Modélisation physique des sursauts gamma

Frédéric Daigne (Institut d'Astrophysique de Paris)

avec Robert Mochkovitch et

(Romain Hascoët), Zeljka Bosnjak, Guillaume Dubus,
Sylvain Guiriec, Manal Yassine, Maria-Grazia Bernardini, Frédéric Piron: prompt emission

(Romain Hascoët), Andrei Beloborodov,
Astrid Lamberts, Eliot Ayache, Hendrik van Eerten: afterglow

Jesse Palmerio, Susanna Vergani: population models, long GRB progenitors

Raphaël Duque: em counterparts to BNS, connection with short GRBs

et d'autres

Journées Théorie PNHE – Institut d'Astrophysique de Paris, 2 octobre 2018

Modélisation physique des sursauts gamma

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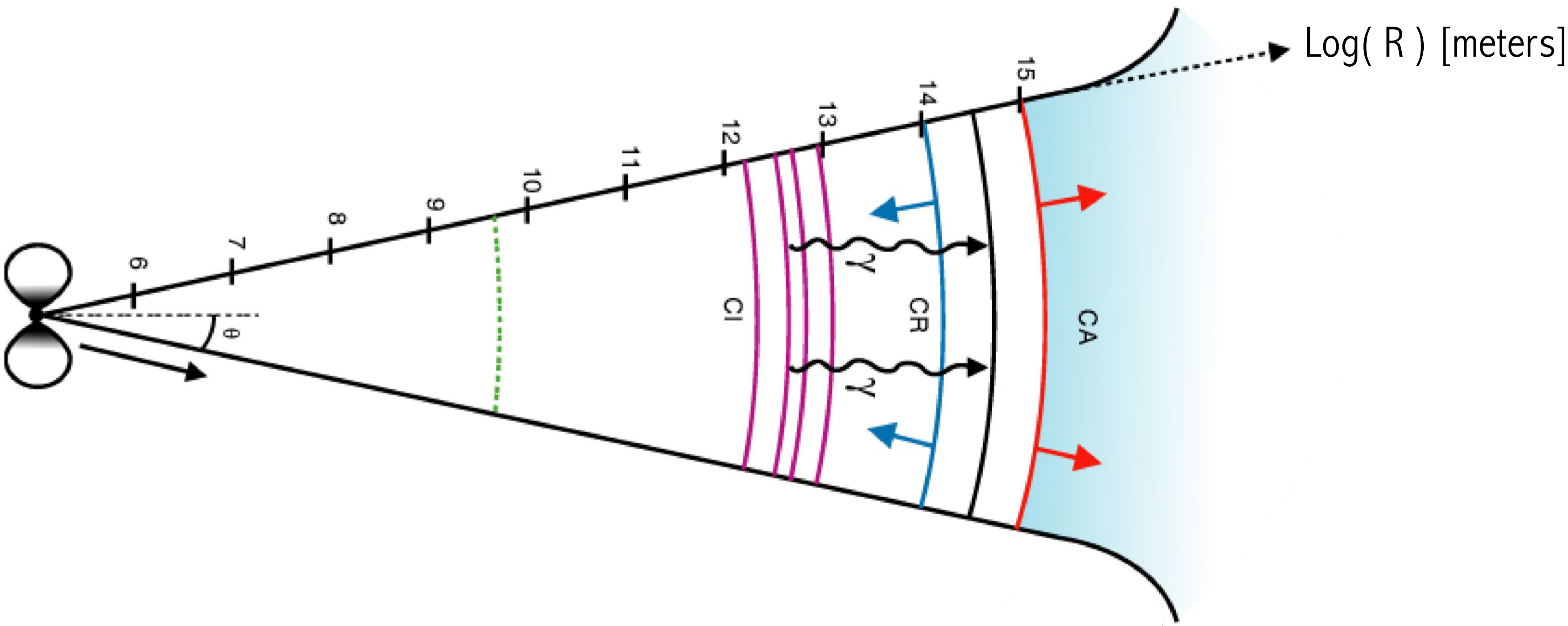
Compact sources and relativistic ejection
Ultra-relativistic jets
Shock waves
Time-dependent radiative transfert at high-energy
Population models
Etc.

GRB physics

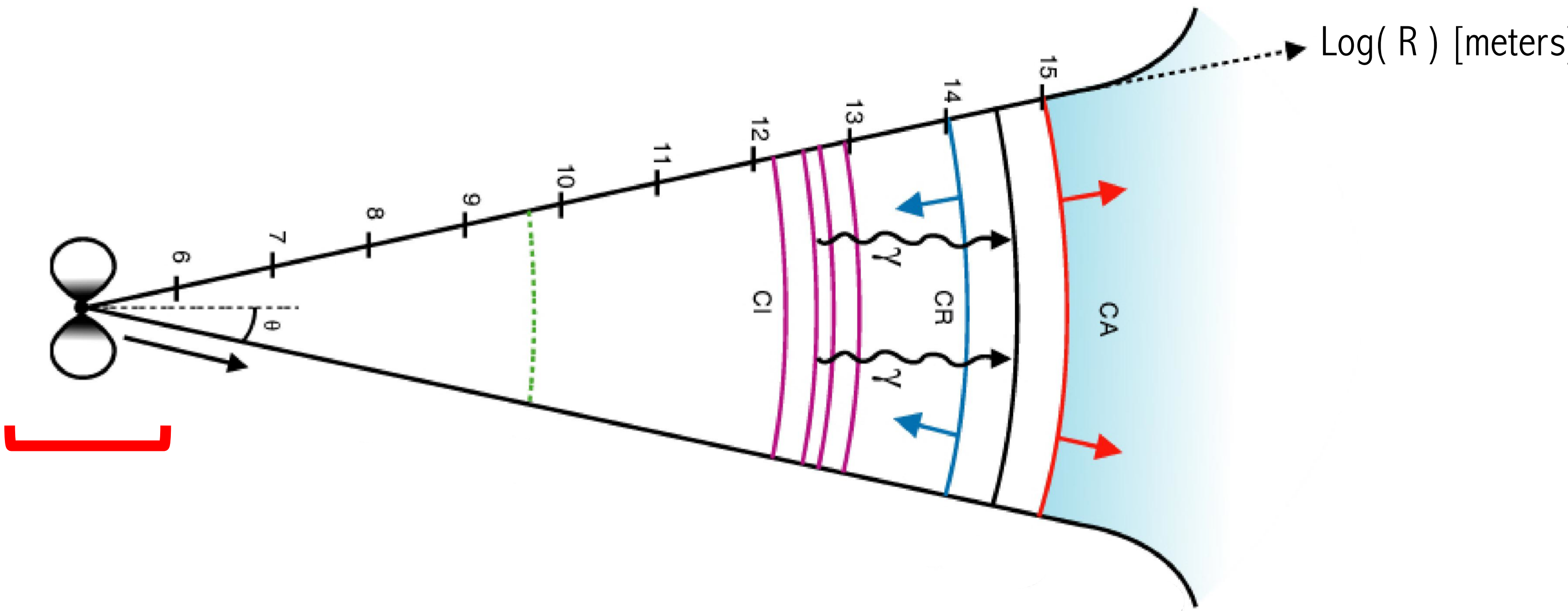


GRB physics

- Cosmological distance: huge radiated energy ($E_{iso,\gamma} \sim 10^{50}$-$10^{55}$ erg)
- Variability + energetics: violent formation of a stellar mass BH/magnetar

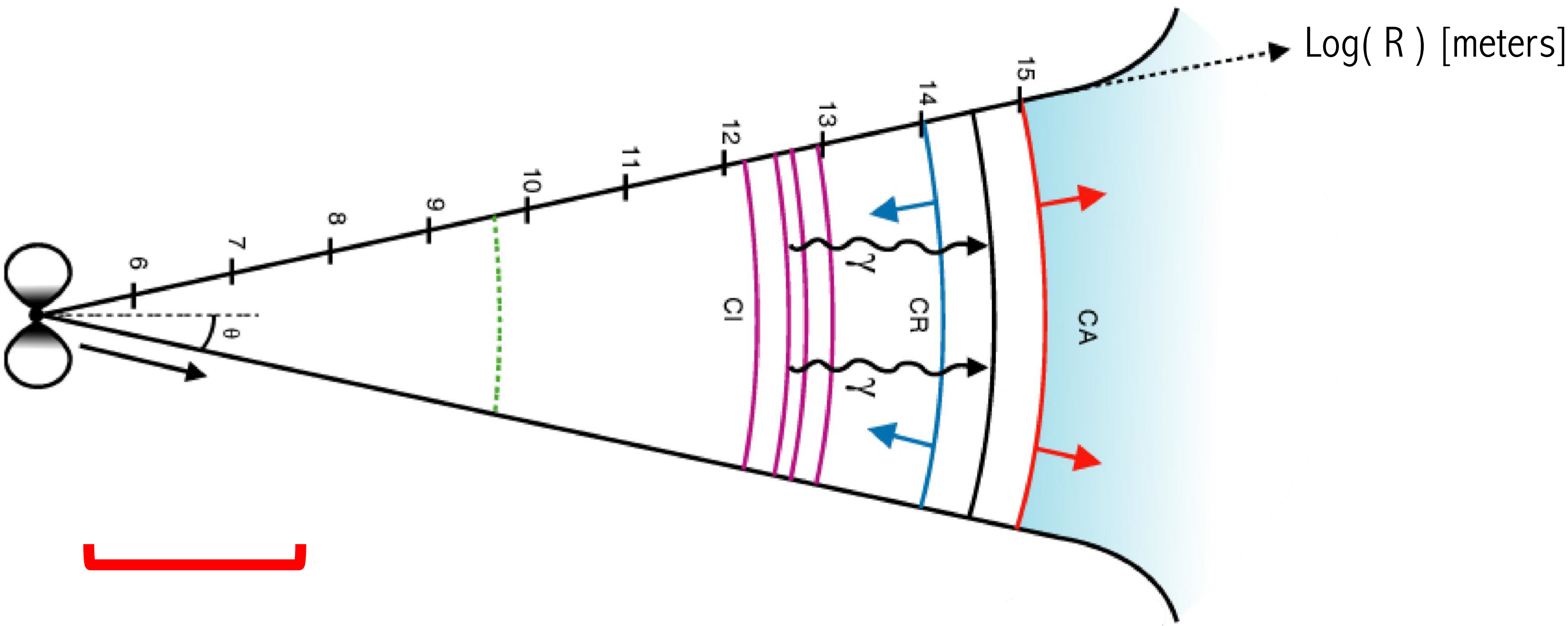
Long GRBs: collapse of a massive star

Short GRBs: NS+NS(/BH ?)merger(?) [GRB170817/GW170817A]



