# GRB prompt emission: Fresh insights from internal shocks

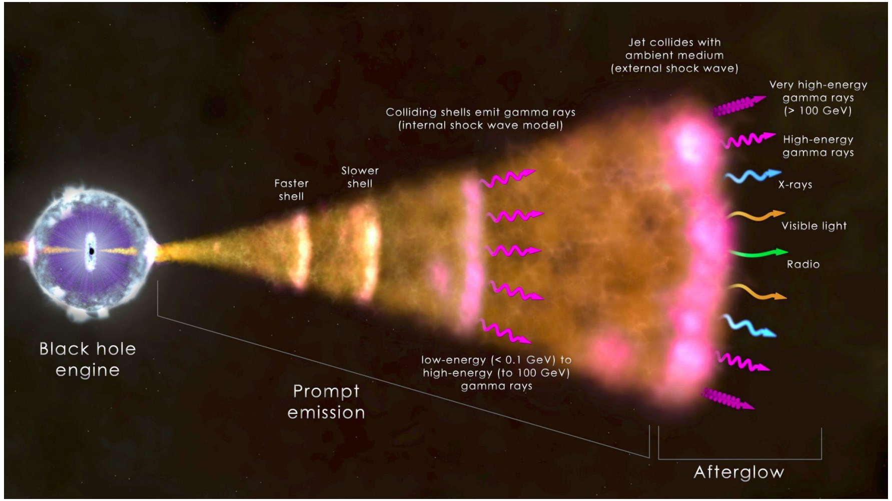



*Image credit: NASA/Goddard Space Flight Center/ICRAR.*


Minhajur Rahaman

Collaborators: Jonathan Granot
Paz Beniamini

ARCO
Astrophysics Research Center of the Open university


YITP

30th Jan' 2026

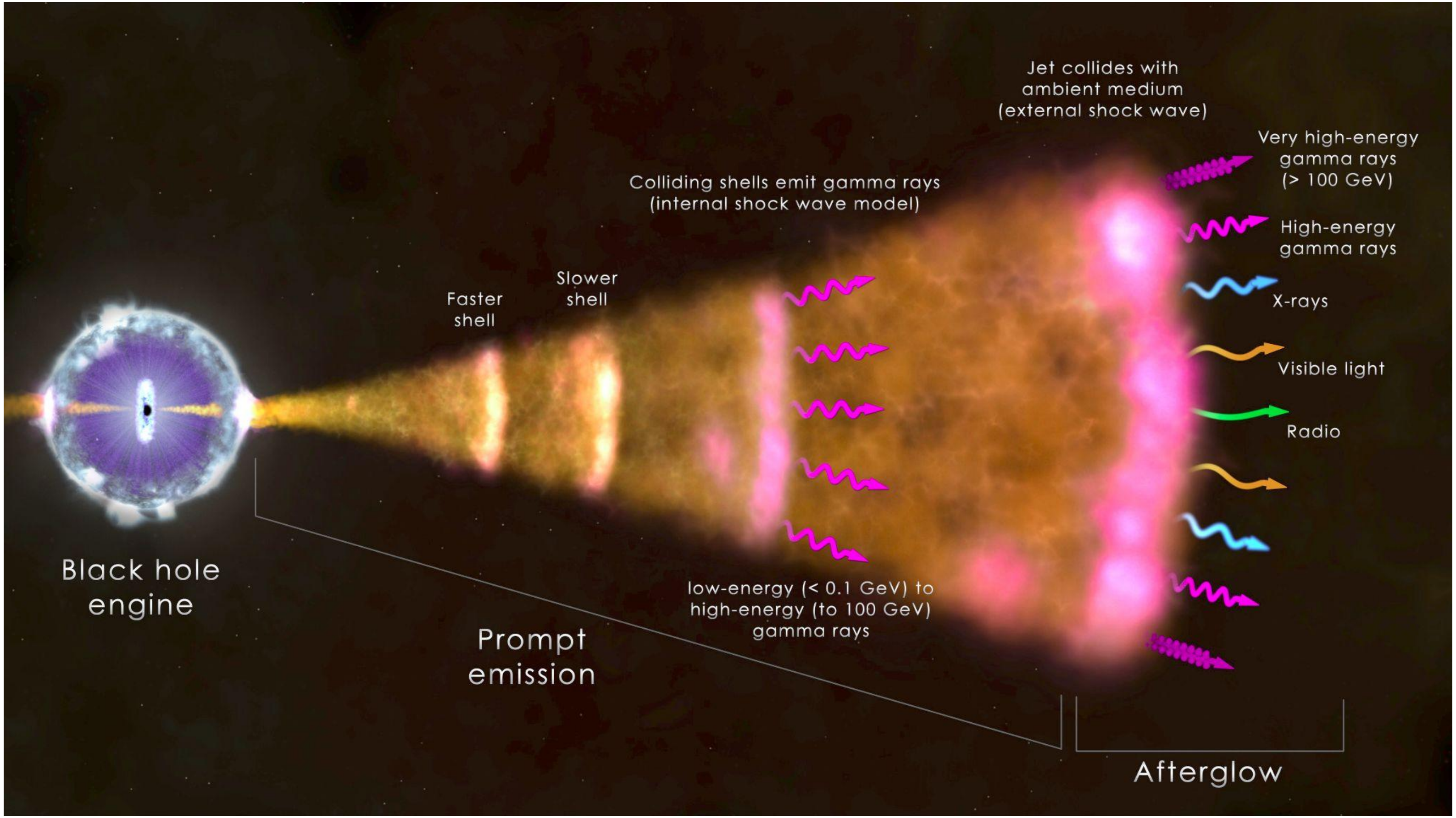



***Image credit: NASA/Goddard Space Flight Center/ICRAR.***

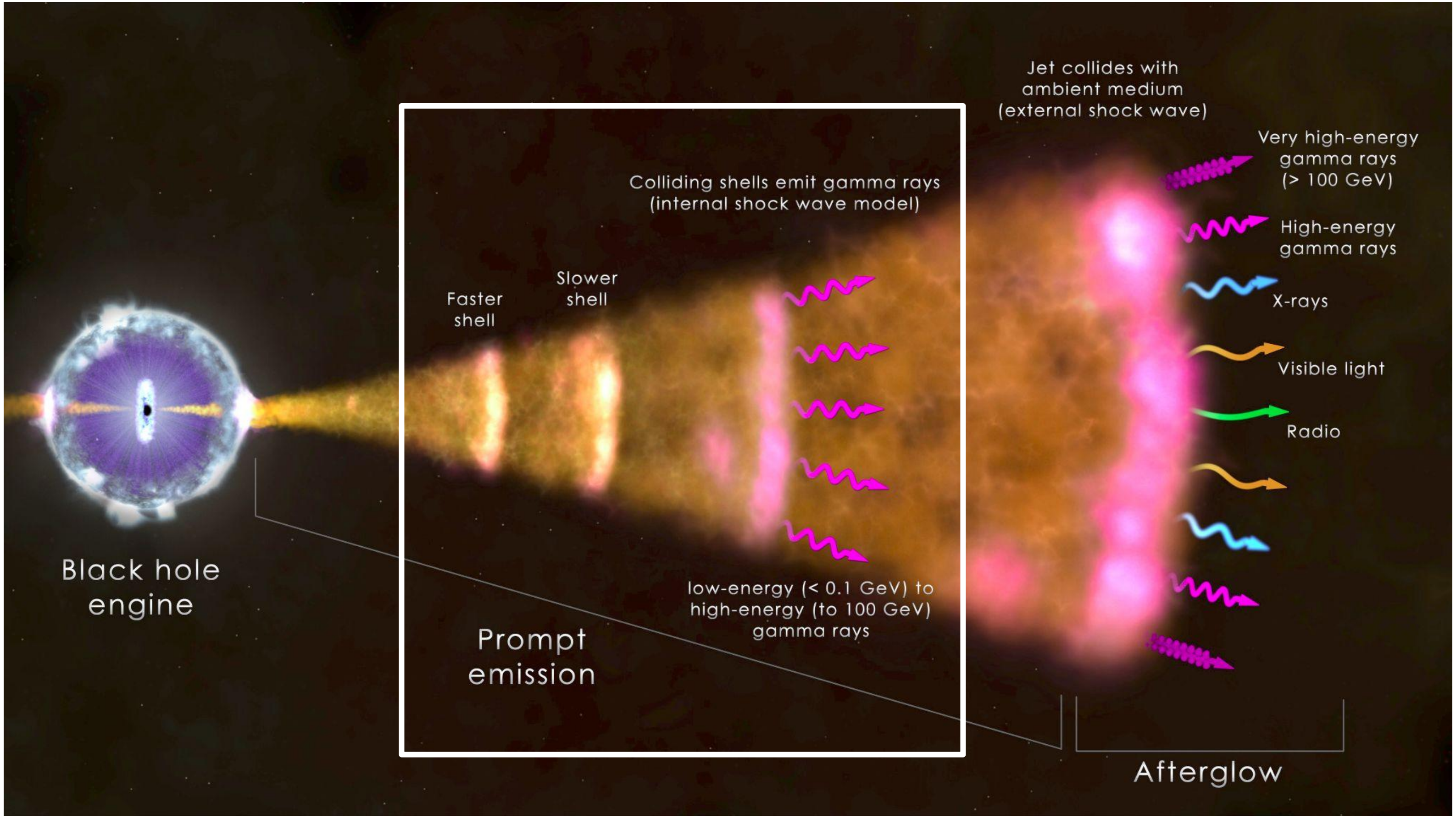
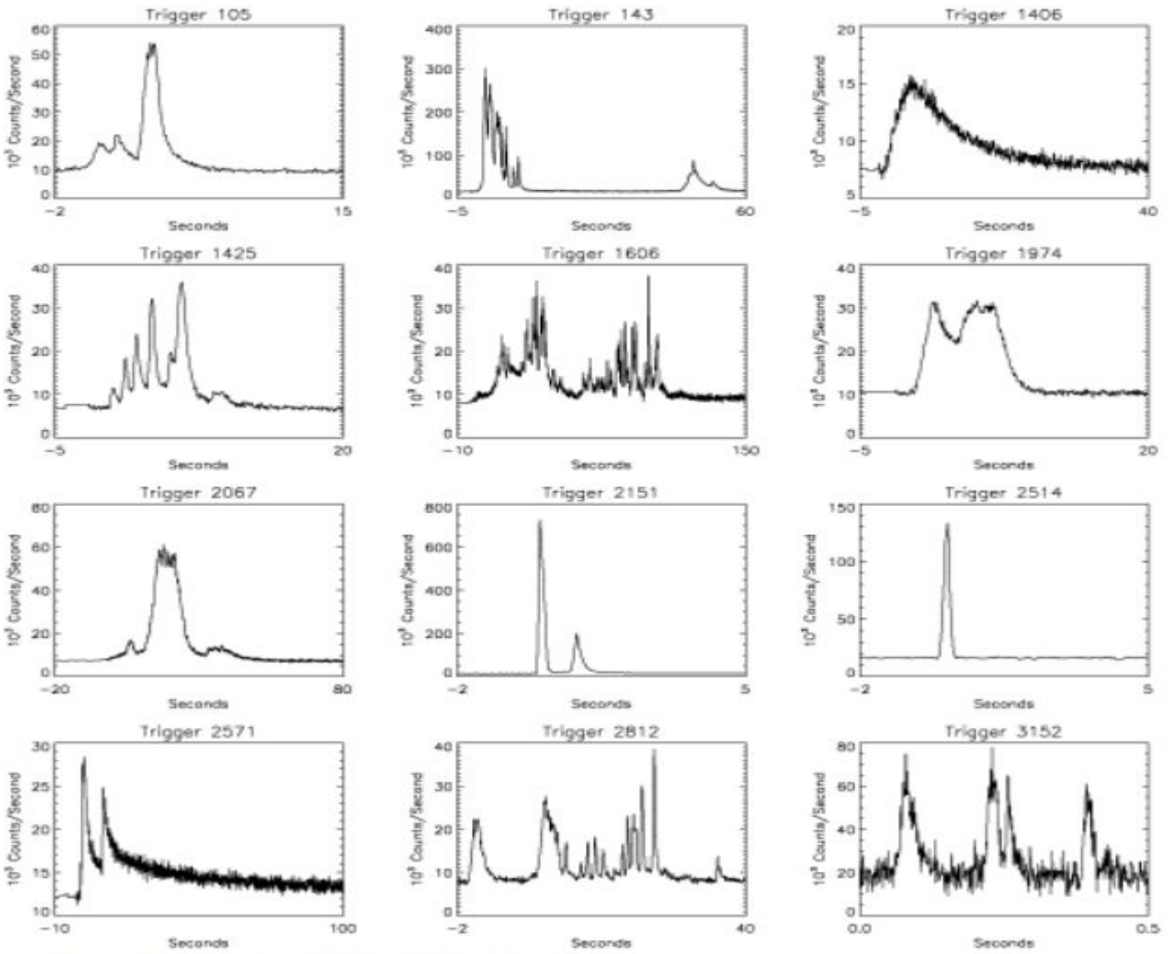
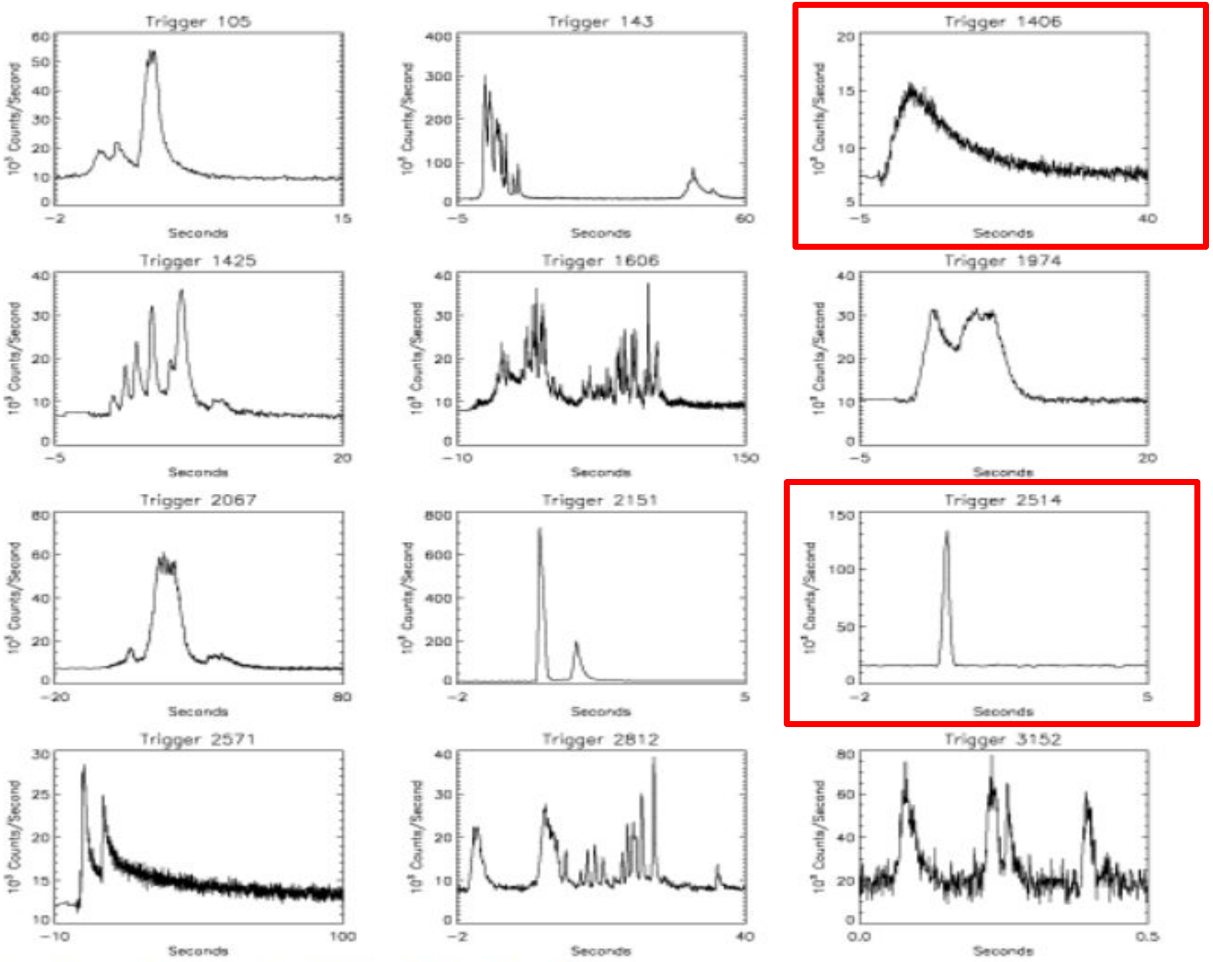



*Image credit: NASA/Goddard Space Flight Center/ICRAR.*




(Credit: J.T. Bonnell (NASA/GSFC))

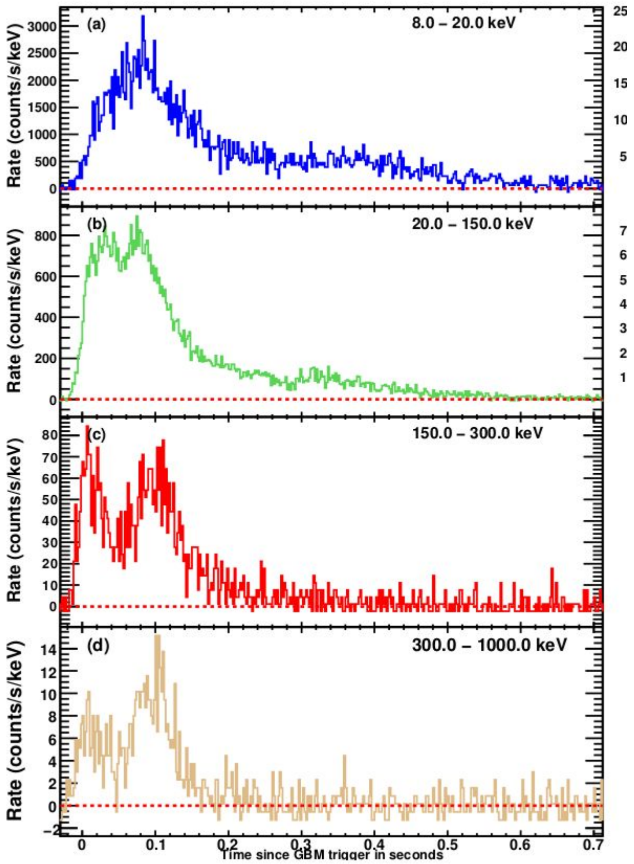
Rich diversity in pulse morphology




(Credit: J.T. Bonnell (NASA/GSFC))

