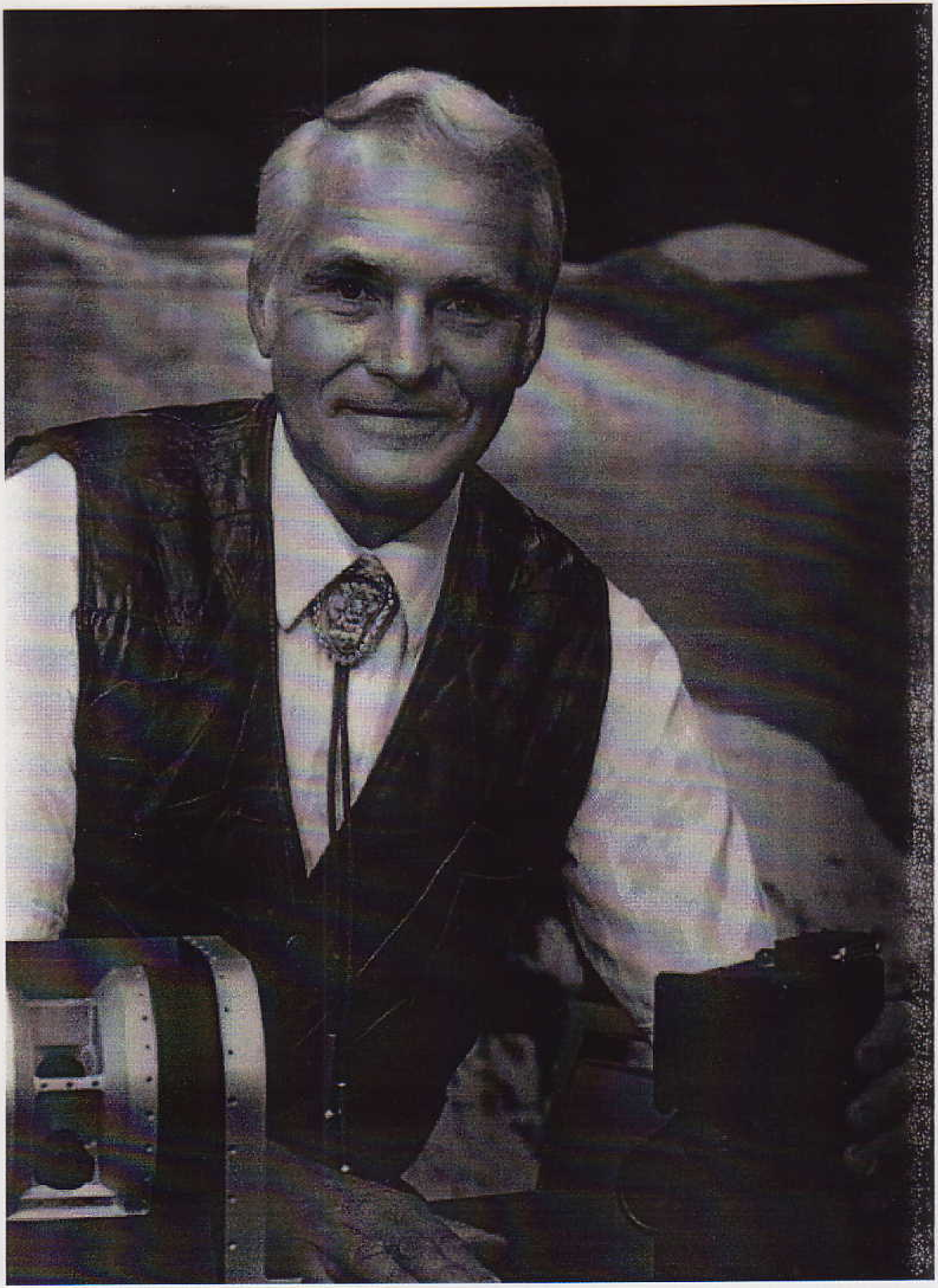
Physical Sciences 120
Winter 2005

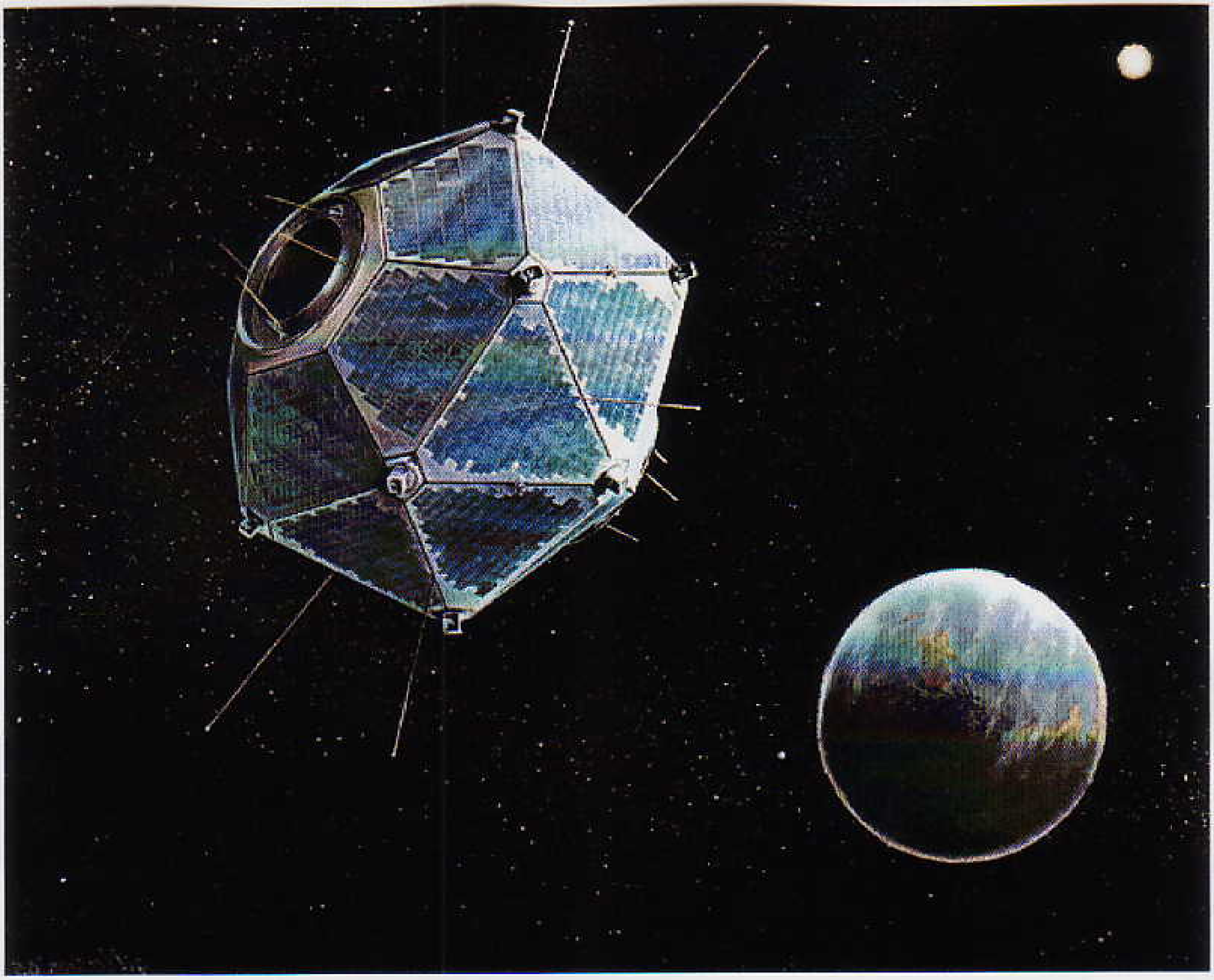
Origin of the Universe,
and How We Know

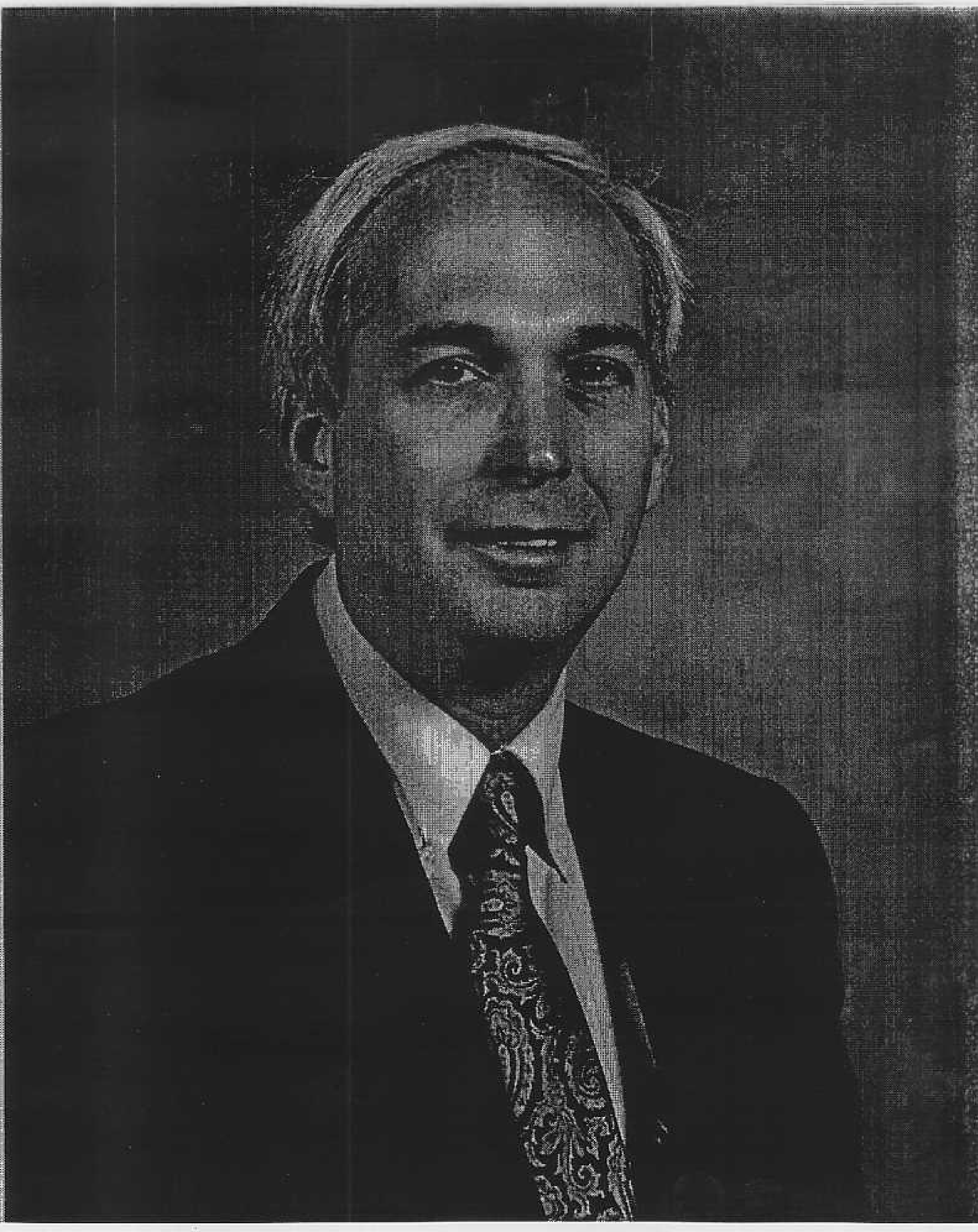
Don Q. Lamb

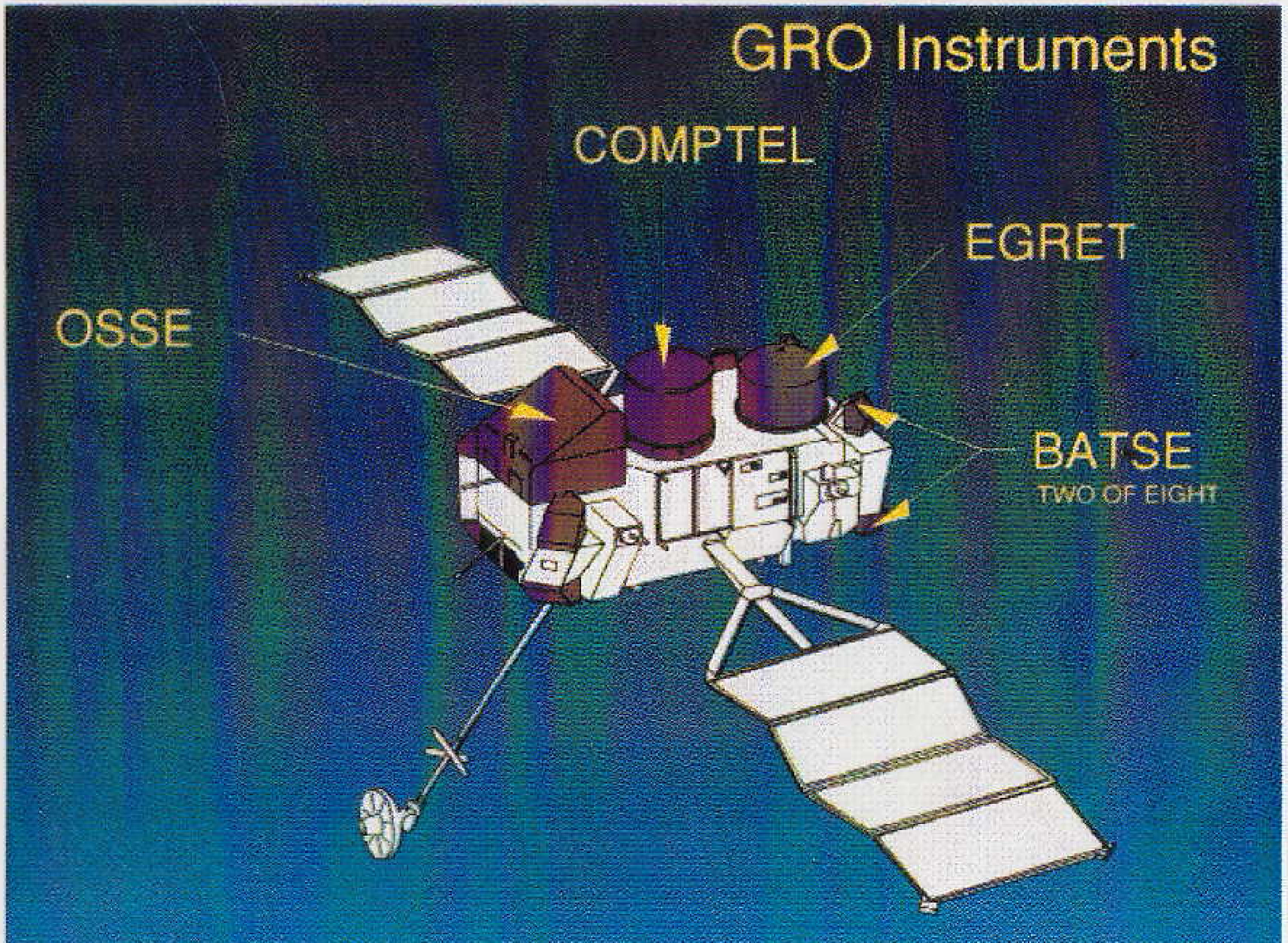
Lecture 21

GAMMA-RAY BURSTERS

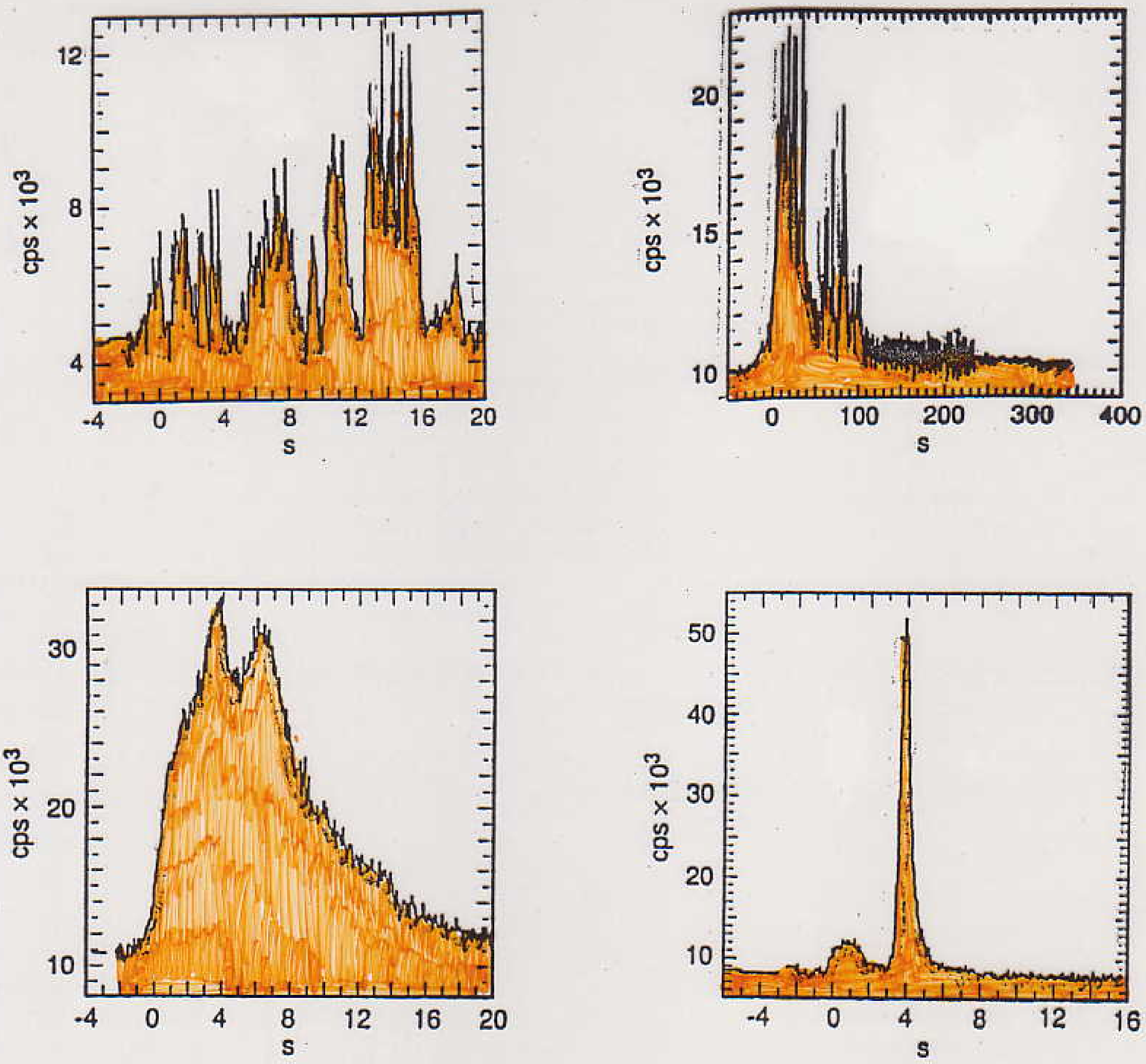