GRB physics

- Variability + energetics + gamma-ray spectrum: relativistic ejection



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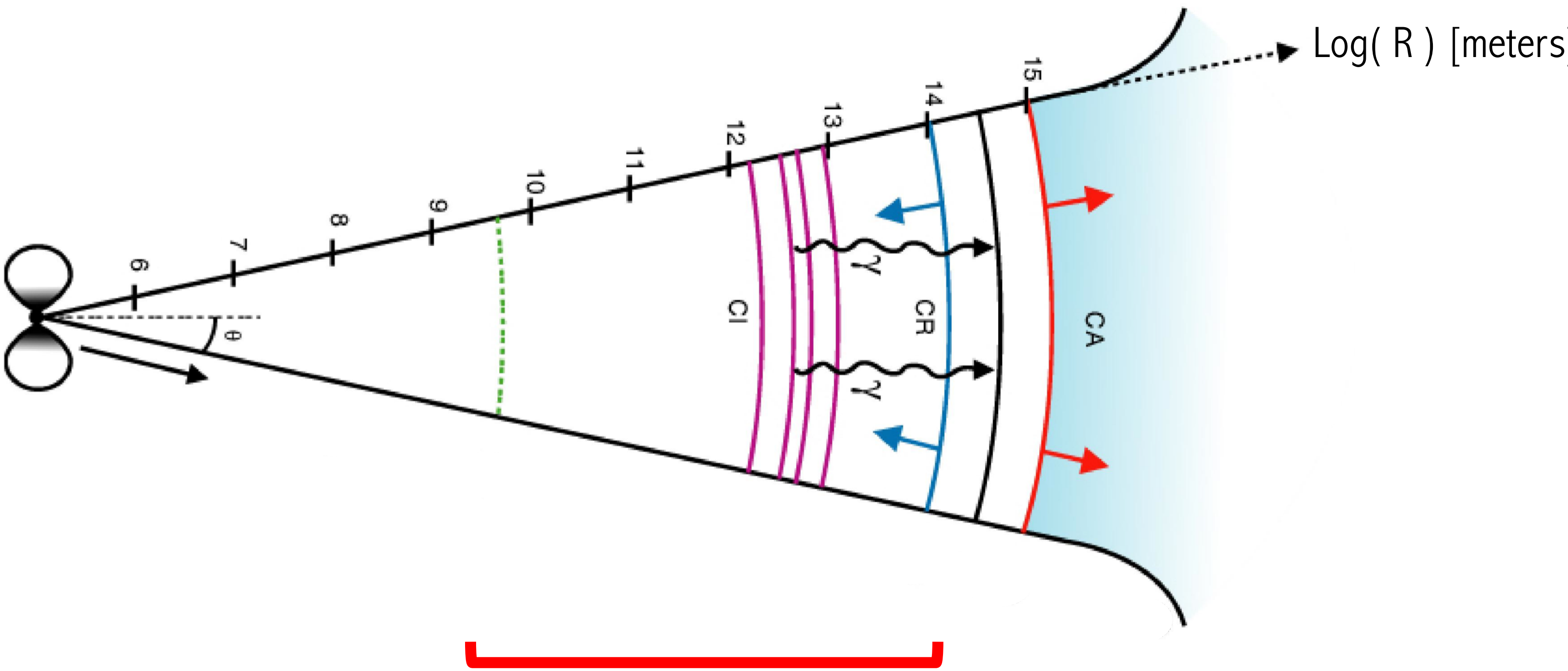
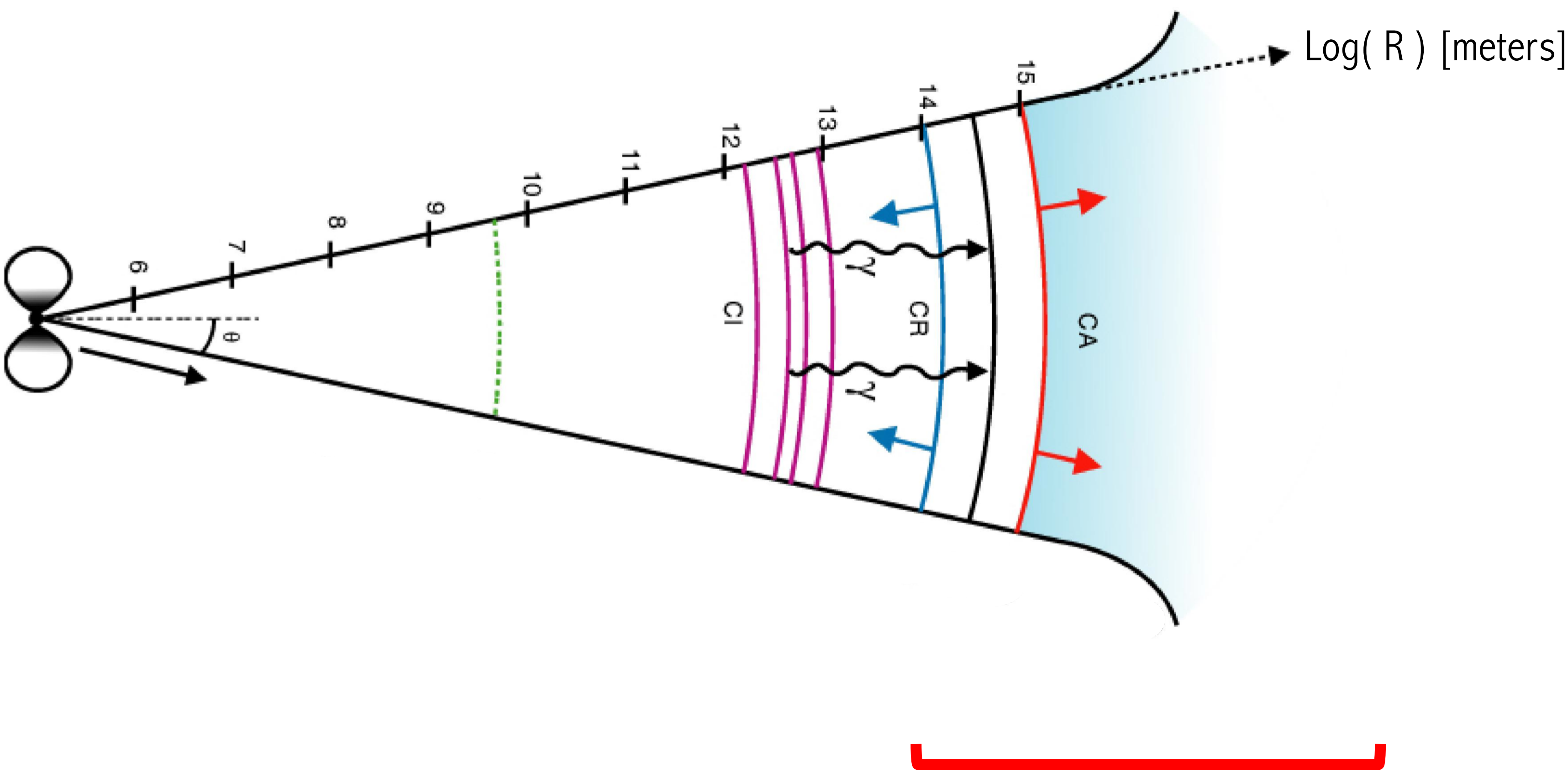
- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt keV-MeV emission: internal origin in the ejecta



GRB physics

- Variability + energetics + gamma-ray spectrum: relativistic ejection
- Prompt keV-MeV emission: internal origin in the ejecta
- Afterglow: deceleration by ambient medium



Some questions about GRB Physics

1. Central engine: nature (BH, magnetar)? Ejection mechanism?
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   - -how relativistic are GRB outflows?
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How relativistic are GRB outflows?

Relativistic motion:

-Direct (in a few cases): apparent super-luminal motion

-Indirect: necessary to avoid a strong $\gamma\gamma$ annihilation

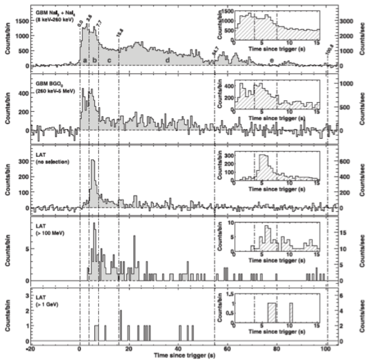
-Other indirect methods: rise of the afterglow, etc.

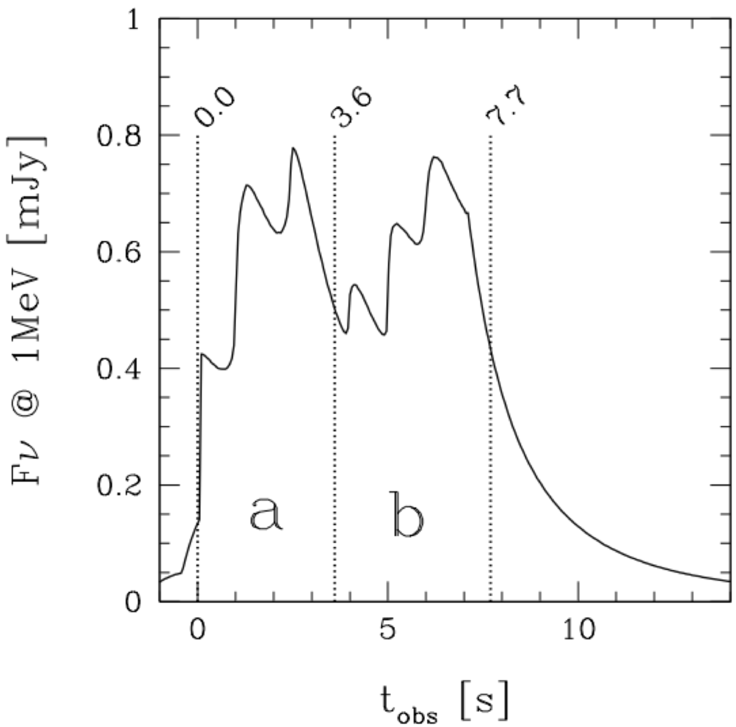
How relativistic are GRB outflows? $\gamma\gamma$ constraints using Fermi

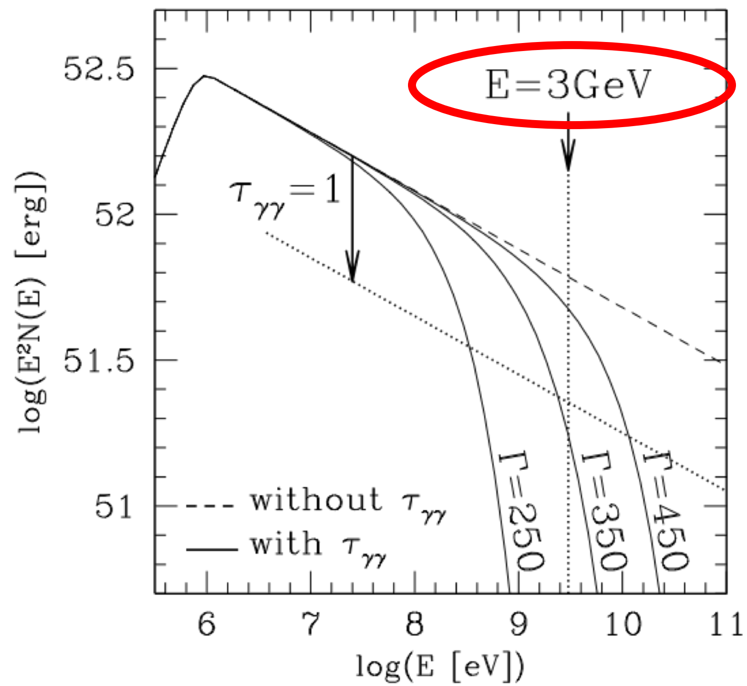
Detailed calculation: space/time/direction-dependent radiation field

the estimate of Γ_{min} is reduced by a factor ~ 2-3

(see Granot et al. 2008; Hascoët, Daigne, Mochkovitch & Vennin 2012)





