TeV γ's and ν's from GRB, SN and AGN

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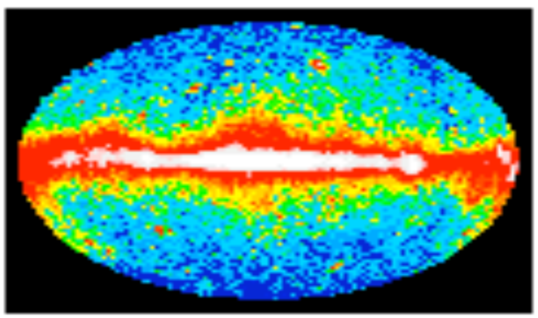
For a few seconds, a GRB dominates the gamma-ray brightness of the entire Universe



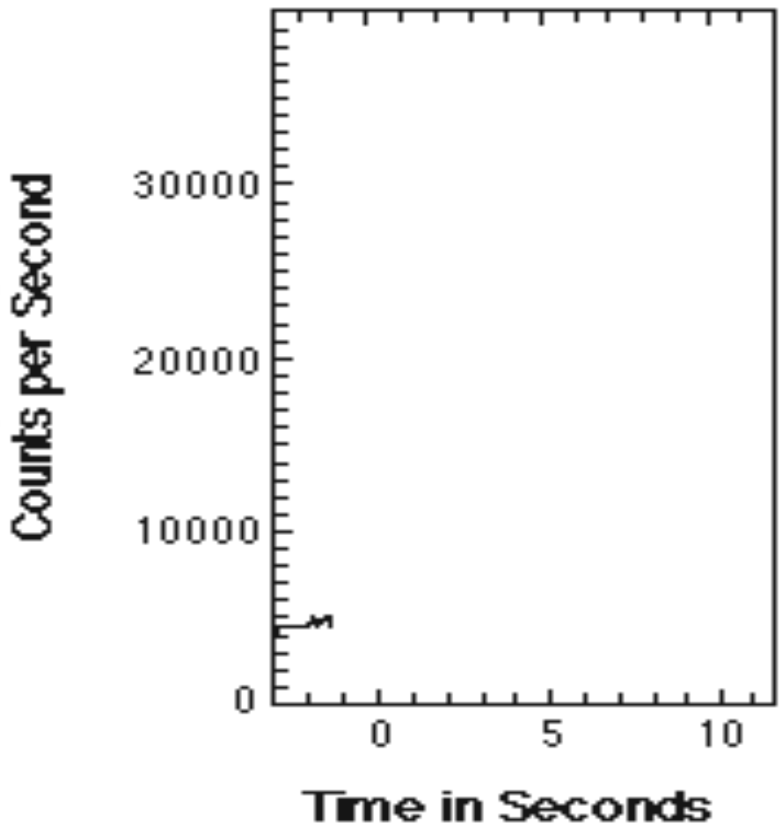
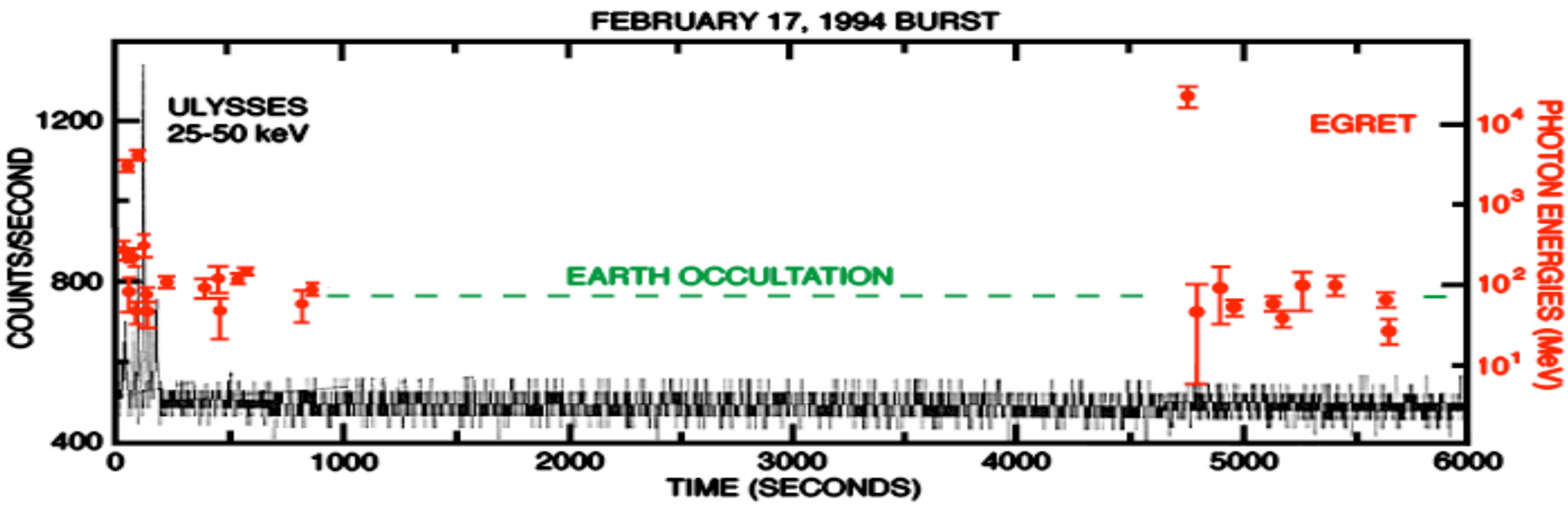
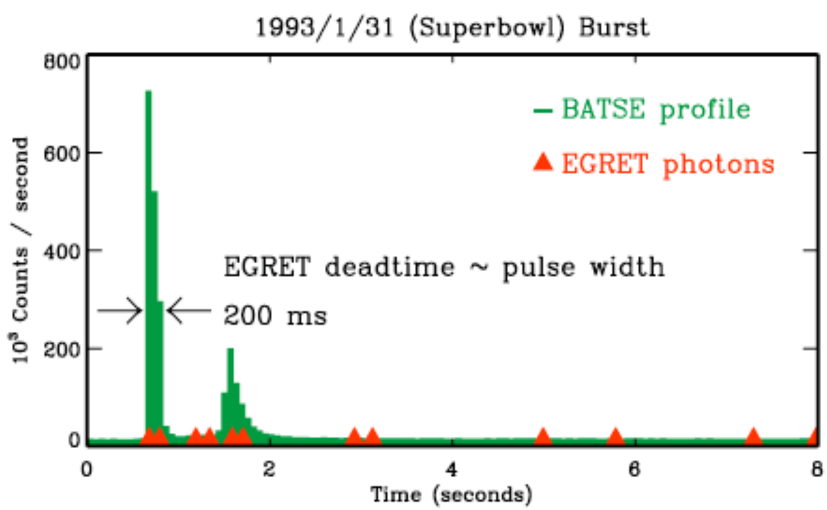


Fig. Credit: Tyce DeYoung

Two EGRET (GeV) Bursts





- >10 GeV photons can last for > 1 hr,

  start w. MeV trigger
- Considerable energy

  at 100 MeV-10 GeV

TeV GRB Detection Status

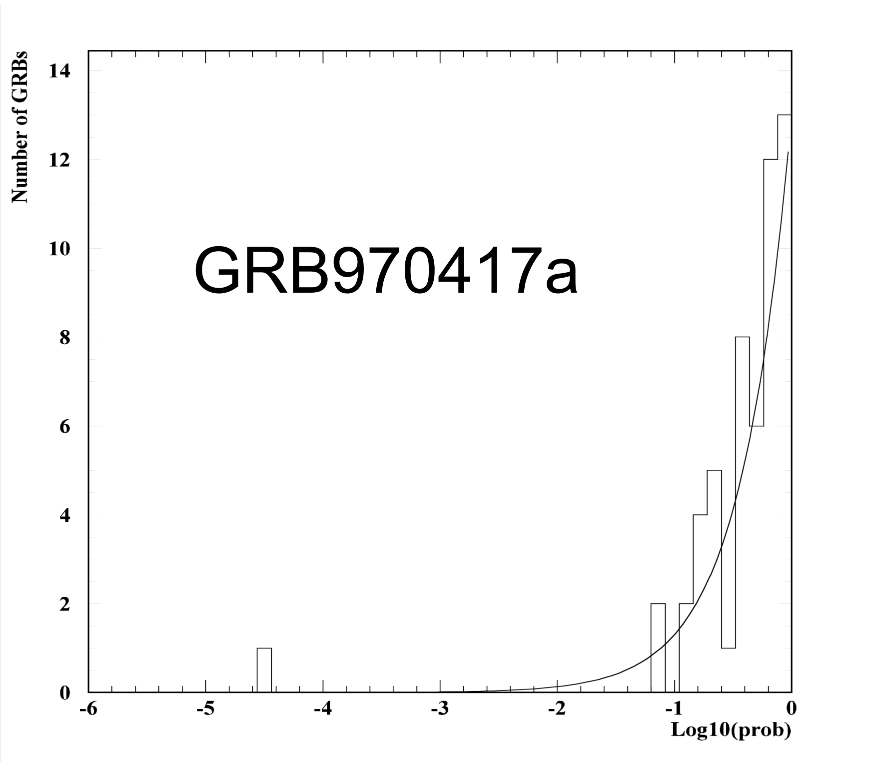


Fig. 1.— Distribution of probabilities that the observed excess no. of events at the candidate TeV position was a background fluctuation, for each of the 54 bursts. The curve indicates the expected prob. distr. for a sample drawn from background. The entry at -4.5 corresponds to GRB 970417a.

- **Milagrito** :Tentative (**3σ**) TeV detection ;

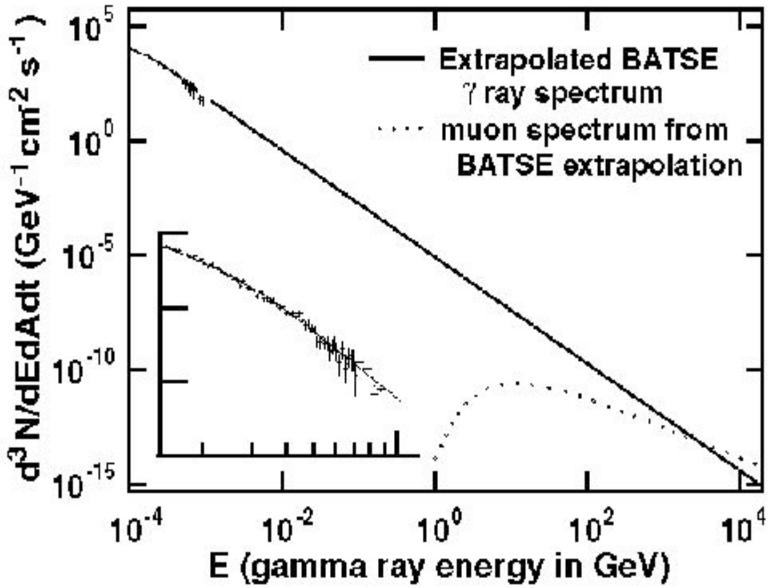
  Φ_{TeV} ~10 Φ_{MeV} ; but, no z (abs? d<100 Mpc?)

  Atkins etal, 00, ApJL..

- **Tibet** array: superpose 50-60 ≠ bursts in time-coincid. w. MeV: joint significance **7σ ?**

(Amenomori et al 01)

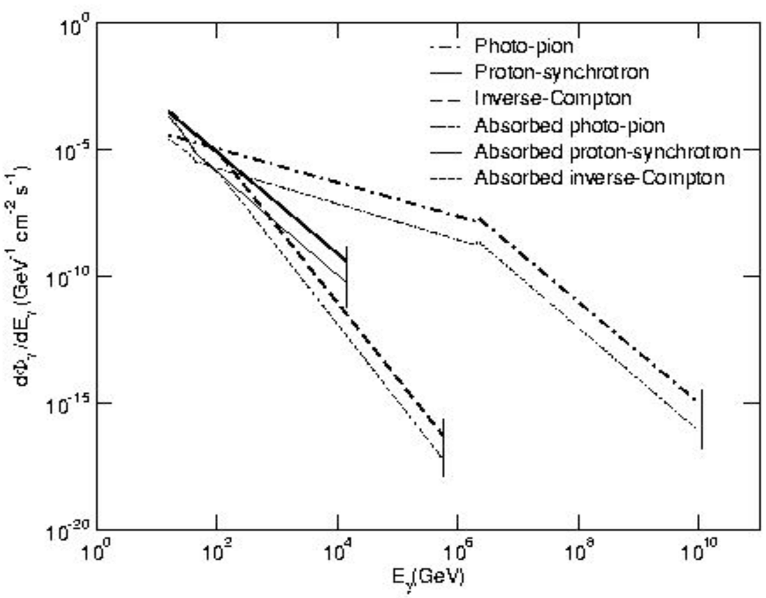
TeV GRB detection status (cont.)



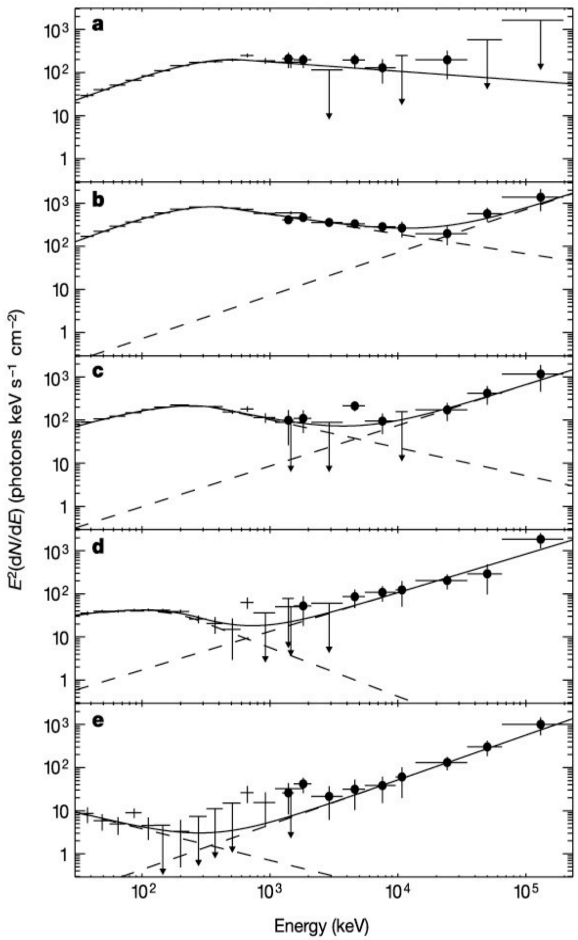
- **GRAND**: grb971110 reported at **2.7σ**
  (Poirier et al PRD 03, aph/0004379)
- model (Fragile etal 03): z~0.7, maximize proton contrib. (and total energetics) $U_p=(m_p/m_e)U_\gamma \sim 10^{56}$ erg ! (isotr.eq.), $B \sim 10^5$ G, p=2

  (see also Totani '98, ApJ 509, L81; '99, 511, 41)

  pγ, p-sy, e-IC, w.(thin) / w.o(thick) internal γγ absorpt.



GRB 941017 : pγ signature?



t<14 s

t <47 s

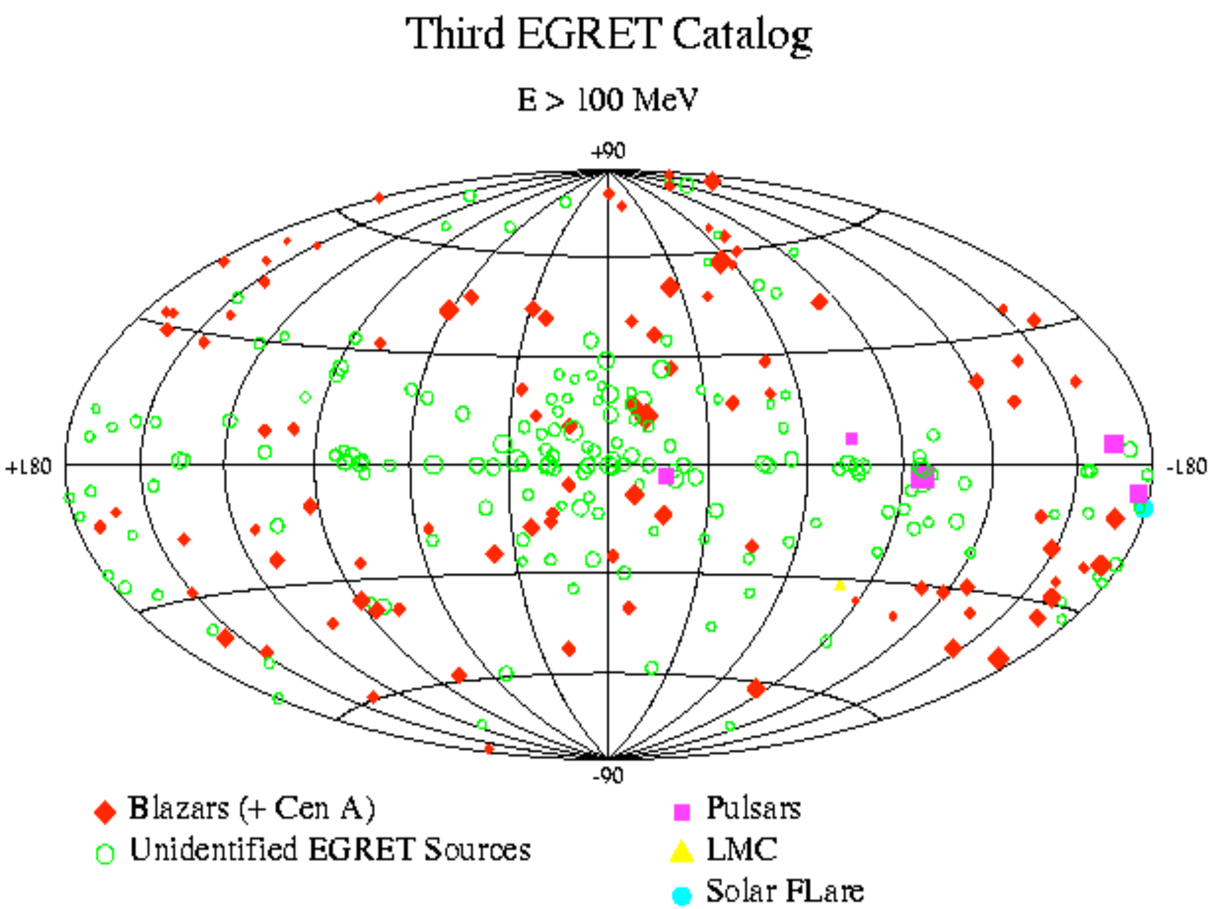
t < 80 s

t < 113 s

t < 211 s

Gonzalez, Dingus et al, 03, Nature 424, 749

- Hard **(10-200 MeV)** comp. in EGRET TASC calorimeter **not** compatible w. BATSE MeV fit (but in 26 other bursts a single BATSE/TASC fit works well)
- Hard comp. more prominent in time → **pγ signature?** might explain delay, hardness
- **Alternative: could be IC**, in regime where IC sp is harder than sync PL ; e.g. scatt. of lower energy synch. asymptote; or observe IC region where electrons with a range of energies scatter off a range of photon energies (Granot,Guetta, astroph/0309231)



GeV γ from Blazars

(and other gal. & unid. sources)

- EGRET(space): 66 + 27 blazars @ > 10GeV
- ACTs (ground): HESS, Whipple, HEGRA, CAT, CANGAROO…:
  > 8 AGN @ > 10 TeV