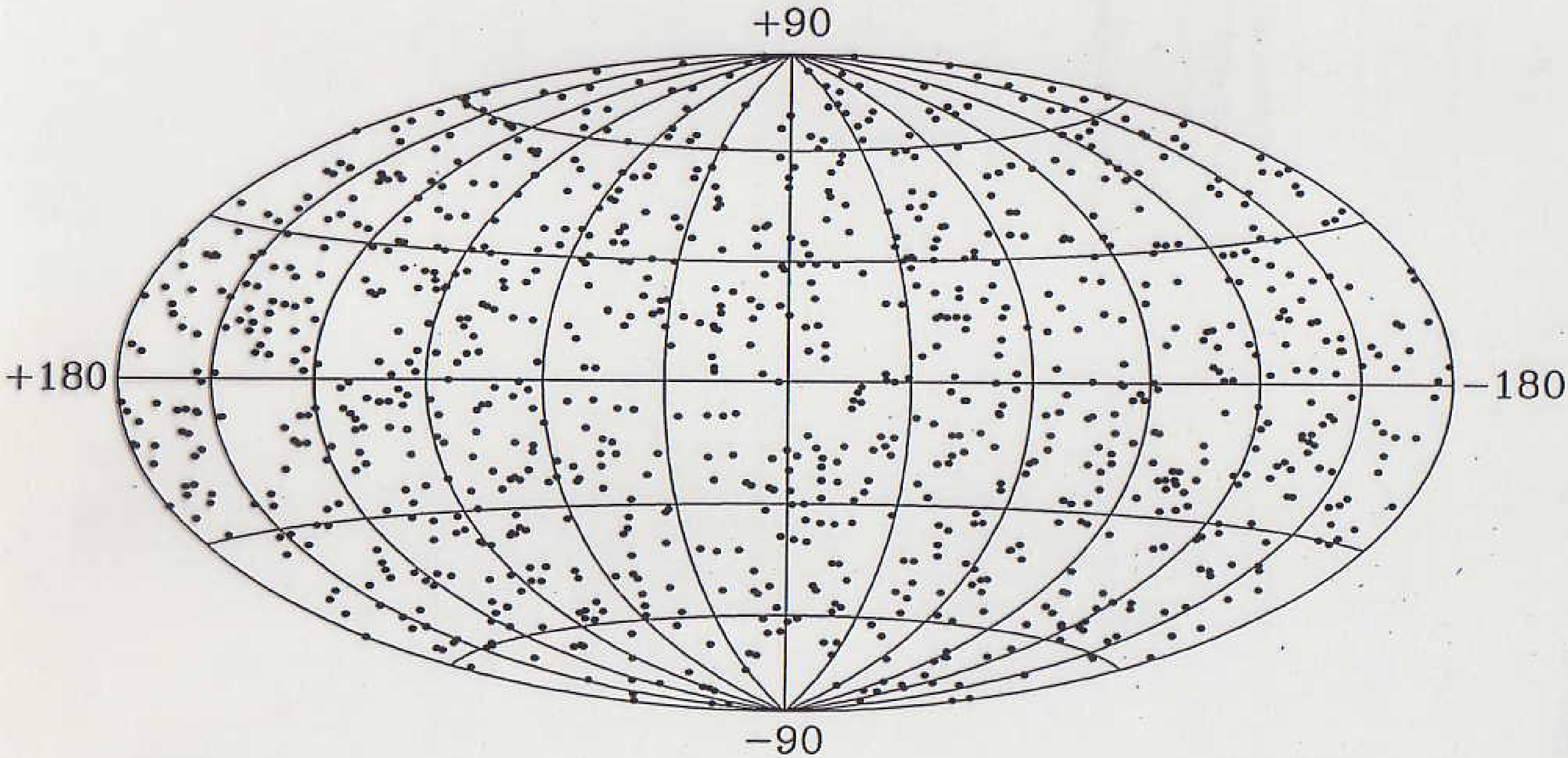


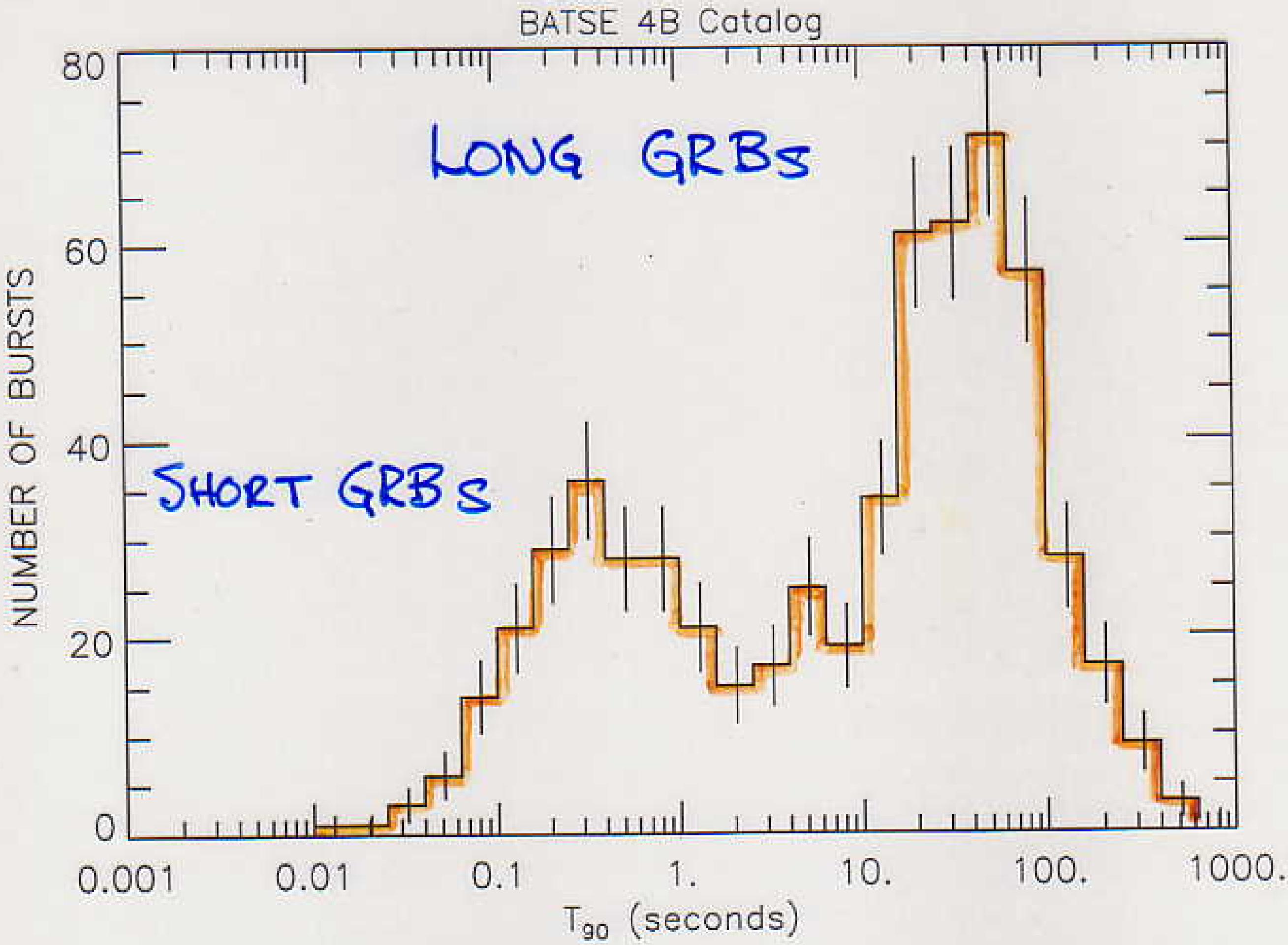

GRO Instruments
COMPTEL
EGRET
OSSE
BATSE
TWO OF EIGHT

FISHMAN ET AL. (1992)



MEEGAN ET AL. (1995)





BATSE 4B Catalog
LONG GRBs
SHORT GRBs
NUMBER OF BURSTS
0
20
40
60
80
0.001
0.01
0.1
1.
10.
100.
1000.
T_{90} (seconds)

★ WHAT ARE THEY?

