Laboratory Generated Photoionization Fronts Relevant to Cosmology

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Abstract

Photoionization Fronts (commonly referred to as Ionization Fronts or PI fronts) are a type of radiation-driven heat front that dictate important physics in the reionization era of the early universe. The first galaxies of the reionization era merged to form minihalos. Subsequently, these minihalos emitted ionizing radiation to the surrounding gas clouds, which generated PI fronts. The attenuation of a PI front within a gas cloud is an active area of study in the early universe cosmology. In the laboratory setting, the Z Astrophysical Plasma Properties (ZAPP) platform on Sandia's Z-Machine facility can generate an intense radiation source to drive a PI front through a gas cell. A set of five experiments were conducted on the Z-Machine to investigate the propagation velocity and visible emitted spectra of PI fronts in Nitrogen and Argon. Front velocities of 300 – 2800 km/s indicate a photoionization front was successfully generated in the laboratory.

Astrophysics Motivation

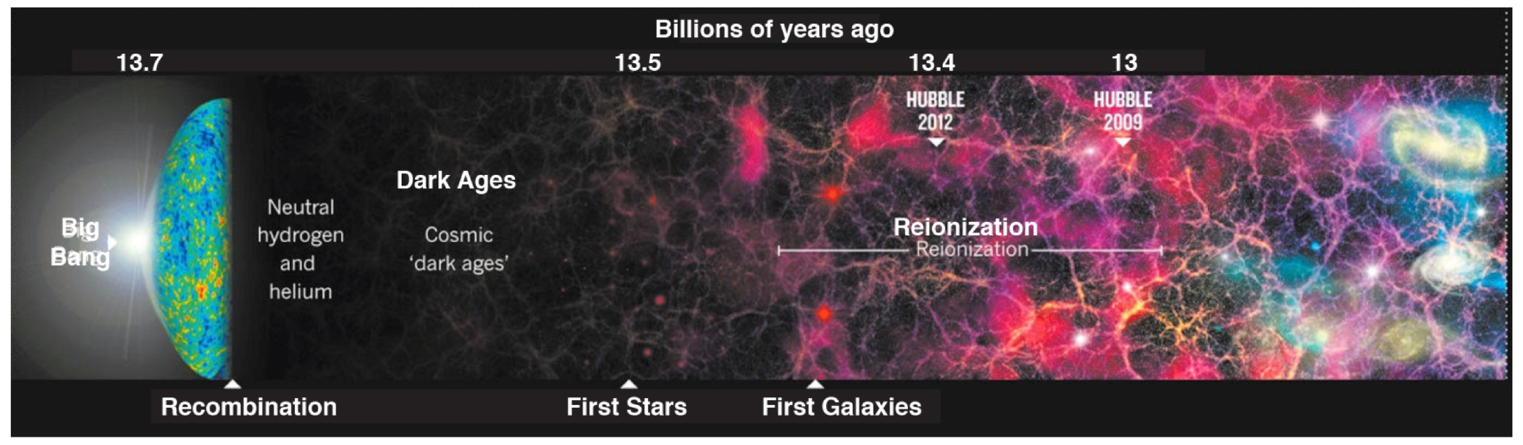

Figure 1. History of Universe[1]

Reionizaiton Era

- **Dark matter Mini-halo's emit ionizing photons into the surrounding intergalactic medium during the Reionization Era**

$$\frac{dn_{ion}}{dt} = f_{esc}\zeta_Q\rho_{SFR}$$

- **[1]The production rate density of ionizing photons (n_{ion}), is proportional to the the escape fraction (f_{esc}), number of photons emitted per star(ζ_Q), and star formation rate (ρ_{SFR})**
- **The escape fraction of photons moving through a PI front help determine when the Reionization Era occurred**

Detection of High Redshift Galaxies

- **[2]Shifts in the Lyman and Balmer spectral lines from high redshift (~z = 6) galaxies can be used to determine age**
- **Metals in the interstellar medium can greatly effect the measurement of the Lyman and Balmer shifts and the resulting galaxy age (~z $\pm$ 3)**
- **Measurement of the downstream line emission spectra from metal enriched PI fronts can reduce the uncertainty in galactic age**

