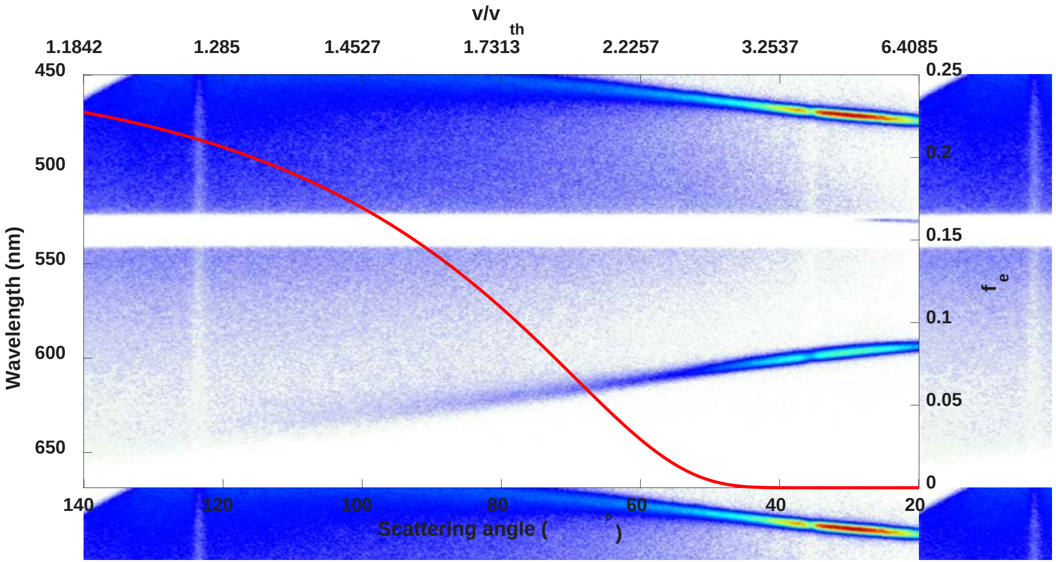
# Measurements of arbitrary distribution functions using angularly resolved Thomson scattering





**A. L. Milder**
**University of Rochester**
**Laboratory for Laser Energetics**


**Thomson Scattering Workshop**
**Rochester, NY**
**13-14 August 2019**

# Non-maxwellian electron distribution functions have been measured using angularly resolved Thomson scattering

- Collective electron plasma wave Thomson scattering is sensitive to electron velocity distributions
- Angularly resolved Thomson scattering allows direct inference of the electron velocity distribution and has been measured
- Measured distribution agree with theoretical predictions for super-Gaussian distributions

# Collaborators

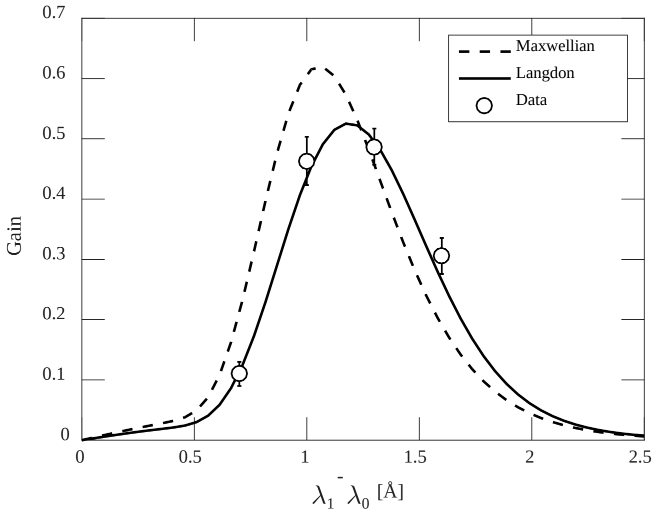
**J. Katz, R. Boni, D. Nelson, J. P. Palastro, K. Daub, R. Follett, and D. H. Froula**
**Laboratory for Laser Energetics**

# The electron velocity distribution function (EDF) is required to accurately model plasmas and laser-plasma instabilities

- **The gain in instabilities such as cross beam energy transfer, stimulated Raman scattering, and two plasmon decay is dependent on EDF**

