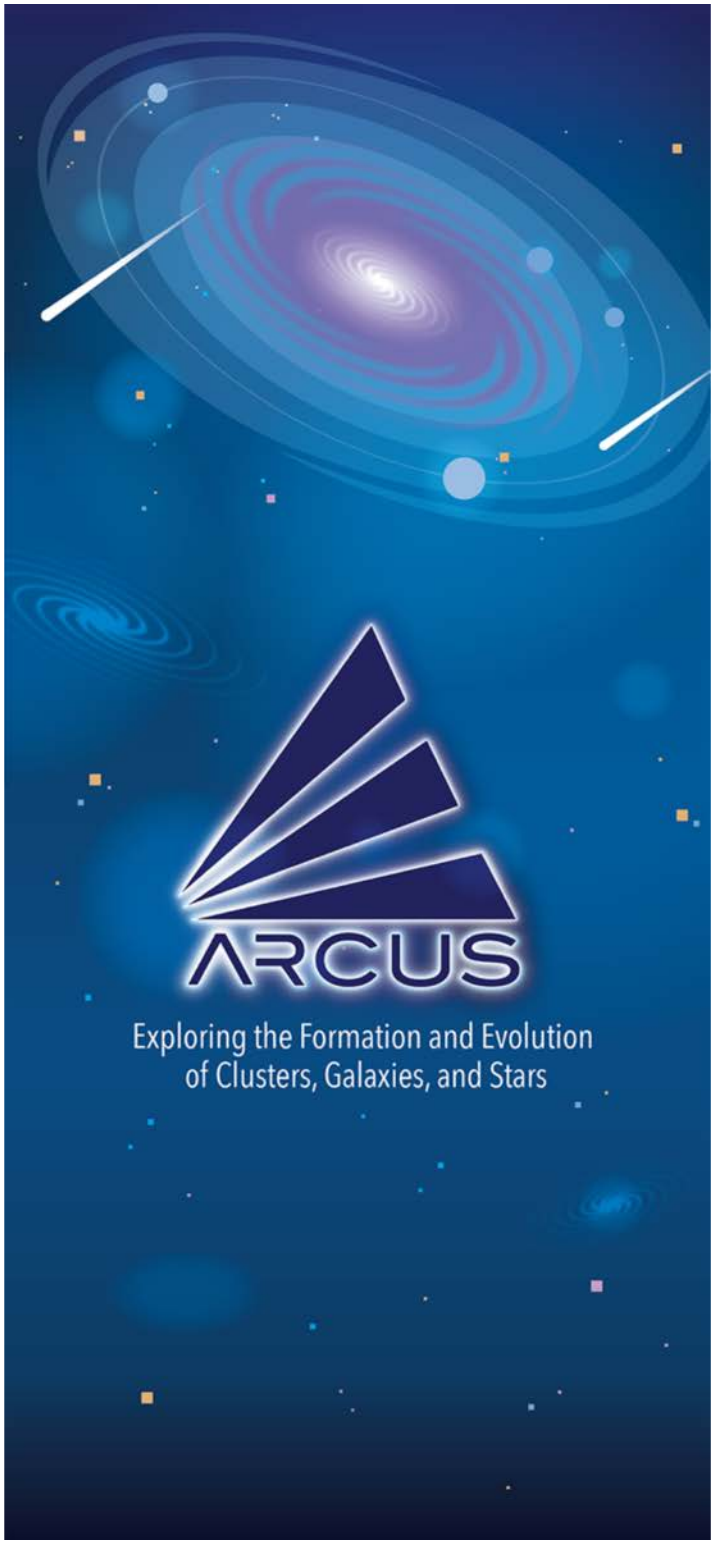


The Arcus Explorer

Randall Smith

For the Arcus Team

July 16, 2019

Addresses *Science Frontier Questions* from the Astrophysics Decadal Survey

Show how baryons cycle in and out of galaxies

Measure the spatial and temperature distribution of hot gas at and beyond the edge of galaxies (including our own) – *revealing how galaxies formed & evolved*

Reveal how black holes impact their surroundings

Determine the mass & energy of winds – 'feedback' – from black holes of all sizes

Learn how stellar systems form & evolve

Observe the processes of stellar formation by watching hot gas accrete onto young stars & survey stellar coronae from stars of all types

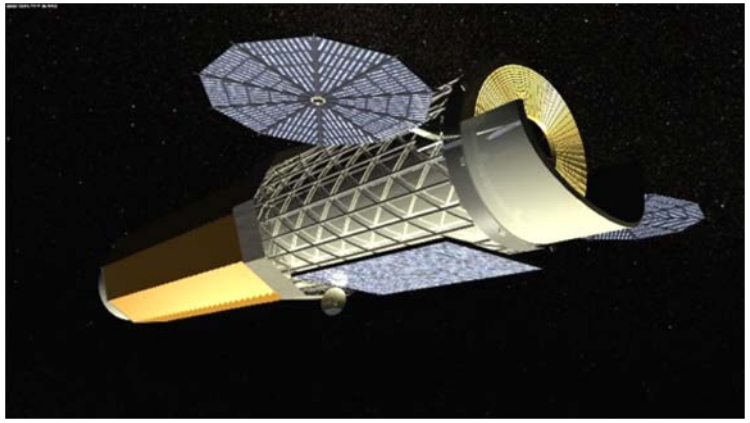
Arcus bears on a broad range of key astrophysics challenges

Long-Awaited Transformational Science

2001 Decadal: “Where is the ordinary matter that is not in luminous stars? A leading contender for at least some of this missing ordinary matter is hot intergalactic gas…”

Constellation-X

2010 Decadal: “How do baryons cycle in and out of galaxies, and what do they do while they are there?”



International X-ray Observatory

McQuinn 2016 ARA&A: “Indeed, the most important problem pertaining to the low-z IGM is not whether the baryons have disappeared between z=1100 and z=0. **Instead it is in understanding how galactic feedback redistributes gas around galaxies (and how this redistribution in turn affects how the IGM feeds galaxies).”**

Where are the baryons at and beyond a galaxy’s edge?

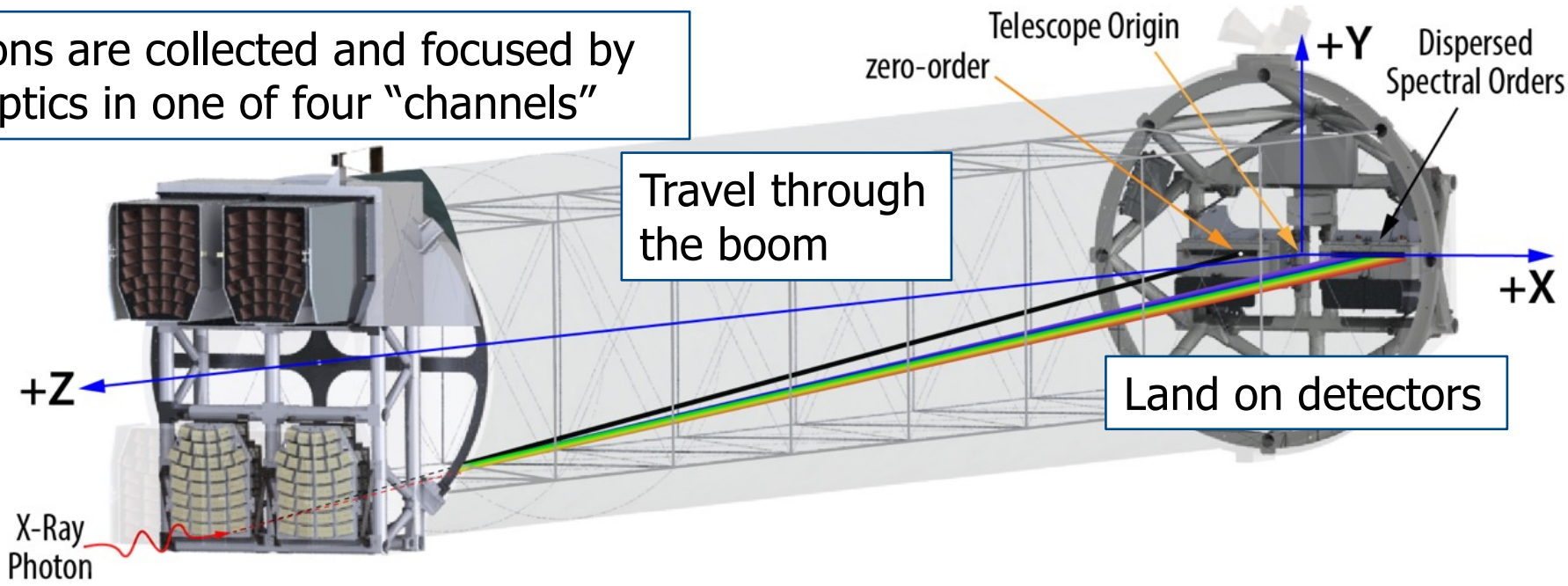
Long-Awaited Transformational Science

Arcus leverages two key technology breakthroughs: Critical Angle Transmission gratings and Silicon Pore Optics

Only Arcus can find & characterize the missing baryons

The Arcus Instrument

Photons are collected and focused by the optics in one of four "channels"



