Arcus: Exploring the Formation and Evolution of Clusters, Galaxies, and Stars

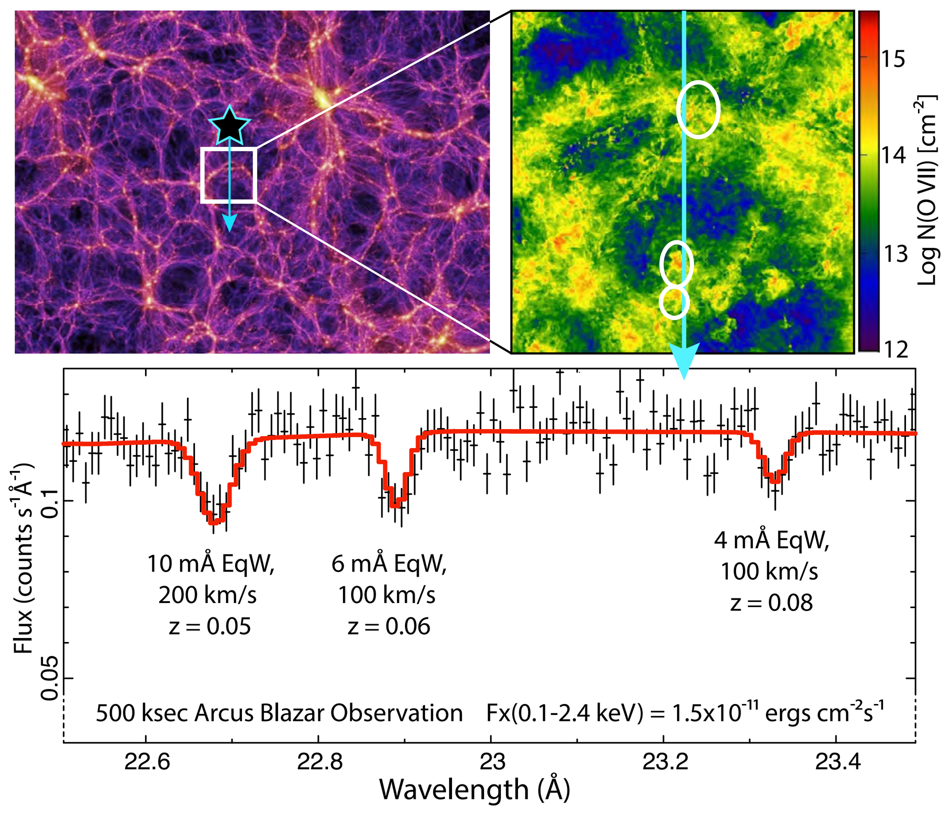
Randall K. Smith[1], R. Allured[1], M. Bautz[2], J. Bookbinder[3], J. Bregman[4], L. Brenneman[1], N. Brickhouse[1], D. Burrows[5], V. Burwitz[6], P. Cheimets[1], E. Costantini[7], S. Dawson[3], C. DeRoo[1], A. Falcone[5], A. R. Foster[1], C. Grant[2], R. K. Heilmann[2], E. Hertz[1], D. Huenemoerder[2], J. Kaastra[7], K. K. Madsen[8], R. McEntaffer[5], E. Miller[2], J. Miller[4], E. Morse[15], R. Mushotzky[9], K. Nandra[6], M. Nowak[2], F, Paerels[16], R. Petre[10], K. Poppenhager[11], A. Ptak[10], J. Sanders[6], M. L. Schattenburg[2], N. Schulz[2], A. Smale[10], P. Temi[3], L. Valencic[10,12], R. Willingale[13], J. Wilms[14], S. Wolk[1]