- **Heat transport is dependent on EDF**

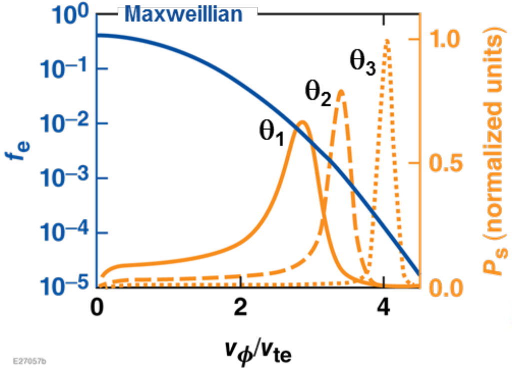
- **Diagnostic techniques are also influenced by EDF**
  - **Thomson scattering**
  - **X-ray spectroscopy**

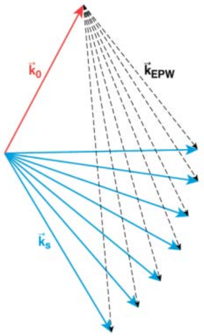


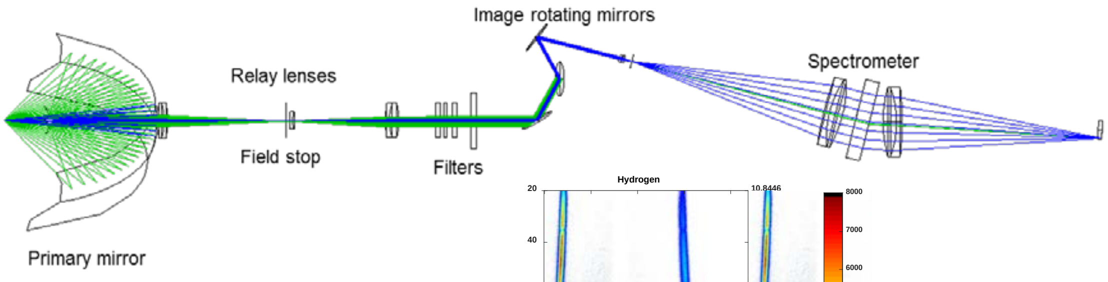

**It is often assumed the EDF is Maxwellian but this may not always be the case**

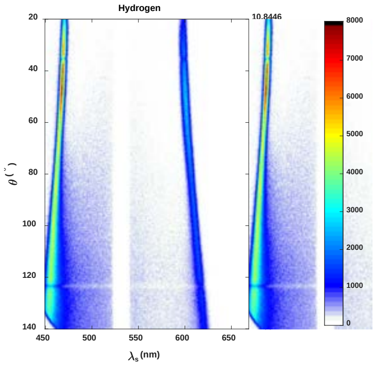
# Angularly resolved Thomson data allows direct measurement of the electron velocity distribution

- Each scattering angle measures at a different phase velocity
- Each phase velocity probes a different location on the distribution

