

# CTE in ULE<sup>®</sup> Glass

2<sup>nd</sup> International Workshop on EUV Lithography  
Oct. 16 through 19 in San Francisco, California

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**Corning Incorporated**



# Defining ULE<sup>®</sup> Glass

Coefficient of Thermal Expansion (CTE)...  
 $0 \pm 30$  ppb/°C from 5-35°C

**Premium Grade ULE:** Axial CTE Range < 10 ppb/°C  
Radial CTE Range < 10 ppb/°C

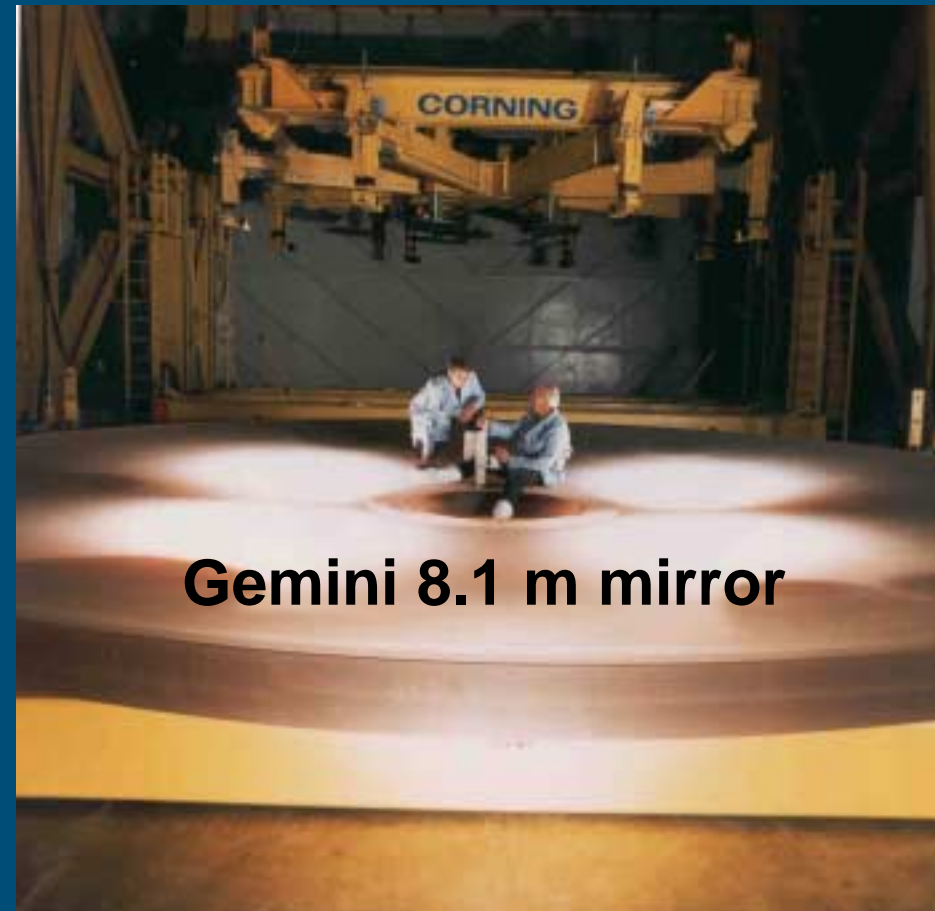
## ©Current uses:

- *precision reference standards*
- *synchrotron mirrors*
- *telescope mirrors*

## ©Evaluation of ULE:

**Glass for EUV**

- **reticles**
- **optics**

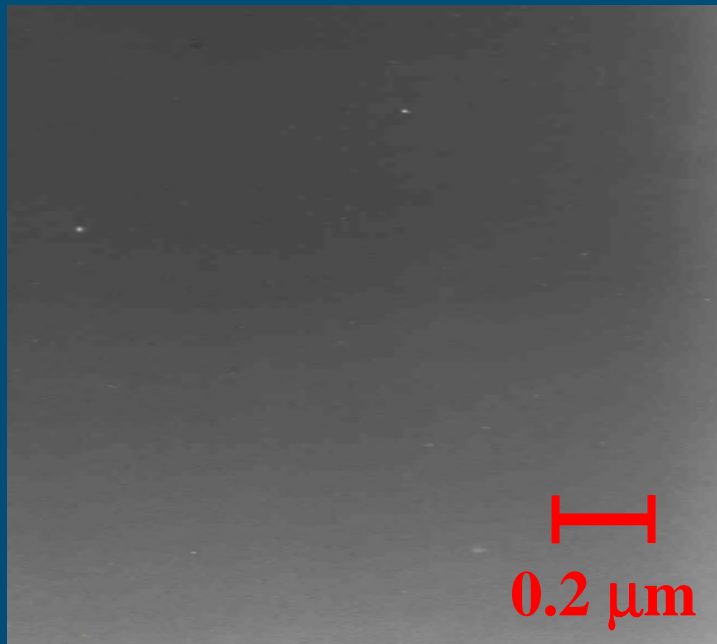


**Gemini 8.1 m mirror**

# Defining ULE<sup>®</sup> Glass

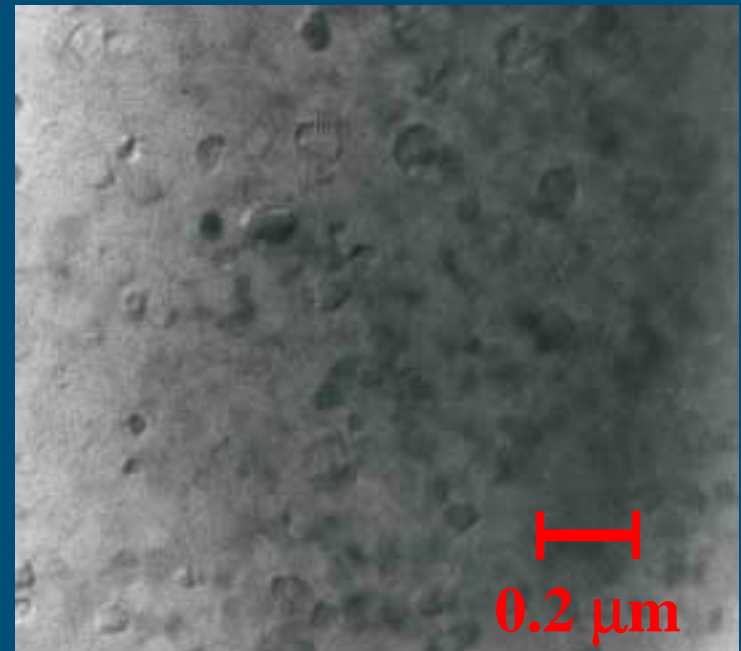
## *TEM micrographs*

ULE<sup>®</sup> Glass



Single phase: no  
crystals

Corning's low expansion  
glass ceramic



Crystalline phase  
and glass phase

# CTE Metrology

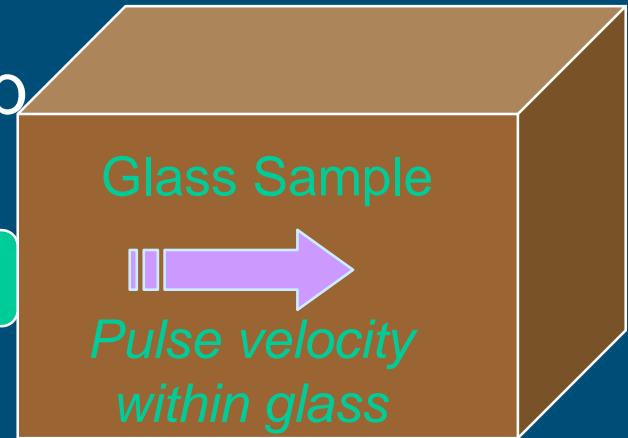
## Measurements

Measured velocities correlated to CTE\*

Ultrasonic  
Velocity  
Measured

Pulse Overlap

Pulse generator  
and detector



Velocity,  $V$ , related to properties of glass\*:

$$V = k \left[ \frac{E(1-\mu)}{\rho(1+\mu)(1-2\mu)} \right]^{1/2}$$

$k = \text{constant}$   
 $E = \text{elastic modulus}$   
 $\mu = \text{Poisson's ratio}$   
 $\rho = \text{density}$

