Gamma-ray bursts

Seminar "Nuclei and the Cosmos"

Patrick Huck

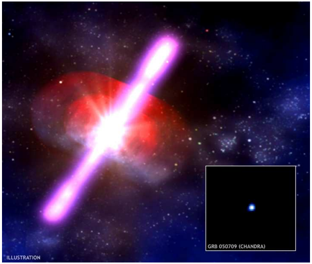
Technical University Munich

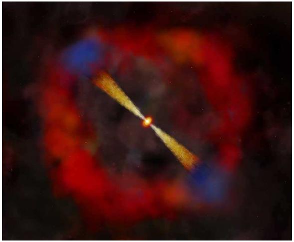
30.01.2008

Overview

Motivation or why to explore GRB?

27-12-04 21:30h Detection of very bright GRB (Superflare of SGR):





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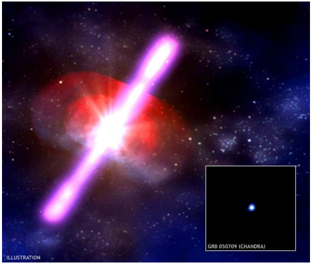

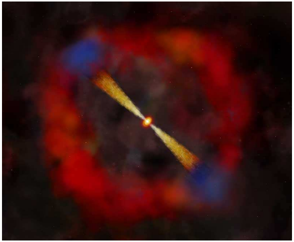

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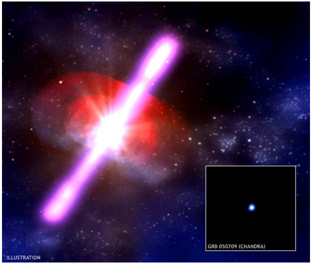

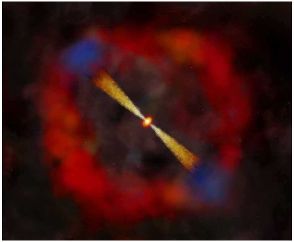

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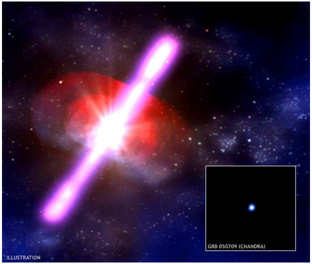

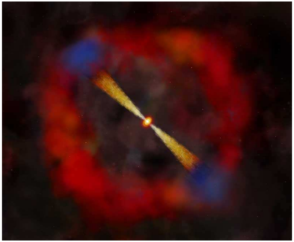

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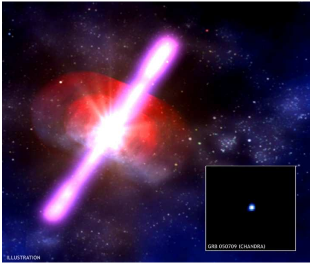

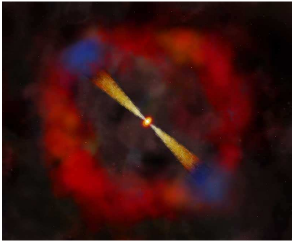

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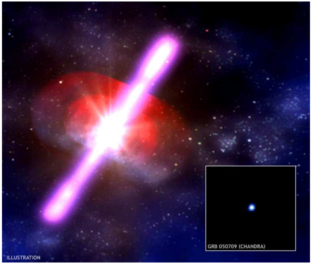

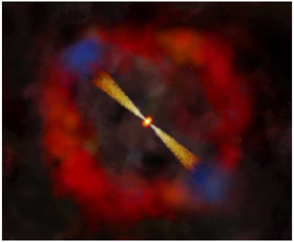

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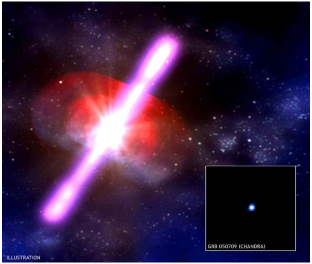

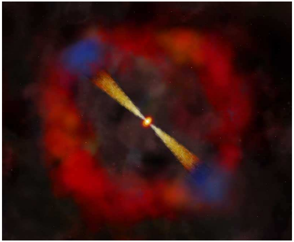

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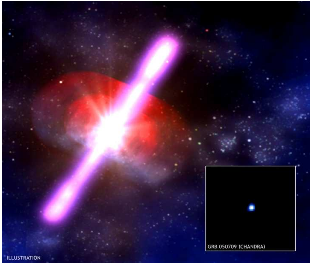
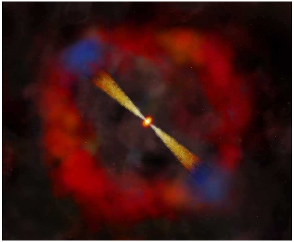
- indicate the birth of a black hole
- affect the atmosphere / mass extinction.





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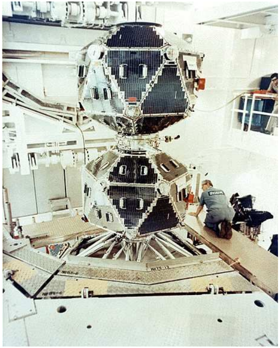

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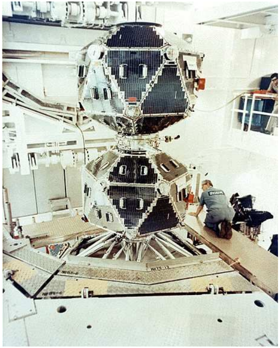

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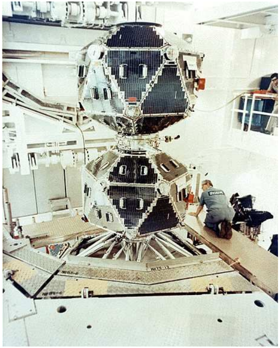

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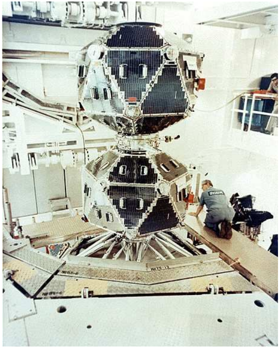
1973:
publication of results and beginning of GRB-studies.



