Resmi Lekshmi
IIST

Multi-Band Modelling Of GRB Afterglows

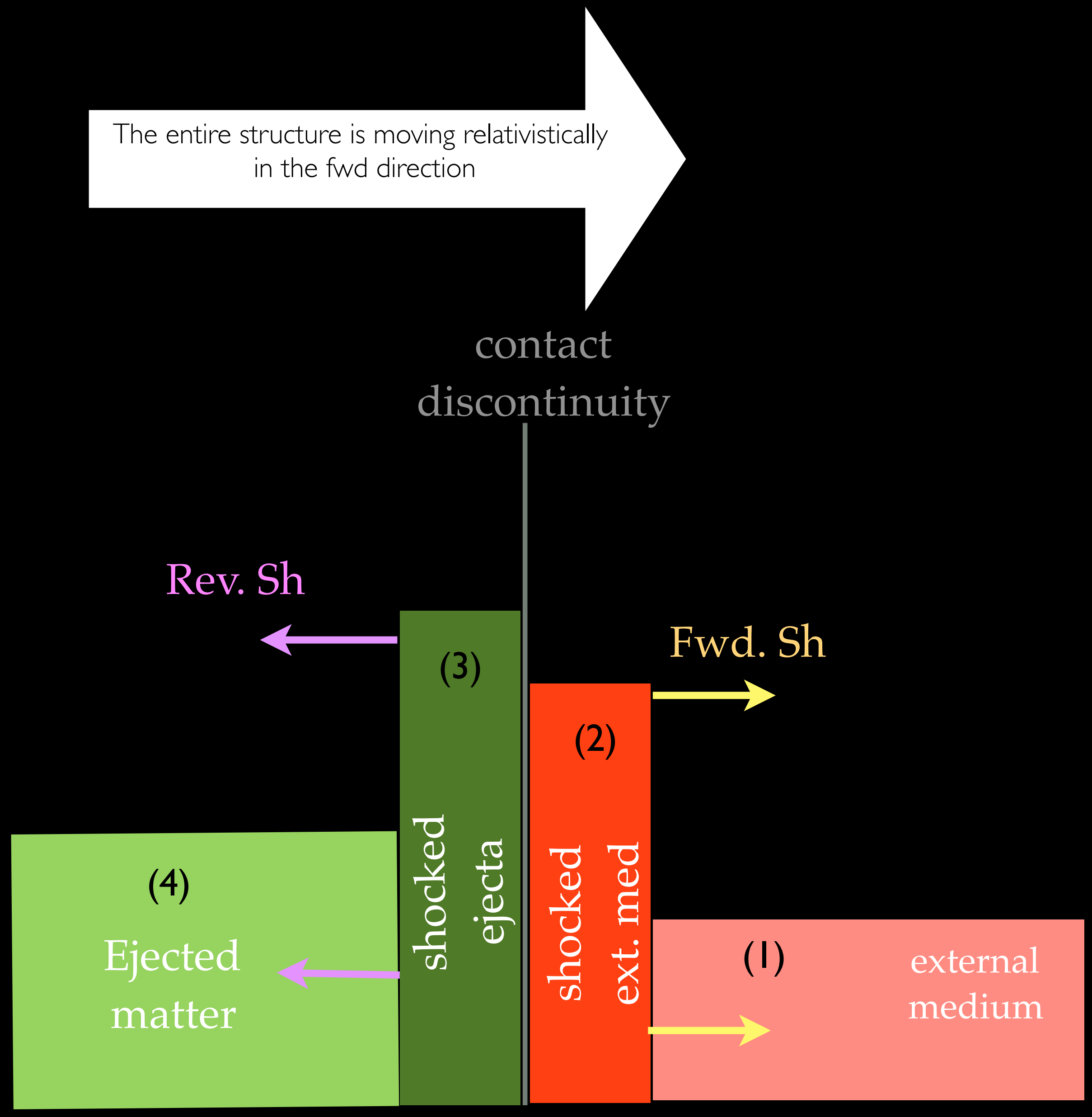
Collaborators: Bing Zhang (UNLV)
Kuntal Misra (ARIES)

Outline

- (a) Reverse shock emission.
- A probe of ejecta from central engine, especially magnetisation
- (b) Multi-wavelength modelling
- Understand the diverse physical processes of AGs

The External Shock Model

- A pair of fwd/rev shock system is generated as the ejecta hits the ambient medium
- Assuming pressure equilibrium at the CD,
- Calculate the thermal energy density at (3) and (2)
- From which non-thermal radiation (syn + ssc) emerges

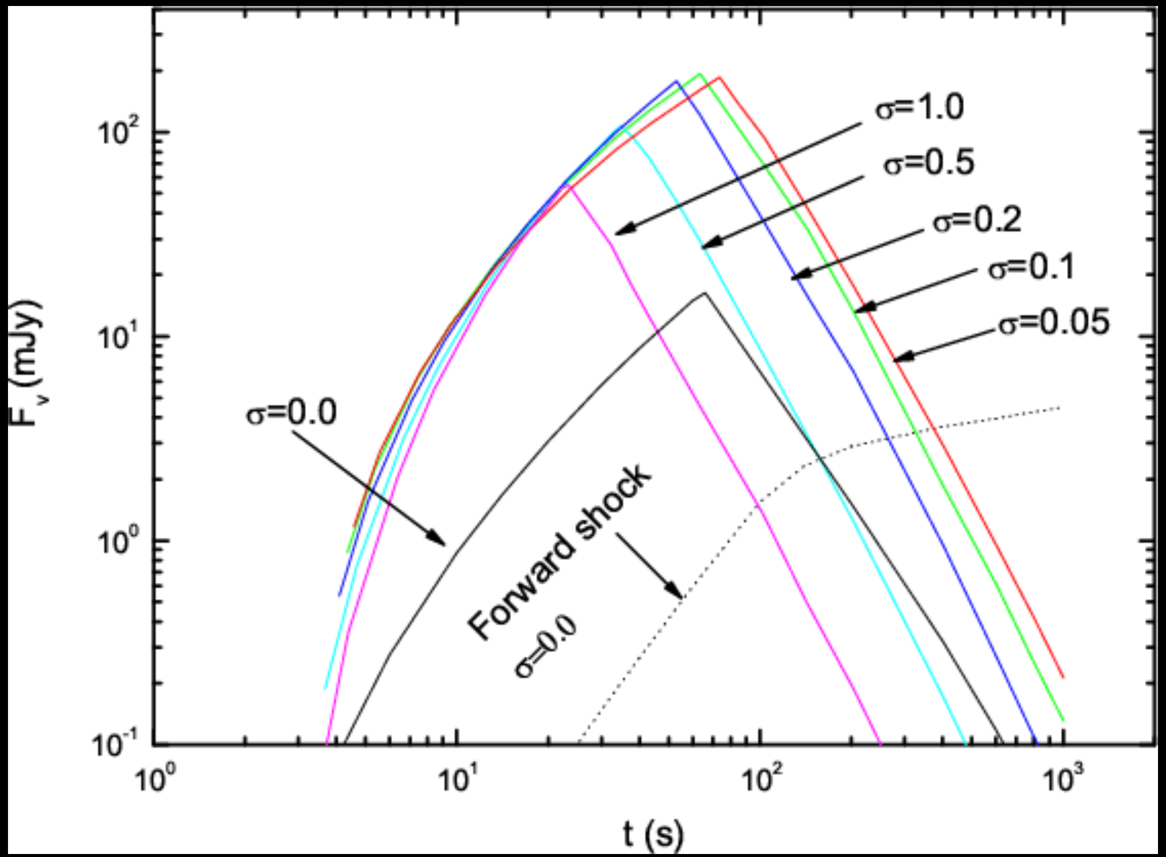


Meszaros & Rees 97,99; Sari, Piran 1999; Kobayashi 2000; Kobayashi &Zhang 2002, 2003; Kumar & Panaitescu 2003

Properties Of The Reverse Shock

σ = Ratio of magnetic to kinetic energy density of the ejecta

- When $\sigma >> 1$, the shock jump conditions are different from BM76 (σ=0). MHD jump conditions by Kennel & Coroniti 84 for high σ cases.
- Upto $\sigma \sim$ 10s or 100s, RS happens (Zhang & Kobayashi, 2005).
- For intermediate values σ, RS flux increases with σ, drops beyond $\sigma \sim 1$ (Zhang & Kobayashi, 2005 ; Fan, Wei, Wang, 2004).
- For $\sigma < 0.01$ or so, BM76 can be used. But the optical/IR reverse shock emission will be enhanced due to higher magnetic energy density in the downstream of the RS.



