Nanosecond Broadband Spectroscopy For Laser-Driven Compression Experiments

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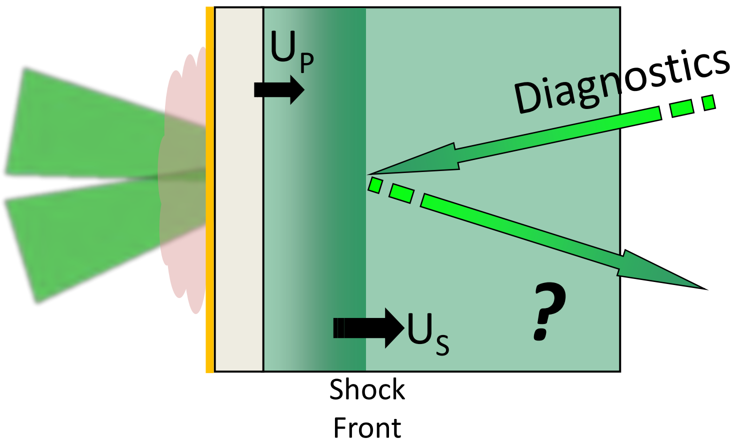
STEWARDSHIP SCIENCE GRADUATE FELLOWSHIP

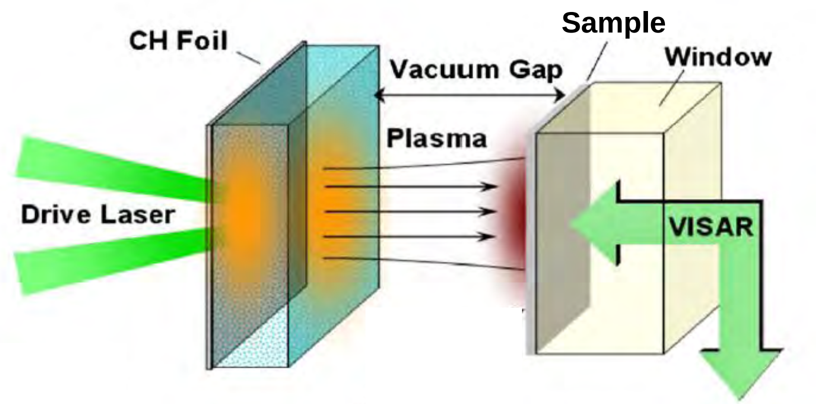
Outline

• Motivation

Shock Compression



Ramp Compression

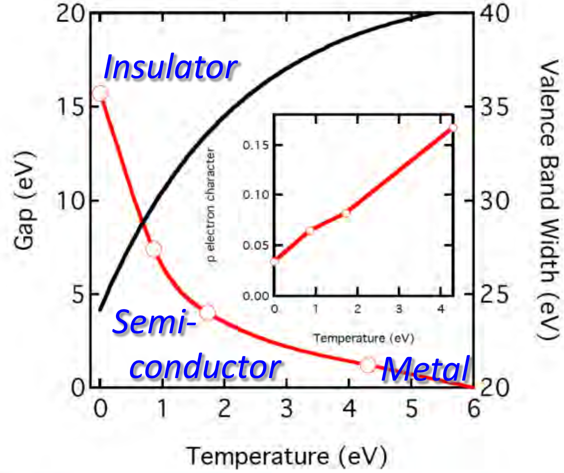


• How do we generate high-pressure and temperature in the laboratory?
Experiments and Diagnostics

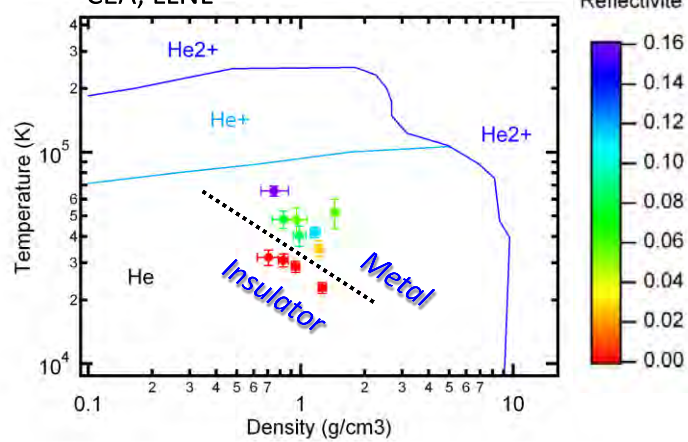
• Proposal and proof of concept for measuring broadband reflectivity

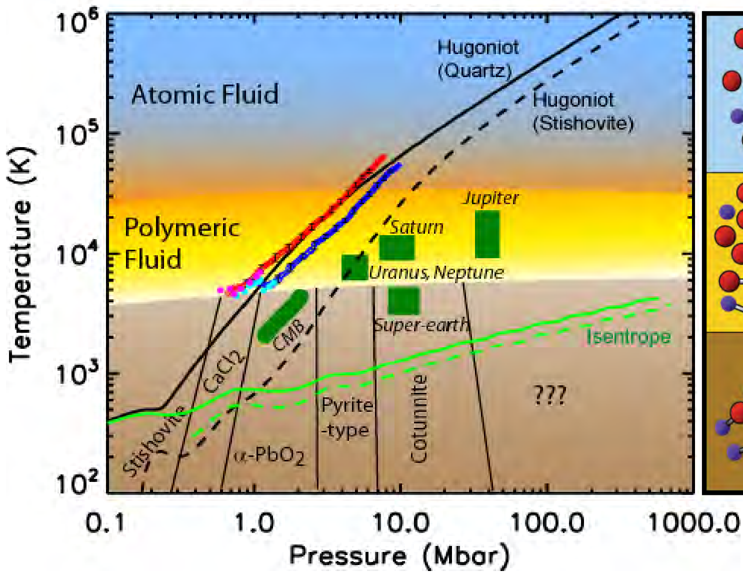
Extreme Chemistry at Ultra-High Pressure

