ARCUS

EXPLORING THE FORMATION AND EVOLUTION
OF CLUSTERS, GALAXIES, AND STARS

Micro-Primer on X-Ray Spectrocopy

- Very hot (galaxy clusters); ~6E7 K
  - Few lines, highly ionized Fe K at 6-7 keV band
- Hot (5E5-1E7 K)
  - Galaxies; Galaxy Groups; Cosmic Web; Stars
  - Many ions (O, C, Si, Fe L)
  - Many lines; E = 0.2 - 1.3 keV
  - *Arcus* Science
- AGN winds (range of T); *Arcus* science

Two Types of Spectrographs

- Calorimeter (*Hitomi*, *Athena*, *Lynx*); IFU
  - Great at high energies, 6-7 keV
  - Fe XXVI; clusters; some AGN physics
  - Spectral resolution 3 eV; Resolution = 2000
  - Bad at lower energies; Resolution = 300
  - Worse than *XMM RGS* today!
- Gratings
  - Great at low energies where all the lines are; Resolution ~3000
  - *Arcus* (also, *Lynx*)

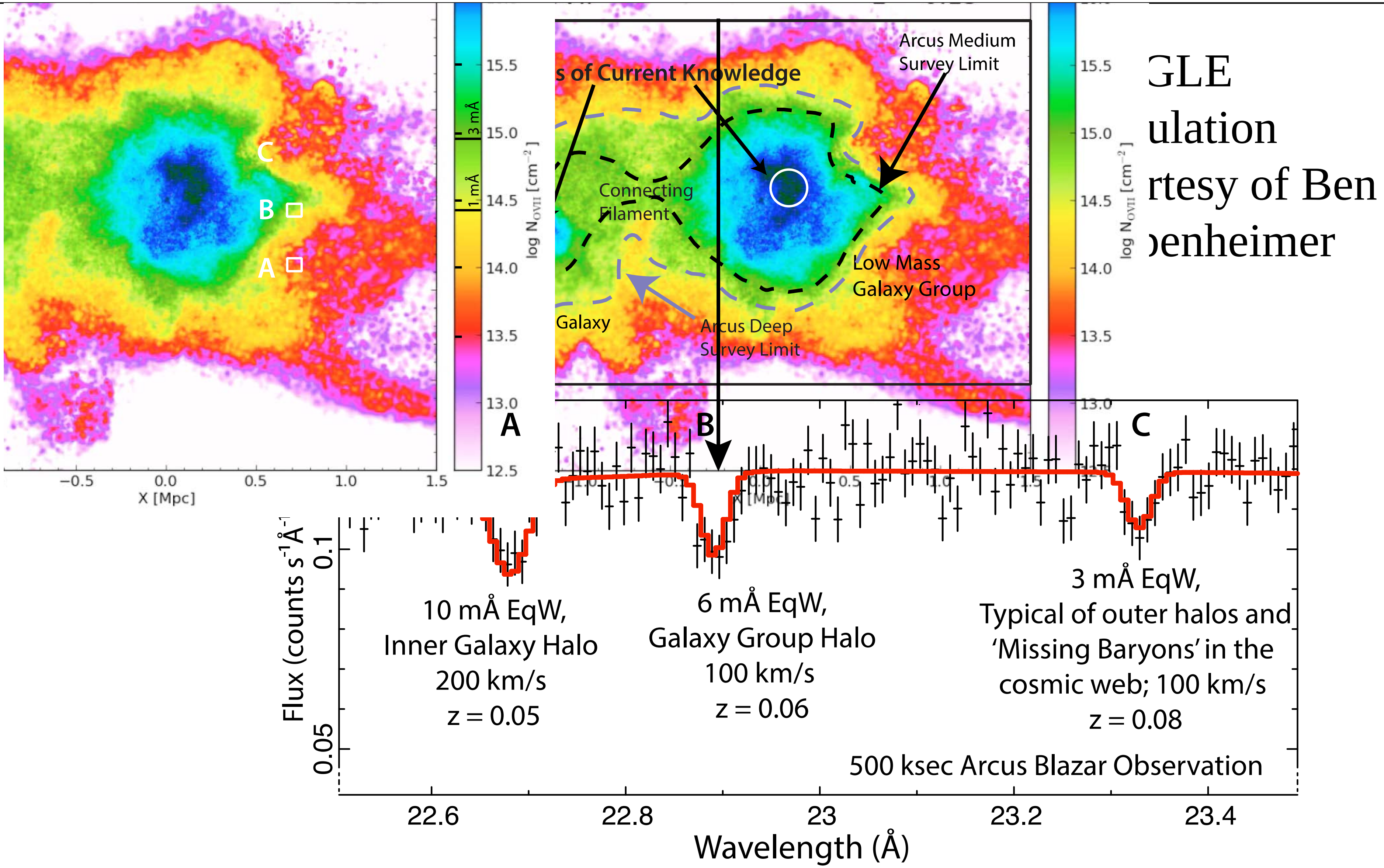
Overview of *Arcus*

- **Soft X-ray grating spectroscopy MIDEX mission**
- **Science**
  - Understanding the formation and evolution of galaxies, clusters of galaxies, black holes, and stars.
- **Key Parameters**
  - Effective Bandpass ~12-50Å (~0.25-1 keV)
  - Resolution $\lambda/\Delta\lambda$ (= R) > 2500 between 22-25Å
    - design is >3500
  - Area = 200-400 cm^2; ~300 cm^2 at O VII (21.6-28Å)
  - About 30-100 x better than *XMM* or *Chandra*
  - 100 km/s resolution (*XMM* is 900 km/s)

