Physics on the Extreme: Theoretical (high energy) Astrophysics

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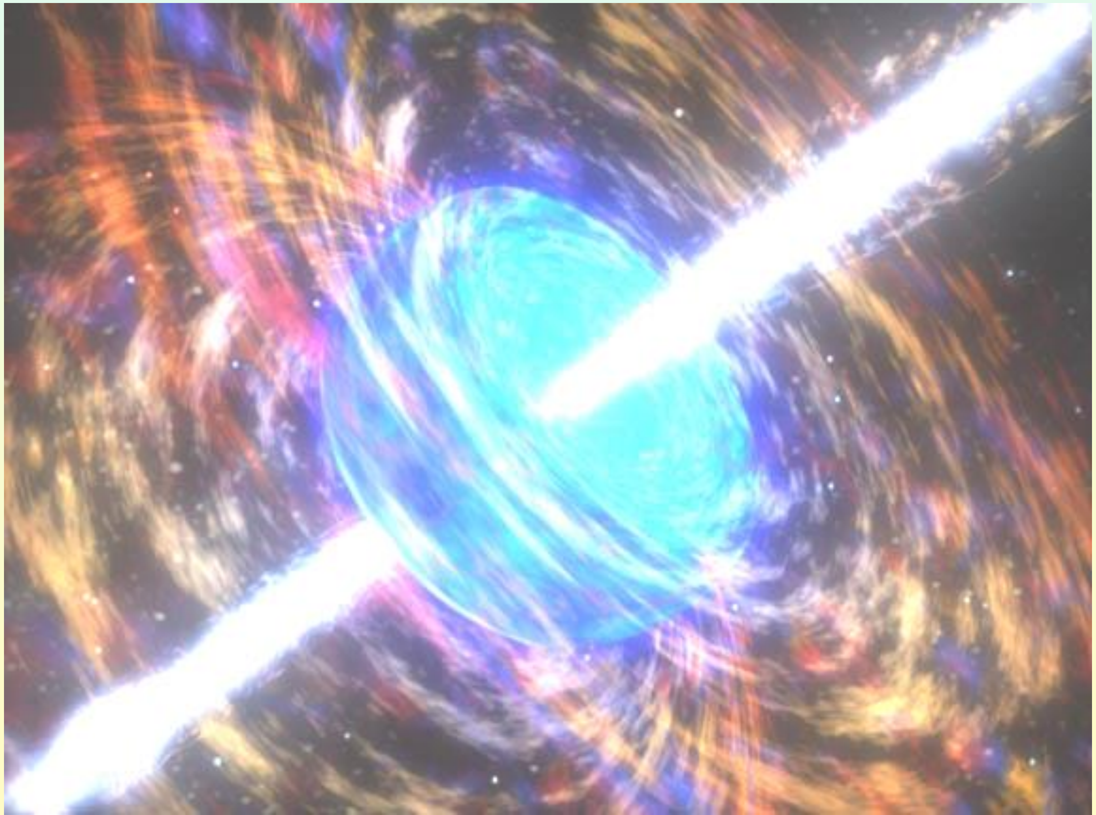

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Astronomical Objects

★ Gamma-Ray Bursts (GRBs)

★ X-ray Binaries (XRBs)

★ High Energy Cosmic Rays

★ Tidal Disruption Events

★ Active Galactic Nuclei (AGNs)

