XXIX Mazurian Lakes Conference 30.8–6.9.2005, Piaski, Poland
"Nuclear Physics and the Fundamental Processes"

# *Gamma Ray Bursts and their optical counterparts*

- Historical overview
- Present status
- Perspectives

Experiment „$\pi$ *of the Sky"*
*http://grb.fuw.edu.pl*

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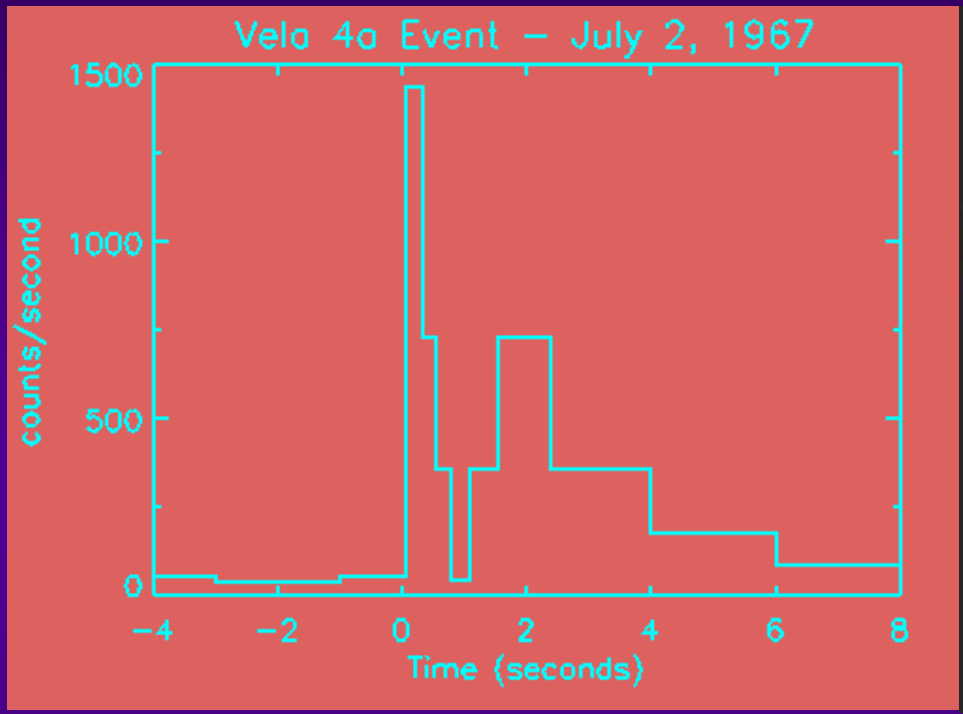
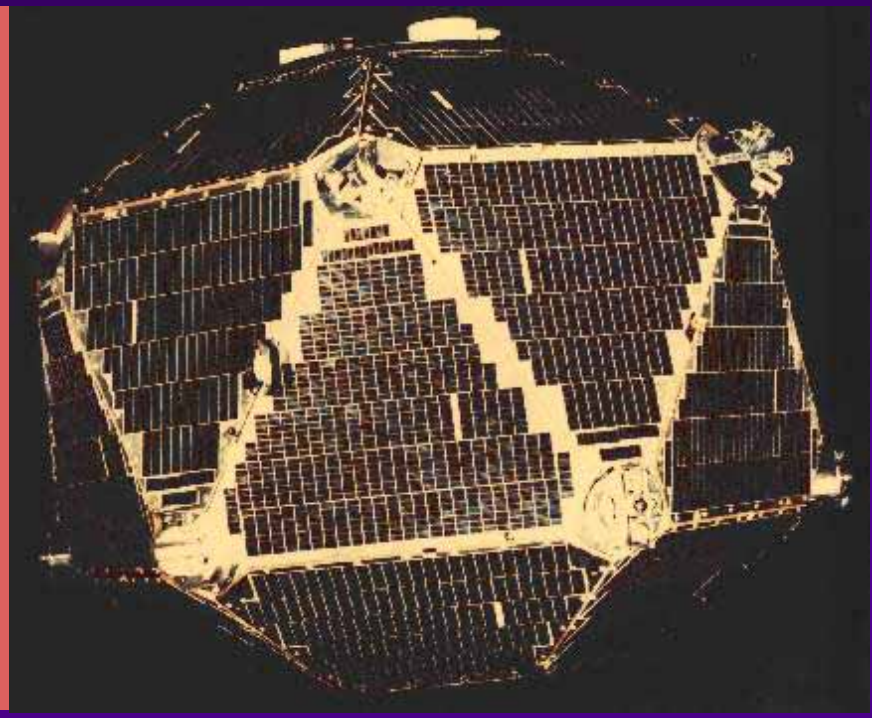
# *Gamma Ray Bursts - GRB*

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

# GRB discovery



- Military satellites VELA sent to monitor nuclear treaty
- 2.6.1967 VELA 4A & 4B observe strange pulses
- 16 GRB's till 1973, ~isotropic distribution
- More GRB seen by InterPlanetary Network of spacecrafts

# Status in 1990

**>95% astronomers: galactic origin**

**Ed Fenimore, Martin Rees, Donald Lamb, ...**

- **GRB in Magellanic Cloud in place of old SN**
- **spectral lines**
- **small energy enough to explain**
- **optical flashes found at old photo-plates**
- **compactness problem** ($\gamma$ >1MeV $\Rightarrow$ $e^+e^-$)

**<5% astronomers: extragalactic origin**

**Bohdan Paczyński, ...**

- **deficit of weak bursts**
- **izotropic distribtion**

# Status in 1990 – from 2005 perspective

**Today we know that all the arguments were based on false assumptions ...**

## *Galactic origin?*

- GRB in Magellanic Cloud in place of old supernova
  - it was Soft Gamma Repeater = magnetar
- spectral lines – deconvolution effect
- small energy enough to explain – but not necessary
- optical flashes found at old photo-plates
  - evidence questioned after reanalysis
- compactness problem – solved by Lorentz boost

## *Extragalactic origin?*

- deficit of weak bursts – apparatus threshold effect
- izotropic distribtion – could be in galactic halo or within the thickness of galactic disk

# *The Great Debate bis*

**1920.04.26 – The Great Debate**
**about distances in the Universe**
**What are nebulas?**
**Galaxies or objects in our Galaxy?**
**Harlow Shapley – Heber Curtis**

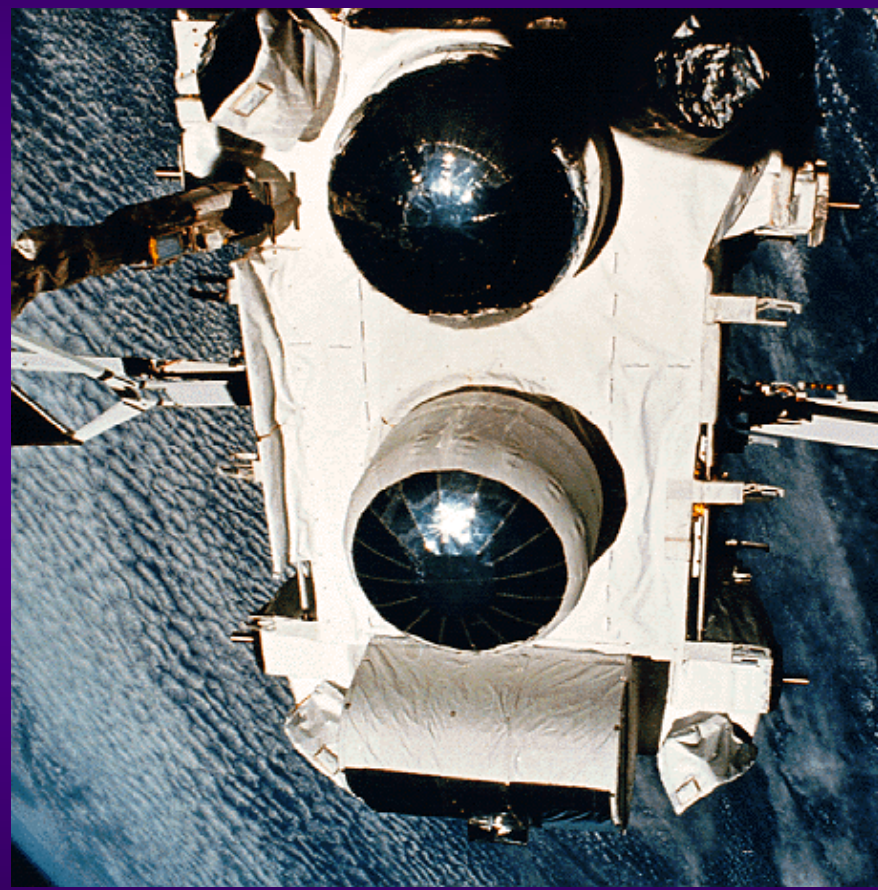

**1995.04.22 – The Great Debate 2**
**GRB are in our Galaxy**
**or in distant Universe?**
**Don Lamb – Bohdan Paczyński**
Lead by: **Martin Rees**

# *Burst And Transient Source Experiment*

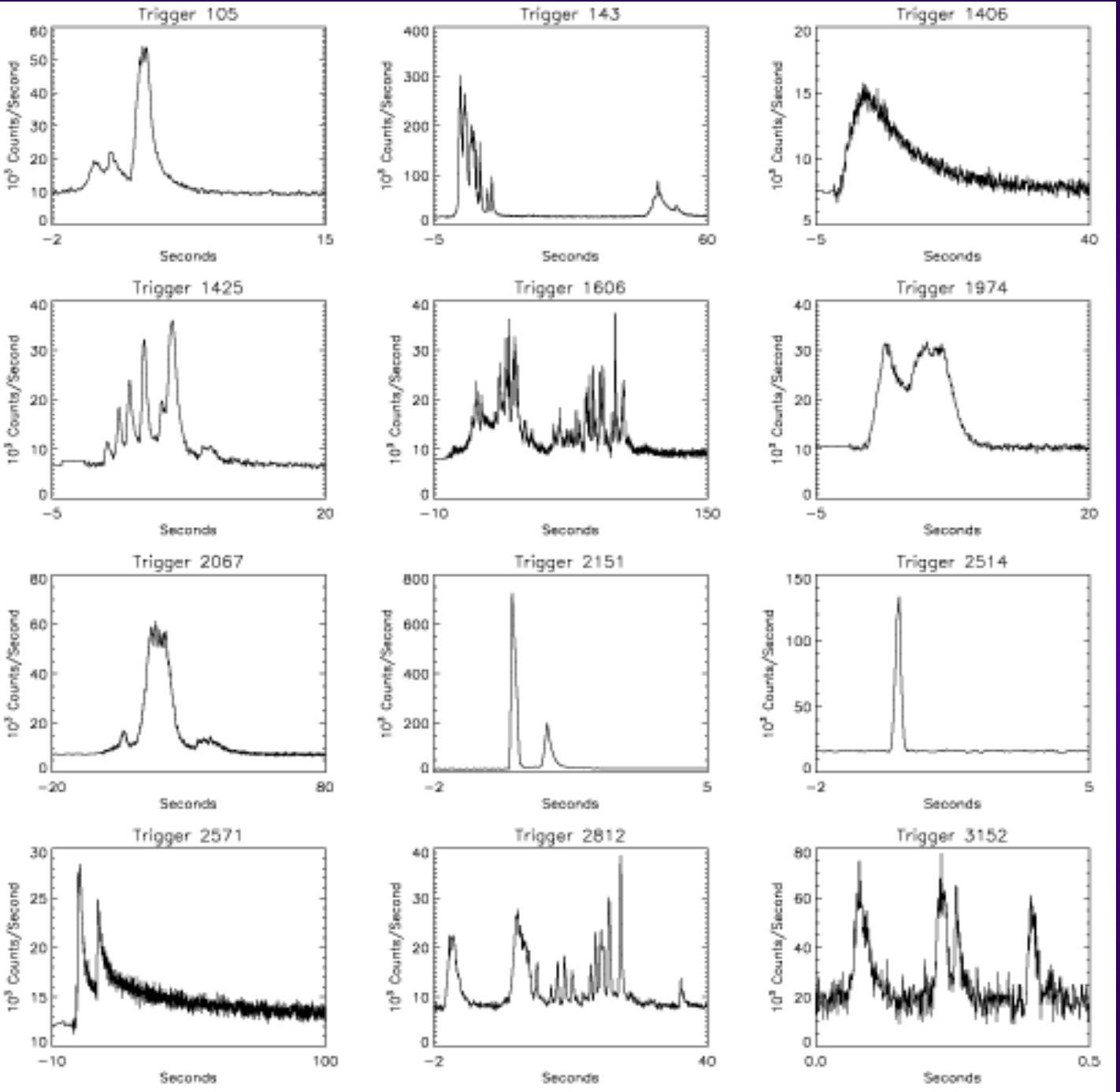
## at Compton Gamma Ray Observatory satellite

