Theoretical Study Of The Effects Of Magnetic Field Geometry On The High-Energy Emission of Blazars

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Layout

- Motivation
- Goal
- Internal shock scenario & MUZORF
- Magnetic field geometry
  - Parameter Study
- Future Work

Motivation

- Phenomena near black holes => understanding of the structure of the magnetic field (B) & particle acceleration.
- Many bright ϒ-ray blazars show variations in both their flux and linear polarization (Gabuzda et al., 2006, MNRAS).
- Degree of polarization usually higher at optical than at radio frequencies => originating from smaller volumes with more uniform Bs than the ones responsible for radio emission.
- Knowledge of the structure of the B inside a blazar jet, as deduced from polarization observations at radio to optical wavelengths, closely related to the formation and propagation of relativistic jets.
- Yet B-geometry - largely unexplored aspect of blazar jet emission physics models (Lyutikov et al. (2005), Jamil & Boettcher (2012), Chen et al. (2014), Zhang & Boettcher (2013)).

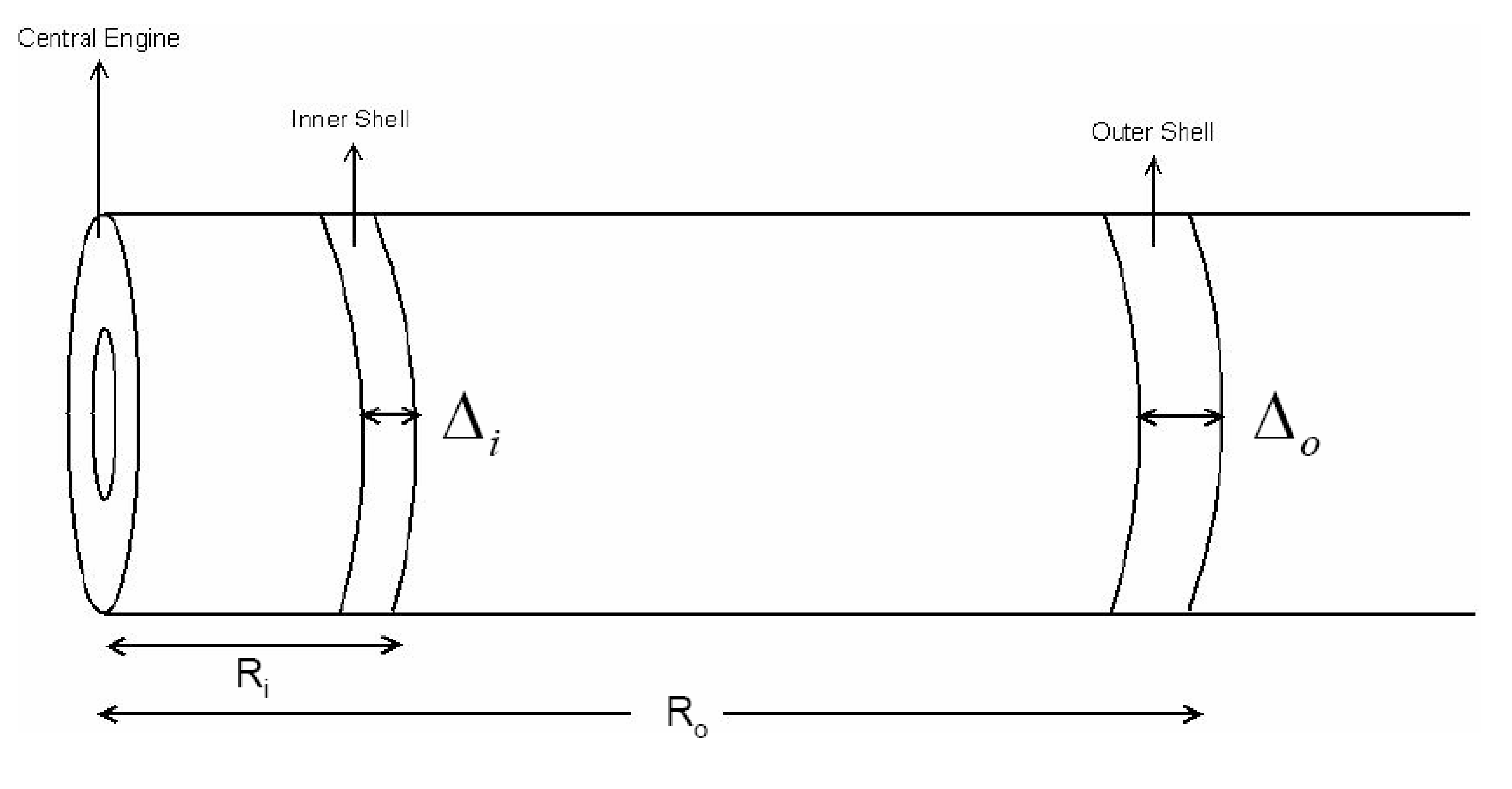
Goal

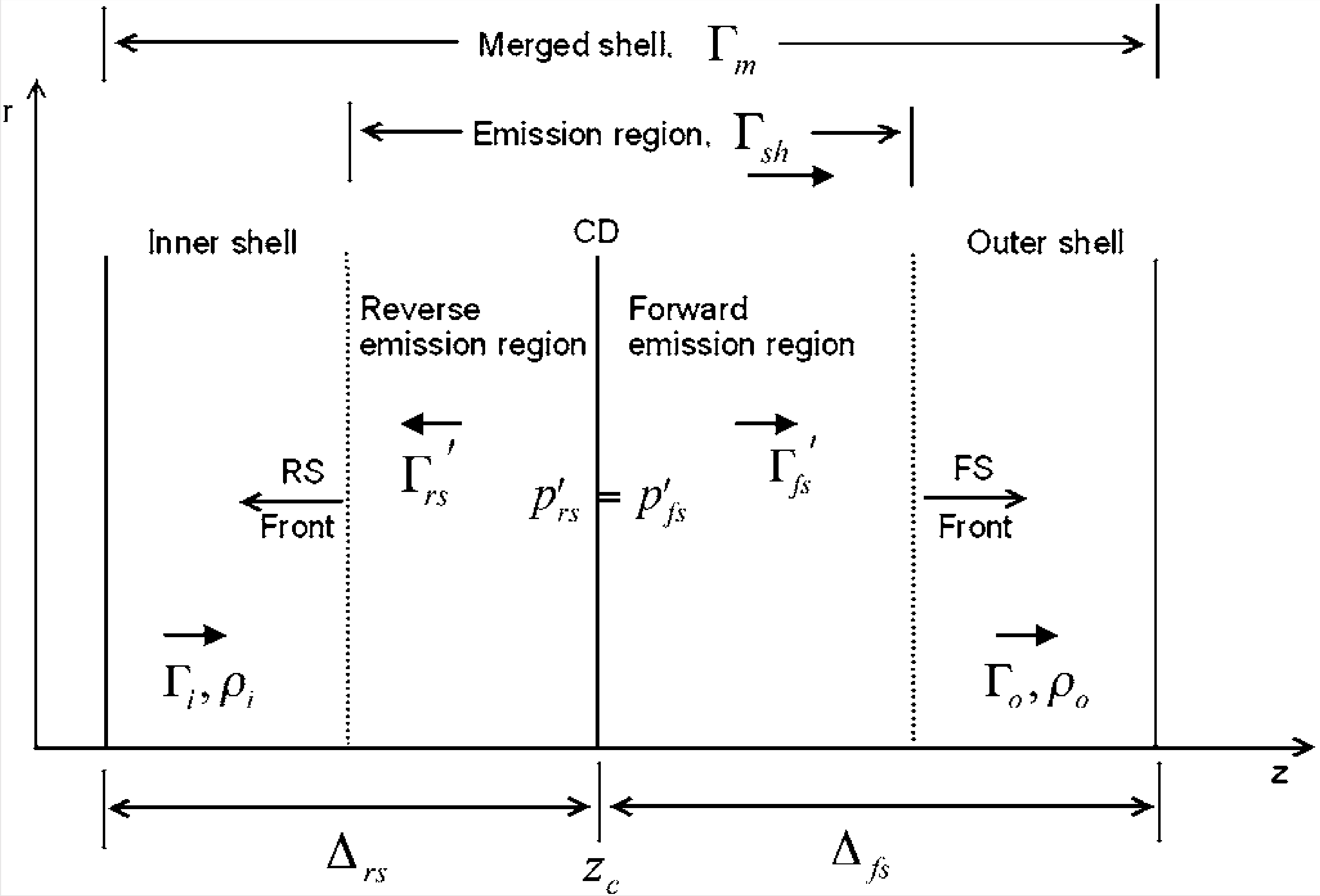
- Consider various magnetic geometries that can exist inside a blazar jet: parallel, transverse, oblique, toroidal, helical, and tangled.
- Investigate the effects of changing each of these orientations on the resulting high-energy (HE) spectral energy distributions (SEDs), spectral variability patterns (SVPs), and spectral hysteresis of a typical blazar.
- Use the MUlti-ZOne Radiation Feedback (MUZORF) model of Joshi et al. (2014) to carry out this study & relate the B-geometry, as indicated by multiwavelength polarization monitoring campaigns, to the observed HE SEDs and SVPs.

Internal Shock Scenario – Basic Assumptions

- Central engine (Black hole + accretion disk) ejects relativistic shells of plasma with different mass, energy, & velocity intermittently into the jet.
- Faster inner shells, closer to central engine, catch up with slower outer shells.
- Undergo inelastic collision to produce internal shocks.
- These shocks accelerate particles, which then radiate.

$$\delta t = \frac{R_o - R_i - \Delta_i}{c(\beta_i - \beta_o)}$$





Three frames:

1. AGN (lab) frame – non-primed quantities.
2. Plasma frame (comoving frame of shocked fluid) – primed quantities.
3. Unshocked fluid frame – quantities with an overline (not shown here) but:

$$\bar{\rho} = \frac{\rho}{\Gamma}$$

Shocks propagate => emission regions keep increasing until shocks hit their respective boundaries of the merged shell.

