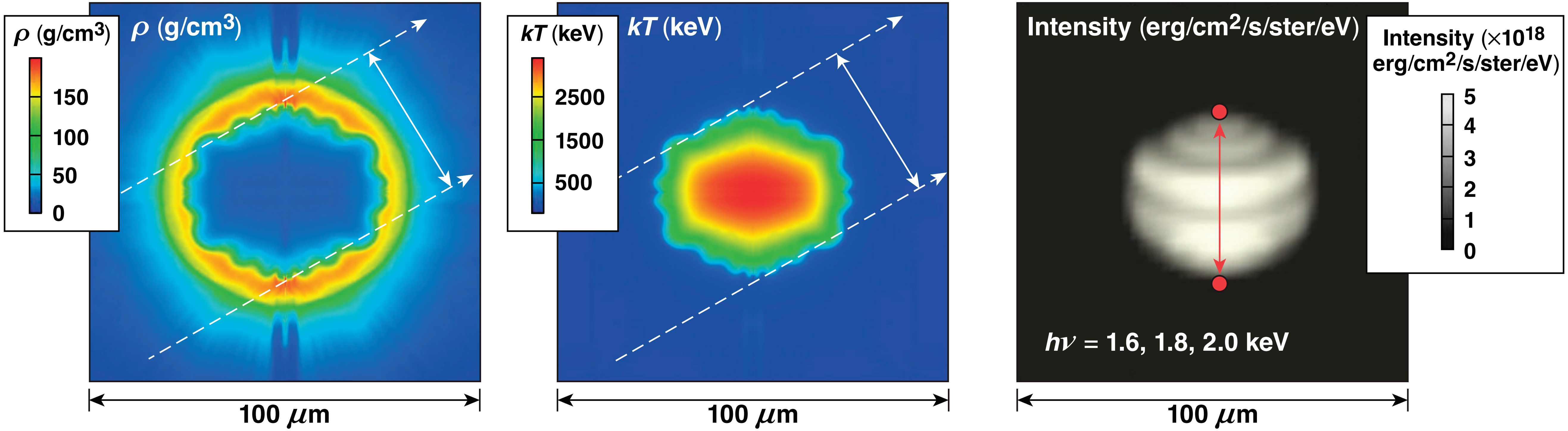
Inferring Shell Nonuniformity in OMEGA Implosions by Self-Emission Radiography



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Summary

Imploded cryogenic DT shells can be radiographed late in the deceleration phase by their own core emission

- This diagnostic uses the spectral content of at least three monochromatic images and a three-parameter spectral model to determine the shell optical thickness, one pixel at a time
- Core self-emission is the backlighter in self-radiography, unlike externally backlit radiography, where self-emission is the limiting background
- Self-radiography of cryo implosions is an advance over earlier self-backlighting that depended on the K-edges and spectral lines of additives*

*V. A. Smalyuk, *et al.*, Phys. Rev. Lett. 87, 155002 (2001);
L. A. Pickworth, *et al.*, Phys. Rev. Lett 117, 035001 (2016).

Collaborators

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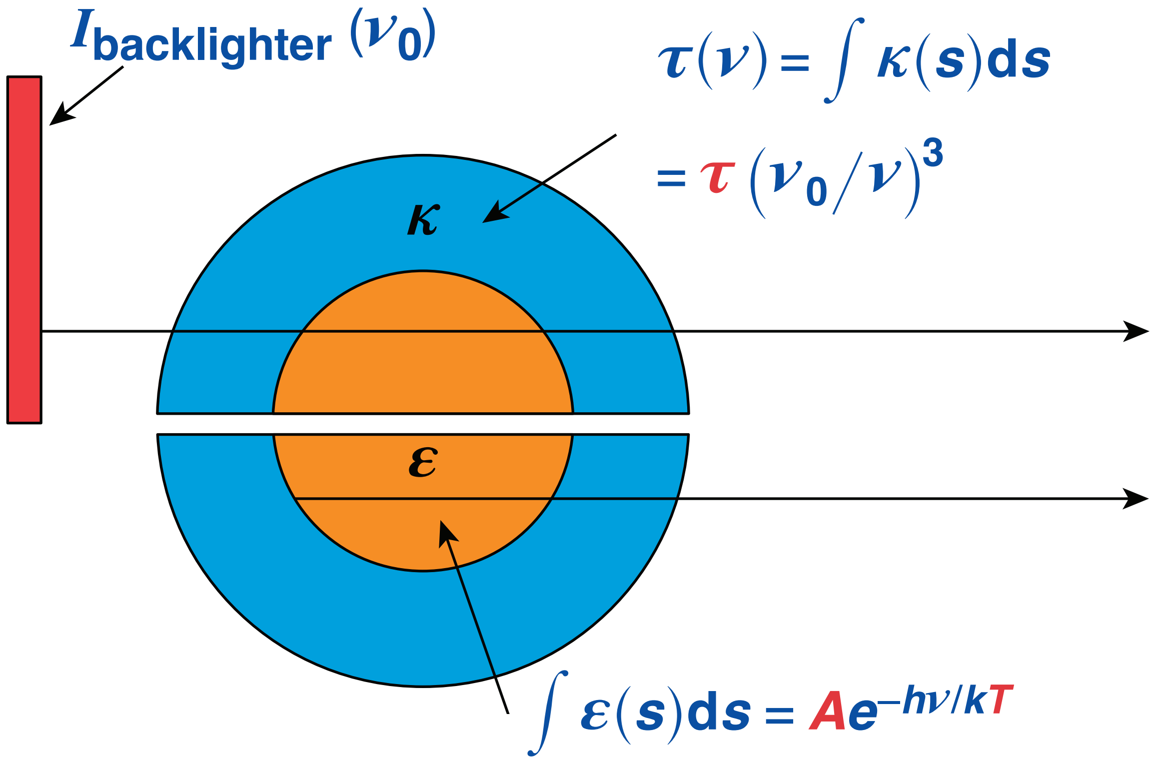
Core self-emission is the limiting background in externally backlit radiography, but in self-radiography, core self-emission is the backlighter