AGNs: GeV-TeV γ - Sp. '05

GeV : (from space)

3C273 RLQ z=0.185 (no TeV)
BL Lac BL Lac z=0.0686 (no TeV)
3C 279 OVV z=0.538 (no TeV)
etc. …(**~ 66**, e.g. in Egret catalogue)
(many are **superluminal** , mod. to high Γ, mod. θ)

TeV: (ACT, ground)

Mkn 421 XBL z= 0.03 (yes Egr)
Mkn 501 XBL z=0.03 (yes Egr)
(appear to be **subluminal** , high Γ, very small $\theta \leq 1^o$)
1ES2344+514 XBL z=0.044 (no Egr)
H1426+428 XBL z=0.129 (no Egr)
1ES1959+650 XBL z=0.046 (no Egr)
PKS2155-304 XBL z=0.116 (yes Egr)
PKS 2155-304 HBL z=0.117 (…. Egr)
PKS 2005-489 HBL z=0.071 (….. Egr)
-------- (not only blazars.. ↓) -------
3C66A RBL z=0.4 (yes Egr)
NGC 253 **SRB/Sp!** , D~2.5Mpc (no Egr)

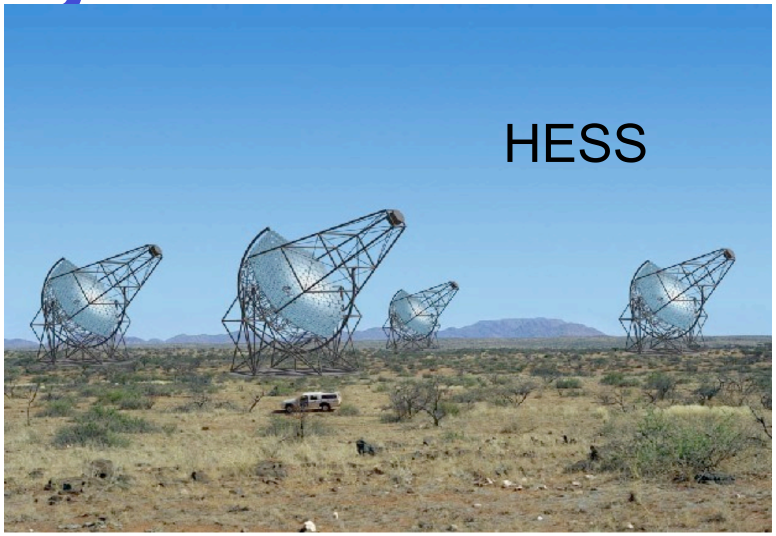
GeV-TeV γ experiments underway

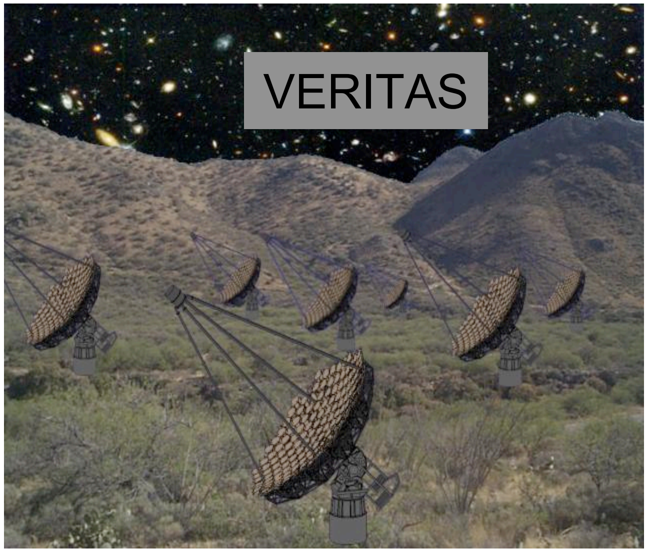
Cherenkov Telescopes

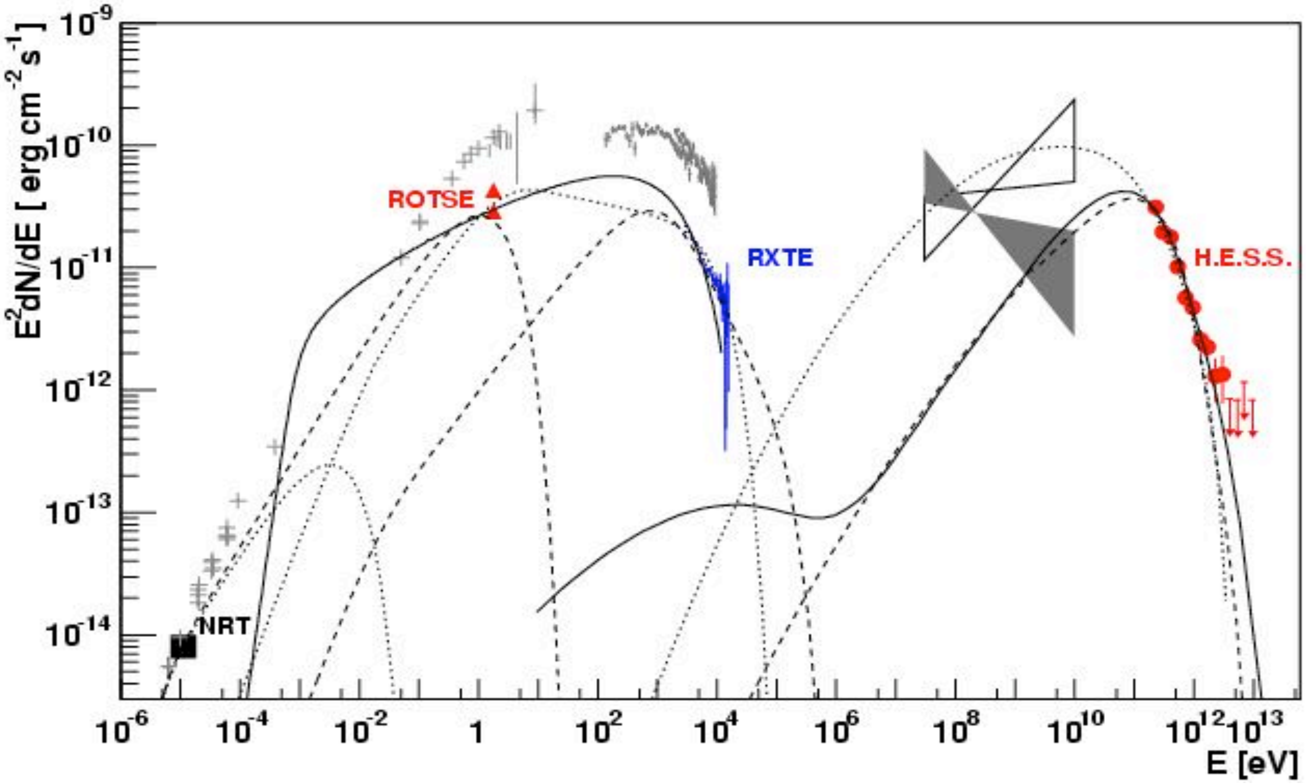
← **Water**

Air →

↓ ↓





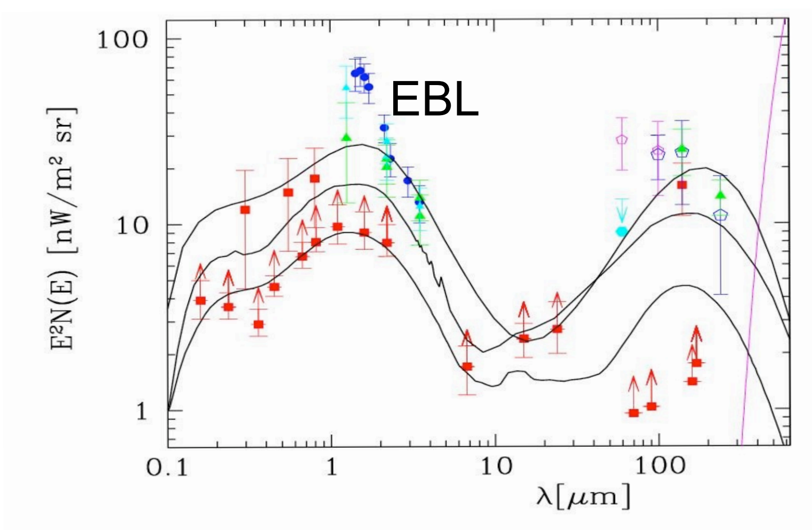


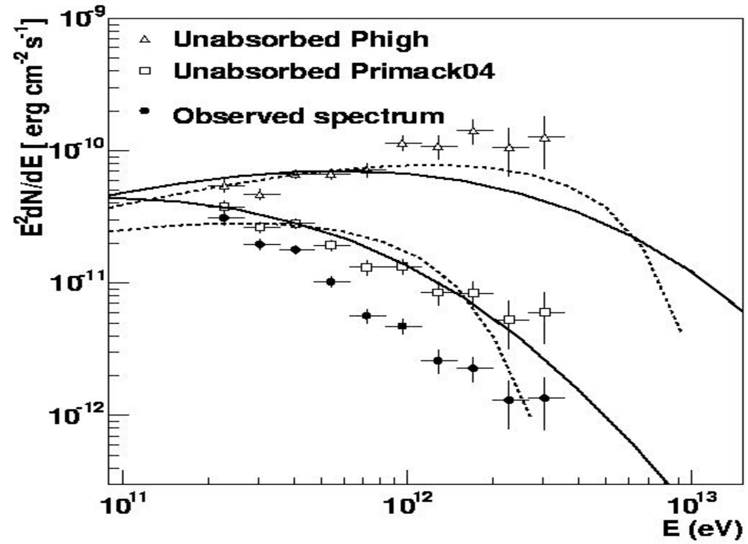
HESS

PKS 2155-304

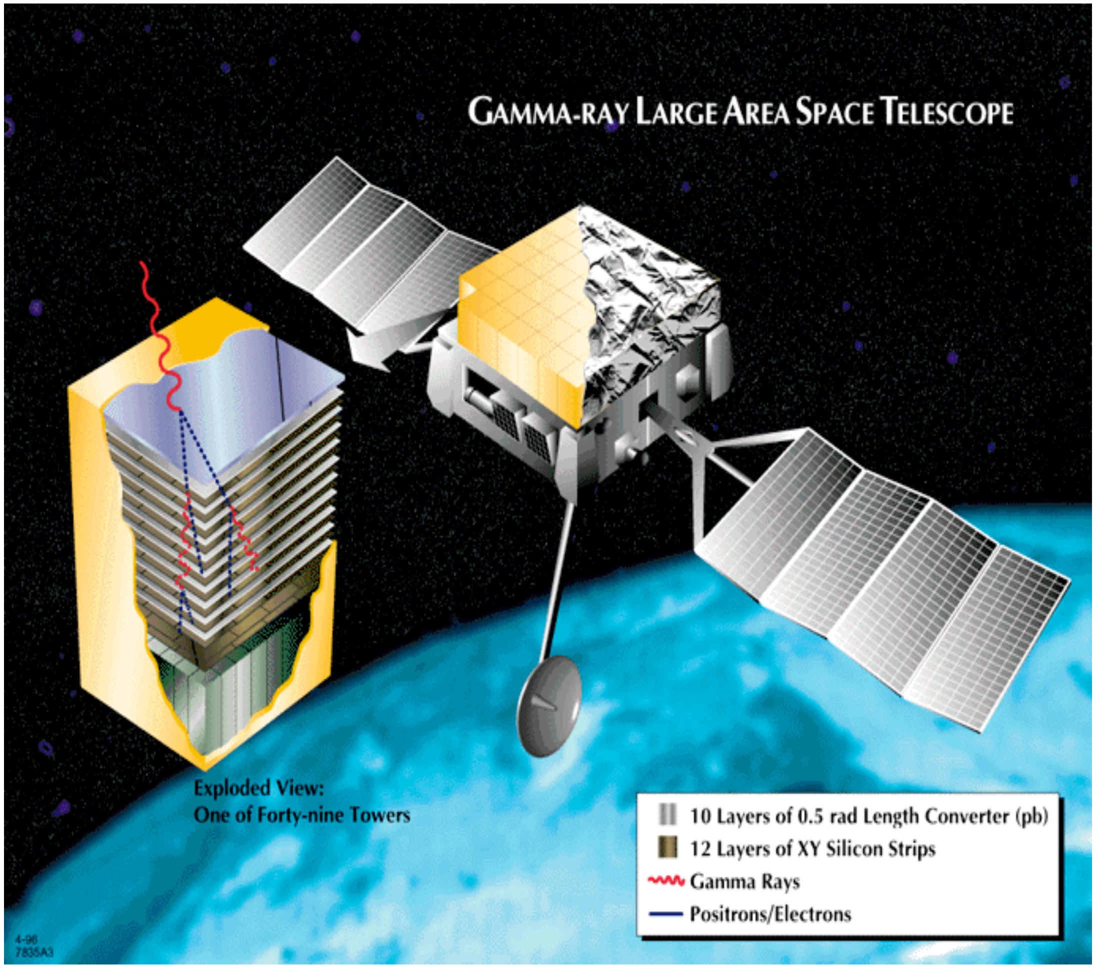
Aharonian et al, 2005, AA in pr., astro-ph/0506593

Spectrum corrected ↓ for EBL absorption





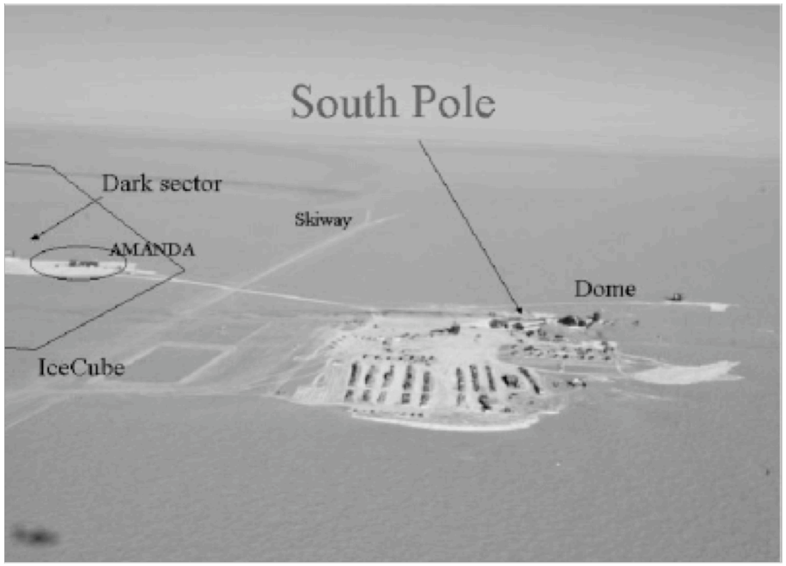
GLAST : LAT (Stanford +)



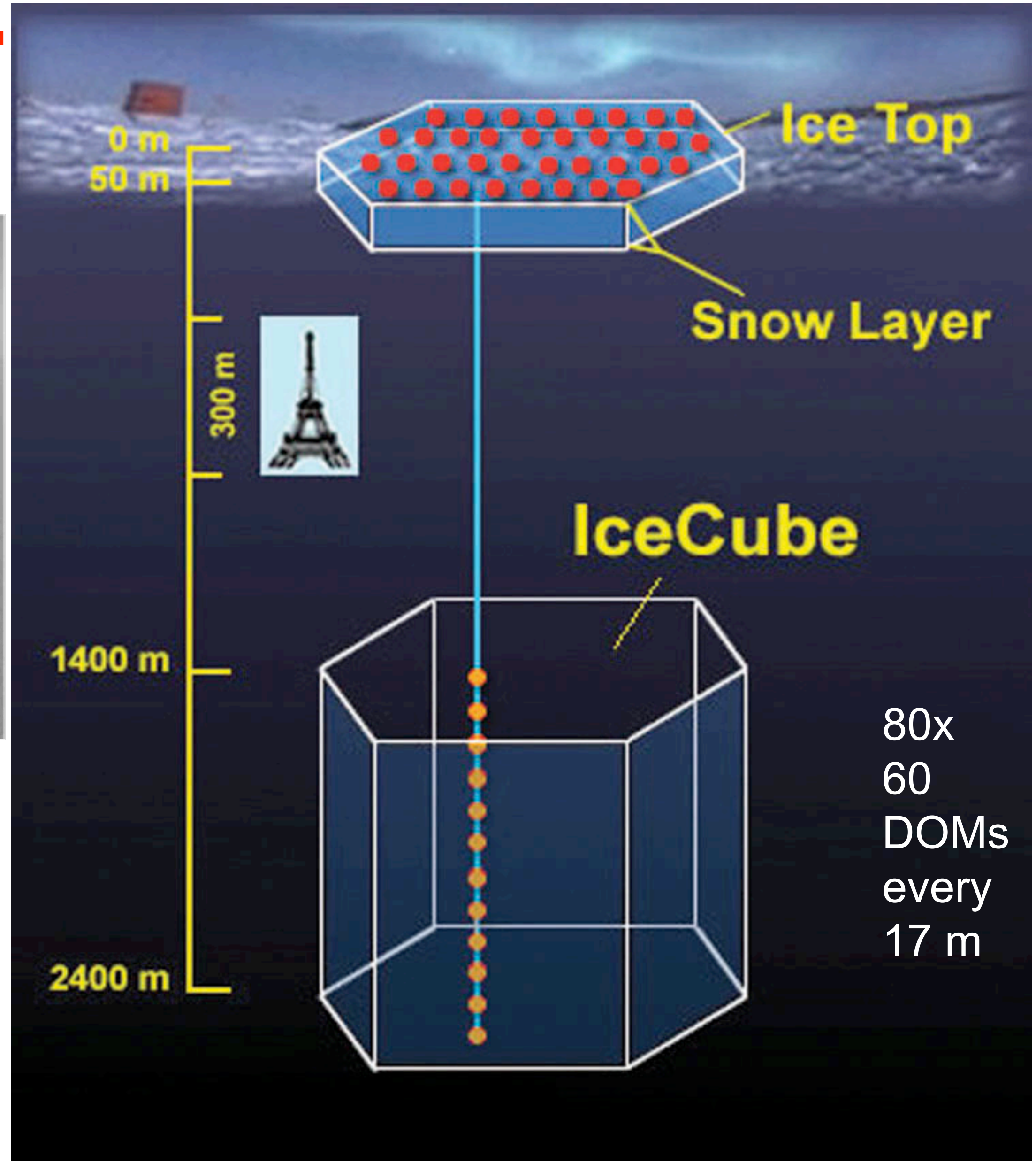
- LAT: launch exp '07, Delta II, 2-300 GRB/2yr
- Pair-conv.mod+calor.
- 20 MeV-300 GeV, $\Delta E/E \sim 10\%$@1 GeV
- fov=2.5 sr (2xEgret), $\theta \sim 30''-5'$ (10 GeV)
- Sens $\sim 2.10^{-9}$ ph/cm^2/s (2 yr; > 50xEgret)
- 2.5 ton, 518 W

Also on GLAST: GBM (~BATSE range)