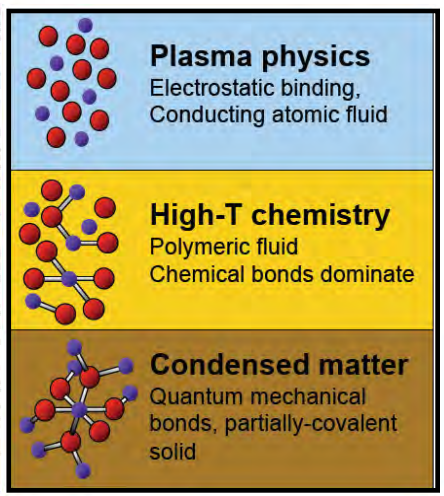
Stixrude & Jeanloz



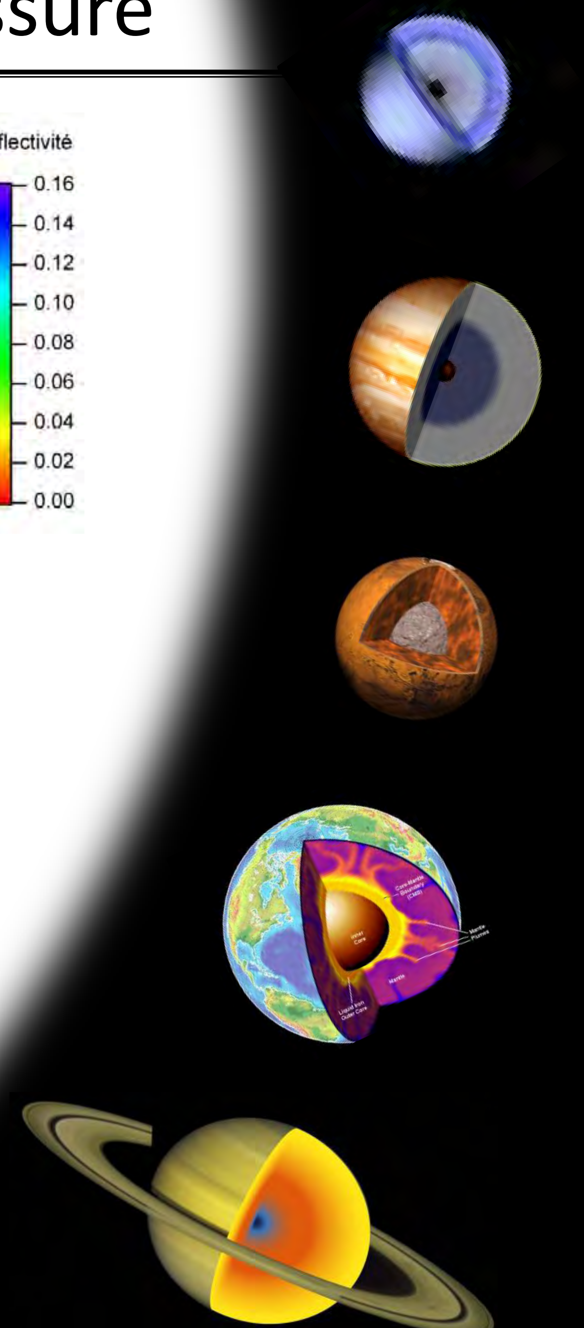
CEA, LLNL



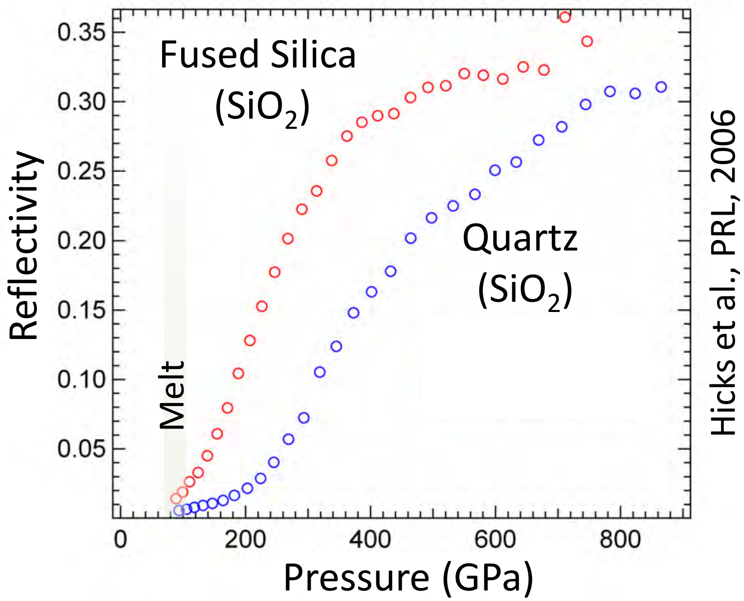


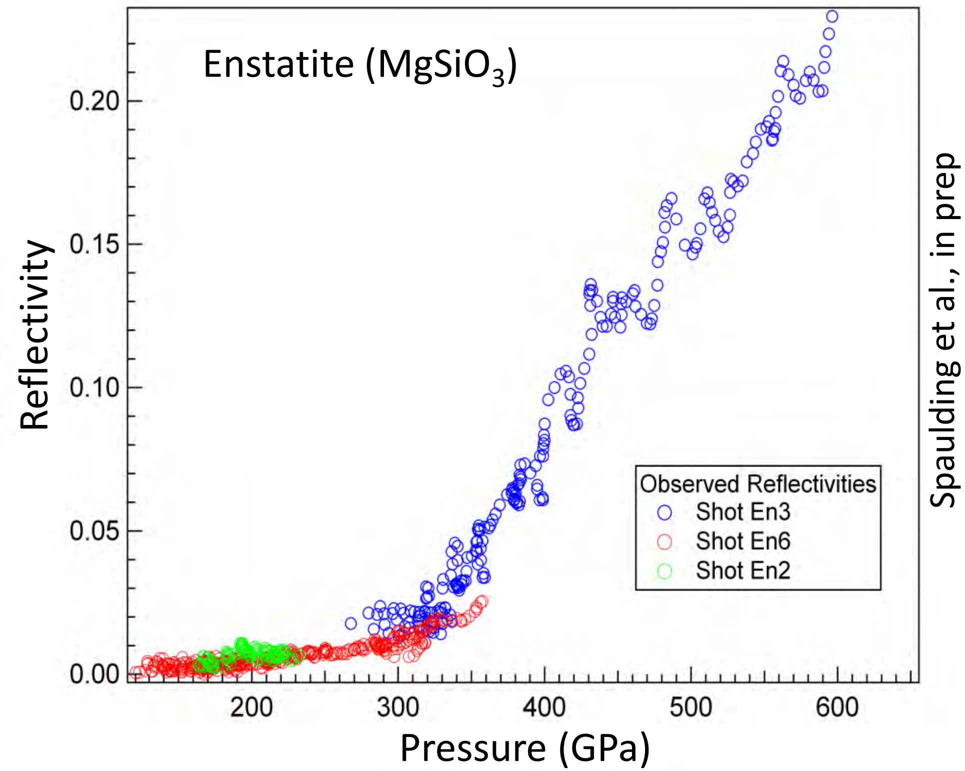


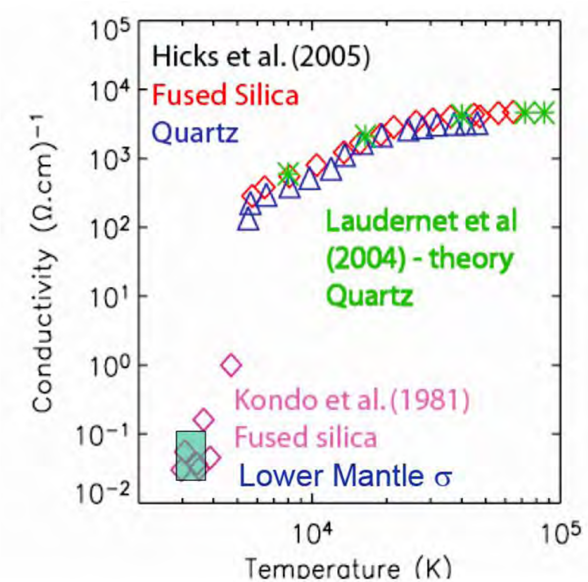
Hicks et al., PRL, 2006



Single Wavelength Reflectivity Reveals That the Deep Earth May Contain *Metallic-like* Silicate Liquids







For SiO_2, a 2-fold increase in temperature (5,000K → 10,000K) gives 3 orders of magnitude increase in conductivity (1 → 1000/(ohm-cm)). $MgSiO_3$ appears to show similar behavior

Nanosecond Broadband Reflectivity Measurements

Broadband reflectometry is a potentially powerful tool for probing electronic structure in condensed matter. However, for HED measurements, a sufficiently bright source is required.

