Radiation-mediated shocks in GRBs observed by Fermi

10th Fermi symposium, October 14th

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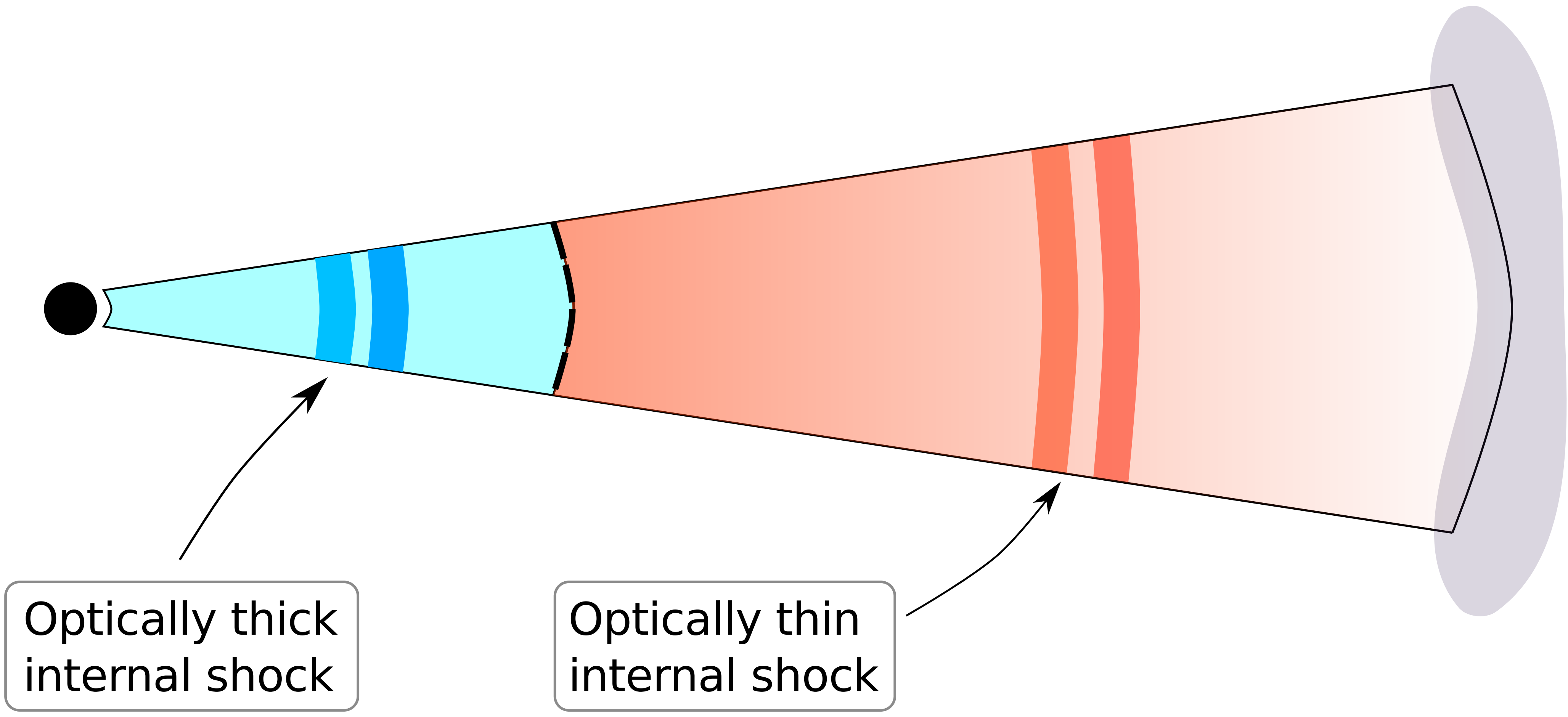
Samuelsson, Lundman, Ryde. (2022) ApJ, 925:65
Samuelsson & Ryde. (2022) arXiv:2206.11701

The motivation

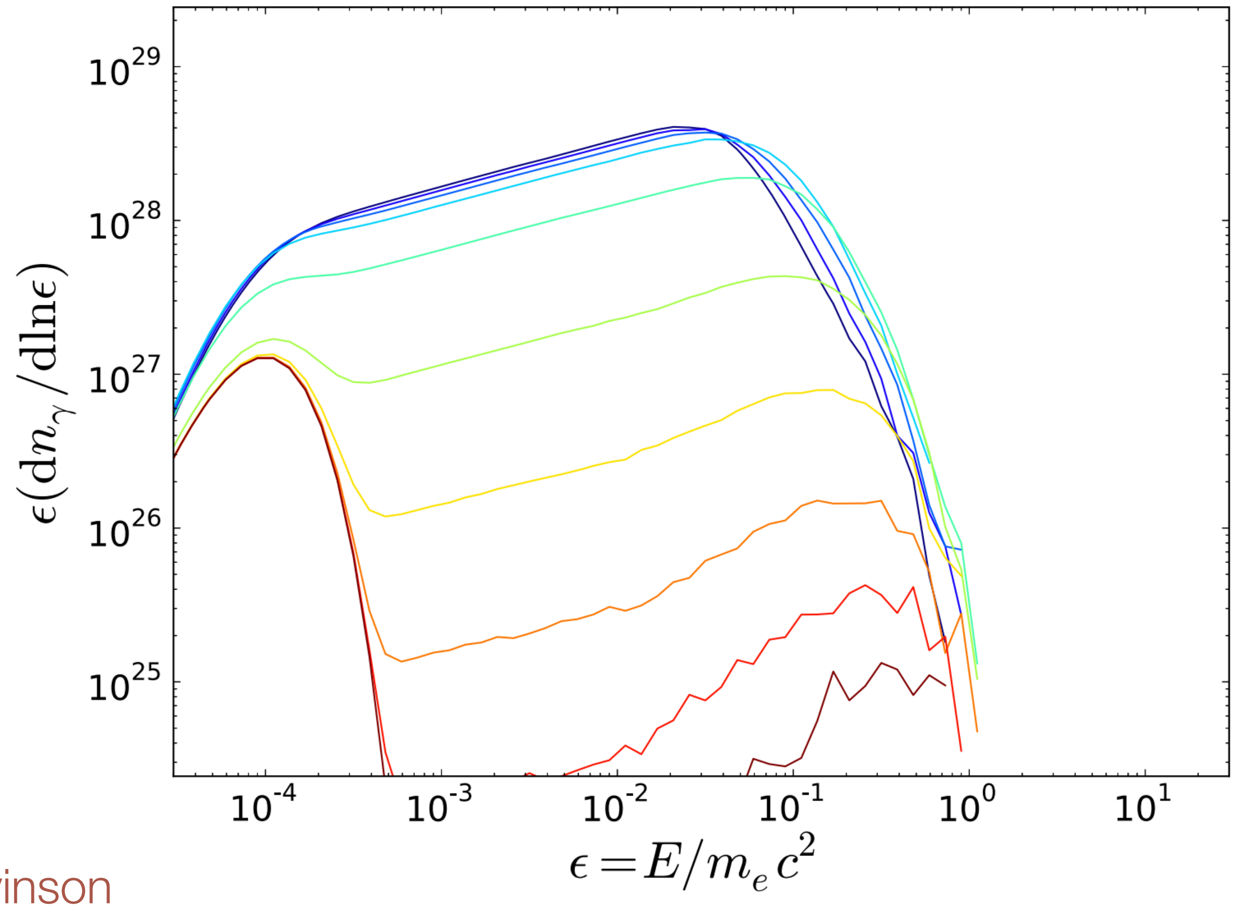
The gamma-ray burst jet

- GRB prompt emission mechanism remains unknown
- Early work predicted quasi-blackbody emission from the photosphere; observed spectra generally broader



Subphotospheric dissipation

- Dissipation alters the spectrum, not necessarily hard
- Subphotospheric shocks are radiation mediated
- Separation in scales makes simulations expensive
- Need for an approximate method



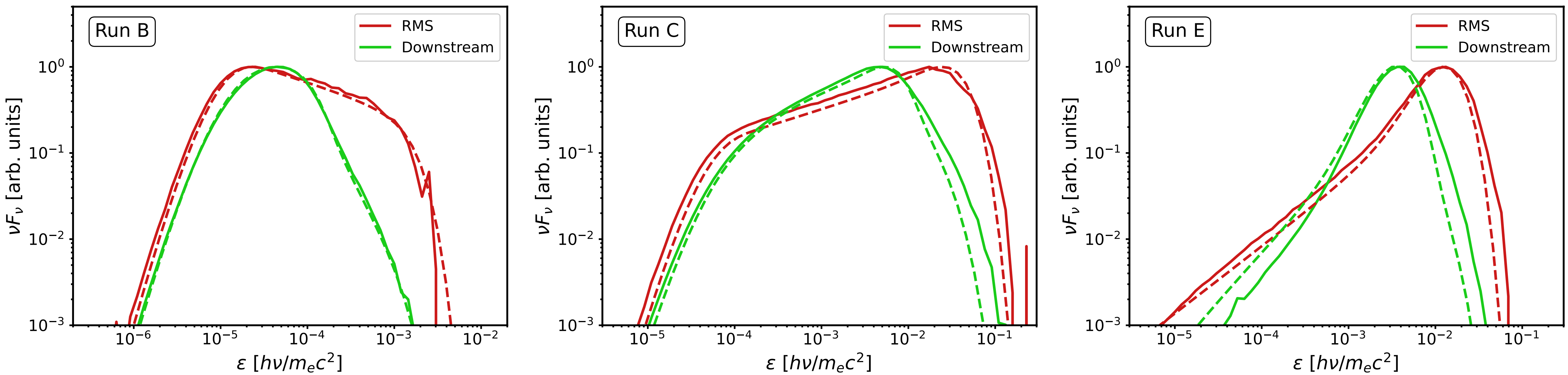
Lundman+ (2018)