## Single pulse of light

# Lightcurves at different frequencies




Guiriec et al. 2013

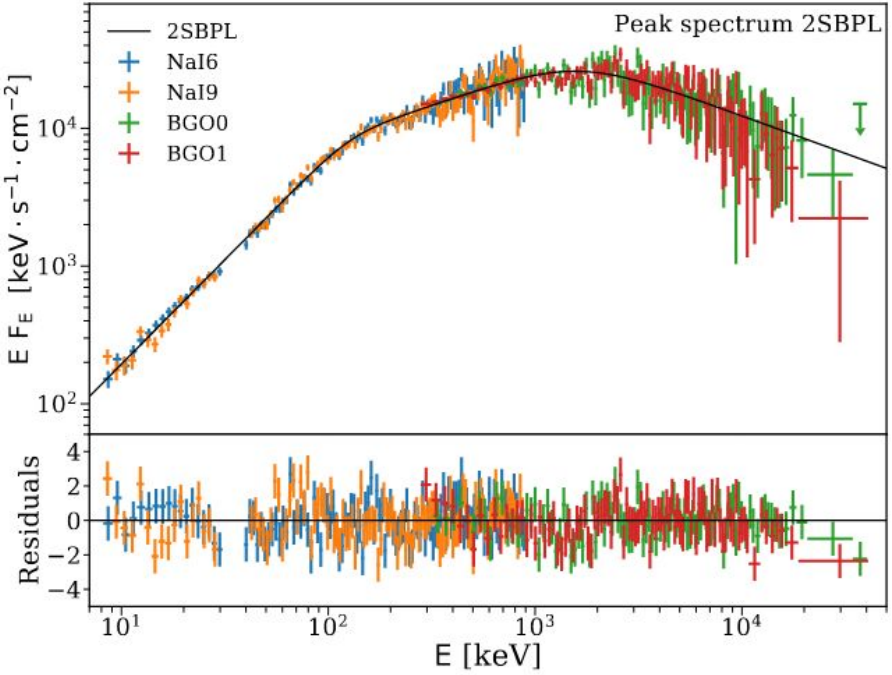
Different morphologies at different energy bands

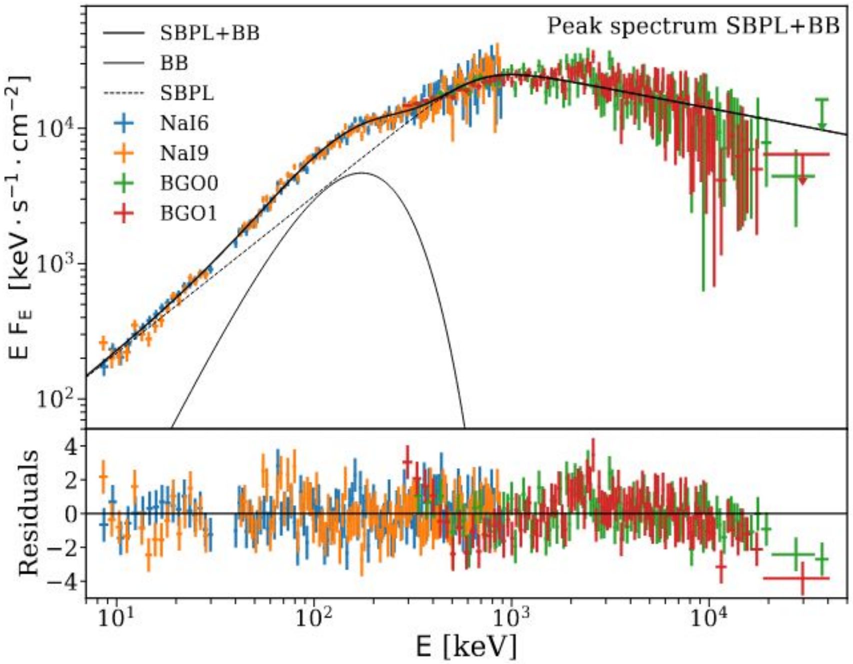
Effective width of the pulse changes with energy

Presence of a trailing tail at longer times

# Time-integrated spectrum

## GRB 160625




Low energy Spectral break/ BB "photospheric" component

**Ravasio et al. 2018**

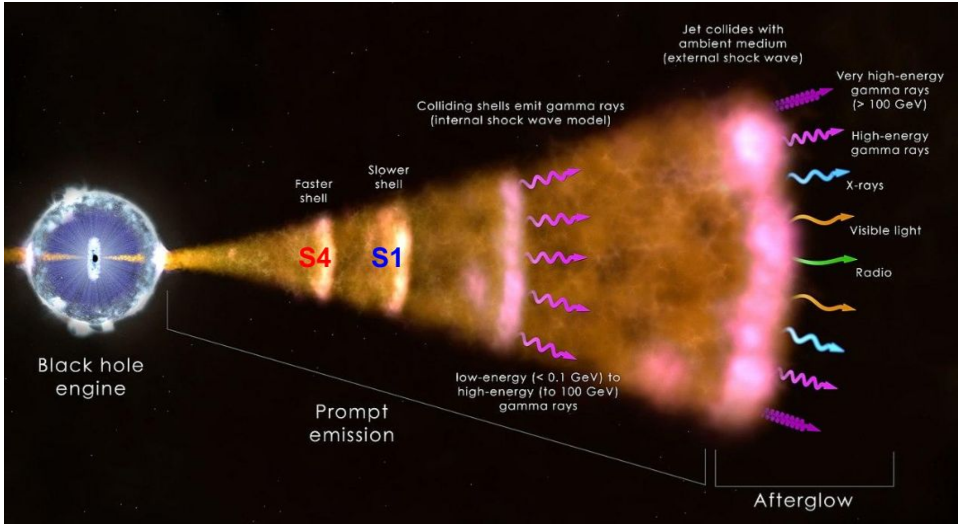
Single pulse of light

One collision

Two shock-fronts

# One collision- Two shock fronts

$$u = \Gamma\beta \gg 1$$

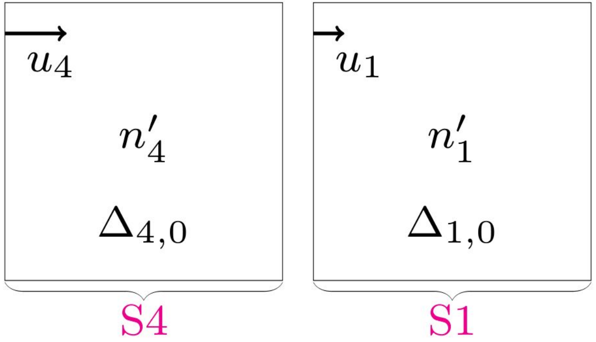



General formalism: Extension of Sari & Piran's 1995 work for arbitrary velocity of colliding shells

**Rahaman et al. 2024a,MNRAS**

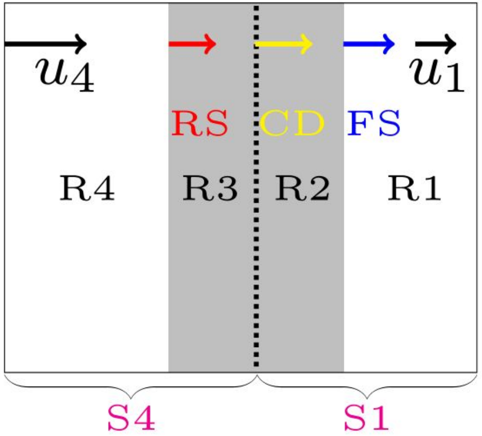
## Pre-collision

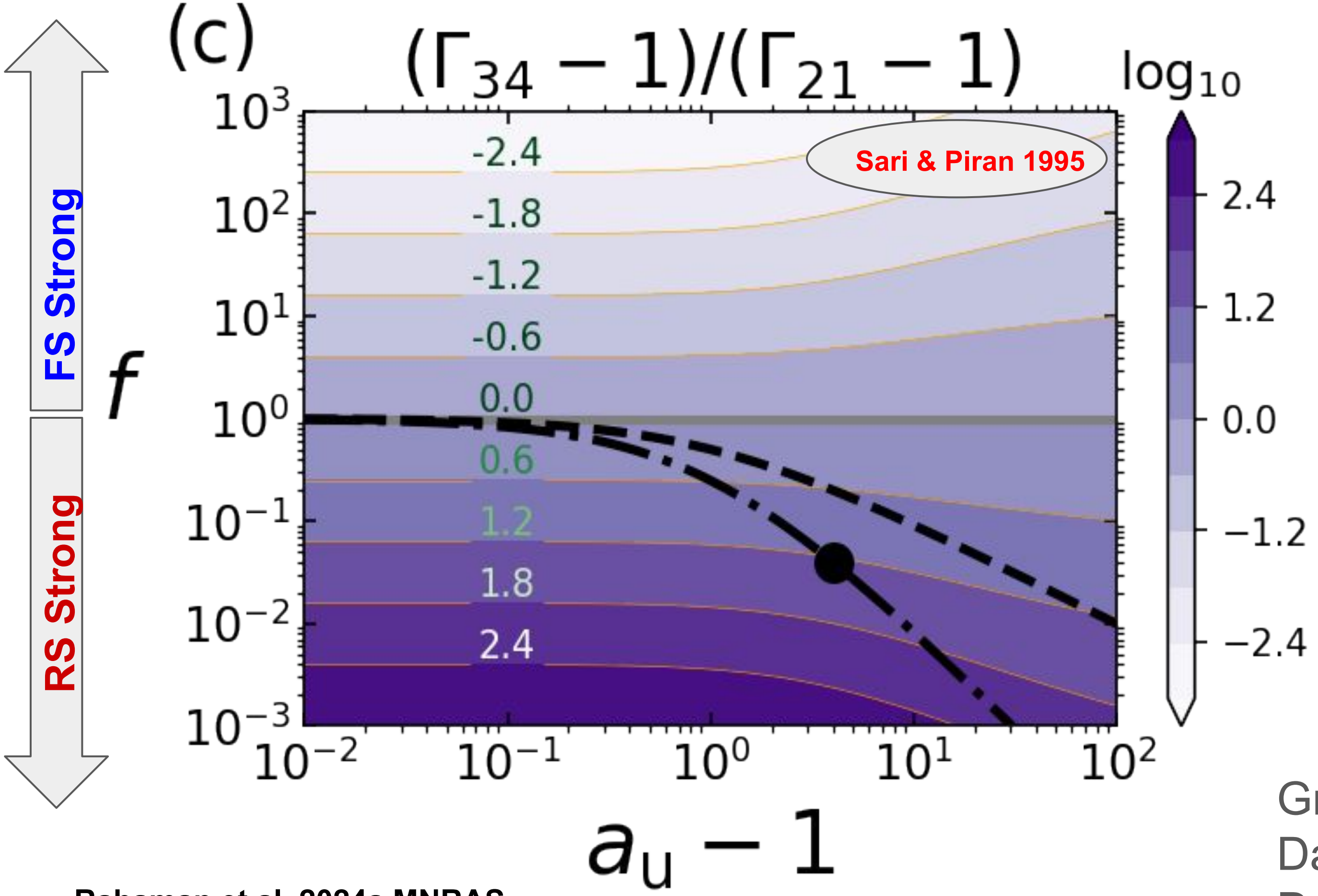
a)




## Post-collision

b)





