The Evolution of Structure and Feedback with *Arcus*

Laura W. Brenneman[1], Randall K. Smith[1], J. Bregman[2], J. Kaastra[3], N. Brickhouse[1], R. Allured[1], A. Foster[1], S. Wolk[1], J. Wilms[4], L. Valencic[5,6], R. Willingale[7], C. Grant[8], M. Bautz[8], R. Heilmann[8], D. Huenemoerder[8], E. Miller[8], M. Nowak[8], M. Schattenburg[8], N. Schulz[8], V. Burwitz[9], K. Nandra[9], J. Sanders[9], J. Bookbinder[10], R. Petre[6], A. Ptak[6], A. Smale[6], D. Burrows[11], K. Popenhager[12], E. Costantini[3], C. DeRoo[13], R. McEntaffer[13], R. Mushotzky[14], J.M. Miller[2], P. Temi[10]
[1]Smithsonian Astrophysical Observatory, [2]U. Michigan, [3]SRON, [4]U. Erlangen-Nürnberg, [5]JHU, [6]NASA/GSFC, [7]U. Leicester, [8]MIT, [9]MPE, [10]NASA/Ames, [11]PSU, [12]Queen's U. Belfast, [13]U. Iowa, [14]U. Maryland

Large Scale Structure Formation

Science Goals	Science Objectives	Selected Instrument Requirements	
Determine how baryons cycle in and out of galaxies	Measure the spatial and temperature distribution of hot gas at and beyond the virial radii of galaxies and clusters, and the distribution and metal abundance of all phases of gas in our Galaxy disk	Spectral Resolution (21.6-28 Å)	2500
		A_{eff}(21.6-28 Å) (avg)	500 cm^2
		Background @ 24 Å	0.006 cts/s
		A_{eff}(16-21.6 Å) (avg)	500 cm^2
		Spectral Resolution (16-21.6 Å)	2000
		Relative A_{eff} cal per resol. element	±10%
		Bandpass	8-51 Å
		CCD energy resolution	150 eV

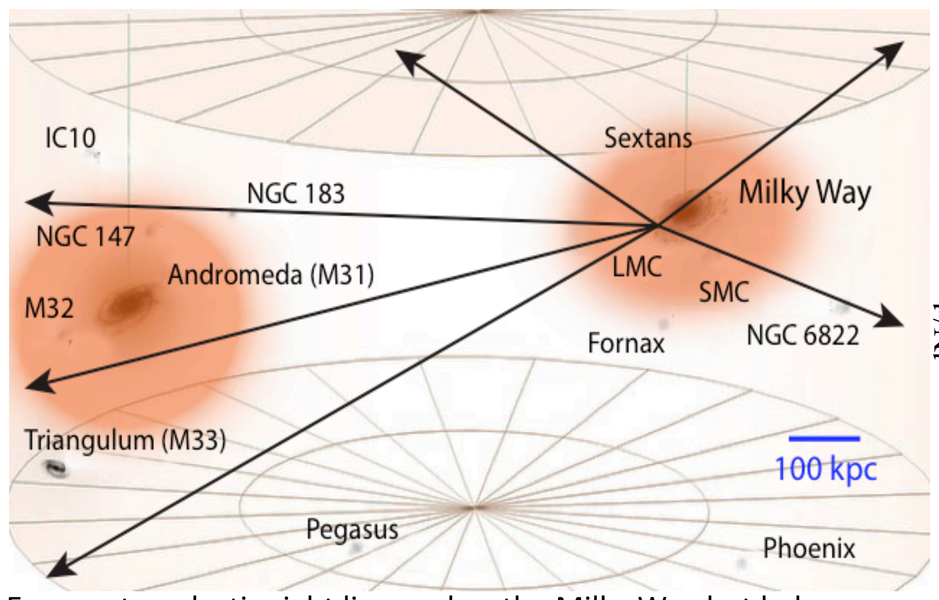
Feedback from AGN and X-ray Binaries

Science Goals	Science Objectives	Selected Instrument Requirements	
Determine how black hole feedback influences surroundings	Measure the mass, energy, and composition of outflowing winds from the inner regions of SMBHs and XRBs	Wavelength calibration	0.4 mÅ
		Absolute A_{eff} calibration	±20%
		Time Resolution	10 s