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After a lot of speculations involving BH, SNe and NS:

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1991: space shuttle *Atlantis* launches **Compton Gamma Ray Observatory (CGRO)** carrying the **Burst and Transient Source Experiment (BATSE)**.

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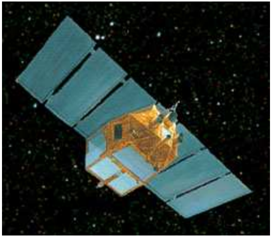
problem

Only chance to solve the question of distance: find a **counterpart** in other wavelengths to **identify host**!
But BATSE is too slow and has too poor resolution for that.

BeppoSAX and Swift

1992-2003: Italian-dutch satellite **BeppoSAX**

GRB970228:



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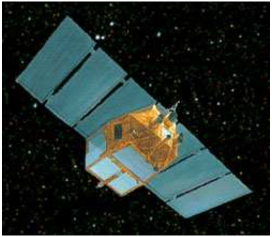

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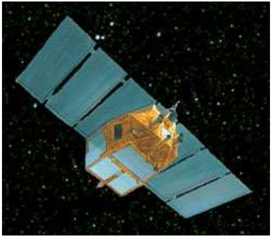

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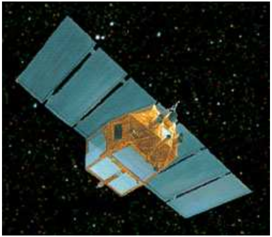

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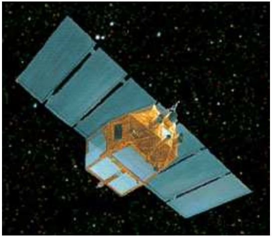

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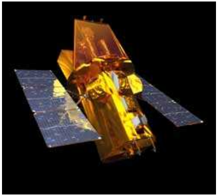

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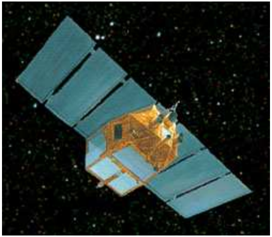

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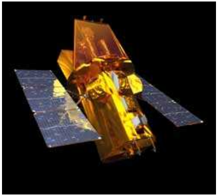

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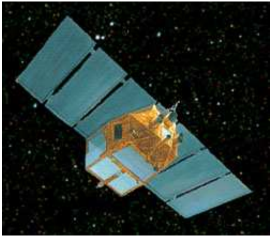

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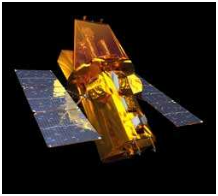

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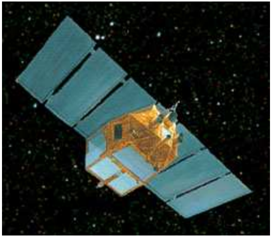

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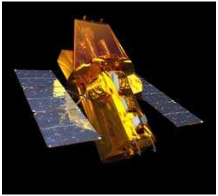

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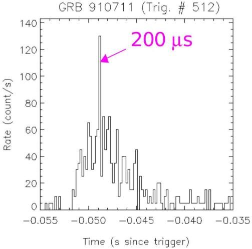
vast amount of data to test models

Special GRBs

GRB910711 shortest GRB of 6ms duration



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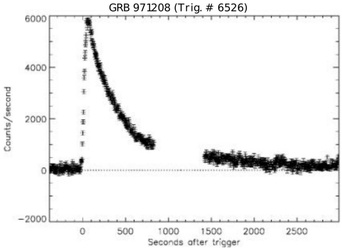
GRB971208 longest GRB of $\sim$ 2000s duration



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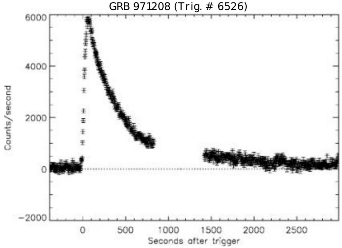

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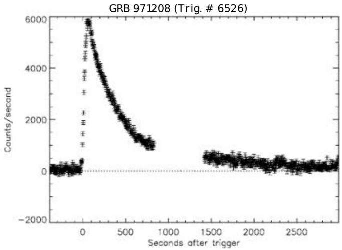

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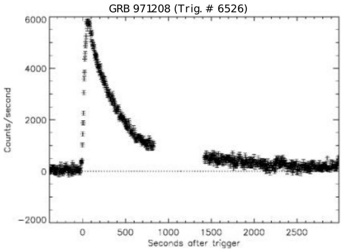


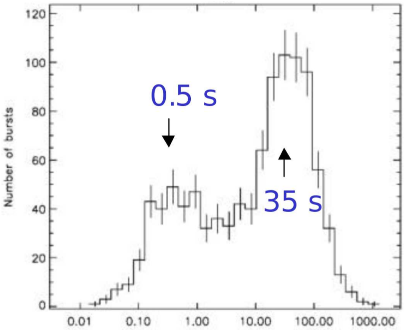
typical distances

Hubble-law $v = H_0 \cdot r \stackrel{!}{=} cz \implies r \approx 4Gpc$

$(1\text{pc}=3 \cdot 10^{16} m)$

Classification and models

bimodal histogram of duration



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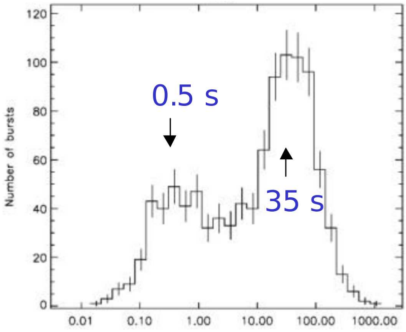

0.01–2s $\rightsquigarrow$

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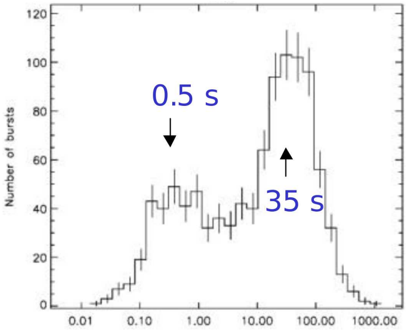

