Xcalibur Workshop, Winchester, UK, 19/07/17

Constraints on AGN Torus and Outflow Geometry from High-resolution X-ray Spectroscopy

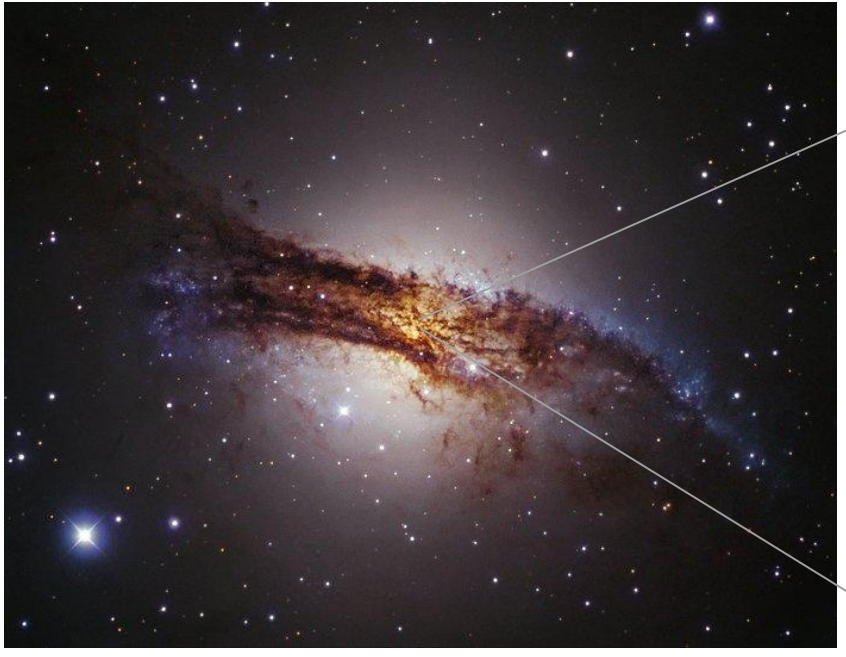
CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

Mislav Baloković

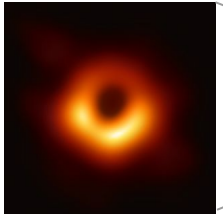
Black Hole Initiative Postdoctoral Fellow, Harvard University

What Obscures AGN?

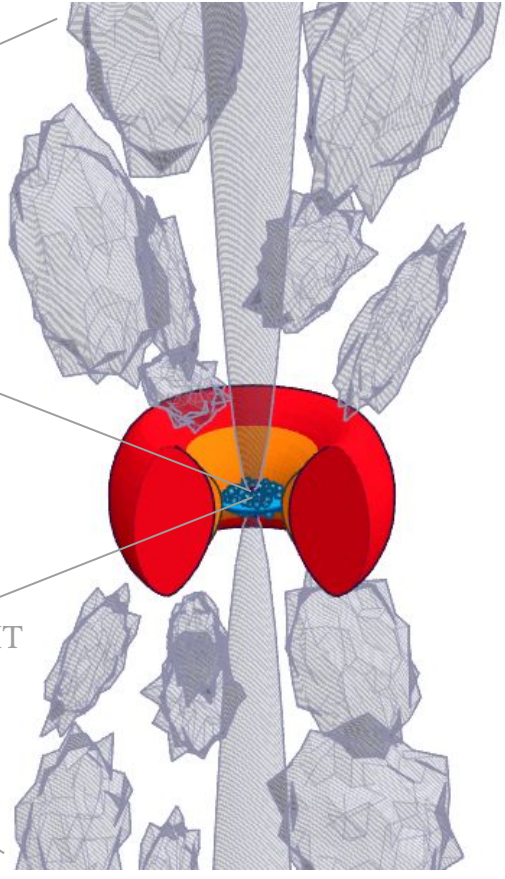
What is their structure?



Centaurus A. Credit: ESO / IDA / Danish 1.5 m /
R. Gendler, J.-E. Ovaldsen, S. Guisard