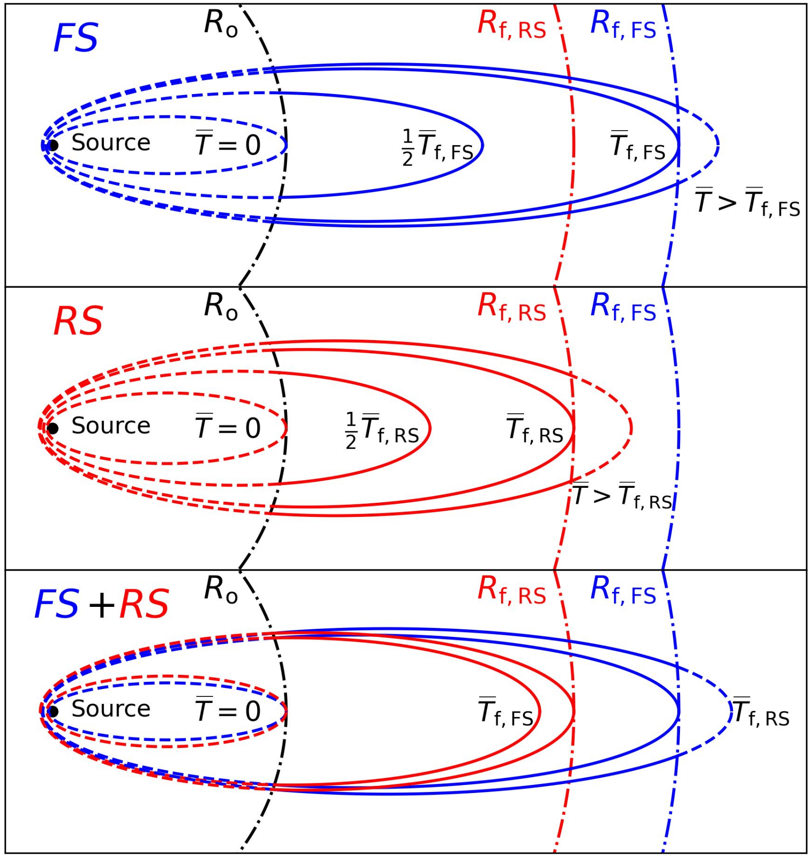

$$f = \frac{\rho'_4}{\rho'_1}$$

$$a_u = \frac{u_4}{u_1}$$

Grey - Eq. density
Dashed- Eq. Mass
Dot Dashed- Eq. Energy

**Rahaman et al. 2024a,MNRAS**

# Equal-Arrival-Time surfaces (EATs)




**Our model:**

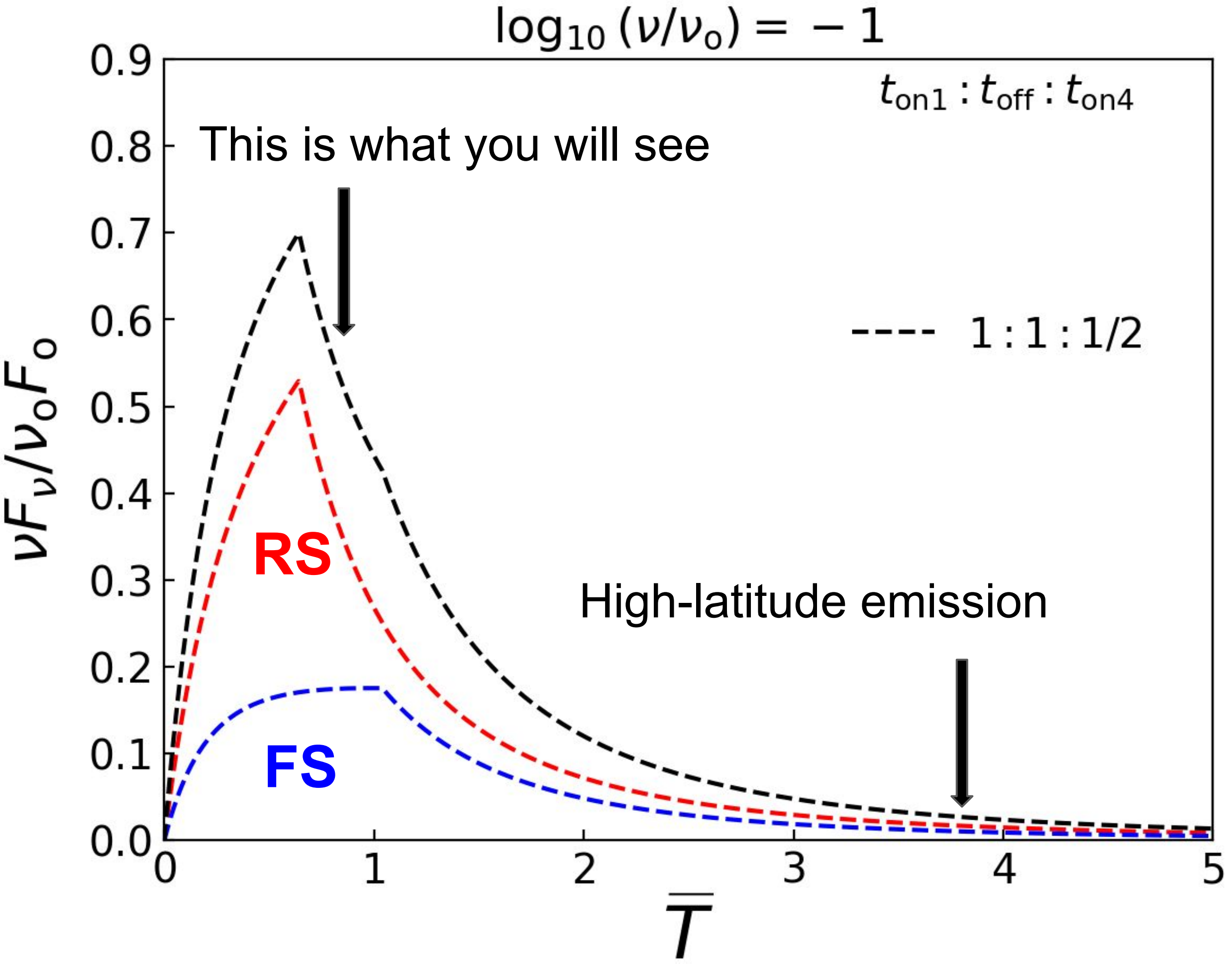
**One collision**

**Two shock fronts**

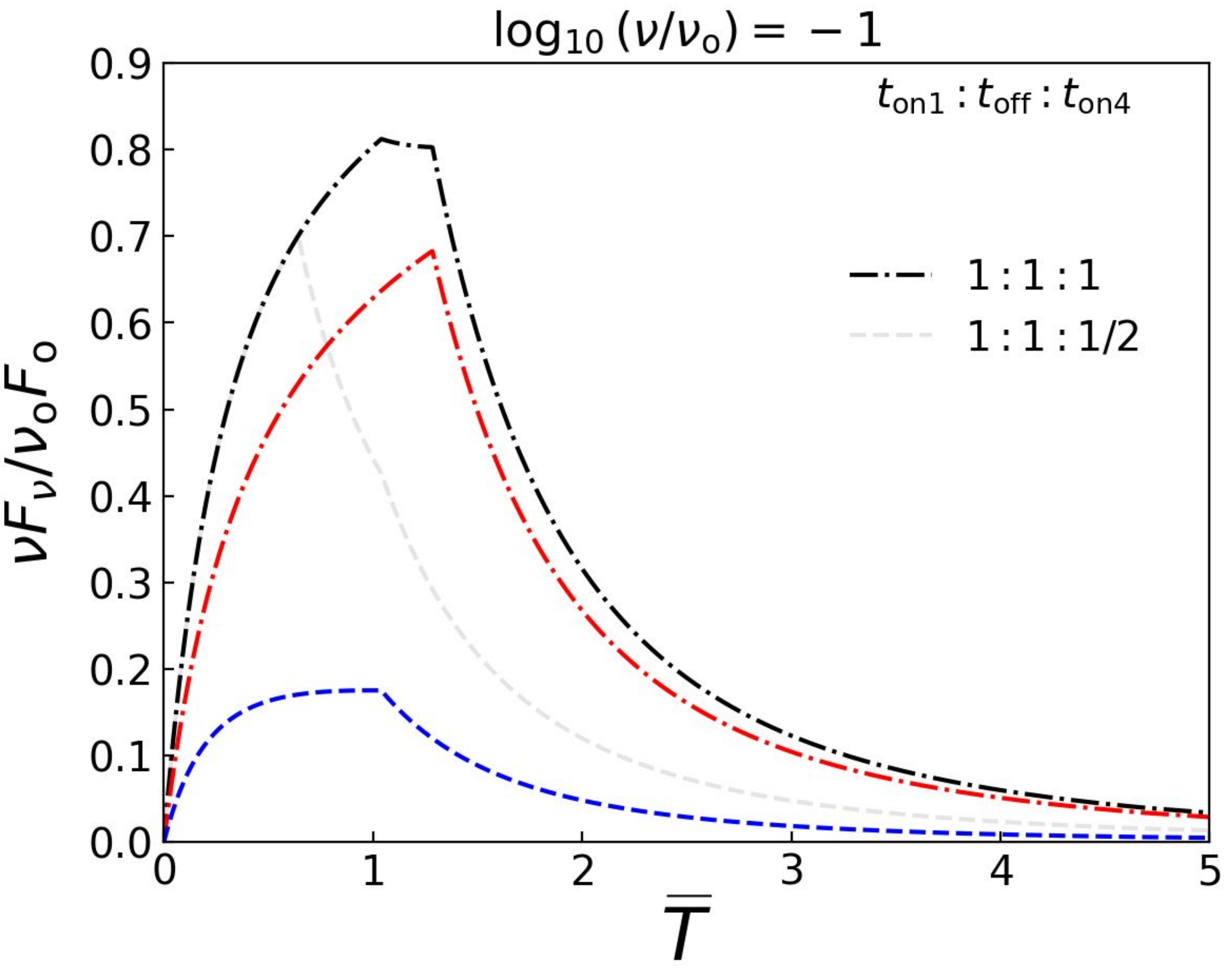
**One pulse**

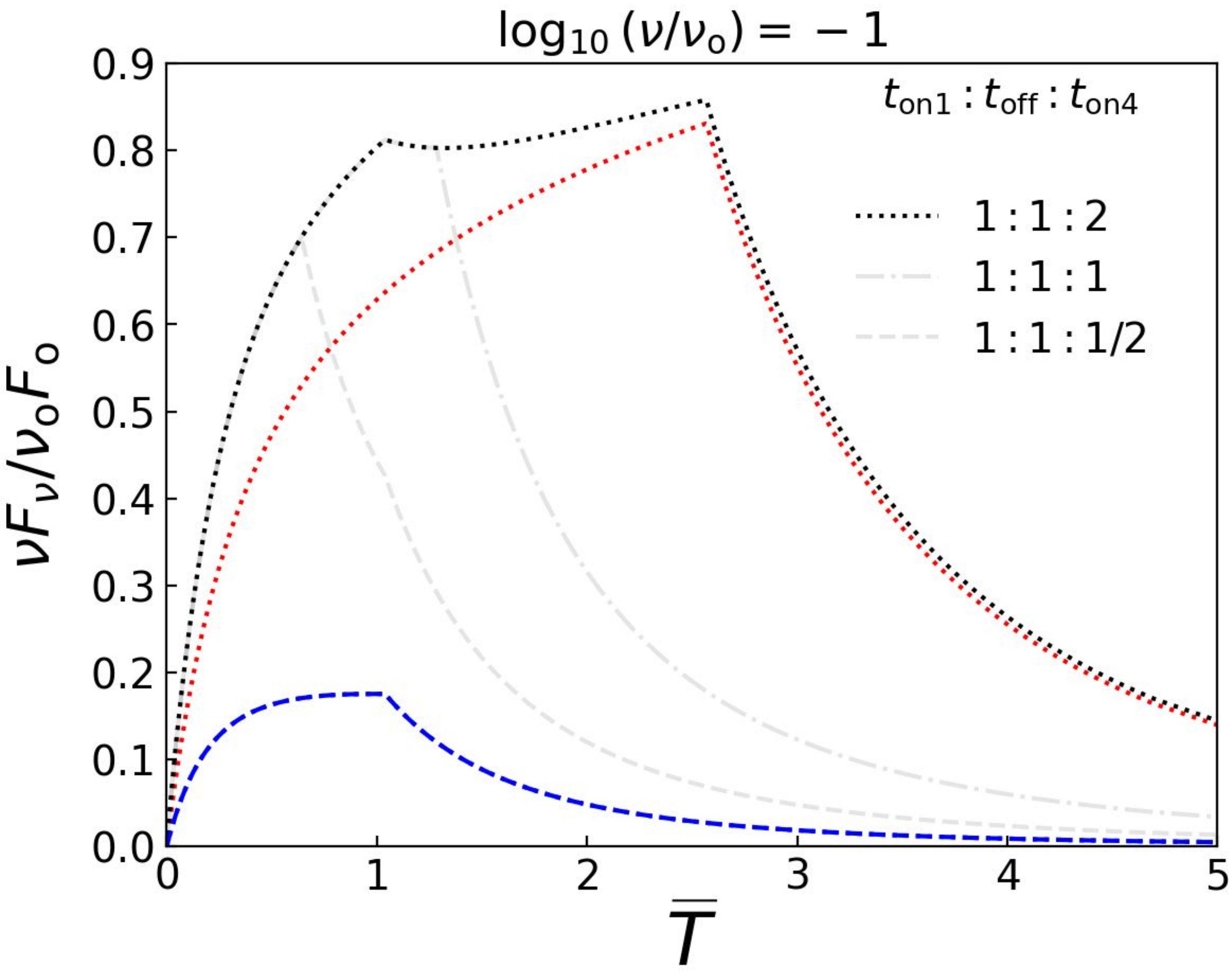
**Rahaman et al. 2024b,MNRASL**

# Light curve at a fixed frequency

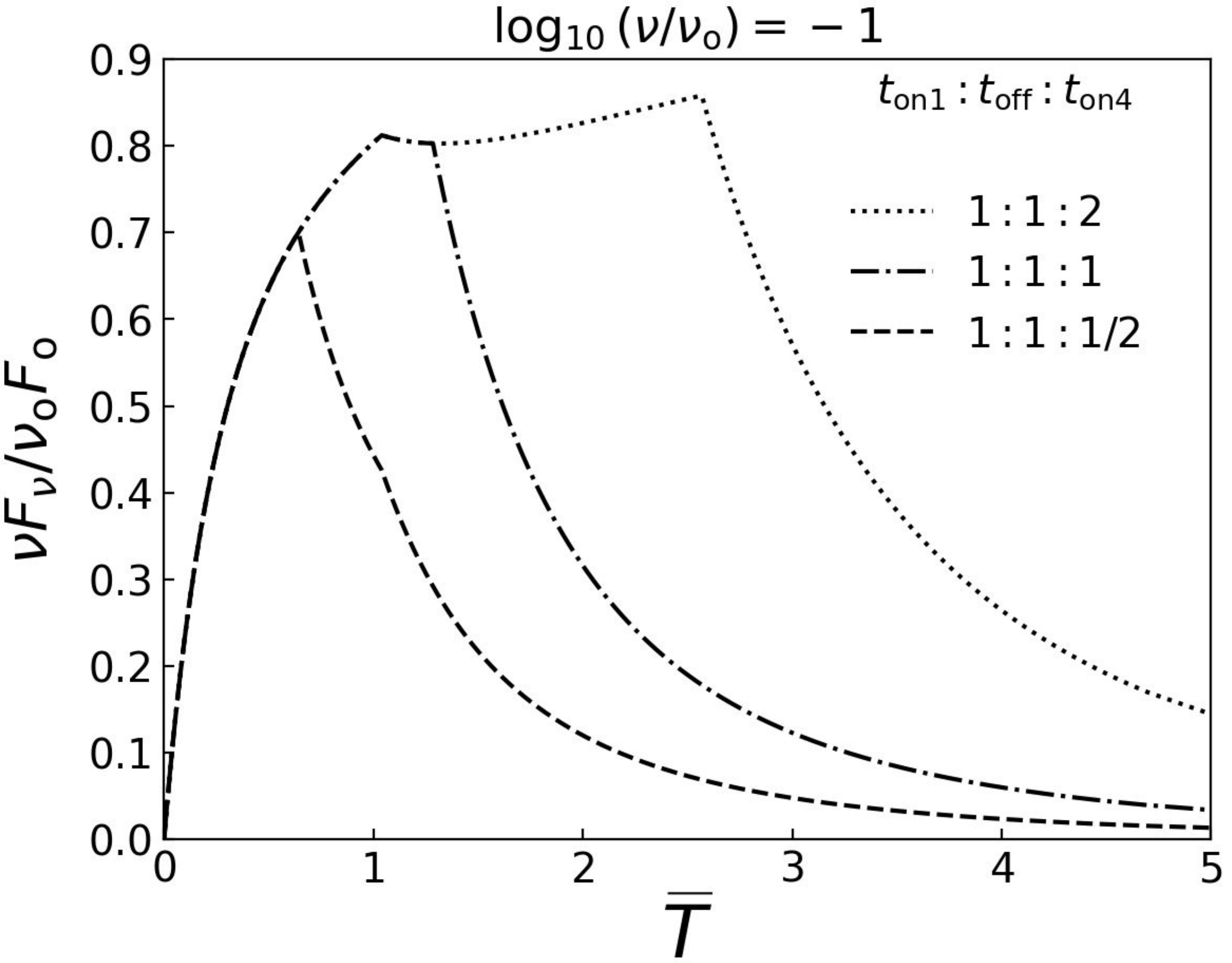


$\log_{10}(\nu/\nu_o) = -1$
$t_{on1} : t_{off} : t_{on4}$
This is what you will see
1 : 1 : 1/2
RS
FS
High-latitude emission
$\nu F_\nu / \nu_o F_o$
$\bar{T}$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
1
2
3
4
5


$\log_{10}(\nu/\nu_o) = -1$
$t_{on1} : t_{off} : t_{on4}$
1 : 1 : 1
1 : 1 : 1/2
$\nu F_\nu / \nu_o F_o$
$\bar{T}$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
1
2
3
4
5

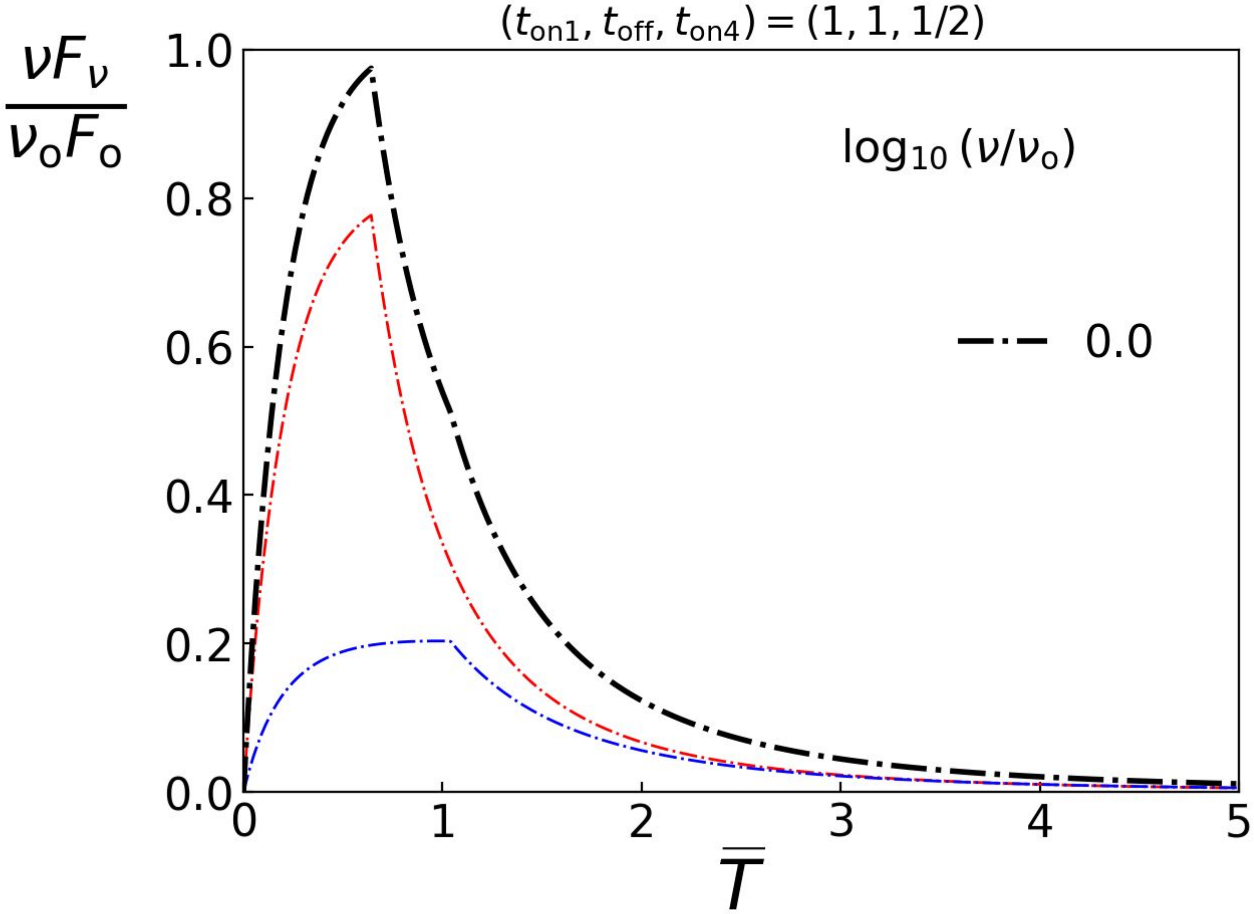


$\log_{10}(\nu/\nu_o) = -1$
$t_{on1} : t_{off} : t_{on4}$
1 : 1 : 2
1 : 1 : 1
1 : 1 : 1/2
$\nu F_\nu / \nu_o F_o$
$\bar{T}$
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
1
2
3
4
5

