

Gamma-Ray Bursts

Multi-wavelength astronomy
and
Multi-Particle astronomy?

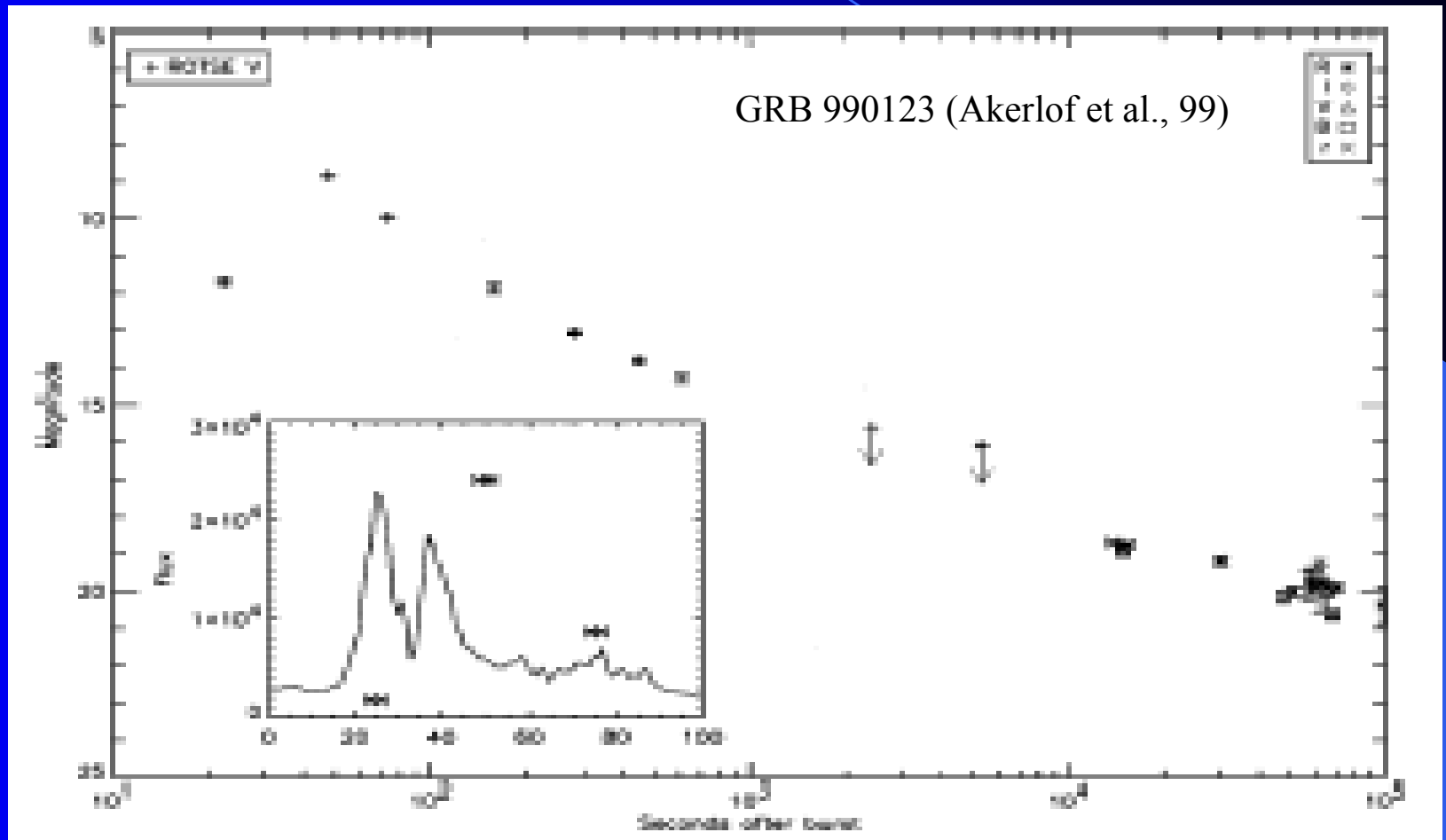
This talk

- What this talk will present
 - Outline of the phenomenon
 - Observed properties
 - Outline of models
 - Summary of experiments
- What this talk will NOT discuss
 - Cannonballs: de Rujula's job
 - Neutrino predictions: Guetta's / Waxman's job

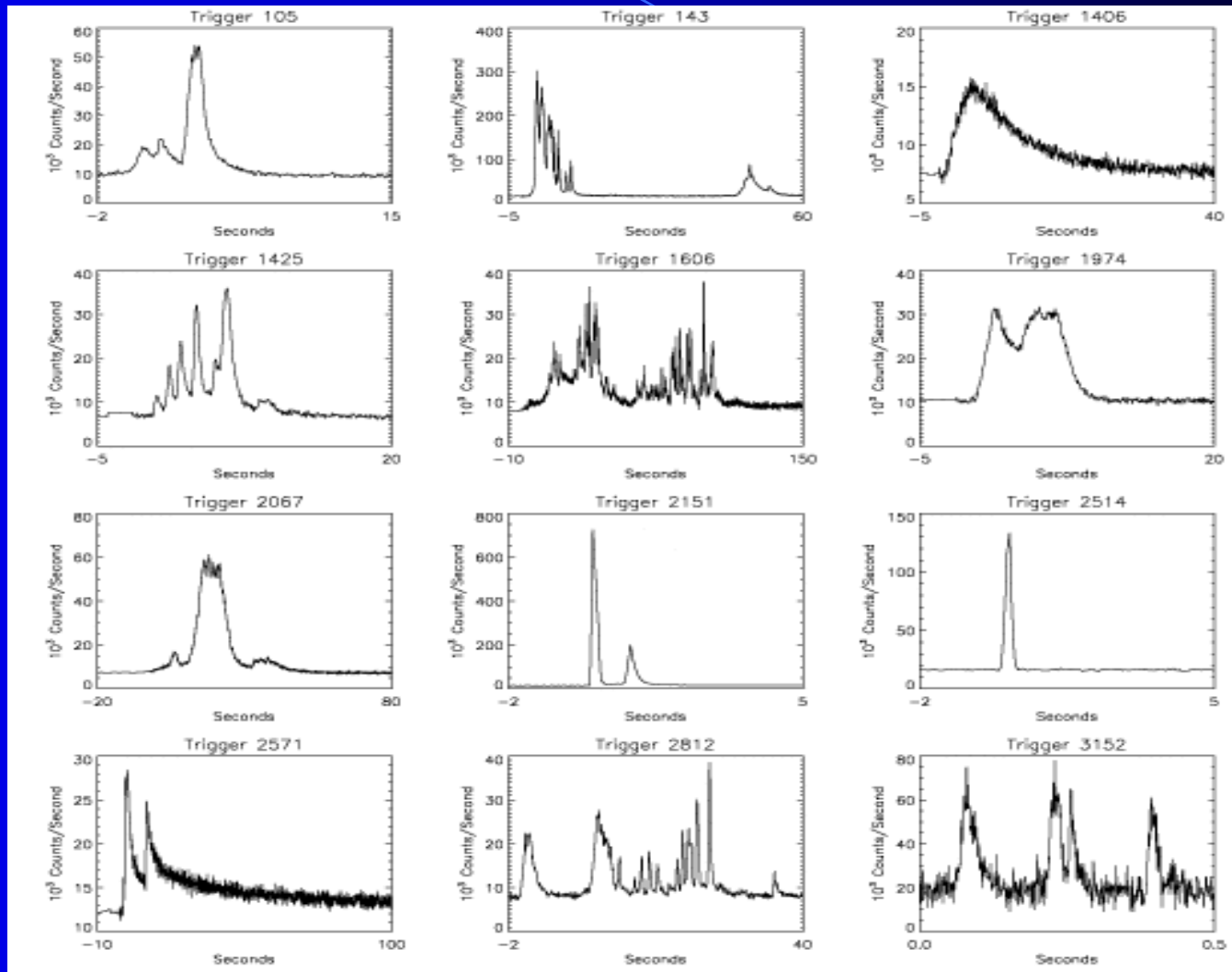
Phenomenology

- An explosive event ($10^{-8} - 10^{-3} \text{ erg.s}^{-1}.\text{cm}^{-2}$): the burst
 - Observed durations 10ms to $> 10 \text{ min}$
 - Variable on timescales $< \text{ms}$
 - No preferred pattern
 - Burst observed
 - Hard X-ray – gamma-ray domain: E_{peak} around 300keV
 - 5 bursts detected by EGRET (1 to 18 GeV)
 - 1 burst detected by ROTSE (optical)

