Self-consistent modeling of the environment of supermassive black holes

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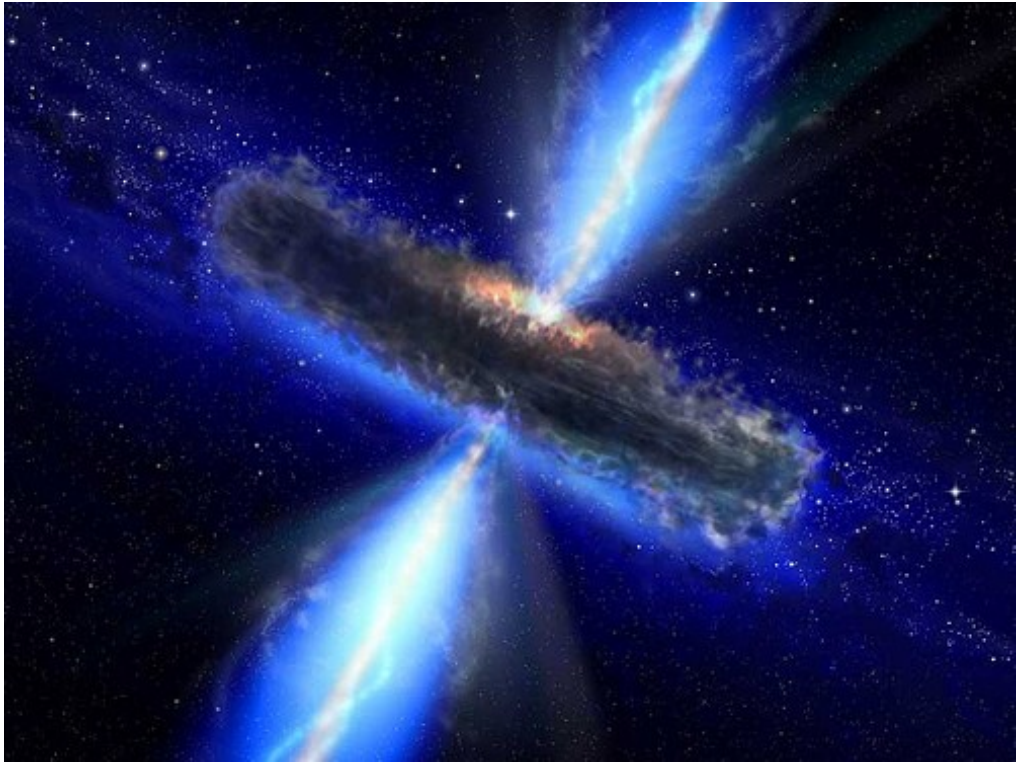
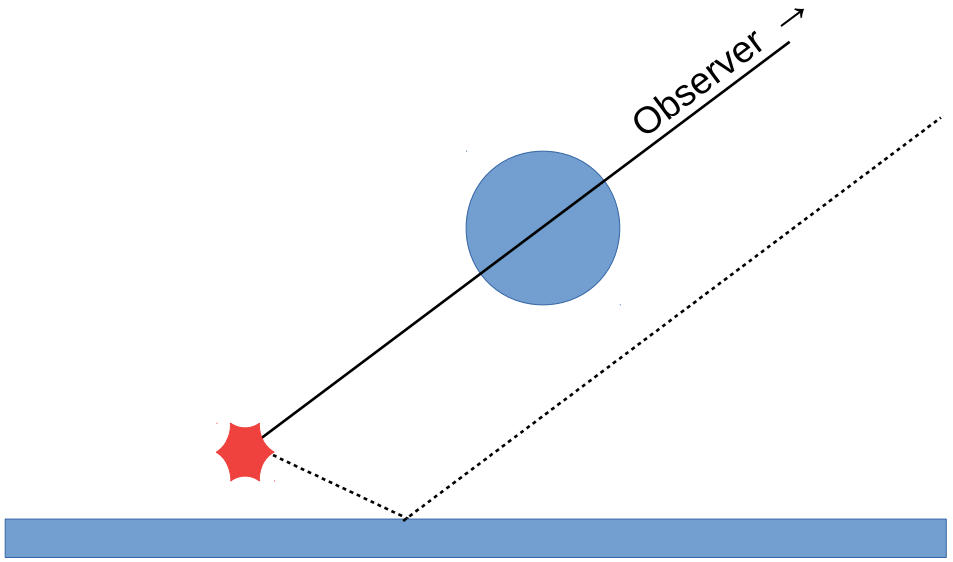
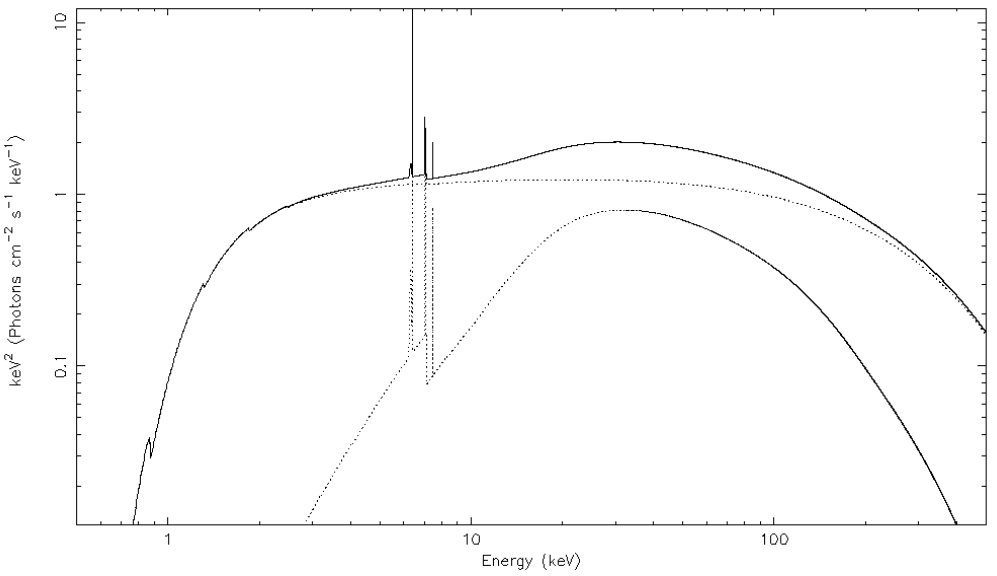
Active Galactic nuclei



- Supermassive black hole
- Surrounded by complex distribution of matter
  - Accretion disk
  - Dusty torus
  - Radial/Polar structures?
- Powerful multi-wavelength emission from the AGN, reprocessed in the surrounding medium
- X-rays are an important probe of the matter distribution

