PYROMETRY CALIBRATION METHOD FOR USE IN Z-PINCH FUSION PROPULSION DEVELOPMENT

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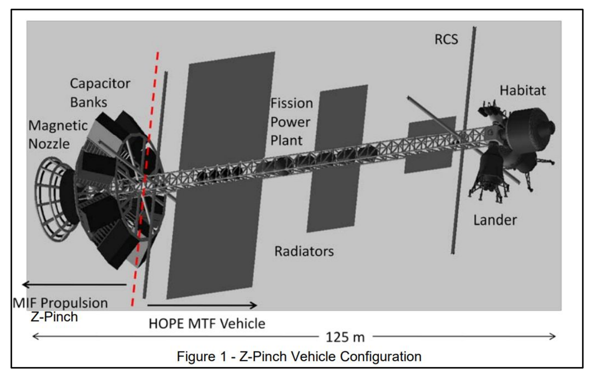
Fusion Spacecraft Propulsion

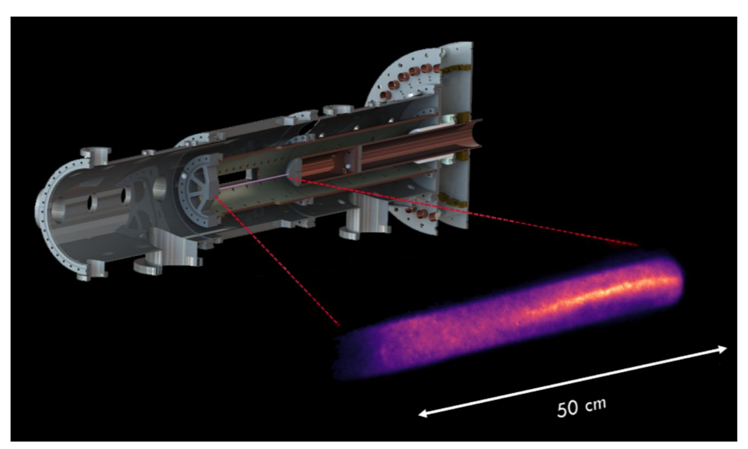
- Fusion Propulsion has the potential of being orders of magnitude more efficient than current methods of spacecraft propulsion.
- Sheared-Flow stabilized z-pinch, researched at the University of Washington, is one of the most viable paths to commercial fusion energy and viable fusion propulsion.



Z-PINCH SPACECRAFT CREDIT: NASA

Sheared Flow Stabilized Z-Pinch Fusion

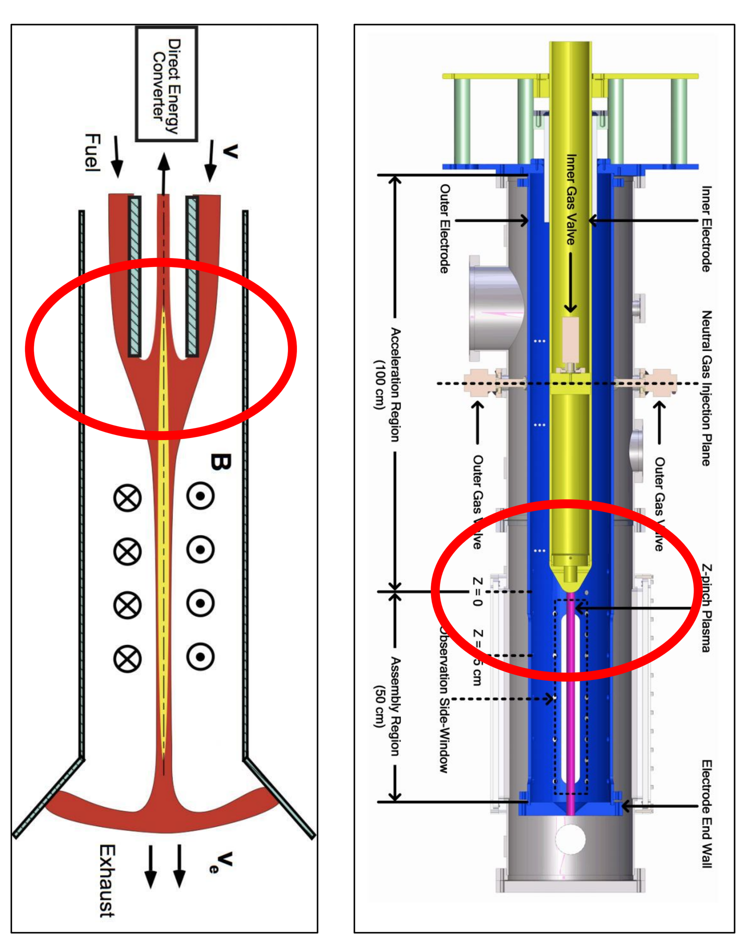
- The ZaP-HD (Z Pinch High Density) device researches the physics of Z-Pinch based magnetic confinement, and it's potential to maintain viable fusion conditions.
- The system creates fusion pressure and temperature conditions by pulsing 9kV through a plasma to induce toroidal magnetic fields to confine and compress the plasma to fusion conditions.