Metals and Baryons are "Missing"

- 1. The Global Missing Baryon Problem
  - Add up all visible mass components in large volume
  - Compare to CMB baryon density
  - 40% (or more) of baryons unaccounted for
- 2. The Galaxy Missing Baryon Problem
  - Obtain total halo mass from rotation, velocity dispersion
  - Calculate baryon mass from Universe baryon/DM
  - We observe stellar + warm/cold gas mass
  - 70-98% of baryons missing (worse at lower halo masses)
- The Missing Metals Problem
  - Metals produced over time gives 0.1-0.2 Solar mean today
  - Observe only 20% of the metals (stars + cold/warm gas)
  - 80% of metals are missing
- It's all in a hot phase,   0.5E6 – 30E6 K (model-dependent)

Science Goal #1: Structure Formation



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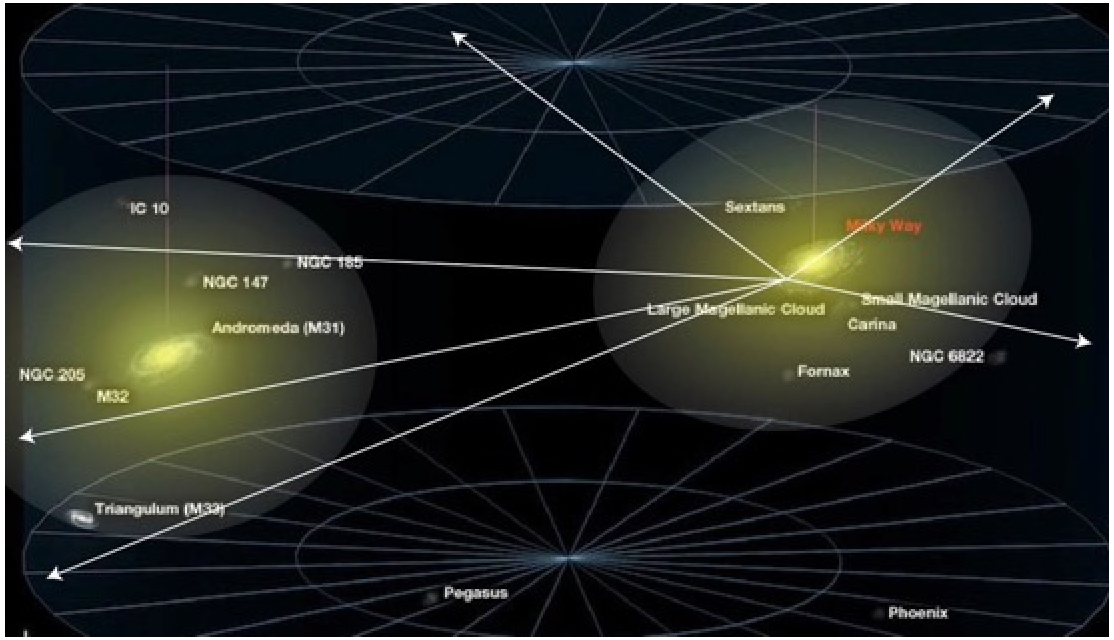
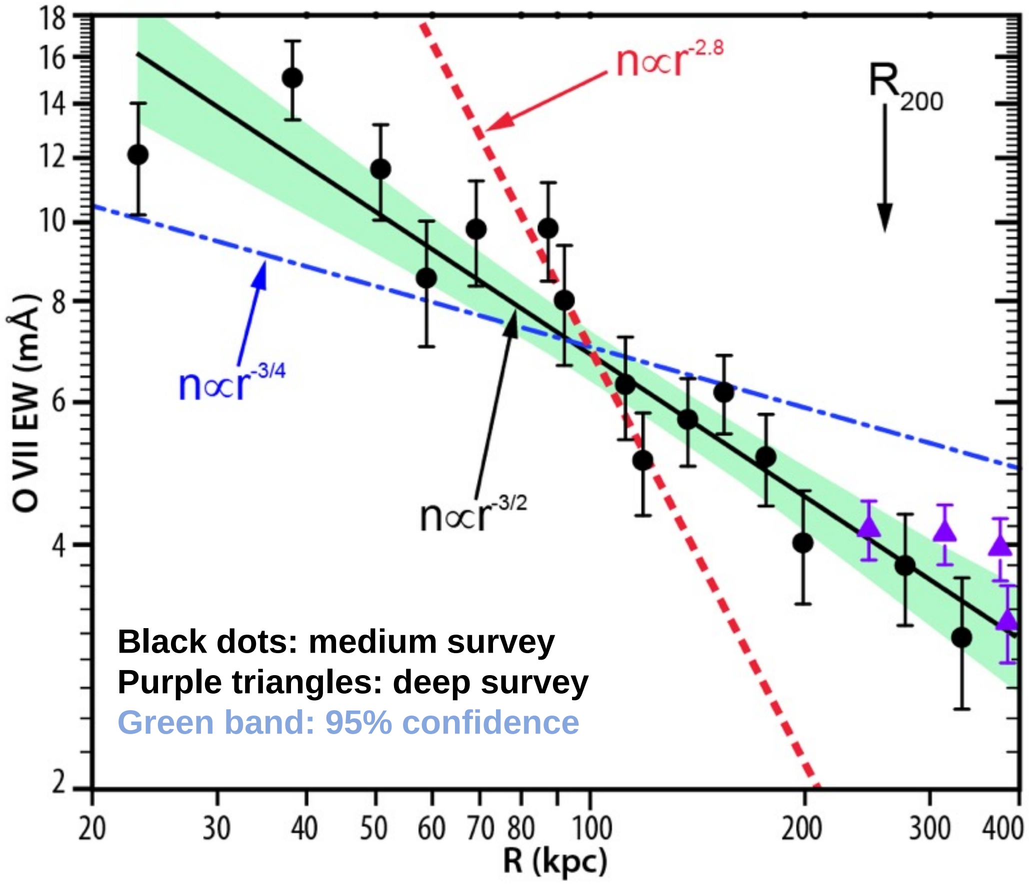
Science Goal #1: Structure Formation

