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Shock Layer Radiation Measurements For Planetary Probes

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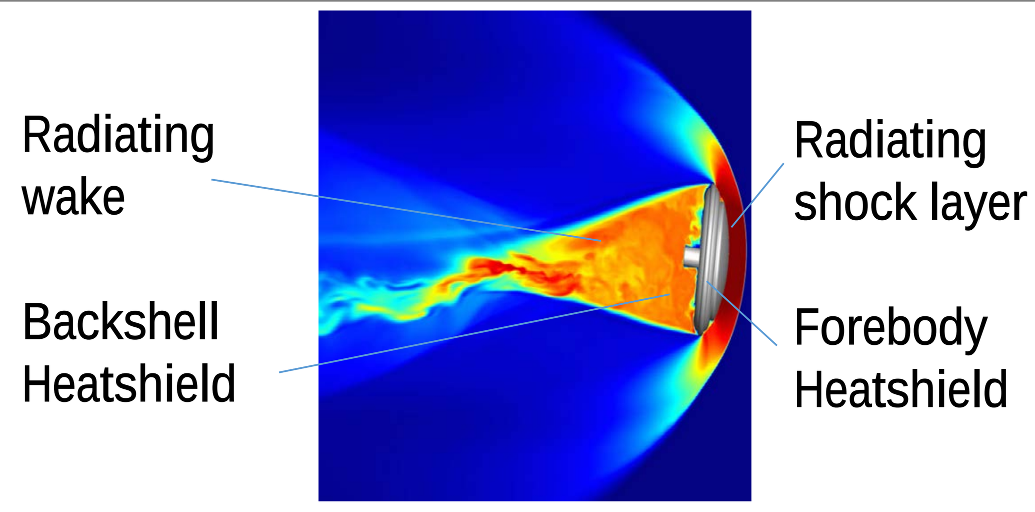
Background and Relevance

- As a probe enters a planetary or lunar atmosphere, entry heating to the TPS can include both convection and radiation. At high masses and speeds, the energized, shocked gas emits significant levels of radiation, characteristic of the gas cap's state.
- Shock layer radiation to a planetary probe's heat shield has been investigated since the 1960s, using ground tests, flight tests, and theoretical modelling. Radiation was a key component of entry heating to Jupiter's Galileo probe, and for Cassini's Huygens probe lander to Saturn's moon Titan with UV CN radiation.

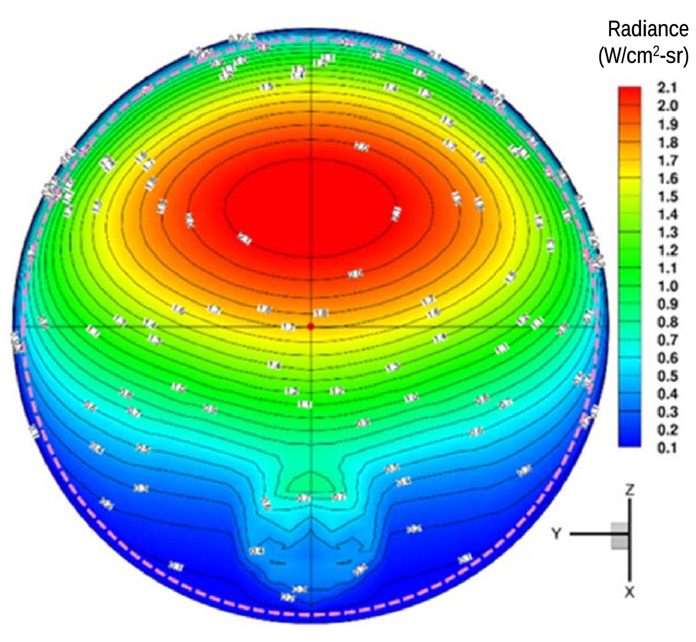


- High fidelity radiation simulations are used to model shock layer radiation for past and future missions, and experimentally validated with high resolution spectrometers in Electric Arc Shock Tube (EAST) tests.
- In future missions, such as Orion high-speed lunar return missions, shock layer radiation is predicted to have a major impact on TPS heating. Outer planet missions to Neptune are expected to have high levels of shock layer radiation.
- Historic and current lab and flight test experience have identified challenges and guided improvements in spacecraft radiation sensors, while spectrometers are miniaturized in commercial and academic laboratories.

