Micropore optics; application, modelling and calibration

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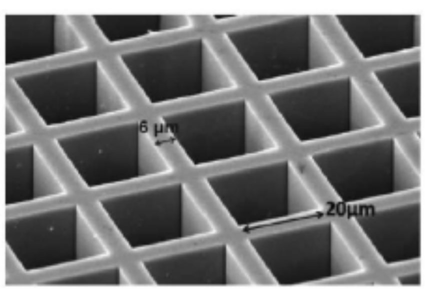
Willingale, R. et al. "Aberrations in square pore micro-channel optics used for x-ray lobster eye telescopes", *Proc. SPIE* 9905, Space Telescopes and Instrumentation, 2016

See also

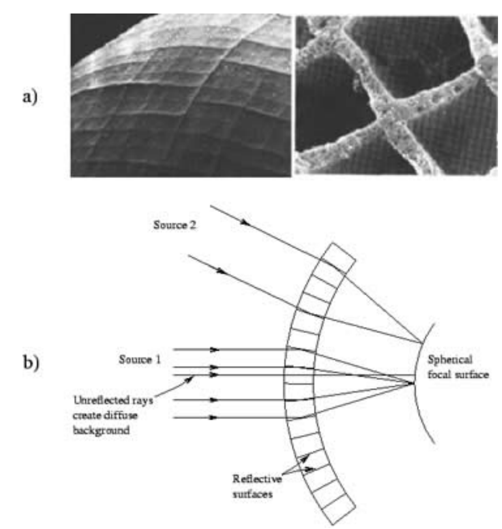
Kuntz, K. et al. "INITIAL TESTS OF SLUMPED MICROPORE OPTICS FOR WIDE-FIELD X-RAY ASTRONOMY", *in prep.*

Micropore Optics: Lobster eye optics – Angel 1979 Square pore micro-channel plates

- Glass plate full of holes!
  - Thickness 0.9-2.3 mm
  - Transmission ~67%
- Square Pores L~1 mm, d~20µm or ~40µm, wall ~4µm - ~12µm, L/d~50



Cartesian packed pores for Lobster Eye



MPO Missions/Instruments

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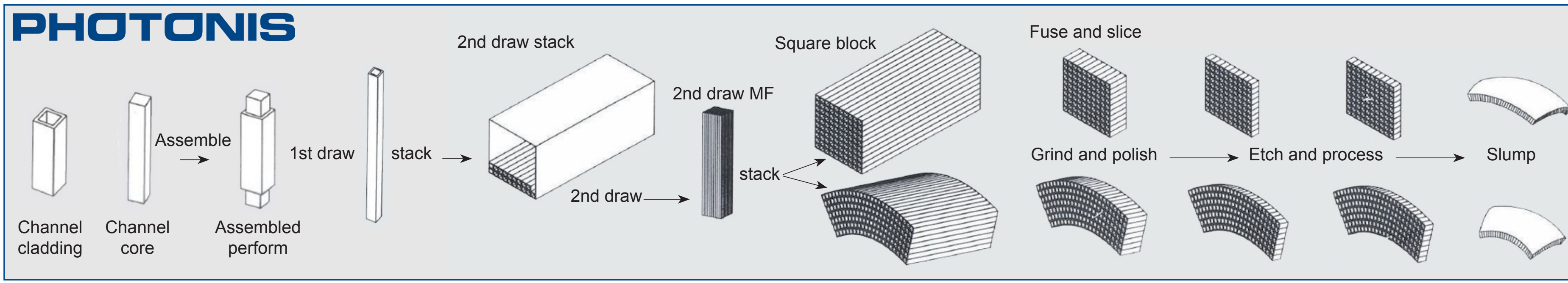
Mission	Type	Instrument	Lead	Status
DXL/STORM	Sounding Rocket	STORM	NASA/GSFC, USA	2 flights, 2012, 2016
BepiColombo	ESA Cornerstone	MIXS	Leicester University, UK	Launch 2018
CUPID	Cubesat	CUPID	Boston University, USA	Launch 2019
SMILE	ESA/CAS S2	SXI	Leicester University, UK	Launch 2021
SVOM	French/CAS	MXT	CNES	Launch 2021
Einstein Probe	CAS	WFI	CAS	Probably selected
Theseus	ESA M5	WFI	Leicester University, UK	Proposed
TAO	NASA MIDEX	WFI	NASA/GSFC, USA	Proposal
STORM	NASA MIDEX	?	NASA/GSFC, USA	Proposal

Micropore optics development by Photonis, Cosine Research BV, ESA and the University of Leicester, UK