GRB 990123 in gamma-ray and visible



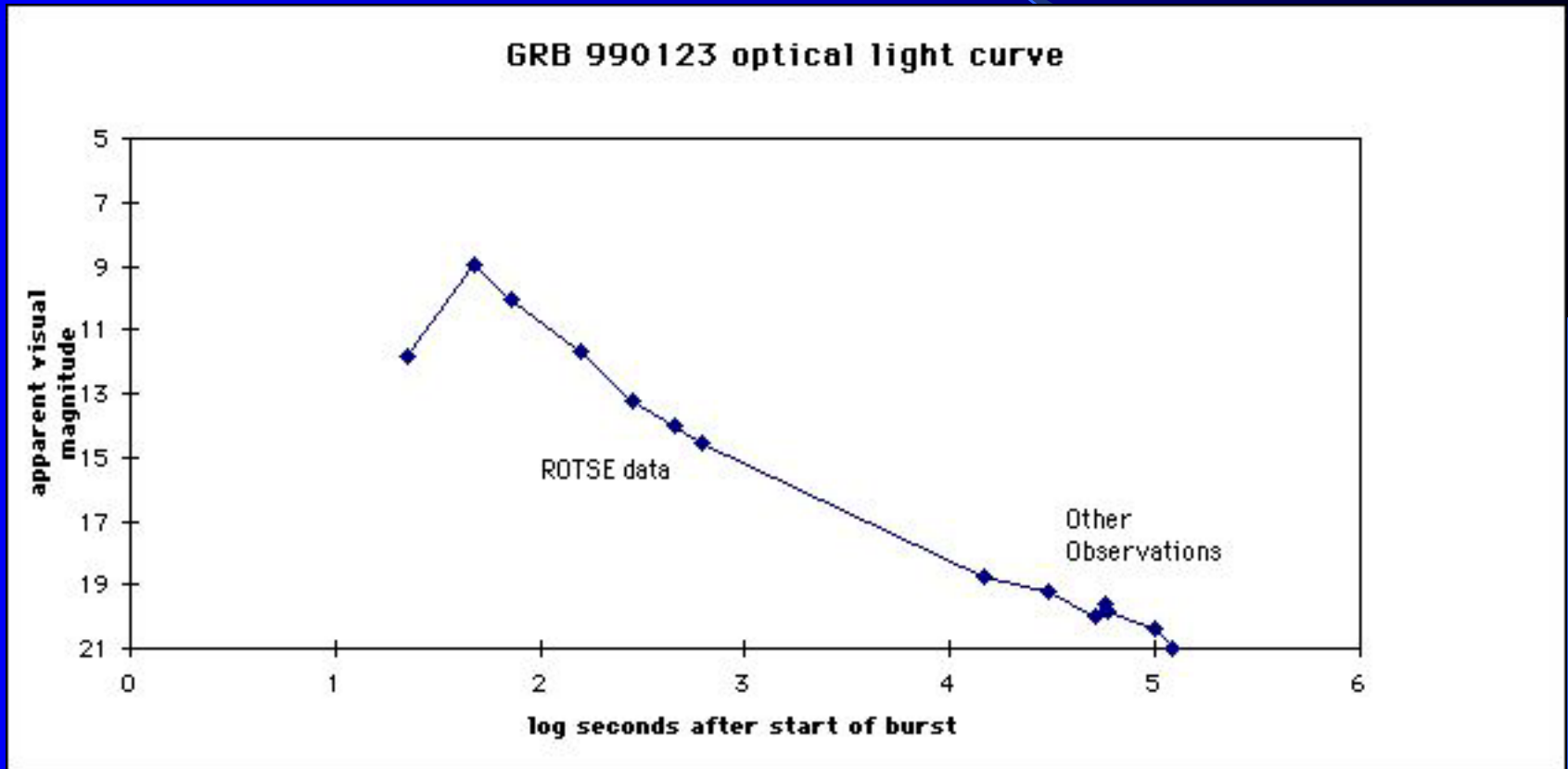
Various BATSE time profiles



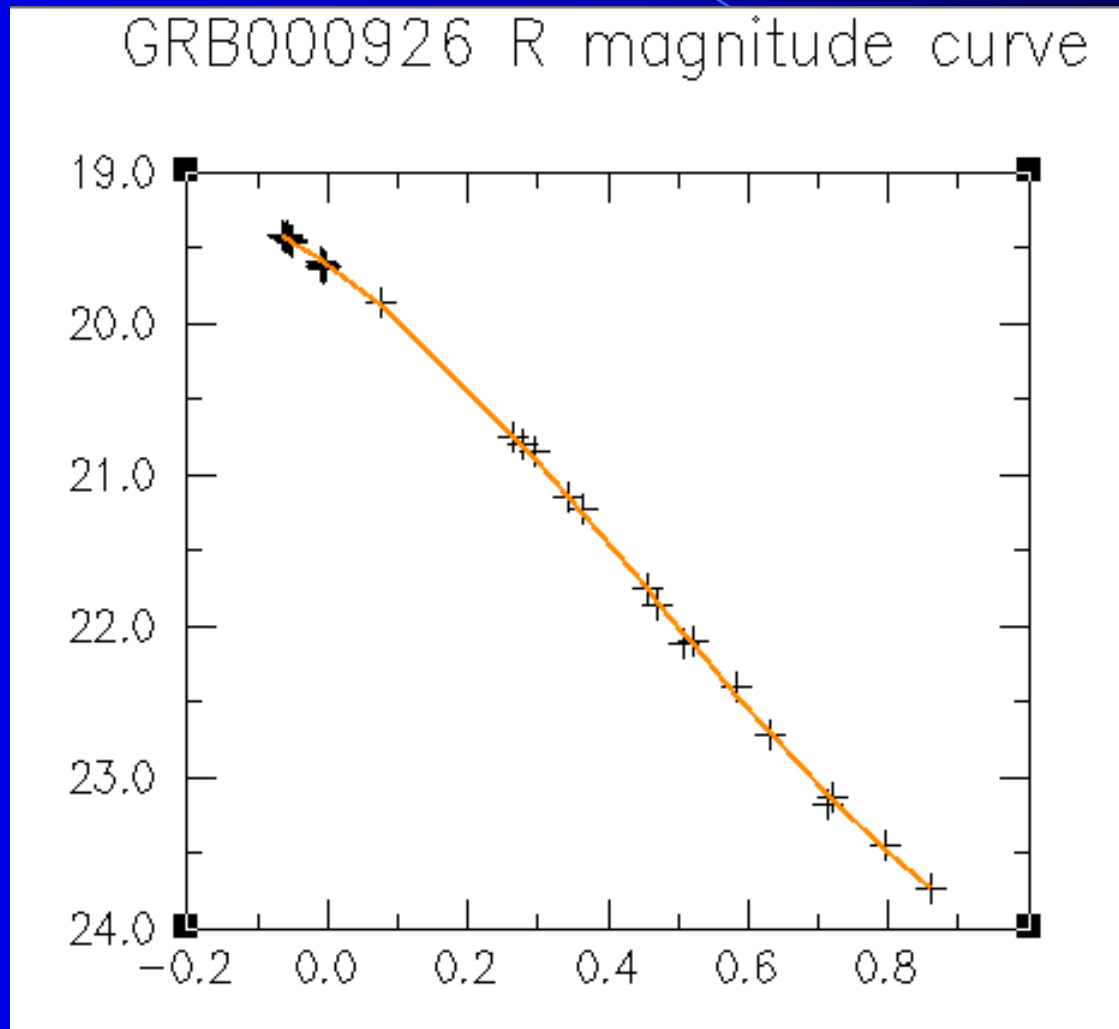
Phenomenology (2)

- ... Followed by a « regular » decrease ($t^{-1,-2}$) in intensity.
 - Observed in soft X-rays, and at visible, IR, and radio wavelengths
 - Only for long bursts (may be one exception) because of observational constraints

GRB 990123 – afterglow



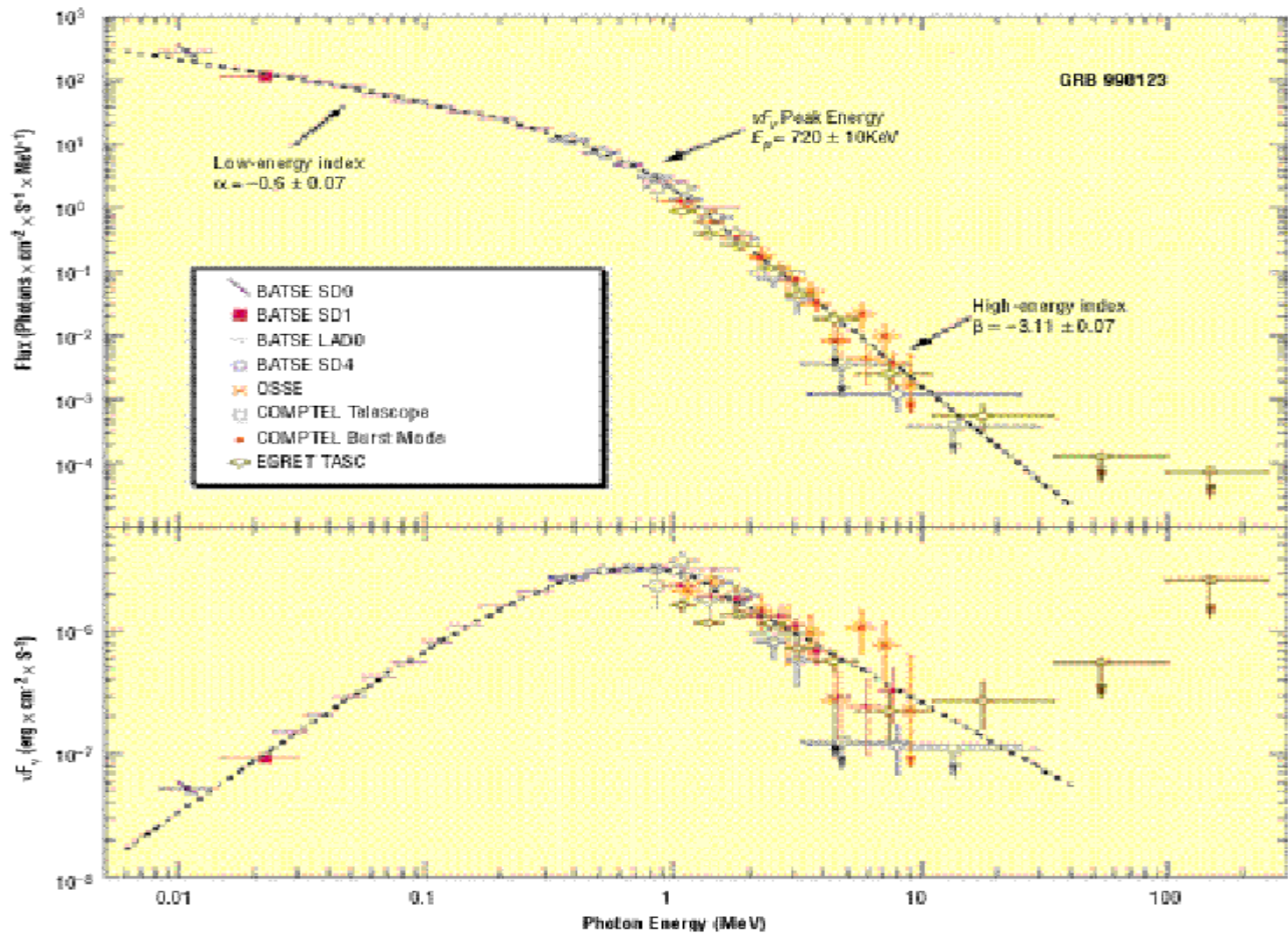
GRB 000926 afterglow



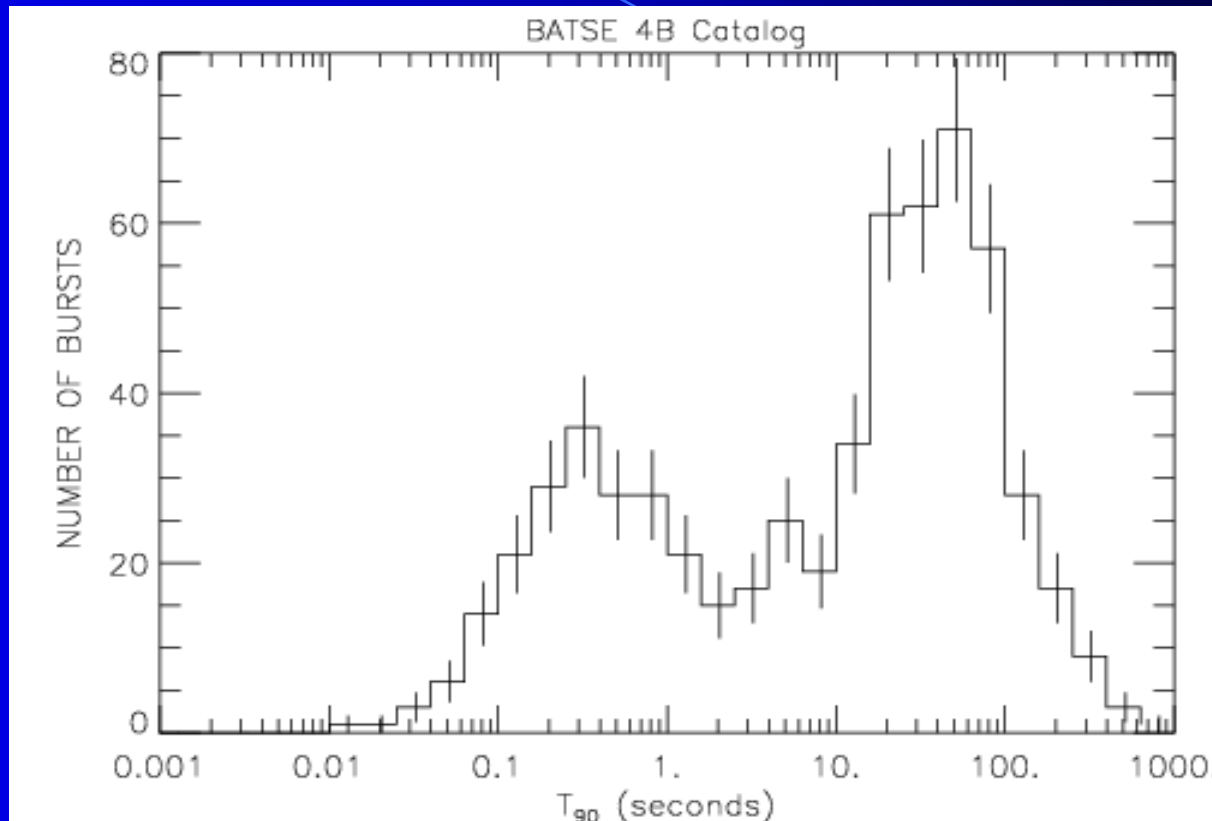
Spectrum of GRBs

- The burst may be approximated by a broken power law (band spectrum)
 - E^α, E_p, E^β
 - $E_p \approx 250 \text{ keV}$, $-2 \leq \alpha \leq 0$, $-3.5 \leq \beta \leq -1.5$
 - High spectral evolution during the burst

GRB 990123 spectrum (CGRO data)