External monochromatic backlighting

$$I(\nu_0) \cong \underbrace{I_{\text{backlighter}}(\nu_0)\,e^{-2\tau}}_{\text{Radiographic signal}} + \underbrace{Ae^{-h\nu_0/kT}\,e^{-\tau}}_{\text{Background}}$$

$$I(\nu) \cong Ae^{-h\nu/kT}\,e^{-\tau(\nu_0/\nu)^3}$$

Multi-monochromatic self-backlighting signal

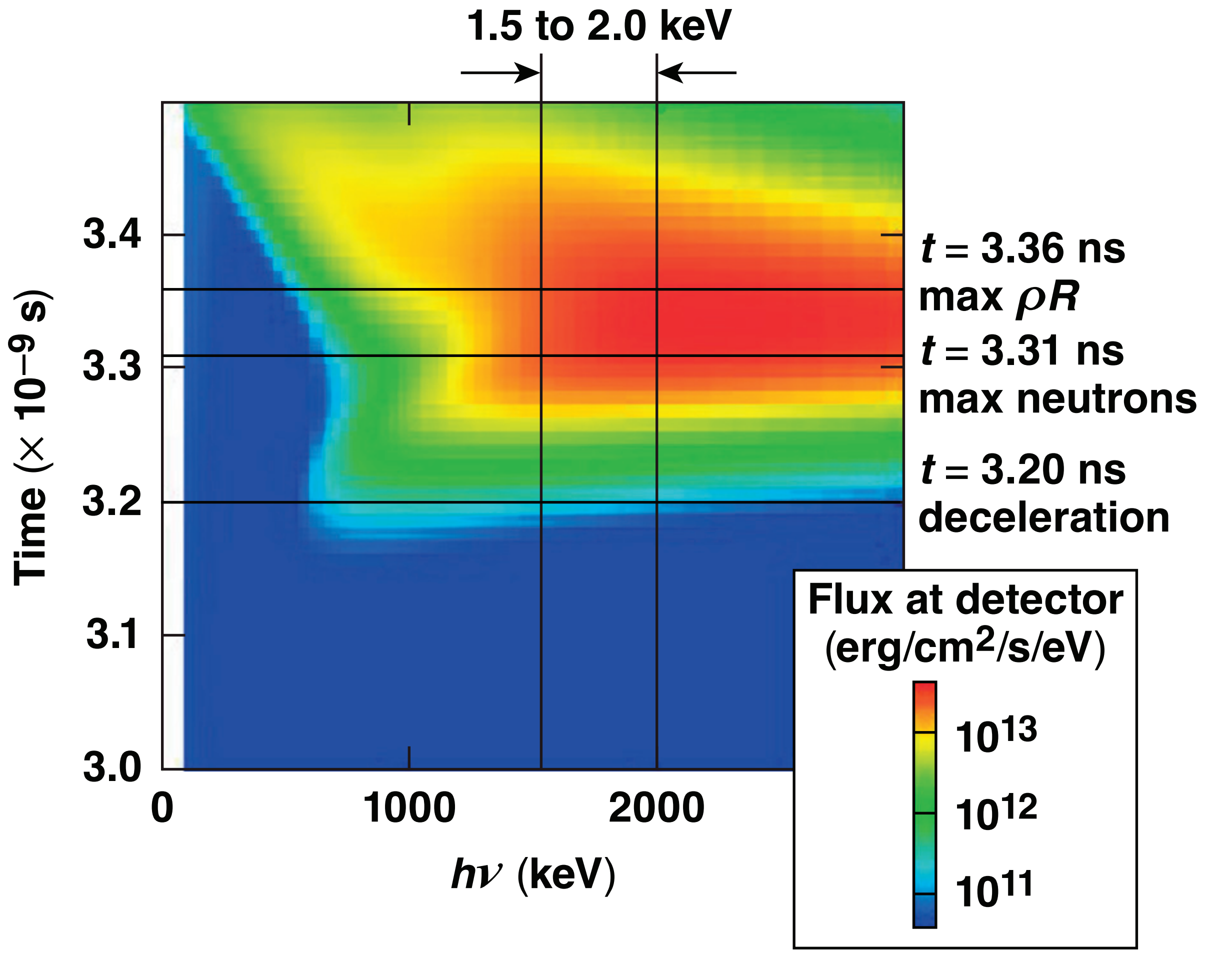
- Three intensities, $I(\nu_1)$, $I(\nu_2)$, $I(\nu_3)$, determine the parameters A, T, and τ at each pixel
- T is a chord-averaged, emission-weighted harmonic mean of a highly variable temperature profile*