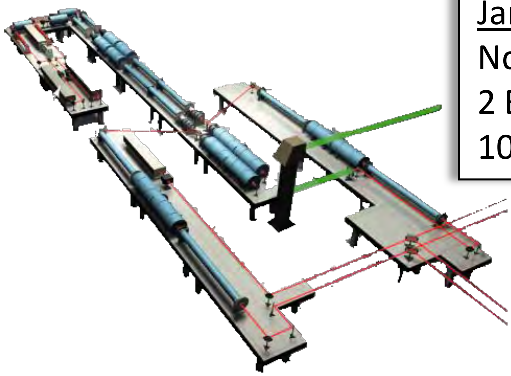
Existing broadband light sources for HED measurements:

- Gas guns, μs: Incandescent flashlamps
- *Long pulse, ns: No broadband light sources exist in the ns regime*
- Short-pulse, ps, fs: Supercontinuum generation in crystals/liquids (self-phase modulation)

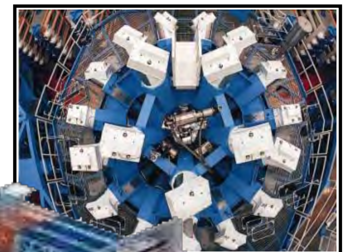
Goal:

1) To develop broadband reflectometry in the ns regime using non-linear pumping of an optical fiber
2) To perform the first time-resolved probing of laser-shock states

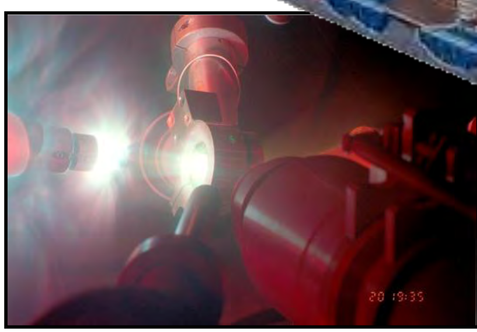
Experiments – Generating High Pressures and Temperatures in the Laboratory

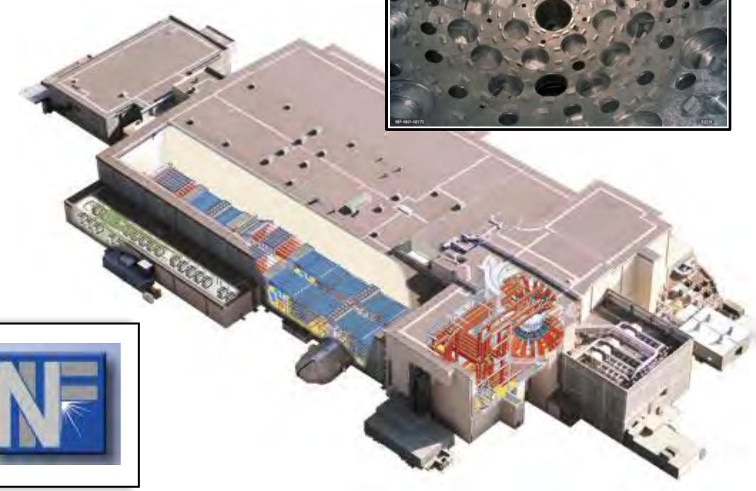


<u>Janus Laser</u>
Nd:glass
2 Beams: 1kJ/beam
1053nm, 527nm, 351nm



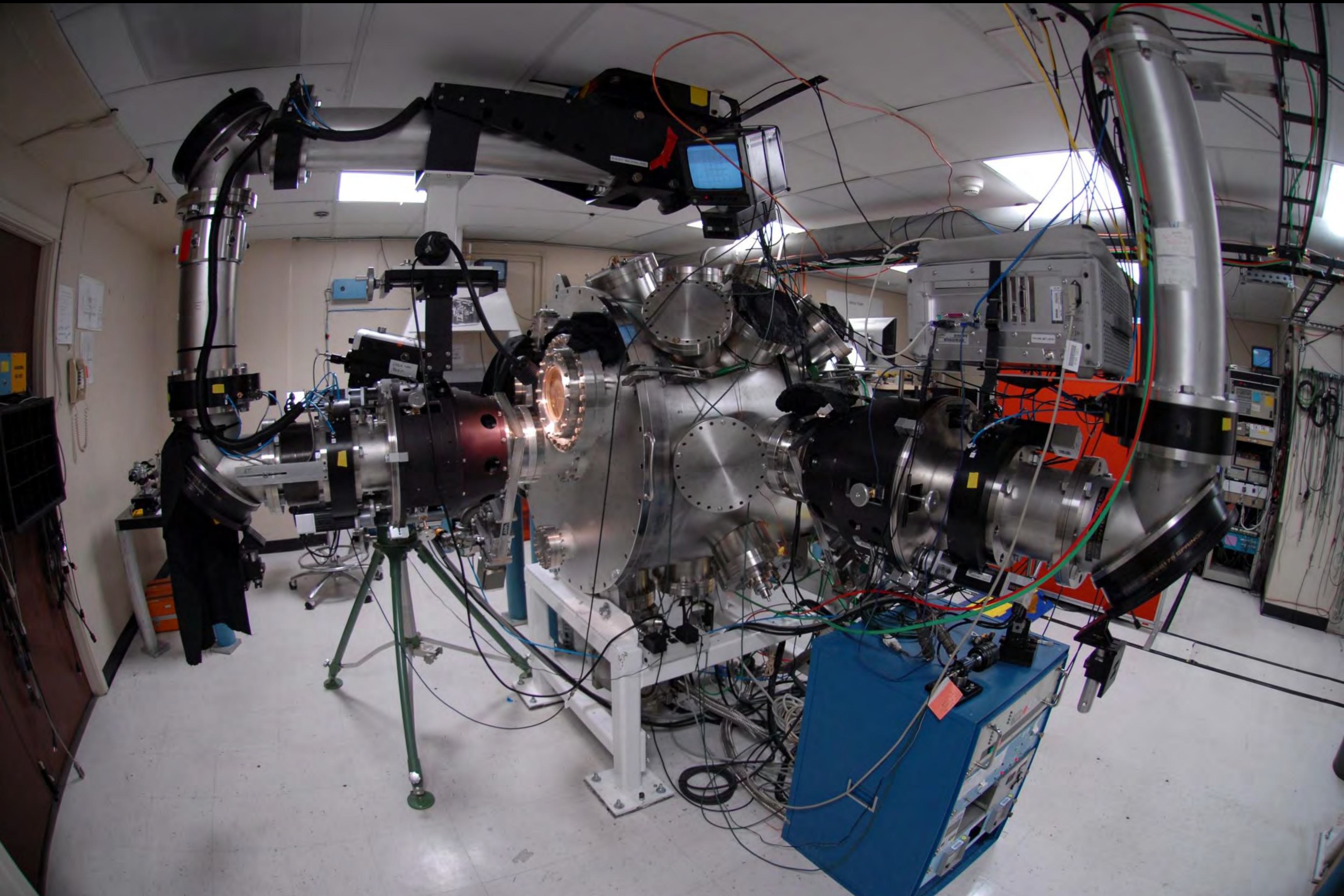
<u>The OMEGA Laser</u>
Nd:glass
Wavelength: UV
60 beams, 30kJ