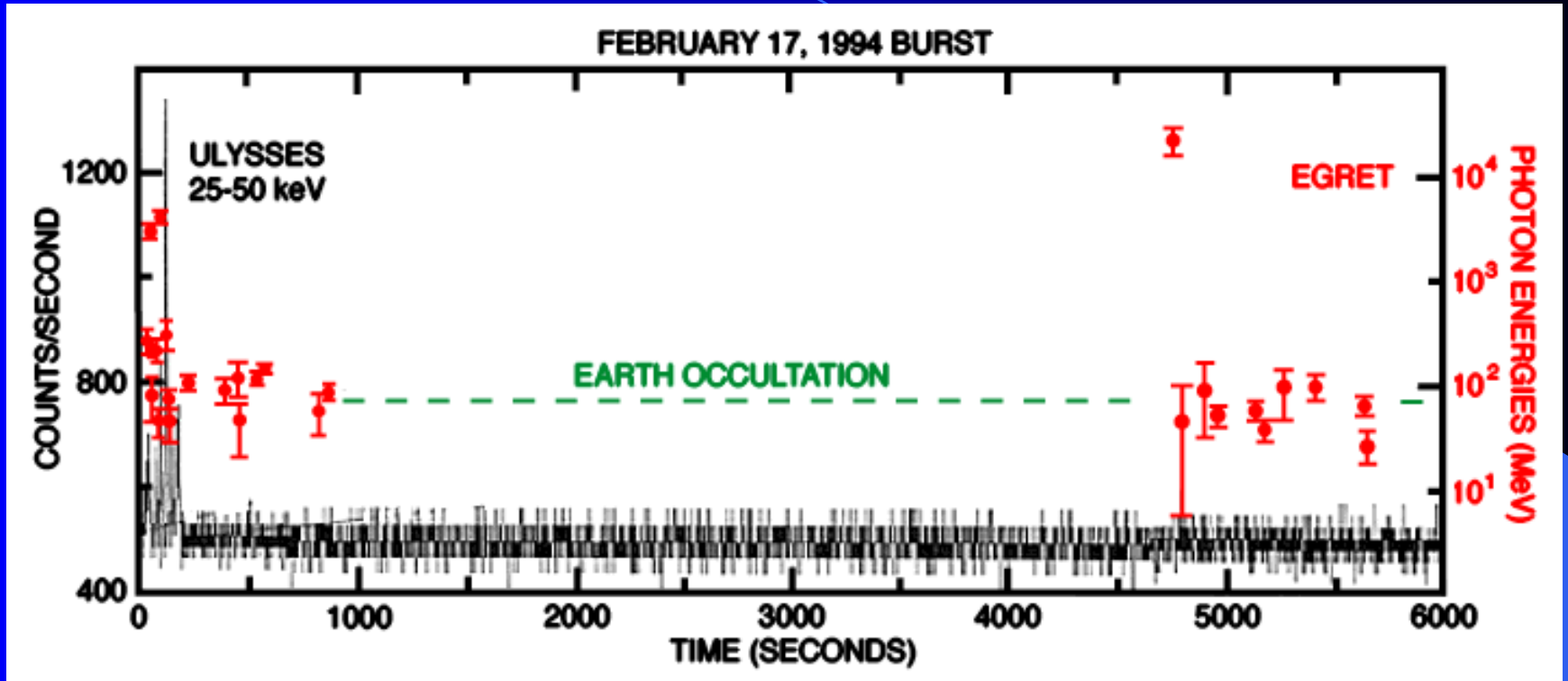


Two burst classes



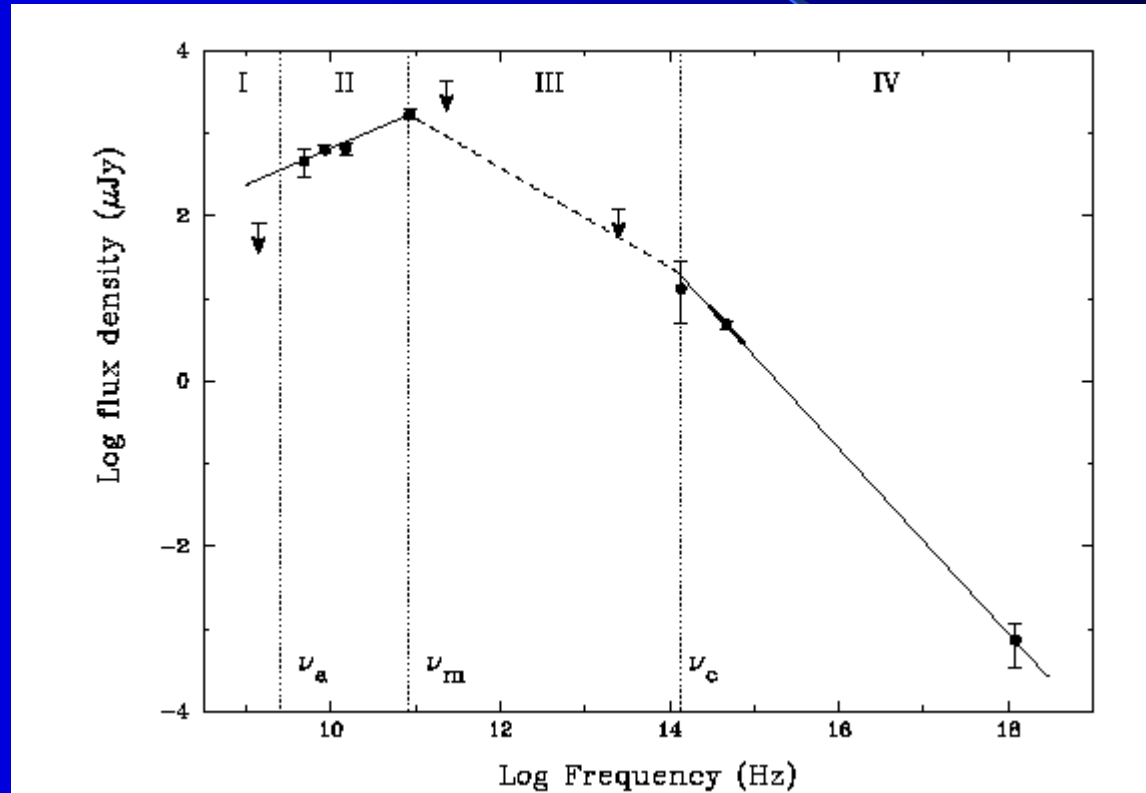
- Short bursts of durations around 2s
- Long bursts of durations around 10s
- On average the shorter the burst the harder

But



And one MILAGRITO event ?

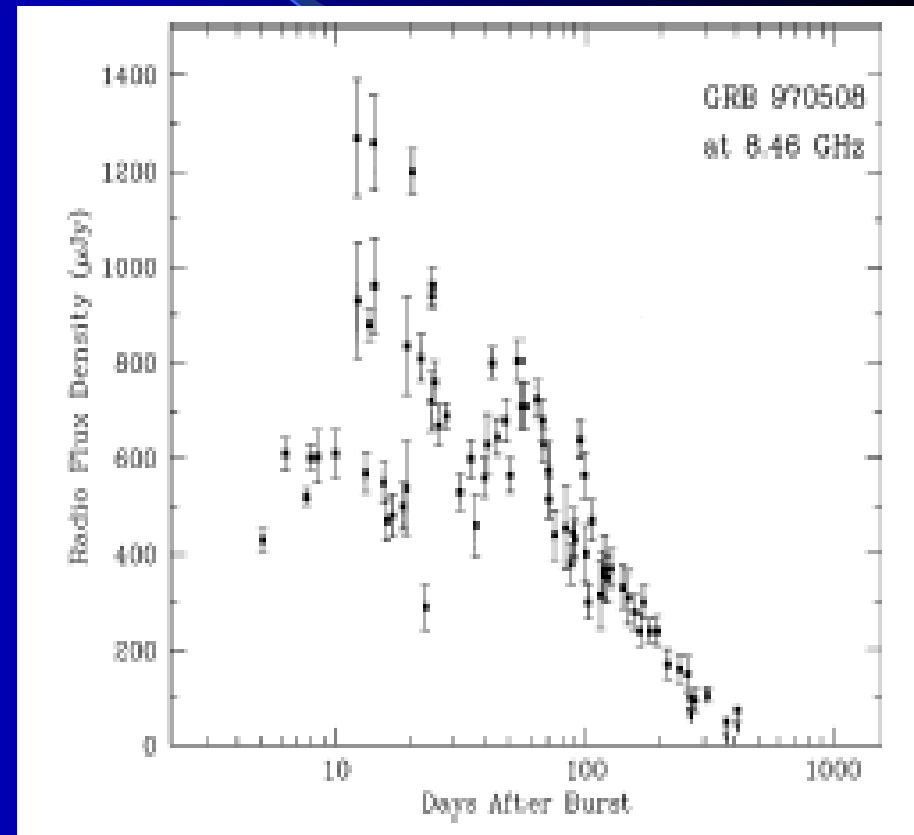
Spectrum of the afterglow



GRB 970508 (Galama et al., 1998)

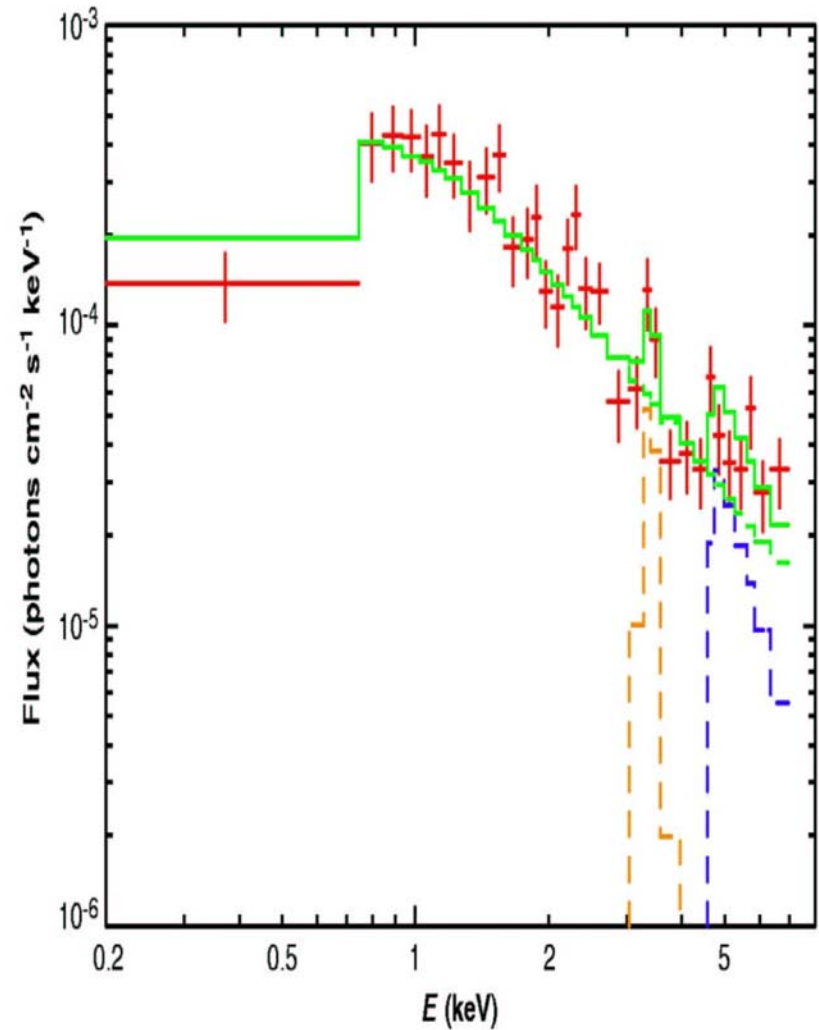
Size of the afterglow source

- GRB 970508 (Kulkarni et al., 1999) @ 8.46 GHz
- Interstellar scintillation produces the first month variations
- Damping means that the source has expanded to a radius of 10^{17} cm



X-ray lines

- If Fe lines (6.2 keV) consistent with redshift
- 1 transient line (GRB 990705), 3 AG
- Large amount of Fe?
 - But alternative explanation by Meszaros and Rees (2000 – late fireball) and Dar and de Rujula (2001 - cannonballs)
- Signature of an underlying SN?