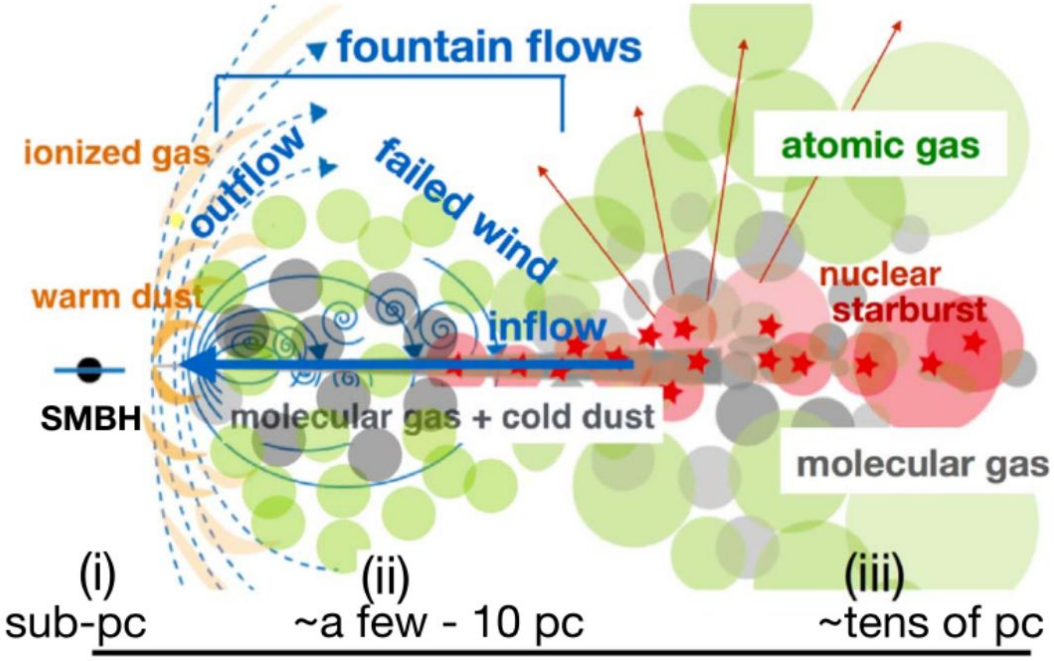


M 87*. Credit: EHT



Definitions

"Torus"



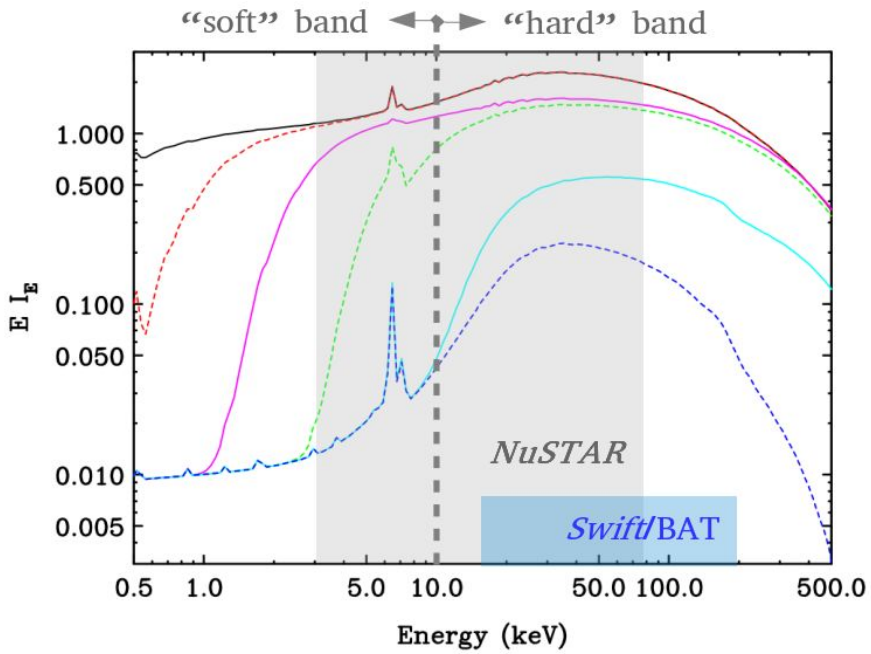
Credit: T. Izumi et al. (2018)

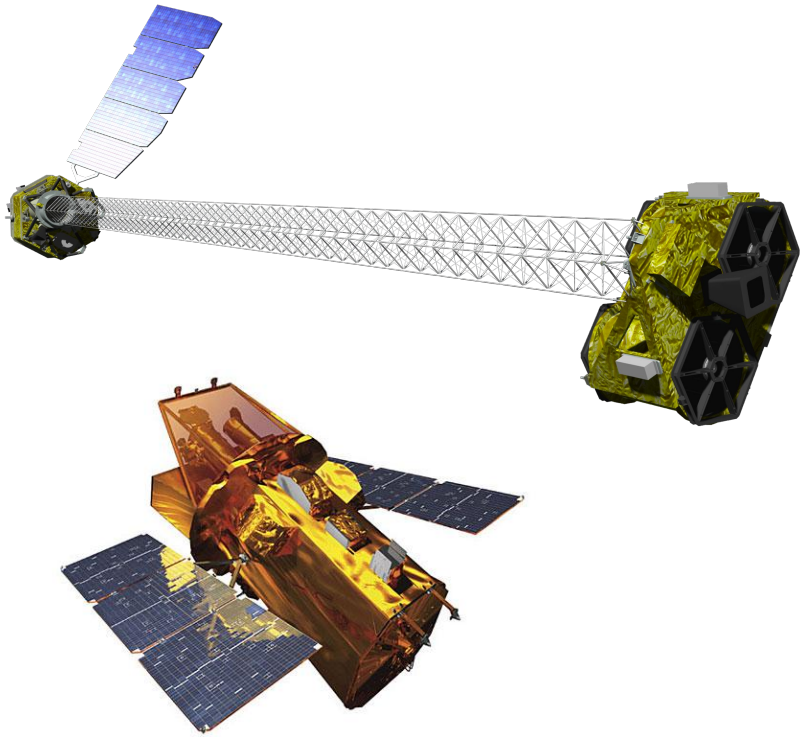
TORUS 2018 meeting (Chile):

- disk-launched wind
- dusty polar outflow
- warped megamaser disk
- broad-line region
- molecular disk(s)
- nuclear star cluster
- host galaxy ISM
- transient accretion

