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Temperature Measurements of Expansion Products

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NNSA

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Shock Thermodynamics Applied Research

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Objective & Goals:

- ***to obtain time-dependent thermal characteristics from the radiative emission of the expansion products resulting from debris generated from metallic and explosive targets shocked to very high pressures and temperatures***

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Assumptions:

- ***Assume we have captured the spectrum of a blackbody with grey emissivity***
  - ***Knowing it is not '1', but emissivity is constant over all wavelengths***
- ***Local thermodynamic equilibrium is assumed***
  - ***Not strictly true: spectral lines are a clear indicator of a non-equilibrated source***
  - ***Making spatial average estimates of temperature where gradients may exist: debris cloud at a single temperature***

Even though these approximations/assumptions may be sources for large uncertainties, the calculated temperature estimates appear quite reasonable—as will be seen

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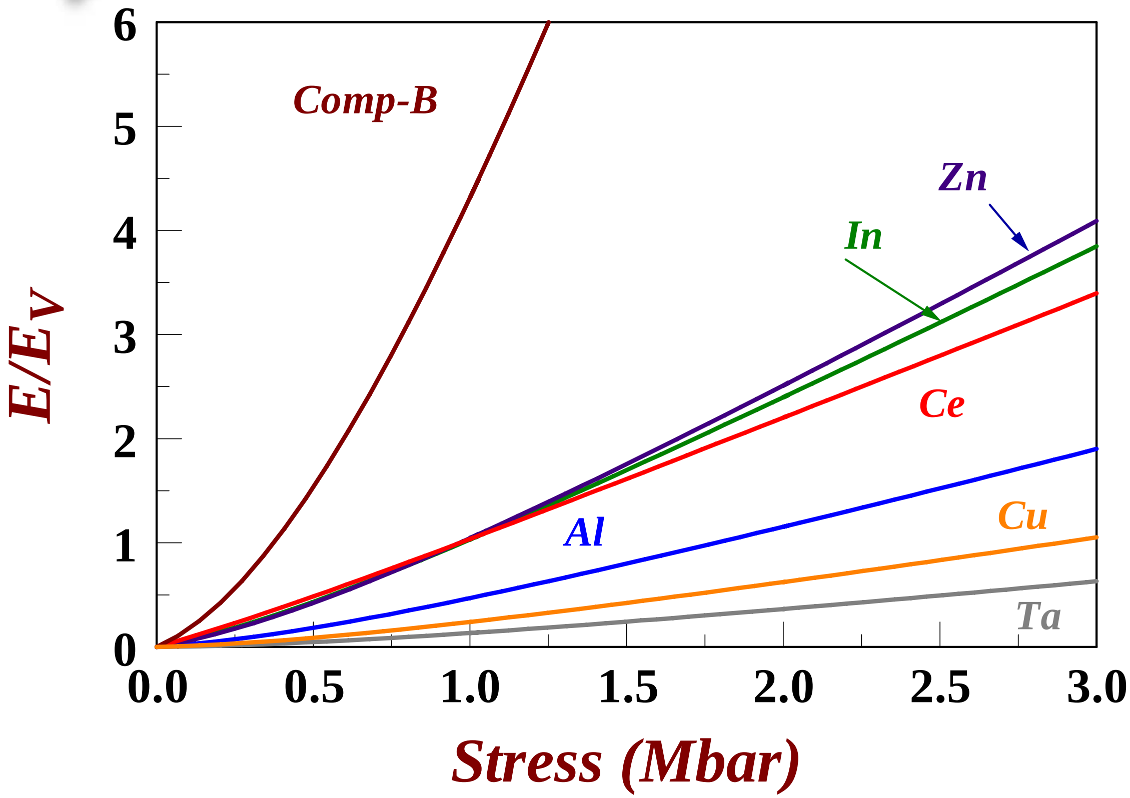
Materials: E/Ev Relation



Experiments conducted on aluminum, cerium, and Composition-B

- *E is the internal energy increase of the shocked material,*
- *Ev is the specific energy required to vaporize the material*