**Launched in 1991**

- ~1 GRB discovered / day
- ~3000 GRB's observed
- position: 4-10°

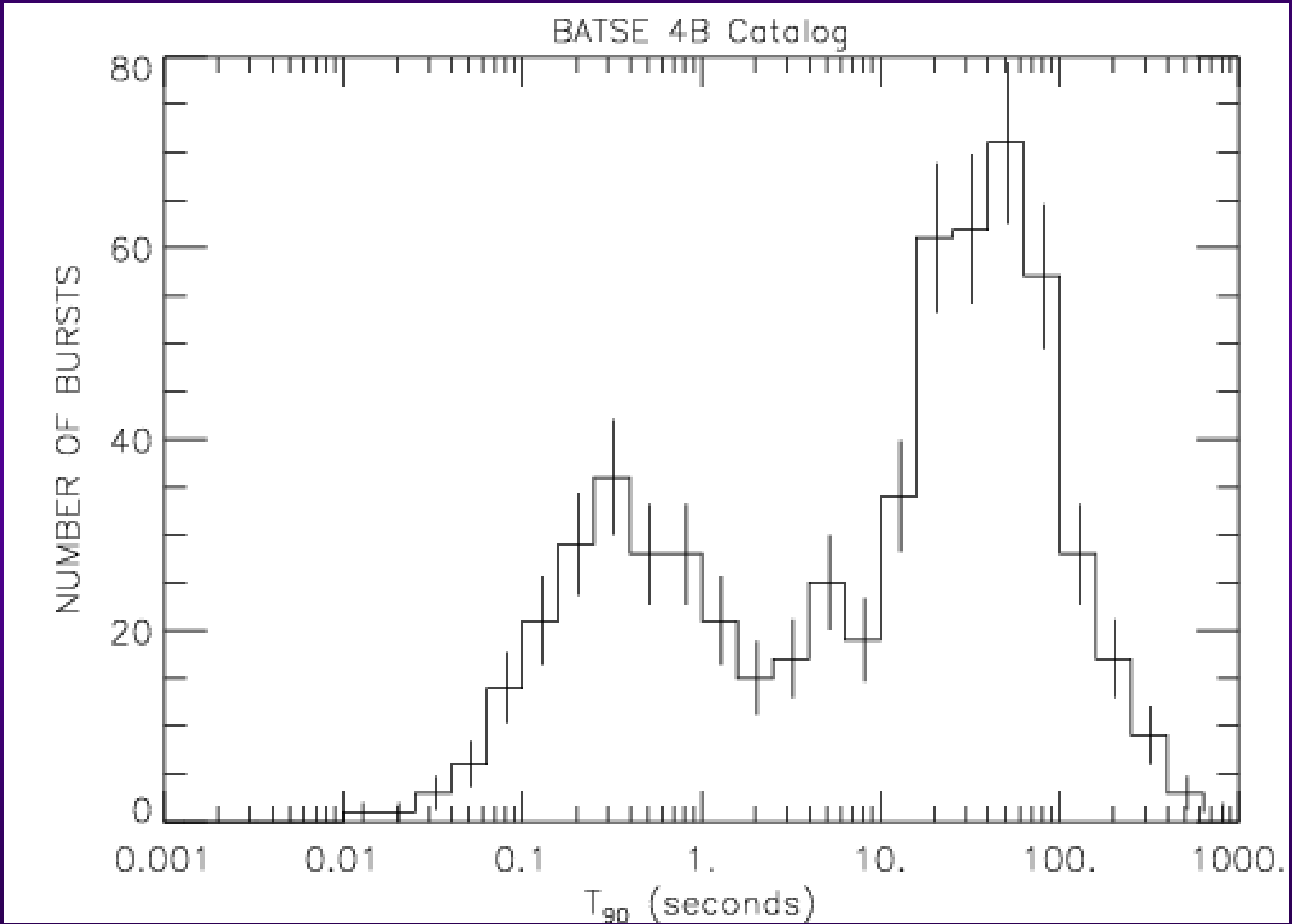
**Burned in 2000**
**for unclear reasons ☹**