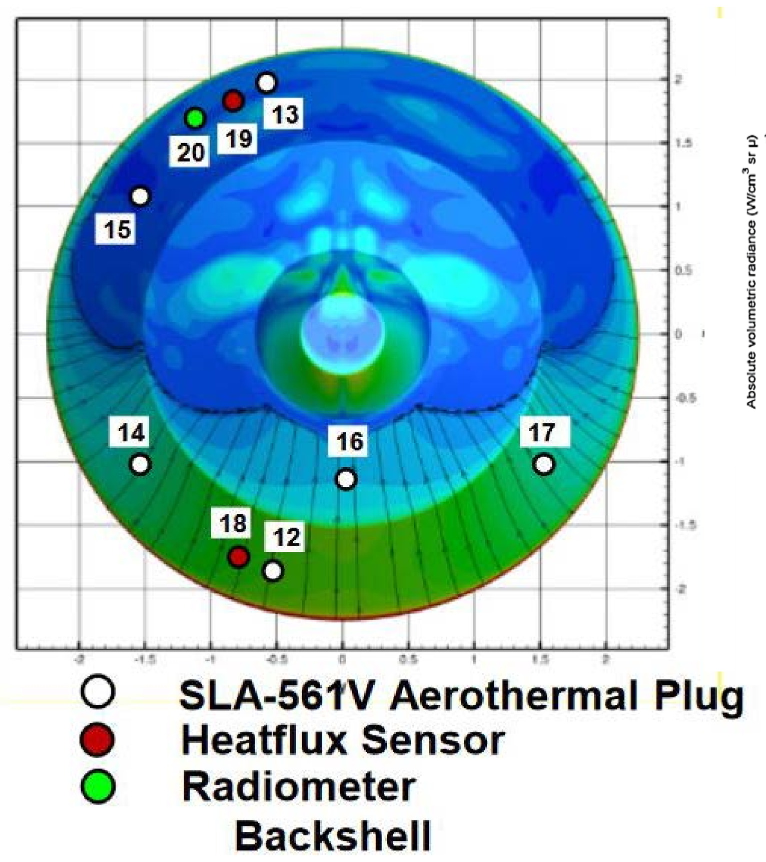
Mission Infusion : Shock Layer Radiation Measurement during Entry

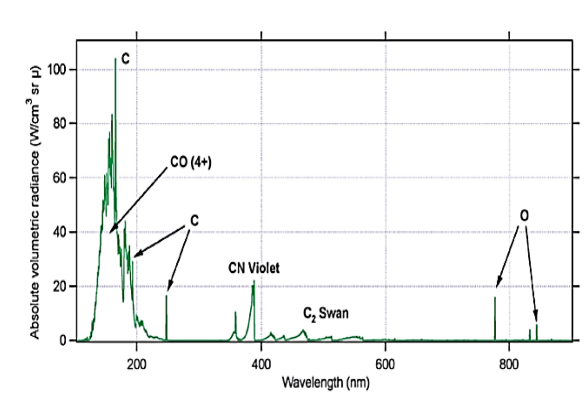
Near Term Missions: Mars and Earth
(Longer term: Venus, Outer planets and Titan)

Mission or Sensor	Radiometers	Spectrometers	Status
MSL EDL Instrument MEDLI-1	0	0	Success Aug 6, 2012 Improved Entry Descent Landing (EDL) Insight
MEDLI-2	1 Backshell	0	Mars 2020
EFT-1	2 Forebody	0	Success Dec. 5, 2014 Results Improved Modelling, Optimization
EM-1	2 Forebody	0	planned 2019
EM-2	1 Backshell	1 Forebody	Planned
EM-3, -4…	hopefully	hopefully	Not Yet Downselected

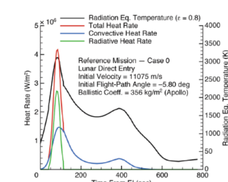


Predicted Mars radiative flux and sensor coverage (Brandis, Cruden, White, Saunders, and Johnston, AIAA 2015-3111)