Multi-zone Radiation Feedback (MUZORF)

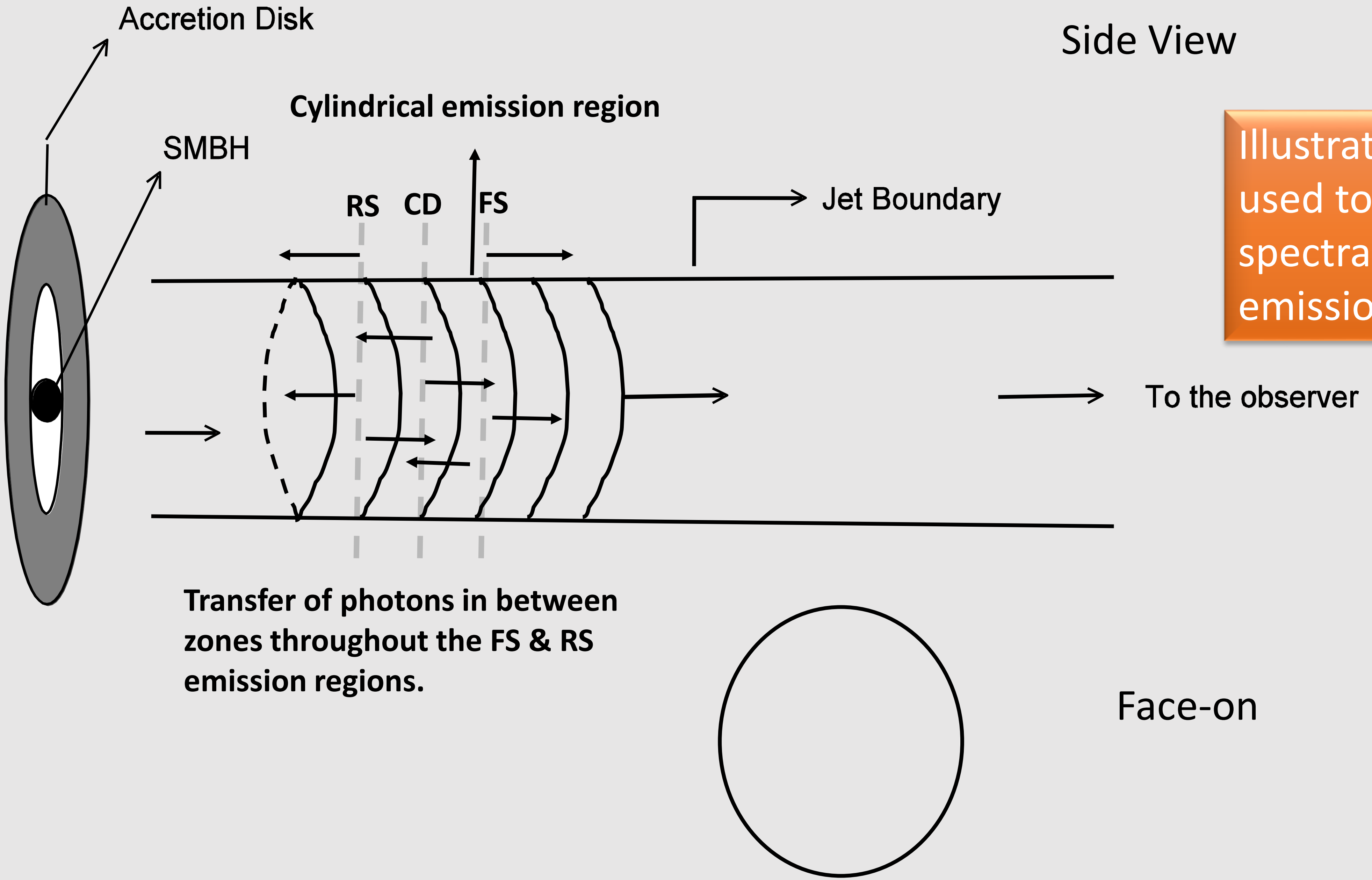


Illustration of the scheme used to calculate radiation spectra resulting from the emission regions.

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

Disk + BLR + DT Schematic

Joshi, Marscher & Boettcher, 2014, ApJ, 785, 132

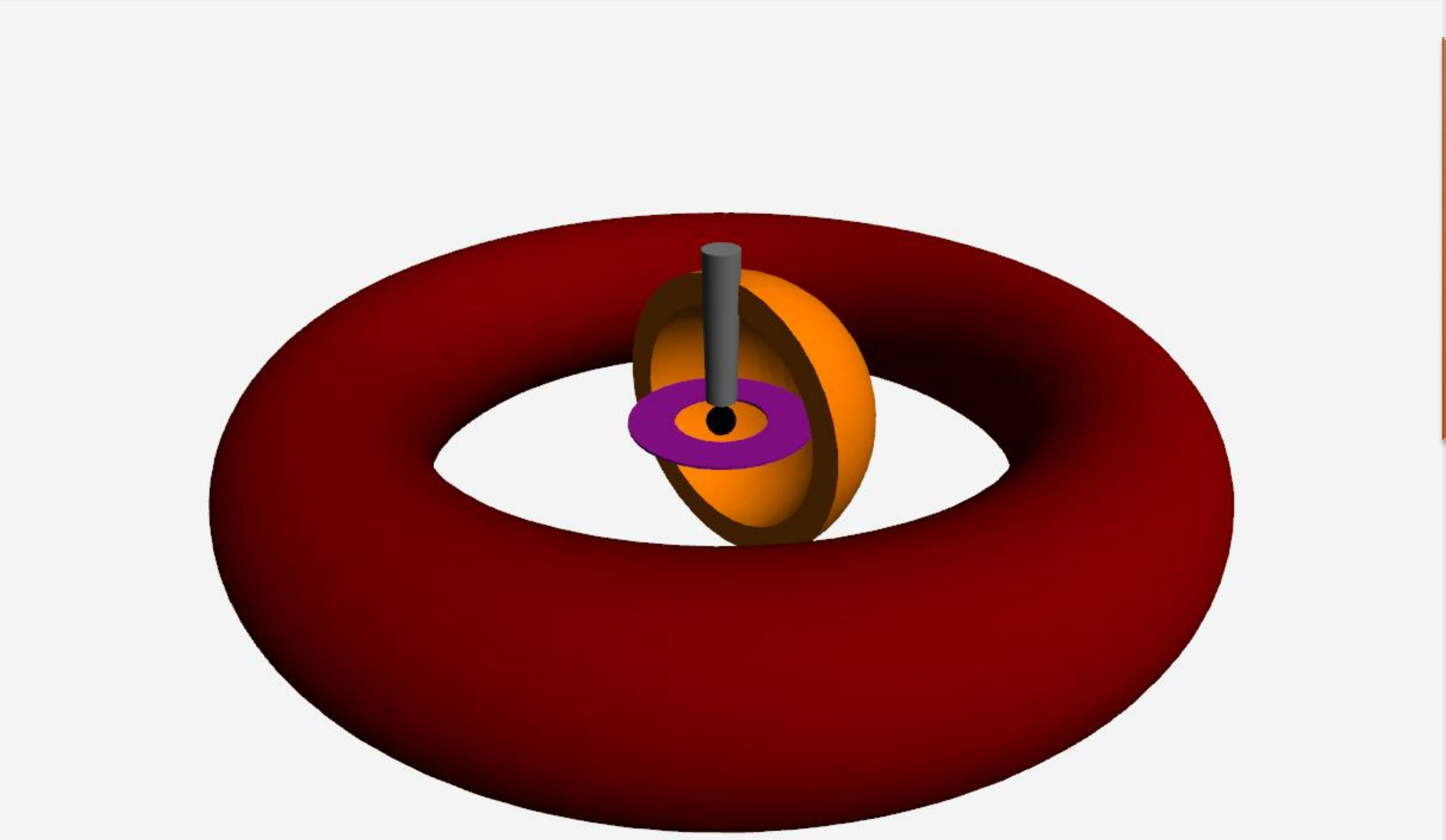


Illustration of the three sources of external radiation influencing the high-energy emission from a blazar jet.

Magnetic Field Geometry

- Step 1 – Include the angle between B and photon direction, corrected for relativistic aberration, in the calculation of synchrotron emission coefficient: $j'_{\nu} \propto (B' \, sin\chi')^{(1+\,\alpha)}$; α = photon energy spectral index.
- Step 2 – calculate the above dependence for various orientations, parallel, transverse, oblique, toroidal, & helical, by obtaining $\widehat{n'} \cdot \widehat{B'}$ product in emission region frame (comoving frame) .
- Step 3 – calculate the corresponding SSC emission resulting from the modified synchrotron emission due to each of these geometries.
- Step 4 – analyze the effects on the resulting SEDs and SVPs.
- Step 5 – fit the actual data….