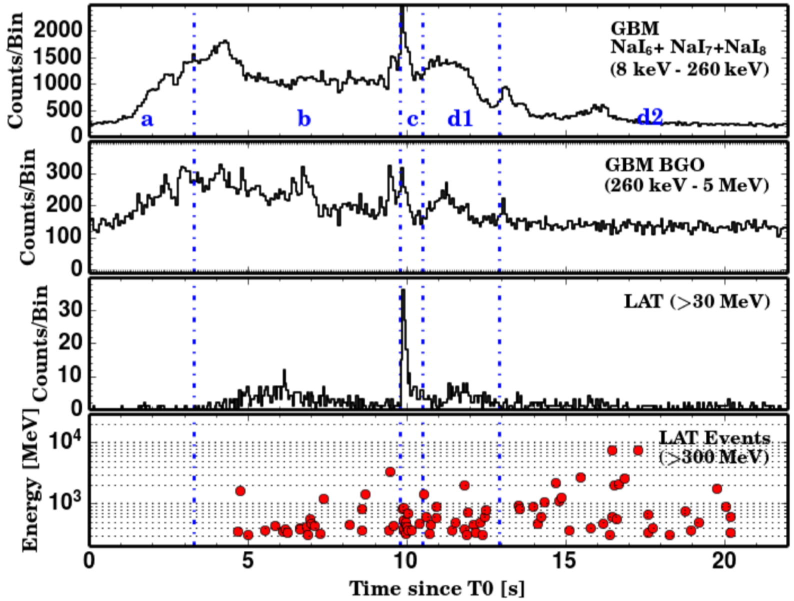


GRB 080916C : Γ_{min} ~ 360 (Hascoët, Daigne, Mochkovitch & Vennin, 2012)

instead of ~900 (Abdo et al. 2009)

First observation of the γγ cutoff ?

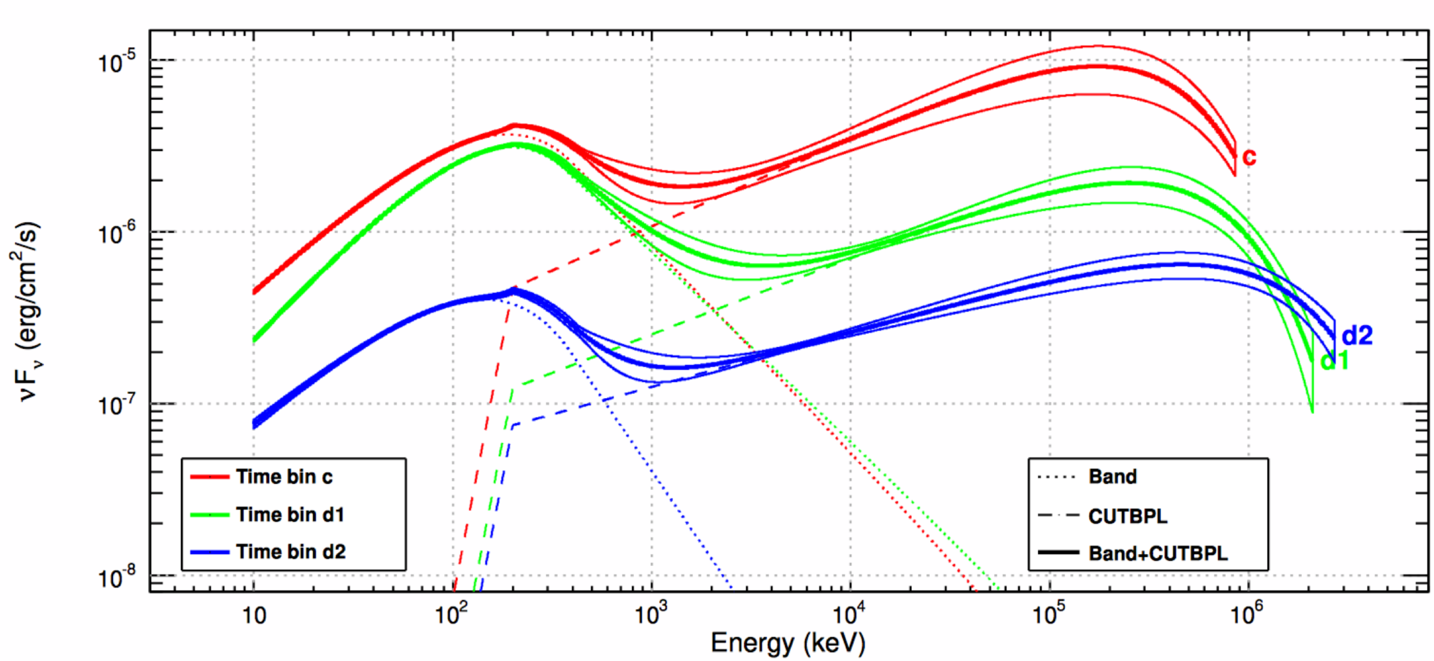
- GRB 090926A (Fermi-LAT):
  first observed cutoff at high-energy
  (Ackermann et al. 2011)



- New analysis and interpretation:

  - Path 8: 447 → 1088 evts in LAT (× 2.4)
  - cutoff is *better* detected, in *several* time bins

Yassine+17 [FD]



First observation of the $\gamma\gamma$ cutoff ?

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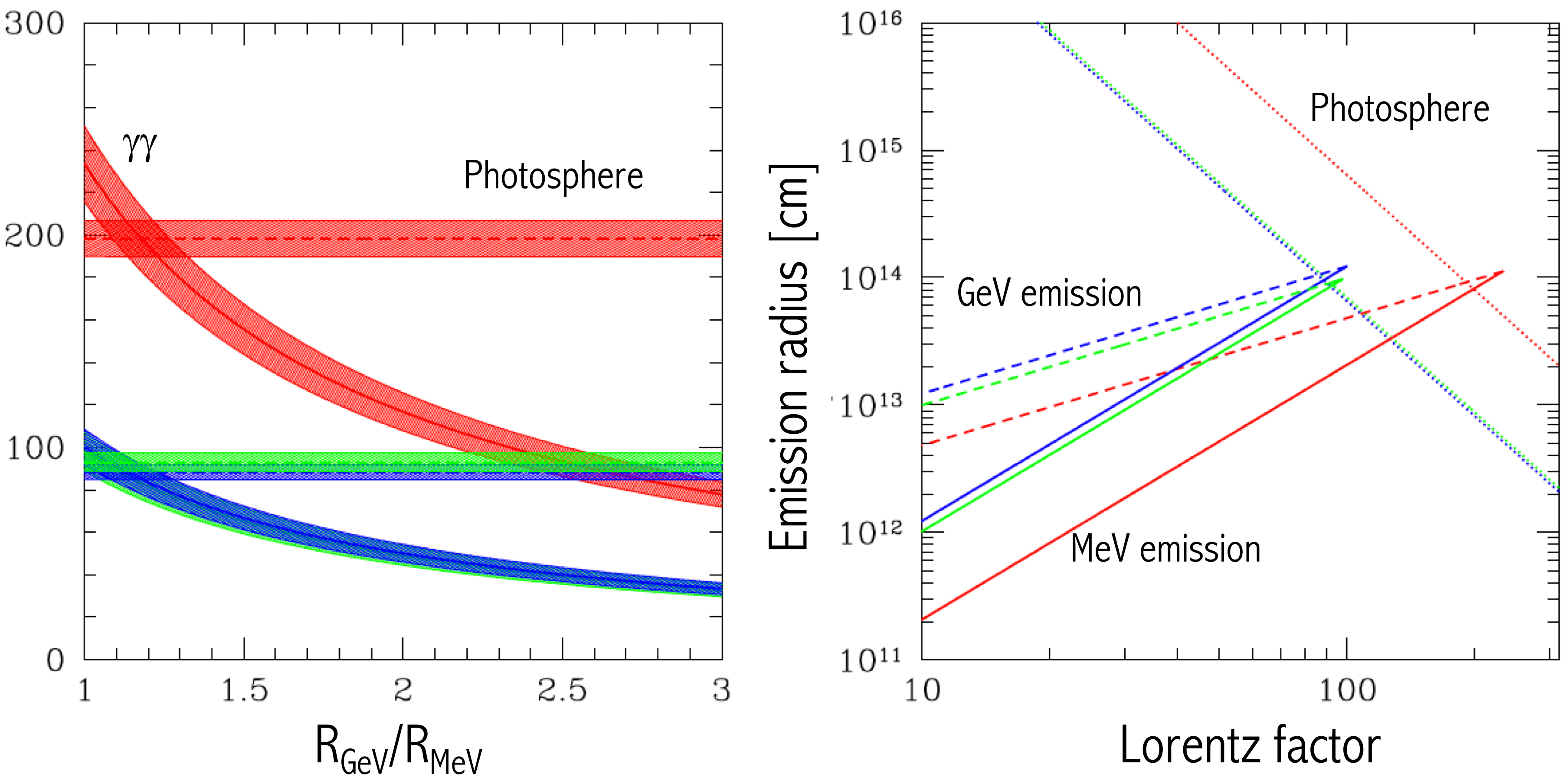

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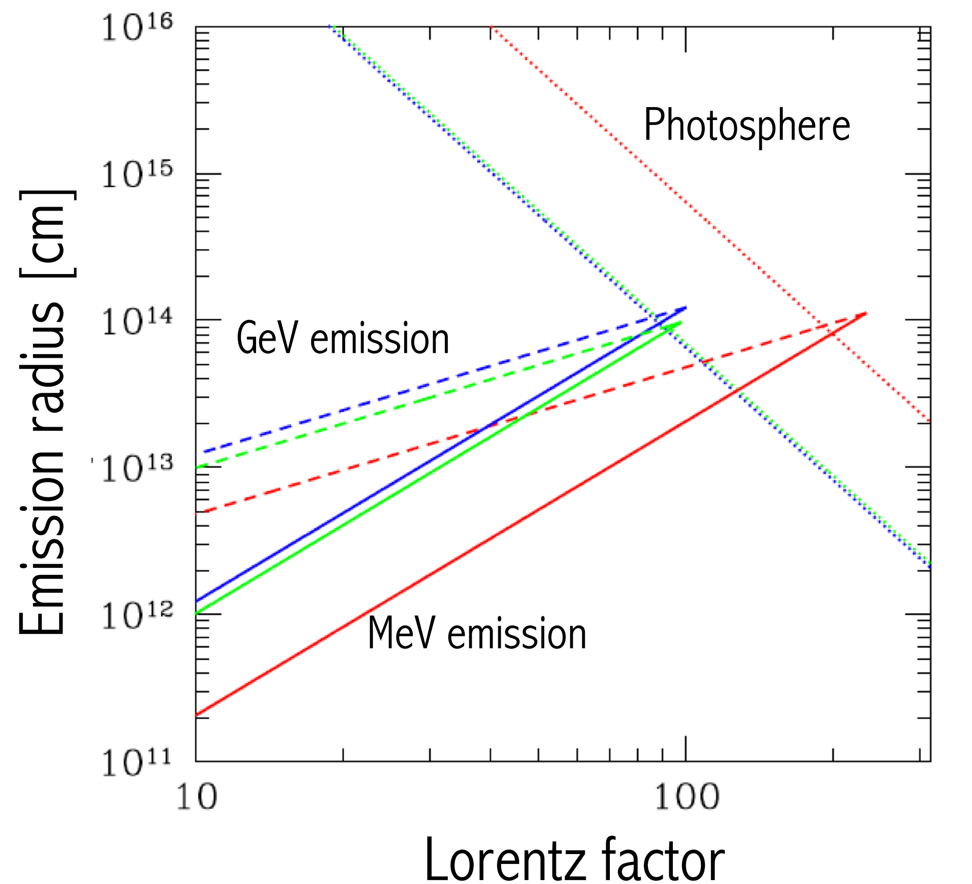
- New analysis and interpretation: cutoff detected in several bins, **strong constraint on Lorentz factor and emission radius!**

Lorentz factor ~ 230 to 100
Emission radius ~ 10^{14} cm
Photospheric radius ~5 10^{13} cm

Compatible with « standard scenario » (internal shocks/reconnection above the photosphere)



Yassine, Piron, Daigne & Mochkovitch, 2017

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Modelling GRB prompt and afterglow emission

Models developped at IAP:

- Dynamics: ballistic approach
  internal / externa reverse+forward shock
  validation by fully relativistic hydro simulations

- Microphysics: parametrized (ε_B, ε_e, ζ, p, ...)