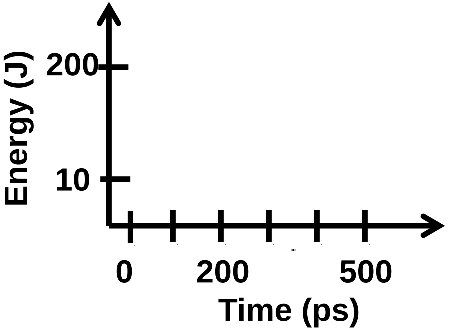


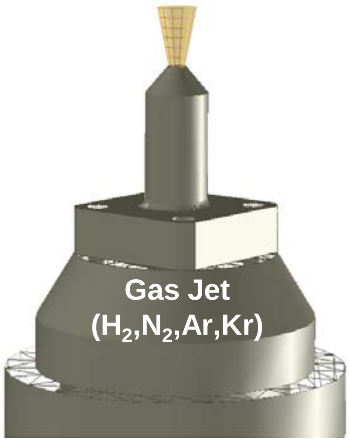



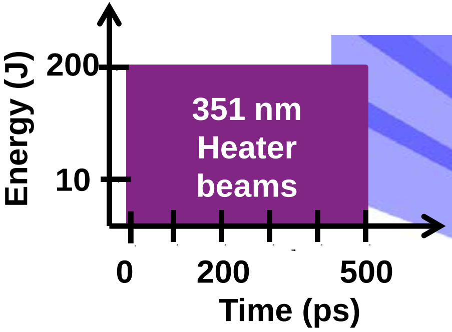



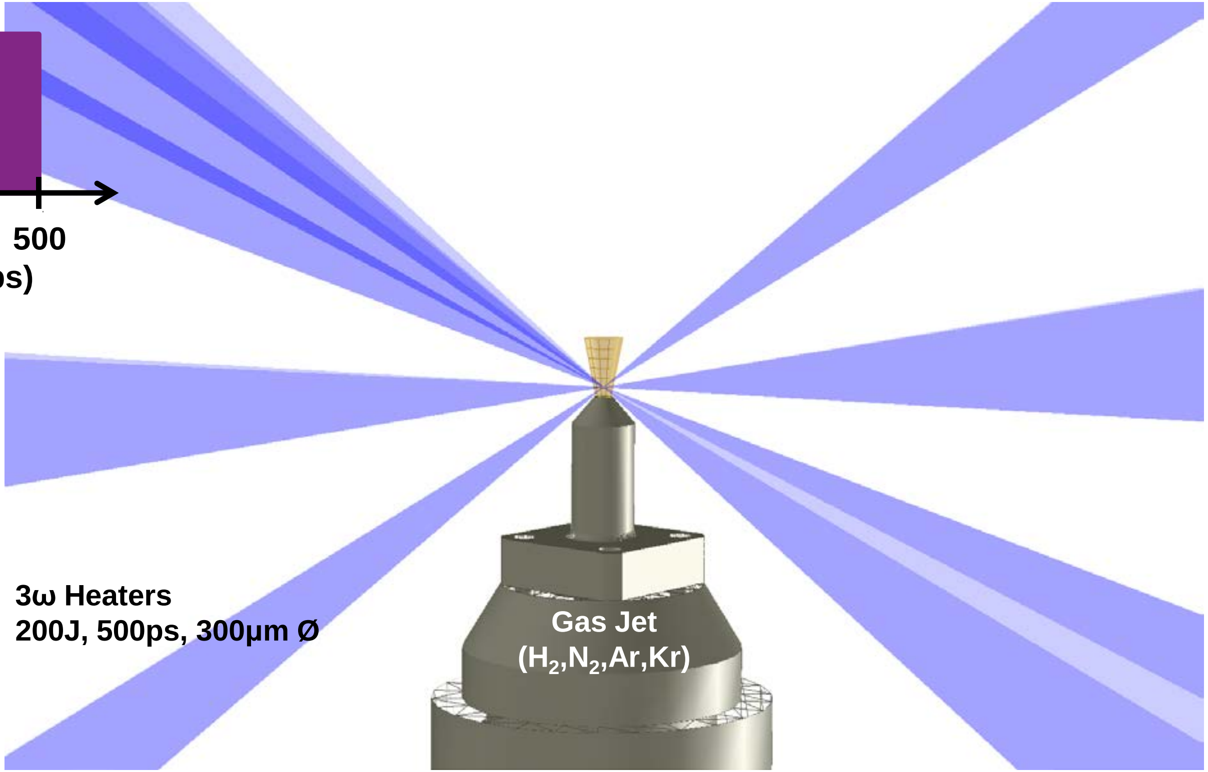
# Angularly resolved Thomson scattering experiments were preformed on the OMEGA60 laser system to measure non-Maxwellian distribution functions



