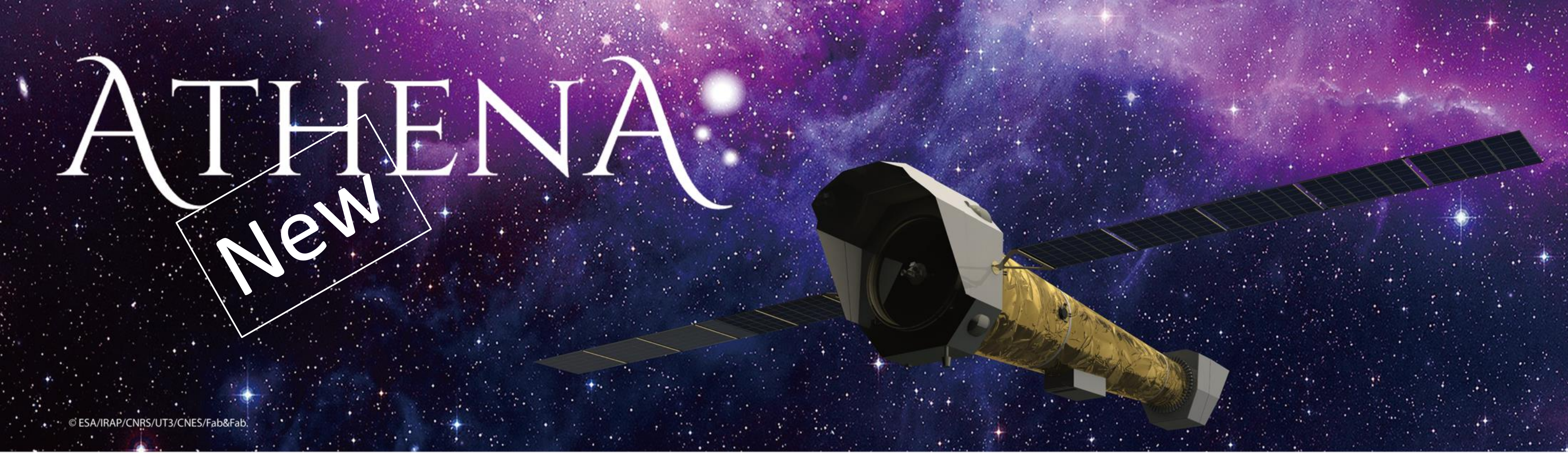


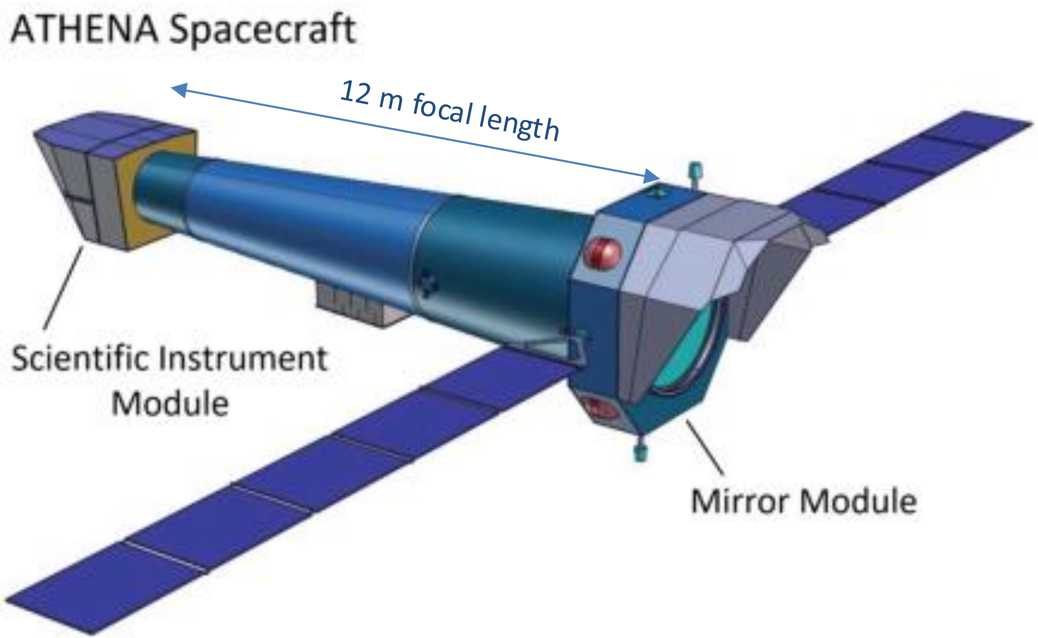
Athena mirror performance characteristics at XRCF
OR
The Challenges of Large Segmented Mirrors

Kristin K. Madsen, Goddard Space Flight Center

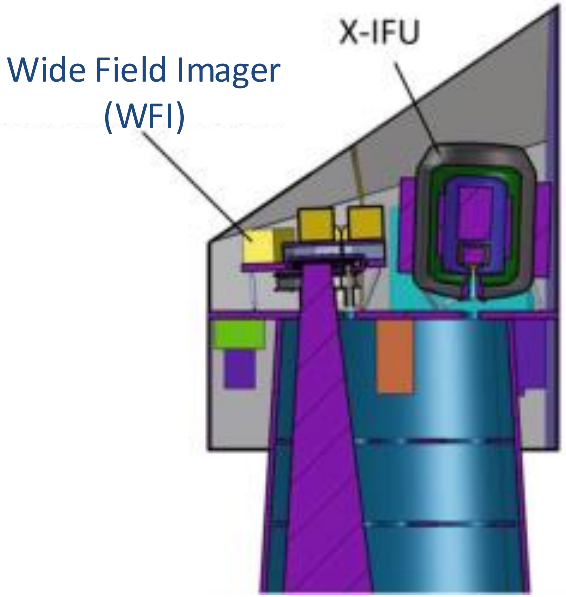
NewAthena Observatory

Mission Adoption: 2027

Launch: 2037, 5-year mission baseline

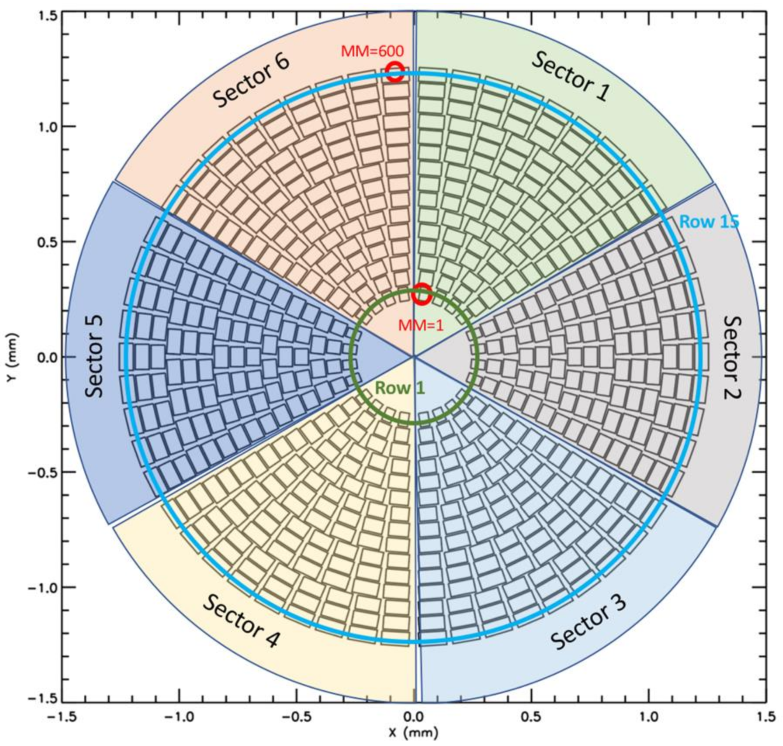


X-ray Integral Field Unit (X-IFU)



