Sursauts Gamma et Cosmologie

Un peu d'histoire…

Moscou, 5 Août 1963

Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and under Water Signed by the Original Parties, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland and the United States of America at Moscow: 5 August 1963

The Governments of the United States of America, the United Kingdom of Great Britain and Northern Ireland, and the Union of Soviet Socialist Republics, hereinafter referred to as the "Original Parties,"

Proclaiming as their principal aim the speediest possible achievement of an agreement on general and complete disarmament under strict international control in accordance with the objectives of the United Nations which would put an end to the armaments race and eliminate the incentive to the production and testing of all kinds of weapons, including nuclear weapons,

Seeking to achieve the discontinuance of all test explosions of nuclear weapons for all time, determined to continue negotiations to this end, and desiring to put an end to the contamination of man's environment by radioactive substances,

Have agreed as follows:

Article I

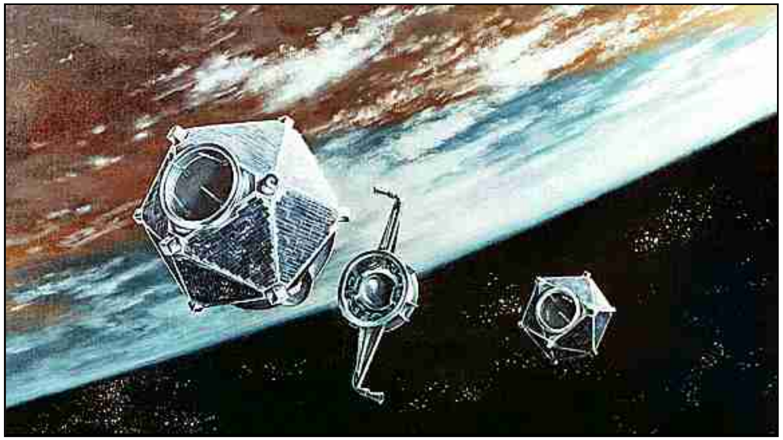
1. Each of the Parties to this Treaty undertakes to prohibit, to prevent, and not to carry out any nuclear weapon test explosion, or any other nuclear explosion, at any place under its jurisdiction or control:

(a) in the atmosphere; beyond its limits, including outer space; or under water, including territorial waters or high seas; or

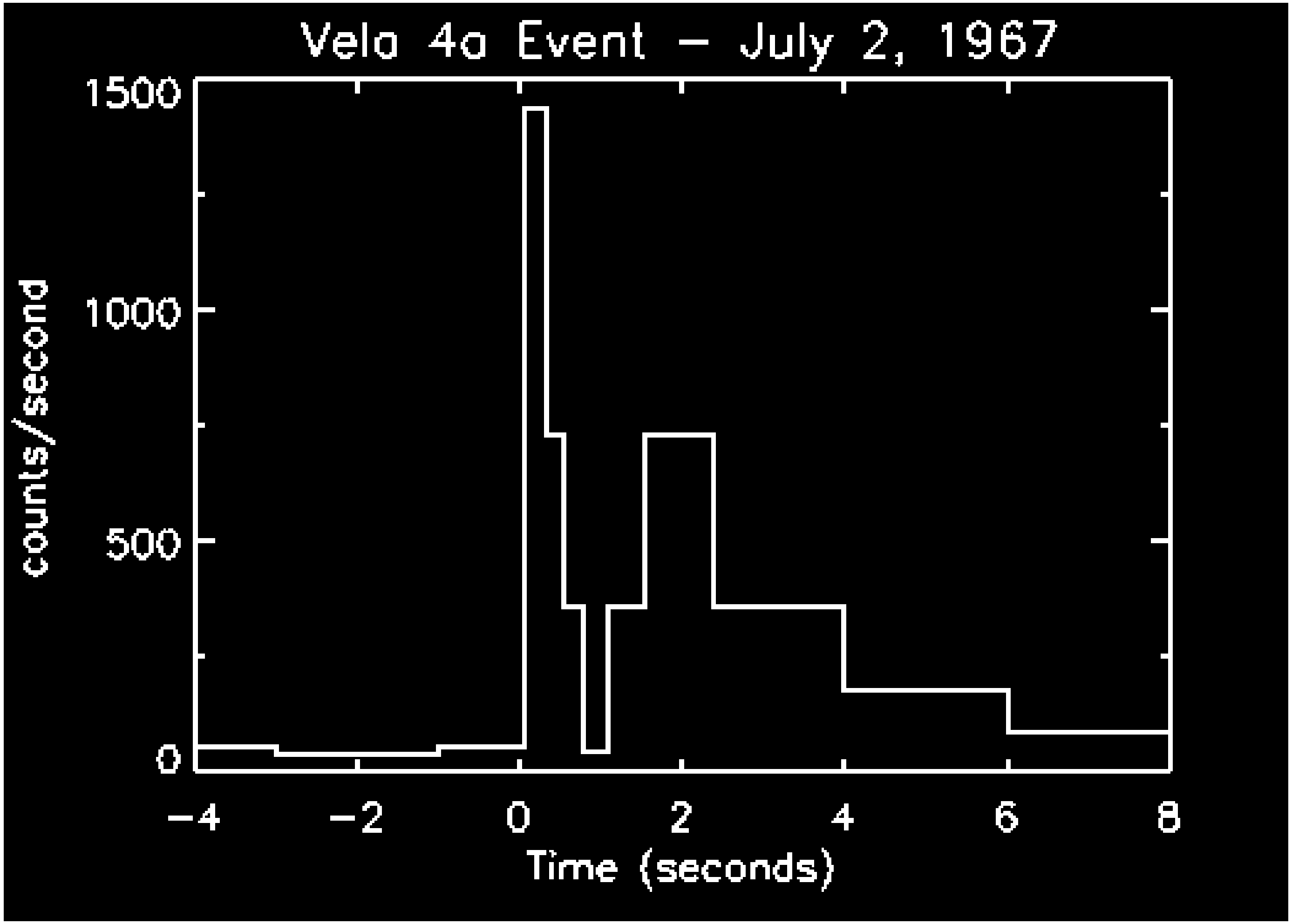
Des outils pour vérifier le respect du traité: les satellites « VELA »

des caméras gamma pour détecter les explosions nucléaires dans l'atmosphère

Trois paires de satellites lancés en 1963, 1964 and 1965



Le premier sursaut gamma



Le premier article

THE ASTROPHYSICAL JOURNAL, 182:L85–L88, 1973 June 1

OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

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Received 1973 March 16; revised 1973 April 2

ABSTRACT

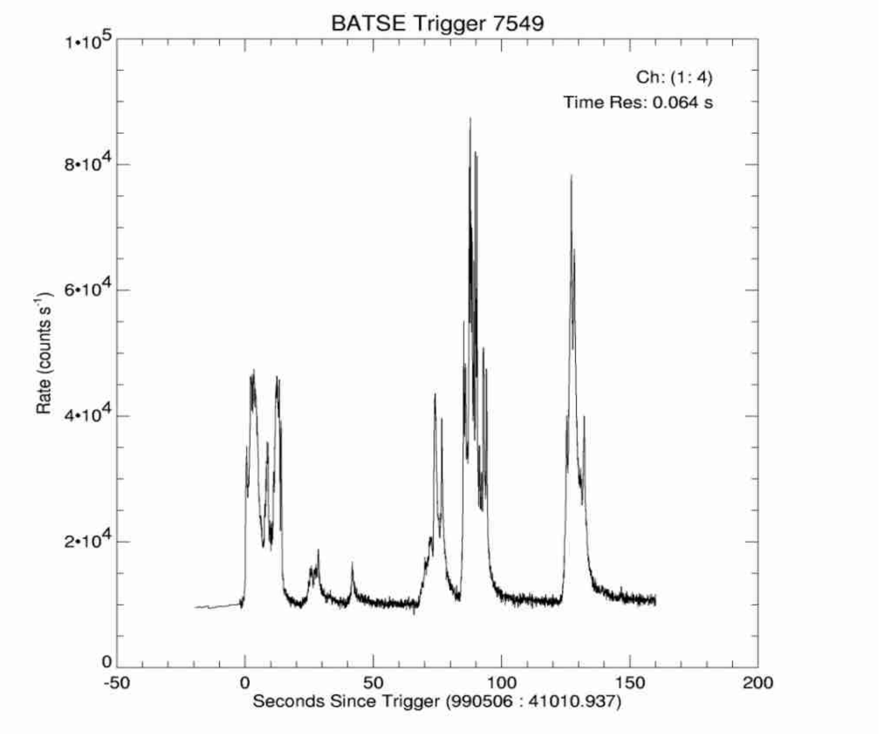
Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to ~30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$ ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

