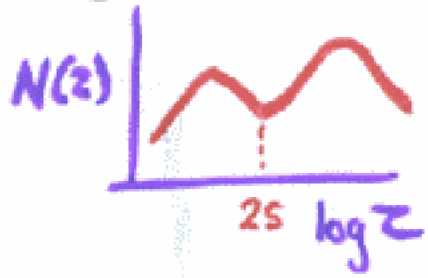
GAMMA RAY BURSTS

PROPERTIES OF GRBs

(γ RAY BURTS)

- DISCOVERY : VELA SATEL. 1960's
- FRECUENCY ~ 3/DAY
- DURATION $10^{-3}s \rightarrow 10^{3}s$

  SOMEWHAT BIMODAL



- STRUCTURE

  VERY VARIABLE, SUCCESIVE SHORT PULSES

- VARIABILITY : DOWN TO 10^{-3} s

  $c\tau = 300$ km VERY COMPACT SOURCE

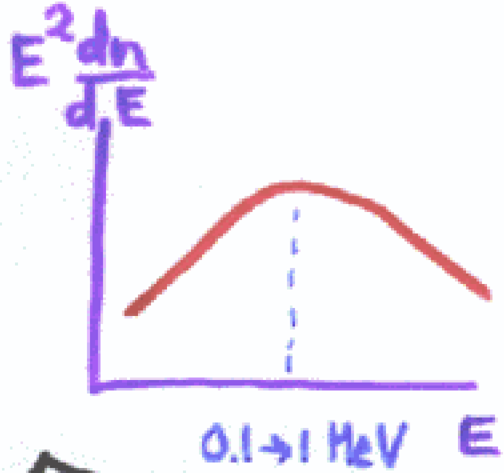
- FLUENCE $10^{-3} \leftrightarrow 10^{-7}$ erg/cm^2

SPECTRUM

$$\frac{dn_\gamma}{dE_\gamma} \propto E_\gamma^{-\alpha}$$

$\alpha \simeq 1.0 \rightarrow \alpha \simeq 2.3$

$\neq$ THERMAL



VERY LITTLE FLUX IN keV, GeV γS

DIRECTIONAL DISTRIBUTION

ISOTROPIC ← GALACTIC HALO

ISOTROPIC ← "COSMOLOGICAL"

AFTERGLOW

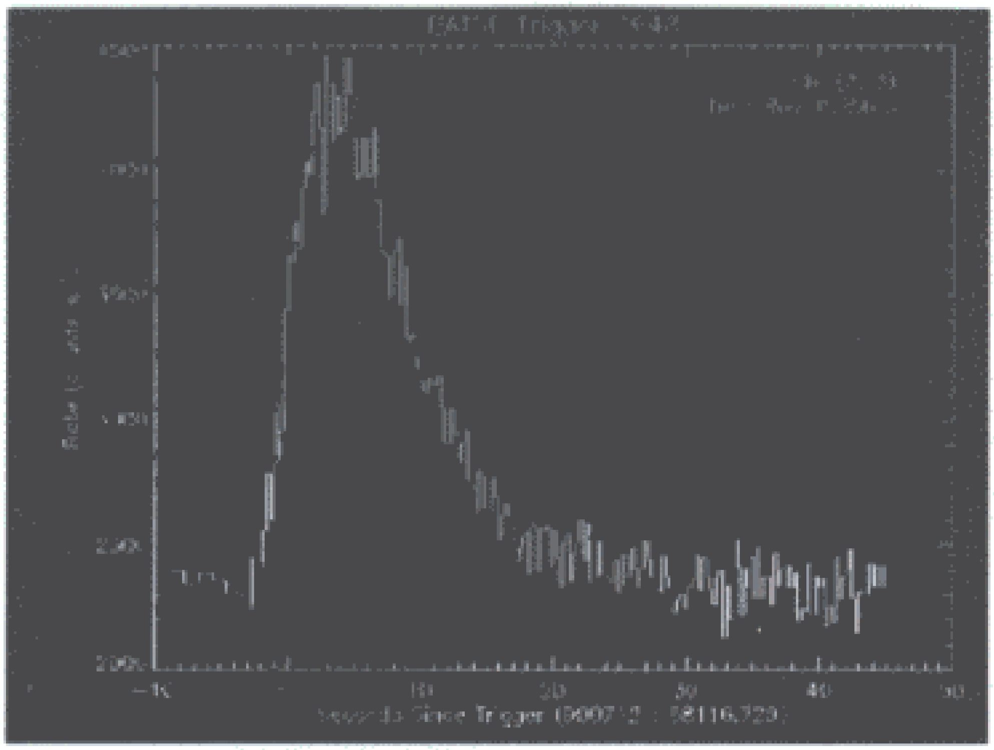
Radio → X ray

BEPPO-SAX

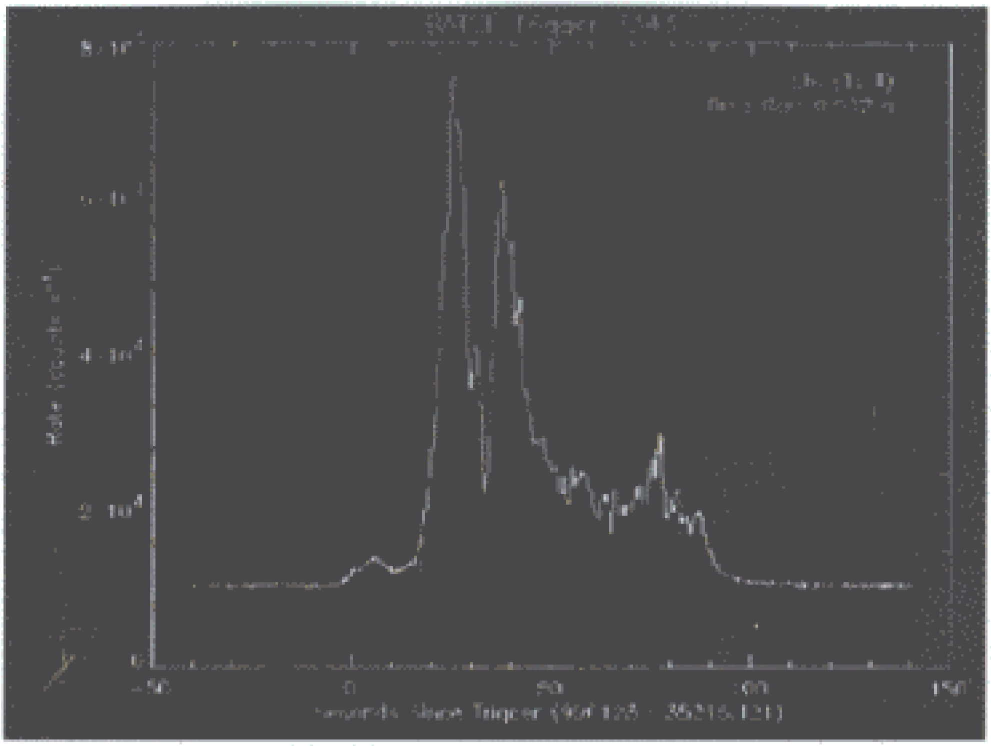
τ_{AG} ~ DAYS/MONTHS

Rossi X-RAY TIMING EXPLORER

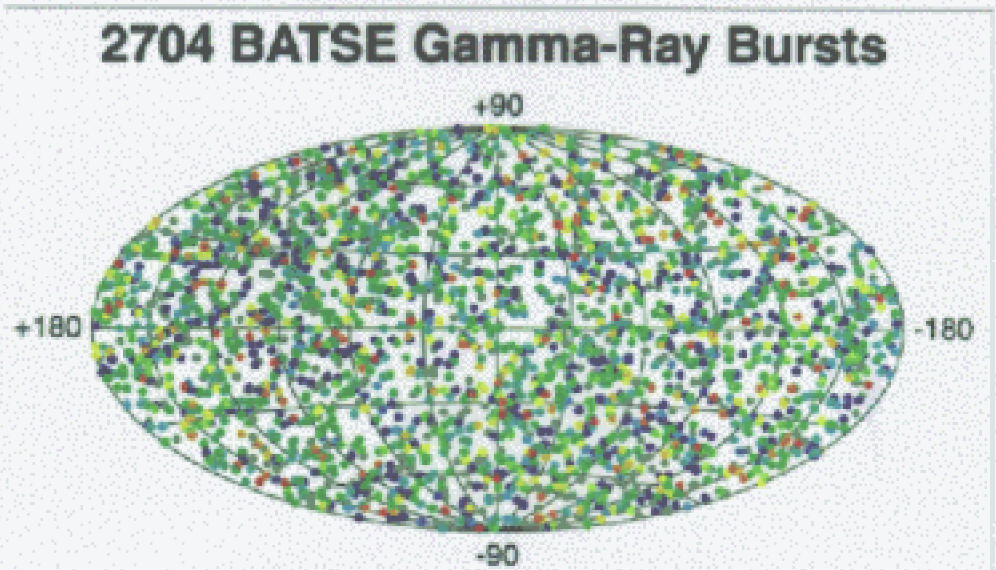
⇨ PROMPT DIRECTIONAL LOCALIZ.


10
20
30
40
50

Fast
Rise
Exponential
Decay


0
-50
0
50
150

GRBs are



ISOTROPIC

SATELLITES

BEPPO-SAX

ROSSI

INTERPLANETARY
NETWORK

FAST AND PRECISE

GRB LOCALIZATIONS

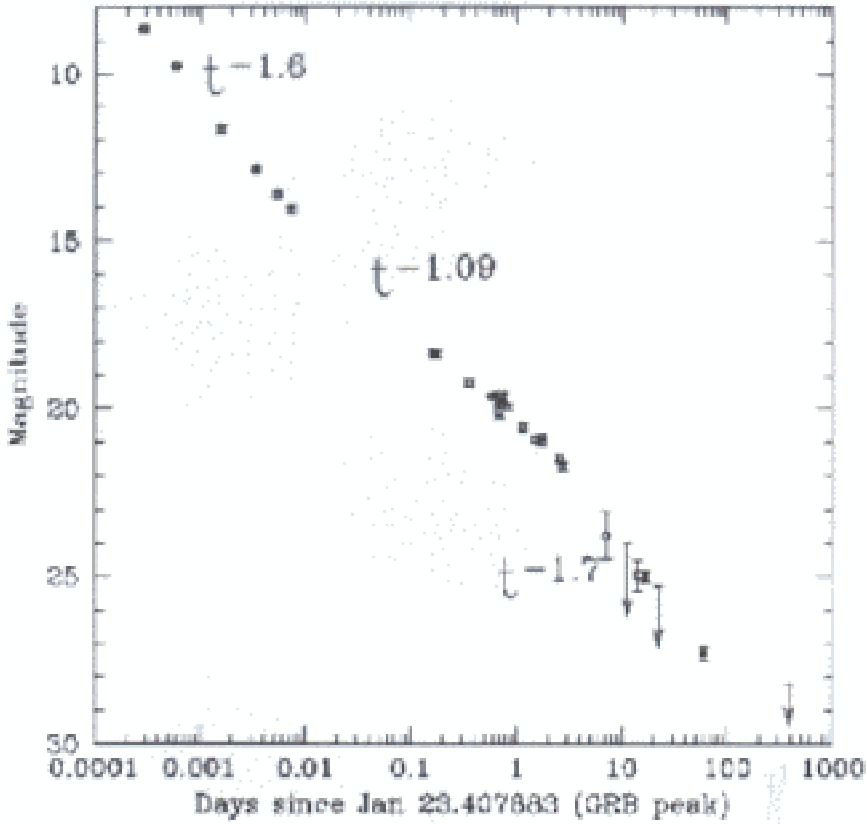
GRBs

HAVE

"AFTER-

GLOWS"

X-RAYS-RADIO



Wide-field Image of GRB 990123 Field

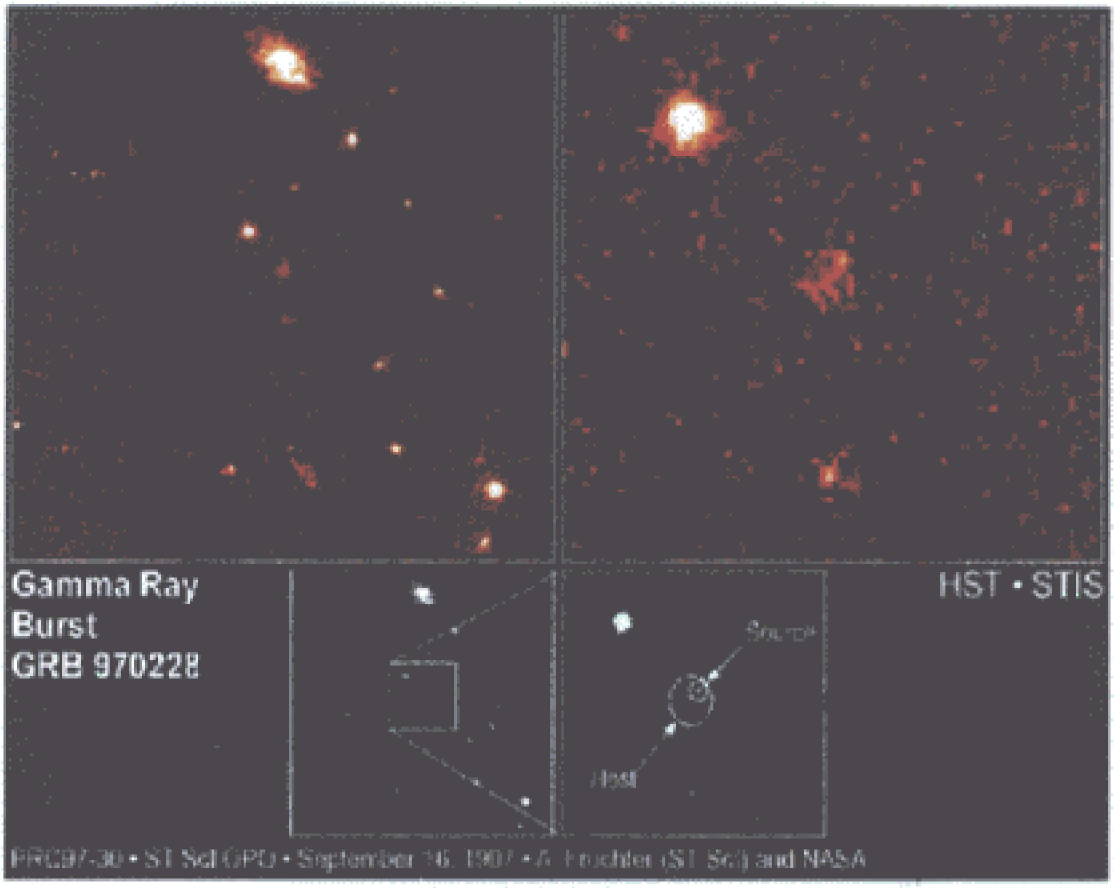

Gamma Ray
Burst
GRB 970228
HST • STIS
Source
Host
PRC97-30 • ST ScI OPO • September 16, 1997 • A. Fruchter (ST ScI) and NASA

Table I - Gamma ray bursts of known redshift z

GRB	z	Ref	D_L [a]	F_γ [b]	E_γ [c]	M [d]	Ref.
970228	0.695	1	4.55	0.17	0.025	25.2	15
970508	0.835	2	5.70	0.31	0.066	25.7	16
970828	0.957	3	6.74	7.4	2.06	—	17
971214	3.418	4	32.0	1.1	3.06	25.6	18
980425	0.0085	5	0.039	0.44	8.14 E-6	14.3	19
980613	1.096	6	7.98	0.17	0.061	24.5	20
980703	0.966	7	6.82	3.7	1.05	22.8	21
990123	1.600	8	12.7	26.5	19.8	24.4	22
990510	1.619	9	12.9	2.3	1.75	*28.5*	23
990712	0.430	10	2.55	—	—	21.8	24
991208	0.706	11	4.64	10.0	1.51	> 25	25
991216	1.020	12	7.30	25.6	8.07	24.5	26
000301c	2.040	13	17.2	2.0	2.32	27.8	27
000418	1.119	14	8.18	1.3	0.49	23.9	28

a: Luminosity distance in Gpc (for $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. *b*: BATSE γ-ray fluences in units of 10^{-5} erg cm^{-2}. *c*: (Spherical) energy in units of 10^{53} ergs. *d*: R-magnitude of the host galaxy, except for GRB 990510, for which the V-magnitude is given.

GRBs

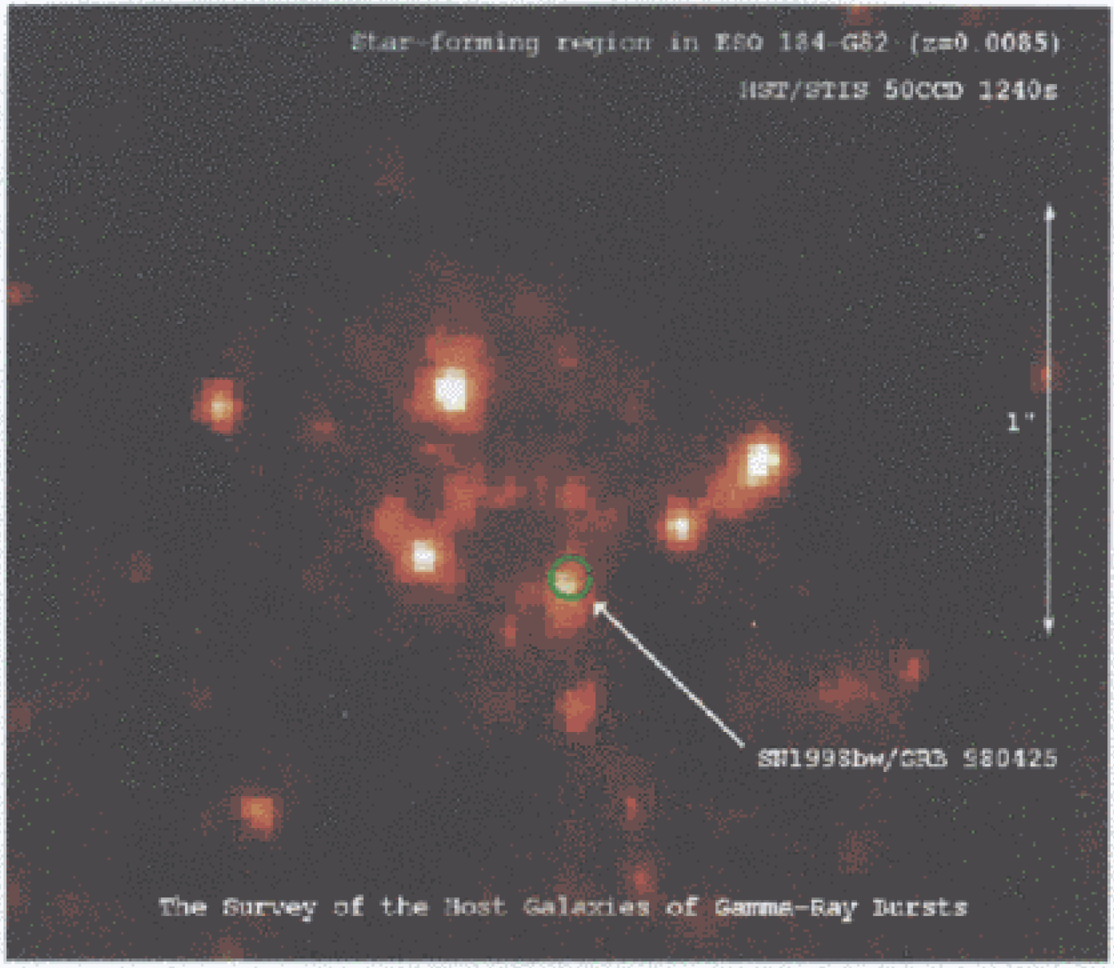
are

"COSMO-
LOGICAL"

GRBS

ARE ASSOCIATED WITH

SUPER-NOVAE



778 d
after
GRB

GRB 1998 :

SUPPOSE SN1998bw

$\approx$ STANDARD CANDLE FOR SUPERNOVAE ASSOC. W. GRBs

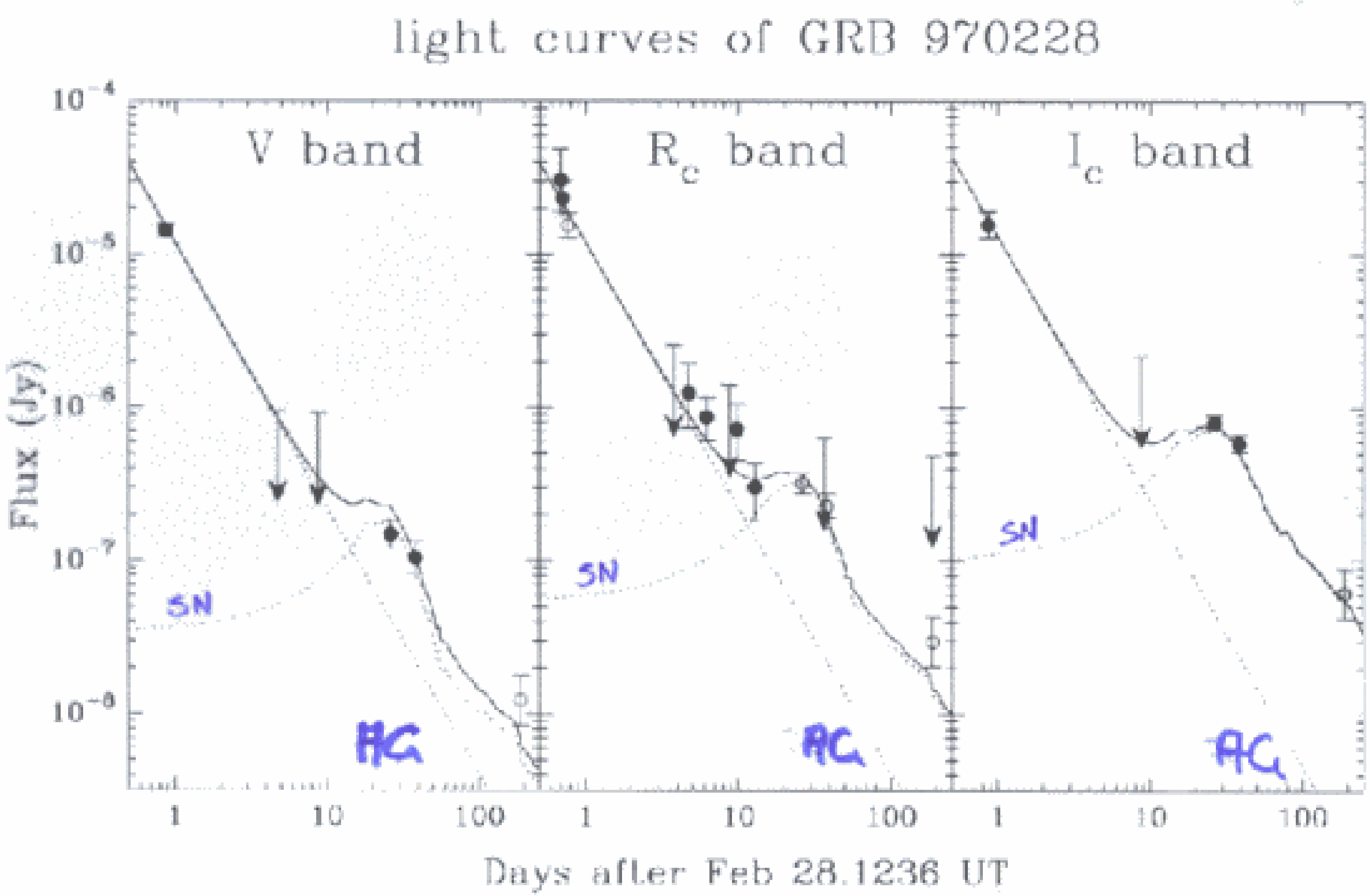
HOW WOULD IT LOOK LIKE AT A DIFFERENT z ?