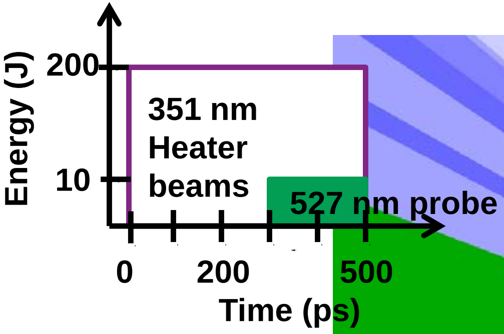



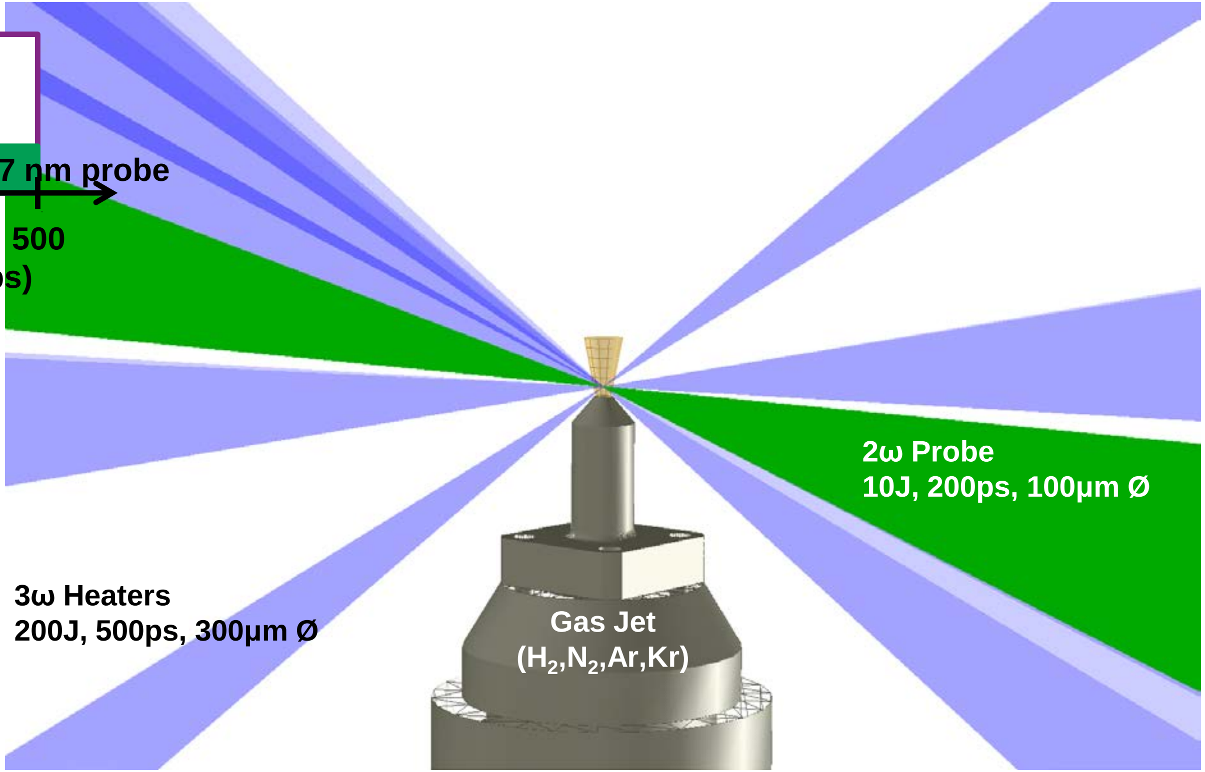
# Angularly resolved Thomson scattering experiments were preformed on the OMEGA60 laser system to measure non-Maxwellian distribution functions



