

Helium gas-jet temperature along the axis



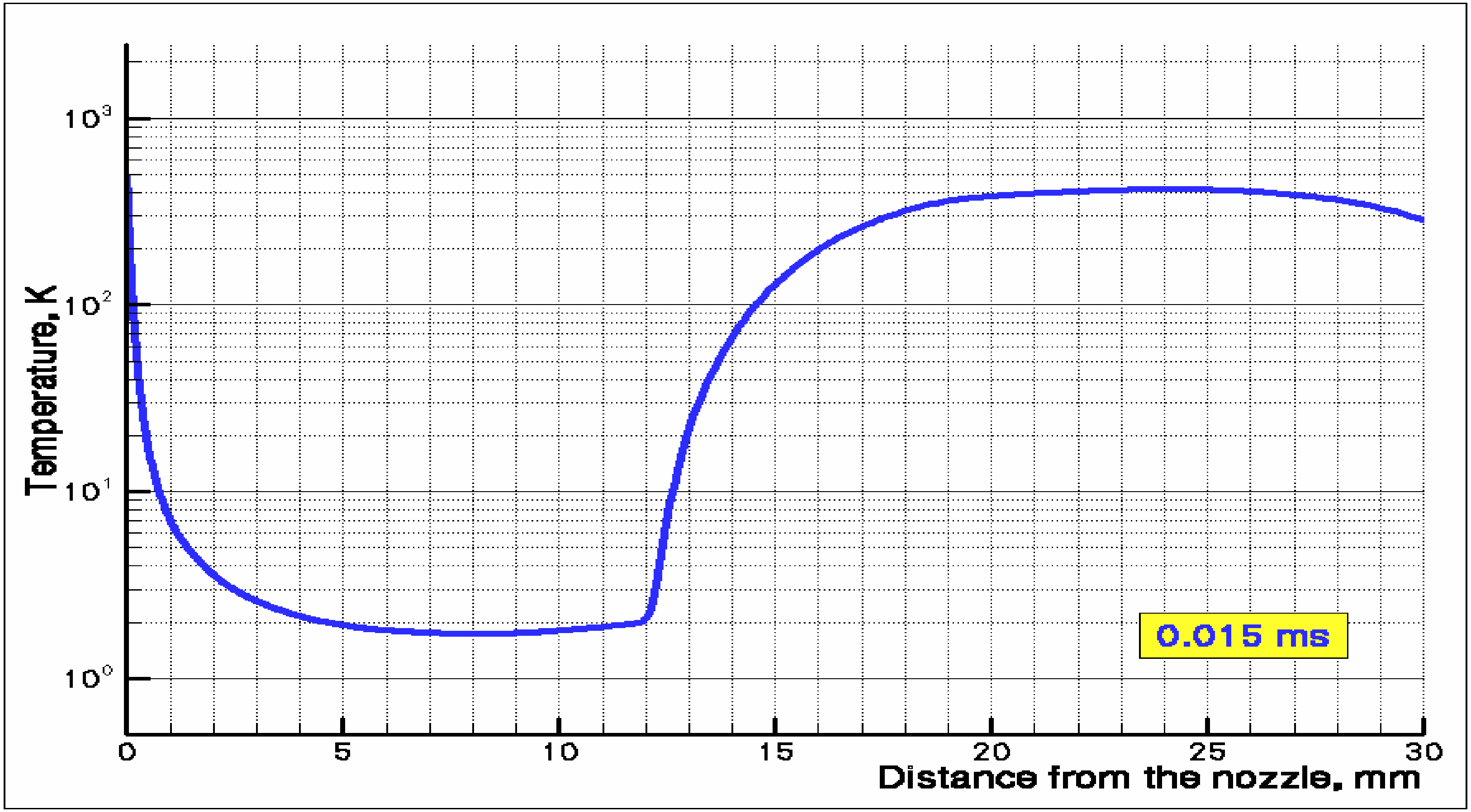
Gas-jet pulse development

Helium gas-jet temperature along the axis



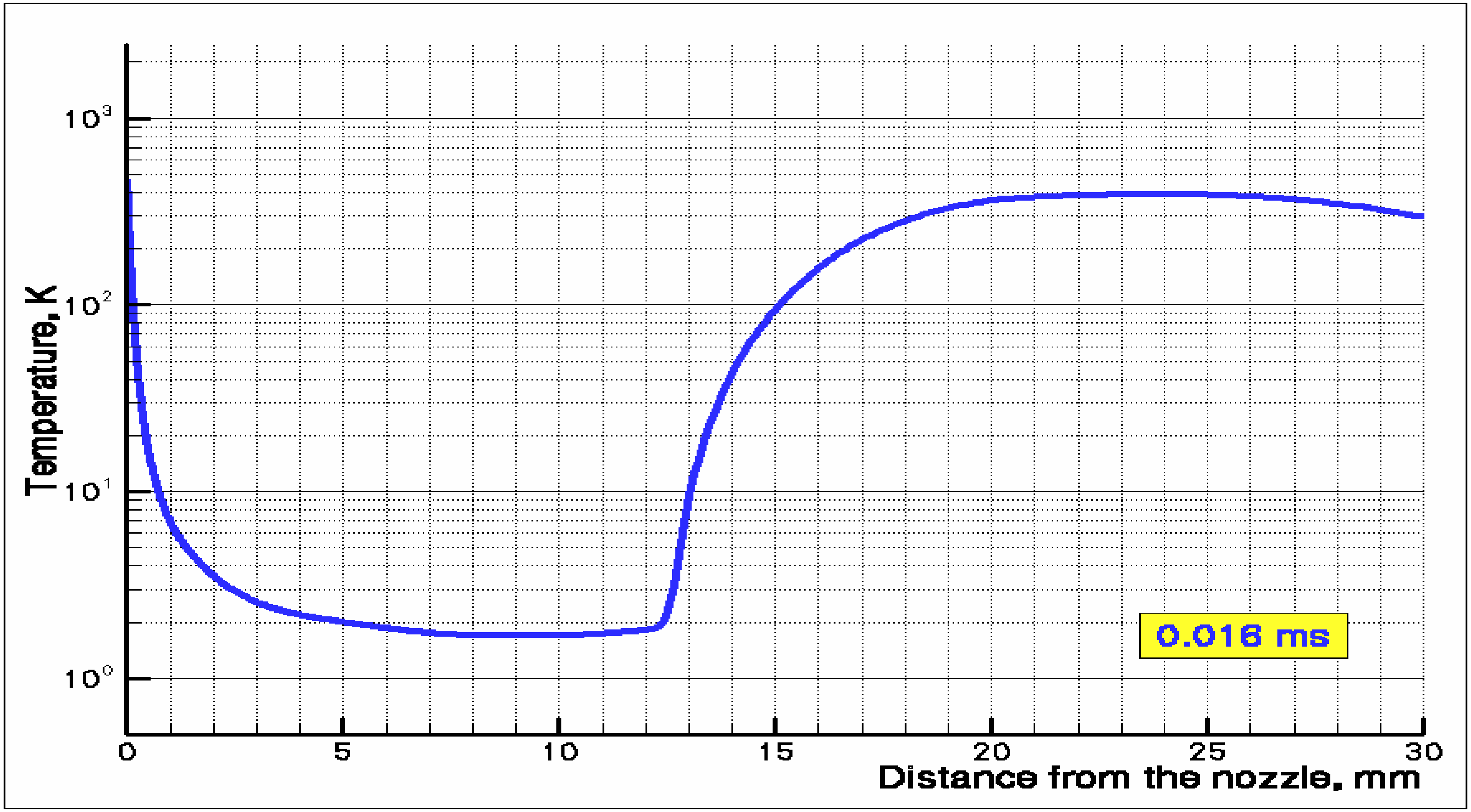
Gas-jet pulse development

Helium gas-jet temperature along the axis



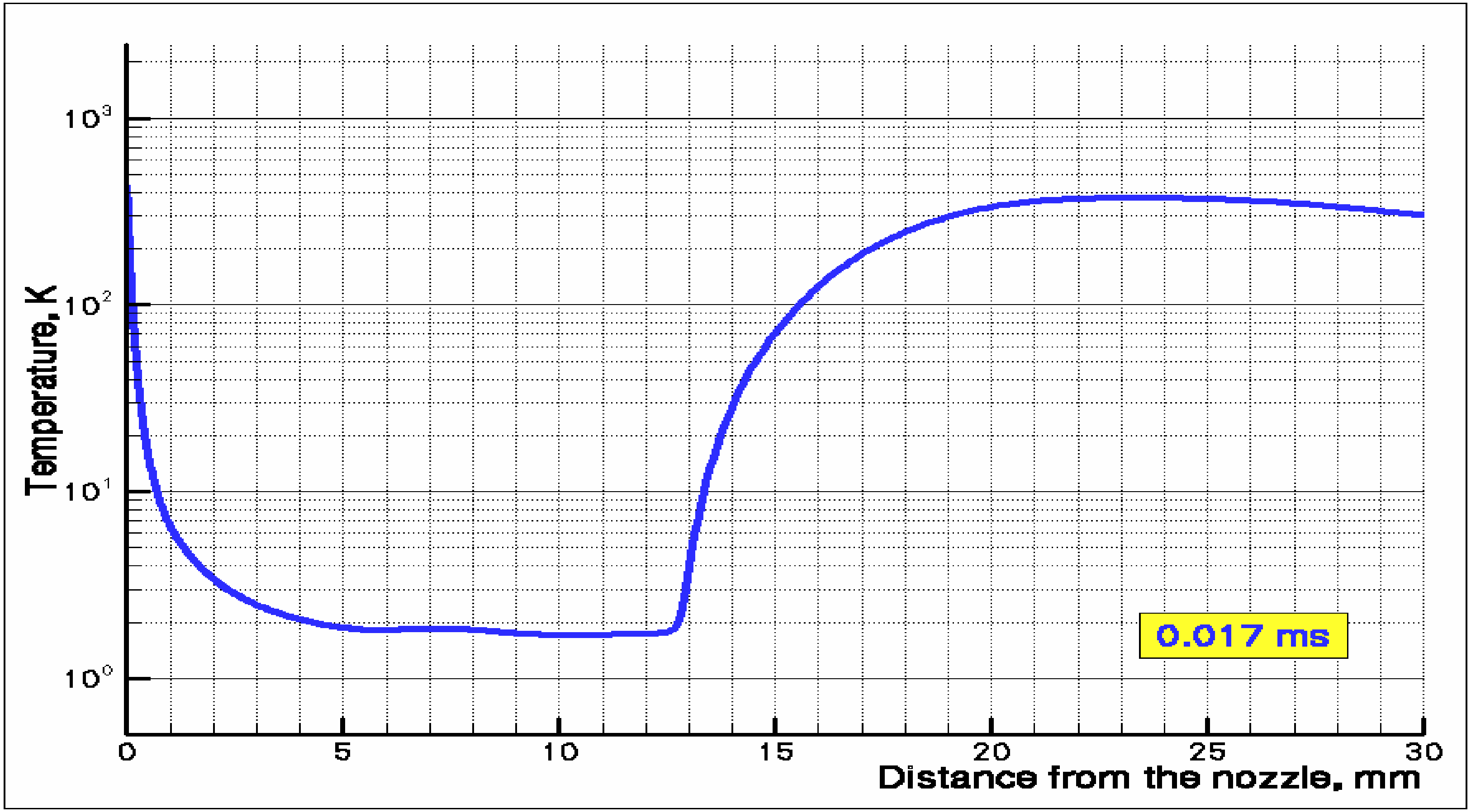
Gas-jet pulse development

Helium gas-jet temperature along the axis



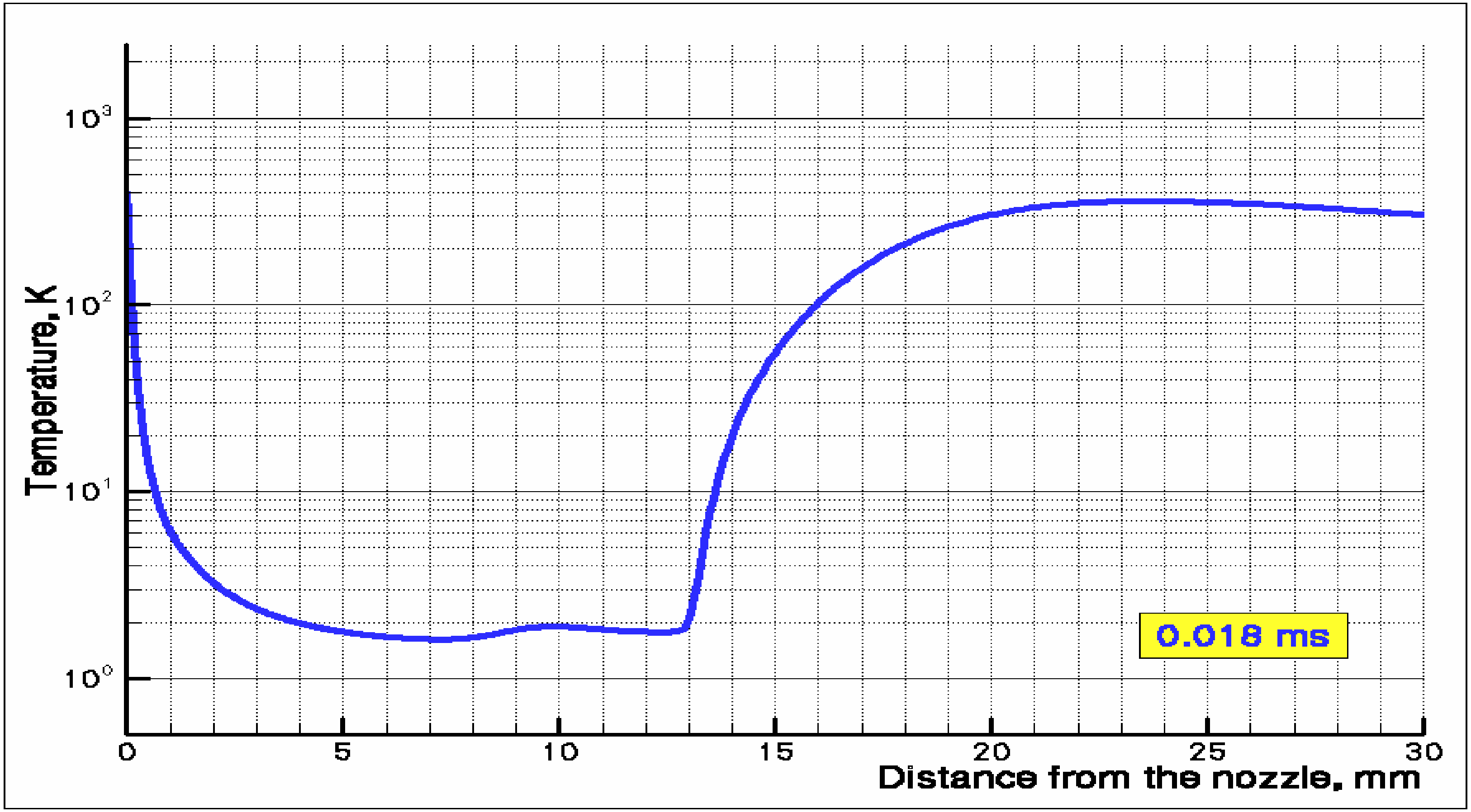
Gas-jet pulse development

Helium gas-jet temperature along the axis



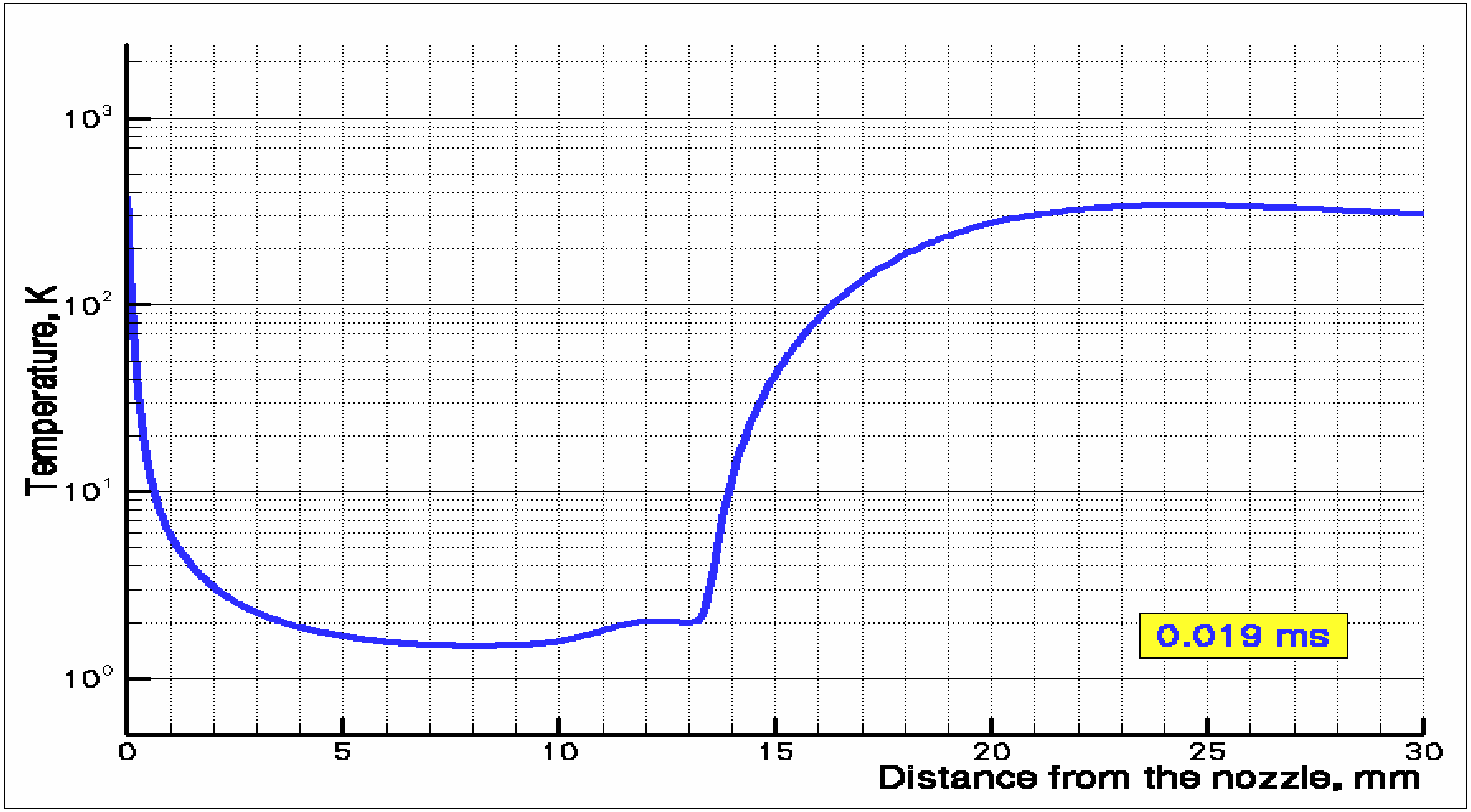
Gas-jet pulse development

Helium gas-jet temperature along the axis