- ★ BRIEF BURSTS OF HIGH-ENERGY RADIATION, LASTING $10^{-3}-10^{3}$ s
- ★ ALMOST ALL (95%) OF LIGHT COMES OUT AT GAMMA-RAY ENERGIES
- ★ SKY DISTRIBUTION IS ISOTROPIC

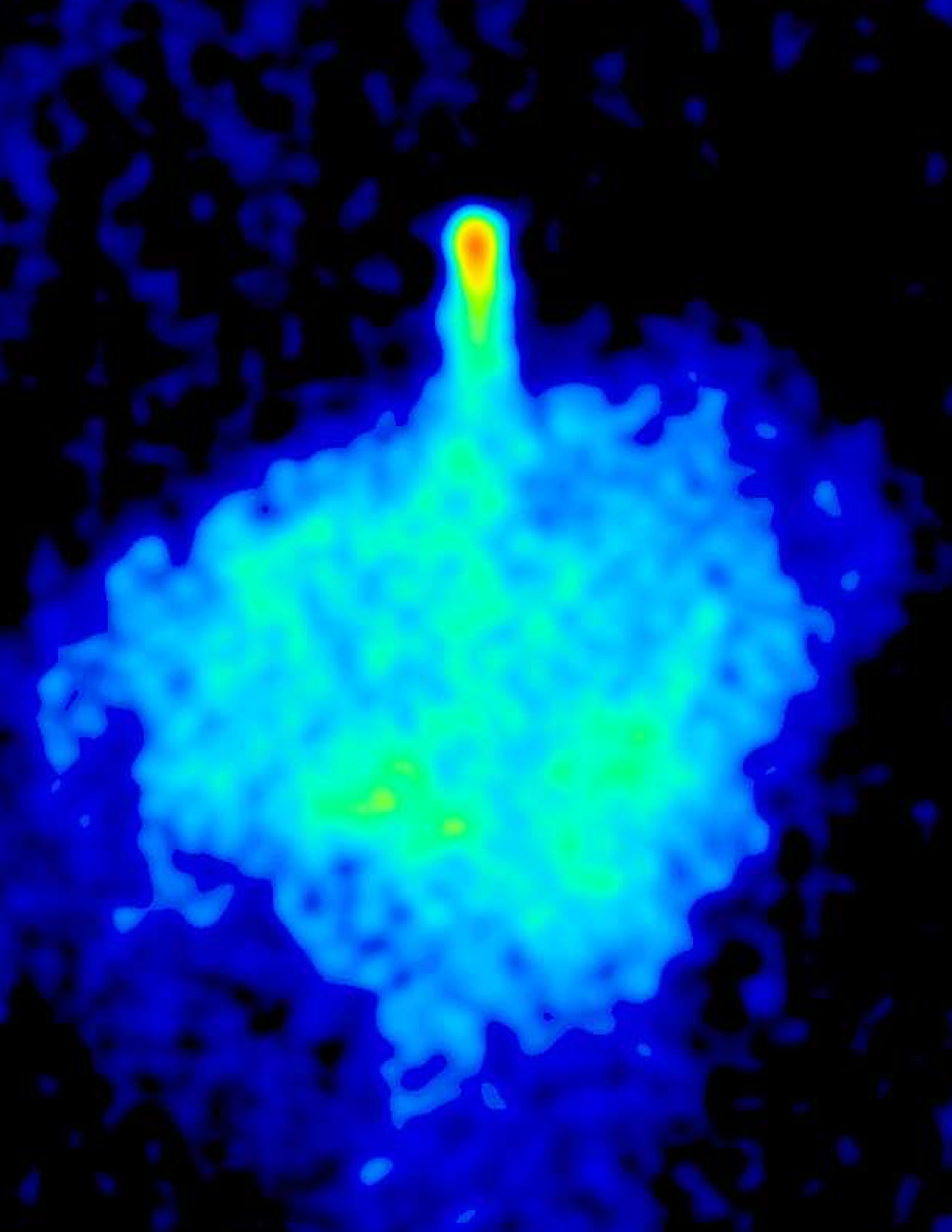
STUDY OF GAMMA-RAY BURSTS MARCHES ON

1973

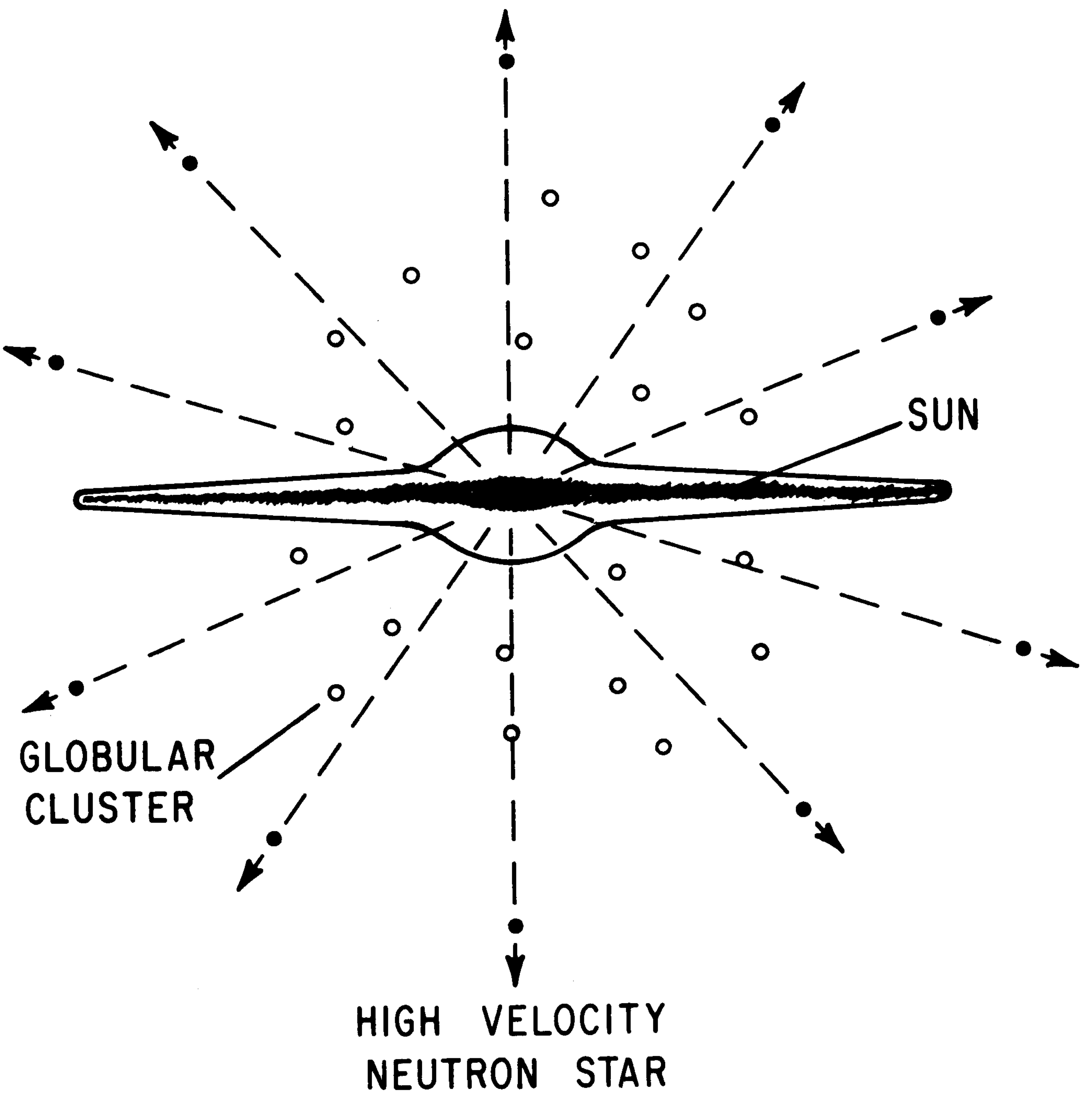
1996

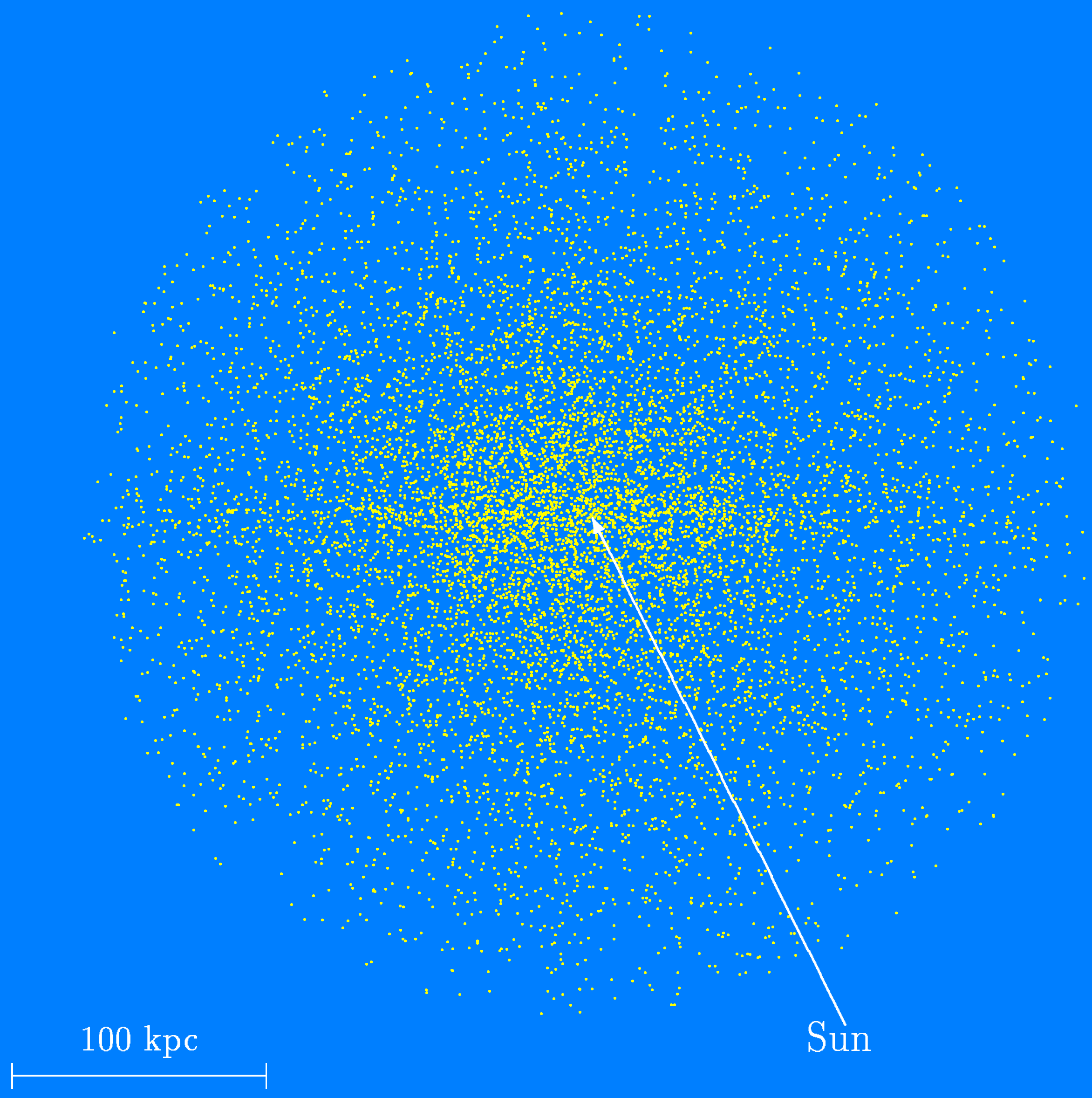
WHY WAS QUESTION SO DIFFICULT TO ANSWER?