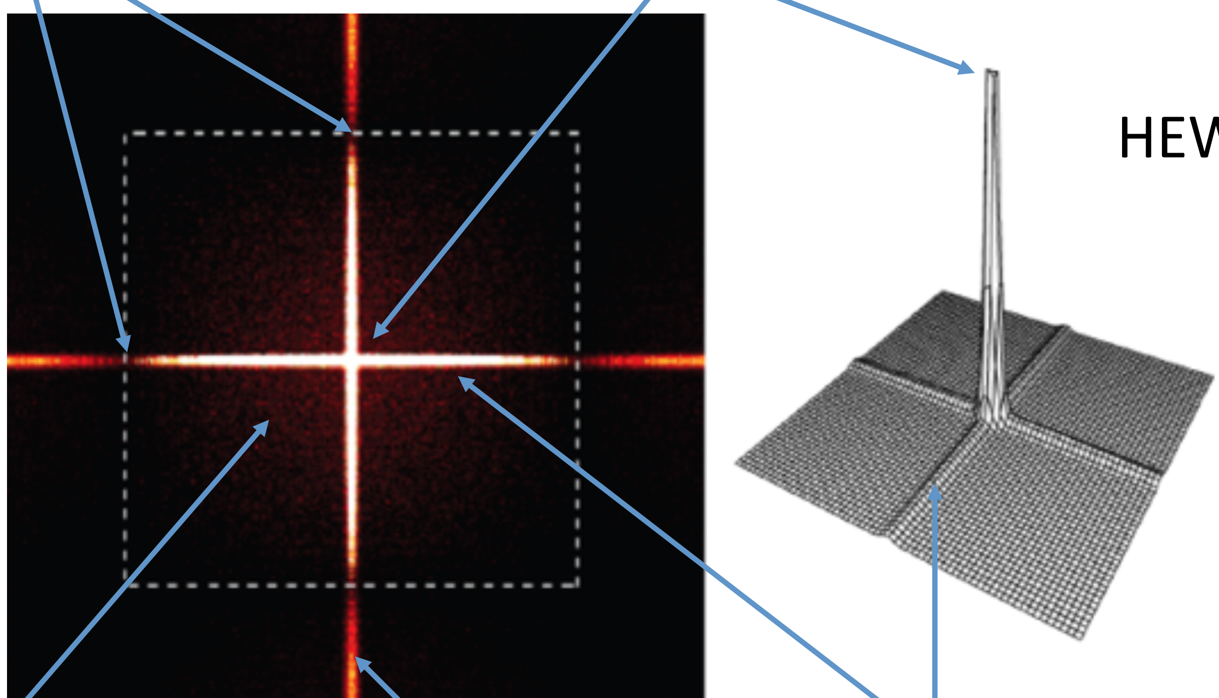
Additional processes offered by Photonis:
Metal coating of pores (Iridium)
Deposition of Aluminium film (filter) on MPO surface

Model point spread function

off-spot angle θ=2d/L

2°.3 for L/d = 50

2-reflection focused spot



Intrinsic Aberrations

Contributions to central core angular resolution

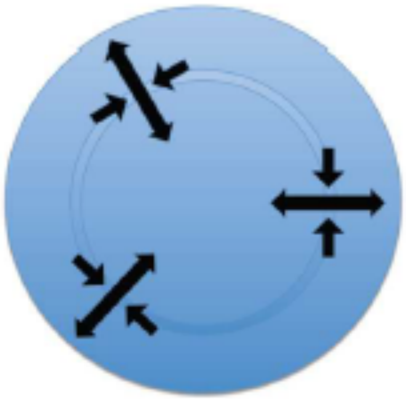
Type	Relation	F = 300 mm d = 27 μm L = 1.35 mm	F = 1000 mm d = 50 μm L = 2.5 mm
Spherical	$\Delta\theta_s = 4\sqrt{2}(d/L)^3$	~9”	~9”
Geometric	$\Delta\theta_g = d/F$	~19”	~10”
Diffraction	$\Delta\theta_d = 2\lambda/d$ (Energy = 1 keV)	~19”	~10”
	$\Delta\theta_i = (\Delta\theta_s^2 + \Delta\theta_g^2 + \Delta\theta_d^2)^{1/2}$	~28”	~17”

