Constraining the Location of Gamma-ray Emission in Blazar Jets

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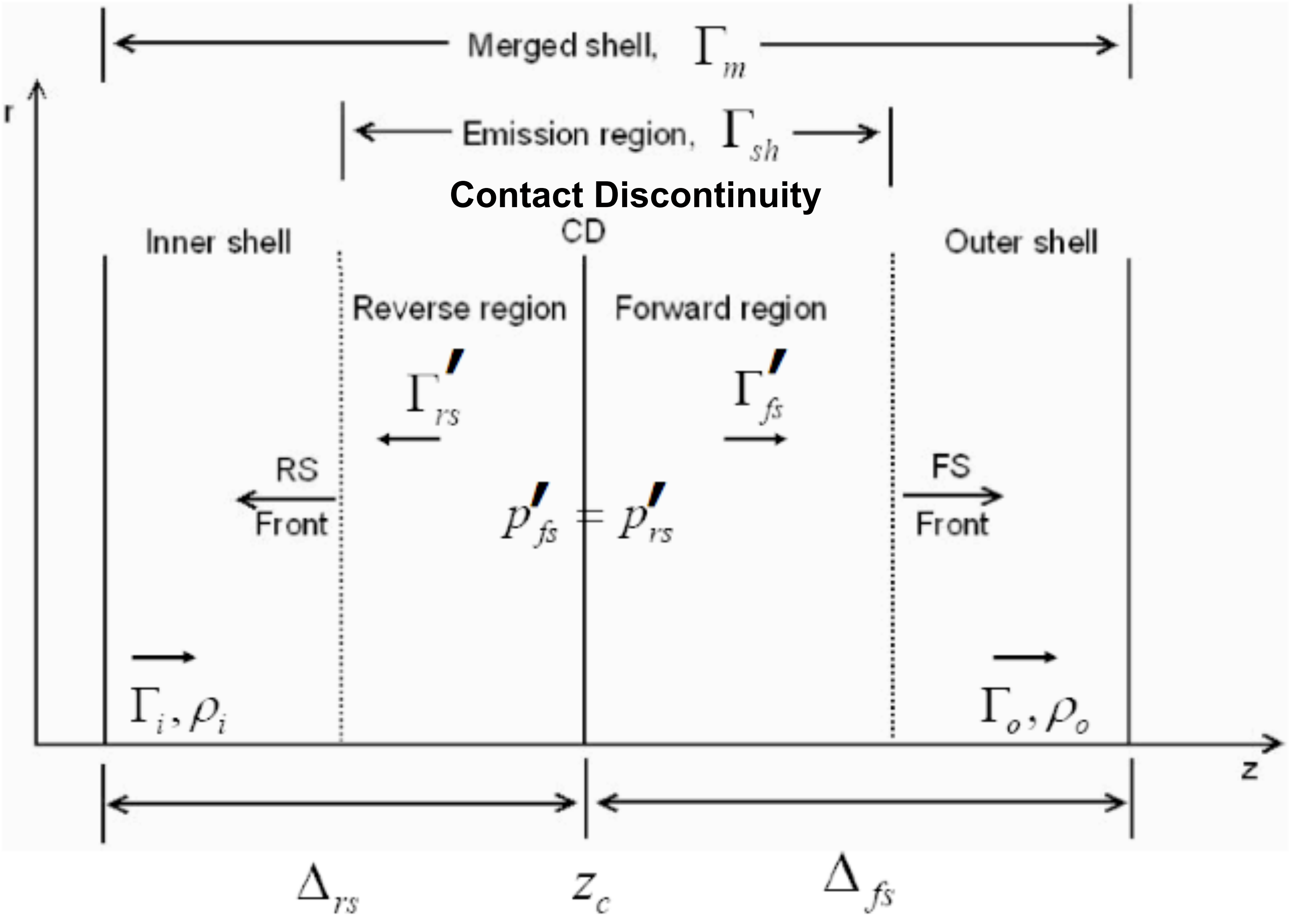
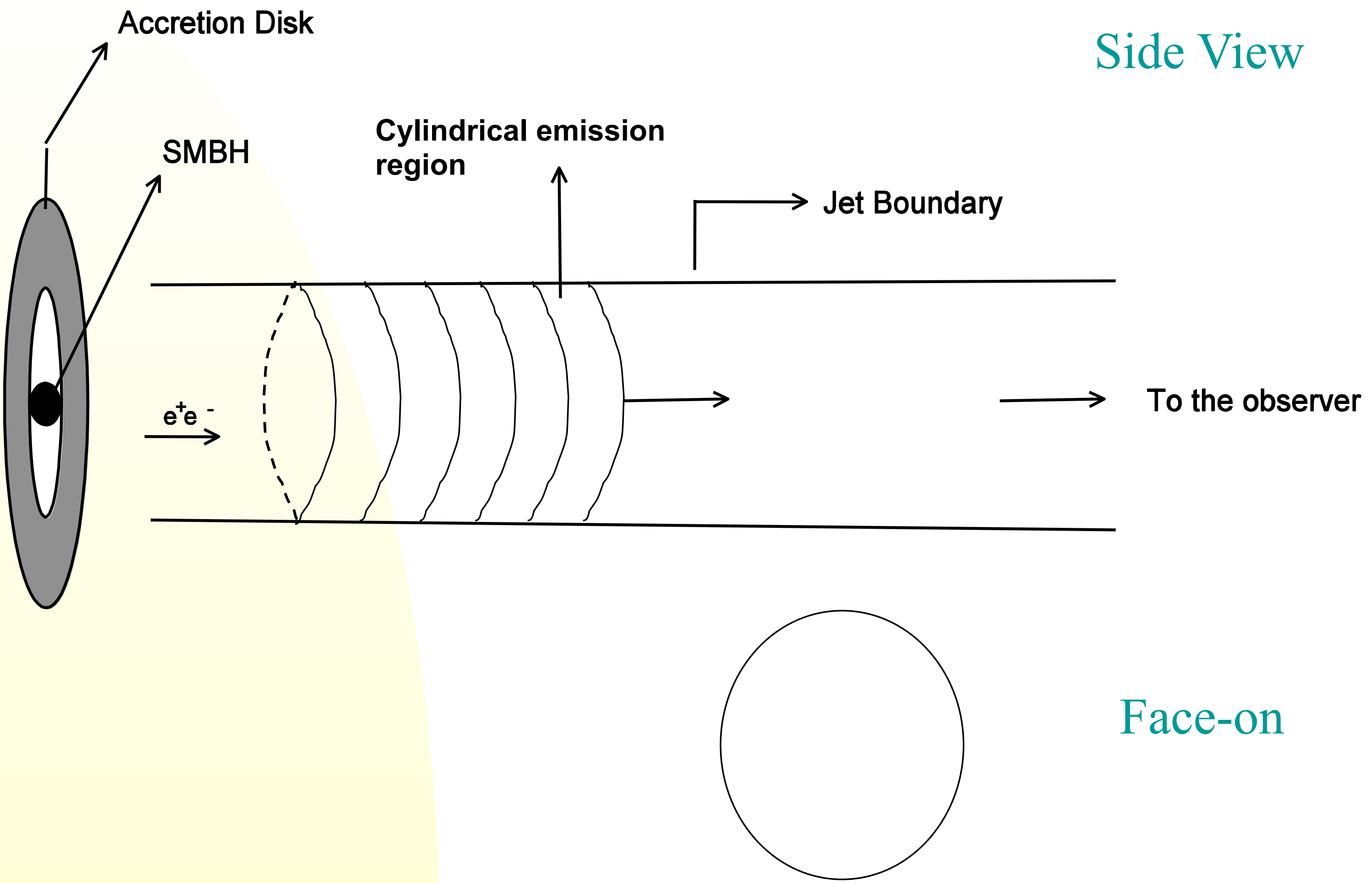
Internal Shock Model



Joshi M. & Boettcher M., 2011, ApJ, 727, 21

Multi-zone Approach With Radiation Feedback



Accretion Disk

SMBH

Cylindrical emission region

Jet Boundary

e^+e^-

To the observer

Side View

Face-on

Joshi M. & Boettcher M., 2011, ApJ, 727, 21

Gamma-ray Emission Location

- γ-ray flares located within sub-pc BLR or within and downstream of "core" at pc scales.
- Core defined as an approximately stationary, bright, compact feature seen in mm-wave (7mm or 43 GHz) VLBI images and located at one end of the jet on pc scales.
- Enough observational evidences (Jorstad et al., Lahteenmaki et al., Leon-Tavares et al.) of coincidences of γ-ray outbursts with radio events on pc scales.
- Theoretical challenge to explain variability of γ-ray flares on intra-day time scales at such length scales.
- Could multi-zone instead of single zone do the trick?
- What are sources of external seed photons & the amount of their individual contribution to gamma-ray emission?