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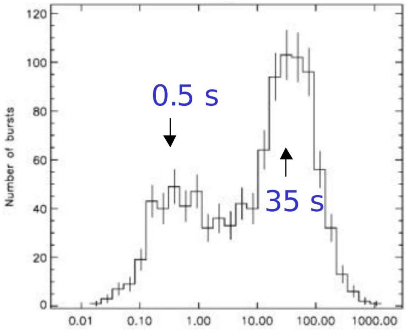

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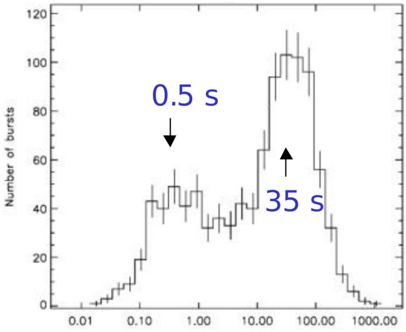

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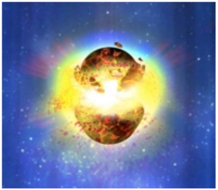
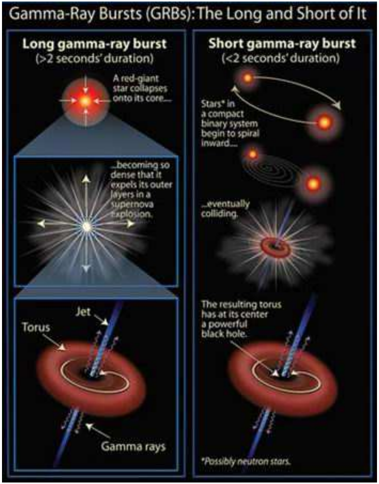
collision and merging in NS-NS or NS-BH Binaries (often old NS)

movie ns-mergers





Classification and models

Short GRBs

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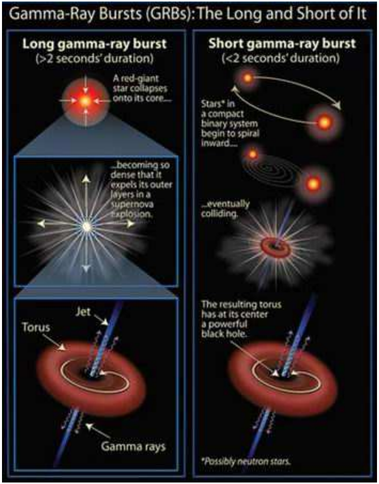
Long GRBs

young, very massive progenitors like O-stars or Wolf-Rayet-stars end in Collapsar and explode in Hypernova

movie collapse



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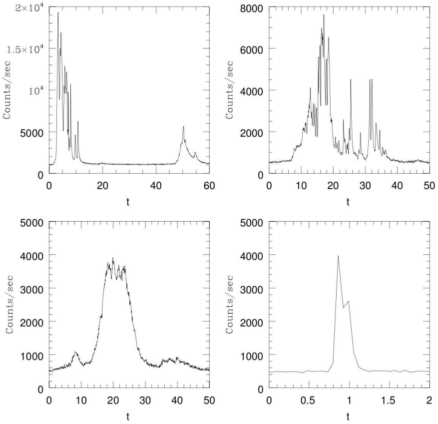
drastically and rapidly varying profiles with variations on a time-scale $\delta T \ll$ duration of GRB:



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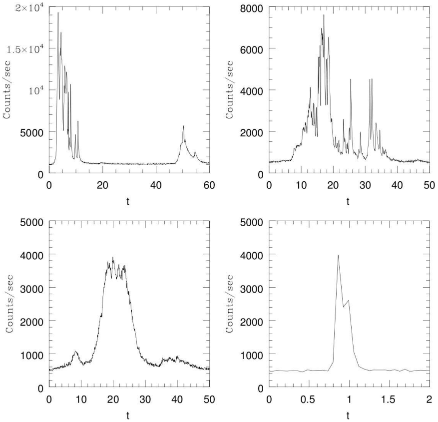

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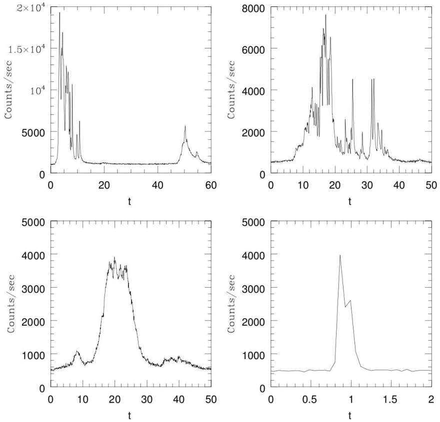

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$\sim$ dim. of NS / BH!

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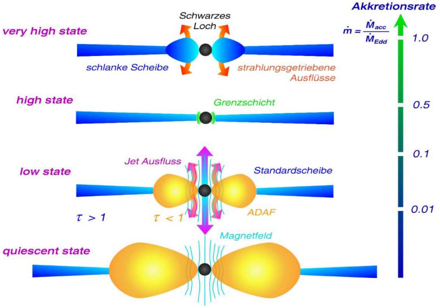

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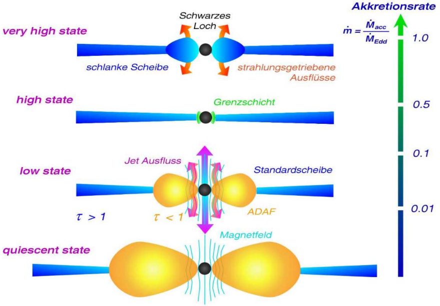

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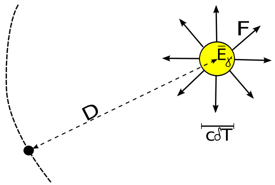

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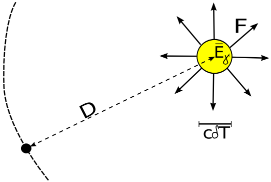

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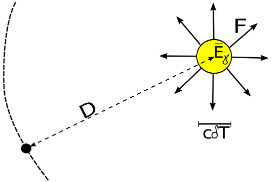

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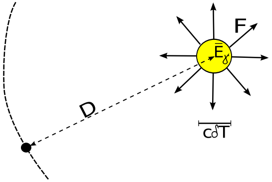