Modeling AGN X-ray Emission

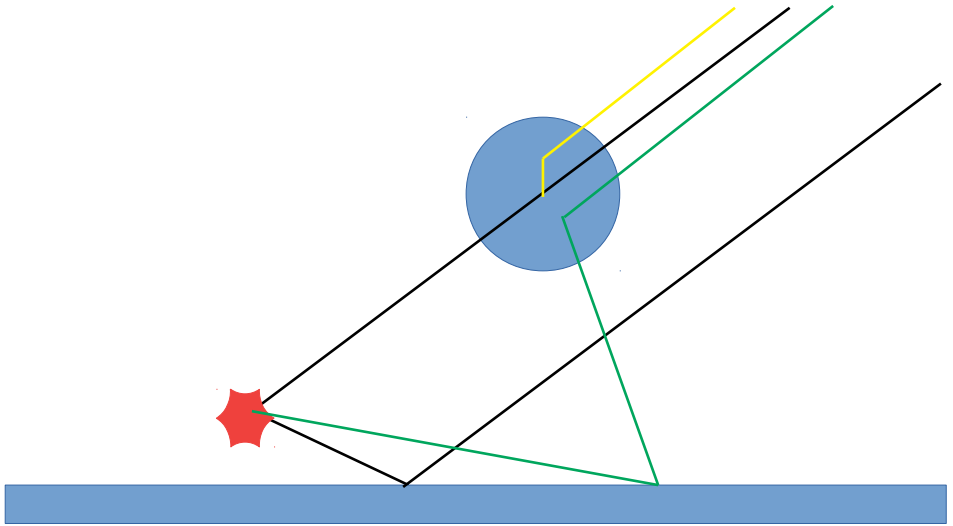


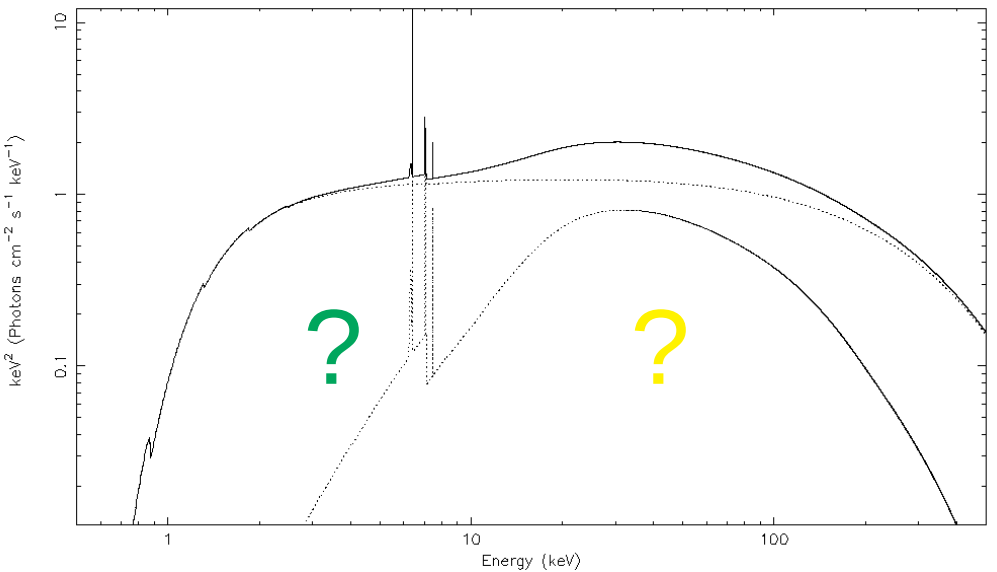


Cut-off power law, neutral absorber, thick reflector

AGN X-ray Emission

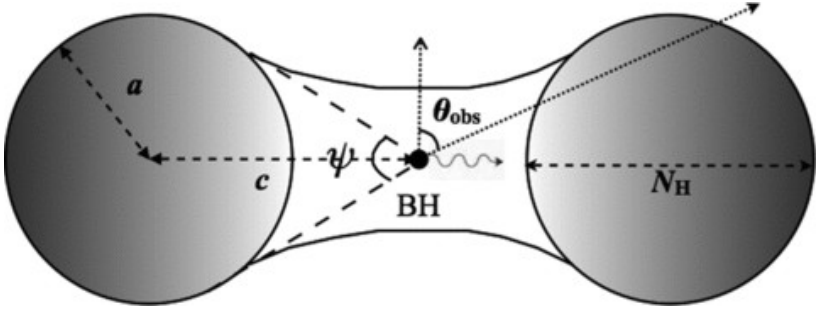
- Scattering and reflection in the absorber
- Interactions between reflector and absorber





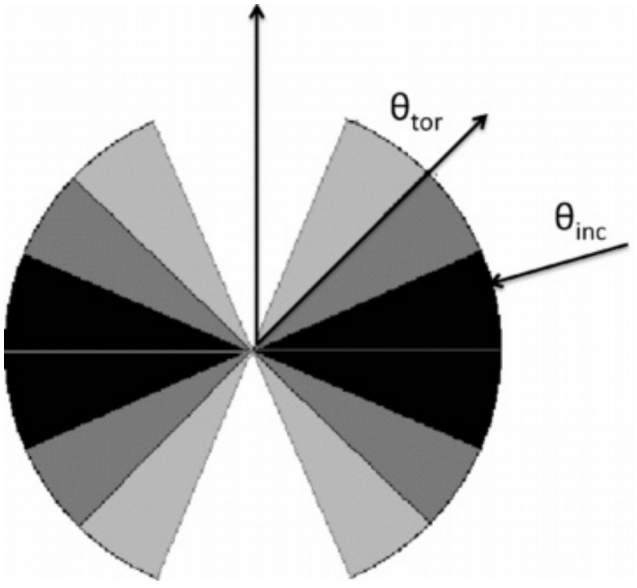
Cut-off power law, neutral absorber, thick reflector

Self-consistent Models of Absorption and Reflection



MYTorus (Murray & Yaqoob 2009)

Torus geometry; c=2a



BNTorus (Brightman & Nandra 2011)

Spherical-toroidal geometry
Variable opening angle

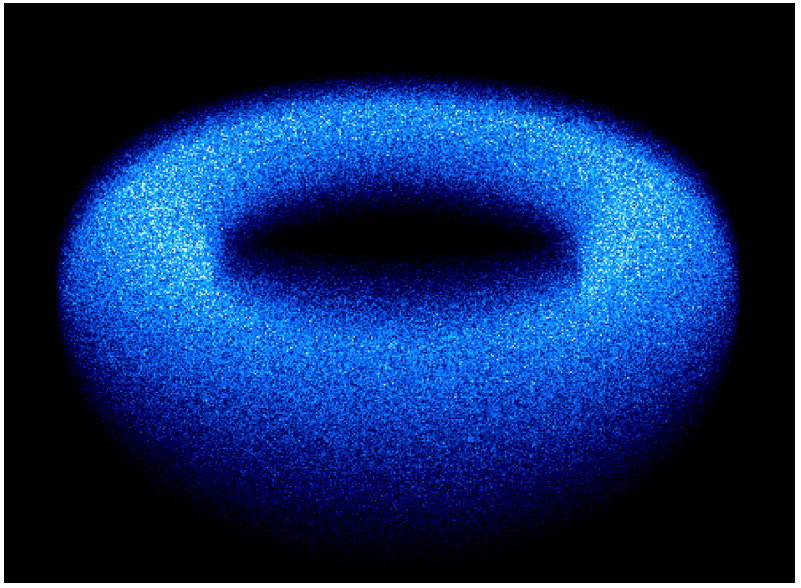
+ Variable cut-off and [Fe/H] (Baloković et al. 2018)

+ Clumpy torus (Liu & li 2014)

+ MONACO (Okada et al. 2011)

Still quite limited geometries

RefleX

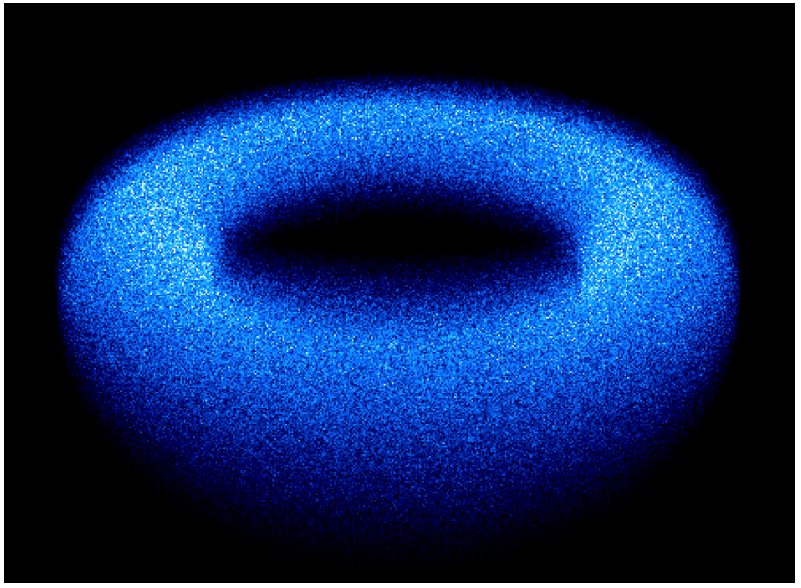


Paltani & Ricci 2017

RefleX is freely available at:
https://www.astro.unige.ch/reflex/

- Ray-tracing code
- Implements all usual physics (photo-electric, Compton scattering, Rayleigh scattering, fluorescence)
- Several X-ray source geometries and spectra
- Several geometries for X-ray emitter and absorbing material, combined like building blocks
- Very simple configuration
- K and L fluorescence lines up to Z=30
- Produces photon lists, spectra, images (time-resolved)
- Polarization
- **Version 2.0 released today!**
- More physics soon: Inverse Compton, dust, temperature, velocities, ...

