

On-Command Pyrotechnic Light Emission Through Controlled Electromagnetic Irradiation

WP19-1163

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NSWC Crane Division
3/25/2022



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REPORT DOCUMENTATION PAGE

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1. REPORT DATE (DD-MM-YYYY) 20/04/2021		2. REPORT TYPE ESTCP Project Outbrief		3. DATES COVERED (From - To) 4/7/2020 - 4/6/2022	
4. TITLE AND SUBTITLE On-Command Pyrotechnic Light Emission Through Controlled Electromagnetic Irradiation				5a. CONTRACT NUMBER 20-P-0040	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Dr. Jonathan Dilger, William Crespo, Dr. Eric Miklaszewski, Dr. Stuart Barkley Naval Surface Warfare Center, Crane Division Dr. Travis Sippel, Dr. Shankar Subramaniam, Dr. James Michael Graduate Students: Joel Lynch, Adam Lawrence Iowa State University				5d. PROJECT NUMBER WP19-1163	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Surface Warfare Center, Crane Division Chief Technology Office, Code 00T, Bldg. 34 Innovation Center 300 Highway 361 Crane, IN 47522				8. PERFORMING ORGANIZATION REPORT NUMBER WP19-1163	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Strategic Environmental Research and Development Program 4800 Mark Center Drive, Suite 16F16 Alexandria, VA 22350-3605				10. SPONSOR/MONITOR'S ACRONYM(S) SERDP	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S) WP19-1163	
12. DISTRIBUTION/AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The technical objectives of this project are listed below: <ul style="list-style-type: none"> • Extending light emission profiles using high power microwaves <ul style="list-style-type: none"> ○ Microwave fields interact with flame products resulting in: <ul style="list-style-type: none"> > Excitation of molecular/atomic species that emit in UV/VIS > Depositing energy in condense phase products- enhanced gray body emission > Sustainment of light emission via continue excitation • This effort explored understanding fundamental mechanism of microwave coupling <ul style="list-style-type: none"> ○ Experimental determine best formulations/mechanisms ○ Computational investigation with 0-D Monte Carlo Simulation 					
15. SUBJECT TERMS On-Command Pyrotechnic Light Emission, Controlled Electromagnetic Irradiation					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UNCLASS	18. NUMBER OF PAGES 20	19a. NAME OF RESPONSIBLE PERSON Jonathan Dilger
a. REPORT UNCLASS	b. ABSTRACT UNCLASS	c. THIS PAGE UNCLASS			19b. TELEPHONE NUMBER (Include area code) 812-854-1452

Project Team

- NSWC Crane PI - Dr. Jon Dilger, Dr. Eric Miklaszewski, Will Crespo
- Iowa State University Team: Dr. Travis Sippel, Dr. Shankar Subramaniam, Dr. James Michael
 - ◆ Graduate Students: **Dr. Stuart Barkley** (former graduate student now at NSWC Crane), Joel Lynch, Adam Lawrence