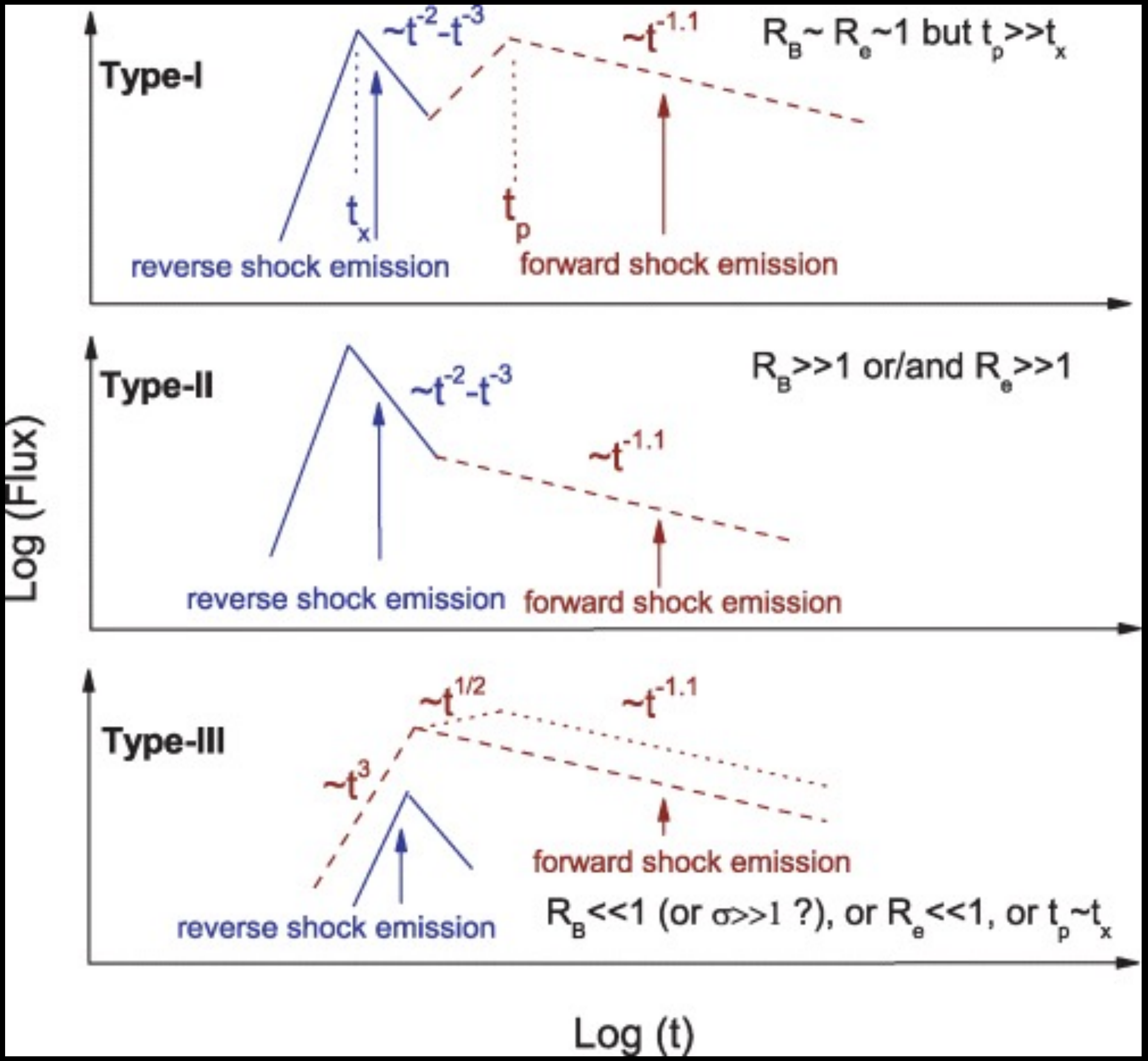
Fan, Wei, & Wang, 2004

Opt/IR RS From Very Mildly Magnetized Ejecta

- Where **σ** < 0.01, and magnetic pressure can be ignored in shock jump conditions (BM76).
- But the magnetization of the RS downstream is likely to be much higher than that of FS.
- $\mathscr{R}_B = \varepsilon_B(RS)/\varepsilon_B(FS)$;

ε_B — the fraction of shock Eth in B-field

- Opt/IR peak of the RS is strongly sensitive to $\mathscr{R}_B$ (Zhang, Kobayashi, & Meszaros, 2003.)



Jin & Fan 2007, extension of ZKM 03.

Resmi & Zhang 2016

How Will The Radio RS Be?

- Include self-absorption effects,
- Of the RS photons by the FS medium too

1. RS peak is when the fireball becomes optically thin
2. Unlike Opt/IR, moderate magnetization do not necessarily produce a bright RS emission in radio (coz of self-absorption)
3. RS wouldn’t be detectable in low radio frequencies (< 1GHz) unless ambient density is low ($n < 10^{-3}$ cm^{3}, $A_* < 10^{-4}$)