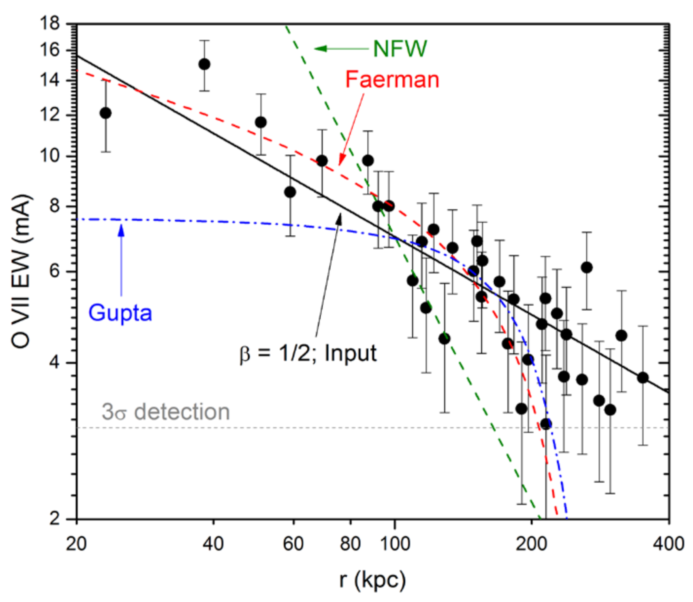
[1]Smithsonian Astrophysical Obs, [2]MIT, [3]NASA/Ames, [4]U. Michigan, [5]Penn State University, [6]MPE, [7]SRON, [8]Caltech, [9]U. Maryland, [10]NASA/GSFC, [11]Queens University Belfast, [12]JHU, [13]U. Leicester, [14]FAU, [15]Orbital-ATK, [16]Columbia

We present the scientific motivation and performance for Arcus, an X-ray grating spectrometer mission to be proposed to NASA as a MIDEX in 2016. This mission will observe structure formation at and beyond the edges of clusters and galaxies, feedback from supermassive black holes, the structure of the interstellar medium and the formation and evolution of stars. Key mission design parameters are R= $\lambda/\Delta\lambda$ >3000 with >500 cm^2 of effective area at the crucial O VII and O VIII lines, with the full bandpass going from ~10-50Å. Arcus will use the silicon pore optics developed for ESA's Athena mission, paired with off-plane gratings being developed at Pennsylvania State University and combined with MIT/Lincoln Labs CCDs. With essentially no consumables, Arcus should achieve its mission goals in under 2 years, after which we anticipate a substantial period of operation as a general observatory.

EXPLORING MATTER AT THE EDGES OF GALAXIES

Bright extra-galactic sources illuminate hot gas beyond the edges of galaxies. Combined with spectra of Milky Way sources, Arcus will expose a complete picture of the formation and cycling of metals in and out of galaxies and clusters. Absorption of bright blazars by material at a range of redshifts will allow us to map the location, motion, and temperature of hot gas around galaxies, groups, and clusters, testing models for the origin and evolution of the hot gas.