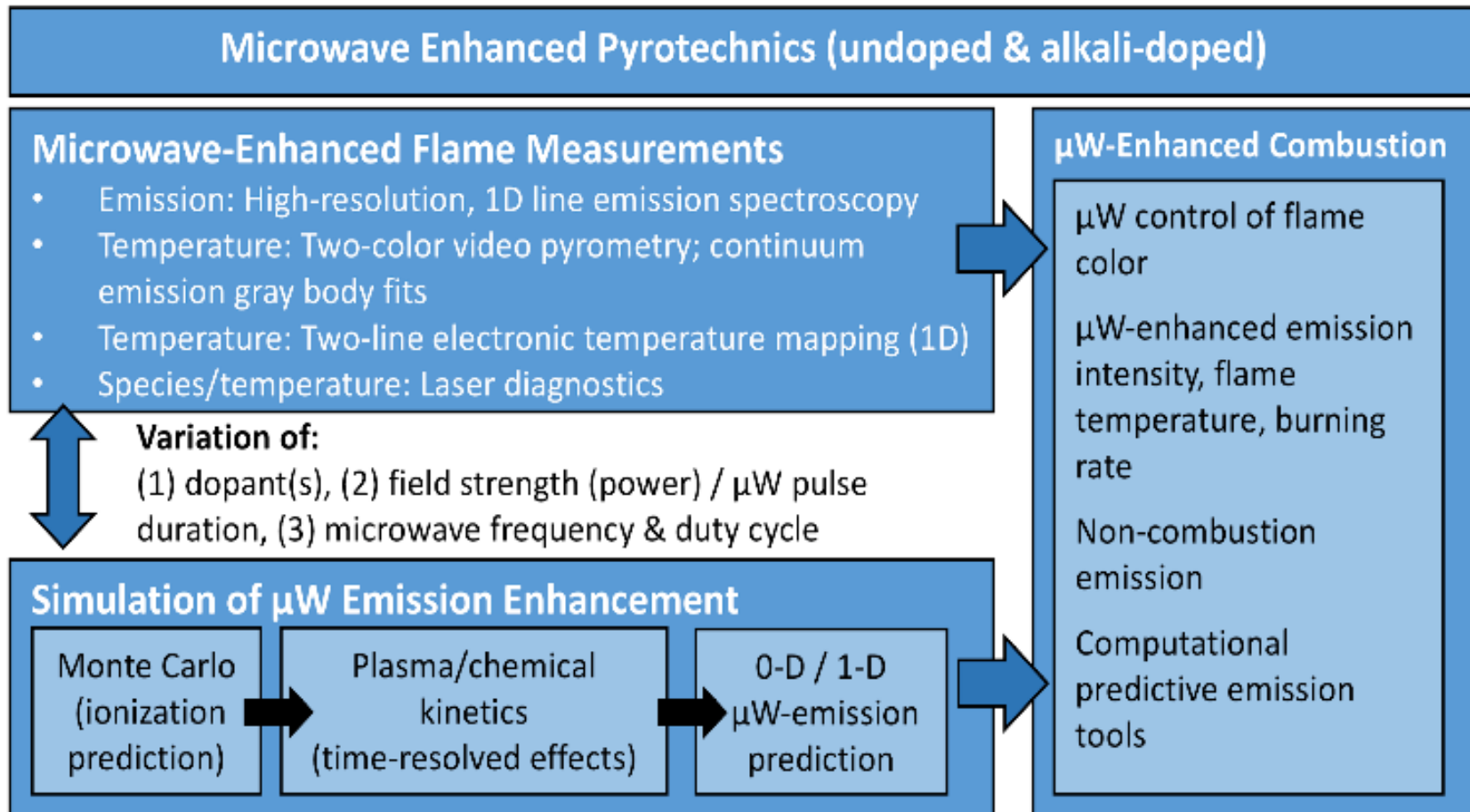
Background

- Next generation of pyrotechnic emitter requires a shift away from emission control via formulations
 - ◆ Hazardous reactants creates the best colors (Sr, Ba, perchlorates)
 - ◆ Light emission by formulations and chemistries
 - ◆ No on-command control of color or intensities- requires multiple formulations
- Ideal solution: Reduce the toxicological and environmental impact while having on-demand multi-color, multi-purpose pyrotechnics

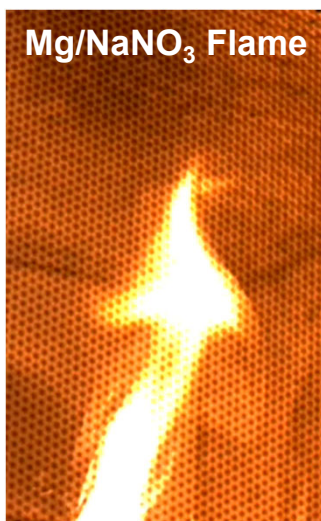
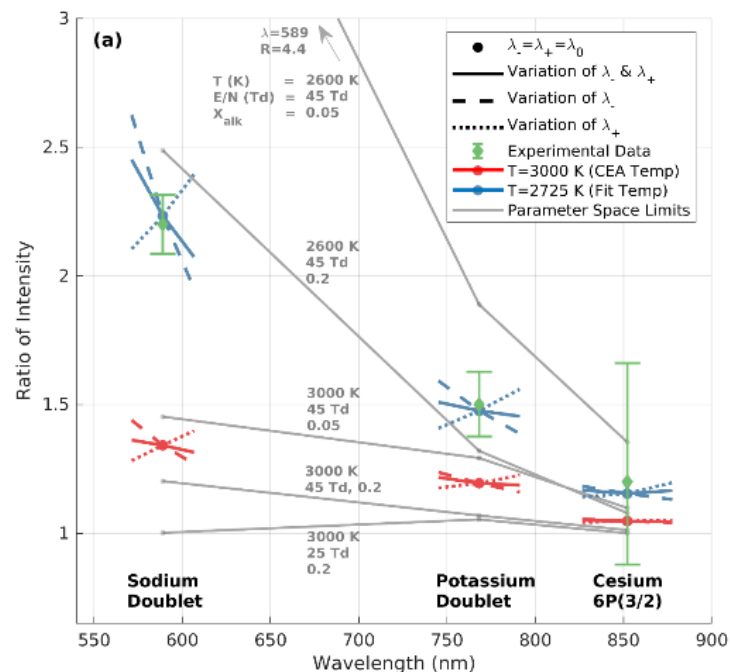
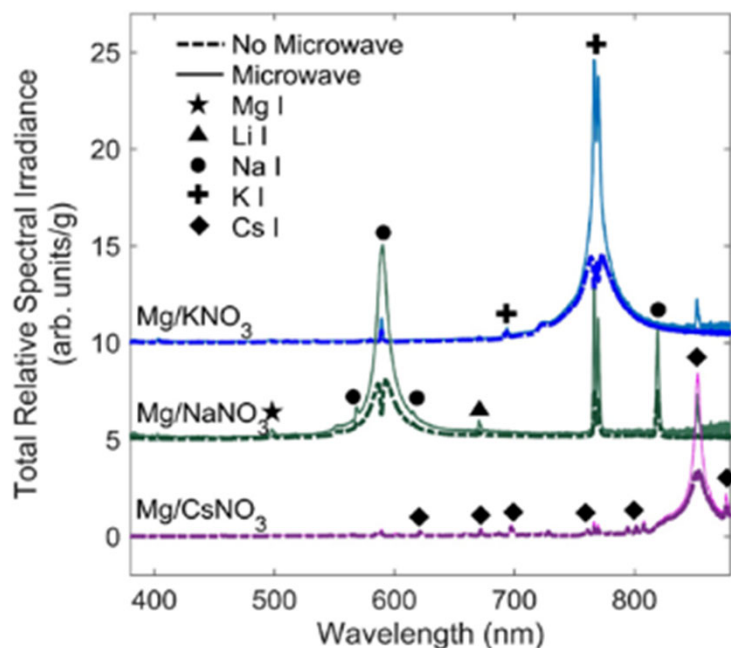
Technical Objectives