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)
  - Differentiated by velocity from the MW
- Local Group absorption has a different velocity than MW



Science Goal #1: Galaxy Halos



Arcus will measure the slope of composite radial density distribution to beyond R_{200}.

- Galaxy halos contain much of the "normal" material in the Universe
- Arcus will determine shape, size of galaxy halos not possible to measure any other way
- Halo gas could follow dark matter distribution ($n \sim r^{-2.8}$); or distribution inferred from r<50 kpc of galaxy ($n \sim r^{-3/2}$); or distribution where baryons are within R_{200} ($n \sim r^{-3/4}$)

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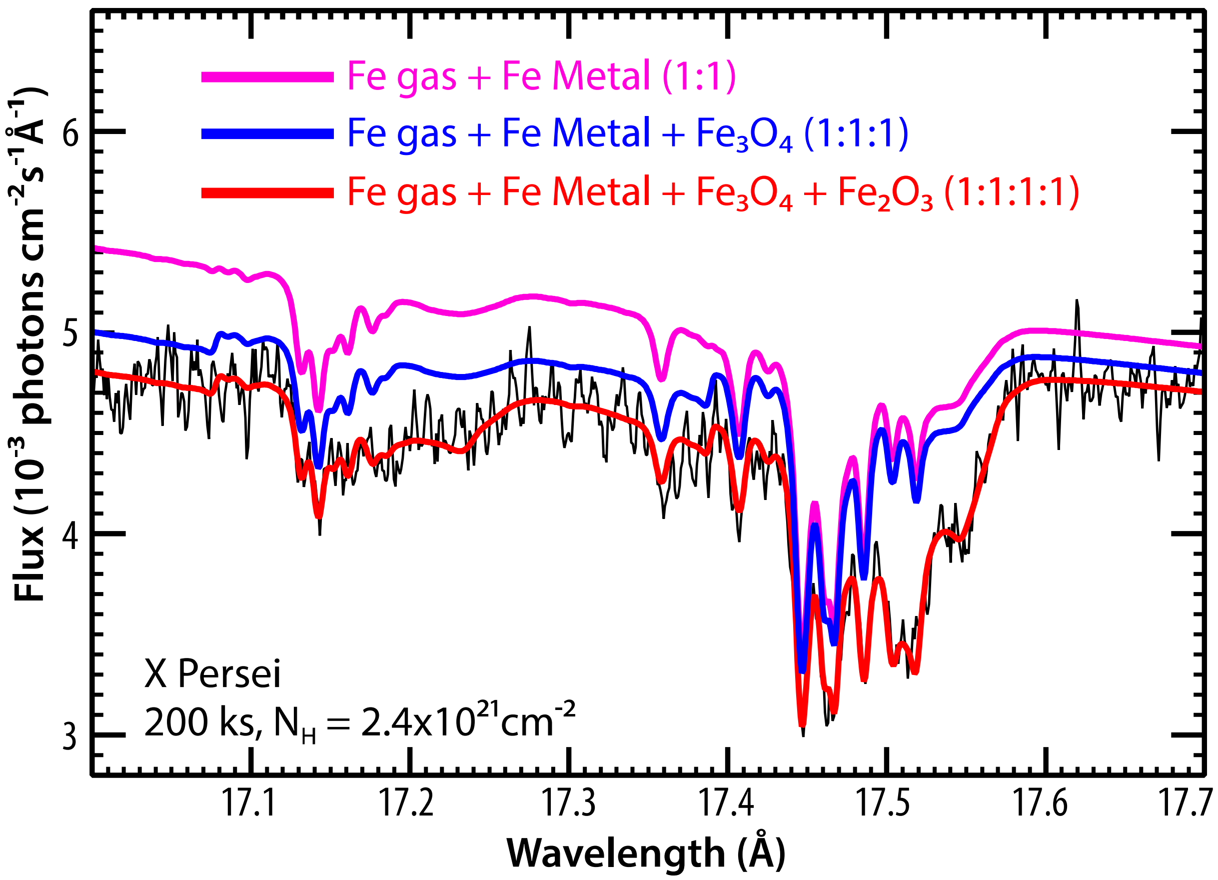
X-rays and CMB polarization…

The CMB has a dusty ‘foreground’

Contamination depends on magnetic inclusions.