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Experimental Design

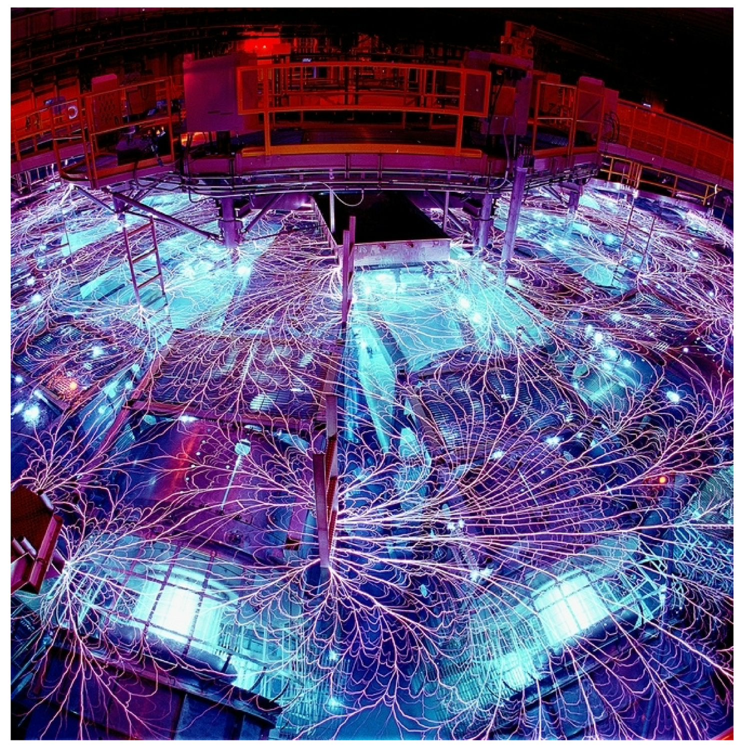


Figure 2. Sandia Z- Machine

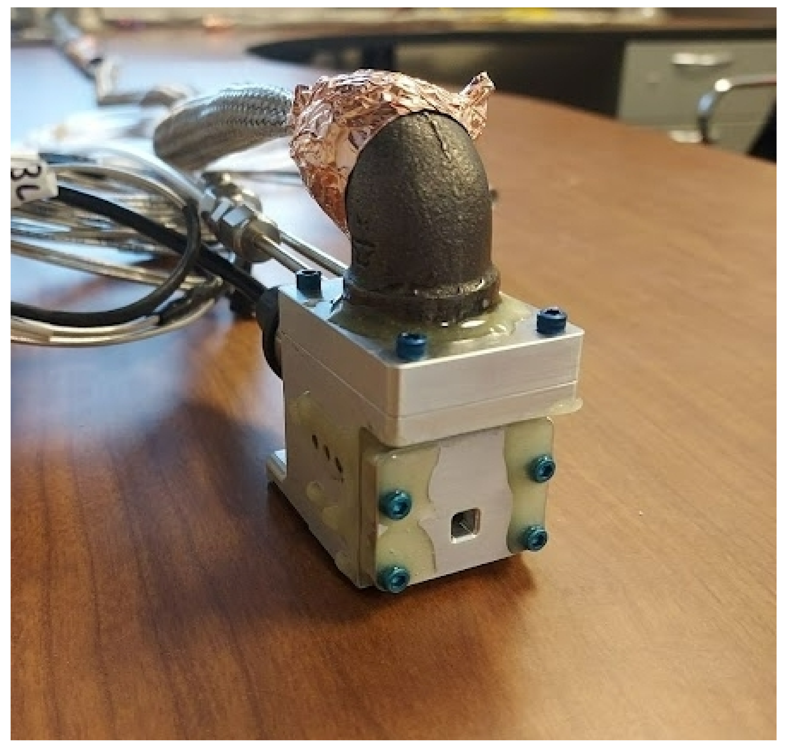


Figure 3. Gas Cell as Built

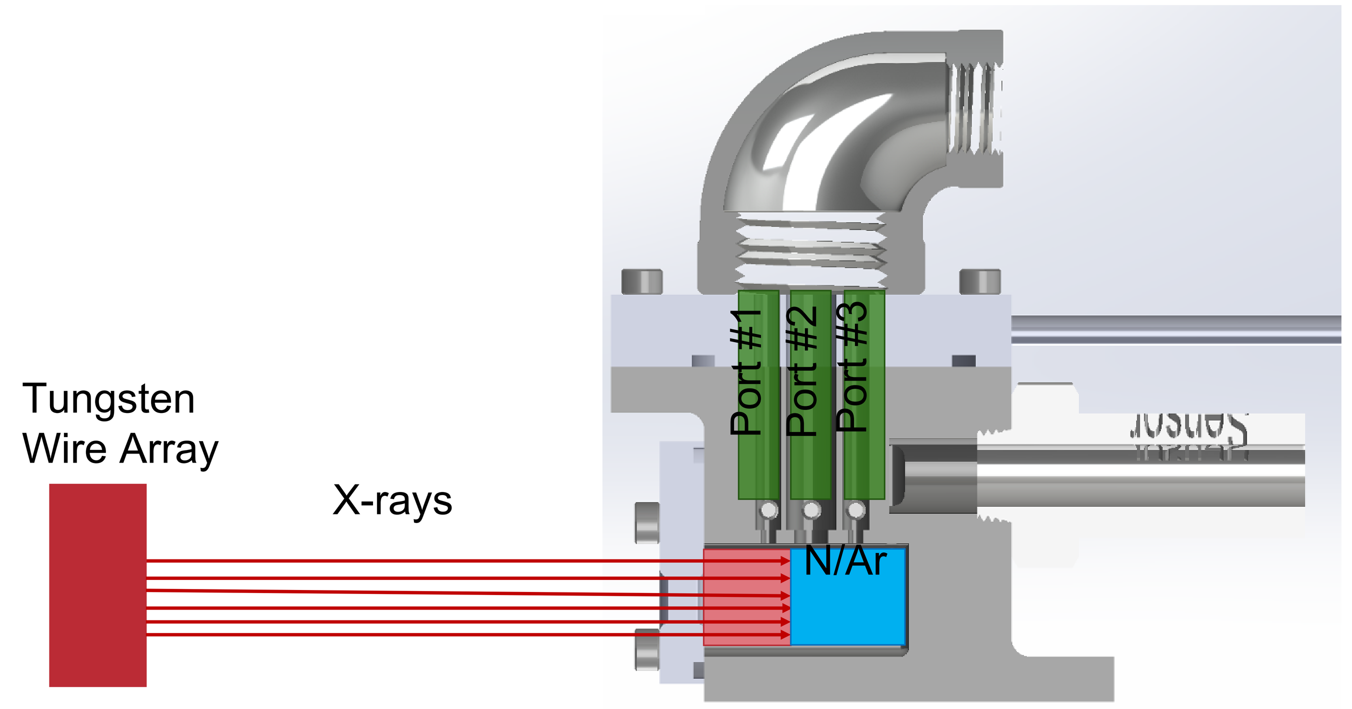


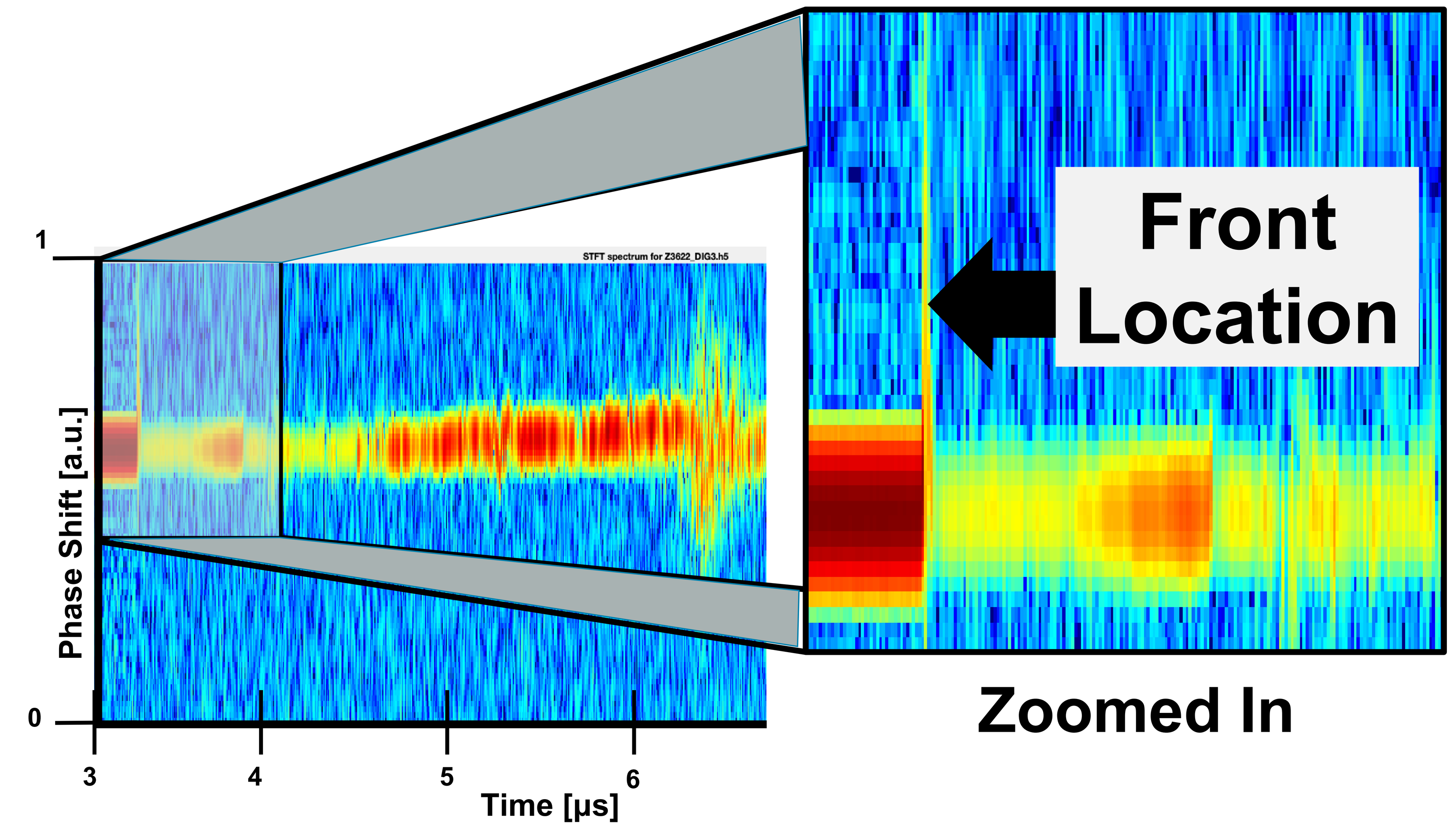
Figure 4. ZAPP Experimental Schematic

Photon Doppler Velocimeter (PDV)

- **2x PDV probes measures Index of Refraction of gas/plasma**
- **Heating from PI Front results in decrease in Index of Refraction**
- **Will use perpendicularly-mounted PDV as a shock arrival measurement**
- **Front Location tracked at Port #1 and #3**

