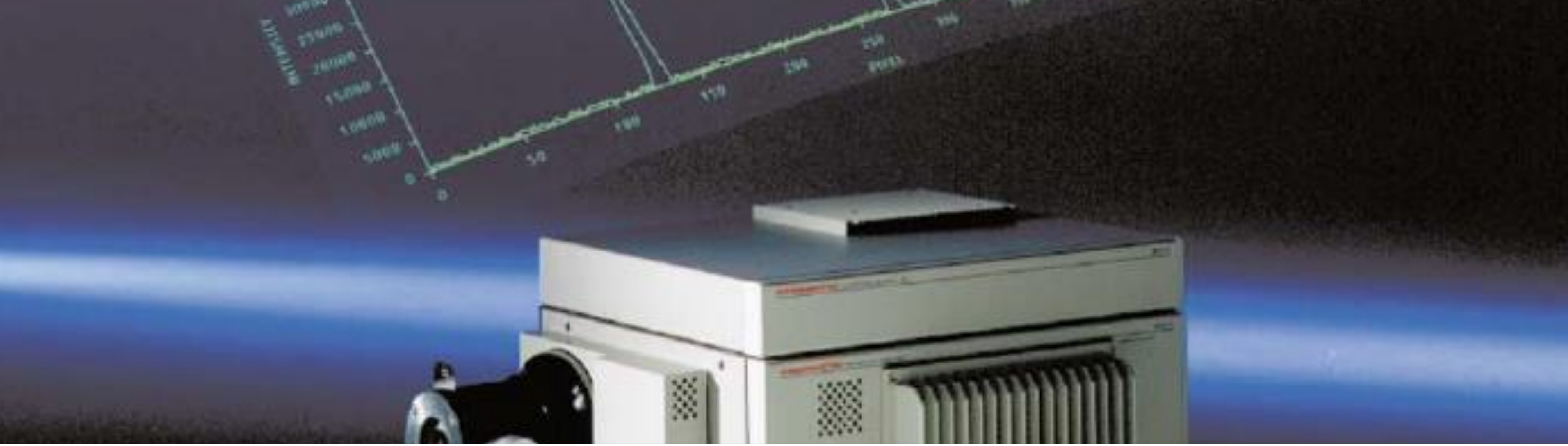

Streak camera diagnostic for high-power laser-matter interactions

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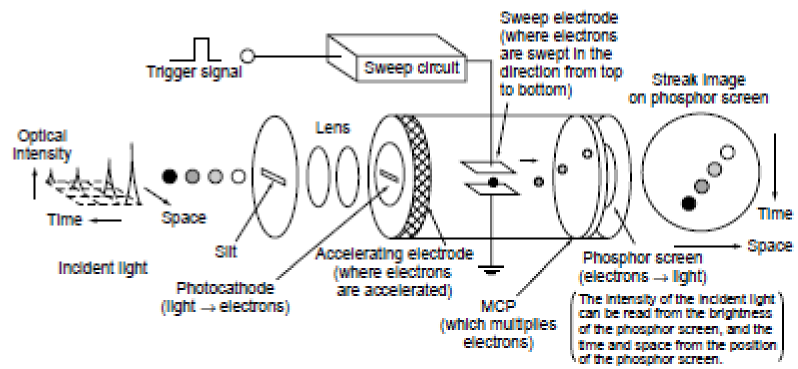
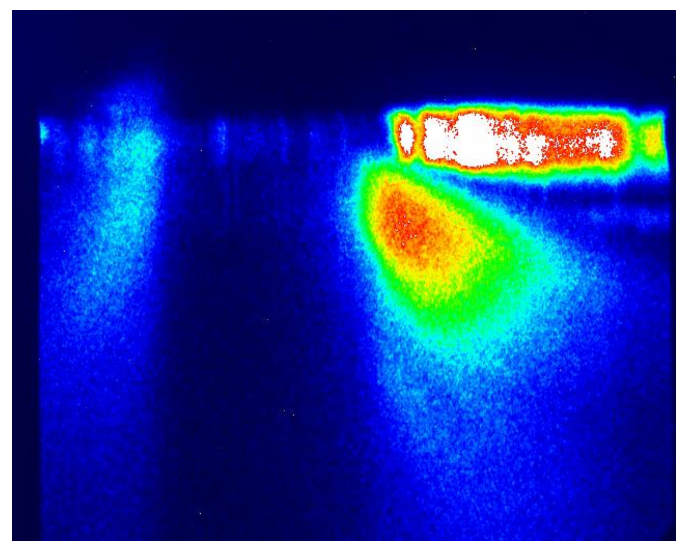
Streak cameras

