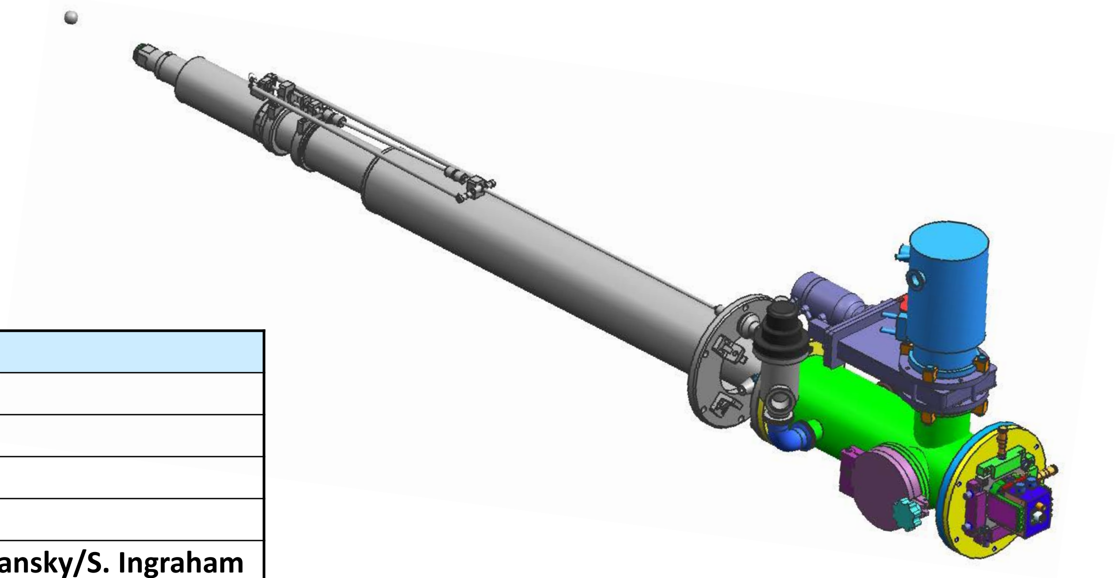
A Framed Kirkpatrick-Baez X-Ray Microscope on OMEGA (KBFRAMED)

16-image x-ray optical assembly

KBFRAMED x-ray microscope/framing camera interface



Project Team	
Principal Investigator	F. J. Marshall
Instrument Specialist	R. Bahr
Experimental Operations	D. Neyland
Mechanical Engineering	D. Guy/M. Shoup
Controls Engineering	J. Konzel/V. Kobilansky/S. Ingraham
System Engineering/PM	R.B. Brannon

Summary

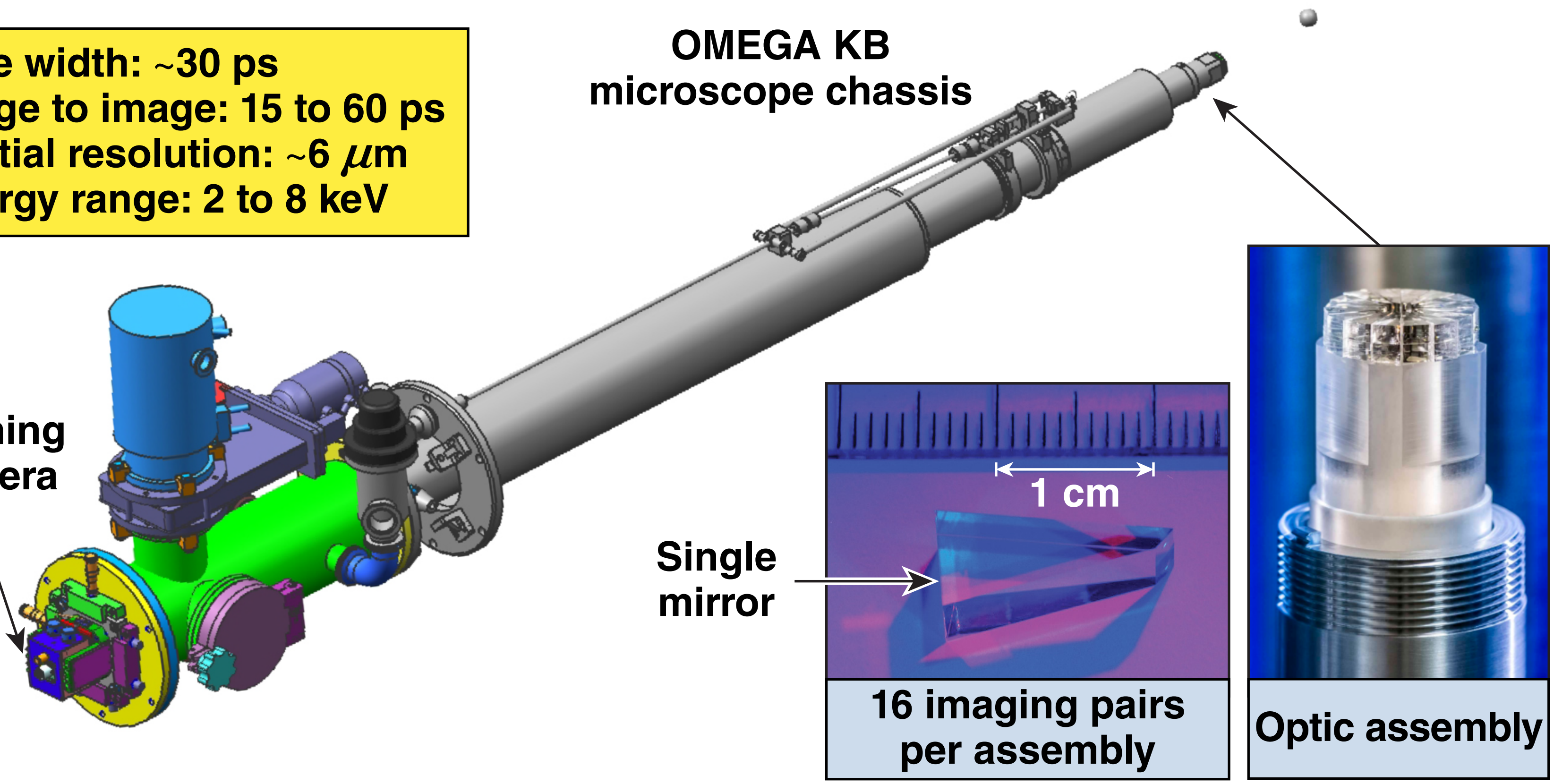
Time-resolved x-ray imaging of cryogenic target-core emission provides improved estimates of bang time, burnwidth, and peak core pressure

- Cryogenic DT target-implosion cores are imaged on OMEGA by a combination of a high-speed framing camera coupled to a pinhole array and a 16-image framed x-ray microscope (KBFRAMED)
- The time history of the core x-ray emission determined by the high-speed framing-camera pinhole array gives absolute values of the bang time and burnwidth (with ~5ps accuracy)
- The core pressure is inferred from the measured core size, ion temperature, neutron yield, and burnwidth

KBFRAMED is a 16-channel Kirkpatrick–Baez (KB) x-ray microscope that provides time-resolved images of the core around stagnation

UR LLE

Gate width: ~30 ps
Image to image: 15 to 60 ps
Spatial resolution: ~6 μm
Energy range: 2 to 8 keV

