LASER ABLATION EXPERIMENTS ON THE TAMDAKHT H5 CHONDRITE

Susan White
Eric Stern

NASA Ames Research Center
Moffett Field, California 94035 USA

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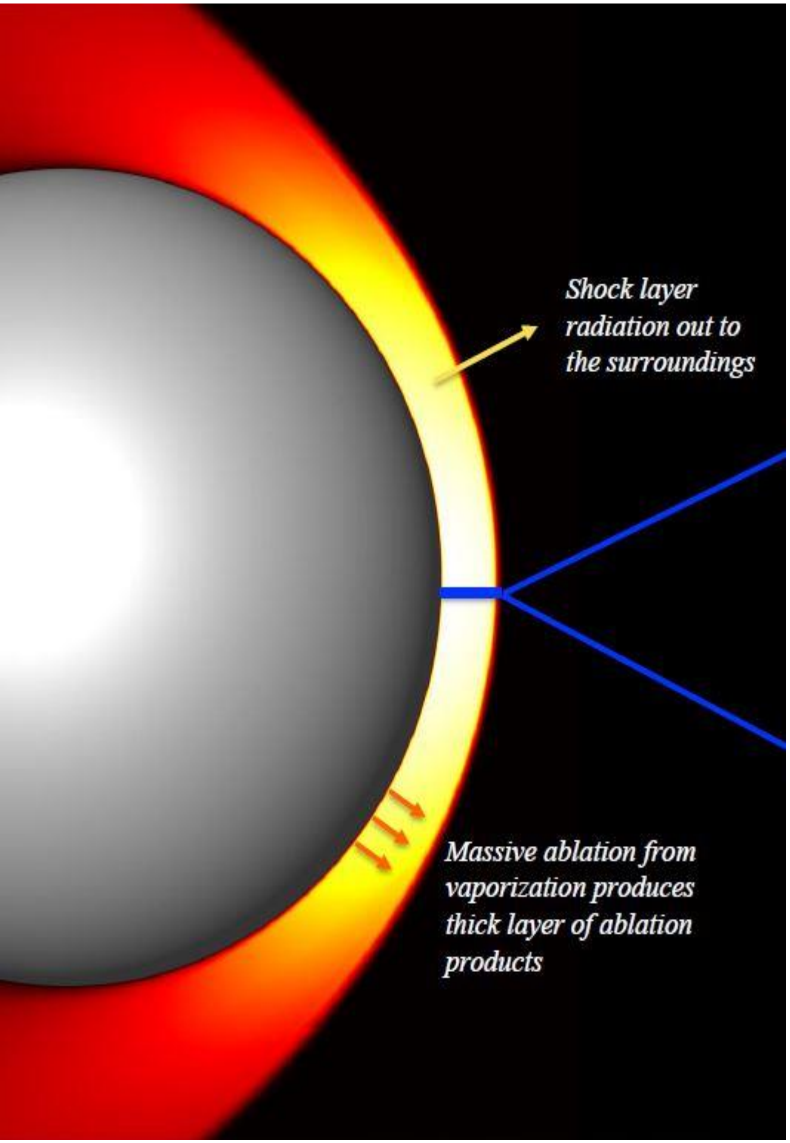
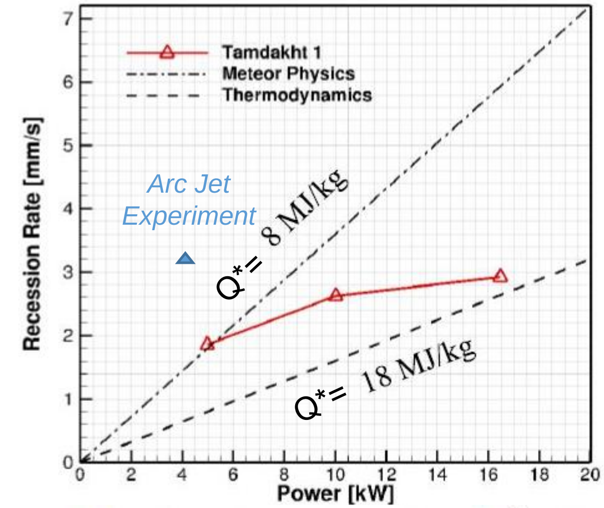
Program Objective: To accurately assess asteroid entry threat

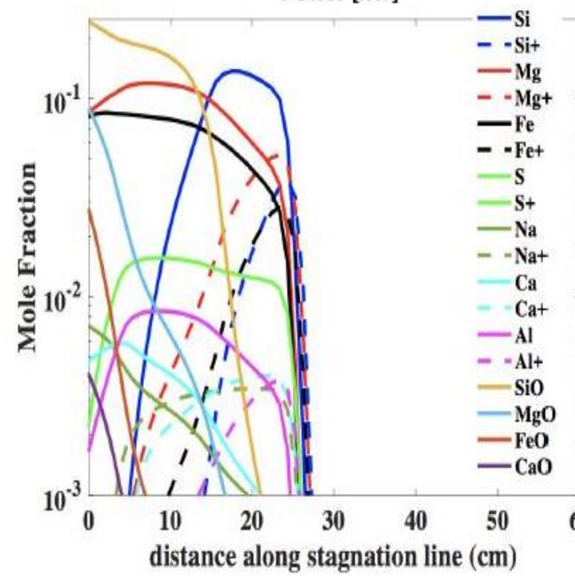
NASA is performing experimental testing and high-fidelity numerical model development under the Asteroid Threat Assessment Program (ATAP).