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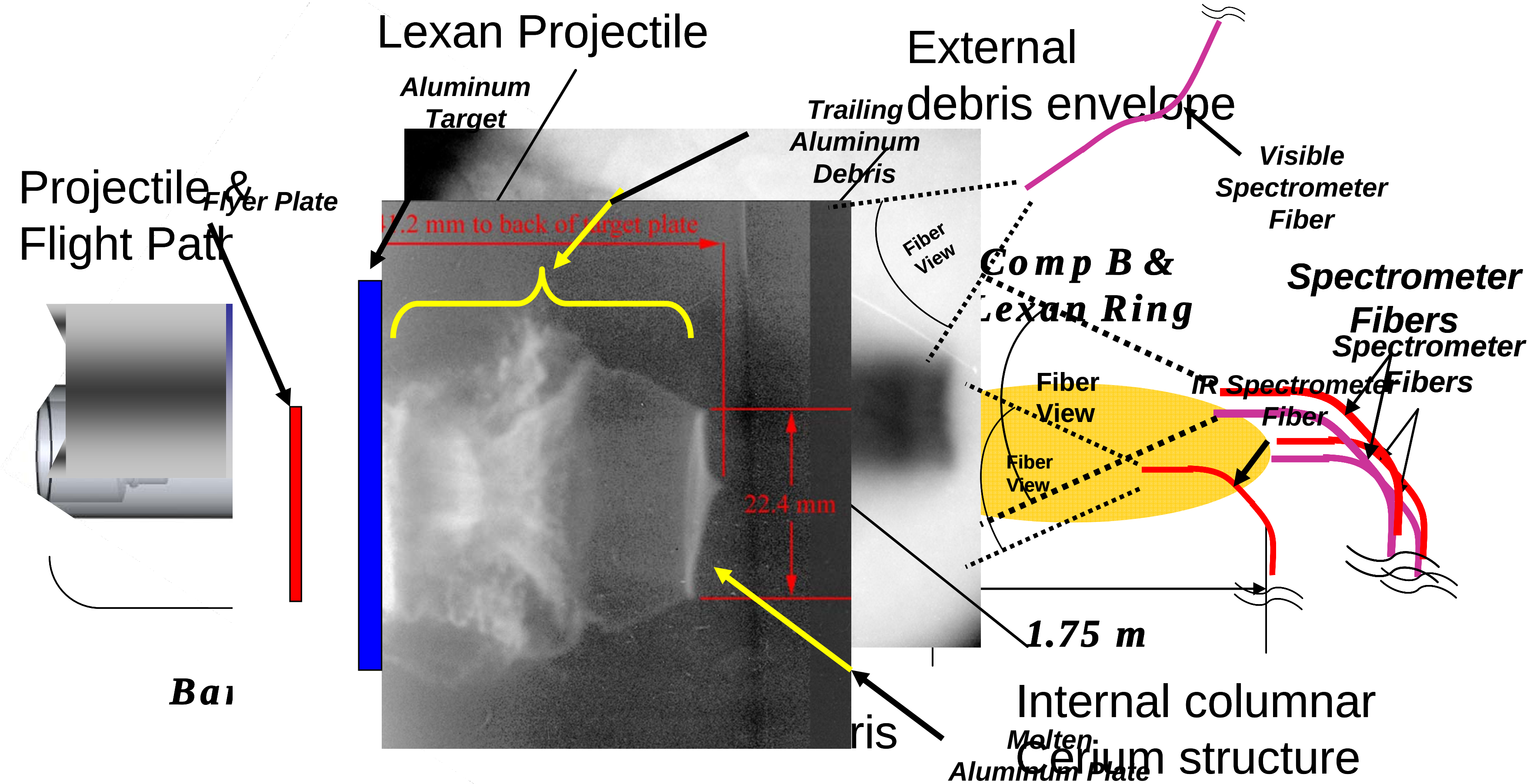
Experimental Method:



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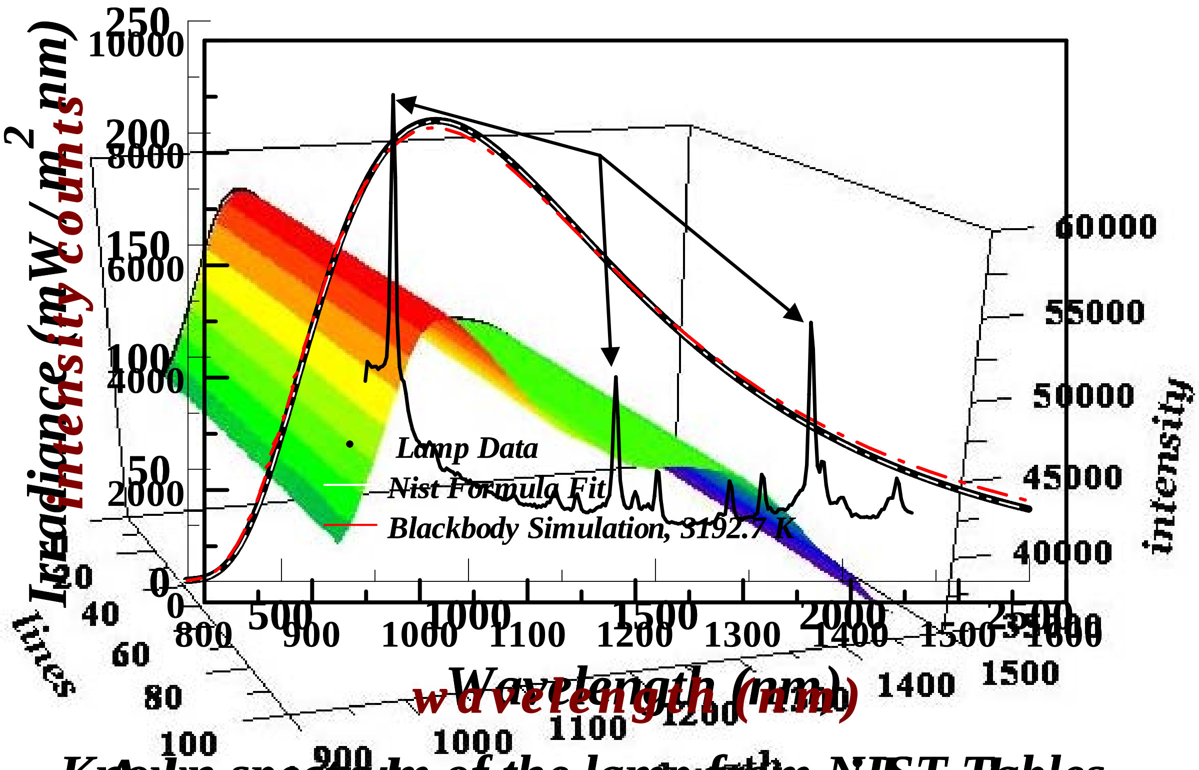
Spectrometer Calibration



Known spectrum of the lamp from NIST Tables, plotted with the measured calibration lamp spectrum multiplied by correction term.

Note that if the measured calibration lamp spectrum is multiplied by the correction term we simply recover the blackbody curve, as well we should.

A krypton lamp source provides three distinct, relatively high intensity lines, (for a specific spectrometer grating), which are plotted as a function of wavelength and intensity.