Travel through the boom

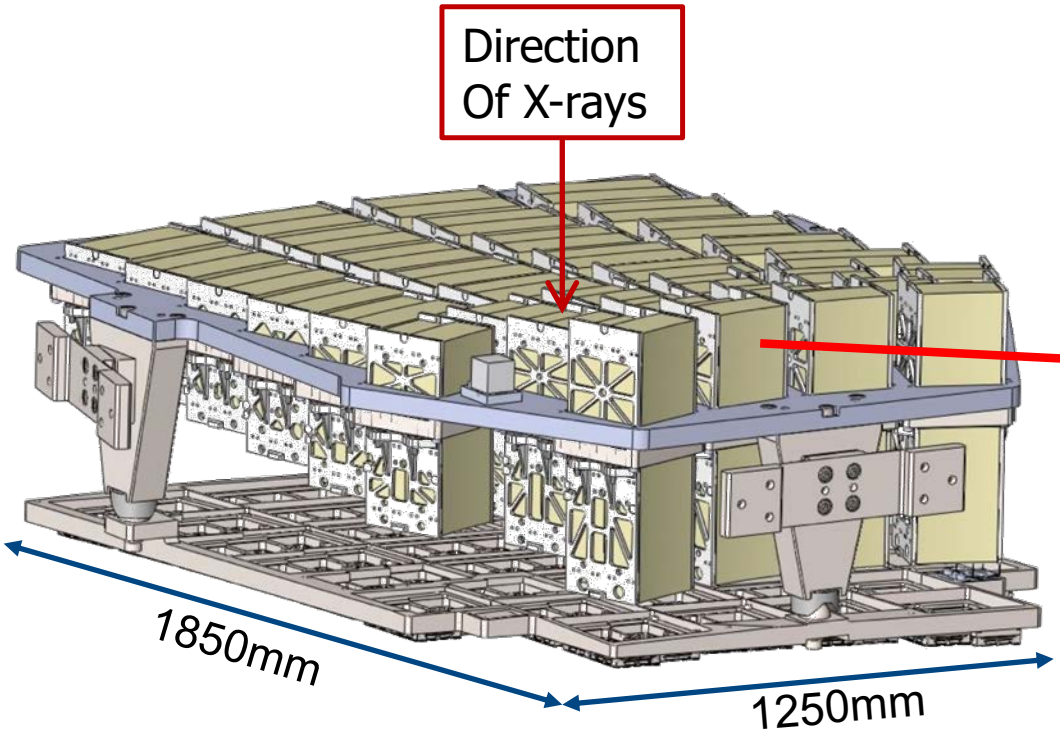
Land on detectors

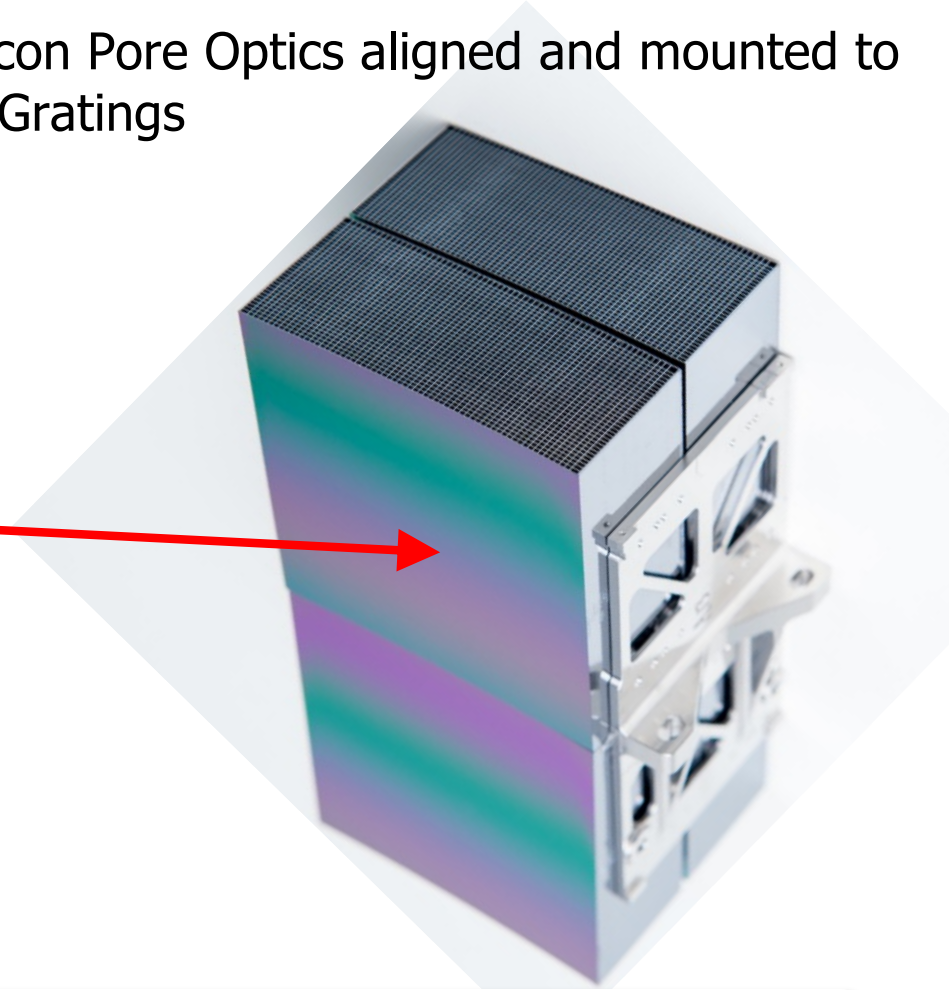
Diffracted by the associated CAT gratings

The Arcus instrument provides a robust platform to achieve mission goals

Arcus Optical Design – Silicon Pore Optics

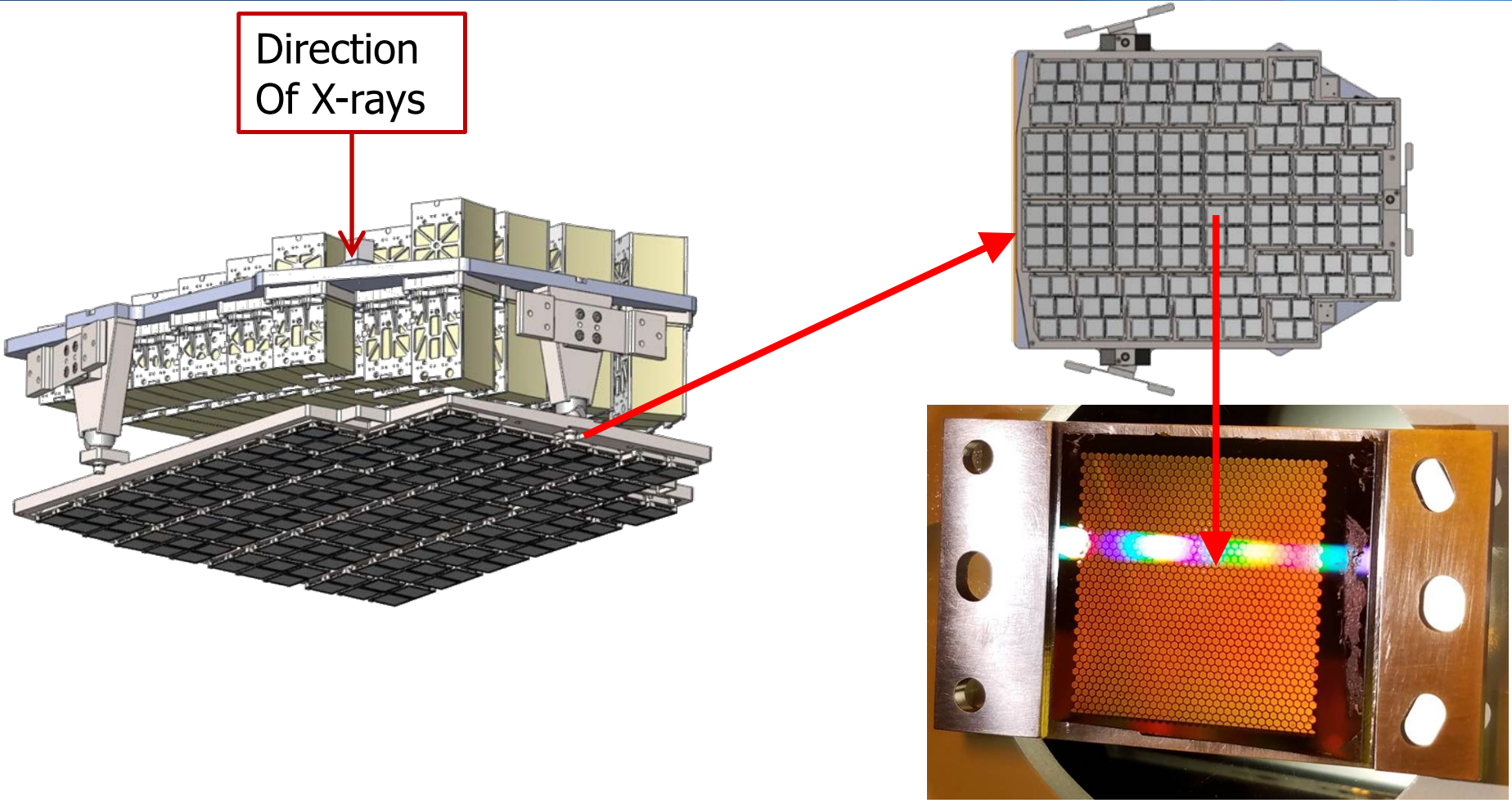
Four individual channels, each a petal with Silicon Pore Optics aligned and mounted to a petal with Critical Angle Transmission (CAT) Gratings





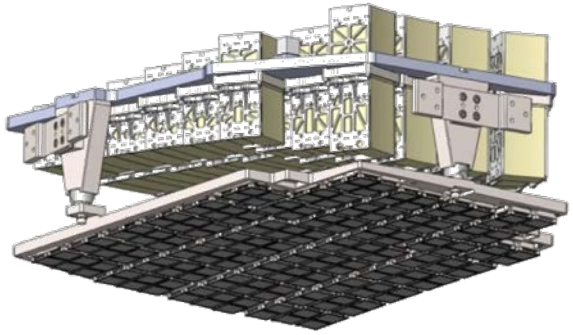
Innovative optics demonstrated to meet Arcus requirements

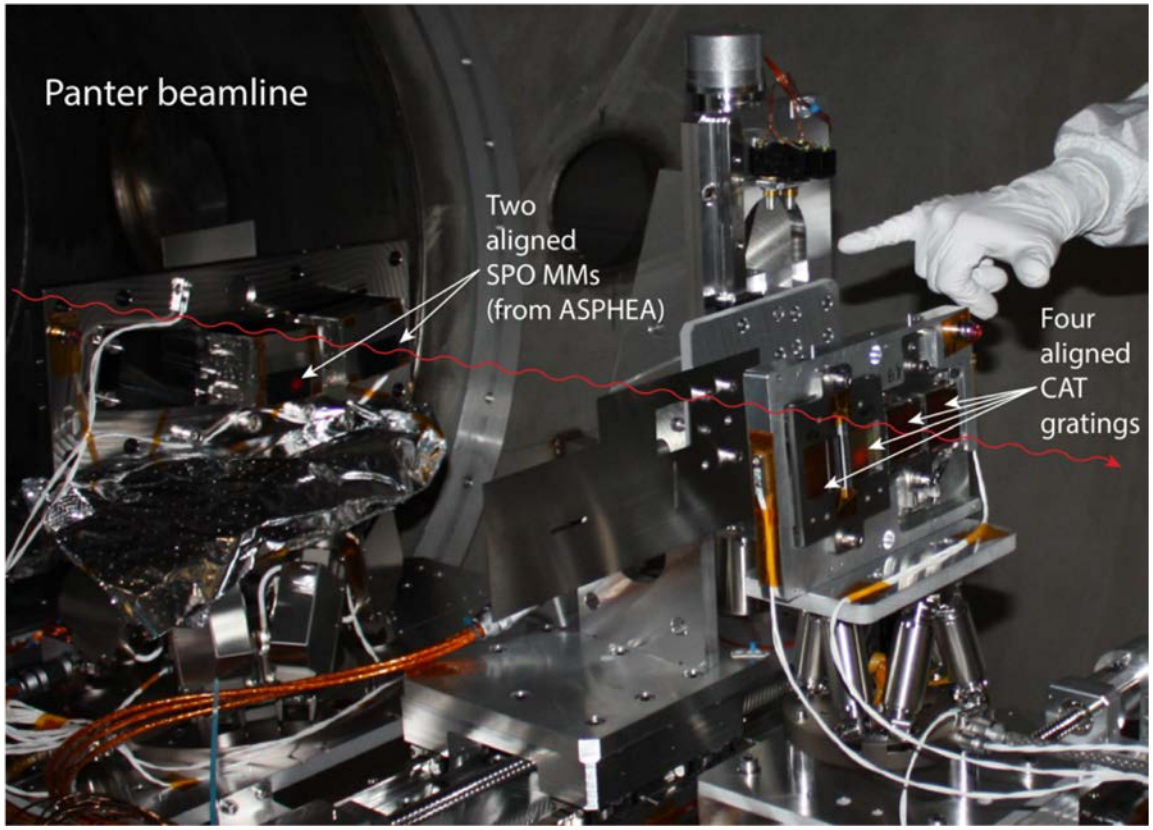
Arcus Optical Design – Critical Angle Transmission Gratings

