Constraint on AGN corona size with fully relativistic modeling of 3D corona

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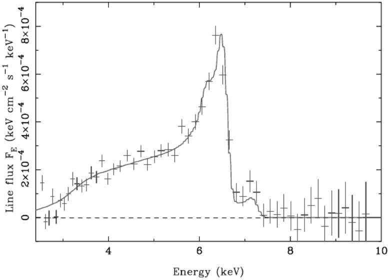
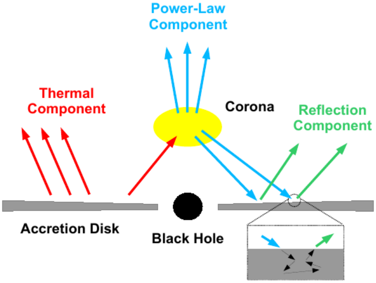
Compact corona required to fit broad iron line in NLS1

Broad, asymmetric iron line in MCG-6-30-15; Fabian+2002



Disc-corona in AGN; Bambi 2018



- broad iron line due to disc illuminated by hard X-ray from corona
- broadened red wing due to gravitational redshift
- iron line radial emissivity law: $\epsilon(r) \propto r^{-q}$; “standard” value $q = 3$
- in NLS1s: steep emissivity: compact corona close to the BH
- 1H 0707-495: $q \sim 7.8$ up to 5 $\mathrm{GM/c^2}$ requires a point-like corona with height $\leq 1.5\ \mathrm{GM/c^2}$ (Fabian+2012)

The lamp-post scenario

- the corona is approximated by an infinitesimal point on the black hole rotation axis
- greatly simplifying calculations

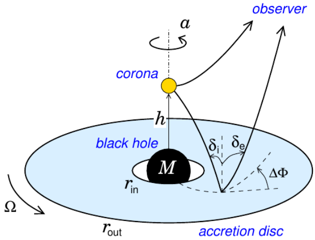


Figure: Dovčiak 2004

However: corona has to intercept enough soft seed photons

Although extended corona may also produce steep emissivity

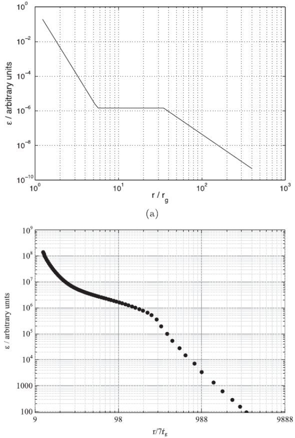
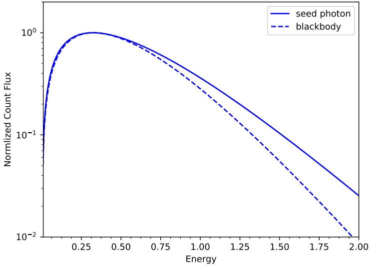


Figure: Wilkins & Fabian 2012

Corona that extends radially to 30 $\mathrm{GM/c^2}$ and between 2 and 10 $\mathrm{GM/c^2}$ above the BH could produce steep emissivity $\leq$ 3 $\mathrm{GM/c^3}$

Estimate of corona size with 1D model



- seed photon spectrum received by lamp-post corona close to blackbody: use NTHCOMP to obtain shape of X-ray spectrum
- Comptonization conserves number of photons: normalization of X-ray spectrum $\rightarrow f_X$
- X-ray luminosity L_X from observed X-ray luminosity
- area of corona is simply L_X/F_X.
- details see Dovčiak & Done 2016

Estimate of corona size with 1D model: 1H 0707-594

- maximum X-ray luminosity: $\sim 3 \times 10^{44}$ erg s^{-1}: $\sim 0.27 L_{\rm Edd}$ for $10^7\ M_\odot$ BH

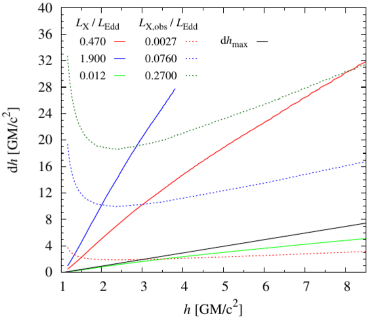


Figure: Dovčiak & Done 2016

For 0.27 $L_{\rm Edd}$: corona size $\gtrsim 18\ {\rm GM/c^2}$

3D Full Relativistic monte carlo modeling

Parameters

- disc: a, M, $\dot{M}$, f_{col}
- corona: T_e, $\bar{\lambda}$, geometry
  - sphere: h, r
  - slab: h, thickness, radius
  - other geometries..

