Representative spectral shapes of nearby AGN

V.P. Koushika[1,a], A. Corral[1], F.J. Carrera[1], A. Akylas[2], A. Georgakakis[2], B. Laloux[2]

1. Instituto de Física de Cantabria (CSIC- Universidad de Cantabria), Santander, Spain
2. National Observatory of Athens, Athens, Greece

a. koushika@ifca.unican.es

Abstract

Signatures of reflection by cold material (presumptive torus) are prominent in X-ray AGN spectra. We have studied NuSTAR spectra of nearby AGN, covering the relevant spectral range to constrain the torus properties (using UXCLUMPY, a clumpy torus model) to have a reference with which to compare higher z objects.

Our sample includes 58 nearby AGNs. Classical fitting with MCMC sampling found that the model parameters were highly degenerate and are not well constrained. Apart from heavily obscured objects preferring more compact tori, a clear tendency of a given object type was not found.

We then performed fitting with parameters fixed to those in the UXCLUMPY table. Parameter combinations (PCs) are chosen based on how well they fit the sample and how well they fit each object. We found just 26 models fit all sources. Heavily absorbed sources preferred a low to medium torus spread, consistent with the classical fitting. The models were sorted into four groups based on column density. The fraction of different AGN types spanned by each group is consistent with what we expect from their type. We have also obtained the average spectral shape of the groups.

Sample & Model

Representative AGN Sample

Data	NuSTAR at 3-50 keV	
Redshift	$z < 0.06$	
Unabsorbed	**Sy1 (TI)**	**29 objects**
Absorbed	**Non CT Sy2 (TII)**	**15 objects**
	CT Sy2 (CT)	**14 objects**

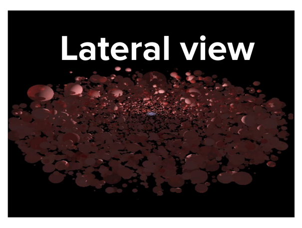
Model: UXCLUMPY[1]

Properties: Up-to-date, clumpy torus, self consistent

Parameters:

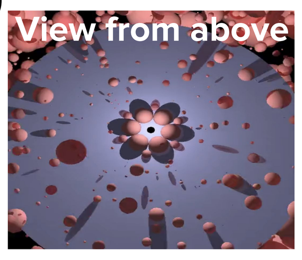
1. Total NH_{los}
2. Photon Index
3. Energy cutoff
4. Vertical cloud dispersion (σ_{torus})
5. Inner CT covering fraction (C)
6. Viewing angle (θ_{inc})
7. Scattering Fraction (fraction)

Lateral view



Credits: Buchner et al [1]

View from above



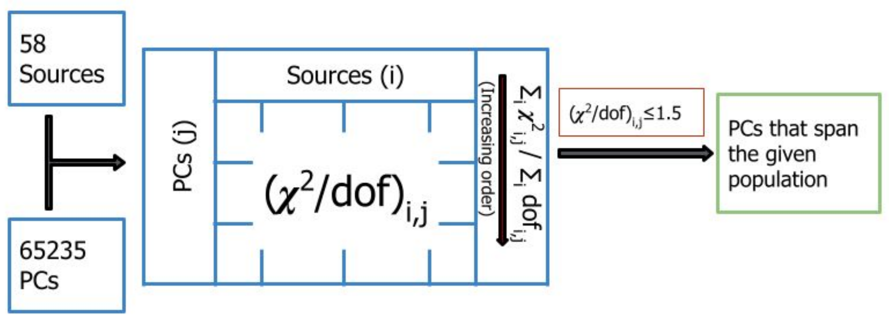
Model in Xspec:
uxclumpy_cutoff.fits + fraction * (uxclumpy_cutoff_omni.fits)

Method I - Classical Fitting

- Full individual spectral analysis in Xspec.
- MCMC sampling was performed following the establishment of the baseline fits, to explore the parameter space.
- Chain length of 5×10^5, 12 walkers, and a burn-in period of 10^4 steps were used.

Method II - Holistic Approach

- Minimal set of **parameter combinations (PCs)** required to span the local population.



[Note: **Overall Chi2/dof$_j$=$\Sigma_i \chi^2_{i,j} / \Sigma_i dof_{i,j}$** - a measure of how well a parameter combination fits all the objects of the sample set. This includes both "good" and "bad" individual fits (**individual $(\chi2/dof)_{i,j}$** < 1.5 and > 1.5 respectively)]