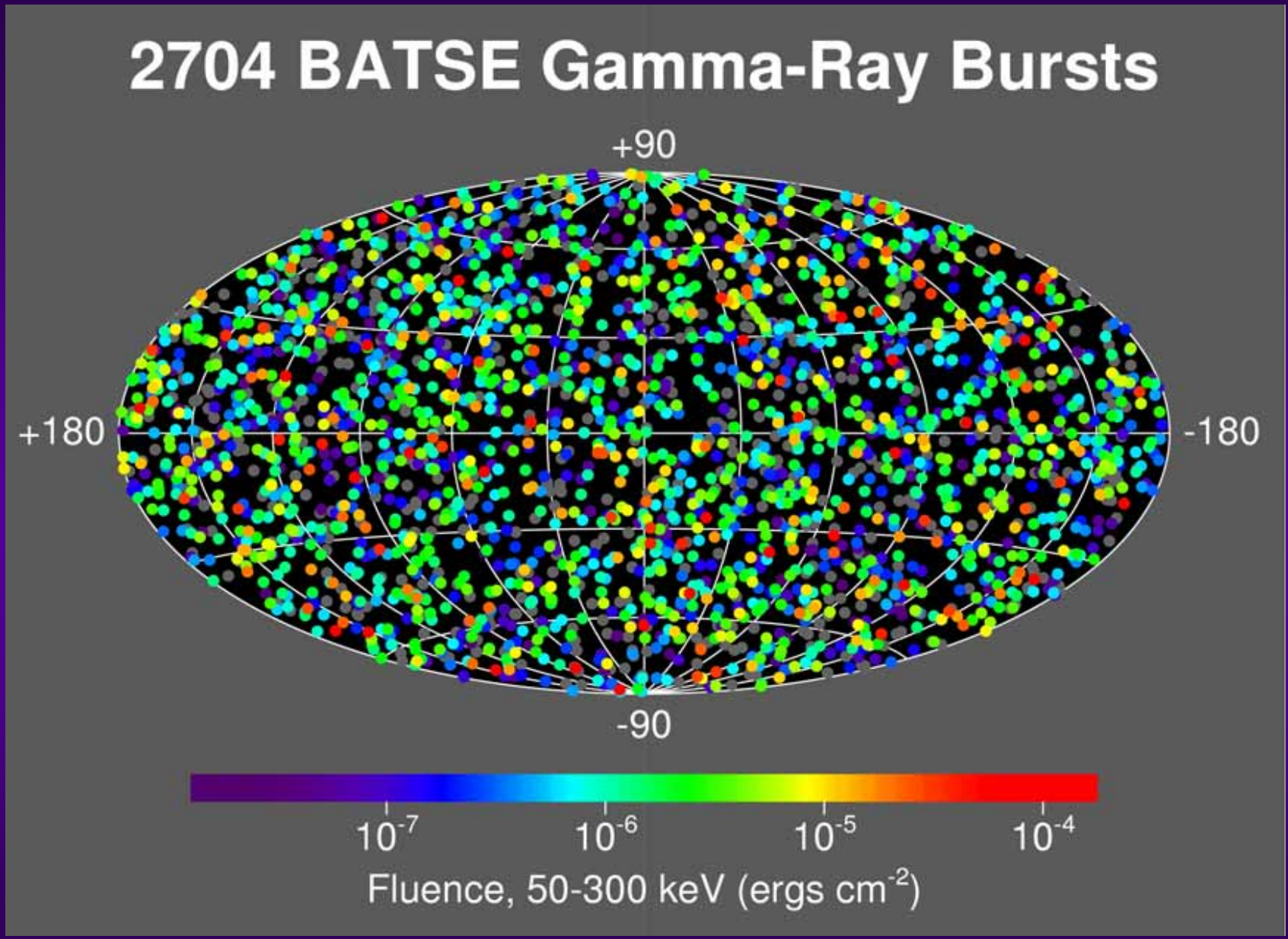



**Different shapes**

**Time: 0.01-100s**

# „Short" and „long" bursts



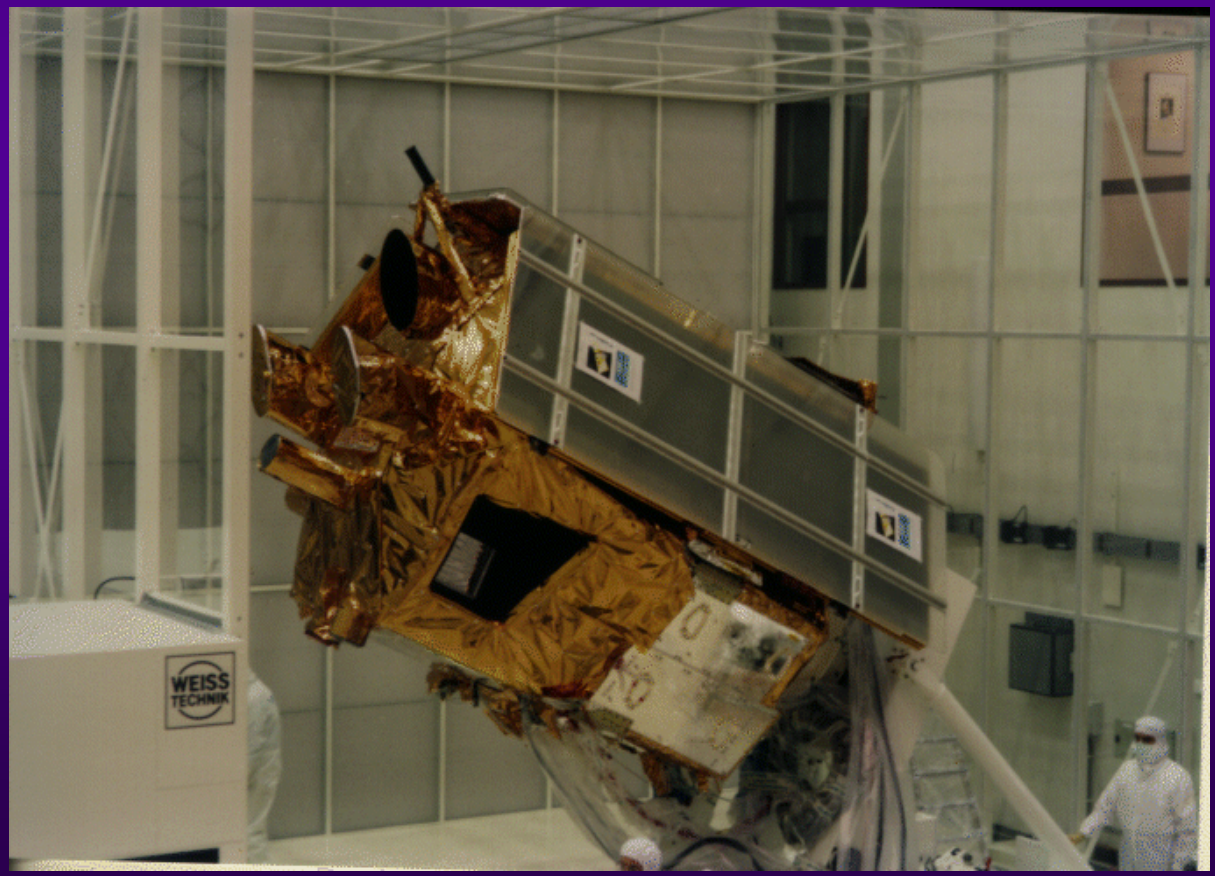



**Izotropic distribution in galactic coordinates**

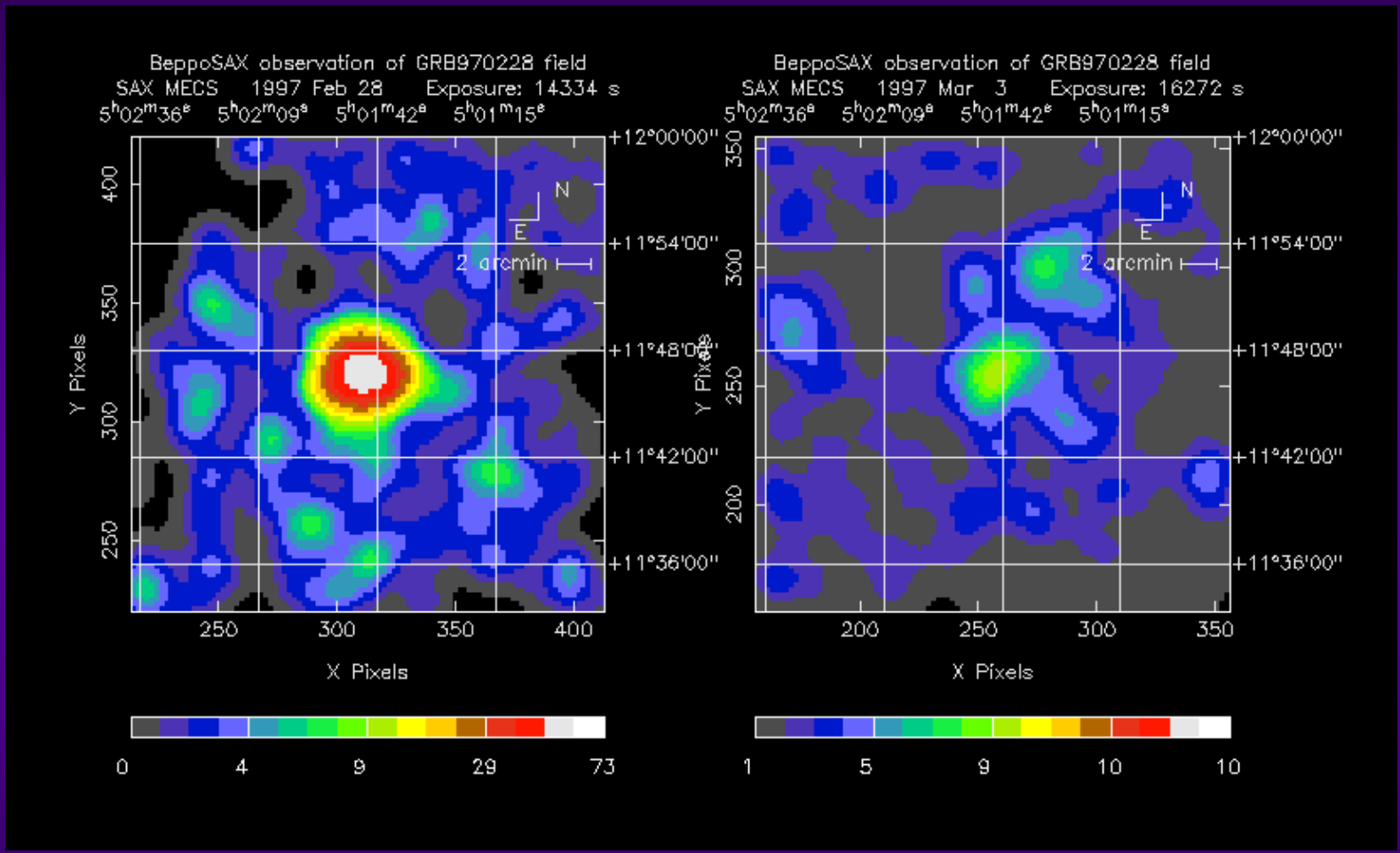
# BeppoSAX

**Italian-Dutch satellite launched in 1996**

- **wide field (40°) X-ray camera**
- **precise (resolution 3') X-ray camera**
- **$\gamma$-ray monitor**



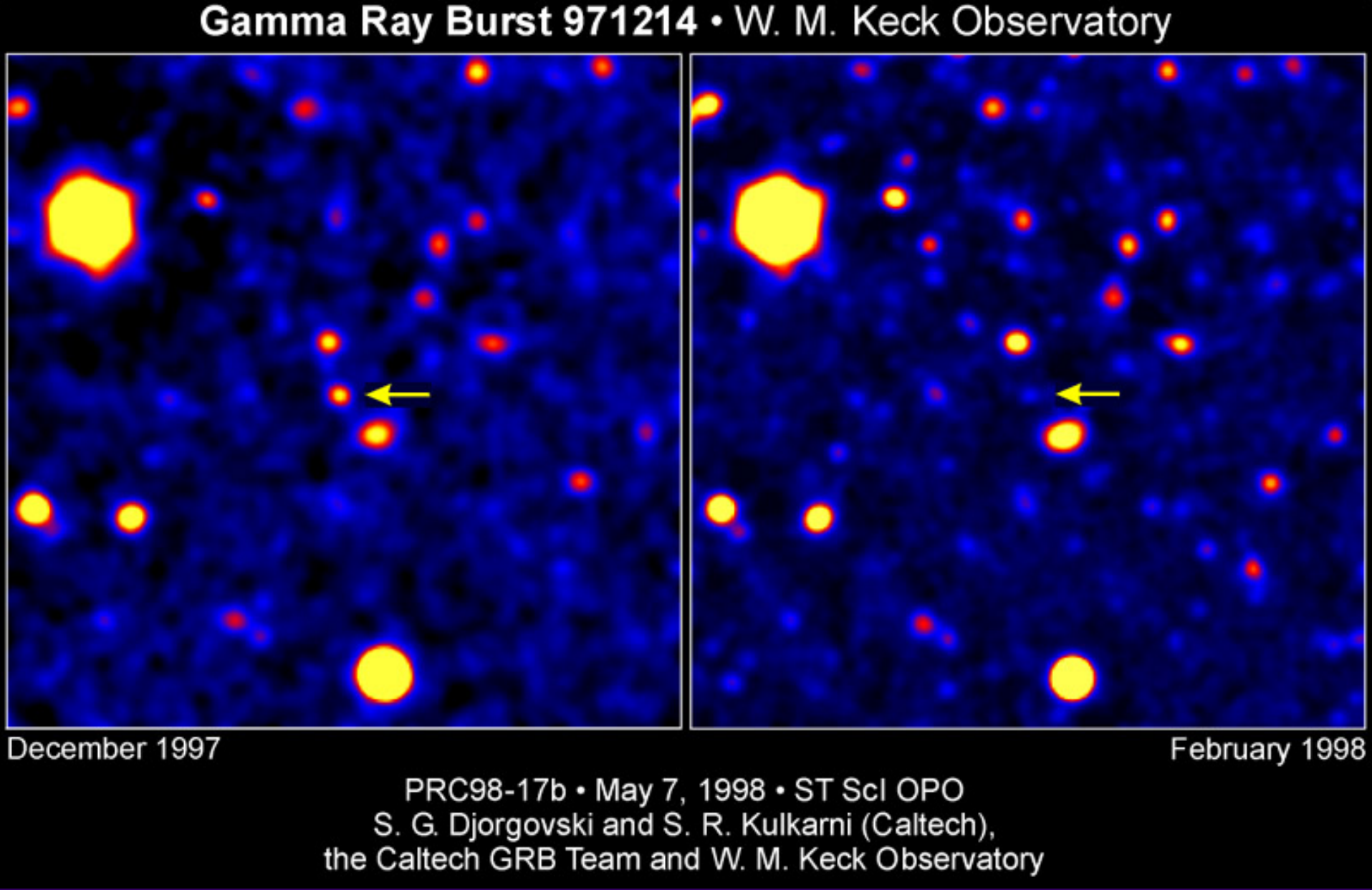
# First afterglows



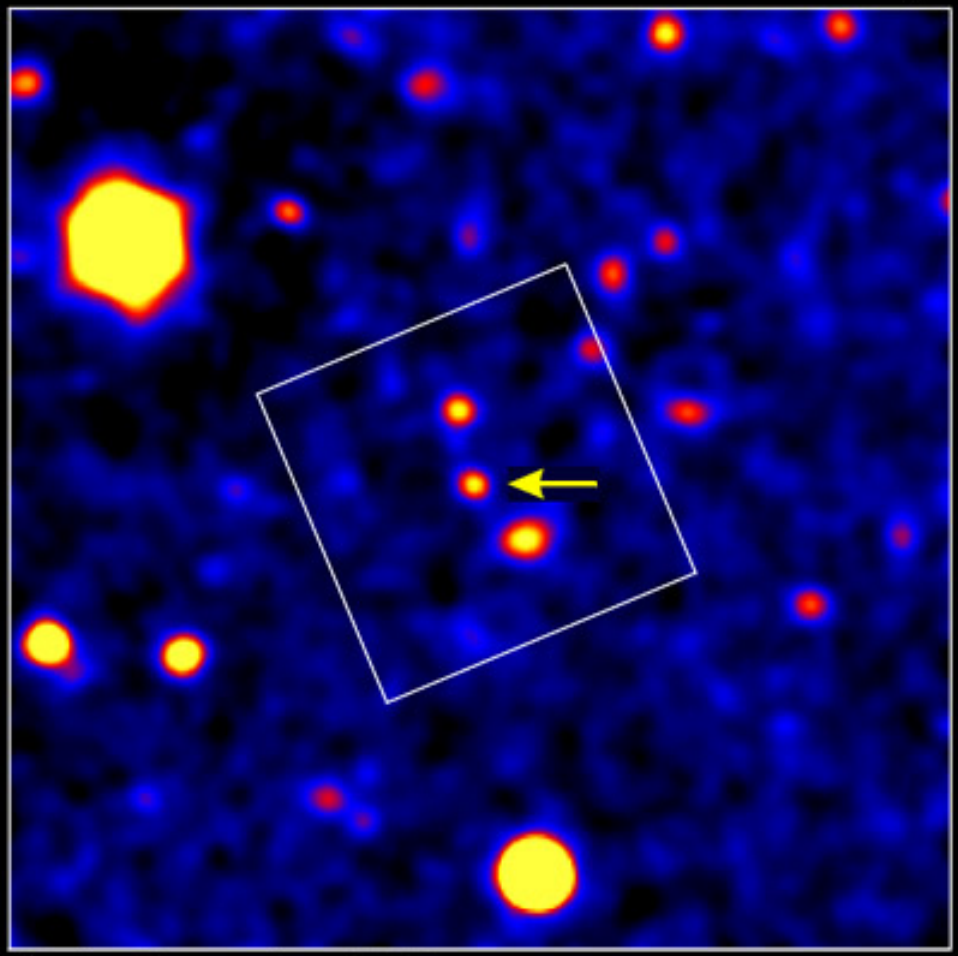

**1997.02.28 – GRB observed in X-rays**

**21 h later – optical observation**

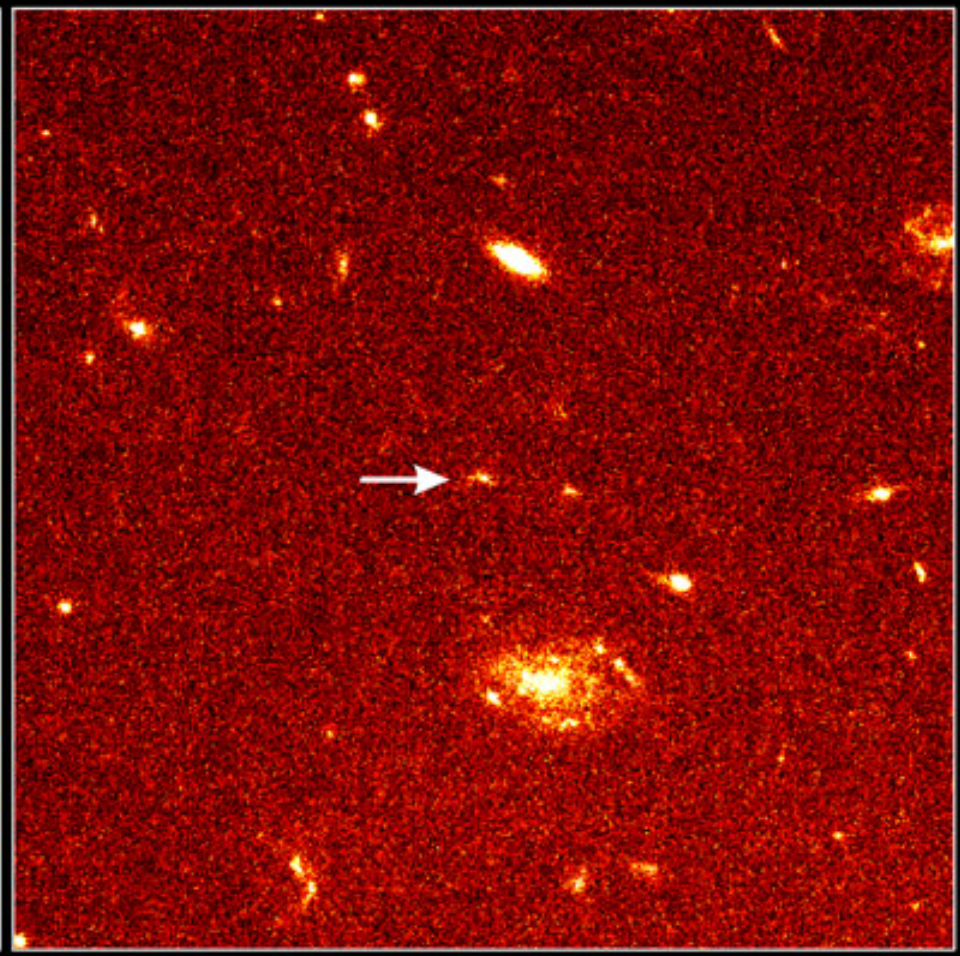
**William Herschel Telescope, 4.2m, La Palma**