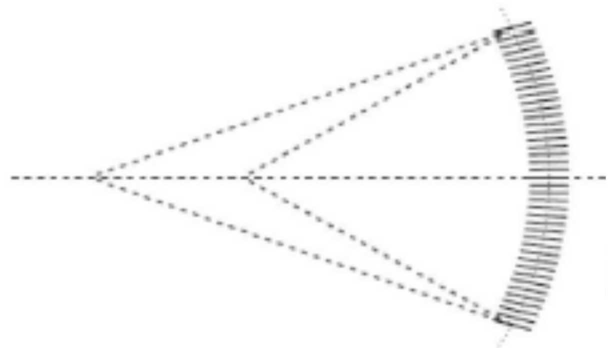
Best possible

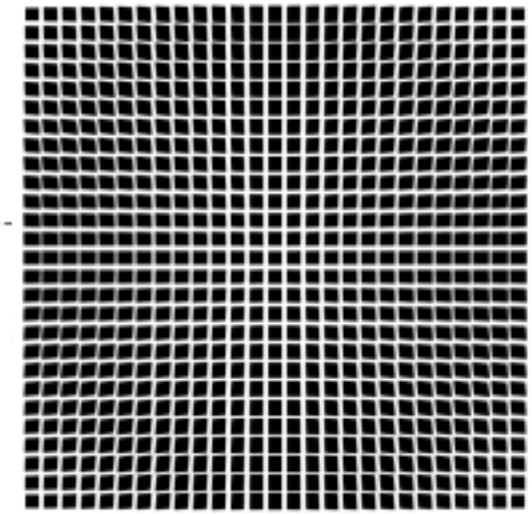
Optimum (for point source detection) L/d ~ 50

Highest angular resolution occurs for $\Delta\theta_g = \Delta\theta_d$

Intrinsic Slumping Errors







Azimuthal compression and radial expansion of pores around each annulus → Pore radial tilt errors & pore cross-section shear errors

Tilt angle, $\theta_a \sim r^2 / (2R^2)$

Tilt error, $\Delta\theta_a \sim (r/R)^2$

Shear angle, $\theta_h \sim r \sin(2\theta)/R$

Shear error, $\Delta\theta_h \sim 2\sin(2\theta)(d/L)(r/R)$

F mm	$\Delta\theta_i$	$\Delta\theta_a$	$\Delta\theta_h$	$\Delta\theta_t$
1000	0'.28	0'.17	0'.60	0'.68
300	0'.48	1'.88	1'.99	2'.78

Manufacturing Errors

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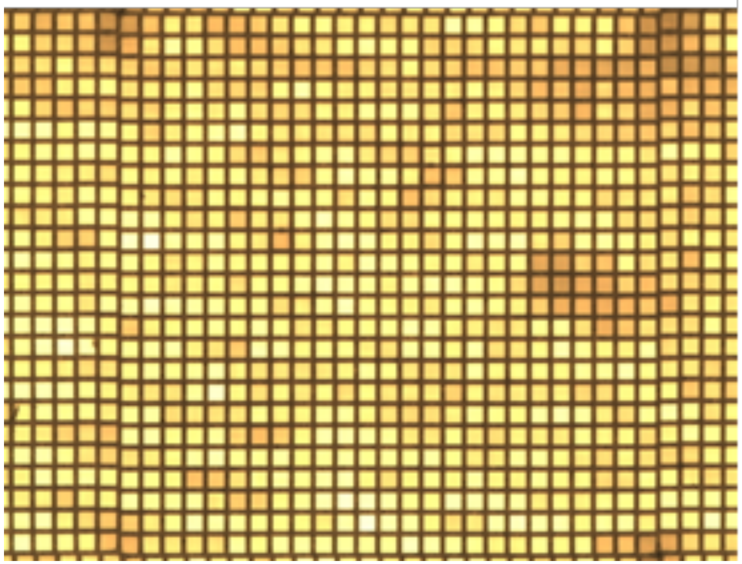
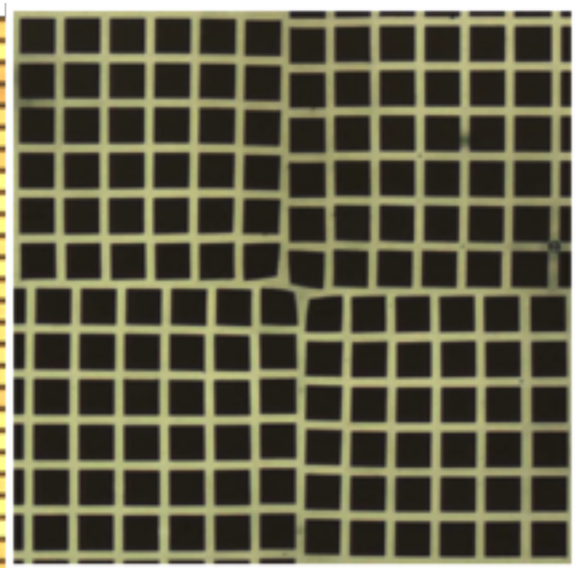
1) Multifibre structure

