National Aeronautics and Space Administration

Supermassive Black Holes and the X-ray to Far-IR Connection

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Program: Topic Area

Project Objective:

Develop a model of the ionization distribution and emission signatures of metal ions in active galactic nuclei (AGN) with supermassive black holes (SMBHs). AGN with SMBHs are sites of intense Extreme UV and X-ray fluxes that produce highly ionized atoms, many of which emit spectral lines in the mid- & far-infrared (Figures 1 & 2). These lines, which must be observed above the atmosphere are important diagnostics of AGN conditions and thus to track the evolution of galaxies in cosmic time.

FY19 Results:

a) We assembled the atomic physics data base relevant to the ionization of carbon, nitrogen, and oxygen by UV and X-rays, necessary to model their ionization states in active galactic nuclei (Fig. 3). These include all Far-UV, EUV, and X-ray L-shell and K-shell photoionization cross-sections. We fit tabulated cross sections as a function of energy, where fits did not exist. b) We assembled and fit all the electron collisional ionization, electron recombination, proton and hydrogen charge exchange reactions needed for the balance equations. c) We developed a 0-D chemical abundance code, X-AGN, to calculate the ionization states as a function of the temperature, density and radiation environment found in AGNs, ULIRGs, and LIRGs. (The 0-D code is a first step in constructing a more realistic 1-D code, an objective of Year 2). d) We assembled a data base of collisional excitation rate coefficients and radiative transition rates for all the FIR and MIR lines arising from carbon, nitrogen, and oxygen, and implemented a radiative transfer model for them. e) We collected a subset of observational data of the fine structure line intensities from galactic nuclei from the *Herschel* and *Spitzer* archives. f) We completed an initial set of model runs in 0-D – see Figure 4.

Benefits to NASA and JPL and Significance of Results):

The code X-AGN, developed under this program, can define science themes and requirements for future MIR and FIR missions, such as suborbital balloons, Flagship missions (e.g. NASA's Origins Space Telescope (OST) which is part of the ASTRO2020 Decadal study), and the potential contributions from concepts such as the SAFARI/BLISS instrument for the European-Japanese Space Infrared telescope for Cosmology and Astrophysics (SPICA). Thus, our program is in line with strategic goals to enable fundamental astrophysics research on the origin and evolution of galaxies, and the supermassive black hole influence on galactic nuclei, while also supporting development of astrophysics instruments and missions.

Our results will be used as the basis for proposals to the ROSES call for the Astrophysics and Data Analysis Program (ADAP) and the Astrophysics Theory Program (ATP). It was used to predict emission line intensities from AGNs and star formation regions for several SOFIA Cycle 8 observing proposals submitted in 2019. It will be used to model observations from a JPL Balloon Borne Mission, ASTHROS, to fly a far-infrared spectrometer in 2023 that was selected by NASA in 2019 and from the funded University of Arizona GUSTO balloon mission (which flies in 2021) in which JPL scientists and technologists are participating.

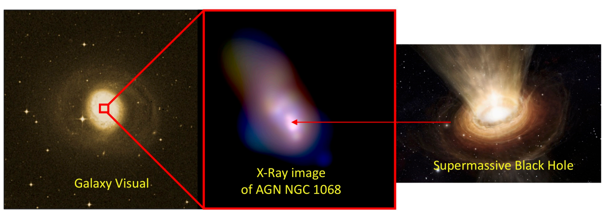

Figure 1. (left) Visual image of NGC 1068 containing an active galactic nucleus (AGN). (center) X-ray image of showing the bright emission from the AGN resulting from gas falling onto the accretion disk of a supermassive black hole, as illustrated on the right.

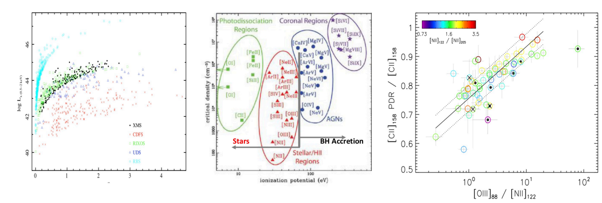

Figure 2. (left) Soft X-ray luminosity for > 10^3 AGNs containing a SMBH (M_{SMBH} > 10^9 $M_\odot$) versus redshift *z*. (center) Illustration of ionization states and their mid- & far-IR diagnostic lines and their specific application to studying star formation, coronal gas, SMBH accretion, and Photon Dominated Regions. (right) Representative FIR line study of luminous infrared galaxies with AGNs, showing [CII] emission versus the ratio of [OIII] to [NII], a measure of the relative contribution from PDRs versus ionized gas.

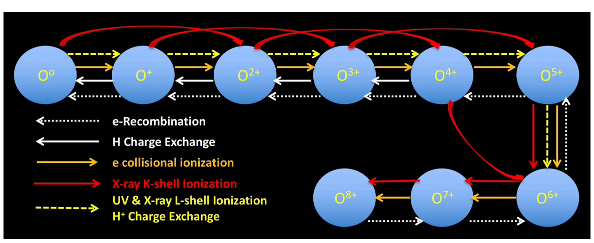

Figure 3. Flow diagram of all the atomic processes determining the ionization balance of oxygen included in the reaction network. Similar reaction networks are required for all other species, although they can be quite complex for heavy atoms such as Argon, Silicon, and Iron.

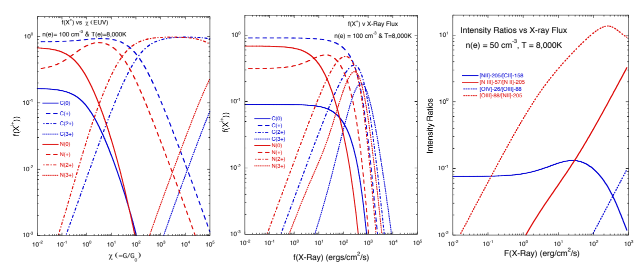

Figure 4. Results from our X-ray dominated region model of the ionic and emission properties of AGNs. The left and center show the difference between photoionization due to extreme UV and intense X-ray fields. (left) Carbon and nitrogen fractional ionization states, C^{n+} and N^{n+}, for n = 0 to 3, versus EUV flux, χ, where χ = 1 is the Habing FUV photon flux in ergs/cm^2/s, with n(e)=10^2 cm^{-3} and T = 8000K. (center) C and O fractional ionization versus X-ray flux (erg/cm^2/s) with no UV. High ionization states are easier to achieve near an X-ray source as compared to UV sources. (right) The ratio of integrated intensities of different mid- and far-infrared tracers of the ionized gas versus X-ray flux, for n(e)=50 cm^{-3} and T=8000 K, characteristic of the AGNs. These plots show the sensitivity of the ratios to the flux over different flux ranges.

Publications: Langer, W. D. & Pineda, J. L., 2019, Mid- and Far-Infrared Emission from AGNs with Super Massive Black Hole X-ray Sources, in preparation.

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