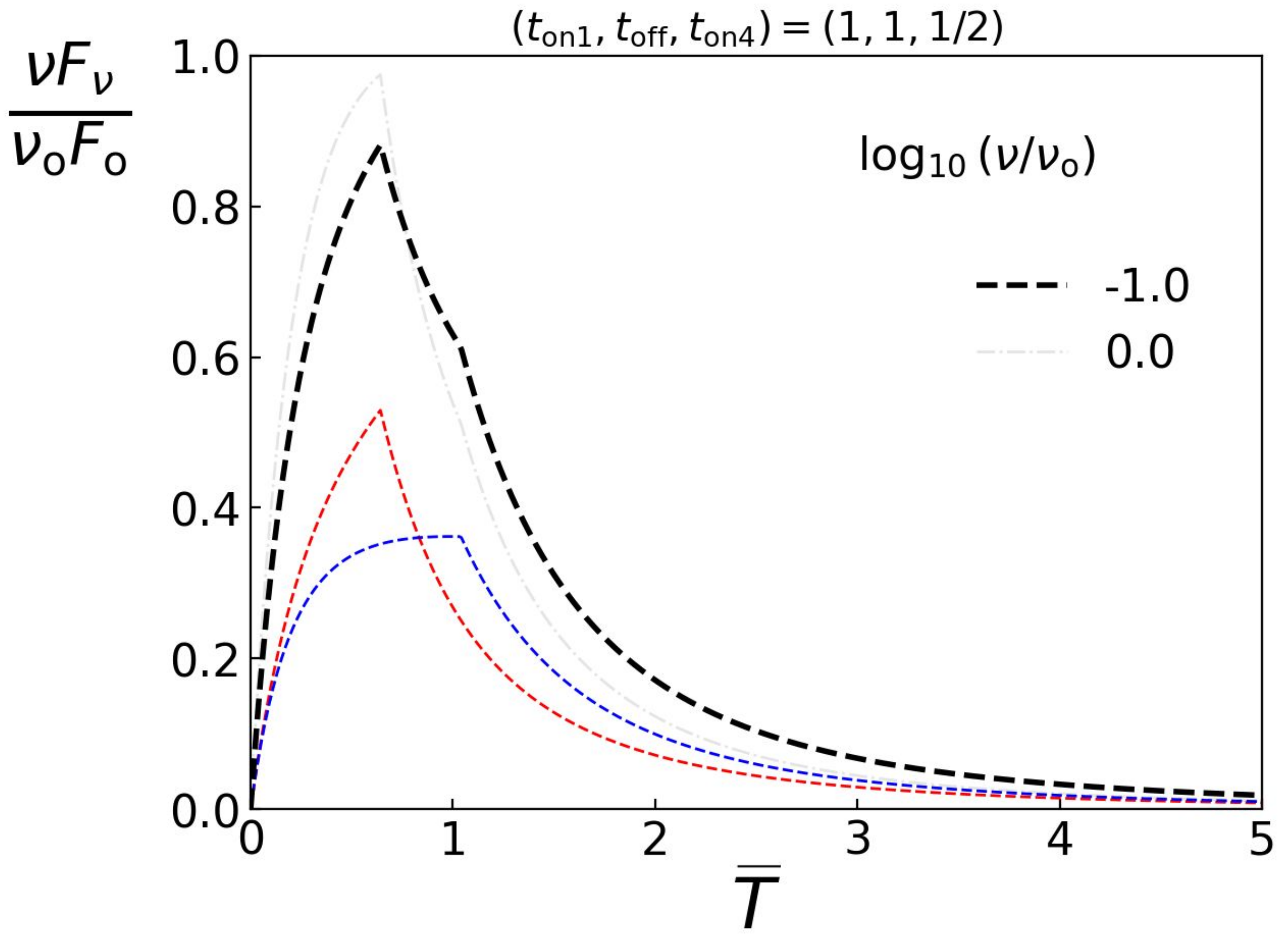



**Why does one pulse look different from another ?**

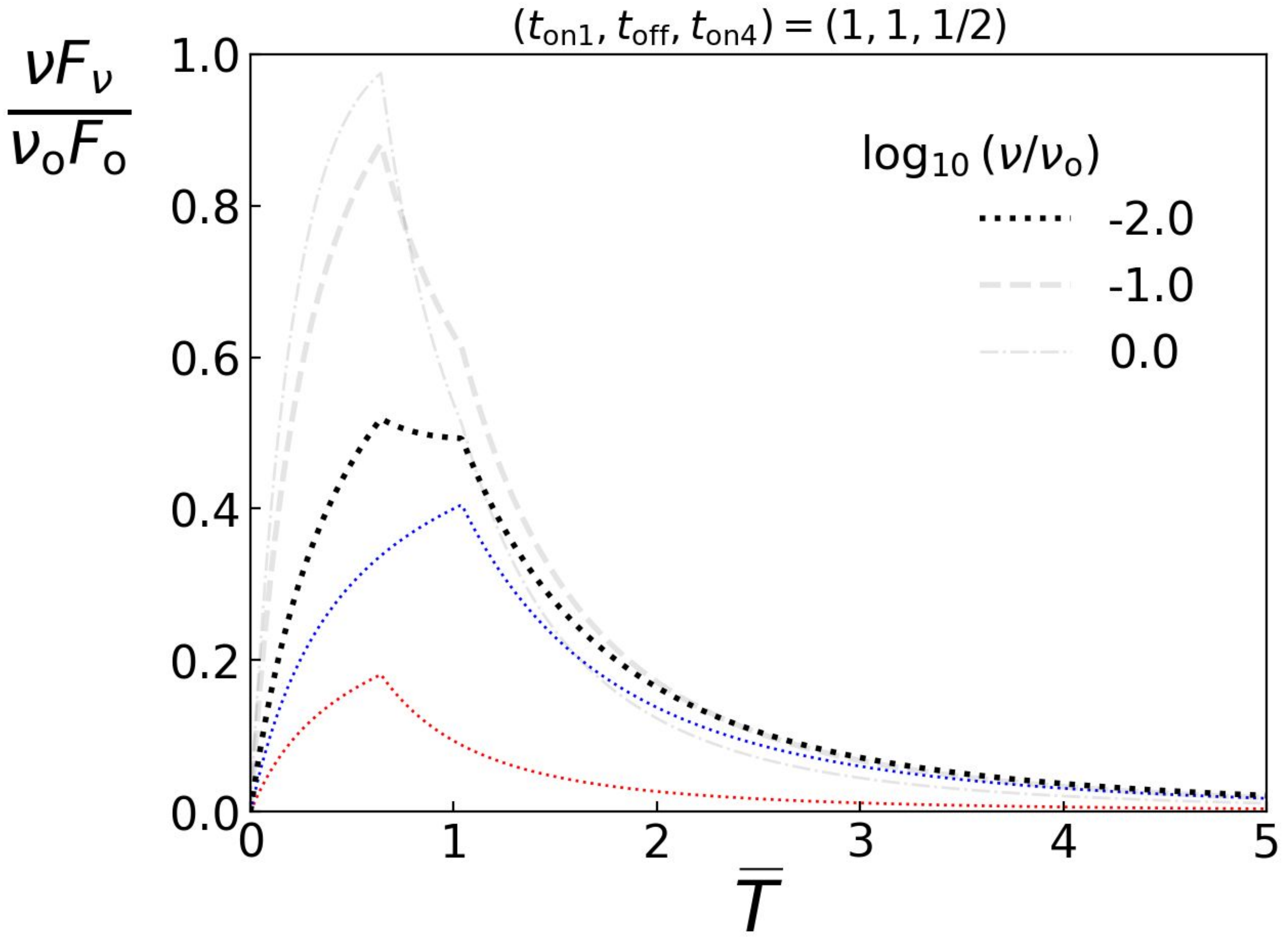
# Light curve at different frequencies

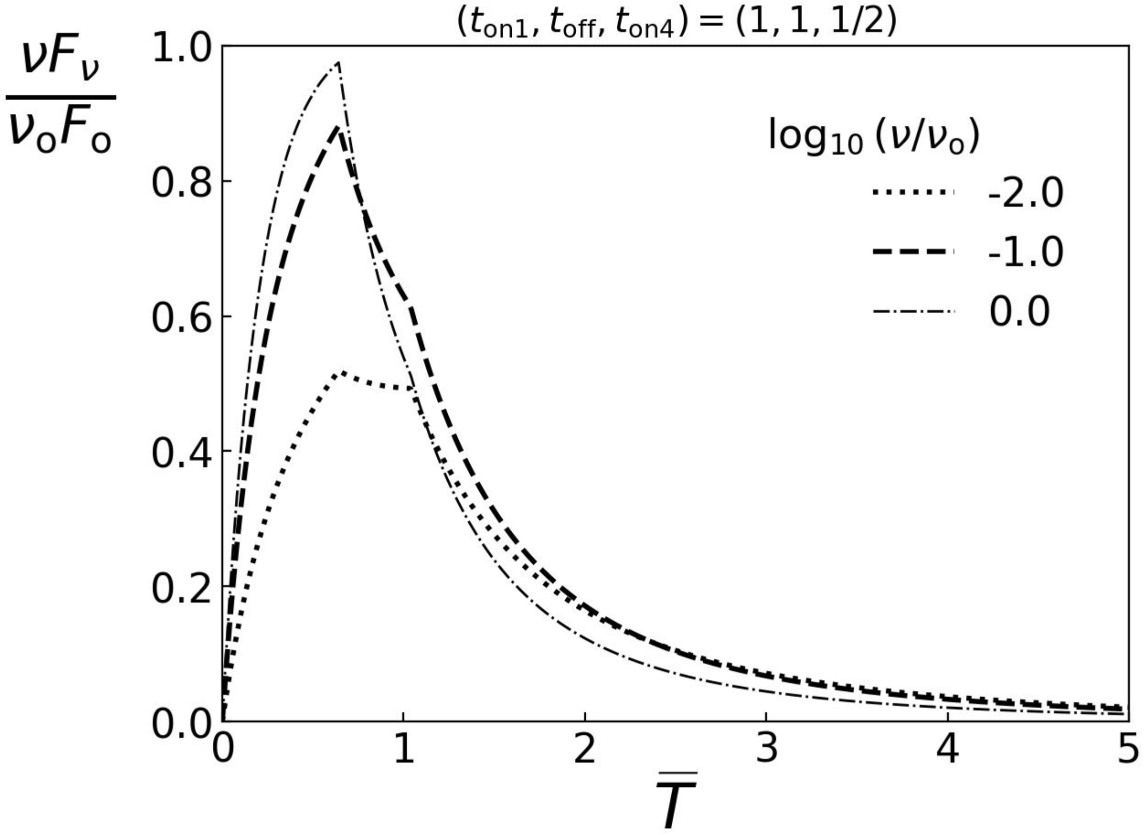


$(t_{\rm on1}, t_{\rm off}, t_{\rm on4}) = (1, 1, 1/2)$
$\frac{\nu F_\nu}{\nu_o F_o}$
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
$\bar{T}$
$\log_{10}(\nu/\nu_o)$
0.0



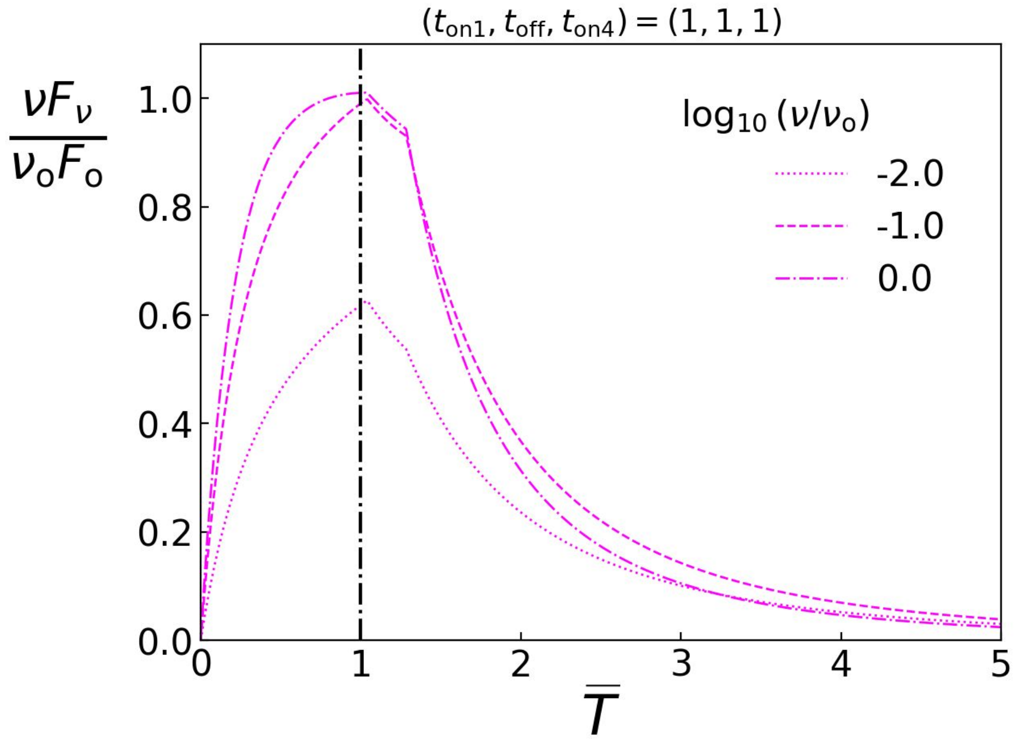
$(t_{on1}, t_{off}, t_{on4}) = (1, 1, 1/2)$
$\frac{\nu F_\nu}{\nu_o F_o}$
$\log_{10}(\nu/\nu_o)$
-1.0
0.0
0.0
0.2
0.4
0.6
0.8
1.0
0
1
2
3
4
5
$\bar{T}$


$(t_{on1}, t_{off}, t_{on4}) = (1, 1, 1/2)$
$\frac{\nu F_\nu}{\nu_o F_o}$
$\log_{10}(\nu/\nu_o)$
-2.0
-1.0
0.0
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
$\overline{T}$

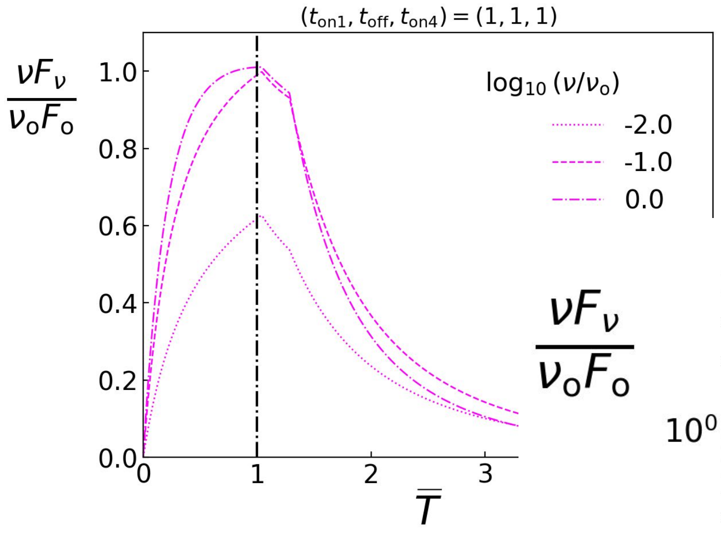



**Why does a pulse look different at different frequencies ?**

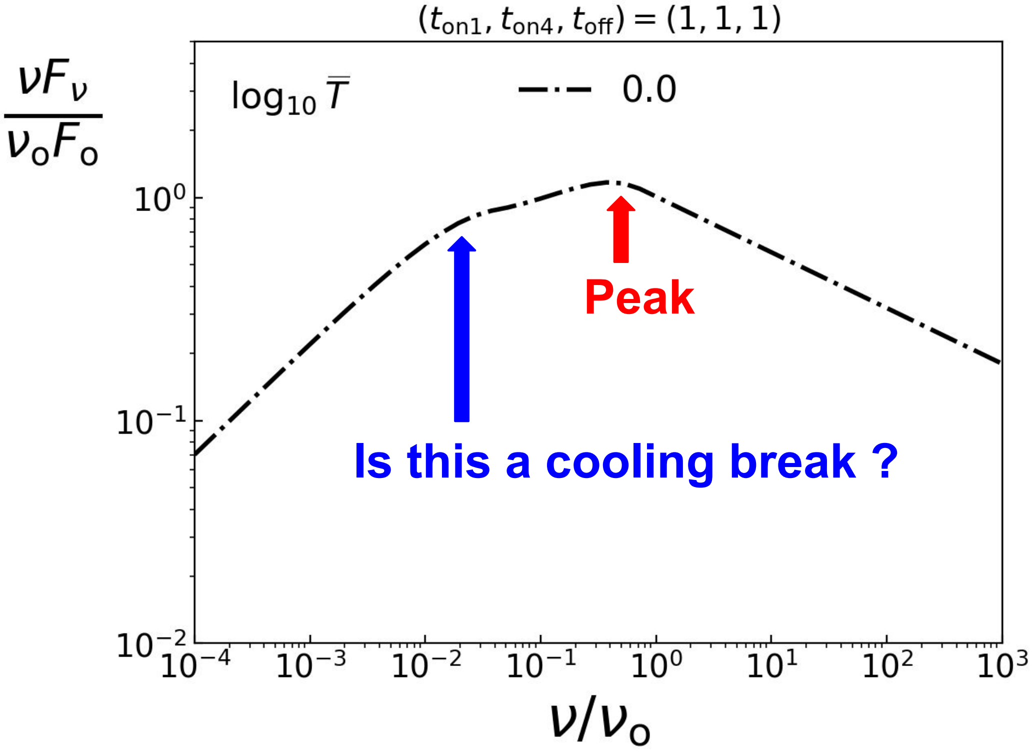
# Instantaneous Spectrum



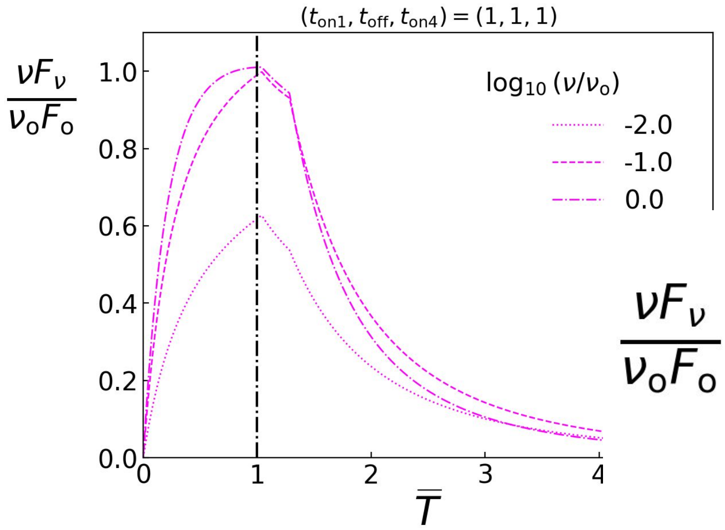
$(t_{\rm on1}, t_{\rm off}, t_{\rm on4}) = (1, 1, 1)$
$\frac{\nu F_\nu}{\nu_o F_o}$
1.0
0.8
0.6
0.4
0.2
0.0
0
1
2
3
4
5
$\overline{T}$
$\log_{10}(\nu/\nu_o)$
-2.0
-1.0
0.0



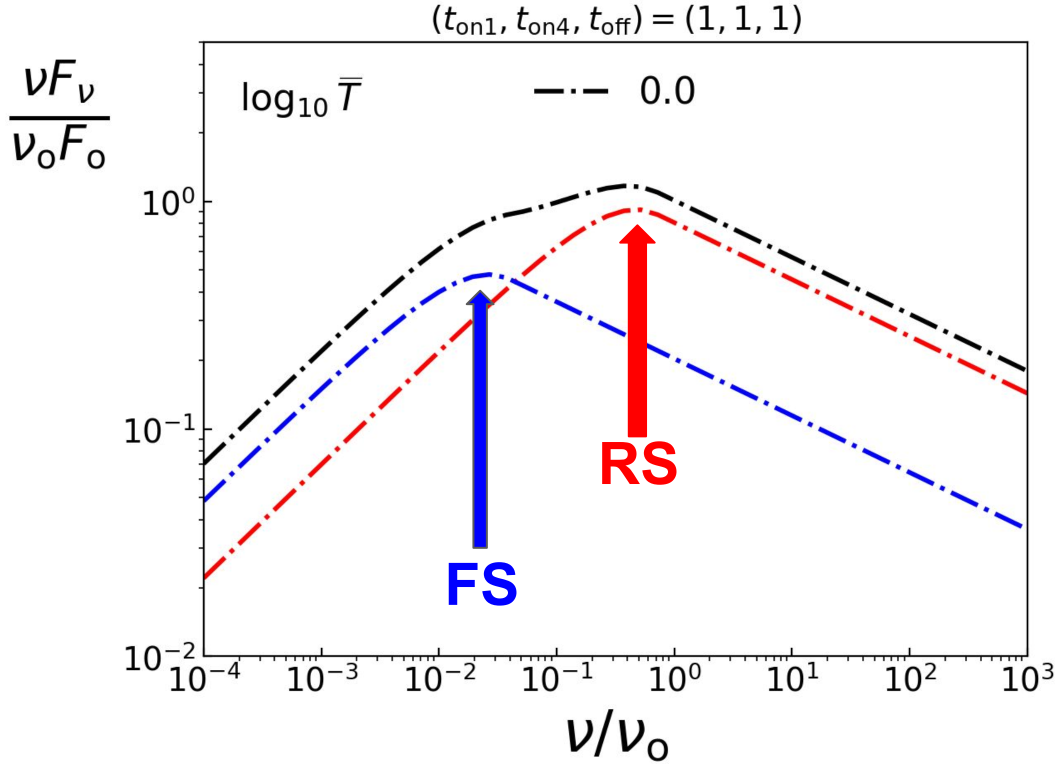
$(t_{on1}, t_{off}, t_{on4}) = (1, 1, 1)$
$\frac{\nu F_\nu}{\nu_o F_o}$
$\log_{10}(\nu/\nu_o)$
-2.0
-1.0
0.0
$\overline{T}$