Eichler (1994), Rees & Mészáros (2005), Pe'er+ (2006), Levinson & Bromberg (2008), Katz+ (2010), Budnik+ (2010), Levinson (2012), Beloborodov (2017), Ito+ (2018), Levinson & Nakar (2020)

The approximation

The Kompaneets RMS approximation (KRA)

- Fermi acceleration of photons in RMS converging flow ≈ repeated scatterings with hot, thermal electrons
- The Kompaneets RMS approximation (KRA)
- ~5 orders of magnitude faster

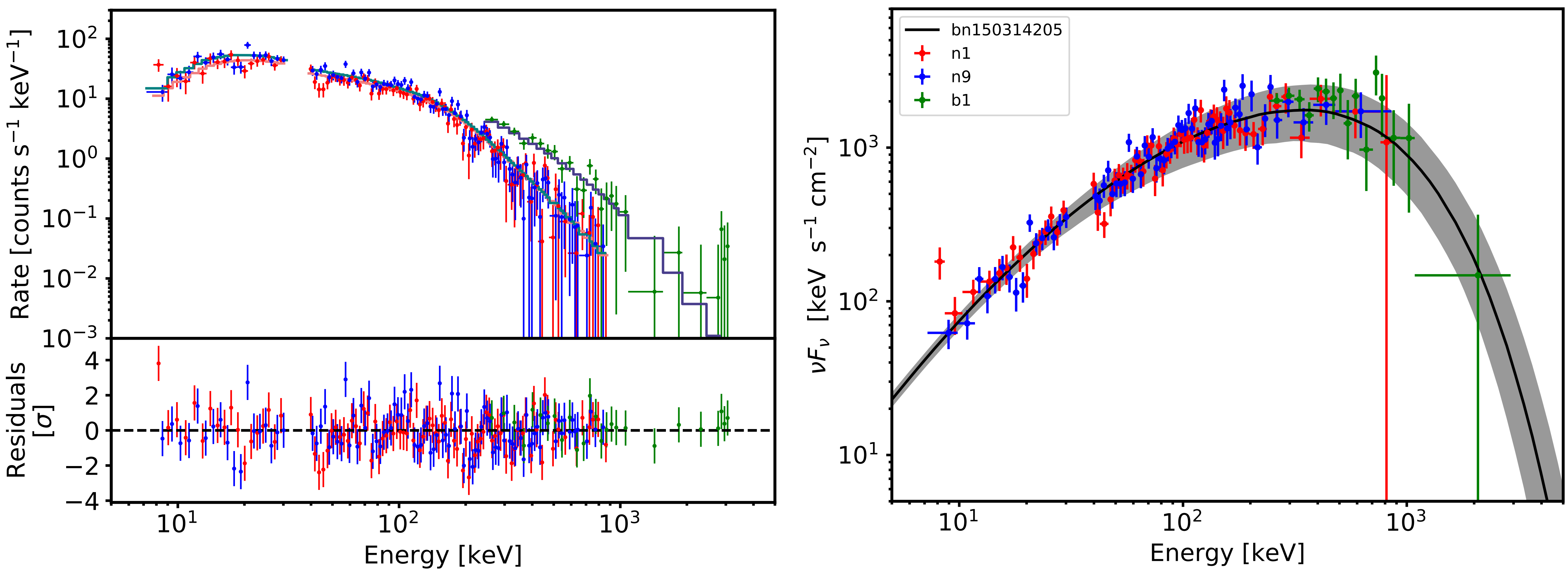


Samuelson+ (2022)

Time resolved spectrum GRB 150314A

- Assuming $\Gamma = 300$ one gets

$$(\beta\gamma)_{\rm u} = 1.89, \quad \theta_{\rm u} = 8.8 \times 10^{-5}, \quad \frac{n_\gamma}{n} = 2.0 \times 10^5$$

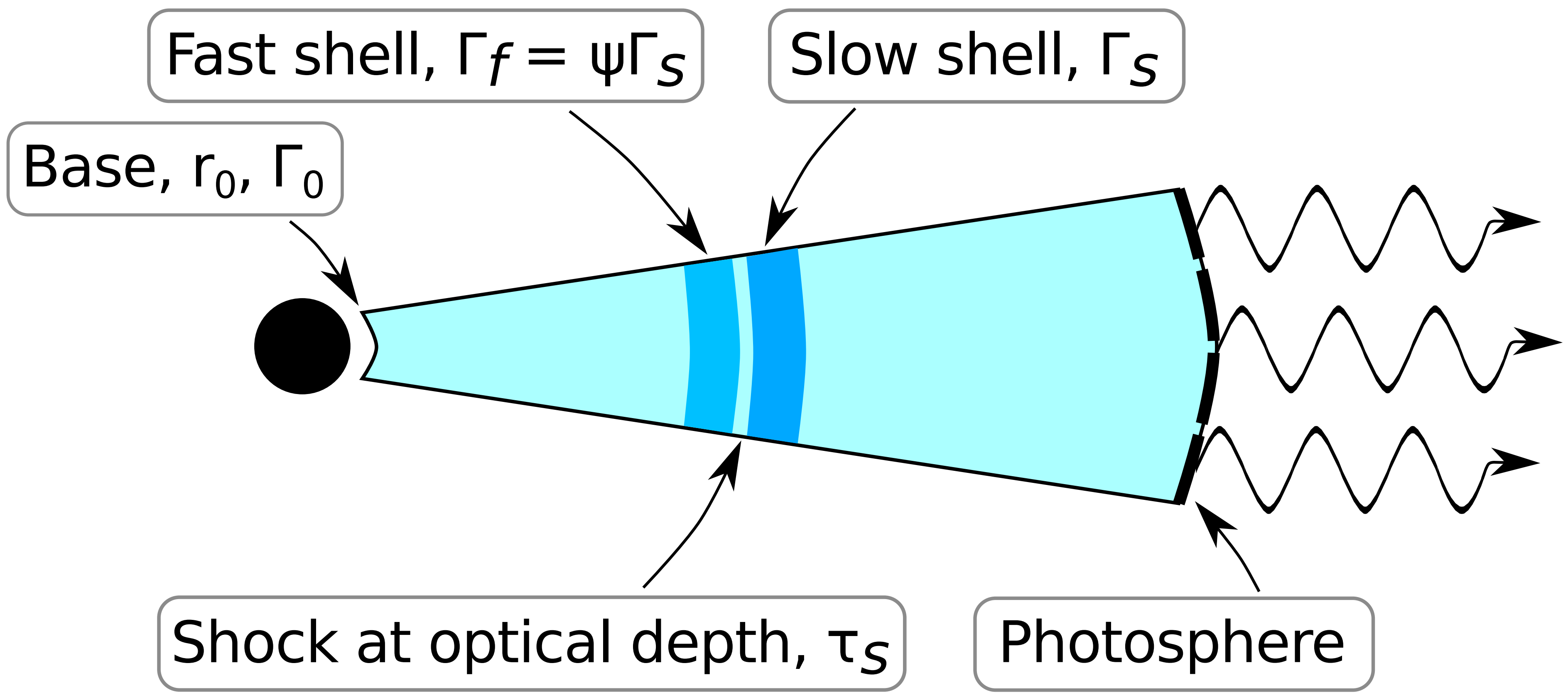


Samuelson+ (2022)

What do photospheric
RMS spectra look like?