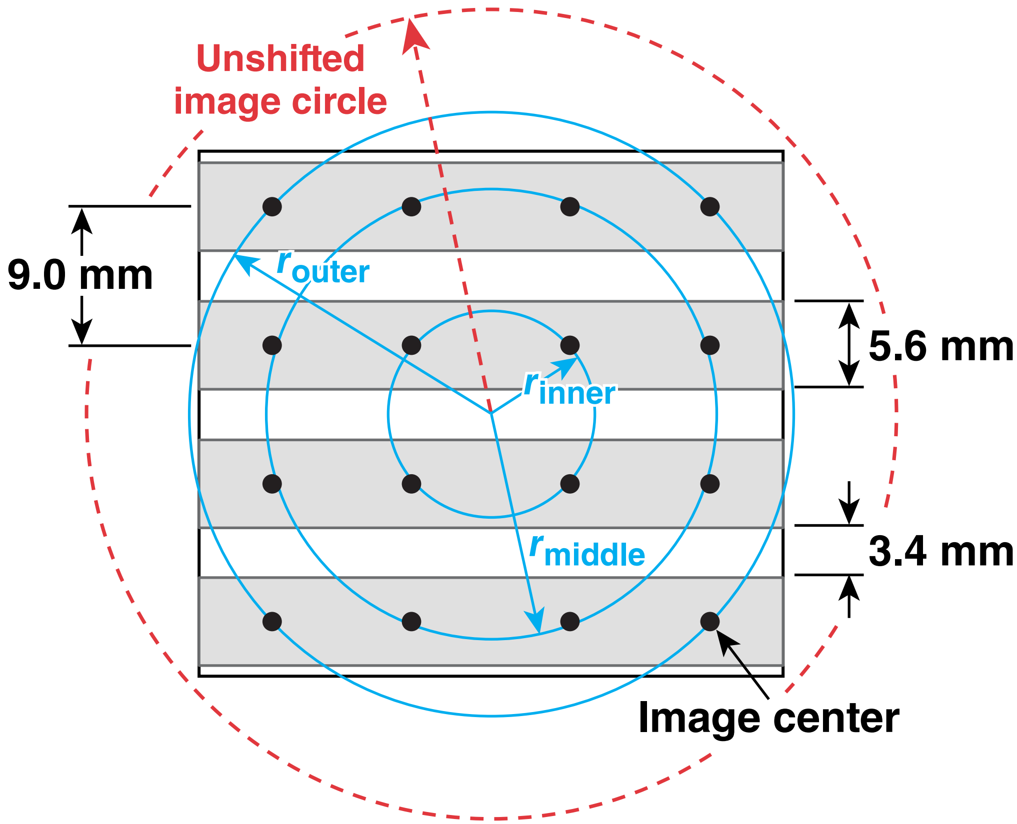


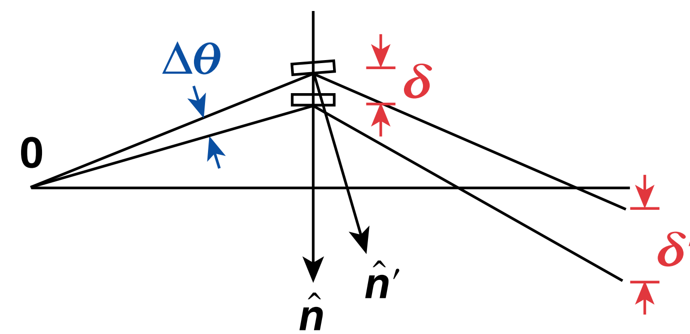
E22996b

F. J. Marshall, J. A. Oertel, and P. J. Walsh, Rev. Sci. Instrum. 75, 4045 (2004).

Mirror repositioning is required to make compact KB mirrors compatible with the four-strip framing camera

Four-strip framing camera schematic





For M = 12

Mirror pair	ϕ (°)	r (mm)	$\Delta\theta_{pitch}$ (°)	$\Delta\theta_{roll}$ (°)
r_{outer}	45	4.27	0.417	0
r_{middle}	±22.5	4.63	0.481	0
r_{inner}	0	5.40	0.724	0.059

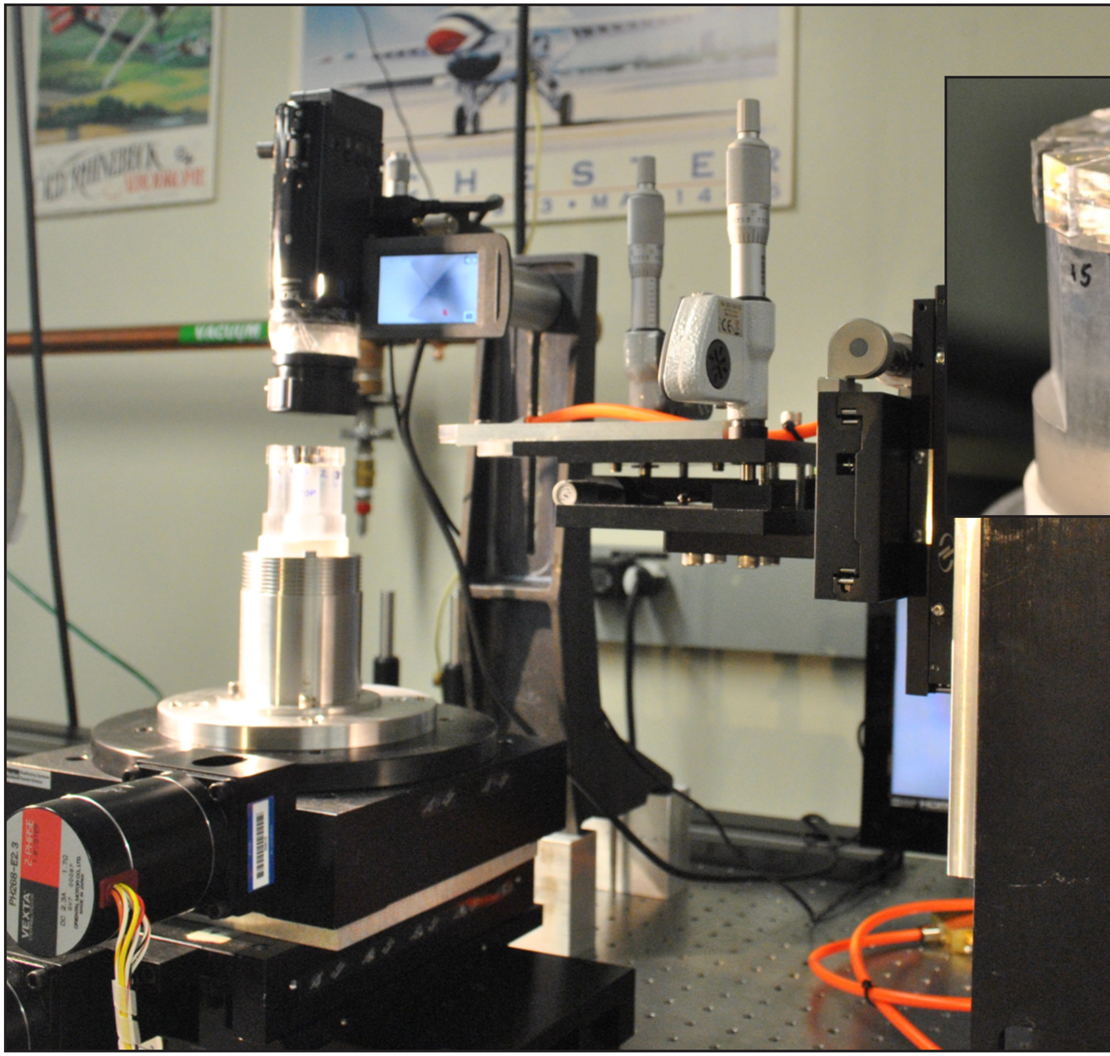
Positions accurate to 10 μm
Tilts accurate to 10 arcsec

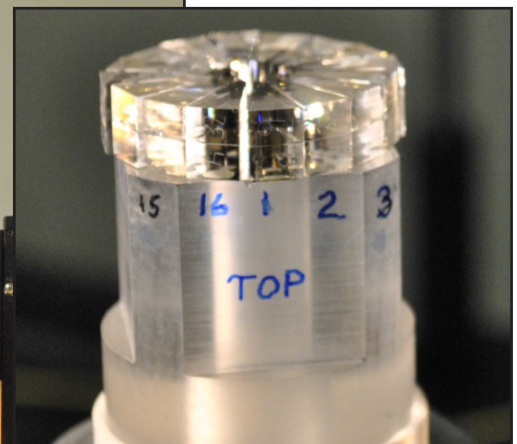
E21102a

F. J. Marshall, Rev. Sci. Instrum. 83, 10E518 (2012).

Assembly and testing of KBFRAMED x-ray optic was accomplished in the LLE x-ray laboratory