QTH lamp is recorded through spectrometer. Determination of amplitude correction term fro any spectrum obtained from 950-1500 nm

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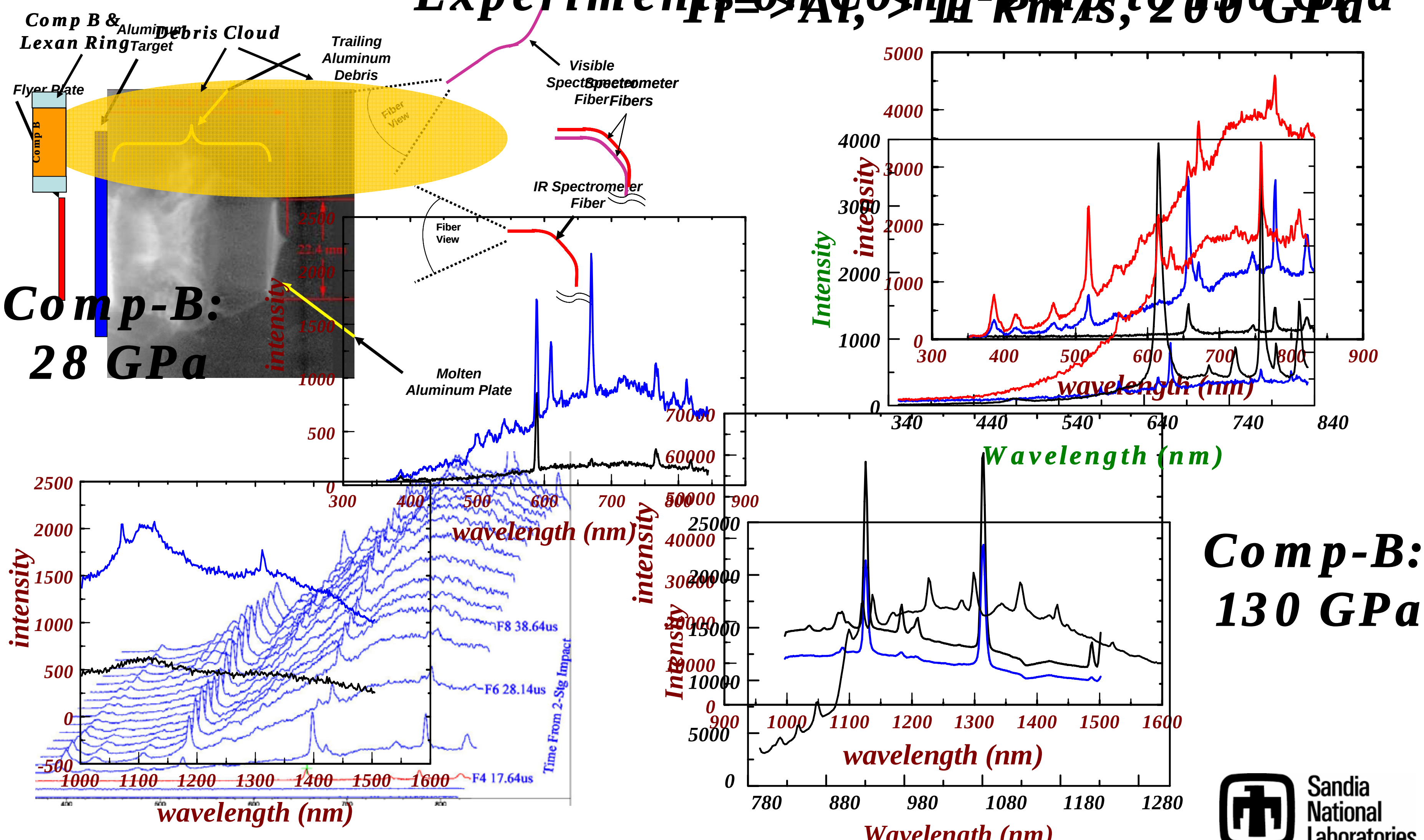
Experimental Results:

Experiments on Comp-B up to 130 GPa

Ti=>Al, >11 km/s, 200 GPa



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Extracting temperature :

From our basic premise, Planck's Law can describe the spectral radiance as:

$$I(\lambda, T) = \varepsilon \frac{2hc^2}{\lambda^5} \frac{1}{e^{c_2/\lambda T} - 1},$$

Assume ε, $2hc^2$ is a constant:

$$I(\lambda) = \frac{s}{\lambda^5 \left(e^{c_2/\lambda T} - 1 \right)}.$$

- ***For non-quantitative measurements of intensity, the factor '*s*' may be used as a scaling value that matches the blackbody shape of the observed signal***
- ***Recorded, corrected spectrum can be fit using non-linear least-squares routine with two adjustable factors: *s* and *T****

- ***Assumptions: grey body, $\varepsilon(\lambda)$ = constant and thermal equilibrium is assumed***

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Extracting temperature : Fitting functions

Wien's approximation for fitting function: 's' and 'T' will be used to estimate starting values

$$I \cong se^{-c_2/\lambda T} \big/ \lambda^5 \, .$$

$$T \cong \frac{c_2\left(1/\lambda_2 - 1/\lambda_1\right)}{\ln\left(I_1/I_2\right) + \ln\left(\lambda_1^5/\lambda_2^5\right)}$$

's' and 'T' : choosing two distinct signal and wavelength values, 'I' and 'λ'

$$s \cong I_1 \lambda_1^5 e^{c_2/\lambda_1 T} \, .$$

- ***These curves give way of visualizing the sensitivity of the fit:***
  - > ***If the curves easily envelop the corrected data—fit is sensitive—estimate is probably reasonable***
  - > ***If the curves do not encompass the spectral lines—fit is insensitive and will not capture a good temperature estimate.***
- ***One can interpret these curves as error bars: 300K for reasonable approximations***