RefleX



Paltani & Ricci 2017

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LENGTH Parsec
MATTER lodd
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OBJECT WORLD  1e8
OBJECT TORUS torus 0.0 0.0 0.0 7.5 2.5
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IMAGE ENERGY > 6380
IMAGE ENERGY < 6404
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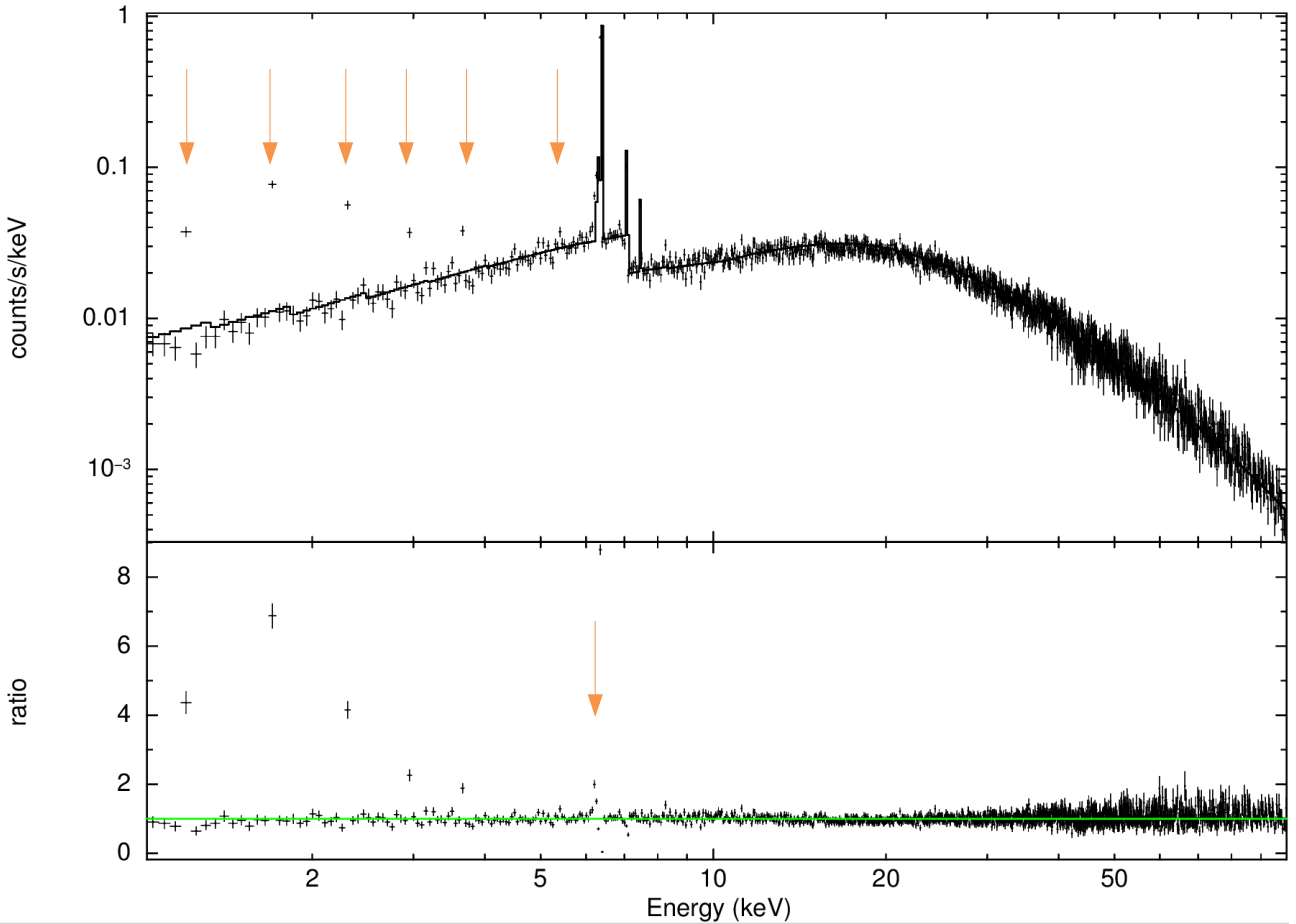
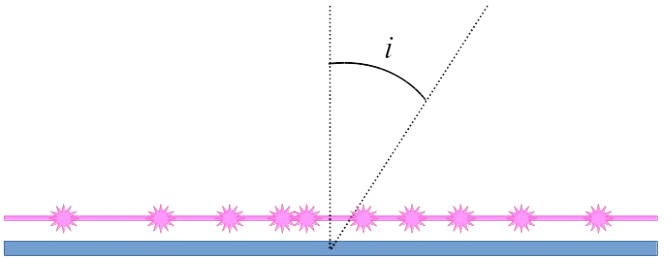
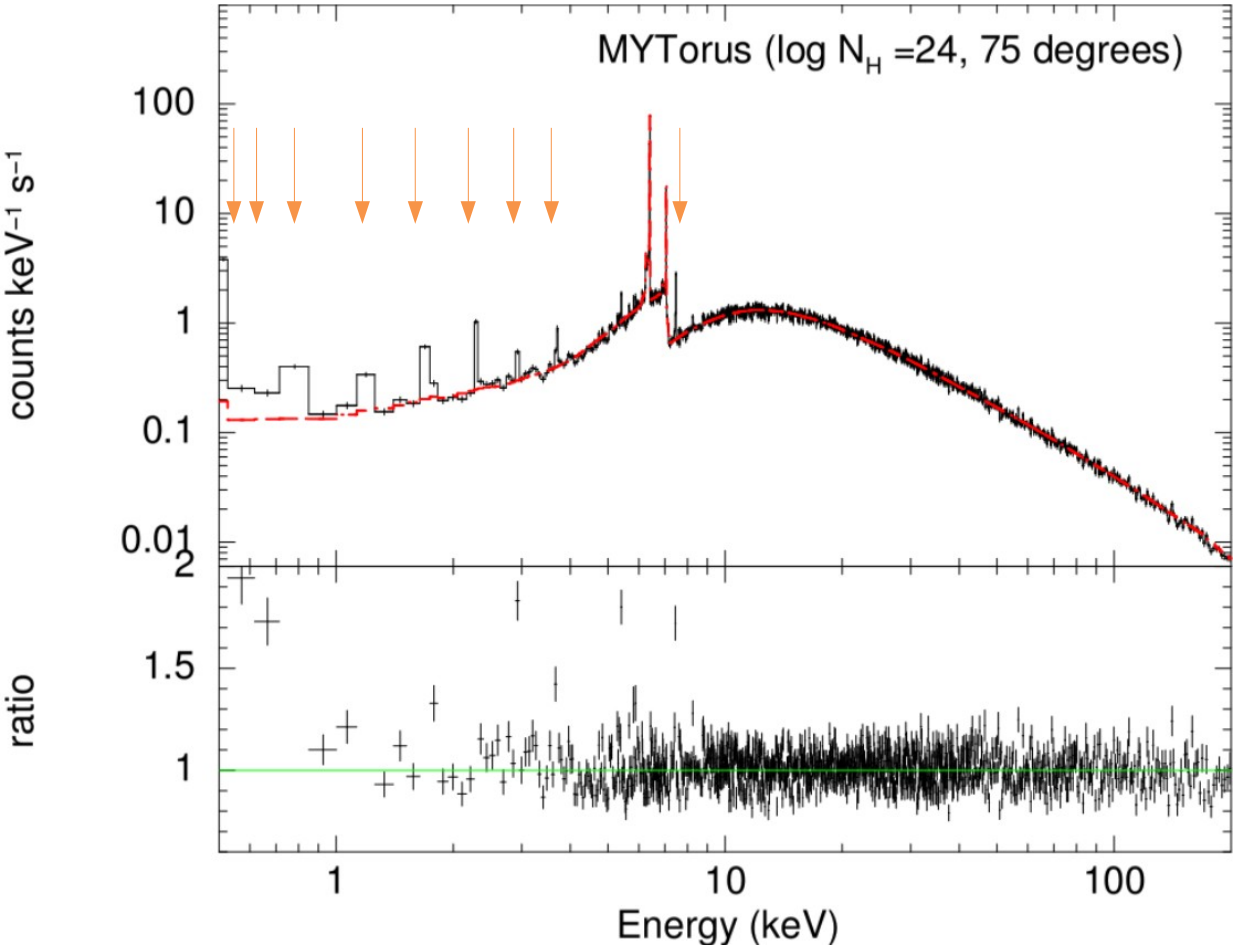
RefleX vs pexrav/pexmon

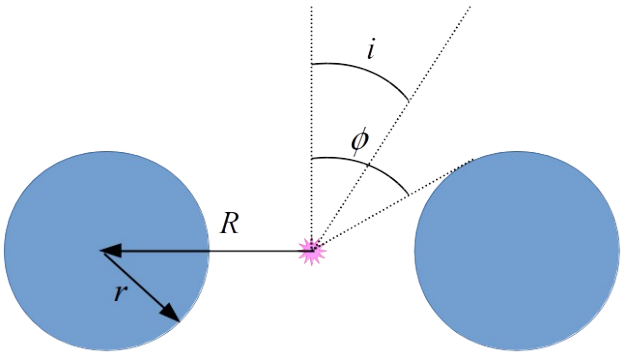




Magdziarz & Zdziarski 1995
Nandra et al. (2007)