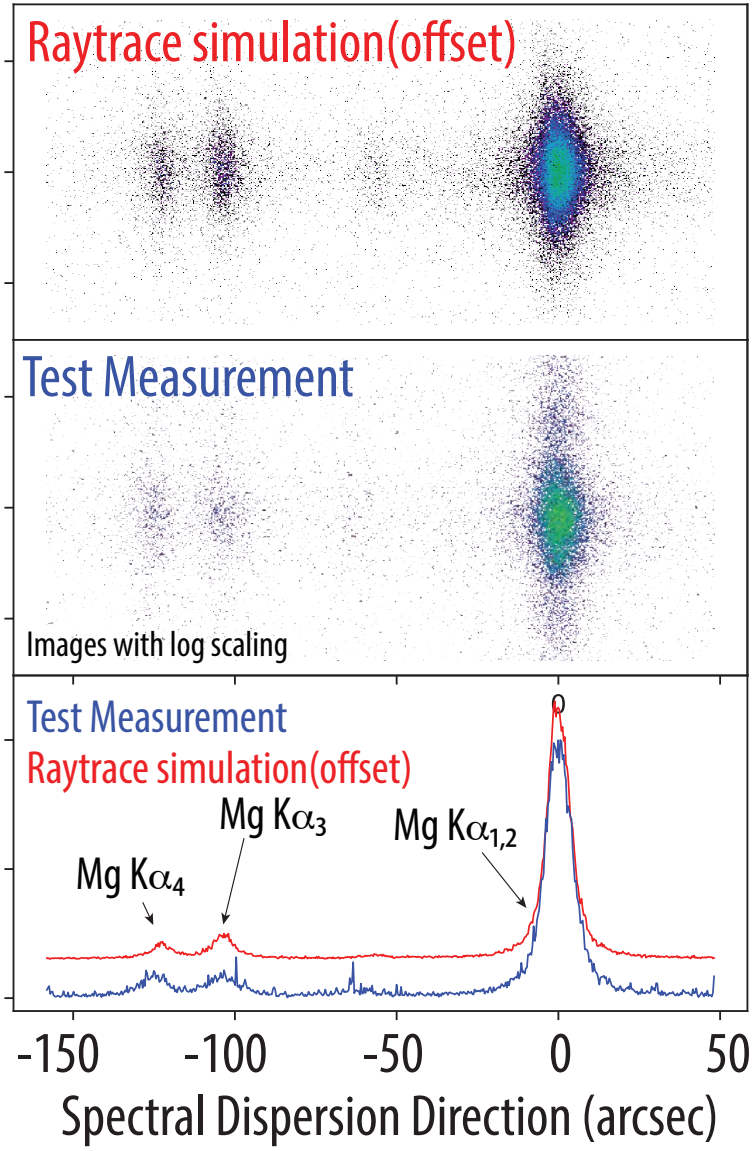


CAT gratings ~10x more efficient than Chandra with ~4x higher resolution

Arcus Optics to TRL6 - GWAT



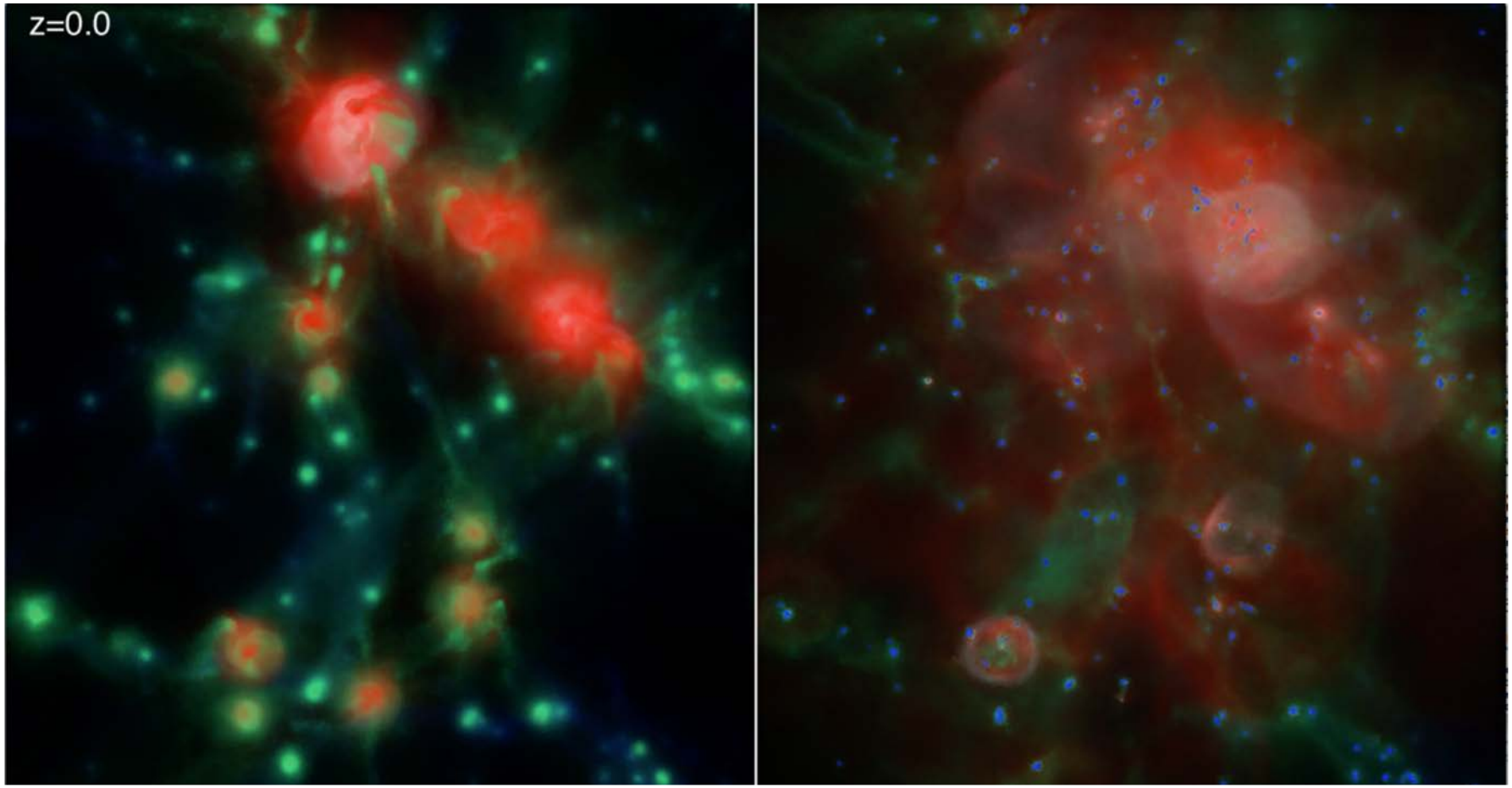




The Arcus Boom

The coilable boom enables a 12m focal length in a well-tested, thermally-stable, stiff and low-cost package

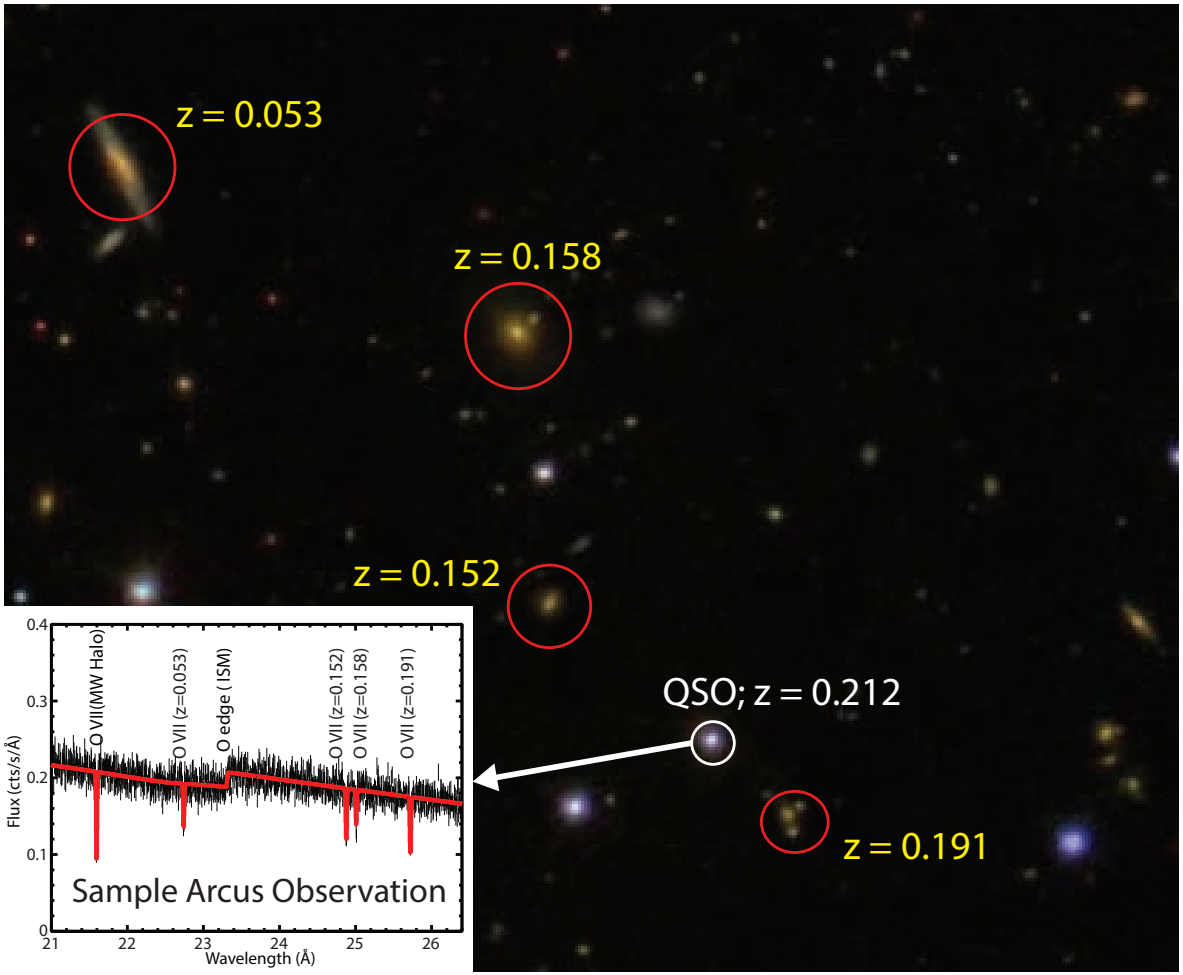
Characterizing the Hot Halos Around Galaxies



Science goals motivated by existing data, simulations, and models

Characterizing the Hot Halos Around Galaxies

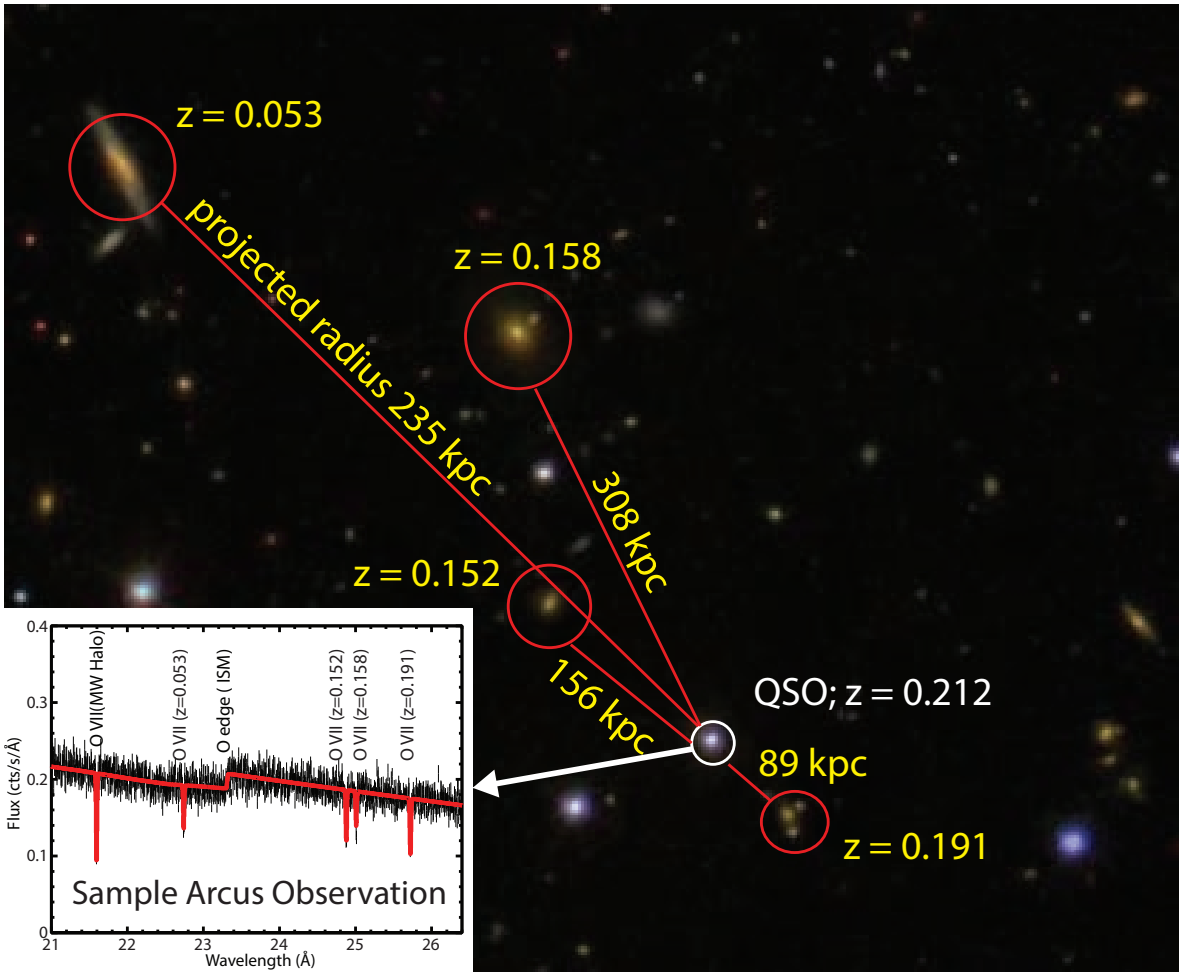
"A statistical sample of robust O VII and O VIII absorption detections requires a future spectroscopic X-ray satellite… Probes of ~10^6 K gas will be most sensitive to dense gas either within or at the outskirts of galactic halos… [and] solve the great mystery of why an increasing number of galaxies at low redshifts are red and dead, with no recent star formation." (McQuinn 2016, ARA&A)