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



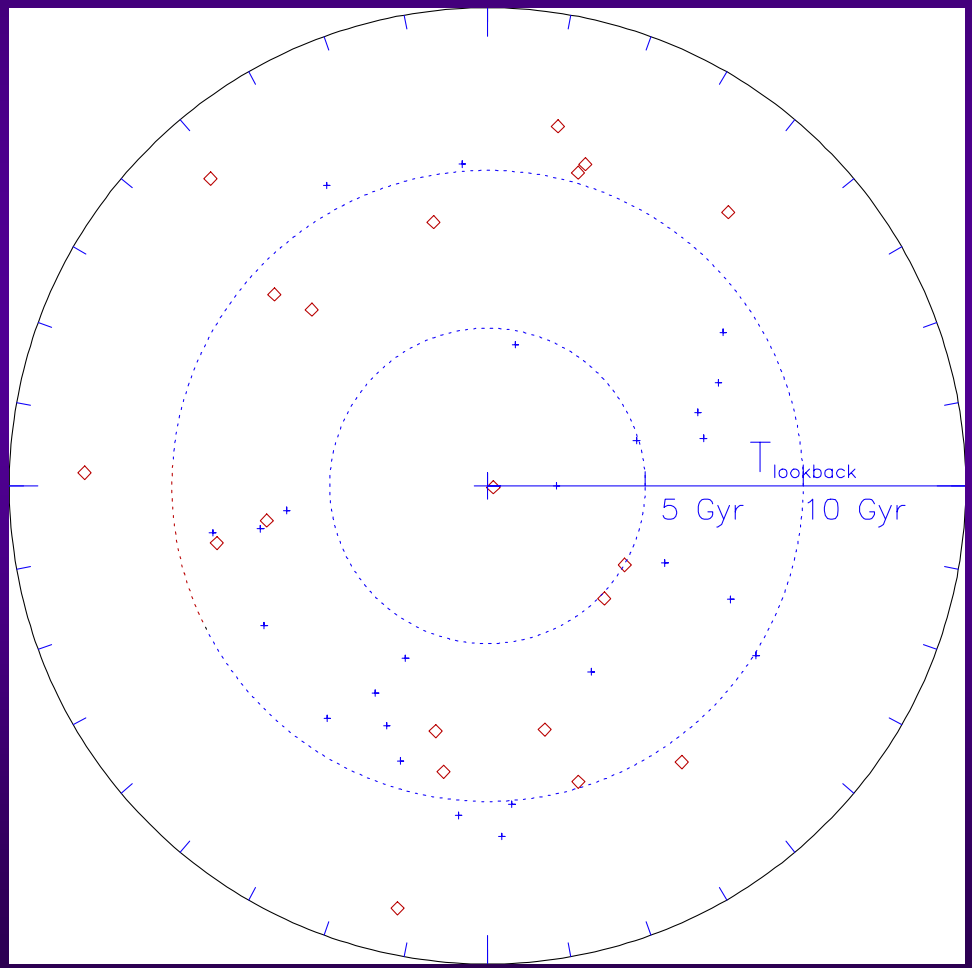
HST/STIS • February 1998

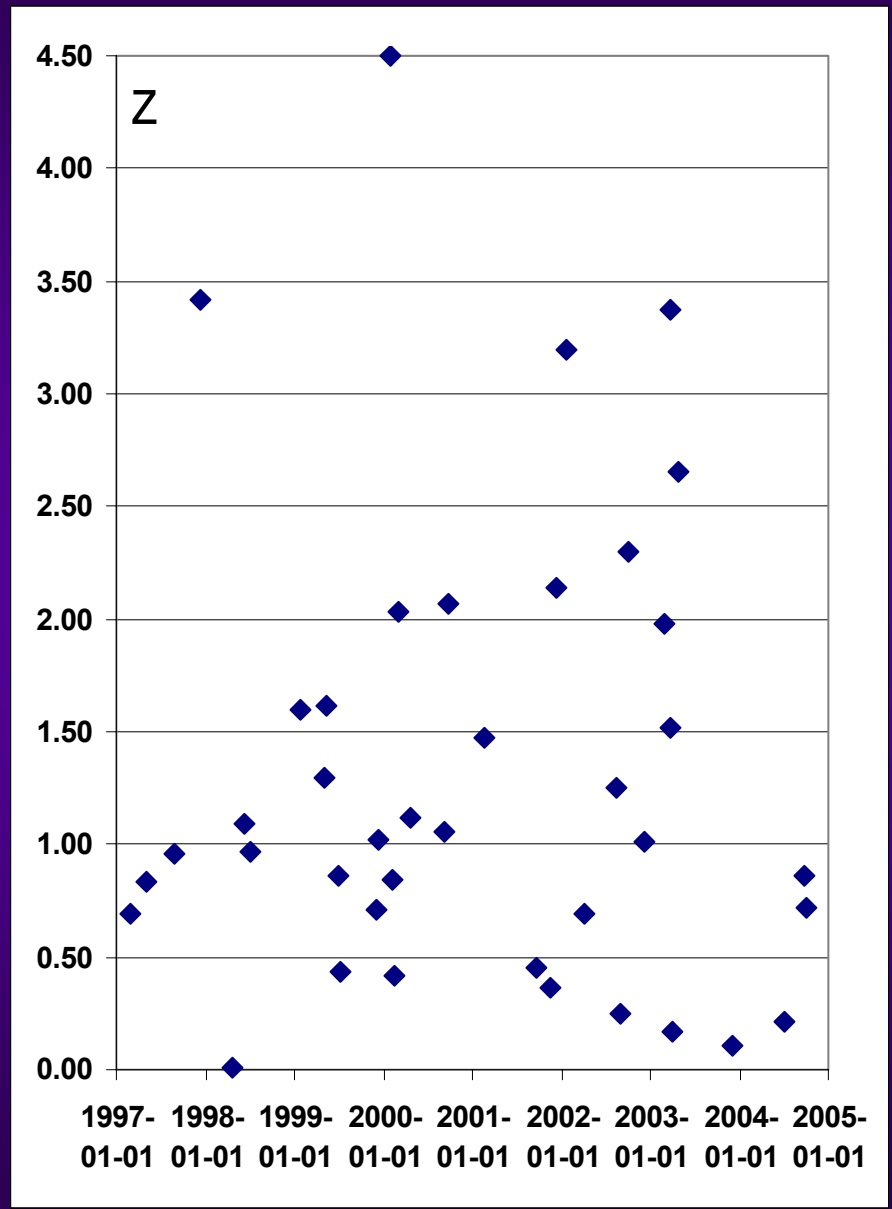
PRC98-17c • May 7, 1998 • ST ScI OPO
S. G. Djorgovski and S. R. Kulkarni (Caltech), the Caltech GRB Team,
W. M. Keck Observatory and NASA

