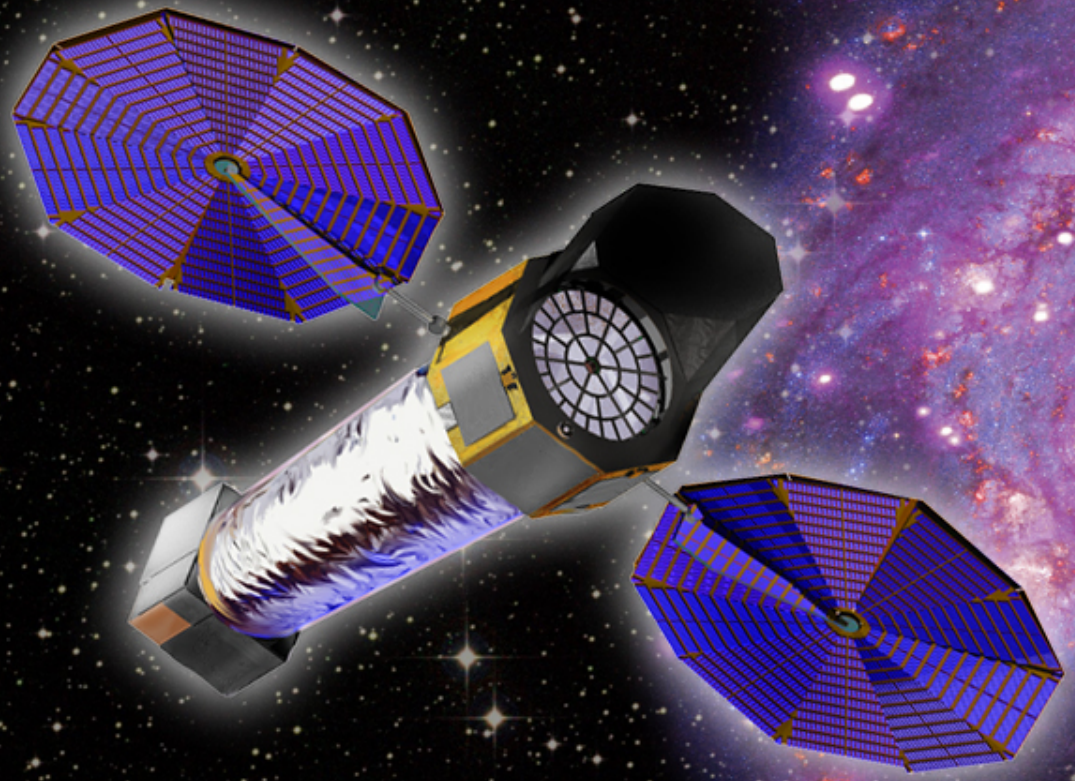
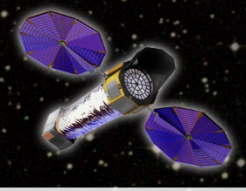
X-RAY OBSERVATORY