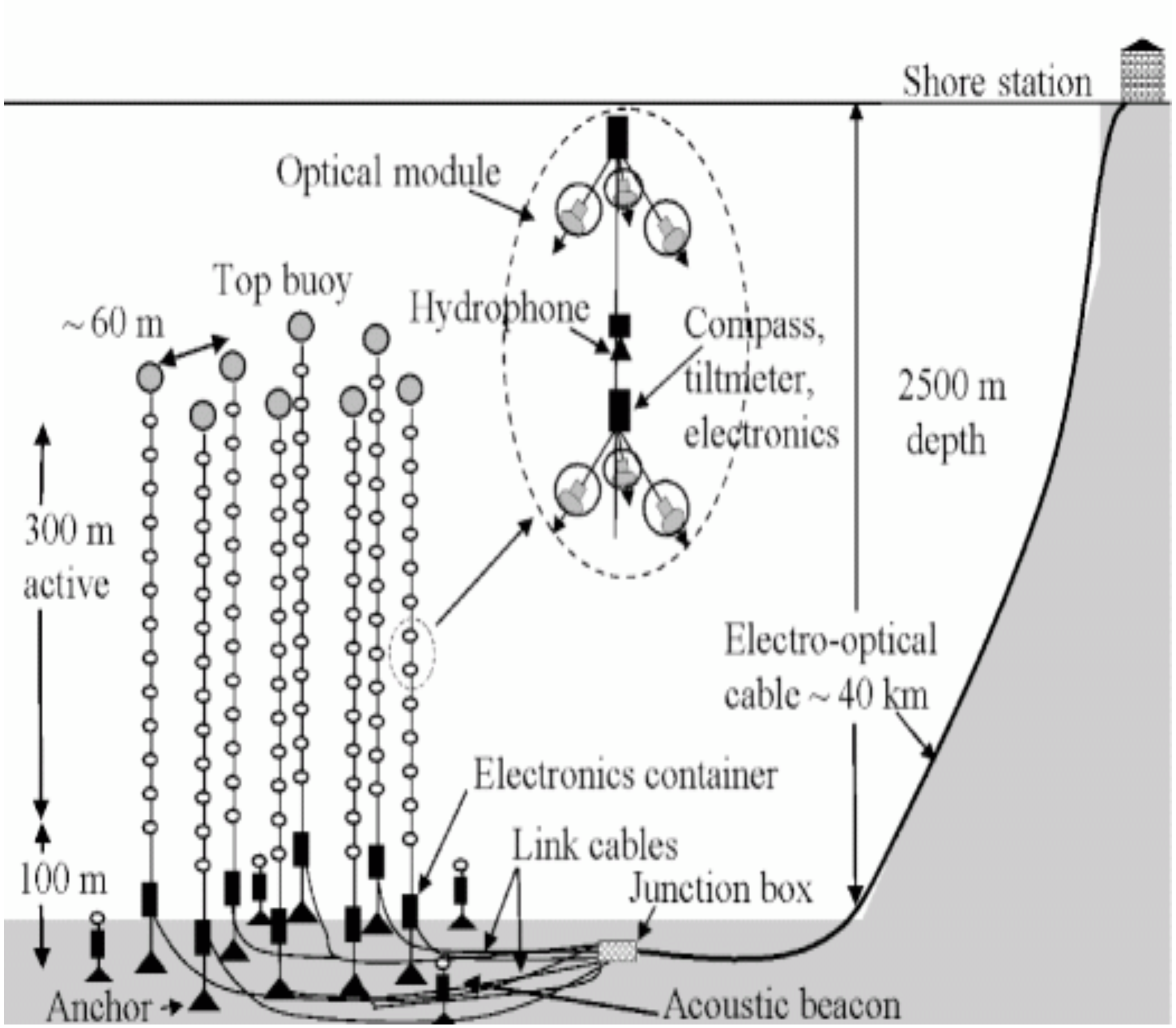
ICECUBE: km^3



- Extension of Amanda (650 pmt) 0.05 km^3 $\rightarrow$ km^3=1Gton
- Funded - 1st IceCube string ✓
- 80 strings , 4800 PMT (DOMs) + 160x2m IceTop surface array
- Design for det.all flavor ν's , from 10^7 eV (SN) to 10^{20} eV

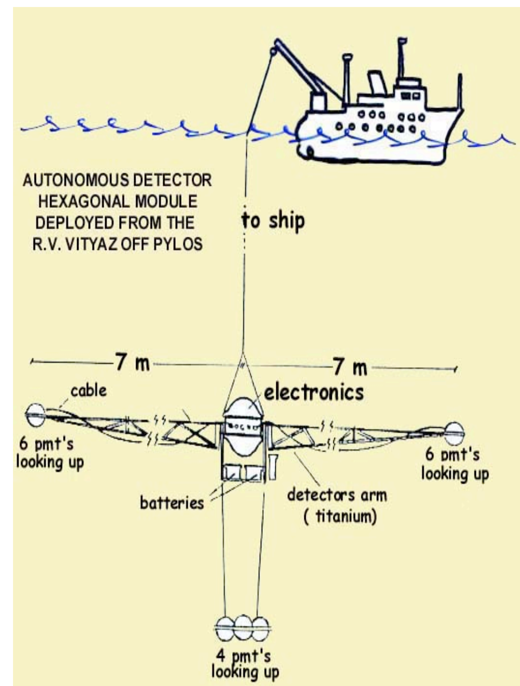


80x 60 DOMs every 17 m



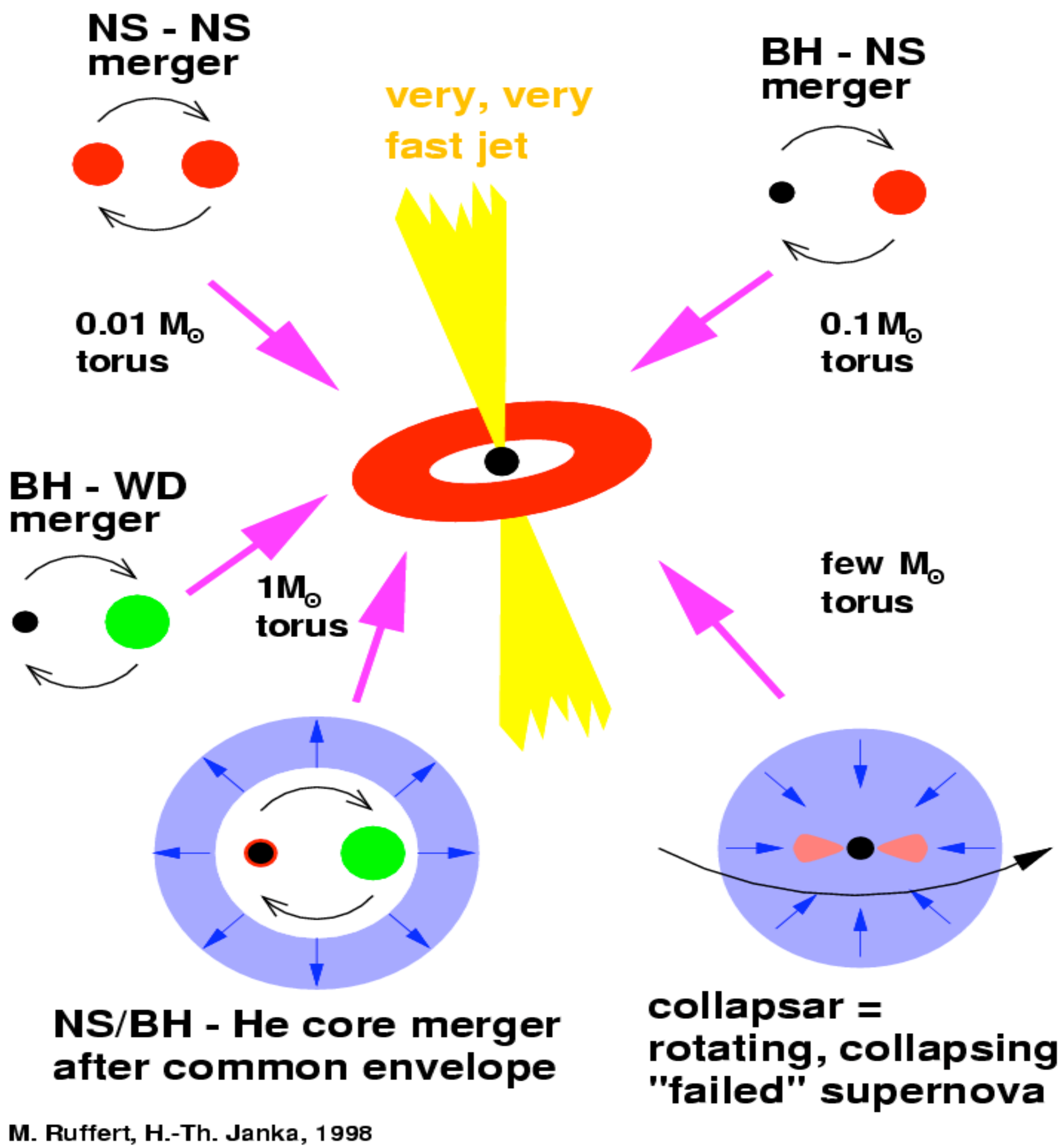
KM3NeT

- EU collaboration
- Site: Mediterranean
- Based on: **Antares, Nestor, Nemo**



- 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

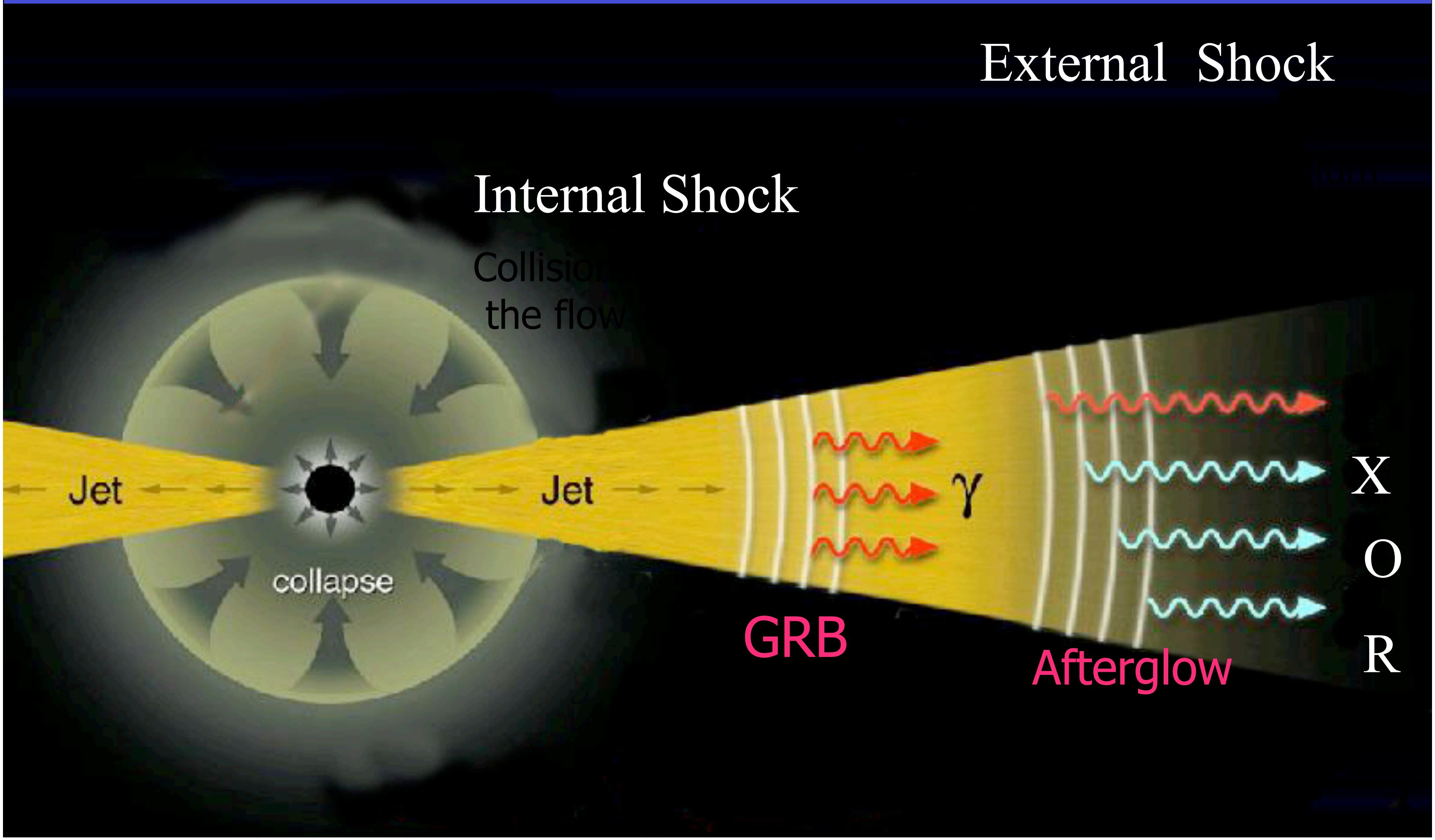
GRB:→ Hyperaccreting Black Holes



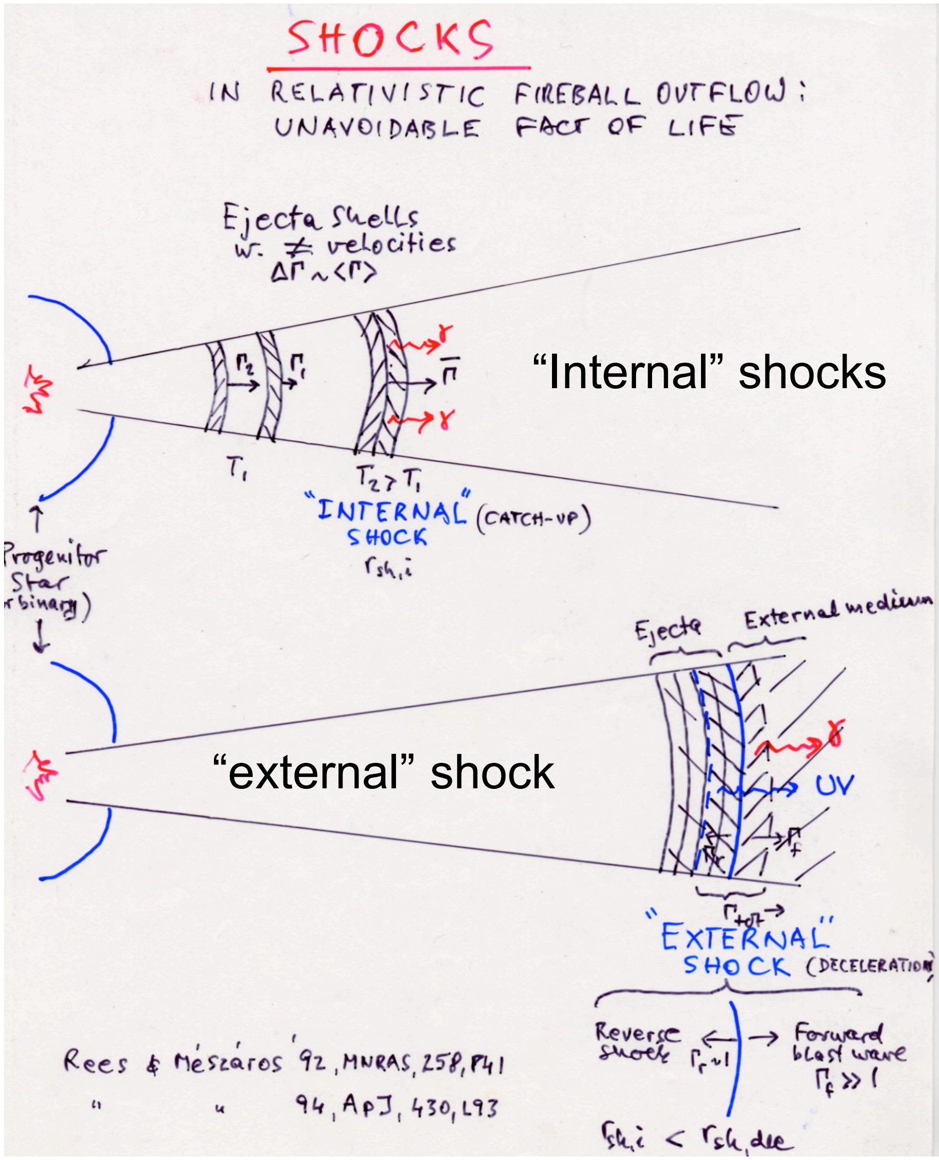
Short

Long

Fireball Model: long GRBs



Shocks in Fireball/Jet Outflow



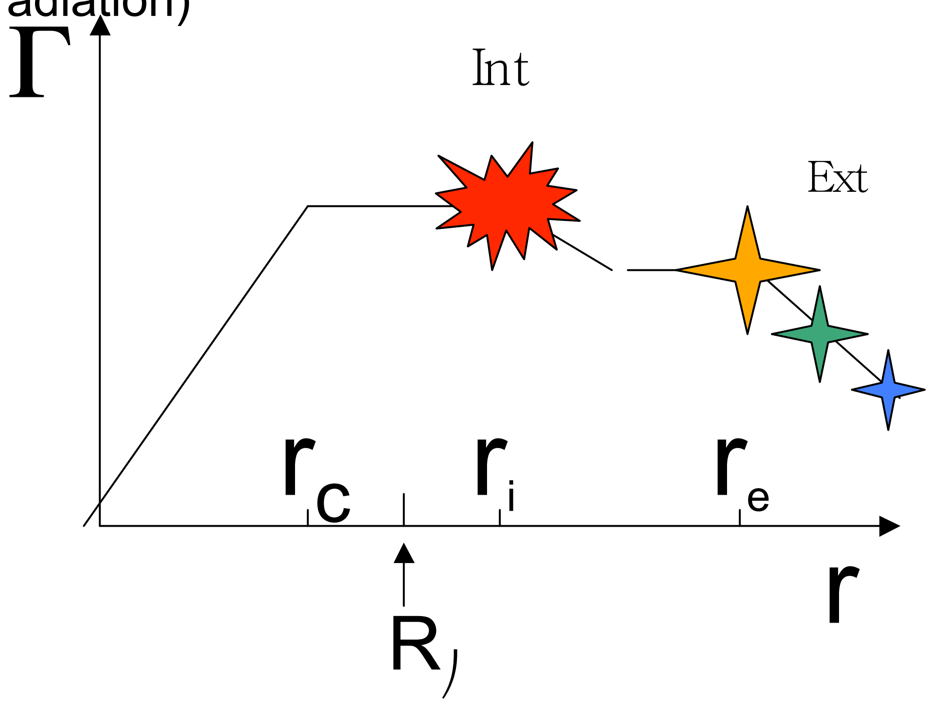
- **Shocks** expected in any unsteady supersonic outflow (esp. in a non-vacuum environment)
- **Internal** shocks: fast shells catch up slower shells (unsteady flow)
- **External** Shock: flow slows down as plows into external medium
- NOTE: “external” and “internal” shocks might be expected both while jet is inside star, as well as after it is outside. Former: γs do not escape; latter: they do.

Internal & External Shocks

in the optically thin medium outside progenitor:

LONG-TERM BEHAVIOR?

