Search for optical counterparts of Gamma Ray Bursts

the most powerfull sources of photons in the Universe from radio waves to TeV

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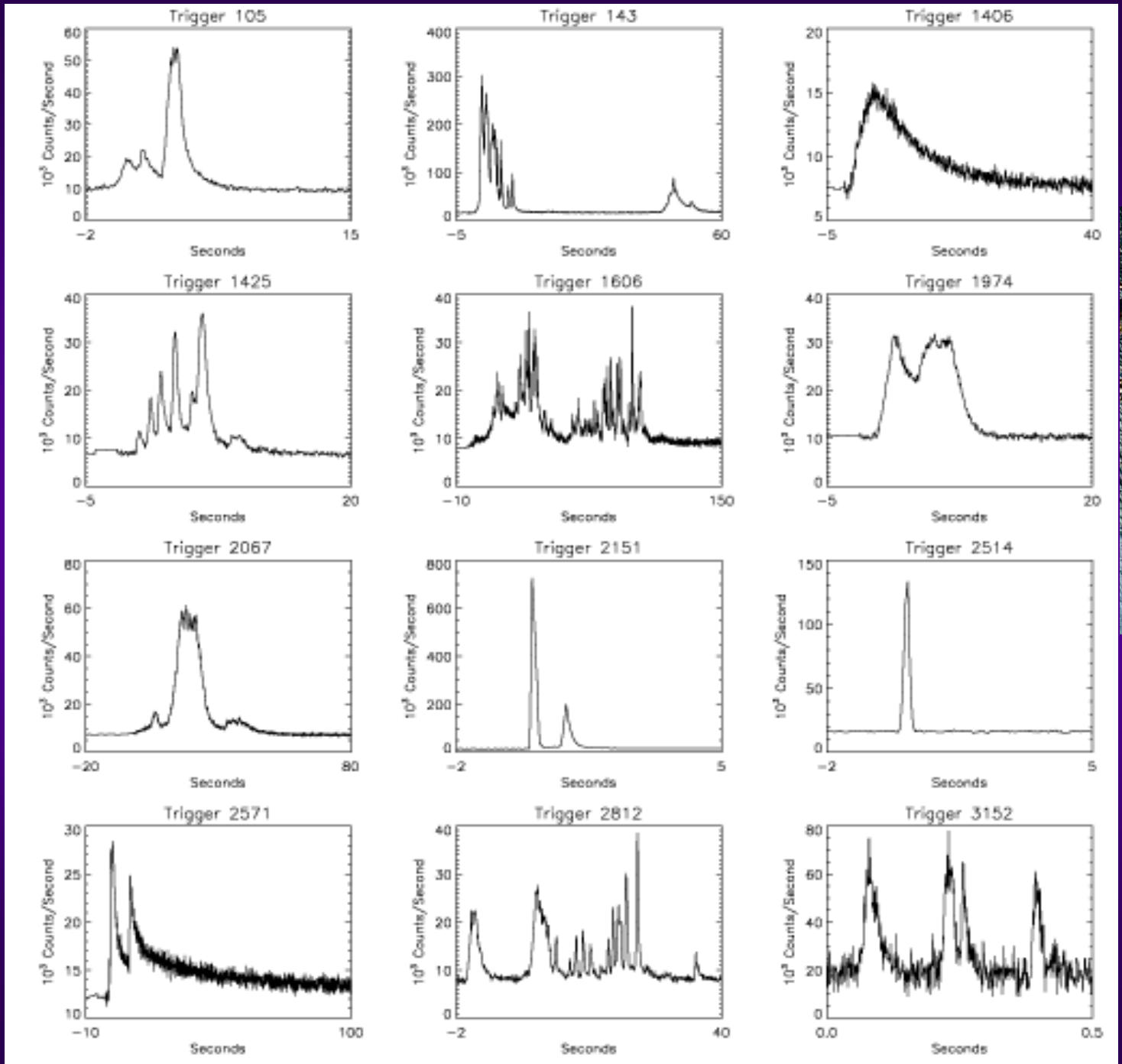
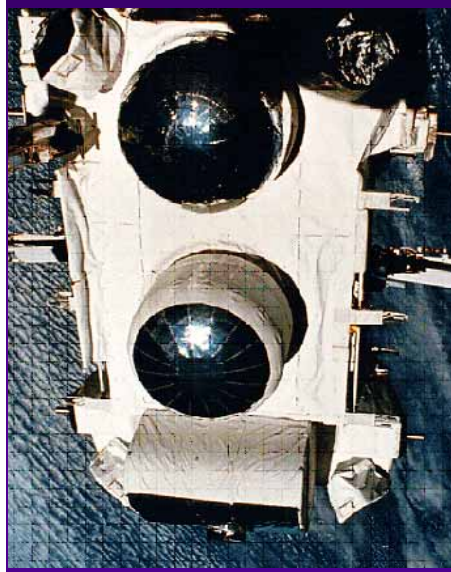
Gamma Ray Bursts - GRB

- **Short (0.01-100s) γ–ray pulses**
- **From pointlike sources in the sky**
- **Brighter than the rest of the sky** (in γ-rays)
- **Energy 10^{51} erg** (=10^{10} years of Sun emission)
- **Distance up to z=4.5** ($13 \cdot 10^9$ light years)
- **Frequency 2-3 per day**
- **Discovered in 1967 by military satellites VELA**
- **So far >3000 observed**
  including ~100 in visible light
  distance measured for ~70
- **Observed in radio waves, X-rays, γ ~GeV,TeV**