UR LLE





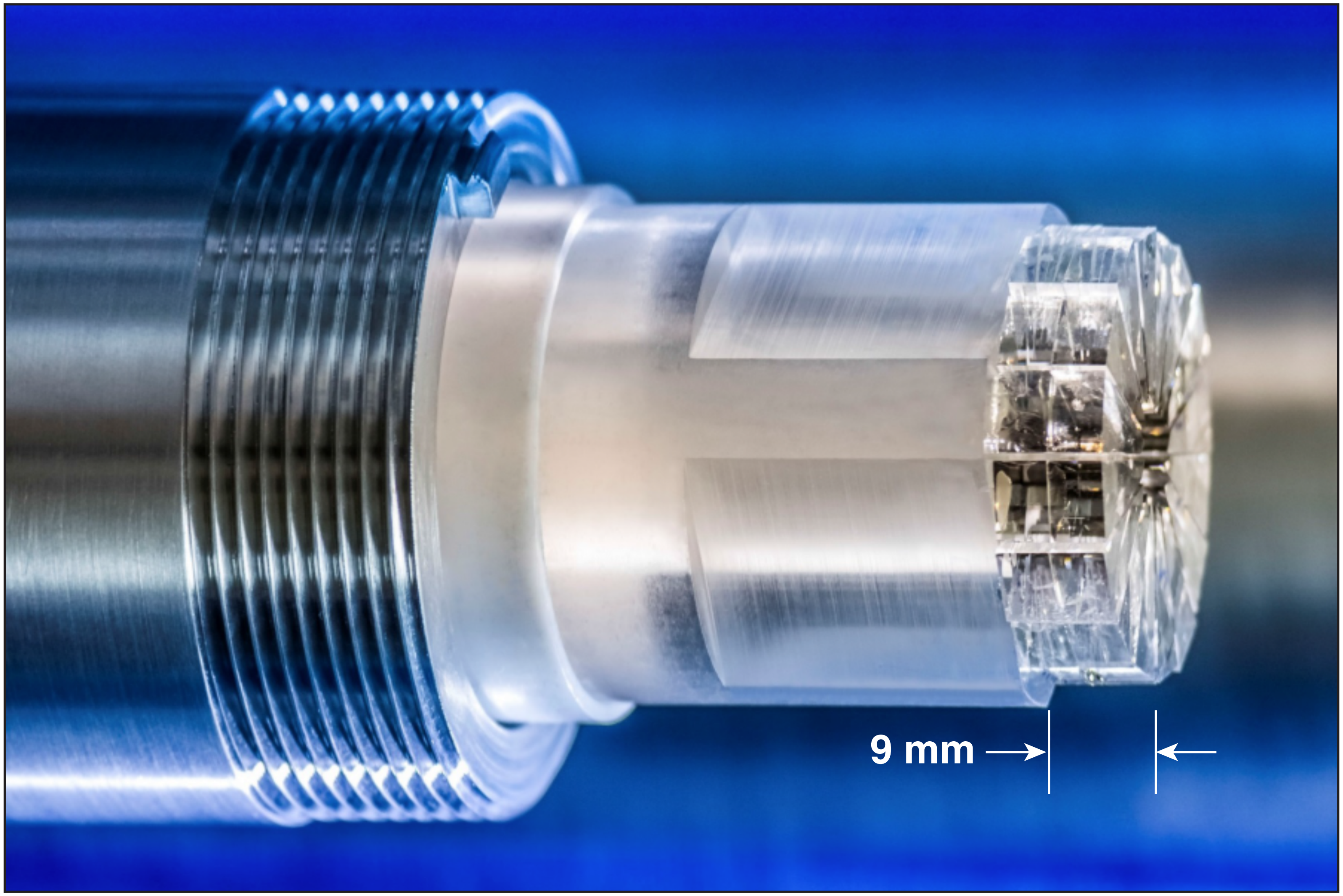
Final assembly

Three-axis base positioner accuracy: *x*, *y*: 2.54 μm
φ: 0.01°

Six-axis mirror positioner accuracy: *x*: 2.54 μm
***y*, *z*: 1 μm**
roll, pitch, yaw: 2.3 arcsec

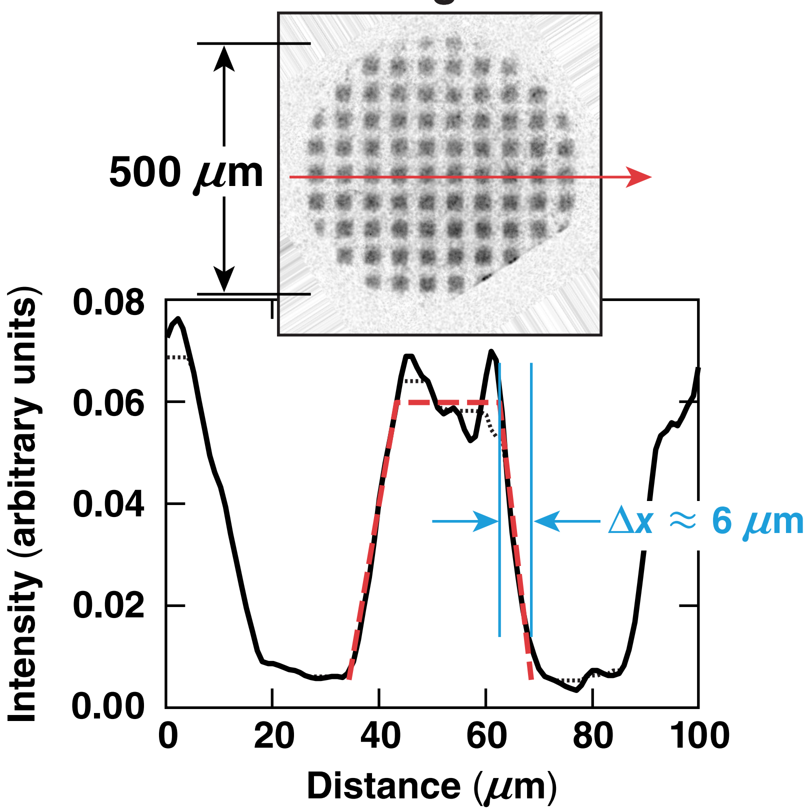
E24418

The KBFRAMED x-ray optic consists of 16 mirror pairs with images aligned to a high-speed framing camera



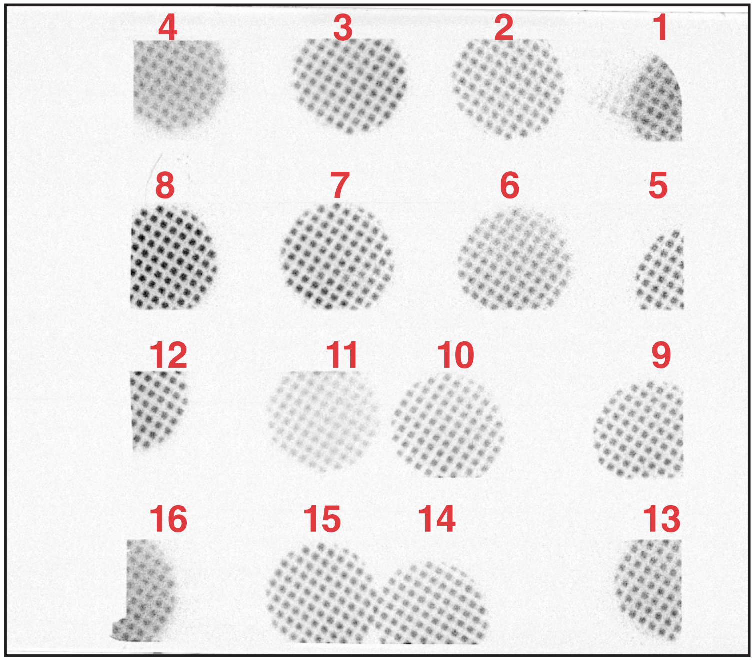
E24419

KBFRAMED optic magnification and framed resolution have been measured using an x-ray backlit grid on OMEGA



