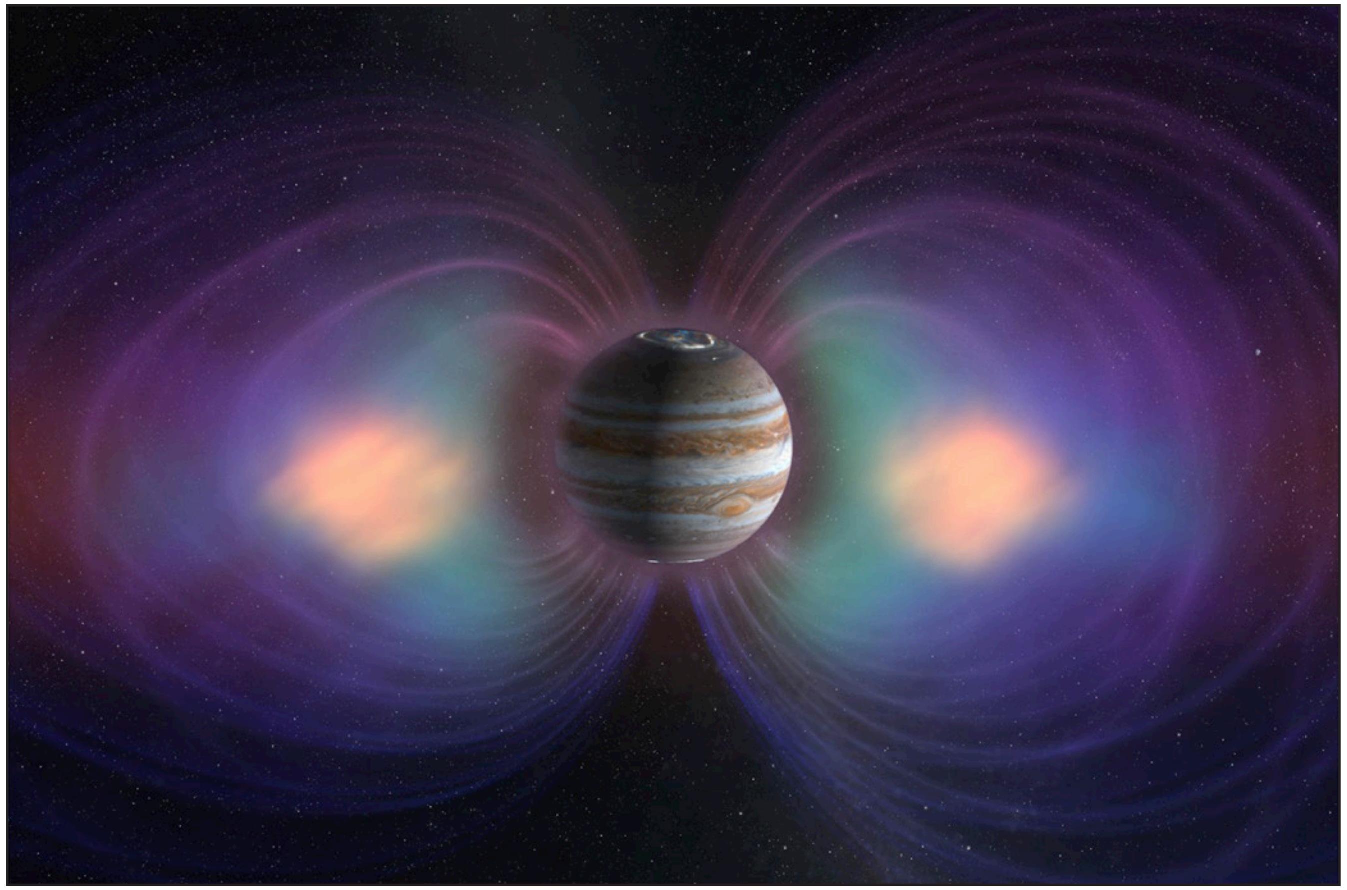
Dynamic Conductivity and Partial Ionization in Metallic Hydrogen