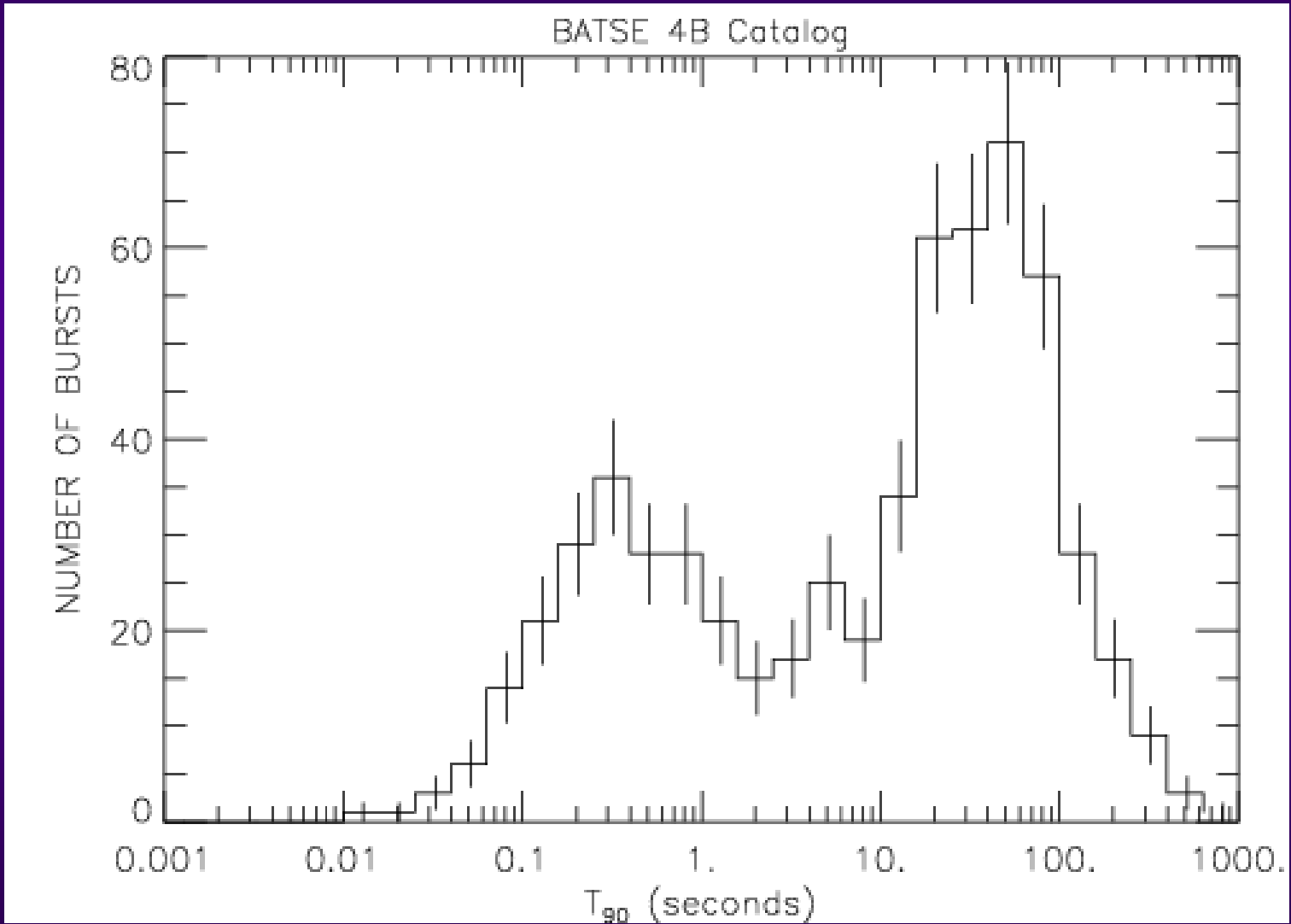
BATSE data

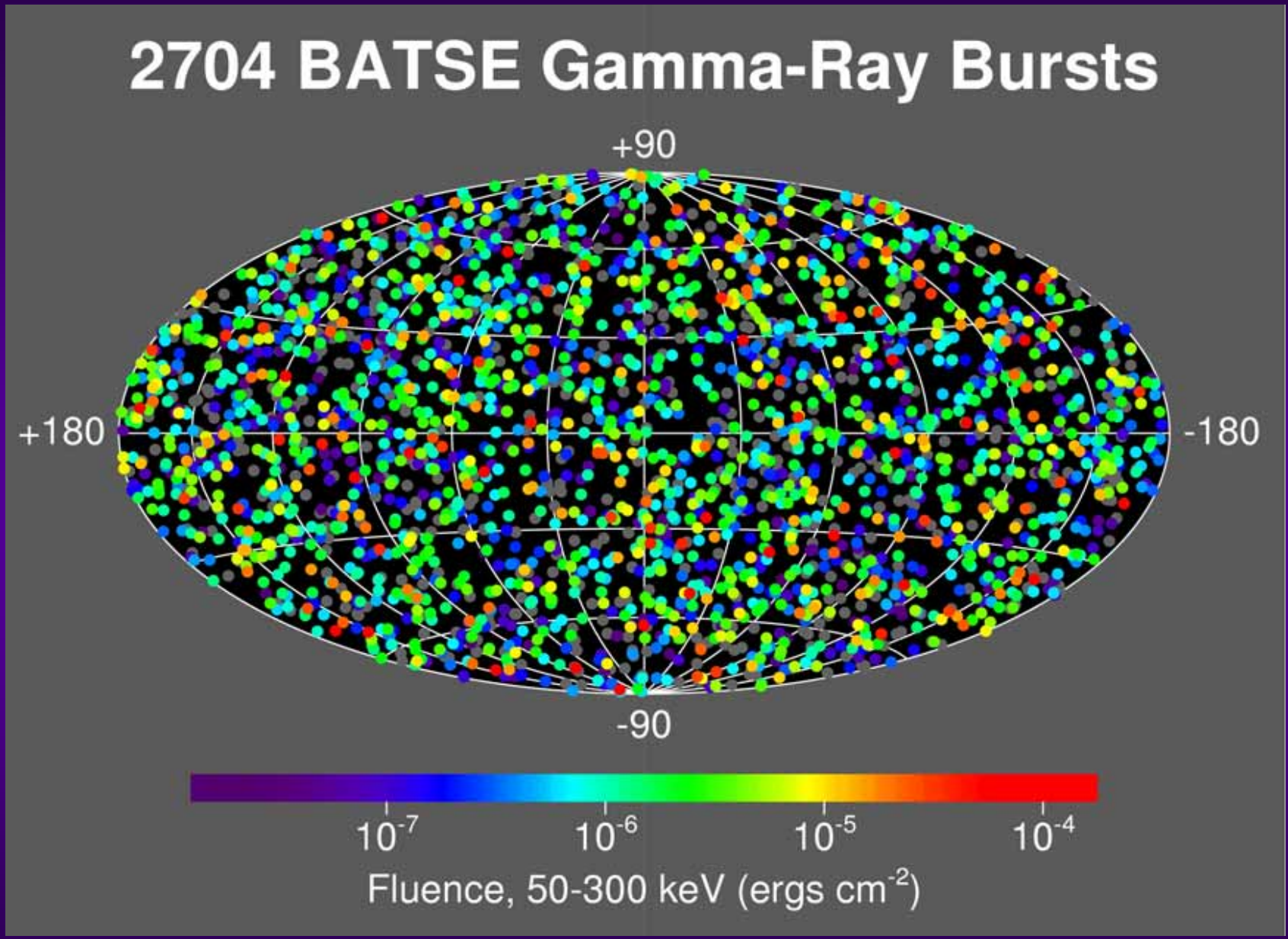


Different shapes

Time: 0.01-100s

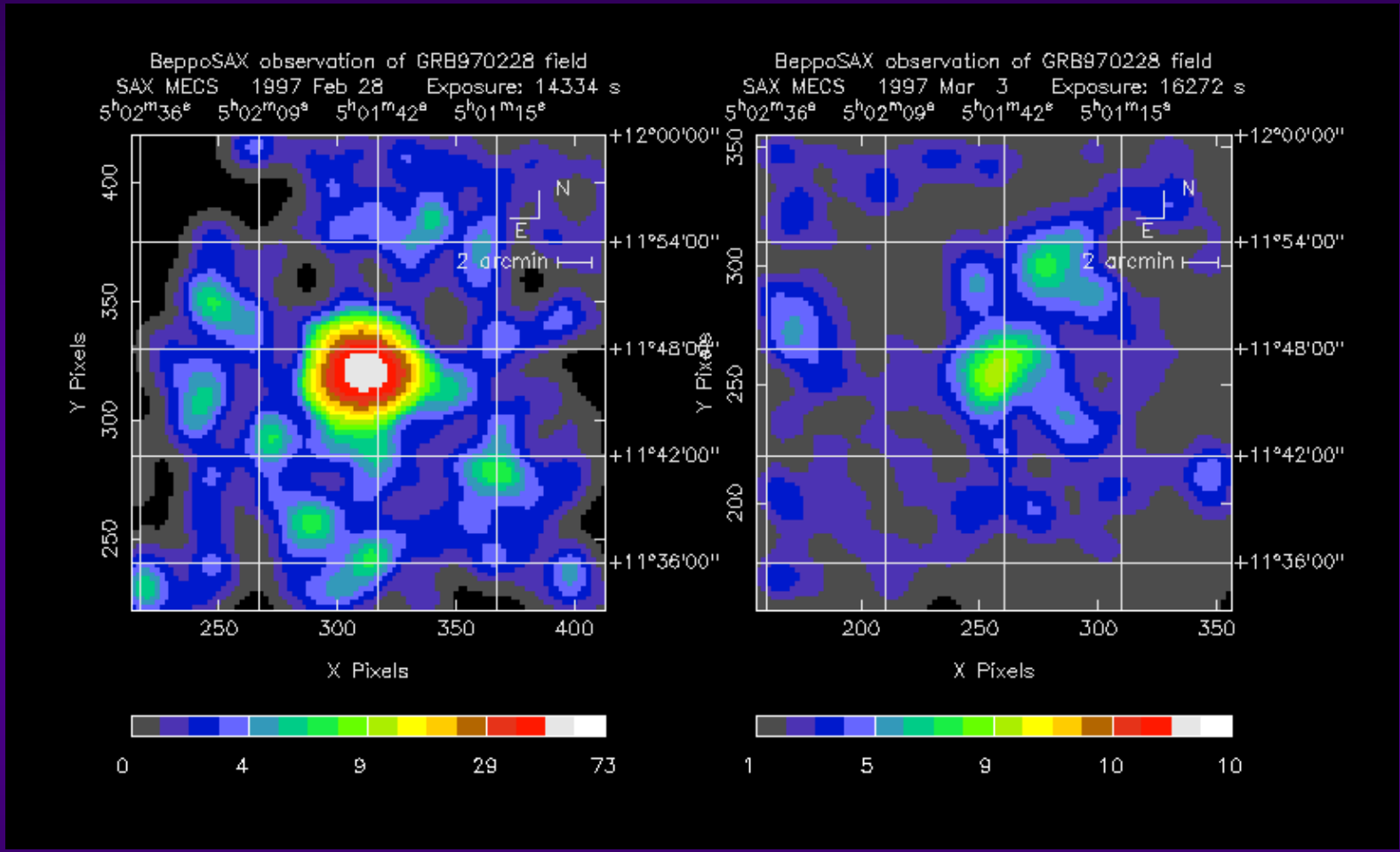
„Short" and „long" bursts





Izotropic distribution in galactic coordinates

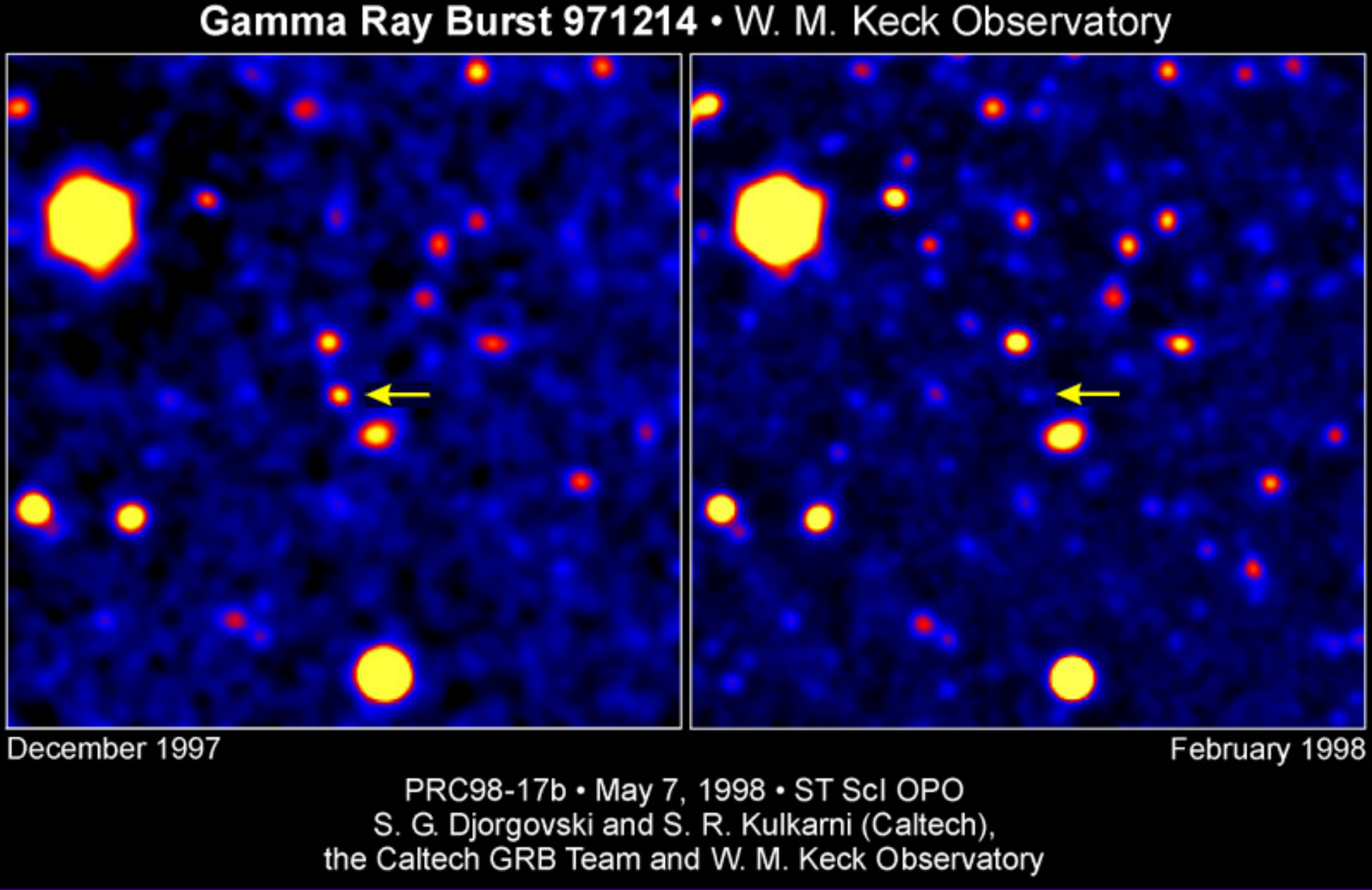
First afterglows



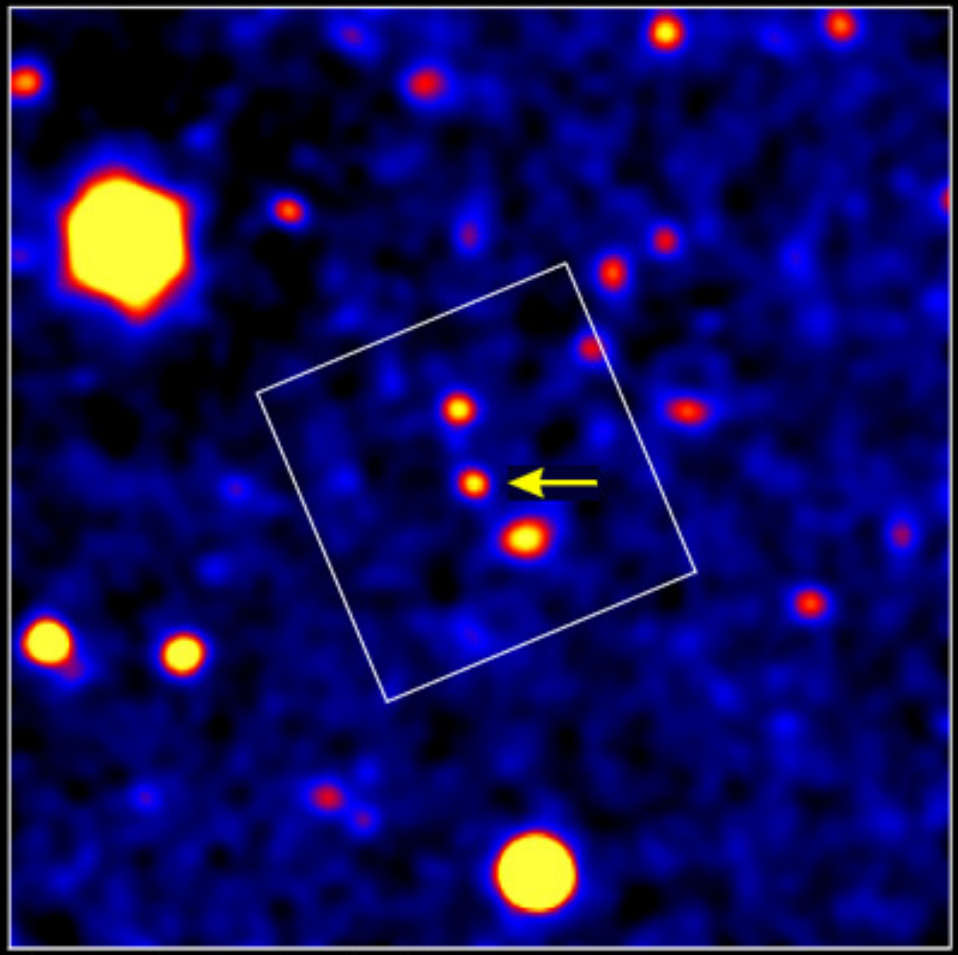
1997.02.28 – GRB observed in X-rays - BeppoSAX satellite

21 h later – optical observation

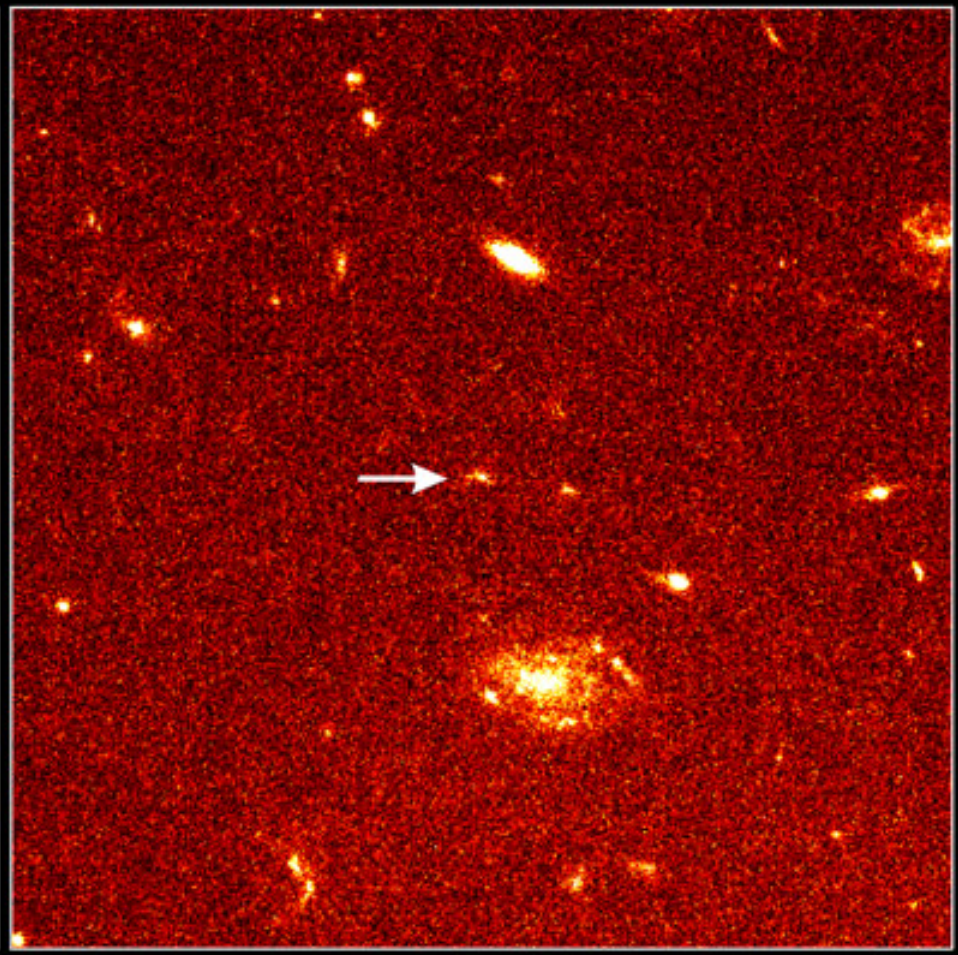
