Kirkpatrick-Baez Microscope for NIF

Diagnostic Workshop, Los Alamos 2015

L. A. Pickworth & the KBO team

LLNL-PRES-XXXXXX
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Lawrence Livermore National Laboratory

The Kirkpatrick- Baez Microscope Effort 2012 - 2015

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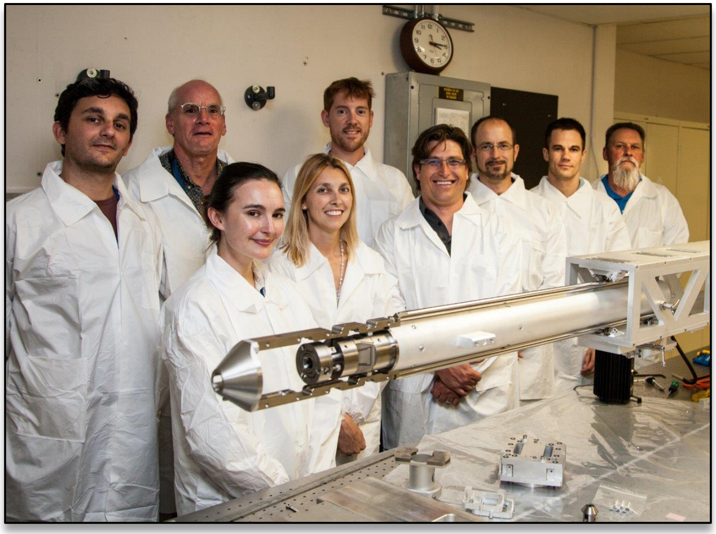
	- P. Bell	- N. Izumi
	- S. Hau-Riege	

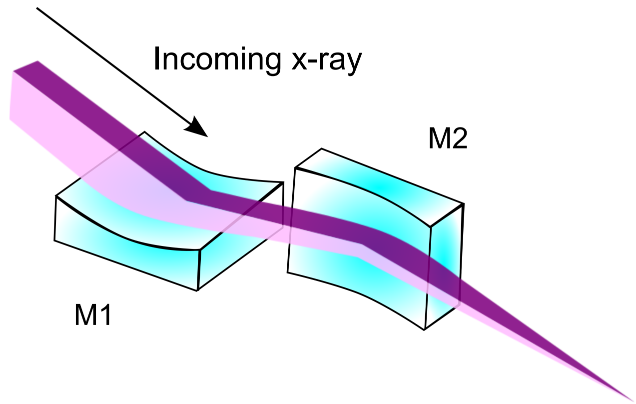
Facility Collaborations:
LLNL
QED
LBNL
Advanced Light Source
NSTec



NIF is building an X-ray optic imaging system to improve S/N, resolution and energy selectivity

- Current pinhole imaging systems do not provide sufficient resolution, throughput or energy selectivity for numerous experiments conducted at NIF
- We have designed, built and fielded a prototype Kirkpatrick-Baez imaging system operating at ~10±1.5keV
- The KBO is in a modular design that allows energy selectivity by ONLY changing the mirror coating
- All aspects of the project proved challenging, and required innovative solutions and accurate alignment:
  - Multilayer coating and characterization
  - Optical alignment of 4 independent imaging channels
  - Pointing and insertion of the diagnostic to the target
  - Exchangeability of mirror packs
- First images have been obtained from NIF at 10.2 keV

X-ray Optic Motivation: An alternative to Pinhole Imaging for ICF experiments on NIF



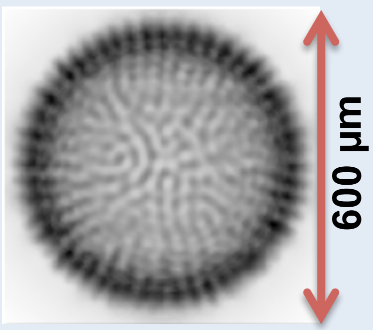
- Better resolution
- <10μm FWHM over full field of view
- Better throughput to the detector
  - Large solid angle (2.4e-7sr compared to ~2e-8sr), good reflectivity
- Control over spectral content, tailored to experiment
  - Experiment specific Multilayer Mirror Coating narrow band in range 5-23keV