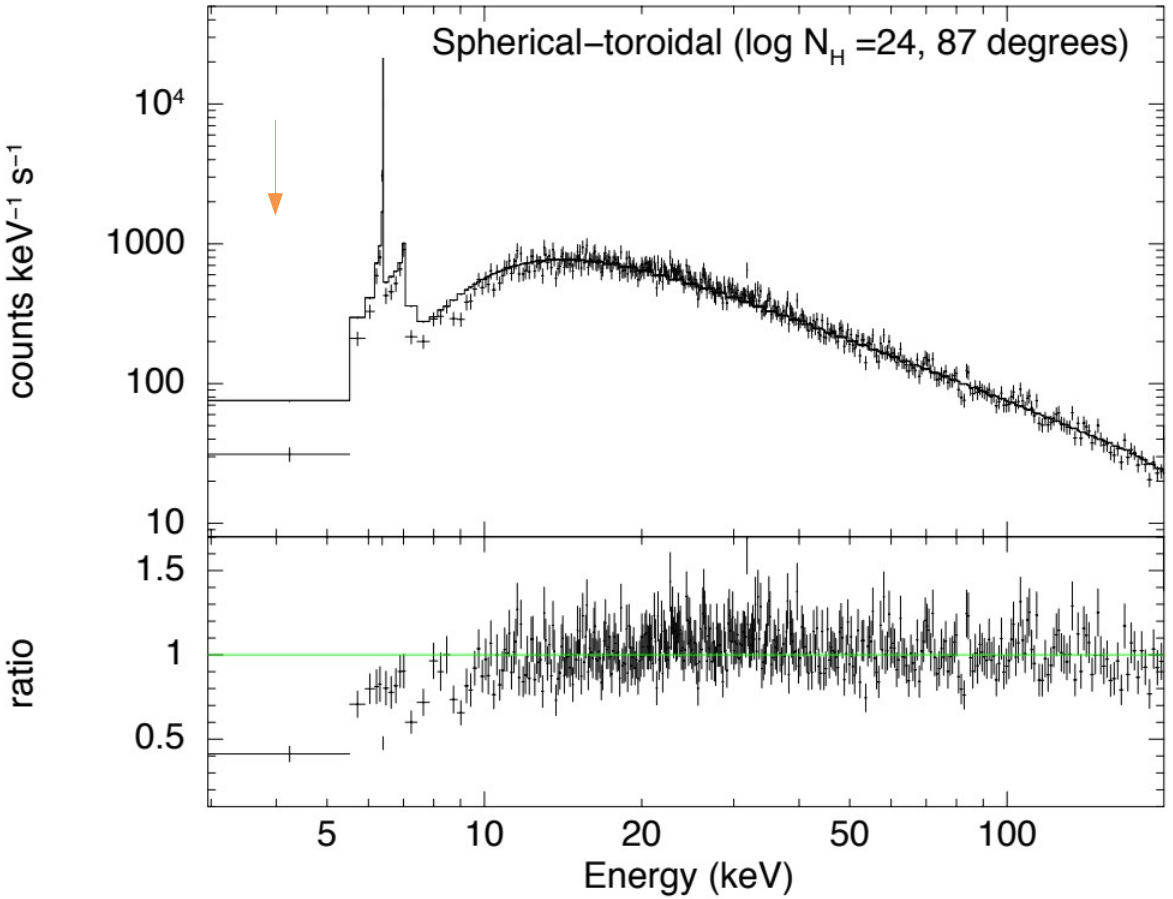
RefleX vs MYTorus



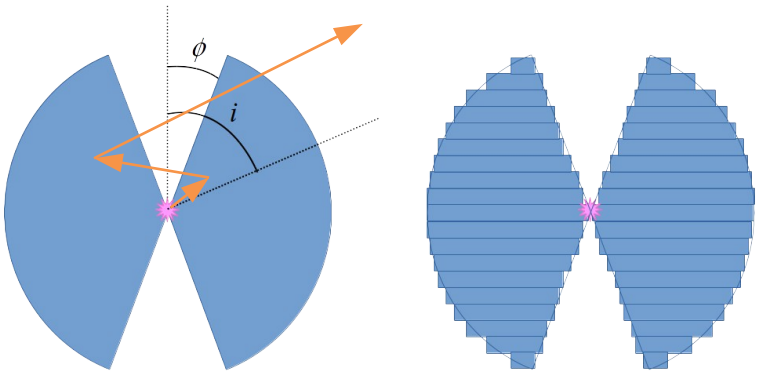


Murray & Yaqoob 2009

RefleX vs BNTorus



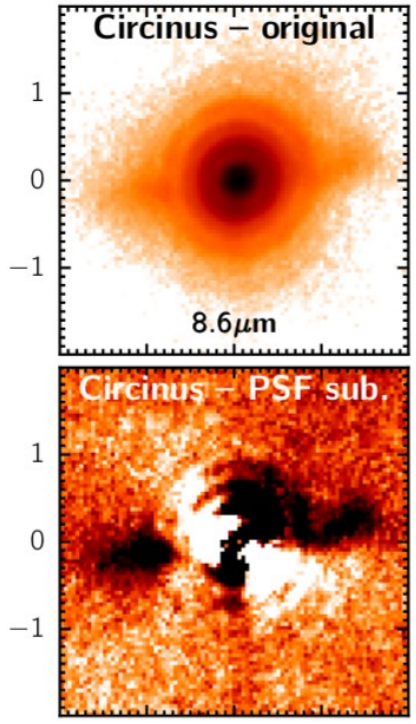
51 annuli



Murray & Yaqoob 2009

cf. Liu & Li 2014

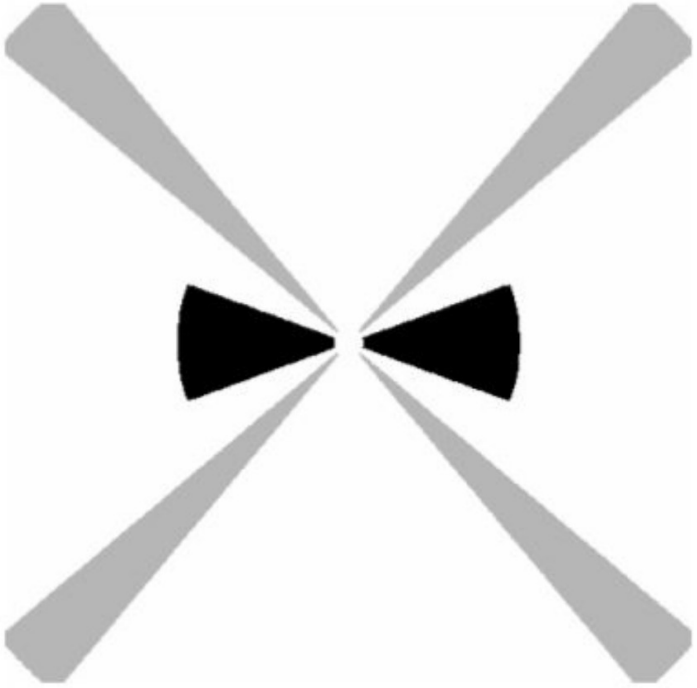
The Circinus Galaxy

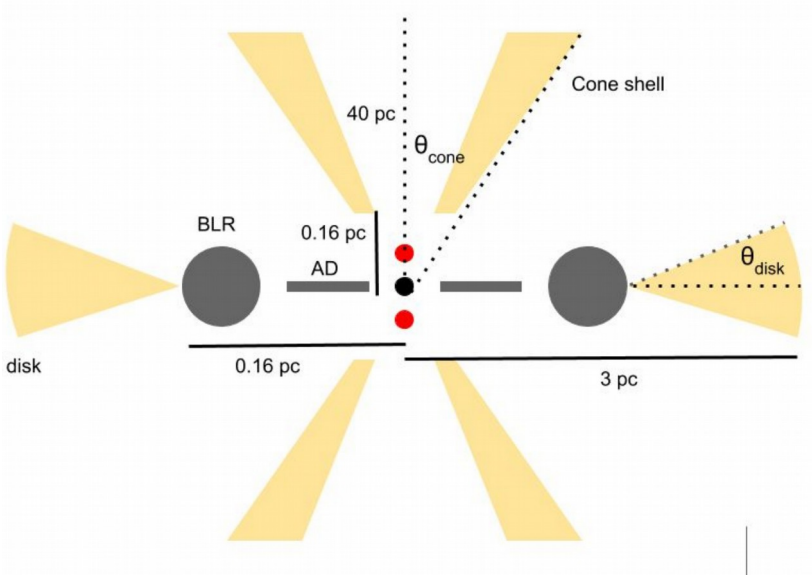


Stalevski et al. (2017)

