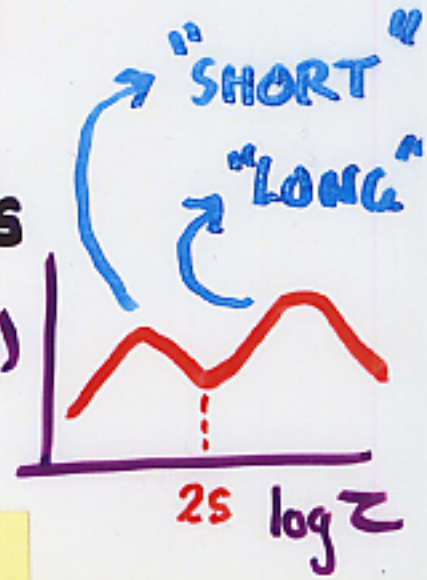
# GAMMA RAY BURSTS

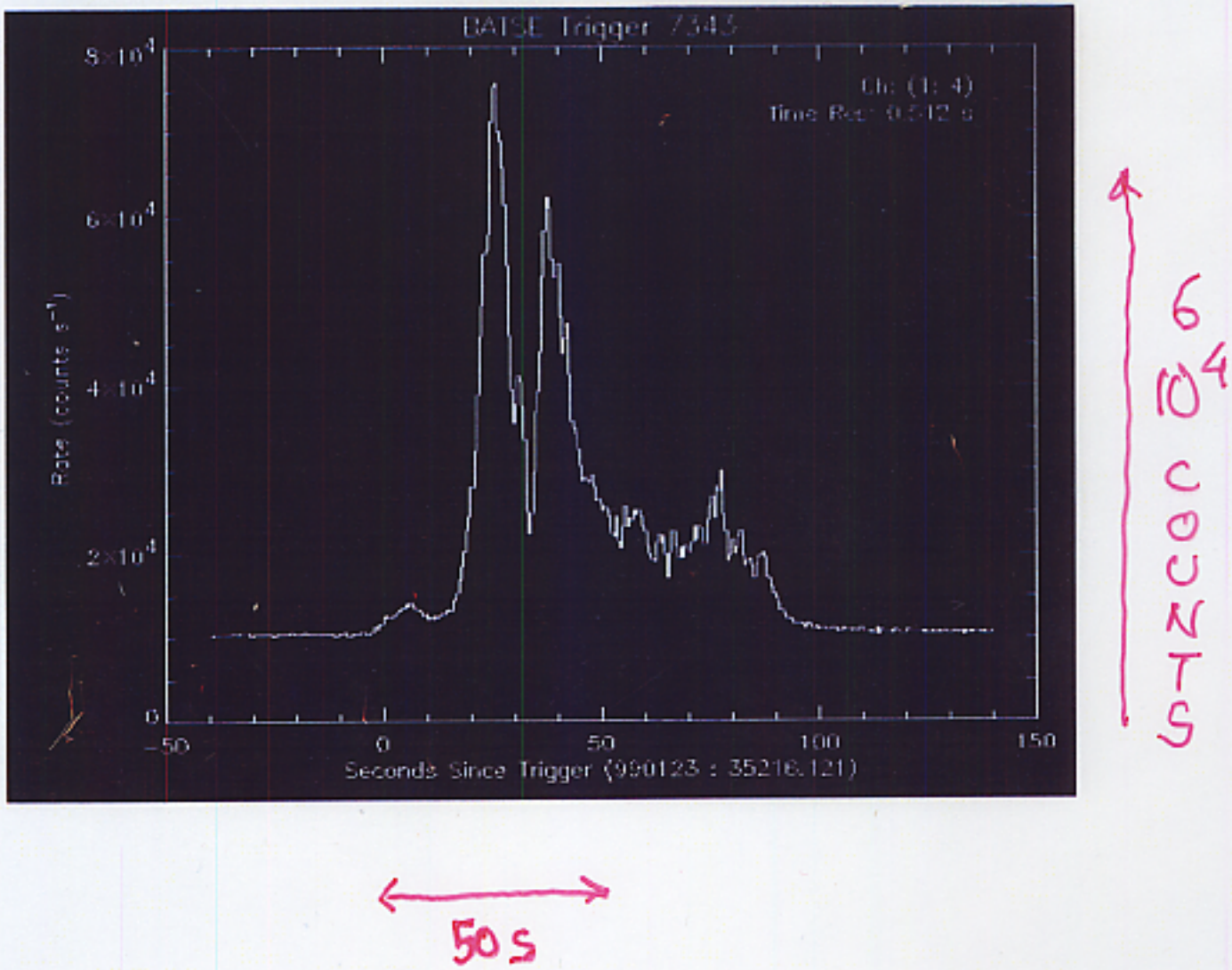
# PROPERTIES OF GRBs
# ($\gamma$ RAY BURTS)

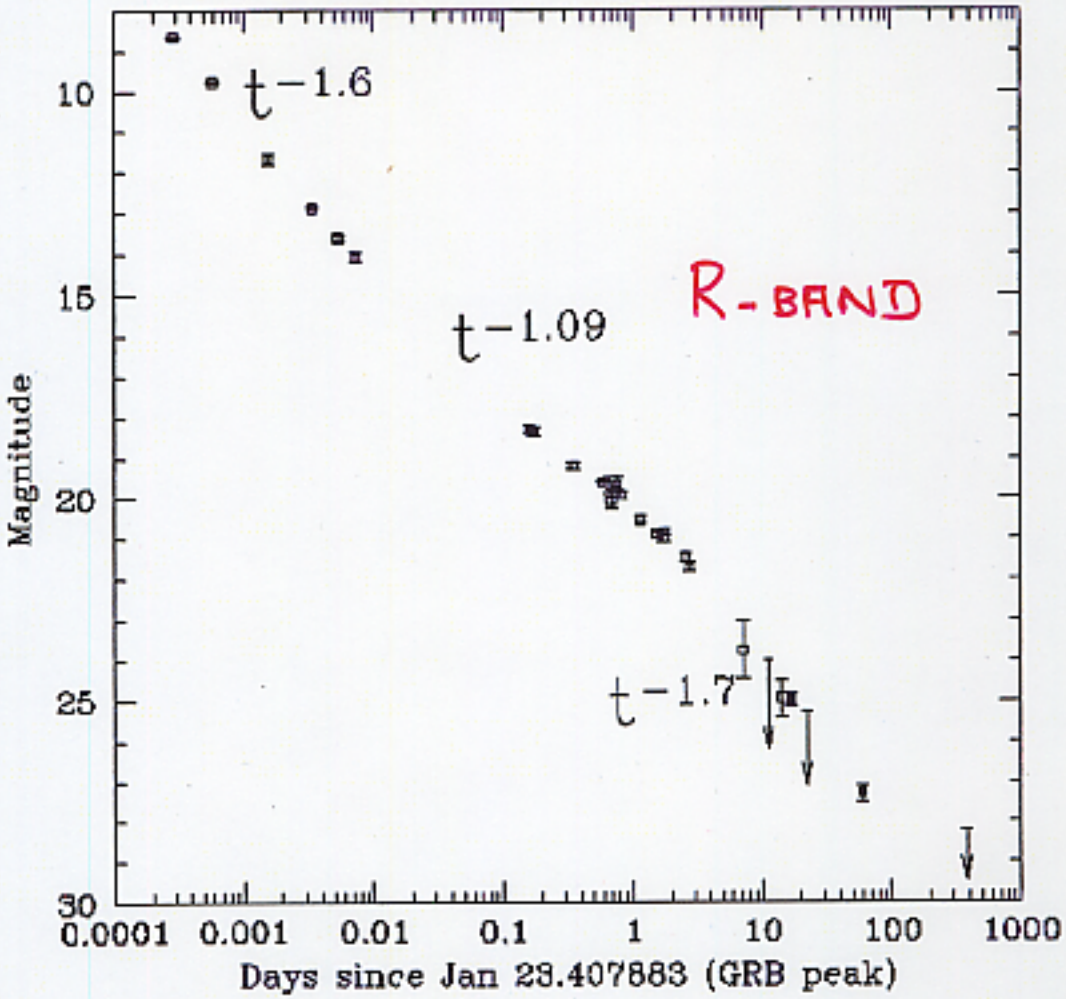
- **DISCOVERY** : VELA SATEL. 1960'S
- **FRECUENCY** ~ 3/DAY
- **DURATION** few $10^{-3}$ s → $10^{3}$ s

SOMEWHAT BIMODAL



GRB 990123 $E_\gamma > 20$ keV





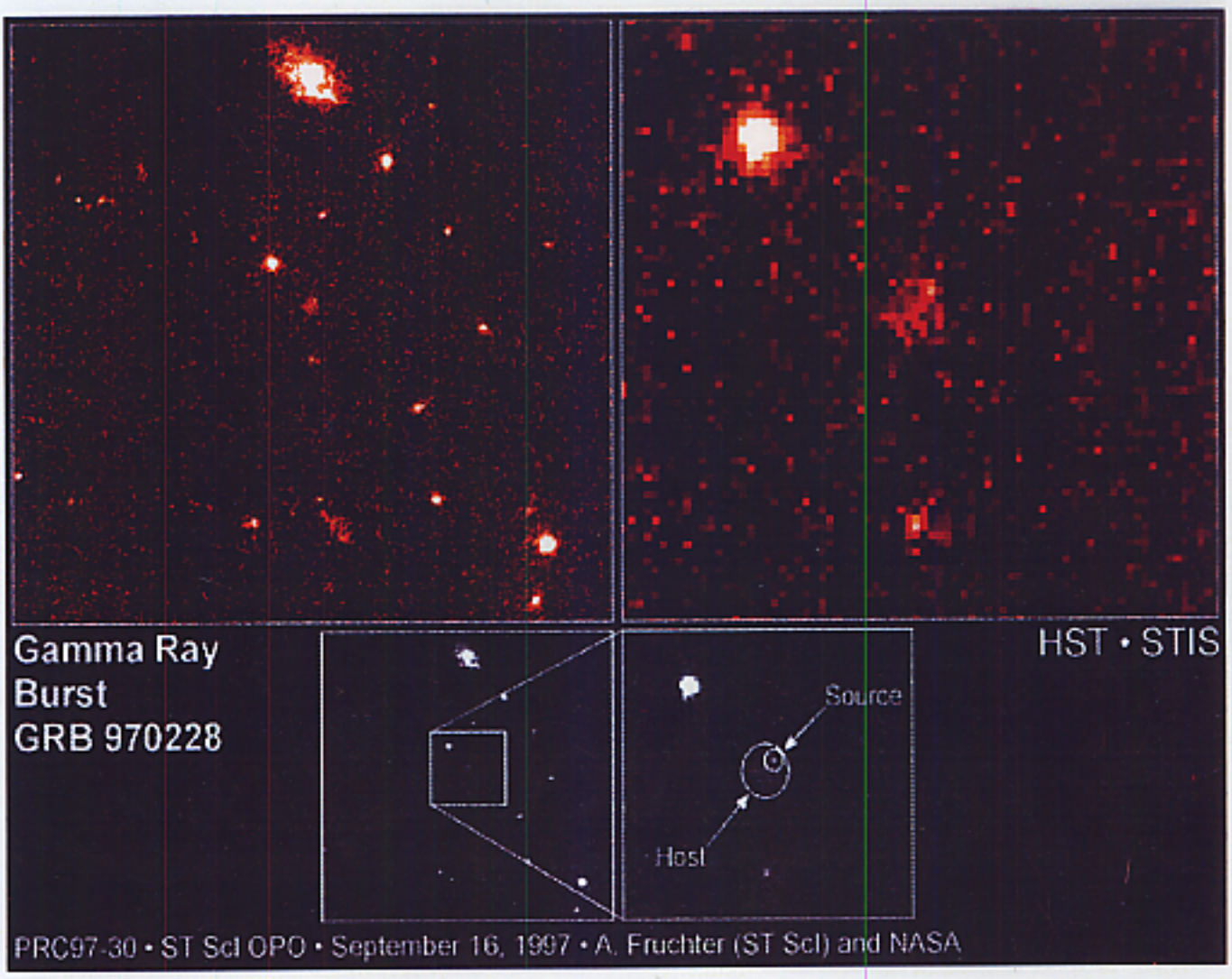

**Wide-field Image of GRB 990123 Field**

# GRBs

# HAVE

# "AFTER-GLOWS"

# X-RAYS-RADIO




AFTERGLOW OF

GRB 970228

AND ITS "HOST" GALAXY AT

$z = 0.695$

< July 2001



**Table I - Gamma-ray bursts of known redshift**

| GRB | z | $D_L$ | $F_\gamma$ | $E_\gamma$ | R[HG] |
|---|---|---|---|---|---|
| 970228[1] | 0.695 | 4.55 | 1.1 | 0.22 | 25.2[18] |
| 970508[2] | 0.835 | 5.70 | 0.32 | 0.07 | 25.7[19] |
| 970828[3] | 0.957 | 6.74 | 9.6 | 2.06 | |
| 971214[4] | 3.418 | 32.0 | 0.94 | 2.11 | 25.6[20] |
| 980425[5] | .0085 | .039 | 0.44 | 8.1E-6 | 14.3[21] |
| 980613[6] | 1.096 | 7.98 | 0.17 | 0.61 | 24.0[22] |
| 980703[7] | 0.966 | 6.82 | 2.26 | 1.05 | 22.6[23] |
| 990123[8] | 1.600 | 12.7 | 26.8 | 19.80 | 23.9[24] |
| 990510[9] | 1.619 | 12.9 | 6.55 | 5.00 | 28.5[25] |
| 990712[10] | 0.434 | 2.55 | 6.5 | 0.53 | 21.8[26] |
| 991208[11] | 0.70 | 4.64 | 10.0 | 1.51 | 24.4[27] |
| 991216[12] | 1.020 | 7.30 | 19.4 | 5.35 | 24.8[28] |
| 000131[13] | 4.500 | 44.4 | 4.2 | 11.60 | 27.8[29] |
| 000301c[14] | 2.040 | 17.2 | 0.41 | 0.46 | 28.0[30] |
| 000418[15] | 1.119 | 8.18 | 2.0 | 0.82 | 23.9[31] |
| 000926[16] | 2.066 | 17.4 | 2.20 | 10.54 | 25.6[32] |
| 010222[17] | 1.474 | 11.5 | 12.0 | 7.80 | > 24[33] |

**Comments:** z: Redshift. $D_L$: Luminosity distance in Gpc, for $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. $F_\gamma$: BATSE $\gamma$-ray fluences in units of $10^{-5}$ erg cm$^{-2}$. $E_\gamma$: (Equivalent spherical) energy in units of $10^{53}$ ergs corrected for galactic extinction. R[HG]: R-magnitude of the host galaxy, except for GRB 990510, for which the V-magnitude is given.

# GRBs

are

"COSMO-LOGICAL"

$3 10^4$

COUNTS/S

$5 10^3$

50 s

# GRB 990510

# At z = 1.619

# WHAT MAKES

[LONG-DURATION]

# GRBs?

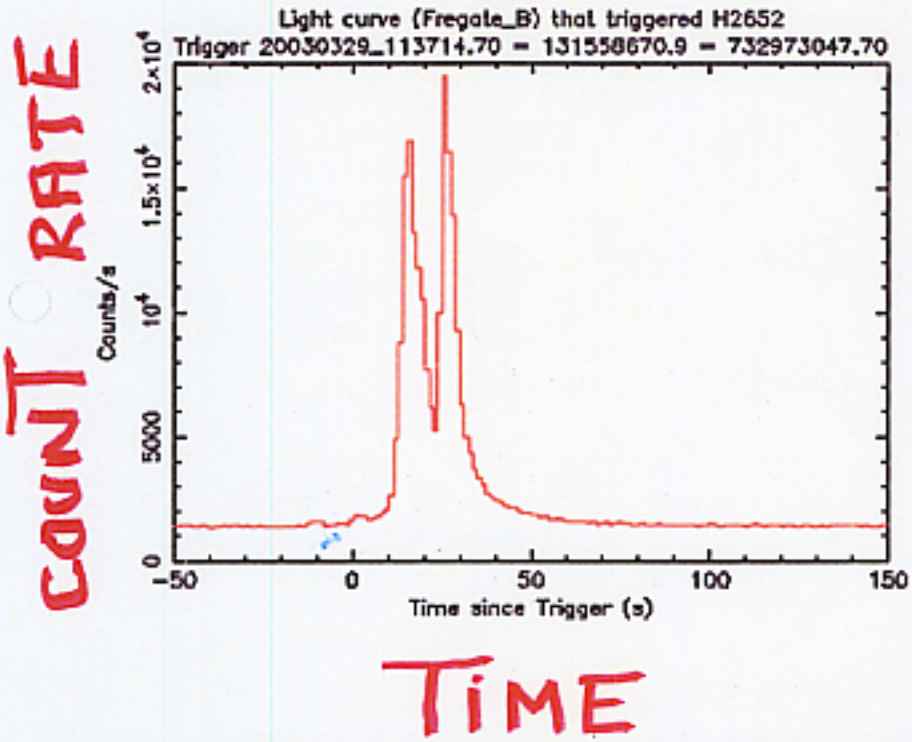
[CORE COLLAPSE]

# SNe!!

GRB 030329

(29 MARCH 2003)

# HETE Burst H2652

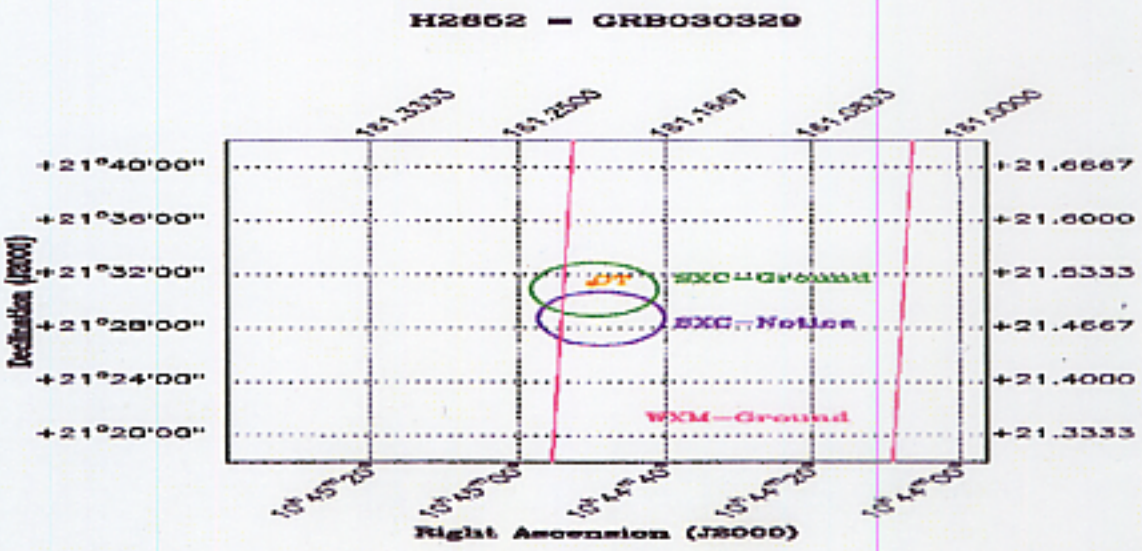



## Burst H2652 summary

- Trigger time is
  - UTC=20030329_11371
  - GRB=GRB030329+41:
- Triggering instrument was **Fregate**
- Trigger timescale was **1.3 seconds**
- Trigger detected in **5-120 keV** band

## Evaluation

*monster GRB*




A COUPLE OF ARC MINUTES

ROBOTIC TELESCOPES, e-HUMANS

(16)

GCN ≡ GRB Coordinates Network

GCN Circs = GRB Observation Reports

# GRB 030329

TITLE: GCN GRB OBSERVATION REPORT
NUMBER: 1997
SUBJECT: GRB030329 (=H2652): A Long, Extremely Bright GRB Localized by the HETE WXM
DATE: 03/03/29 19:53:03 GMT
FROM: Don Lamb at U.Chicago <lamb@oddjob.uchicago.edu>

R. Vanderspek, G. Crew, J. Doty, J. Villasenor, G. Monnelly, N. Butler, T. Cline, J.G. Jernigan, A. Levine, F. Martel, E. Morgan, G. Prigozhin, G. Azzibrouck, J. Braga, R. Manchanda, and G. Pizzichini, on behalf of the HETE Operations and HETE Optical-SXC Teams;

G. Ricker, J-L Atteia, N. Kawai, D. Lamb, and S. Woosley on behalf of the HETE Science Team;

T. Donaghy, M. Suzuki, Y. Shirasaki, C. Graziani, M. Matsuoka, T. Tamagawa, K. Torii, T. Sakamoto, A. Yoshida, E. Fenimore, M. Galassi, T. Tavenner, Y. Nakagawa, D. Takahashi, R. Satoh, and Y. Urata, on behalf of the HETE WXM Team;

M. Boer, J-F Olive, J-P Dezalay, C. Barraud and K. Hurley on behalf of the HETE FREGATE Team;

write:

At 11:37:14.67 UTC (41834.67 s UT) on 29 Mar 2003, the HETE FREGATE, WXM, and SXC instruments detected event H2652, a long, extremely bright GRB.

The burst triggered FREGATE in the 6-120 keV energy band. The burst occurred outside of the effective FOV of the WXM Y-camera. Ground analysis of the SXC data produced a localization that was reported in a GCN Notice at 12:50:24 UT, 73 minutes after the burst. The SXC ground localization SNR was 20. Further ground analysis of the SXC data has provided an SXC localization that can be expressed as a 90% confidence circle that is 2 arcminutes in radius and is centered at

SXC-Ground: RA = +10h 44m 50s, Dec = +21d 30' 54" (J2000).

The SXC localization is dominated by systematic errors, which are larger than usual because the burst occurred at the edge of the SXC FOV. (The error circle radius of 2 arcminutes reported in the GCN Notice for H2652 did not include the larger systematic errors.)

Ground analysis of the WXM data produced a WXM localization. The WXM ground localization SNR is > 20. The WXM localization can be expressed as a 90% confidence rectangle that is 12 arcminutes in width and 2.25 degrees in length. The center of the rectangle lies at

WXM-Ground: RA = +10h 44m 24.7, Dec = +23d 20' 20" (J2000),

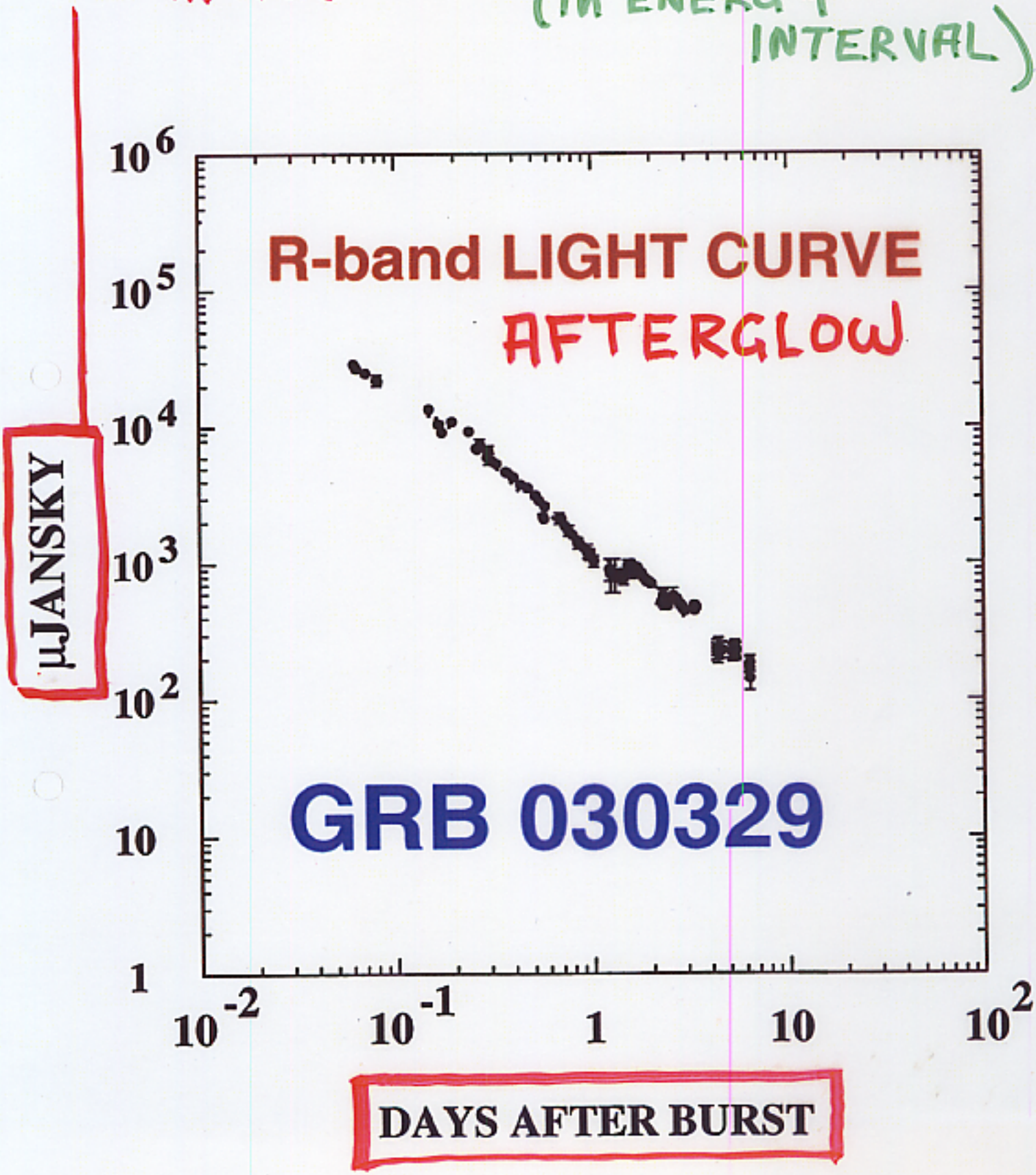
and its corners lie at

RA = +10h 44m 39.6s, Dec = +23d 29' 20",
RA = +10h 43m 53.5s, Dec = +23d 26' 35",
RA = +10h 44m 09.8s, Dec = +21d 11' 38",
RA = +10h 44m 55.9s, Dec = +21d 14' 17" (J2000).

The width of the WXM localization is dominated by systematic errors, which are larger than usual because the burst occurred at the edge of the WXM FOV. The WXM localization is a long, narrow strip because the burst occurred at the edge of the WXM FOV in a region of the sky that

$10^{-26} \frac{W}{m^2 Hz} \equiv J$

ENERGY FLUX
(in ENERGY INTERVAL)



# GRB 030329

One of the brightest ever

$z = 0.1685$

Brightest AG at $t \sim 1h$

$$L(\text{optical}) = 10^{15}\ L_{\odot}$$
$$= 10^{5}\ \text{Galaxies}$$

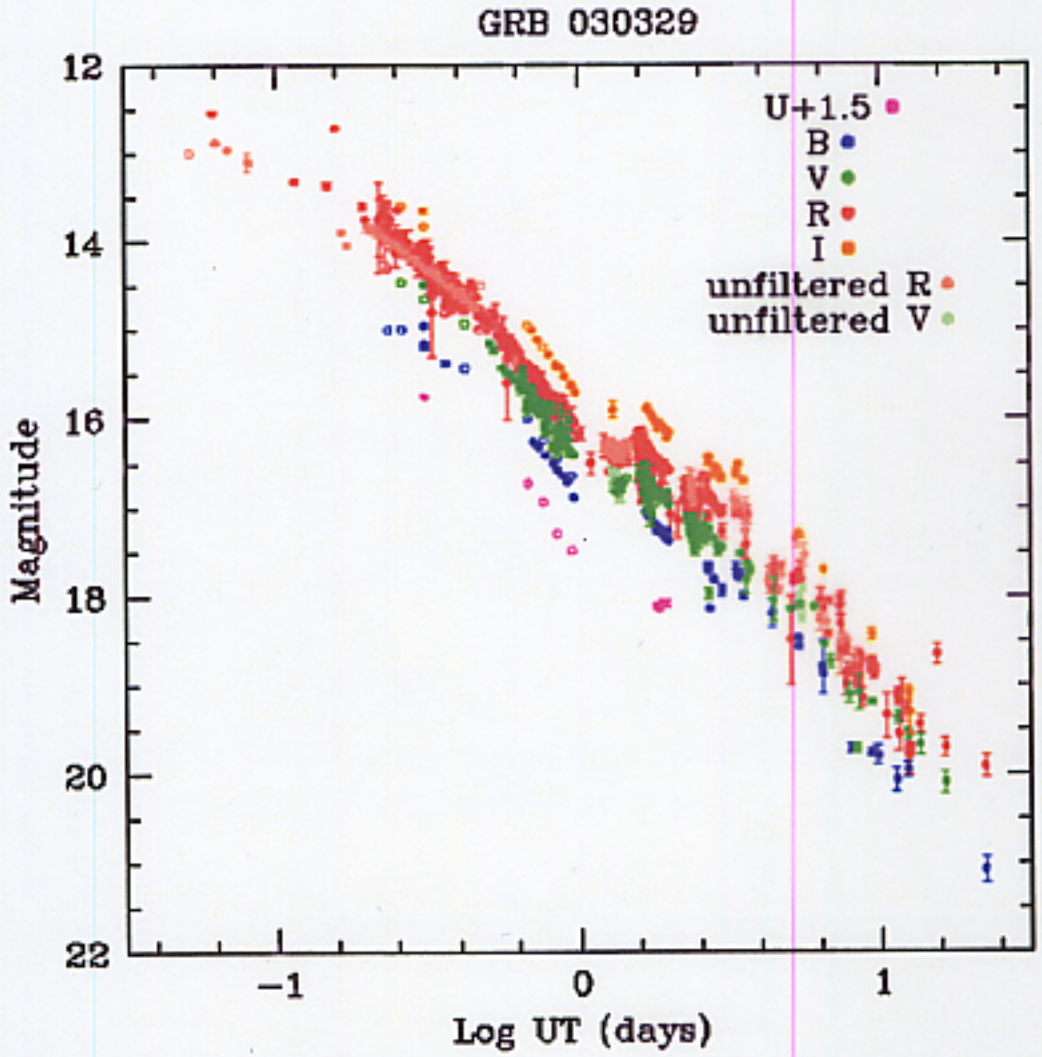
At $t \sim 0$, could be seen by eye

> 200 GCN Communications

**Spectral Flux Distribution Plots**

**GCN Archive for GRB 030329**
**J. Greiner's GRB 030329 Page**

# Lightcurve for GRB 030329




**Open circles denote values with no included error bars**
**Includes all data through GCN 2160 and all AAVSO data**
**(Thanks to Aaron Price of AAVSO for supplying data files)**

# Astrophysics, abstract astro-ph/0304106

From: Arnon Dar <Arnon.Dar@cern.ch>
Date: Sun, 6 Apr 2003 19:52:40 GMT (90kb)

## The Supernova associated with GRB 030329 (29th MARCH, 2003)

**Authors:** Shlomo Dado, Arnon Dar, Alvaro De Rujula

The relative proximity of the recent gamma ray burst (GRB) 030329 resulted in a large gamma-ray fluence and in the brightest-ever afterglow (AG), hours after the burst, in the radio, optical and X-ray bands, permitting precise AG measurements, sensitive tests of models and an excellent occasion to investigate the association of GRBs with supernovae (SNe). The Cannonball (CB) model provides a good, simple and universal description of all AGs of GRBs of known redshift, so that it is straightforward to use it to predict what the expected SN signatures are. In the case of GRB 030329, 10 days after burst the AG should begin to reveal the lightcurve, spectrum and polarization of an underlying SN --akin to SN1998bw-- which will peak in the NIR/optical band around day 15. These effects will be easily observable if indeed SN1998bw is a good ``standard candle'' for GRB-associated SNe and if the so far unknown extinction in the host galaxy is not too large.

10 d = April 8th

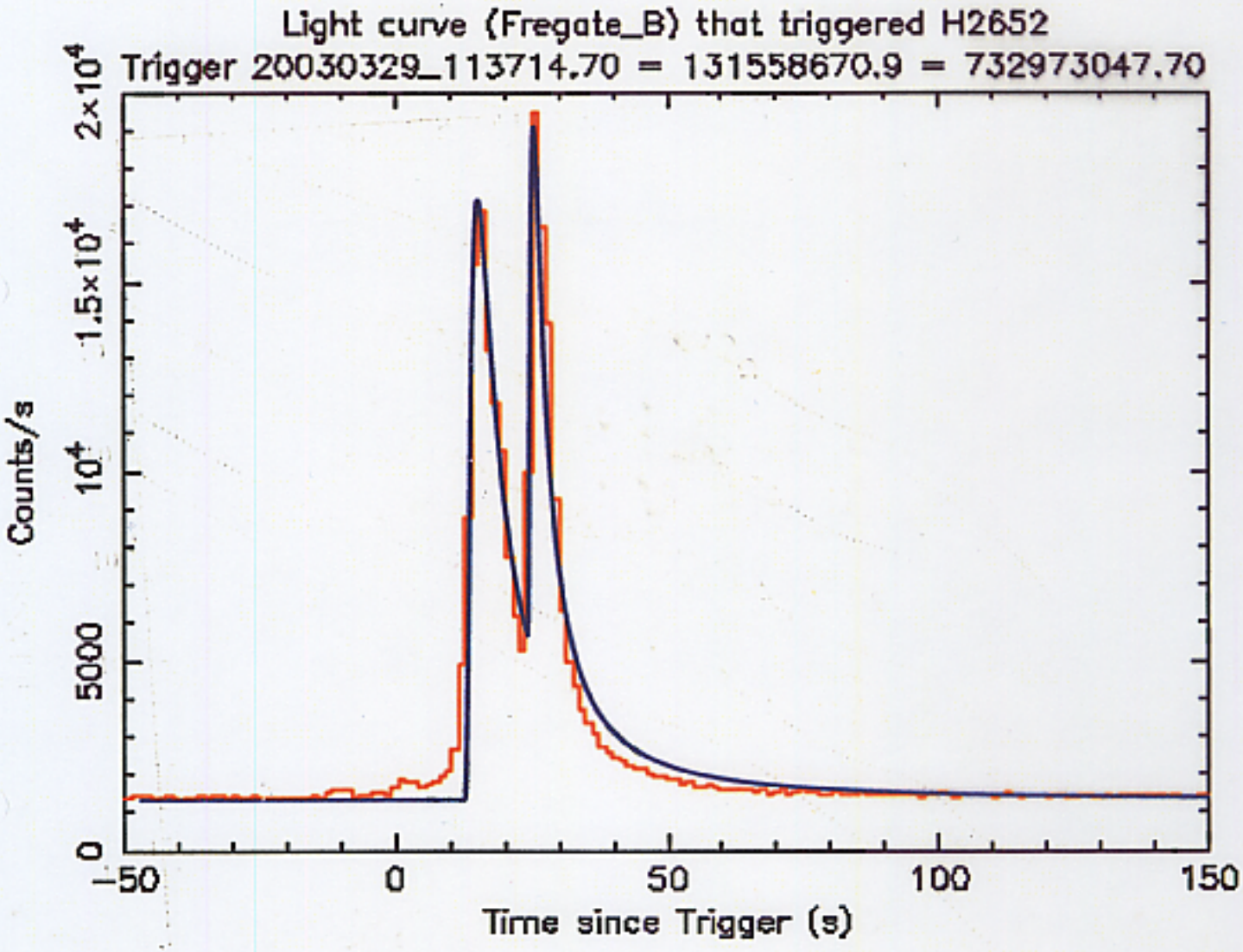
postings concerning GRB 030329, the observers' attitude is more positive: many GCNs discuss minor changes in the smooth afterglow (AG) decline as possible SN signatures, even much before —and a fluence level much larger— than one may expect them to occur.