Thermal modelling: Experiments can provide better inputs into traditional "heat of ablation" models.



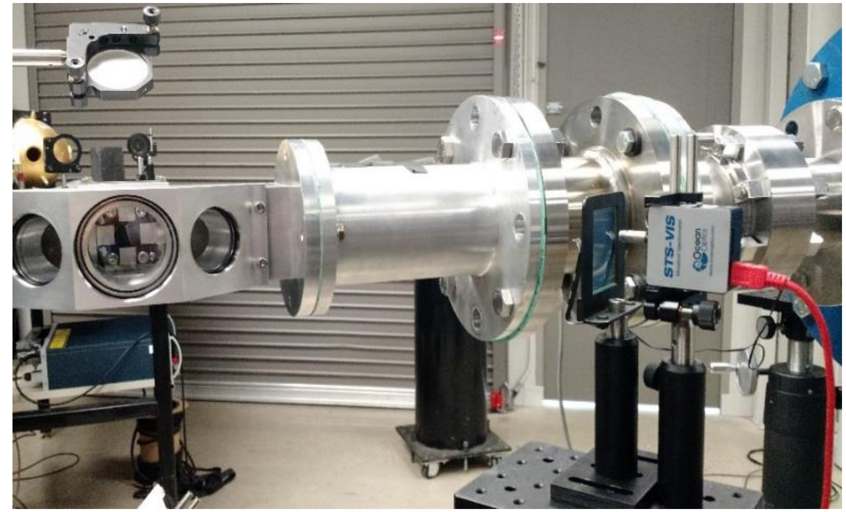
Chemistry modelling: Shock layer models predict gas composition profiles during entry, which will affect radiation energy transport through the shock.

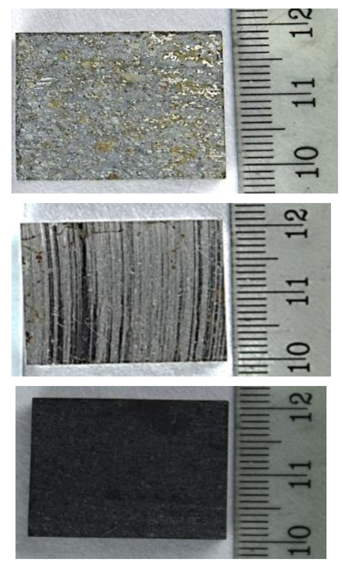


* Johnston and Stern., 2017

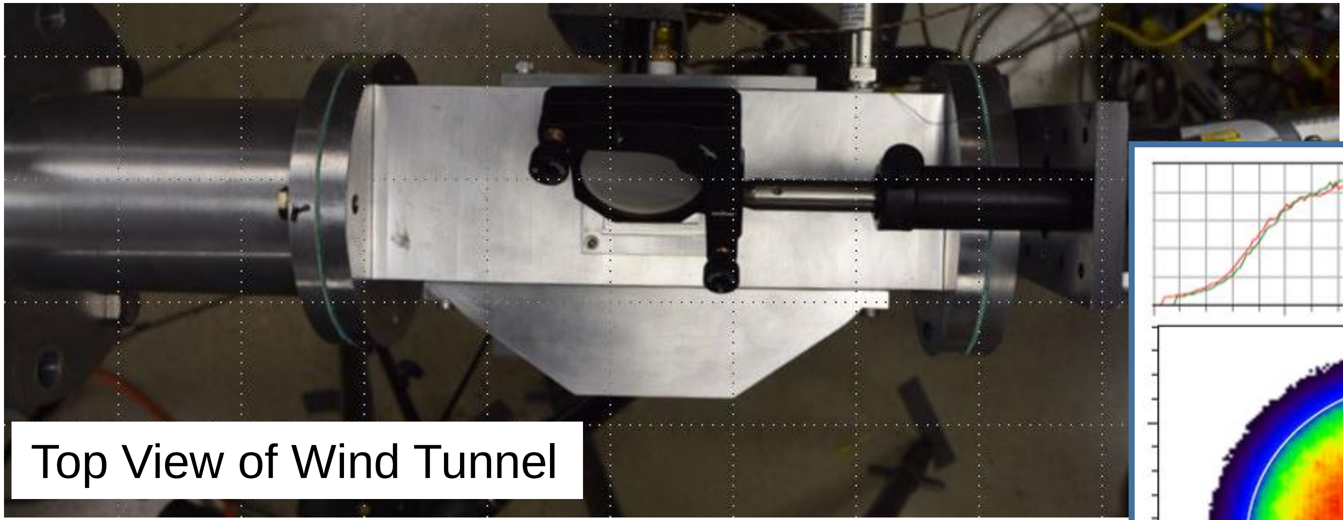
Laser ablation experiment objectives: generate needed data to model and predict asteroid entry

- **Provide insight into meteoroid ablation phenomena under the influence of strong radiative heating.**
- **The dominant source of heating for larger meteoroids is radiation. The LHMEL laser facility at Wright-Patterson Air Force Base allows us to achieve heating level near that which meteoroids experience during flight.**
- **Test conditions included 3 levels each of**
  - **Radiant heat flux (2, 4 and 8 kW/cm^2) and**
  - **Shear cross-flow (Mach 0.05, 0.5, 0.9).**
- **Instrumentation included high-speed video, reflectance and emission measurements, and mass and recession changes.**
- **Test materials included:**
  - **Tamdakht H5 Chondrite**
  - **Iron IAB-MG Meteorite**
  - **Flood Basalt (as analog)**

