Galaxies Étoiles Physique et Instrumentation

X-Shooter and the GRBs

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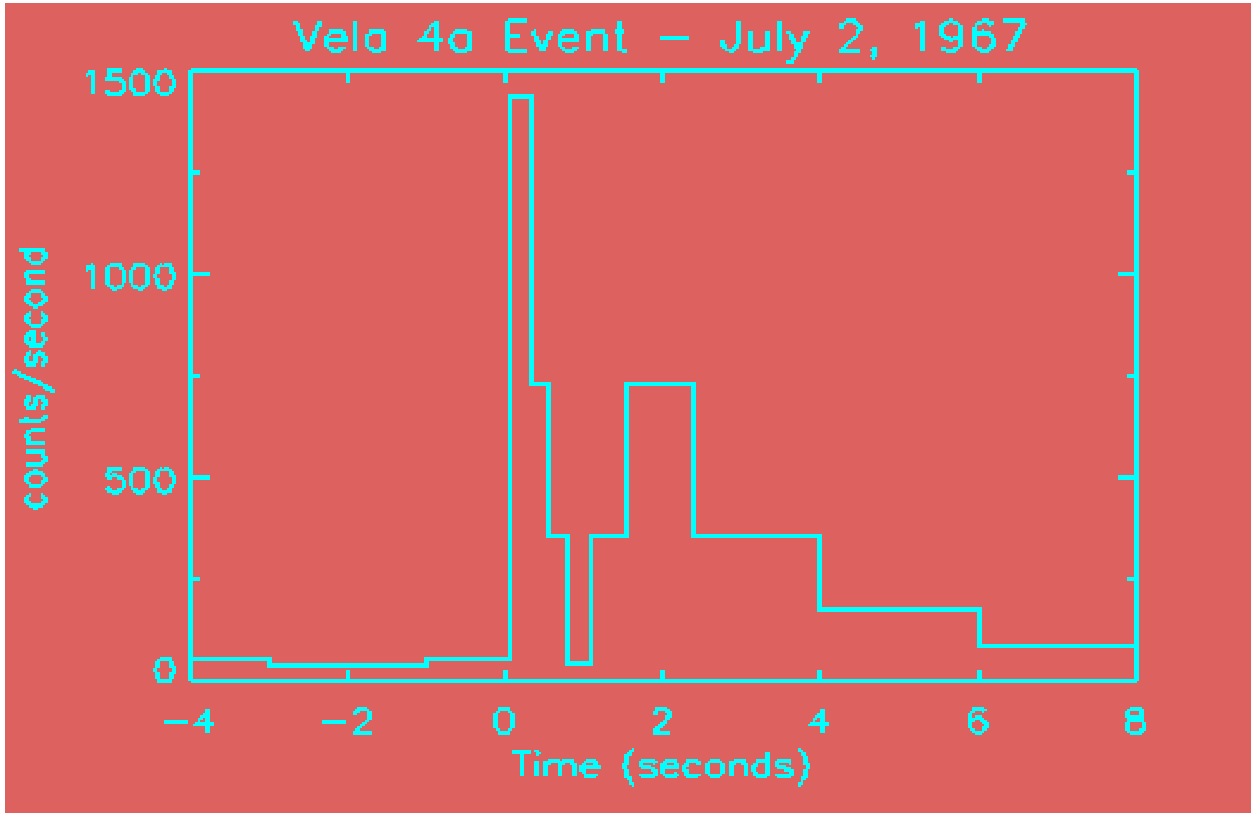
GRBs - Discovery (1967-1973)

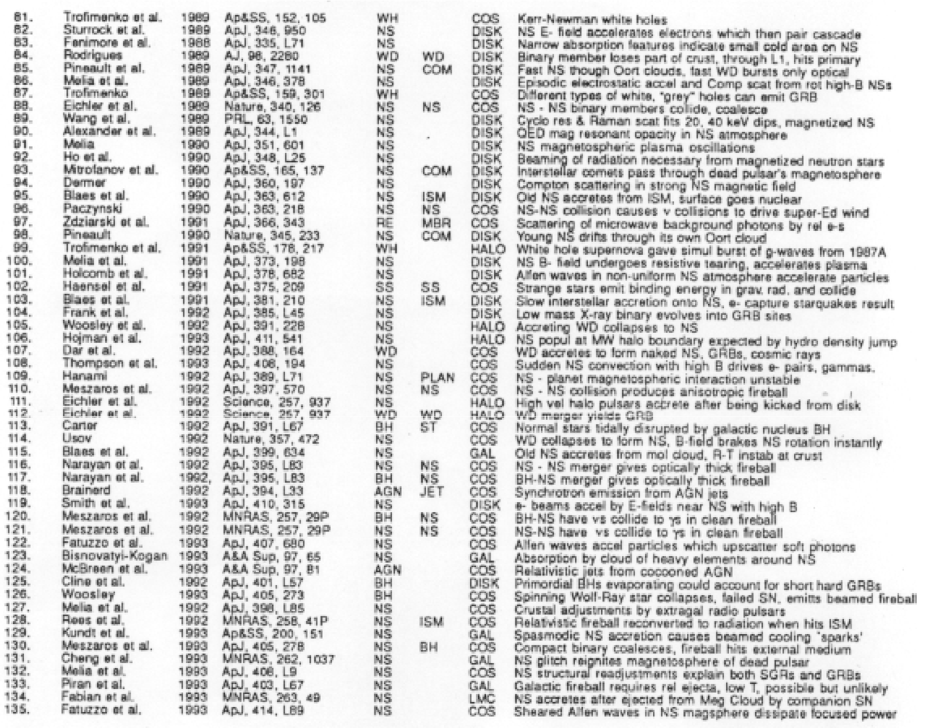
- US Vela Nuclear test detection satellites



GRB, who you are…

- ***GRBs remained a complete mystery for almost 30 years !***
- More than 100 different theories:
  - Magnetic flares
  - Black Hole evaporation
  - Anti-matter accretion
  - Deflected AGN jet
  - Magnetars, Soft Gamma-Ray Repeaters (SGRs)
  - Mini BH devouring NS
  - …..
  - message from the Aliens

135 models (1993)

Nemiroff, R. J., 1993, Comments on Astrophysics, in press.

Table 1

Model #	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
3.	Stecker et al.	1973	Nature, 245, PS70	ST		DISK	Stellar superflare from nearby star
4.	Stecker et al.	1973	Nature, 245, PS70	WD		DISK	Superflare from nearby WD
5.	Harwit et al.	1973	ApJ, 186, L37	NS	COM	DISK	Relic comet perturbed to collide with old galactic NS
6.	Lamb et al.	1973	Nature, 246, PS52	WD	ST	DISK	Accretion onto WD from flare in companion
7.	Lamb et al.	1973	Nature, 246, PS52	NS	ST	DISK	Accretion onto NS from flare in companion
8.	Lamb et al.	1973	Nature, 246, PS52	BH	ST	DISK	Accretion onto BH from flare in companion
9.	Zwicky	1974	Ap&SS, 28, 111	NS		HALO	NS chunk contained by external pressure escapes, explodes
10.	Grindlay et al.	1974	ApJ, 187, L93	DG		SOL	Relativistic iron dust grain up-scatters solar radiation
11.	Brecher et al.	1974	ApJ, 187, L97	ST		DISK	Directed stellar flares on nearby stars
12.	Schlovskii	1974	SovAstron, 18, 390	WD	COM	DISK	Comet from system's cloud strikes WD
13.	Schlovskii	1974	SovAstron, 18, 390	NS	COM	DISK	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
17.	Pacini et al.	1974	Nature, 251, 399	NS		DISK	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
19.	Tsygan	1975	A&A, 44, 21	NS		HALO	NS corequake excites vibrations, changing E & B fields
20.	Chanmugam	1974	ApJ, 193, L75	WD		DISK	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
23.	Piran et al.	1975	Nature, 256, 112	BH		DISK	Inv Comp scat deep in ergosphere of fast rotating, accreting BH
24.	Fabian et al.	1976	Ap&SS, 42, 77	NS		DISK	NS crustquake shocks NS surface
25.	Chanmugan	1976	Ap&SS, 42, 83	WD		DISK	Magnetic WD suffers MHD instabilities, flares
26.	Mullan	1976	ApJ, 208, 199	WD		DISK	Thermal radiation from flare near magnetic WD
27.	Woosley et al.	1976	Nature, 263, 101	NS		DISK	Carbon detonation from accreted matter onto NS
28.	Lamb et al.	1977	ApJ, 217, 197	NS		DISK	Mag gating of accret disk around NS causes sudden accretion
29.	Piran et al.	1977	ApJ, 214, 268	BH		DISK	Instability in accretion onto rapidly rotating BH
30.	Dasgupta	1979	Ap&SS, 63, 517	DG		SOL	Charged intergal rel dust grain enters sol sys, breaks up
31.	Tsygan	1980	A&A, 87, 224	WD		DISK	WD surface nuclear burst causes chromospheric flares
32.	Tsygan	1980	A&A, 87, 224	NS		DISK	NS surface nuclear burst causes chromospheric flares
33.	Ramaty et al.	1981	Ap&SS, 75, 193	NS		DISK	NS vibrations heat atm to pair produce, annihilate, synch cool
34.	Newman et al.	1980	ApJ, 242, 319	NS	AST	DISK	Asteroid from interstellar medium hits NS
35.	Ramaty et al.	1980	Nature, 287, 122	NS		HALO	NS core quake caused by phase transition, vibrations
36.	Howard et al.	1981	ApJ, 249, 302	NS	AST	DISK	Asteroid hits NS, B-field confines mass, creates high temp
37.	Mitrofanov et al.	1981	Ap&SS, 77, 469	NS		DISK	Helium flash cooled by MHD waves in NS outer layers
38.	Colgate et al.	1981	ApJ, 248, 771	NS	AST	DISK	Asteroid hits NS, tidally disrupts, heated, expelled along B lines
39.	van Buren	1981	ApJ, 249, 297	NS	AST	DISK	Asteroid enters NS B field, dragged to surface collision
40.	Kuznetsov	1982	CosRes, 20, 72	MG		SOL	Magnetic reconnection at heliopause
41.	Katz	1982	ApJ, 260, 371	NS		DISK	NS flares from pair plasma confined in NS magnetosphere
42.	Woosley et al.	1982	ApJ, 258, 716	NS		DISK	Magnetic reconnection after NS surface He flash
43.	Fryxell et al.	1982	ApJ, 258, 733	NS		DISK	He fusion runaway on NS B-pole helium lake
44.	Hameury et al.	1982	A&A, 111, 242	NS		DISK	e- capture triggers H flash triggers He flash on NS surface
45.	Mitrofanov et al.	1982	MNRAS, 200, 1033	NS		DISK	B induced cyclo res in rad absorp giving rel e-s, inv C scat
46.	Fenimore et al.	1982	Nature, 297, 665	NS		DISK	BB X-rays inv Comp scat by hotter overlying plasma
47.	Lipunov et al.	1982	Ap&SS, 85, 459	NS	ISM	DISK	ISM matter accum at NS magnetopause then suddenly accretes
48.	Baan	1982	ApJ, 261, L71	WD		HALO	Nonexplosive collapse of WD into rotating, cooling NS
49.	Ventura et al.	1983	Nature, 301, 491	NS	ST	DISK	NS accretion from low mass binary companion
50.	Bisnovatyi- et al.	1983	Ap&SS, 89, 447	NS		DISK	Neutron rich elements to NS surface with quake, undergo fission
51.	Bisnovatyi- et al.	1984	SovAstron, 28, 62	NS		DISK	Thermonuclear explosion beneath NS surface
52.	Ellison et al.	1983	A&A, 128, 102	NS		HALO	NS corequake + uneven heating yield SGR pulsations
53.	Hameury et al.	1983	A&A, 128, 369	NS		DISK	B field contains matter on NS cap allowing fusion
54.	Bonazzola et al.	1984	A&A, 136, 89	NS		DISK	NS surface nuc explosion causes small scale B reconnection
55.	Michel	1985	ApJ, 290, 721	NS		DISK	Remnant disk ionization instability causes sudden accretion
56.	Liang	1984	ApJ, 283, L21	NS		DISK	Resonant EM absorp during magnetic flare gives hot synch e-s
57.	Liang et al.	1984	Nature, 310, 121	NS		DISK	NS magnetic fields get twisted, recombine, create flare
58.	Mitrofanov	1984	Ap&SS, 105, 245	NS		DISK	NS magnetosphere excited by starquake
59.	Epstein	1985	ApJ, 291, 822	NS		DISK	Accretion instability between NS and disk
60.	Schlovskii et al.	1985	MNRAS, 212, 545	NS		HALO	Old NS in Galactic halo undergoes starquake
61.	Tsygan	1984	Ap&SS, 106, 199	NS		DISK	Weak B field NS spherically accretes, Comptonizes X-rays
62.	Usov	1984	Ap&SS, 107, 191	NS		DISK	NS flares result of magnetic convective-oscillation instability
63.	Hameury et al.	1985	ApJ, 293, 56	NS		DISK	High Landau e-s beamed along B lines in cold atm. of NS
64.	Rappaport et al.	1985	Nature, 314, 242	NS		DISK	NS + low mass stellar companion gives GRB + optical flash
65.	Tremaine et al.	1986	ApJ, 301, 155	NS	COM	DISK	NS tides disrupt comet, debris hits NS next pass
66.	Muslimov et al.	1986	Ap&SS, 120, 27	NS		HALO	Radially oscillating NS
67.	Sturrock	1986	Nature, 321, 47	NS		DISK	Flare in the magnetosphere of NS accelerates e-s along B-field
68.	Paczynski	1986	ApJ, 308, L43	NS		COS	Cosmo GRBs: rel e+/- opt thk plasma outflow indicated
69.	Bisnovatyi- et al.	1986	SovAstron, 30, 582	NS		DISK	Chain fission of superheavy nuclei below NS surface during SN
70.	Alcock et al.	1986	PRL, 57, 2088	SS	SS	DISK	SN ejects strange mat lump craters rotating SS companion
71.	Babul et al.	1987	ApJ, 316, L49	CS		COS	GRB result of energy released from cusp of cosmic string
72.	Livio et al.	1987	Nature, 327, 398	NS	COM	DISK	Oort cloud around NS can explain soft gamma-repeaters
73.	McBreen et al.	1988	Nature, 332, 234	GAL	AGN	COS	G-wave bkgrd makes BL Lac wiggle across galaxy lens caustic
74.	Curtis	1988	ApJ, 327, L81	WD		COS	WD collapses, burns to form new class of stable particles
75.	Melia	1988	ApJ, 335, 965	NS		DISK	Be/X-ray binary sys evolves to NS accretion with recurrence
76.	Ruderman et al.	1988	ApJ, 335, 306	NS		DISK	e+/- cascades by aligned pulsar outer-mag-sphere reignition
77.	Paczynski	1988	ApJ, 335, 525	CS		COS	Energy released from cusp of cosmic string (revised)
78.	Murikami et al.	1988	Nature, 335, 234	NS		DISK	Absorption features suggest separate colder region near NS
79.	Melia	1988	Nature, 336, 658	NS		DISK	NS + accretion disk reflection explains GRB spectra
80.	Blaes et al.	1989	ApJ, 343, 839	NS		DISK	NS seismic waves couple to magnetospheric Alfen waves
81.	Trofimenko et al.	1989	Ap&SS, 152, 105	WH		COS	Kerr-Newman white holes
82.	Sturrock et al.	1989	ApJ, 346, 950	NS		DISK	NS E- field accelerates electrons which then pair cascade
83.	Fenimore et al.	1988	ApJ, 335, L71	NS		DISK	Narrow absorption features indicate small cold area on NS
84.	Rodrigues	1989	AJ, 98, 2280	WD	WD	DISK	Binary member loses part of crust, through L1, hits primary
85.	Pineault et al.	1989	ApJ, 347, 1141	NS	COM	DISK	Fast NS though Oort clouds, fast WD bursts only optical
86.	Melia et al.	1989	ApJ, 346, 378	NS		DISK	Episodic electrostatic accel and Comp scat from rot high-B NSs
87.	Trofimenko	1989	Ap&SS, 159, 301	WH		COS	Different types of white, "grey" holes can emit GRB
88.	Eichler et al.	1989	Nature, 340, 126	NS	NS	COS	NS - NS binary members collide, coalesce
89.	Wang et al.	1989	PRL, 63, 1550	NS		DISK	Cyclo res & Raman scat fits 20, 40 keV dips, magnetized NS
90.	Alexander et al.	1989	ApJ, 344, L1	NS		DISK	QED mag resonant opacity in NS atmosphere
91.	Melia	1990	ApJ, 351, 601	NS		DISK	NS magnetospheric plasma oscillations
92.	Ho et al.	1990	ApJ, 348, L25	NS		DISK	Beaming of radiation necessary from magnetized neutron stars
93.	Mitrofanov et al.	1990	Ap&SS, 165, 137	NS	COM	DISK	Interstellar comets pass through dead pulsar's magnetosphere
94.	Dermer	1990	ApJ, 360, 197	NS		DISK	Compton scattering in strong NS magnetic field
95.	Blaes et al.	1990	ApJ, 363, 612	NS	ISM	DISK	Old NS accretes from ISM, surface goes nuclear
96.	Paczynski	1990	ApJ, 363, 218	NS	NS	COS	NS-NS collision causes v collisions to drive super-Ed wind
97.	Zdziarski et al.	1991	ApJ, 366, 343	RE	MBR	COS	Scattering of microwave background photons by rel e-s
98.	Pineault	1990	Nature, 345, 233	NS	COM	DISK	Young NS drifts through its own Oort cloud
99.	Trofimenko et al.	1991	Ap&SS, 178, 217	WH		HALO	White hole supernova gave simul burst of g-waves from 1987A
100.	Melia et al.	1991	ApJ, 373, 198	NS		DISK	NS B- field undergoes resistive tearing, accelerates plasma
101.	Holcomb et al.	1991	ApJ, 378, 682	NS		DISK	Alfen waves in non-uniform NS atmosphere accelerate particles
102.	Haensel et al.	1991	ApJ, 375, 209	SS	SS	COS	Strange stars emit binding energy in grav. rad. and collide
103.	Blaes et al.	1991	ApJ, 381, 210	NS	ISM	DISK	Slow interstellar accretion onto NS, e- capture starquakes result
104.	Frank et al.	1992	ApJ, 385, L45	NS		DISK	Low mass X-ray binary evolves into GRB sites
105.	Woosley et al.	1992	ApJ, 391, 228	NS		HALO	Accreting WD collapses to NS
106.	Hojman et al.	1993	ApJ, 411, 541	NS		HALO	NS popul at MW halo boundary expected by hydro density jump
107.	Dar et al.	1992	ApJ, 388, 164	WD		COS	WD accretes to form naked NS, GRBs, cosmic rays
108.	Thompson et al.	1993	ApJ, 408, 194	NS		COS	Sudden NS convection with high B drives e- pairs, gammas.
109.	Hanami	1992	ApJ, 389, L71	NS	PLAN	COS	NS - planet magnetospheric interaction unstable
110.	Meszaros et al.	1992	ApJ, 397, 570	NS	NS	COS	NS - NS collision produces anisotropic fireball
111.	Eichler et al.	1992	Science, 257, 937	NS		HALO	High vel halo pulsars accrete after being kicked from disk
112.	Eichler et al.	1992	Science, 257, 937	WD	WD	HALO	WD merger yields GRB
113.	Carter	1992	ApJ, 391, L67	BH	ST	COS	Normal stars tidally disrupted by galactic nucleus BH
114.	Usov	1992	Nature, 357, 472	NS		COS	WD collapses to form NS, B-field brakes NS rotation instantly
115.	Blaes et al.	1992	ApJ, 399, 634	NS		GAL	Old NS accretes from mol cloud, R-T instab at crust
116.	Narayan et al.	1992	ApJ, 395, L83	NS	NS	COS	NS - NS merger gives optically thick fireball
117.	Narayan et al.	1992,	ApJ, 395, L83	BH	NS	COS	BH-NS merger gives optically thick fireball
118.	Brainerd	1992	ApJ, 394, L33	AGN	JET	COS	Synchrotron emission from AGN jets
119.	Smith et al.	1993	ApJ, 410, 315	NS		DISK	e- beams accel by E-fields near NS with high B
120.	Meszaros et al.	1992	MNRAS, 257, 29P	BH	NS	COS	BH-NS have vs collide to γs in clean fireball
121.	Meszaros et al.	1992	MNRAS, 257, 29P	NS	NS	COS	NS-NS have vs collide to γs in clean fireball
122.	Fatuzzo et al.	1993	ApJ, 407, 680	NS		COS	Alfen waves accel particles which upscatter soft photons
123.	Bisnovatyi-Kogan	1993	A&A Sup, 97, 65	NS		GAL	Absorption by cloud of heavy elements around NS
124.	McBreen et al.	1993	A&A Sup, 97, 81	AGN		COS	Relativistic jets from cocooned AGN
125.	Cline et al.	1992	ApJ, 401, L57	BH		DISK	Primordial BHs evaporating could account for short hard GRBs
126.	Woosley	1993	ApJ, 405, 273	BH		COS	Spinning Wolf-Ray star collapses, failed SN, emitts beamed fireball
127.	Melia et al.	1992	ApJ, 398, L85	NS		COS	Crustal adjustments by extragal radio pulsars
128.	Rees et al.	1992	MNRAS, 258, 41P	NS	ISM	COS	Relativistic fireball reconverted to radiation when hits ISM
129.	Kundt et al.	1993	Ap&SS, 200, 151	NS		GAL	Spasmodic NS accretion causes beamed cooling 'sparks'
130.	Meszaros et al.	1993	ApJ, 405, 278	NS	BH	COS	Compact binary coalesces, fireball hits external medium
131.	Cheng et al.	1993	MNRAS, 262, 1037	NS		GAL	NS glitch reignites magnetosphere of dead pulsar
132.	Melia et al.	1993	ApJ, 406, L9	NS		COS	NS structural readjustments explain both SGRs and GRBs
133.	Piran et al.	1993	ApJ, 403, L67	NS		GAL	Galactic fireball requires rel ejecta, low T, possible but unlikely
134.	Fabian et al.	1993	MNRAS, 263, 49	NS		LMC	NS accretes after ejected from Mag Cloud by companion SN
135.	Fatuzzo et al.	1993	ApJ, 414, L89	NS		COS	Sheared Alfen waves in NS magsphere dissipate focused power