$z_{bw} = 0.0086$; $F_{bw}[\nu, t]$

$$F_z[\nu, t] = \frac{1+z}{1+z_{bw}} \frac{D_L^2(z_{bw})}{D_L^2(z)} *$$

$$* F_{bw}\left[\frac{1+z}{1+z_{bw}}\nu, \frac{1+z_{bw}}{1+z} t\right] *$$

$$* \frac{A[\nu, z]}{A[\nu, z_{bw}]}$$


light curves of GRB 970228
V band
R_c band
I_c band
Flux (Jy)
Days after Feb 28.1236 UT
SN
SN
SN
AG
AG
AG

OUT OF THE 15 GRBs WITH

KNOWN z (ca DEC 2000)

≥ 6 980425, 000418, ?
970228, 991208,
990712, 980703,

HAVE A BUMP IN THEIR

AFTERGLOW WITH THE

TEMPORAL SHAPE (AND,

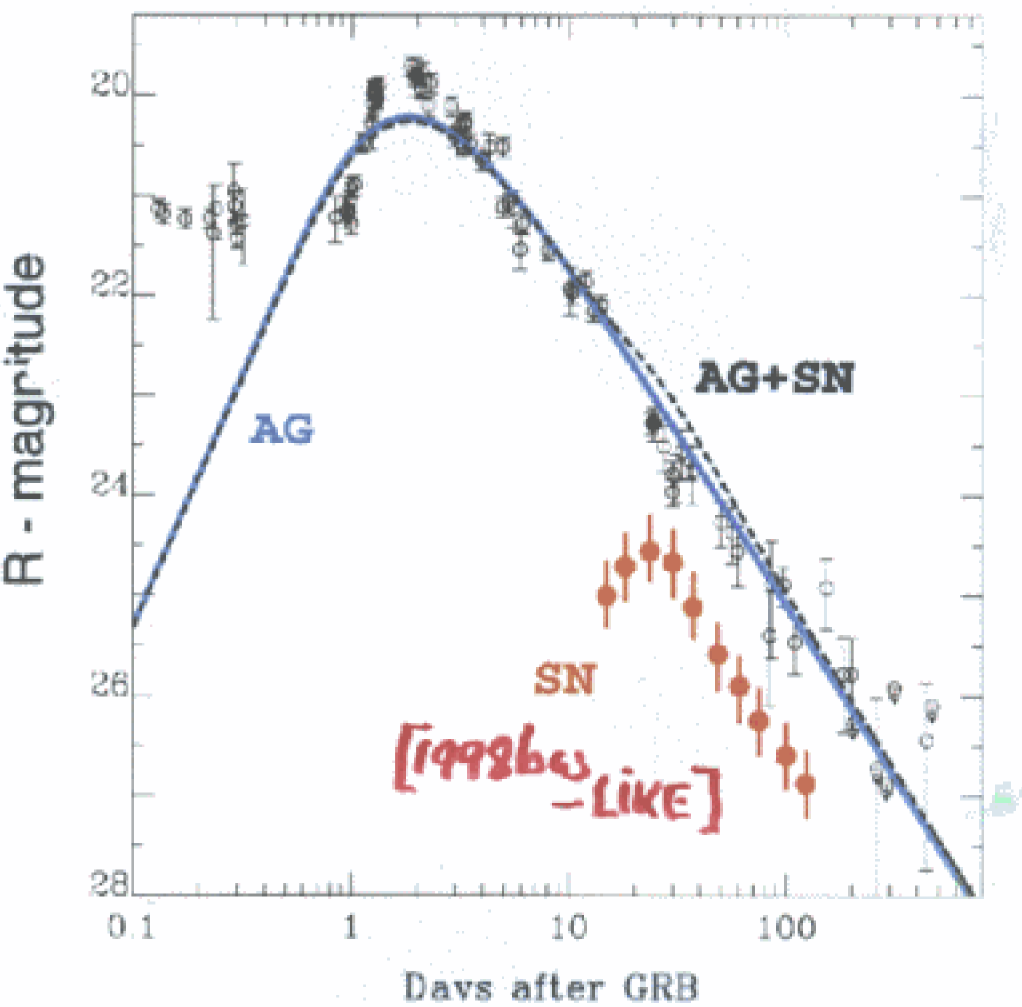
WHEN MEASURED, THE SPECTRUM)

OF A PROPERLY z-SHIFTED SN1998bw

HOW ABOUT THE

OTHER ≤ 9 ??

GRB 97058



R - magritude
20
22
24
26
28
0.1
1
10
100
Days after GRB
AG
AG+SN
SN
[1998bw -LIKE]

IN **ALL** OTHER GRBs WITH KNOWN Z

ONE OR MORE OF THE FOLLOWING IS THE CASE:

I THE AFTERGLOW IS TOO LUMINOUS

II THE HOST GALAXY IS TOO LUMINOUS

III $F(\nu)|_{1998bw}$ NOT KNOWN AT $\nu \ni \nu \to \nu(1+z)$

IV NOBODY WAS LOOKING

EVEN IF A SUPERNOVA WAS THERE...

... YOU COULD NOT SEE IT

POSSIBLY, NOT ONLY

MOST (LONG DURATION)

GRBs ARE ASSOCIATED

WITH SNe (>6/15)

...

BUT, ALSO

A HEFTY FRACTION OF

(CORE-COLLAPSE) SNe

EMIT GRBs

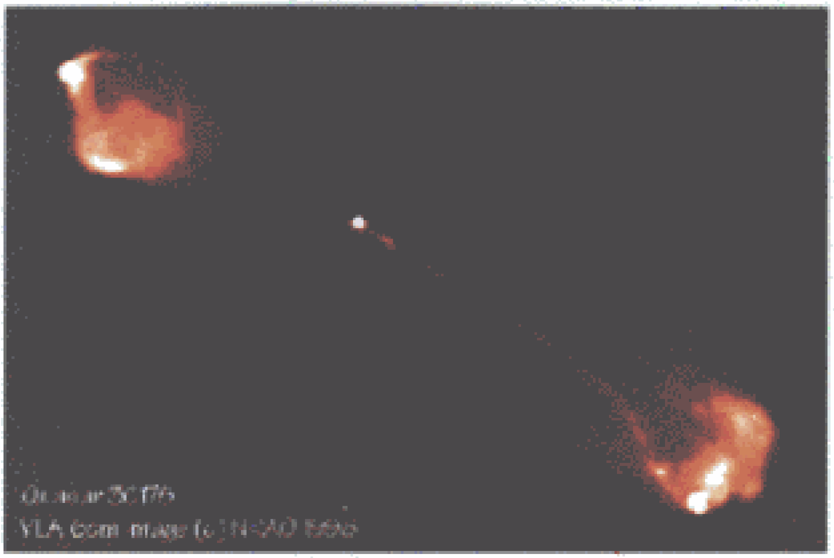
(TO MAKE THE OBSERVED
GRB and SN RATES
COMPATIBLE, THIS WOULD
REQUIRE YOU TO SEE
THE GRB IN ONLY
ONE OUT OF ~ 10^6 SNe)

JETS

in

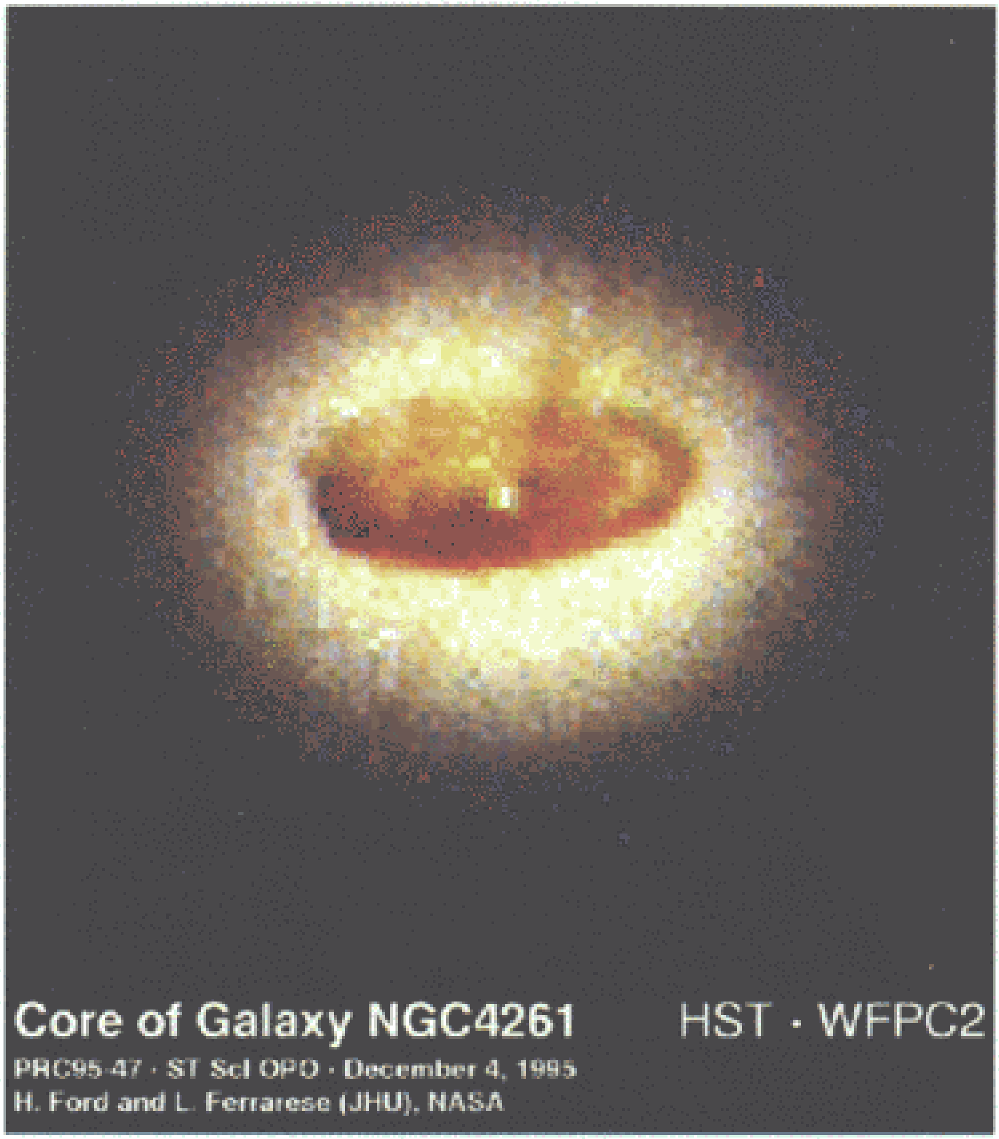
ASTRO-
PHYSICS

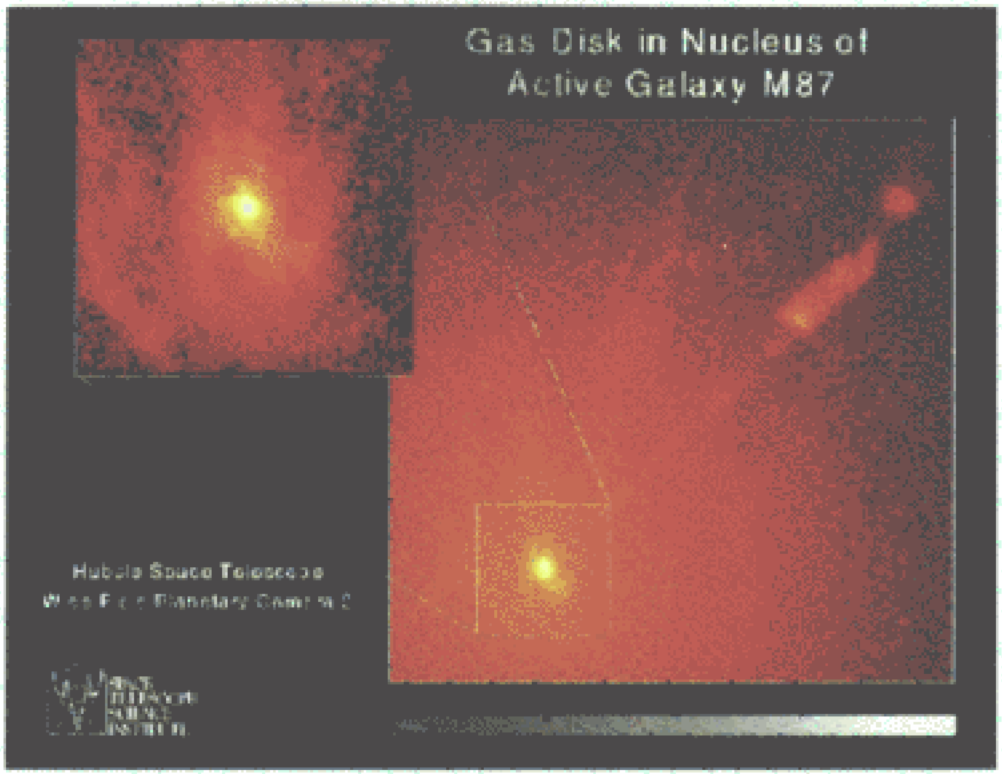
3C175



- Quasar at z=0.768
- Overall linear size 212/*h* kpc (Hubble constant H = 100*h* km/s/Mpc)
- Double lobes with prominent hot spots
- Narrow jet, no counterjet (Doppler hidden?)
- Jet brightens and bends as it enters its lobe
- VLA 4.9 GHz image at 0.35 arcsec resolution

See also Deep VLA Imaging of Twelve Extended 3CR Quasars, by Alan H. Bridle, David H. Hough, Colin J. Lonsdale, Jack O. Burns and Robert A. Laing, *The Astronomical Journal*, **108**, 766-820 (1994). Also related abstract from AAS Meeting #183.


Core of Galaxy NGC4261
HST · WFPC2
PRC95-47 · ST ScI OPO · December 4, 1995
H. Ford and L. Ferrarese (JHU), NASA

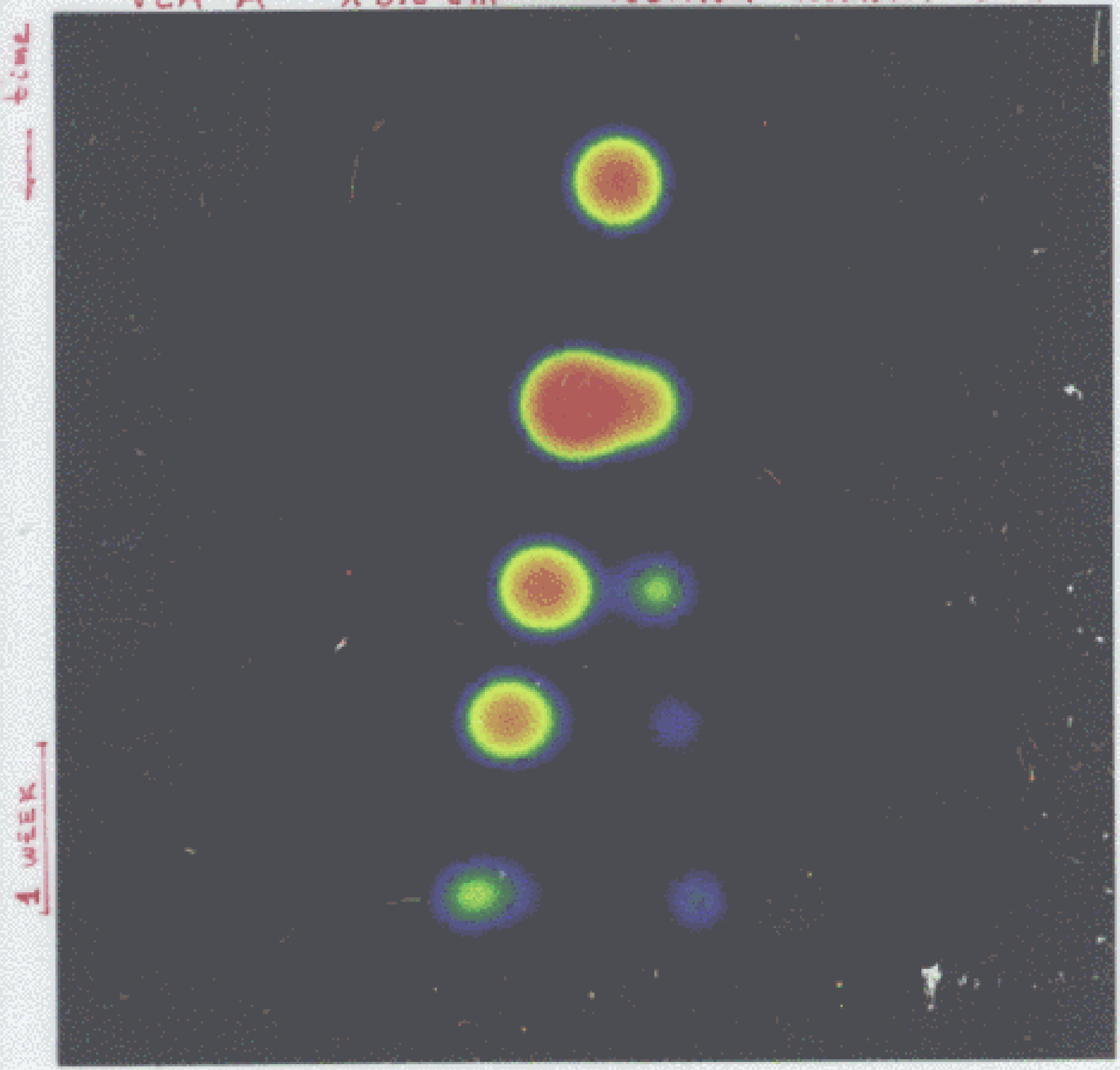

Gas Disk in Nucleus of
Active Galaxy M87
Hubble Space Telescope

μ-QUASARS

GRS 1915+105 ($\ell = 45°$, $b = 0°$)

ANTI-PARALLEL EJECTION OF A TWIN PAIR OF CLOUDS MOVING AT $V = 0.92c$ AND $\theta = 70°$

VLA-A λ 3.5 cm POSITION ACCURACY 0.02"