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Summary

We present experimental results on the optical conductivity of metallic hydrogen that is consistent with it being a free-electron partially ionized plasma

- Optical reflectance of dense hydrogen was measured as a function of energy in the 1.4- to 1.7-Mbar region and up to 2500 K
- The energy dependence of the optical data was analyzed using the Drude free-electron model and the Ziman nearly free model*
- The conductivity of the metallic hydrogen is substantially higher than that predicted by the strong scattering Mott–Ioffe–Regel model**

*J. M. Ziman, Philos. Mag. 6, 1013 (1961);
**N. F. Mott, Philos. Mag. 26, 1015 (1972).

Collaborators

I. F. Silvera

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The transport properties of metallic hydrogen are of fundamental importance

- Metallic hydrogen is exceptional
  - no bound electrons
  - more substantial zero-point motion than any other metal
- Metallic hydrogen is a benchmark system for warm dense matter

Coulomb coupling parameter: $\Gamma = r_s / k_B T \gg 1$ Strong coupling

Electron-degeneracy parameter: $\Theta = T/T_F \ll 1$ High degeneracy

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The transport properties of metallic hydrogen are critical inputs for planetary modeling and ignition simulations

- Metallic hydrogen is the most-abundant form of condensed matter in our planetary system
  - thermal and dynamo action models depend crucially on electronic and thermal properties
- Inertial confinement fusion (ICF)
  - the pressure–temperature conditions transversed by deuterium–tritium targets are typical of warm dense matter

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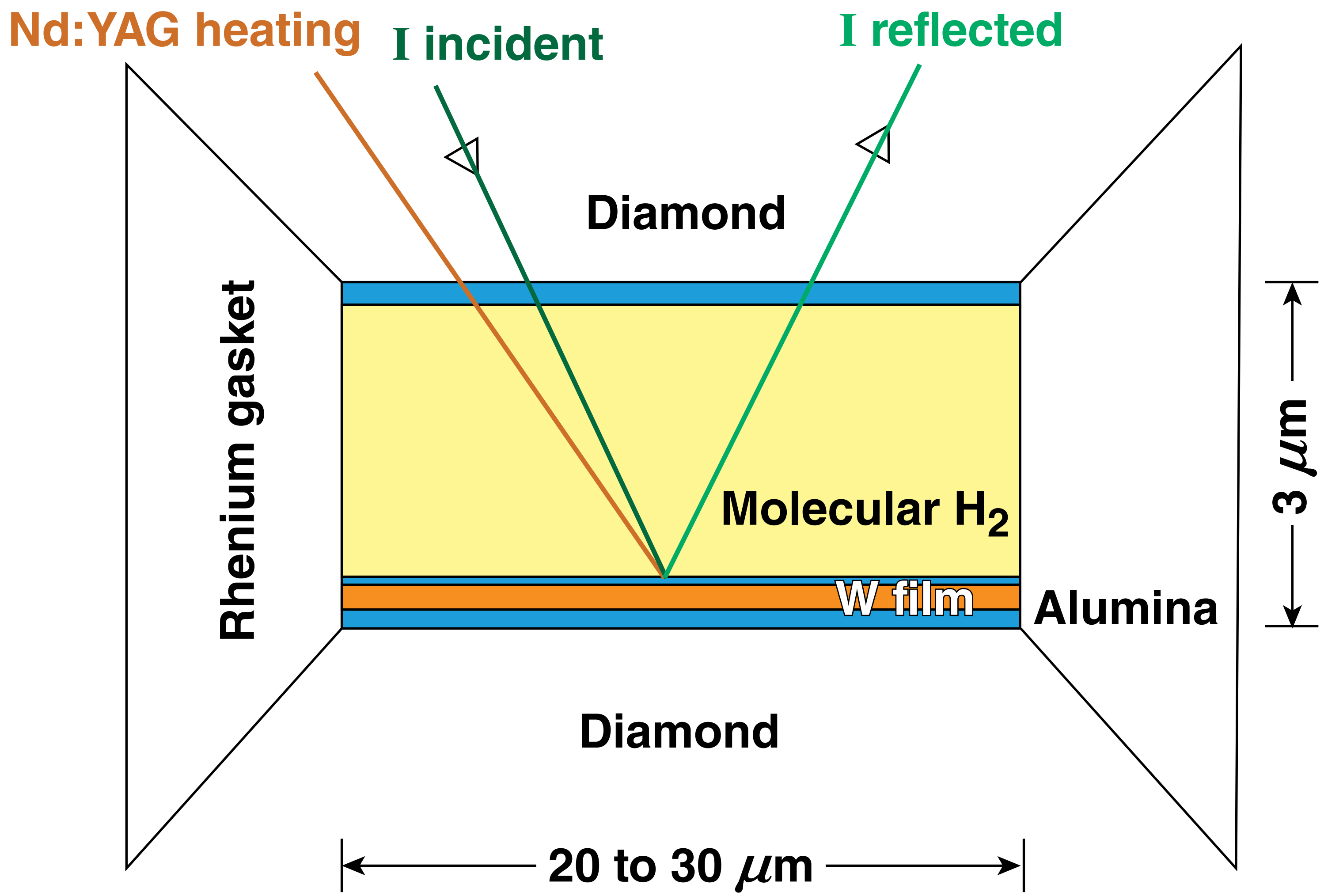
Thermal emission and spectrally resolved reflectance were measured as a function of temperature