In the CB model long-duration GRBs are assumed to be associated with common core-collapse SNe (Dar and De Rújula 2000). In this model there is nothing special about GRB 980425, which is describable in exactly the same way as all other GRBs of known redshift; nor is SN1998bw particularly peculiar: it did not emit the observed puzzling radio and X-ray signals, the CB responsible for the GRB did it, as discussed in tiresome detail in Dado el al. (2003a). It follows that, *in the CB model,* it makes sense to use SN1998bw as a putative standard candle for SNe associated with GRBs. The result of that exercise is that, *in the CB model,* there is evidence for a GRB/SN association in all cases in which the SN could in practice be observed, about 1/2 of the total (Dado et al. 2002a,b,c; 2003a,b,c).

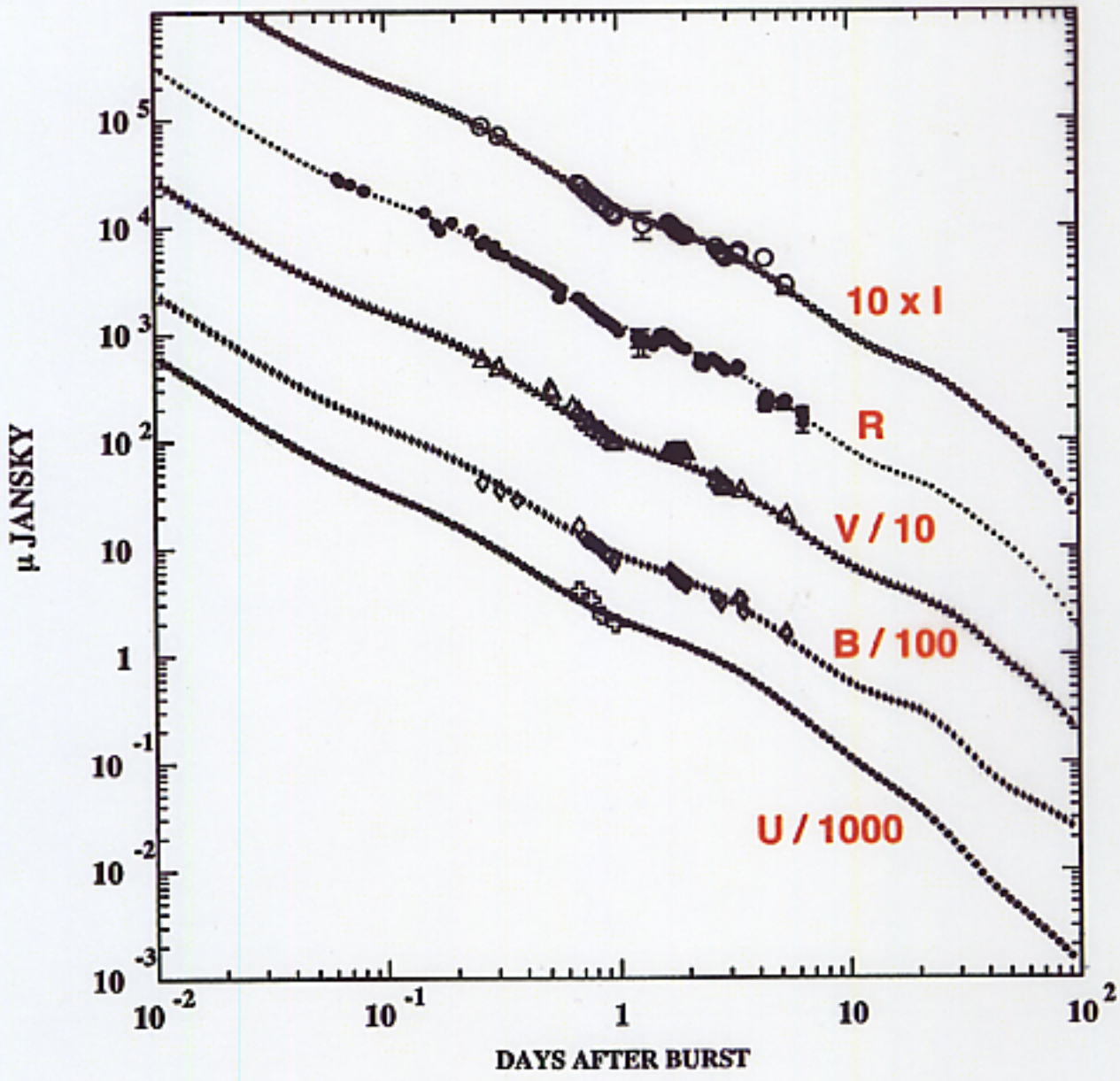
The Cannonball (CB) model provides a good, simple and universal description of all AGs of GRBs of known redshift, $z$, so that it is straightforward to use it to predict what the expected SN contribution to the AG should be, since one is confident on the extrapolated CB contribution, a "background" to the SN signal. By making a fit to the observed AGs, *before* the SN contribution became observable, we have, in three cases, succesfully *predicted* what this contribution would be (Dado et al. 2002b,c, 2003b). We endeavour to do the same for GRB 030329, by submitting this paper to the astro/ph archives ~2 days before the SN contribution ought to become discernible. The credibility of our predictions is weakened by the fact that the data, so far preliminary and unpublished, are insufficient to estimate the extinction in the host galaxy. Also if —unlike in all other cases for which there is evidence of an association— the SN that generated GRB 030329 turns out to be more than two times less intrinsically luminous than SN1998bw, it will be difficult to see its contribution to the AG light curves, though its presence may still significantly distort the late-time AG spectrum.

We also show that –in the CB model– most of the "unusual" features of the AG of GRB 030329 occured before in other GRBs and could, in this sense, be anticipated. The early optical AG of GRB 030329 is, as for GRBs 990123, 021004 and 021121, a direct tracer of the expected circumburst density profile: in all these cases the AGs were "caught" very early and they provide extremely clean evidence for the expected $1/r^2$ profile generated by a pre-SN stellar wind (Dado et al. 2003c). Both GRB 030329 and 021004 have $\gamma$-ray light curves dominated by two pulses or, in the CB model, two cannonballs. Both AGs display two wide shoulders that, in the same model, correspond to the contributions of the two CBs. The superimposed variations in the predicted smooth AG lightcurve, ups and downs of $\sim 1/2$ magnitude, are, as for GRBs 021004, 000301c and 970508, to be expected: they directly trace, like a needle on a vynil record, moderate deviations from a constant-density

# GRB 030329

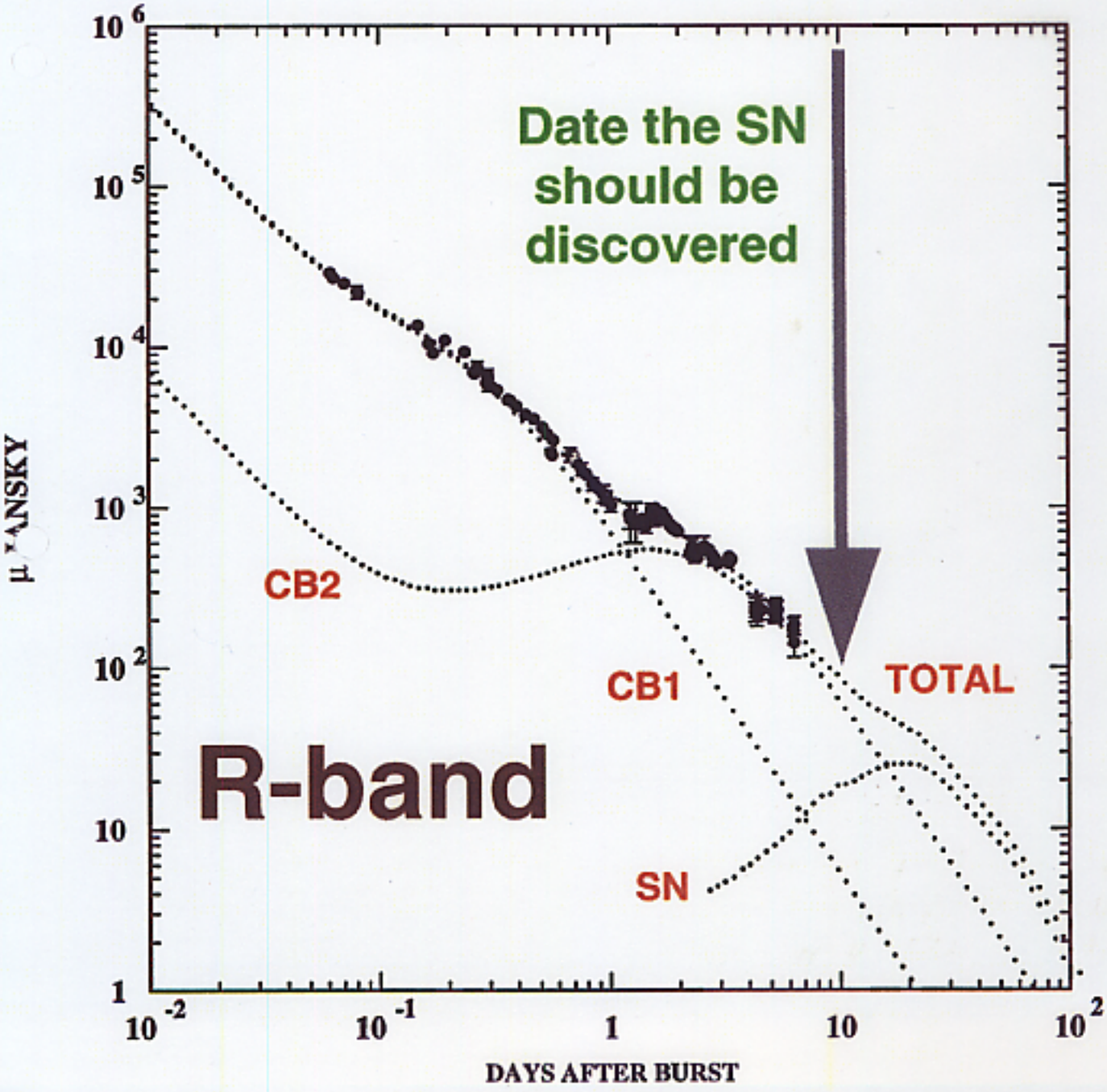



# $\gamma$ - Ray Count Rate with two CBs


10 x I
R
V / 10
B / 100
U / 1000
μ JANSKY
DAYS AFTER BURST
10^5
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-2
10^-1
1
10
10^2

# GRB 030329

## z = 0.168



# Astrophysics, abstract astro-ph/0304173

From: Krzysztof Stanek <kstanek@cfa.harvard.edu>
Date: Thu, 10 Apr 2003 02:30:13 GMT (54kb)
Date (revised v2): Sun, 13 Apr 2003 19:35:08 GMT (54kb)

## Spectroscopic Discovery of the Supernova 2003dh Associated with GRB 030329

**Authors:** K. Z. Stanek, T. Matheson, P. M. Garnavich, P. Martini, P. Berlind, N. Caldwell, P. Challis, W. R. Brown, R. Schild, K. Krisciunas, M. L. Calkins, J. C. Lee, N. Hathi, R. Jansen, R. Windhorst, L. Echevarria, D. J. Eisenstein, B. Pindor, E. W. Olszewski, P. Harding, S. T. Holland, D. Bersier
**Comments:** submitted to ApJL, 9 pages, 2 figures; minor typos corrected

We present early observations of the afterglow of the Gamma-Ray Burst (GRB) 030329 and the spectroscopic discovery of its associated supernova 2003dh. We obtained spectra of the afterglow of GRB 030329 each night from March 30.12 (0.6 days after the burst) to April 8.13 (UT) (9.6 days after the burst). The spectra cover a wavelength range of 350 nm to 850 nm. The early spectra consist of a power-law continuum (F_{nu} ~ nu^{-0.9}) with narrow emission lines originating from HII regions in the host galaxy, indicating a low redshift of z=0.1687. However, our spectra taken after 2003 Apr. 5 show broad peaks in flux characteristic of a supernova. Correcting for the afterglow emission, we find the spectrum of the supernova is remarkably similar to the type Ic 'hypernova' SN 1998bw. While the presence of supernovae have been inferred from the light curves and colors of GRB afterglows in the past, this is the first direct, spectroscopic confirmation that a subset of classical gamma-ray bursts originate from supernovae.

**Full-text: PostScript, PDF, or Other formats**

References and citations for this submission:
**SLAC-SPIRES HEP** (refers to , cited by, arXiv reformatted)

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**Links to: arXiv, astro-ph, /find, /abs (-/+), /0304, ? form interface**

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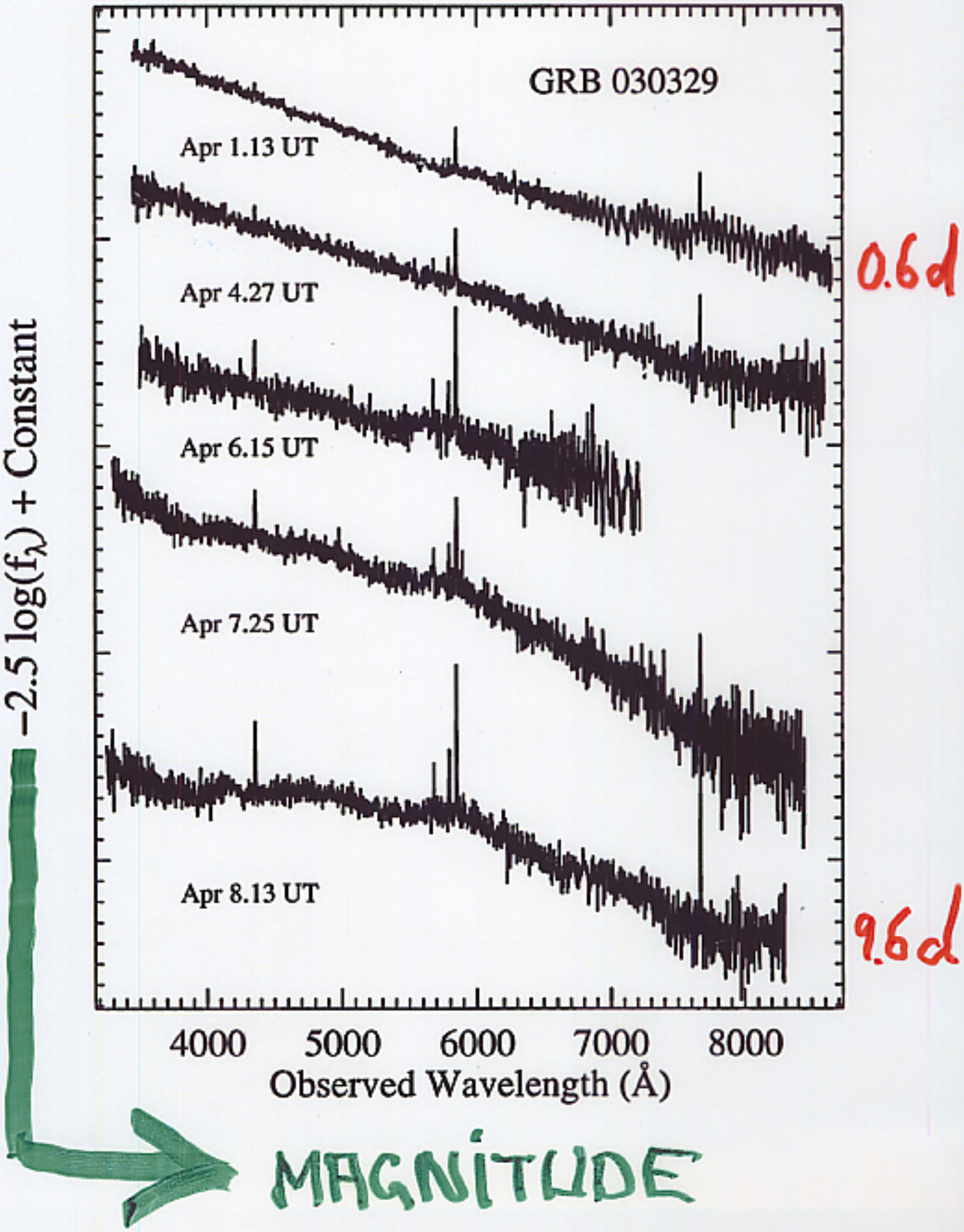
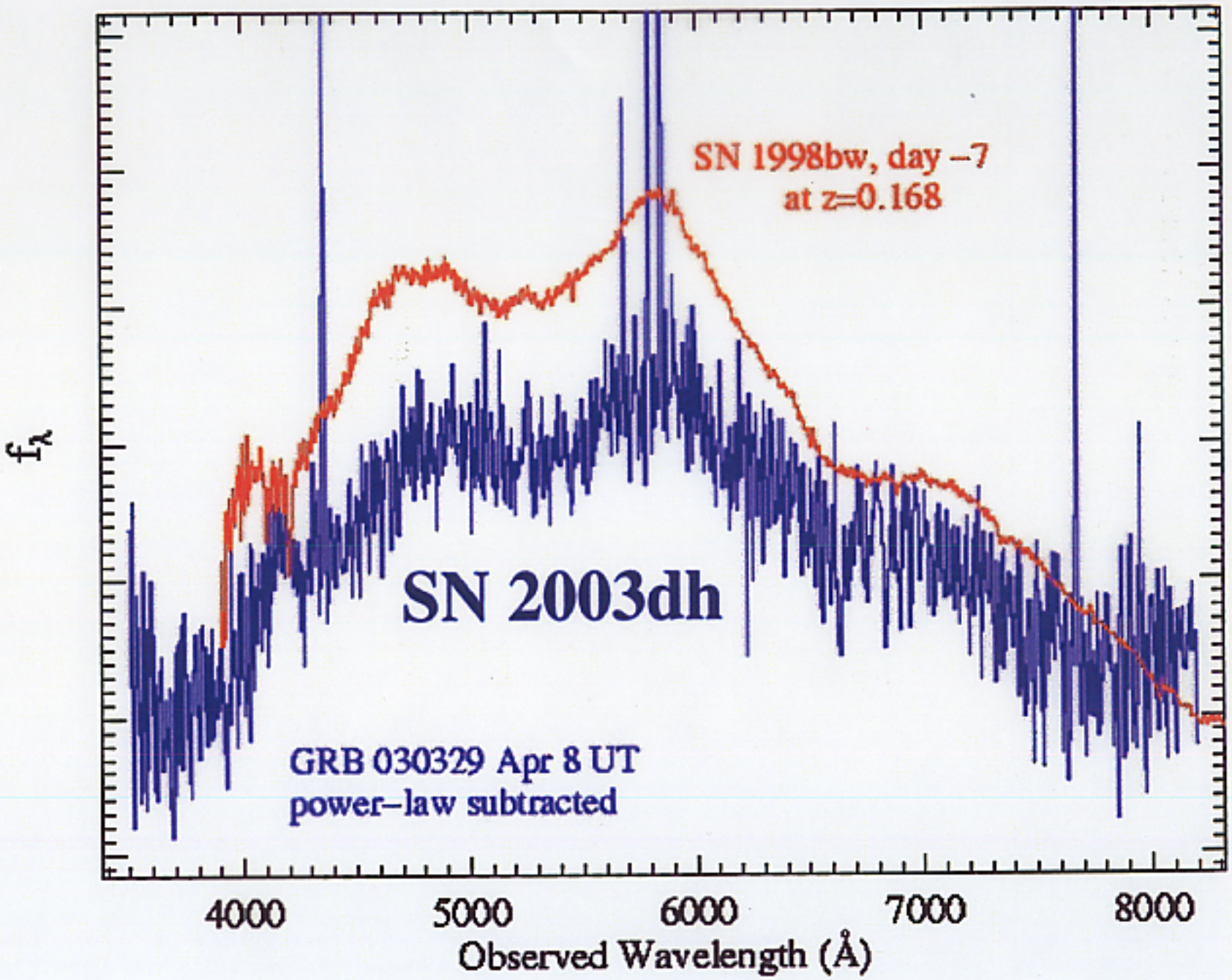
we L.E. these gs

Stanek et al. (astroph)

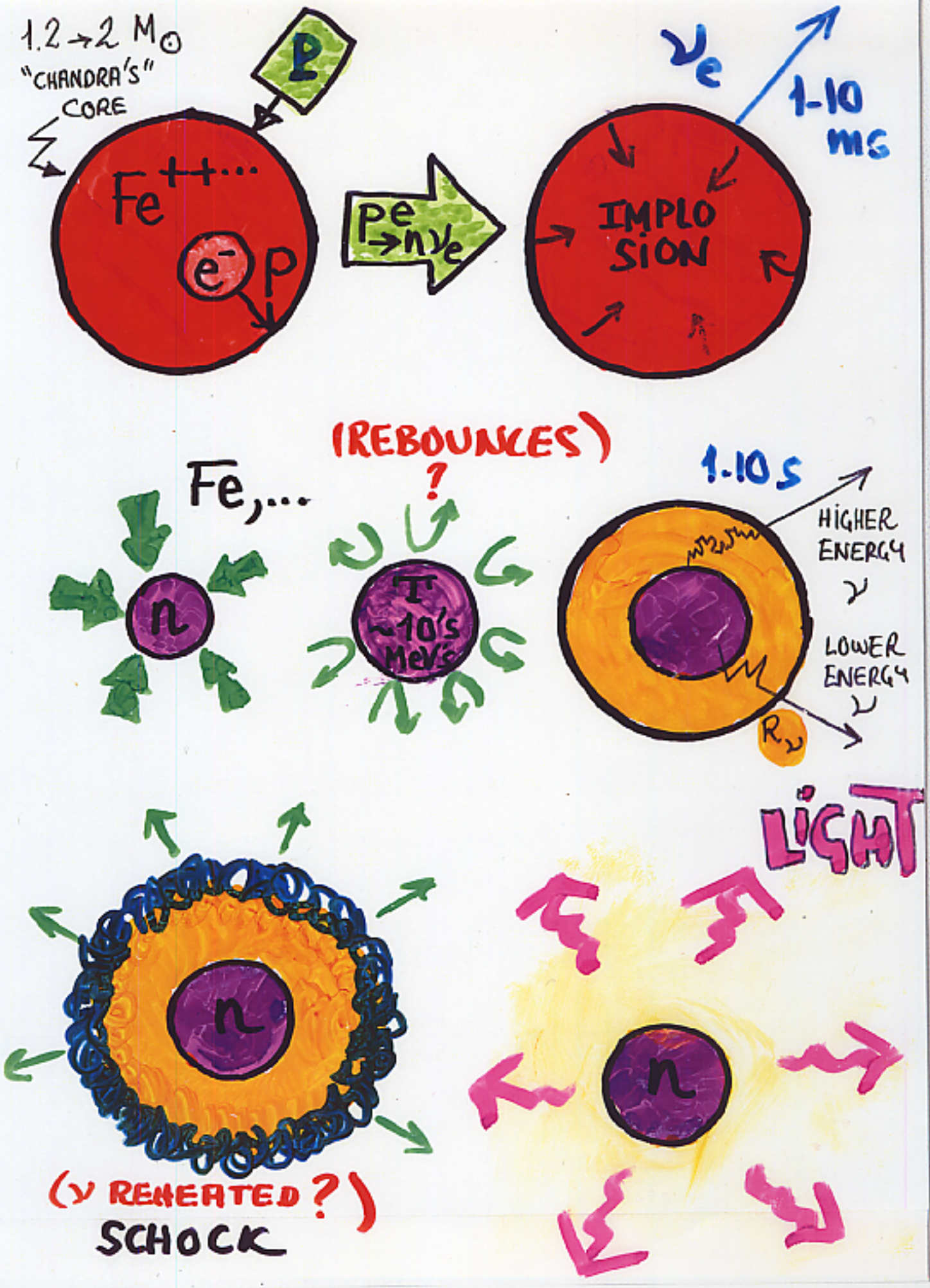



SN 1998bw, day −7
at z=0.168
SN 2003dh
GRB 030329 Apr 8 UT
power−law subtracted
$f_\lambda$
4000
5000
6000
7000
8000
Observed Wavelength (Å)

# END

# of

# Commercial


1.2 → 2 M⊙
"CHANDRA'S" CORE
P
Fe++...
e⁻
P
Pe → nνe
IMPLO SION
νe
1-10 ms
Fe,...
n
(REBOUNCES)
?
T ~10's MeV's
1-10 s
HIGHER ENERGY ν
LOWER ENERGY ν
Rν
n
(ν REHEATED?)
SCHOCK
LIGHT
n

# OED

# Simulation

1.a The action or practice of simulating, with intent to deceive.

False pretense.

Deceitful profession

ACCEPTED VIEW:

in SOME FEW

GRB AGs

∃ EVIDENCE FOR

AN ASSOCIATED

SUPER NOVA

**Table I - Gamma-ray bursts of known redshift**

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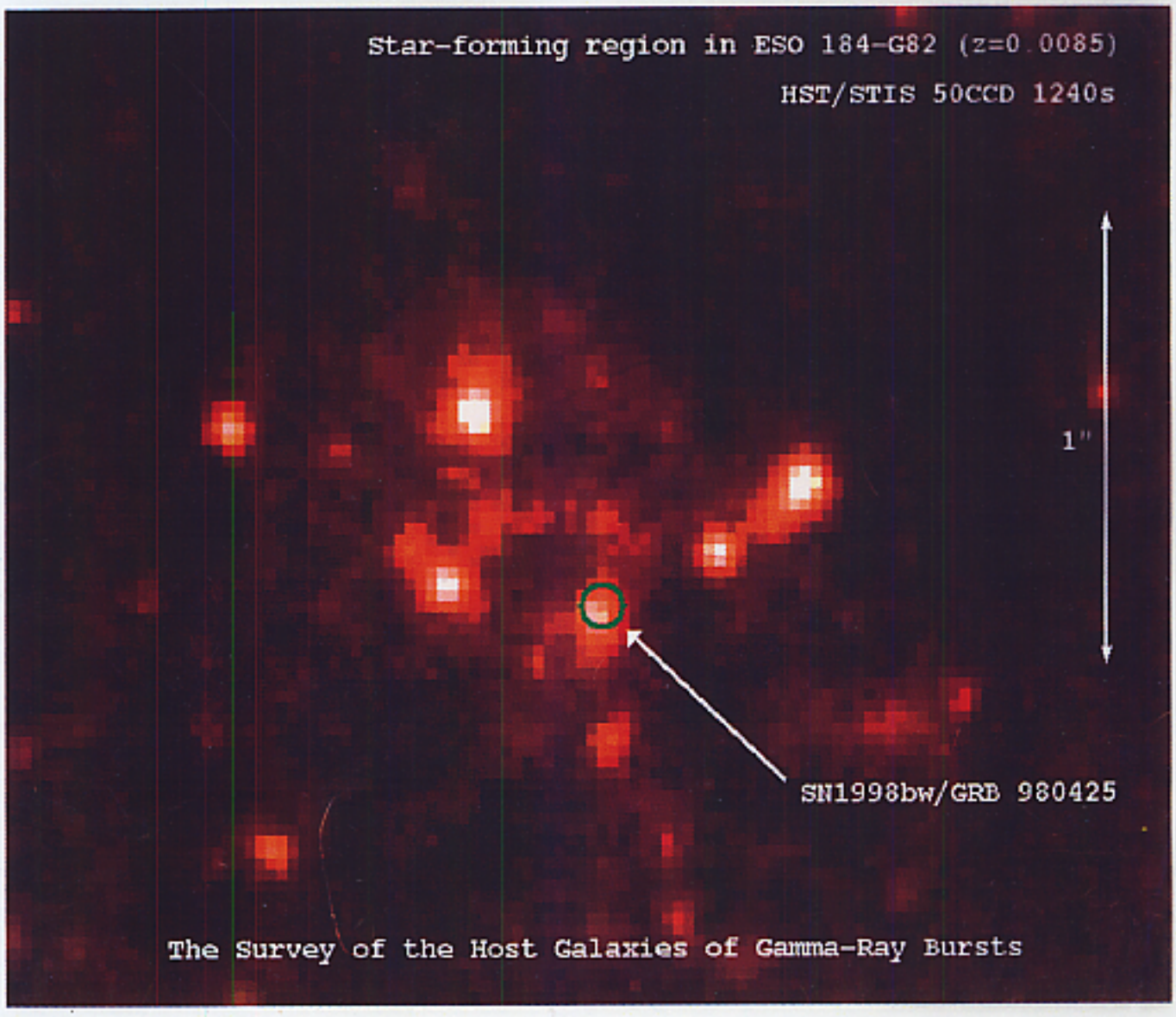

Star-forming region in ESO 184-G82 (z=0.0085)
HST/STIS 50CCD 1240s
1"
SN1998bw/GRB 980425
The Survey of the Host Galaxies of Gamma-Ray Bursts

# SN1998bw/GRB980425

(IF NOT FOURTUITOUS)

## The standard lore

### 1 GRB is most peculiar

100 x closer than average

Yet, similar fluence

### 2 SN is most peculiar

- Radio emission 20/40 x other SNe, peaking earlier ----> v(SNS) ~ (2/3) c
- X-rays steady for 100d! (instead of falling abruptly)

## Conclusions

- SN is... a "hypernova" !!
- GRB not understood ---> such a SN not possibly assoc. w. other GRBs

# Eli Waxman

## GRBs: The underlying theory

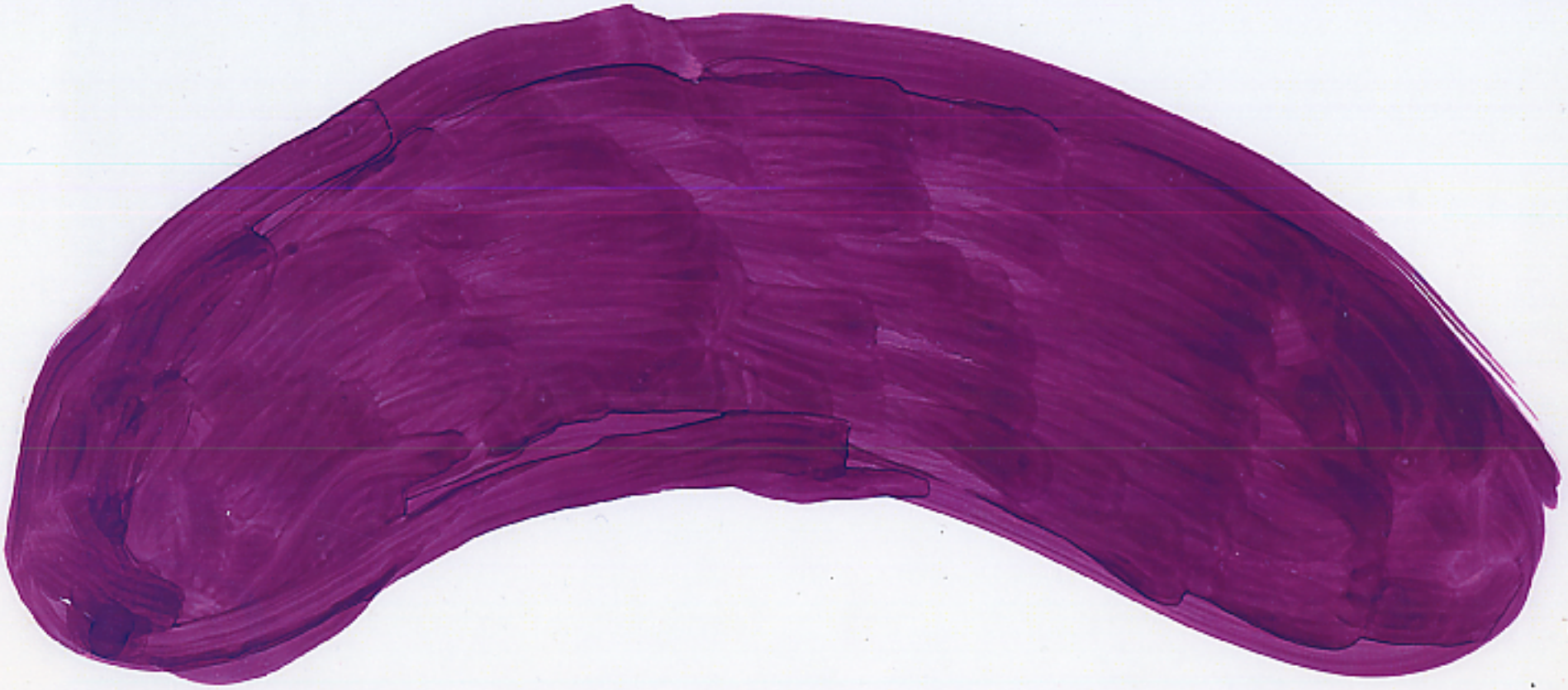
(March 23, 2003)