X-ray imaging on NIF is critical to the physical understanding of ICF implosions

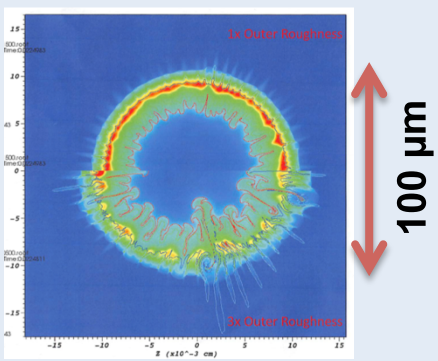
MIX

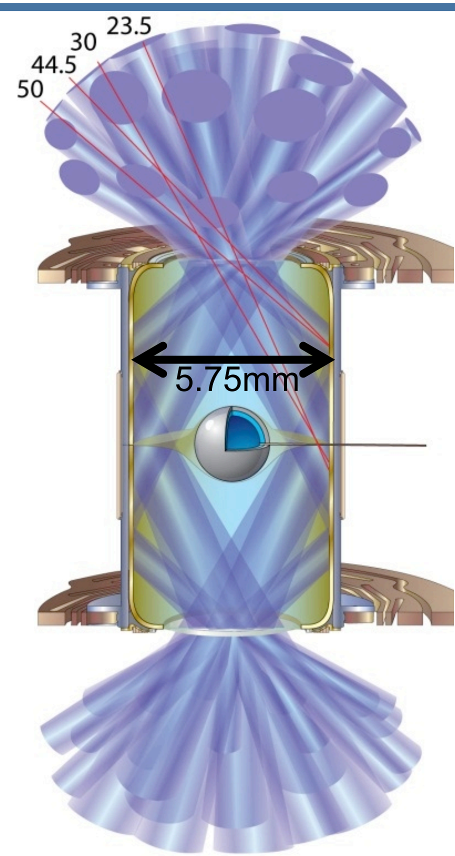
Roughness on the surface of the capsule, or at the ice/gas interface can cause bubbles or spikes to grow during the compression that disrupt the formation of the Hot Spot

S. Weber



Dimonte & Tipton



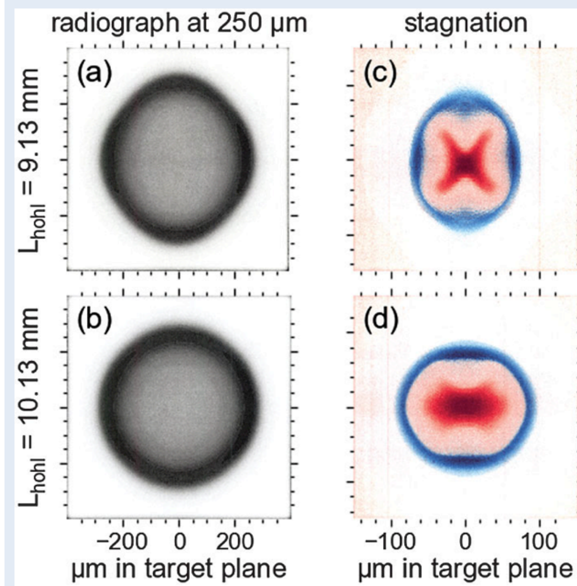


Self-emission

Radiography

SHAPE

The roundness of the implosion at various points in time provides the tuning information, such as x-ray drive uniformity



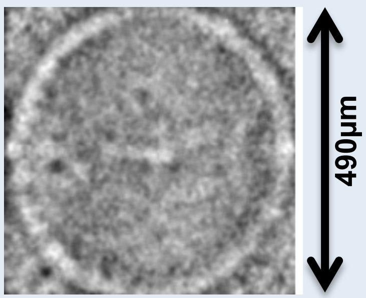
R. Rygg et. al PRL (2014)

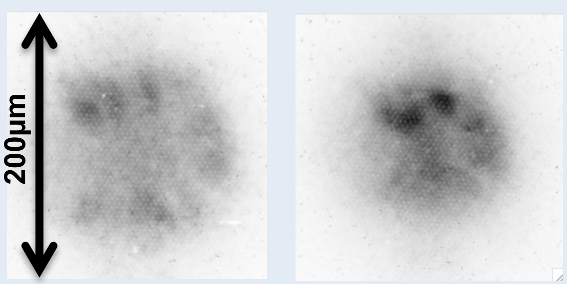
The current x-ray imaging systems provide tantalizing hints of underlying structure

MIX

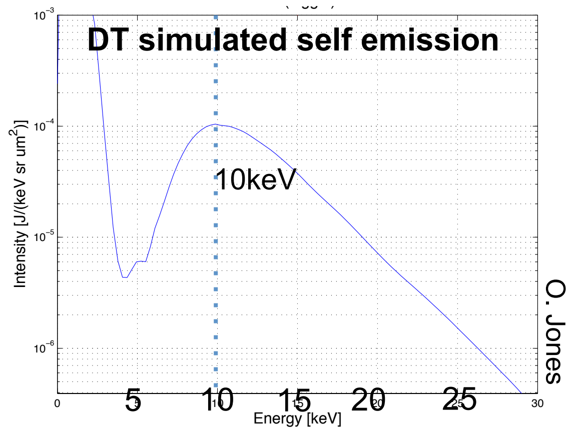
Roughness on the surface of the capsule, or at the ice/gas interface can cause bubbles or spikes to grow during the compression that disrupt the formation of the Hot Spot

Optical Depth modulations
Processed data (N140507)





N091117 Tri doped SymCap



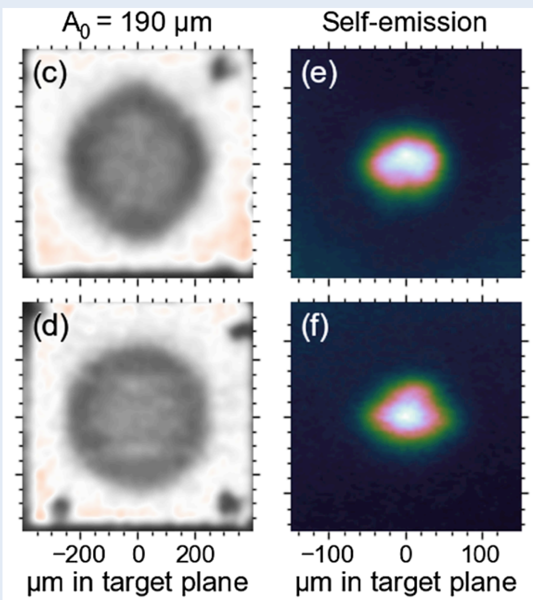
Primary diagnostic :
10-25µm Pinhole with
10-12x Magnification

