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PURDUE ENGINEERING

PURDUE UNIVERSITY ZUCROW LABS ENERGETICS LABORATORY

Imaging Pyrometry and Optical Depth Measurements in Explosive Fireballs using High-Speed Imaging

Alex D. Brown , Mateo Gomez , Terrence R. Meyer , Steven F. Son
Purdue University, West Lafayette, Indiana 47907

Daniel R. Guildenbecher
Sandia National Laboratories, Albuquerque, NM 87185

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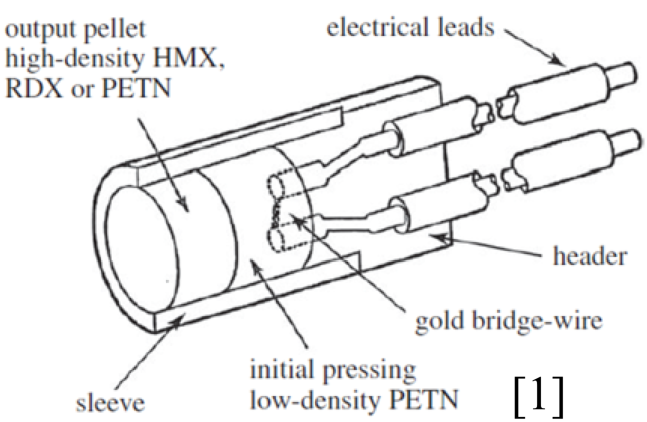
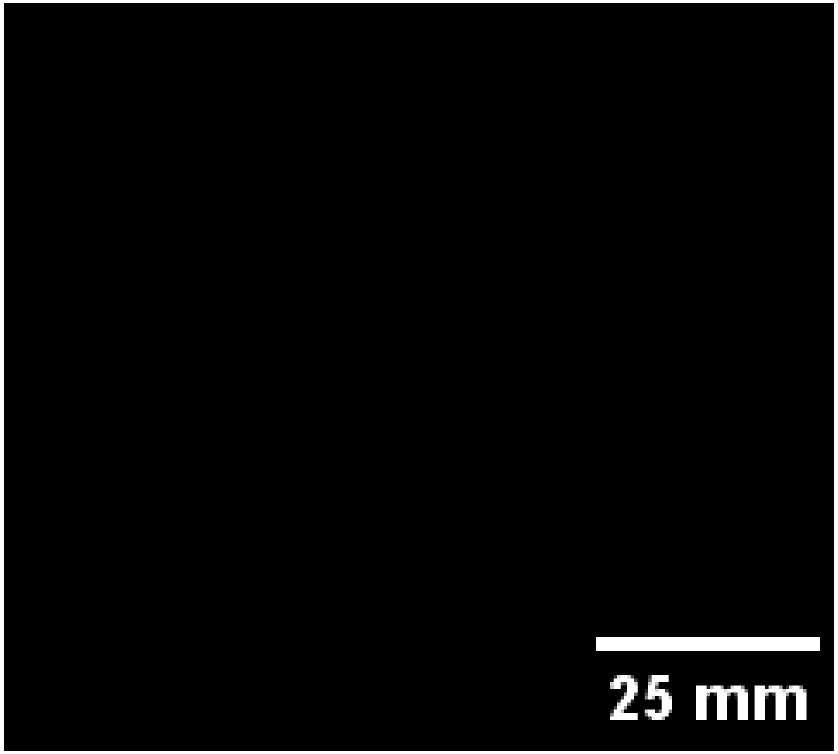
Motivations

- Characterization of post-detonation fireball properties
- Produce data for computational model validation
- Development and application of practical measurement techniques using commercially available camera architectures



