GRB

Recent Developments and Cosmological Context

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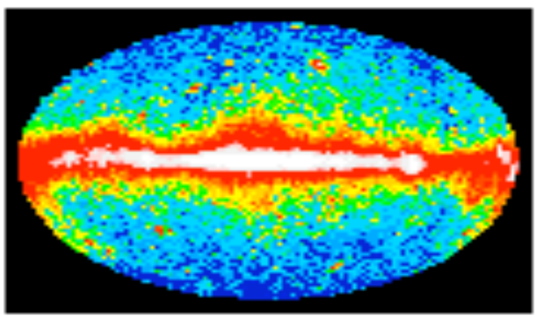
For a few seconds, a GRB dominates the gamma-ray brightness of the entire Universe



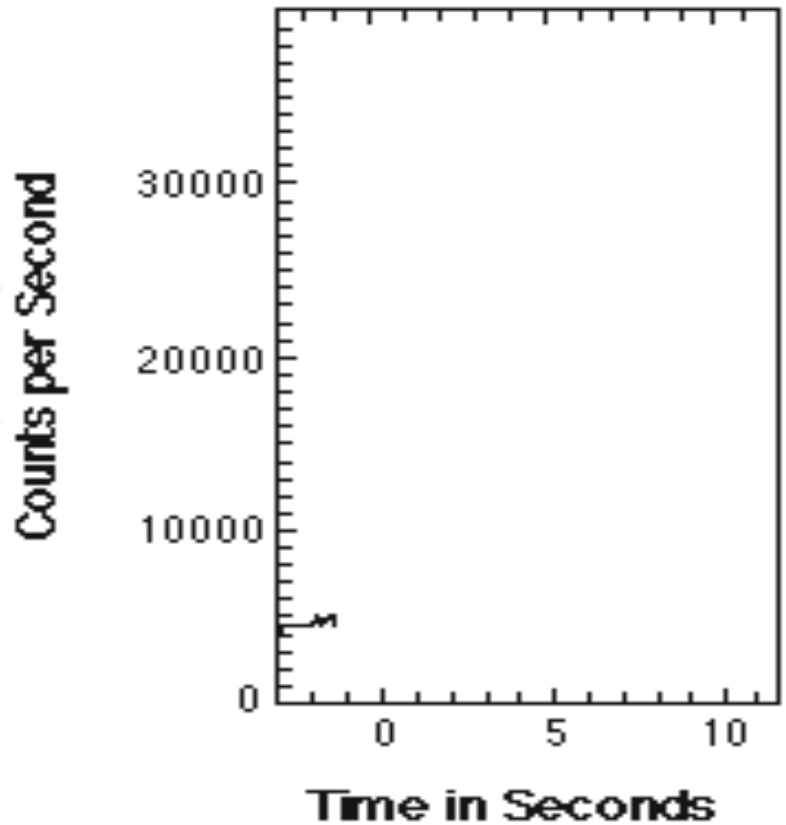


Fig. Credit: Tyce DeYoung

GRB: *basic numbers*

- Rate: ~ 1/day inside a Hubble radius
- Distance: $0.1 \leq z \leq$ **6.3 !** $\rightarrow D \sim 10^{28}$ cm
- Fluence: $F = \int flux.dt \sim 10^{-4} - 10^{-7}$ erg/cm^2

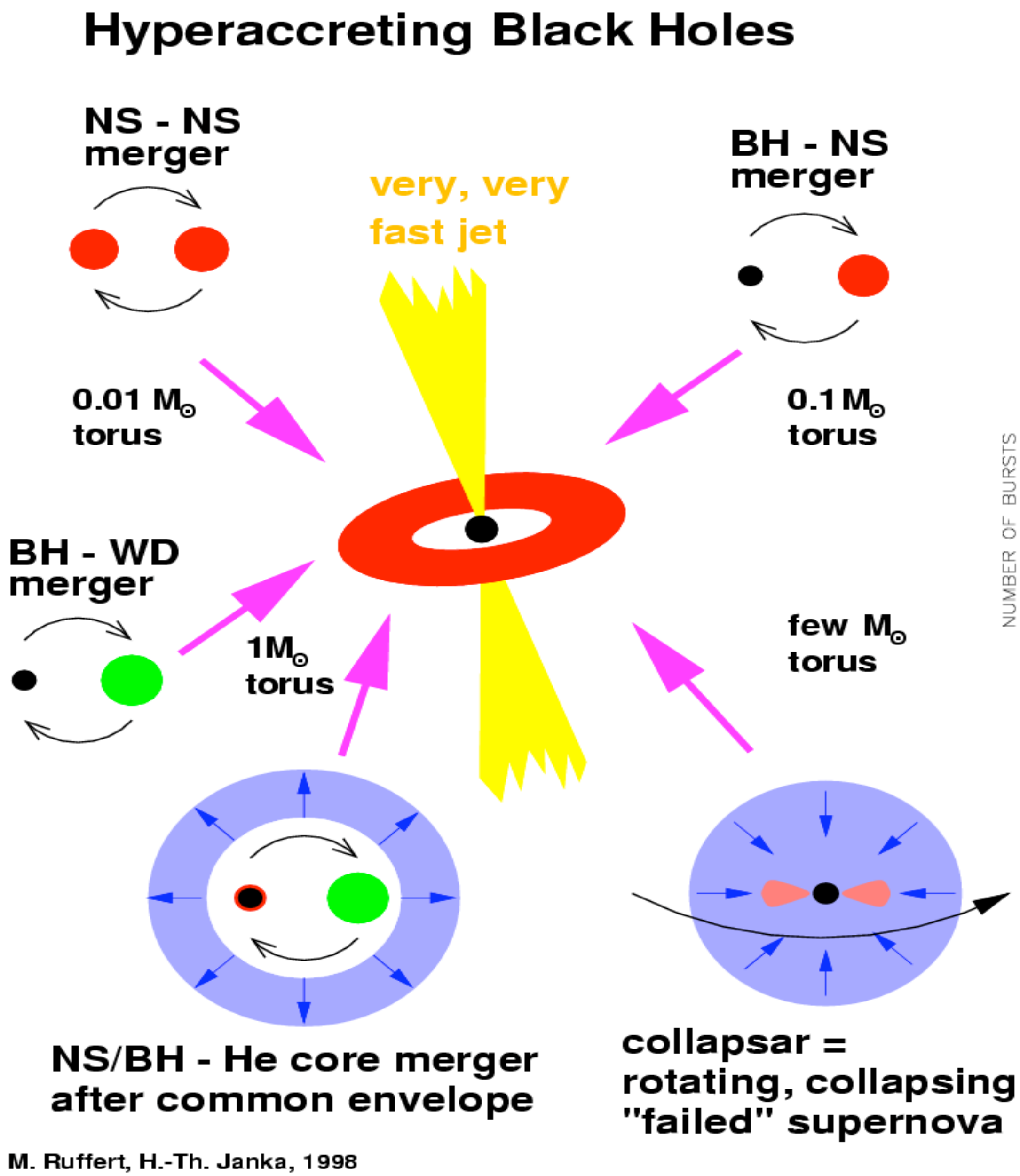
  ~ 1 ph/cm^2 (γ-rays !)
- Energy output: $10^{53} (\Omega/4\pi) D^2_{28.5} F_{-5}$ erg

  jet: $(\Omega_j/4\pi) \sim 10^{-2} \rightarrow E_{\gamma,tot} \sim 10^{51}$ erg

  $E_{\gamma,tot} \sim L_\Theta \times 10^{10}$ year $\sim L_{gal} \times 1$ year
- Rate(GRB) $\sim 10^{-6}(2\pi/\Omega)$ /yr/gal $\rightarrow$ 1/day ($z \leq 3$)

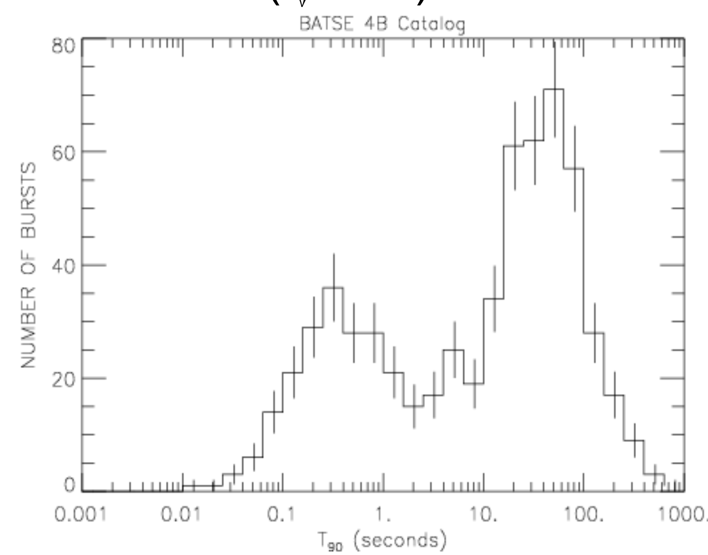
  whereas Rate [SN] ~ 10^{-2}/yr/gal, or 10^7 /yr ~ 1/s ($z < 3$)

GRB: current paradigm



Bimodal distribution of t_γ duration

← ↓Short (t_γ< 2 s)



← ↑Long (t_γ >2 s)

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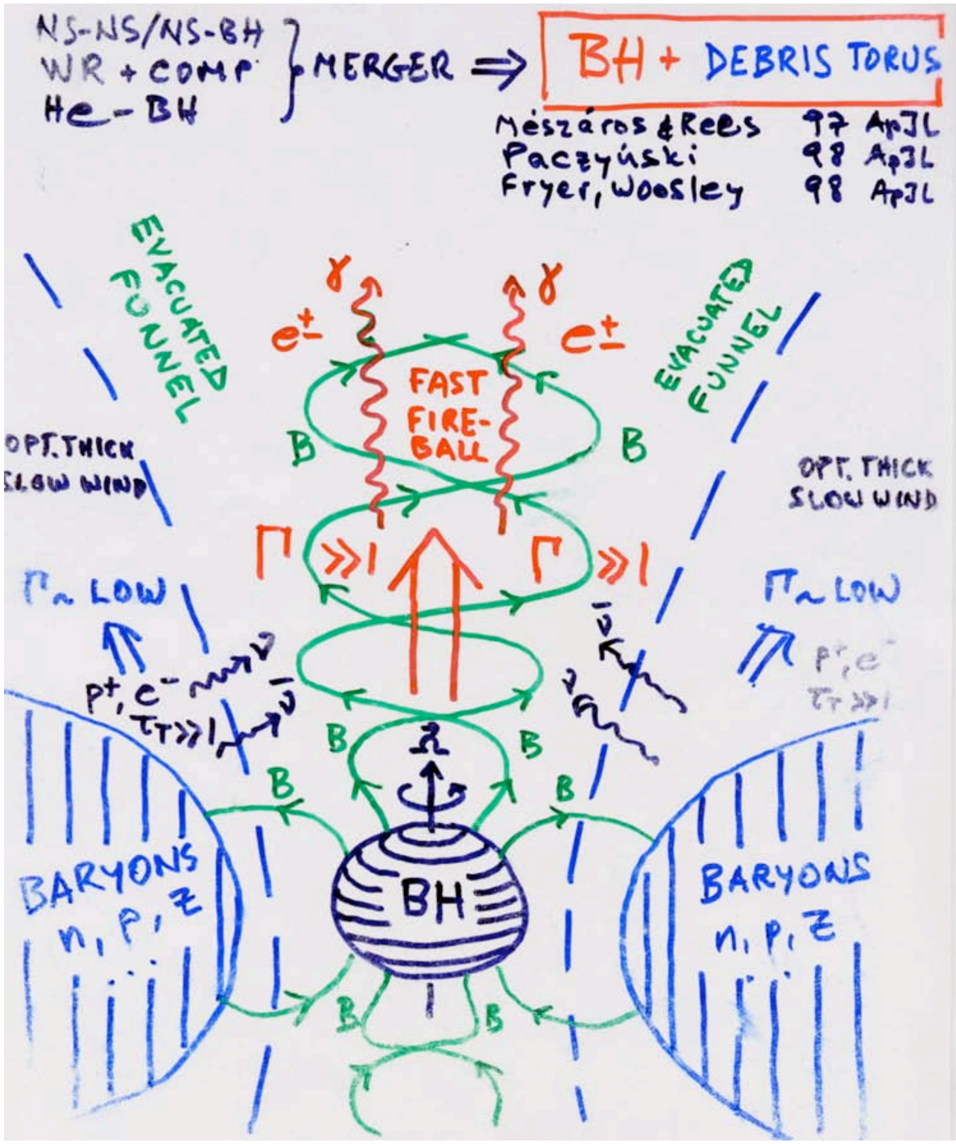
BH + Accr. Torus ⟶ Jet



- Both collapsar or merger → BH+accr.torus→fireball
- Massive rot. *: sideways pressure confines/channel outflow ⟶ **fireball Jet**
- Nuclear density hot torus → can have **$\nu\nu \to e^{\pm}$ jet**
- Hot infall →convective dynamo → $B \sim 10^{15}$ G, twisted (thread BH?)

→**Alfvénic** or $e^{\pm}p\gamma$ **jet**

- (Note: magnetar might do similar)

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Explosion → *FIREBALL*

- $E_\gamma \sim 10^{51}\ \Omega_{-2}\ D^2_{28.5}\ F_{-5}$ erg
- $R_0 \sim c\ t_0 \sim 10^7\ t_{-3}$ cm

→ Huge energy in very small volume

- $\tau_{\gamma\gamma} \sim (E_\gamma / R^3{}_0 m_e c^2)\sigma_T R_0 >> 1$

  → Fireball: $e^\pm,\gamma,p$ relativistic gas
- $L_\gamma \sim E_\gamma / t_0 >> L_{Edd}$ → expanding ($v \sim c$) fireball

(Cavallo & Rees, 1978 MN 183:359)

- Observe $E_\gamma > 10$ GeV …but

  $\gamma\gamma \rightarrow e^\pm$, degrade 10 GeV → 0.5 MeV?

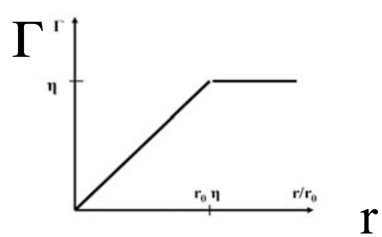
  $E_\gamma\ E_t > 2(m_e c^2)^2/(1-\cos\Theta) \sim 4(m_e c^2)^2/\Theta^2$

→ Ultrarelativistic flow → $\Gamma \geq \Theta^{-1} \sim 10^2$

(Fenimore etal 93; Baring & Harding 94)

Relativistic Outflows

- Energy-impulse tensor : $T_{ik} = w\, u_i\, u_k + p\, g_{ik}$,
  $\mathbf{u^i}$: 4-velocity, $\mathbf{g_{ik}}$= metric, $g_{11}=g_{22}=g_{33}=-g_{00}=1$, others 0;
  ultra-rel. enthalpy: $w = 4p \propto n^{4/3}$; w, p, n : in comoving-frame
- 1-D motion : $u^i=(\gamma,u,0,0)$, where $\mathbf{u = \Gamma\, (v/c)}$,
  v = 3-velocity, **A**= outflow channel cross section :
- Impulse flux — $Q=(w\,u^2 + p)\, A$
  energy flux — $L= w u\, \Gamma\, c\, A$
  particle number flux — $J= n\, u\, A$
- Isentropic flow : **L, J constant** →
  $w\,\Gamma/n = \text{constant}$ (relativistic Bernoulli equation);
  for ultra-rel. equ. of state $p \propto w \propto n^{4/3}$, and cross section $A \propto r^2$
  → $n \propto 1/r^2\,\Gamma$ comoving density drops
  → $\Gamma \propto r$ "bulk" Lorentz factor initially grows with **r**.
- But, eventually saturates,
  $\Gamma \rightarrow E_j/M_jc^2 \sim$ constant



⇨ ***JET MOVIE***

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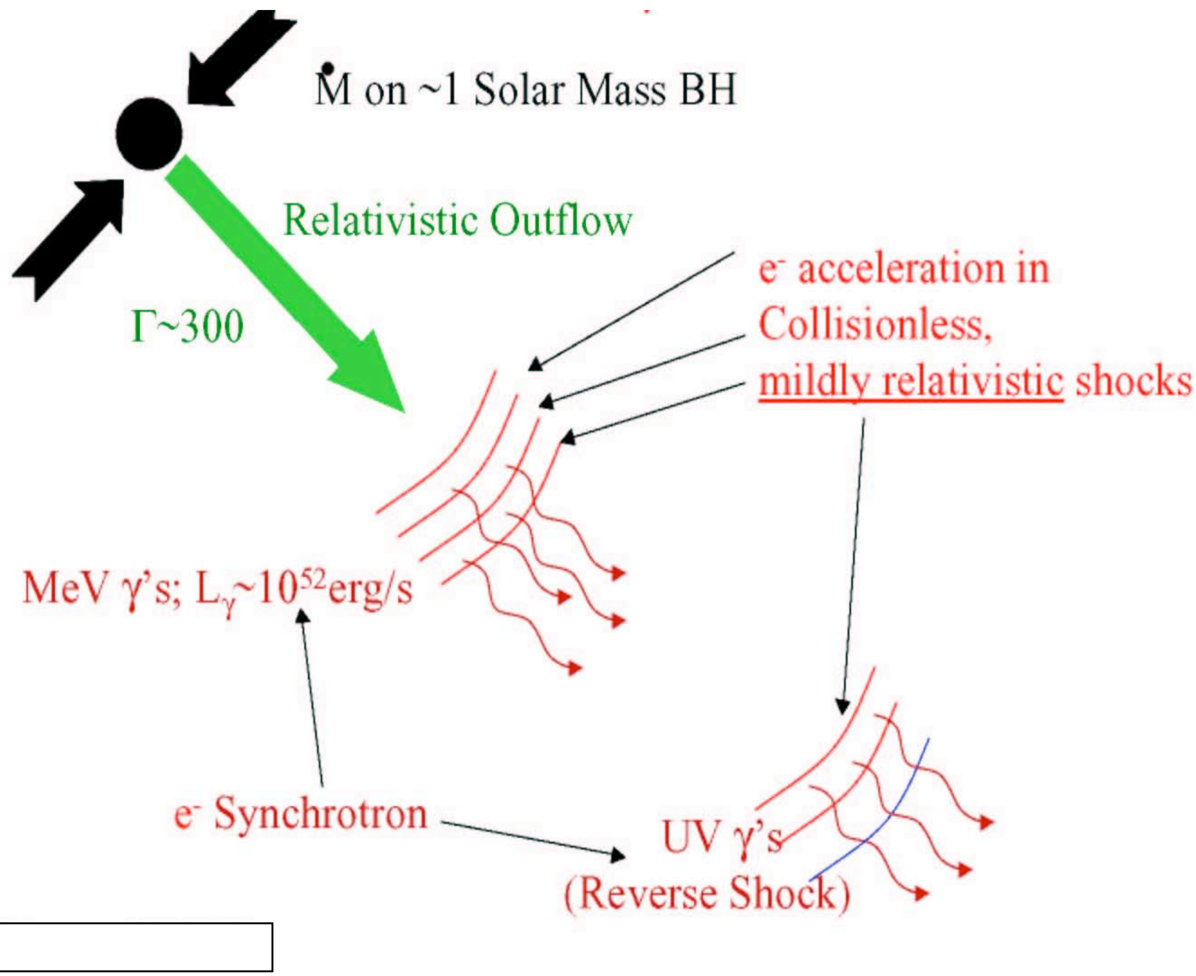
GRB: internal & external shocks

(outside progenitor star)



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Shock formation

- Collisionless shocks (gas too rare)
- "Internal" shock waves: where ?