Physical Disciplines

✪ (relativistic) Dynamic

✪ Radiative Processes

✪ Particle Acceleration

✪ Nuclear Interactions

✪ Plasma (astro)physics

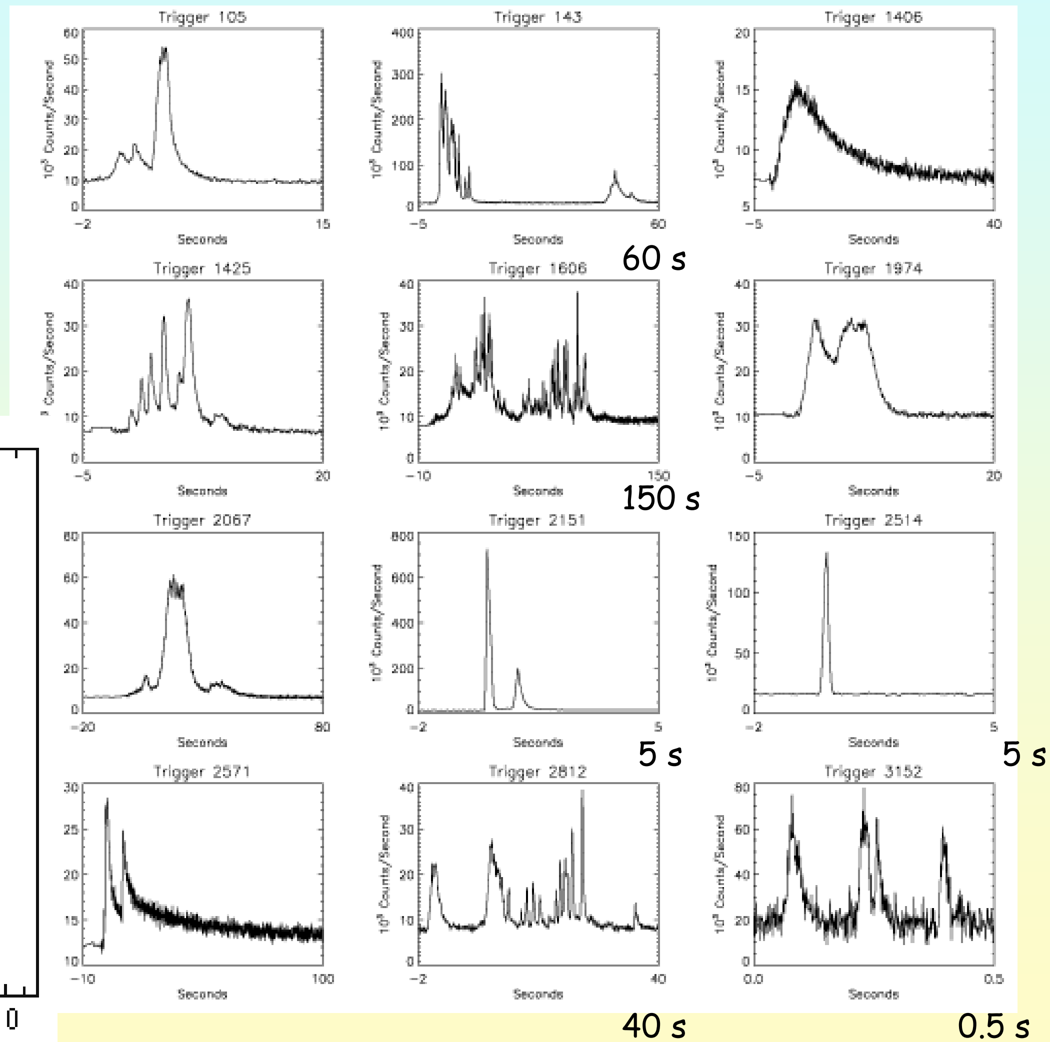
Demonstration:

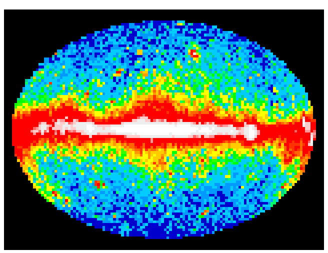
GRBs: flashes of gamma-rays that appear randomly in the sky.

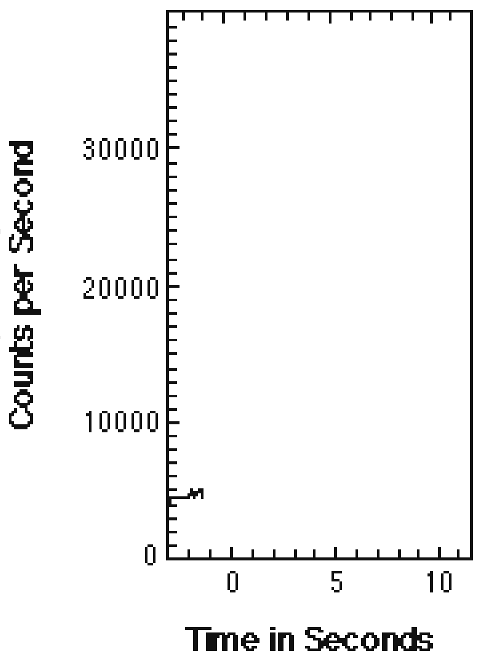
Basic facts (1): GRB light curves- ZOO !