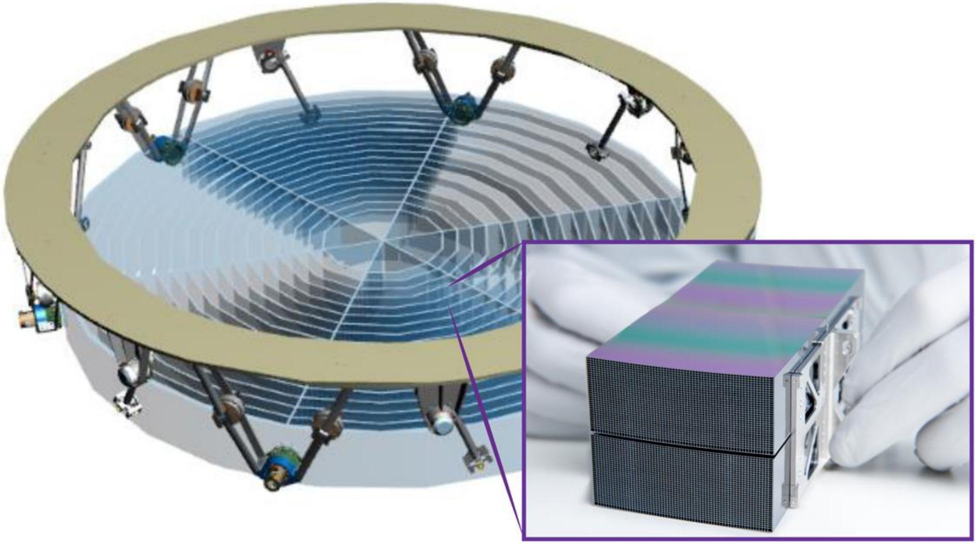
The Athena Silicon Pore Optic Mirror

600 Mirror Modules (15 row)



For 15 rows:

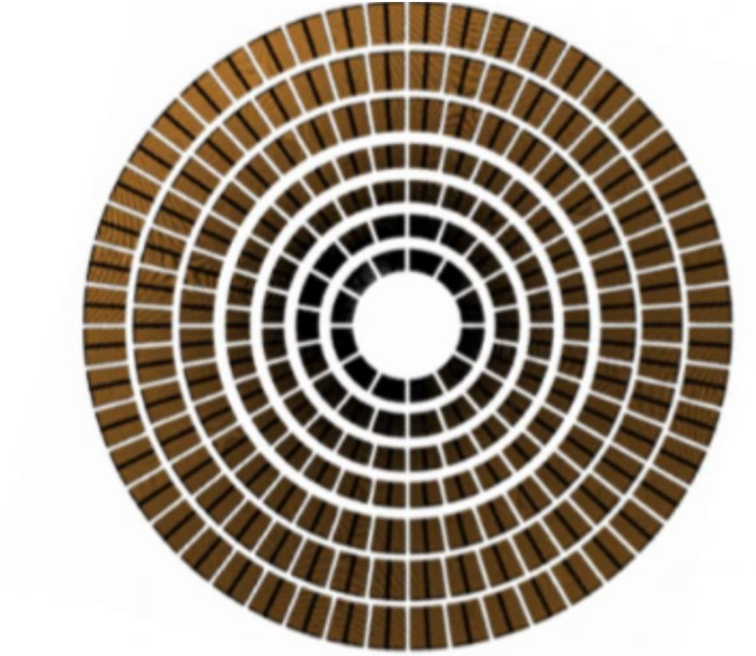
Silicon mass	= 300 kg
Structure mass + Si	= 1000 kg
Effective Area @ 1 keV	= 18,000 cm2
HPD (system)	= 9 arcsec
Max diameter	= 2.4 m



Credit: ESA. Cosine and ACO Team

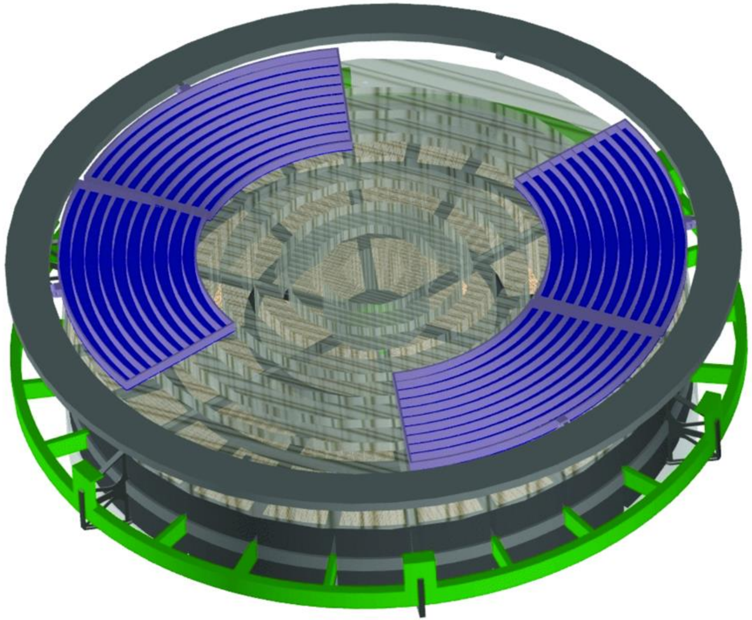
Other Large Segmented Optics

AXIS, NASA probe, phase A concept



~1.8m
(could be selected in 2026)

Lynx, NASA Flagship concept



~3m
(Earliest selection 2040'ish)

