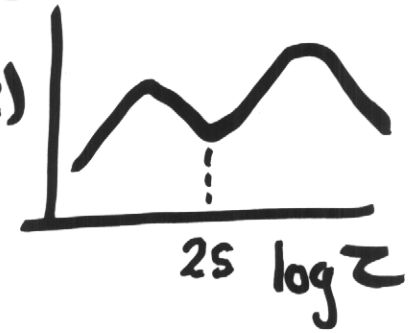
GAMMA RAY BURSTS

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**

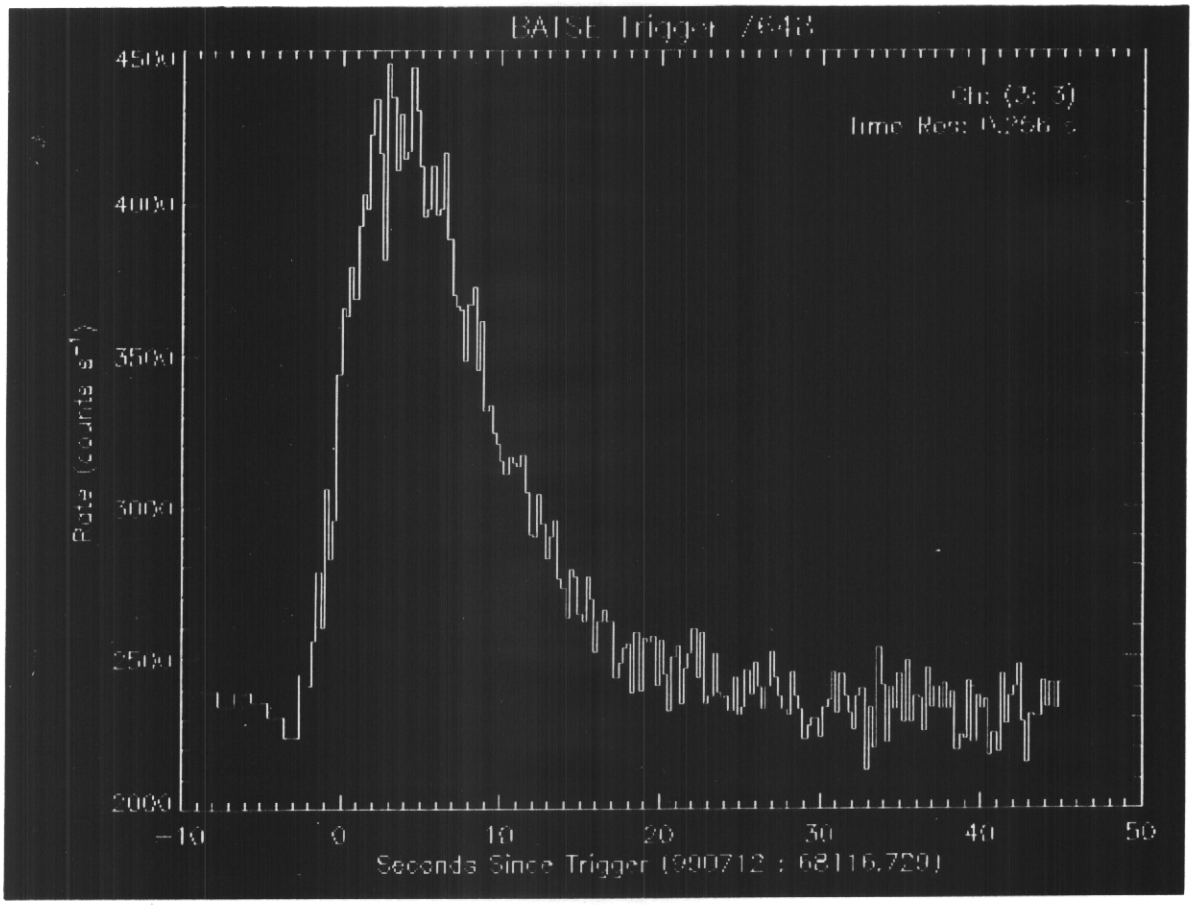
  VERY VARIABLE, SUCCESIVE SHORT PULSES

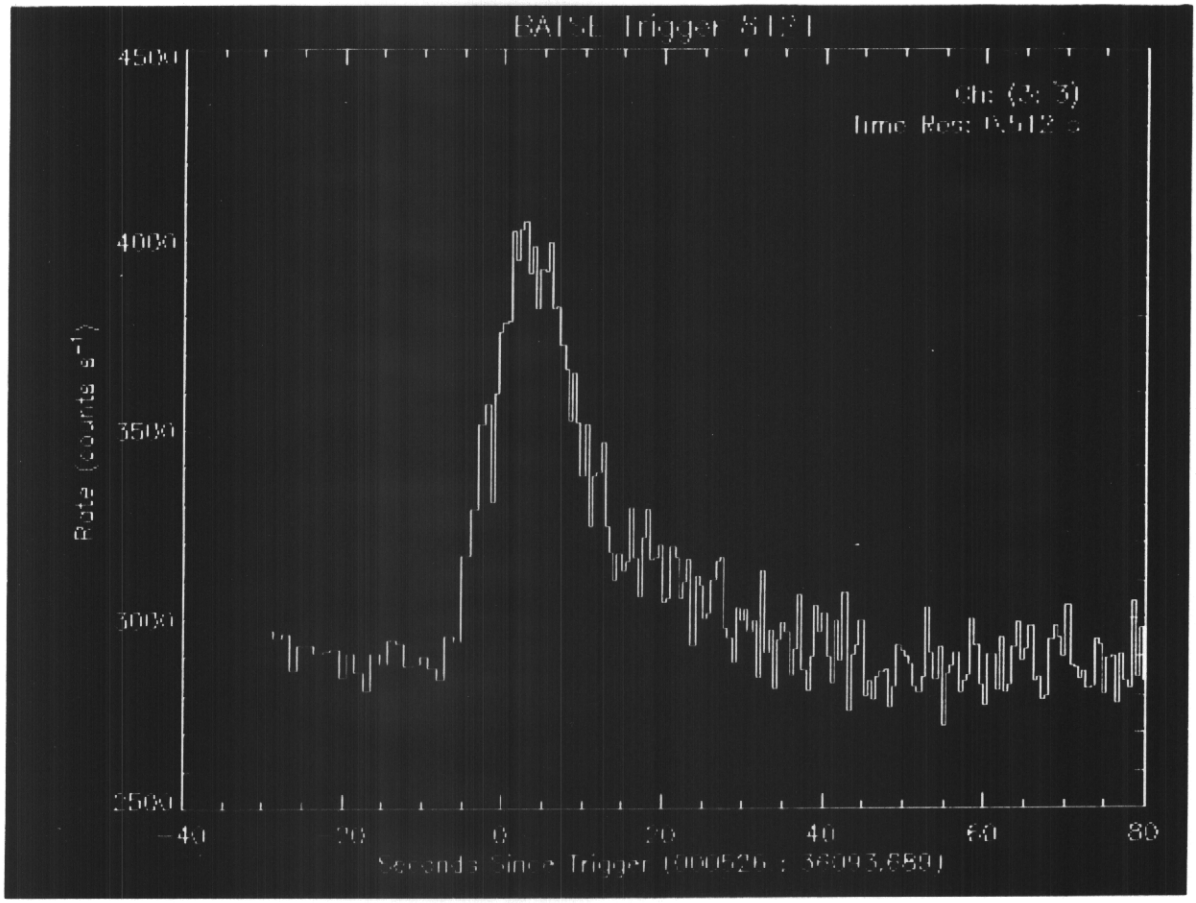
- **VARIABILITY** : DOWN TO 10^{-3} s

  $ct = 300$ km VERY COMPACT SOURCE

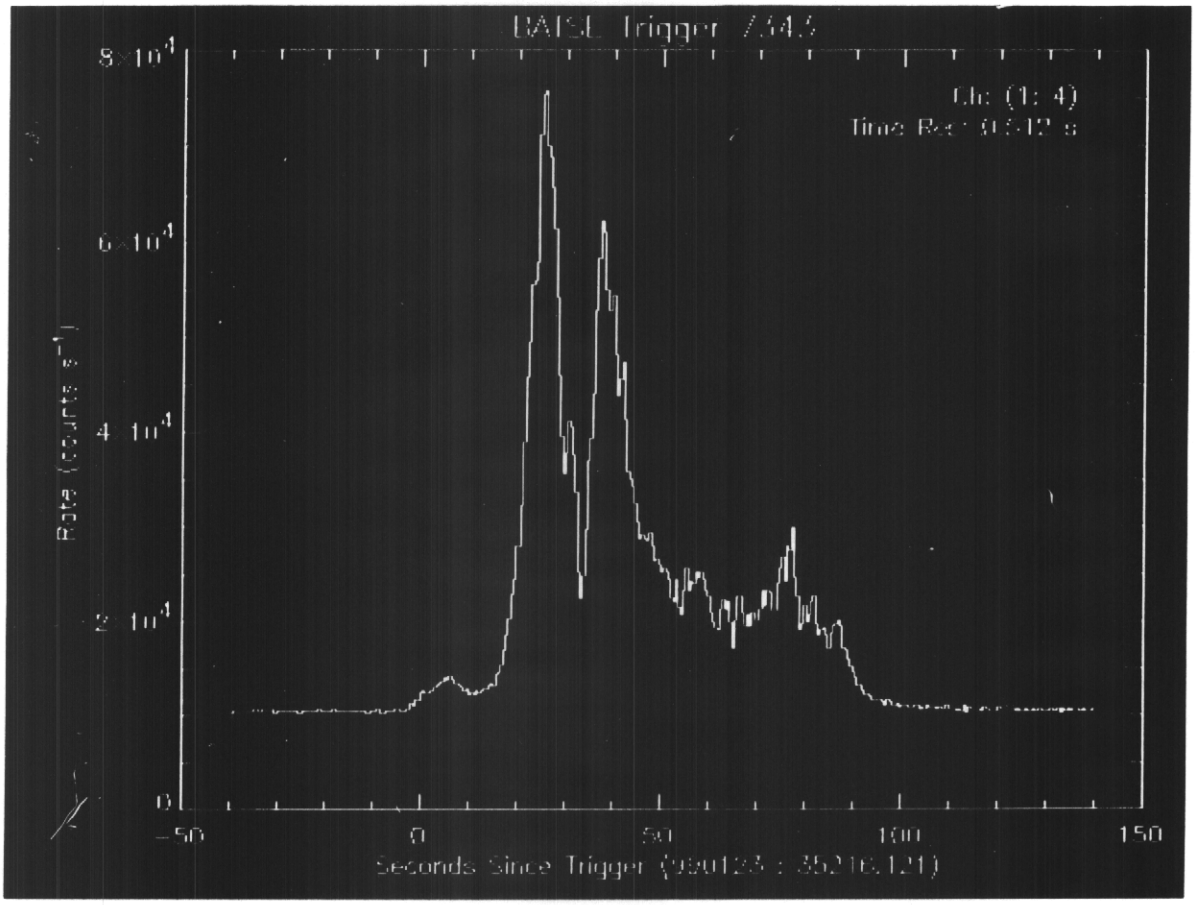
- **FLUENCE** $10^{-3} \leftrightarrow 10^{-7}$ erg/cm^2