\*Hagy, Applied Optics, 12 [7] July 1973



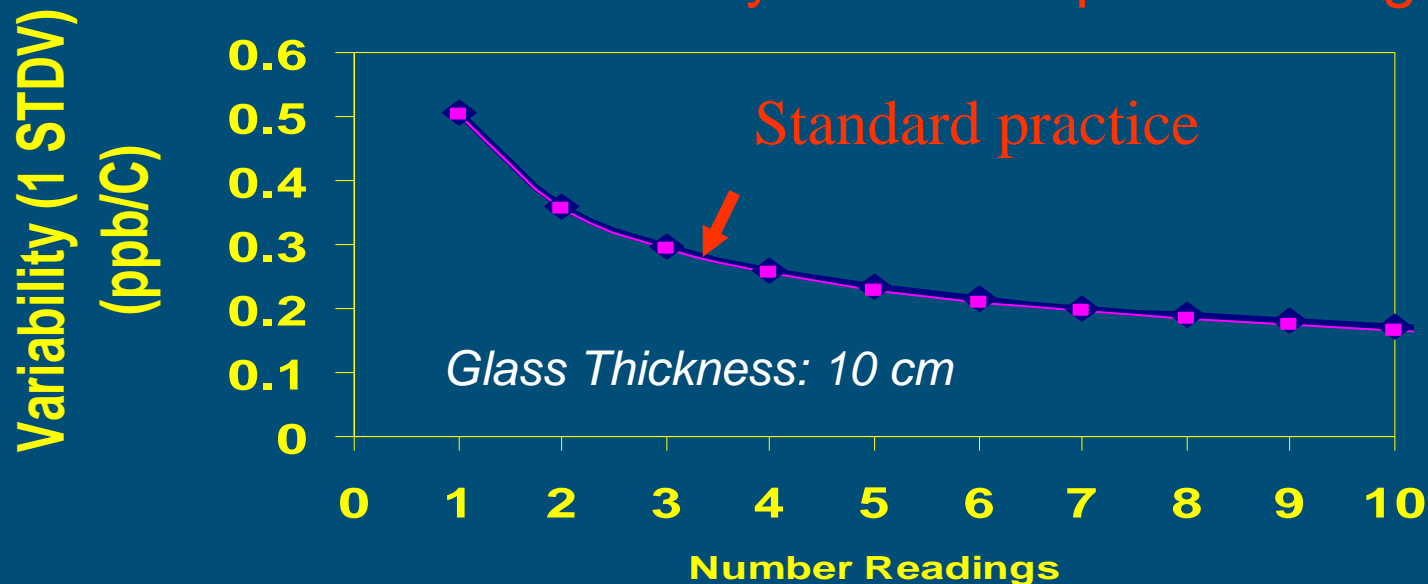
# CTE Metrology

## CTE Precision: Past Results\*

- Instrument variability

- ⊙ transit time:  $\sigma = 0.5$  ppb/C: 1 measurement
- ⊙ thickness:  $\sigma = 0.07$  ppb/C: 1 measurement

### Total Instrument Variability from Multiple Readings



\*Edwards, Bullock and Morton, SPIE, Denver Co, vol 2857, Aug 8, 1996  
L 5211 PRE