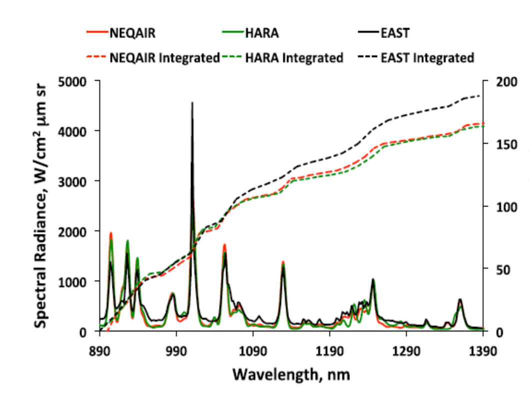




Mars: Representative plot identifying UV/visible lines of shock layer radiation (Grinstead, Wright, Bogdanoff and Allen, 'Shock Radiation Measurements for Mars Aerocapture Radiative Heating Analysis" JTHT 23(2) 2009)



Radiation can dominate entry heating (Robinson et al. JSR 46 (1) 2009)

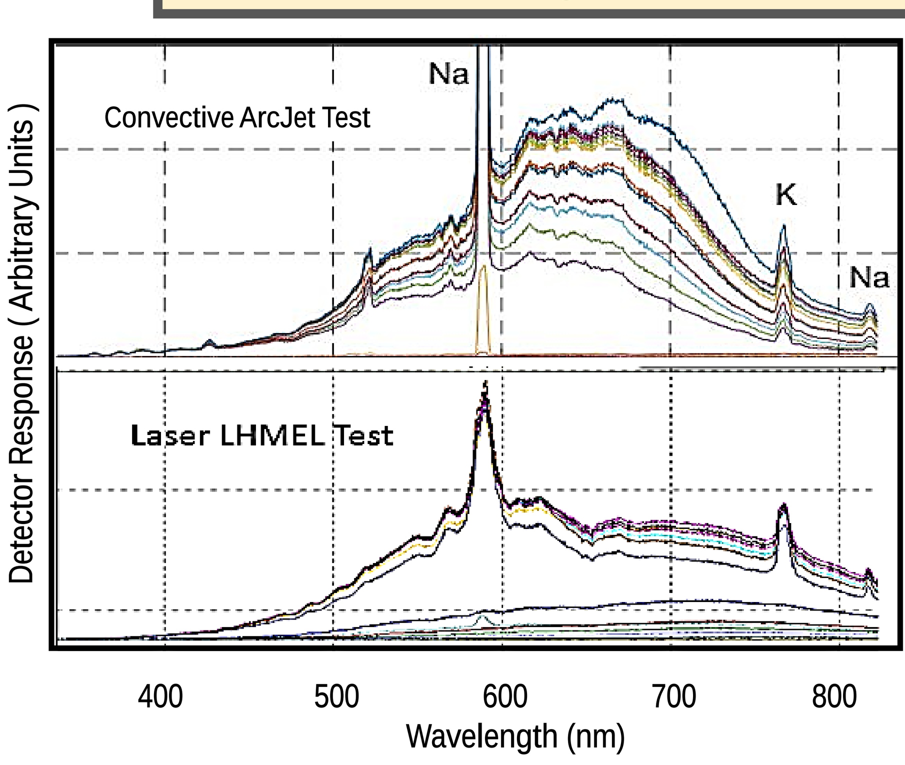


Earth : Representative plot shows shock layer radiation spectral distribution modelling (NEQAIR and HARA) agree well with experiments in NASA Electric Arc Shock Tube (EAST) tests ranging from VUV to IR. (see Brandis et al., JTHT 31, 1, 2017)

Optical Component Testing: Performance, Transmission & Effect of Contamination

This characterization of the radiometer and spectrometer devices' components includes the radiative transport properties of the optical components and surfaces. Previous extensive launch environment and thermal arc jet testing of the radiometer were described by Swanson, Santos, White, Hwang et al. in IPPW-14 2017 in "Mars2020 Entry, Descent, and Landing Instrumentation 2 (MEDLI-2) Do No Harm Test Series". Mini-spectrometers have been pre-conditioned and used on Space Station and on the Mars Rover.