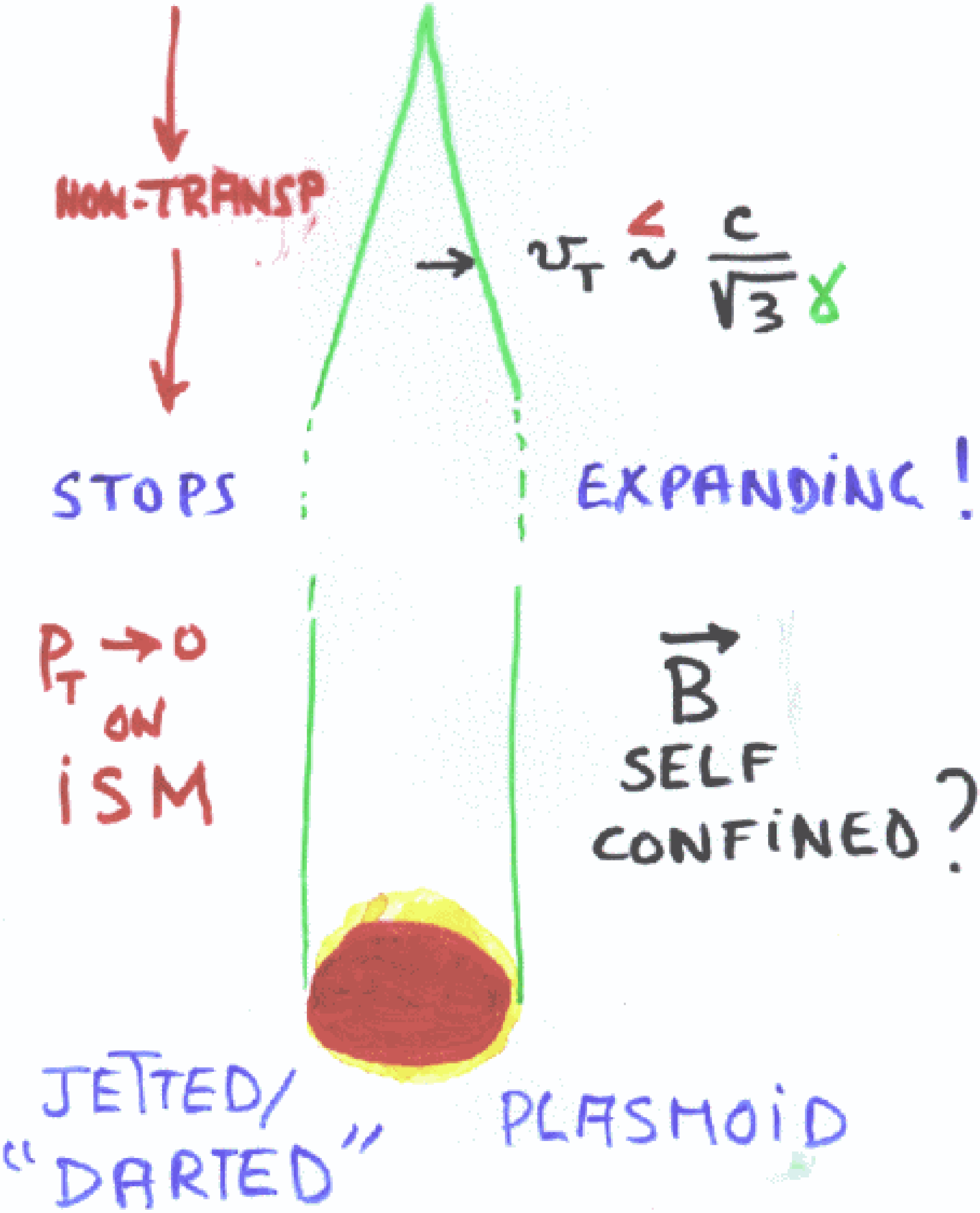
Chandra X-ray Observatory Center

Harvard-Smithsonian Center for Astrophysics
60 Garden St. Cambridge, MA 02138 USA
http://chandra.harvard.edu

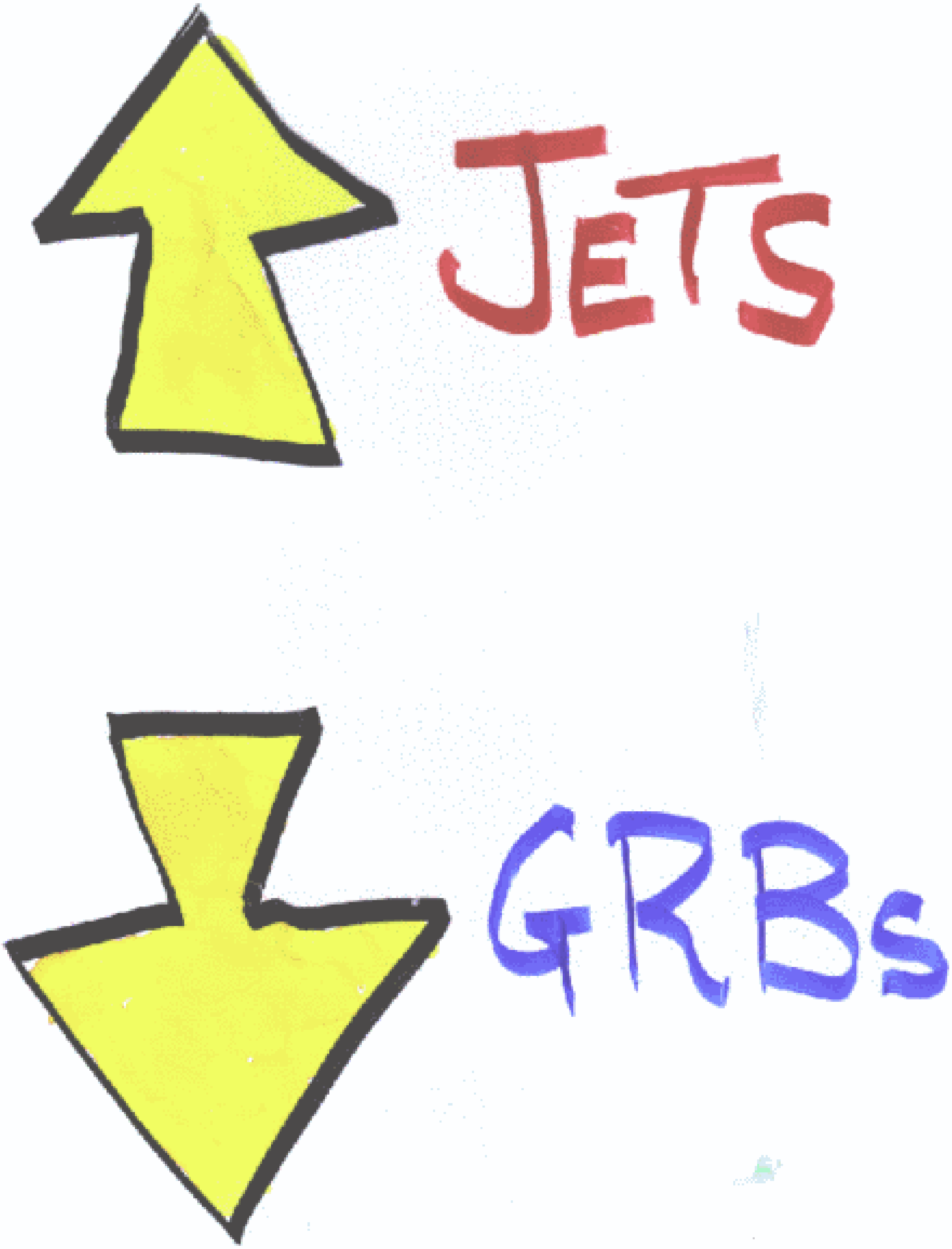
Pictor A: The brightest radio galaxy in the Constellation Pictor.
(Credit: NASA/UMD/A.Wilson et al.)

Caption: Chandra's image of Pictor A gave scientists their first look at a spectacular X-ray jet. The jet originates near a giant black hole in the central region of the galaxy and streaks toward a brilliant X-ray hot spot 800 thousand light years (8 times the diameter of our Milky Way galaxy) away. The hot spot is thought to represent the advancing head of the jet which brightens as it plows into the tenuous gas of intergalactic space.

Scale: The hot spot is 4.2 arcmin from the galaxy.


NON-TRANSP
$v_T \lesssim \frac{c}{\sqrt{3}\,\gamma}$
STOPS
EXPANDING !
$P_T \to 0$ ON iSM
$\vec{B}$
SELF CONFINED ?
JETTED/ "DARTED"
PLASMOiD

CANNON BALL


JETS
GRBs

THE COSMOLOGICAL-GRB ENERGY CRISIS

- TYPICAL FLUENCE $F_\gamma \approx 10^{-5}\ \mathrm{erg/cm^2}$
- 'LUMINOSITY' DISTANCE

$$D_L(z\sim 1.27)\sim 9.6\ \mathrm{Gpc}$$

($\Lambda = .7$, $\Omega_M = 0.3$, $H_0 = 65\ \mathrm{km/s/Mpc}$)

#

$$\bar{E}_\gamma = 4\pi\,\frac{D_L^2 F_\gamma}{1+z} \sim 3.1\ 10^{53}\ \mathrm{erg}$$

E_γ (GRB990123) $\sim 2.6\ 10^{54}$ erg

★-ENERGIES (GRB/SN ASSOCIATION!)

$$\frac{G M_\odot^2}{r_{NS}} \sim 10^{53}\ \mathrm{erg} \qquad M_\odot c^2 \sim 1.8\ 10^{54}\ \mathrm{erg}$$

$\eta(\Rightarrow \gamma$ RAYS$) \sim 10^{-4}$

STRONG INDICATION AGAINST SPHERICITY

INDICATIONS of RELATIVISTIC MOTION

FAST VARIABILITY (SMALL SIZE) ⇓ LARGE LUMINOSITY

OPTICALLY THICK TO $\gamma\gamma \rightarrow e^+e^-$

⇓

EXPECT CUTOFF $F(E_\gamma > 0.5\text{-}1\,\text{MeV})$

NOT SEEN !

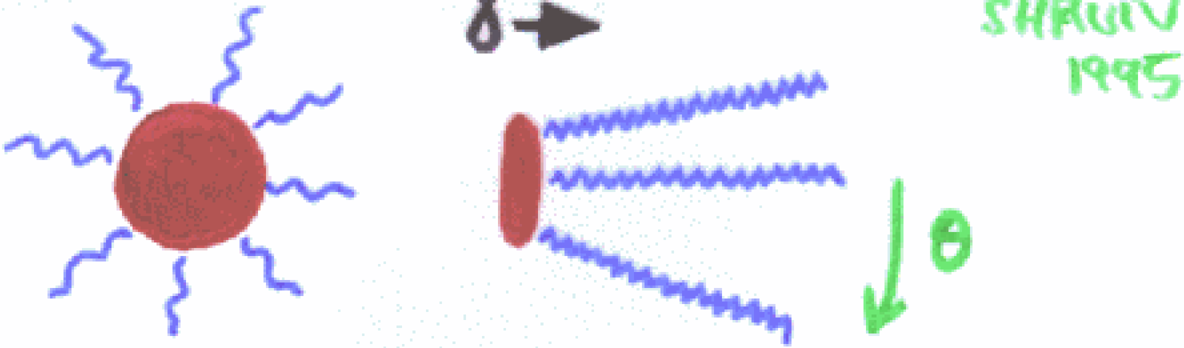
BOO ⇓ OOOST !!

$\gamma = E/m \sim 10^{2\div3}$

e^+e^- CUTOFF RISES TO UNOBSERV. HIGH ENERGY (FLUX SMALL)

WHAT IS MOVING FAST AND IS NOT SPHERICAL ¿?

A JET!

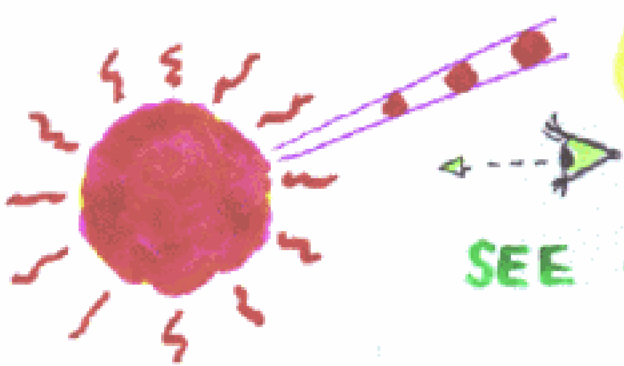


$$\theta \sim 1/\gamma$$

$$\Delta\Omega \sim \pi/\gamma^2$$

$\gamma > 100$ SOLVES THE ENERGY CRISIS

$\gamma \sim 10^3$ MAKES THE GRB and SN RATES COMPARABLE

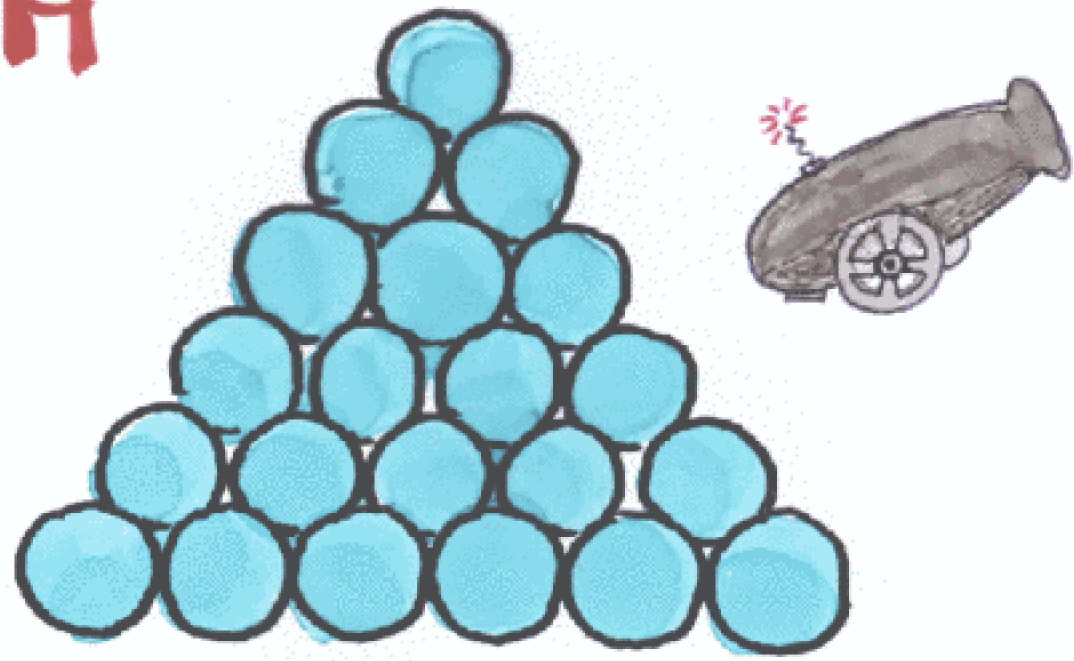


$$\frac{\Delta\Omega}{4\pi} \sim \frac{1}{4\gamma^2}$$

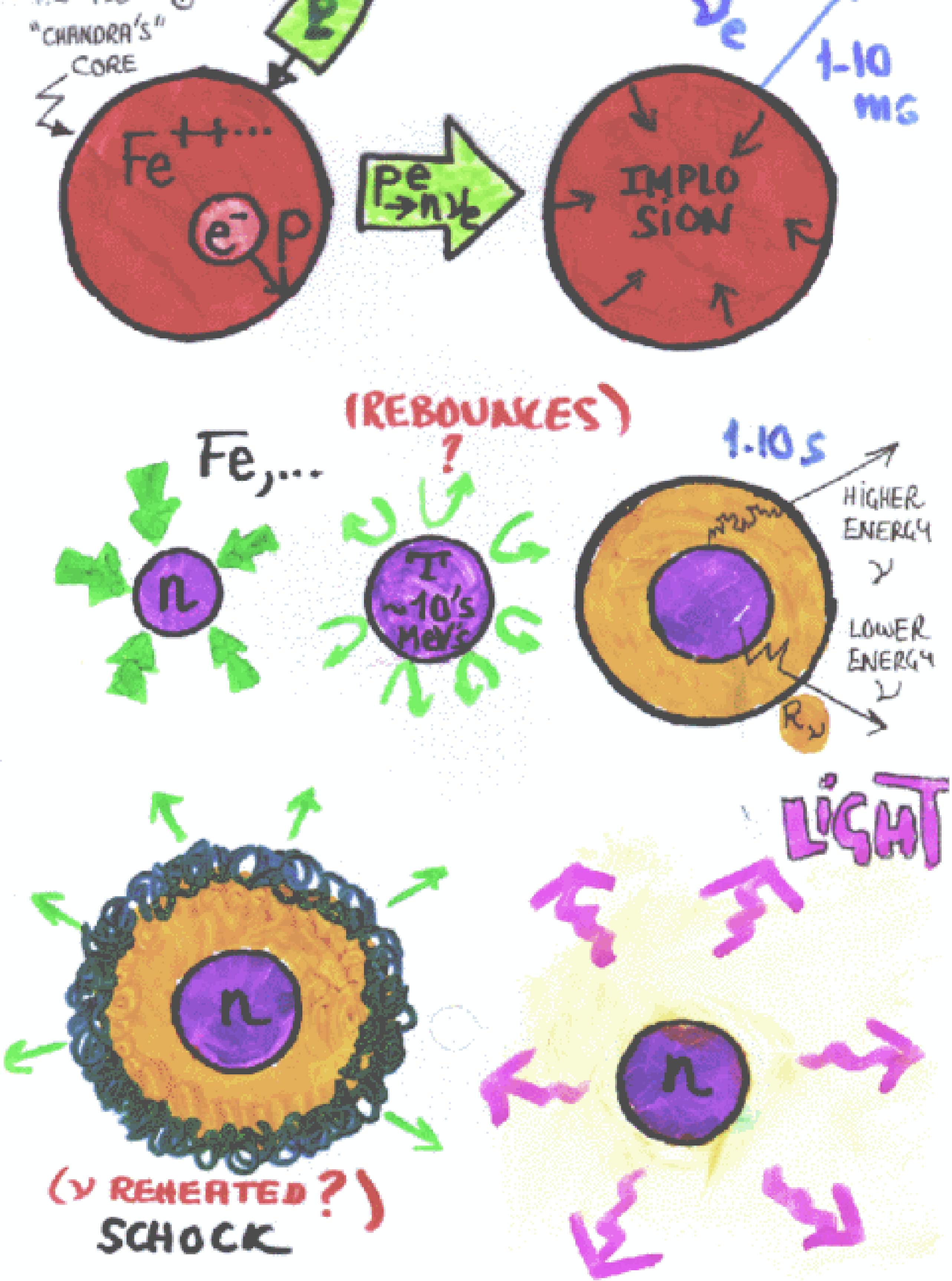
SEE $O(10^6)$ SNe PER GRB

A

ADR



MODEL of GRBs

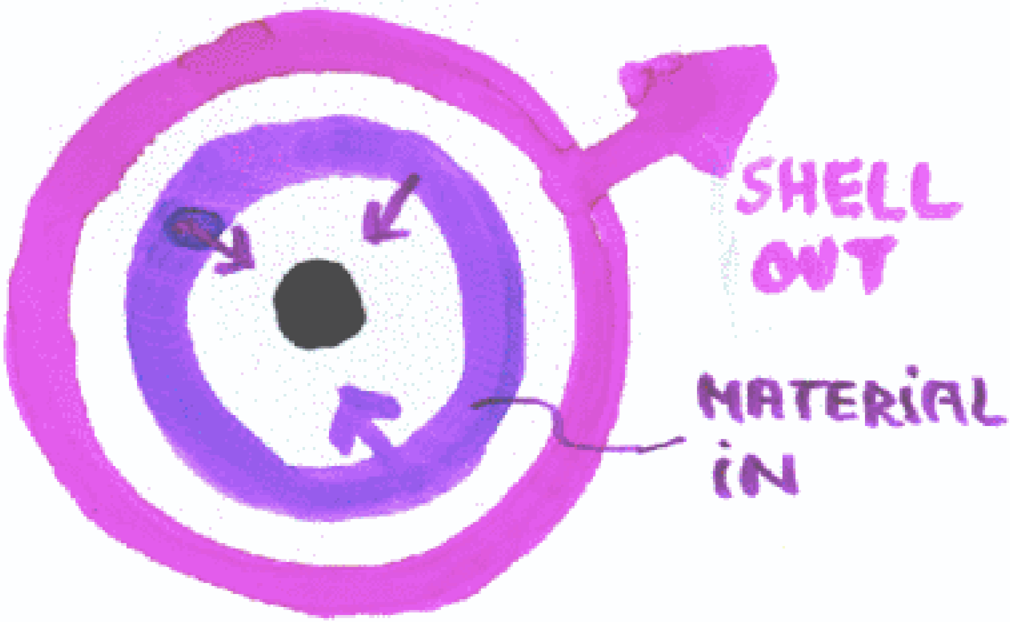

"CHANDRA'S"
CORE
Fe+++...
e⁻
p
pe→nν_e
IMPLOSION
ν_e
1-10 ms
(REBOUNCES)
?
Fe,...
n
T
~10's MeV's
1-10 s
HIGHER ENERGY ν
LOWER ENERGY ν
R_ν
n
(ν REHEATED ?)
SCHOCK
LIGHT
n

1. CORE-COLLAPSE "SN-CODES" FAIL TO EXPLODE THE STARS "SHOCK STALLS"

2. SN1987A MAY HAVE HAD 2 ν BURSTS

ADR 1987 : SNe MAY "BANG" TWICE

→ NS → BH (SS)