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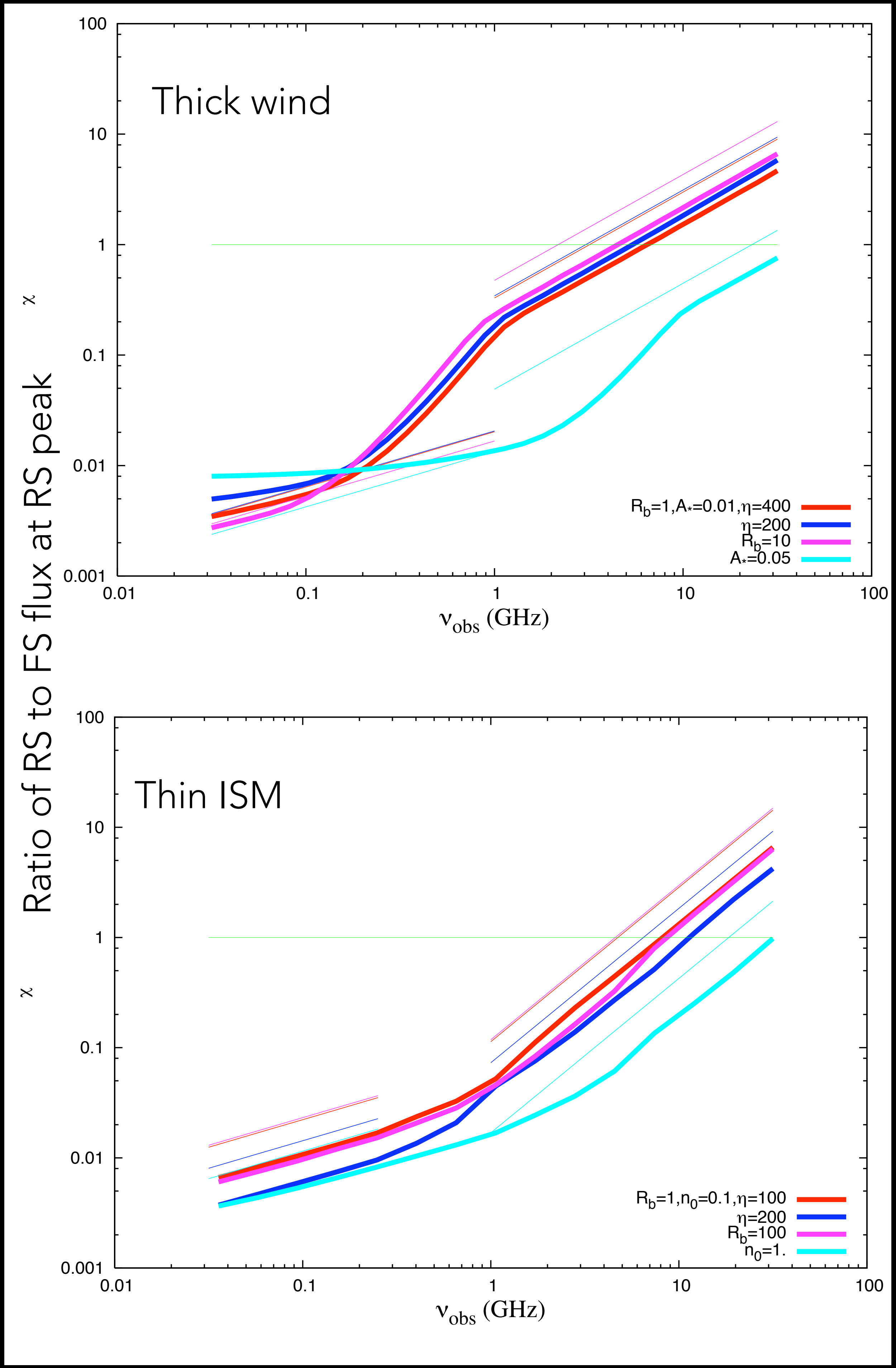
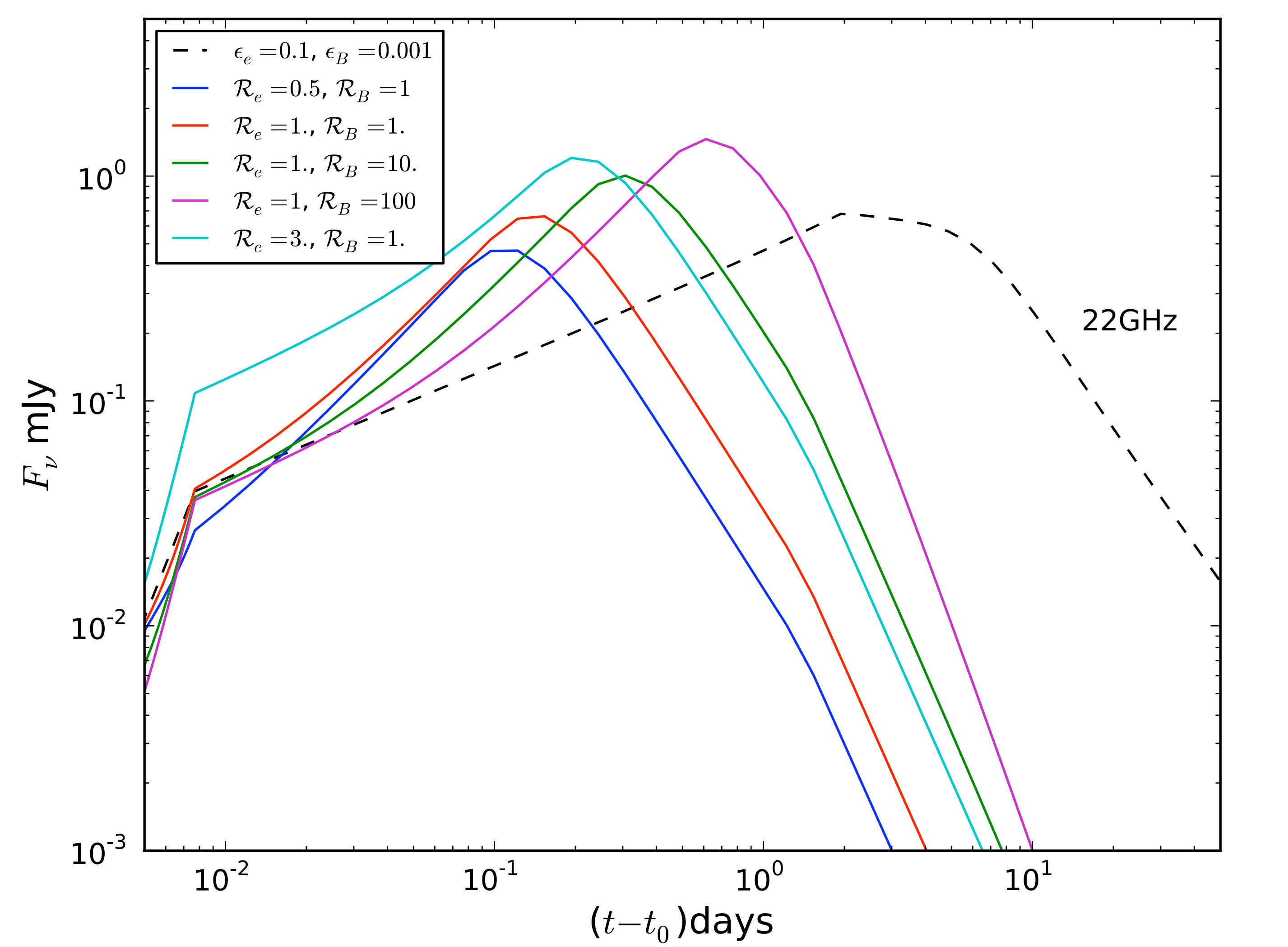
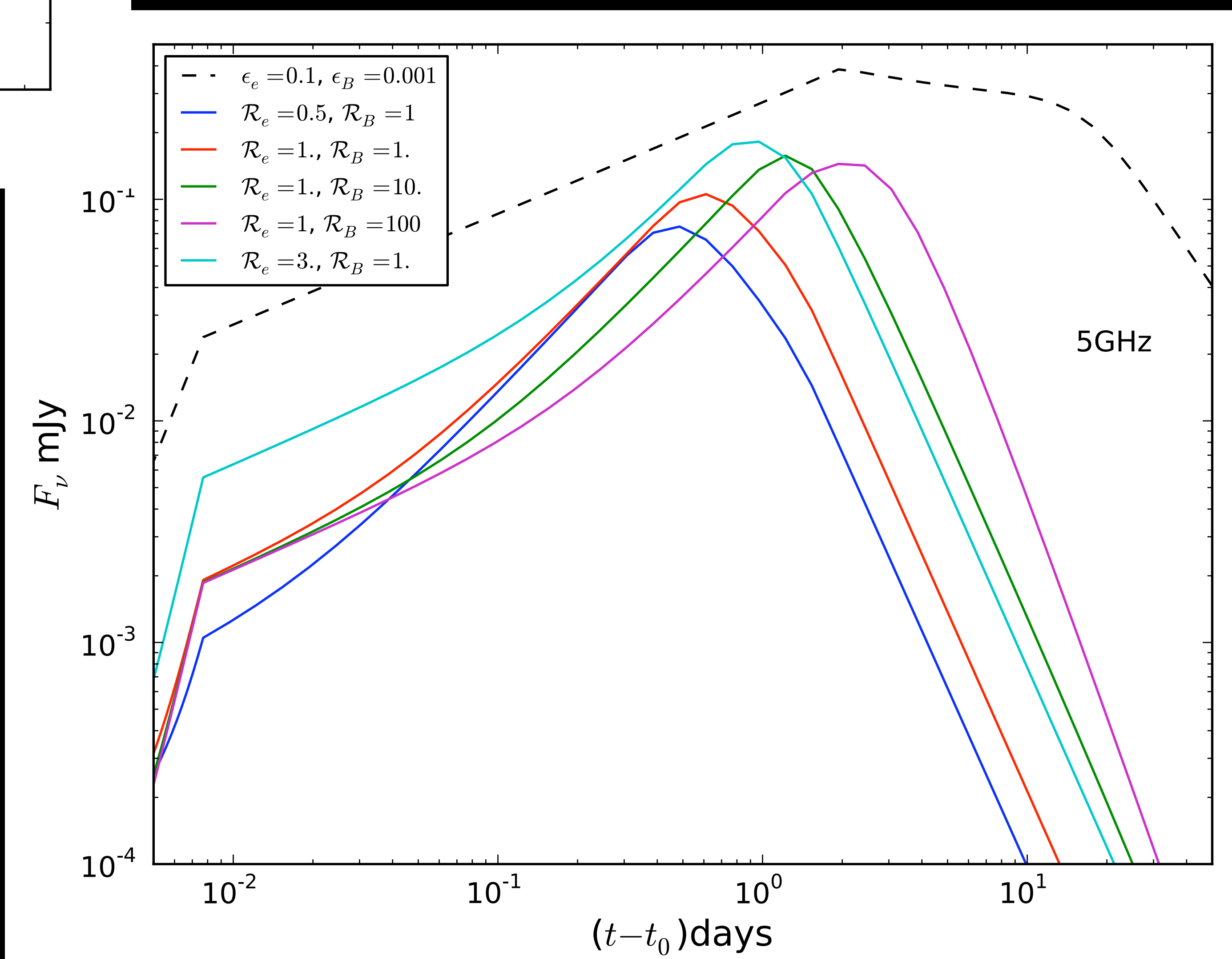