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Extracting temperature : fitting the data

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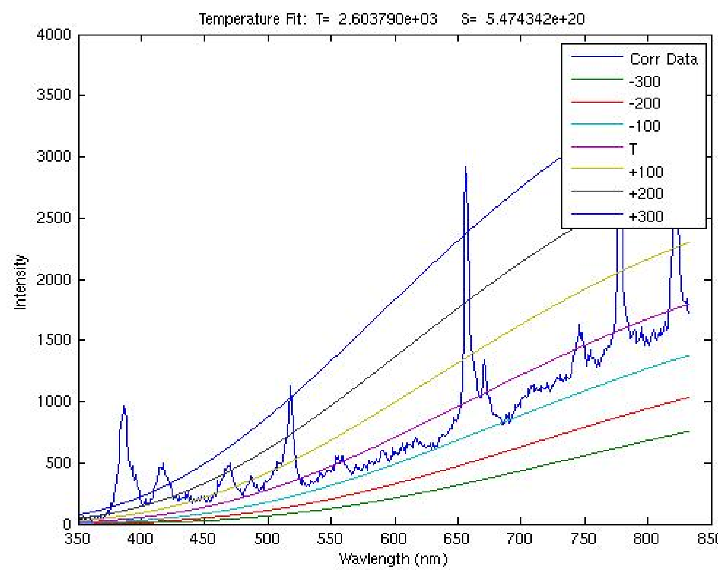
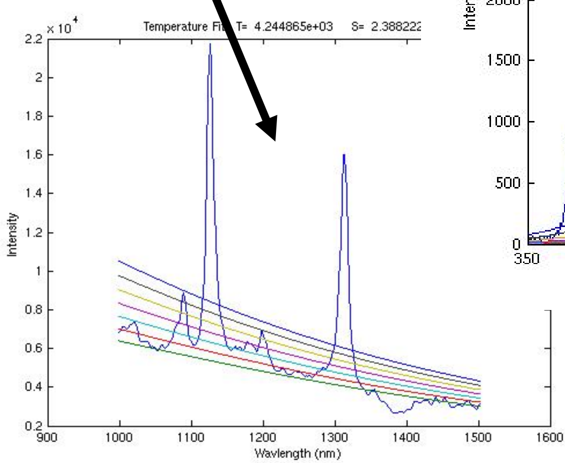
  - > If the curves easily envelop the corrected data—fit is sensitive—estimate is probably reasonable
  - > If the curves do not encompass the spectral lines—fit is insensitive and will not capture a good temperature estimate.
- One can interpret these curves as error bars: 300K for reasonable approximations