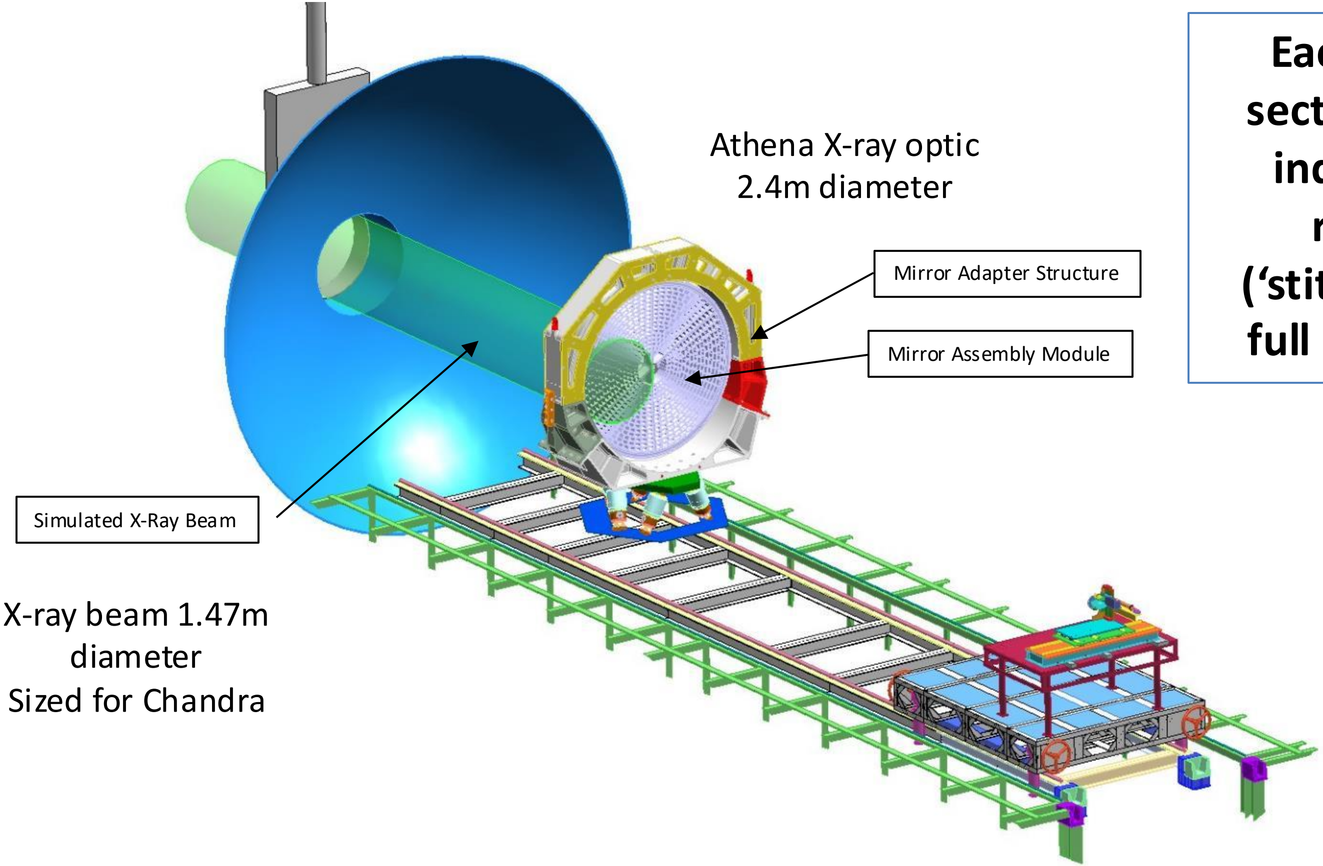
MSFC XRCF 500-meter Beamline

X-Ray and Cryogenic Facility

As the only existing facility capable of testing the Athena mirror, XRCF was selected as the baseline performance testing facility in 2020

- Part of the NASA Athena contribution
- Development plans for MAMD testing were begun in 2020
- Athena went into re-definition in 2022
- XRCF contribution was dropped in 2024

Mirror in the XRCF Chamber



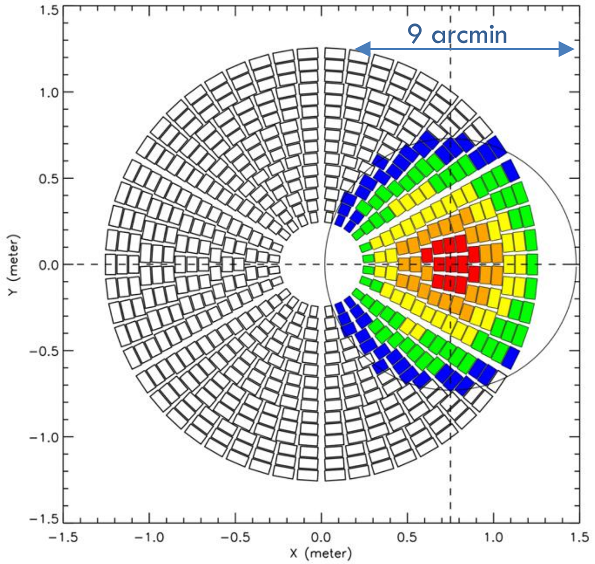
X-ray beam 1.47m diameter
Sized for Chandra

Each of the six mirror sectors would be tested individually, with the results combined ('stitched') to obtain the full mirror performance

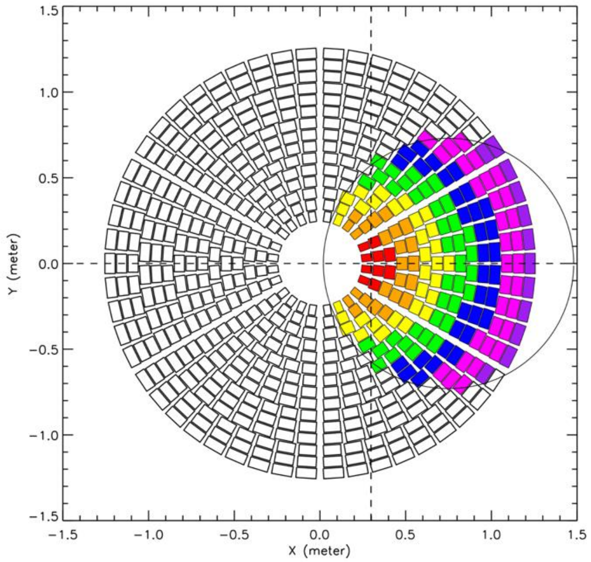
NewAthena Calibration Requirements

Parameter	Functionality & Core Test	FM calibration
Xray Optical axis	≤20'' with 68% confidence	≤30'', with 99.7% confidence
Focal length	≤ 1mm with 99.7% confidence	≤1 mm, with 99.7%
Effective Area (on-axis)	≤10% with 68% confidence	1% count statistical error
Effective Area (off-axis)	Aeff to 1% count statistical error	• A_eff to 1% count statistical error • ±25' from the boresight at 5' increments, known to ≤0.25'' with 99.7% confidence.
PSF (on-axis)	PSF HEW (core) ≤2% with 68% confidence	• PSF HEW ≤0.25'' with 99.7% confidence • ≤0.5'' with 99.7% confidence over a range of Focal Lengths (12050 mm --> 11950 mm)
PSF (off-axis)	PSF centroid/HEW ≤0.25”/0.5'' with 68% confidence	• PSF centroid/HEW ≤0.25”/0.5” with 99.7%