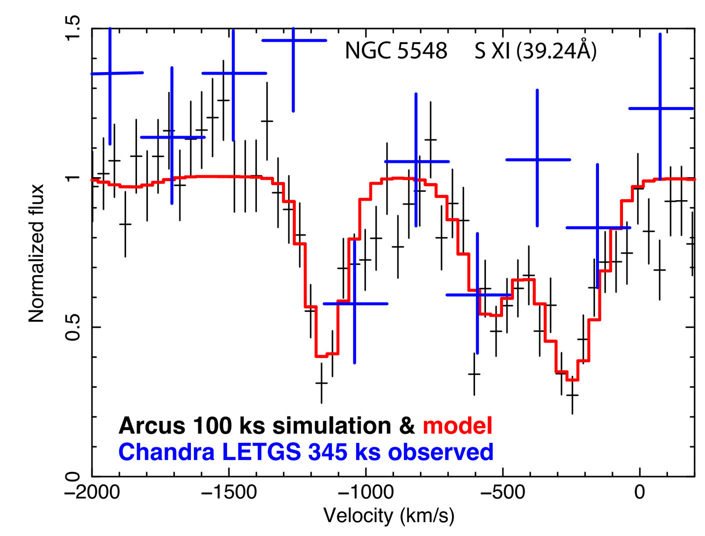




GOALS	METHOD	SELECTED INSTRUMENT REQUIREMENTS	
Determine how baryons cycle in and out of galaxies	Measure the radial profiles of hot gas at and beyond the virial radii of galaxies and clusters, and all phases of gas in our Galaxy	Spectral Resolution (21.6-25Å)	2500
		A_{eff}(21.6-25Å) (avg)	500 cm^2
		Background @ 24Å	0.006 cts/s
		A_{eff}(16-21.6Å) (avg)	500 cm^2
		Spectral Resolution (16-21.6Å)	2000
		Relative A_{eff} cal per resol. element	±10%
		Bandpass	8-51Å
		CCD energy resolution	150 eV
Determine how black holes grow and influence their surroundings	Measure the mass, energy, and composition of outflowing winds from the inner regions of black holes	Wavelength calibration	0.4mÅ
		Absolute A_{eff} calibration	±20%
		Time Resolution	10 s
Understand how accretion forms and evolves stars and circumstellar disks	Observe material accreting onto young stars along with stellar coronae from young and main sequence stars	Bandpass	8-51Å
		Min Spectral Res. (8-51Å)	1000
		A_{eff}(8-51Å) (avg)	300 cm^2
		A_{eff}(19Å)	300 cm^2

Arcus will address all of the scientific recommendations of the 2010 Decadal Survey for soft X-ray grating science in a MIDEX mission.

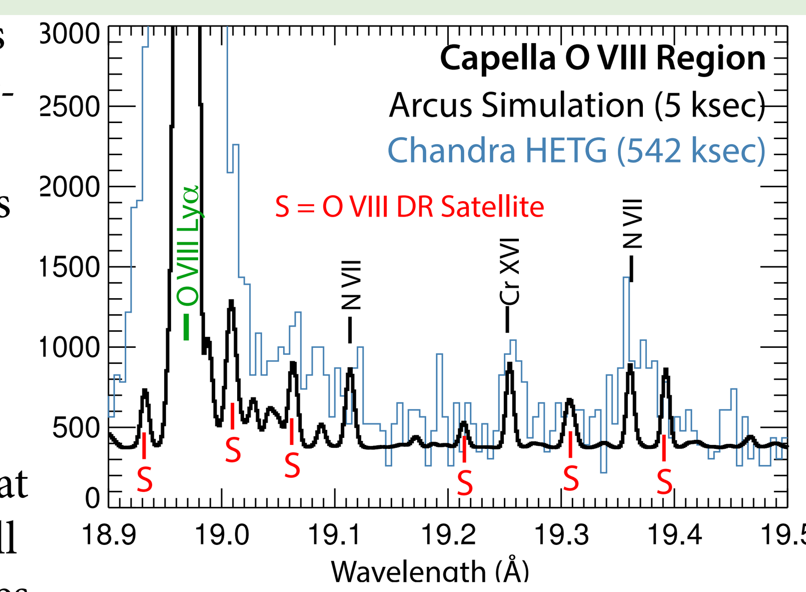
FEEDBACK FROM SUPERMASSIVE BLACK HOLES



Exploring how physics behaves at the extremes of space and time near a black hole and learning how supermassive black holes have formed and evolved requires high resolution X-ray spectra of density-dependent lines. Arcus will allow us to identify features in hot gas outflow that match cooler gas detected by HST, and use their density sensitivity to measure the total mass outflow from the SMBH.