# Distances

**up to z=4.5**

**$\Rightarrow 13 \cdot 10^9$ light years**

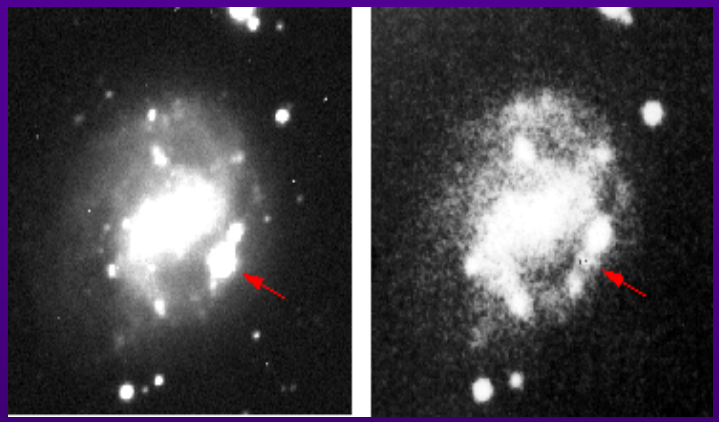


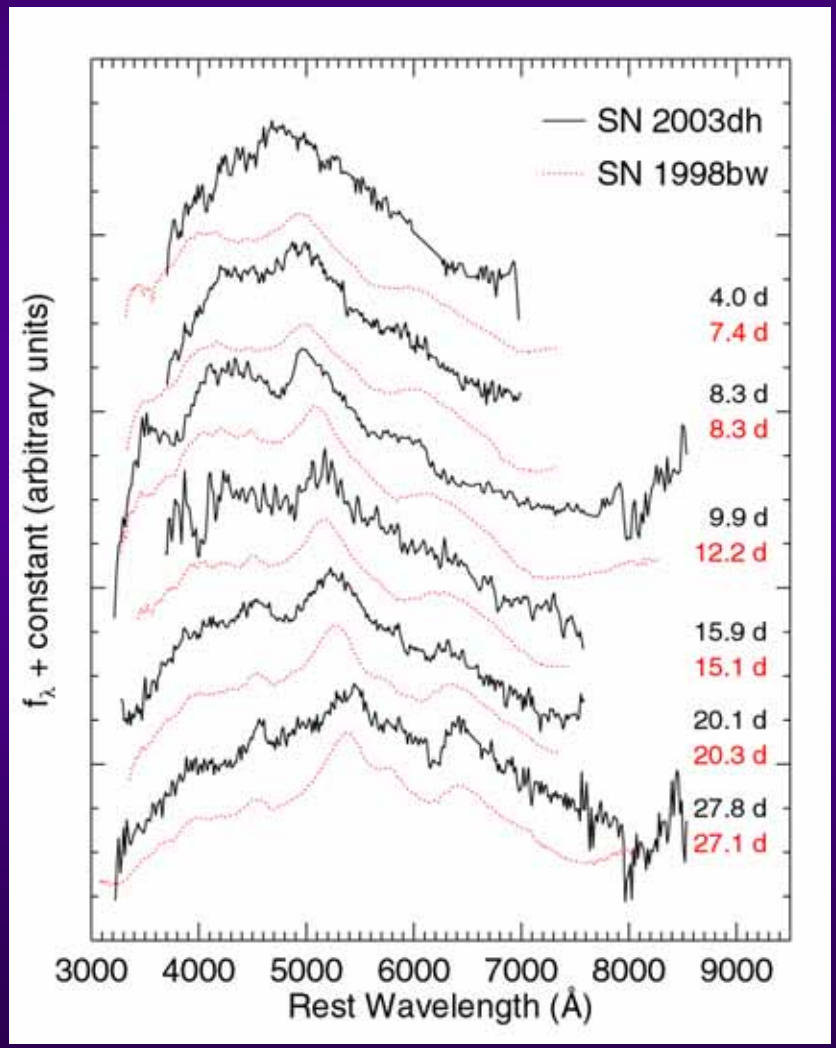



# Supernowa SN1998bw

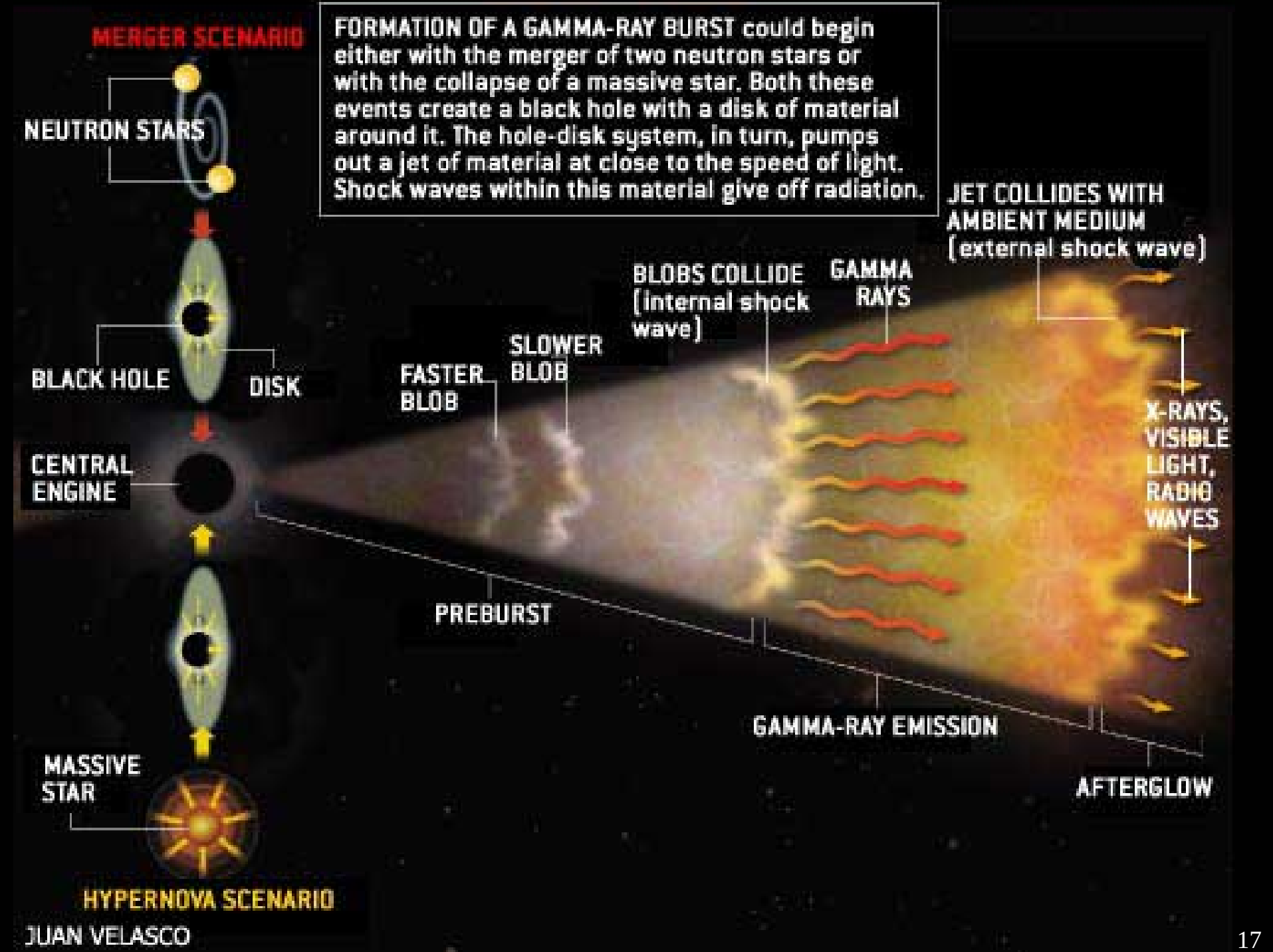
**1998.04.25 – GRB discovered by BeppoSAX**

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

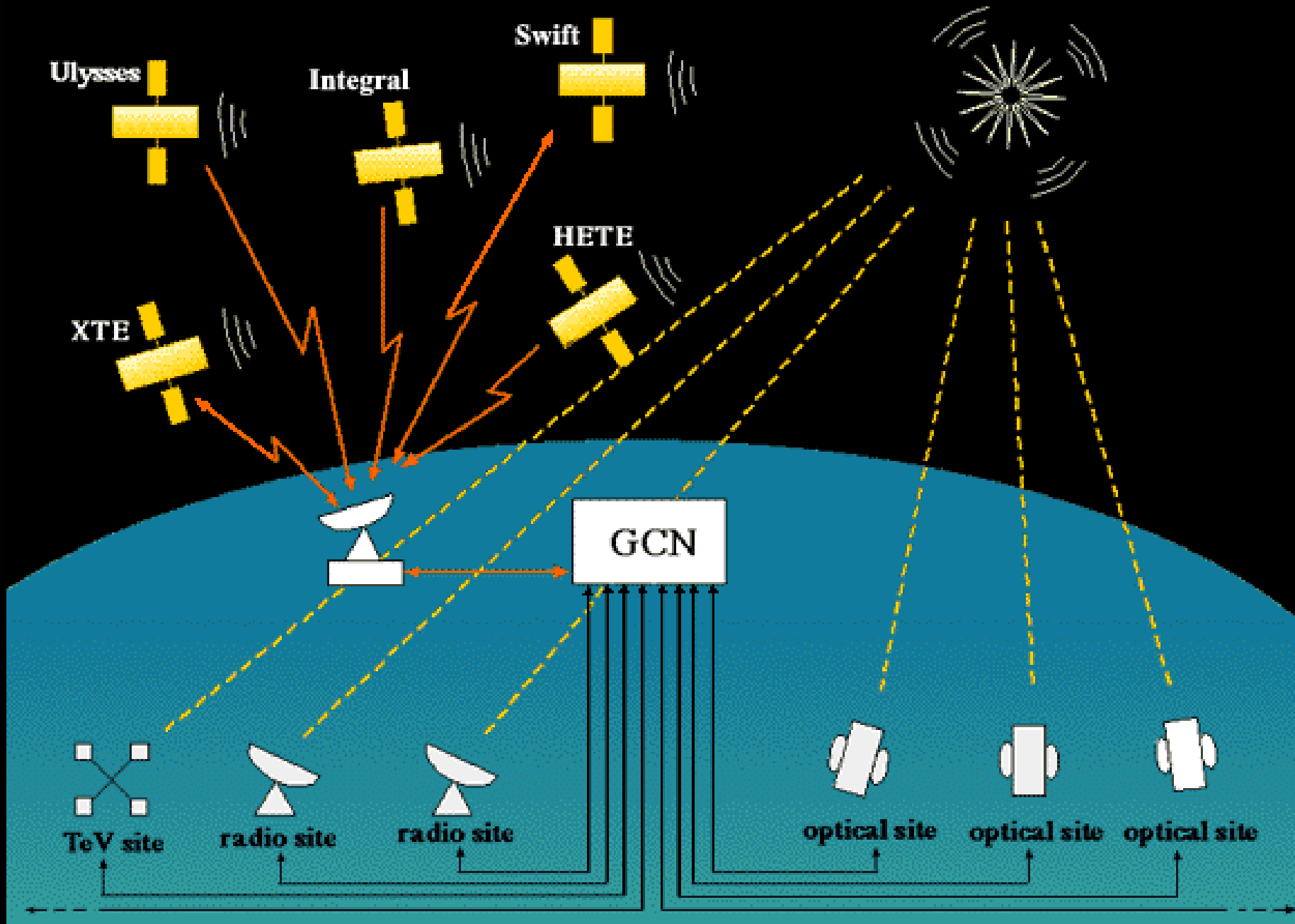





**Several GRB-SN pairs found so far**


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
BLACK HOLE
DISK
CENTRAL ENGINE
MASSIVE STAR
HYPERNOVA SCENARIO
FASTER BLOB
SLOWER BLOB
BLOBS COLLIDE (internal shock wave)
GAMMA RAYS
JET COLLIDES WITH AMBIENT MEDIUM (external shock wave)
X-RAYS, VISIBLE LIGHT, RADIO WAVES
PREBURST
GAMMA-RAY EMISSION
AFTERGLOW
JUAN VELASCO

# GRB Coordinate Network (GCN)



# 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

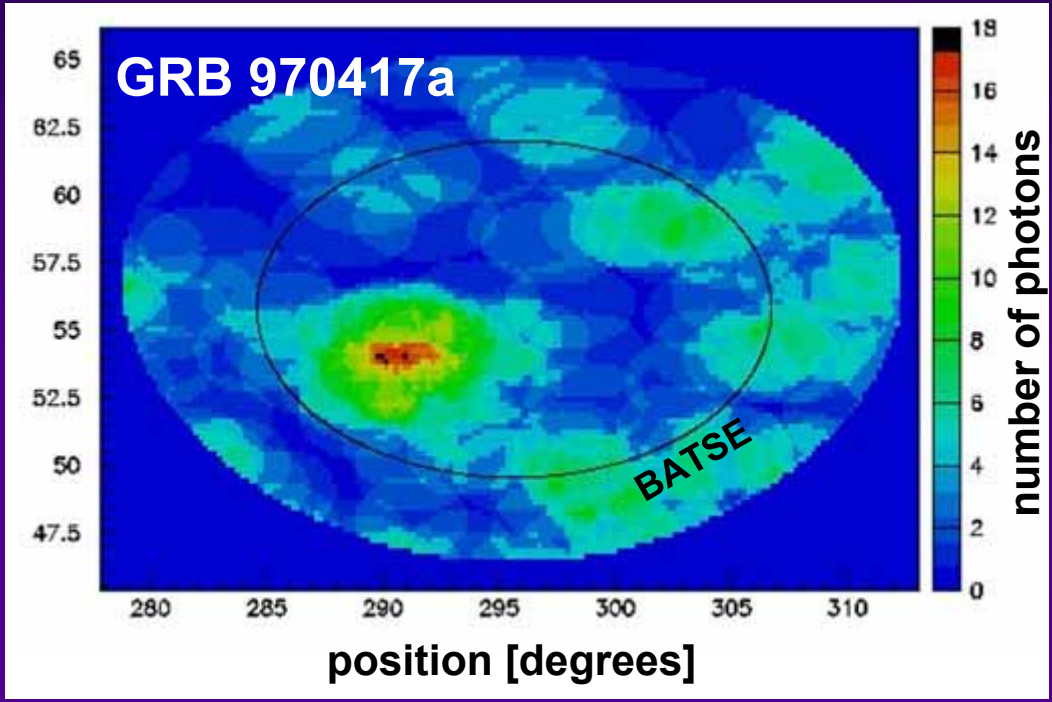
**Ulysses/BATSE observed GRB (25-150 keV) 180 s long**
**EGRET observed 18 photons (>40 MeV) over 1.5 h !**
**3 of them had energy > 2 GeV**

***Why hard photons are late?***

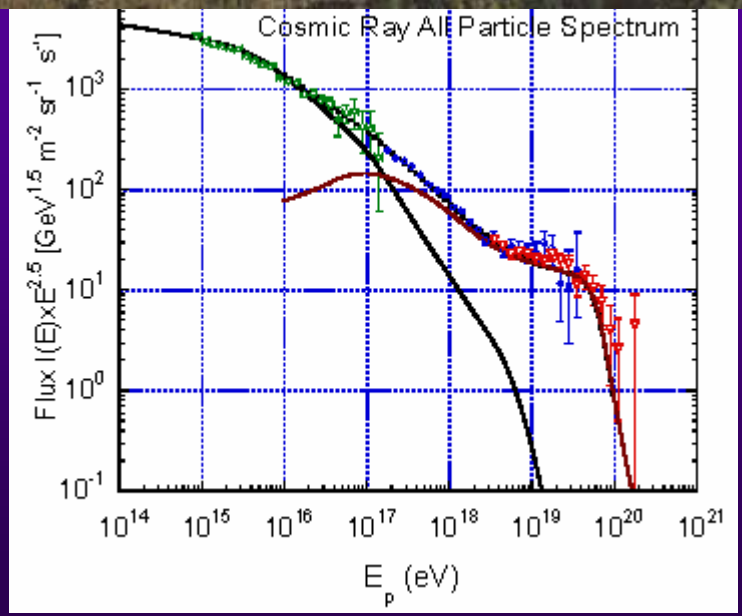
**Different production mechanism?**
**Different speed?!**

