Infrared emission in metal-halide arc lamps

D J Smith, G A Bonvallet and J E Lawler
University of Wisconsin-Madison

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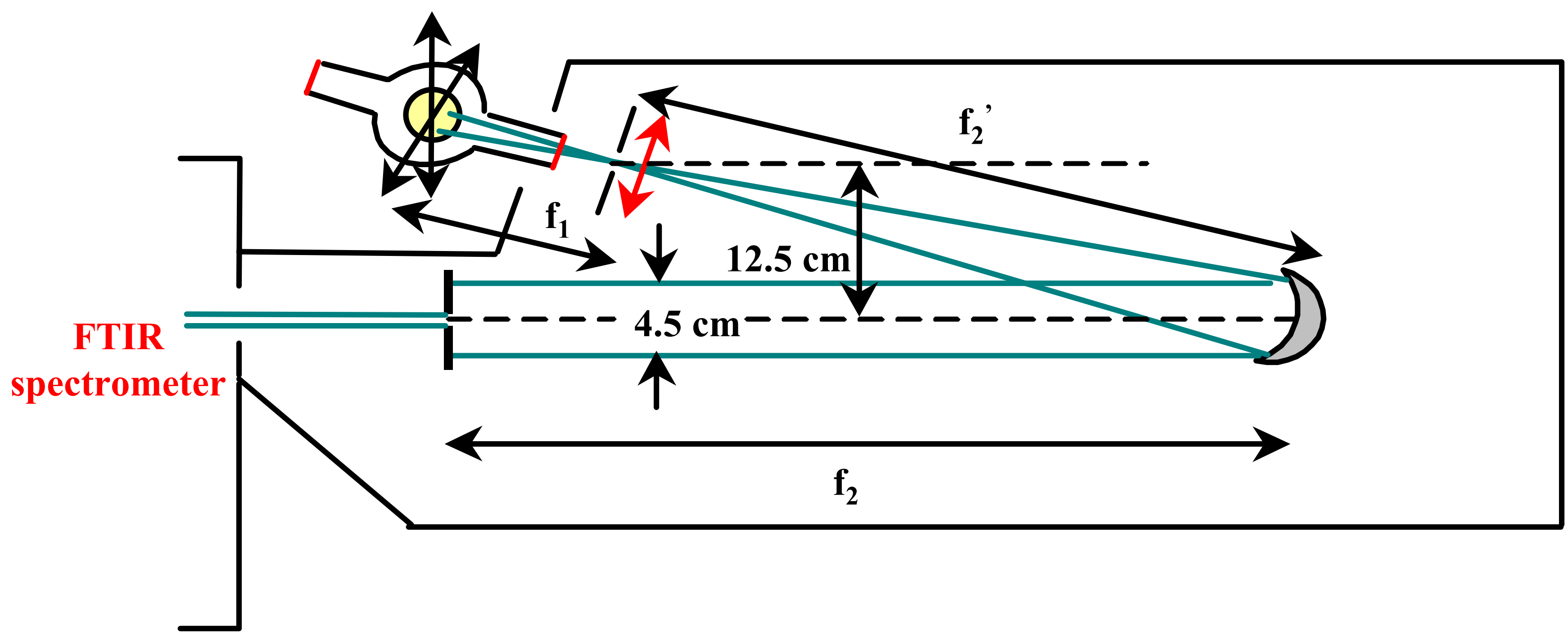
HID lamps – IR losses

- Understand and control the infrared (IR) losses in commercial high-intensity discharge (HID) lamps
- Determine the total IR power output up to the fused silica limit (~3.5μm)
- Identify the major contributions to losses in the IR
  - Initially Osram Sylvania 250W Metalarc lamp (Na Sc chemistry)
  - Custom Philips HID lamp (rare earth chemistry)