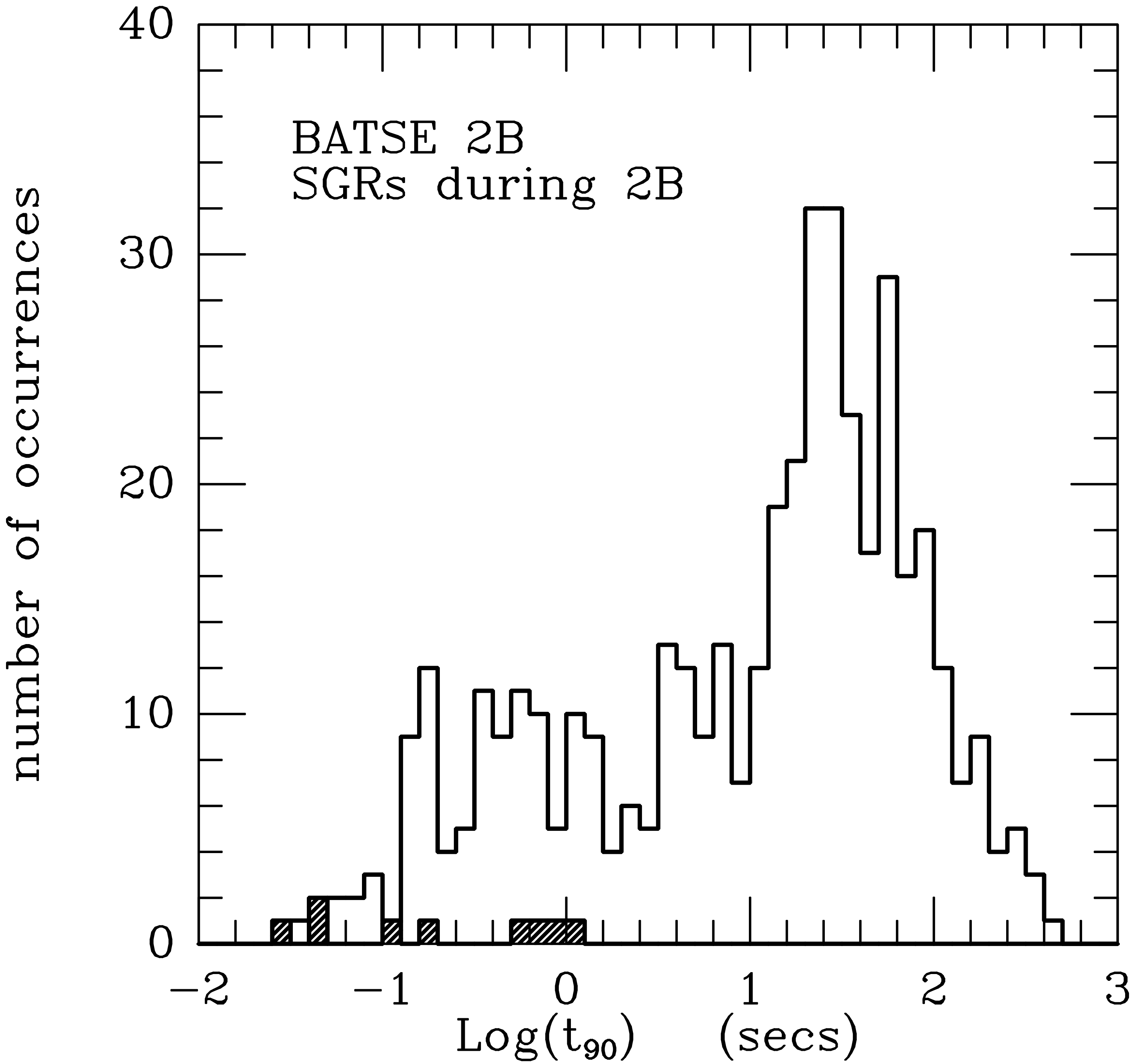
- BURSTS COME AT RANDOM TIMES
- BURSTS COME FROM RANDOM DIRECTIONS
- BURSTS HAVE WIDE DIVERSITY OF TIME HISTORIES
- BURSTS ARE NON-THERMAL PHENOMENON
- NO COUNTERPARTS DETECTED
  - ⇒ STUDY OF γ-RAY BURSTS ISOLATED FROM REST OF ASTRONOMY
  - ⇒ SCIENTISTS WHO STUDY BURSTS HAVE ONLY LAWS OF PHYSICS AND PROPERTIES OF THE BURSTS TO GUIDE THEM