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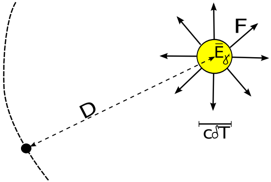

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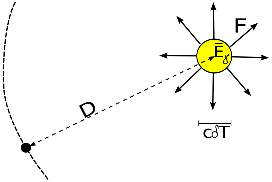

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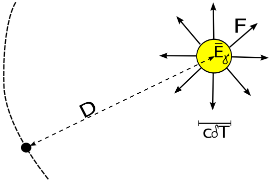

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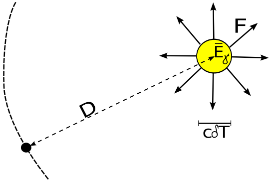

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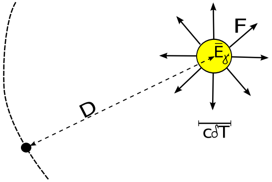

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Black-Body

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Black-Body

Thompson
6.7E-29 m²

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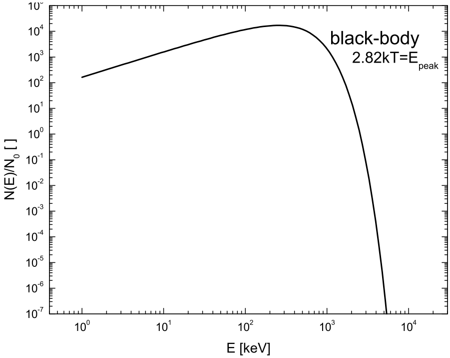

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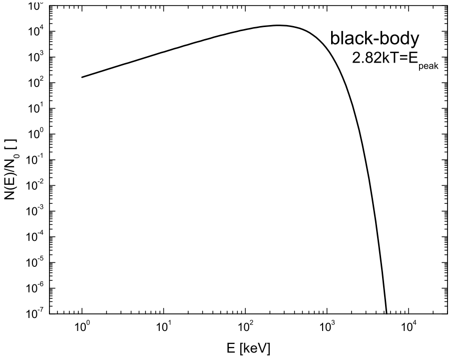

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Band spectrum and Compactness problem

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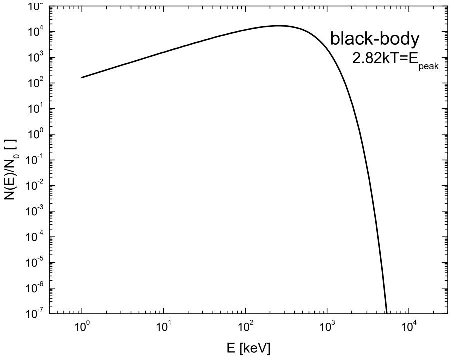
$$N(E) = N_0 \begin{cases} E^{\alpha} \exp\left(-\frac{E}{E_0}\right), & \text{for } E < (\alpha - \beta)E_0 \\ [(\alpha-\beta)E_0]^{\alpha-\beta} E^{\beta} \exp(\beta - \alpha), & \text{for } E > (\alpha - \beta)E_0 \end{cases}$$



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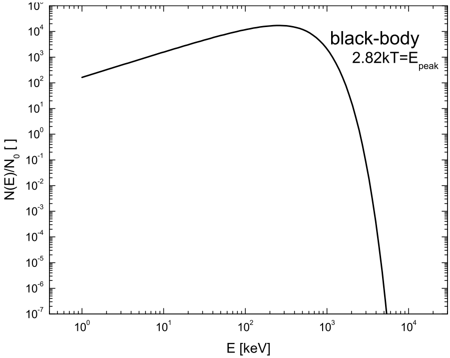

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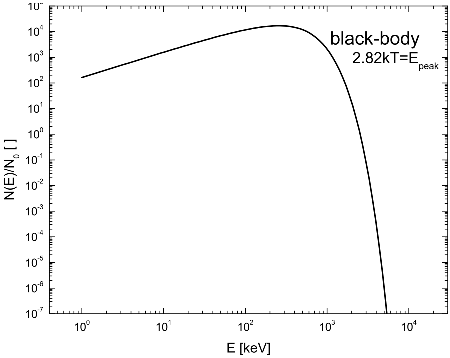

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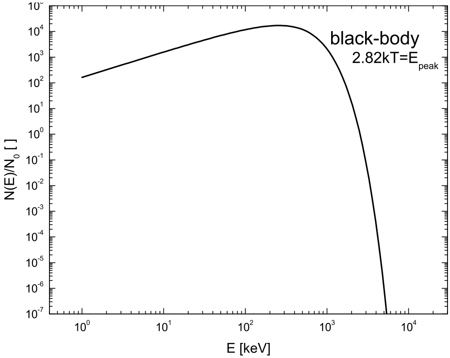

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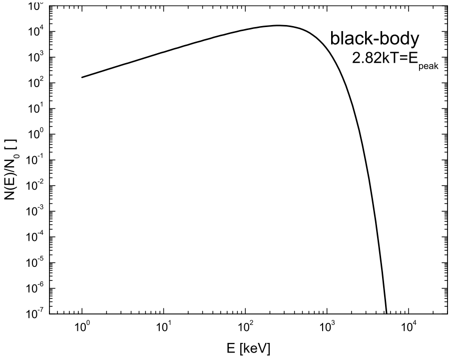

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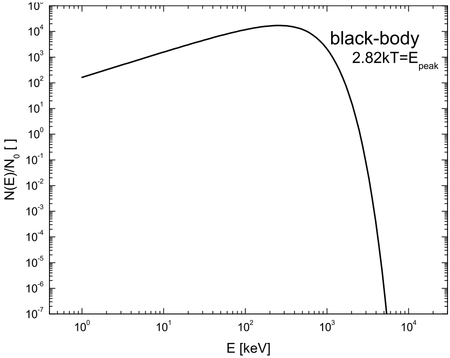

GRB920602:

$$E_{peak} \overset{(\alpha+2)E_0}{=} 457keV$$

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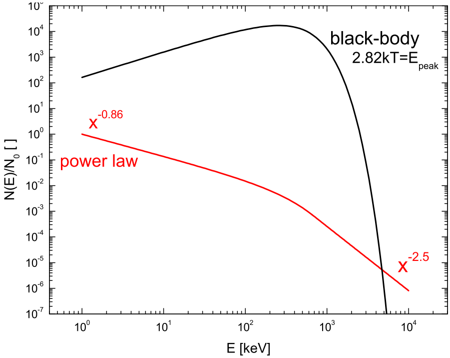