- The closest Seyfert 2 (absorbed AGN) galaxy: 4.2 Mpc
- Compton-Thick: $N_H = (6\text{-}10) \times 10^{24}$ cm^{-2}
- 2 components in the IR at parsec scale:
  - Torus-like component in the equatorial plane of the system
  - Large structure elongated in the polar direction
- Stalevski et al. (2017) proposed for the dusty emitting regions:
  - A flared disk for the torus-like component
  - A cone/hyperboloid shell for the elongated emission

The Circinus Galaxy





$N_{H,cone} = 10^{22}$ cm^{-2}

$N_{H,disk} = 3 \times 10^{24}$ cm^{-2}

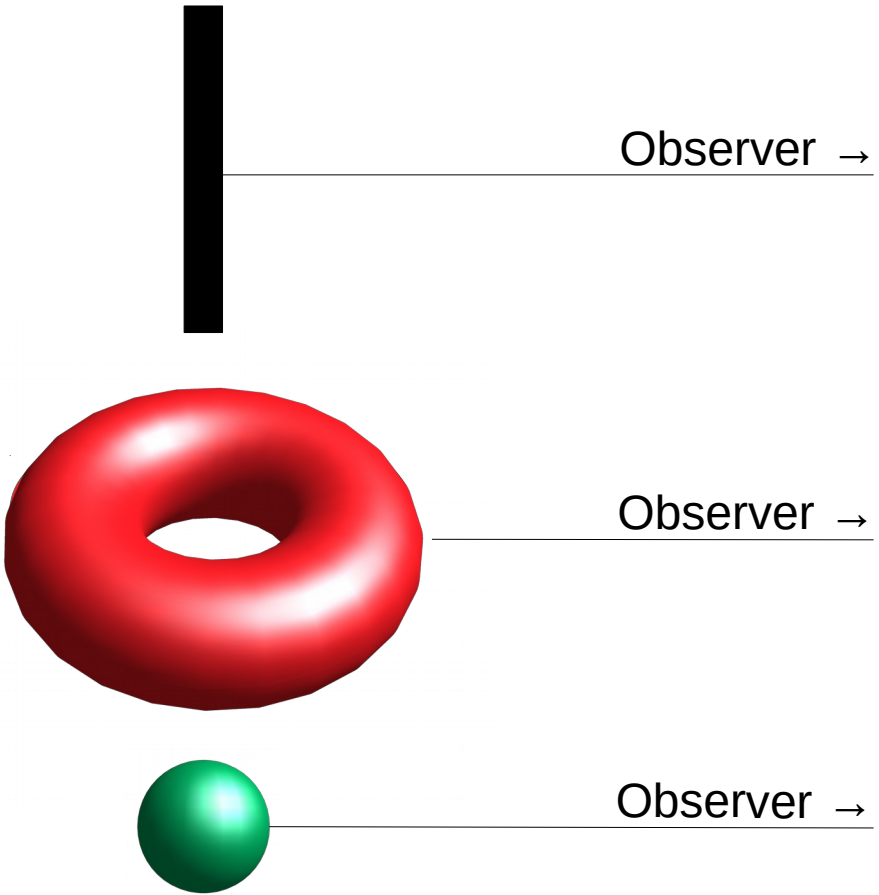
$\theta_{disk} = 5°$

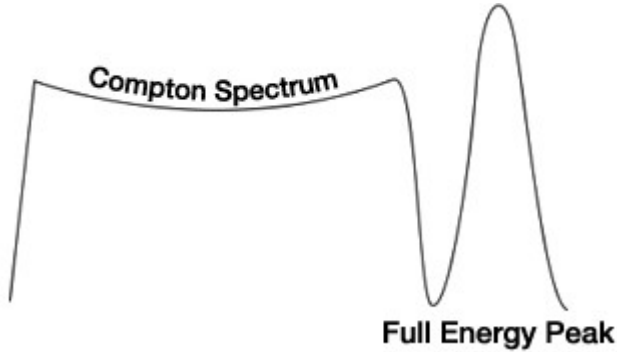
$\theta_{cone} = 40°$

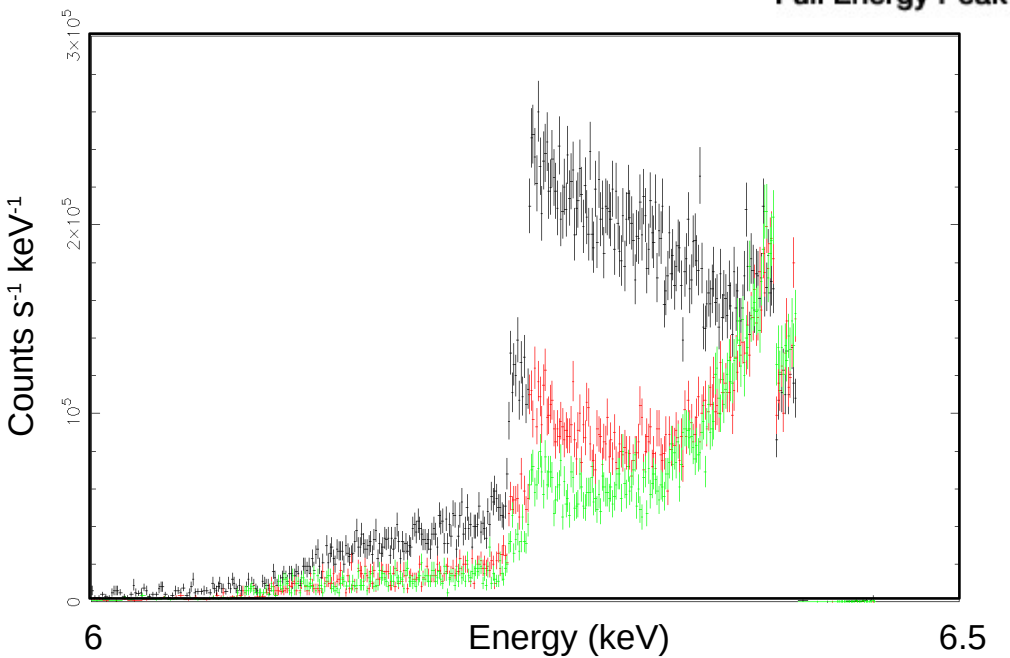
Stalevski et al. (2017)