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

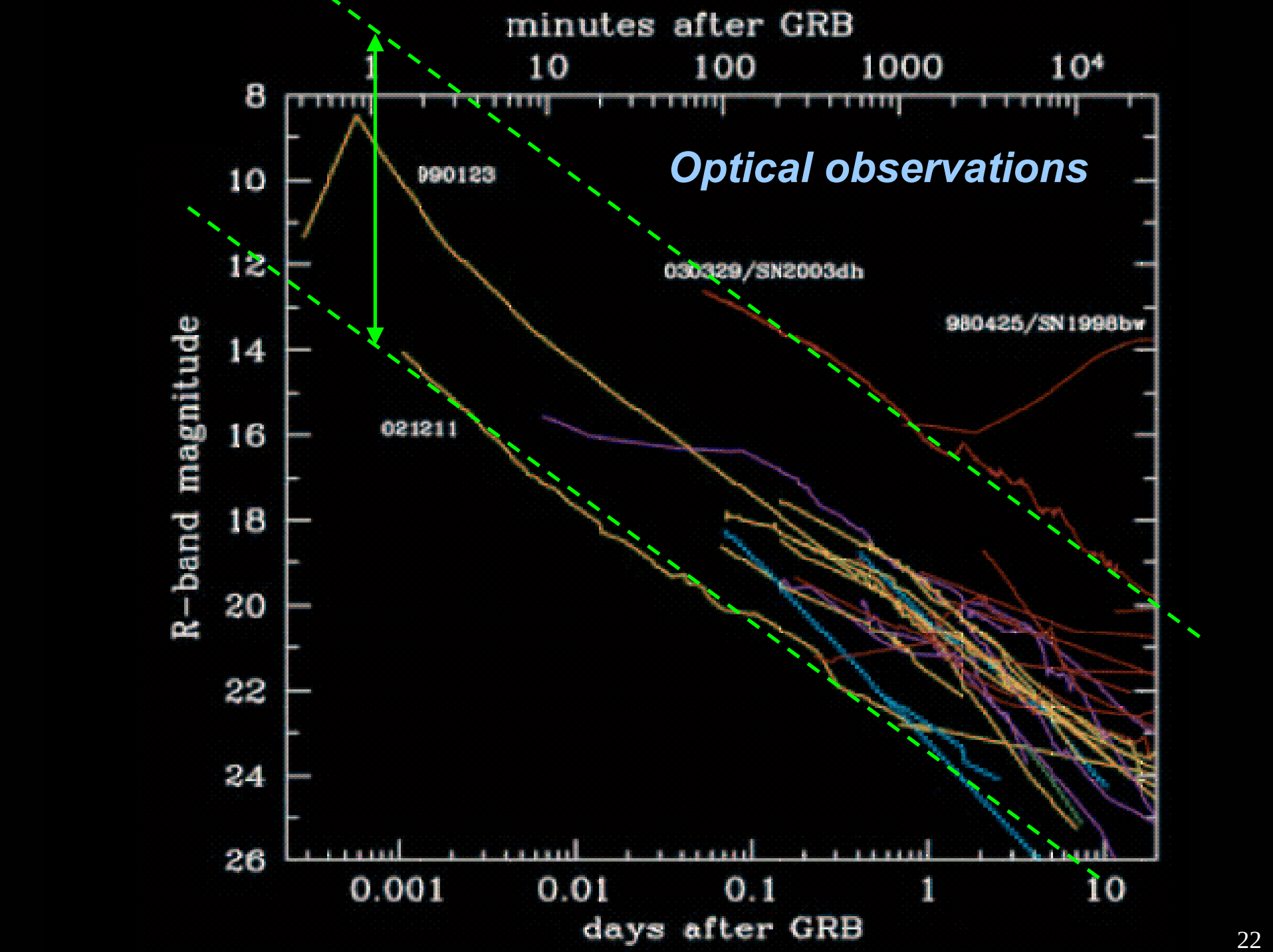
# GRB's today and tomorrow

***Today:***

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

***Tomorrow:***

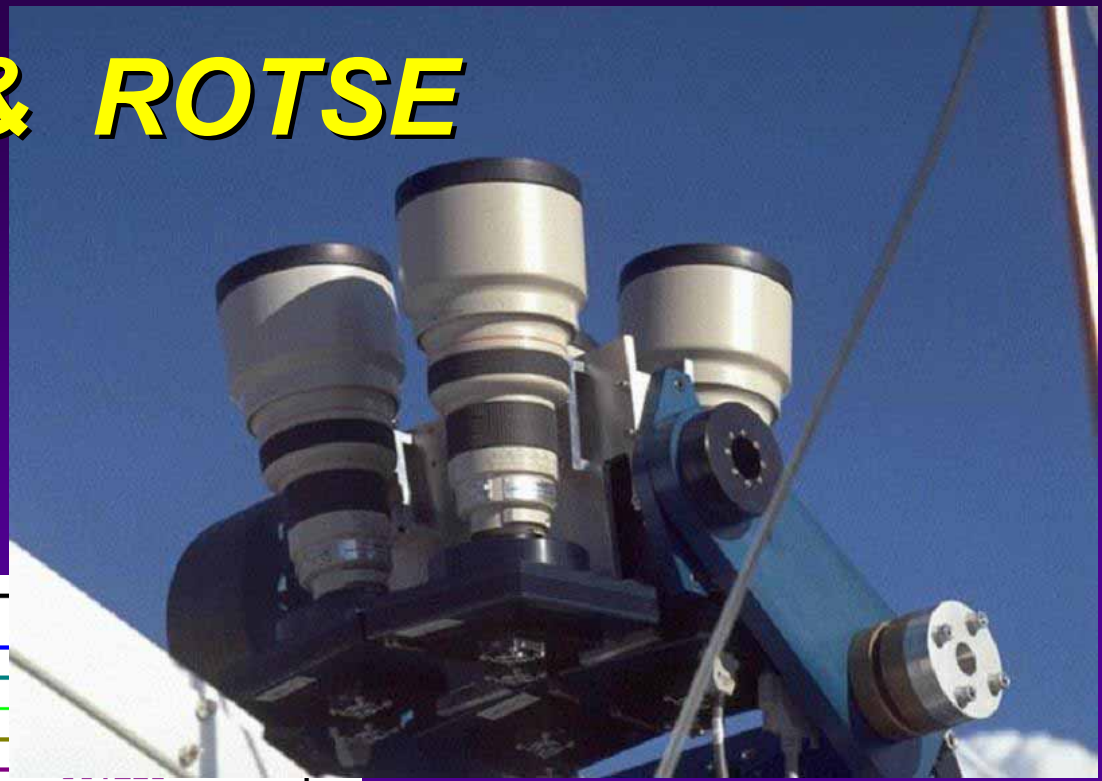
- coincidence with TeV photons, neutrinos, etc
- optical observations before and during GRB