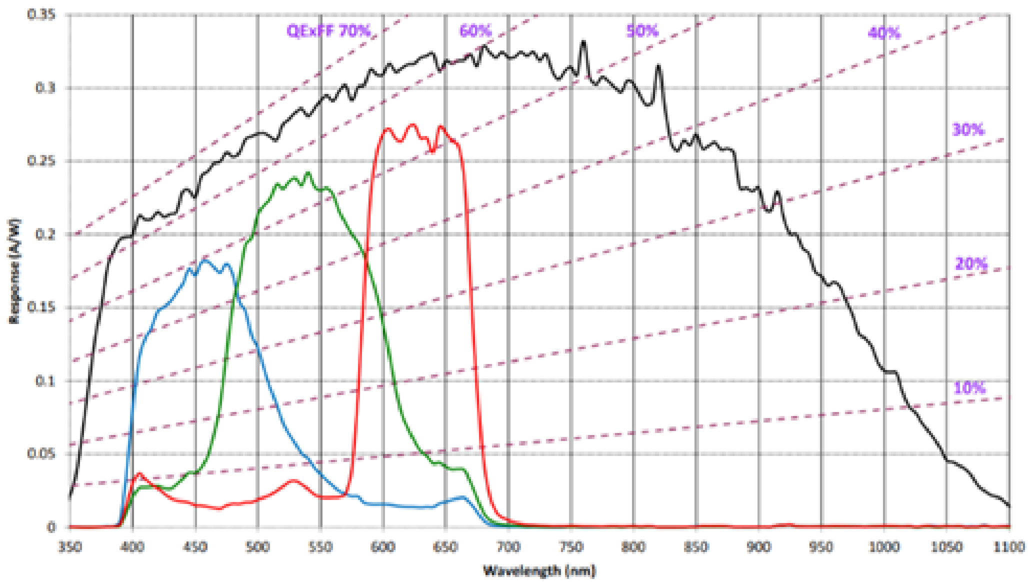
[1]



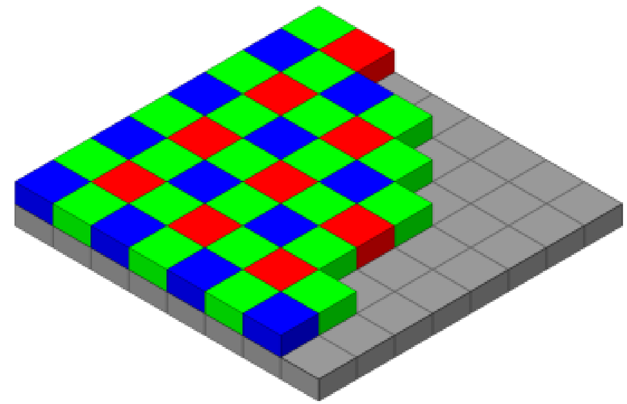
2 MHz video of a post-detonation blast

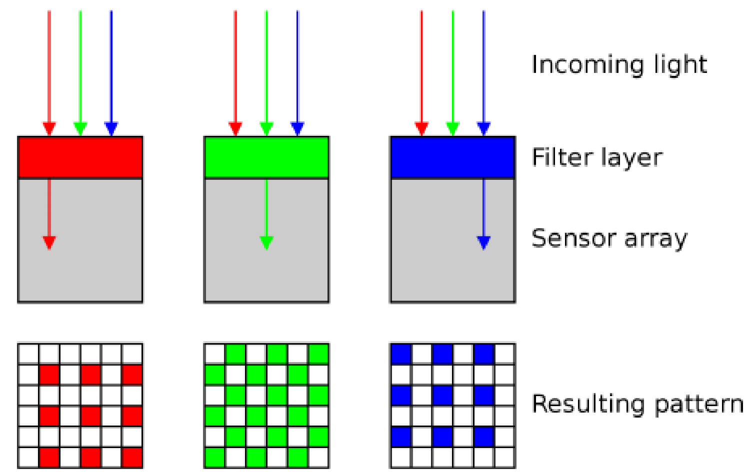
Color Camera Architecture

- Bayer filters overlaid on grayscale camera chips provide color imaging
- Note significant spectral overlap