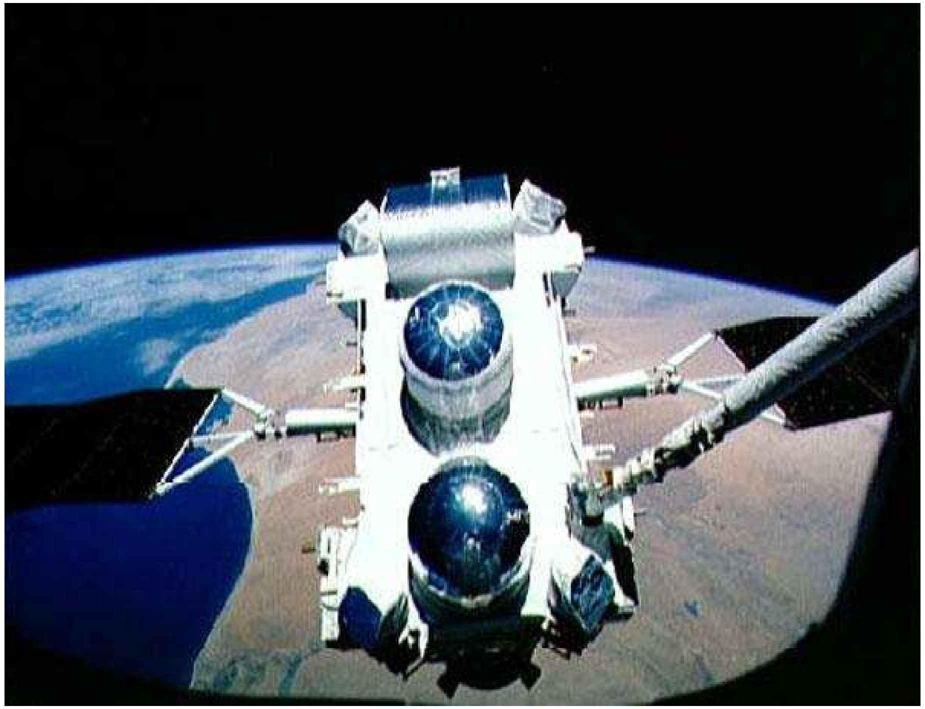
Note: most are Galactic

BATSE: the revolution of the 1990s

Compton Gamma-Ray Observatory (CGRO)

Launched in 1991(orbit above atmospheric absorption)

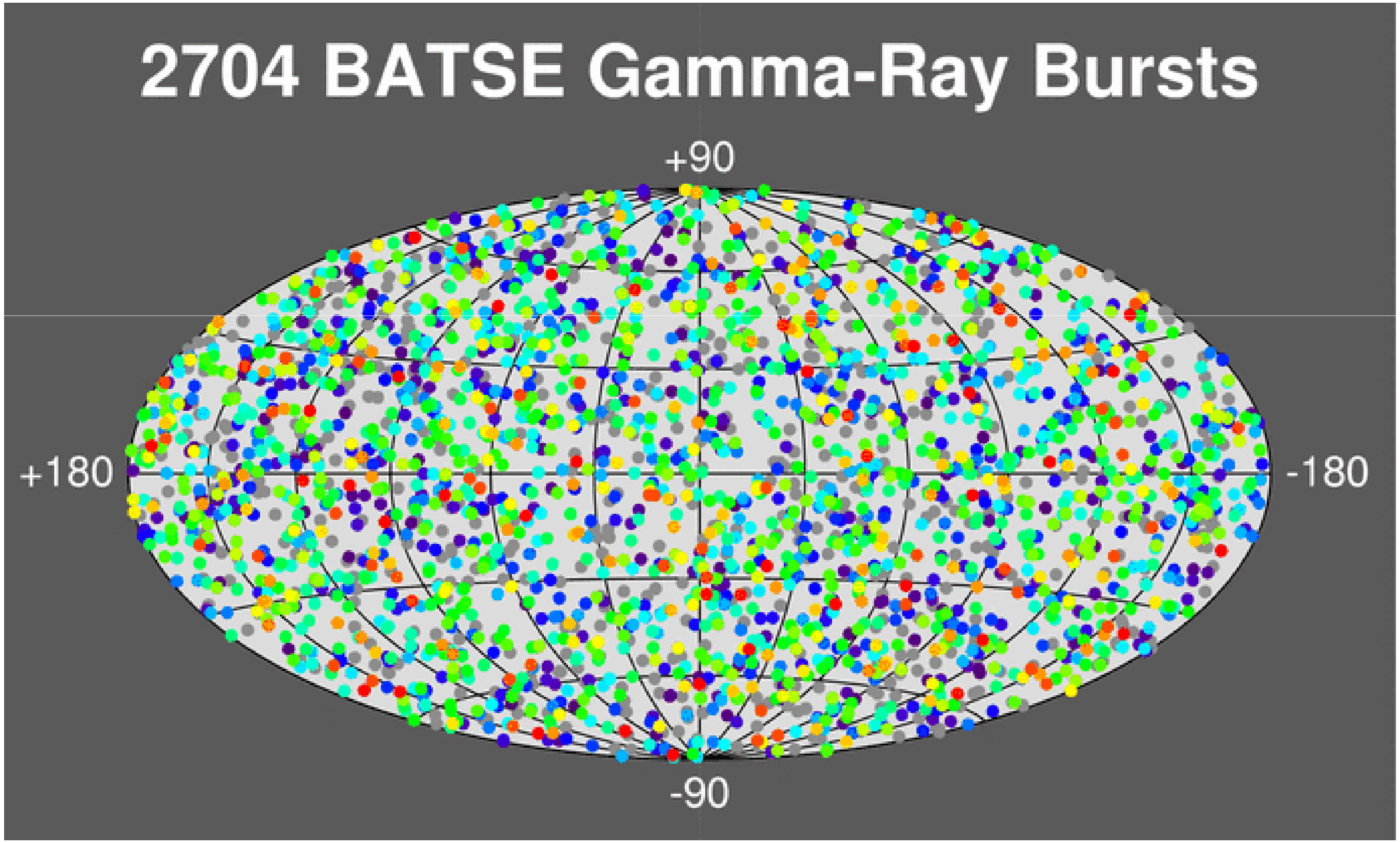
- BATSE (20 keV-1 MeV):
  - extremely sensitive gamma-ray detector (scintillator)
- EGRET (20 MeV-30 GeV):
  - Pair production detector



Looked at the whole sky

- GRB detection rate ~ 1 GRB/day
- thousands of GRBs detected over the whole mission

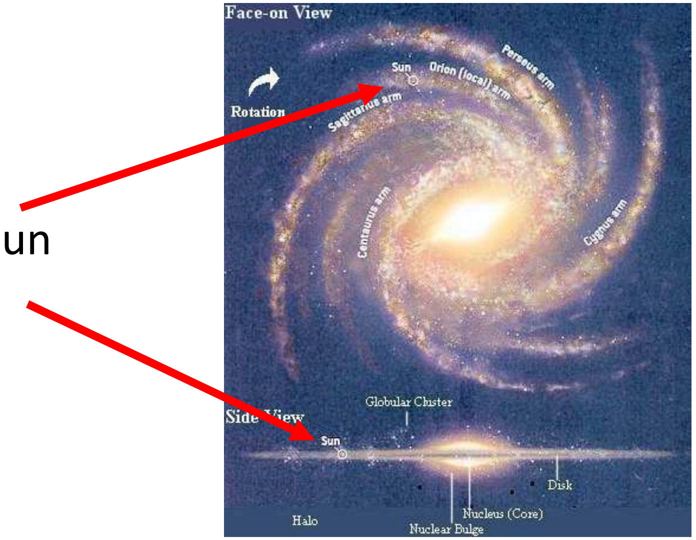
First lesson: Isotropic on the sky

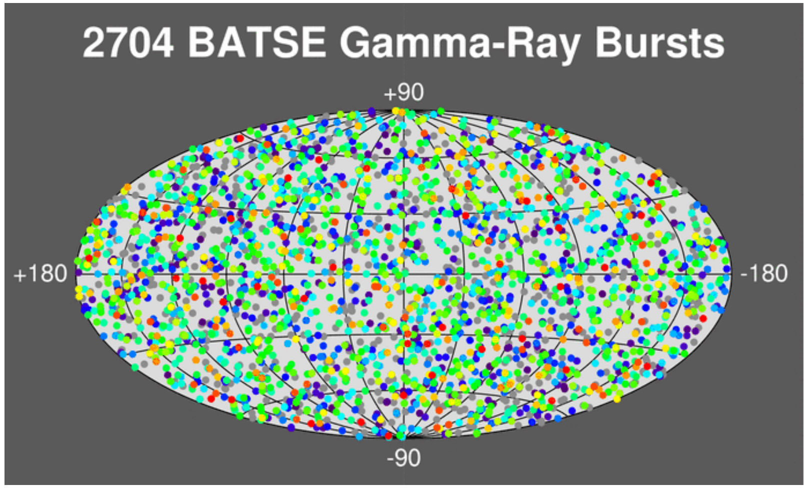


Isotropy = Cosmological distance

- Objects that follow the Galactic distribution (of mass, stars etc) look different
- GRBs are *NOT* Galactic
- They are cosmological

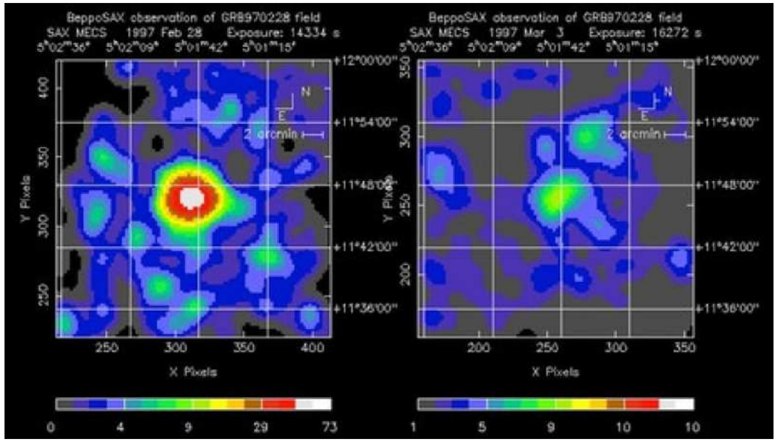
Sun

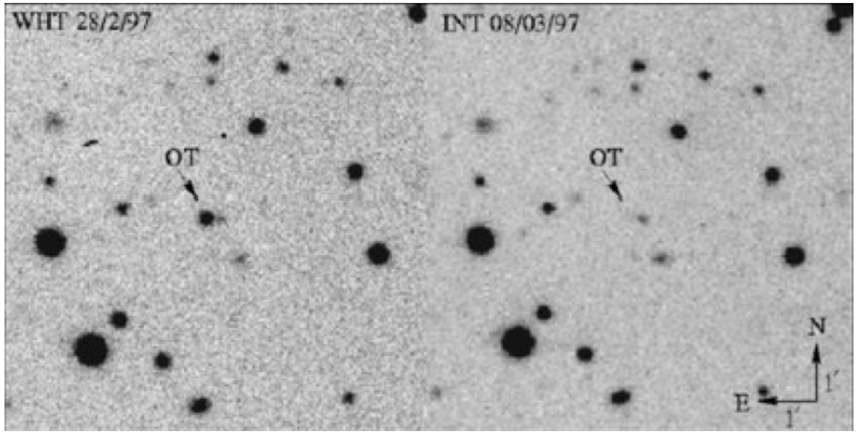




Cosmological ?

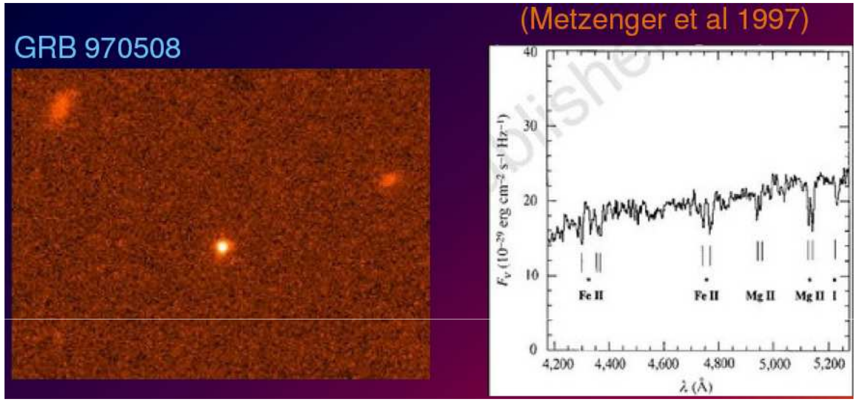
- BeppoSax satellite made the breakthrough in 1997
- Detected in low-energy γ rays
- Localized in X rays at the same time
- People found optical counterpart ~1 day later (arcsec resolution)





Cosmological !

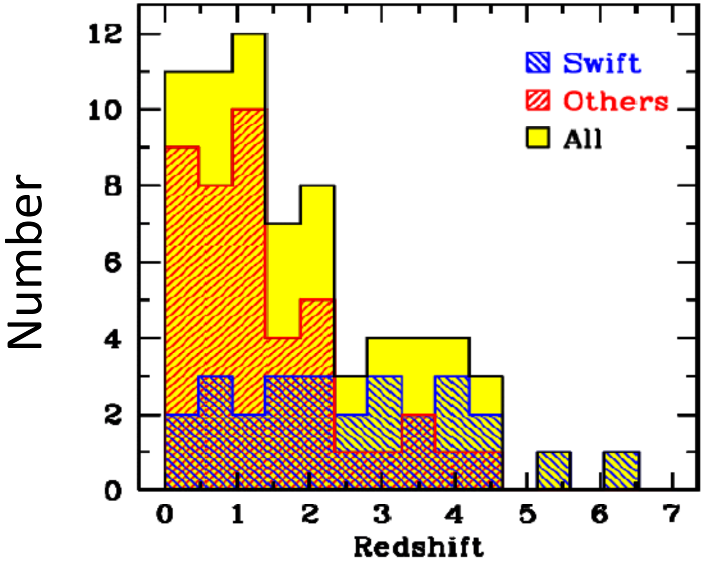
- A month later the region is observed with a large telescope
  - From lines in the spectrum of the galaxy the redshift is measured


GRB 970508

(Metzenger et al 1997)

- Today we have more than ~200 redshift measurements

- The furthest away at *z~8.2*! (600 Myr after the big Bang)



The last 12 years, it is verified that γ-ray bursts are cosmological

- Detecting emission that *follows* the burst in the X-rays, optical, radio

- Good localization (less than arcmin)