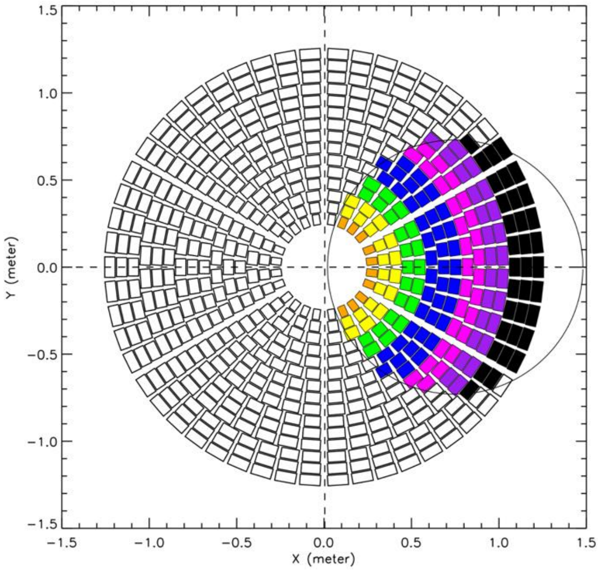
The challenge



Yaw = 0 arcmin

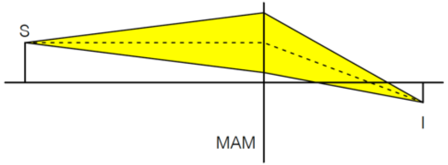


Yaw = 3 arcmin

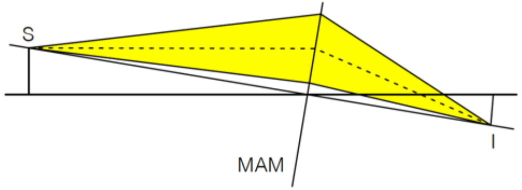


Yaw = 4.95 arcmin

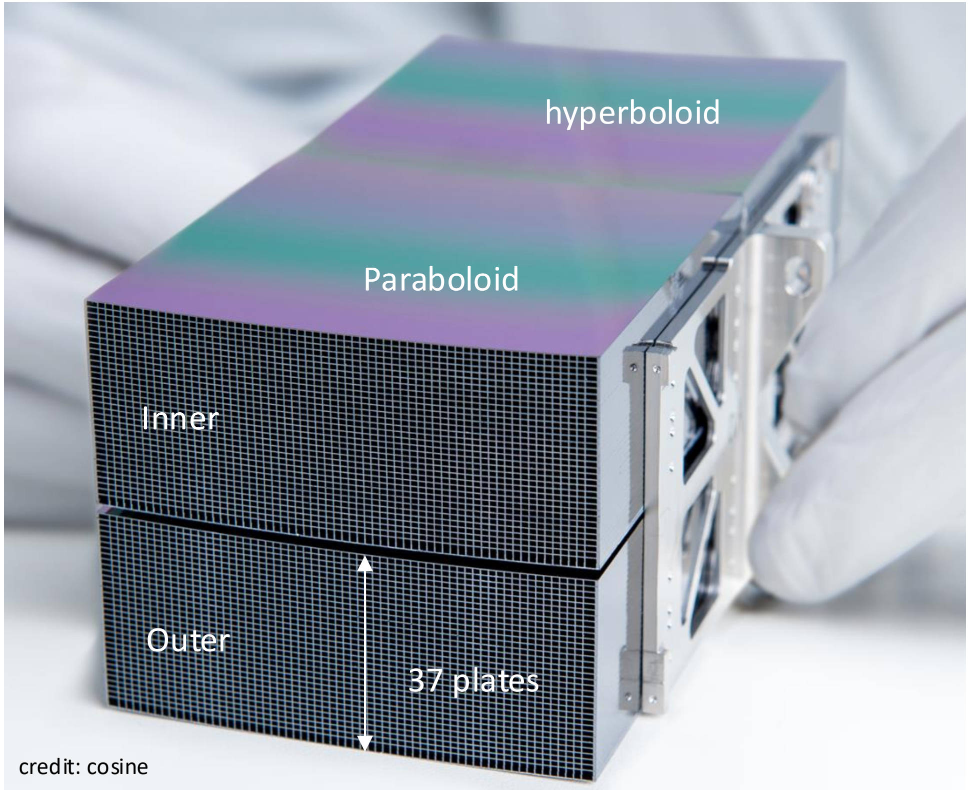
quasi-parallel



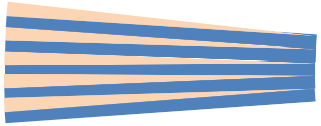
on-axis



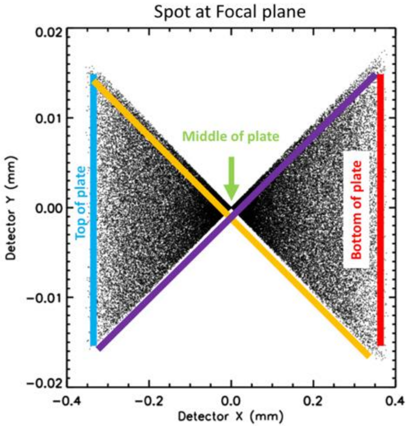
Anatomy of SPO Mirror Module (MM)

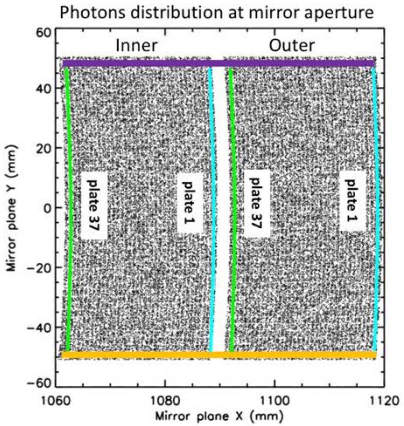


Only plate #19 in each stack obeys the WS prescription. The incidence angle from neighboring plates are advanced with a fixed angle (wedge) and these have slightly different focal lengths.