- Extending light emission profiles using high power microwaves
 - ◆ Microwave fields interact with flame products resulting in:
 - Excitation of molecular/atomic species that emit in UV/VIS
 - Depositing energy in condense phase products- enhanced gray body emission
 - Sustainment of light emission via continue excitation
- This effort explored understanding fundamental mechanism of microwave coupling
 - ◆ Experimental determine best formulations/mechanisms
 - ◆ Computational investigation with 0-D Monte Carlo Simulation

Technical Approach

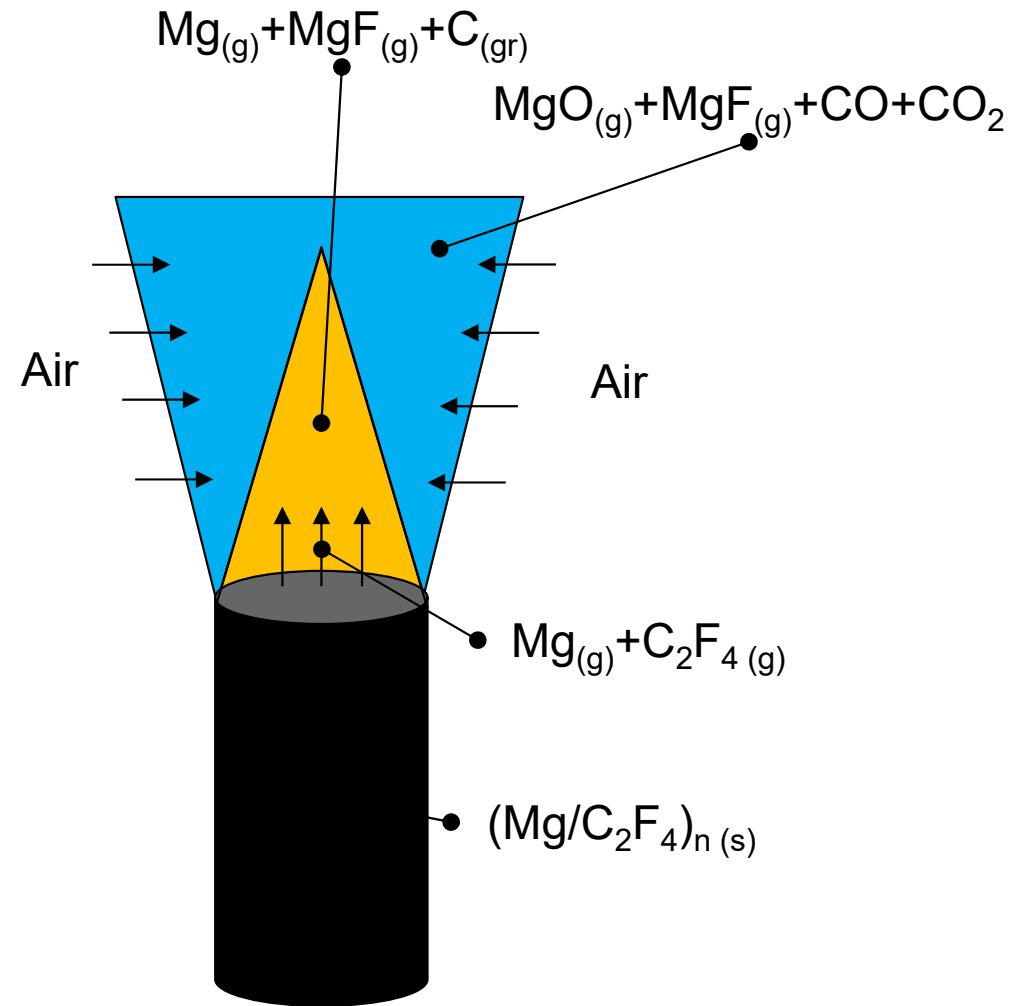
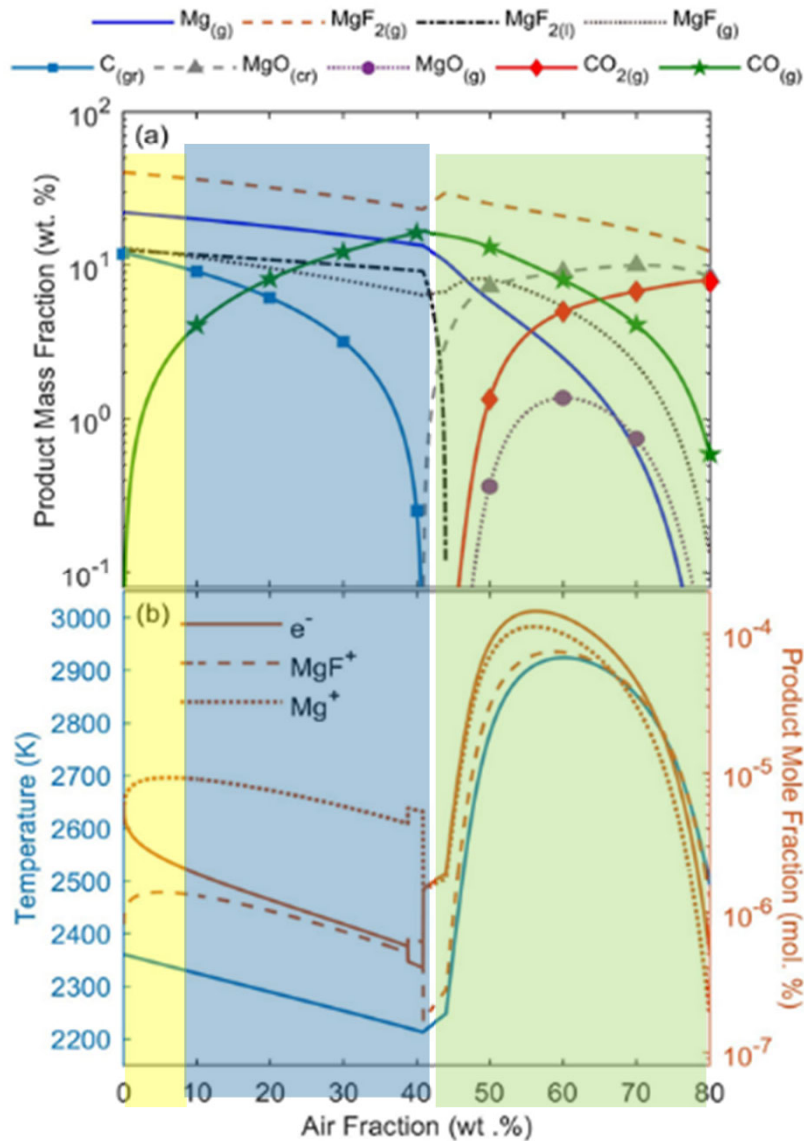