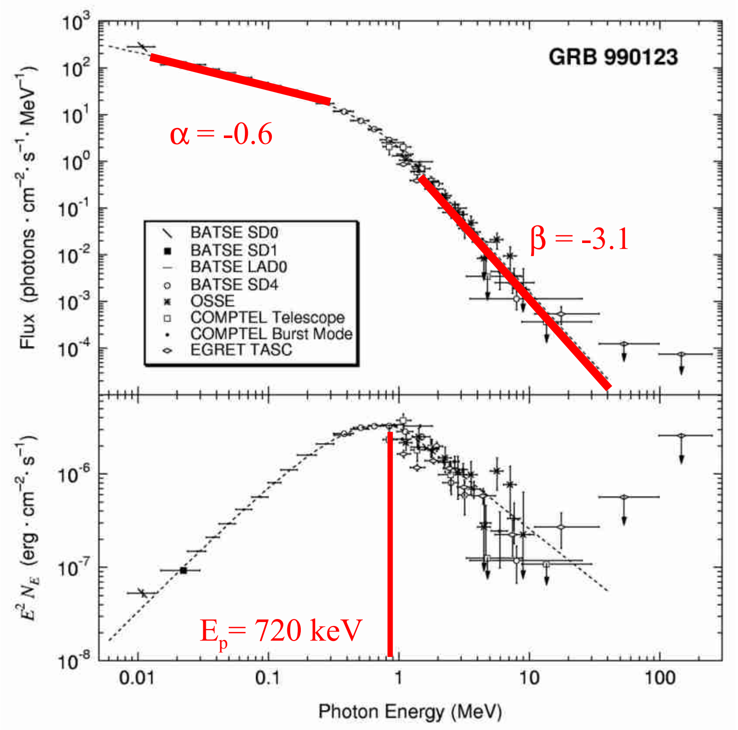
Subject headings: gamma rays — X-rays — variable stars

1973 – 1990: l’époque pré-BATSE

Les principales propriétés observationnelles des sursauts sont mises en évidence:

- deux groupes de durée: longs **(> 2 s)** et courts **(< 2 s)**
- profils variables
- spectres non thermiques





- pas de contrepartie à basse énergie → distance non connue
- distribution isotrope sur le ciel → sources proches ?

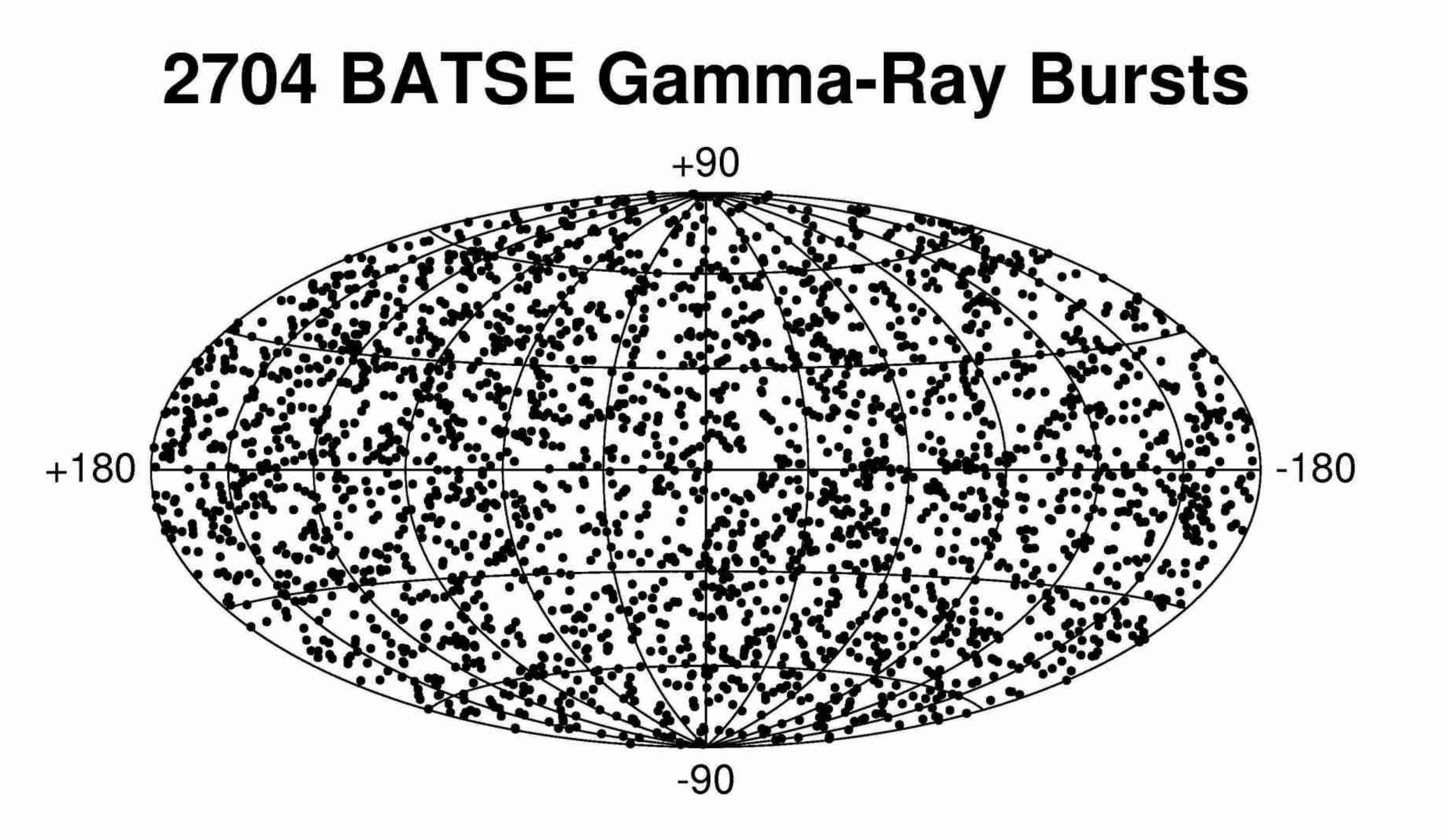
Les premiers modèles: événement violent à la surface d'une étoile à neutrons:

→ flash thermonucléaire, impact d'un petit corps, craquement de croûte…

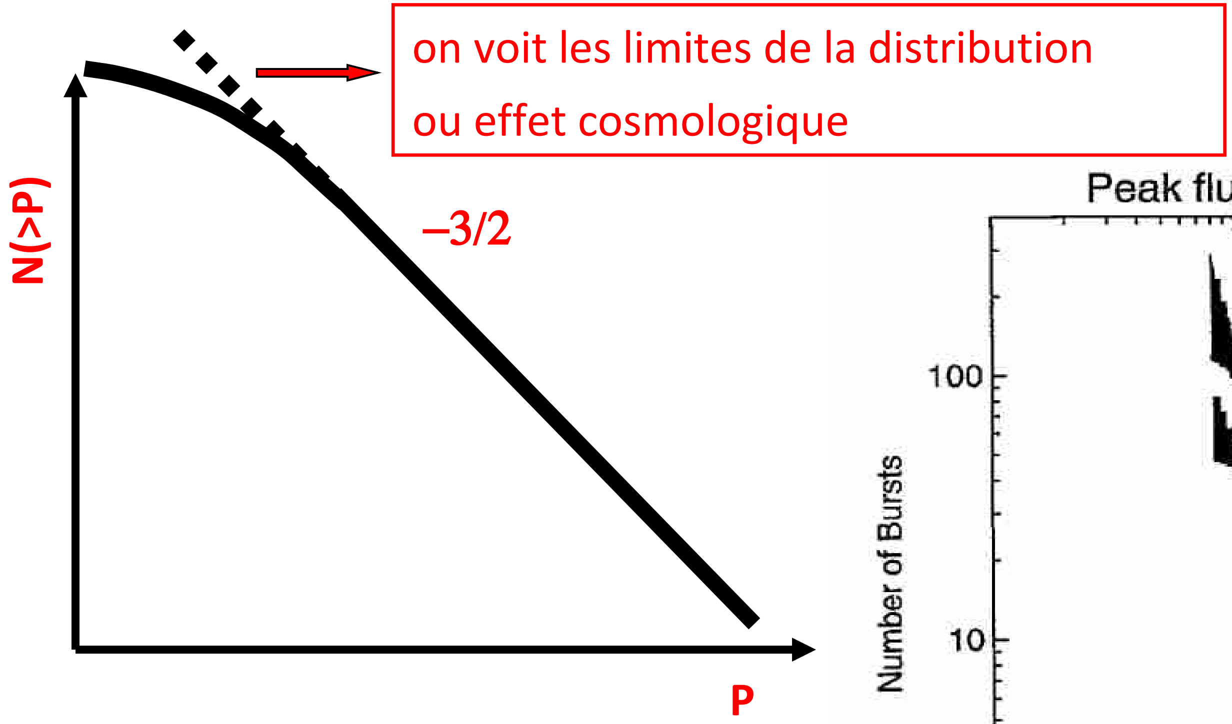
la luminosité d'Eddington à ~100 pc peut expliquer les flux observés

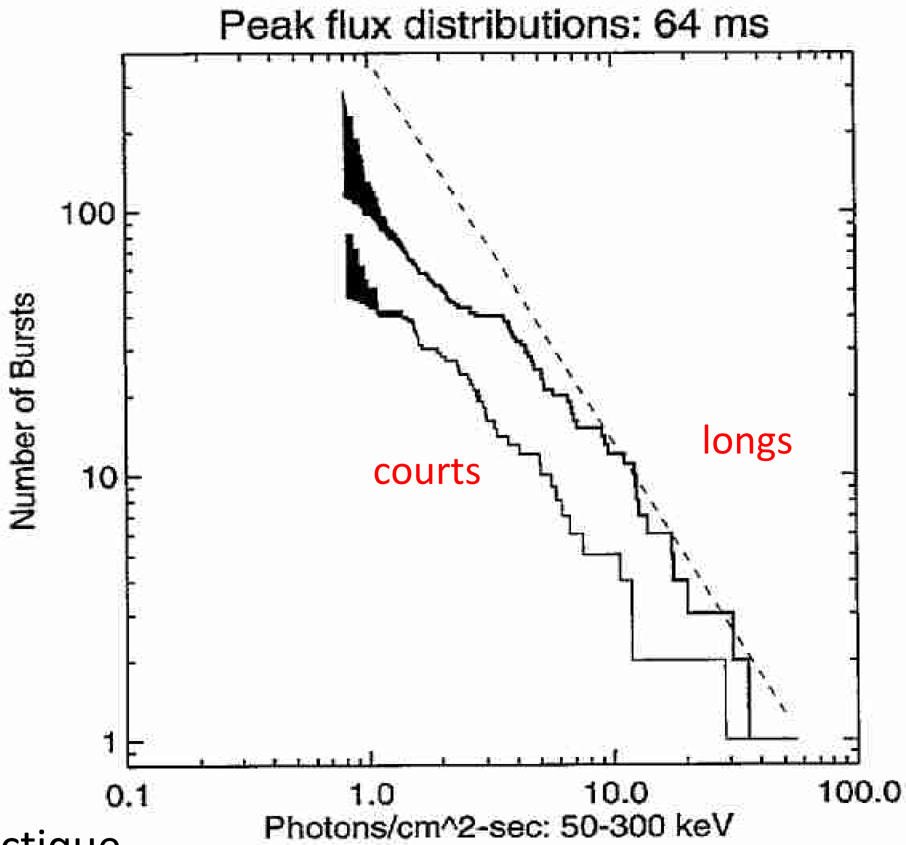
1991: la révolution BATSE

Contre toute attente, la distribution reste isotrope…



La distribution Log N - Log P





isotropie + non homogénéité

→ les sursauts n’appartiennent pas au plan galactique

→ 1ère indication d’une échelle de distance cosmologique

Le « grand débat » (1995) sur l'échelle de distance des sursauts

Écho au débat de 1920 sur l'échelle de distance des galaxies
H. Shapley et H.D. Curtis

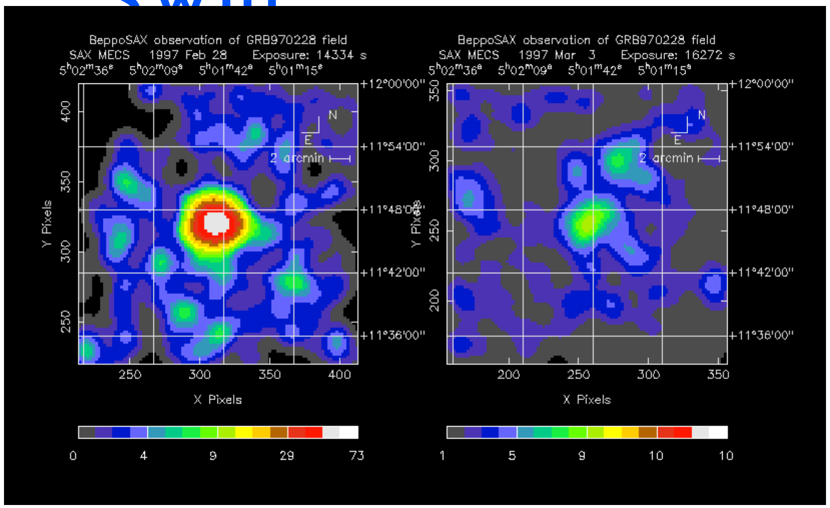
H. Shapley : nébuleuses spirales = nuages de gaz dans la Voie Lactée
H.D. Curtis : nébuleuses spirales = autres galaxies à l'extérieur de la Voie Lactée

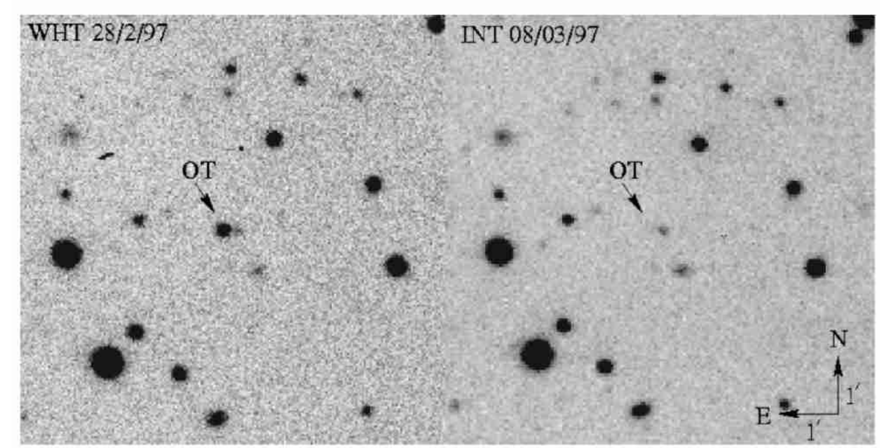
Tranché au début des années 20 par Hubble (Céphéides de M31)

1995 : B. Paczynski et D. Lamb
(moderateur: M. Rees)