*No mention of "supernovae" in Abstract or Introduction*

**There is evidence in three cases that a SN may be associated with the GRB**

**The evidence is, however, not yet conclusive**

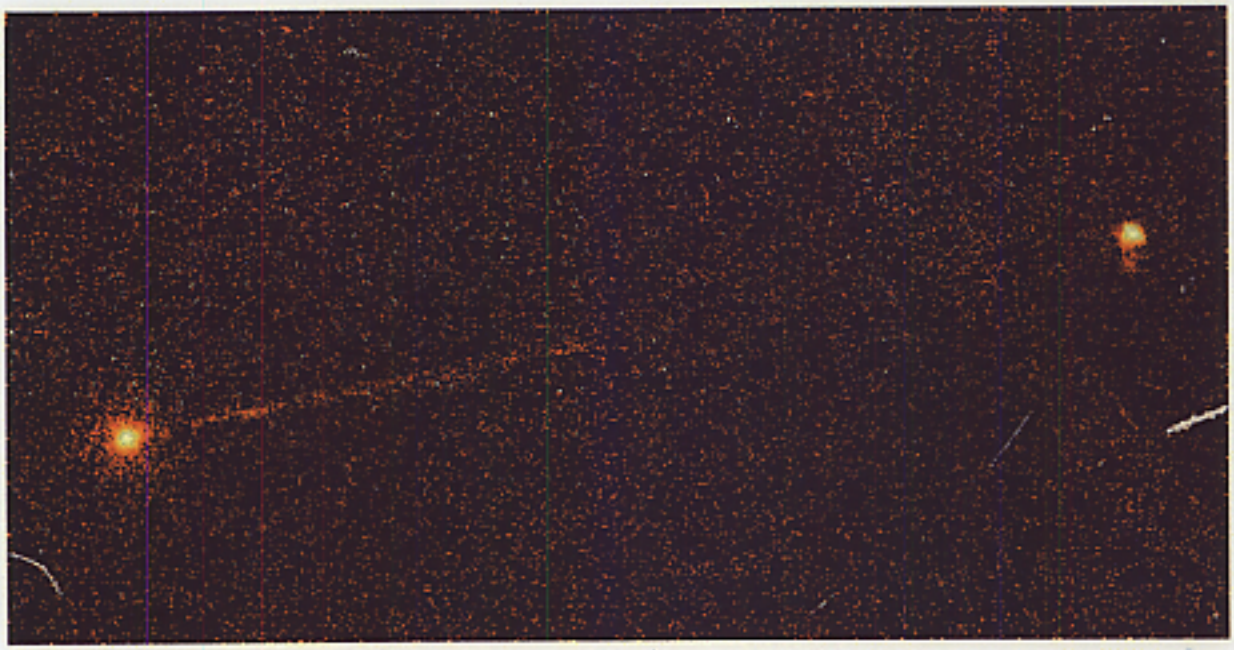
**PREDICTION : CHANGE**

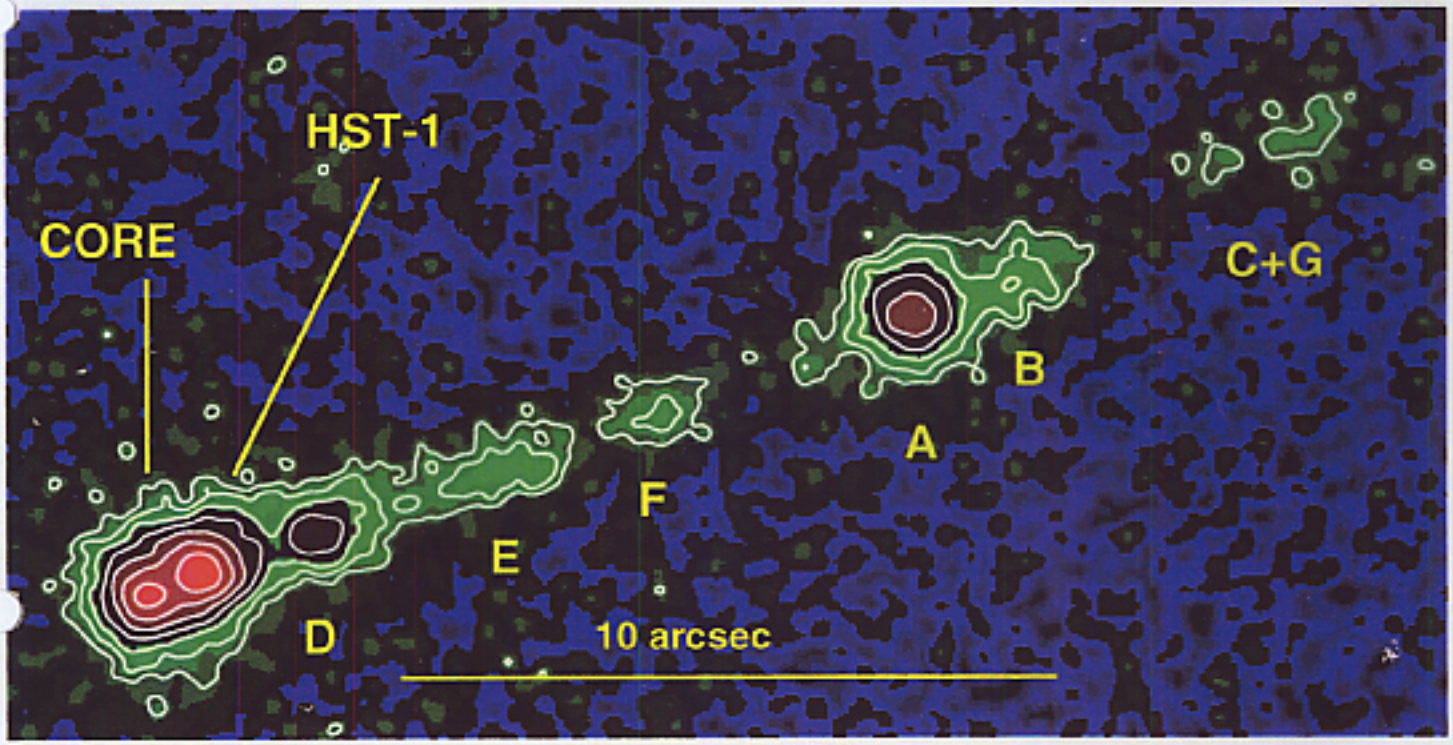


# JETS in ASTRO-PHYSICS

CHANDRA

PICTOR-A






M-87

BULK-MOTION LORENTZ FACTORS

$\gamma \sim 10$'s

(GHISELLINI et al. 1992)

PKS 0405-385

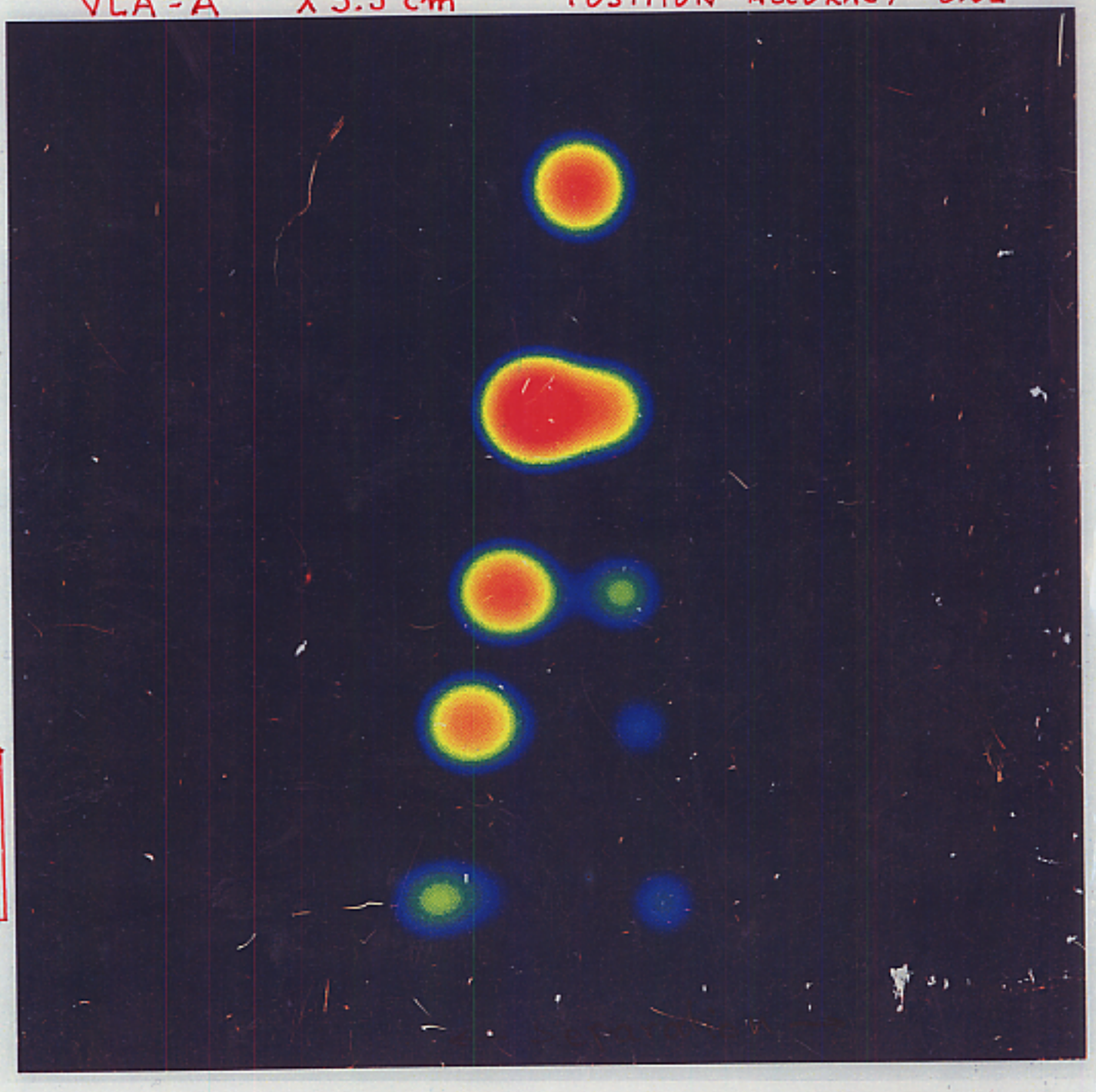
$\gamma \sim 10^3$

(KEDZIORA-CHUDCZU et al 1997)

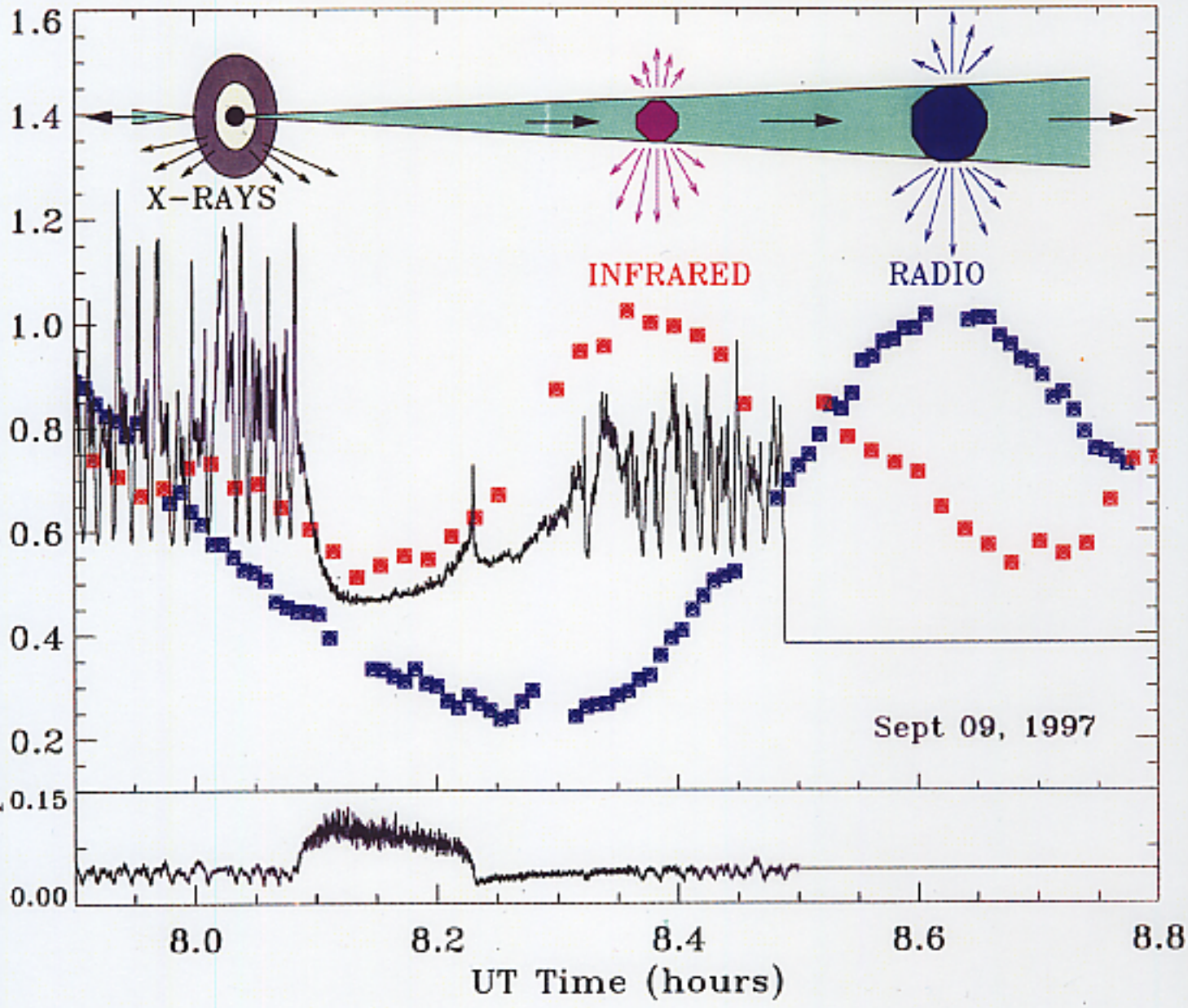
MIRABEL RODRIGUEZ and colls

# μ-QUASARS

VLA-A λ 3.5 cm POSITION ACCURACY 0.02"



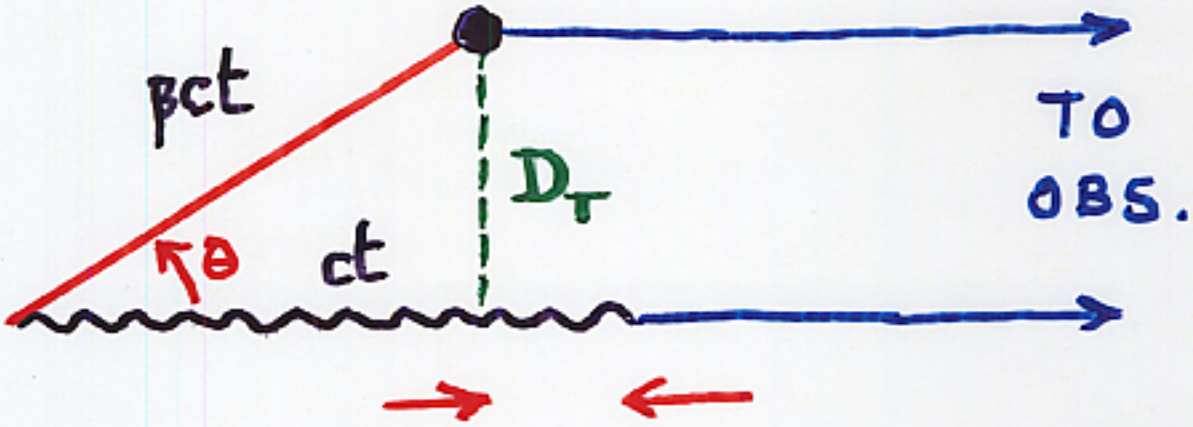

GRS 1915+105




arXiv:astro-ph/9902062v1 4 Feb 1999

# (APPARENT) SUPERLUMINAL MOTION

AT TIME $t$ AFTER PHOTON EMITTED AT $t=0$




$$c\Delta t = ct - \beta ct \sin\theta$$

$$v_T = \frac{D_T}{\Delta t} = \frac{\beta\sin\theta}{1-\beta\cos\theta}c > c \quad \text{if} \quad \beta\sin\theta > 1-\beta\cos\theta$$

(REES 1966)

FOR $\theta \ll 1$, $\gamma = 1/\sqrt{1-\beta^2} \gg 1$

$$v_T \cong \frac{2\gamma^2\theta}{1+\theta^2\gamma^2}c$$

$$\equiv \gamma\delta c$$

Doppler Boost

$\theta^2\gamma^2 \ll 1$ $\quad 2\gamma^2\theta c$

$\theta^2\gamma^2 = 1$ $\quad \frac{c}{\theta}$

$\theta^2\gamma^2 \gg 1$ $\quad \frac{2c}{\theta}$

# SS 433

BALMER H, He

$K_\alpha$ Fe

CBs ARE MADE OF ORDINARY MATTER

NOT FANCIER $e^+e^-$ PAIRS WITH FINE-TUNED B-LOAD

LIGHT EMITTED BY

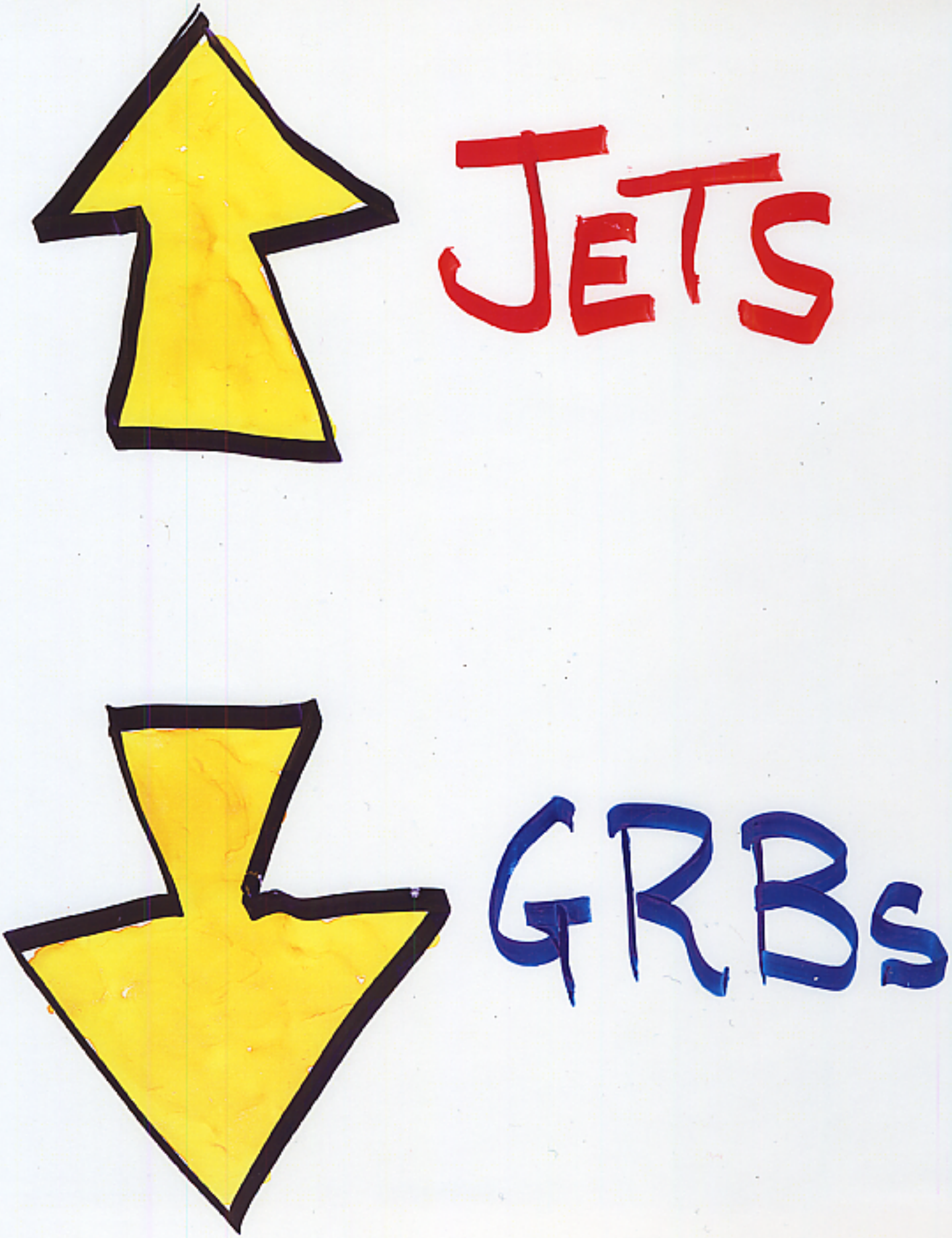
"CANNON BALLS"

JETTED BY (μ-)QUA☆

SYNCHROTRON Rad.

ELECTRONS IN

ENCLOSED $\vec{B}$


JETS
GRBs

# COSMO-ENERGY CRISIS DAR

FOR ISOTROPIC EMISSION

$E_\gamma$[AVERAGE GRB] $\sim 3\ 10^{53}$ erg

$E_\gamma$[GRB 990123] $\approx 2.6\ 10^{54}$ erg

SENSIBLE EFFICIENCY FOR

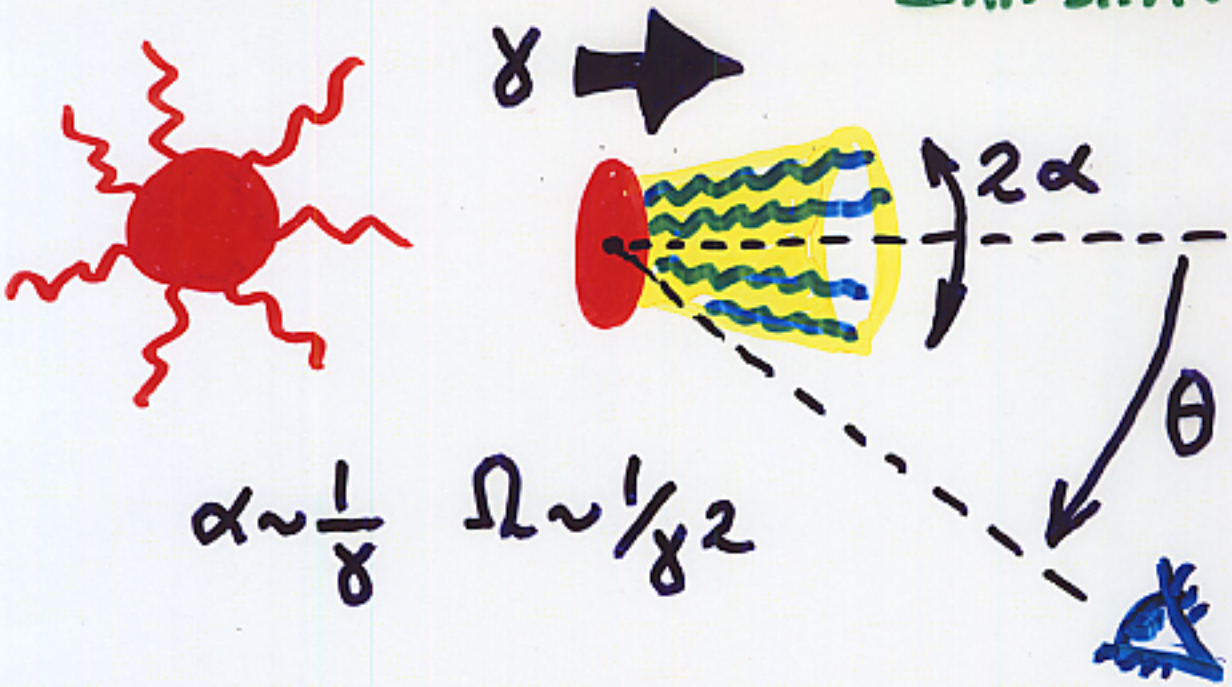
$\gamma$-EMISSION $\lesssim 1\%$

$$M_\odot c^2 \approx 1.8\ 10^{54}\ \text{erg}$$

GRBs = MIRACLE
[HN]

EMISSION NOT SPHERICAL

DAR·SHAVIV 95




$\alpha \sim \frac{1}{\gamma}$ $\Omega \sim 1/\gamma^2$

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

DOPPLER FACTOR

$$F_{TOT} = \int E\,dE \left.\frac{dn_\gamma}{dS}\right|_\theta = E_{TOT}^{REST} \frac{\delta^3(1+z)}{4\pi D_L^2}$$

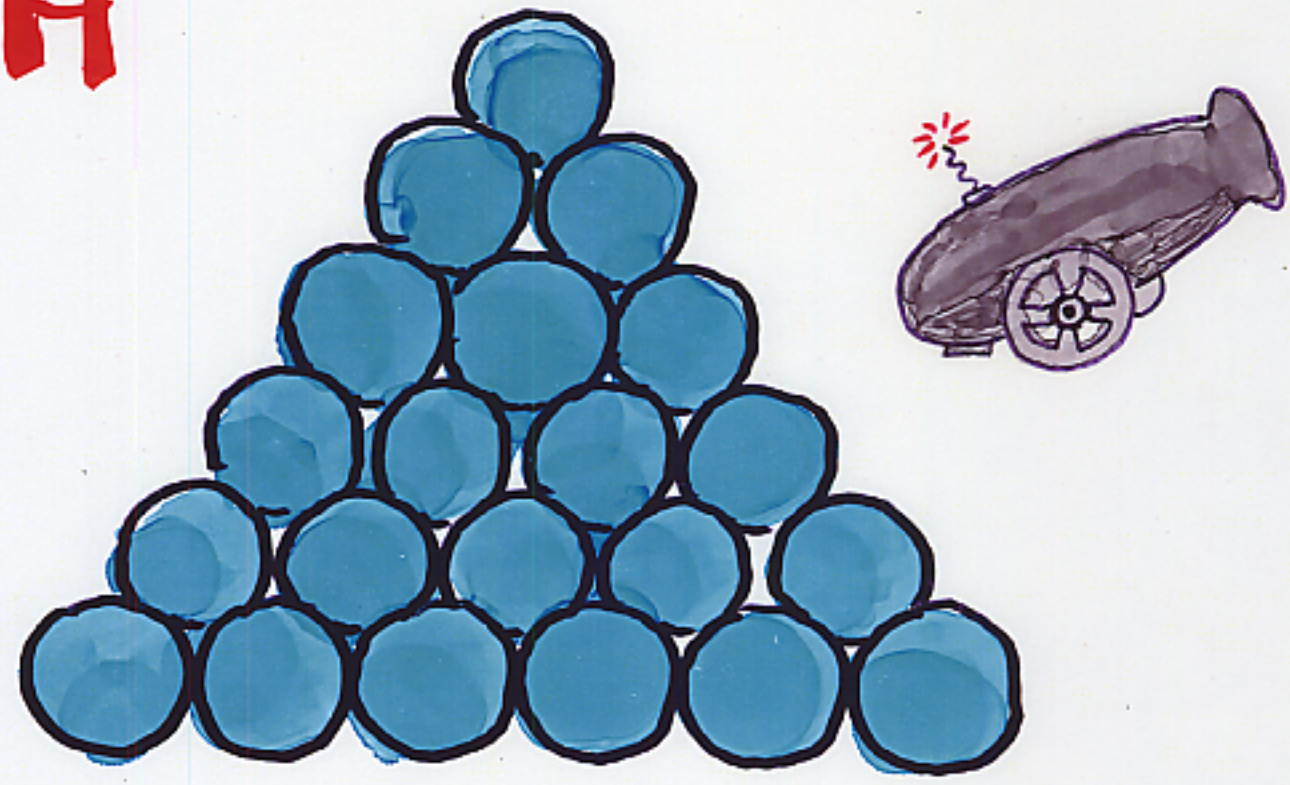
$$\theta \sim \frac{1}{\gamma} \sim 10^{-3} \qquad \delta^3 \sim 10^9$$

NO ENERGY CRISIS

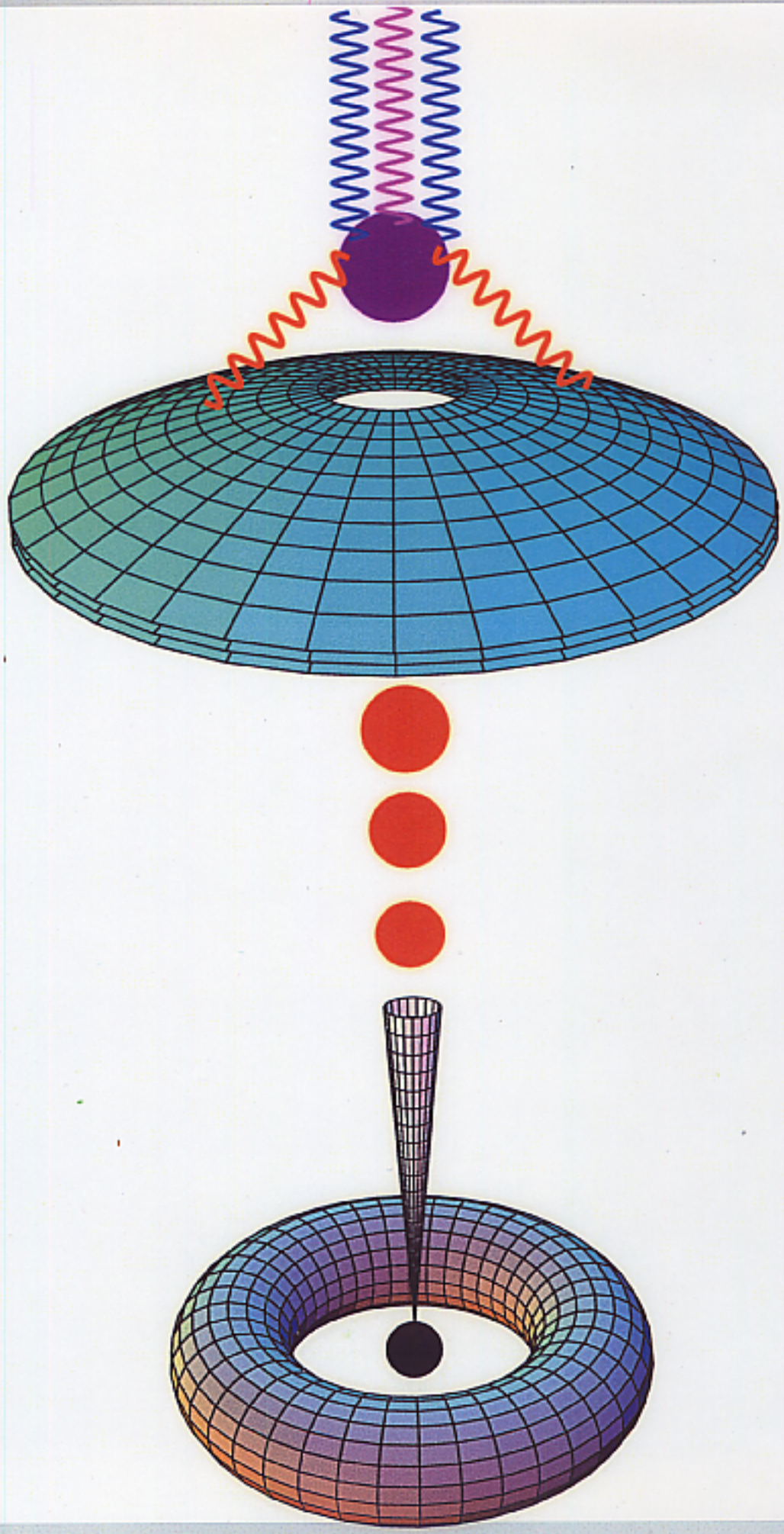
LASER

DAR
ADR

# A



# MODEL of GRBs



CB MADE of
ORDINARY
MATTER

1 EXITING CB
=
1 PULSE of GRB

WIND
or SHELL

TIME-SEQUENCE
of
PULSES is
NOT PREDICTABLE

BUT
→ PROPERTIES
of SINGLE
PULSES
→ PROPERTS.
of
AGs
are
PREDICT
ABLE

# CB PROPS. (PREVIEW)

E[$\gamma$'s] ∈ GRB

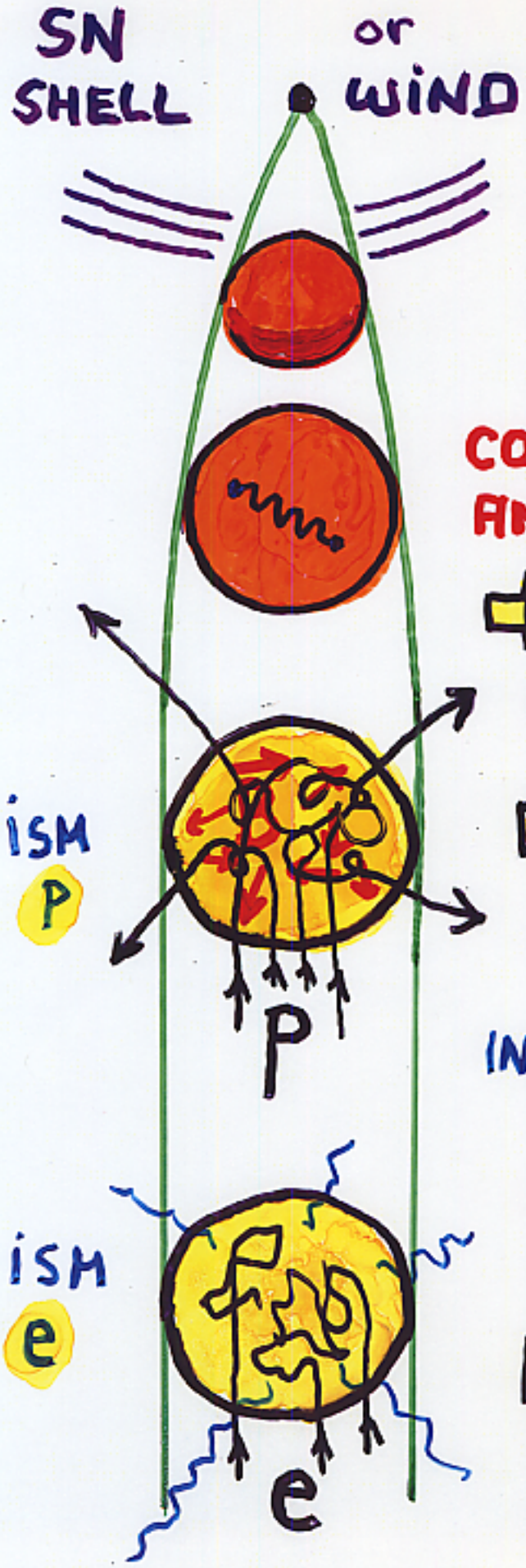
AG PROPERTS.