NO NS SEEN IN 1987A

ACCRETION-INDUCED GRBS

DAR et al 1992

WOOSLEY 1993

WOOSLEY MACFADYEN 1999

$r < R_\star$

$$t_{fall} \sim \pi \left[\frac{R_\star^3}{8GM_c}\right]^{1/2}$$

FALL-BACK MATERIAL

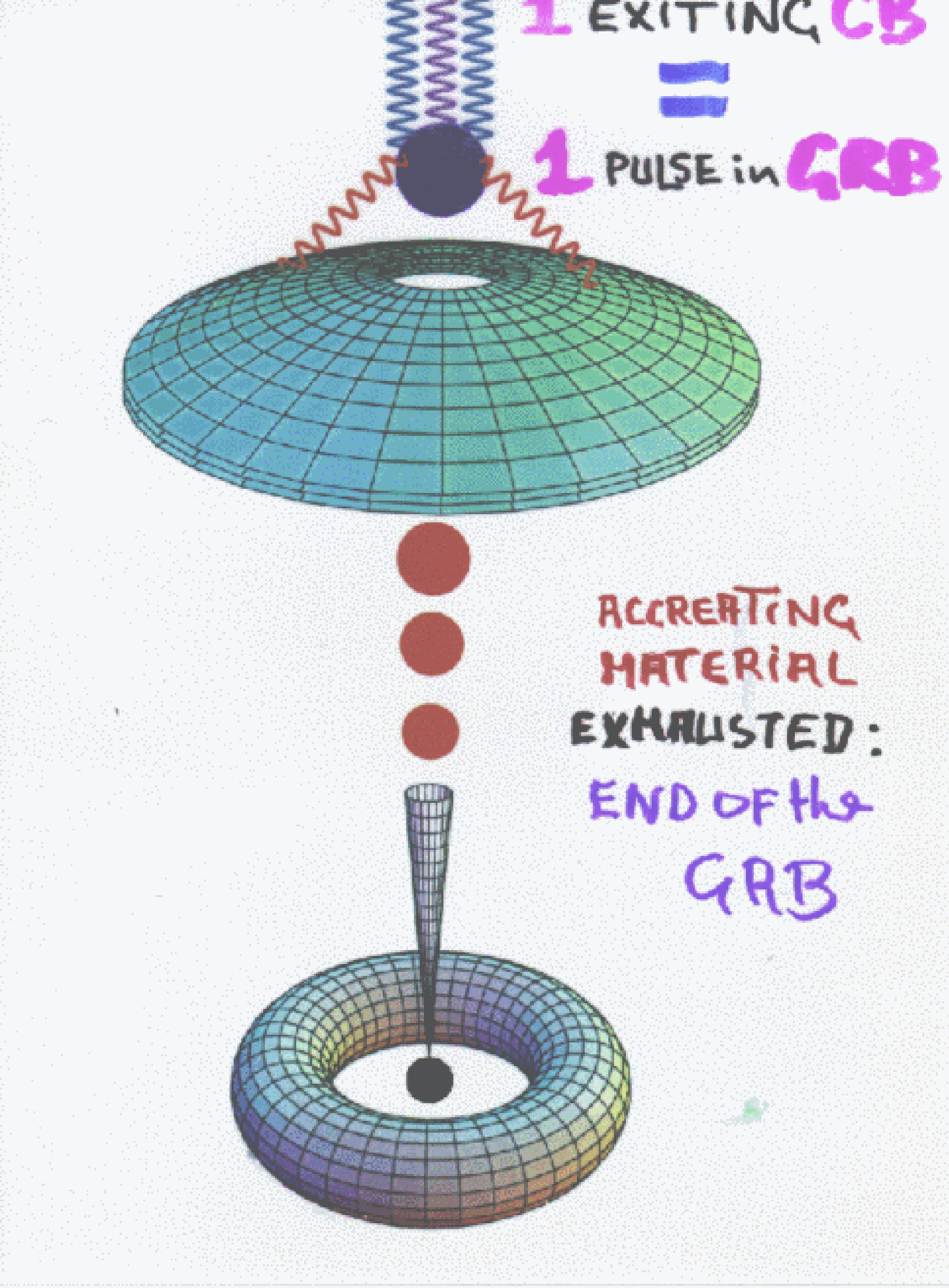
$$\sim 1 \text{ day} \left[\frac{R_\star}{10^{12}\,\text{cm}}\right]^{3/2} \left[\frac{1.4 M_\odot}{M_c}\right]^{1/2}$$

EJECTED MATERIAL:

SUPERNOVA SHELL, RADIUS:

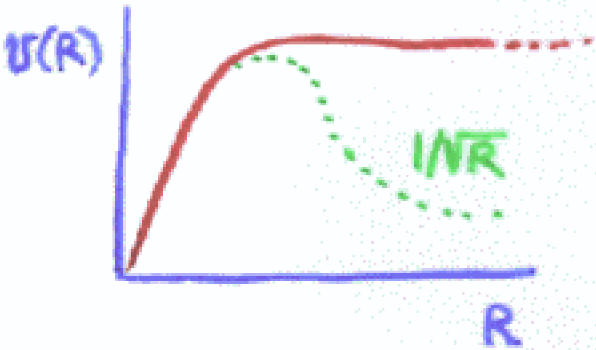
$$R_s = v_{ejec}\, t_{fall}$$

$$\sim 2.6\, 10^{14}\,\text{cm}\, \frac{v_{ejec}}{(c/10)}\, \frac{t_{fall}}{1\,\text{day}}$$



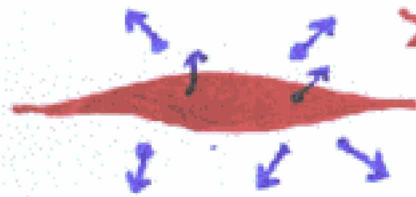
1 EXITING CB
=
1 PULSE in GRB
ACCRETING
MATERIAL
EXHAUSTED:
END OF the
GRB

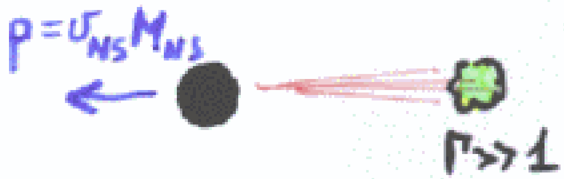
NS KICKS & JETS (DAR & PLAGA)



$v_\star \sim v_\odot \sim 250$ km/s

$v_{NS} \sim 450 \pm 90$ km/s





$E_p \sim v M_{NS} c \sim 4\,10^{51}$ erg

$\sum_{CB} E_{CB} \sim 10^{52} - 10^{53}$ erg ?

HYPOTHESIS GIVES O(MAGNITUDE) OF KINETIC ENERGY OF THE JETTED (DARTED) PLASMOID

GRBs AND COSMIC RAYS ?

AVERAGE # OF SIGNIFICANT

PULSES (CBs) IN A GRB

$\sim 5/10$

IF $E_{jet} \sim 10^{53}$ erg (say)

THEN $E_{CB} \sim 10^{52}$ erg

NOT VALUES THAT WE ADOPT AS FIXED

BUT REFERENCE VALUES IN OUR

ESTIMATES (TO WHICH WE SCALE

THE RESULTS)

SAME FOR γ, R_s, M_s ...

SOME CB PROPS :

I MASS ~ $M_{\otimes} \approx 3\ 10^{-6} M_{\odot}$

$\approx 3.6\ 10^{51}\ m_p$ p.p.p.

II E/NUCLEON ~ 1 TeV ($\gamma \sim 10^3$)

III COMPOSITION

n, p, e (AFTER CB-SHELL COLLISION; FOR SURE)

↳ p, e

"BARYONIC"

(AS FOR JETS OF SS433 ∧ QUASAR Ly_α, K_α Fe-LINES)

1 CB → 1 PULSE of a GRB

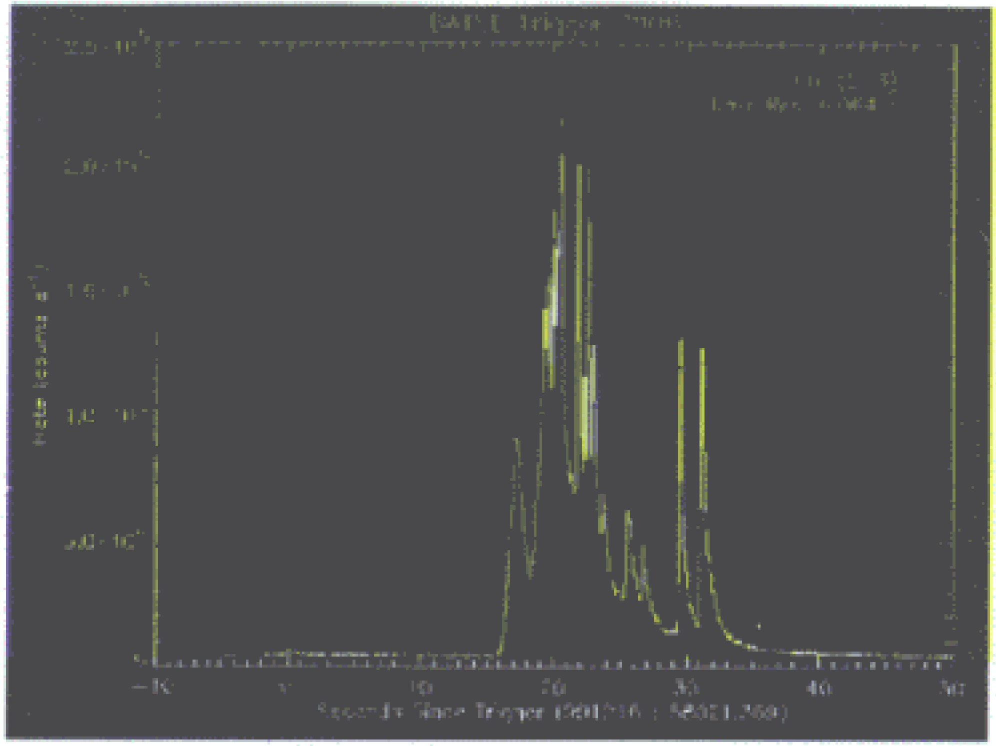
⇓

(SINCE WE DO NOT UNDERSTAND THE EJECTION PROCESS)

- TIME-SEQUENCE OF PULSES (MACHINE-GUN PROPERTIES) IS NOT PREDICTABLE

- BUT,
  → PROPS. OF SINGLE PULSES
  → PROPS. OF AFTERGLOW

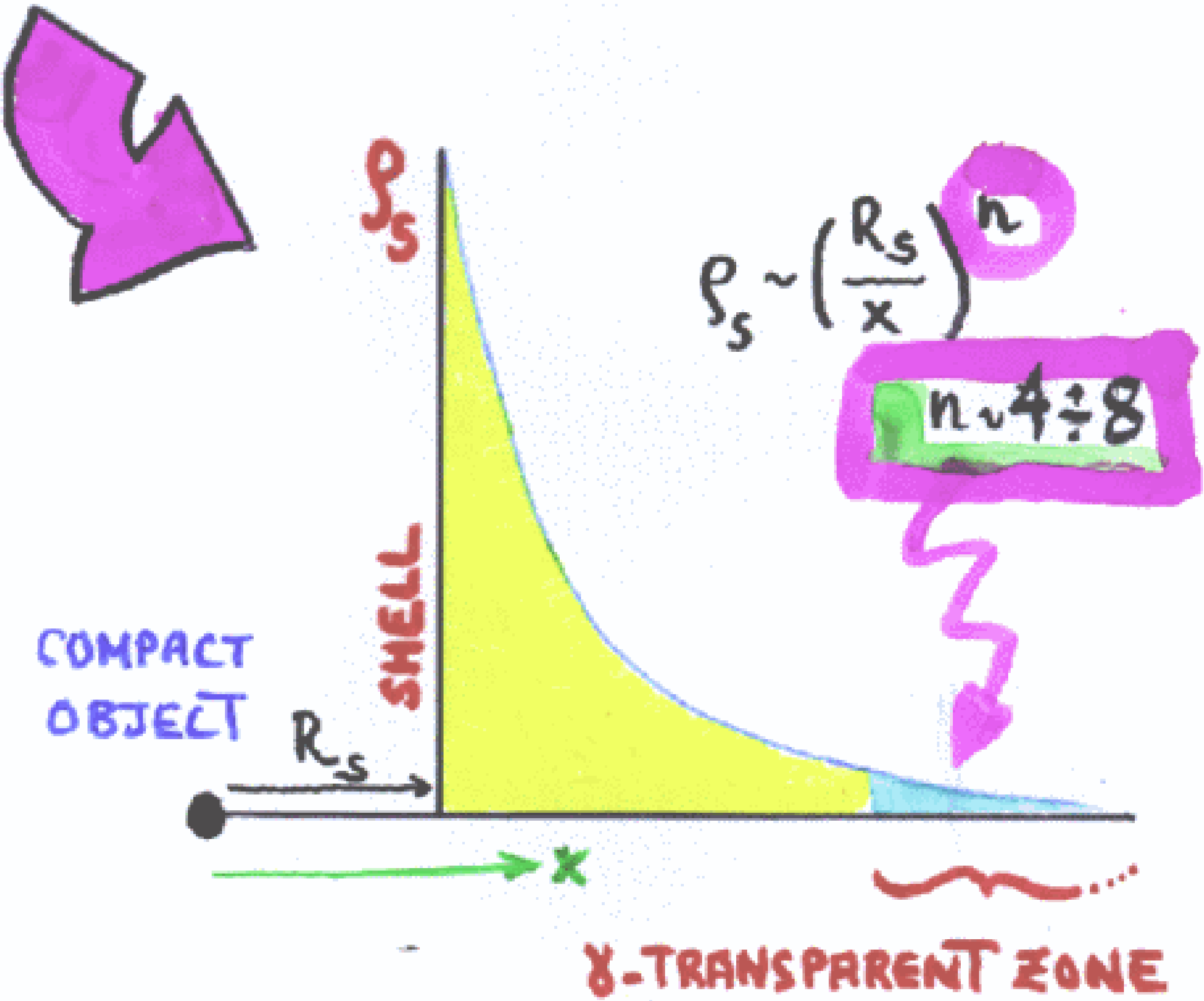
  ARE PREDICTABLE



GRB 991216

At z=1.020

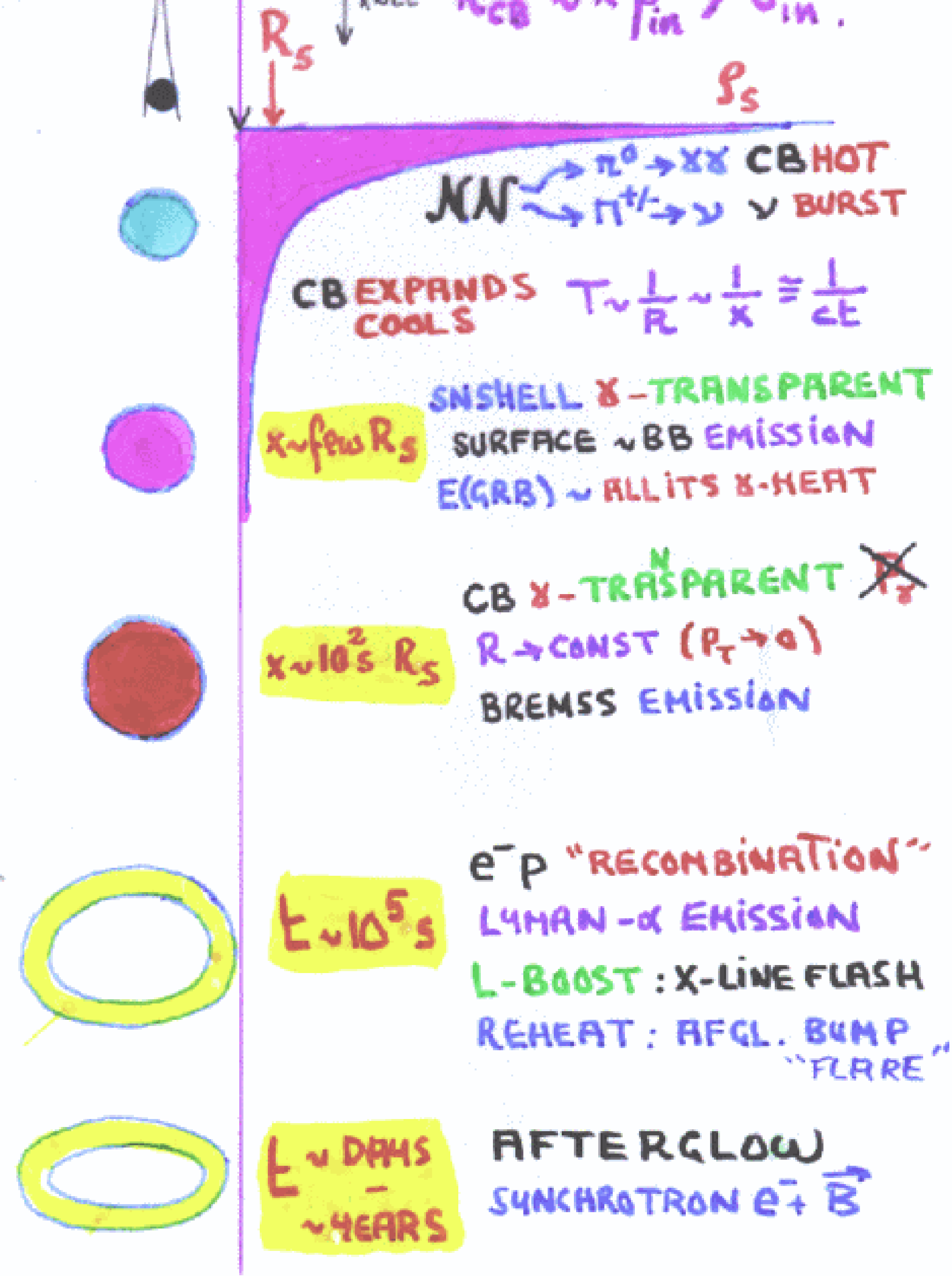
EVOLUTION OF THE SPECTRUM AND LINE FEATURES OF SUPERNOVAE



$\rho_S(x)$-DETAILS INMATERIAL

$$\rho_S = \rho_S(R_S)\left(\frac{R_S}{x}\right)^n \theta(x - R_S)$$

THROUGHOUT

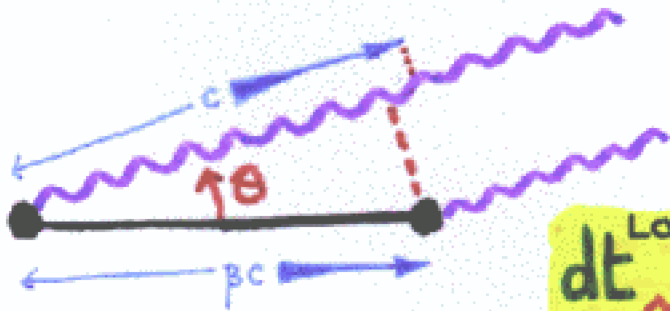


R_S
ρ_S
NN → π⁰ → γγ CB HOT
π^{+/-} → μ ν BURST
CB EXPANDS COOLS
T ~ 1/R ~ 1/x ≅ 1/ct
x ~ few R_S
SN SHELL γ-TRANSPARENT
SURFACE ~BB EMISSION
E(GRB) ~ ALL ITS γ-HEAT
CB γ-TRANSPARENT
x ~ 10²s R_S
R → CONST (P_T → 0)
BREMSS EMISSION
t ~ 10⁵ s
e⁻p "RECOMBINATION"
LYMAN-α EMISSION
L-BOOST : X-LINE FLASH
REHEAT : AFGL. BUMP "FLARE"
t ~ DAYS – ~YEARS
AFTERGLOW
SYNCHROTRON e⁻ + B

4 CLOCKS

$\gamma = \sqrt{1-\beta^2}$ $\quad \theta = \theta(\ldots)$

$$dt_{univ.} = \frac{dx}{c} = \gamma \, dt_{CB}$$



$$dt_{OBS}^{LOCAL} = \frac{dt_{CB}}{\delta}$$

$$\delta = \frac{1}{\gamma(1-\beta\cos\theta)} \simeq \frac{2\gamma}{1+\theta^2\gamma^2} \qquad \gamma \gg 1, \ \theta \ll 1$$

$$dt_{OBS}^{DISTANT} = (1+z)\, dt_{OBS}^{LOCAL}$$

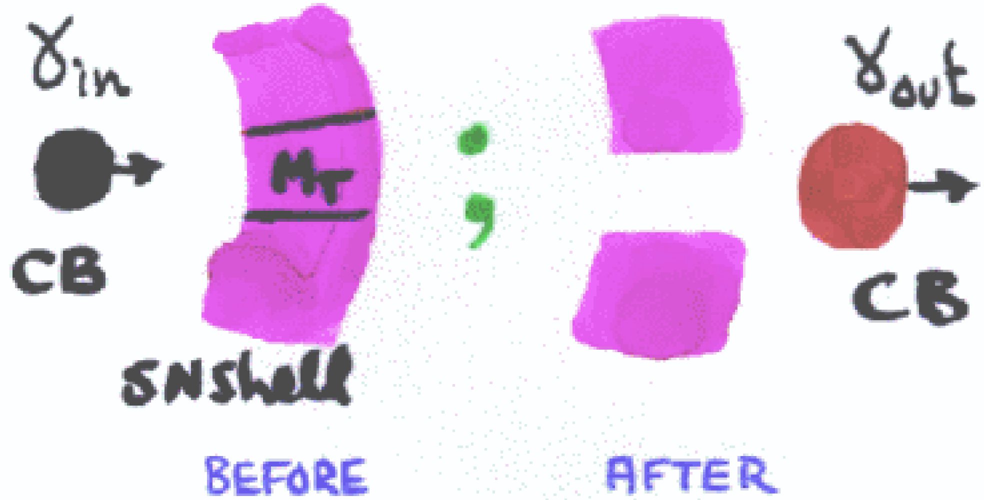
e.g. : $z = 1$, $\gamma = 10^3$, $\theta\gamma = 1$

