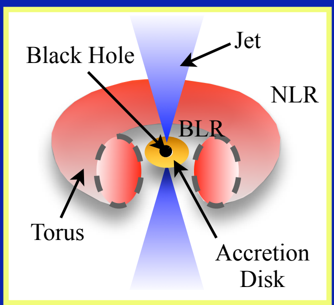
An X-ray Spectral Model for Compton-Thick Toroidal Reprocessors

K. D. Murphy[1] & T. Yaqoob[2,3]

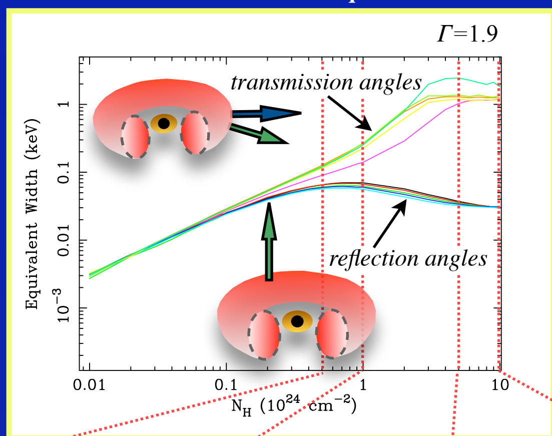
1) MIT Kavli Institute for Astrophysics & Space Research; 2) Johns Hopkins University, 3) NASA/GSFC

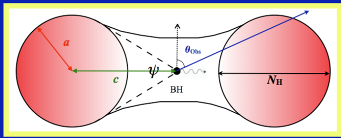
The central engines of both type 1 and type 2 Active Galactic Nuclei (AGN) are thought to harbor a toroidal structure that reprocesses high-energy photons from the central X-ray source. Unique features in the reprocessed spectra can provide powerful physical constraints on the geometry, column density, element abundances, and orientation of the circumnuclear matter. The calculation of such spectra that are suitable for direct fitting to X-ray data is challenging because the reprocessed emission depends on the spectral shape of the incident continuum, which may not be directly observable. We present new, fully-relativistic Monte-Carlo calculations of Green's functions for a toroidal reprocessor that enable the construction of X-ray spectral fitting models that allow for arbitrary incident spectra and provides other significant improvements over currently available models, including better low-energy statistics relative to comparable reprocessor models. The calculations have been performed for column densities that cover the Compton-thin to Compton-thick regime and treat the reprocessed continuum and fluorescent line emission due to Fe Kα, Fe Kβ, and Ni Kα self-consistently, eliminating the need for ad hoc modeling that is currently common practice. The Compton-thick reflection spectrum in the X-ray band from our toroidal geometry differs significantly from that obtained from disk models that are often used to mimic this component in both spectral shape and amplitude.



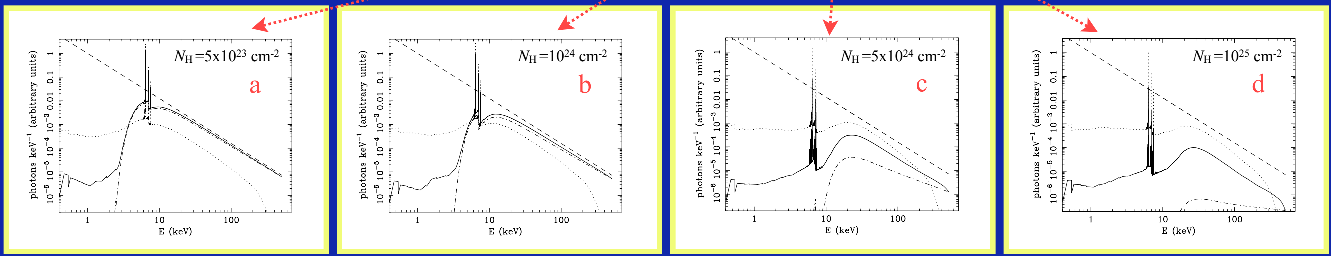
The putative Compton-thick (or -thin) toroidal structure in AGN reprocesses an incident spectrum through photoelectric absorption and Compton scattering, giving rise to the “Compton hump” and narrow fluorescent emission features with “Compton shoulders”.