Goal

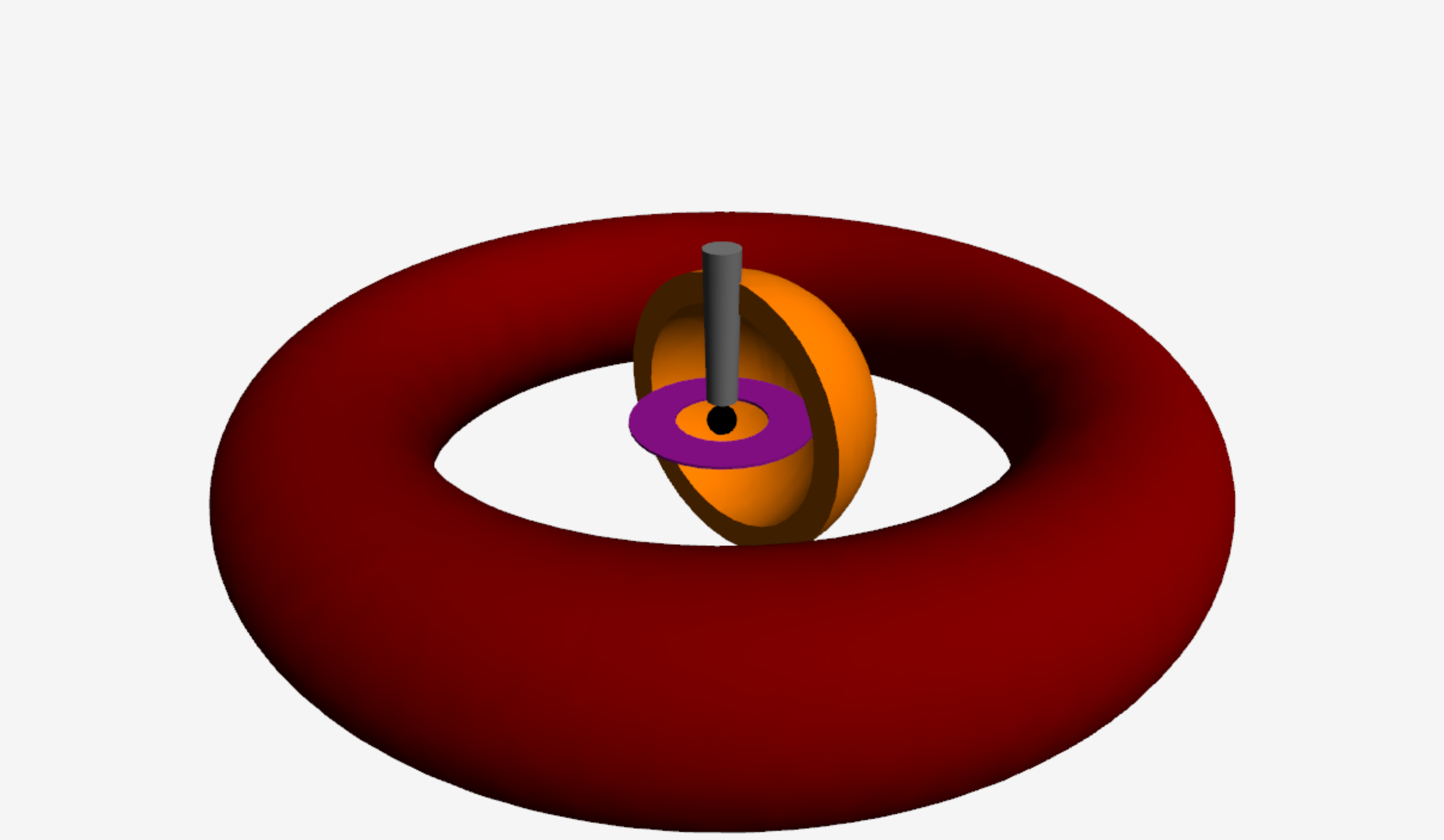
- Include anisotropy in external Comptonization calculation to better constrain the location of γ-ray emission in the jet.
- Develop a self-consistent scheme to dynamically follow the system along the jet axis.
- Role of intrinsic parameters.
- Interplay of various radiative processes responsible for different spectral states.

Methodology

- Radiation transfer code of Joshi & Böttcher (2011) with multi-zone feedback scheme.
- Include the contribution from accretion disk (ECD), broad line region (BLR; ECC), and dusty torus (ECDT).
- Evolve the system & follow the emission region to beyond BLR.

Joshi, Marscher & Boettcher (2013, in prep.)

Disk + BLR + DT Schematic



Disk Schematic: Shakura-Sunyaev

$\varepsilon^{*}_{\mathrm{Disk}}$ - optical to 10 keV

Relevant Parameters:

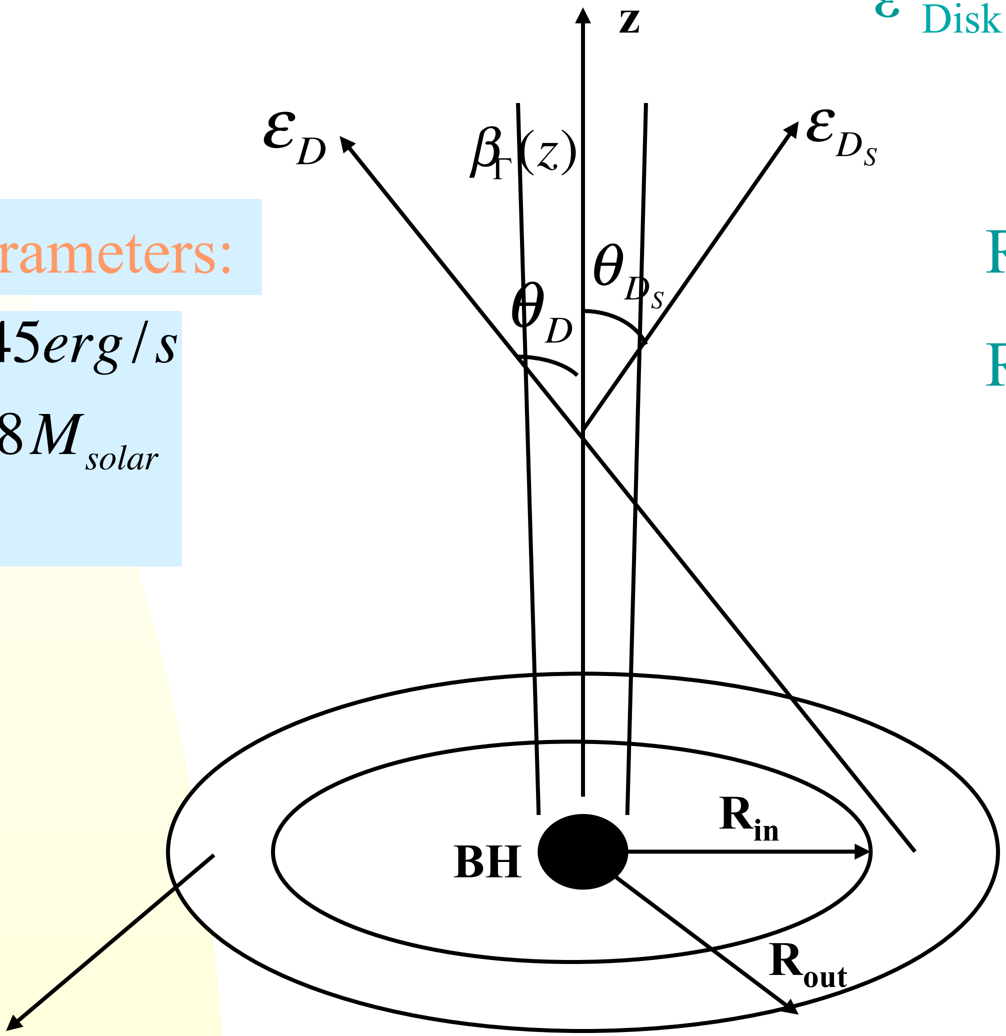
$L_{disk} \sim 8.0e45 erg/s$

$M_{BH} \sim 2.0e8 M_{solar}$

$\eta_{acc} \sim 0.06$

$R_{in} = 1.92e14$ cm

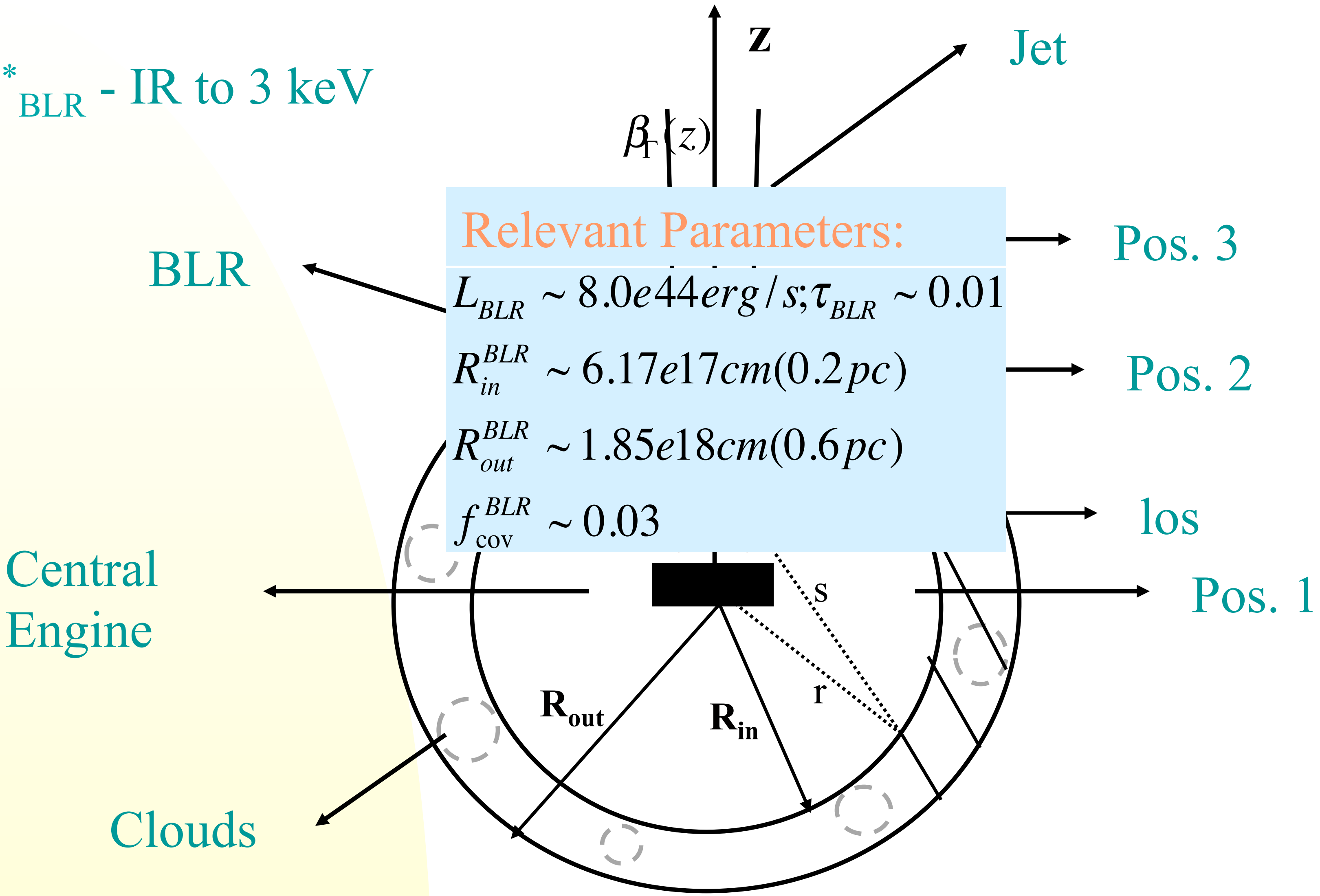
$R_{out} = 1.78e17$ cm



Accretion Disk

BLR Schematic

ε^{*}_{BLR} - IR to 3 keV



Relevant Parameters:

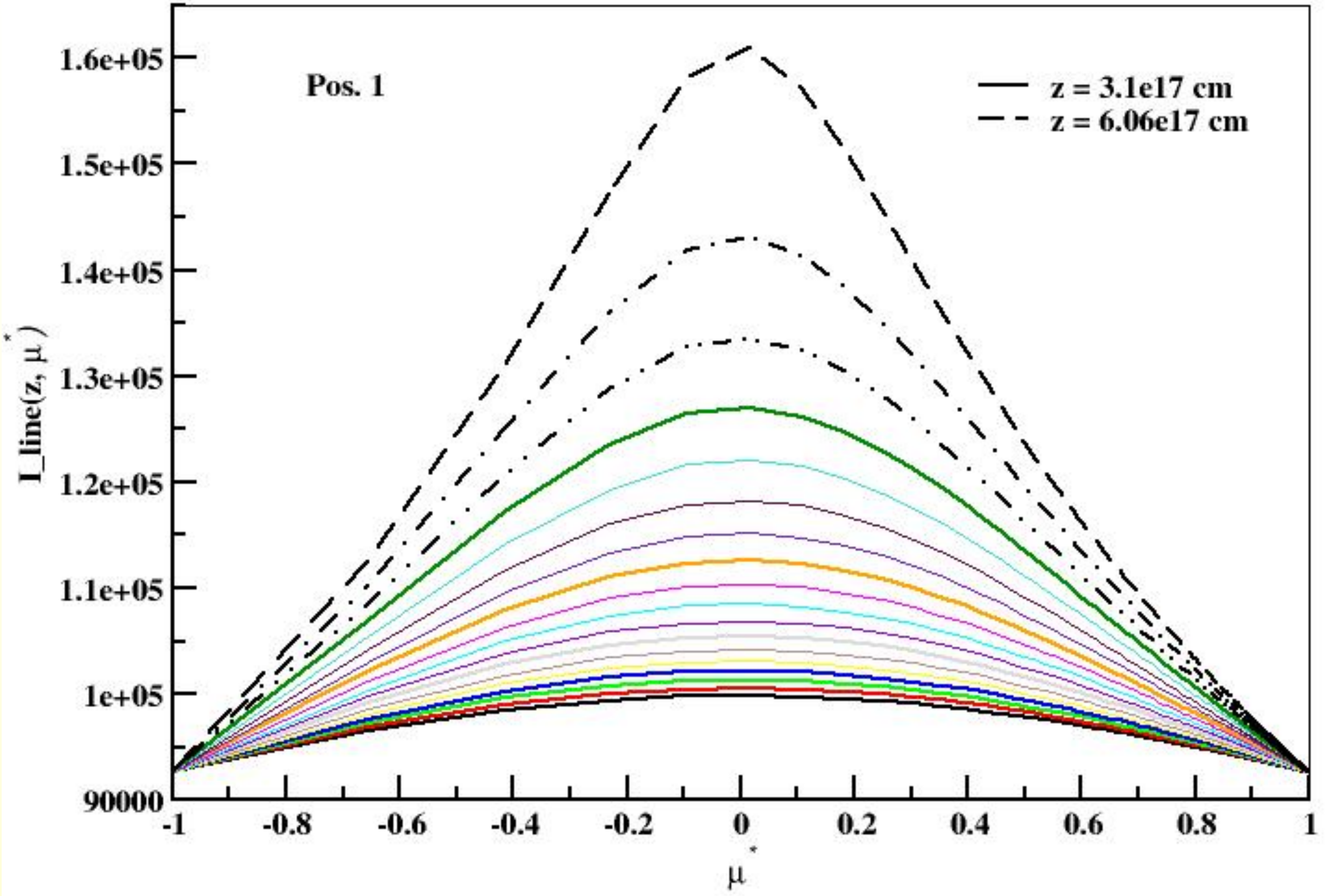
$L_{BLR} \sim 8.0e44 erg/s; \tau_{BLR} \sim 0.01$

$R_{in}^{BLR} \sim 6.17e17 cm (0.2 pc)$

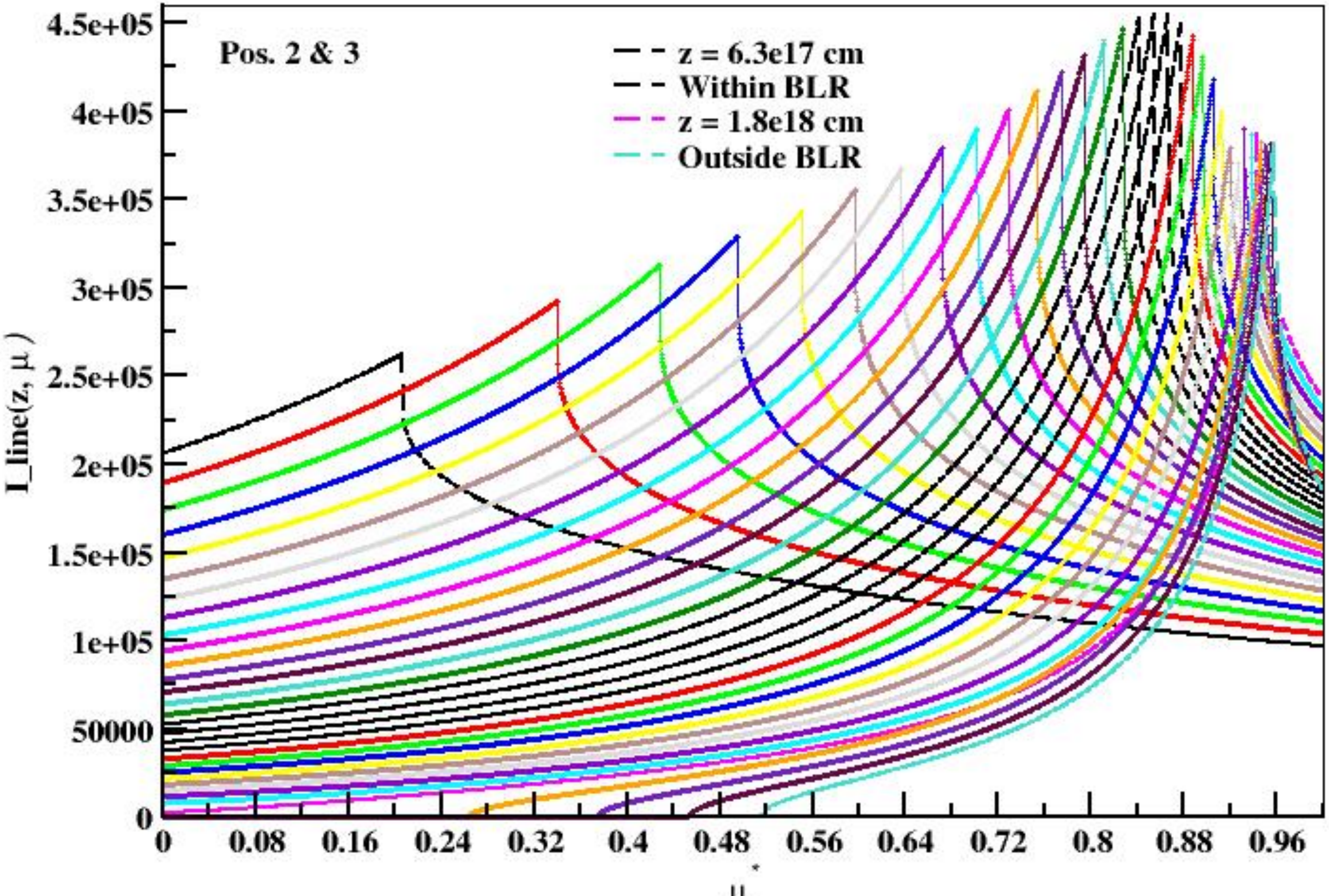
$R_{out}^{BLR} \sim 1.85e18 cm (0.6 pc)$