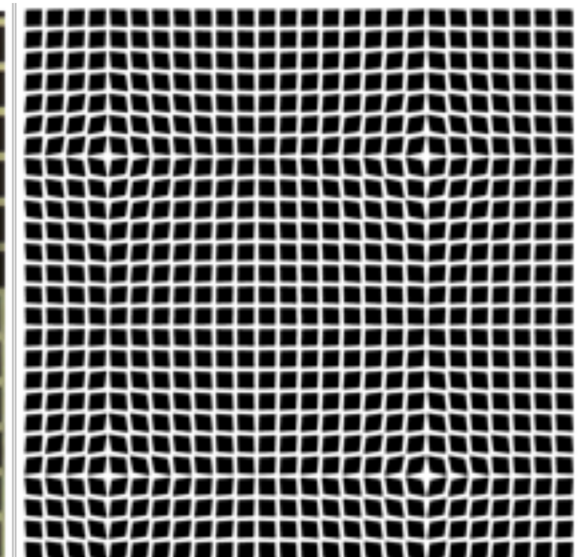
1 25x25 multi-fibre



corner distortion



simulation



Regular array of packed multi-fibres

25x25 for 40 µm pores

35x35 for 20 µm pores

Shear distortion at corners - removes flux from the cross-arms

Shear error amplitude modeled as a Gaussian

$\theta_h = A \exp(-r^2_f / 2\sigma^2_f)$; $\sigma_f \sim 4d$; $A \sim 4$ degrees

R_f is radial distance of pore from corner of multibre

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Manufacturing Errors

1) Multifibre structure

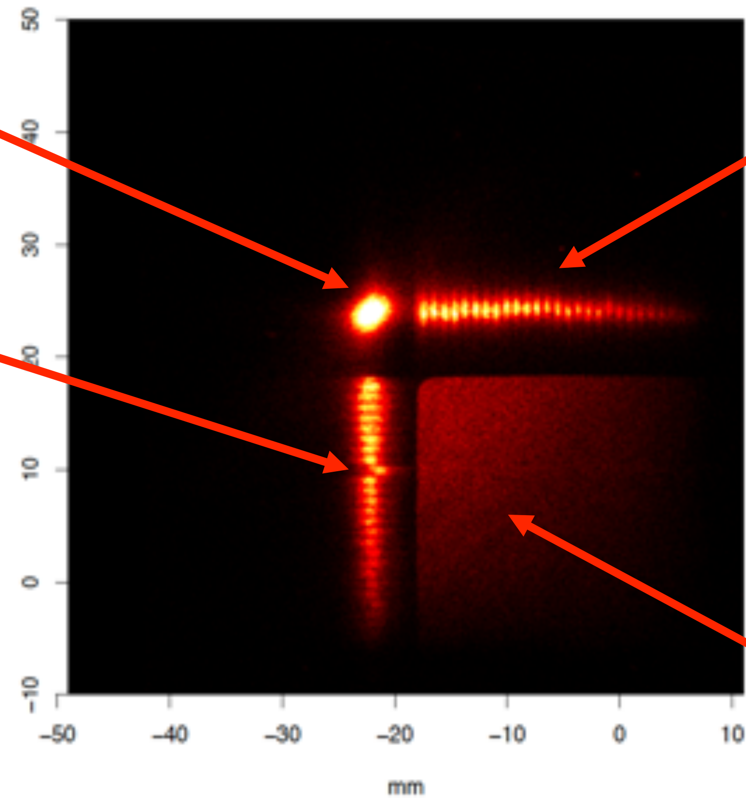
focused spot diamond shaped

&

cross arm displacement/waviness

cause:

multifibre tilt errors between rows and/or columns



cross-arm Modulation (loss of flux)

Cause:

Large shear angle errors at multifibre intersections

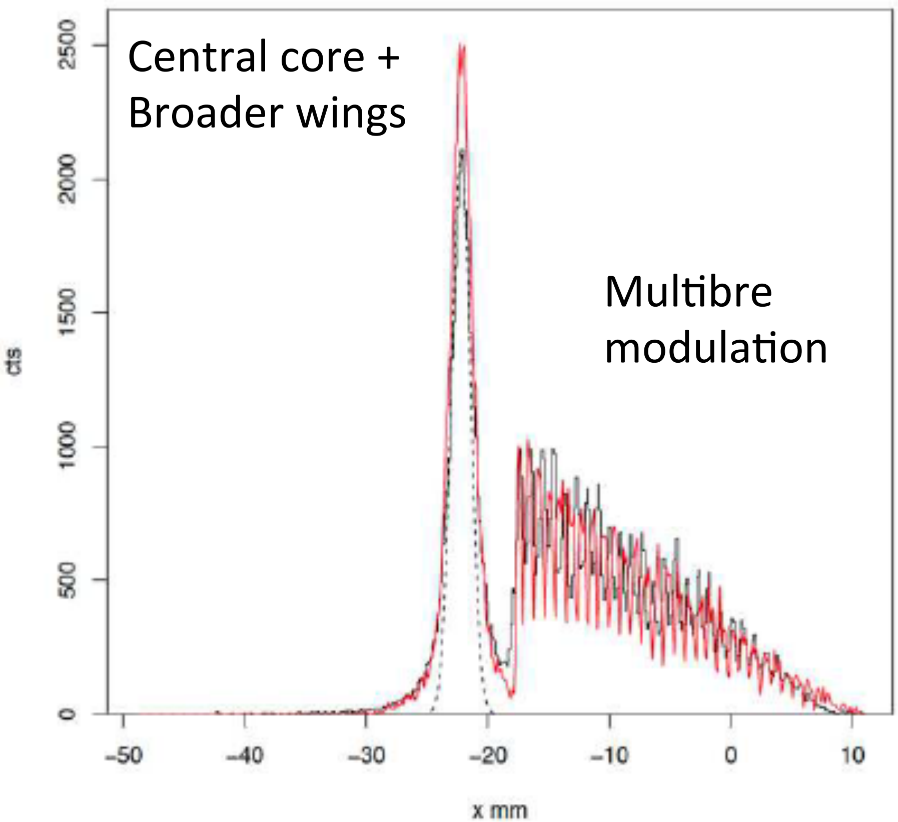
straight through component

Data at 1.49 keV. Single plate illuminated at an angle

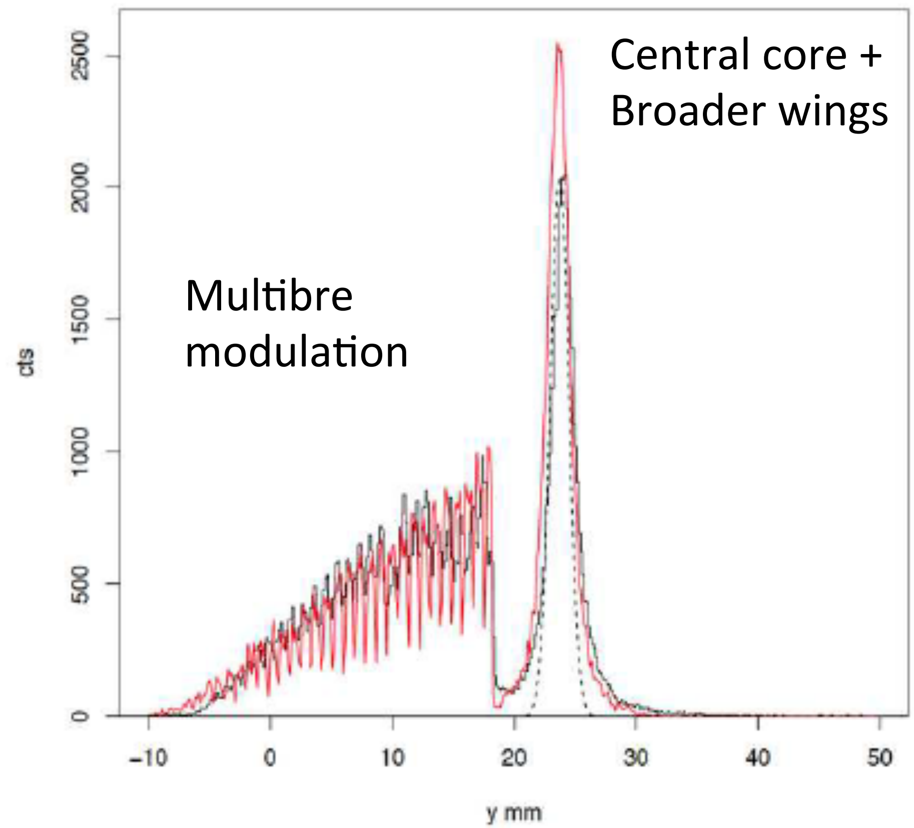
Manufacturing Errors

1) Multifibre structure

Horizontal



Vertical



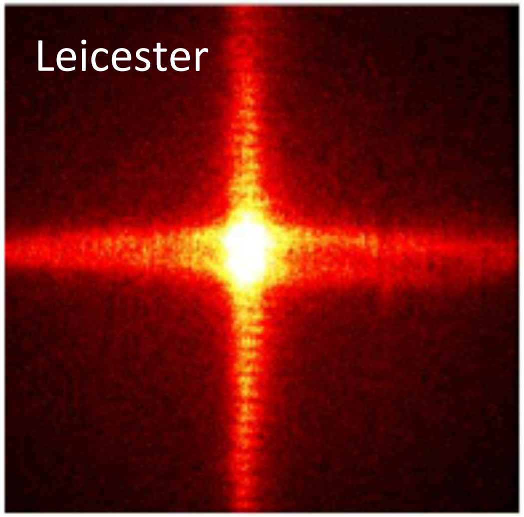
In addition to shear and tilt errors there will be pore wall figure errors:
Modelled as two populations of pores; Inner 25:25 & Outer 5 pore band (50:50 split)
Outer band has rms figure error ~4 times Inner population.