Relevant Expressions – B-field orientation wrt z-axis in comoving frame

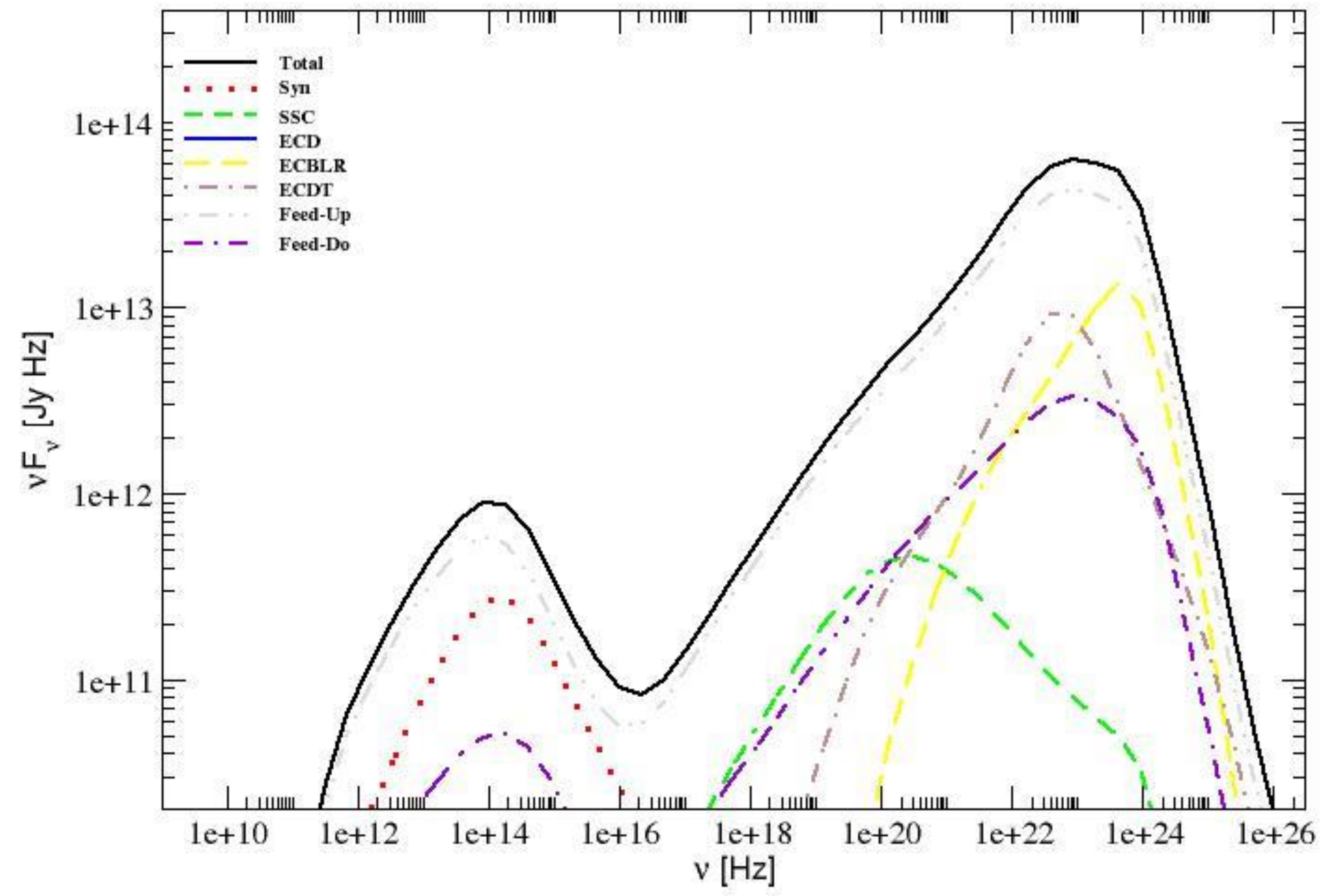
- Parallel: $\sin\chi' = D\sin\theta_{obs}$ - Dependence on Doppler factor & observing angle
- Transverse: $\sin\chi' = \sqrt{1 - (D\sin\theta_{obs}\ \cos\phi'_{xy})^2}$ - Dependence on the angle in the x-y plane
- Oblique: $\sin\chi' =$ $\sqrt{1 - D^2\left[\sin\theta_{obs}\ \sin\psi'_z\ \cos\phi'_{xy} + \Gamma\ \cos\psi'_z\left(\cos\theta_{obs} - \beta\right)\right]^2}$ - Dependence on the angle with z-axis

contd…

- Toroidal: $\sin\chi' = \sqrt{1 - (D\sin\theta_{obs}\ \sin\phi')^2}$ - Dependence on azimuthal angle

- Helical: $\sin\chi' = \sqrt{1 - D^2\left[\Gamma\ \cos\psi'_z\left(\cos\theta_{obs} - \beta\right) - \sin\theta_{obs}\ \sin\psi'_z\ \sin\phi'\right]^2}$ - Dependence on combination of azimuthal angle and angle with z-axis

Parameter Study:



Base Set – Generic blazar with input parameters (Z, D, Γ, θ_{obs}etc.) corresponding to that of 3C454.3

Tangled B-field

Input Parameters:

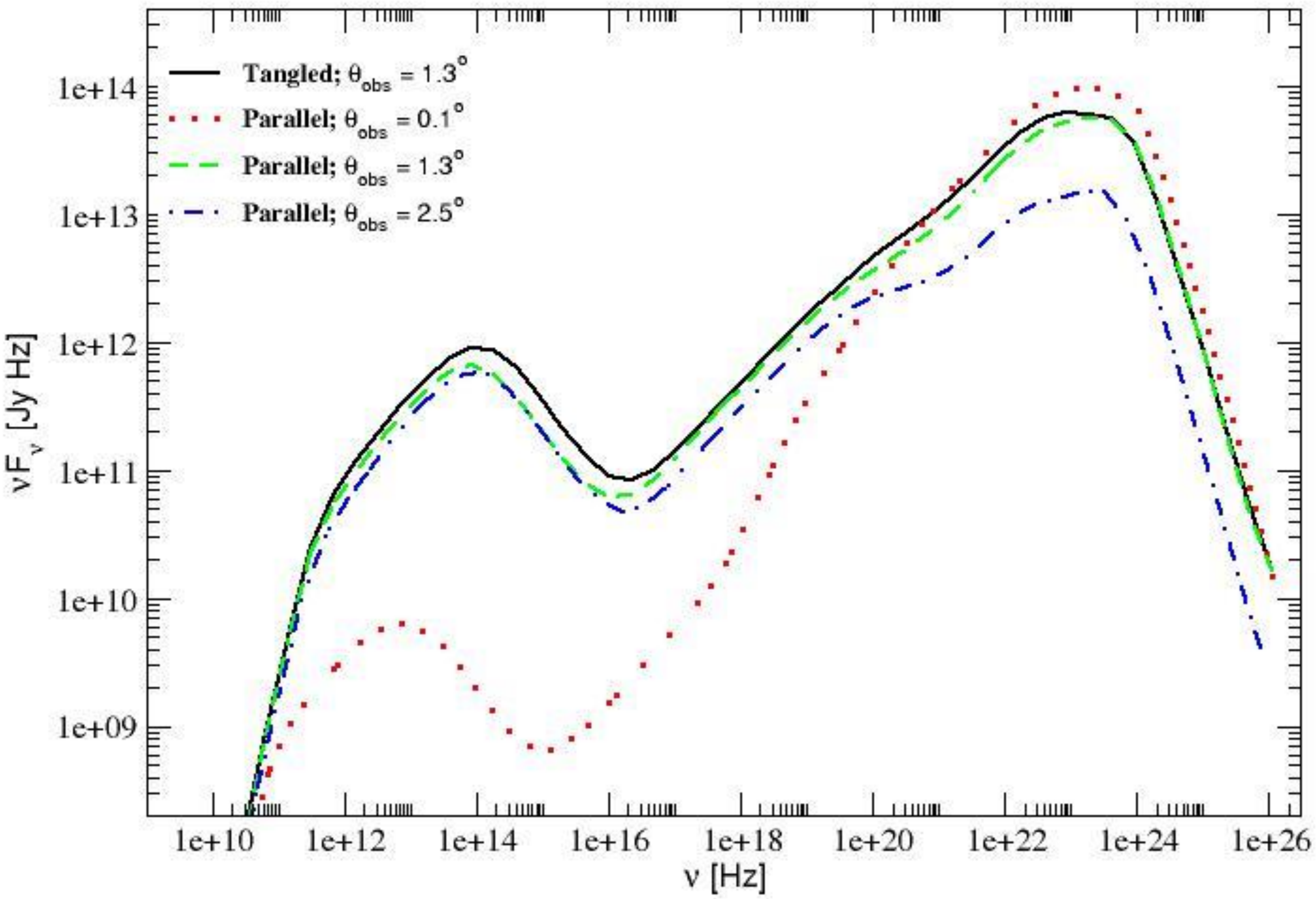
$$\theta_{obs} = 1.3^0;\ \Gamma = 16; D = 28$$
$$L_{kin} = 10^{48}\frac{erg}{s}; Z = 0.859$$

$z_c = 1.2 \times 10^{17}$cm = 0.04 pc

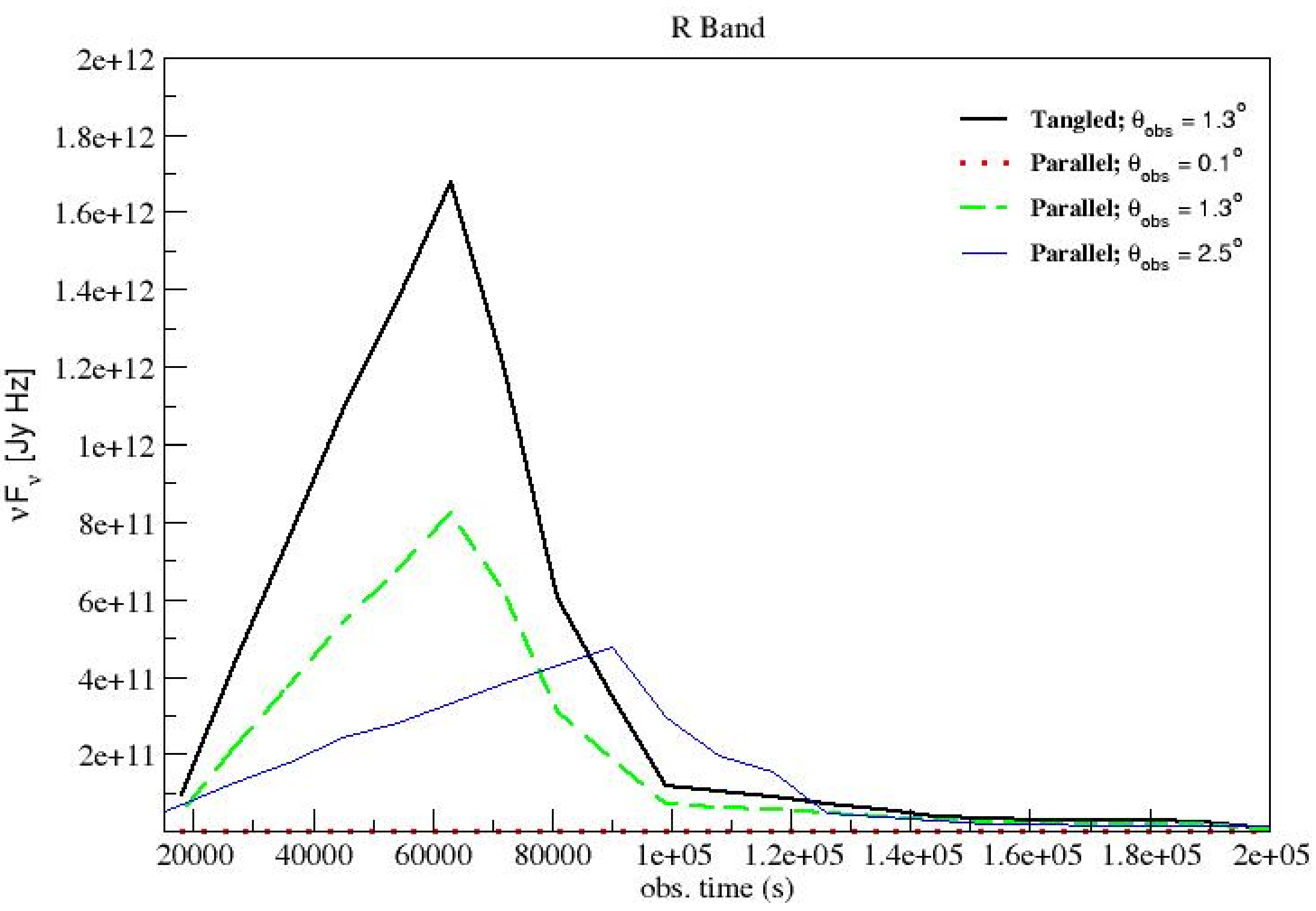
$$\gamma_{min} = 1.12 \times 10^3;$$
$$\gamma_{max} = 3.9 \times 10^4$$