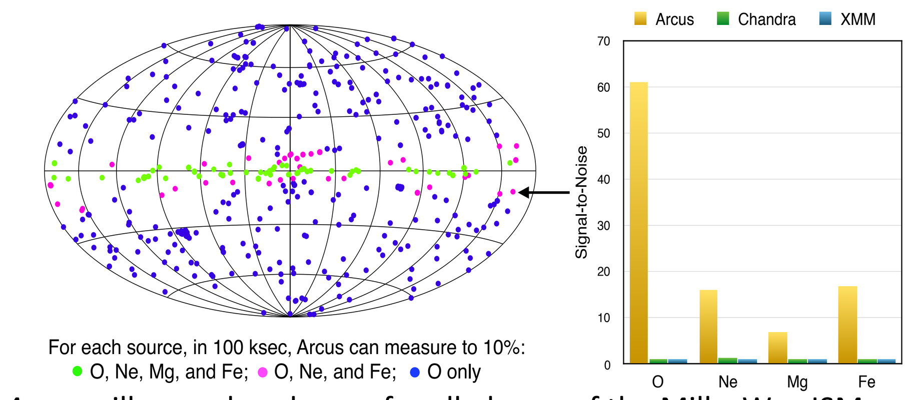
The Birth and Evolution of Stars

Science Goals	Science Objectives	Selected Instrument Requirements	
Understand how stellar systems form and evolve	Observe coronal emission from a range of stellar types and ages, including accreting material in young stars; characterize absorption by planetary atmospheres in exoplanet transits	Bandpass	8-51 Å
		Min Spectral Res (8-51 Å)	1000
		A_{eff}(8-51 Å) (avg)	300 cm^2
		A_{eff}(19 Å)	300 cm^2