William Herschel Telescope, 4.2m, La Palma


Gamma Ray Burst 971214 • W. M. Keck Observatory
December 1997
February 1998
PRC98-17b • May 7, 1998 • ST ScI OPO
S. G. Djorgovski and S. R. Kulkarni (Caltech),
the Caltech GRB Team and W. M. Keck Observatory

Gamma Ray Burst 971214



Keck • December 1997



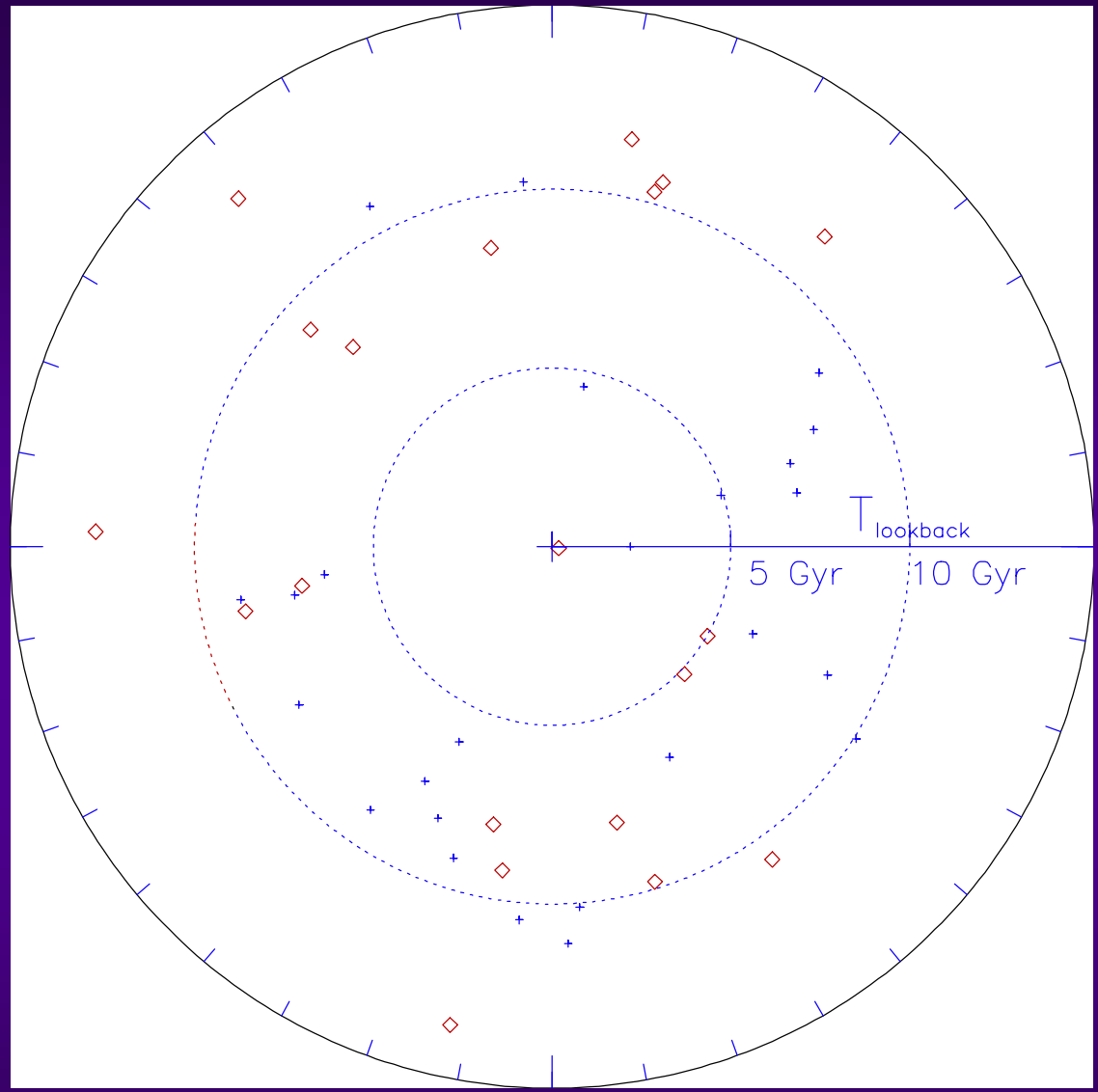
HST/STIS • February 1998

PRC98-17c • May 7, 1998 • ST ScI OPO
S. G. Djorgovski and S. R. Kulkarni (Caltech), the Caltech GRB Team,
W. M. Keck Observatory and NASA