~10-25um Resolution
~2.4-15x10^{-7}sr

To extend experimental platforms a higher resolution higher throughput system is required

SHAPE

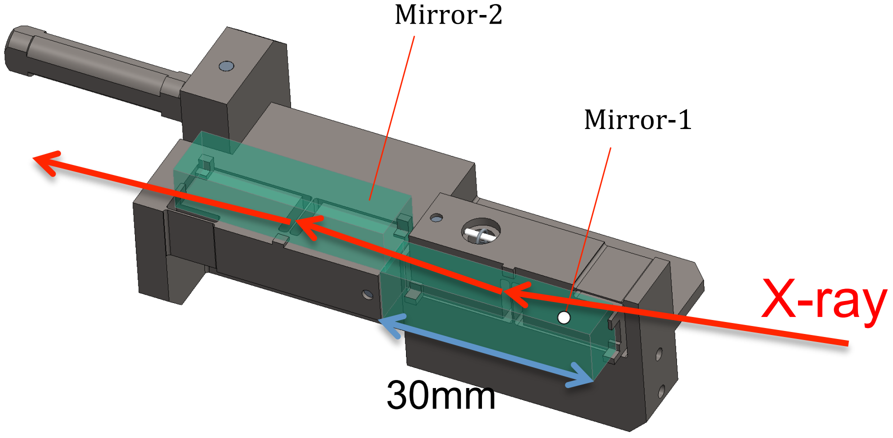
The roundness of the implosion at various points in time provides the tuning information, such as x-ray drive uniformity

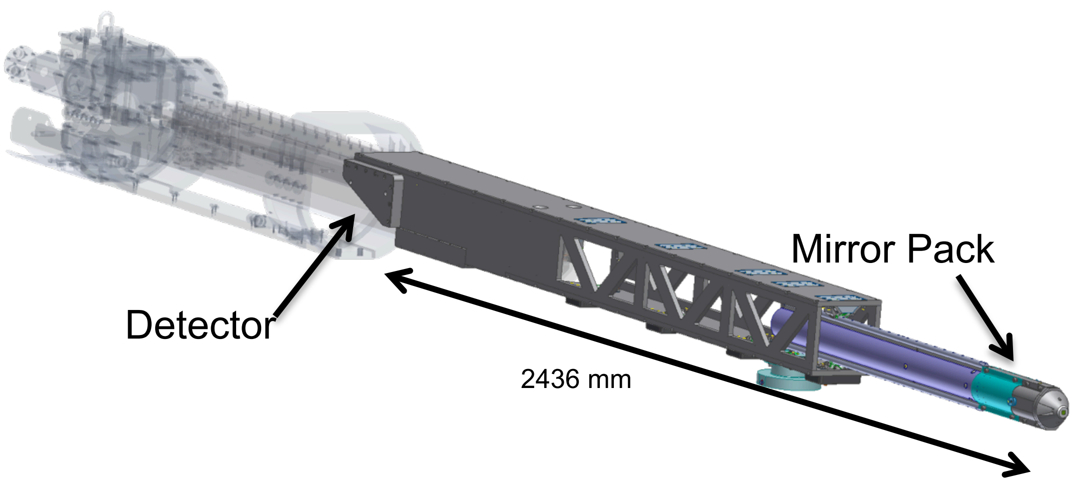


R. Rygg et. al PRL (2014)

We have built a KB Microscope that gives improved resolution and throughput

DIM	Equatorial
Images	4
Magnification	**10.5x & 12.5x**
Resolution	<10µm (detector limited at center)
Field of View	300µm diameter
Stand off	~18cm
∆t	~100ps (GXD)
Coating	∆E~3keV @ 10.2keV (KBO1)
Yield tolerance	1e14 n (detector limited)





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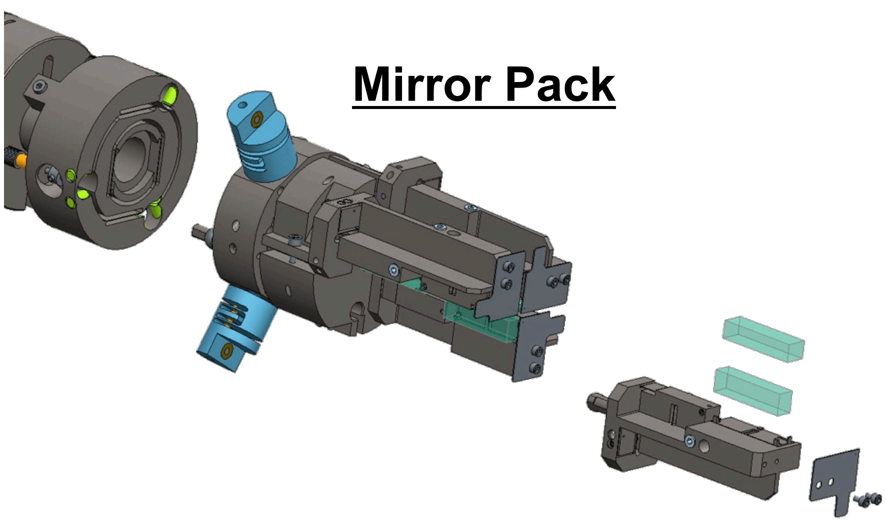
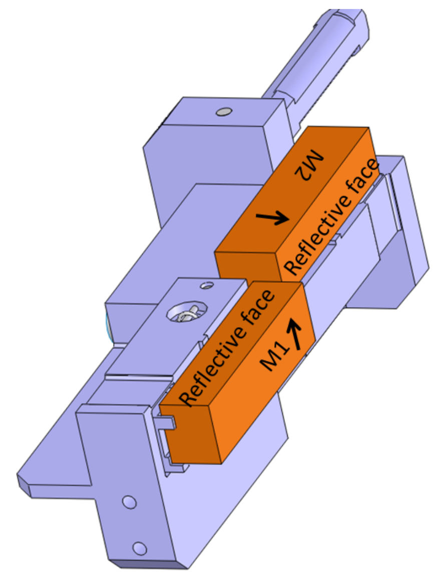
The KBO is designed to be modular with energy sensitivity determined by only the coating

