OMEGA Supersonic Gas-Jet Target System Characterization

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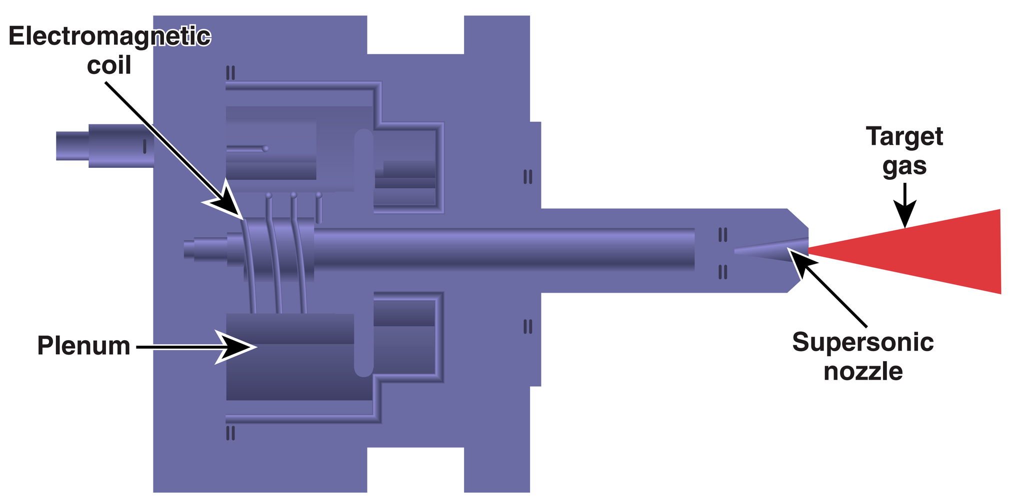
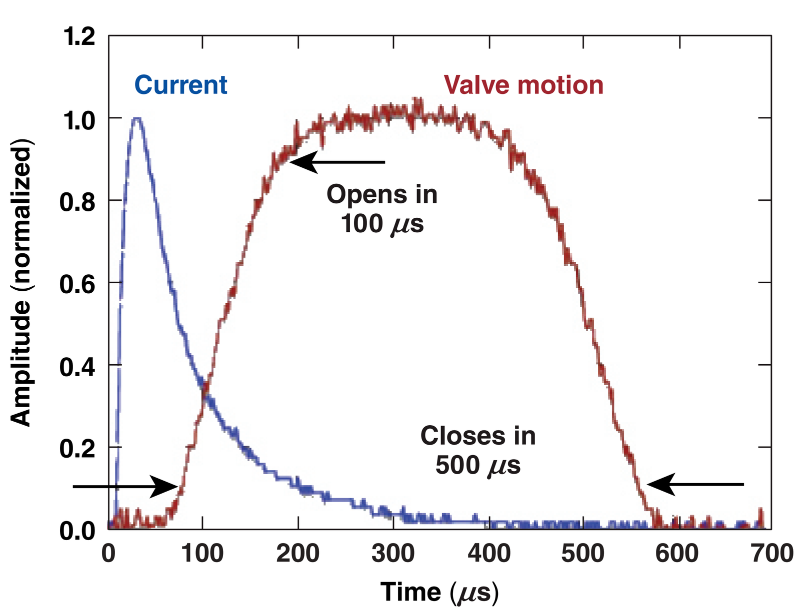


Gas-Jet Overview

- The gas target has a long-range density profile, is flat topped, and has a steep density gradient
- Windowless gas target with excellent access to plasma
- High-repetition-rate, consistent, and flexible gas targets
- Uses an electromagnetic valve controlled by an electronic pulser unit
- Nozzles may be customized for specific Mach numbers and jet sizes
- Rapid opening and closing



Characterizing the Gas Jet

- The gas-jet density profile is characterized using a Mach–Zehnder interferometer
- 532-nm continuous wave (cw) laser expanded and collimated to a 1-cm beam
- PI-MAX 3 provides fast gating
- The jet is imaged using a 4*f* optical system