Only Arcus can detect the hot gas halos around galaxies

Characterizing the Hot Halos Around Galaxies

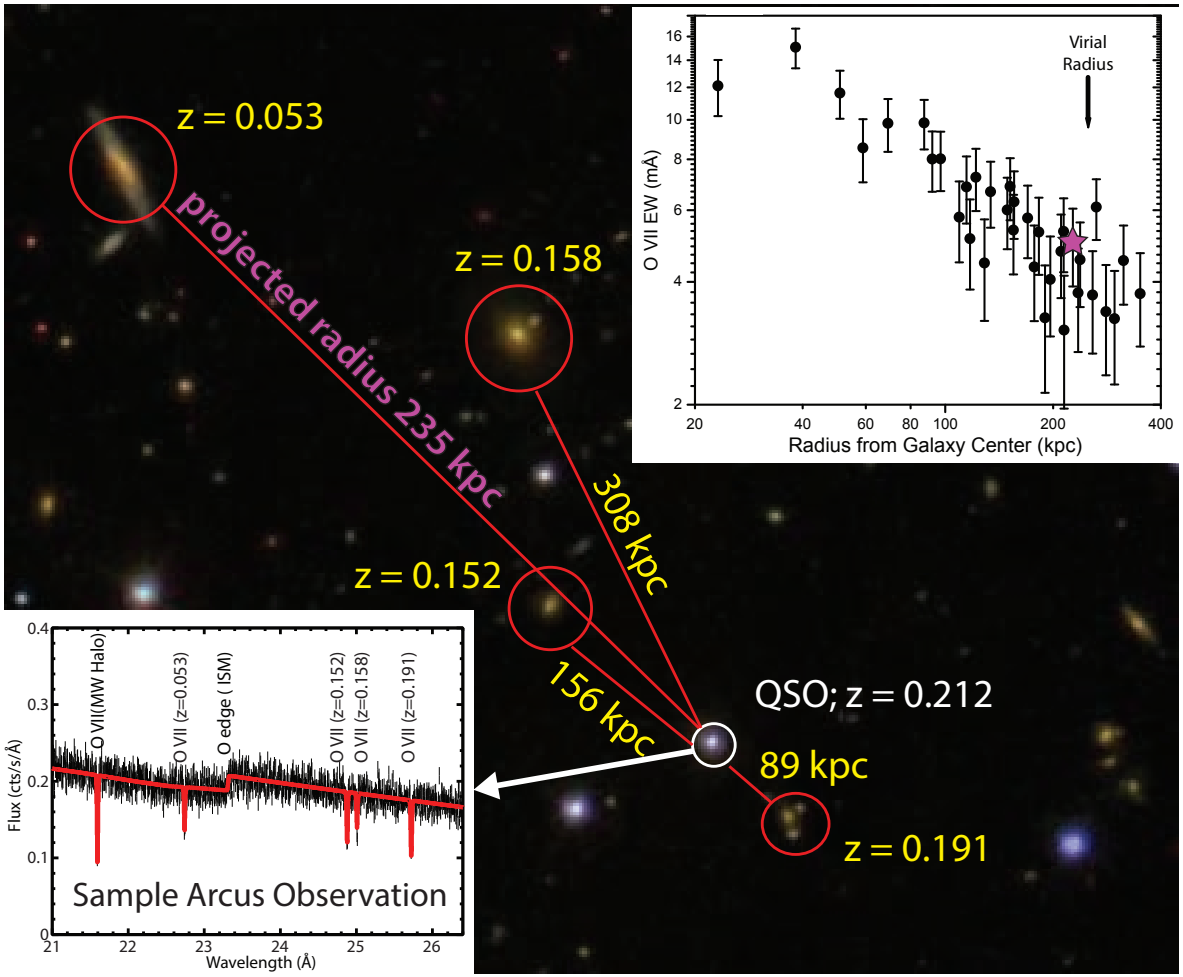
"A statistical sample of robust O VII and O VIII absorption detections requires a future spectroscopic X-ray satellite… Probes of ~10^6 K gas will be most sensitive to dense gas either within or at the outskirts of galactic halos… [and] solve the great mystery of why an increasing number of galaxies at low redshifts are red and dead, with no recent star formation." (McQuinn 2016, ARA&A)



Only Arcus can detect the hot gas halos around galaxies

Characterizing the Hot Halos Around Galaxies

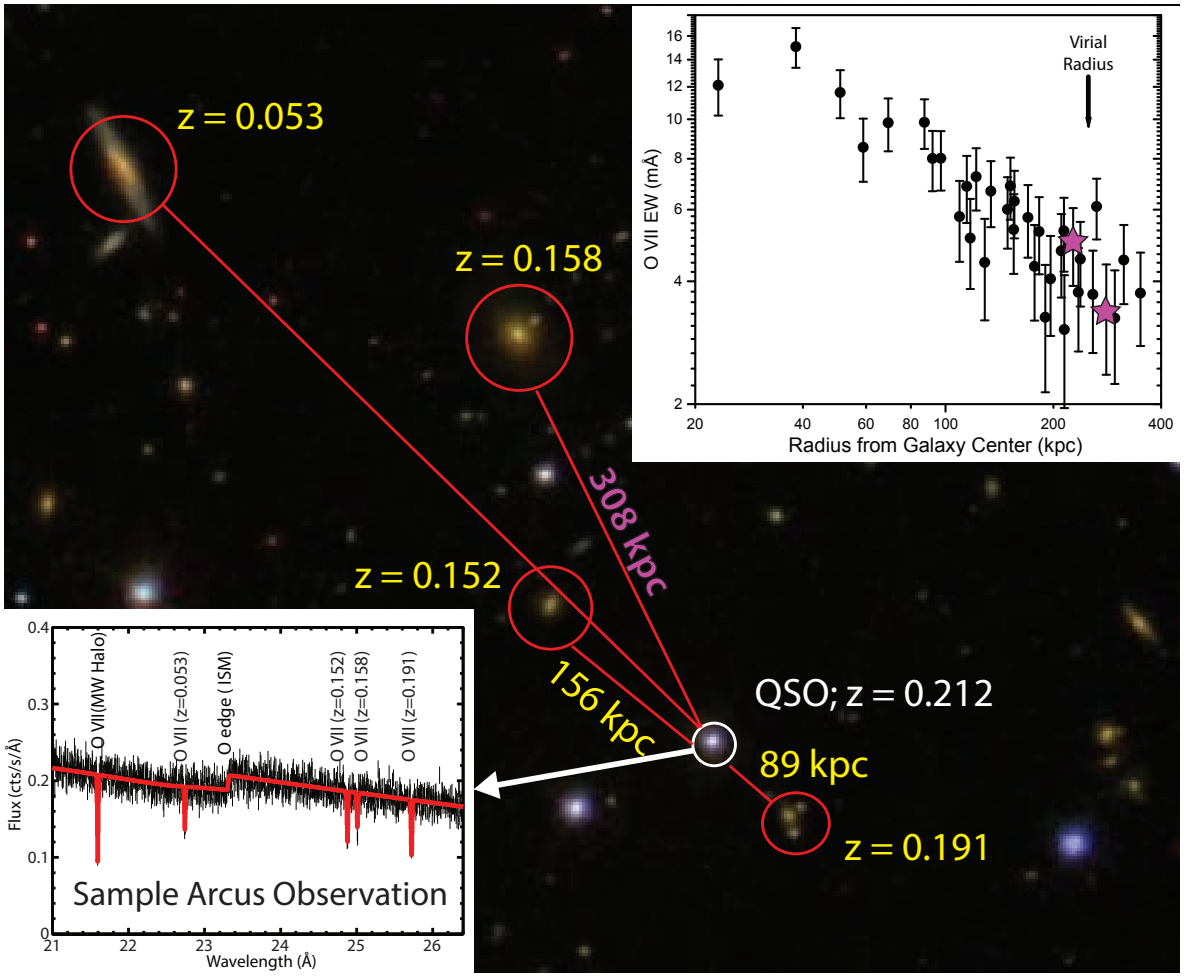
"A statistical sample of robust O VII and O VIII absorption detections requires a future spectroscopic X-ray satellite… Probes of ~10^6 K gas will be most sensitive to dense gas either within or at the outskirts of galactic halos… [and] solve the great mystery of why an increasing number of galaxies at low redshifts are red and dead, with no recent star formation." (McQuinn 2016, ARA&A)



Only Arcus can detect the hot gas halos around galaxies

Characterizing the Hot Halos Around Galaxies

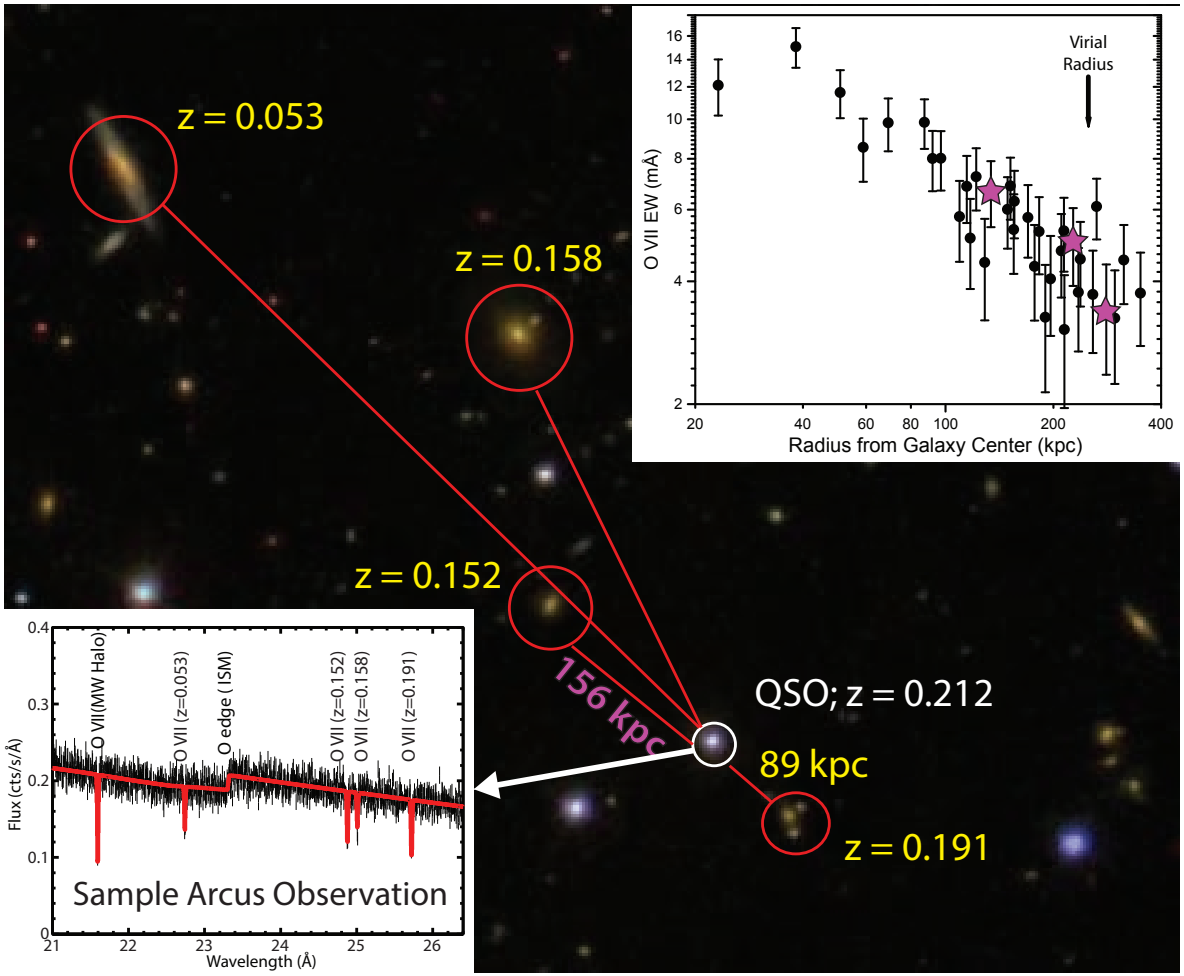
"A statistical sample of robust O VII and O VIII absorption detections requires a future spectroscopic X-ray satellite… Probes of ~10^6 K gas will be most sensitive to dense gas either within or at the outskirts of galactic halos… [and] solve the great mystery of why an increasing number of galaxies at low redshifts are red and dead, with no recent star formation." (McQuinn 2016, ARA&A)