Andonie et al. in preparation

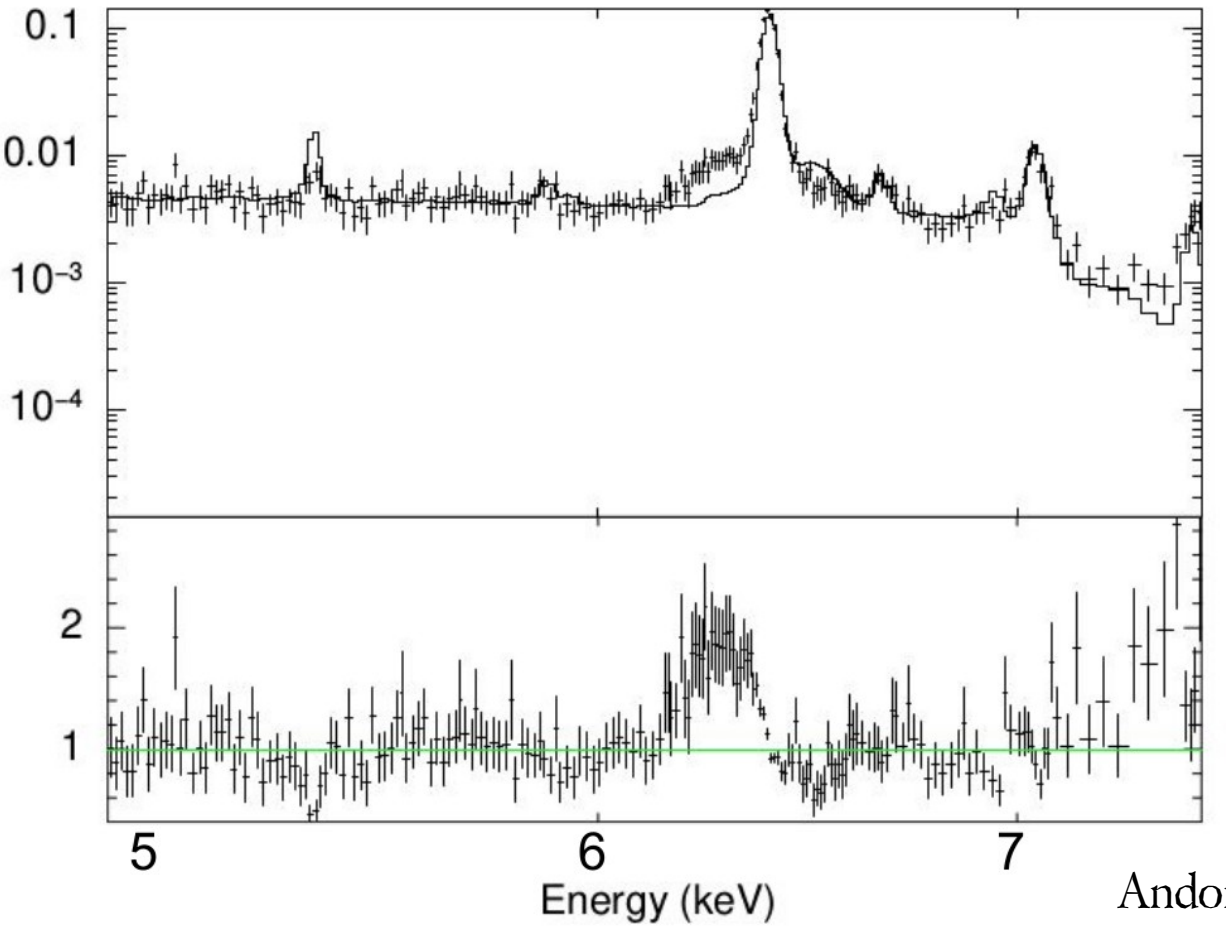
Compton Shoulder





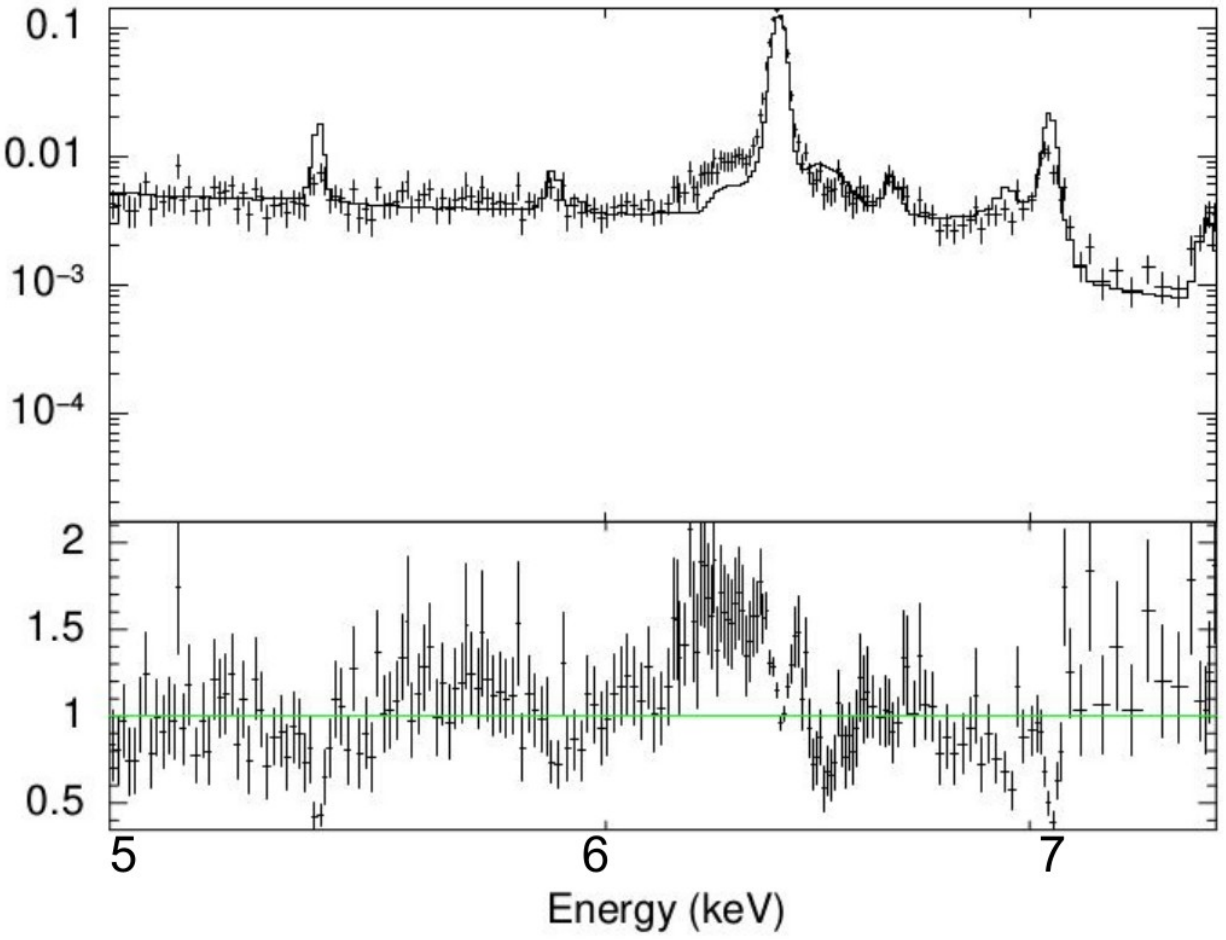


Chandra HEG Spectrum



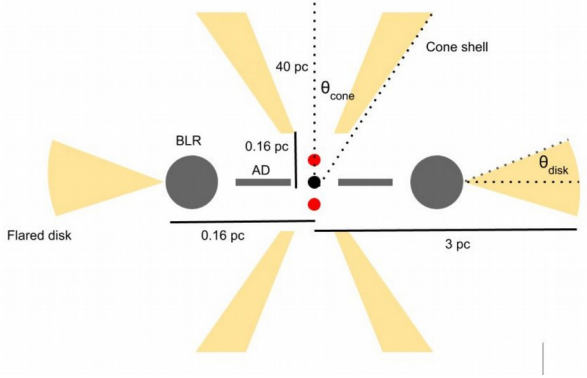
Andonie et al. in preparation

Chandra HEG Spectrum



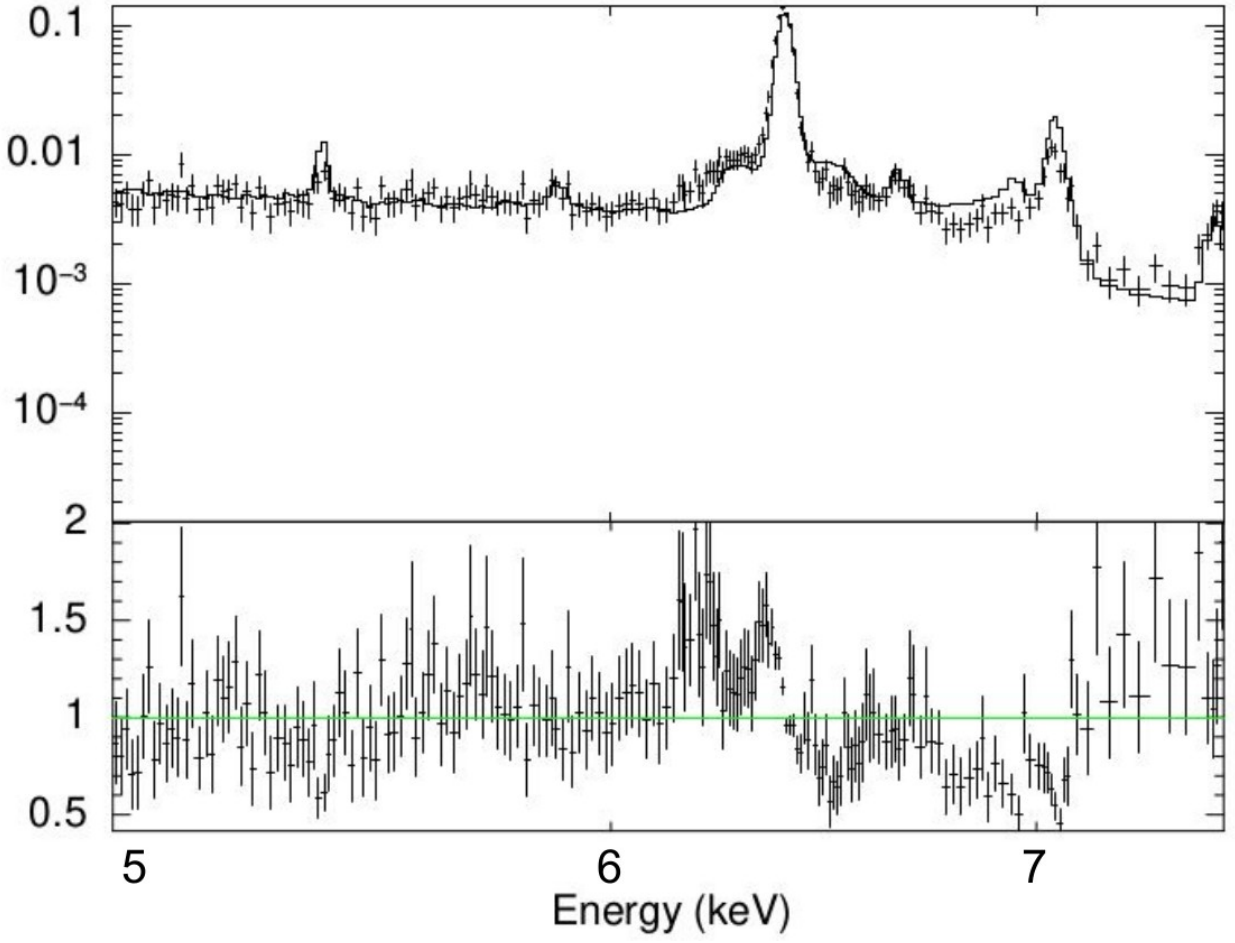