If two gas shells ejected with $\Delta\Gamma=\Gamma_1-\Gamma_2\sim\Gamma$, starting at time intervals $\Delta t \sim t_v$, they collide at r_{is},

$r_{is} \sim 2\, c\, \Delta t\, \Gamma^2 \sim 2\, c\, t_v\, \Gamma^2 \sim 6.1O^{11}\, t_{-3}\, \Gamma_2^{\,2}$ cm

(internal shock)

- "External shock": merged ejected shells coast out to r_{es}, where they have swept up enough enough external matter to slow down, $E=(4\pi/3)r_{es}^{\,3}\, n_{ext}\, m_p\, c^2\, \Gamma^2$,

$r_{es} \sim (3E/4\pi n_{ext} m_p c^2)^{1/3}\Gamma^{-2/3} \sim 3.1O^{16}(E_{51}/n_O)^{1/3}\Gamma_2^{\,-2/3}$ cm

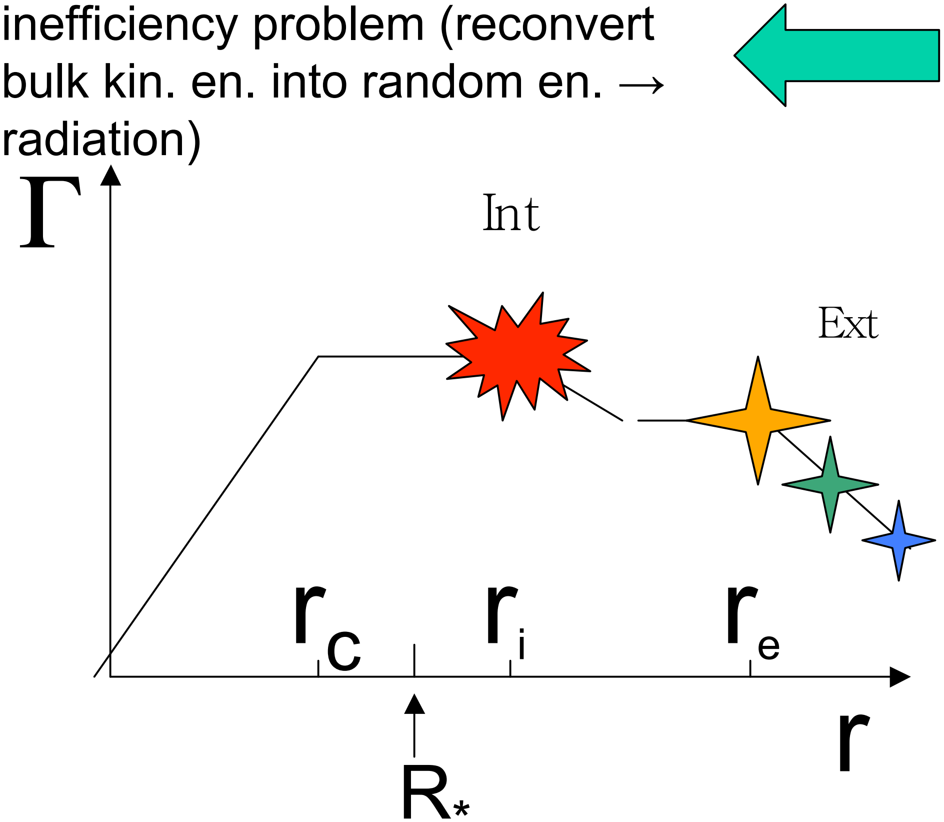
(external shock)

Non-thermal γs: *Internal & External Shocks*

in optically thin medium outside progenitor:

SHORT & LONG-TERM BEHAVIOR

Shocks solve radiative inefficiency problem (reconvert bulk kin. en. into random en. → radiation)

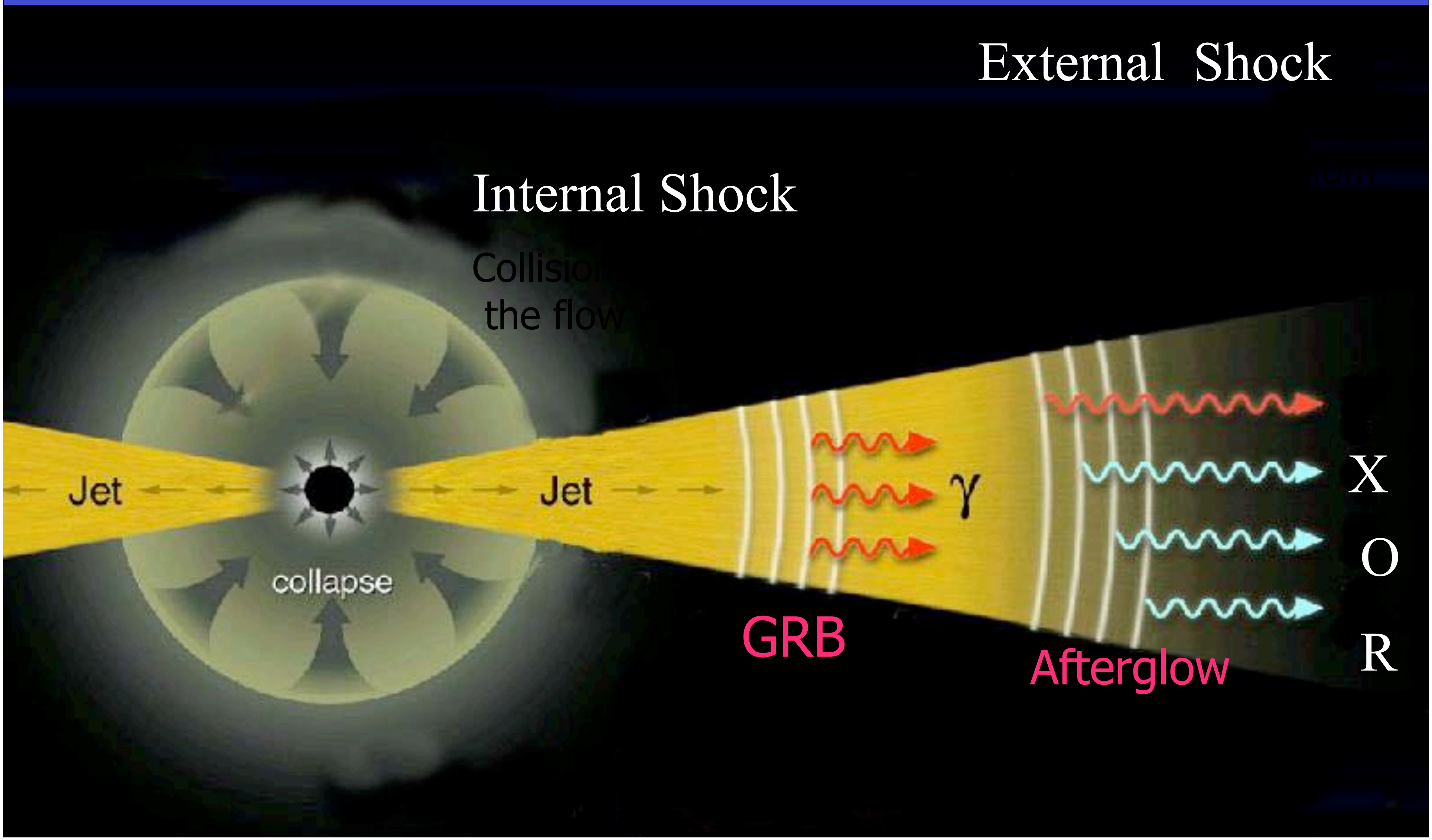


- Lorentz factor Γ first grows Γ∝ r, then saturates, Γ∝constant, until …
- **Outside** the star, after jet is opt. thin: Internal shocks: r_i~10^{12}cm
  →**γ-rays** (burst, t~sec)
- Externals shocks start at r_e ~10^{16}cm, progressively weaken as it decelerates

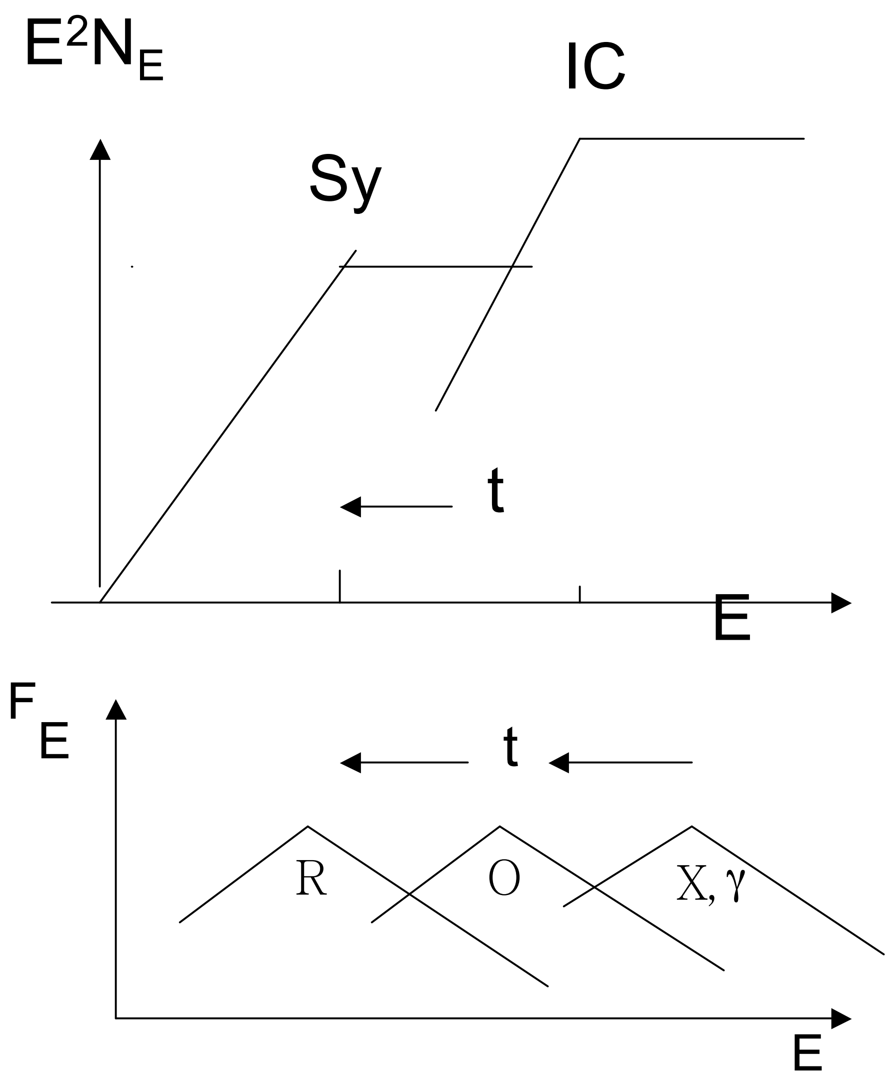
PREDICTION :

- External **forward** shock spectrum **softens** in time:
  X-ray, optical, radio …
  →**long fading afterglow !**
  (t ~ min, hr, day, month)
- External **reverse** shock (less relativistic):
  Optical → quick fading (t ~ mins)
  (Mészáros & Rees 1997 ApJ 476,232)

Fireball Model: long GRBs

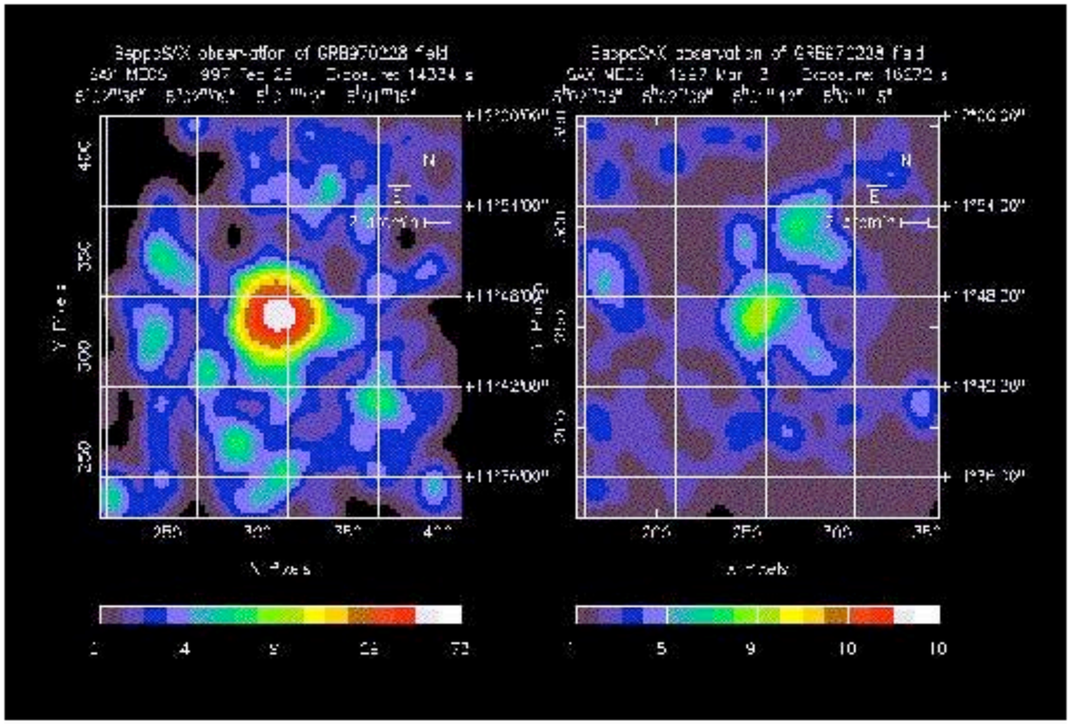


Shock Photon Spectrum



- **Non-thermal** power law spectrum, both in int. and ext. shocks, due to
- **Synchrotron**, peak at ~200 keV (or ~ eV?)
- **Inv. Compton**, peak ~ GeV (or ~200 keV ?
- Sy peak location, ratio Sy/IC dep. on $\mathbf{B_{sh}}$, $\boldsymbol{\gamma_{e,m}}$
- Peak **softens** with time
- Ratio Sy/IC **decr** w. time

GRB 970228 : **BeppoSAX**
Discovery of an **afterglow**



Feb 28 March 3

F_x ~3E-12 erg.cm2/keV/s , decr. By 1/20

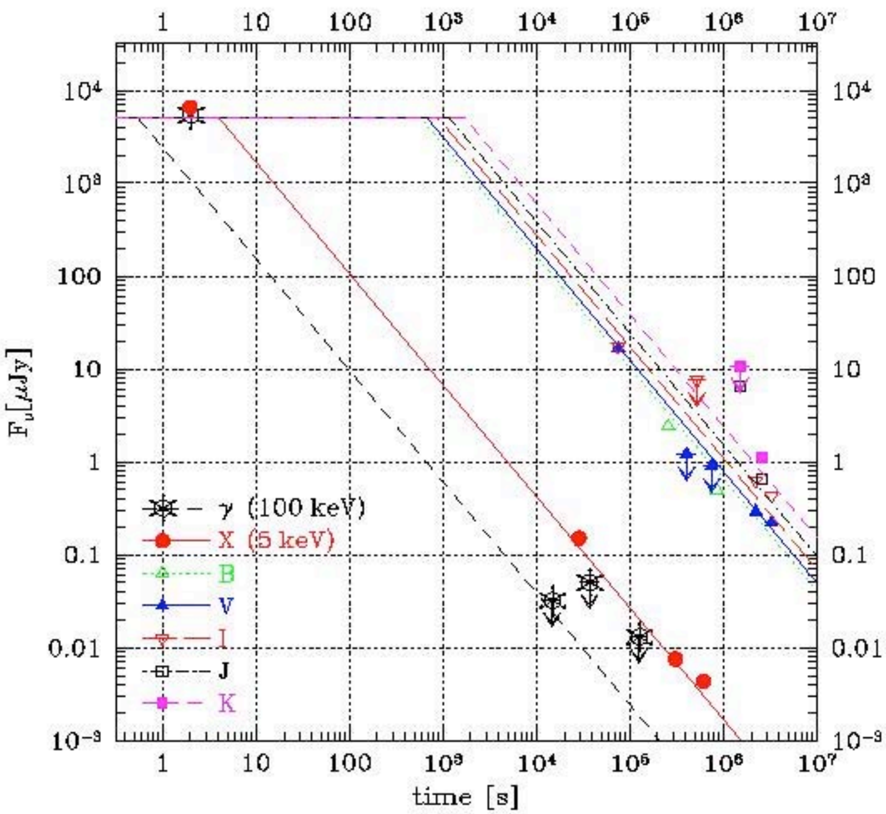
(Costa et al 1997, Nature 387:783)

- X-ray location:2-3 arcmin → raster
- →optical (arcsec) & radio location
- Can identify host galaxy, redshift

located at cosmological dist.

NEW ERA!