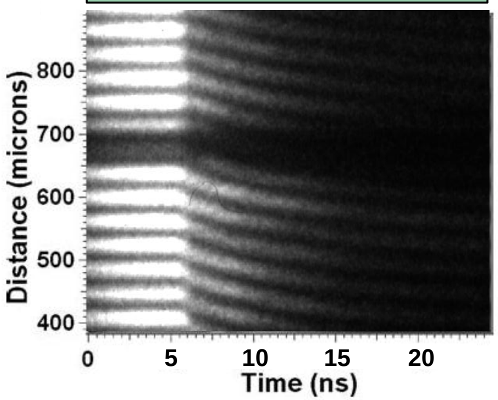
<u>The NIF</u>
192 beams, 2Megajoules
Wavelength: 351nm

Images: Jlf.llnl.gov, lle.rochester.edu, NIF



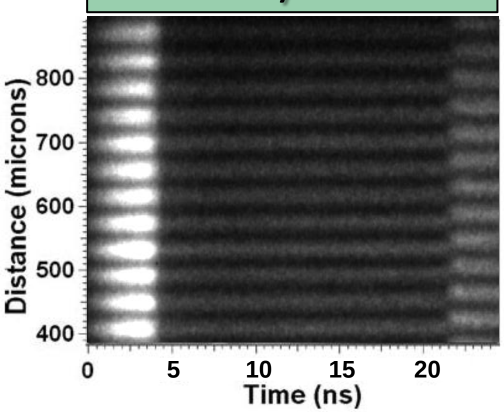
Laser-Driven Compression – Different Kinetics, Different Processes

Decaying Shock

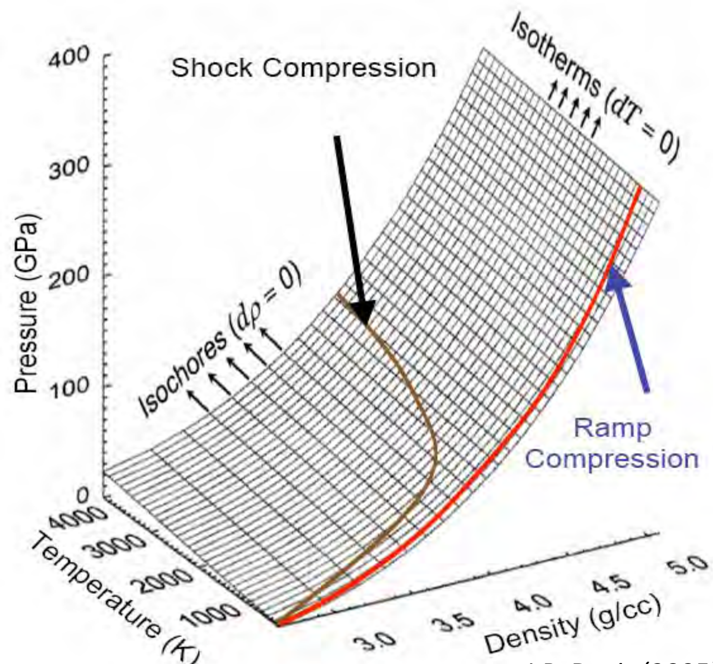


Spaulding

Steady Shock

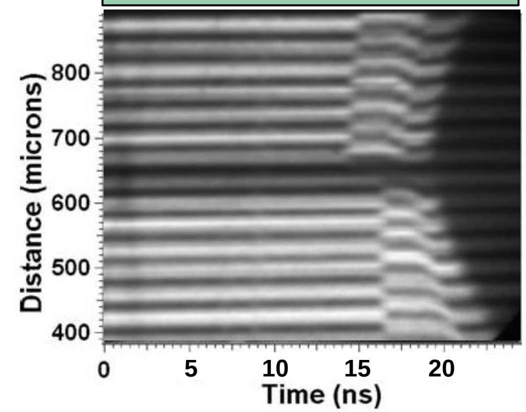


McWilliams



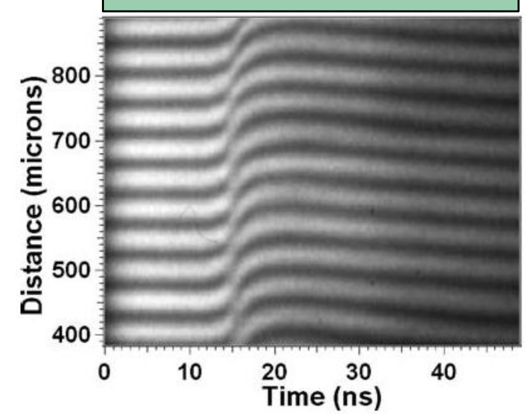
J.P. Davis (2005)