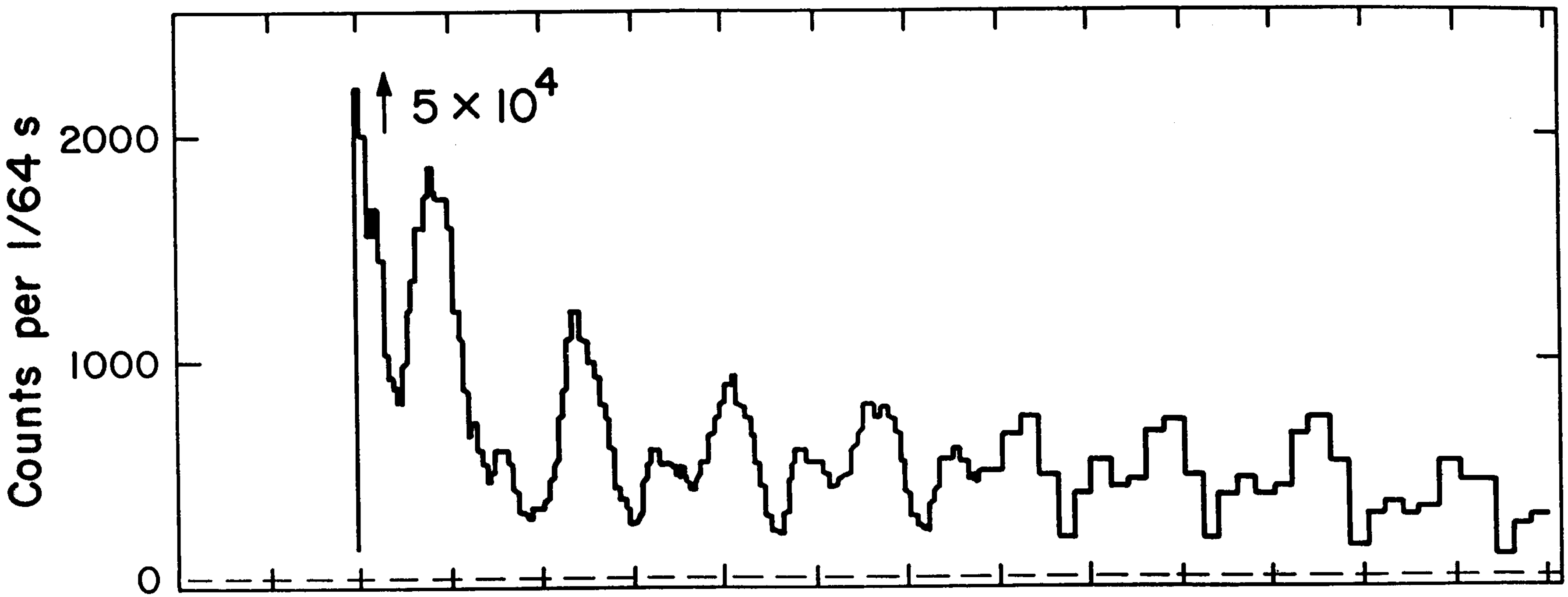


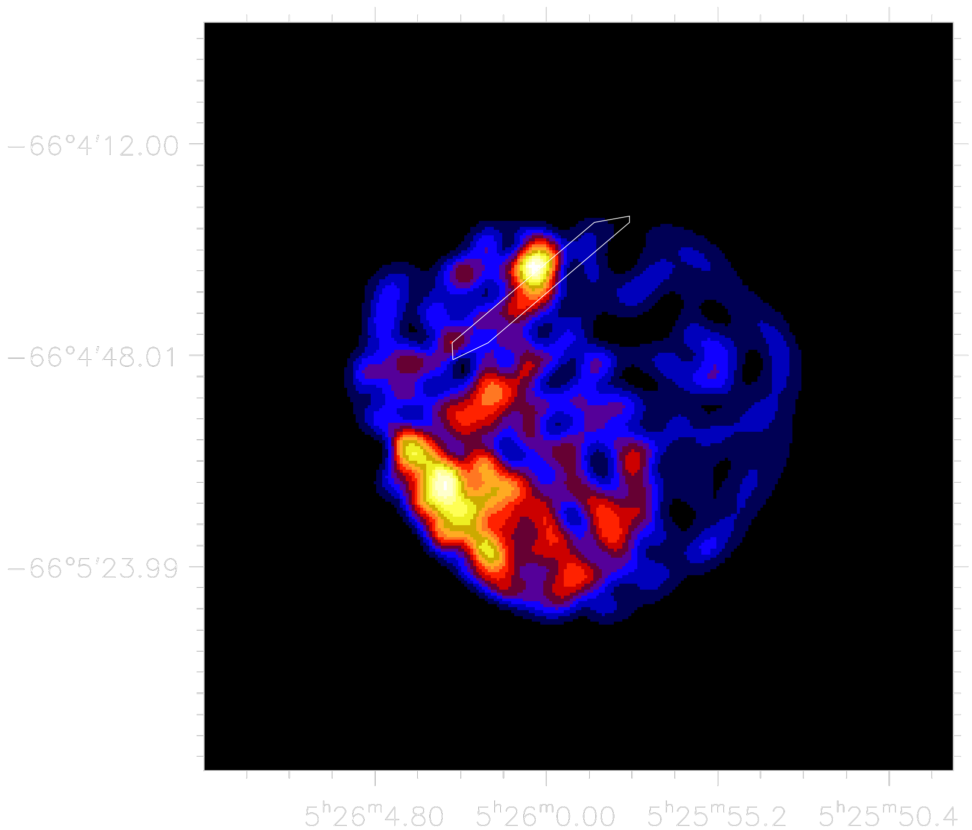
THE MILKY WAY



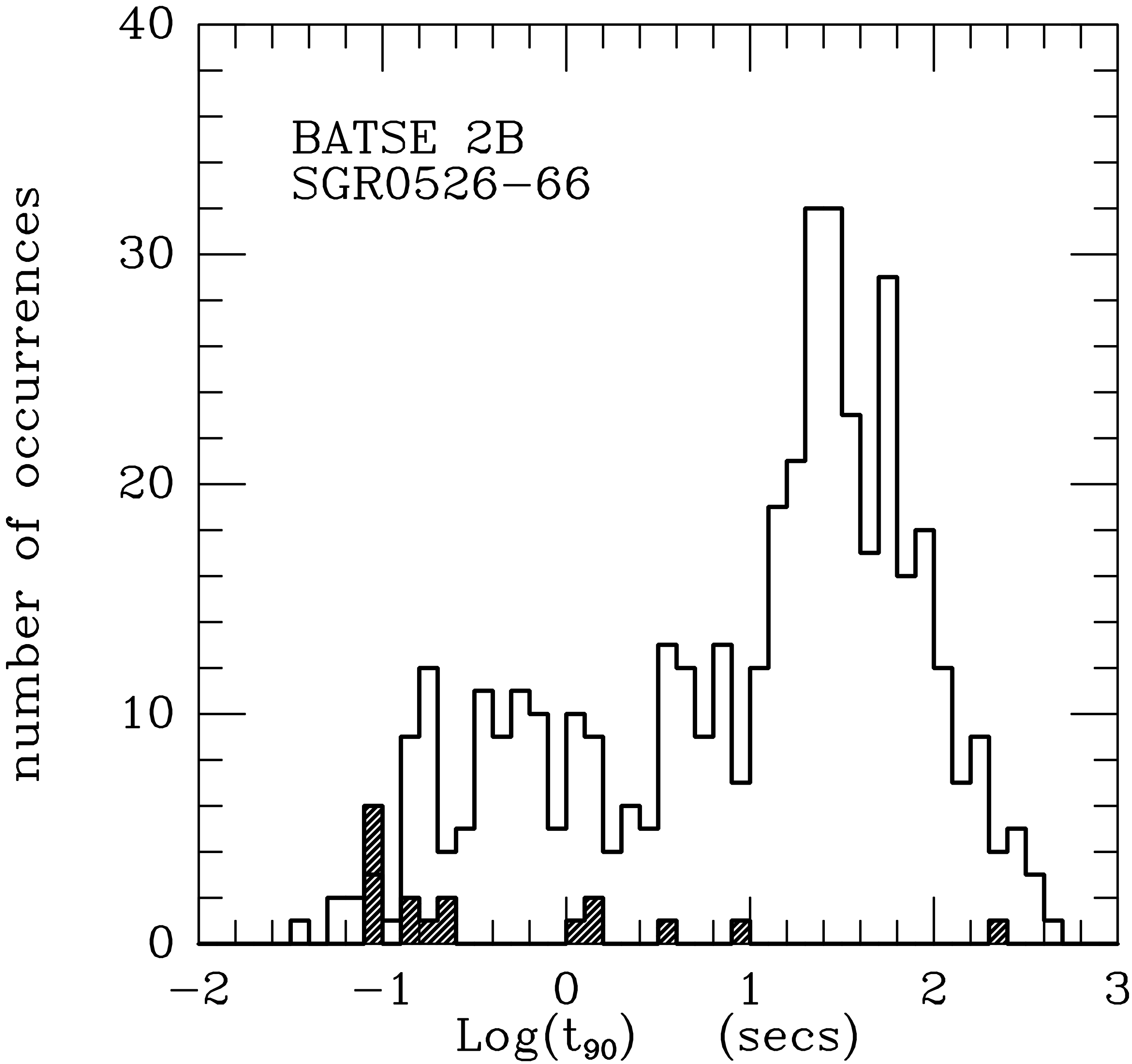

100 kpc
Sun

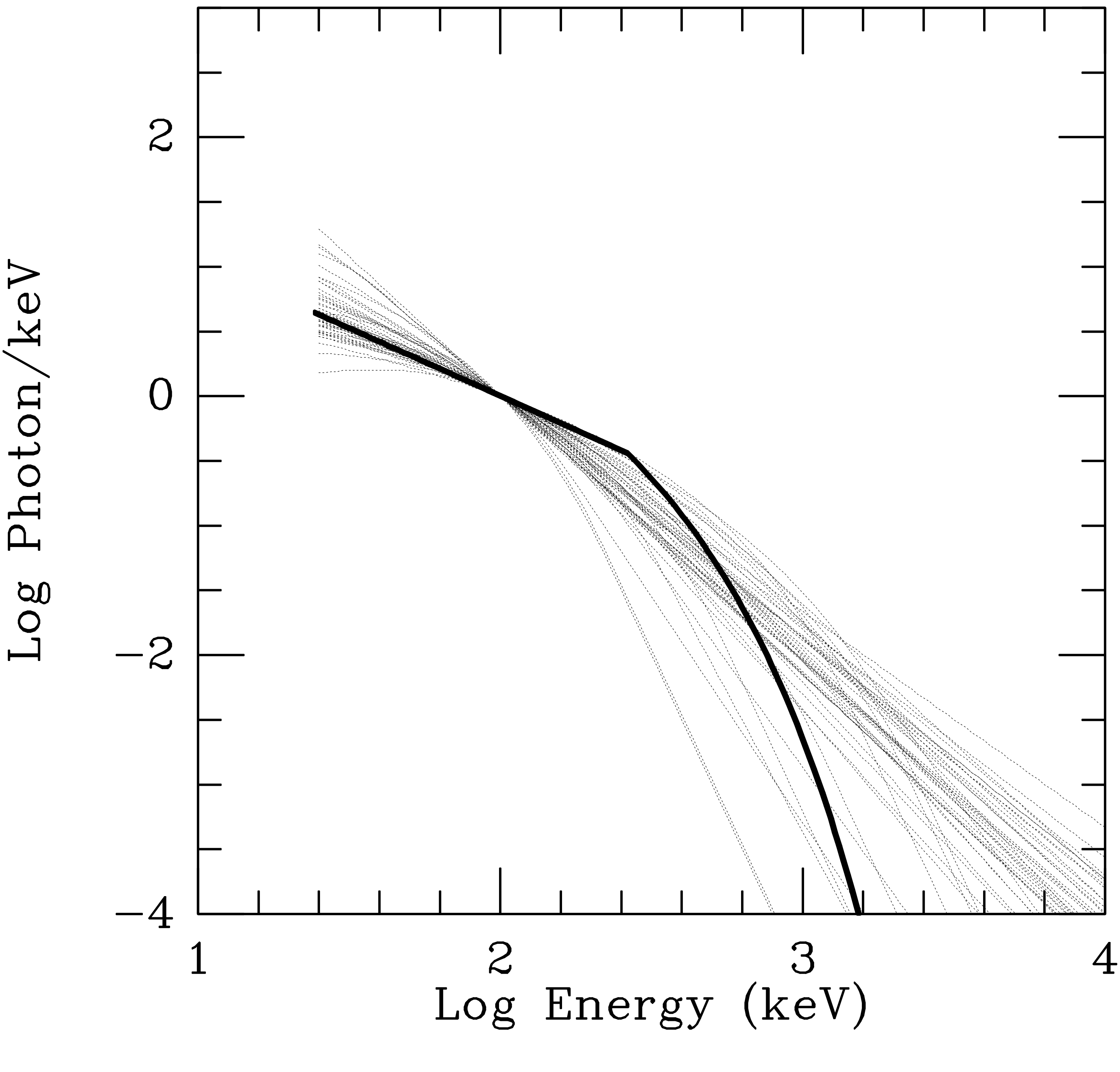

BATSE 2B
SGRs during 2B
number of occurrences
Log(t_{90}) (secs)
0
10
20
30
40
−2
−1
0
1
2
3


Counts per 1/64 s
2000
1000
0
5 × 10^4

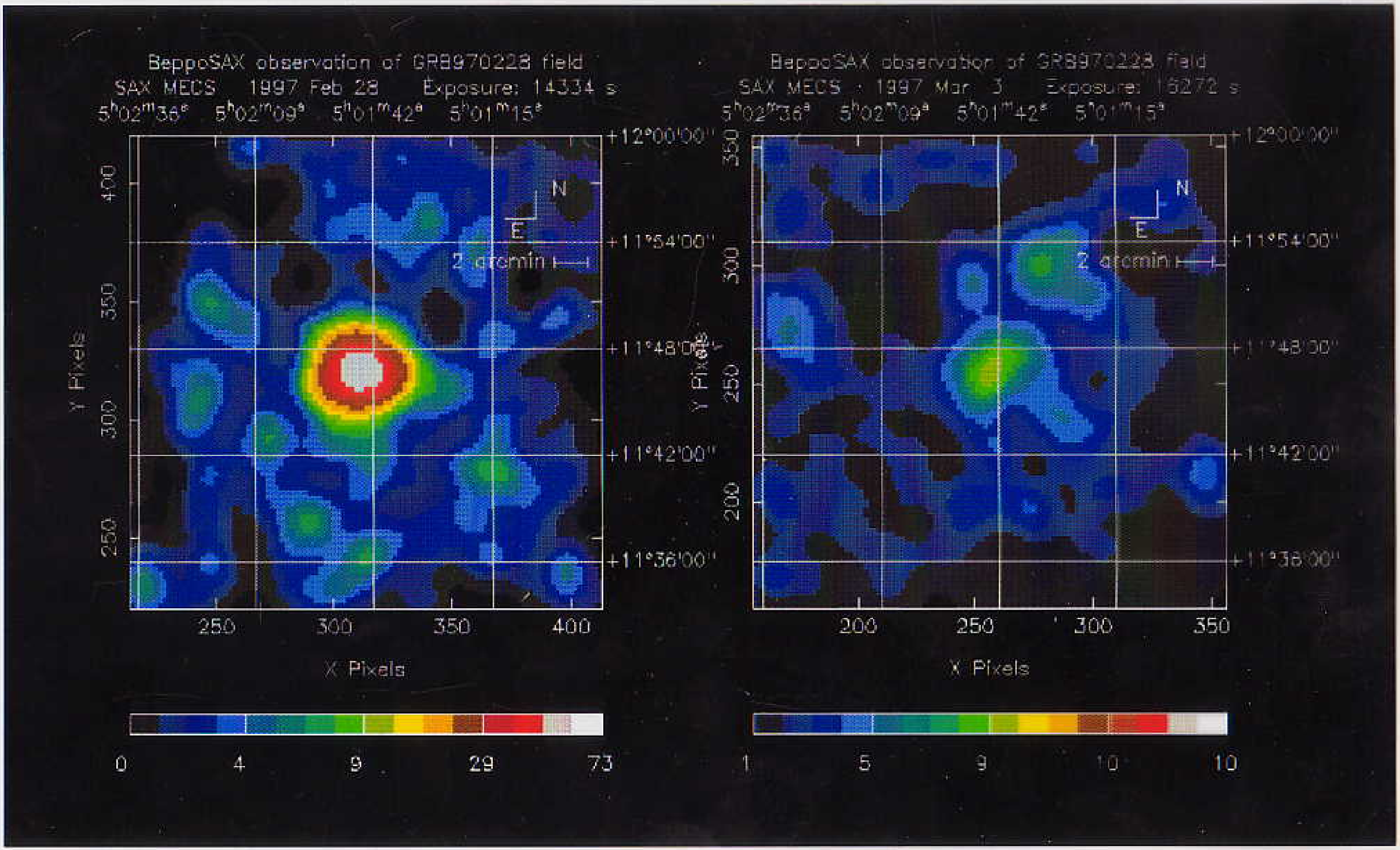


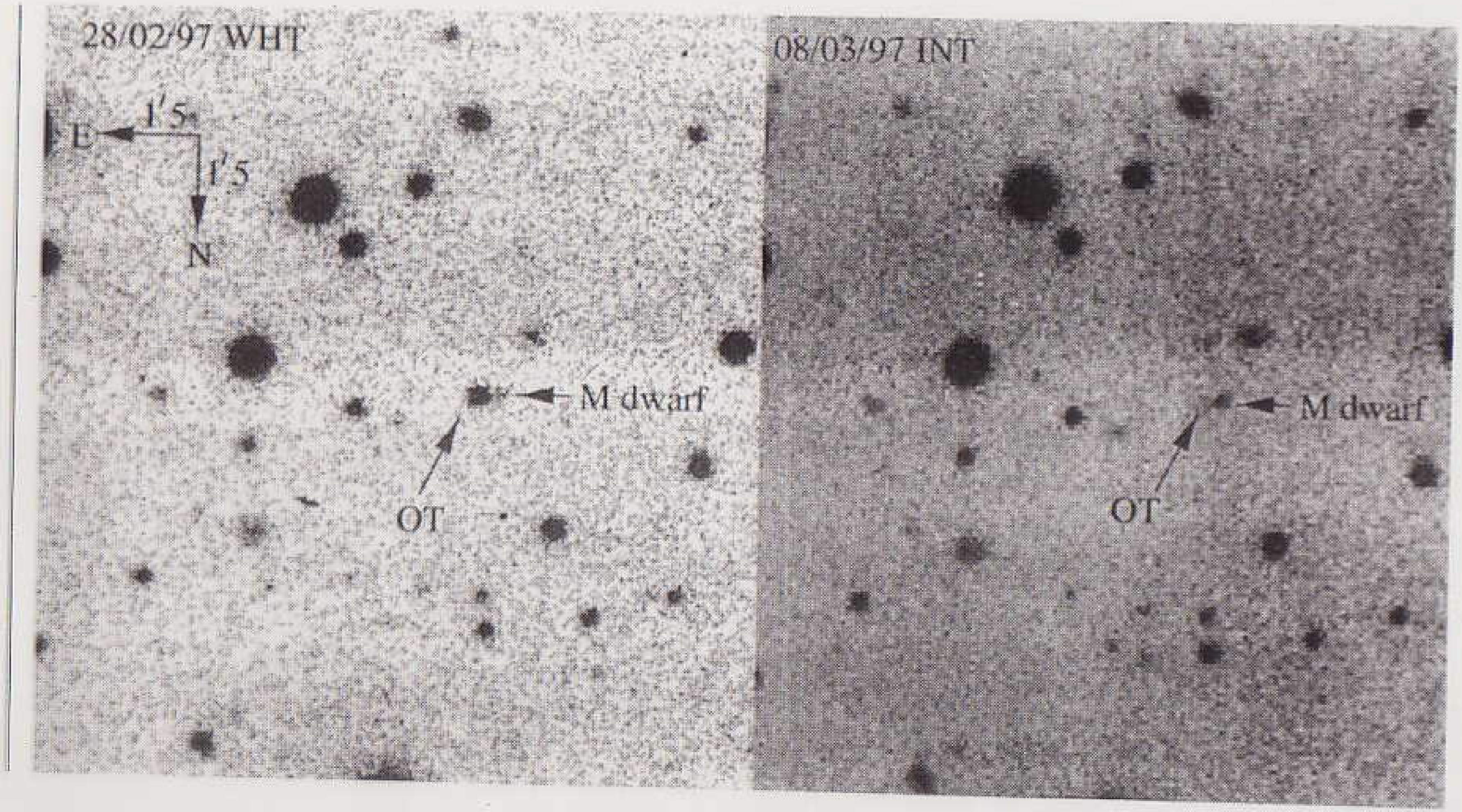
−66°4′12.00
−66°4′48.01
−66°5′23.99
5h26m4.80
5h26m0.00
5h25m55.2
5h25m50.4


BATSE 2B
SGR0526-66
number of occurrences
40
30
20
10
0
−2
−1
0
1
2
3
Log(t90) (secs)



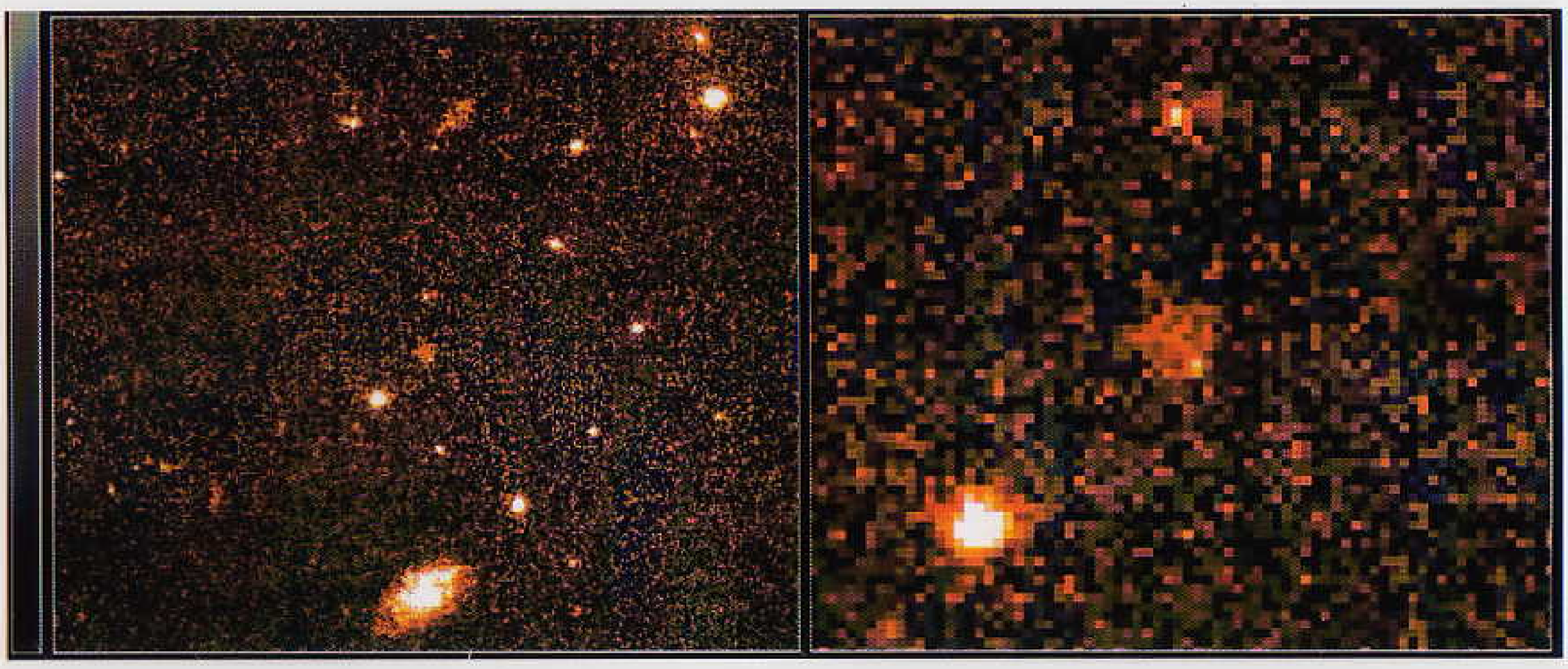
2
0
−2
−4
1
2
3
4
Log Photon/keV
Log Energy (keV)