Sensitive to composition of exclusions: Fe_2O_3, Fe_3O_4, or metallic Fe.

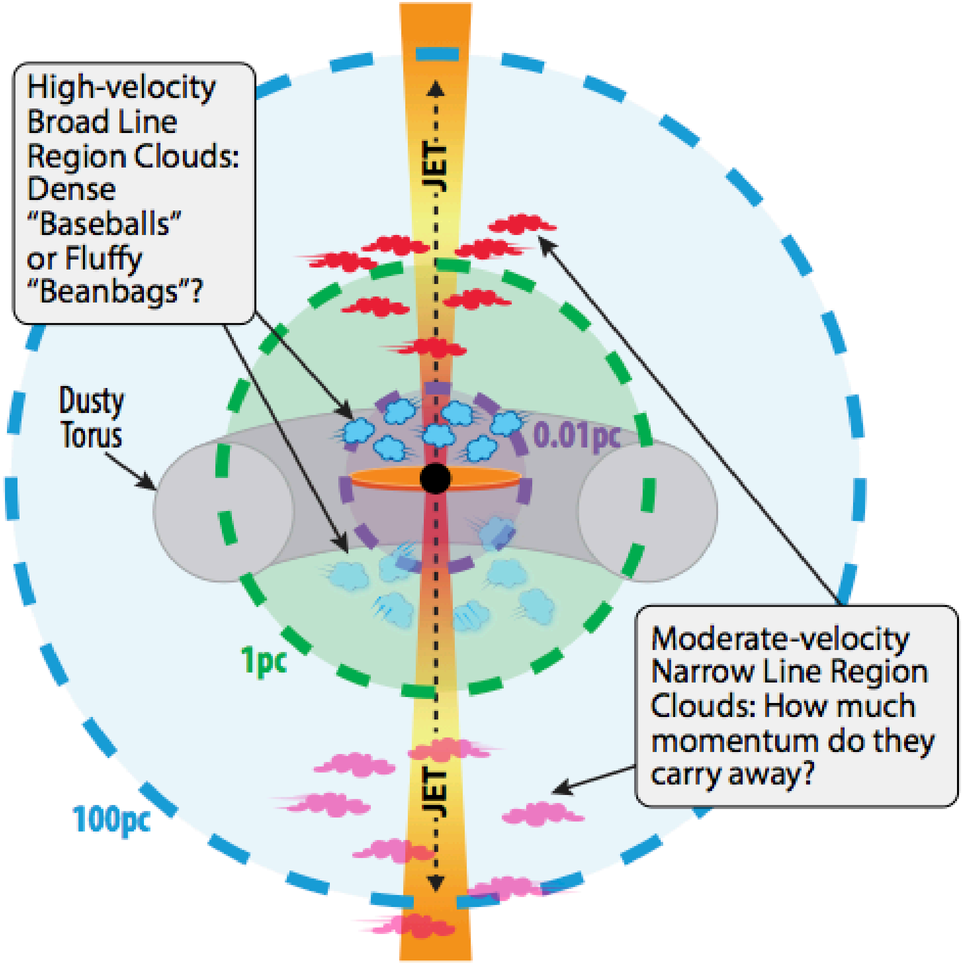
Arcus will identify inclusion composition.



Science Goal #2: SMBH Feedback

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

- *Arcus* will measure 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.
- Defines the role of AGN feedback in shaping host galaxies.