B = 1.43G

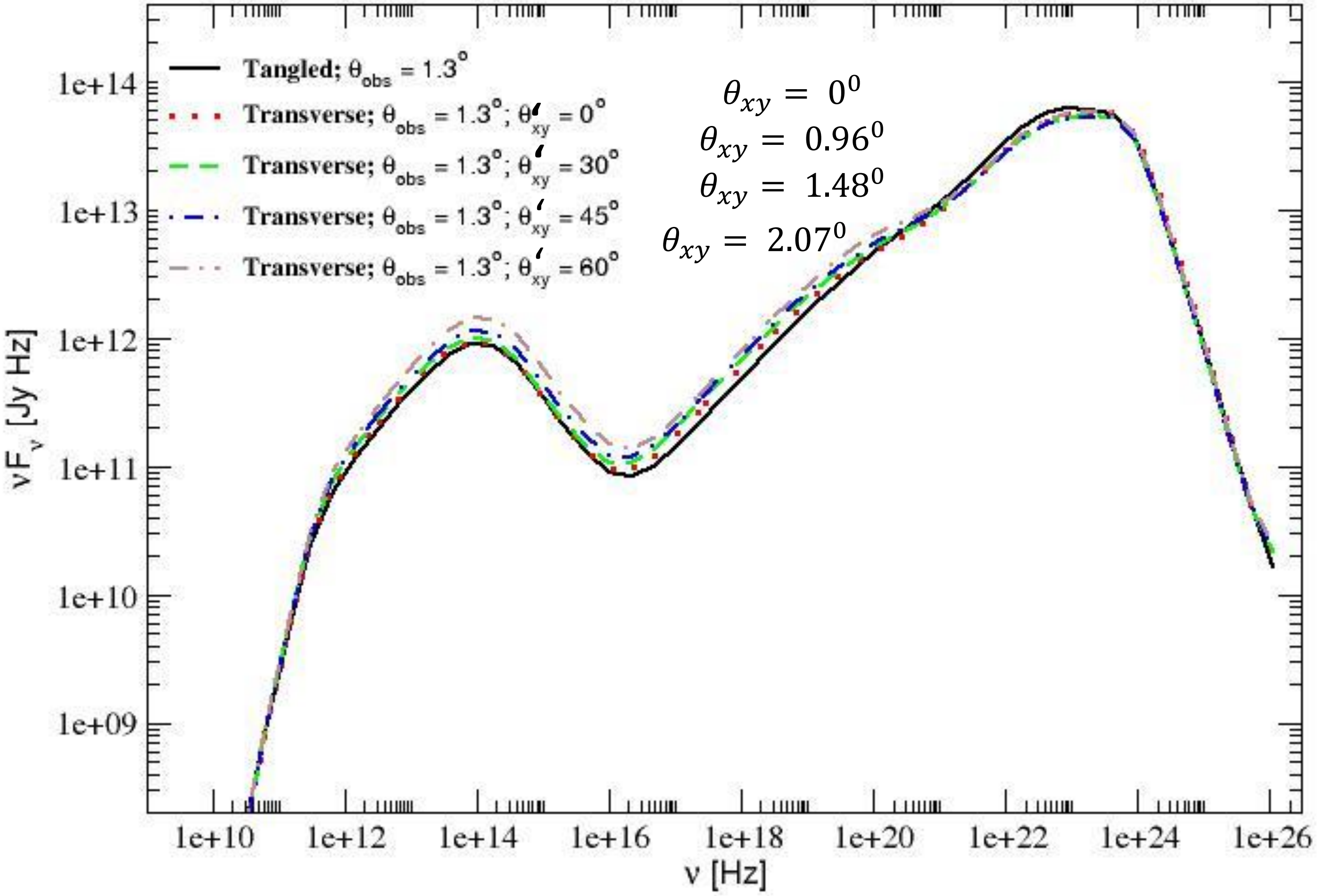
$$\theta_{obs} = \frac{1}{\Gamma} = 3.6^0$$



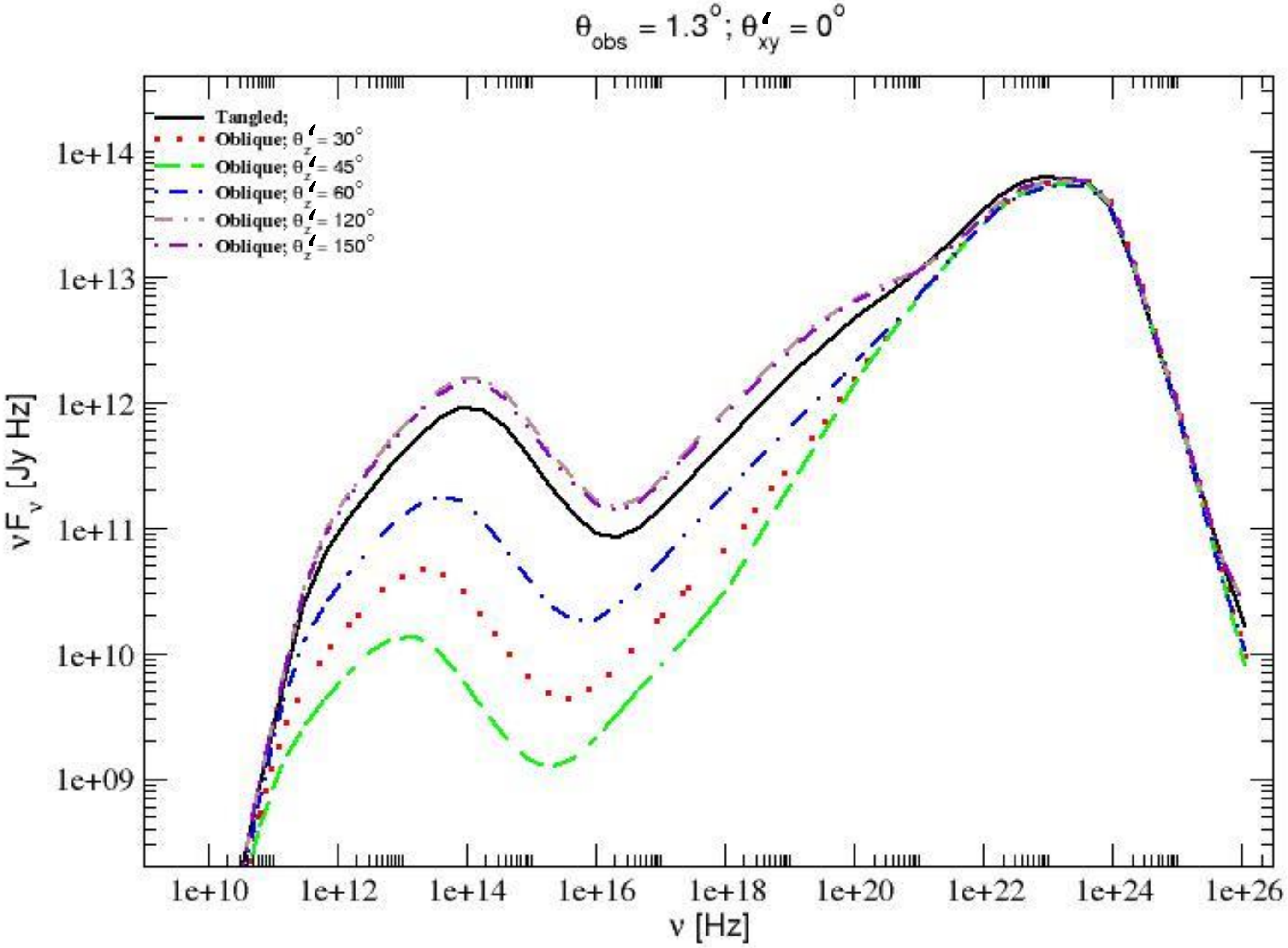
Tangled; θ_{obs} = 1.3°
Parallel; θ_{obs} = 0.1°
Parallel; θ_{obs} = 1.3°
Parallel; θ_{obs} = 2.5°
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
νF_ν [Jy Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]