- Soft external backlighters are overwhelmed by core self-emission near peak conditions
- We rely on the simple atomic physics of free–free opacity and emissivity; no additives needed

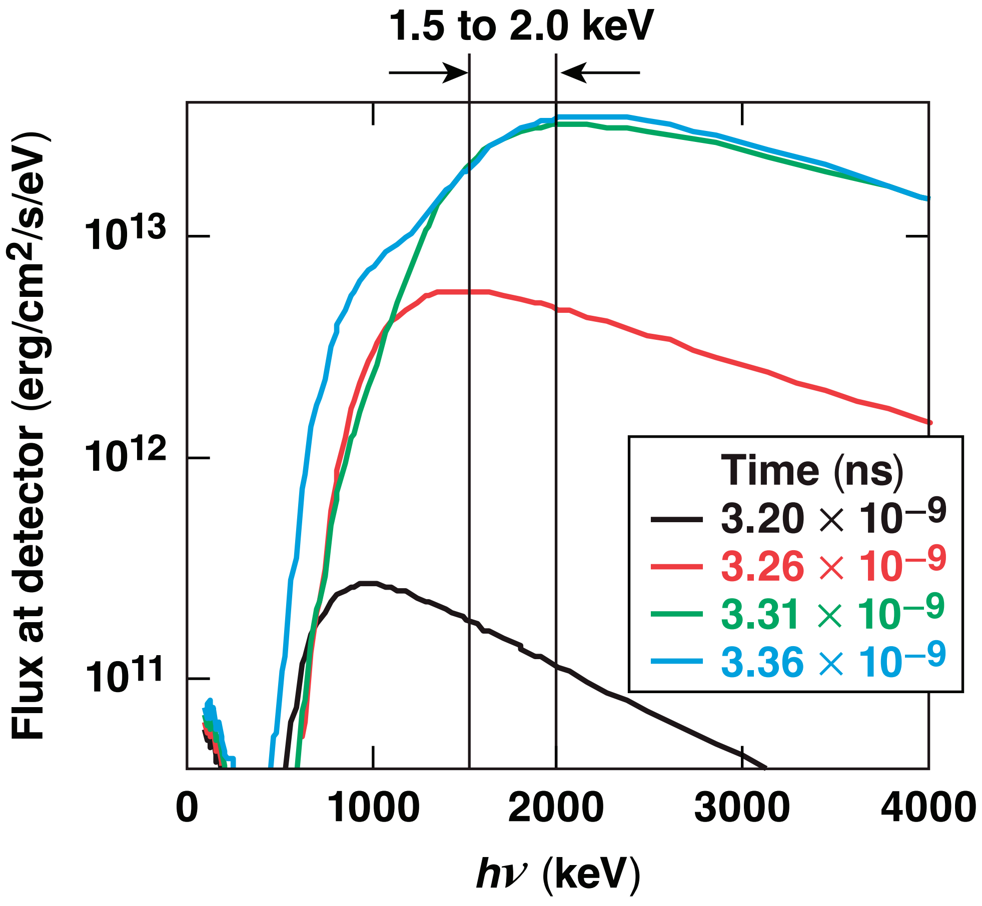
*D. M. Cao *et al.*, BO7.00002, this conference.

The preferred optical thickness, $\tau \approx 1$, is obtained at the onset of peak conditions near $h\nu \approx 2$ keV

Shot 82383, *LILAC/Spect3D**



Flux, 1 cm from the target, from a 10-μm-radius circular area on its surface



- HDT continuum spectroscopy using:

  $I(h\nu) \cong Ae^{-h\nu/kT} e^{-\tau(\nu_0/\nu)^3}$**

* *Spect3D*, Prism Computational Sciences Inc., Madison, WI 53711.
** F. J. Marshall *et al.*, Phys. Rev. E 49, 4381 (1994).

TC14510

Estimates of the three continuum parameters can be very uncertain if the intensity measurements are imprecise or the bandwidth is too narrow

- Perform a formal error analysis of the continuum model:

$$I(\nu) \cong A e^{-h\nu/kT} e^{-\tau(\nu_0/\nu)^3}$$

$$\sigma_I \cong \left\langle \left(\frac{\delta I}{I}\right)^2 \right\rangle_{\text{rms}}^{1/2}, \quad \sigma_T \cong \left\langle \left(\frac{\delta T}{T}\right)^2 \right\rangle_{\text{rms}}^{1/2}, \quad \delta\tau \cong \left\langle (\delta\tau)^2 \right\rangle_{\text{rms}}^{1/2}$$

- Assume three samples of the spectrum at $\Delta\nu$ near $\nu = \nu_0$
- Assume intensity measurement precision σ_I and a prior temperature precision σ_T
  - if you know the backlighter *A* and *T*, then $\delta\tau \cong \sigma_I / \sqrt{3}$
  - if you know *T*, $\sigma_T \left(h\nu_0 / kT \right) \ll \sigma_I \left(\nu_0 / \Delta\nu \right)$, then $\delta\tau \cong \sqrt{2}/3 \, \sigma_I \left(\nu_0 / \Delta\nu \right)$
  - if you know neither *A* nor *T*, $\sigma_T \left(h\nu_0 / kT \right) \gg \sigma_I \left(\nu_0 / \Delta\nu \right)$, then $\delta\tau \cong \sqrt{2/3} \, \sigma_I \left(\nu_0 / \Delta\nu \right)^2$