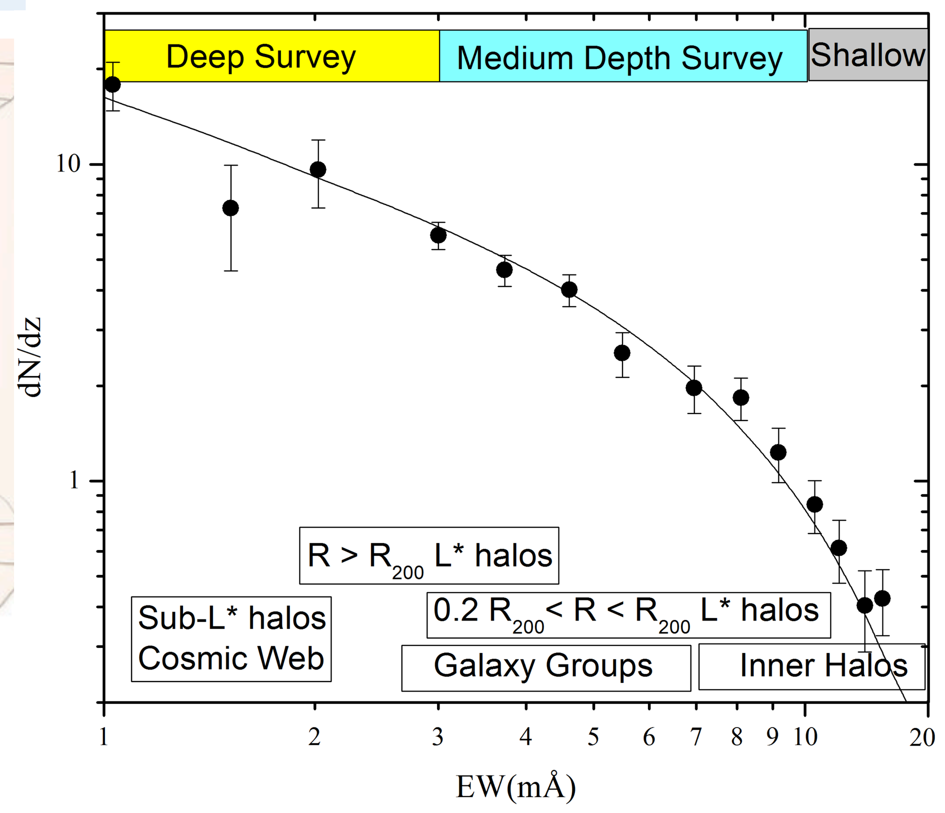
Large Scale Structure Formation



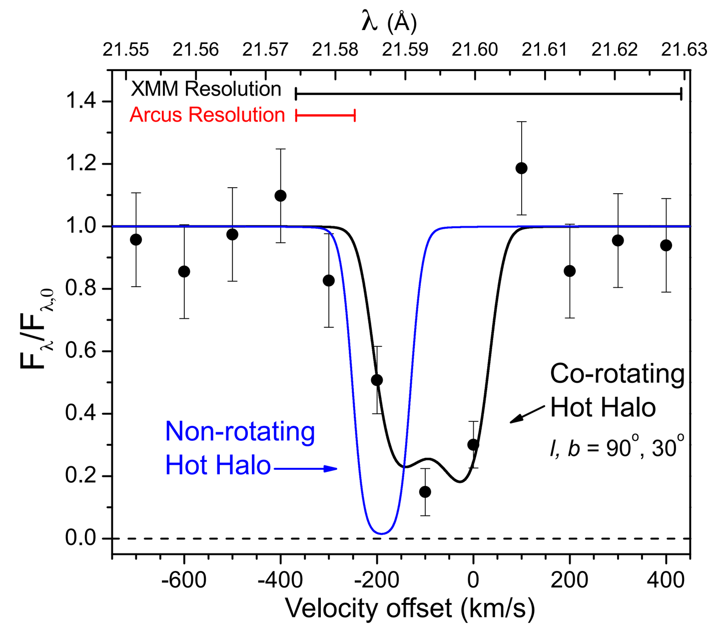
Every extragalactic sight line probes the Milky Way hot halo, allowing measurements of the density, temperature, mass distribution, and velocity of the gas therein, while multiple lines probe nearby galaxies like M31.

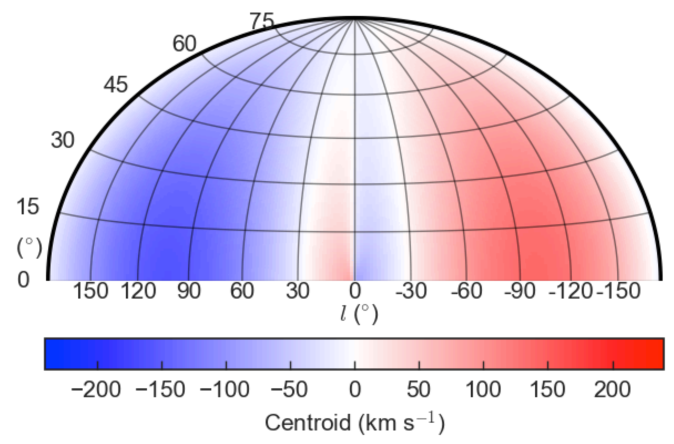


Arcus will map abundances for all phases of the Milky Way ISM with accuracies and precisions impossible to achieve with current observatories.