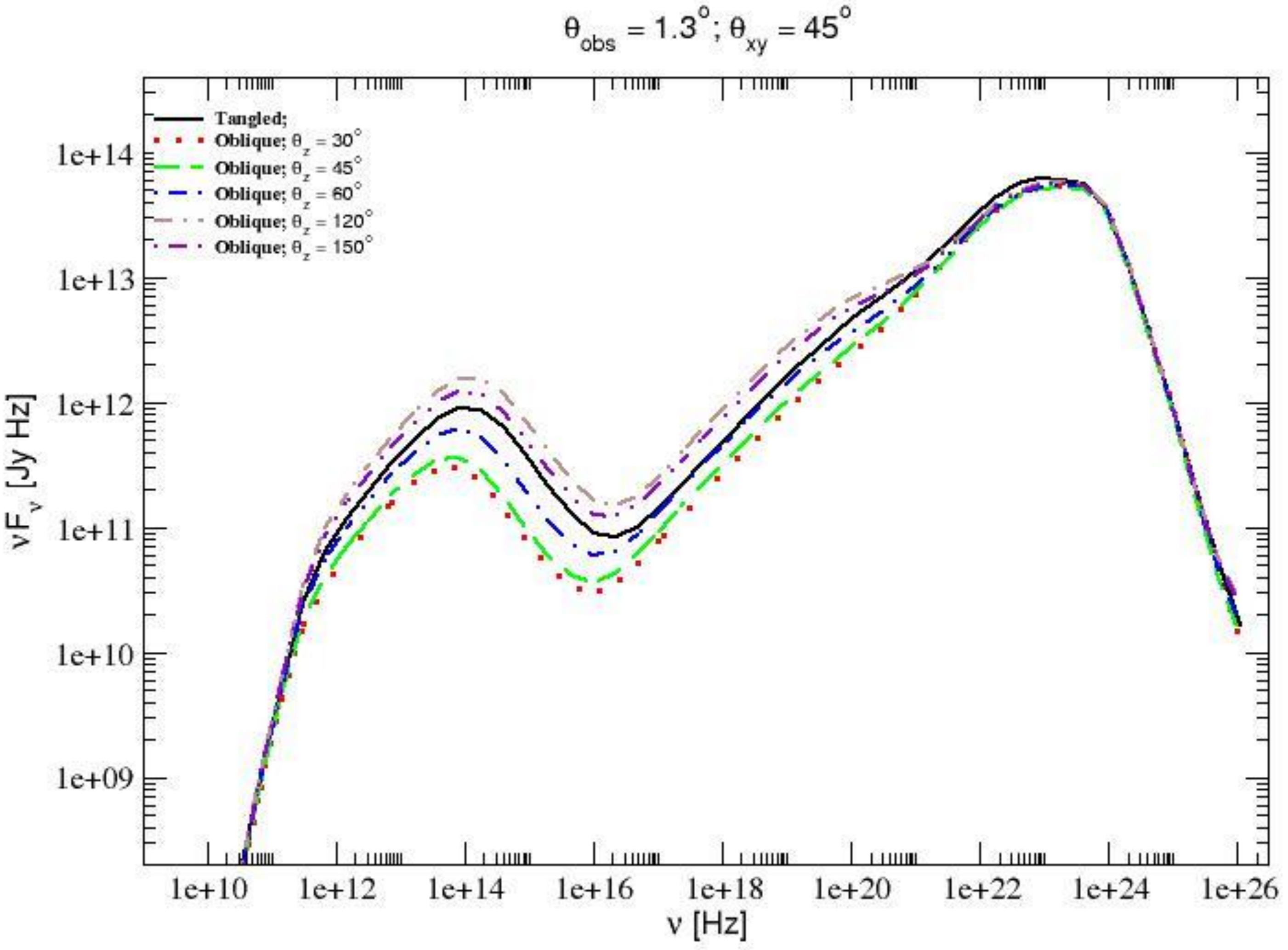
R Band
Tangled; θ_{obs} = 1.3°
Parallel; θ_{obs} = 0.1°
Parallel; θ_{obs} = 1.3°
Parallel; θ_{obs} = 2.5°
νF_ν [Jy Hz]
obs. time (s)
2e+12
1.8e+12
1.6e+12
1.4e+12
1.2e+12
1e+12
8e+11
6e+11
4e+11
2e+11
20000
40000
60000
80000
1e+05
1.2e+05
1.4e+05
1.6e+05
1.8e+05
2e+05



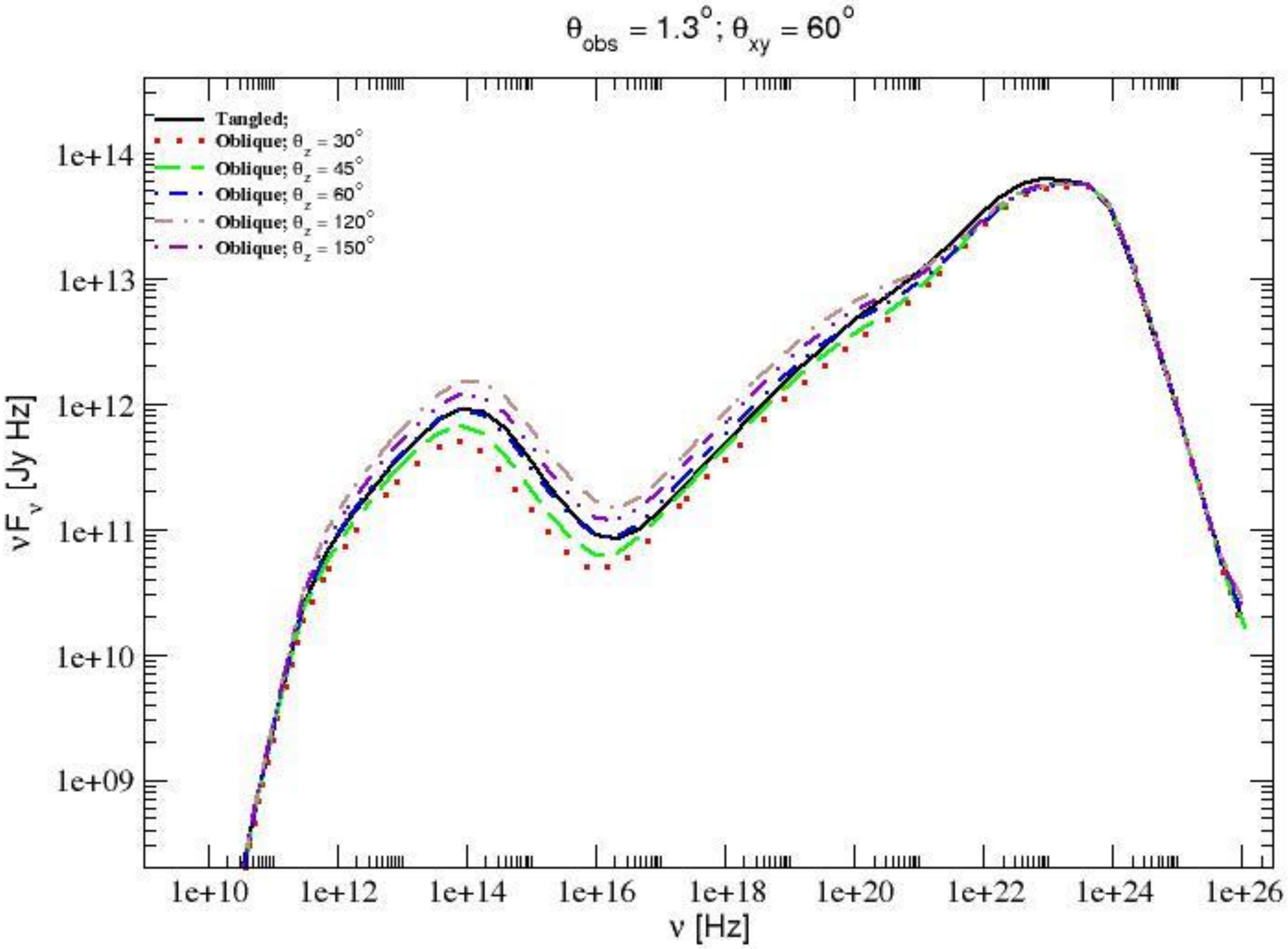
Tangled; θobs = 1.3°
Transverse; θobs = 1.3°; θ'xy = 0°
Transverse; θobs = 1.3°; θ'xy = 30°
Transverse; θobs = 1.3°; θ'xy = 45°
Transverse; θobs = 1.3°; θ'xy = 60°
$\theta_{xy} = 0^0$
$\theta_{xy} = 0.96^0$
$\theta_{xy} = 1.48^0$
$\theta_{xy} = 2.07^0$
νFν [Jy Hz]
ν [Hz]
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26



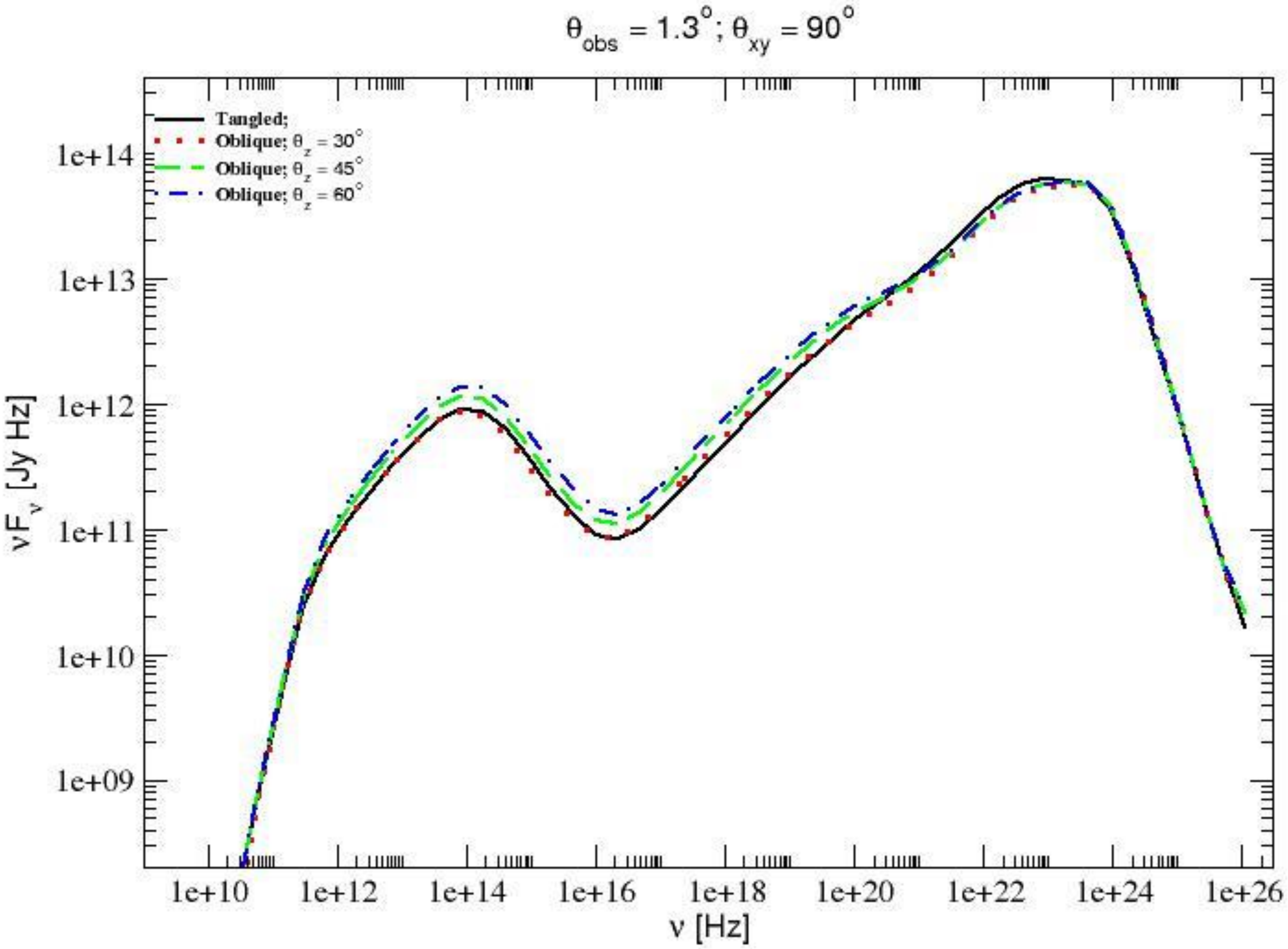
θobs = 1.3°; θ'xy = 0°
Tangled;
Oblique; θ'z = 30°
Oblique; θ'z = 45°
Oblique; θ'z = 60°
Oblique; θ'z = 120°
Oblique; θ'z = 150°
νFν [Jy Hz]
ν [Hz]
1e+09
1e+10
1e+11
1e+12
1e+13
1e+14
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26