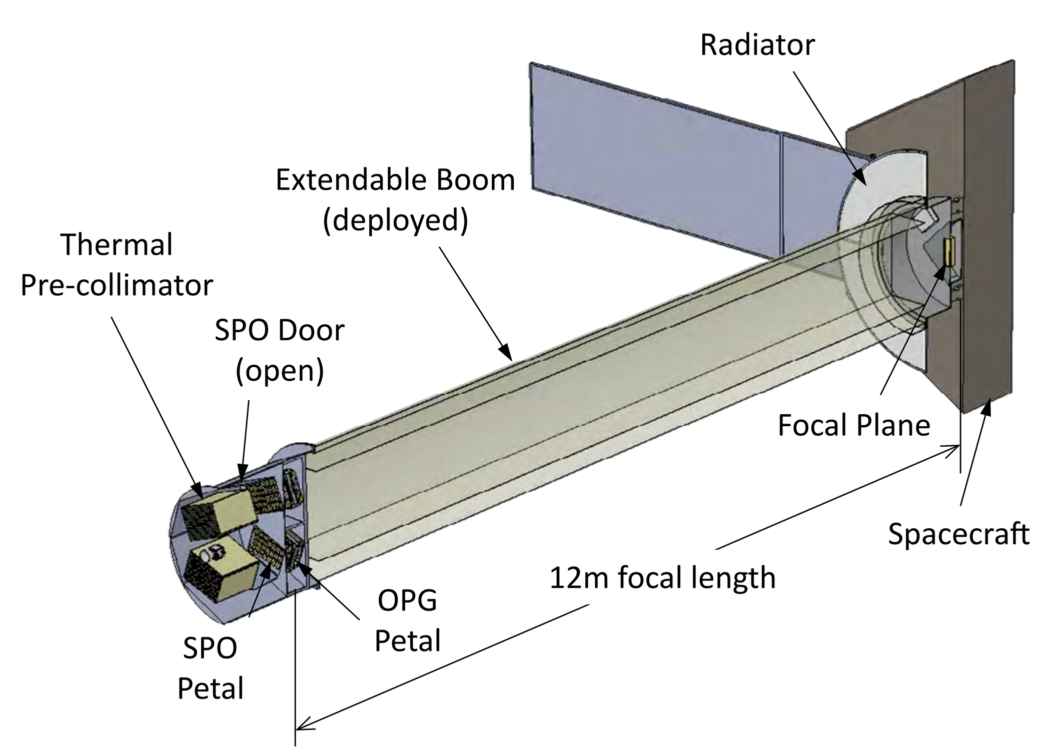
THE BIRTH AND EVOLUTION OF STARS

Accreting young stars are spinning too slowly, given that they are still contracting. Does the accretion drive a wind that removes angular momentum? Arcus will detect turbulent broadening that would test this, as well as the DR satellite lines that will test coronal heating models.