- Time-resolved information on plasma evolution
- Problem: converting streaked image into quantitative data
- Accurate emission modeling required
- Emission dependency on electron density, temperature and wavelength
- Further extracted information:
  - Ion sound speed
  - Plasma position

Bottom right: raw streak data from Ref.[1]

The operating principle of the streak camera





Plasma emission

- Free-free absorbtion coefficient

$$k_{ff}(\lambda) = 1.3674 * \ 10^{-27}\lambda^3 n_e T_e^{-1/2} \sum_z z^2 \, n_z G_Z(T_e, \lambda)$$

  - Wavelength λ
  - Electron number density n_e
  - Ion number density (atomic number Z) n_z
  - Electron temperature T_e
  - Gaunt factor for Inverse Bremsstrahlung

$$G_Z(T_e, \lambda) = \frac{\sqrt{3}}{\pi} [log\left(2.1 * 10^8 \frac{\lambda T_e^{\frac{3}{2}}}{zc}\right) - \frac{5}{2}\gamma]$$

with γ=0.544

Plasma emission

- Free-bound absorbtion coefficient (per neutral atomic species)

$$k_{fb}(\lambda) = 8.6 * \ 10^{-19}\lambda^3 n_a n_e T_e^{\frac{3}{2}} \sigma_{ea}(T_e)\left(1 + \left(1 + \frac{hc}{\lambda k T_e}\right)\right)$$

- Neutral atom number density n_a
- Saha equation to calculate n_a
- Electron-neutral atom scattering cross-section $\sigma_{ea}(T_e)$
- Binary Encounter-Bethe model for $\sigma_{ea}(T_e)$

- Bound-bound absorbtion coefficient (for relevant bands centered on λ_0)

$$k_{bb}(\lambda) = n \sum_{\lambda_0} f_{\lambda_0} \sigma_{\lambda,\lambda_0}$$

- Oscillator number f_{λ_0}
- Band cross section $\sigma_{\lambda,\lambda_0}$
- Atom number density n

Plasma emission

- Detailed balancing in Local Thermal Equilibrium $$\frac{\eta(\lambda)}{k_{tot}(\lambda)} = \frac{2KT_e}{\lambda^2}$$ with $\eta(\lambda)$ emissivity per unit wavelength

- Luminous intensity *I* variation per plasma unit length *dl* $$\frac{dI_\lambda}{dl} = (\eta(\lambda) - k(\lambda)I_\lambda)$$

- Bound-bound cross section can be neglected for visible spectra

$$k_{tot}(\lambda) = \left(k_{ff}(\lambda) + k_{fb}(\lambda) + k_{bb}(\lambda)\right)\left(1 - \exp\left(-\frac{hc}{\lambda KT_e}\right)\right)$$

$$k_{ff}(\lambda) = 1.3674 * \ 10^{-27}\lambda^3 n_e T_e^{-1/2} \sum_z z^2\, n_z G(T_e)$$

$$k_{fb}(\lambda) = 8.6 * \ 10^{-19}\lambda^3 n_a n_e T_e^{\frac{3}{2}} \sigma_{ea}(T_e)\left(1 + \left(1 + \frac{hc}{\lambda k T_e}\right)\right)$$

$$k_{bb}(\lambda) = n \sum_k f_{\lambda_0} \sigma_{\lambda,\lambda_0}$$

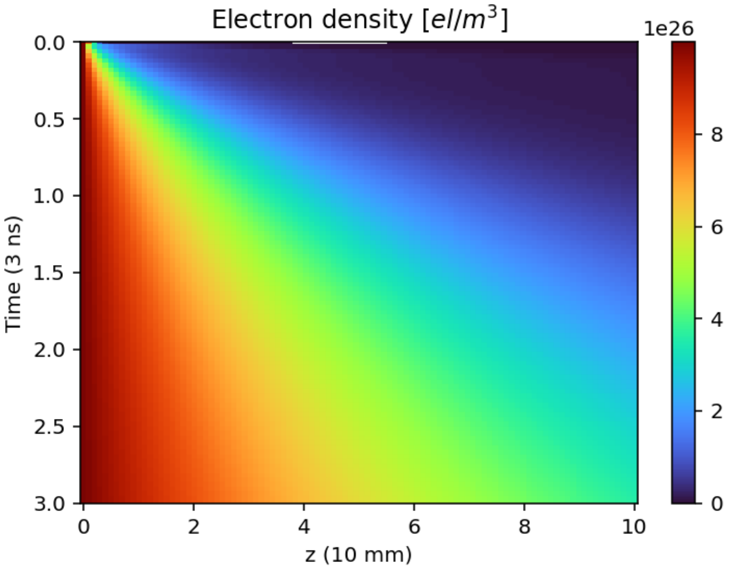
Developing a Synthetic

- Test on toy model (1D simple plasma expansion into vacuum at constant electron temperature) on visible range.
- Emulation of laser-generated plasma in front of an undercritical foam target
- Starting profile is gaussian (200 μm half-width, $10^{27} \frac{el}{m^3}$ density peak, $1.6 * 10^7 K$ electron temperature)