$dt_{OBS}^{DIST.} = 2s$ $\qquad dt_{CB} = 10^3 s$

$dt_{OBS}^{LOCAL} = 1s$ $\qquad dt_{univ.} = 10^6 s$

~11.6 d

ENERGY IN THE OUTGOING CANNONBALL



$NN \rightarrow \pi^{\pm} \rightarrow \nu' \ldots$ ~ 2/3 E is LOST

$NN \rightarrow \pi^0 \rightarrow \gamma\gamma$ ~ 1/3 E is RETAINED

$$E_{CB}^{OUT} \sim E_{CB}^{IN} \frac{1}{3} \gg M_T, M_{CB}$$

E IN SN REST SYST.

$$E_{CB}^{OUT,REST} \simeq \frac{E_{CB}^{IN}}{3\gamma_{out}} > M_{CB} \text{ [IN BARYONS]}$$

INERTIAL MASS PROVIDED BY ENCLOSED RADIATION

COOLING AND EXPANSION

$$R_{CB} \approx \beta_T c \frac{t}{\gamma} \qquad \beta_T \sim \frac{1}{\sqrt{3}}$$

$$T \propto 1/R_{CB}$$

TOTAL EMITTED ENERGY

$$E_{TOT} \sim \frac{1}{e} E_{RAD}^{TRANS}$$

$$\sim \frac{1}{3e} \frac{E_{CB}}{\gamma_{in}} \frac{R_s}{x_{TRANS} - R_s} \frac{\beta_{in}\gamma_{out}}{\beta_{out}\gamma_{in}}$$

$$\approx 4.5\, 10^{45} \text{erg} \quad f_E(\text{PARAMS})$$

BOOST TO OBSERVER'S FRAME

TIME AND ENERGY INTEGRATED FLUENCE

$$\frac{dF}{d\Omega} = \frac{1+z}{4\pi D_L^2} E_{TOT} \left[\frac{2\gamma_{out}}{1+\theta^2\gamma_{out}^2}\right]^3$$

$\gamma \sim 10^3$
$\gamma\theta \sim O(1)$
} RIGHT BALLPARK ↔ OBSERVATIONS

$$\frac{4\pi a}{3}\left(R_{CB}^{TRANS}\right)^3\left(T_{CB}^{TRANS}\right)^4 = E_{RAD}^{TRANS}$$

$$\Rightarrow T_{CB}^{TRAS} \sim 0.1\,\mathrm{keV}_*$$

$$f_T\,(\mathrm{PARAMS})$$

RIGHT BALLPARK FOR E_γ IN GRBs

WHEN BOOSTED BY

$$\delta = \frac{2\gamma}{1+\theta^2\gamma^2}$$

AND REDSHIFTED BY

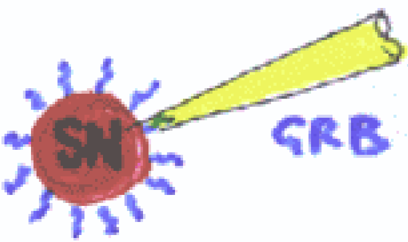
$$\frac{1}{1+z}$$

GRB FLUENCE

⇒ $\gamma \sim O(10^3)$

INDIVIDUAL γ-ENERGIES in GRB

⇒ $\gamma \sim O(10^3)$



$$\frac{\Delta\Omega}{4\pi} \sim \frac{1}{4\gamma^2}$$

$\gamma \sim O(10^3)$: A ROUGHLY 1÷1 SN-GRB ASSOCIATION

$t_{tr} = t_{tr}$ (PARAMS)

$F = F$ (PARAMS)

$H = H$ (PARAMS)

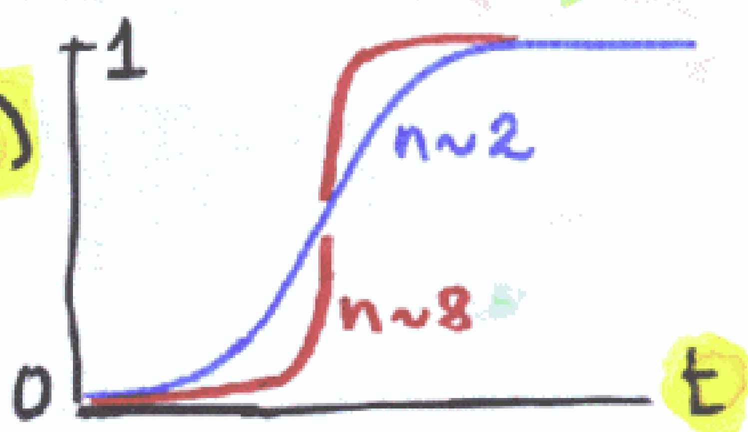
THERMAL EMISS. FROM THE CB's SURFACE $\propto [R_{CB}(t)]^2$

ABRUPT SN-SHELL TRANSPARENCY

$$\frac{dn}{dE\,dt} = F\, t^2 \frac{E^2}{e^{tE/H} - 1}\, \Theta(t - t_{tr})$$

THERMAL SPECTRUM WITH $T \sim 1/t$

$1 - Abs(t)$



GRB Properties

The GRB fluences, integrated in energy and time, lie within one or two orders of magnitude of

$$10^{-5}\ \mathrm{erg\ cm^{-2}}$$

(e.g., Paciesas et al. 1999)

Individual pulses are narrower in time, the higher the energy interval of their photons

(e.g., Fenimore et al. 1995)

Individual pulses rise and peak at earlier time, the higher the energy interval of their photons

(e.g., Norris et al. 1999; Wu and Fenimore 2000)

Individual pulses have smaller photon energies, the later the time-interval of observation

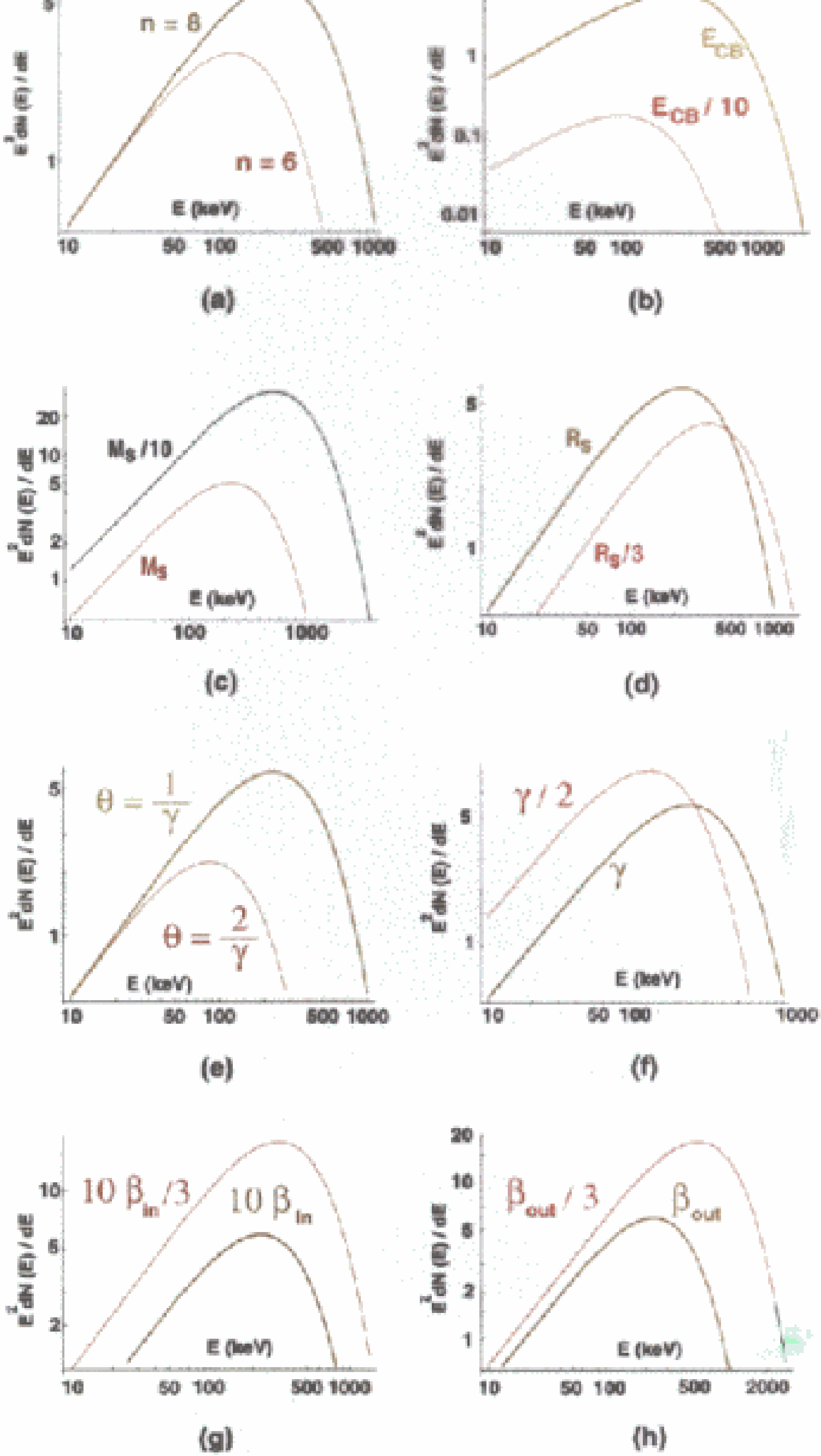
(e.g., Preece et al. 1998)

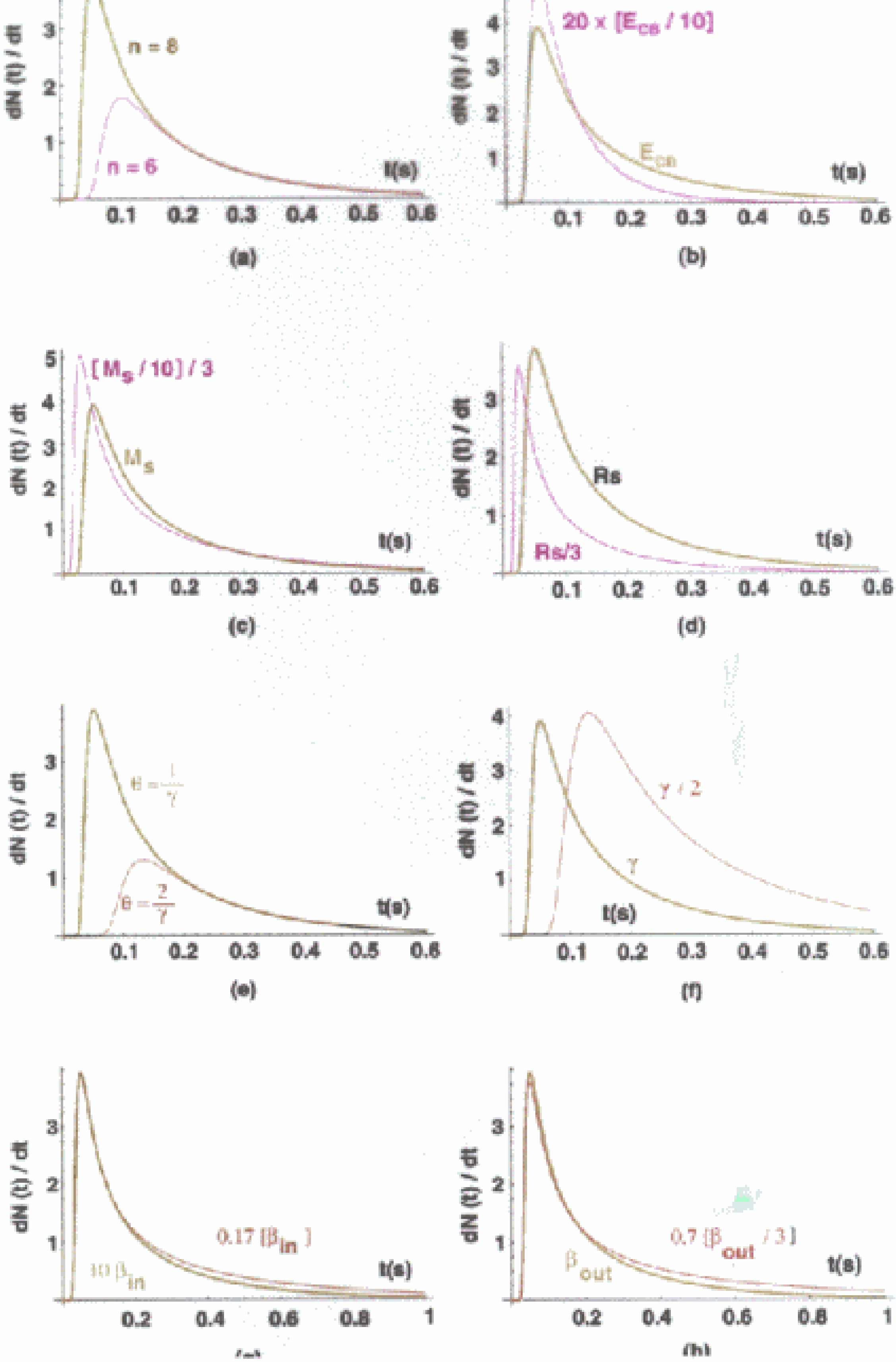
$E^2\, dN/dE$ rises as $E^{\approx 1}$, has a broad peak at 0.1 to 1 MeV, decreasing thereafter

(e.g., Preece 2000)

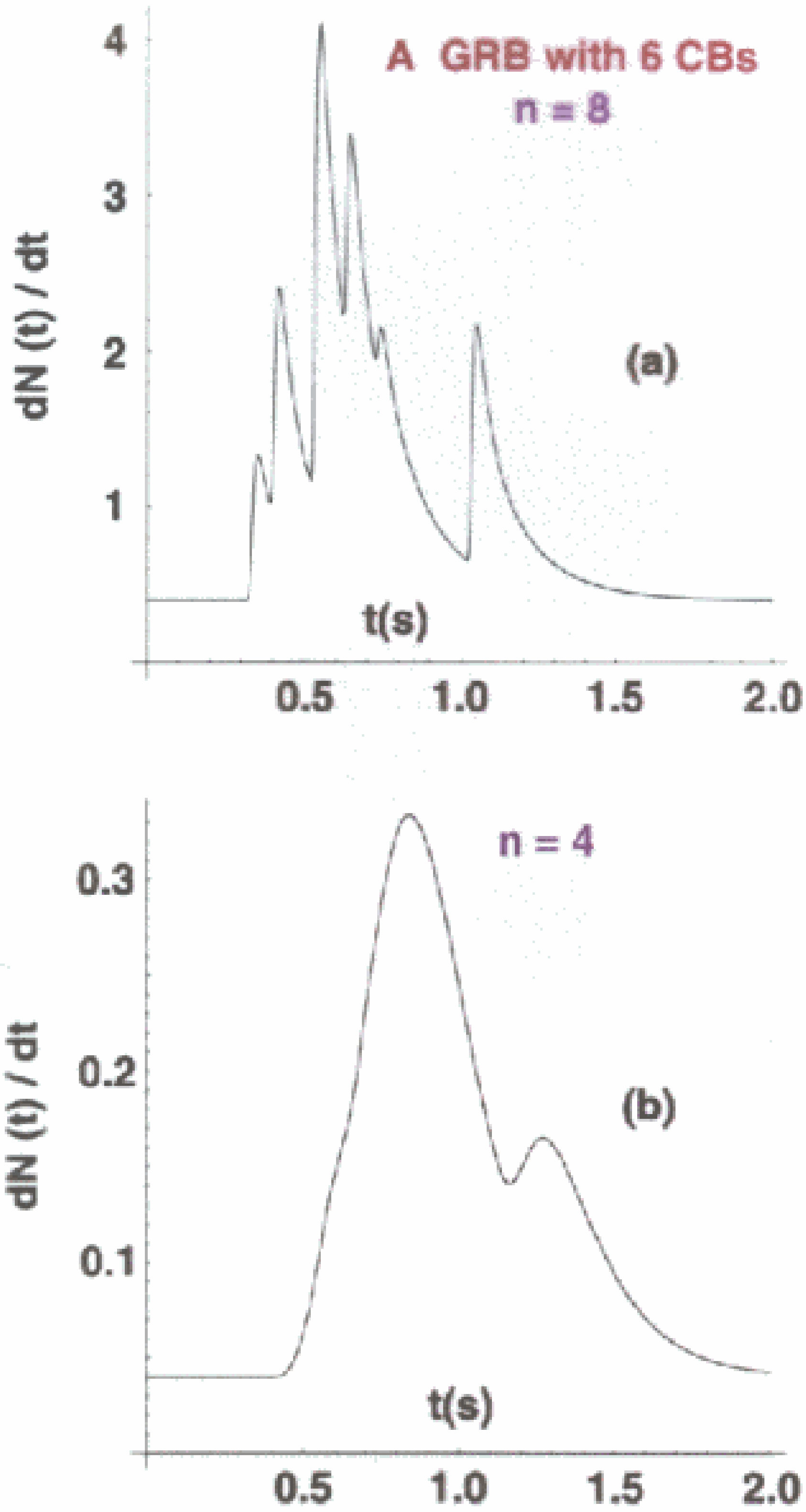
Most pulses are FREDs, other $\approx$ symmetrical Non-FREDs. GRBs either all FRED or all Non-FRED

(e.g. Fenimore et al. 1995 and refs. therein)


n = 8
n = 6
E²dN (E) / dE
E (keV)
(a)
E_CB
E_CB / 10
(b)
M_S /10
M_S
(c)
R_S
R_S/3
(d)
θ = 1/γ
θ = 2/γ
(e)
γ / 2
γ
(f)
10 β_in/3
10 β_in
(g)
β_out / 3
β_out
(h)



dN (t) / dt
n = 8
n = 6
t(s)
(a)
20 x [E_cs / 10]
E_cs
t(s)
(b)
[M_s / 10] / 3
M_s
t(s)
(c)
Rs
Rs/3
t(s)
(d)
θ = 1/γ
θ = 2/γ
t(s)
(e)
γ / 2
γ
t(s)
(f)
0.17 [β_in]
10 β_in
t(s)
0.7 [β_out / 3]
β_out
t(s)


A GRB with 6 CBs
n = 8
(a)
dN (t) / dt
t(s)
4
3
2
1
0.5
1.0
1.5
2.0
n = 4
(b)
dN (t) / dt
t(s)
0.3
0.2
0.1
0.5
1.0
1.5
2.0

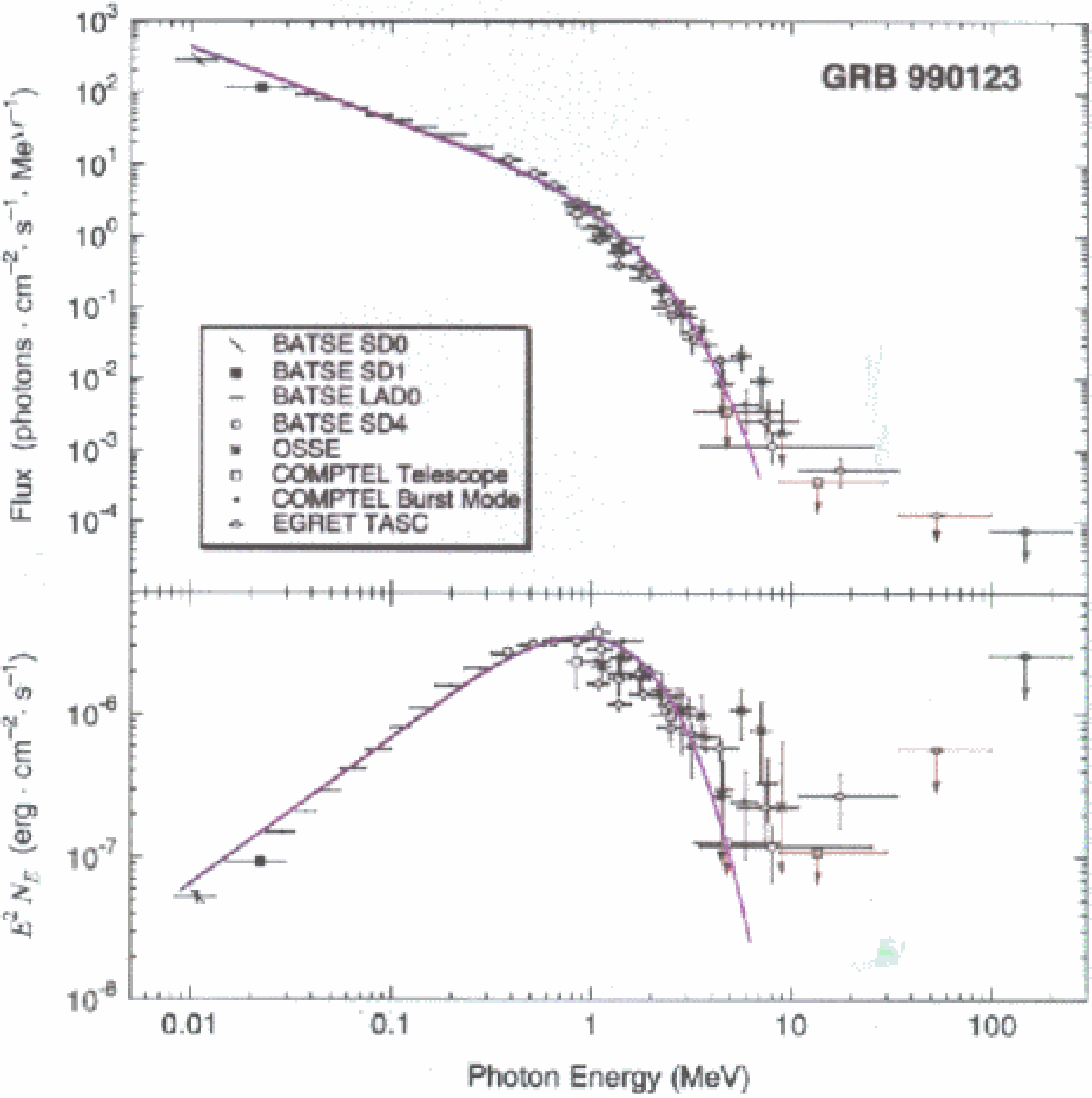
$\beta_{in} = \frac{\,}{10\sqrt{3}}$, $\beta_{out} = \frac{\,}{3\sqrt{3}}$,