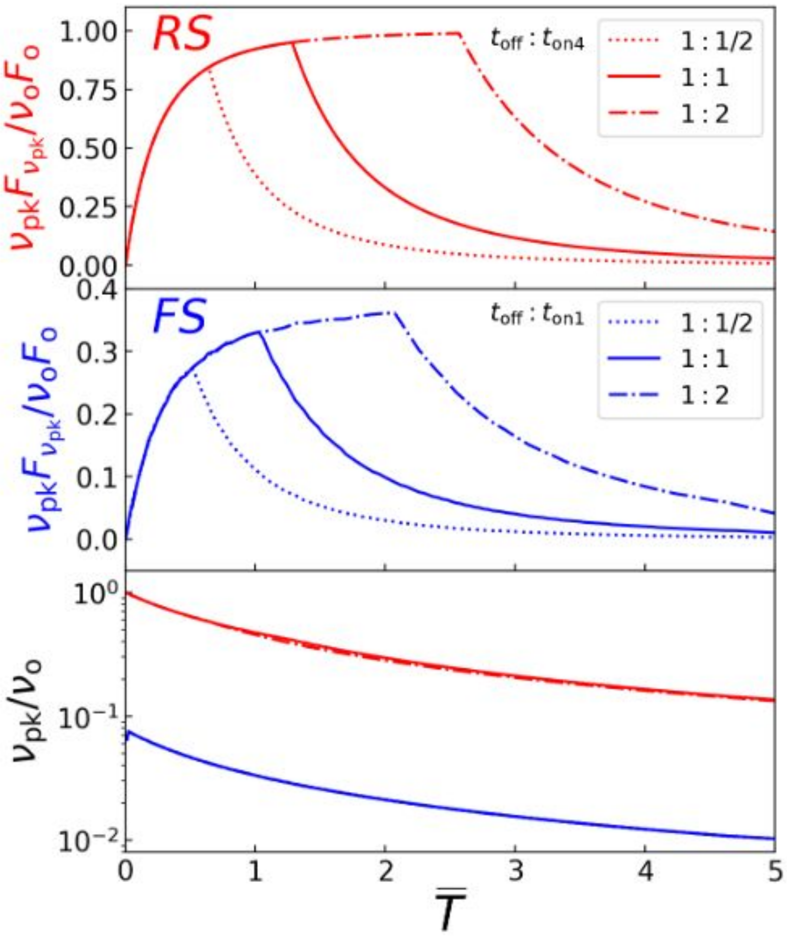
$(t_{on1}, t_{on4}, t_{off}) = (1, 1, 1)$
$\frac{\nu F_\nu}{\nu_o F_o}$
$\log_{10} \overline{T}$
0.0
Peak
Is this a cooling break ?
$\nu/\nu_o$

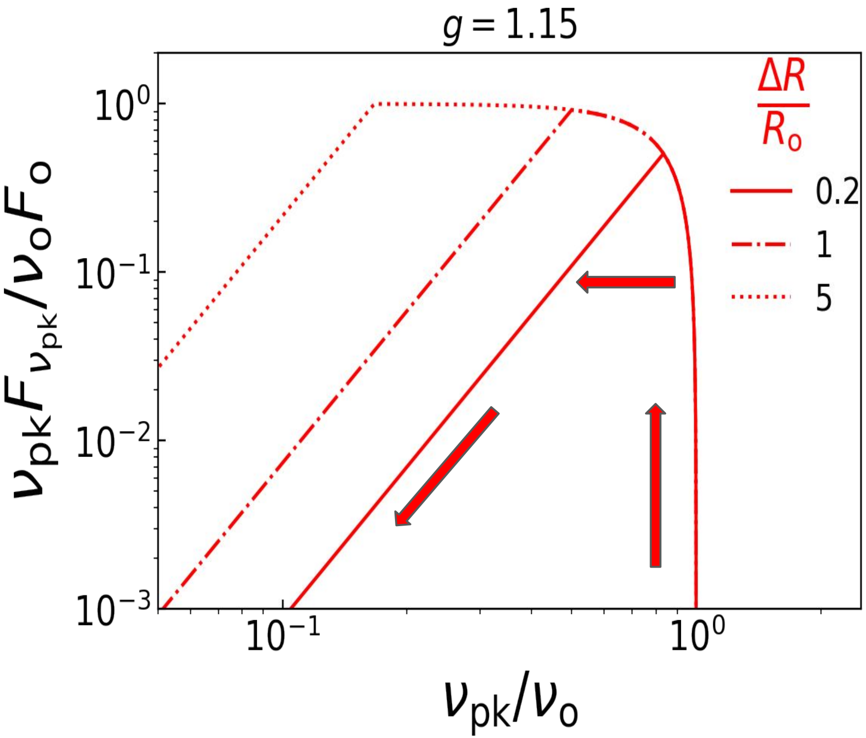


$(t_{on1}, t_{off}, t_{on4}) = (1, 1, 1)$
$\frac{\nu F_\nu}{\nu_o F_o}$
$\log_{10}(\nu/\nu_o)$
-2.0
-1.0
0.0
$\overline{T}$

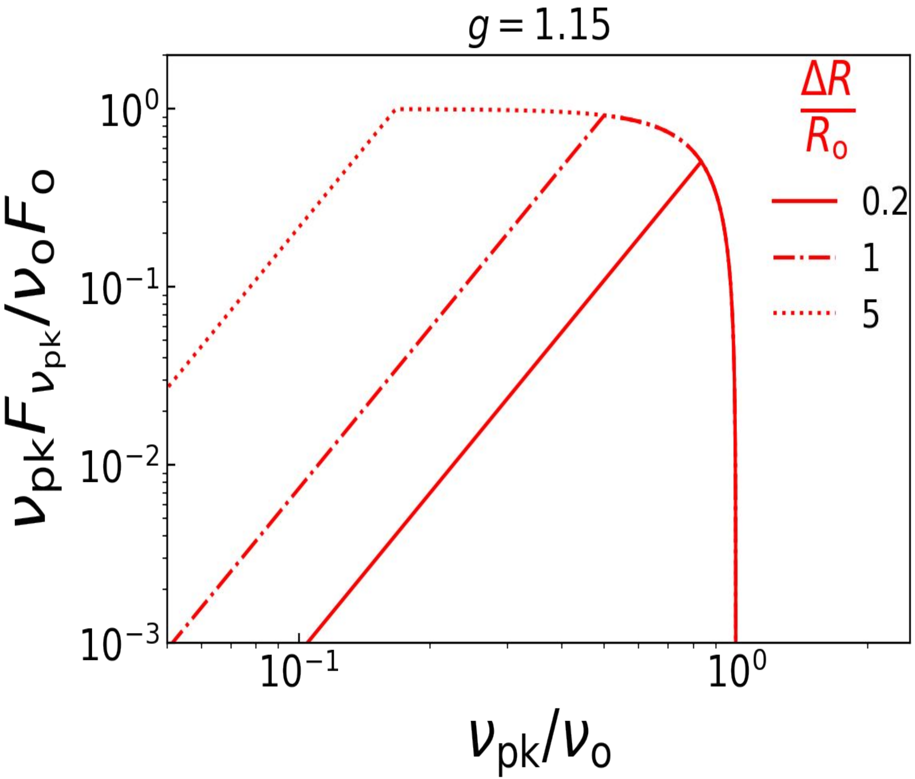
$(t_{on1}, t_{on4}, t_{off}) = (1, 1, 1)$
$\frac{\nu F_\nu}{\nu_o F_o}$
$\log_{10}\overline{T}$
0.0
RS
FS
$\nu/\nu_o$



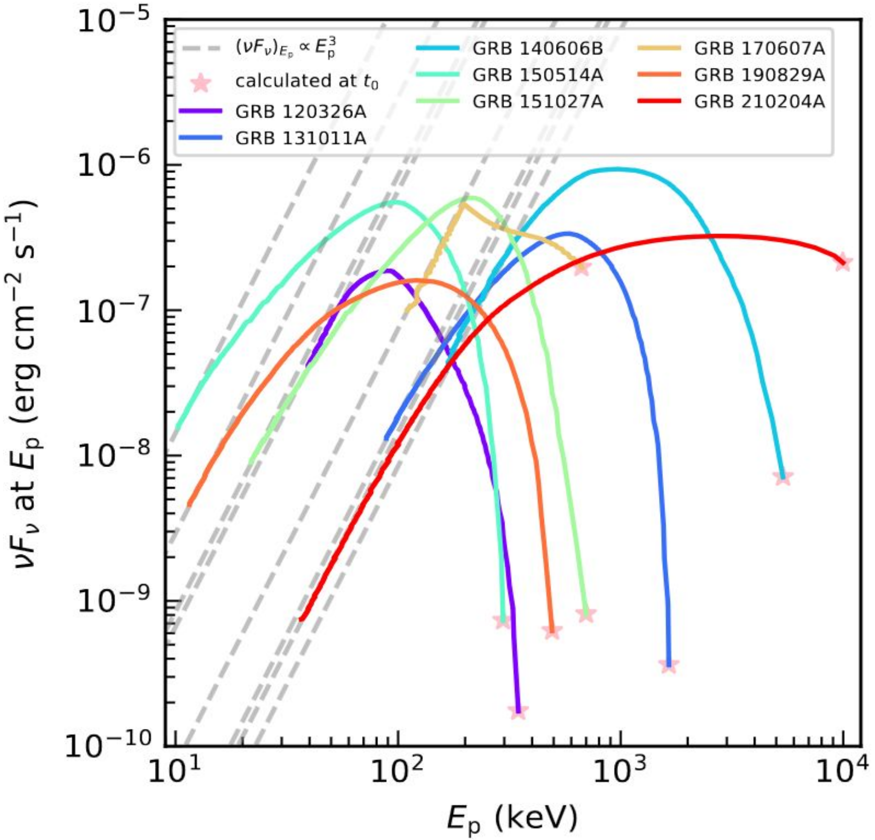




**Rahaman et al. 2024b, MNRASL**

# Tool for inferences

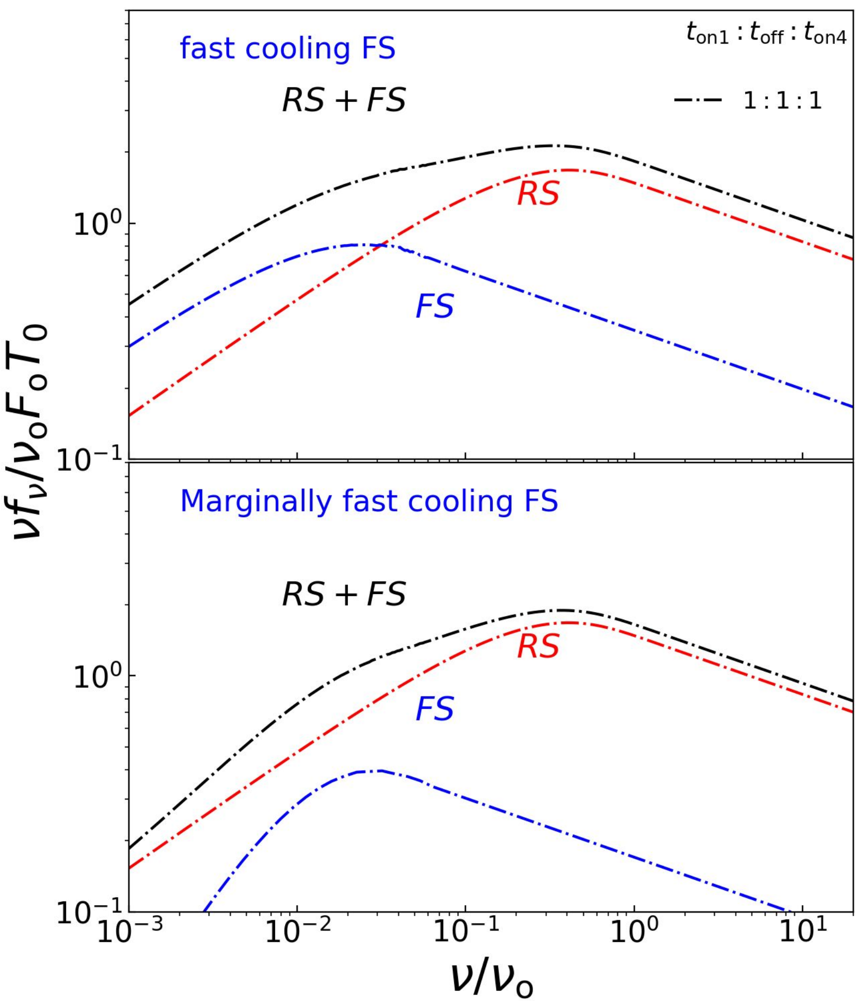



Rahaman et al. 2024a, MNRASL




Yan et al. (2023)