GRB afterglow blast wave model



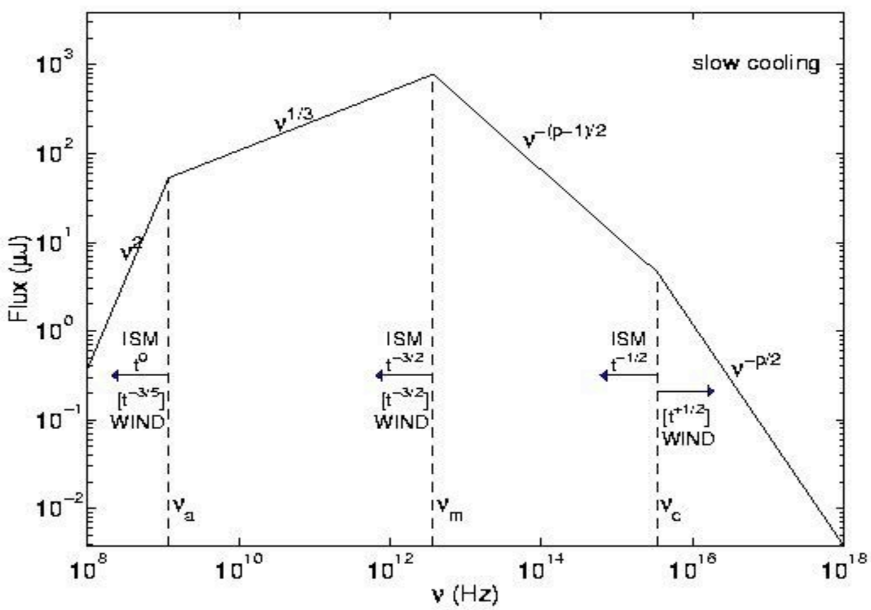
GRB 970228 as blast wave:

Wijers, Rees & Mészárosl 97 MNRAS 288:L51 fit to

Mészáros, Rees 97 ApJ 476:232 model

- Simplest case: adiabatic forward shock synchrotron radiation from (Fermi) shock accel. non-thermal e^-
- **$F(\nu,t) \propto \nu^{-\beta}\, t^{-\alpha}$**
- $\alpha = (3/2)\, \beta$
- Params: E_0, ε_e, ε_B, n_{ext} ($\beta=(p-1)/2$, $p/2$)

Snapshot Afterglow Fits



Sari, Piran, Narayan '98 ApJ(Let) 497:L17)

Break frequency decreases in time (at rate dep. on whether ext medium homog. or wind (e.g. $\rho \propto r^{-2}$)

- Simplest case: $t_{cool}(\gamma_m) > t_{exp}$, where $N(\gamma) \propto \gamma^p$ for $\gamma > \gamma_m$ (i.e. $\gamma_{c(ool)} > \gamma_m$)
- 3 breaks: $\nu_{a(bs)}$, ν_m, ν_c
- $F_\nu \propto \nu^2$ ($\nu^{5/2}$) ; $\nu < \nu_a$;

  $\propto \nu^{1/3}$; $\nu_a < \nu < \nu_m$;

  $\propto \nu^{-(p-1)/2}$; $\nu_m < \nu < \nu_c$

  $\propto \nu^{-p/2}$; $\nu > \nu_c$

(Mészáros, Rees & Wijers '98 ApJ499:301)

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Collapsar & SN connection

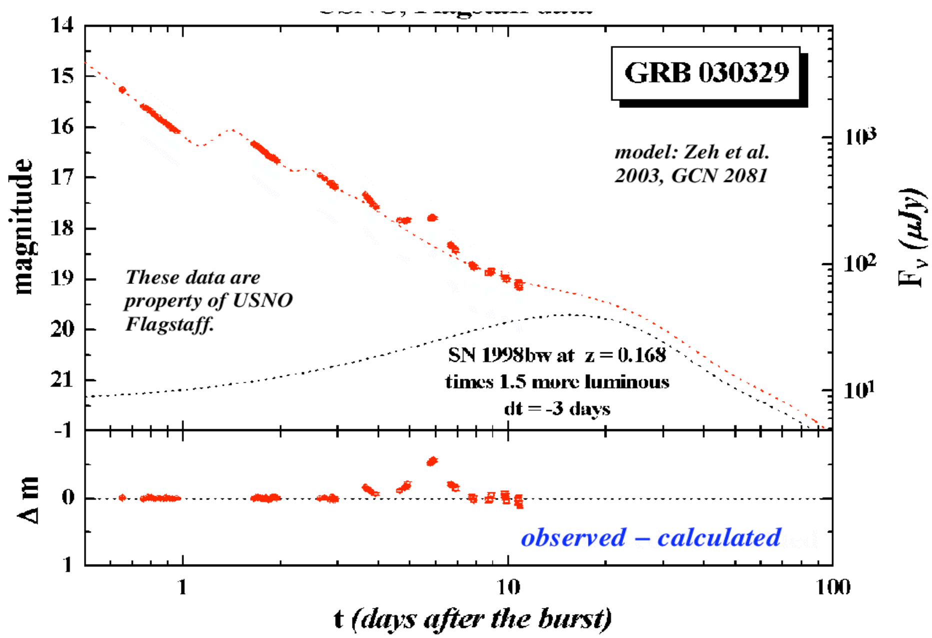
GRB030329 / SN2003dh

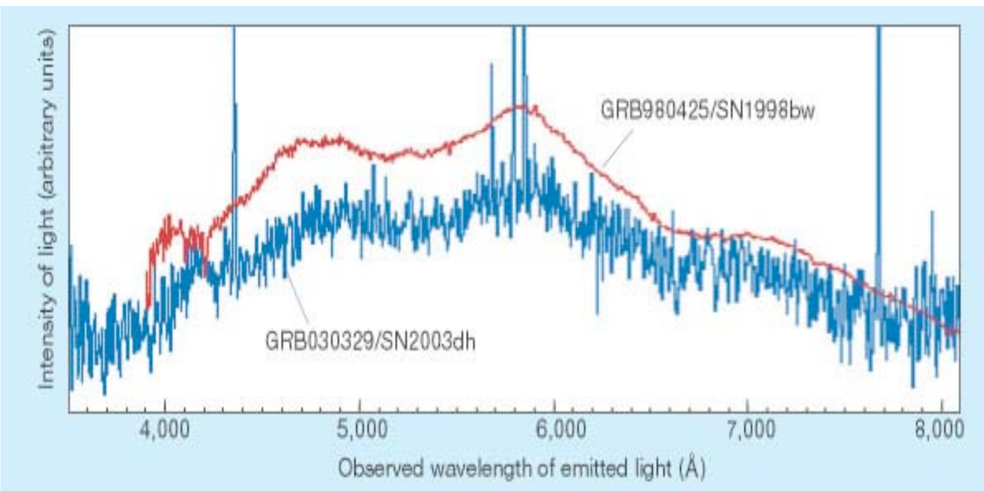
Animation: Derek Fox & NASA ↓

- Core collapse of star w. $M \sim 30\ M_{sun}$ → BH
- If fast rot.core → BH+disk+jet [MHD? baryonic? high Γ?
  + SNR envelope eject (?) ..]
- 3D hydro simul. (Newtonian, SR) →baryonic jet w. high Γ
  can develop and escape
- SNR envelope ejection:
  not calculated *numerically* yet…
  (**but:** several photom. observ. have suggested it occurs, e.g. detected lat
  light curve hump + reddening) ;
  … and more recently …

Collapsar & SN : does one imply the other ?

GRB 030329 ⇔ SN 2003dh : Yes !





- 2nd Nearest "unequivocal" cosmological GRB: **z=0.17**
- **GRB-SN association**: **"strong"**
- Fluence: 10^{-4} erg cm^{-2} , among highest in BATSE, but $\Delta t_\gamma \sim 30$s, nearby; $E_{\gamma,iso} \sim 10^{50.5}$erg: ~typical,
- $E_{SN2003dh,iso} \sim 10^{52.3}$ erg ~ $E_{SN1998bw,iso}$ (↔grb980425) $v_{sn,ej} \sim 0.1c$ (→ "hypernova")
- GRB-SN imultaneous? at most: δ 2 days off-set (from opt. lightcurve) (→ i.e. not a "supra-nova")
- But: might be 2-stage (<2 day delay) *- NS-BH collapse ? → ν predictions may test this !

(other: GRB031203/SN2003lw, z=0.1055, aph/0403608)

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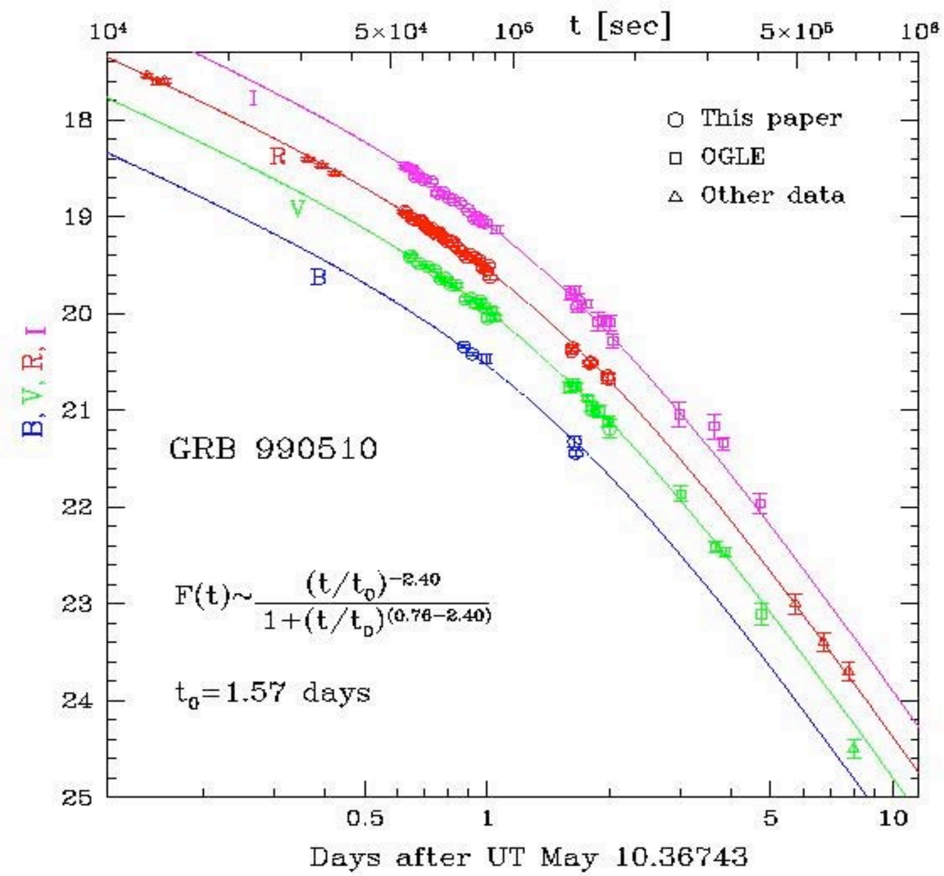
Light curve break: Jet Edge Effects



- Monochromatic break in light curve time power law
- expect $\Gamma \propto t^{-3/8}$, as long as $\theta_{light\ cone} \sim \Gamma^{-1} < \theta_{jet}$, (spherical approx is valid)
- "see" jet edge at $\Gamma \sim \theta_{jet}^{-1}$
- Before edge, $F_\nu \propto (r/\Gamma)^2 . I_\nu$
- After edge, $F_\nu \propto (r\theta_{jet})^2 . I_\nu$,

  $\rightarrow F_\nu$ steeper by $\Gamma^2 \propto t^{-3/4}$
- After edge, also side exp.

$\rightarrow$ further steepen $F_\nu \propto t^{-p}$

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Jet break implications

■ **Opening Angle**

$$\theta_j < 0.3\,\mathrm{deg}\left(\frac{t_j}{150\,\mathrm{sec}}\right)^{3/8}\left(\frac{1+z}{2}\right)^{-3/8}\left(\frac{E_{iso}}{10^{53}\,erg}\right)^{-1/8}\left(\frac{\eta_\gamma}{0.2}\right)^{1/8}\left(\frac{n}{0.1}\right)^{1/8}$$

$$\gamma(t_j) = 1/\theta_j > 200$$

Early jet break <-> high ambient density <-> low nu_c

- Beppo-SAX (1997-2002): follow-up after 4-6 hours,

  $t_j > 0.5$ day → **few^o < θ_j < 30^o**

  (if jet uniform - "top-hat")
- Swift (2005 on): follow-up after t~100 s,

  $t_j > 10^3$ s → **$\theta_j > 0.3^o$**

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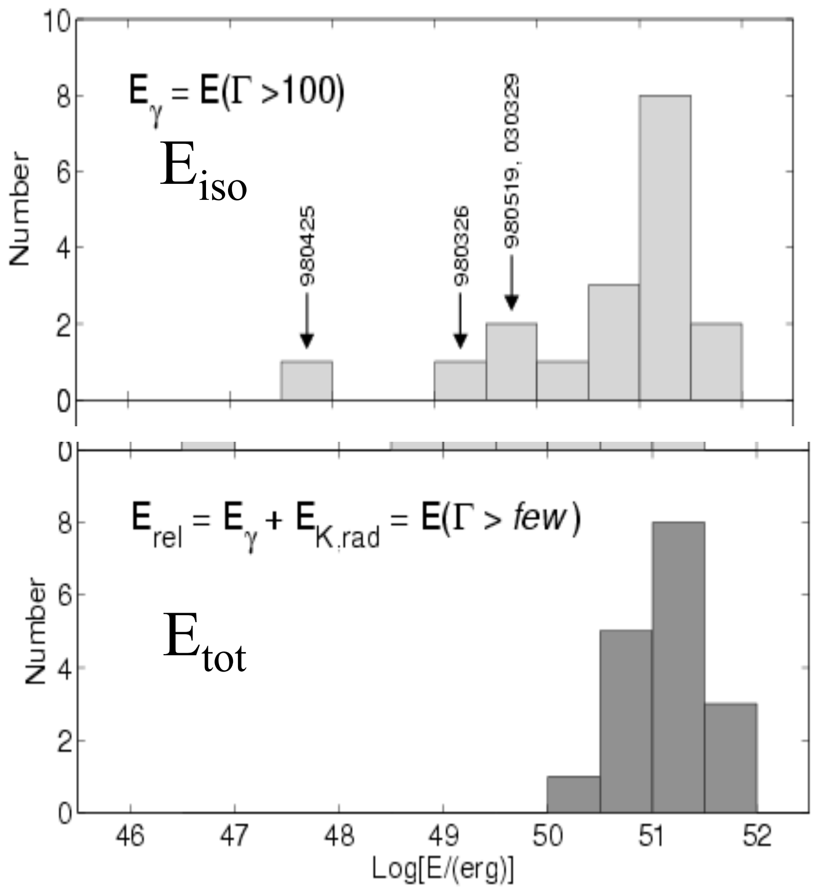
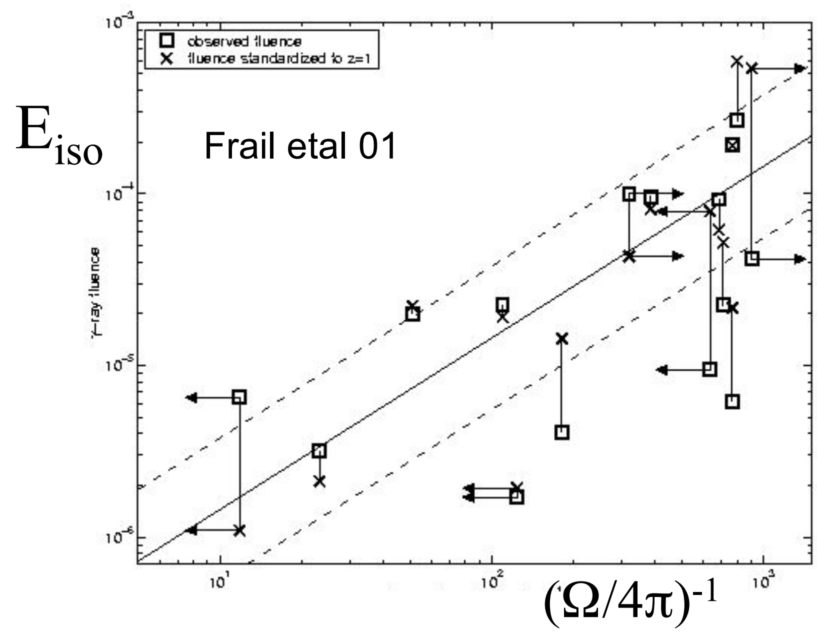
Jet Collimation & Energetics





- ↑Jet opening angle inv. corr. w. $L_{\gamma(iso)}$
- ← $L_{\gamma(corr)}$ **~ const.**
- Mean collim. "correction" $<(4\pi/2\Delta\Omega_j)> \sim 10^{-2}$
- **GRB030329:** 2-comp. jet? $\theta_\gamma \sim 5^o < \theta_{radio} \sim 17^o$
- **→ $E_{total} = E_\gamma + E_{kin}$ ~ const.** (→ **quasi-standard candle**)

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GRB z-measures?

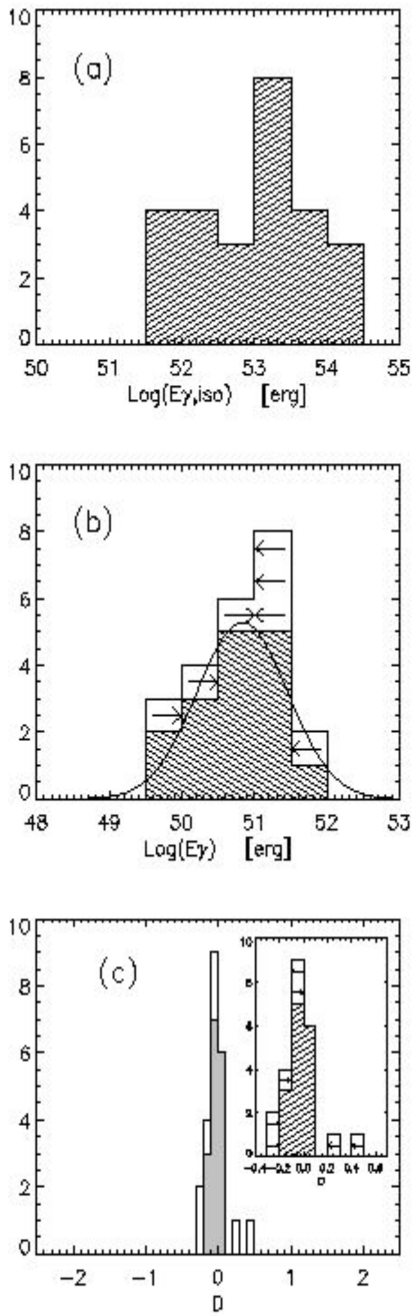
- Variability measure ***V vs. $E_{\gamma iso}$***

  (Fenimore, Ramirez-Ruiz, Lamb, Reichart..)
- Spectarl time ***lag vs. $E_{\gamma iso}$*** (Norris, Bonnell,..)
- Spectral break (hardness ratio) ***HR vs. $E_{\gamma iso}$***

  (Amati etal, Bagoly etal, Schmidt..)
- AND more recently: ***E_{pk} vs. E_{iso}, $E_{\gamma tot}$***

  (Amati et al, 02, Ghirlanda et al 04)

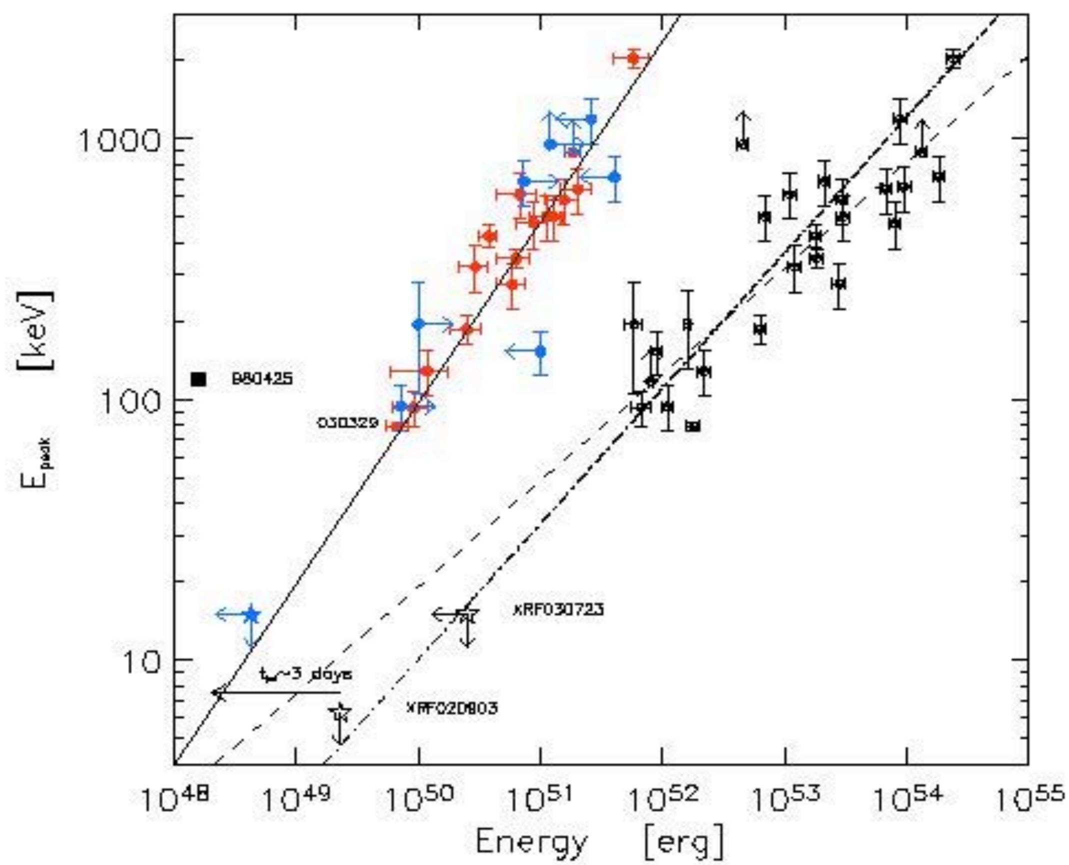
E_{pk} vs $E_{\gamma tot}$



Better correl. than E_{pk} vs $E_{\gamma iso}$ (?)

