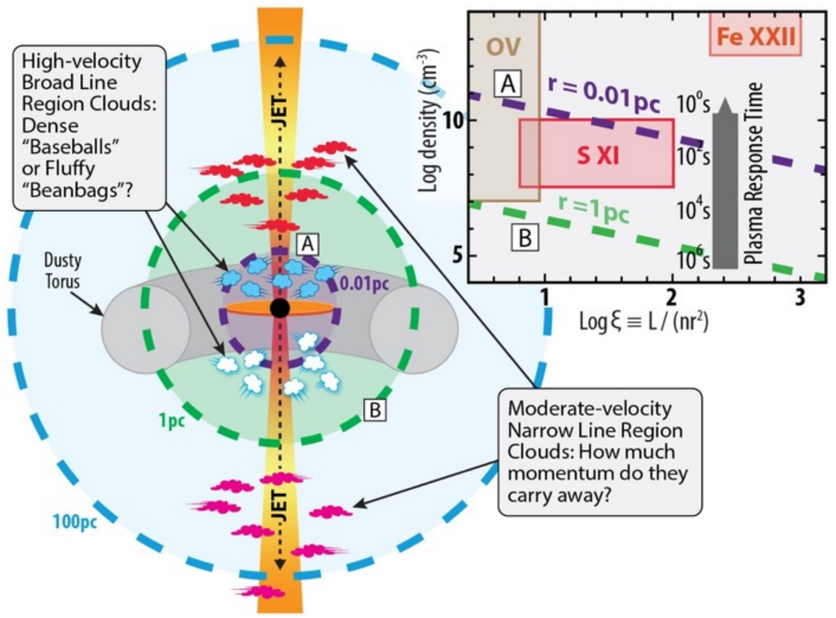
# *Arcus*: Black Hole Feedback Science

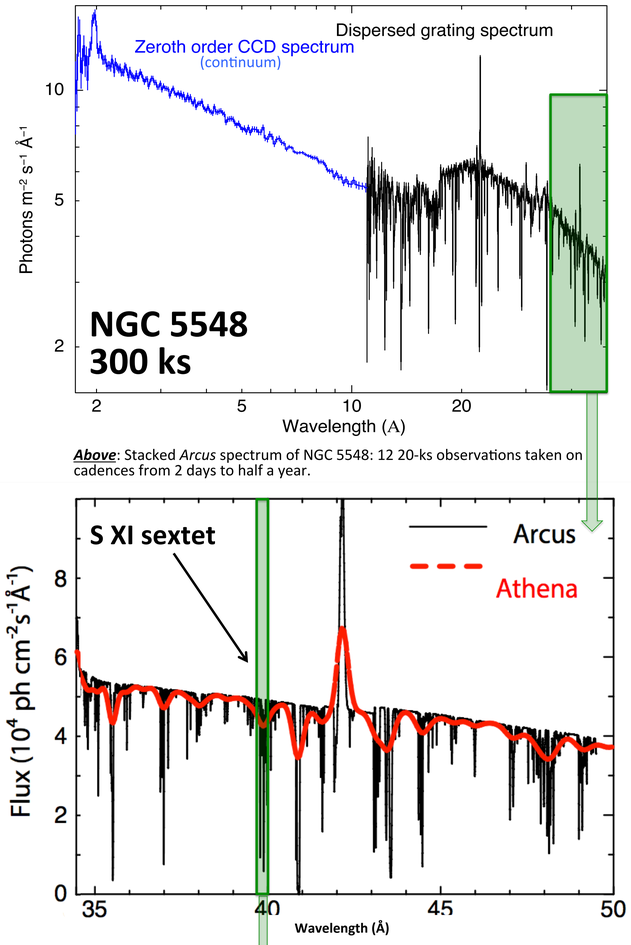
**Laura Brenneman on behalf of the *Arcus* Science Team**