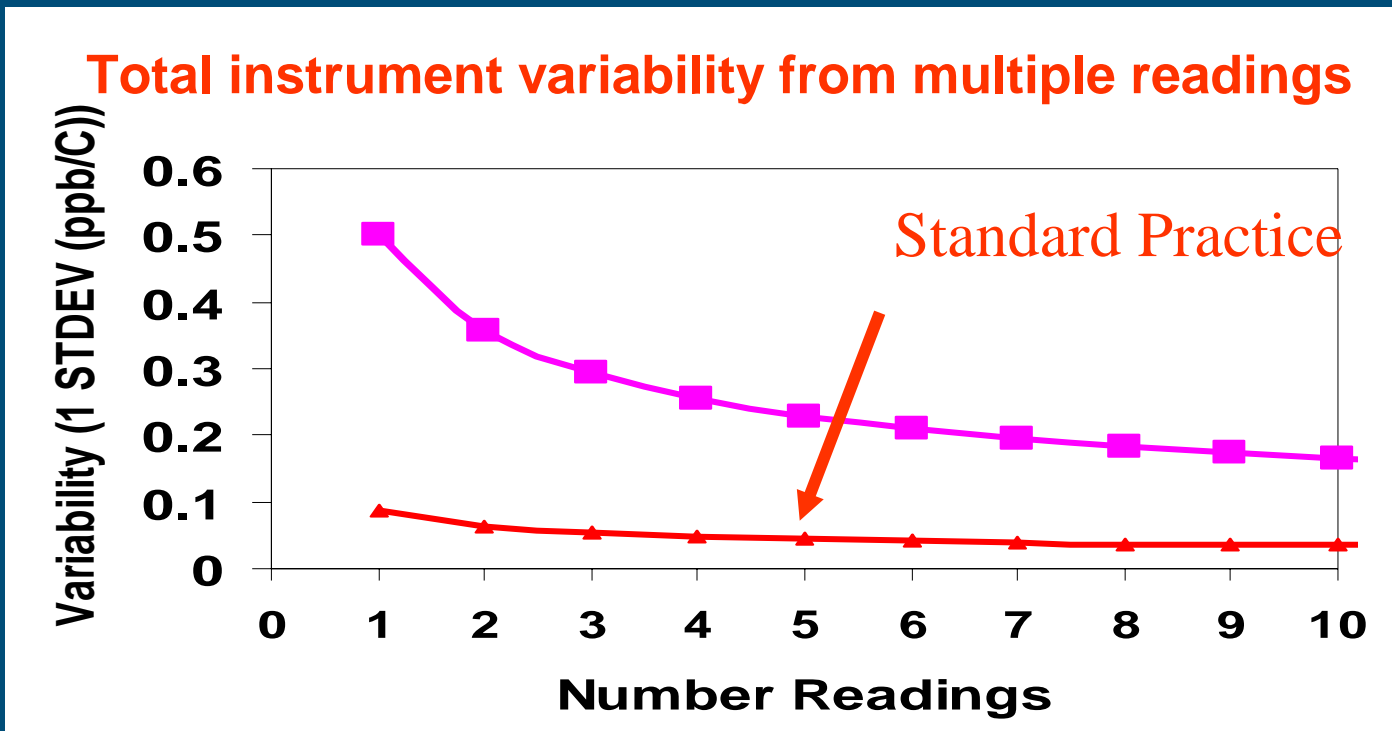


# CTE Metrology

## *Metrology improvement since 1996*

### © Year 2000 Instrument variability

- © transit time:  $\sigma = 0.085$  ppb/C: 1 measurement
- © thickness:  $\sigma = 0.031$  ppb/C: 1 measurement



**Instrument Variability reduced ~5X since 1996**

# CTE Metrology

## Current Results -- Continued

1999 Study included variability between operators  
(not previously examined)

Total CTE variability = 0.41 ppb/C (1 stdv in 10 cm glass)

- Current sources of variability
  - ⊙ Instrument small ~10%
  - ⊙ Operator-to-operator largest factor ~90%