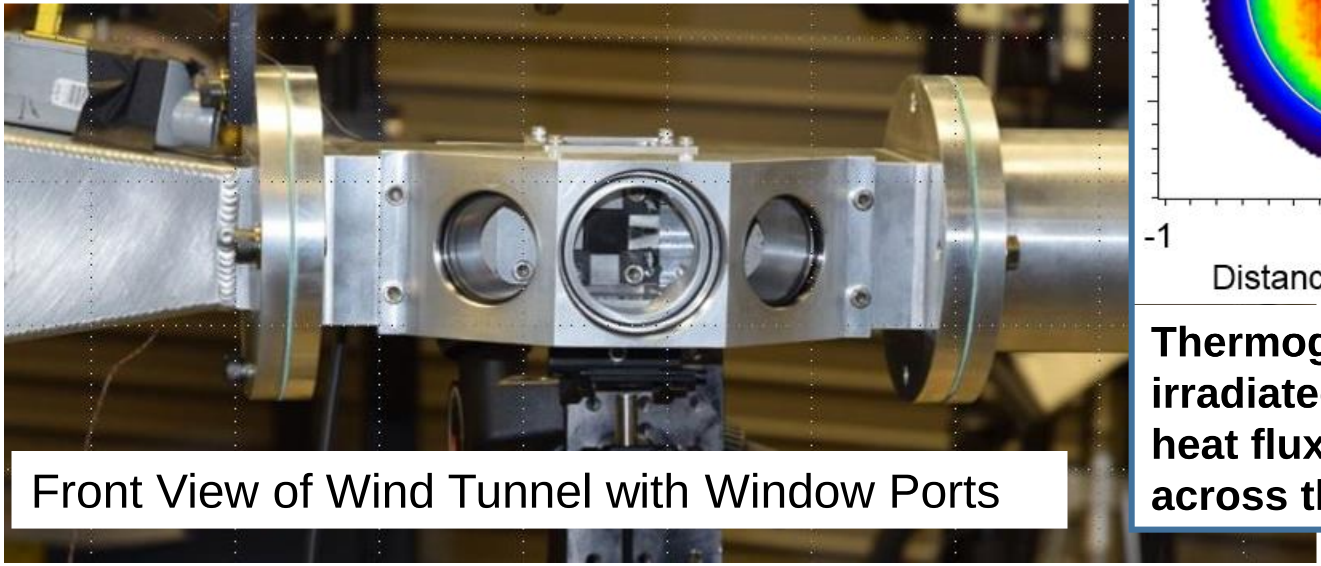




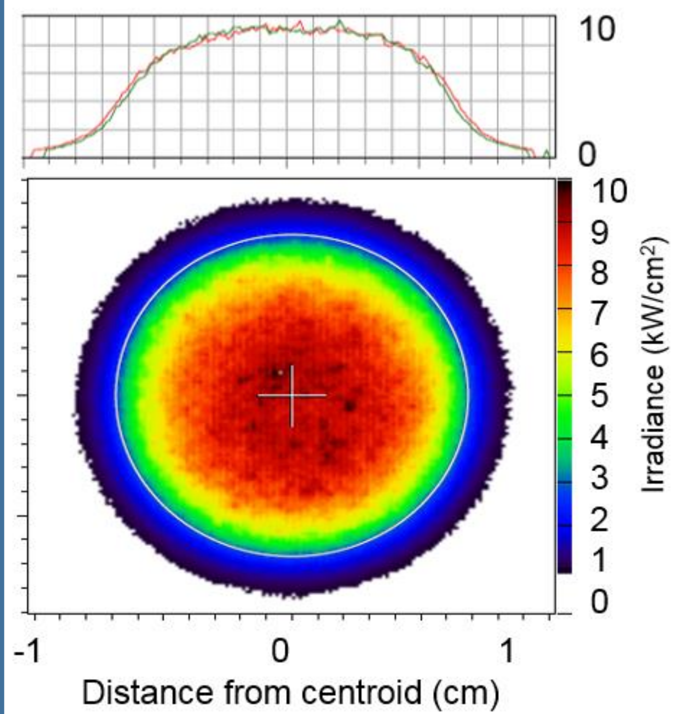
Test Setup with wind tunnel



Top View of Wind Tunnel



Front View of Wind Tunnel with Window Ports



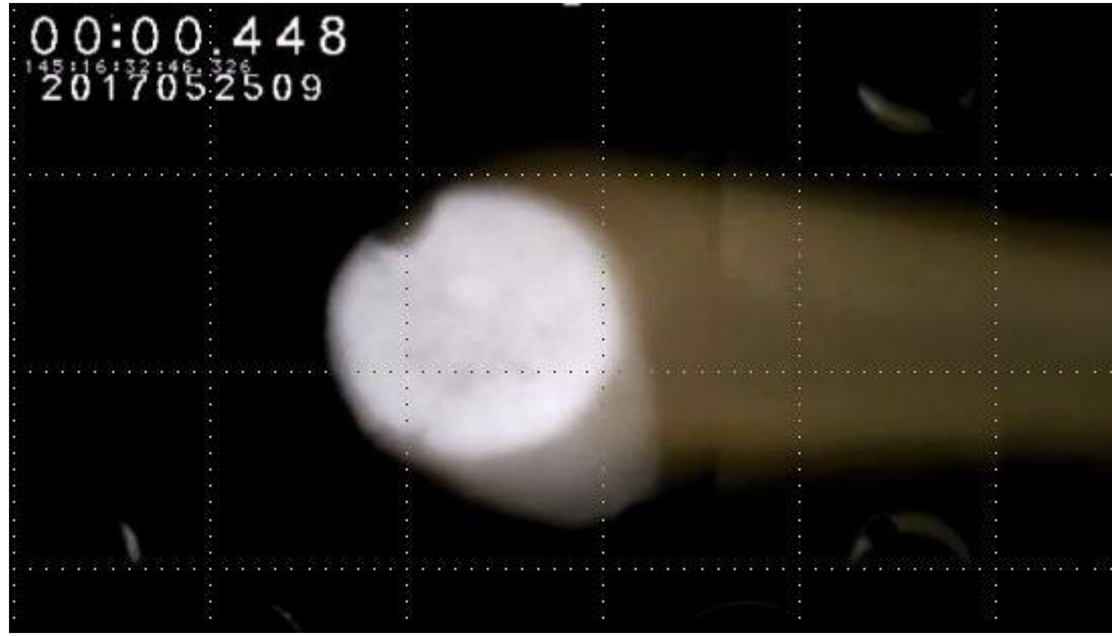
Thermographic image of laser irradiated test spot shows heat flux distribution is even across the test area.