$f_{\mathrm{cov}}^{BLR} \sim 0.03$

Donea & Protheroe (2003); Liu & Bai (2006)

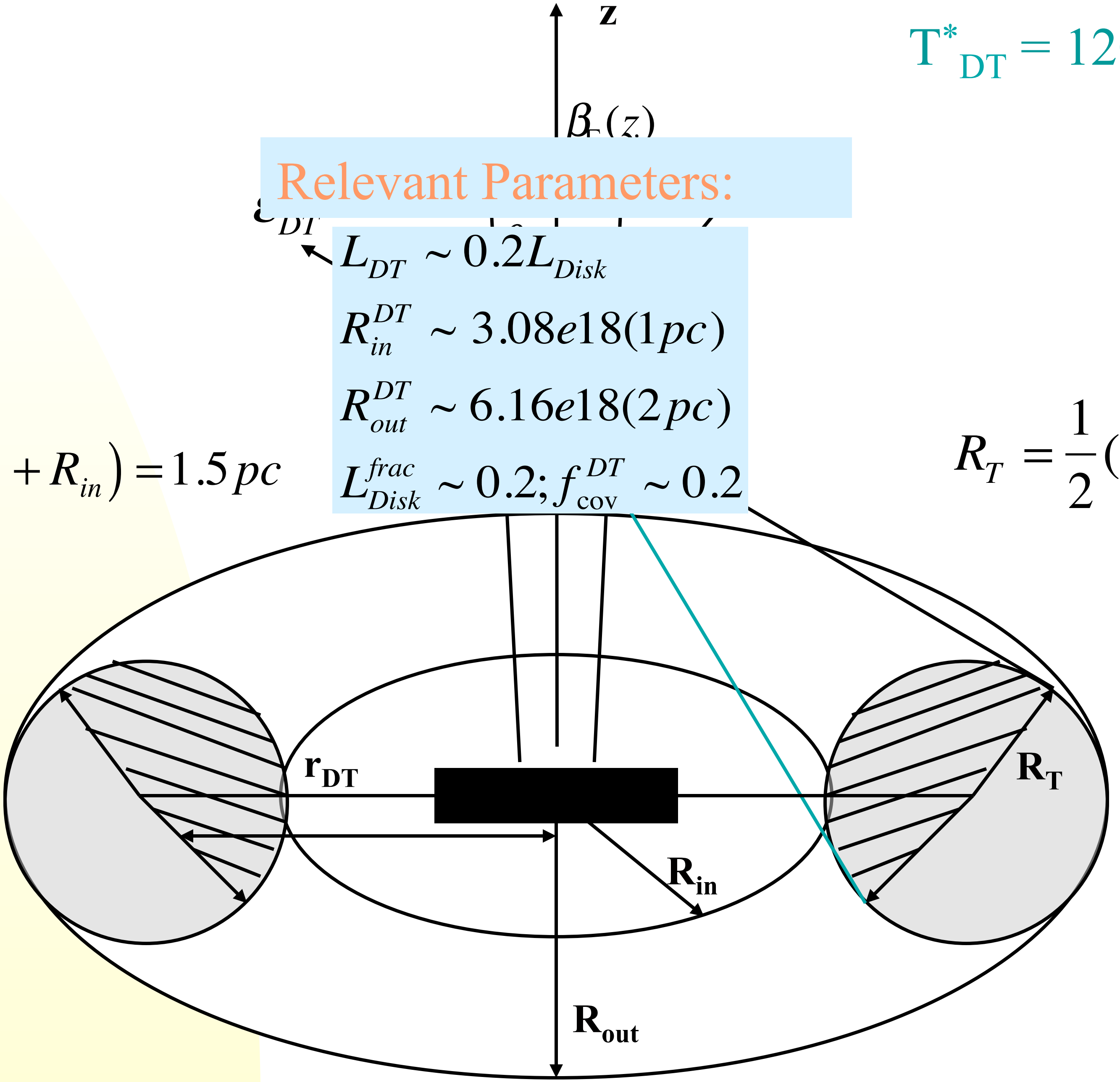


Joshi, Marscher & Boettcher (2013, in prep.)


Pos. 2 & 3
z = 6.3e17 cm
Within BLR
z = 1.8e18 cm
Outside BLR
I_line(z, μ*)
μ*
4.5e+05
4e+05
3.5e+05
3e+05
2.5e+05
2e+05
1.5e+05
1e+05
50000
0
0
0.08
0.16
0.24
0.32
0.4
0.48
0.56
0.64
0.72
0.8
0.88
0.96

Dust Torus Schematic

$T^{*}_{DT} = 1200\ \mathrm{K}$



Relevant Parameters:

$$L_{DT} \sim 0.2 L_{Disk}$$

$$R_{in}^{DT} \sim 3.08e18(1pc)$$

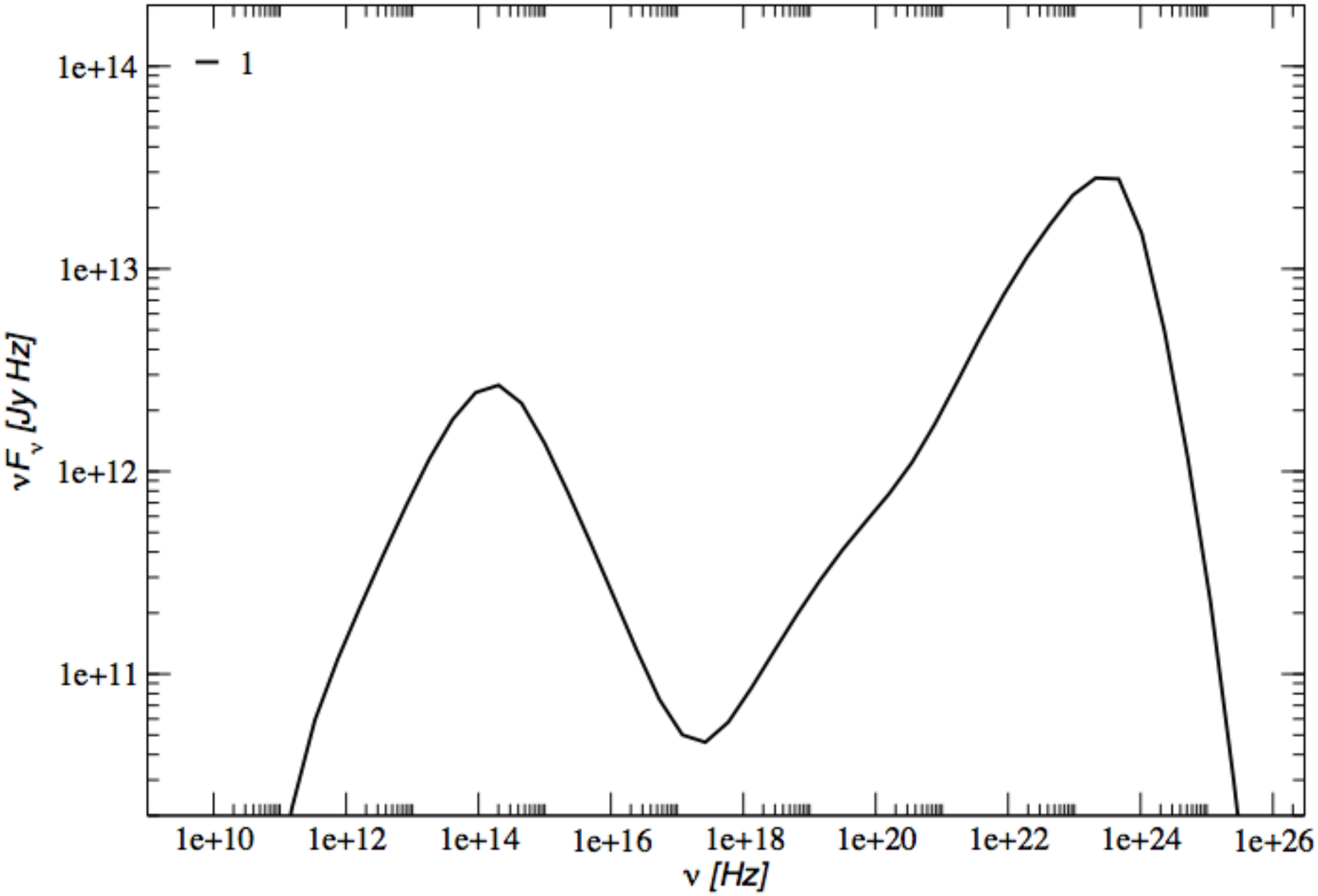
$$R_{out}^{DT} \sim 6.16e18(2pc)$$

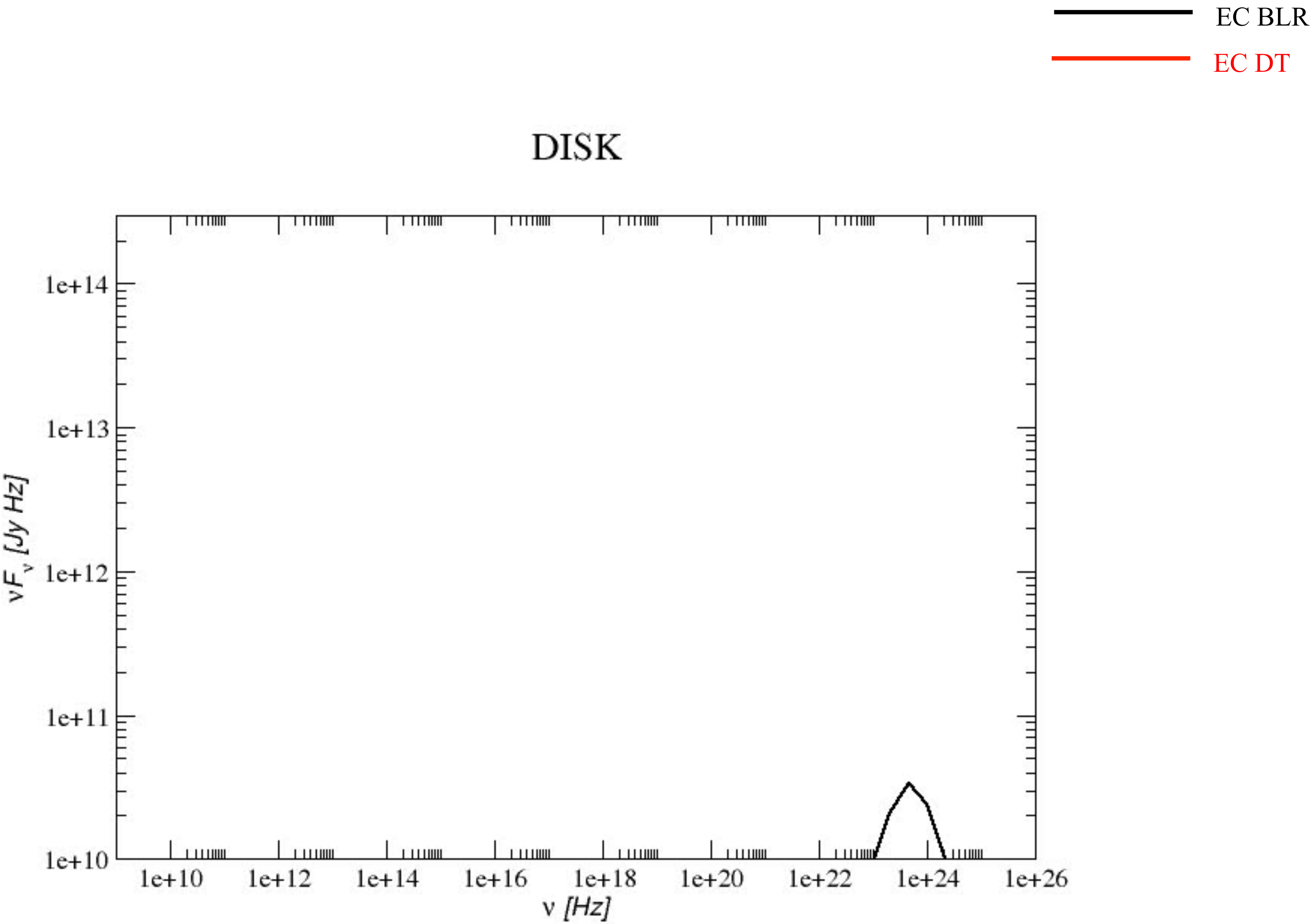
$$L_{Disk}^{frac} \sim 0.2; f_{\mathrm{cov}}^{DT} \sim 0.2$$

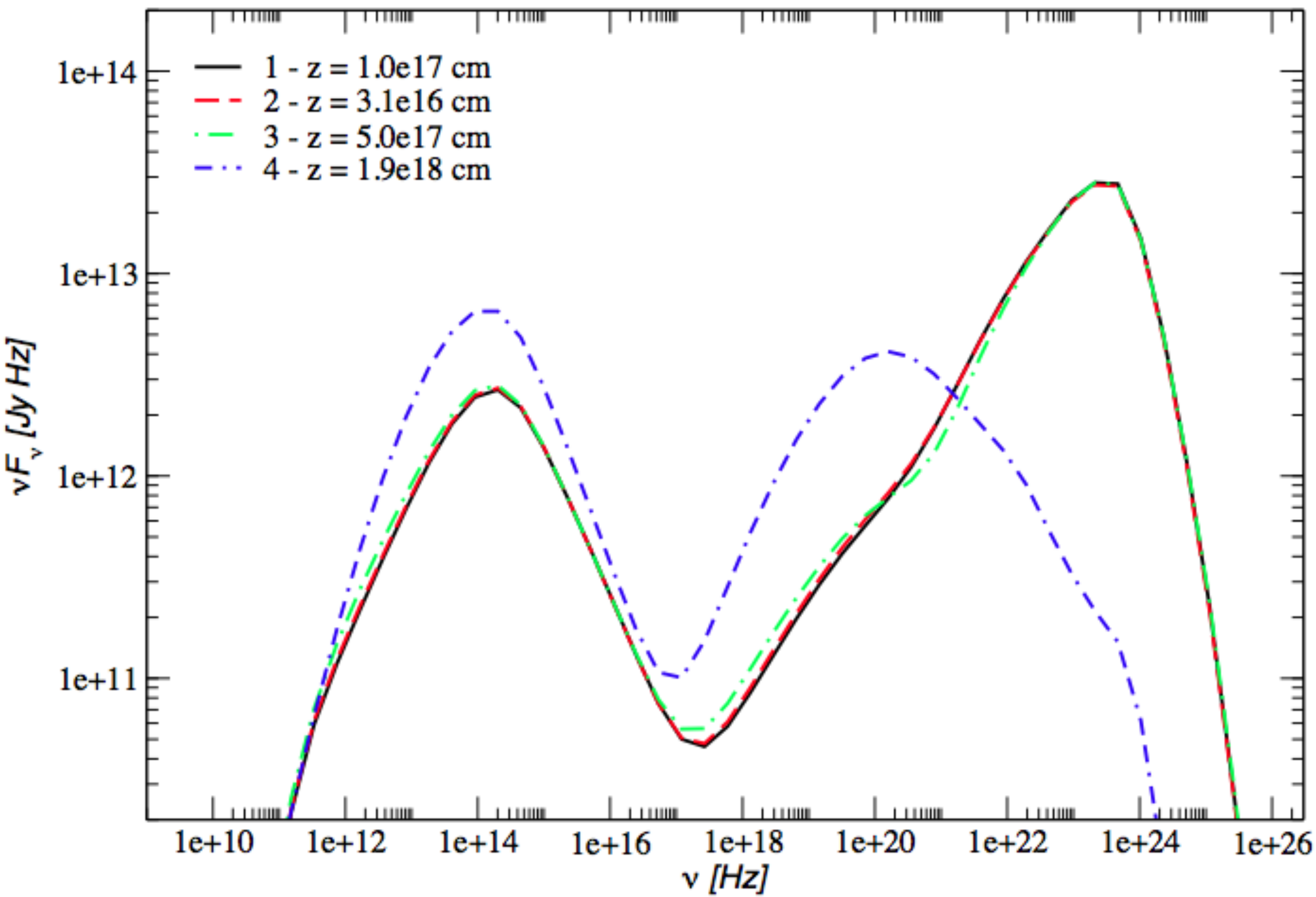
$$r_{DT} = \frac{1}{2}\left(R_{out} + R_{in}\right) = 1.5pc$$