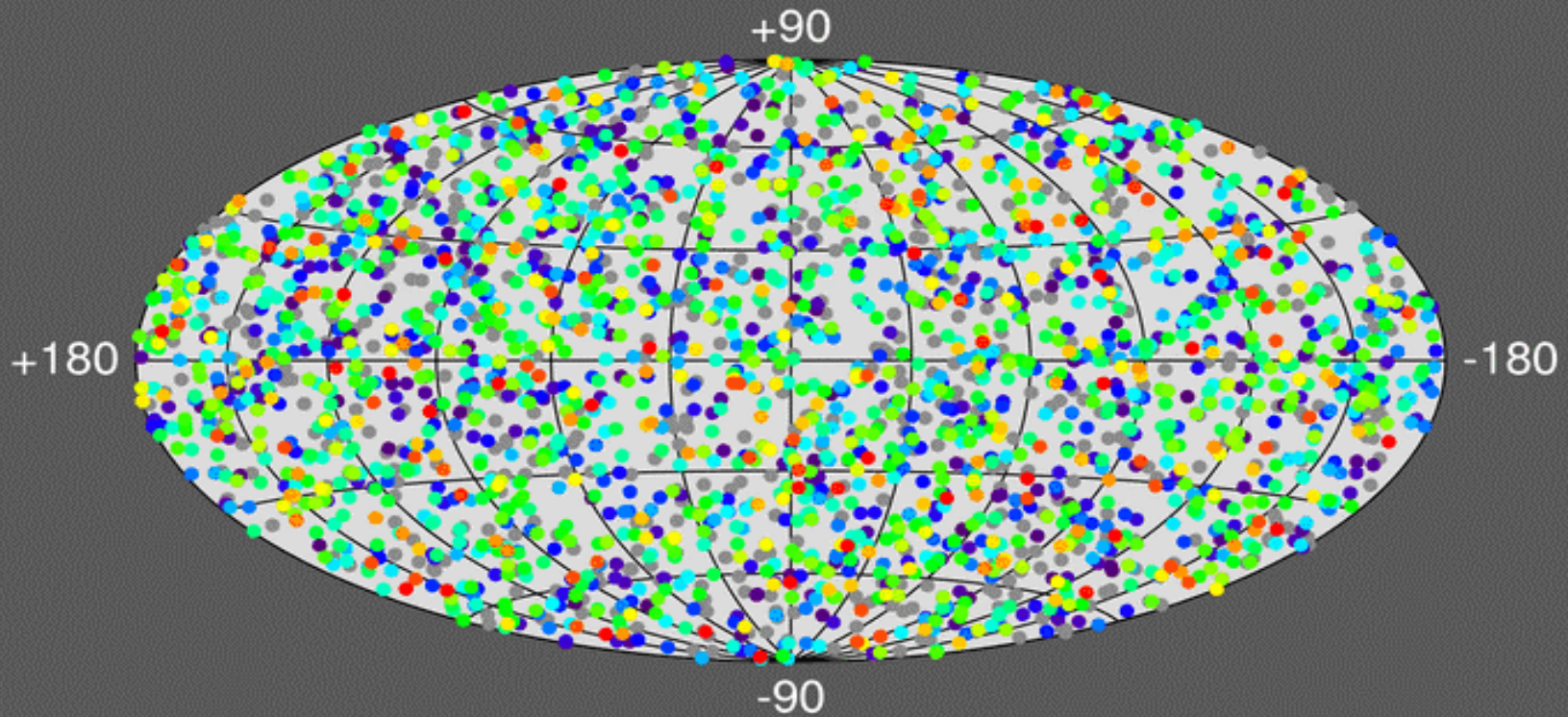
GRB 991216
(Piro et al. 2000)

A Third Burst Class

- X-Ray Flashes
- Detected by BeppoSAX and HETE-II
- Very weak (or no) emission above 30 keV
- Non thermal emission in X-rays
- 1 afterglow

Where do they come from?

2704 BATSE Gamma-Ray Bursts



Where do they come from?

- Since 1997 26 GRB source redshifts measured
- (0.001??) $0.3 < z < 4.5$ (median 1)
- Host galaxies typical of star forming galaxies
- GRB distribution relative to the center of galaxies consistent with star forming regions
- Favors short lived sources, but applies only to long duration GRBs
 - Collapsars
 - Short lived binary mergers?
- Short burst A/G? (expect HETE-II / INTEGRAL / SWIFT)

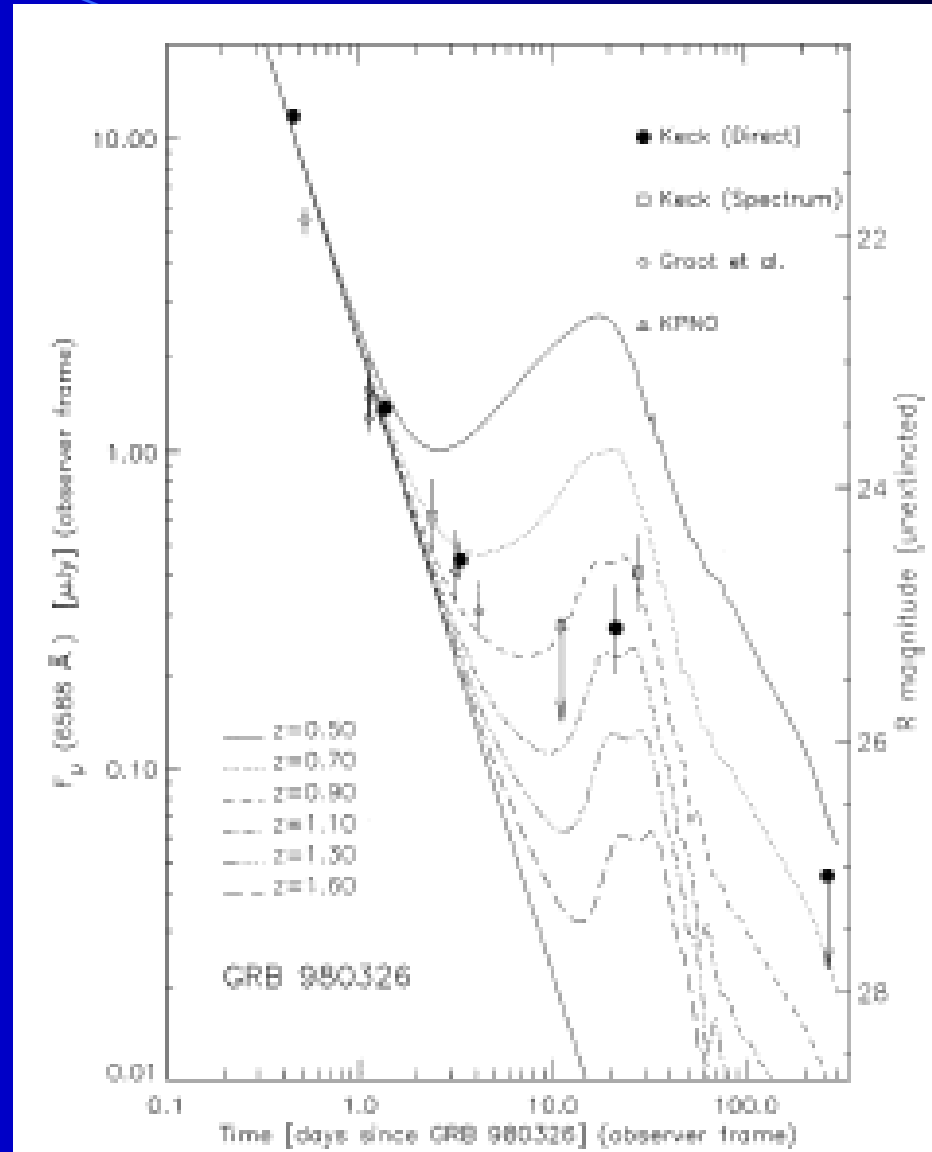
SN – GRB connection

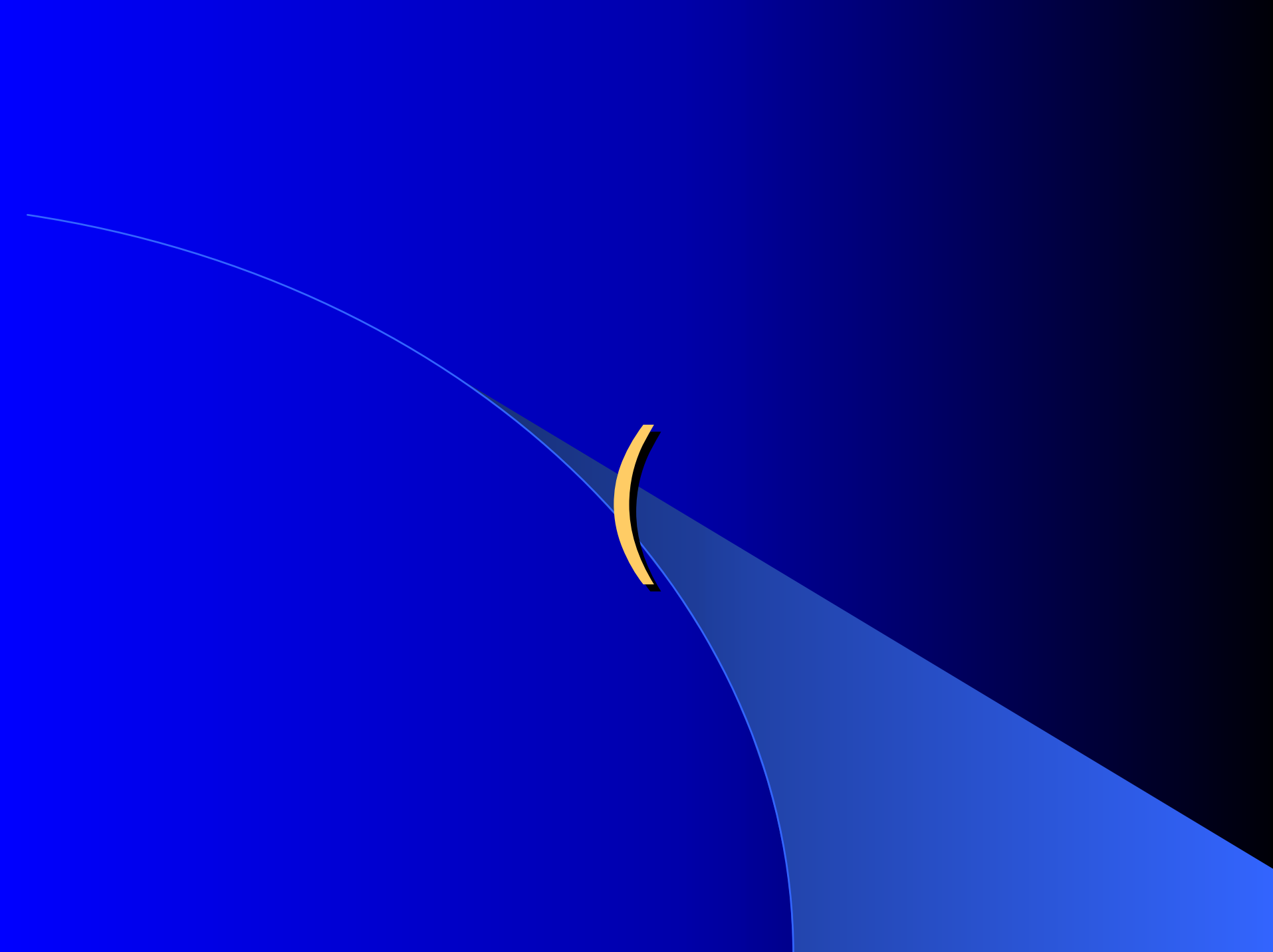
- Possible association of GRB 980425 with SN 1998bw
 - Still an open question
 - 2 variable sources in BeppoSAX error box
- Flattening / reddening of several light curve attributed to underlying SN event (10 day after GRB).
- If real, this connection may be investigated by wide angle ground searches.