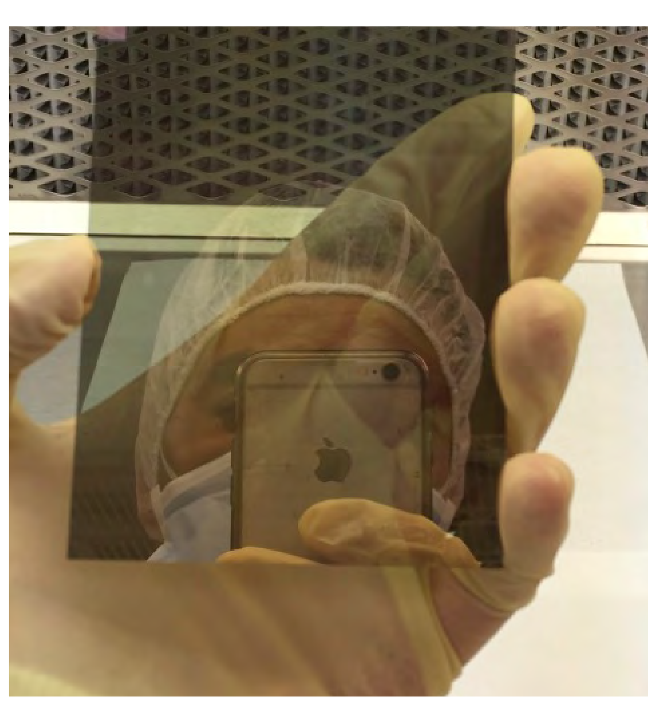
Arcus Spacecraft & Instrument

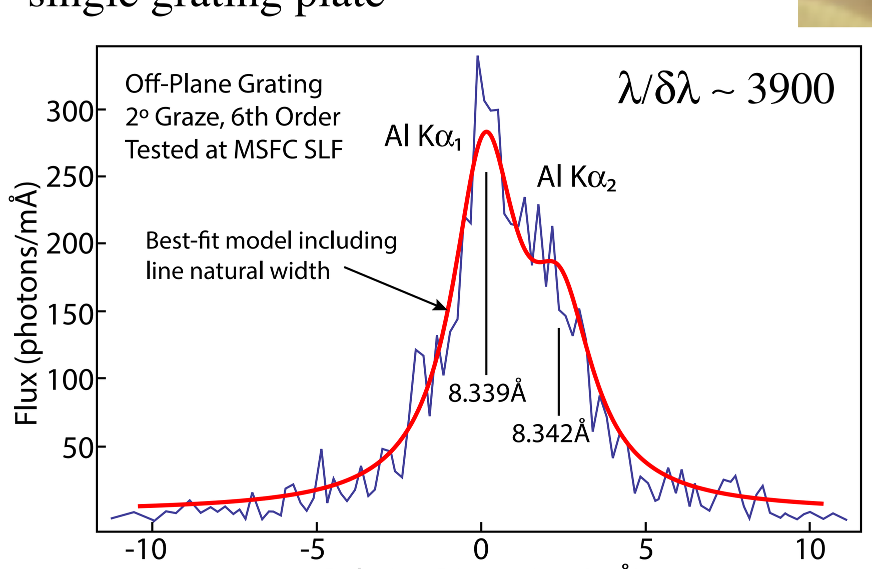
Arcus uses power, telemetry, and pointing systems with substantial heritage. Launch into a high altitude 4:1 lunar resonant orbit will be by a Falcon 9 or similar. The 12m focal length is achieved with an extendable optical bench. Spacecraft will be provided by Orbital ATK based on their high heritage LEOStar platform.

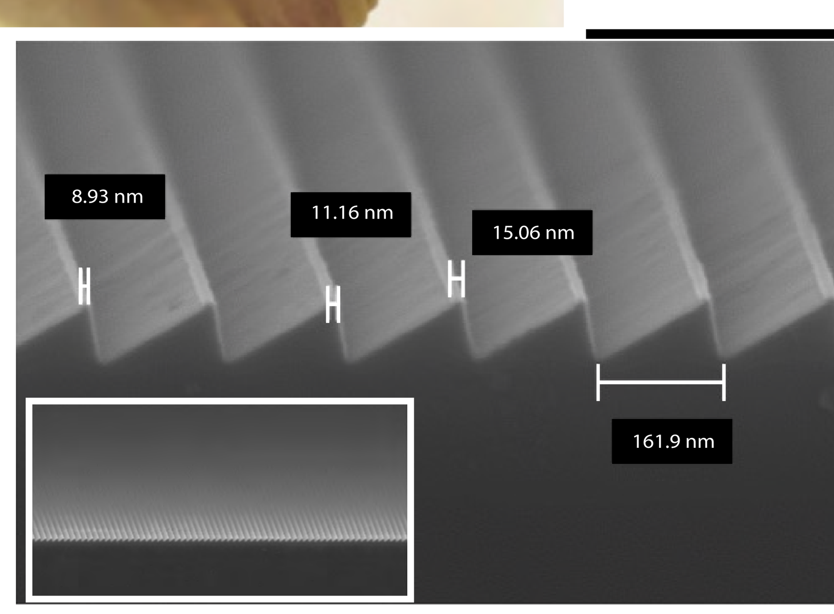


Off-Plane Gratings (OPGs)

- Arcus leverages NASA's long-term investment in OPGs for Con-X, IXO, and now X-ray Surveyor.
- Flight-like gratings meeting Arcus size, efficiency, flatness, and resolution requirements have been fabricated (picture at right) with preliminary testing at NASA/MSFC's stray light facility (see talk by R. McEntaffer at this meeting)
- Tests at NASA/MSFC stray light facility show that R>3000 can be obtained for a single grating plate