$E_{jet}, \langle N_{CB} \rangle \rightarrow M_{CB} \lesssim M_{\odot}$

$R_{CB}[\infty] \sim R[\odot]$

CBs MADE OF ORDINARY MATTER

# THE FATE of a CB




CBs' COLLISIONALLY HEATED SURFACE

⇨ GRB

COOLING BY EXPANSION AND BREMSS. EMISSION

⇨ EARLY X-RAY AG

OUTGOING p-PRESSURE $P_p$

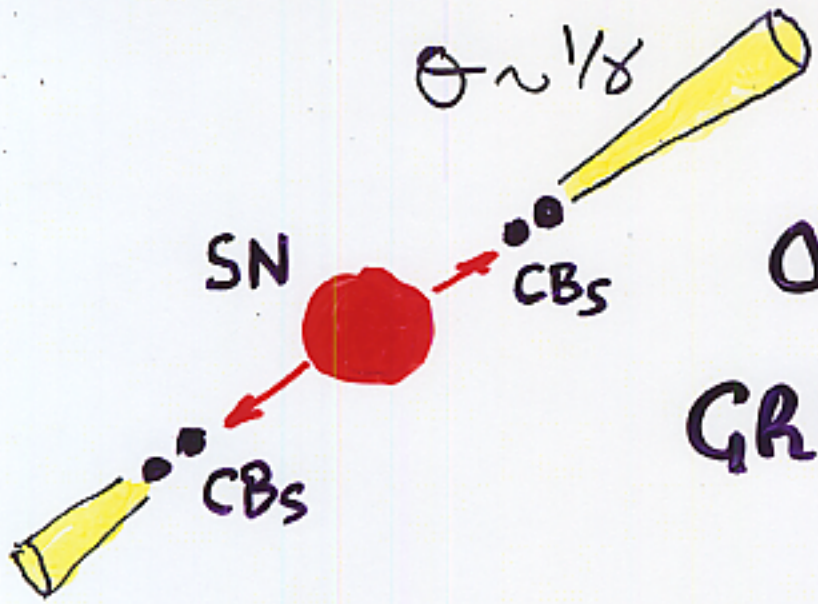
⇨ $R_{CB}$ STABILIZES B(t)'s PRESSURE BALANCES $P_p$

INCOMING $\vec{P}_p$ ⇨ $\gamma(t)\downarrow$

e-SYNCH. RADIATION

⇨ RADIO, OPTICAL, LATE X-RAY AGs

TO
OBSER-
VER
$\sim 10^{-3}$




4π-
OBSERVED
GRBs/DAY ~ 3

# SNe in uis.
UNIVERSE/DAY

SEVE-
RAL * $10^6$

↑

HIGH-Z STAR-FORMATION RATE

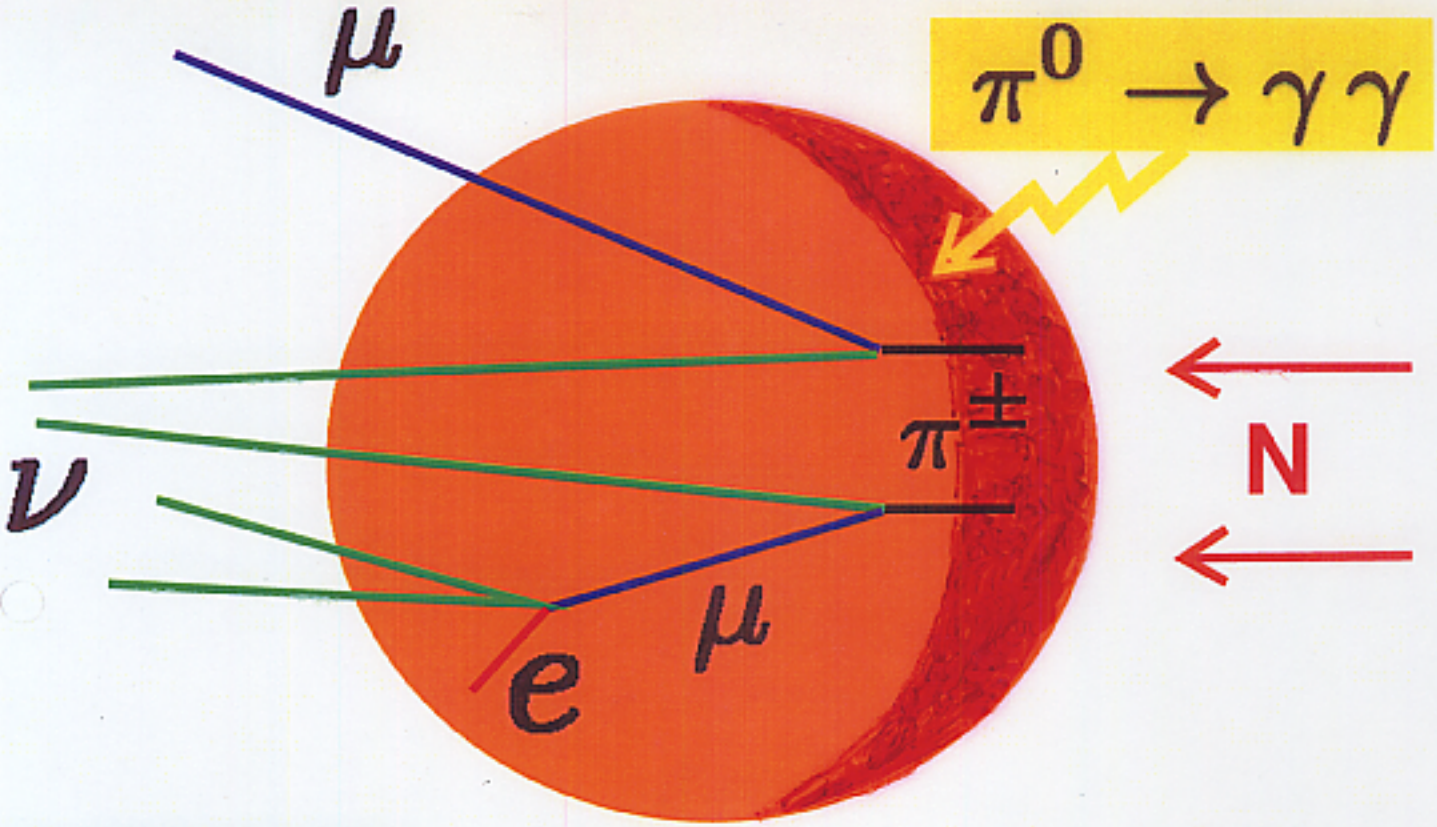
IFF $\gamma \sim 10^3$

FRACTION OF SNe
WHOSE GRB is SEEN ~ $10^{-6}$

A GOOD FRACTION OF
ALL SNe EMIT GRBS

$\dot{M} \sim$ constant

$\rho \sim 1 / r^2$




$\Delta t \propto E^{-0.5}$ (obs: $\Delta t \propto E^{\approx -0.46}$)

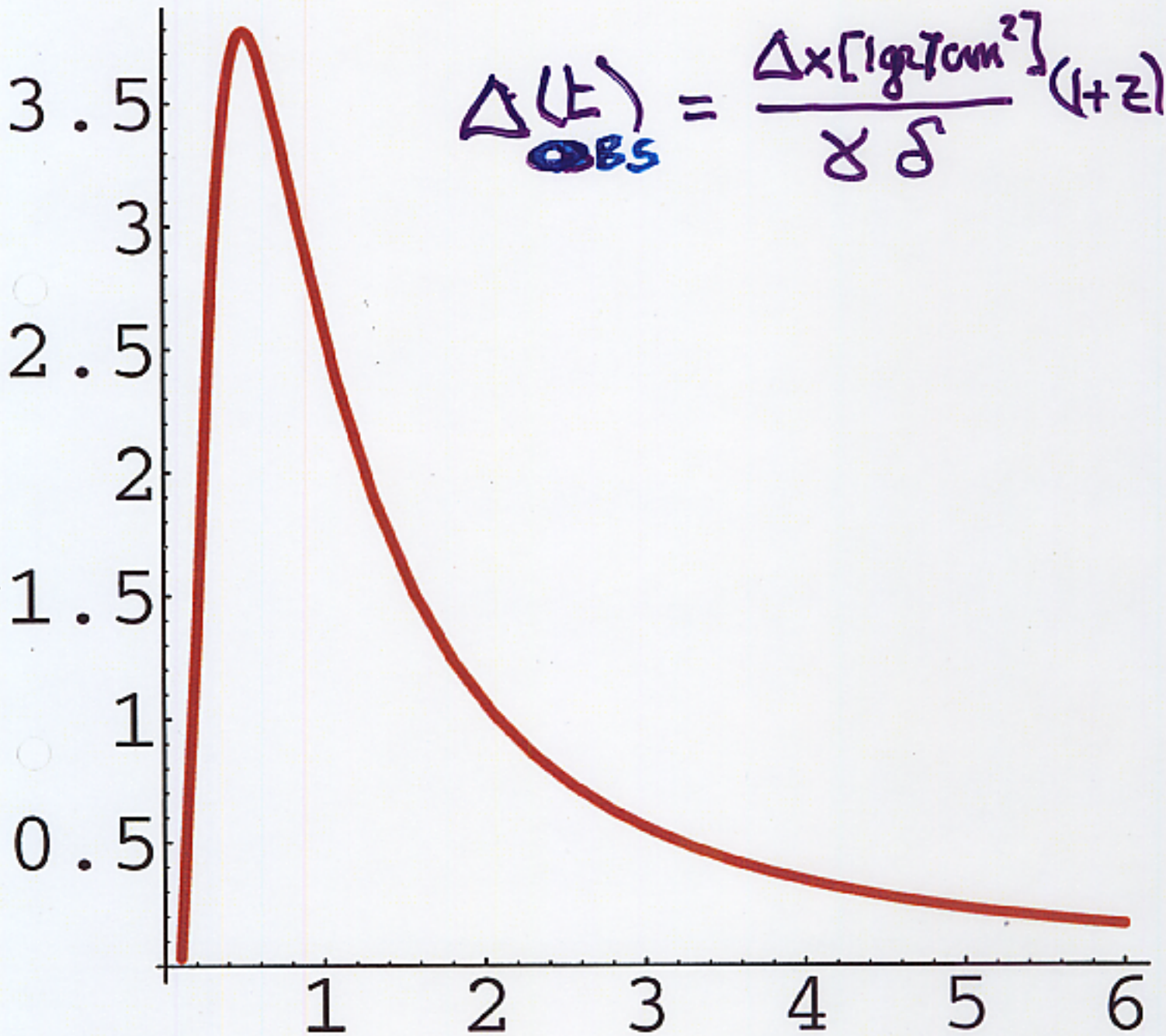
(Fenimore et al. 1995)

- A [GOOD, CONSTANT] FRACTION OF THE DEPOSITED ENERGY IS REEMITTED AS A [QUASI-] THERMAL SPECTRUM

$T = T(t)$

$$F(t) \propto \left(\frac{t_{fr}}{t}\right)^2 e^{-\frac{t_{fr}}{t}}$$

$$\Delta(t)_{OBS} = \frac{\Delta x\,[1\,gr/cm^2]}{\gamma\,\delta}(1+z)$$




ERFD ~~FRED~~

# PEAK ENERGY in $EF(E)$ $E_{max}$

## TYPICAL $\gamma$ ENERGY IN GRB

OBS : $E_{max} \sim$ few 100 keV

**FIREBALLS**

$$E_{max} \sim 4\,\mathrm{MeV}\,\frac{\epsilon_e^{1/2}\,\epsilon_B^{1/2}\,L_{s,52}^{1/2}}{R_{i,13}\,(1+z)}$$

**CB (OR PULSE) OF WIDTH $\Delta t$**

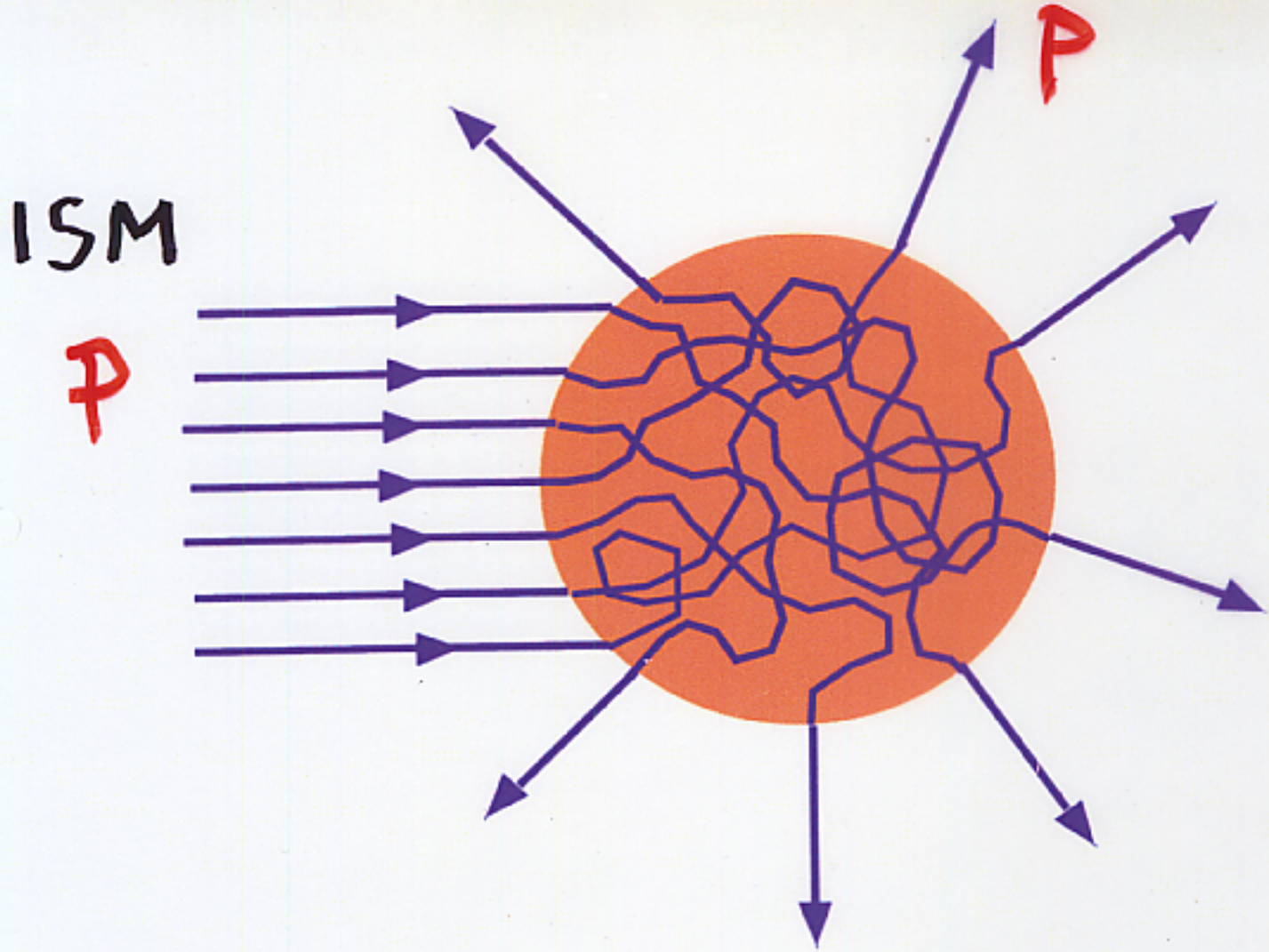
$$T \sim \frac{\delta}{1+z}\,T_{trans}$$

$$E_{max} \sim 3T = 250\,\mathrm{keV} \; *$$

$$* \left(\frac{\gamma\,\delta^3}{10^{12}}\right)^{3/4} \left[\frac{1+z}{2}\right]^{-3/4} \left(\frac{\Delta t}{1\,\mathrm{s}}\right)^{-1/4}$$

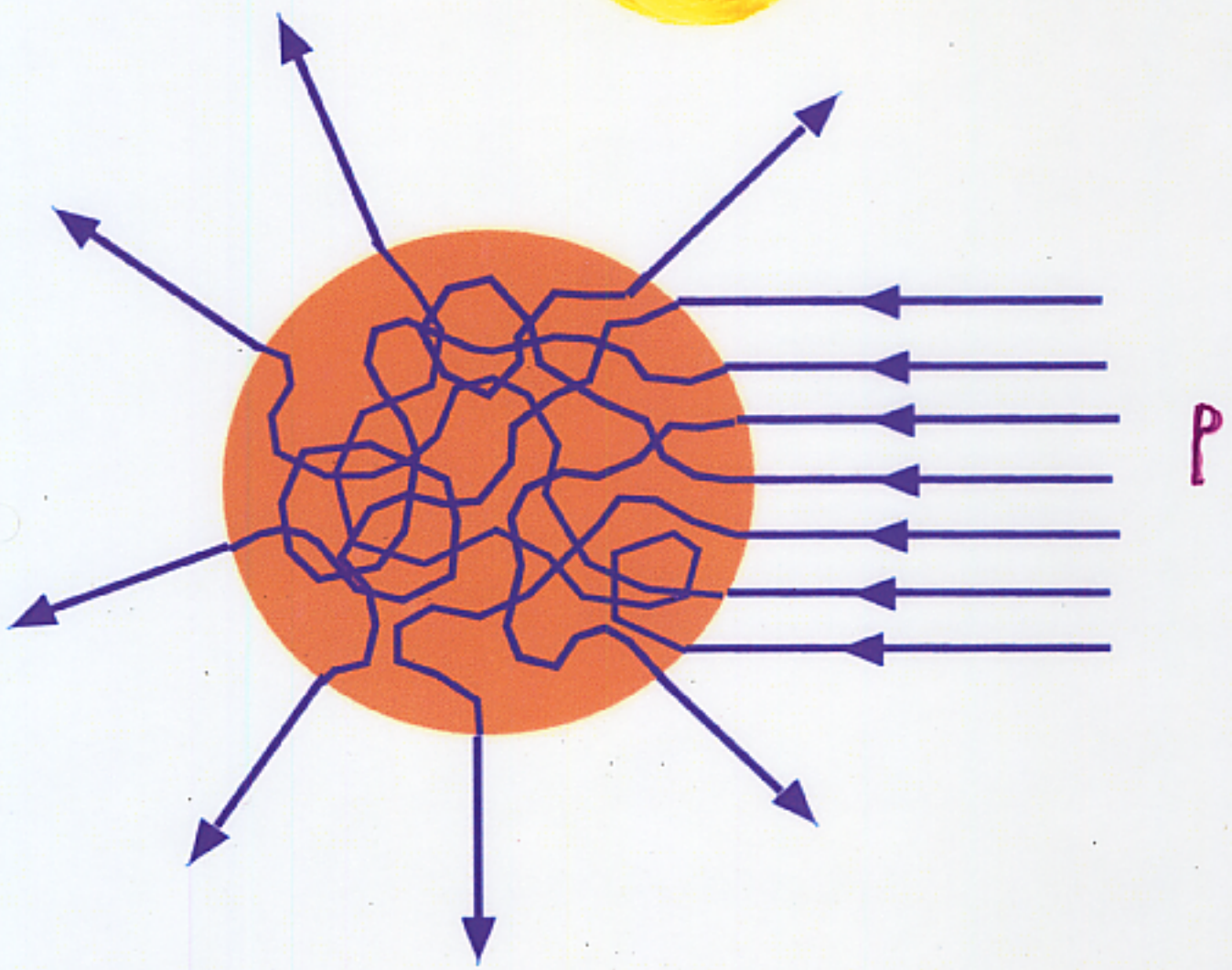
$\gamma \sim \delta \sim 10^3$

$T$ ? QUASI-THERMAL




OUTGOING p-momentum quenches initial relativistic expansion $R \rightarrow R_\infty \sim 10^{13/14}$ cm in minutes of t[OBS]

# B ?



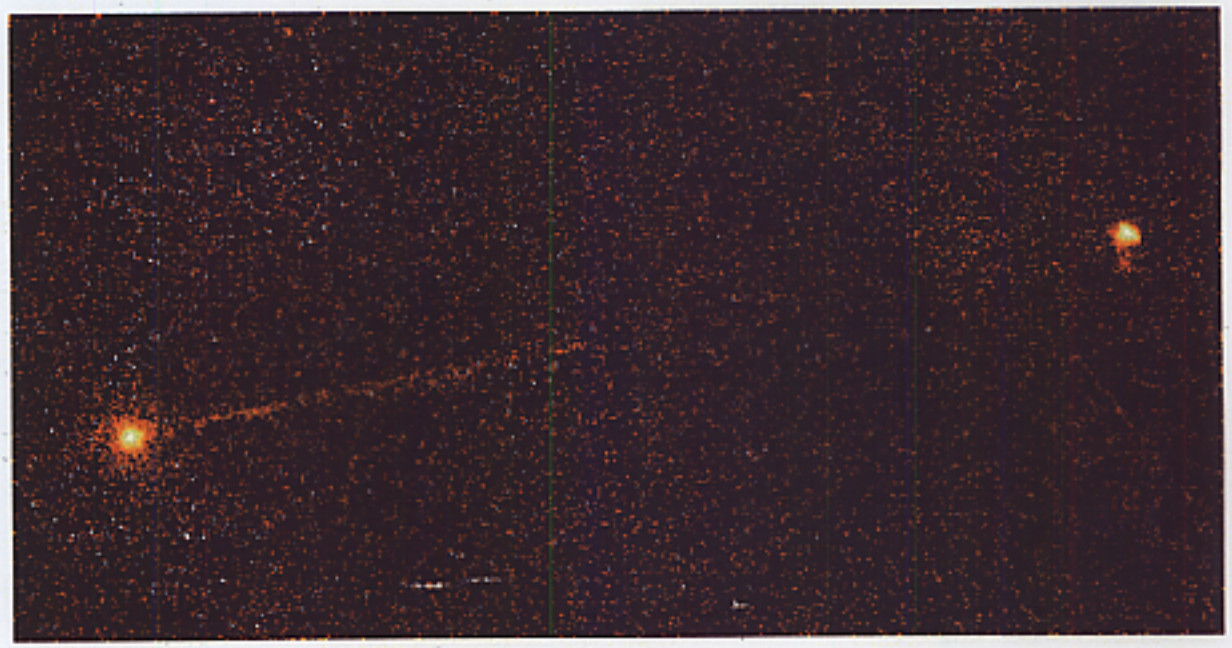

$$\frac{B_\infty^2}{4\pi} = P_B = P_p = \frac{1}{4} m_p \gamma^2 n_{ISM} c^2$$

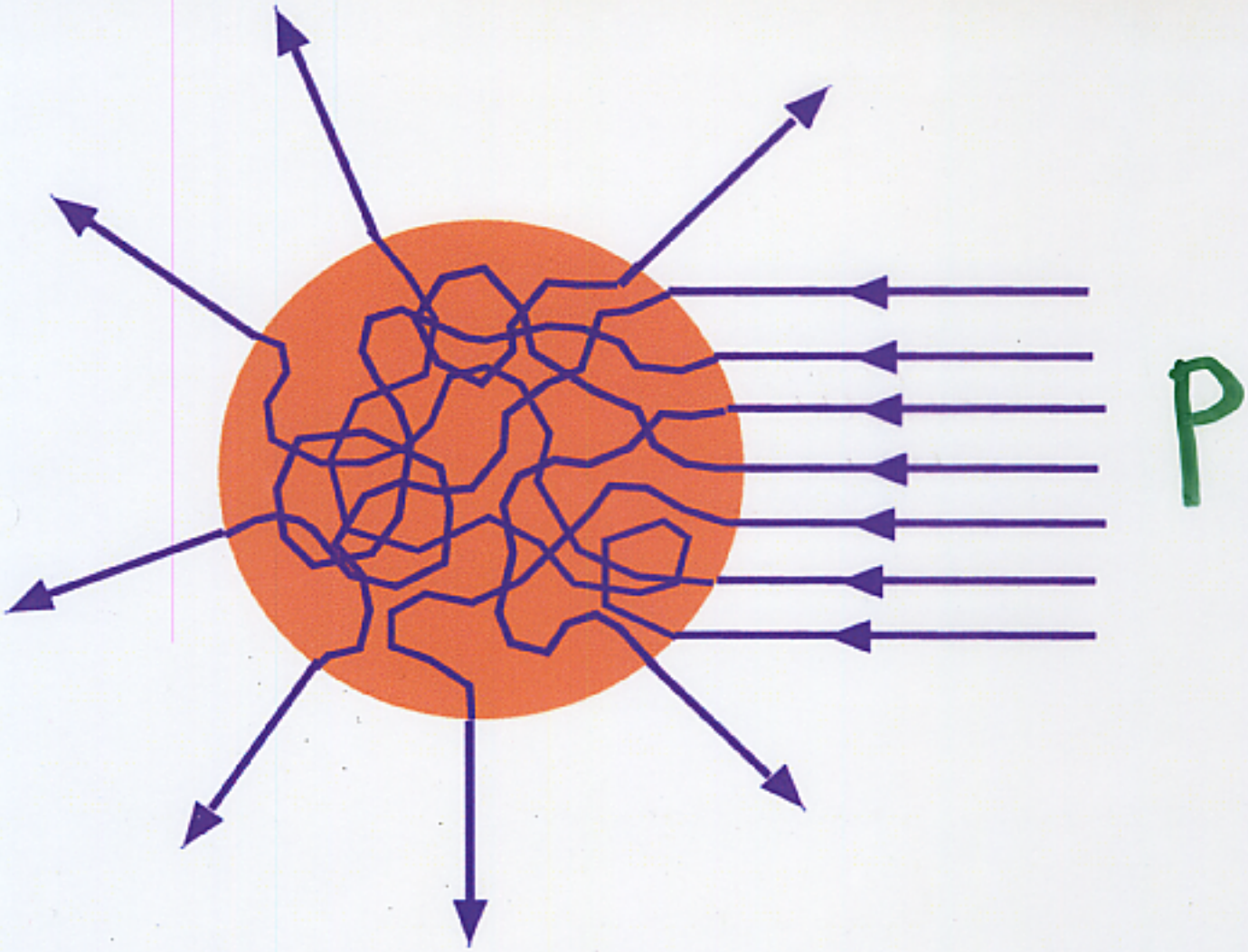
$$B_\infty = 10\,G \left[\frac{n_p}{.01\,cm^{-3}}\right]^{1/2} \left[\frac{\gamma}{10^3}\right] \qquad \gamma = \gamma(t)$$

IF B IN ENERGY EQUIPARTITION WITH THE ENCLOSED H.E. PROTONS $B_\infty \rightarrow B_\infty/\sqrt{2}$

CHANDRA

PICTOR-A

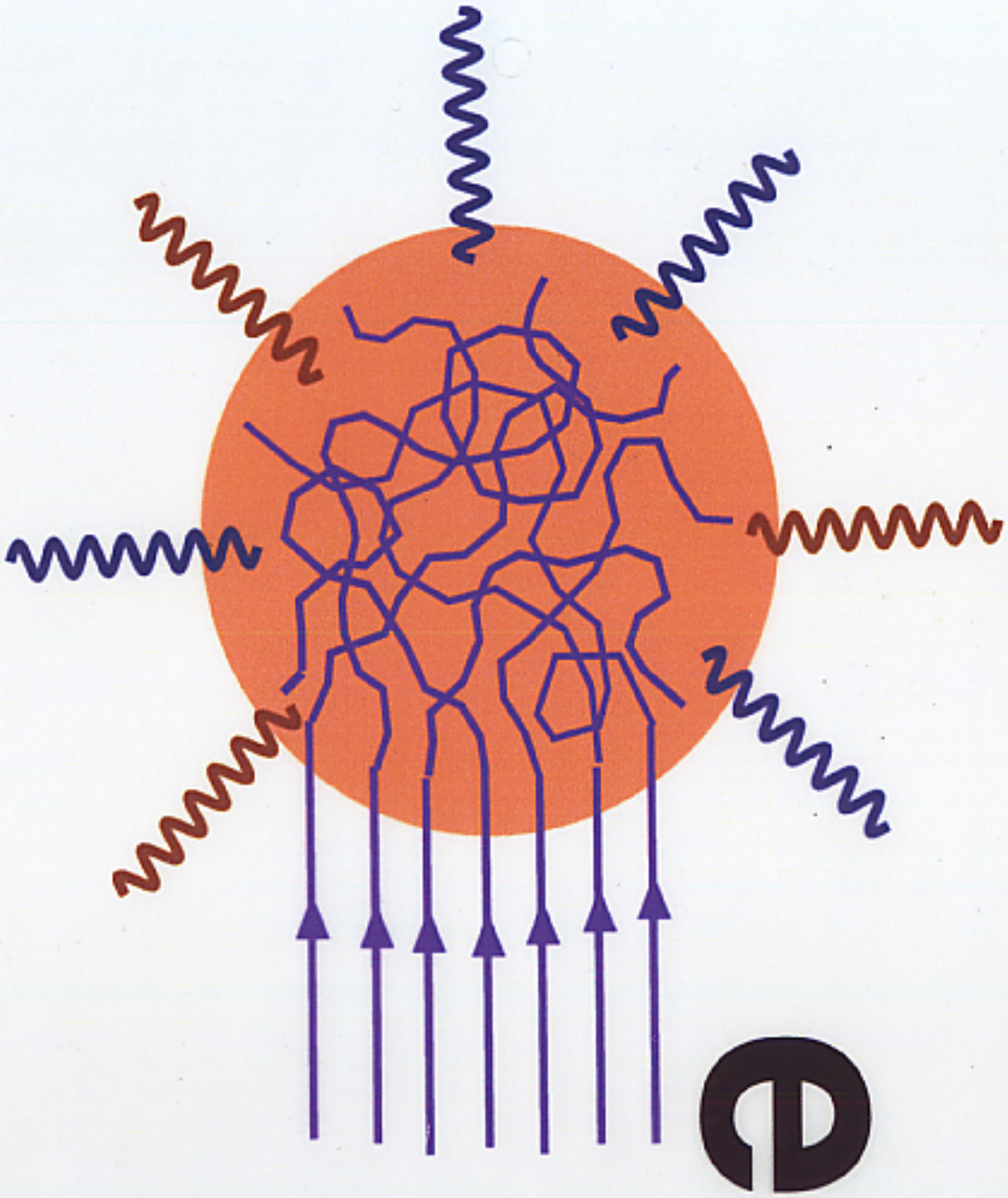





CONSTANT $S_{CB}$ , $n_{ISM}$

$$\gamma = \gamma(t, \gamma_0, x_\infty)$$

$$x_\infty = \frac{M_{CB}/m_p}{S_{CB}\, n_{ISM}}$$



# NOT-VERY-EARLY OPTICAL AFTERGLOW

## DADO, DAR, ADR

$$F_\nu \equiv \frac{dF[\nu,t,\theta]}{dt\,d\nu\,d\Omega} \simeq n_{CB}\,(\alpha-1)\,\pi\,\nu_0^{\alpha-1}\,[1+z]^{-(1+\alpha)}\,m_e\,c^3$$

$$\times \frac{n_e(x[t])\,[R(t)]^2\,[\gamma(t)]^{2\alpha}}{4\pi\,[D_L(z)]^2}\left[\frac{2\gamma(t)}{1+[\theta\gamma(t)]^2}\right]^n \nu^{-\alpha}$$

$$n \equiv 3+\alpha \simeq 4.1$$

$$\nu_0 = \frac{3\,e\,B_\perp}{4\pi\,m_e} \simeq 0.42\,\frac{B_\perp}{100\ \text{Gauss}}\ \text{GHz}$$

$$\frac{1}{\gamma^3} - \frac{1}{\gamma_0^3} + 3\,\theta^2\left[\frac{1}{\gamma} - \frac{1}{\gamma_0}\right] = \frac{6\,c\,t}{(1+z)\,x_{1/2}}$$

$$x_{1/2} \equiv \frac{N_{CB}}{\pi\,R_\infty^2\,n_p} \simeq (1.3\ \text{Mpc})\times$$

$$\left[\frac{N_{CB}}{6\times10^{50}}\right]^{\frac{1}{3}}\left[\frac{10^{-3}\text{cm}^{-3}}{n_p}\right]\left[\frac{n_p^{SN}}{1\,\text{cm}^{-3}}\right]^{\frac{2}{3}}\left[\frac{\gamma_0}{10^3}\,\frac{1/(3\sqrt{3})}{\beta_{trans}}\right]^{\frac{4}{3}}$$