Distances

up to z=4.5
$\Rightarrow 13 \cdot 10^9$ light years

could be used
to probe Universe
10× farther than SN

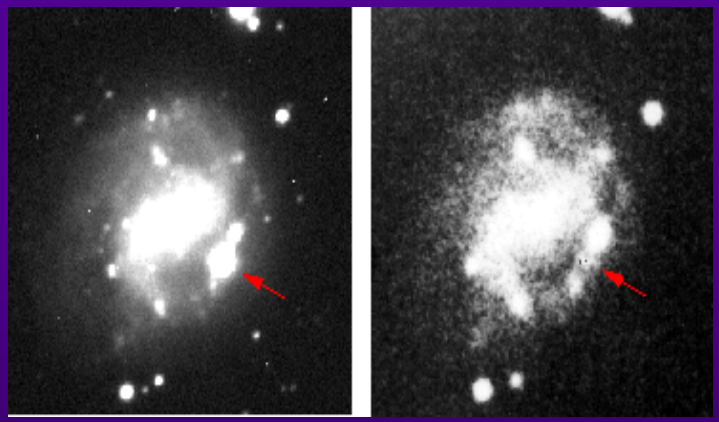


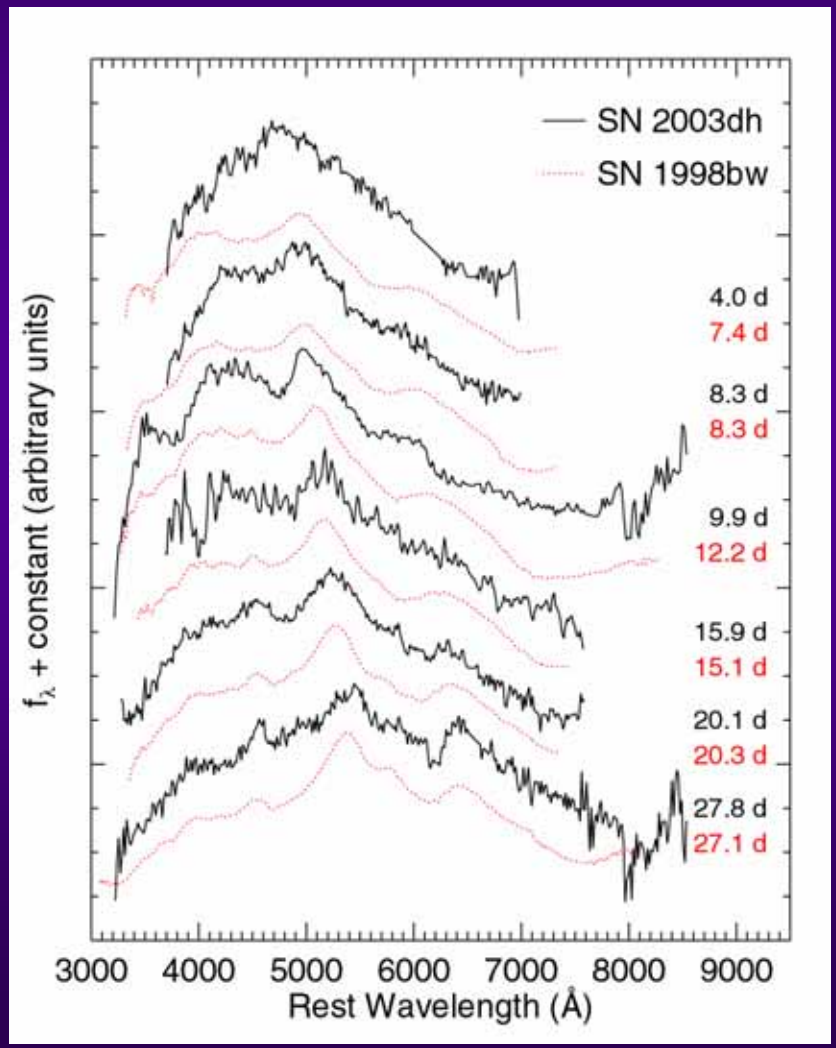
GRB's projected on galactic plane
visible Universe radius ≈14G light years

Supernowa SN1998bw

1998.04.25 – GRB discovered by BeppoSAX

- **very bright afterglow – 14^m**
  (all so far >20^m)
- **SN-like spectrum**
- **max. after 2 weeks**





Several GRB-SN pairs found so far

GeV photons from GRB's

Cosmic spark chamber EGRET

GRB	Max γ energy	Emission time
910503	10 GeV	84 s
910601	0.3 GeV	200 s
930131	1.2 GeV	100 s
940217	18 GeV	1.5 h
940301	0.2 GeV	30 s

GRB 940217

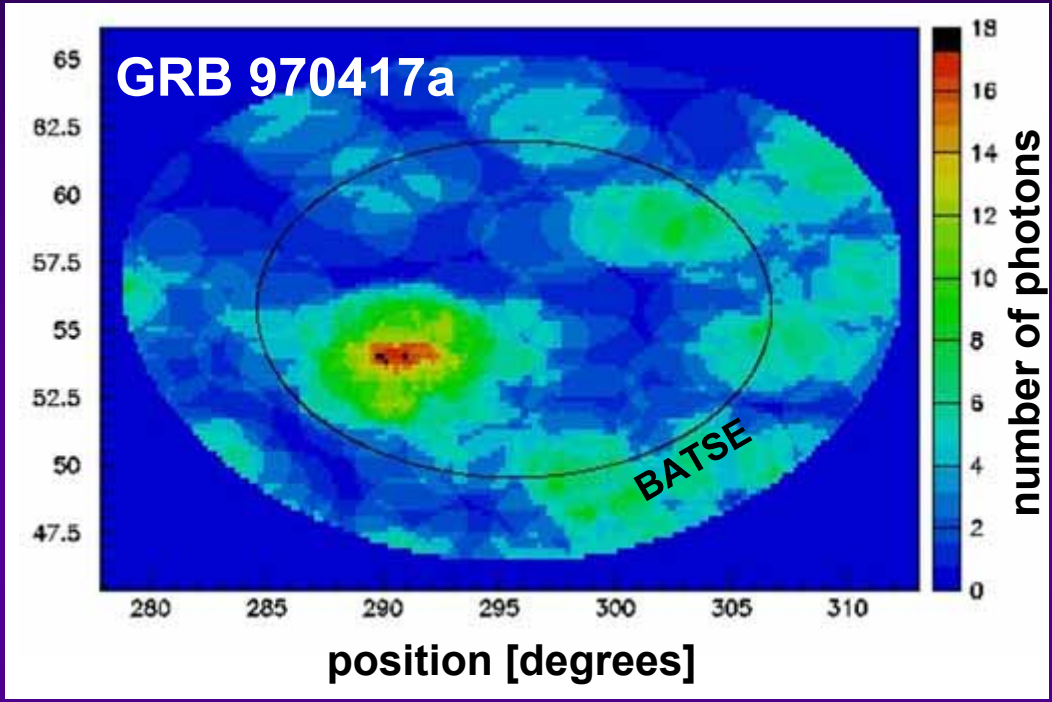
Ulysses/BATSE observed GRB (25-150 keV) 180 s long
EGRET observed 18 photons (>40 MeV) over 1.5 h !
3 of them had energy > 2 GeV

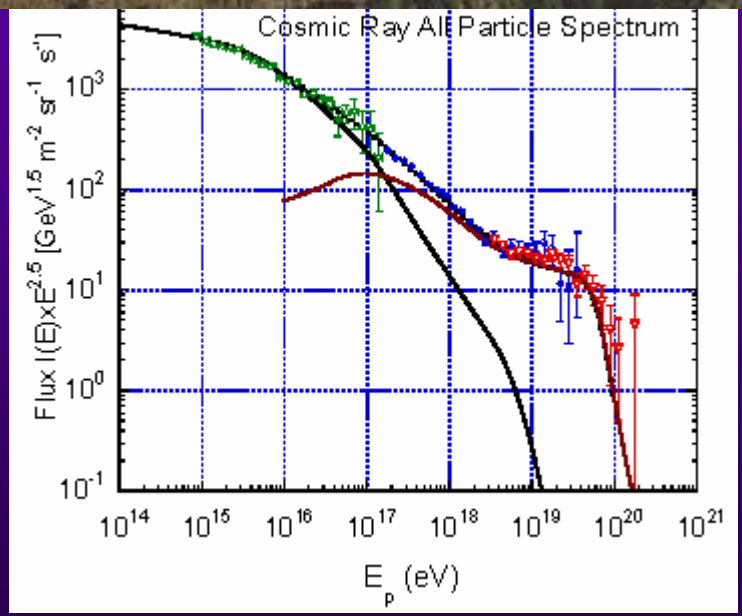
Why hard photons are late?

Different production mechanism?
Different speed?!

quantum gravity effects (J.Ellis et al., Nature 393, p.763)
extra spacial dimensions (K.S.Cheng, T.Harko, astro-ph/0407416)

TeV photons from GRB





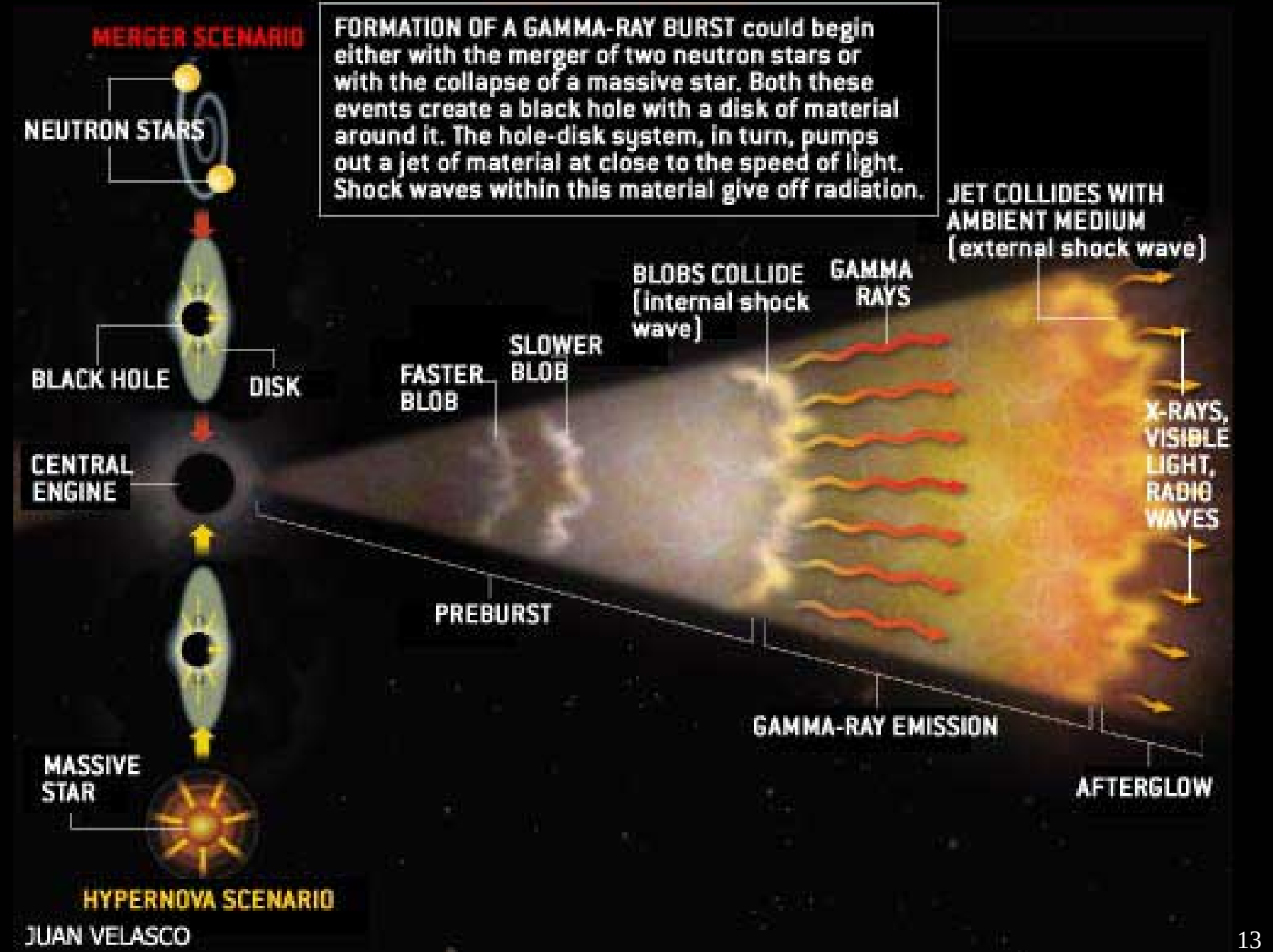
18 photons > 650 GeV during 8 s

Models proposed with GRB as cosmic ray sources.