Wedge has fixed angle

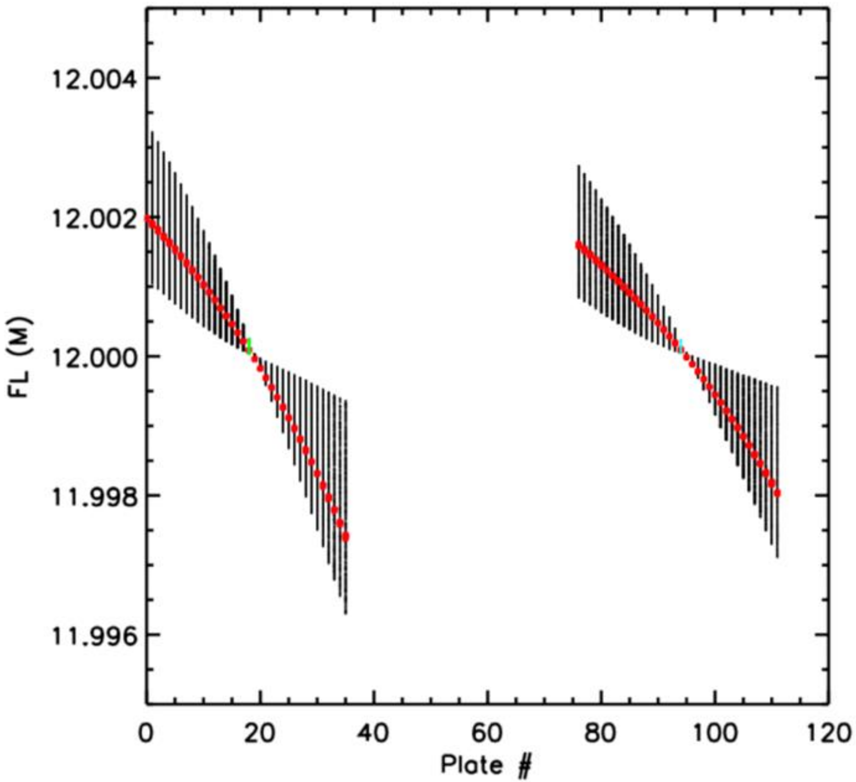




Anatomy of a MM

No scattering

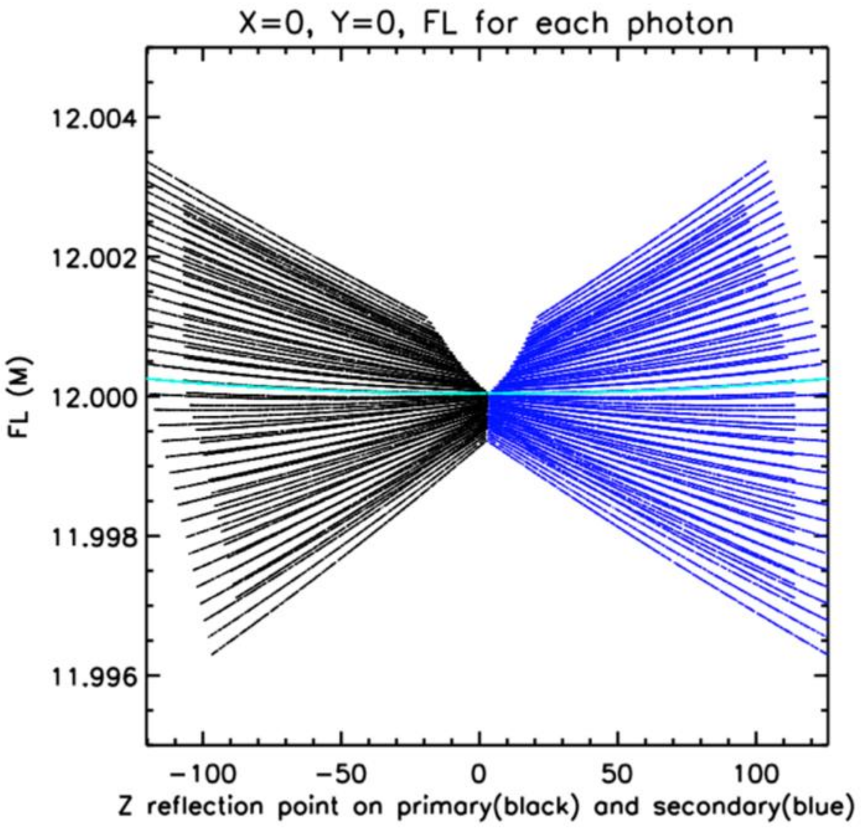
Plate 19 (in cyan) is designed to focus at 12 meters



Anatomy of a MM

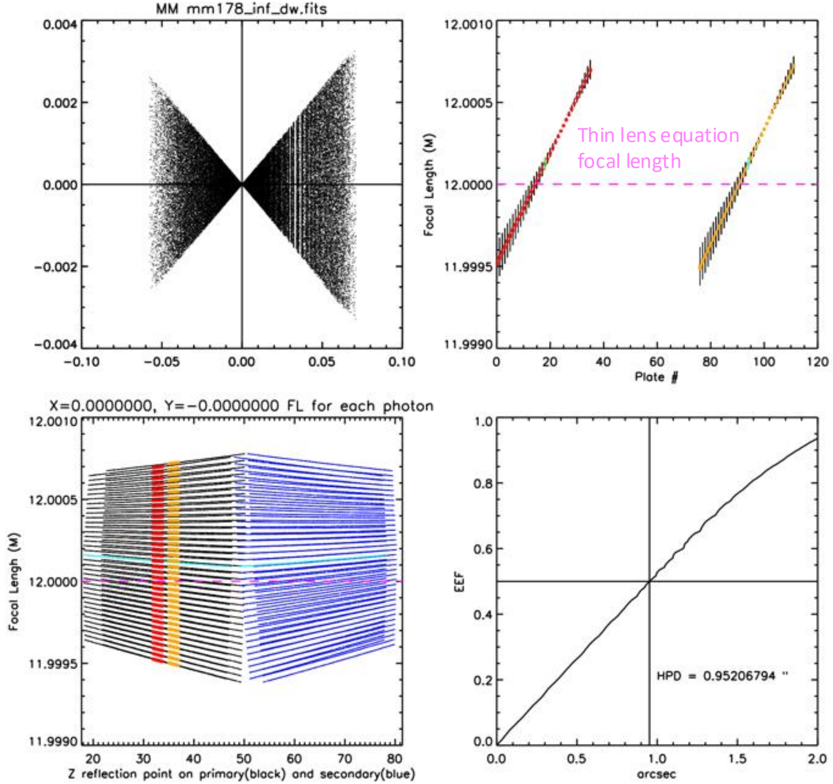
No scattering

Plate 19 (in cyan) is designed to focus at 12 meters

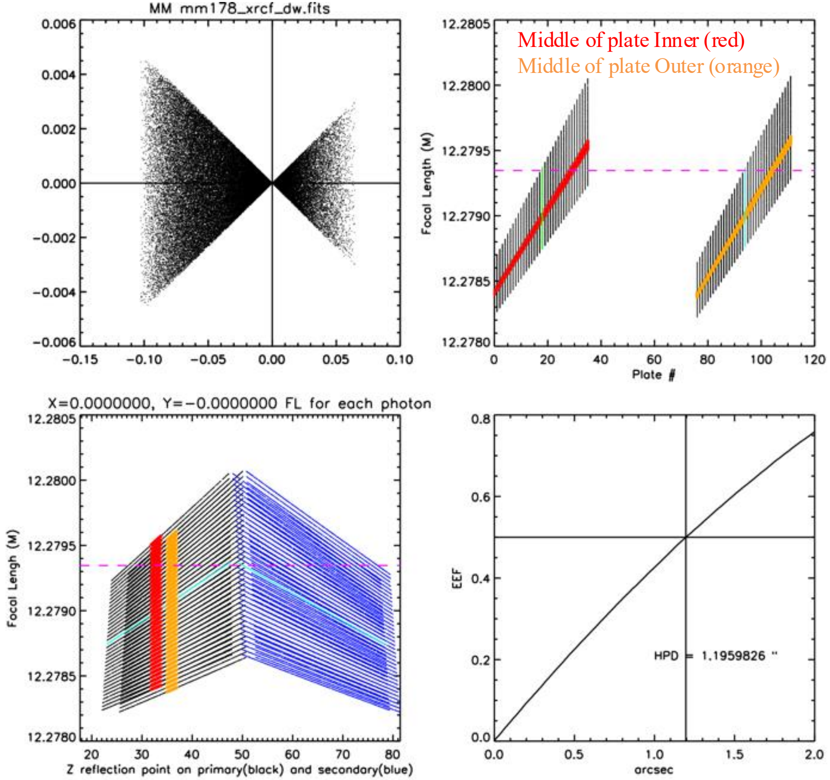


Infinite vs. finite

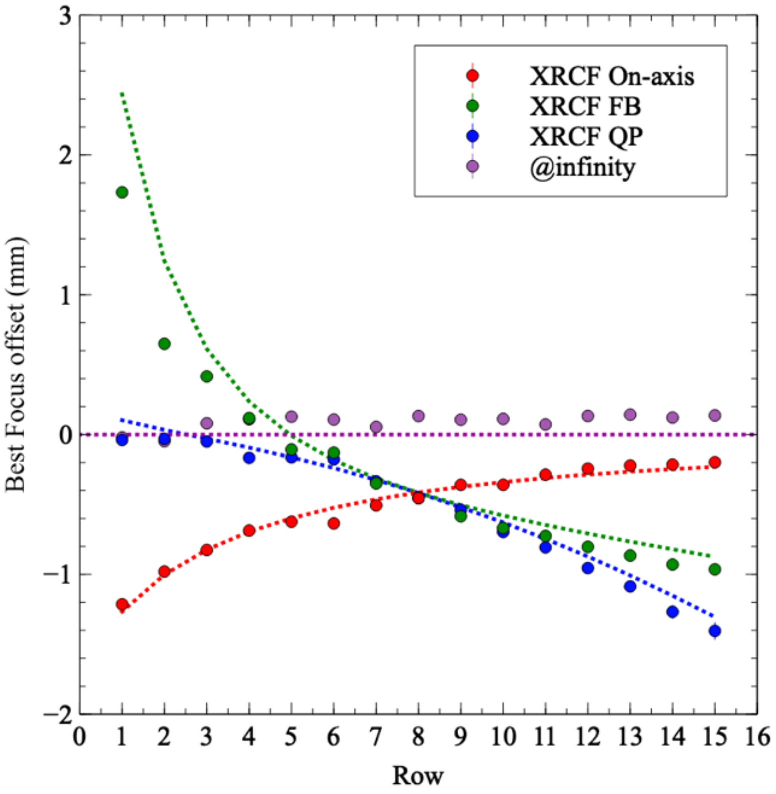
Infinite



Finite



Individual MMs as a function of Row



XRCF on-axis (X_{src}=0 mm)
XRCF Fixed Beam (X_{src}=750 mm)
Quasi parallel = QP (centered on MM)