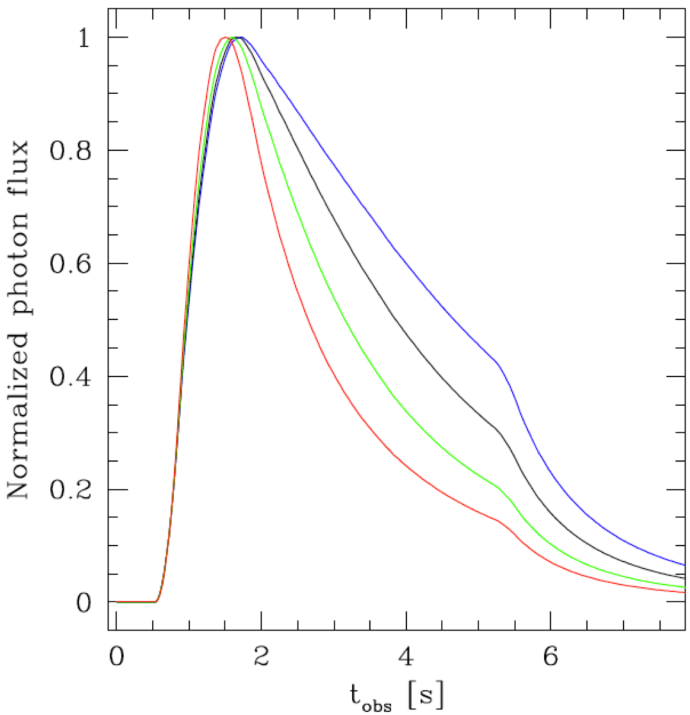
- Radiation: time-dependent radiative code adapted to fast cooling (synchrotron emission and self-abs ; inverse Compton including KN ; pair production ; adiabatic cooling) – no secondary leptons

- Integration over equal-arrival time surfaces + cosmological effects: simulated light curves and spectra

- Specific calculation for photospheric emission

Spectral evolution

Example of a simulated GRB pulse produced by internal shocks
(full simulation: dynamics+radiation)



Light curve in BATSE range :
channels 1 (blue) to 4 (red)

Bosnjak & Daigne 2014

Spectral evolution

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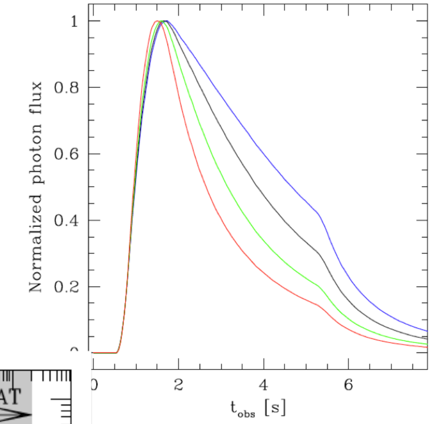
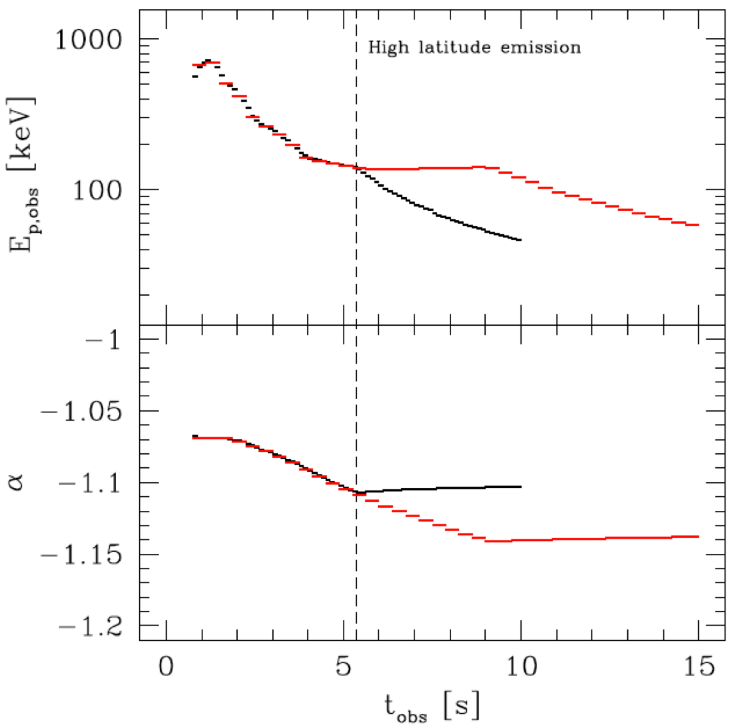
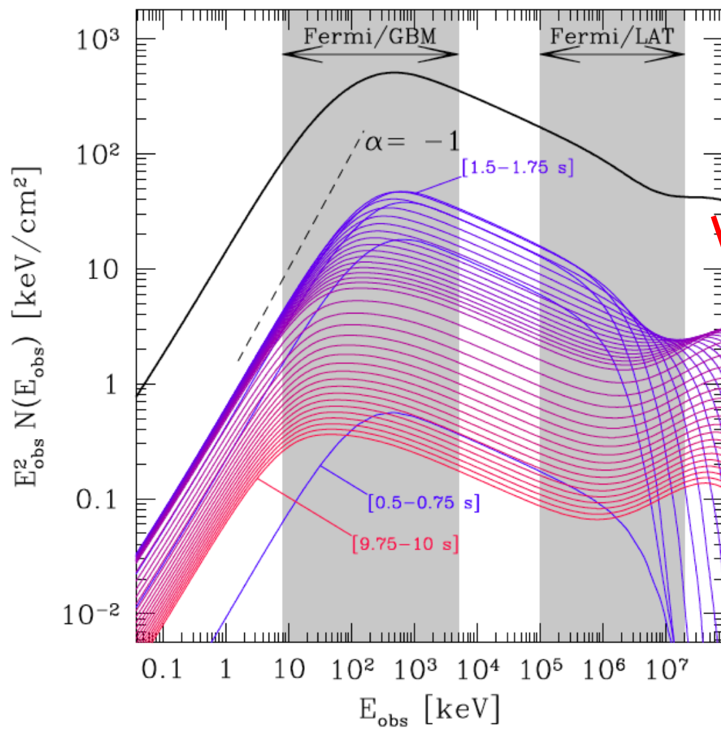