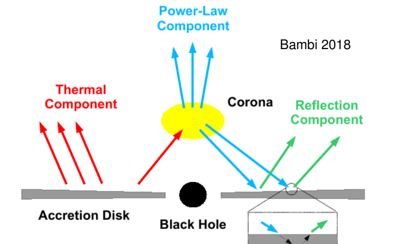
Assumptions

- Thin disc:
  - Novikov-Thorne temperature profile
  - local spectrum: color corrected blackbody
- semi-infinite scattering atmosphere (Chandrasekhar 1960)
  - angular distribution of disc photon:
  - polarization degree: monotonically increase with polar angle, un-polarized at face-on, $\delta = 11.7\%$ edge-on
  - polarization angle: perpendicular to meridian plane
- thermal electron: velocity follows Maxwell-Jüttner distribution

3D Full Relativistic monte carlo modeling

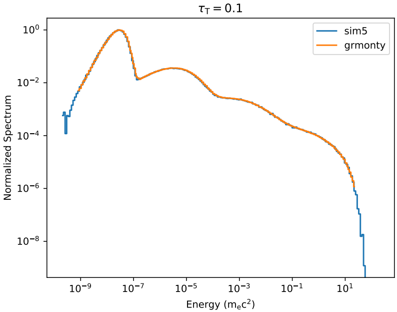
Procedures

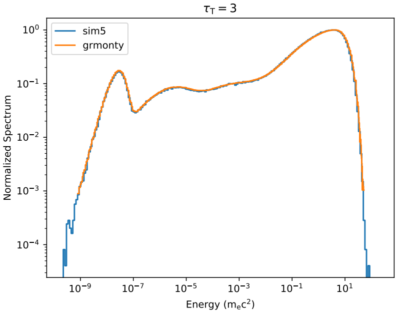
1. sample disc photons: x^μ, k^μ, E_∞, δ, $K_{\rm WP}$
2. propagate x^μ, k^μ along null geodesic in Kerr spacetime; step size $\ll \bar{\lambda}$
3. if photon enters corona:
   - covariant evaluation of optical depth τ, then scattering probability $P = 1 - e^{-\tau}$;
   - if scattering:
     - sample electron four-momentum
     - scattering kernel follows Pozdnyakov+1983; Klein-Nishina cross section
     - update E_∞, k^μ, δ, f^μ, then $K_{\rm WP}$
4. at infinity:
   - E_∞
   - $x^\mu \to i_{\rm obs}$
   - $k^\mu, \delta, K_{\rm WP} \to Q, U$



Comparison with GRMONTY

- GRMONTY: GR radiative transfer code (Dolence+2009); scattering kernel follows Pozdnyakov+1983
- For comparison:
  - central photon source; $T_{bb} = 10^{-8}\ m_e c^2$
  - spherical cloud; $\tau_\mathrm{T} = n_e \sigma_T R$; $T_e = 4\ m_e c^2$
  - no polarization; non-GR

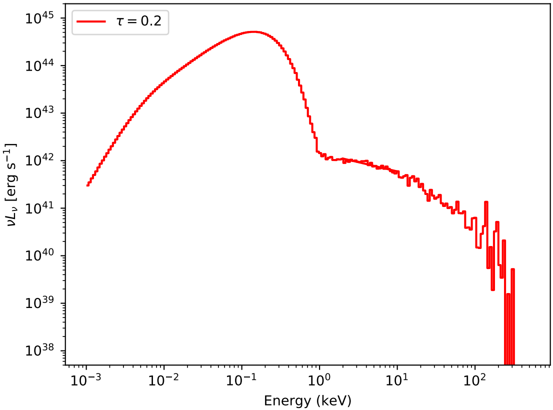




Our result is consistent with GRMONTY

Varying optical depth

$a = 0.998$, $M = 10^7\ M_\odot$, $\dot{M} = \dot{M}_{\rm Edd}$, $T_e = 100\ \rm{keV}$, $i = 30^\circ$, $f_{\rm col} = 2.4$
Spherical corona: $h = 10\ \rm{GM/c^2}$, $r = 4\ \rm{GM/c^2}$

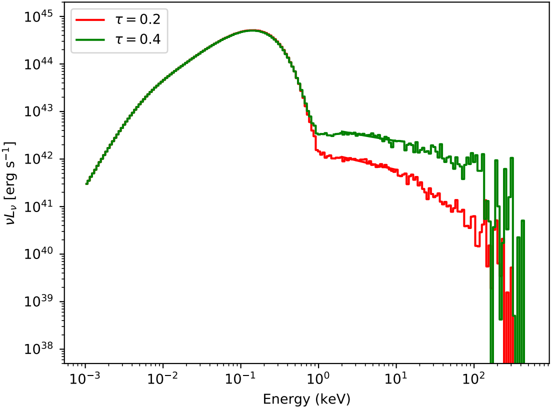


$\Gamma = 2.39$

- Spectral cut-off around hundreds of keV

Varying optical depth

$a = 0.998$, $M = 10^7\ M_\odot$, $\dot{M} = \dot{M}_{\rm Edd}$, $T_e = 100\ \rm keV$, $i = 30°$, $f_{\rm col} = 2.4$
Spherical corona: $h = 10\ \rm GM/c^2$, $r = 4\ \rm GM/c^2$