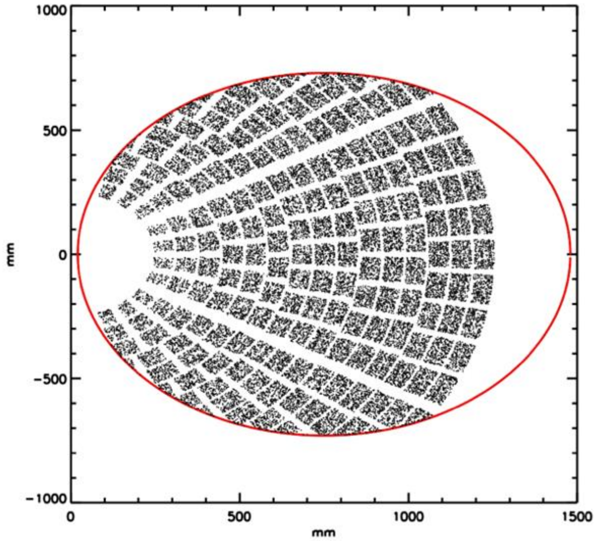
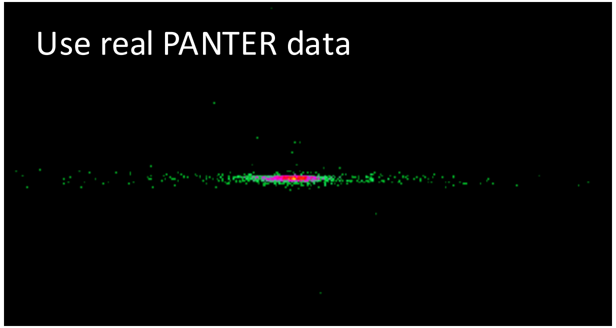
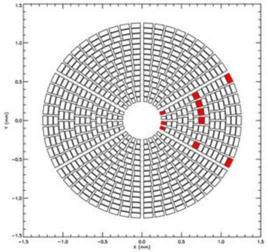


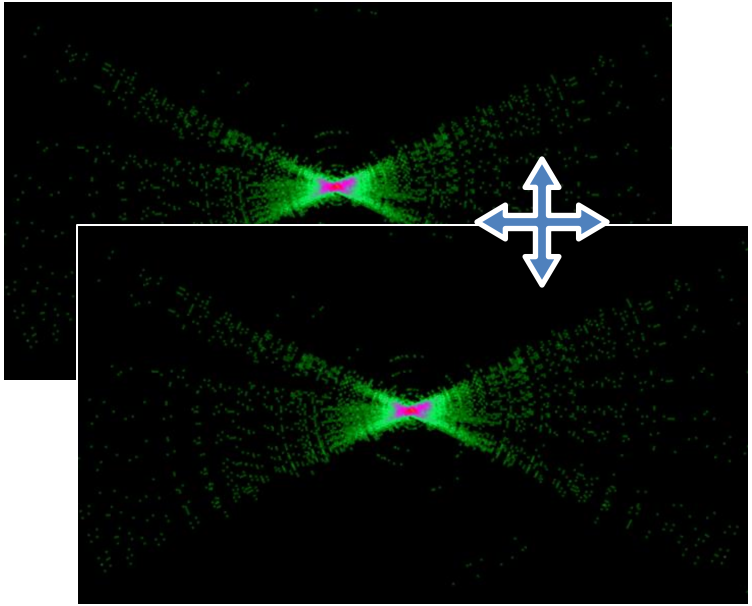
Image stitching

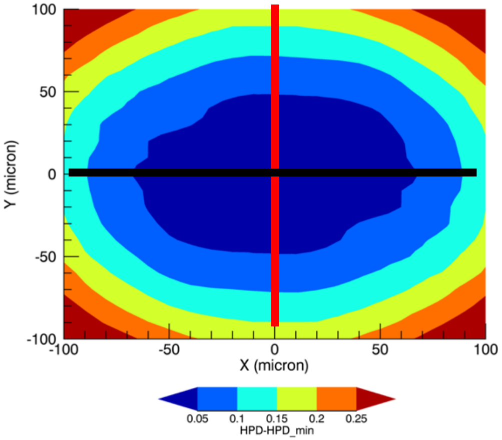
2% of 5” = 0.1”