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

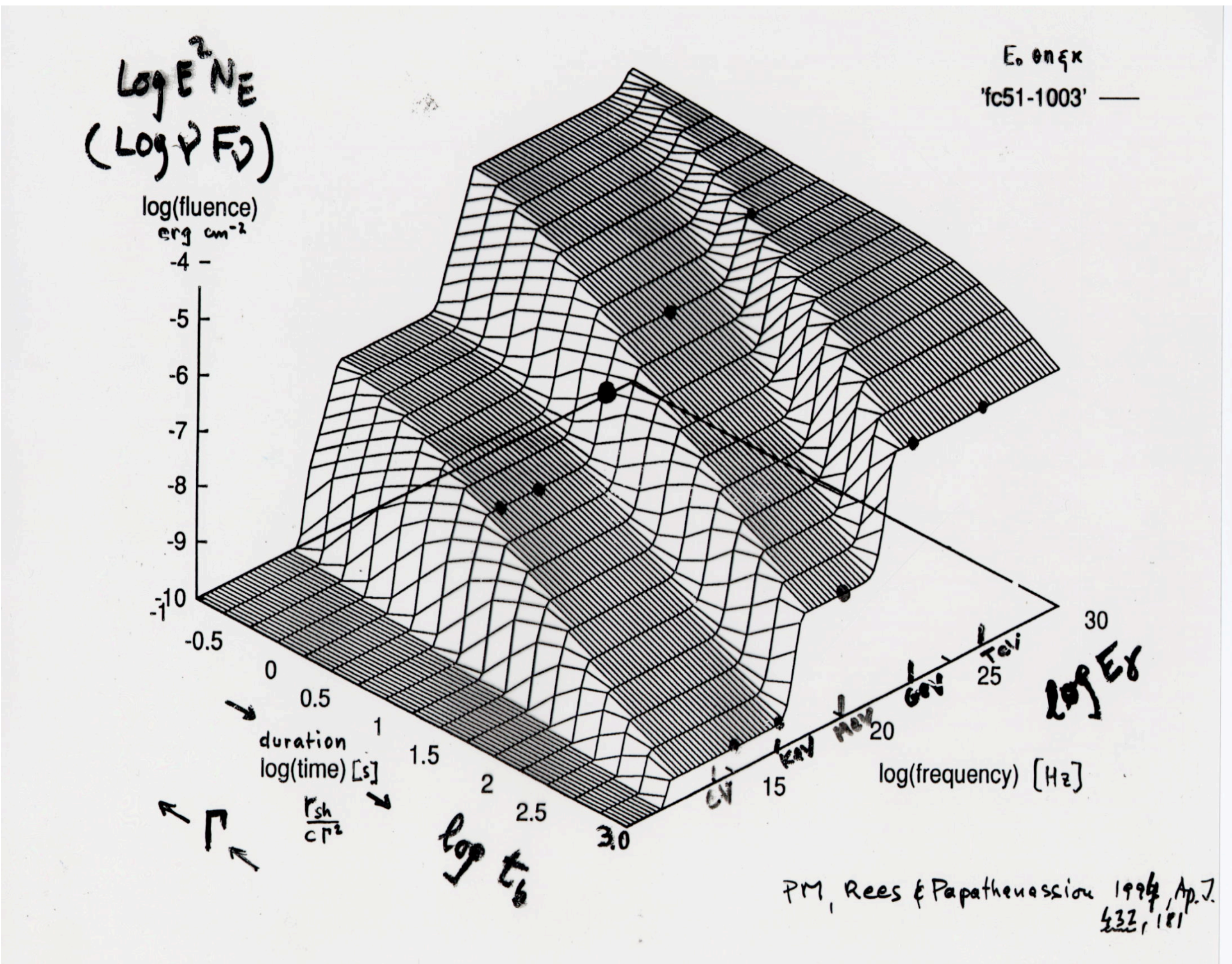


- Lorentz factor Γ first grows $\Gamma \propto r$, then coasts $\Gamma \propto$ constant, until …
- **Outside** the star, after jet is opt. thin: Internal shocks: $r_i \sim 10^{12}$cm
  →**γ-rays** (burst, t~sec)
- Externals shocks start at $r_e \sim 10^{16}$cm, progressively weaken as it decelerates

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)
  (Meszaros & Rees 1997 ApJ 476,232)

External Forw. & Rev. Shock Synchroton & IC spectrum



EGRET GeV Bursts

- GeV emission, starting ~ with MeV trigger, but lasting τ 1 hr:

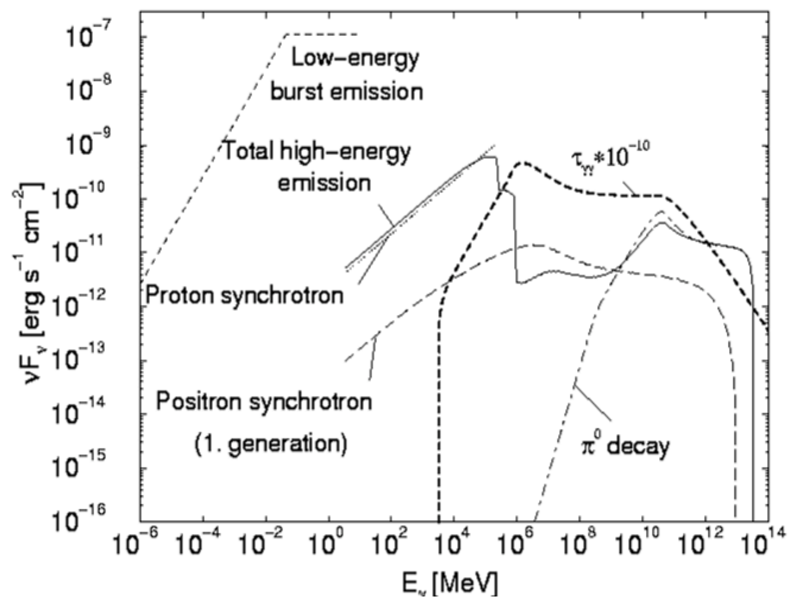
  $\rightarrow$ could be

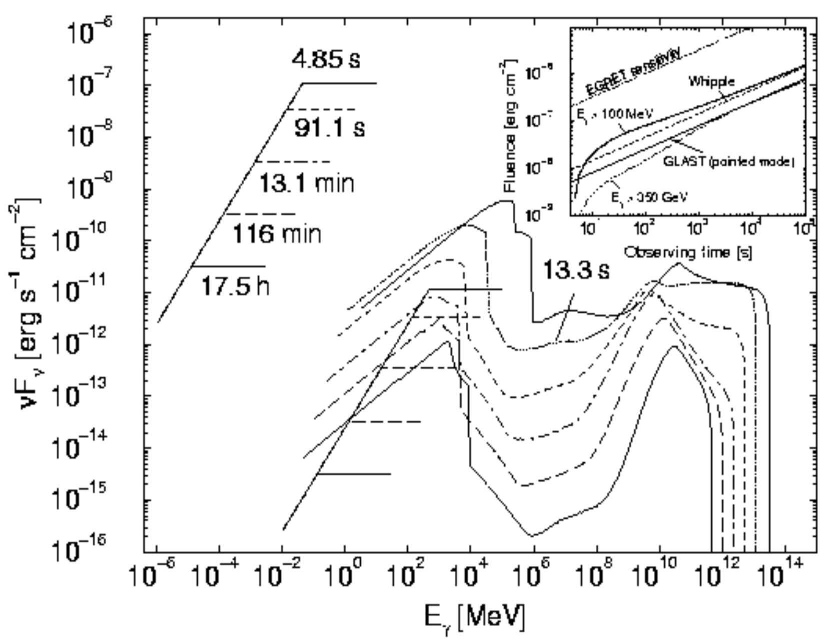
  a) normal duration MeV synchrotron **internal** shock,

  b) followed by long-lasting GeV I.C. **external** shock (moder. Γ, low n_{ext})

(Meszaros & Rees 1994)

GRB pγ EM cascades

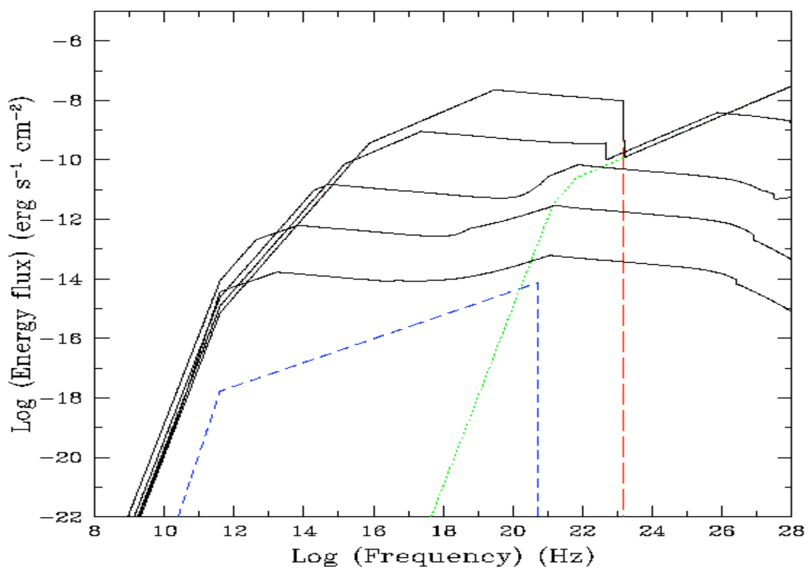


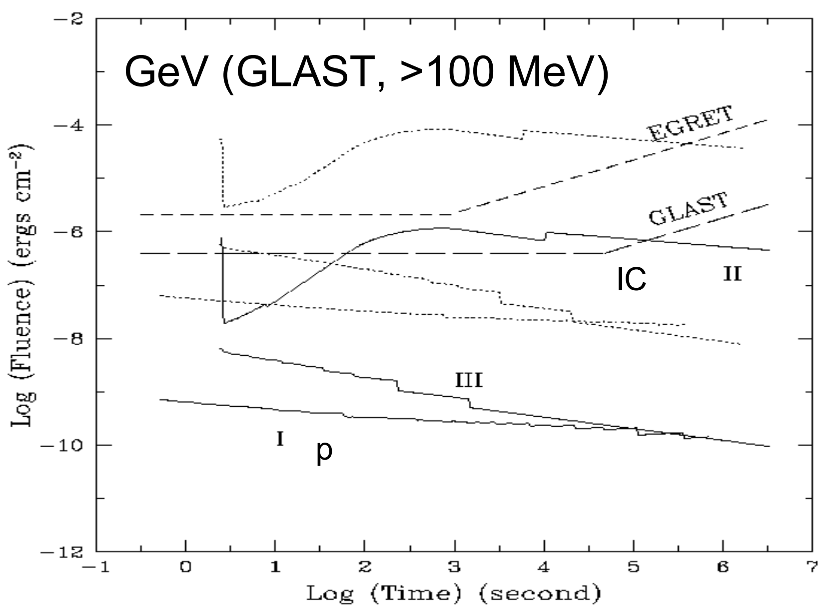


- Low energy: normalize to GRB 970508 (z=.83)
- Ext. forw. shock → MeV γs
- Proton index -2, $U_p \sim U_e$, p-sy & pγ cascades, e^+ sync, π^0 dec.
- Time decay of cascade rad, slower than a'glow decay (p's have less rad. losses)

Boettcher & Dermer 98 ApJ 499, L131 ;
Dermer, Atoyan 03, PRL 91, 1102;
Dermer, Atoyan 04, AA418, L5

GeV light-curves





- Lightcurves start at $t_{dec,}$, until reach Γ~2.
- IC of sync. ext. shock
- Full lines: z=1, flat U

  Dotted: z=0.1
- Model **IC** : recognize from **late GeV** peak 10-20 min after MeV), and

  from **late XR** hump (day)

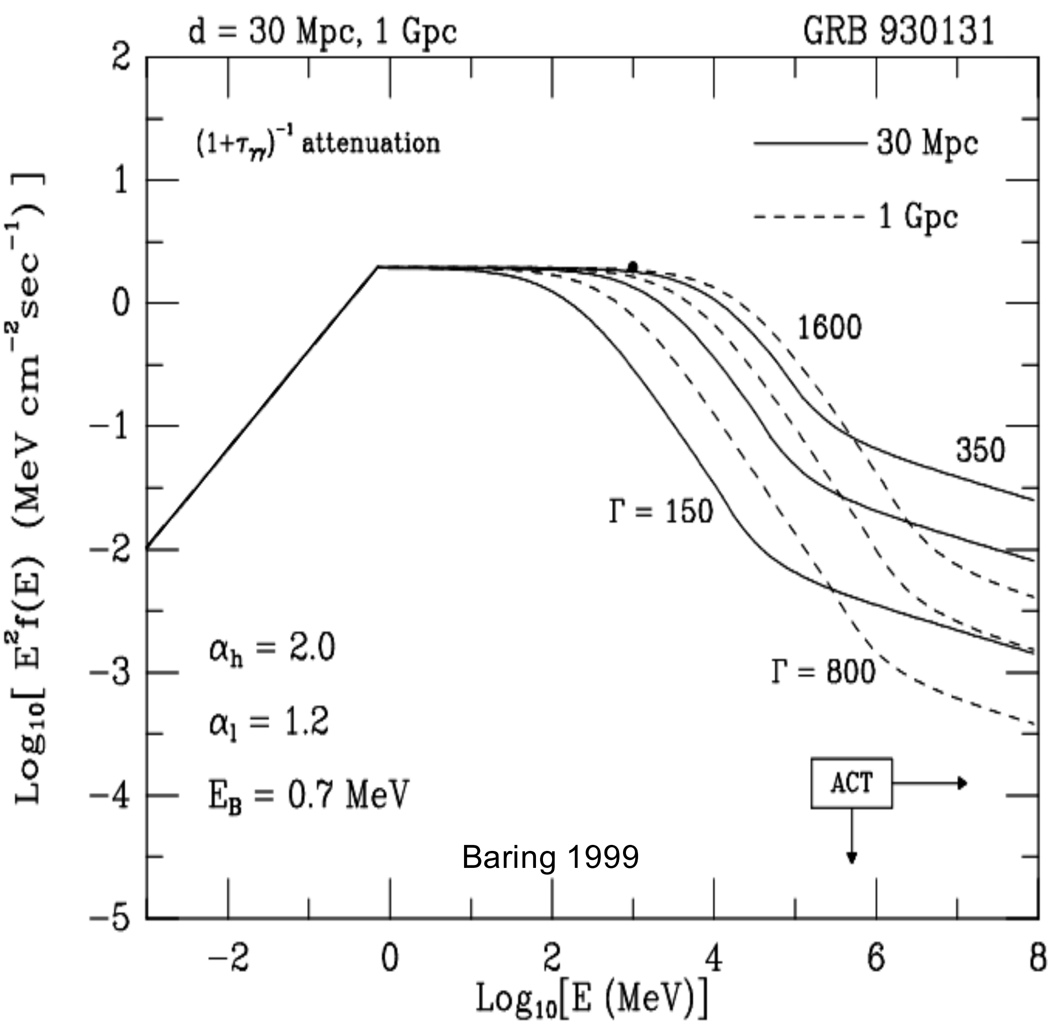
- Long-dash lc: e-sy radn component

  short-dash lc: p-sy(pγ), radn

  dotted lc : e-IC radn

Zhang & Mészáros 01 ApJ 559, 110

GeV-TeV photons from GRB



- Internal shocks: $\gamma\gamma \rightarrow e^{\pm}$, $\tau_{\gamma\gamma} \geq 1$ @ $E_\gamma \tau\, \Gamma^2_{300}$ GeV
  → pair cutoff in spectr
  → get info about r_{sh} (compactness,$\tau_{\gamma\gamma}$)
- In ext.shock, $\tau_{\gamma\gamma} \leq 1$ on GRB target γ;
- test if shock is int. or ext;
  test bulk Lorentz factor, shock accel efficiency, magnetic field in shock (max. $e^{\pm}$ energy? →size of accel region)

Γ_{max} upper limits in sel. GRB

Lithwick & Sari 01 ApJ 555,540 :

Use Γ-dependence of comoving photon density which determines max. escaping photon energy

	E_m/m_ec^2	z	Γ_{m1}	Γ_{m2}
910503	333	1	340	300
910601	9.8	1	72	110
910814	117	1	200	190
930131	1957	1	420	270
940217	6614	1	340	120
950425	235	1	300	280
990123	37	1.6	150	180
971214*	1	3.42	192	410
980703*	1	.966	69	140
990510*	1	1.62	98	200

$p + \gamma, p \longrightarrow$ 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.) **: ICECUBE**

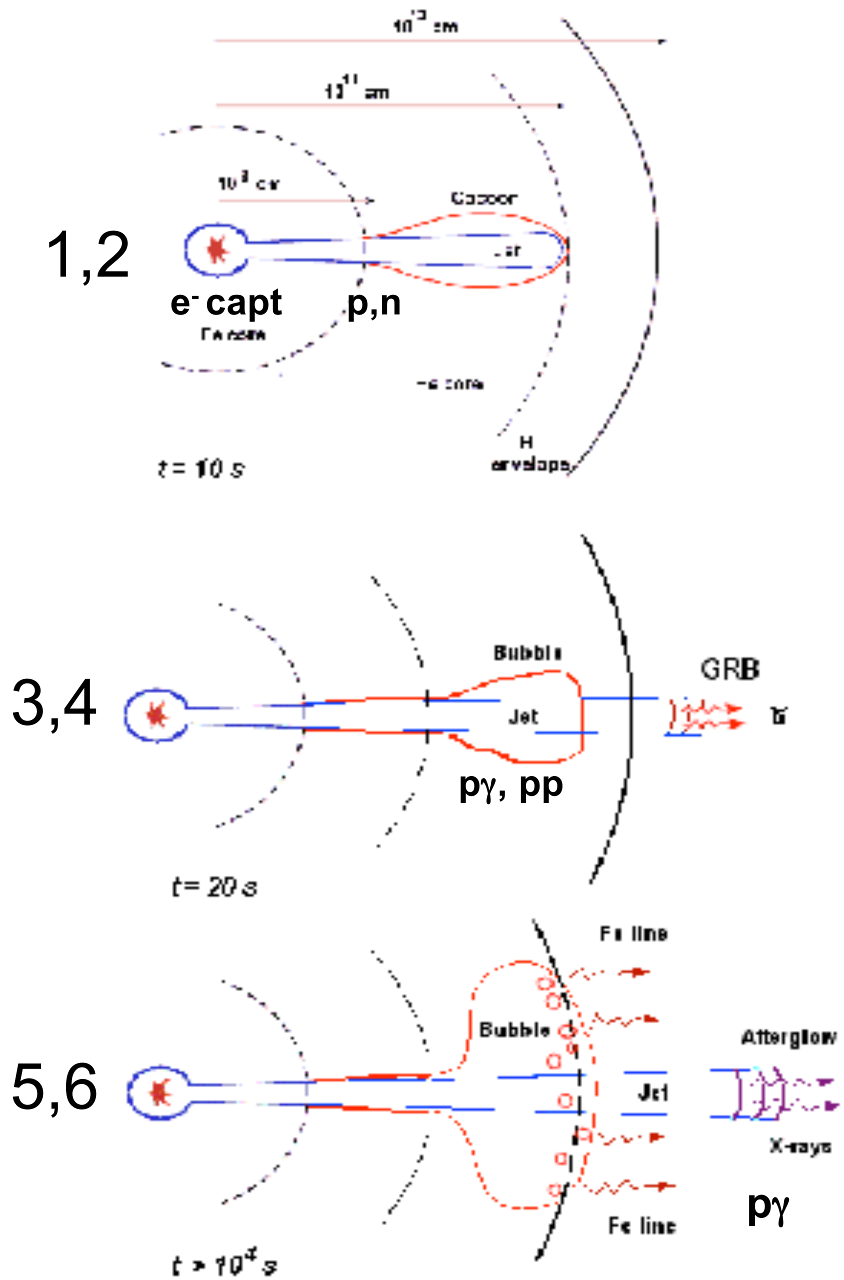
- $\rightarrow \pi^0 \rightarrow 2\gamma \rightarrow$ $\gamma\gamma$ cascade **: GLAST, ACTs..**