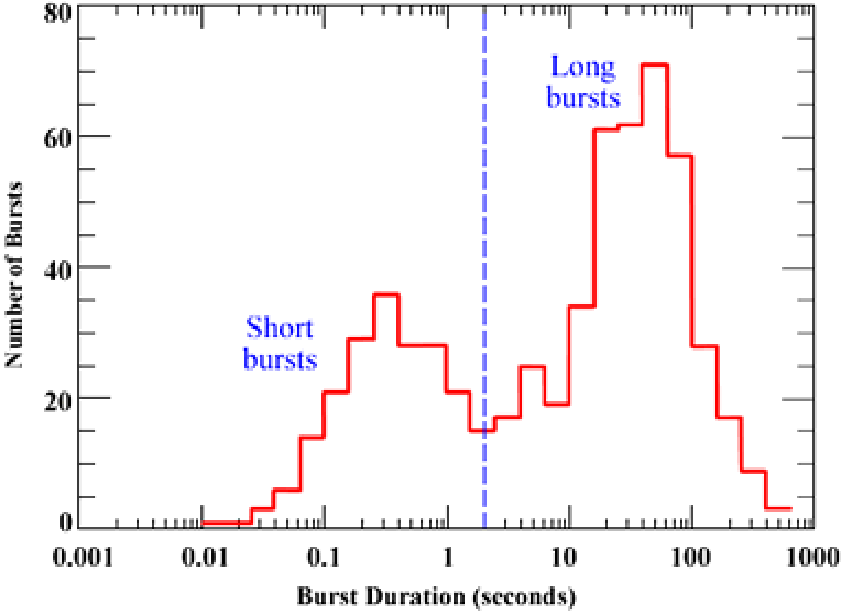
- Detecting the galaxies they come from

- Measuring the redshift of the galaxies

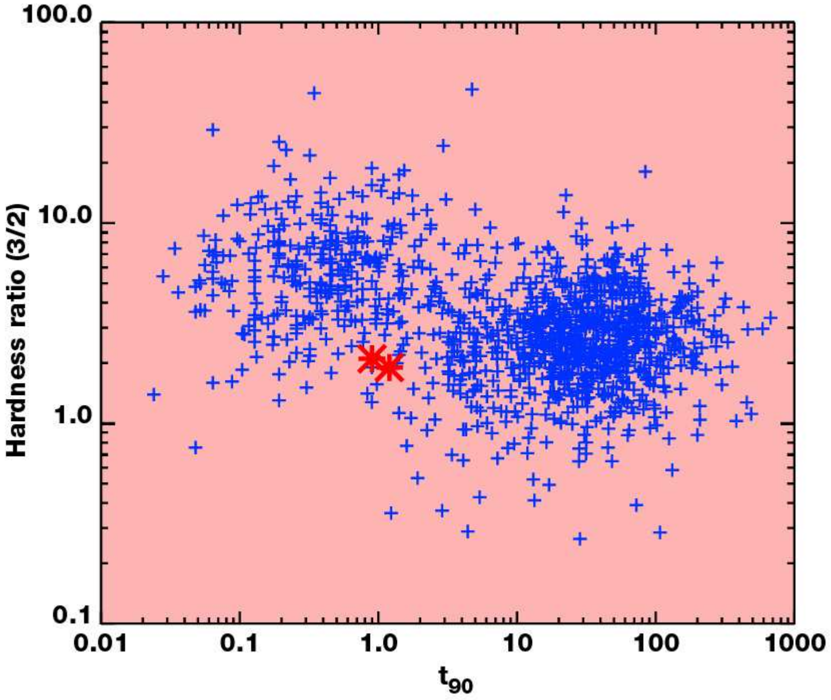
Second lesson

- 2 populations of GRBs:
  - Short-Hard / Long-Soft Bursts

Long Duration $T > 2$ sec



Burst duration



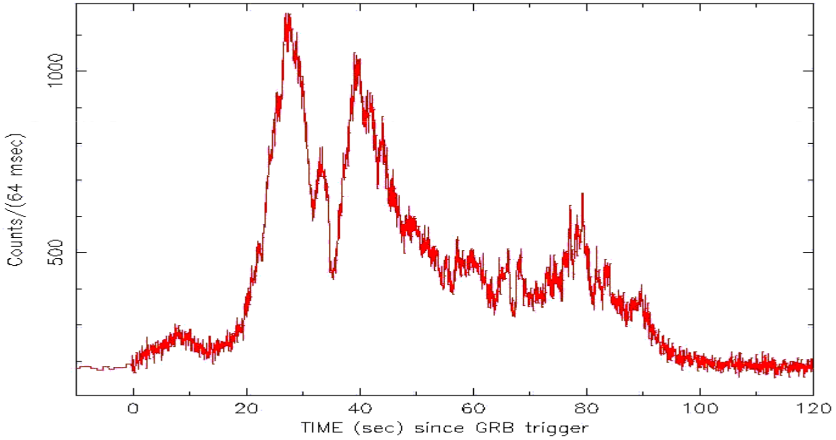
Hardness-duration diagram

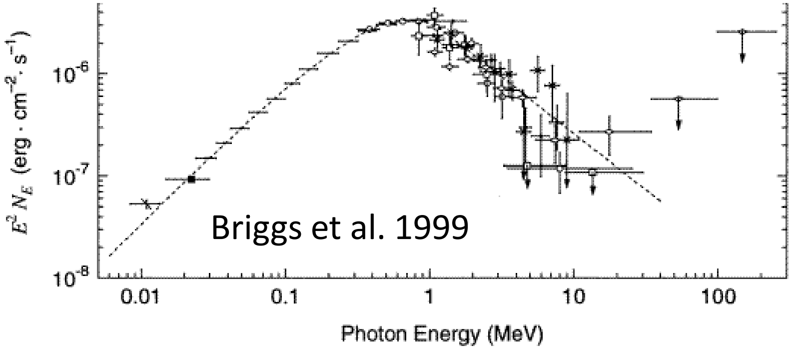
GRB lightcurve / spectrum

- Non thermal prompt emission
- Best spectral fit: smoothly joining broken power law

- <u>Compactness problem:</u>
  - Emitting region optically thin if emitting material has Lorentz factor > 100

  -> Ultrarelativistic outflow (fastest bulk flow in the universe)




Briggs et al. 1999

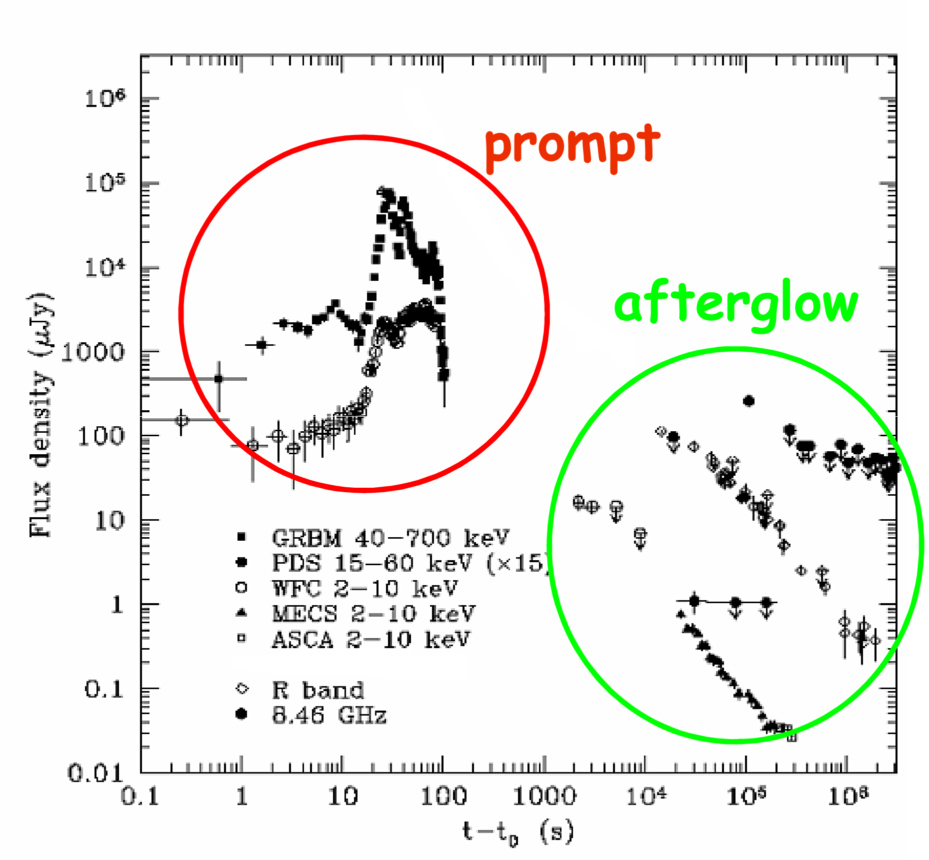
GRB lightcurve / spectrum

A burst : the sum of two phenomena

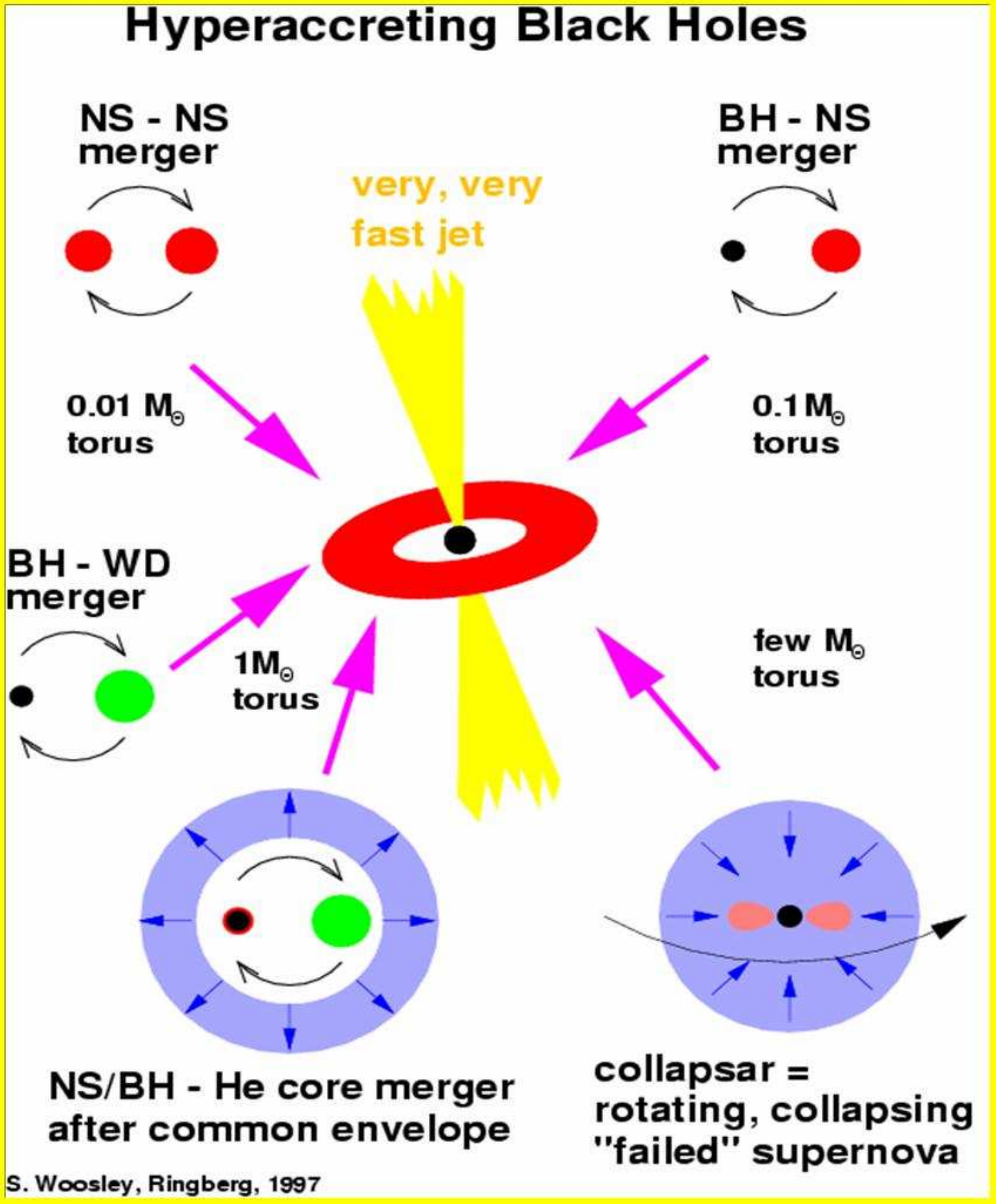
- the classical GRB phenomenon , the "**prompt emission**"
- the subsequent fading emission, the "**afterglow emission**"

When in 1997 BeppoSAX discovered a fading emission following the GRB (Costa et al. 1997)

- Observed at all wavelengths (radio to X-ray)
- Detectable for days to weeks.



GRB progenitors



ms time variability implies a compact object

Energy > ~10^{52} erg :
Stellar mass black hole

Forming a black hole

- Merging of two compact objects : SHORT GRB (<2s)
- Gravitational collapse of a massive star ($M > 20\ M_\odot$) : LONG GRB (>2s)

Woosley & McFadyen 1999; Heger et al. 2001

For the short ones…

- Neutron stars merging model
  - Short duration GRBs (<2sec):
    - Appear dimmer by a factor 10
    - Not observed on star formation regions
    - Have a large fraction of hard gamma-rays
    - Too fast to be explained with the 'collapsar' model
  - Possible model → Merger of two neutron stars:
    - The stars lose angular momentum radiating gravitational waves
    - Eventually they collide forming a Black Hole

(Models with Neutron star - BH systems have been also proposed)

www.eso.org

Some groups propose that shorts GRBs are Good candidate for gravitational wave detection

Other progenitor still possible (giant magnetar flares…)

Gravitational waves

Can be produced

- Before the collapse of the binary progenitor (efficient)
- During the bounding of the core-collapse (inefficient)

Main target are short bursts

To date, no detection

Due to small volume sampled (detection limit is ~ 100 Mpc)

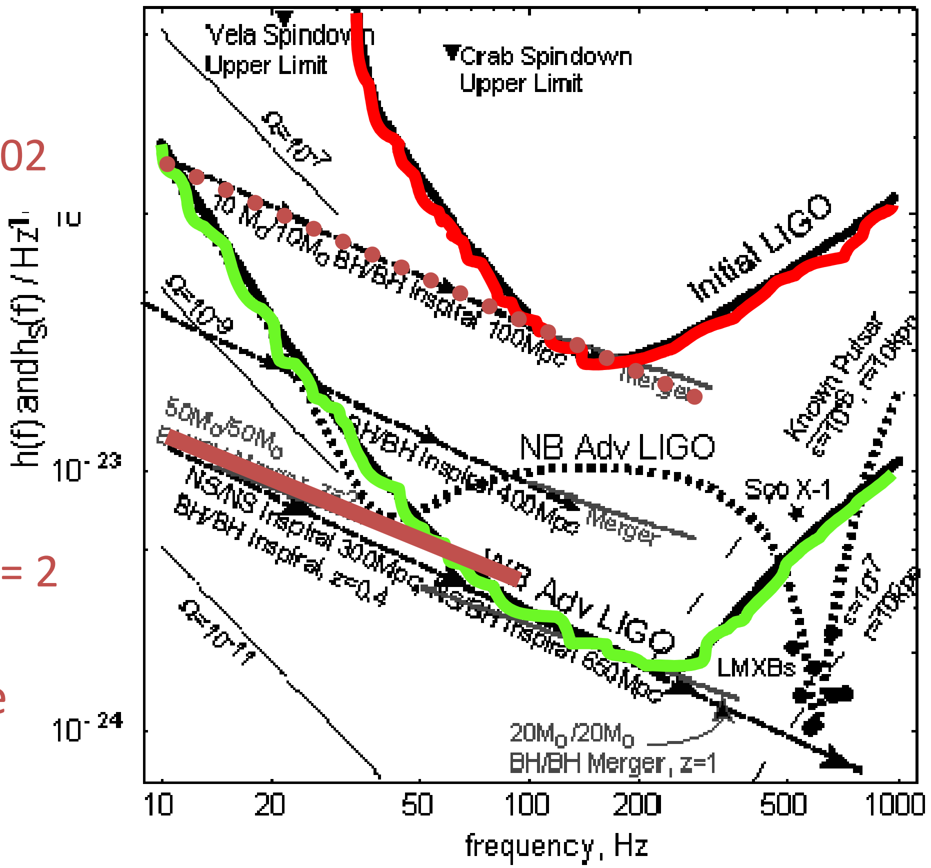
z = 0.02

Next step : new instruments

- Should trigger on GRBs

Z = 2

→Will provide information on the progenitor mass, geometry.



High energy photons

- GRB 940217 (Hurley et al. 1994): detected by EGRET, with a 18 GeV photon;
- GRB 941017 (Gonzalez et al. 2003)
- GRB 090514B (AGILE collaboration) : detected in the GRID

However, no clear idea of what happen after a few MeV.

- Unknown GRB sky above 100 GeV.

Cosmic rays

During the acceleration of the fireball, baryons, electrons and positrons are accelerated up to relativistic velocities

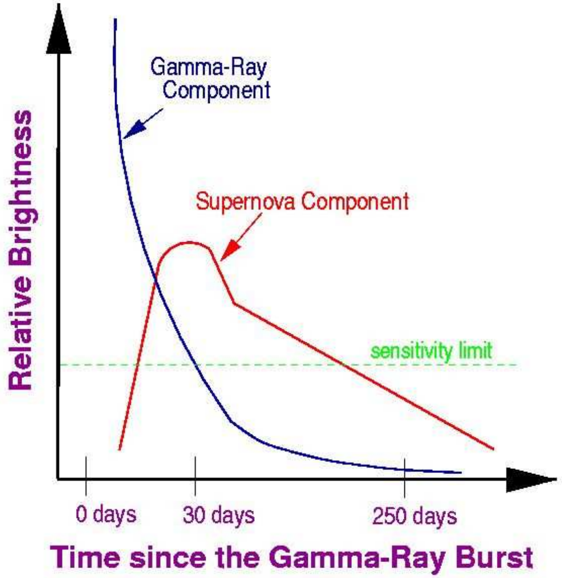
- Possible candidate to produce energetic CRs
- But not clear if GRB produce detected CRs

To date, no claimed detection from any GRB
(but we detect only ~ 40% of GRBs seen on-axis, and none can be seen off-axis !)

For the long-soft burst:
Evidence for the core collapse model

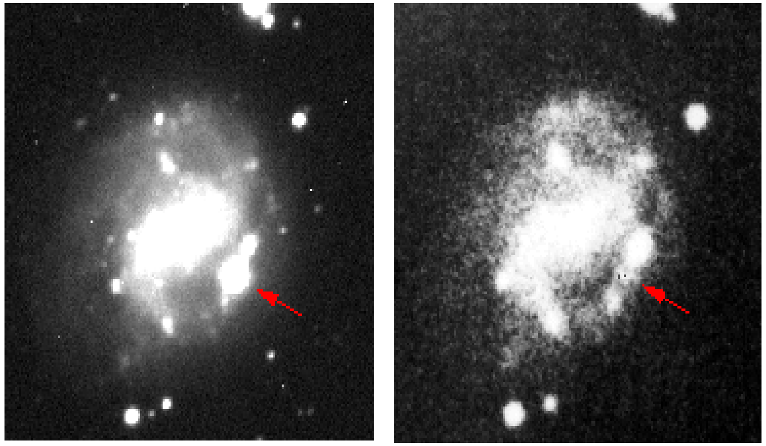
- Long-Soft Bursts located in star forming region (irregular galaxies, arms of spiral galaxies) were massive stars are always found

- Supernovae connection:
  - Bump observed in the optical afterglow
  - Connection with Type Ib/c (core-collapse supernovae)



GRB-SN connection

- GB980425: in the BeppoSAX error box: SN1998bw (Pian et al99,Kulkarni et al, Galama et al al 98).
- Exploded within 1 day from the GRB. Chance P=10^{-4}

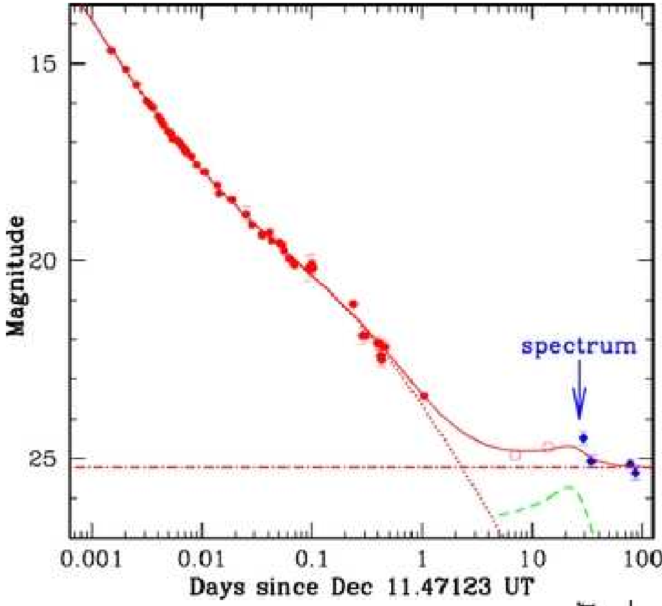


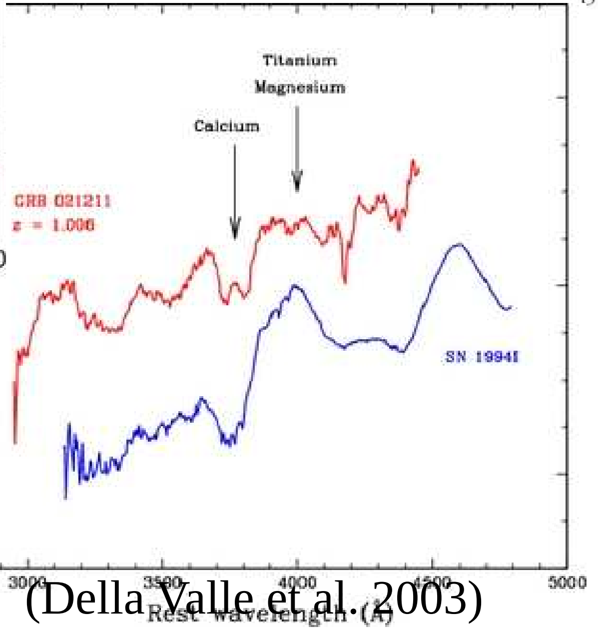
Type Ic supernova, d = 40 Mpc
Modeled as the 3 x 10^{52} erg explosion
of a massive CO star
(Iwamoto et al 1998; Woosley, Eastman, & Schmidt 1999)