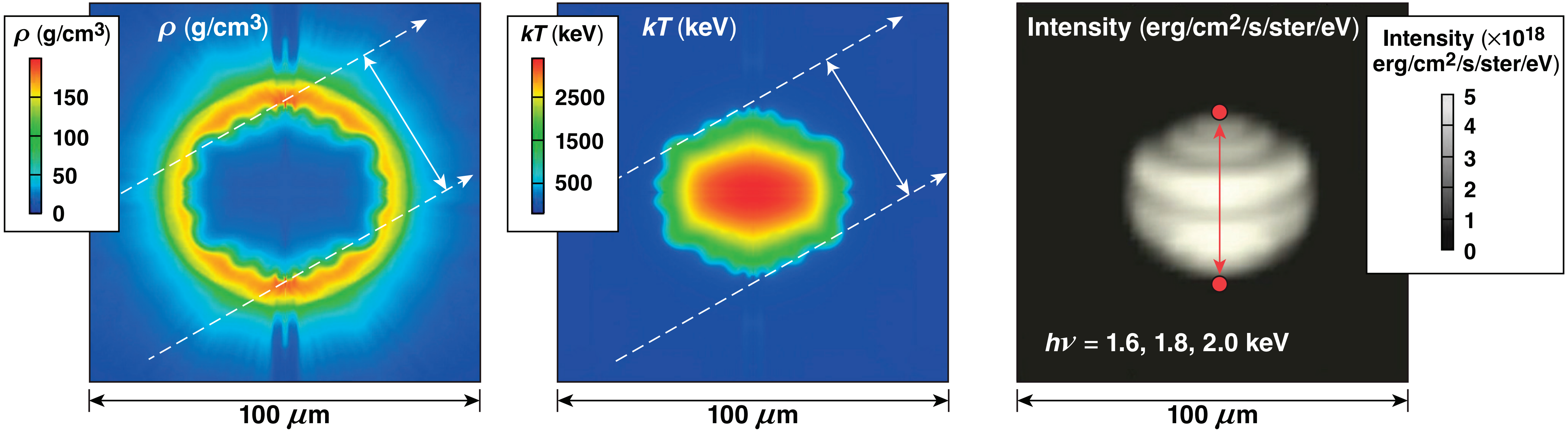
Even a rough prior constraint on *T* tightens the τ estimate variance $\delta\tau$ significantly

TC14513

Synthetic monochromatic image data was constructed from a *DRACO/Spect3D* simulation of a cryo implosion near peak compression

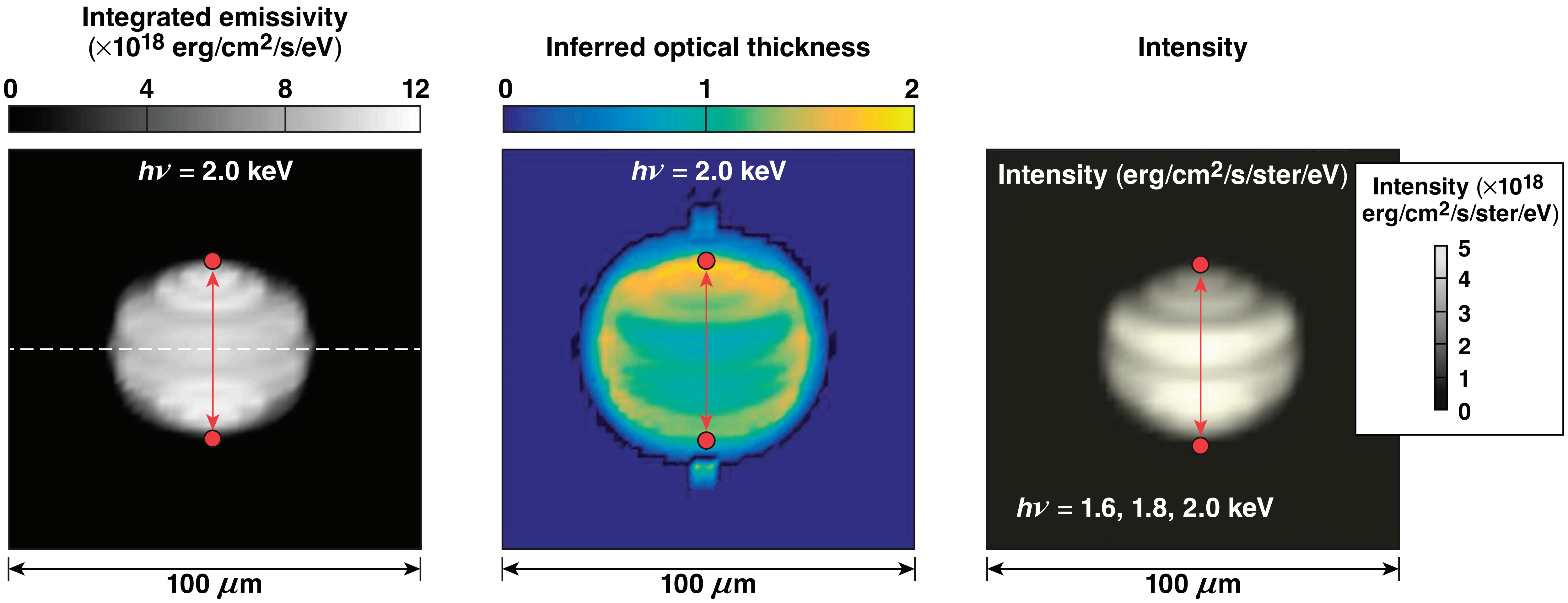
- Inhomogeneous core and shell tests the simplicity of the 3-parameter continuum model
- 2-D geometry tests the simplifying assumption that absorption follows emission