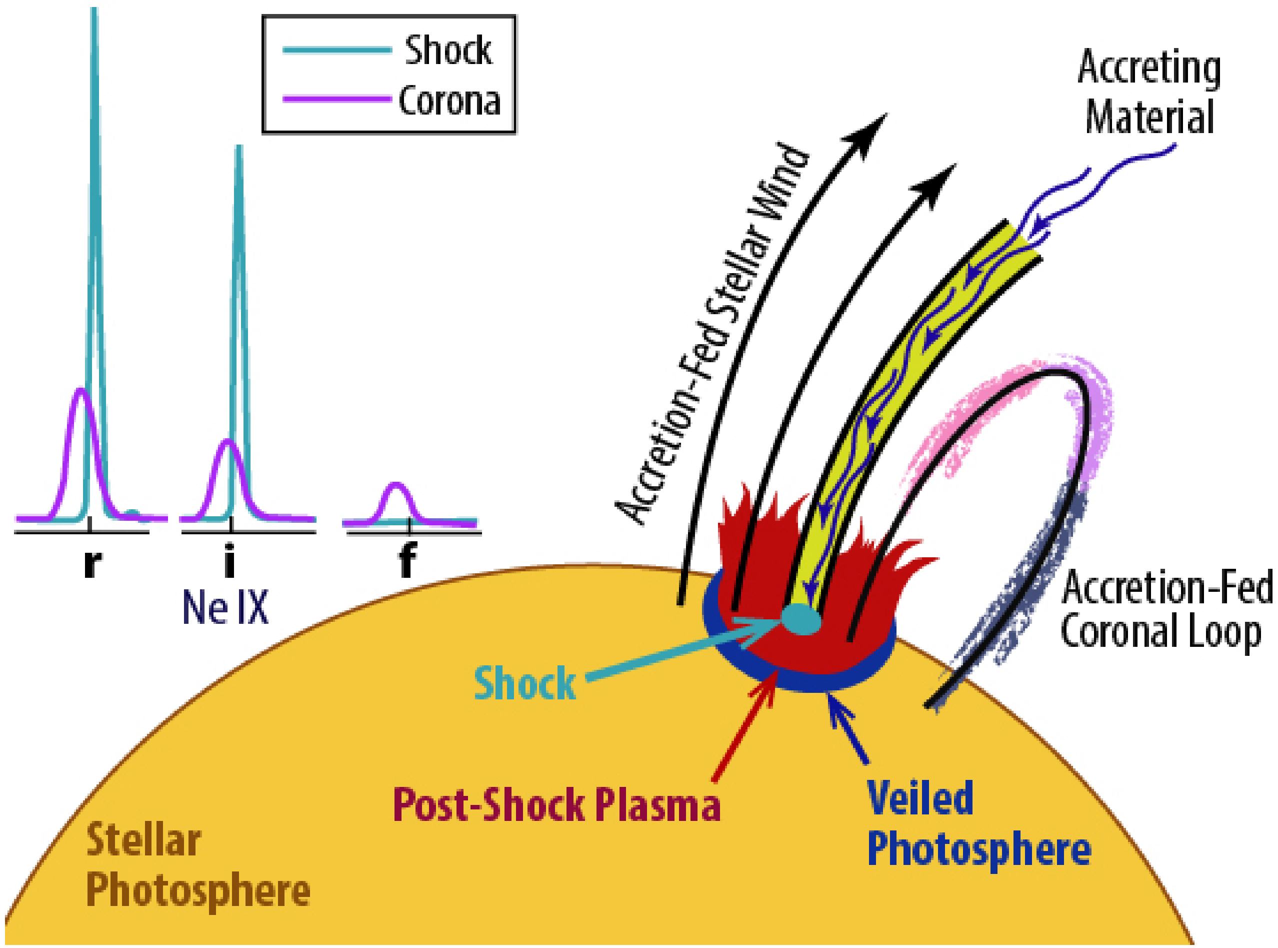


Science Goal #3: Stars & Stellar Formation

Stellar accretion physics: accretion shocks near the surface vs. those from coronal emission

Differentiate between models by line shapes.

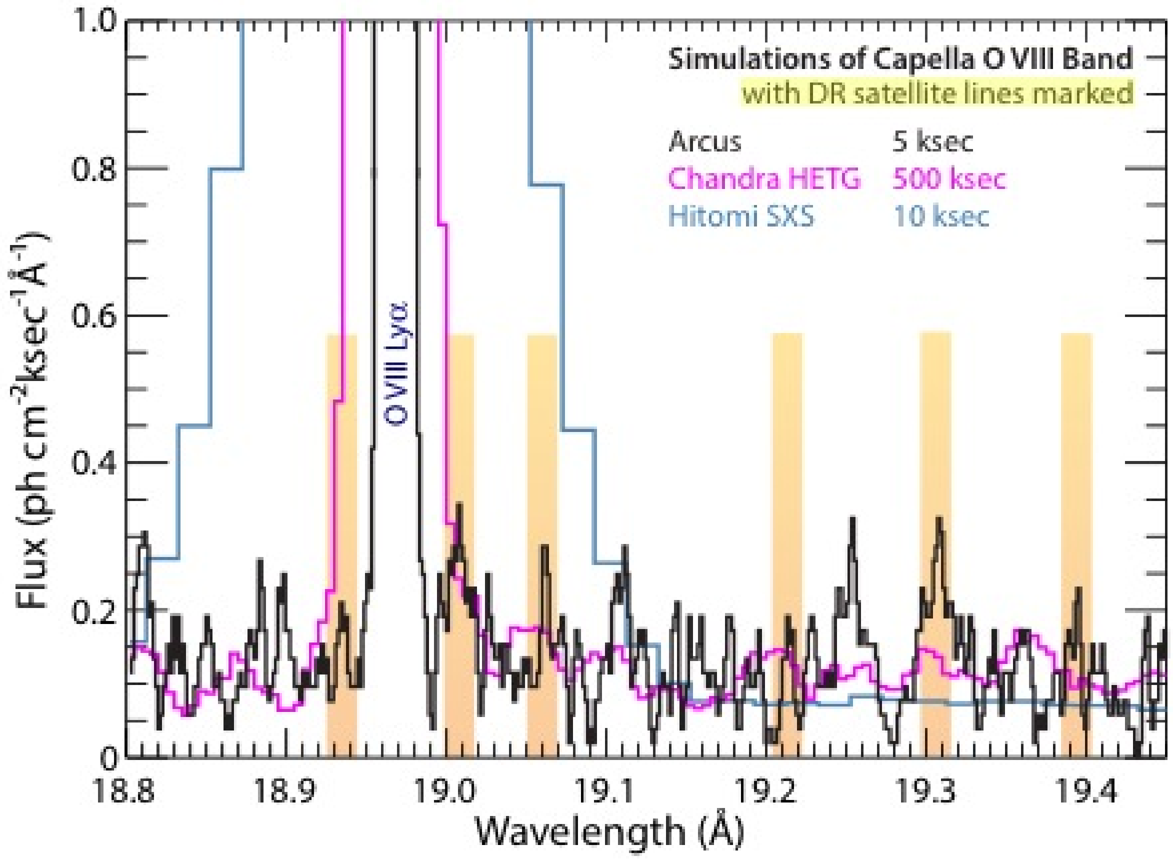
Arcus maps density, column, shock velocity and turbulence from He-like ion lines.