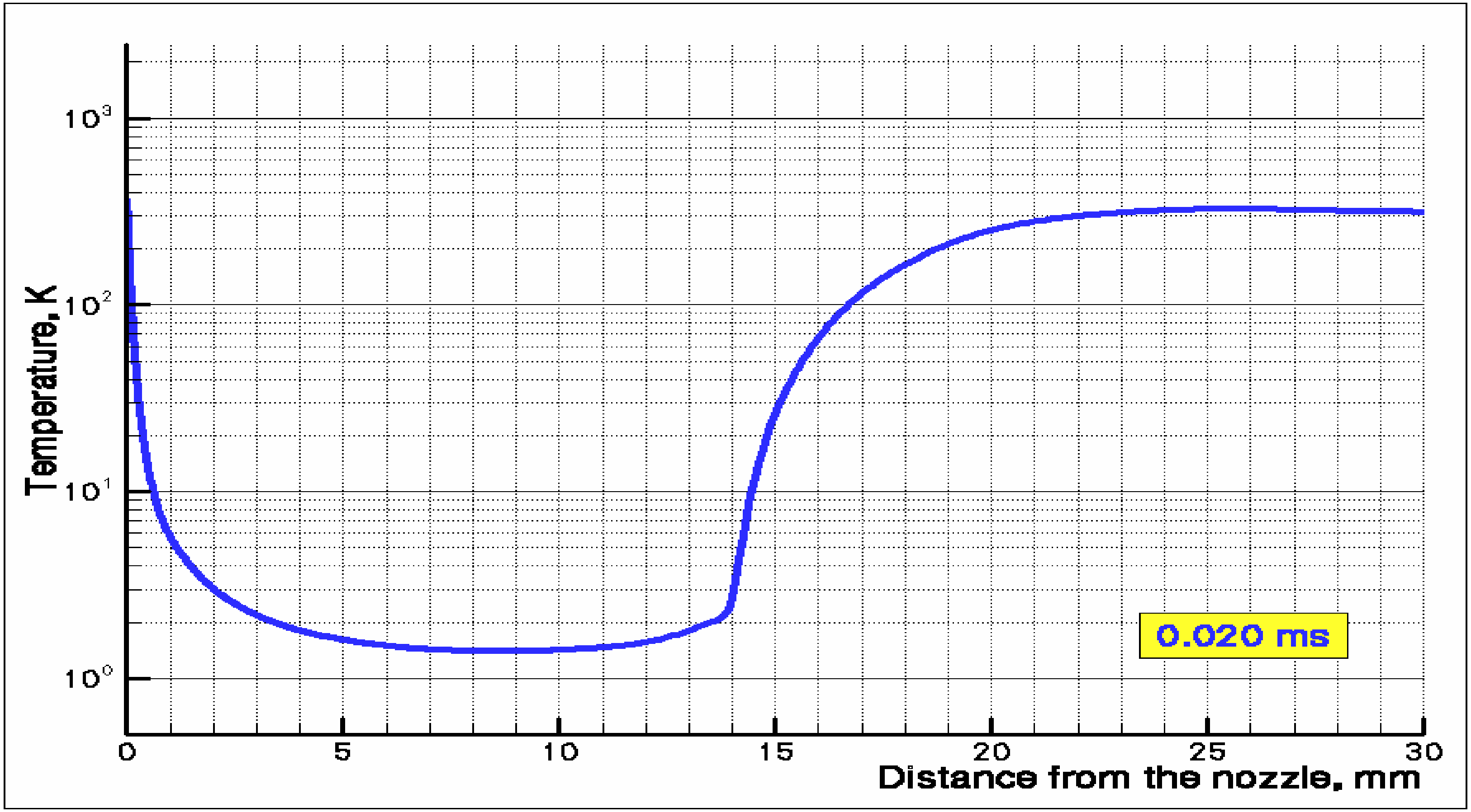
Gas-jet pulse development

Helium gas-jet temperature along the axis



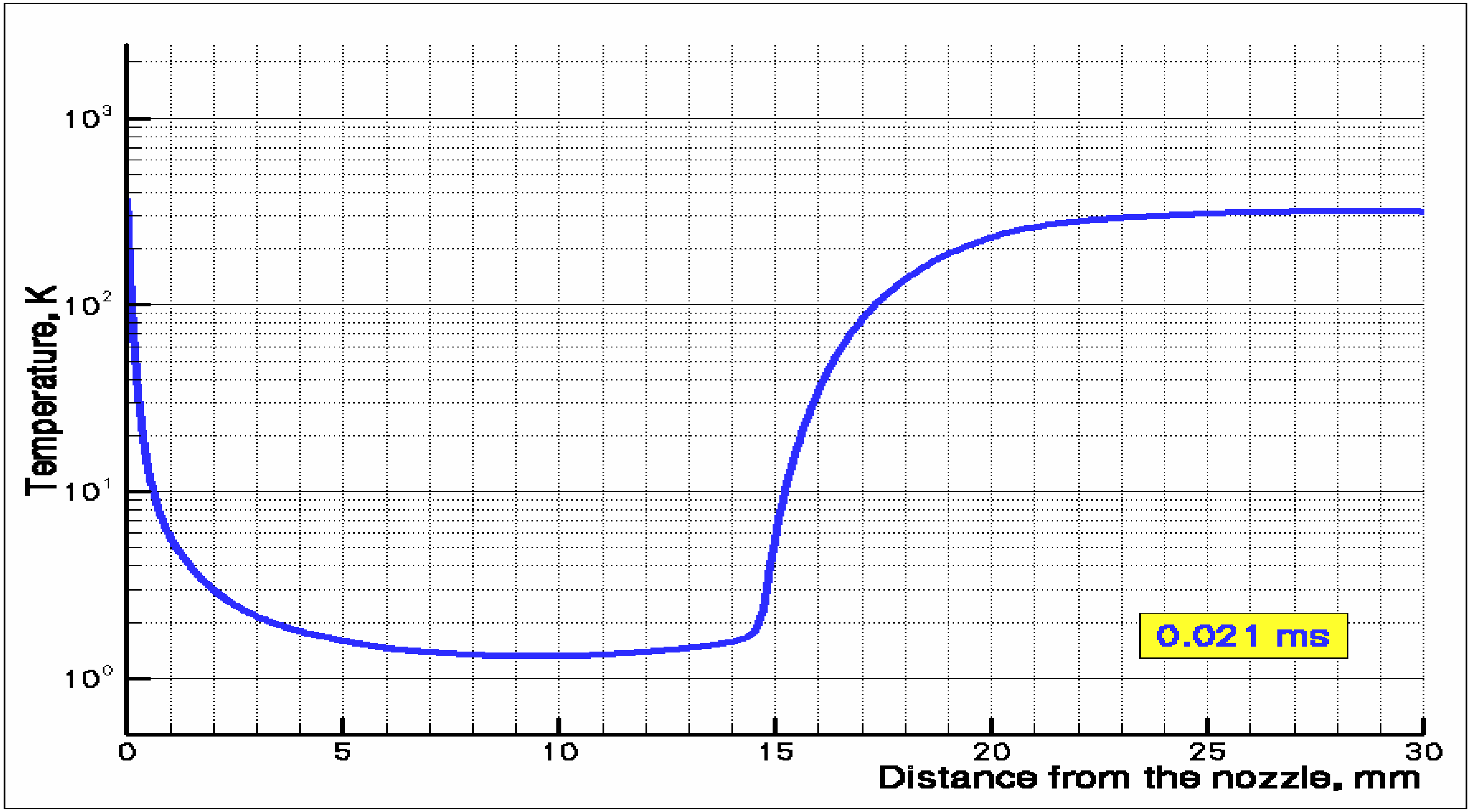
Gas-jet pulse development

Helium gas-jet temperature along the axis



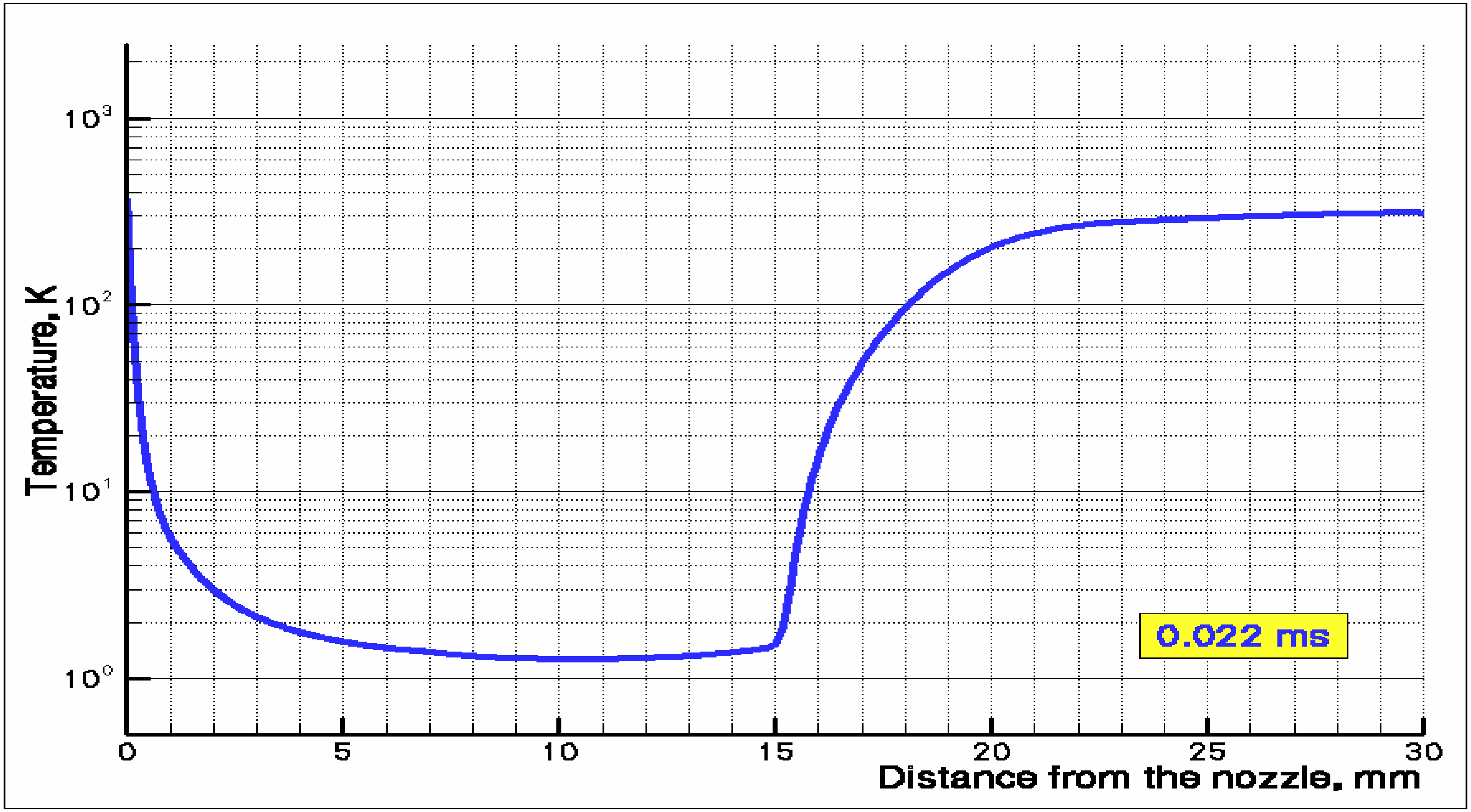
Gas-jet pulse development

Helium gas-jet temperature along the axis



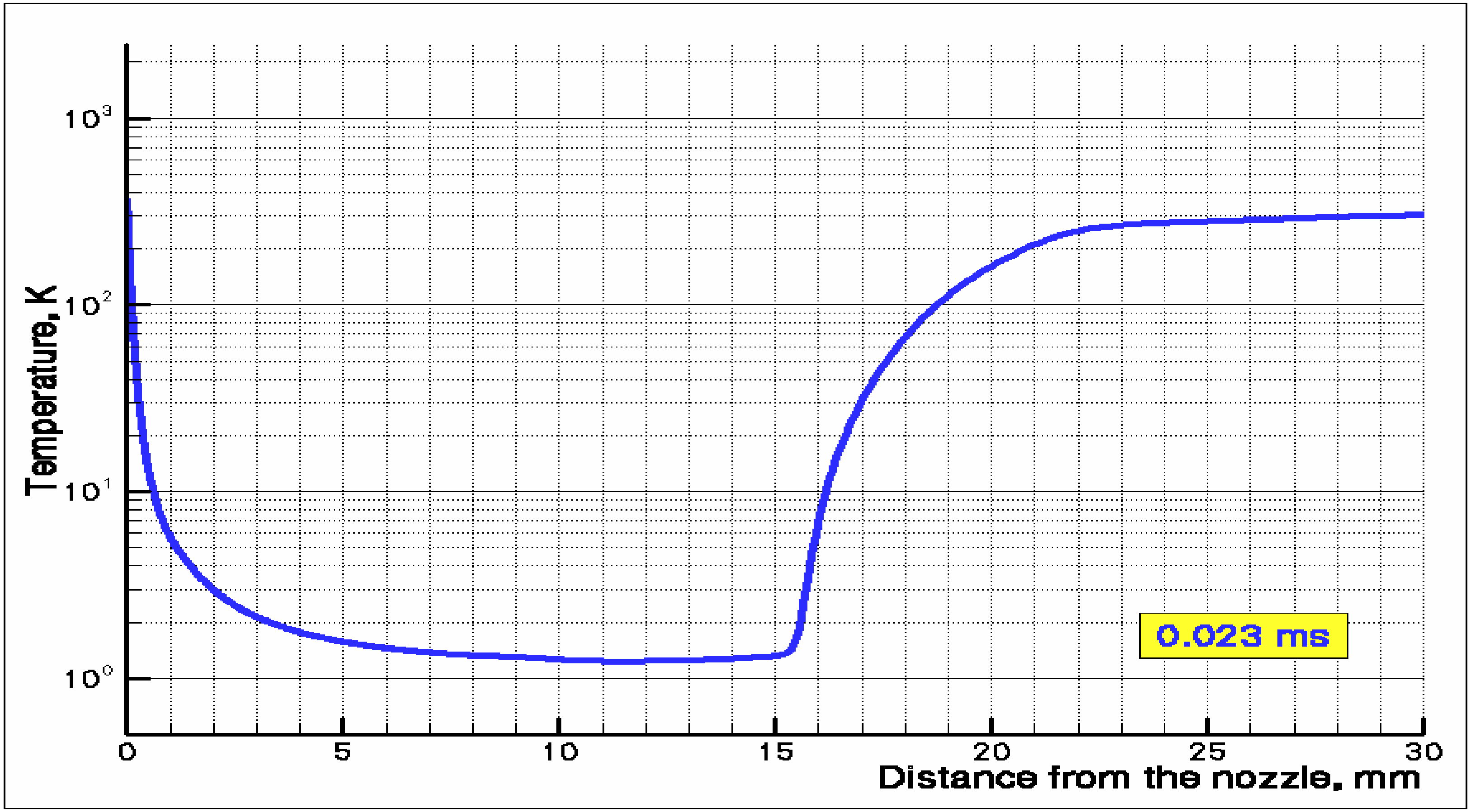
Gas-jet pulse development

Helium gas-jet temperature along the axis



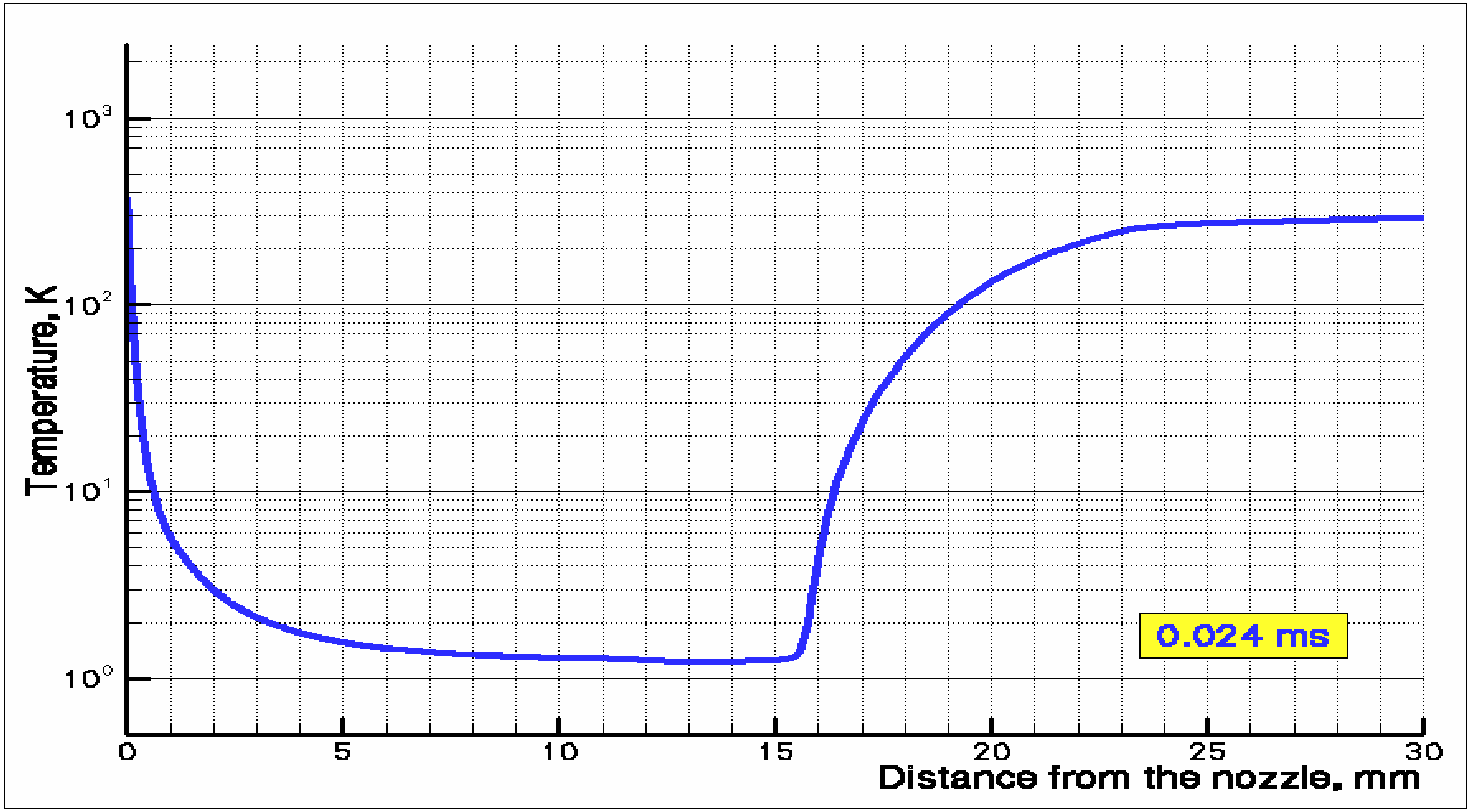
Gas-jet pulse development

Helium gas-jet temperature along the axis



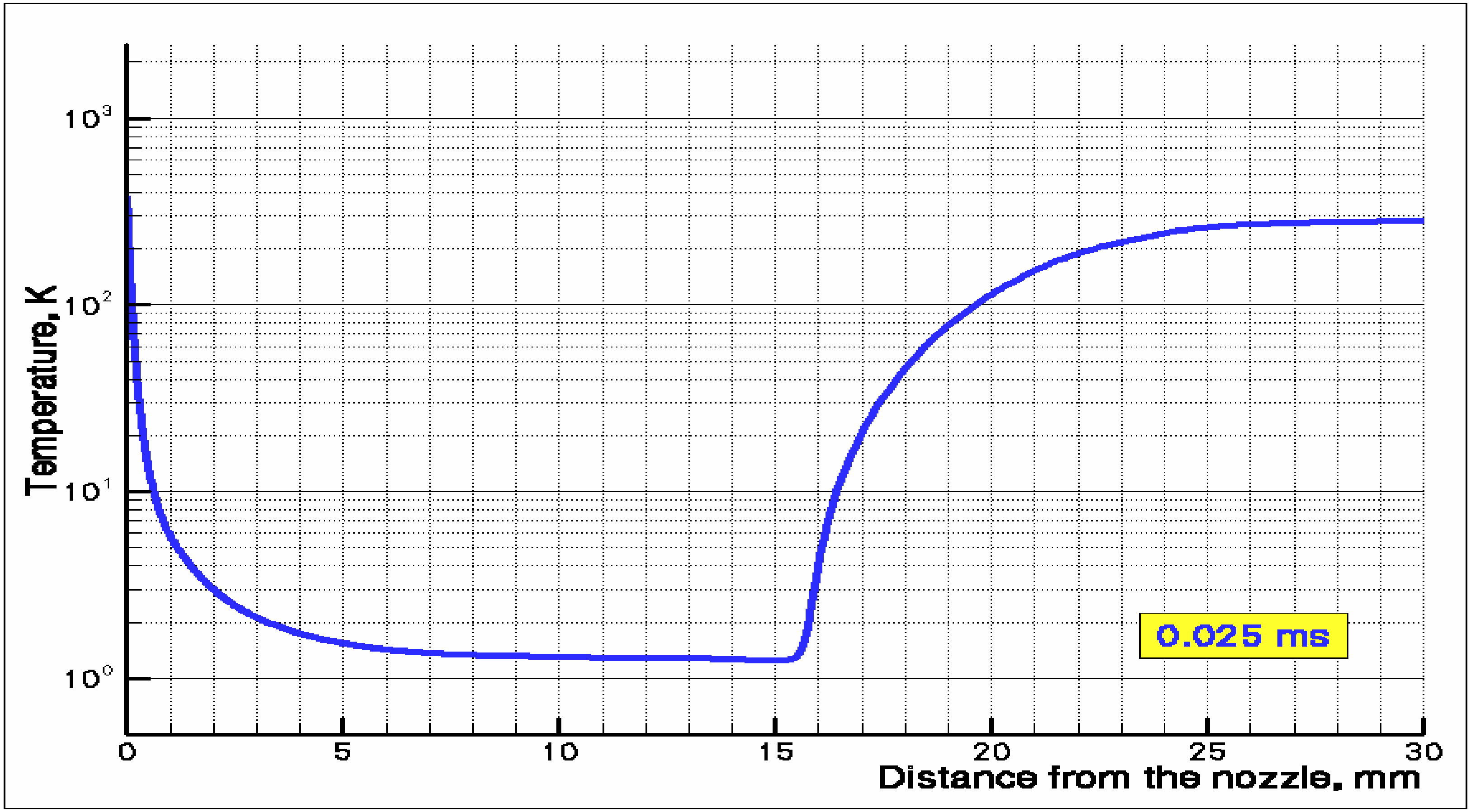