BeppoSAX observation of GRB970228 field
SAX MECS 1997 Feb 28 Exposure: 14334 s
5h02m36s 5h02m09s 5h01m42s 5h01m15s
+12°00'00''
+11°54'00''
+11°48'00''
+11°42'00''
+11°36'00''
N
E
2 arcmin
Y Pixels
X Pixels
250 300 350 400
0 4 9 29 73
BeppoSAX observation of GRB970228 field
SAX MECS 1997 Mar 3 Exposure: 16272 s
5h02m36s 5h02m09s 5h01m42s 5h01m15s
+12°00'00''
+11°54'00''
+11°48'00''
+11°42'00''
+11°36'00''
N
E
2 arcmin
Y Pixels
X Pixels
200 250 300 350
1 5 9 10 10

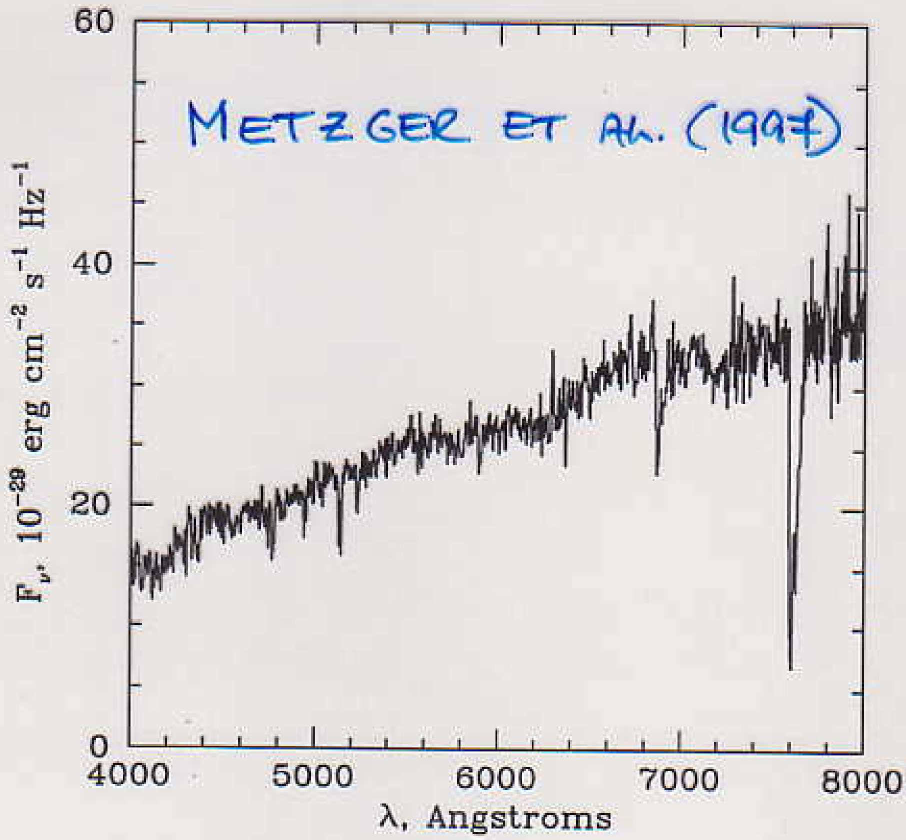

28/02/97 WHT
E
1'5
1'5
N
M dwarf
OT
08/03/97 INT
M dwarf
OT

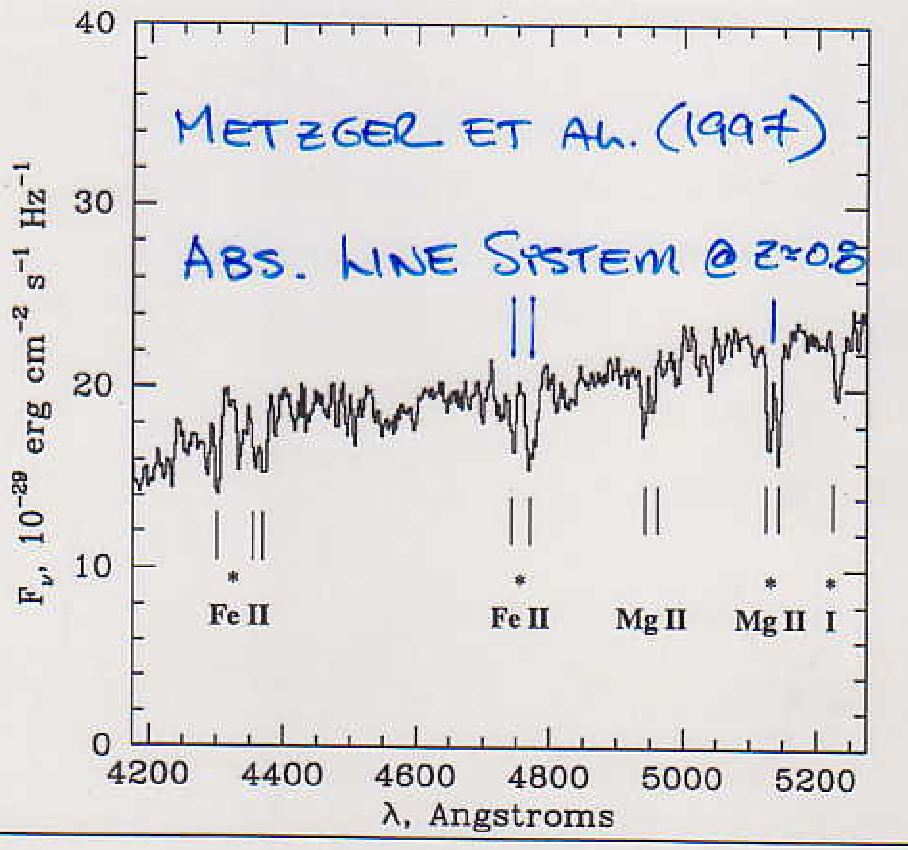
HST STIS OBSERVATION OF GRB 970228

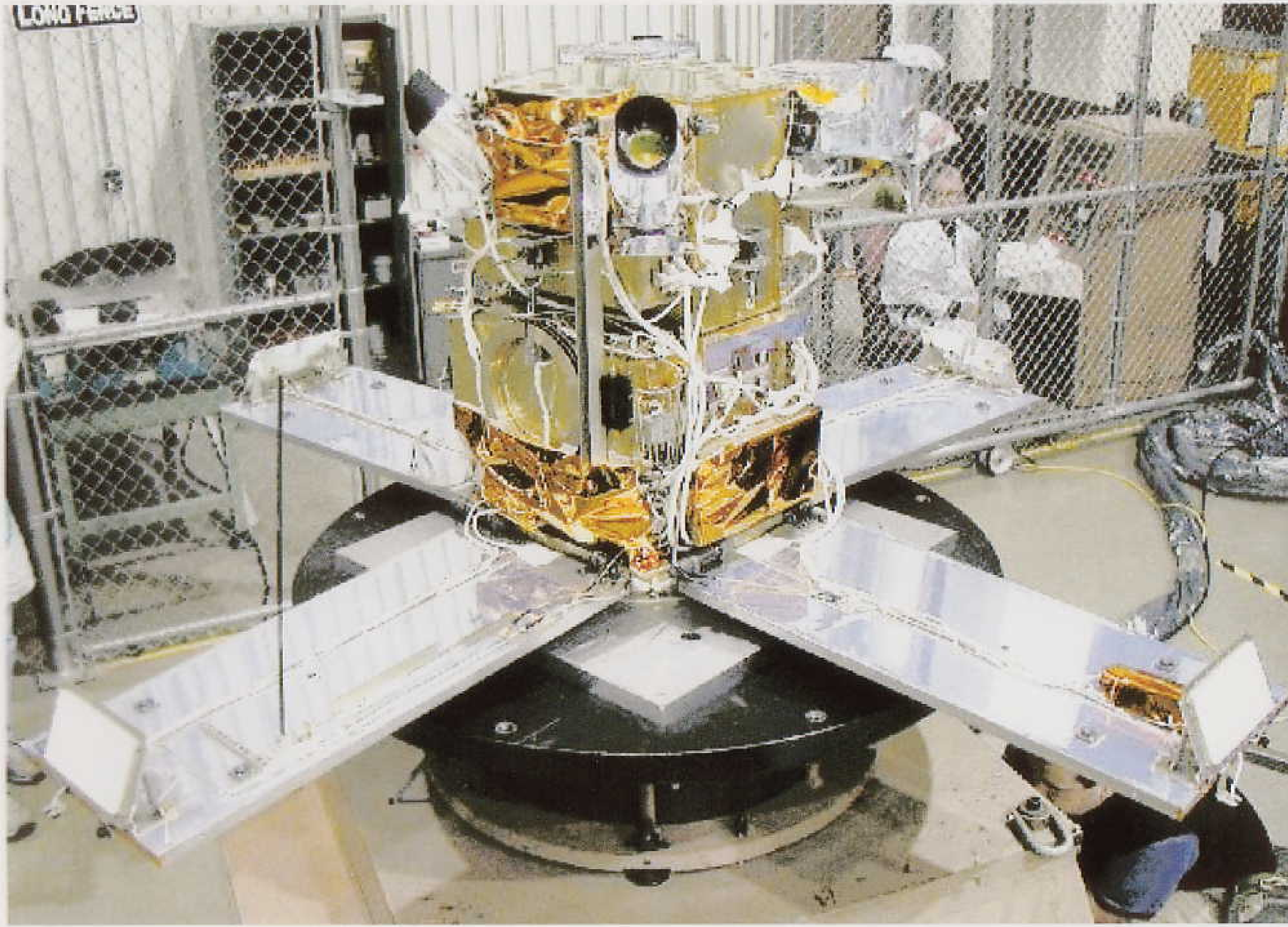
(FRUCHTER ET AL. 1998)