Evolution of E_{peak} and α



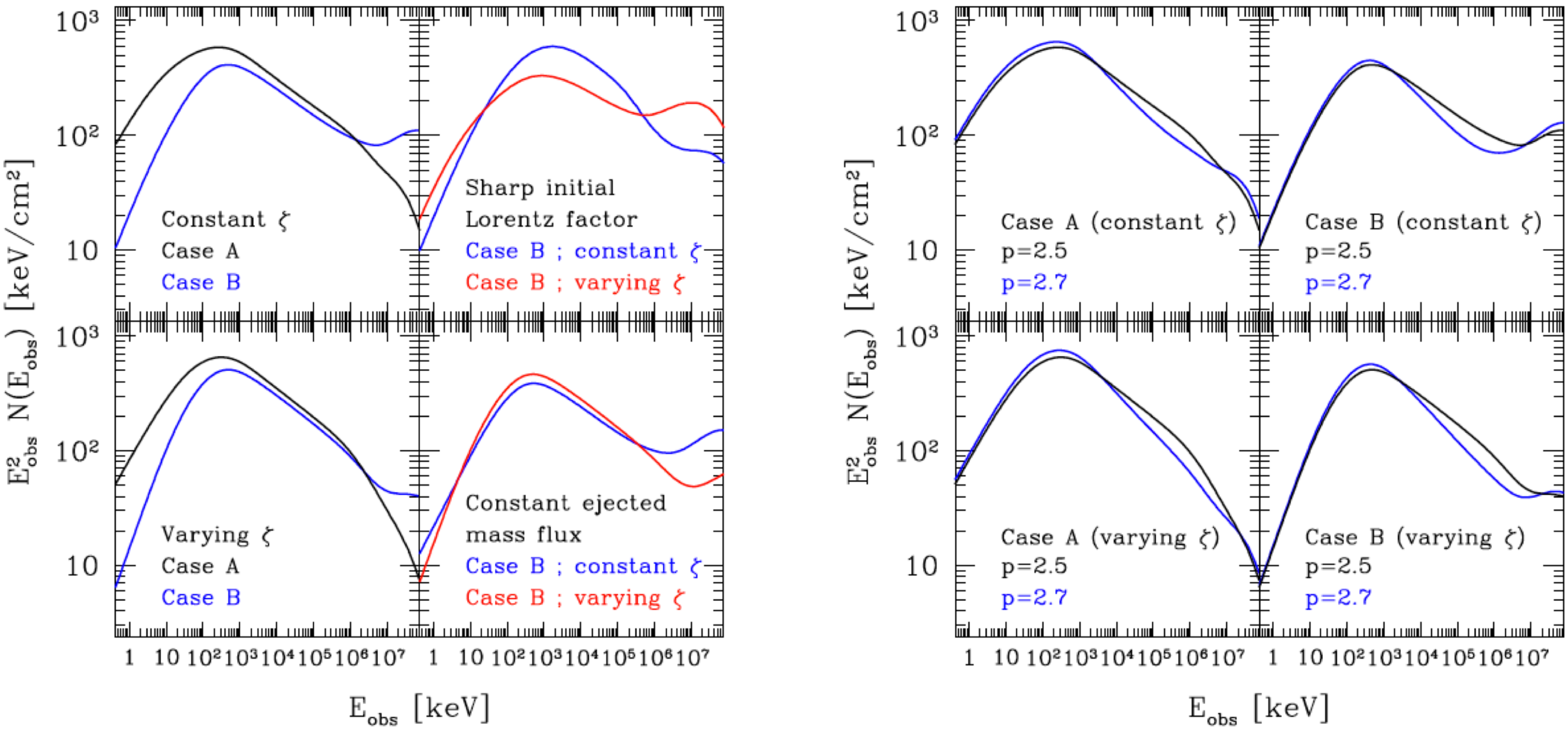
Time-evolving spectrum



Extra component

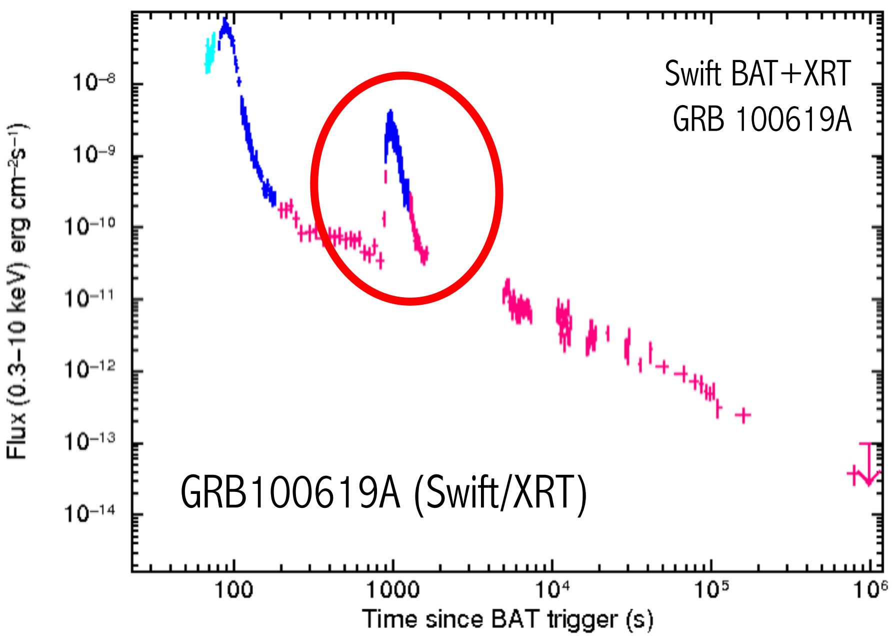
Bosnjak & Daigne 2014

Prompt GeV emission from internal shocks



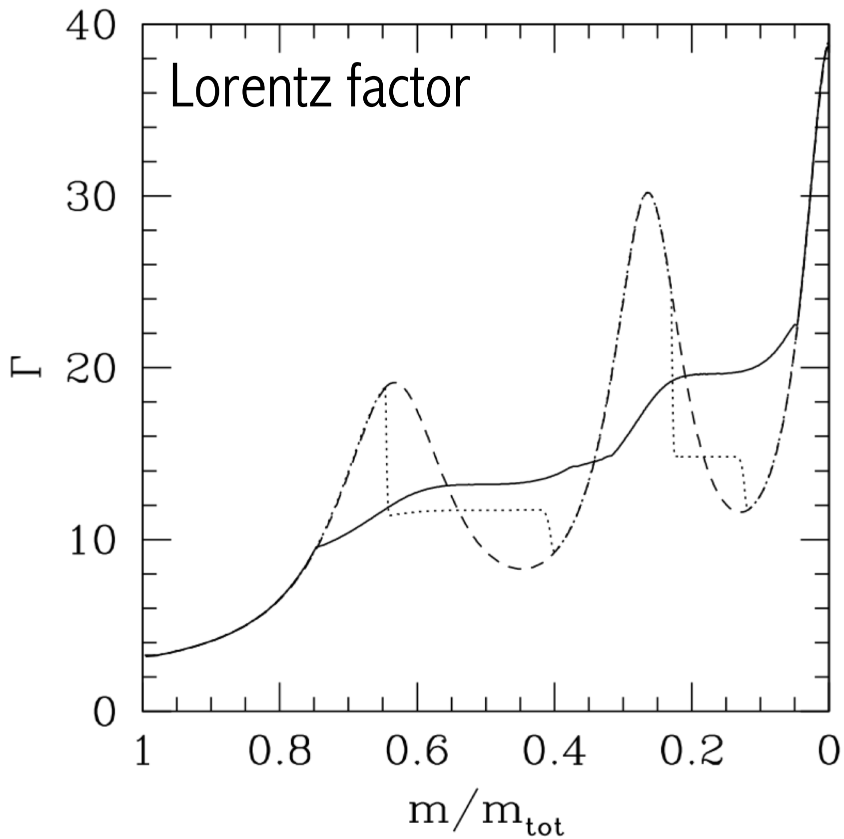
Bosnjak & Daigne 2014 ; see also Asano & Meszaros.

X-ray flares produced by a long-lived RS:
an indirect evidence for shocks within the ejecta?



X-ray flares

-propagation of the reverse shock in a structured outflow
-a signature of internal shocks?



An exemple of the distribution of Lorentz factor in the ejecta: (relativistic hydro simulation)

- - - - Initial
------- During IS phase
——— End of IS phase (before deceleration)

Hascoët, Beloborodov, Daigne & Mochkovitch, 2017

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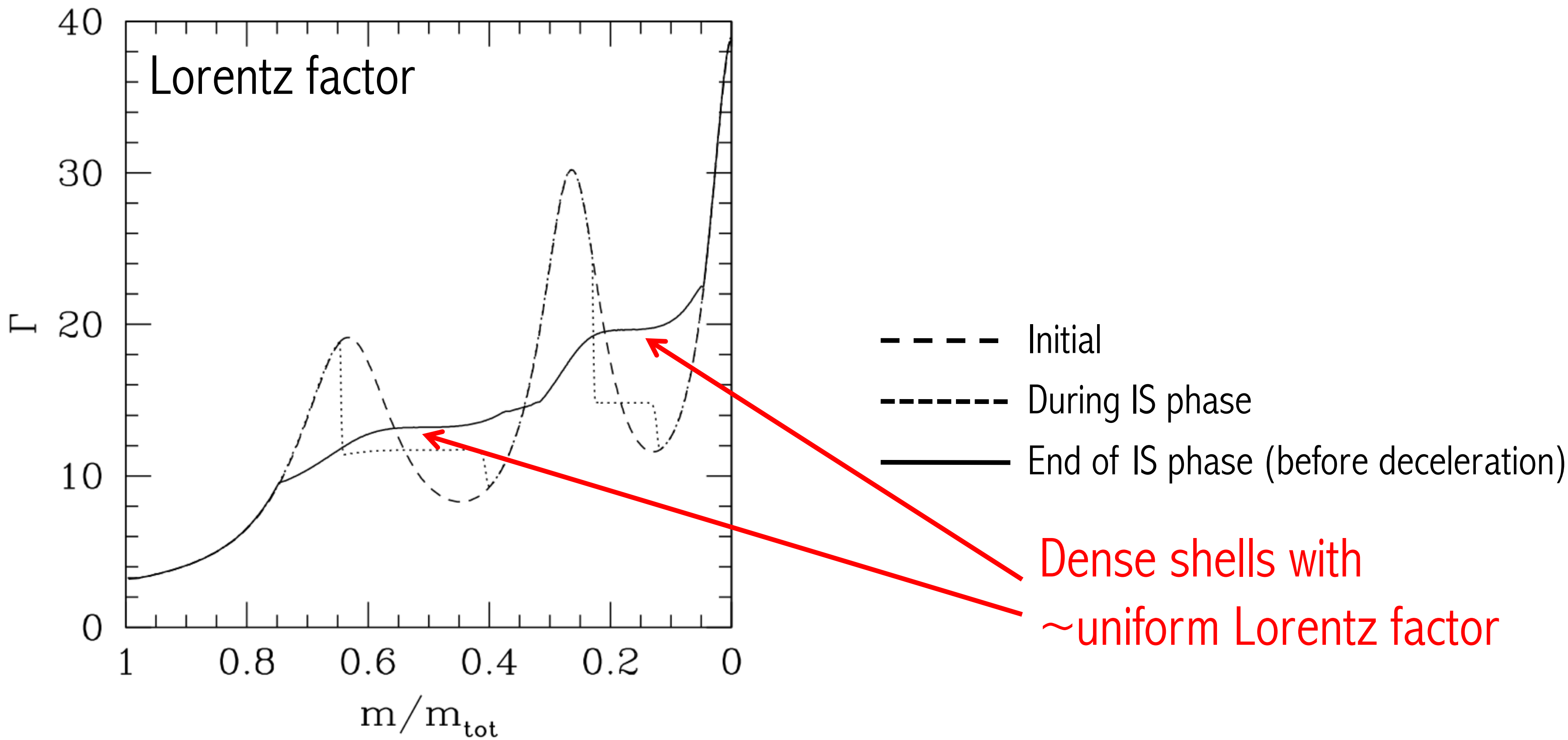

Hascoët, Beloborodov, Daigne & Mochkovitch, 2017

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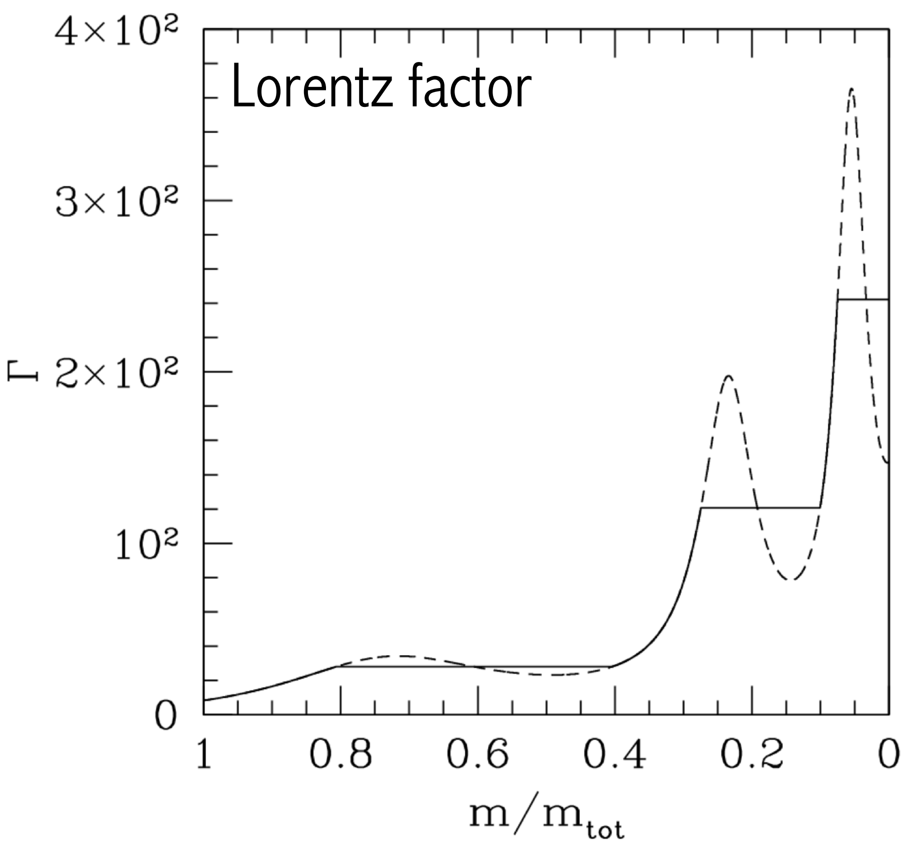