GRB 8 x 10^{47} erg; 23 s

GRB -SN Connection

GRB 021211





(Della Valle et al. 2003)

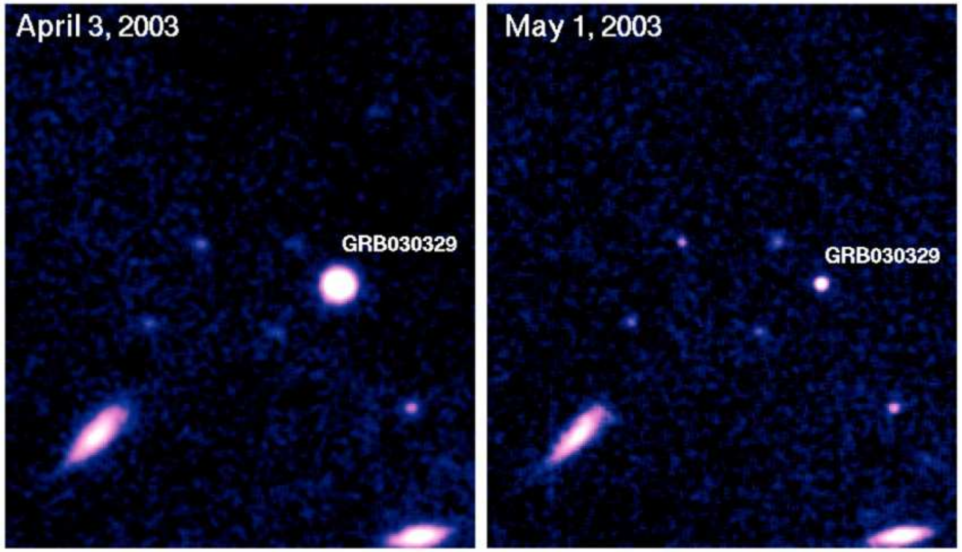
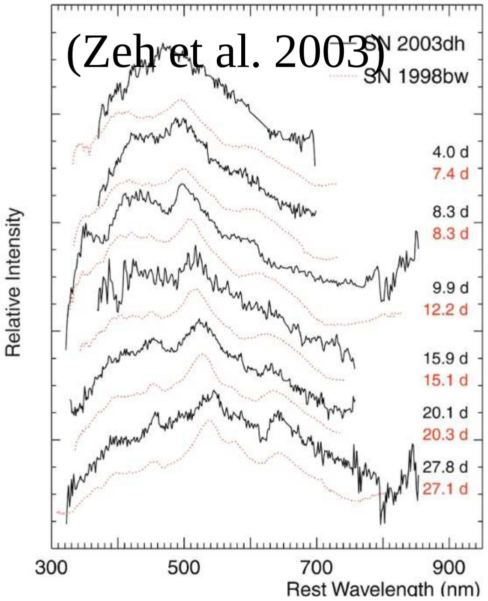


Image of Afterglow of GRB 030329
(VLT + FORS)

©European Southern Observatory



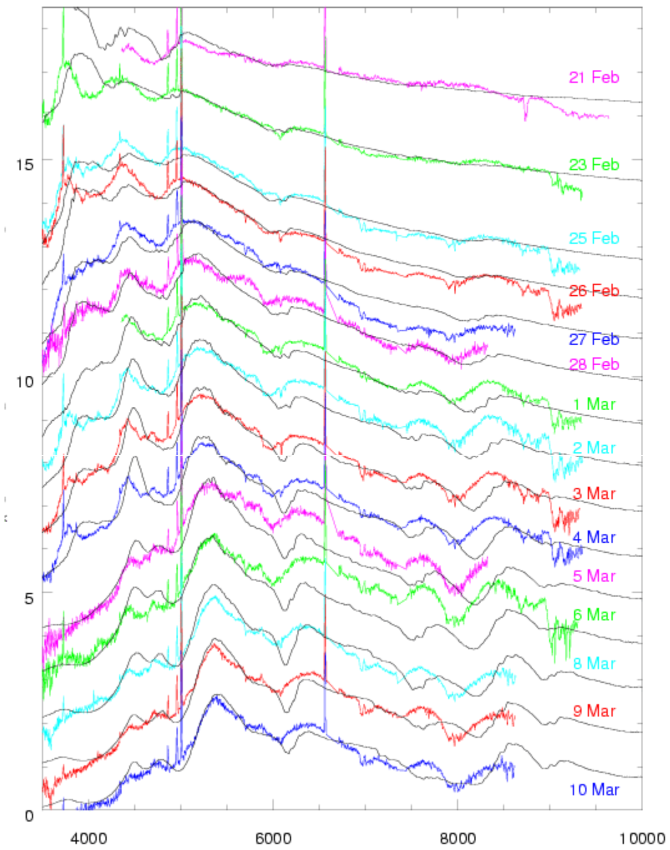
(Zeh et al. 2003)

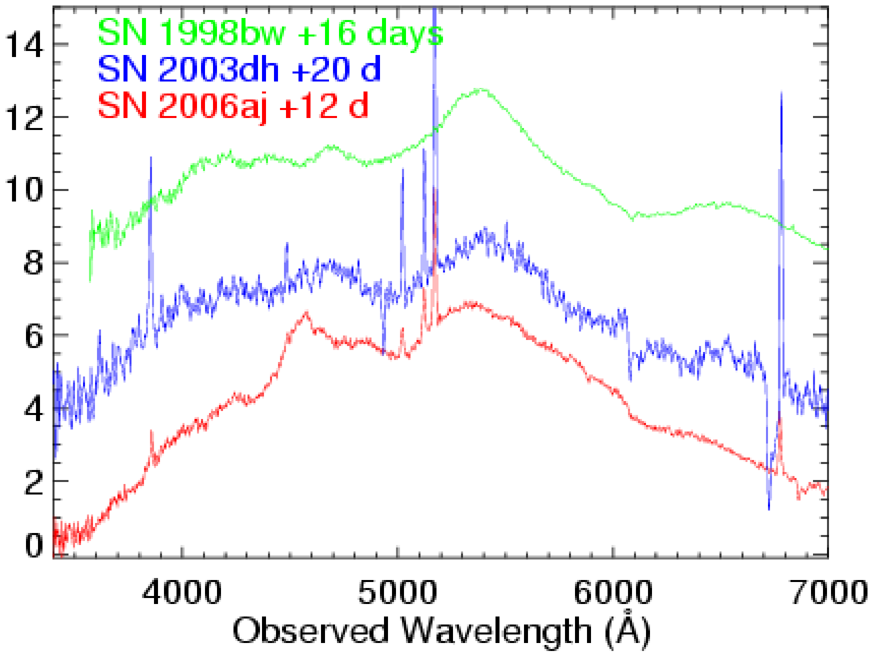
- "Bumps" seen in the optical afterglows of at least three GRBs - 970228, 980326, and 011121 – at the time and with a brightness like that of a Type I supernova

The GRB-Supernova Connection

GRB 060218 (the second closest GRB)

$z = 0.03352$





Detailed spectroscopic monitoring

Broad-lined "**hypernova**"

GRB and cosmology

GRBs can be used to study cosmology

- Distant events
- Present empirical relations
- Good complement to SNe

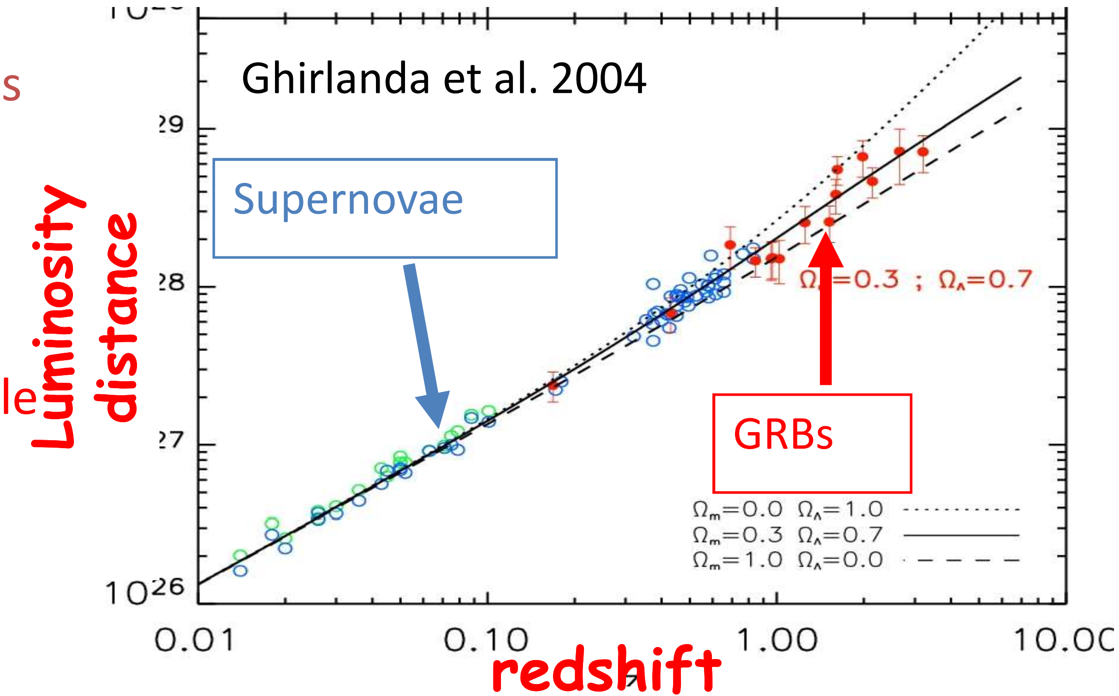
But…

No nearby event to
calibrate any standard candle

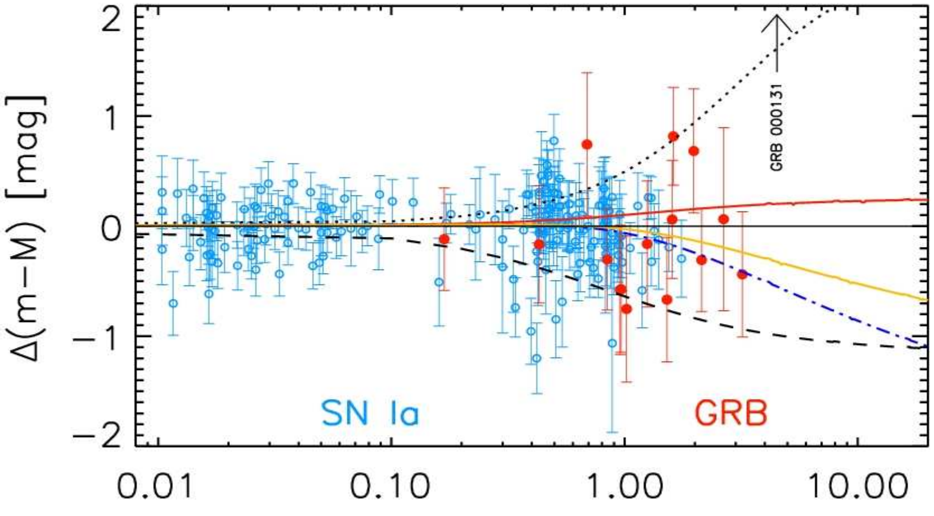
Actual solutions

- Do not care (may be problematic)
- Use sample of same distant events (statistical significance still low)
- Try to understand the empirical standard candles (complicated, but accurate)

They claims that GRBs can be used as cosmological RULERS



Ghirlanda et al. 2004



Afterglows before SWIFT

Afterglows => redshift => distance & energetics

Cosmological events: <z> = 1

GRBs energies: $10^{51} - 10^{54}$ erg => 10^{51} erg if collimated

Very rare in the Universe (~1/100 of SNe)

LONG GRBs

- Association with **core-collapse SNe**
- Star-forming host galaxies
- Connection with **cosmic star formation**

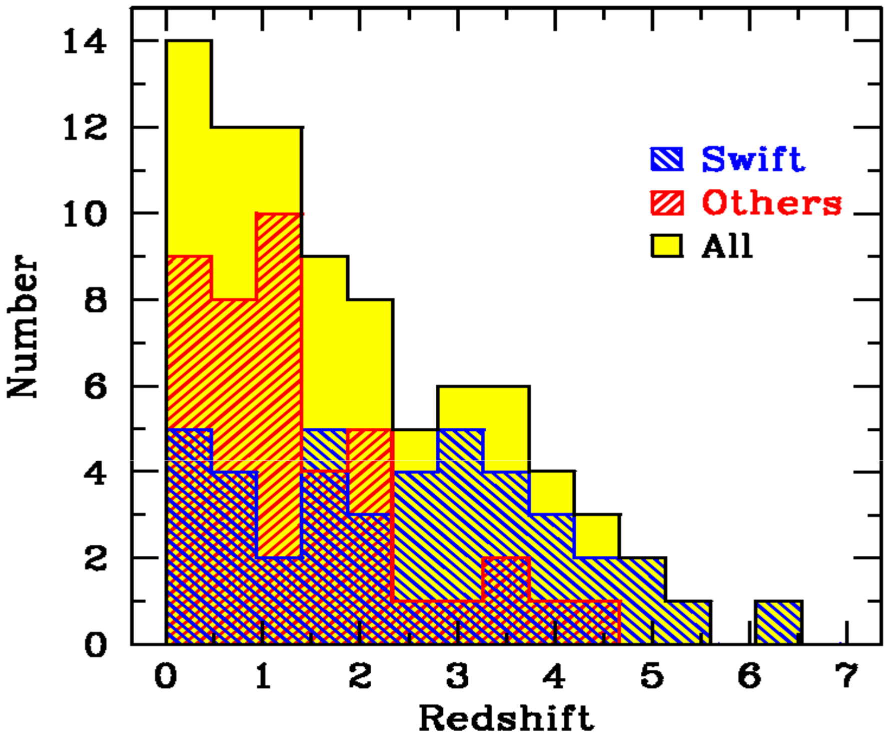
SHORT GRBs

- Binary compact object binary mergers

SWIFT: Optical-NIR observations

- 40-50% of the Swift GRBs have no optical counterpart or in any case the optical counterpart is very weak (absorption? intrinsically optically weak? high redshift?)

- The average redshift is quite high <z>~2.5 to be compared with a value of <z>~1 expected before the launch of Swift. Due to the higher sensitivity and harder energy band of BAT with respect to BeppoSAX WFC and HETE II and also to faster reaction in the otical-NIR follow-up (e.g. Fiore et al. 2007, AA 470. 515)

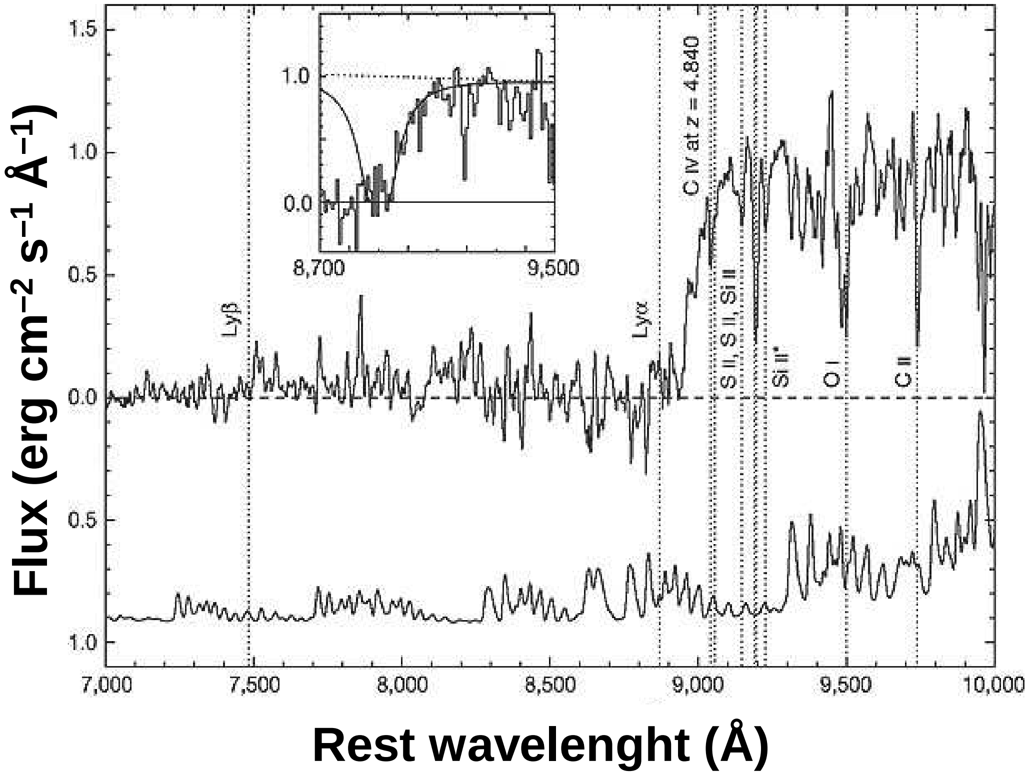


GRBs are thus ideal probes of the high-redshift Universe

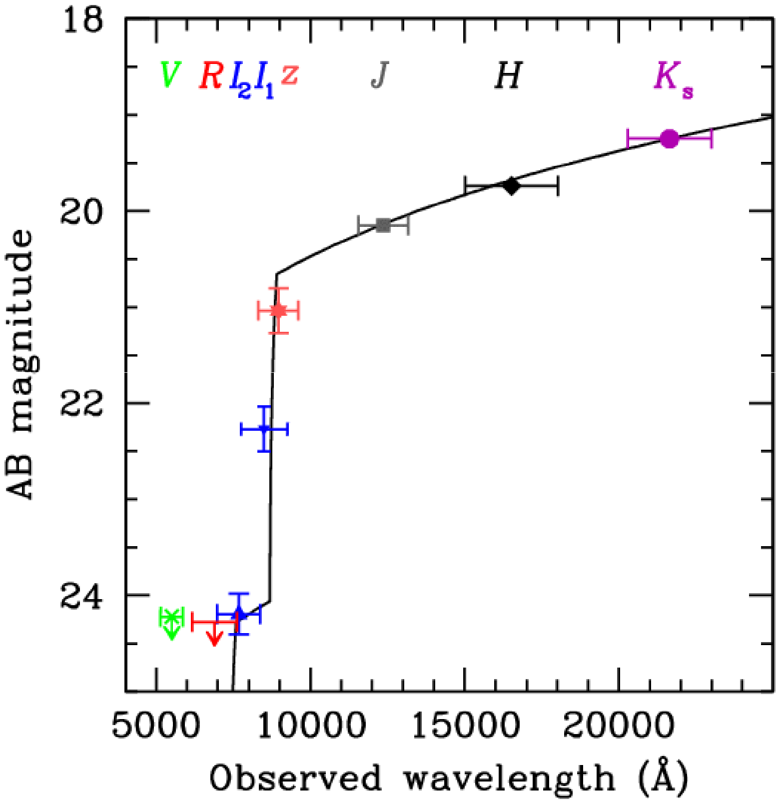
Looking at the origins of the univers

Example at $z = 6.3$

Lyα dropout suppressing optical emission



Tagliaferri et al. 2005



Spectroscopic confirmation!