Shot 82383, *DRACO/Spect3D*



t = 3.51 ns

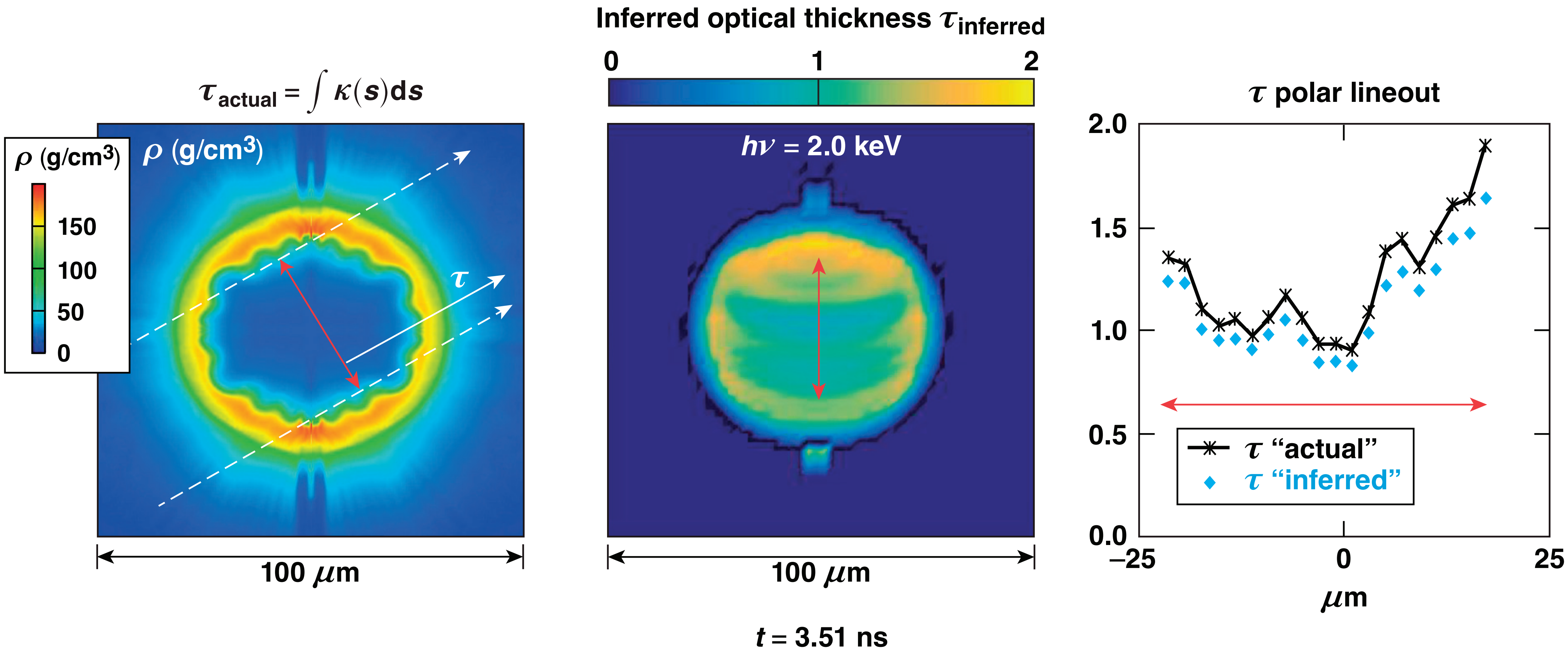
With multi-monochromatic images, the emission and absorption contributions to the total image can be separated



t = 3.51 ns

TC14516

The radiograph, based on spectral analysis, recovers nearly all of the actual projected optical thickness profile of the shell