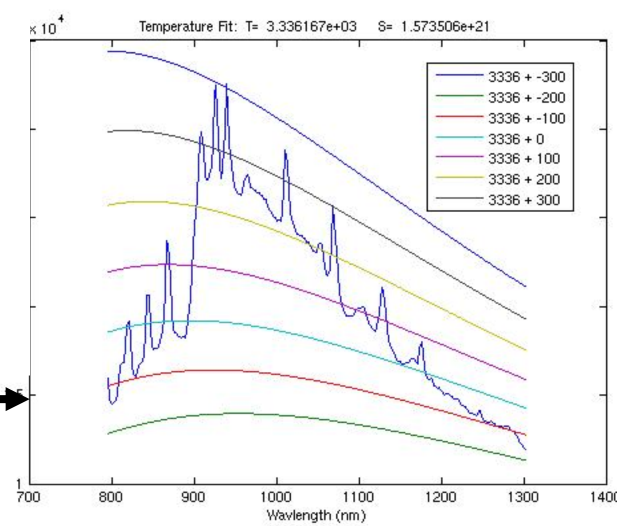
Al: 200 GPa



Poor Estimate

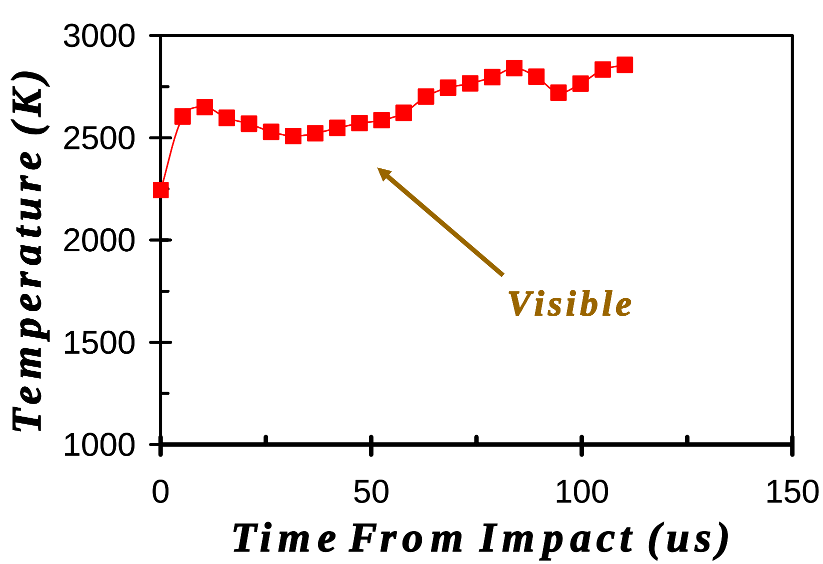


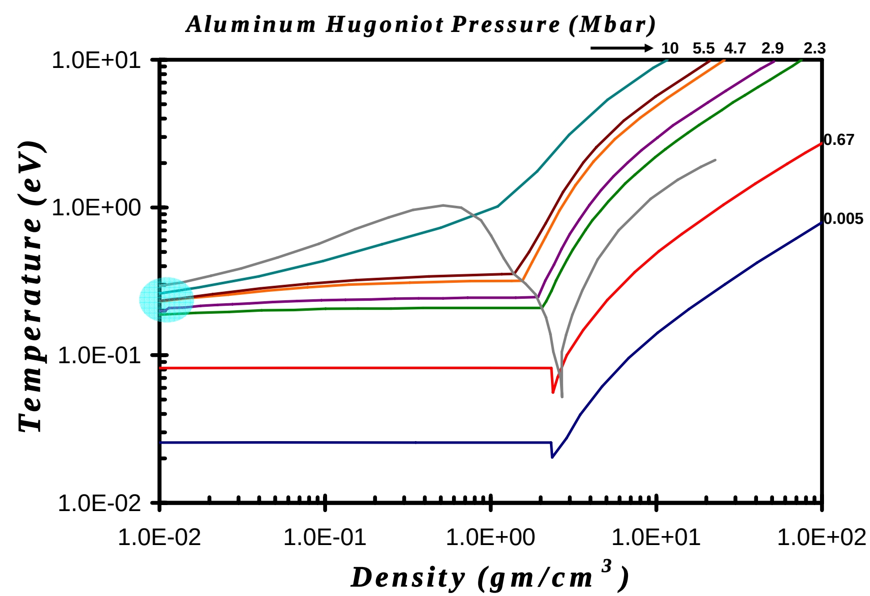
Comp-B: 130 GPa



Temperature Estimates: Aluminum

- *Aluminum: not trivial, greater uncertainty*
  - > *Large magnitude of spectral radiance*
  - > *Presence of large atomic emission lines*
- *Temperature history suggests constant temperature*
  - > *Consistent with a solid—cooling is not as rapid*
- *Reasonable results when compared to phase diagram*





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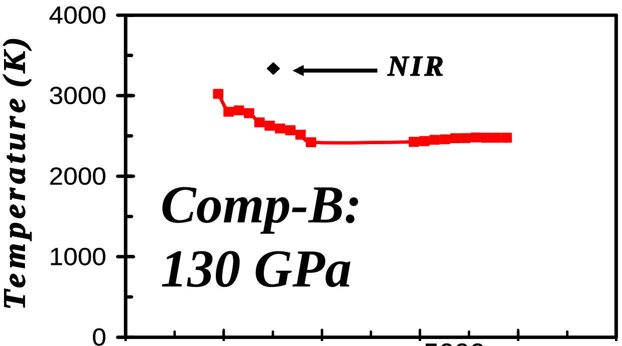
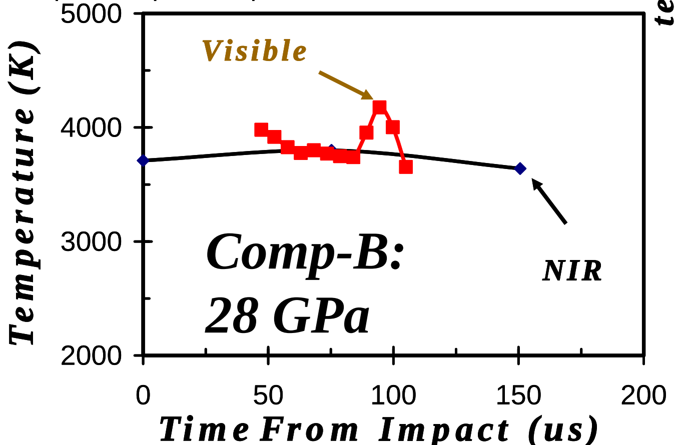
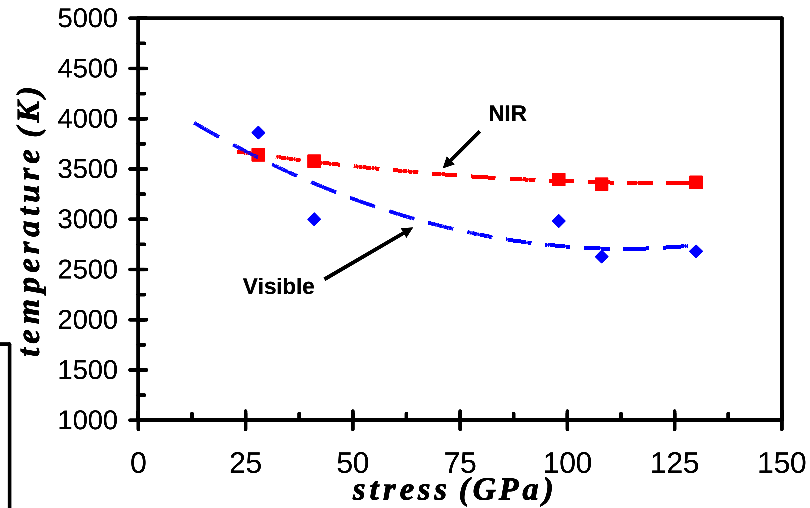
Temperature Estimates: Comp-B

- *Using dissociation energy (E/Ev): 0.5 – 5 for tests*
  - *Tests represent experiments that undergo detonation, and those where detonation is overdriven (or delayed)*
- *Lower pressure experiment produced higher temperature*
  - *Same trend for tests at 41, 98, and 108 GPa*
- *Released from higher pressure: velocity is faster*







Conclusions:

- ***First temperature measurements/estimates of expansion products from materials shocked to high temperatures***
  - ***Ascertained temperatures are estimates, results appear reasonable***
- ***Lower pressure experiments produced higher temperature***
  - ***Encouraging results based on simplistic assumptions***
- ***Further research is necessary to validate assumptions.***
- ***Experiments providing early time measurements: shocked temperatures***
- ***Combination of pressure, density measurements of shocked and expanded materials: potential to determine phase diagrams.***

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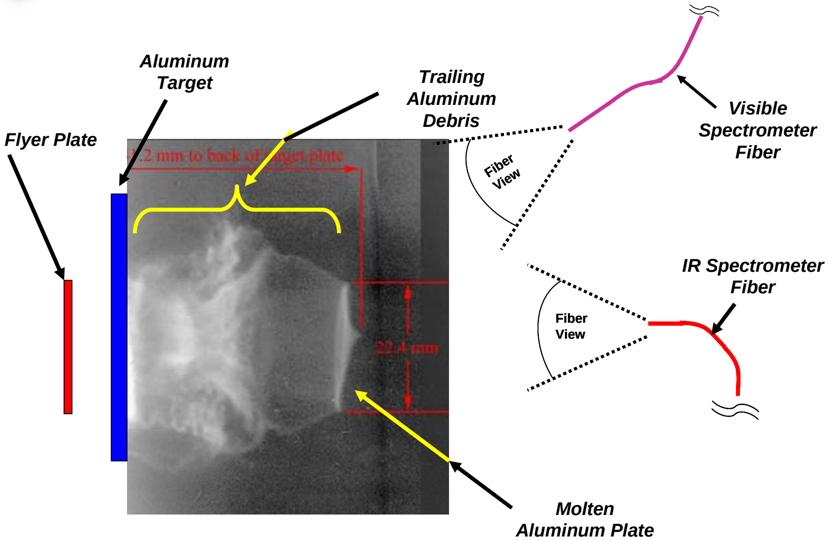
Acknowledgements:

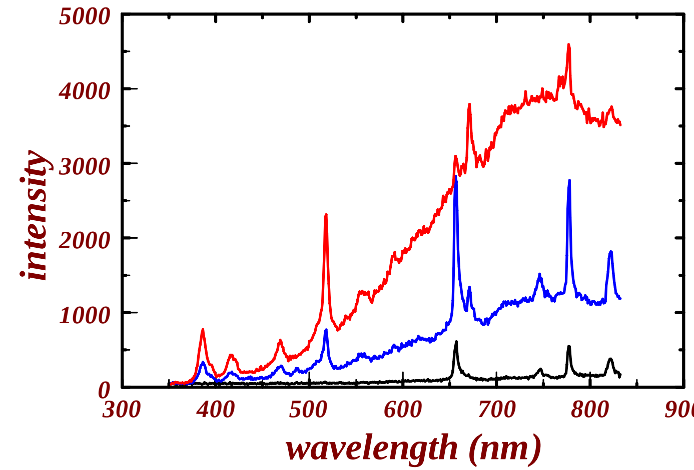
- **William G. Breiland: Sandia National Laboratories**
- **Justin L. Brown: California Institute of Technology**
- **Tom F. Thornhill: Ktech Corporaton**
- **John R. Martinez: Ktech Corporation**

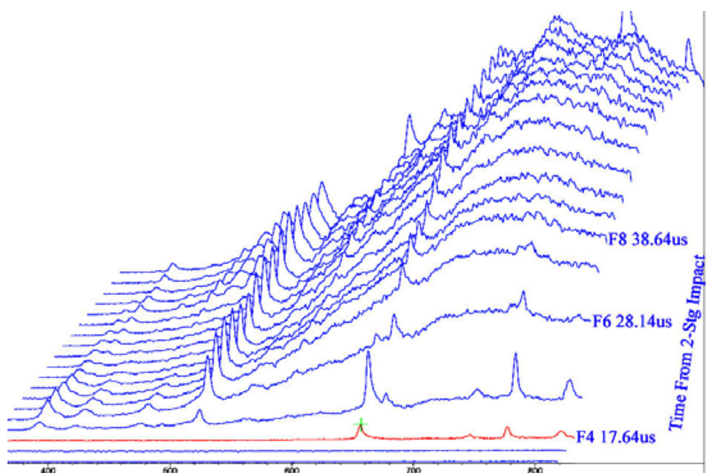
End:

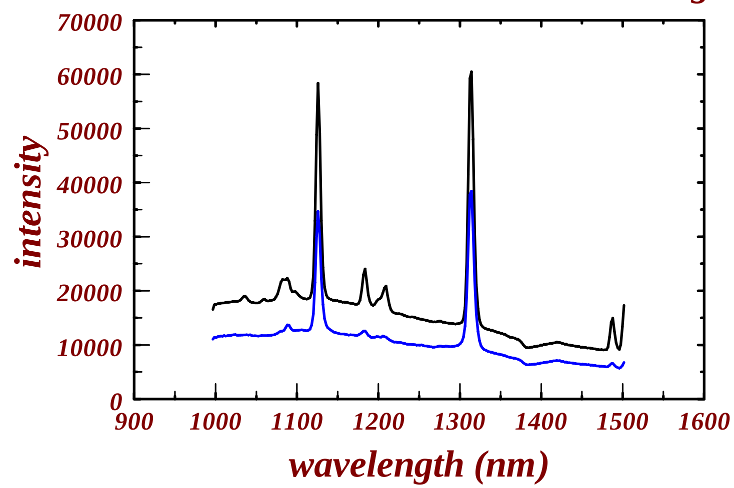
Dup. slide 7 :