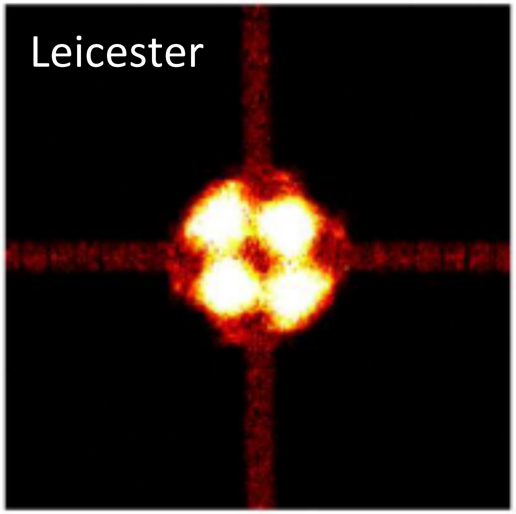
Manufacturing Errors

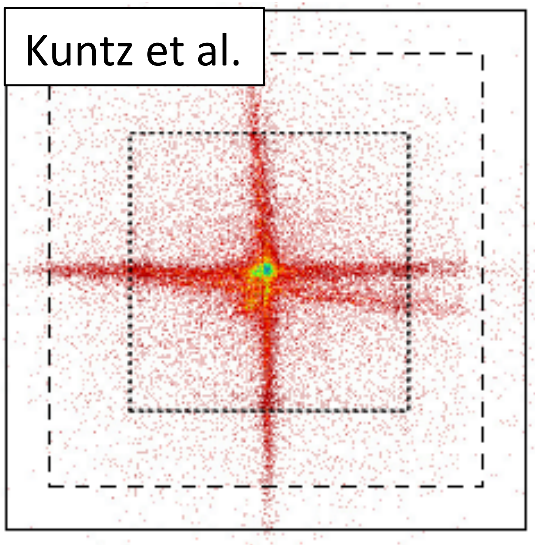
2) Large scale bias angle variation

Type 1) Introduced when plates are cut from a block. Not serious as long as multiple plates In a frame are mounted with same relative bias angle

Type 2) Variation across a plate due to slumping (or mounting) process. Potentially more serious.







Contributions to FWHM for SVOM breadboard plate

	arc mins
geometric pore size $d = 20\ \mu$m	0.07
spherical aberration pore $L/d = 50$	0.15
slumping - intrinsic radial tilt errors	0.17
slumping - intrinsic shear errors	0.60
surface roughness 11 Å rms, $\omega_b = 10$ mm^{-1}	2.46
figure errors at centre of multifibres	2.48
shear errors at centre of multifibres	-
multifibre tilt errors along primary axes	3.54
figure errors at edge of multifibres	9.92
shear errors at edge of multifibres	-
global shear errors	-
global tilt errors	-

Combine*

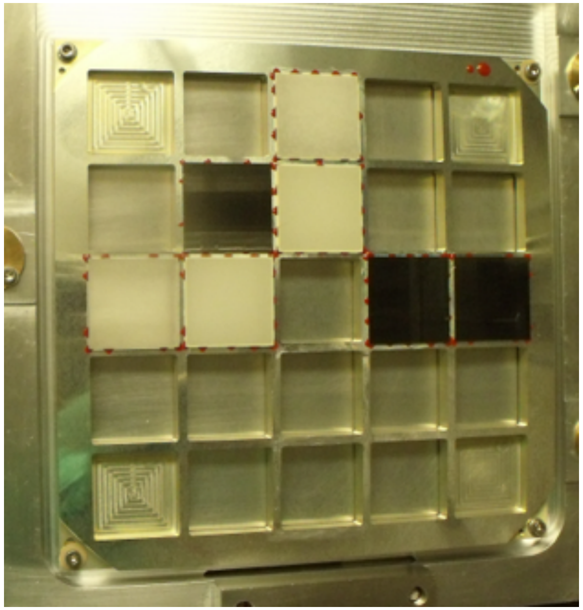
to give observed

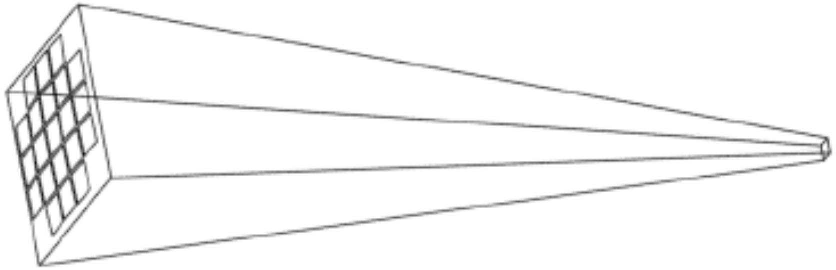
FWHM ~ 6'.5

*Not rms sum

Compare with instrinsic + slumping errors which predict ultimate angular resolution in range 1 – 3 arcminutes depending on focal length

