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

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Motivation

- Phenomena near black holes & relativistic jets => 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 B 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 – reverse is equally true (see Tchekhovskoy et al., & Sironi et al.).
- Yet B-geometry - largely unexplored aspect of blazar jet emission physics models.
- Recent advancements in polarization studies - Lyutikov et al. (2005), Jamil & Boettcher (2012), Chen et al. (2014), Zhang & Boettcher (2013) – focused largely toward helical geomety.

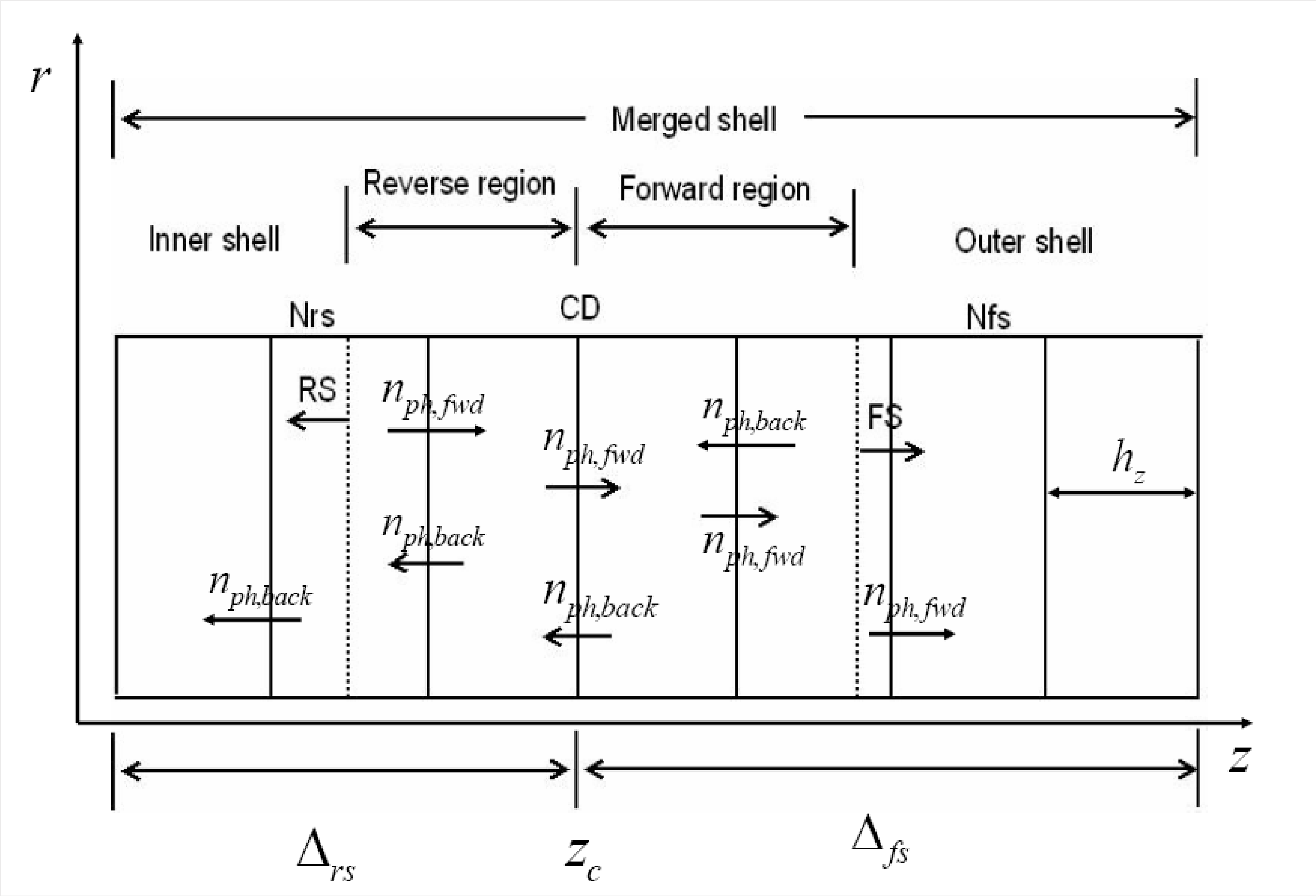
Goal

- 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) 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 to the HE SEDs and SVPs.

Questions to be answered

- What are the signatures of the orientation of the magnetic field in the SEDs and light curves of blazars – ratio of SSC (EC) vs synchrotron flux density via Compton dominance?
- How does the spectral hardness of a blazar depend on the orientation of the field?
- How is the location of the peak synchrotron & SSC frequencies affected by this orientation, if at all?
- What are the intrinsic parameter differences between various blazar subclasses arising from the orientation of the magnetic field in the jet?

MUlti-ZOne Radiation Feedback (MUZORF)



Time-dependent radiation transfer leptonic jet model.

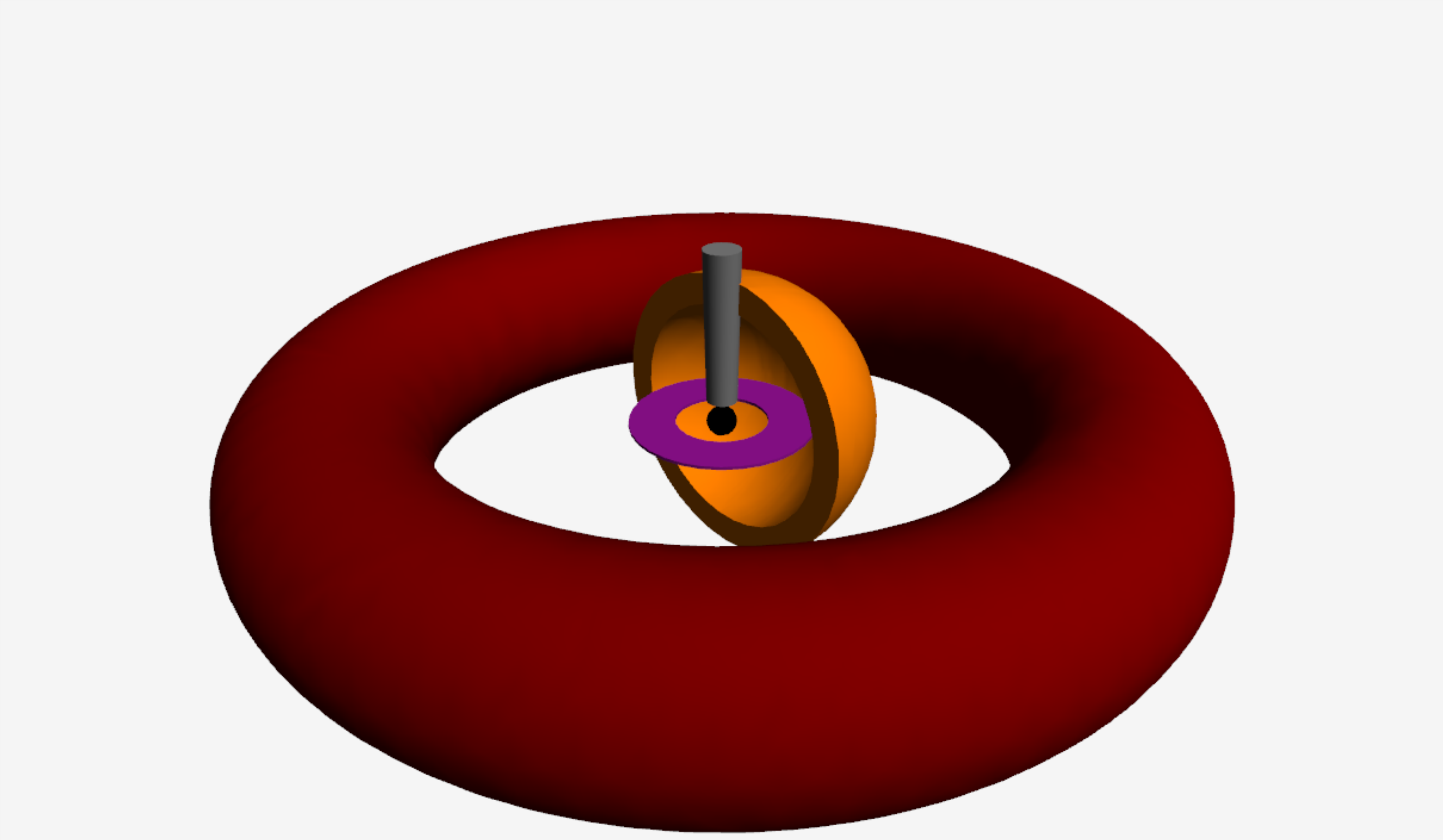
Based on internal shock scenario.