Increasing disk width

θ_{disk}=30°

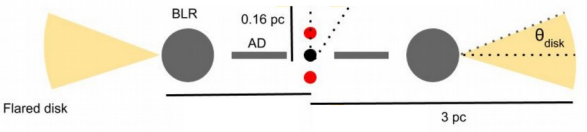


Andonie et al. in preparation

Chandra HEG Spectrum



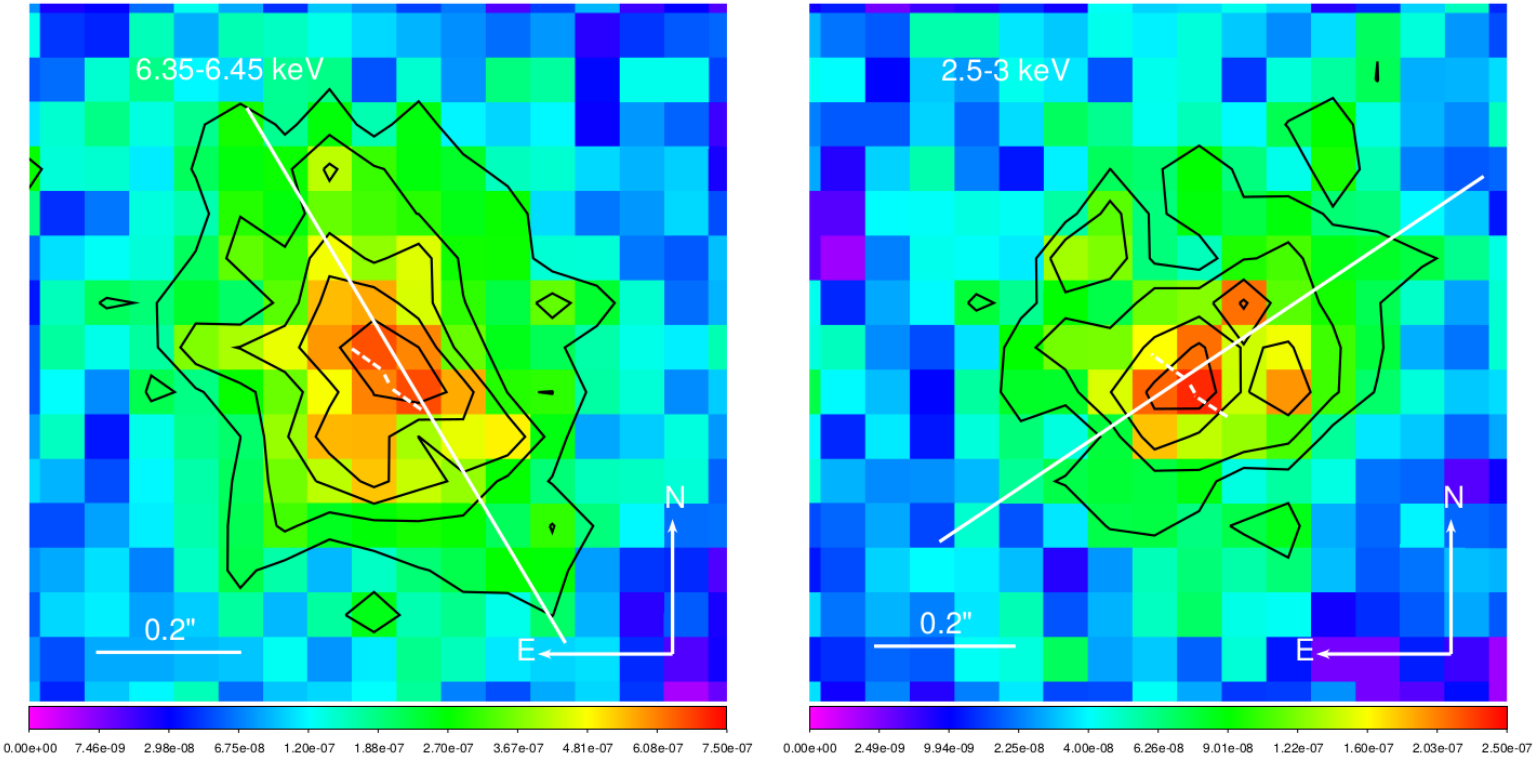
Removing cone and
Increasing disk width
$\theta_{disk}=30°$



Few Fe Kα photons from the cone; dust? clumpy medium?