Fig. 1. Distribution of Parameter Modes from MCMC sampling of Method I

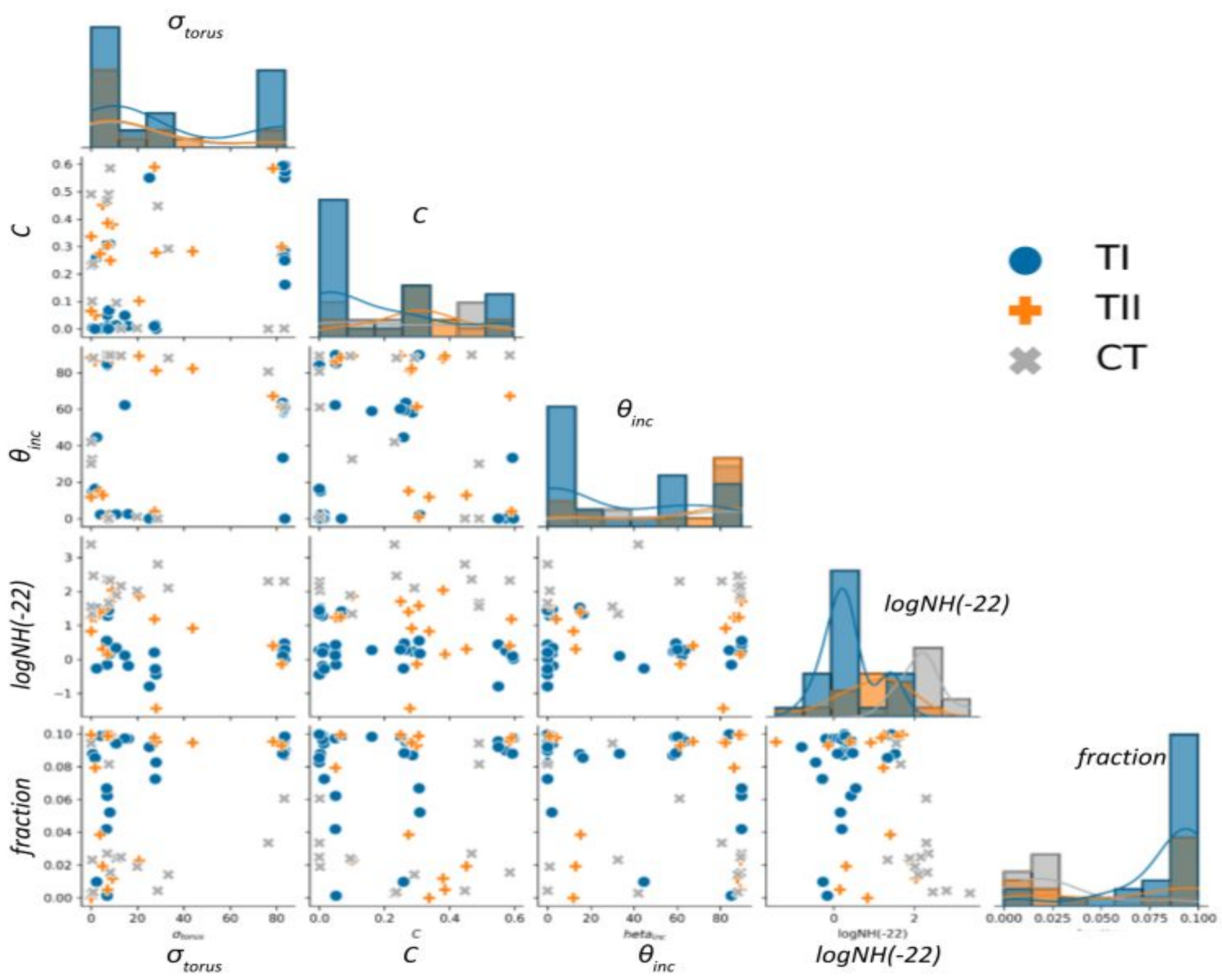
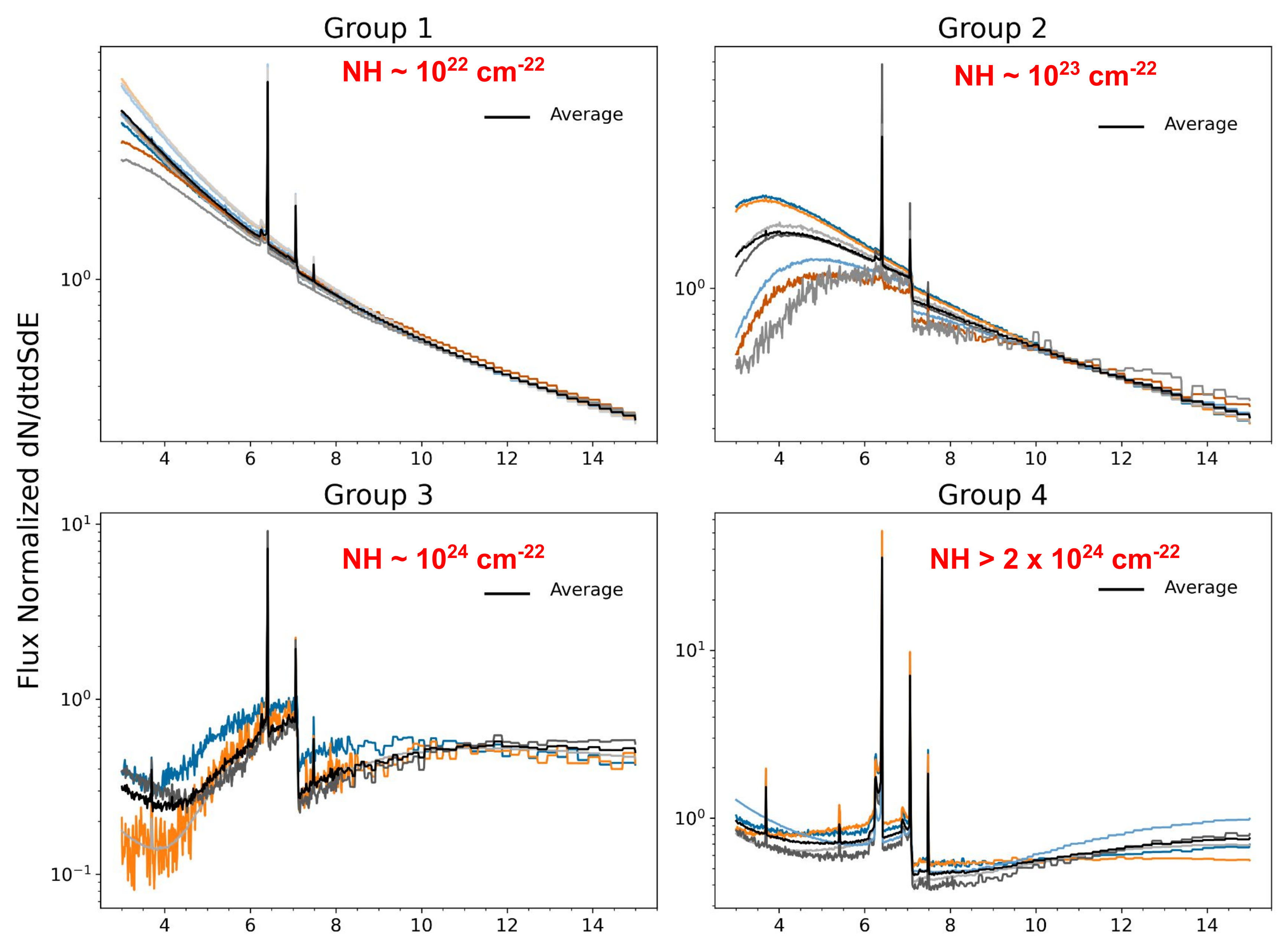