Self consistently calculates electron and photon populations in each zone.

Internal light travel time delays incorporated for every zone in observer's frame.

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

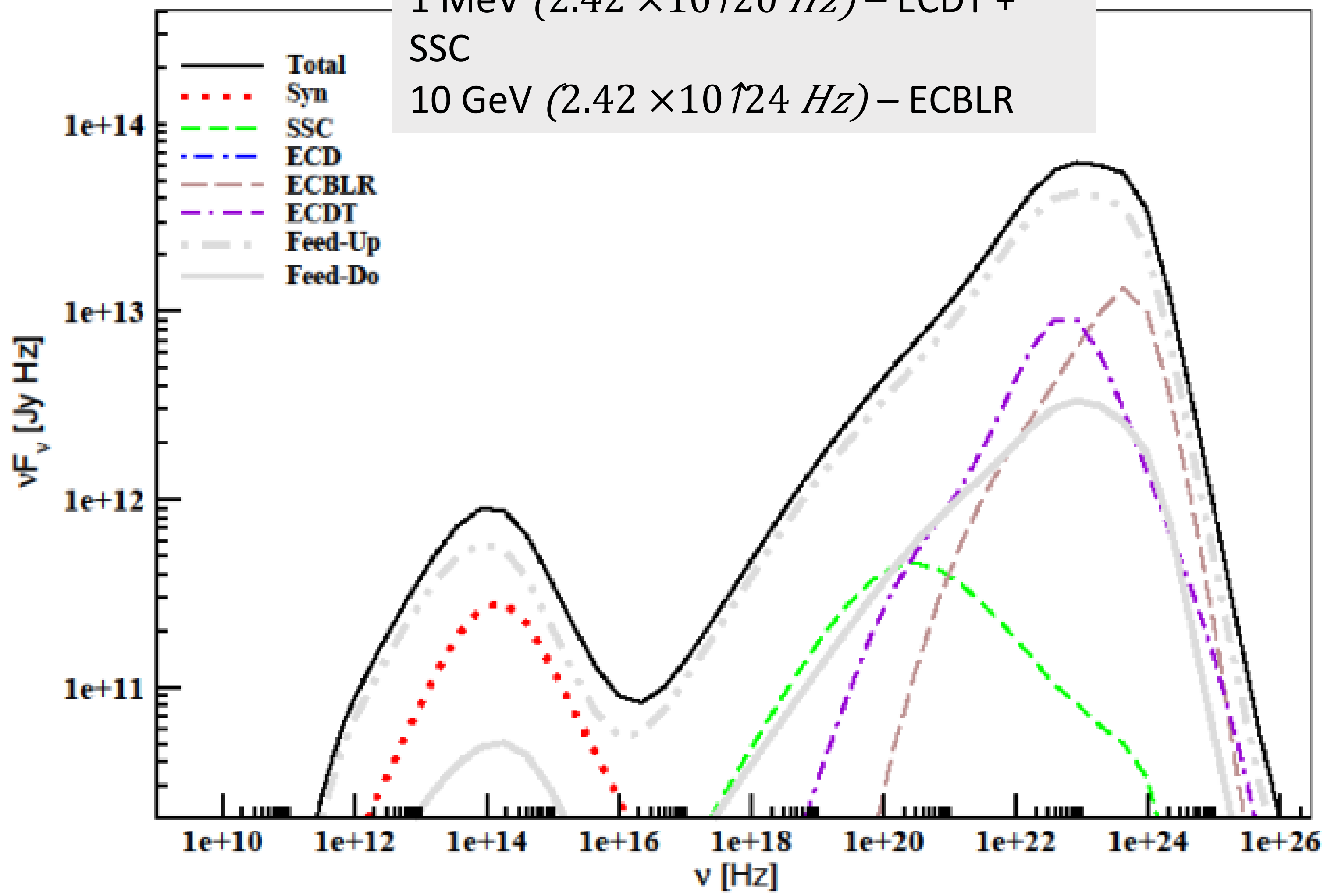
Disk + BLR + DT Schematic



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

Magnetic Field Geometry

- Step 1 – Include the pitch angle between B and photon direction, corrected for relativistic aberration, in 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 $n' \cdot B'$ product in emission region frame (comoving frame) – *numerical approximation to calculate F'(x'/$\sin\chi'$) where* $x' = \nu/\nu_c$.
- Step 3 – calculate the corresponding SSC emission resulting from the modified synchrotron emission due to each of these geometries – *discrepancy between SSC from isotropic vs full KN cross section*.
- Step 4 – analyze the effects on the resulting SEDs and SVPs.



R Band $(4.29 \times 10^{14}\ Hz)$ – Syn
10 keV $(2.42 \times 10^{18}\ Hz)$ – SSC
1 MeV $(2.42 \times 10^{20}\ Hz)$ – ECDT + SSC
10 GeV $(2.42 \times 10^{24}\ Hz)$ – ECBLR

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:

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

$z_c = 1.2 \times 10^{17}$ cm = 0.04 pc ~ $8 \times 10^4\ r_g$; $M_{BH} = 10^9\ M_S$
$\gamma_{min} = 1.12 \times 10^3$
$\gamma_{max} = 3.9 \times 10^4$