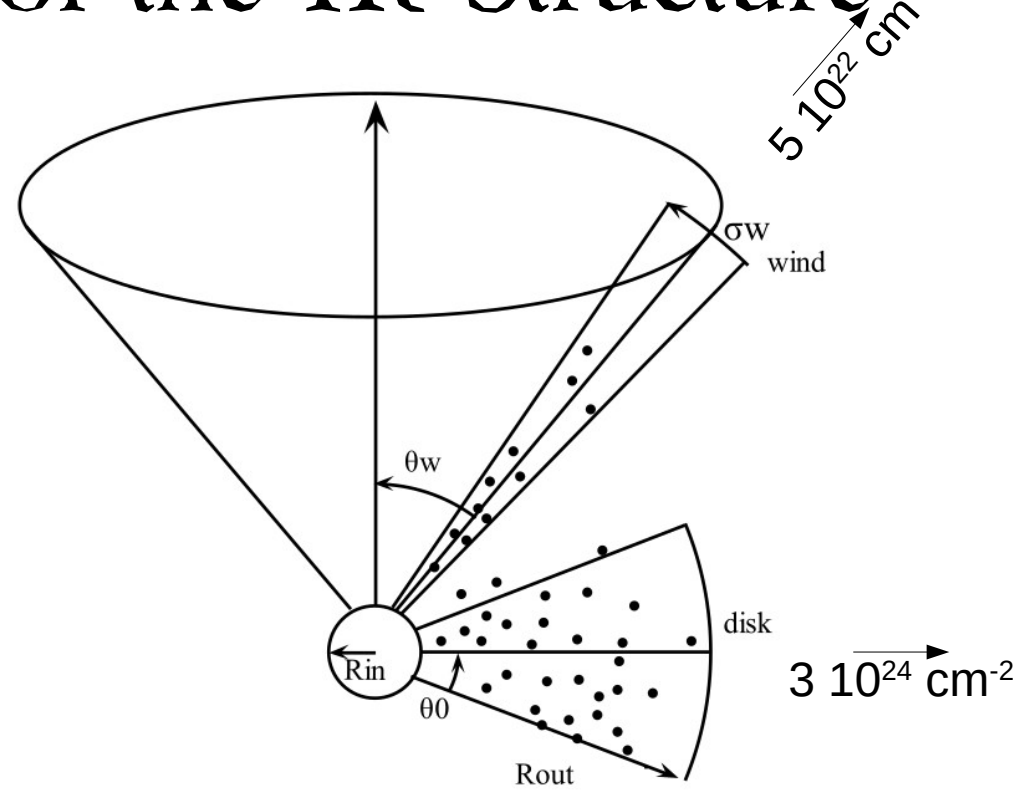
Andonie et al. in preparation

Chandra X-ray Imaging of Circinus



Liu et al. in preparation

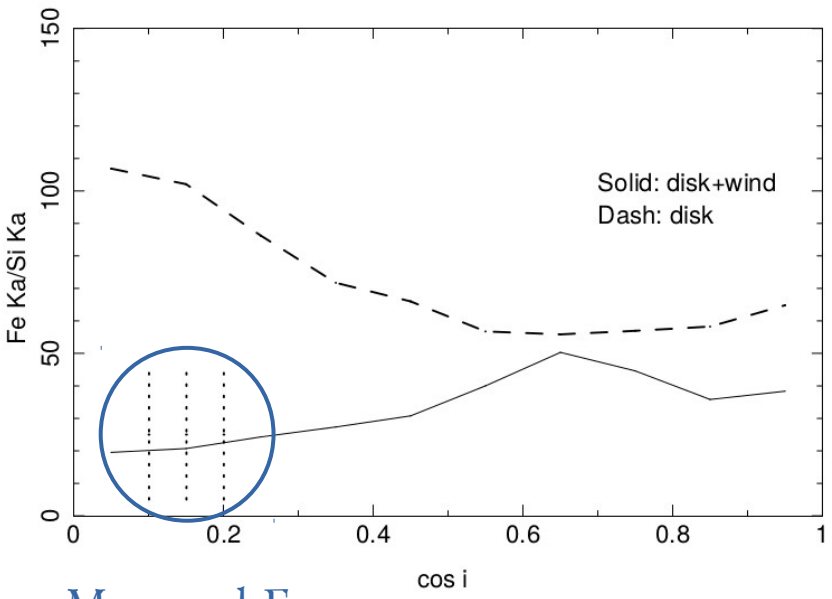
Clumpy Modeling of the IR Structure



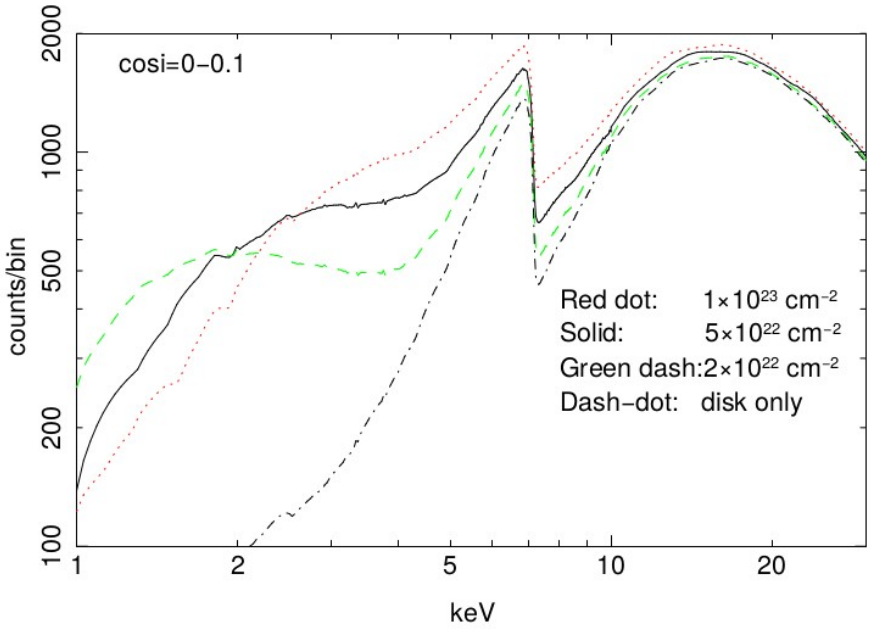
RefleX simulation with 50'000 clouds

Liu et al. in preparation

Fe Kα/Si Kα Ratio in Obscured AGN

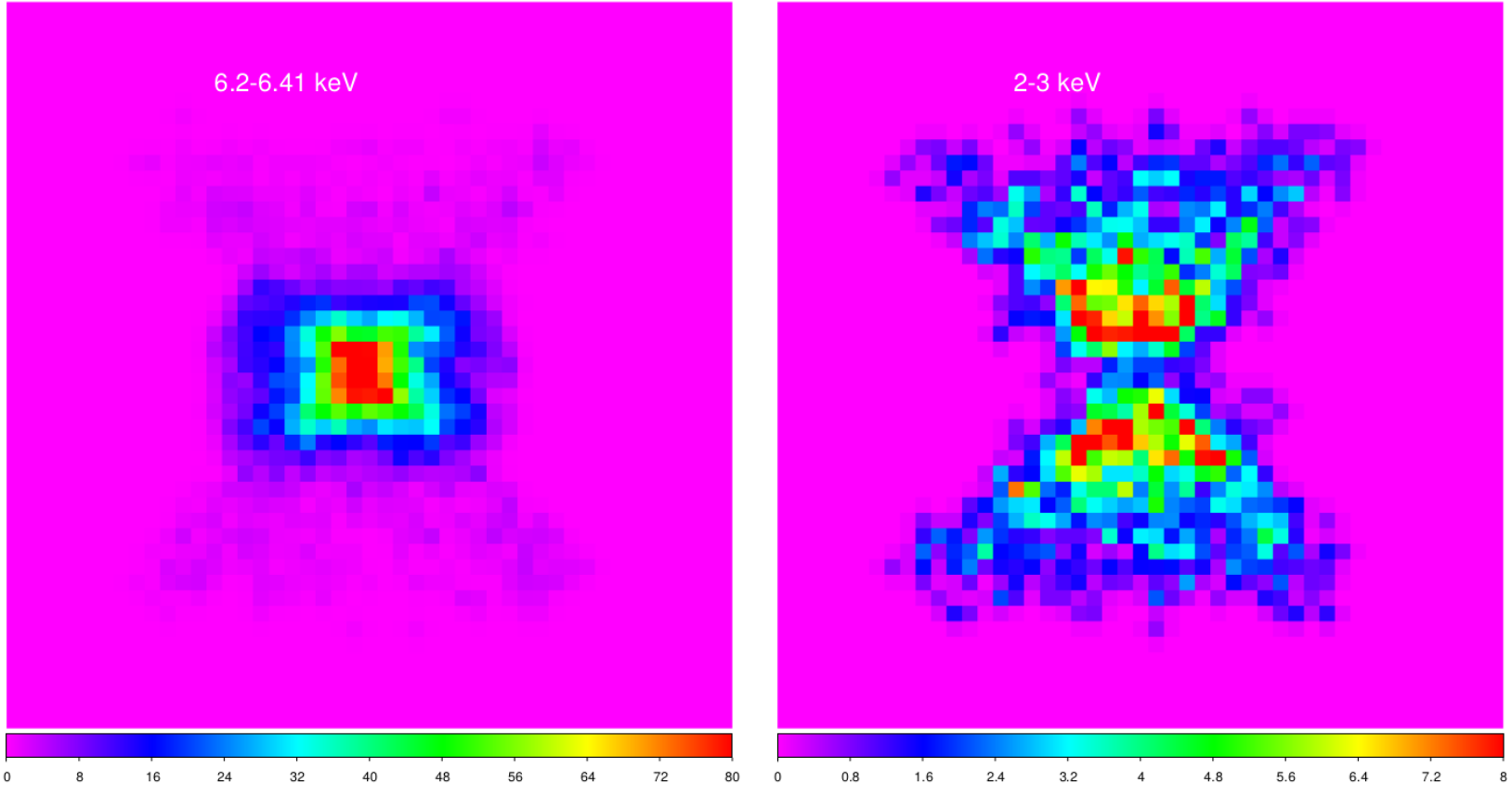


Measured Fe Kα/Si Kα ratio (Liu et al. 2016)



Liu et al. in preparation

RefleX Imaging of the Circinus Galaxy



Liu et al. in preparation

Conclusion

- RefleX allows self-consistent modeling of absorbers and reflector in X-rays
  - A lot of flexibility in the geometry and physics
  - Provides insights into the geometry and physical conditions
  - Freely available and in continuous development!
- Application to Circinus galaxy
  - Important constraints from IR, but still a huge parameter space
  - Compton shoulder too strong; something should prevent Fe Kα in the cone. Dust? Clouds?
  - Much stronger low-energy emission from the cone due to lower cloud densities
    - Explains morphology of the soft and hard X-ray emission
    - Explains the very low Fe Kα/Si Kα line ratios observed in obscured galaxies