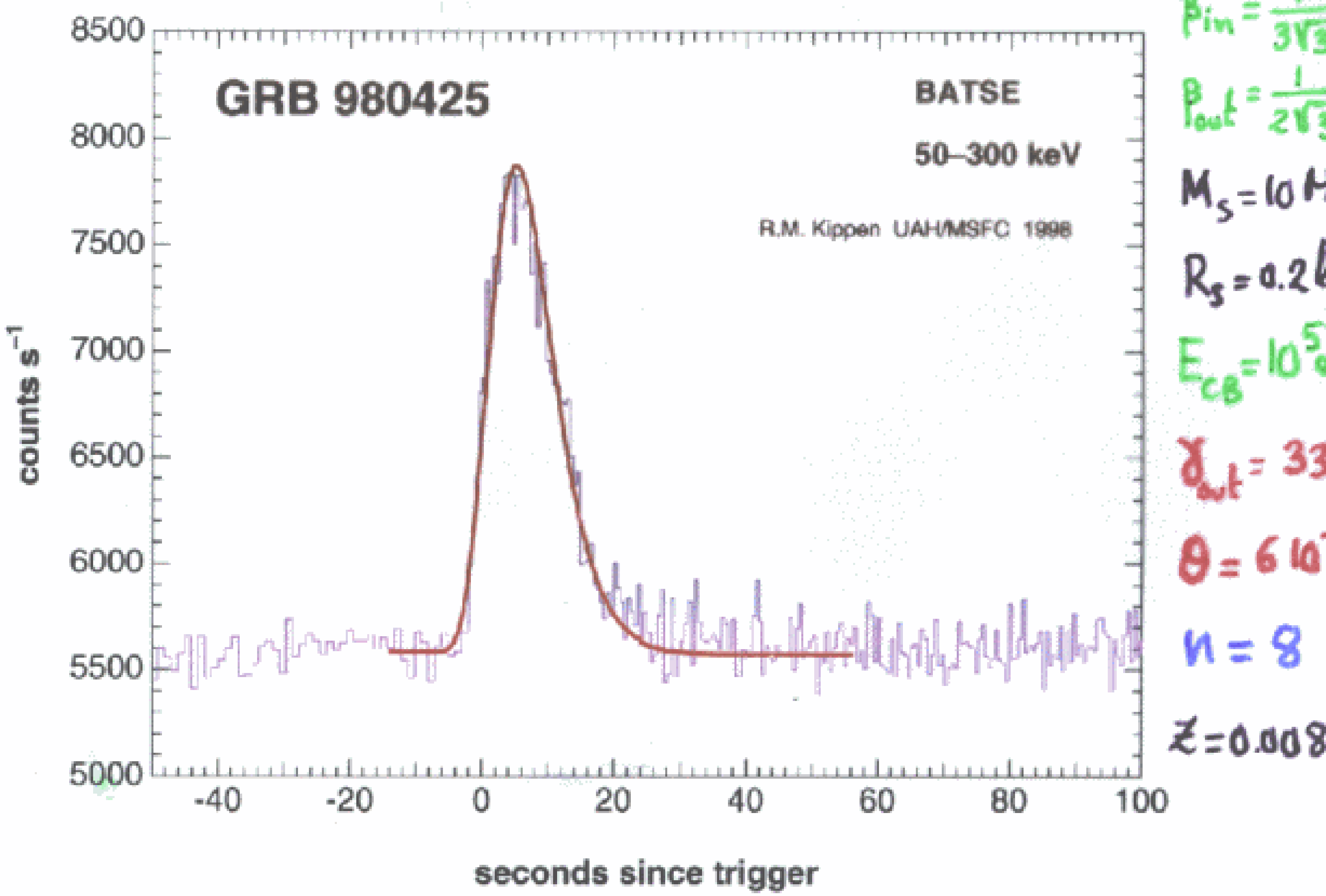
$E_{JET} = 5.10^{53}$ erg

$M_s = 2.5\, M_\odot$; $R_s = 0.3$ ld

$\gamma_{out} = 1.5\, 10^3$, $\theta = 1.5\, 10^{-3}$, $n = 6$

$z = 1.60$




GRB 980425
BATSE
50–300 keV
R.M. Kippen UAH/MSFC 1998
counts s^{-1}
8500
8000
7500
7000
6500
6000
5500
5000
-40
-20
0
20
40
60
80
100
seconds since trigger
n = 8

GRB AFTERGLOWS

$R_{CB} \simeq$ CONST

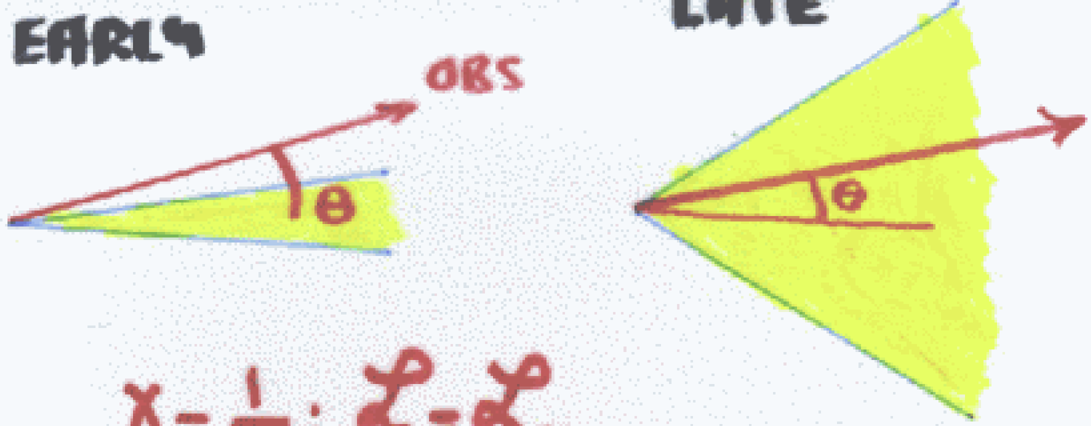
ISM $n_p \simeq$ CONST

$$\frac{d\gamma}{dx} = -\gamma^2/x_0 \qquad x_0 = \frac{M_{CB}}{\pi R_{CB}^2\, n_p\, m_p}$$

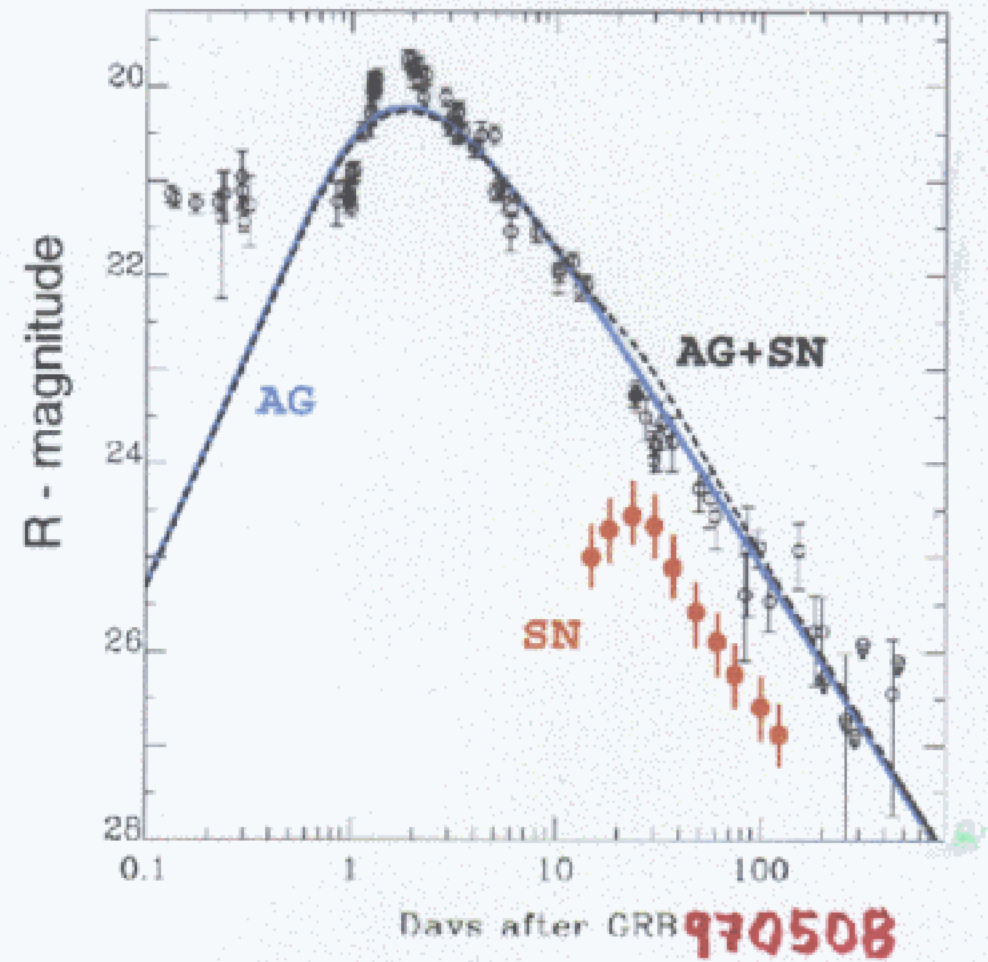
$\gamma(t)$ DECREASING WITH TIME

LIKE IN QUASARS, μ-QUASARS

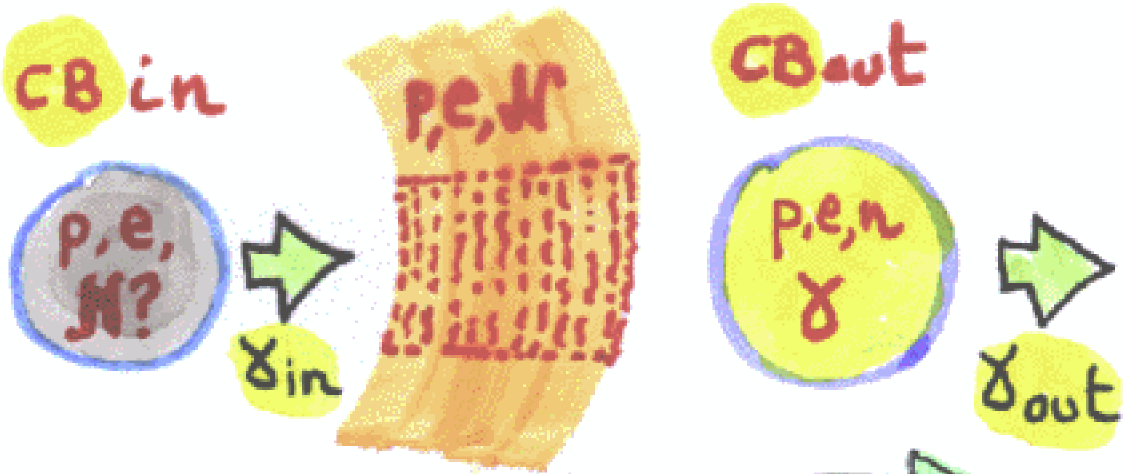
CB EMITTING UV → RADIO
BY SYNCHROTRON
RADIATION ON $\vec{B}_{CB}$



$$\gamma = \frac{1}{\theta} : \mathcal{L} = \mathcal{L}_{max}$$



ORIGIN OF HIGH-ENERGY ν'S



NEXT

CLAIM: ALL OF THE INCOMING CB's BARYONS SUFFER HIGH CMS-ENERGY COLLS.

COROLLARY: THEY LOSE MOST OF THEIR ENERGY IN HARD π-PRODUCING INTERACS.

PROOF ① MICROSCOPIC DESCRIPTION OF CB-SNS COLLISION

② SHORTCUT

ONE CAN CHECK :

BOTH CB AND SN SHELL ARE :

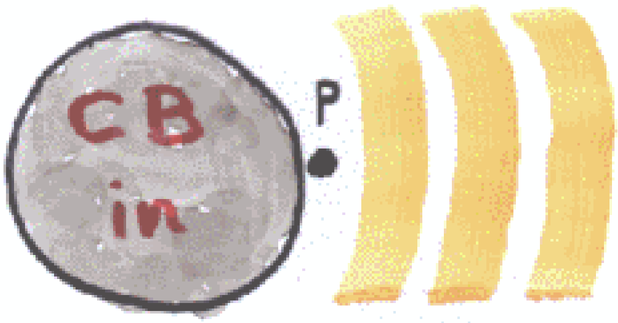
1. MANY pp INTER. LENGTHS LONG $\sim 10^3$
2. SUFFICIENTLY THIN (LOW ρ)

   FOR ALL PRODUCED π, μ TO DECAY WITHOUT SIGN. ENERGY LOSS

↓

IDEAL BEAM-DUMP FOR ν-PRODUCTION

THE "FIRST" CB PROTON

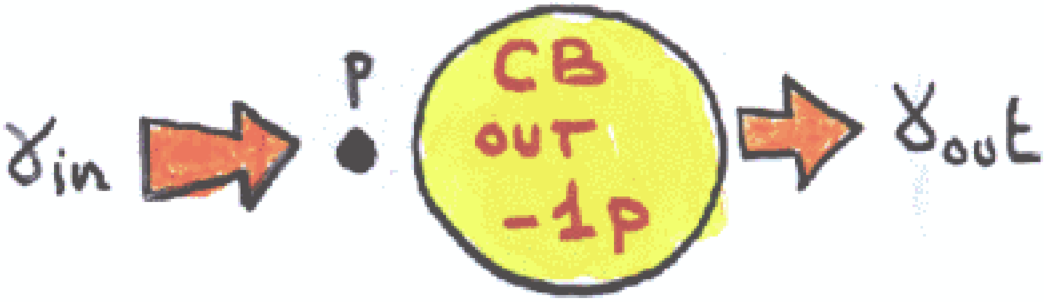


γ_{in} ON

SNS STUFF

AT REST

THE "LAST" CB PROTON



$$\gamma_{in} = (3 \div 10)\, \gamma_{out}$$

LAST p:

$\bullet p \xrightarrow[\gamma_{in}]{} \quad \bullet p \xrightarrow[\gamma_{out}]{}$ $\quad M^2 \approx m_p^2 \left(2 + \frac{\gamma_{out}}{\gamma_{in}}\right)$

SUFFICES FOR MULTI-π PRODUCT.

EXAMPLE :

ICE OR WATER DETECTOR

LOOKING FOR

$$\nu_\mu \rightarrow \mu$$

$$X_\mu = \frac{E_\mu}{m_p \gamma_{in}}$$

MUON ENERGY HERE

PROTON ENERGY "THERE"

OBSERVED μ FLUX

(per CB)

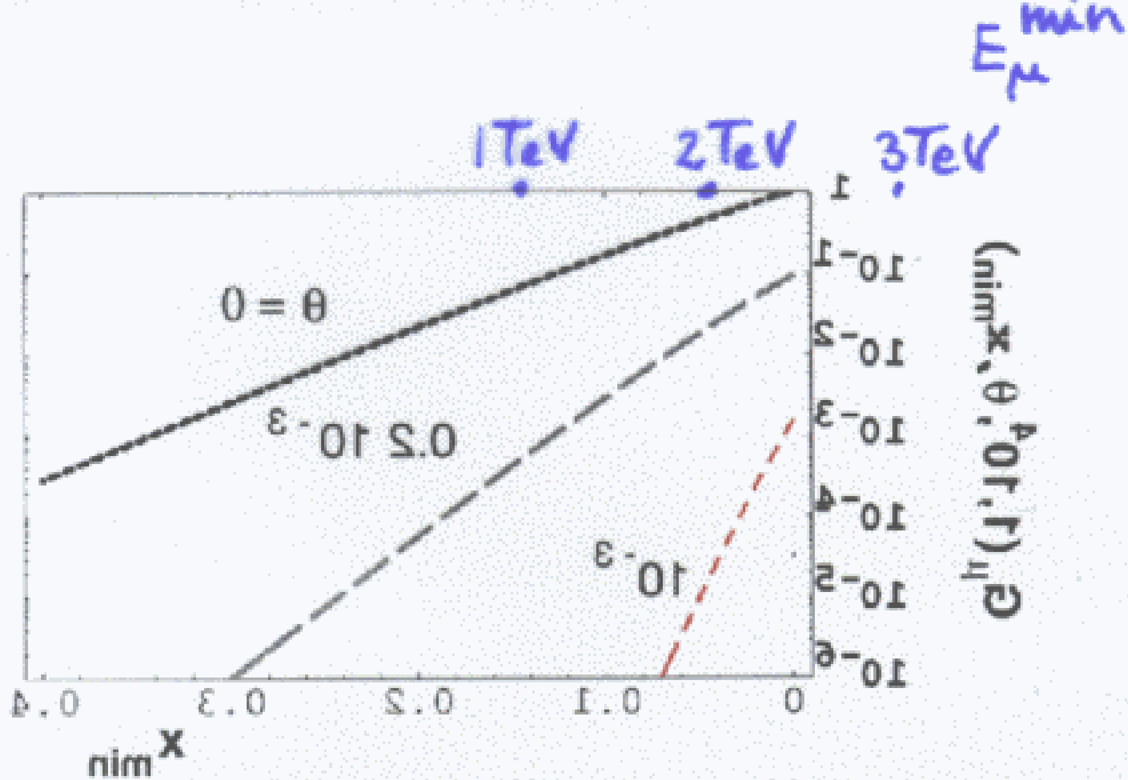
$$\frac{dF^T_\mu[x^\mu_{min},\theta]}{d\Omega} \sim \frac{dF^T_\mu[0,0]}{d\Omega}\, G_\mu(z,\gamma_{in},\theta,x^\mu_{min})$$

$$x^\mu_{min} \equiv \frac{E^\mu_{min}}{m_p\,\gamma_{in}}$$

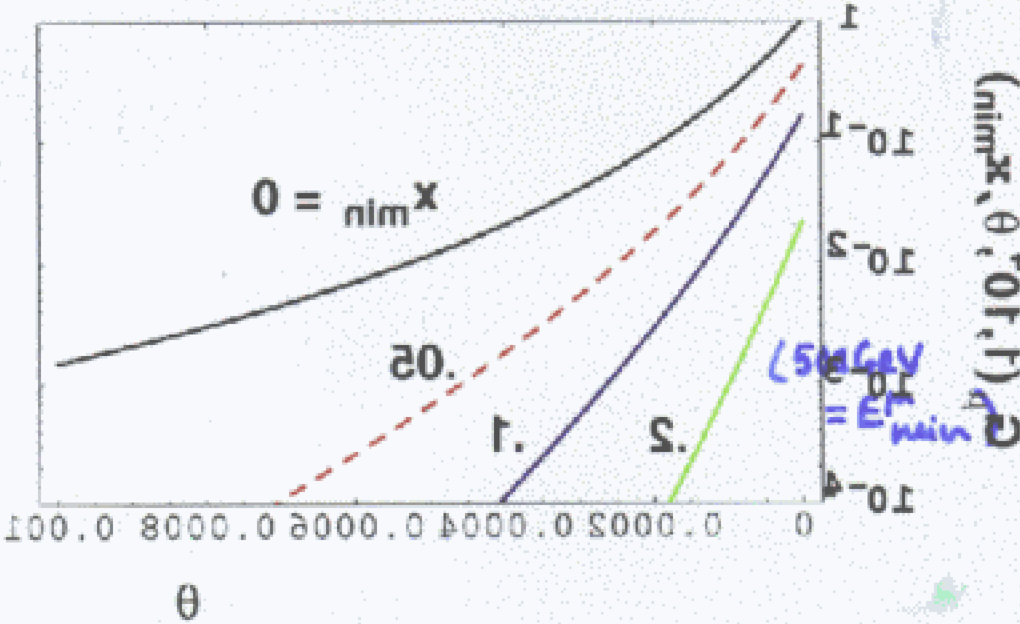
$$\frac{dF^T_\mu[0,0]}{d\Omega} \simeq \frac{1.2\times 10^4}{km^2}$$

$$\times$$

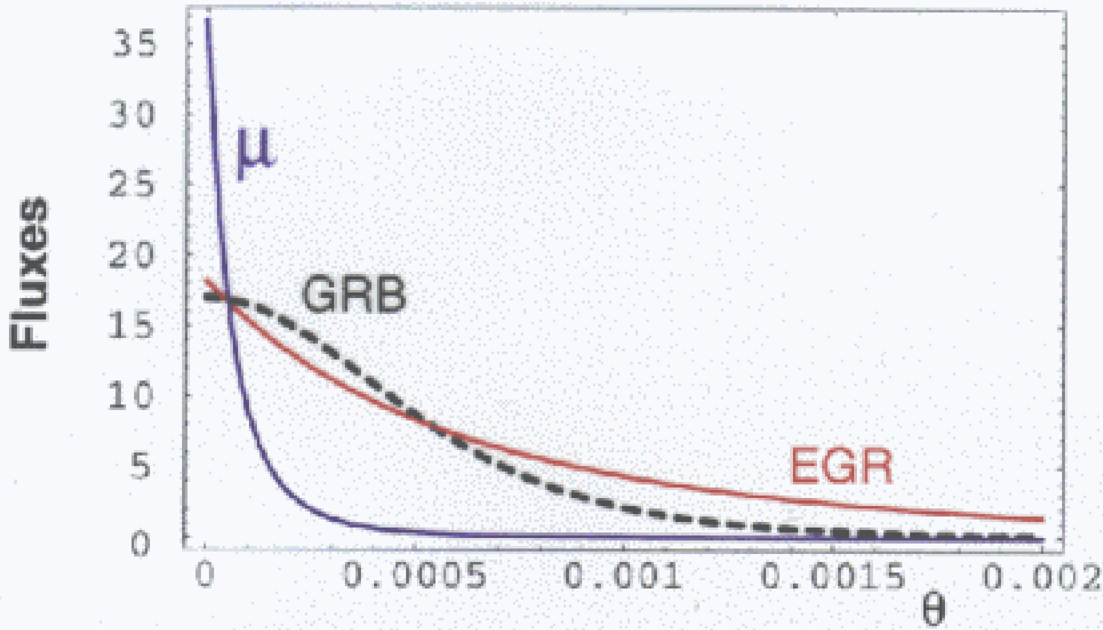
$$\frac{E_{CB}}{10^{52}\ erg}\left[\frac{\gamma_{in}}{3\,10^3}\right]^3\left[\frac{D_L(1)}{D_L(z)}\right]^2$$