B = 1.43G

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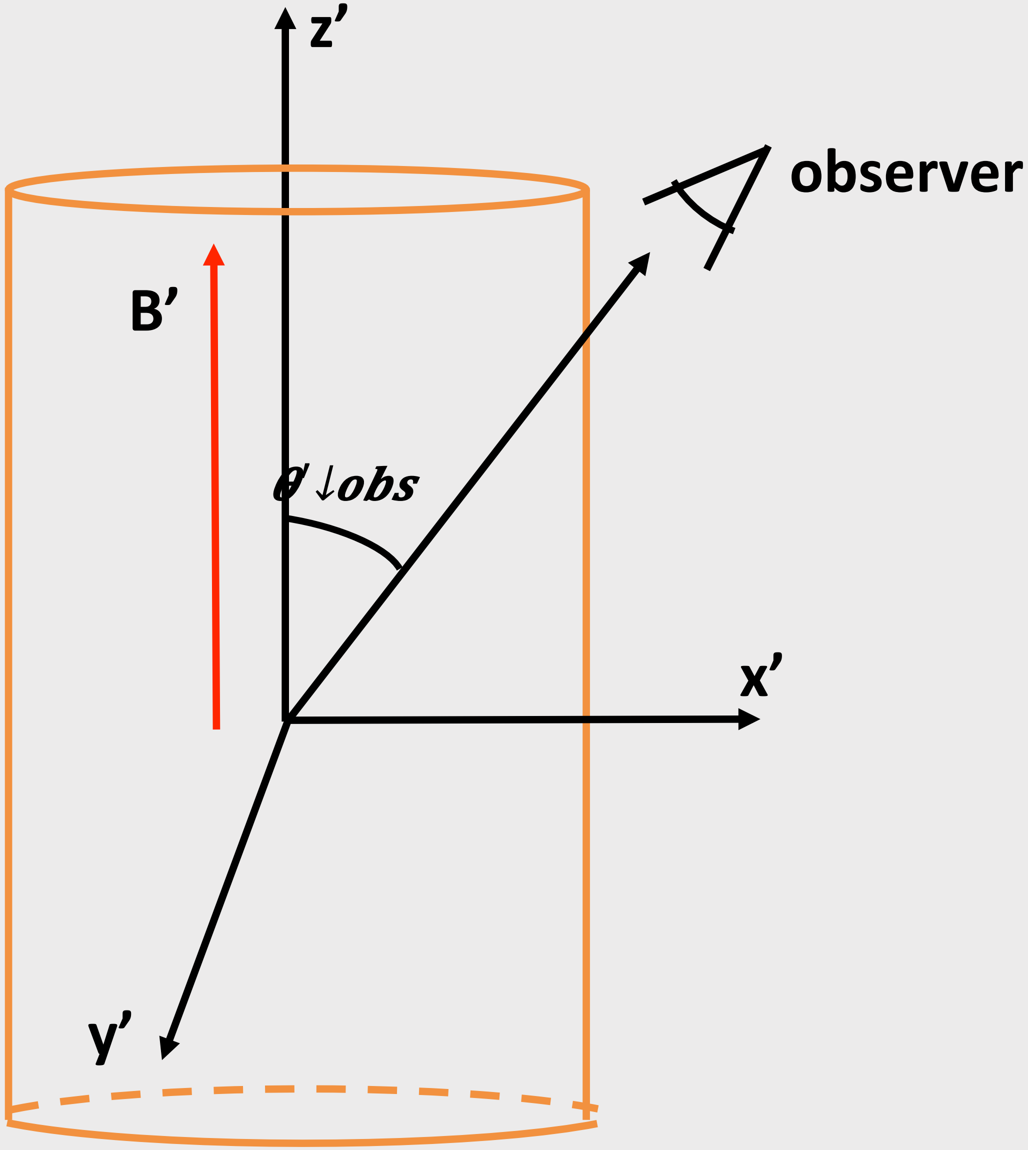
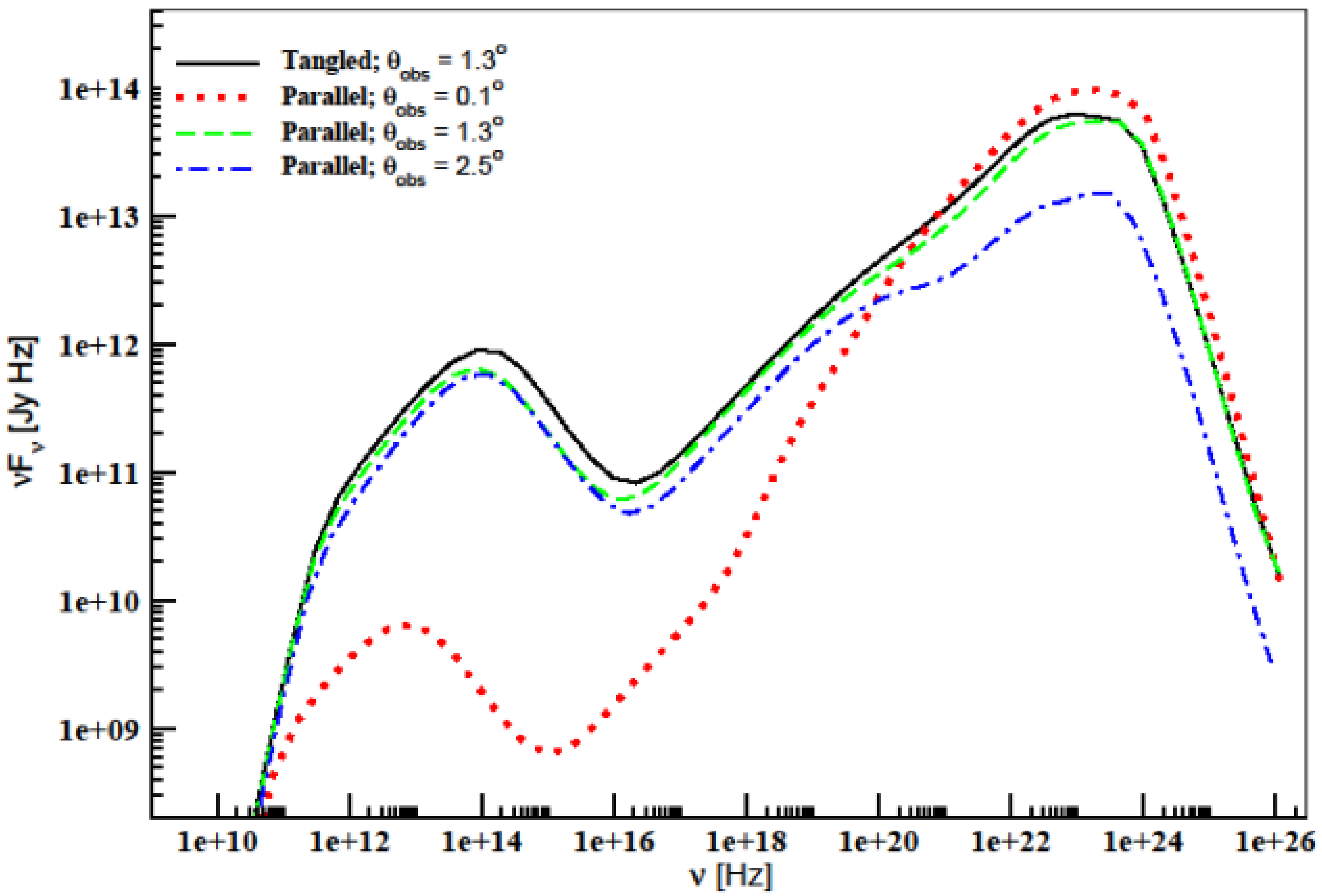
$\theta_{cone} = 1/\Gamma = 3.6^0$

Field Topology:

Parallel: $\sin \chi \uparrow' = D \sin \theta \downarrow obs$



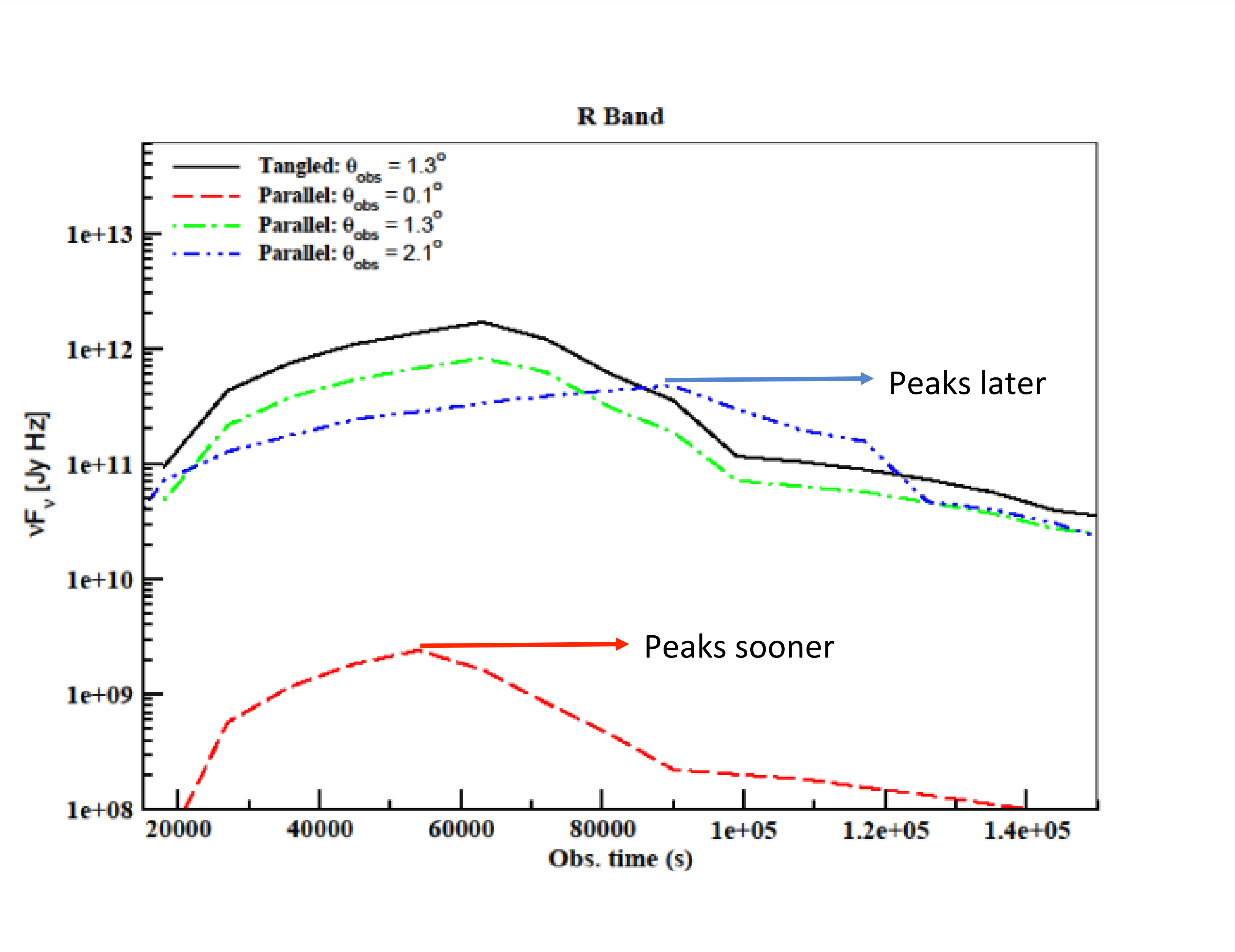
Varying θ_{obs}



1. Syn & SSC governed by $\sin \theta_{obs}$ ⇒ they go down as θ_{obs} goes down.

2. EC continues to be guided by D.

R Band $(4.29 \times 10^{14}\ Hz)$ – Syn
10 keV $(2.42 \times 10^{18}\ Hz)$ – ECDT – Harder spectra
1 MeV $(2.42 \times 10^{20}\ Hz)$ – ECDT + ECBLR
10 GeV $(2.42 \times 10^{24}\ Hz)$ – ECBLR



Forward shock exits forward emission region in ~ 20 hours.

Reverse leaves its region in ~ 26 hours.

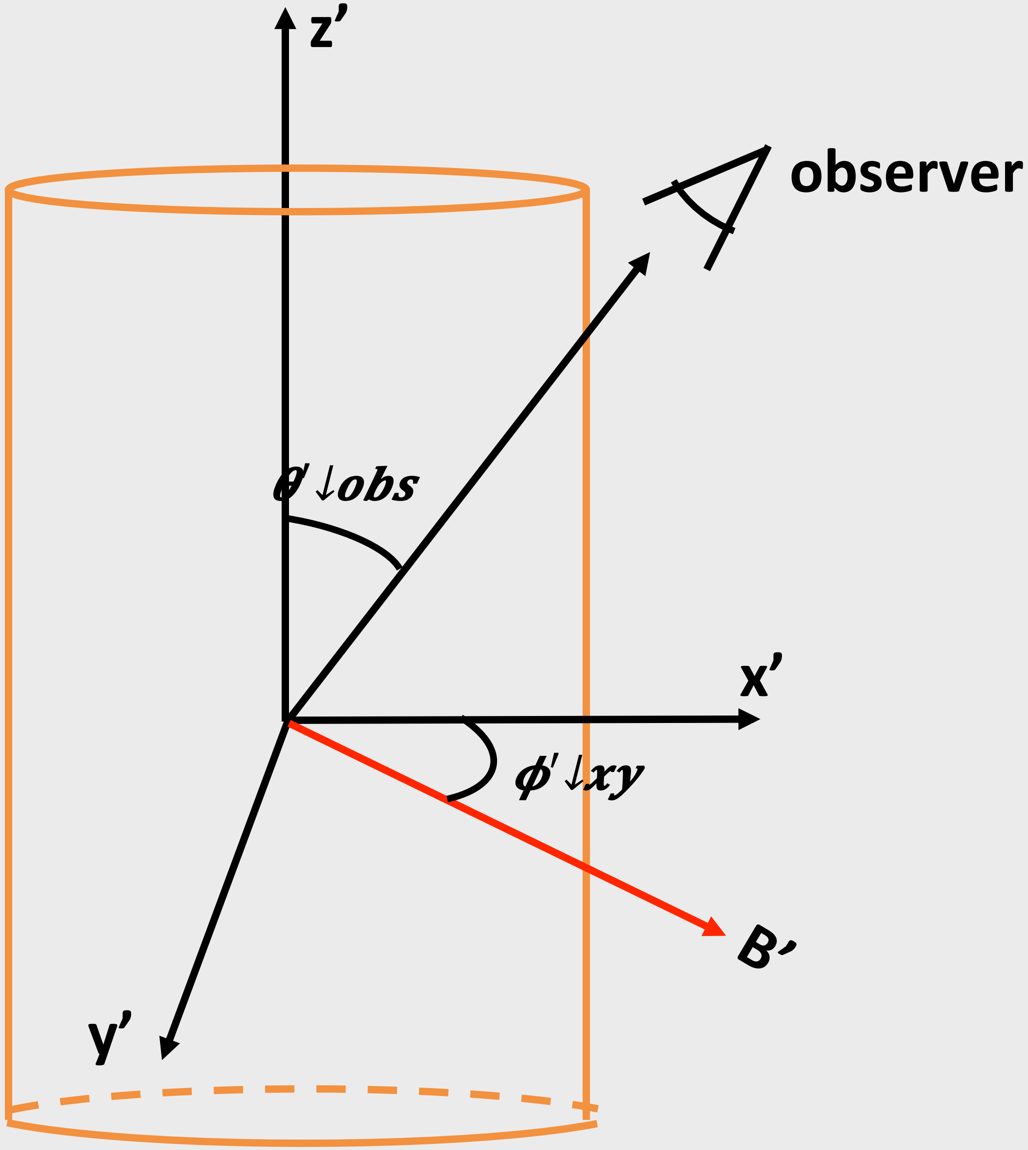
Flare profile in R band guided by the presence of both the shocks in the system and higher energy electrons.

Overall profile for all cases remains the same.