FAST
RISE
EXPONENTIAL
DECAY

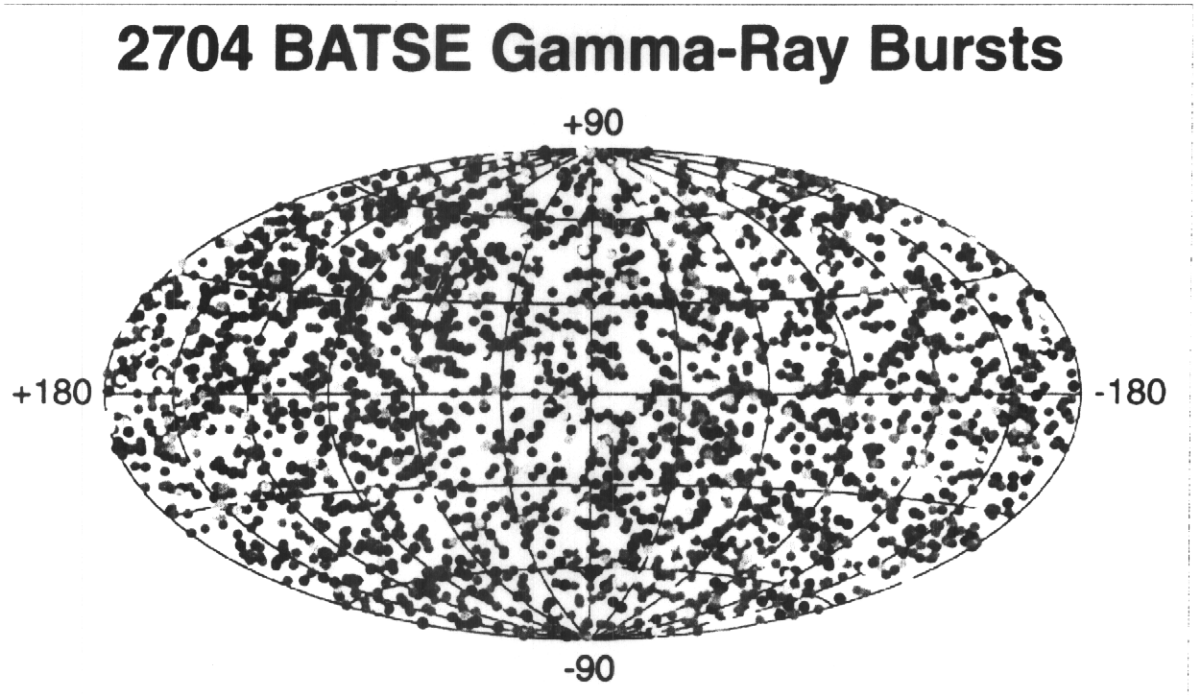

BAISE Trigger
Ch: (3, 3)
Seconds Since Trigger (980712 : 62116.720)


BATSE Trigger 5121
Chs (3:3)
Time Res: 0.512 s
4500
4000
3500
3000
2500
Rate (counts s-1)
-40
-20
0
20
40
60
80
Seconds Since Trigger (T0=26 : 56093.688)