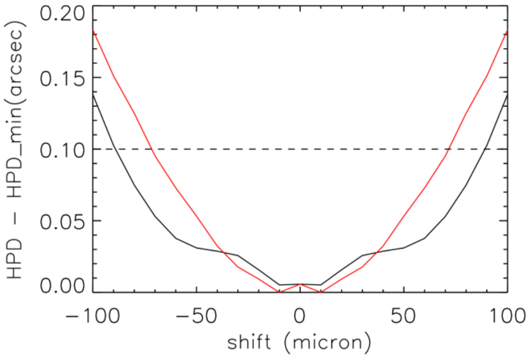


Combine 10 MMs



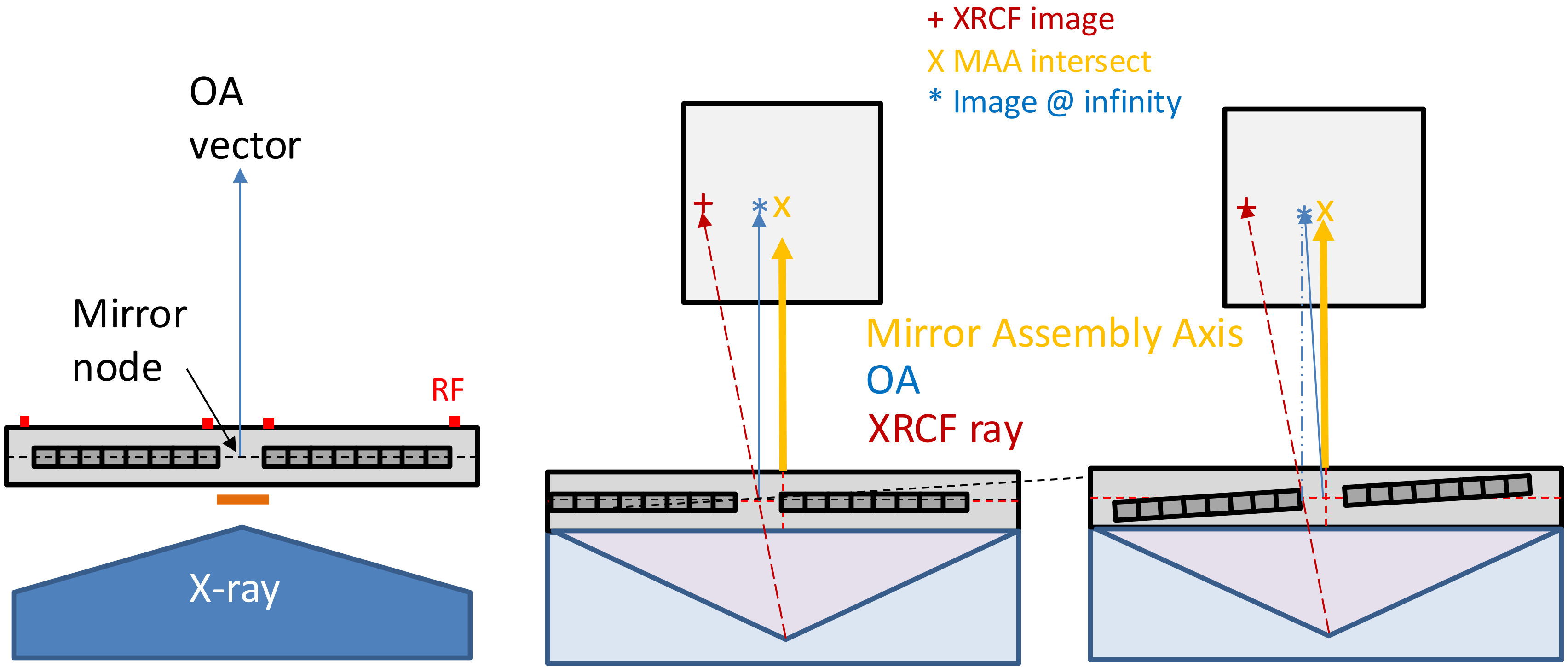






A 75-micron misalignment can change the measured PSF by 0.1”

Mirror misalignment

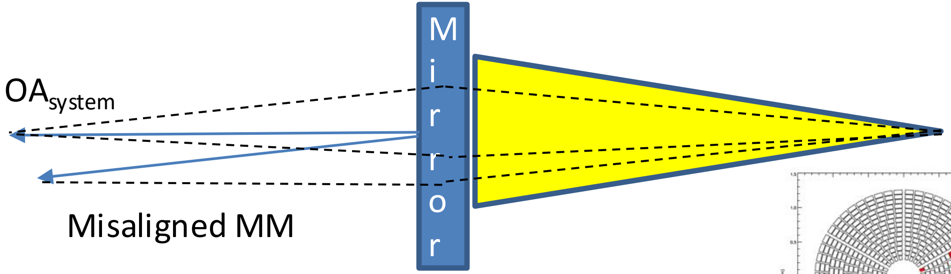


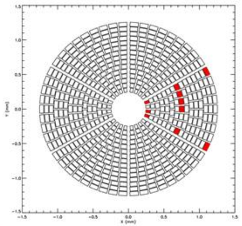
Mirror Node and Optical axis

The determination of the optical axis is the most challenging measurement at XRCF. It has two components:

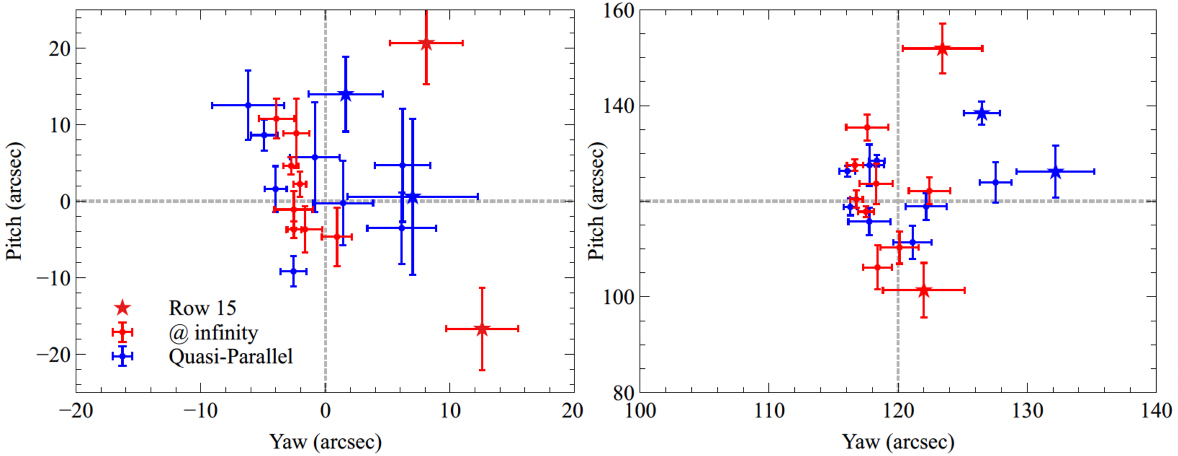
1. **mirror node location** with respect to the MCS
2. **tilt of the OA** with respect the MCS.

MCS = Mirror Coordinate System is defined by metrology





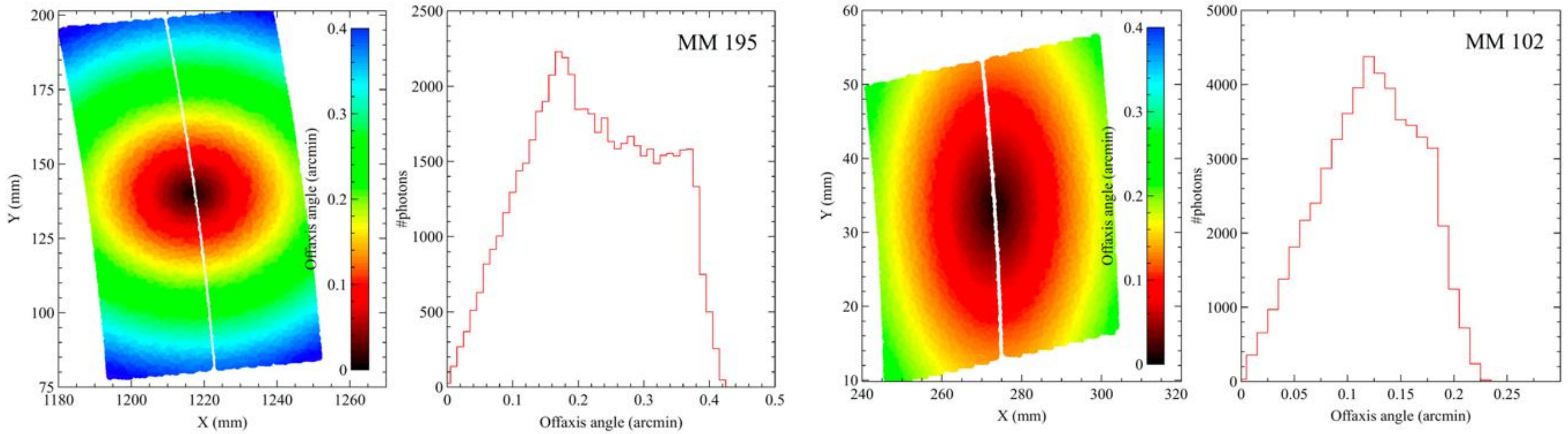
Must use vignetting curves to determine the OA_{sys} direction



Mirror node location by 150 µm
Determine OA direction by:
10” in yaw
20” in pitch

The challenge of obtaining responses ‘on-axis’