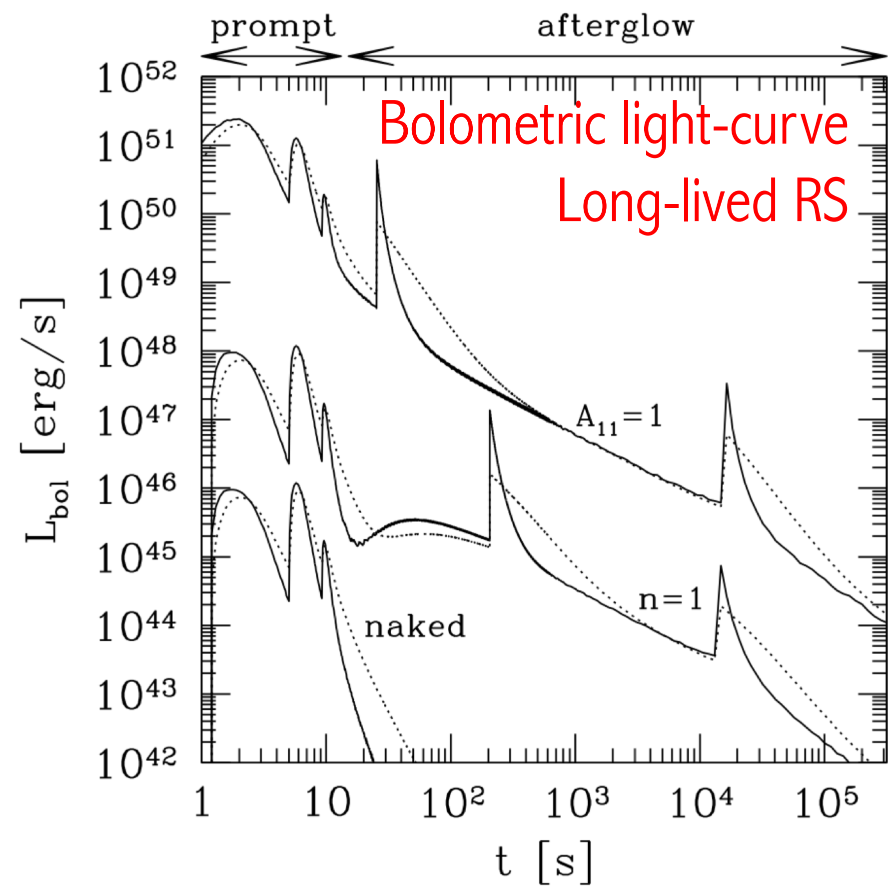

Hascoët, Beloborodov, Daigne & Mochkovitch, 2017

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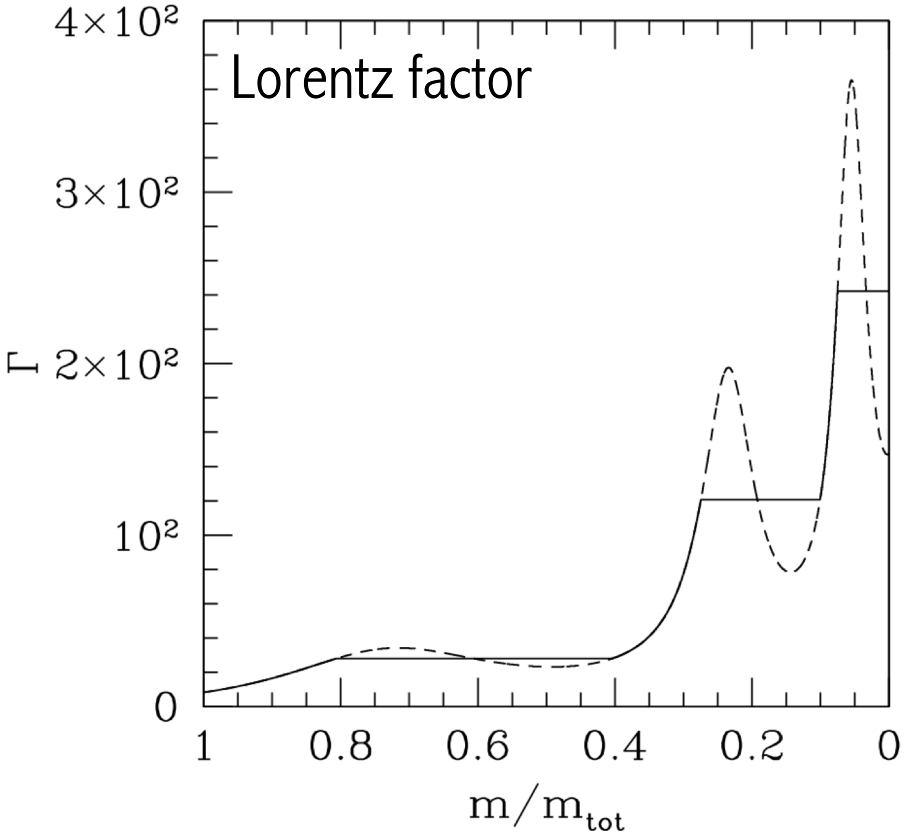
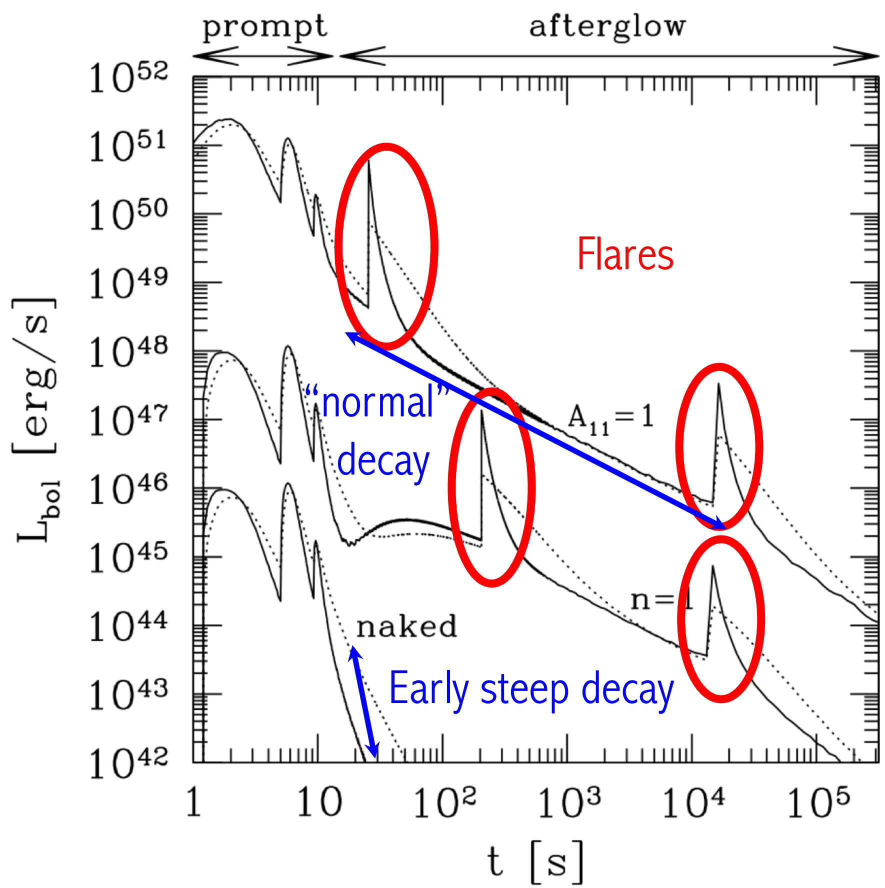




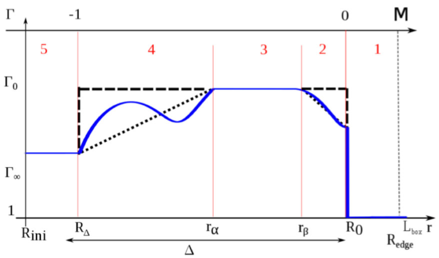
Flares are produced when the RS crosses a dense shell formed in the IS phase

Hascoët, Beloborodov, Daigne & Mochkovitch, 2017

X-ray flares

-propagation of the reverse shock in a structured outflow
-a signature of internal shocks?

- **Relativistic 1D hydrocode**
- Moving Eulerian grid
- Initial states: UR head+tail+variability



- Observe predicted interaction of RS with overdensities
Complex shocked region with reflected shocks

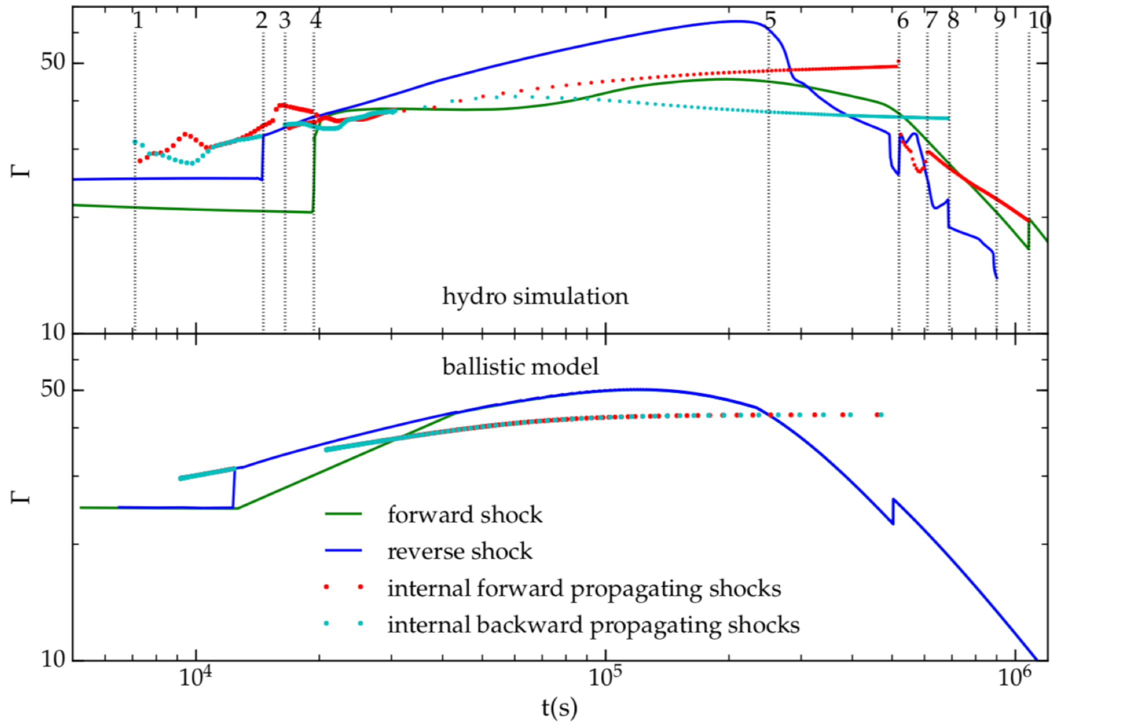


Figure 7. Lorentz factor in *run5*, which includes variability in the tail region and a slower head region. The upper and lower panels show the Lorentz factor in the shocked material behind the forward shock (FS), reverse shock (RS) and the internal forward (IFS) and backwards propagating shocks (IRS) in the hydrodynamic simulation and ballistic model respectively. Sudden variations are indicated with numbers and vertical lines and are detailed in the text.