Kawai et al. 2006

The Early Universe Composition

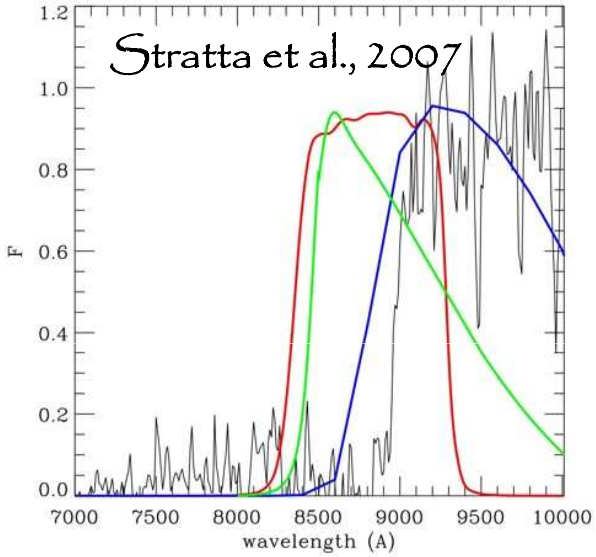
Dust composition/evolution: the case of GRB 050904 @z=6.3

A large X-ray absorption and UV dust extinction is observed.

Haislip WFCAM-UKIRT
~0.5 days
Lyα corr. = 3.02

Tagliaferri FORS-VLT
~1 day
Lyα corr. = 1.27

Haislip GMOS-Gemini
~3 days
Lyα corr. = 2.38



QSO@6.2 extinction curve
0.5 day A_{3000}=0.89+\-0.16
1 day A_{3000}=1.33+\-0.29
3 days A_{3000}=0.46+\-0.28

NH~10^{23} cm^{-2} => AV/NH~50 times lower than Galactic!!

@z~6 no dust from AGB stars.

Much less dust and much smaller A_V/N_H

Less dust => less extinction @z>5 => high-z afterglows easier to detect => Swift GRB sample with redshifts not strongly biased against high-z objects.

- There may be several hundred unusual explosions for every gamma-ray burst we see

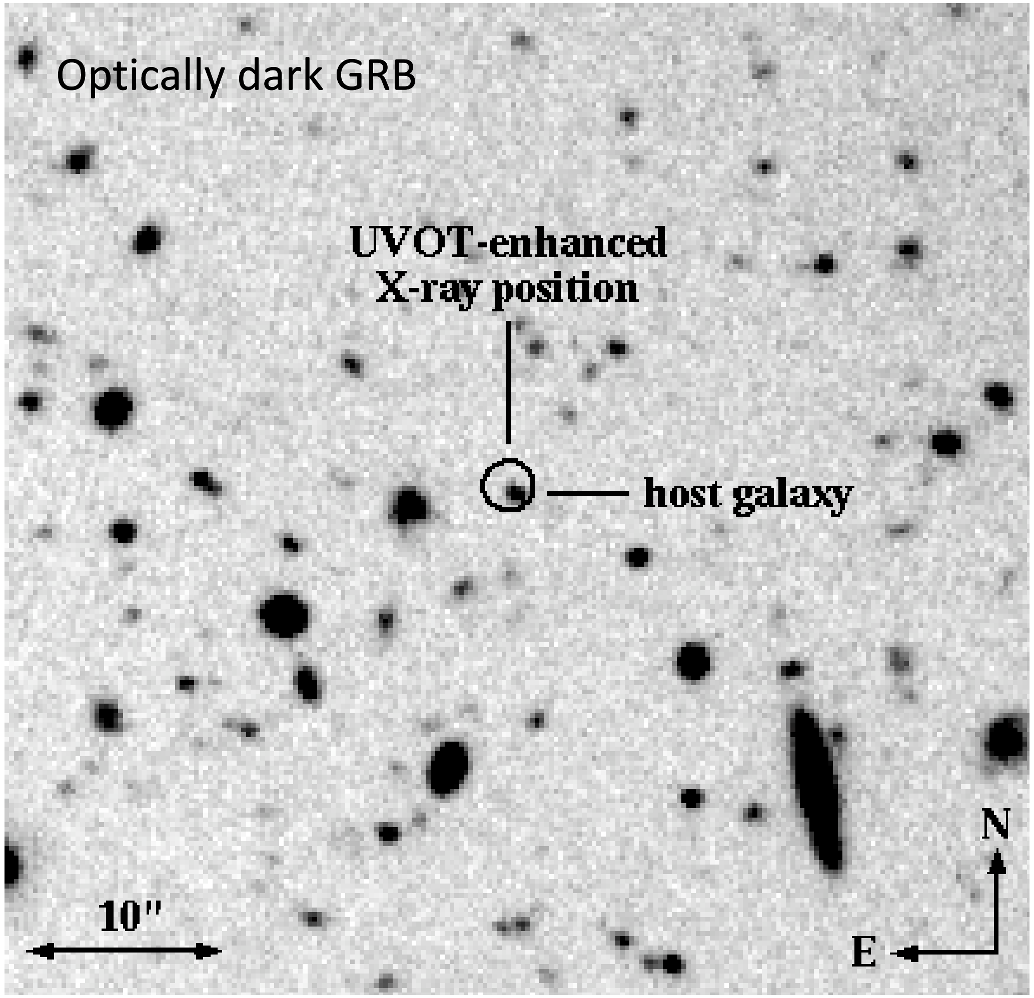
Very approximately 1% of all supernovae make GRBs but we only see about 0.5% of all the bursts that are made – a rare phenomenon

- If typical GRBs are produced by massive stars, the star must have lost its hydrogen envelope before it died.

A jet that loses its power source after the mean duration of 10 s can only traverse 3 x 10^{11} cm. This is long enough to escape a Wolf-Rayet star but not a giant.

$\Rightarrow$ Not SN II!

And the HOST? Chasing hosts galaxies



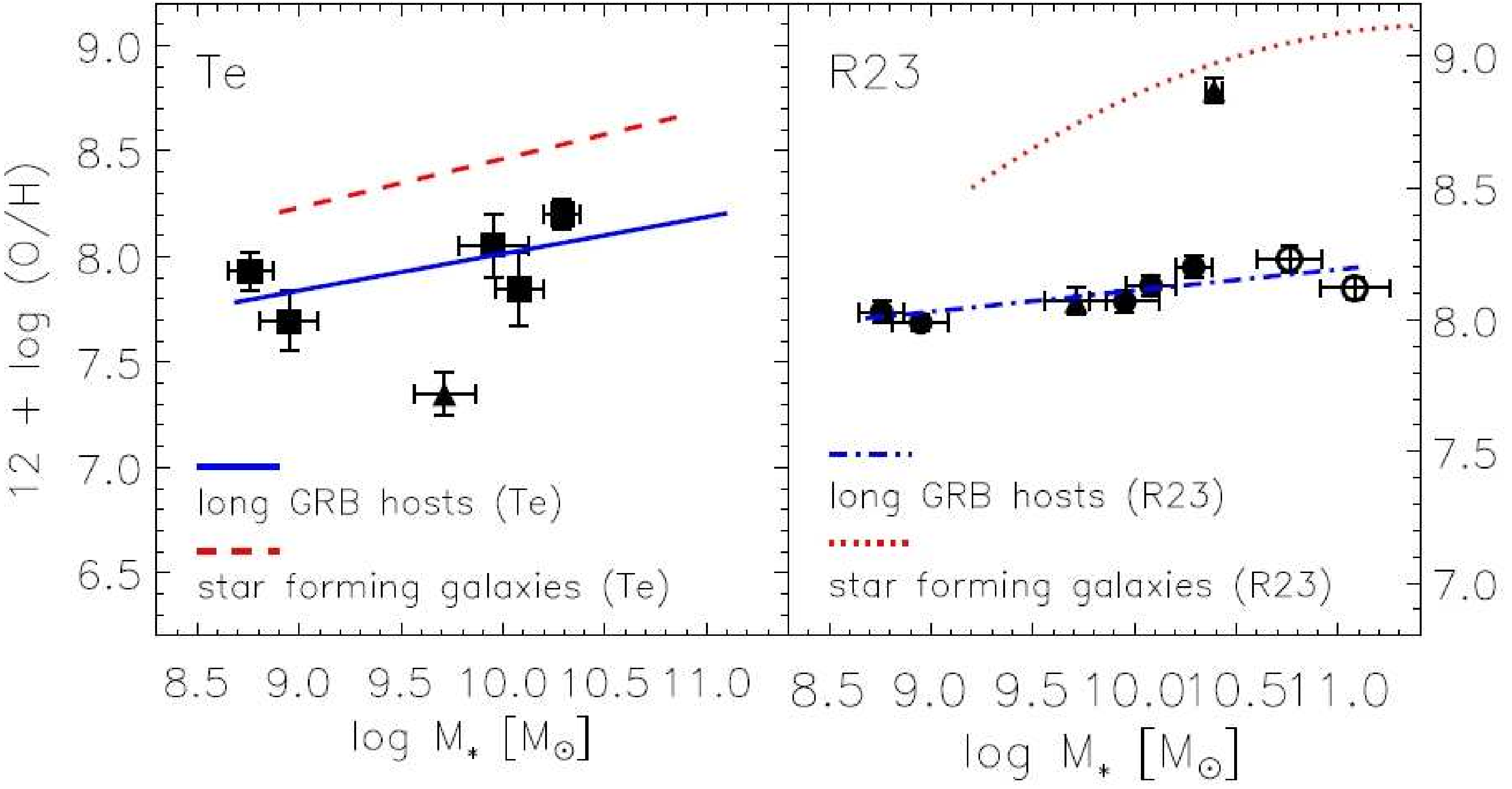
X-ray position
usually good
enough

(Butler, Evans)

Host galaxies properties

Facts:

Metal poor Irregulars Young stellar population



Han et al 2009

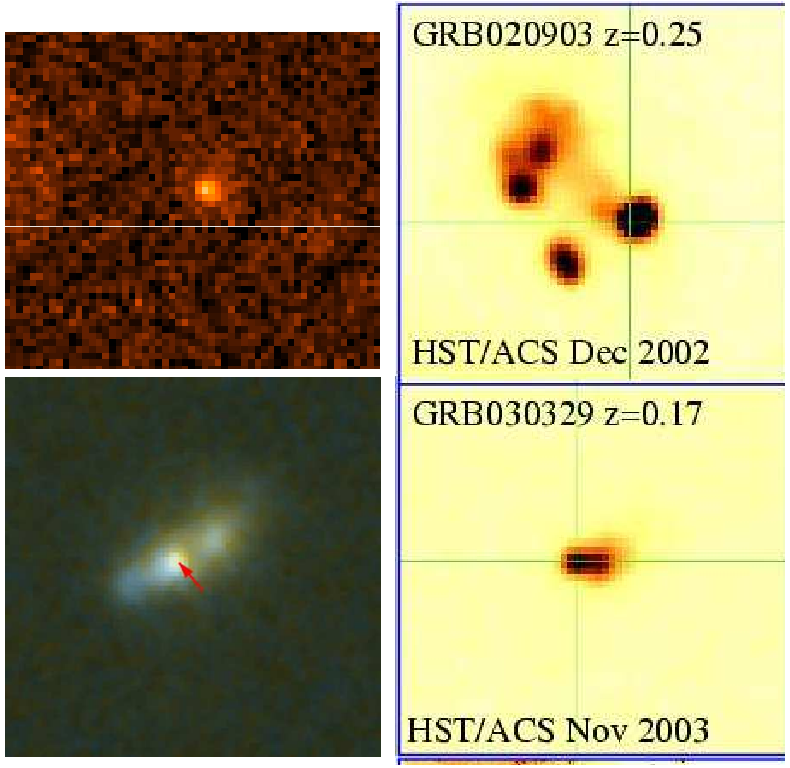
Host galaxies properties

Facts:

Metal poor

Irregulars

Young stellar population



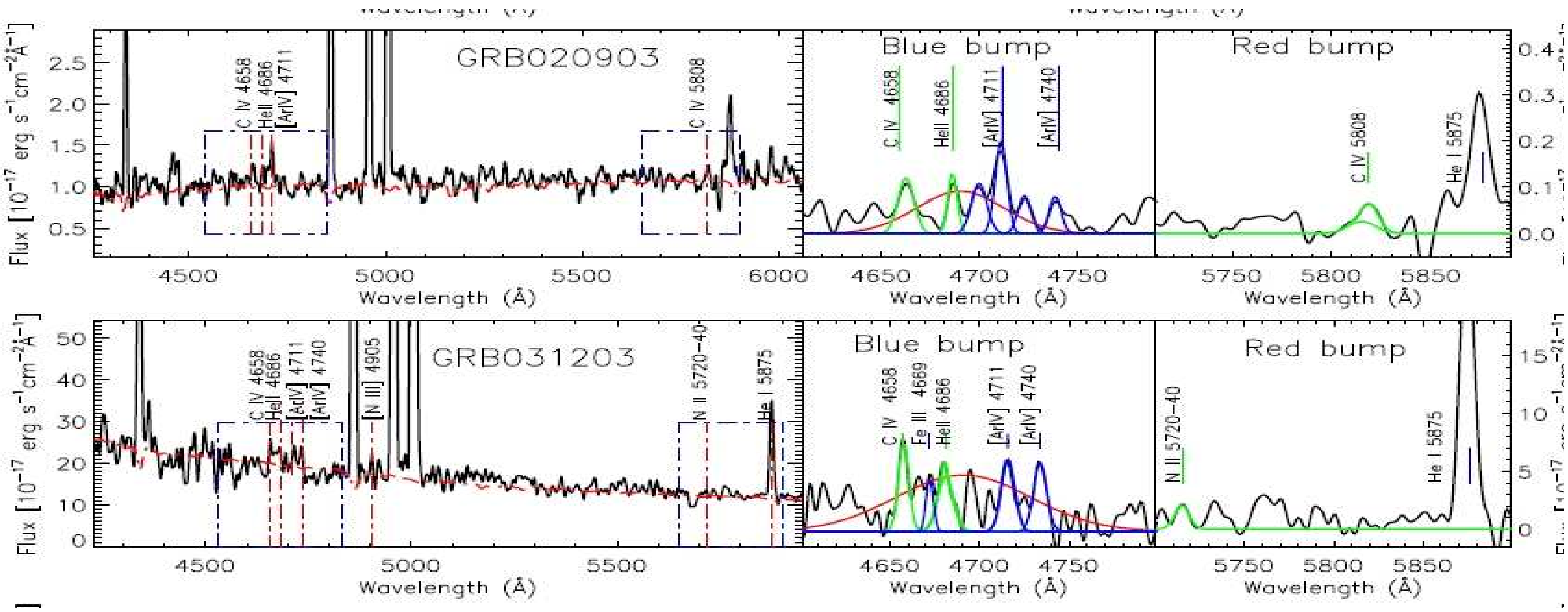
Host galaxies properties

Facts:

Metal poor

Irregulars

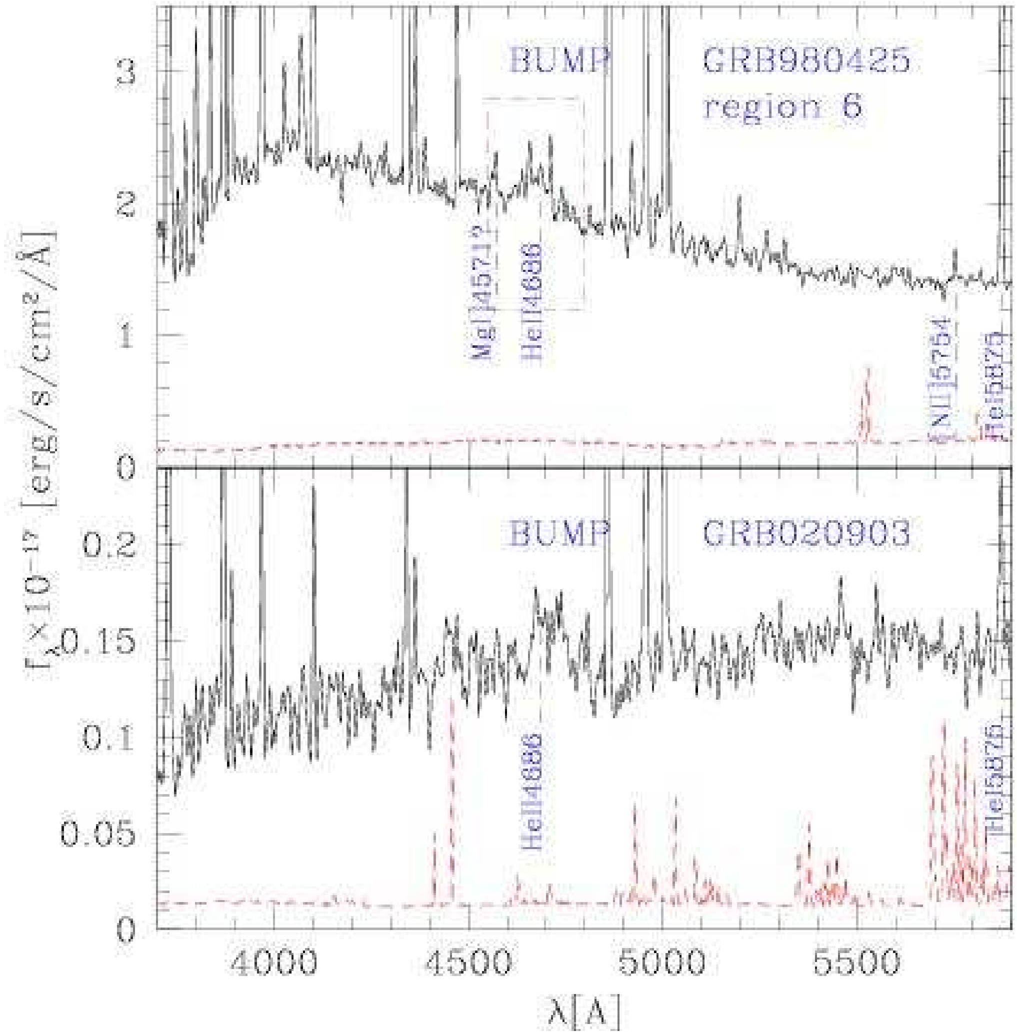
Young stellar populatior



And now we known that are WR galaxies

Detection of WR in host galaxies

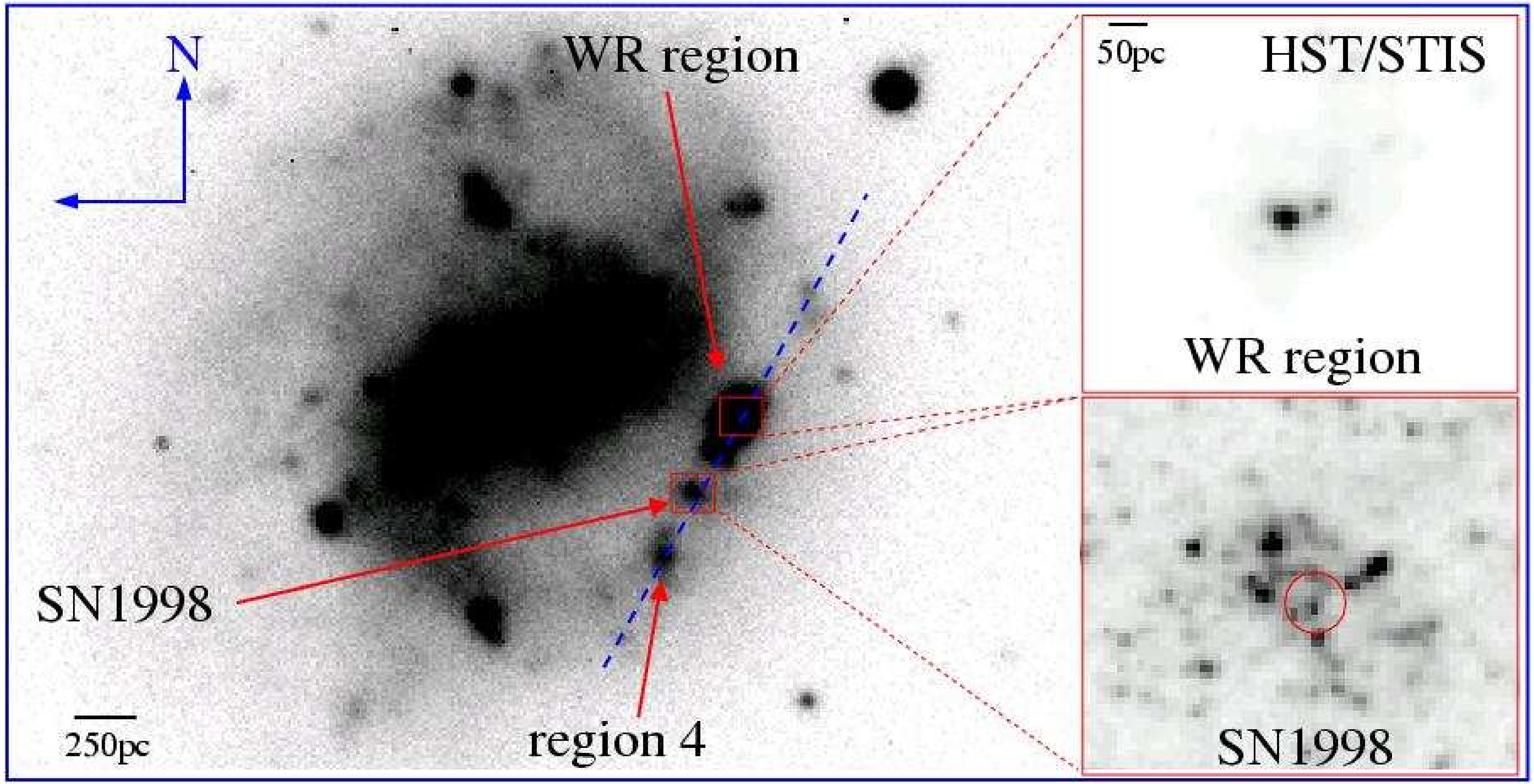
Observations FORS2 at R~1200 of 8 GRBs (Hammer et al 2006)



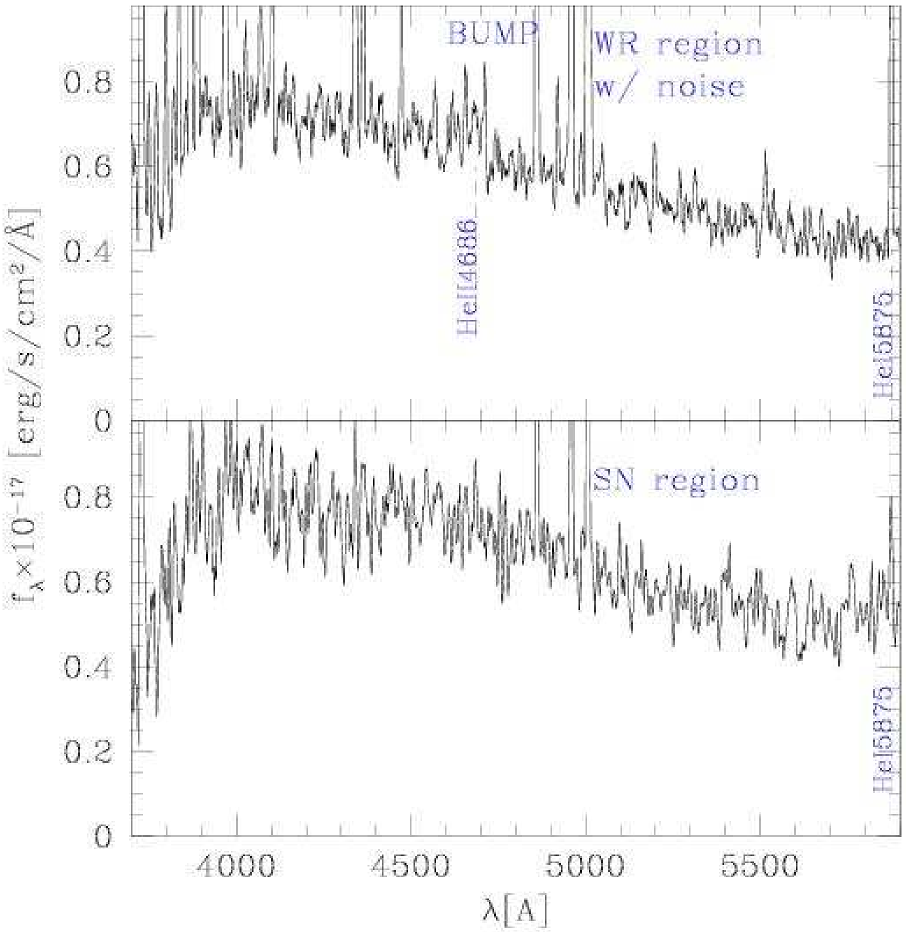
Large variety of bumps
(Guseva et al 2000)

Combining multi instrumental information

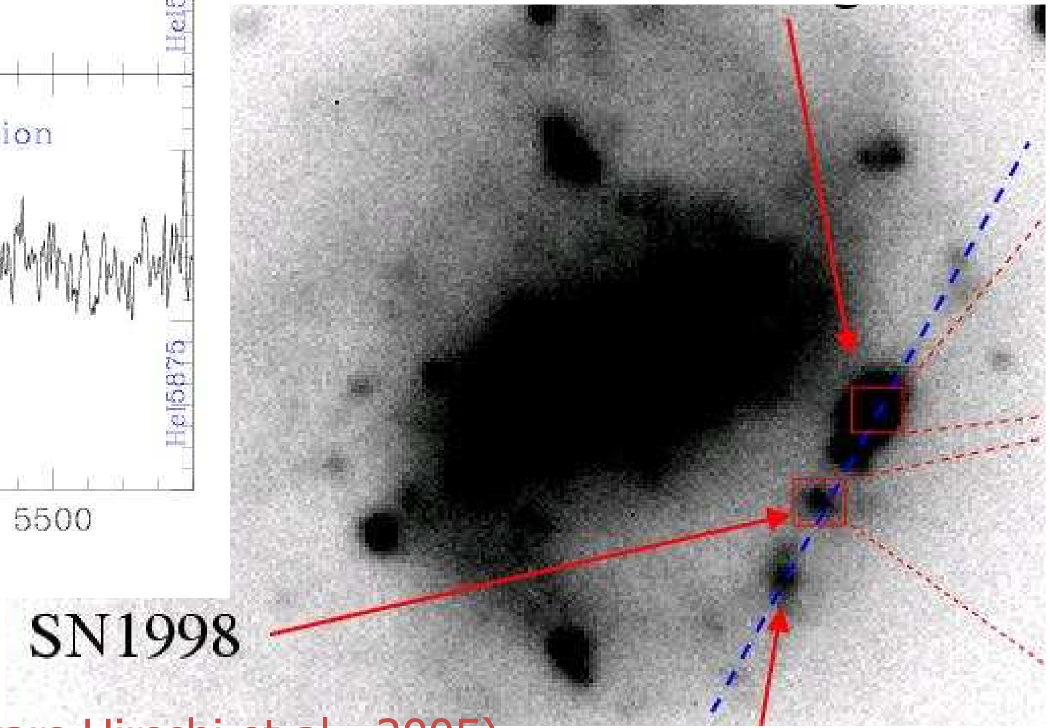
GRB980525 at z=0.0086



Detection of WR stars in host galaxies

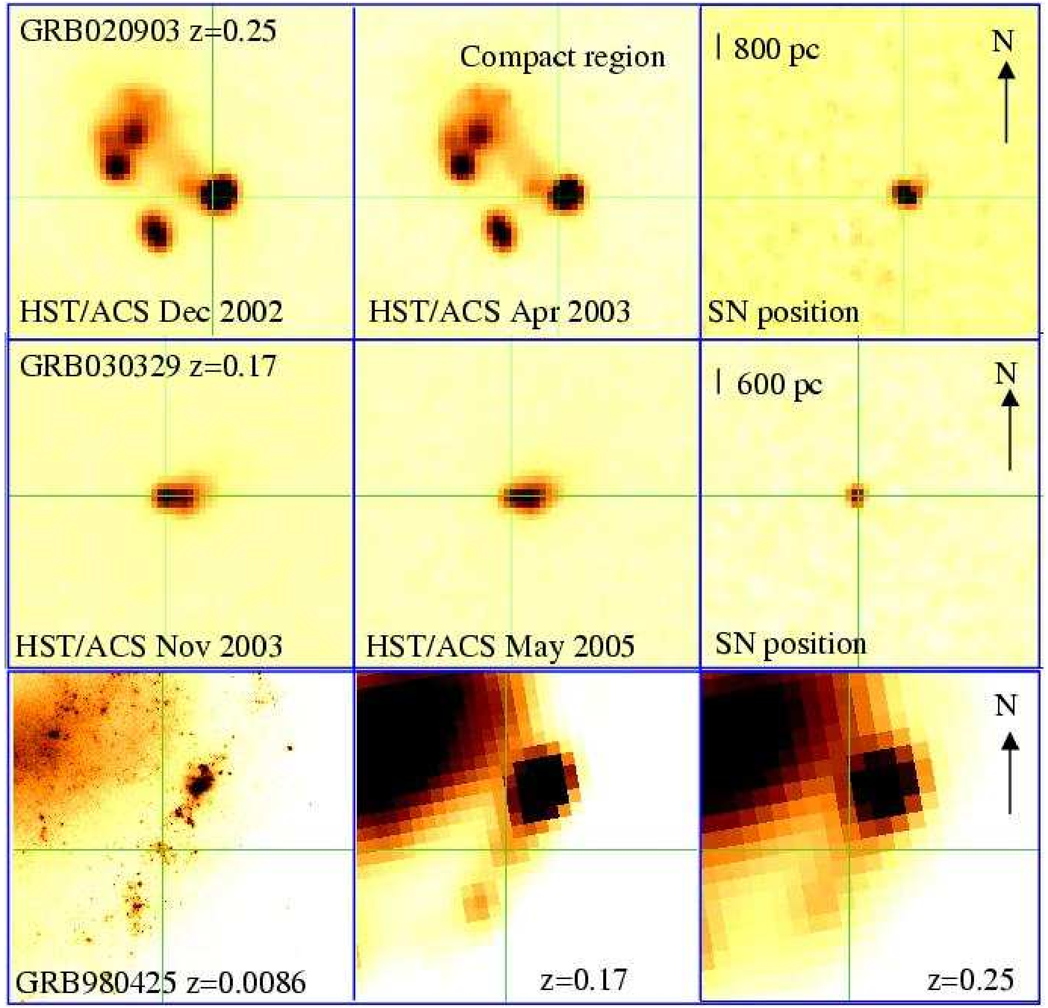


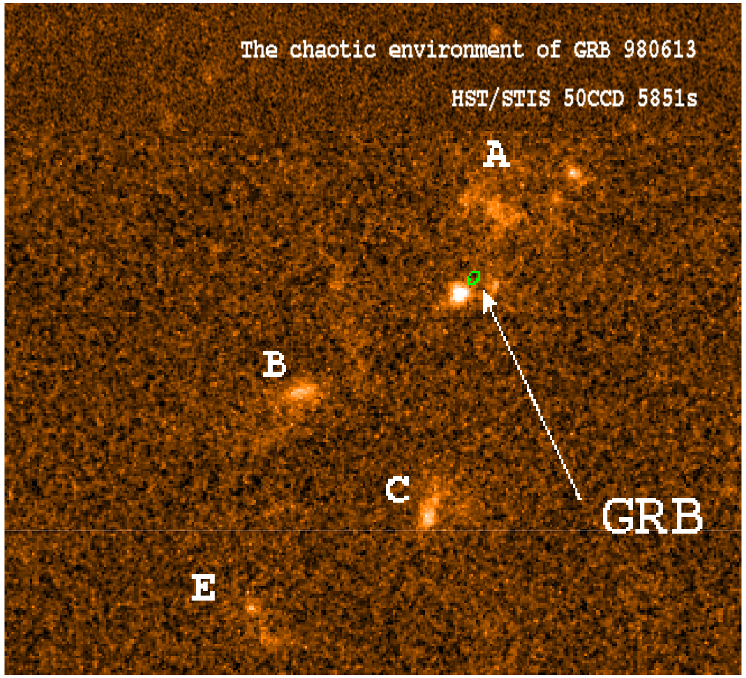
+ of 2300 0 stars
&
80 to 100 WR stars



1> WR star in SN region
SN1998, < 10 0 stars,
But [S/N]=0.24 (expected for rotating stars Hirschi et al , 2005)

GRB progenitors: Always a gap between the position of GRB and a bright region (HII)

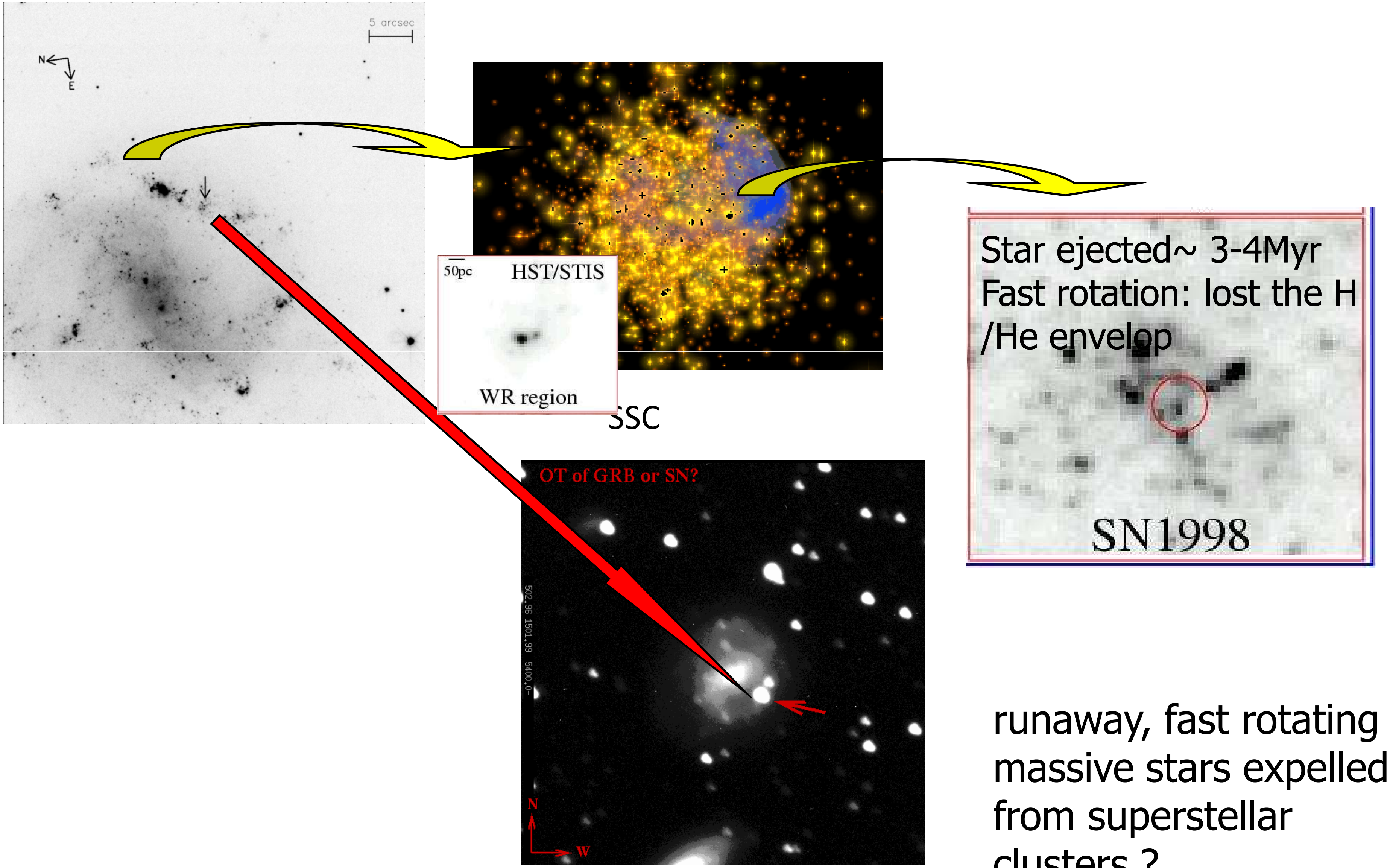




Distance from 400 to 800pc ➔ a star will need 3 to 4My at 200 à 300 km/s

What mean?

GRB/SNIb-c: A runaway scenario



SSC

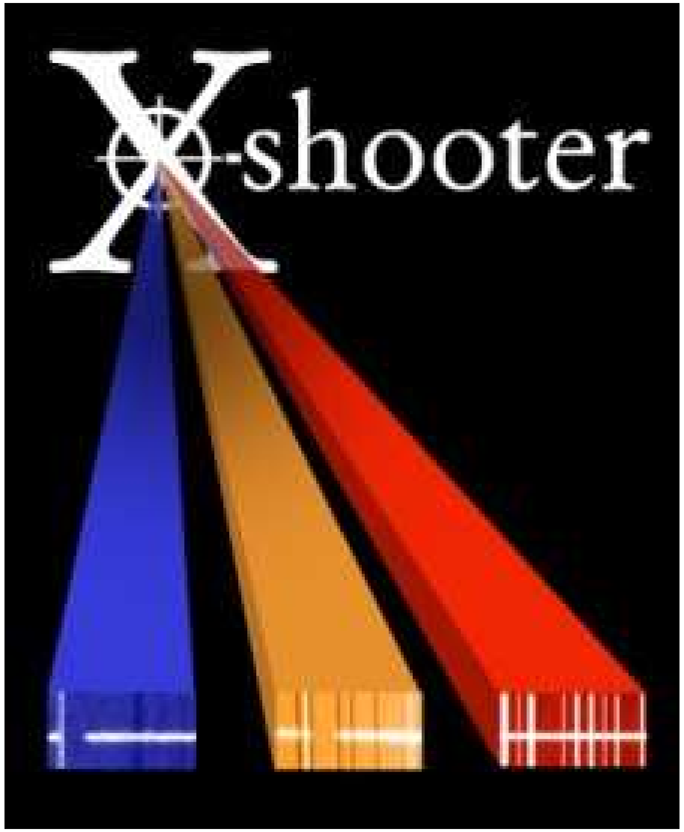
Star ejected~ 3-4Myr
Fast rotation: lost the H
/He envelop

runaway, fast rotating
massive stars expelled
from superstellar
clusters ?