M = 12 with 6-μm resolution

KBFRAMED OMEGA shot 76806

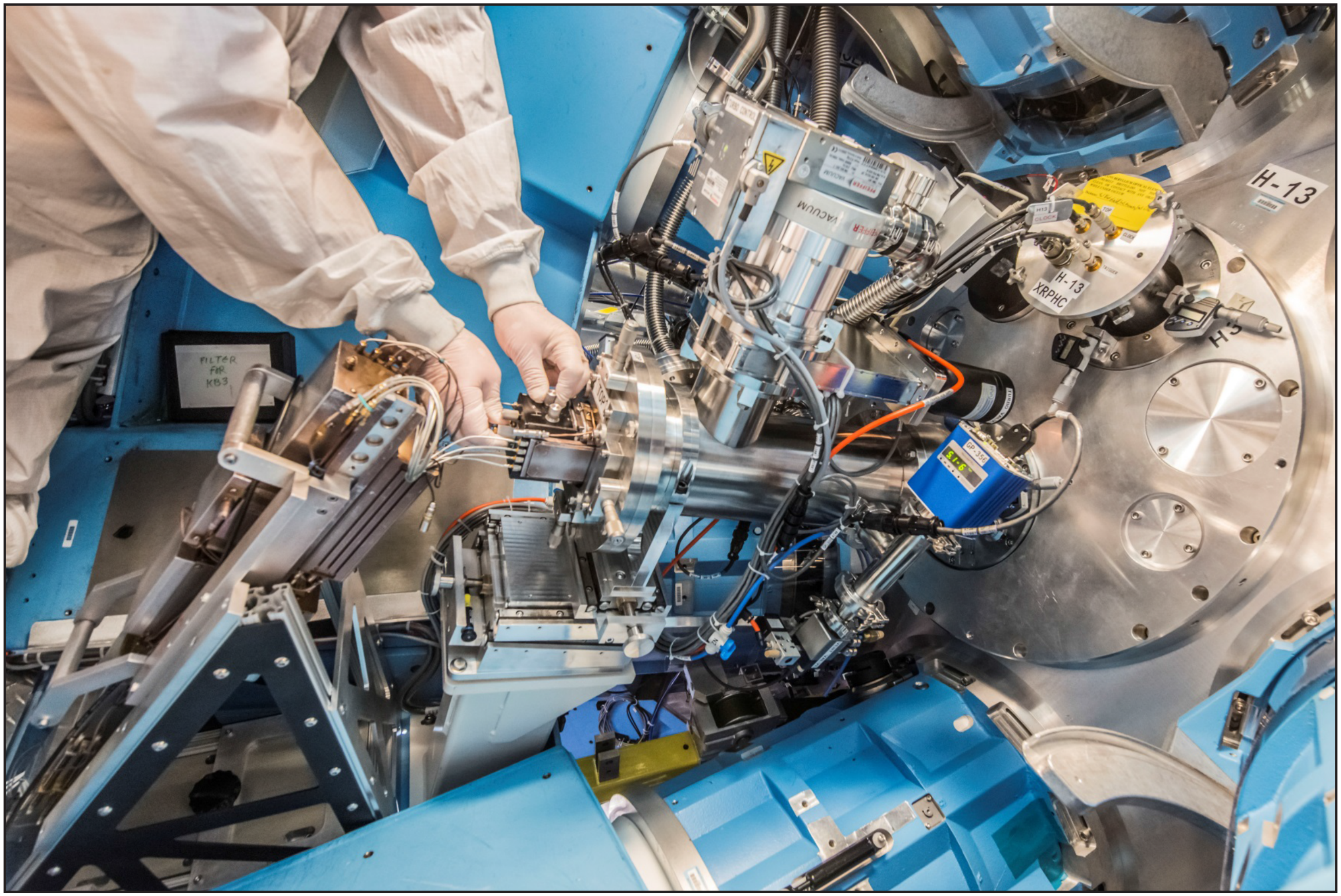


M = 12.0 within 1%
Resolution (FWHM* of the PSF**) ≈ 6 μm
varies from image to image

*FWHM: full width at half maximum
**PSF: point spread function

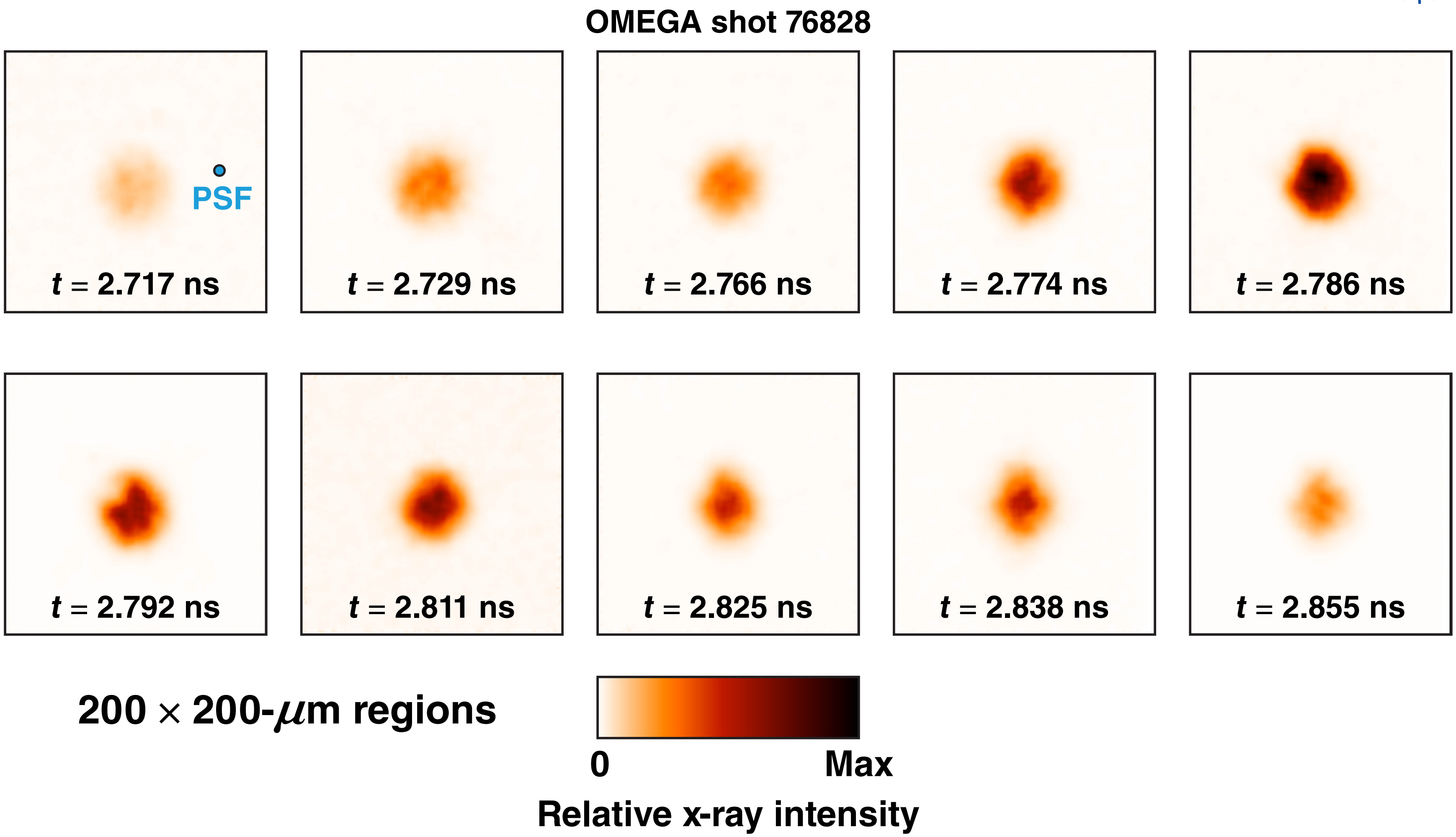
E23991

The KBFRAMED fixed port installation allows the framing-camera electronics and film back to be operated in air