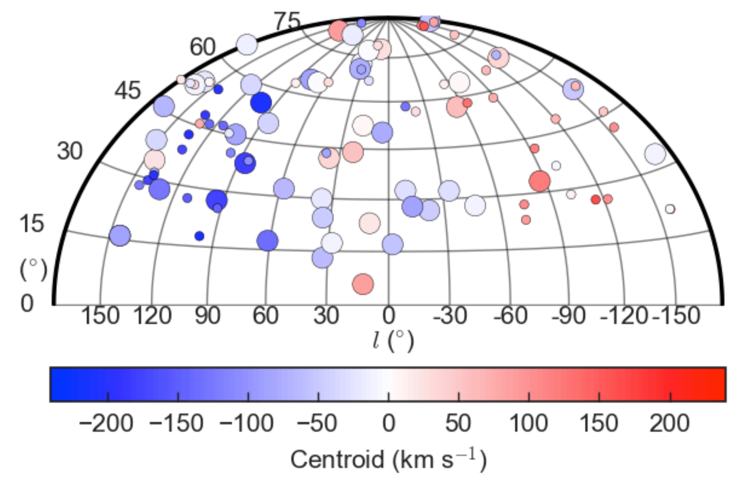


Arcus will execute deep, medium, and shallow surveys to establish the differential distribution of O VII absorption line strengths, revealing their hosts and determining whether this hot gas contains the missing metals of the Universe. The solid line is the prediction from Cen & Fang (2006). The primary goal is to determine dN(O VII)/dz, the frequency of O VII absorbers per redshift, over the widest possible range of EW, with secondary goals of determining dN/dz for O VIII and C VI. When combined with existing O VI measurements, we will have a complete census of metals in the WHIM over this critical temperature range, 0.1 - 5×10⁶ K.





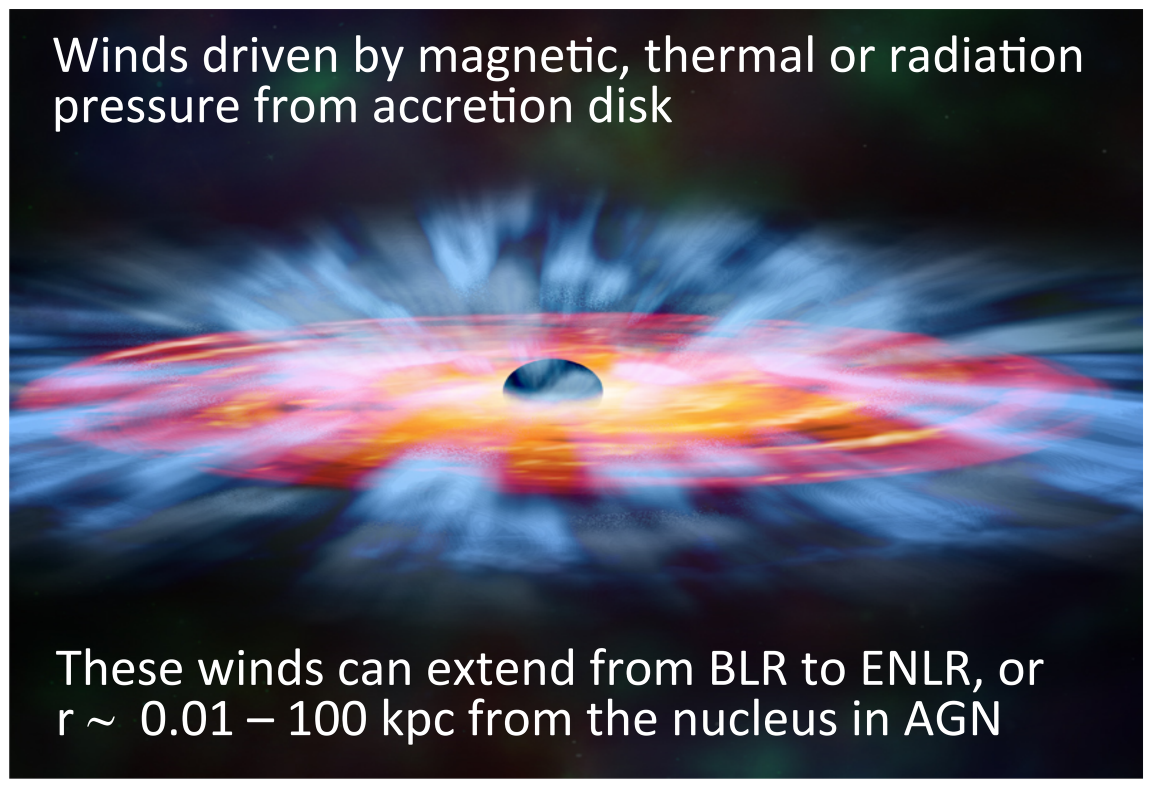
Left: *Arcus* can distinguish between non-rotating or co-rotating galactic halo models by the difference in line centroids. For the co-rotating halo, the line shape reveals the radial extent and angular momentum of the hot gas. *Above*: The velocity centroid for a rotating Milky Way halo as seen around the sky.