Even if properties of GRBs and GRBs host galaxies starting to be well known

Community request ed an instrument to increase the positive identification of GRBs

- Identification of dark GRBs
- construct ion of an homogeneous sample



X-Shooter :

It ‘s the most sensitive VLT single object spectrograph

Large wavelength range (IFU mode) open new possibilities

The main scientific aim will be the GRBs with the possibility
of detecting the farthest sources at the reionization epoch or
beyond (+ SnIa at z > 1 and X -ray Binaries)

Scientific return: more than 200n Guaranteed time ongoing:
GRBs: ToO for three years

GRBs host galaxies; two programs: One from Danemark (long slit) and another
from a Italy-French collaboration (long slit and IFU)

X-shooter technical drivers

- High efficiency
  - Most efficient optical/nIR spectrograph in the world
- Large wavelength coverage
  - Atmospheric cut-off to near-IR (300 – 2500 nm)
  - Complete wavelength range in one shot (split in three arms using dichroics)
- Resolving power R ~ 7 000 - 12 000 with 0.6” slit:
  - 80-90% of all spectral elements are unaffected by sky lines ➔ sky-background limited
- Single instrument mode
  - Direct slit
  - IFU (image slicer)
- Only second-generation VLT instrument in Cassegrain
  - High efficiency, but flexure and weight limitations

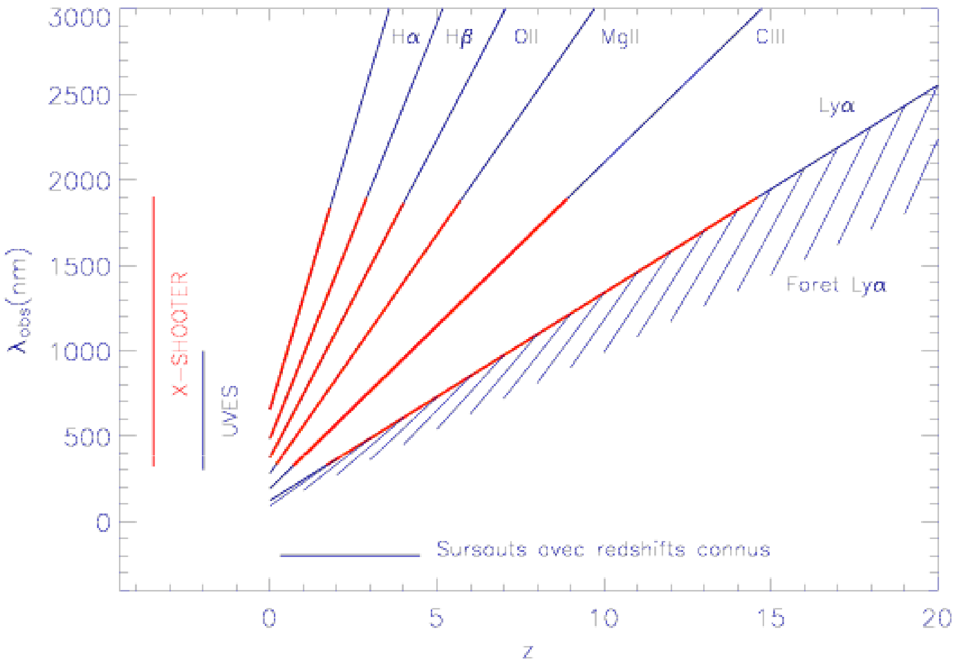
X-shooter consortium

- ESO: PI S. D'Odorico, PM/SE H. Dekker
  Instrument scientist: J. Vernet
  - Detector systems
  - System integration
- Denmark: PI/PM P. Kjaergaard Rasmussen
  - Backbone
  - UV/VIS spectrographs
- Italy: PI R. Pallavicini, PM F. Zerbi
  - UV/VIS spectrographs
  - Instrument control software
- Netherlands: PI L. Kaper, PM R. Navarro
  - NIR spectrograph
  - Data reduction software
- France: PI F. Hammer, PM I. Guinouard
  - **IFU**
  - **Data reduction software**

Observing modes and available slits

Wavelength range	300-2500 nm split in 3 arms
UV-Blue arm	Range: 300-550 nm in 11 orders Resolution: 4500 (1" slit) Detector: 4k x 2k E2V CCD
Visual-red arm	Range: 550-1000 nm in 14 orders Resolution: 7000 (1" slit) Detector: 4k x 2k MIT/LL CCD
Near-IR arm	Range: 1000-2500 nm in 16 orders Resolution: 4500 (1" slit) Detector: 2k x 1k Hawaii 2RG
Slit width and length	0.6 1.0 & 1.5 -- 12"
Beam separation	Two high efficiency dichroics
Atmospheric dispersion compensation	In the UV-Blue and Visual-red arms
Integral field unit	1.8" x 4" reformatted into 0.6" x 12"

X- shooter Spectral range and maximum redshift



X-Shooter can observe the GRBs till z=15

Wavelength position of absorption lines and Lyman-α forest as a function of redshift. To the right X-shooter spectral range with respect to UVES

X-shooter VIS first light images 19.07.2007

Performance

S/N = 10 in 1 hour per resolution element, no binning

- Atmosphere
- Telescope (M1 & M2)
- Dichroics
- Pre-slit optics and spectrograph optics
- Gratings
- Detectors

Band	AB mag
U	22.0
B	22.1
V	22.1
R	21.8
I	21.5
z	20.8
J	20.6
H	20.7
K	18.7

Total throughput > 25%
Best optical and infrared spectrograph
in the world

Status and milestones

- Hardware and integration completed 01/2009
- Version 0.1 DRS package delivered 06/2009
- ETC ready 03/2009
- First ligth 03/2009
- Science verification 08/2009
  - ➔ 98 proposal submitted by the community !!!!!!!!

- Preparations GTO program started (Total : 200 nights)

Common ToO/RRM GRB program (20% to 25%) of the total.

- Instrument release to the community (P84) Oct 2009

More than 150 proposal submitted UT2 pressure 7.5 !!!!

X-Shooter:

Science Case: The physical properties of distant galaxies: GRB host and/or field galaxies

Integrated properties (longslit) or maps(IFU)

✓Velocity field and sigma map
✓Electronic density
✓Extinction
✓Metal content
✓SFR
✓Etc …

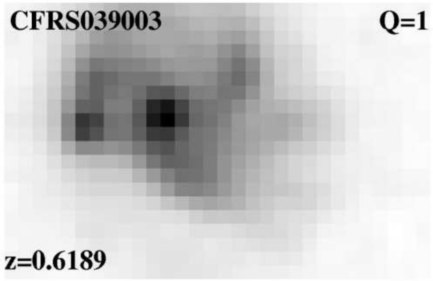
xample of science w/ IFUs

HST+3D info + multi- λ

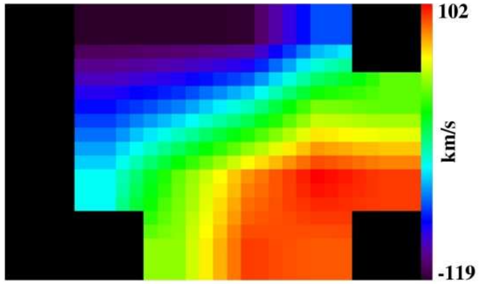
LIRGs : we have integrated properties:
metallicity, A_V and SFR(Hα and IR),
and maps: color Morph + VF

Liang Y., et al (2004)
Zheng, X.Z. et al (2004-2005)

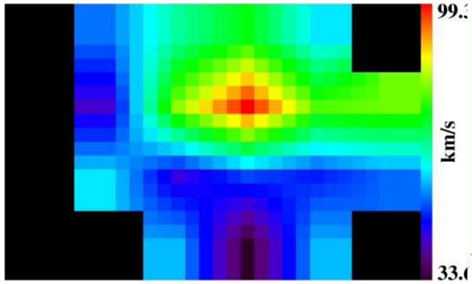
HST/F814W



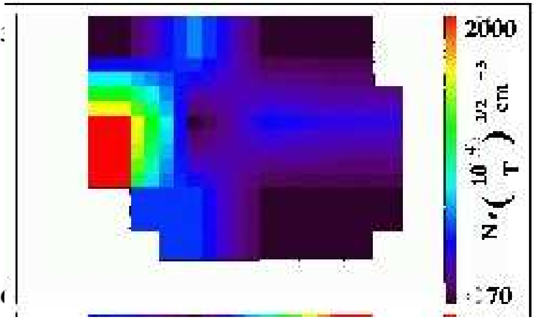
VF



Sigma



Ne



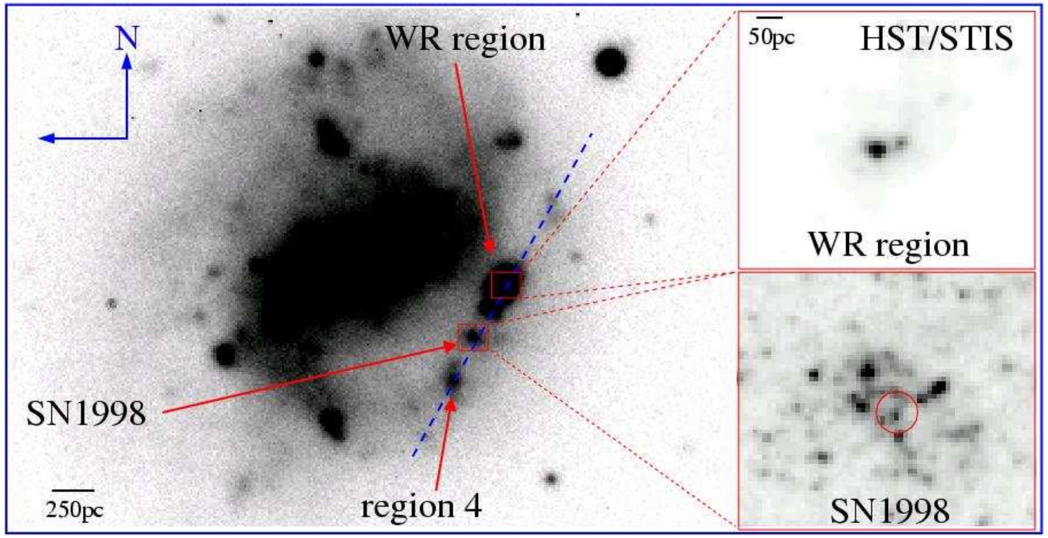
(S/N>5)