Gas-jet pulse development

Helium gas-jet temperature along the axis



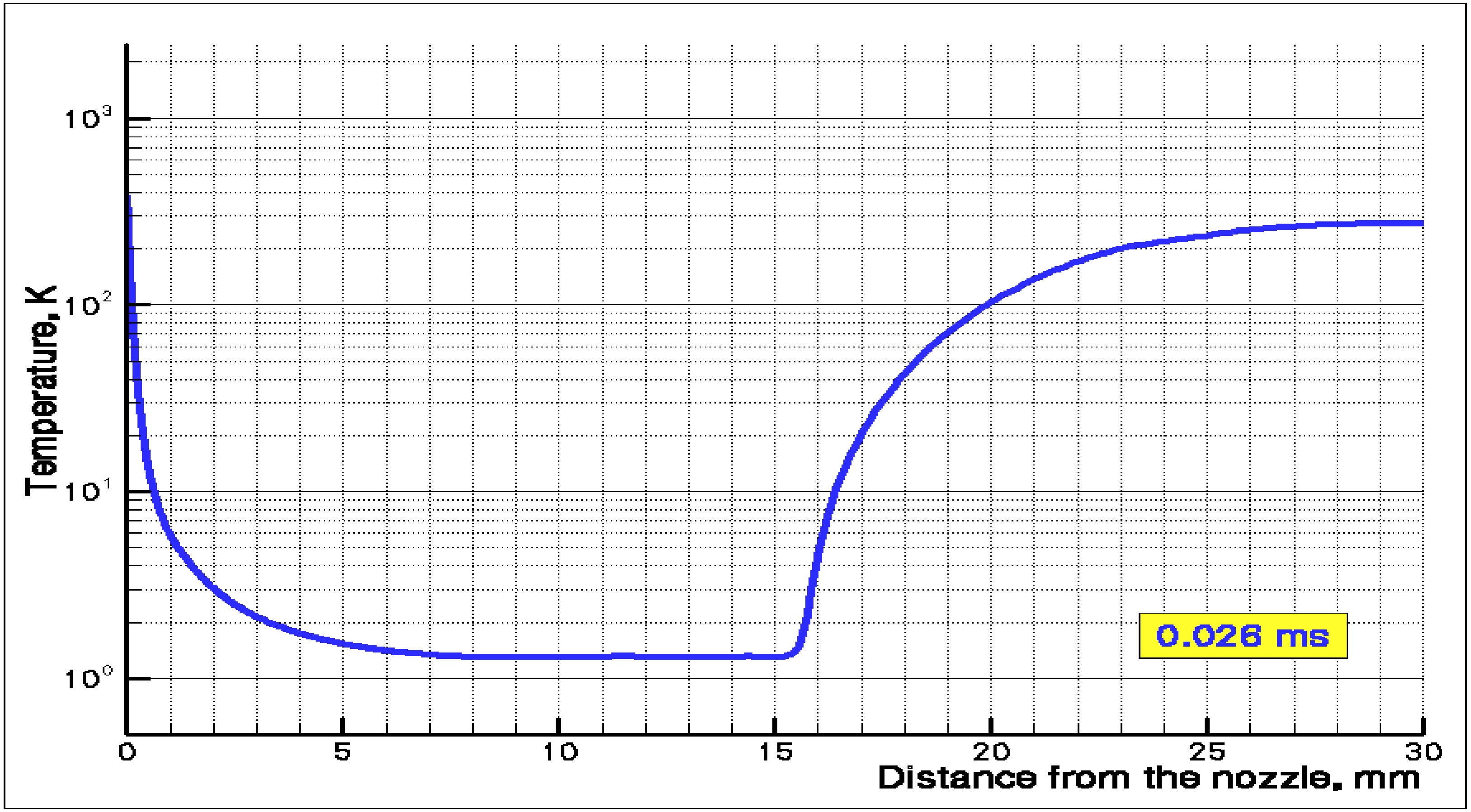
Gas-jet pulse development

Helium gas-jet temperature along the axis



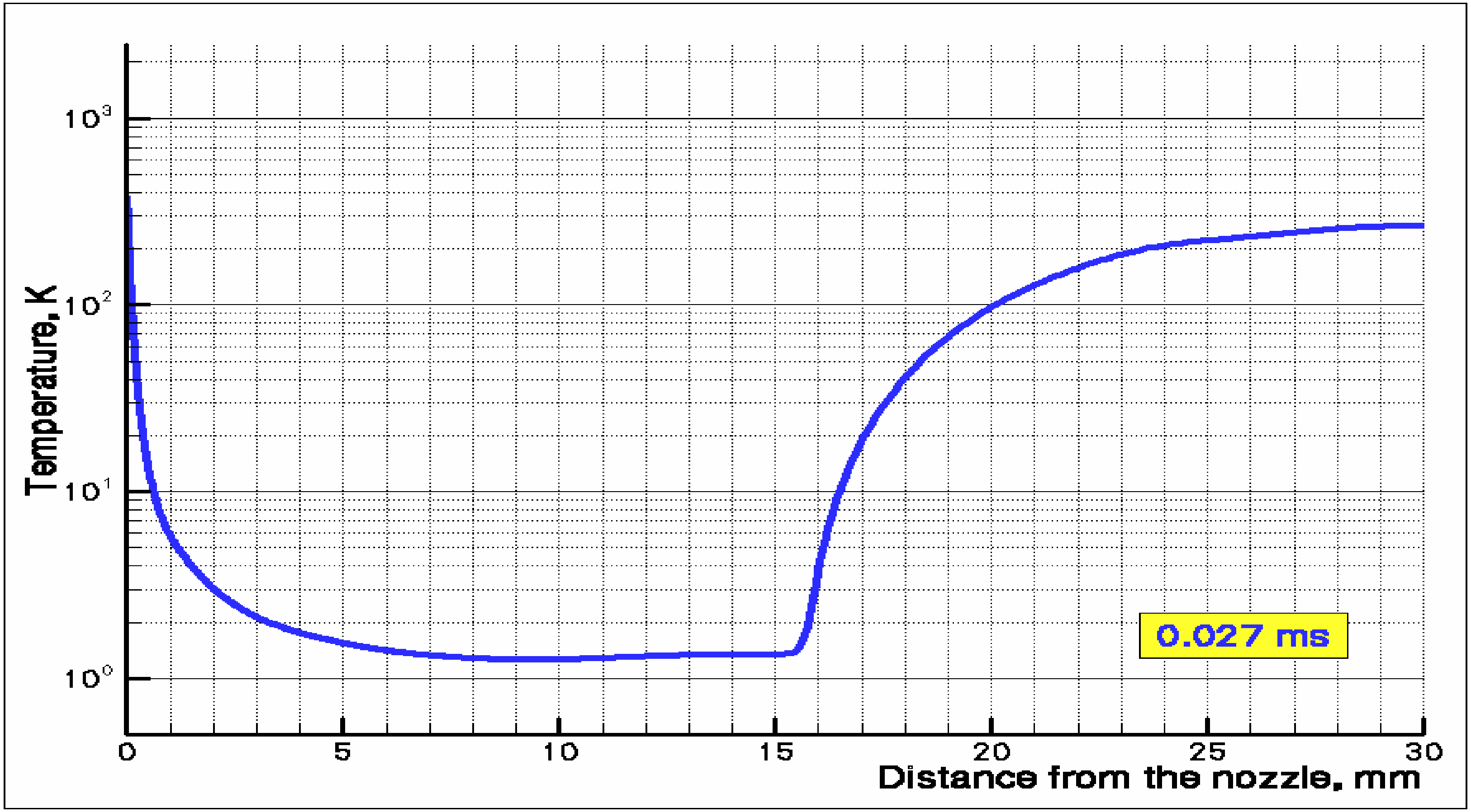
Gas-jet pulse development

Helium gas-jet temperature along the axis



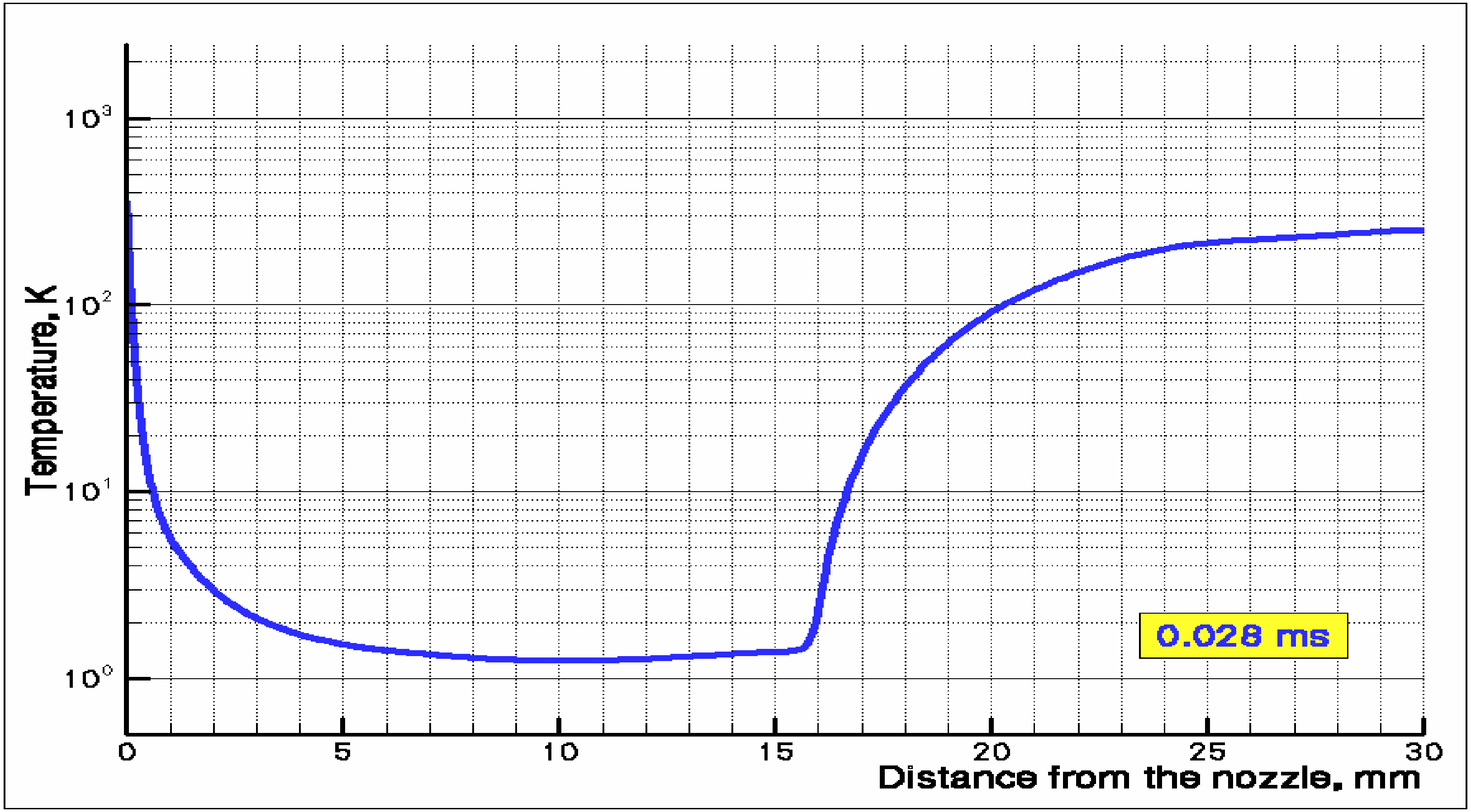
Gas-jet pulse development

Helium gas-jet temperature along the axis



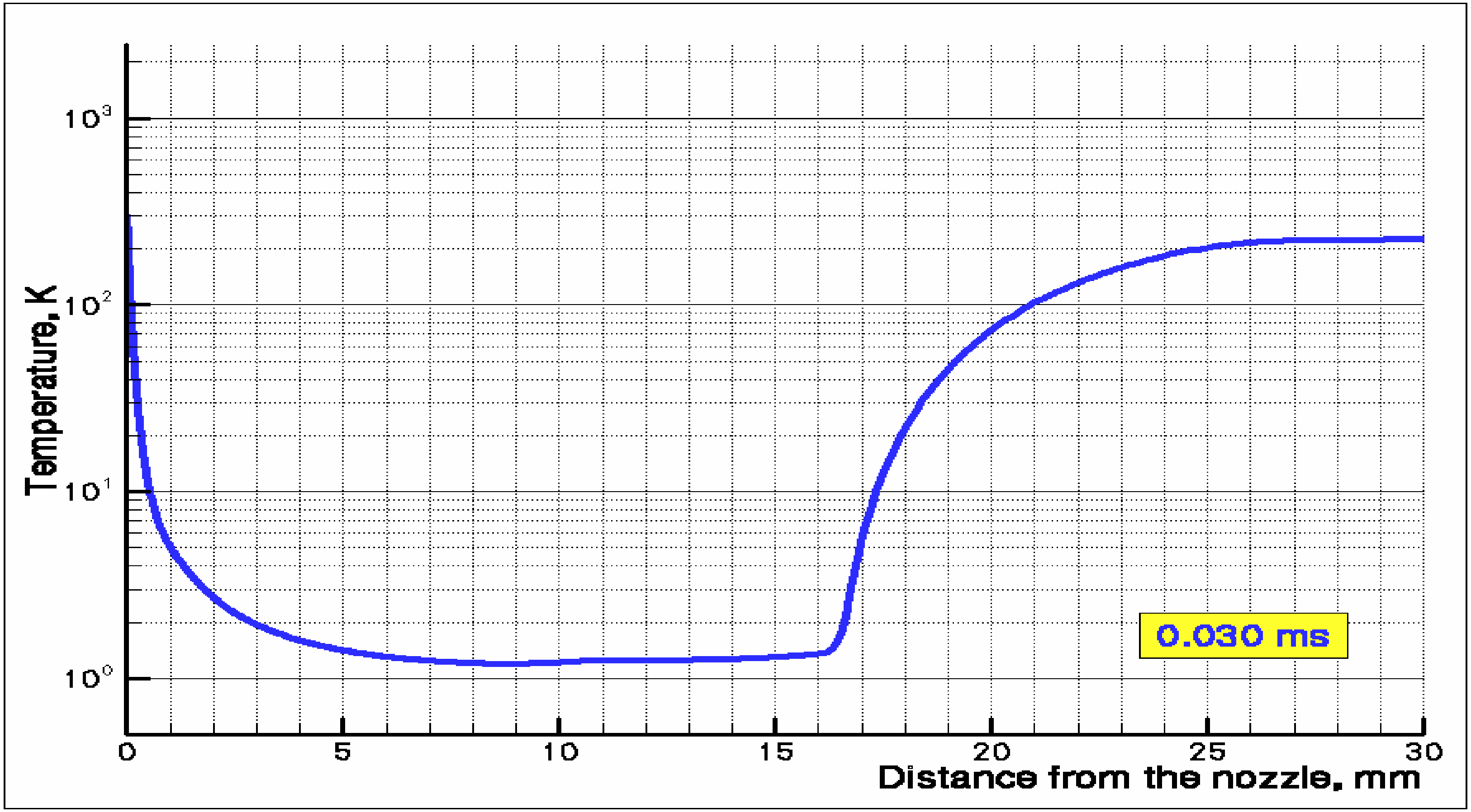
Gas-jet pulse development

Helium gas-jet temperature along the axis



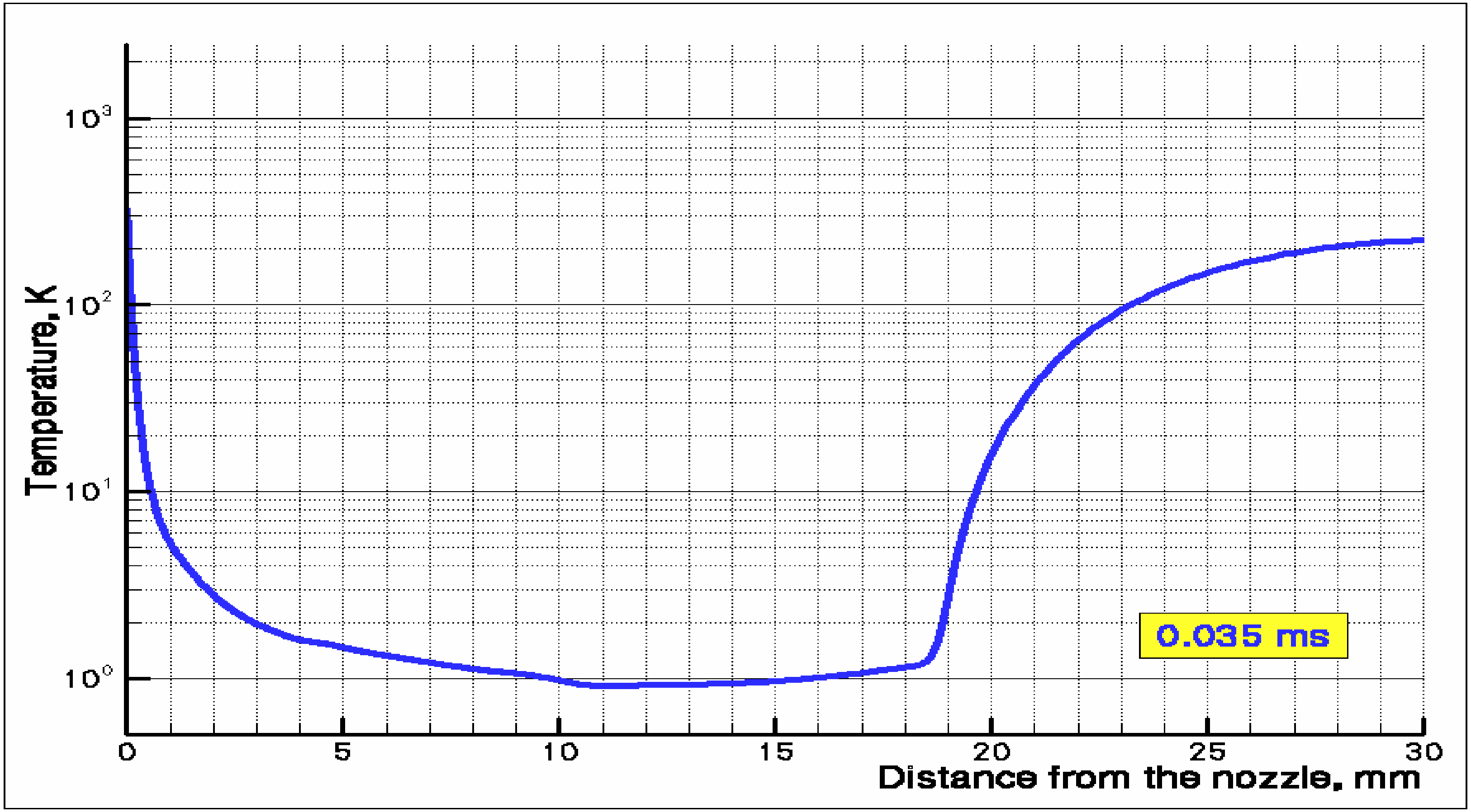
Gas-jet pulse development