E.g. astro-ph/0310667

points: KASKADE + HIRES I + HIRES II

curves: 1. galactic, 2. extragalactic


MERGER SCENARIO
FORMATION OF A GAMMA-RAY BURST could begin either with the merger of two neutron stars or with the collapse of a massive star. Both these events create a black hole with a disk of material around it. The hole-disk system, in turn, pumps out a jet of material at close to the speed of light. Shock waves within this material give off radiation.
NEUTRON STARS
JET COLLIDES WITH AMBIENT MEDIUM (external shock wave)
BLOBS COLLIDE (internal shock wave)
GAMMA RAYS
SLOWER BLOB
FASTER BLOB
BLACK HOLE
DISK
X-RAYS, VISIBLE LIGHT, RADIO WAVES
CENTRAL ENGINE
PREBURST
GAMMA-RAY EMISSION
AFTERGLOW
MASSIVE STAR
HYPERNOVA SCENARIO
JUAN VELASCO

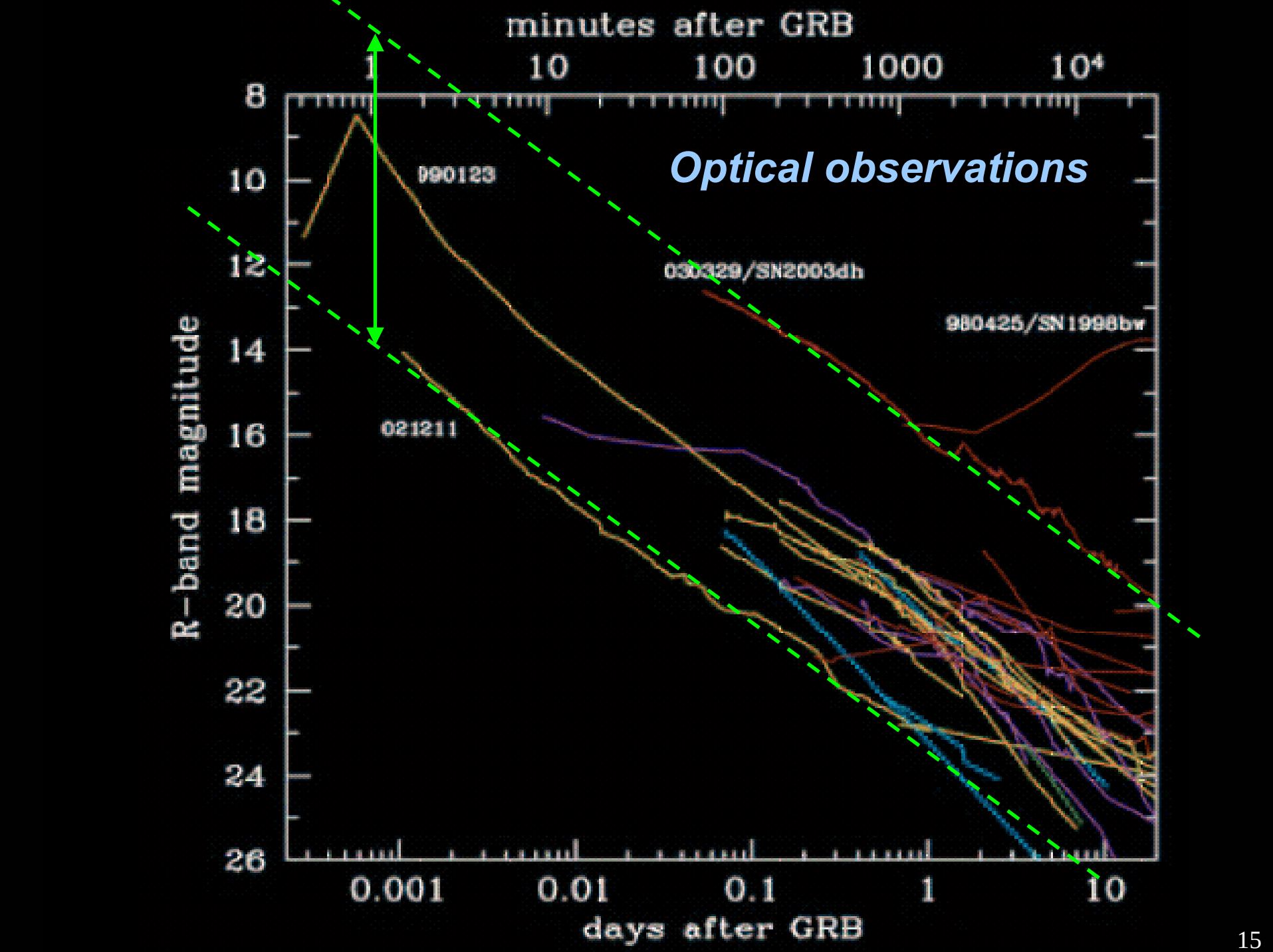
GRB's today and tomorrow

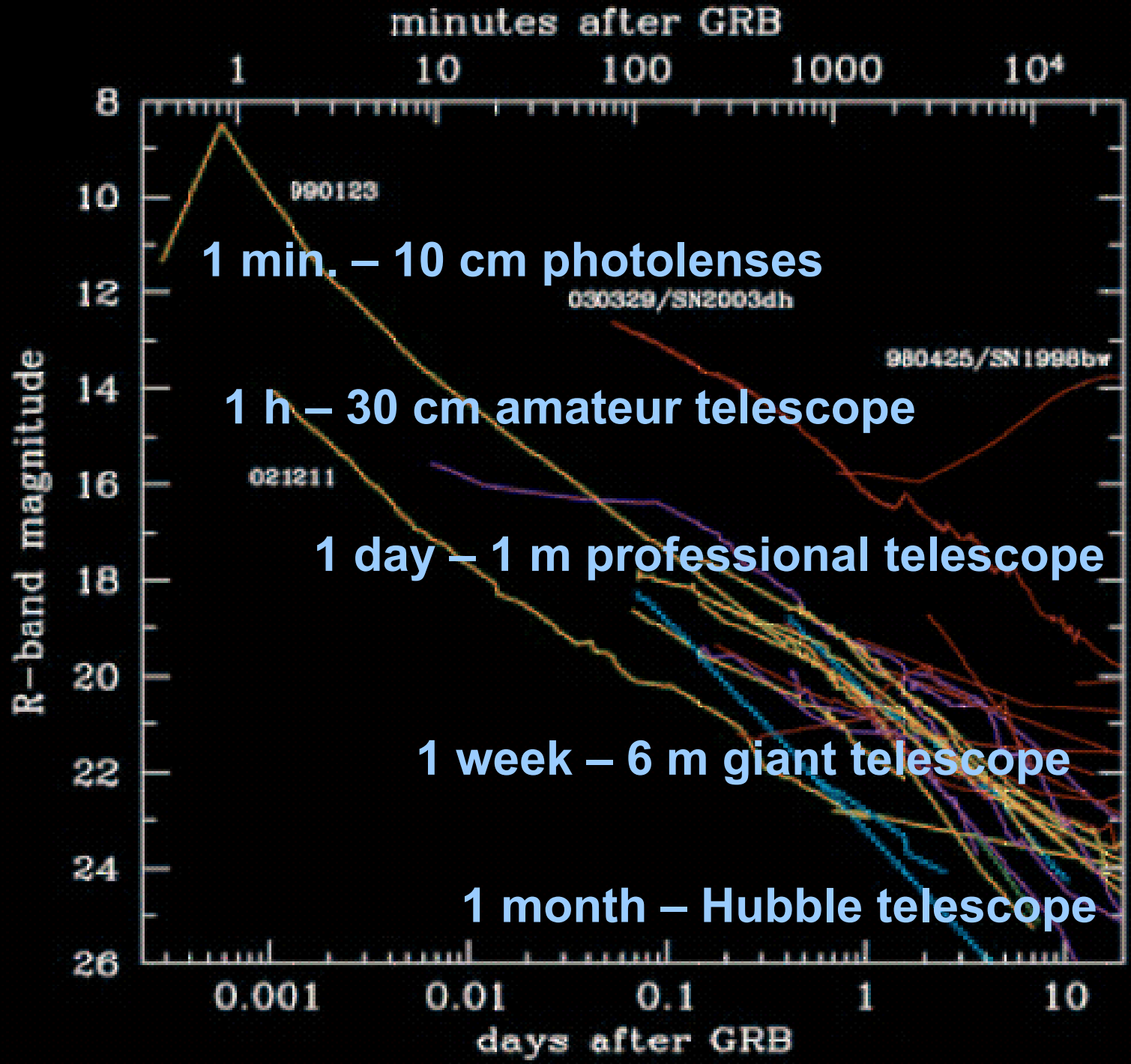
Today:

- gamma emission well understood
- central engine(s) still uncertain

Tomorrow:

- coincidence with TeV photons, neutrinos, etc
- optical observations before and during GRB


minutes after GRB
1
10
100
1000
10⁴
8
10
12
14
16
18
20
22
24
26
R-band magnitude
990123
030329/SN2003dh
980425/SN1998bw
021211
Optical observations
0.001
0.01
0.1
1
10
days after GRB


minutes after GRB
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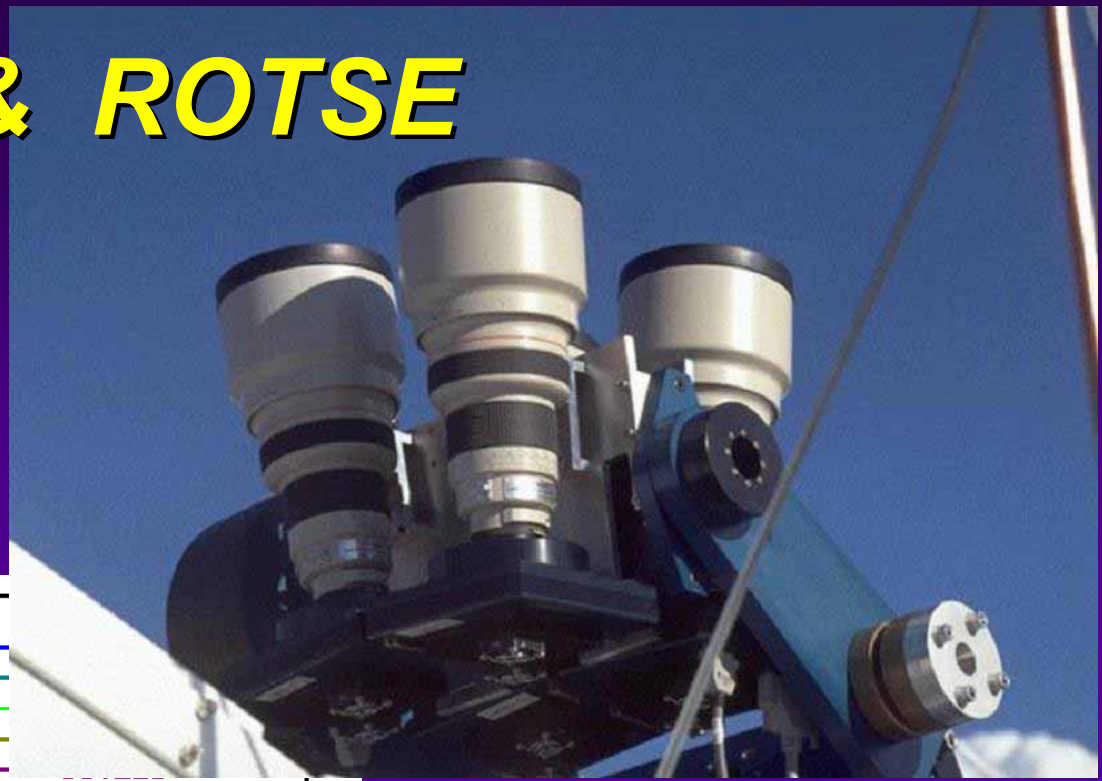
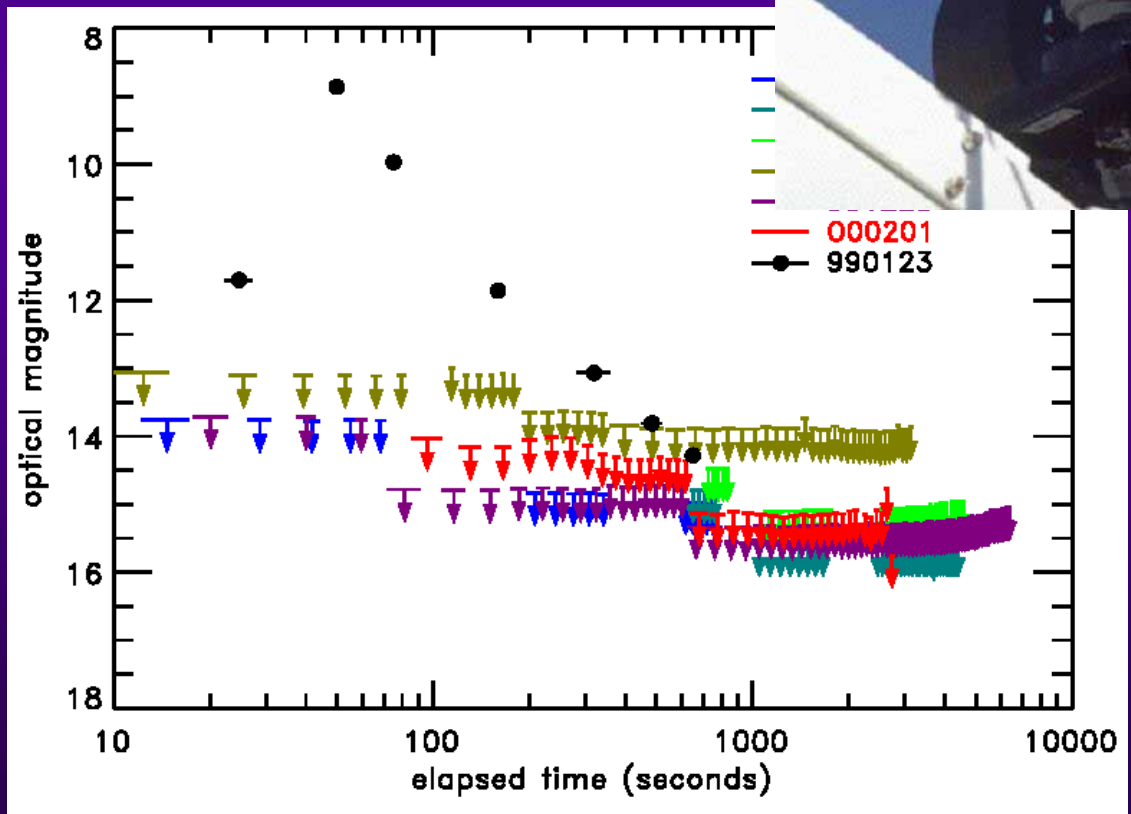
18
20
22
24
26
R-band magnitude
990123
030329/SN2003dh
980425/SN1998bw
021211
1 min. – 10 cm photolenses
1 h – 30 cm amateur telescope
1 day – 1 m professional telescope
1 week – 6 m giant telescope
1 month – Hubble telescope
0.001
0.01
0.1
1
10
days after GRB

BATSE & ROTSE

4 telephoto lenses
CANON d=10 cm
robotic mount
follows GCN alerts





Images 1999.01.23
20 s after BATSE alert

Optical flash 9^m !
could be seen by binocular!