Vision Research Phantom TMX Color Quantum Efficiency

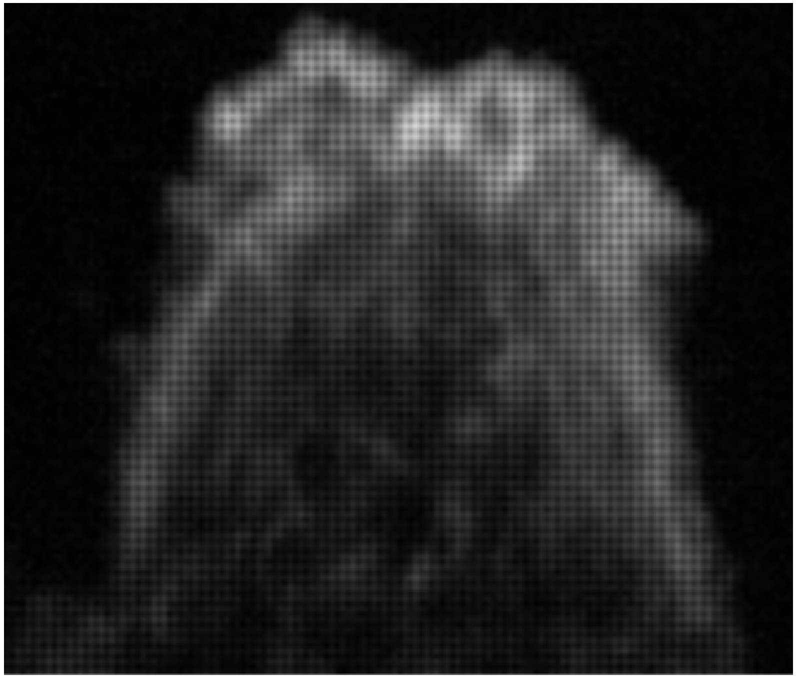




Bayer Filter [2]

Example Images

- Demosaicing algorithms reconstruct a color field to approximate human vision
- Use this capability to measure spectral characteristics of blasts

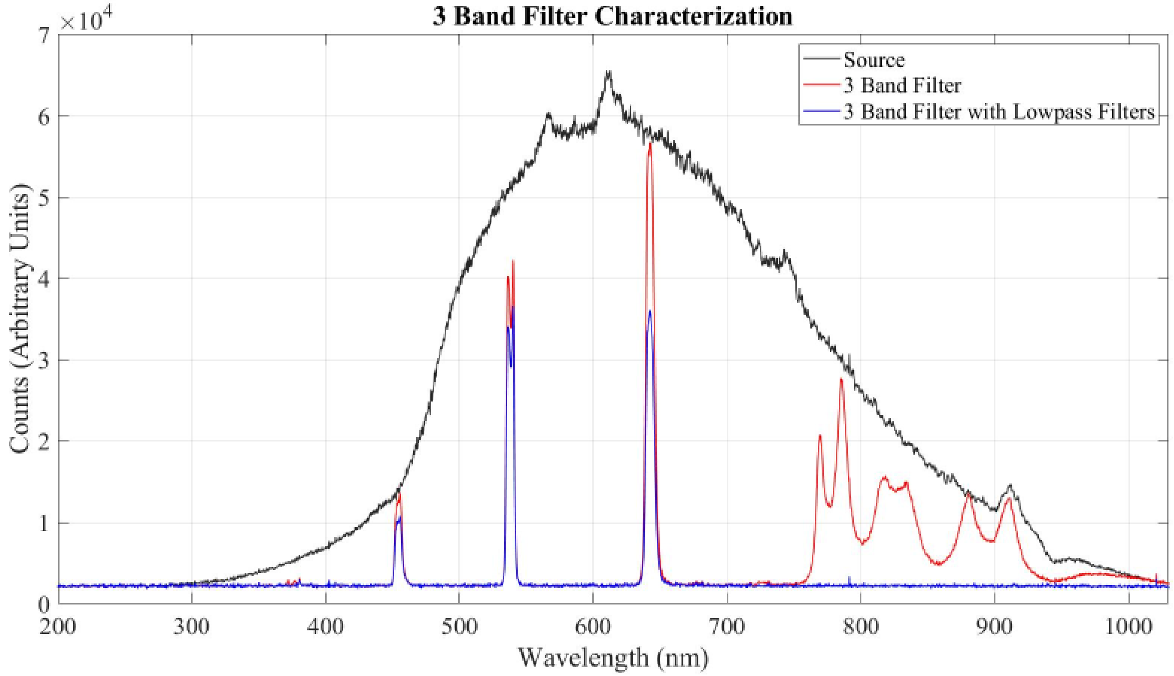


Raw “color” image

Demosaiced image

Custom Filtering

- Using a custom triple-band filter specially developed by Dr. Kevin McNesby at the Army Research Lab, it is possible to further filter the light and separate the color channels