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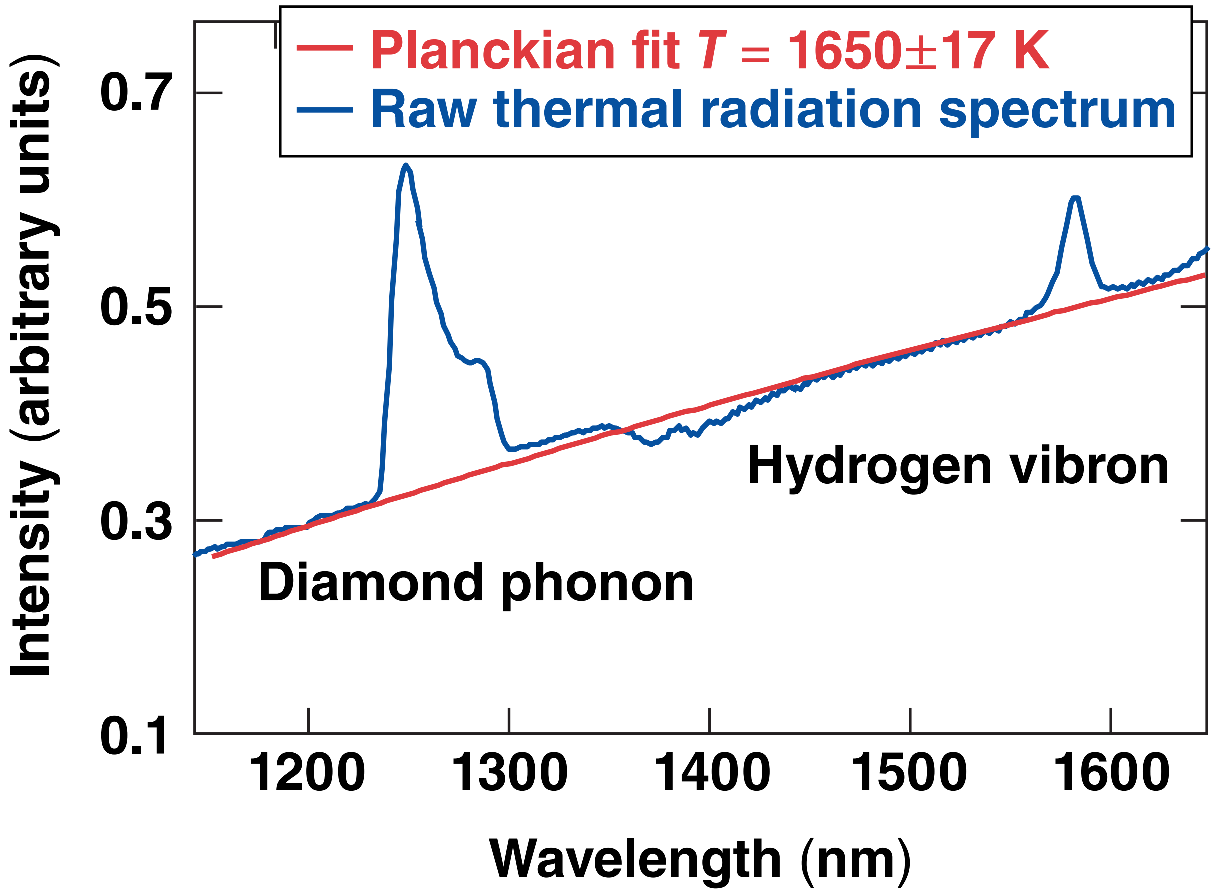
Pressure was determined from Raman spectroscopy; temperature was determined from pyrometry