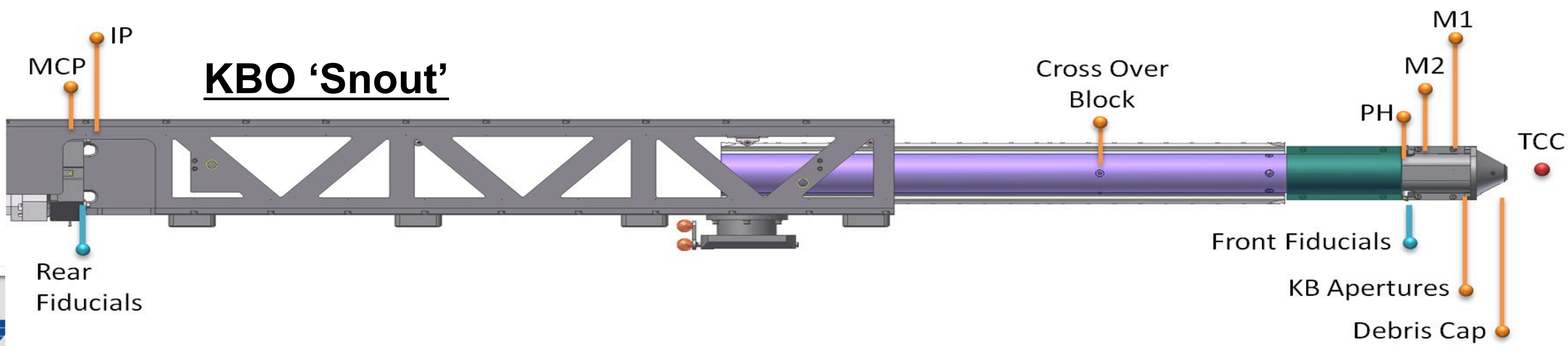
Mirror Pack



Single Imaging 'Quad'

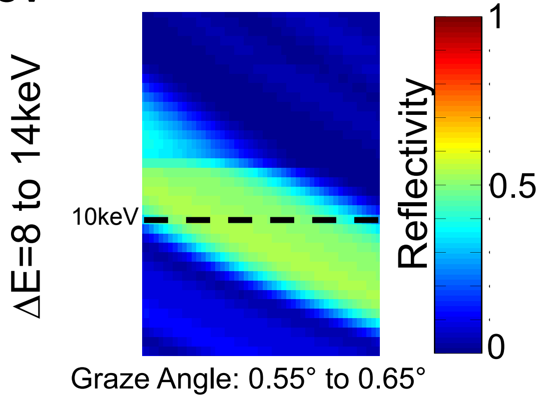


KBO 'Snout'

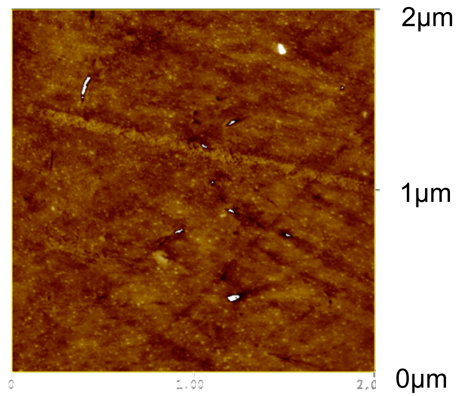


The multilayer coating was designed for the optical system and optimized for the experimental application

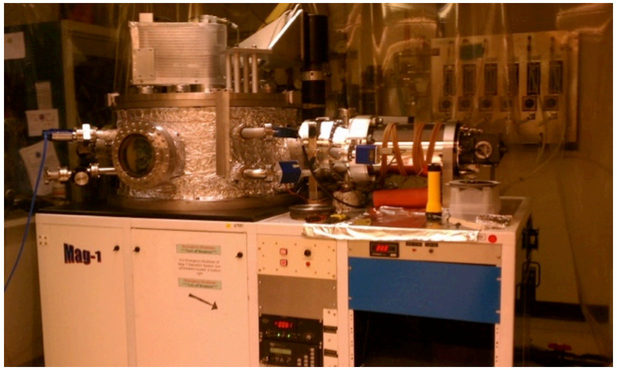
1. Simulate multilayer reflectivity for experiment energy band and FOV