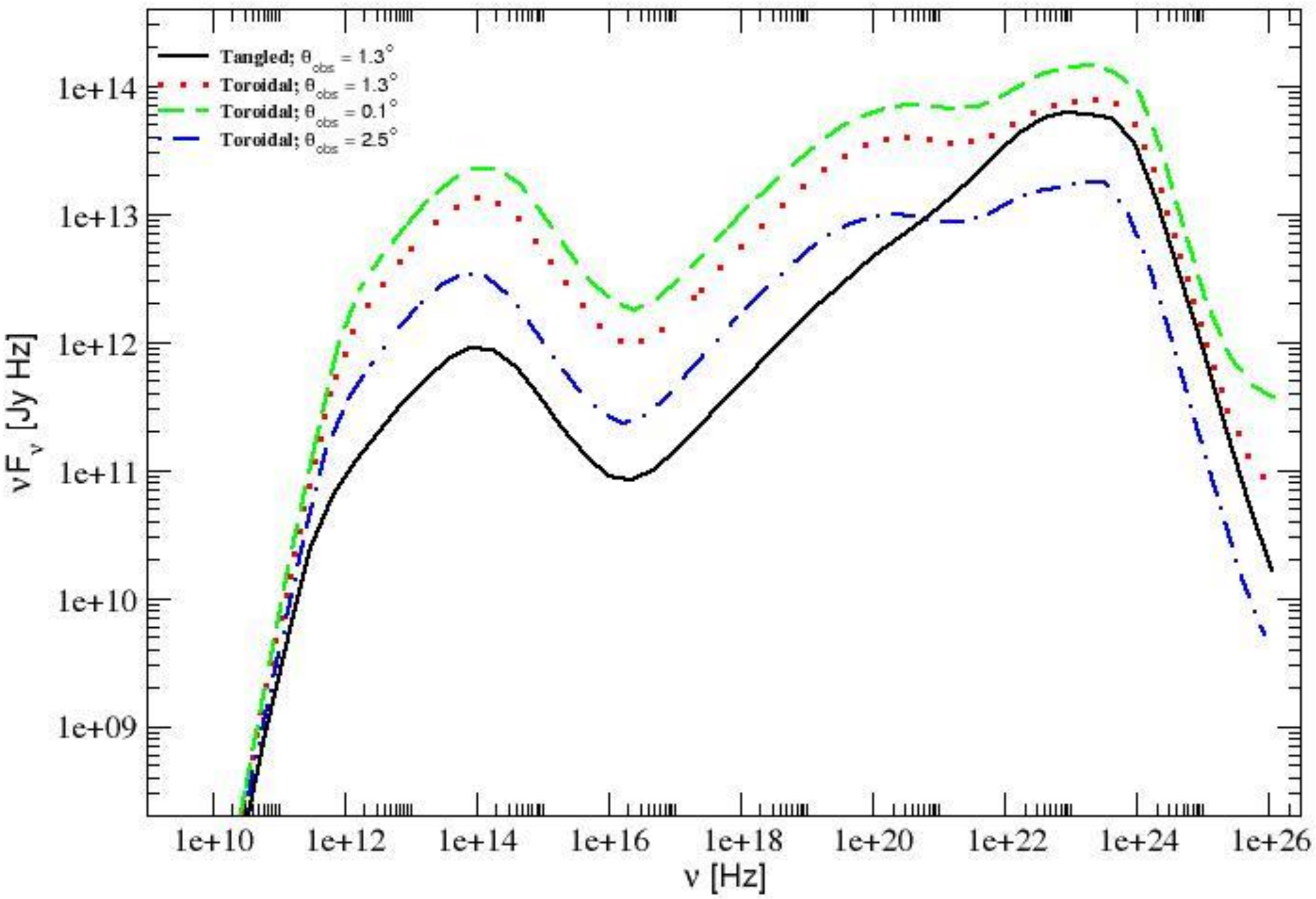
θ_{obs} = 1.3°; θ_{xy} = 45°
Tangled;
Oblique; θ_z = 30°
Oblique; θ_z = 45°
Oblique; θ_z = 60°
Oblique; θ_z = 120°
Oblique; θ_z = 150°
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
νF_ν [Jy Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]

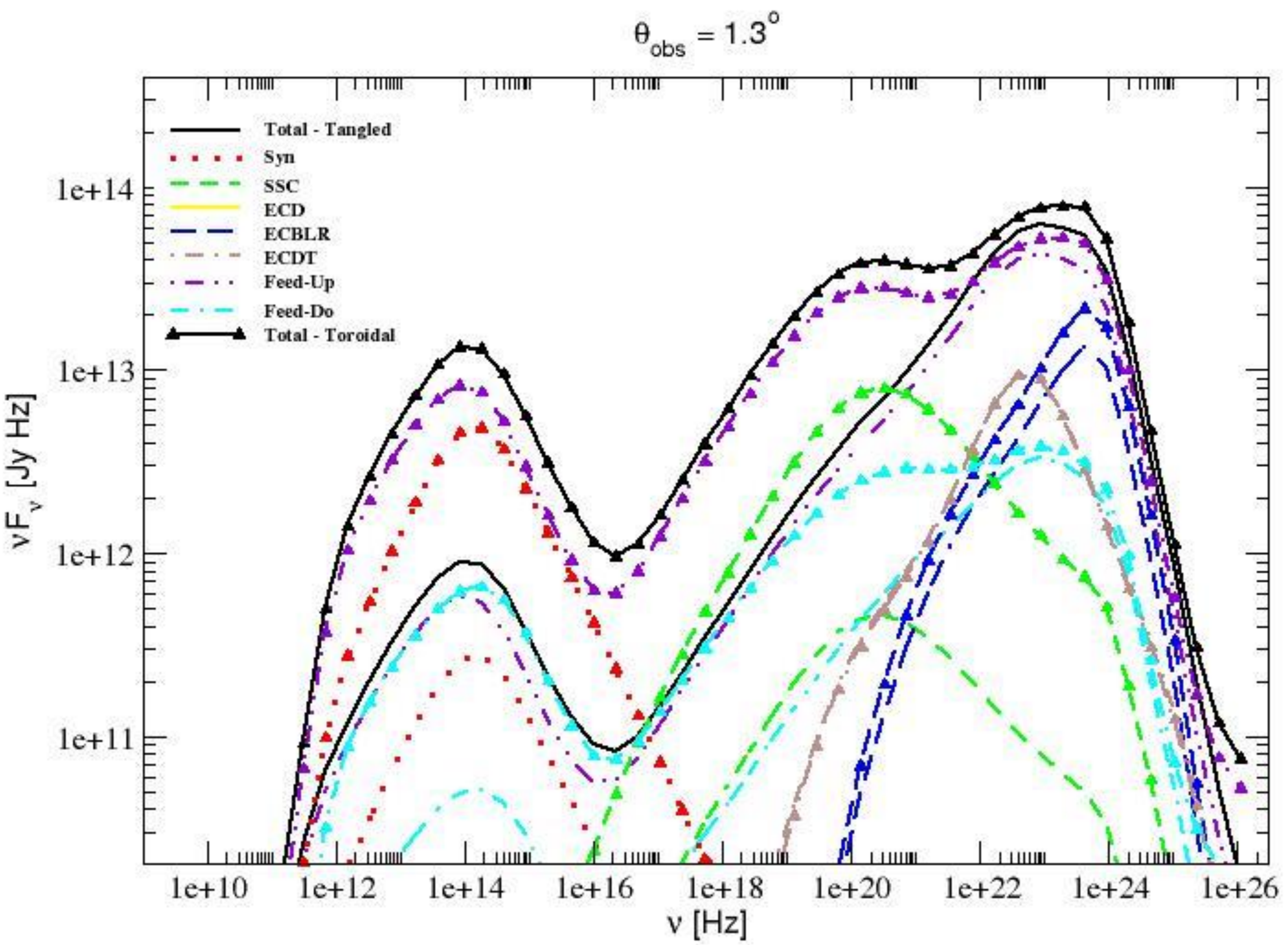


$\theta_{obs} = 1.3^\circ; \theta_{xy} = 60^\circ$
Tangled;
Oblique; $\theta_z = 30^\circ$
Oblique; $\theta_z = 45^\circ$
Oblique; $\theta_z = 60^\circ$
Oblique; $\theta_z = 120^\circ$
Oblique; $\theta_z = 150^\circ$
νF_ν [Jy Hz]
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]