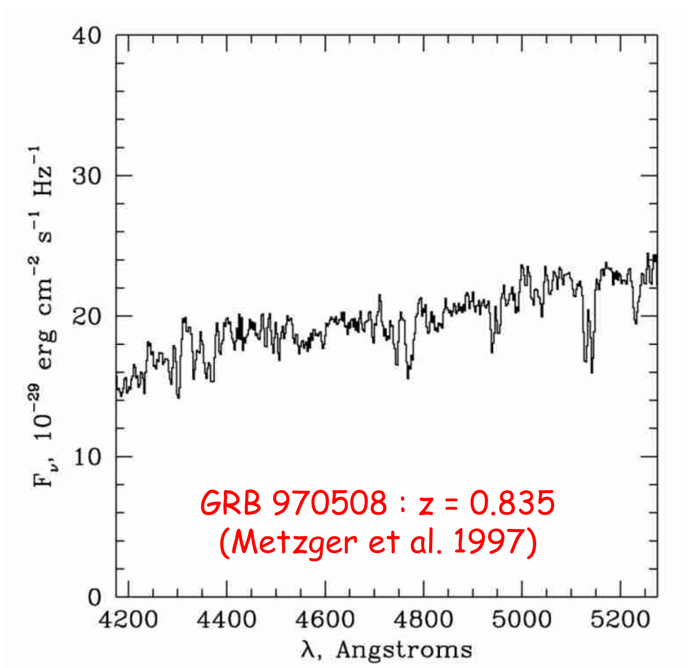
D. Lamb : « super-halo » galactique
B. Paczynski : distance cosmologique

L'ère des rémanences: Beppo-SAX, HETE 2, Swift





La première rémanence



Le premier redshift

Les sursauts gamma sont à distance cosmologique!
→ révolution dans les idées théoriques