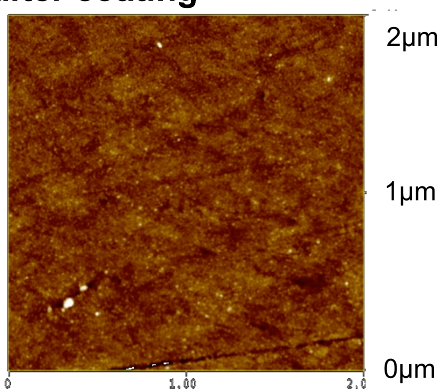
2. Characterize surface finish prior to coating (AFM, Interferometry)



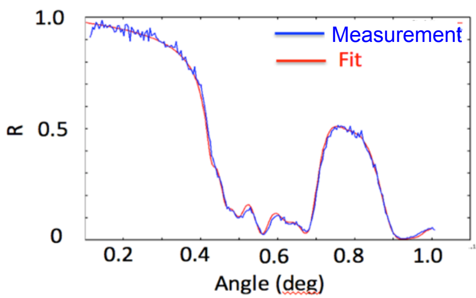
3. Multilayer deposition on MAG1 (pictured) – coater is also calibrated



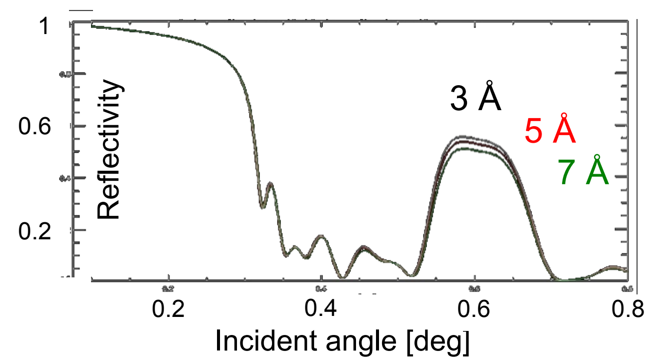
4. Characterize surface finish after coating



5. Measured reflectivity – LLNL & LBNL



6. Update modeled response based on measured roughness and reflectivity



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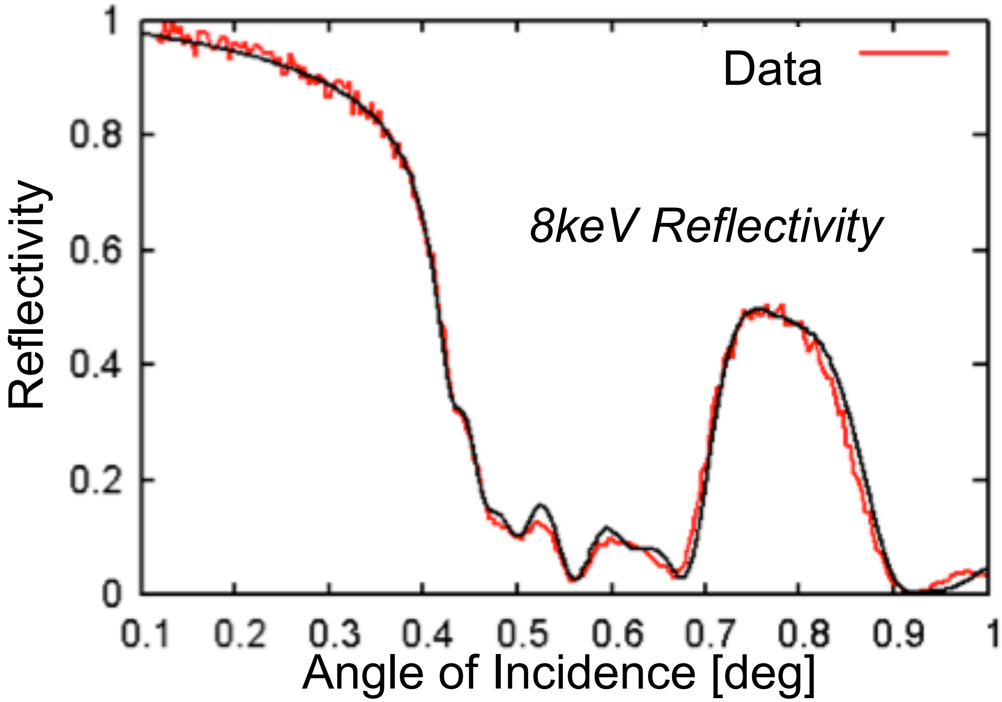
The first mirror pack achieves ~46% reflectivity over a ~3keV band at 10.2keV



10keV response is extrapolated from fit at 8keV

Total of 24 substrates were characterized, the 8 with lowest High-spatial Frequency Roughness (HSFR) were chosen:

3.1< HSFR < 5 Å

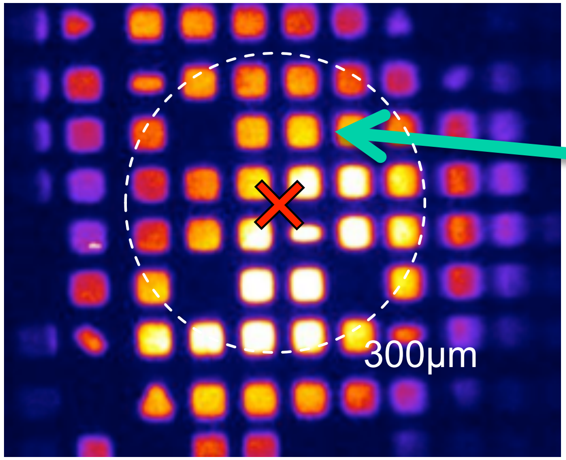
To gain higher reflectivity in future KB systems better HSFR is required