Science Goal #3: Stars & Stellar Formation

Test coronal heating models by temperature-sensitive dielectronic recombination lines.

Arcus observation detects these lines and captures changes in the dynamic corona.



Chandra HETG is limited by resolution and throughput, and a microcalorimeter like Hitomi cannot resolve the features.

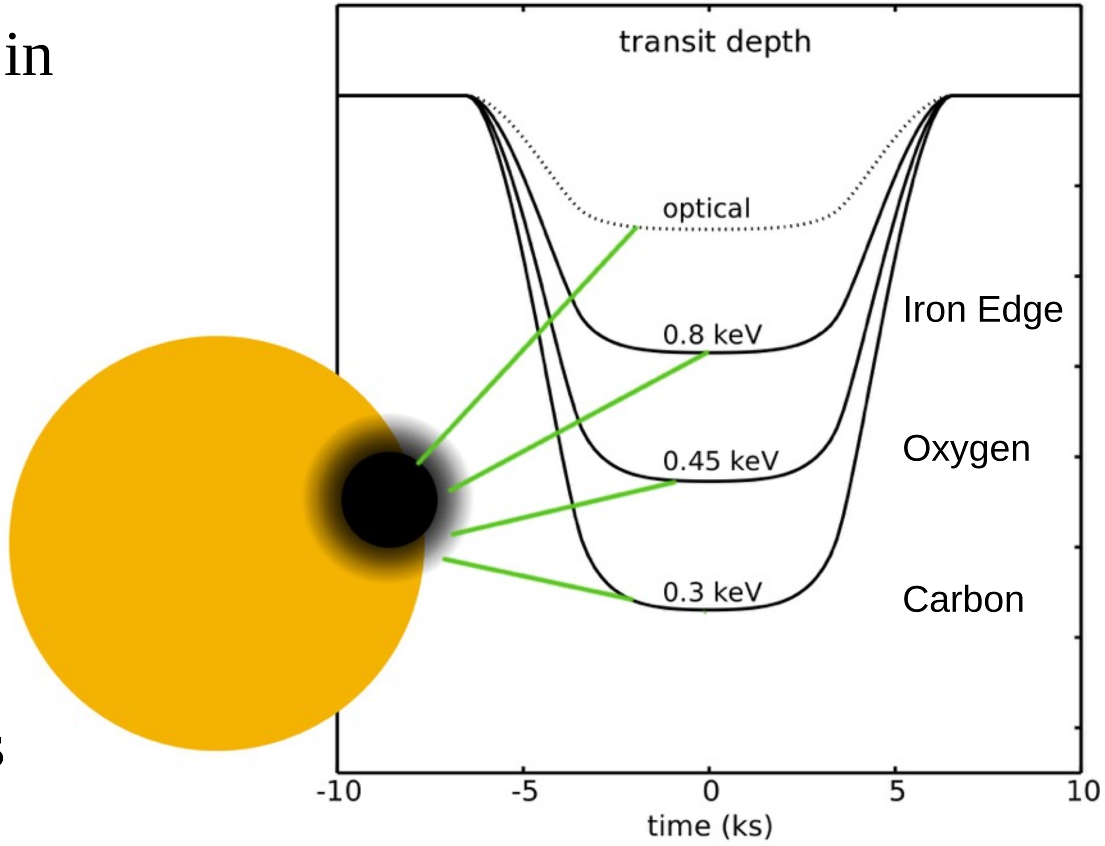
Arcus & Exoplanets

- Low-altitude exoplanet atmospheres are accessible in the Opt/IR

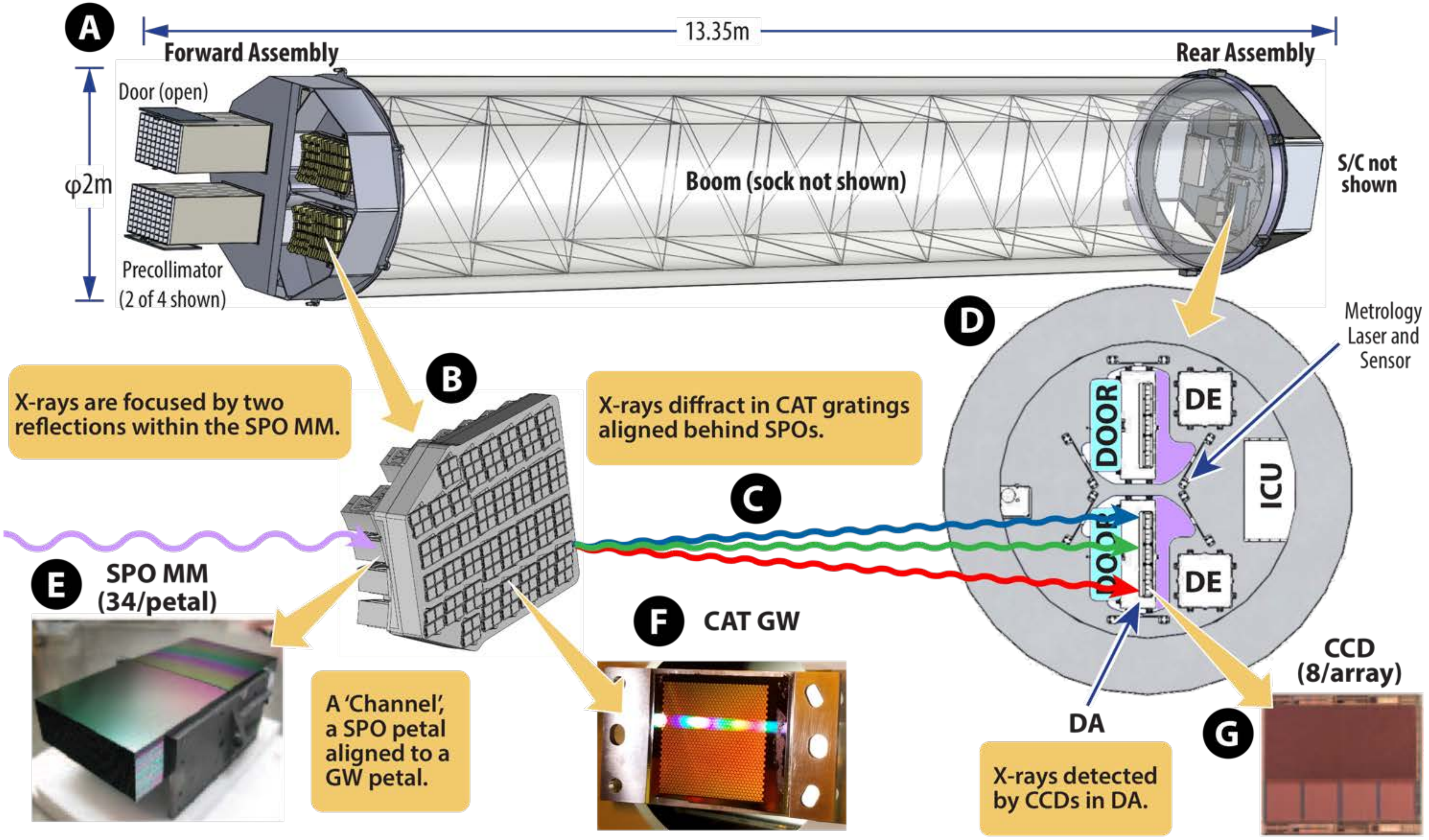
- *Arcus* will measure the thermal profile and composition of the high-altitude outer layers

- Optical depth is energy-dependent: elemental edges

- Detected in one exoplanet with *Chandra*, HD 189733b.