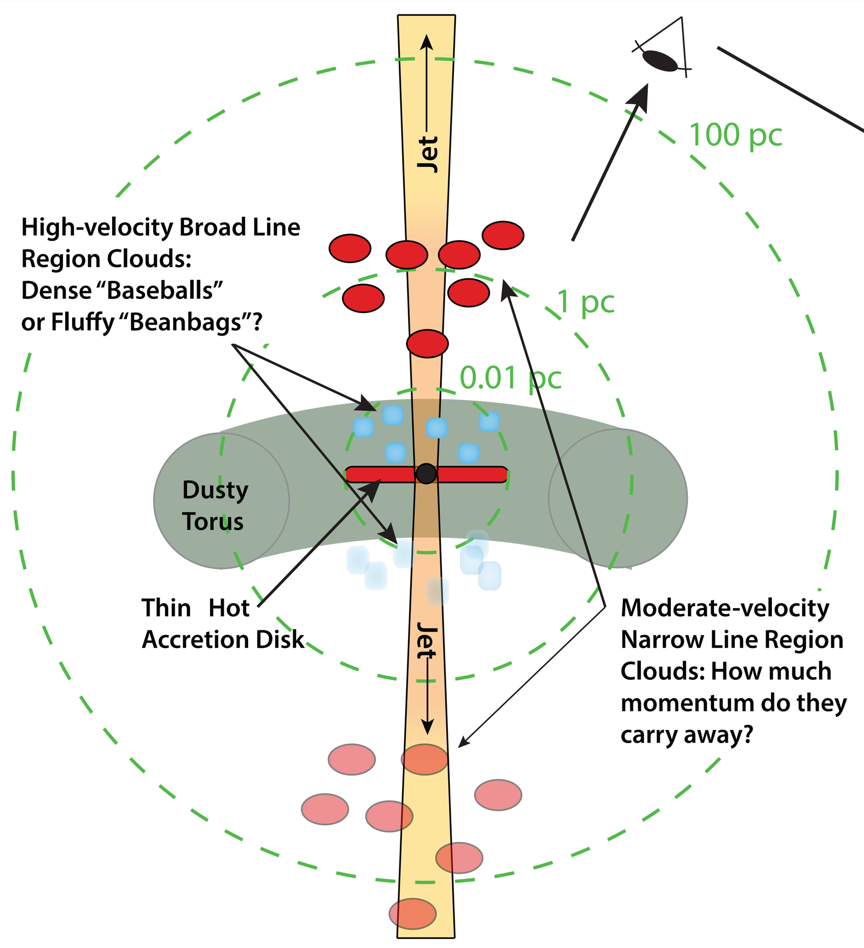


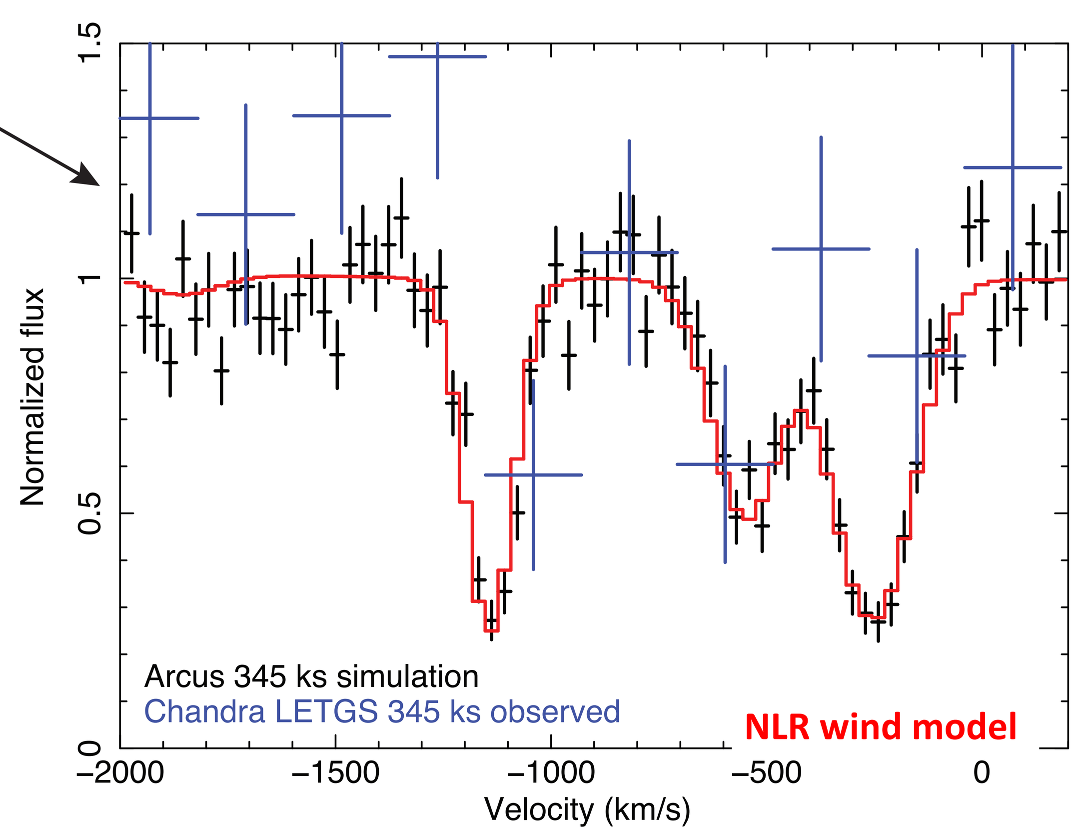
The planned *Arcus* surveys will also probe the Milky Way's rotation. The deep and medium surveys are shown with large circles (same size used for both); the shallow survey is in smaller circles. The colors represent the velocity centroids for a simulation applied to those surveys.

- Structure formation → hot gas (10^5-10^8 K) on the scales of galaxy groups and clusters, galactic halos, collapsing intergalactic filaments.
- This gas accounts for ~half of the baryons in the Universe, and encodes vital information about the formation and evolution of large-scale structure (LSS).
- Its high temperature and tenuous nature make it challenging to detect with present X-ray observatories.
- Galaxy formation → massive stars and supernovae, central supermassive black hole (SMBH) → feedback heats the accreting halo → energy and metals injected into the Warm-Hot Intergalactic Medium (WHIM).
- ***Arcus* will probe the WHIM along a variety of sight lines through our Milky Way and nearby galaxies, using distant AGN as backlights to study LSS and the hot halos of galaxies in absorption (mainly through O VII and O VIII).**
- **Will also address the critical missing baryon problem and provide much-needed data on the chemical abundances, dust composition and even halo rotation of the Milky Way.**