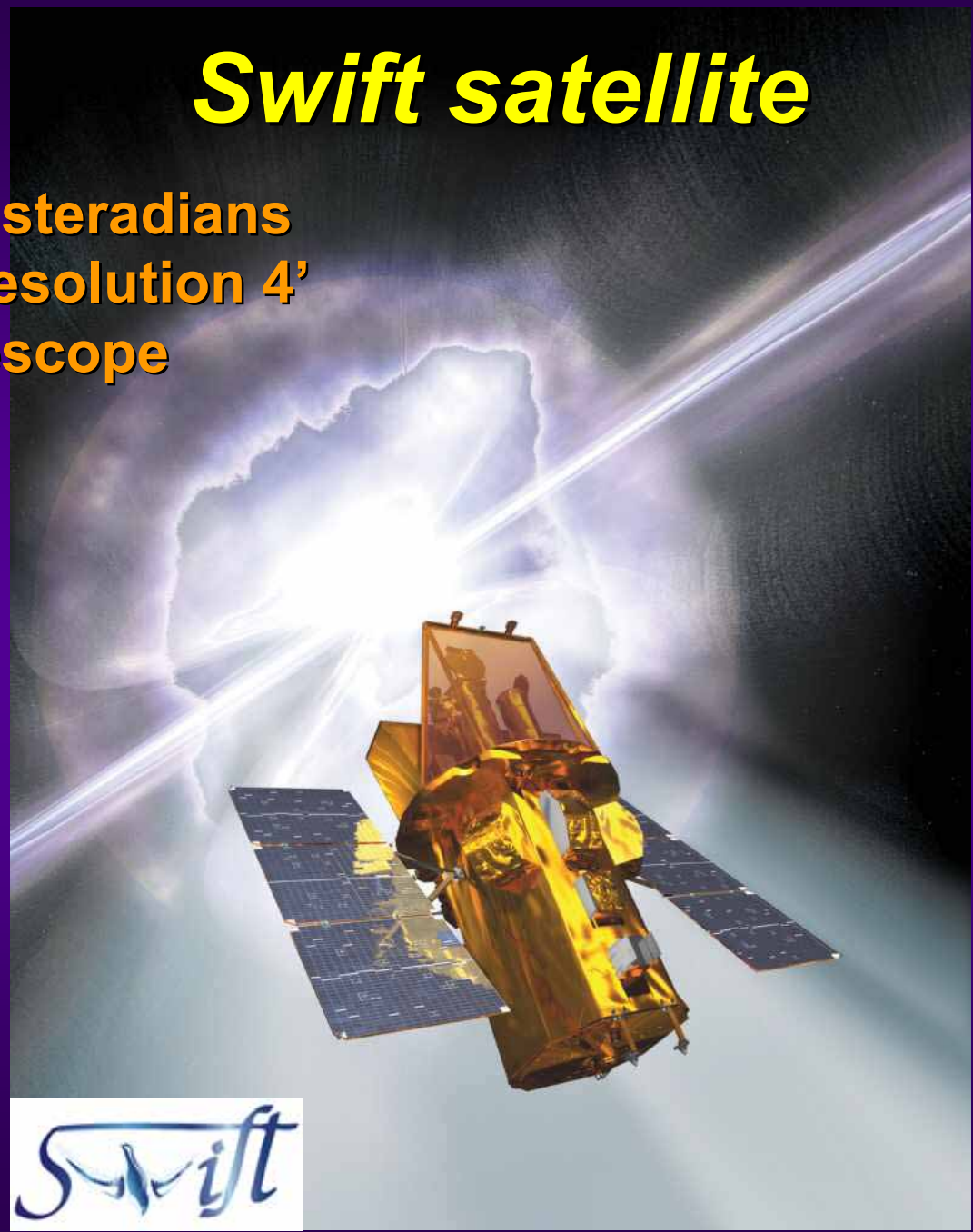
The brightest so far

Swift satellite

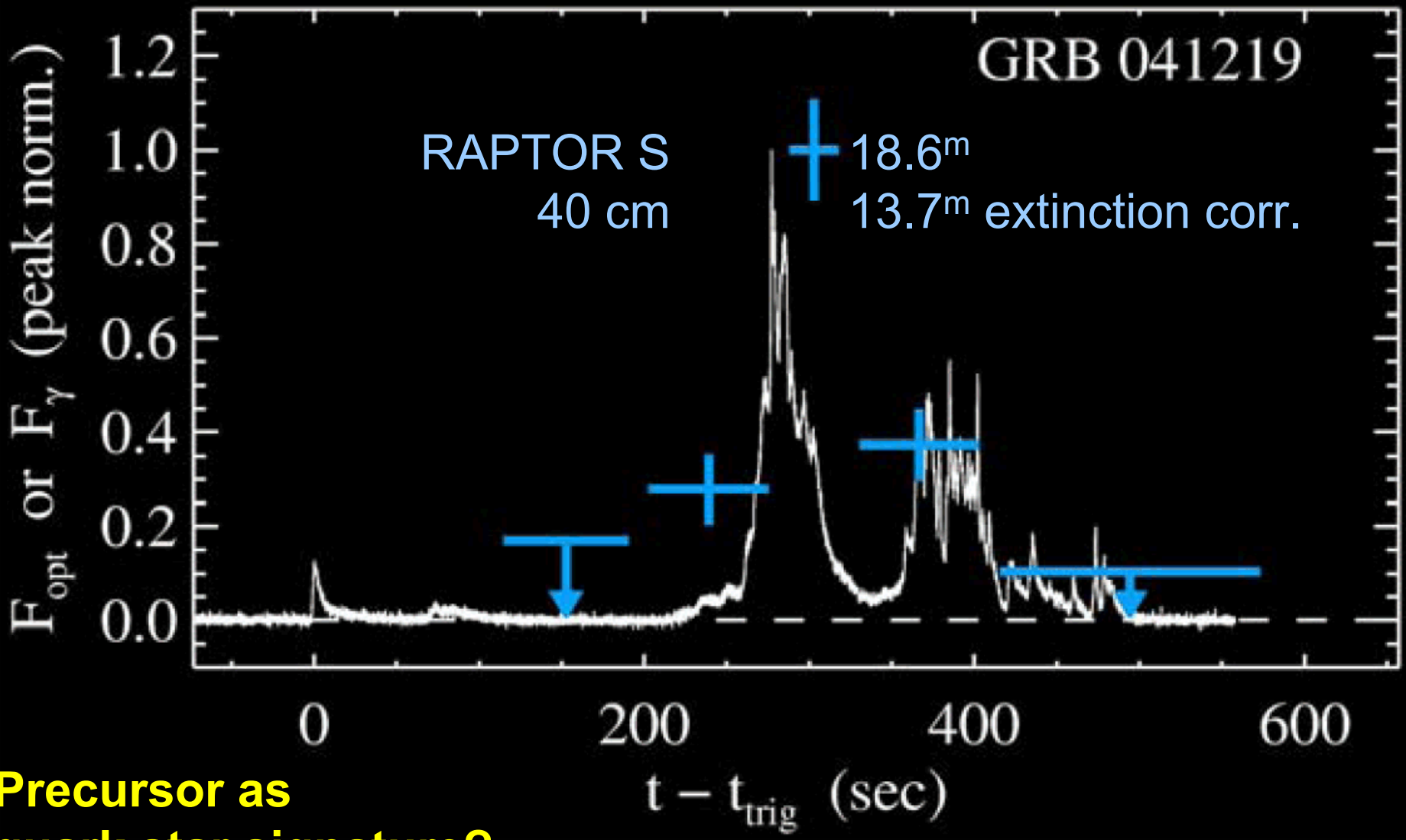
Launched Nov. 2004

3 instruments:

- **BAT – γ-ray detector: 2 steradians**
- **XRT – X-ray detector: resolution 4'**
- **UVOT – optical+UV telescope**

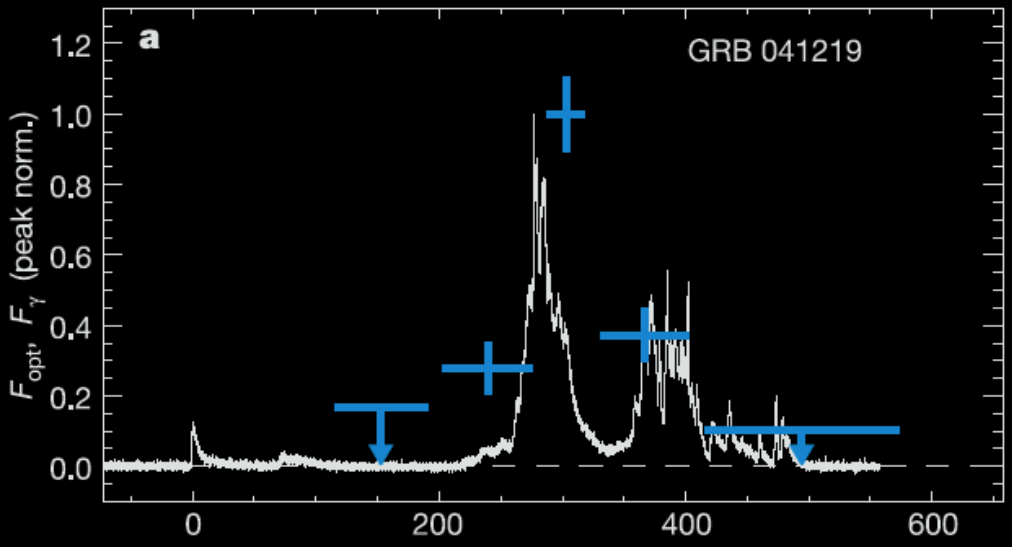


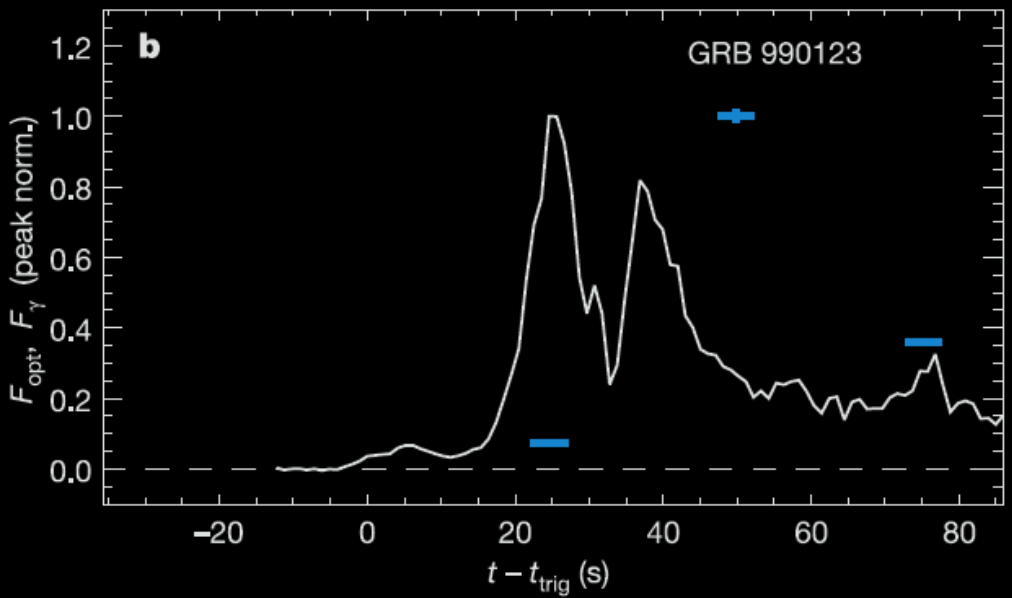
Optical observation before GRB!



Precursor as quark star signature?

B.Paczyński & P.Haensel, astro-ph/0502297





GRB 050820
optical peak 7 min. after GRB

Prompt optical emission

Crucial to understand GRB central engine

Begins before, during or after GRB?

- **3 observed cases**
- **3 different answers**

More observations very much needed!

Catching prompt optical emission

No one knows were the next GRB will happen

Two approaches:

- **wait for GRB alert and move there quickly**
  - **robotic telescopes listening to GCN:**
  - **BOOTES, (SUPER)LOTIS, MASTER, RAPTOR, REM, ROTSE, TAROT, ...**
- **look everywhere**
  - **robotic telescopes with self-triggering watching ~all sky continuously:**
  - **„π of the Sky" – π steradians field of view**

„π of the Sky”

Concept:

- continuous ~all sky survey (32×3000 images / night)
- large data stream (1 Terabyte / night)
- real time analysis
- multilevel trigger

Project:

- 2×16 CCD cameras, each 2000×2000 pixels
- Canon lenses f=85mm, f/d=1.2
- field of view = 2 steradians = Swift BAT

Collaboration:

- Soltan Institute for Nuclear Studies, Warsaw
- Center for Theoretical Physics PAS, Warsaw
- Warsaw University
- Warsaw University of Technology
- Cardinal Stefan Wyszyński University, Warsaw

„π of the Sky" prototype

- 2 CCD cameras 2000×2000 pixels
  custom design, 2Mpixels/s, USB2.0
- Zeiss lenses f=50mm, d=f /1.4
- common field of view 33°×33°

- robotic mount
- < 1 min. to any point in the sky

„π of the Sky”: robotic detector

Autonomic operation according to programme:

- follows HETE or INTEGRAL field of view
- detects itself optical flashes
- all sky survey twice a night (2×20min)
- follows targets of GCN alerts

High reliability:

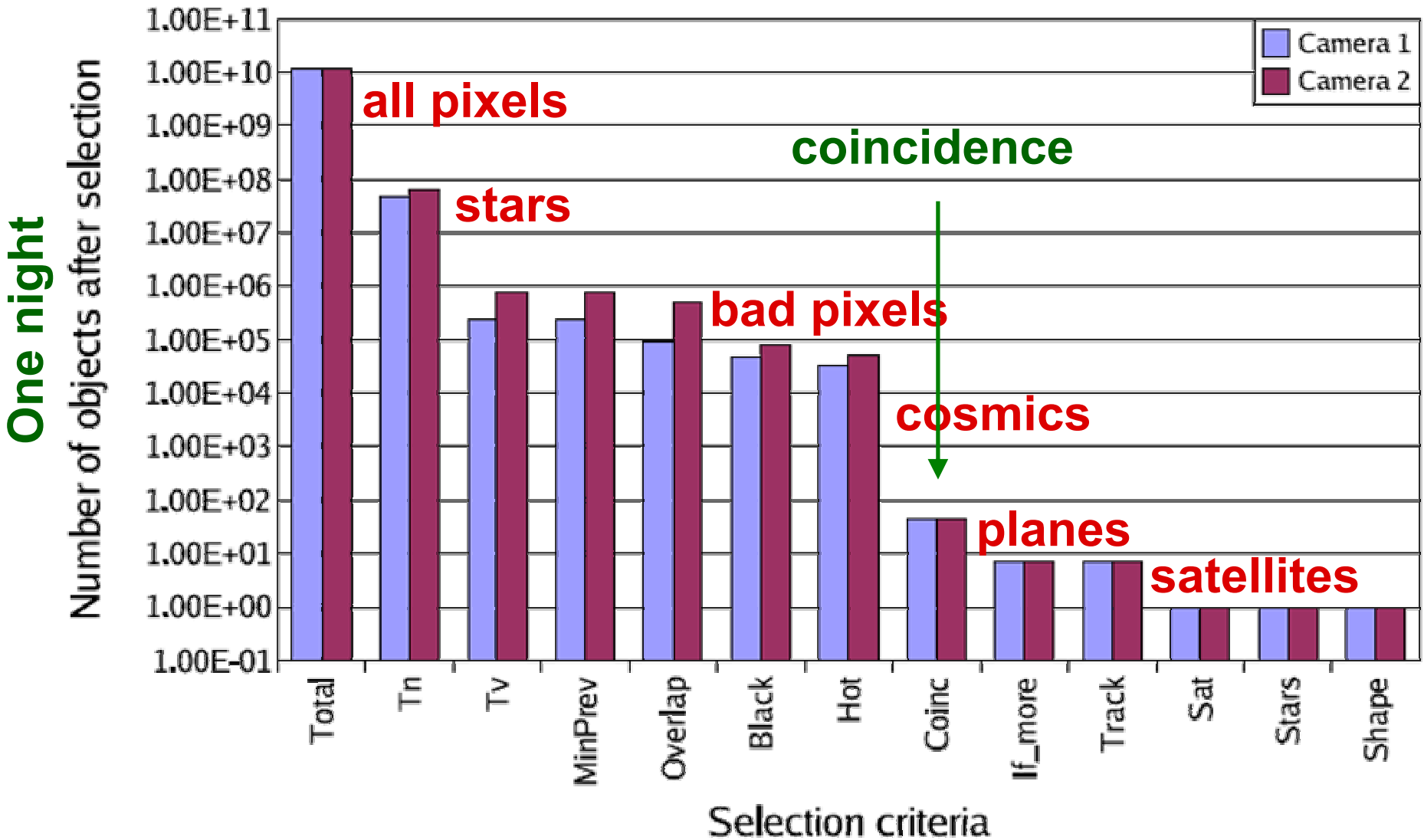
- remote-reset, Wake-on-LAN, Boot-from-LAN
- selfdiagnostics (e-mail and SMS to Poland)