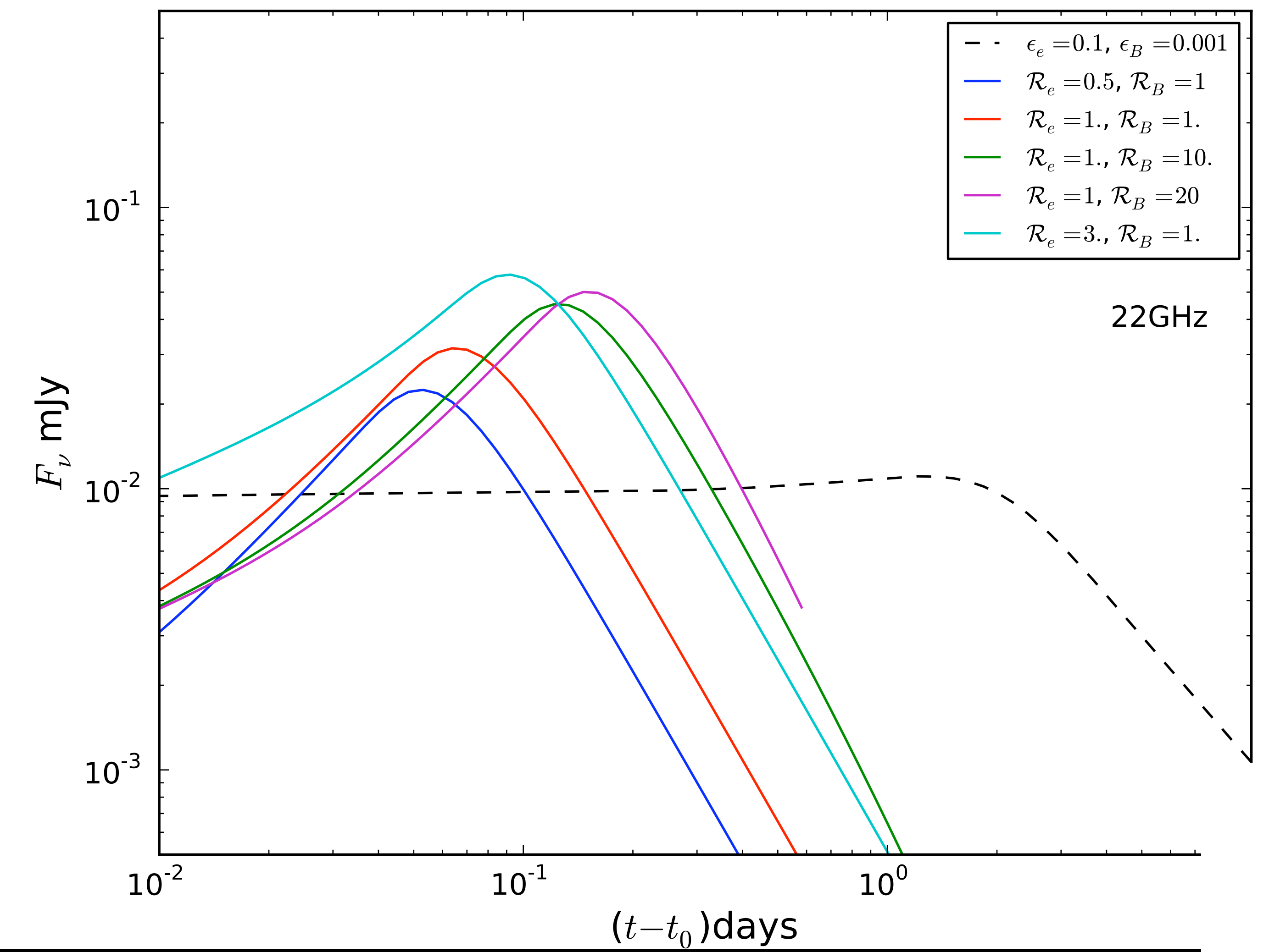


Thin ISM

$E_{iso,52} = 5$, $\eta = 100$, $n_0 = 1.$,
$\theta_j = 5°$, $z = 1.$

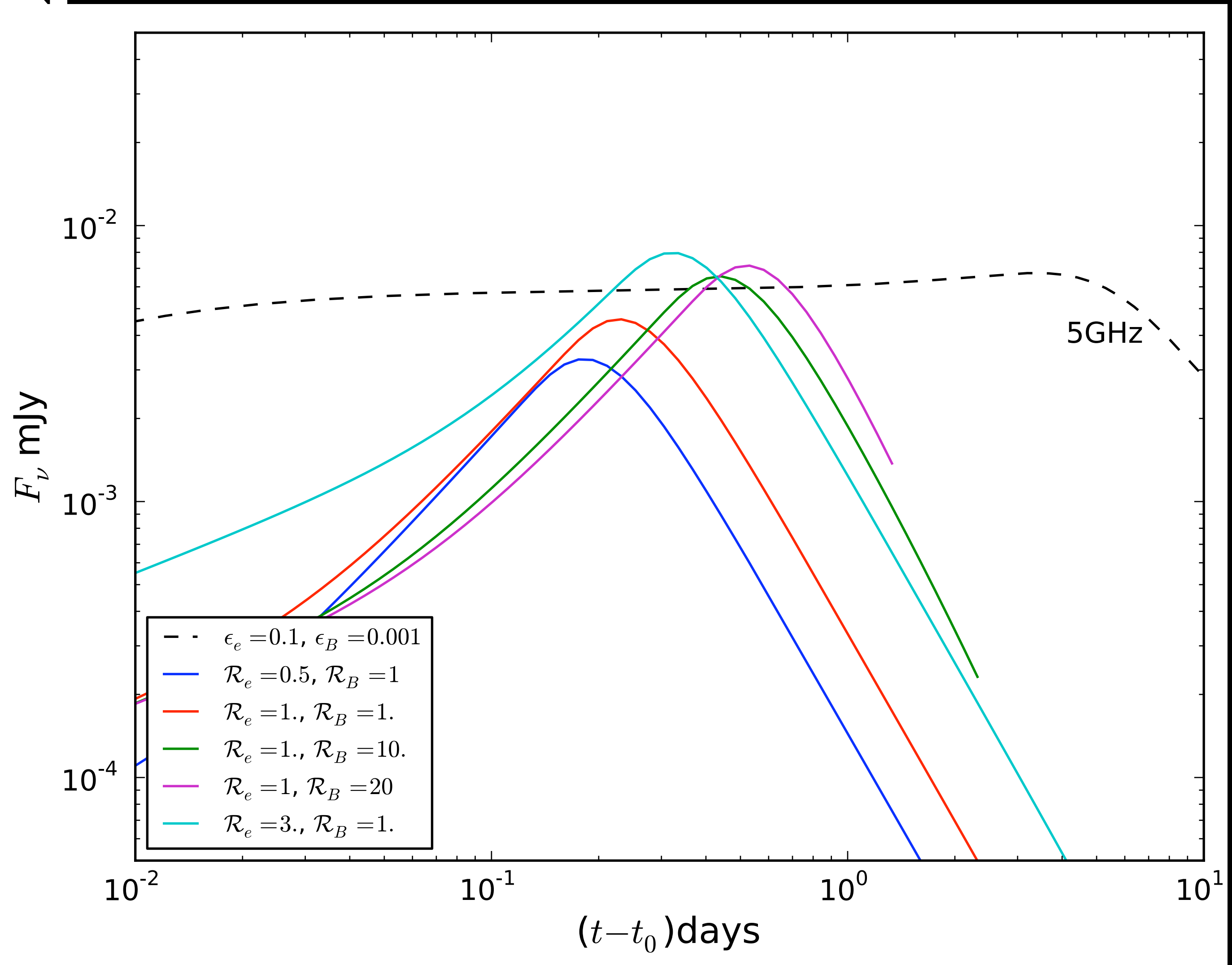
Resmi & Zhang 2016





Thick Wind

$E_{iso,52} = 5$, $\eta = 300$, $A_* = 0.01$, $T = 200s$, $\theta_j = 5°$, $z = 1$