The wind tunnel supplies a controlled shear cross flow up to Mach 0.9.
The incident laser goes through the front center window to the test material.

Tamdakht Chondrite testing

Cross
-Flow

Tamdakht after laser testing with simulated fusion crust.



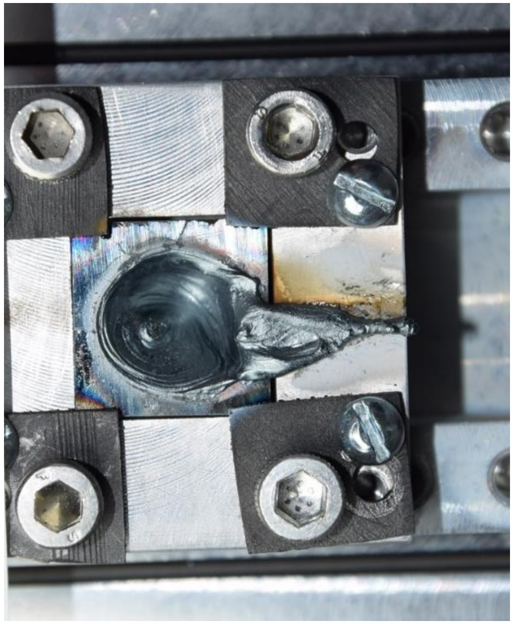
Video of the 8kW/cm^2 test run.

Tamdakht H5 Chondrite material was machined into 2 x 2 x 1 cm test specimens after cutting off the fusion crust of the collected specimen.
Test conditions included :

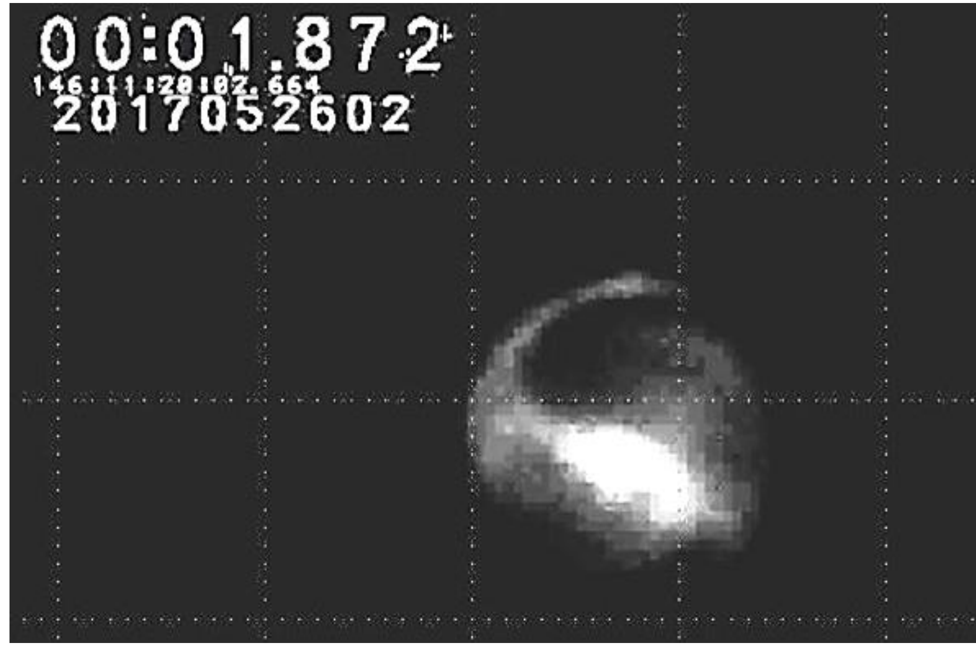
- **radiant heat flux (2, 4 and 8 kW/cm^2) and**
- **cross-flow (Mach 0.05, 0.5, 0.9) using using a wind tunnel air flow.**

Iron Meteorite Test

Cross
-Flow



This post-test photo shows recession and melt flow onto the model holder

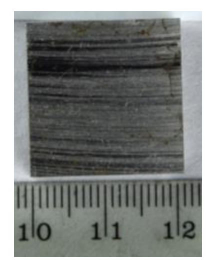


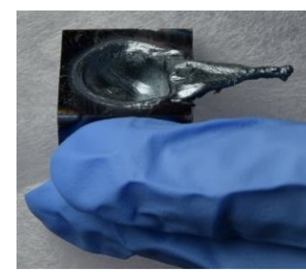
Video shows Iron during the 8kW/cm^2 test run.