Definitions

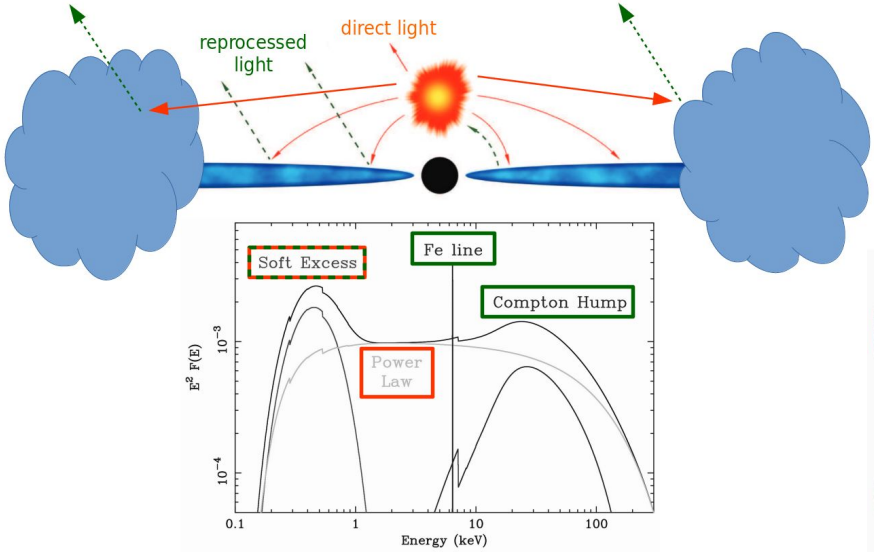
"Broadband X-ray Spectra"



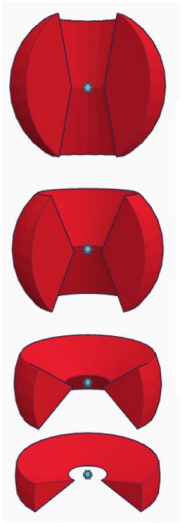


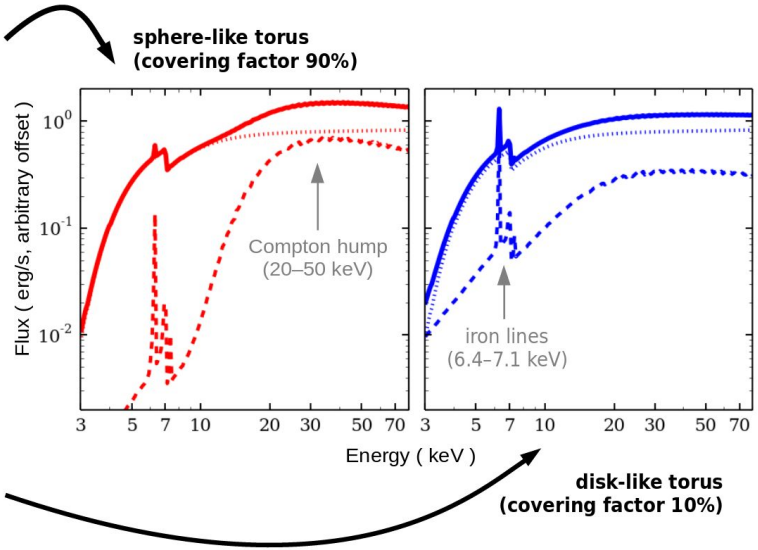
AGN X-ray Spectrum

Main Reprocessing Features



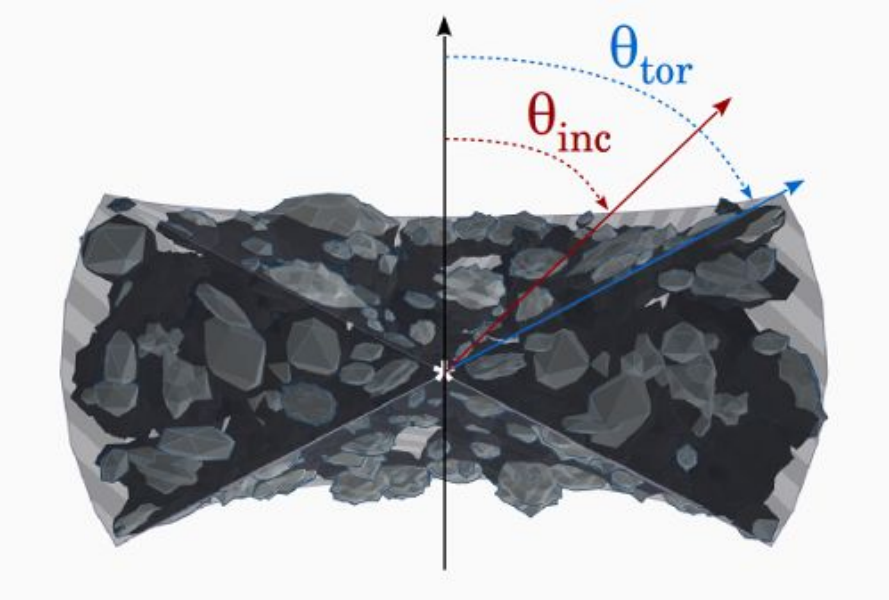
Any material surrounding the central X-ray source will produce a reprocessed spectrum.





Model Example: `borus02`

Framework, first model and examples of its application presented in Baloković et al. (2018).