# Integrated Spectrum

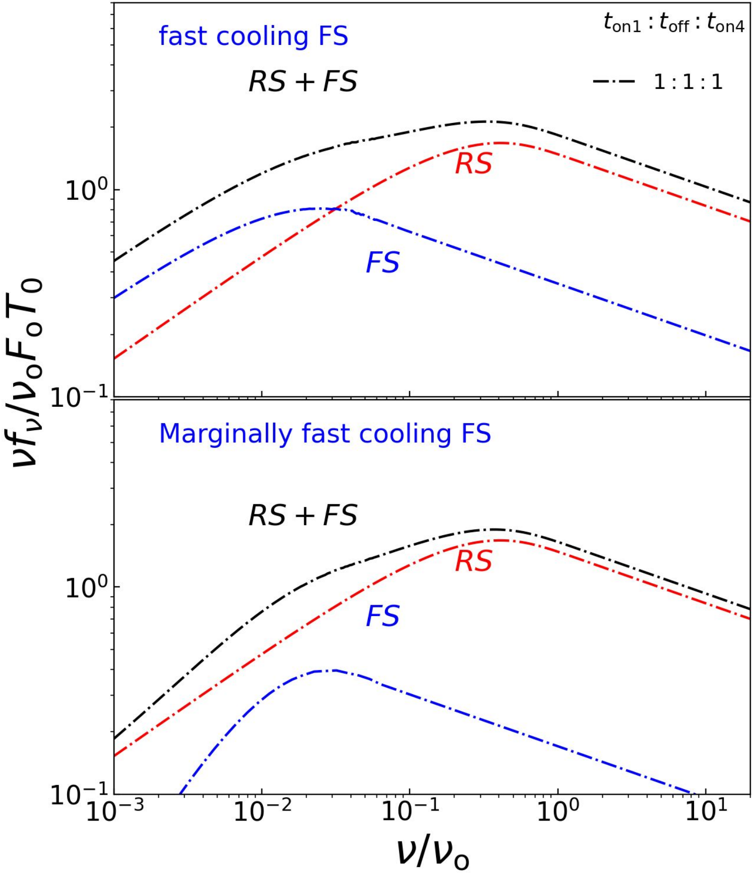


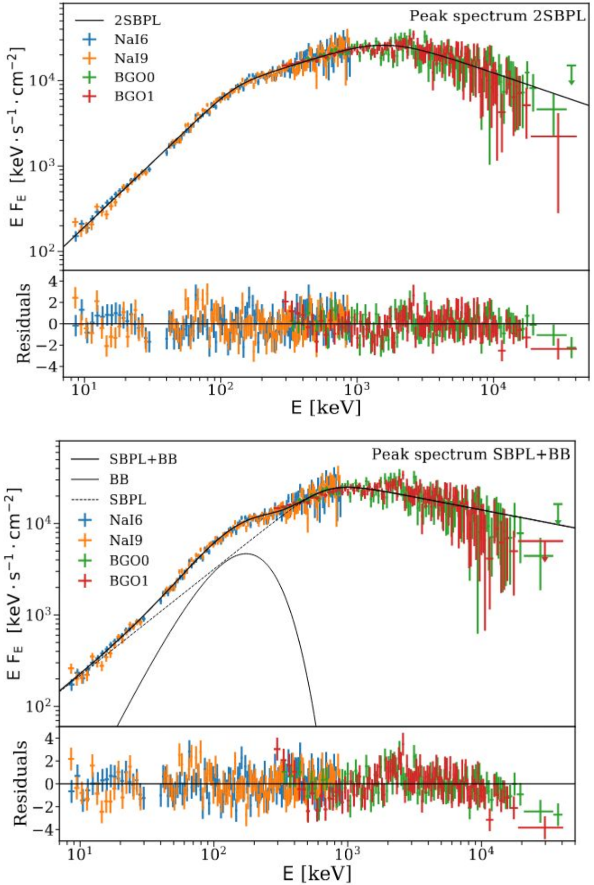

Fast - electrons cooling time faster than shock crossing

Marginally fast - electrons cooling time comparable to shock crossing

**Daigne et al. 2011, Beniamini et al. 2018**

# GRB 160625

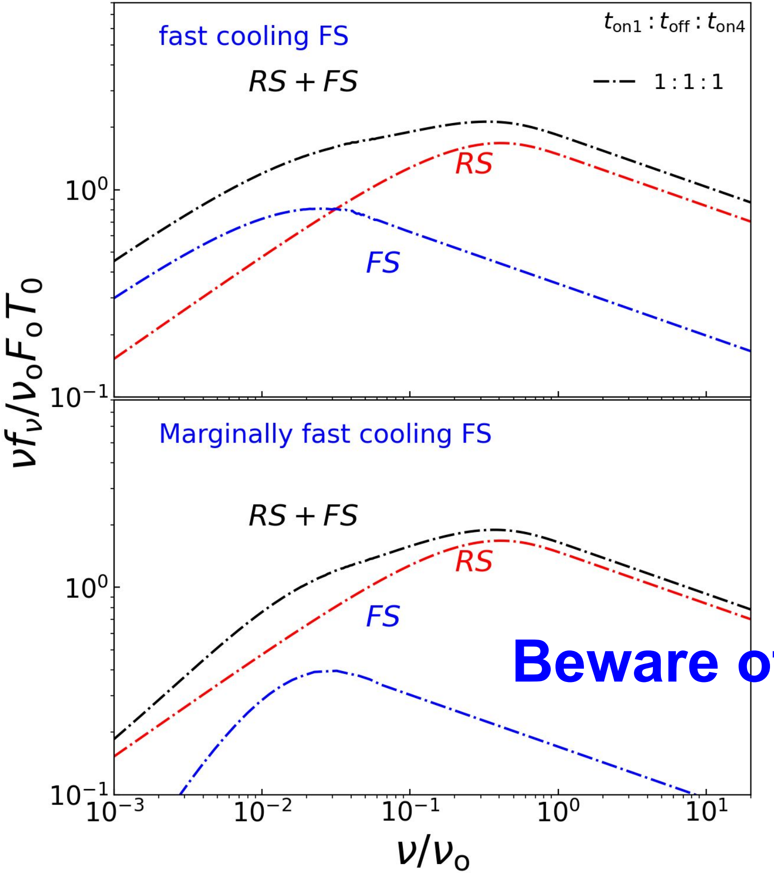


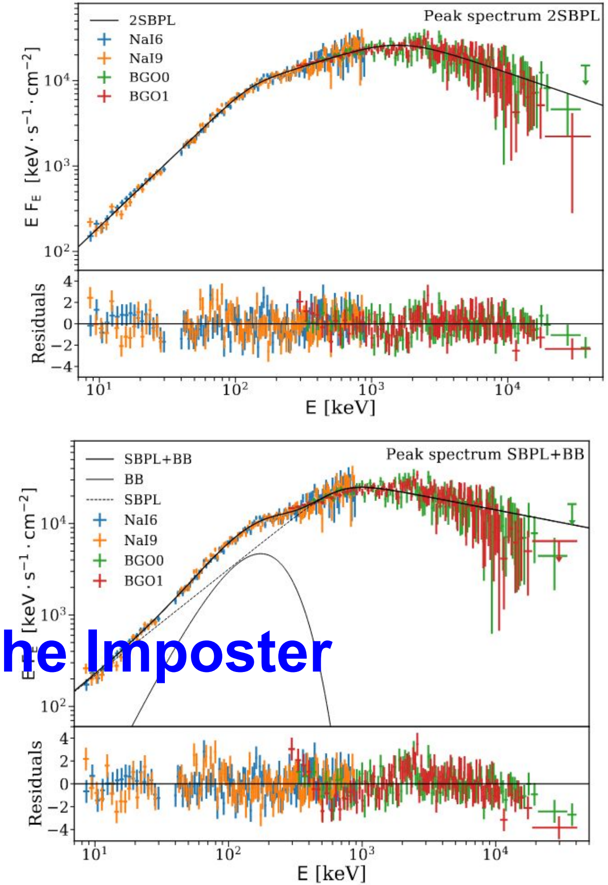




Ravasio et al. 2018

**Marginally-fast FS can mimic phostopheric behaviour**

## GRB 160625




**Beware of the Imposter**

Ravasio et al. 2018

**Marginally-fast FS can mimic phostopheric behaviour**

# Conclusions

*Reverse shock is usually stronger than the forward shock*

*Observed emission is superposition of emission from both shocked regions*

*Diversity of pulse morphology can be reproduced*

**Predictive power to derive important physical parameters associated with the outflow**

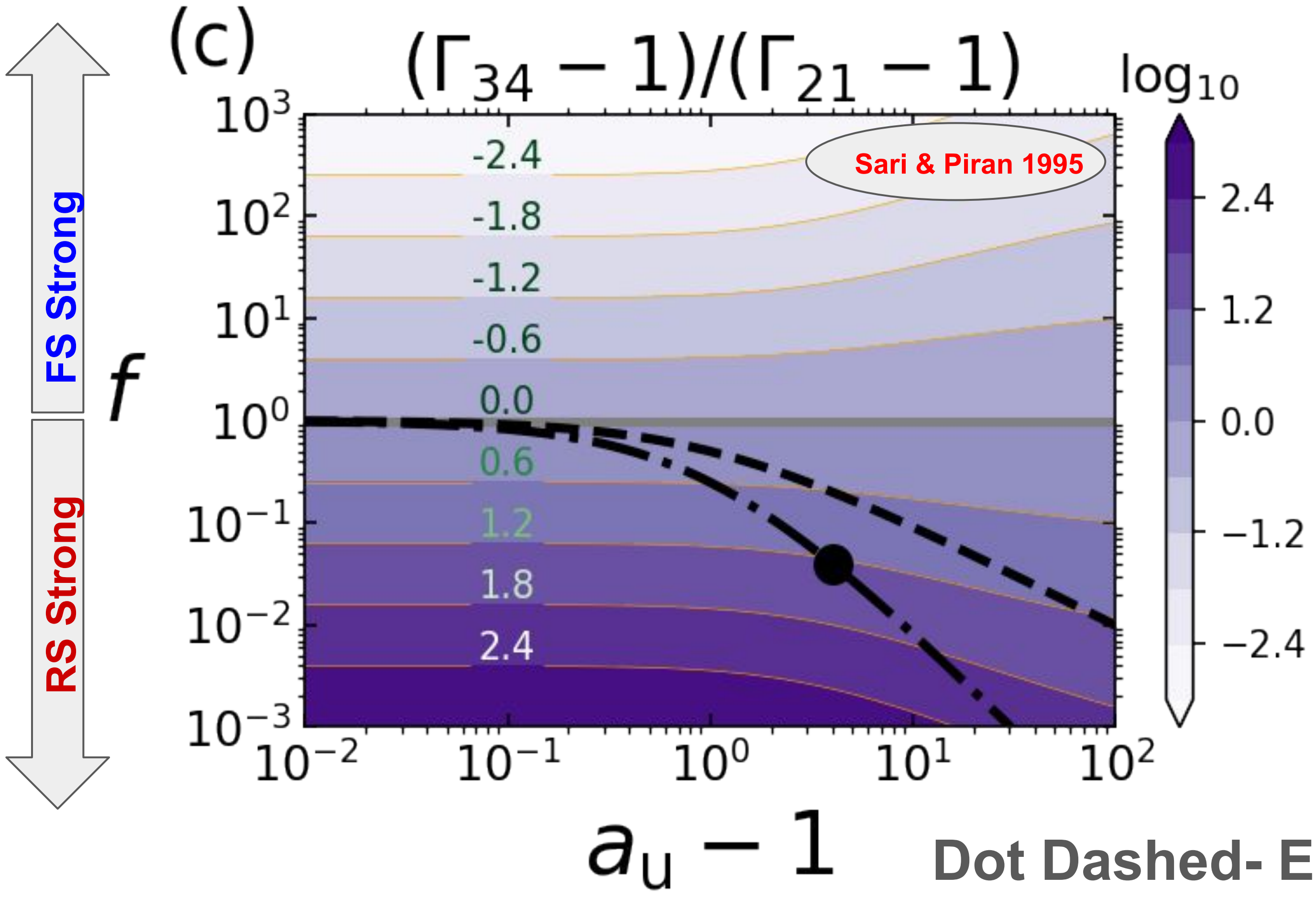
**Rahaman et al. 2024 a,b**

Granot Rahaman Beniamini

*“And Now I see with my eyes serene*
*The very pulse of the machine ; ”*

- Wordsworth

Thank you for your attention

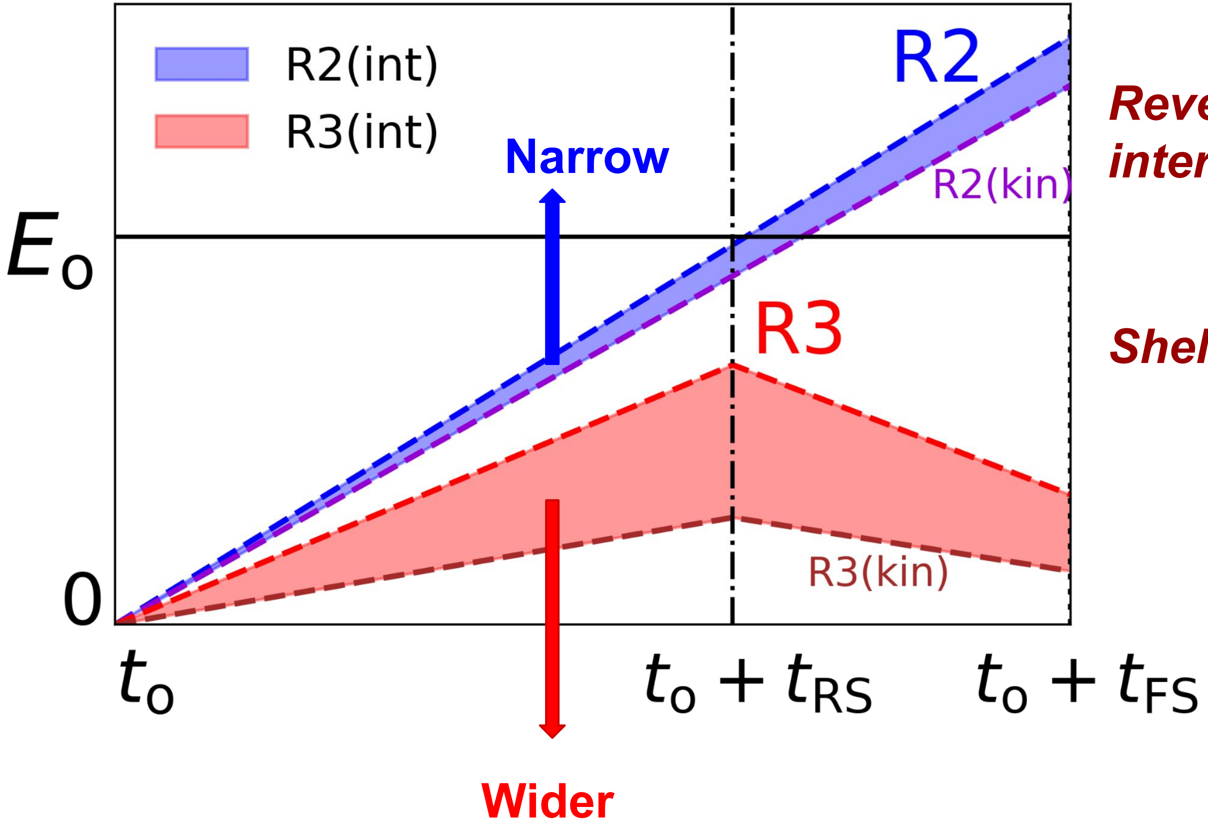



$$f = \frac{\rho'_4}{\rho'_1}$$

$$a_u = \frac{u_4}{u_1}$$

**Dot Dashed- Eq. Source power**

## Two- shock fronts- Internal energy dissipation



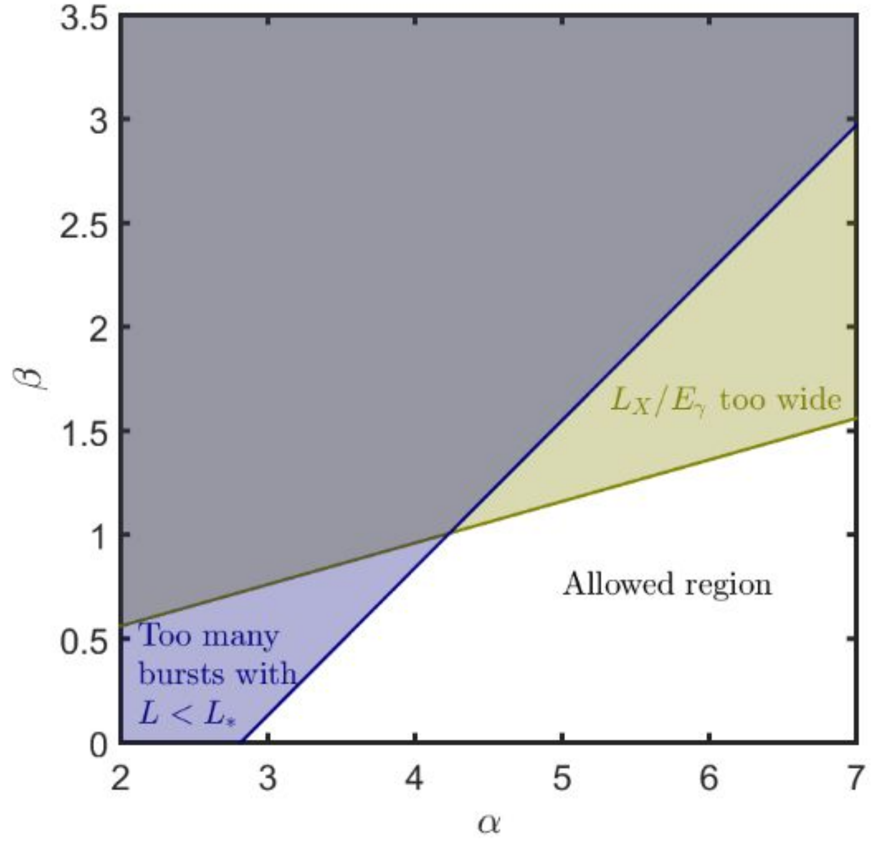

***Reverse shock dominates internal energy dissipation.***

***Shell crossing times different.***

Rahaman et al. 2024a,MNRAS

## **Suggestion:** Gamma-ray production must fall very sharply in the Off-axis region

**Beniamini & Nakar 2018**



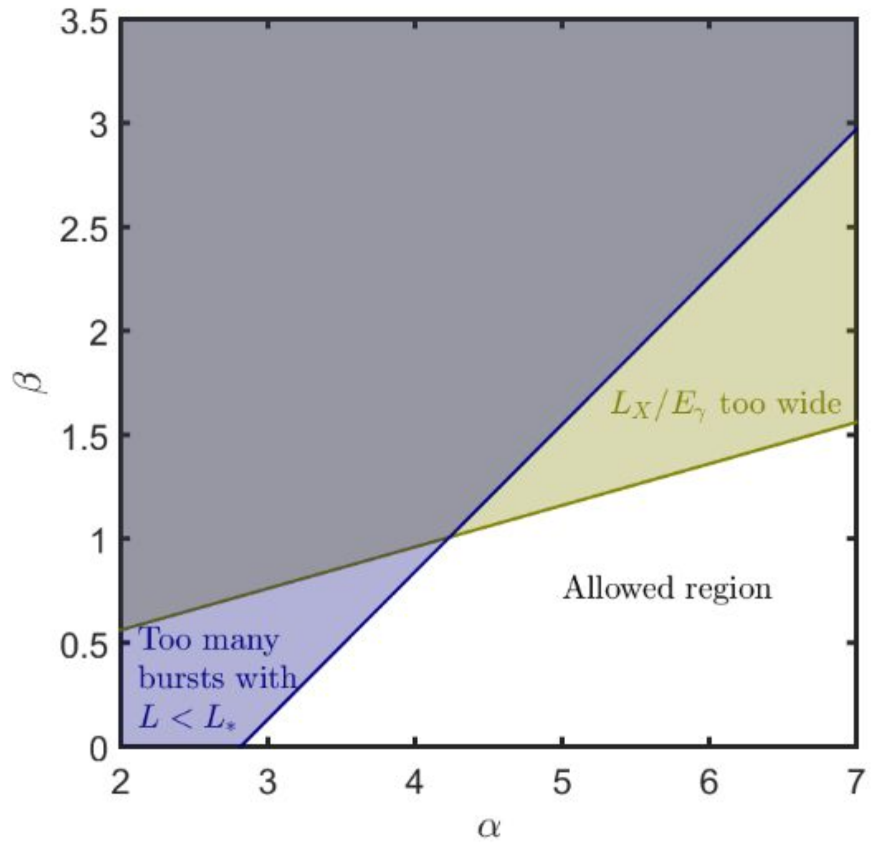

$$\epsilon(\theta) = \frac{dE}{d\Omega} = \epsilon_0 \begin{cases} 1 & \theta < \theta_0 \,, \\ \left(\frac{\theta}{\theta_0}\right)^{-\alpha} & \theta \geqslant \theta_0 \,, \end{cases}$$

$$\Gamma(\theta) = 1 + (\Gamma_0 - 1) \begin{cases} 1 & \theta < \theta_0 \\ \left(\frac{\theta}{\theta_0}\right)^{-\beta} & \theta \geqslant \theta_0 \end{cases}$$

Assumption: Dissipation efficiency is constant across the profile

**Suggestion:** Gamma-ray production must fall very sharply in the Off-axis region

**Beniamini & Nakar 2018**




$$\epsilon(\theta) = \frac{dE}{d\Omega} = \epsilon_0 \begin{cases} 1 & \theta < \theta_0 \,, \\ \left(\frac{\theta}{\theta_0}\right)^{-\alpha} & \theta \geqslant \theta_0 \,, \end{cases}$$