Only Arcus can detect the hot gas halos around galaxies

Characterizing the Hot Halos Around Galaxies

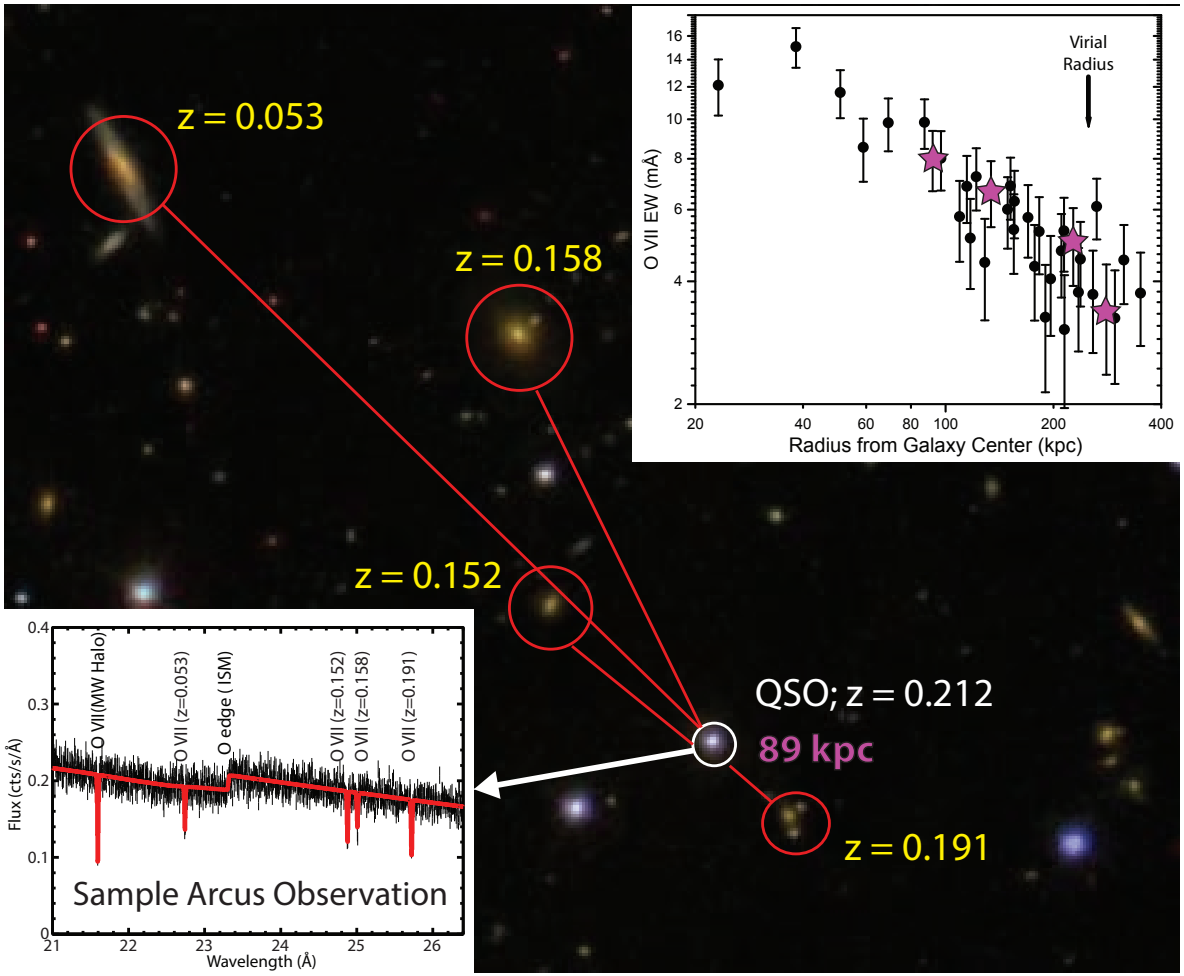
"A statistical sample of robust O VII and O VIII absorption detections requires a future spectroscopic X-ray satellite… Probes of ~10^6 K gas will be most sensitive to dense gas either within or at the outskirts of galactic halos… [and] solve the great mystery of why an increasing number of galaxies at low redshifts are red and dead, with no recent star formation." (McQuinn 2016, ARA&A)



Only Arcus can detect the hot gas halos around galaxies

Characterizing the Hot Halos Around Galaxies

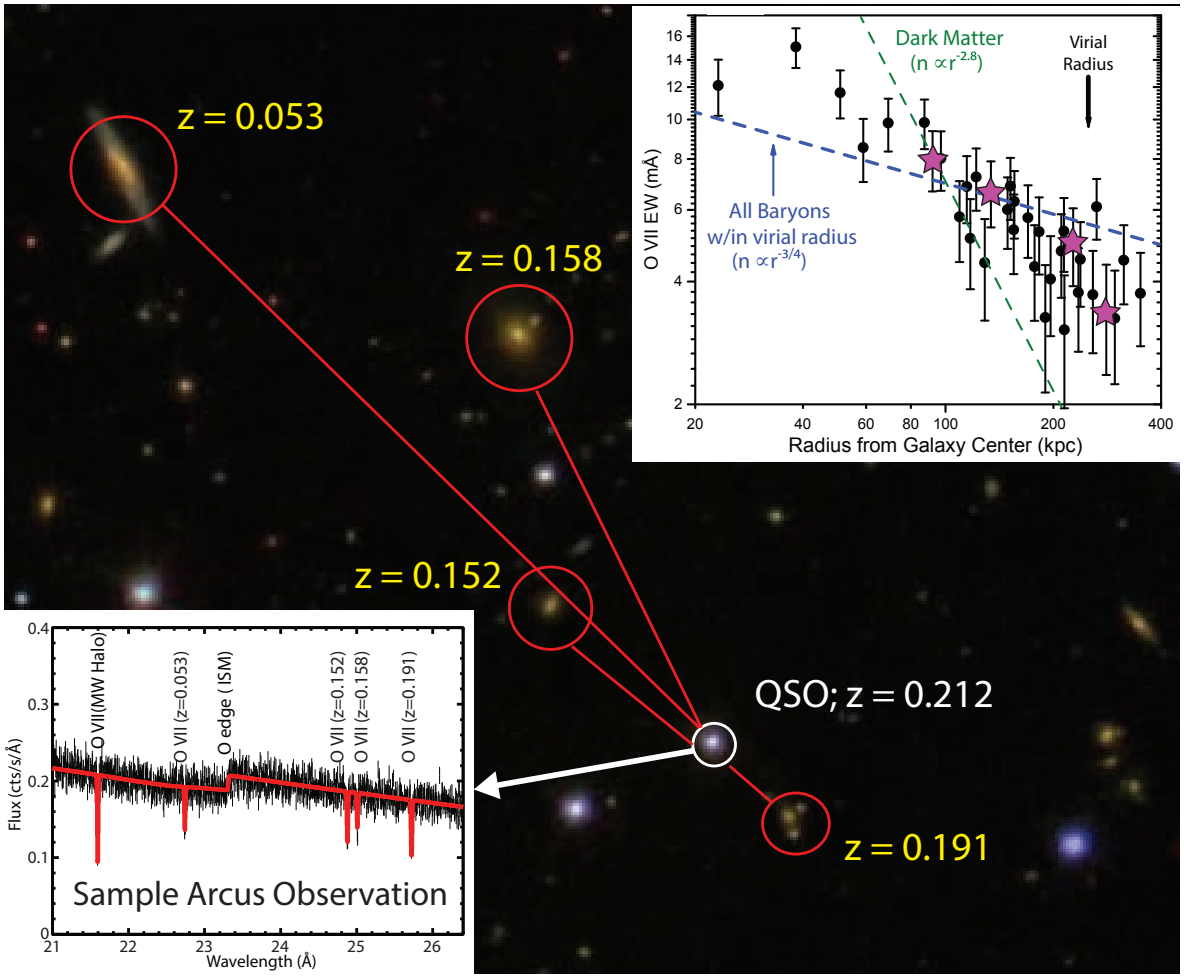
"A statistical sample of robust O VII and O VIII absorption detections requires a future spectroscopic X-ray satellite… Probes of ~10^6 K gas will be most sensitive to dense gas either within or at the outskirts of galactic halos… [and] solve the great mystery of why an increasing number of galaxies at low redshifts are red and dead, with no recent star formation." (McQuinn 2016, ARA&A)



Only Arcus can detect the hot gas halos around galaxies

Characterizing the Hot Halos Around Galaxies

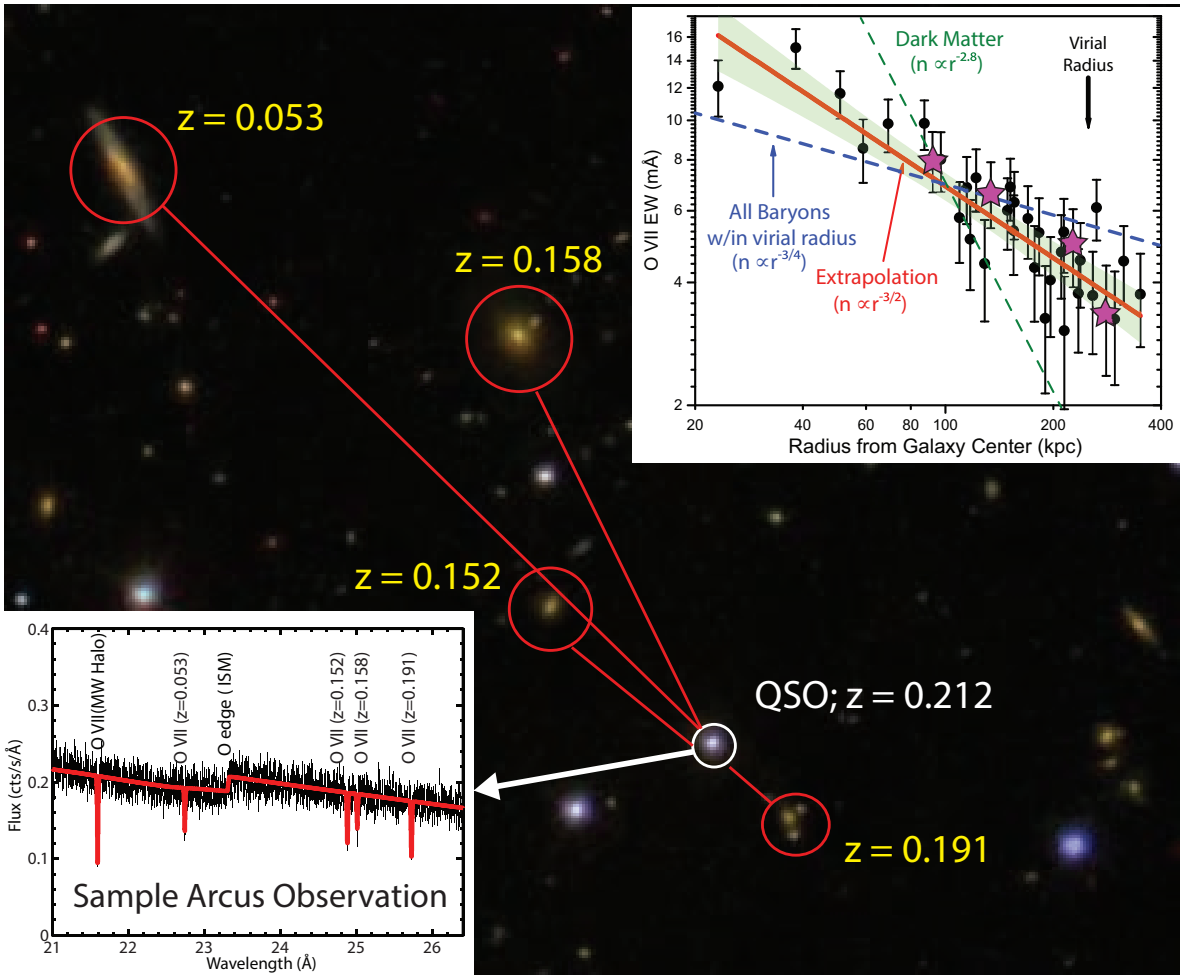
"A statistical sample of robust O VII and O VIII absorption detections requires a future spectroscopic X-ray satellite… Probes of ~10^6 K gas will be most sensitive to dense gas either within or at the outskirts of galactic halos… [and] solve the great mystery of why an increasing number of galaxies at low redshifts are red and dead, with no recent star formation." (McQuinn 2016)