LYNX



The *Lynx* Off-Plane X-ray Grating Spectrograph

Randall L. McEntaffer
Penn State University



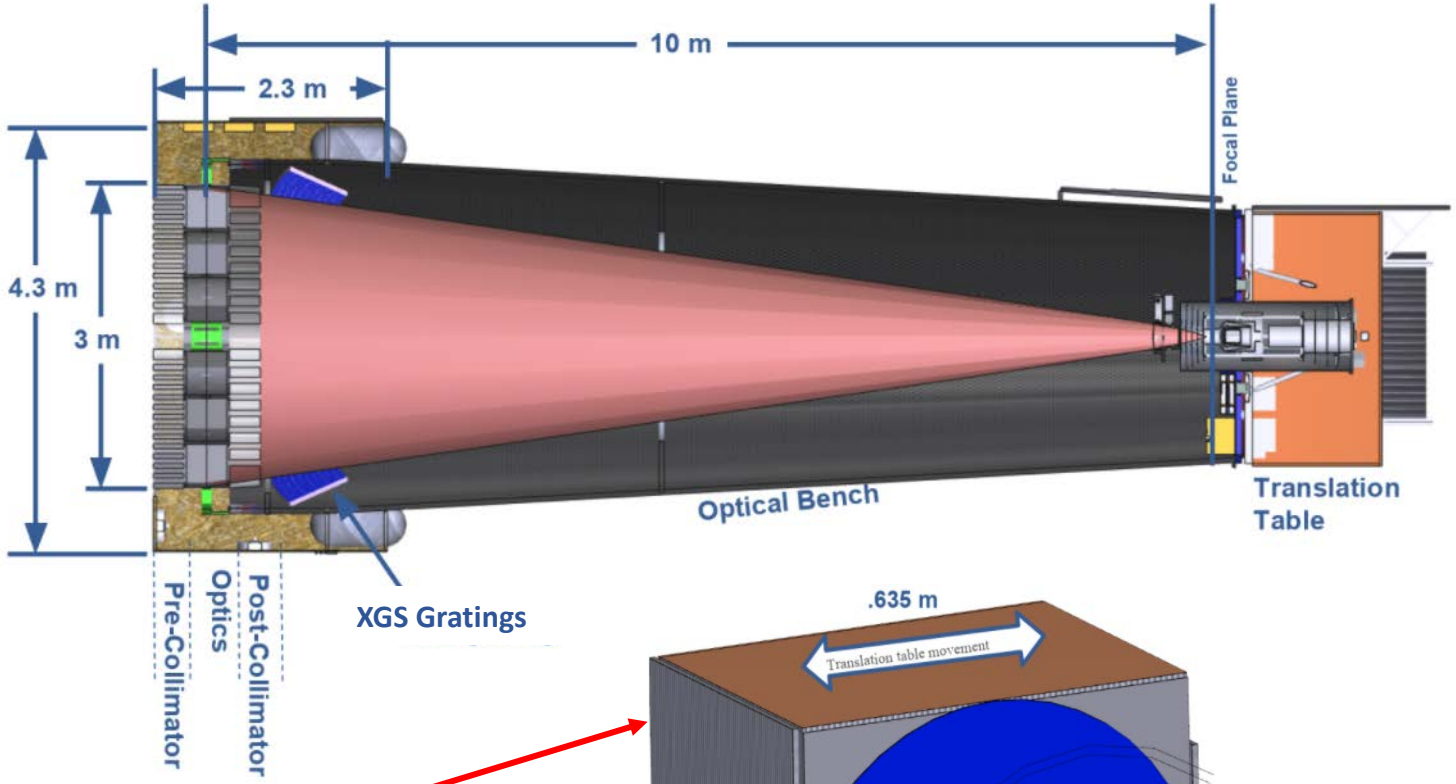
X-RAY OBSERVATORY
LYNX
REVEALING THE INVISIBLE UNIVERSE

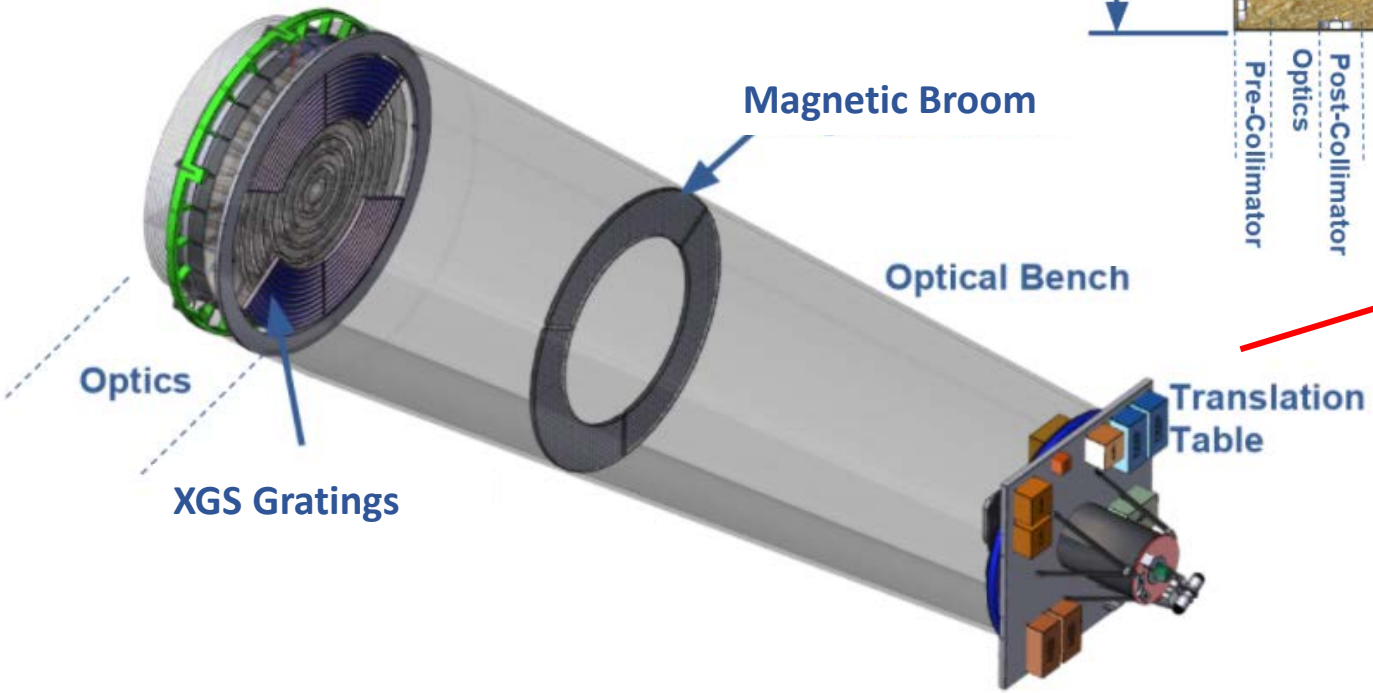
Lynx Overview

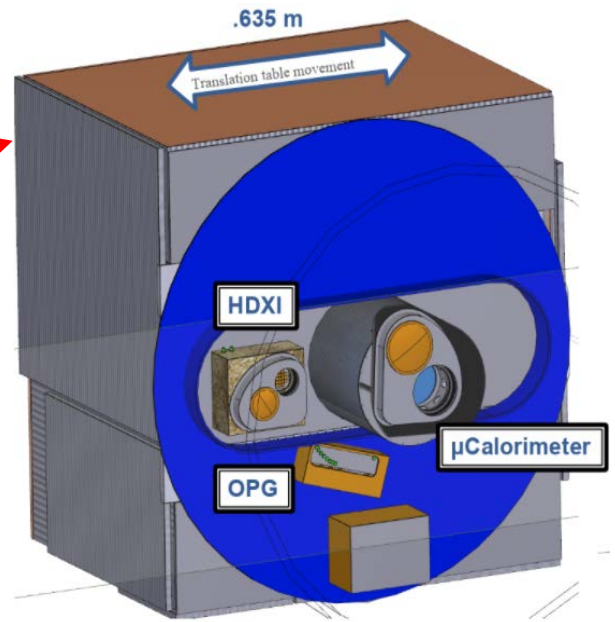
- Optics
  - Full shell
  - Slumped glass
  - Polished Si
- Instruments
  - High Definition X-ray Imager (HDXI)
  - Lynx X-ray Microcalorimeter (LXM)
  - X-ray Grating Spectrograph (XGS)

- XGS Science
  - Map hot gas around galaxies and in Cosmic Web
  - Detail galactic feedback
  - Study stellar coronal physics and stellar activity
- XGS Requirements
  - Spectral resolving power, $\lambda/\delta\lambda > 5000$
  - Effective area >4000 cm^2 for X-ray emission/absorption lines of C, O, Ne, Mg, Fe
  - Energy band: 0.2 – 2.0 keV

Lynx Overview





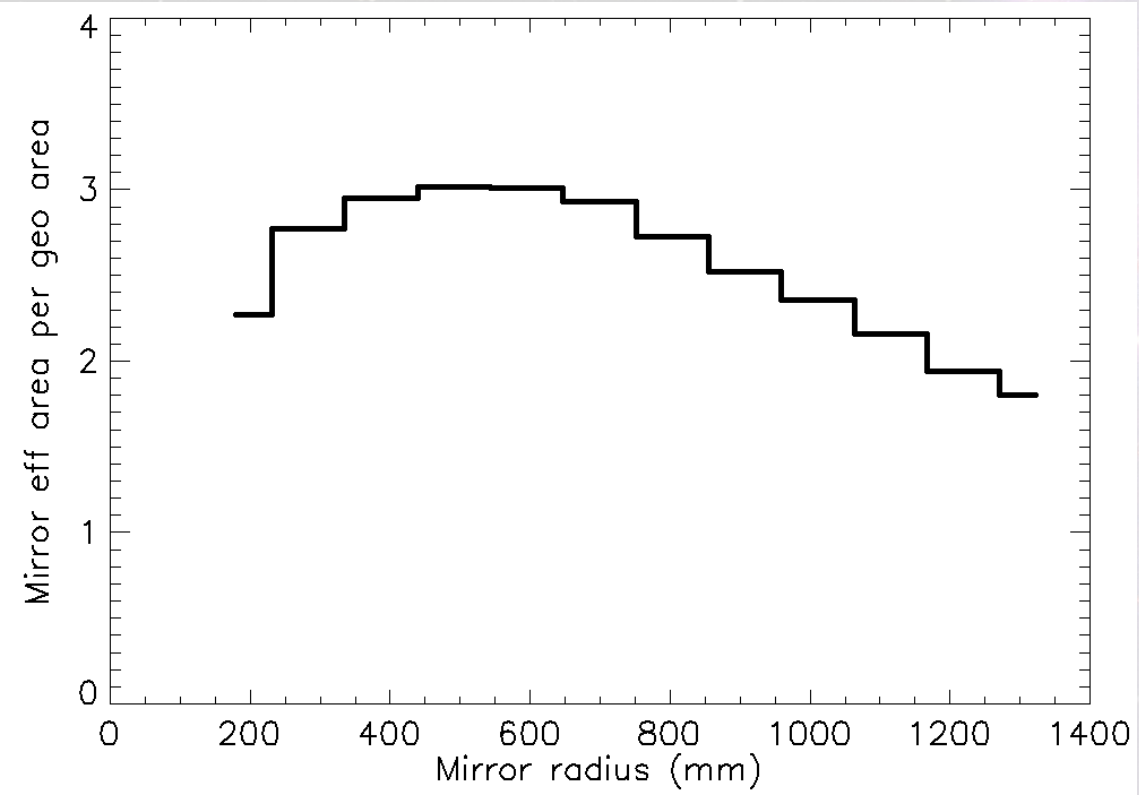


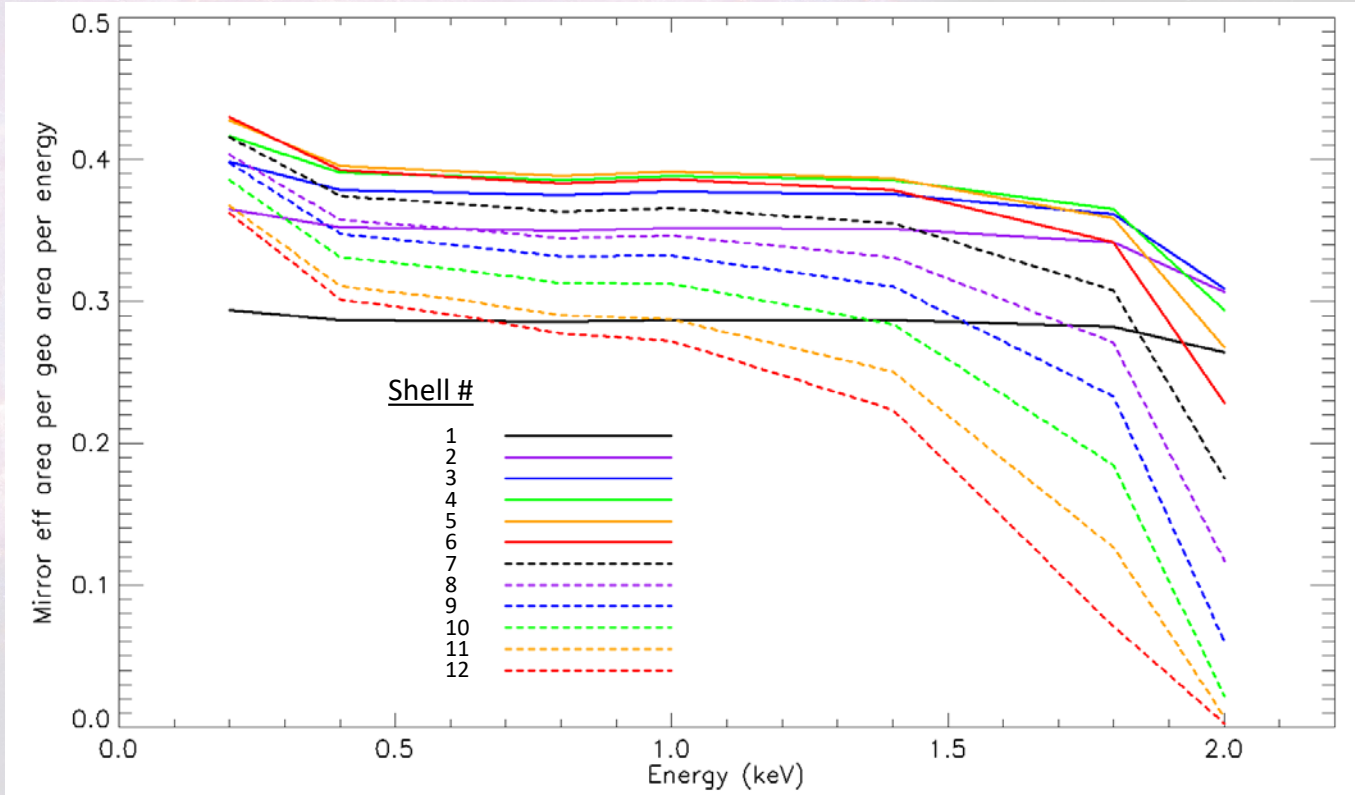
Design considerations for effective area