Lamberts & Daigne, 2017

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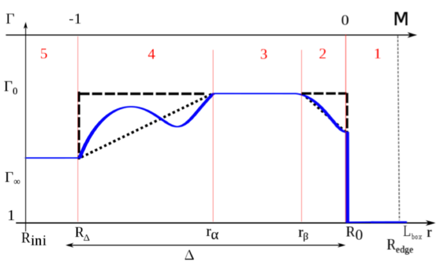

- **Flares are present in the bolometric lightcurve**

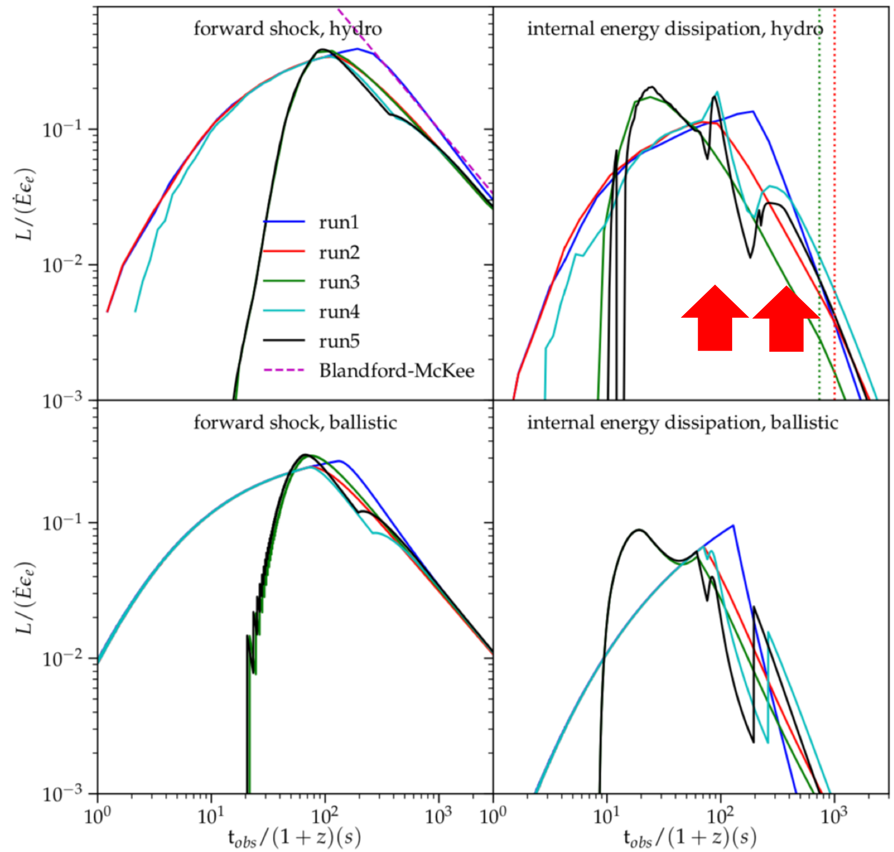

Figure 8. Bolometric light curves of the forward shock (left column) and internal and reverse shocks (right column) assuming isotropic emission in the comoving frame. The five main runs are shown (color coded), comparing the simulations (upper row) and the ballistic model (lower row). On the top-left panel, the magenta dashed line shows the t_{obs}^{-1} (Blandford & McKee 1976) self-similar solution. The dotted vertical lines indicate the time beyond which some of the off-axis emission is missing because the reverse shock has left the simulation domain. As seen in the right column, internal dissipation leads to flare-like features for $t_{obs} \geqslant 70$ s in *run4* and *run5*.

Lamberts & Daigne, 2017

X-ray flares

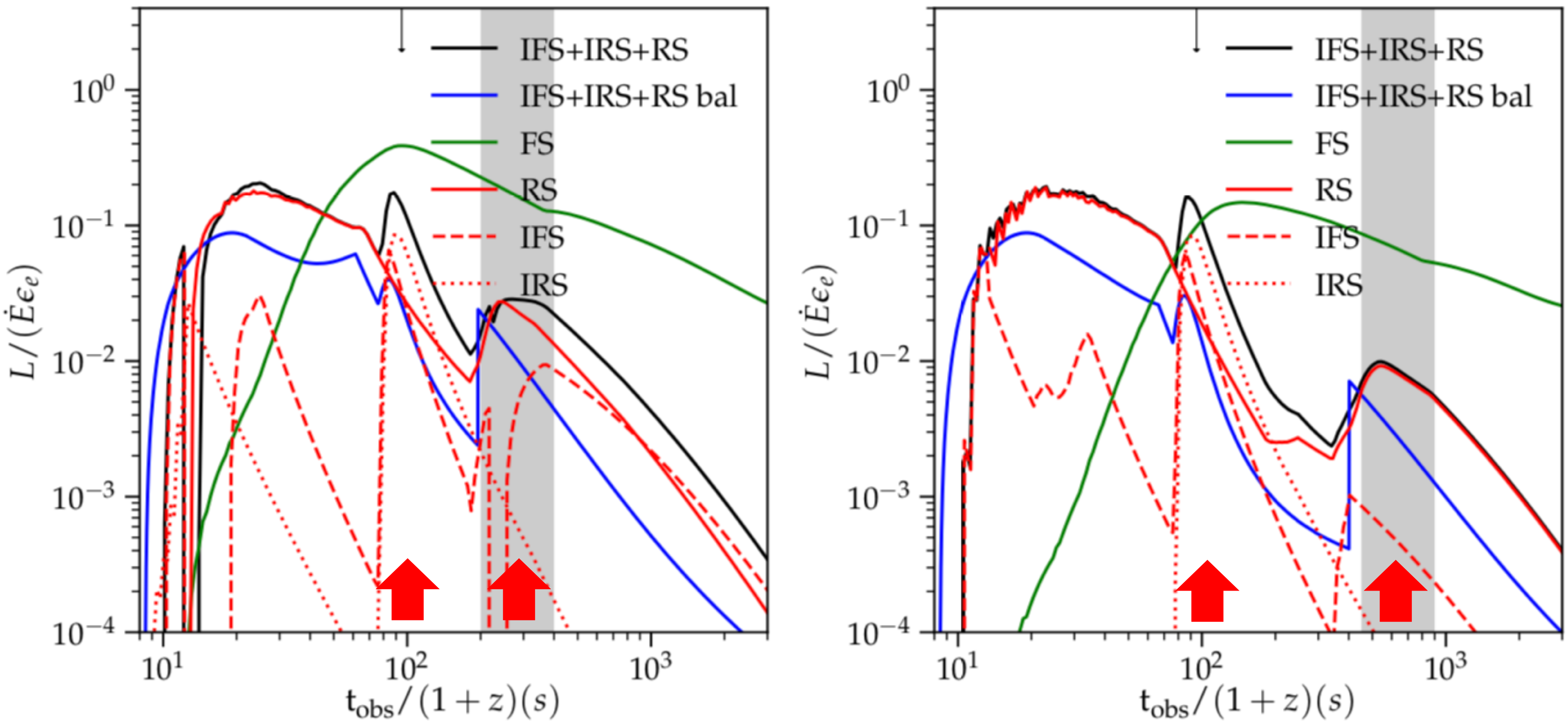

Figure 9. Contribution to the bolometric lightcurves of the different shocks in *run5* (left) and *run5b* (right). We separately show the energy dissipation at the forward shock (FS) and the sum of all the internal dissipation (IFS+IRS+FS), and compare with the ballistic model (blue). The flares and rebrightenings are shown by arrow and shaded regions, respectively.

Lamberts & Daigne, 2017

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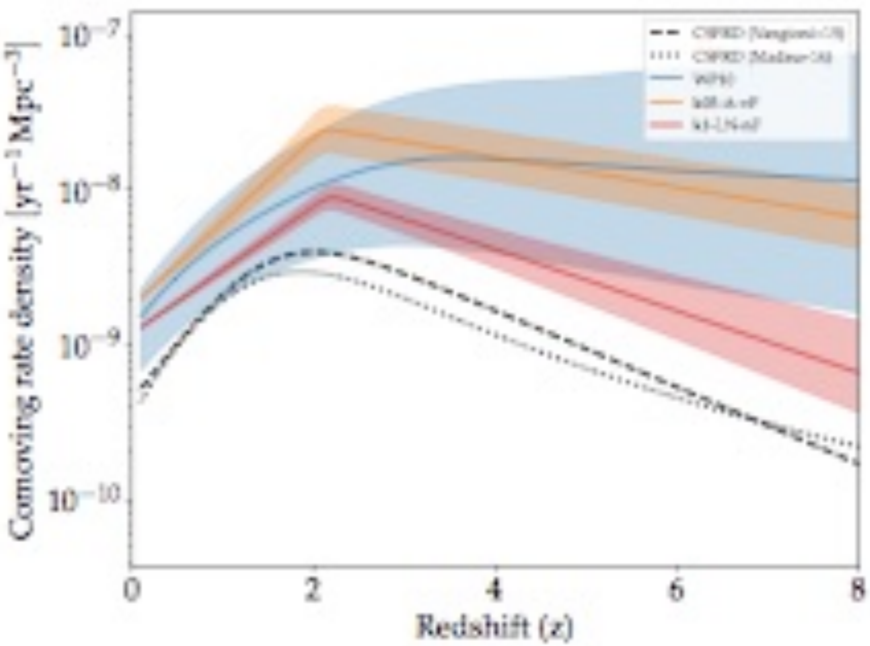
Population model for long GRBs

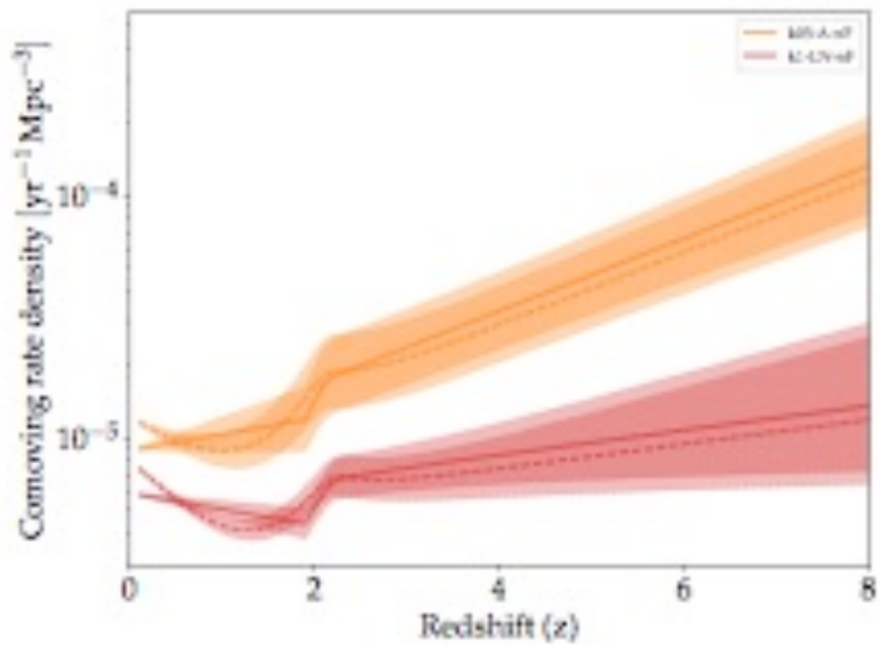
Part of the PhD work of Jesse Palmerio (defense: September 19, 2018)

- Generation of synthetic intrinsic populations for a set of parameters (luminosity function, rate(z), ...): MC
- Set of carefully selected constraints (BATSE, GBM, Swift)
- Exploration of parameter space: MCMC