Results: Control of Light Emission Intensity

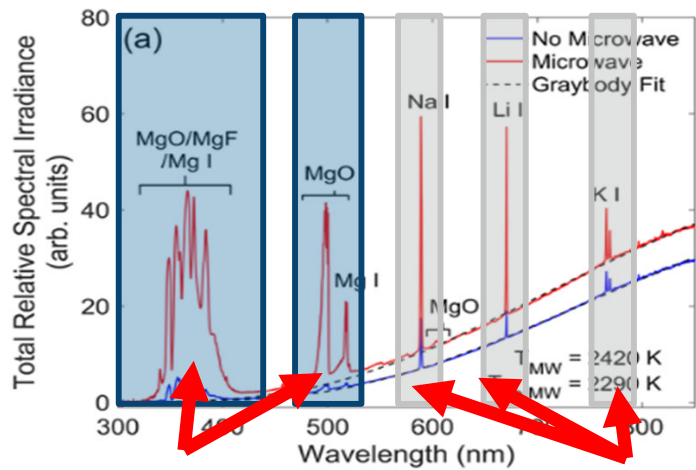


Species	Wavelength (nm)	Transition	Spontaneous Emission Rate, A_{ki} (10^8 s^{-1})	Transition Energy (eV)
Cs I	852.1	6s-6p	0.328	1.455
Na I	819.1	3p-3d	0.495	1.514
K I	767.6	4s-4p	0.385	1.615
Na I	589.2	3s-3p	0.615	2.104
Mg I	517.8	3s3p-3s4s	1.040	2.394