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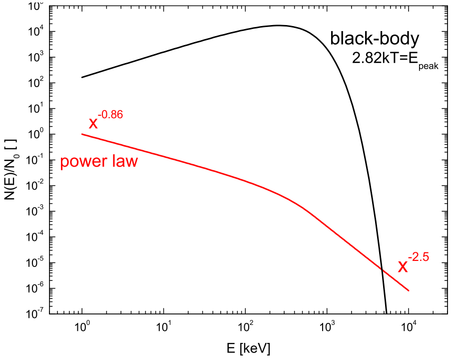

↯

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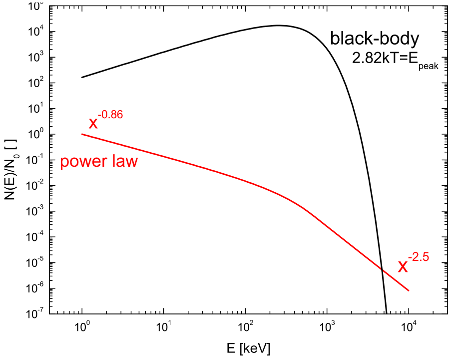

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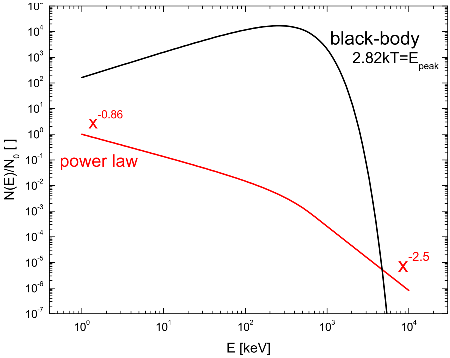

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solution?

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Emitted matter moves towards observer with relativistic velocity.

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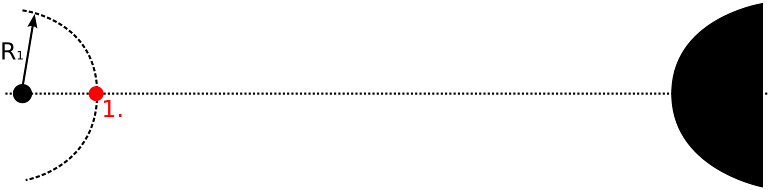

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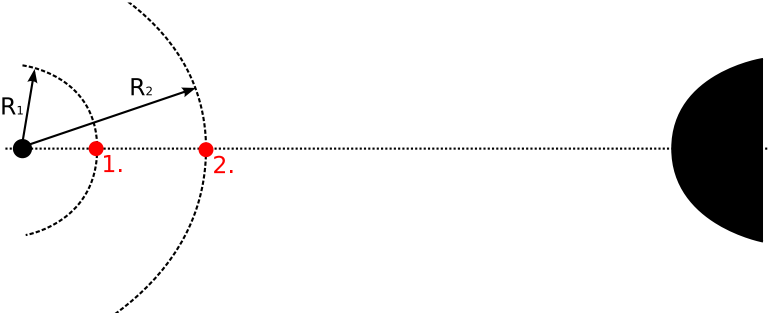

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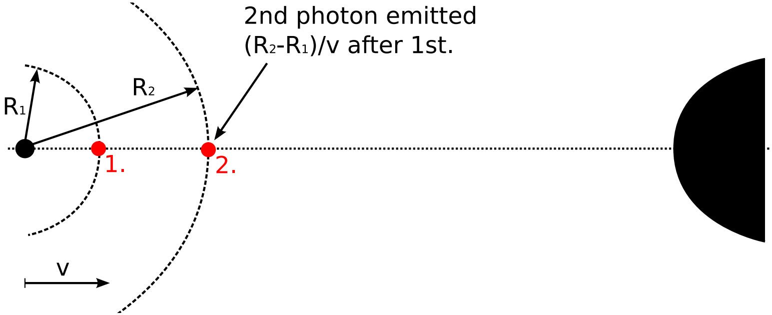

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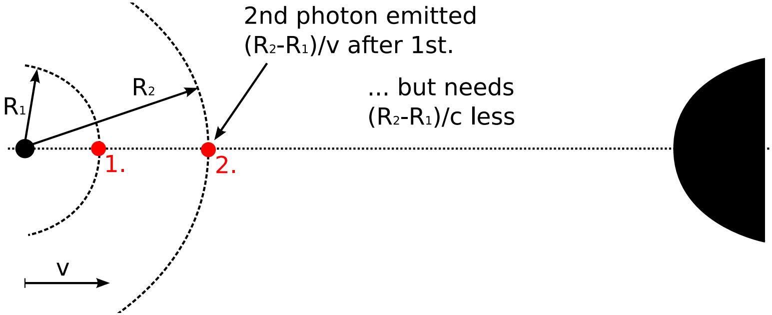

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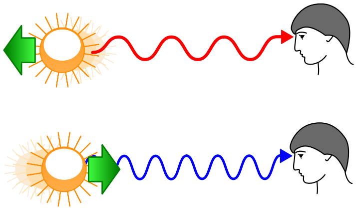
★



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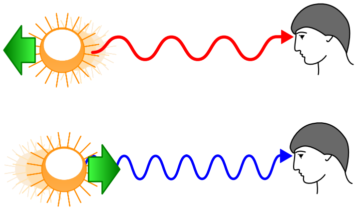

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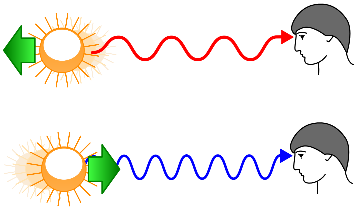

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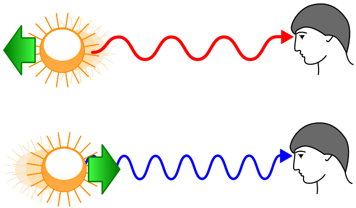