Helium gas-jet temperature along the axis



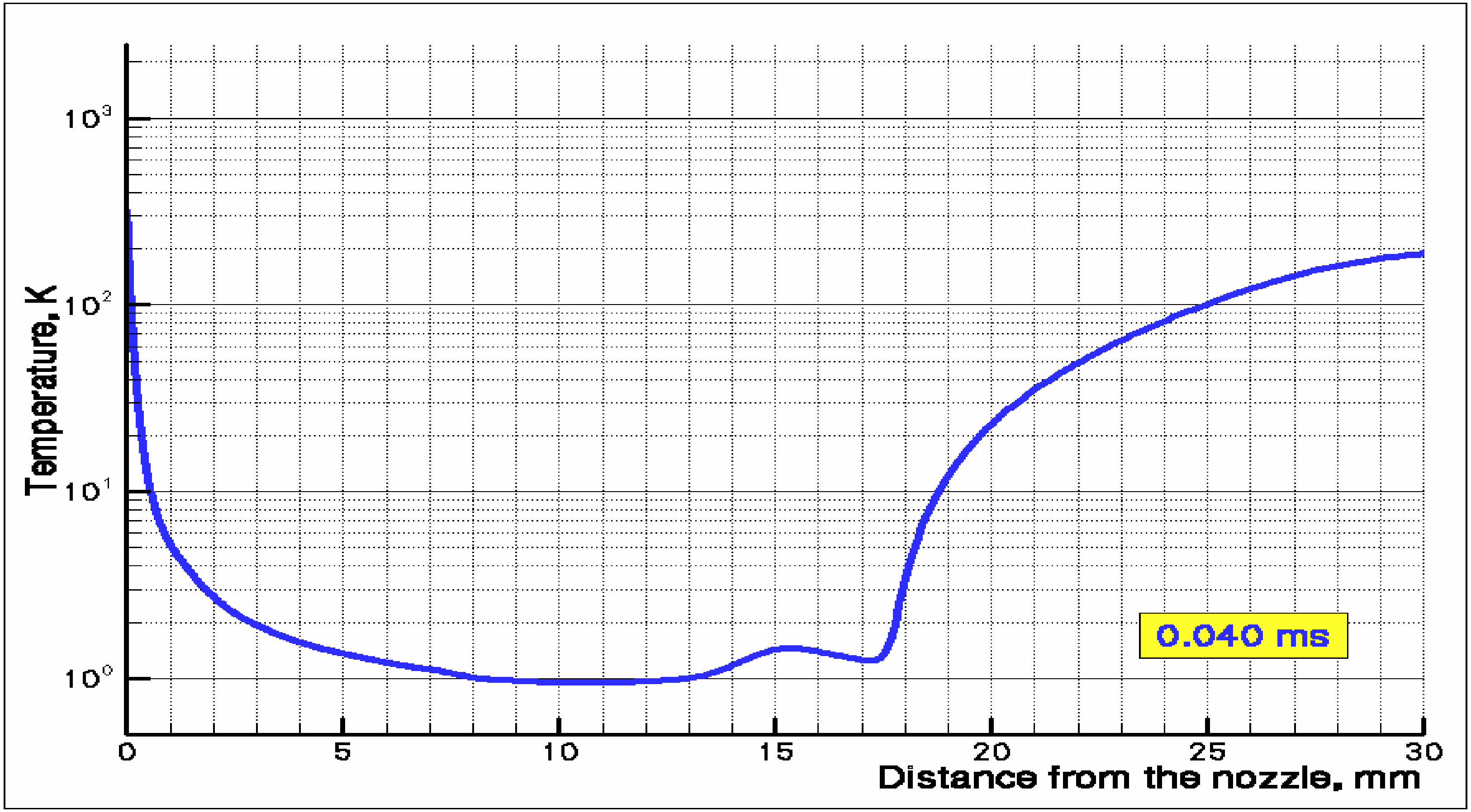
Gas-jet pulse development

Helium gas-jet temperature along the axis



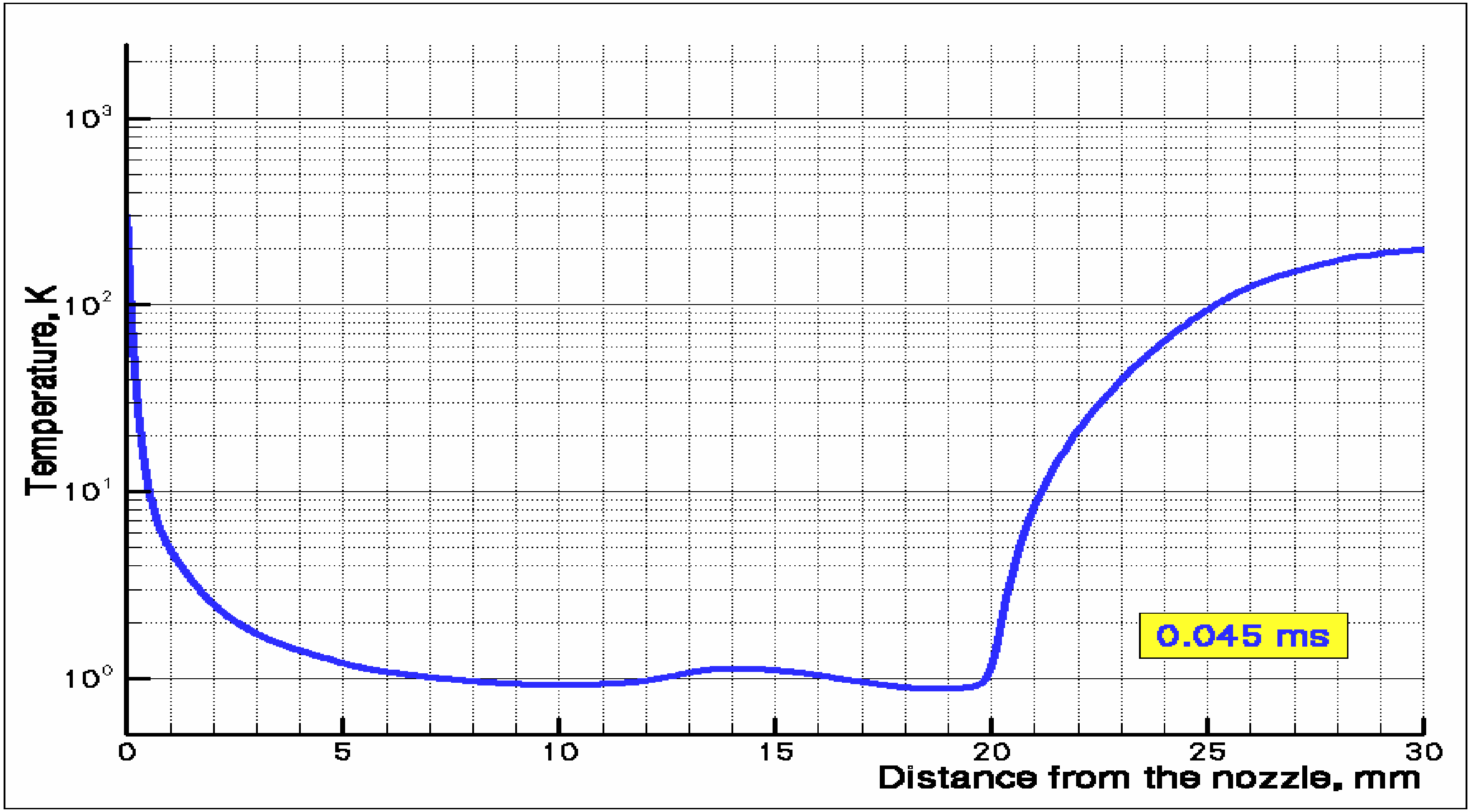
Gas-jet pulse development

Helium gas-jet temperature along the axis



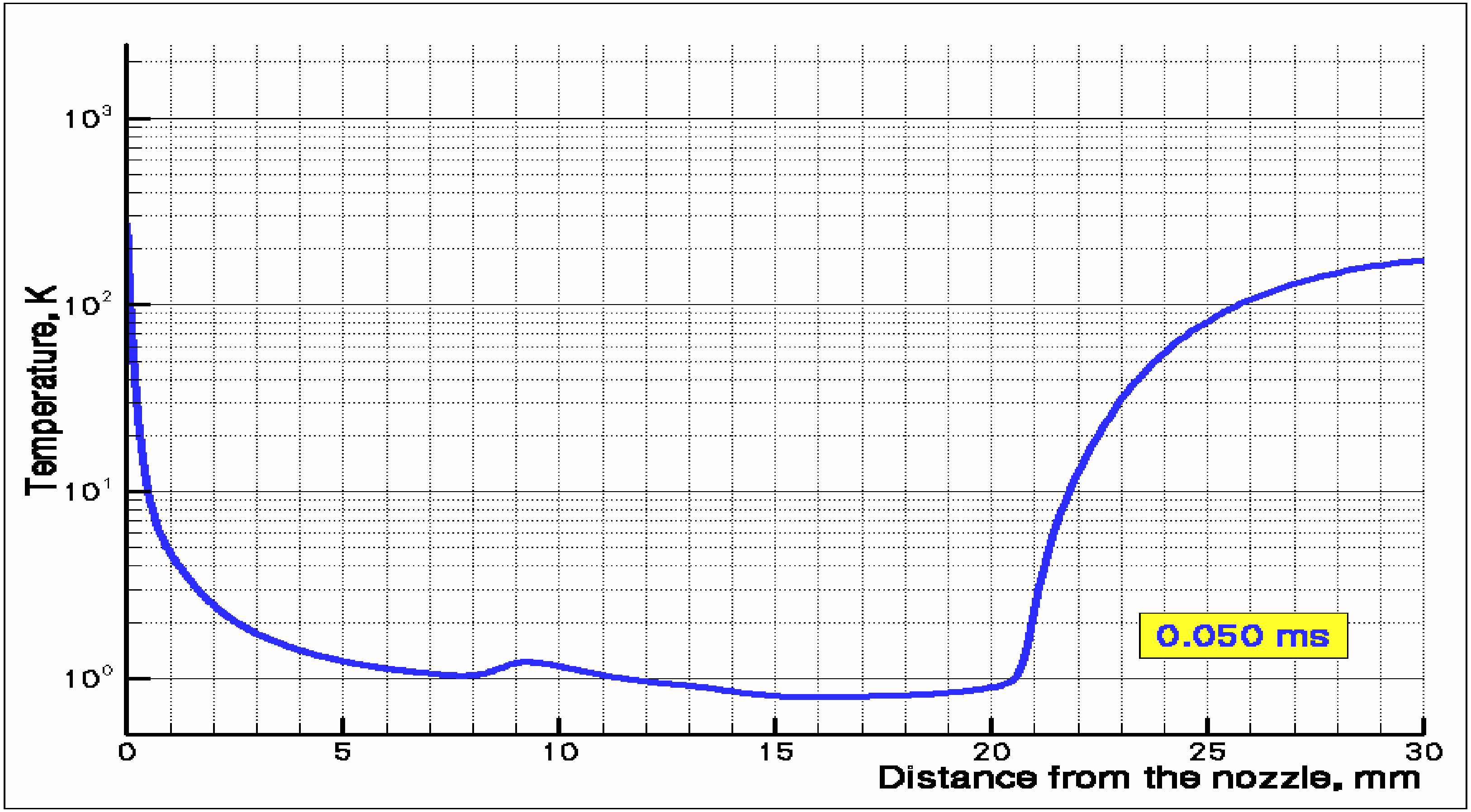
Gas-jet pulse development

Helium gas-jet temperature along the axis



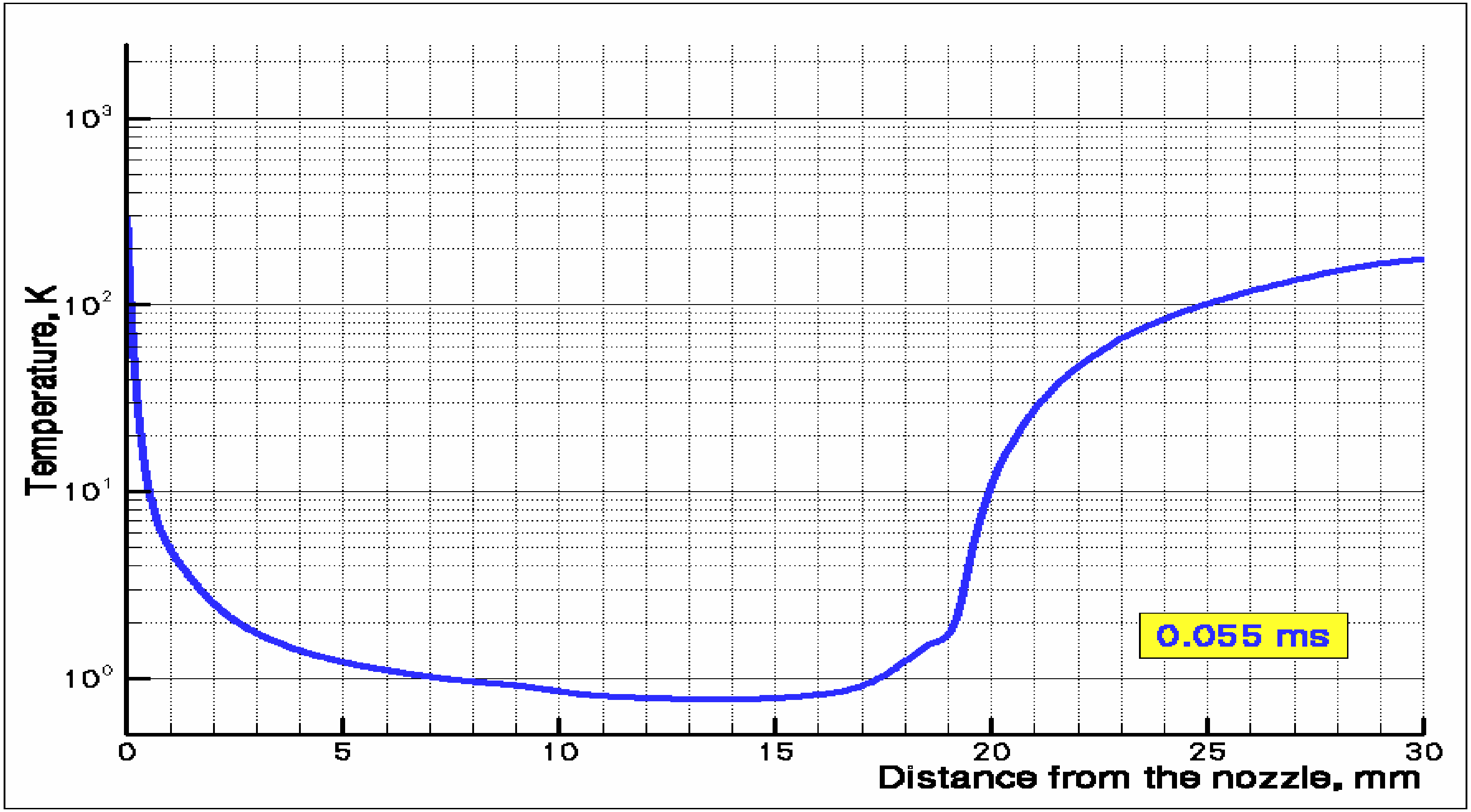
Gas-jet pulse development

Helium gas-jet temperature along the axis



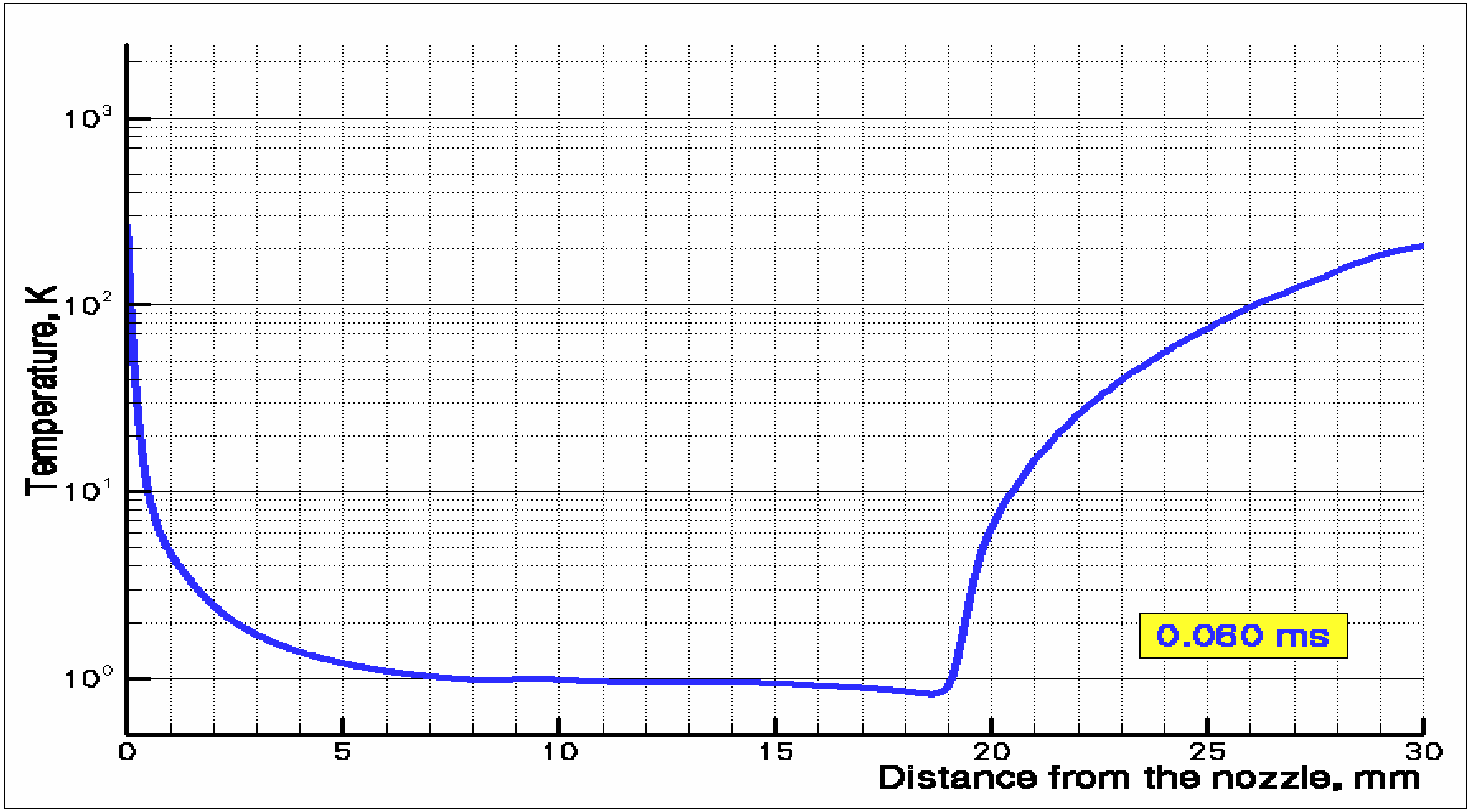
Gas-jet pulse development

Helium gas-jet temperature along the axis