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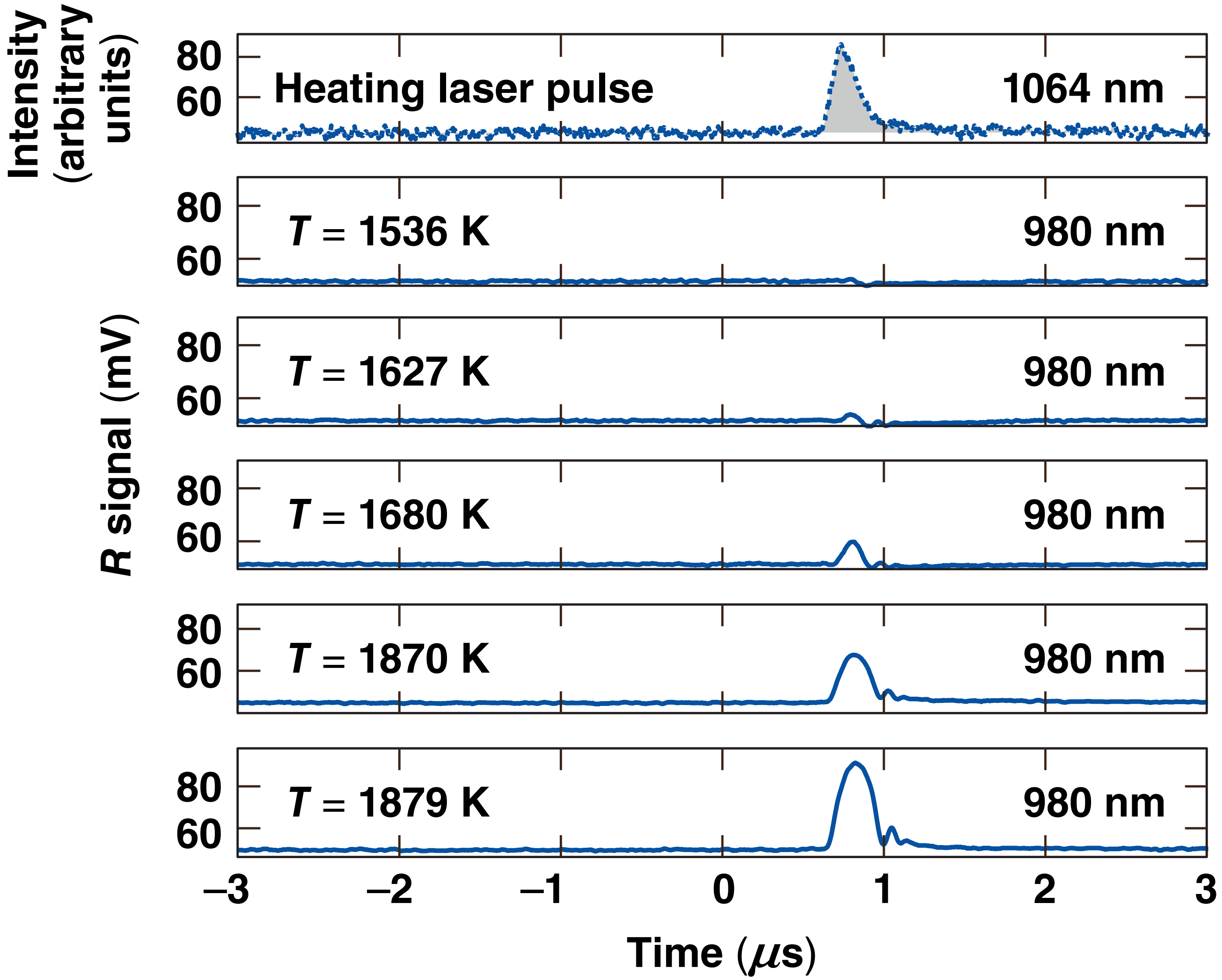