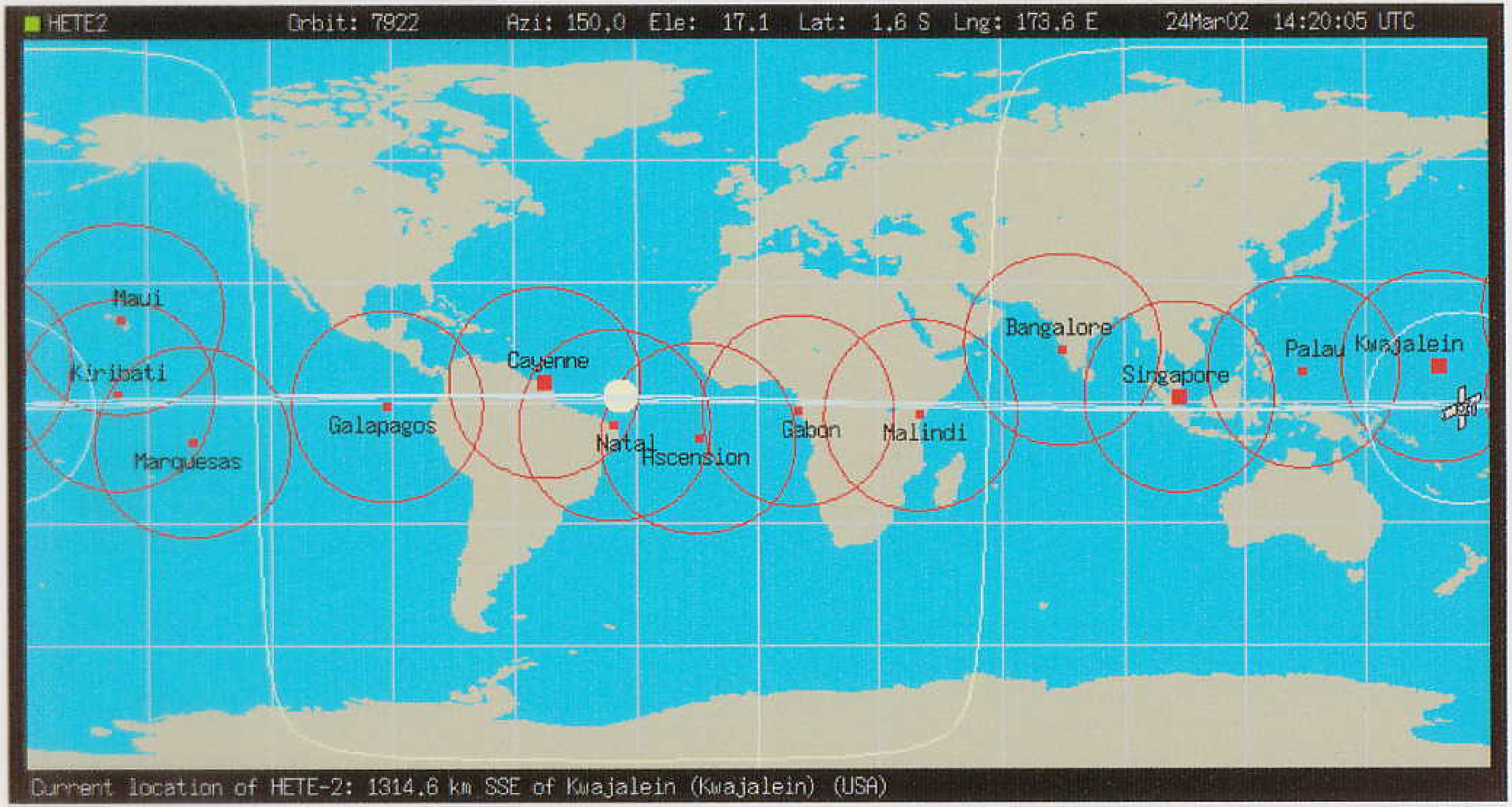


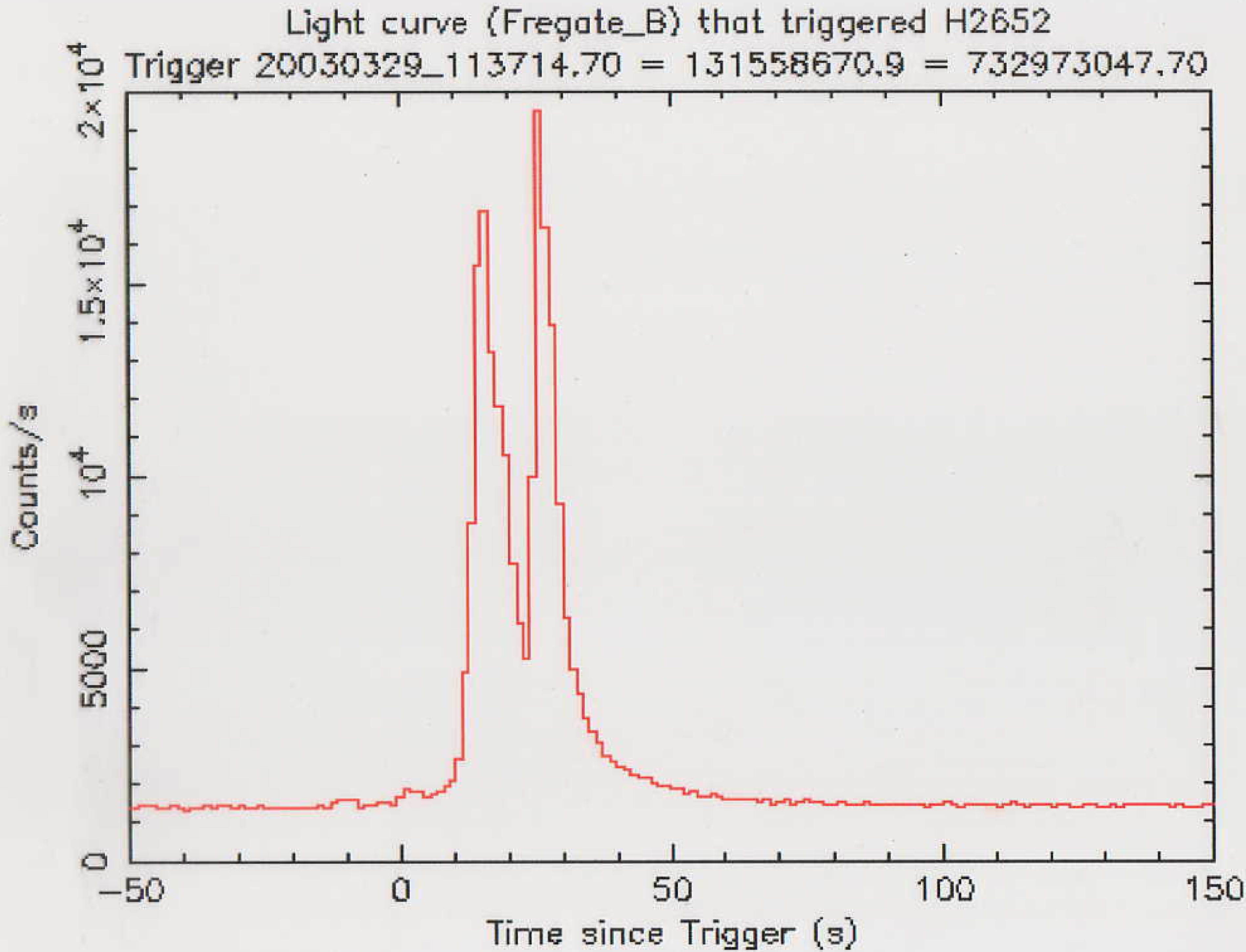
BOND'S OBJECT

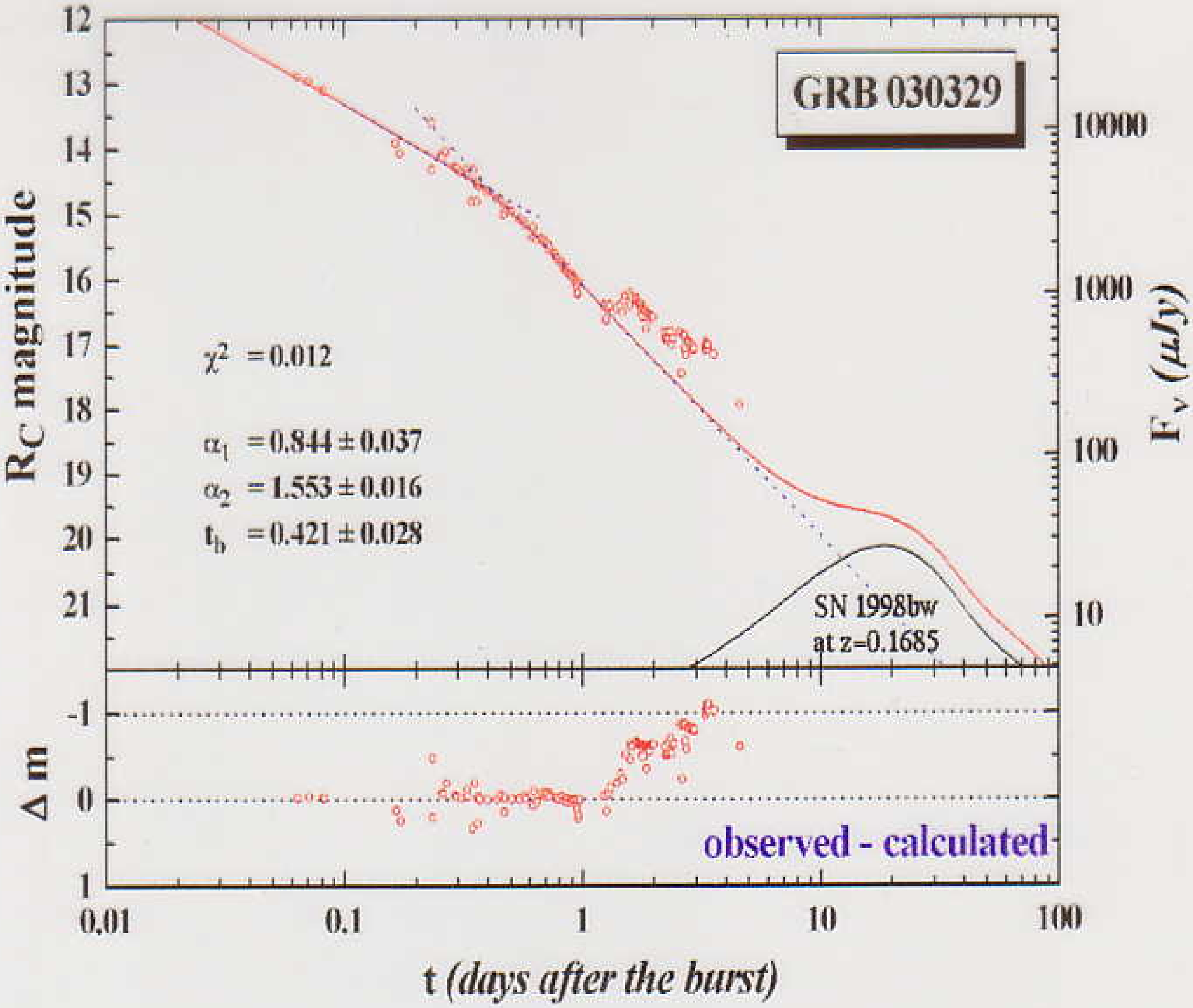


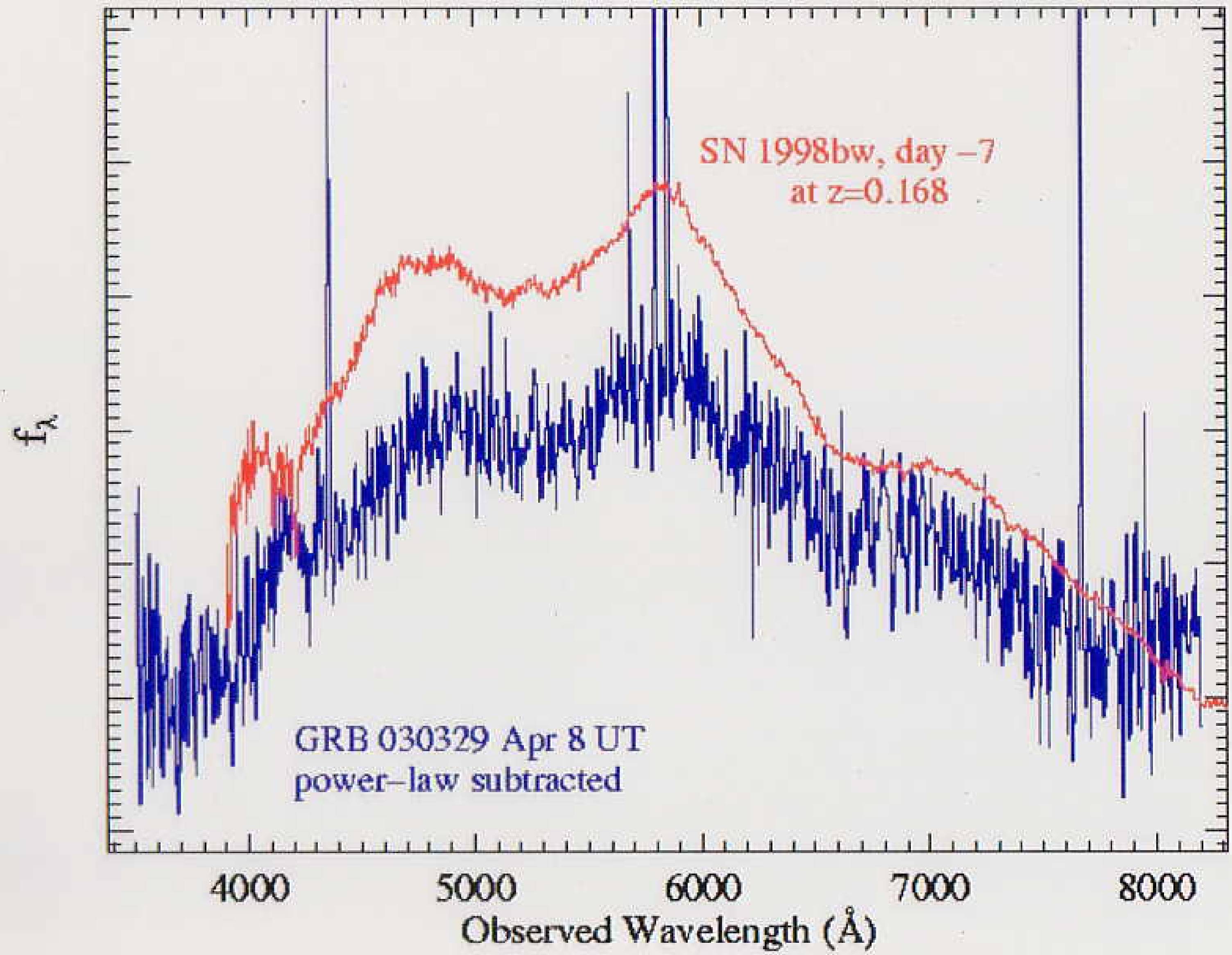



LONG FENCE

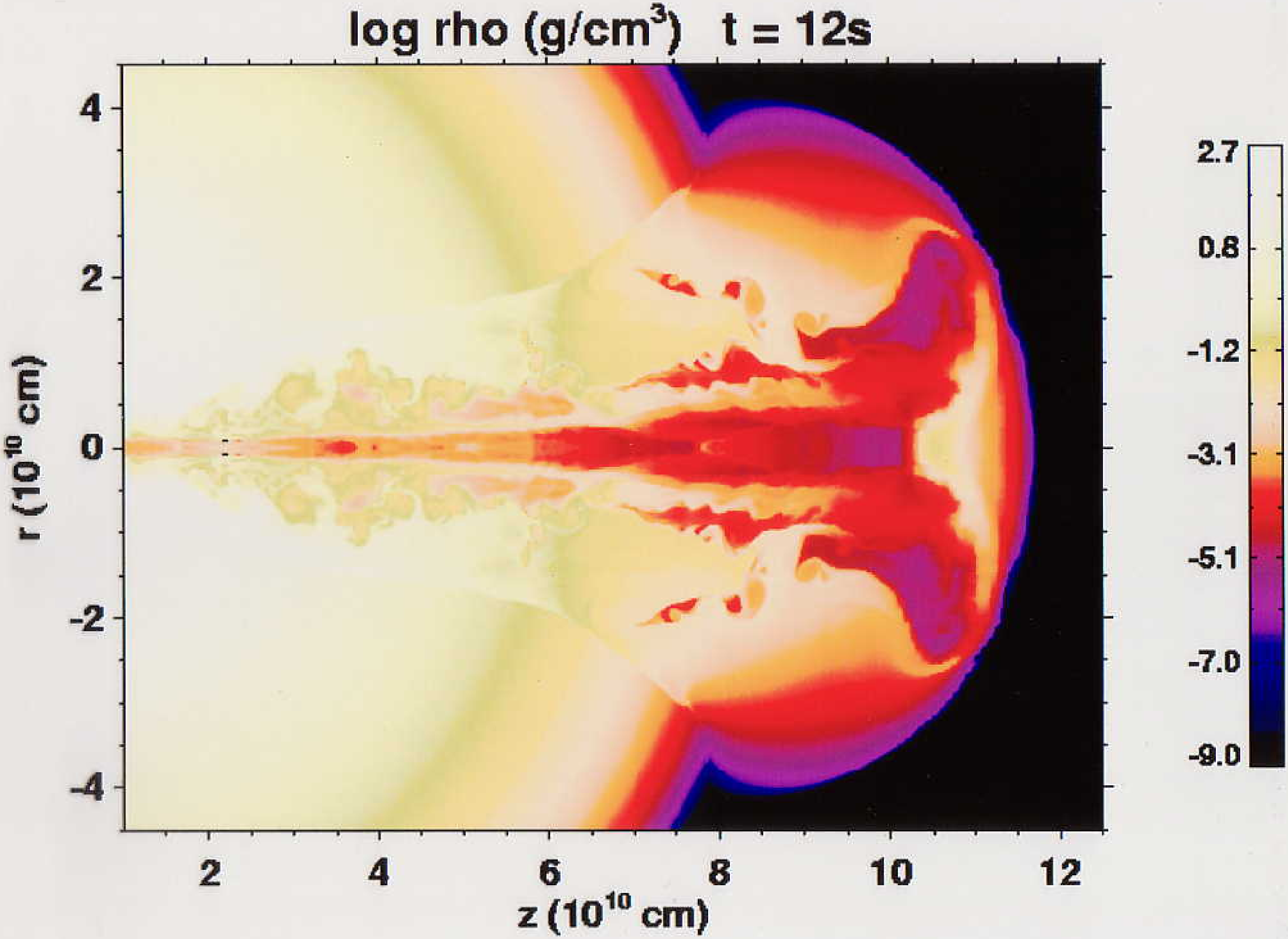

HETE2
Orbit: 7922
Azi: 150.0 Ele: 17.1 Lat: 1.6 S Lng: 173.6 E
24Mar02 14:20:05 UTC
Maui
Kiribati
Marquesas
Galapagos
Cayenne
Natal
Ascension
Gabon
Malindi
Bangalore
Singapore
Palau
Kwajalein
Current location of HETE-2: 1314.6 km SSE of Kwajalein (Kwajalein) (USA)

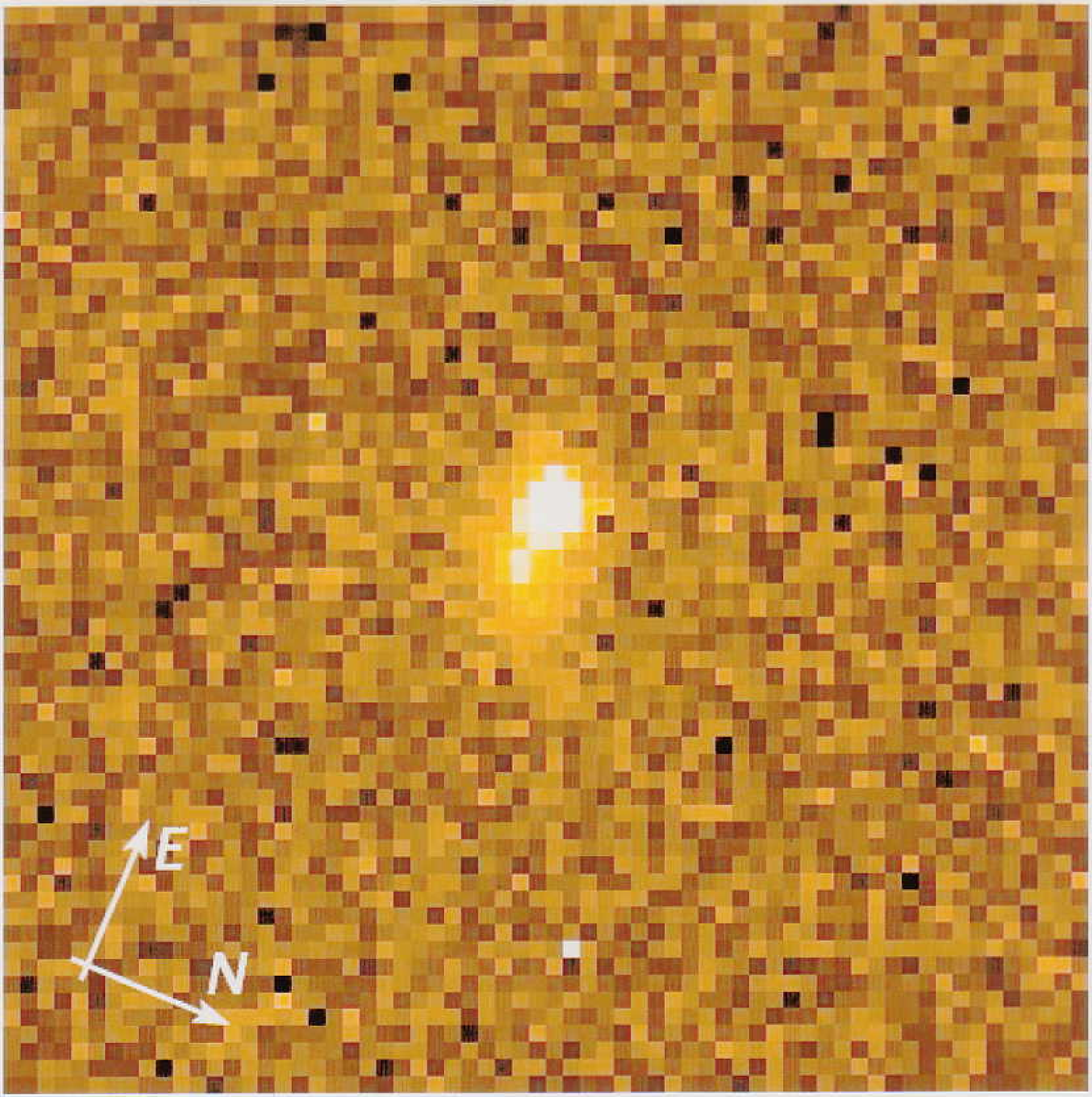

Light curve (Fregate_B) that triggered H2652
Trigger 20030329_113714.70 = 131558670.9 = 732973047.70
Counts/s
0
5000
10^4
1.5×10^4
2×10^4
-50
0
50
100
150
Time since Trigger (s)

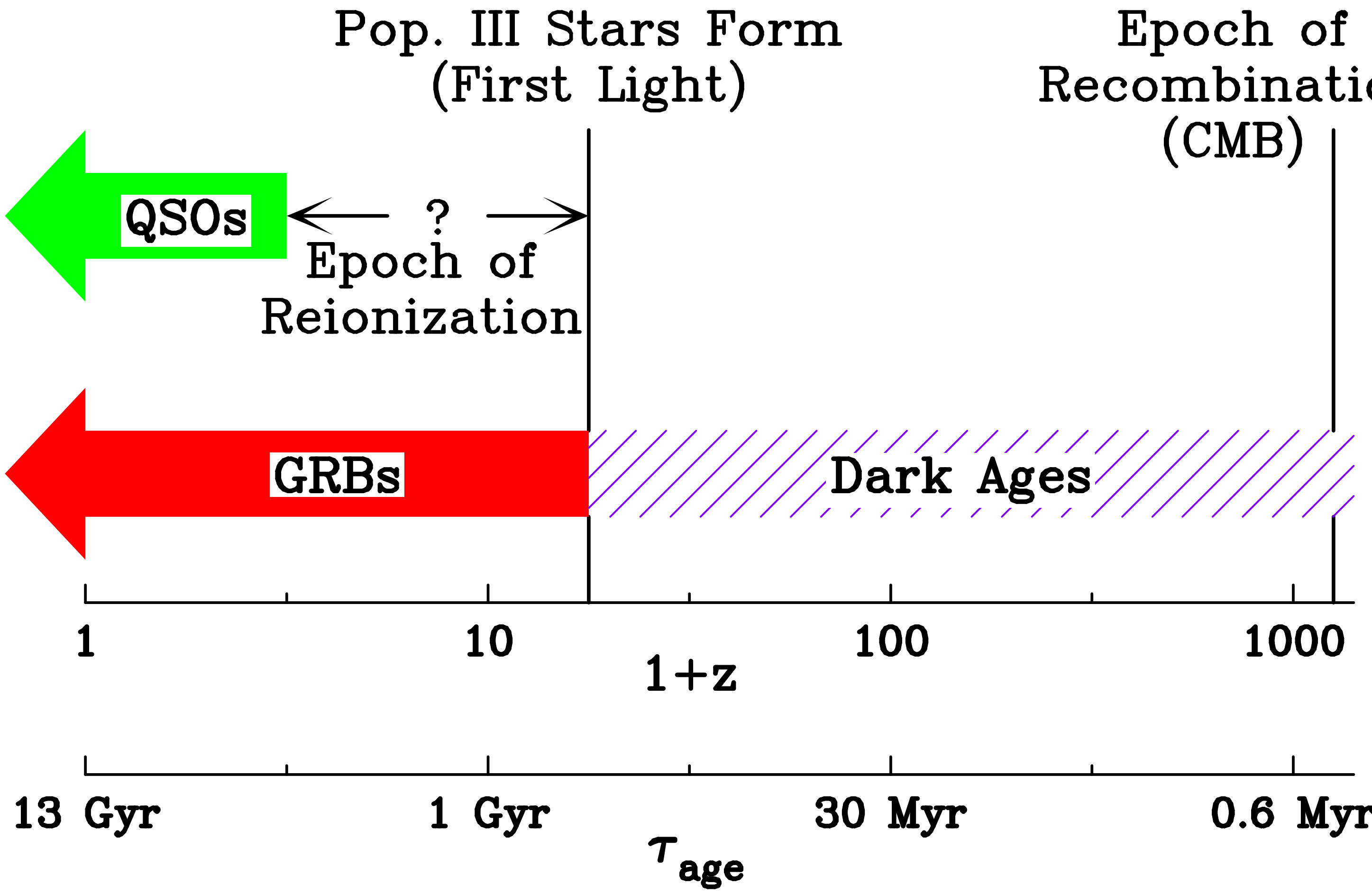

GRB 030329
χ^2 = 0.012
α_1 = 0.844 ± 0.037
α_2 = 1.553 ± 0.016
t_b = 0.421 ± 0.028
SN 1998bw
at z=0.1685
observed - calculated
R_C magnitude
F_ν (μJy)
Δ m
t (days after the burst)



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


log rho (g/cm³) t = 12s
r (10¹⁰ cm)
z (10¹⁰ cm)
4
2
0
-2
-4
2
4
6
8
10
12
2.7
0.8
-1.2
-3.1
-5.1
-7.0
-9.0


E
N


Pop. III Stars Form
(First Light)
Epoch of
Recombination
(CMB)
QSOs
?
Epoch of
Reionization
GRBs
Dark Ages
1
10
100
1000
1+z
13 Gyr
1 Gyr
30 Myr
0.6 Myr
τ_{age}

The ways in which GRBs may be used to probe the very high redshift ($z > 5$) universe include the following:

o GRBs may allow astronomers to determine the epoch of first light, since they are thought to come from the collapse of massive stars -- which are the kind of stars that are thought to form first.

o GRBs are thought to be the result of the collapse of massive stars. Thus they may provide information about how the rate of formation of massive stars has evolved in the universe.

o GRBs may be a unique probe of the earliest stars (Pop III stars, which have zero metals -- i.e., no C, N, O, Mg, Fe, etc.), which are thought to have formed at z \approx 20.