*Current efforts targeting measurements in thinner glass (photomasks).*

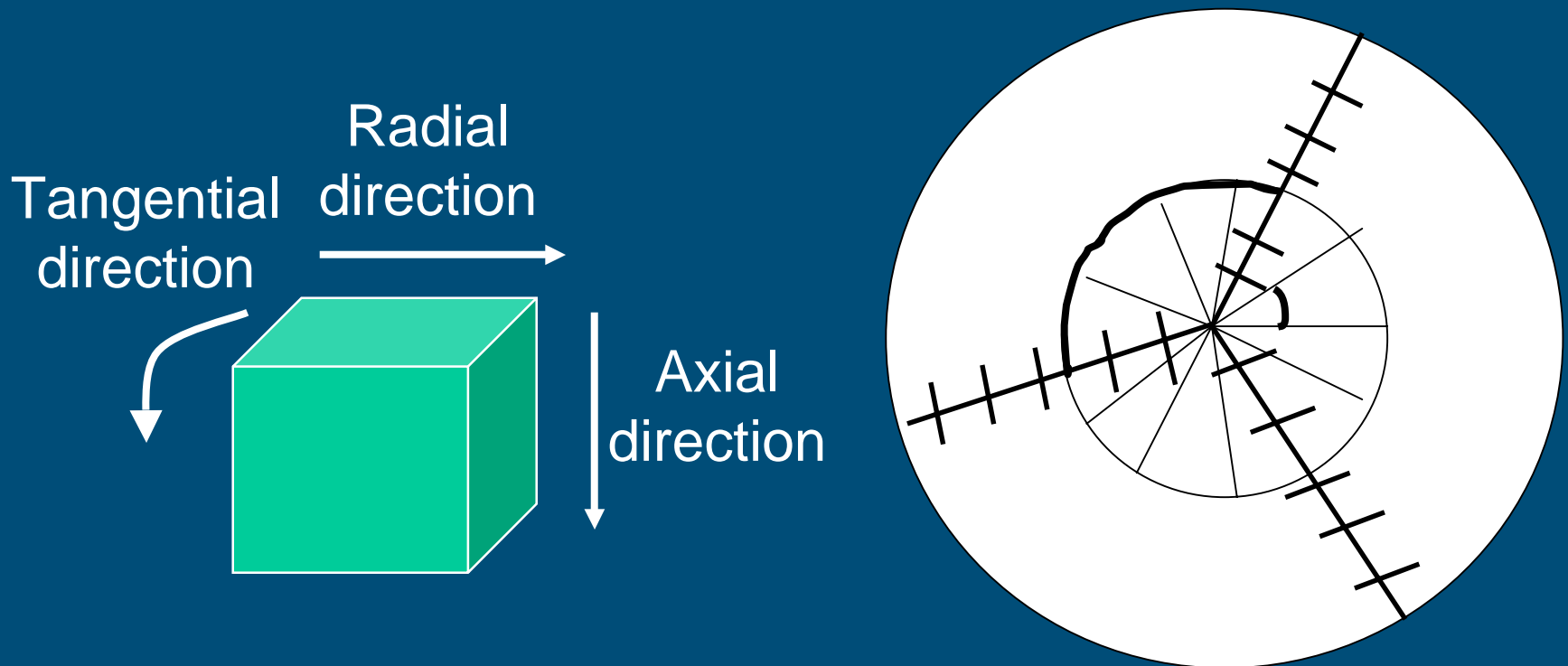
L 5211 PRE



# Glass Attributes

## Spatial CTE Variations