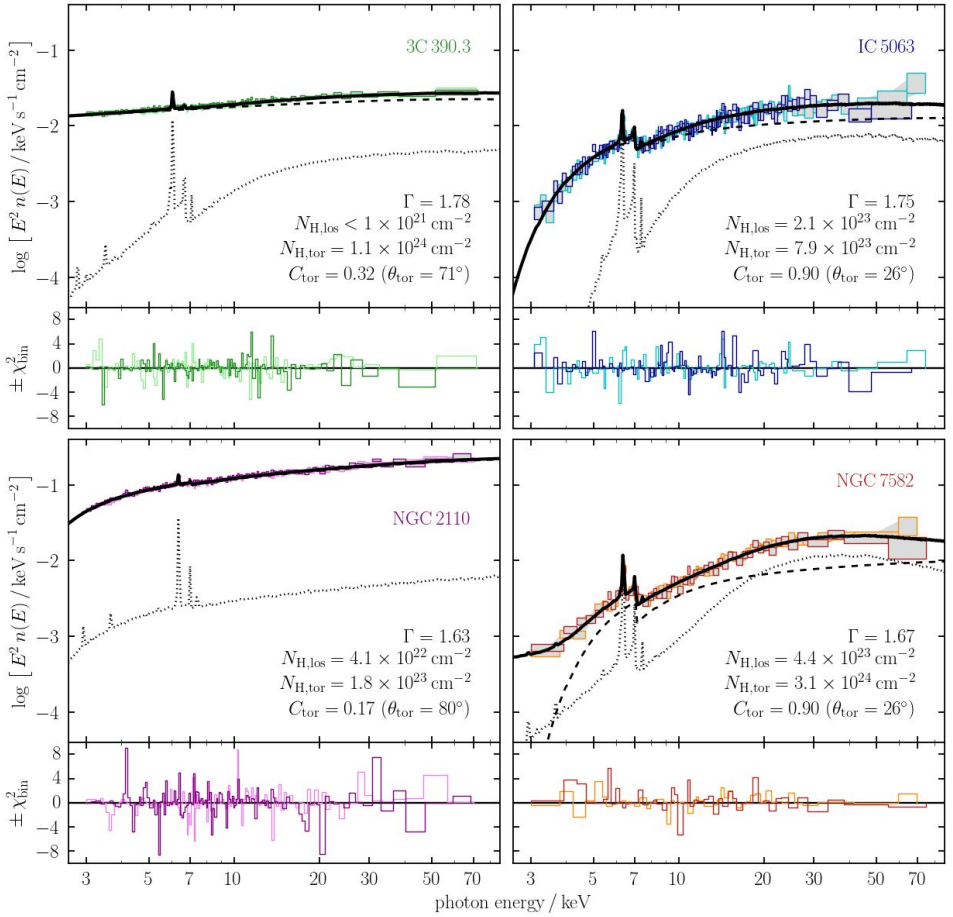


- shares the geometry and supersedes the Brightman & Nandra (2011) model
- self-consistent calculation of fluorescent lines of many chemical elements
- additional model parameters: relative iron abundance, high-energy cutoff
- decoupled and more flexible
- applicable to a wider AGN pool
- **available as an Xspec table at** http://www.astro.caltech.edu/~mislavb/download