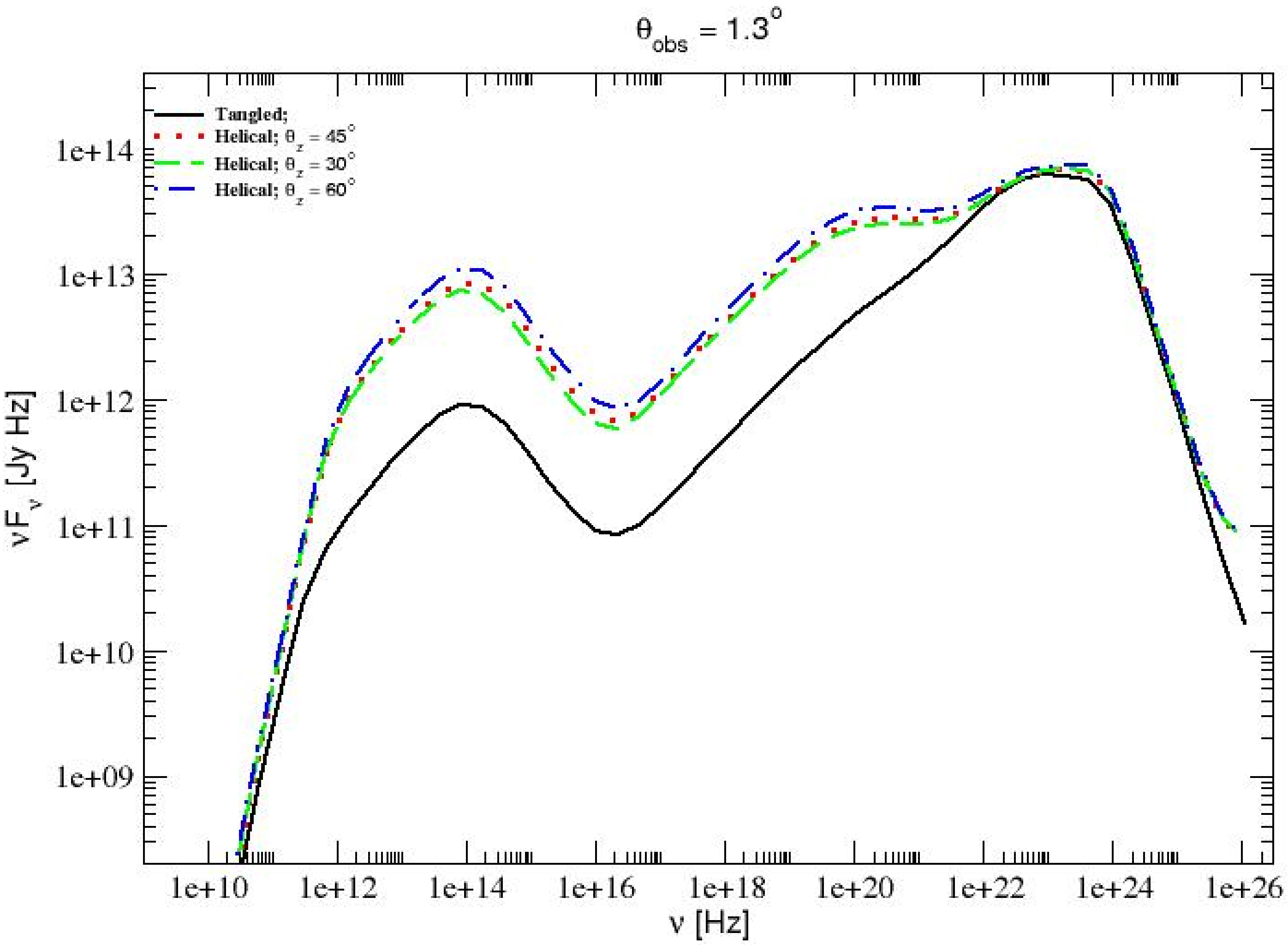


θobs = 1.3°; θxy = 90°
Tangled;
Oblique; θz = 30°
Oblique; θz = 45°
Oblique; θz = 60°
νFν [Jy Hz]
ν [Hz]
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26

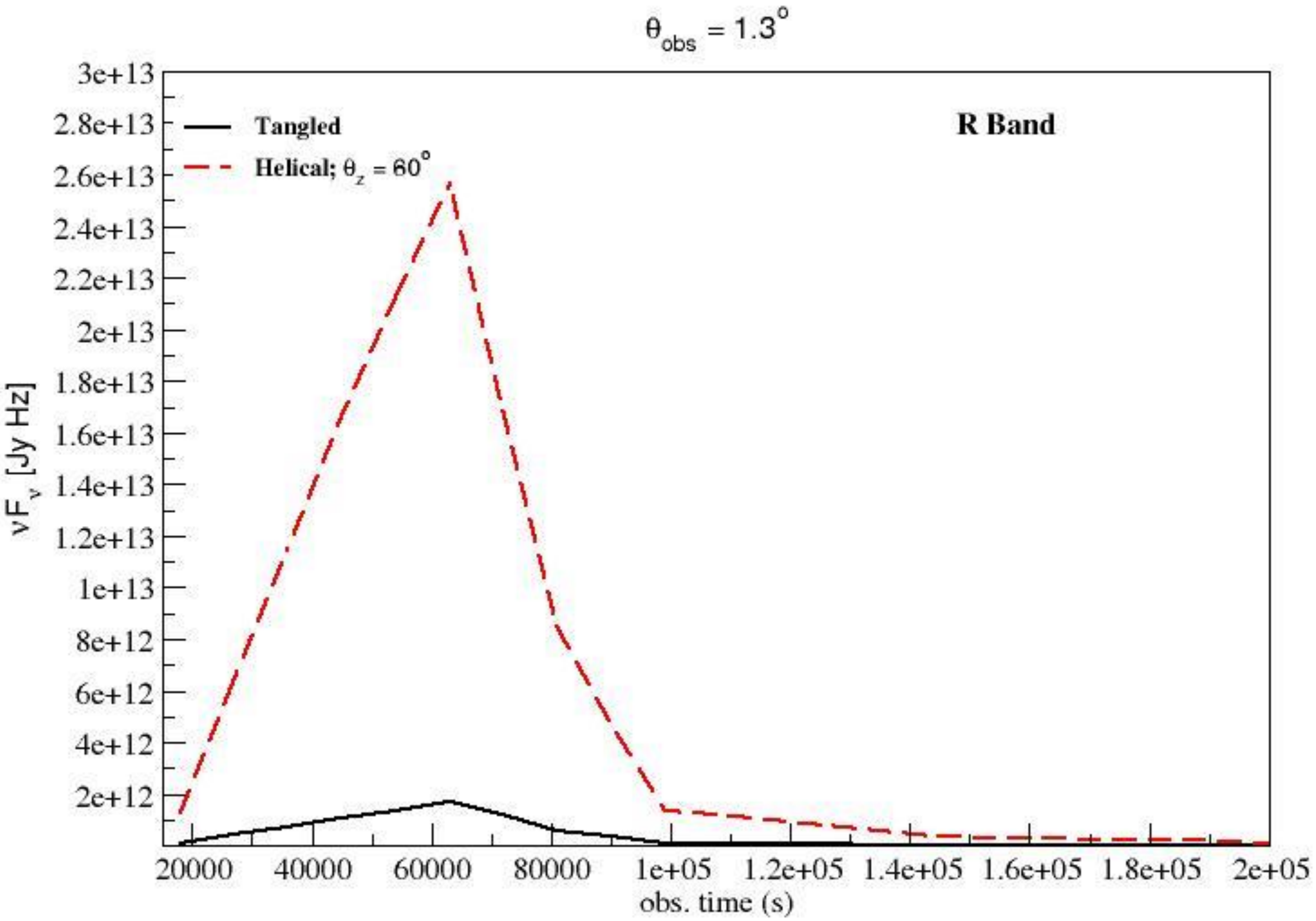

Tangled; θobs = 1.3°
Toroidal; θobs = 1.3°
Toroidal; θobs = 0.1°
Toroidal; θobs = 2.5°
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
νFν [Jy Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]



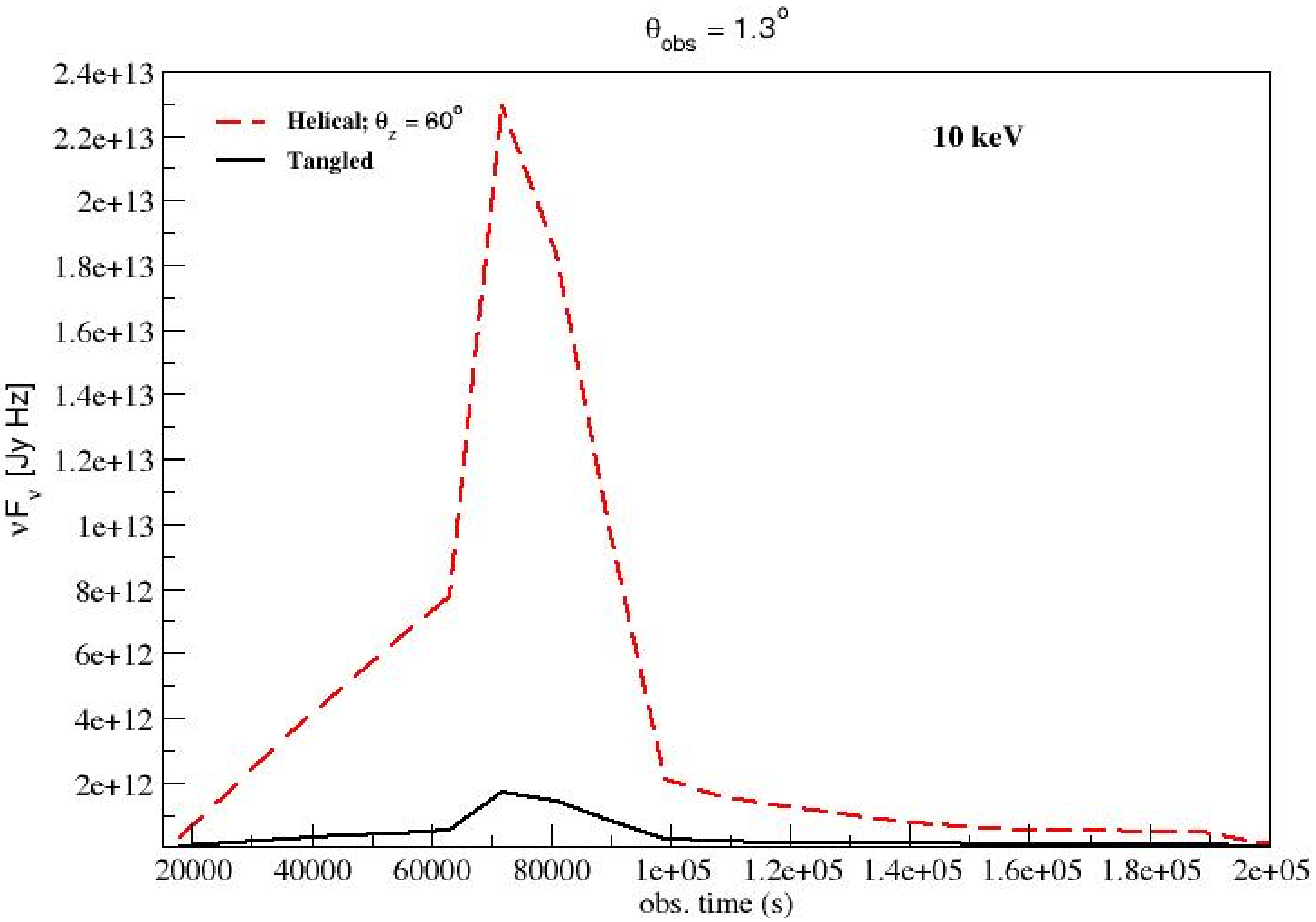
$\theta_{obs} = 1.3^{o}$
Total - Tangled
Syn
SSC
ECD
ECBLR
ECDT
Feed-Up
Feed-Do
Total - Toroidal
1e+14
1e+13
1e+12
1e+11
νF_{ν} [Jy Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]