GRB 990123 $E_\gamma > 20$ keV



GRBs are



ISOTROPIC

SATELLITES

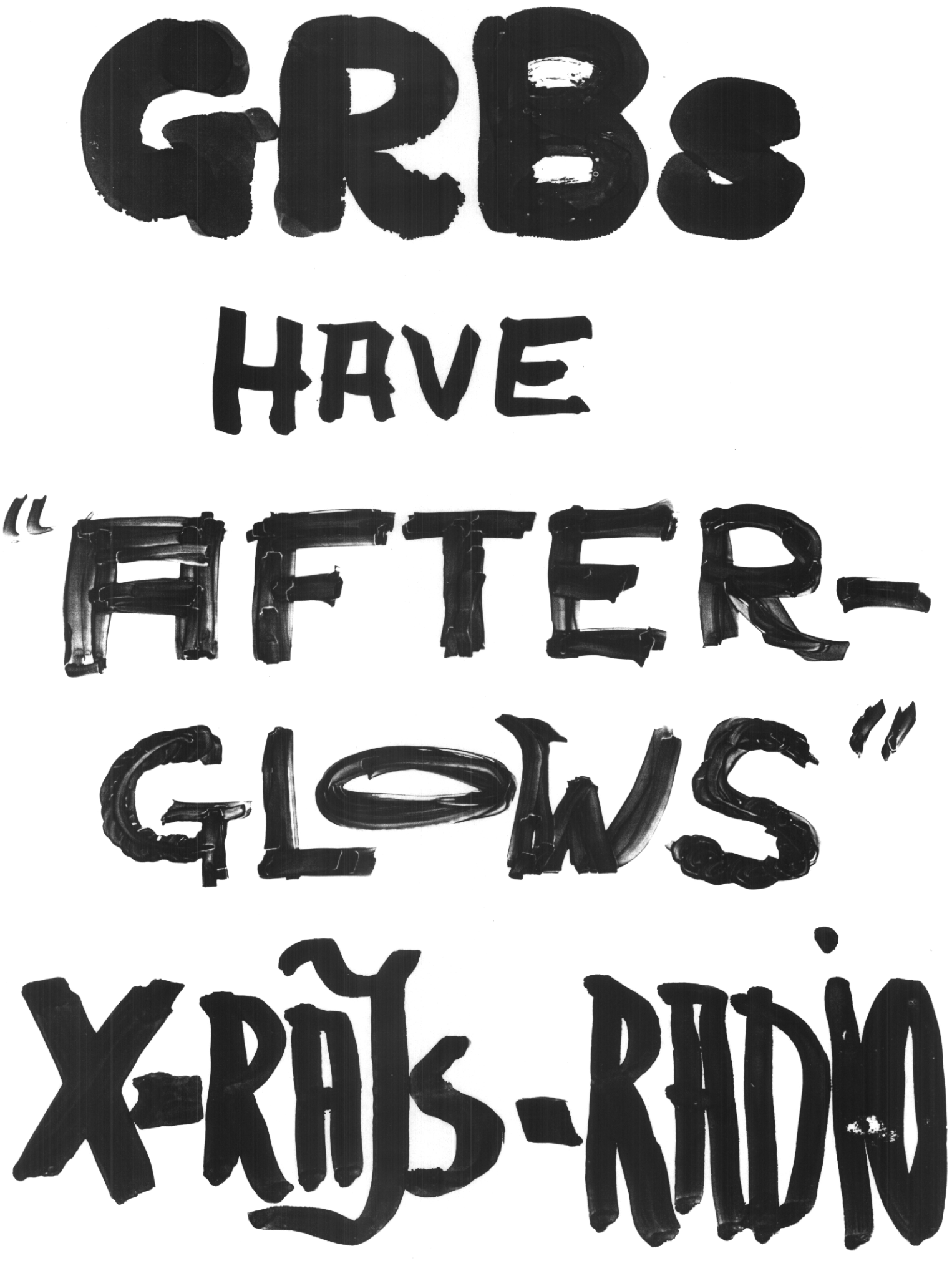
BEPPO-SAX

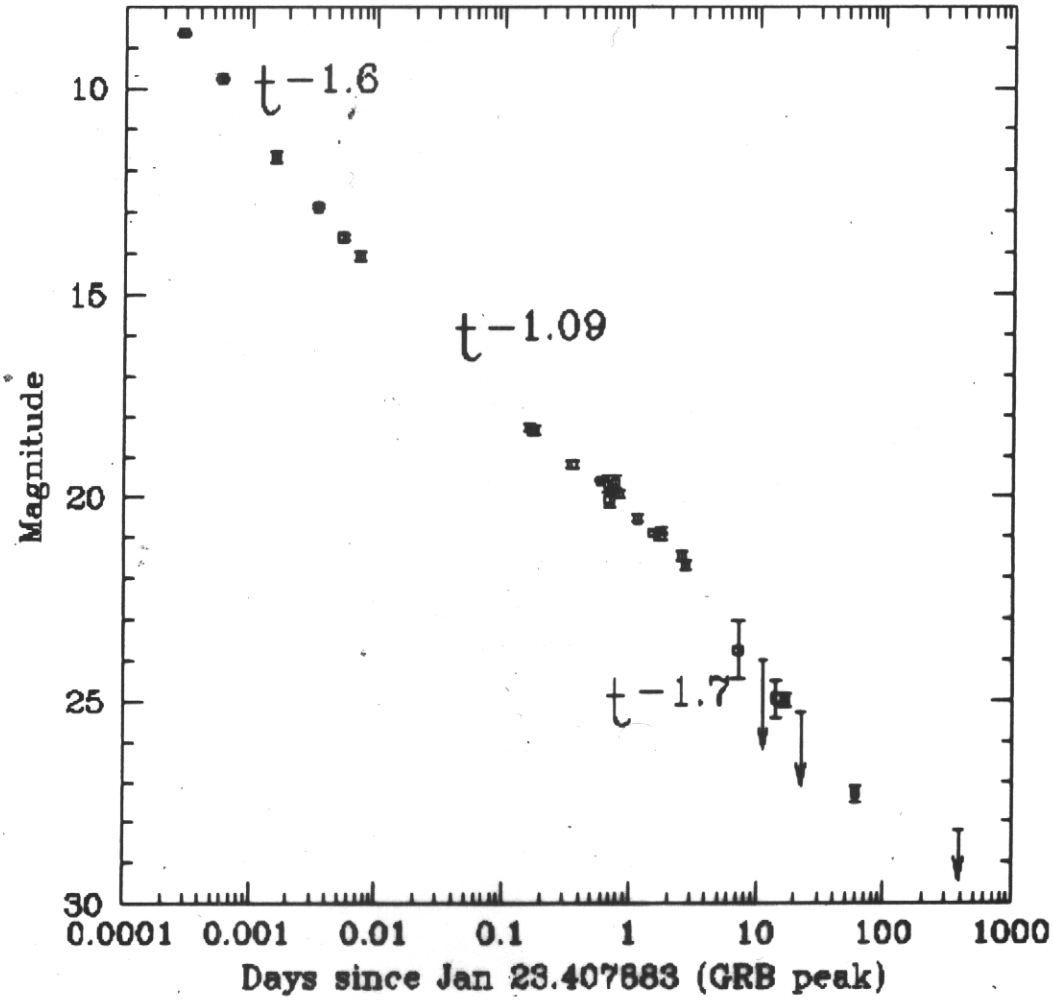
ROSSI

INTERPLANETARY NETWORK

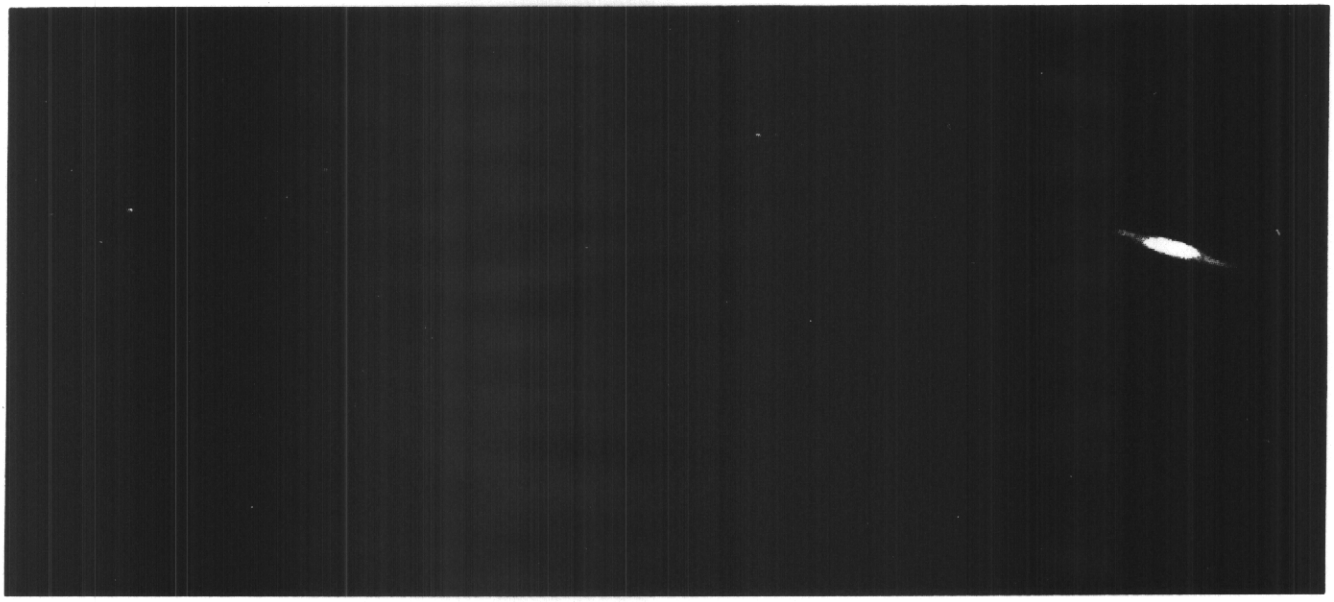
FAST AND PRECISE

GRB. LOCALIZATIONS


GRBs
HAVE
"AFTER-
GLOWS"
X-RAYS-RADIO



Wide-field Image of GRB 990123 Field



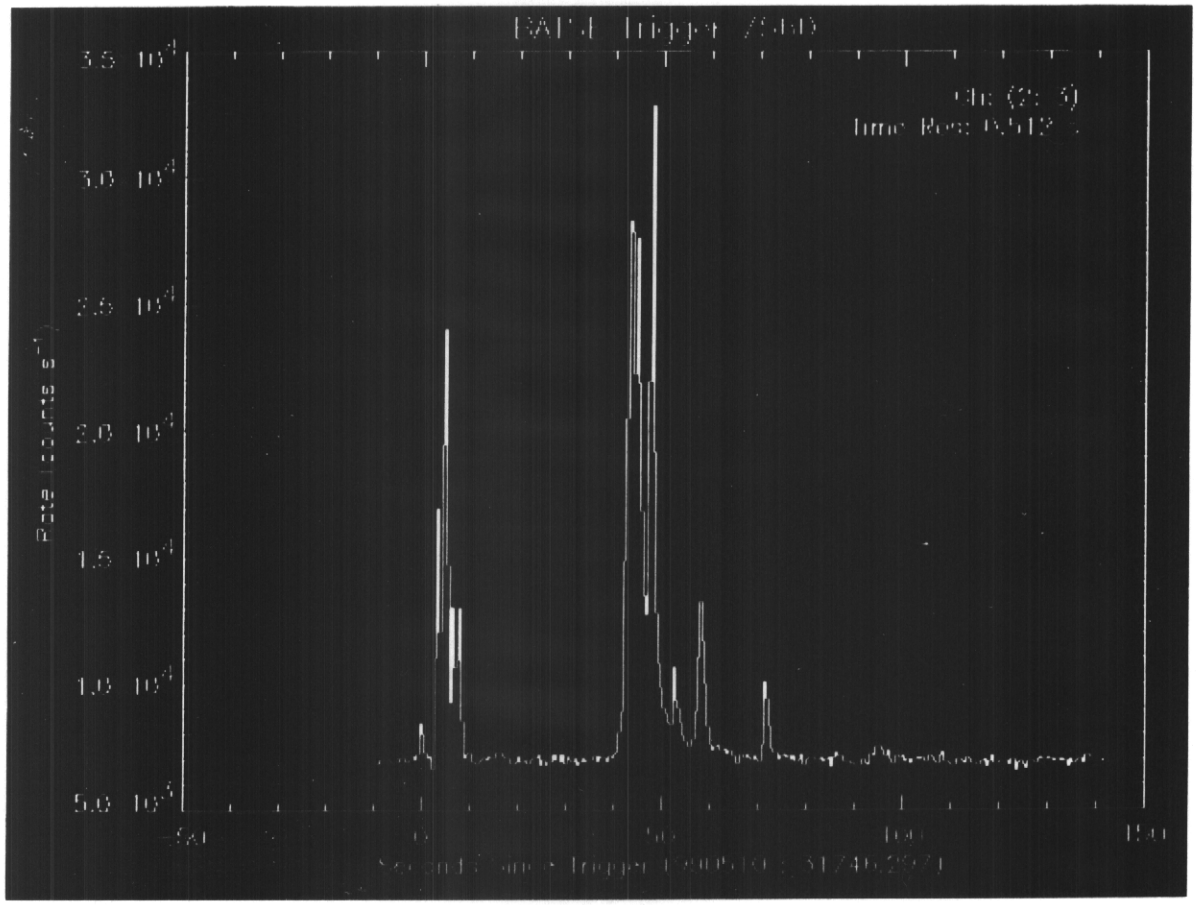

Gamma Ray
Burst
GRB 970228
HST • STIS
Source
Host
PRC97-30 • ST ScI OPO • September 16, 1997 • A. Fruchter (ST ScI) and NASA

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 $H_0 = 65\,km\,s^{-1}\,Mpc^{-1}$. *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.

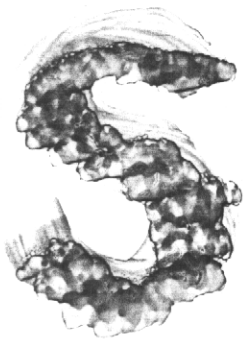

GRBs
are
"COSMO-
LOGICAL"

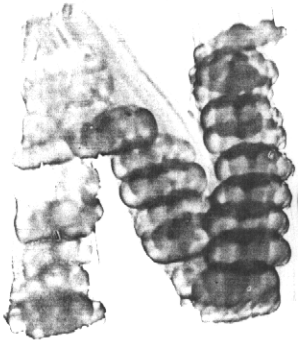


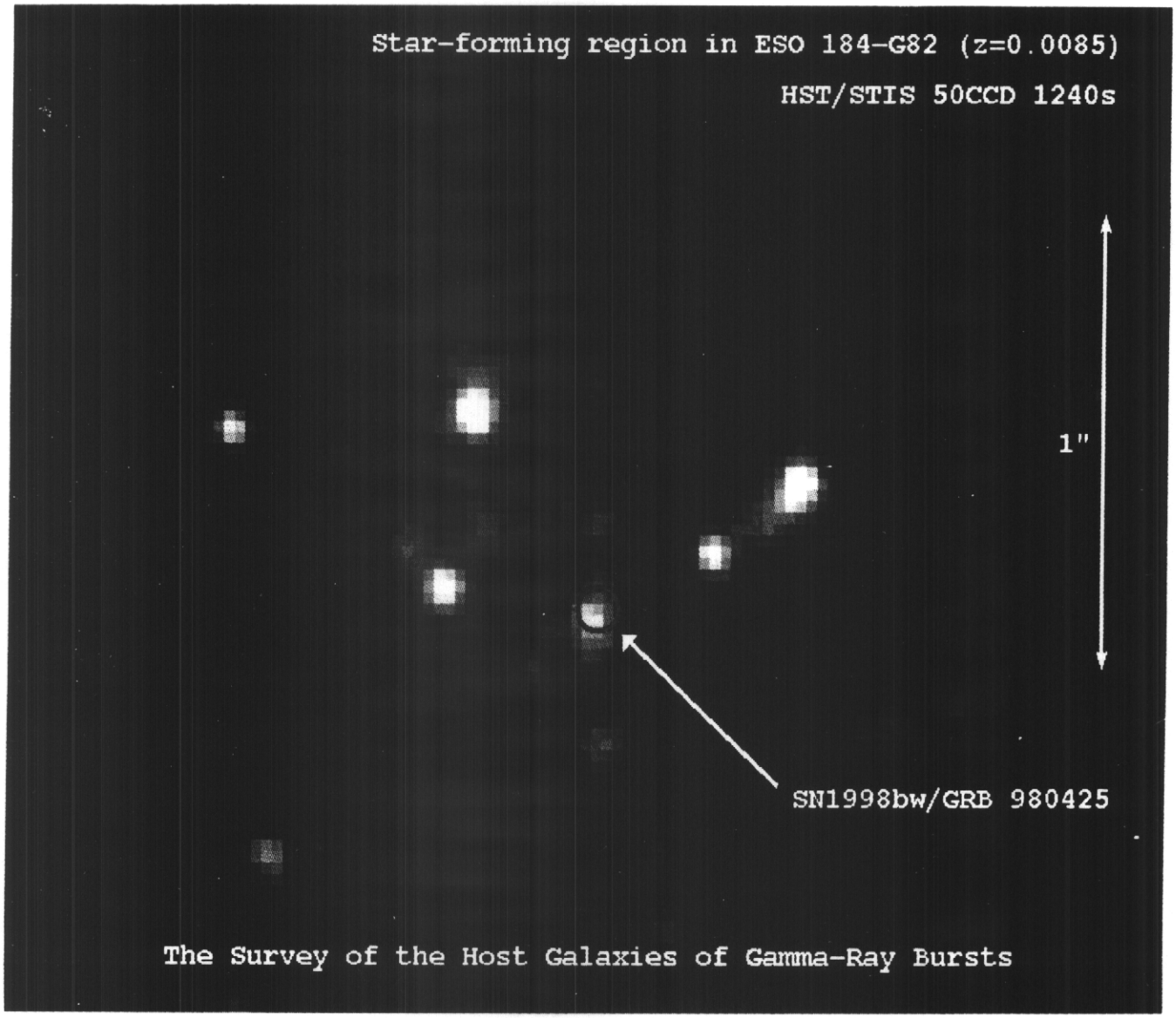
GRB 990510

At z = 1.619

GRBS ARE ASSOCIATED WITH SUPER-NOVAE







778 d after GRB

DAR 1998:

SUPPOSE SN1998bw

$\approx$ STANDARD CANDLE FOR

SUPERNOVAE ASSOC. W. GRBs

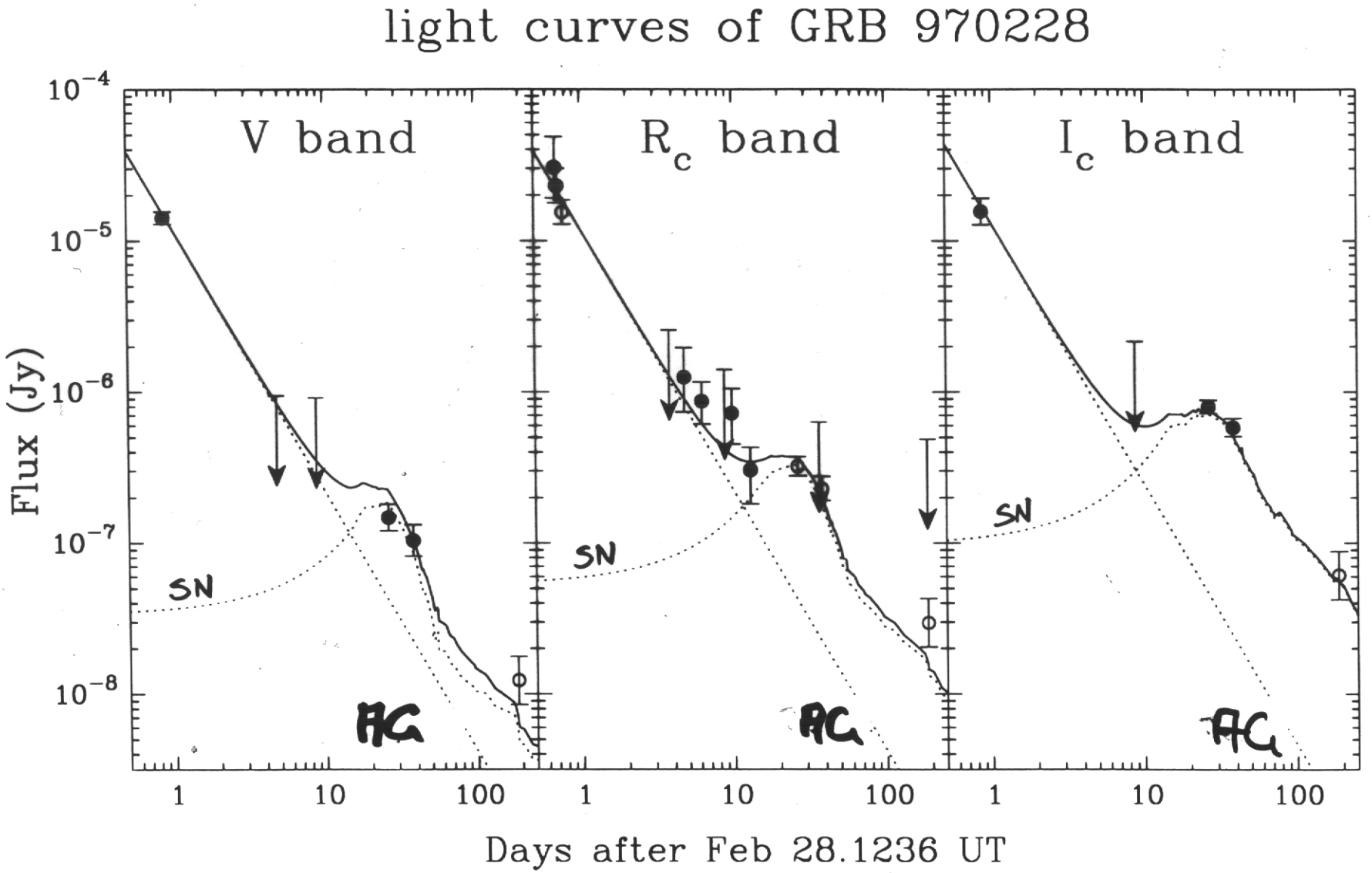
HOW WOULD IT LOOK LIKE AT A DIFFERENT z ?

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

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

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

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


light curves of GRB 970228
V band
R_c band
I_c band
Flux (Jy)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
SN
AG
1
10
100
Days after Feb 28.1236 UT

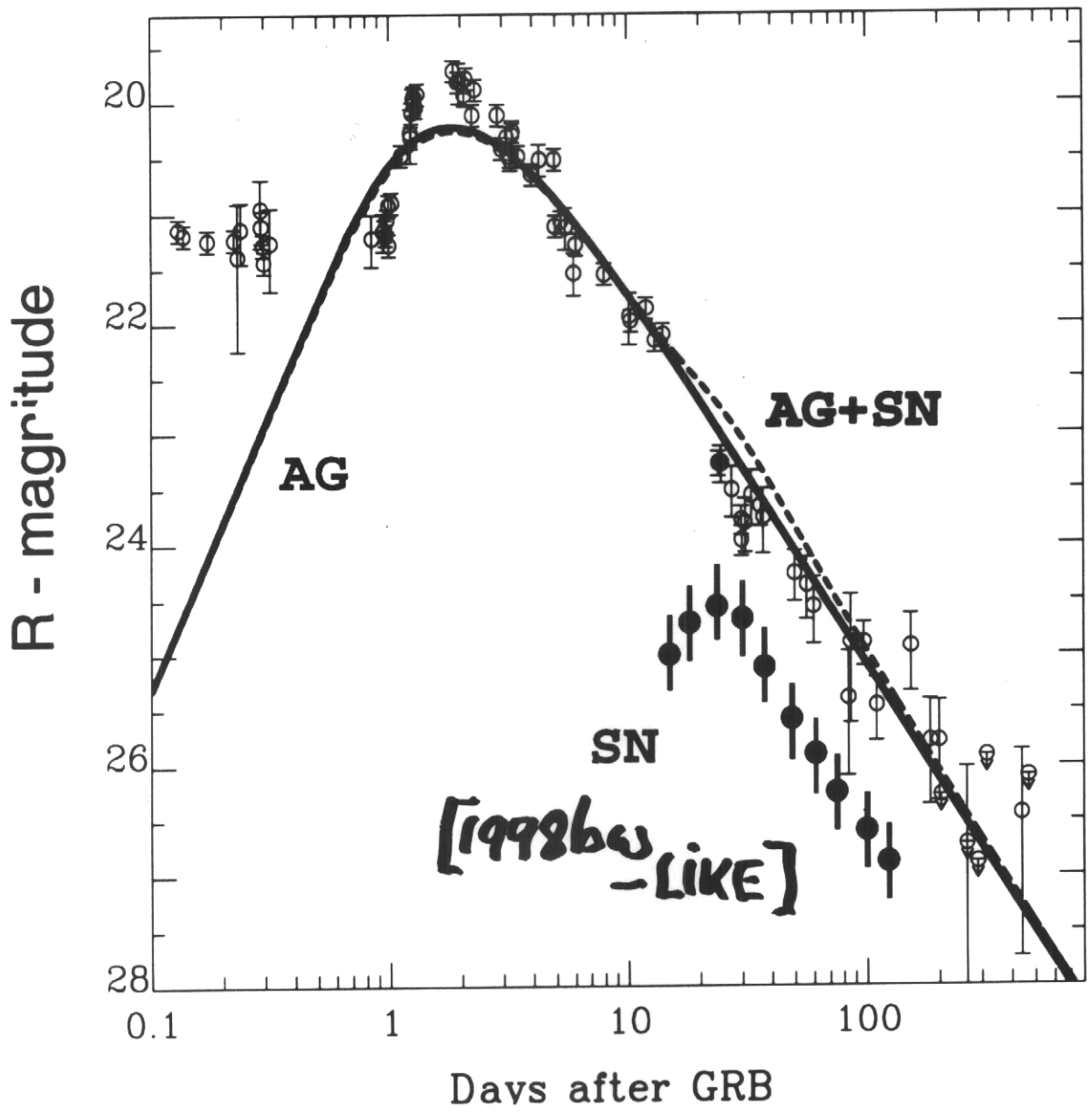
OUT OF THE 15 GRBs WITH KNOWN z (ca DEC 2000)

≥ 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 970228


R - magnitude
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

$$\nu \ni \nu \rightarrow \nu(1+z)$$

IV NOBODY WAS LOOKING

EVEN IF [illegible]

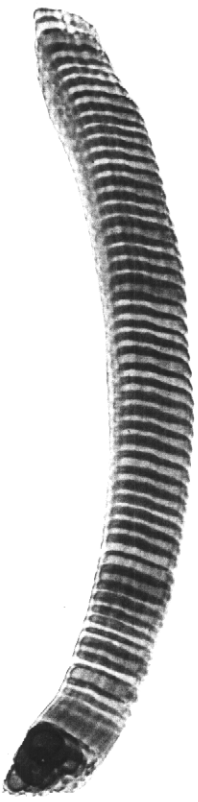
[illegible] TIME ...

... YOU COULD NOT SEE IT

POSSIBLY, NOT ONLY,
MOST (LONG DURATION)
GRBs ARE ASSOCIATED
WITH SNe (>6/15)

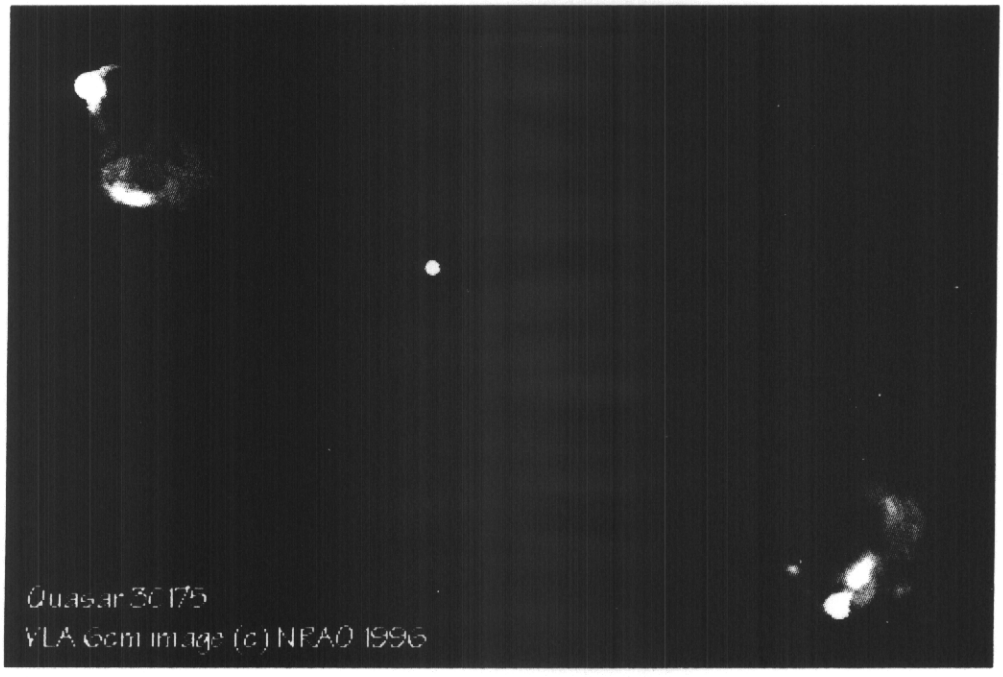
BUT, ALSO,
A HEFTY FRACTION OF
(CORE-COLLAPSE) SNe
EMIT GRBs