Ghirlanda, Ghisellini, Lazatti, aph/0405602
(see also Friedman & Bloom, aph/0408413)

$$E_{pk} \propto E_{\gamma tot}^{\ 0.7}$$



Reasons for Amati - Ghirlanda?

- E.g, internal shocks, $E_p \sim E_{sy} \sim \Gamma B'\gamma_e^2 \sim \Gamma B' \sim B \sim U^{1/2} \sim (L/r^2)^{1/2}$
  $\sim L^{1/2}\, t_v^{-1}\, \Gamma^{-2}$ (Zhang, Mészáros 02 ApJ 581, 1236)

  (since $r \sim c t_v \Gamma^2$ - but: is t_v , $\Gamma \sim$ const. for different L?)
- E.g photospheric characteristic temperature,

  $E_p \sim \Gamma T' \sim \Gamma (L/\Gamma^2 r_{ph}^2)^{1/4} \sim \Gamma^2 L^{-1/4}$ (since $r_{ph} \sim L/\Gamma^3$) ;

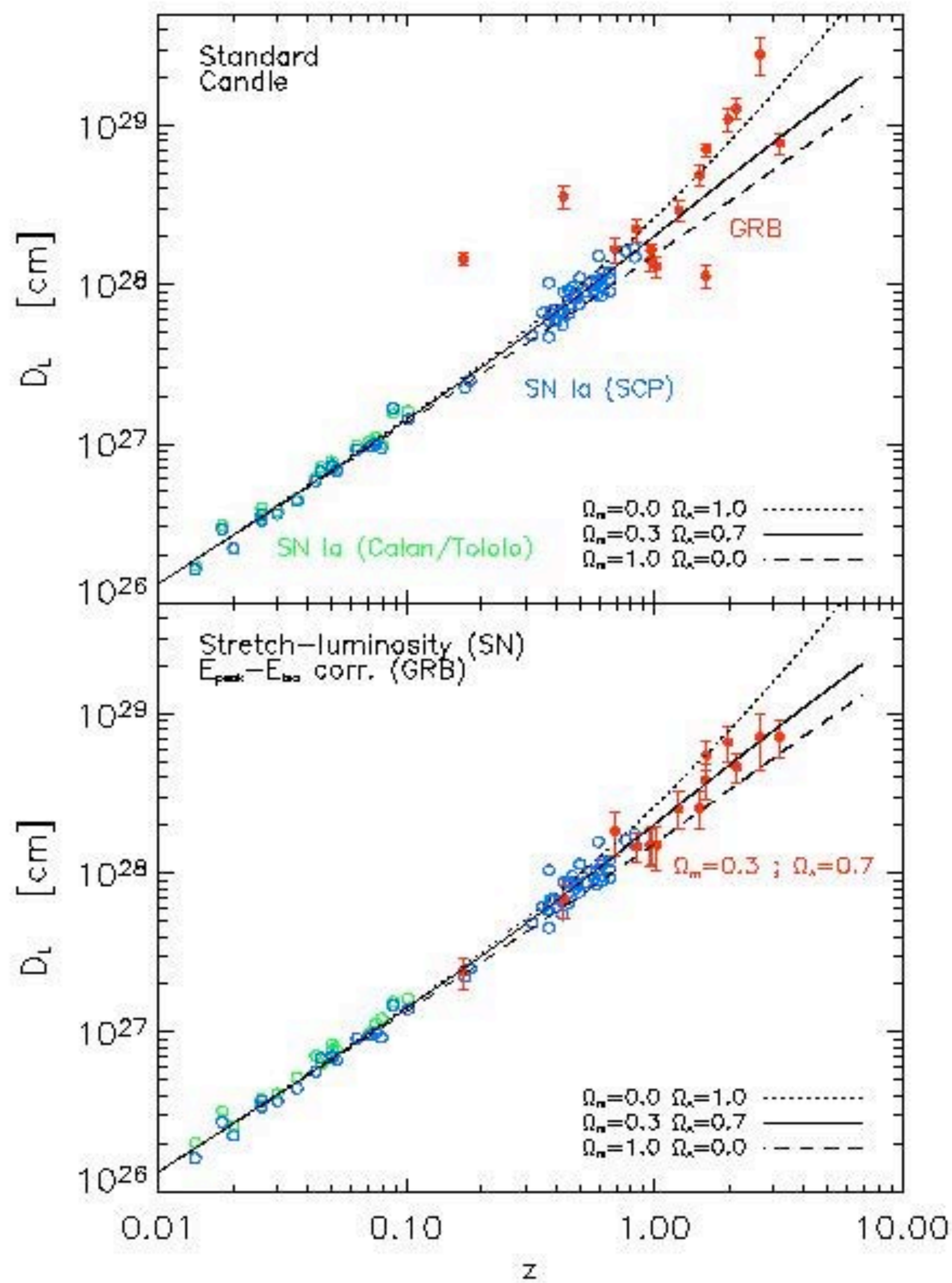
  if use Frail : $L \sim \theta^{-2}$, and causality : $\Gamma \sim \theta^{-1}$

  $\rightarrow$ $\mathbf{E_p \sim L^{3/4}}$ (Rees, Mészáros 05 ApJ 628, 847)
- If photosphere is at known radius of WR *,

  $E_p \sim \Gamma T' \sim \Gamma (L/\Gamma^2 R_*^2)^{1/4} \sim \Gamma^{1/2} L^{1/4}$;

  bulk of fluid moves at $\Gamma \sim 3^{-1/2}\, \theta^{-1}$ since outside that KH mix

  $\rightarrow$ $\mathbf{E_p \sim L^{1/2}}$ (Thompson astroph/0507387)



GRB as standard candles?

DE task force white paper, astro-ph/0507362

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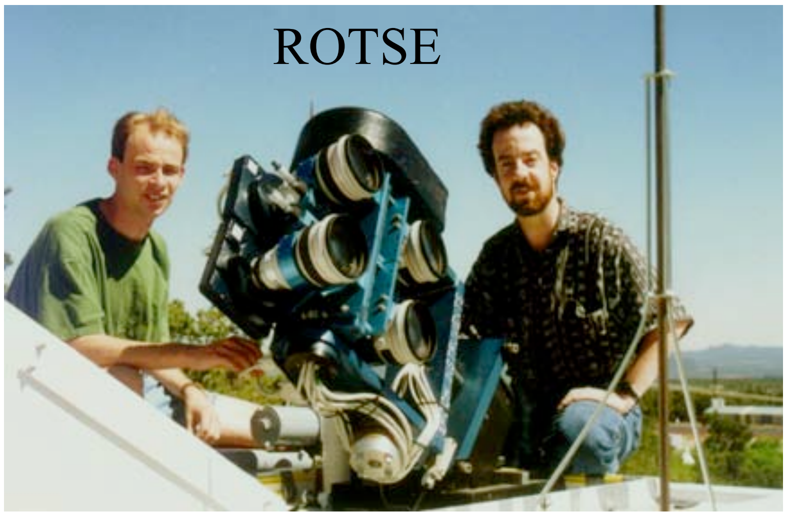
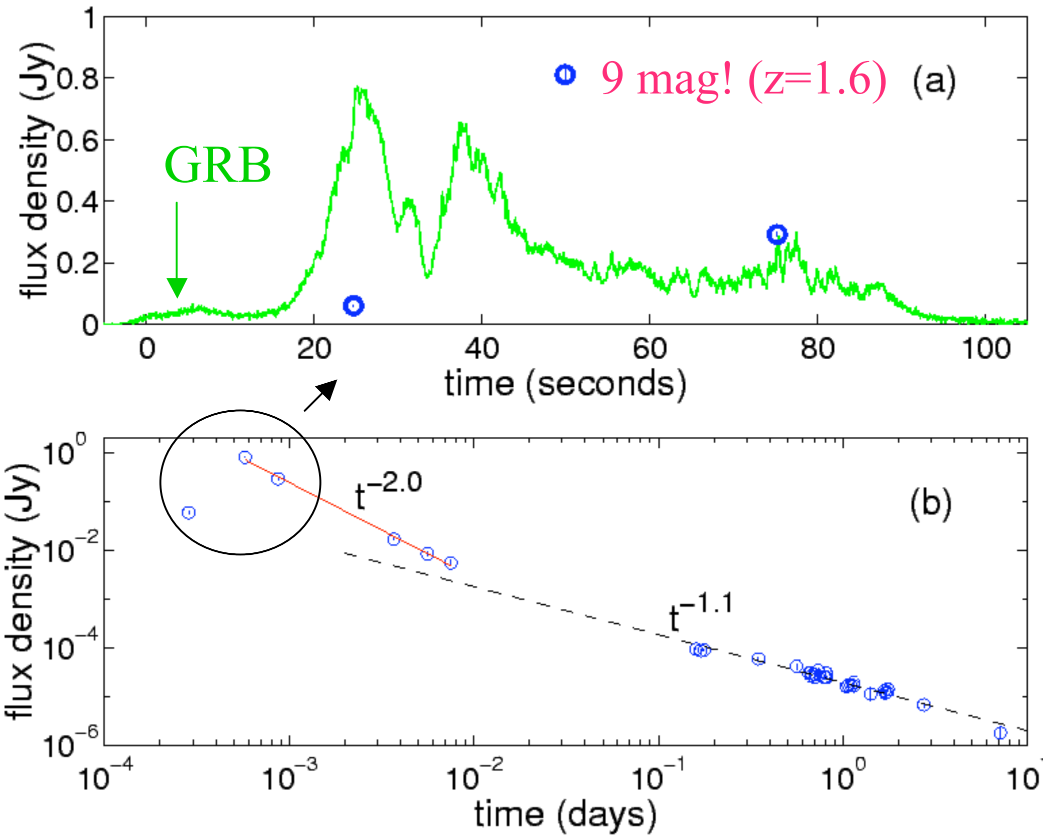
Optical Flash : GRB 990123

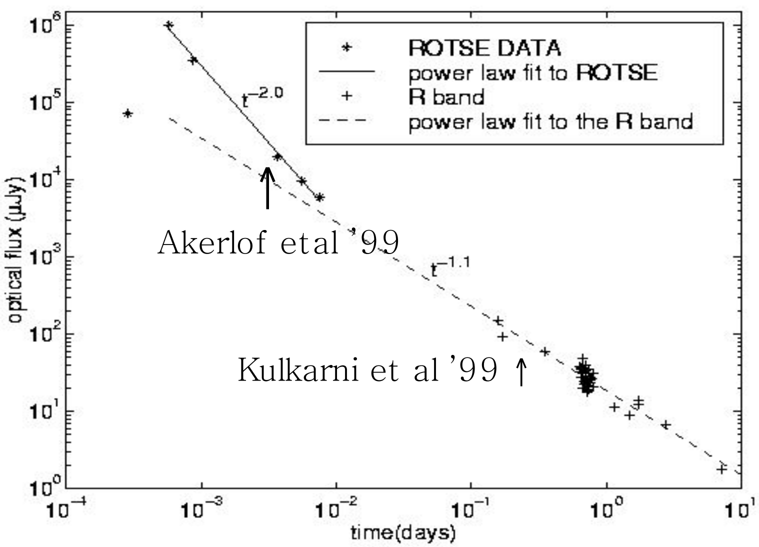


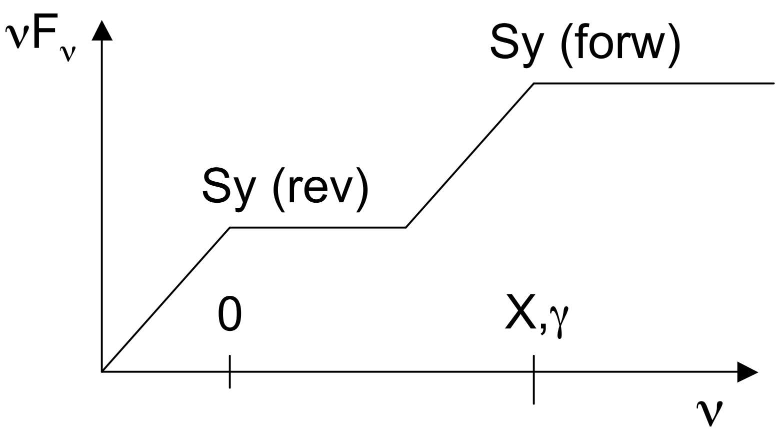


Reverse shock can produce a prompt (minutes) and bright (m_v>9) optical flash

(Akerlof et al. 1999; Meszaros & Rees 1997; Sari & Piran 1999; Kobayashi 2000)

Prompt Optical Flashes





- **GRB 990123** ⟶ bright (9^{th} mag) **prompt opt. transient** (Akerlof etal 99)
  – 1st 10 min: decay steeper than forw. shock
- Interpreted as **reverse external shock**
- (pred : Mészáros&Rees '97)
- **99-02**: **Great Desert:** **Lack of flashes**, **upper limits m_v~12-15**
- **but: New** generation robotic tels: **ROTSE III, Super-LOTIS, RAPTOR, KAIT, TAROT, NEAT, Faulkes, REM**; etc
- ⟶ **new** prompt optical flashes: **GRB 021004, 021211:** similar to GRB 990123
- ⟶ **new "semi- prompt"** flashes, (**ROTSE IIIa** (AU), **ROTSE IIIb** (TX)):
  GRB 030418, 30723 : ≠ from GRB 990123 !
  → t >211, 50 s resp, see f**orw**. shock only?
  steep rise (ascribed to dusty stell. wind)
  m_R ~ 17 at t~ 30 min, then PL -1.35 decay
  (Rykoff etal astro-ph/0310501)

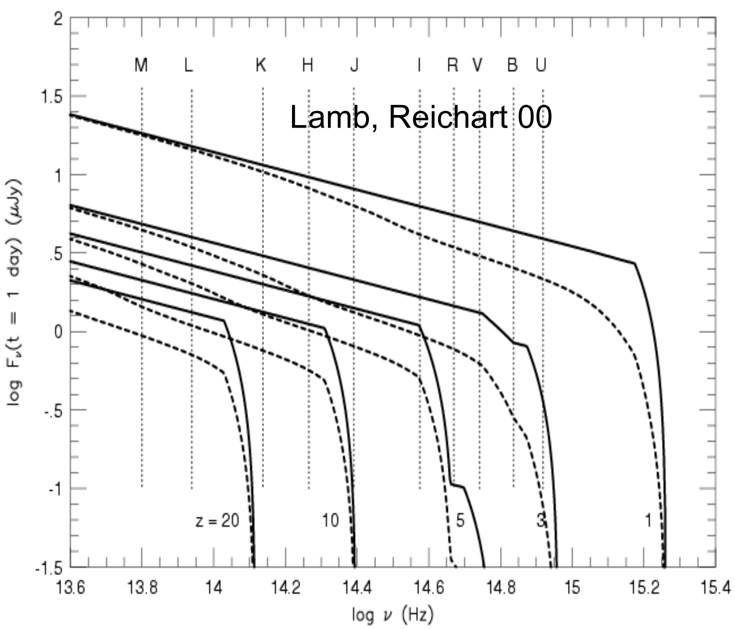
Cosmology with GRBs?

High-z GRB distance measures

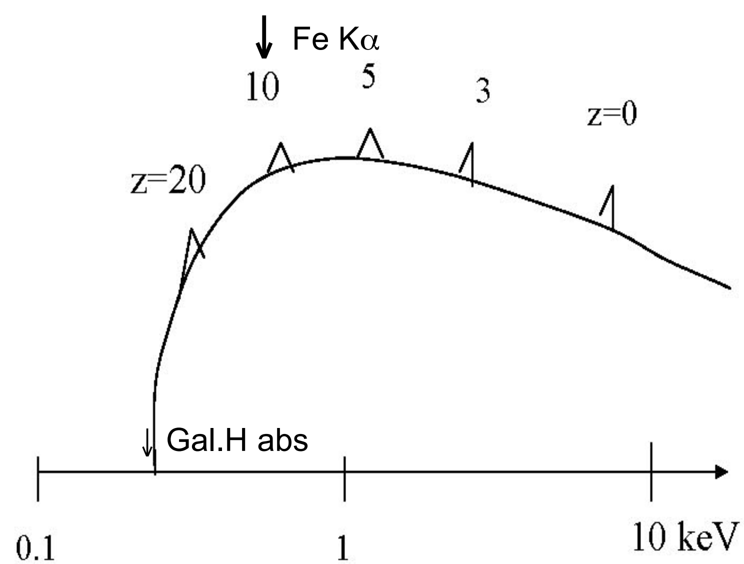
•Positive K-correction:
 → flux ~ constant at zτ5
•Optical/UV: Ly α cutoff → redshift out to z<5 for Swift
•Forward shock exp. fluxes↓

•XR cont: detect with Swift for z< 20 @ t < 1 dy
•Fe Kα XR line unabsorbed by gal. for zδ20
•Swift det. Fe Kα to z<3 @ t<3 hrs , 3σ level
•XMM det. Fe Kα to z<15 @ t<1day, 3σ level