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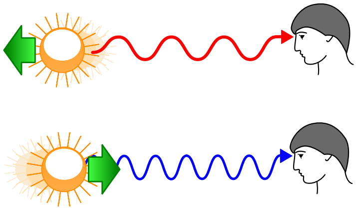

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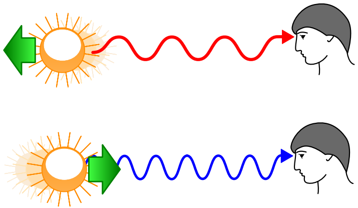

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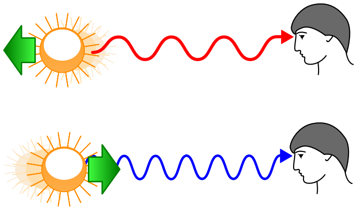

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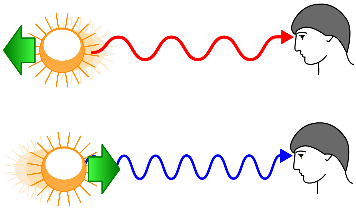

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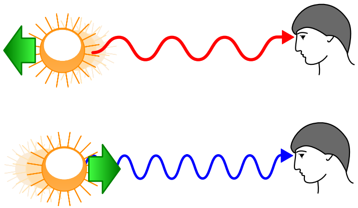

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$$f_p \propto (\underbrace{E_{obs}^{-\alpha}}_{\propto N(E)})^2 = (\Gamma E_{source})^{-2\alpha}.$$

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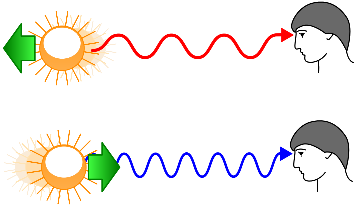

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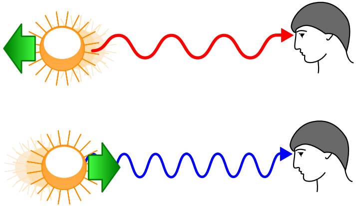

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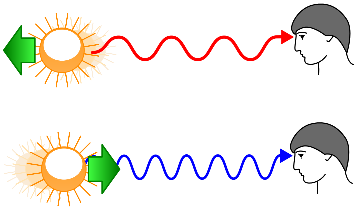

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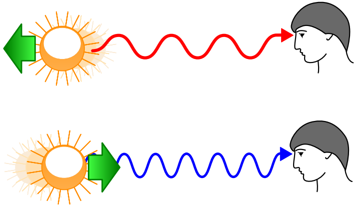

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With $\alpha \sim 2$: ultra-relativistic $\Gamma \gtrsim 100$ to obtain an optically thin source!!

Constraints to a model

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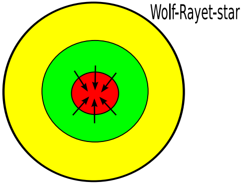
FIREBALL-model

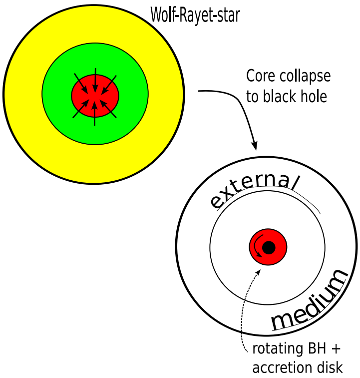
Fireball-model



No matter what – Collapsar of a massive star or NS/NS-mergers –

Fireball-model

No matter what – Collapsar of a massive star or NS/NS-mergers –the central compact object is likely to be a **black hole** of several solar masses!



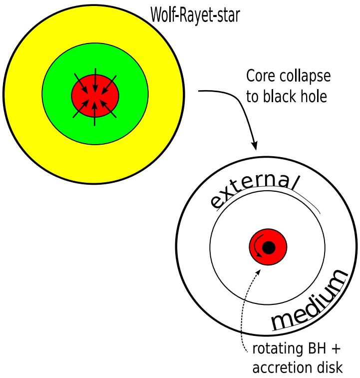
Fireball-model

WR/O-star – NS/NS

$\Downarrow$

Black Hole

liberated E_{grav} ~few $M_\odot$ $\curvearrowright$ **free energy** in ms inside small volume



Fireball-model

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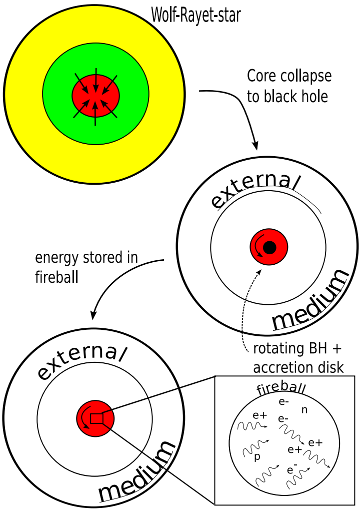
Black Hole

$\downarrow$

$E_{grav} \rightsquigarrow$ free energy

Result: conversion into ν_e's and grav. waves $\oplus$ $10^{-2} - 10^{-3} E_{grav}$ into high temperature (kT$\gtrsim$**MeV**) **fireball** out of $\{e^{\pm},\gamma,p,n,...\}$



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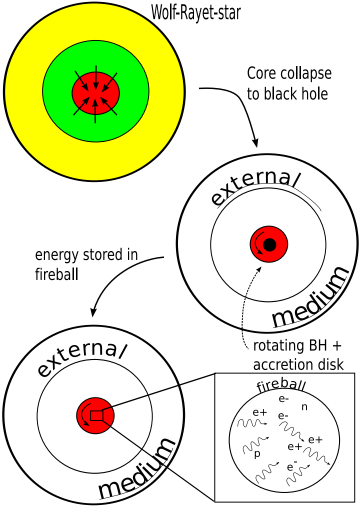

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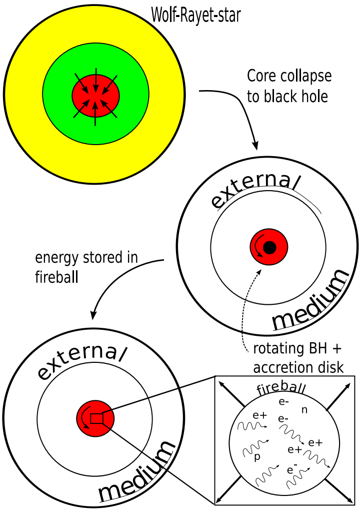
$10^{50} - 10^{52}$erg remains trapped in fireball and produces non-thermal γ-ray