Resmi & Zhang 2016

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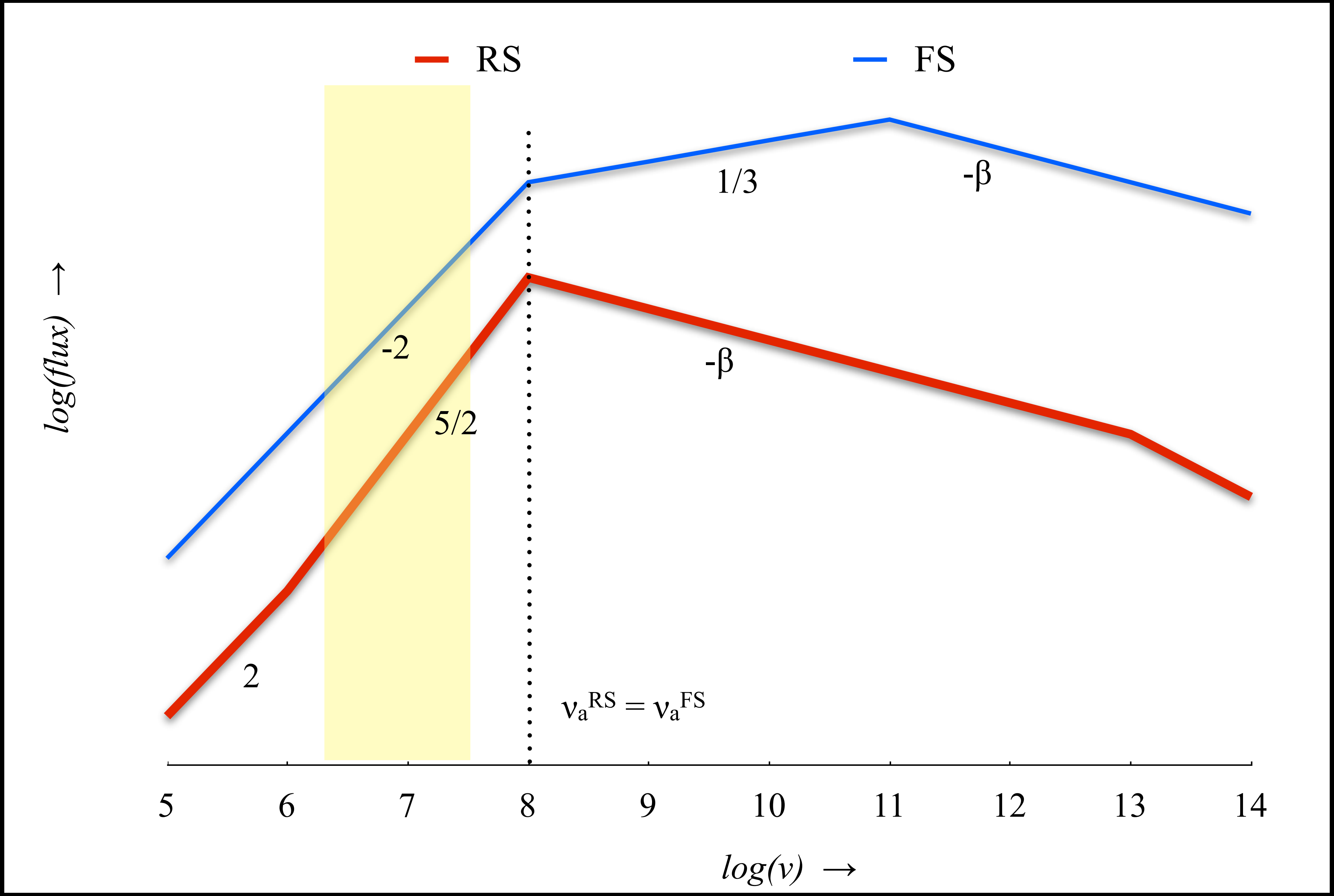
In Low Radio Frequency Regime

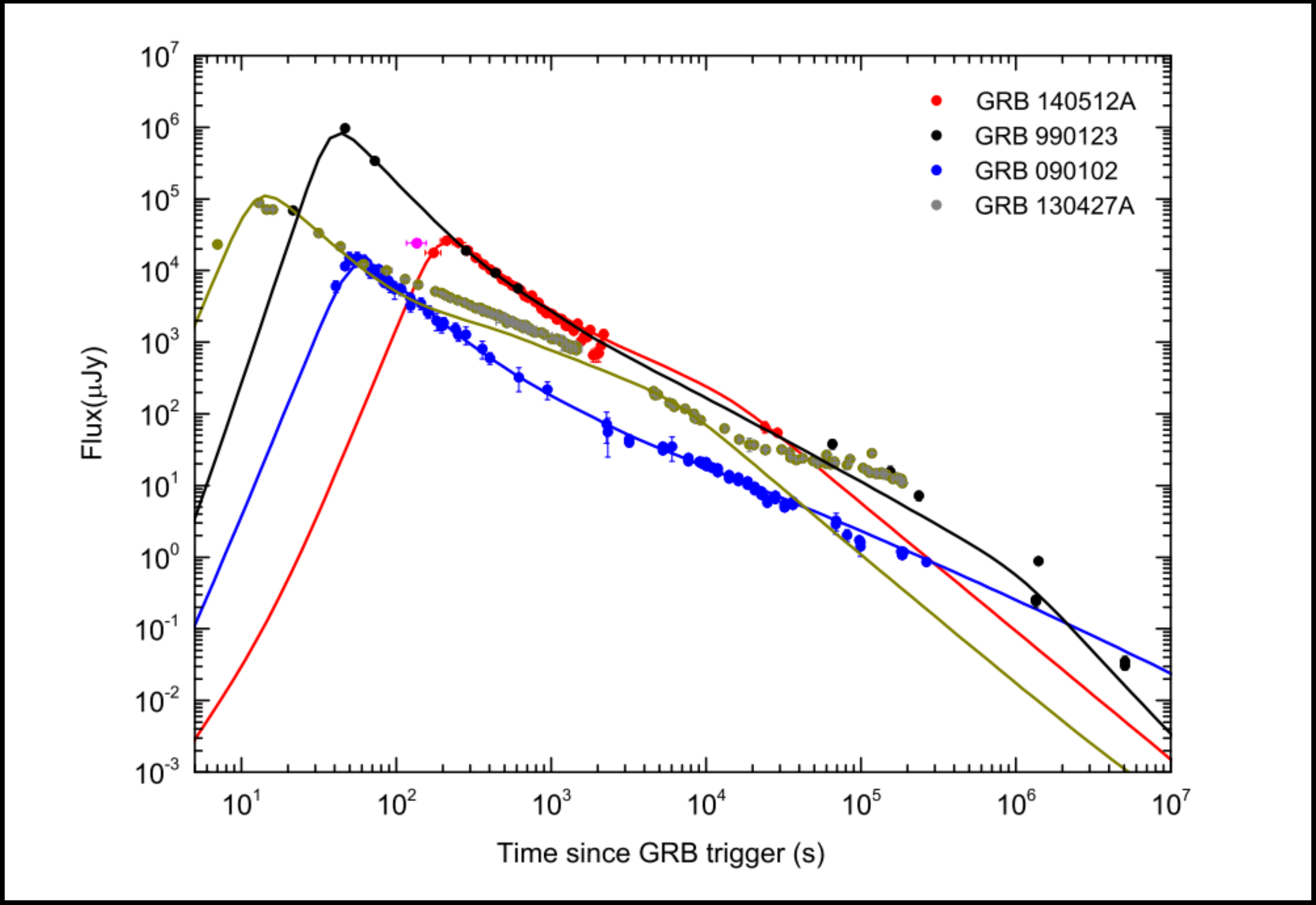


- In MHz regime, RS will not outshine FS for typical parameters.
- By the time the RS peak occurs, the f_{max} in RS will be too low.

Half-Summary

- High $\mathscr{R}_B$ can enhance opt/IR reverse shock emission.
- Low ambient density for RS to dominate in radio.
- Need to mention the long lived RS (pressure eq. condition is not valid at CD). Daigne & Mochkovitch; Several papers by Uhm, Z.

Comparison With Data



- Very bright RS in 140521A, $\mathscr{R}_B \sim 8000$. Huang+ 2016
- Fits of optical afterglow data alone. 10 bursts conforms to RS+FS model, with a range of $2<\mathscr{R}_B<1000$. RS outshines FS only if $\mathscr{R}_B>1$. Japelj+ 2014