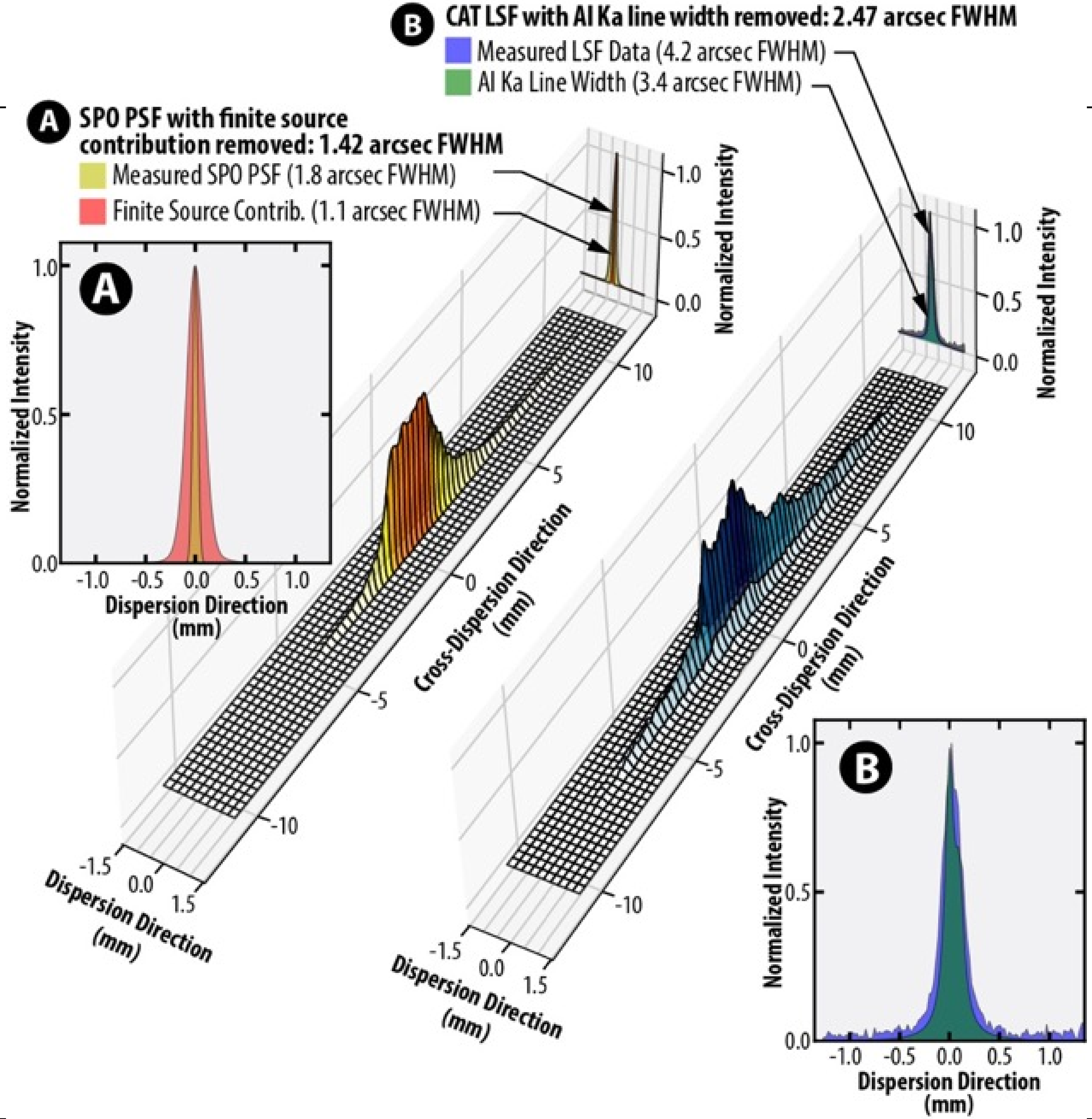
Schematic Overview



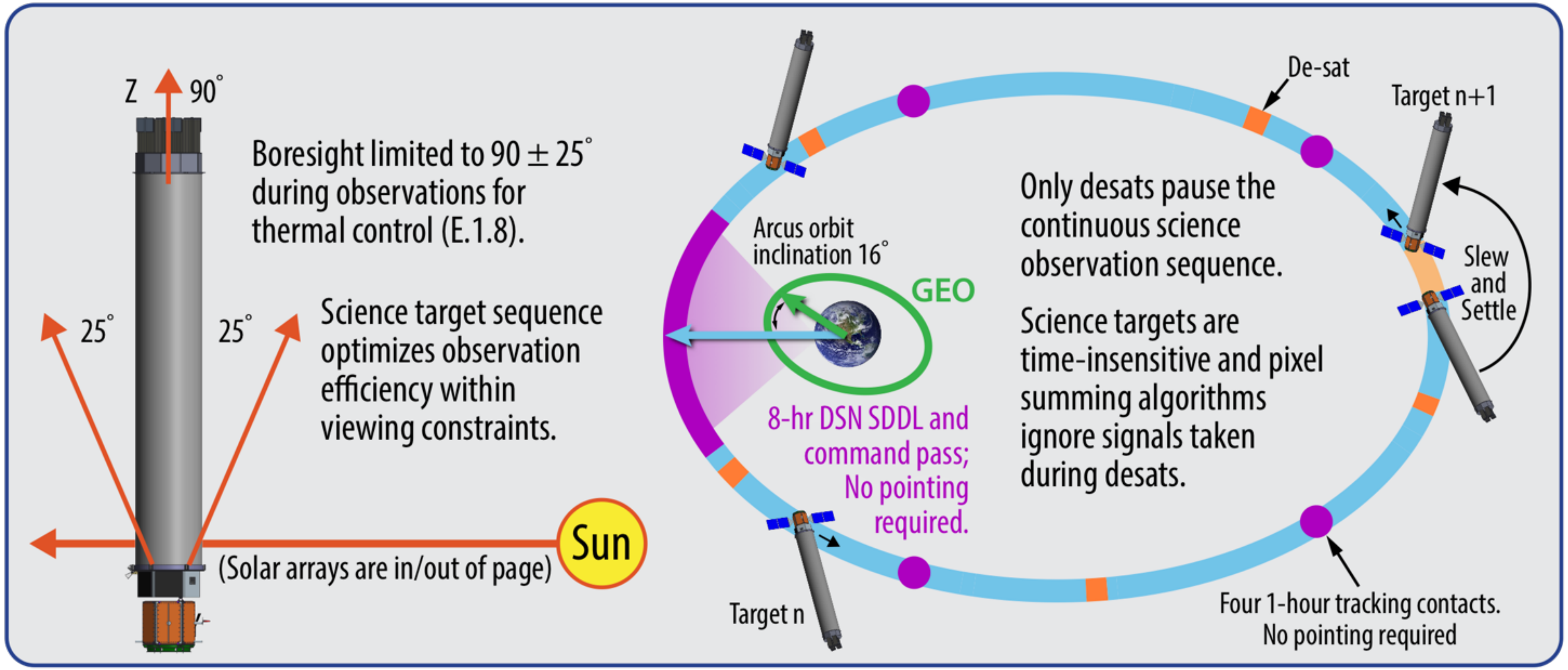
Measurements

Same focal length and optics tech as ESA's *Athena* mission

X-ray tests of silicon pore optics (SPOs) and Critical-Angle Transmission (CAT) gratings show they already meet *Arcus* requirements



Mission - Orbit



Lunar resonant orbit offers infrequent eclipses, a stable thermal environment, and long-term orbit stability that enables simple operations.

Science Orbit Parameters	Value
Perigee Altitude	11 Re
Apogee Altitude	35 Re
Inclination	16 degrees
Orbital Period	6.85 days (0.59 Msec)
Maximum Eclipse	4.5 hours

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Arcus Team Members

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Arcus Status

- Downselected for Phase A in Aug. 2017
- Phase A document submitted, May 2018
- Site visit in September 2018
- Final decision by NASA Assoc. Administrator for Science by Jan 2019
  - Down to two missions: Arcus and Sphere-X
- Launch in 2023
- Glory in 2024

Arcus in Summary (arcusxray.org)