The Iron-Nickel Meteorite material was machined into 2 x 2 x 1 cm test specimens. It was tested at

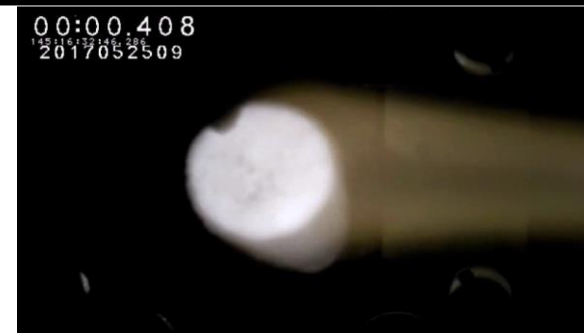
- **4 and 8 kW/cm^2 flux levels with a Mach 0.5 cross-flow.**

Both tests caused significant melt and flow, with greater recession at the higher flux as expected.

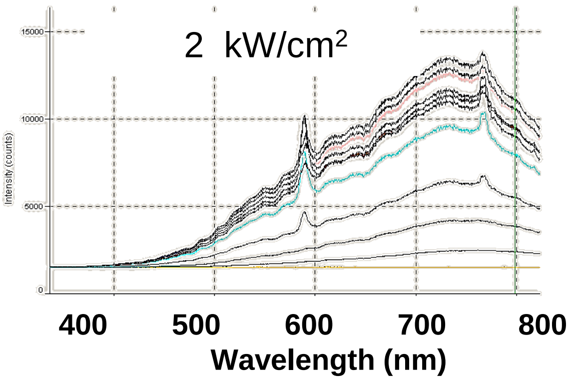




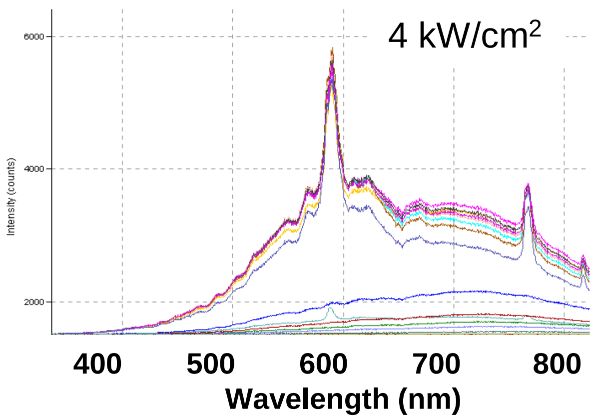
Increasing heat flux produced stronger line emission for Tamdakht



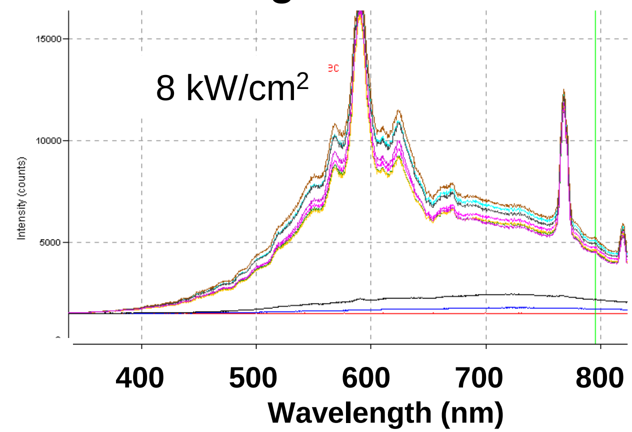
Low Flux



Medium Flux



High Flux



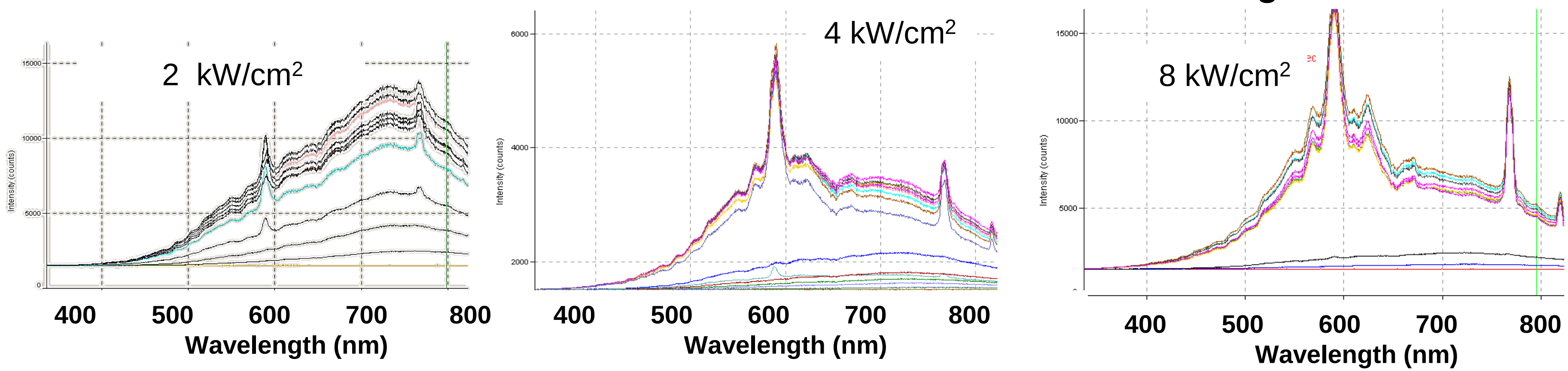
These tests were run at 2, 4 and 8 kW/cm^2 flux at Low shear cross flow (Mach 0.05). As heat flux increased, doubling from 2 to 4 to 8 kW/cm^2, the spectra show anticipated features:

- **The gas emission lines became Increasingly relatively stronger than blackbody – overpowering surface BB thermal radiation.**
- **Thermal emission shifting to shorter wavelengths for higher heat fluxes, as expected.**

Note: the y-axis absolute signal intensity levels are not directly comparable since the integration time was tailored for each condition.