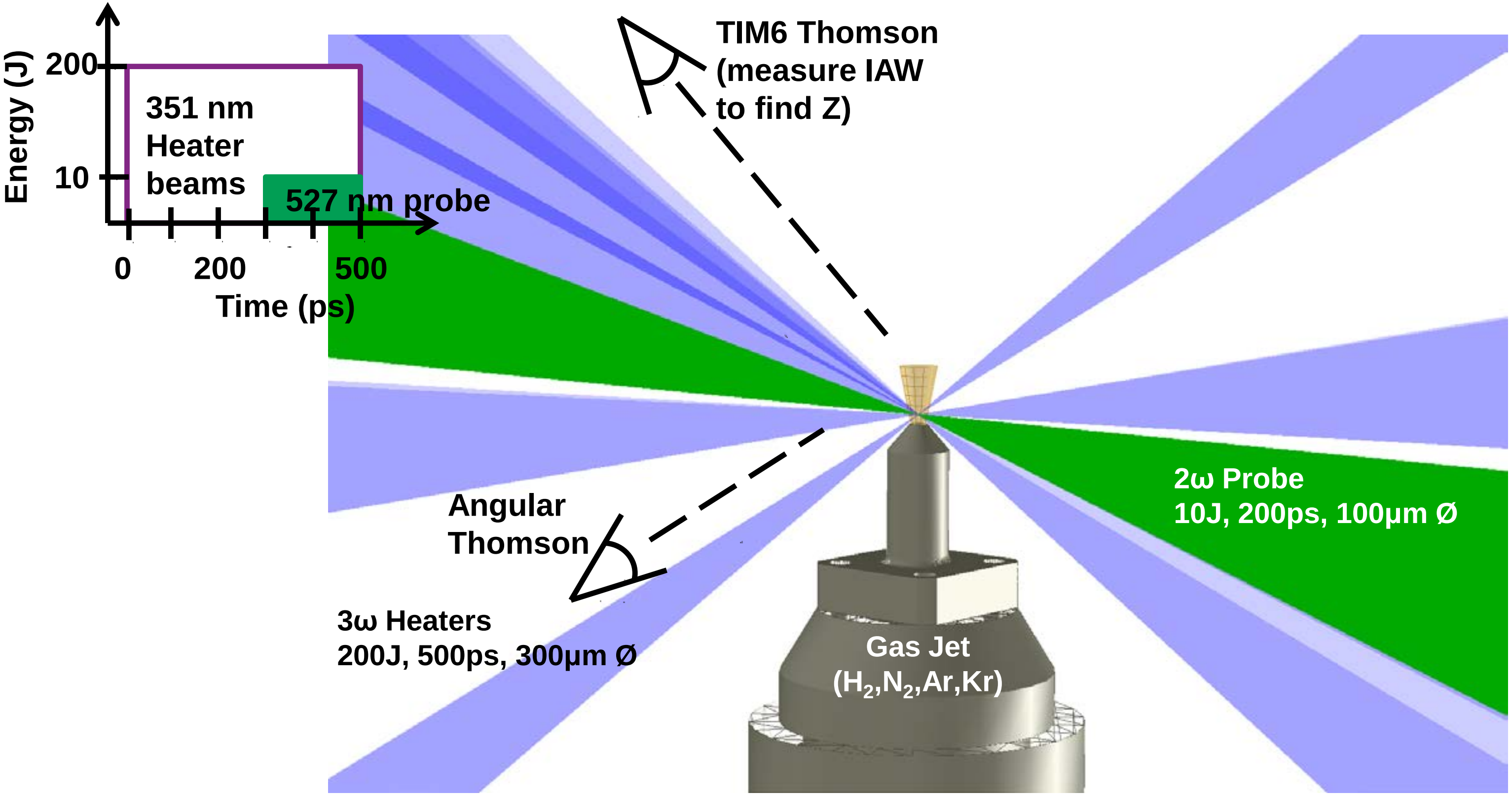



# Angularly resolved Thomson scattering experiments were preformed on the OMEGA60 laser system to measure non-Maxwellian distribution functions



# Angularly resolved Thomson scattering experiments were preformed on the OMEGA60 laser system to measure non-Maxwellian distribution functions