The Lamp

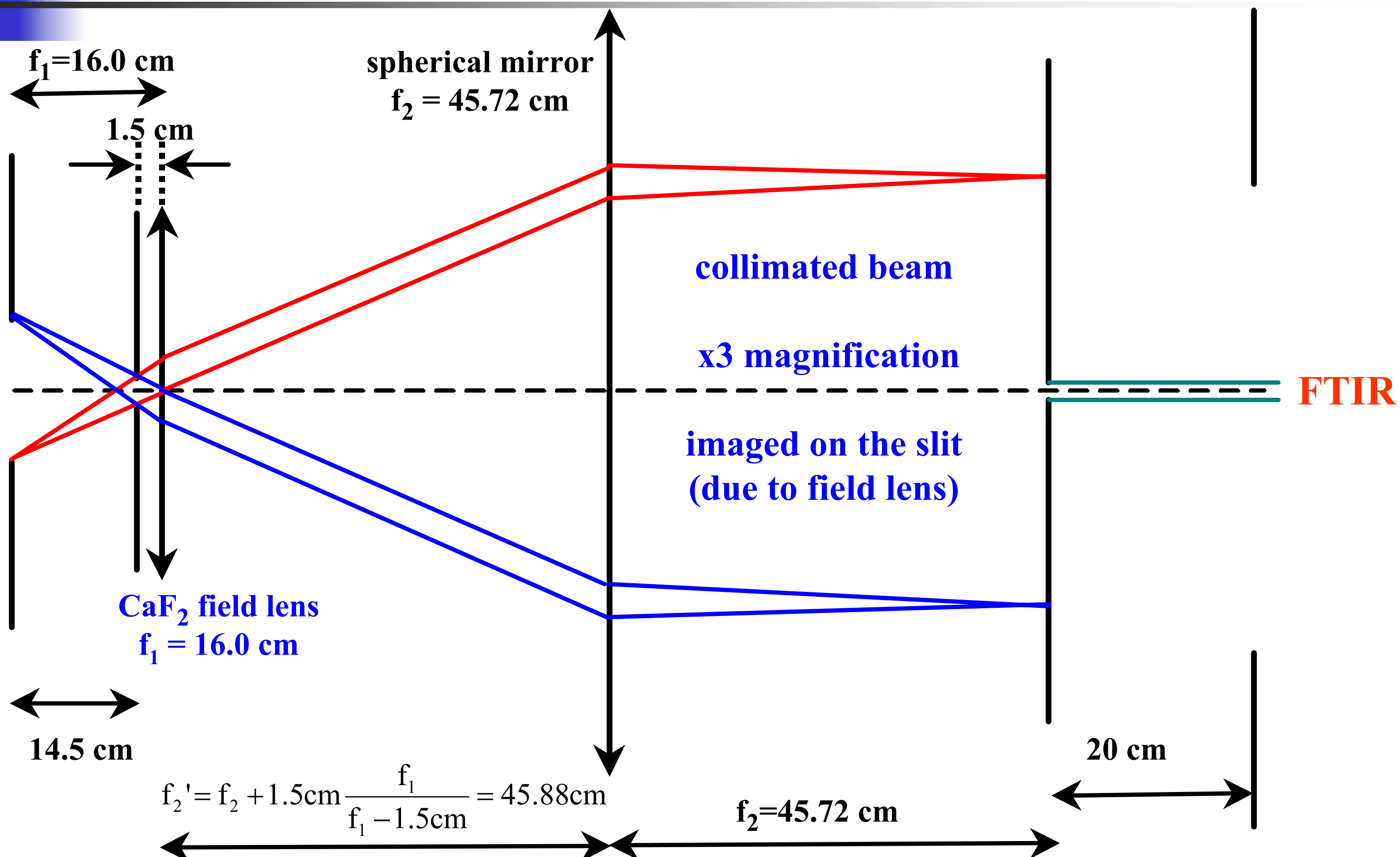
- Osram Sylvania ‘250W Metalarc’ lamp
  - Metal-halide lamp
    - Scandium, Sodium, Caesium, Thorium
- Visible emission spectrum dominated by Sc I
- Lamp chamber is anodized Al with MgF_2 window to allow through the IR
  - chamber pressure of ~15 mTorr

Experiment - optical set-up



external optics encased to ensure dry, CO_2-free air

Experiment - Ray tracing



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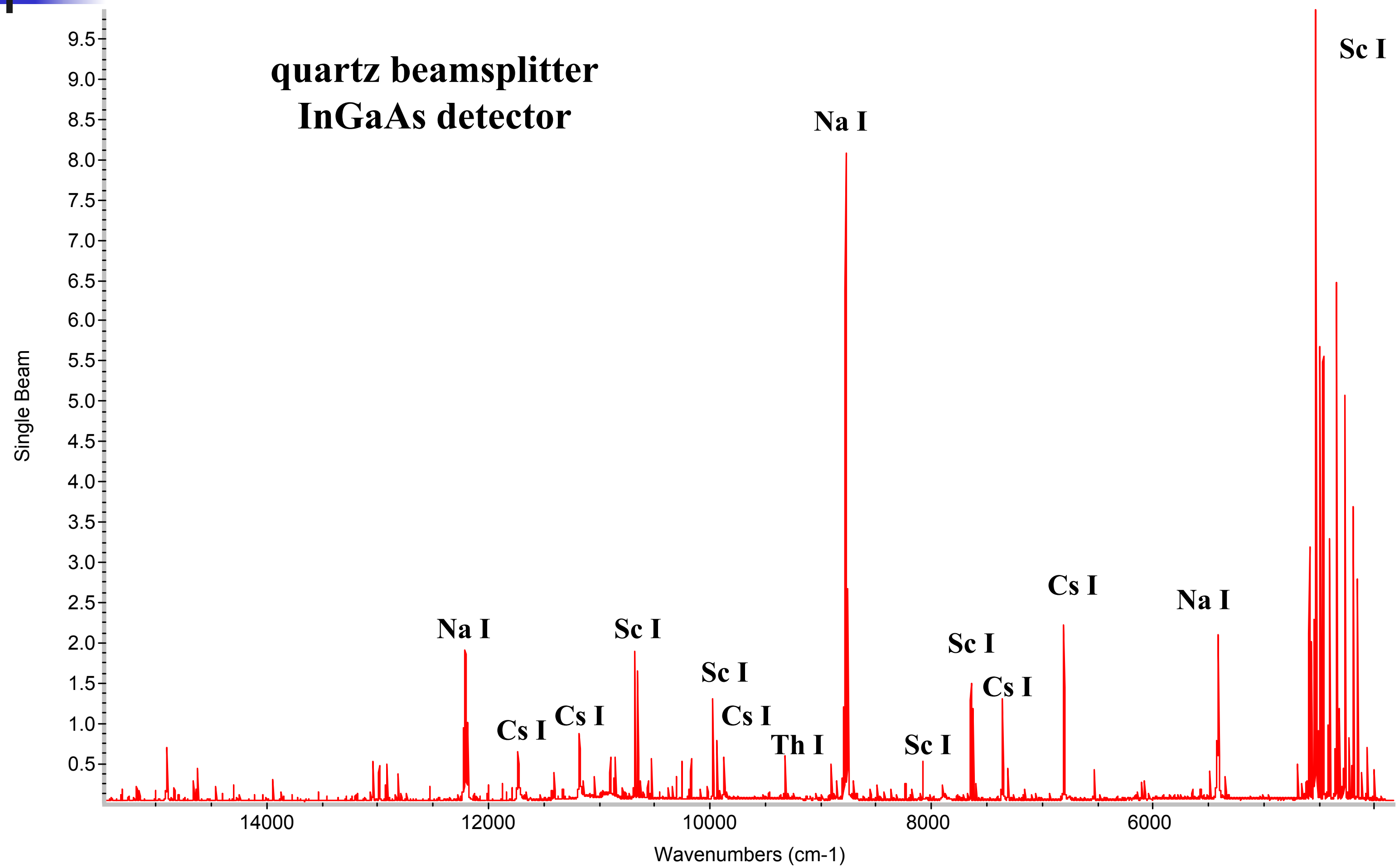
Experiment - spatial resolution