(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:

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

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



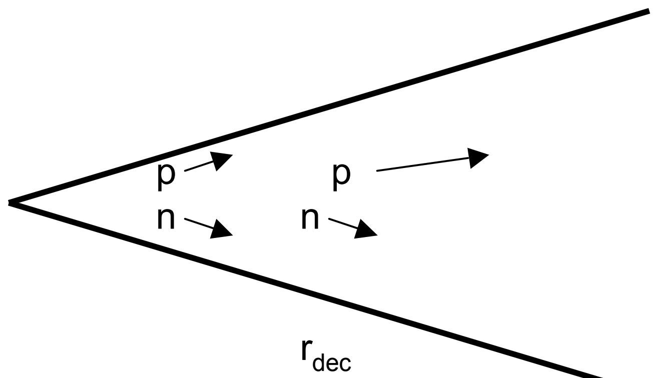
UHE ν in GRB

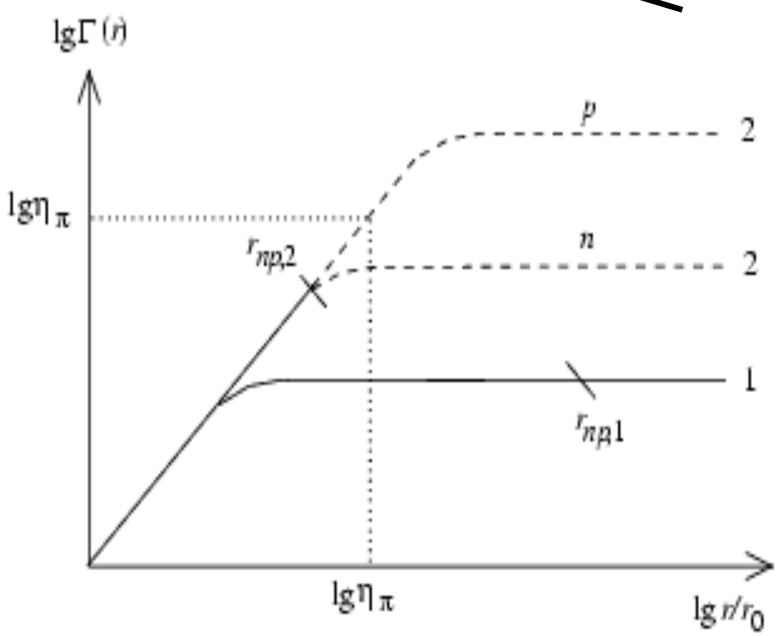
*6 possible collapsar **GRB** ν-sites*

- 1) at collapse, make GW + **thermal νs (MeV)**
- 2) If jet outflow is baryonic, have p,n
  → p,n relative drift, **pp/pn** collisions
  → inelastic nuclear collisions
  → **VHE ν** ***(GeV)***
- 3 Int. shocks while jet is inside / can accel. protons → **pγ, pp/pn** collisions
  → **UHE ν** ***(TeV)***
- 4 Int. shocks outside / accel. protons
  → **pγ** collisions → **UHE ν (*100 TeV*)**
- 5) ← Ext. rev. shock → **EeV ν (10^{18} eV)**
- 6) ***If*** supranova shell present outside
  (SN ocurred >2 days before GRB?)
  → **pγ, pp** of jet protons on shell targets
  → **UHE ν (> *TeV*)** ***[..now constrained]***

“Hadronic” GRB Fireballs:

Thermal p,n decoupling $\rightarrow$ VHE ν,γ

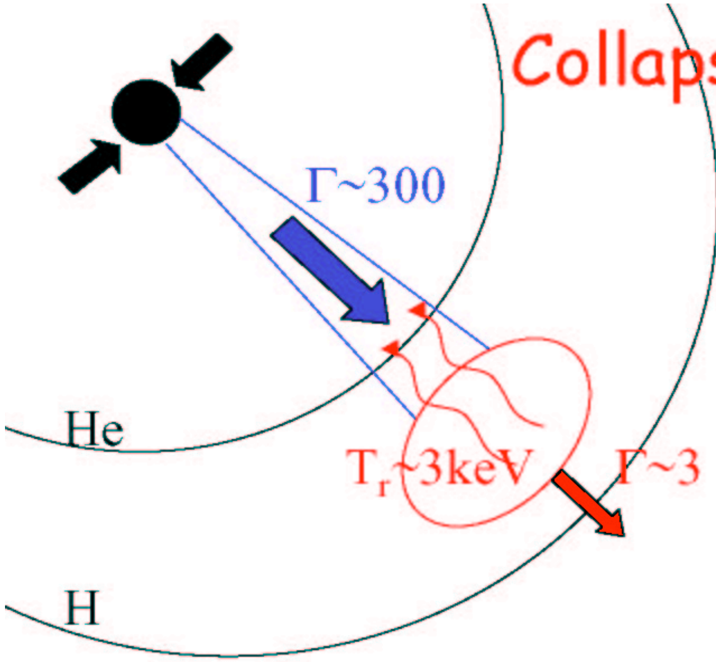




(Bahcall & Meszaros 2000 PRL 85:1362); Lemoine 2002; Beloborodov, 2002

- **p,n** in fireball move together while $t_{pn} < t_{exp}$ (rad. acts on p, elastic scatt. couples p,n)
- **p,n** decouple when $t_{pn} > t_{exp}$, where τ_{pn}~1, $v_{rel} \rightarrow c$, $\sigma_{pn} \rightarrow$ inelastic; this occurs for $\Gamma > \Gamma_\pi$~400
  (Derishev etal 99; Bahcall,Meszaros 00; Fuller etal 00)
- Inelastic pn $\rightarrow$ $\pi^\pm \rightarrow \mu^\pm, \nu_\mu \rightarrow e^\pm, \nu_e, \nu_\mu$
  $\rightarrow \pi^0 \rightarrow 2\gamma$
- ν_μ : $\varepsilon_{\nu\mu}$~5-10 GeV $\rightarrow$ ICECUBE?
  det @ z~1, R_ν~7/yr from all GRB, **but** only if larger PMT density
- **γ-rays:** $\pi^0 \rightarrow 2\gamma$, $\rightarrow$ **GLAST,** ε_γ **~10 GeV**, detect @ **z < 0.1**

While jet is inside progenitor:



$$\frac{\varepsilon_p}{\Gamma}\Gamma\varepsilon_\gamma \geq 0.3\,\mathrm{GeV}^2$$

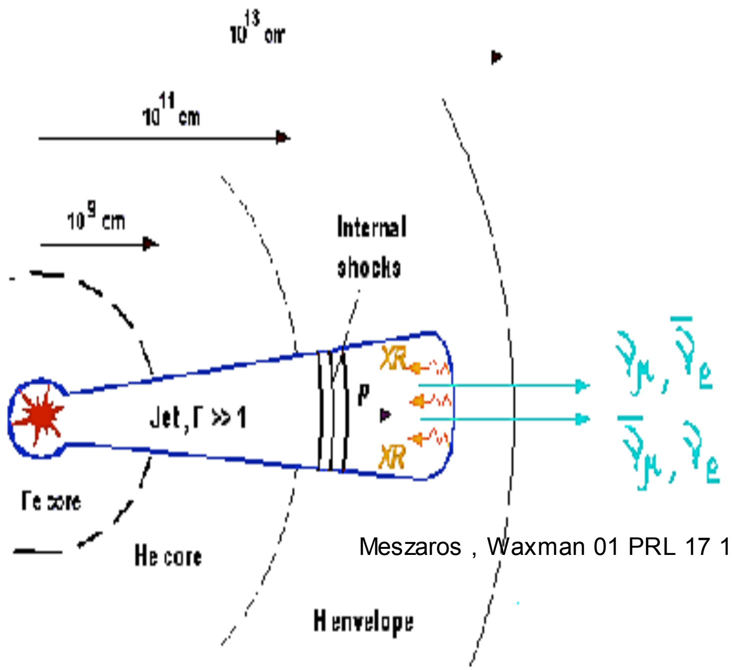
$$\Rightarrow \quad \varepsilon_p \geq 100\,\mathrm{TeV}$$

- $\varepsilon_\nu \geq 10^{12.5}$ eV
  $N_{\nu\to\mu} \approx 0.2\,/\,\mathrm{km}^2/\mathrm{Collapse}$ (10^3 GRBs/yr)
- Both "Chocked" and "successful" jets

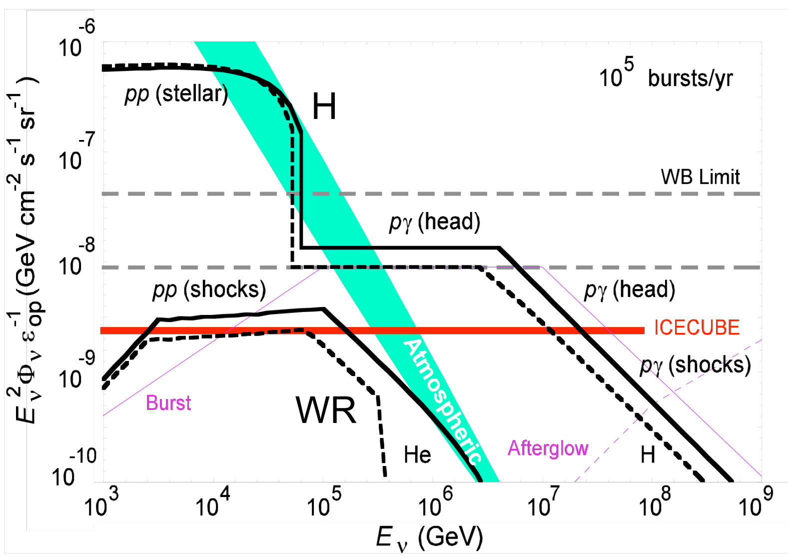
[Meszaros & EW 01]

(2) Jet inside star:

GRB ν,γ Precursor



Meszaros , Waxman 01 PRL 17 1102



Razzaque, Mészáros, Waxman 03 PRD 68, 3OO1)

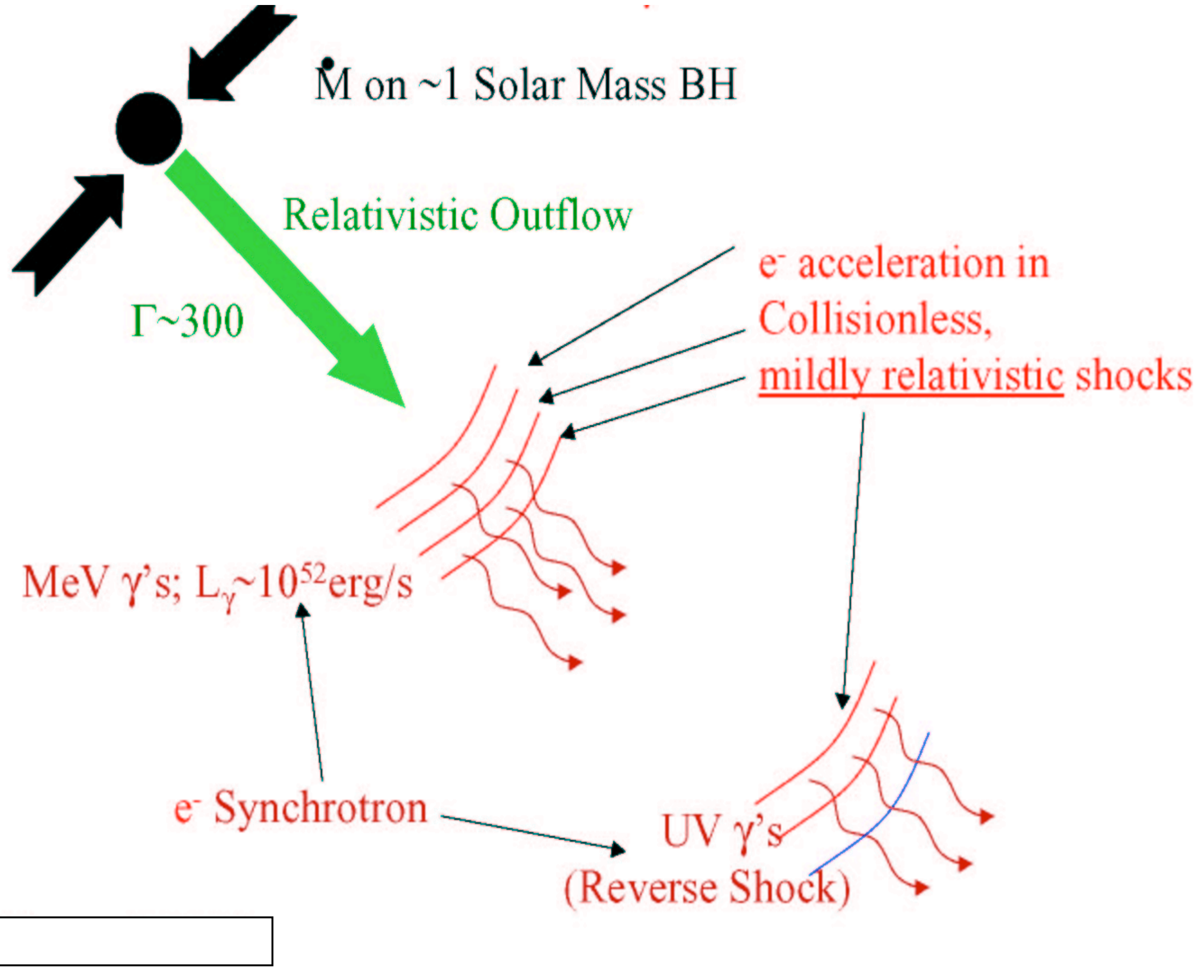
- Jet propagating through progenitor, *BEFORE* emerging from stellar envelope, can have int. shocks which accel. p^+ →
  pγ on unobserved X-rays , → $\pi^\pm$, ν
  pp, pn on stellar envelope → $\pi^\pm$, ν

  →~ few TeV neutrino precursor
- If progenitor has H-layer R_J~10^{12} cm (BSG) →
  Rate($\nu_{\mu\,,\,TeV}$) prec > Rate($\nu_{\mu\,,\,100\,TeV}$)int.shock
  (easier to detect in ICECUBE)
- but, if WR (He core), R_J~10^{11} cm →
  Rate($\nu_{\mu\,,\,TeV}$) prec < Rate($\nu_{\mu\,,\,100\,TeV}$) int.shock
  → test progen. size (e.g. @ high z : popIII?)
- If jet DOES NOT escape ⇒ "choked" jet,
  νs escape, γs don't → "hidden ν source"
- If jet break-out: → photon flashes

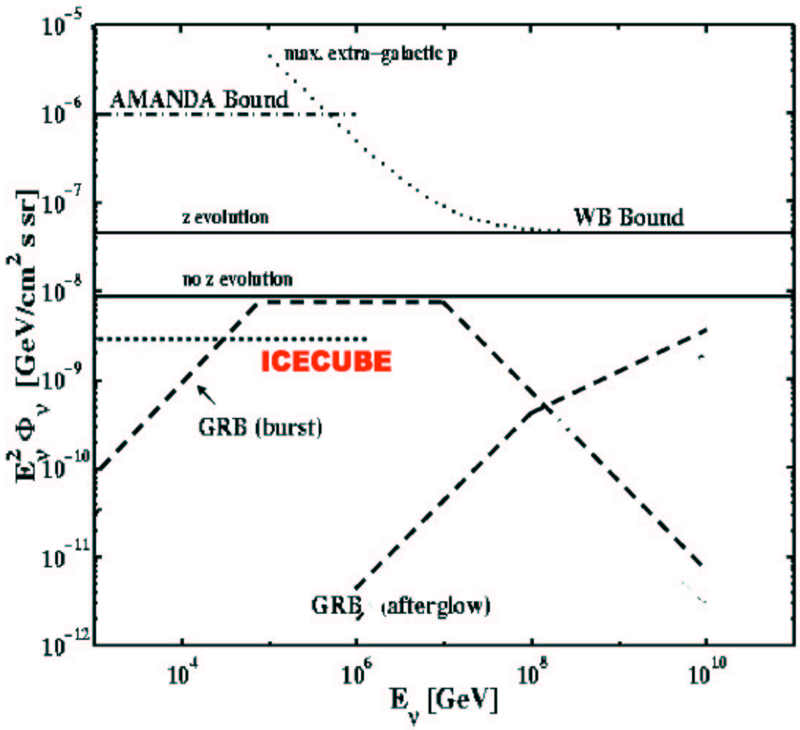
  → Blue ν- spectrum: ~100 TeV
  p,γ→ν from shocks outside star

When jet is outside progenitor star:

GRB internal & external shocks



νs from pγ in internal & external shocks in GRB



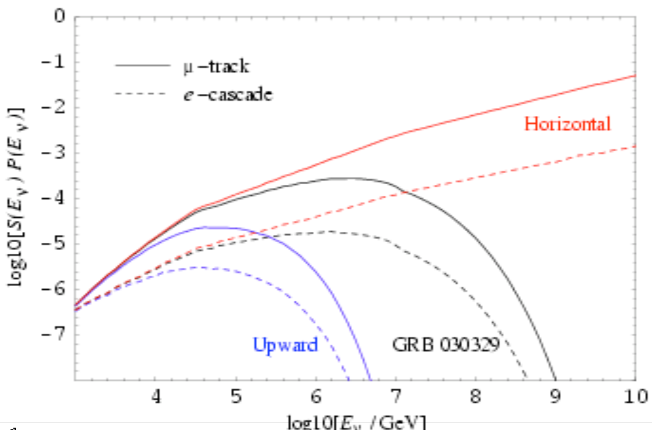
Waxman, Bahcall 97 PRL

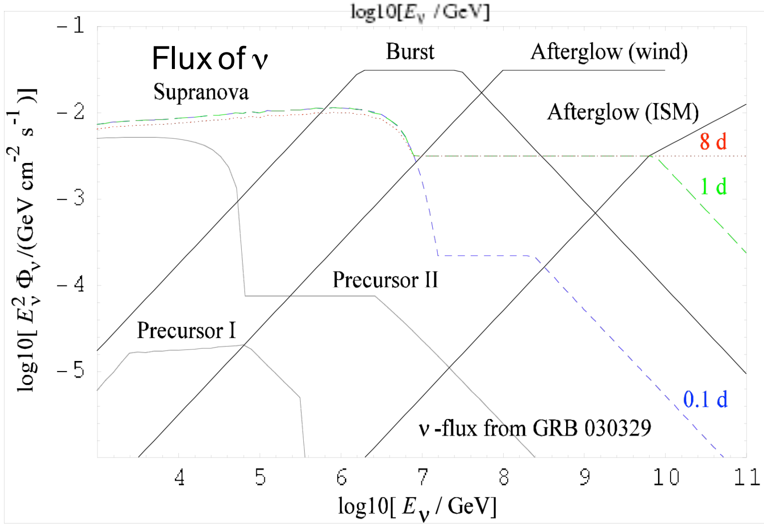
- Shocks accelerate p^+ (as well as the e^- which produce γ_{MeV})
- Δ-res.: $E'_p\, E'_\gamma \sim 0.3\,GeV^2$ in comoving frame, in lab:
  - $\rightarrow E_p \geq 3x10^6\, \Gamma_2^{\,2}$ GeV
  - $\rightarrow E_\nu \geq 1.5x10^2\, \Gamma_2^{\,2}$ TeV
- Internal shock p,γ_{MeV}
  $\rightarrow$ ~100 TeV νs
- External shock p,γ_{UV}
  $\rightarrow$ ~ 0.1-1 EeV νs
- Diffuse flux: detect in km^3