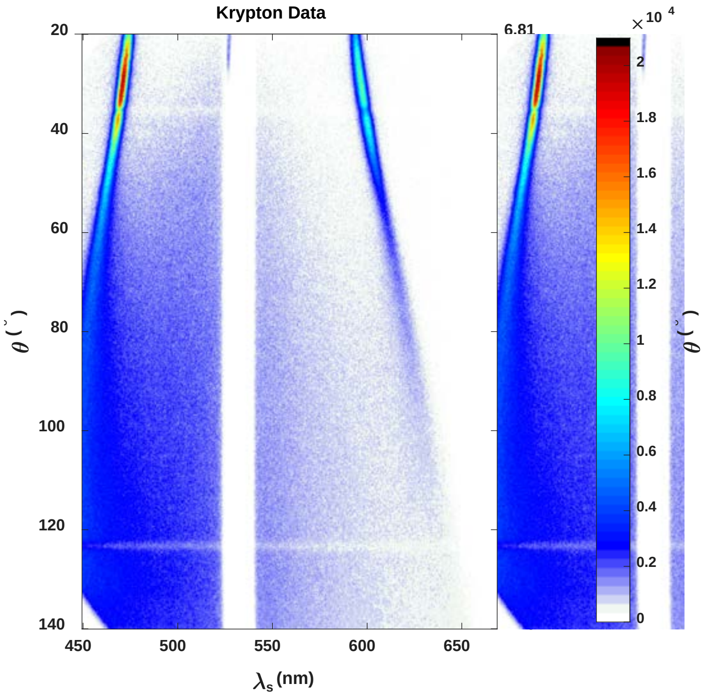


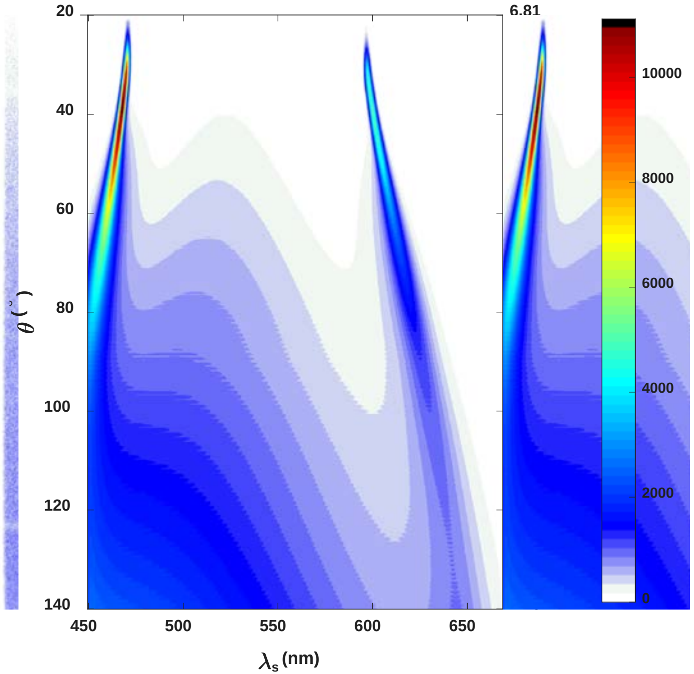
# Angularly resolved Thomson data is fit iteratively with numerical distributions

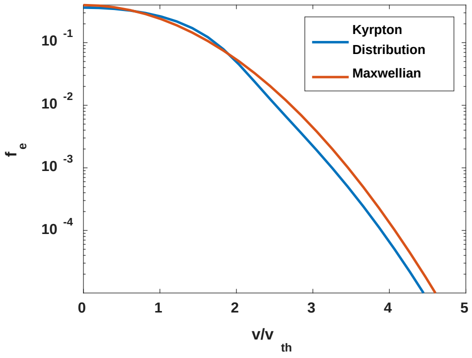
- A numerical distribution function is generated from a starting Maxwellian or super-Gaussian distribution
  - i.e. a set of amplitude values and their corresponding velocities
- Electrons are moved around in the distribution
- A spectrum and susceptibility for this new distribution is calculated numerically over the entire angular range and compared to the data
- The process is repeated until agreement is found with the data