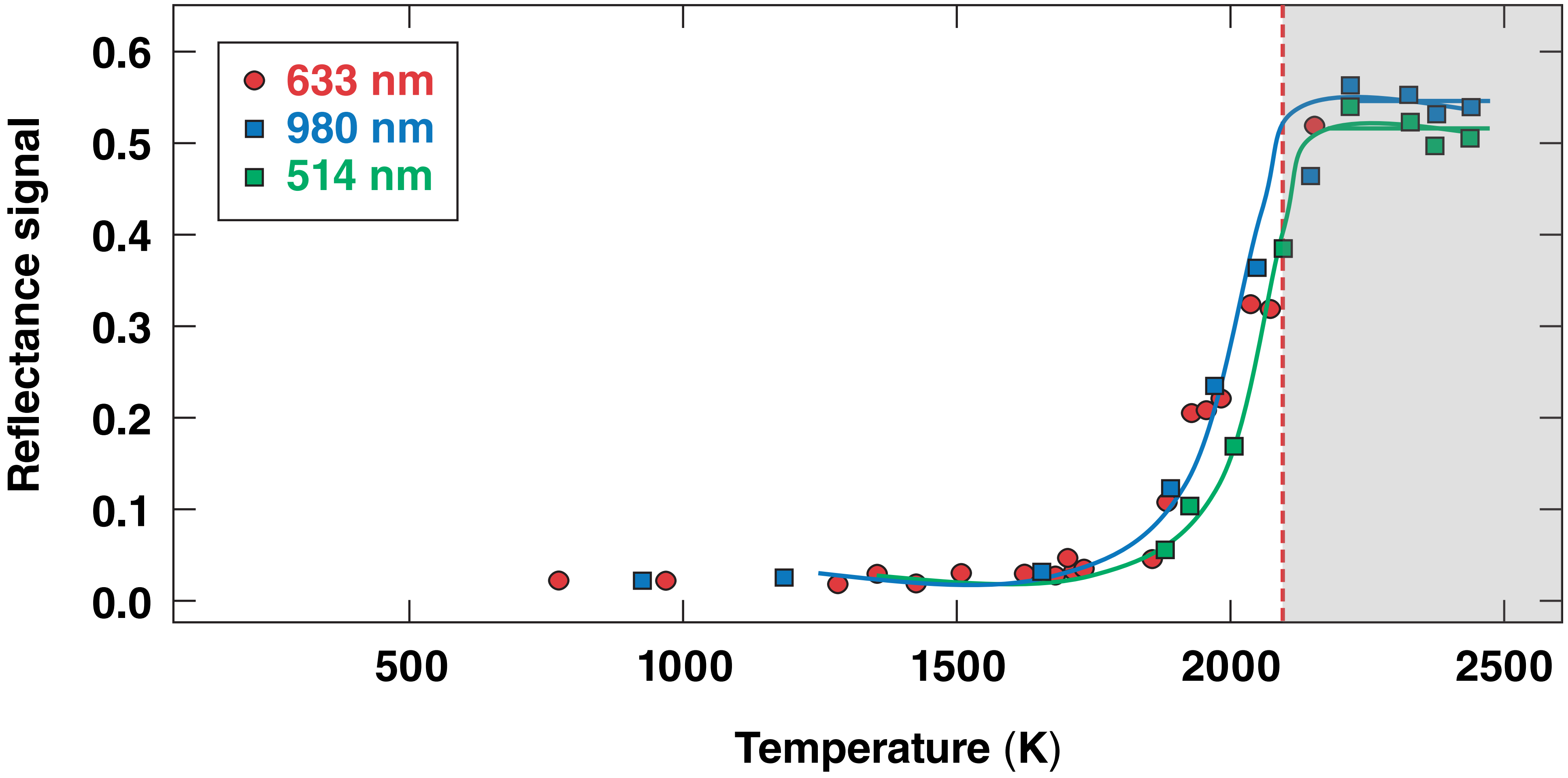
Time-resolved reflectance was measured as a function of temperature and wavelength