Smithsonian Astrophysical Observatory

**Introduction**: *Arcus*, a proposed NASA/MIDEX mission currently in Phase A, will revolutionize high-resolution X-ray spectroscopic investigations of outflows from both supermassive and stellar-mass black hole systems. With an effective area >250 cm$^2$ between 12-50 Å and R~2500, *Arcus* will offer an order-of-magnitude improvement over the sensitivity of present-day gratings. These advances will enable measurements of the column densities, ionization states and velocities of the outflowing gas with unprecedented precision and accuracy in both absorption and emission. Multiple ions of C, N, O, Ne, S and Fe fall within *Arcus's* energy range, facilitating gas density measurements through helium-like emission line groupings. These density measurements, when combined with ionization measurements and knowledge of the continuum flux (obtained through *Arcus's* zero-order spectrum), will provide the first definitive constraints on the launching radii and the physical mechanisms driving the outflows. Simultaneous knowledge of the outflowing gas velocity will then yield the total momentum carried away by these winds. Connecting the momenta of AGN and stellar-mass black hole outflows from their launching points to downstream in the outskirts of galaxies through synergistic observations with *JWST* and *ALMA* will provide the first comprehensive view of feedback between black holes and their surrounding ISM/IGM.

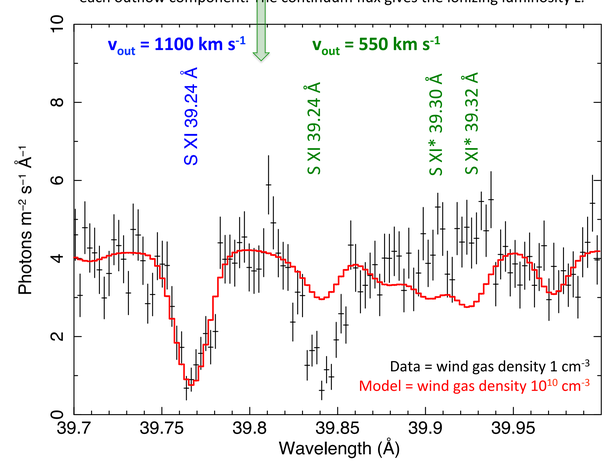



***Above:*** Schematic illustrating the typical structure of an actively-accreting supermassive black hole in an AGN. Outflowing winds are hypothesized to originate in both the broad-line region/accretion disk surface and narrow-line regions, though the inability of present-day instruments to precisely measure the density of the outflowing gas has hindered our ability to constrain the launching radii of different velocity components. *Arcus* will allow us to break this critical spectral modeling degeneracy for the first time by measuring the outflowing gas density (*n*) in at least one of two ways: through density-sensitive line ratios and constraining the response time of the gas in the wind to changes in the ionizing luminosity (*L*) of the continuum. The latter method is demonstrated in the inset plot above, which shows the regions in density-ionization space of the absorbing gas in which three different ions in the *Arcus* bandpass act as critical gas density diagnostics (O V, S XI and Fe XXII). Similarly, measuring the change in the absorbing gas ionization parameter ($\xi$) in response to continuum variations will provide an independent constraint on the distance (*r*) between the outflowing gas and the ionizing source.