Results: Mg/PTFE Flame Chemistries

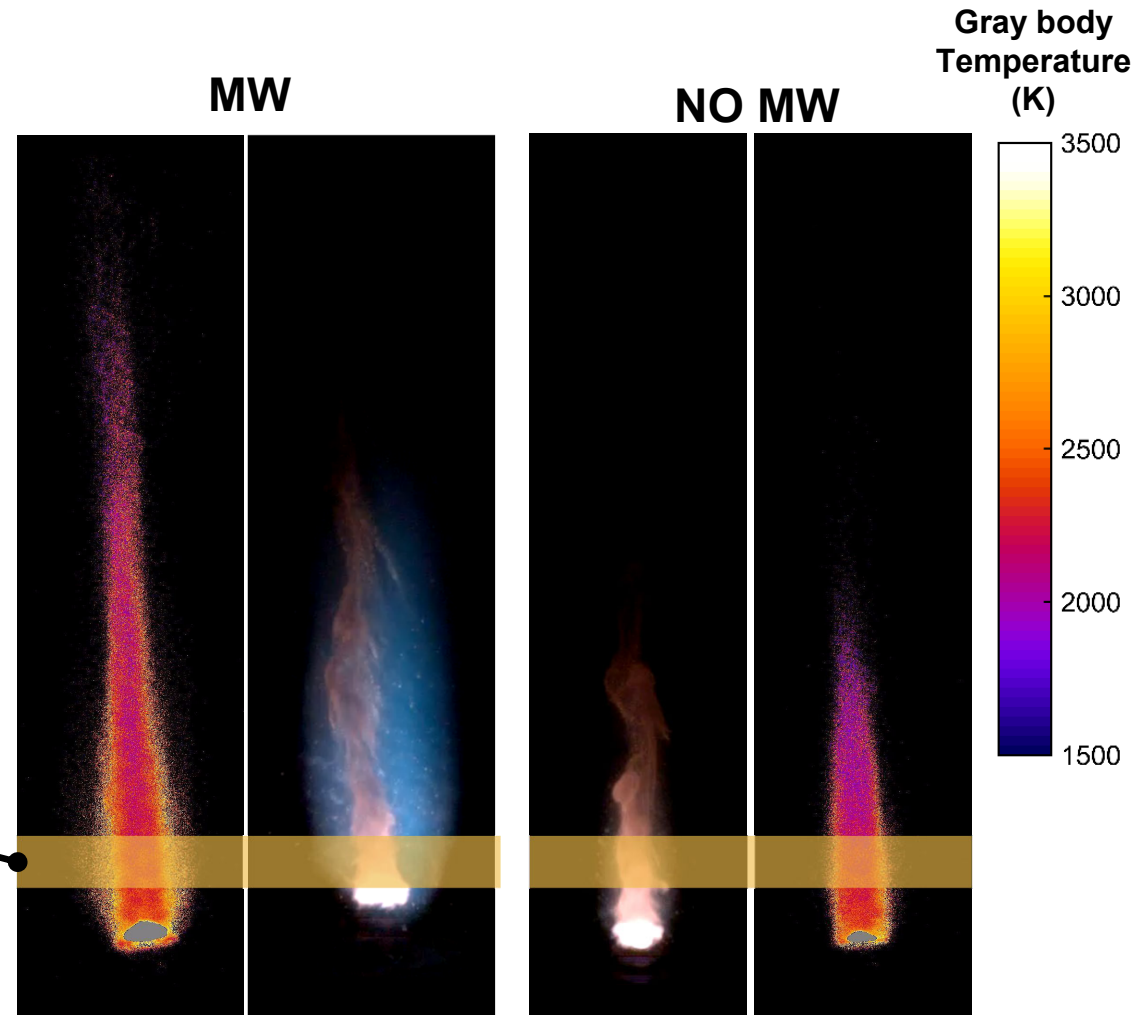
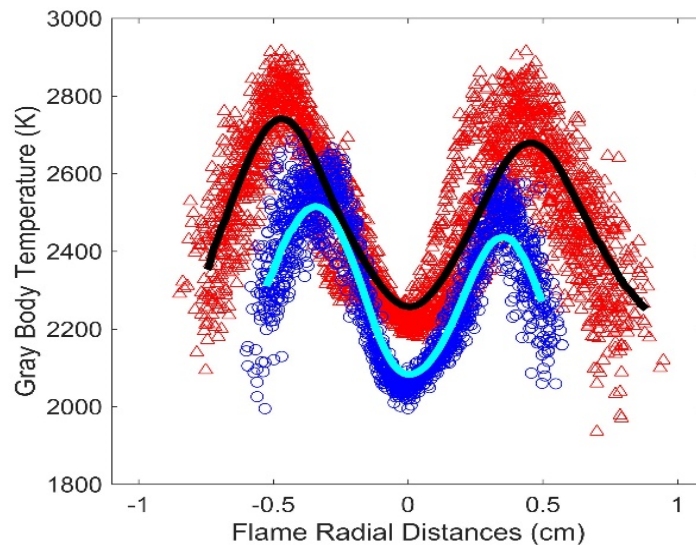