Only Arcus can detect the hot gas halos around galaxies

Characterizing the Hot Halos Around Galaxies

- Expect ~3 detections of O VII-bearing hot gas per line of sight (plus ~one other hot ion) based on conservative models
- Hot gas has no transitions in IR/Opt/UV; can only be seen in high-resolution soft X-ray spectra



Only Arcus can detect the hot gas halos around galaxies

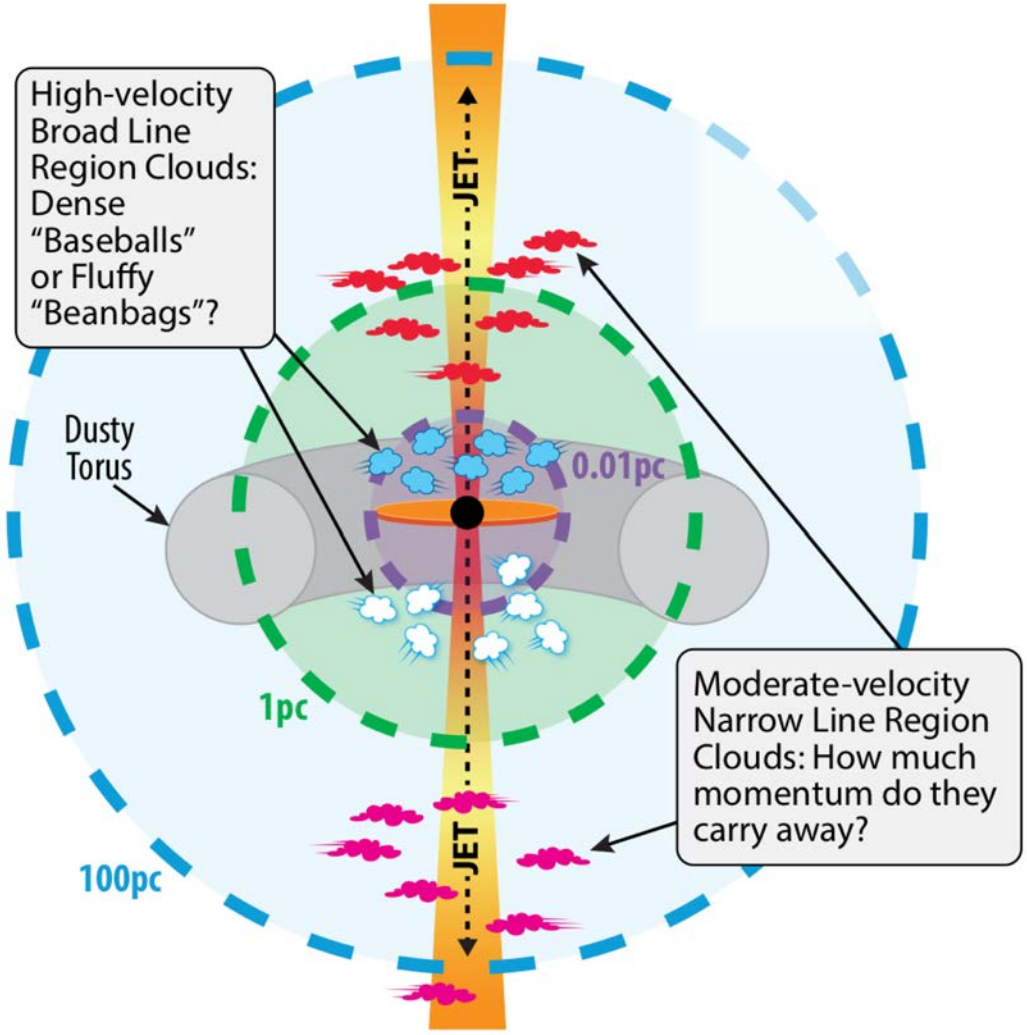
Supermassive Black Hole Outflows

- Arcus measures wind momentum by tracking the response time of the wind properties to changes in the continuum on timescales from 10 ks to 10 Ms.

- Breaks degeneracy between the density of the outflowing wind and its launching radius:

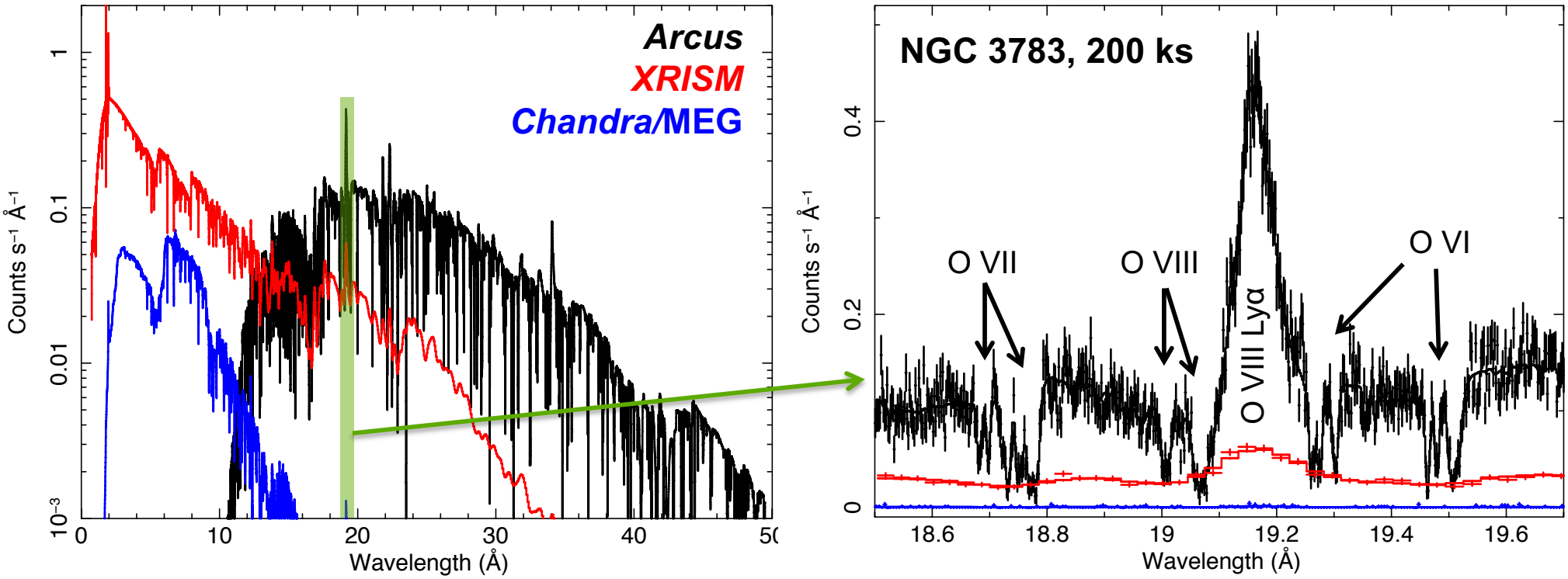
$$\text{Gas ionization} \propto \frac{L}{nr^2}$$

- Important implications for the role of AGN feedback in shaping host galaxies: kinetic power $\propto v^3 N_H r$



The bulk of outflowing material in AGN winds is highly ionized and accessible only in X-rays

Supermassive Black Hole Outflows

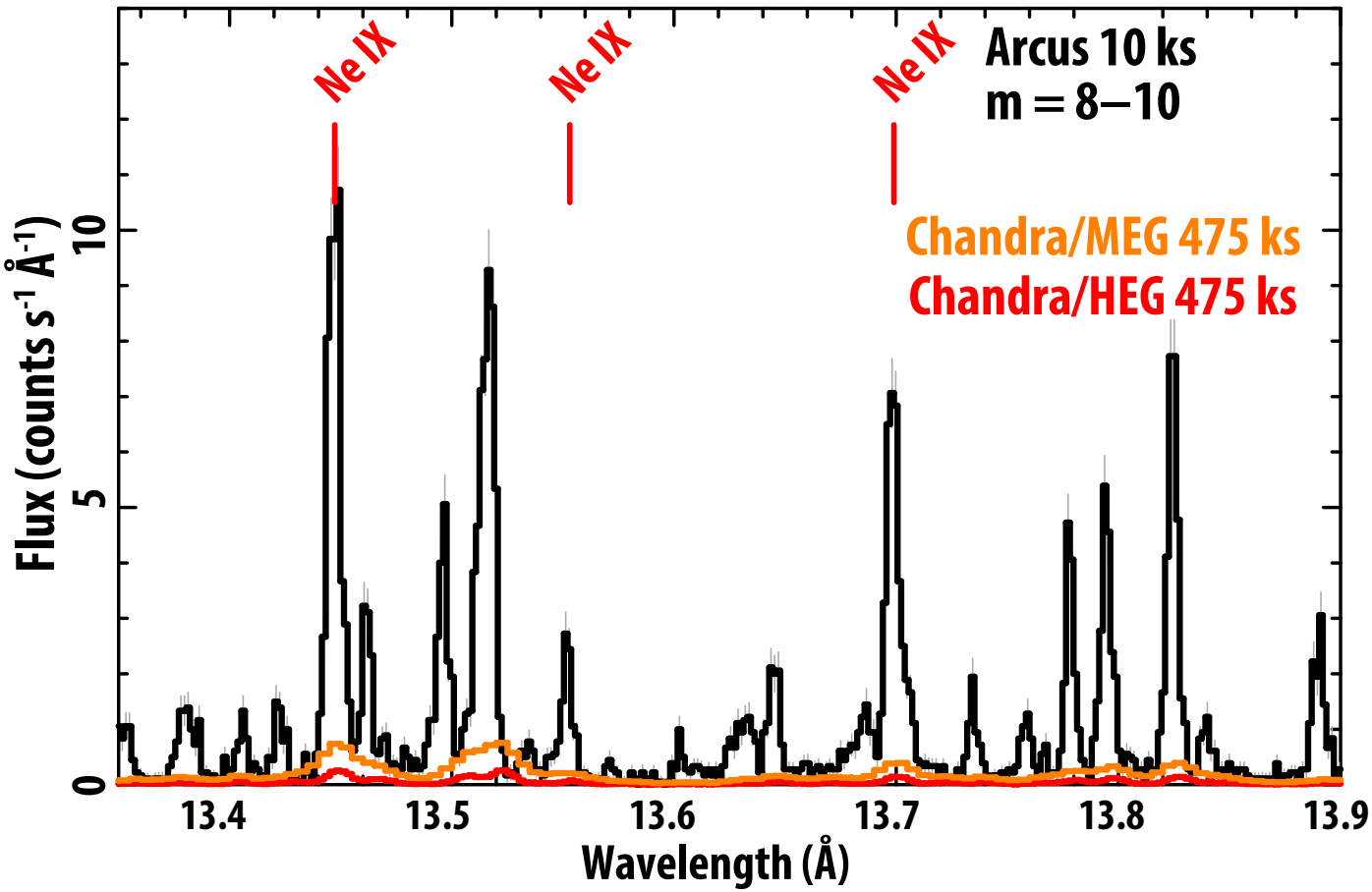


Arcus is superior to current gratings, both in spectral resolution and effective area, providing an order-of-magnitude improvement in sensitivity across the 10-50 Å bandpass. Microcalorimeters cannot achieve such sensitivity at these wavelengths.