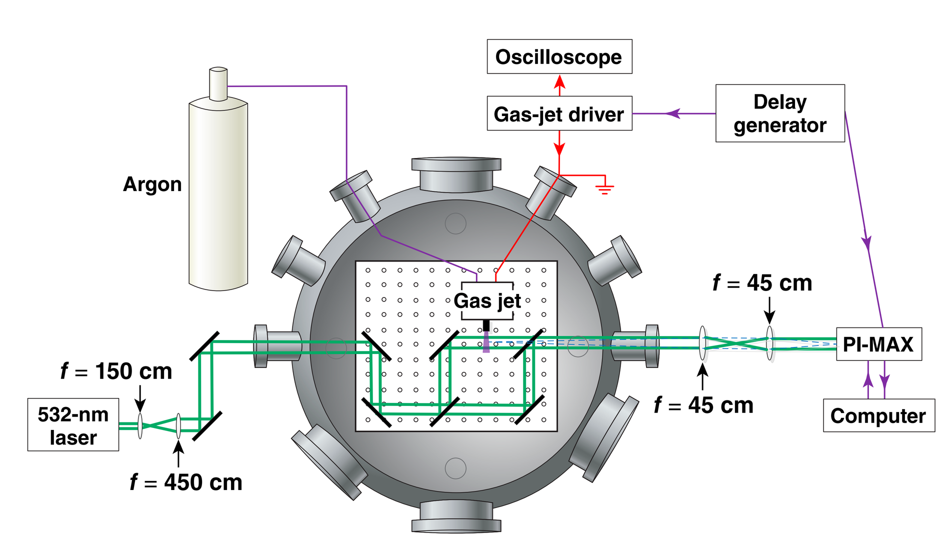


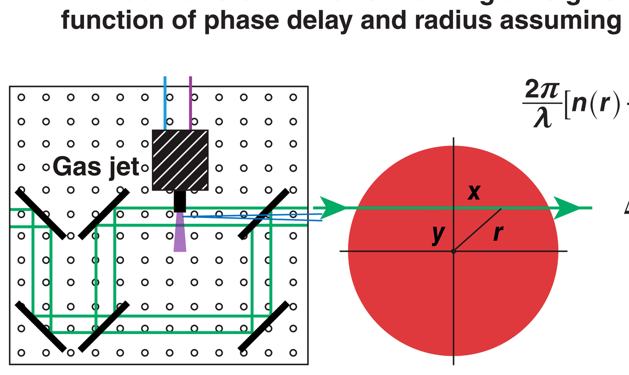
Image Analysis

- The jet's refractive index (n) depends on the gas density

$$\frac{n^2-1}{n^2+2}=\frac{\rho}{3}\gamma$$

n: refractive index
ρ: particle density
γ: molecular polarizability

- The beam passing through the jet will accumulate phase ($\Delta\theta$) relative to the unobstructed beam
- An Abel transform inverts the integral to give refractive index as a function of phase delay and radius assuming cylindrical symmetry



$$\frac{2\pi}{\lambda}\left[n(r)-1\right]=\frac{-1}{\pi}\int_y^{r_0}\frac{d}{dy}\frac{\Delta\theta(y)}{\sqrt{r^2-y^2}}dy$$