- Achieve >4400 cm^2 at OVII (~568 eV)
- Limit telescope area covered
  - Reduces array mass
  - Allows for concurrent observation by other focal plane instrumentation
  - Has potential for increased resolving power
- Requires a study of telescope effective area as a function of area

Design considerations for effective area

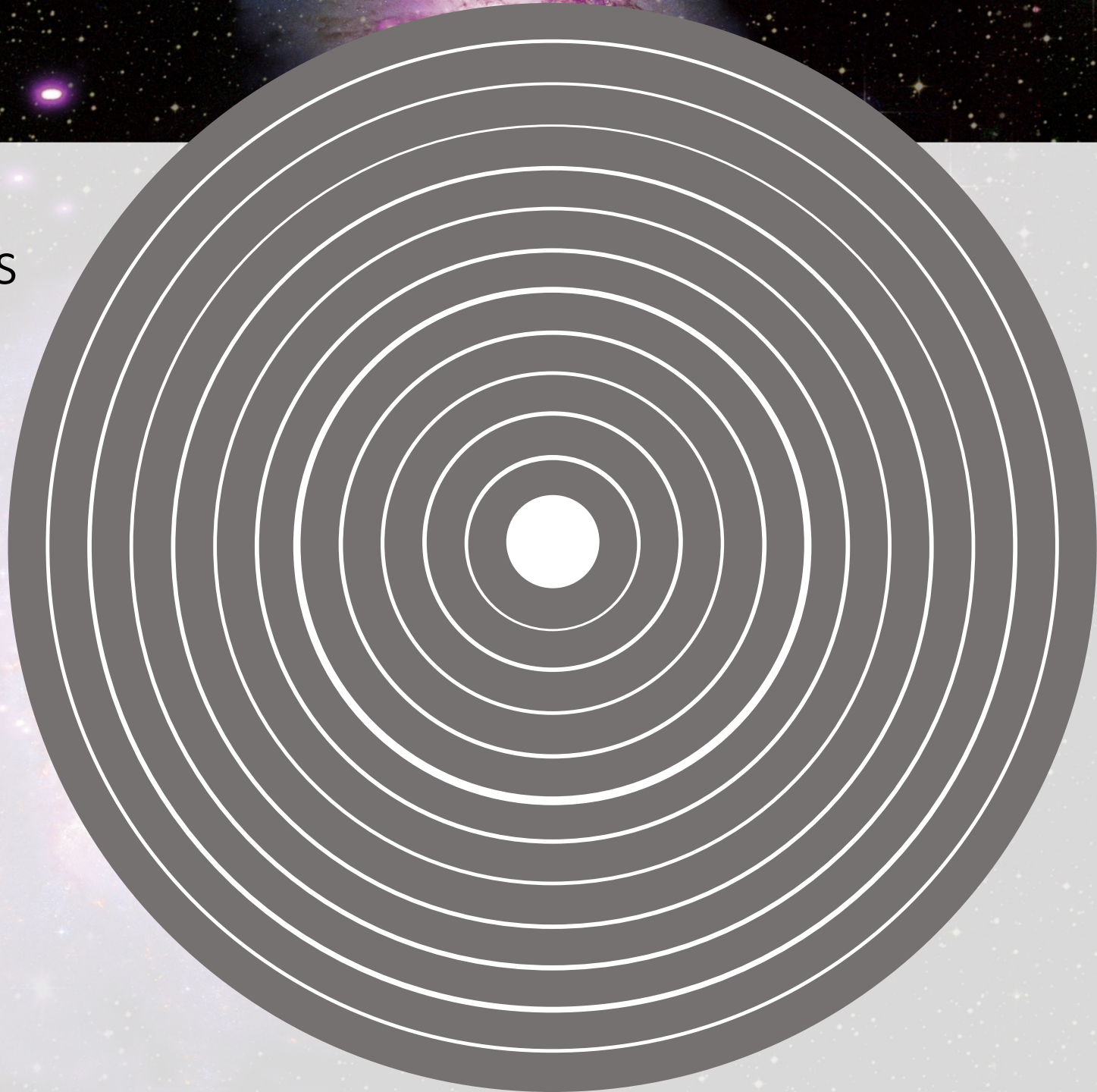
- Representative mirror
  - R = 127 – 1496 mm; section into 12 shells