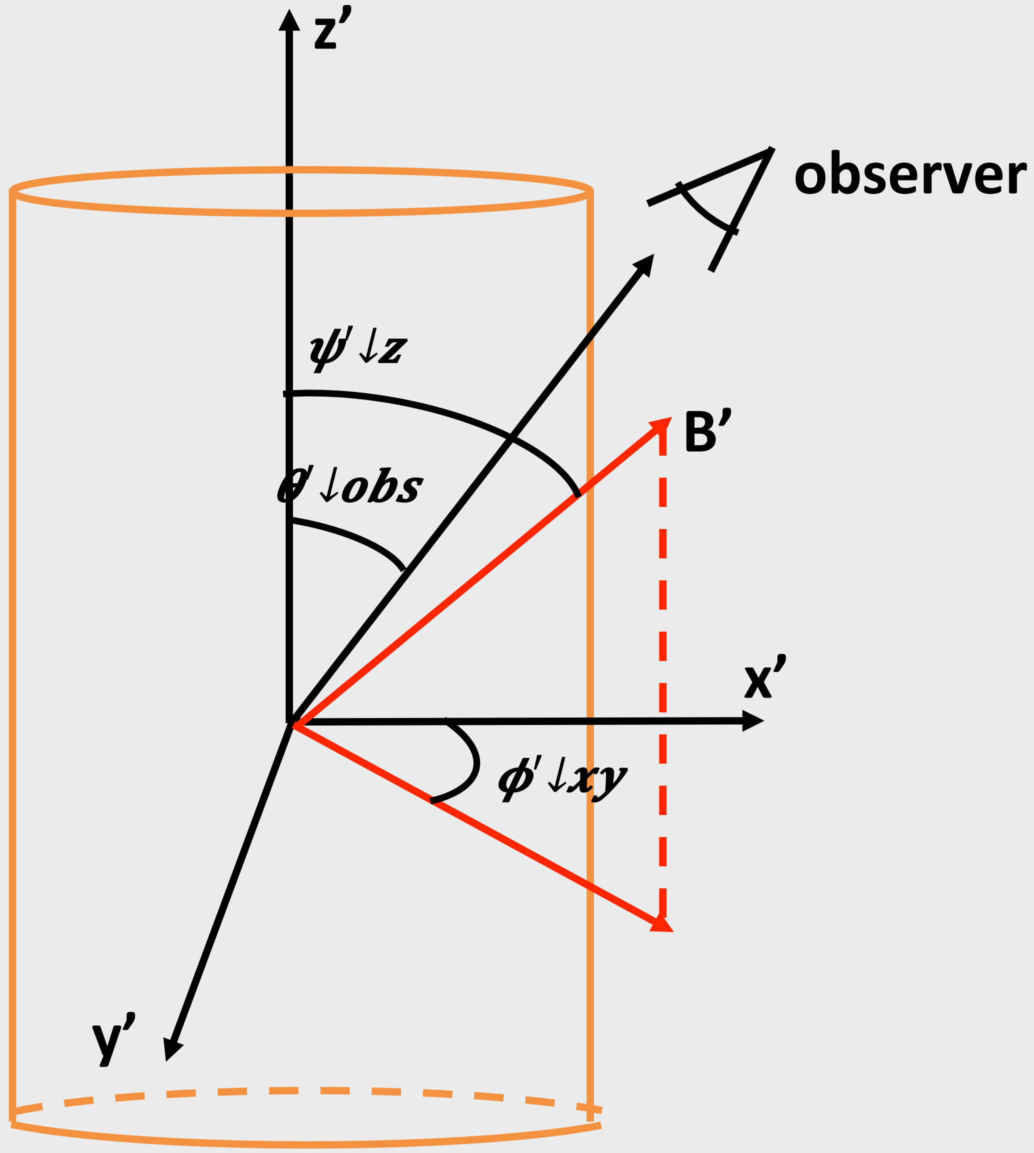
Peaking of flare still governed by boosting as the shock crossing time is dependent on that.

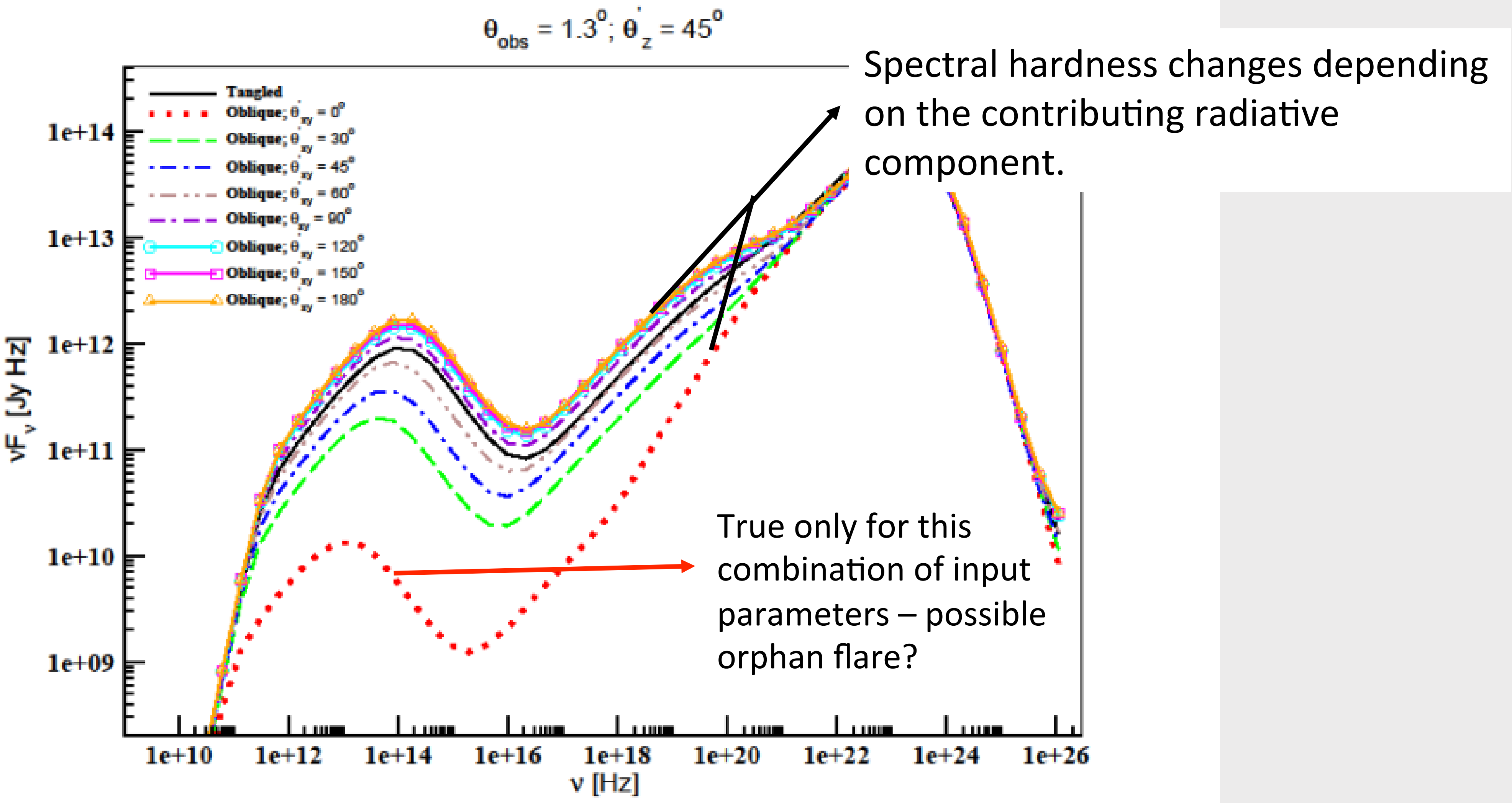
Transverse: $\sin\chi' = \sqrt{1-(D\sin\theta_{obs}\cos\phi'_{xy})^2}$

Overall flux level and flare profiles remain almost the same.

