Minimum X-ray source size for a lamppost corona in light-bending models for AGN

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Scheme of the lamp-post geometry

- **central black hole** – mass, spin
- **accretion disc**
  - Keplerian, geometrically thin, optically thick
  - Novikov-Thorne thermal emission
    \( T_{NT}, M, \dot{M} = \frac{L_b}{\eta c^2}, a, f_c \)
- **compact corona** with isotropic emission
  - height, luminosity, size (radius), optical depth \( (h, L_X \text{ or } L_{obs}, R, \tau) \)
- **up-scattering** in the corona
  - \( \text{nthcomp}(E; \Gamma, E_c, T_{BB}) \)
- **relativistic effects**:
  - Doppler and gravitational energy shift
  - light bending (lensing)
  - aberration (beaming)

\[ M = 10^7 M_\odot, \quad L_b = L_{Edd}, \quad a = 0.998, \quad \eta = 32.4\%, \quad f_c = 2.4 \]
Size of the corona – constant intrinsic luminosity

\[ L_X = 0.031 L_{\text{Edd}} \]
\( (L_{\text{obs}} = 0.02 L_{\text{Edd}} \) at \( h = 10 G M/c^2 \)\)

\[ \Sigma_e = \frac{\tau}{\sigma_t} \sim 10^{23} - 10^{24} \text{ cm}^{-2} \]
\[ n_e = \frac{\Sigma_e}{l} \sim 10^{9} - 10^{12} \text{ cm}^{-3} \]

\[
\frac{F_e}{L_X} = 1 - \frac{F_{\text{in}}}{L_X} \frac{f_{\text{out}}}{f_{\text{in}}}
\]

\[ R = \sqrt{\frac{1}{\pi} \frac{g_L}{1 - e^{-\tau}} \frac{f_{\text{out}}}{f_{\text{in}}}} \]

\[ \Gamma \]

\[ 3.0 \quad \text{red} \]
\[ 2.5 \quad \text{green} \]
\[ 2.0 \quad \text{blue} \]
\[ R_{\text{max}} \quad \text{black} \]
What size of the corona is needed for the given observed luminosity if the corona is at height $h$?

$L_{\text{obs}} = 0.001 L_{\text{Edd}}$

\[
\frac{L_{\text{obs}}}{L_X} = g_L \frac{d\Omega_L}{d\Omega_o}
\]
Application to 1H0707-495

\[ \frac{L_X}{L_{\text{Edd}}} \quad \frac{L_{\text{obs}}}{L_{\text{Edd}}} \]

- **dotted red** → size for the minimum \( L_{\text{obs}} \)
- **solid red** → size for the light bending scenario, \( L_X \) set from the minimum \( L_{\text{obs}} \) at \( h = 1.5 \)
- **dotted dark green** → size for the maximum \( L_{\text{obs}} \)
- **dotted blue** → size for the average \( L_{\text{obs}} \)
- **solid blue** → size for the light bending scenario, \( L_X \) set from the average \( L_{\text{obs}} \) at \( h = 2 \)
- **solid green** → size for the light bending scenario, \( L_X \) set from the minimum \( L_{\text{obs}} \) at \( h = 3.5 \) → pure light bending scenario cannot reach maximum \( L_{\text{obs}} \)

\[ F_0(0.3 - 10\text{keV}) = \]

\[ 2 \times 10^{-13} - 2 \times 10^{-11} \text{ erg cm}^{-2} \text{s}^{-1} \]

\[ L_{\text{obs}} = 4\pi D^2 F_0(0.3 - 10\text{keV}) \int_{10/g_L}^{\infty} \frac{E \text{ nthcomp}(E; \Gamma, E_c, T_{BB}) \text{ d}E}{\int_{0.3/g_L}^{10/g_L} E \text{ nthcomp}(E; \Gamma, E_c, T_{BB}) \text{ d}E} \]
Conclusions

General conclusions:

▶ for reasonable assumptions the corona is not tiny but still may be quite small (even of the order of $1 - 10 \, r_g$),

▶ in light bending scenario with inverse Compton the corona has to change size (geometry), it scales with height,

▶ for larger $\Gamma$ we need smaller $\tau$ and both increase $R$,

▶ point-source approximation is not valid, 3D computations with non-spherical geometry and corona rotation are needed for more accurate corona size (and shape) estimation.
Conclusions on 1H0707-495:

- due to high observed flux in 1H0707-495, in the pure light bending scenario the small spherical patch of corona does not fit above the horizon,

- Wilkins & Fabian (2012) reproduce the steep radial emissivity with an extended corona (up to $30R_g$) at low height ($2R_g$),

- such an extended corona probably cannot change its emissivity to $100 \times$ larger luminosity either through light bending scenario or by extending it even further outside,

- thus could the inner accretion have higher temperature to produce more photons? (the disc in our assumptions already shines at $L_{\text{Edd}}$),
Conclusions

- however, the steep decrease of radial emissivity might be artificial due to wrong assumptions on local emission directionality and radial decrease of ionisation, see Svoboda et al (2012) and his poster A20,

- thus the extension may be much smaller \((2 \, r_g \text{ at height } 2 - 3 \, r_g)\) and maybe the maximum flux could be explained by changing corona size and geometry, e.g. by extending it further outside \((20 \, r_g \text{ at height } 2 - 3 \, r_g)\)?

- 3D computations with non-spherical geometry and corona rotation are needed for more accurate estimations.
Thermal photon flux arriving at corona

\[ f_{\text{in}} = \frac{8\pi\zeta(3)k^3}{h^3c^2} \int_{r_{\text{in}}}^{r_{\text{out}}} \frac{d\Omega_L}{dS_d} (gT_{\text{NT}})^3 \]

\[ F_{\text{in}} = \frac{4\pi^5k^4}{15h^3c^2} \int_{r_{\text{in}}}^{r_{\text{out}}} \frac{d\Omega_L}{dS_d} (gT_{\text{NT}})^4 \]

\[ \frac{d\Omega_n}{dS_d} = \frac{h}{D^3}, \quad g = \frac{E_L}{E_d} \]

\[ T_{\text{BB}} = \frac{E_{\text{peak}}}{2.82}, \quad E_{\text{BB}} = \frac{F_{\text{in}}}{f_{\text{in}}}, \quad E_P = \frac{L_X}{f_{\text{out}}} \]

\[ F_{\text{th}}(E_{\text{peak}}) = \text{MAX}[F_{\text{th}}(E)] \]

\[ f_{\text{out}} = \int_{0}^{\infty} \text{nthcomp}(E; \Gamma, E_c, T_{\text{BB}}) dE \]
Size of the corona - components

\[ (1 - e^{-\tau}) f_{\text{in}} dS_L = f_{\text{out}} \]

\[ R = \sqrt{\frac{1}{\pi} \frac{g_L}{1 - e^{-\tau}} \frac{f_{\text{out}}}{f_{\text{in}}}} \]

![Graph showing the relationship between R and h]