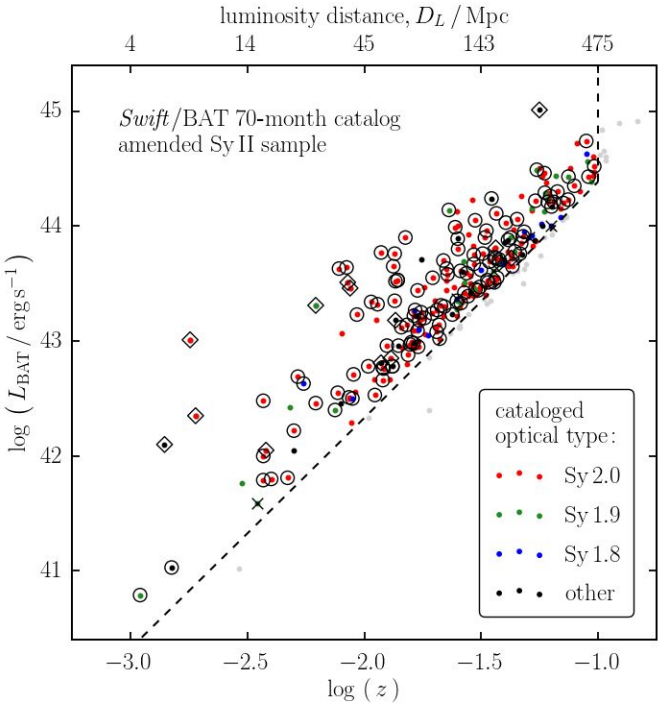
Individual Tori

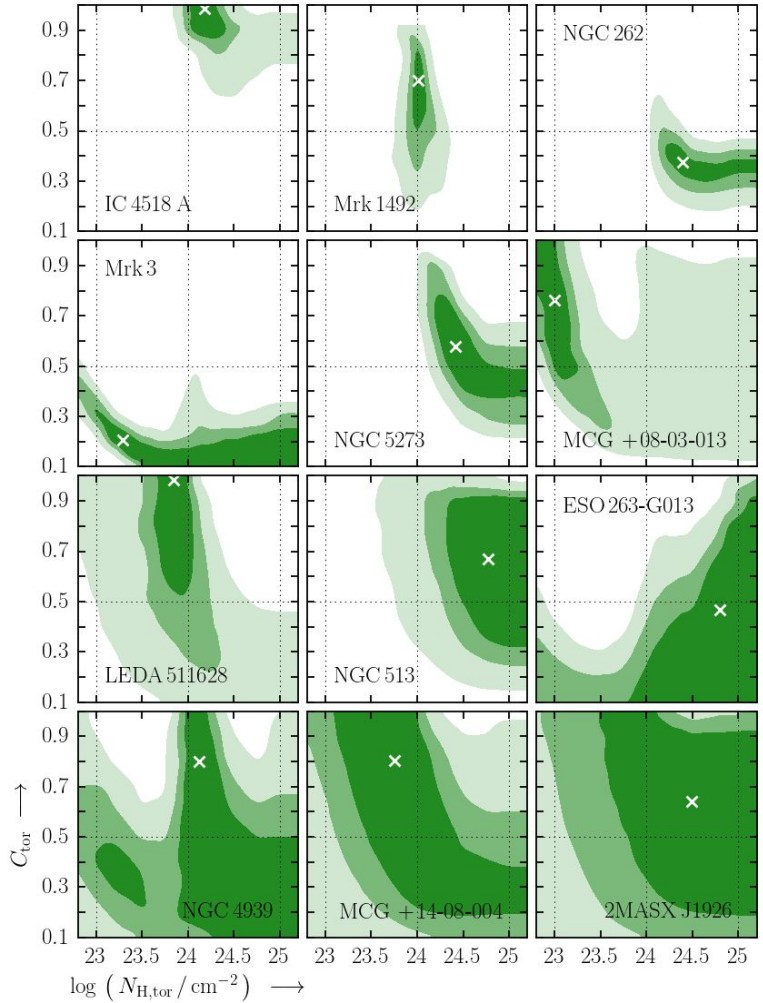
Four AGN of different type and data quality -- four different torus spectra.

NOTE: Energy resolution of the model is exaggerated in these plots.. *NuSTAR* needs coupling with a better resolving soft X-ray telescope for tighter constraints.



Sy II Population

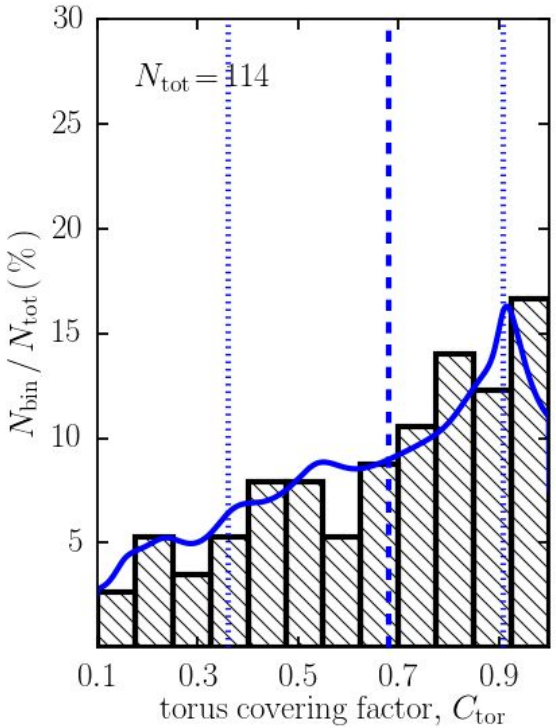




Sy II Population

Main Torus Parameters

- used both `MYtorus` and `borus02` for comparison
- both models agree that $N_{H,los} \neq N_{H,tor}$ typically, and that $\langle N_{H,tor} \rangle \approx 10^{24.2}$ cm^{-2}
- `borus02` provides the distribution of covering factors: wide, peaks at ~0.9
- covering factor depends on intrinsic luminosity