TC14599

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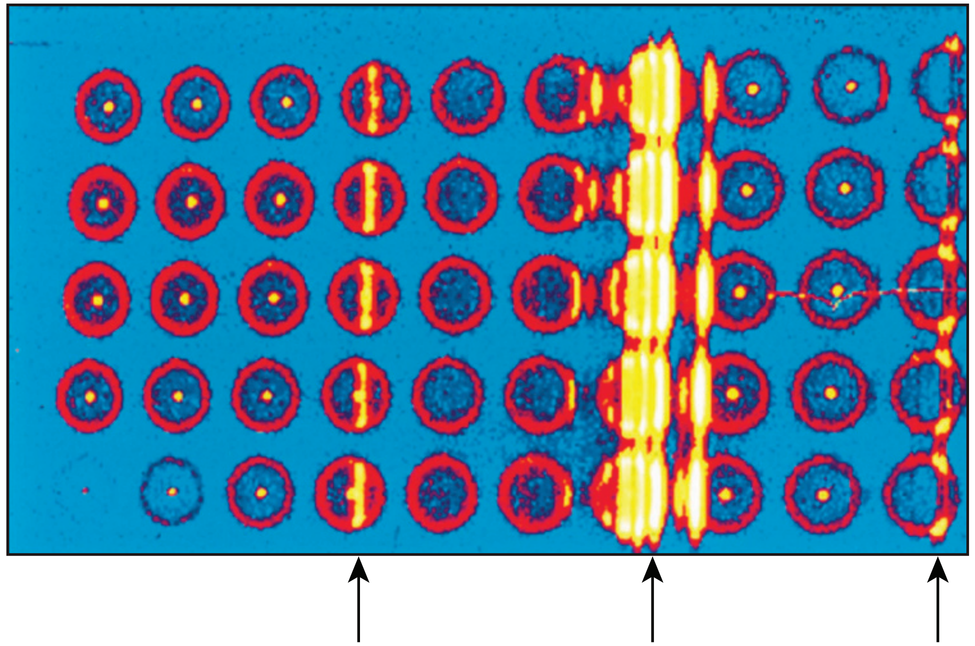
Multi-monochromatic imaging (MMI) has been successfully applied to line-spectral imaging and may be similarly applied to continuum-spectral imaging



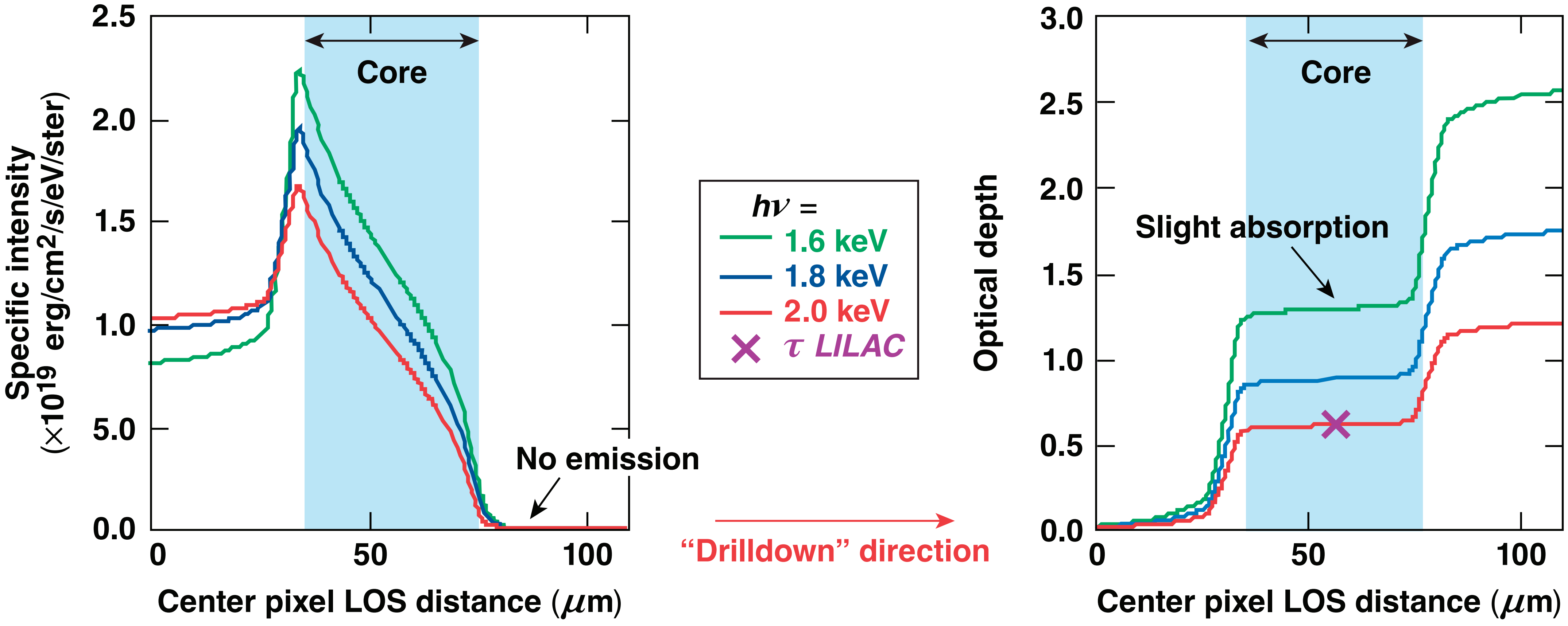
- Ti-doped imploding shell imaged with pinhole array and Bragg reflector by B. Yaakobi, F. J. Marshall, and D. K. Bradley, Appl. Opt. 37, 8074 (1998)

- Pinhole array used by H. Azechi *et al.*, Appl. Phys. Lett. 37, 998 (1980)
- Development and successful applications to Ar-filled shells by Koch, Nagayama, Welser, Nagayama, Mancini, Florido, many references
- Based on an early application to Ar-filled implosion [J. A. Koch *et al.*, Rev. Sci. Instrum. 76, 073708 (2005)], Bragg reflection at 6.6°±1.26° for Ar corresponds to reflection at 13.4°±1.51° in the same instrument for the spectral range 1.6 to 2.0 keV
- Fresnel lenses are a promising development, with high resolution (~1 μm) and high throughput