Une conséquence immédiate …

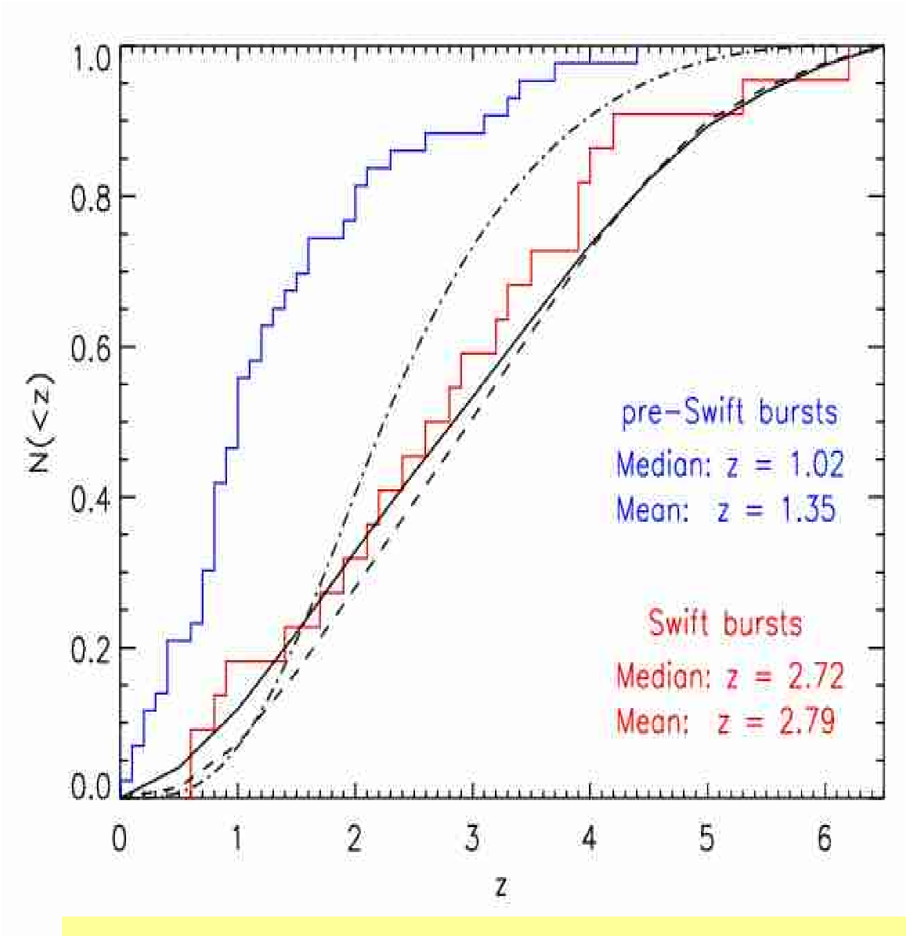
Table 1

#	Author	Year Pub	Reference	Main Body	2nd Body	Place	Description
1.	Colgate	1968	CJPhys, 46, S476	ST		COS	SN shocks stellar surface in distant galaxy
2.	Colgate	1974	ApJ, 187, 333	ST		COS	Type II SN shock brem, inv Comp scat at stellar surface
[redacted]							Stellar superflare from nearby star
[redacted]							Superflare from nearby WD
[redacted]							Relic comet perturbed to collide with old galactic NS
[redacted]							Accretion onto WD from flare in companion
[redacted]							Accretion onto NS from flare in companion
[redacted]							Accretion onto BH from flare in companion
[redacted]							NS chunk contained by external pressure escapes, explodes
[redacted]							Relativistic iron dust grain up-scatters solar radiation
[redacted]							Directed stellar flare on nearby star
[redacted]							Comet from system's cloud strikes WD
[redacted]							Comet from system's cloud strikes NS
14.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	ST		COS	Absorption of neutrino emission from SN in stellar envelope
15.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	ST	SN	COS	Thermal emission when small star heated by SN shock wave
16.	Bisnovatyi- et al.	1975	Ap & SS, 35, 23	NS		COS	Ejected matter from NS explodes
[redacted]							NS crustal starquake glitch; should time coincide with GRB
18.	Narlikar et al.	1974	Nature, 251, 590	WH		COS	White hole emits spectrum that softens with time
[redacted]							NS corequake excites vibrations, changing E & B fields
[redacted]							Convection inside WD with high B field produces flare
21.	Prilutski et al.	1975	Ap & SS, 34, 395	AGN	ST	COS	Collapse of supermassive body in nucleus of active galaxy
22.	Narlikar et al.	1975	Ap & SS, 35, 321	WH		COS	WH excites synchrotron emission, inverse Compton scattering
[redacted]							Inv Comp scat deep in ergosphere of fast rotating, accreting BH
[redacted]							NS crustquake shocks NS surface
[redacted]							Magnetic WD suffers MHD instabilities, flares
[redacted]							Thermal radiation from flare near magnetic WD
[redacted]							Carbon detonation from accreted matter onto NS
[redacted]							Mag grating of accret disk around NS causes sudden accretion
[redacted]							Instability in accretion onto rapidly rotating BH
[redacted]							Charged intergal rel dust grain enters sol sys, breaks up
[redacted]							WD surface nuclear burst causes chromospheric flares
[redacted]							NS surface nuclear burst causes chromospheric flares
[redacted]							NS vibrations heat atm to pair produce, annihilate, synch cool
[redacted]							Asteroid from interstellar medium hits NS
[redacted]							NS core quake caused by phase transition, vibrations
[redacted]							Asteroid hits NS, B-field confines mass, creates high temp
[redacted]							Helium flash cooled by MHD waves in NS outer layers
[redacted]							Asteroid hits NS, tidally disrupts, heated, expelled along B lines
[redacted]							Asteroid enters NS B field, dragged to surface collision
[redacted]							Magnetic reconnection at heliopause
[redacted]							NS flares from pair plasma confined in NS magnetosphere
[redacted]							Magnetic reconnection after NS surface He flash
[redacted]							He fusion runaway on NS B-pole helium lake
[redacted]							e- capture triggers H flash triggers He flash on NS surface
[redacted]							B induced cyclo res in rad absorp giving rel e-s, inv C scat
[redacted]							BB X-rays inv Comp scat by hotter overlying plasma
[redacted]							ISM matter accum at NS magnetopause then suddenly accretes
[redacted]							Nonexplosive collapse of WD into rotating, cooling NS
[redacted]							NS accretion from low mass binary companion
[redacted]							Neutron rich elements to NS surface with quake, undergo fission
[redacted]							Thermonuclear explosion beneath NS surface
[redacted]							NS corequake + uneven heating yield SGR pulsations
[redacted]							B field contains matter on NS cap allowing fusion
[redacted]							NS surface nuc explosion causes small scale B reconnection
[redacted]							Remnant disk ionization instability causes sudden accretion
[redacted]							Resonant EM absorp during magnetic flare gives hot sync e-s
[redacted]							NS magnetic fields get twisted, recombine, create flare
[redacted]							NS magnetosphere excited by starquake
[redacted]							Accretion instability between NS and disk
[redacted]							Old NS in Galactic halo undergoes starquake
[redacted]							Weak B field NS spherically accretes, Comptonizes X-rays
[redacted]							NS flares result of magnetic convective-oscillation instability
[redacted]							High Landau e-s beamed along B lines in cold atm of NS
[redacted]							NS + low mass stellar companion gives GRB + optical flash
[redacted]							NS tides disrupt comet, debris hits NS next pass
[redacted]							Radially oscillating NS
[redacted]							Flare in the magnetosphere of NS accelerates e-s along B-field
68.	Paczynski	1986	ApJ, 308, L43	NS		COS	Cosmo GRBs: rel e- e+ opt thk plasma outflow indicated
[redacted]							Chain fission of superheavy nuclei below NS surface during SN
[redacted]							SN ejects strange mat lump craters rotating SS companion
[redacted]							Magnetically active stellar system gives stellar flare
72.	Babul et al.	1987	ApJ, 316, L49	CS		COS	GRB result of energy released from cusp of cosmic string
[redacted]							Oort cloud around NS can explain soft gamma-repeaters
74.	McBreen et al.	1988	Nature, 332, 234	GAL	AGN	COS	G-wave bkgrd makes BL Lac wiggle across galaxy lens caustic
75.	Curtis	1988	ApJ, 327, L81	WD		COS	WD collapses, burns to form new class of stable particles
[redacted]							Be/X-ray binary sys evolves to NS accretion GRB with recurrence
[redacted]							e+ e- cascades by aligned pulsar outer-mag-sphere reignition
78.	Paczynski	1988	ApJ, 335, 525	CS		COS	Energy released from cusp of cosmic string (revised)
[redacted]							Absorption features suggest separate colder region near NS
[redacted]							NS + accretion disk reflection explains GRB spectra
[redacted]							NS seismic waves couple to magnetospheric Alfen waves
82.	Trofimenko et al.	1989	Ap & SS, 152, 105	WH		COS	Kerr-Newman white holes
[redacted]							NS E-field accelerates electrons which then pair cascade
[redacted]							Narrow absorption features indicate small cold area on NS
[redacted]							Binary member loses part of crust, through L1, hits primary
[redacted]							Fast NS wanders though Oort clouds, fast WD bursts only optical
[redacted]							Episodic electrostatic accel and Comp scat from rot high-B NS
88.	Trofimenko	1989	Ap & SS, 159, 301	WH		COS	Different types of white, "grey" holes can emit GRBs
89.	Eichler et al.	1989	Nature, 340, 126	NS	NS	COS	NS - NS binary members collide, coalesce
[redacted]							Cyclo res & Raman scat fits 20, 40 keV dips, magnetized NS
[redacted]							QED mag resonant opacity in NS atmosphere
[redacted]							NS magnetospheric plasma oscillations
[redacted]							Beaming of radiation necessary from magnetized neutron stars
[redacted]							Interstellar comets pass through dead pulsar's magnetosphere
[redacted]							Compton scattering in strong NS magnetic field
[redacted]							Old NS accretes from ISM, surface goes nuclear
97.	Paczynski	1990	ApJ, 363, 218	NS	NS	COS	NS-NS collision causes neutrino collisions, drives super-Ed wind
98.	Zdziarski et al.	1991	ApJ, 366, 343	RE	MBR	COS	Scattering of microwave background photons by rel e-s
[redacted]							Young NS drifts through its own Oort cloud
[redacted]							White hole supernova gave simultaneous burst of g-waves from 1987A
[redacted]							NS B-field undergoes resistive tearing, accelerates plasma
[redacted]							Alfen waves in non-uniform NS atmosphere accelerate particles
103.	Haensel et al.	1991	ApJ, 375, 209	SS	SS	COS	Strange stars emit binding energy in grav rad and collide
[redacted]							Slow interstellar accretion onto NS, e- capture starquakes result
[redacted]							Low mass X-ray binary evolve into GRB sites
[redacted]							Accreting WD collapsed to NS
107.	Dar et al.	1992	ApJ, 388, 164	WD		COS	WD accretes to form naked NS, GRB, cosmic rays
108.	Hanami	1992	ApJ, 389, L71	NS	PLAN	COS	NS - planet magnetospheric interaction unstable
109.	Meszaros et al.	1992	ApJ, 397, 570	NS	NS	COS	NS - NS collision produces anisotropic fireball
110.	Carter	1992	ApJ, 391, L67	BH	ST	COS	Normal stars tidally disrupted by galactic nucleus BH
111.	Usov	1992	Nature, 357, 472	NS		COS	WD collapses to form NS, B-field brakes NS rotation instantly
112.	Narayan et al.	1992	ApJ, 395, L83	NS	NS	COS	NS - NS merger gives optically thick fireball
113.	Narayan et al.	1992	ApJ, 395, L83	BH	NS	COS	BH - NS merger gives optically thick fireball
114.	Brainerd	1992	ApJ, 394, L33	AGN	JET	COS	Synchrotron emission from AGN jets
115.	Meszaros et al.	1992	MNRAS, 257, 29P	BH	NS	COS	BH-NS have neutrinos collide to gammas in clean fireball
116.	Meszaros et al.	1992	MNRAS, 257, 29P	NS	NS	COS	NS-NS have neutrinos collide to gammas in clean fireball
[redacted]							Primordial BHs evaporating could account for short hard GRBs
118.	Rees et al.	1992	MNRAS, 258, 41P	NS	ISM	COS	Relativistic fireball reconverted to radiation when hits ISM

Table from: Nemiroff, R. J. 1993, Comments on Astrophysics, 17, No. 4, in press

Nemiroff 1994

La distribution en redshift: ~ 150 valeurs de z de 0.01 à 8.2 !

