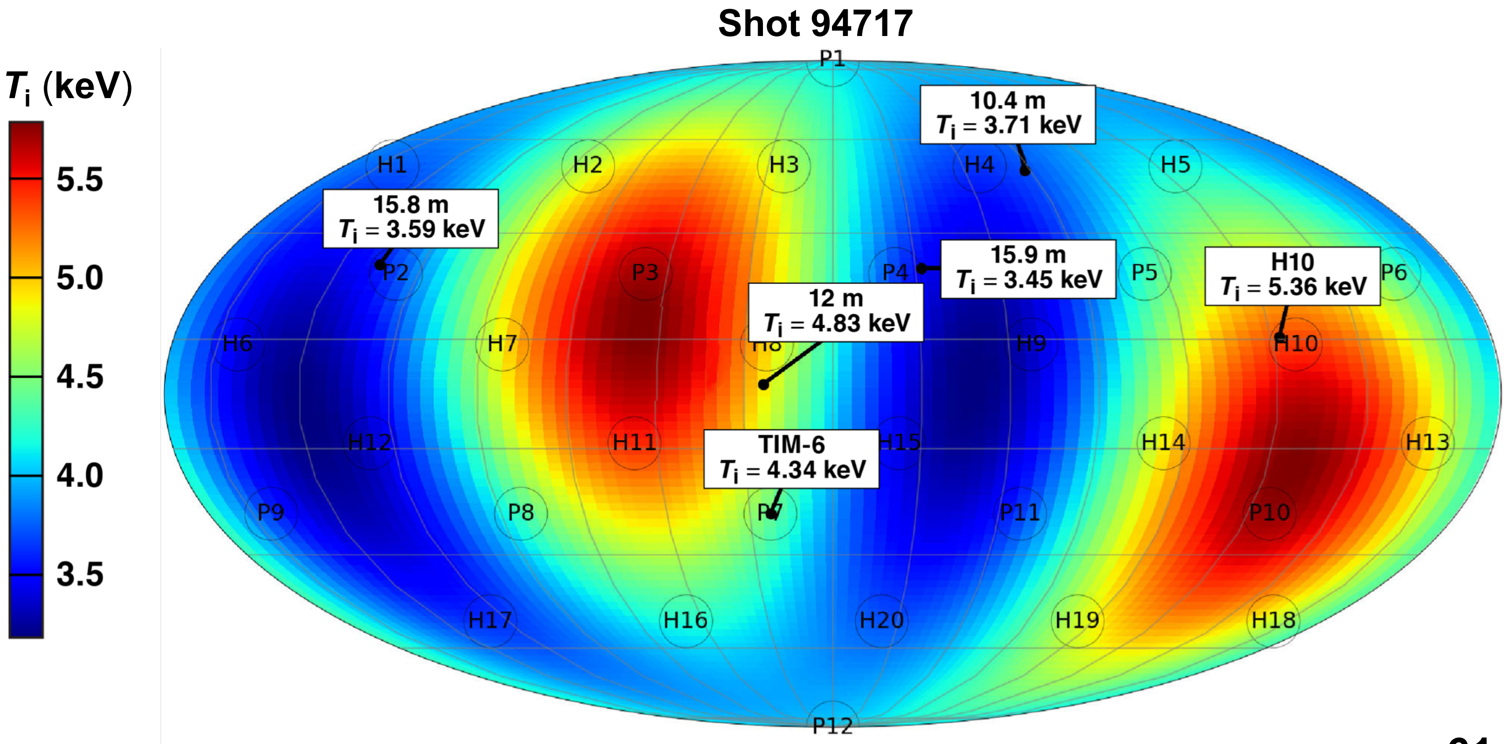
Inferring the Thermal Ion Temperature and Residual Kinetic Energy from Nuclear Measurements in Inertial Confinement Fusion



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Summary

A velocity variance analysis was developed to explain the 3-D flow effects on ion-temperature (T_i) measurements and the modal dependence of T_i asymmetries in ICF

- A method using six line-of-sight (LOS) ion-temperature measurements was developed to determine the full temperature map and account for the contribution of anisotropic flows
- The contribution of isotropic flows and the thermal temperature can be determined using both DD and DT ion-temperature measurements
- The minimum of DD neutron-inferred ion temperature was derived from DD and DT ion-temperature measurements along the same single LOS and demonstrated a strong correlation with the experimental yields in the OMEGA implosion database
- Analytical expressions were derived to infer the yield-over-clean in terms of mode-1 ion-temperature asymmetries

ICF: inertial confinement fusion

Collaborators

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Outline

- Introduction to the ion-temperature measurement (T_i) asymmetry
- Impact of anisotropic flows on T_i asymmetry
- Impact of isotropic flows on inferring the minimum DD and thermal ion temperatures

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- **Introduction to the ion-temperature measurement (T_i) asymmetry**
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The variation of apparent ion-temperature measurements along different lines of sight (LOS) is uniquely determined by the behavior of the variance*,** of the hot-spot fluid velocities

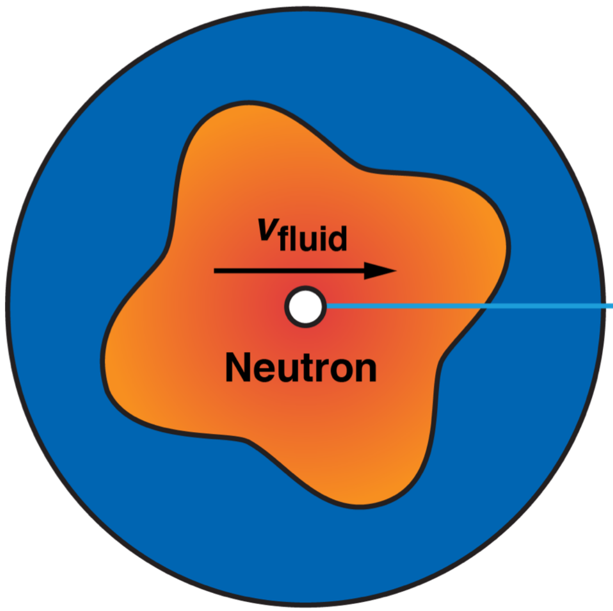
UR LLE

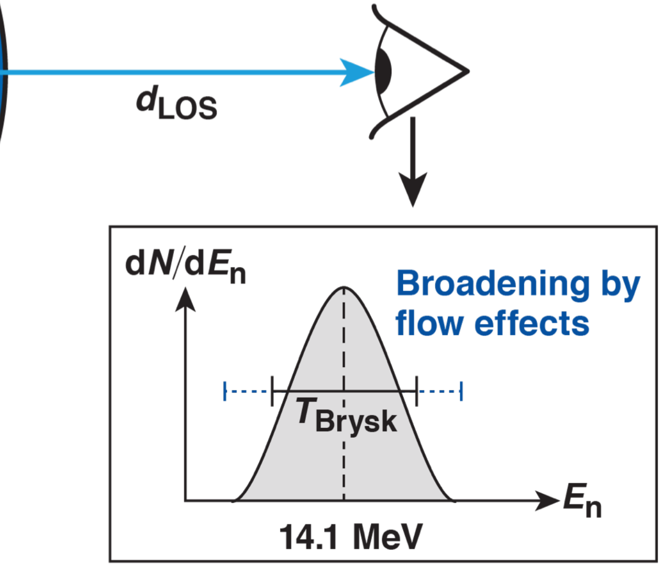
Isotropic and anisotropic flow effects

$$T_{\mathrm{LOS}} = T_{\mathrm{Brysk}} + M_{\mathrm{DT}} \mathrm{var}\left[\vec{v}_{\mathrm{fluid}} \cdot \hat{d}\right]$$

~ Total width of the neutron energy spectrum

$$v_{\mathrm{n}} = v_{14.1\ \mathrm{MeV}} + v_{\mathrm{cm}} + v_{\mathrm{rel}} + v_{\mathrm{fluid}}$$ **Signal broadening**





v_{cm}: velocity of the DT center-of-mass (CM) frame
v_{rel}: relative velocity of D,T ions in the CM frame
v_{fluid}: fluid velocity in the lab frame
d: unit vector along LOS

$$\mathrm{var}[f] = \left\langle \left(f - \bar{f}\right)^2 \right\rangle = \left\langle \Delta f^2 \right\rangle, \ \Delta f \equiv f - \bar{f}$$

TC15207

* T. J. Murphy, Phys. Plasmas 21, 072701 (2014).
** D. H. Munro, Nucl. Fusion 56, 036001 (2016)

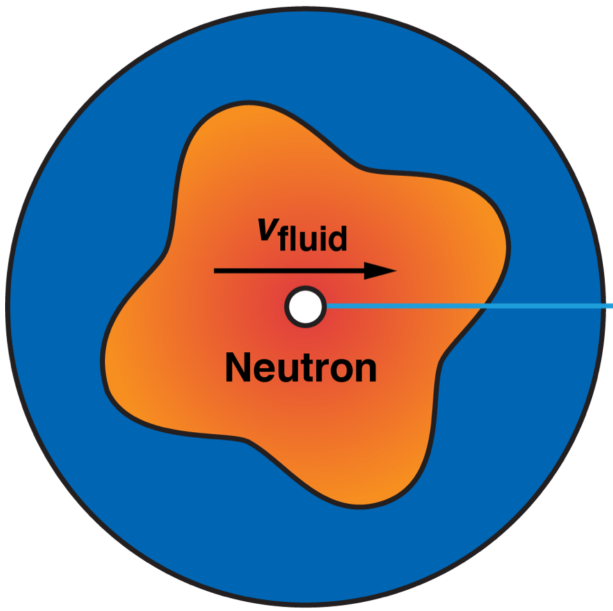
The variation of apparent ion-temperature measurements along different lines of sight (LOS) is uniquely determined by the behavior of the variance*,** of the hot-spot fluid velocities

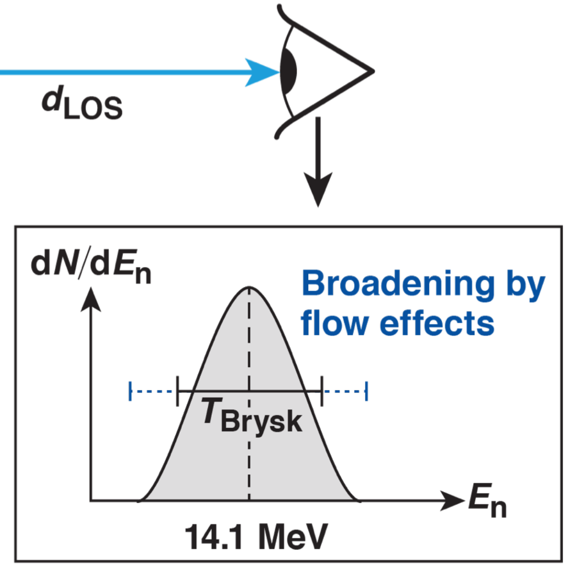
Thermal temperature†

$$T_{\mathrm{LOS}}(\theta,\phi) = T_{\mathrm{Brysk}} + \Delta T_{\mathrm{LOS}}(\theta,\phi)$$

Influence of isotropic and anisotropic flow effects

$$v_{\mathrm{n}} = v_{14.1\ \mathrm{MeV}} + v_{\mathrm{cm}} + v_{\mathrm{rel}} + v_{\mathrm{fluid}}$$ Signal broadening





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** D. H. Munro, Nucl. Fusion 56, 036001 (2016)
† H. Brysk, Plasma Phys. 15, 611 (1973).