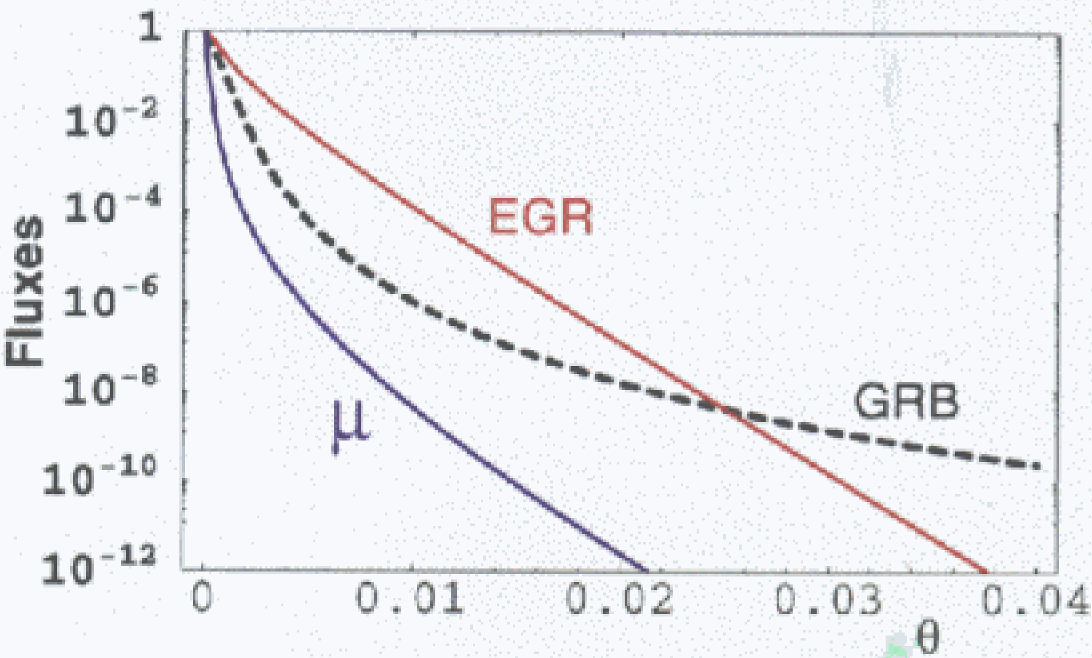


E_μ^{min}
1TeV
2TeV
3TeV
$\theta = 0$
0.2 10^{-3}
10^{-3}
$G_\mu(1, 10^4, \theta, x_{min})$
x_{min}



$x_{min} = 0$
.05
.1
.2
(50 GeV $= E^\mu_{min}$)
$G_\mu(1, 10^4, \theta, x_{min})$
θ





$\gamma_{in} = 10^4$ $E_\gamma^{min} = 50\,\text{GeV}$

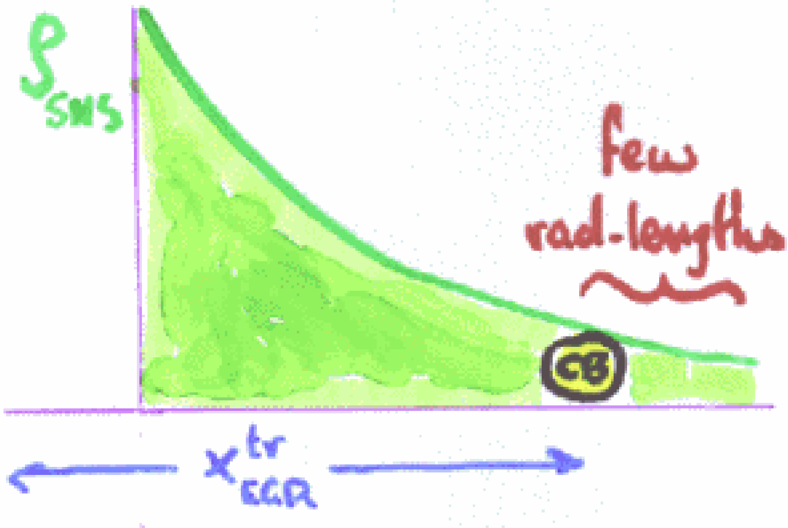
$\gamma_{out} = 10^3$ $E_\mu^{min} = 50\,\text{GeV}$

GRB : few (100) MeV γ's

EGR : ~ few (10) GeV γ's

ENERGY GAMMA RAYS

$p\mathcal{N} \rightarrow \pi^0 (\rightarrow \gamma\gamma) + \ldots$



$\gamma_{CB} \sim \gamma_{out}$

\# OF SNS NUCLEONS MAKING EGR WHICH GET OUT OF SNS N_p

$X_{EGR} \simeq 70 gr/cm^2$ (ABSORPTION LGTH)

$$N_p \simeq \pi \left[R_{CB}(x^{ECR}_{tr}) \right]^2 \frac{X_{EGR}}{m_p}$$

$$\approx 10^{49} \ll N_B \sim 10^{51}$$

OBSERVED γ FLUX

(per CB)

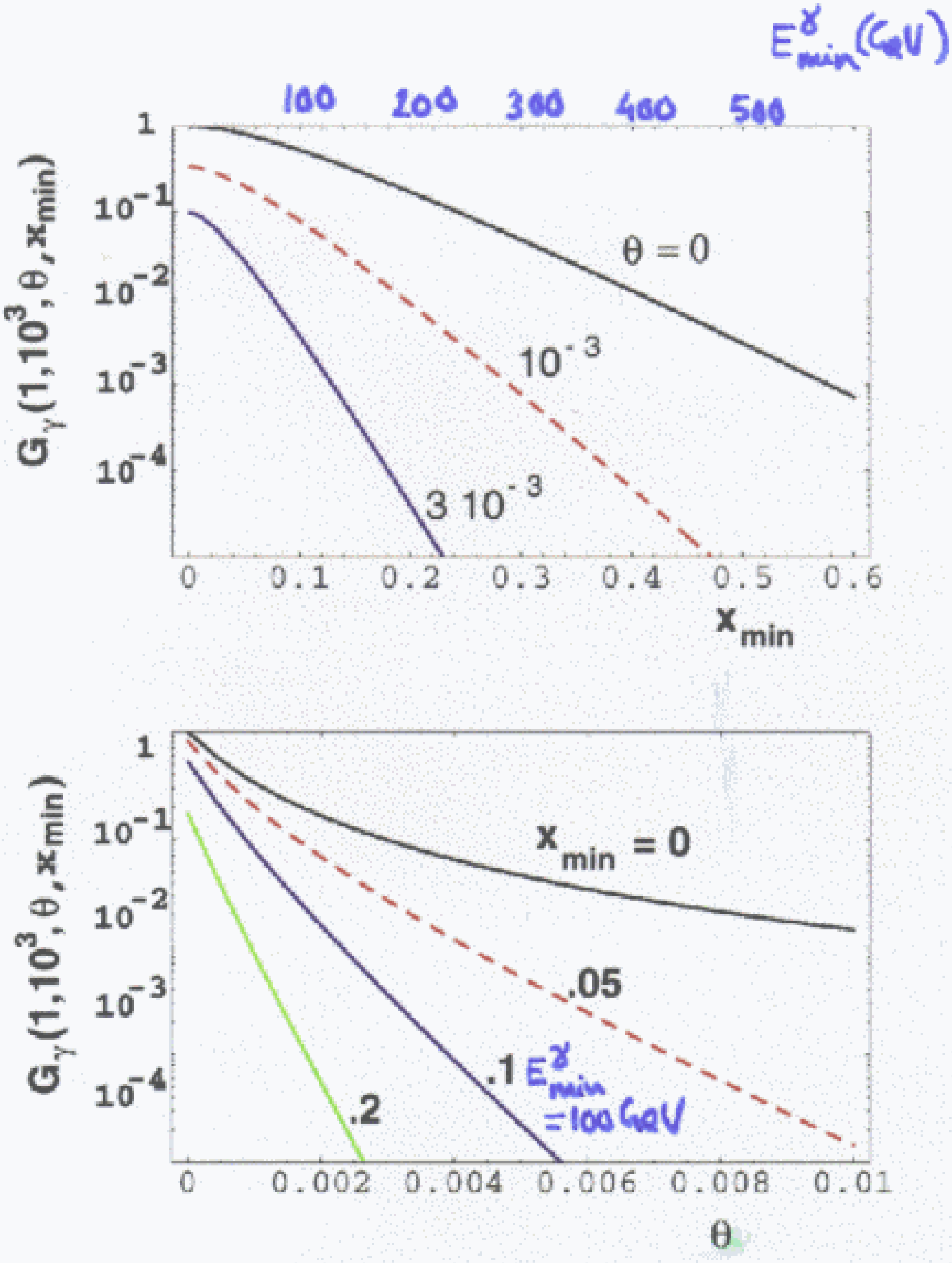
$$\frac{dF_\gamma^T[x_{min},\theta]}{d\Omega} \sim \frac{dF_\gamma^T[0,0]}{d\Omega}\, G_\gamma(z,\gamma_{out},\theta,x_{min}^\gamma)$$

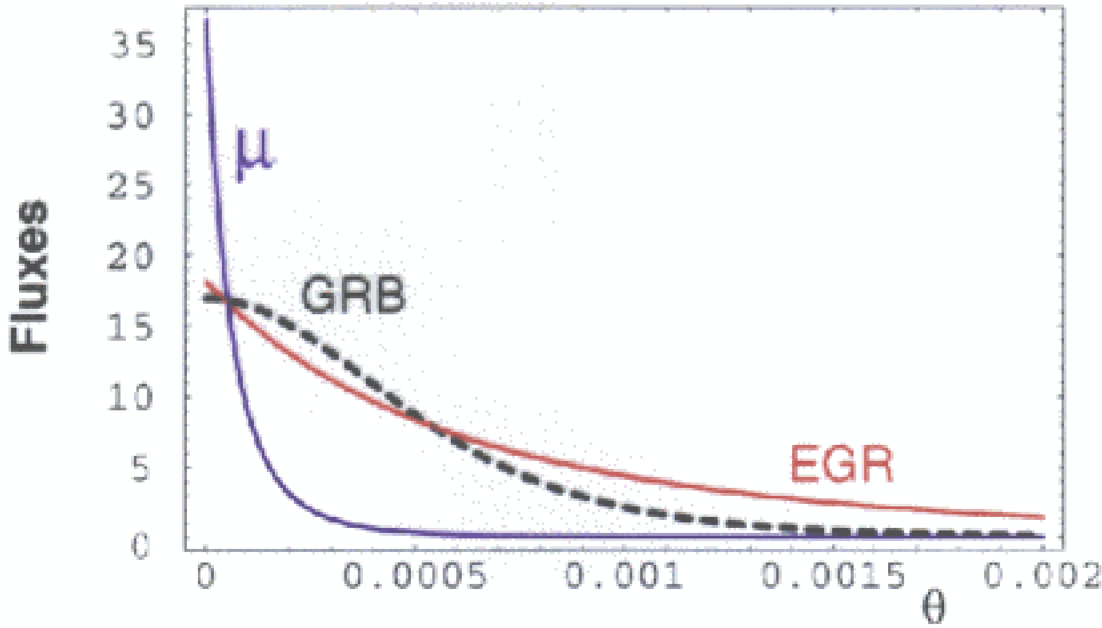
$$x_{min}^\gamma \equiv \frac{E_{min}^\gamma}{m_p\,\gamma_{out}}$$

$$\frac{dF_\gamma^T[0,0]}{d\Omega} \simeq \frac{1.1 \times 10^8}{km^2}$$

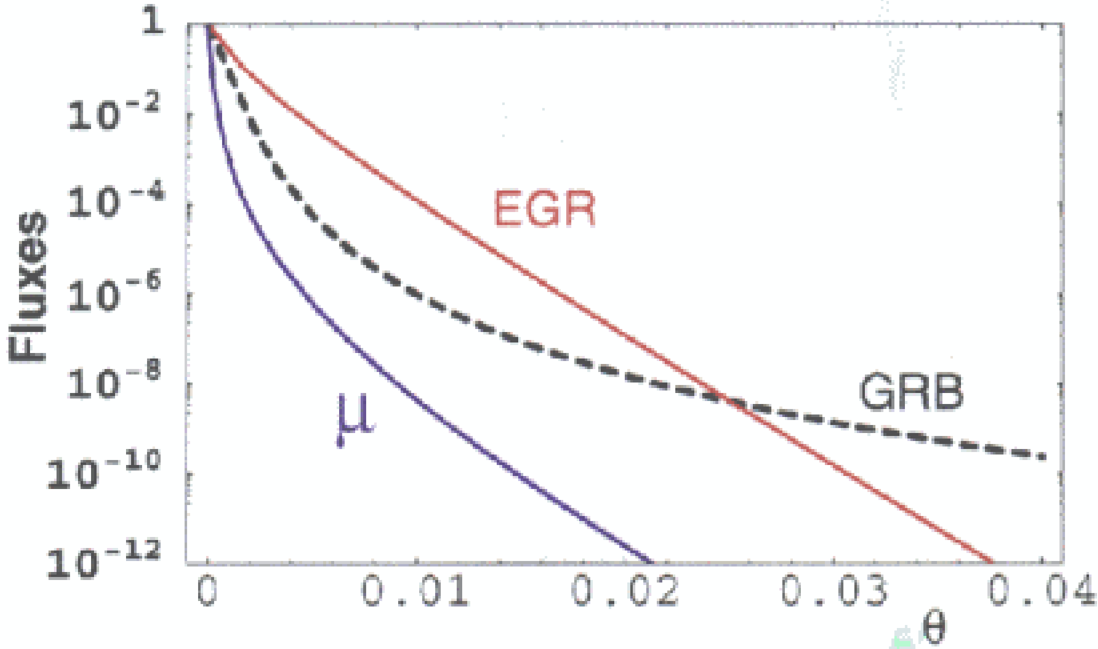
$$\times$$

$$\frac{N_p}{1.4\ 10^{49}}\left[\frac{\gamma_{out}}{10^3}\right]^2\left[\frac{1+z}{2}\right]^2\left[\frac{D_L(1)}{D_L(z)}\right]^2$$


E^{γ}_{min}(GeV)
100 200 300 400 500
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$G_{\gamma}(1,10^3,\theta,x_{min})$
$\theta = 0$
10^{-3}
$3\ 10^{-3}$
0 0.1 0.2 0.3 0.4 0.5 0.6
x_{min}
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
$G_{\gamma}(1,10^3,\theta,x_{min})$
$x_{min} = 0$
.05
.1 E^{γ}_{min} = 100 GeV
.2
0 0.002 0.004 0.006 0.008 0.01
θ



35
30
25
20
15
10
5
0
Fluxes
μ
GRB
EGR
0
0.0005
0.001
0.0015
0.002
θ



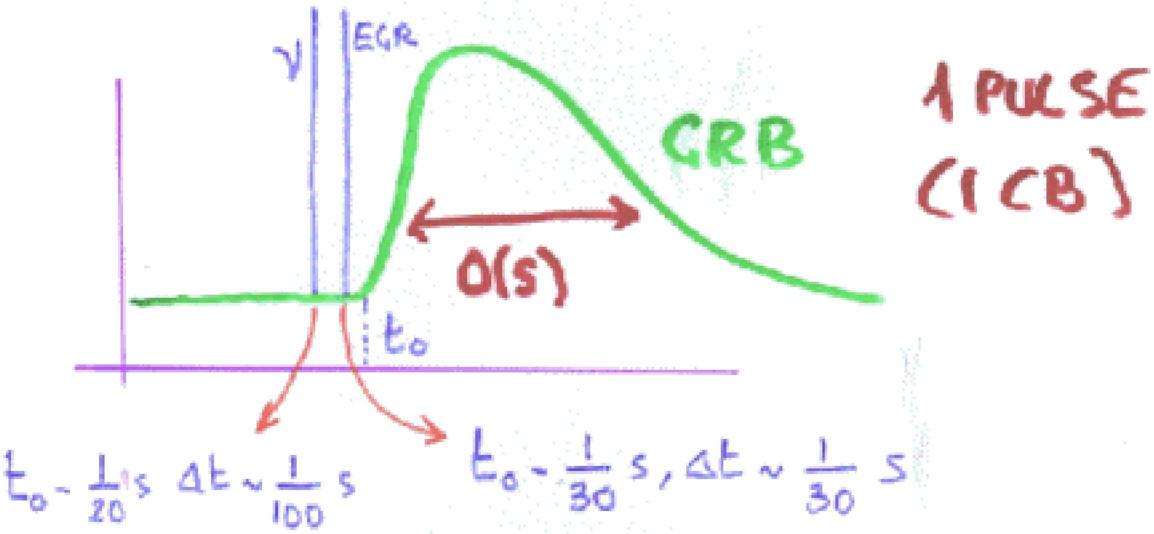
1
10^-2
10^-4
10^-6
10^-8
10^-10
10^-12
Fluxes
EGR
GRB
μ
0
0.01
0.02
0.03
0.04
θ

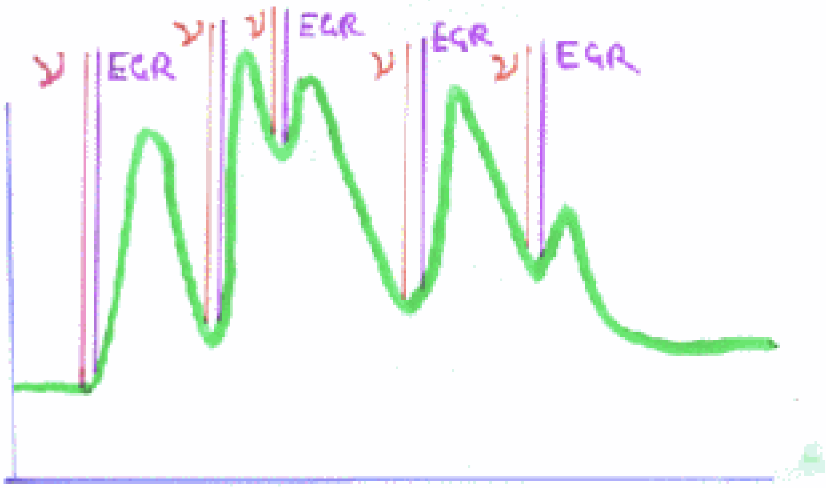
TIMING CONSIDERATIONS

γ's MADE ~ START OF SNS CROSSING by CB

EGRs MADE ~ END OF SNS CROSSING

GRB as EGR, BUT COOLING PROLONGS IT





$$R \equiv \frac{\text{TOTAL ENERGY IN EGR}}{\text{TOTAL ENERGY IN GRB}}$$

$$\sim \frac{(X_\gamma[\sim 20\,\text{GeV}])^2}{X_\gamma(1\,\text{MeV})} \frac{\sigma_T^2(\gamma e)}{m_p \sigma_{TOT}(pp)}$$

$$* \left[\frac{X_\gamma(1\,\text{MeV})}{X_\gamma(\sim 20\,\text{GeV})} \right]^{\frac{2}{n-1}}$$