Multi-Shock



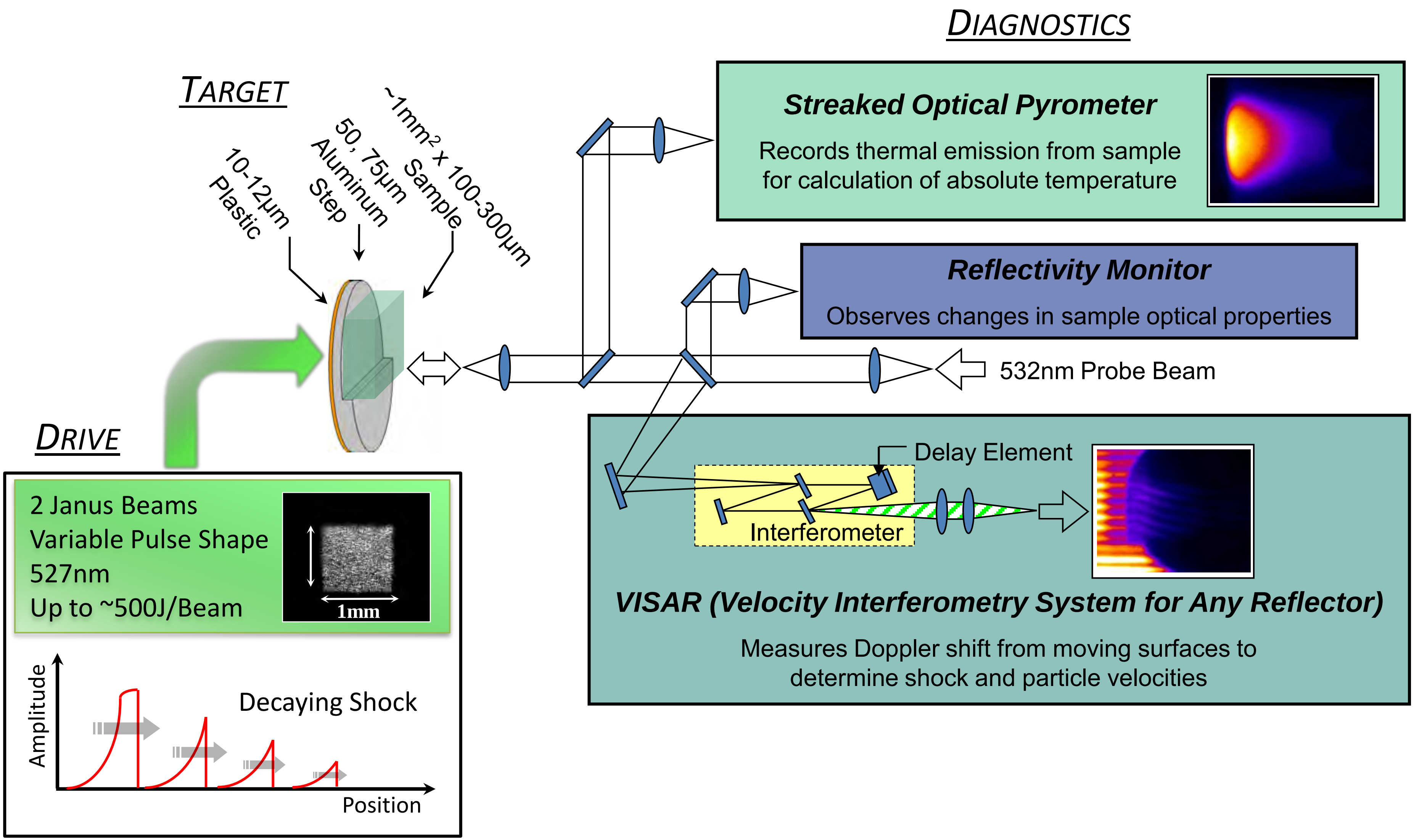
Lee et al, 2006

Ramp Compression

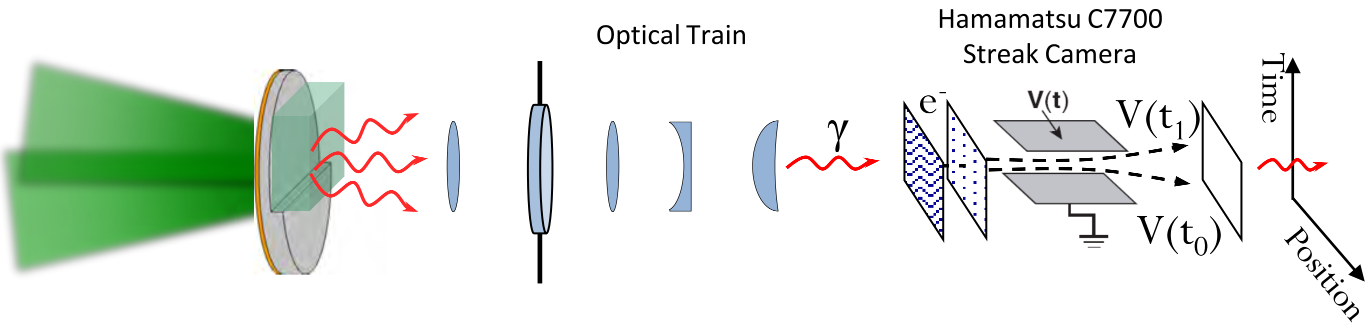


Smith et al. 2007

Measuring High Pressure and Temperature States

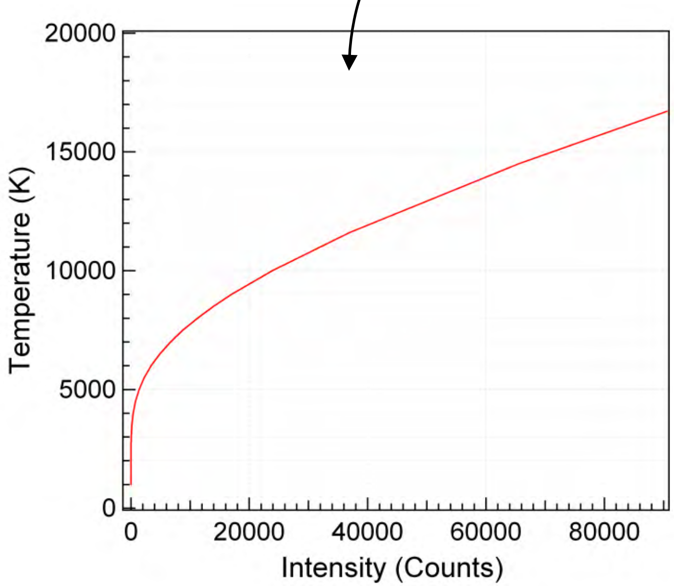


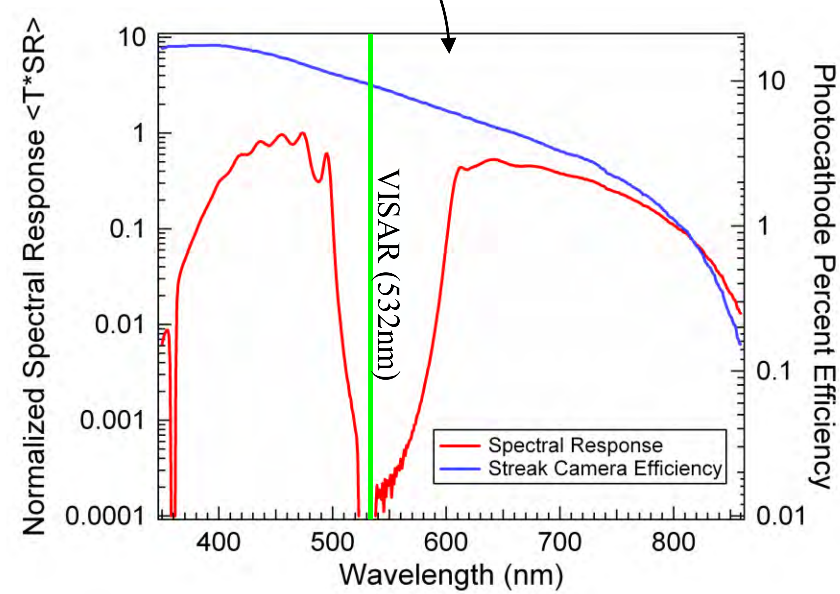
Temperature Measurements With Streaked Optical Pyrometry (SOP)



Calibrate against a source of known spectral radiance (tungsten ribbon filament) to determine the relationship between measured intensity and temperature

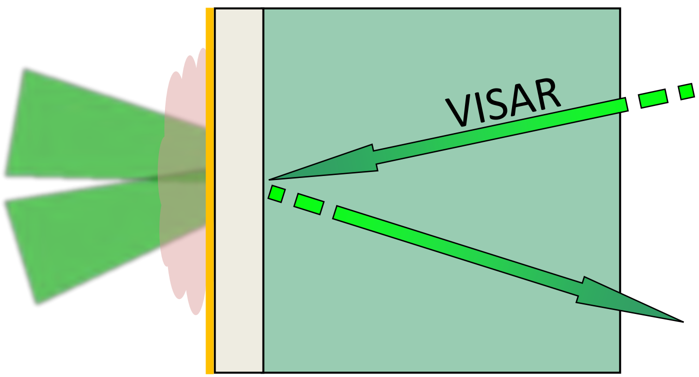
$$Intensity\ (T) \propto \left(P_{system} \cdot \int_{\lambda} \varepsilon \cdot L_S(\lambda, T) \cdot T_x(\lambda) \cdot S(\lambda) d\lambda \right)$$