Duration: few s

Variability: >~10 ms







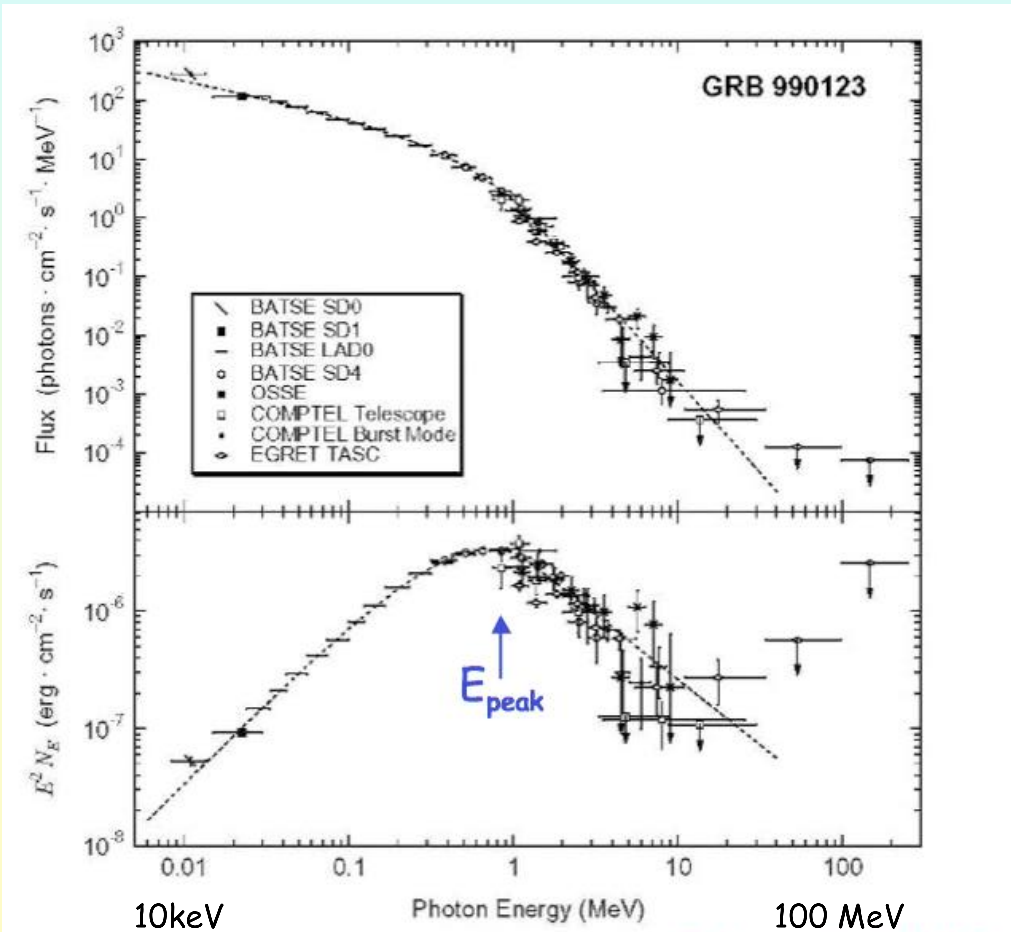
Basic facts (2): observed spectrum

Observed Flux: ~10^{-7} - 10^{-4} erg cm^{-2} s^{-1}

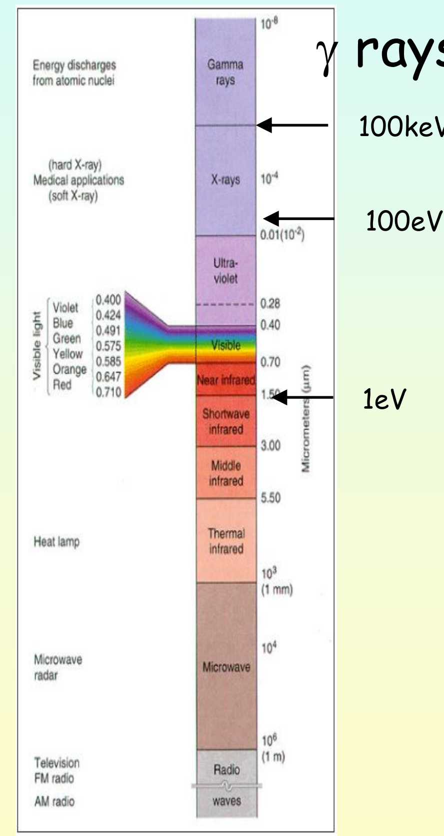
Typical observed energy: <~ MeV

Spectrum: non-thermal;
extends to >GeV

Isotropic in the sky



Briggs et al. 1999



Theoretical implications

Observed Flux: F ~10^{-7} - 10^{-4} erg cm^{-2} s^{-1}

Cosmological distance d_L~ 10^{28} cm

L_{iso} = F 4πd_L^2 ~ 10^{50} - 10^{53} erg/s, released in few seconds→

(for comparison: $M_\odot c^2$~10^{54} erg: I.e., few % of solar rest mass released !)