Meszaros, Rees 03 ApJ 591, L91



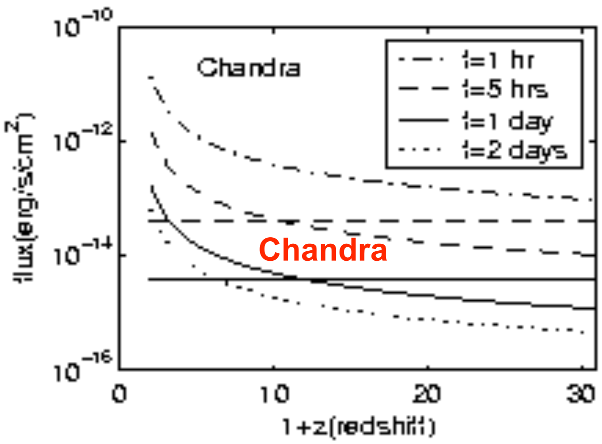
O/IR

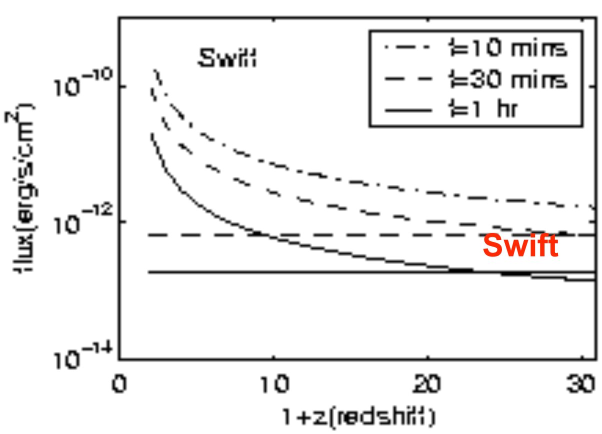


XR

IR & XR
hi-z detectability

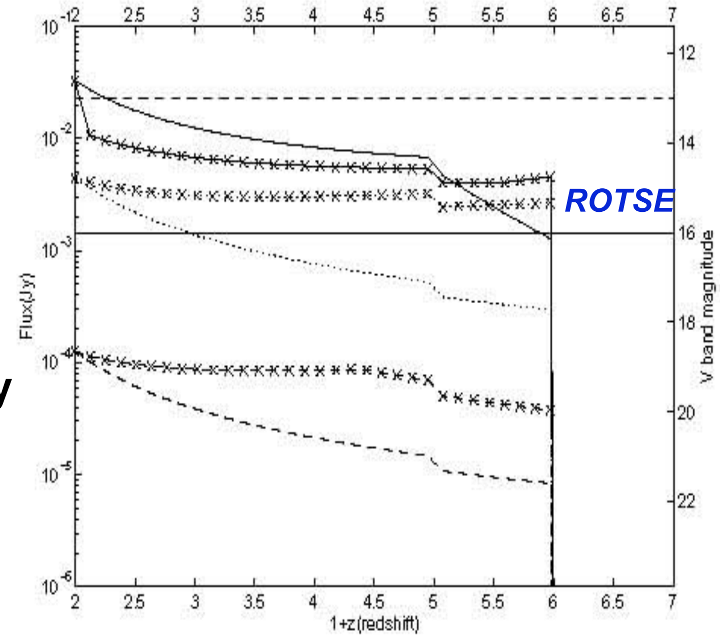
XR detectability ↓



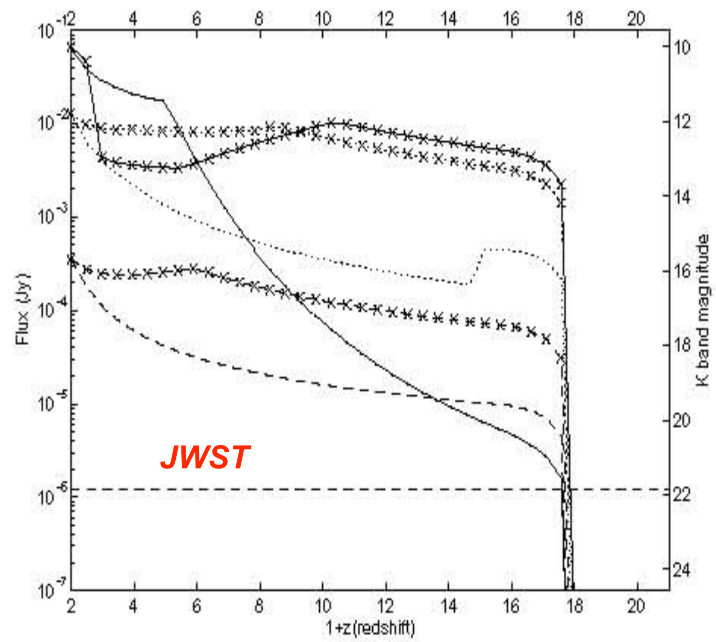


O/IR detectability

V-band



K-band



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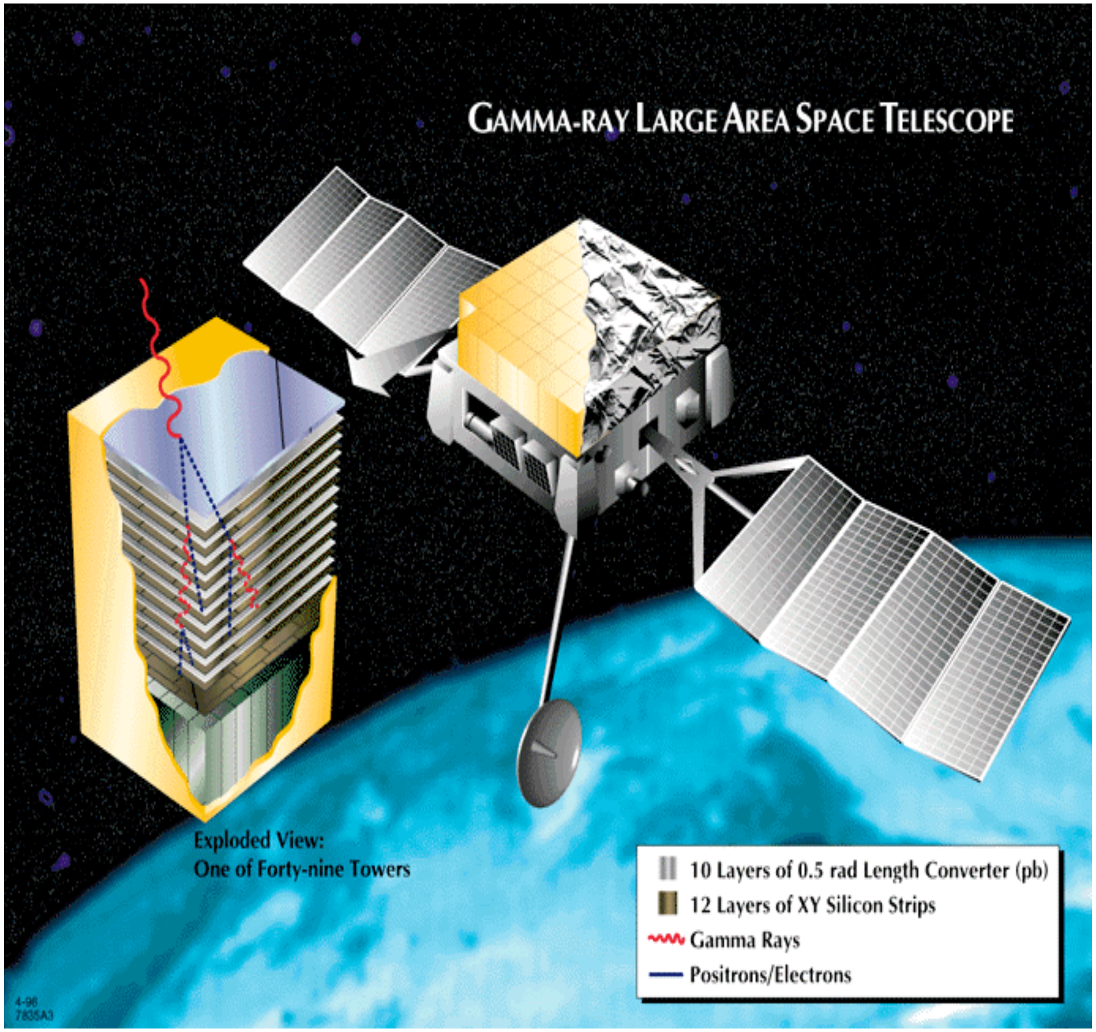
GLAST : LAT (Stanford +)



- LAT: launch exp ’07
  Delta II, 2-300 GRB/2yr
- Pair-conv.mod+calor.
- 20 MeV-300 GeV,
  $\Delta E/E \sim 10\%$@1 GeV
- fov=2.5 sr (2xEgret), $\theta \sim 30'' - 5'$ (10 GeV)
- Sens $\sim 2.10^{-9}$ ph/cm^2/s
  (2 yr; > 50xEgret)
- 2.5 ton, 518 W
- Also on GLAST: GBM
  (0.2 keV - 20 MeV, c.f. BATSE)

$p,\gamma \rightarrow$ UHE ν,γ

- If protons present in (baryonic) jet $\rightarrow p^+$ Fermi accelerated (as are e^-)
- $p,\gamma \rightarrow \pi^{\pm} \rightarrow \mu^{\pm}, \nu_\mu \rightarrow e^{\pm}, \nu_e, \nu_\mu$ (Δ-res.: $E_p E_\gamma \sim 0.3$ GeV^2 in jet frame)

  $\rightarrow$ **$E_{\nu,br} \sim 10^{14}$ eV** for MeV γs (int. shock)

  $\rightarrow$ **$E_{\nu,br} \sim 10^{18}$ eV** for 100 eV γs (ext. rev. sh.) **$\rightarrow$ICECUBE**
- $\rightarrow \pi^0 \rightarrow 2\gamma \rightarrow$ $\gamma\gamma$ cascade **$\rightarrow$ GLAST, ACTs..**

(Waxman-Bahcall 1997;99; Boettcher-Dermer 1998; 00;)

- Test hadronic content of jets (are they pure MHD/$e^{\pm}$, or baryonic …?)
- Test acceleration physics (injection effic., **ε_e, ε_B..**)
- Test scattering length (magnetic inhomog. scale?..or non-Fermi?..)
- Test shock radius: $\gamma\gamma$ cascade cut-off:

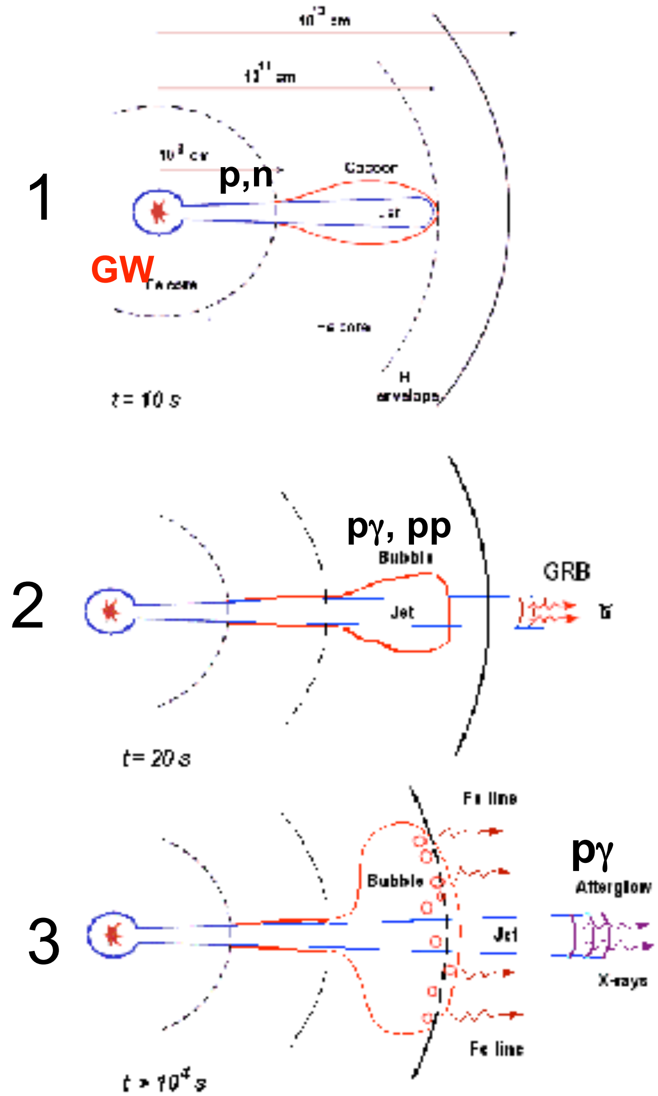
  $\varepsilon_\gamma <$ GeV (internal shock) ; $\varepsilon_\gamma <$ TeV (ext shock/IGM)

  Different $\gamma\gamma$ cut-off due to $\neq$ compactness param. ($\tau_{\gamma\gamma}$, R_{sh})

$\longrightarrow$ **photon cut-off: diagnostic for int. vs. ext-rev shock**

UHE ν (&γ) in GRB

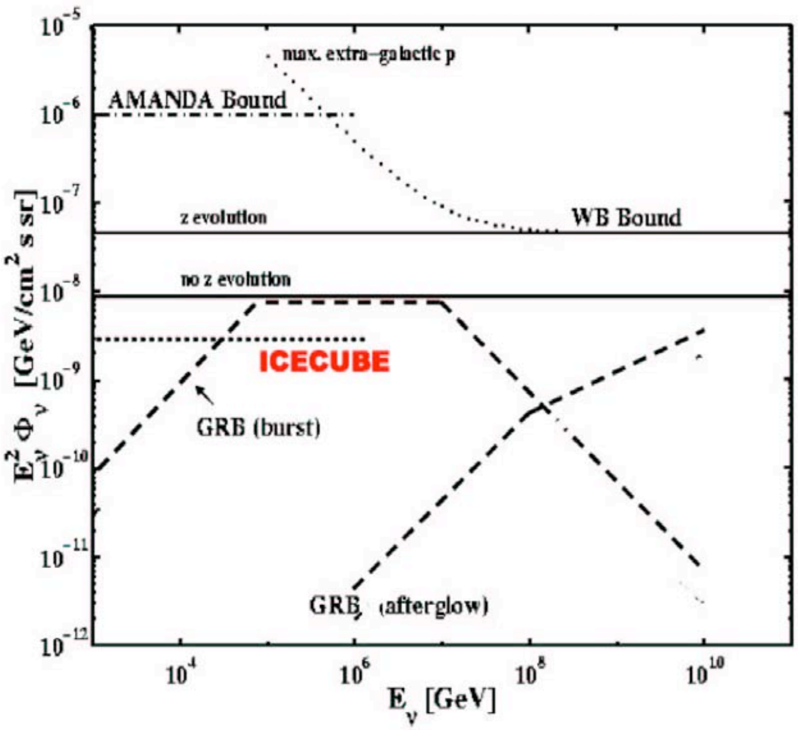
4 possible collapsar-jet sites



- 0) at collapse, make GW + thermal νs
- 1) If jet outflow is baryonic, have p,n
  → p,n relative drift, **pp/pn** collisions
  → inelastic nuclear collisions
  → **VHEν *(GeV)***
- 2) Shocks while jet is inside ⟩ can accel. protons → **pγ, pp/pn** collisions
  → **UHEν *(TeV)***
- 3) Shocks outside ⟩ accel. protons
  → **pγ** collisions (+pp/pn - if supranova)
  → **UHECR , UHEν, UHEγ**
  (~10^{20} , 10^{14}-10^{18}, ~10^{9} eV)
- 4) ***If*** external beam dump (bin.comp., SNR..)
  → **pγ, pp** of jet protons on shell targets
  → **UHEν (> *TeV)***

Mészáros, min05

ν from pγ in internal & external shocks in GRB

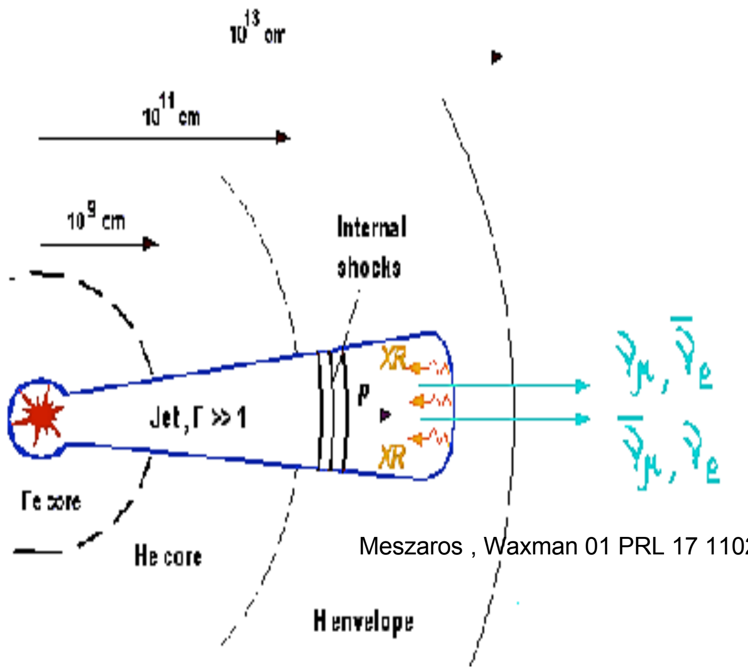


Waxman, Bahcall 97 PRL

- Shocks accel p^+ as well as $e^- \rightarrow$ p PL
- **Δ**-res.: $E'_p \, E'_\gamma \sim 0.3 \mathrm{GeV}^2$ in comoving frame, in lab:

  $\rightarrow E_p \geq 3 \mathrm{x} 10^6 \, \Gamma_2^{\,2}$ GeV

  $\rightarrow E_\nu \geq 1.5 \mathrm{x} 10^2 \, \Gamma_2^{\,2}$ TeV
- Internal shock $p\gamma_{MeV} \rightarrow \sim 100$ TeV νs
- External shock $p\gamma_{UV} \rightarrow \sim 0.1\text{-}1$ EeV ν
- Diffuse flux: det. w. km^3



Meszaros , Waxman 01 PRL 17 1102

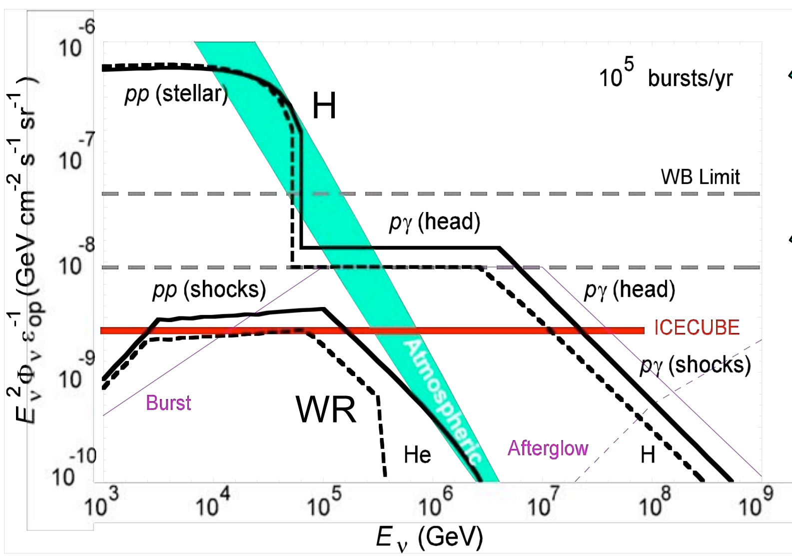
(2) Jet inside star:

GRB ν,γ Precursor

- Jet propagating through progenitor, ***BEFORE*** emerging from stellar envelope, can have int. shocks which accel. p^+ → pγ on unobserved X-rays , → $\pi^\pm$, ν
pp, pn on stellar envelope → $\pi^\pm$, ν

E_ν~ few TeV **neutrino precursor**

- **If** progenitor has $R_J \sim 10^{12}$ cm (BSG) →
Rate($\nu_{\mu, TeV}$) prec > Rate($\nu_{\mu, 100\,TeV}$)int.shock
(easier to detect in ICECUBE)
- **but**, if WR, $R_J \sim 10^{11}$ cm →
Rate($\nu_{\mu, TeV}$) prec < Rate($\nu_{\mu, 100\,TeV}$) int.shock
→ test progen. size (e.g. @ high z : popIII?)