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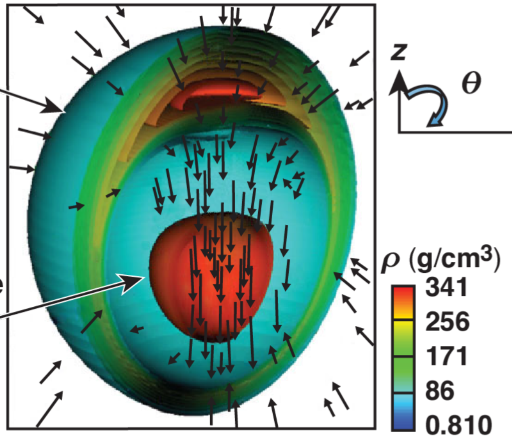
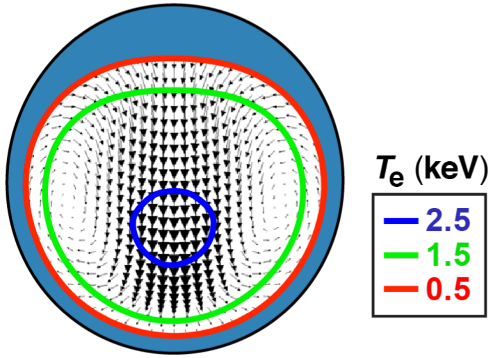
Magnitudes of hot-spot flows in the deceleration-phase simulations are large enough to cause significant variations in ion-temperature measurements

*DEC3D** mode-1 simulation



Velocity field vector



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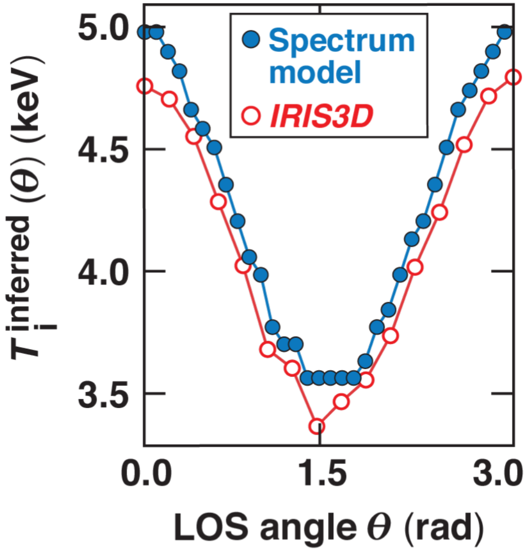
Simulation methods

Generate the synthetic neutron energy spectrum**,†

$$f_{\mathrm{LOS}}(E_n) = \sum_{\mathrm{cell}} \frac{Y_{\mathrm{cell}}}{Y_{\mathrm{total}}} e^{-\frac{(E_n - \bar{E})^2}{2\sigma^2}}$$

Infer T_i at different LOS and compare with *IRIS3D*



* K. M. Woo, *et al.* Phys. of Plasmas 25, 052704 (2018)
** F. Weilacher, *et al.* Phys. of Plasmas 25, 042704 (2018)
† V. N. Goncharov, *et al.* Phys. of Plasmas 21, 056315 (2014)

The modal dependence of T_i asymmetries was determined using 3-D simulations

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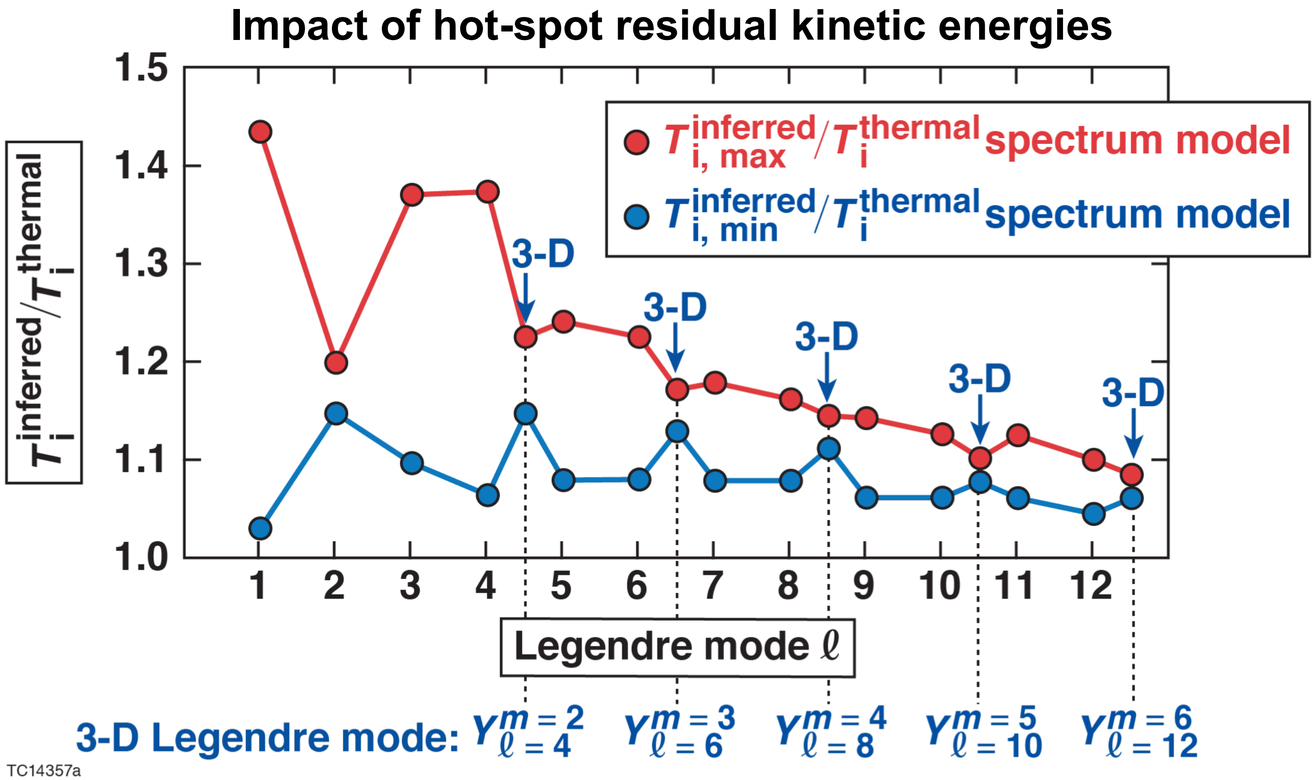
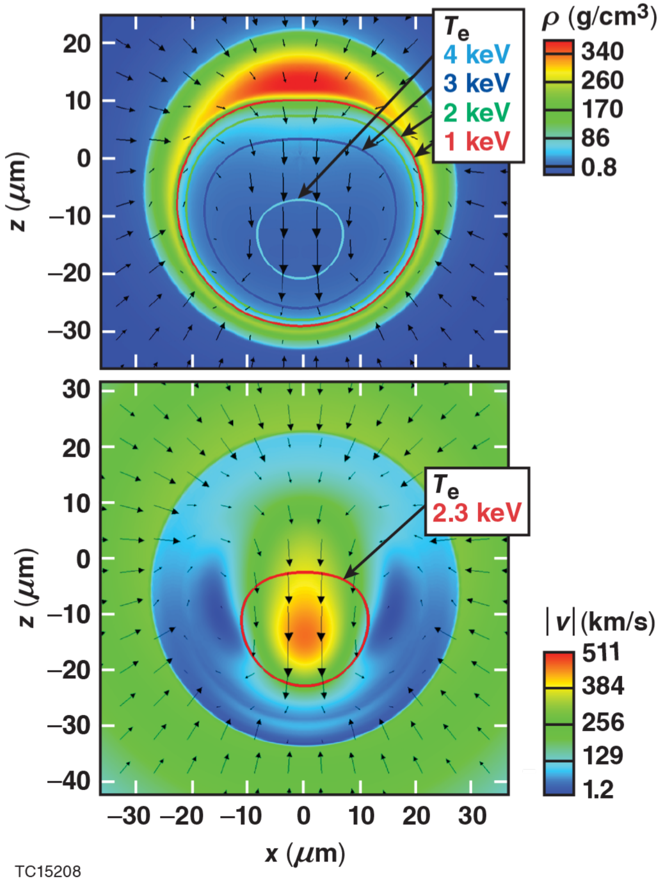


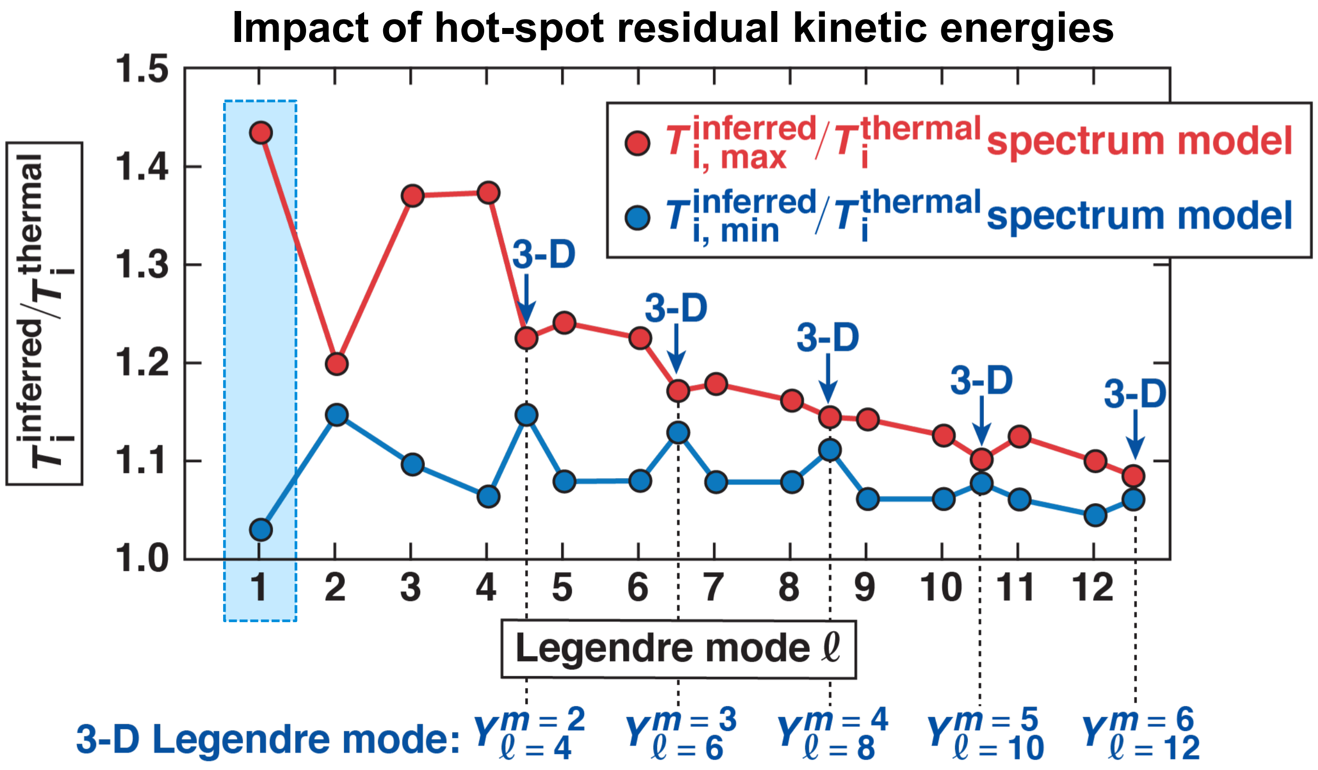
T_i asymmetries are characterized by isotropic and anisotropic flows