TC14517

LILAC/*Spect3D* simulation of cryo shot 82383 validates the simplifying assumption of emission only in the core and absorption only in the shell

Shot 82383, *LILAC*/*Spect3D* line-of-sight "drilldown,"
t = 3.31 ns, peak neutron production

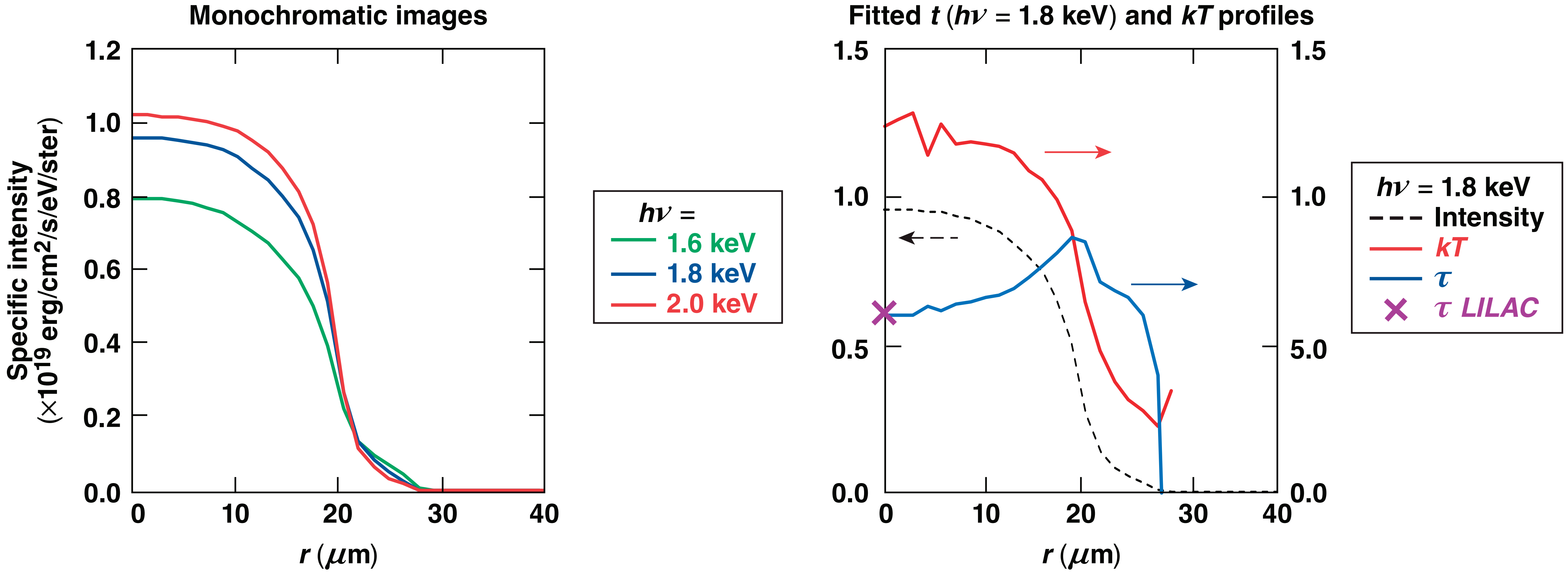


LOS: line of sight

TC14511

Three spectral channels allow temperature and optical thickness to be estimated at each resolution element based on their distinct spectral signatures