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

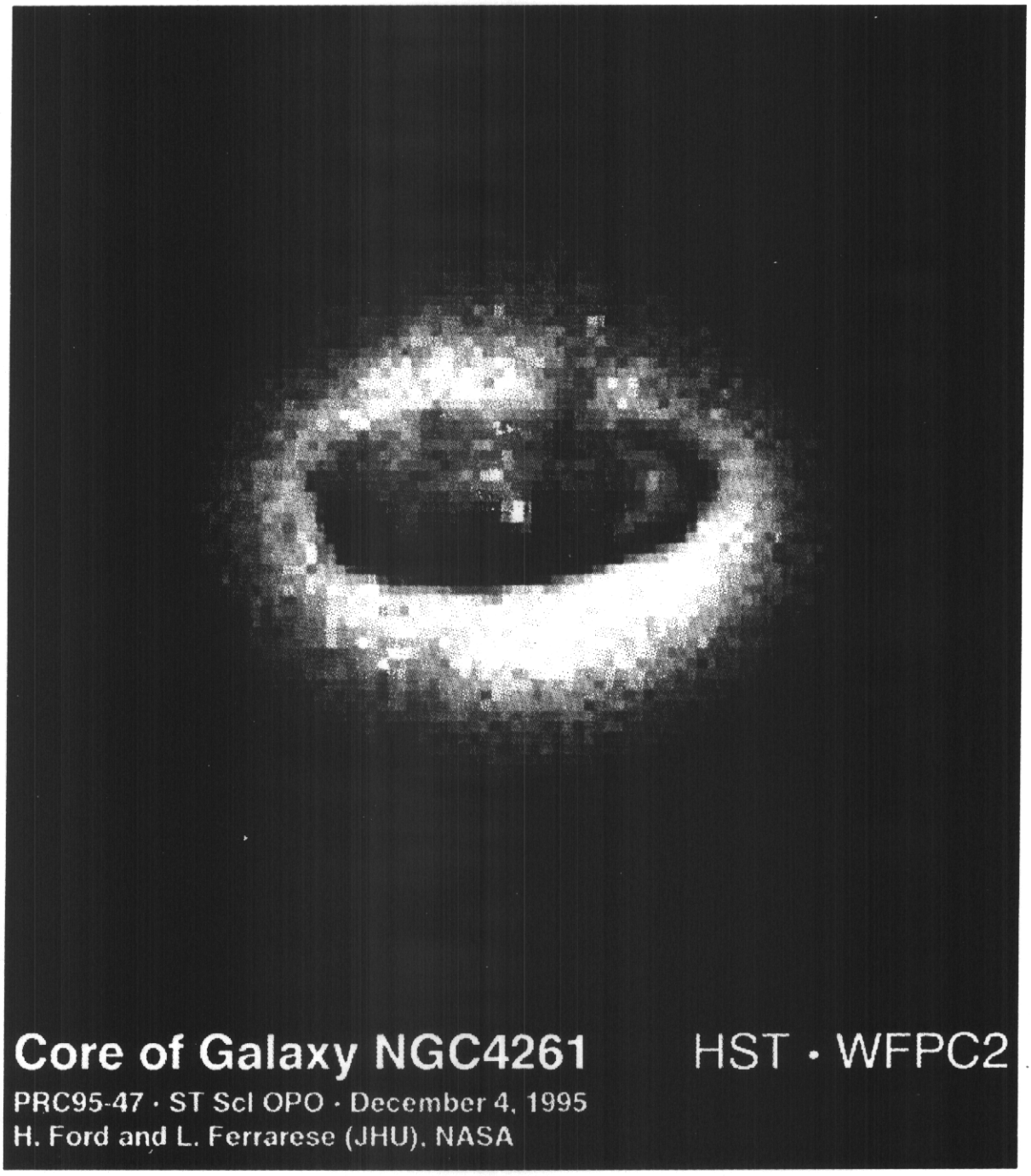


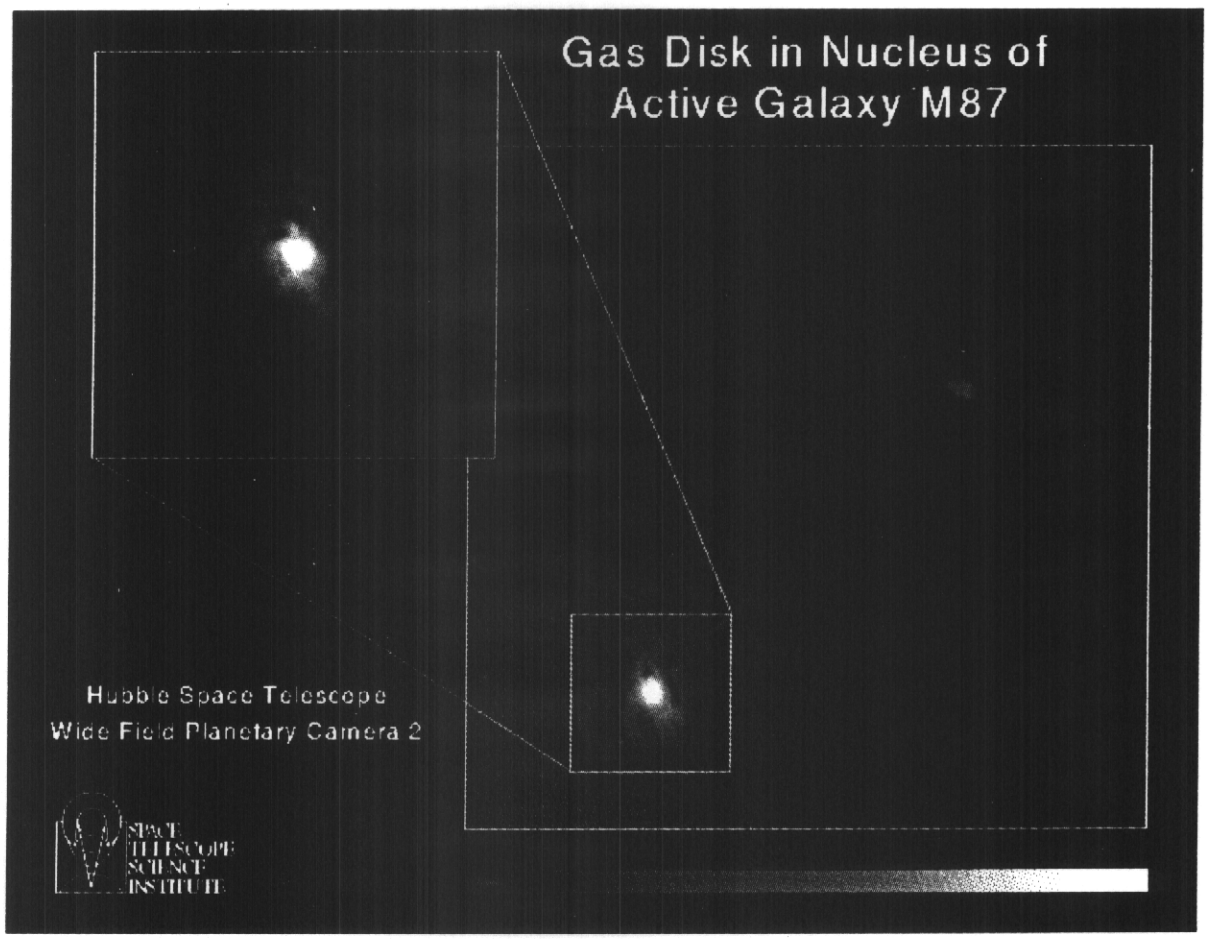
- Quasar at z=0.768
- Overall linear size 212/*h* kpc (Hubble constant H = 100*h* km/s/Mpc)
- Double lobes with prominent hot spots
- Narrow jet, no counterjet (Doppler hidden?)
- Jet brightens and bends as it enters its lobe
- VLA 4.9 GHz image at 0.35 arcsec resolution

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.

Go back to:

- Alan Bridle's Image Gallery
- Alan Bridle's Home Page
- NRAO Charlottesville Home Page
- NRAO VLA Home Page
- AstroWeb Home Page


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
Wide Field Planetary Camera 2
SPACE
TELESCOPE
SCIENCE
INSTITUTE