SHEARED FLOW OPERATION CREDIT: ZAP ENERGY

Section Title

- Electrical current is applied to the generated plasma to form the z-pinched plasma.
- This current is applied through a graphite electrode on the interior of the device.
- Temperatures of this electrode are not well understood. Sublimation estimates based on Carbon detection on the plasma estimate temperatures exceeding 3800 Kelvin at the surface.
- Z-Pinched power or propulsion systems pulse at 50Hz. This heat transfer needs to be characterized to influence the design of sustainable electrode designs for sustained reactor use.



MAGNETIC CONFINEMENT AND ZAP-HD DIAGRAM CREDIT: ZAP LAB – DR. URI SHUMLAK

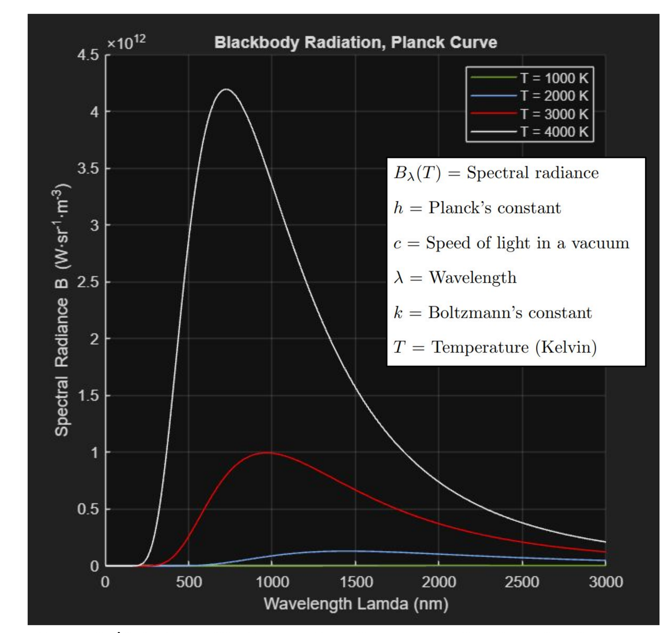
Methods of Thermal Measurement

- Thermocouples (electromagnetic interference and temperature resilience)
- Infrared Cameras (interference from light generated and reflected from the high-density plasma)
- Dual-Wavelength Pyrometry (enables low resolution thermal emission detection)

Pyrometry Overview

$$B_\lambda(T) = \frac{2hc^2}{\lambda^5}\frac{1}{e^{\frac{hc}{\lambda kT}} - 1}$$