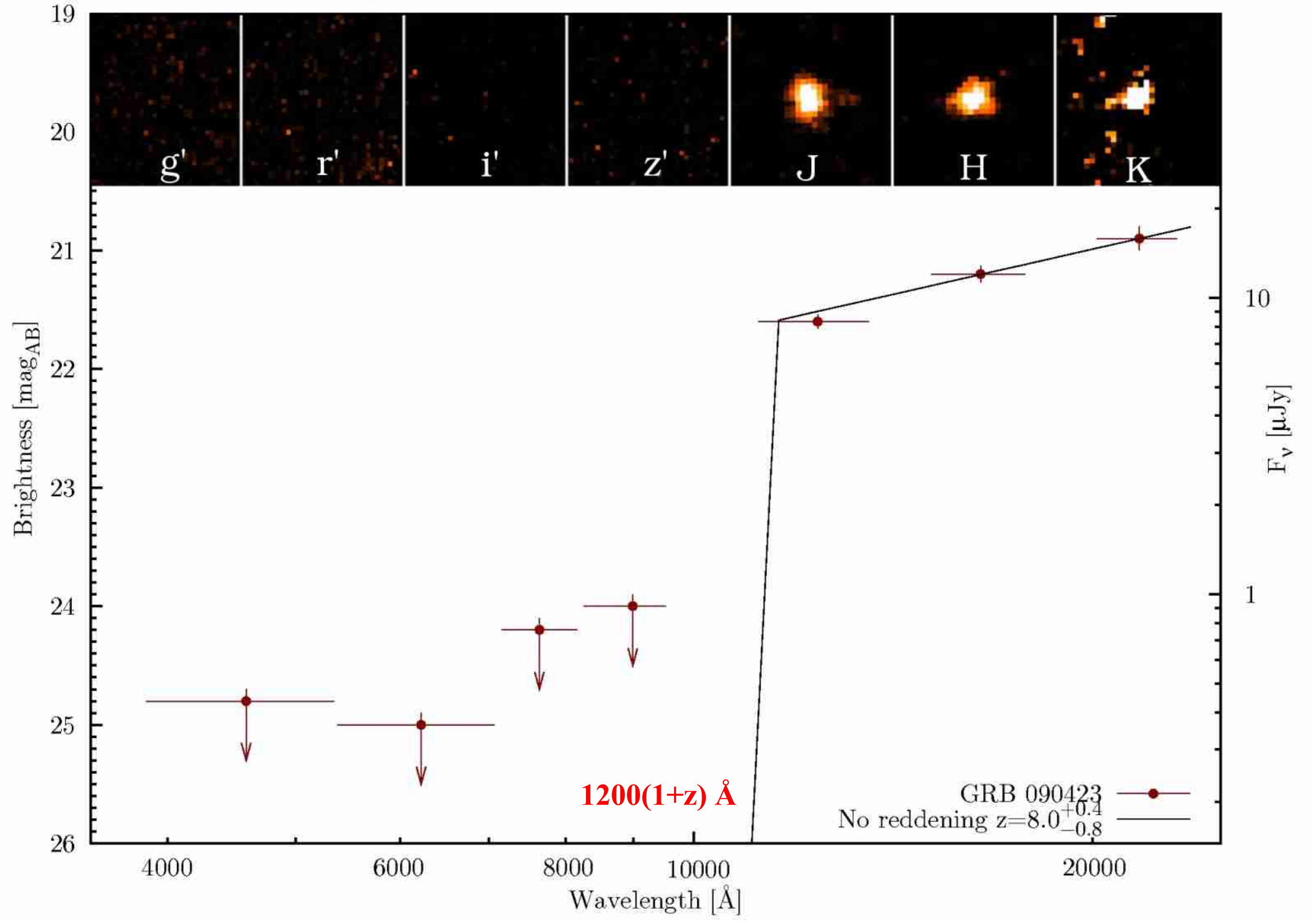


⚠ biais de sélection instrumental

Sursauts longs ↔ étoiles massives, SN Ic

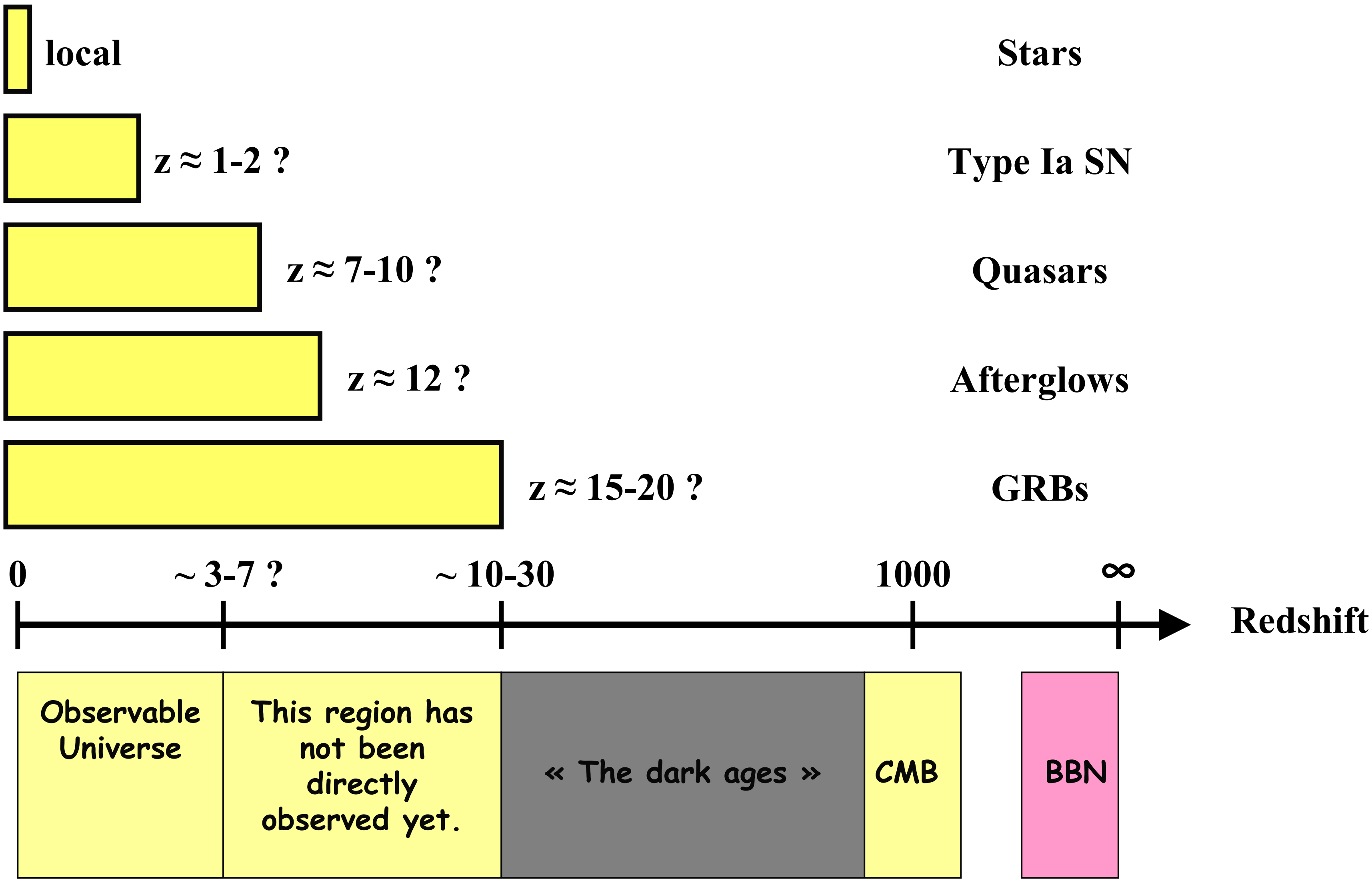
Les records:

- GRB 050904 à z = 6.3
- GRB 090423 à z = 8.2



Les sursauts comme outils pour la cosmologie

Les sursauts et leurs rémanences sont détectables à grand z



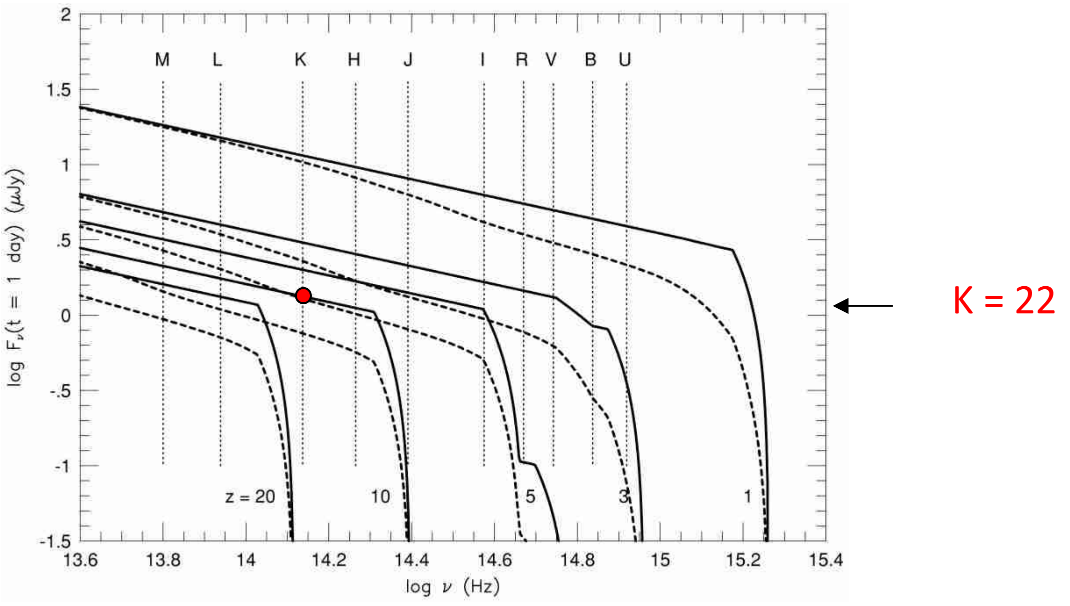
• Comment détecter une rémanence à grand z ?