Ti=>Al, > 11 km/s, 200 GPa









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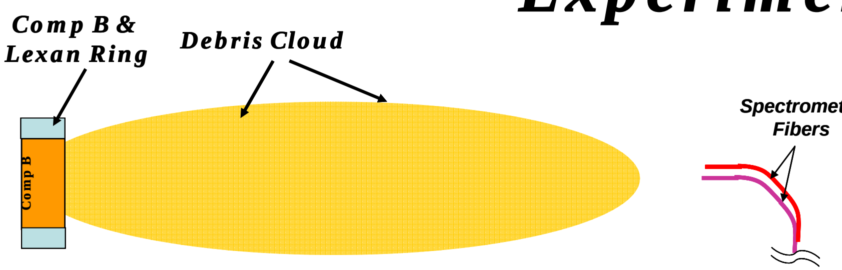
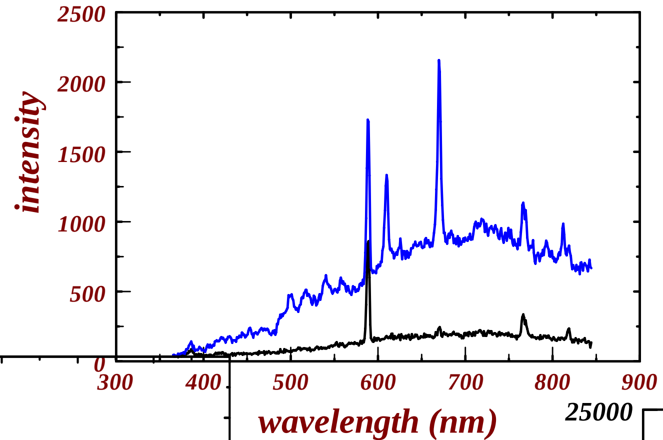
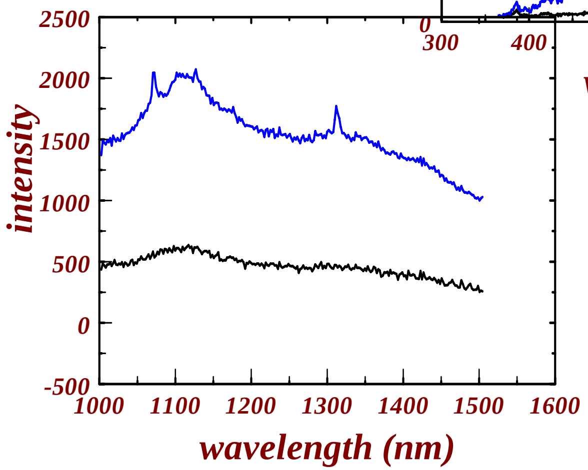
Dup. slide 7 : :