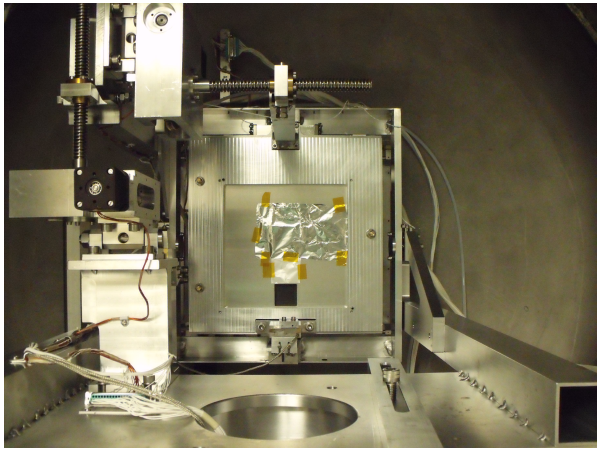
SVOM Breadboard Model X-ray Testing





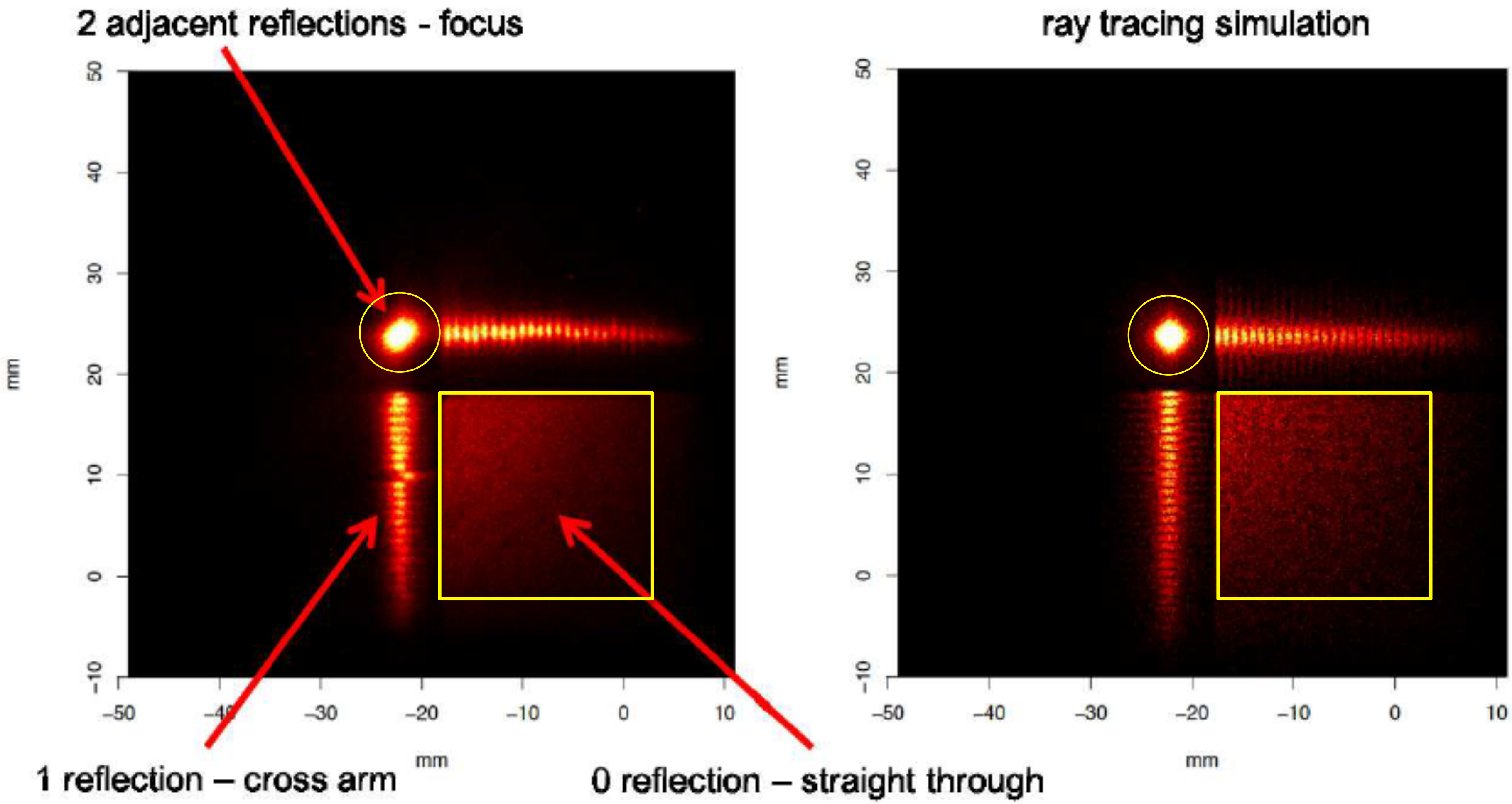
Mass of frame plus 21 MPOs ~1 kg

Leicester TTF – source at 27 m
MPE Panter – source at 128 m



Al support frame – array of 21 MPOs 40x40mm^2
spherical surface R=2000mm – F=1000mm
Machining accuracy ±10µm
2x 20µm MPOs, 2x 40µm MPOs, 1x 20µm Ir coated MPOs, 2x40µm Ir coated MPOs