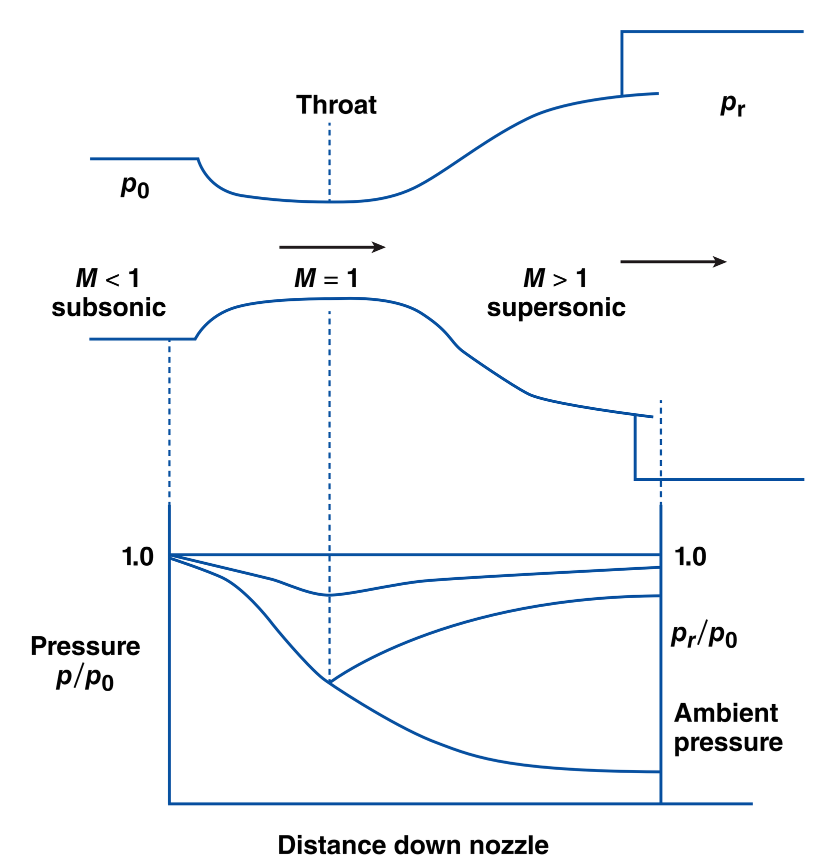
$$\Delta\theta(y)=\frac{4\pi}{\lambda}\int_y^{r_0}\frac{\left[n(r)-1\right]r}{\sqrt{r^2-y^2}}dr$$

Supersonic Nozzles

- Utilizes a convergent-divergent de Laval geometry
- Ratio of nozzle exit area (A) over throat area (A^*) determines the Mach number (M) for a given gas with an adiabatic index (γ)
- In a converging section, the gas velocity increases as the area shrinks
- The flow reaches maximum velocity (Mach 1) at the smallest area
- In a diverging supersonic section, the velocity increases as the area increases
- The Mach number determines the density at the nozzle exit

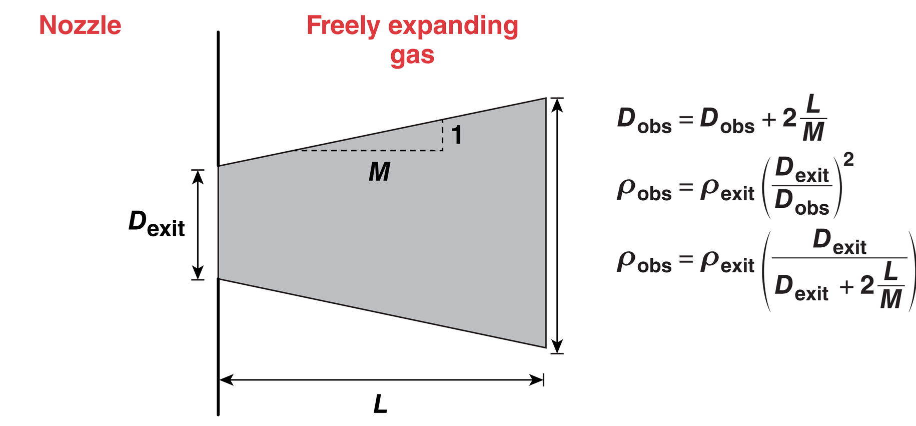
$$\frac{A}{A^*}=\frac{1}{M}\left(\frac{1+\frac{\gamma-1}{2}M^2}{\frac{\gamma+1}{2}}\right)^{\frac{\gamma+1}{2(\gamma-1)}}$$

$$\frac{\rho_0}{\rho}=\left(1+\frac{\gamma-1}{2}M^2\right)^{\frac{1}{\gamma-1}}$$