Estimating shock initial conditions

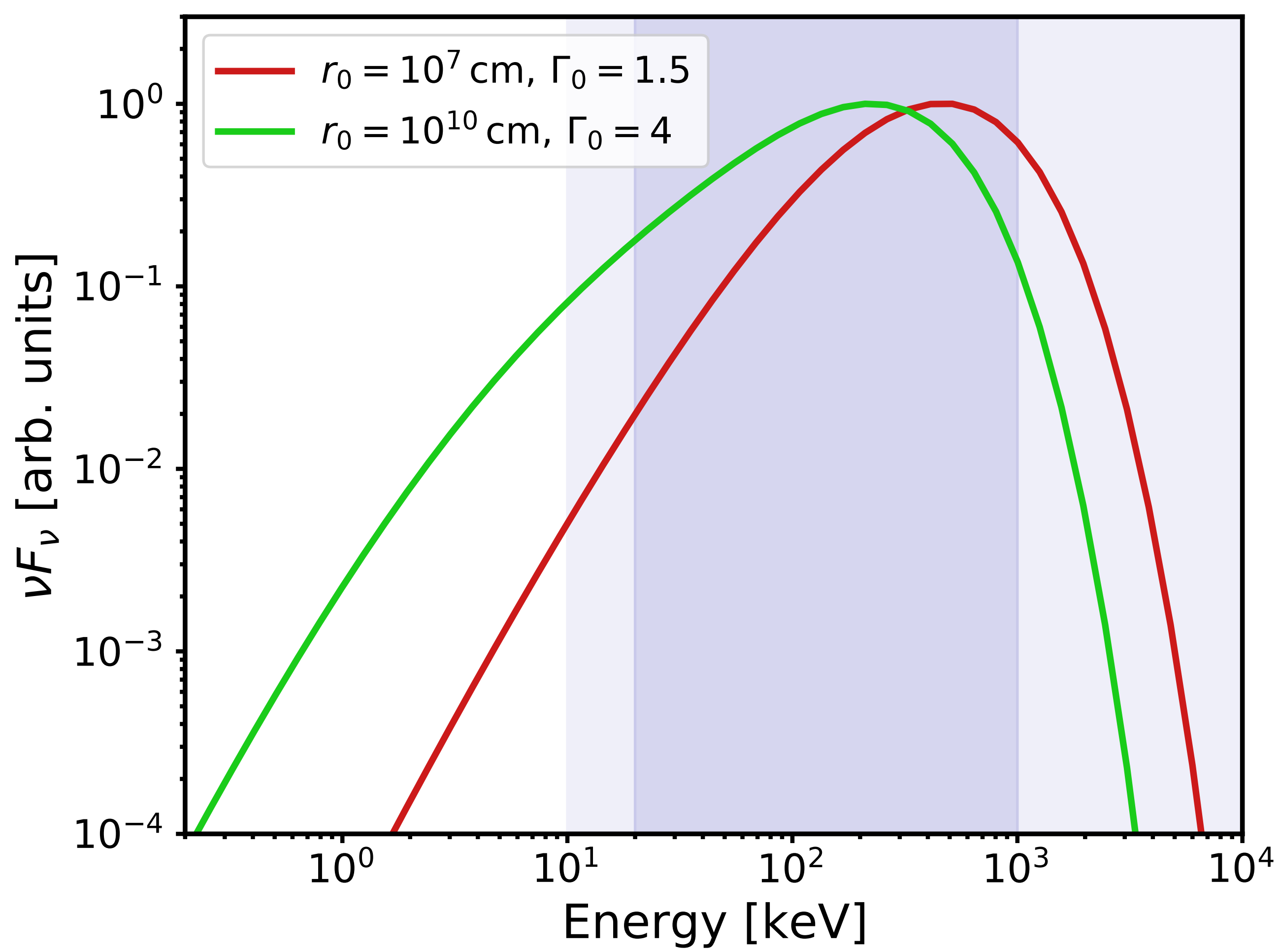
- Without context, shock initial conditions can be anything
- Here, we employ a simple internal collision framework

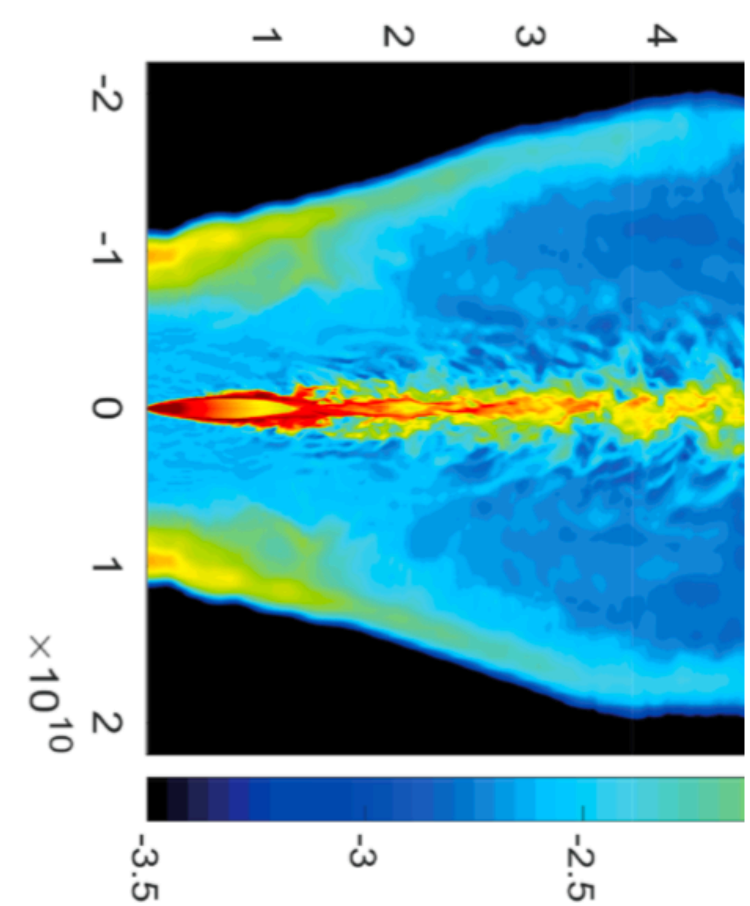


Kobayashi+ (1997), Daigne & Mochkovitch (1998), Rees & Mészáros (2005)

Two internal shock scenarios

- Early and delayed acceleration scenario
- Delayed scenario gives smooth spectra with a high-energy cutoff and a hardening in X-rays