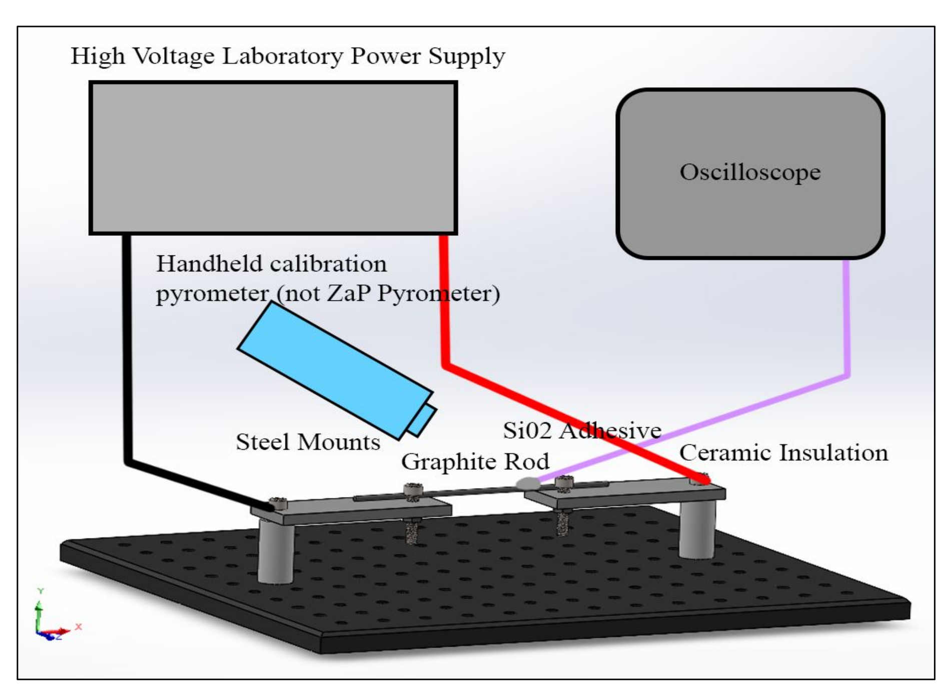
- Planck's law relates spectral radiance to temperature of an idea "blackbody".
- **By measuring wavelength intensity, temperature can be determined (Pyrometry)**
- Real objects are not ideal blackbodies and reflect/absorb different wavelengths of light.
- Dual-wavelength pyrometers measure the intensity of two wavelengths and **use a calculated linear relationship from the ratio of the two intensity measurements to determine temperature**.
- Dual-Wavelength pyrometers cancel out emissivity and other environmental factors.



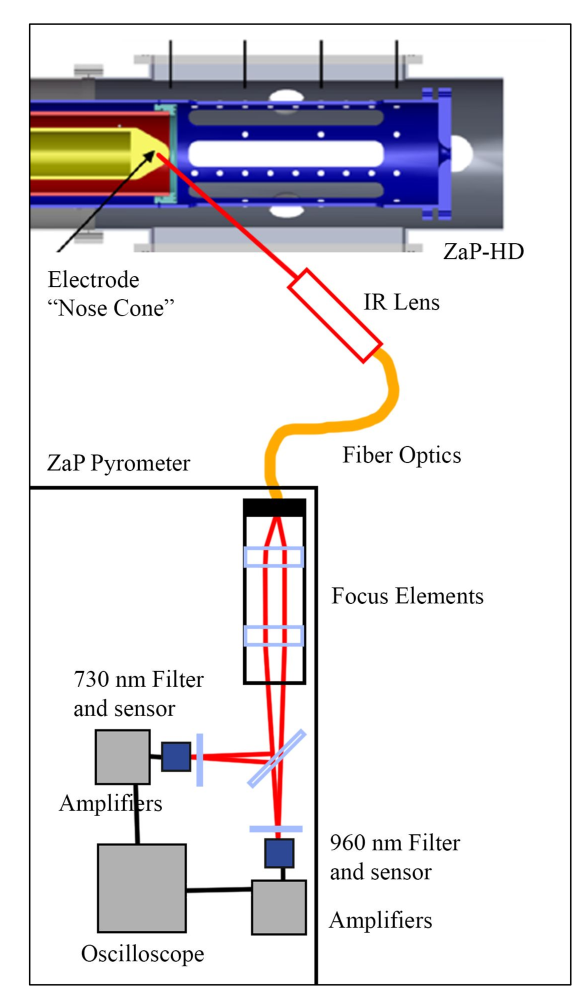
PLANCK'S CURVE CREDIT: ZAP LAB – WALKER HOLMQUIST