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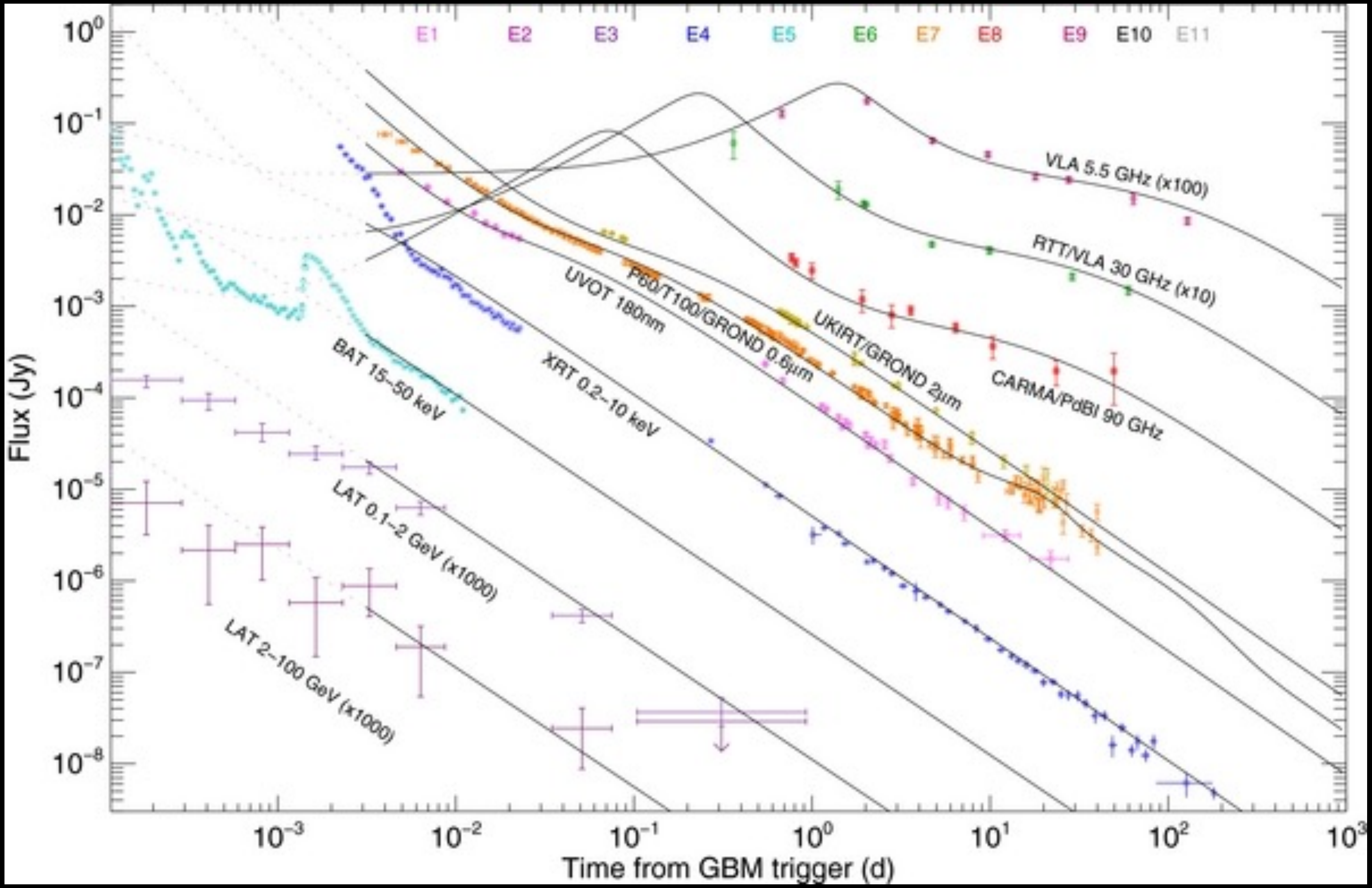


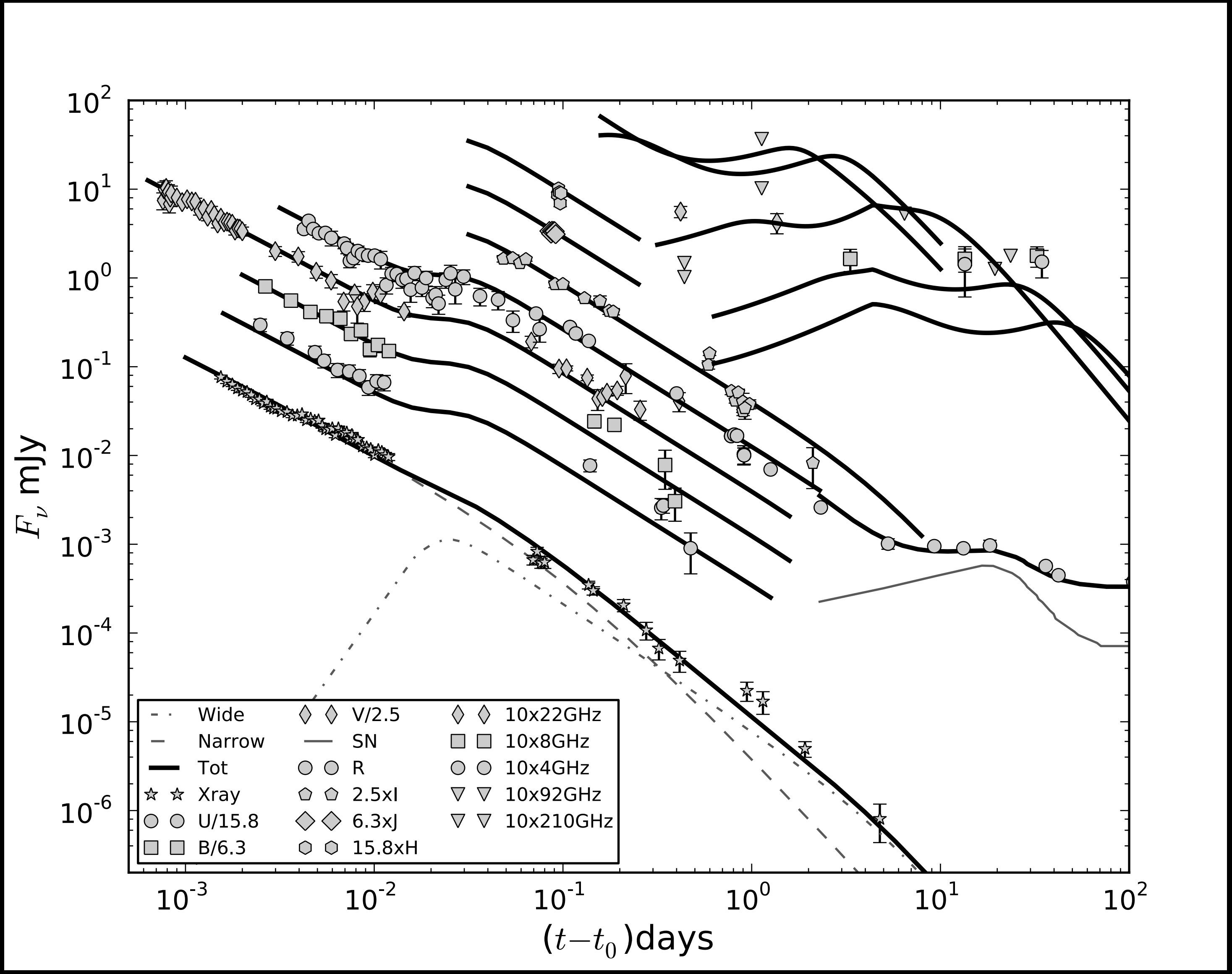
- GRB130427a. RS+FS model. Radio RS seen. Low density ($A_* \sim 10^{-3}$) ambient medium inferred from fits (Laskar+2013, Perely+2013).

- GRB160509a, another radio RS burst. Again low density ambient medium $n_0 \sim 10^{-3}$ (Laskar+2016)