GRB 980326

Bloom et al., 1999

An underlying SN ?



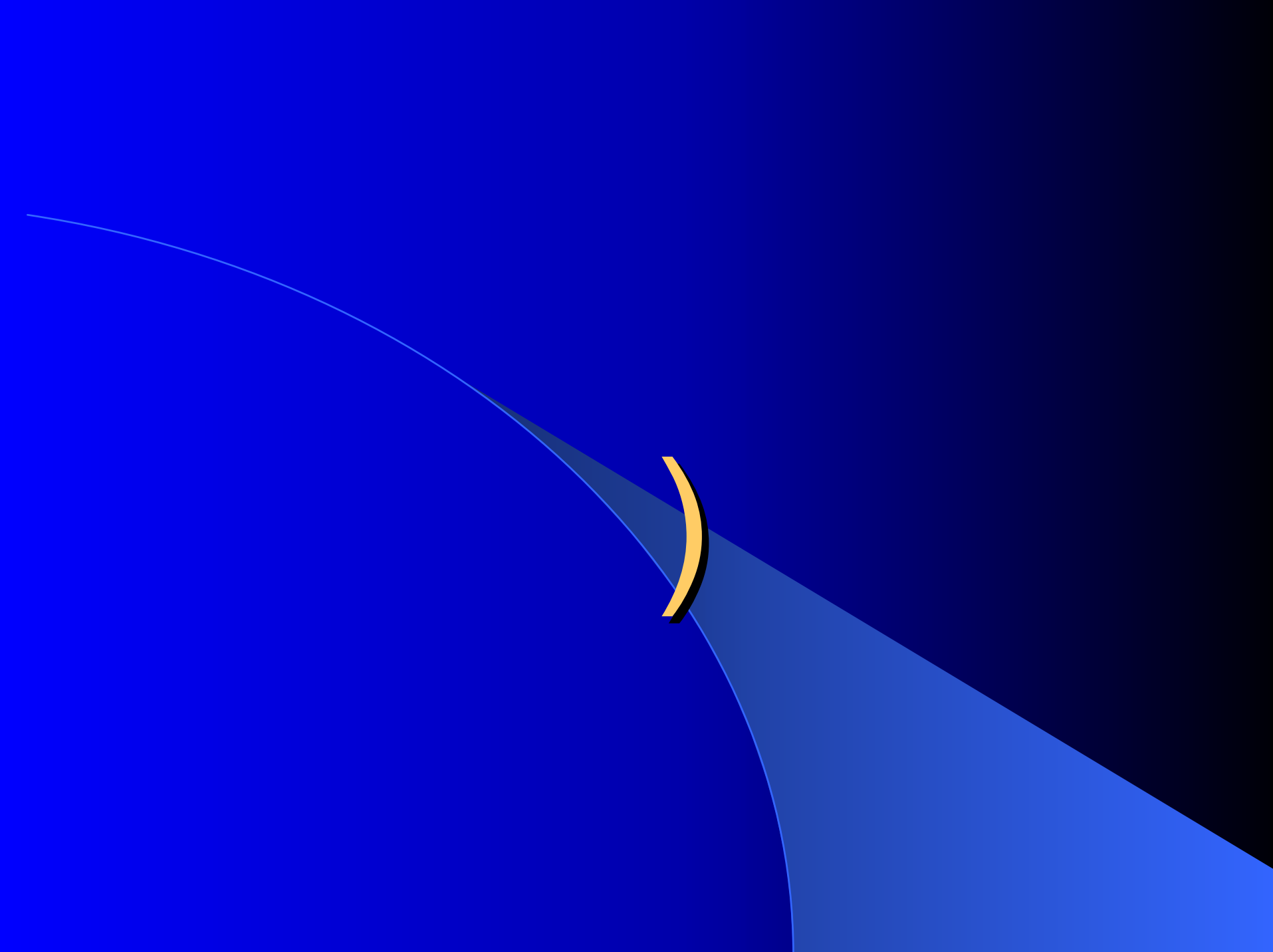


Why studying GRBs?

- It may be interesting to understand unexplained phenomena (at least we are paid (to try) to do that)

If this is not enough

- GRB and astronomy
 - Cosmological probe: GRB are detected as far as $z = 4.5$, and are luminous
 - Powerful lighthouse
 - Probing the re-ionization frontier and behind
 - Evolution of massive stars – Pop. III stars
 - Star formation rate
 - Black hole formation
 - Etc.
- Physics
 - Physics in
 - UHECR
 - Neutrino
 - Gravitational waves
 - Physics of hyper-relativistic shocks
 - Etc.



GRB and SFR

- BATSE peak flux distribution compatible with GRB – SFR distribution
- In this model, present days GRB rate about 10^{-8} /year/galaxy, but much higher at $z > 1$
- Implies BATSE bursts at $z \leq 4$, but influence of GRB luminosity function?
- Host galaxy data support idea that GRBs are connected with massive star formation

Energetic constraints

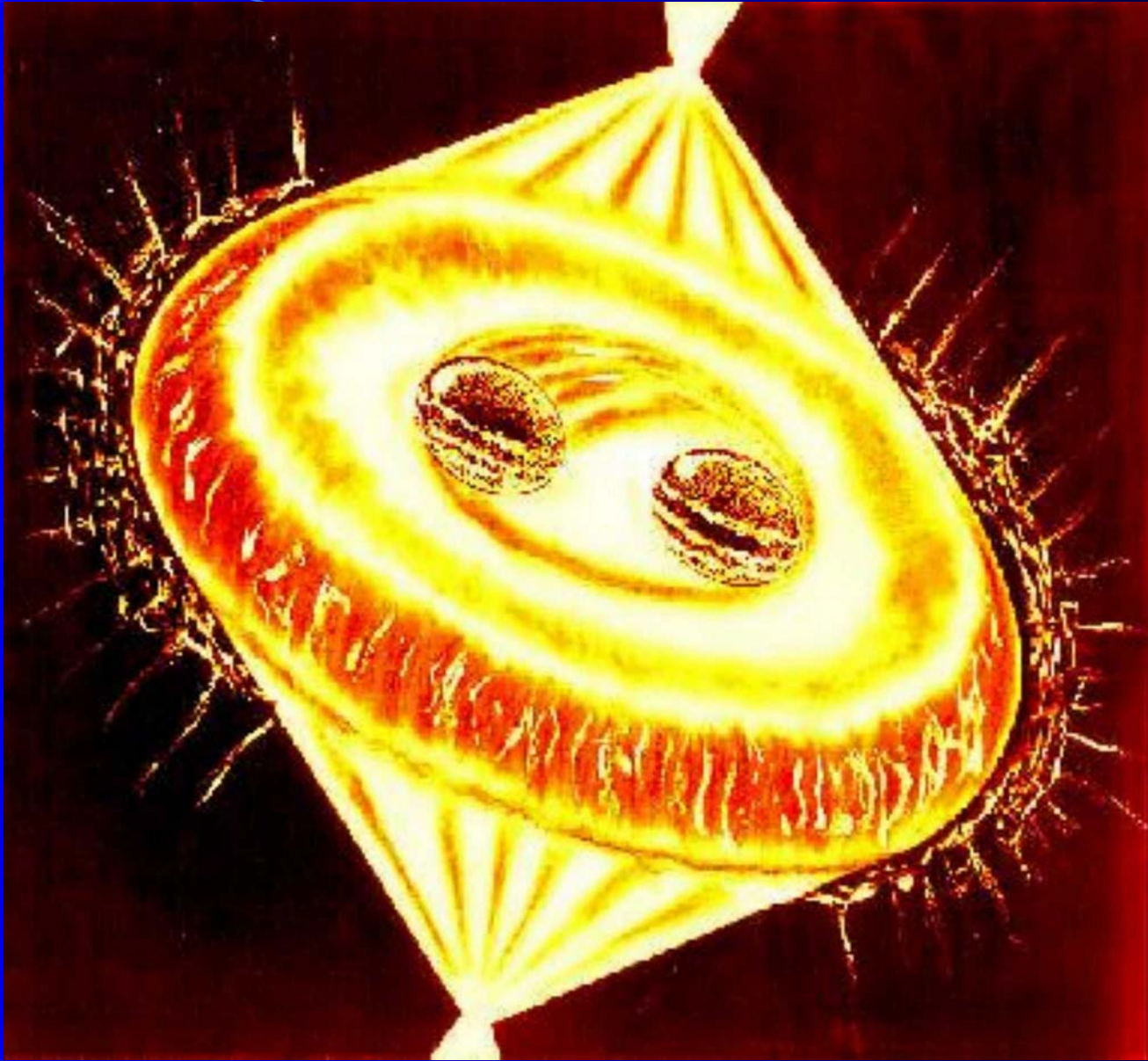
- If isotropic, detected source energy is about $10^{52} - 10^{54}$ ergs.
- Beaming proposed (+- narrow cone)
 - Achromatic breaks in light curve
 - Allows GRB luminosity about 10^{51} ergs
 - If $\langle \text{beaming} \rangle \approx 1/500$, then ≈ 1 new BH / min. in the Universe

Progenitor

- Collapse of massive star / core collapse supernovae
 - Collapsar model (for long bursts)
 - Canonball model
- Coalescence of binary systems
 - Merger rate dominated by short lived systems (1Myr)
 - NS-NS and NS-BH
 - Short bursts ?
 - Gravitational waves and low energy neutrinos

Extraction of energy

- Release of 10^{52} ergs (or more)
 - Power supply: accretion of a massive ($0.1M_{\odot}$) accretion disk
 - Gravitational energy and neutrino annihilation
 - Electromagnetic extraction of the rotational energy of the BH
 - Formation of a blast wave, probably collimated