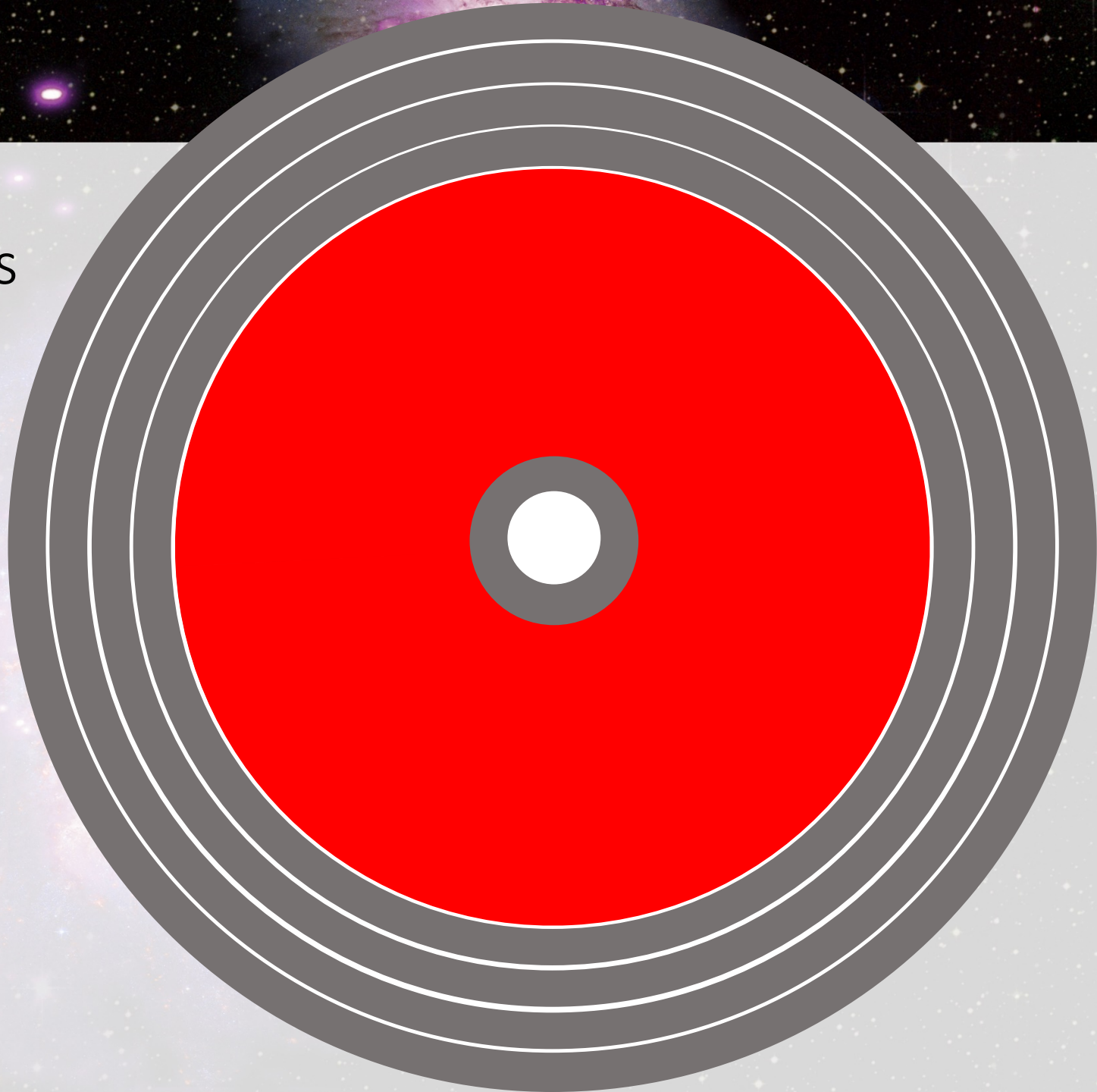
Mirror coverage considerations

- Trade of azimuth vs. radius
- Achieve 4400 cm^2 @ OVII



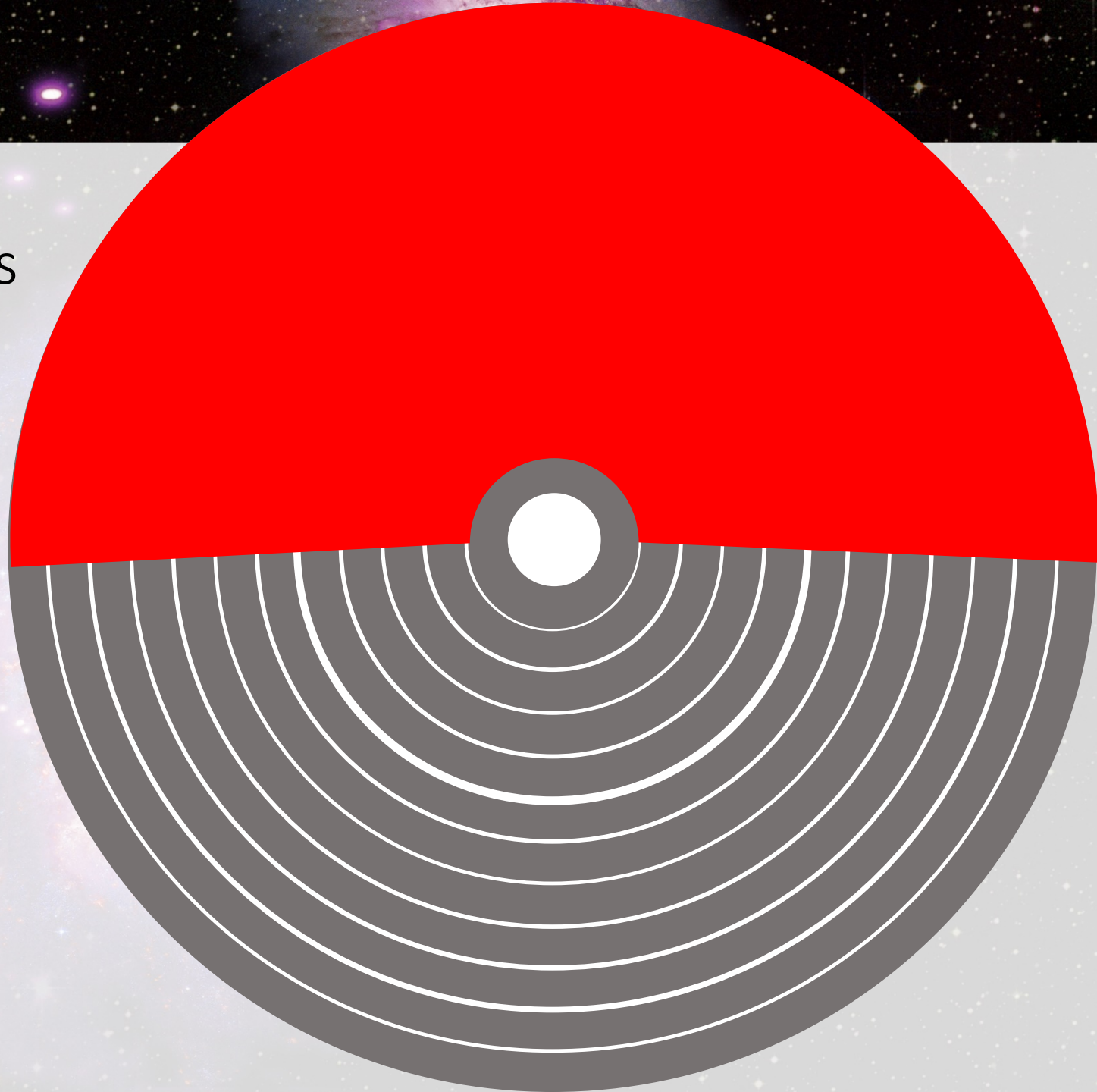
Mirror coverage considerations

- Trade of azimuth vs. radius
- Achieve 4400 cm^2 @ OVII
- Options
  - Shells 2-8; full coverage
    - 54% uncovered mirror



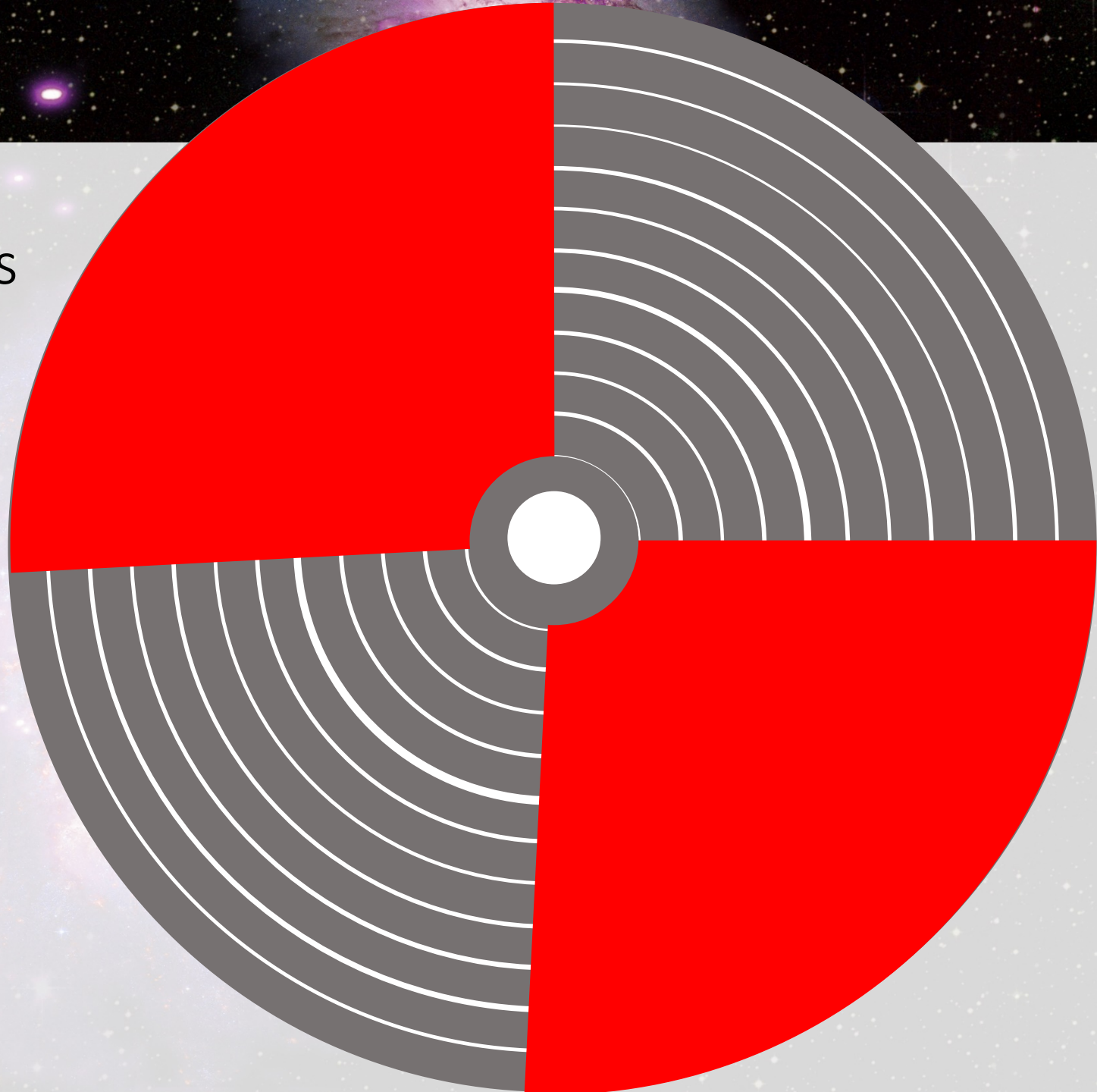
Mirror coverage considerations

- Trade of azimuth vs. radius
- Achieve 4400 cm^2 @ OVII
- Options
  - Shells 2-8; full coverage
    - 54% uncovered mirror
  - Shells 2-12; 184°



Mirror coverage considerations

- Trade of azimuth vs. radius
- Achieve 4400 cm^2 @ OVII
- Options
  - Shells 2-8; full coverage
    - 54% uncovered mirror
  - Shells 2-12; 184°; continuous or two 92° segments on either side
    - 50% uncovered mirror