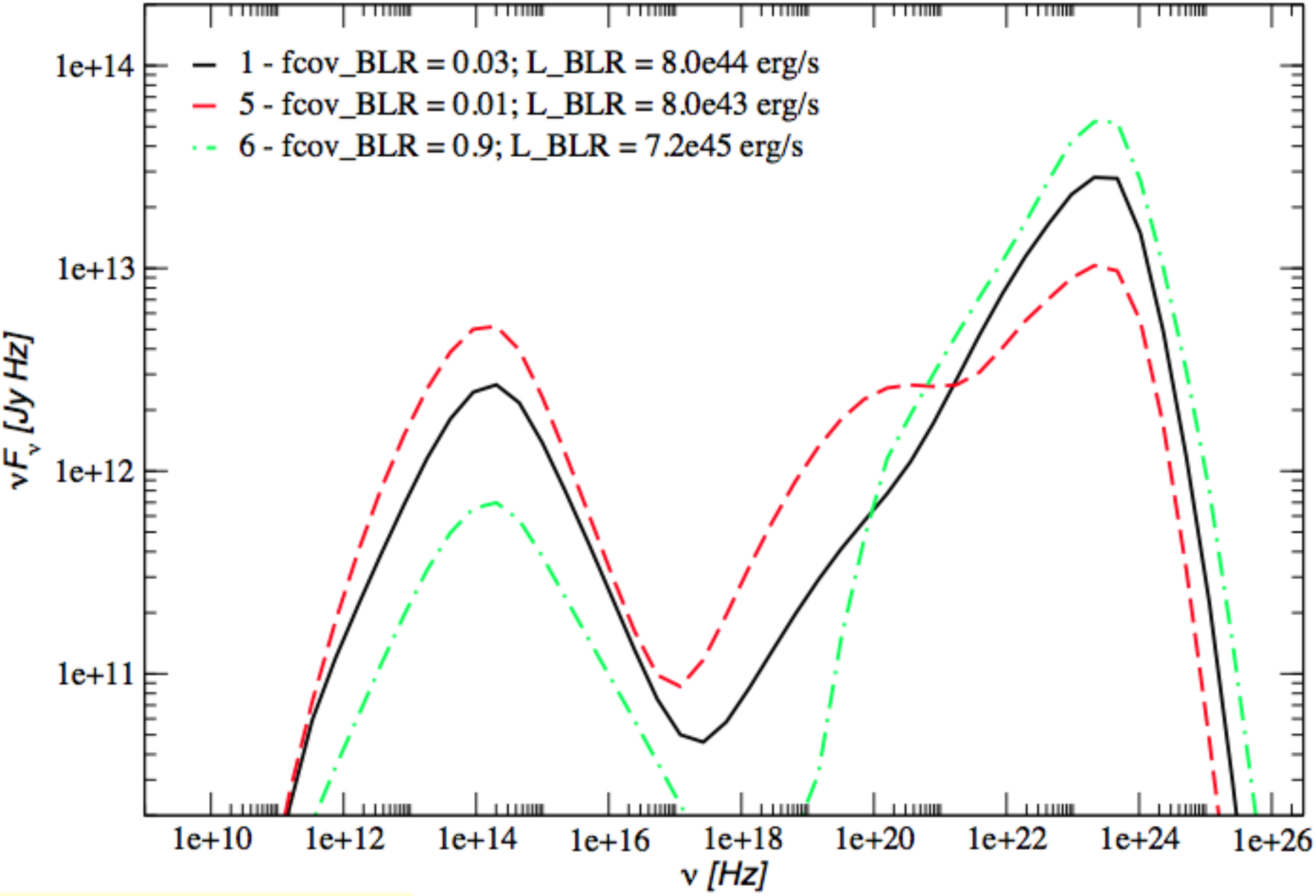
$$R_T = \frac{1}{2}(R_{out} - R_{in})$$

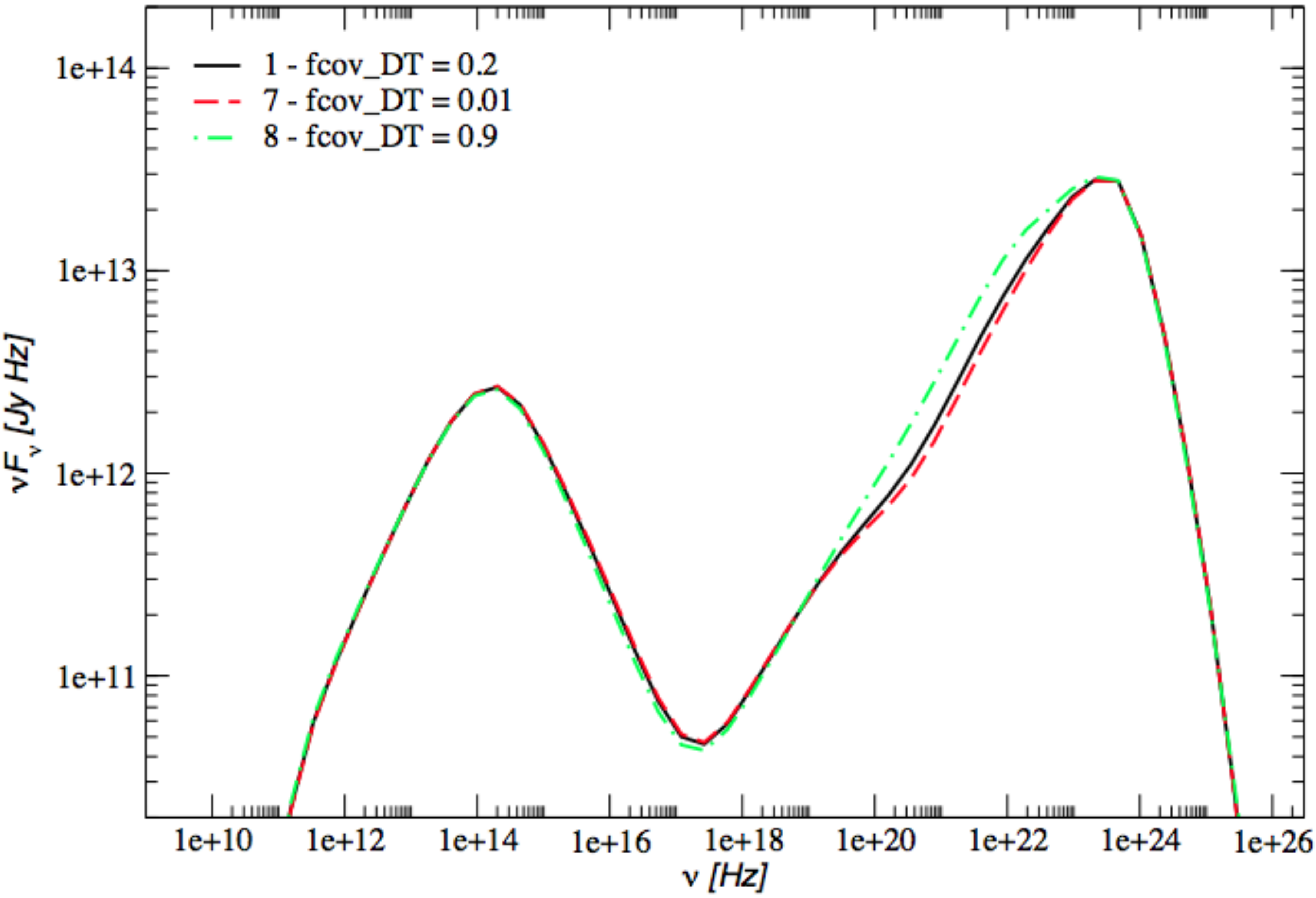
Flat Spectrum Radio Quasar (FSRQ)




EC BLR
EC DT
DISK
1e+14
1e+13
1e+12
1e+11
1e+10
νF_ν [Jy Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]


1 - z = 1.0e17 cm
2 - z = 3.1e16 cm
3 - z = 5.0e17 cm
4 - z = 1.9e18 cm
1e+14
1e+13
1e+12
1e+11
νF_ν [Jy Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]


1 - fcov_BLR = 0.03; L_BLR = 8.0e44 erg/s
5 - fcov_BLR = 0.01; L_BLR = 8.0e43 erg/s
6 - fcov_BLR = 0.9; L_BLR = 7.2e45 erg/s
νF_ν [Jy Hz]
1e+14
1e+13
1e+12
1e+11
ν [Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26

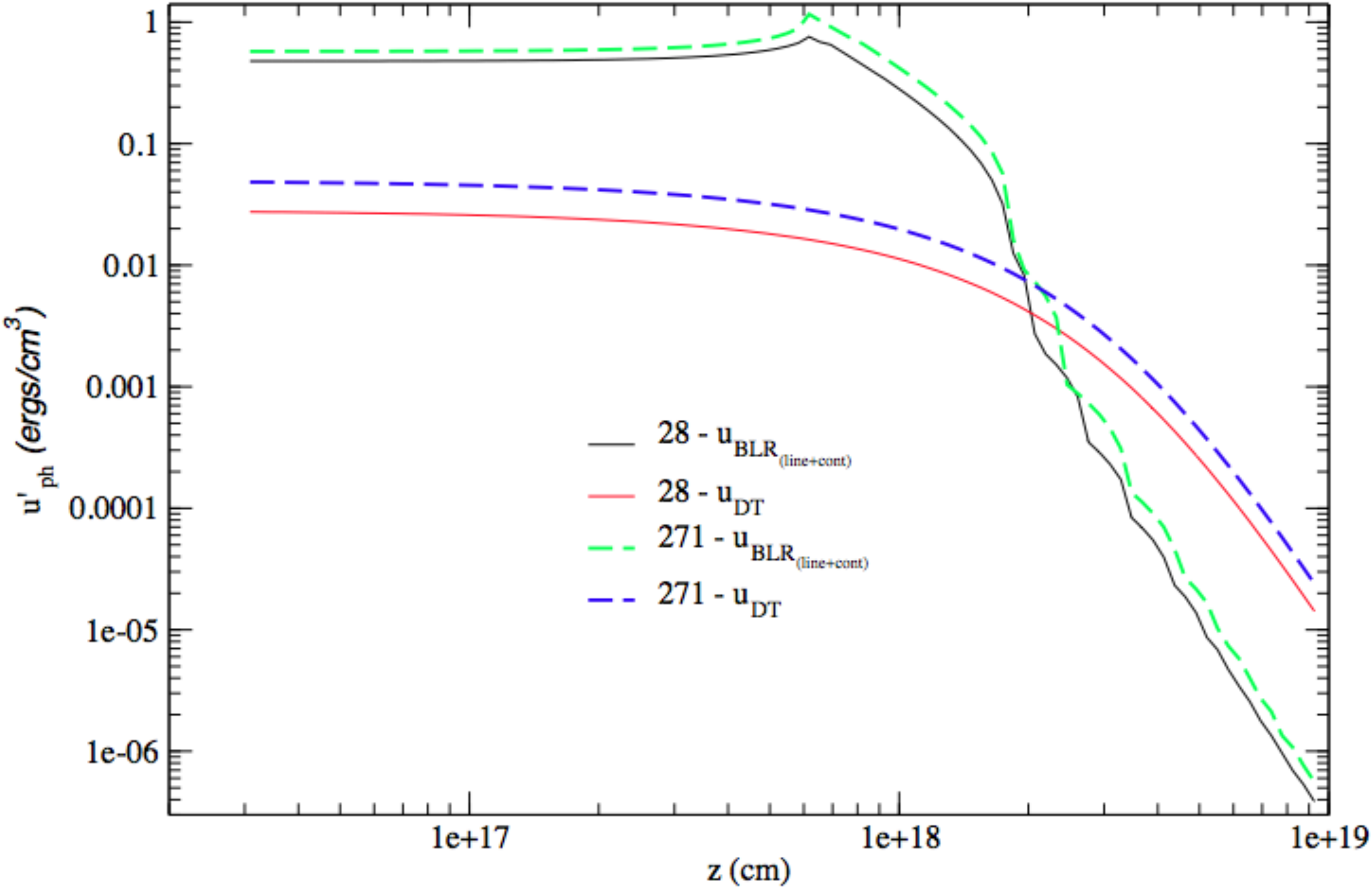

1 - fcov_DT = 0.2
7 - fcov_DT = 0.01
8 - fcov_DT = 0.9
νF_ν [Jy Hz]
1e+14
1e+13
1e+12
1e+11
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]