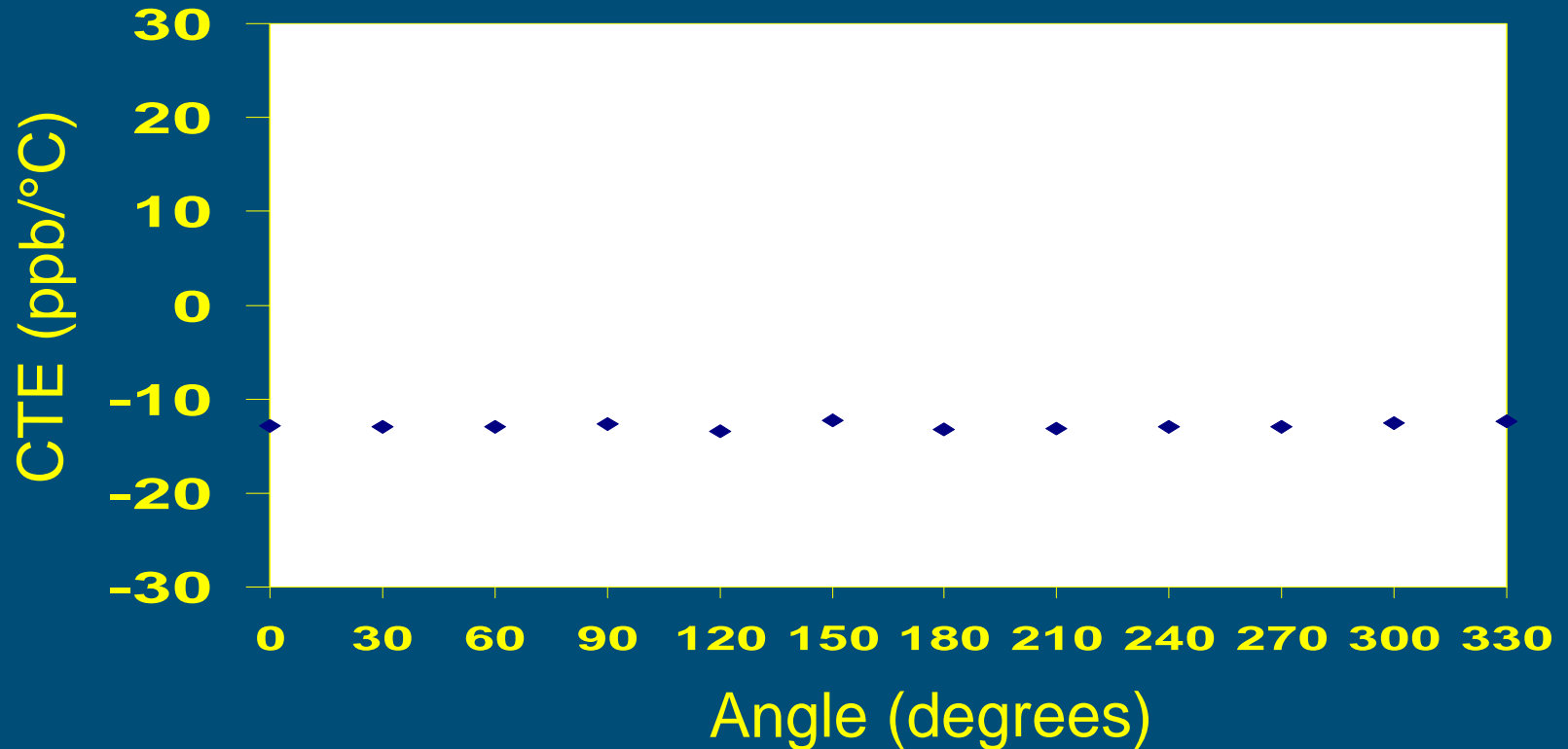
*May Impact How Glass is Utilized for EUV Applications\**



\* Roux, Meda, Spence, Applicability of ULE for EUV Lithography, this workshop.