Shot 82383, *LILAC/Spect3D*
t = 3.31 ns, peak neutron production

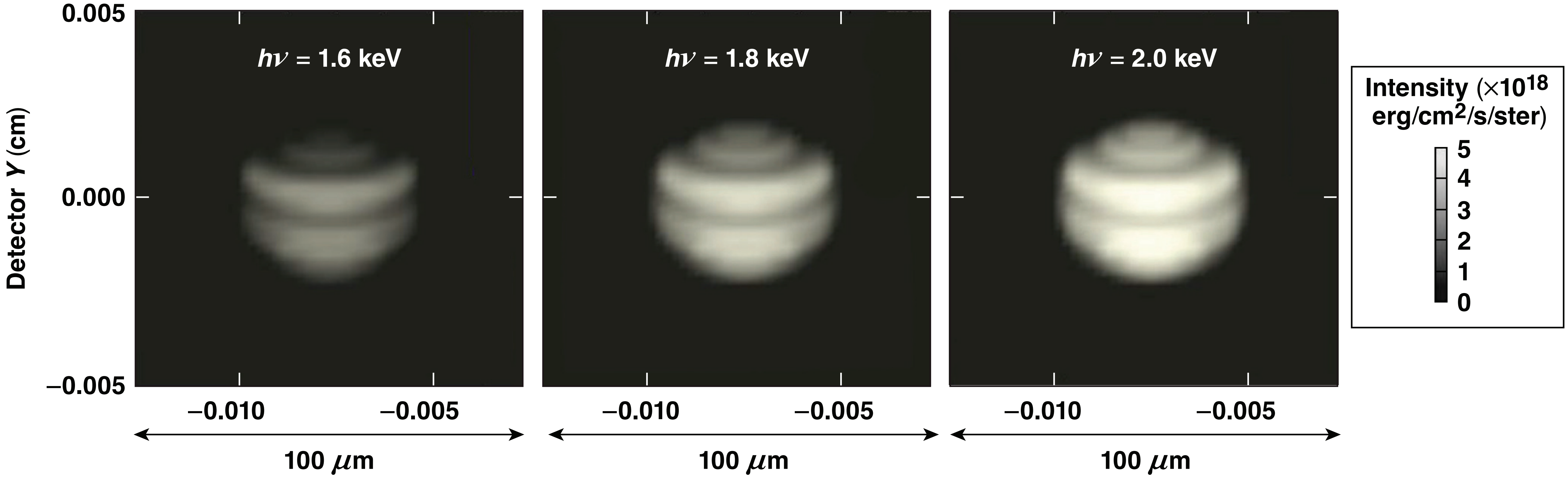


kT is an emission-weighted harmonic mean of a highly variable temperature profile.

TC14512

DRACO/Spect3D monochromatic images of shot 81590 provide a more-stringent test of the spectral fitting method

Synthetic image data viewed 30° above the equatorial plane



t = 3.515 ns
Shot 81590, *DRACO/Spect3D*

TC14514

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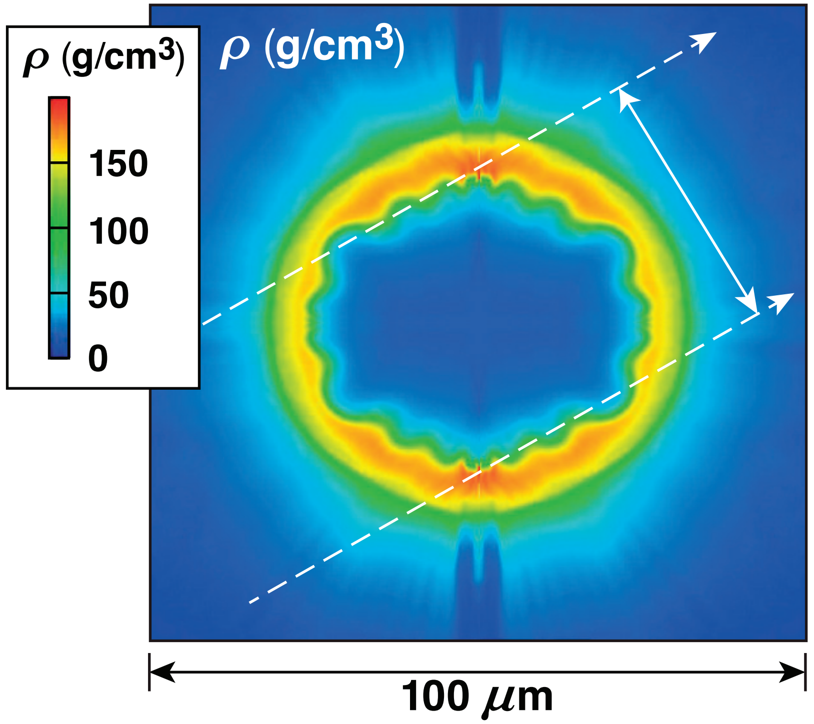

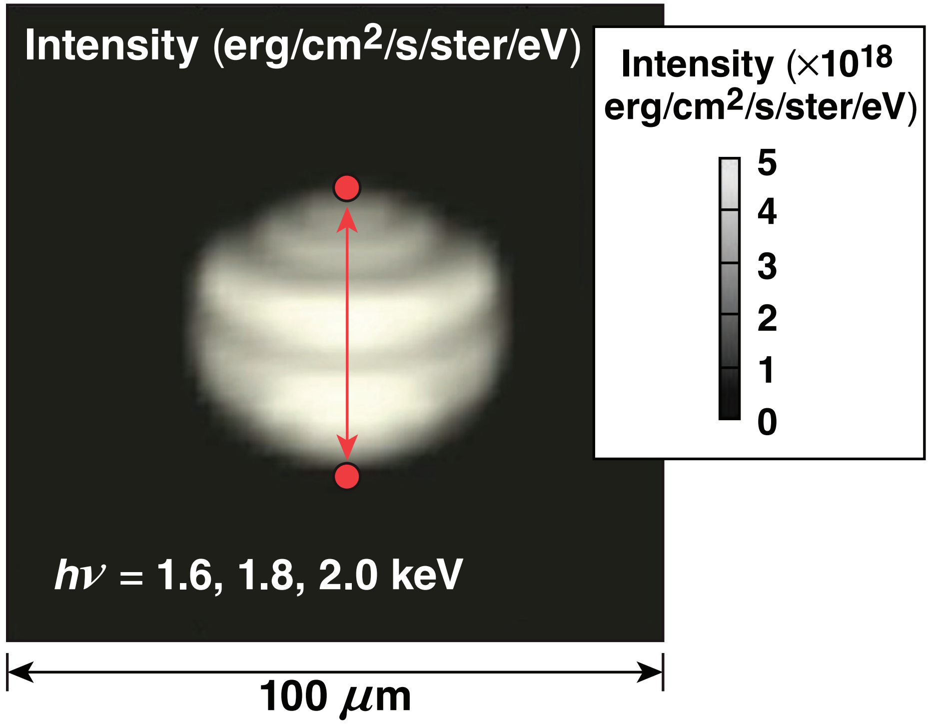

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