$$x(\gamma) = x_{1/2}\left[\frac{1}{\gamma} - \frac{1}{\gamma_0}\right]$$

$\gamma_0 \to \gamma_0/2 \qquad x_{half} = \frac{1}{\gamma_0}\,x_{1/2}$

# OPTICAL and X-RAY

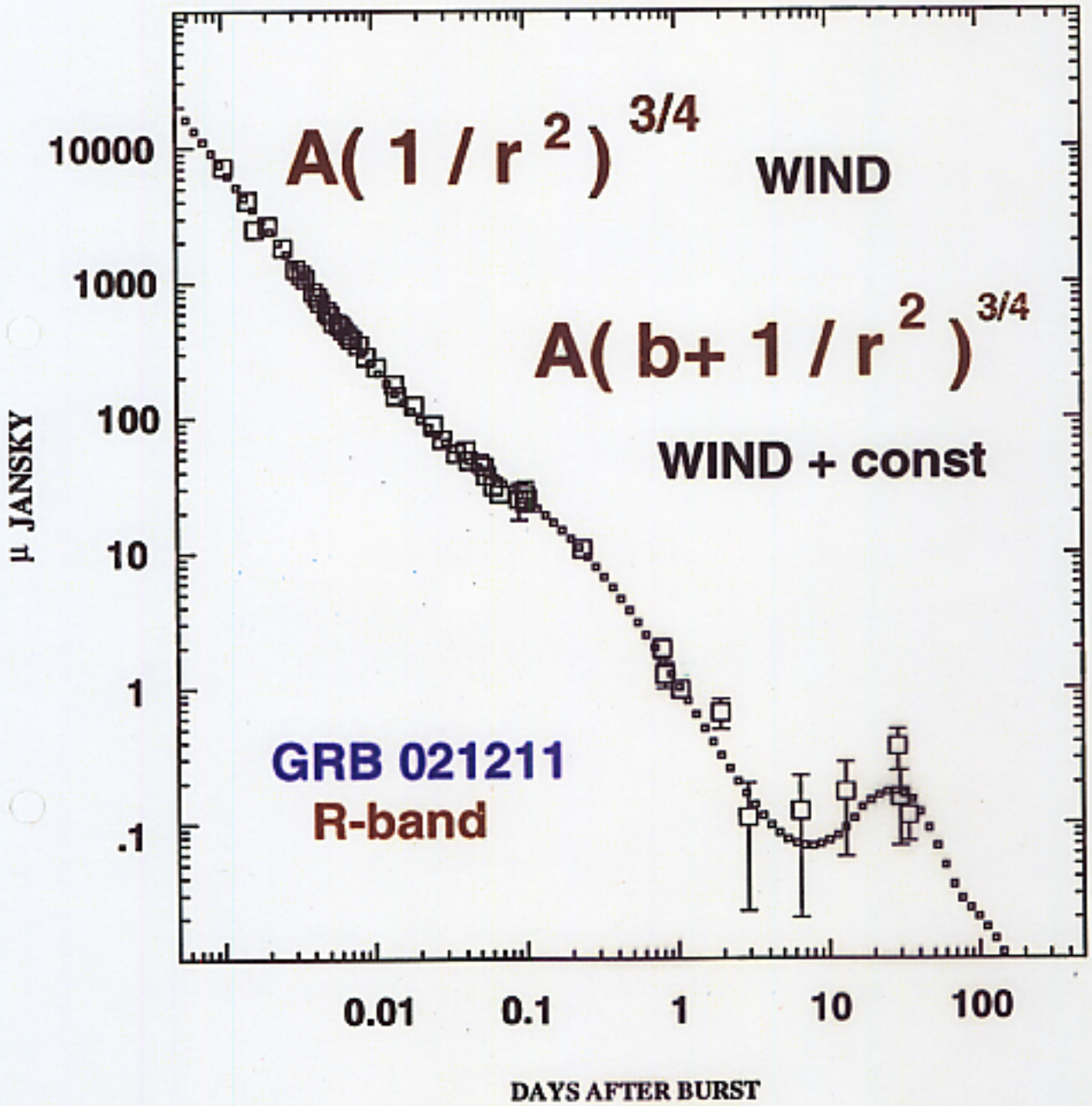
# AFTER-GLOWS

DDD

- DADO
- DAR
- DE RÚJULA

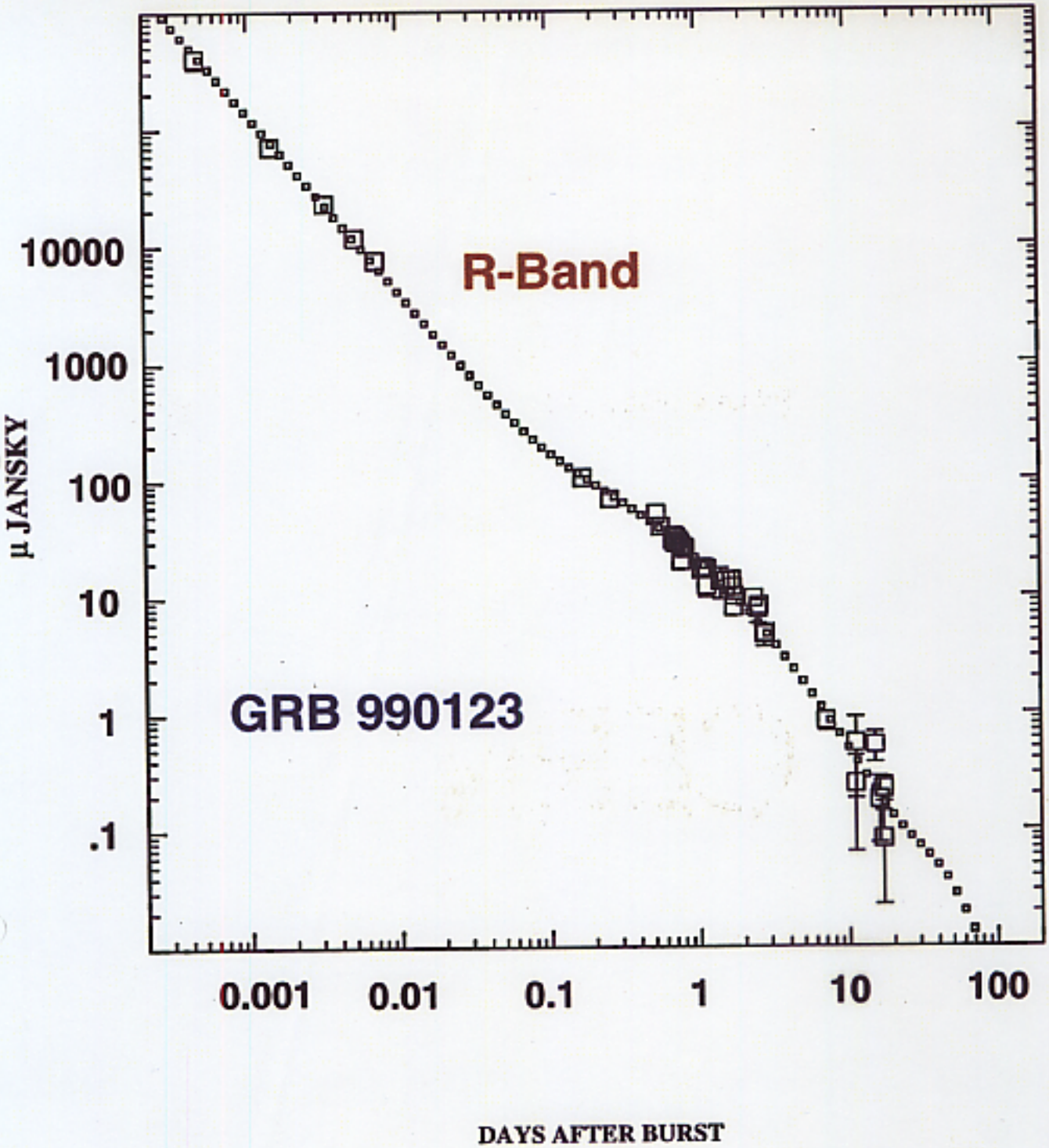
# Early AG $\Delta\gamma/\gamma \ll 1$

$$F \propto n_e^{3/4}$$




Fit "a" in $A( b+ 1 / r^{a} )^{3/4}$

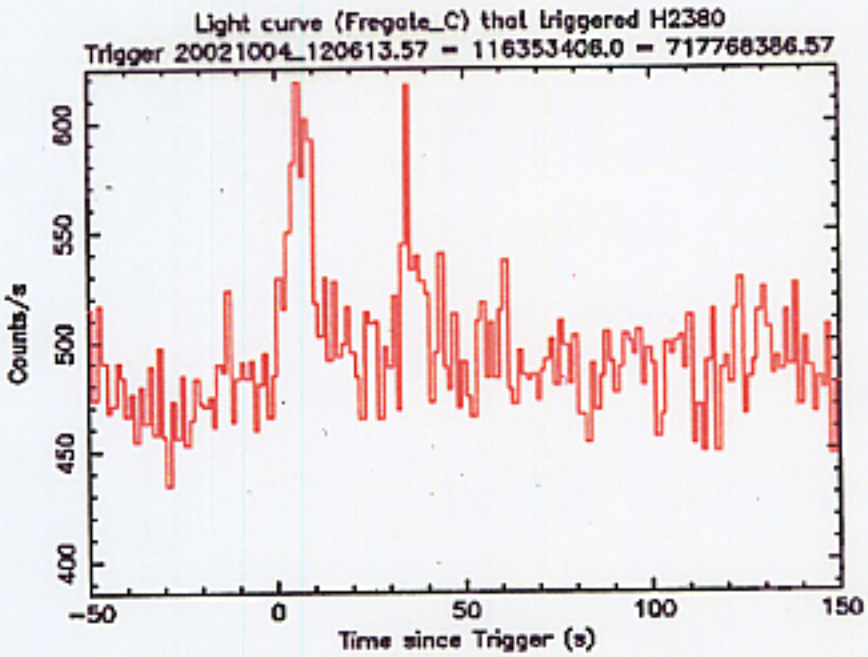
$$a = 1.92 +/- 0.03$$




Fit "a" in $A( b+ 1 / r^{a} )^{3/4}$

$a = 1.98 +/- 0.06$

# HETE Burst H2380




## Burst H2380 summary

- Trigger time is
  - UTC=20021004_12061
  - GRB=GRB021004+43:
- Triggering instrument was **Fregate**
- Trigger timescale was **5.2 seconds**
- Trigger detected in **30-400 ke band**

## Evaluation

*Definite GRB. Bright OT detected 9.5 minutes after burst.*

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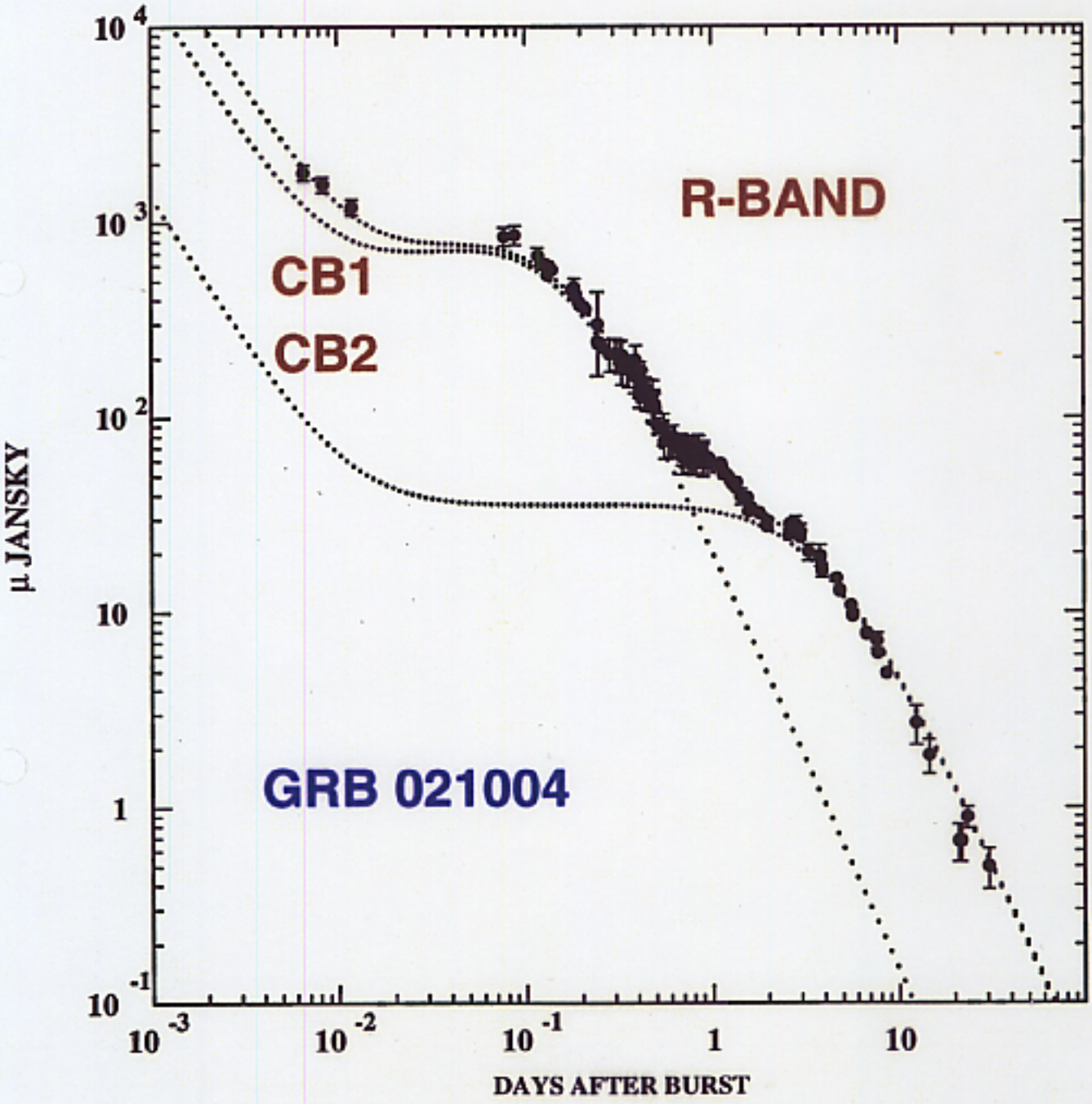
**The localization history of H2380 (GRB021004)**


R-BAND
CB1
CB2
GRB 021004
μ JANSKY
DAYS AFTER BURST
10^4
10^3
10^2
10
1
10^-1
10^-3
10^-2
10^-1
1
10

# AG PARAMETERS in the CB MODEL

## INTRINSIC

$\eta$ **AG Normalization**

Fraction of ISM-e energy reradiated as AG

$\gamma_0$ **CBs' Initial Lorentz factor**

$x_0$ **Deceleration parameter**

( ~ ISM density)

$\nu_a$ **Characteristic Absorption Frequency**

(Relevant only in radio AG)

## EXTRINSIC (like z)

$\theta$ **Viewing Angle**

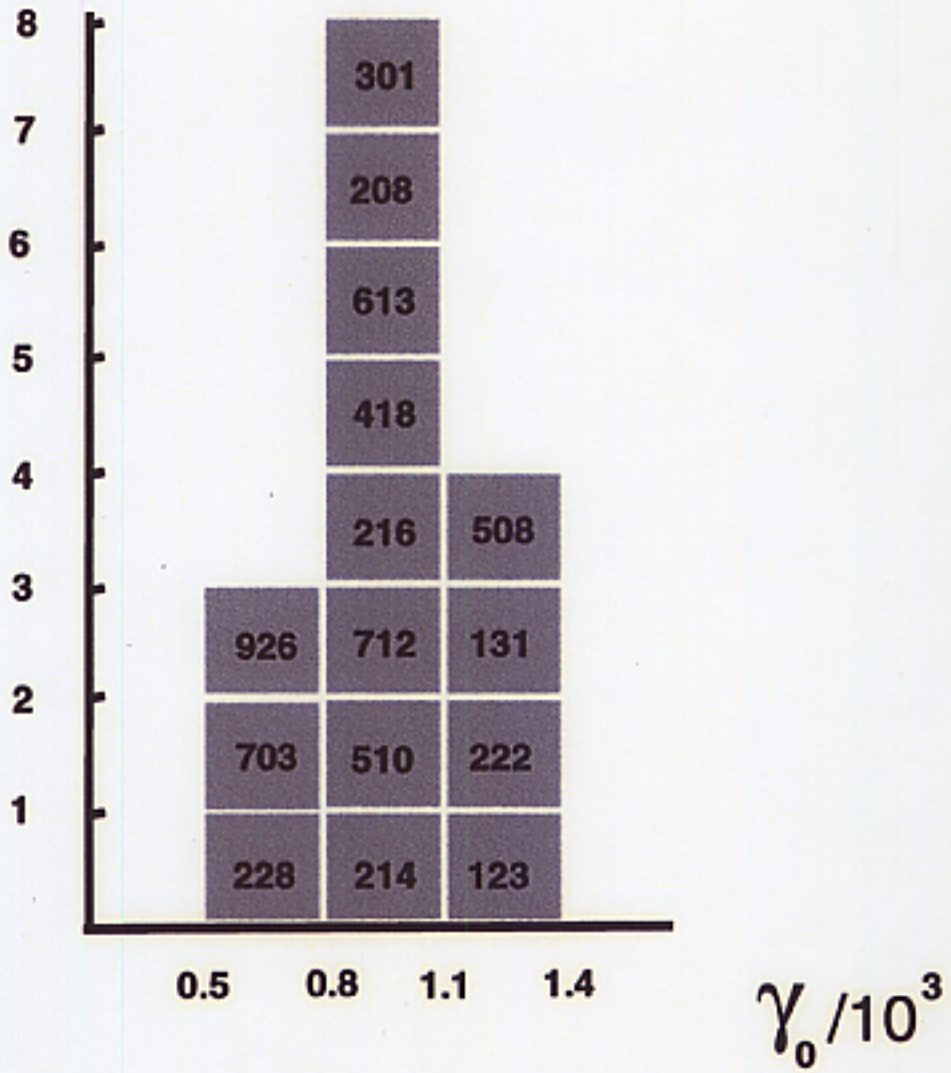
(between observer and CBs' motion)

## ~~FIXED~~

~~p High-E electron's spectral index~~

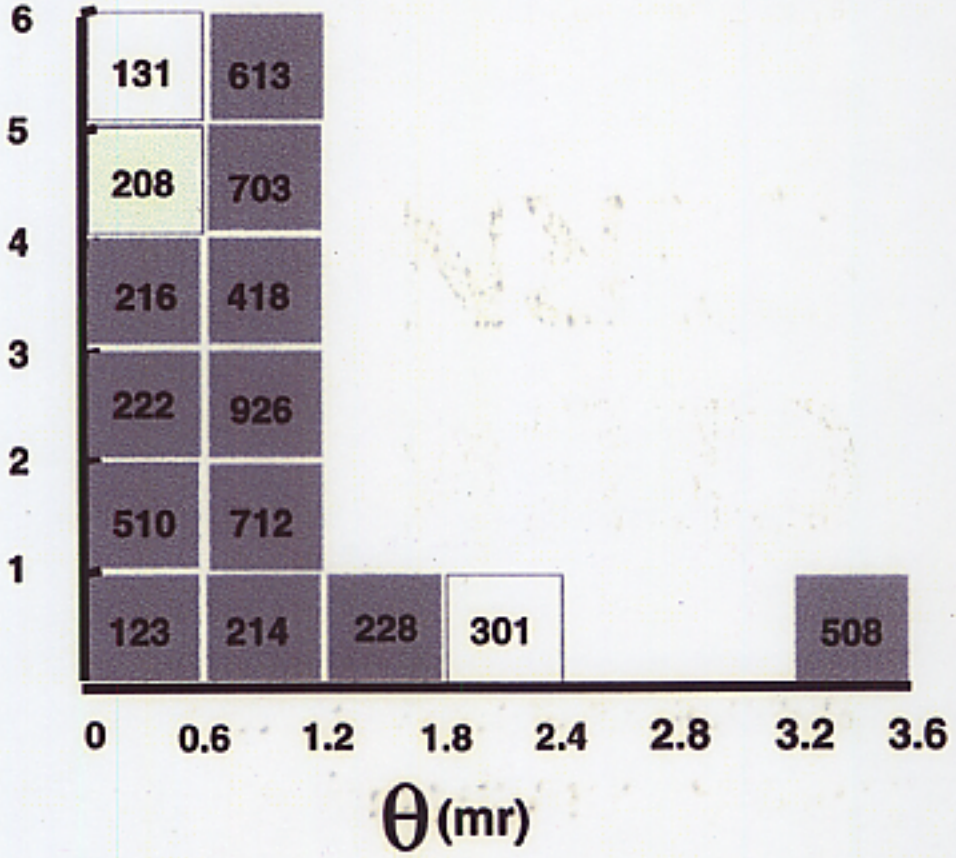
# DISTRIBUTIONS of FITTED PARA-METERS

FROM R-BAND AGs




EXPECT $\gamma_0 \sim 10^3$.

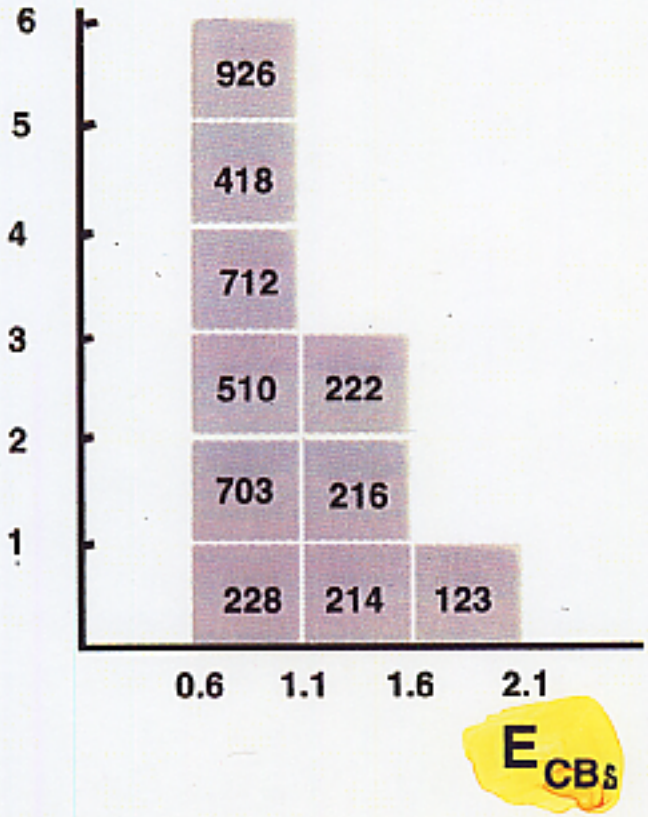
$$\frac{dF}{d\cos\theta} \propto \left(\frac{2\gamma}{1+\theta^2\gamma^2}\right)^3$$



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

$D_L$: LUMINOSITY DISTANCE

$F_\gamma$: BATSE / BEPPOSAX FLUENCE

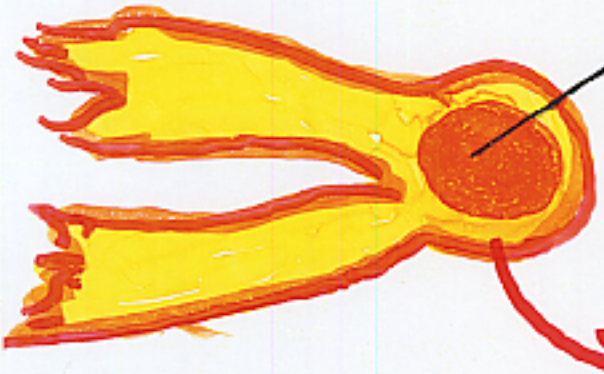



(in $10^{44}$ erg)

$E_{CB}$ : GRB TOTAL ENERGY IN CB'S REST FRAME

$$\sum_{CB} E_{CB} = \frac{4\pi D_L^2 F_\gamma}{(1+z)\,\delta_0}$$

# CBs are not RADIO-TRANSPARENT



OPTICAL AND X-RAY EMISSION FROM VOLUME

RADIO EMISSION FROM SURFACE

APPROX :

JUST ONE EXTRA "RADIO-PARAMETER"

TO FIT : $\nu_a$ CHARACTERISTIC ABSORPTION FREQUENCY

[ABSORPTION IN CB IS DOMINATED BY FREE-FREE ATTENUATION]

$$\nu \frac{dn_\gamma}{d\nu} \propto f_{sync}(\nu) \equiv$$

$$\frac{\sqrt{\pi}}{\Gamma\left[\frac{2p-1}{2(p-1)}\right]\Gamma\left[\frac{2p-3}{2(p-1)}\right]} \frac{1}{\nu_b} \frac{[\nu/\nu_b]^{-1/2}}{\sqrt{1+[\nu/\nu_b]^{(p-1)}}}$$

$$\nu_b(t) = 0.29\,(3/4)\gamma(t)^2\,\nu_L$$

$$\nu_L = e\,B/(2\,\pi\,m_e\,c)$$

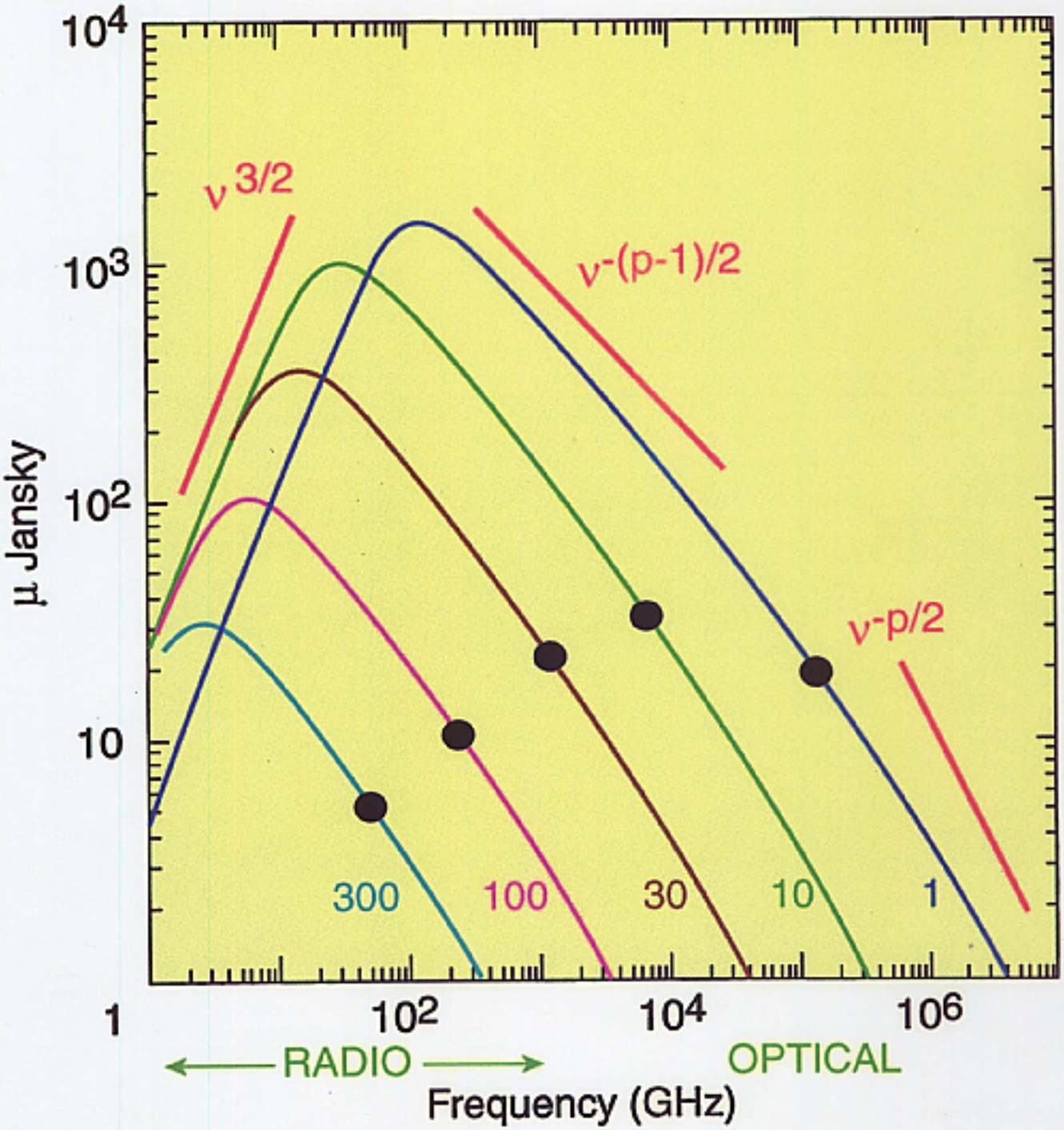
B = B(t)

$$F_{CB}[\nu,t,\theta_{CB}] \simeq \pi\,R_{max}^2\,n_e\,m_e\,c^3\gamma(t)^2\,f_{sync}(\nu)$$
$$\times C(\nu,t)\,A_{CB}[\nu]\,L_{CB}(\nu,t,\theta_{CB})$$

$$A[\nu] = \frac{[1-e^{-\tau_\nu}]}{\tau_\nu}$$

$$\tau = \left[\frac{\nu_a}{\nu}\right]^2 \left[\frac{\gamma(t)}{10^3}\right]^2$$

DOMINATED BY FREE$^2$ ABSORPTION


$10^4$
$10^3$
$10^2$
10
1
μ Jansky
$\nu^{3/2}$
$\nu^{-(p-1)/2}$
$\nu^{-p/2}$
300
100
30
10
1
$10^2$
$10^4$
$10^6$
RADIO
OPTICAL
Frequency (GHz)

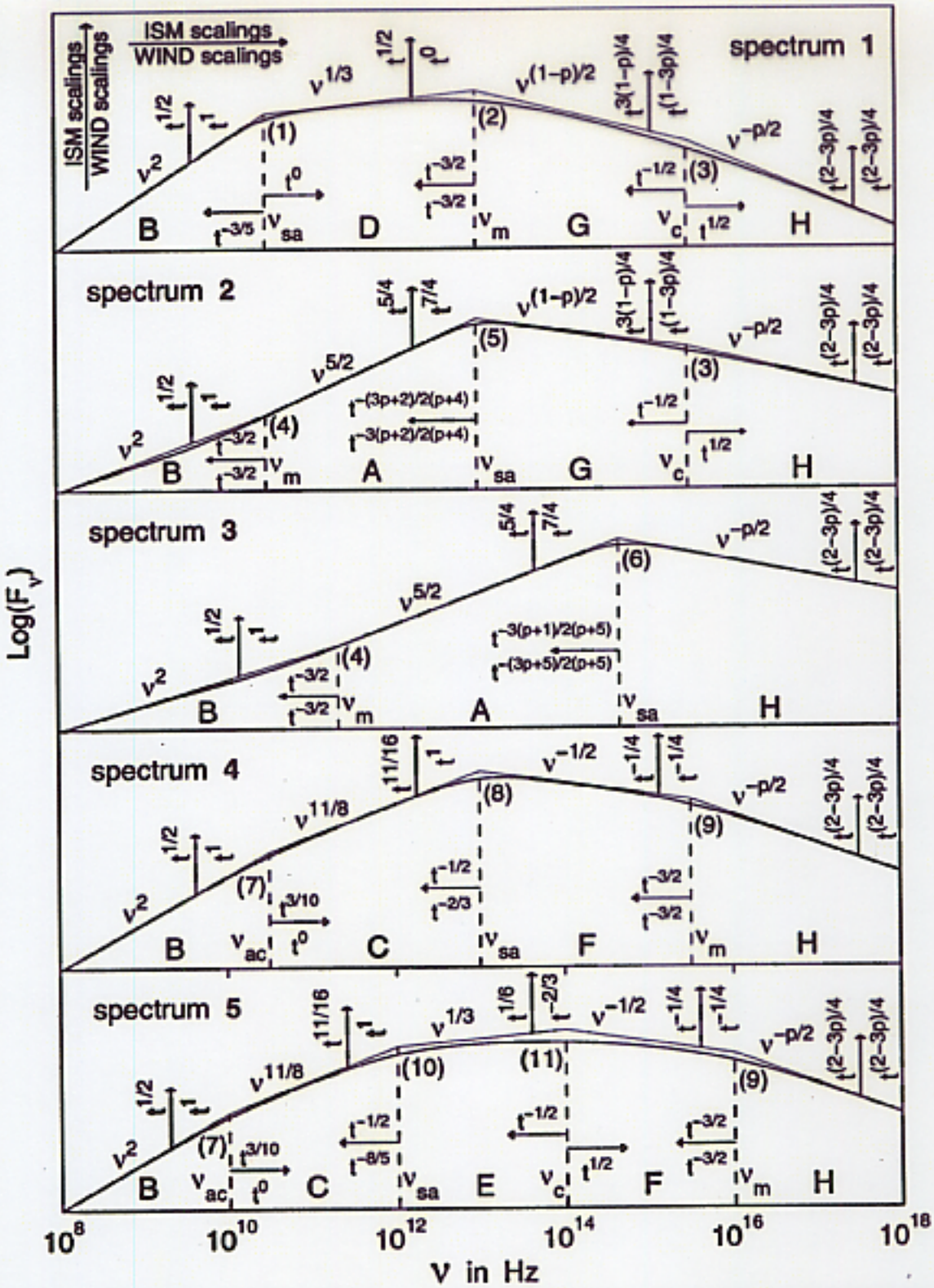



FIG. 1.— The different possible broad band synchrotron spectra from a relativistic blast wave, that accelerates the electrons to a power law distribution of energies. The thin solid line shows the asymptotic power law segments (PLSs), and their points of intersection, where the break frequencies, $\nu_b$, and the corresponding flux densities, $F_{\nu_b,ext}$, are defined. The different PLSs are labeled A through H, while the different break frequencies are labeled 1 through 11. The temporal scalings of the PLSs and the break frequencies, for an ISM ($k = 0$) or stellar wind ($k = 2$) environment, are indicated by the arrows. The thick solid line shows the spectrum we calculated in this paper, where the broad band spectrum is constructed according to the prescription suggested in §4. The different spectra are labeled 1 through 5, from top to bottom. The relevant spectrum is determined by the ordering of the break frequencies. The top two panels (spectra 1 and 2) correspond to slow cooling ($\nu_m < \nu_c$). Spectrum 1 applies when $\nu_{sa} < \nu_m$, while spectrum 2 applies when $\nu_m < \nu_{sa} < \nu_c$. The two bottom panels (spectra 4 and 5) correspond to fast cooling ($\nu_c < \nu_m$). Spectrum 5 applies when $\nu_{sa} < \nu_c$, and spectrum 4 applies when $\nu_c < \nu_{sa} < \nu_m$. Spectrum 3 (middle panel) applies when $\nu_{sa} > \nu_m, \nu_c$, where in this case the relative ordering of $\nu_c$ and $\nu_m$ is unimportant (i.e. spectrum 3 may apply both to slow cooling or fast cooling).