E24508

KBFRAMED records an image (Δt = 30 ps) of the stagnating core every ~15 ps in the 4- to 8-keV photon-energy range



E24014a

The detailed cryogenic core hot-spot evolution is seen every ~15 ps with KBFRAMED

OMEGA shot 77064
KBFRAMED x-ray images

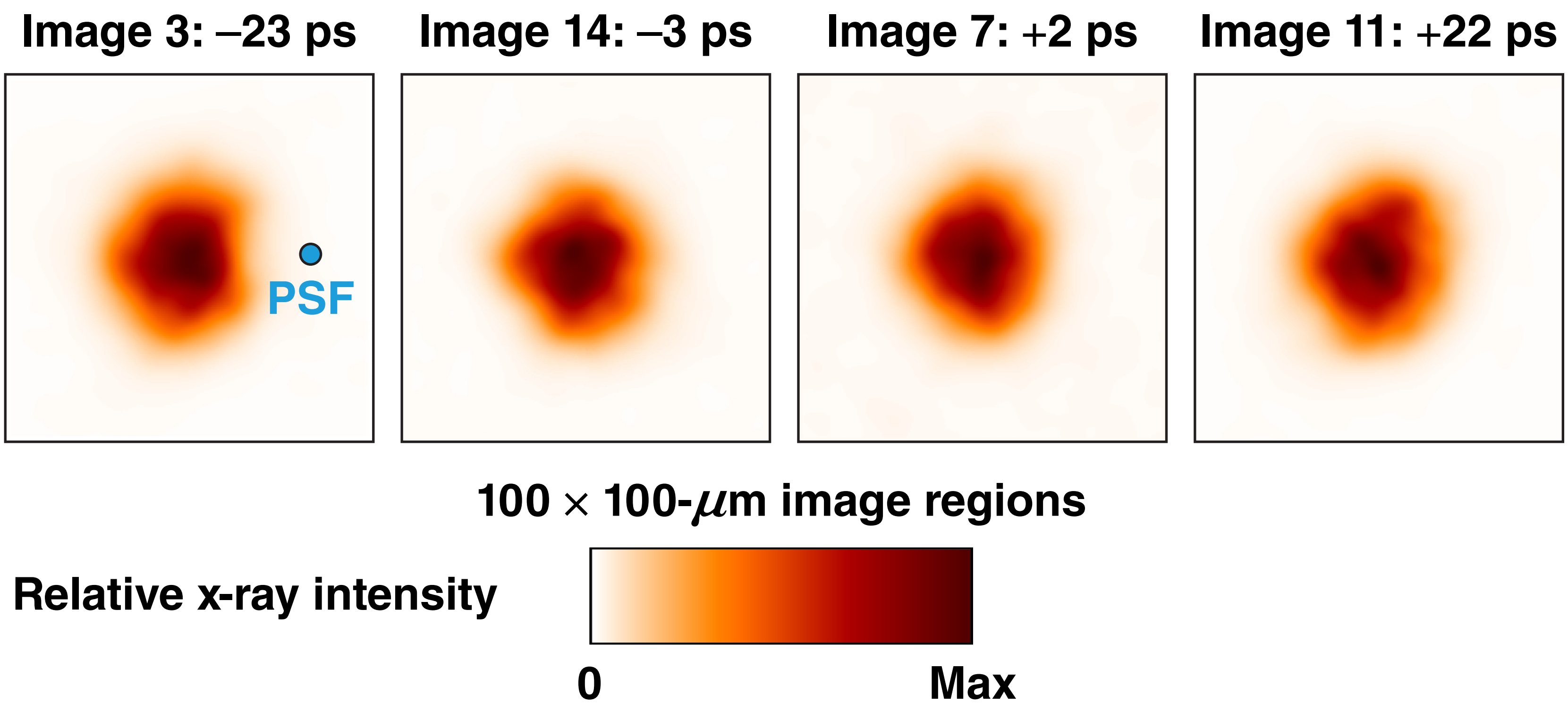


Image-to-image timing is precisley determined from position and the use of measured cables (±2 ps).

E24420

The cryogenic-target implosion, hot-spot size is determined from an elliptical super-Gaussian fit

UR LLE

OMEGA shot 77064 KBFRAMED core image near peak compression

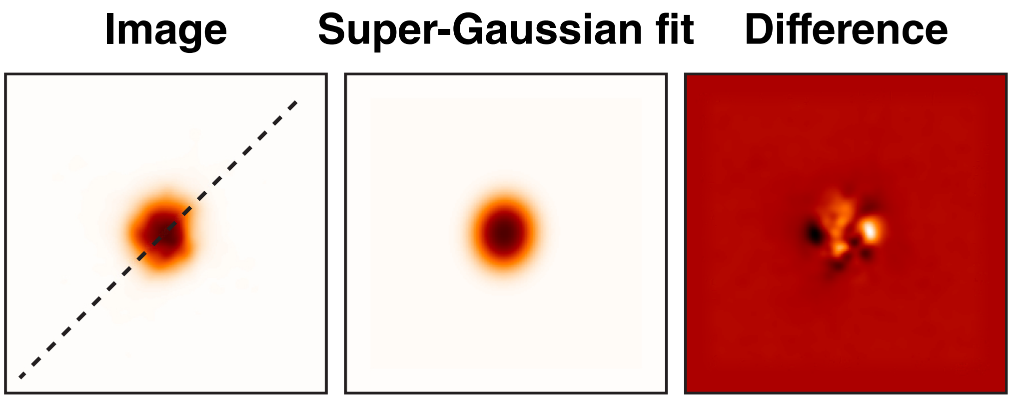
$$I = I_0 \times \exp\left[-\frac{(x-x_c)^2}{a^2} - \frac{(y-y_c)^2}{b^2}\right]^{n/2}$$

$$I^* = I \otimes PSF\,(x, y)$$

$$R_{1/e} = \sqrt{ab}$$

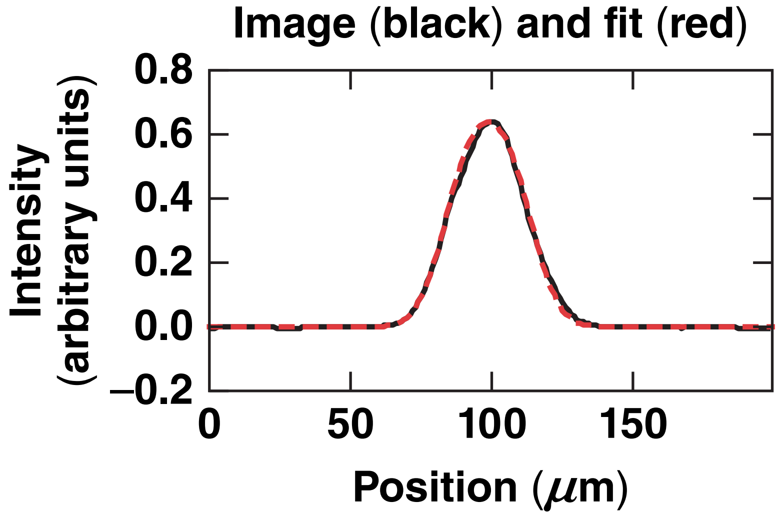
$$R_{17} = (1.77)^{1/n} \times R_{1/e}$$

- Fit is to super-Gaussian Convolved with PSF (I^*)
- For KBFRAMED: PSF ≈ 6 μm FWHM Gaussian