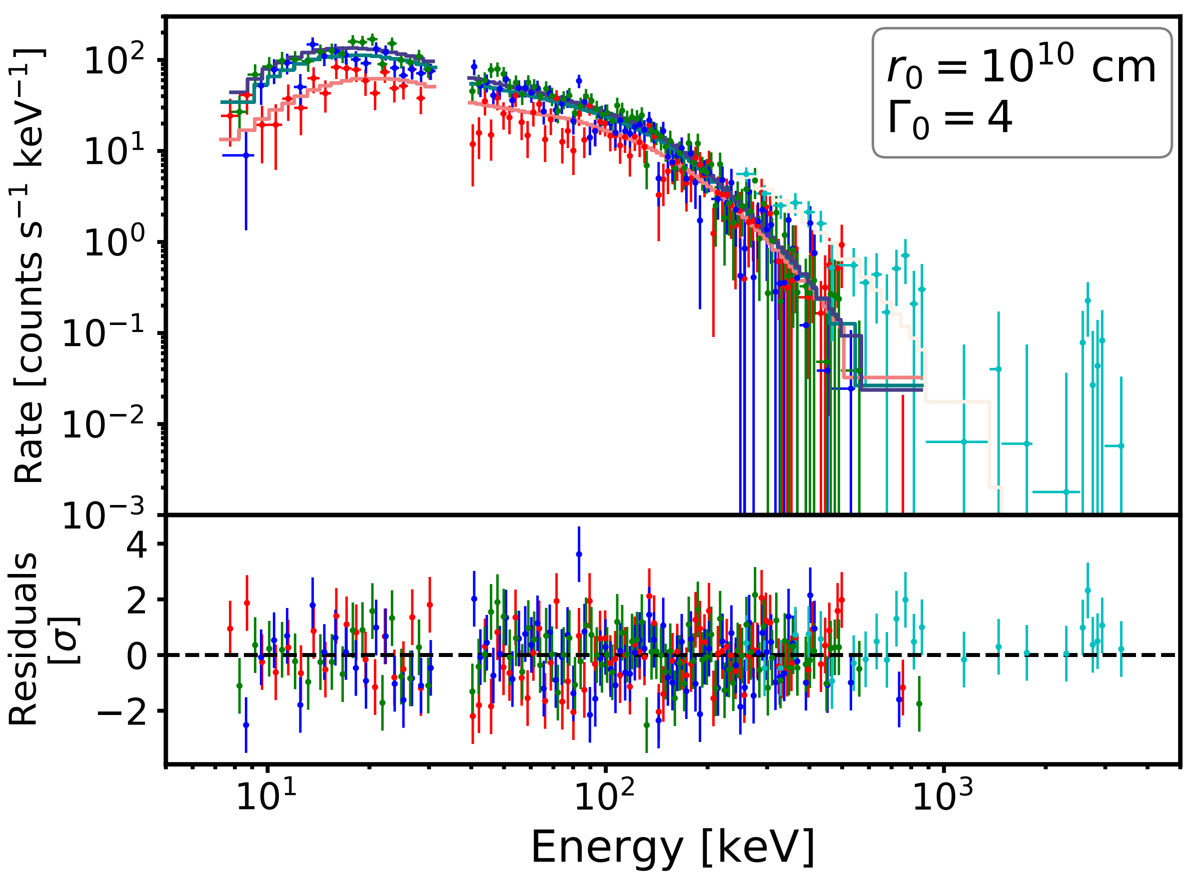


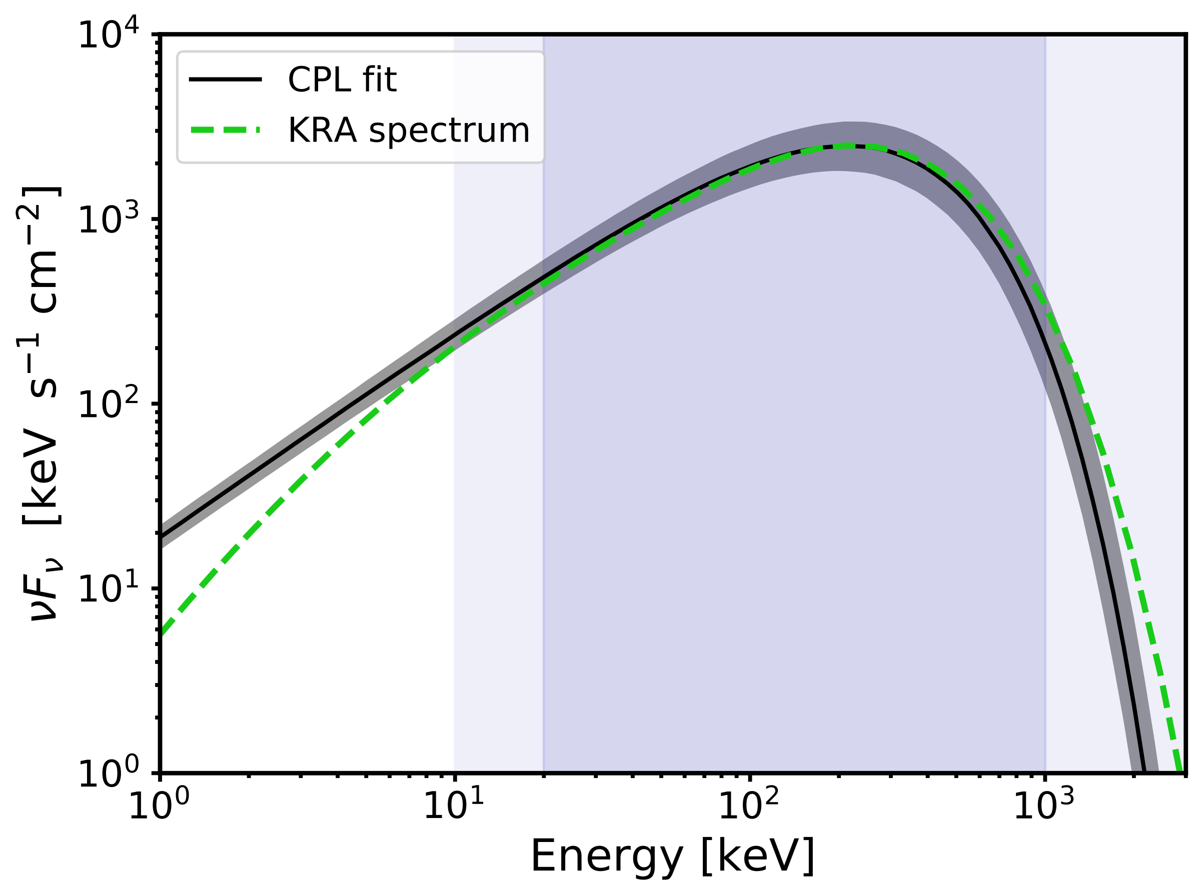


Gottlieb+ (2019)

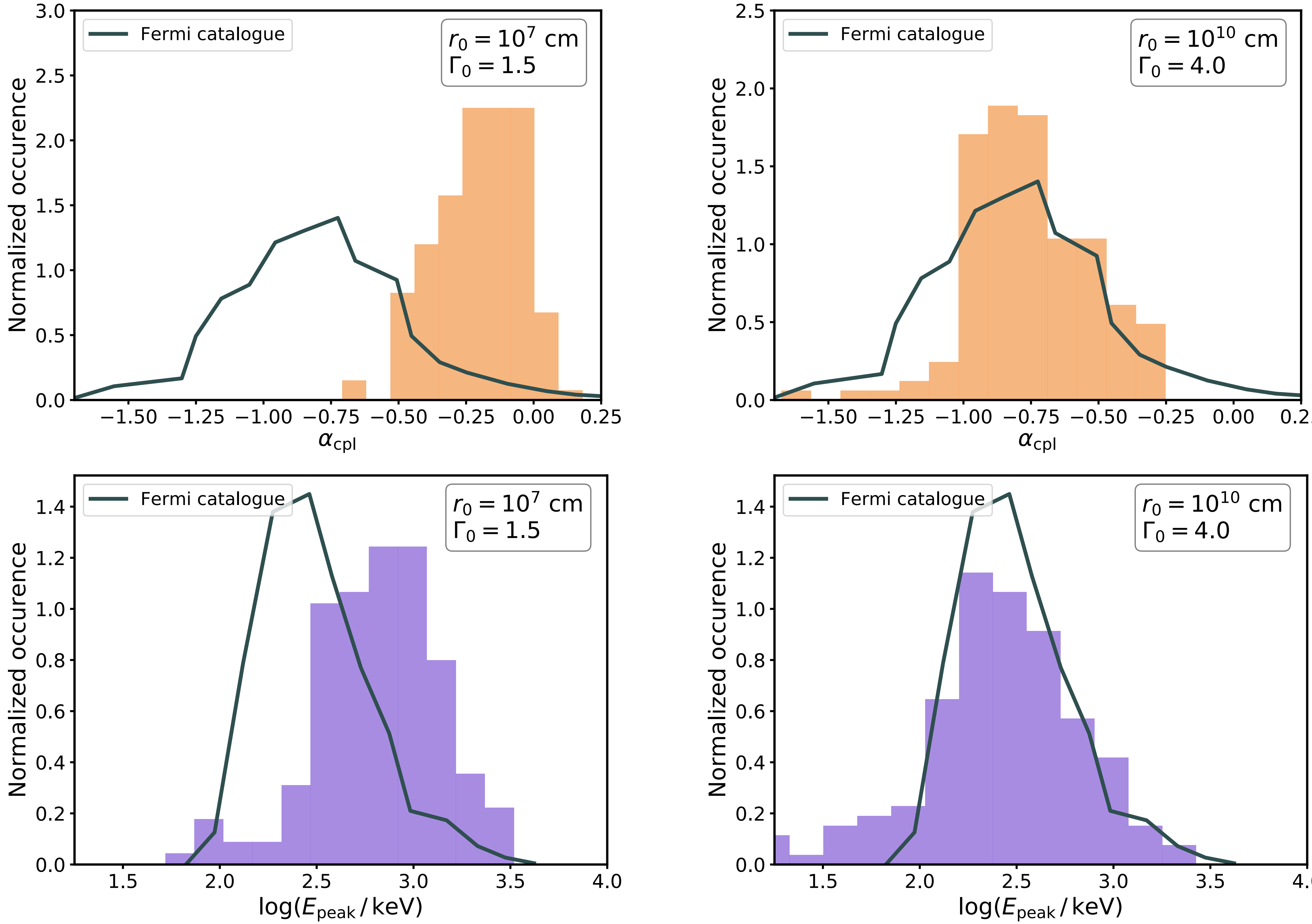
Fit with a cutoff power-law (CPL) function

- Forward fold through Fermi GBM response matrix
- Spectra generally well fitted with a CPL; complexity outside detector window