Feedback from AGN and X-ray Binaries



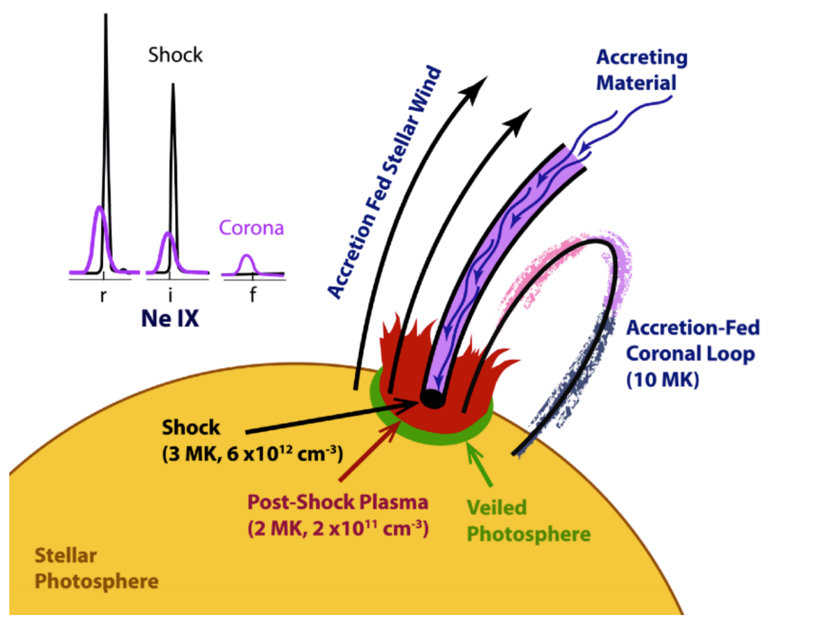




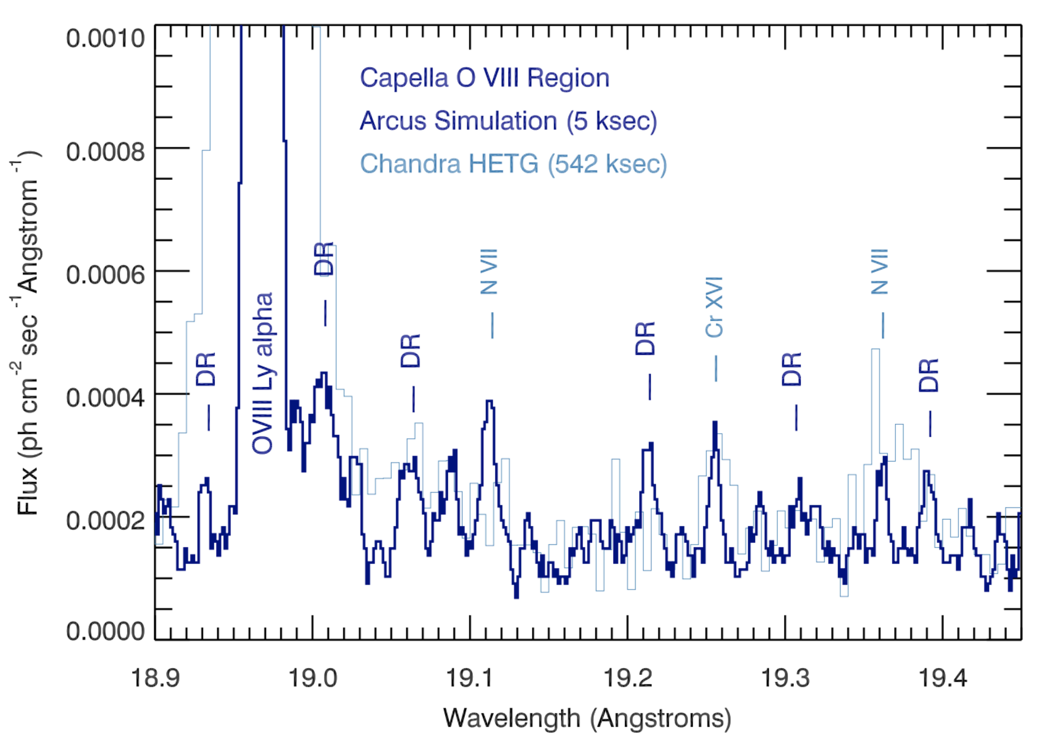
A comparison of the *Chandra*/LETGS spectrum of the S XI triplet of absorption lines in the AGN NGC 5548 (Kaastra et al. 2014) with what *Arcus* would see.