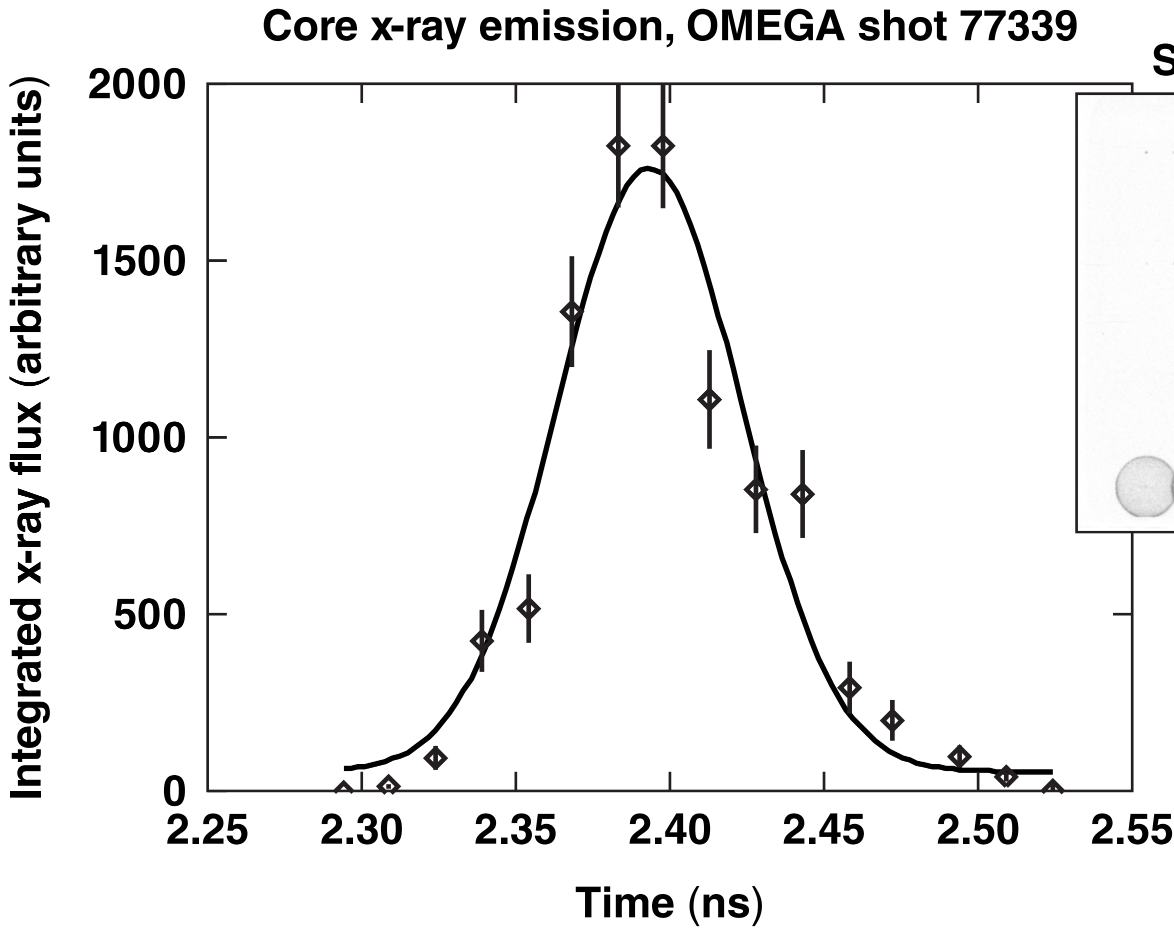
Lineout indicated by dotted line

200 × 200 μm regions

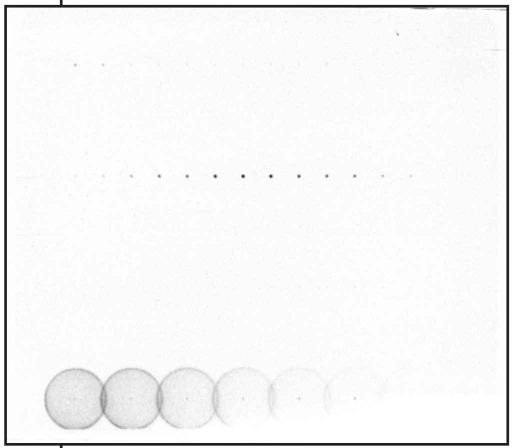


E24509

The pinhole array framing-camera images determine the absolute x-ray bang time and burnwidth



SFC3* with 46-pinhole array



Best fit:
I_0 = 1710
t_{bang} (exp) = 2.393±0.005 ns
t_{bang} (1-D) = 2.38 ns
} From first picket
FWHM (exp) = 64±5 ps
FWHM (1-D) = 64 ps

Flat fielded by framing constant-emission x rays.

E24421

*SFC3: Sydor framing camera

The hot-spot pressure and volume are inferred from the neutron yield, burnwidth, ion temperature, and core size

$$\langle P \rangle^* = \sqrt{\frac{Y_n / 10^{16}}{\xi(T) V_{hs} \tau}}, \text{ where } \xi(T) \equiv \frac{1}{V_{hs}} \int V_{hs} \frac{\langle \sigma v \rangle}{T^2} dV \text{ and } V_{hs} \approx \frac{4\pi}{3} R_{17\%}^3$$

<u>OMEGA cryogenic target shot 77066</u>

R_{17} = 22.0±0.4 μm (framed images + KB microscope images)
$Y_n = 4.0 \times 10^{13}$
τ = 63±5 ps (x rays), 67±5 ps (neutrons), 66 ps (1-D)
T_i = 3.2±0.4 keV
$\langle P \rangle$ = 56±7 Gbar
$\langle P \rangle_{1\text{-D}}$ = 90 Gbar

*C. Cerjan, P. T. Springer, and S. M. Sepke, Phys. Plasmas <u>20</u>, 056319 (2013); R. Betti *et al*., Phys. Plasmas <u>17</u>, 058102 (2010).