Resmi, Misra, Jóhanneson + 2012

Unsolved Bursts-1

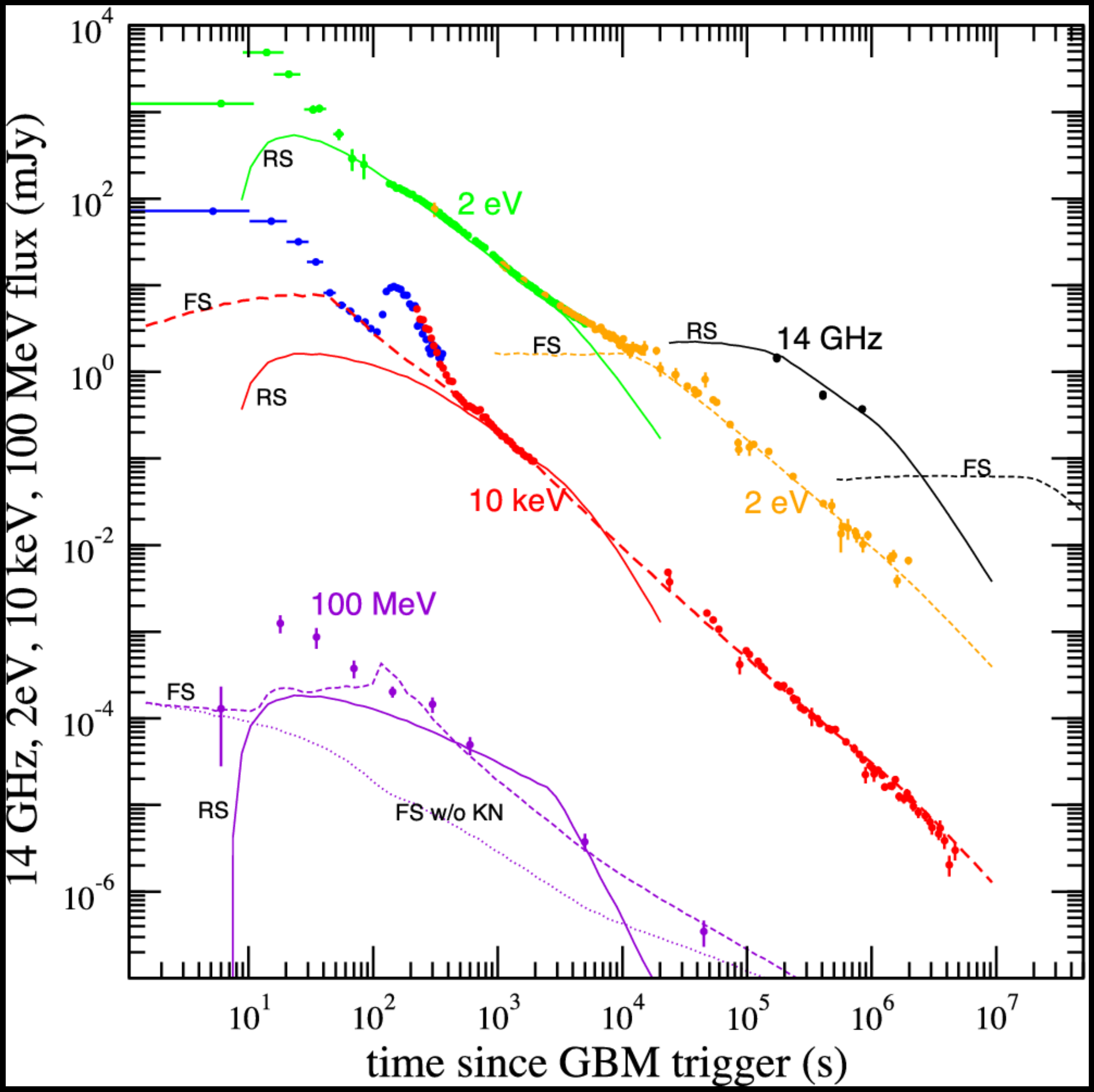
- GRB050525a was thought to be consistent with RS+FS. But, our multi-band modelling resulted in unphysical parameters.
- Either a two-component jet or a wind termination shock can broadly explain the AG evolution.
- Former fails to get early flux variation, later deviates from late evolution.



Unsolved Bursts-2,3

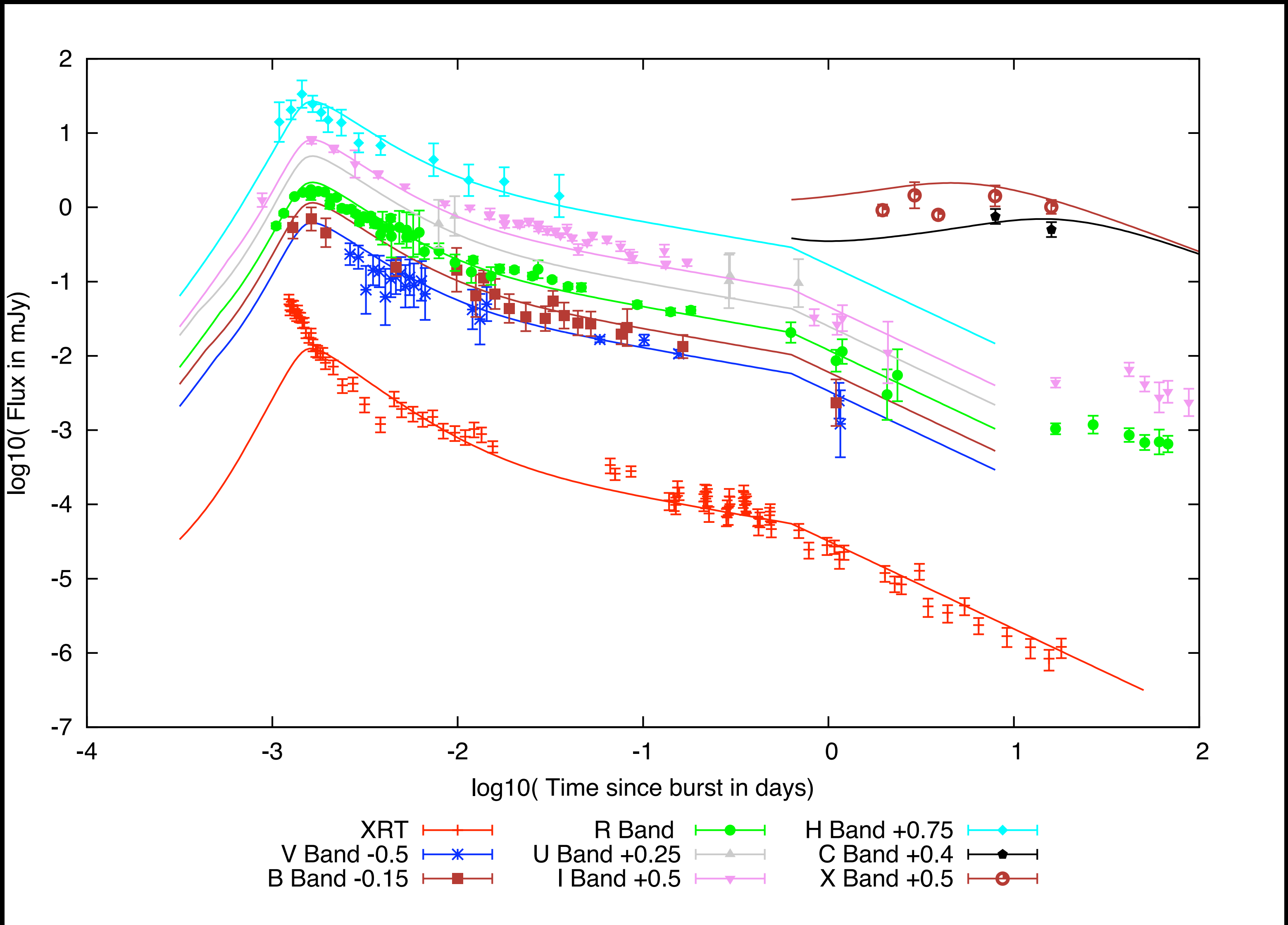
- GRB110715a. First ALMA burst. Sanches-Ramirez+ 2017
- Attempted a variety of models. General behaviour can be explained by ambient medium shaped by a wind termination shock. But it can not fully explain the data.
- GRB130427a. Panaitescu & Vestrand 2013; van der Horst + 2014.
- Not fully explained. Especially vdH+14 reports unphysical parameters if RS model is applied to radio (still required it for optical, and density is low too). They require 2nd jet for X-ray/Radio along with time evolving microphysics.

Best fit model of 130427a from PV13



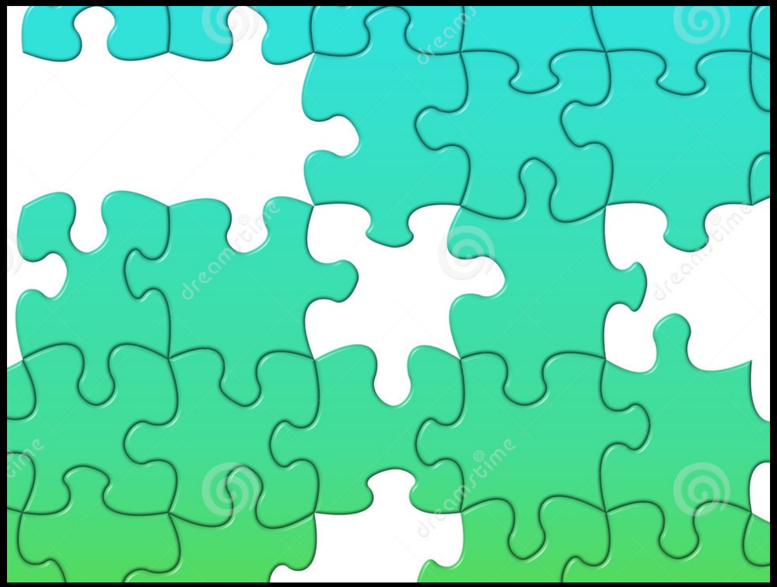
Unsolved Bursts-4

- GRB081007 again was thought to be consistent with RS+FS. But, our multi-band modelling shows otherwise.
- We see a jet break, but no jet lateral expansion effects.



Where Do We Stand?