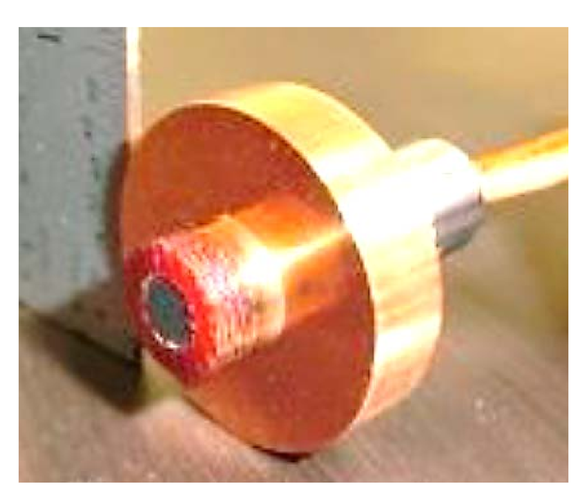
Spectrometer



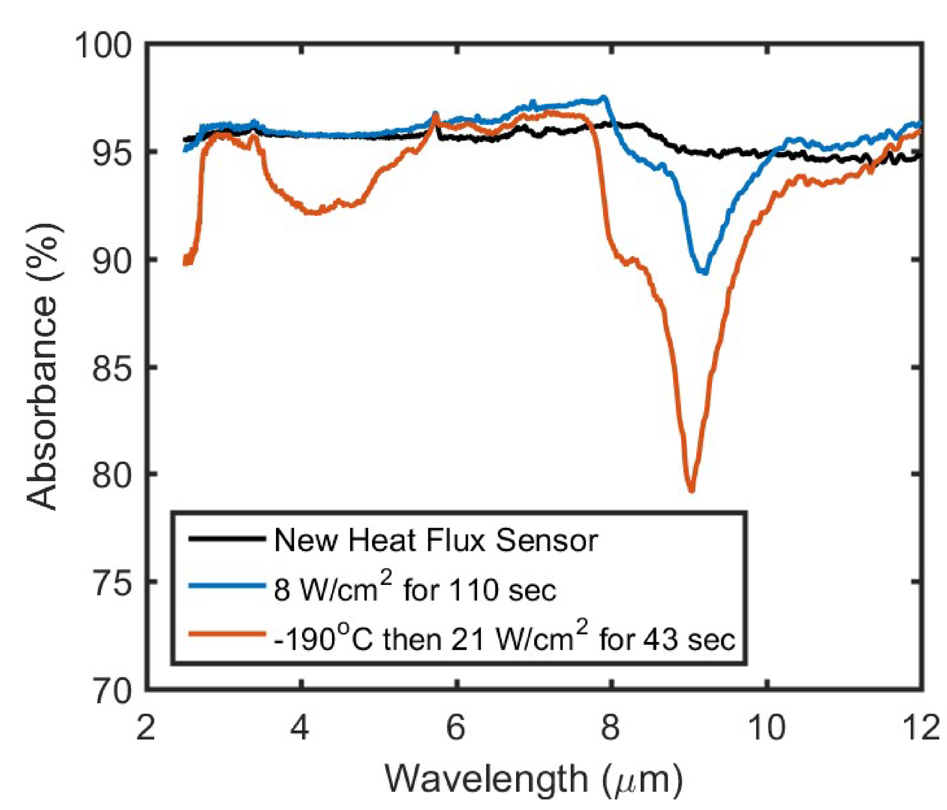
Proof of concept tests: Ocean Optics mini-spectrometers detected the strongest Na and K spectral lines in both Arcjet test and Laser tests above the blackbody thermal radiation background. Multiple scans from time steps shown on each plot show consistent emission over increased thermal radiation from heated surfaces. (MacDonald & White. See also Winter and Prabhu AIAA 2012-0215 for shock layer emission w/o thermal background measured with mini-spectrometers.)