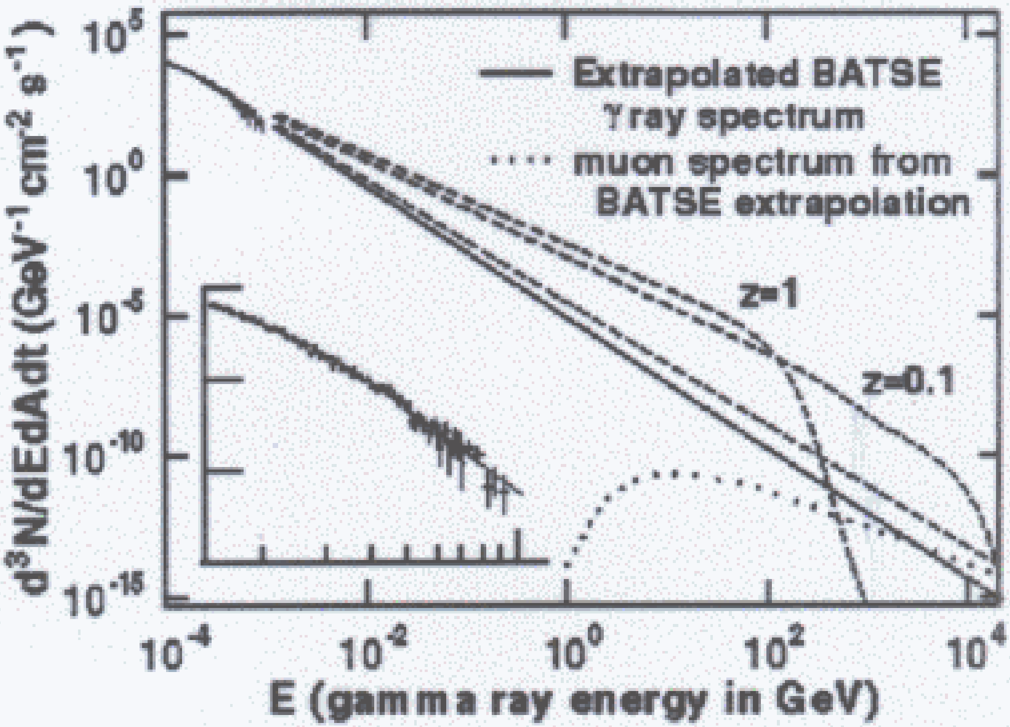
$$\sim O(10^3)$$

GRAND

6 BATSE EVENTS NEAR ZENITH

GRB 971110 : HIGHEST GRAND ACCEPTANCE

HIGHEST GRB FLUX



$\sim 3.2\sigma$ ABOVE BKGD

$5\,10^{-4}$ PROBABILITY IN 6 TRIALS

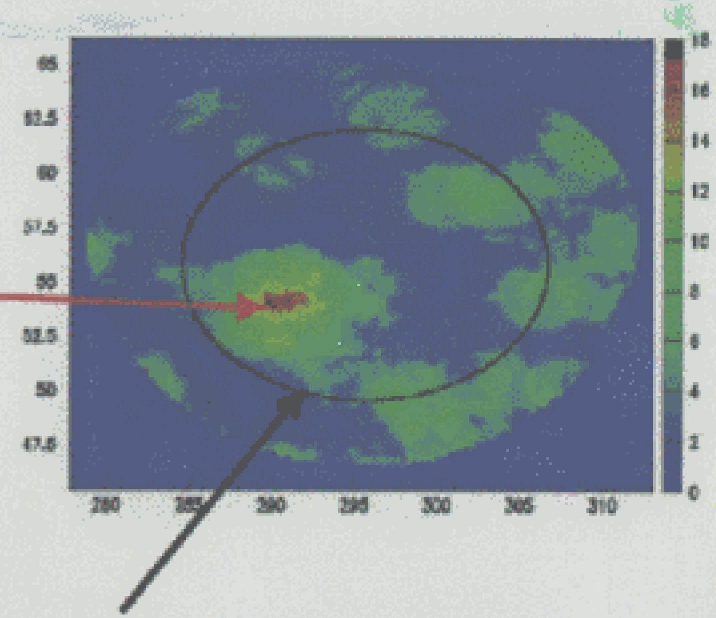
REQUIRES A LARGE NEW COMPONENT

WELL ABOVE GRB-FLUX EXTRAPOL.

Milagrito - GRB 970417a

- Searching 54 Batse bursts (T90)
- One burst 970417a showed 18 events w/background of 3.46
- This has a prob< 2.9×10^{-8}
- Accounting for all search trials – combined accidental chance 1/150
- This could mean TeV emission from GRBs

$10 - 10^4$ * GRB FLUENCE



THE (SERIOUS) ASTROPHYSICIST'S

DREAM

(TO OBSERVE A GRB ORIGINATING IN OUR OWN GALAXY)

IS

DANGEROUS

(S)HE WOULD DIE

IN THE

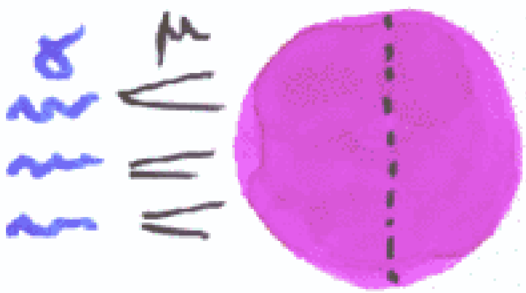
ACT

EXTINCTIONS ON EARTH

$\frac{1 \text{ SN}}{\text{OUR GALAXY}}$ EVERY ~100 y

WITH GRB POINTING TO US EVERY ~100 My

(≈ AVERAGE PERIOD BETWEEN EXTINCTIONS)



$\mu N \to \mu + \text{FRAGMENTS}$

- $\frac{1}{2}$ EARTH HIGHLY RADIOACTIVE WITHIN SECONDS
- THE OTHER ½ (WINDS) WITHIN WEEKS

⇒ BAD NEWS

TESTS AND PREDICTIONS OF THE CB MODEL

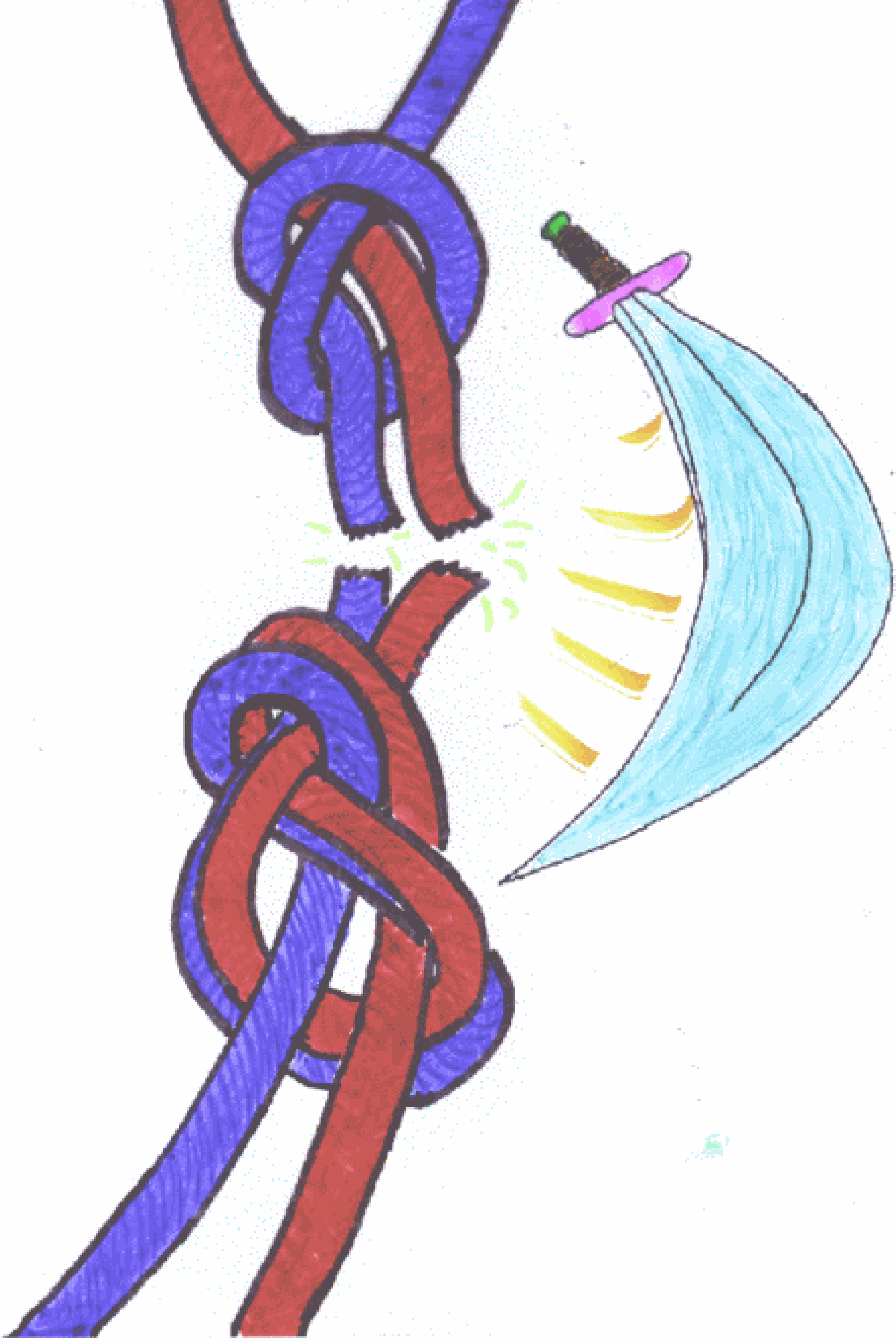
γ-RAYS
- TOTAL FLUENCE ✓✓✓
- PULSE t-SHAPE ✓✓✓
- ENERGY SPECTRUM ✓✓
- E-t CORRELATION ✓(✓)

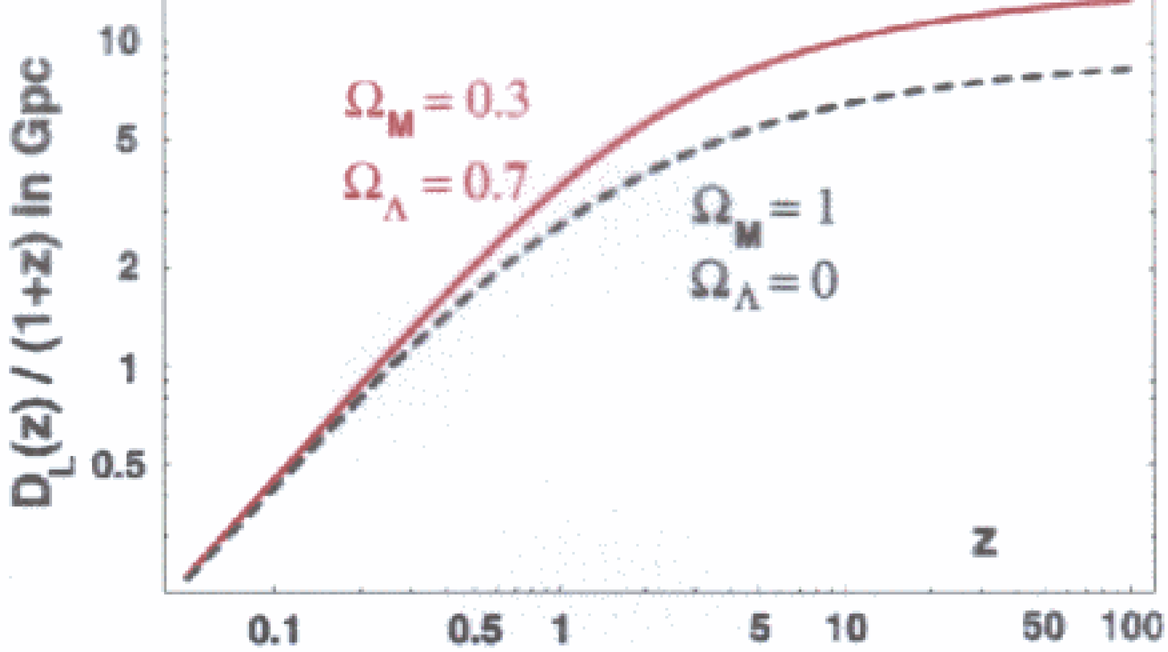
AFTER-GLOWS
- TEMPORAL EVOLUT. ✓✓✓
- SPECTRAL EVOL. WIP
- e-p RECOMB. FLARE ✓✓
- Ly-α RECOMB. LINE ✓✓
- SUPERLUM. MOTION ??

OTHER SIGNALS
- ν-BURST AT PULSES' ONSET ?
- $\pi^0 \to \gamma\gamma$ AT PULSES' ONSET ✓?

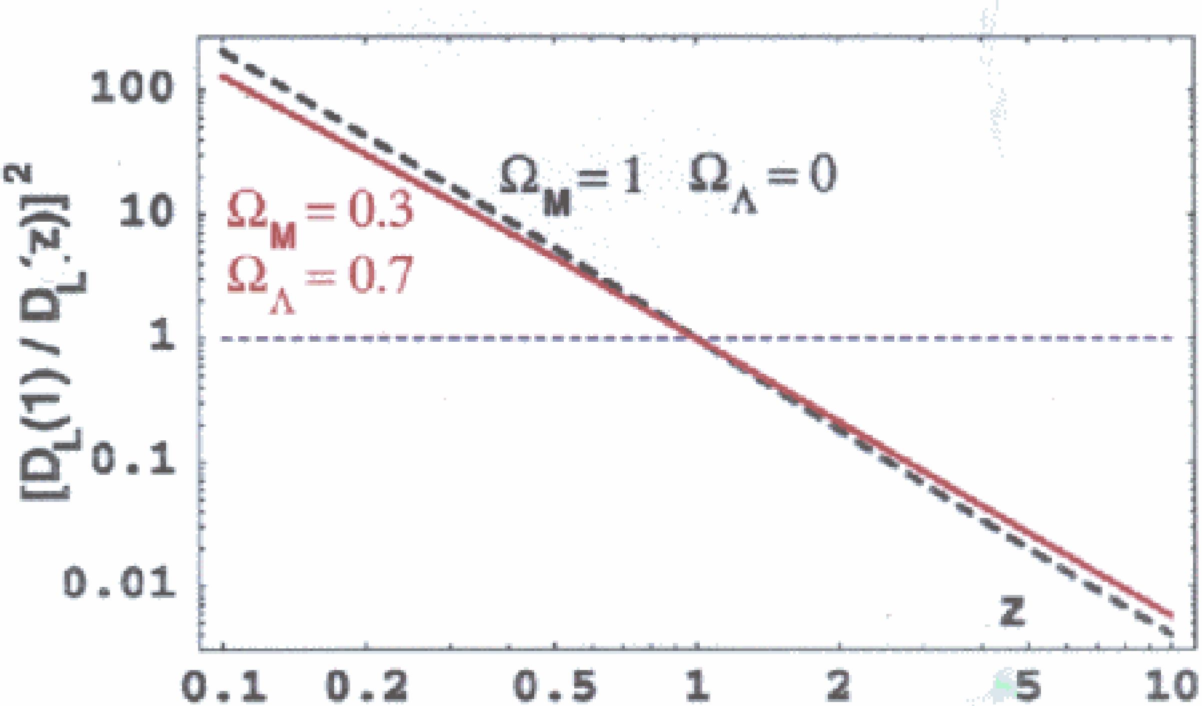
STATISTICAL SPECTRAL PROPERTIES
- VARIABILITY/LUMINOS. RELATION etc ★★ (PLAGA 2000)

The GORDIAN KNOT of the GRB CONUNDRUM

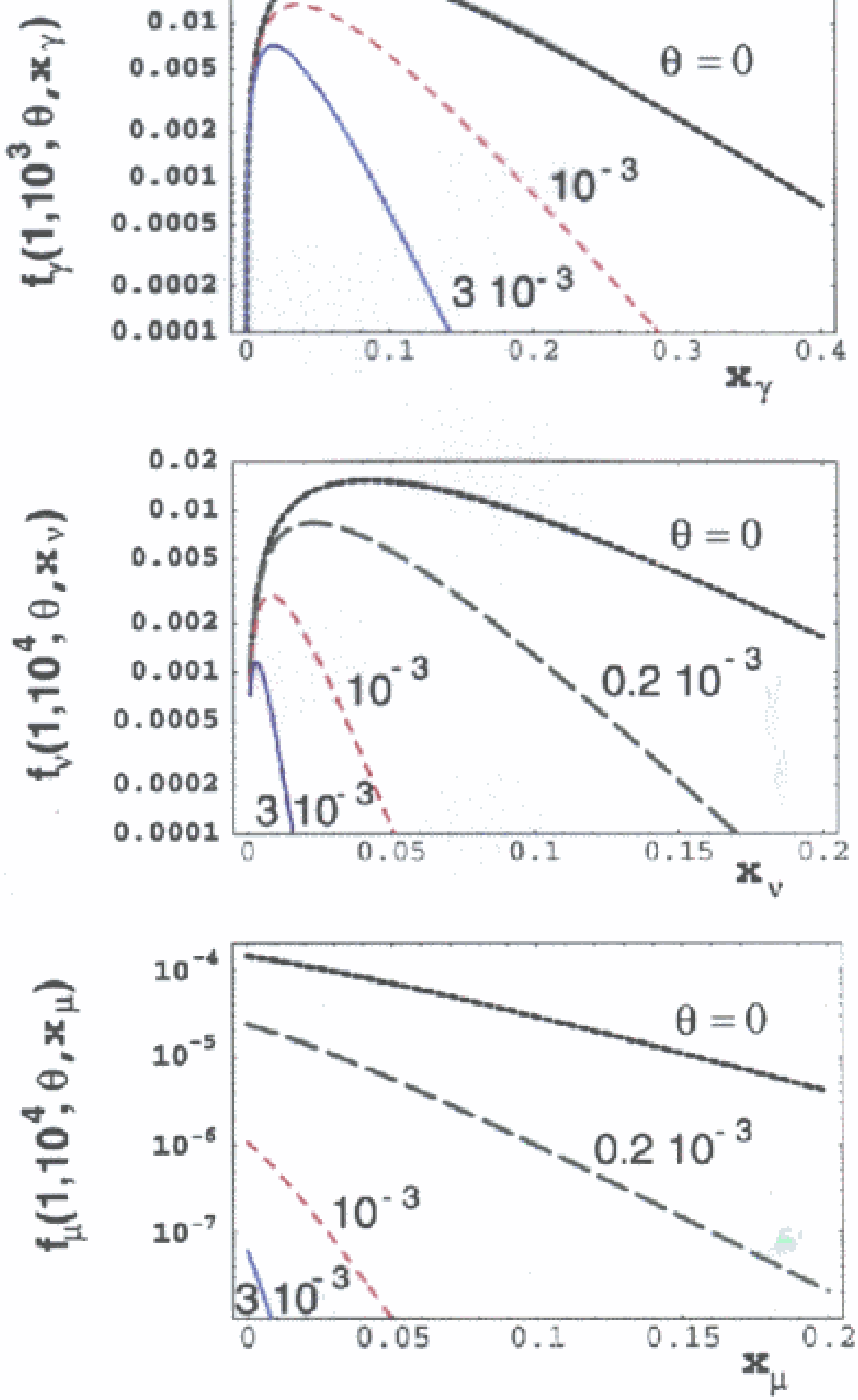




D_L(z) / (1+z) in Gpc
10
5
2
1
0.5
Ω_M = 0.3
Ω_Λ = 0.7
Ω_M = 1
Ω_Λ = 0
z
0.1
0.5
1
5
10
50
100



[D_L(1) / D_L(z)]^2
100
10
1
0.1
0.01
Ω_M = 1   Ω_Λ = 0
Ω_M = 0.3
Ω_Λ = 0.7
z
0.1
0.2
0.5
1
2
5
10



f_γ(1,10^3,θ,x_γ)
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
θ = 0
10^-3
3 10^-3
0
0.1
0.2
0.3
0.4
x_γ
f_ν(1,10^4,θ,x_ν)
0.02
0.01
0.005
0.002
0.001
0.0005
0.0002
0.0001
θ = 0
0.2 10^-3
10^-3
3 10^-3
0
0.05
0.1
0.15
0.2
x_ν
f_μ(1,10^4,θ,x_μ)
10^-4
10^-5
10^-6
10^-7
θ = 0
0.2 10^-3
10^-3
3 10^-3
0
0.05
0.1
0.15
0.2
x_μ