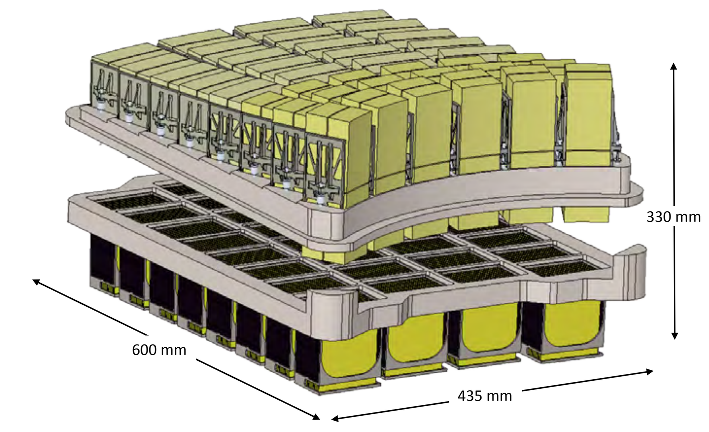


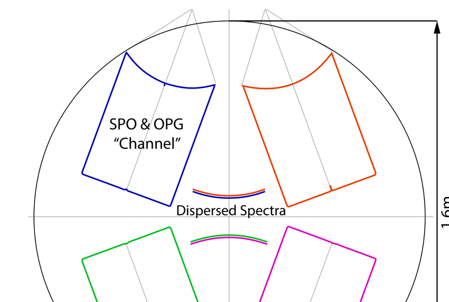


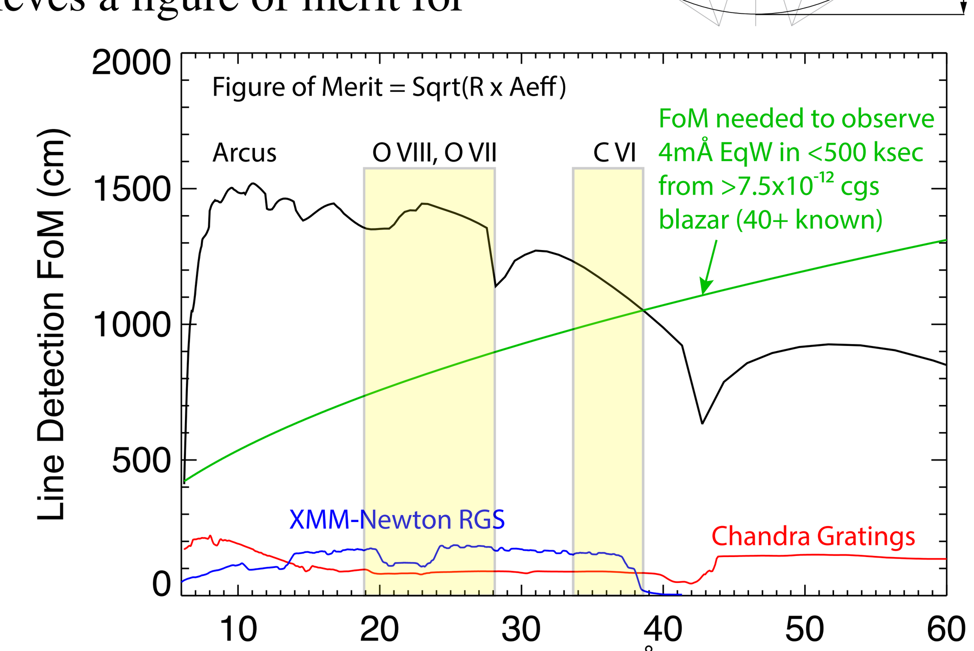


Optical Design

- Arcus optical design uses 4 identical 'channels,' each of which has 38 SPO mirror modules mounted in one 'petal' with 32 Off-Plane Grating (OPG) grating modules mounted in a second 'petal,' as shown at right.
- The photons are dispersed into an arc at the focal plane, with the channels aligned so that one CCD detector array can read out photons from two channels.
- CCDs will be built by MIT/Lincoln Labs with requirements similar to the Suzaku mission.
- Uses high-throughput silicon-mesh filters similar to those used for he Hitomi SXS detector.
- Overall design achieves a figure of merit for primary science requirement to detect weak absorption features from O VII, O VIII, and C VI that is nearly an order of magnitude larger than currently available with Chandra or XMM-Newton observatories.