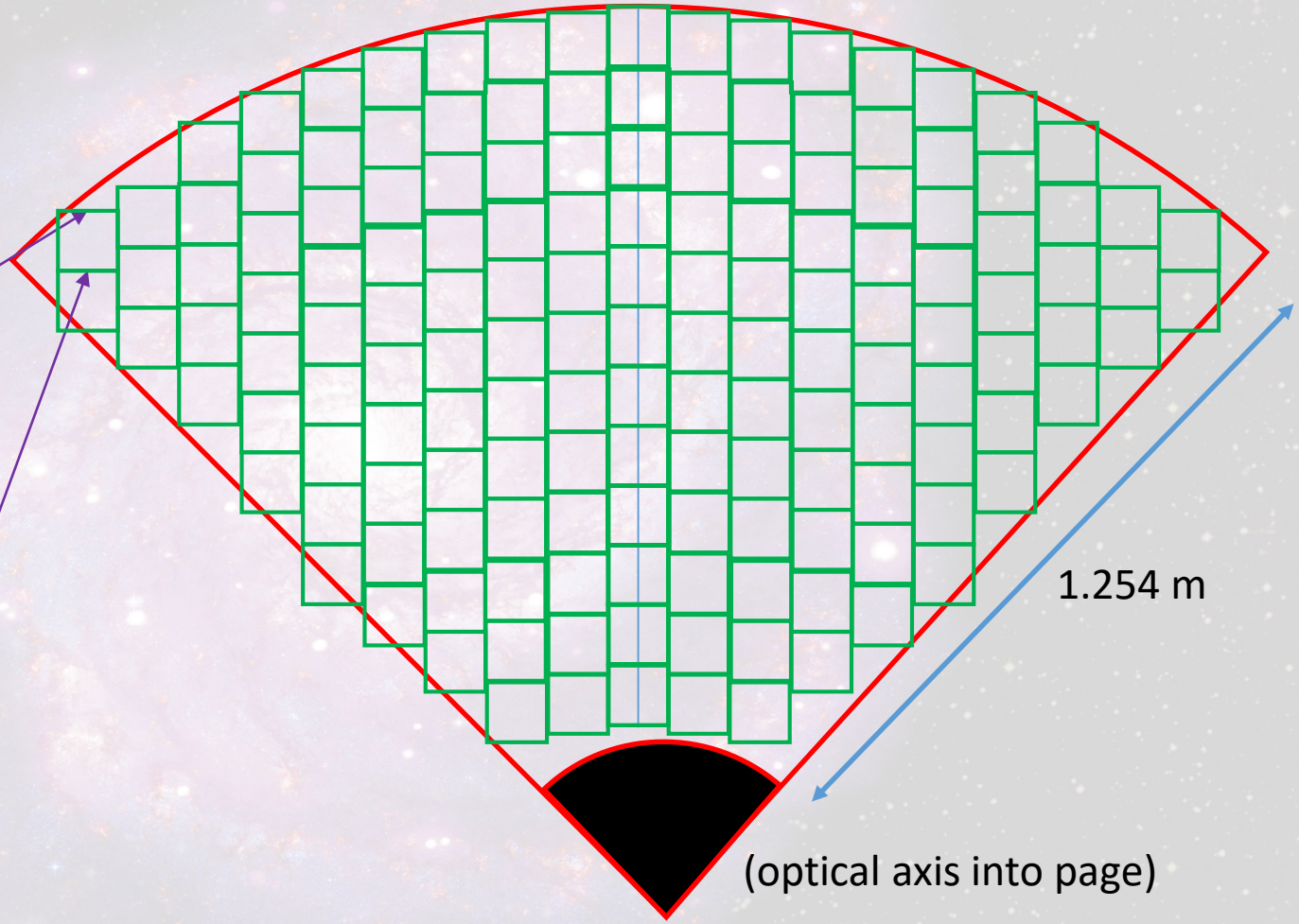


Mirror coverage considerations

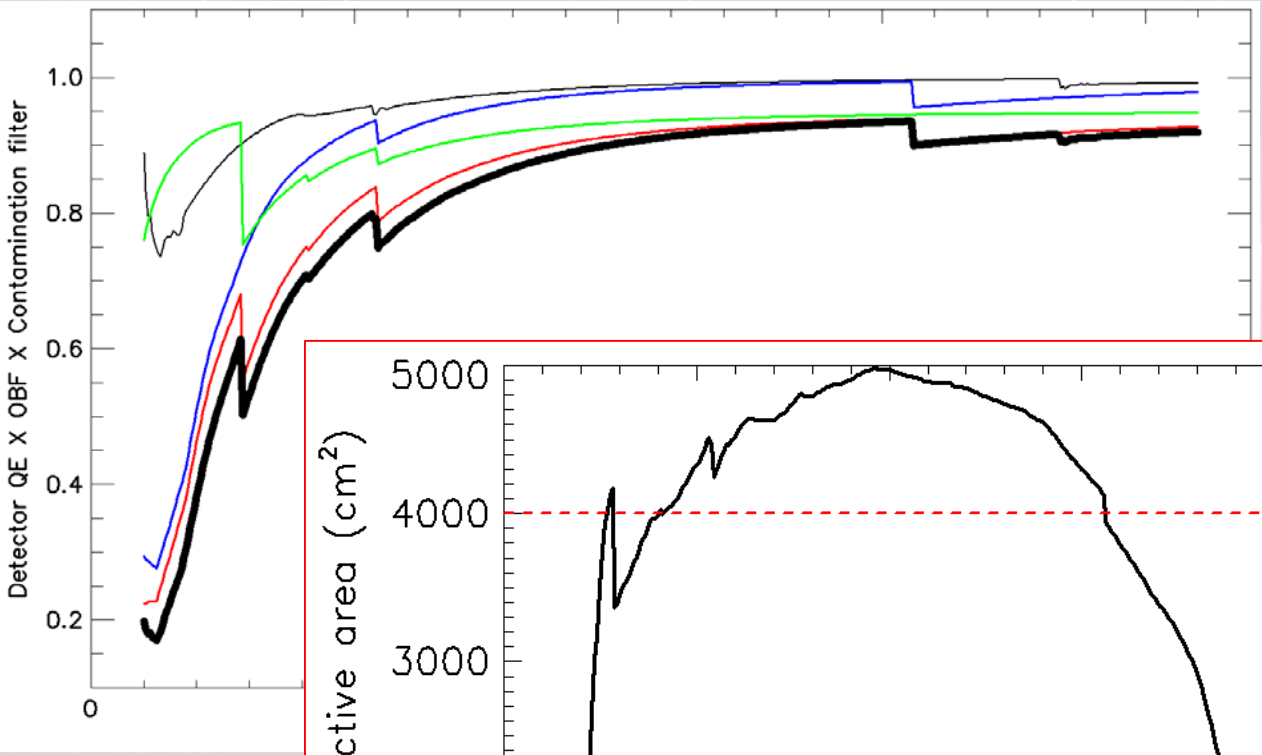
- Trade of azimuth vs. radius
- Achieve 4400 cm^2 @ OVII
- Options
  - Shells 2-8; full coverage
    - 54% uncovered mirror
  - Shells 2-12; 184°; continuous or two 92° segments on either side
    - 50% uncovered mirror
  - Shells 2-10; two 123° segments
    - 52% uncovered mirror