- Low odd-mode numbers give large T_i asymmetries because of anisotropic flows
- Low even-mode numbers give $T_{min} > T_{thermal}$ because of isotropic flows
- 3-D modes are more isotropic than 2-D modes

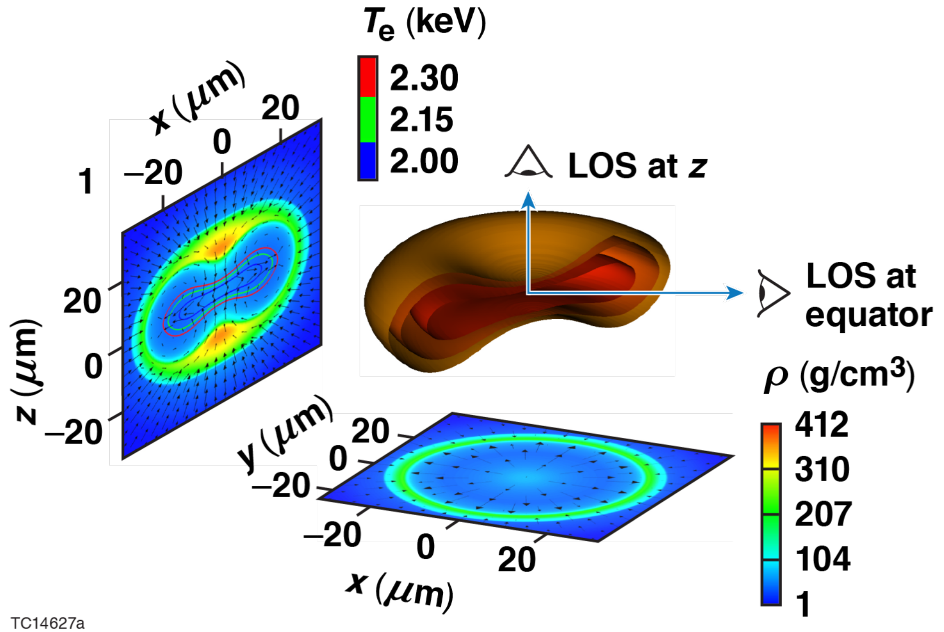
7% dv/v_0 perturbations with YOC ~ 0.4 to 0.6

Mode 1 exhibits a large T_i asymmetry and small isotropic flows





Mode 2 exhibits a small T_i asymmetry and large isotropic flows



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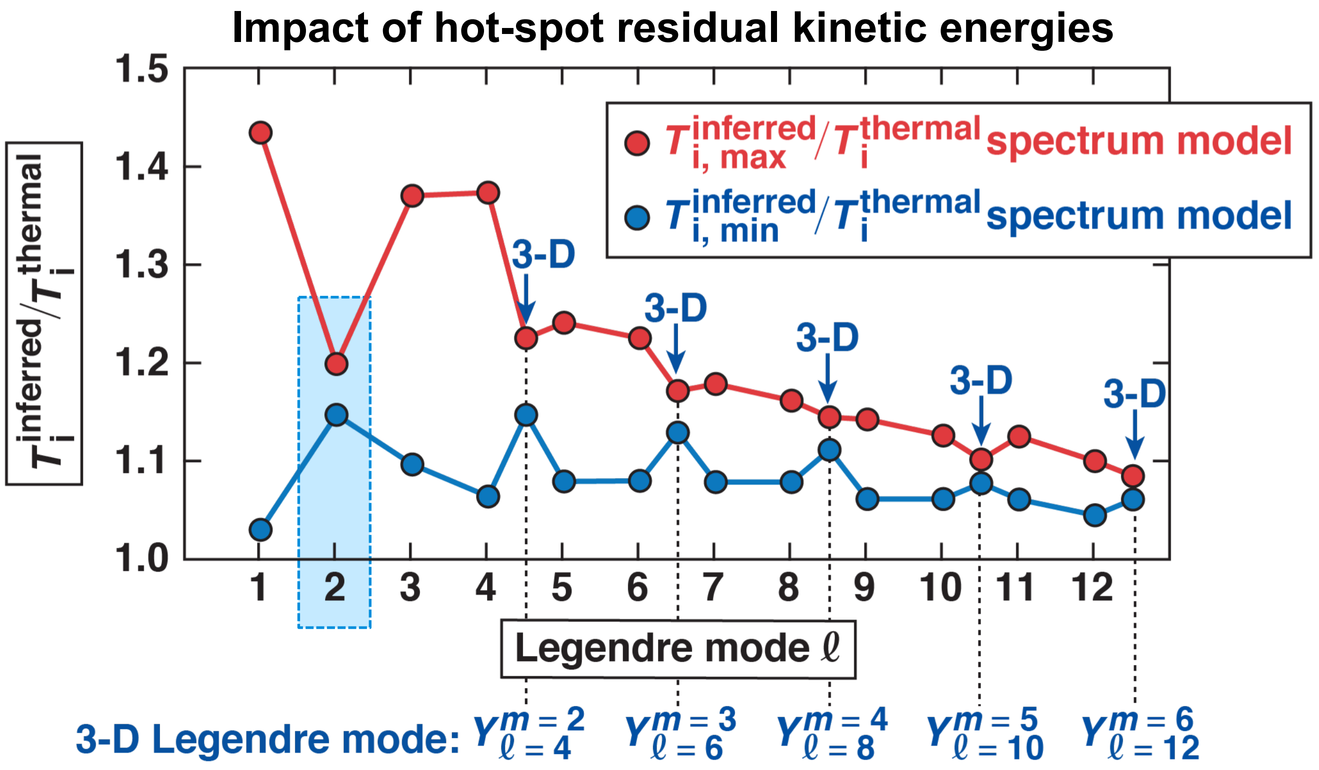
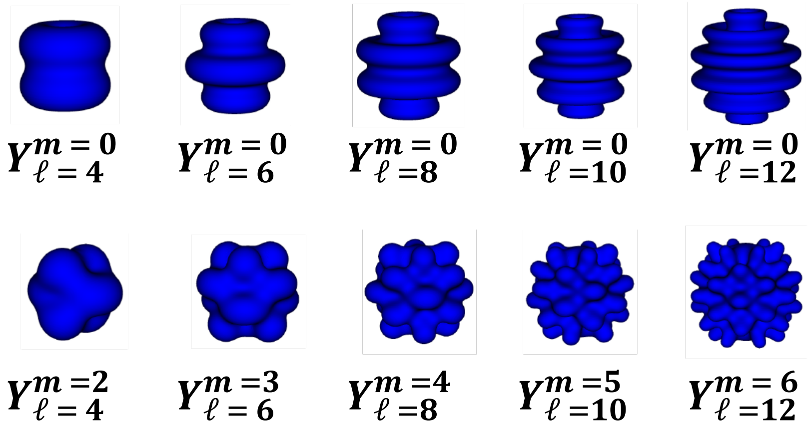


Three-dimensional modes exhibit lower T_i asymmetries than 2-D

3-D spikes/bubbles along the rotational axis



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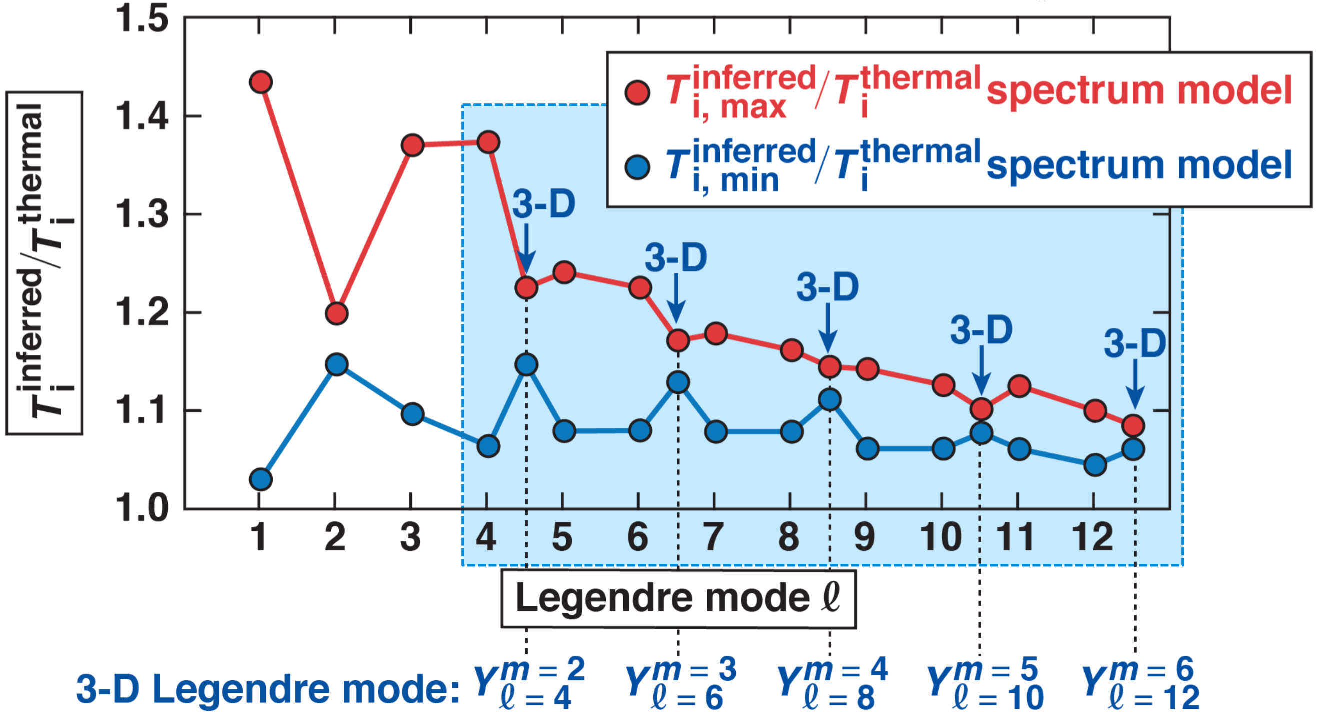
Impact of hot-spot residual kinetic energies