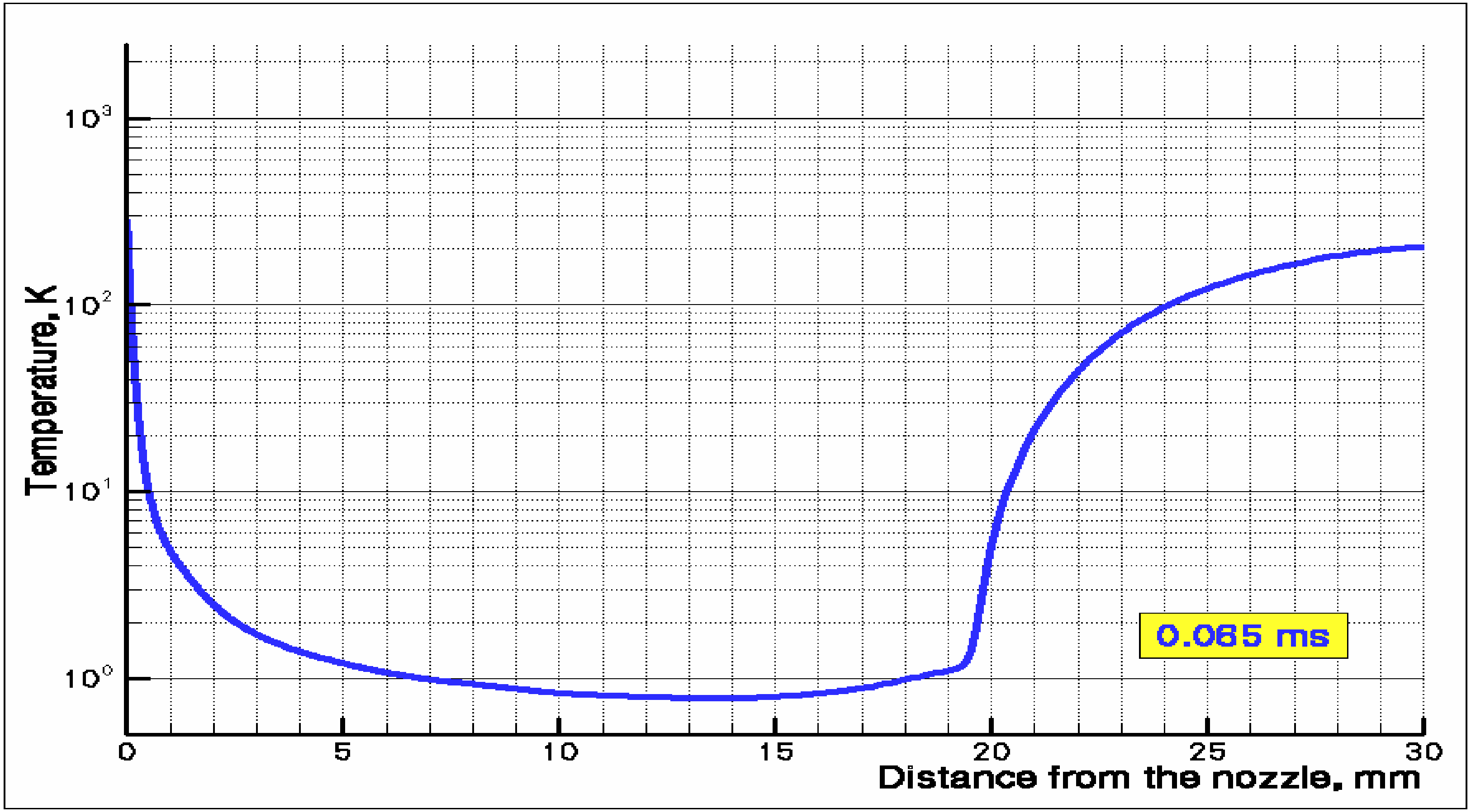
Gas-jet pulse development

Helium gas-jet temperature along the axis



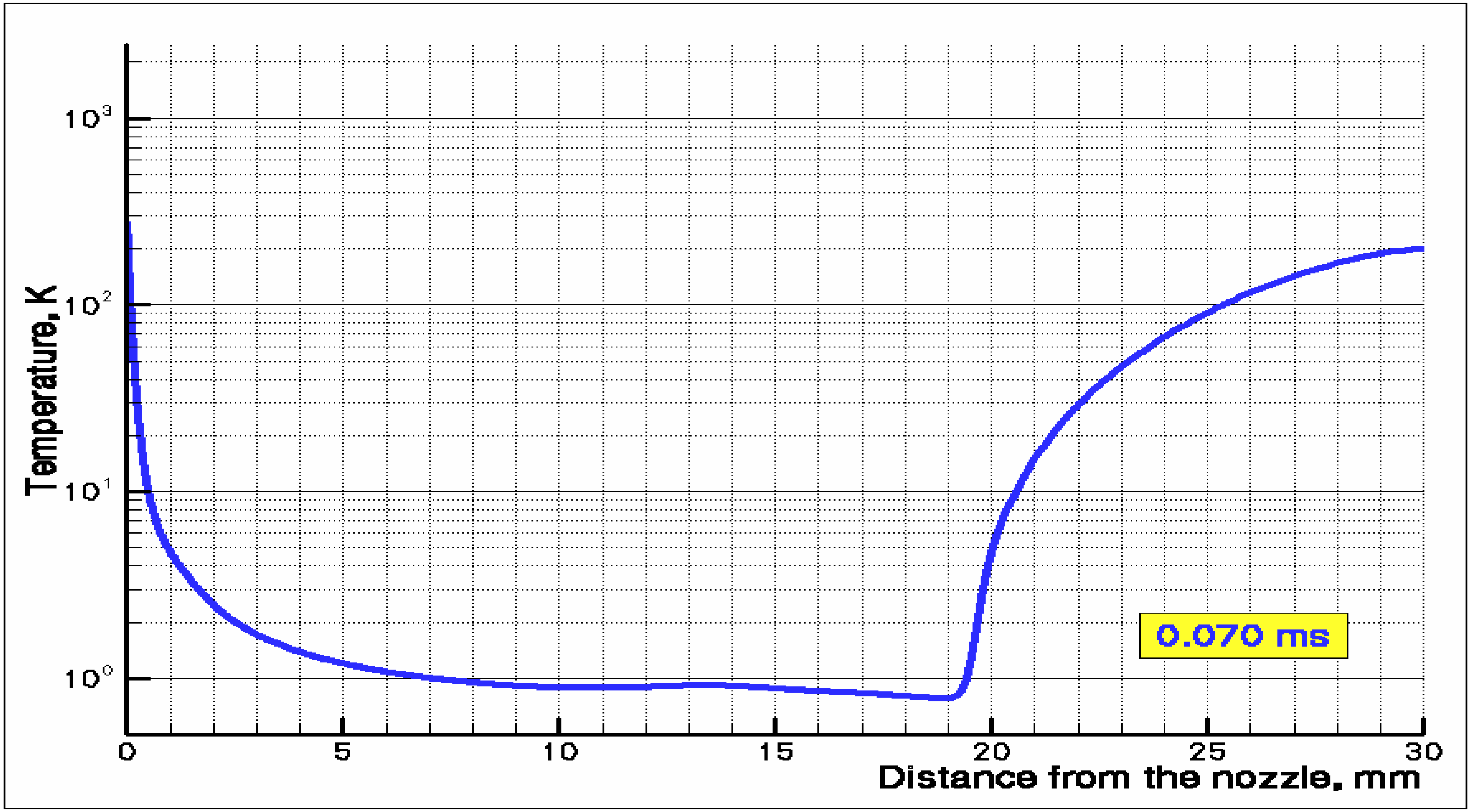
Gas-jet pulse development

Helium gas-jet temperature along the axis



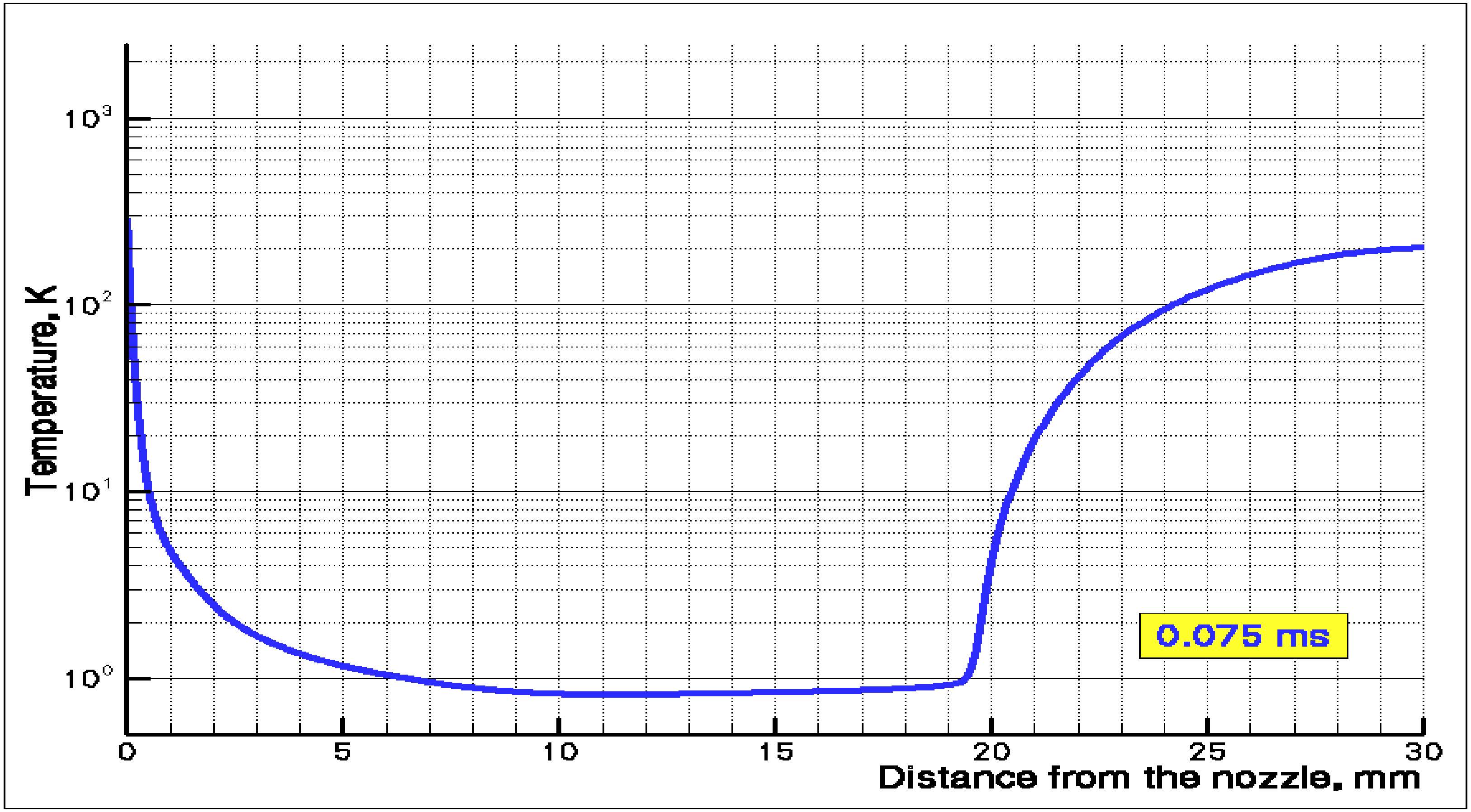
Gas-jet pulse development

Helium gas-jet temperature along the axis



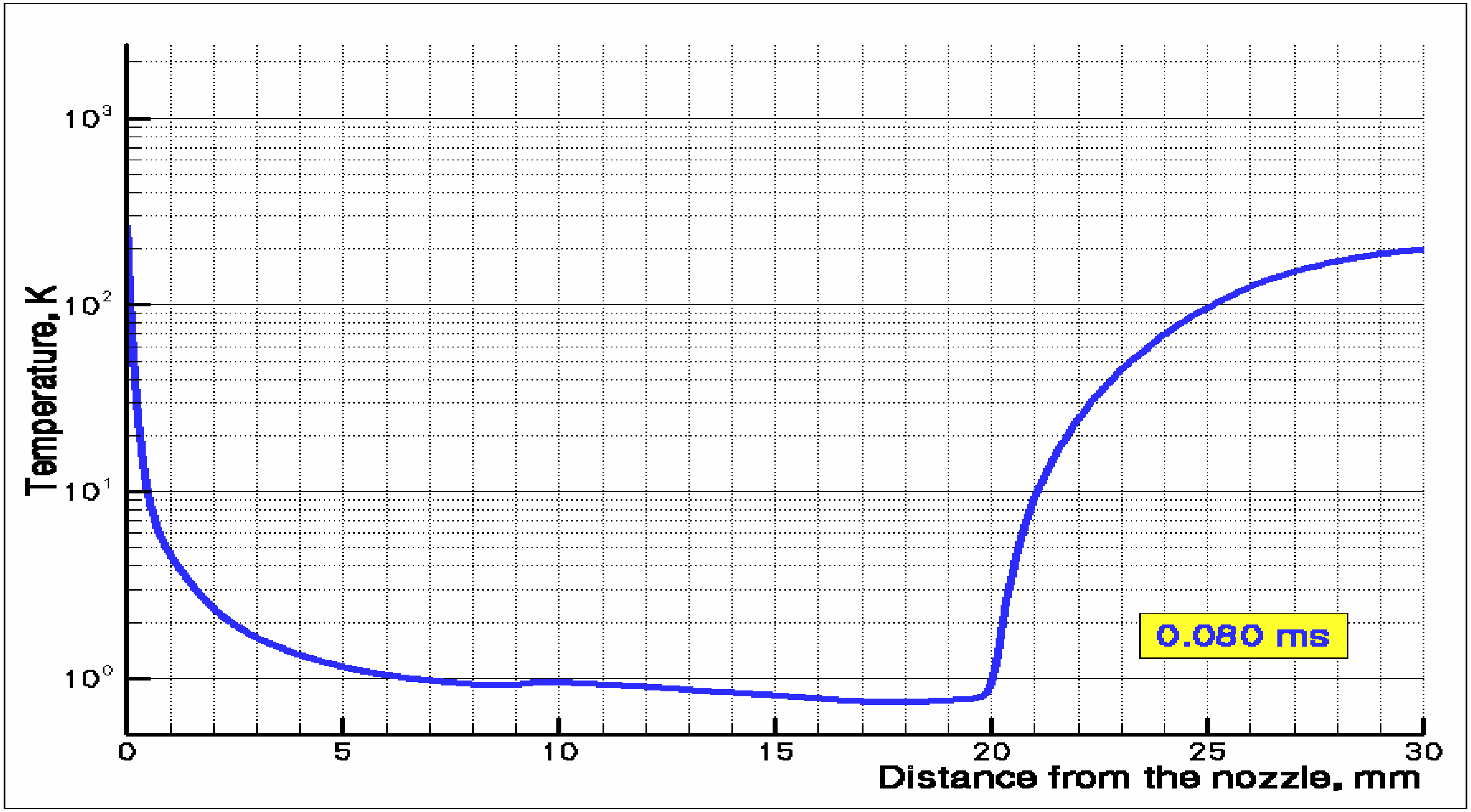
Gas-jet pulse development

Helium gas-jet temperature along the axis



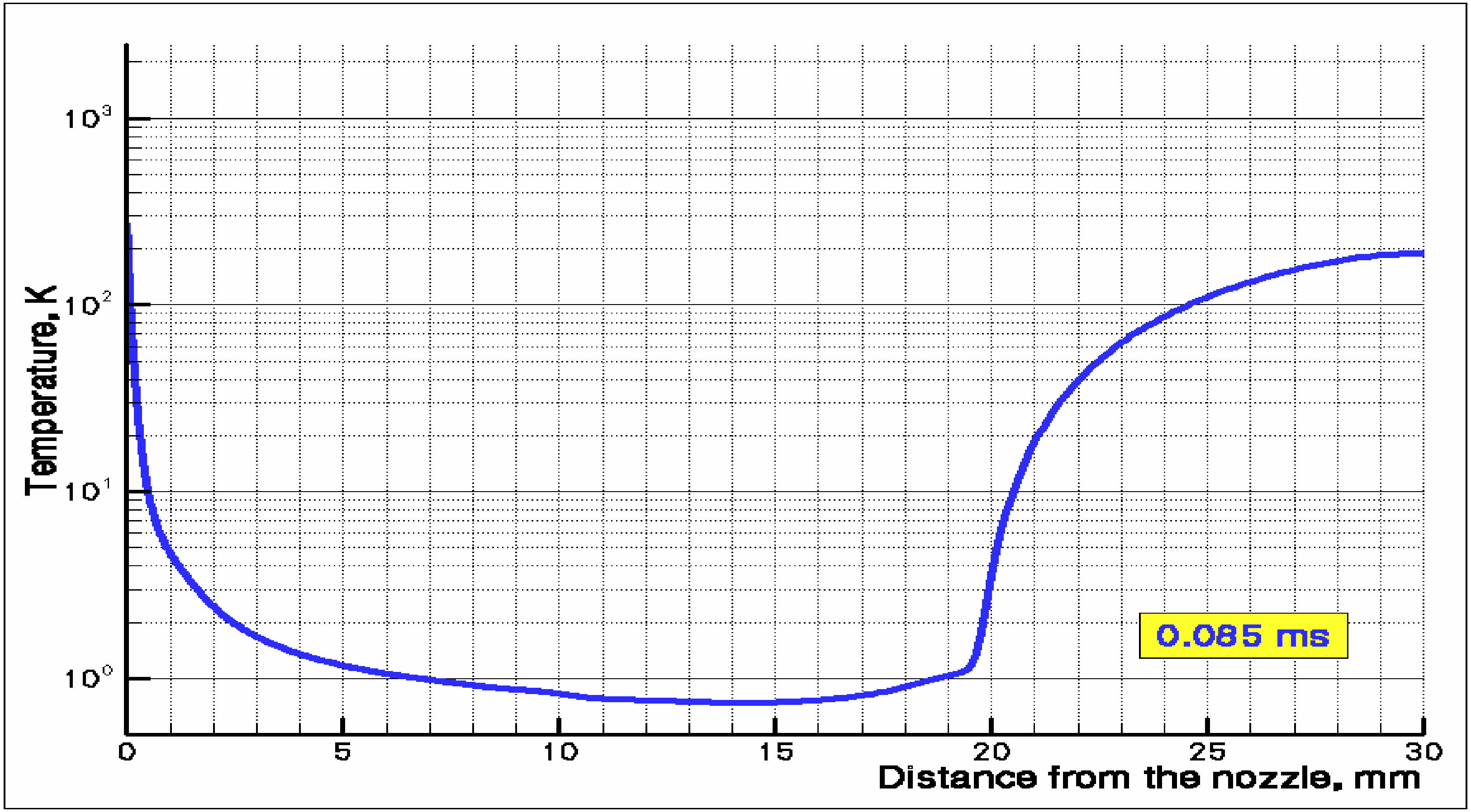
Gas-jet pulse development

Helium gas-jet temperature along the axis



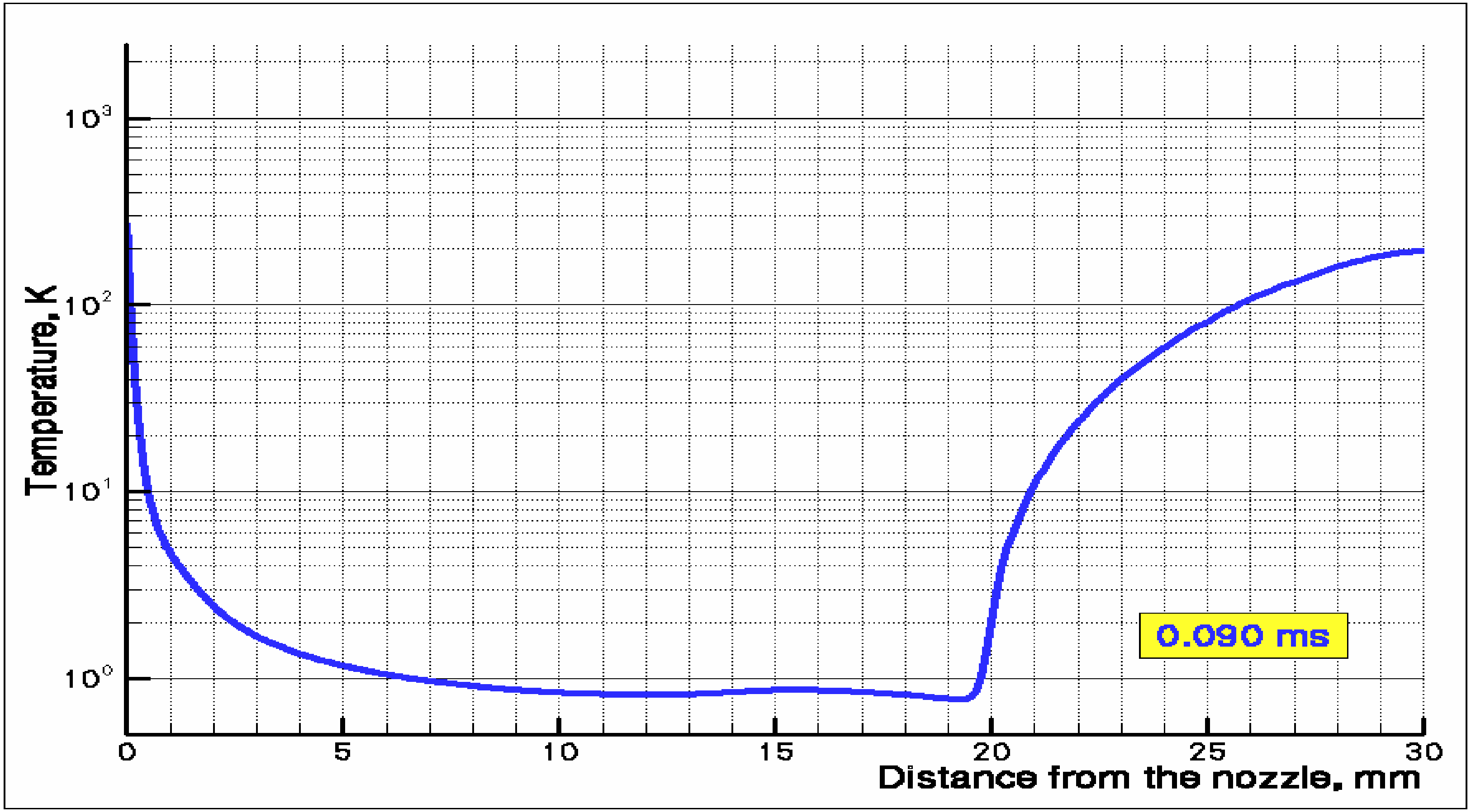