Arcus is the only mission capable of providing revolutionary spectral diagnostics in the 10-50 Å bandpass

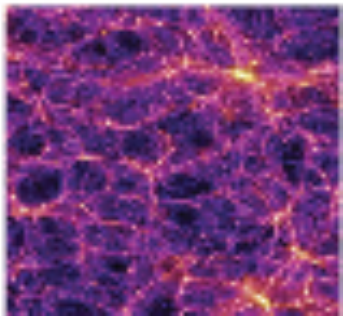
Stars & Stellar Formation

- Arcus measures the ratio of, e.g., Ne IX emission line fluxes to those of smaller satellite lines in order to test coronal heating models.
- A 10-ks Arcus observation of Capella will have high enough S/N to identify these lines. Chandra/HETG cannot do this science, as it is limited by both spectral resolution and throughput.



High-sensitivity X-ray spectral diagnostics are the only way to determine how stellar atmospheres are heated to millions of degrees

Inspiring Science for Scientists and the Public

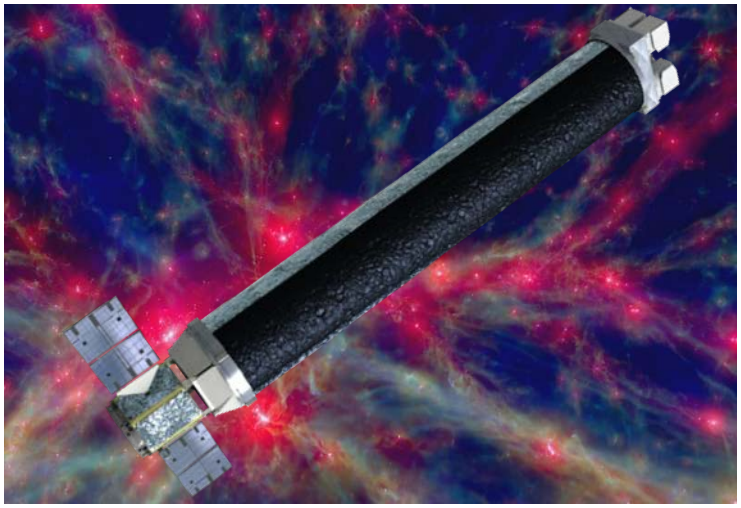


Find & Characterize the Universe's missing baryons and metals

Reveal how black holes impact their surroundings

Learn how stars & stellar systems form & evolve

Technology breakthroughs enable transformational science



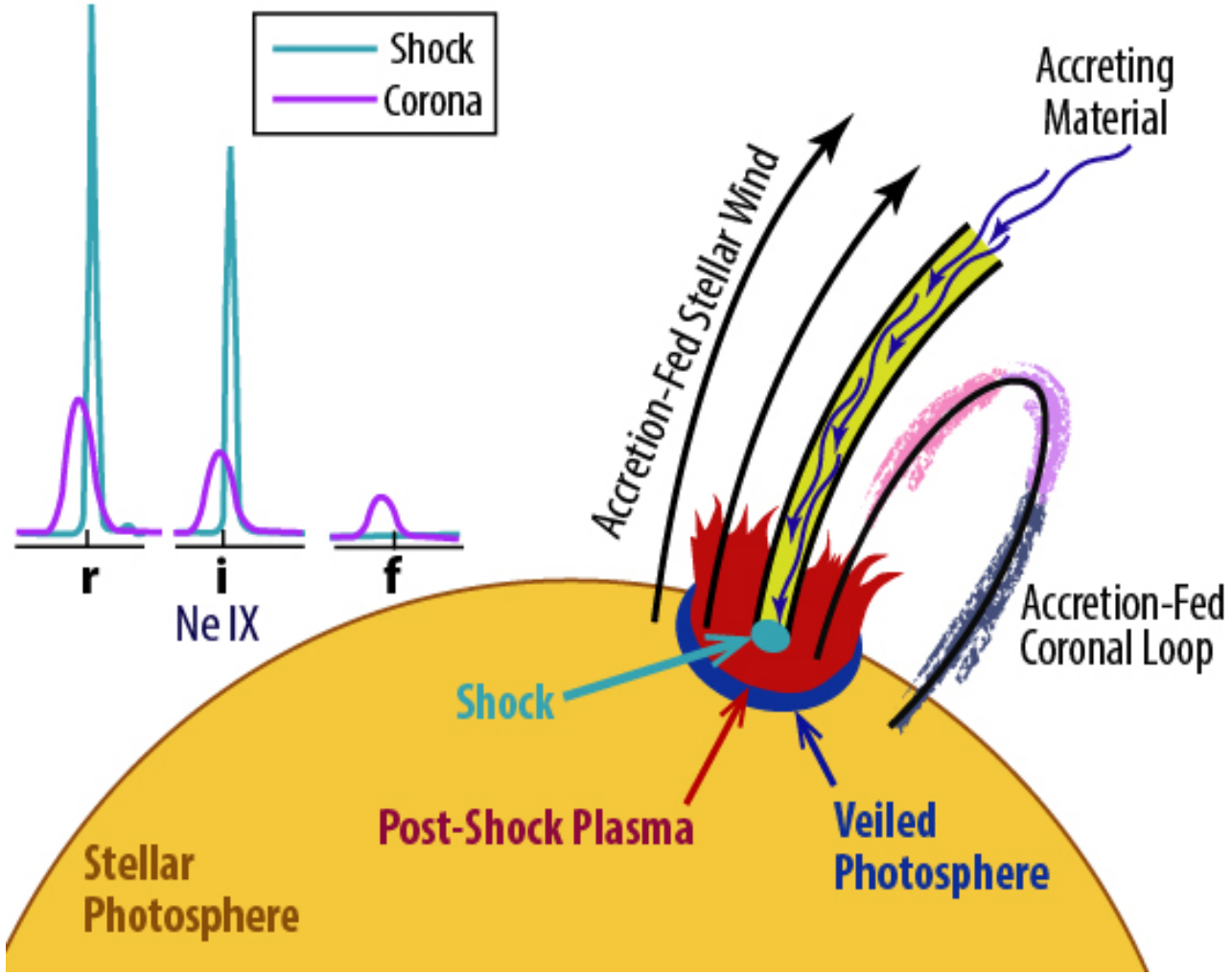
Arcus is ready to reveal the Universe's hidden mysteries

Backup

Stars & Stellar Formation

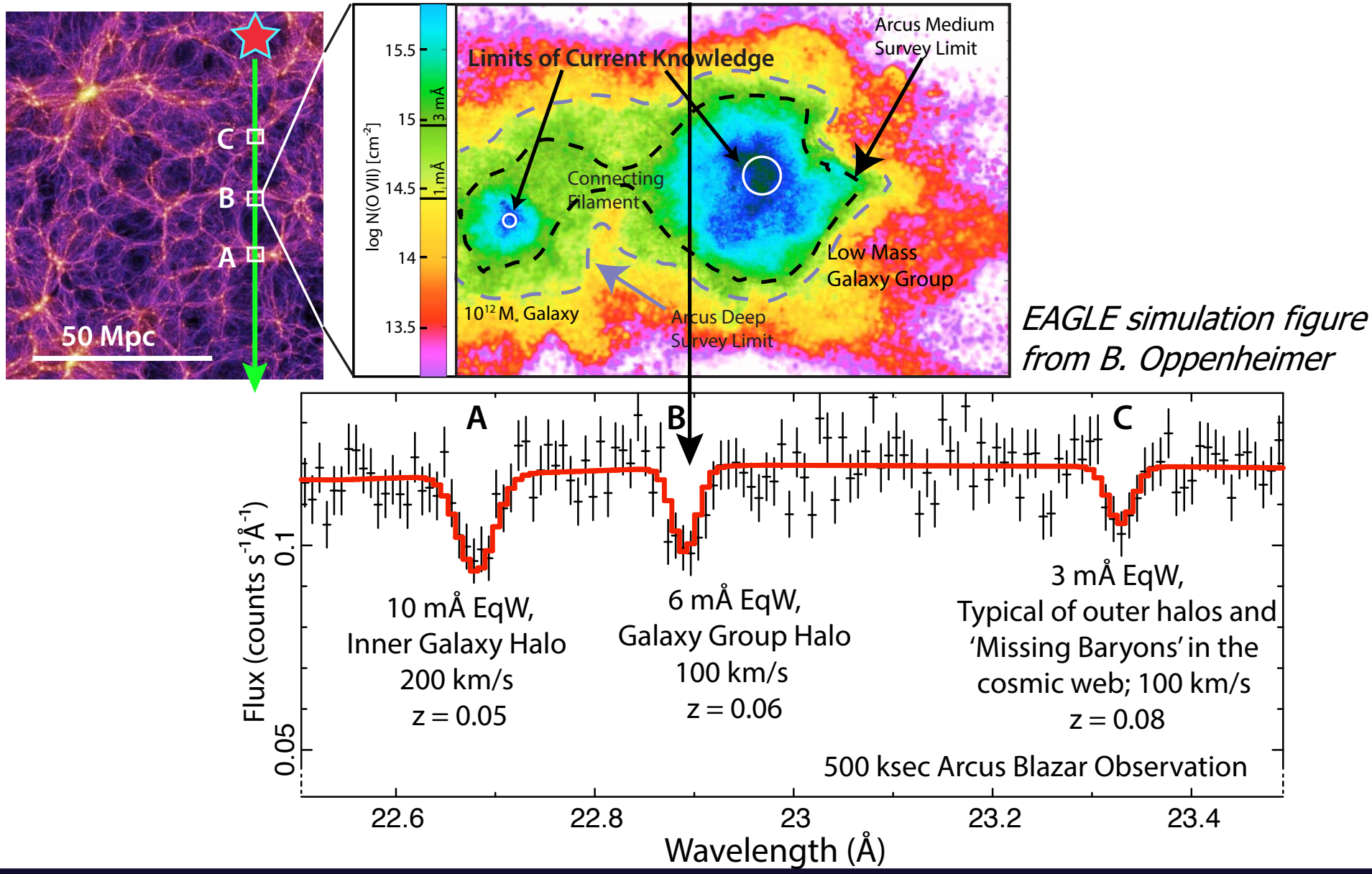
- Arcus differentiates between the distinct line signatures produced by accretion shocks near the surface vs. those from coronal emission, revealing the origin of the accretion flow.

- Arcus maps the density, absorbing column, shock velocity and turbulence of the accreting gas using Helium-like ion emission line diagnostics.



High-sensitivity X-ray spectra uniquely determine the mechanisms by which young stars grow and evolve

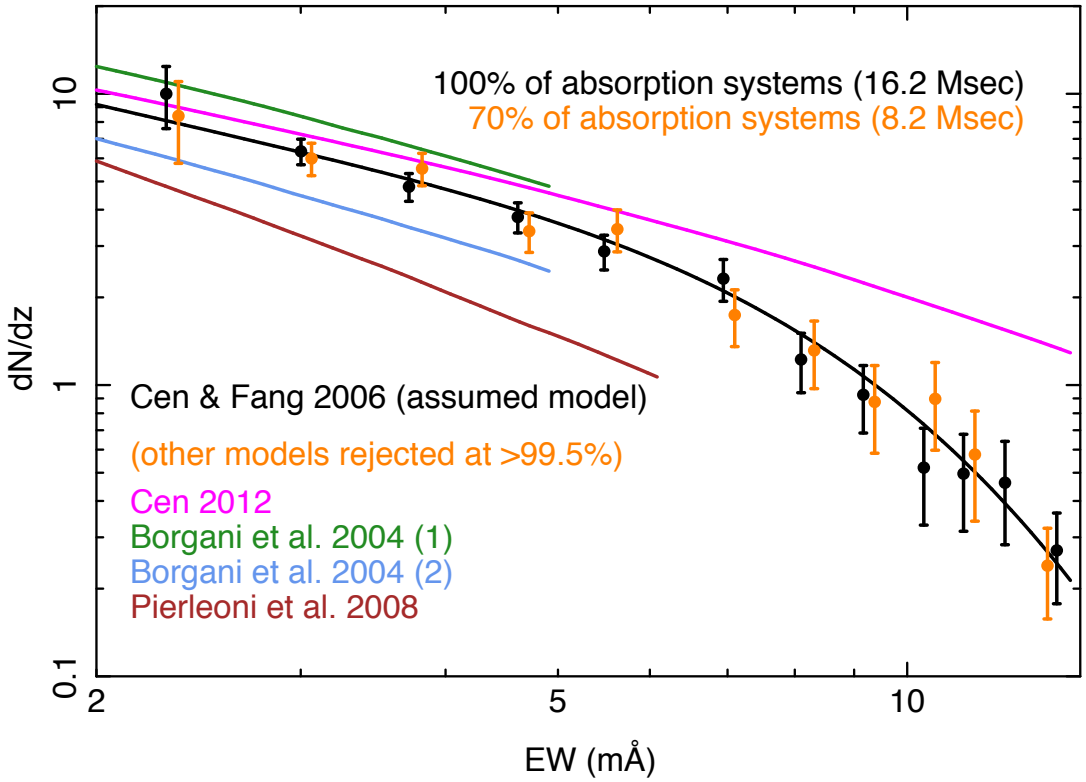
Structure Formation



EAGLE simulation figure from B. Oppenheimer

Characterizing the Hot Halos Around Galaxies

- Models can still be robustly distinguished even at the threshold. We expect ~100 absorption lines based on the (median) Cen 2006 model