The six components of the velocity variance determine the full T_i distribution in 4π

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$$T_{LOS} = T_{th} + M_{DT}\mathrm{var}(v_{fluid} \cdot d)$$

$$\mathrm{var}(\vec{v}_{fluid} \cdot \hat{d}_{LOS}) = \sigma_{11}g_1g_1 + \sigma_{22}g_2g_2 + \sigma_{33}g_3g_3 + 2\sigma_{12}g_1g_2 + 2\sigma_{23}g_2g_3 + 2\sigma_{31}g_3g_1$$

Directional variance $\sigma_{i=j}$

Covariance $\sigma_{i\neq j}$

Residual kinetic energy

Azimuthal asymmetry

Geometrical factors from LOS locations

$g_1 = \sin\theta \cos\phi$

$g_2 = \sin\theta \sin\phi$

$g_3 = \cos\theta$

Six hot-spot flow parameters: directional-variance and covariance

$$\sigma_{ij} = \langle (v_i - \langle v_i \rangle)(v_j - \langle v_j \rangle) \rangle$$
$$= \langle \triangle v_i \triangle v_j \rangle$$

Burn-averaged brackets

Non-translational velocity fluctuations

K. M. Woo *et al.* Phys. Plasma. 25, 102710 (2018).

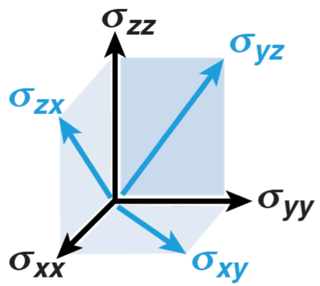
The 3-D reconstruction of apparent ion temperatures using the six components of velocity variance agrees with the ion temperatures inferred from *IRIS3D*

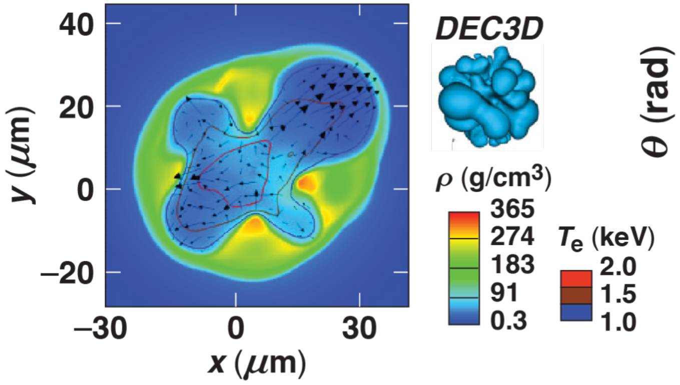
Compute the six hot-spot flow parameters from the *DEC3D* hydrocode

Reconstruct the T_i distribution using

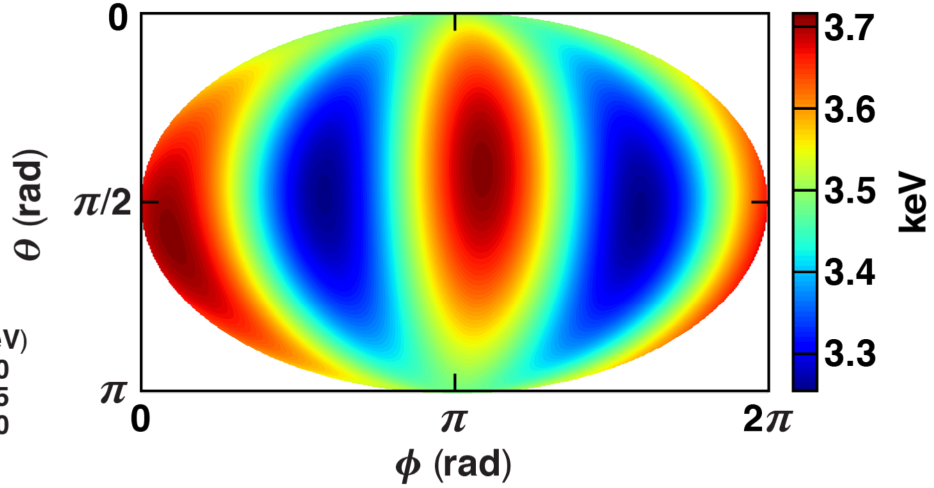
$$T_\mathrm{i}^\mathrm{inferred} = T_\mathrm{i}^\mathrm{thermal} + \mathrm{M_{DT}}\sigma_{ij}g_i g_j$$

Compare with T_i inferred from synthetic neutron energy spectra

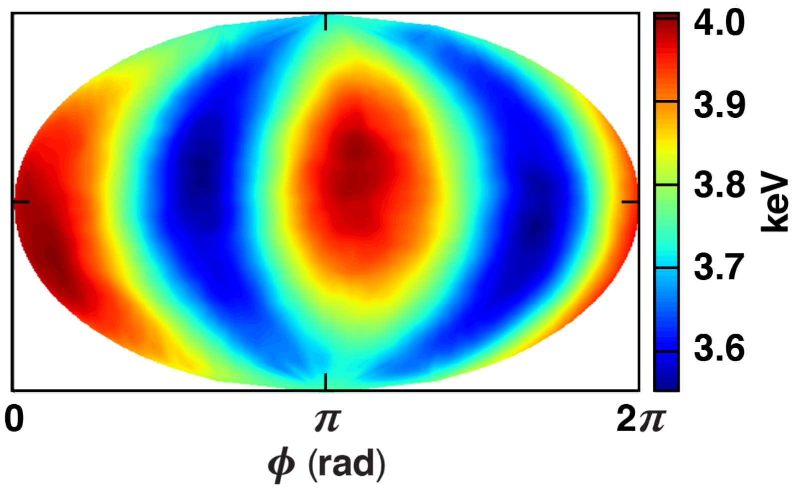




Model: $T_\mathrm{LOS}^\mathrm{inferred}(\theta, \phi)$



IRIS3D: $T_\mathrm{LOS}^\mathrm{inferred}(\theta, \phi)$



TC15209

Example of a multimode simulation

Outline

- Introduction to the ion-temperature measurement (T_i) asymmetry
- **Impact of anisotropic flows on T_i asymmetry**
- Impact of isotropic flows on inferring the minimum DD and thermal ion temperatures

The full T_i distribution can be reconstructed using six LOS measurements

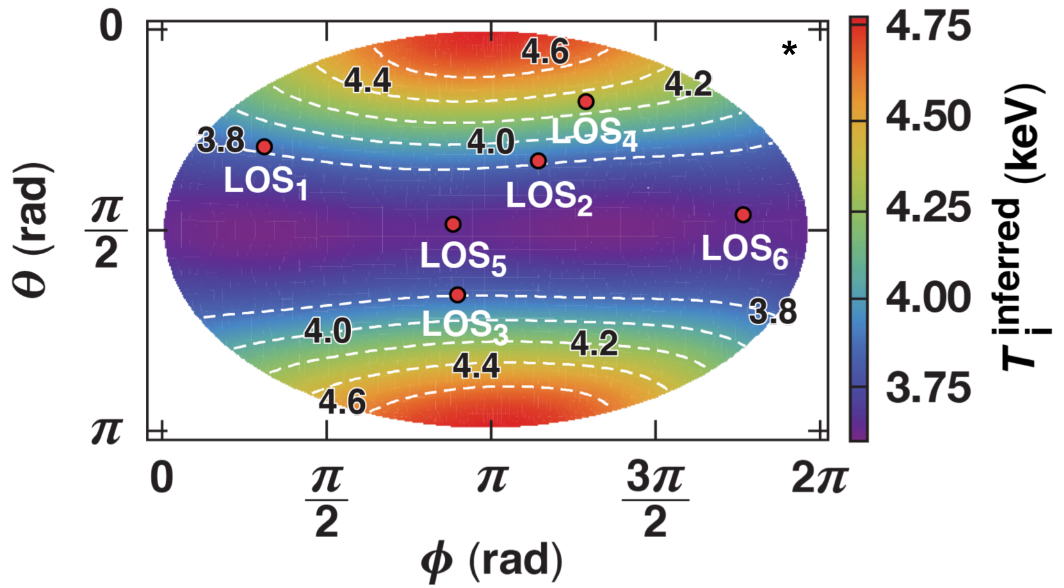
$$T_i^{\text{inferred}} = T_i^{\text{thermal}} + M_{DT}\sigma_{ij}g_ig_j$$

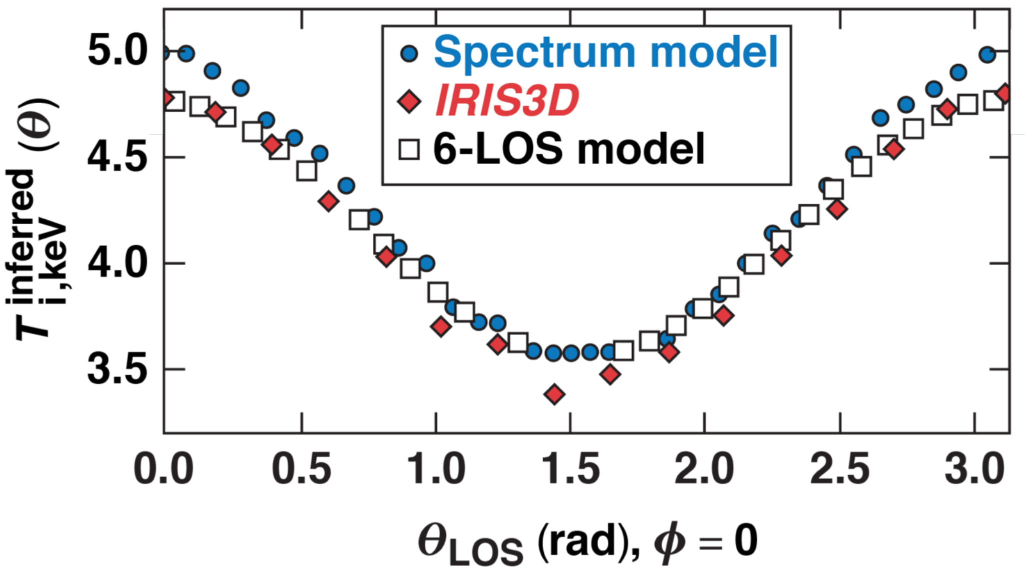
T_i distribution from six LOS

The departure matrix is close to zero

$$\vec{T}_p(\theta,\phi) = \hat{M}_p(\theta,\phi)\cdot\hat{M}_{LOS}^{-1}\cdot\vec{T}_6 + \left(\hat{I} - \hat{M}_p\cdot\hat{M}_{LOS}^{-1}\right)\cdot\vec{T}_{th}$$