- Field lens is used to image the arc lamp onto the slit
  - provides excellent spatial resolution
- Lamp is translated on a X-Z translation stage to allow measurements of emission for both radial and longitudinal information
- Impact parameter is unaffected by the arc tube in emission measurements

Experimental measurements

- Fourier transform infrared (FTIR) spectrometer
  - $\sigma = 25{,}000\text{-}100\ cm^{-1}$
    - MgF_2 window limits the experiment to 1,000 cm^{-1}
    - ultimately replace with CaF_2 to measure further into the IR (blackbody radiation)
- Spatially-averaged measurements in the visible, near IR and mid IR
- Spatially-resolved measurements in the near IR
- External optics encased to ensure dry, CO_2-free air

Spatially-averaged near IR emission (uncorrected spectrum)



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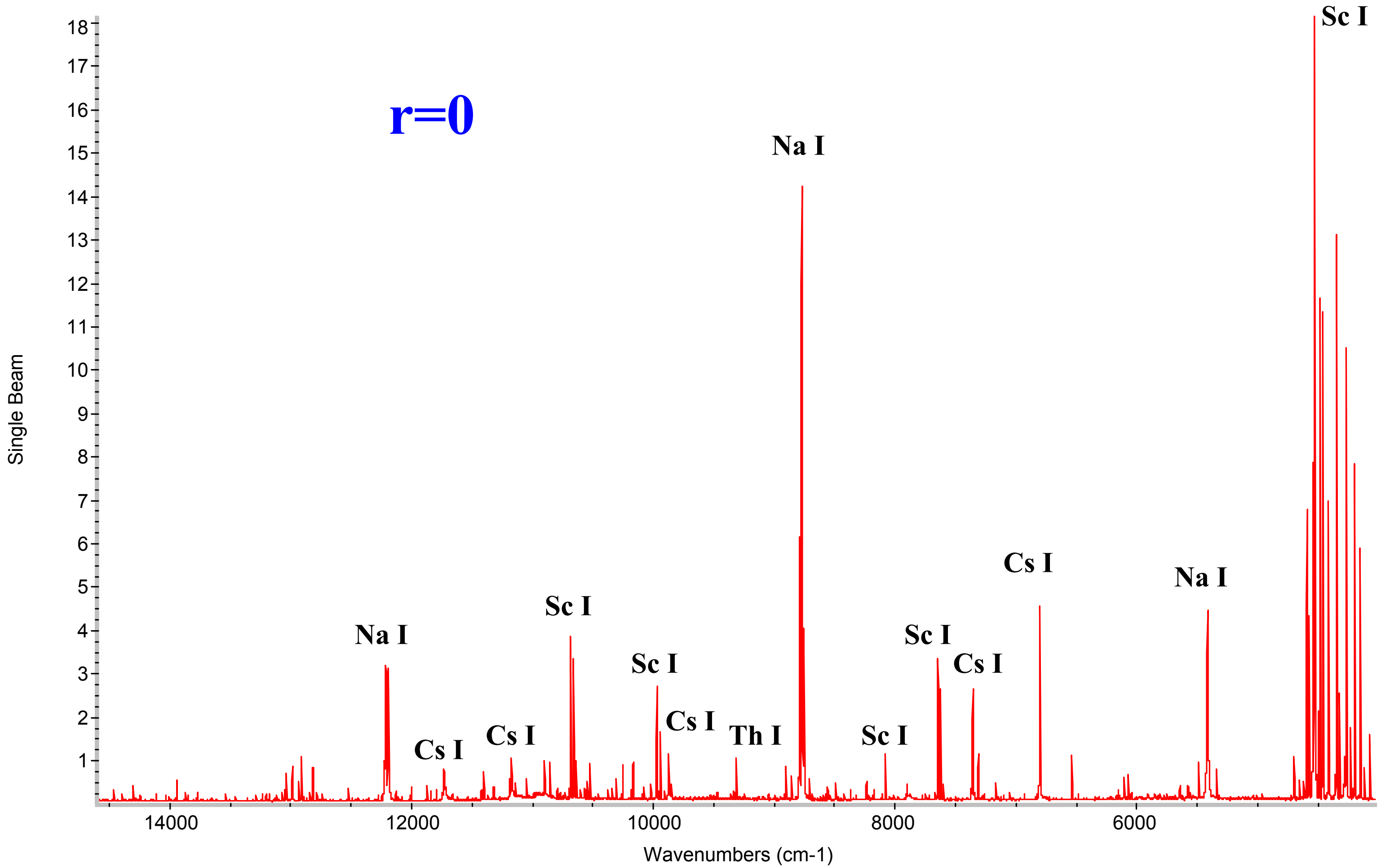
Spatially-resolved near IR measurements (uncorrected spectrum)