Gas-jet pulse development

Helium gas-jet temperature along the axis



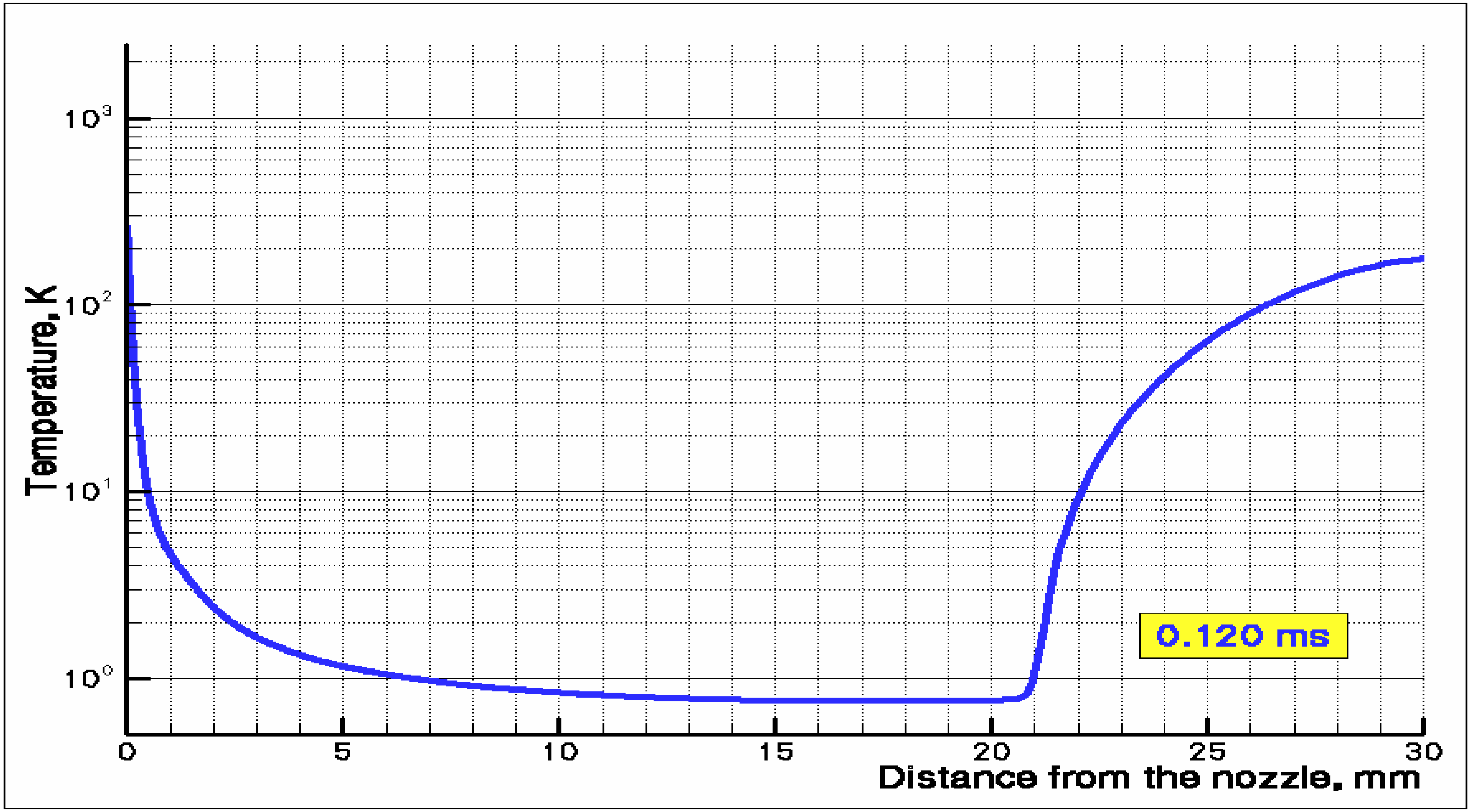
Gas-jet pulse development

Helium gas-jet temperature along the axis



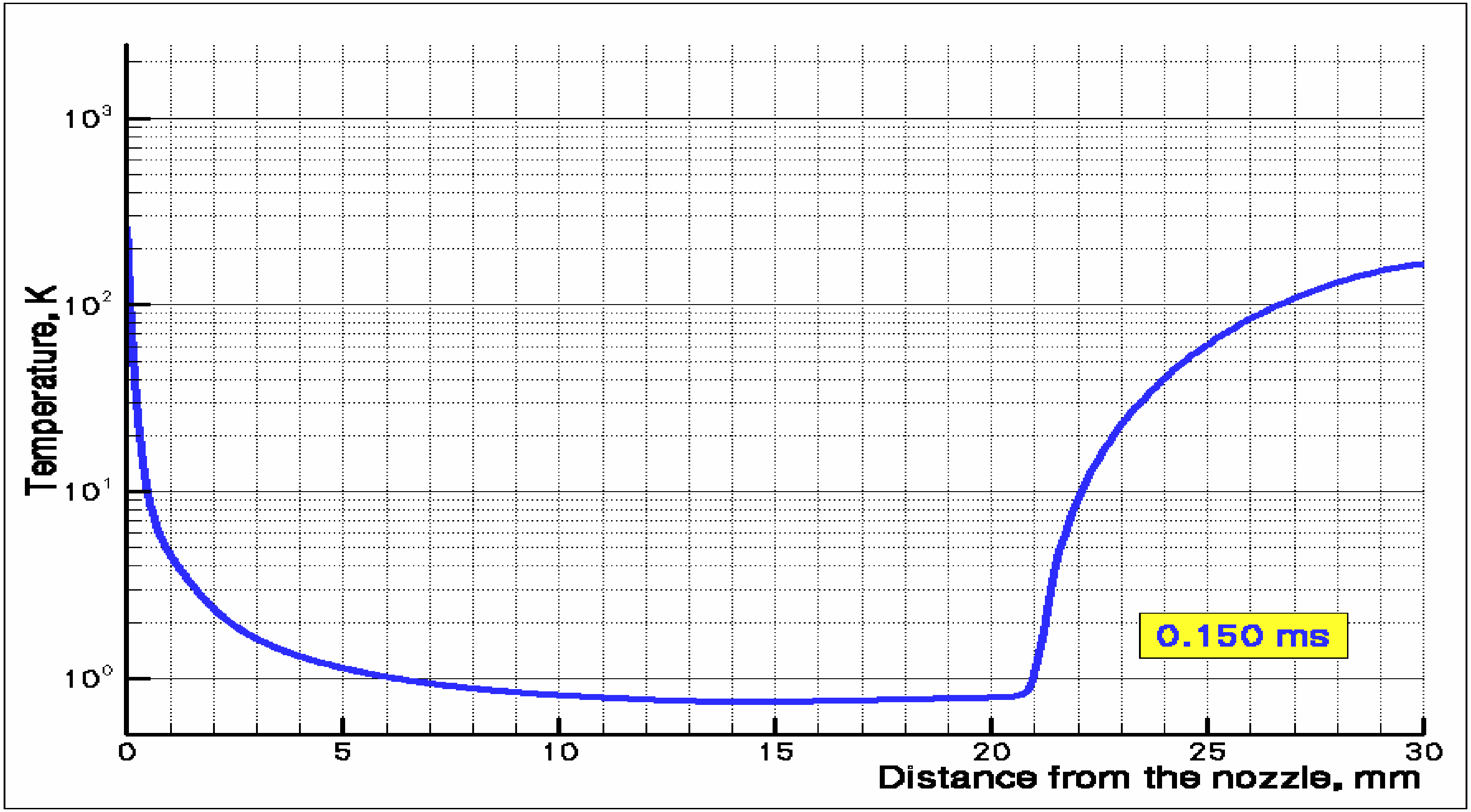
Gas-jet pulse development

Helium gas-jet temperature along the axis



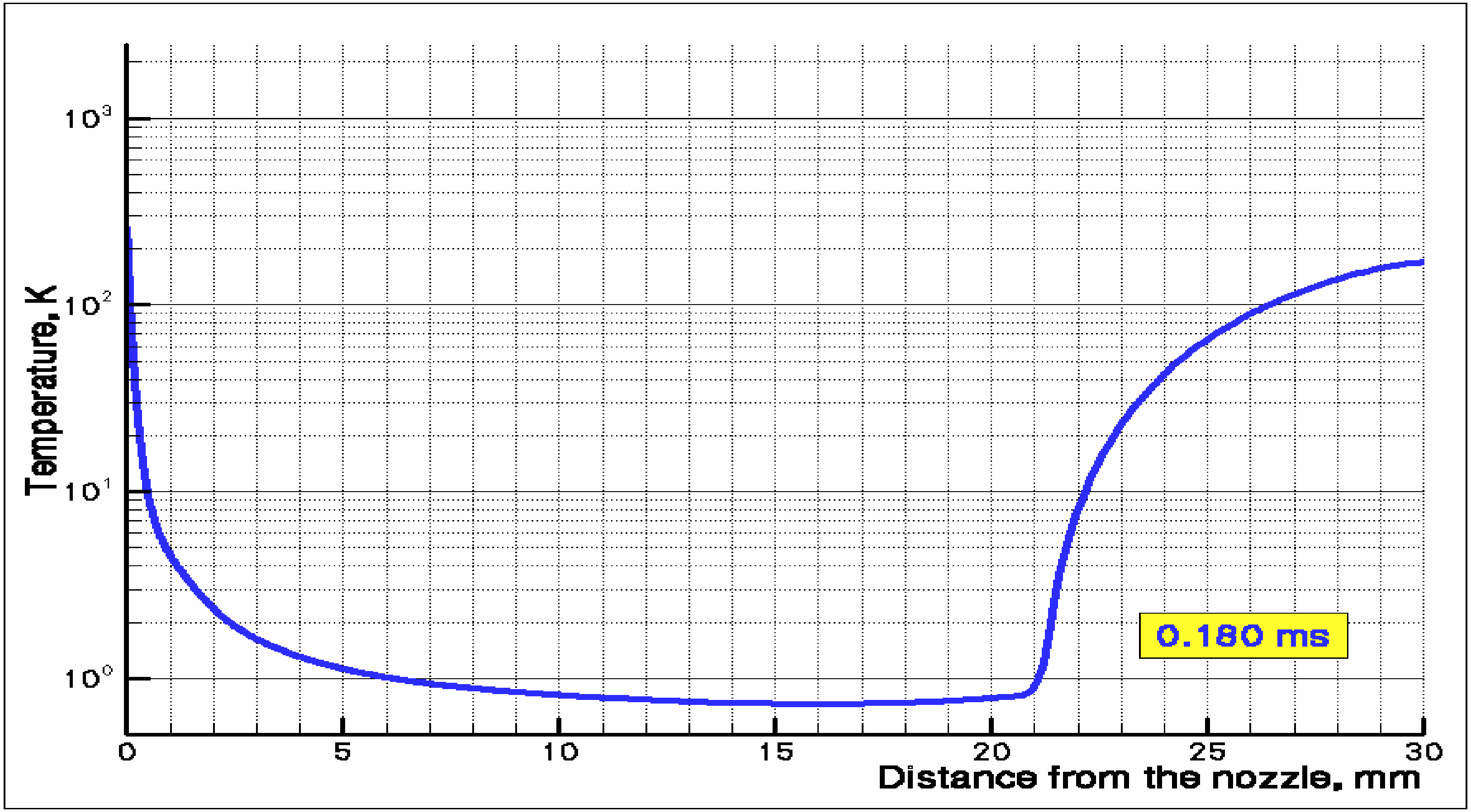
Gas-jet pulse development

Helium gas-jet temperature along the axis



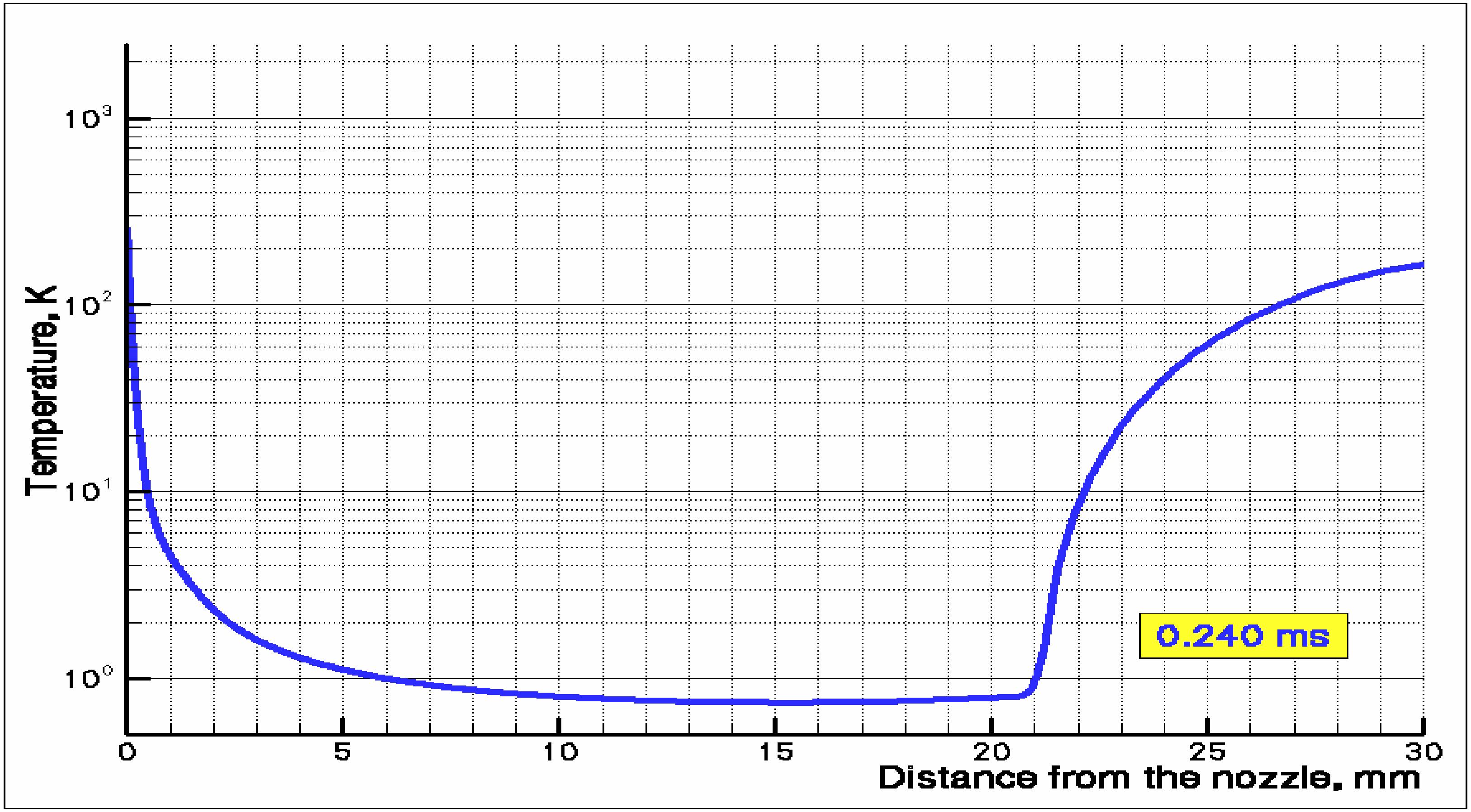
Gas-jet pulse development

Helium gas-jet temperature along the axis



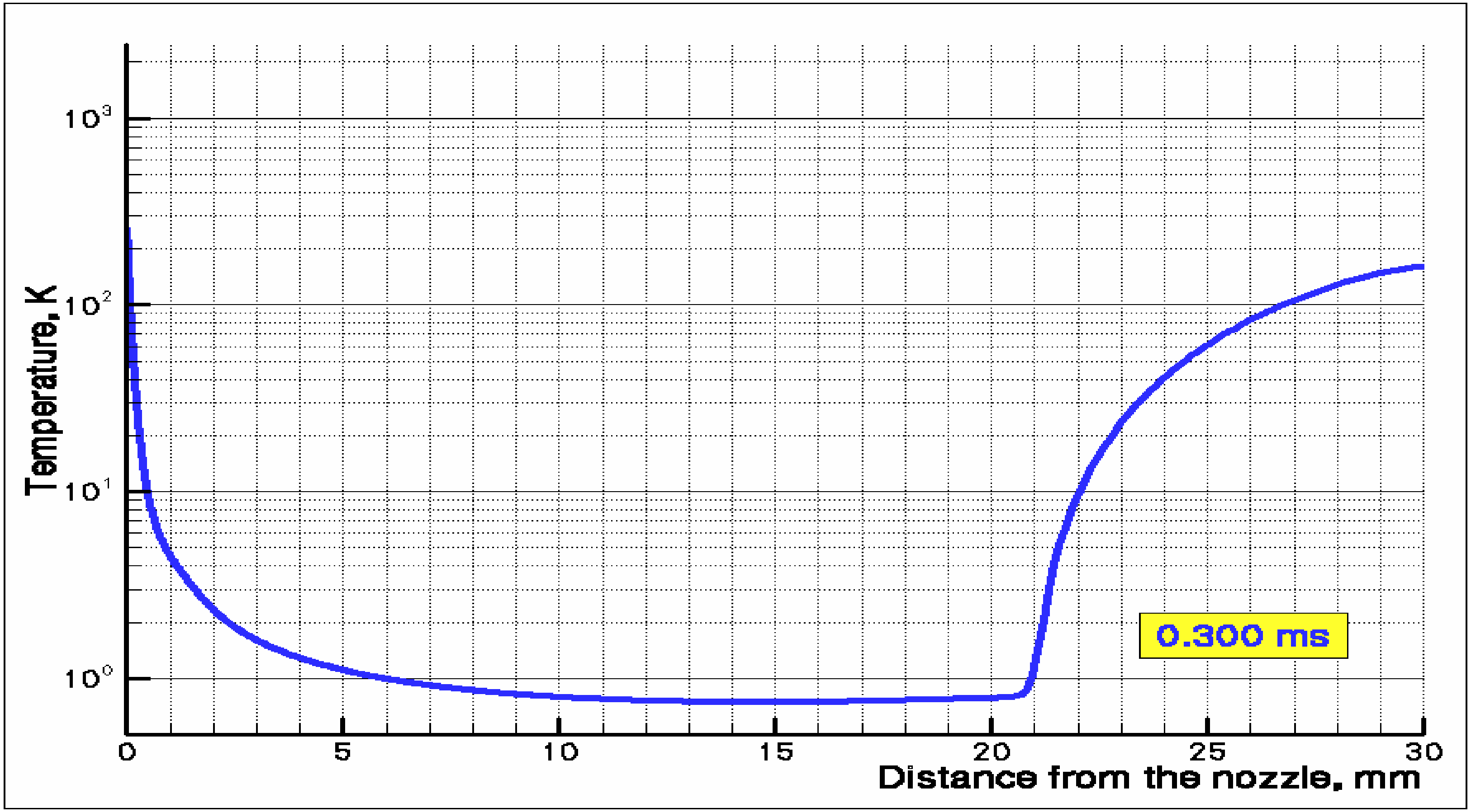
Gas-jet pulse development

Helium gas-jet temperature along the axis