GRB 030329: precursor (& pre-SN shell?) with ICECUBE

Burst of $L_\gamma \sim 10^{51}$ erg/s, $E_{SN} \sim 10^{52.5}$ erg, @ z~0.17, $\theta \sim 68^o$

Prob.of ν interaction

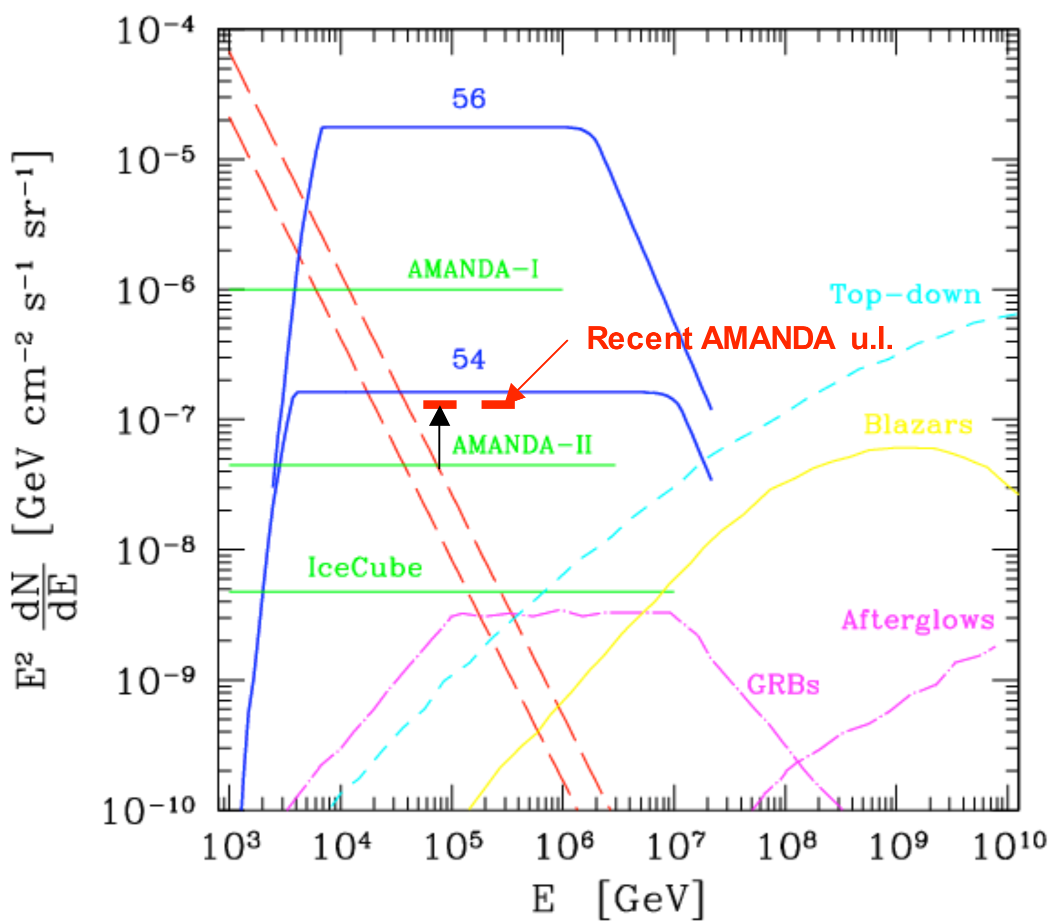




Flux Component	TeV-PeV μ-track	TeV-PeV e-cascade	PeV-EeV μ track	PeV-EeV e-cascade
Precursor I	$9 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	-	-
	$6 \cdot 10^{-3}$ ↑	$2 \cdot 10^{-3}$ ↑	-	-
	0.01 →	$2 \cdot 10^{-3}$ →	-	-
Precursor II	4.1	1.1	$3 \cdot 10^{-3}$	$2 \cdot 10^{-4}$
	2.9 ↑	0.9 ↑	-	-
	4.4 →	1.2 →	0.01 →	$8 \cdot 10^{-4}$ →
Burst	1.8	0.2	1.4	0.1
	0.3 ↑	0.04 ↑	-	-
	2.9 →	0.3 →	7.6 →	0.4 →
Afterglow (ISM)	$2 \cdot 10^{-4}$	$2 \cdot 10^{-5}$	$2 \cdot 10^{-4}$	$1 \cdot 10^{-5}$
	$3 \cdot 10^{-5}$ ↑	$4 \cdot 10^{-6}$ ↑	-	-
	$2 \cdot 10^{-4}$ →	$2 \cdot 10^{-5}$ →	0.01 →	$5 \cdot 10^{-4}$ →
Afterglow (wind)	0.03	$3 \cdot 10^{-3}$	0.05	$3 \cdot 10^{-3}$
	$5 \cdot 10^{-3}$ ↑	$7 \cdot 10^{-4}$ ↑	-	-
	0.05 →	$5 \cdot 10^{-3}$ →	1.4 →	0.06 →
Supranova 0.1 d	12.4	2.4	0.5	0.03
	6.1 ↑	1.6 ↑	-	-
	14.9 →	2.7 →	1.6 →	0.1 →
Supranova 1 d	12.4	2.4	0.5	0.03
	6.1 ↑	1.6 ↑	-	-
	14.9 →	2.7 →	1.9 →	0.1 →
Supranova 8 d	10.9	2.2	0.4	0.03
	5.4 ↑	1.4 ↑	-	-
	13.2 →	2.4 →	1.7 →	0.1 →

Razzaque, Mészáros, Waxman 03 PRD 69, 23001

Diffuse UHE ν from pop.III



Schneider, Guetta, Ferrara aph/0201342

- At z~5-30(?) pop.III , M/ ~ 30-300 M$_\odot$, core coll →BH+ accr.
- Buried jets→pγ→ ν_μ , → ν-bursts (but: dep. on stellar rot.rate)
- E_{iso}~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}~10^{56} erg only for ≤1%,
→ E_{iso}≥10^{54} erg for ≤ 50% !

Core collapse SN

(Waxman & Loeb, 2001, PRL, 87, 1101)

- Simplest possibility:

  "Normal" c.c. (type II) SN, without GRB

  $\rightarrow$ shock break-out mildly relativistic

  (e.g. Colgate 74 "whiplash",…)

- For RSG (type II SN) shock emerging from surface may become collisionless

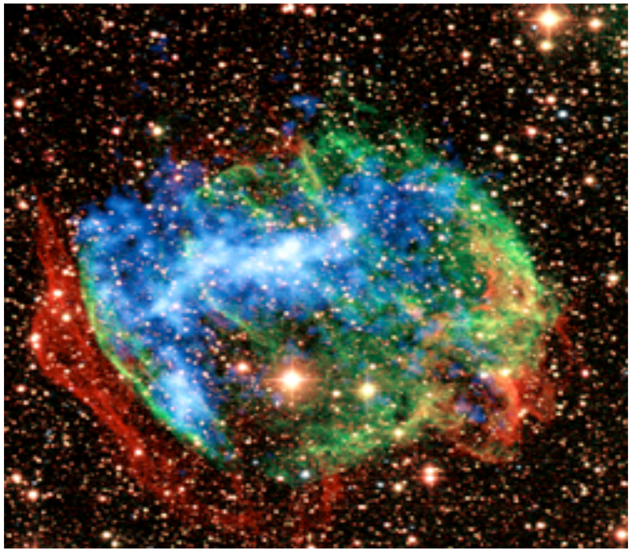
  $\rightarrow$ proton/e acceleration $N(E) \propto E^{-2}$

  $\rightarrow$ pp $\rightarrow \pi^{\pm}\ \pi^{0} \rightarrow \nu$ (TeV) ,γ (10 GeV)

- $F_\gamma \sim F_\nu \sim 10^{-4}\ \xi_p\ d_{10kpc}^{-2}$ erg/s/cm^2 , $\rightarrow$ **GLAST**

  spread over $t \sim 2R_*/c \sim 1$ hour

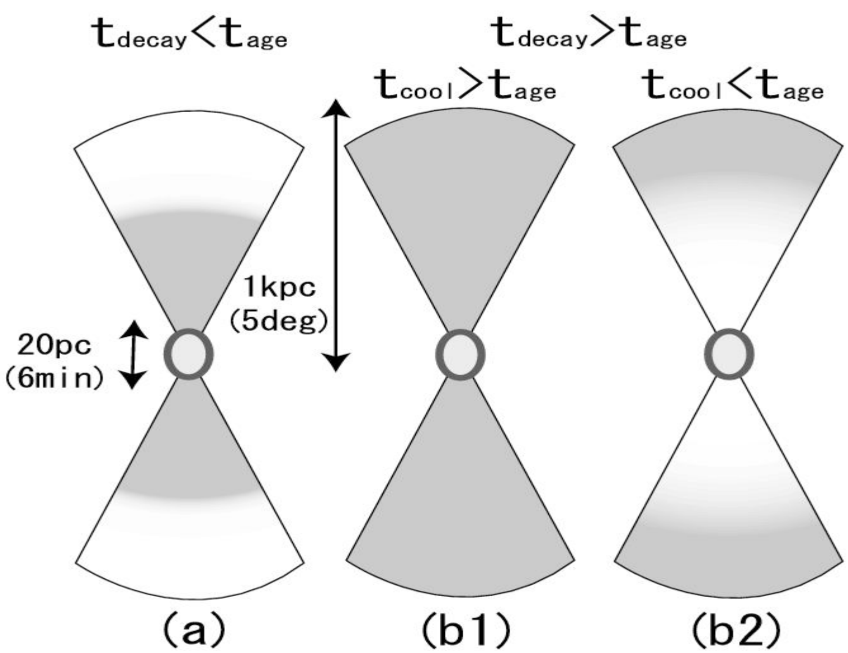
- $N_\mu \sim 100\ \xi_p\ d_{10kpc}^{-2}$ km^{-2} $\rightarrow$ **ICECUBE**



W49B:

a GRB remnant?

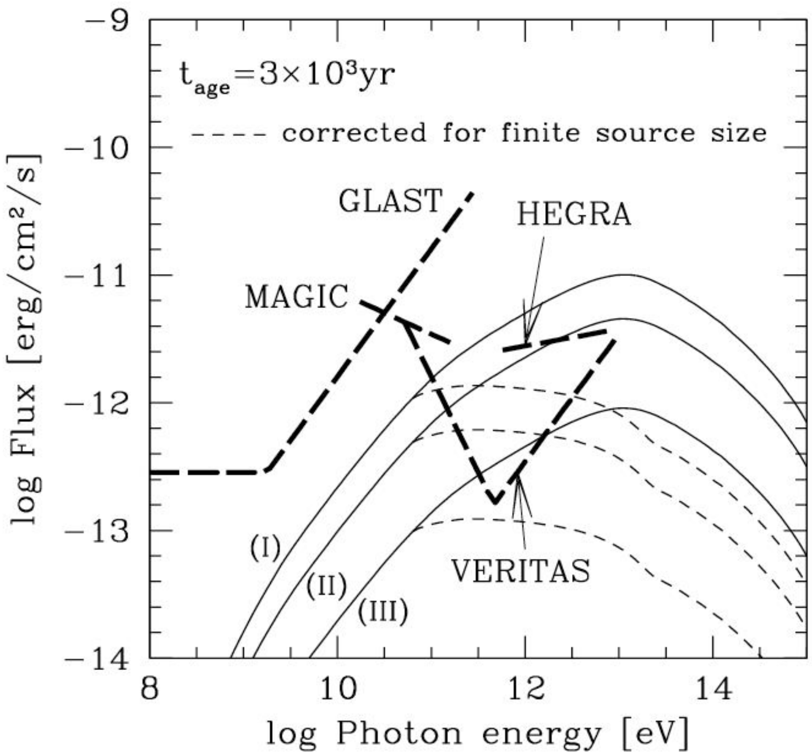
← CXC/Spitzer obs: two jets, rich in Fe (~ GRB remnant) (Clavin, Roy, Watzke '04)



- ~3000 yr old: **any UHE signature?**
- Paradigm: GRB as CR accelerator → cosmic ray n escaped the ejecta (uncharged), later decay
- β decay e^- → synchrotron + IC in B_{gal} and CMB → ***GeV-TeV γ***
- Geometry depends on ratio of t_{dec}, t_{cool} and t_{age}

(Ioka, Kobayashi,Mészáros 04 ApJ 613, L17)

W49 as a smouldering GRB CR accelerator



- $\varepsilon_{ic,cmb}$ ~ 50 TeV
- Depending on n (CR) flux normalization rel. to GRB,

$\varepsilon F_\varepsilon \sim 10^{-11}$ erg/s/cm^2

$\varepsilon F_\varepsilon /\Omega \sim 5\ 10^{-9}$ erg/s/cm^2/sr → possibly detectable w.

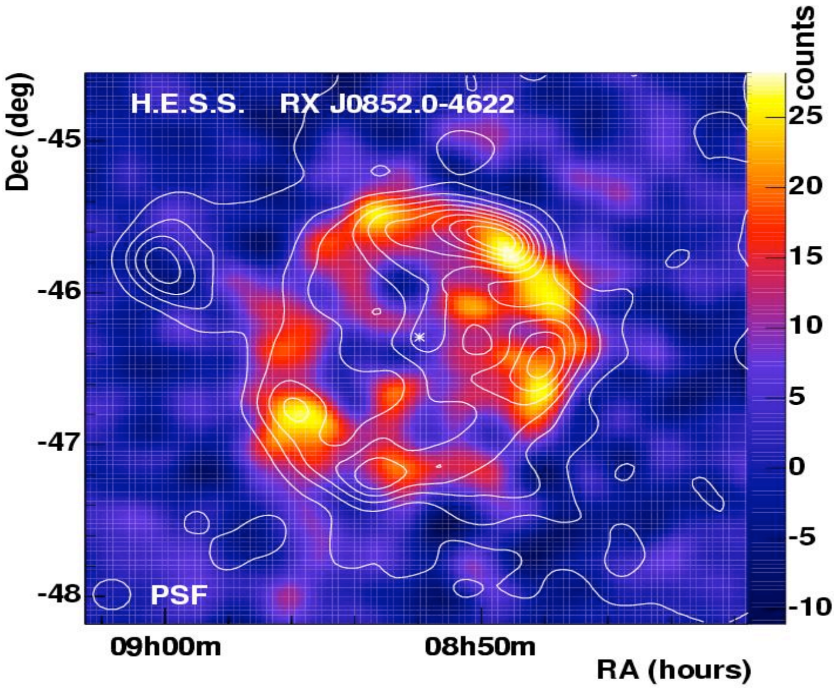
VERITAS, MAGIC, HEGRA

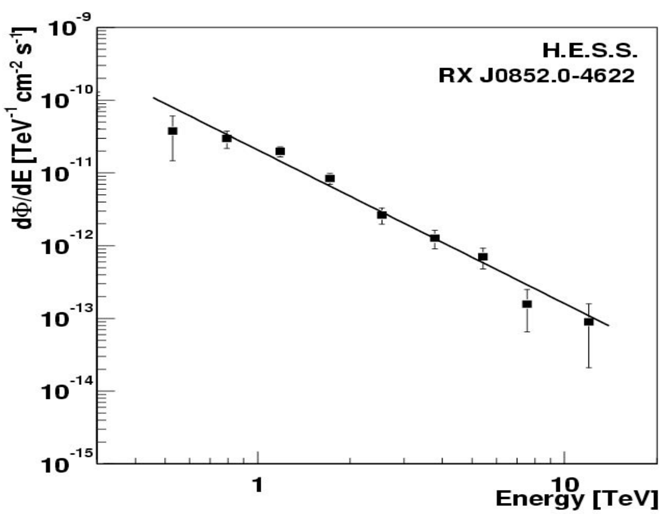
(northern location → not observable with HESS, CANGAROO)

Note: neutrons escape remnant, imaging permits distinguishing n-decay outside source from possible π^0 decay following proton acceleration in the SNR shock

Ioka, Kobayashi, Mészáros 04, ApJL 613, L17

SNR observed TeV γ





- HESS, CANGAROO… have observed TeV γ up to

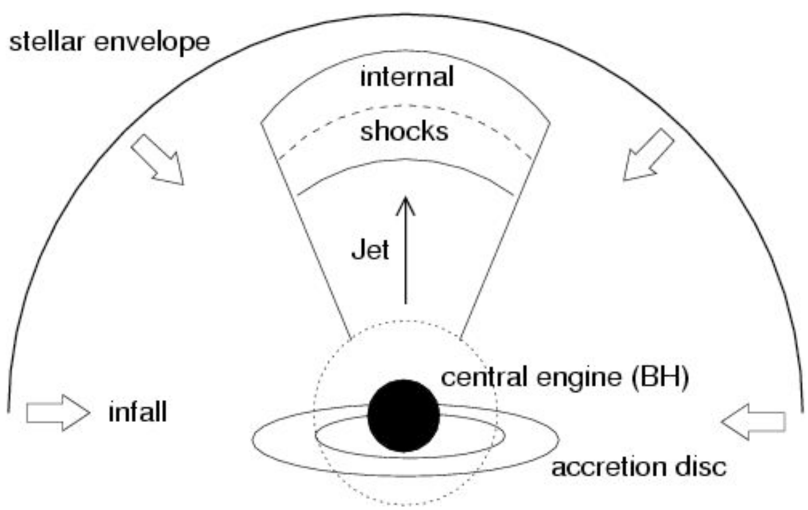
  ≥20 TeV
- E.g. RXJ0852, RJX1713..

  are weak RS, with strong nonthermal XR
- IC? Maybe, but infer large B → π^0 **decay?**

  → *open question*
- NOTE: imaged, TeV confined to SNR itself, corr. with XR

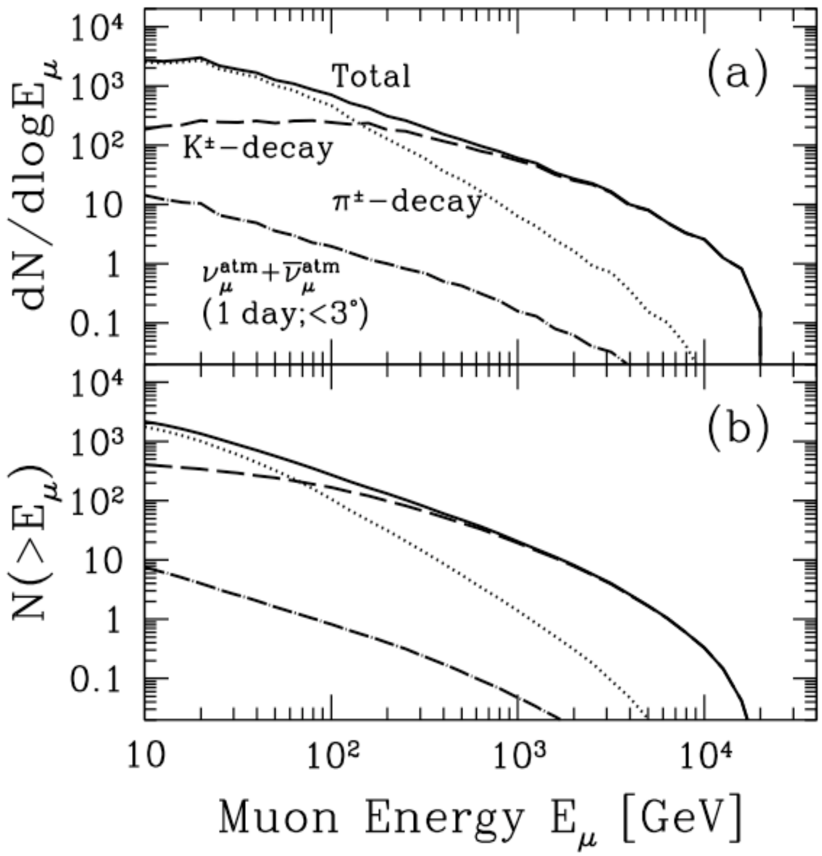
See talk by Aharonian (Friday);
e.g. astro-ph/0505380, etc)

Semi-relat. (“slow”) jets in core-collapse SN?