Results: Flame Temperature Enhancement

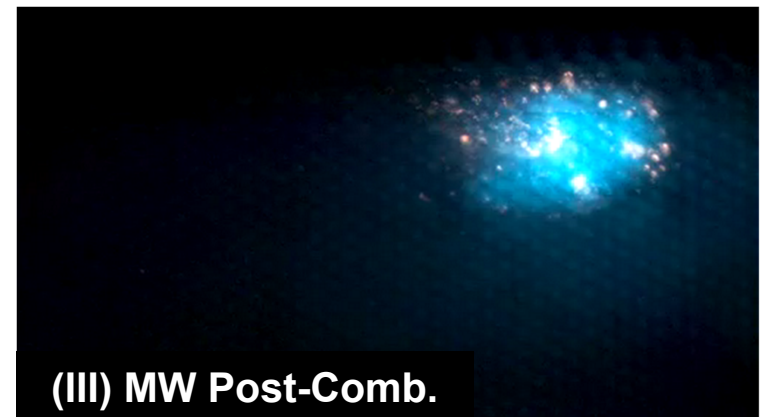
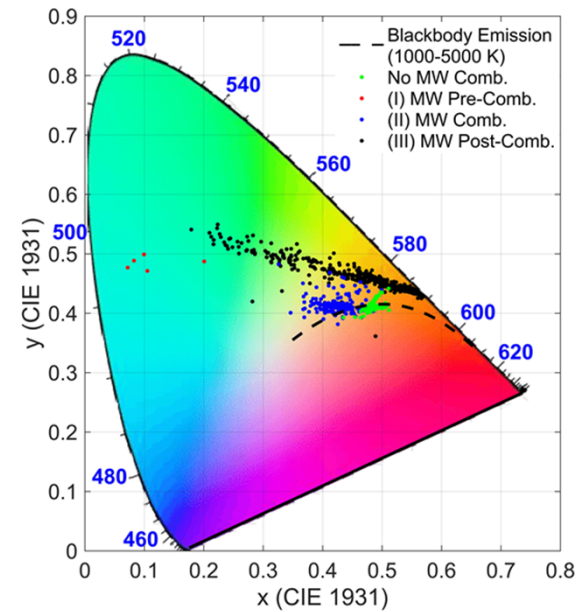
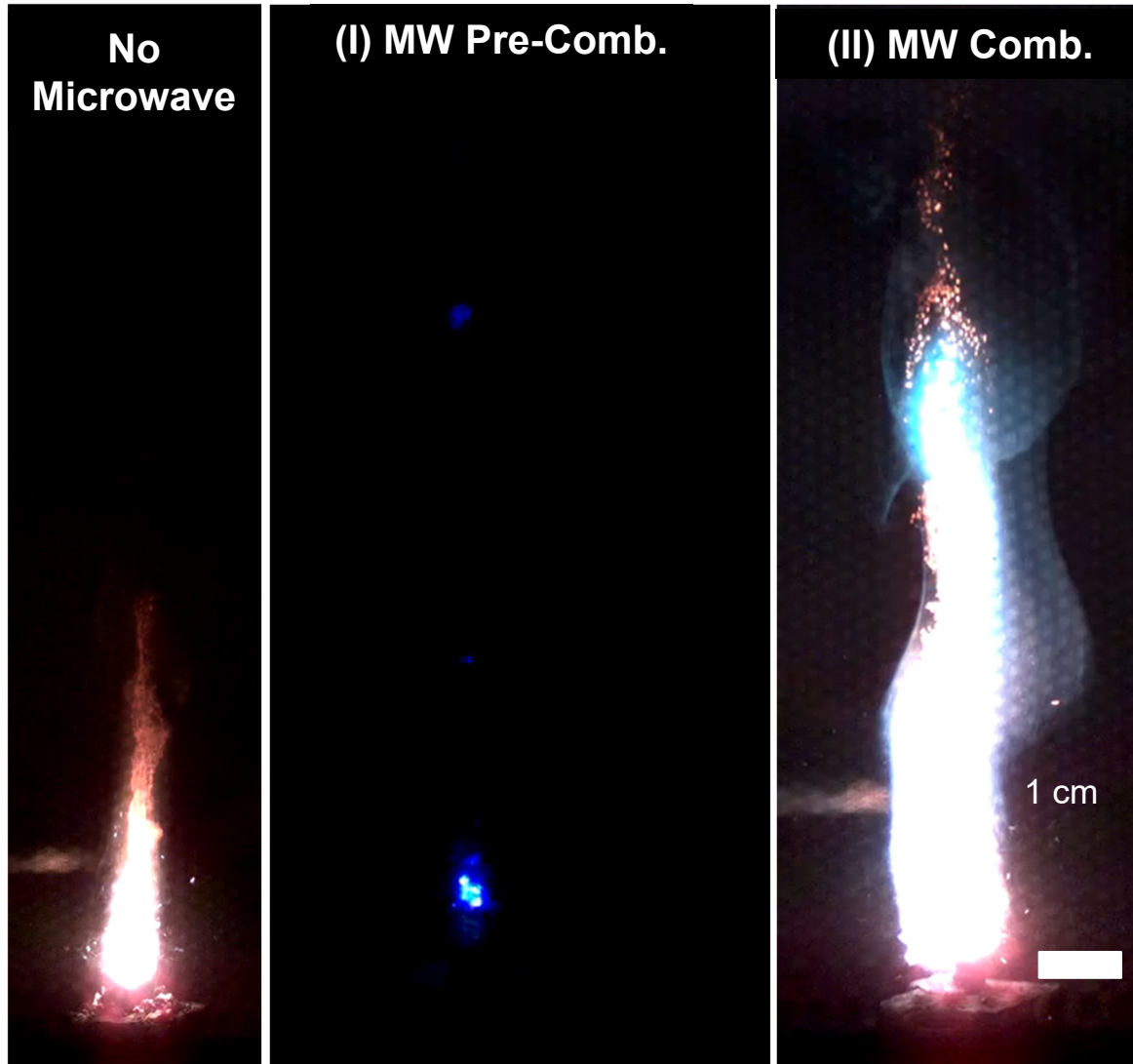


Molecular Band Enhancement

Atomic Band Enhancement

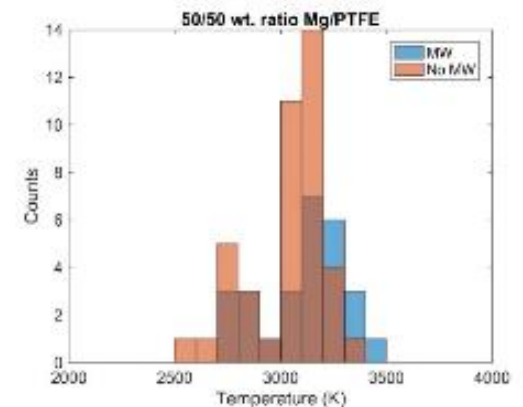
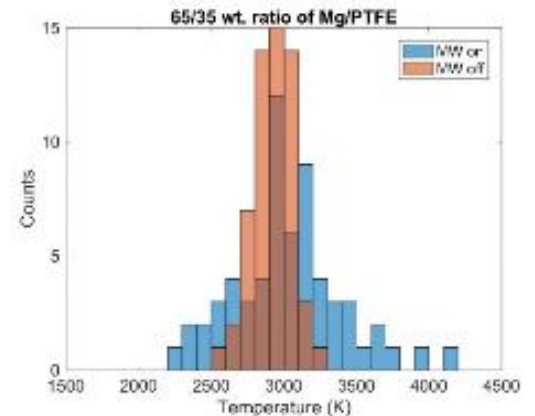