$\ll 1$

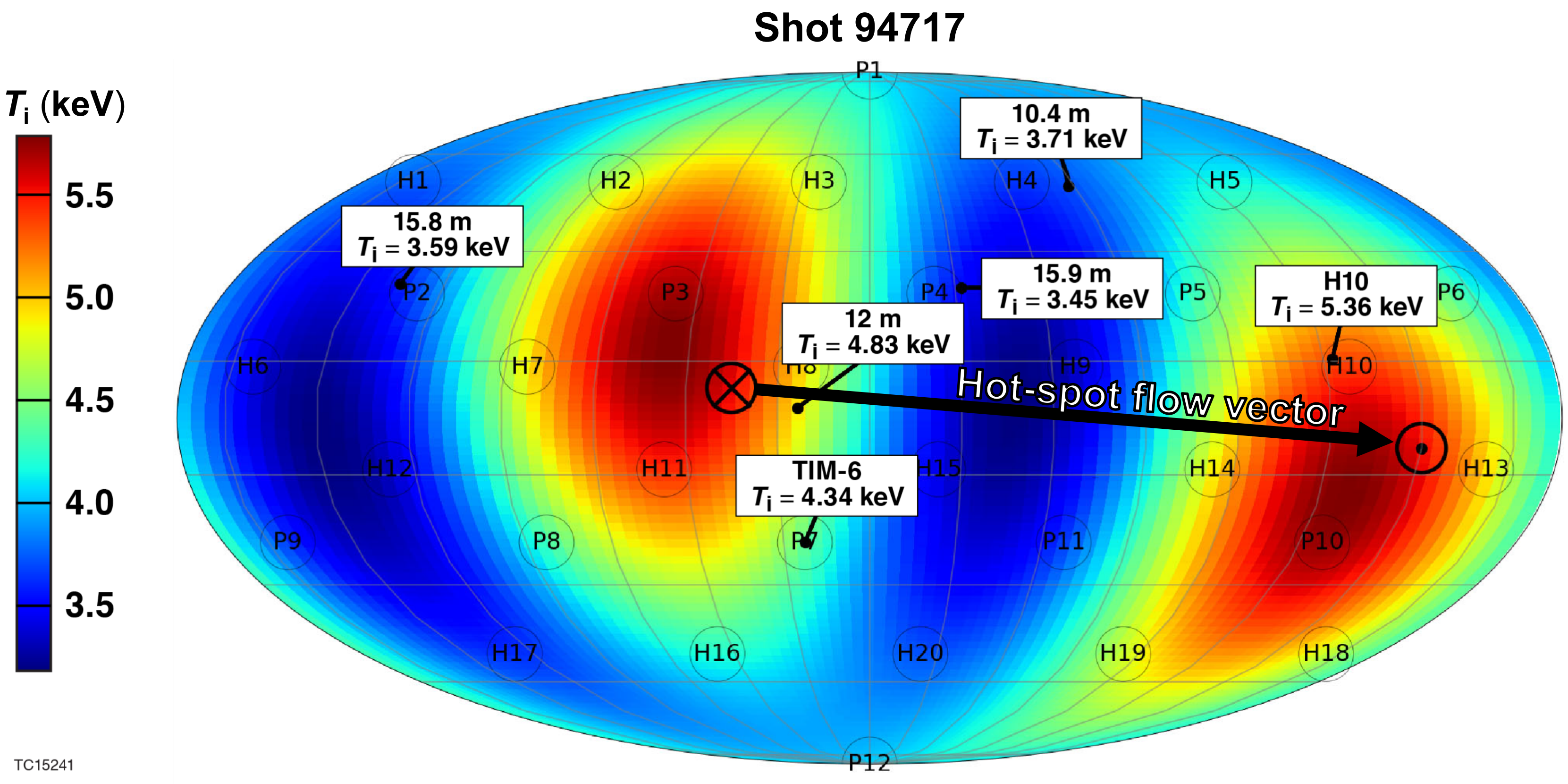




TC14362a

* Mode-1 simulation

The six-LOS reconstruction map was used on OMEGA implosions and found to be in good agreement with the hot-spot flow measurement



TC15241

Flow measurement* from the first moment of the spectrum

Flow direction (113 km/s)

* Flow measurement by O. Mannion

The T_i asymmetry of mode 1 determines the fusion yield degradation (YOC = $Y_{3\text{-D}}/Y_{1\text{-D}}$)

T_i asymmetry for mode 1:*

$$\frac{T_{\max}}{T_{\min}} \simeq 1 + 4\overline{\mathrm{RKE}}_{\mathrm{tot}}/(1 - \overline{\mathrm{RKE}}_{\mathrm{tot}})$$

Total residual kinetic energy:

$$\overline{RKE}_{\mathrm{tot}} = \frac{E^{3D}_{\mathrm{K,stag}} - E^{1D}_{\mathrm{K,stag}}}{E^{\mathrm{in\ flight}}_{\mathrm{K,max}}}$$

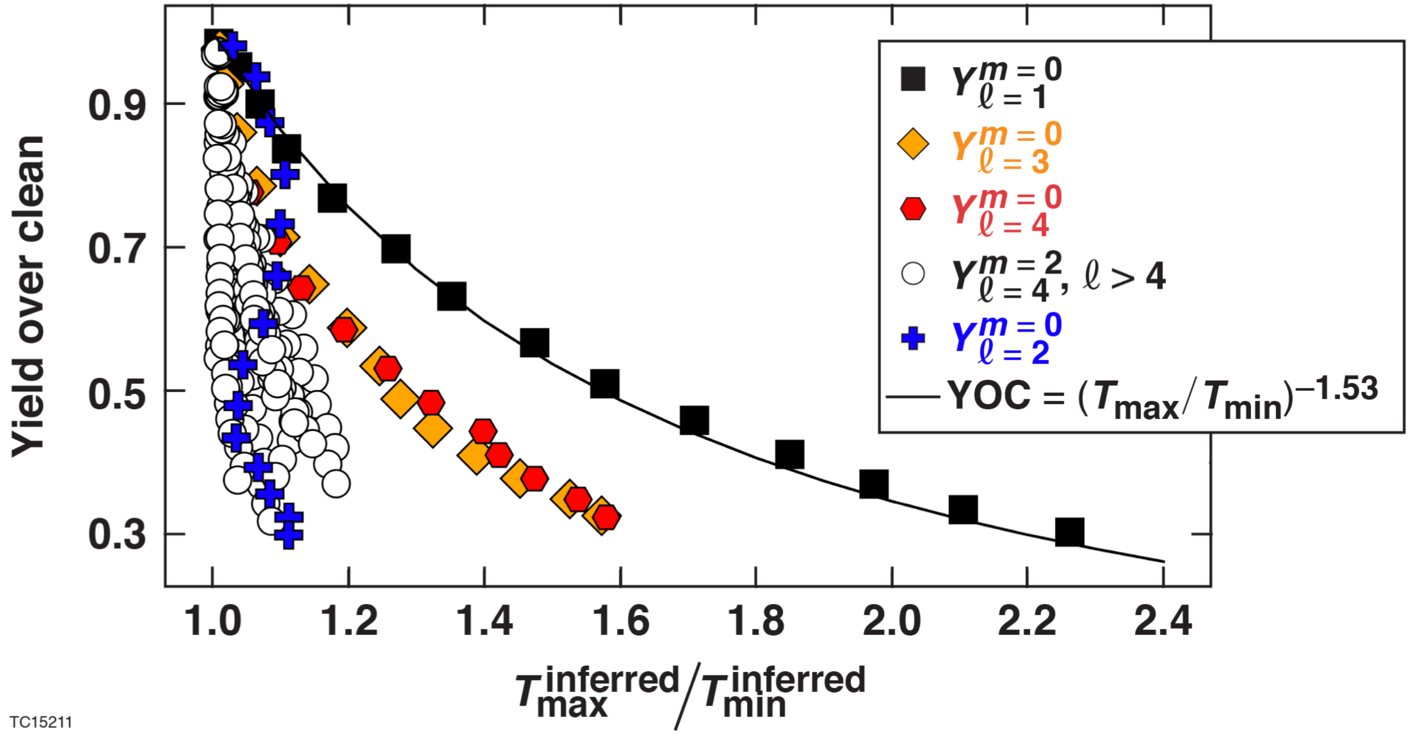
The YOC and RKE_{tot} is related,† to the T_i asymmetry for mode 1:**

$$\mathrm{YOC} \simeq (1 - \overline{\mathrm{RKE}}_{\mathrm{tot}})^5$$

$$\mathrm{YOC} \simeq \left[1 - \frac{\frac{1}{4}\left(\frac{T_{\max}}{T_{\min}} - 1\right)}{\frac{1}{4}\left(\frac{T_{\max}}{T_{\min}} - 1\right) + 1}\right]^5 \rightarrow \mathrm{fit} \simeq (T_{\max}/T_{\min})^{-1.53}$$

* K. M. Woo, Ph.D. thesis, University of Rochester, 2019.
** A. L. Kritcher, *et al.* Phys. Plasmas 21, 042708 (2014).
† K. M. Woo, *et al.* Phys. Plasmas 25, 052704 (2018).

The analytic curve shows a good agreement to explain the strong correlation between the yield degradation and mode-1 T_i asymmetries



In experiments, the fitting exponent* is in between 1.25 and 1.43.

* V. Gopalaswamy, NO5.00004, this conference.

Outline

- Introduction to the ion-temperature measurement (T_i) asymmetry
- Impact of anisotropic flows on T_i asymmetry
- **Impact of isotropic flows on inferring the minimum DD and thermal ion temperatures**

The isotropic part of the velocity variance is required to find the true thermal temperature from the minimum ion temperature

Minimum T_i > thermal T_i

T_i asymmetry

$$\mathrm{var}[\vec{v}_{\mathrm{fluid}} \cdot \hat{d}_{\mathrm{LOS}}] = \sigma_{\mathrm{iso}} + \sigma_{\mathrm{aniso}}^{\mathrm{LOS}}$$