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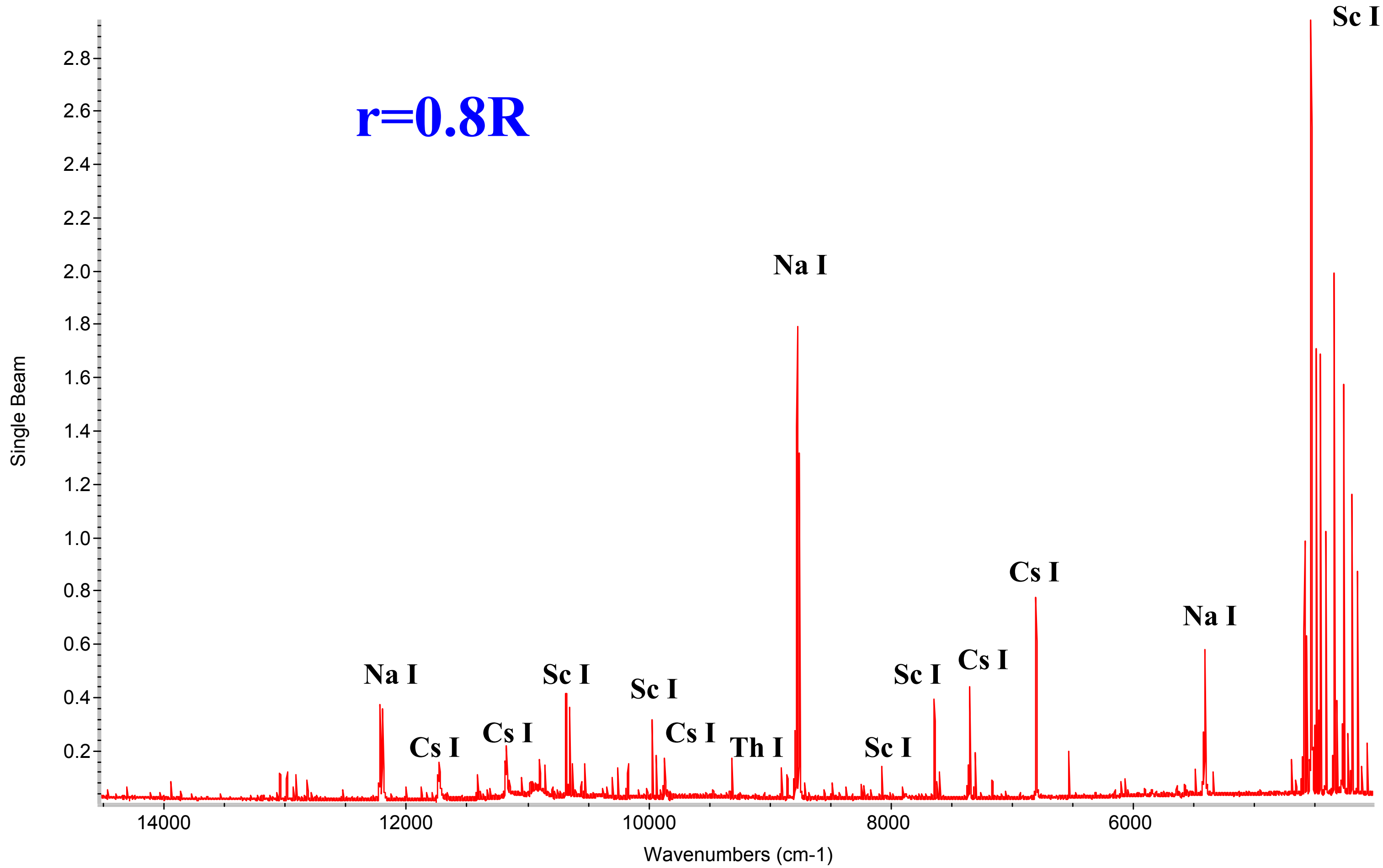
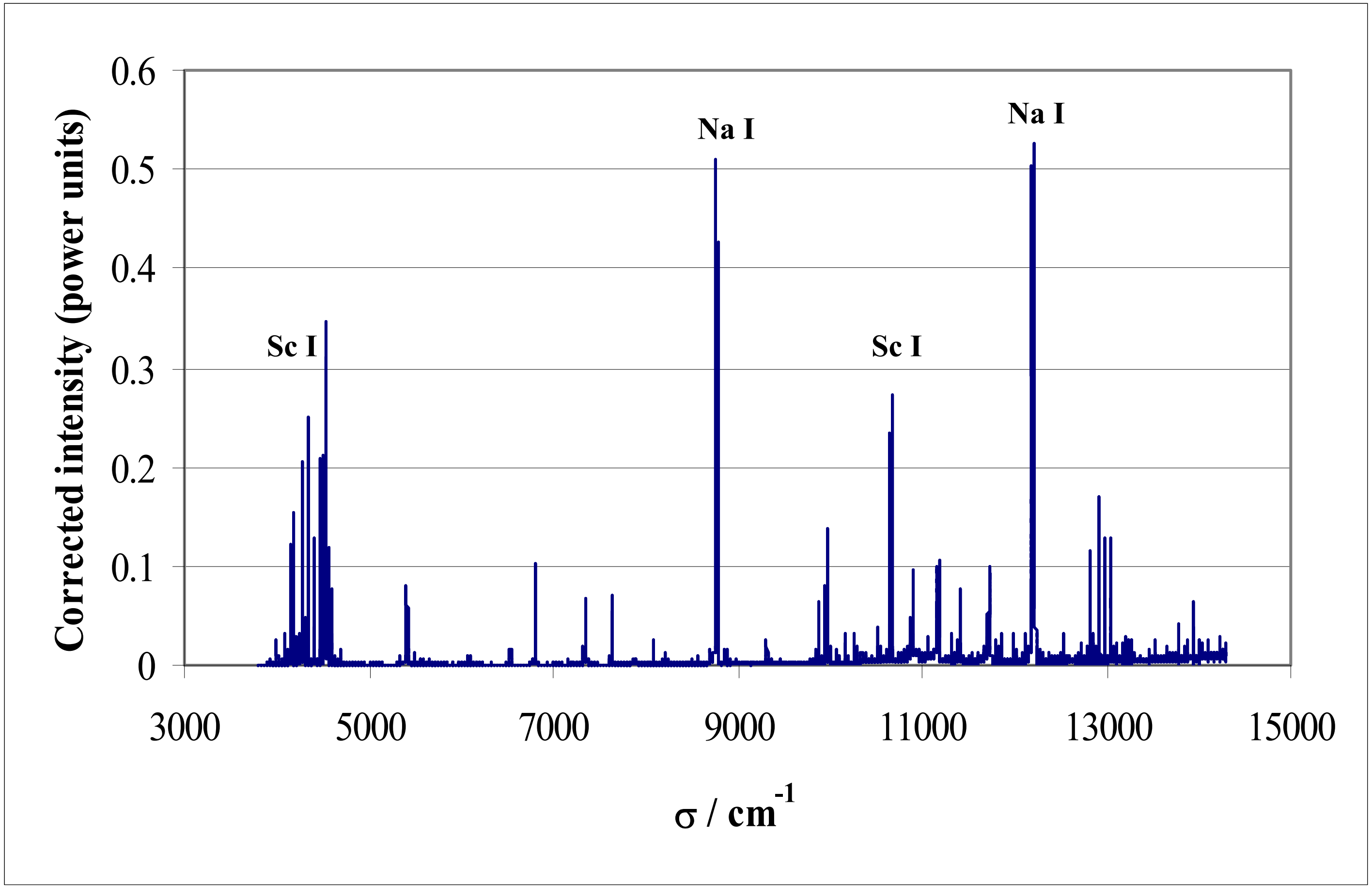
Spatially-resolved near IR measurements (uncorrected spectrum)