The Fe K Emission Line Equivalent Width

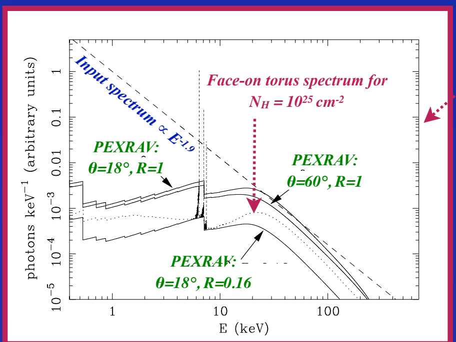




We have constructed a Monte-Carlo code to create grids of Green's functions to model the passage of X-rays through a distant, toroidal reprocessor. The Green's functions are calculated by firing mono-energetic photons into the structure (illustrated above) and tracing each photon until it is absorbed or escapes the torus. We have calculated Green’s functions for 28 N_H values between 10^{22} and 10^{25} cm^{-2}; each is stored in 10 angle bins (θ_{obs}) between 0° and 90°.

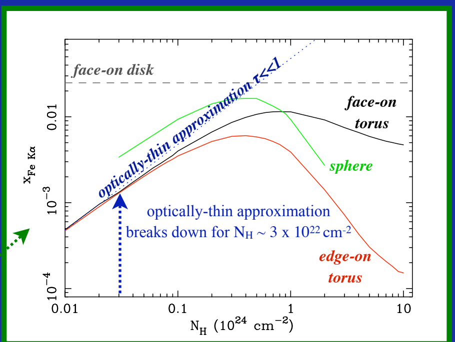


- One important advantage of utilizing our Green’s functions is that they eliminate the need for ad hoc modeling of the reprocessed continuum and the resulting Fe Kα, Fe Kβ, and Ni Kα emission lines, enabling the derivation of self-consistent constraints on the physical parameters.
- Broadband spectra may be produced by integrating the Green's functions over an arbitrary input spectrum. Examples of such spectra, using a simple power-law input spectrum (*photon flux* $\propto E^{-\Gamma}$ keV^{-1}, with Γ =1.9; ***dashed line***), are illustrated here. Spectra are shown for the face-on θ_{obs} bin (***dotted curves***) and edge-on θ_{obs} bin (***solid curves***), for 4 values of equatorial column density (N_H). The zeroth-order (non-scattered) spectrum for the edge-on θ_{obs} bin is also shown (dot-dashed curves), to illustrated that, as the column density increases, the reprocessed spectrum becomes dominated by scattered photons. Althought the continuum emission in the soft X-ray band is suppressed, the toroidal geometry gives rise to a soft excess that is not present in spherical models.
- The corresponding equivalent width (EW) of the core of the Fe Kα emission line for each of these spectra are indicated on the curves of EW versus N_H above (at the intersections of the red, dotted, vertical lines). Curves are shown for 5 lines-of-sight that do not intercept the structure (pure reflection from the torus, including the face-on view) and 5 lines-of-sight that do intercept the structure (transmission through the torus, including the edge-on view). The angle bins allow us to study inclination effects in detail.



A disk-reflection model is often used to mimic the scattered spectrum from the torus when modeling AGN spectra. Here we compare the face-on spectrum shown in Fig. d above with 3 PEXRAV spectra. The reflection spectrum from the torus is a factor of ~6 weaker than that from PEXRAV. The detailed spectral shape across the entire X-ray band is also significantly geometry-dependent.

The ratio of the line flux to the integrated incident continuum flux above the Fe K absorption edge ($x_{Fe\ K\alpha}$) essentially gives an efficiency of the production of the Fe Kα line. Here we compare the efficiency as a function of N_H for the cases of a disk, a sphere, a face-on torus, and an edge-on torus. For an input spectrum with Γ=1.9, none of these geometries yields an efficiency > 3%.



See **Murphy & Yaqoob 2009, MNRAS, 397, 1549** & **Yaqoob *et al.* 2009, MNRAS, *in press*** for more details.

kdmurphy@space.mit.edu