ZaP Pyrometer, Calibration Method, and Target Design

- Pyrometry target uses resistance to heat a graphite rod to Si02 adhesive limits of up to 1500 Celsius.
- Temperature difference between thermocouple measurement and graphite temperature will be modeled empirically through use of a hand-held low temperature pyrometer at steady state conditions.



ZAP PYROMETER TARGET DIAGRAM CREDIT: ZAP LAB – WALKER HOLMQUIST



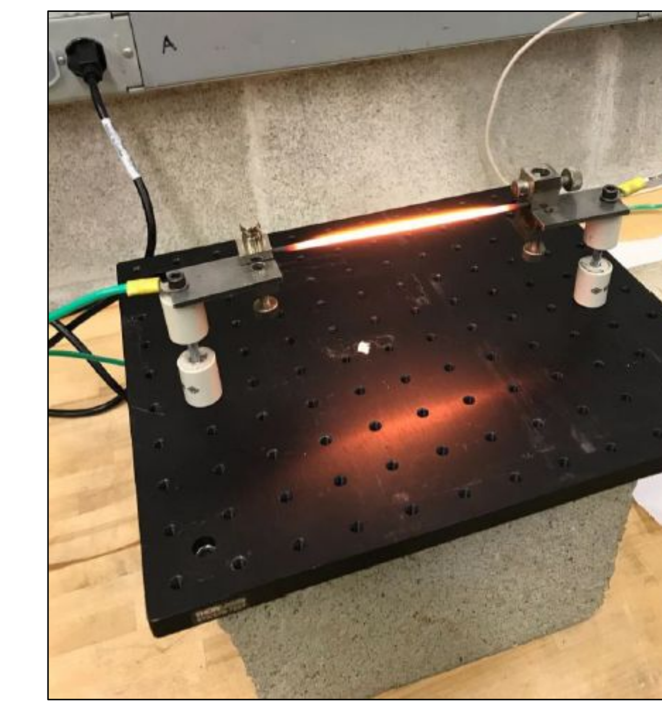
ZAP PYROMETER DIAGRAM CREDIT: ZAP LAB – AQIL KHAIRI

Preliminary Results and Measurements

- Based on image color, pyrometer target capable of reaching 1500 C.
- Readings were taken off sensors in ZaP Pyrometer, significant EM noise remains from plasma / high voltage conditions.
- Temperature gradient will exist between graphite and thermocouple due to adhesive