GRANOT and SARI

# GRBs

and the

# SOS

EXAMPLE:

# FIREBALLS & CANNONBALLS confront GRB 991208

G1

Galama et al. astro-ph/0006201 ApJLetters

G2

Galama et al. astro-ph/0211211 ApJ

## DDD Dado, Dar & De Rújula

DDD1 astro-ph/0107367 A&A

DDD2 astro-ph/0204474 A&A

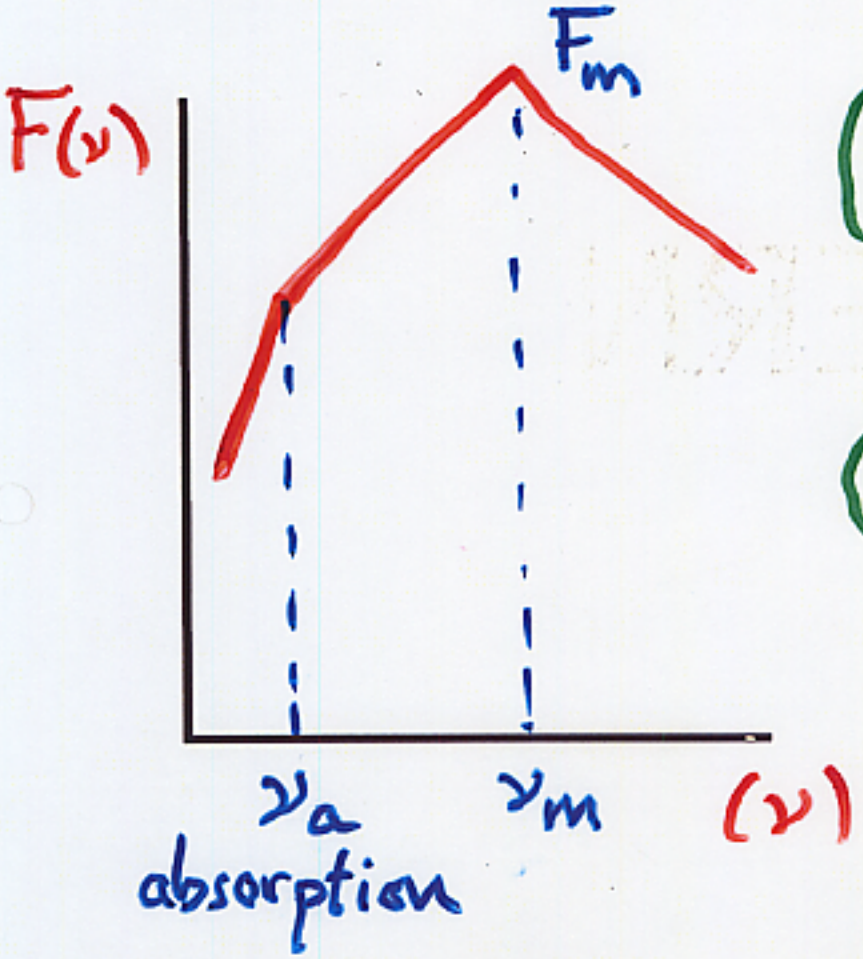
DDD3 astroph/0211596

# G1 The bright GRB 991208:

## Tight constraints on AG models from observations of the early radio evolution

### A 13-parameter phenomenological fit

$p: \frac{dn_e}{dE} \propto E^{-p}$ SYNCHROTRON-RADIATING e.s




$(F_m, \nu_m, \nu_a)$

$*$

(4 diff times)

**Compare with Standard Models which constrain the time-dependence of the parameters**

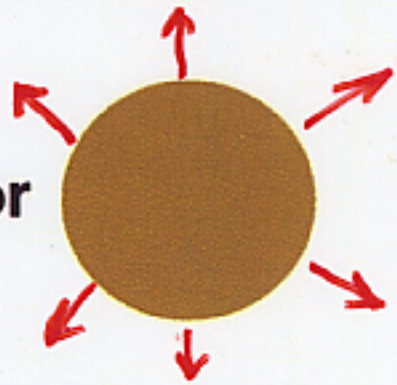
# G1 (cont)

ISM model (constant density)

JET model (fireball --> firetrumpet)

WIND model (density ~ $1 / r^2$ )

Progenitor



"Wind" of constant $\dot{M}$

ALL MODELS FAIL

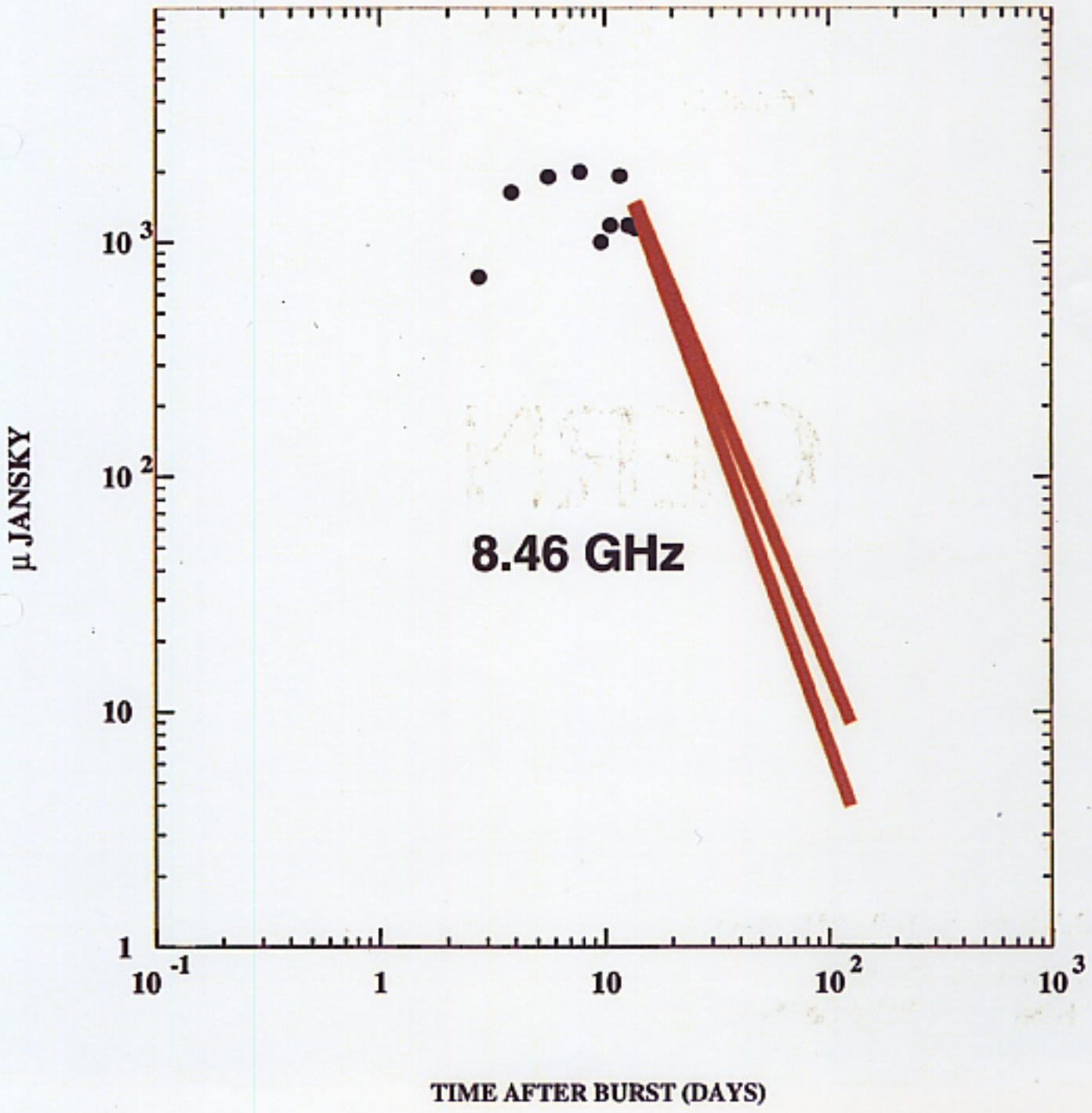
## CONCLUSIONS:

1. "The jet model can account for the [observations...] provided the jet transition had not been completed in the first two weeks..."

2. $F \propto t^{-(2.2 \text{ to } 2.5)}$ at 8.46 GHz and t > 12 days

# $t^{-(2.2 \text{ to } 2.5)}$

# after 12 d



# G2 Continued radio monitoring of GRB 991208

ISM model (constant density)

JET model (fireball --> firetrumpet)

WIND model (density ~ $1 / r^2$ )

ALL THESE MODELS FAIL

FREE model

Three frequency breaks in the spectrum (absorption, maximum, cooling) and $F_m$ all behaving as $A\ t^{-a}$ (+ p -> 9 params)

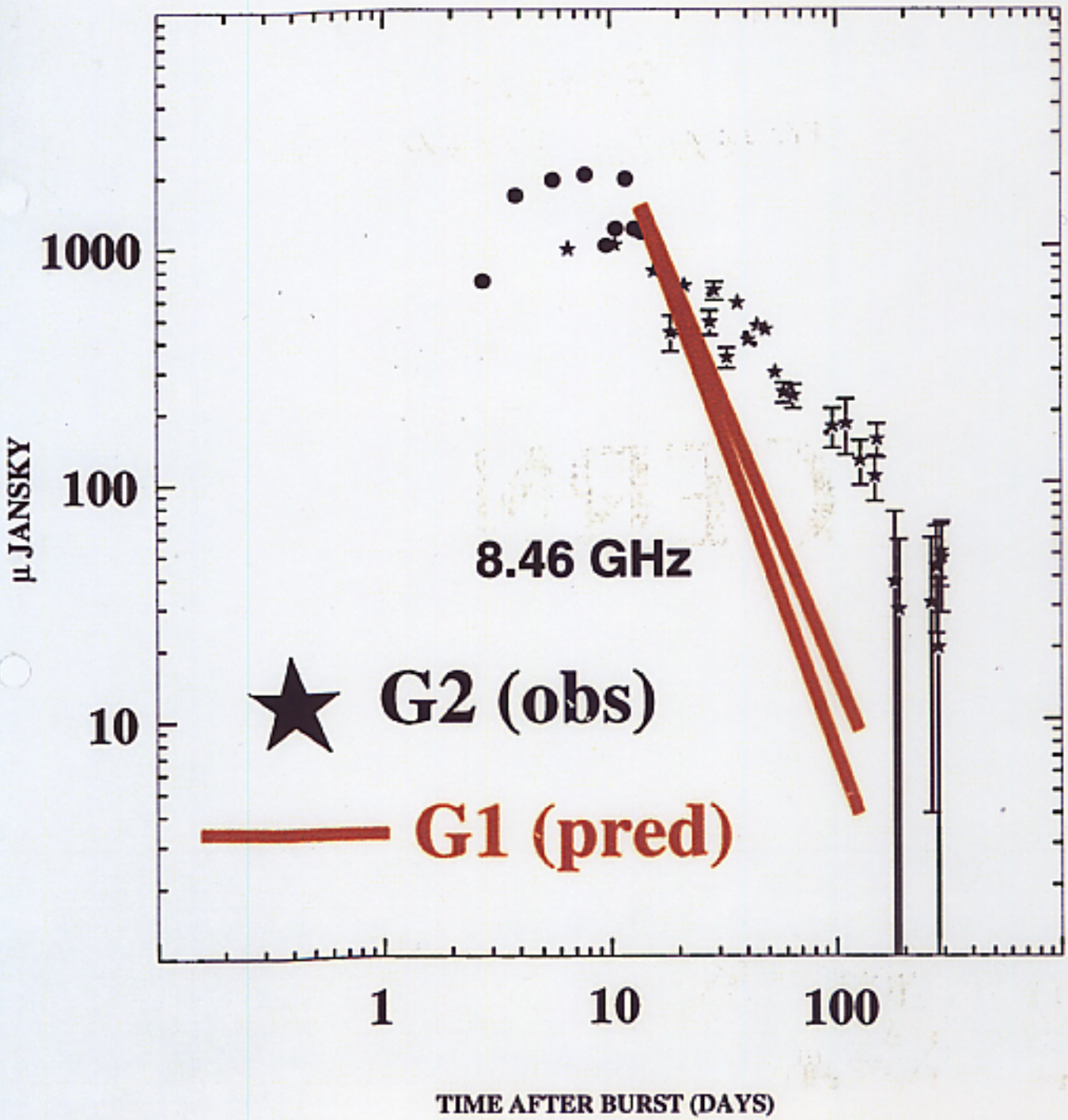
## CONCLUSIONS:

1. Free model OK, but == > $\gamma B^3$ ~ constant

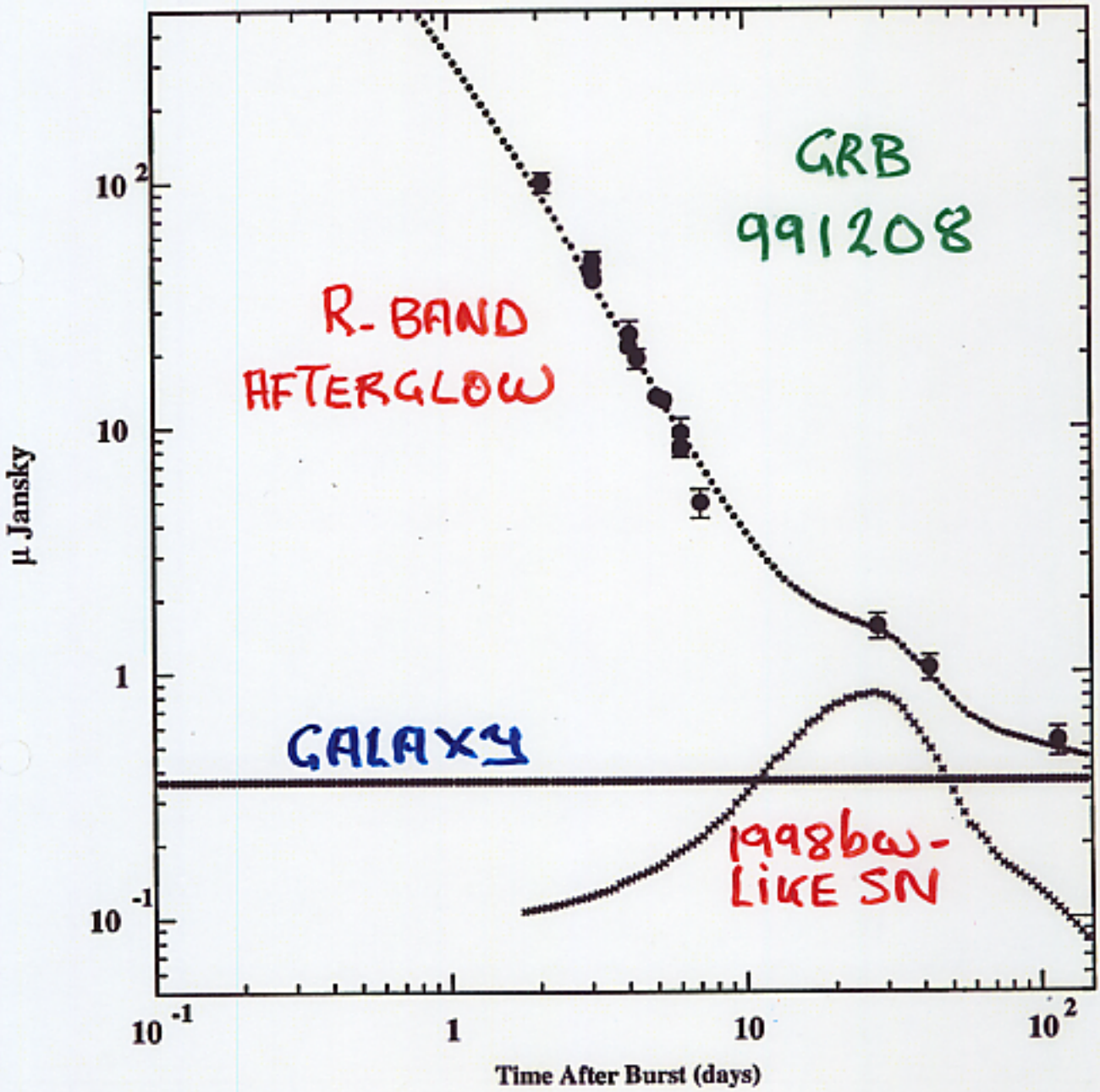
2. "The simplest explanation which is consistent with the data and requires no significant modifications is that the blast wave entered a non-relativistic expansion phase several months after the burst."

# $t^{-(2.2 \text{ to } 2.5)}$

# after 12 d



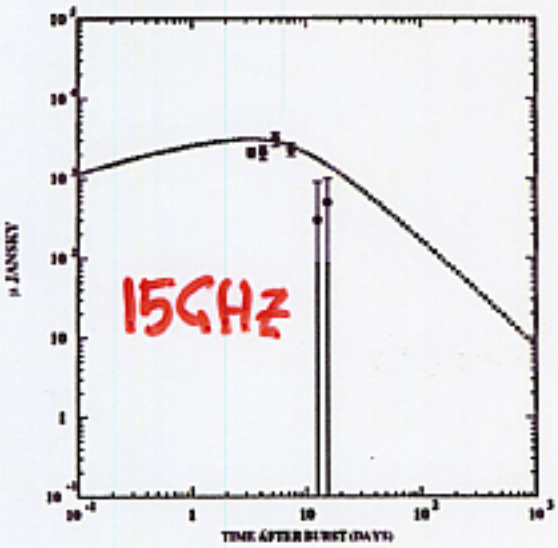
# DDD1

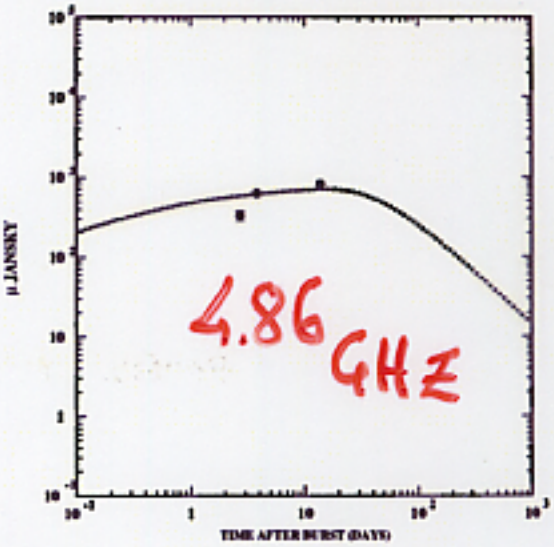


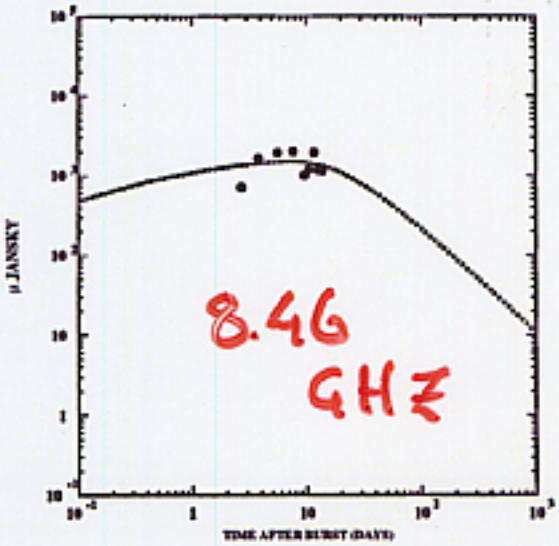

PARS: NORMALIZ.
$[\theta]_{EXT.}$
$\gamma_0$
$x_\infty = \frac{M_{CB}}{S_{CB}\,\rho_{ISM}}$

DDD2 GRB 991208





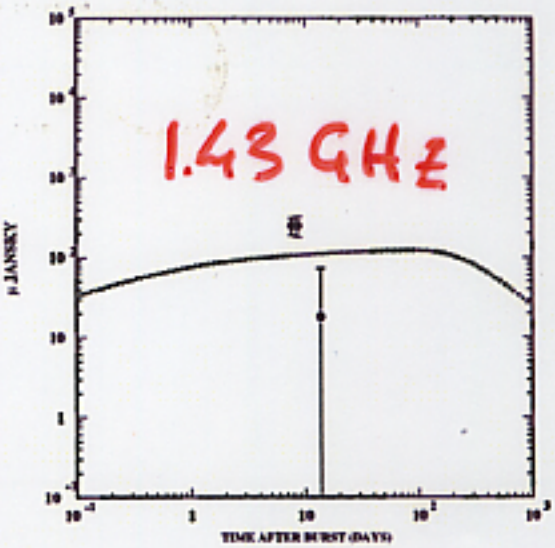
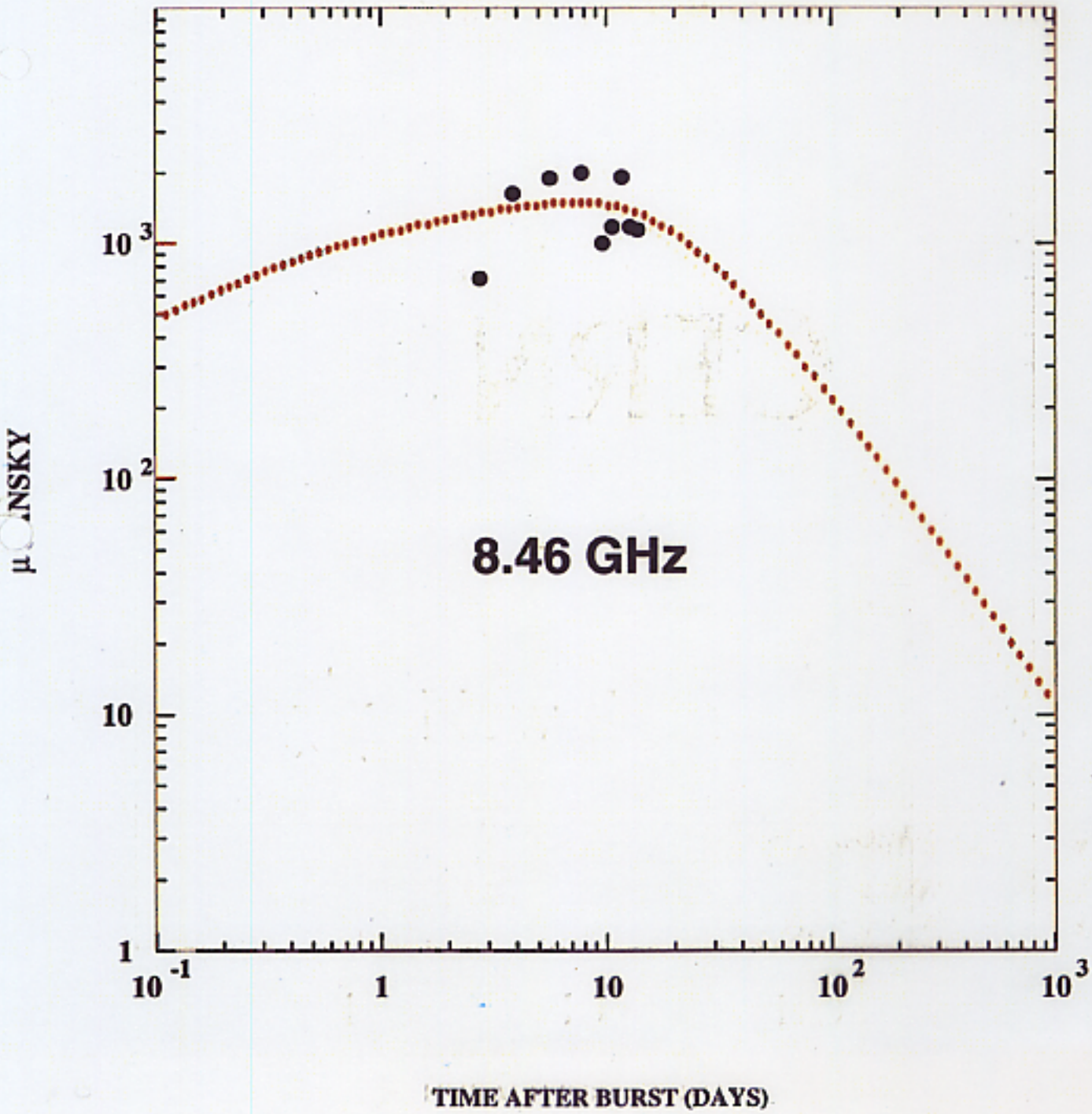




FIG. 30.— Comparisons between our fitted CB model afterglow, Eq. (8), and the observed radio afterglow of GRB 991208. Upper panel: the light curve at 15 GHz. Lower panel: the light curve at 8.46 GHz.

FIG. 31.— Comparisons between our fitted CB model afterglow, Eq. (8), and the observed radio afterglow of GRB 991208. Upper panel: the light curve at 4.86 GHz. Lower panel: the light curve at 1.43 GHz.

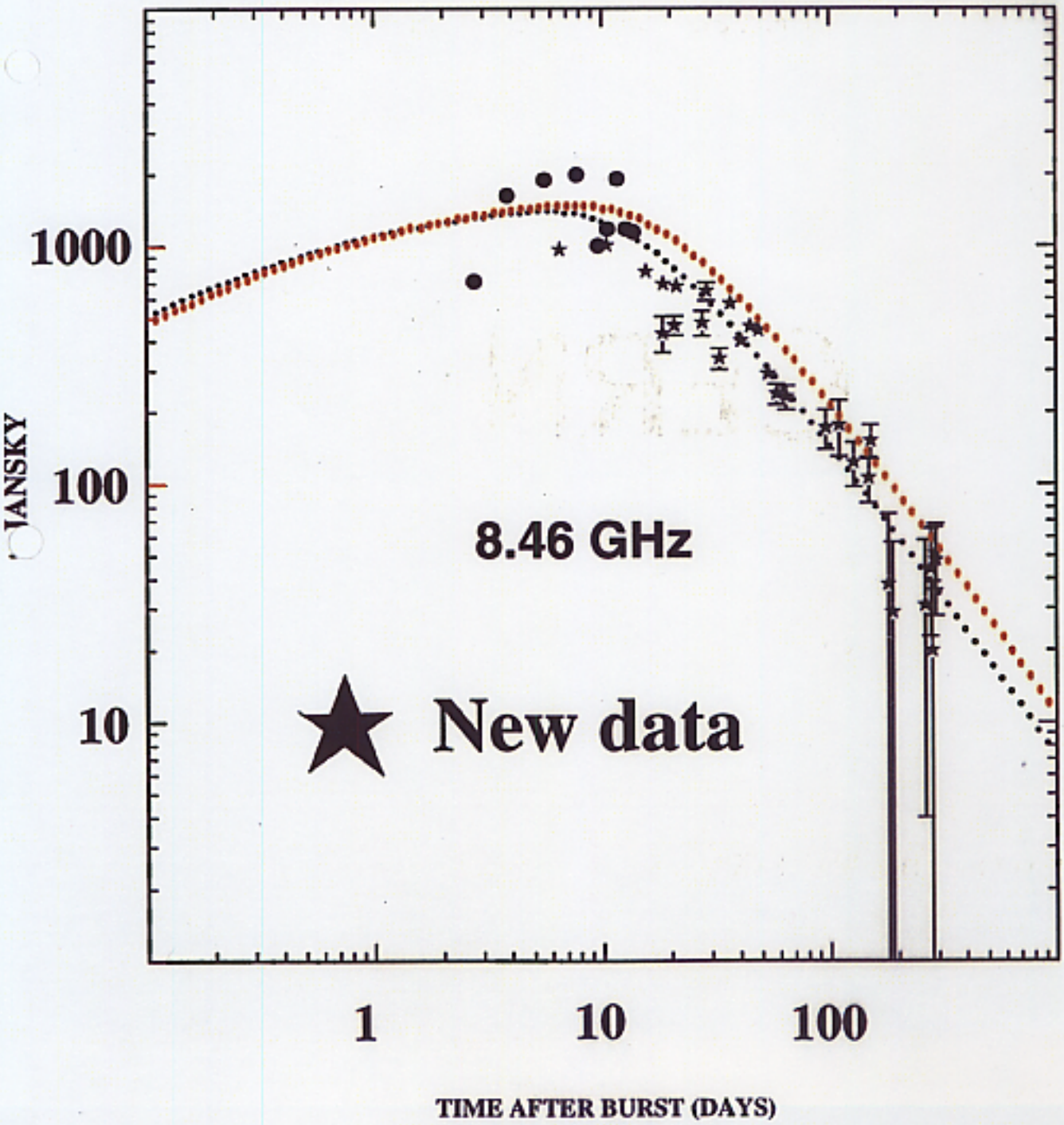
# CB-model fit to the early data

# (and prediction for t > 12 d)



# CB-model fit to the early data (and prediction for t > 12 d)

# New fit to all data



| Parameter | DDD1 | DDD2 | DDD3 |
|---|---|---|---|
| $\theta$ [mrad] | 0.100 | 0.111 | 0.103 |
| $\gamma_0$ | 1034 | 1034 | 1089 |
| $x_\infty$ [Mpc] | 1.357 | 1.014 | 1.382 |
| $\nu_a$ [MHz] | **** | 103 | 98 |

# Ap J Letters

## Ref #1

- There is nothing new in this manuscript
- If Dado et al. are right, then surely the referee of Galama et al. will catch this gross oversight and have it fixed in the revised submission.

## Ref #2

The claim that the CB model works better than the standard fireball models is not made in a way that would convince any objective reader

## Editor

I make no claim to infallibility...

# Mission Impossible

# GRBS ARE ASSOCIATED WITH SUPER-NOVAE

O[100]* CLOSER/OTHERS

SIMILAR FLUENCE

+SN1998bw

Table I - Gamma-ray bursts of known redshift

| GRB | z | $D_L$ | $F_\gamma$ | $E_\gamma$ | R[HG] |
|---|---|---|---|---|---|
| 970228[1] | 0.695 | 4.55 | 1.1 | 0.22 | 25.2[18] |
| 970508[2] | 0.835 | 5.70 | 0.32 | 0.07 | 25.7[19] |
| 970828[3] | 0.957 | 6.74 | 9.6 | 2.06 | |
| 971214[4] | 3.418 | 32.0 | 0.94 | 2.11 | 25.6[20] |
| 980425[5] | .0085 | .039 | 0.44 | 8.1E-6 | 14.3[21] |
| 980613[6] | 1.096 | 7.98 | 0.17 | 0.61 | 24.0[22] |
| 980703[7] | 0.966 | 6.82 | 2.26 | 1.05 | 22.6[23] |
| 990123[8] | 1.600 | 12.7 | 26.8 | 19.80 | 23.9[24] |
| 990510[9] | 1.619 | 12.9 | 6.55 | 5.00 | 28.5[25] |
| 990712[10] | 0.434 | 2.55 | 6.5 | 0.53 | 21.8[26] |
| 991208[11] | 0.70 | 4.64 | 10.0 | 1.51 | 24.4[27] |
| 991216[12] | 1.020 | 7.30 | 19.4 | 5.35 | 24.8[28] |
| 000131[13] | 4.500 | 44.4 | 4.2 | 11.60 | 27.8[29] |
| 000301c[14] | 2.040 | 17.2 | 0.41 | 0.46 | 28.0[30] |
| 000418[15] | 1.119 | 8.18 | 2.0 | 0.82 | 23.9[31] |
| 000926[16] | 2.066 | 17.4 | 2.20 | 10.54 | 25.6[32] |
| 010222[17] | 1.474 | 11.5 | 12.0 | 7.80 | > 24[33] |

**Comments:** z: Redshift. $D_L$: Luminosity distance in Gpc, for $\Omega_m = 0.3$, $\Omega_\Lambda = 0.7$ and $H_0 = 65\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$. $F_\gamma$: BATSE $\gamma$-ray fluences in units of $10^{-5}$ erg cm$^{-2}$. $E_\gamma$: (Equivalent spherical) energy in units of $10^{53}$ ergs corrected for galactic extinction. R[HG]: R-magnitude of the host galaxy, except for GRB 990510, for which the V-magnitude is given.

IN FIREBALL MODS.

GRB 980425

IS EXCEPTIONAL

SN 1998bw

IS EXCEPTIONAL

YET!

USED AS POSSIBLE

"STANDARD CANDLE"

FOR SNe ASSOCIATED

WITH OTHER NOT-EXCEPTIONAL GRBs!