**The result is a electron distribution which represents the data without specifying the relevant physics**

# These fits are able to reproduce the spectrum and therefore the underlying distribution



# Inverse bremsstrahlung (IB) heating is predicted to generate non-Maxwellian electron distribution functions

UR LLE

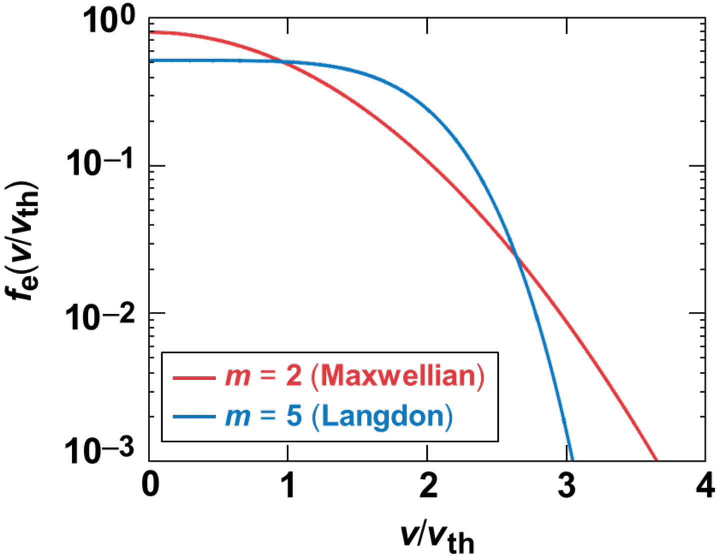
- **IB heating causes the electron distribution function to go to a fifth order super-gaussian* (Langdon Effect)**

$$f_m(x,v,t) = C_m \exp[-(v/v_m)^m]$$

$$v_m^2 = \frac{3k_B T_e}{M_e}\frac{\Gamma(3/m)}{\Gamma(5/m)} \quad \text{and} \quad C_m = \frac{n_e}{4\pi}\frac{m}{\Gamma(3/m)v_m^3}$$

- **Supergaussian order varies continuously with the Langdon parameter****

$$L = Z\left(\frac{v_{osc}}{v_{th}}\right)^2 \qquad m = 2 + \frac{3}{1+1.66/L^{0.724}}$$

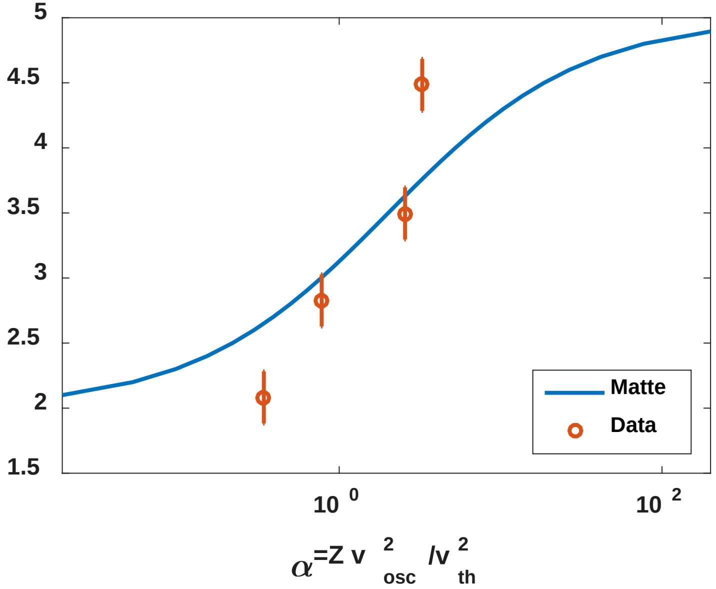



*A. B. Langdon, Phys. Rev. Lett. 44, 575 (1980).
**J. P. Matte *et al.*, Plasma Phys. Controlled Fusion 30, 1665 (1988).

# The distributions measured with angular Thomson scattering can be compared to the theoretical predictions

$$L = Z\left(\frac{v_{osc}}{v_{th}}\right)^2$$

$$m = 2 + \frac{3}{1 + 1.66 / L^{0.724}}$$




**Future work will focus on comparing the measured distribution functions to other predictions especially regarding the tails of the distribution function**

J. P. Matte *et al.*, Plasma Phys. Controlled Fusion 30, 1665 (1988).

# Non-maxwellian electron distribution functions have been measured using angularly resolved Thomson scattering

- **Collective electron plasma wave Thomson scattering is sensitive to electron velocity distributions**
- **Angularly resolved Thomson scattering allows direct inference of the electron velocity distribution and has been measured**
- **Measured distribution agree with theoretical predictions for super-Gaussian distributions**