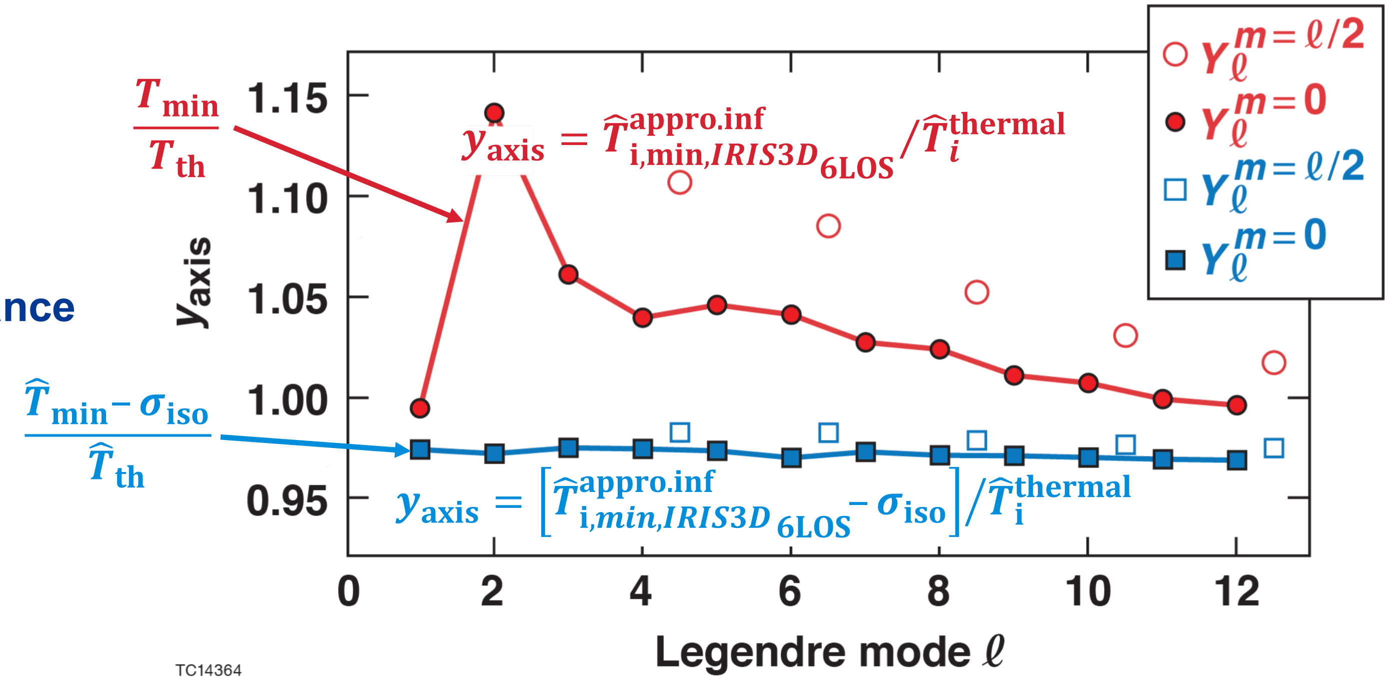
Define the isotropic part of the velocity variance

$$\sigma_{\mathrm{iso}} = \mathrm{Min}\left[\mathrm{var}[\vec{v}_{\mathrm{fluid}} \cdot \hat{d}_{\mathrm{LOS}}]\right]_{4\pi}$$

Solve for the thermal temperature by subtracting the isotropic part of velocity variance from the minimum temperature

$$T_{\mathrm{thermal}} = T_{\mathrm{min}} - M_{\mathrm{DT}}\,\sigma_{\mathrm{iso}}$$

Removal of isotropic velocity variance



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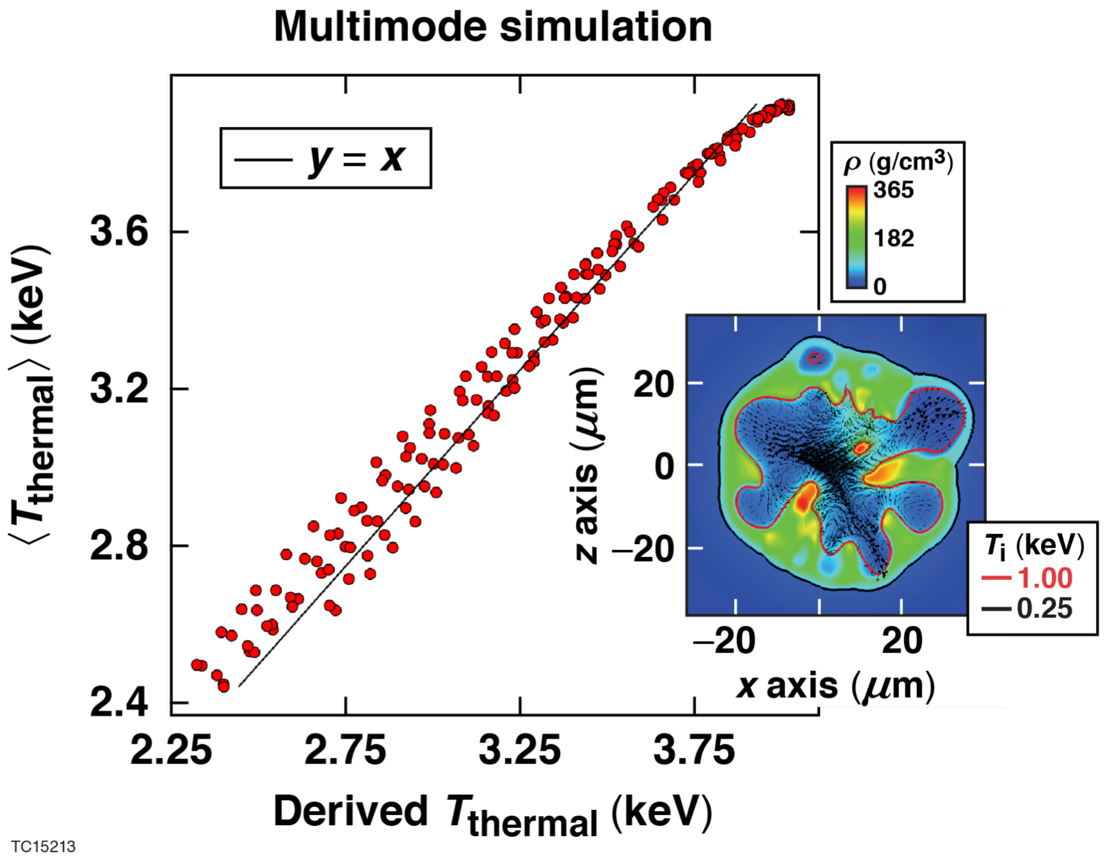
Normalized temperature: $\hat{T} \equiv T/M$

In experiments, measuring the minimum DD temperatures enables the inference of the isotropic velocity variance and the true thermal temperature



Isotropic velocity variance

$$T_{\text{min}}^{\text{DT}} = T_{\text{th}}^{\text{DT}} + M_{\text{DT}} \langle \sigma_{\text{iso}}^{\text{DT}} \rangle$$

$$T_{\text{min}}^{\text{DD}} = T_{\text{th}}^{\text{DD}} + M_{\text{DD}} \langle \sigma_{\text{iso}}^{\text{DD}} \rangle$$

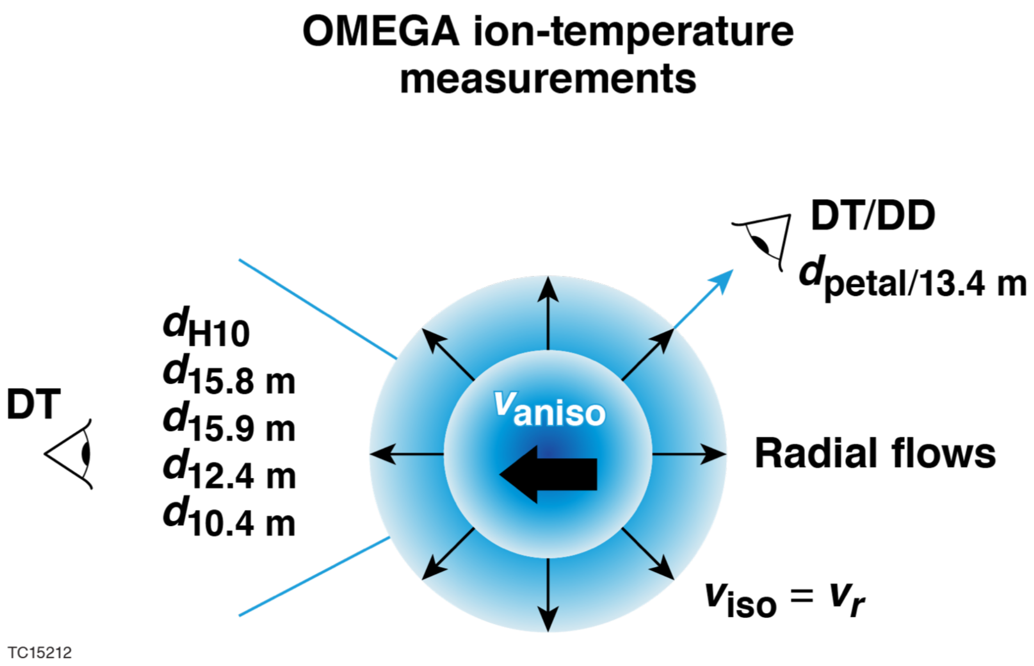
Remove the isotropic part using the DD T_{min}

$$\langle \sigma_{\text{iso}}^{\text{DD}} \rangle = \left(T_{\text{min}}^{\text{DD}} - T_{\text{th}}^{\text{DD}} \right) / M_{\text{DD}}$$

$$\langle T_{\text{th}} \rangle \simeq \left(T_{\text{min}}^{\text{DT}} - \frac{M_{\text{DT}}}{M_{\text{DD}}} \cdot T_{\text{min}}^{\text{DD}} \right) \Big/ \left[1 - \frac{M_{\text{DT}}}{M_{\text{DD}}} \right]$$

Assumptions: $\langle T_{\text{th}}^{\text{DD}} \rangle \approx \langle T_{\text{th}}^{\text{DT}} \rangle$ and $\langle \sigma_{\text{iso}}^{\text{DD}} \rangle \approx \langle \sigma_{\text{iso}}^{\text{DT}} \rangle$

The minimum DD ion temperature is inferred by performing DD and DT ion-temperature measurements along the same LOS



Anisotropic velocity variance

$$T_{\text{DT}}^{\text{LOS}} = T_{\text{min}}^{\text{DT}} + M_{\text{DT}} \langle \sigma_{\text{aniso}}^{\text{LOS}} \rangle$$

$$T_{\text{DD}}^{\text{LOS}} = T_{\text{min}}^{\text{DD}} + M_{\text{DD}} \langle \sigma_{\text{aniso}}^{\text{LOS}} \rangle$$