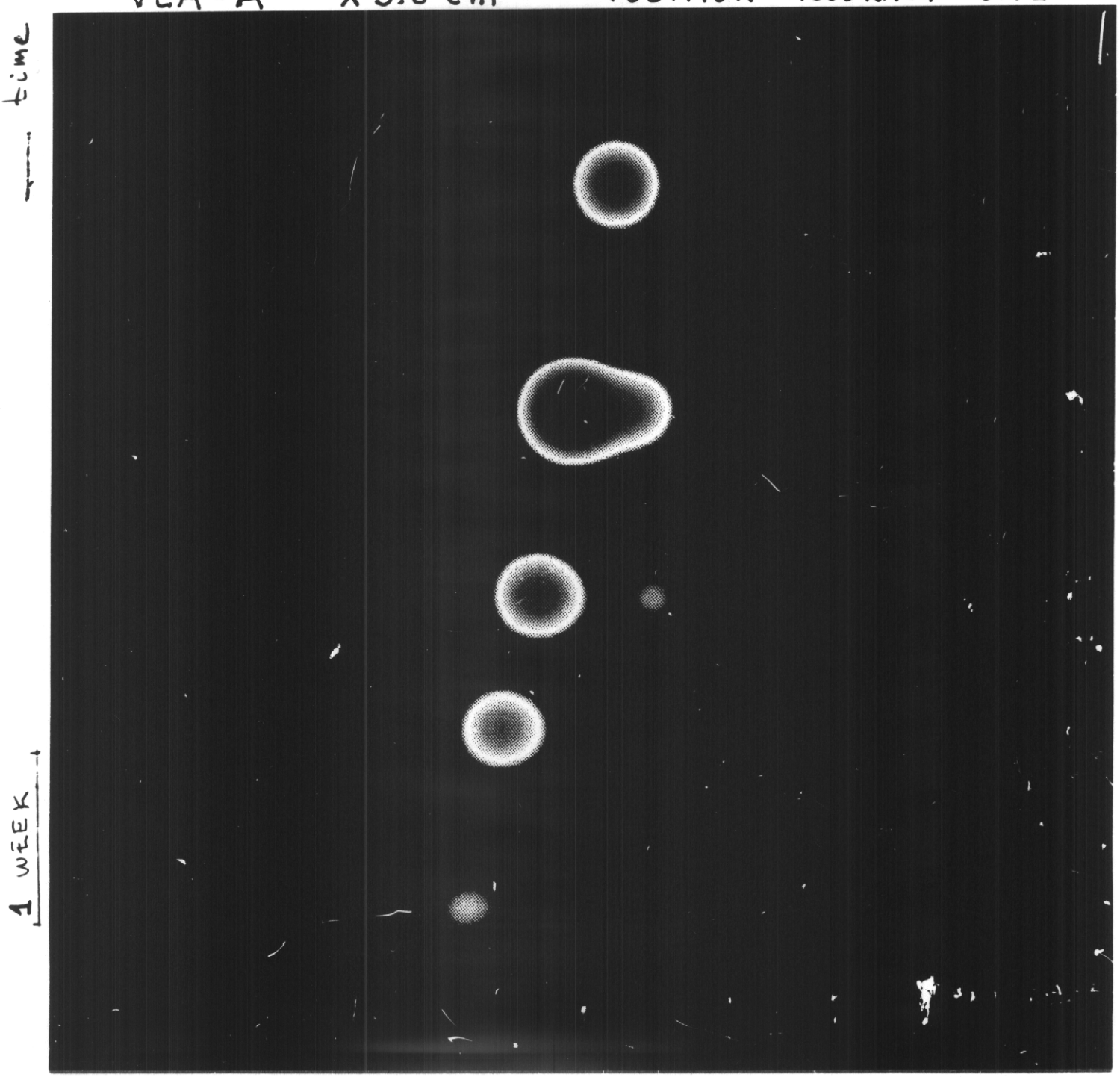
MIRABEL / RODRIGUEZ and colls

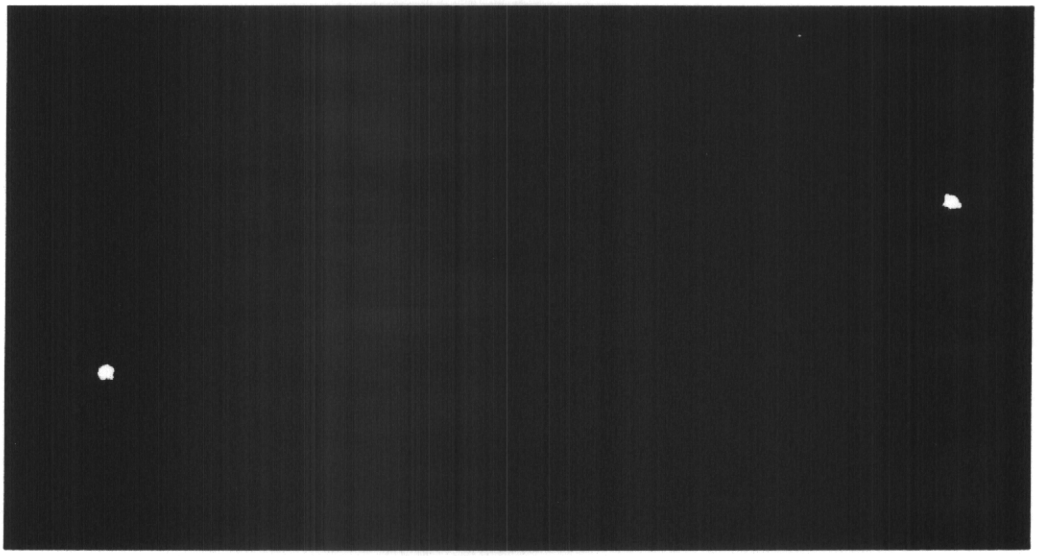
μ-QUASARS

GRS 1915+105 ($l = 45°$, $b = 0°$)

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

VLA-A λ 3.5 cm POSITION ACCURACY 0.02"





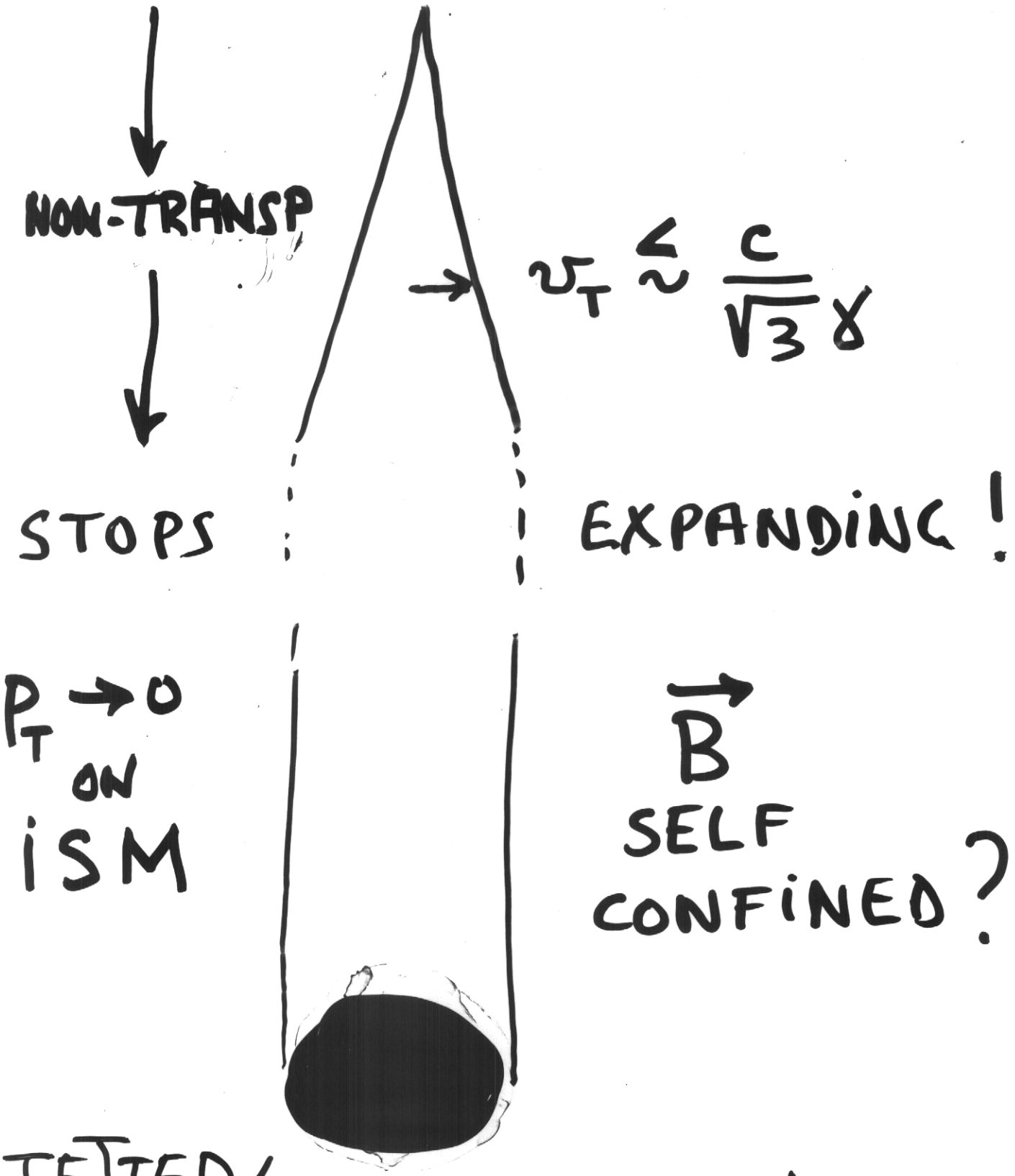
Chandra X-ray Observatory Center

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

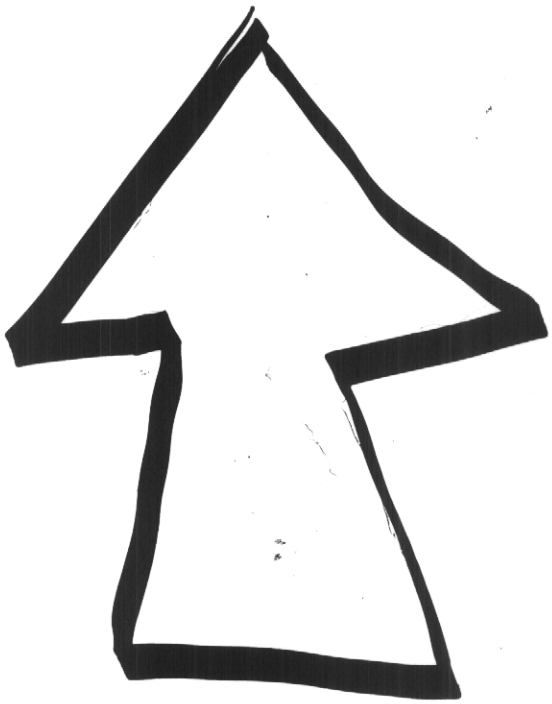
Pictor A: The brightest radio galaxy in the Constellation Pictor.
(Credit: NASA/UMD/A.Wilson et al.)

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.

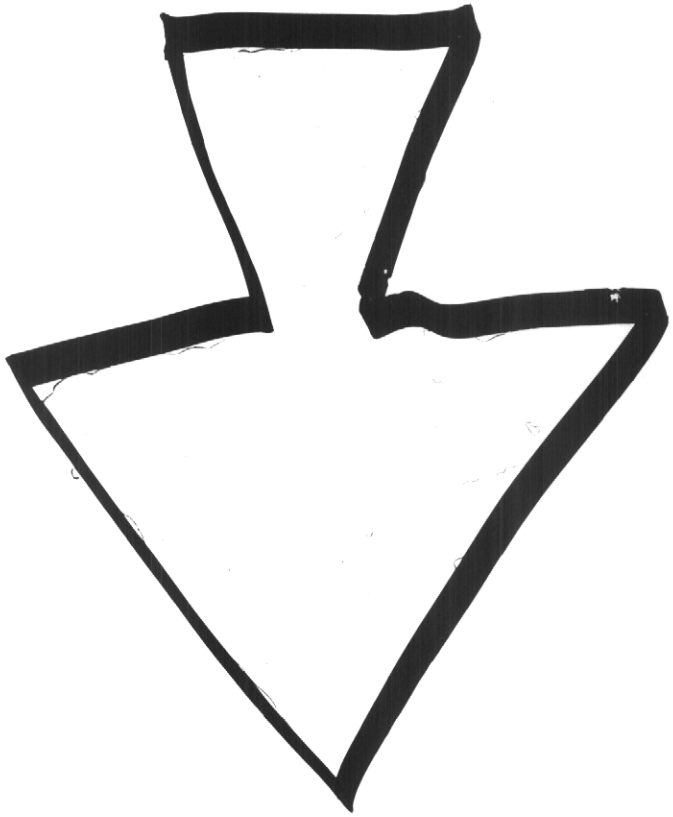
Scale: The hot spot is 4.2 arcmin from the galaxy.


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



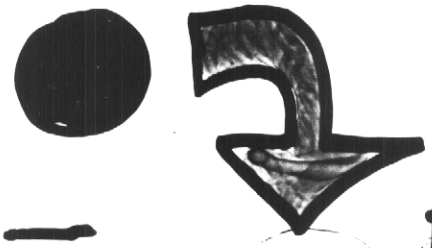
GRBs

THE COSMOLOGICAL-GRB ENERGY CRISIS

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

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

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



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

$$E_\gamma(\mathrm{GRB\,990123}) \sim 2.6\ 10^{54}\ \mathrm{erg}$$

★-ENERGIES (GRB/SN ASSOCIATION!)

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

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

STRONG INDICATION AGAINST SPHERICITY

INDICATIONS of RELATIVISTIC MOTION

FAST VARIABILITY (SMALL SIZE) + LARGE LUMINOSITY

⇓

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

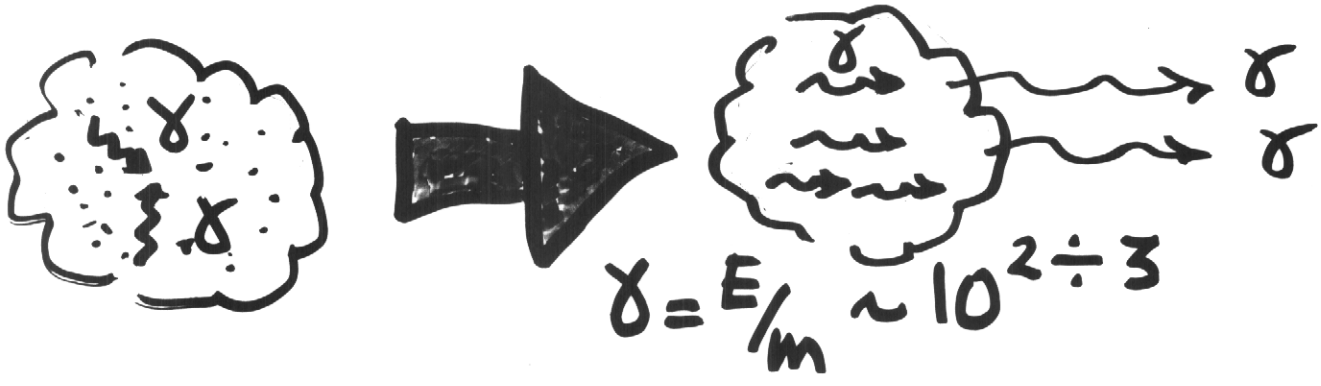
⇓

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

NOT SEEN !