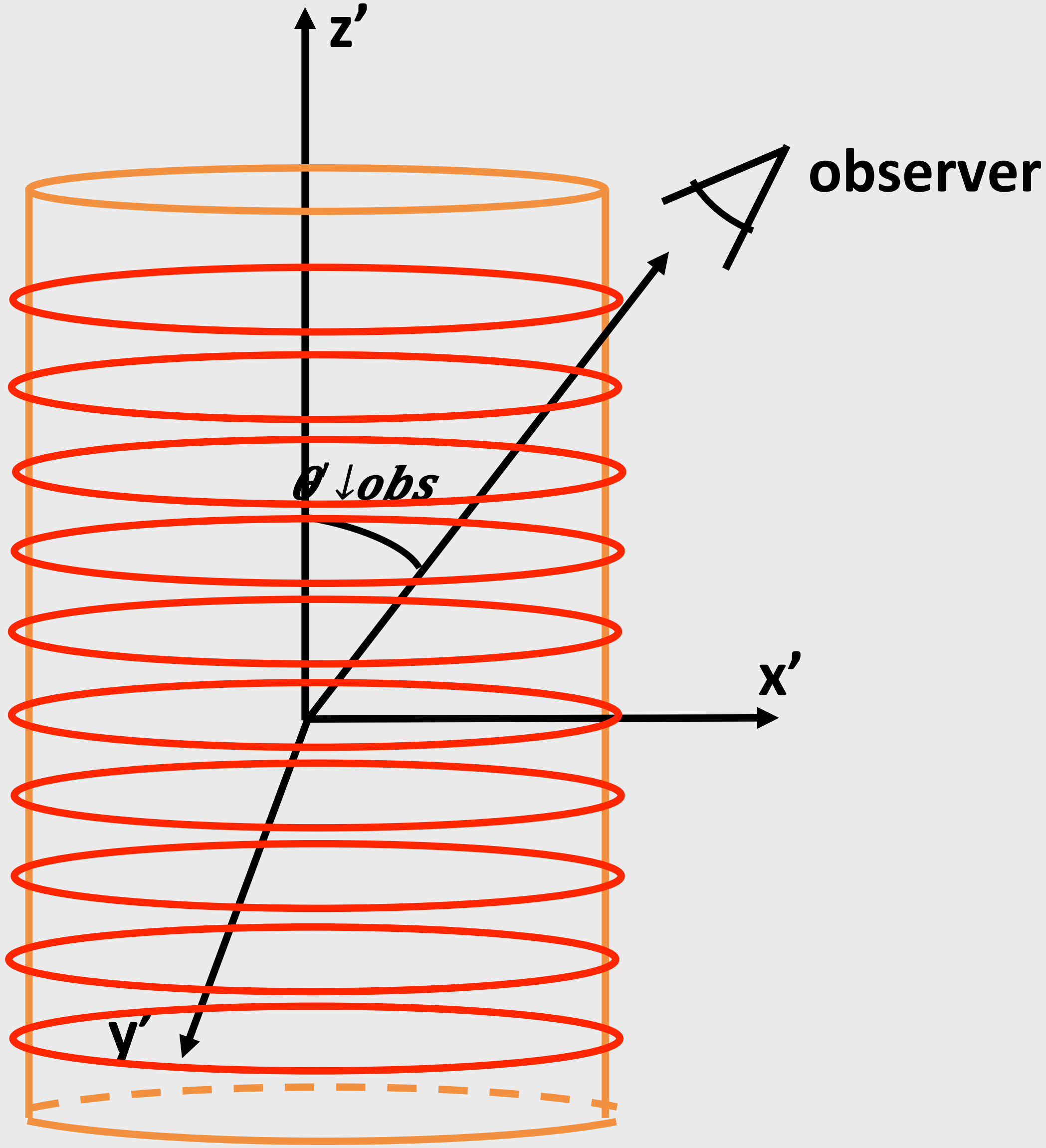


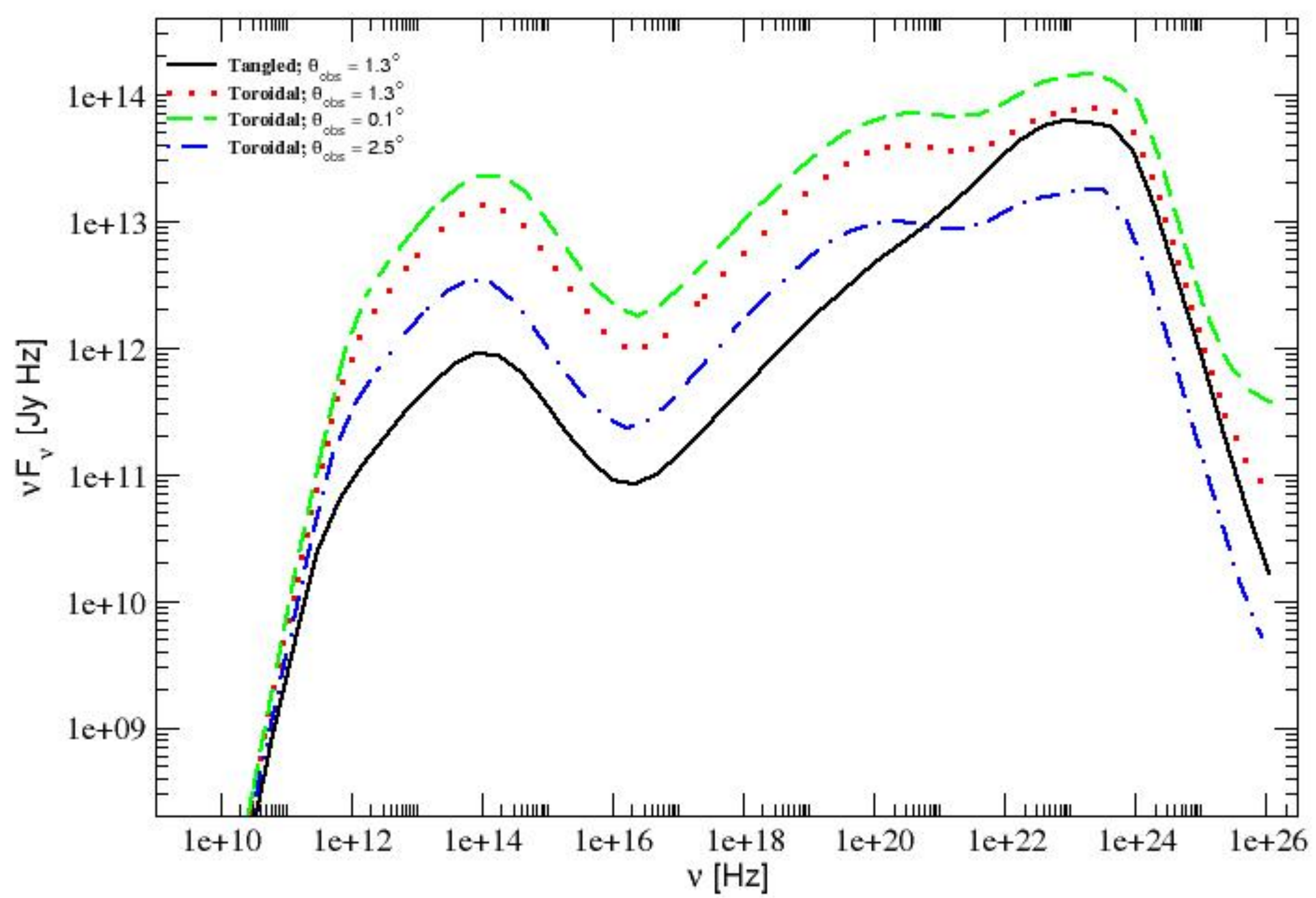
Oblique: $sin\chi' \rightarrow D, \theta_{obs}, \psi'_{z}, \phi_{xy}', \Gamma$




θobs = 1.3°; θ'z = 45°
Tangled
Oblique; θ'xy = 0°
Oblique; θ'xy = 30°
Oblique; θ'xy = 45°
Oblique; θ'xy = 60°
Oblique; θ'xy = 90°
Oblique; θ'xy = 120°
Oblique; θ'xy = 150°
Oblique; θ'xy = 180°
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]
Spectral hardness changes depending on the contributing radiative component.
True only for this combination of input parameters – possible orphan flare?