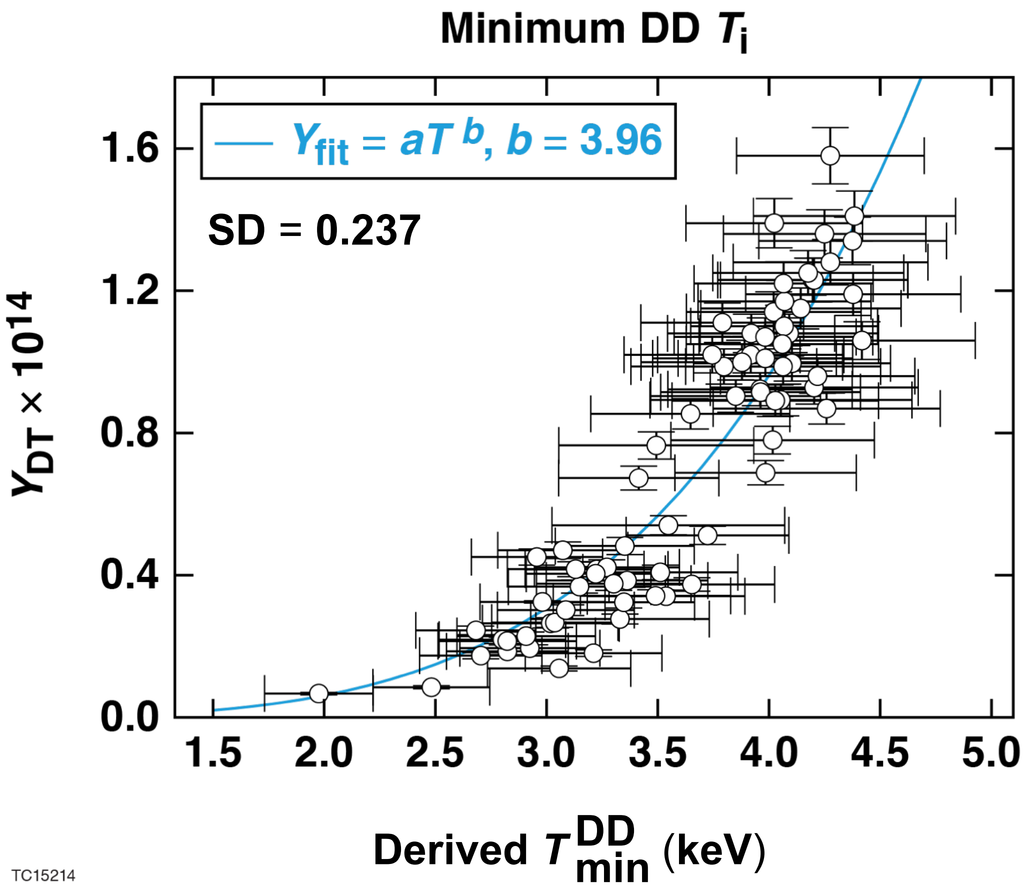
Remove the anisotropic part in DD temperature using DT measurements

$$T_{\text{min}}^{\text{DD}} = T_{\text{DD}}^{\text{LOS}} - \left(T_{\text{DT}}^{\text{LOS}} - T_{\text{min}}^{\text{DT}}\right) \cdot \frac{M_{\text{DD}}}{M_{\text{DT}}}$$

The minimum of DT temperature is obtained from six LOS (as described earlier)

Definition $M_{DD} = m_n + m_{He_3}$ $M_{DT} = m_n + m_\alpha$

In OMEGA cryogenic implosion experiments, the derived DD minimum ion temperatures are strongly correlated with the yields as ~T^4



TC15214

A velocity variance analysis was developed to explain the 3-D flow effects on ion-temperature (T_i) measurements and the modal dependence of T_i asymmetries in ICF

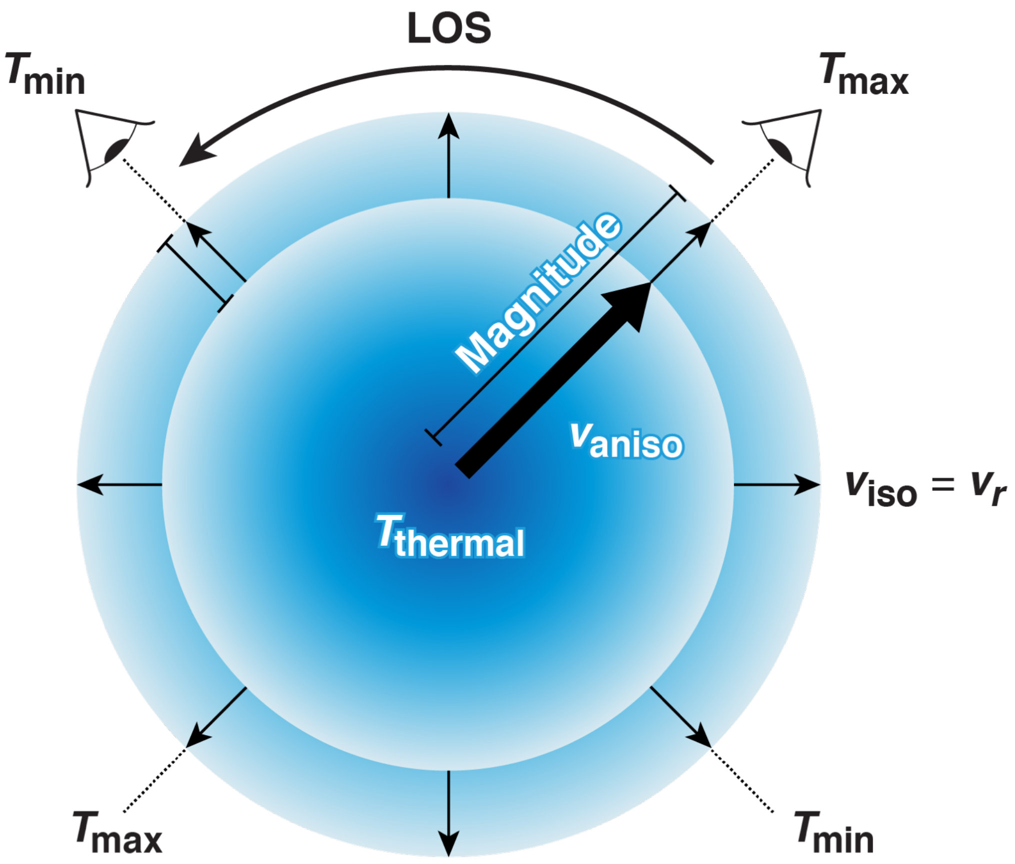
- A method using six line-of-sight (LOS) ion-temperature measurements was developed to determine the full temperature map and account for the contribution of anisotropic flows
- The contribution of isotropic flows and the thermal temperature can be determined using both DD and DT ion-temperature measurements
- The minimum of DD neutron-inferred ion temperature was derived from DD and DT ion-temperature measurements along the same single LOS and demonstrated a strong correlation with the experimental yields in the OMEGA implosion database
- Analytical expressions were derived to infer the yield-over-clean in terms of mode-1 ion-temperature asymmetries

Appendix

The variation of apparent ion-temperature measurements along different lines of sight (LOS) is uniquely determined by the behavior of the variance*,** of the hot-spot fluid velocities

$$\mathrm{var}\left[\vec{v}_{\mathrm{fluid}}\cdot\hat{d}\right]=\left\langle\left|\Delta\vec{v}_{\mathrm{fluid}}\cdot\hat{d}\right|^{2}\right\rangle$$

- Residual kinetic energy
- Square of the velocity fluctuation vector



TC15240

- Radial flows
- Counter-flowing fluid motion

* T. J. Murphy, Phys. Plasmas 21, 072701 (2014).
** D. H. Munro, Nucl. Fusion 56, 036001 (2016).
† H. Brysk, Plasma Phys. 15, 611 (1973).

The isotropic flow velocity is not measured in the hot-spot flow velocity vector reconstruction

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Neutron velocity measured along a given LOS

$$\vec{v}_{\mathrm{LOS}} = \underbrace{v_{14.1\ \mathrm{MeV}} + v_{\mathrm{cm}} + v_{\mathrm{rel}}}_{v_0} + \underbrace{\vec{v} \cdot \hat{d}}$$

Expand the fluid velocity into isotropic and anisotropic components

$$\vec{v} = \vec{v}_{\mathrm{iso}} + \vec{v}_{\mathrm{aniso}}$$

Burn-averaged neutron velocity

$$\langle \vec{v}_{\mathrm{LOS}} \rangle = v_0 \underbrace{\langle \vec{v}_{\mathrm{iso}} \cdot \hat{d} \rangle} + \langle \vec{v}_{\mathrm{aniso}} \cdot \hat{d} \rangle = v_0 + \langle \vec{v}_{\mathrm{aniso}} \cdot \hat{d} \rangle$$

Expand the isotropic flow velocity into parallel and antiparallel components with respect to the LOS unit vector

$$\langle \vec{v}_{\mathrm{iso}} \cdot \hat{d} \rangle = \langle \vec{v}_{\mathrm{iso}}^{+} \cdot \hat{d} \rangle + \langle \vec{v}_{\mathrm{iso}}^{-} \cdot \hat{d} \rangle = \langle \vec{v}_{\mathrm{iso}} \cdot \hat{d} \rangle - \langle \vec{v}_{\mathrm{iso}} \cdot \hat{d} \rangle = 0$$

The general expression for the isotropic velocity variance is derived

Neutron velocity measured along a given LOS

$$\mathrm{var}(\vec{v}\cdot\hat{d}) = \left\langle(\vec{v}\cdot\hat{d})^2\right\rangle + \langle\vec{v}\cdot\hat{d}\rangle^2 = \left\langle(\vec{v}_{\mathrm{iso}}\cdot\hat{d}+\vec{v}_{\mathrm{aniso}}\cdot\hat{d})^2\right\rangle + \langle\vec{v}_{\mathrm{aniso}}\cdot\hat{d}\rangle^2$$

Expand the fluid velocity into isotropic and anisotropic components

$$\left\langle(\vec{v}\cdot\hat{d})^2\right\rangle = \left\langle(\vec{v}_{\mathrm{iso}}\cdot\hat{d})^2 + (\vec{v}_{\mathrm{aniso}}\cdot\hat{d})^2 + 2(\vec{v}_{\mathrm{iso}}\cdot\hat{d})(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})\right\rangle$$

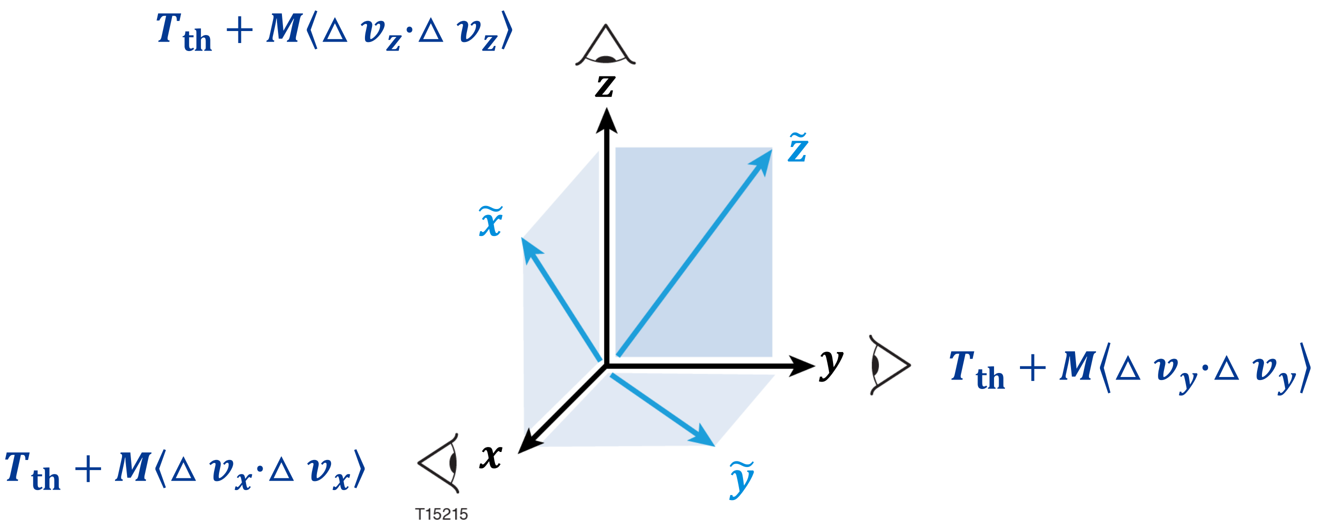
$$= \langle v_{\mathrm{iso}}^2\rangle + \left\langle(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})^2\right\rangle + 2\langle(\vec{v}_{\mathrm{iso}}\cdot\hat{d})(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})\rangle$$