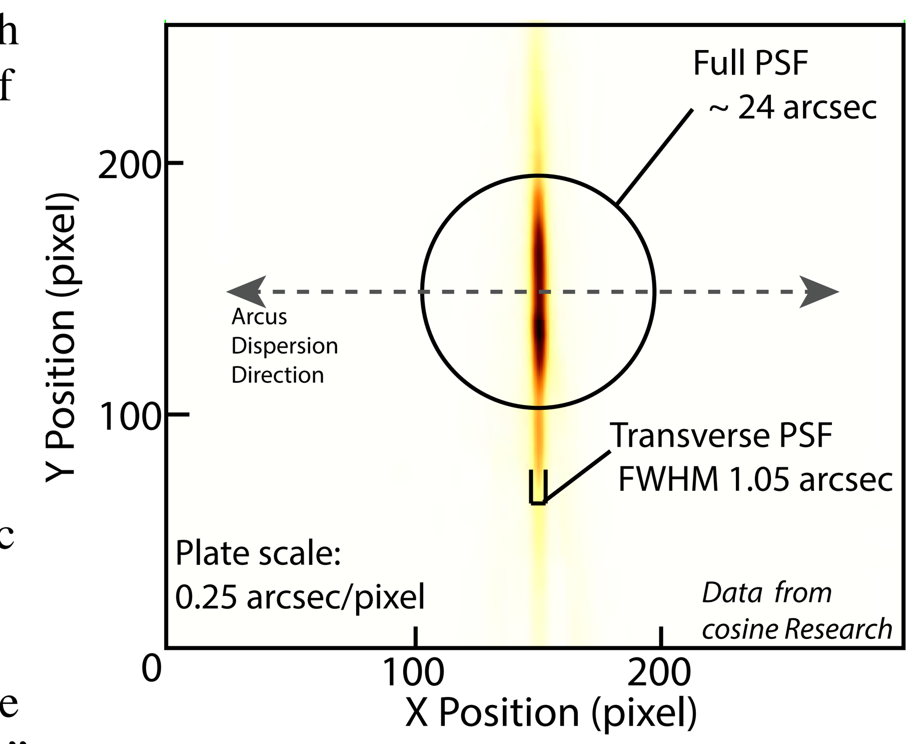


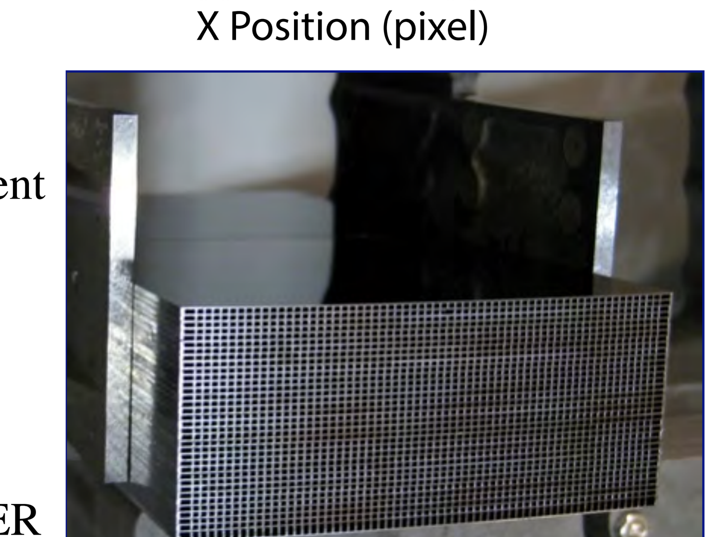




Silicon Pore Optics (SPO)

- Arcus' design leverages ESA's substantial and ongoing investment in advancing SPO technology by using the same focal length and radii of curvature mirrors as Athena.
- Optical design aligns the highly asymmetric SPO PSF in order to disperse the "transverse" PSF into a spectrum, achieving the equivalent of a 1" mirror in one dimension, all that is required for a non-imaging spectroscopy mission like Arcus.
- Test data from PANTER runs shown here at right find a 1" HEW in the transverse PSF, meeting Arcus requirement.
- Further PANTER tests planned for September to test latest generation of 12m SPO mirror module from Cosine Research with a flight-like grating module.





Off-Plane Grating Modules

- An Arcus grating module will consist of 15 aligned and mounted OPG plates
- Translational tolerances are easily met through machine tolerances and mechanical constraints
- Rotational tolerances require optical and UV metrology and tracking throughout module population. See poster by R. Allured at this meeting for details