E23702a

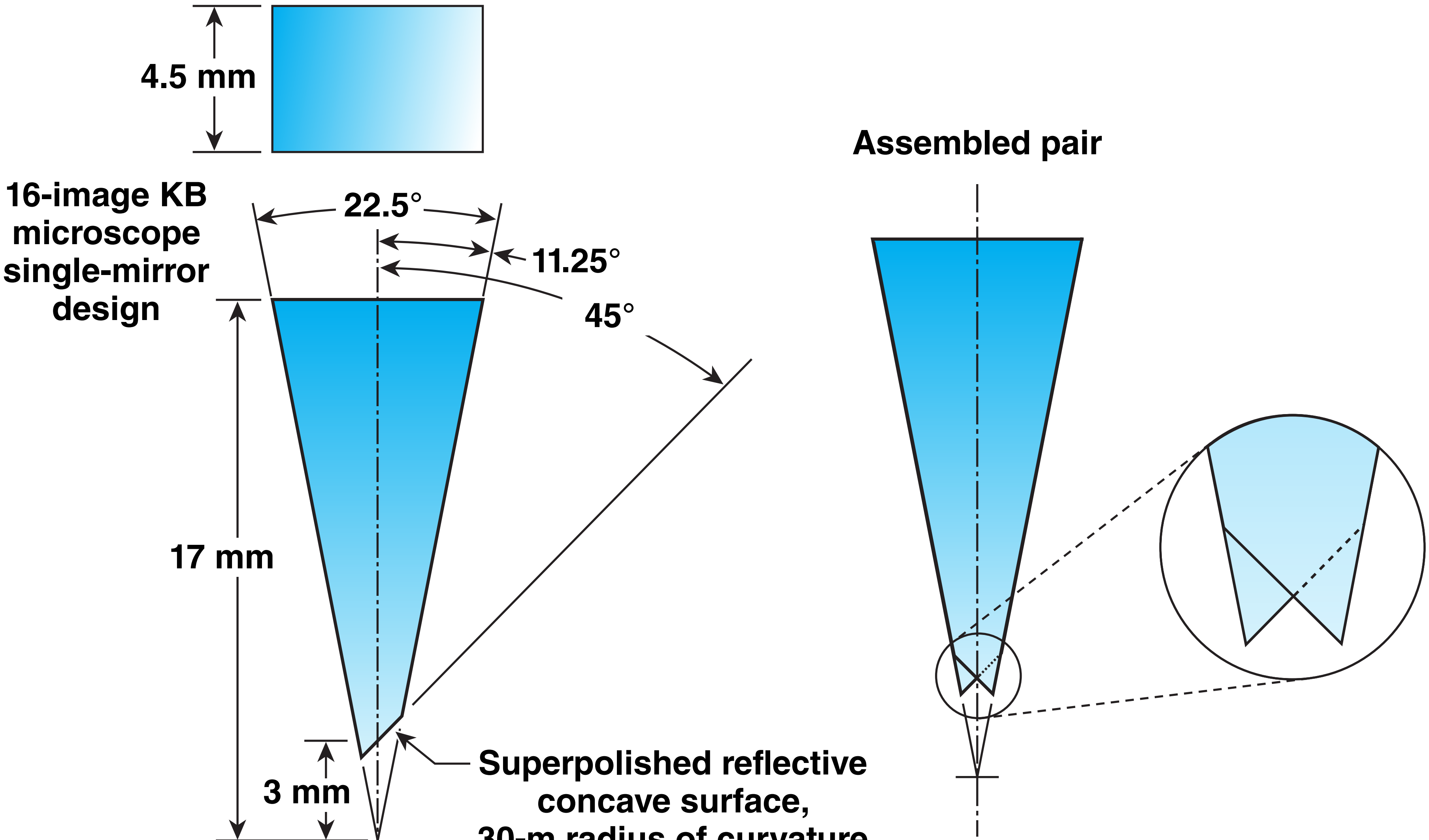
Summary

Time-resolved x-ray imaging of cryogenic target-core emission provides improved estimates of bang time, burnwidth, and peak core pressure

UR LLE

- Cryogenic DT target-implosion cores are imaged on OMEGA by a combination of a high-speed framing camera coupled to a pinhole array and a 16-image framed x-ray microscope (KBFRAMED)
- The time history of the core x-ray emission determined by the high-speed framing-camera pinhole array gives absolute values of the bang time and burnwidth (with ~5ps accuracy)
- The core pressure is inferred from the measured core size, ion temperature, neutron yield, and burnwidth

All mirror components are the same, simplifying manufacture and assembly



E12931a

The off-axis resolution of a KB microscope is limited by spherical aberration and diffraction

Single mirror focus*:

$$\frac{1}{p} + \frac{1}{q} = \frac{2}{R \sin i}$$

Primary spherical aberration and obliquity of field**:

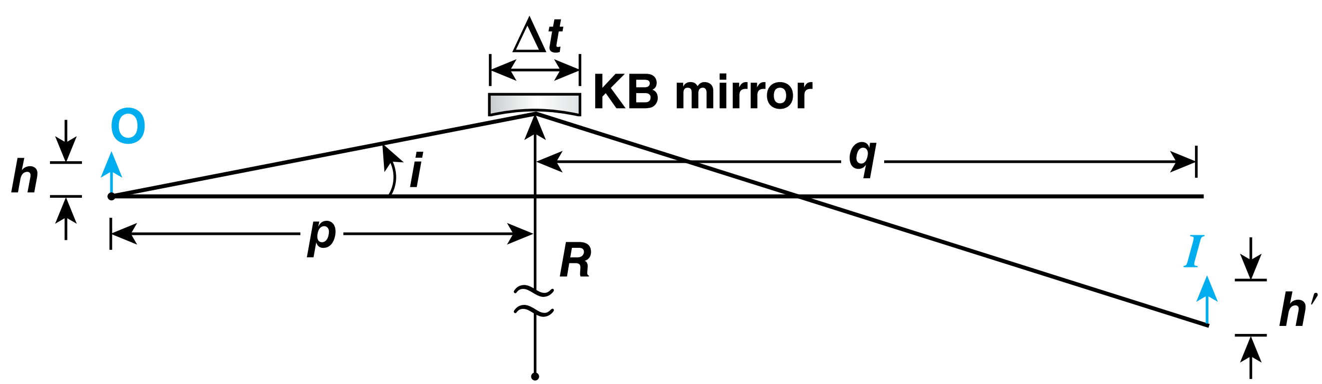
$$\delta_{ab} = \left(\frac{3M + 7}{2M + 2}\right) \frac{(\Delta t)^2}{R} + 2h \frac{\Delta t}{R \sin i}$$

Diffraction:

$$\delta_{diff} \approx \frac{\lambda p}{\Delta t \sin i}$$

Total aberration and diffraction:

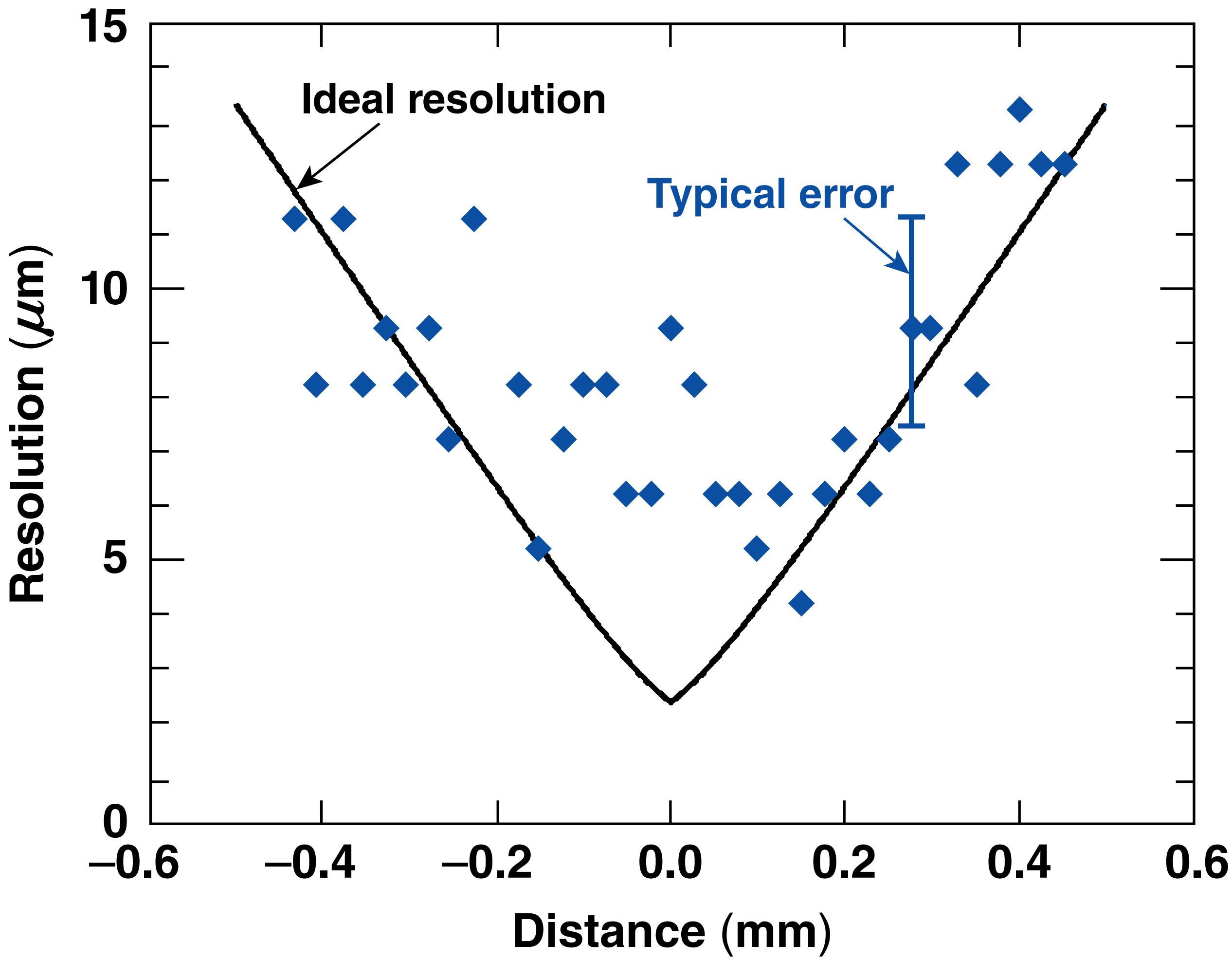
$$\delta = \sqrt{\delta_{diff}^2 + \delta_{ab}^2 (h)}$$



*P. Kirkpatrick and A. V. Baez, J. Opt. Soc. Am. 38, 766 (1948).
**J. F. McGee and J. W. Burrows, in *X-Ray Imaging*, edited by R. C. Chase and G. W. Kuswa (SPIE, Bellingham, WA, 1977), Vol. 106, pp. 107-112.