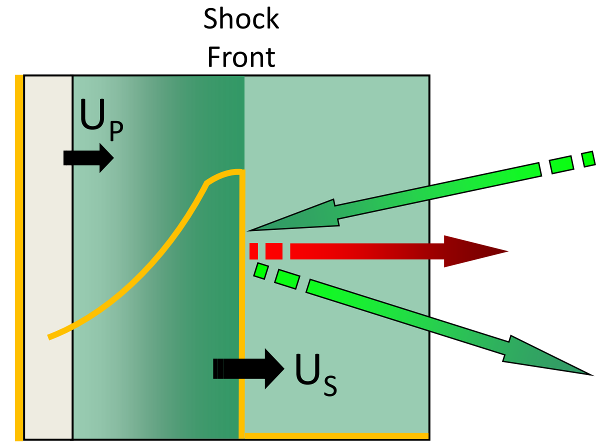


Complications in Optical Pyrometry

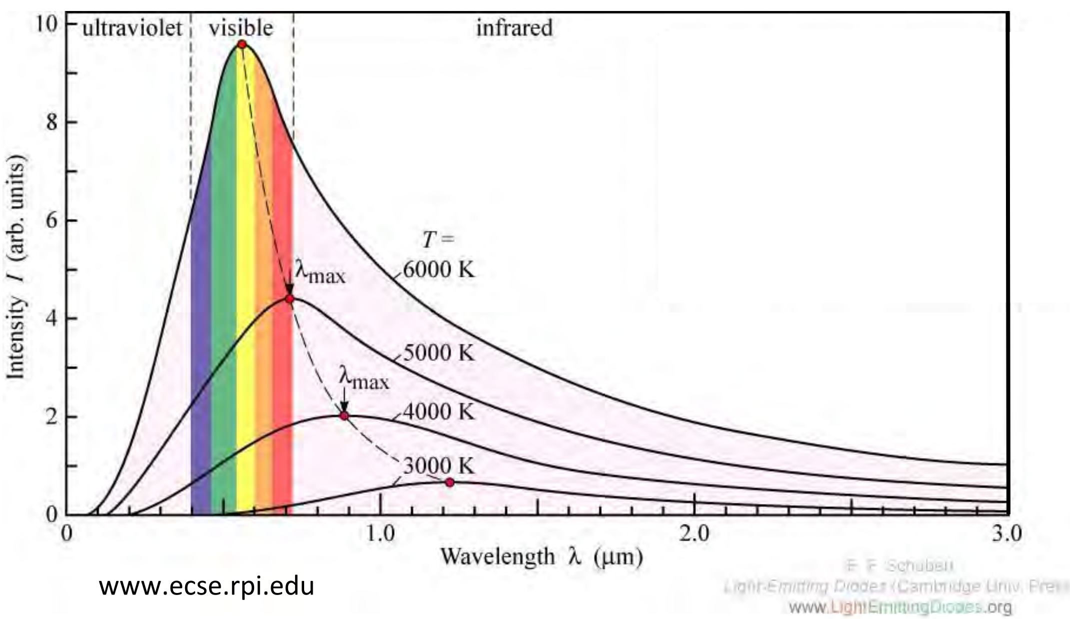
Is the Shock Front Transparent to Thermal Emission?