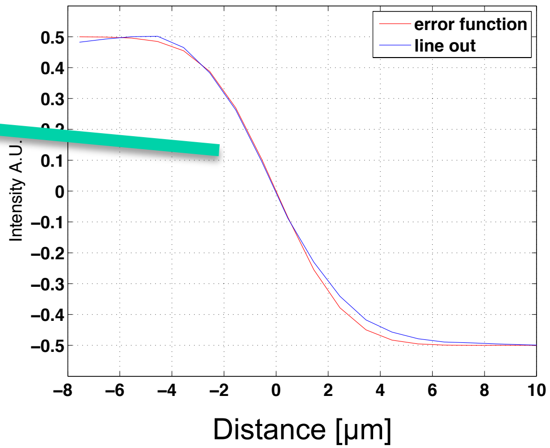
Multilayer Recipe

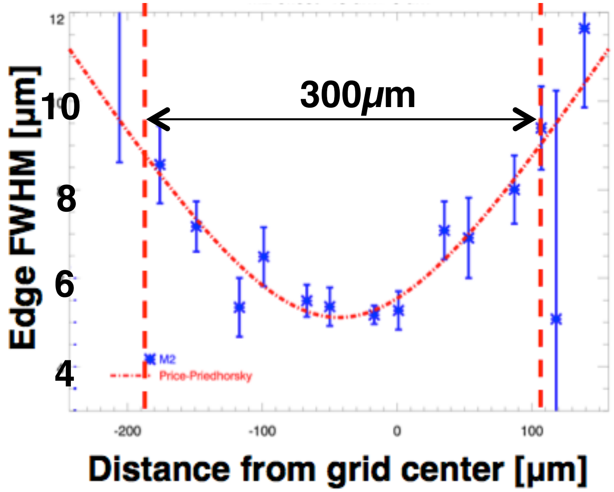
	N layers	d (Å)	Γ
Pt/C	5	65.4	0.44
Pt/C	4	41.1	0.47
Σ thickness		**491**	

T. Pardini et. al.

We have aligned and tested the first coated mirror pack showing the expected resolution (<8μm)







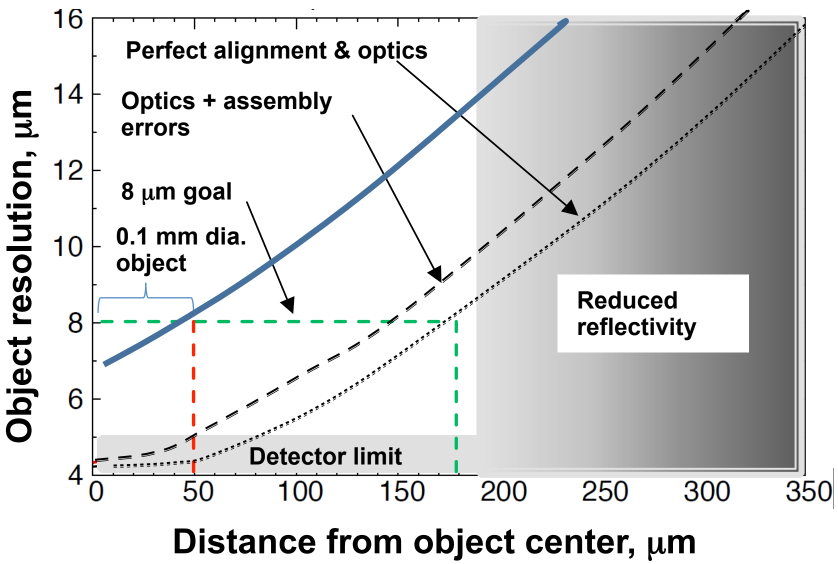
Time integrated image from single uncoated KB channel viewing a back lit grid at 1.5keV in 12x configuration

FWHM of line out from bar edges across the grid gives assessment of resolution and coma in the optic

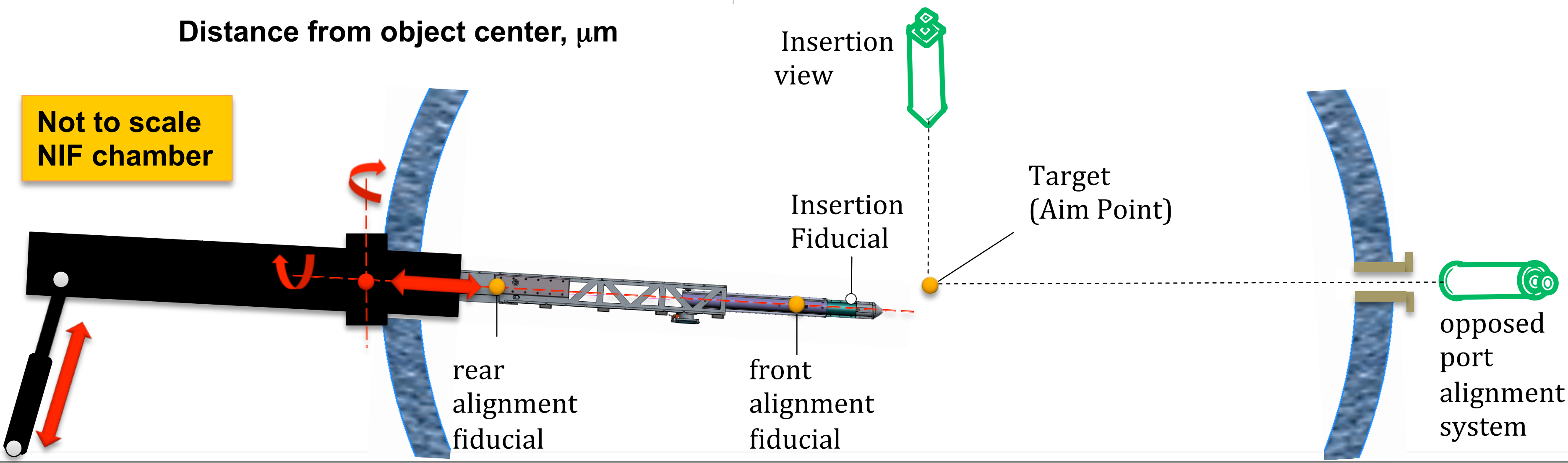
Multiple edge measurements show good agreement with the model. The presence of coma requires tight DIM alignment.