Results: Shifting Color

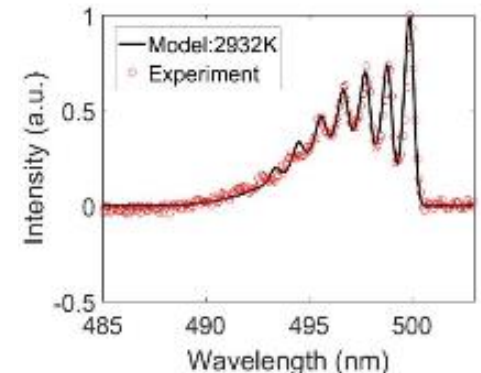
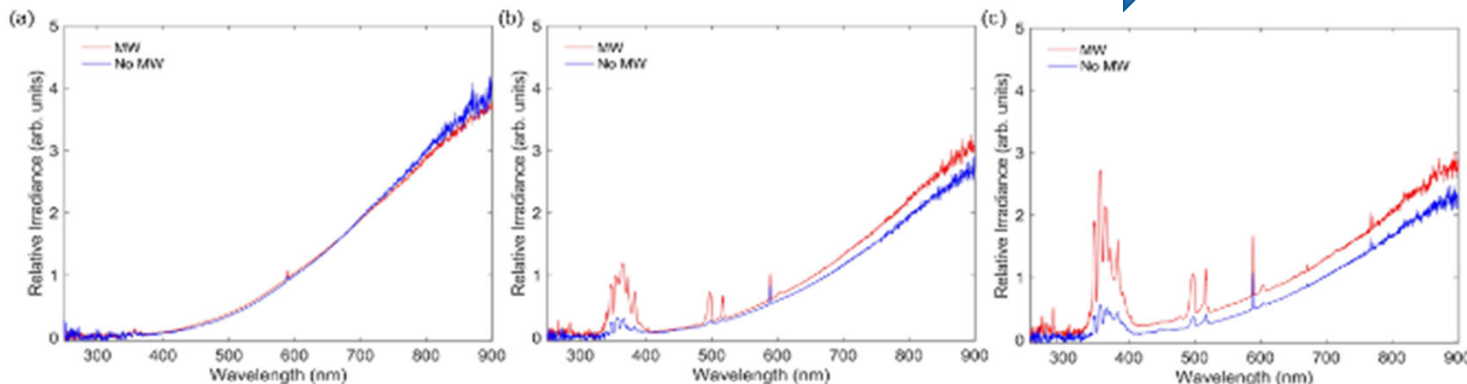


Results: Diffusion Flame Effects

- Investigation of diffusion flame effects on Mg/PTFE combustion
- Three formulations chosen: 35/65, 50/50, and 65/35 wt. % Mg to PTFE
- 35/65 wt. % Mg/PTFE saw no microwave enhancement
- Increase diffusion flame resulted in increase blue emission from MgO/MgF
- Due to diffusion flame higher temperatures and more oxidization of Mg