Razzaque, PM, EW 03 PRD 68, 3OO1)

- **At jet break-out: → photon flashes**

(Ramirez-Ruiz, McFadyen, Lazzati 02; Waxman, Mészáros 02)

i) thermal keV γ flash

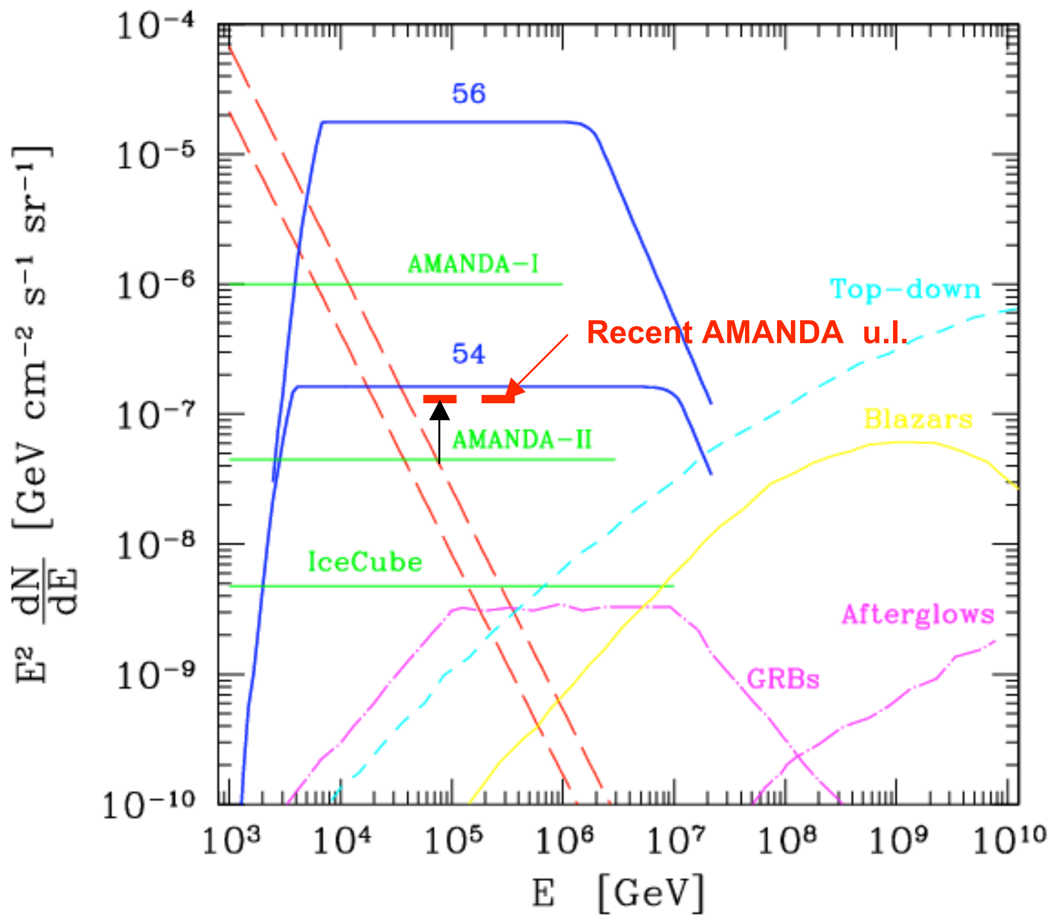
ii) non-therm.10-100 MeV γ (IC upscatt of XR)

→ precursors (δ few sec.) of "usual" MeV γ

- **Blue: ν- spectrum: E_ν ~ 100 TeV, p,γ→ π,μ,ν from shocks outside star**

Mészáros, min05

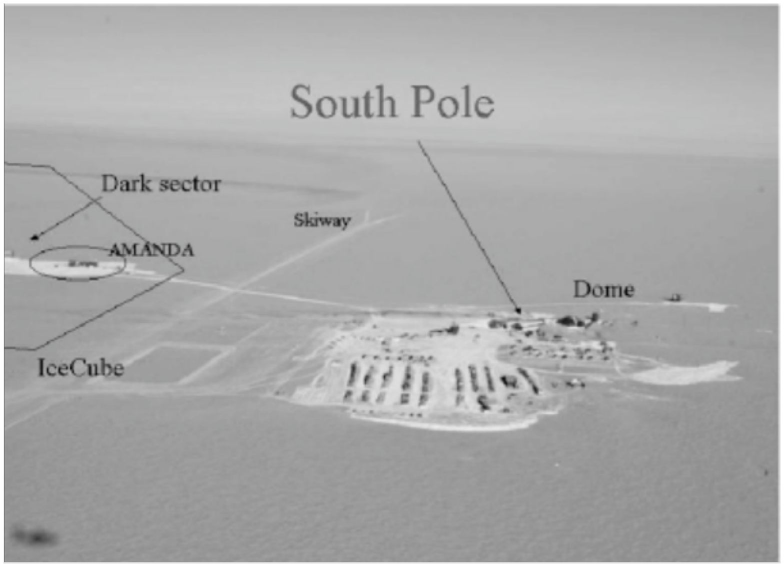
Diffuse UHE ν from pop.III



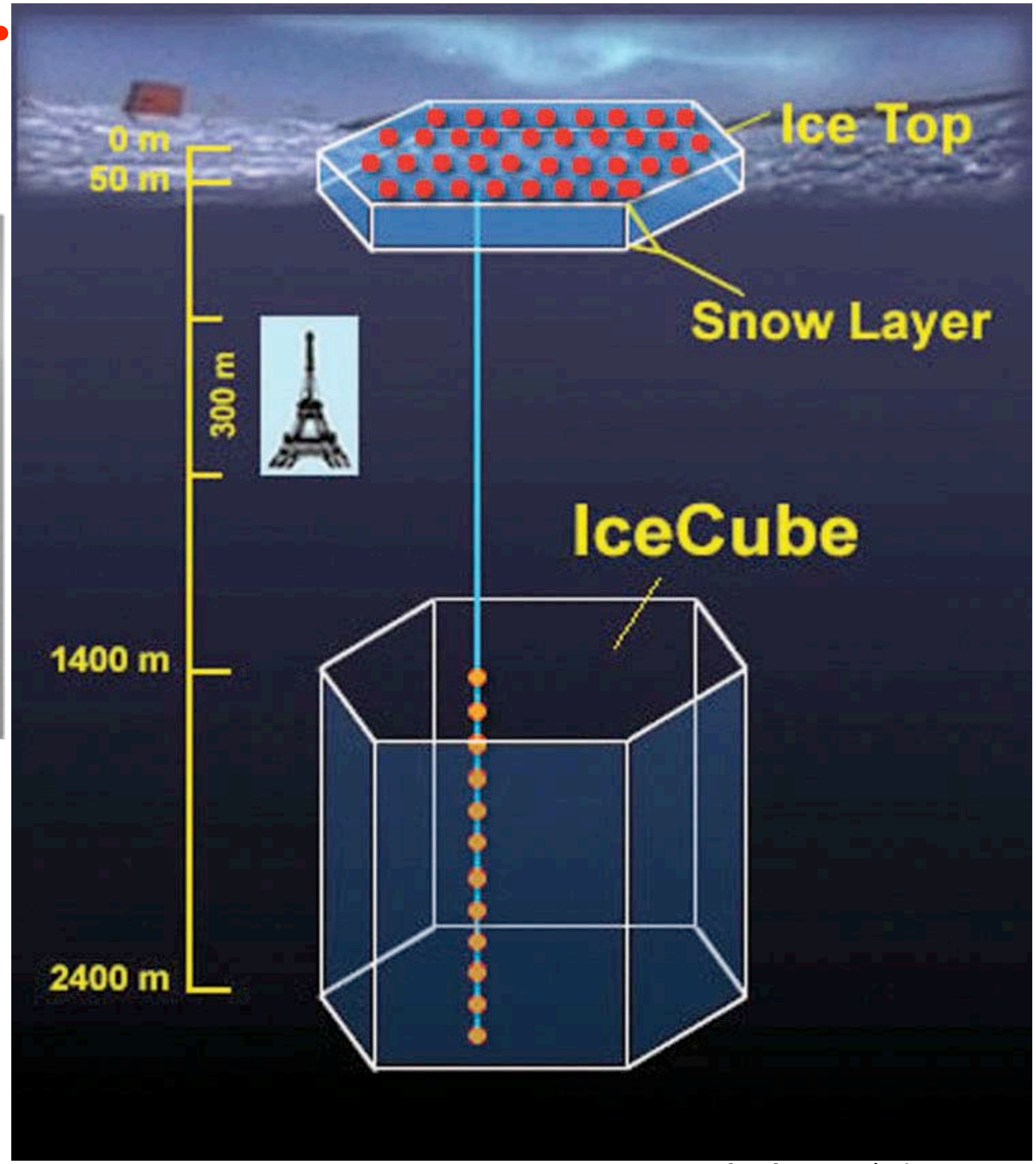
- At z~5-30(?) pop.III , $M_* \sim$ 30-300 M_{sun} core coll →BH+ accr.
- Buried jets→pγ→ ν_μ , → ν-bursts (but: dep. on stellar rot.rate)
- $E_{iso} \sim 10^{54}$-10^{56} (?) erg (dep. on BH mass, dM/dt)
- Detect high z star formation, primordial IMF
- **Recent (8/04) :** can constrain w. **AMANDA** latest results:
  → $E_{iso} \sim 10^{56}$ erg only for ≤1%,
  → $E_{iso} \geq 10^{54}$ erg for ≤ 50% !

Schneider, Guetta, Ferrara aph/0201342

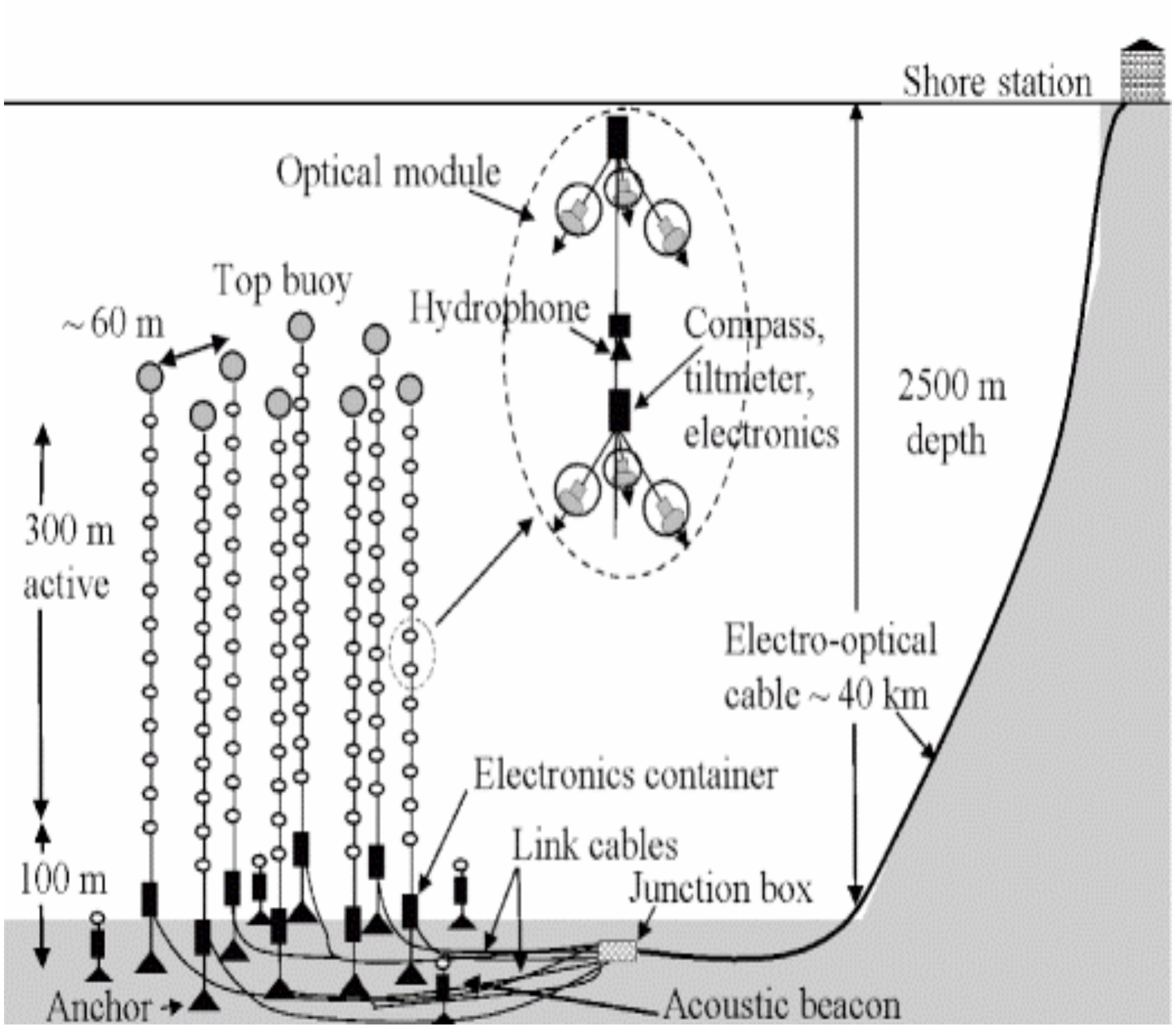
ICECUBE: km^3



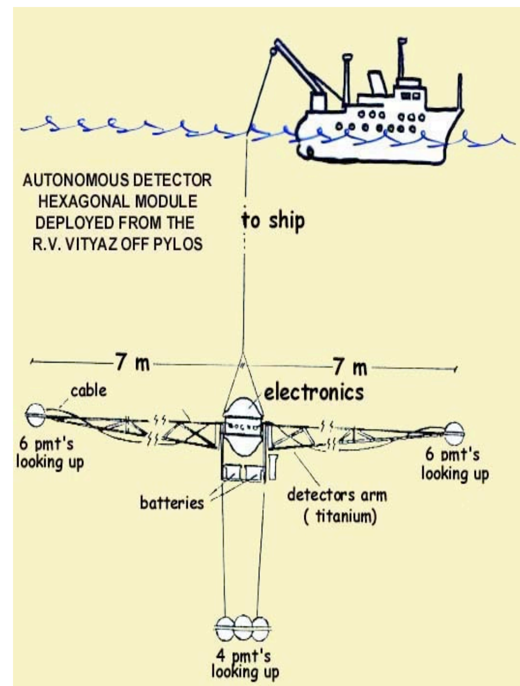
- Extension of Amanda
  0.05 km^3 $\rightarrow$ km^3=1Gton
- Amanda gave proof of concept, useful science results.
- IceCube funding in place, 1st new string beyond Amanda already installed.
- Completion by 2010



KM3NeT



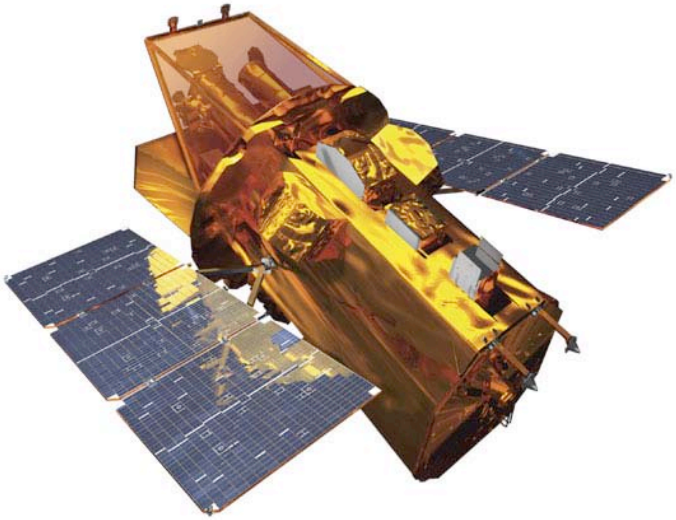
- EU collaboration
- Site :Mediterranean Sea
- based on: **NESTOR, NEMO, ANTARES**



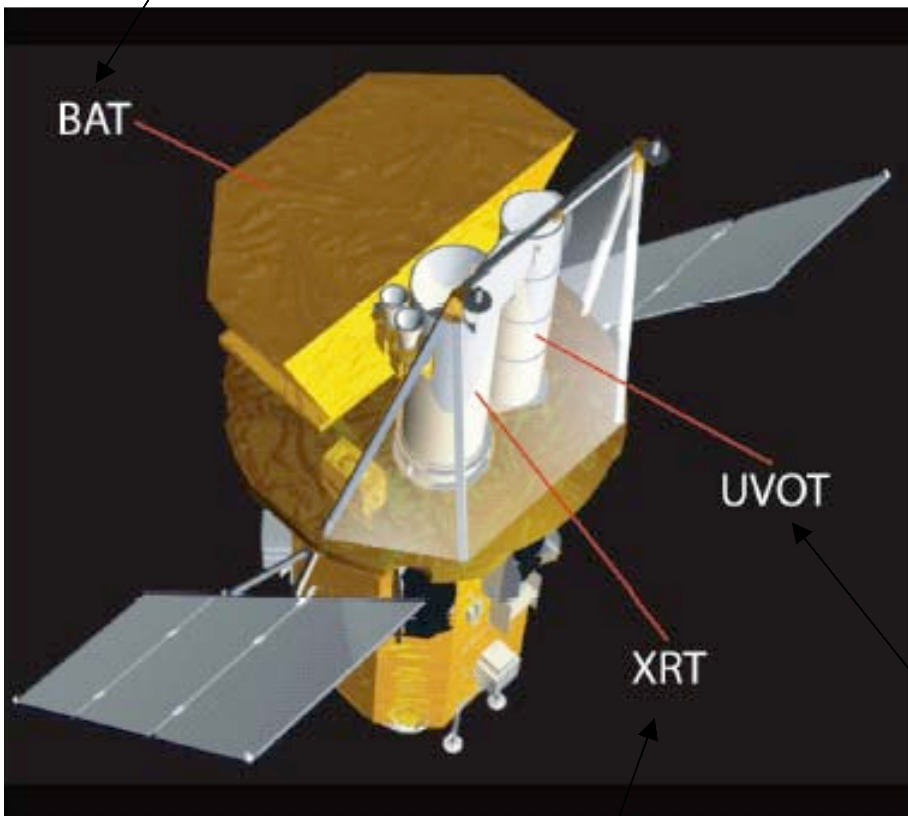
- Km^3 water Cherenkov detector
- Deployment approx. 2010
- Complement ICECUBE: $\lambda_{sc,abs}$~(100,10) $H_2 0$, $\lambda_{sc,abs}$~(20,100) Ice
- Northern site: at lower E , complementary sky coverage

SWIFT

Blasted off on 11/20/2004



BAT: Energy Range: 15-150kev
FoV: 2.0 sr
Burst Detection Rate: 100 bursts/yr



Three instruments

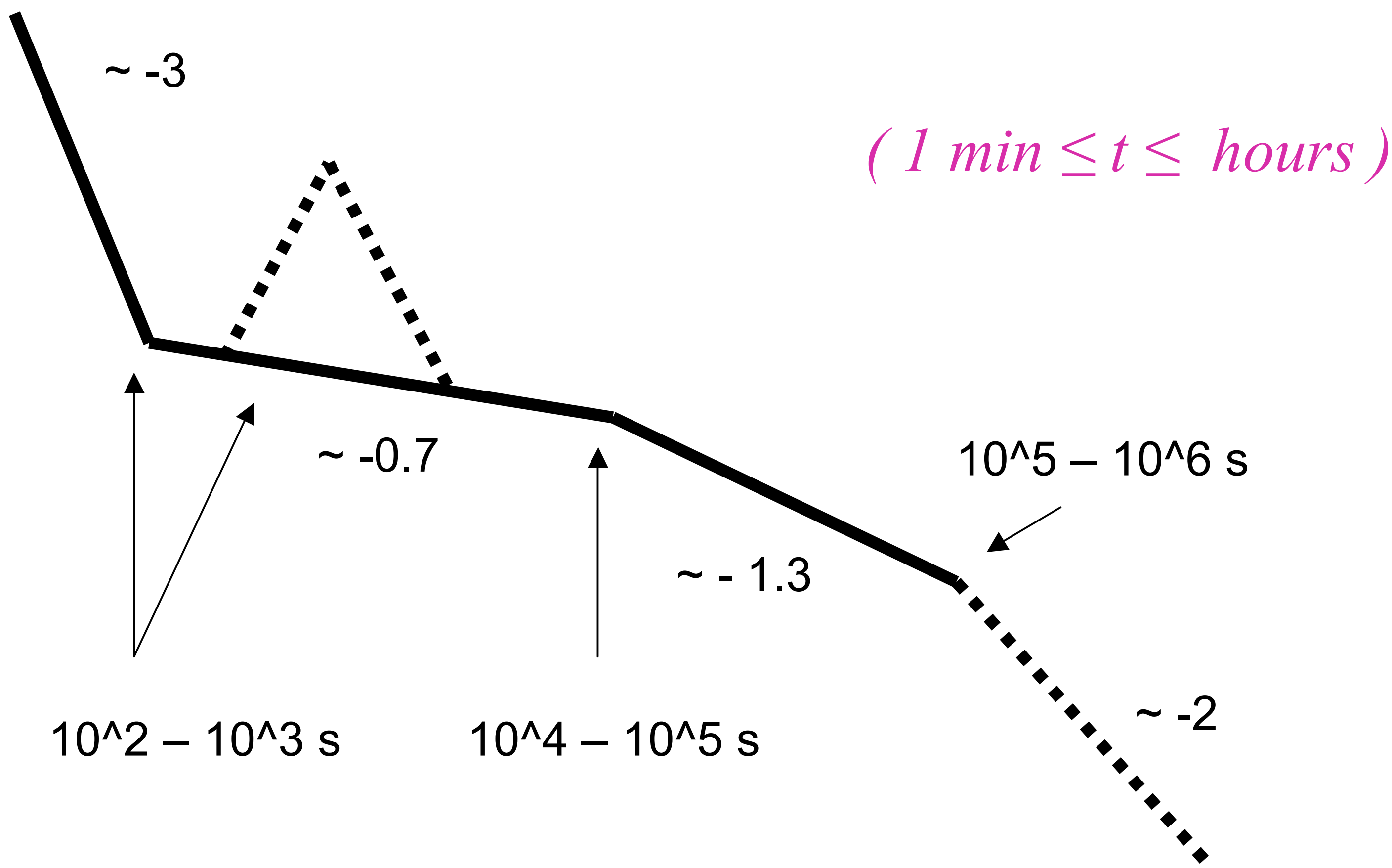
Gamma-ray, X-ray and optical/UV

Slew time: 20-70 s !