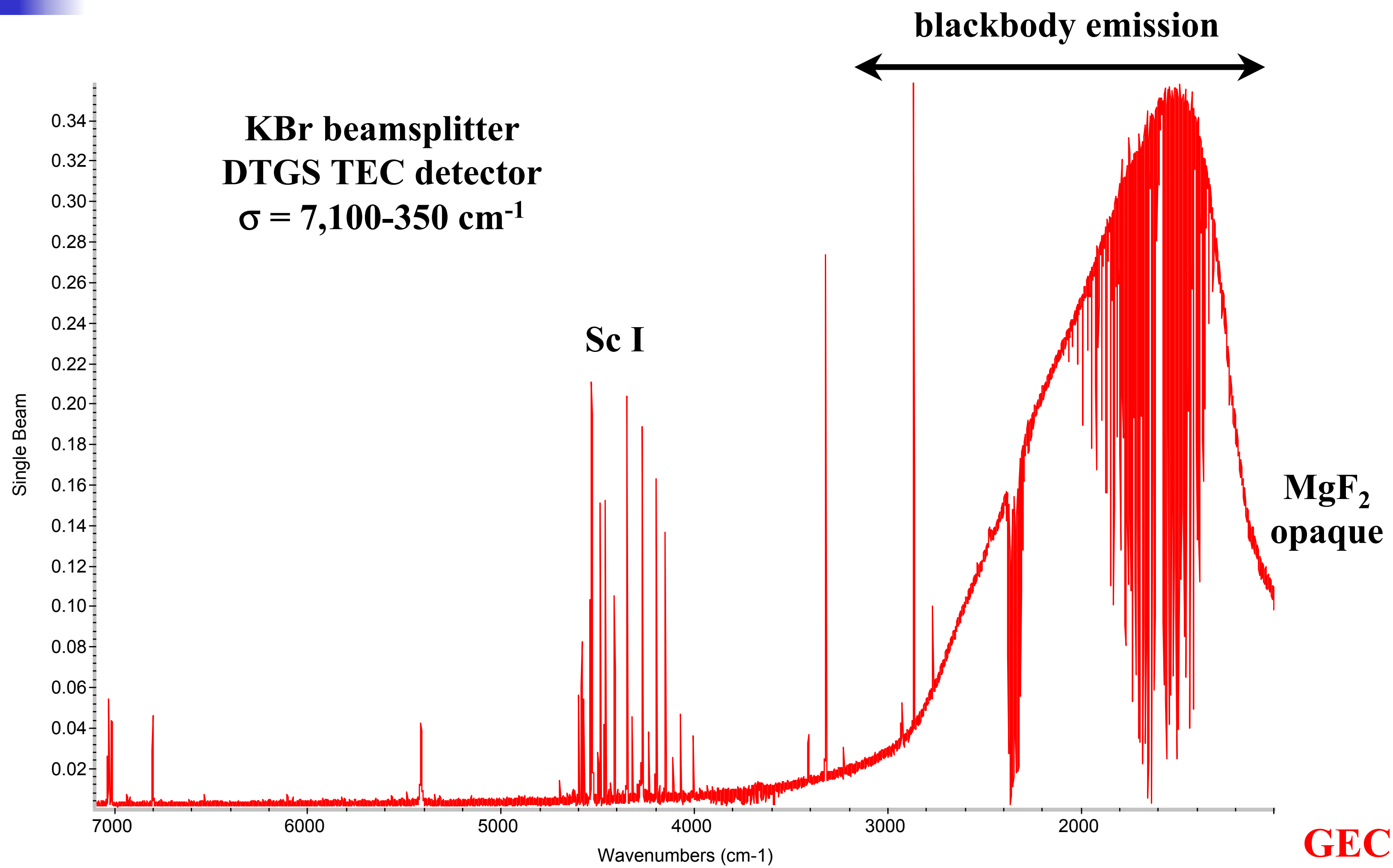


Corrected spatially-resolved near IR measurements

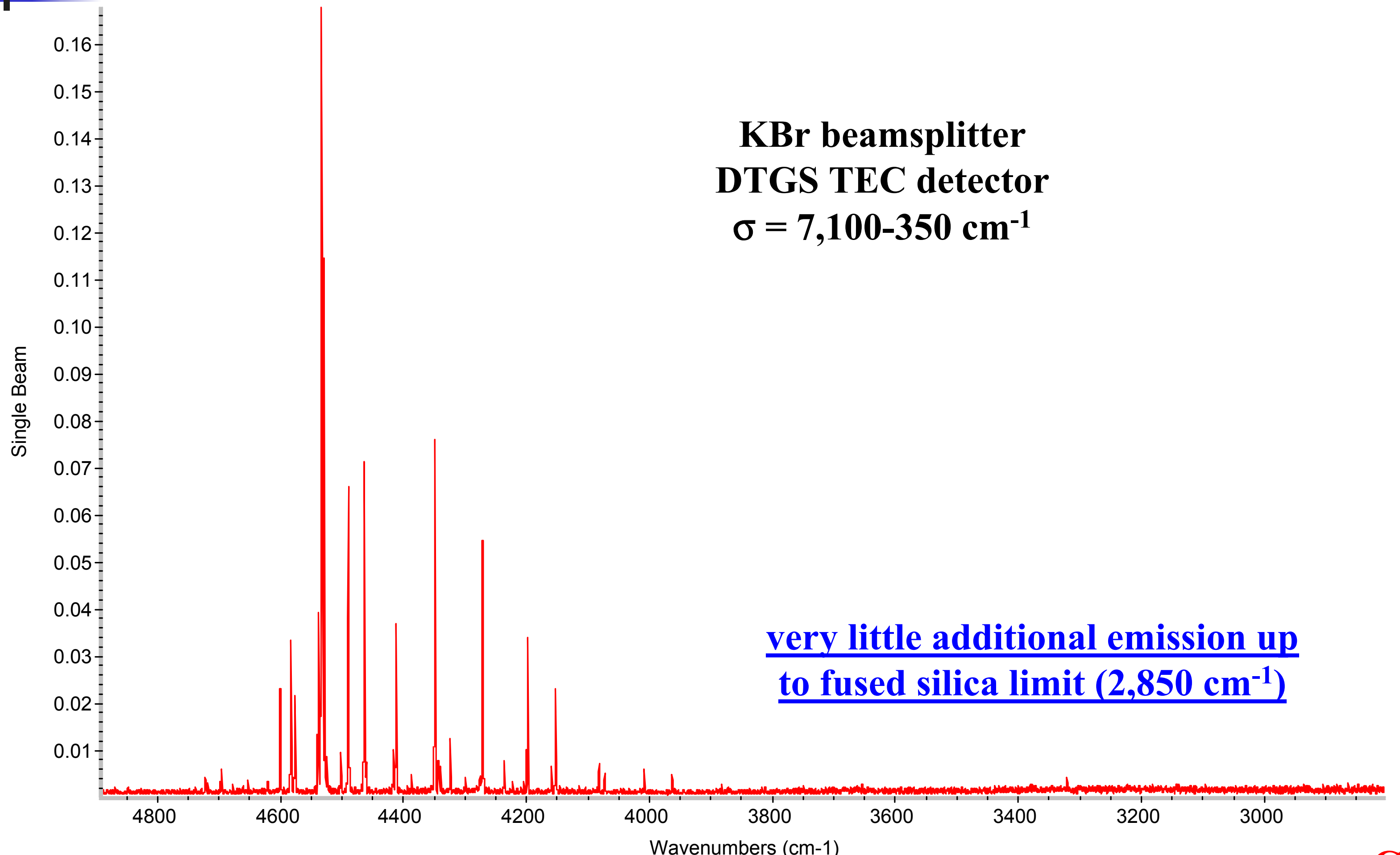
r=0



Spatially-averaged mid IR, σ = 7,100-1,000cm^{-1}