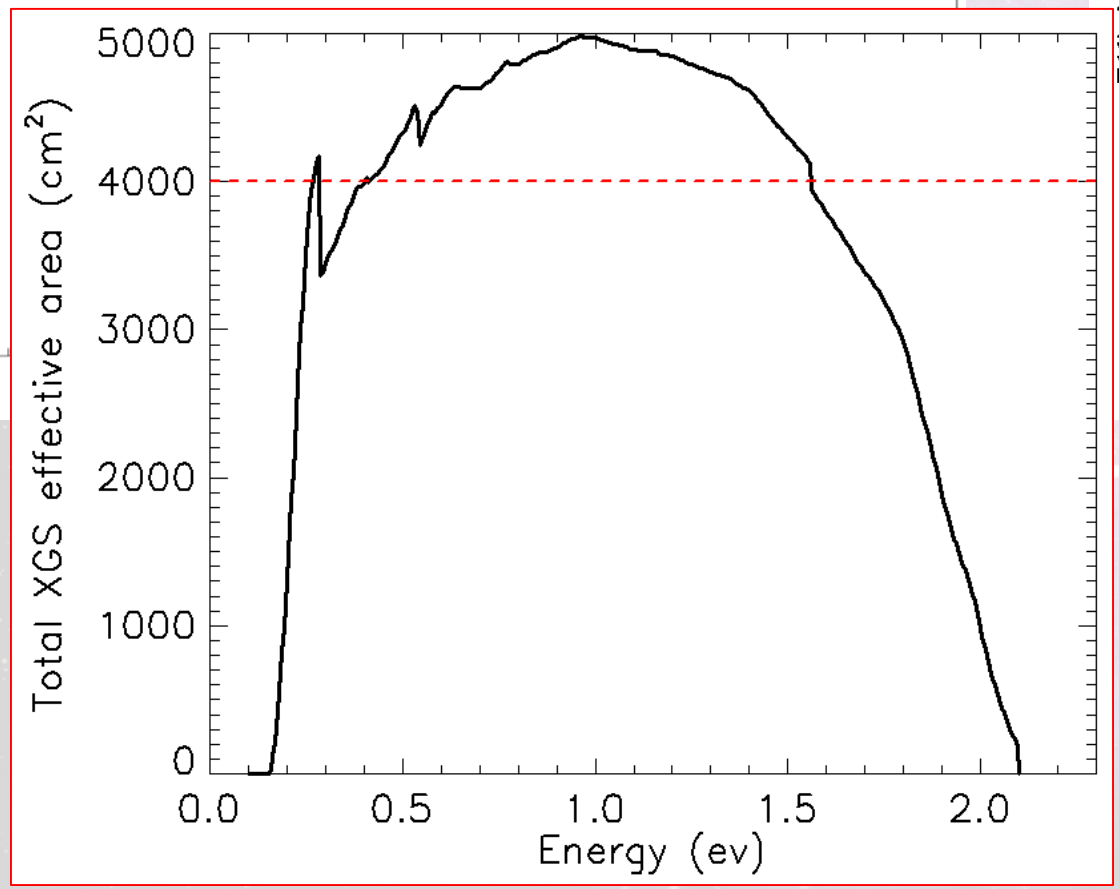
Module layout

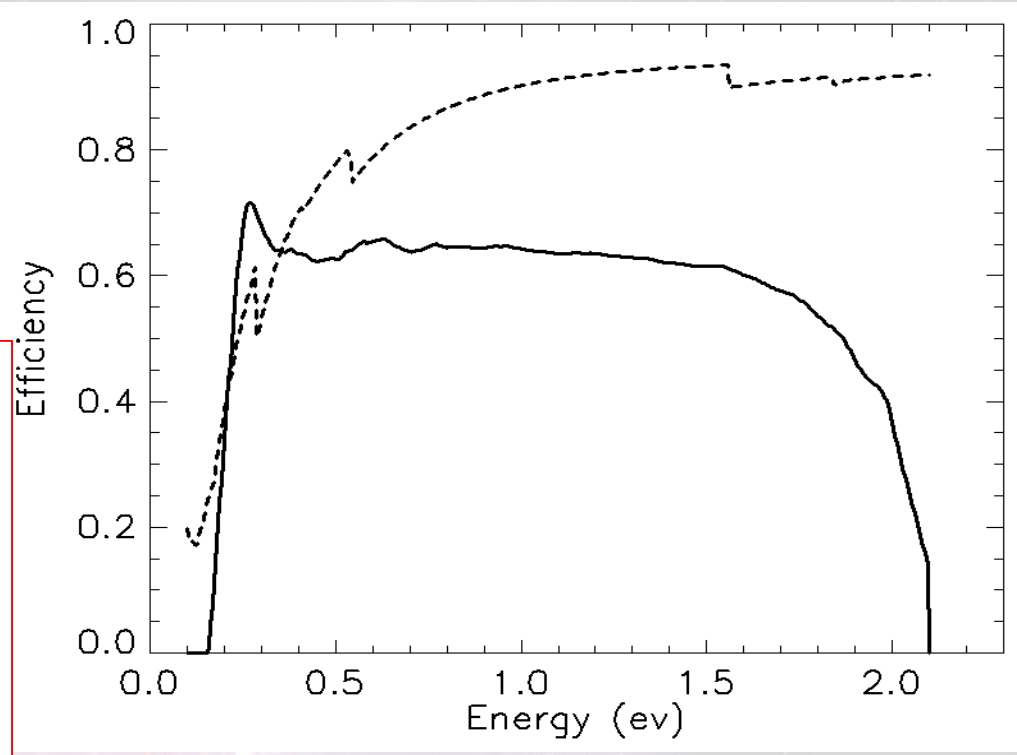
- Assuming module cross section ~10 x 10 cm
- Using 92° wedge as an example



Representative grating module with 3.12 mm grating spacing (32 gratings – each grating is 10 x 10 x 0.05 cm)

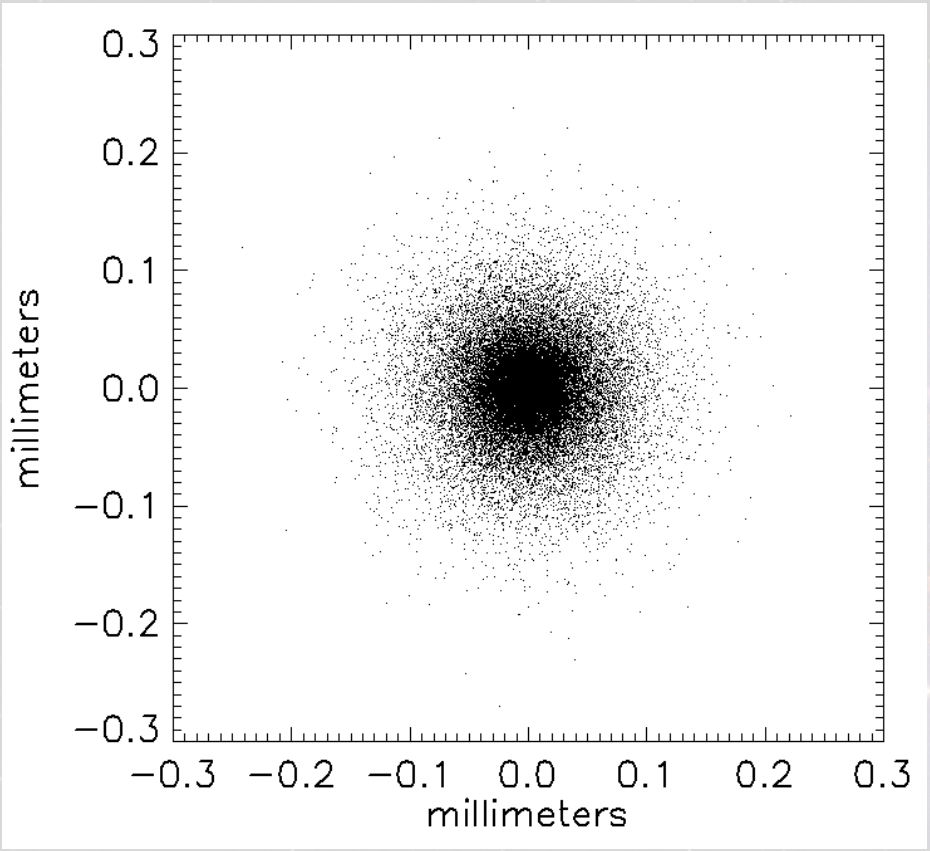

Detector QE X OBF X Contamination filter
1.0
0.8
0.6
0.4
0.2
0


Total XGS effective area (cm^2)
5000
4000
3000
2000
1000
0
0.0
0.5
1.0
1.5
2.0
Energy (ev)

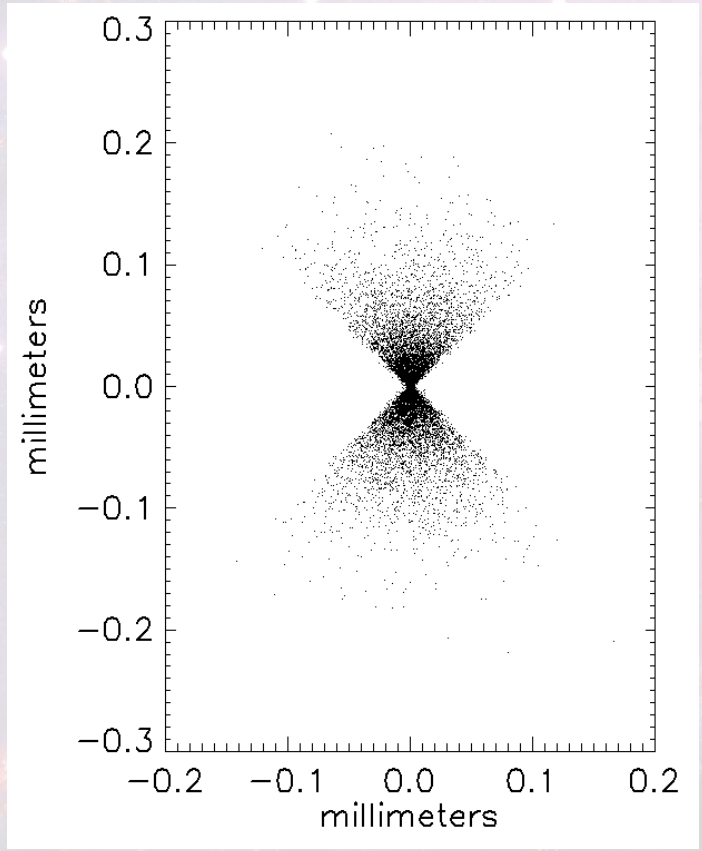

Efficiency
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
Energy (ev)