N.F. Brejnholt et. al.

The KBO has a small field of view that requires tighter alignment in the NIF chamber

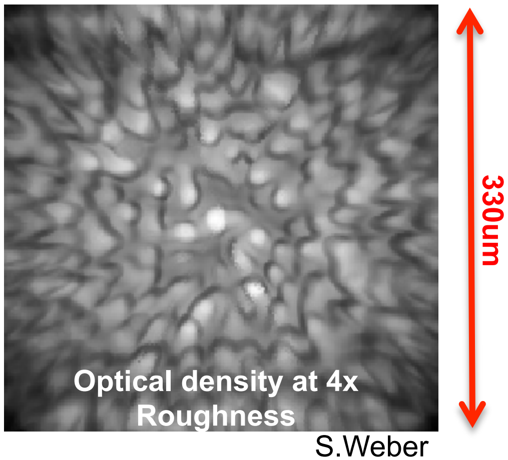


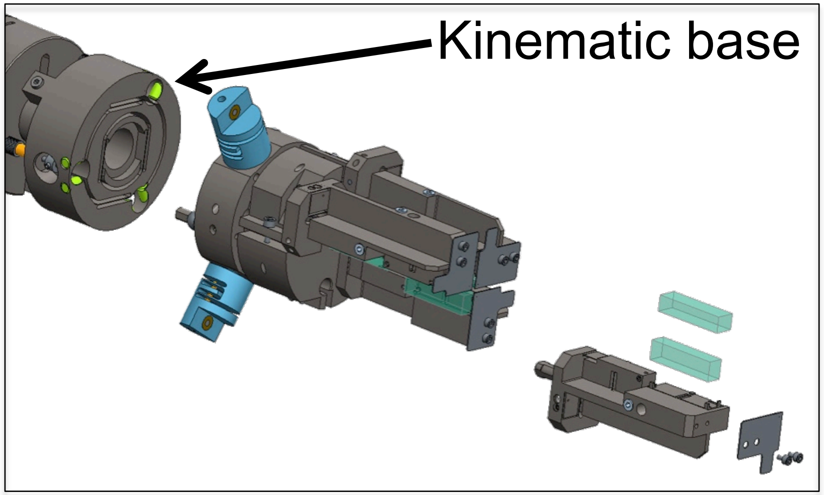
- Resolution < 8 μm over 0.4 mm FOV with perfect mirrors & alignment
- Realistic mirror pack fabrication & assembly tolerances reduce FOV to ≅0.3 mm (resolution held constant)
- Alignment in the target chamber reduces the FOV to ≅ 0.1 mm

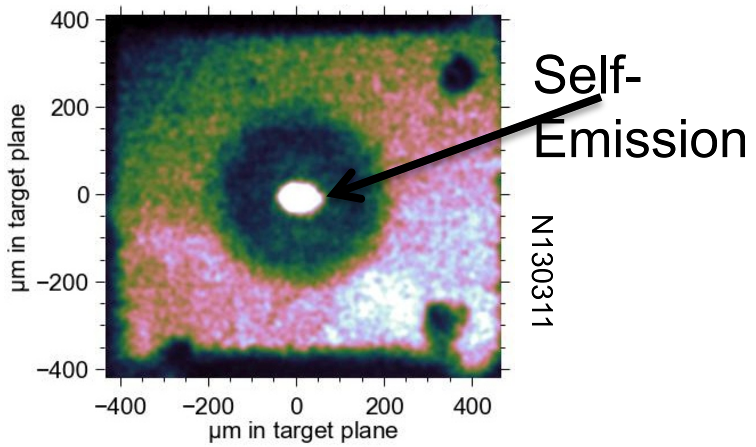


We are planning 2 more mirror packs with different experimental goals

- Low Energy Broadband: KBO2
  - For "Ultimate 3D" Experiment
  - Up to 7keV
- High Energy: KBO3
  - For 2DconA Experiments
  - ΔE~1keV @ 18keV







We have taken the first alignment shots on NIF which show good resolution and illumination at 10.2keV