150 fits with a CPL function

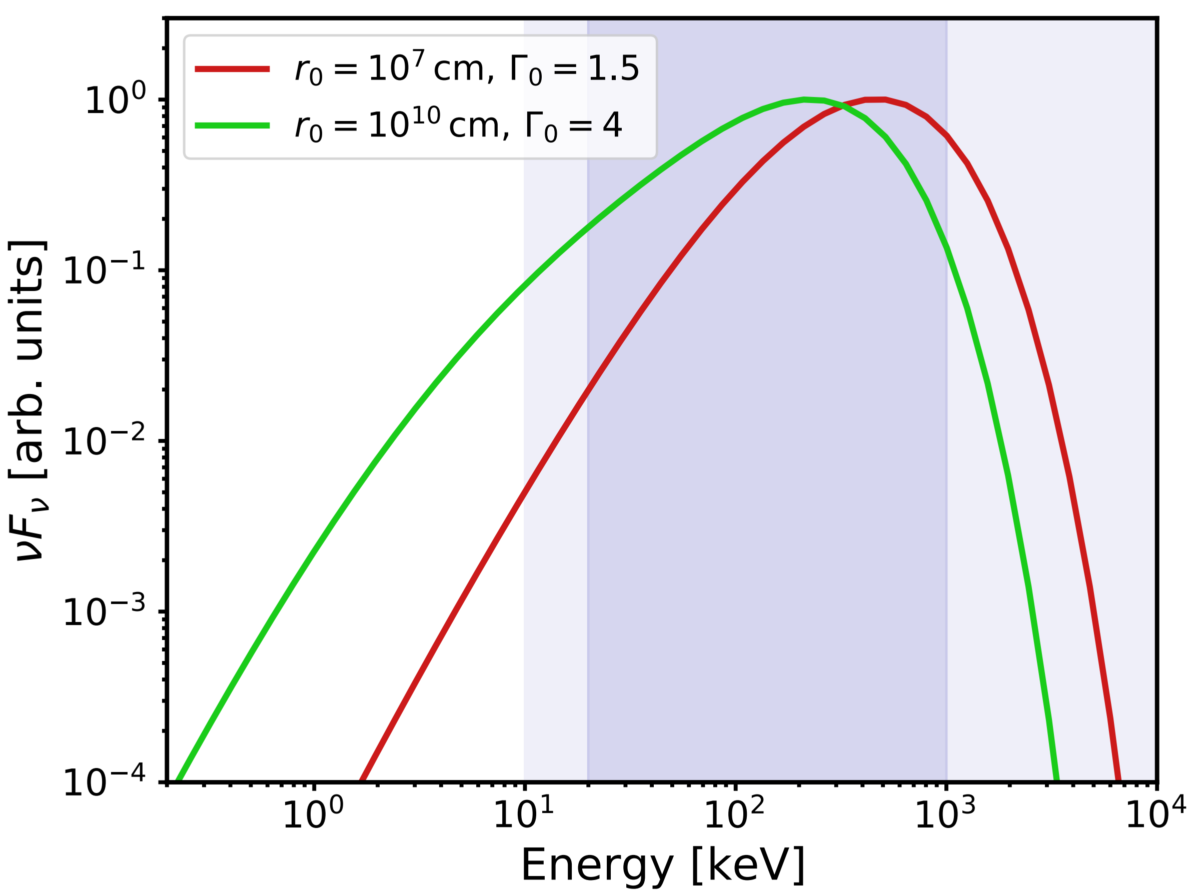


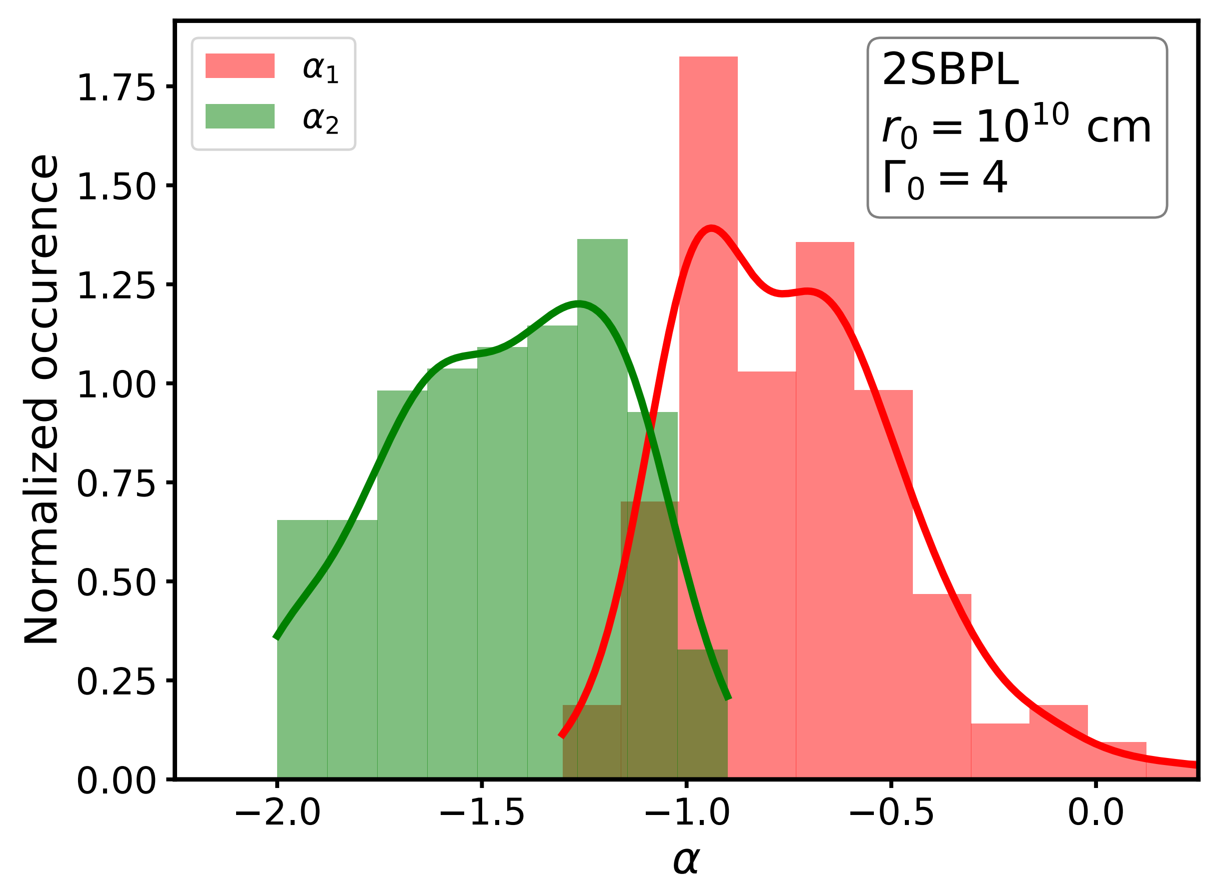
Samuelsson & Ryde (2022). Yu+ (2016)

Additional X-ray break

- Evidence for spectral complexity in GRB fits

- 150 fits allowing for an additional break below the peak-energy





Samuelsson & Ryde (2022). Ryde (2005), Guiriec+ (2011), Axelsson+ (2012), Ravasio+ (2018, 2019), Oganesyan+ (2018, 2019), Gompertz+ (2022)

Conclusions

- Radiation mediated shocks are expected below the photosphere of a GRB
- KRA allows us to bridge the gap between theory and observations
- Generated spectra are very soft, similar to observations, and an additional break in X-rays is expected within the model

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Samuelsson & Ryde. (2022) arXiv:2206.11701

A post doc position is available at the Oskar Klein Center and KTH in Stockholm on GRB research