Toroidal: $sin\chi^{\prime} = \sqrt{1-(D sin\theta_{obs}\ sin\phi^{\prime})^{2}}$

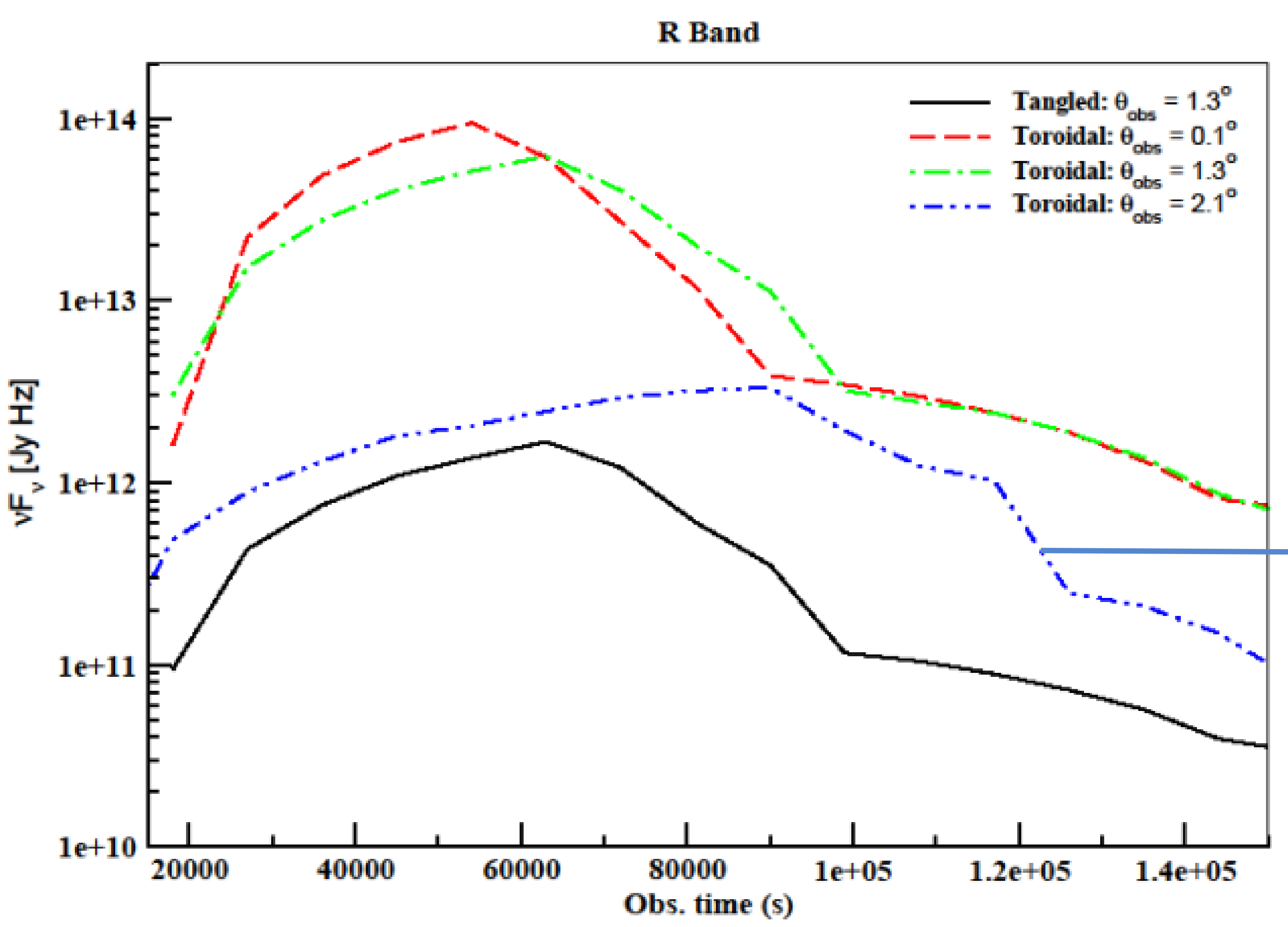




Varying $\theta{\downarrow}obs$

1. Syn & SSC governed by overall orderness of the field ⇒ they go up as $\theta{\downarrow}obs$ goes down.

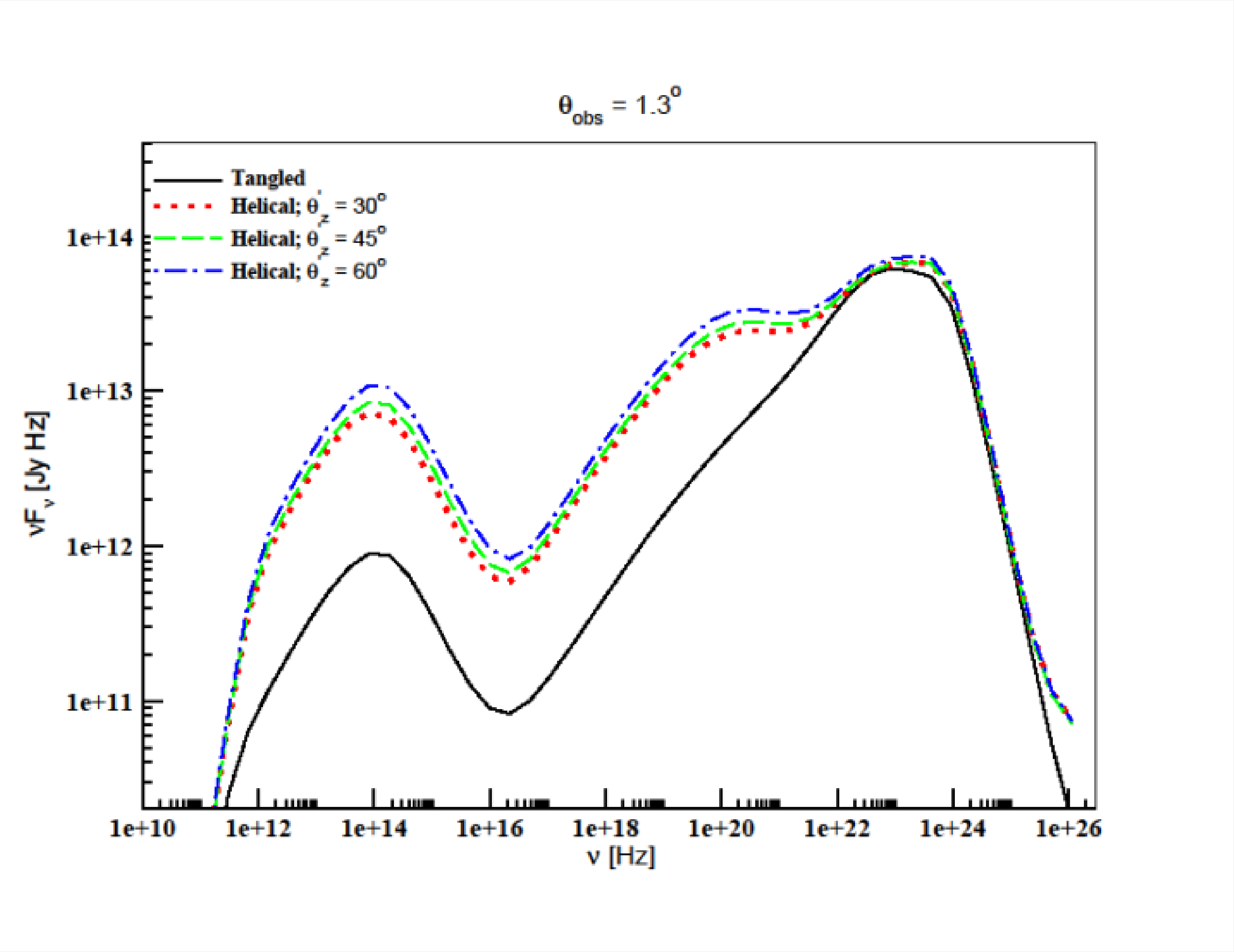
2. EC continues to be guided by D but gets affected by highly ordered field through change in electron population of the region.



Shocks leave the system at same time, as mentioned before for all cases, except for cases with different θ_{obs}.

Overall profile for all cases remains the same except for their flux levels.

Larger θ_{obs} but higher than baseset due to ordered field.