Expand the cross term

$$\langle(\vec{v}_{\mathrm{iso}}^{+}\cdot\hat{d})(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})\rangle + \langle(\vec{v}_{\mathrm{iso}}^{-}\cdot\hat{d})(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})\rangle = \langle v_{\mathrm{iso}}(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})\rangle - \langle v_{\mathrm{iso}}(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})\rangle = 0$$

Therefore $\mathrm{var}(\vec{v}\cdot\hat{d}) = \langle v_{\mathrm{iso}}^2\rangle + \mathrm{var}(\vec{v}_{\mathrm{aniso}}\cdot\hat{d})$

The ability to determine the true minimum ion temperature depends on the number of LOS



The sum of T_i measurements at three orthogonal directions is rotational invariant; this implies the T_i measurements at a given set of LOS is related to another set of LOS by a coordinate transformation

$$3T_{th} + M\langle \triangle \vec{v} \cdot \vec{v} \rangle = 3T_{th} + M\langle \triangle \tilde{v} \cdot \triangle \tilde{v} \rangle$$ **by substituting** $\tilde{v} = \hat{R} \cdot \vec{v}$

Conservation of the total hot-spot fluid residual kinetic energy

$\tilde{x}, \tilde{y}, \tilde{z}$ are rotated axes

The measurements of DT ion temperatures cannot be applied to solve for the thermal temperature because the apparent temperatures contain isotropic flows

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The orange parts form $\hat{M}_{\mathrm{LOS}}$

T_1	1	$g^1_x g^1_x$	$g^1_y g^1_y$	$g^1_z g^1_z$	$2g^1_x g^1_y$	$2g^1_y g^1_z$	$2g^1_z g^1_x$
T_2	1	$g^2_x g^2_x$	$g^2_y g^2_y$	$g^2_z g^2_z$	$2g^2_x g^2_y$	$2g^2_y g^2_z$	$2g^2_z g^2_x$
T_3	1	$g^3_x g^3_x$	$g^3_y g^3_y$	$g^3_z g^3_z$	$2g^3_x g^3_y$	$2g^3_y g^3_z$	$2g^3_z g^3_x$
T_4	1	$g^4_x g^4_x$	$g^4_y g^4_y$	$g^4_z g^4_z$	$2g^4_x g^4_y$	$2g^4_y g^4_z$	$2g^4_z g^4_x$
T_5	1	$g^5_x g^5_x$	$g^5_y g^5_y$	$g^5_z g^5_z$	$2g^5_x g^5_y$	$2g^5_y g^5_z$	$2g^5_z g^5_x$
T_6	1	$g^6_x g^6_x$	$g^6_y g^6_y$	$g^6_z g^6_z$	$2g^6_x g^6_y$	$2g^6_y g^6_z$	$2g^6_z g^6_x$
T_7	1	$g^7_x g^7_x$	$g^7_y g^7_y$	$g^7_z g^7_z$	$2g^7_x g^7_y$	$2g^7_y g^7_z$	$2g^7_z g^7_x$

T_{th}		T_{th}
$M_{\mathrm{DT}}\sigma_{xx}$		$M_{\mathrm{DT}}\sigma_{\mathrm{iso}}$
$M_{\mathrm{DT}}\sigma_{yy}$	Turbulence	$M_{\mathrm{DT}}\sigma_{\mathrm{iso}}$
$M_{\mathrm{DT}}\sigma_{zz}$	$\longmapsto$	$M_{\mathrm{DT}}\sigma_{\mathrm{iso}}$
$M_{\mathrm{DT}}\sigma_{xy}$		0
$M_{\mathrm{DT}}\sigma_{yz}$		0
$M_{\mathrm{DT}}\sigma_{zx}$		0

Apparent ion temperatures for turbulence at all LOS's

$$T_{\mathrm{LOS}} = T_{\mathrm{th}} + M_{\mathrm{DT}}\sigma_{\mathrm{iso}}$$

The consequence of introducing DD ion-temperature measurements leads to a complete solution for the true thermal temperatures

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This 7 × 7 matrix is invertible with a nonzero determinant

LOS_1^{H10}	T_1^{DT}	1	$g^1_x g^1_x$	$g^1_y g^1_y$	$g^1_z g^1_z$	$2g^1_x g^1_y$	$2g^1_y g^1_z$	$2g^1_z g^1_x$	T_{th}
$LOS_2^{15.8\ m}$	T_2^{DT}	1	$g^2_x g^2_x$	$g^2_y g^2_y$	$g^2_z g^2_z$	$2g^2_x g^2_y$	$2g^2_y g^2_z$	$2g^2_z g^2_x$	$M_{DT}\sigma_{xx}$
$LOS_3^{15.9\ m}$	T_3^{DT}	1	$g^3_x g^3_x$	$g^3_y g^3_y$	$g^3_z g^3_z$	$2g^3_x g^3_y$	$2g^3_y g^3_z$	$2g^3_z g^3_x$	$M_{DT}\sigma_{yy}$
$LOS_4^{12\ m}$	T_4^{DT}	1	$g^4_x g^4_x$	$g^4_y g^4_y$	$g^4_z g^4_z$	$2g^4_x g^4_y$	$2g^4_y g^4_z$	$2g^4_z g^4_x$	$M_{DT}\sigma_{zz}$
$LOS_5^{10.4\ m}$	T_5^{DT}	1	$g^5_x g^5_x$	$g^5_y g^5_y$	$g^5_z g^5_z$	$2g^5_x g^5_y$	$2g^5_y g^5_z$	$2g^5_z g^5_x$	$M_{DT}\sigma_{xy}$
LOS_6^{Petal}	T_6^{DT}	1	$g^6_x g^6_x$	$g^6_y g^6_y$	$g^6_z g^6_z$	$2g^6_x g^6_y$	$2g^6_y g^6_z$	$2g^6_z g^6_x$	$M_{DT}\sigma_{yz}$
$LOS_7^{13.4\ m}$	T_7^{DD}	R_T	$R_M g^7_x g^7_x$	$R_M g^7_y g^7_y$	$R_M g^7_z g^7_z$	$R_M 2g^7_x g^7_y$	$R_M 2g^7_y g^7_z$	$R_M 2g^7_z g^7_x$	$M_{DT}\sigma_{zx}$

Add more T_{DD} here, and compute the pseudo inverse

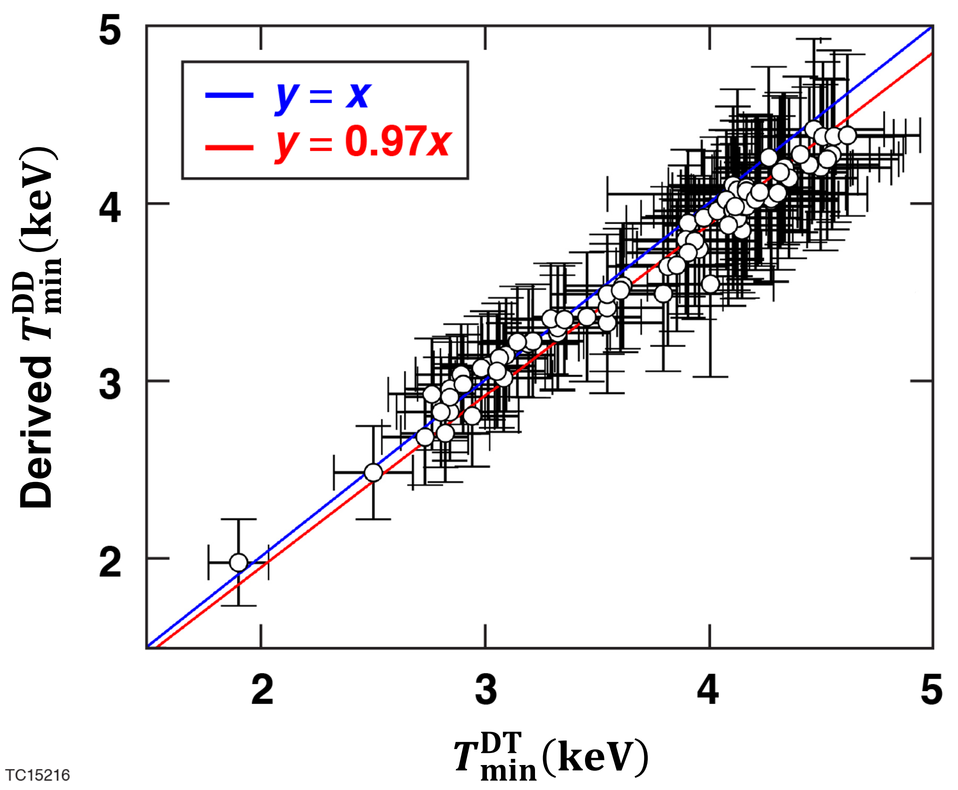
$R_T = T_{th}^{DD} / T_{th}^{DT}$

$R_M = M_{DD} / M_{DT}$

OMEGA implosions exhibit a small amount of isotropic flows as shown by comparing the minimum DD and DT ion temperatures

Isotropic flows

$$T_{\text{min}}^{\text{DT}} = T_{\text{min}}^{\text{DD}} + \Delta T_{\text{th}}^{\text{DT/DD}} + 0.2 M_{\text{DT}} \langle \sigma_{\text{iso}} \rangle$$



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Define the residual kinetic energy for isotropic flows

$$T_{\text{min}}^{\text{DD}} = T_{\text{th}} + M_{\text{DD}} \langle \sigma_{\text{iso}} \rangle$$

$$T_{\text{min}}^{\text{DT}} = T_{\text{th}} + M_{\text{DT}} \langle \sigma_{\text{iso}} \rangle = T_{\text{th}}(1 + f_{\text{RKE}})$$

$$f_{\text{RKE}} = \frac{\text{kinetic energy of isotropic fluid motions}}{\text{ion thermal energy}} = \frac{M_{\text{DT}} \langle \sigma_{\text{iso}} \rangle}{T_{\text{th}}}$$

$$T_{\text{min}}^{\text{DD}} / T_{\text{min}}^{\text{DT}} = \frac{1 + (M_{\text{DD}}/M_{\text{DT}}) f_{\text{RKE}}}{1 + f_{\text{RKE}}}$$

Definition $\Delta T_{\text{th}}^{\text{DT/DD}} \equiv T_{\text{th}}^{\text{DT}} - T_{\text{th}}^{\text{DD}}$