Commercial palm-sized mini-spectrometers
R&D: quantum dots / spectrometers-on-a-chip

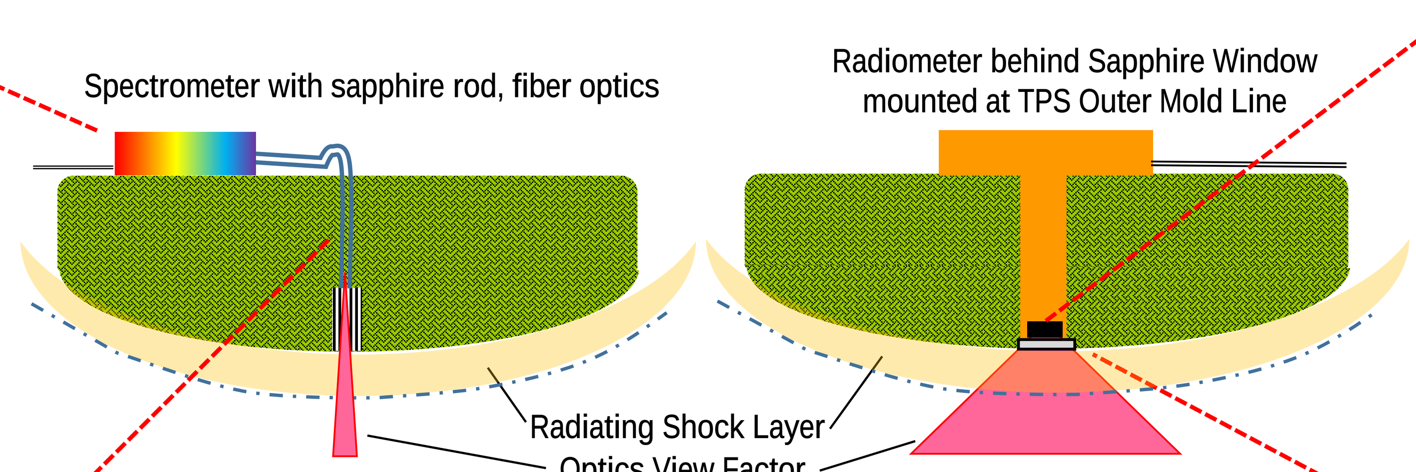
Radiometer

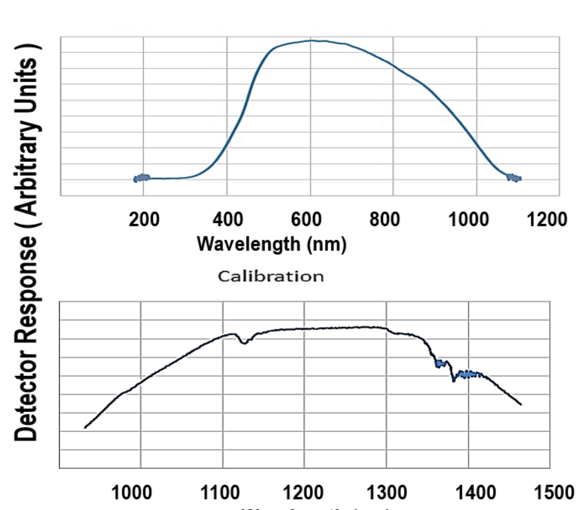


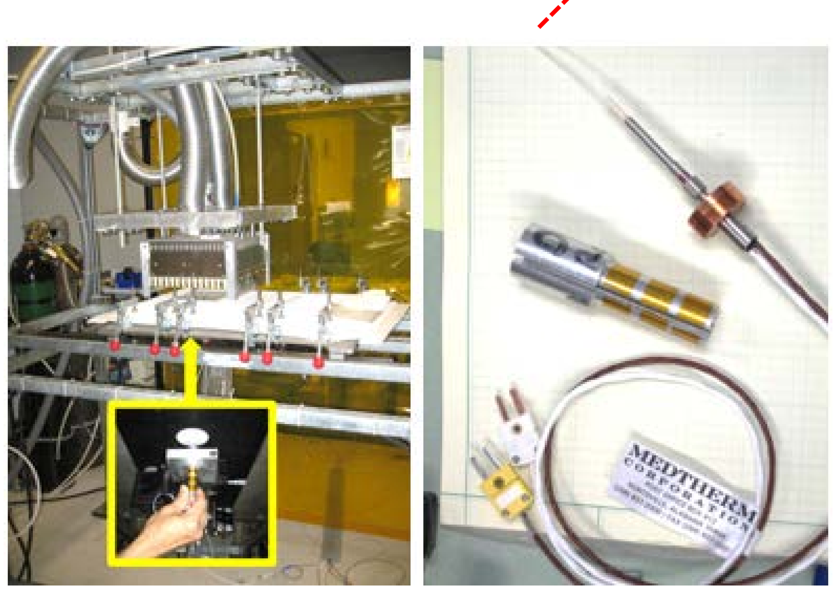
Radiometer sensor / heat flux gage



Measured coating absorbance showed nominal change from imposed heating but degradation after aggressive thermal cycling / thermal shock (Miller & White)

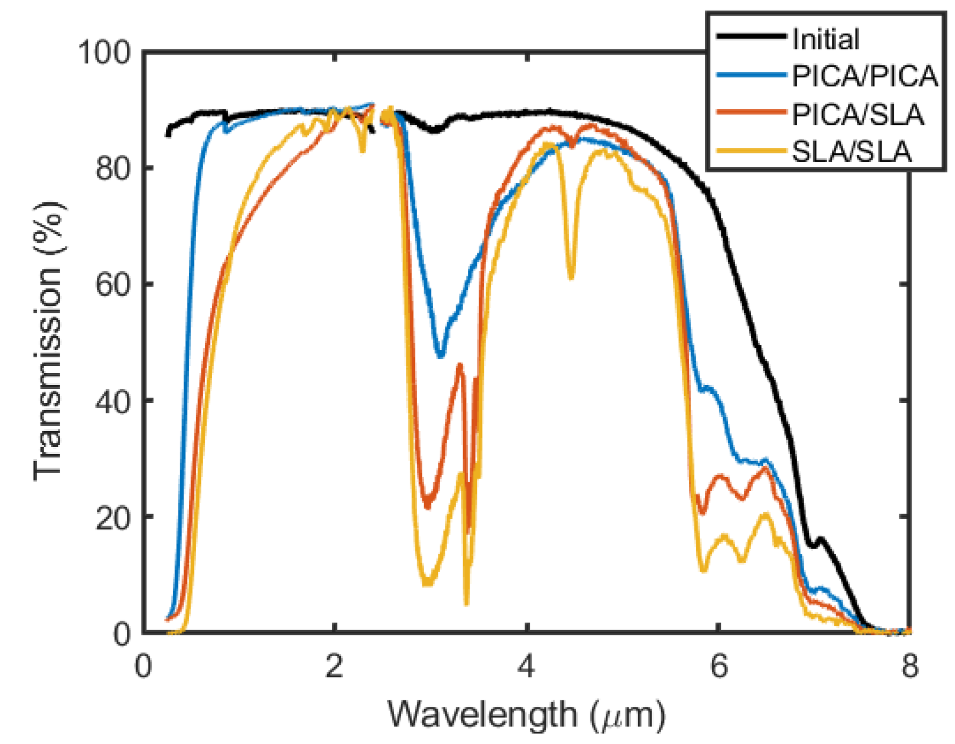






High-temperature sapphire rod coupled to mini-spectrometer configuration was tested using NASA Quartz Lamp source. Plots shown give effect of sapphire rod on system response and a representative calibration using integrating sphere. (Cruden & White)

Sapphire windows shown post-test contaminated by charring ablators



Effect of Window Contamination: UV/Vis and IR radiometer window STP show transmission after mini-ARC screen testing. (Miller & White , see R. Miller et al. "Characterization of a Radiometer Window", AIAA Aviation 2018)

Summary: Entry spacecraft are subject to increasing levels of radiation as they grow more massive and/or on faster trajectory entries. We are characterizing the optical performance of down-selected components to enable robust and accurate measurement of shock layer radiation. Future Work (in progress): Attack challenge of contamination and blockage from ablation boundary layer products of the cold sapphire radiometer window; Evaluate mini-spectrometer function after pre-conditioning and launch into space environment.

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