Long GRBs:

- GRB efficiency (GRB/core-collapse) evolves with redshift $\rightarrow$ progenitors? Role of metallicity? …
- A weak evolution of the luminosity function is possible
- An intrinsic L-Ep correlation is slightly favored





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Electromagnetic counterparts to NS-NS/BH mergers
The short GRB-merger connection

Physics of the short GRB-afterglow – Study of the short GRB-merger connection
=PhD project of Raphaël Duque (starting October 1st, 2018)

Kilonova: rates? Production of r-process elements and chemical evolution?
=on-going project with Irina Dvorkin, Elisabeth Vangioni, Stéphane Goriely

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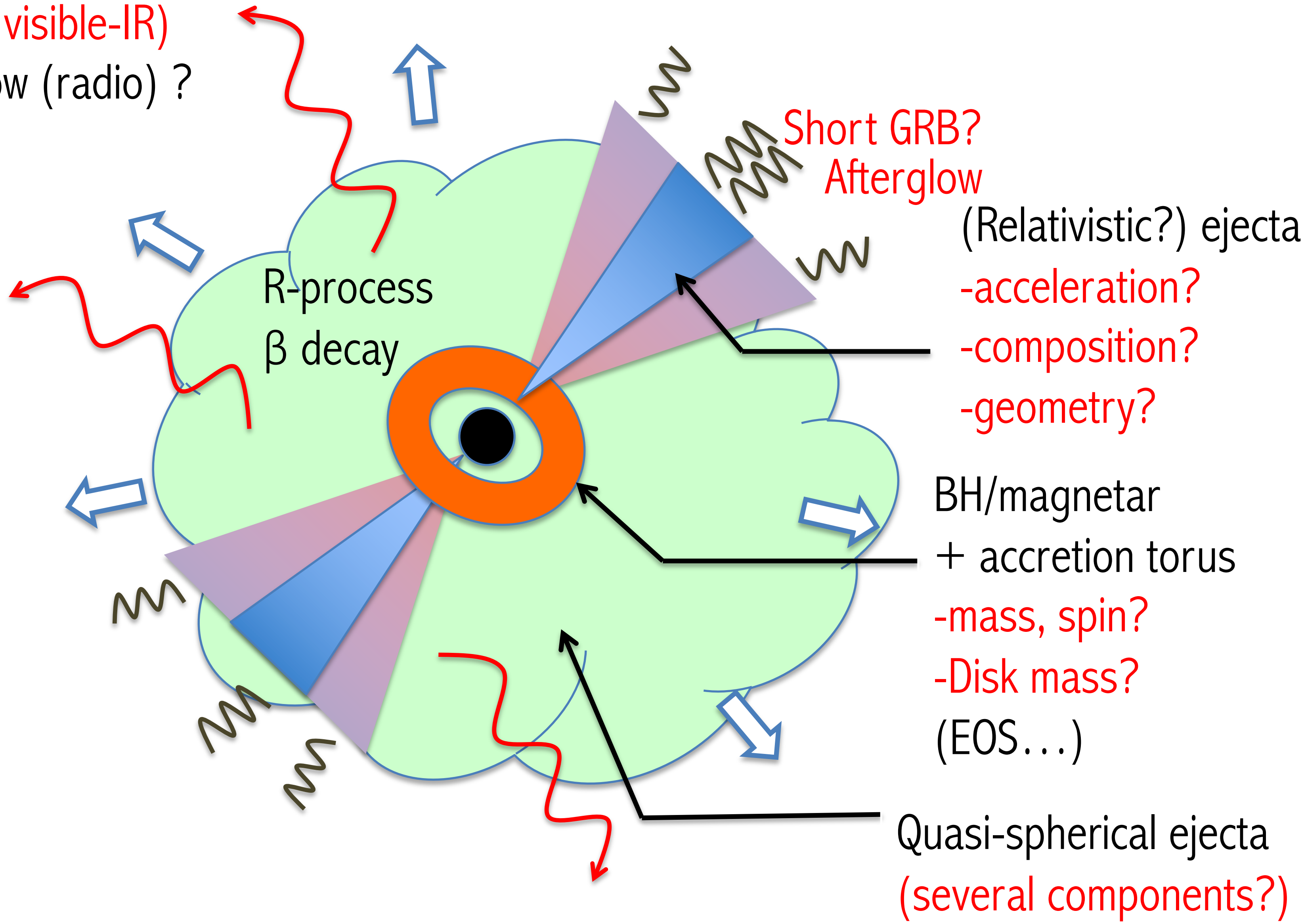
Remnant of NS+NS merger:

Radioactively powered emission
(kilonova: visible-IR)
+ afterglow (radio) ?



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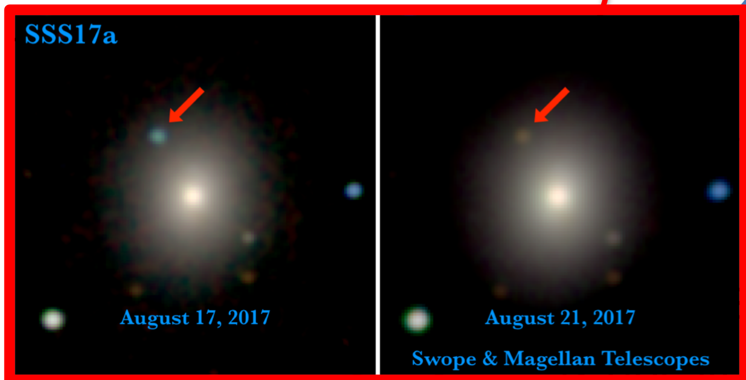

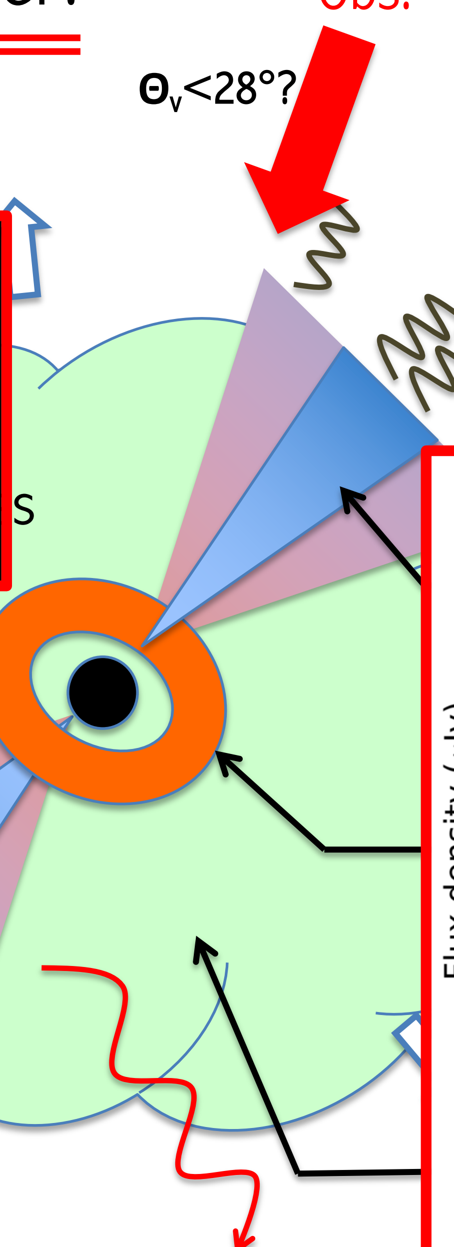

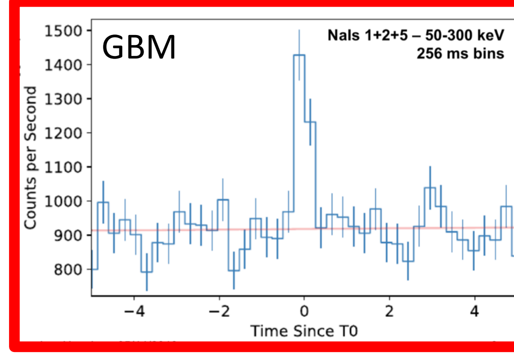

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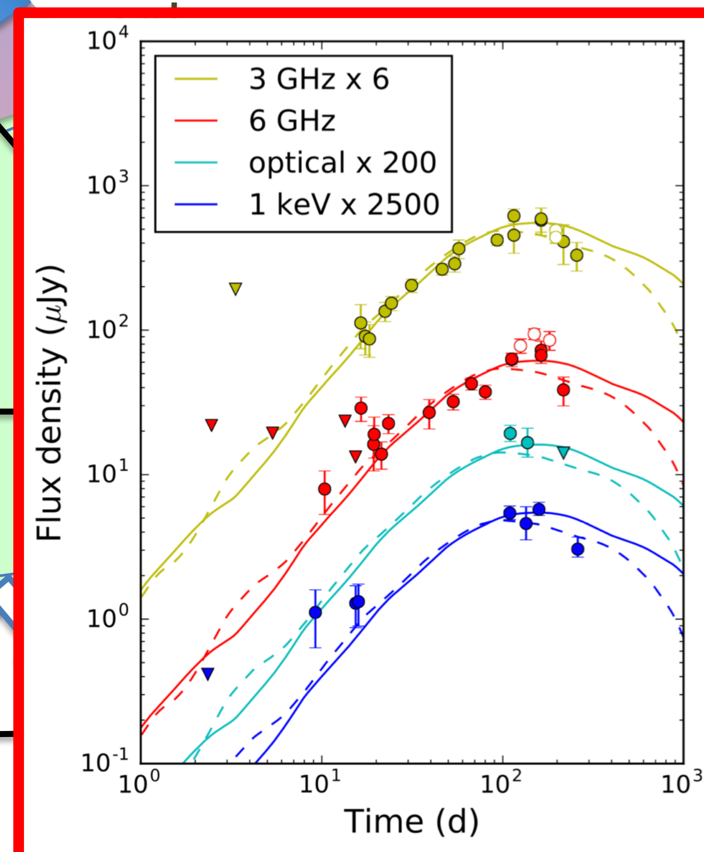

Alexander et al. 2018

The case of 170817

Questions:

- **GRB170817A**: atypical (not very hard, very under-luminous)
  -physical origin?
  -would an on-axis observer have seen a standard short GRB?
  -consequences for the short-GRB-merger connection?

- **Afterglow**: long-term evolution (still observed in radio)
  many observations (including polarization, VLBI: proper motion)
  -geometry: radial vs lateral structure?
  -signature of a central jet?
  -counterparts at high-energy?

- **Population**: evolution of the expected counterparts when varying
  -viewing angle
  -distance
- Etc.
- **More events during O3?**

Conclusion

Modélisation physique des sursauts gamma :

- Une physique très riche
- Une modélisation difficile
- Un âge d'or pour les observations

  Beppo-SAX ; HETE-2 ; Swift ; Fermi

  LIGO/Virgo – 2019: prise de données O3

  2021+: SVOM)

Annonce

SORBONNE UNIVERSITÉ

Un poste de maître de conférences en section 34/29
va être ouvert au concours à l'IAP au printemps 2019

Profil : « Sources astrophysiques à haute énergie
et ondes gravitationnelles »

Contact: Frédéric Daigne (daigne@iap.fr)

N'hésitez pas à diffuser l'information aux candidat-e-s potentiel-le-s, merci !