⇓

BOOOOST !!



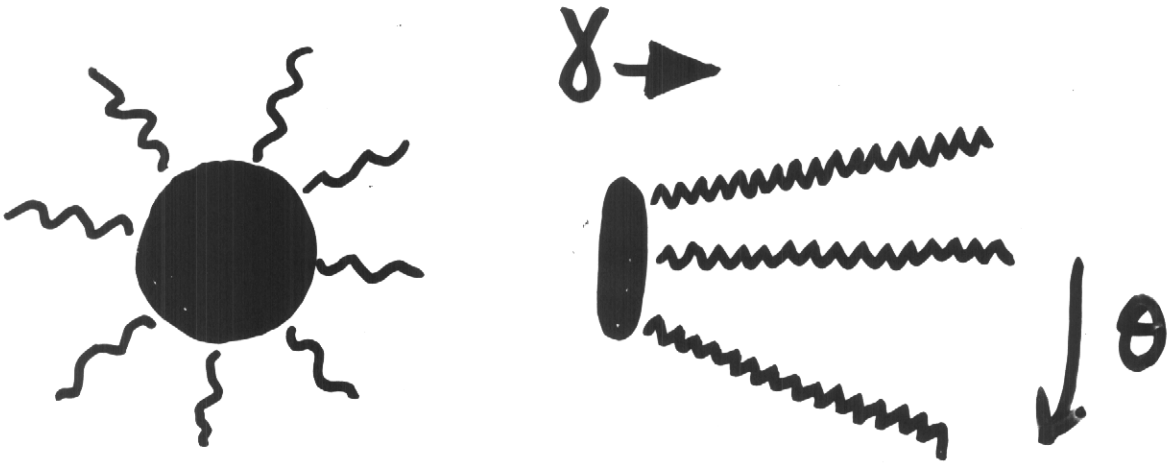
e^+e^- CUTOFF RISES TO UNOBSERV.

HIGH ENERGY (FLUX SMALL)

WHAT IS MOVING FAST AND IS NOT SPHERICAL

A JET!

DAR / SHAVIV 1995

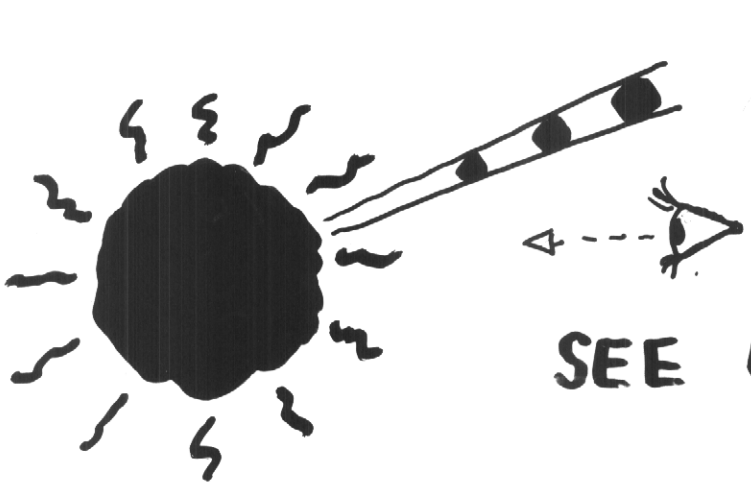


$$\theta \sim 1/\gamma$$

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

$\gamma > 100$ SOLVES THE ENERGY CRISIS

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

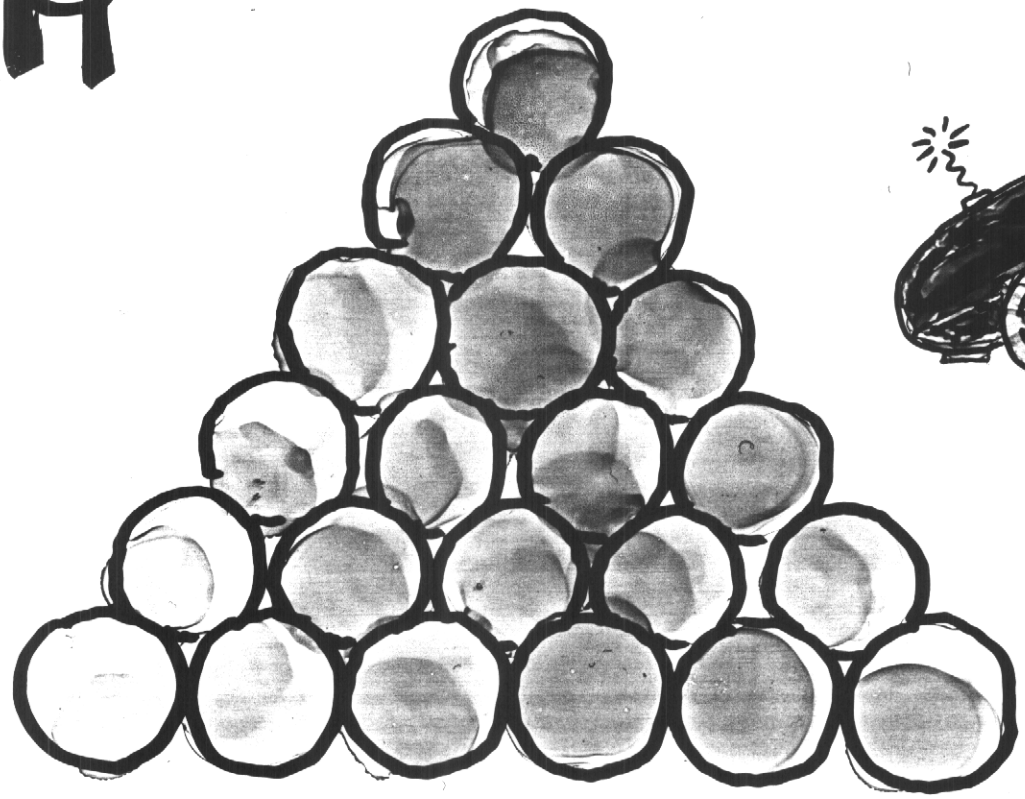


$$\frac{\Delta\Omega}{4\pi} \sim \frac{1}{4\gamma^2}$$

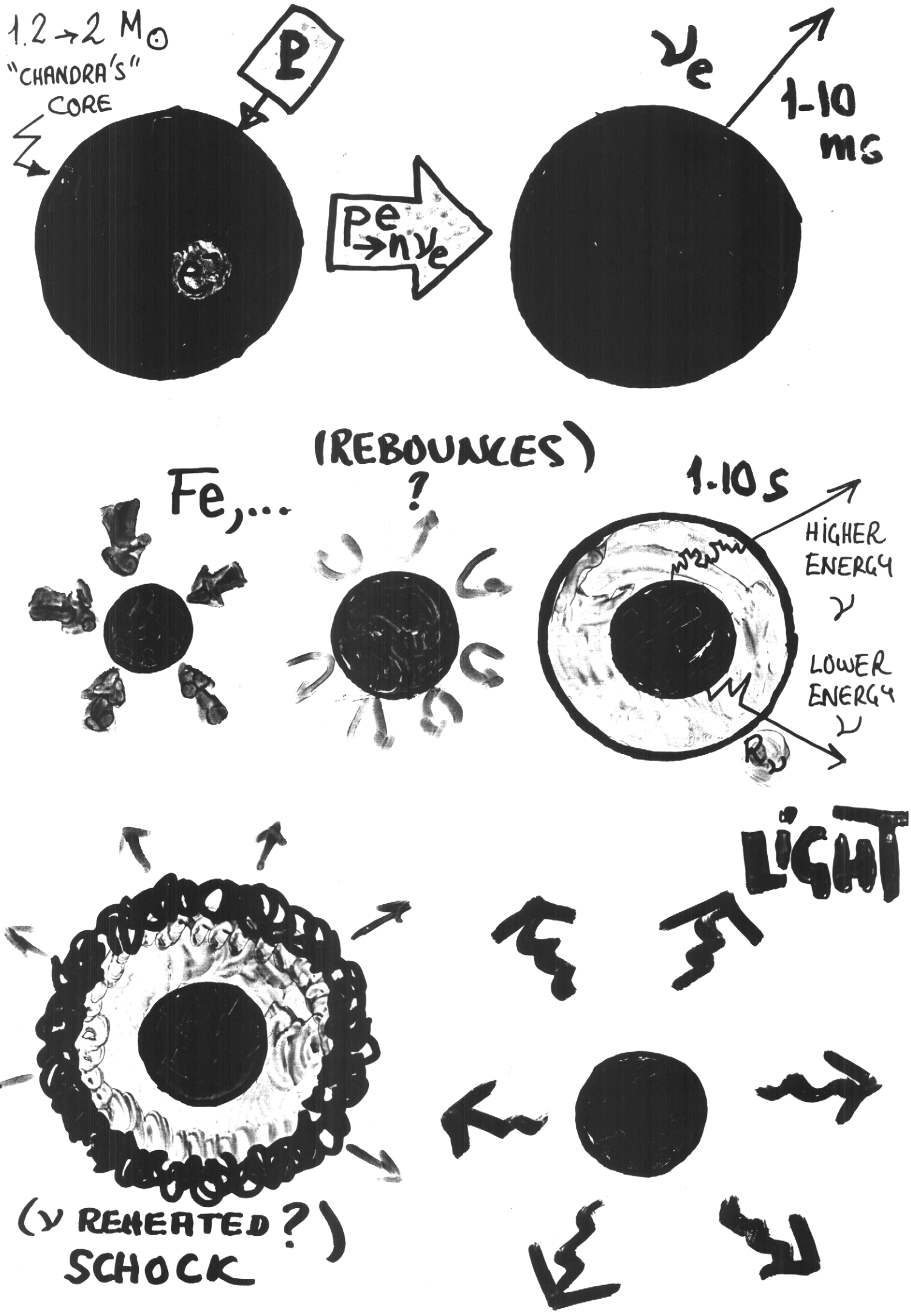
SEE $O(10^6)$ SNe PER GRB

DAR
ADR

A



MODEL of GRBs


1.2→2 M⊙
"CHANDRA'S"
CORE
P
pe→nνe
νe
1-10
ms
Fe,...
(REBOUNCES)
?
1-10 s
HIGHER
ENERGY
ν
LOWER
ENERGY
ν
LIGHT
(ν REHEATED ?)
SCHOCK