Variability: δt~10 ms

Light crossing time: R_0 <~ cδt ~ 3*10^8 cm

→Very compact object !

Number density of photons at MeV: $n_g = \frac{L_g}{4 p R_0^2 c \epsilon}$ e @1MeV

Optical depth for pair production γγ→ $e^{\pm}$: (m$_e$ = 511 keV)

$$t_{gg} \sim R_0 n_g s_T \gg \frac{s_T L_g}{4 p R_0 c e} \gg 10^{16}$$

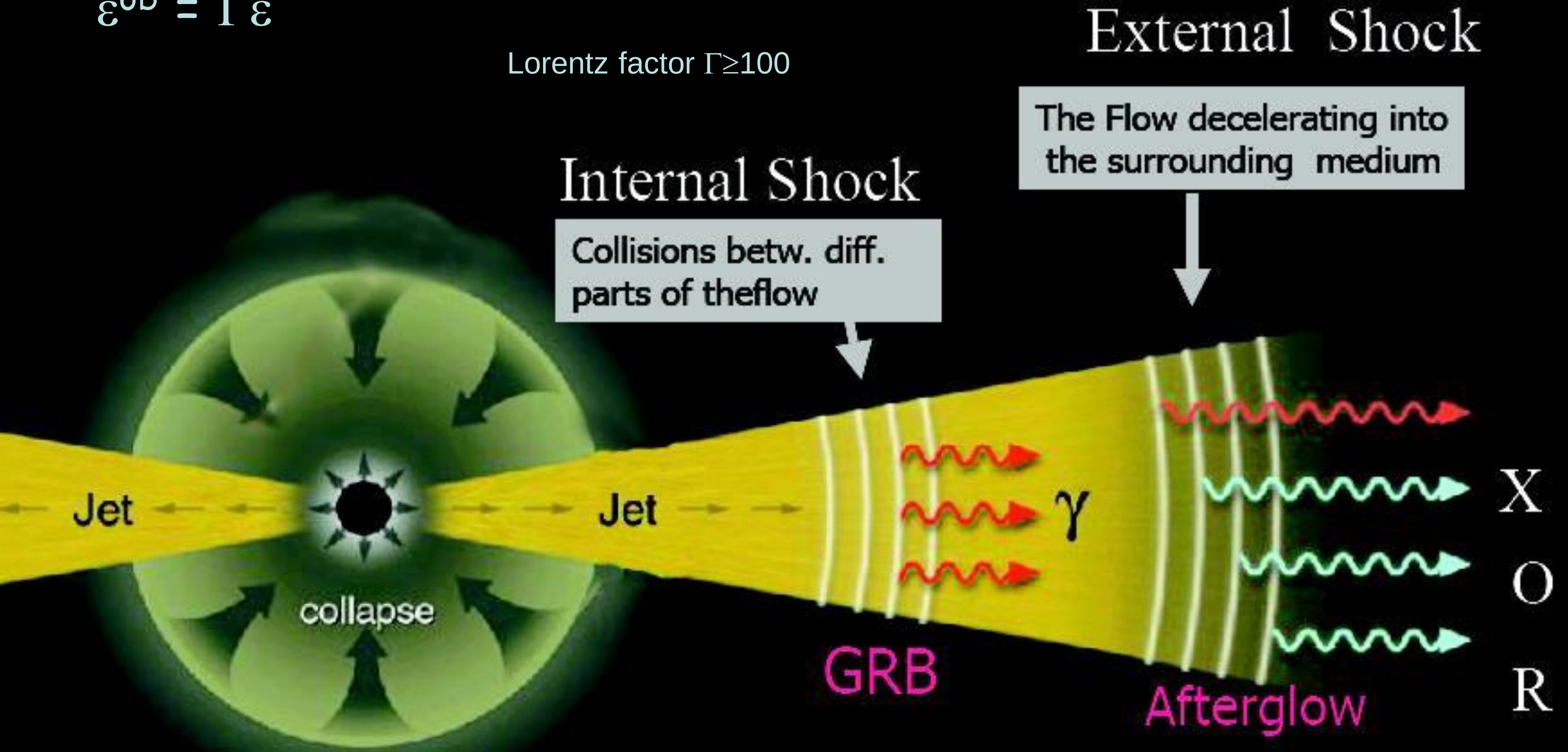
We cannot see anything (>511 keV) !!