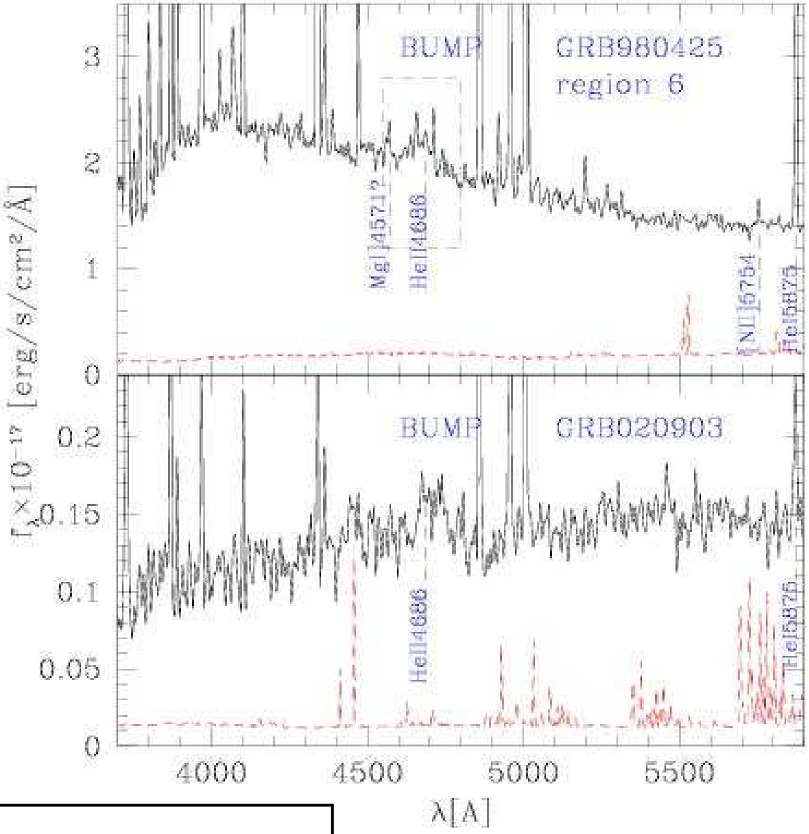
Ne comp w/ HII region

Maps but small $\Delta\lambda$

Science Case: GRB host galaxies

GRB980525 à z=0.0086

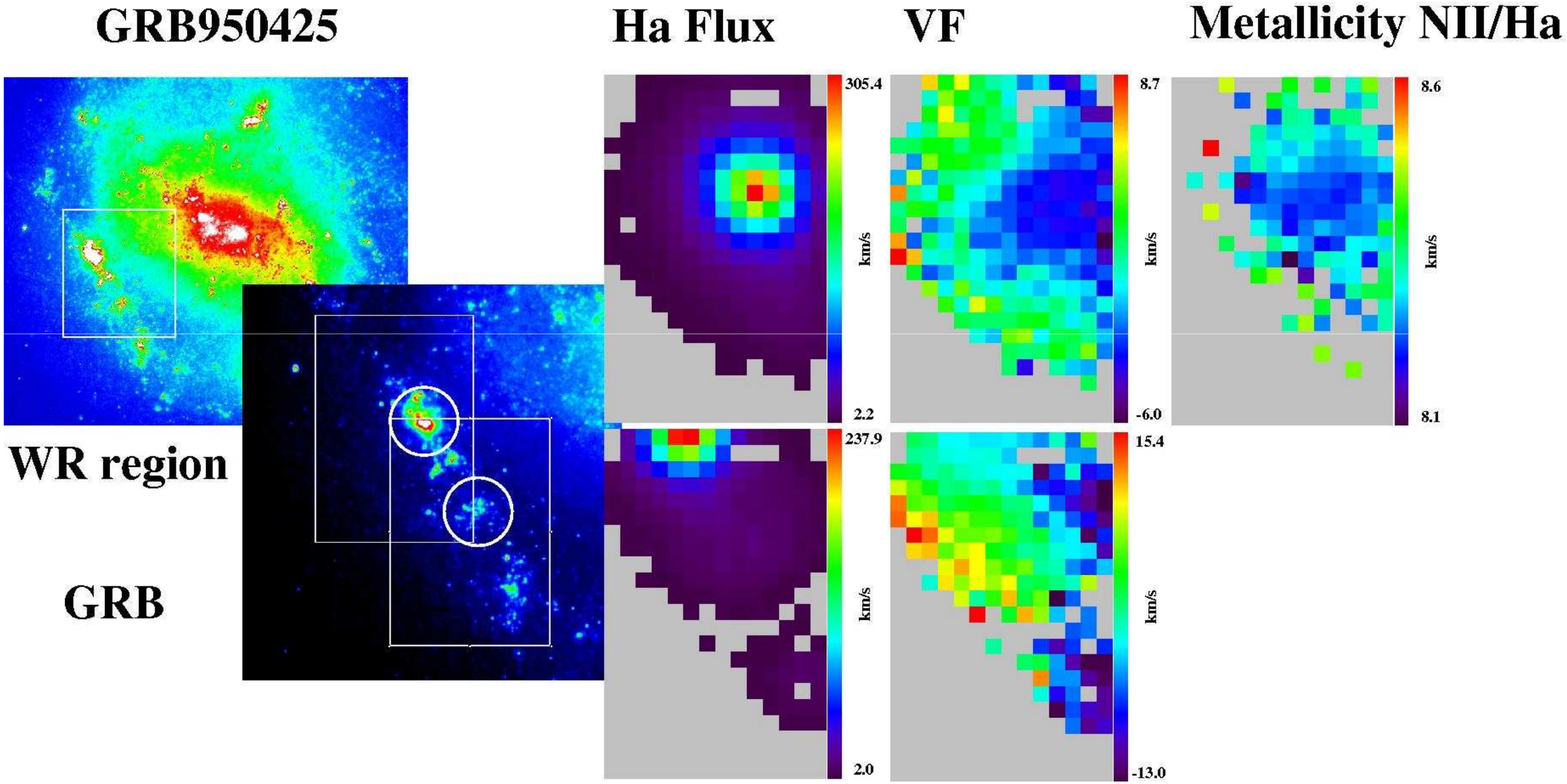




Δλ >> but only integrated properties

Science Case: GRB host galaxies

Argus Observations R ~ 27000

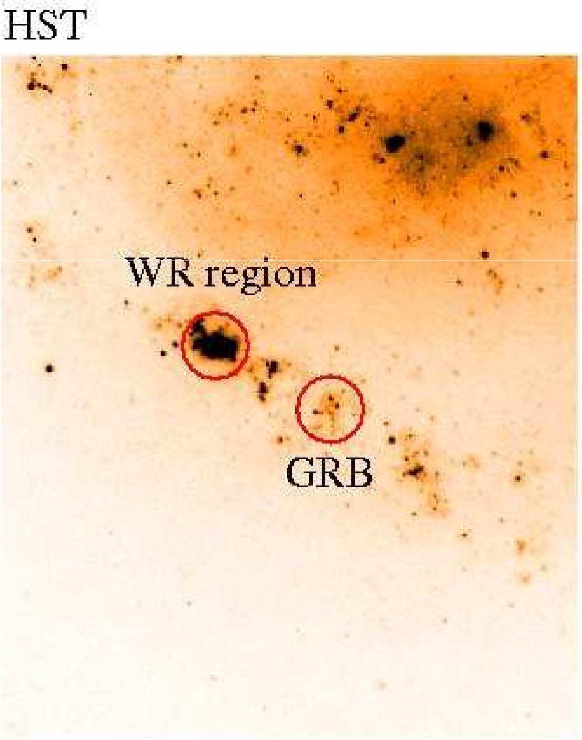


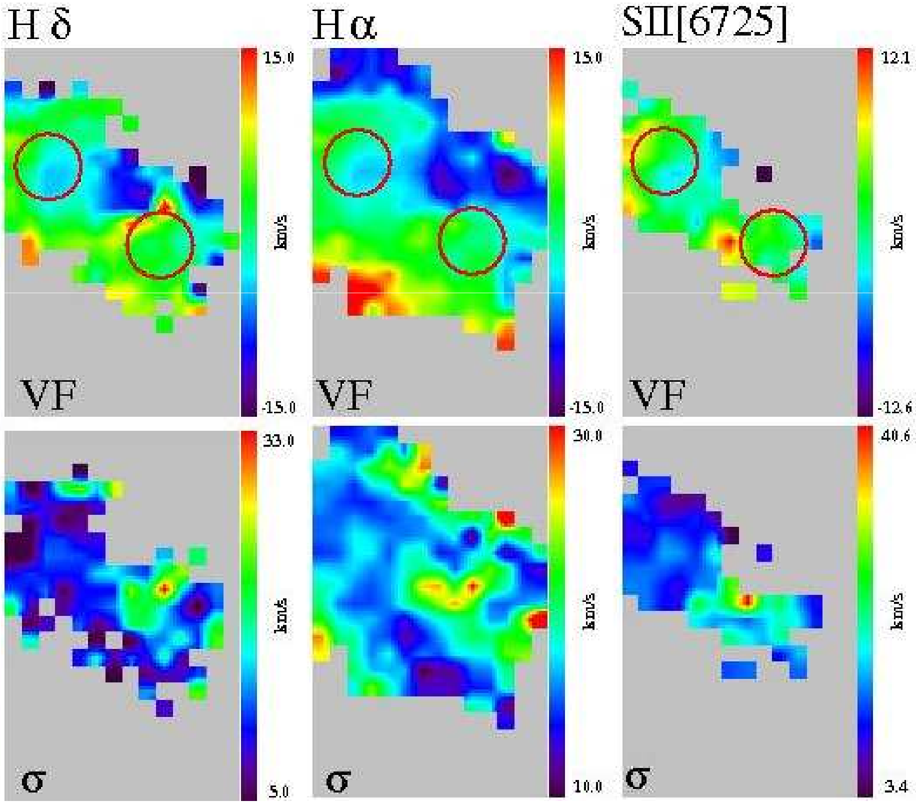
Large FoV but really small Δλ

Science Case: GRB host galaxies

Argus Observations R ~ 10000 : new observations from OII to Ha

GRB980525 à z=0.0086

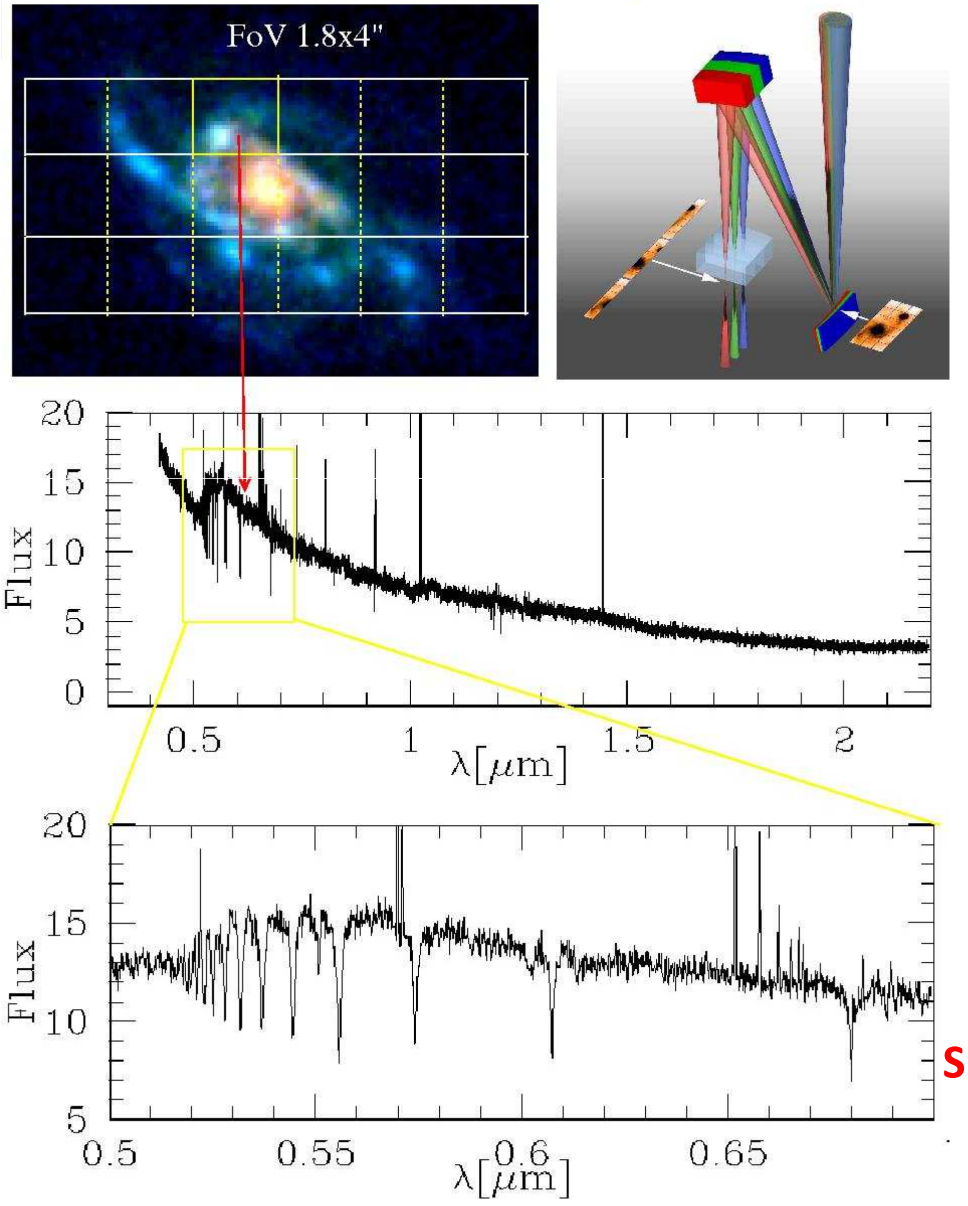




Large FoV but really small $\Delta\lambda$

Science Case: GRB host galaxies

Simulated metal poor galaxy at z=0.4



And X-Shooter?

- ⇨ Large wavelength coverage: 300 – 2500 nm
- ⇨ R ~ 7 000 - 12 000 with 0.6” slit: Direct slit or IFU (image slicer)

Simulations + new tools of analyses

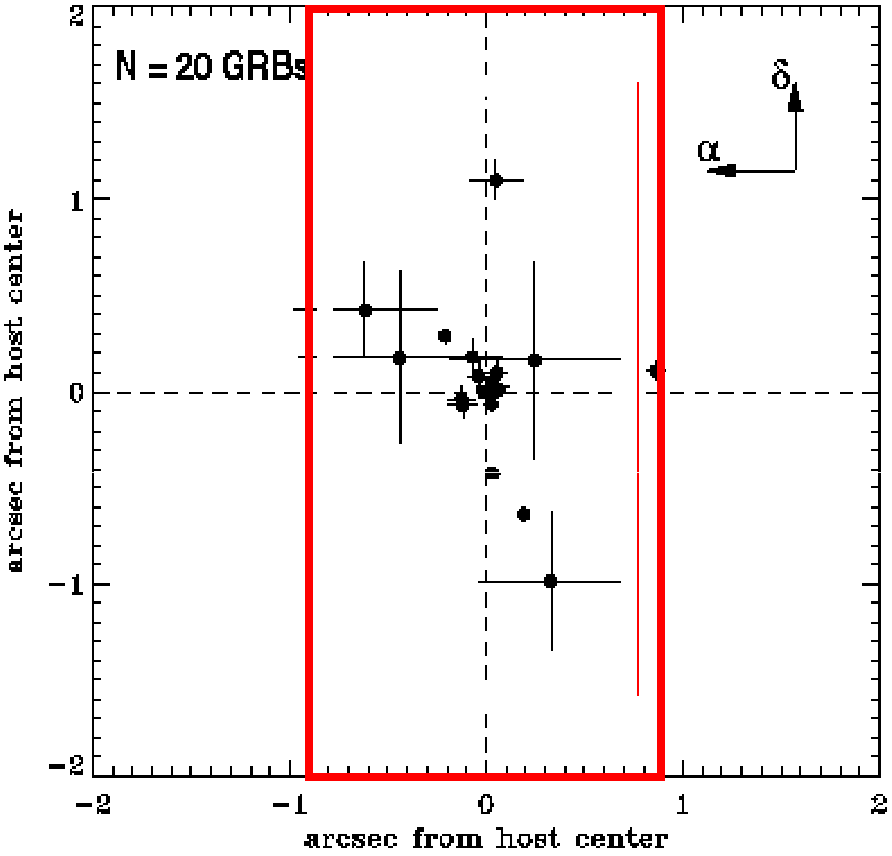
Y. Yang (GEPI) M.Puech (ESO) H. Flores (GEPI)

X-shooter science

Scientific driver for this instrument

- **To study the physical origin of gamma-ray bursts and the nature of their host galaxies**,
- To study faint brown dwarfs,
- to identify the progenitors of Type Ia supernovae,
- To quantify the properties of high redshift (lensed) galaxies, and
- To probe the structure of the intergalactic medium.
- Identification of sources of which astrophysical nature (or redshift) is not known
- Spectroscopic follow-up of new sources discovered with survey instruments (VST/OmegaCam, VISTA,…)
- Complementary observations (Chandra, XMM, INTEGRAL, ALMA, …)

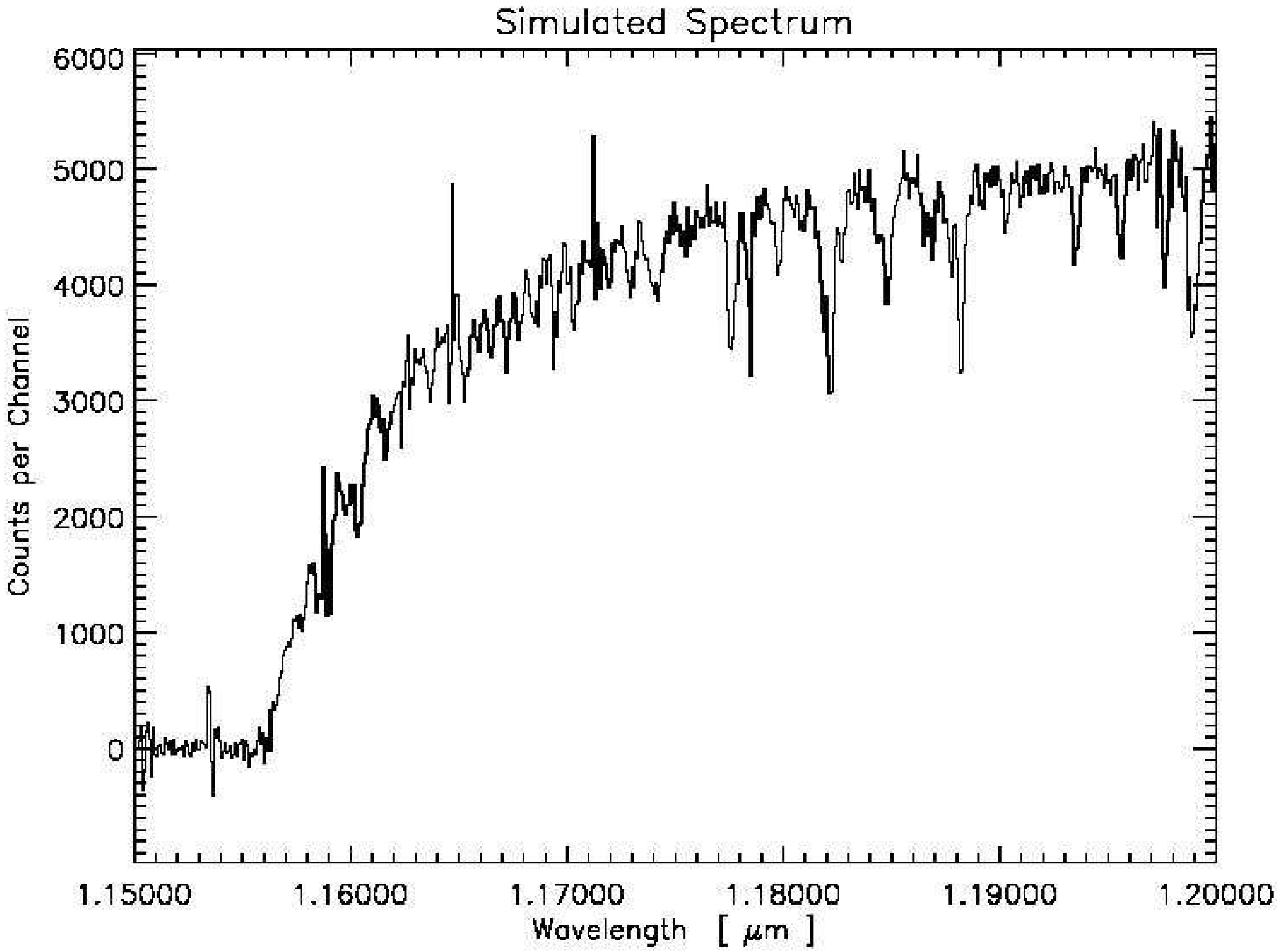
IFU advantage for GRBs: X-shooter FOV & OT positions



X-shooter FOV with IFU (1.4” x 4”) is superposed to the angular distribution of 20 OTs in their galaxy.

Bloom et al. 2001

X-shooter spectrum of GRB 021004 at z=8.5



Texp = 2 hr, reionization at z=7, 7 hours post burst.

P. Goldoni

And …

- Spectral properties and gas kinematics of protostars
- Properties of cool white dwarfs
- The nature of neutron stars in close binary systems
- Physical processes in the atmospheres of brown dwarfs
- Properties of core-collapse supernovae; Type Ia supernovae to z =1.7
- Gamma-ray bursts as high-energy laboratories and cosmological probes of the intergalactic medium
- The role of faint emission line galaxies in the redshift interval z = 1.6-2.6
- Properties of high mass star formation and massive galaxies at high z
- Metal enrichment in the early universe through the study of high z absorption systems
- Tomography of the Intergalactic Medium through the observations of faint background QSOs

First X-Shooter GCN

=====================================

X-shooter observations of GRB 090313

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A. de Ugarte Postigo, S. D?Odorico (ESO PI), J. Vernet, A. Modigliani,
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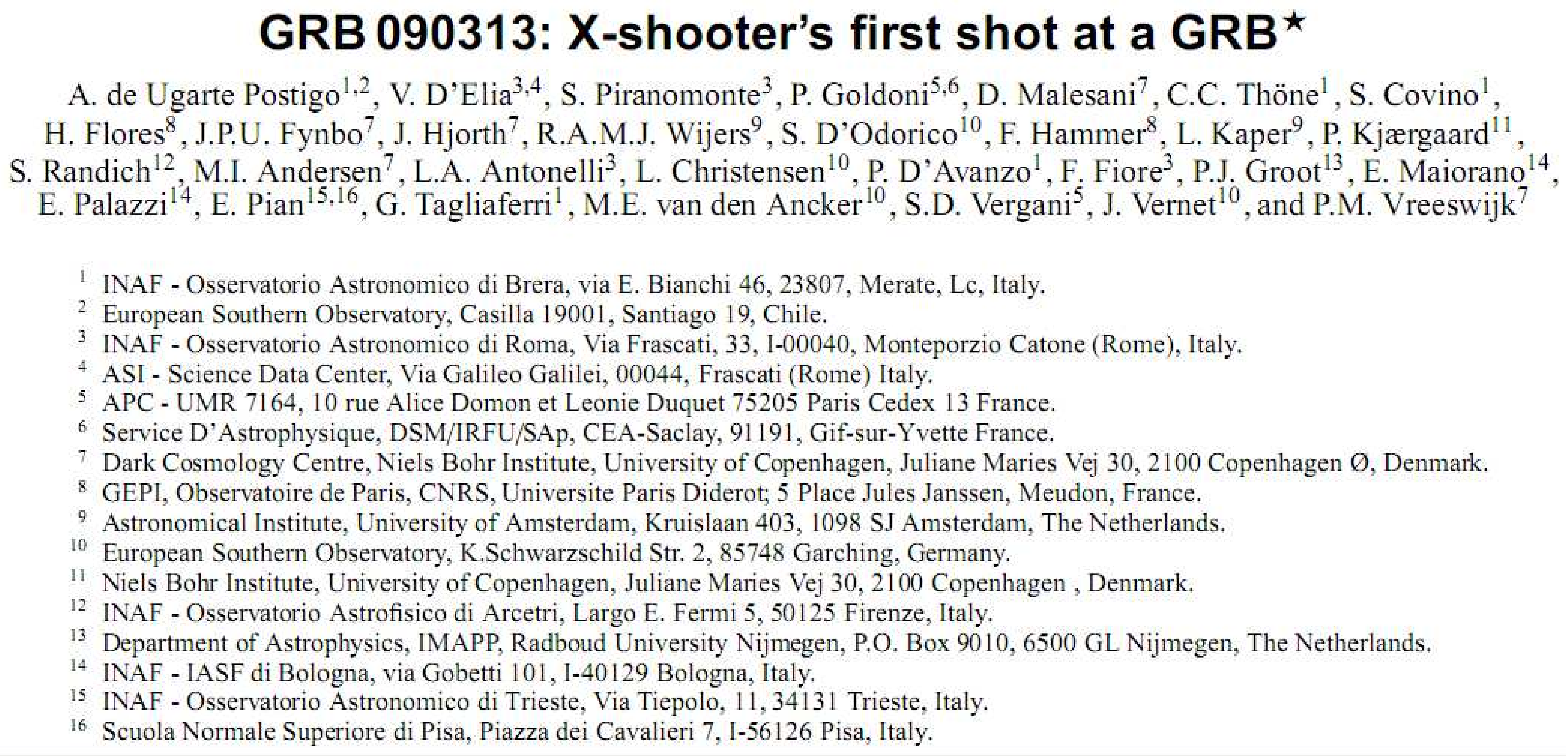
S. Covino (INAF Brera), H. Flores (Obs. Paris), J. Fynbo, J. Hjorth
(NBI/DARK, U. Copenhagen) and R.A.M.J. Wijers (Astr. Institute,
U. Amsterdam) from the X-shooter GRB team;
F. Hammer (Obs. Paris), L. Kaper (Astr. Institute, Univ. Amsterdam),
P. Kjaergaard (NBI, U. Copenhagen), S. Randich (INAF Arcetri) as
X-shooter PIs;
P. Groot (U. Nijmegen Univ.) from the X-shooter Science Team.

On March 15.22 UT we initiated observations of GRB 090313 (Chornock et al., GCNC 8979; Mao et al., GCNC 8980) with X-shooter at the ESO VLT. X-shooter is the first of the second-generation VLT instruments, equipped with three Echelle spectrographs, the Ultraviolet/Blue (UVB), the Visible (VIS) and the Near Infrared (NIR). Combined, they provide a fixed spectral format and cover in one shot the spectral range 3000 - 24000 A at medium spectral resolution (R = 4000 - 10000 depending on the arm and slit width). The mean epoch of the observation was 45.3 hours after the burst, when the afterglow had faded to R ~ 21.6 (Perley et al. GCNC 9001; Cobb et al. GCNC 9008). In the 4 x 1500 s combined spectrum we clearly detect continuum above 5580 A with several absorption lines; below this, the signal is dominated by background emission produced by the nearby Moon (90 % illumination at 37 deg from the field). The spectrum indicates an absorption redshift of $z = 3.3721 \pm 0.0004$ (consistent with that measured by Chornock et al., GCNC 8994 and Thoene et al., GCNC 9012) through the detection of Si II (1304.5), C II (1334.5), Si IV (1393.8), Si IV (1402.8), Si II (1526.7), C IV (1548.2,1550.8), Fe II (1608.5), Fe II (1611.2), Al III (1854.7), Al III (1862.8), Zn II (2062.6), Fe II (2600.1), Mg II (2796.3, 2803.5) and Mg I (2853.0). The intervening system identified by Thoene et al. (GCNC 9012) is resolved into multiple components through the detection of Fe II, Mg II and Mg I lines with its main absorption at redshift 1.800. A further system at $z = 1.959$ shows Fe II, Mg II and Mg I absorption.

The spectra of GRB 090313 will be made public on the ESO web as other data of scientific relevance obtained during the commissioning of the instrument.

First paper submitted



GRB 090313: X-shooter's first shot at a GRB★

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