- The broad picture is fine.
- Fine details are not.
- (For long bursts that is; very less modelling for short bursts)



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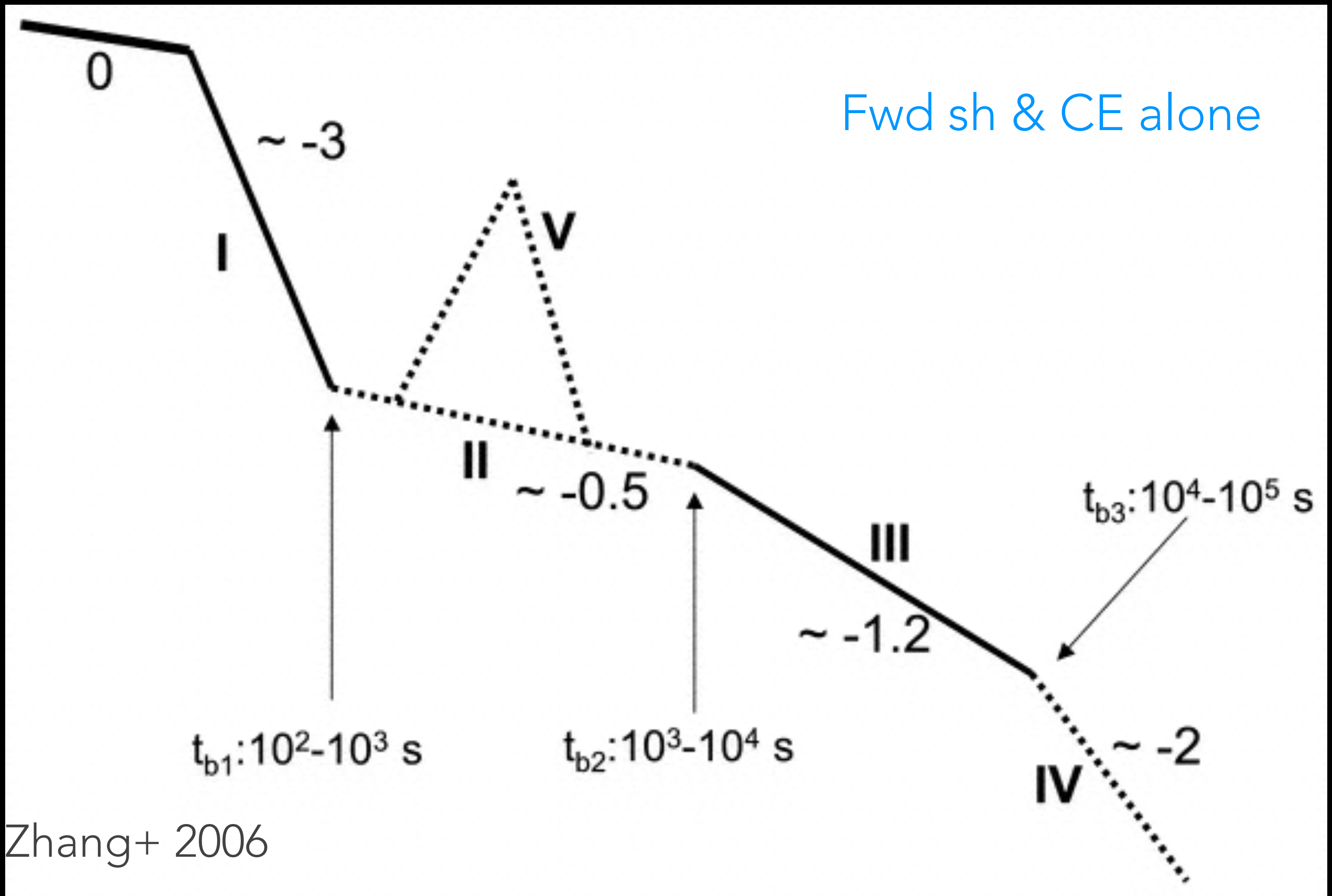
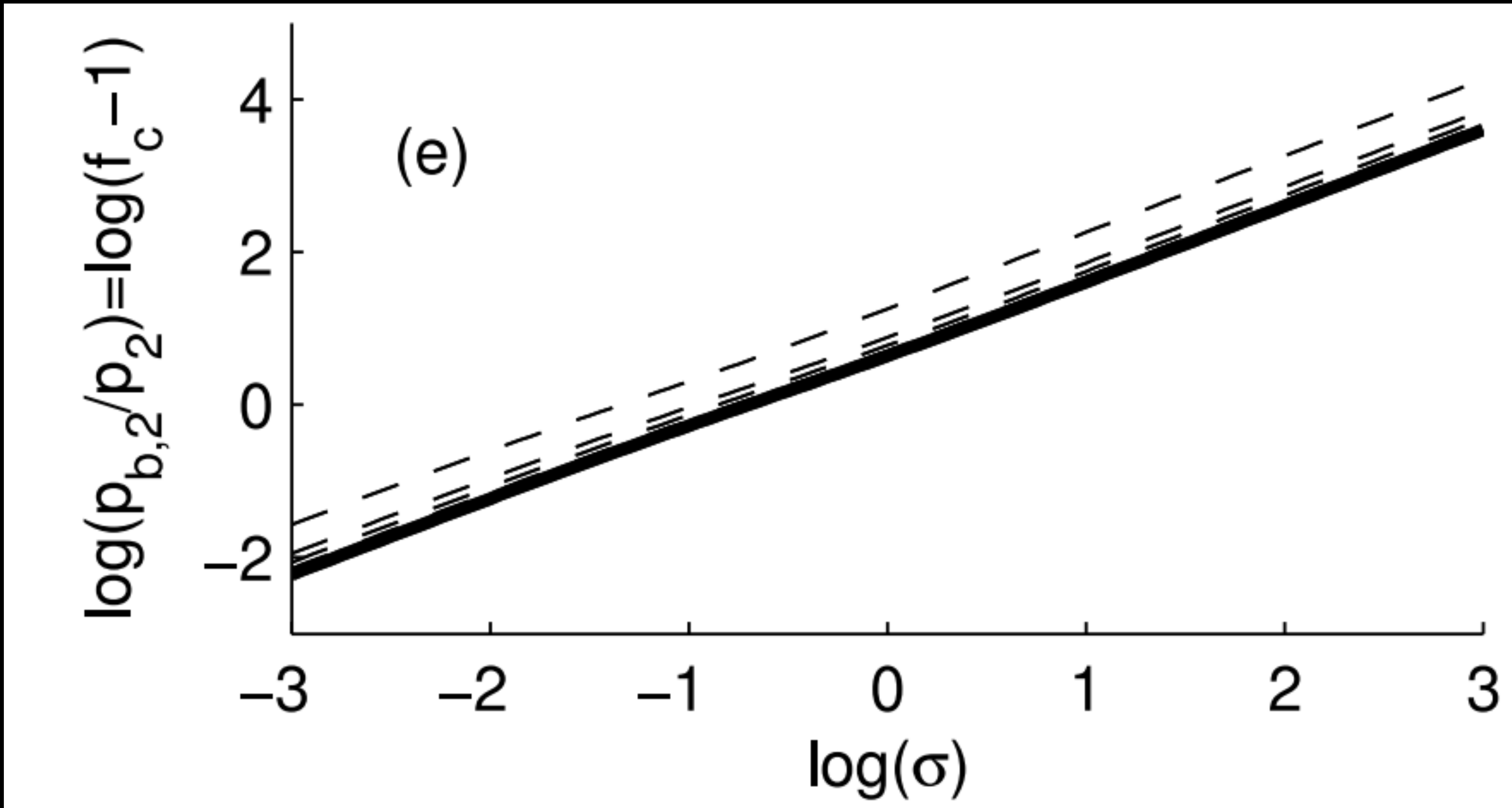


Zhang+ 2006

Way Forward

- A (biased) list of open questions to be resolved through AG modelling.
  - Outflow magnetization.
  - Outflow structure.
  - Jet opening angle & energetics (see KM's talk).
- Data with dense and long sampling of multi-wavelength lightcurves.
  - Most unexplored band is radio (See PC talk), which is partly the reason we do not have real late time AG information. SKA & pathfinders will fill the gap.
- Robust modelling exercises.
  - For forward shock alone, hydro-dynamical codes exist (eg., van Eerten's code). Especially important in handling jet lateral expansion & non-rel transition (review Granot & van der Horst 2014).
  - Several groups have also been doing Bayesian parameter estimations.
  - Important to include a zoo of emission models. All the more so for well observed bursts.



(e)
log(p_{b,2}/p_2)=log(f_c−1)
log(σ)
4
2
0
−2
−3
−2
−1
0
1
2
3

Unusual Bursts

GROND burst 100621a