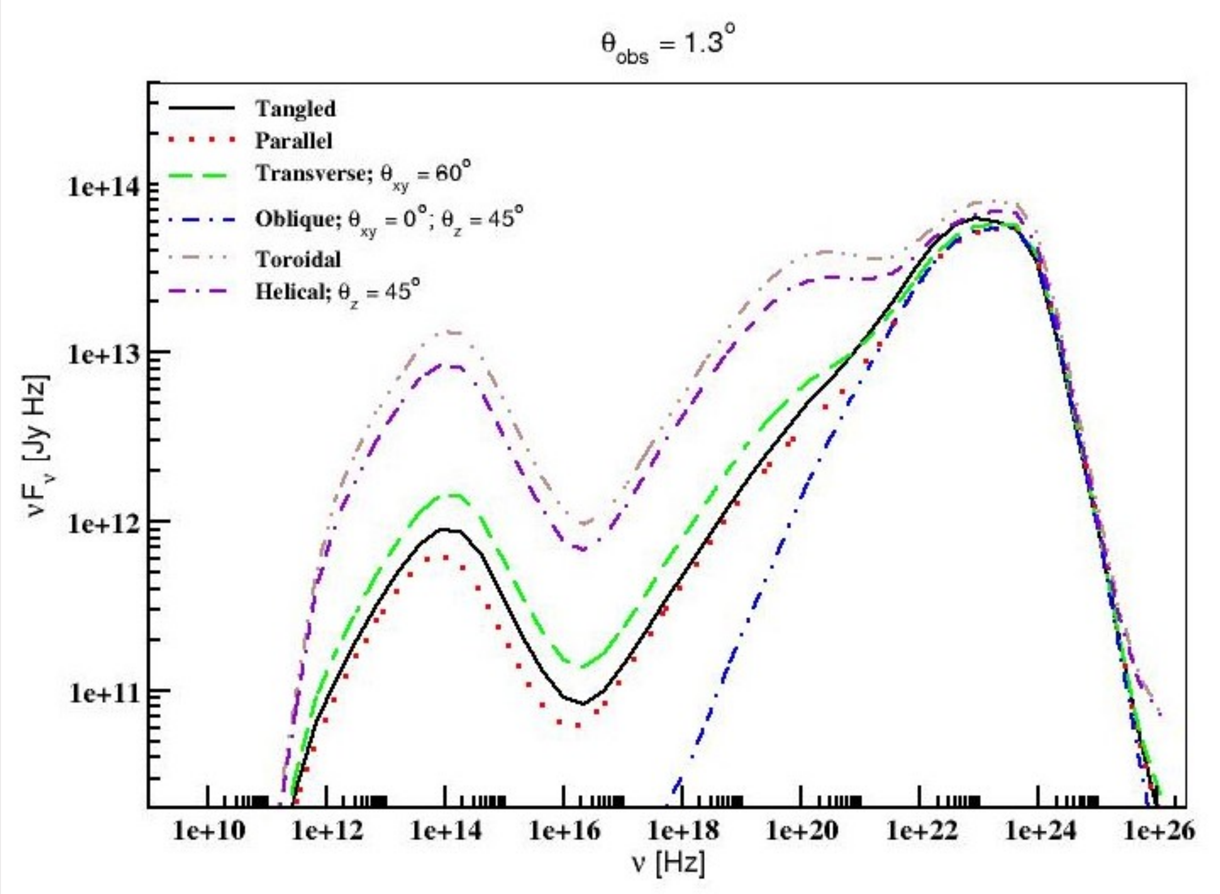


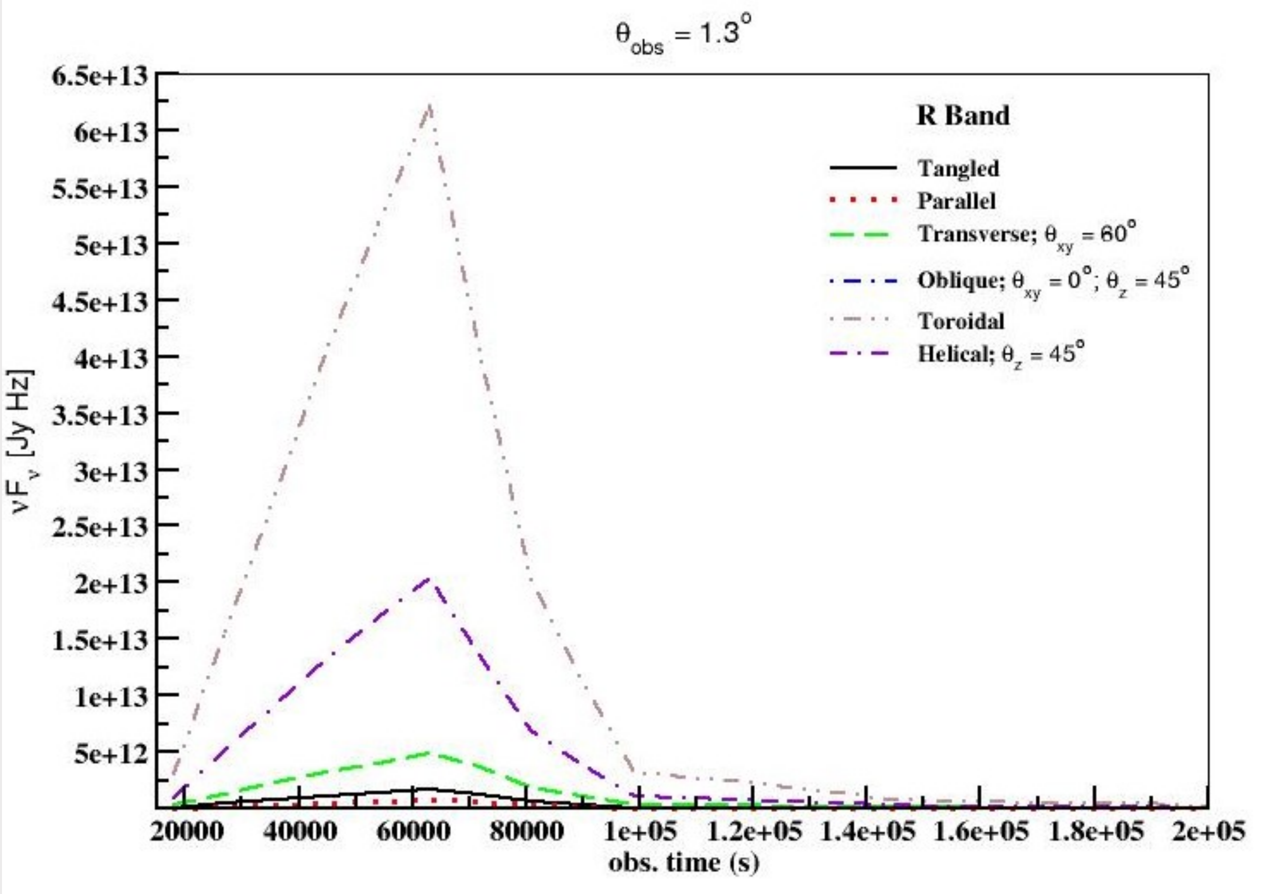
Helical: $sin\chi' \rightarrow D, \Gamma, \theta'_z, \theta_{obs}, \phi'$

Dependent on angle helix makes with z' - θ'_z

$\theta'_z = 0^o$ => Parallel case

$\theta'_z = 90^o$ => Toroidal case


θobs = 1.3°
Tangled
Parallel
Transverse; θxy = 60°
Oblique; θxy = 0°; θz = 45°
Toroidal
Helical; θz = 45°
1e+14
1e+13
1e+12
1e+11
νFν [Jy Hz]
1e+10
1e+12
1e+14
1e+16
1e+18
1e+20
1e+22
1e+24
1e+26
ν [Hz]


θobs = 1.3°
R Band
Tangled
Parallel
Transverse; θxy = 60°
Oblique; θxy = 0°; θz = 45°
Toroidal
Helical; θz = 45°
6.5e+13
6e+13
5.5e+13
5e+13
4.5e+13
4e+13
3.5e+13
3e+13
2.5e+13
2e+13
1.5e+13
1e+13
5e+12
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)

Limitations & Future Work

- Purely ordered magnetic field considered with no contamination from disordered component.
- Strength and orientation of the field assumed to not revert back to their original values once the shock leaves a particular zone.
- Together => effects calculated are upper limits of impact on SEDs and SVPs.
- 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.
- Include fraction of disordered component to target BL Lacs with low degree of polarization and enable exploring intrinsic parameter differences between various blazar subclasses.
- Calculate P% & relate that to SVPs – is it low during an orphan flare in the gamma-rays? What about its value during an orphan flare in the optical? – e.g. PKS 1510-089 in April 2009.