Parameter	Symbol	Equation
Ionization State	Z	$Z \cong 0.63\sqrt{T_{e,eV}}$
Electron Density	n_e	$n_e = Z\,n_0$
Plasma Electron Frequency	ω_p	$\omega_p = \sqrt{\frac{n_e e^2}{\epsilon m_e}}$
Index of Refraction	n	$n = \sqrt{1 - \left(\frac{\omega_p^2}{\omega^2}\right)}$

PI Front Velocity



PI front moves at radiation time scale which is faster than hydrodynamic time scale

- $v_{PI\ front} \cong \frac{F_\gamma}{n_e}$ $\quad v_{PI\ front} \cong 2,131\,\frac{km}{s}$ $\quad v_{e-front} \cong 291\,\frac{m}{s}$

Measured Photoionization Front Velocities

Gas	Pressure [Torr]	Front Velocity [km/s]
Nitrogen	570	$\pm$
Nitrogen	460	$\pm$
Argon	222	$\pm$

Future Work

- **Parameter scan of PI front velocities by Z and n_e**
- **Capture emission spectra to characterize plasma**
- **Determine charge state distribution**
- **Compare with Astrophysics Simulation codes (XSTAR, Cloudy)**

Acknowledgments/References

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[1]B. E. Robertson, R. S. Ellis, J. S. Dunlop, R. J. McLure, and D. P. Stark, "Early star-forming galaxies and the reionization of the universe," Nature 468, 49–55 (2010).

[2]Schaerer, D. and de Barros, S., "The impact of nebular emission on the ages of zfns f napproxg 6 galaxies," A&A 502, 423–426 (2009).