$$(dt + v\nabla)v = -\frac{ze}{m_i}\frac{d\Phi}{dx}, \quad n_e = n_{e0}\exp\left(\frac{e\Phi}{KT_e}\right)$$

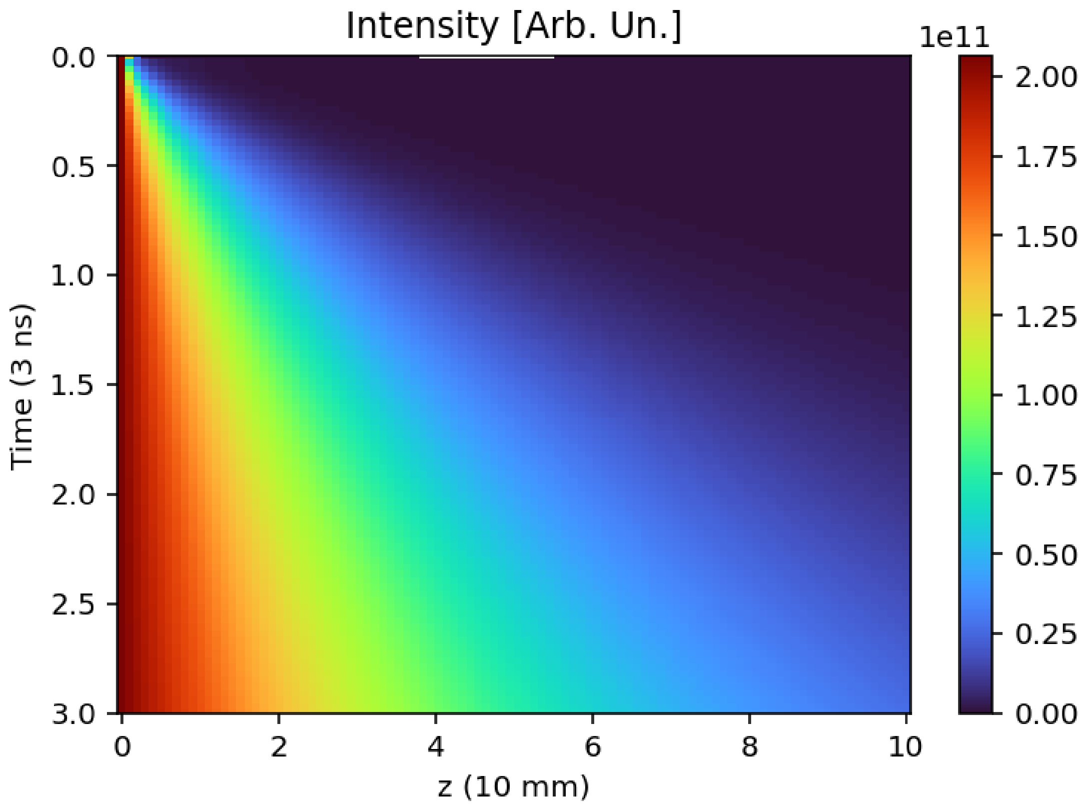
$$(dt + v\nabla)n_z = -n_z\frac{dv}{dx}, \quad \epsilon_0\frac{d^2\Phi}{dx^2} = e(n_e - zn_z)$$

- 1D velocity *v*
- Electric field Φ
- Dielectric constant ϵ_0
- Solved numerically assuming self-similar motion



Developing a Synthetic

- Calculate absorbtion coefficients and emissivity from density and temperature profile
- Integrate over specral range sampled from streak camera datasheet (model C5680-N5716)



Conclusions

- Relative orders of magnitude in luminous intensity for different parameters are compatible with experimental data [1]
- Free-free and free-bound effects scale correctly for commonly used plasma chemical compositions (4-5 orders of magnitude for visible light)
- Dominant density and temperature scaling

How to proceed?

- Test x-ray emission for relevant atomic species and ions
- Test with simulation profiles and compare to experiments
- Account streak pixel overlap
- Direct integration in simulation code (FLASH code)

Thank you for your attention

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