M. Zaghoo and I. F. Silvera, "Conductivity and Dissociation in Metallic Hydrogen: Implications for Planetary Interiors," to be published in the Proceedings of the National Academy of Sciences.

We observe an abrupt rise in reflectance



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The Drude or Ziman transport models were fitted to the data to determine the carrier density and collisional frequency

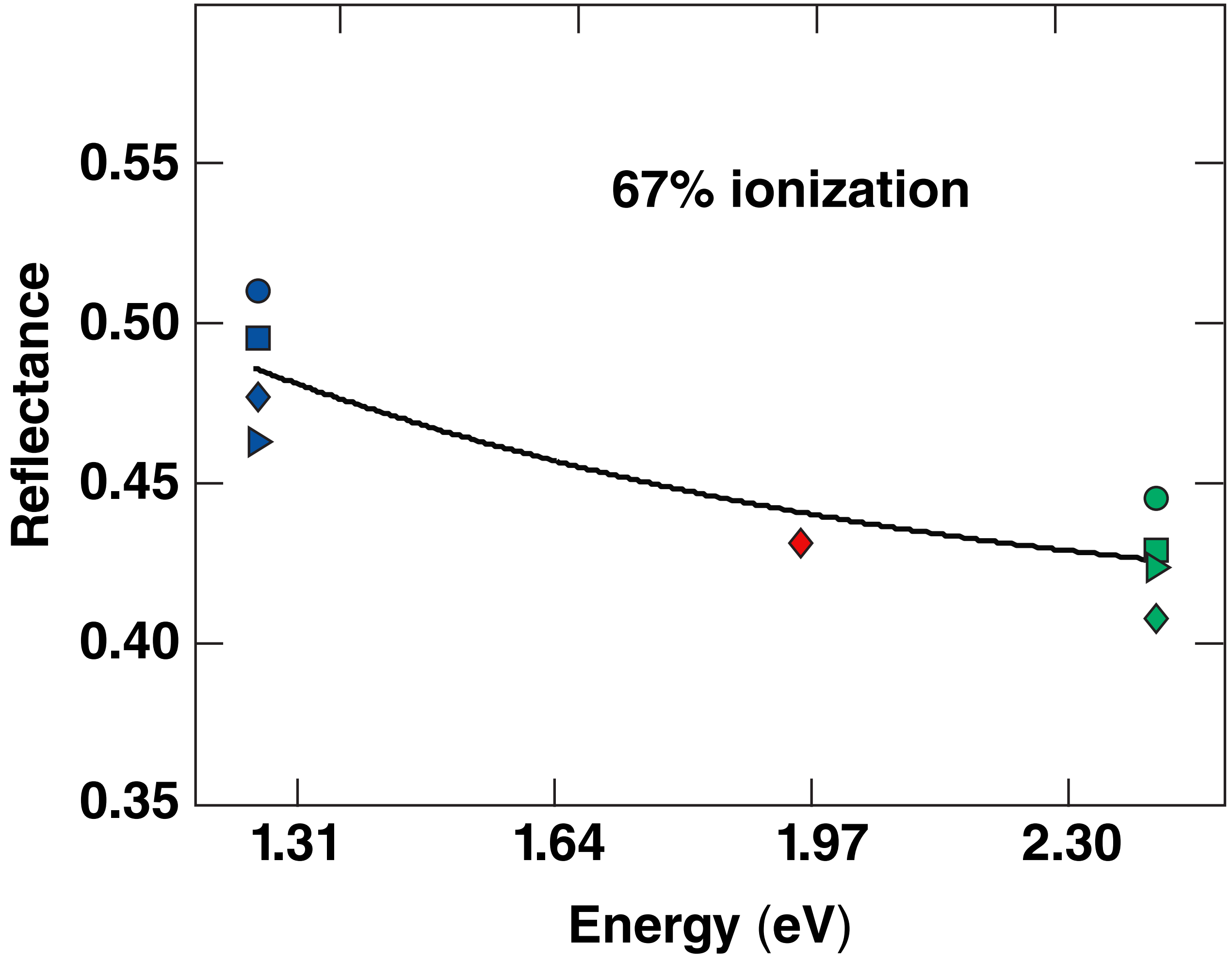
- The dielectric function of metallic hydrogen was determined by fitting the measured Fresnel reflectance to two electron transport models