- Observations dans l'IR (break Ly à 0.12(1+z) µ)
- Réactivité

Observer … 10 min après le sursaut

correspond dans le repère de la source à … 5 min après le sursaut à z = 1
55 s après le sursaut à z = 10

La source est plus lumineuse ce qui compense en partie la plus grande distance



Le taux de sursauts et/ou le taux de formation d 'étoiles en fonction de z

Observations

Courbe Log N – Log P

Distribution en z: N(>z)

Taux d'événements BATSE : ~ 1/jour

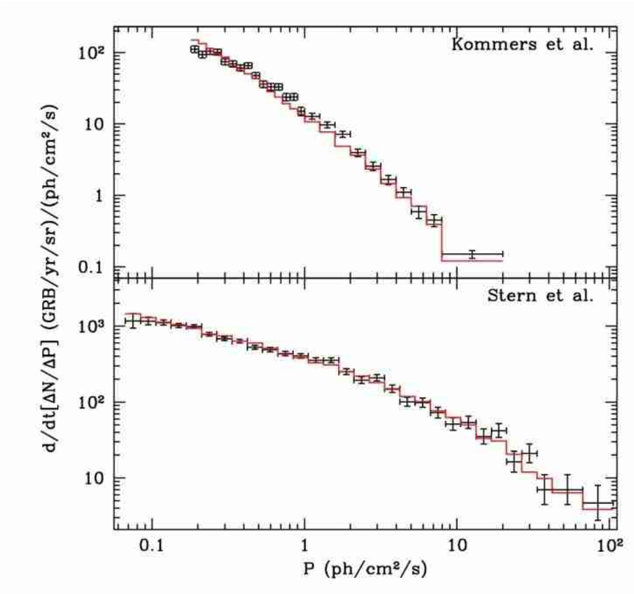
Sensibilité des détecteurs

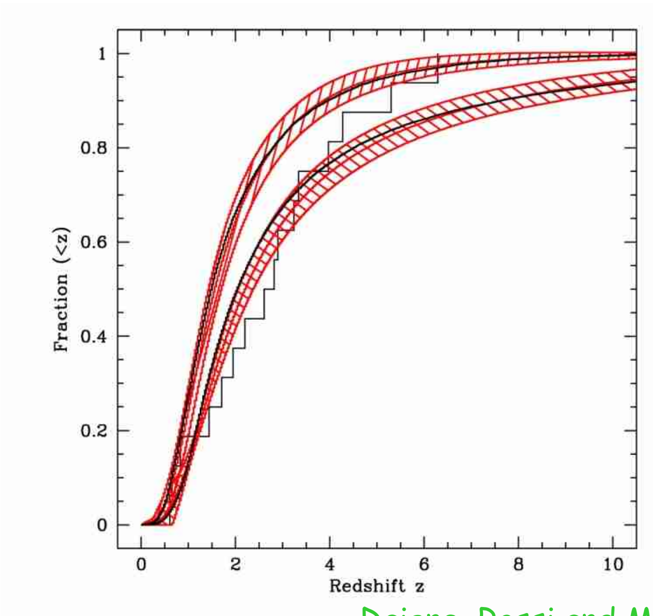
Hypothèses

SFR : $\Psi(t)$ and $R_{GRB} = k(z) \times \Psi(t)$

$\Phi(L) \alpha L^{-\delta}$

Fit de : Log N – Log P , N(>z)





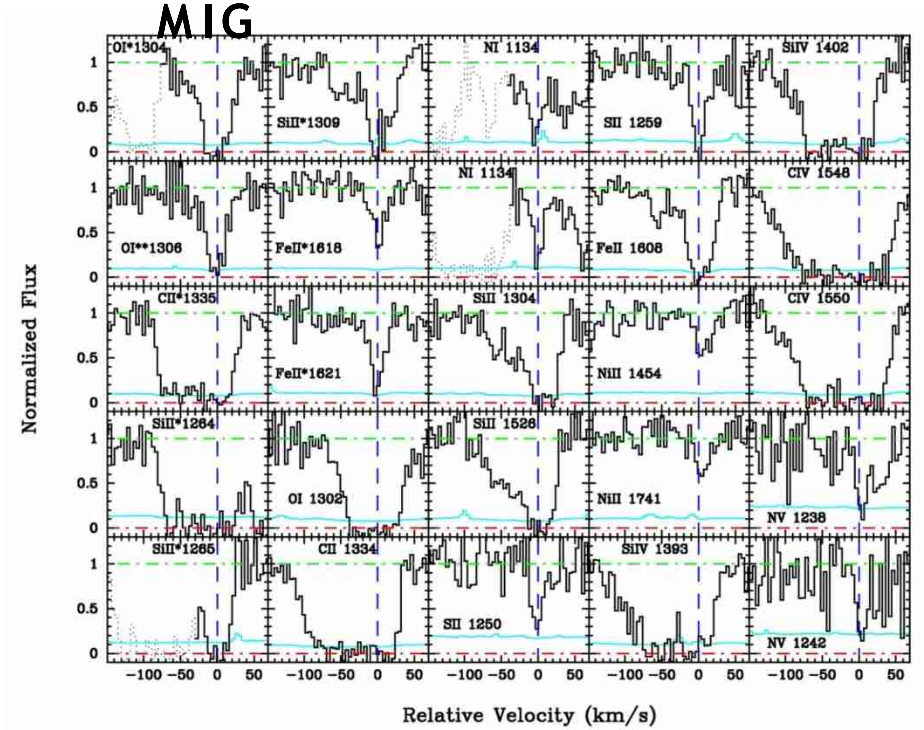
Daigne, Rossi and Mochkovitch, 2006

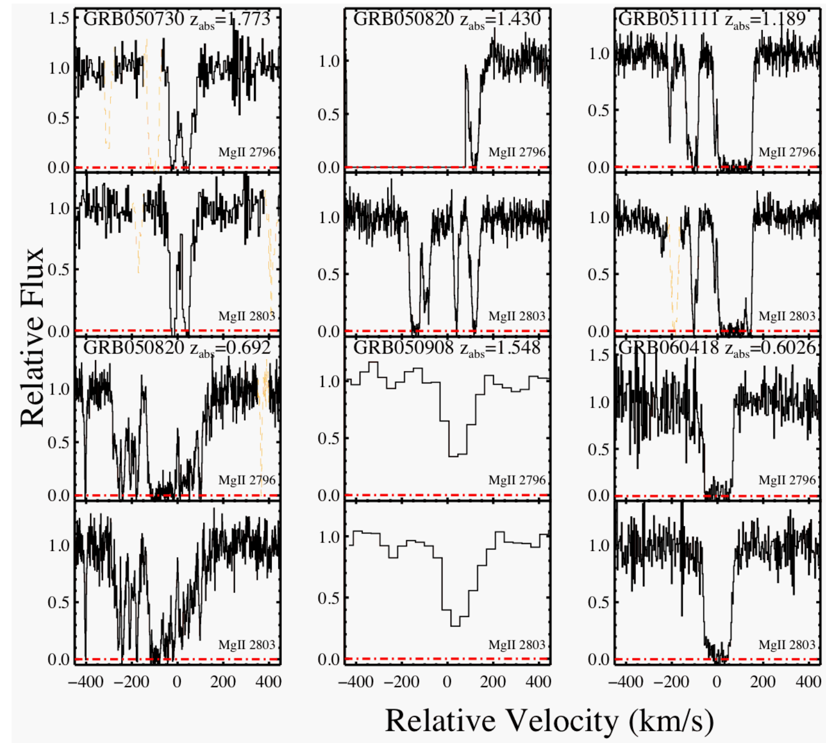
→ Le taux de sursauts croît plus vite que le SFR à grand z

15 % des événements à z > 6 (au seuil) , 2% (à 5 x seuil) ?