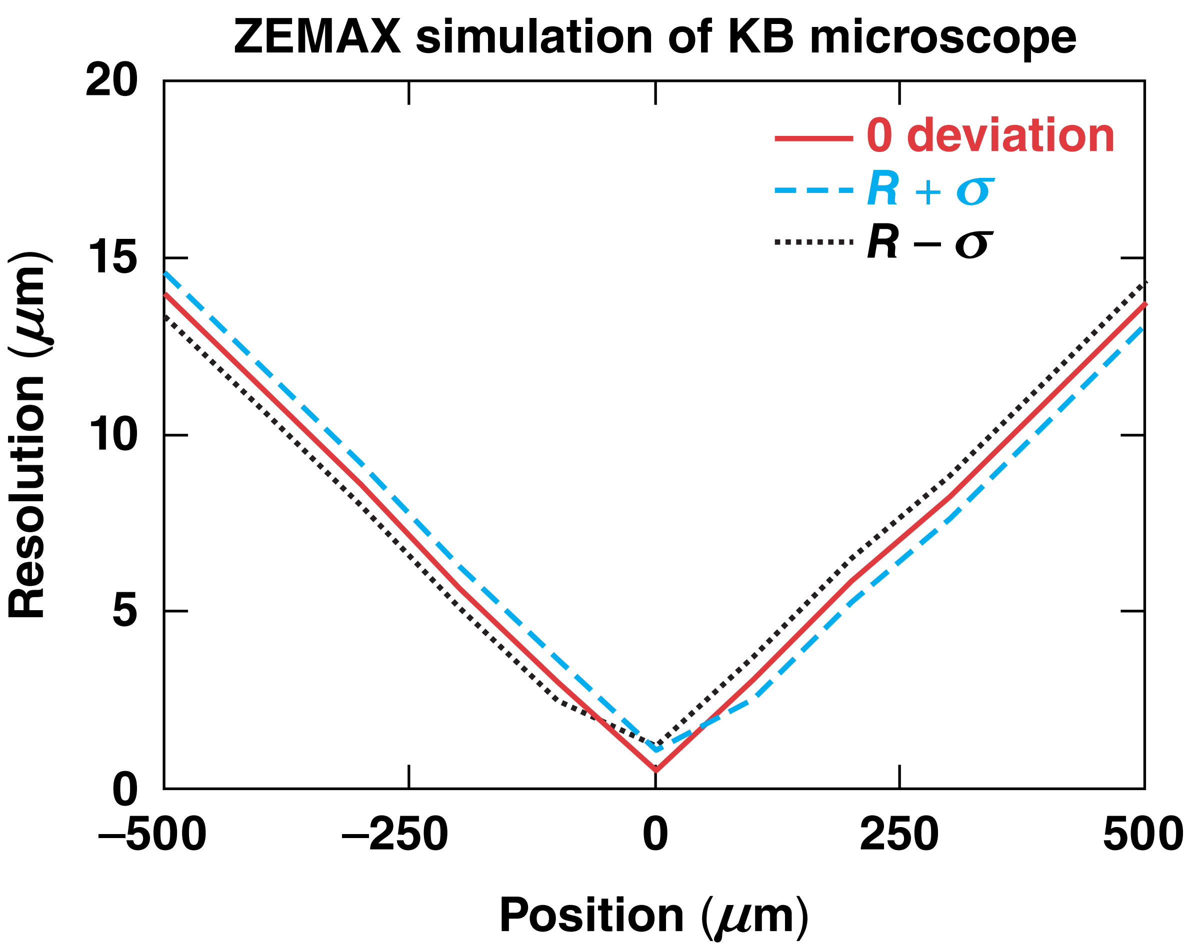
The new KB optic has a best resolution of ~5 μm with better than 10 μm over a 1-mm field of view

UR LLE



E8626b

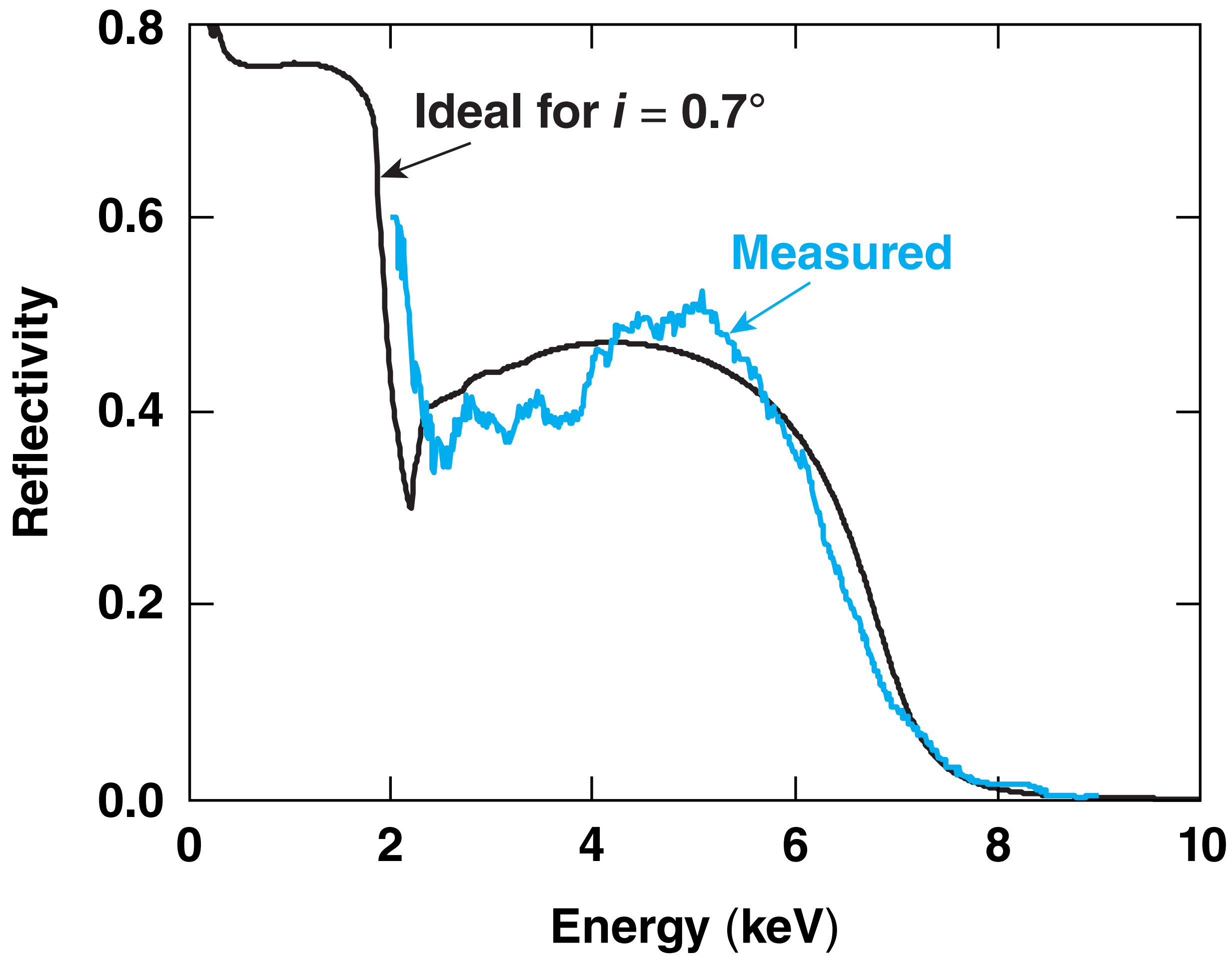
Ray tracing indicates that curvature variation will have a small effect on the spatial resolution



R_{ideal} = 25.6 m
M = 13.6
σ_R = 0.3 m
(measured variation of four mirrors)

E12934a

The measured reflectivity of an individual Ir-coated KB mirror pair is close to the ideal predicted reflectivity



E21090