$$R(\omega) = \left| \frac{\sqrt{\varepsilon(\omega)}_{\mathrm{MH}} - \mathrm{ND}}{\sqrt{\varepsilon(\omega)}_{\mathrm{MH}} + \mathrm{ND}} \right|^2$$

$$\varepsilon(\omega) = 1 + \frac{i}{\omega\varepsilon_0}\sigma(\omega) = 1 - \frac{\omega_p^2}{\omega[\omega + i\nu(\omega)]}$$

ND: index of refraction of diamond

Fitting the Drude free-electron model to the energy dependence of the reflectance data reveals a partial ionization of 67%



The data were also fit to quantum statistical electron transport models

- Weak scattering: the electron–ion interaction is a weak perturbation

$$\nu_{\text{dc–degenerate}}^{\text{Ziman}} = \frac{n_p m_e}{4\pi\hbar^3 \kappa_F^3} \int_0^1 dy\, y^3 W^2(y) \int_{-\infty}^{\infty} \frac{d\omega}{2\pi} S^p(y,\omega) \frac{\beta\hbar\omega}{e^{\beta\hbar\omega} - 1}$$

- $W(q) = -V(q)/\varepsilon(q)$ describes the electron–proton pseudopotential, which in liquid metallic hydrogen corresponds to the screened Coulomb interaction
  - $V(q)$ is the Fourier transform of the Coulomb interaction
  - $\varepsilon(q)$ is the dielectric permittivity of the degenerate electron gas in the long-wavelength limit