# SN1998bw/GRB980425

~~The standard lore~~

The CB model

## 1 GRB is NORMAL

100 x closer than average

Yet, similar fluence

It was viewed sideways

$\theta \sim 8$ mrad

$\gamma_0 \sim 495$

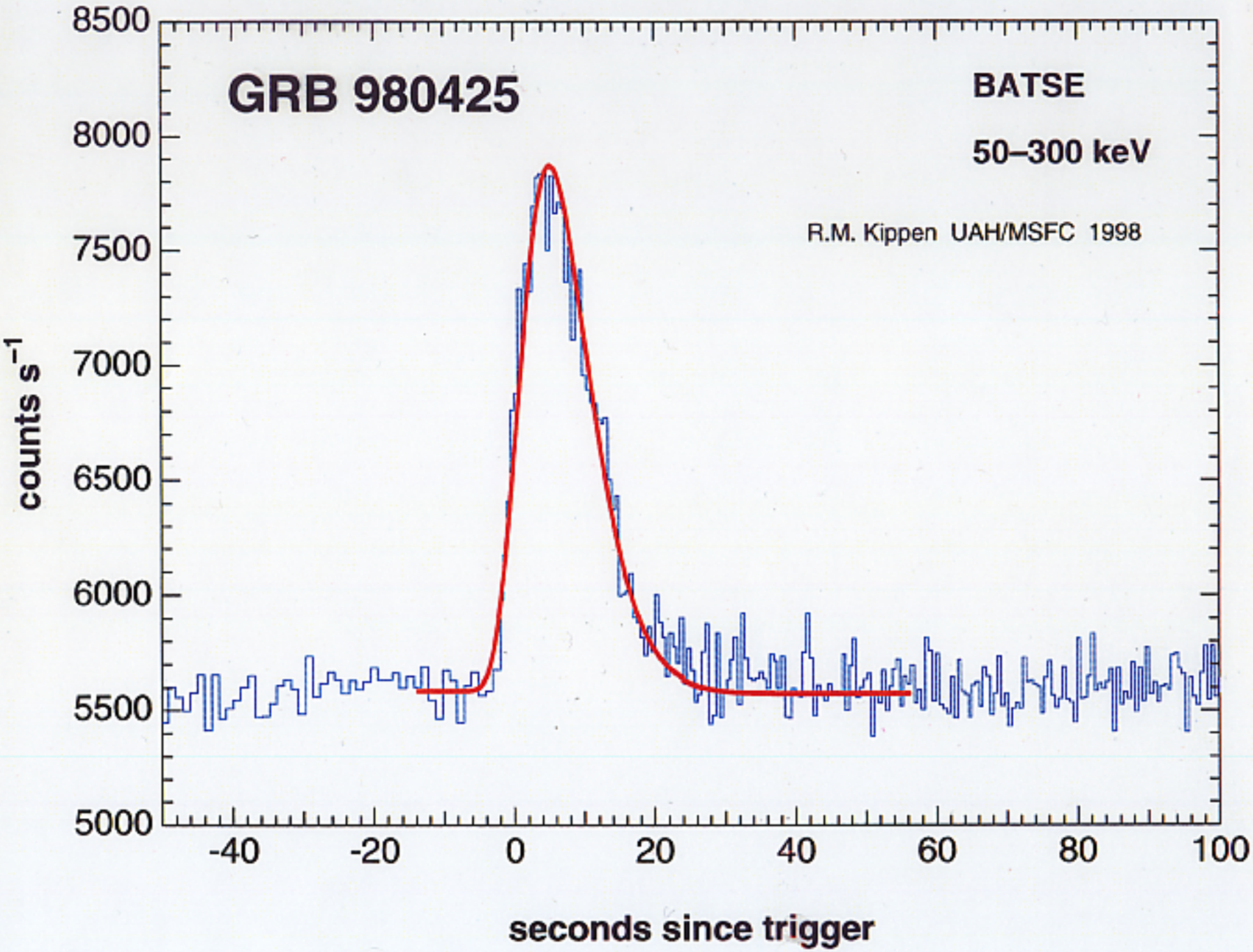
## 2 SN is NOT peculiar

- Radio emission 20/40 x other SNe, peaking earlier ----> v(SNS) ~ (2/3) c
- X-rays steady for 100d! (instead of falling abruptly)

These emissions are the CB's AG

## Conclusions

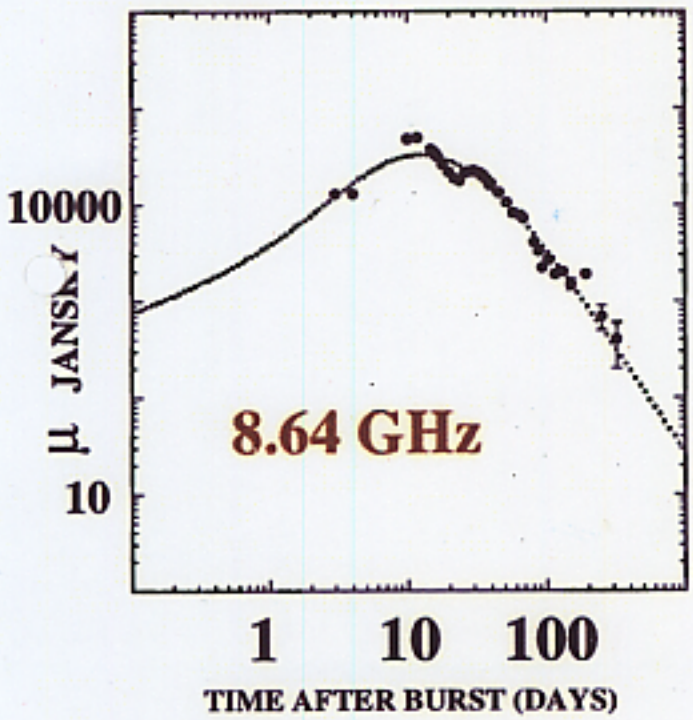
- SN is...NOT a "hypernova"!!
- GRB ~~not~~ understood ---> such a SN ~~not~~ possibly assoc. w. other GRBs

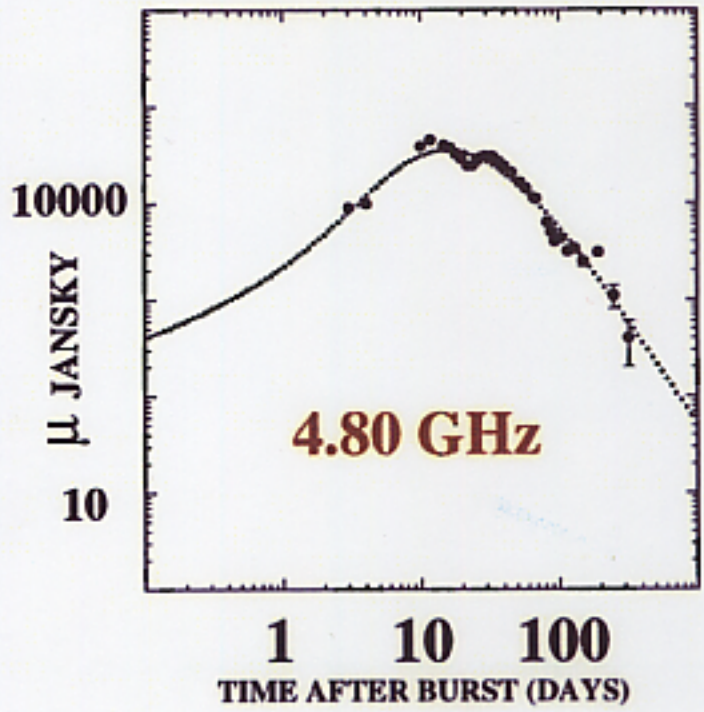

GRB 980425
BATSE
50–300 keV
R.M. Kippen UAH/MSFC 1998
counts s$^{-1}$
8500
8000
7500
7000
6500
6000
5500
5000
-40
-20
0
20
40
60
80
100
seconds since trigger

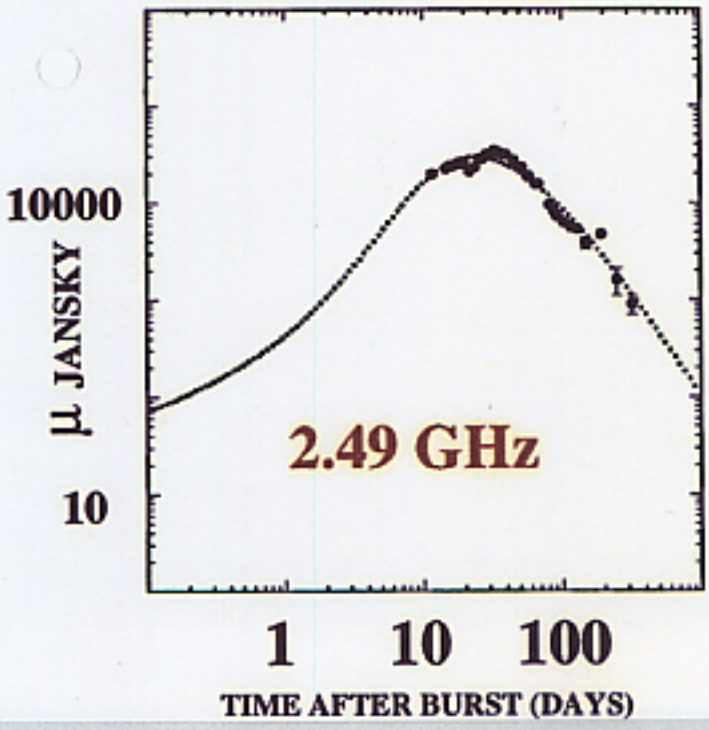
# GRB 980425

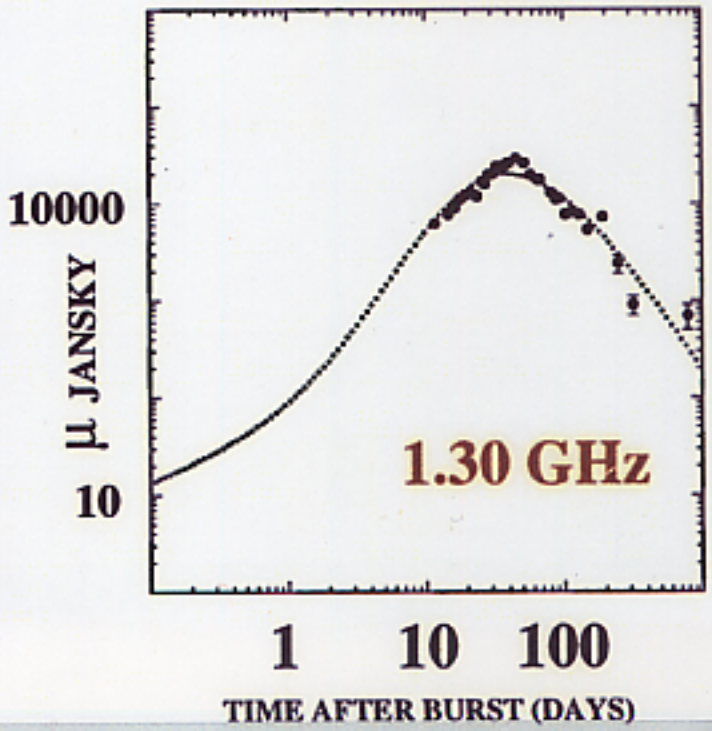
## z=0.0085

# CB's RADIO AFTERGLOW



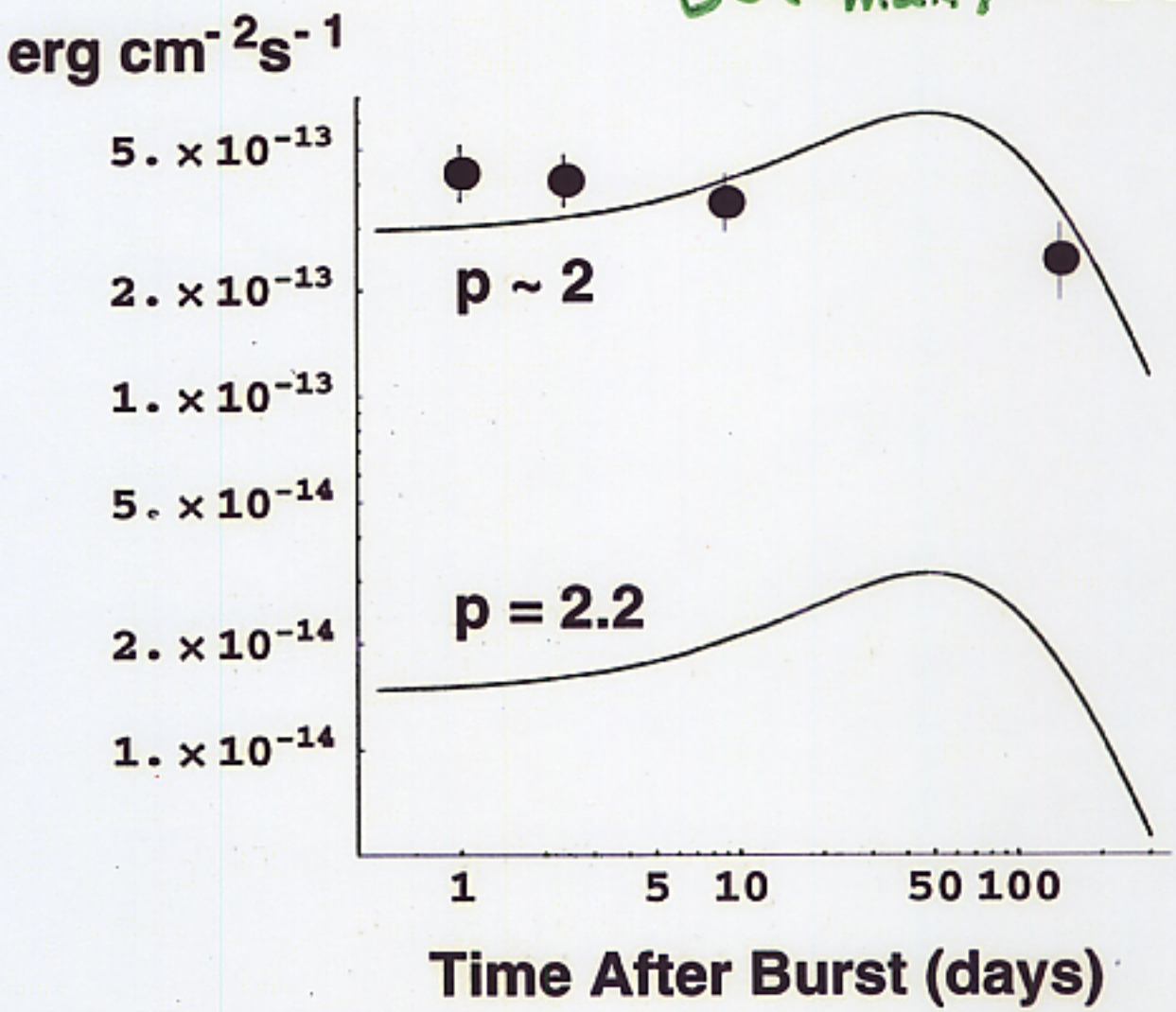



$$\delta = \frac{2\gamma(t)}{1+[\theta\gamma(t)]^2}$$

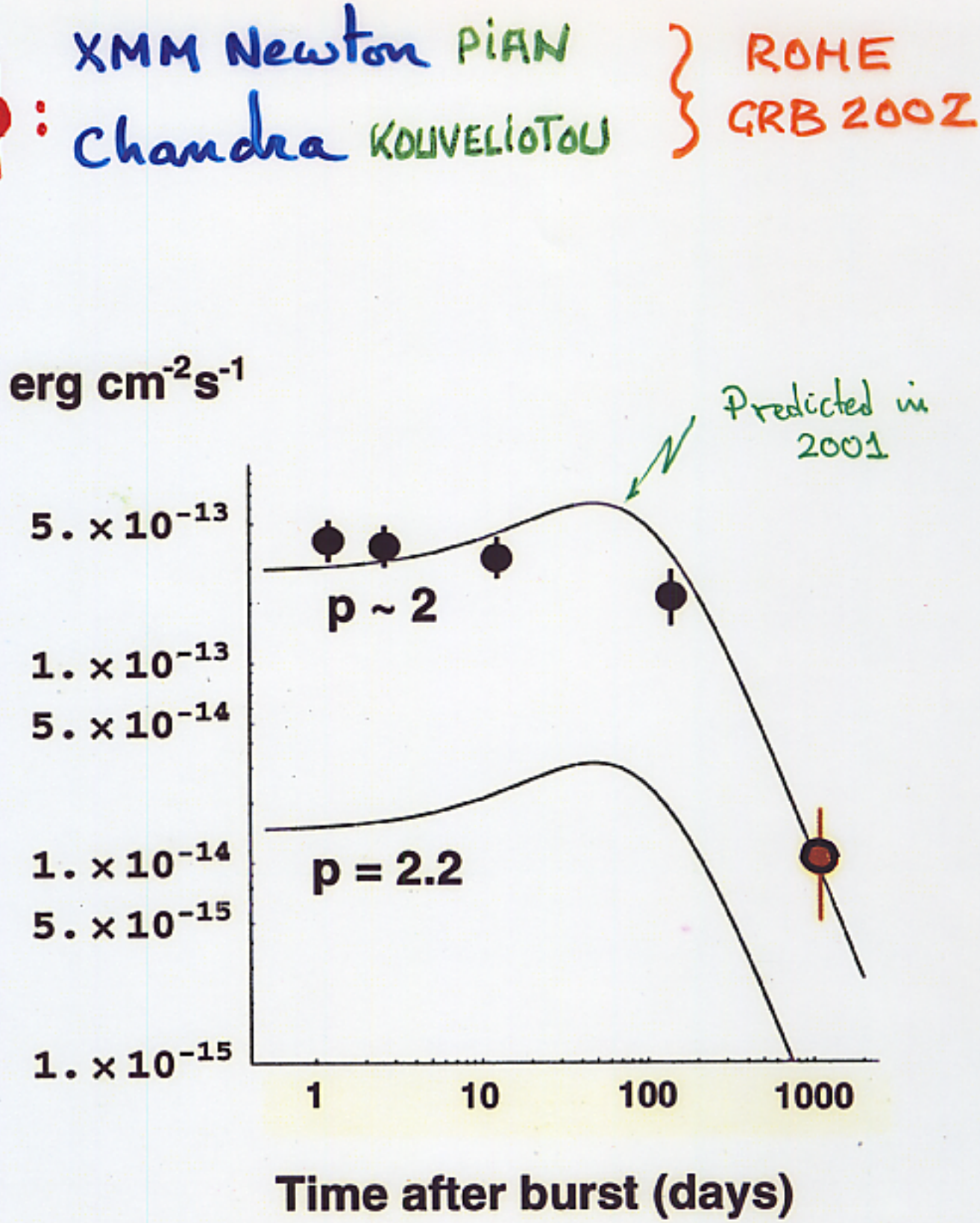
$$F_\nu^{obs} \propto \delta^3 \left(\frac{\delta}{\nu}\right)^{1.1}$$

$$\theta\gamma(t_{max}) \sim O(1)$$




TYPICALLY $\theta\gamma_0 \sim 0.4$

GRB 980425 $\theta\gamma_0 \sim 4$


XMM Newton PIAN
Chandra KOUVELIOTOU
ROHE
GRB 2002
erg cm$^{-2}$s$^{-1}$
Predicted in 2001
5. × 10$^{-13}$
1. × 10$^{-13}$
5. × 10$^{-14}$
1. × 10$^{-14}$
5. × 10$^{-15}$
1. × 10$^{-15}$
p ~ 2
p = 2.2
1
10
100
1000
Time after burst (days)

# SN 1998bw

as a

STANDARD CANDLE SN

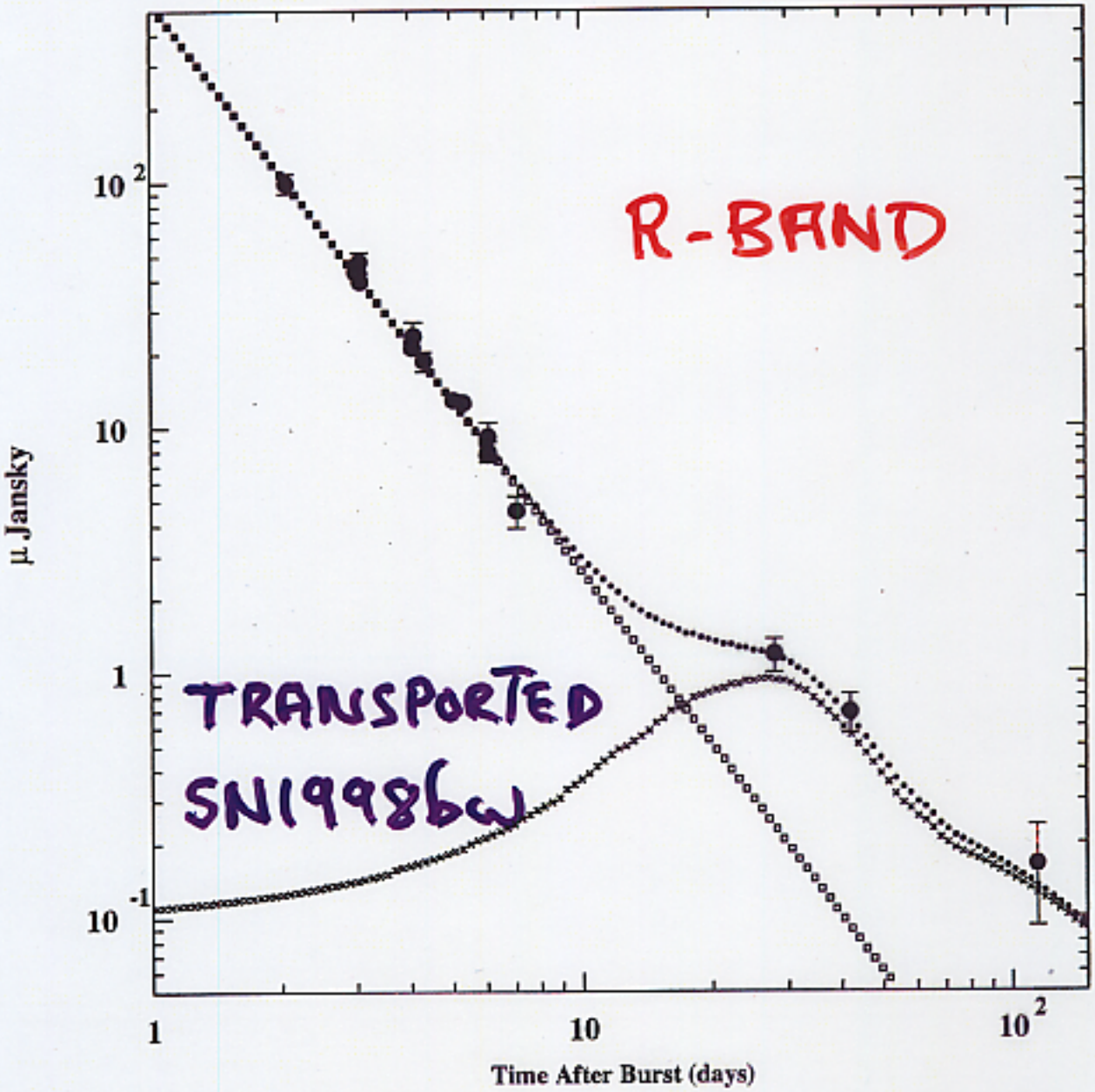
ASSOCIATED with

# GRBs

(DAR)

991208

G-SUBTR.

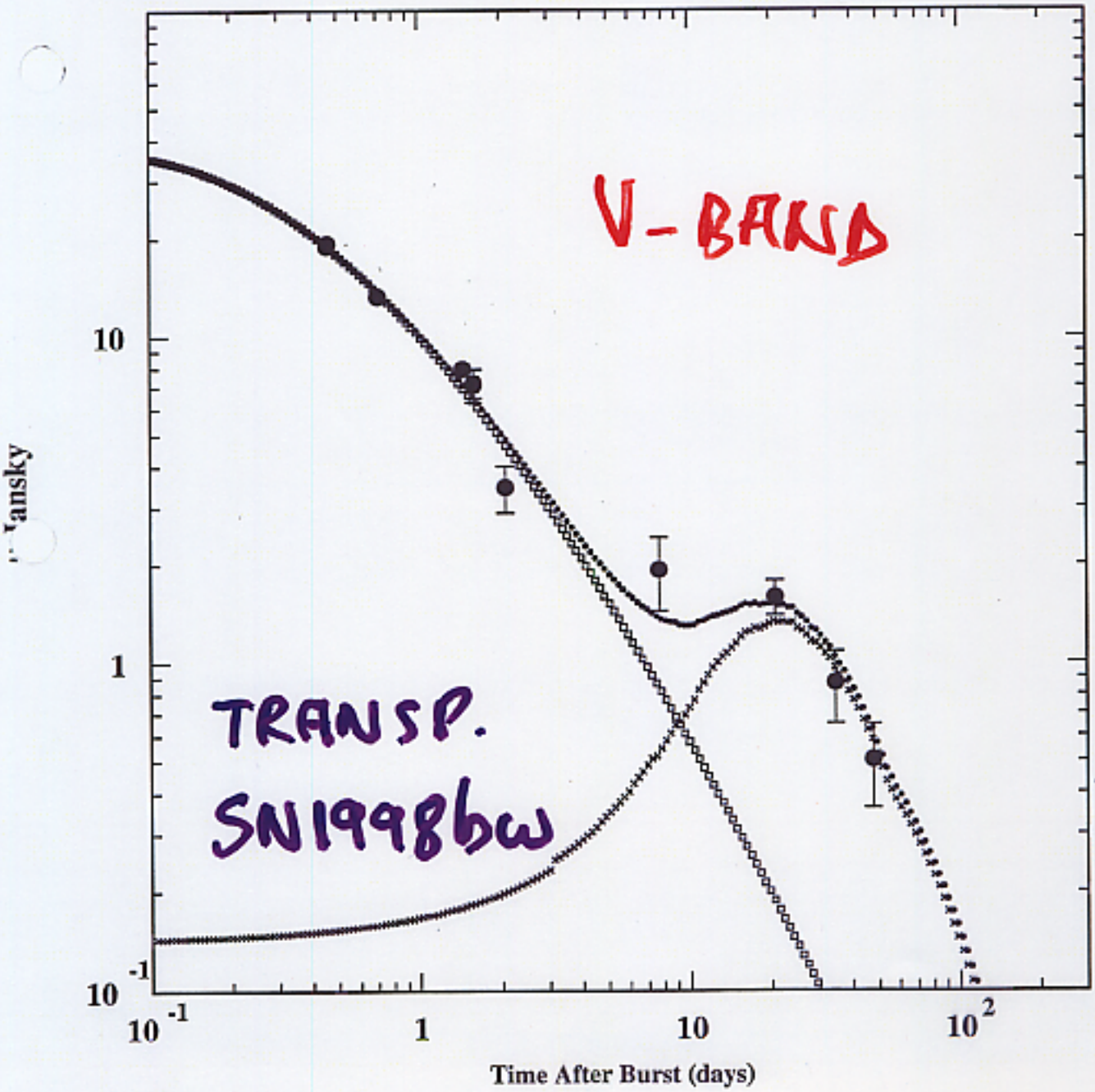



Z=0.706

990712

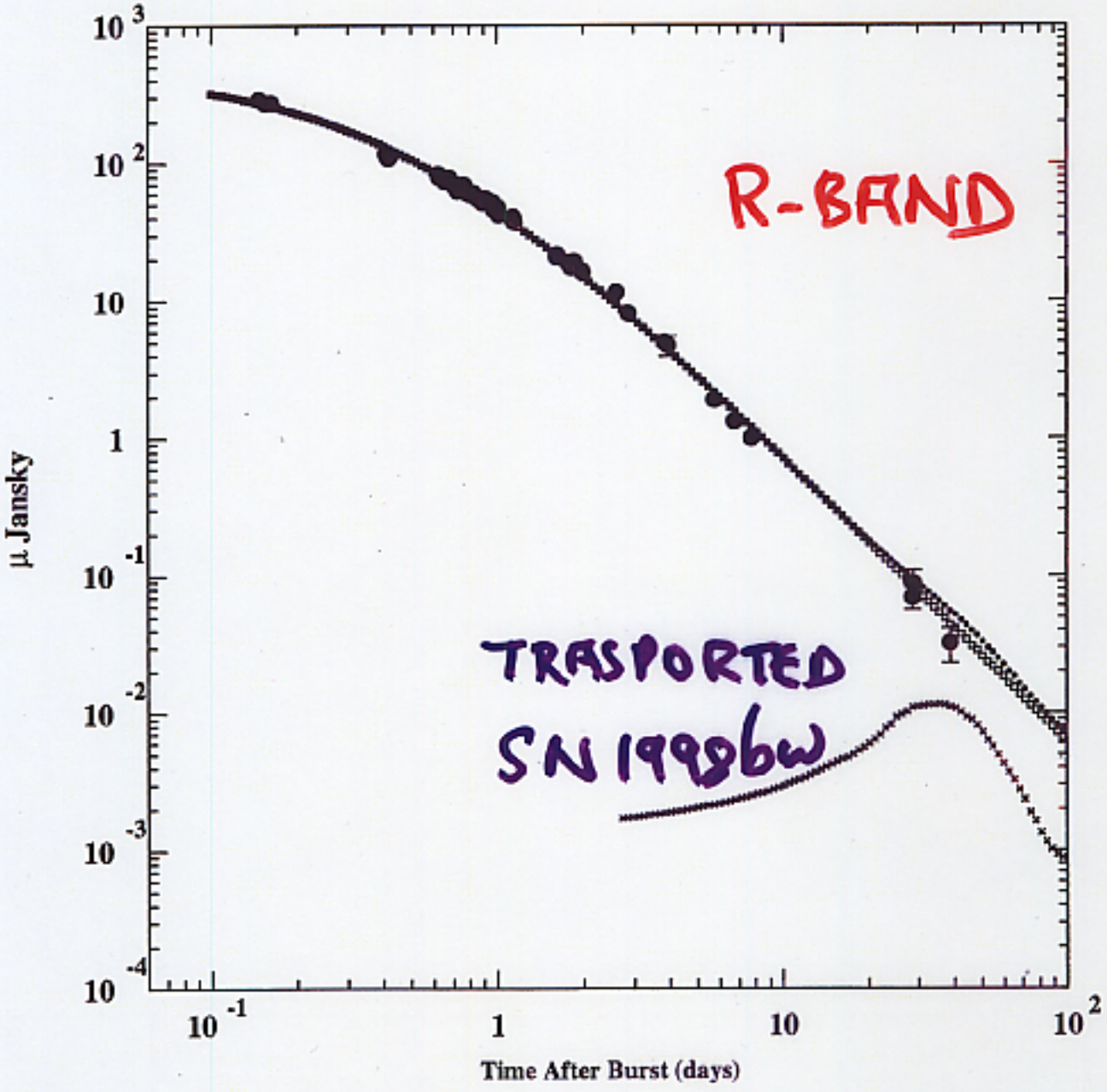
Z = 0.434

G SUBTRACTED



990510

G-SUBTRACTED




$z = 1.619$

[redacted] DDD [redacted] 2002 (astro-ph/0107367)