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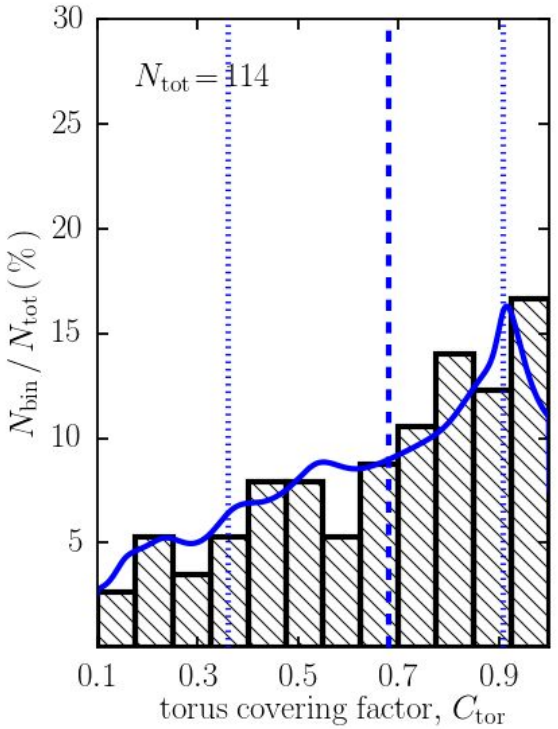
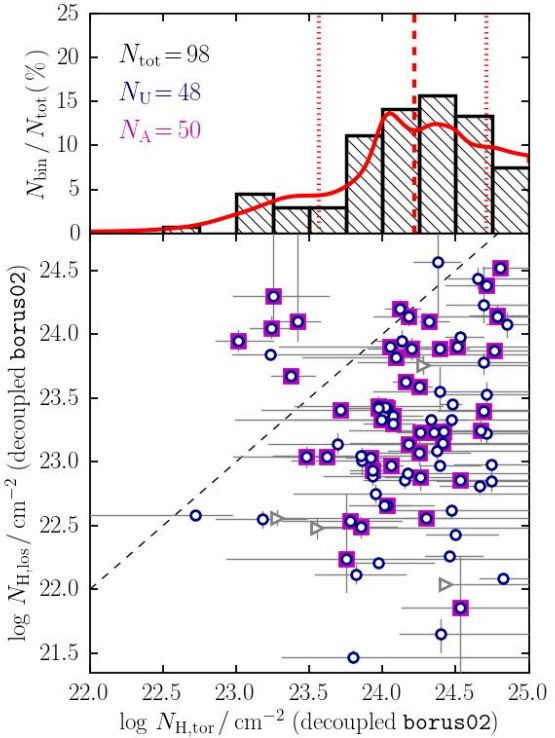
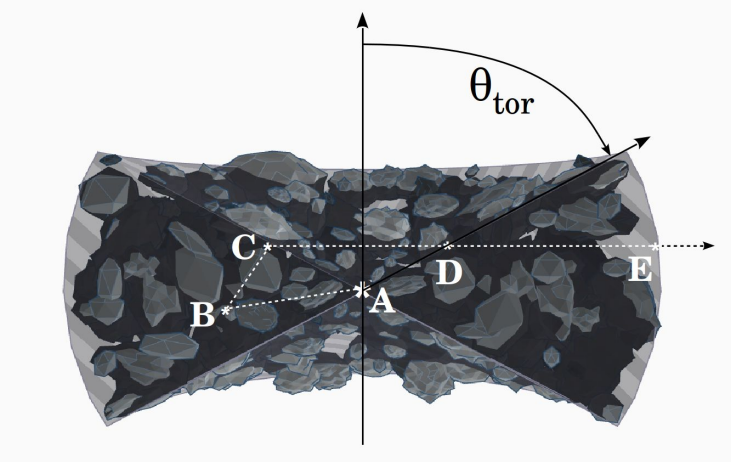
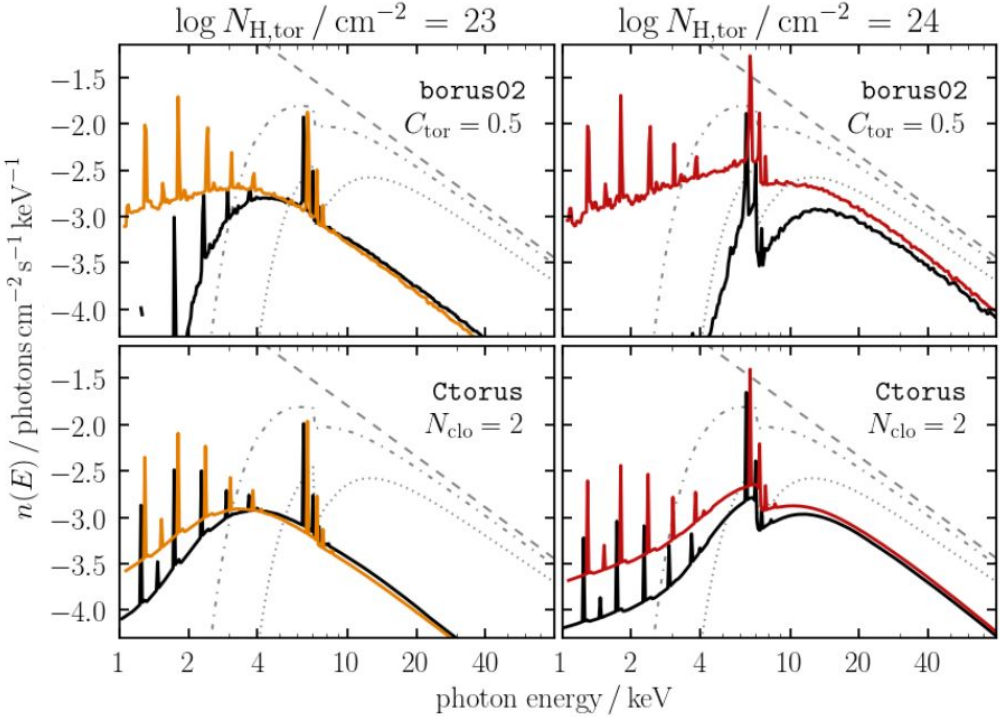




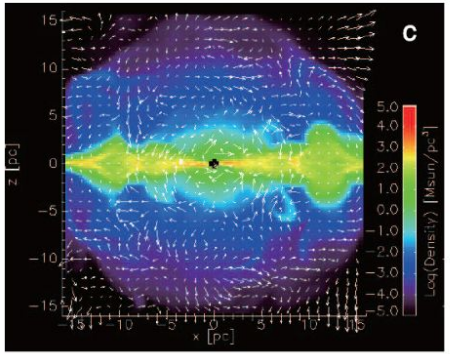
Sy II Population

Inclination or Clumpiness?