Measurements

Temperature

Wien's blackbody approximation allows for the ratio of blackbody emission signal at two different wavelengths [3]

$$T = \left[\frac{k}{hc} \frac{\lambda_1 \lambda_2}{\lambda_2 - \lambda_1} \left(\ln\left(\frac{I_2}{I_1} \frac{\eta_1}{\eta_2} \right) - 5 \ln\left(\frac{\lambda_1}{\lambda_2} \right) \right) \right]^{-1}$$

Resultant measurement is a blackbody approximation of the temperature of the blast. The camera and filter system was calibrated similarly to the techniques used by McNesby [2].

Optical Density

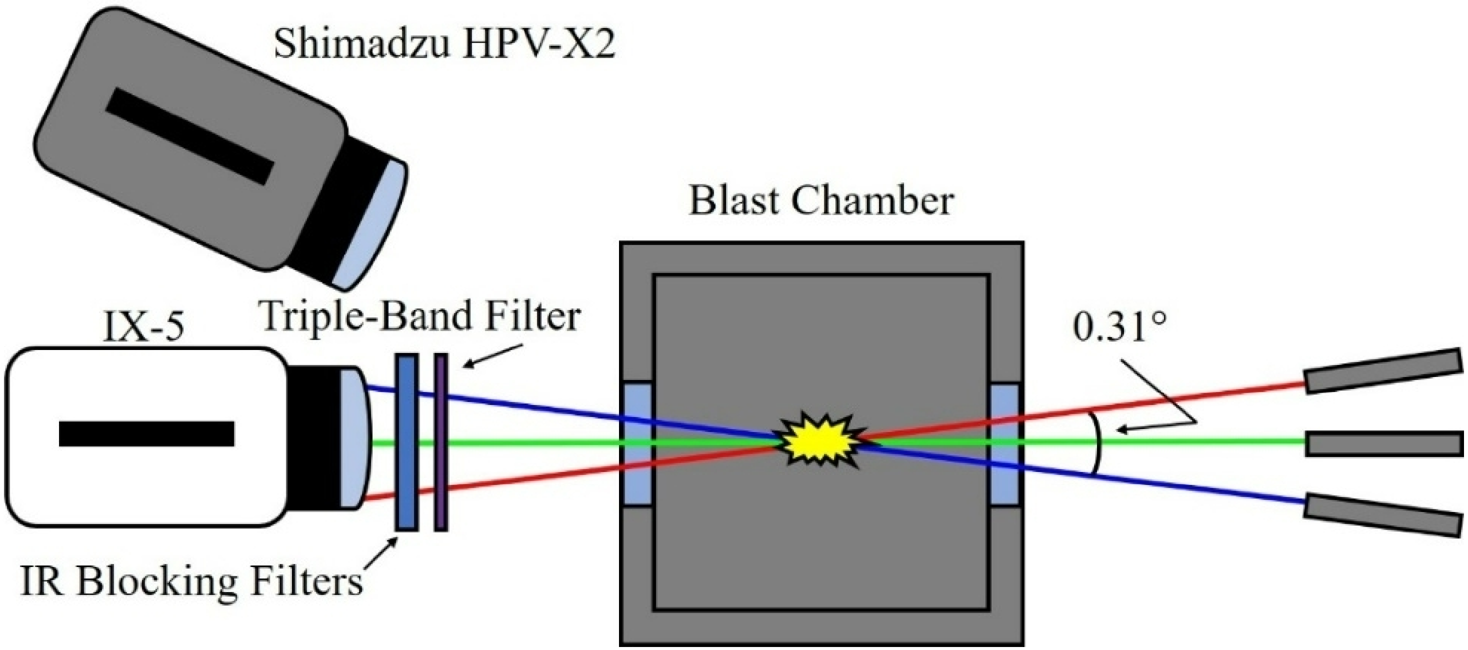
Optical density is a measurement of the fraction of light that penetrates a medium