- Maybe all core coll. (II or Ib/c) SN resemble (watered-down) GRB?
- Evidence for asymmetric expansion of c.c. (Ib/c) SNR:
  - asymmetric remnants
  - optical polarization
  - jets may help eject envelope
- $\rightarrow$ slow jets $\Gamma\sim$ few ?

TeV ν from slow jet SN?



Razzaque, Mészáros, Waxman ‘04, PRL 93, 181101;
(err: ‘05, PRL 94, 9903)
Ando, Beacom (Kaons from pp - astro-ph/0502521)

- If slow jets, accel protons while jet inside star,

  $p\gamma \rightarrow \pi\mu \rightarrow$ ν_μ (*TeV*)
- **Diffuse flux: might be interesting**

  (if 100% SNII make jets),

  but, more interestingly:
- **individual SN** in nearby (2-3 Mpc) gals, e.g. M82, NGC253,

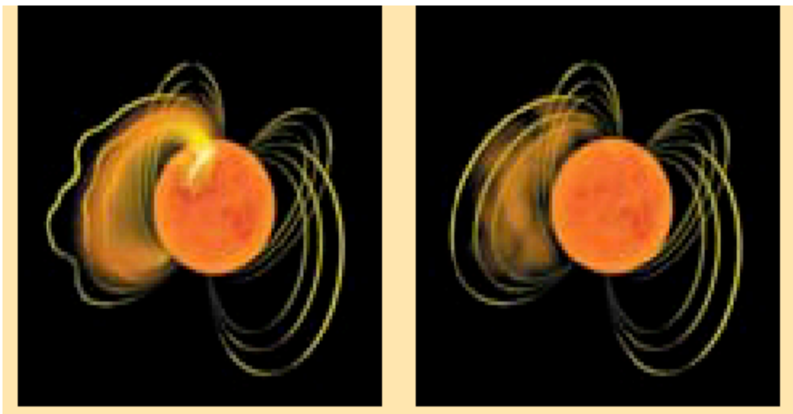
  → ***detectable*** (if have slow jets),

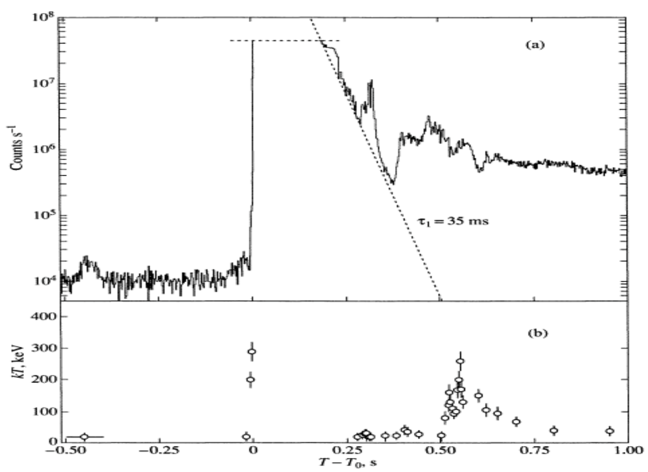
  at a rate ~ 1 SN/few yr,

  fluence ~ 100 up-muons/SN,

  negligible background, in km^3 detectors - **ICECUBE, KM3NeT**

SGR 1806-20 giant flare



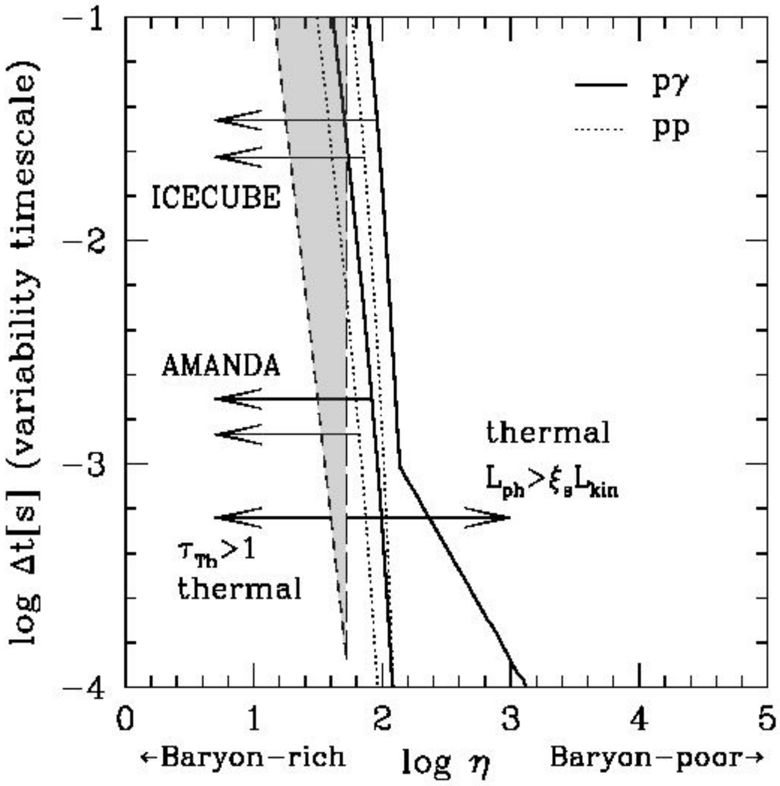


- SGRs are thought to be galactic NS with ultra-strong magnetic fields (magnetars)
- Occasionally “giant flares”,
- E.g. SGR1806-20 Dec 27 ‘04,
  $E_\gamma \sim 3\ 10^{46}$ erg , t~0.1 s ;
- but energy of radio afterglow
  > kin. en. of surviving $e^\pm$
  $\rightarrow$ baryons in fireball ?
  $\rightarrow$ shocks, γ-rays

(e.g. Nakar et al, aph/0502148, …)

UHE ν , γ , CR

from SGR 1806-20 giant flare?

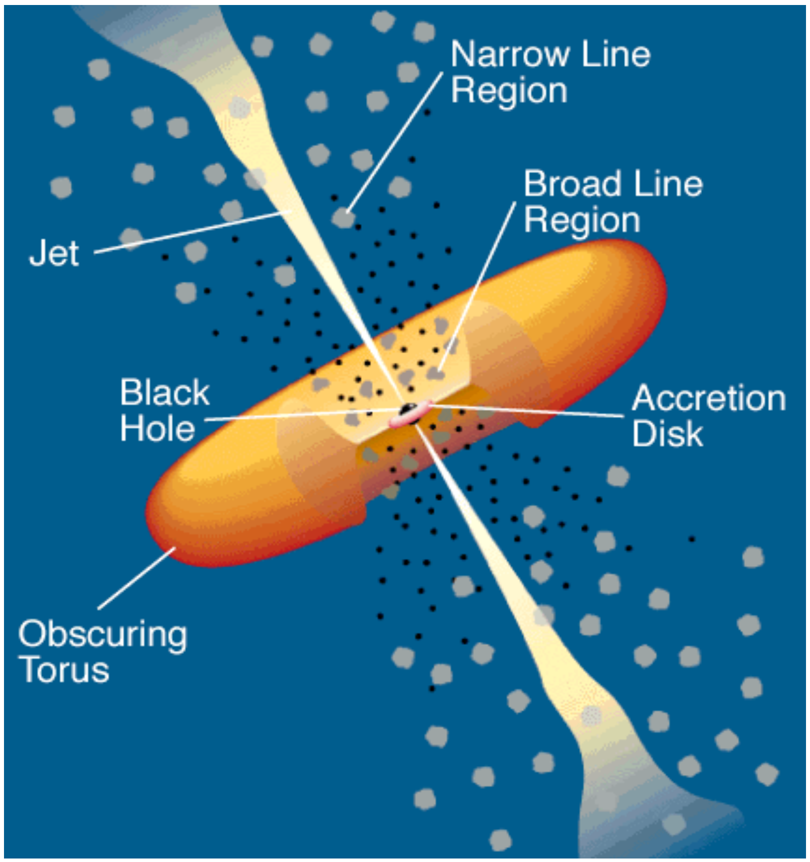


- γ-flare spectrum poorly constrained →Lorentz factor, baryon load unconstrained
- baryon-poor (Γ~100), γ therm, shocks outside photosphere
- baryon-rich (Γ~10), γ nontherm, shocks inside photosphere

Ioka, Razzaque, Kobayashi, Mészáros astroph/0503279

Halzen et al, aph/0503348, Asano et al, aph/0503335, Fan et al, aph/0505483

AGN as UHE ν sources



- Big brother of GRB: massive BH (10^7-10^8 M_{sun}�) fed by

  an accretion disk → jet –
- But, jet $\Gamma_{jet,agn}$ ~10-20

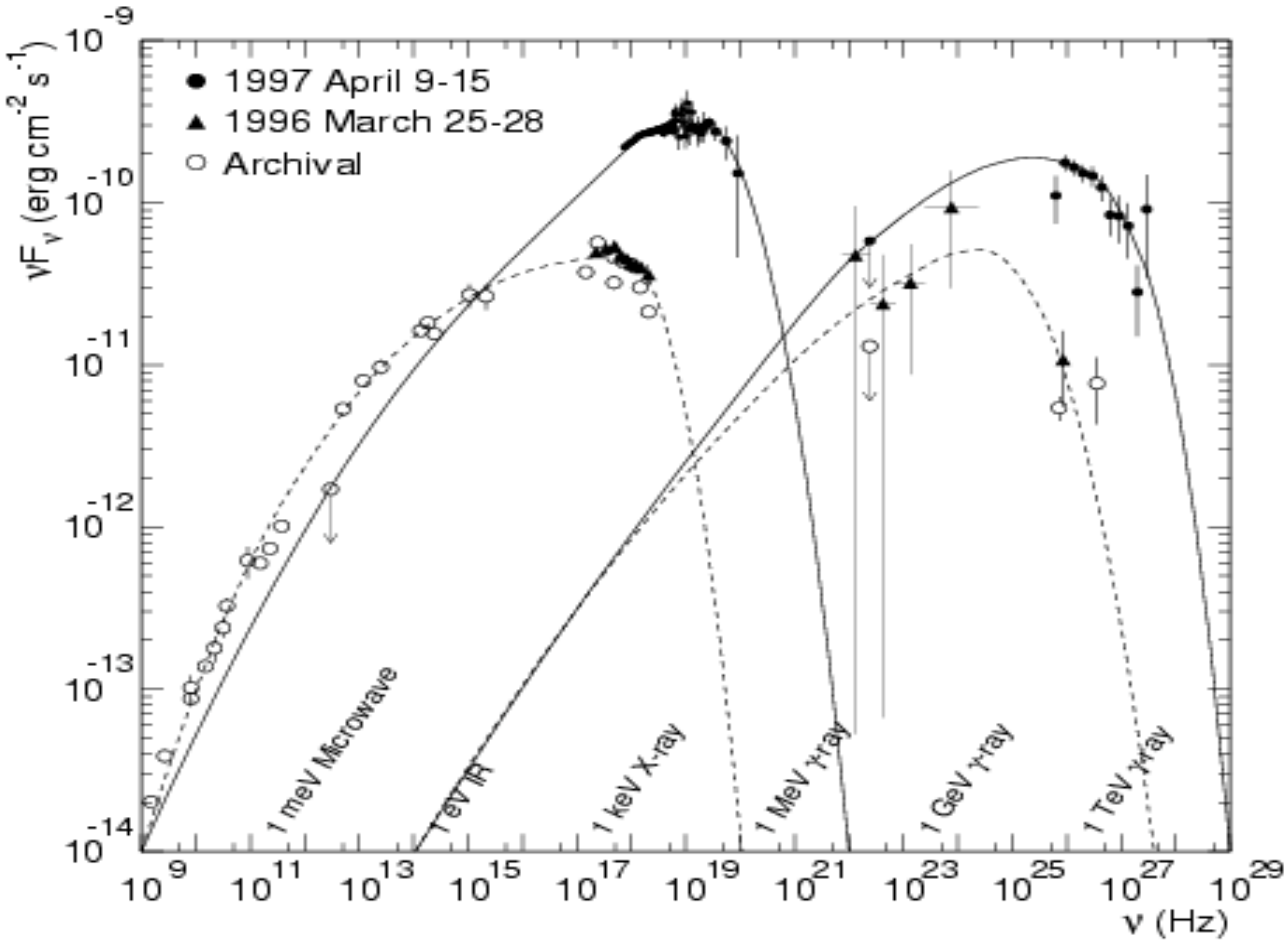
  (while Γ_{grb} ~ 10^2-10^3)
- UV photons from disk; in addition, line clouds provide extra photons

  (+back-scatter)
- Typical ("leptonic") model:

  SSC (sync-self-compton); SEC(sync-exter.compton)

Radio-loud blazars (jet nearly head-on):

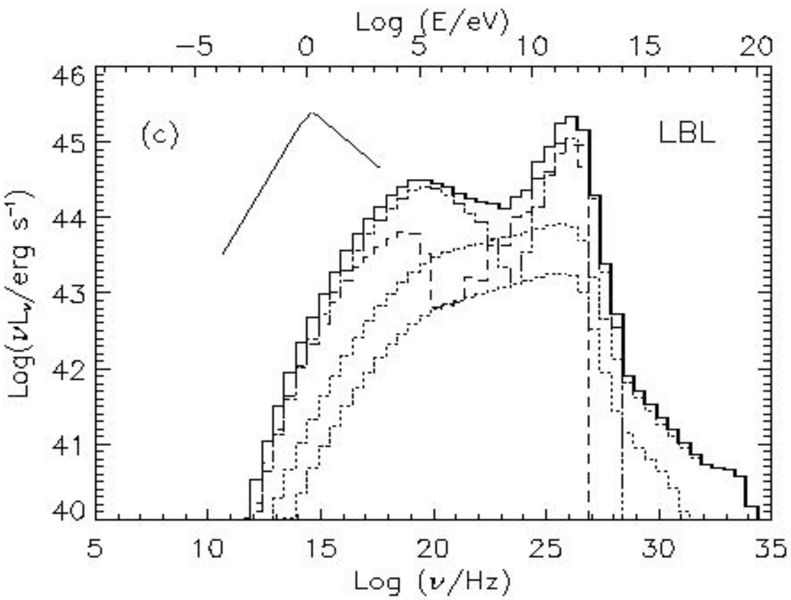
Mrk 501

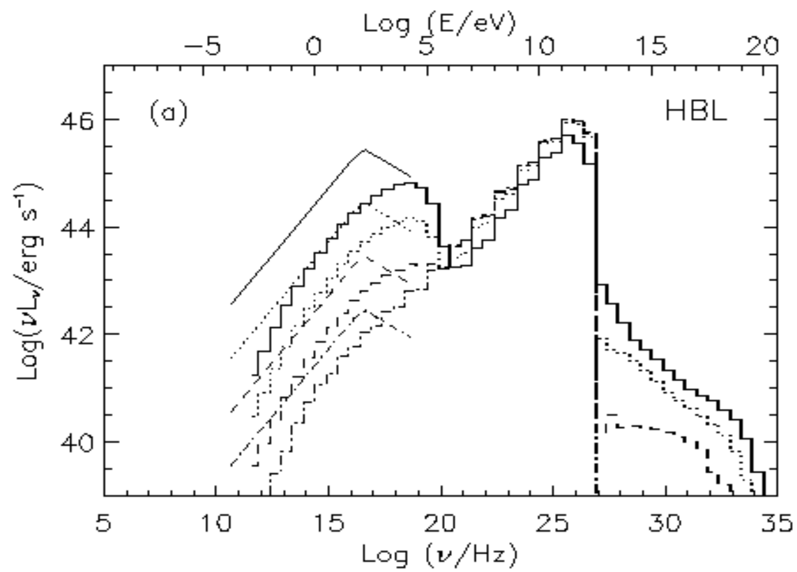


- 1997 flare: TeV; (GeV: upper lim only w EGRET)
- GeV detected sometime @ quiescence
- ←Typical "astrophysical" SSC or ESC "**leptonic**" jet γ model fit
- But: competing "**hadronic**" jet γ model fits ∃

Radio-loud hadronic Blazar models

(PSB-proton synchrotron blazar - γ-ray spectrum from cascades)

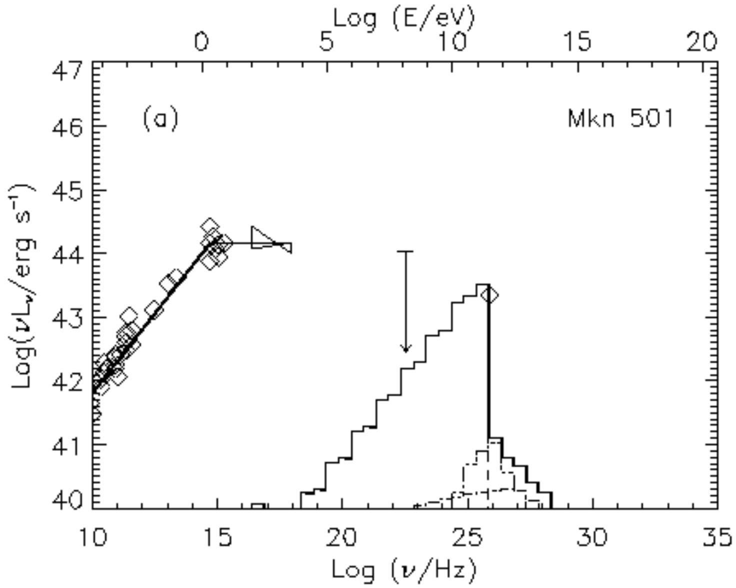


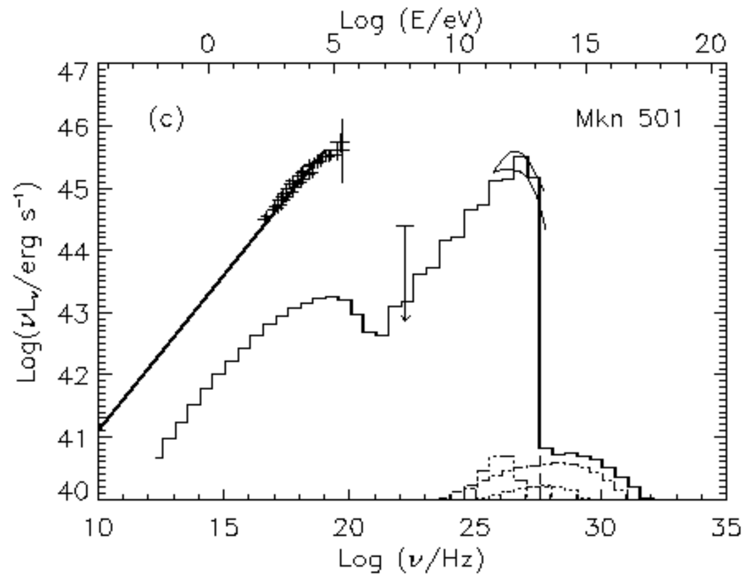


- Full : synchrotron γ SED (target photons)
- Dash: p-sync. casc.; Dash-3 dot: $\mu^{\pm}$-sync. casc; Dots: π^0 casc; Dash-dot: $\pi^{\pm}$ casc