Summary & Next Steps

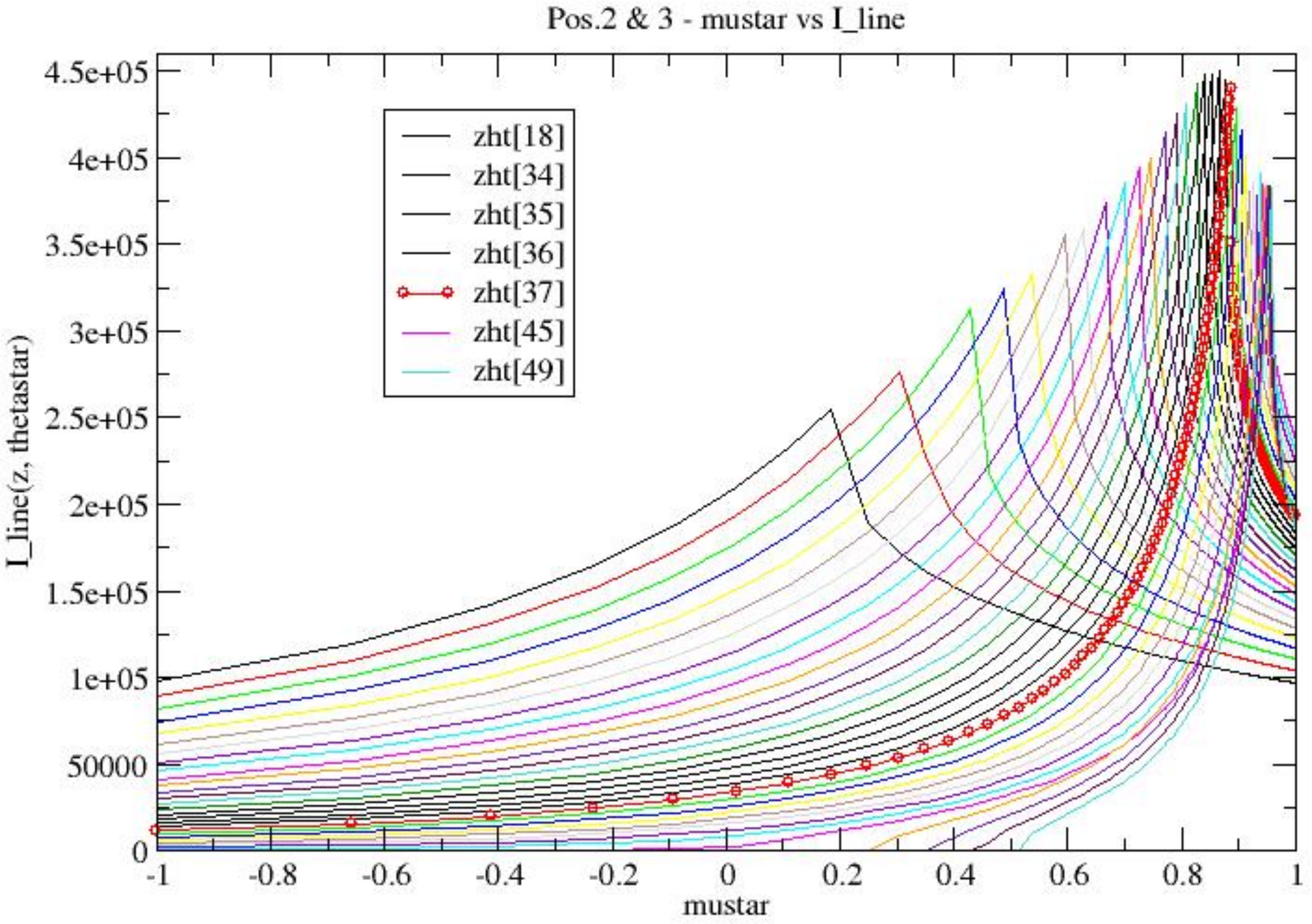
- High energy emission significant from within BLR for this case of FSRQ.
- Anisotropy important for disk, BLR & DT contribution.
- Understanding of source(s) of seed photons:
  - Are there only 3 conventional sources?
  - Could stratification of BLR with various ionization lines originating from different distance resulting in larger size and location of BLR (Stern & Poutanen, 2011) do the trick?
  - Could single emission line cloud along the line of sight of emission region located further out in the jet be responsible?
  - Do we need to get creative with sources of seed photons at pc scales?

contd….

- Careful with generalization of location of γ-ray emission.
- Apply the external Compton model to understand its effect on evolution of e^- energy dist. and resulting SED of blazars.



1
0.1
0.01
0.001
0.0001
1e-05
1e-06
u'_{ph} (ergs/cm^3)
1e+17
1e+18
1e+19
z (cm)
28 - $u_{BLR_{(line+cont)}}$
28 - u_{DT}
271 - $u_{BLR_{(line+cont)}}$
271 - u_{DT}


Pos.2 & 3 - mustar vs I_line
I_line(z, thetastar)
mustar
4.5e+05
4e+05
3.5e+05
3e+05
2.5e+05
2e+05
1.5e+05
1e+05
50000
0
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
zht[18]
zht[34]
zht[35]
zht[36]
zht[37]
zht[45]
zht[49]