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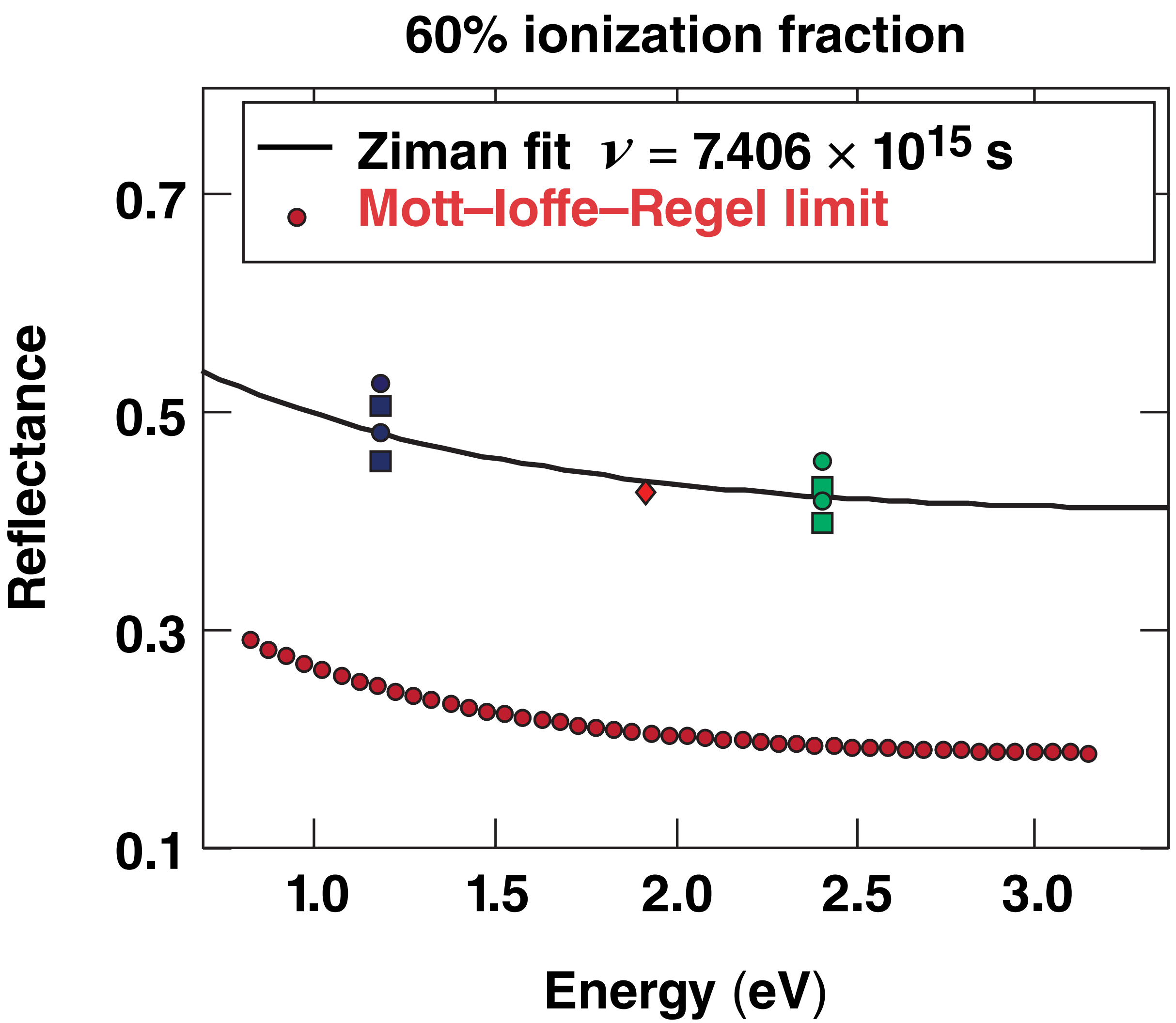
The fit to the weak scattering model reveals 60% ionization, consistent with analysis in the Drude model

- Partial-ionization in the Ziman weak scattering model provides great agreement with the data

- The strong scattering Mott–Ioffe–Regel limit does not describe the magnitude of the observed *R*



M. Zaghoo, "Dynamic Conductivity and Partial Ionization in Warm Dense Hydrogen," to be submitted to Physical Review E.

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Summary/Conclusions

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