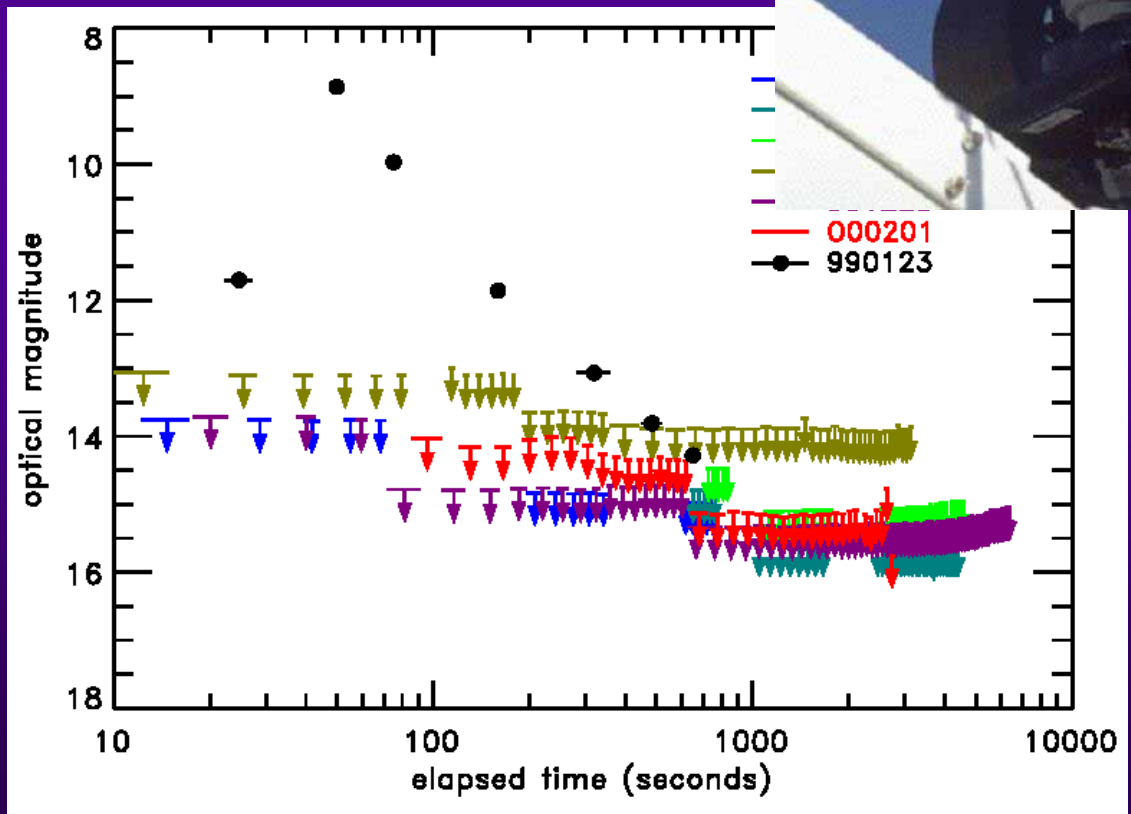



***Optical observations***

# 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!**

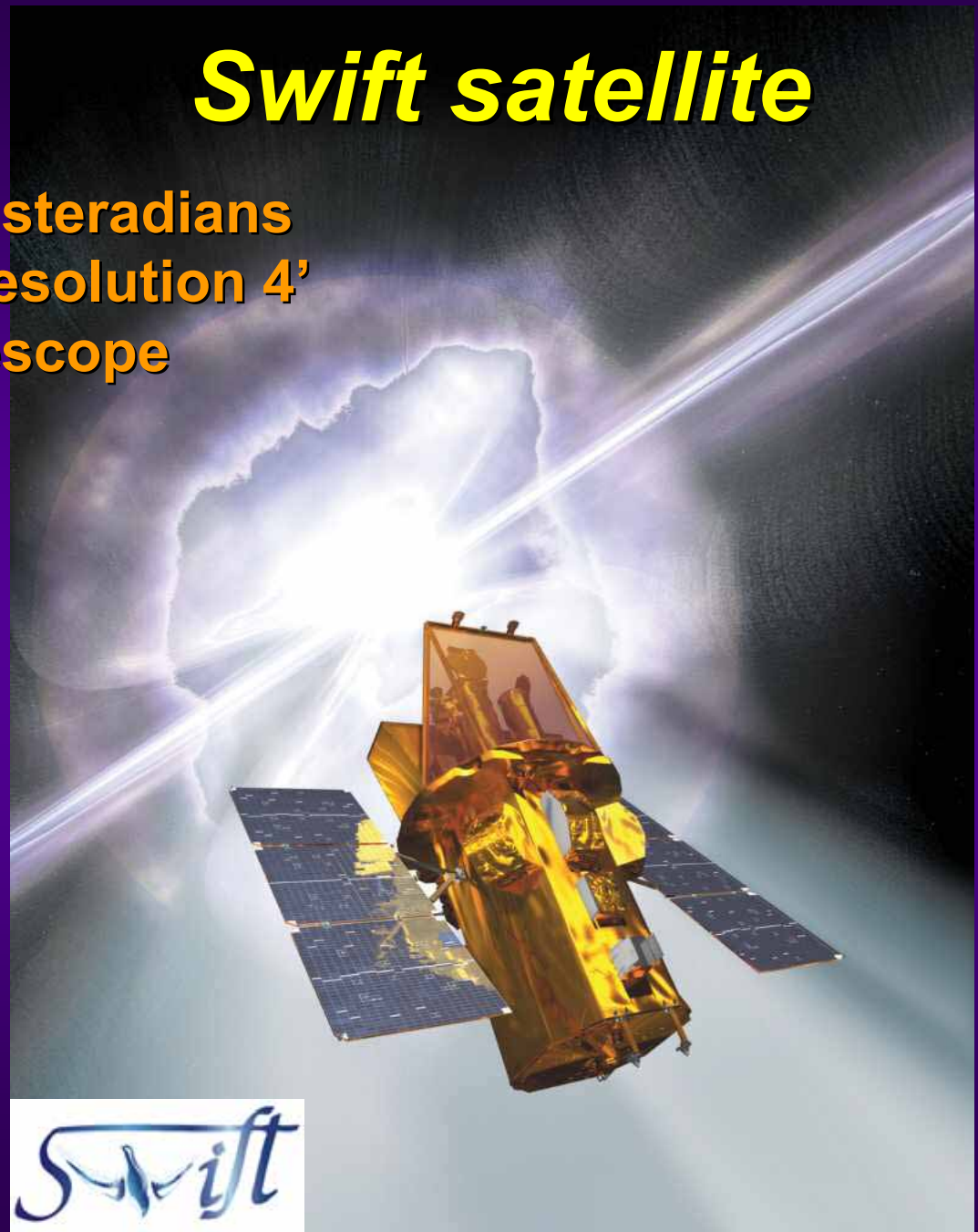
**The brightest so far**

# Swift satellite

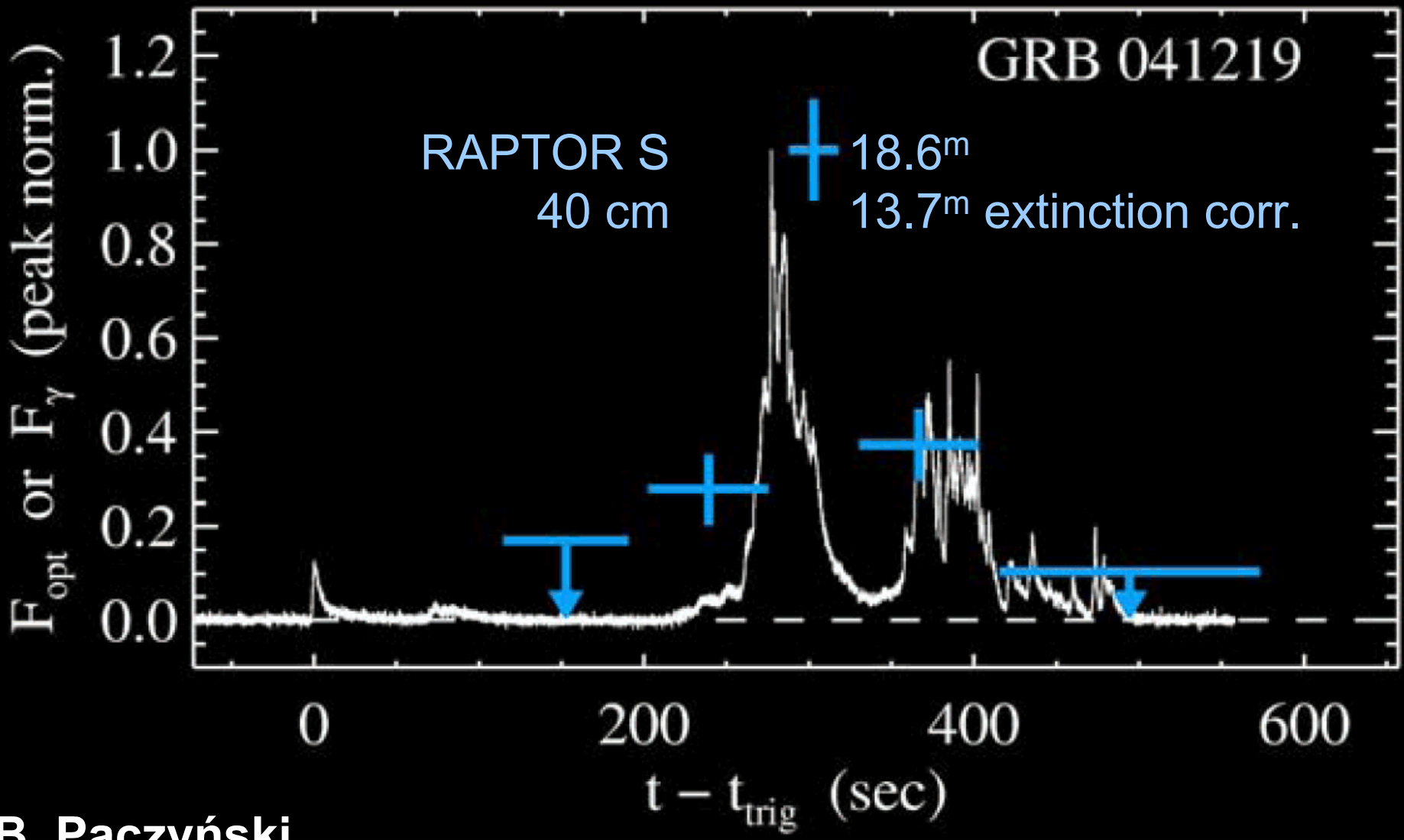
Launched Nov. 2004

3 instruments:

- BAT – $\gamma$-ray detector: 2 steradians
- XRT – X-ray detector: resolution 4'
- UVOT – optical+UV telescope

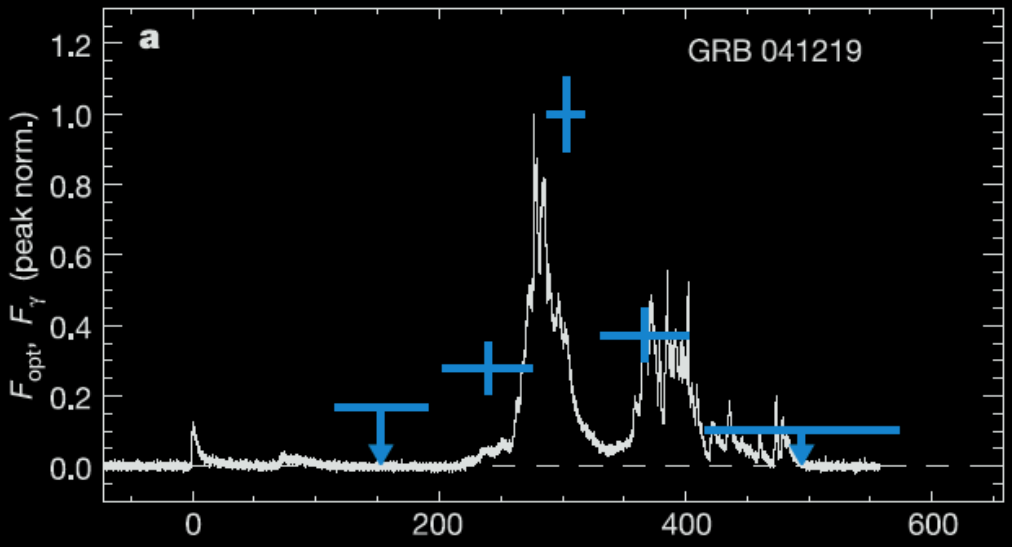


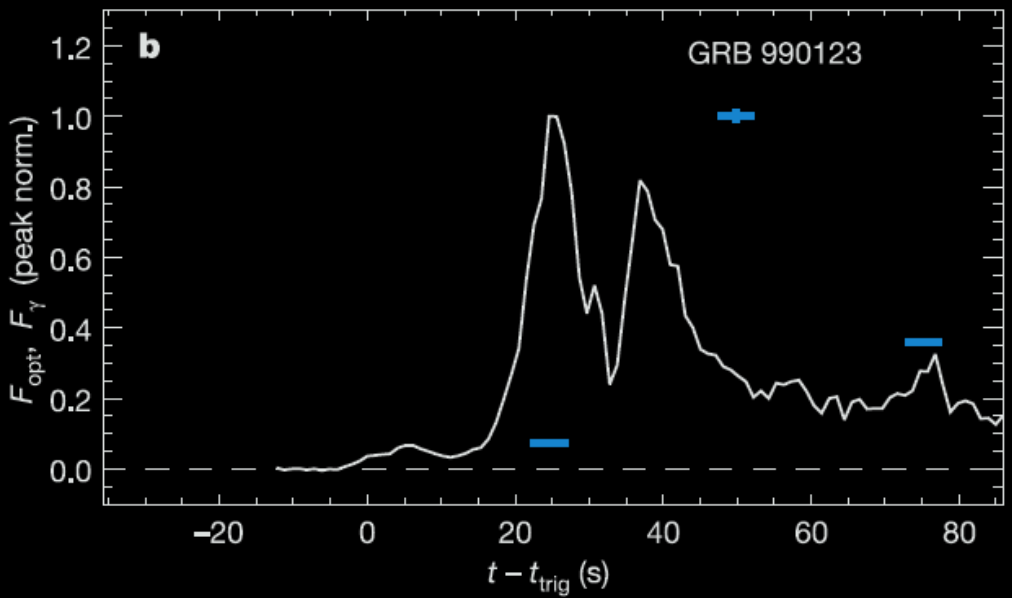
# *Optical observation before GRB!*




**B. Paczyński**

**„*Optical Flashes Preceding GRBs*", astro-ph/0108522**




**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!**

# General Rule for Bursts

H – arbitrary hipothesis about GRB

$G_1$, $G_2$ – gamma ray burts

$$\forall_H \; \exists_{G_1,G_2} \; G_1 \Rightarrow H,\ G_2 \Rightarrow \sim H$$

*Examples:*

- optical emission begins before / after GRB
- GRB out of / in the Galaxy (SGR / „normal” GRB)
- GRB with / without Supernova
- GRB = single, double, multi-pulses

# 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

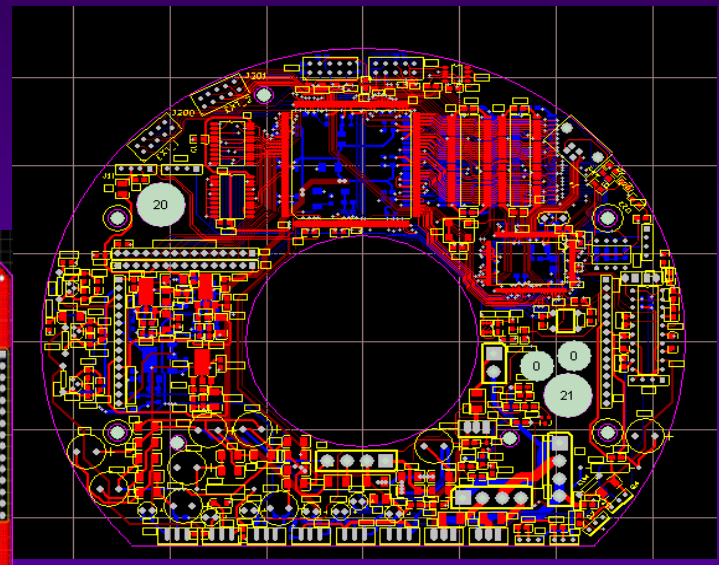
# „π of the Sky" prototype

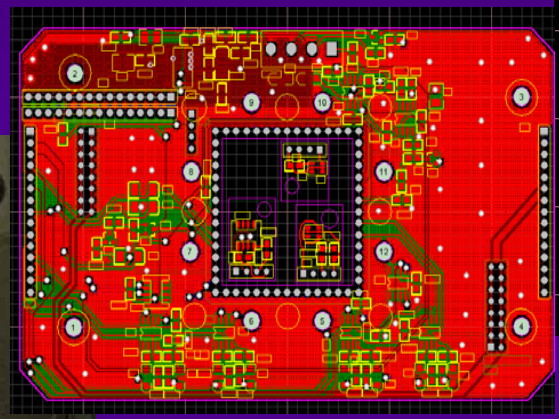

- 2 CCD cameras 2000×2000 pixels
- Zeiss lenses f=50mm, d=f /1.4
- common field of view 33°×33°