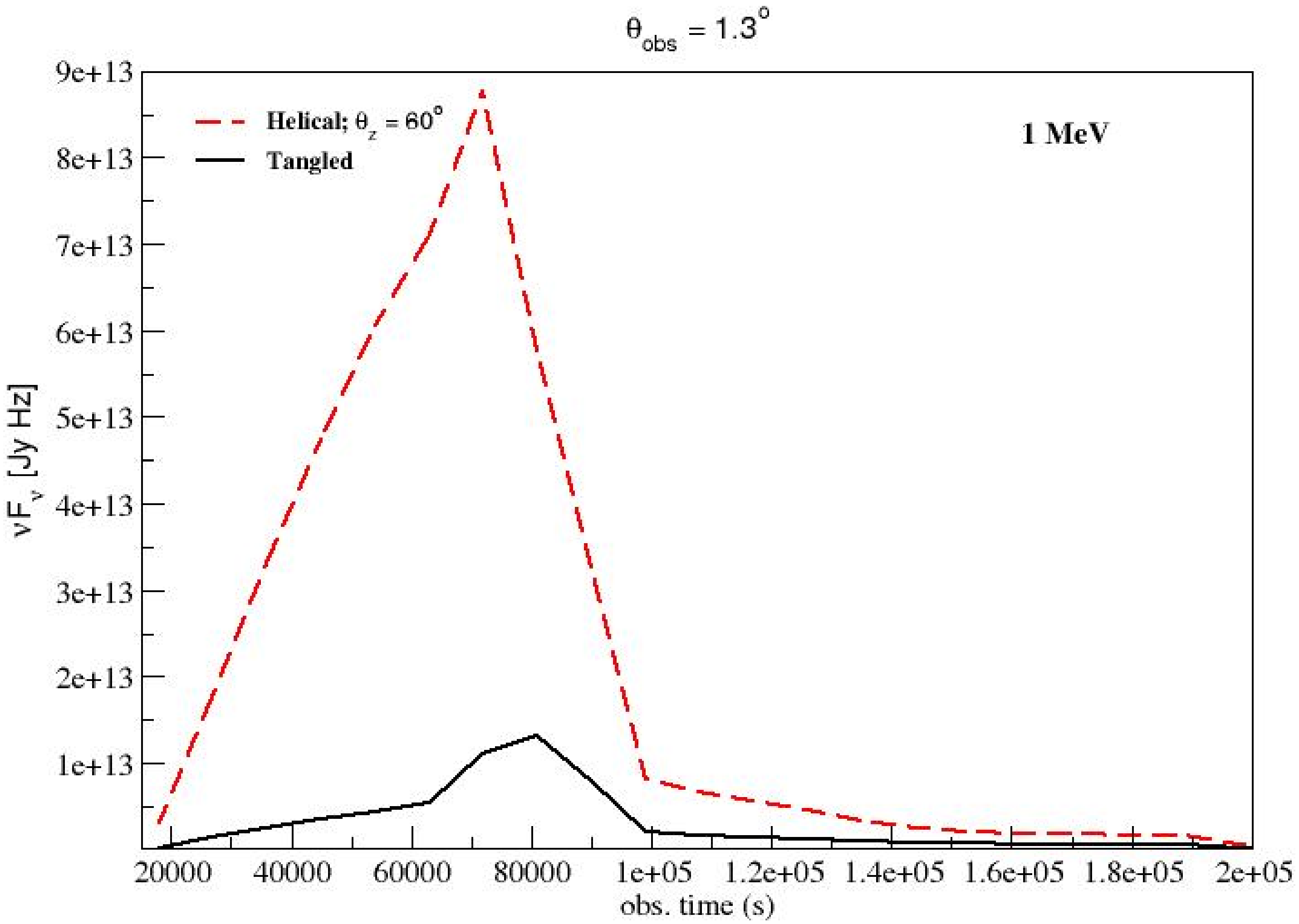
$\theta_{obs} = 1.3^\circ$
Tangled;
Helical; $\theta_z = 45^\circ$
Helical; $\theta_z = 30^\circ$
Helical; $\theta_z = 60^\circ$
1e+14
1e+13
1e+12
1e+11
1e+10
1e+09
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
νF_ν [Jy Hz]
ν [Hz]



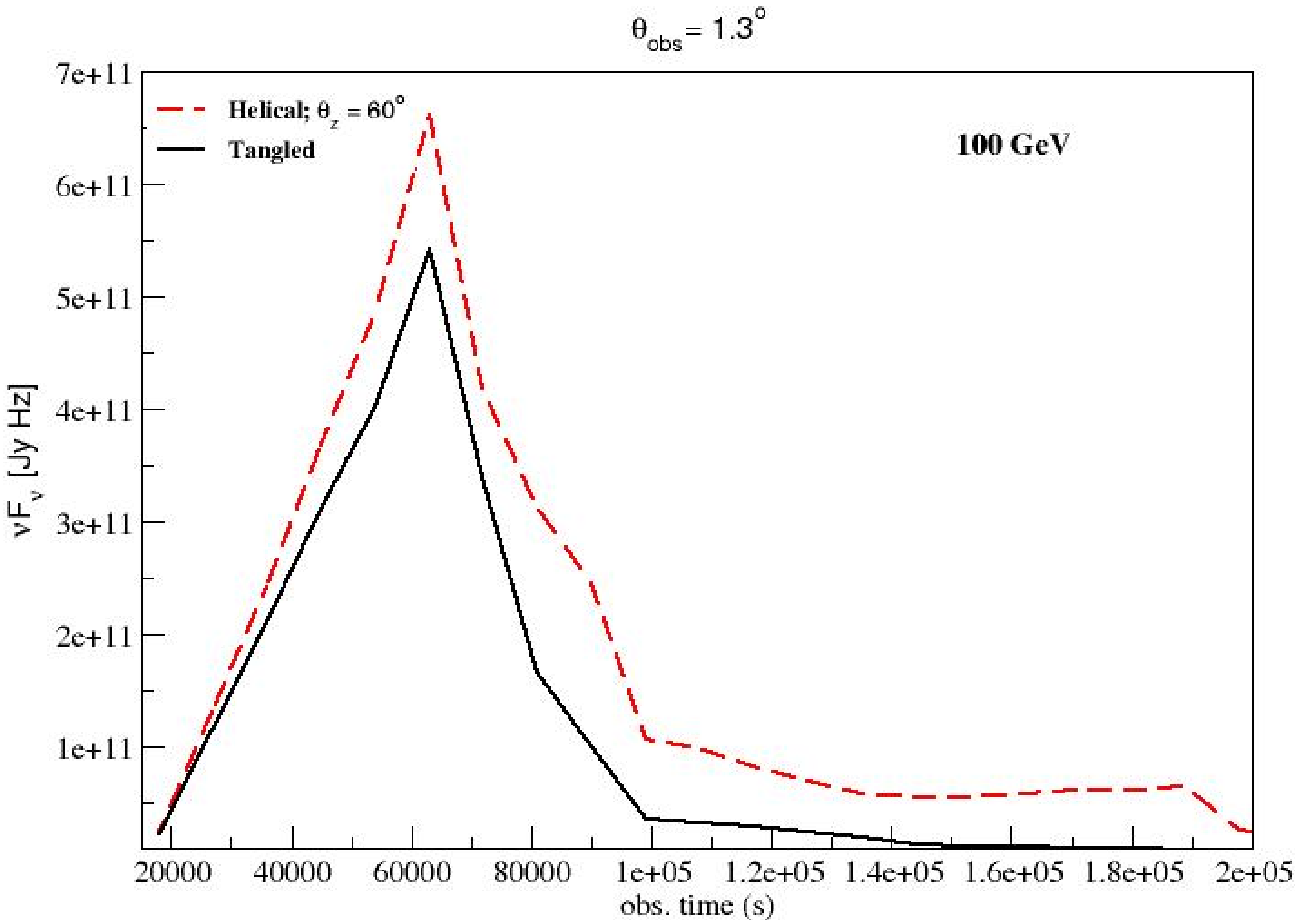
θ_{obs} = 1.3°
Tangled
Helical; θ_z = 60°
R Band
νF_ν [Jy Hz]
obs. time (s)
3e+13
2.8e+13
2.6e+13
2.4e+13
2.2e+13
2e+13
1.8e+13
1.6e+13
1.4e+13
1.2e+13
1e+13
8e+12
6e+12
4e+12
2e+12
20000
40000
60000
80000
1e+05
1.2e+05
1.4e+05
1.6e+05
1.8e+05
2e+05



θobs = 1.3°
Helical; θz = 60°
Tangled
10 keV
νFν [Jy Hz]
obs. time (s)
2.4e+13
2.2e+13
2e+13
1.8e+13
1.6e+13
1.4e+13
1.2e+13
1e+13
8e+12
6e+12
4e+12
2e+12
20000
40000
60000
80000
1e+05
1.2e+05
1.4e+05
1.6e+05
1.8e+05
2e+05



θobs = 1.3°
Helical; θz = 60°
Tangled
1 MeV
9e+13
8e+13
7e+13
6e+13
5e+13
4e+13
3e+13
2e+13
1e+13
νFν [Jy Hz]
20000
40000
60000
80000
1e+05
1.2e+05
1.4e+05
1.6e+05
1.8e+05
2e+05
obs. time (s)



θ_{obs}= 1.3°
Helical; θ_z = 60°
Tangled
100 GeV
7e+11
6e+11
5e+11
4e+11
3e+11
2e+11
1e+11
νF_ν [Jy Hz]
20000
40000
60000
80000
1e+05
1.2e+05
1.4e+05
1.6e+05
1.8e+05
2e+05
obs. time (s)

Limitations & Future Work

- In this treatment, electron distribution considered to be isotropic.
- Magnetic field generation not dealt here & strength and orientation assumed to not revert back to their original values once the shock leaves a particular zone.
- Together => over estimation of field strength and degree of polarization.
- Include SSC calculation using full KN cross section.
- Include radio emission calculation in the model to enable the study of spectral features at pc scale jets.