Design considerations for resolving power

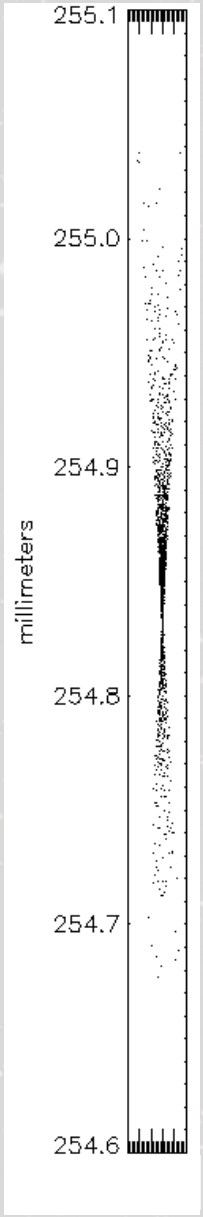
Full telescope (0.5” HPD)



92° wedge (0.4” HPD)



One module (0.03” HPD)

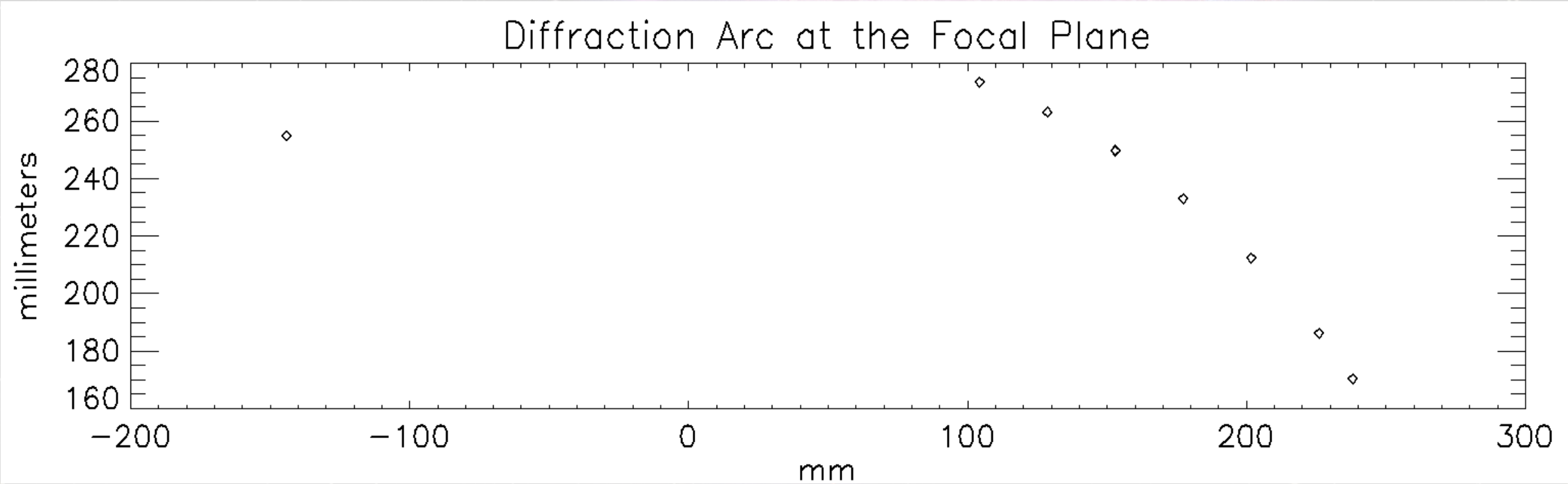


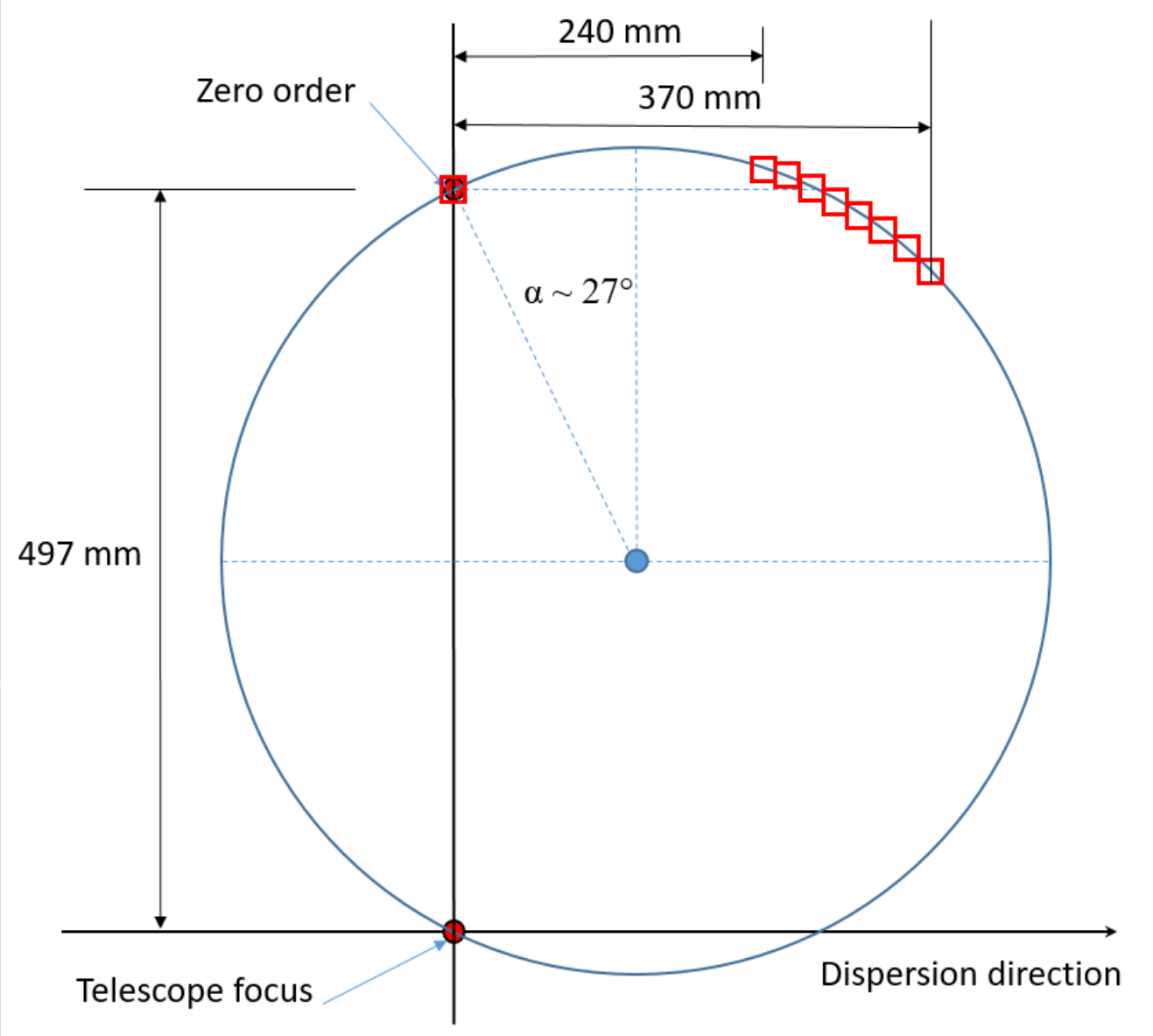
Design considerations for resolving power

- Requirement – $\lambda/\delta\lambda > 5000$
  - Key science around 22 Å
- Assumption
  - The 0.06” modules are aligned to create a 1” line spread function (LSF)
    - Gives a 0.87” error budget for grating contributions
      - Period errors, alignment, astigmatism, pointing, detector pixilation, …
- Diffraction characteristics
  - Groove density = 2500 gr/mm
  - Graze angle = 1.5°
  - Dispersion = 0.42 Å/mm
  - 1” LSF = 0.0485 mm width at focal plane = 0.0204 Å width, which gives R = 5000 @ 102 Å
  - Therefore, place blaze at 109 Å (5^{th} order OVII) => ~27.5° blaze angle

Focal plane layout

- 8 sensors can cover the required band (0.2-2.0 keV/6.2-62Å) without gaps
- Order overlap requires ~80 eV detector energy resolution
- Results in R = 5000 – 7700 per order





Sensor Layout

- Uses 9x (8 spectral, 1 zero order) sensors measuring
- Each measure 16.384 mm.
- Spectral sensors detect orders 1-17 which requires 80 eV sensor energy resolution.
- XGS science completely decoupled from telescope focus instrument

A recent reflection grating design by ACO (MSFC)