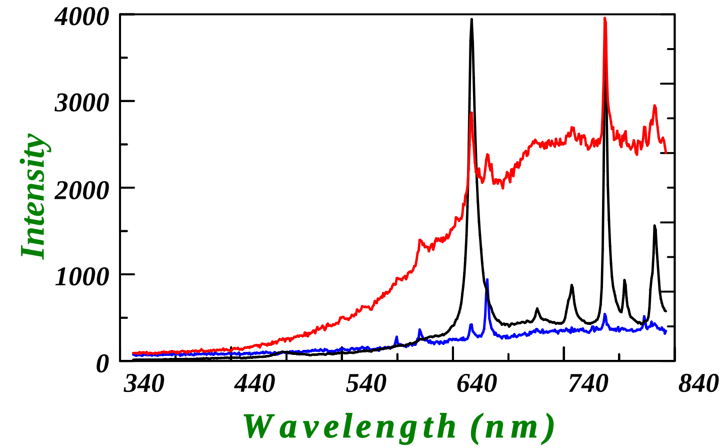
Experiments on Comp-B up to 130 GPa

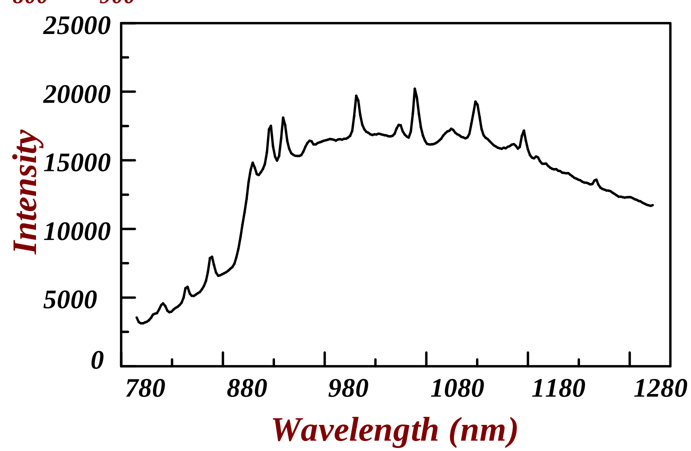


**Comp-B:
28 GPa**









**Comp-B:
130 GPa**

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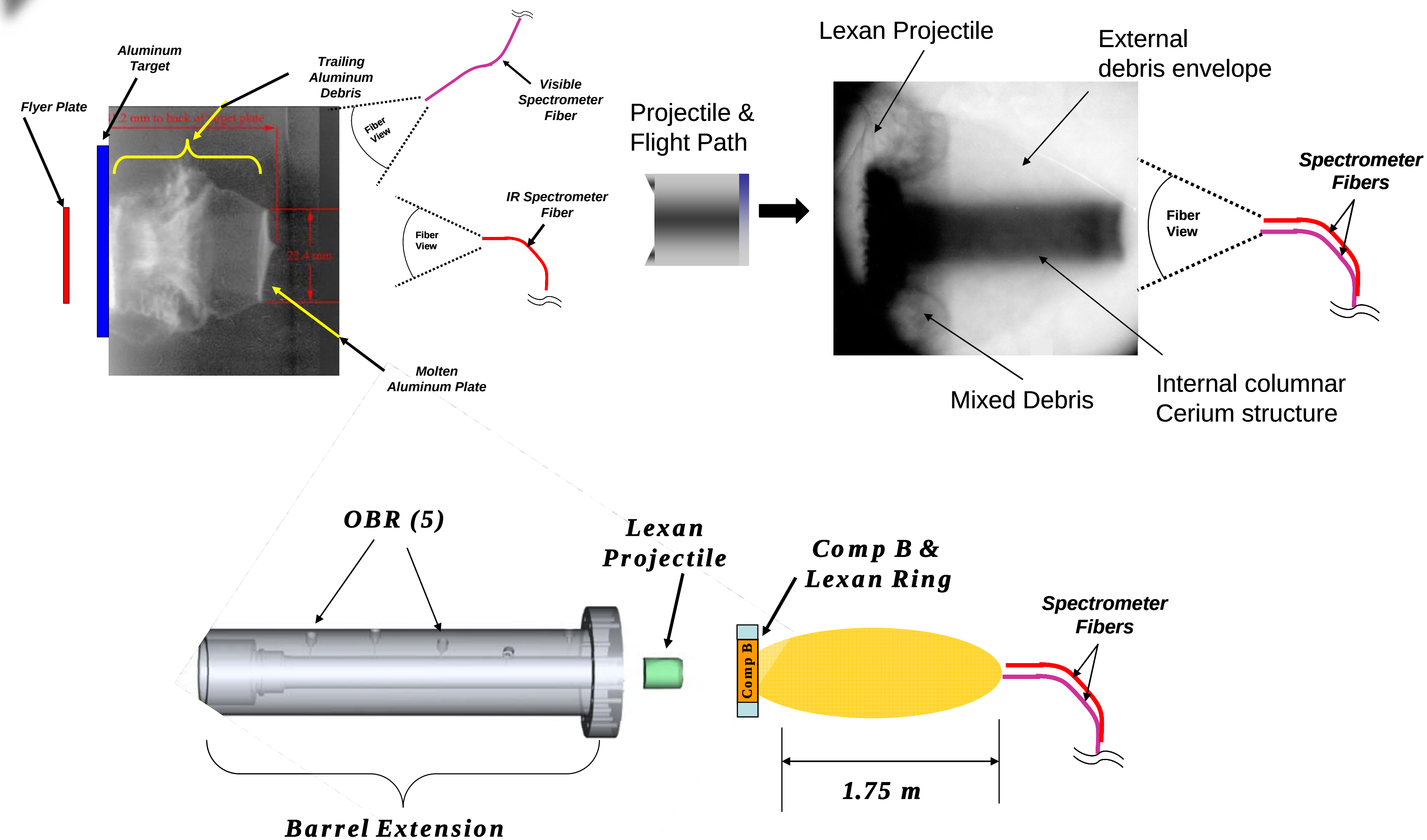
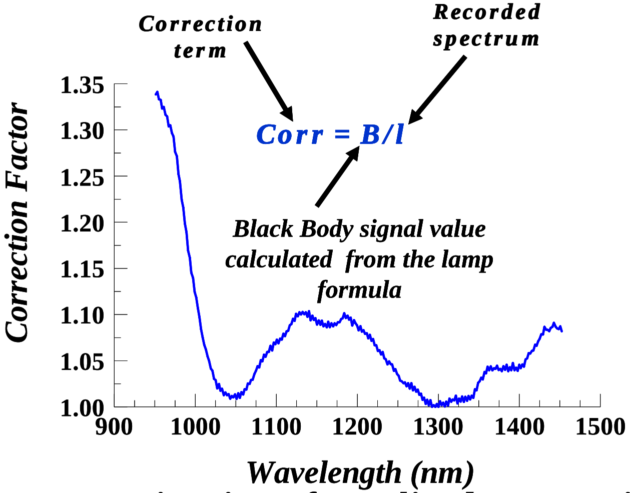
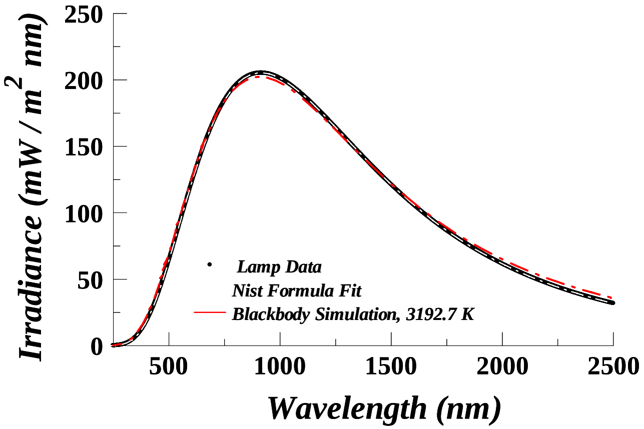
Duplicate slide



Dup. slide 6 :



Determination of amplitude correction term fro any spectrum obtained from 950-1500 nm



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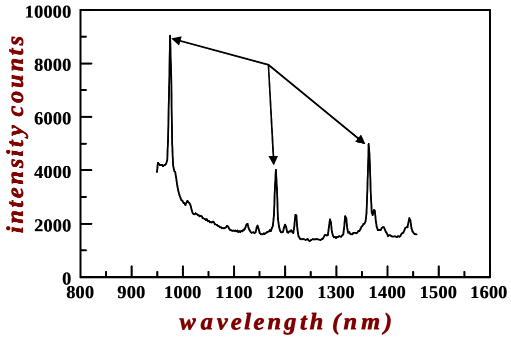

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