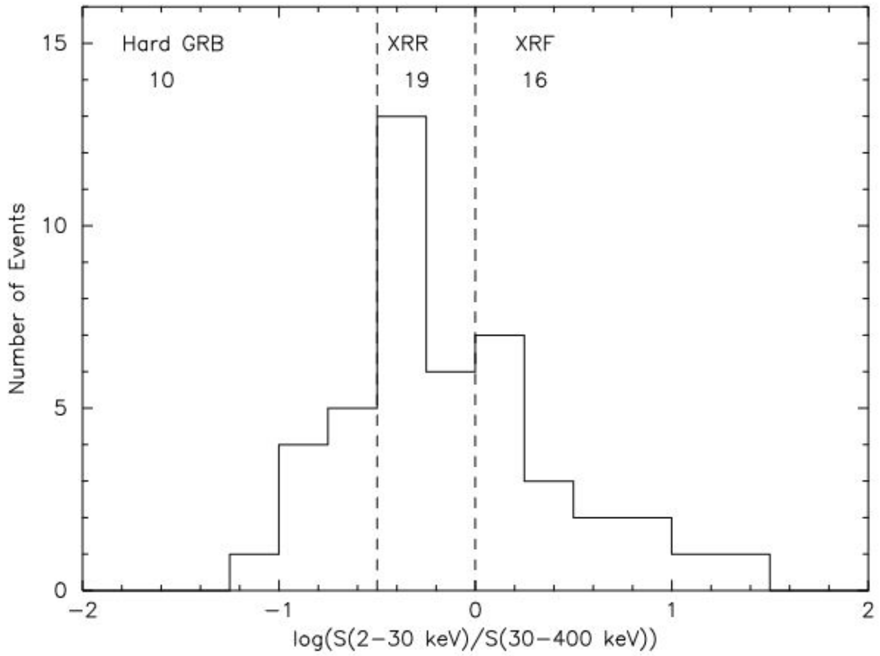
$$\Gamma(\theta) = 1 + (\Gamma_0 - 1) \begin{cases} 1 & \theta < \theta_0 \\ \left(\frac{\theta}{\theta_0}\right)^{-\beta} & \theta \geqslant \theta_0 \end{cases}$$

Suggestion: Dissipation efficiency **CANNOT BE CONSTANT** across the profile

**Proof by contradiction !!!**

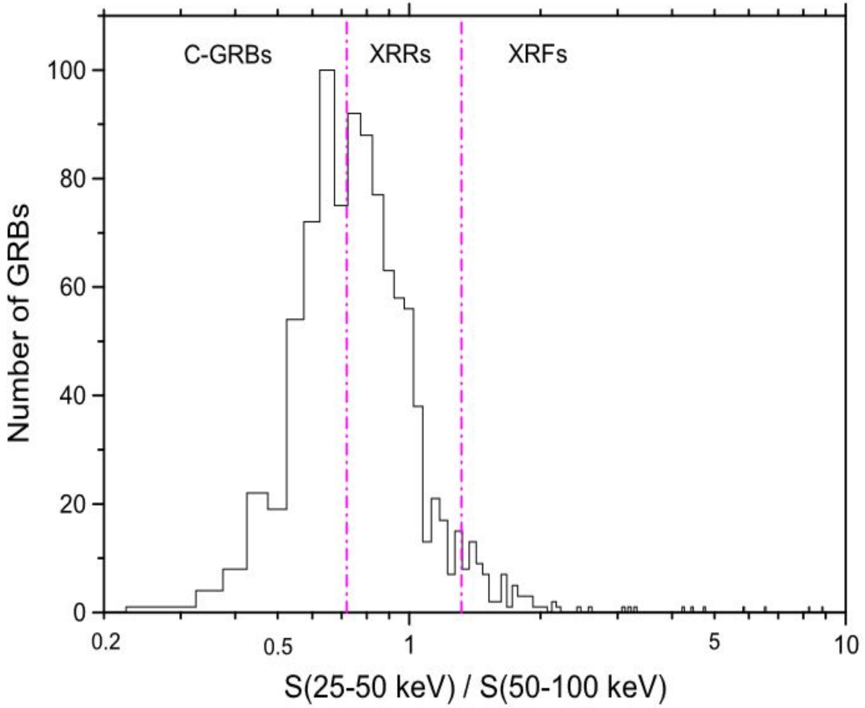
**Observations:** Three different classes from the same underlying distribution

*HETE-2*



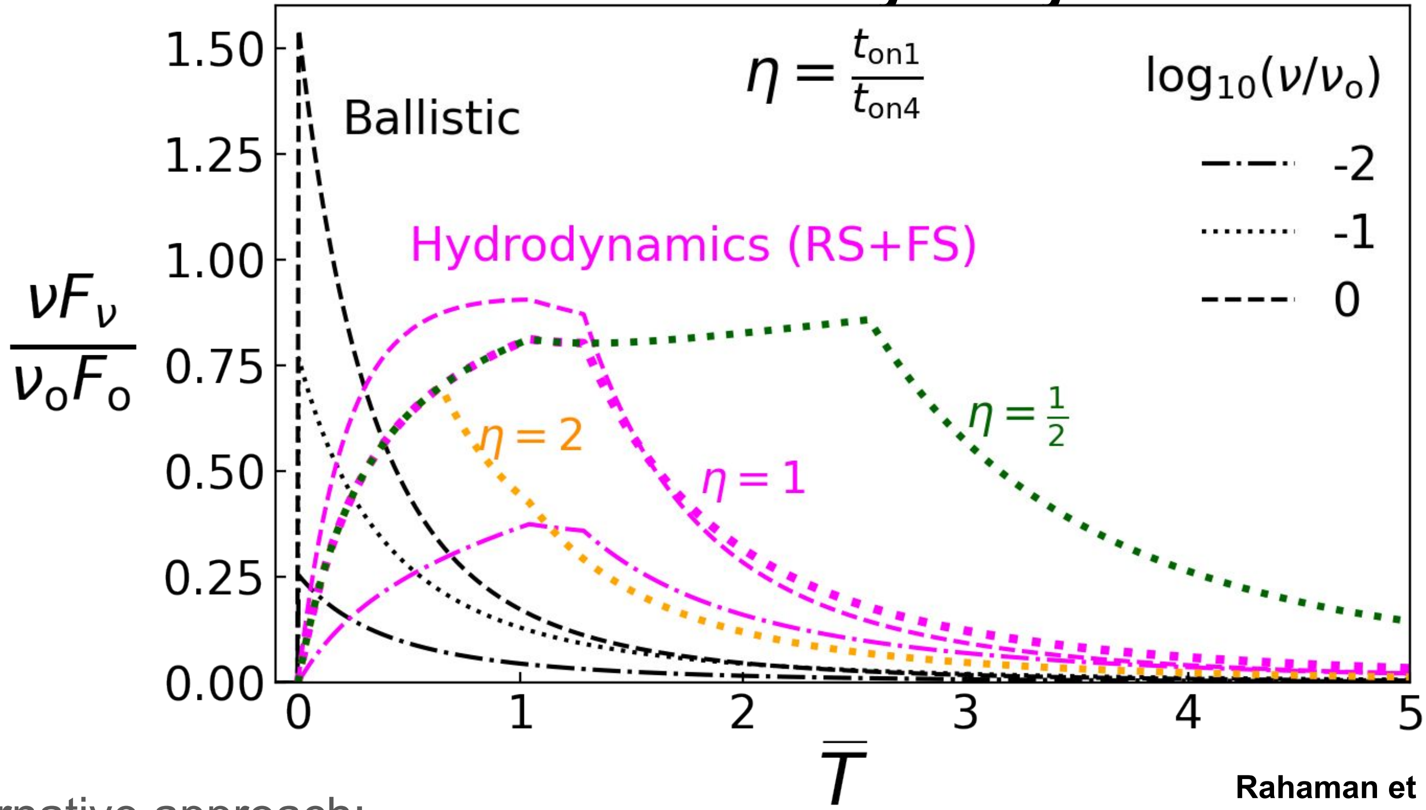

Sakamoto et al. 2005

*SWIFT/BAT*




Bi et al. 2018

# Ballistic vs Hydrodynamic



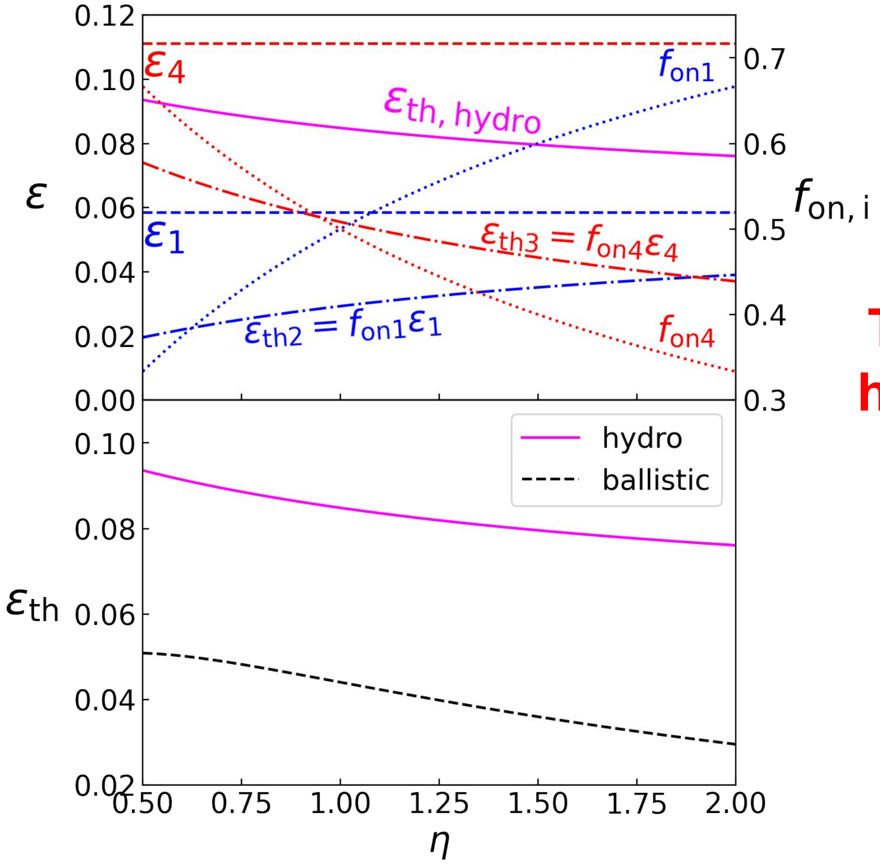

**Rahaman et al. 2024b**

Alternative approach:

**Ballistic Approximation**

**Daigne & Mochkovitch 1998,Bosnjak et al. 2009,Rudolph et al. 2022**

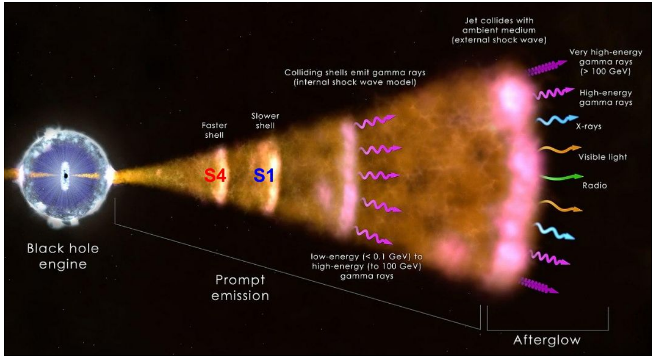
# Thermal efficiency




**The hydrodynamic efficiency is higher than than the ballistic case**

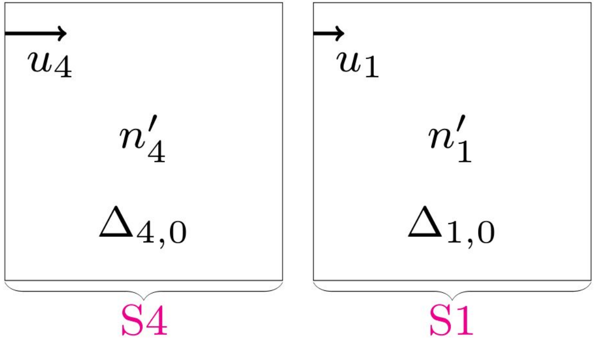
**Rahaman et al. 2024b**

# Two cold shell collision

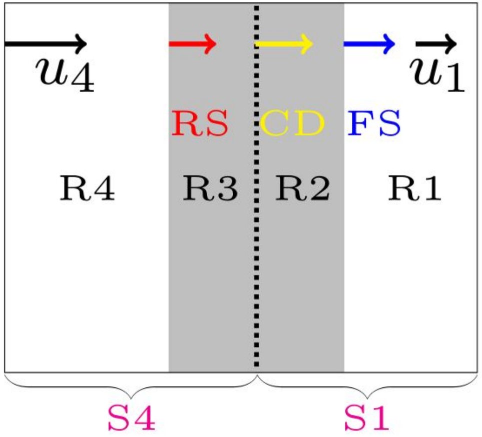



$$u = \Gamma\beta \gg 1$$

## Pre-collision

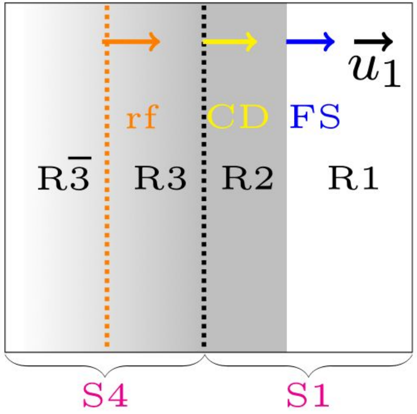


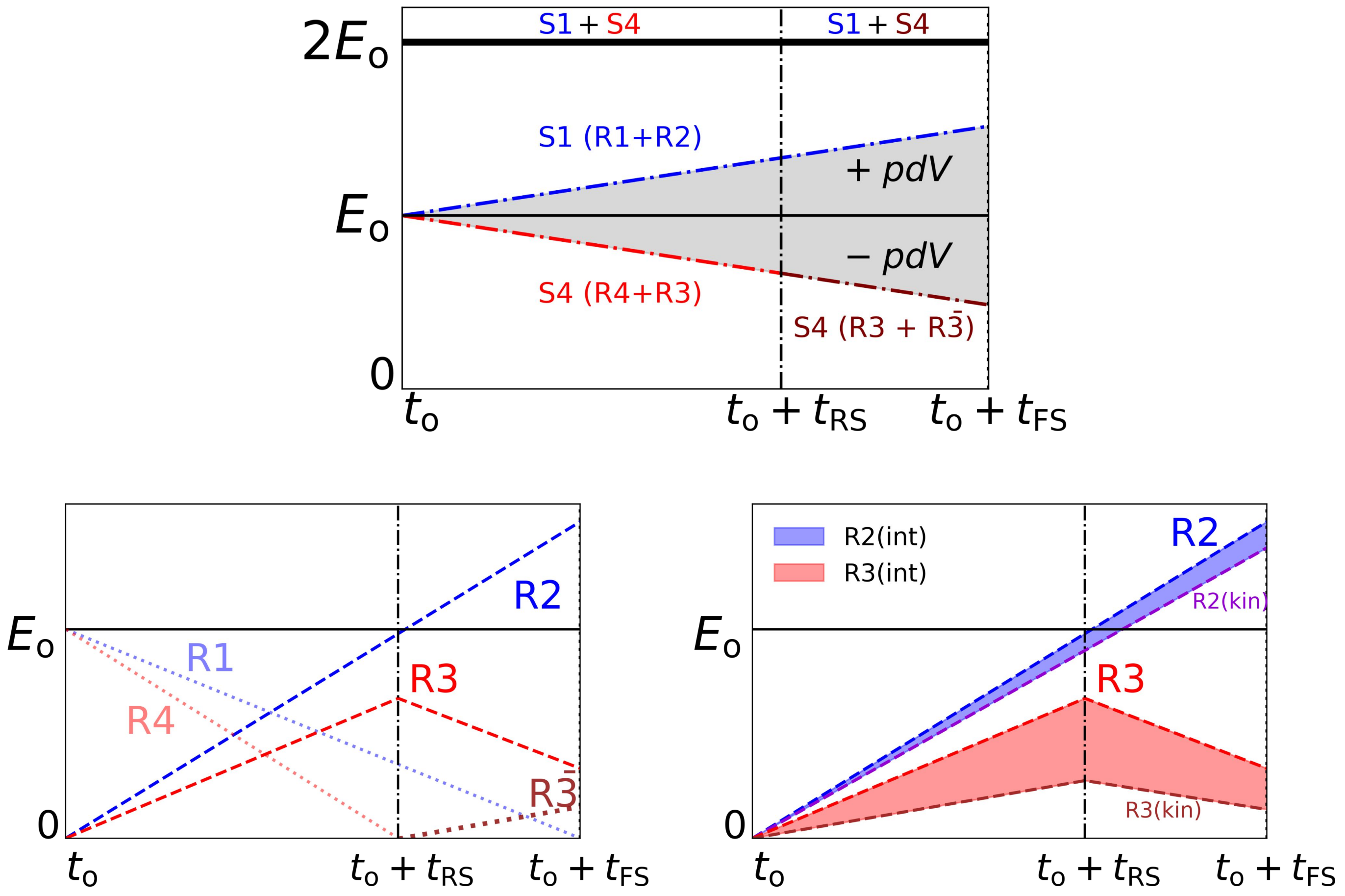

## Post-collision



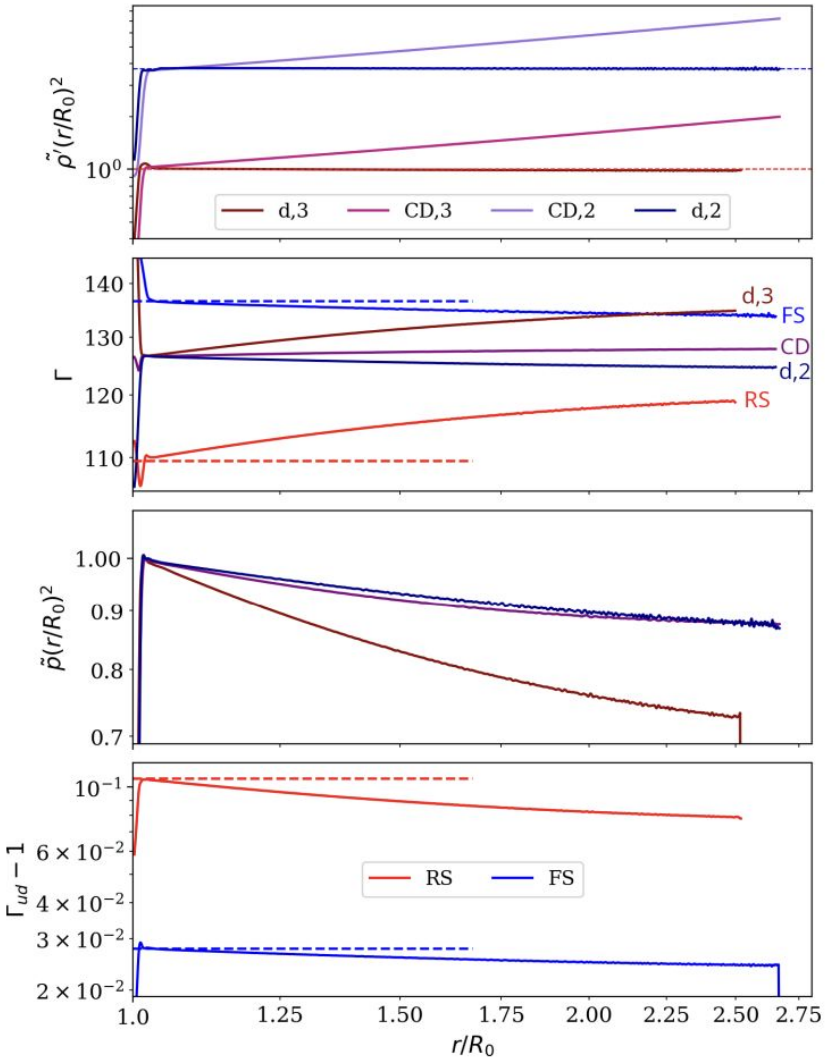

$$t_{FS} < t_{RS}$$

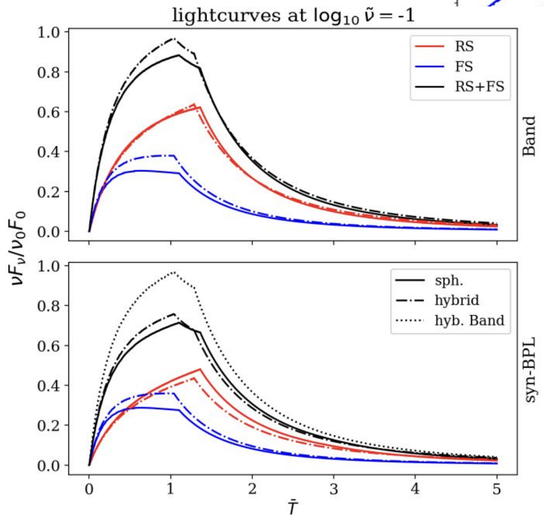
## Post shock crossing

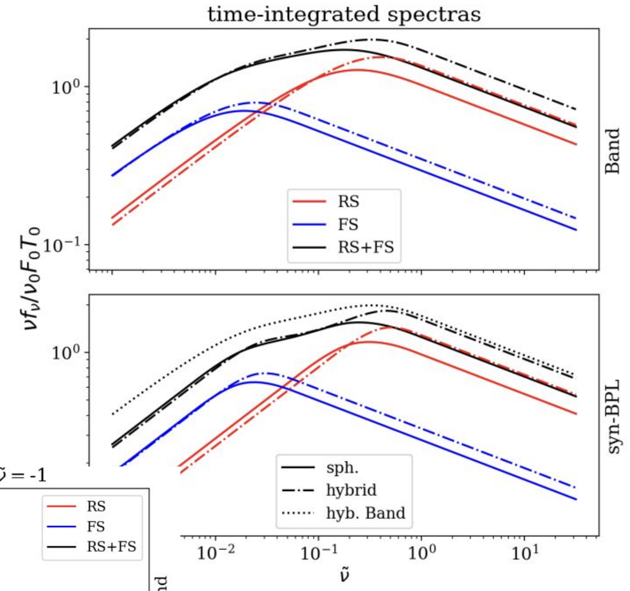





**Rahaman et al. 2024a**

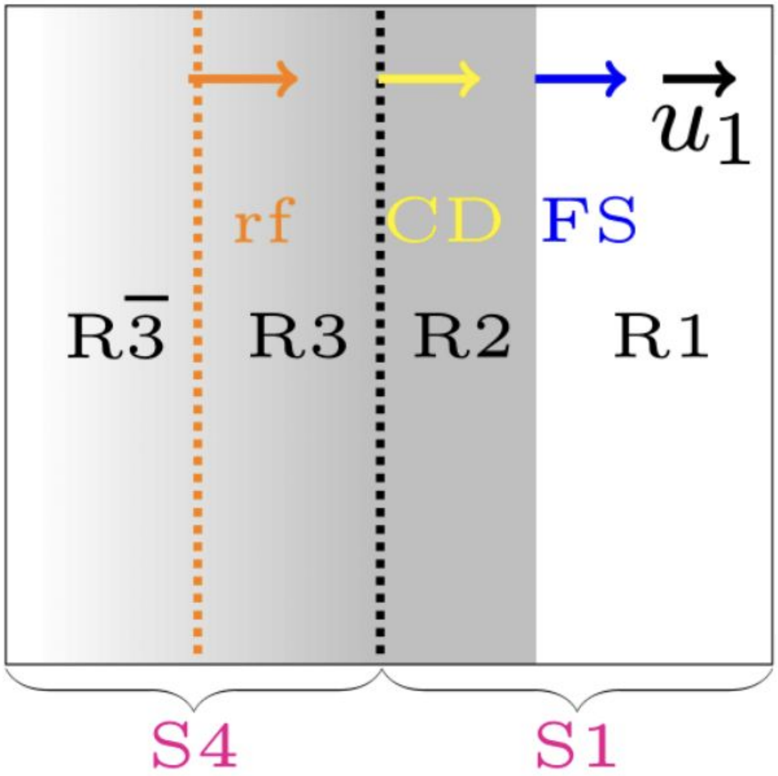


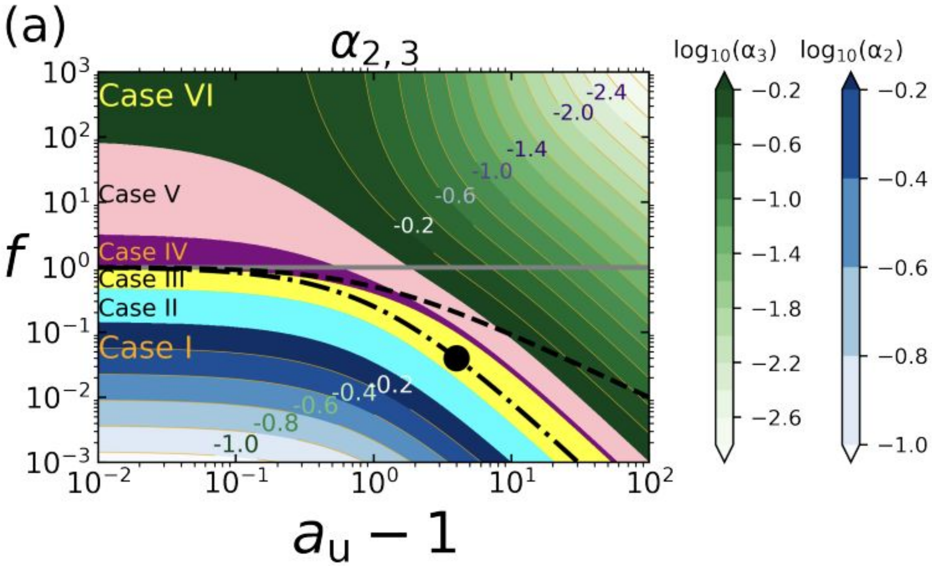




Charlet et al. 2025

# Can we not change radial widths arbitrarily ?

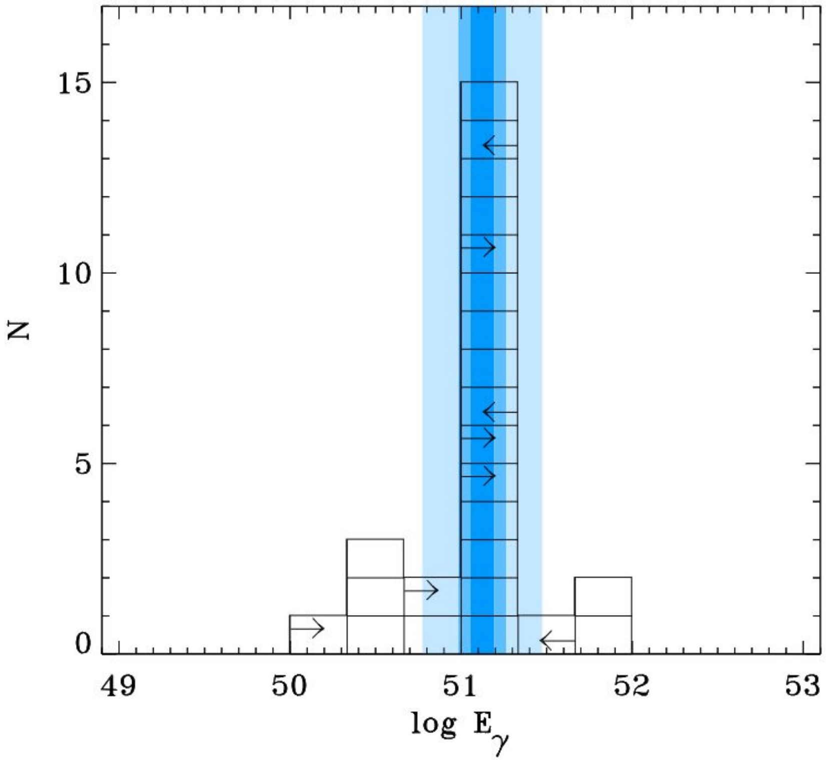



Rahaman et al. 2024 (a)

# Gamma Ray Bursts

## Brightest electromagnetic phenomenon in the Universe



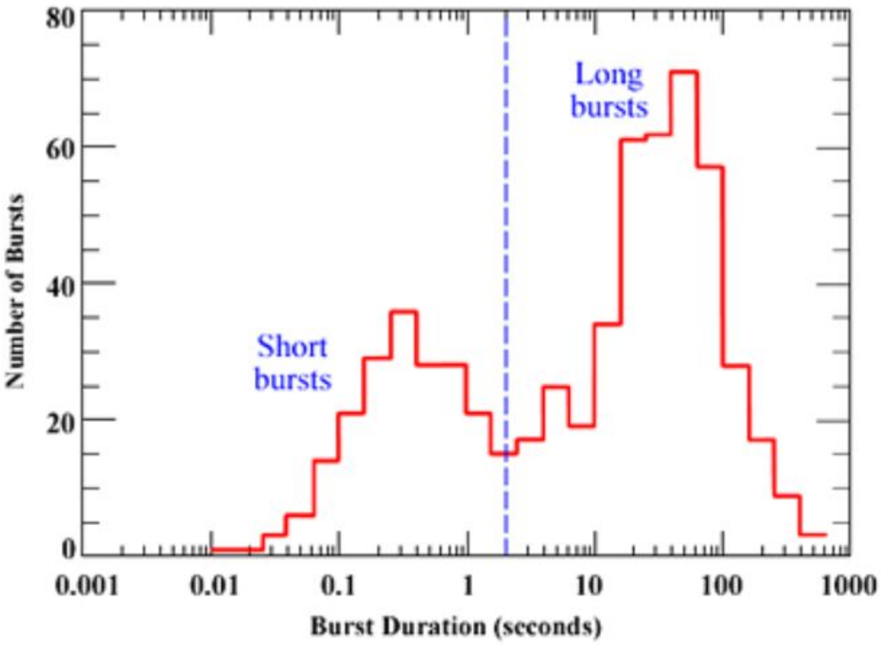

Bloom et al. 2003

**What about the BOAT GRB221009A?**

$$E_{\gamma,\mathrm{iso}} \sim (2-6) \times 10^{54}\ \mathrm{erg}$$

**Kann & Agui 2022**

# Gamma Ray Bursts



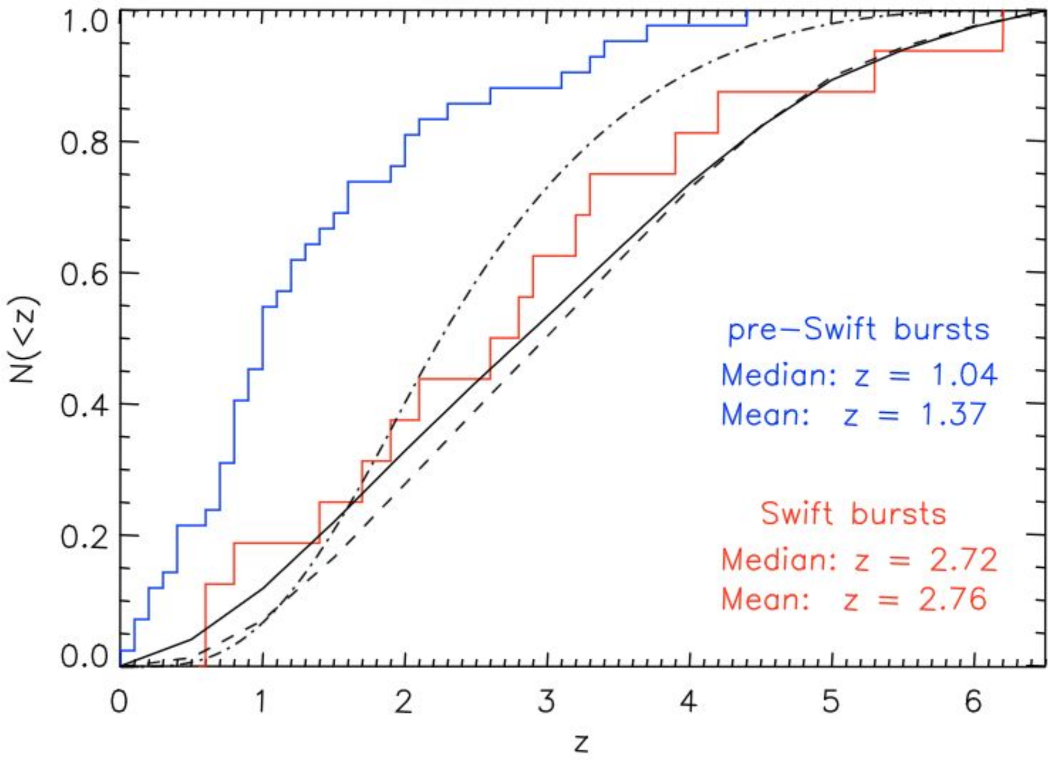

Bi-modality in burst duration

Considerable range in burst duration

**Credit: Swinburne University of Technology**

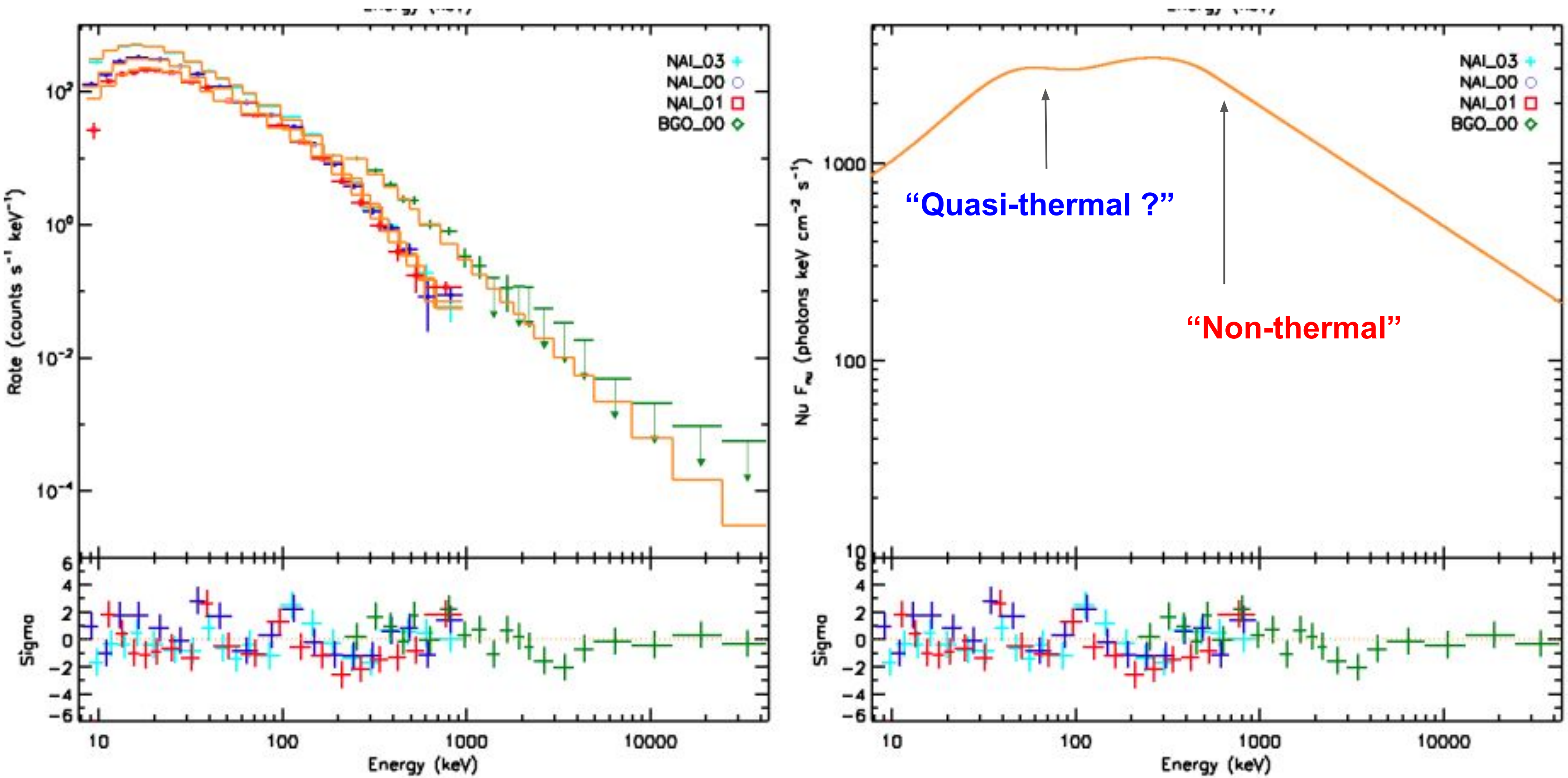
# Gamma Ray Bursts

## Originates from cosmological distances




Jakobsson et al. 2006

# Time-integrated spectrum




Guiriec et al. 2013