Rem.: SNe look similar but energy is emitted over months in optical band
$\lightning$ GRB in seconds and mainly γ-ray! $\rightsquigarrow$**'Hypernova'**

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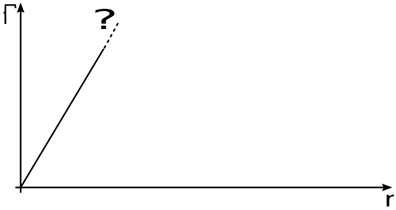
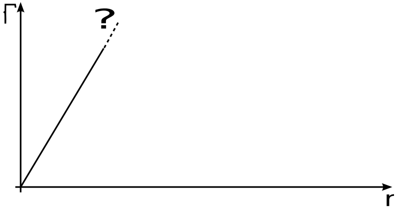


Questions

★ fireball expansion and acceleration



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1. How long does acceleration last?

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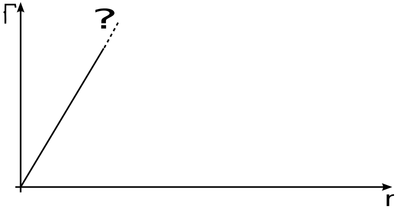

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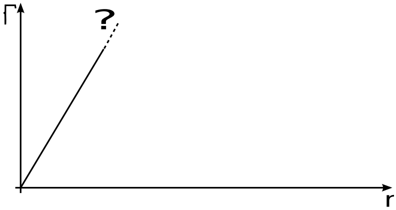

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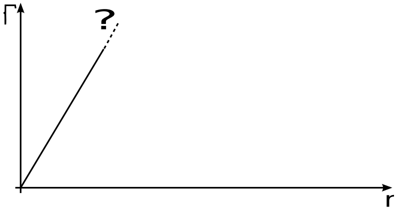

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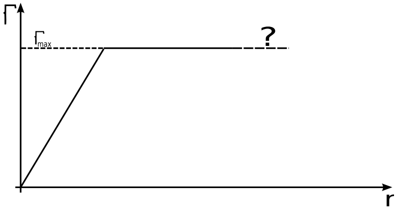

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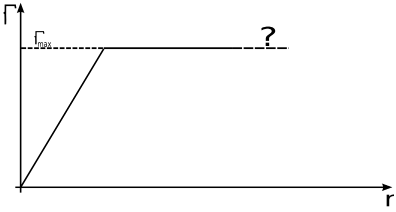

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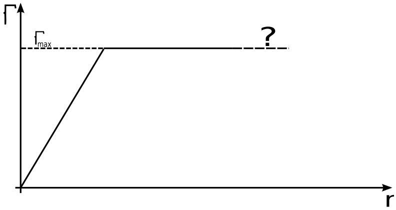

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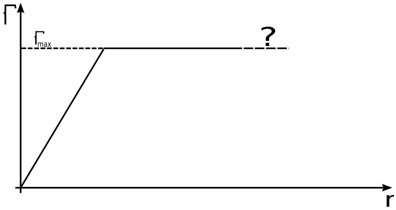

Questions

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- ★ fireball expansion and acceleration
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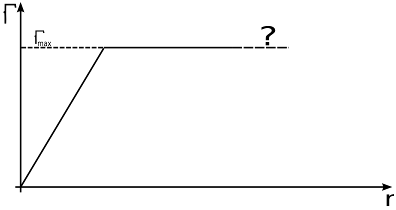

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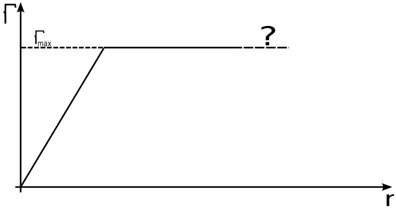

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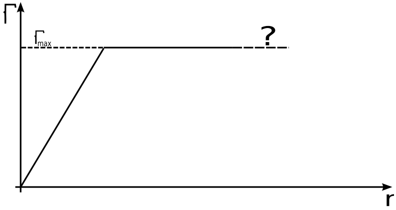

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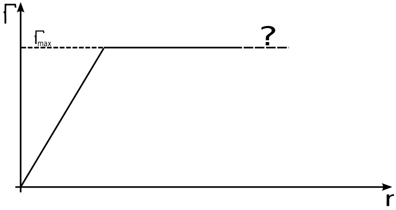

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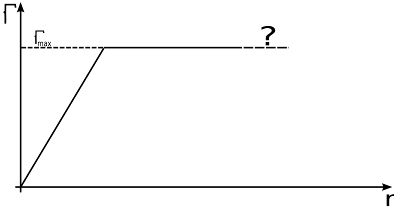

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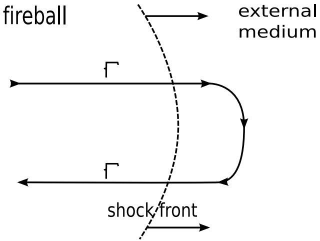

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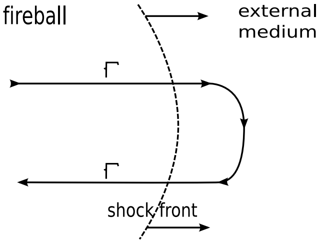

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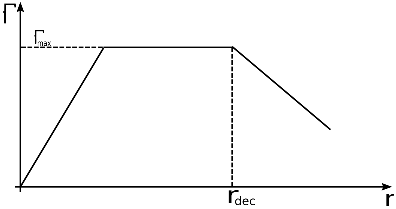
$\Rightarrow$ fireball decelerates in external shock and



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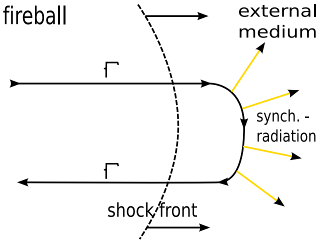
$\Rightarrow \Gamma = \text{const. up to } E_f \approx E_{swept}$:

$$E_f \approx \Gamma^2 m_{swept} c^2 = \Gamma^2 \frac{4}{3} \pi \rho_{ext} r_{dec}^3 c^2$$

$\Rightarrow$ fireball decelerates in external shock and emits synchrotron radiation

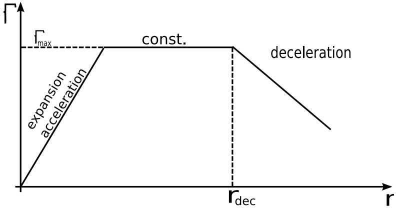
$\Rightarrow$ power-law!