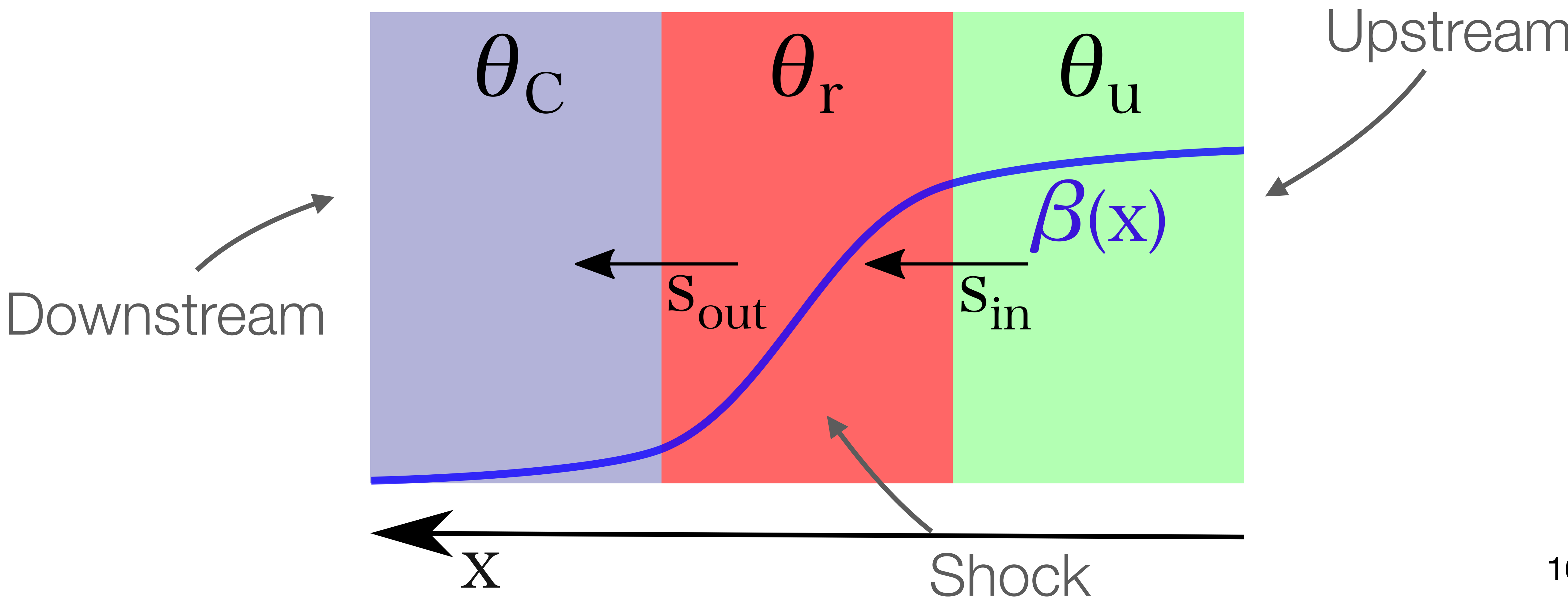
Reference number
S-2022-1814

https://kth.varbi.com/en/what:job/jobID:552765/

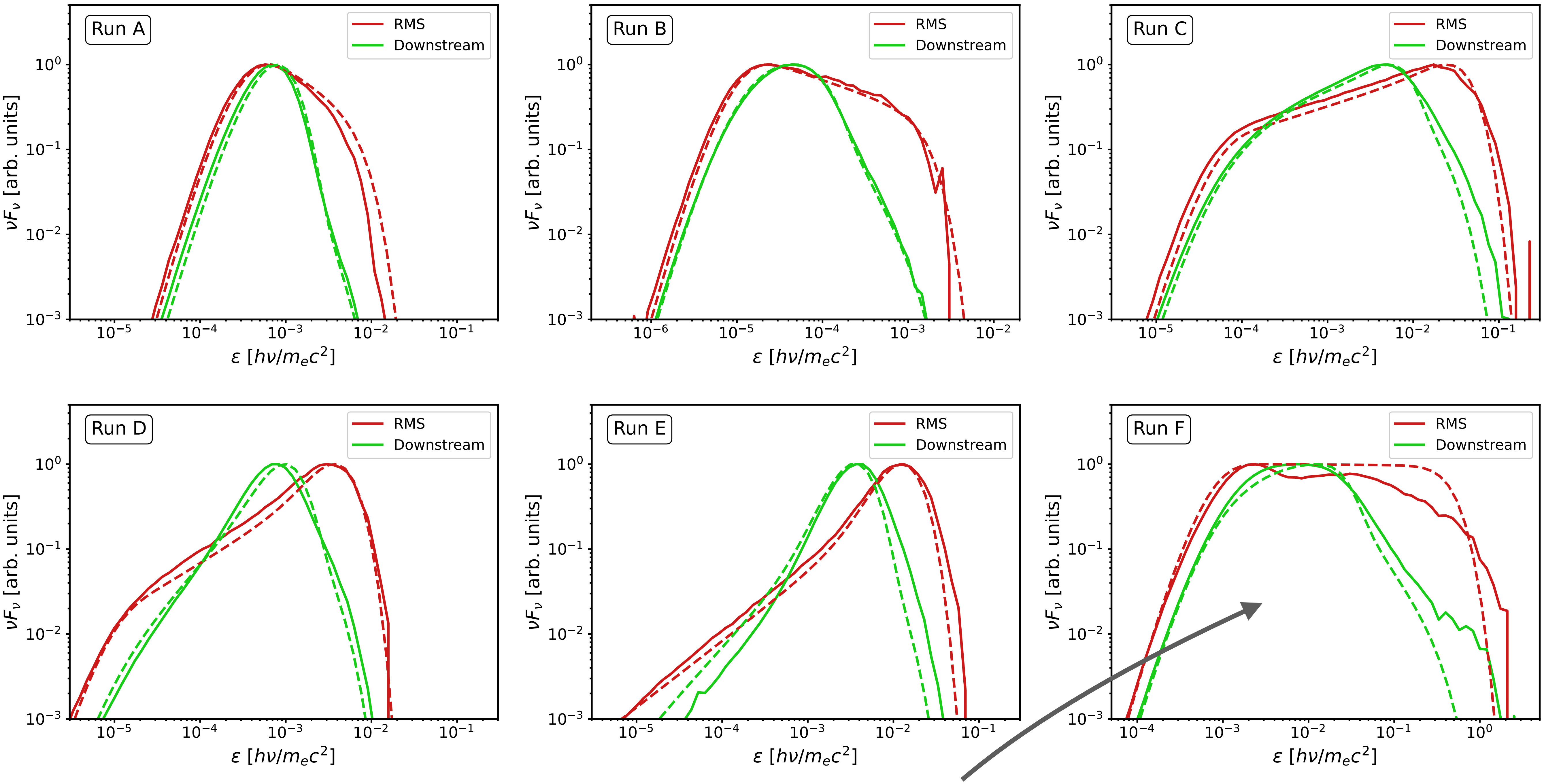
Extra slides

The Kompaneets RMS approximation (KRA)

- Fermi acceleration of photons in RMS converging flow ≈ repeated scatterings with hot electrons
- The Kompaneets RMS approximation (KRA)