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

- 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

$\lesssim$ because $r < R_\star$ $\gtrsim$ BECAUSE OF ANGULAR MOMENTUM

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

FALL-BACK MATERIAL

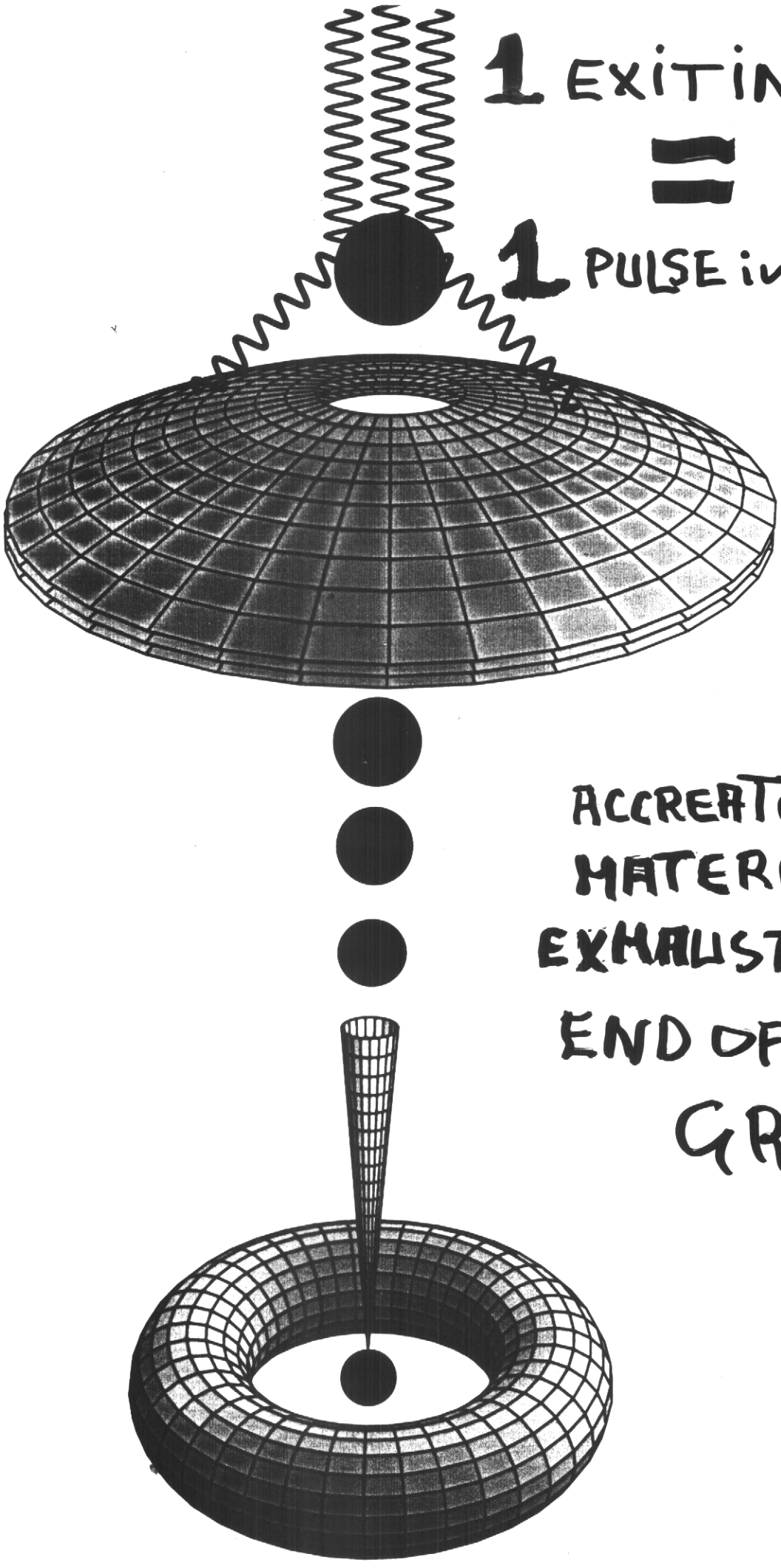
$$\sim 1\,\text{day} \left[\frac{R_\star}{10^{12}\,\text{cm}}\right]^{3/2} \left[\frac{1.4 M_\odot}{M_c}\right]^{1/2}$$

EJECTED MATERIAL:

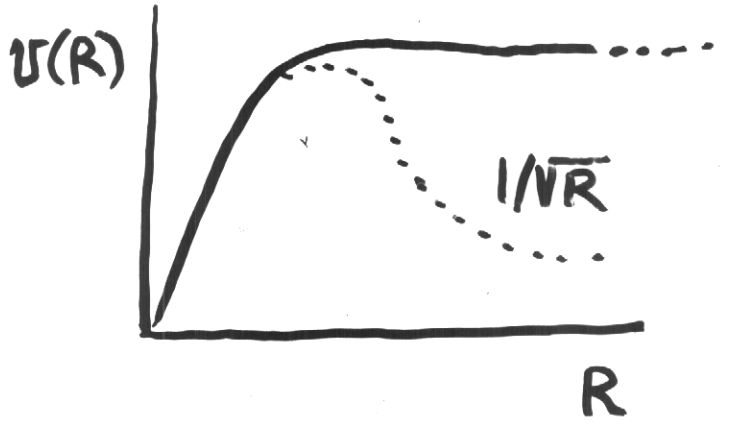
SUPERNOVA SHELL, RADIUS:

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

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

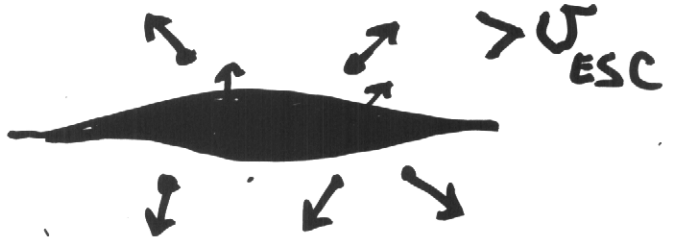

1 EXITING CB
=
1 PULSE in GRB
ACCREATING MATERIAL EXHAUSTED: END OF the GRB

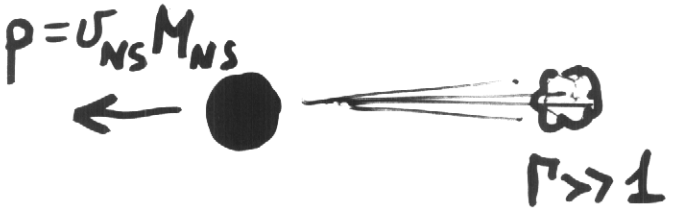
NS KICKS & JETS (DAR & PLAGA)



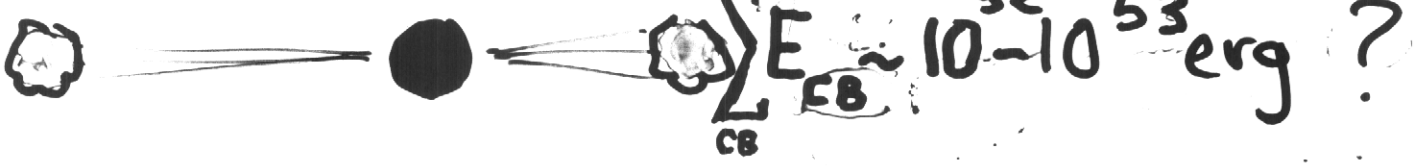
$v_\star \sim v_\odot \sim 250\ km/s$

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





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



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 $E/_{NUCLEON} \sim 1$ TeV ($\gamma \sim 10^3$)

III COMPOSITION

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

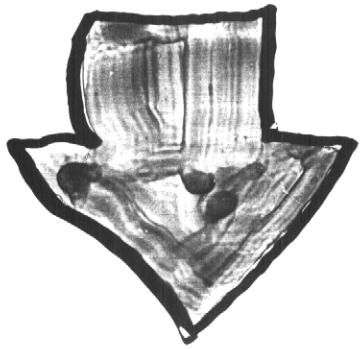
↳ p, e

"BARYONIC"

(AS FOR JETS OF SS433 & QUASAR

Ly_α, K_α Fe-LINES)

1 CB → 1 PULSE of a GRB

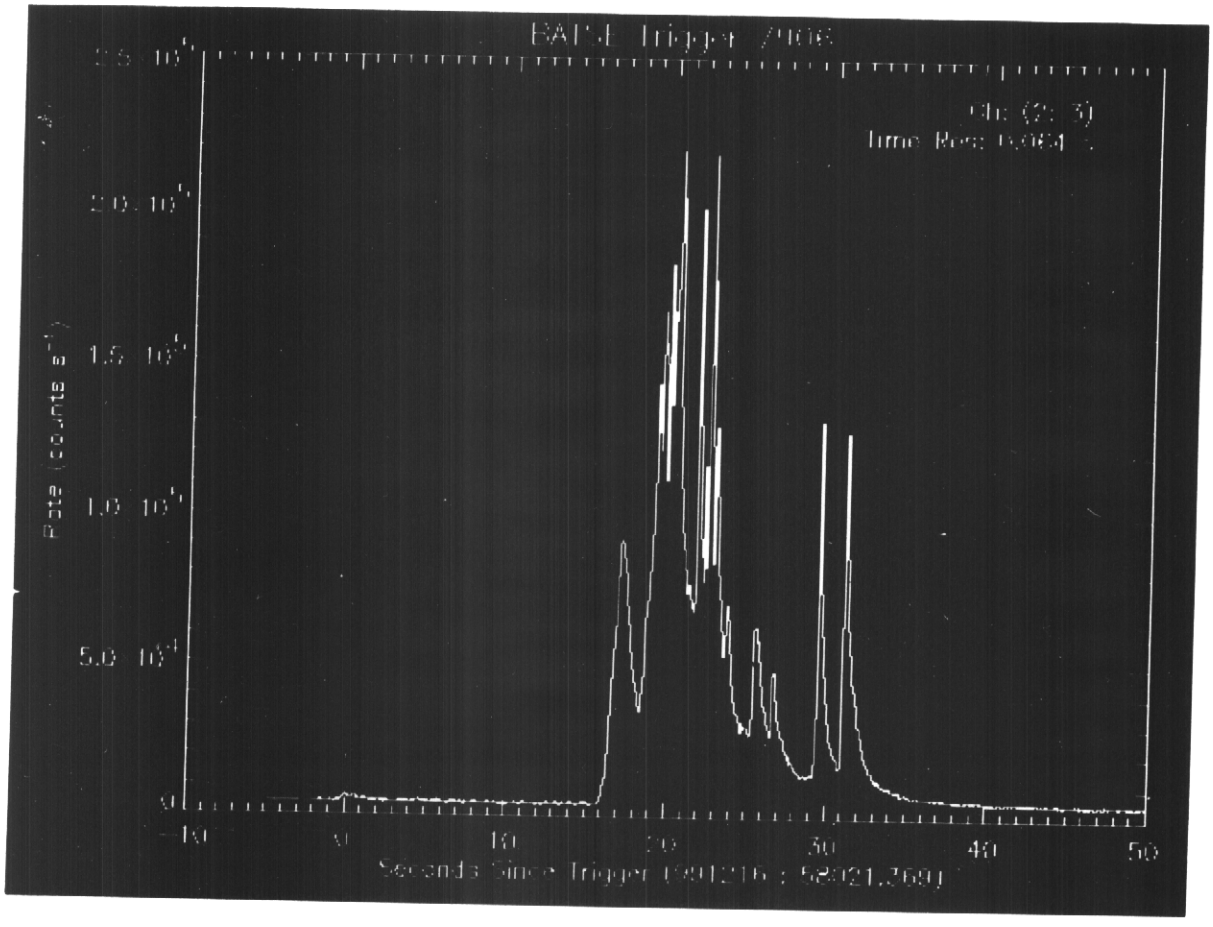


(SINCE WE DO NOT UNDERSTAND THE EJECTION PROCESS)

- 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