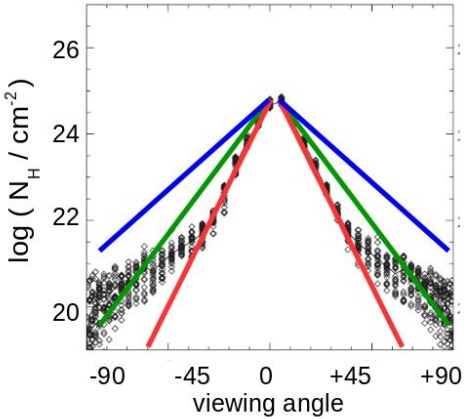


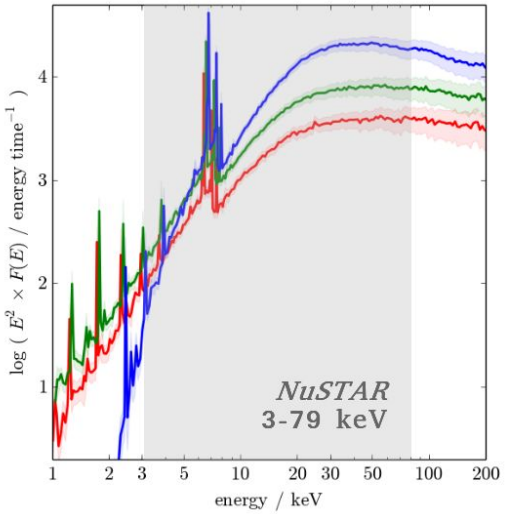


High Energy Resolution



hydrodynamical model with radiation
and star formation feedback (Wada 2015)





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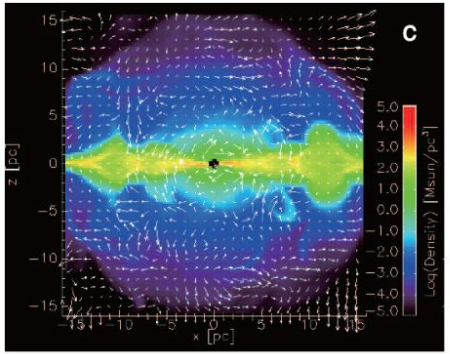

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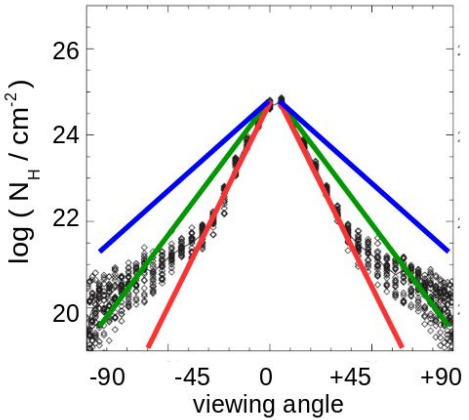
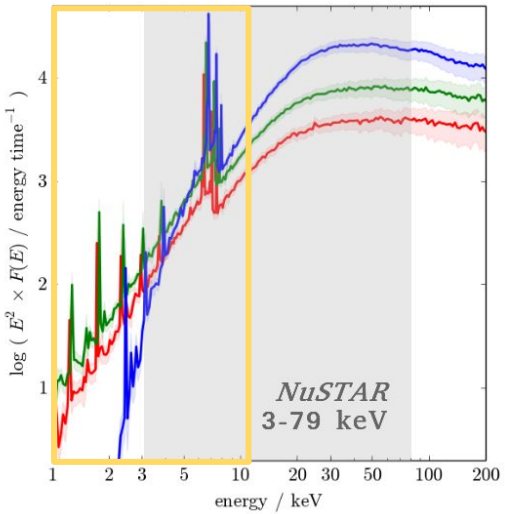


XRISM, Athena



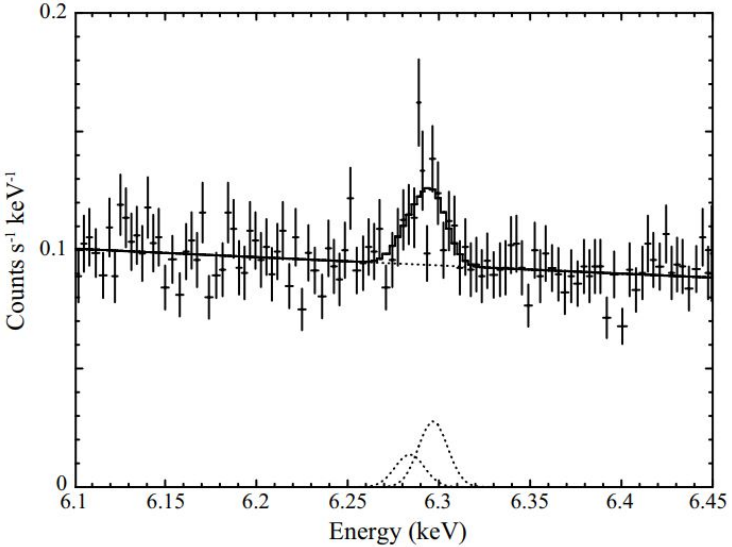
Existing fitting models are:

- lacking scale
- insufficiently detailed
- at CCD resolution
- missing lines
- missing physics
- not public

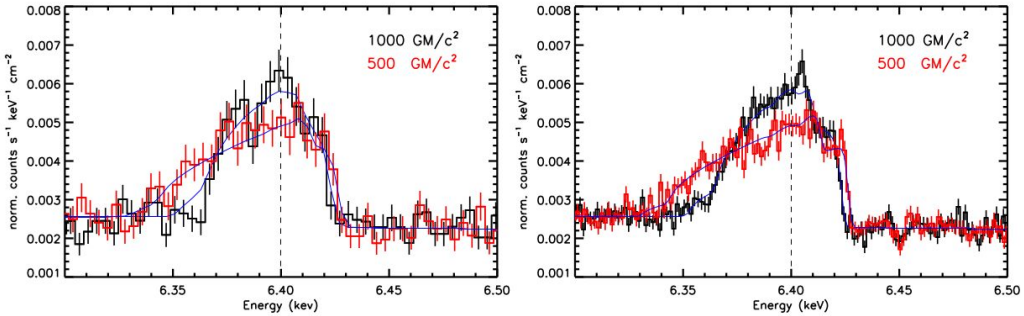
Resolving The Torus

Using Line Diagnostics

Resolved emission lines can provide kinematics and connection to the BLR, winds, and outflows.