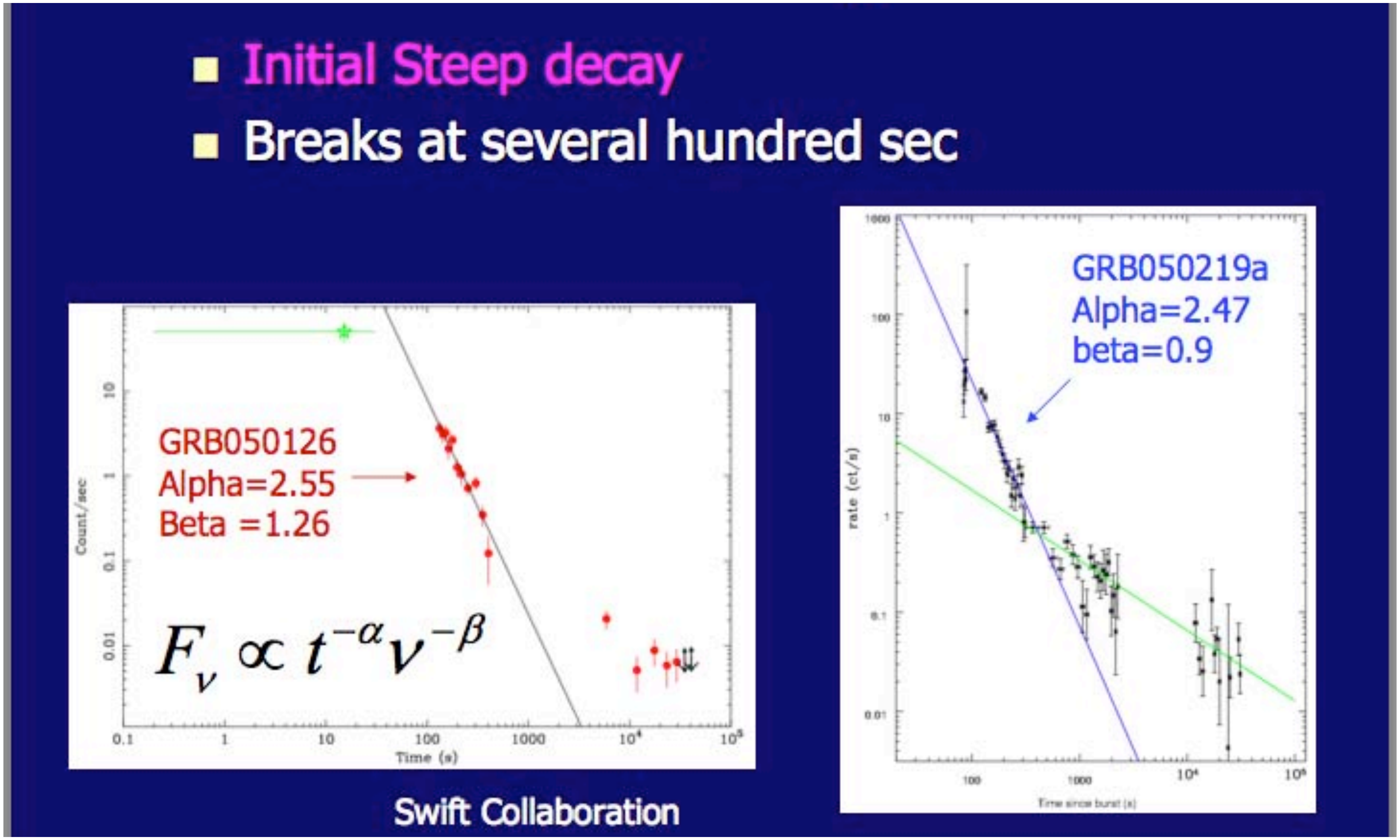
UVOT: Wavelength Range: 170-650nm

XRT: Energy Range: 0.2-10 keV

New features seen by Swift : A Generic X-ray Lightcurve?

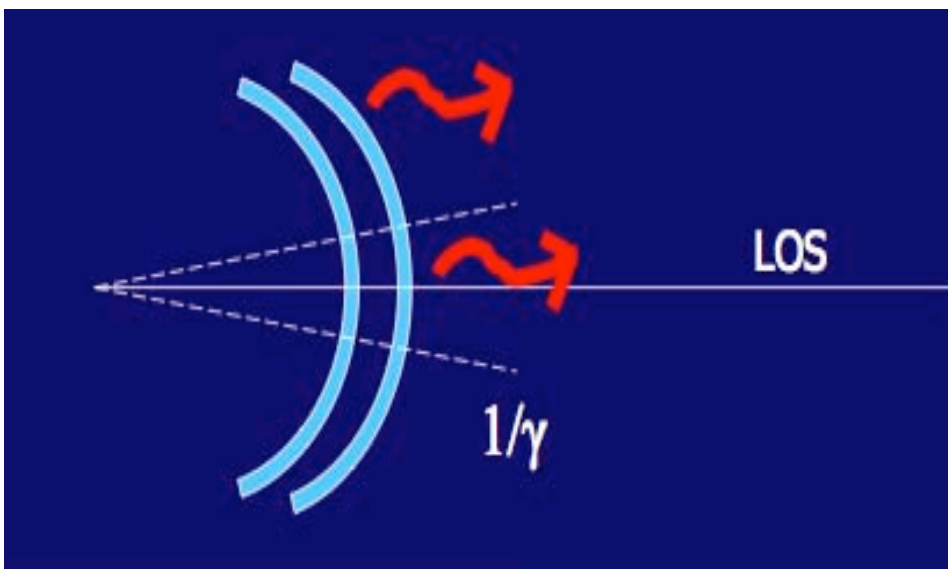


Mészáros, min05



- Small angle jet break? (patchy jet?)
- Thermal cocoon expansion?
- Photospheric emission?
- High latitude emission (“curvature effect”)?

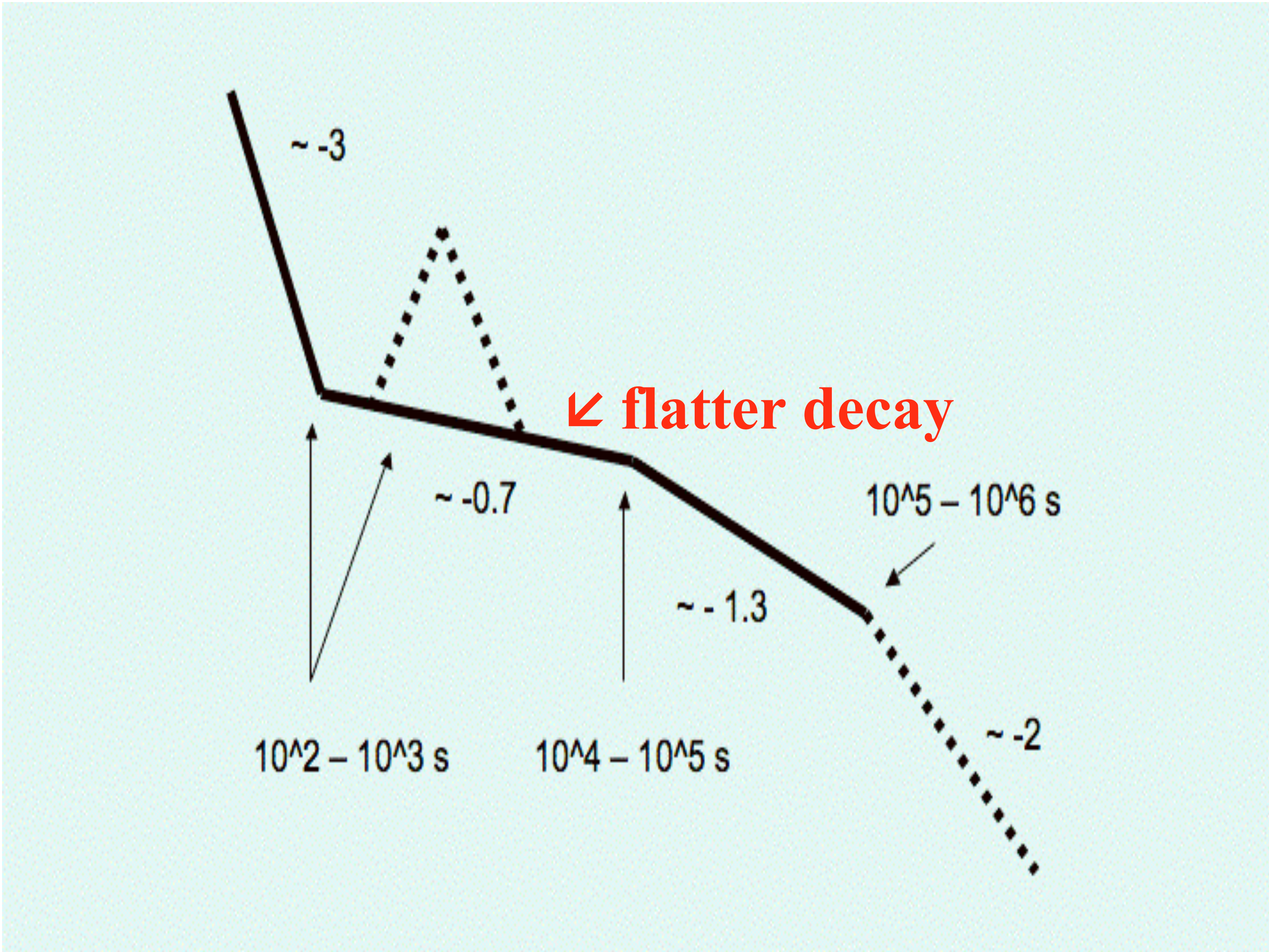
Initial rapid decay: **High latitude emission**



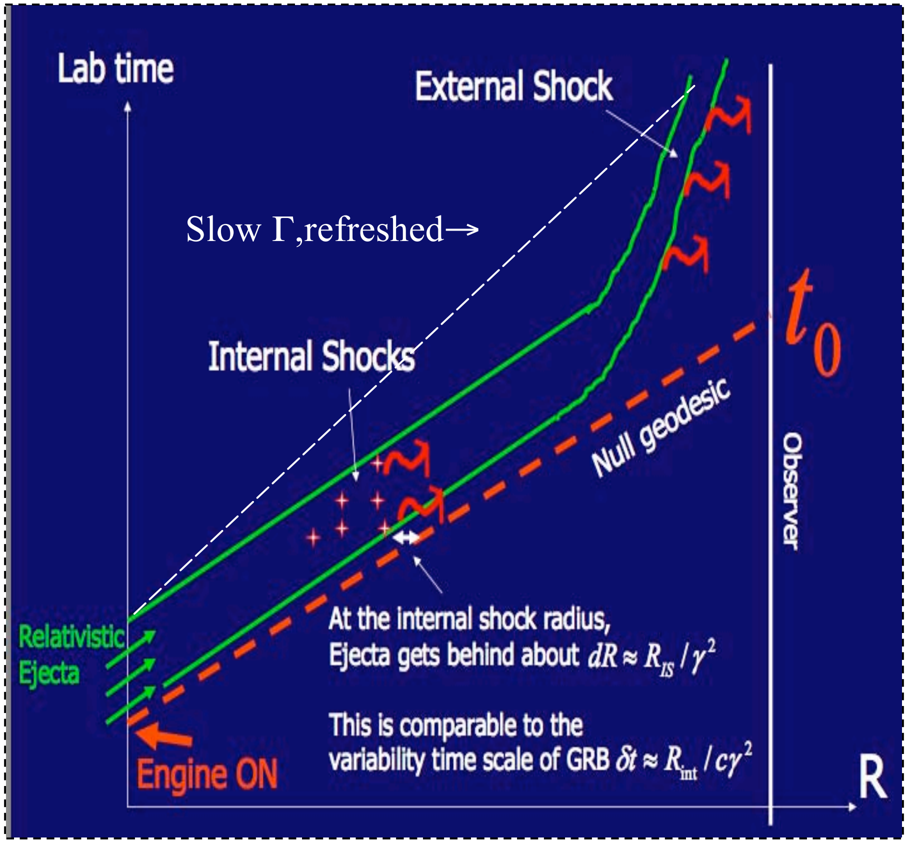
- Might be patchy shell (mini- jet break) - but α-β relation does not generally fit (where $F_\nu \sim t^{-\alpha}\,\nu^{-\beta}$)
- More likely : drop is due to **tail end of GRB** (high latitude emission) : rad'n from angles $\boldsymbol{\theta > \Gamma^{-1}}$ arrives at time $\mathbf{t \sim R\theta^2/2c}$ later than from θ~0, and is softer by $D \sim t^{-1}$; expect

$\alpha = 2 + \beta$, ~ OK

Mészáros, min05



Mészáros, min05



Flatter decay $(0.2 \leq \alpha \leq 1)$

- Probably due to "refreshed shocks",

due ***either*** to:

- ***Long*** duration ejection

$(t \sim t_{flat})$; ***or***

- ***Short*** ejection $(t \sim t_\gamma)$, but with range of Γ, e.g. $M(\Gamma) \sim \Gamma^{-s}$, $E(\Gamma) \sim \Gamma^{-s+1}$,

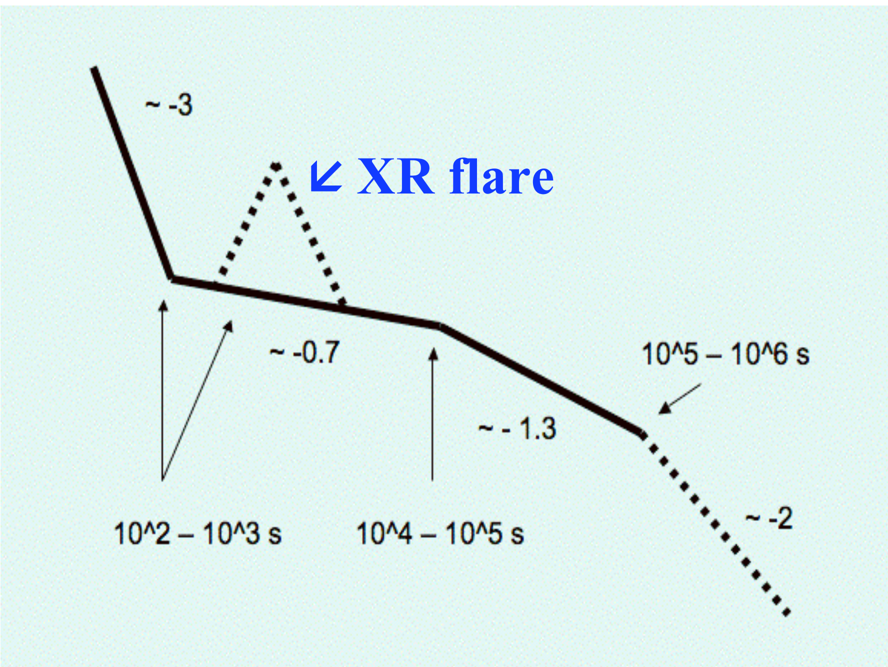
for $\rho \sim r^{-g}$ ext. medium :

FS: $\alpha=[-4-4s+g+sg+\beta(24-7g+sg)]/[2(7+s-2g)]$

RS: $\alpha=[8-4s-3g+sg+\beta(12-3g+sg)]/[2(7+s-2g)]$

Rees+PM, 98 ApJ 496, L1 ; Sari +PM, 00, ApJ 535, L33 ; Zhang +PM 01, ApJ 552, L35

XR Flares in GRB late XR l.c.