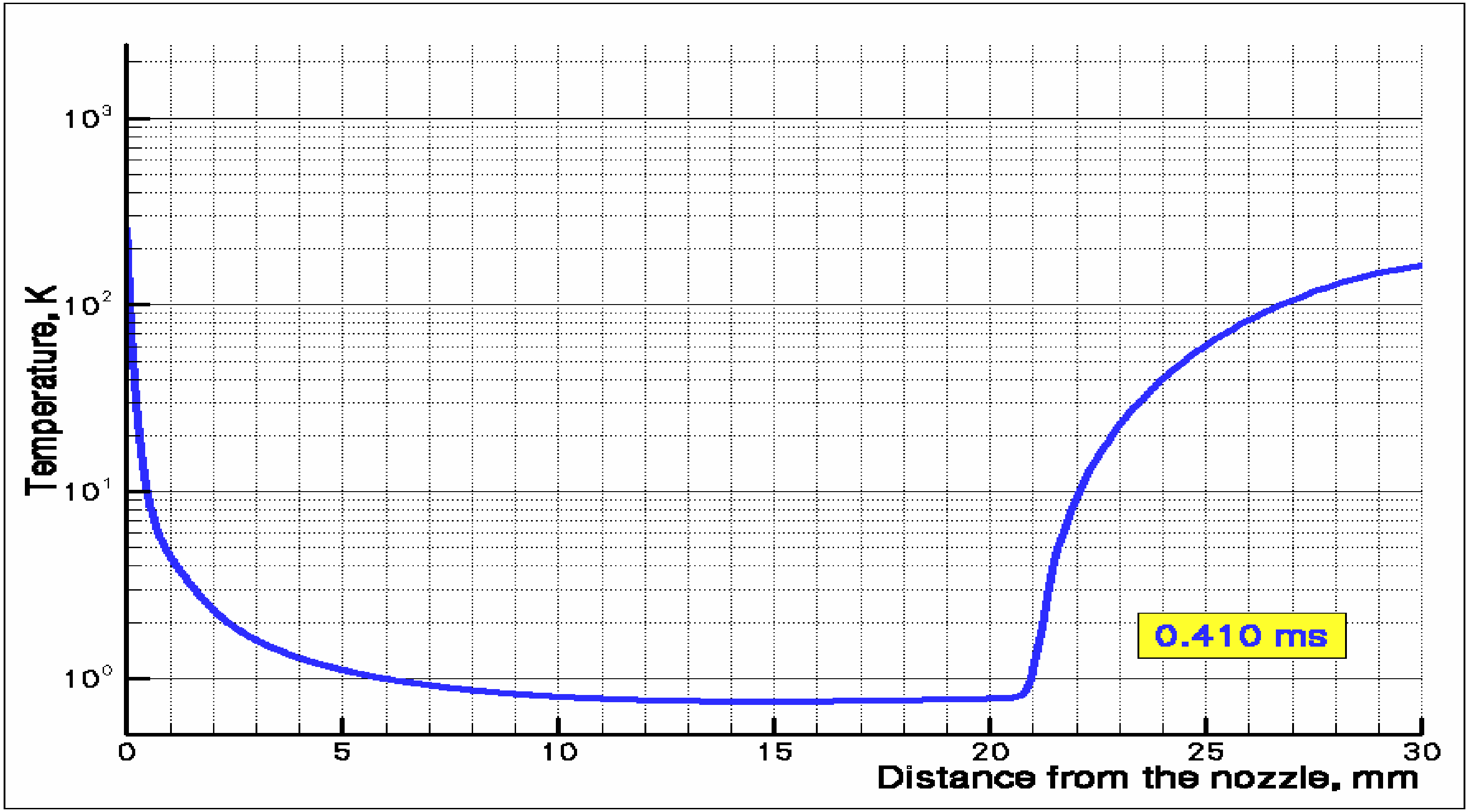
Gas-jet pulse development

Helium gas-jet temperature along the axis



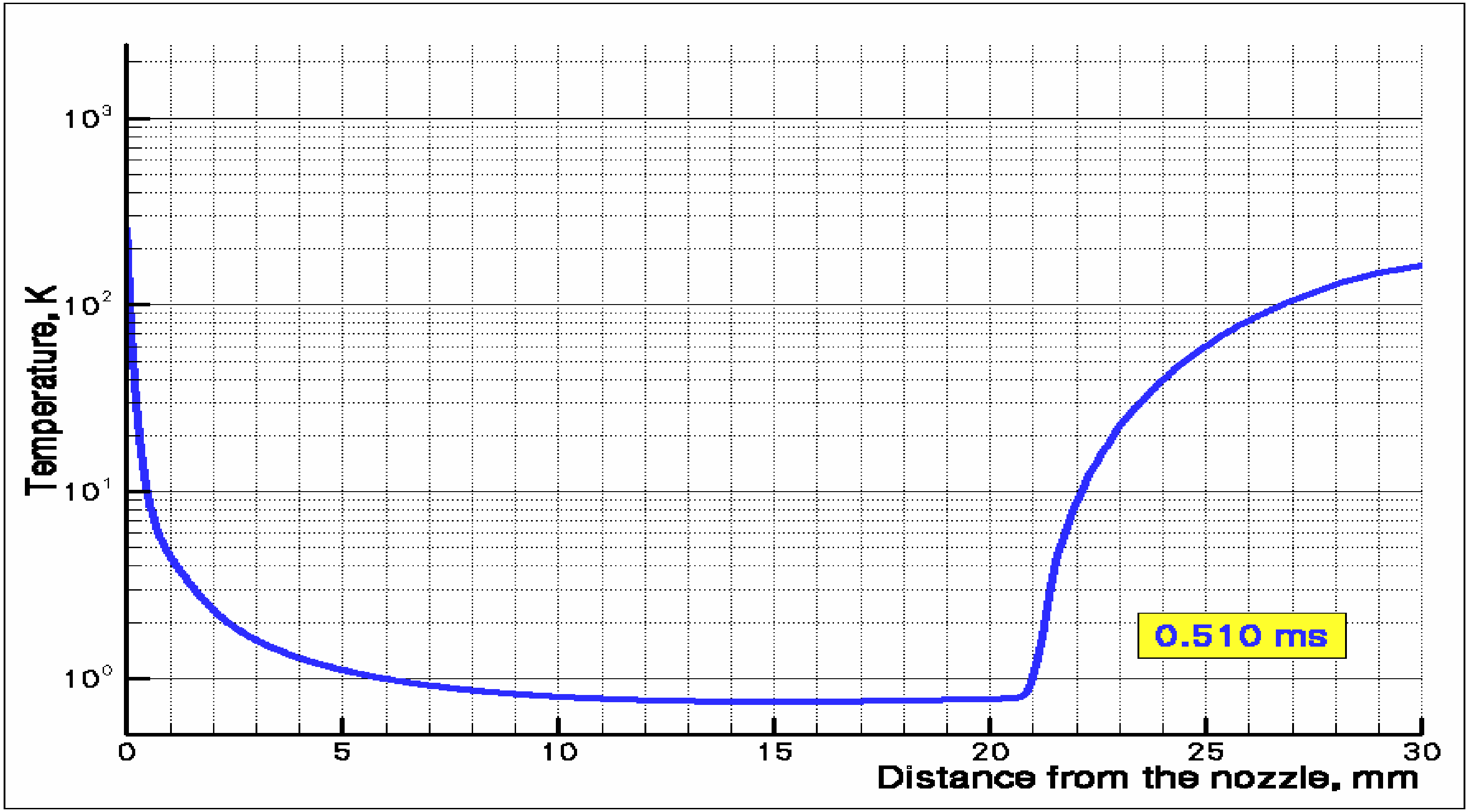
Gas-jet pulse development

Helium gas-jet temperature along the axis



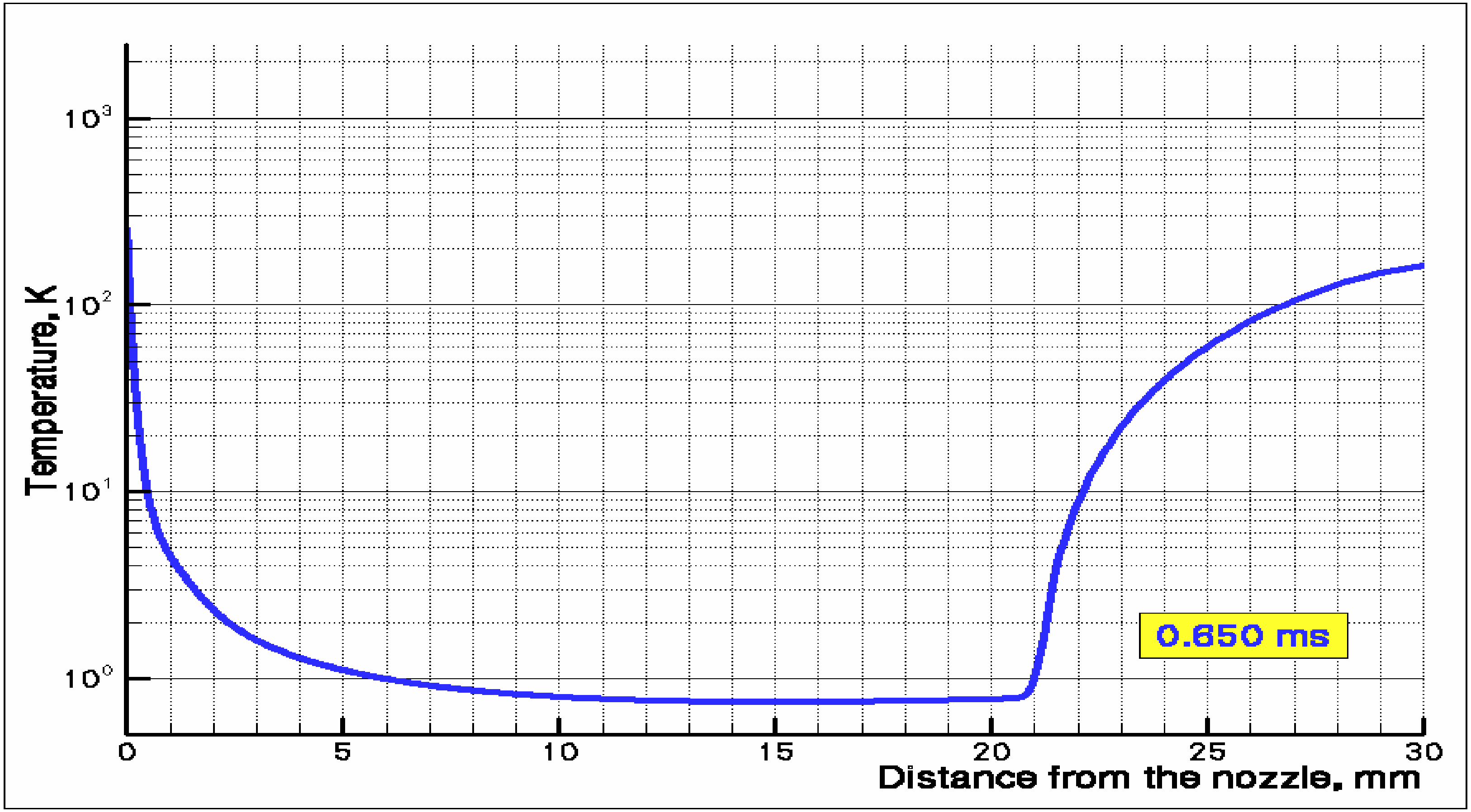
Gas-jet pulse development

Helium gas-jet temperature along the axis



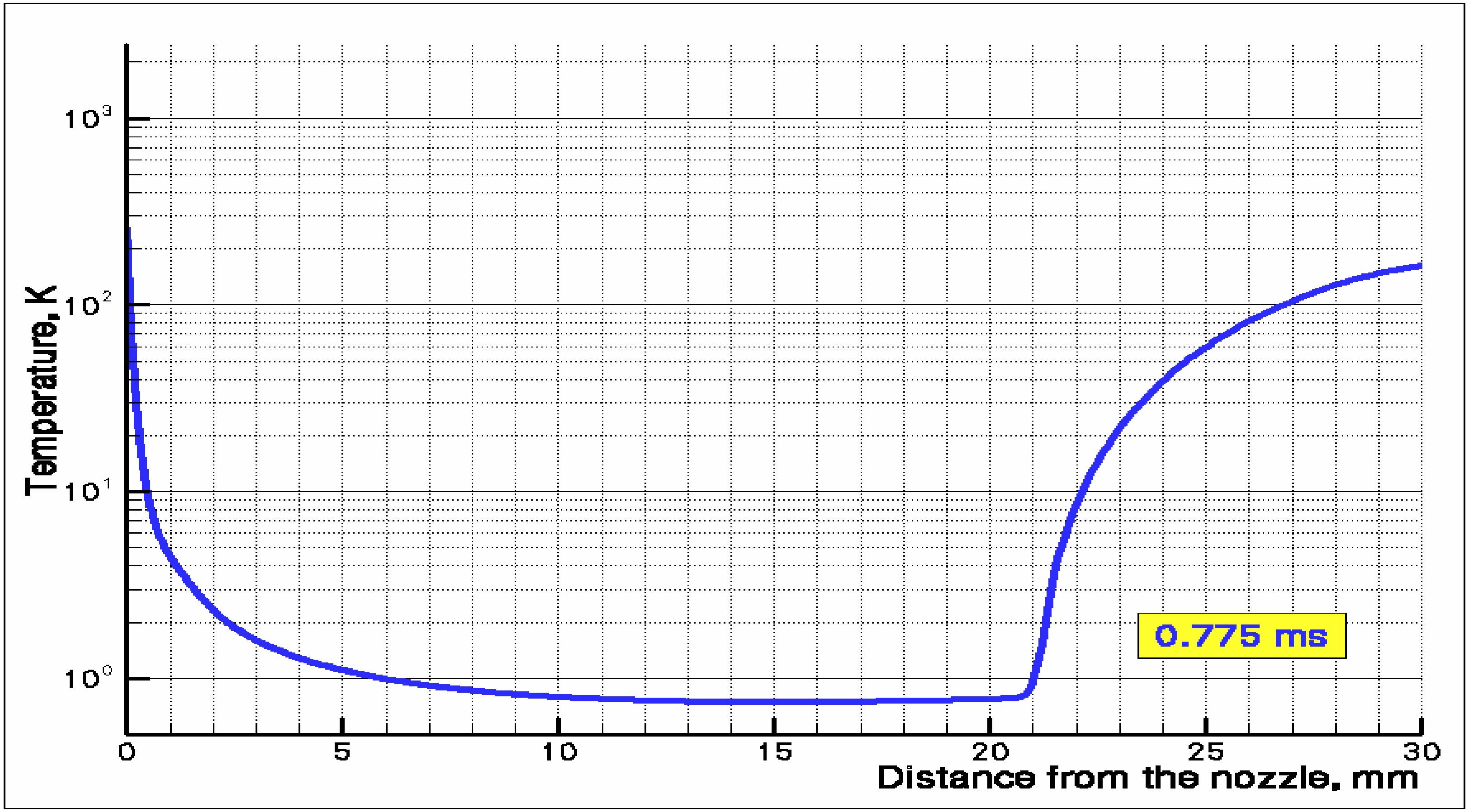
Gas-jet pulse development

Helium gas-jet temperature along the axis



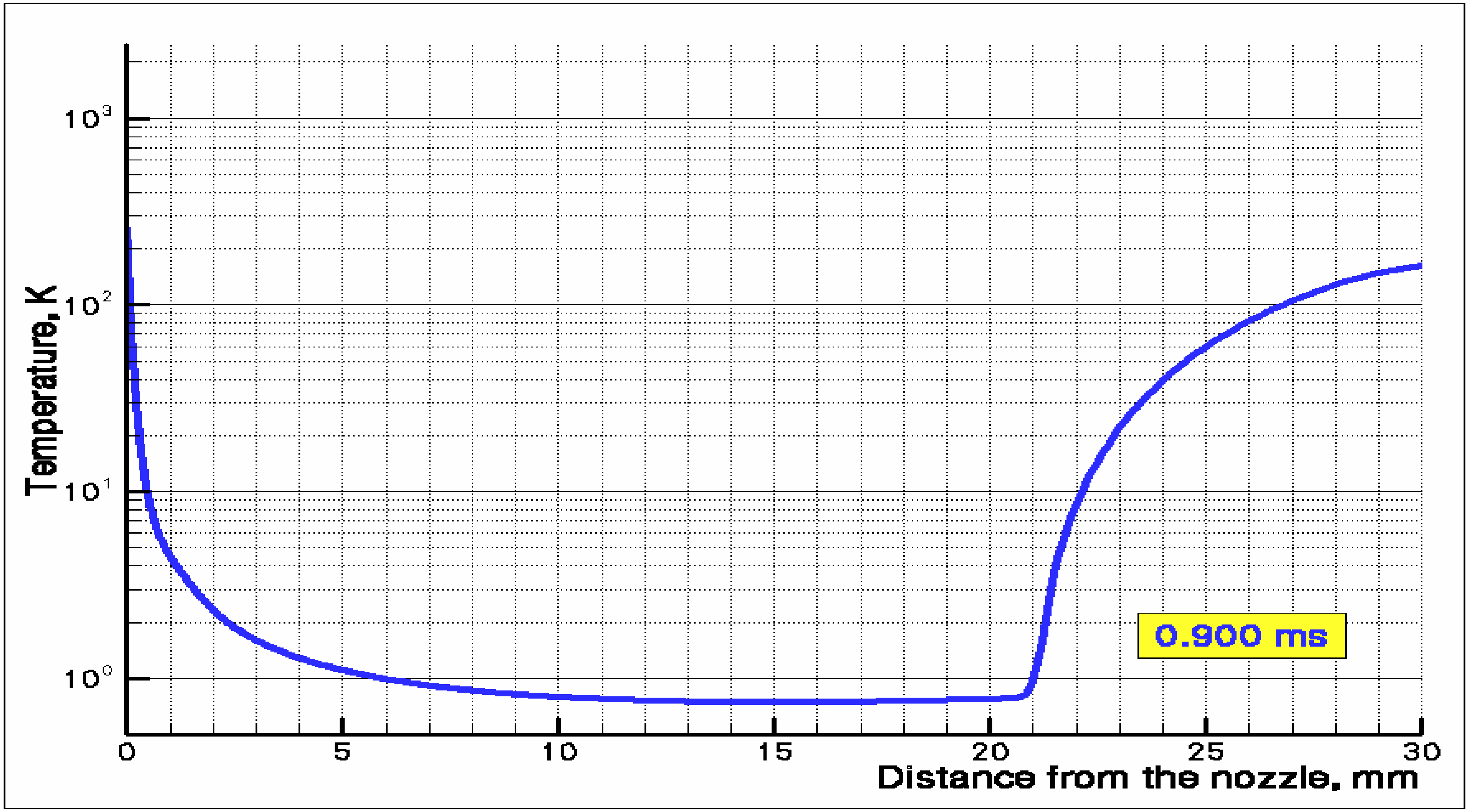
Gas-jet pulse development

Helium gas-jet temperature along the axis



Gas-jet pulse development