# Spatial CTE Variations

## Examples of Premium Glass (Tangential variations)

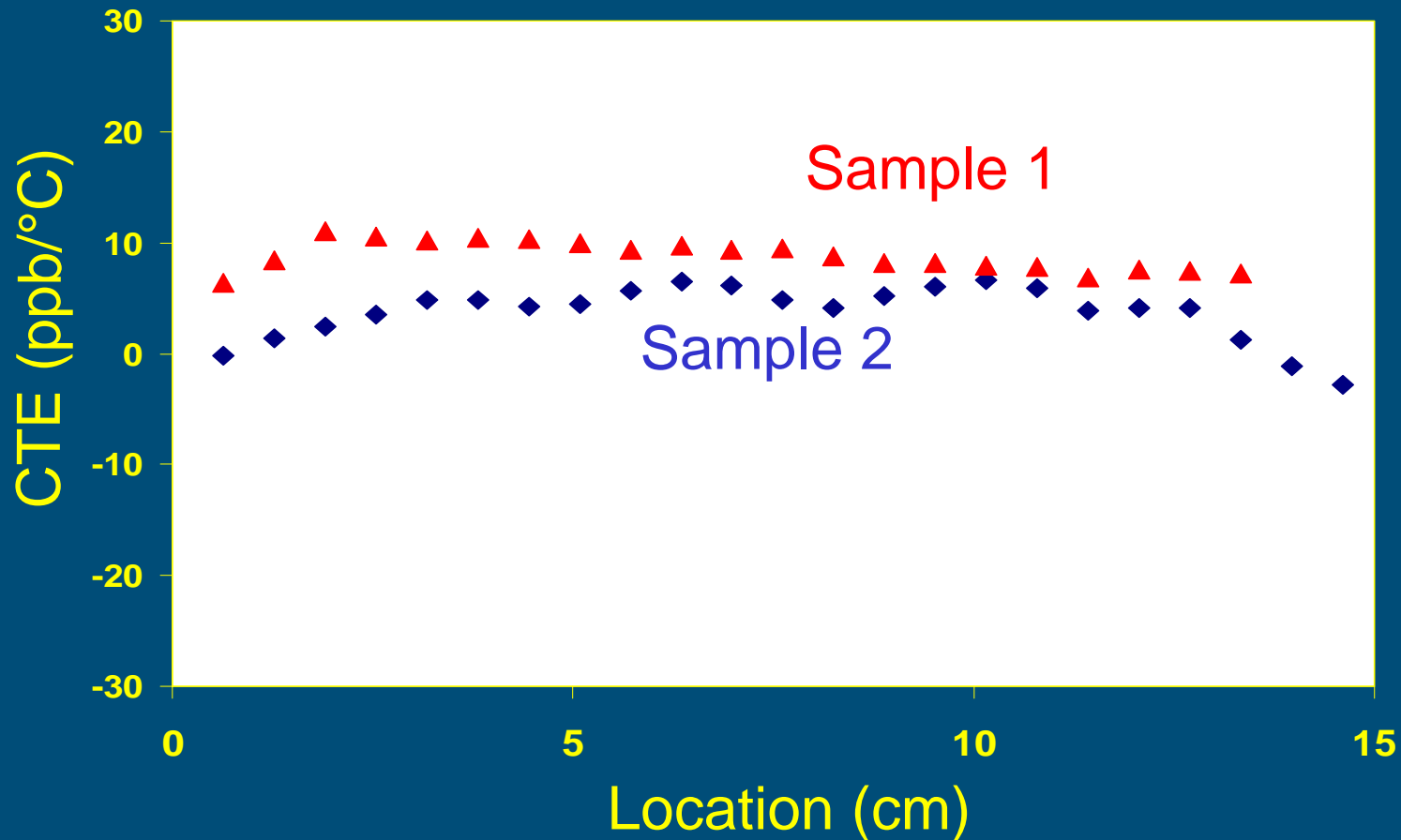


**Good tangential symmetry: 0.4 ppb/C (1 stdev)**



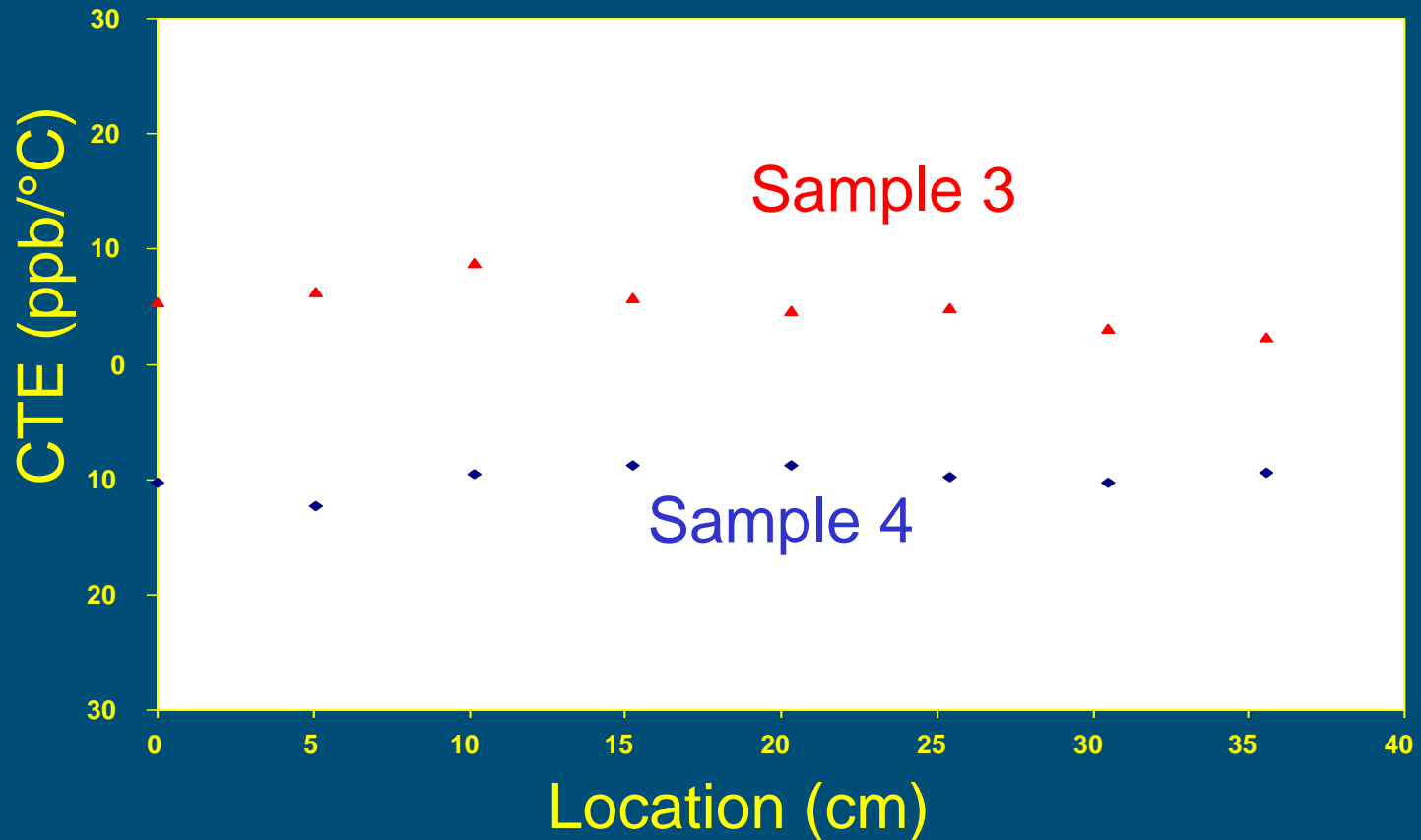
# Spatial CTE Variations

## Examples of Premium Glass (Axial Variations)



# Spatial CTE Variations

## Examples of Premium Glass (Radial Variations)



# Conclusions

- Instrument Variability reduced ~5X since 1996
- Total CTE variability = 0.41 ppb/°C (1 stdv in 10 cm glass)
  - ~10% from instrument
  - ~90% procedural/operator
- **Good tangential symmetry: 0.4 ppb/°C (1 stdev)**



# Future Work

- Improve precision of metrology
- *Current efforts targeting measurements in thinner glass (photomasks).*



# Acknowledgements

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