NGC 1275; *Hitomi* Collaboration (2018)

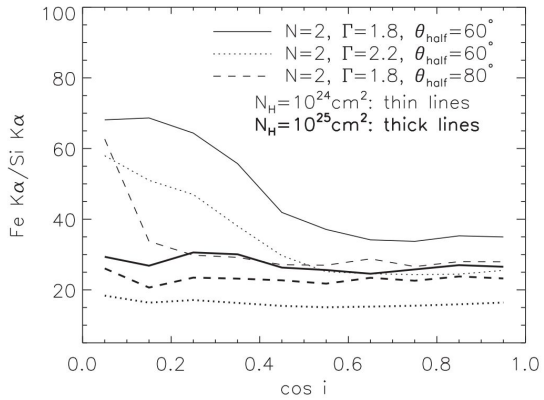


NGC 4151, 20 ks simulations for *XRISM* and *Athena*; Miller et al. (2018)

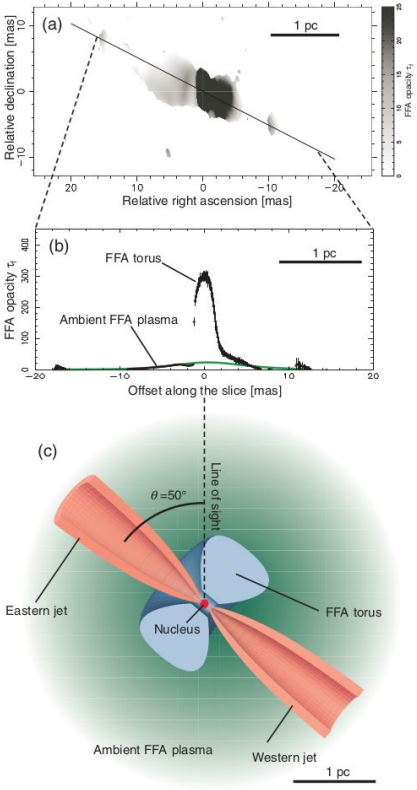
Resolving The Torus

Probing Scale & Geometry

- flourescent lines are simpler than ionized (fixed yields)
- line widths & shifts: complex non-Gaussian shapes if blended, contributions from dense outflow, Compton shoulders
- line ratios influenced by absorption, abundances, ionization
- joint modeling with broadband & multi-wavelength data, e.g. VLBI



Liu et al. (2016)



NGC 1052; Kameno et al. (2001), Sawada-Satoh et al. (2009)

Summary

- AGN “torus” geometry imprints spectra with features
- broadband X-ray spectroscopy provides some geometrical constraints for local Sy II population
- dynamics/distances expected from line diagnostics
- exploring different models now, increasing complexity as each new instrument provides new constraints

Chandra -- scratching surface

XRISM -- breaking ice

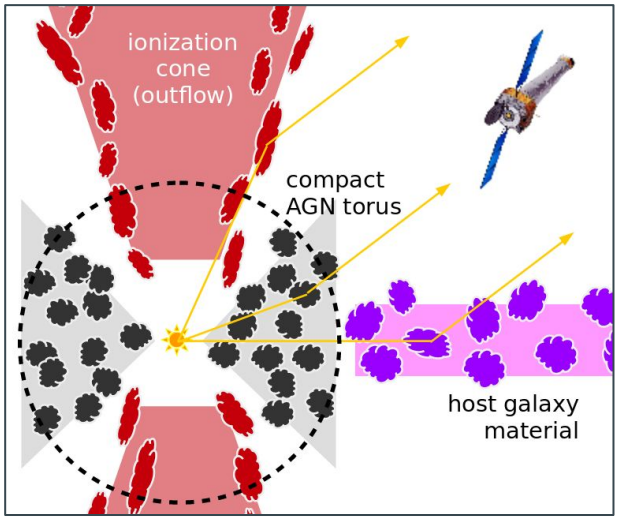
Athena -- sampling diversity

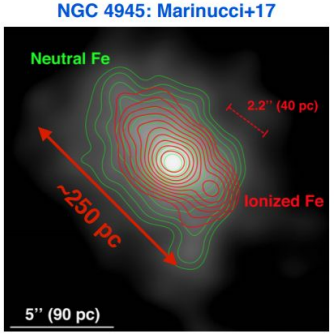
Lynx -- resolving spatially

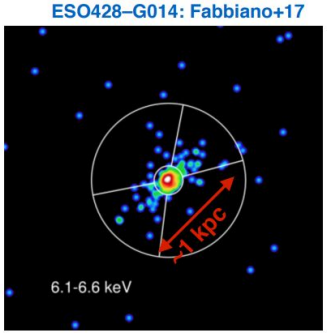
Resolving the Torus

Two “Resolutions”

1) **Spatial resolution** to resolve non-compact emission (*Chandra*, *AXIS*)







Around 50% of Fe Kα flux is not nuclear. Survey underway to quantify better.

2) **Energy resolution** to get dynamics (*XRISM*, *Athena*)
3) Both (*Lynx*)