Data versus Simulation



X-ray image and simulation at 1.49 keV

Efficiency Measurements

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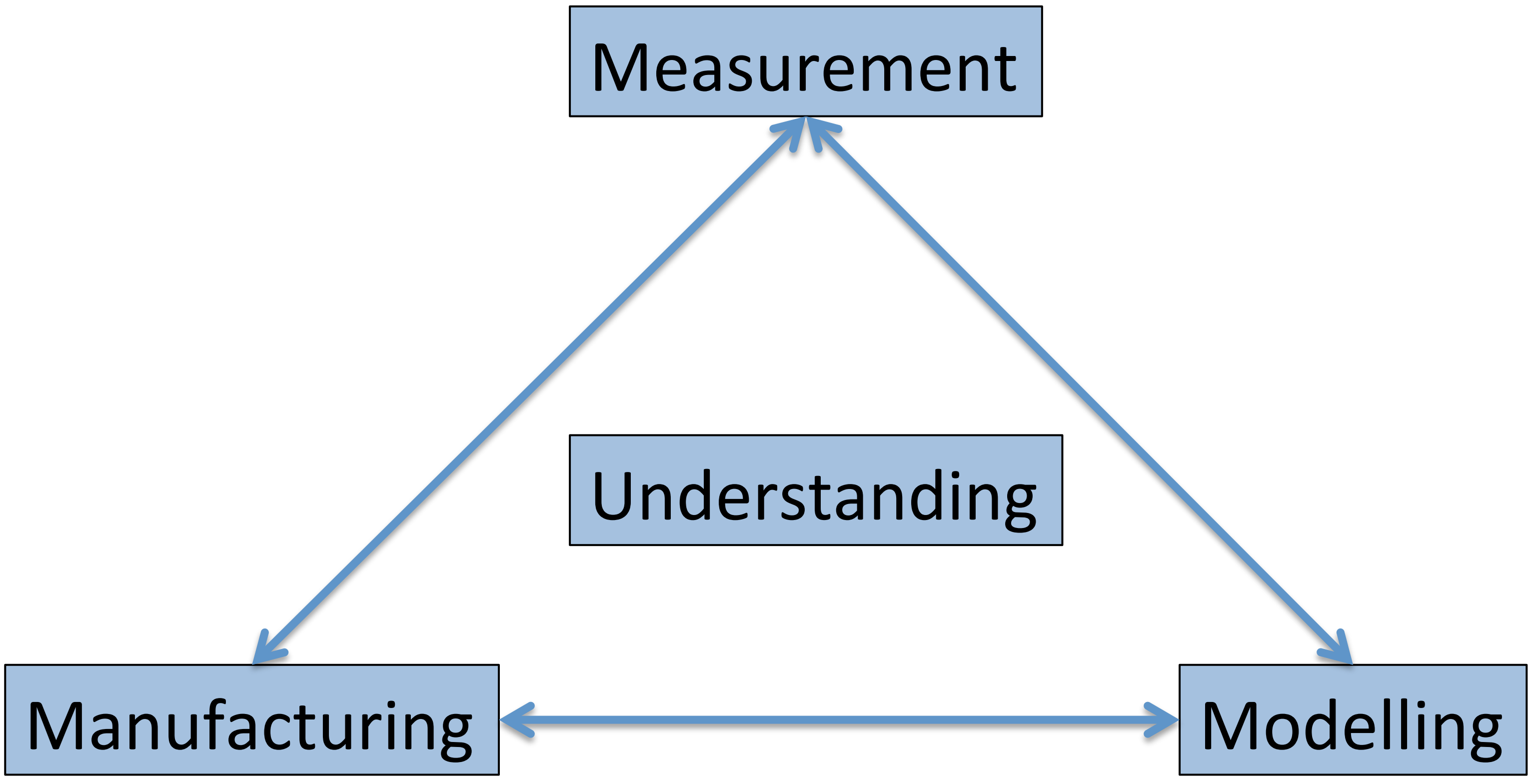
MPO	X-ray R (mm)	Thickness (mm)	Double reflection efficiency	Best FWHM (arcmin)
YC001-A6	1874	1.05	0.87	6.46
YC001-D1	1970	1.20	0.90	6.39
YC001-D5	1906	1.20	0.92	7.52
YC001-C3	1906	1.70	0.97	7.55
YC001-C4	1906	1.70	0.95	7.15

Single reflection efficiency in range 0.93 – 0.98

MPO Calibration



Thankyou