Fireball Model: long GRBs

Energy transfer: release -> kinetic -> dissipation

$\varepsilon^{ob} = \Gamma\varepsilon'$

Lorentz factor $\Gamma \geq 100$



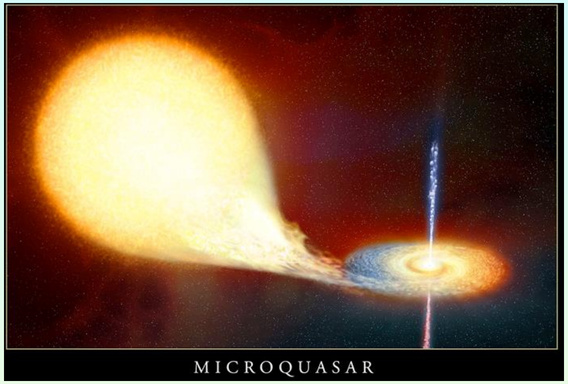
Prediction: Afterglow !

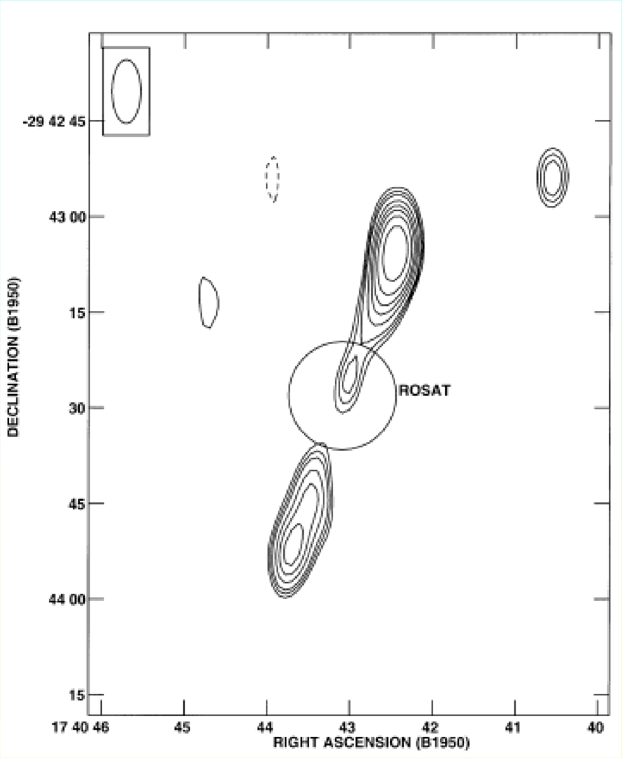
Goodman, 1986; Paczynski, 1986;

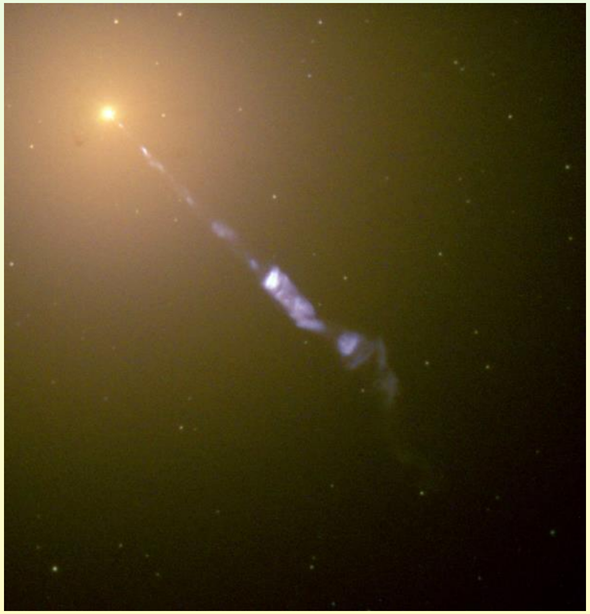
Rees & Meszaros, 1992,1994

Relativistic jets: Very common in astronomy

XRB's
1E1740.7-2942 – 10's AU
(Mirabel & Rodriguez 1999)