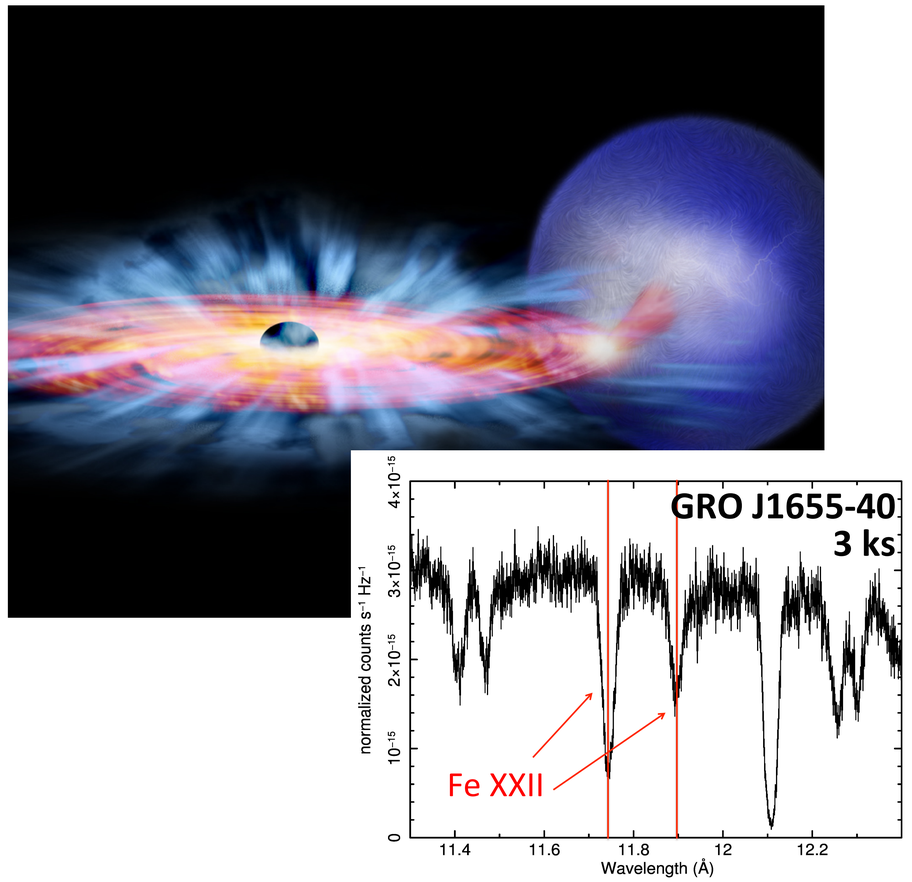



***Above***: Stacked *Arcus* spectrum of NGC 5548: 12 20-ks observations taken on cadences from 2 days to half a year.

***Above***: *Arcus* can resolve the density-sensitive S XI sextet while the *ATHENA* calorimeter cannot. Photoionization modeling yields the total column density, ionization parameter, outflow velocity, turbulence and chemical abundances for each outflow component. The continuum flux gives the ionizing luminosity *L*.




***Above***: For low densities (<$10^7$ cm$^{-3}$), all ions are in the ground state and therefore the absorption spectrum will show only lines from this ground state. For higher densities (>$10^8$ cm$^{-3}$), the meta-stable levels are populated (S XI*). Comparing the intensity of the lines from the ground state with those from the meta-stable levels yields the density.




## AGN Feedback

- The bulk of outflowing material in AGN winds is highly ionized and accessible only in X-rays.
- *Arcus* will measure the momenta of these winds for the first time by measuring the response time of the wind properties to changes in the continuum.
- These measurements will break the degeneracy between the density of the outflowing wind and its launching radius.
- Knowing how these winds propagate and affect their surroundings has important implications for the role of AGN feedback in shaping host galaxies.
- *Arcus* will observe 20 AGN with deep observations on a variety of cadences in order to track continuum variations and absorption line response. The mission will then perform an exploratory survey of 113 additional AGN from the *ROSAT* All-Sky Survey to identify candidates for future study.

## Black Hole Binary Feedback

- *Chandra* spectra reveal equatorial disk winds in X-ray binaries, but the nature of these winds, and how they are launched, remains unclear.
- Regardless of whether the launching mechanisms are similar to those seen in AGN, we can utilize the same observational techniques in both cases to determine wind densities and launching radii.
- *Arcus* can detect density-sensitive lines from Fe XXII in just 3 ks in bright X-ray binaries (e.g., above simulation of GRO J1655-40), making it possible to study density variations on the local dynamical time scale, $t_{dyn} = r_{launch} / v_{out}$.
- *Arcus* will perform 64 observations of black hole X-ray binaries in order to characterize their wind properties on dynamical timescales.