Quasi-parallel centered on the middle of an MM



Gravitational Sag of the System

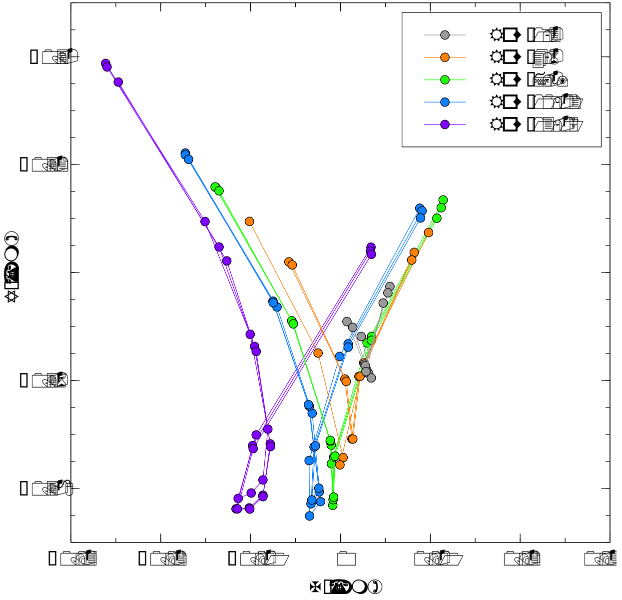
Distortions taken from CAD model and applied to the location of each SPO in the raytrace.

Only need to worry about the gravitational loads on the 3 and 9 o'clock positions, and they are mirrored.

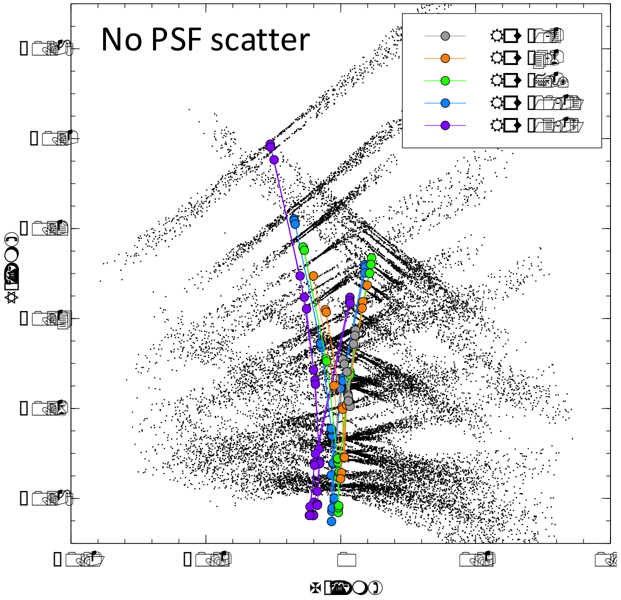
Sag of the structure and PSF matches what the LTTs measure

LTT = laser tracker targets
OD = outer diameter
ID = inner diameter

Sector 2, CAD (3 o'clock)

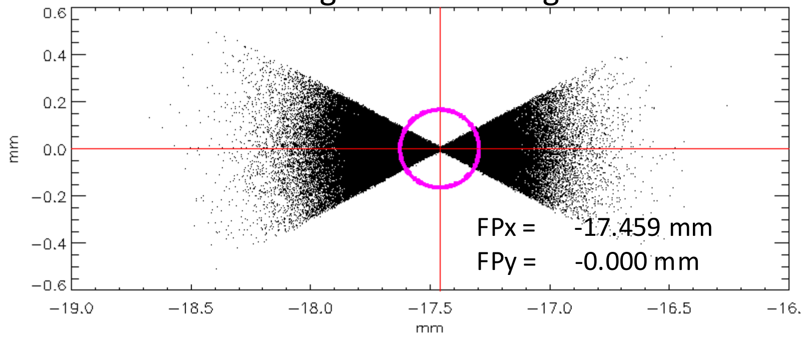


Sector 2, CAD & Raytrace

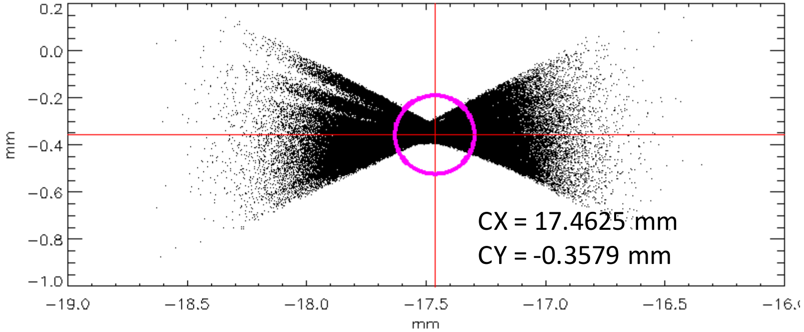


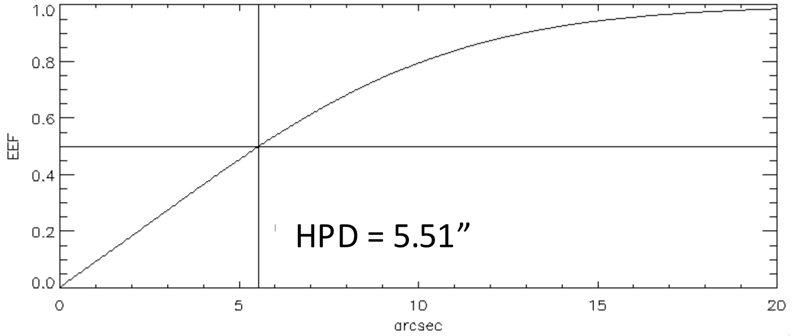
Gravitational Sag: HPD

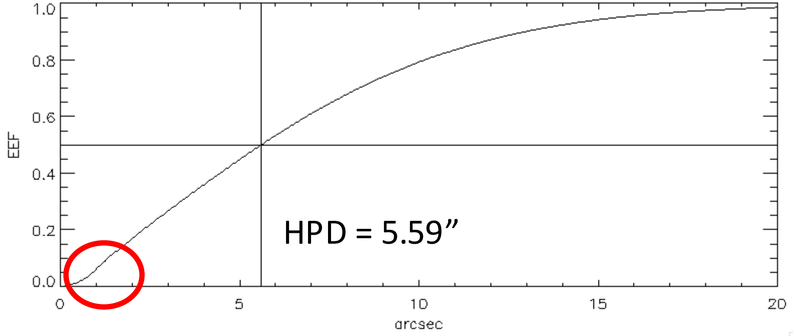
No gravitational sag



Gravitational sag







There is a global shift of 300 microns, but the distortion of PSF happens within the HPD

metrology driven requirements

- MAM Optical Axis (20”, 1-sigma)
  - Driving requirement is alignment knowledge of MCS with respect to PRS
    - 150-micron in X and Y (6-mm mirror install)
    - Initial mirror tilt of 10"
- PSF (HPD 2%, 1-sigma)
  - addition of PSF images is driven by the stitching to 75-micron
- Focal length (1-mm, 3-sigma)
  - Distance known between detector system and MAM to 300-micron
- Effective area (10%, 1-sigma)
  - Determine peak of vignetting curve to 10”
  - Measuring the effective area to 10% is a matter of photons

Summary

- Large segmented optics (diameter > 1.5m) are on the horizon
- NewAthena ground calibration will occur within the next decade
- Horizontal calibration facilities can meet the NewAthena calibration requirements
- But there are challenges
  - requires an accurate model and raytrace to interpret results
  - requires a very accurate external metrology system capable of microns and mrad precision