Table 1. Fraction of different types of objects spanned in each group from Method II

	NH (x 10^{22} cm^{-2})	N(PCs)	Fraction of objects spanned		
			TI	TII	CT
Group 1	**~ 1**	10	1.00	0.53	0.00
Group 2	**~ 10**	8	0.14	0.73	0.14
Group 3	**~ 100**	3	0.00	0.13	0.50
Group 4	**> 200**	5	0.00	0.00	0.71

Fig. 2. Spectral shapes of the 26 PCs from Method II with average shape for each group



Results - Method I

- There is no clear part of the parameter space where objects of a given type cluster.
- Best fit parameter values for certain objects do not agree with the results from other independent studies.
- TII and CTs prefer lower σ_{torus} values -> compact torus.
- TIs prefer more contribution from the warm mirror component.

Results - Method II

- Reduced parameter combinations from 65235 to just 26.
- Clear trend of increasing NH with worse overall Chi2/dof.
- Increase in NH, spans fewer objects.
- Models with low to medium NH span almost ~ 67% of the sample and prefer high vertical cloud dispersion.
- Models with high NH prefer low to moderate vertical cloud dispersion.
- We have defined four groups based on increasing NH and obtained weighted average spectral shapes of each group, with weights being the number of objects each model in that particular group has spanned.

Conclusions

- Classical fitting results of the best fit parameter values do not agree with the type of the object.
- Partly because the model used in this study is highly complex and degenerate and even MCMC sampling cannot resolve the degeneracy of the local minima.
- We have tried instead an alternative holistic approach.
- The holistic approach resulted in just 26 models spanning the given population.
- The parameter values spanning each type of objects agree with what is expected to an extent.
- Low to mild absorption models are able to span a higher fraction of low obscuration sources.
- Larger number of models are required to span high obscuration sources.
- This indicates that obscuration is complex and has unique geometry.
- The weighted average spectral shapes for each group of nearby objects could be used for comparison to similar studies at higher redshifts and could help in studying the evolution of the collective properties of AGN with redshift.
- The 26 models obtained from this study will be used for simulations to test and optimize the redshift extraction algorithm[2].

References

1. Buchner J, Brightman M, Nandra K, Nikutta R and Bauer F E 2019 X-ray spectral and eclipsing model of the clumpy obscurer in active galactic nuclei A&A 629 A16
2. Castelló-Mor N, Barcons X and Ballo L 2011 X-ray redshifts with the International X-ray Observatory (IXO) Advances in Space Research 48 1304–10

Interested in this work?

1. Detailed explanation in Koushika et al (in prep)
2. More about the redshift algorithm in the Talk by Koushika VP on 16 Jun 2023 at 15:45 in SAS to Athena session.