o The metal absorption lines in the spectra of GRB afterglows glows can be used to trace the history of the growth of metallicity of the universe. The light from the brilliant optical afterglow of a GRB intercepts gas clouds and galaxies along the line-of-sight from the GRB to us. The metal atoms in each of these clouds and galaxies absorbs light at specific wavelengths, telling astronomers the redshift of the cloud or galaxy. The strength of the absorption line tells astronomers the abundance of the metal (a stronger line means more of the metal is present; a weaker line means less is present). These two pieces of information allow astronomers to trace out the increase in the metallicity of the universe from $z = 20$ until now.

o The absorption lines in the spectra of GRB afterglows provide information about the formation of large-scale structure in the universe. Again, the light from the brilliant optical afterglow of a GRB intercepts gas clouds and galaxies along the line-of-sight from the GRB to us. The metal atoms in each of these clouds and galaxies absorbs light at specific wavelengths, telling astronomers the redshift of the cloud or galaxy. Using the direction of the GRB and the redshifts of the clouds and galaxies allows astronomers to plot the locations of the clouds and galaxies in 3-dimensional space. Using many GRBs, astronomers may be able to build up a map of the large-scale structure of the universe at redshifts as large as $z = 20$. This would provide another check of the picture that the large-scale structure of the universe arises from fluctuations in the density (primarily the density of dark matter) of the universe on which gravity then operates to produce the voids and sheets of galaxies that we now see.

o The spectra of GRB afterglows may allow astronomers to explore the epoch of reionization. The brilliant optical afterglows of GRBs that occur before the epoch of reionization (i.e., at redshifts larger than those at which reionization occurs) will have no light in the UV, since it will have been absorbed by neutral hydrogen gas in the intergalactic medium (IGM). In contrast, the brilliant optical afterglows of GRBs that occur after the epoch of reionization (i.e., at redshifts less than those at which reionization occurs) will have an abundance of light in the UV, since all of the hydrogen gas in the ISM between the GRB and us will have been ionized and so cannot absorb the UV light of the afterglow. This may allow astronomers to determine the epoch (i.e., the redshift) at which the universe became reionized.