Beyond 4,000 cm^{-1}



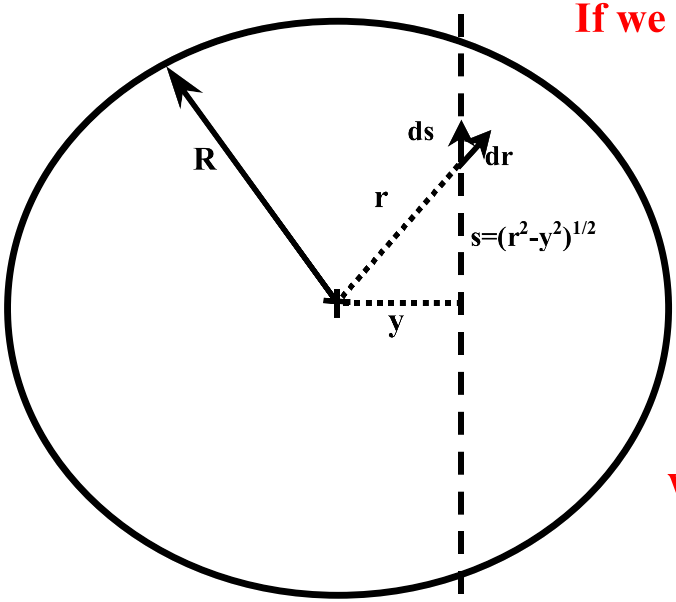
KBr beamsplitter
DTGS TEC detector
σ = 7,100-350 cm^{-1}

very little additional emission up to fused silica limit (2,850 cm^{-1})