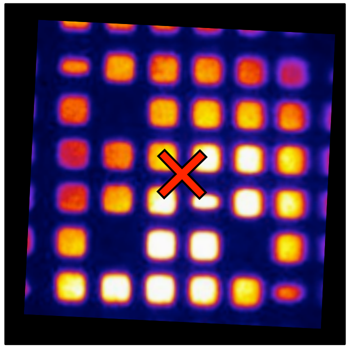


Image at 1.5keV
Manson Source

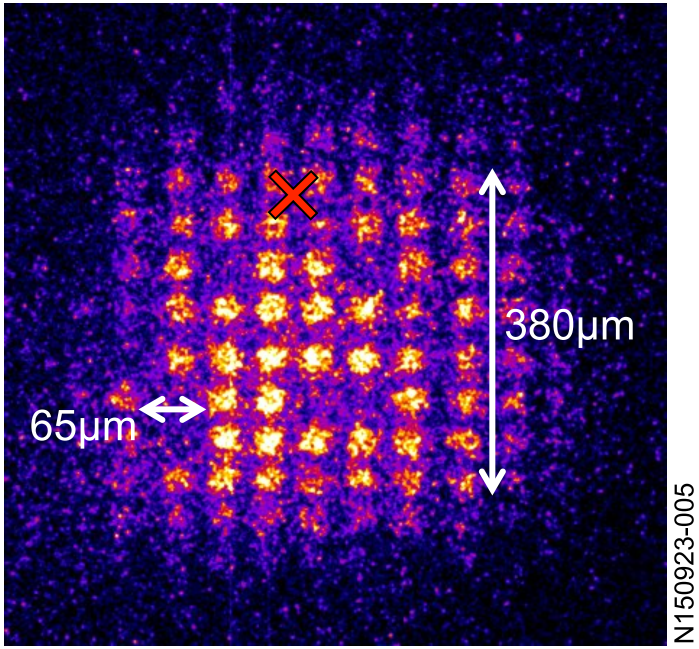
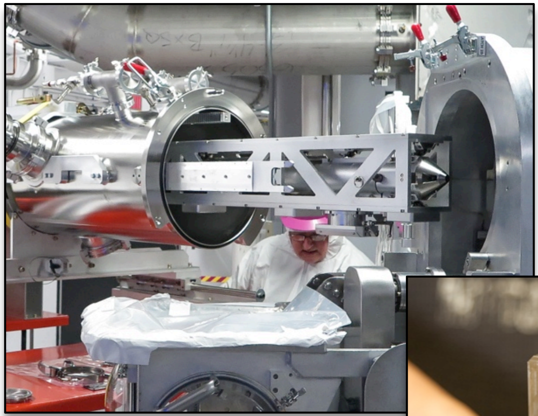


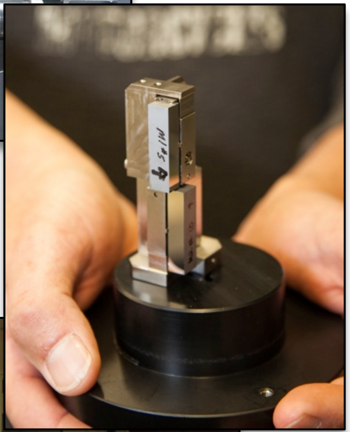
Image at 10.2keV
Ge back light

Full field of view is ~380µm diameter with <8µm resolution

We have designed built and fielded a modular KBO system for NIF

- The NIF KBO has <8um resolution across a ~300µm field of view
- The first mirror pack operates at 10.2keV with plans for two more operating at different enegies
- We have developed an alignment scheme for the diagnostic to achieve better pointing to TCC
- First images have been obtained from NIF at 10.2 keV





Publications

- **2015 SPIE: Submitted**
  “Calibration results for first NIF Kirkpatrick-Baez microscope”
  N.F. Brejnholt, J. Ayers, T.J. McCarville, T. Pardini, L. A. Pickworth, D.K. Bradley, T.A. Decker, S.P. Hau-Riege, R.M. Hill, R. Soufli, J. K. Vogel, C.C. Walton

- **2014 SPIE**
  “Engineering Precision Relocation Capability Into A Large-Cantilevered Telescoping Diagnostic For Kirkpatrick-Baez X-ray Optic”
  M.J. Ayers, L. A. Pickworth, T. Decker, R. Hill, T. Pardini, T. McCarville, N. Shingleton, C. Smith, C. G. Bailey, P. M. Bell, D. K. Bradley, N. F. Brejnholt, S. Hau-Riege, M. Pivovaroff, P. B. Mirkarimi, M. Vitalich, J. Vogel, C. Walton and J. Kilkenny

- **2014 RSI**
  "A Kirkpatrick-Baez microscope for the National Ignition Facility."
  L. A. Pickworth, T. McCarville, T. Decker, T. Pardini, J. Ayers, P. Bell, D. Bradley, N. F. Brejnholt, N. Izumi, P. Mirkarimi, M. Pivovaroff, V. Smalyuk, J. Vogel, C. Walton, and J. Kilkenny

- **2013 SPIE**
  "Optical and multilayer design for the first Kirkpatrick-Baez optics for x-ray diagnostic at NIF."
  T. Pardini, T.J. McCarville, C. C. Walton, T. A. Decker, J.K. Vogel, P.B. Mirkarimi , J.B. Alameda, R. M. Hill, L. A. Pickworth, V. A. Smalyuk, M.J Ayers, P.M. Bell, D.K. Bradley, J.D. Kilkenny, M.J. Pivovaroff

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