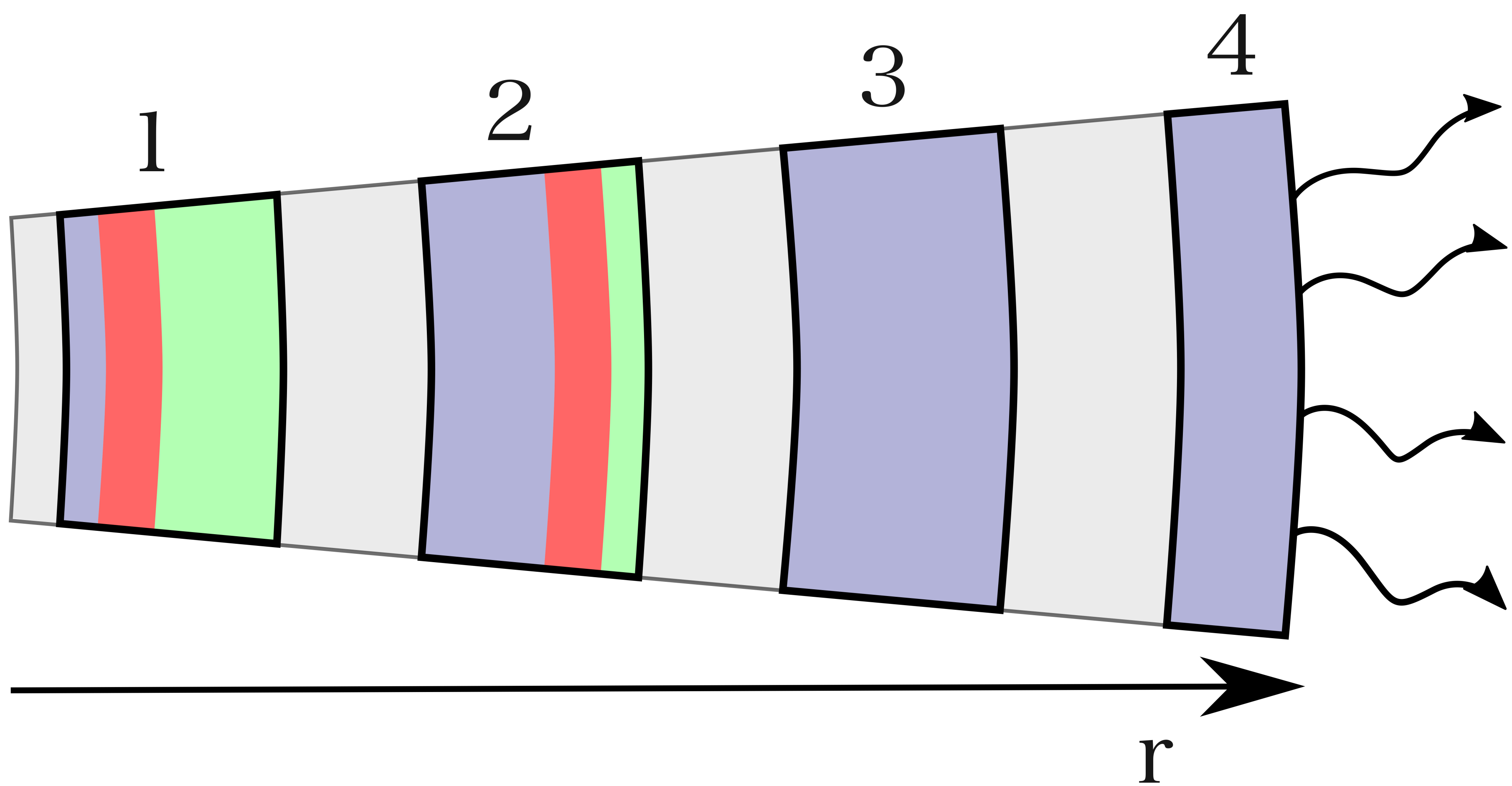
Verification of the approximation



Mildly relativistic shock: $(\beta\gamma)_{\rm u} = 3$

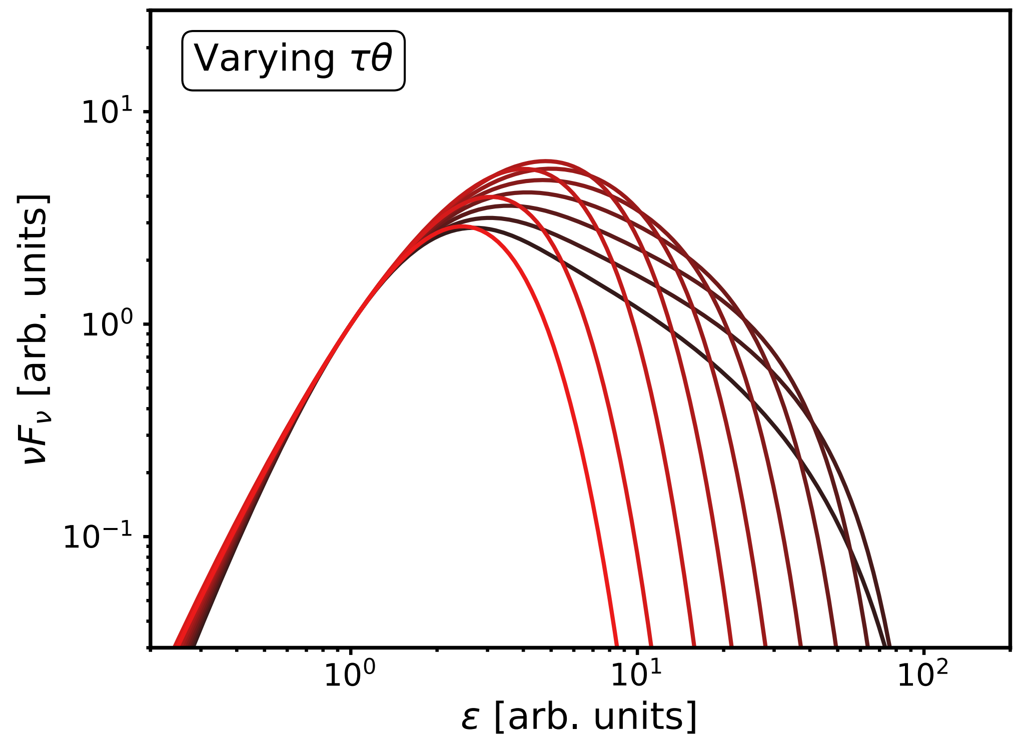
A minimal jet model

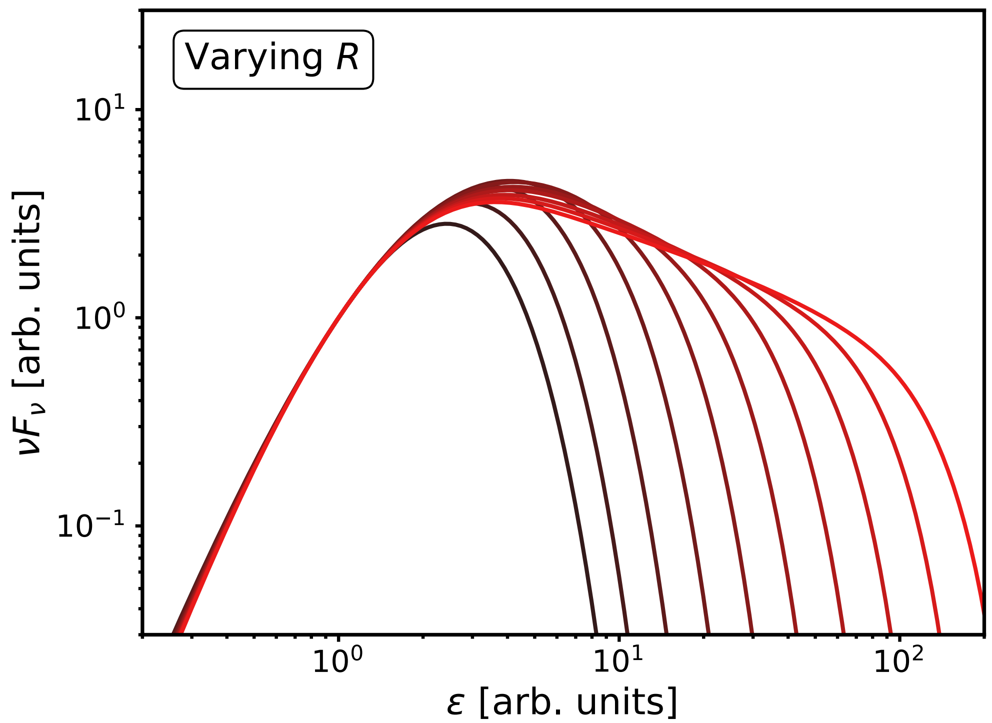
- Implementing the KRA in a minimal jet scenario
- All zones account for adiabatic cooling and thermalization