L'analyse de la ligne de visée

Environnement immédiat du sursaut, MIS de la galaxie hôte, MIG





GRB 050730 à z = 3.969

R=17.7, 4 heures après le sursaut

MIS : **N(HI)=22.15**

$Z/Z_{\odot}$ ~ 1/100

MIG : **DLA à z=3.564**

MgII à z=2.253,1.773

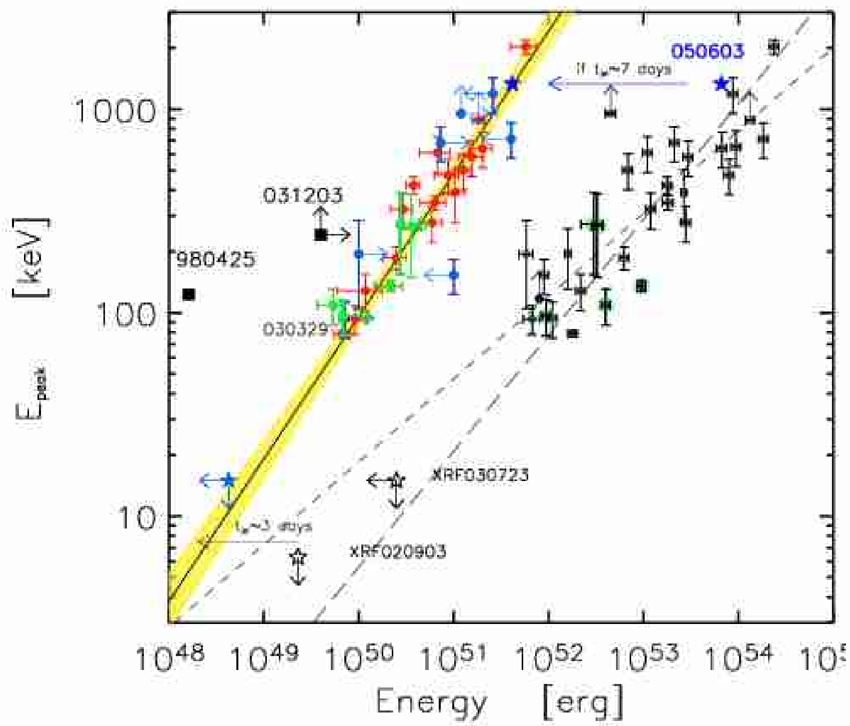
Excès d'absorbants MGII par rapport aux quasars ?

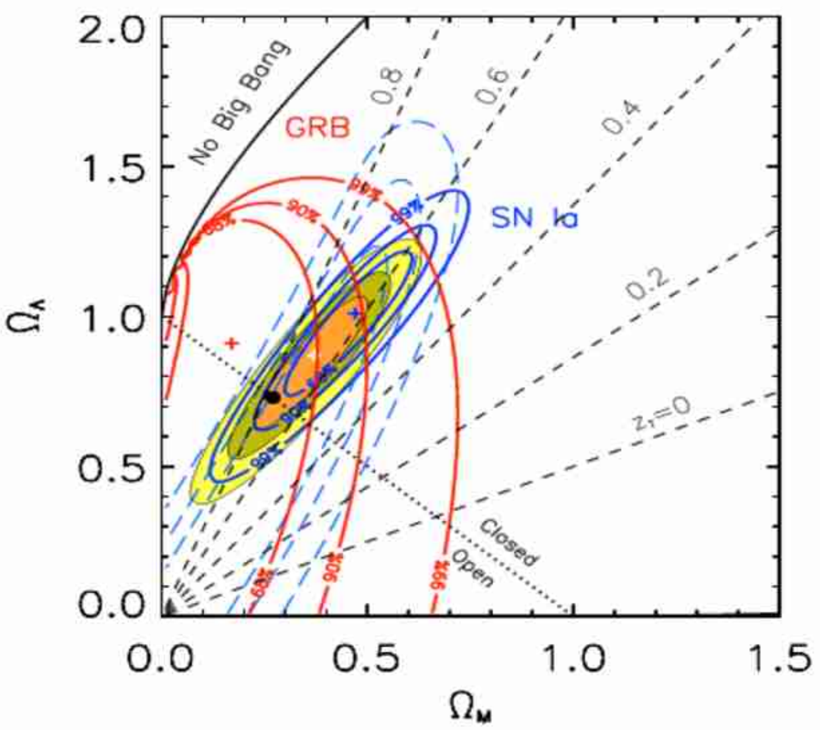
→ X-SHOOTER sur le VLT

La détermination des paramètres cosmologiques

Les sursauts ne sont pas des chandelles standards…

Tentative de « standardisation »: la relation de Ghirlanda





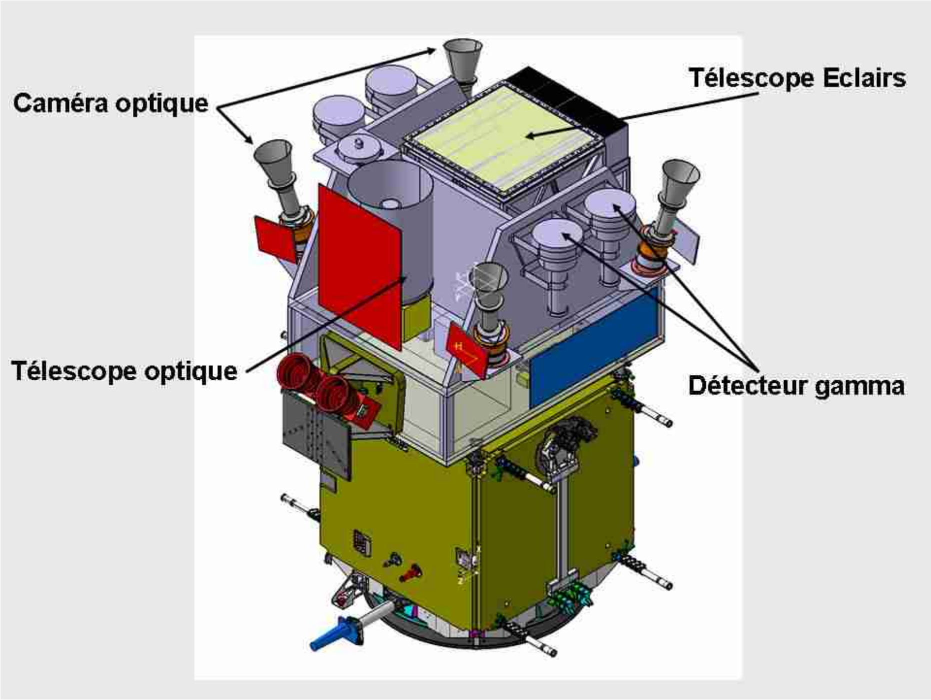
Méthodologie fortement contestée:

- validité de la relation de Ghirlanda ?
- « circularité » de l'argument ?

Le Futur

Swift financé jusqu'en 2014

2014 - 2015: SVOM



Au sol:

GFT: T1m avec détecteur IR

GWAC: caméras à grand champ

- large couverture spectrale: 8 keV – 5 MeV + IR/optique
- optimisé pour la recherche de sursauts à grand z