SCORE OF GRBs WITH KNOWN Z

$\forall$ CASES $\supset$ SN

COULD BE SEEN

IT WAS SEEN

$\sim 1/2$

$\forall$ CASES $\supset$ SN

COULD NOT BE SEEN

IT WAS NOT SEEN

$\sim 1/2$

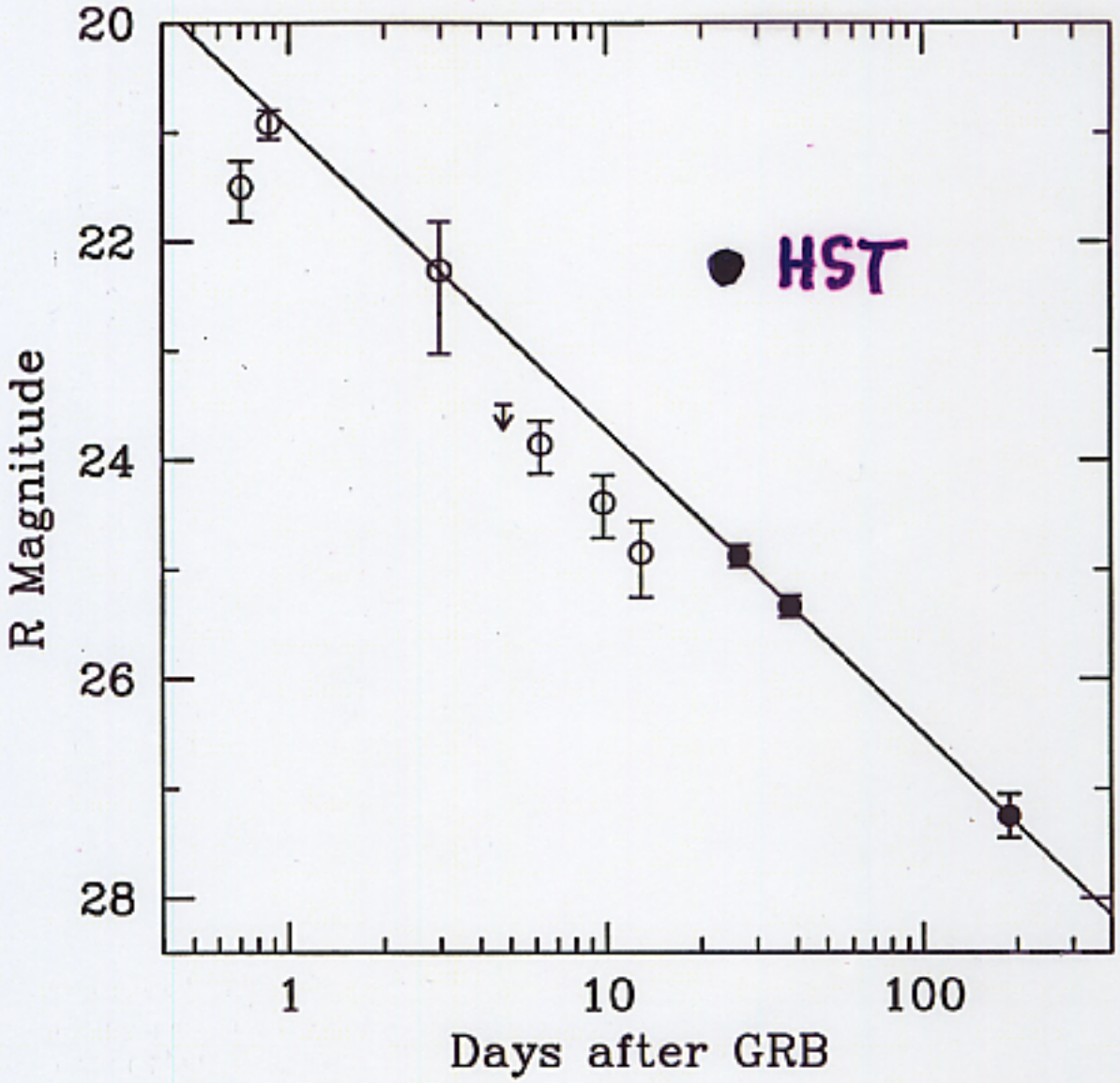
# SNe

ARE IN THE

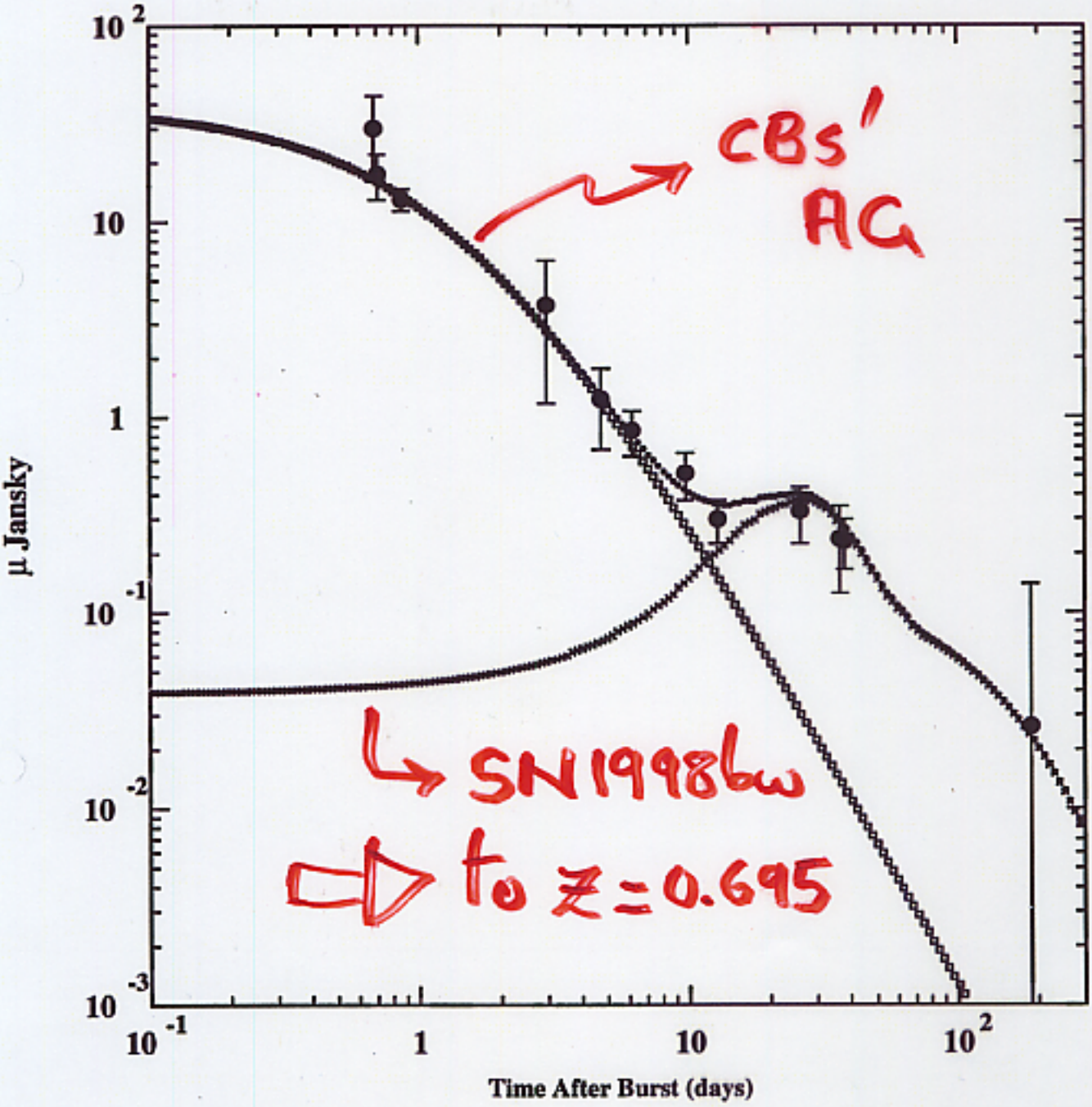
OF THE

# BEHOLDER

R-BAND
970228



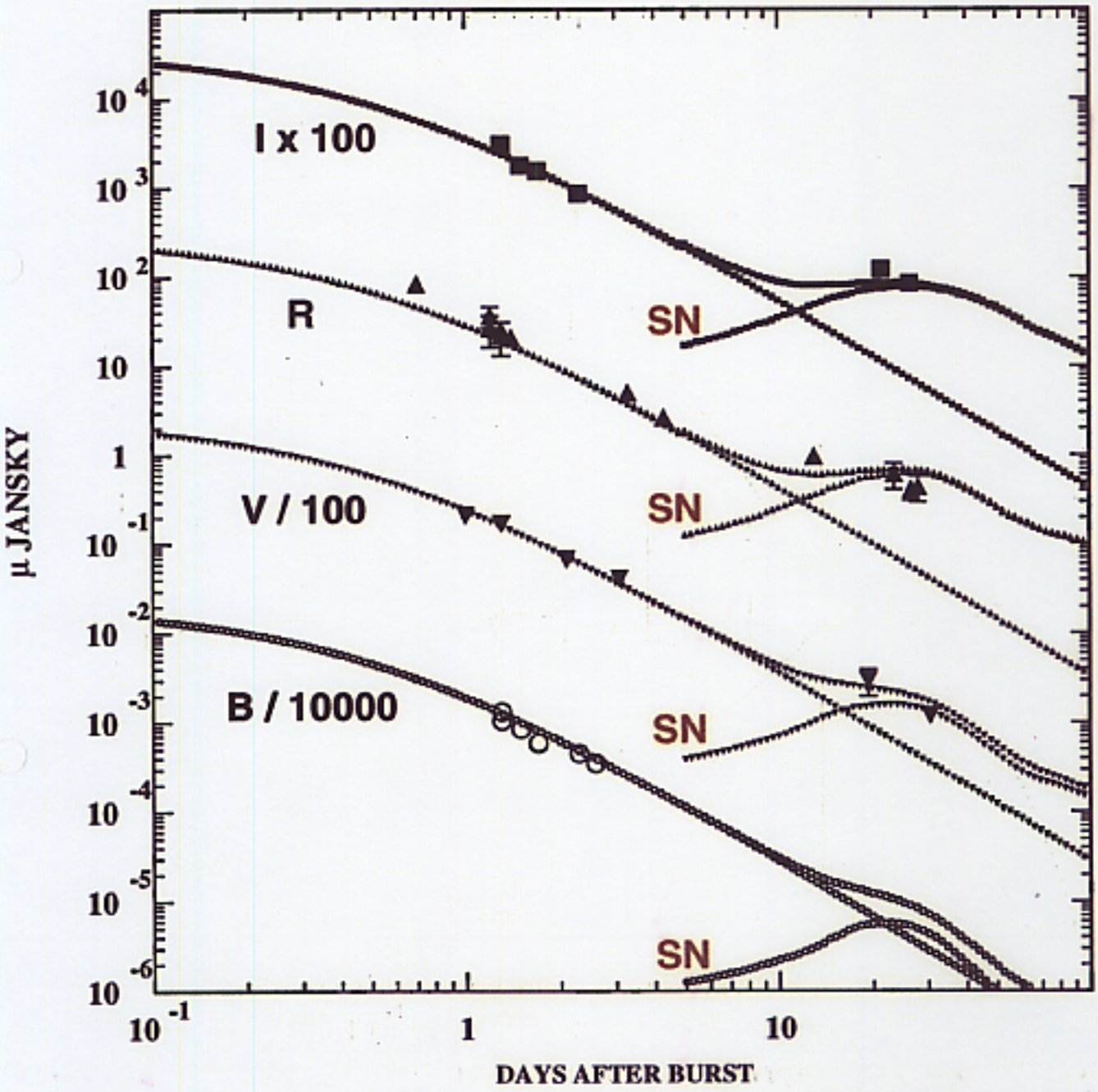
R. BAND
970228



POST-
DICTIONS

PRE-
DIC-
TIONS

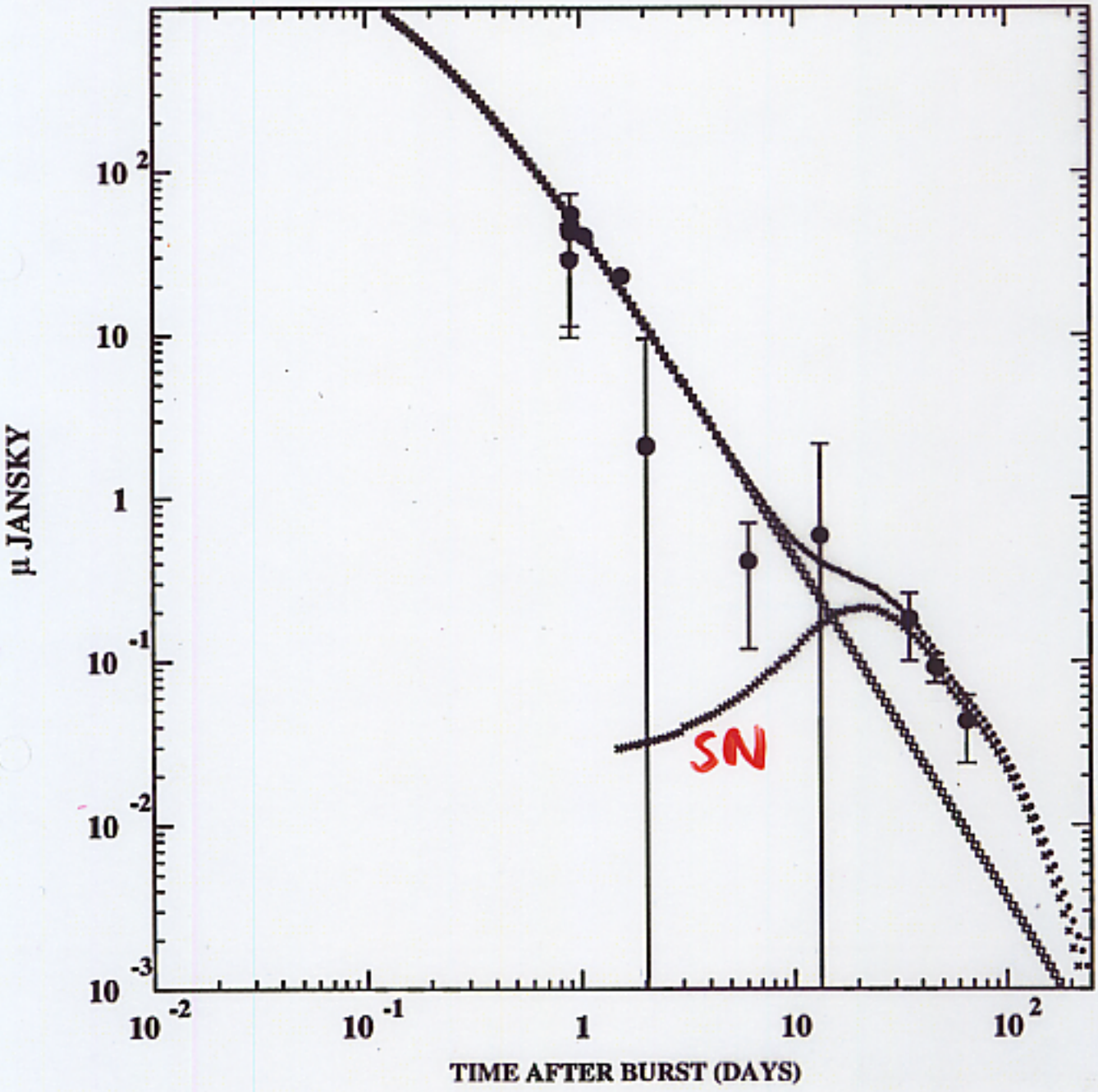
GRB 020405 Z=0.69




G-SUBTRACTED

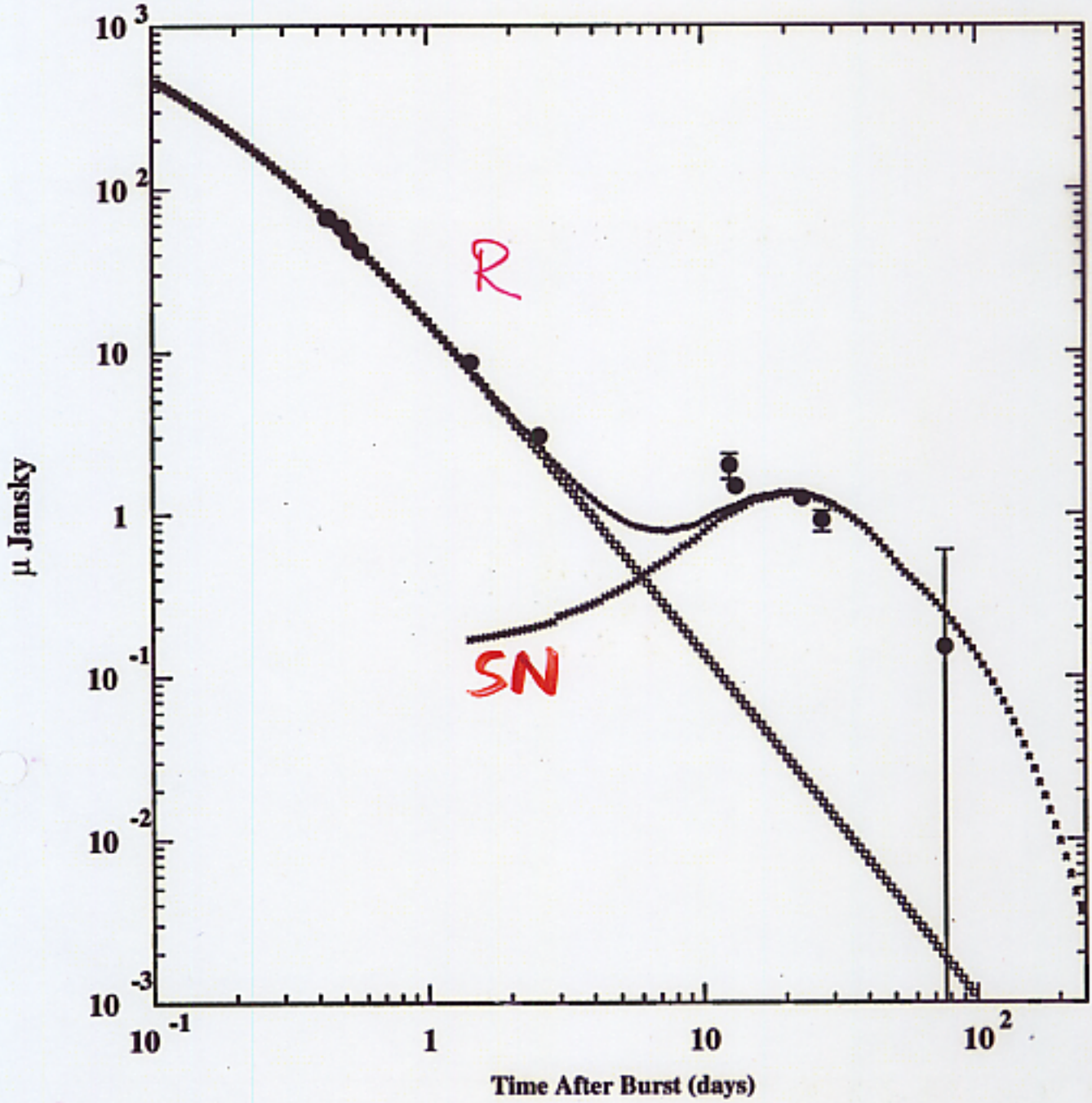
R-BAND

GRB 010921




Z = 0.451

GRB 011121

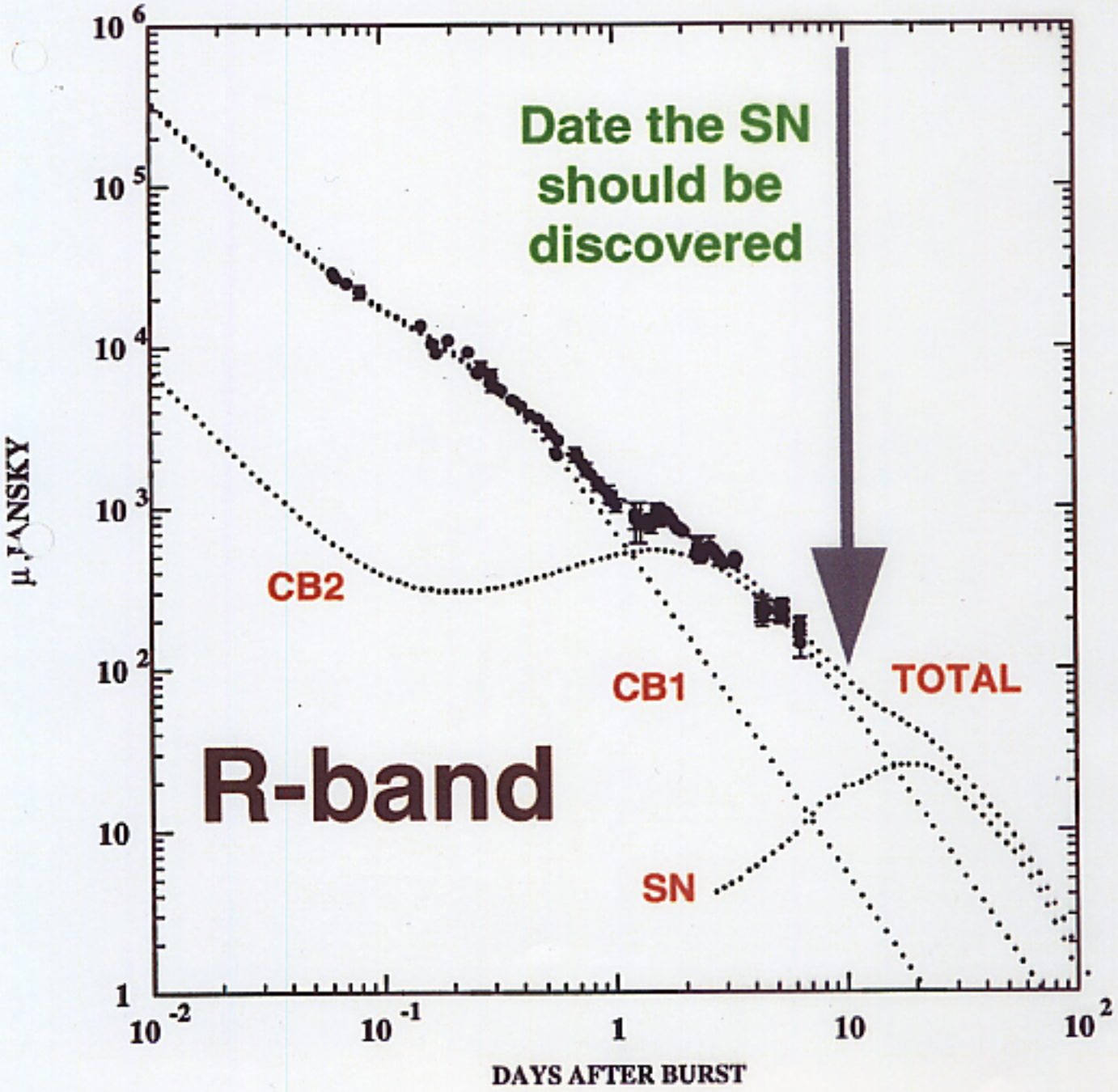



$z = 0.36$

G-SUBTRACTED

# GRB 030329

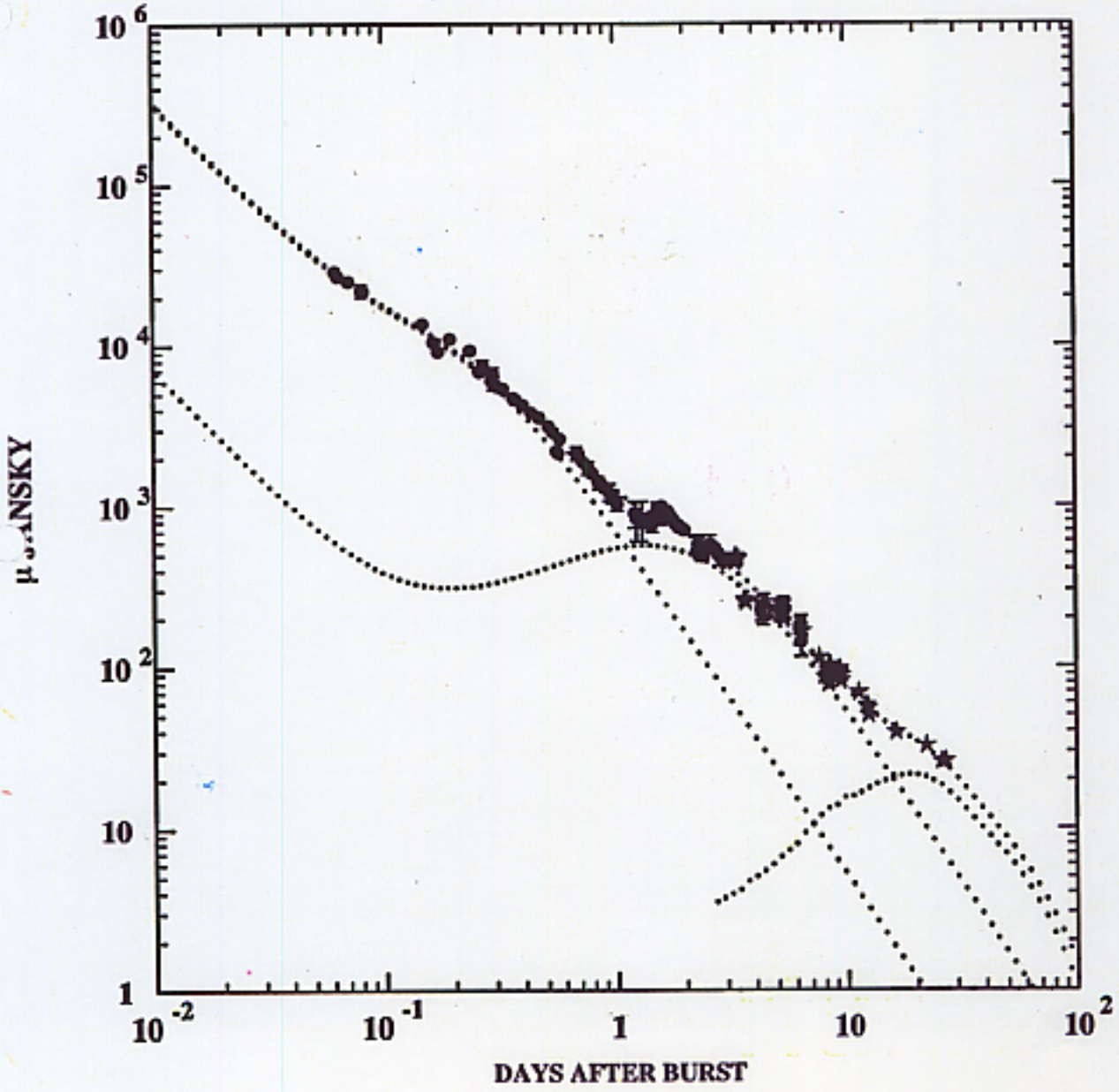
## z = 0.168



FROM BETTER EARLY AG SPECTRA WE CAN NOW DEDUCE THE HOST-GALAXY EXTINCTN.

SN → 0.75 * SN

★ NEW DATA

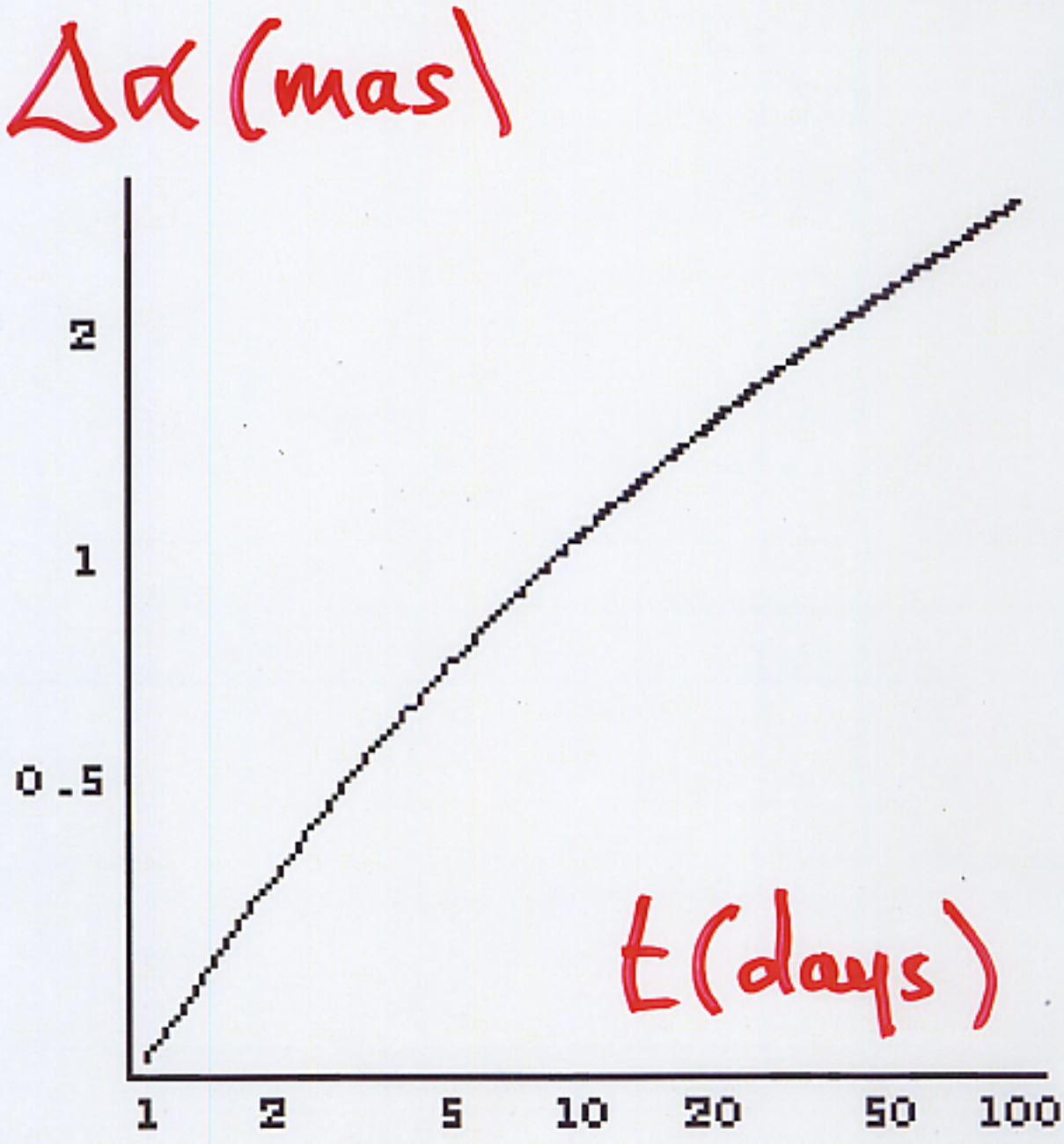


# other CB-model predictions

- H.E. $\nu$'s hard to see
- GVs observable

  (A. ORI and E. SIGALIS)
  PRD 64 (2001)
- X-ray lines not ``Fe", predictable, moving
- CBs superluminal

GRB 030329



NINELSON AND PAPALIOLIOS



# SN1987A

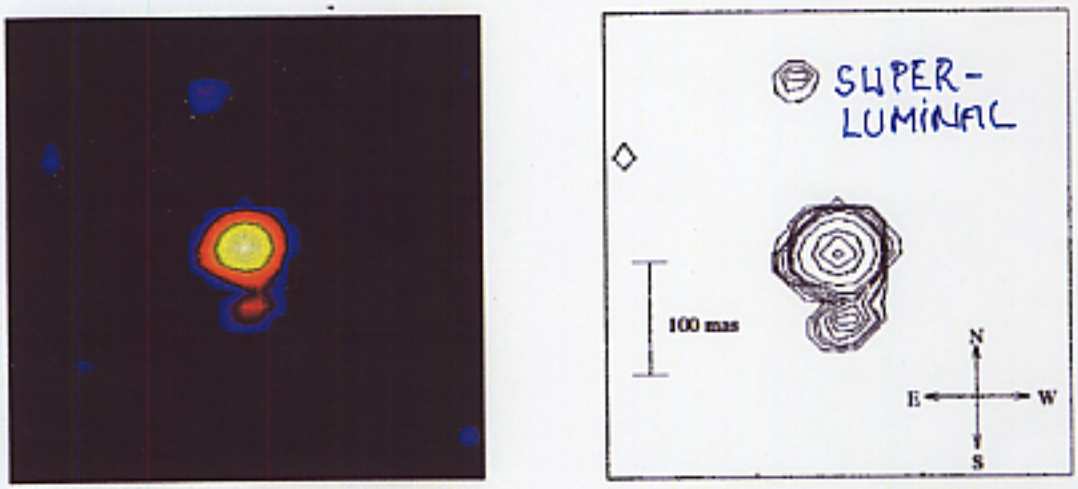
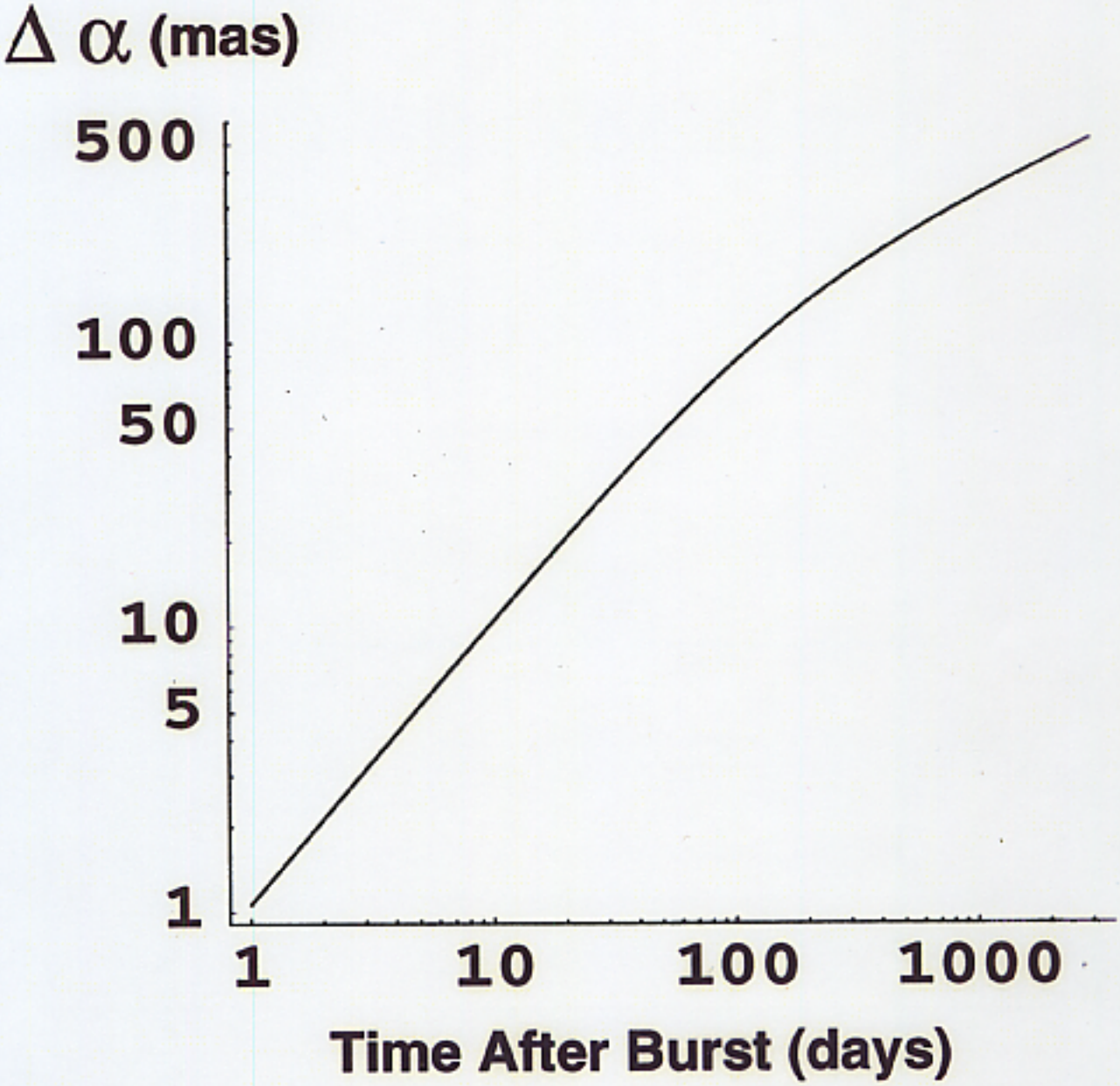



Fig. 1.— New reconstructed image (left) and contour plot (right) of a 300 mas field around SN1987A from speckle data recorded with a 10 nm Wide Filter centered at 653.6 nm. Note that two of the noise spikes (in the lower left and right) do not show up in the contour plot because their intensity falls below the lowest contour level (1%).

$$\frac{v}{c} = 0.8 \pm^{0.31}_{0.17}$$

$$\theta = 54 \pm 3^\circ$$

GRB 980425/SN 1998bw



# The CB Model's

predictions,

for ALL times, for ALL measured

OPTICAL, X-RAY, RADIO

AFTERGLOWS,

are

- Univocal (no multi-choice)
- Explicit
- Analytical in fair approxims
- Very simple and

••• VERY SUCCESSFUL

and... the parameter values

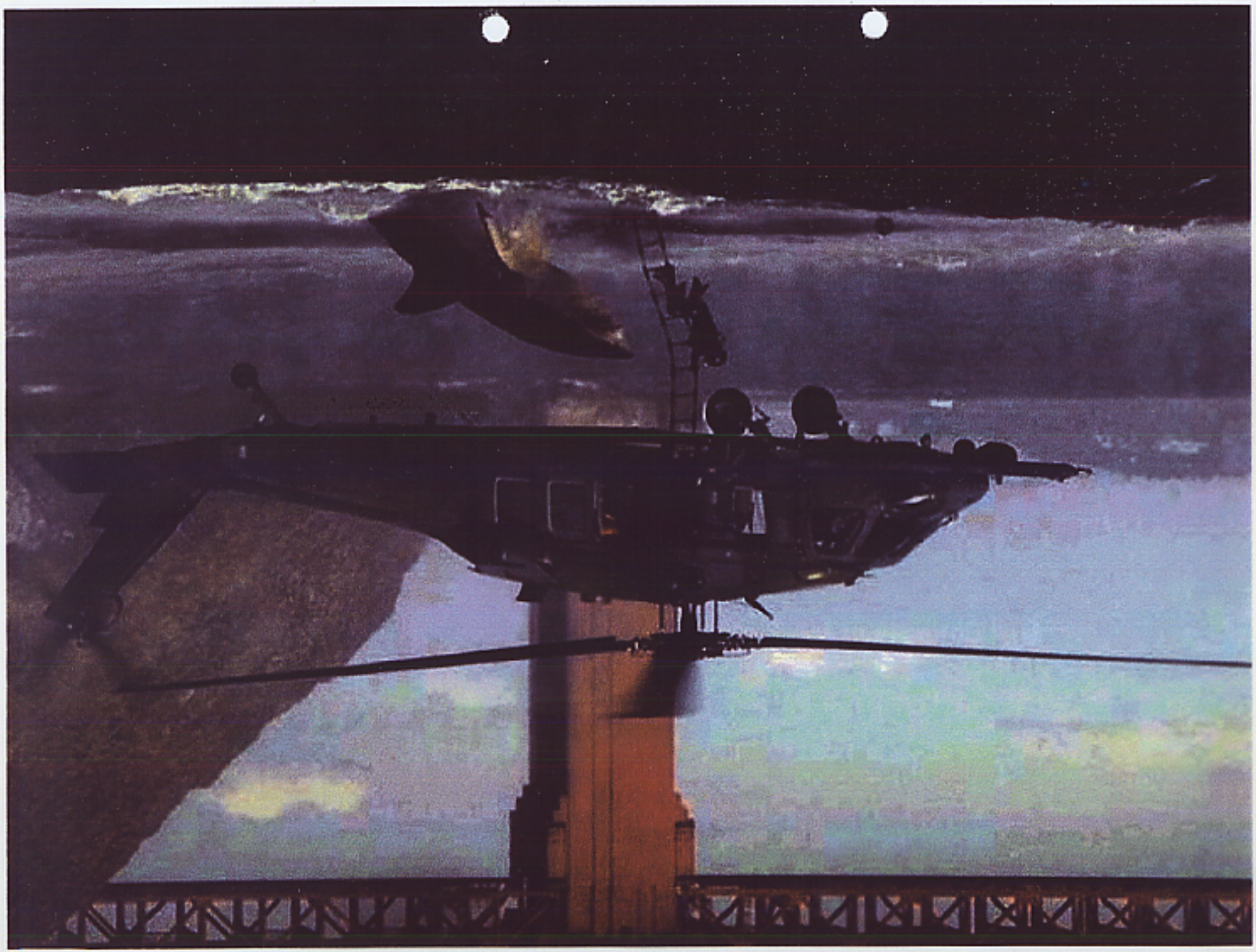
GRB's $\gamma$ rays

The

is

# Predictive

# FALSIFIABLE



# A Unified Theory of High Energy Astro - $\Phi$

Arnon Dar, Reiner Plaga, Shlomo Dado, ADR

## CBs are:

Quasar emissions

$\mu$ – Quasar emissions

## CBs explain:

- Neutron-S natal kicks
- Cosmic Rays
- GBR: $\gamma$ "Background" radiat.
- GRBs: Gamma Rays Bursts
- X-ray Bursts
- Cluster "Cooling Flows"