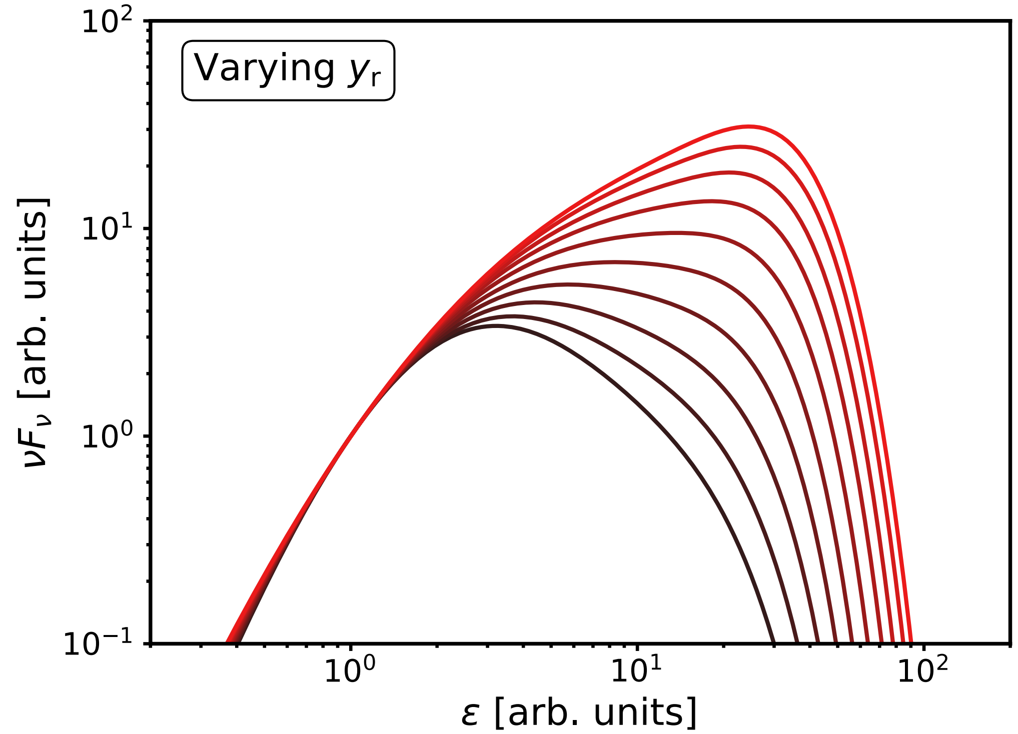


Parameters

- Three parameters for the shape





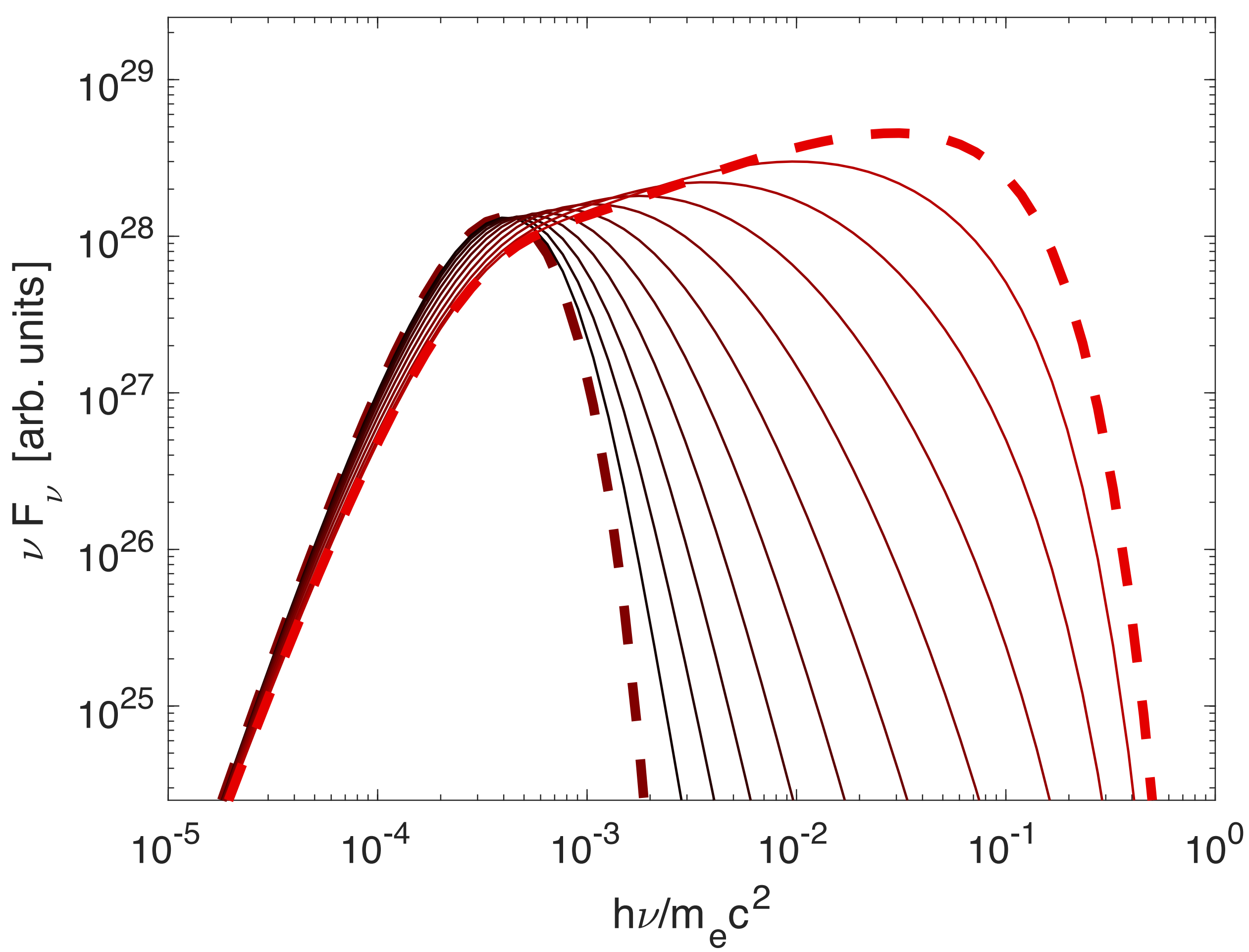


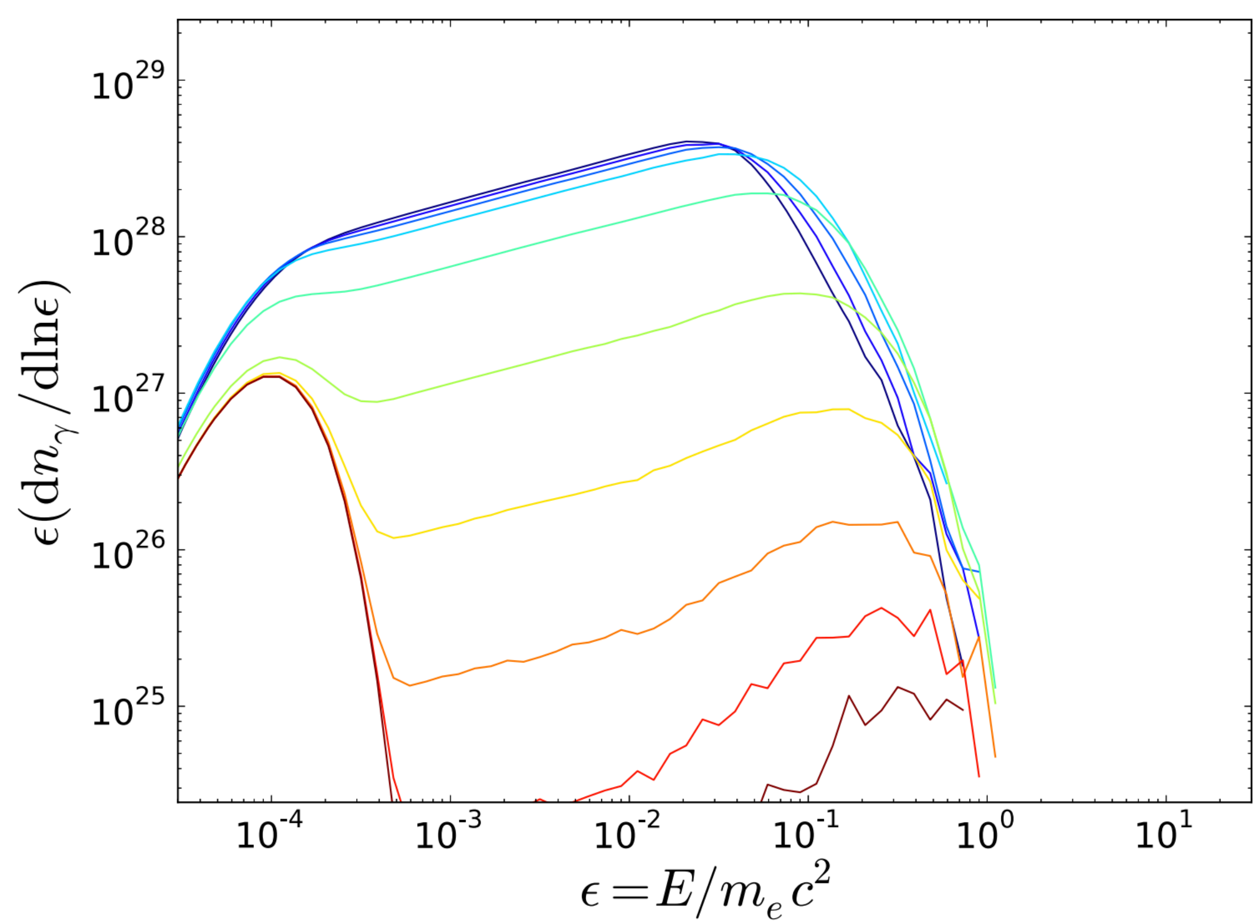
Kompaneet's equation

- Repeated scatterings of non-relativistic thermal electrons

$$\frac{\partial}{\partial \bar{r}}\left(\bar{r}^2 n\right) = \frac{1}{\epsilon^2}\frac{\partial}{\partial \epsilon}\left[\frac{\epsilon^4}{\bar{r}^2}\left(\theta\frac{\partial(\bar{r}^2 n)}{\partial \epsilon} + (\bar{r}^2 n)\right) + \frac{2}{3}\frac{\epsilon^3(\bar{r}^2 n)}{\bar{r}}\right] + s$$

Spectrum — Heating — Cooling — Ad. cooling — Sources

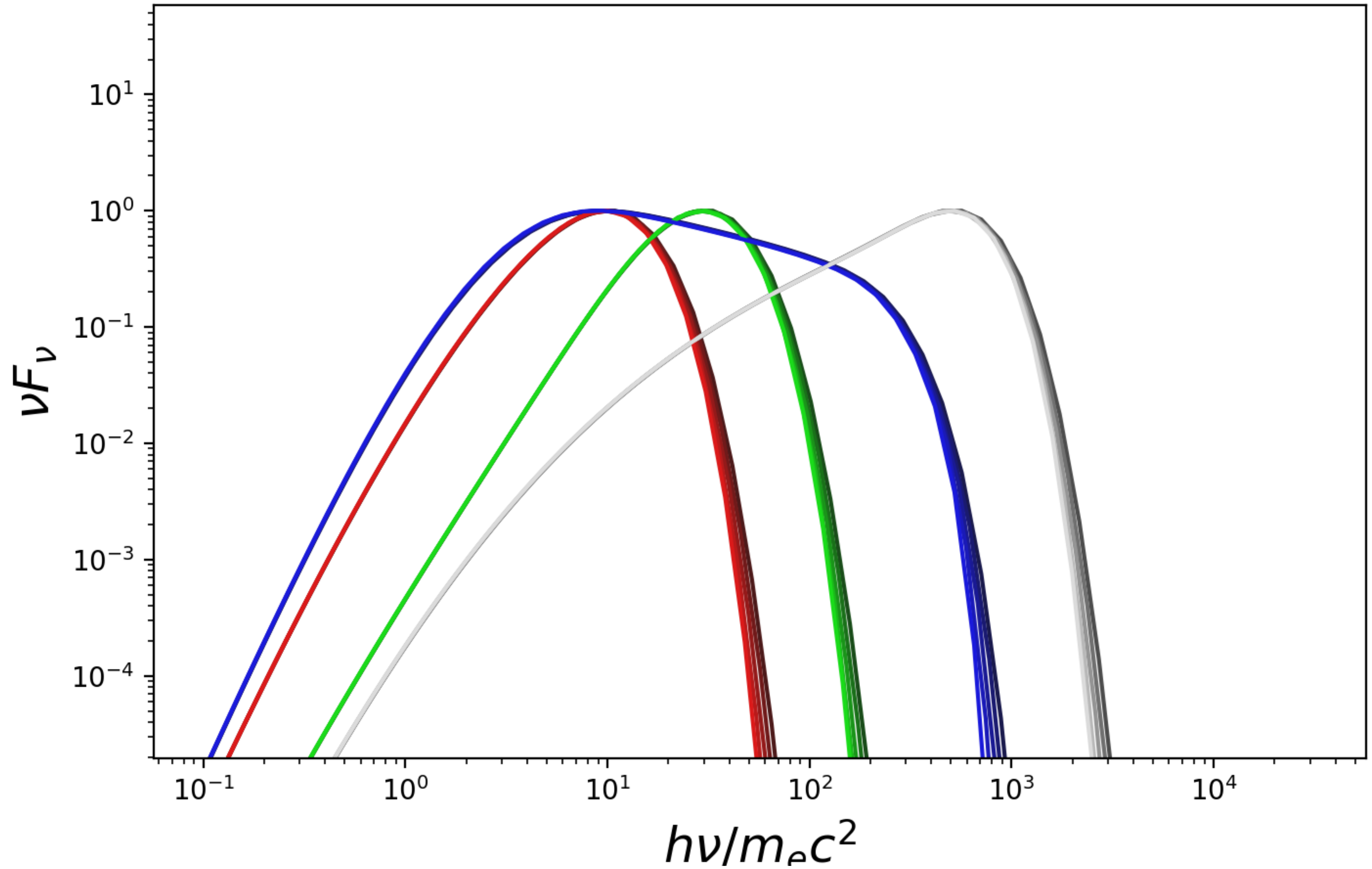




Lundman+ (2018); ApJ, 858:7

Degeneracy

- Varying tau and theta_r without changing their product



Higher order effects at the photosphere

- We never observe a Planck or Wien spectrum
- High-latitude emission and fuzzy photosphere including angle dependent beaming and adiabatic cooling