IR power loss

- Near IR losses dominated by Na I emission – we require accurate knowledge of the
  - density of the ground state of Na
    - absorption measurements using the synchrotron radiation source
  - temperature profile, assuming LTE
    - Boltzmann analysis of the absorption data and emission spectra
  - transition probabilities for the important IR transitions

Spatially-resolved emission: Abel Inversion



If we assume that the excited-state densities are described by a Gaussian-like function

which acts to force to zero the values at the wall

$$n(r) = \frac{a \exp\left\{-b \frac{r^2}{1-r^2}\right\}}{(1-r^2)^{3/2}}$$

where r is the relative radius (i.e. normalized to R)

Hence the intensity measured along a line-of-sight, whose point of closest approach is y.

$$I(y) = 2 \int_{s=0}^{\sqrt{1-y^2}} n(r)\,ds \longrightarrow I(y) = \frac{\sqrt{\pi}}{\sqrt{1-y^2}} \frac{a \exp\left\{-b \frac{y^2}{1-y^2}\right\}}{\sqrt{b}}$$

Spatially-resolved emission: Abel Inversion

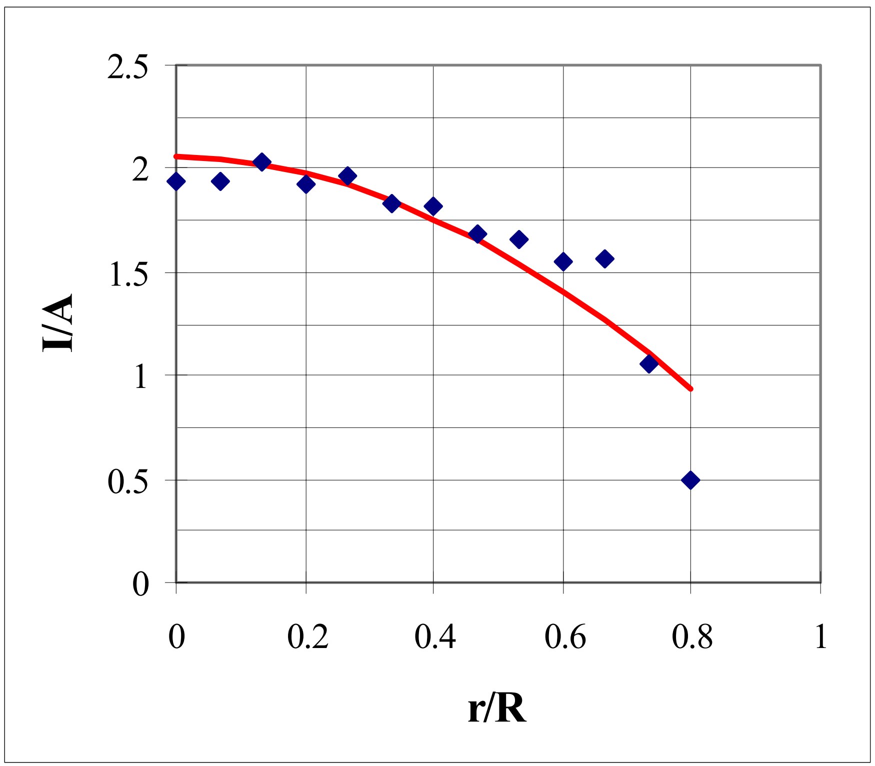
The intensity measured along a line-of-sight, whose point of closest approach is y.

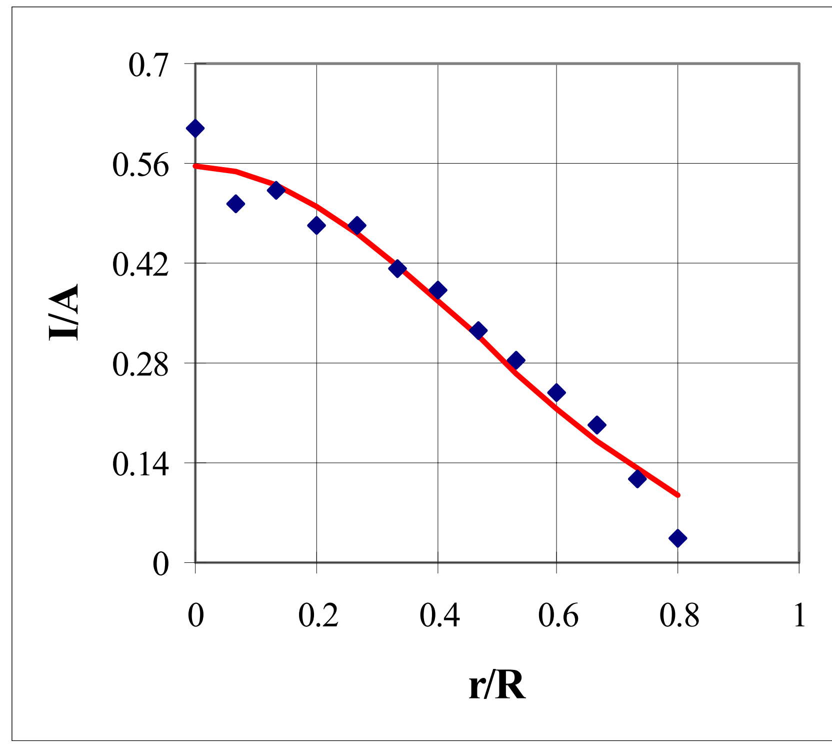
$$I(y) = \frac{\sqrt{\pi}}{\sqrt{1 - y^2}} \frac{a \exp\left\{-b \frac{y^2}{1 - y^2}\right\}}{\sqrt{b}}$$

We may then fit this equation to the observed data as a function of impact parameter to obtain numerical values of the parameters a and b.