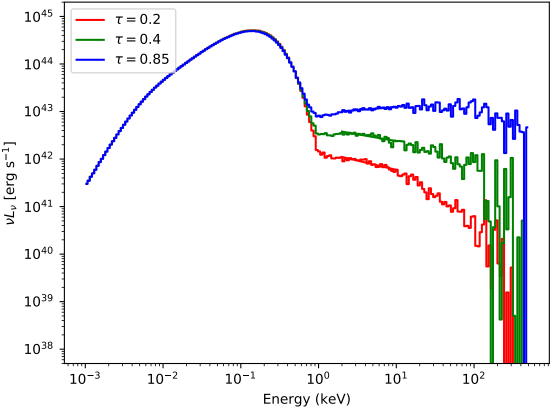
$\Gamma = 2.29$

$\Gamma = 2.39$

- Spectral cut-off around hundreds of keV
- τ increases: more luminous & harder X-ray emission

Varying optical depth

$a = 0.998$, $M = 10^7\ M_\odot$, $\dot{M} = \dot{M}_{\mathrm{Edd}}$, $T_e = 100\ \mathrm{keV}$, $i = 30^\circ$, $f_{\mathrm{col}} = 2.4$
Spherical corona: $h = 10\ \mathrm{GM/c^2}$, $r = 4\ \mathrm{GM/c^2}$

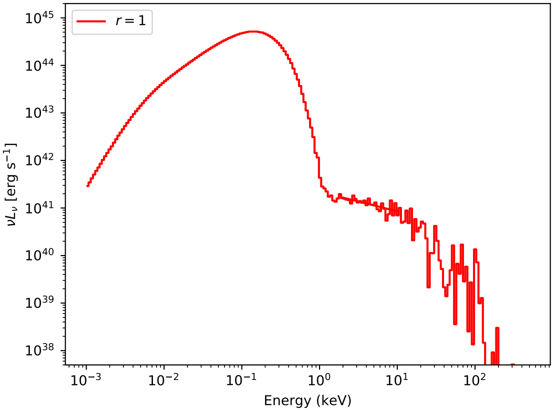


$\Gamma = 1.87$
$\Gamma = 2.29$
$\Gamma = 2.39$

- Spectral cut-off around hundreds of keV
- τ increases: more luminous & harder X-ray emission

Varying size

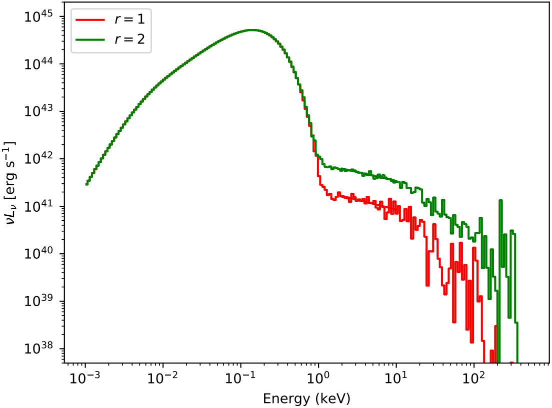
$a = 0.998$, $M = 10^7\ M_\odot$, $\dot{M} = \dot{M}_{\mathrm{Edd}}$, $T_e = 100$ keV, $i = 30°$, $f_{\mathrm{col}} = 2.4$
Spherical corona: $h = 5\ \mathrm{GM/c^2}$, $\tau = 0.2$



$\Gamma = 2.41$

Varying size

$a = 0.998$, $M = 10^7\ M_\odot$, $\dot{M} = \dot{M}_{\rm Edd}$, $T_e = 100\ \rm keV$, $i = 30^\circ$, $f_{\rm col} = 2.4$
Spherical corona: $h = 5\ \rm GM/c^2$, $\tau = 0.2$



$\Gamma = 2.37$

$\Gamma = 2.41$

Larger corona → more luminous X-ray

Comparison with observations (in progress)

CHEESES sample (Ursini, Ph.D. Thesis) (subsample of CAIXA catalogue (Bianchi 2009))

- un-obscured, radio-quiet AGNs
- more than one exposure with XMM/pn
- observations have at least one XMM/OM filters out of six

Putting constraint

- select CHEESES AGNs with:
  - $\dot{M} \leq \dot{M}_{Edd}$: Novikov-Thorne disc assumption
  - simultaneous *XMM* UV/X-ray observations
- assume spin a
- $L_{\rm UV}, a, M \rightarrow \dot{M}$
- find out corona geometry to produce observed X-ray luminosity and spectrum

Future work

polarization

- currently we include polarization calculation
  - rotation of polarization vector in Kerr space-time
  - dependence of differential cross-section on polarization degree
- long computation time required to obtain good SNR of polarization degree and angle;

corona motion

- investigate the effect of corona rotation or motion along vertical direction (jet base)

energy balance

- disc heated by corona $\rightarrow$ more seed photons $\rightarrow$ more luminous X-ray .....
- could be accounted for by a few iterations

Summary

- Lamp-post scenario usually used in modeling corona; however, corona should have finite size; luminous X-ray requires large enough corona to intercept enough seed photons
- simple 1D estimate for 1H 0707-594 high state put a constraint of corona size $\gtrsim$ 18 $\mathrm{GM/c^2}$
- we carry out fully relativistic monte carlo modeling of AGN disc-corona emission
- constraint on corona size with simultaneous X-ray/UV observation (in progress)