(Muecke, et al, Apph, astro-ph/0206164)

Mrk 501 : protypical HBL



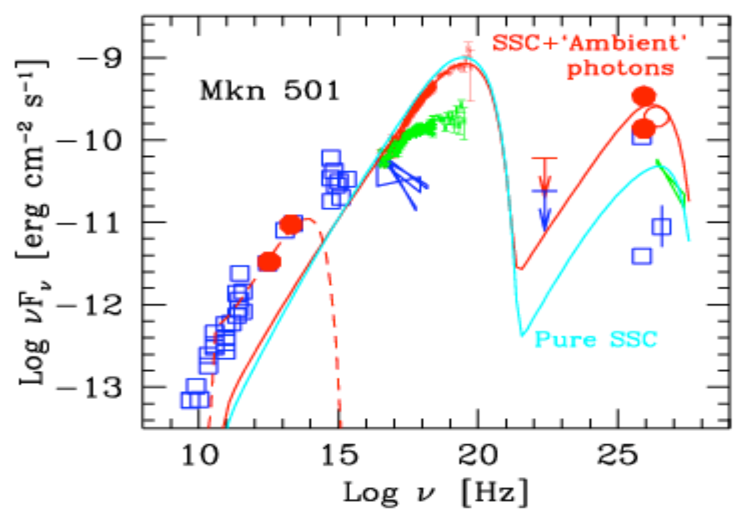


- a) ↑ PSB: Quiet state γ
- b) ↑ PSB: Flare state γ

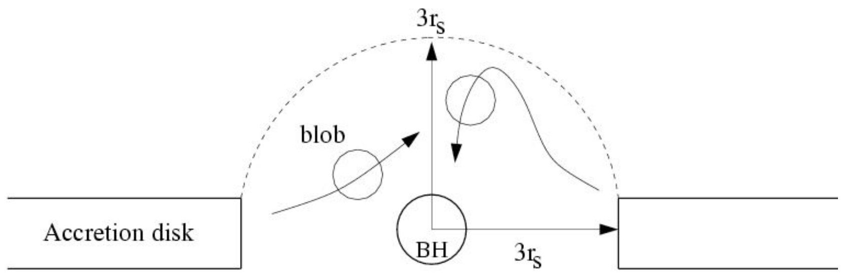
↑ e-sync γ targets + p-sync γ + p,γ casacdes, $\pi\mu$ casacdes & sync (Muecke et al, a-ph/0206164)

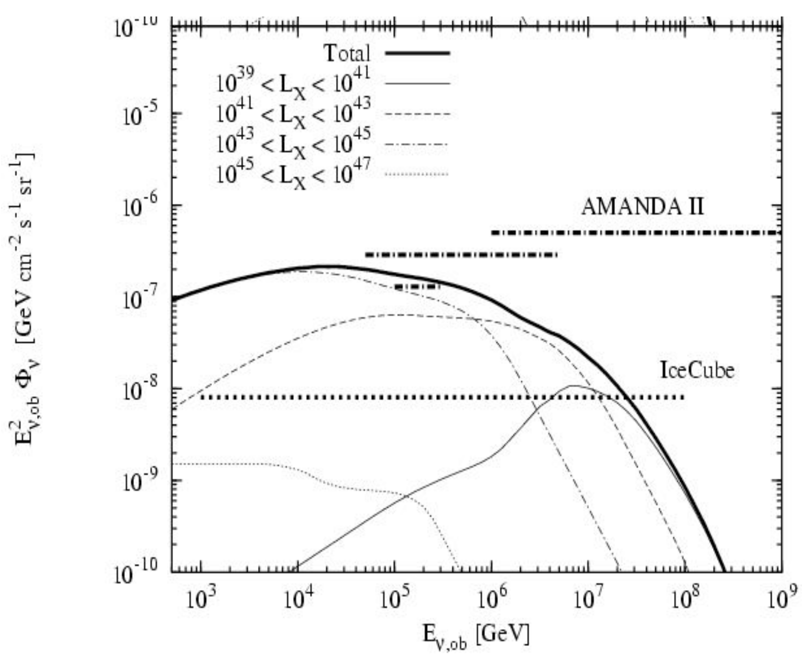
- c) → LEP:Flare state γ

→ e-sync γ + e-Inv. Compton scatt (Ghisellini et al, e.g. A&A 386, 833 (2002) etc – "standard" astrophysical. picture



Radio-quiet (core) AGN νs





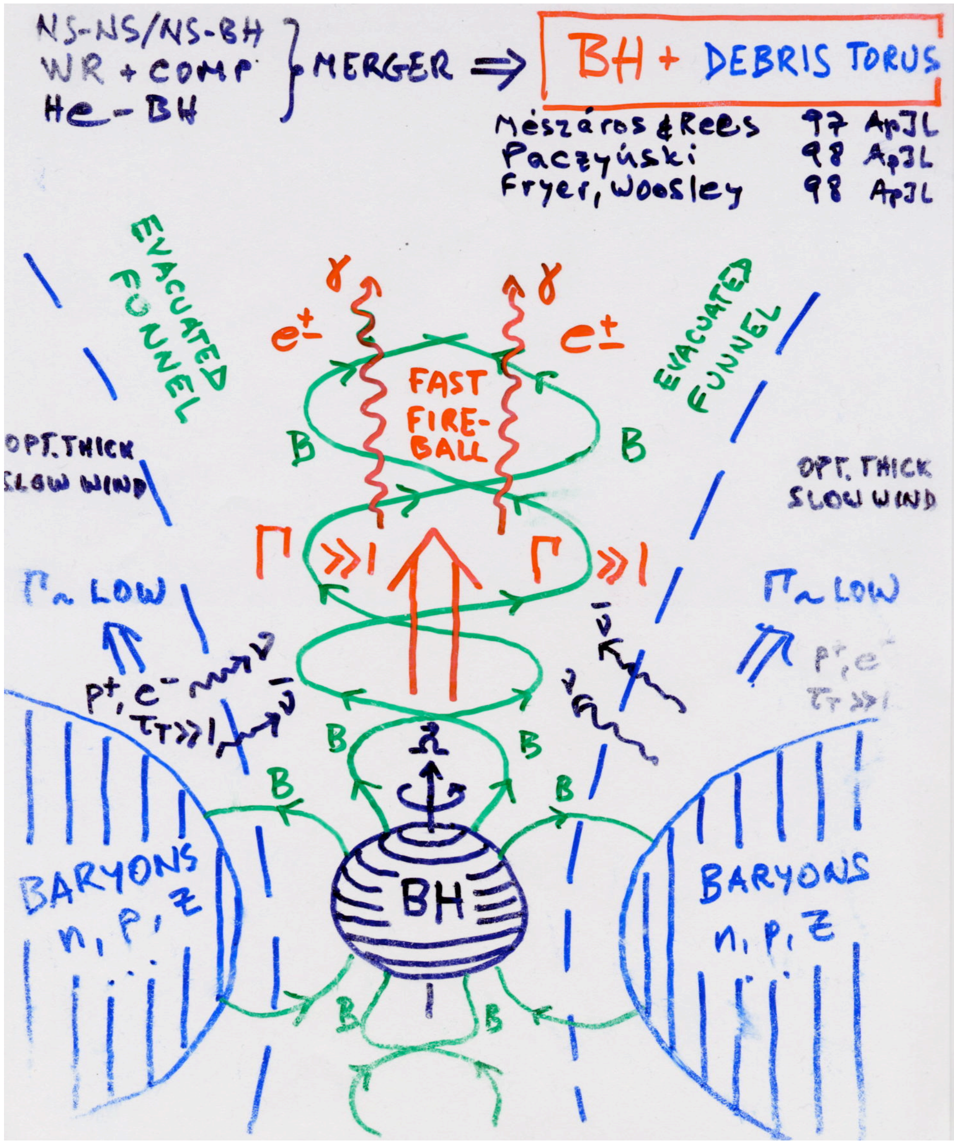
Alvarez-Muñiz & Mészáros, 2004, PRD 70, 123001

- AGN are powered by accretion on massive (10^6-10^8 $M_{\odot}$) BHs
- 90% of AGNs are radio-quiet (no jets), core X-ray
- Core emission model: aborted jet → cloud collisions →shocks → p accel → pγ → ν
- **← Diffuse flux: already constrained by latest AMANDA results**

Conclusions

- Will learn much about GRB in GeV range; many with good photon stats. to 0.1-0.2 TeV
- Will constrain electron acceleration / shock parameters, compactness of emission region (dimension, mag.field,.)
- TeV γ detection: mainly from few/nearby GRB
- TeV ν signals: provide complementary info on hadronic cascade components
- UHE ν will allow test of proton content of jets, test shock accel.physics, magn. field
- If UHE ν NOT detected, $\rightarrow$ jets are MHD!
- Probe ν interactions at ~ TeV CM energies
- Constraints on stellar evolution and death, star formation rates at redshifts of first structures
- Could be probes of “pop III” first gen. Objects
- May test SN-GRB connection & transition

BH + accr. Torus → Jet



- Collapsar or merger →BH+accr.torus
- Nuclear density hot torus → $\nu\nu \rightarrow e^{\pm}$
- Hot infall →conv.
- Dynamo → $B \sim 10^{15}$ G, twisted (thread BH?)
- →Alfvénic or $e^{\pm}p\gamma$ jet
- (Note: magnetar might do similar)

Explosion → FIREBALL

- $E_{\gamma} \; \tau \; 10^{51} \; \Omega_{-2} \; D^{2}_{28.5} \; F_{-5}$ 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~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?

  $E\gamma \; Et > 2(m_e c^2)^2/(1-\cos\Theta) \sim 4(m_e c^2)^2/\Theta^2$

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

  (Fenimore etal 93; Baring & Harding 94)

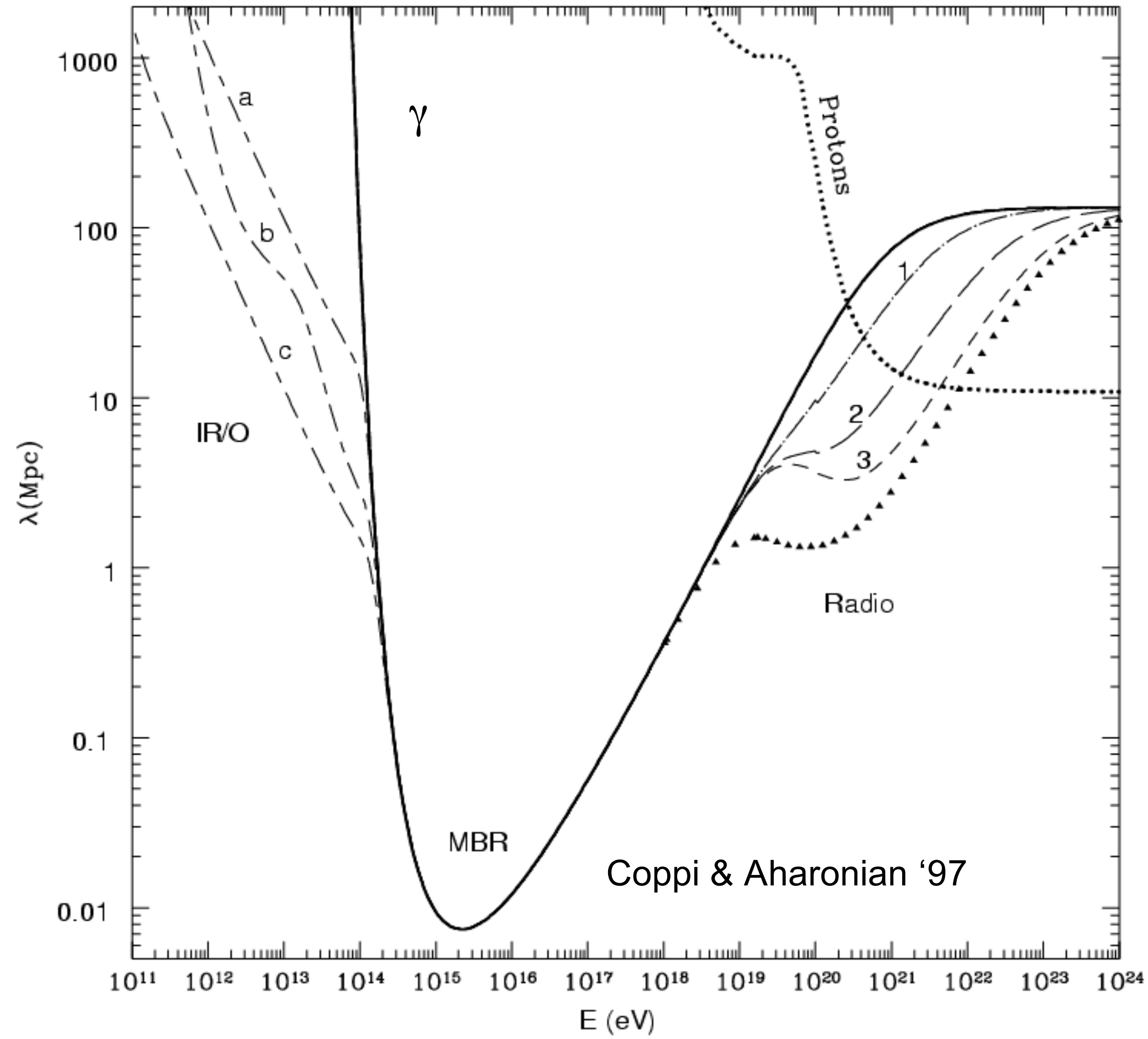
BUT:

- Why is the γ-spectrum non-thermal?
- What explains the very short (τms) variability of the γ- light-curves?
- If bulk Lorentz factor Γ>>1, most energy is kinetic, not radiative → inefficiency?

- **Shocks** in optically thin regime outflow

Rees & Mészáros; external shocks: 1992 MNRAS 258, 41P,
" ; internal shocks, 1994, ApJ(Lett), 430, L93

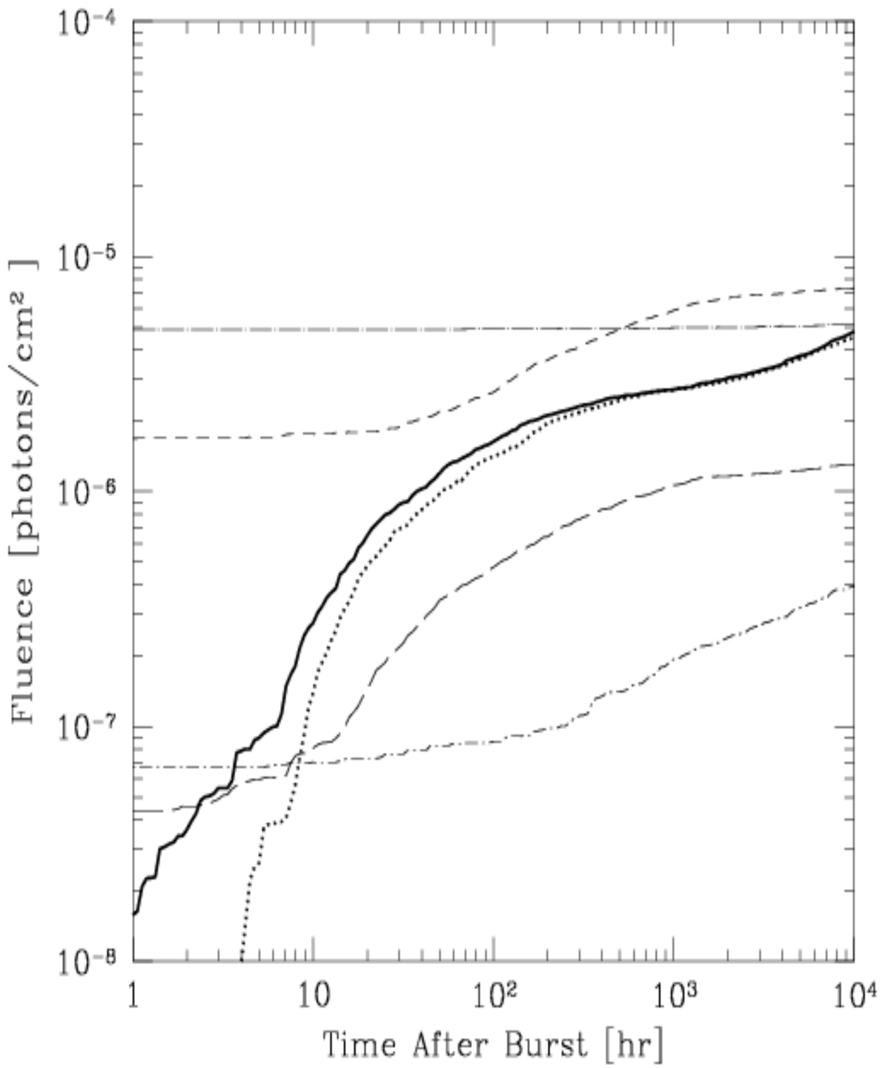
γγ Opacity of the Universe



- All but the densest (veiled) AGN sources (e.g. gal.nuc?) are **transparent**, $\tau_{\gamma\gamma}$ <1, for >TeV γs on "**local**" target photons,

  but..

- Intergalactic medium is **opaque**, $\tau_{\gamma\gamma} \geq 1$, for >TeV γ on **IR** bkg γ (D<100-500 Mpc) →test IR bkg sp. density,
- constrain early star formation rate & z-distr of SFR, LSS, cosmology



Fluence of > 1 TeV γ from E=10^{51} erg GRB at 100 Mpc
In patchy IGM (80% voids w. B~10^{-15} G, 20% B~10^{-11} G;
TeV Fluence ~2% of energy in GZK protons

TeV secondary γ from UHE p

- GRB can accelerate p to E_p ~10^{20} eV
- Cascades on bkg CMB & IR $\gamma \rightarrow e^{\pm}$
- $e^{\pm}, \gamma_{cmb,ir} \rightarrow e^{\pm}, \gamma_{TeV}$
- Delay: p, $e^{\pm}$ in B_{igm} → 0.1-1 TeV γ from d<100 Mpc in Δt~dy
(Waxman & Coppi 96, ApJL (/9603144)
- More detailed calculation: Dermer, 02 ApJ,

Delayed Secondary GeV γ-rays from GRB

- TeV γ-rays from GRB shocks pair-produce on IR bkg γ's, and $e^{\pm}$ IC upscatter CMB γ's, $\rightarrow$ 60-800 MeV secondary γ
  $\Delta t \sim 10^3$ s delayed (max[$t_{\gamma\gamma}$, t_{IC}] obs frame), $N_{sc}/N_{\nu} \sim 5$, $E_{GeV} \sim E_{MeV}$, $N_{\nu}^{sc} \sim \nu^{-(p+6)/4}$ ($N^{\nu} \sim \nu^{-(p+2)/2}$)

  (Dai, Lu '02, ApJL , a-ph/0203084)