Parameter Study

$$L_w = 10^{47} erg/s$$

$$\Gamma_i = 25$$

$$\Gamma_o = 10$$

$$\varepsilon_e = \frac{U_e}{U_{sh}} = 0.5$$

$$\varepsilon_B = \frac{U_B}{U_{sh}} = 0.002$$

$$q = 3.4$$

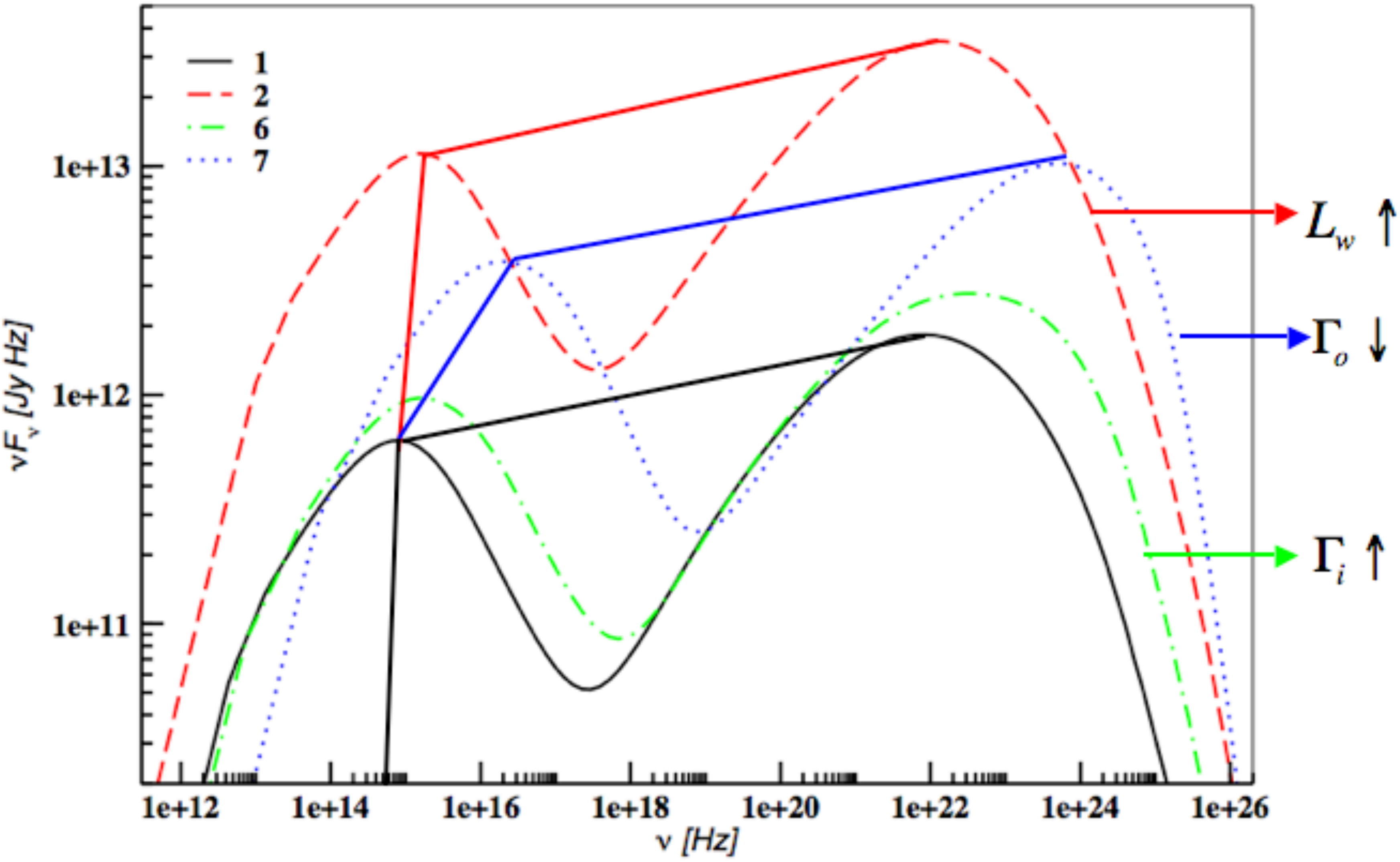
$$R = 3 \times 10^{16} cm$$

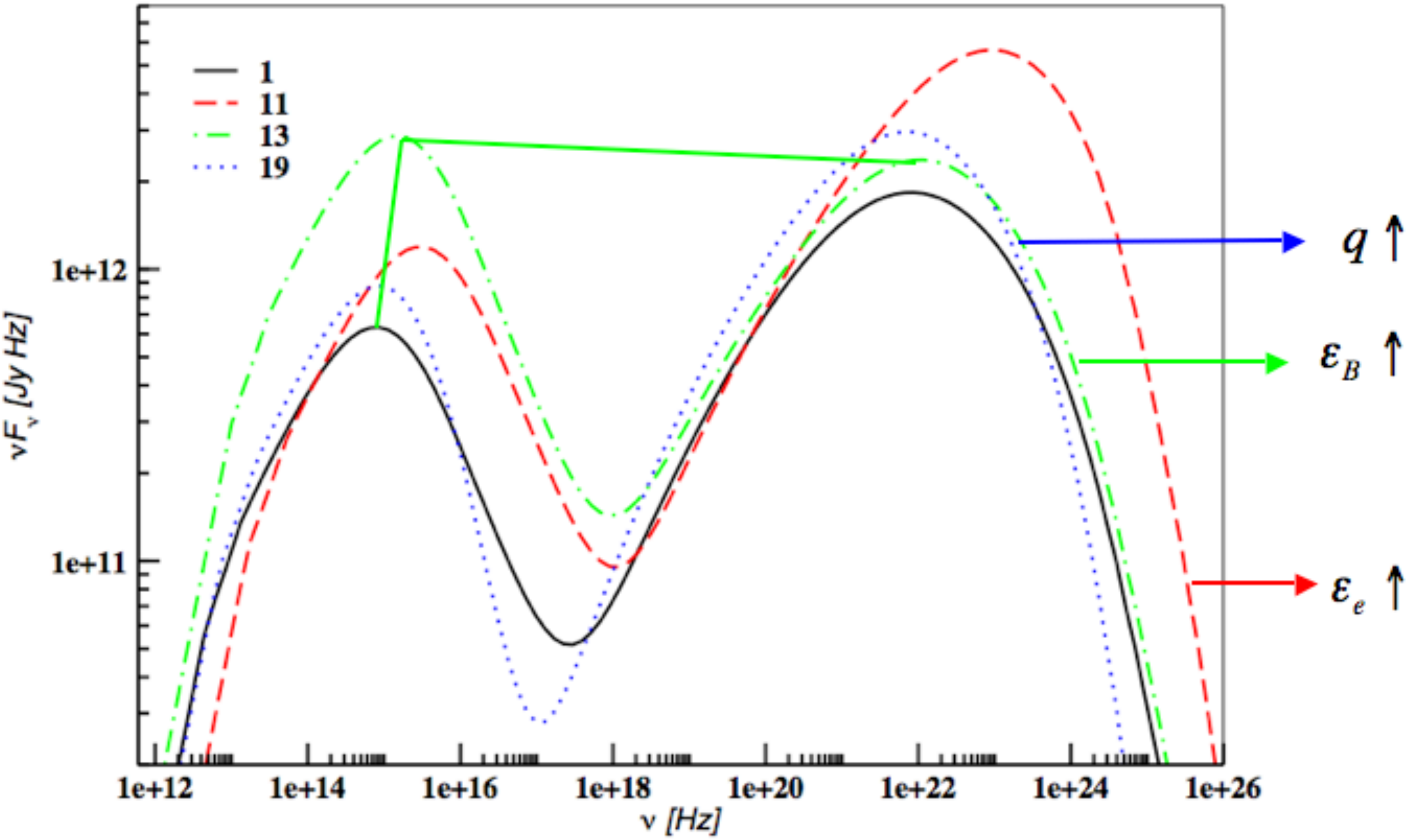
$$B = 2.51G$$

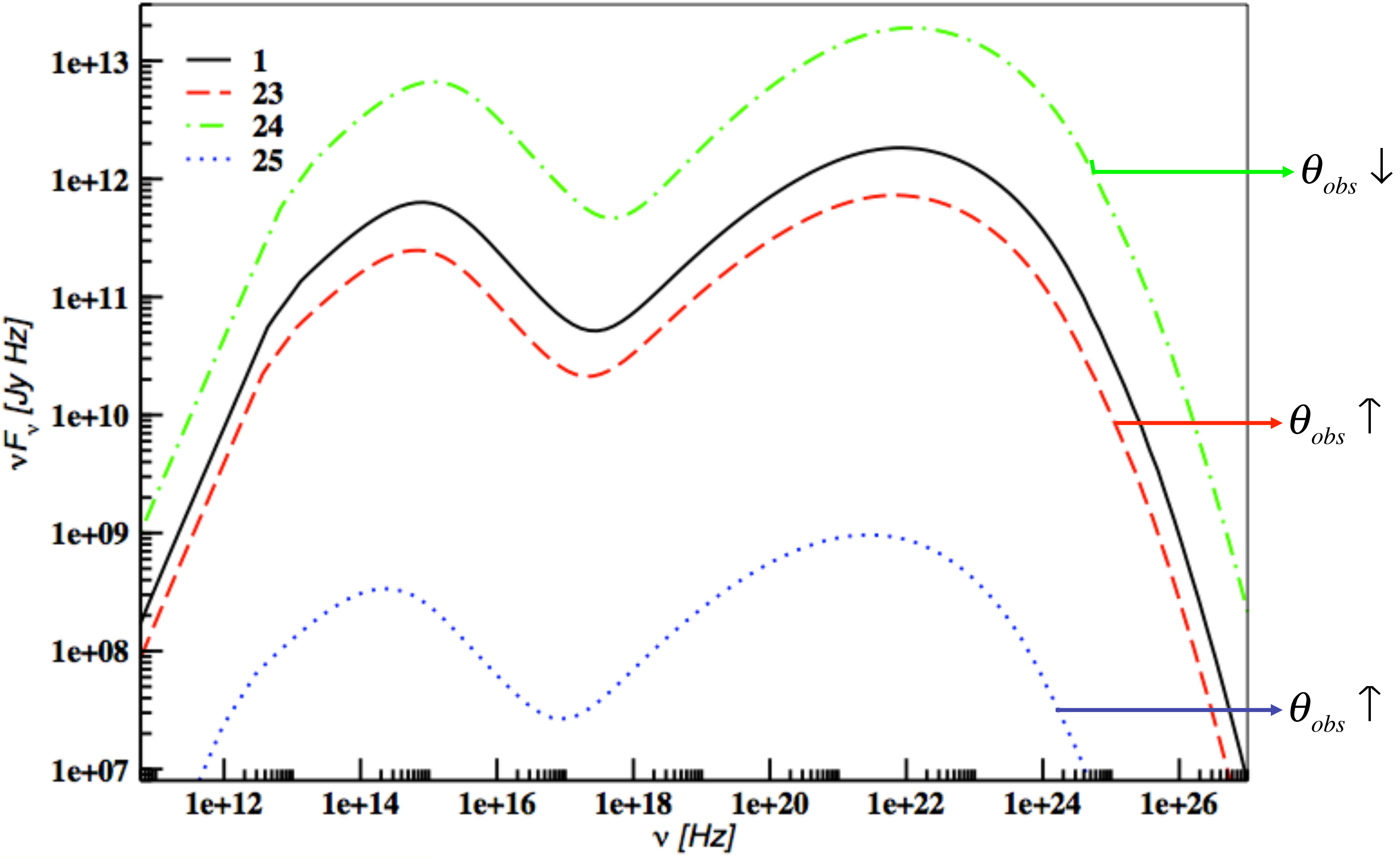
$$\gamma_{\max} = 8.31 \times 10^4$$

$$\gamma_{\min,fs} = 2.18 \times 10^3$$

$$\gamma_{\min,rs} = 3.74 \times 10^3$$


1
2
6
7
1e+13
1e+12
1e+11
νF_ν [Jy Hz]
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]
L_w ↑
Γ_o ↓
Γ_i ↑


1
11
13
19
1e+12
1e+11
νF_ν [Jy Hz]
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]
q ↑
ε_B ↑
ε_e ↑



$\theta_{obs} \downarrow$

$\theta_{obs} \uparrow$

$\theta_{obs} \uparrow$