$$OD = \log_{10} \frac{I}{I_0},$$

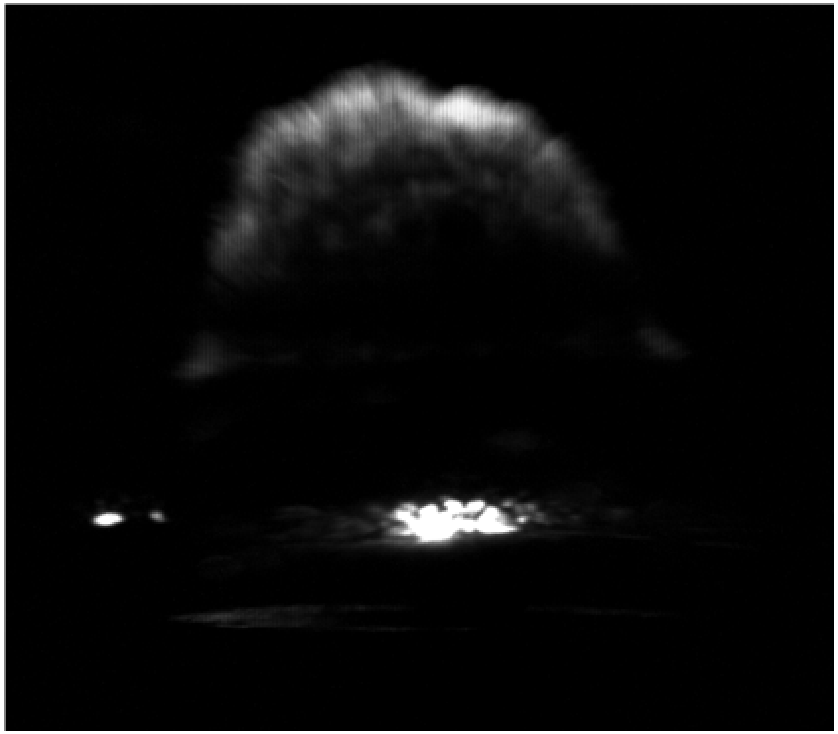
By saturating the camera by a factor of 10, optical densities in excess of 3 were possible.

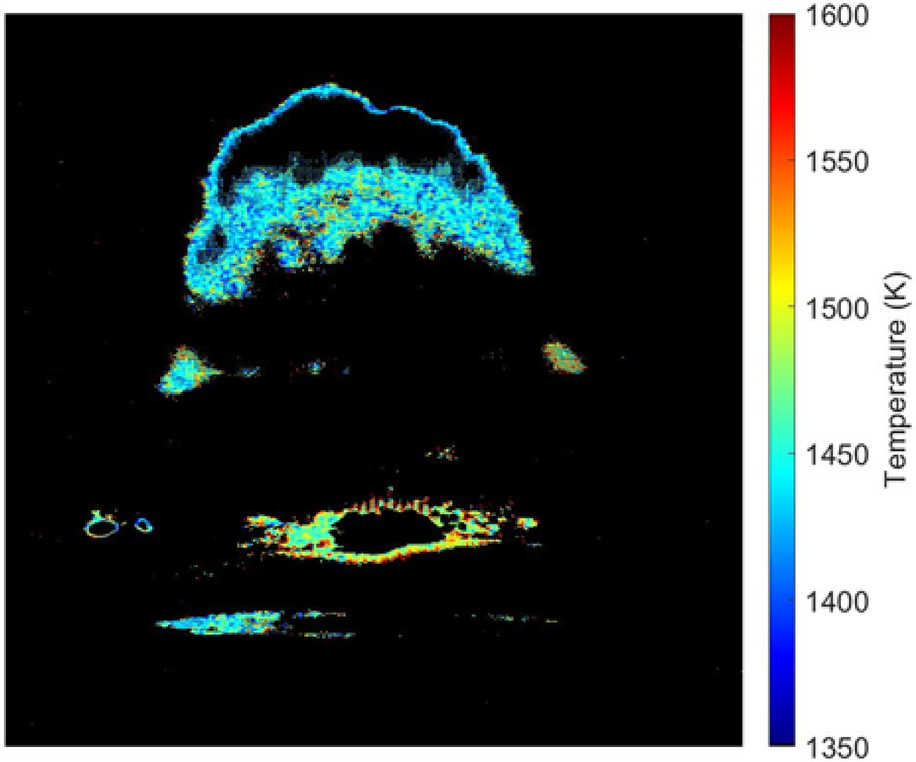
Experimental Setup

- OD measurements conducted using Thorlabs laser diodes at wavelengths that match the triple bandpass filter
- Pyrometric measurement only requires the color camera and filters