$t=t_0$



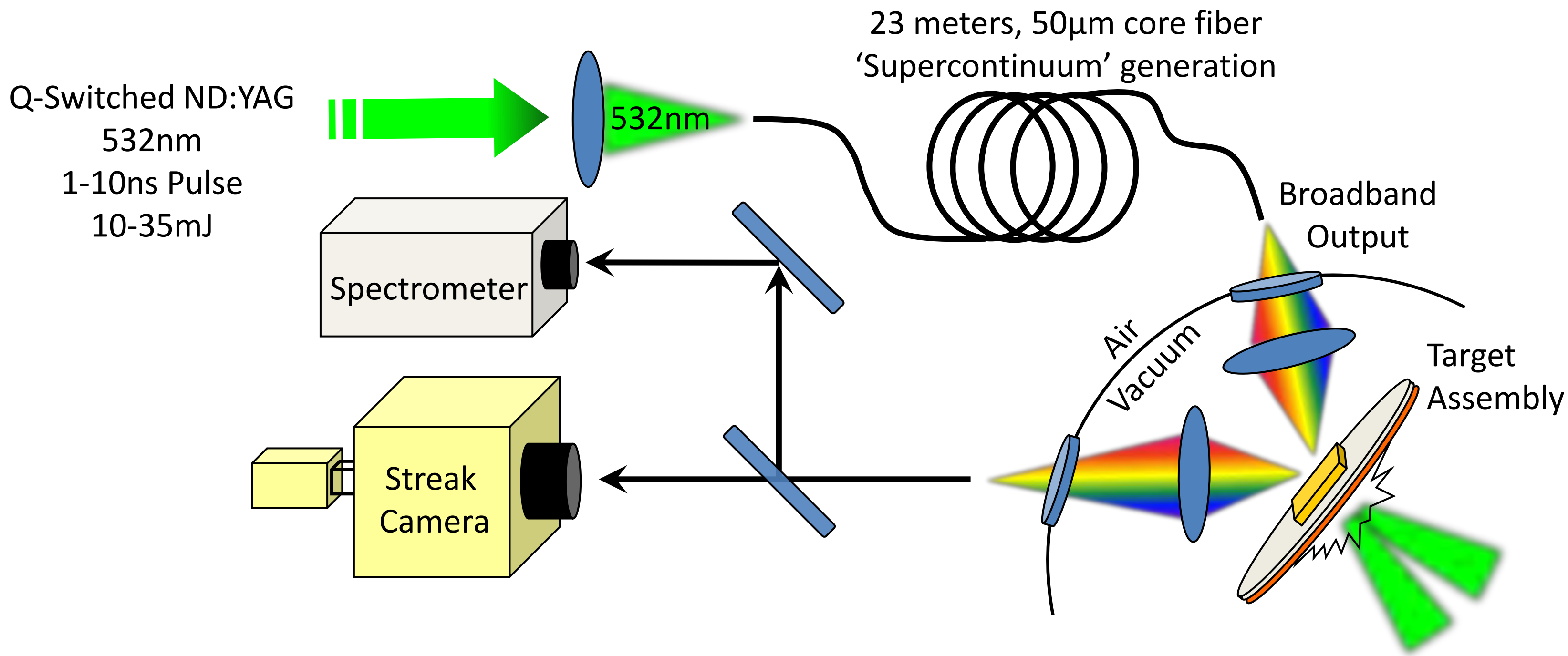
$t=t_0+\Delta t$



www.ecse.rpi.edu

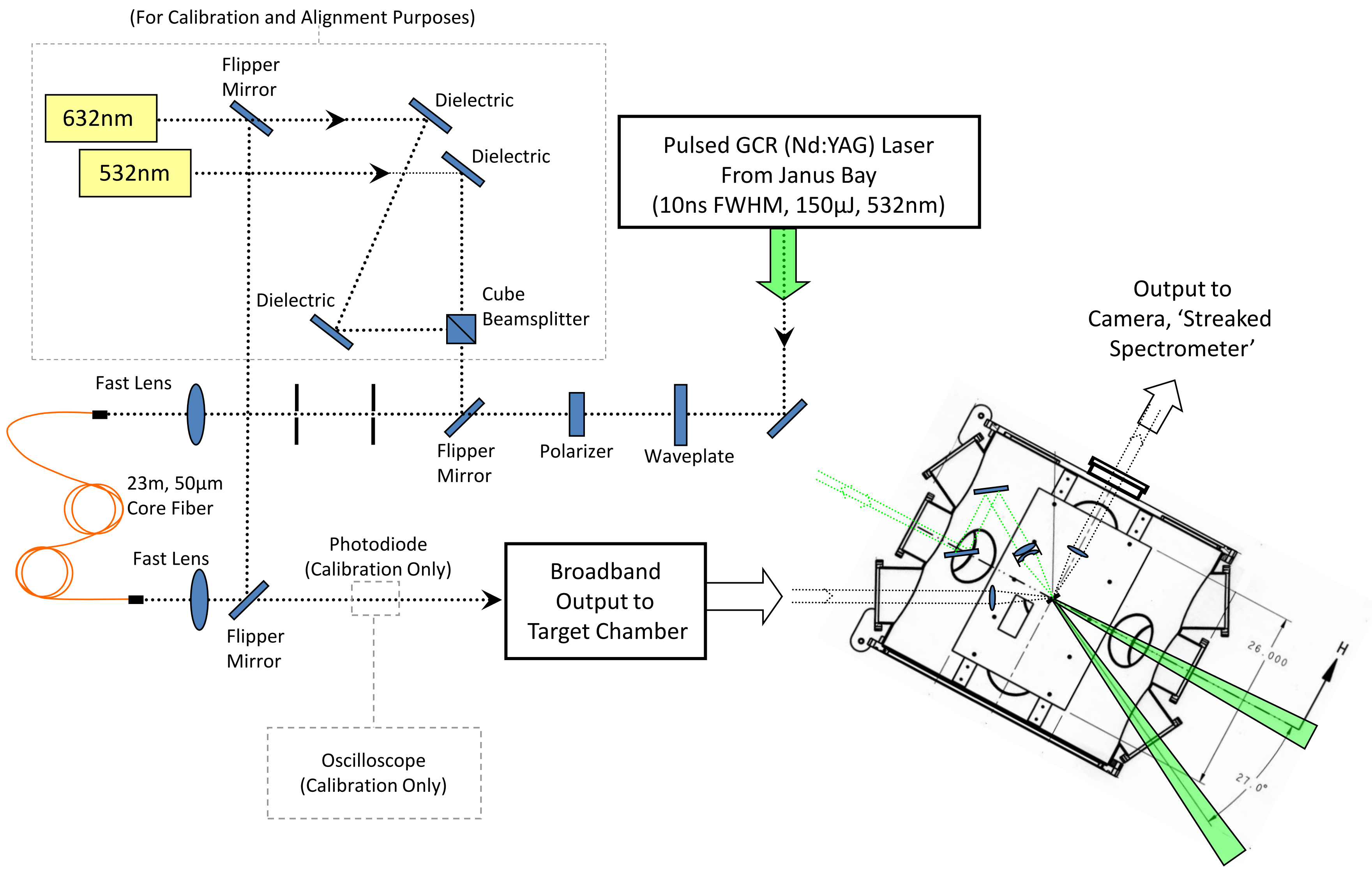
Broadband reflectivity allows Determination of wavelength-dependent emissivity as a function of time for better gray-body temperature correction

Supercontinuum Generation Via Non-Linear Pumping Of An Optical Fiber

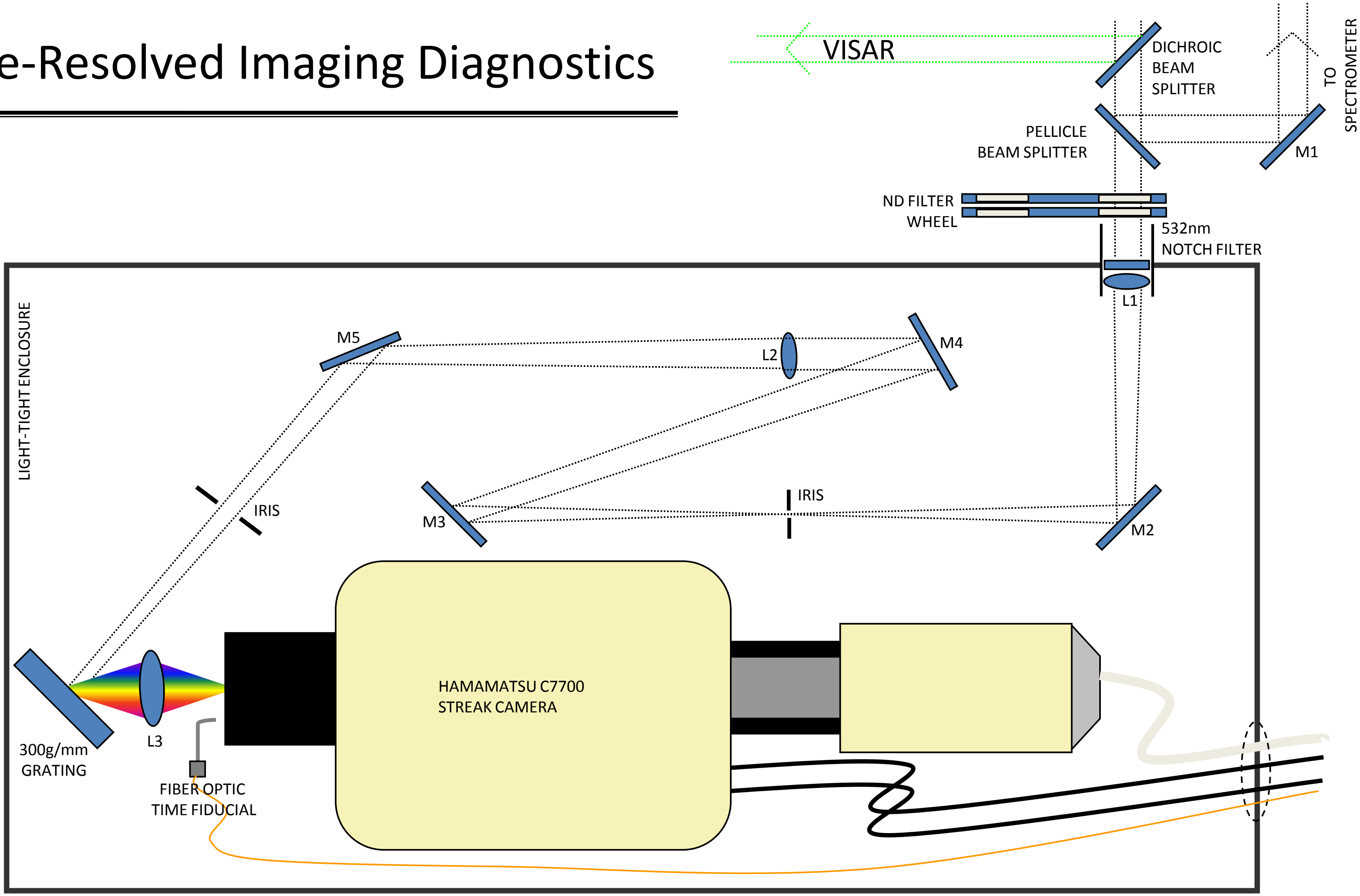


- Self Phase Modulation
  - Induced change in refractive index
- Stimulated Raman Scattering
  - Inelastic photon scattering
- "Four-Photon" Mixing
  - Interference of three fields results in creation of a fourth

Possible Layout for White Light Supercontinuum Generation Using Existing Jupiter GCR Laser



Time-Resolved Imaging Diagnostics



M1-4: 3” diameter mirrors
M5: 4” diameter mirror
L1,2: 1m achromat lenses
L3: 146mm fast achromat
Dichroic beam splitter may be replaced with a 50/50 beamsplitter depending on VISAR performance for better spectral response
Spectrometer (Acton SpectraPro 2300i or fiber-coupled Ocean Optics HR4000) is along the east wall of the Janus target bay. The latter could be placed in the enclosure, replacing M2 with the pellicle beamsplitter and eliminating M1.