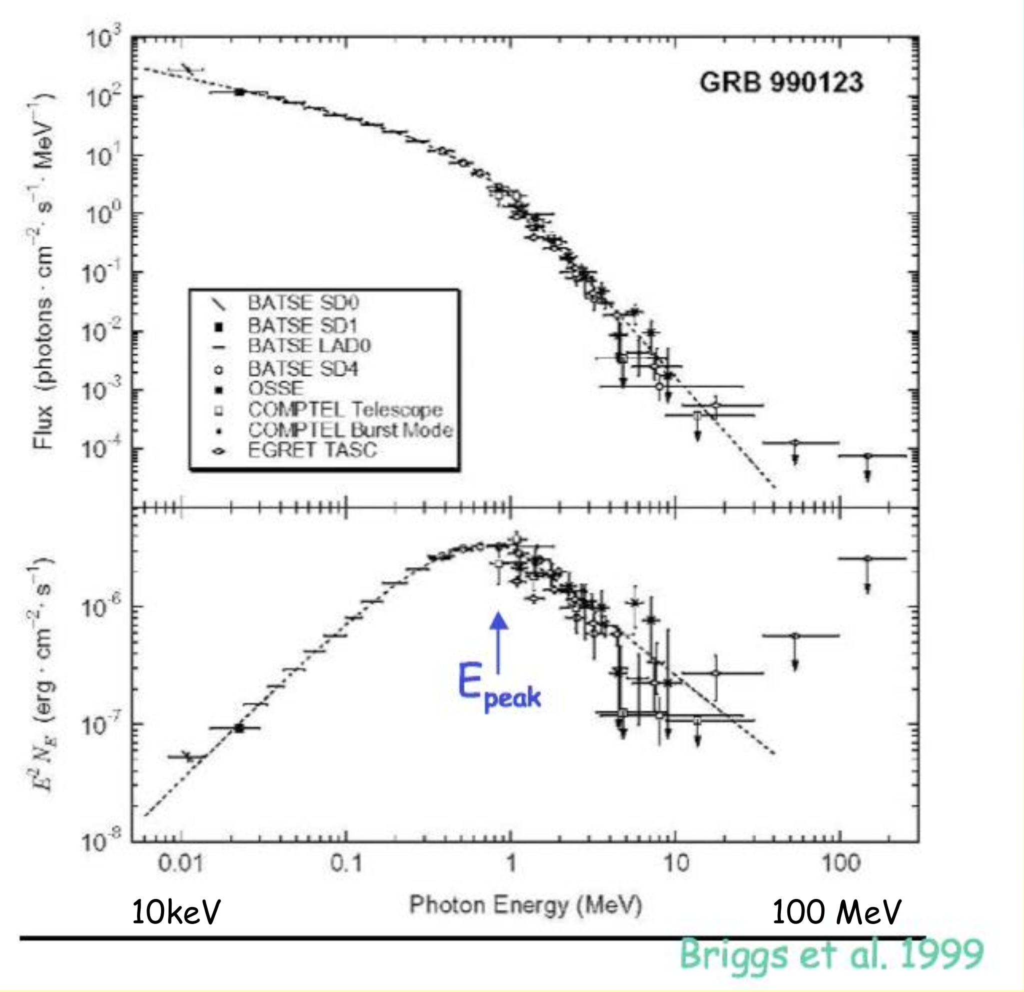


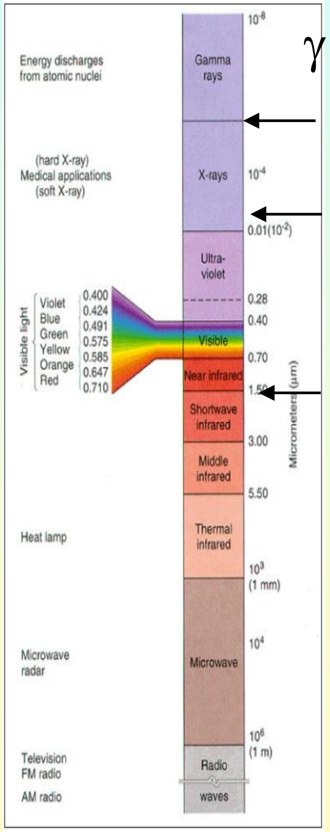


AGN's
M87 (>~1.5 kpc)

Basic Question:
Origin of the observed spectra ?

Isotropic in the sky





γ rays

100keV

100eV

1eV

Photons must originate Somehow. Synchrotron ??

A very efficient way of producing non-thermal ➢ spectrum

believed

~~Known~~ to exist in many astronomical objects ➢

Well understood ➢

Ingredients:

Energetic electrons

Magnetic field

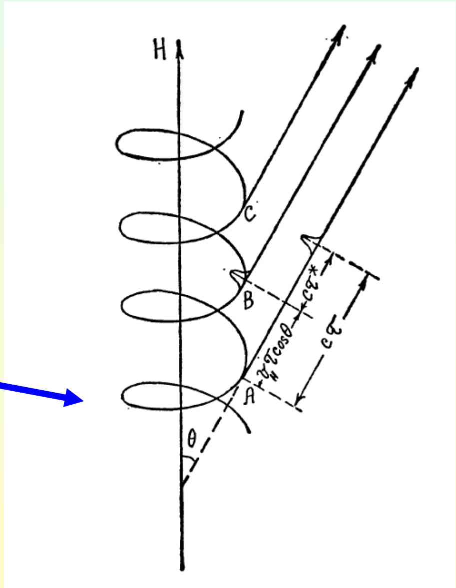


FIG. 2

Known (at least) from the 60's

(e.g., Ginzburg & Syrovatskii, 1965, 1969)