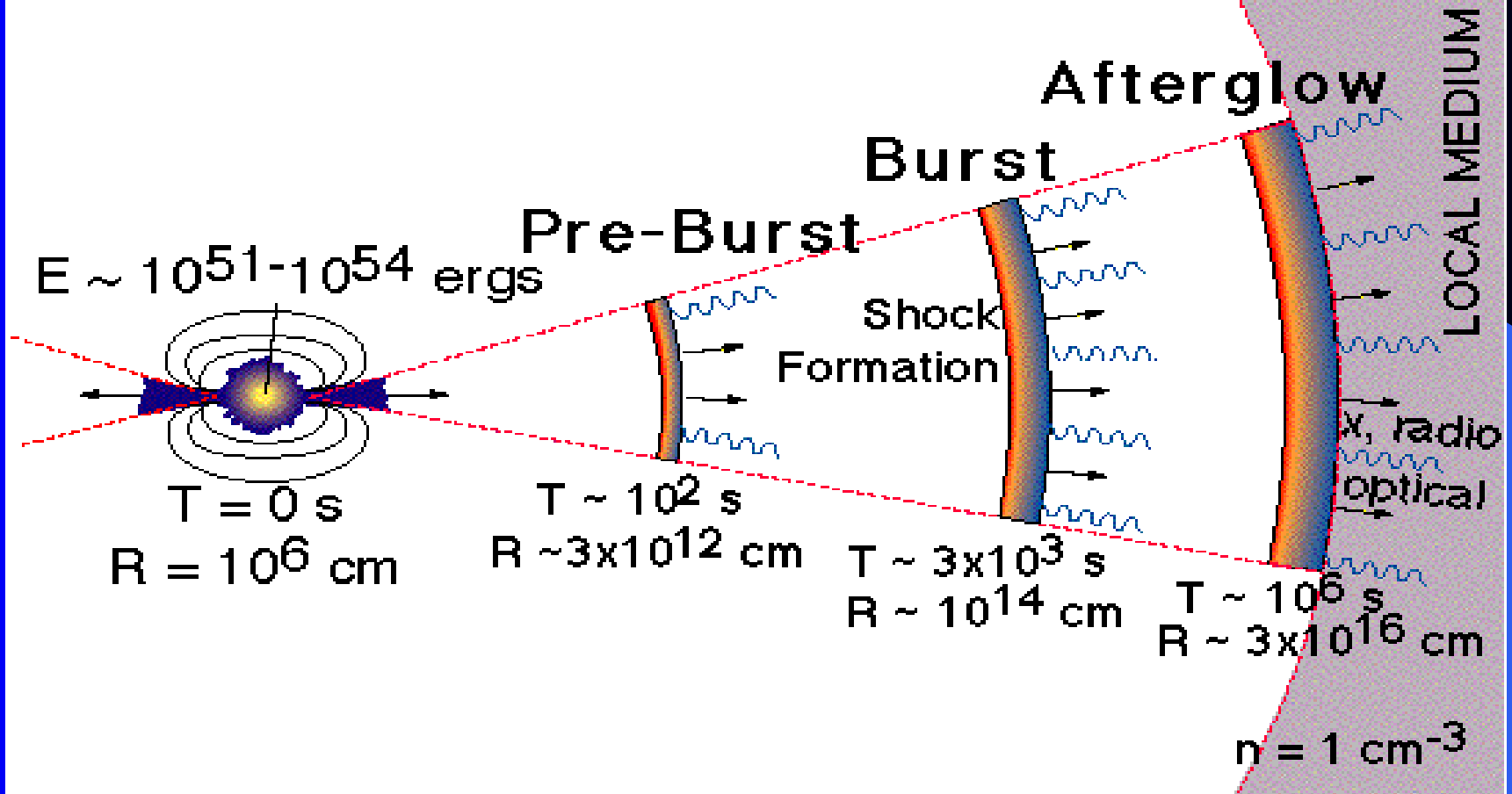


Emission: Fireballs

- Release of 10^{50-52} ergs (e.g. from transient accretion)
 - High optical depth implies conversion in kinetical energy, i.e. adiabatic expansion (with $\Gamma > 100$)
 - T decreases
 - Synchrotron emission from acceleration of e^- in relativistic shocks
 - Internal shocks (mildly relativistic - due to variation of bulk Lorentz factor. (GRB?))
 - External shocks (ultra-relativistic – with interstellar medium)
 - Reverse shocks (Optical Transient?)

Fireballs ...

GRB FIREBALL MODEL

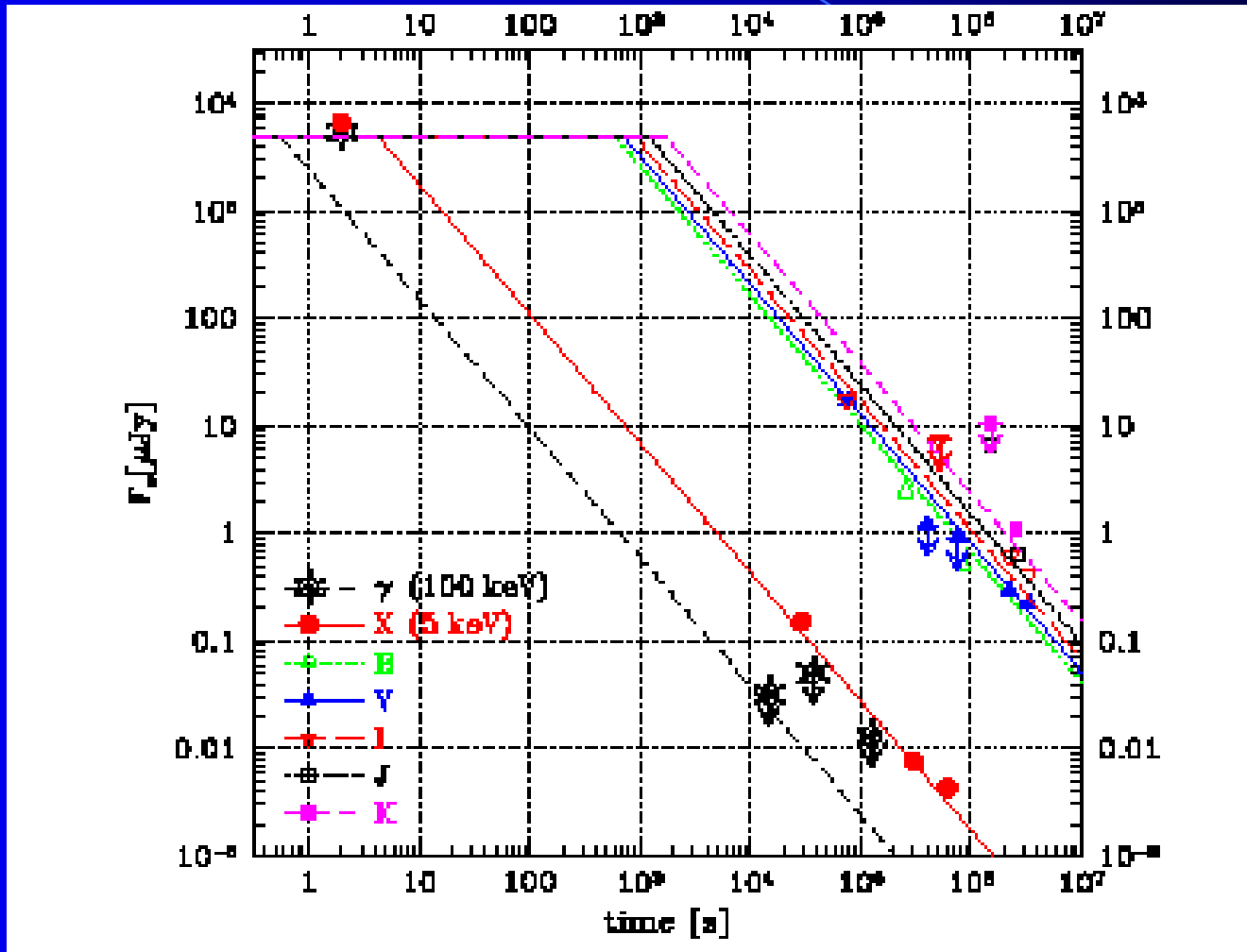


Fireballs

- Photospheric emission
 - X-ray precursor?
 - Seems not as luminous as expected
 - Less luminous photosphere (Daigne, 2001), magnetic energy
- Fireballs fits well A/G
- Orphan afterglow if beamed
 - From decrease of Lorentz factor
 - From lateral expansion of fireball

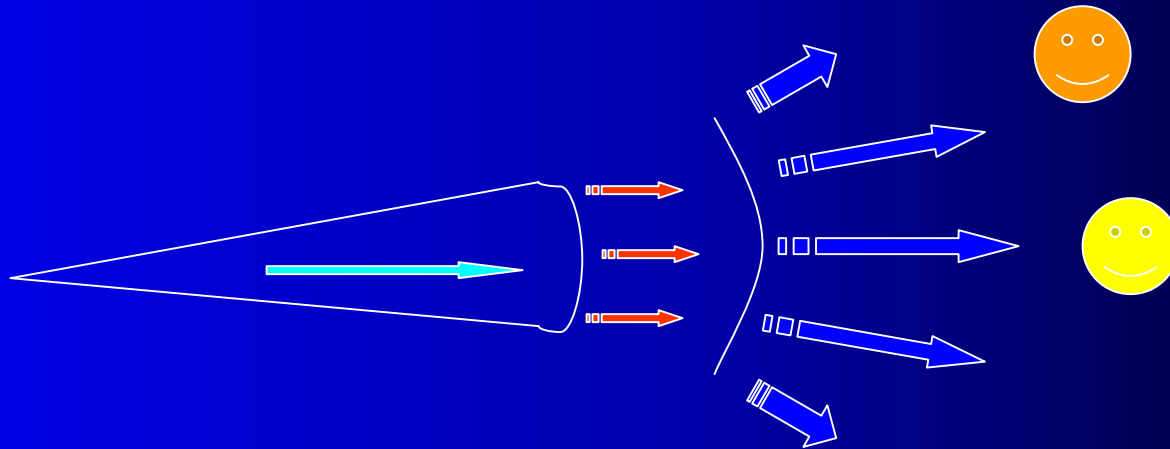
Fireball prediction and GRB 970228

Rees and Meszaros 97

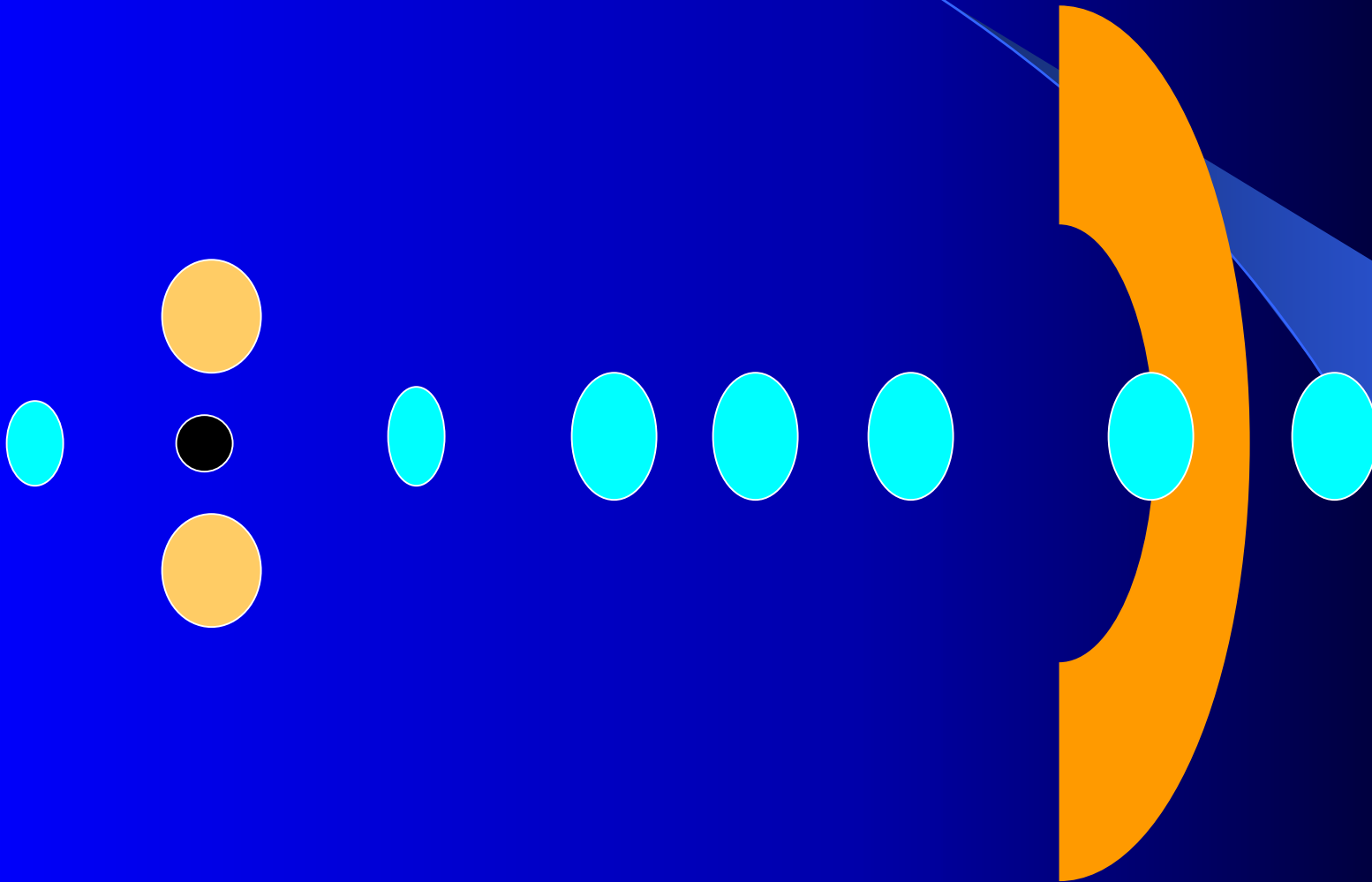


Orphan afterglows

- If fireball jetted
- From decrease of Lorentz factor
- From lateral expansion of the fireball
- When not in fireball axis, GRB not seen, only afterglow
- Many orphan GRBs, i.e. afterglows of GRB without GRB should be detectable at X, visible, radio wavelength.
- How to detect them? Need wide sky coverage