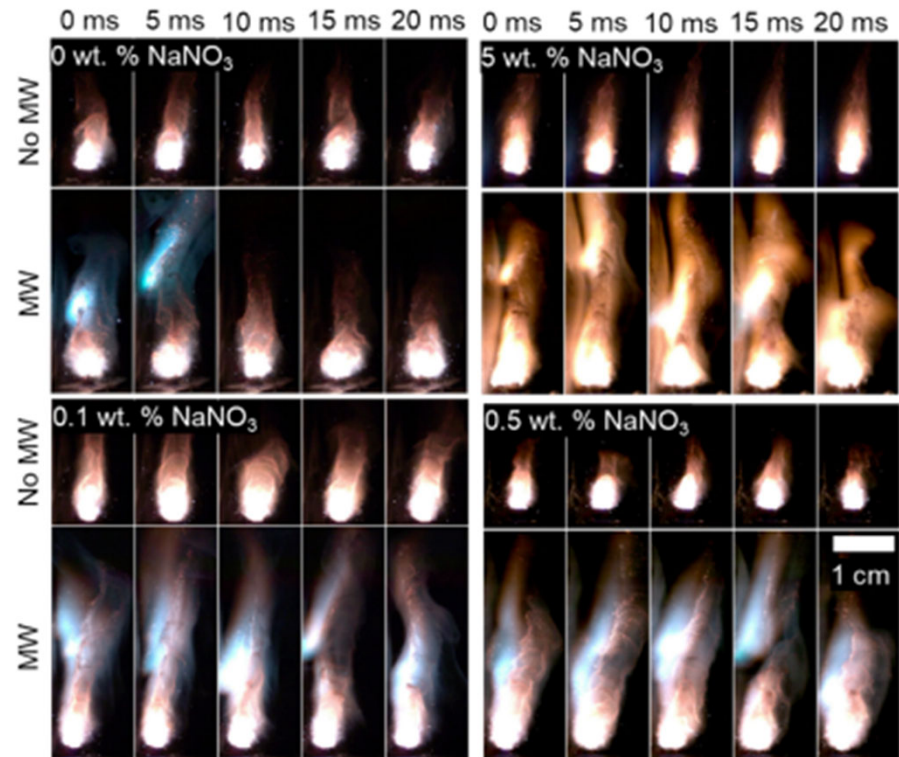


Increase Fuel Content



Results: Free Electron Population

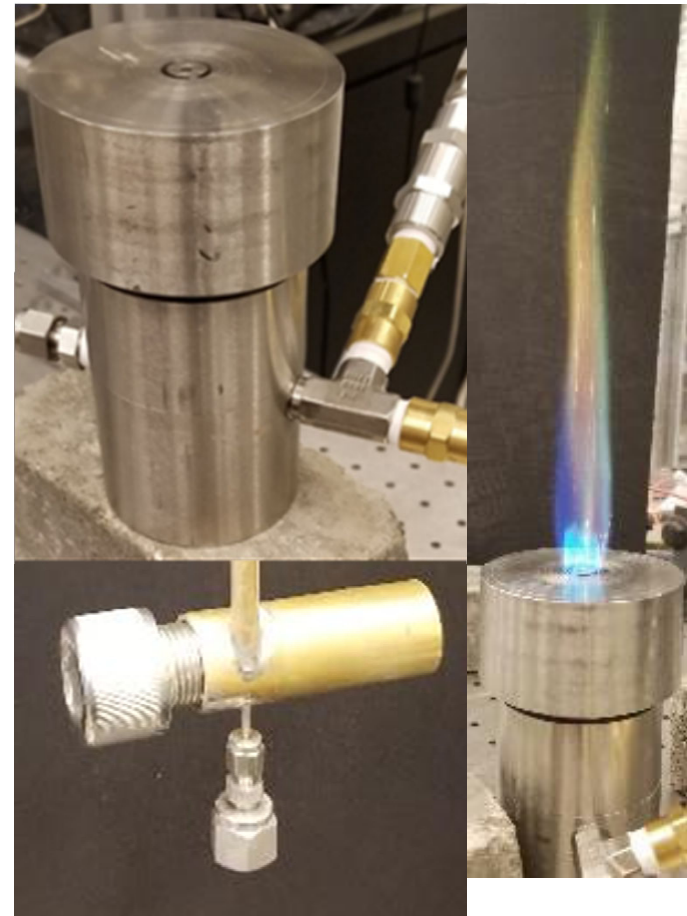
- Free Electron population enhancement investigated for color/light intensity modulation of 50/50 wt.% Mg/PTFE pyrotechnics
- Increase NaNO₃ -> Increase free electrons
- Field coupling increased for increasing NaNO₃ content
- 5 wt.% NaNO₃ was dominated by Na D-line, which appears more orange
- Blue emission features is expected to be caused by MgO green bands
- Slight doping between 0.1-0.5 wt.% may be key to increase emission of other pyrotechnic formulations



Mg/PTFE (1/1)
/NaNO₃ (varying)

Results: Premixed Metal Particle Burner

- Burner designed for stable acetelyne-air flames and injection of small clusters or individual metal particles through flame axis
- Flame equivalence ratio controlled with a mass flow controller
- Metal powders injected using a nitrogen flow across a coated screw
- Sodium injection accomplished using a separate aerosolizing feeder system



Next Steps

- Continue investigation of formulations
 - ◆ Effects of Na doping increase to a limit before shielding problems
 - ◆ Study of E-field strength effects
 - ◆ Exploring other color emitters such as Li (red) and B (green)
 - ◆ Validating model in an experimental system
- Exploring options for power delivery on target
 - ◆ Understanding limitations of RF/Microwave systems
 - ◆ Exploring pulse rate/duty cycle for lowering average power
 - ◆ Refining field strength requirements for plasma generation

Technology Transfer

- Presentations:
 - IPS Seminar 2022
 - American Physical Society Division of Plasma Physics Meeting 2019
- Publications:
 - Microwave-assisted modulation of light emission intensity in alkali-pyrotechnic plumes, C&F 2021
 - Microwave-assisted modulation color and flame temperature in Mg/PTFE pyrotechnic flames (in preparations)

Key Points

- This effort demonstrated the ability to use microwave fields to
 - ◆ Modulate or Strobe
 - ◆ Increase light intensities
 - ◆ Increase flame temperatures
 - ◆ Change colors
- Exploring power delivery on pyrotechnic targets is key to transitioning work

Future Research

- Exploring other ways of depositing microwave energy to control energetic materials
 - ◆ Targeting the condense phase through ignition
 - ◆ Thermally switchable energetics to target burning surface
- Investigating other spectral effects in the EO/IR/RF
 - ◆ Tune-able countermeasures
 - ◆ Pyrotechnics as RF antennas

BACKUP SLIDES

Publications

- Microwave-assisted modulation of light emission intensity in alkali-pyrotechnic plumes, C&F 225 2021
- Microwave-assisted modulation color and flame temperature in Mg/PTFE pyrotechnic flames (in preparations)
- IPS Seminar: Microwave Enhancement of Pyrotechnic Flames 2022
- American Physical Society Division of Plasma Physics Meeting 2019

WP19-1163: On-Command Pyrotechnic Light Emission Through Controlled Electromagnetic Irradiation

Performers: Dr. Jon Dilger, Dr. Eric Miklaszewski, Will Crespo, and Dr. Stuart Barkley

Technology Focus

- *This technology could deliver a tunable, multi-color, multi-purpose pyrotechnic, where environmental impact is achieved via reductions in size, weight, and numbers of military flare inventories.*

Research Objectives

- *The overarching aim of this effort is to develop a fundamental understanding of how to use microwave energy to control the emission color and brightness of a pyrotechnic flame through targeted energy deposition to color-emitting species within the flame or to one/multiple flame colorant dopants.*

Project Progress and Results

- *Efforts have demonstrated that microwave light emission enhancement can be extracted from a number of pyrotechnic formulations illuminated by a free-space microwave field and a number of different effects have been demonstrated*

Technology Transition

- *ONR-351 Microwave control of energetics*