Increasing heat flux produced stronger line emission for Tamdakht

Low Flux | **Medium Flux** | **High Flux**



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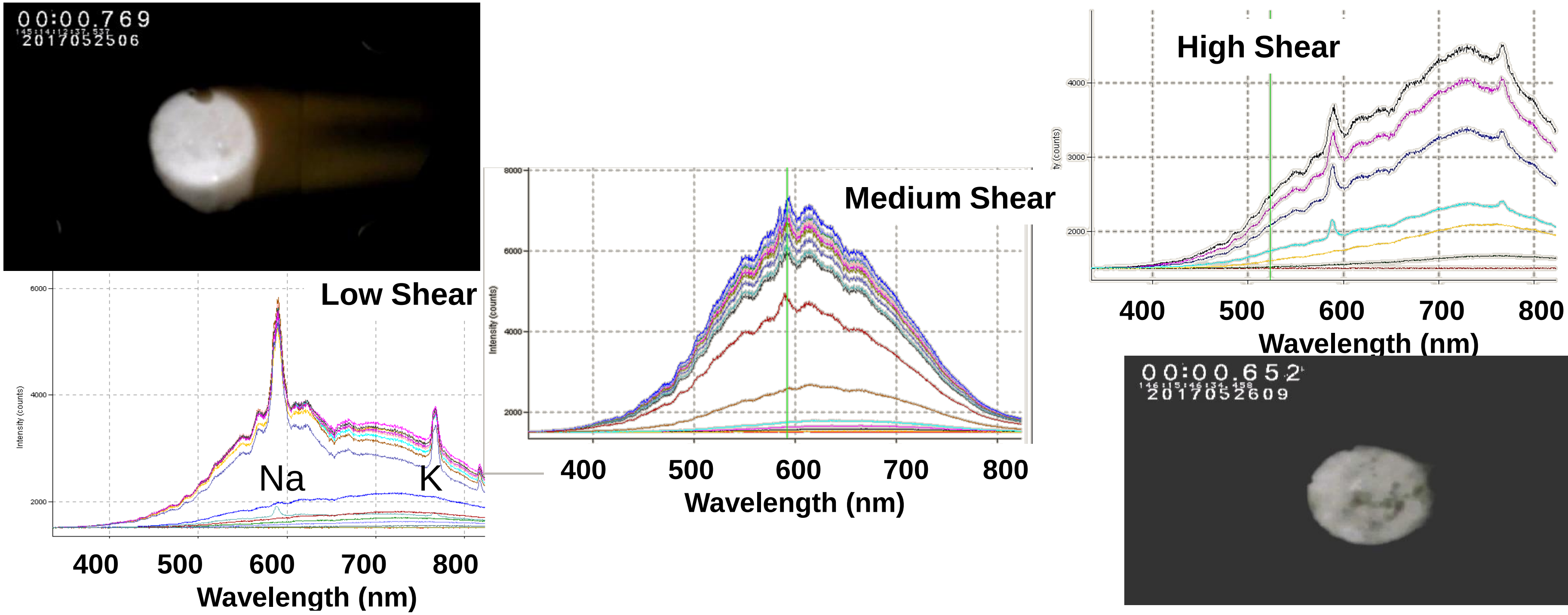
Tamdakht at low, medium and high cross-flow shear



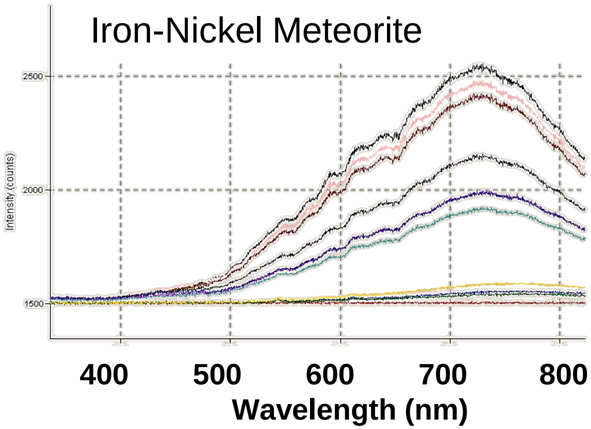
Low Shear **Medium Shear** **High Shear**

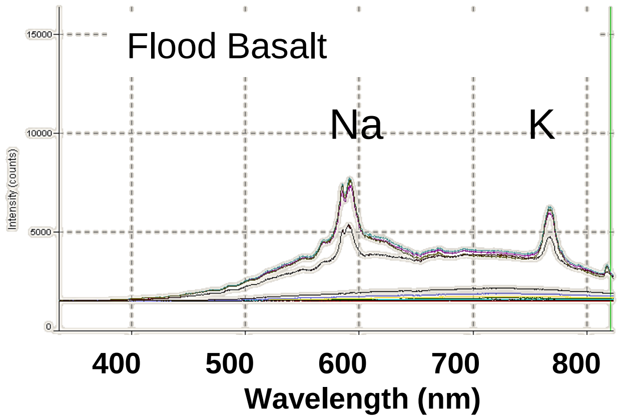
Tamdakht exposed to 4 kW/cm^2 at low shear (Mach 0.05), medium shear (Mach 0.5) , and High Shear (Mach 0.9) all at 4kW/cm2, shows two key effects of shear stress:

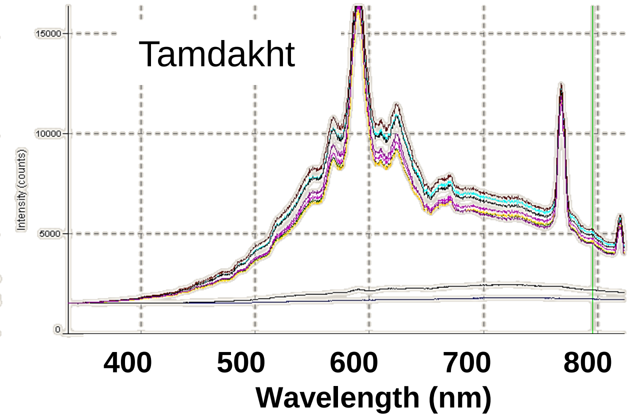
- **Shear removes much of the potentially emitting boundary layer so it reduces the pressure path length for gas emission.**
- **Convective cooling by the shear flow and melt removal (which shifts the wavelength distribution of the thermal emission to longer wavelengths).**

Note: the y-axis absolute signal intensity levels are not directly comparable as the integration time was tailored for each condition.

Different test materials at same test conditions







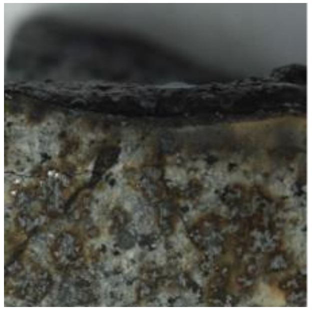
Iron-Nickel Meteorite vs. Flood Basalt vs. Tamdakht spectra

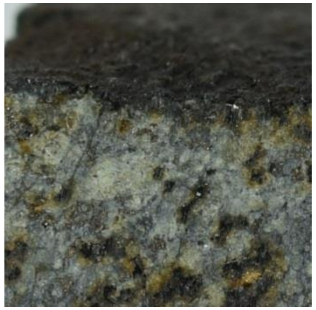
- **Iron exhibits blackbody-like thermal radiation, no peaks.**
- **Tamdakht and Basalt show the same distinct major peak emission lines (Na and K), but the relative levels are different and Tamdakht shows additional line emission.**
- **Tamdahkt, as expected, shows other spectra features including Chromium lines superimposed over its thermal radiation from the heated material.**

- *Note: the y-axis absolute signal intensity levels are not directly comparable since the integration time was tailored for each condition.*

Basalt 4 kW/cm^2 Low Shear

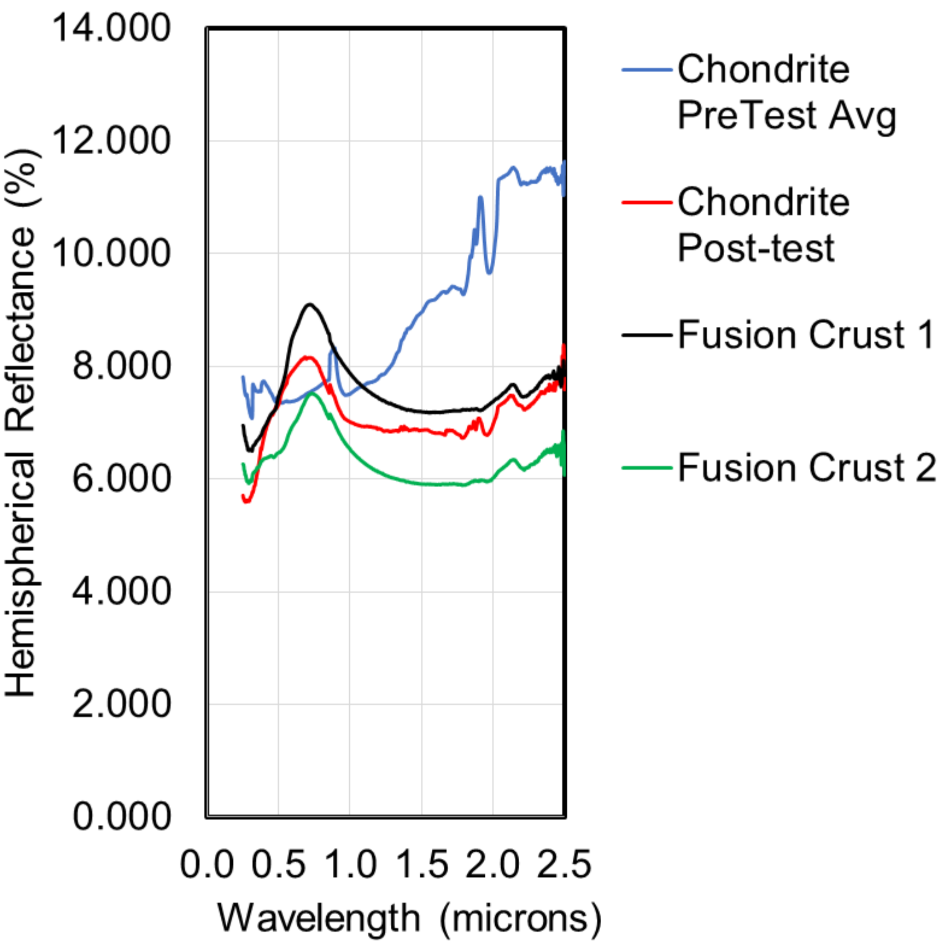
Tamdakht reflectance before and after heating