... and Cannonballs



Cannonballs

- Core-collapse SN
 - 1 day before GRB
 - Catastrophic accretion episodes
 - Beams of blobs of matter ($\Gamma \approx 1000$)
 - When « cannonball » crosses SN shell, heating
 - 1 GRB pulse per cannonball
 - Doppler shifted quasi-thermal spectra

GRBs and multi-messenger astronomy

- Gravitational waves:
 - Probably more intense for mergers
 - Search in coincidence with GRBs
- Neutrinos
 - Predicted from fireball and cannonball models
 - Produced by π^+ (interaction of gamma-rays with fireball protons)
 - What fraction of energy converted in neutrinos?
- UHECR
 - Proton acceleration in internal shocks

Detection

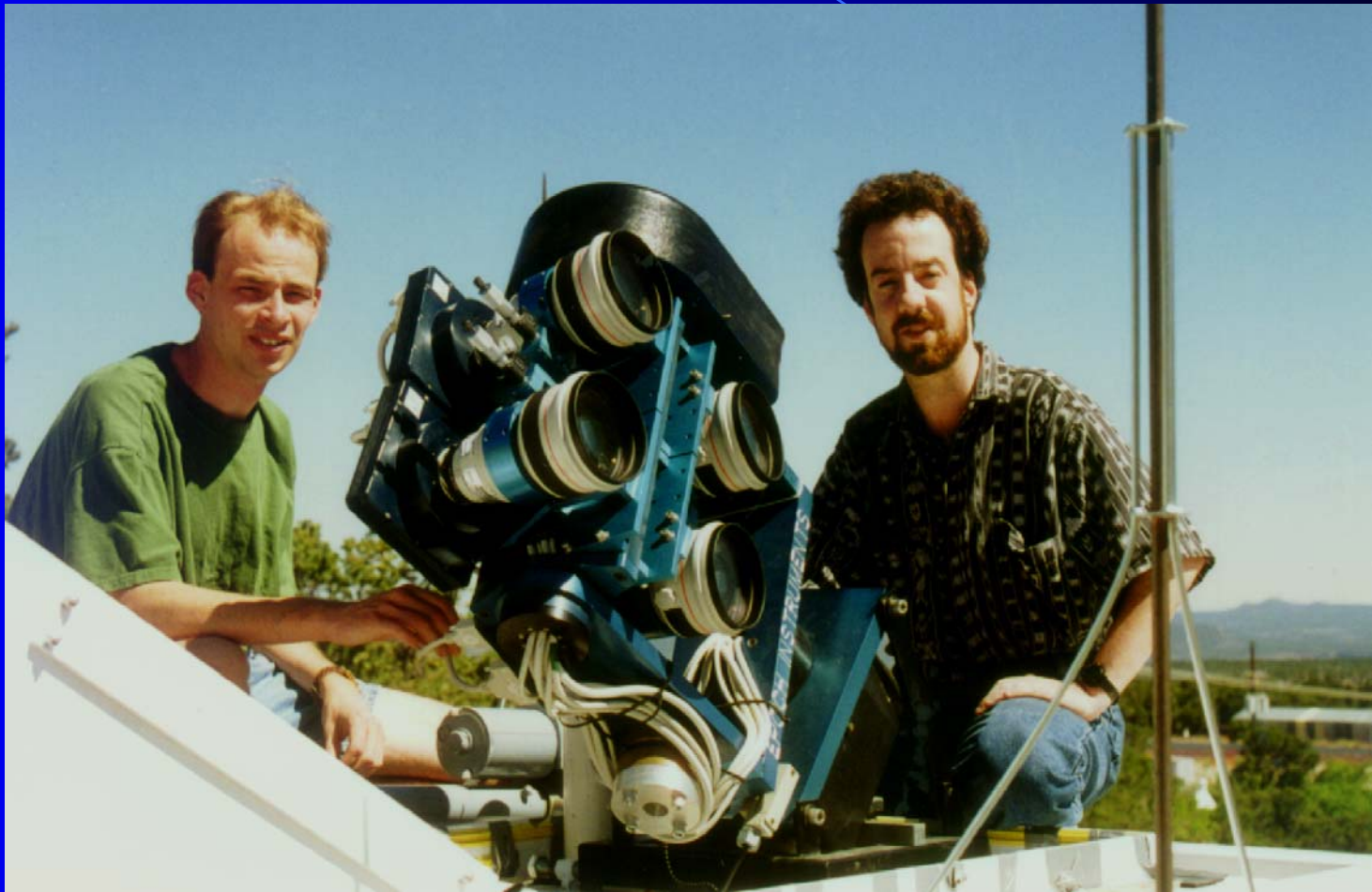
- GRBs are (very) limited in time
 - Advantage is a weaker background
 - Disadvantage is combination of experiment duty cycles and field of view.
 - If jets, a small part (1/1000) of GRBs is detected in the best case.
 - Optical surveys will provide statistics

Satellite	Start	End?	Instrument	Energy range	GRB/y	Accuracy	Delay
HETE-2	2000	2006?	FREGATE	4 - 400 keV	50	N/A	N/A
			WXM	1 - 10 keV	20	30'	8s
			SXC	0.5 - 2 keV	10	30'	8s
AGILE	2003	2008?	GRID	30 MeV - 30 GeV	20	20'	60s
			S-AGILE	10 - 40 keV	20	3'	> 1h
INTEGRAL	2003	2010?	IBIS	15 keV - 10 MeV	12	2'	15s
			SPI	20 keV - 8 MeV	20	30'	15s
SWIFT	2004	2010?	BAT	10 - 150 keV	300	5'	8s
			XRT	0.3 - 10 keV	300	2.5"	90s
			UVOT	170 - 650 nm	300	0.5"	90s
GLAST	2006	2016?	LAT	10 MeV - 100 GeV	200	10'	30s
			GBM	5 keV - 30 keV	200	15°	5s
ECLAIRS	2006	2009?	LAXT	3 - 50 keV	200	30'	5s
			SXC	0.5 - 14 keV	200	30'	5s
			WFOC	500 - 700 nm	200	30'	5s

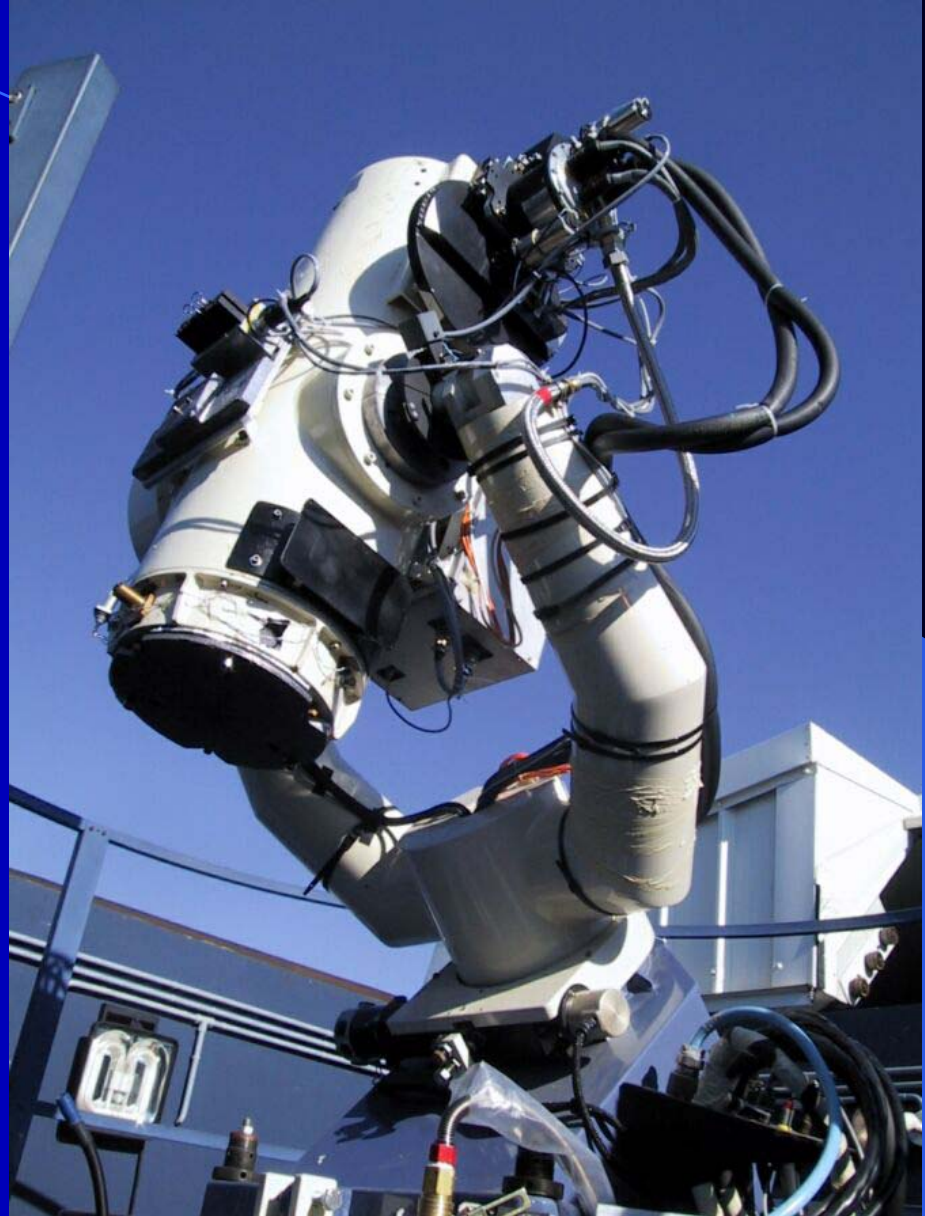
Experiments: Ground

- Several ground automated telescopes
 - In operation
 - ROTSE resulted in 1 detection and upper limits (30s - $V > 14$)
 - LOTIS: upper limits (30s - 10cm $V > 14$)
 - TAROT: upper limits (1s 25cm - $V > 16$ for 30min)
 - SuperLOTIS (20s – 60cm - no rapid observations yet)
 - In preparation
 - ROTSE-III network (15s - 45cm $V_{\max} = 18$ in 10s)
 - TAROT-Chile (1s - 25cm $V_{\max} = 17$ in 10s)
 - REM-Chile (20s – IR $K_{\max} = 13$ in 1 min)
 - ARAGO (1s - 150cm - $V_{\max} = 21$ in 10s)