Questions

1. How long does acceleration last?
2. How to reconvert kinetic energy into radiation?

- ★ fireball expansion and acceleration
- ★ coasting Γ
- ★ decelerating external shock



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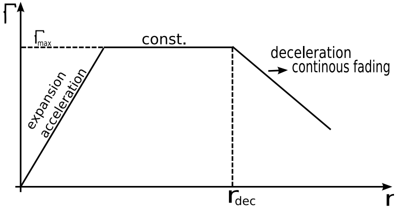

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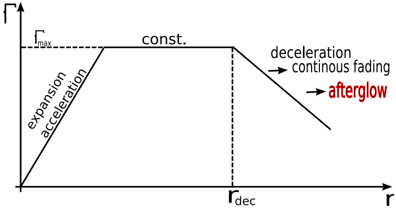

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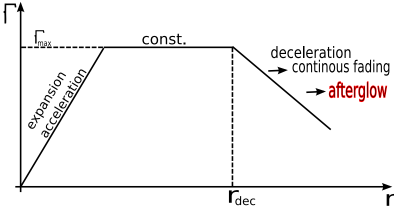

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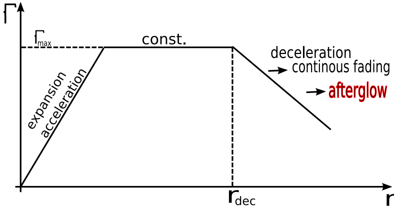

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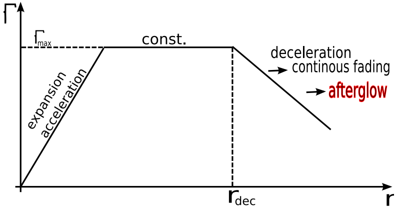
Problems:

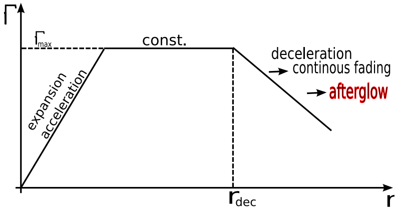
- $B \sim 100G$; $\Gamma \sim 100$ too low to produce γ-rays.
- no highly variable time-scale.



Internal shocks

Internal shocks to explain time-variability and y-rays:

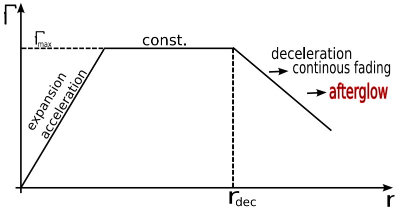
$\hookrightarrow$ inhomogenous Γ



Internal shocks

Internal shocks to explain time-variability and γ-rays:

- ↪ inhomogenous Γ
- ↪ shells with different velocities collide in **internal shocks**



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- ↪ inhomogenous Γ
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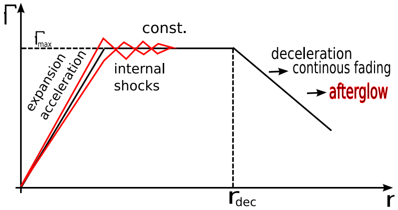
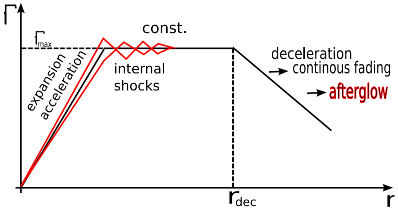
- ↪ like 'electron cooling' the gas cools down to a const. homogenous Γ



Internal shocks

Internal shocks to explain time-variability and y-rays:

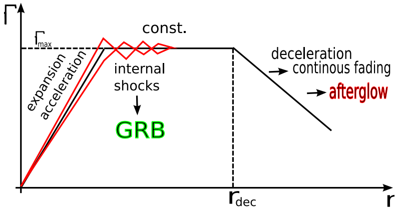
- $\hookrightarrow$ inhomogenous Γ
- $\hookrightarrow$ shells with different velocities collide in **internal shocks**
- $\hookrightarrow$ like 'electron cooling' the gas cools down to a const. homogenous Γ
- $\hookrightarrow$ which then runs into the external medium.



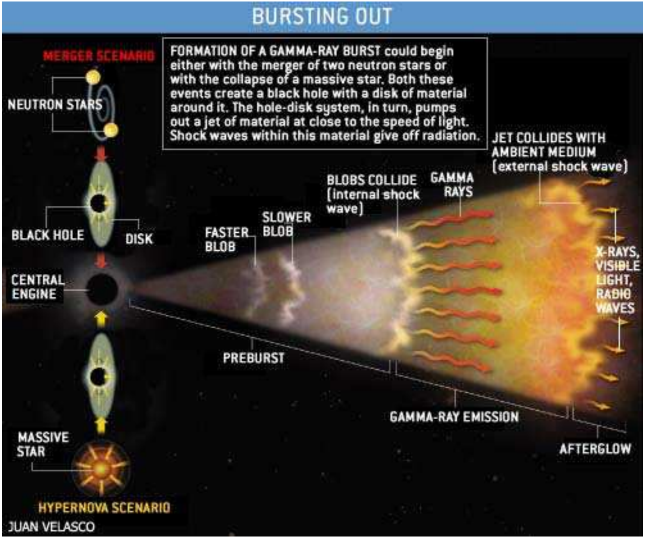
Internal shocks

Internal shocks to explain time-variability and y-rays:

- ↪ inhomogenous Γ
- ↪ shells with different velocities collide in **internal shocks**
- ↪ like 'electron cooling' the gas cools down to a const. homogenous Γ
- ↪ which then runs into the external medium.
- ↪ internal collisions produce y-ray synchrotron radiation due to $B \sim 10^5 G$ and Γ_{max}



Closing course of GRB



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