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

# „$\pi$ of the Sky” cameras

- quantum efficiency ~30%
- readout noise ~15 $e^-$
- ADC 16 bit × 2 MHz ⇒ 2 s / frame
- USB 2.0 interface





- programmable electronics (FPGA)
- on board processor
- hermetic case filled with Ar
- thermoel. cooling 30 below ambient
- shutter designed for $10^7$ openings
- focusing motor

# „$\pi$ 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:**

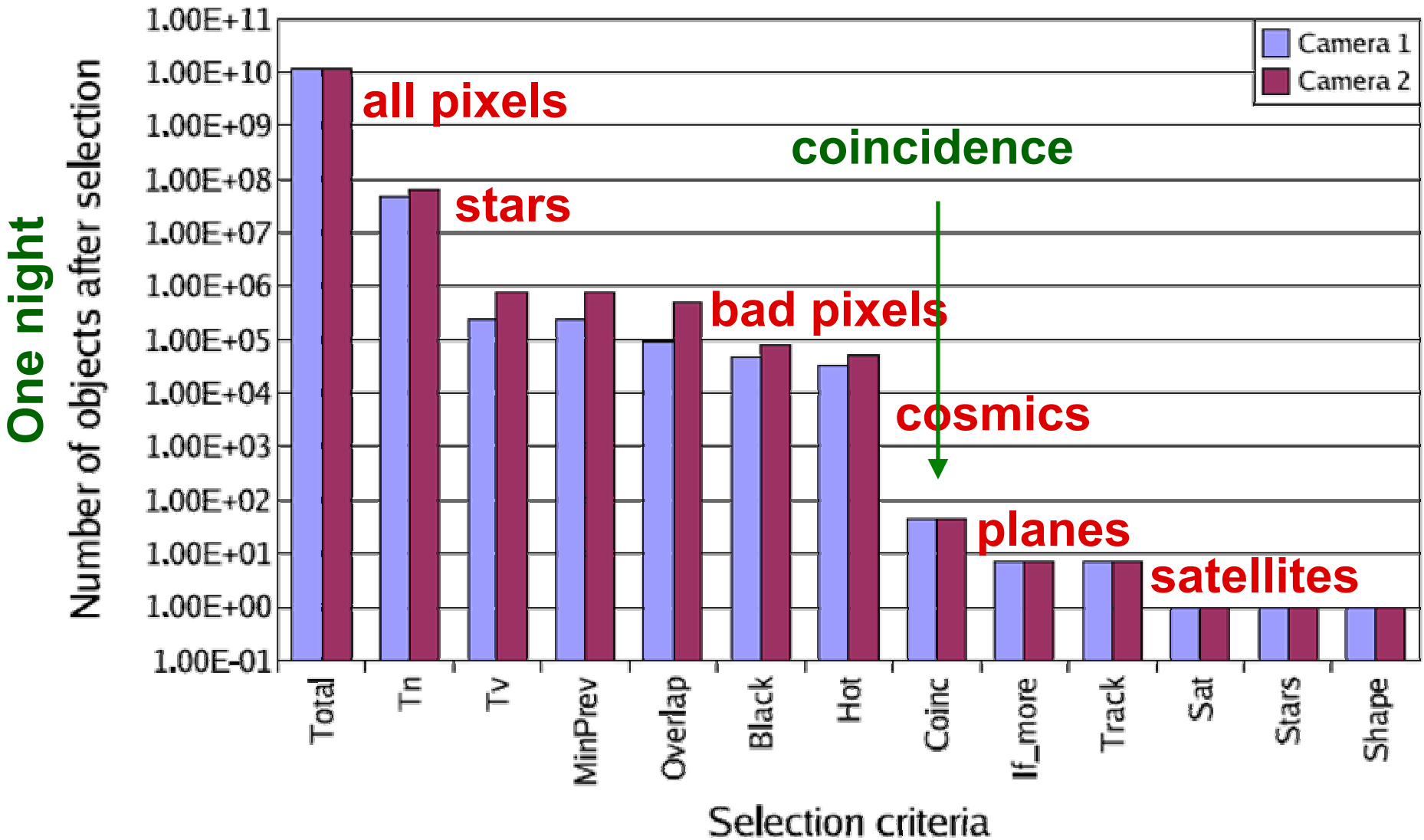
- remote-reset, Wake-on-LAN, Boot-from-LAN
- selfdiagnostics (e-mail and SMS to Poland)

**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*

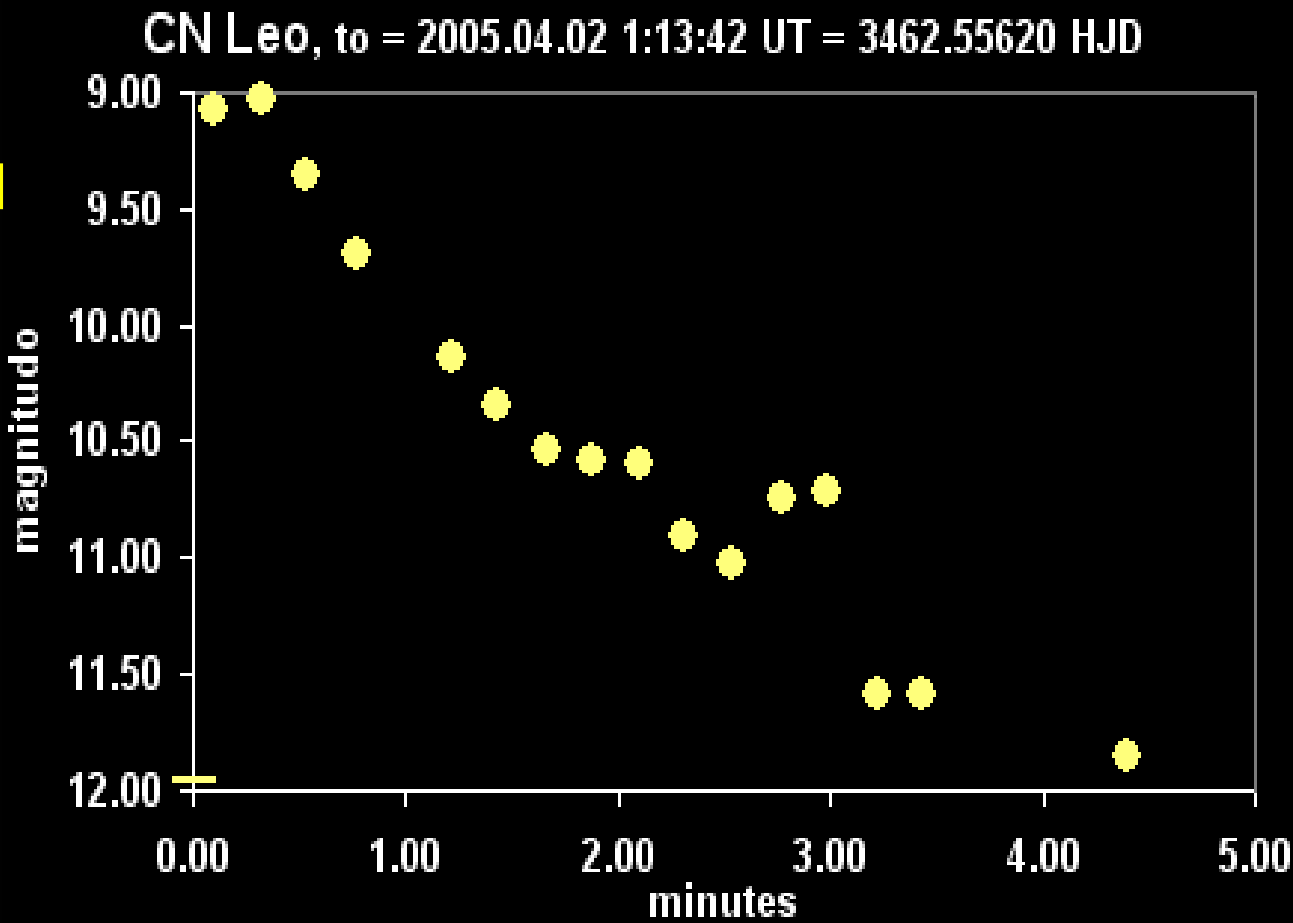
## multilevel trigger concept



# 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



# „$\pi$ 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 $t > t_0+7s$**

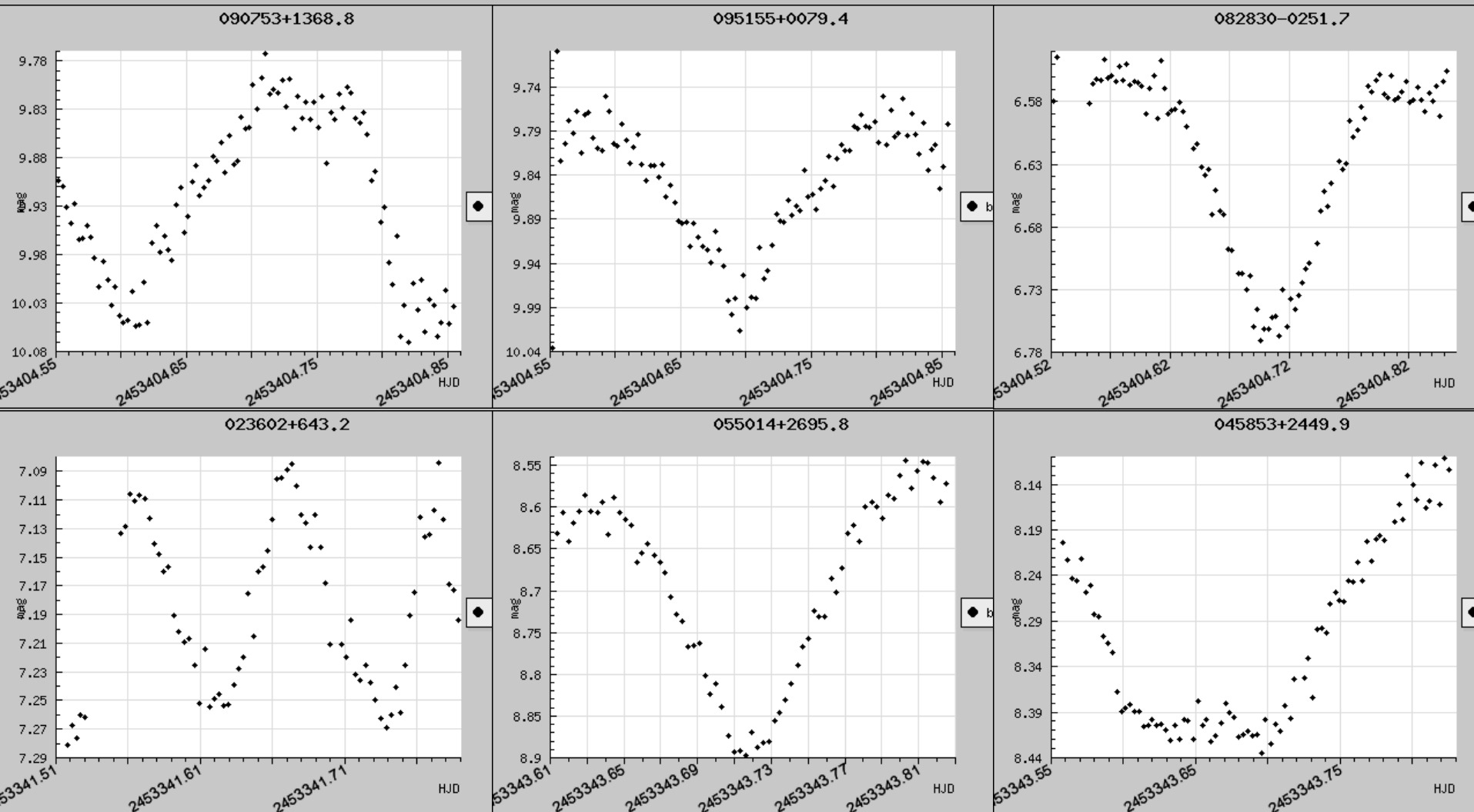
**limits before and during GRB**

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)



# „$\pi$ 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**

**Welcome to our WWW page**
**and enjoy pretty images**
***grb.fuw.edu.pl***