Calibrations

System must be spectrally and temporally calibrated for reliable data

- Spectral calibration achieved using the two lasers (532nm and 632 nm) and Ne and/or He/Ar lamps

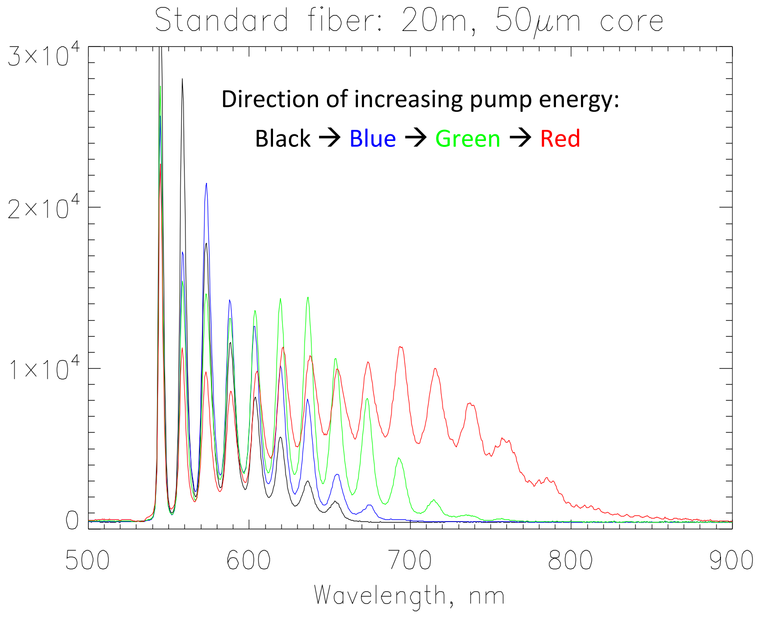
- Temporal calibrations are provided for the streak camera and can be checked using a comb generator

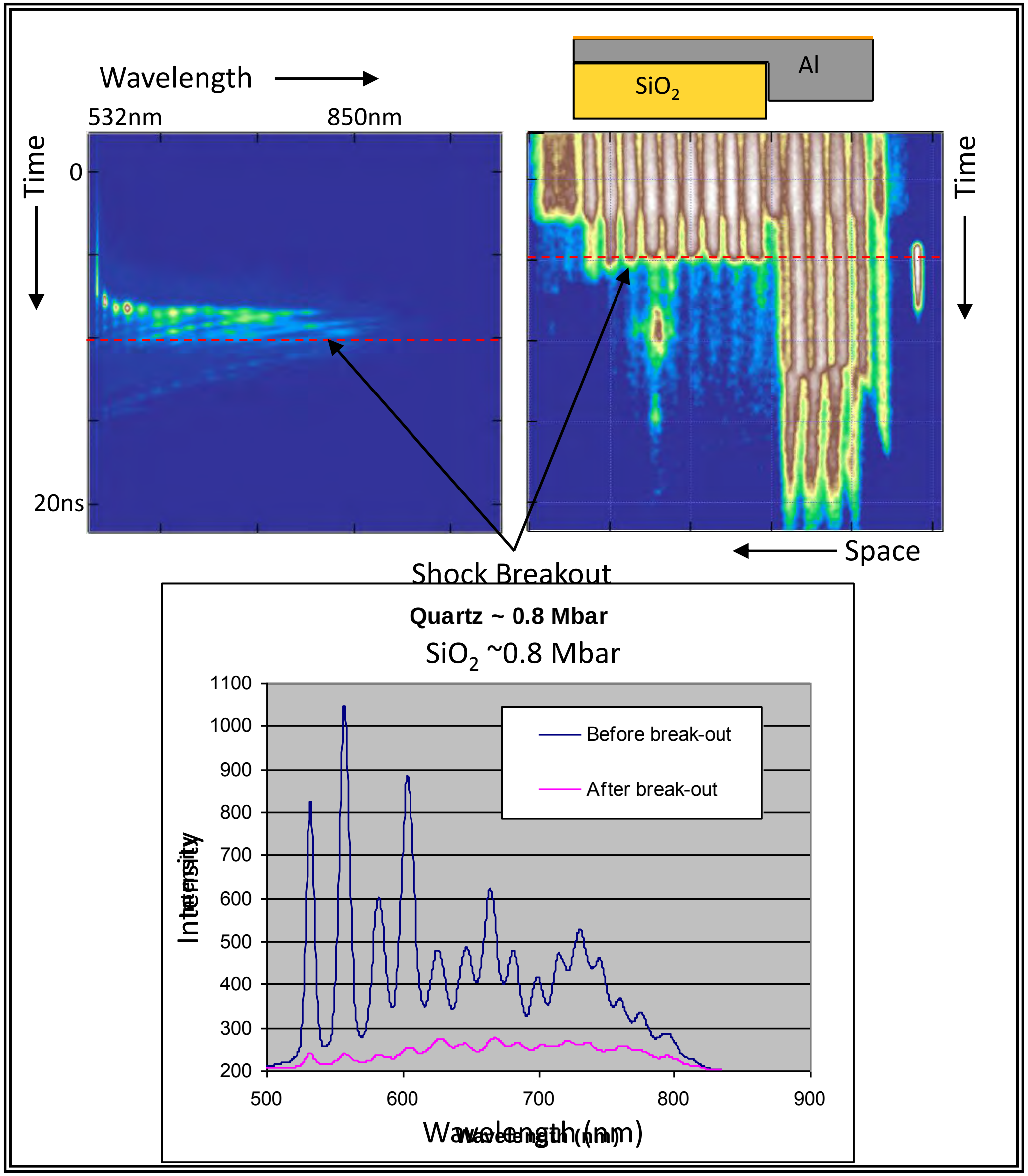
- Ambient reflectivity measurements can be taken from a static target by pulsing the laser without driving the sample. A mirror or polished Al target would allow characterization of the extent of spectral broadening

Proof of Concept

Proof of Concept: Spectrally Resolved Reflectivity on Shocked SiO_2

Spectral broadening up to >800nm was observed using a standard fiber pumped at 532nm. Shift to longer wavelengths appears to deplete energy in shorter wavelengths.





Conclusions

• Time-resolved spectroscopy of shock and ramp-compressed states has direct implications for high-pressure chemistry and will also serve to improve uncertainty in measurements from other optical diagnostics

•A bright broadband nanosecond source was successfully demonstrated > 30 μJ/pulse (more than enough for streak camera)

• Reflectivity measurements on Terrestrial mantle compositions (SiO_2, MgO and $MgSiO_3$) suggest the possibility of dense, metallic-like fluid states

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