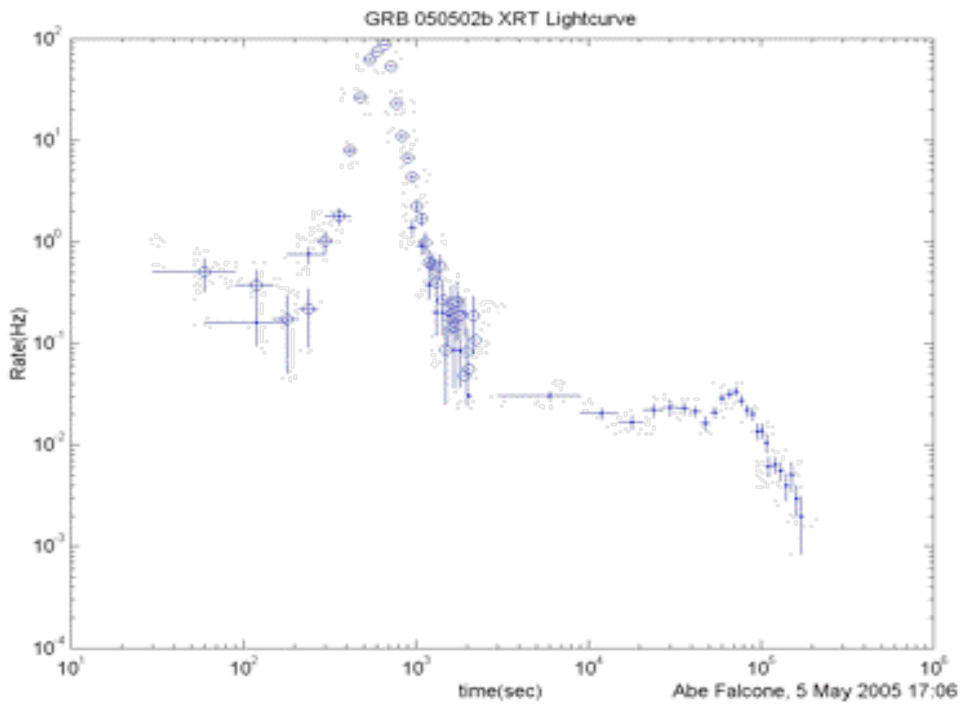
Could be due to:

- Refreshed shocks
- IC from reverse shock
- External density bumps
- 2- or multiple comp. jet
- Continued ctrl. engine activity
- ….
- Main constraints: very (to extremely) sharp rise and decline ($t^{\pm 3} \longleftrightarrow t^{\pm 6}$)

Continued central engine activity?

e.g.:

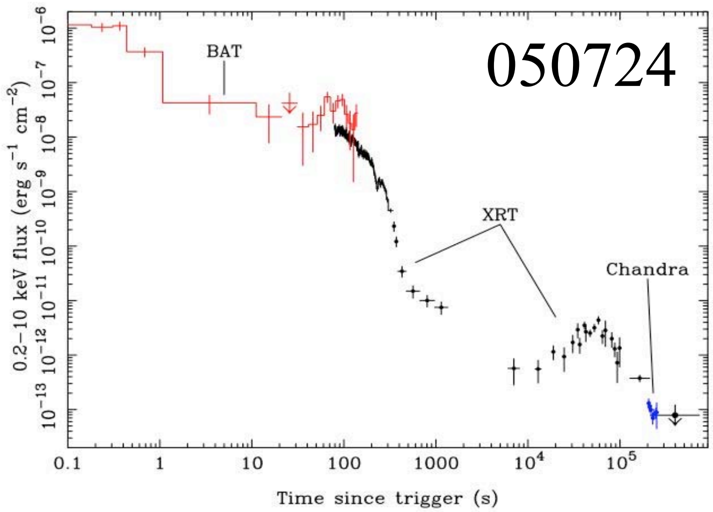
Late Internal Shocks

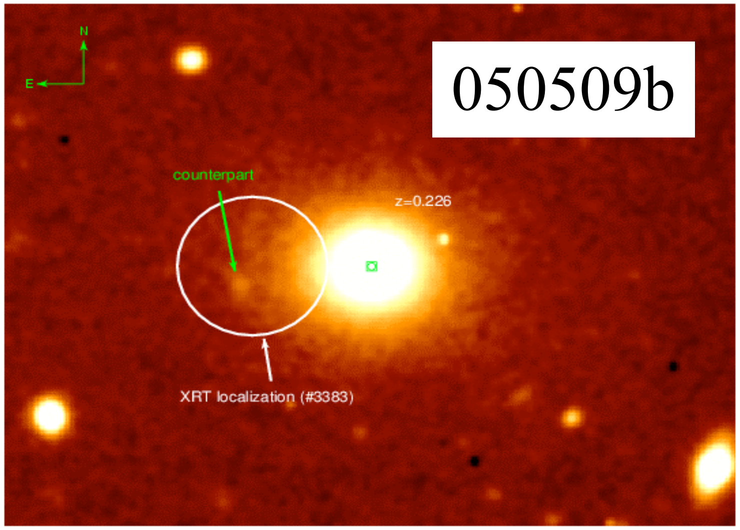


- Rapid falling rules out density bump, refreshed shocks & two-component models
- A factor of 500 re-brightening is difficult for the SSC model
- The central engine is active again hundreds of seconds later!
- Implications for XRFs.

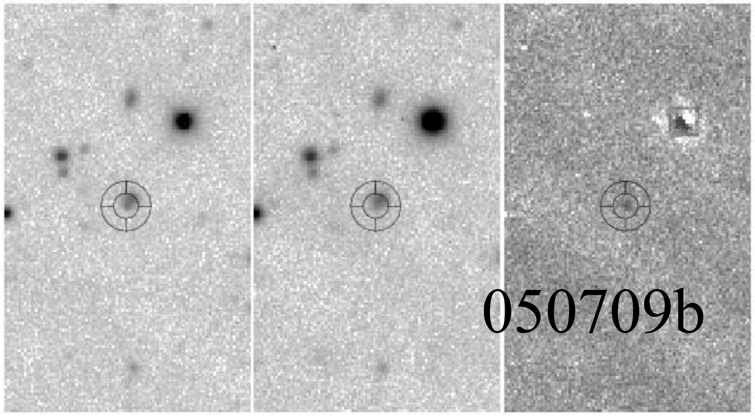
Burrows et al., 2005
Zhang et al. 2005

Short Bursts

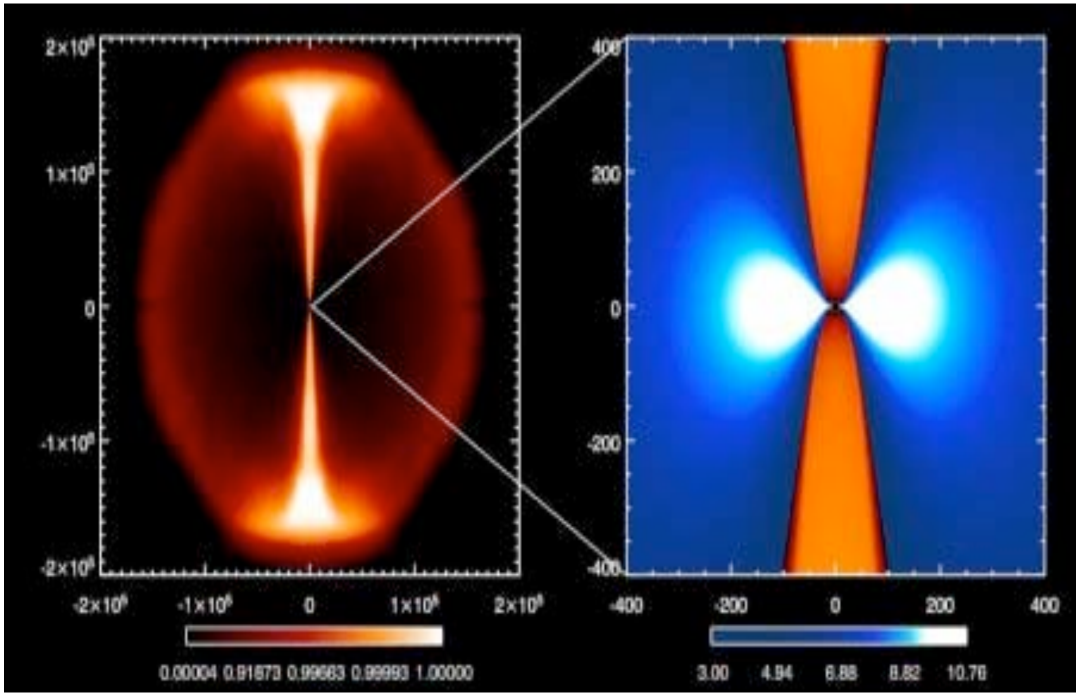




- Hosts: **E , Irr , SFR**
  (compat. W. NS merg,
  but: some SGR, other?)
- Redshift : < 0.1 to > 0.7
- XR, OT, RT: yes (mostly)
- XR l.c.: similar to long bursts?
  (XR bumps too- late engine?)



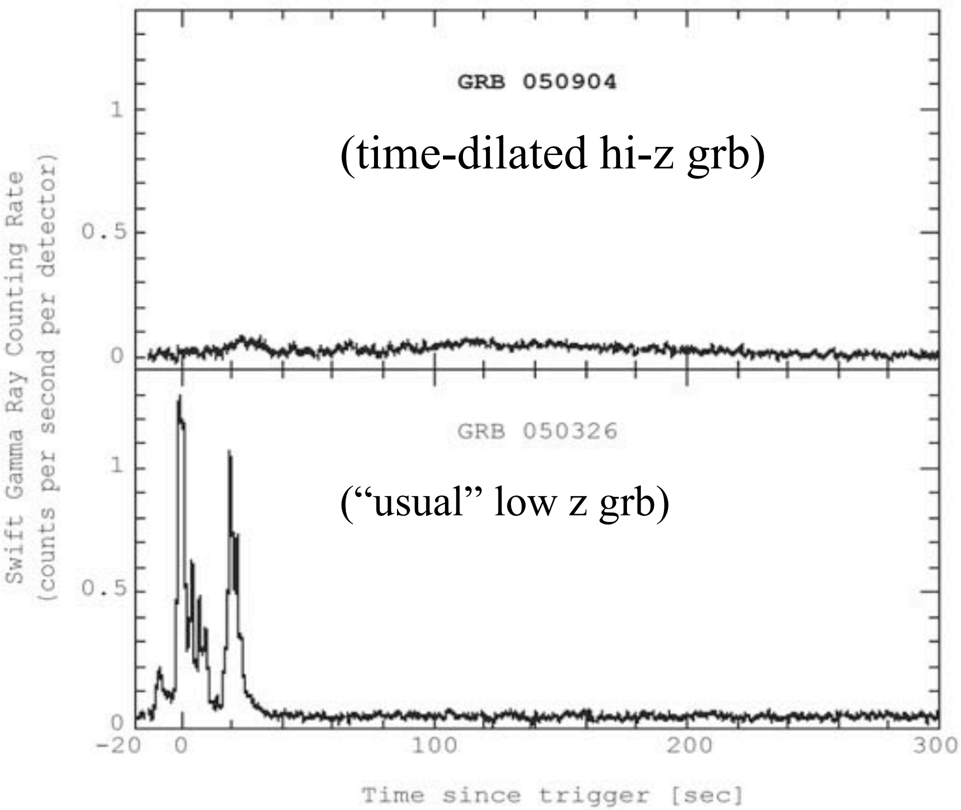
Mészáros, min05

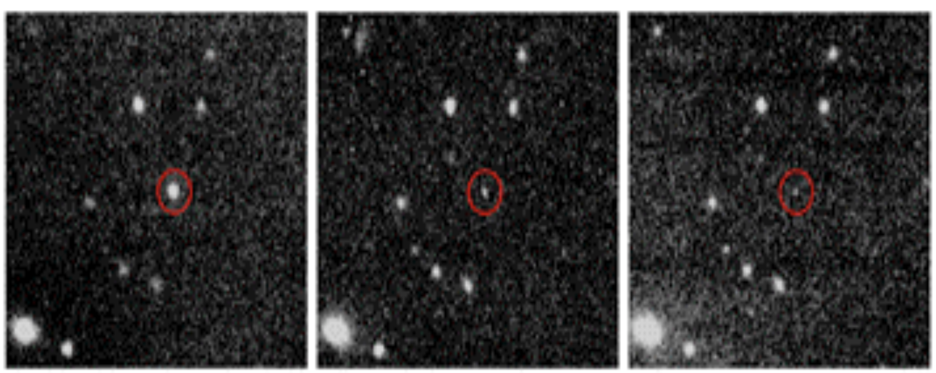


Short burst paradigm: ***NS-NS*****, or** ***NS-BH*** **merger**

- ***NS-NS merger movie***
- ***NS-BH merger movie***

Mészáros, min05





Time decay of OT, t →

Most distant

long burst from Swift

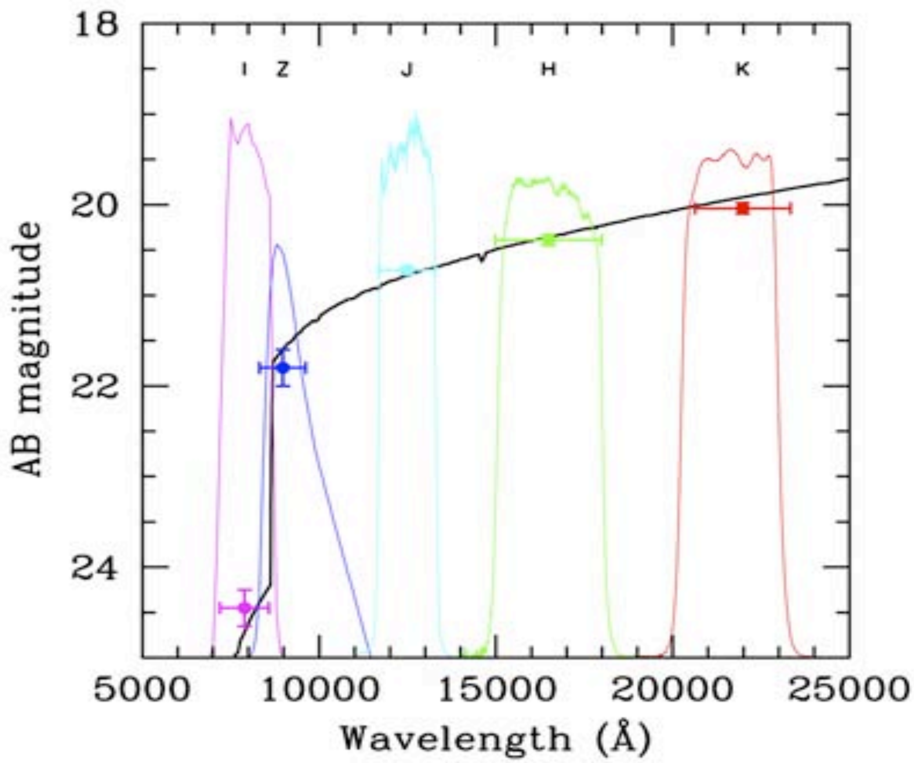
(z=6.29):

GRB050904

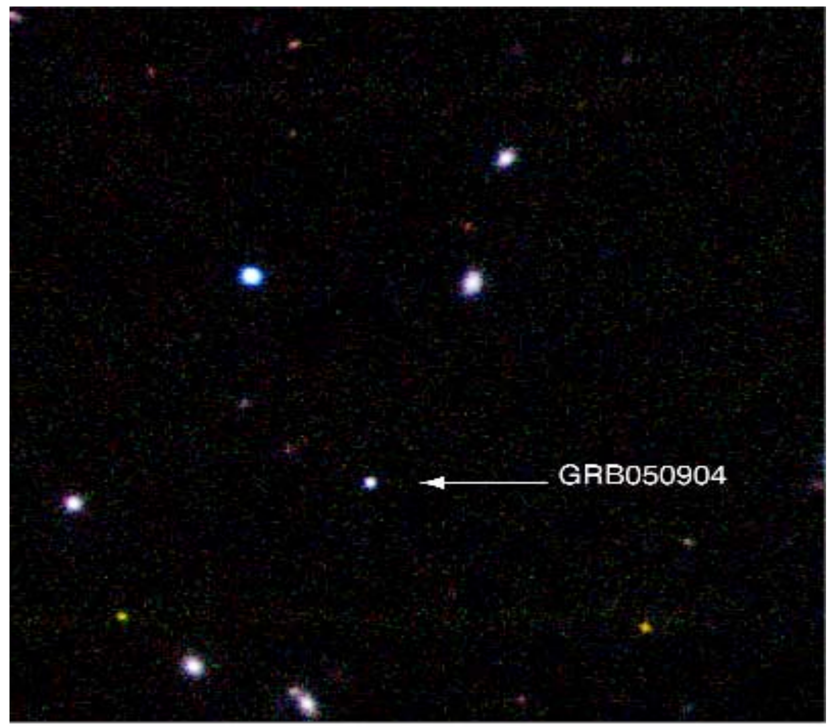
- Discovered/localized by **Swift** **BAT, XRT, UVOT**
- Prompt robotic ground I,R band **TAROT, P60** upper limits, detection J=17 mag **FUN/SOAR**

→photometric z>6

GRB 050904



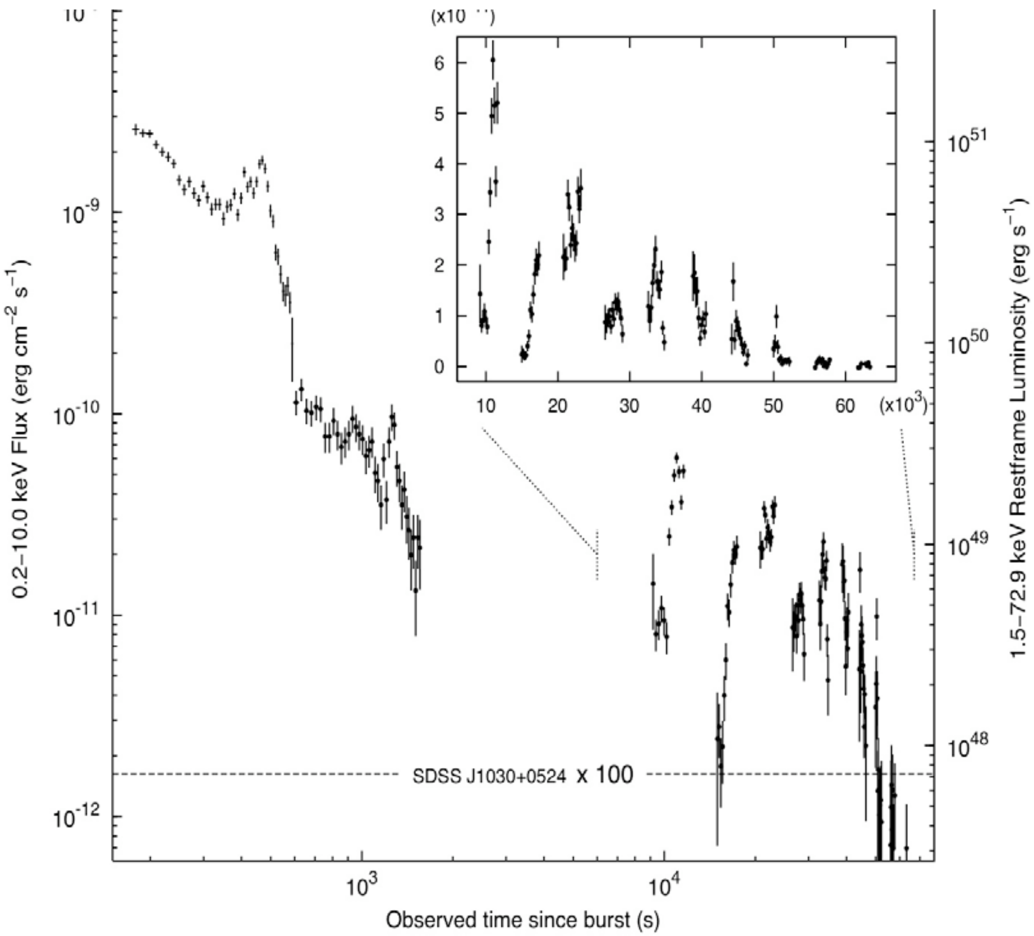
Ly α(1210 A) abs. cut-off → photometric z > 6



The Distant Gamma-Ray Burst GRB050904
(ISAAC/VLT)

and **…** ***Subaru*** 8.2m telescope **spectrum**, 3.2 days later: **z=6.29 !**

GRB 050904 as XR torch



- At high **z=6.29,** exceeded the brightest known X-ray quasar, SDSS J0130+0524 (same redshift) by up to **10^5** for days

← SDSS J0130 (multiplied by 100)

Mészáros, min05

High z GRB as warm IGM probes

- Outshine quasars at z ≥ reionization in X-rays
- For the first few days GRB050904 (z=6.3) was brighter than all known XR sources at z>4
- In first few minutes: $F_x > 10^{-9}$ erg cm^{-2} s^{-1}, i.e. $L_x \sim 10^5 - 10^6$ x brightest XR QSR @ same z
- More XR photons (~10^7) obtained by Swift in first few minutes from GRB 050904 than XMM or Chandra (with much greater area) get in 3 days from z >5 AGNs

Summary & Prospects

- GRB continuum radation (if present) detectable to z <30
- Swift is making great progress
  - doubled mean det. z to **2.4**, increased maximum z to **6.3 !**
  - elucidated the "missing time gap" afterglow behavior
  - found 5+ short GRB afterglows, leading ID of hosts and z
  - still missing: ≠short progenitors? exceed quasar z? X-ray lines?
- Uses as standard candles becoming interesting but need work
- Uses as "shine-through" O/UV/XR probes of IGM promising
- Likely to exist at pre-galactic (pop III) distances **6 < z < 10-20**..?