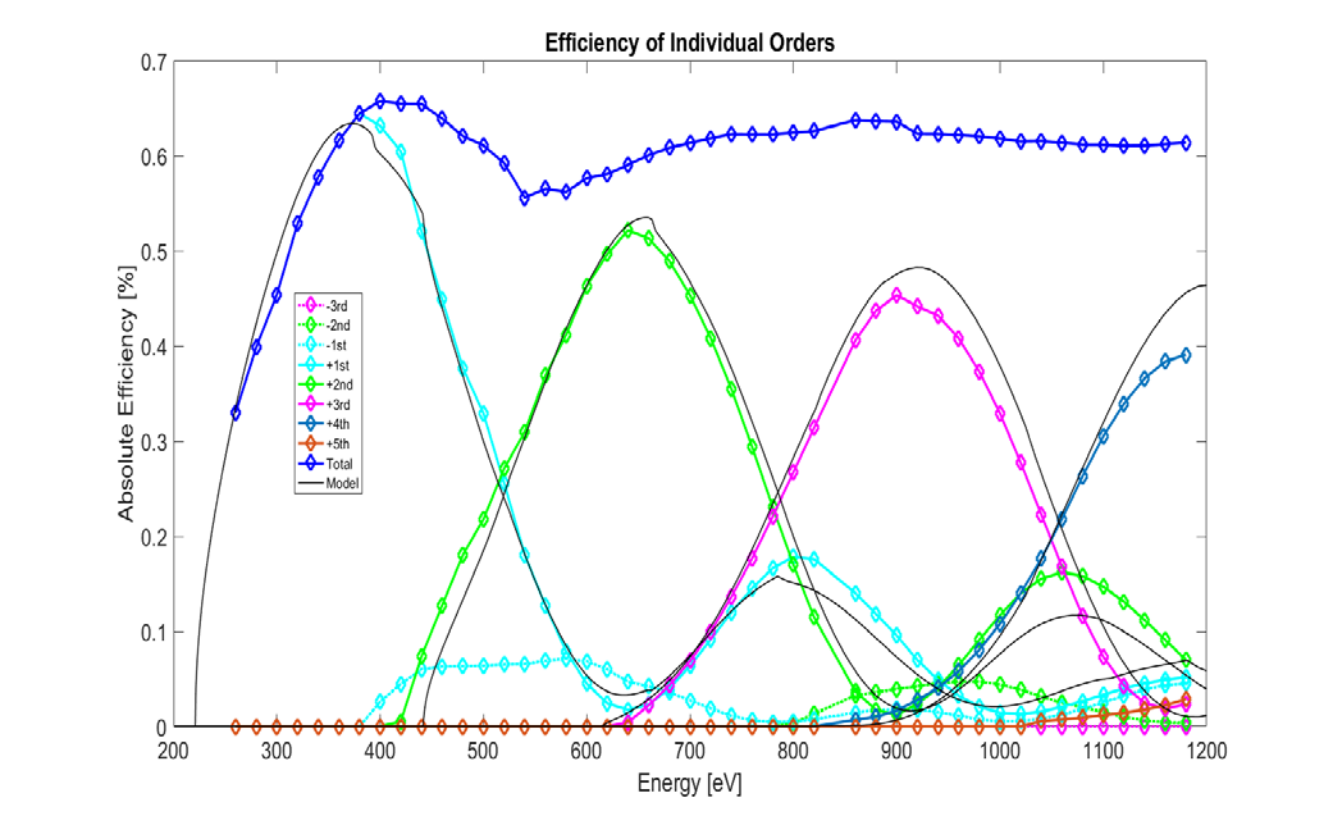
Mass Estimation List (MEL)			Qty	Mass Each (kg)	Basic Mass (kg)	MGA (%)	MGA (kg)	Predicted Mass (kg)
4.0 Structures					**8.101**	**30%**	**2.4303**	**10.531**
	4.1	XGS-OPG Detector Assembly Housing	1	5.5510	5.551	30%	1.665	7.216
	4.2	Secondary Structures	1	2.5500	2.550	30%	0.765	3.315
XGS-OPG Gratings Array								
11.0 Grating Assembly A					**28.948**	**30%**	**8.684**	**37.632**
	11.1	Grating Assembly Structure	1	4.273	4.273	30%	1.282	5.555
	11.2	OPG Module Assembly	75	0.329	24.675	30%	7.403	32.078
12.0 Grating Assembly B					**28.948**	**30%**	**8.684**	**37.632**
	12.1	Grating Assembly Structure	1	4.273	4.273	30%	1.282	5.555
	12.2	OPG Module Assembly	75	0.329	24.675	30%	7.403	32.078
13.0 Grating Assembly C					**28.948**	**30%**	**8.684**	**37.632**
	13.1	Grating Assembly Structure	1	4.273	4.273	30%	1.282	5.555
	13.2	OPG Module Assembly	75	0.329	24.675	30%	7.403	32.078
14.0 Grating Assembly D					**28.948**	**30%**	**8.684**	**37.632**
	14.1	Grating Assembly Structure	1	4.273	4.273	30%	1.282	5.555
	14.2	OPG Module Assembly	75	0.329	24.675	30%	7.403	32.078

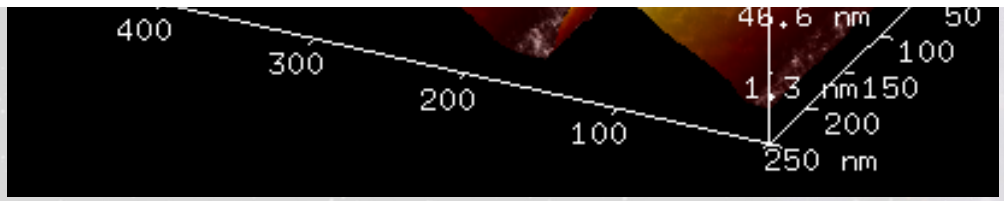
- Total array mass = ***115.792 kg***

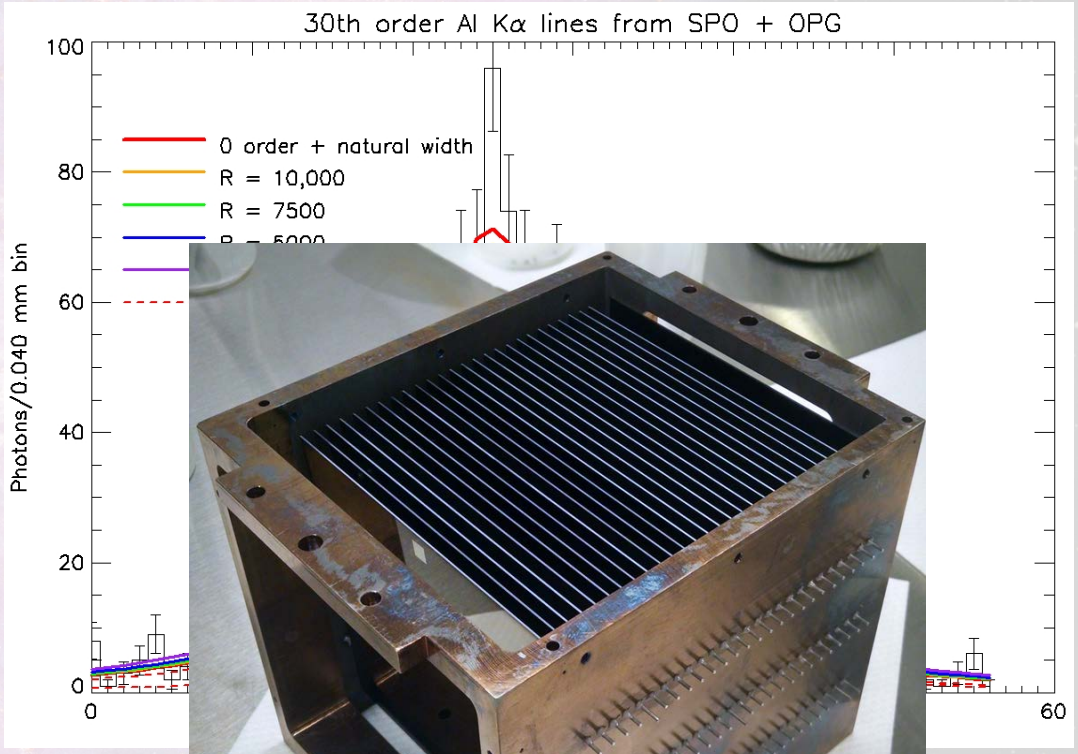
Technology development challenge examples

- Fabrication of 1,000s of grating elements
  - Requires replication
    - Current study of replication techniques is ongoing and promising (have created ~30 high quality replicas in one day with capacity for more)
  - Requires a high quality master
    - Custom blaze profiles have been successfully realized
    - Custom radial profiles have been successfully realized
    - Next step - fabricate and test a Lynx-specific prototype
- Alignment of 1,000s of gratings
  - Requires analysis but at least one degree of freedom is likely to be <10”
    - XMM aligned to ~1”
    - Knowledge of telescope PSF and detailed raytracing required to assess tolerances
- Module/Array design

…at the beginning of the tech dev road:







Summary

- Reflection gratings are currently being studied for the Lynx X-ray Grating Spectrograph
- A conceptual design meets requirements for effective area and resolving power
- ~50% of the telescope area is covered, thus allowing for efficient concurrent observation with another focal plane instrument
- Further design details need to be constrained with more knowledge of the telescope PSF and additional detailed raytracing, tolerancing, etc.

- *Thank you for you attention!*