Helium gas-jet temperature along the axis



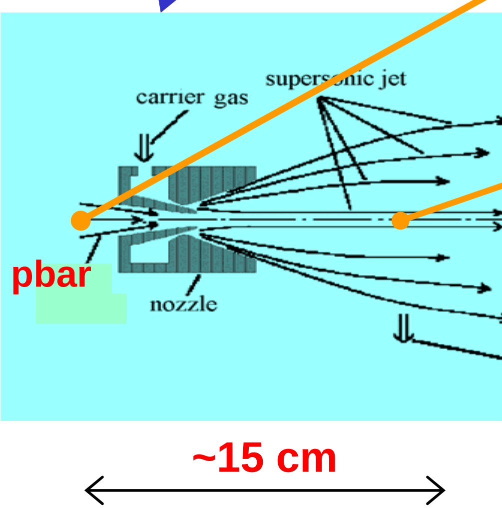
ASACUSA supersonic gas-jet target:
present status and future development

The end

Thank you very much

With a new type of gas target Pbar energies up to **100KeV** and target thickness up to 10^{18} atoms/cm^2 will be available

E.g. see: *"A cooler for intense low-energy ion beams", V. Varentsov and D. Habs, NIMA 490 (2002) 16*



Picture from "Addendum to the proposal CERN/SPSC 97-19 and CERN/SPSC 2000-04"

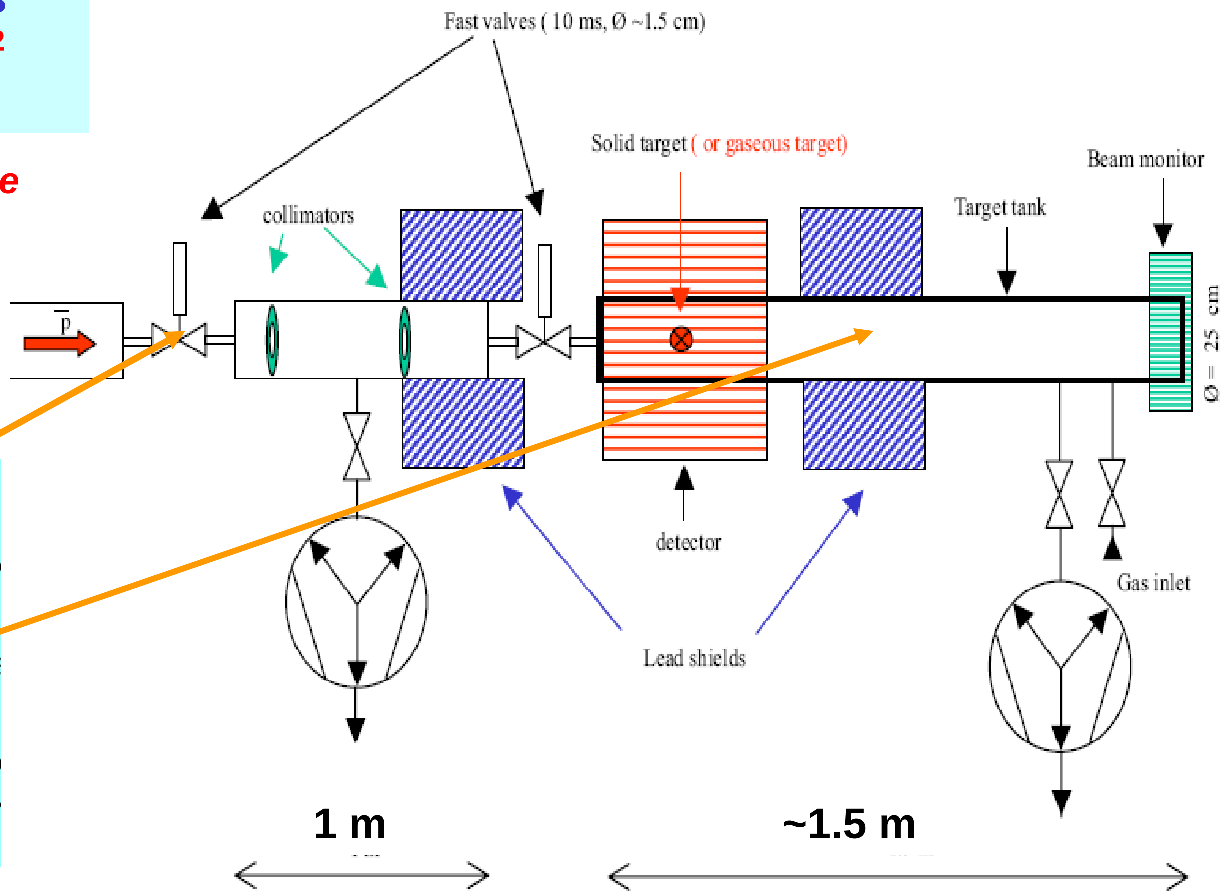


Figure 2.5: Experimental set-up for $E_k \lesssim 1.5$ keV.