- Understanding how SMBHs formed and evolved with their host galaxies involves closely examining their inner regions.
- Innermost nucleus = launching location for outflows of matter and energy from the black hole via winds and jets.
- These outflows likely play a major role in galaxy formation and evolution.
- ***Arcus* will uniquely allow us to compare wind flow properties at the launch point and downstream → insight into how such feedback acts on the host galaxy.**
- **Will reveal the velocity distribution, chemical composition, ionization states, locations, and overall structure of the gas intrinsic to AGN and many X-ray binaries (XRBs).**

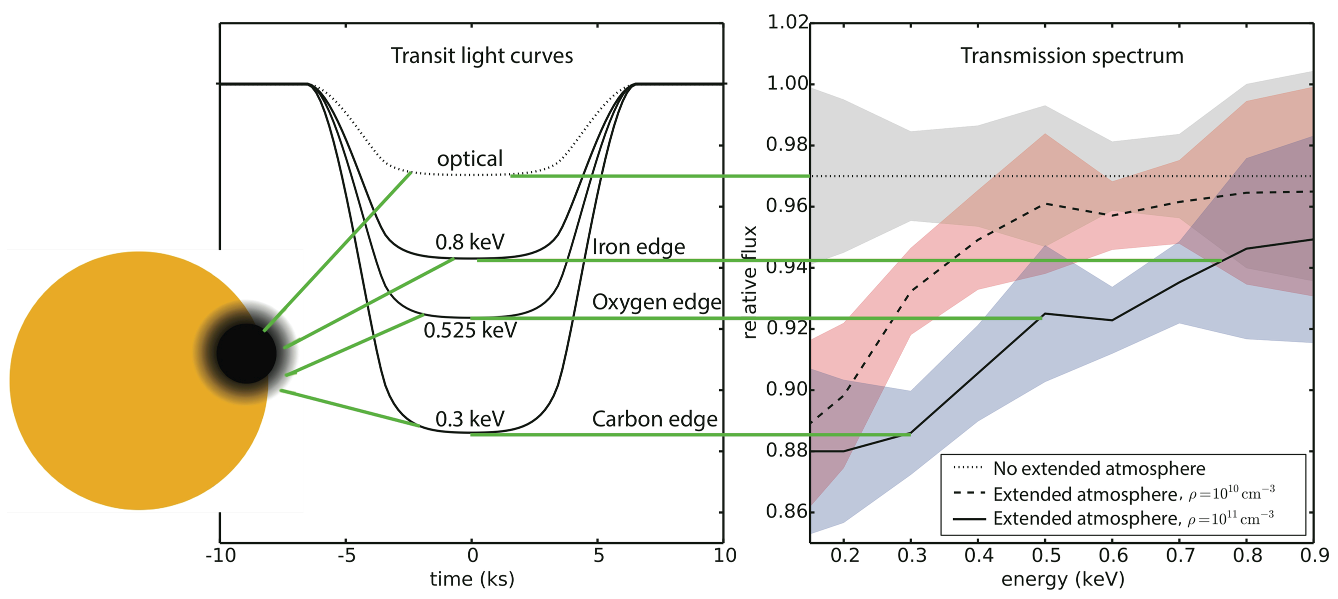
The Birth and Evolution of Stars



Arcus will be able to detect potential turbulent broadening of the O VII line in the post-shock plasma from an accretion shock impacting onto a young star. Figure adapted from Brickhouse et al (2010), © AAS. Reproduced with permission.



Simulated *Arcus* O VIII region of Capella overlaid on the *Chandra*/HETG spectrum. DR satellite lines of O VIII marked (DR) are identified using the AtomDB v3.0 spectral database. A 5-ks Arcus simulation will have high enough S/N to identify these lines, enabling longer observations to capture their changes in the dynamic environment of the stellar corona.



Arcus can study the density and extent of high-altitude atmospheric layers of exoplanets in close orbits by using energy-resolved transit observations sensitive to different elements. Soft X-ray photons are absorbed by low column densities in the atmosphere, causing deep transit light curves, while harder X-rays probe yet deeper layers.

- Young stars show high levels of magnetic activity: unclear whether a more active stellar dynamo or magnetically-controlled accretion the cause.
- ***Arcus's* high spectral resolution will be able to uniquely find the answer by measuring the turbulent broadening of spectral lines in the post-shock plasma.**
- ***Arcus* will be the first mission to accurately measure dielectronic recombination (DR) satellite lines, to be used as diagnostics to test coronal heating models.**
- **Will also be the first mission able to directly measure the density and infer the composition of the high-altitude outer layers of exoplanet atmospheres.**