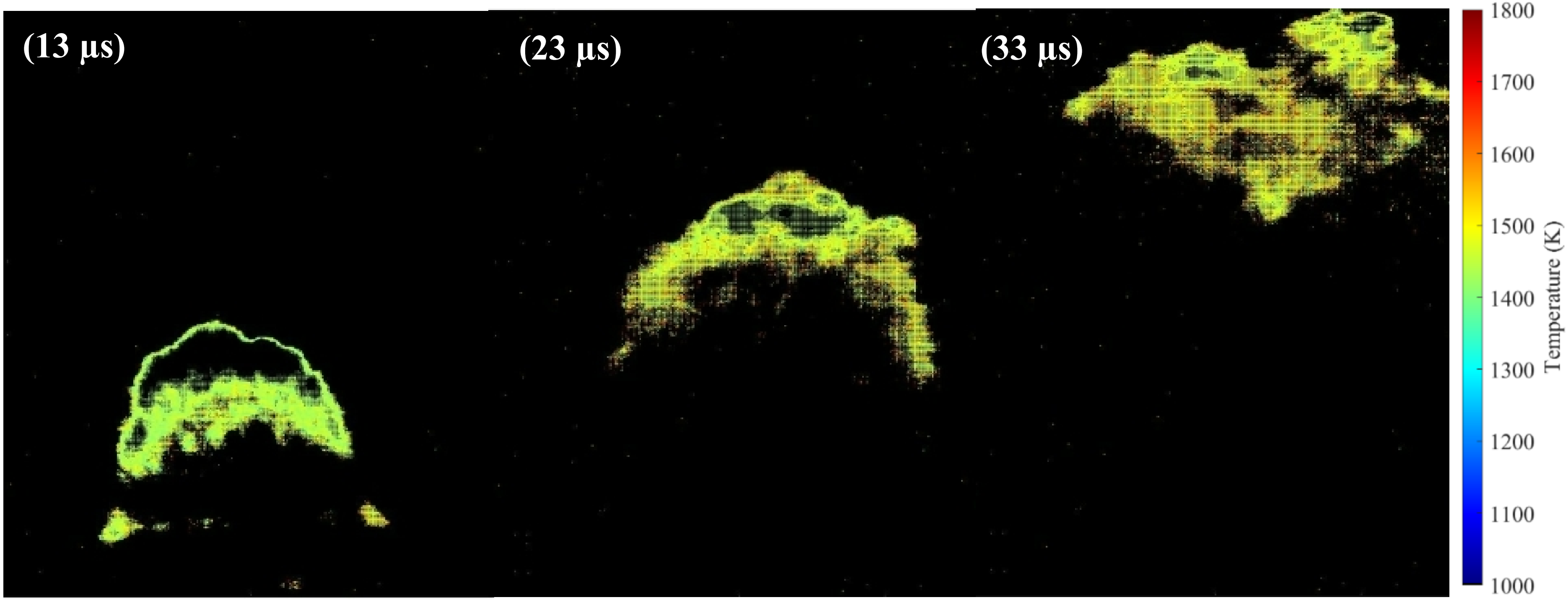


Example Pyrometric Results

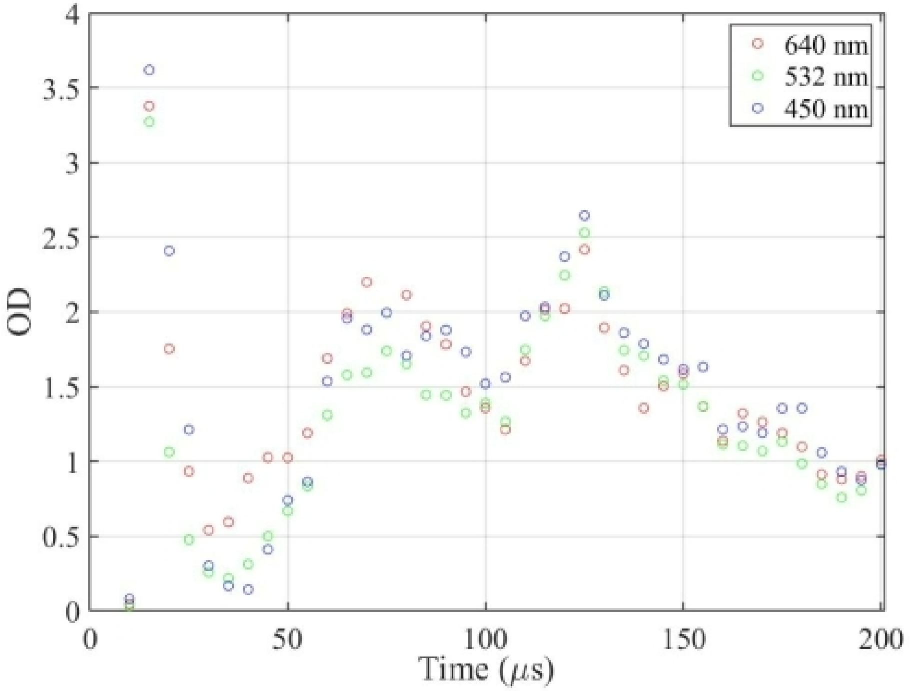


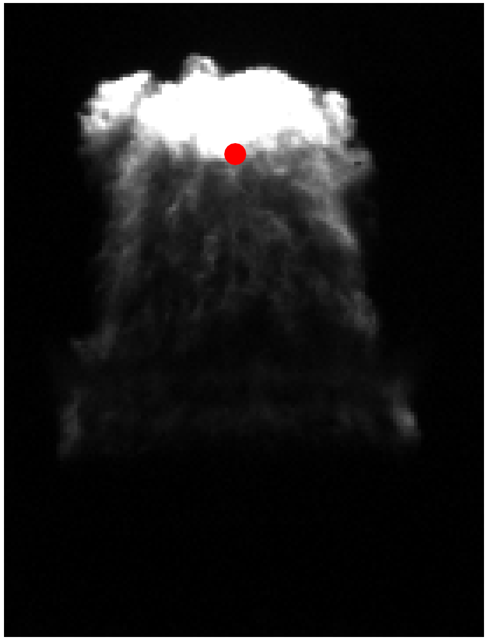


Example Pyrometric Time History



Optical Density Results





Conclusions

- Demonstrated the use of a high-speed color camera and custom filters elements to conduct pyrometric temperature and optical density measurements in post-detonation blasts.
- Slight temperature increases may be associated with sustained exothermic reaction in the post-detonation blast, similar to gas phase temperature measurements [4].
- In-situ measurement of OD at camera wavelengths may allow for future resolution of wavelength dependent optical characteristics.
- At early times, high OD shows that pyrometric temperatures are surface measurements.

References

[1] P. J. Rae and P. M. Dickson, “A review of the mechanism by which exploding bridge-wire detonators function,” *Proc. R. Soc. Math. Phys. Eng. Sci.*, vol. 475, no. 2227, p. 20190120, Jul. 2019, doi: 10.1098/rspa.2019.0120.
[2] McNesby K, Dean S, Benjamin R, Grant J, Anderson J, Densmore J. Imaging pyrometry for most color cameras using a triple pass filter. Rev Sci Instrum. 2021 Jun 1;92(6):063102. doi: 10.1063/5.0037230. PMID: 34243502
[3] Y. Chen *et al.*, “Study of aluminum particle combustion in solid propellant plumes using digital in-line holography and imaging pyrometry,” *Combust. Flame*, vol. 182, pp. 225–237, Aug. 2017, doi: 10.1016/j.combustflame.2017.04.016
[4] D. R. Richardson, S. P. Kearney, and D. R. Guildenbecher, “Post-detonation fireball thermometry via femtosecond-picosecond coherent anti-Stokes Raman Scattering (CARS),” *Proc. Combust. Inst.*, vol. 38, no. 1, pp. 1657–1664, 2021, doi: 10.1016/j.proci.2020.06.257.