Expansion Cone

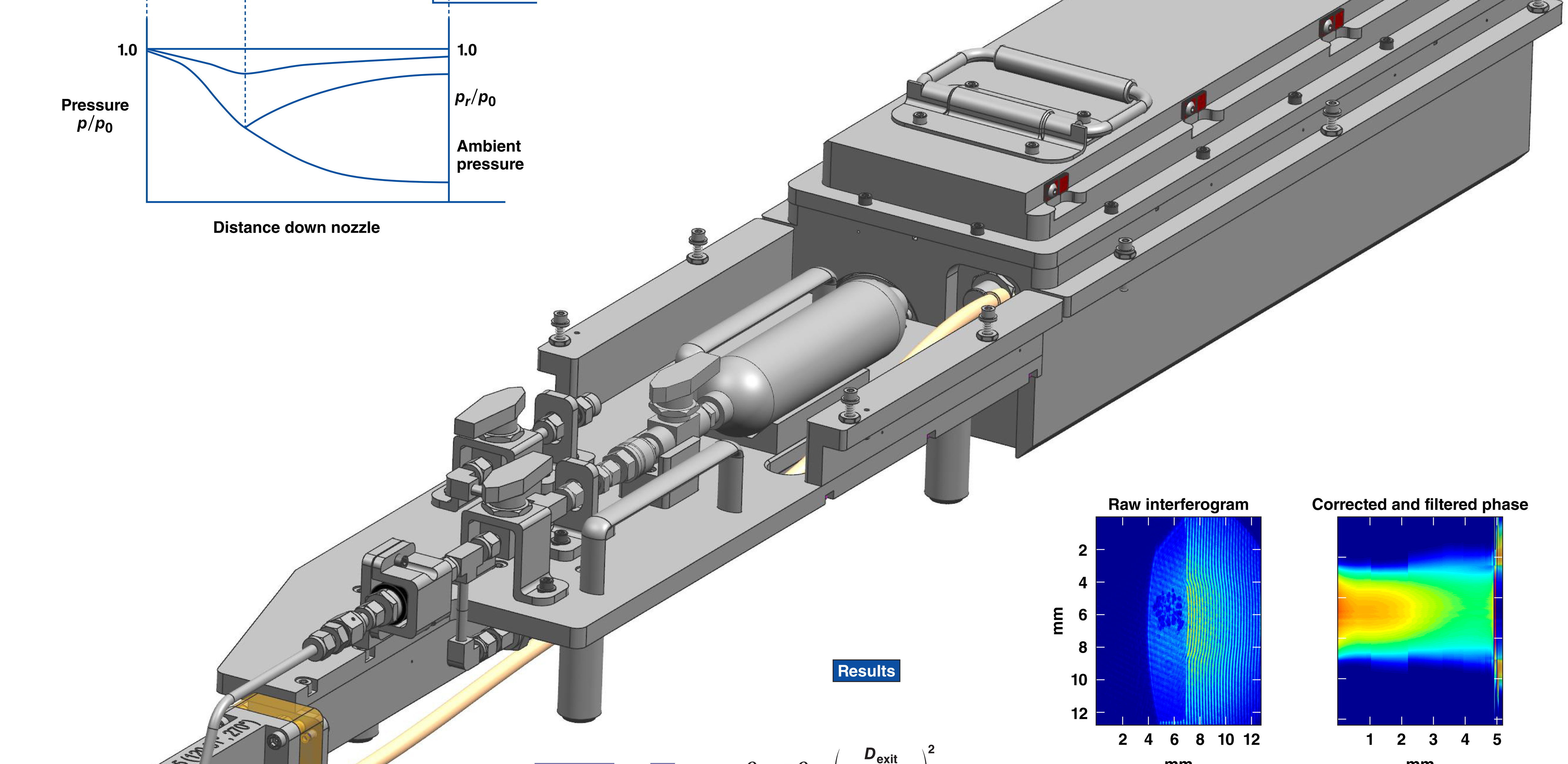
- The gas continues to expand radially at $M \approx 1$ once it leaves nozzle, forming a cone geometry
- The expansion cone's angle is determined by the nozzle's Mach number
- The jet's number density decreases as the area of the cone it fills increases