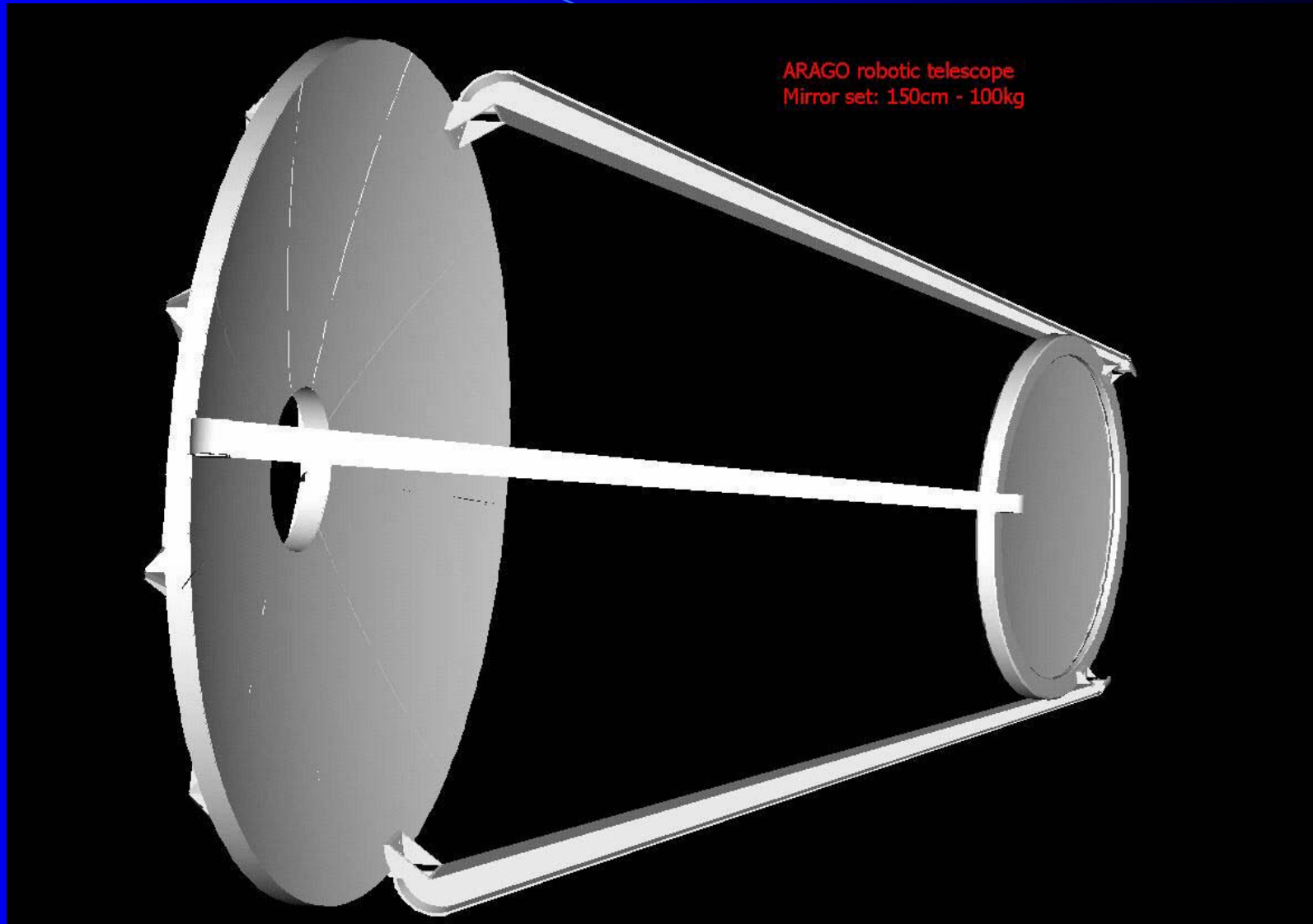
ROTSE



TAROT

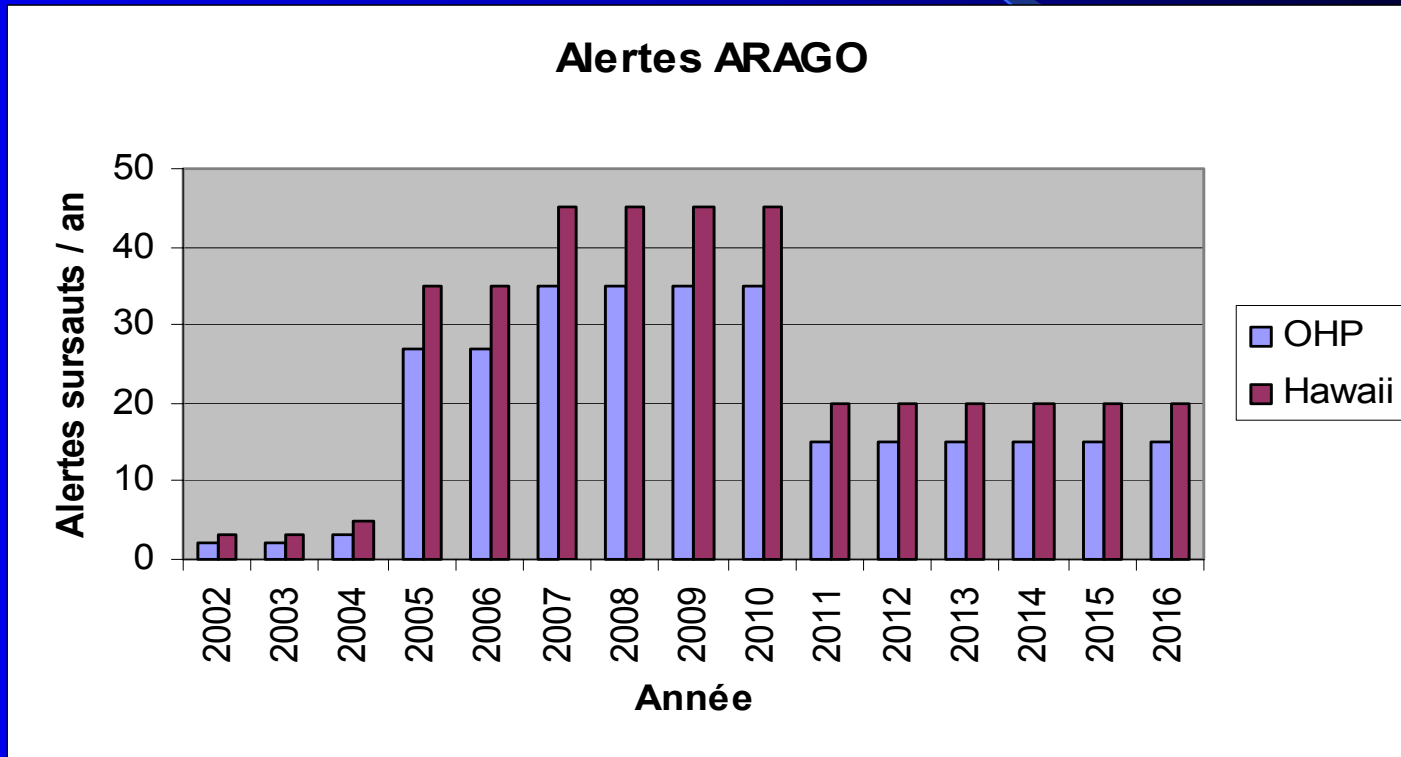


ARAGO

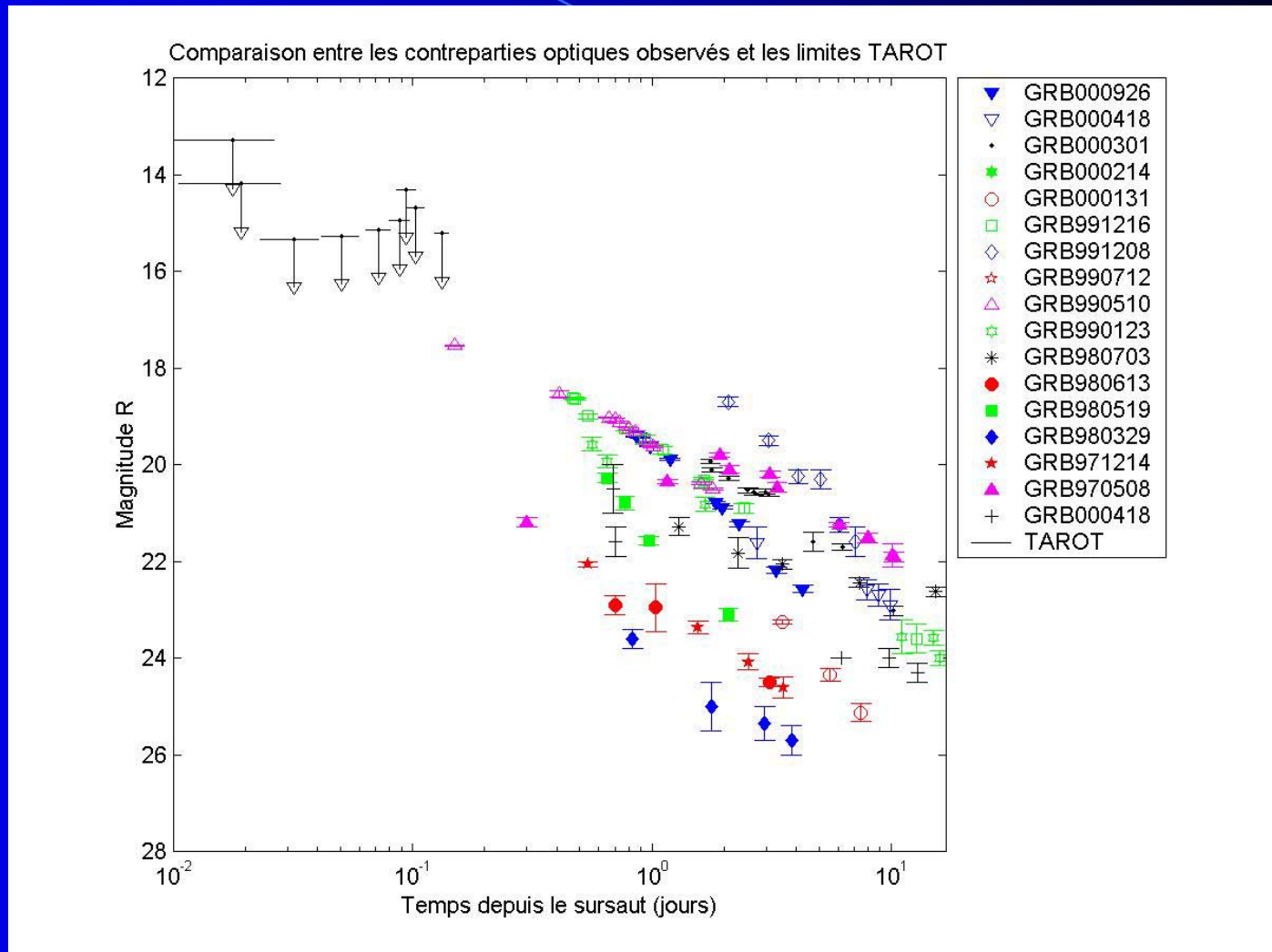


ARAGO robotic telescope
Mirror set: 150cm - 100kg

Expected GRB alert rate from satellite for a ground based experiment



1 detection – upper limits



Ground observations

- Use of medium – large facilities
 - Almost every observatory produced data
 - Not always consistent
 - Typical reaction times of hours
 - Observation of A/G
 - Source redshift – Polarimetry
 - Near Infrared
 - Orphan afterglow: 1 claim from SDSS, but recent claim (19/01/2002) appeared to be an M dwarf on the line of sight of a galaxy
- Radio observations led to size of A/G source
- VHE - Čerenkov astronomy
 - CELESTE – WHIPPLE – VERITAS – HEGRA - HESS
 - Few observations by Čerenkov telescopes
 - MILAGRO / MILAGRITO: 1 detection?
- SOON!
 - AUGER / EUSO
 - AMANDA / ANTARES / NESTOR / etc.
 - VIRGO / LIGO



Final remarks

- In the last years, many progress towards the understanding of GRBs
- But still open questions:
 - Progenitor
 - GRB / SN association
 - Role of merger (short lived binary systems)
 - Short bursts and collapsars
 - Energy extraction
 - Role of magnetic field
 - Energy transport
 - Fraction of magnetic energy?
 - Understanding X-ray observations
 - Beaming and jets: ground observations (ARAGO) may prove to be a sensitive test of jets (or fire-trumpets) / cannonballs
 - Internal shocks / Reverse shocks
 - Connection optical /gamma-rays

- Questions and questions...
 - Association of GRBs with « first light » stars (high redshift SFR)
 - Probing the Universe with GRBs
 - Failed GRBs (i.e. no Gamma-RBs), XRFs...
 - Prove association with SNs
 - Detectability of ν Bs
 - Are GRBs a viable explanation for UHECRs?