During one year of operation:

- ~10 nights lost due to apparatus problems
  + ~30 nights lost due to weather
- > 300 „good” nights, 1 000 000 sky images,
  10^{10} photometric measurements

Flash recognition in real time

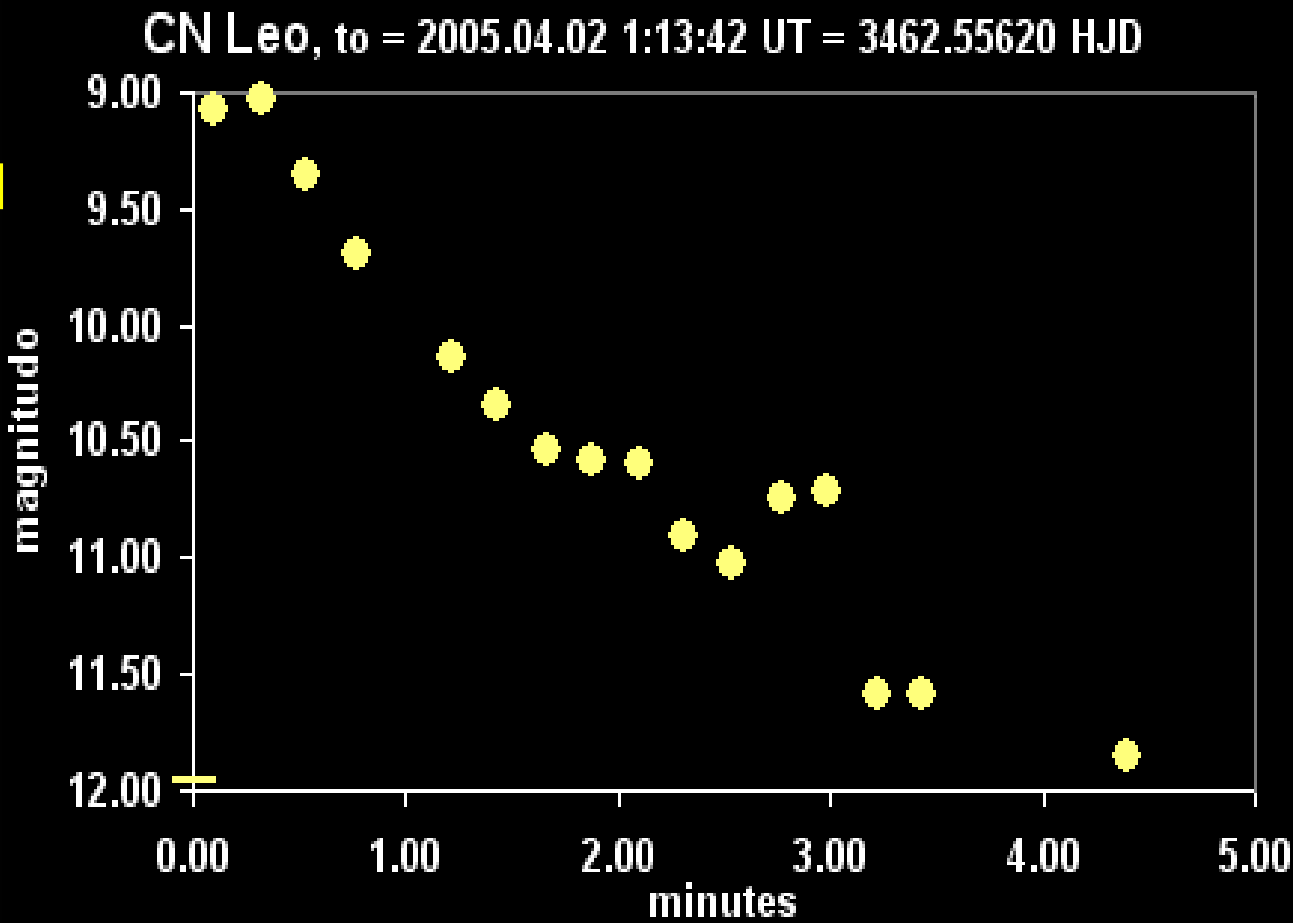
multilevel trigger concept



Search for cosmic flashes

„π of the Sky" prototype at LCO, July 2004 – July 2005

- ~100 flashes seen by both cameras, in one frame only
  (could be satellites reflecting sunlight)
- 6 flashes seen in >1 frame
  neither confirmed nor excluded by others
- 1 flash identified as CN Leo flare star outburst
  100× brighter in <1s,
  faded in 5 min



„π of the Sky”: GRB observations

89 GRB's discovered by satellites 7.2004-7.2005:

5 – clouds (4) or apparatus off (1)

18 – Northen hemisphere

48 – daytime or below horizon

16 – outside field of view, 4 limits better than others

GRB 040916B, $>13^m$ for $t > t_0+17min$ (publ. GCN 2725)
GRB 041217, $>11.5^m$ for $t > t_0+30min$ (publ. GCN 2862)
GRB 050123, $>12^m$ for $t < t_0-108min$ (publ. GCN 2970)
GRB 050326, $>11^m$ for $t < t_0-33min$ (publ. GCN 3146)

2 – within FOV: GRB 040825A (published: GCN 2677)

$>10^m$ for $t < t_0-11s$
$>12^m$ for $t = t_0$
$>9.5^m$ for $t > t_0+7s$

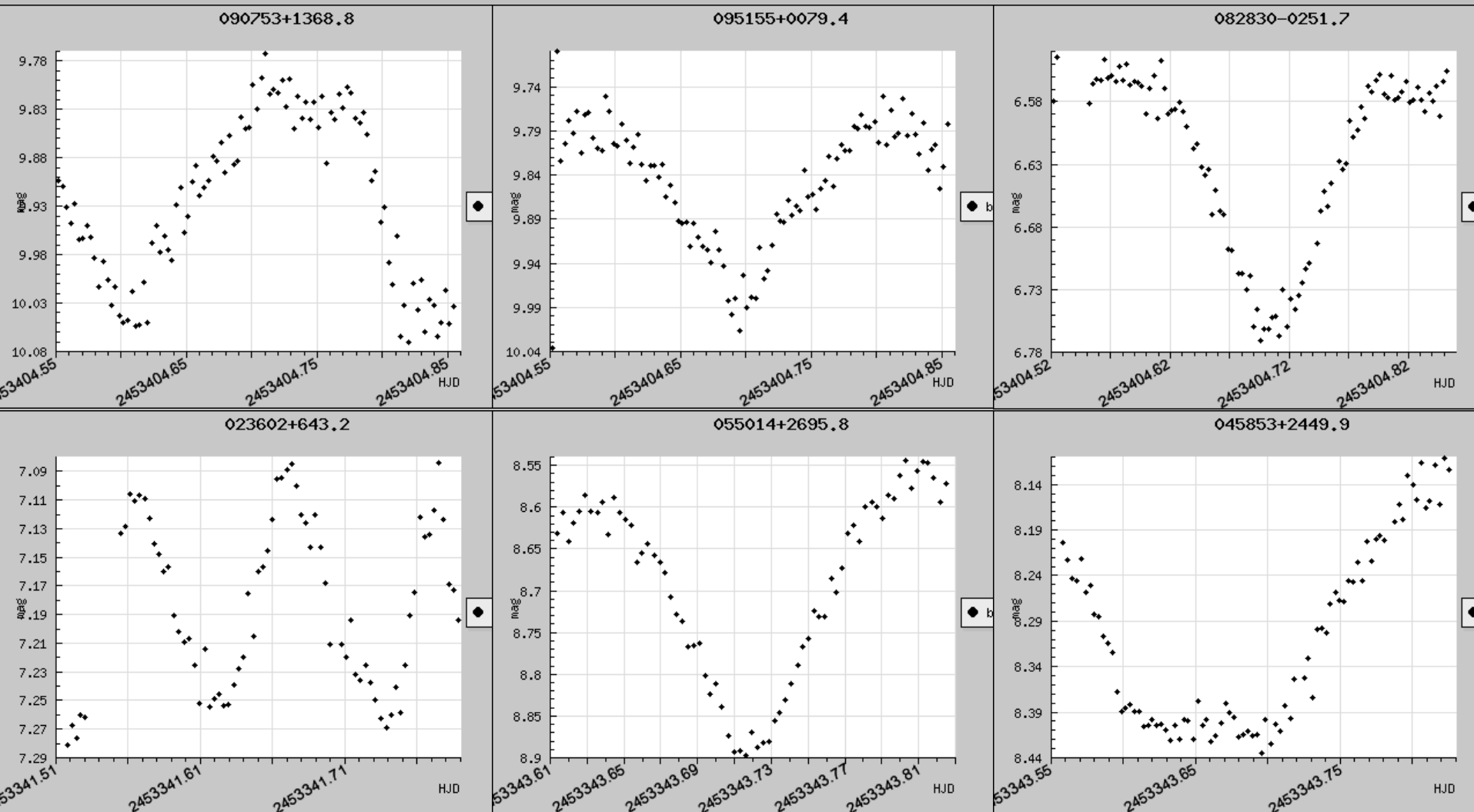
limits before and during GRB

GRB 050412 (GCN 3240) **$>11.5^m$ / $>11^m$ / $>11.5^m$**

„π of the Sky” general goal:

study objects varying on scales from seconds to months

Examples of night-life of stars - brightness vs time (one night)



„π of the Sky" perspectives

- **LCO prototype being upgraded**
  85mm/1.2 lenses, range increased by 1.5^m
- **Analysis of the first year data in progress**
  400 000 stars, each 25 000 measurements
- **Full size apparatus under construction**
  2×16 cameras, 2×2 steradians

We are looking for good site

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and enjoy pretty images
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