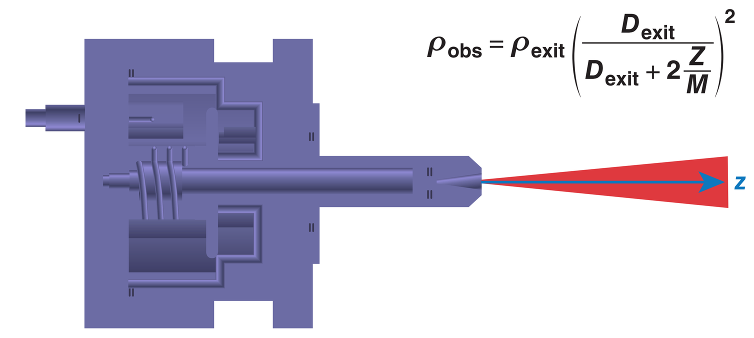
$$D_{obs}=D_{obs}+2\frac{L}{M}$$

$$\rho_{obs}=\rho_{exit}\left(\frac{D_{exit}}{D_{obs}}\right)^2$$

$$\rho_{obs}=\rho_{exit}\left(\frac{D_{exit}}{D_{exit}+2\frac{L}{M}}\right)^2$$

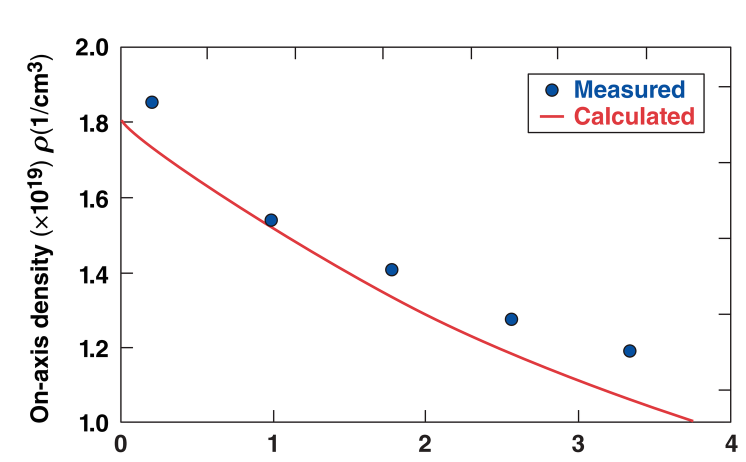


Results

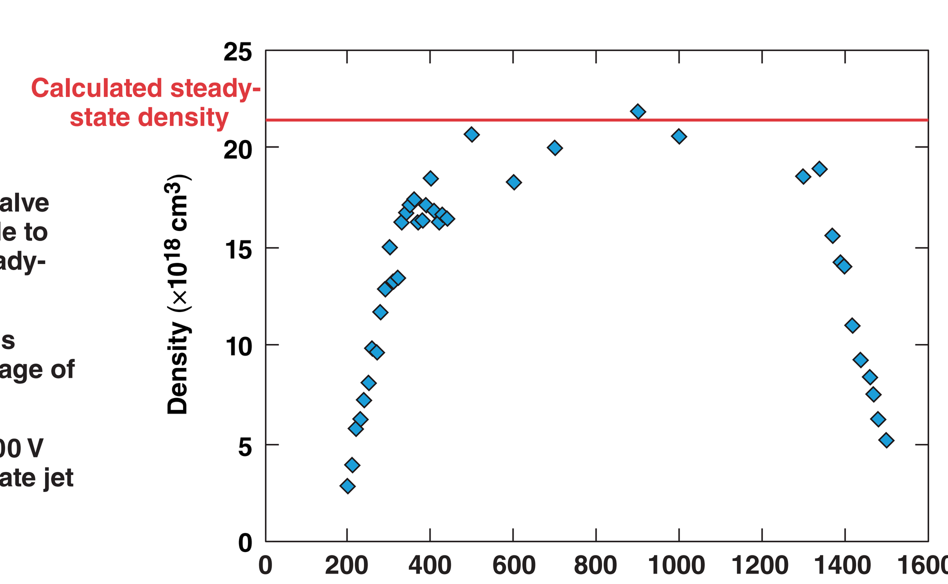


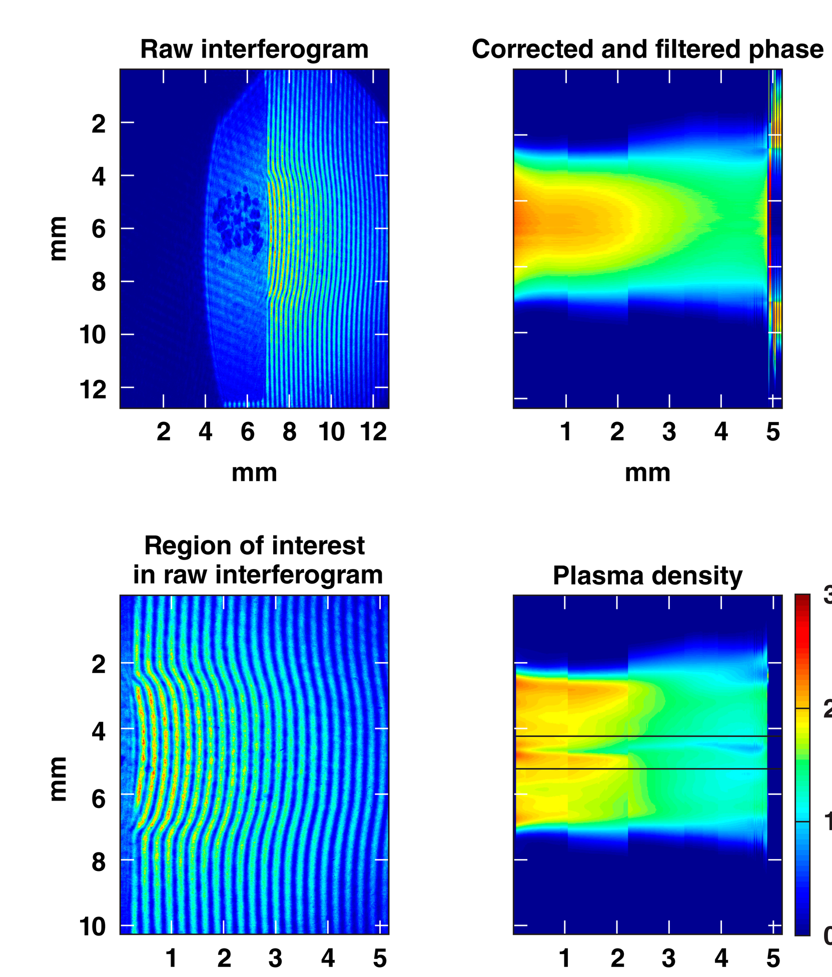
$$\rho_{obs}=\rho_{exit}\left(\frac{D_{exit}}{D_{exit}+2\frac{Z}{M}}\right)^2$$

- Density is measured along the central axis and compared to the density predicted by the expansion cone
- Variations away from expectations are largely attributed to the assumption of constant expansion at $M \approx 1$



- Density is measured at a location over the entire valve opening and closing cycle to find valve speed and steady-state behavior
- The length of open time is controllable with the voltage of the electrical input pulse
- Charging the pulser to 400 V gives an ~1-ms steady-state jet





- The phase is extracted from the measured fringe shifts using an Abel inversion; phase is then converted to atomic number density
- Density is measured perpendicular to the gas flow to measure the jet density profile
- Profiles with steep density gradients and flat tops were found