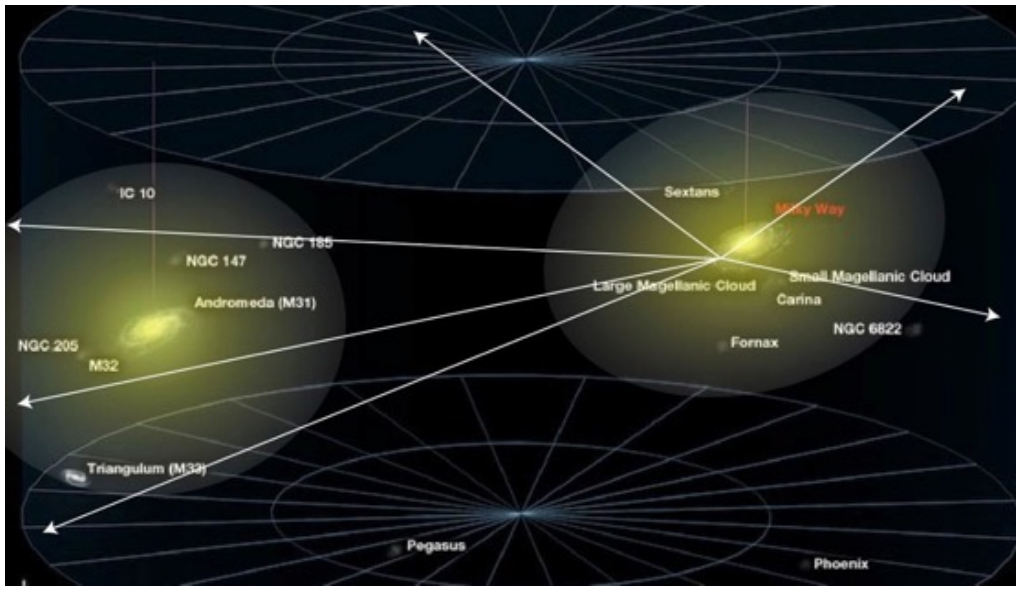


Only Arcus can detect the hot gas halos around galaxies

Milky Way & Other Nearby Halos

X-Ray Absorption in the Milky Way, M31, and "Local Group"

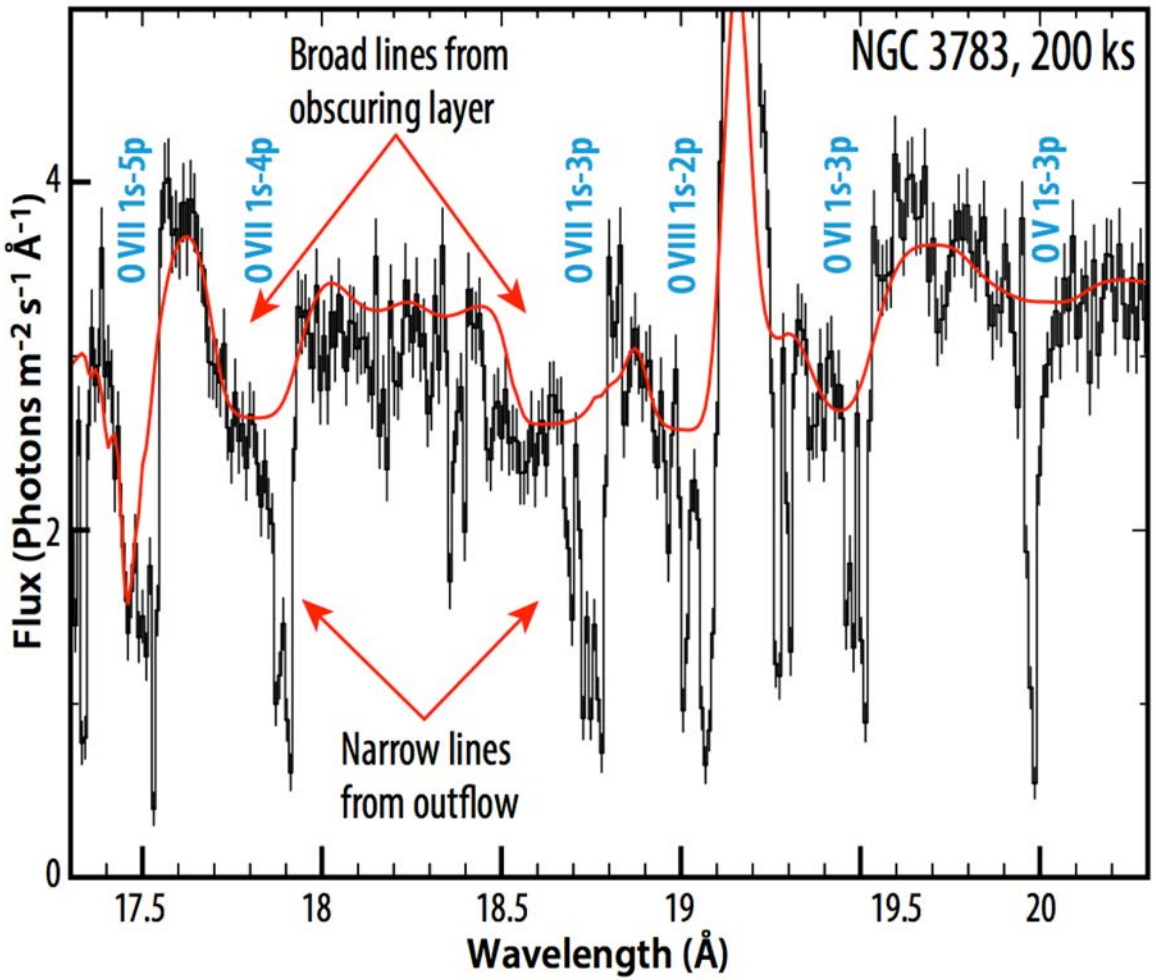
- Every extragalactic sight line probes our Galaxy's hot halo
  - Arcus will obtain density, temperature, mass distribution, and shape
- M31 (6 sight lines within 200 kpc; 2 near M33)
- Local Group, if detectable, has a different velocity than MW



Arcus uniquely provides detailed "maps" of nearby hot gas

Supermassive Black Hole Outflows

- AGN typically show multiple layers of obscuring gas along our line of sight, complicating the interpretation of their absorption spectra.
- Arcus definitively characterizes the obscuration in AGN such as NGC 3783.
- Arcus's superior sensitivity will allow it to separate the narrow absorption line complexes of the parsec-scale outflow from the broad and strongly blueshifted absorption lines of the obscuring stream.

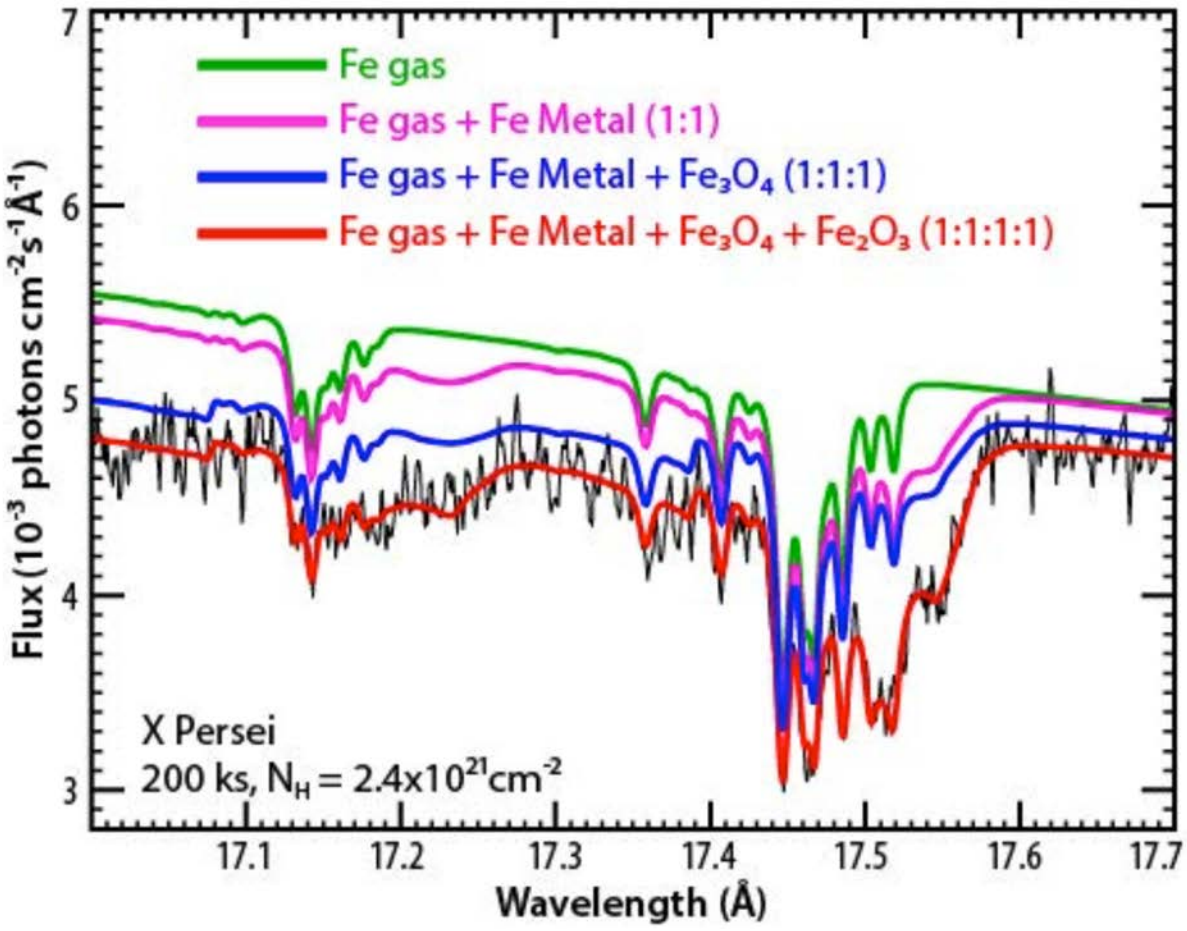


Arcus will provide the most sensitive spectra ever taken of distinct kinematic components of AGN outflows

Interstellar Dust in the Milky Way

- Using accreting X-ray binaries in the Milky Way as background lights, Arcus spectra (black line) can distinguish between models with different Fe inclusions in interstellar dust grains via their distinct XAFS.

- Grain composition significantly impacts cosmic microwave background polarization measurements, as the foreground dust emission can increase by ~4x depending on specific magnetic inclusions.



Only Arcus can distinguish between ISM dust types via their composition-specific X-ray absorption fine structures (XAFS)

The Arcus team is expert and committed to what we do

- SAO: X-ray Instruments and Science Operations
- GSFC: Science and the HEASARC
- ARC: Mission Management and Mission Operations
- NGIS: MIDEX-class Spacecraft and Booms
- MIT & LL: CCDs and Gratings
- MPE & Cosine: Silicon Pore Optics
- PSU & SwRI: X-ray instrument control and photon analysis

The Arcus team represents organizations and individuals who bring world-class capability to perform cutting-edge science