This gives us n(r)

Fitted I(y) assuming a Gaussian profile for the excited-state densities





E_k = 16,022 cm^{-1}
a = 1.235, b = 0.5992

E_j = 21,086 cm^{-1}
a = 0.5042, b = 2.463

IR power loss

The total power radiated on a given kJ transition is given by

$$P(\lambda_{kJ}) = \int_V n_k(r,l) A_{kJ} hc\sigma_{kJ} dV$$

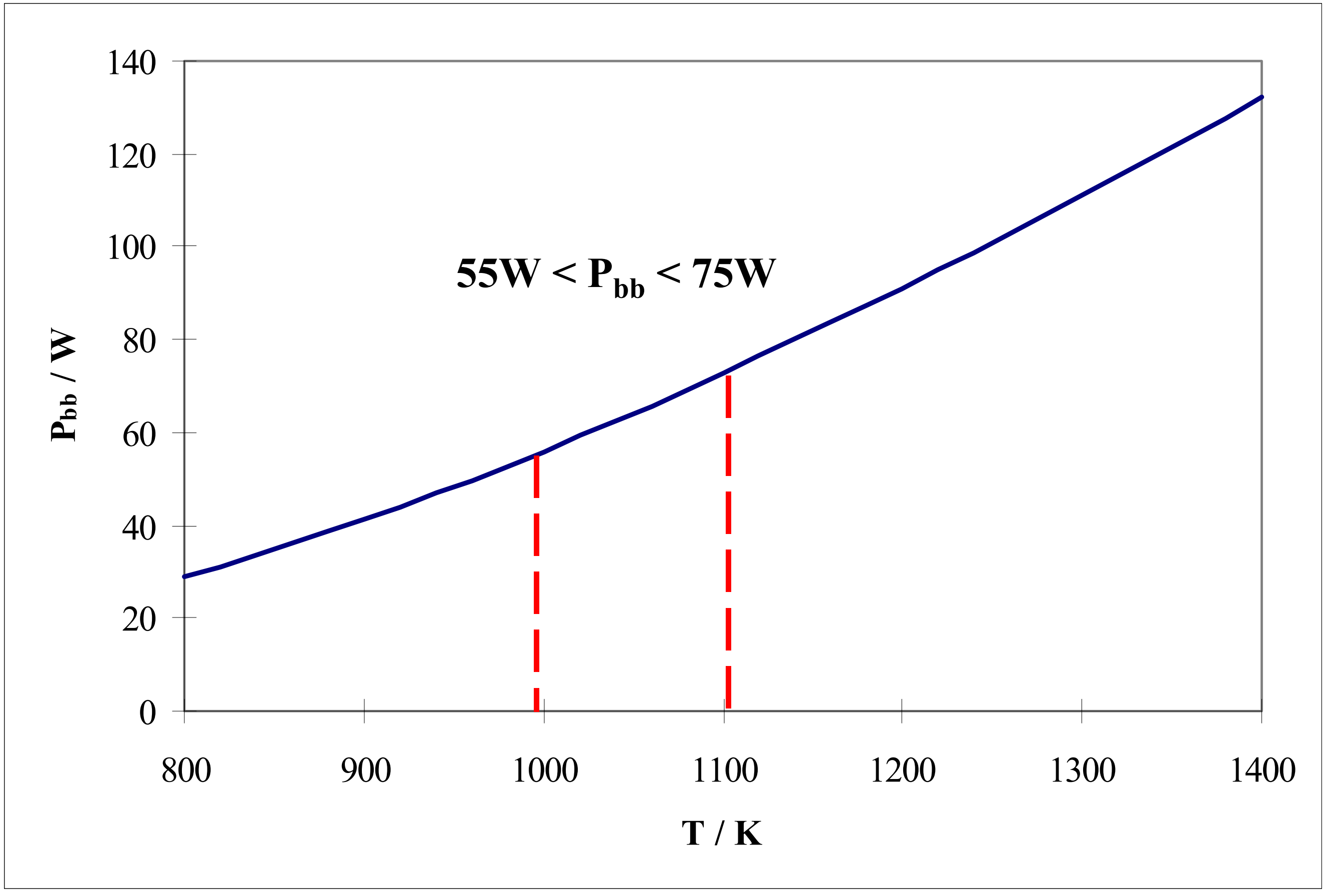
which can be expressed in terms of $n_0(r)$ and $T(r)$, where A_{kJ} is known

$$P(\lambda_{kJ}) = A_{kJ} hc\sigma_{kJ} l \int_{r=0}^{0.75\text{cm}} \frac{g_k}{g_0} n_0(r) \exp\left\{-\frac{E_k}{kT(r)}\right\} 2\pi r\, dr$$

Total IR power loss

- From absorption/emission measurements:
  - <u>total near IR atomic and molecular losses ~ 10-15 W</u>
  - the 3p-3d Na I lines contribute ~ 1 W
  - the 3p-4s Na I lines contribute ~ 3 W
- From thermopile measurements:
  - <u>total near IR atomic and molecular losses ~ 60 W</u>
  - blackbody losses ~ 55-60 W
  - visible emission ~ 85 W
  - UV losses ~ 45 W

Power balance - blackbody radiation



e = 0 for λ < 3.5 µm, e ~ 1 for λ > 3.5µm

Conclusions and future work

- Na I dominates atomic emission in the near IR
- Discrepancy between calculated near IR power loss by
  - thermopile measurements (~ 60 W)
  - results calibrated to absorption measurements (~ 10-15 W)
- Blackbody radiation contributes a further 60 W to the IR losses

Planned future work

- Resolve the discrepancy
- Extend techniques to custom research lamps
- Compare the IR power / lumen output between Scandium-based lamps and rare-earth lamps

Acknowledgments

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