NEXT STEPS

- Develop empirical model of thermocouple measurement vs true graphite temperature
- Use target to develop linear relationship (with window accounted for) between ratio of IR wavelength intensities and true temperature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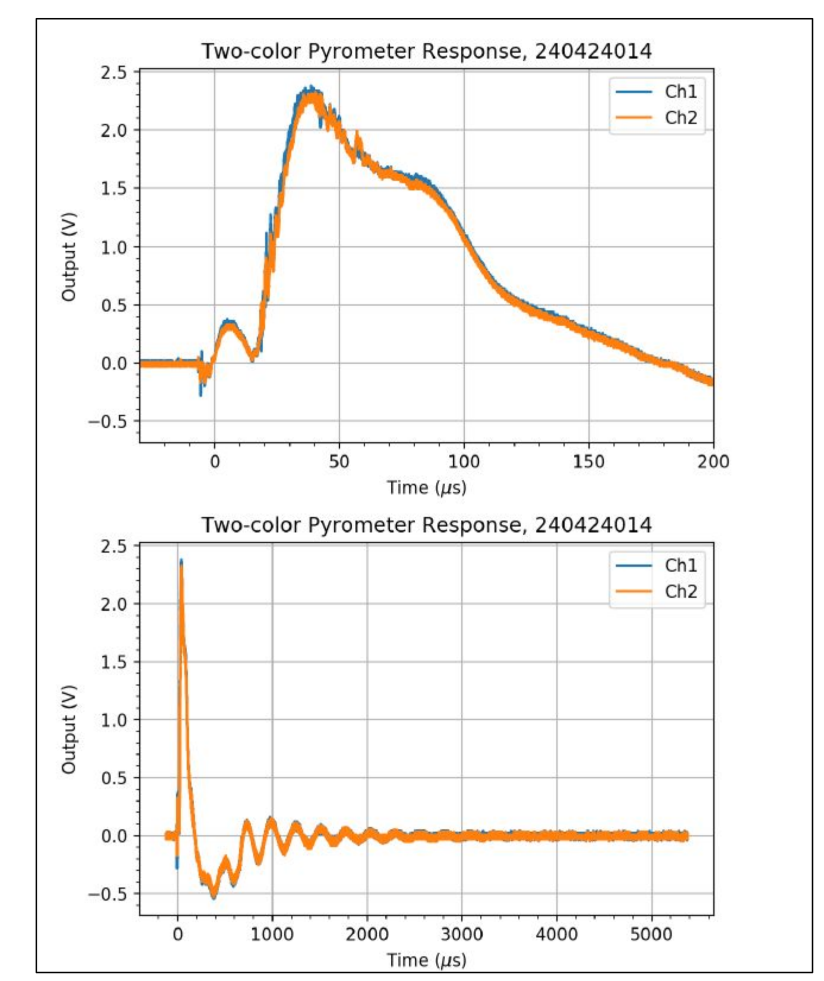

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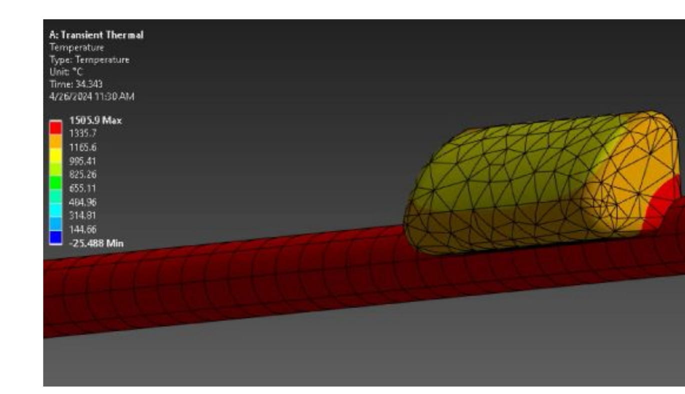
NOTE: Measurements correspond to sensor output not temperature.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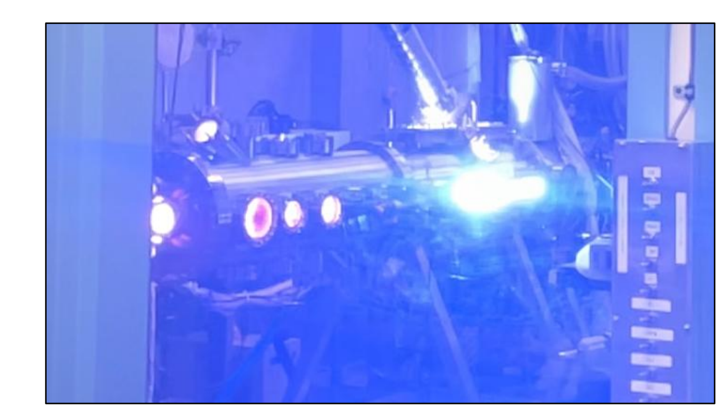
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S Amiel et al 2012 J. Phys.: Conf. Ser. 395 012074

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SPONSORS: WA NASA SPACE GRANT, ZAP ENERGY, DEPARTMENT OF ENERGY