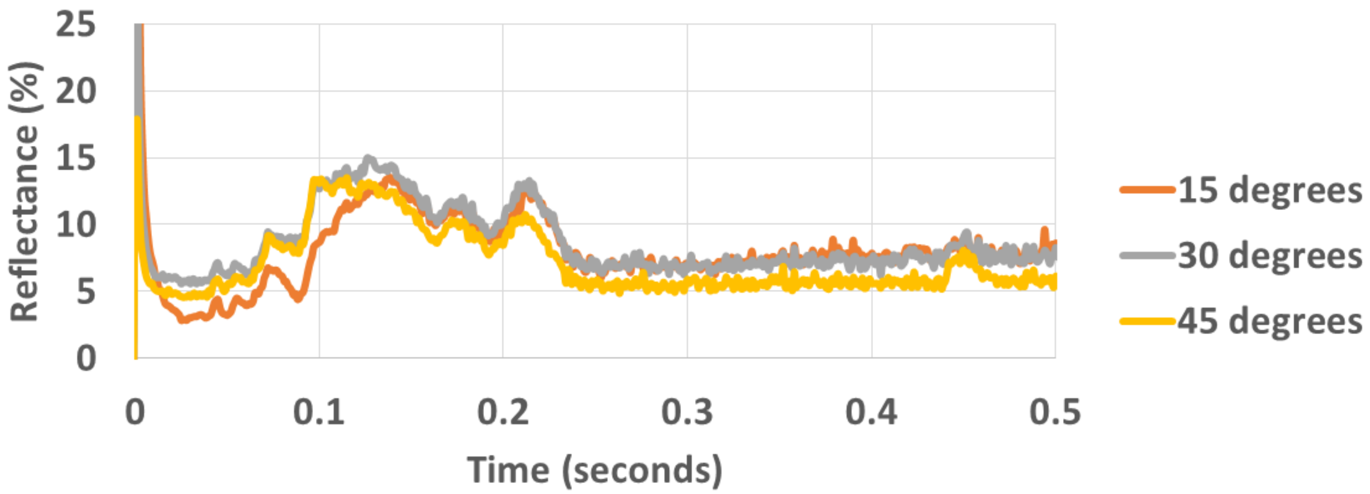
Comparison of experimental (left) and entry (right) fusion crusts

- **Pre-test (Blue line): Reflectance measured before testing shows the machined chondrite is not spectrally similar to the fusion crust.**
- **Post-test (Red line): The laboratory-generated fusion crust is similar to natural Tamdakht fusion crust two samples (Black and Green lines).**
- These hemispherical reflectance measurements at STP with an integrating sphere in NASA ARC's Lambda 10.



Post-test spectral reflectance of Tamdakht surface melt is bracketed by the reflectance of two different specimens of natural fusion crust.

Reflectance measured vs. observation angle



Lower reflectance at near-normal vs. greater angles during the first 0.15 seconds of testing. Variable angular reflectance may complicate remote astronomical observations!

Lunar dust retro-reflection is well known. Reflectance depends on angle for many materials.

Observation angle, surface aging, oxidation, roughness, temperature, and wavelength all affect measured reflectance. Surface melting and fusion crust development alter the angular distribution of reflectance. Measurements are shown from one test on Tamdakht H5 Chondrite. During the initial stages of surface melt, the reflectance measurements at the near-normal 15 degrees observation angle was lower than at 30 and 45 degree angle.

During an actual meteorite entry, the shock layer radiation and wake radiation dominate the observed light.

Summary and Conclusions

- Spectroscopic measurements in these tests showed strong peaks for Sodium and Potassium for Tamdakht and Basalt, but not Iron meteorite.
- The Tamdakht spectra show, as heating doubled from 2 to 4 , then to 8 kW/cm^2 :
  - The gas emission lines became increasingly strong – overpowering the surface blackbody thermal radiation.
  - Thermal emission shifted to shorter wavelengths for higher heat fluxes, as expected from the increased heating rate.
- Comparing Tamdakht at low shear (Mach 0.05), medium shear (Mach 0.5) , and High Shear (Mach 0.9) all at 4kW/cm^2, showed two key effects of shear flow:
  - Shear flow removed much of the potentially emitting boundary layer, and
  - Shear flow convectively and melt removal cooled the surface, shifting the surface blackbody thermal radiation to longer wavelengths.
- Post test, reflectance measurements showed the laser-heated Tamdakht and Basalt surfaces were spectrally similar to natural fusion crust.
- Lessons learned: Reconfigure for boundary layer absorption / flow visualization. The the optical path of the sheet of 1080 nm laser across front of heated surface was bent and dstorted by density / refractive index gradients in this unsteady boundary layer flowing across a heated cavity!
- Acknowledgements: Sincere thanks to the ATAP program, Dan Seibert and Braden Childers of LHMEL, Andrew Meade of Rice University, and Megan MacDonald, NASA Ames / Jacobs spectroscopist.

Questions?

National Aeronautics and
Space Administration

Ames Research Center
Entry Systems and Technology Division