So, basically the problem is reduced to:

Produce B field .1

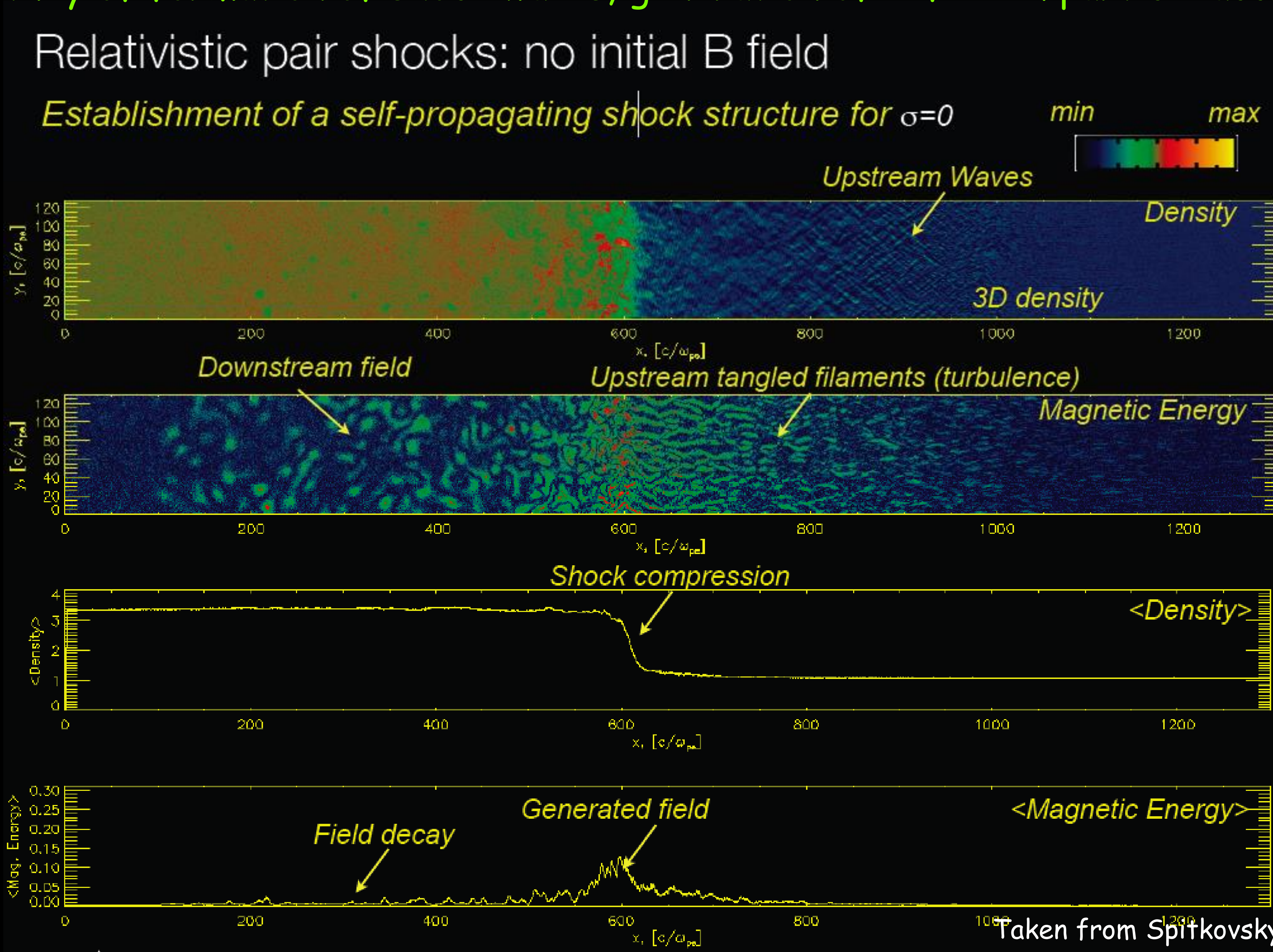
Accelerate particles (elec.) to high energies .2

Non is really known….

However, it is **believed**, that shock waves can make all of this

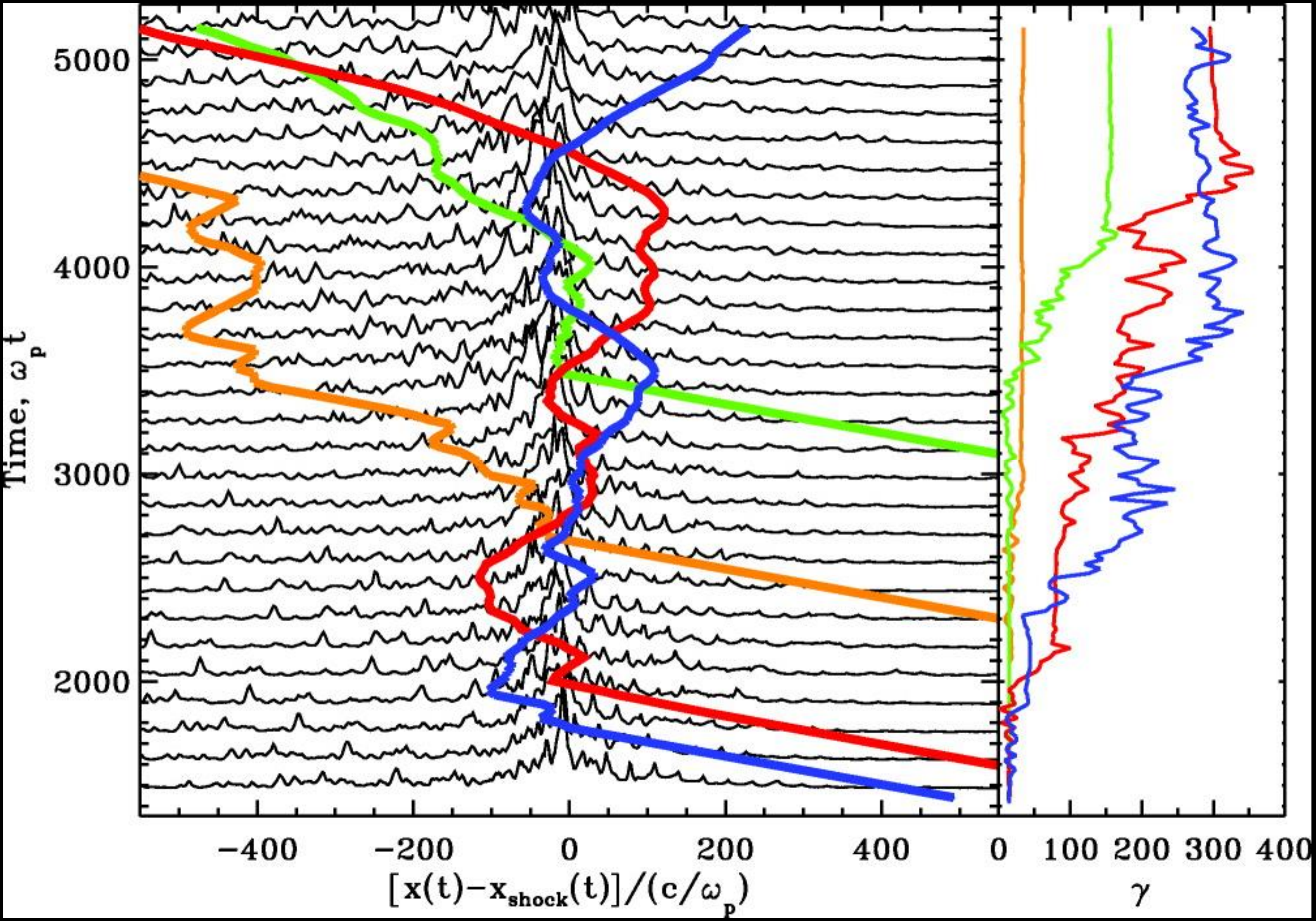
Introduce "ignorance parameters": ε_e, ε_B

State of the art Particle-in-cell simulation: study of formation of shock waves, generation of B-field & particle acc.

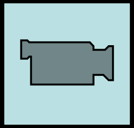


Taken from Spitkovsky, 08

In every shock crossing, particles gain energy



Movie !



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Few ideas for projects: (depends on student's interest & background)

- Population studies of Long / Short GRBs
- Properties of second (pair) photosphere
- Construct Monte-Carlo simulation of EM cascade following particle acceleration
- Study the properties of X-ray flares: predictions for pre-cursor emission from late-time measurements
- How can one explain the "fast-rise-exponential-decay" (FRED) shape of pulses ?
- Analyze LOFAR data

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