Evidences for a dual population of CBC from sGRBs observations

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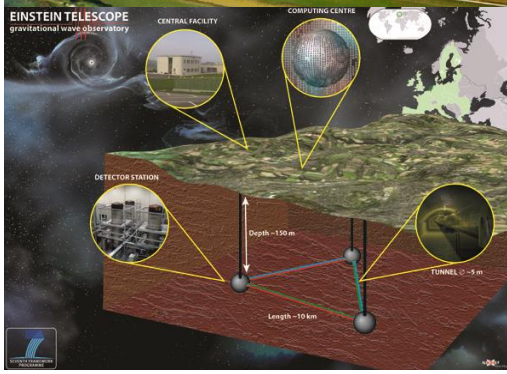
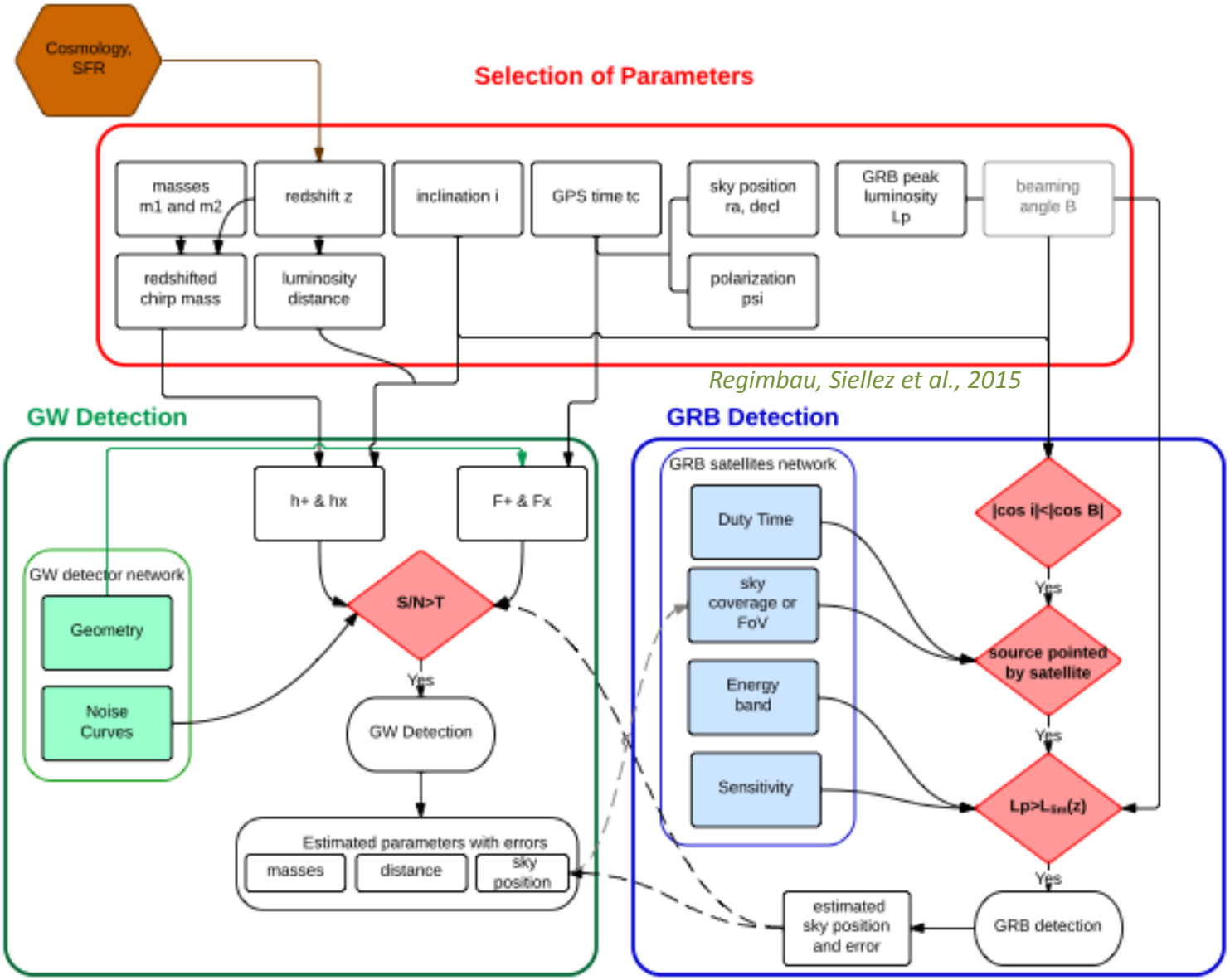
The link with GW

- **Link between gravitational waves and short GRBs**
  - They have possibly the same progenitor : the coalescence of compact objects
  - Rate estimation of simultaneous detection by gravitational wave and gamma ray needed
- **Why getting a coincident detection ?**
  - Improving the confidence of a GW detection by ALV
  - Improving knowledge about CBC progenitors
  - Targeted search with sGRB as a trigger to detect fainter signal with ALV
  - GW alert could increase the chance of an early detection
  - Obtaining a direct value of the cosmological constant



Process


Cosmology, SFR
Selection of Parameters
masses m1 and m2
redshift z
inclination i
GPS time tc
sky position ra, decl
GRB peak luminosity Lp
beaming angle B
redshifted chirp mass
luminosity distance
polarization psi
Regimbau, Siellez et al., 2015
GW Detection
GRB Detection
h+ & hx
F+ & Fx
GW detector network
Geometry
Noise Curves
S/N>T
Yes
GW Detection
Estimated parameters with errors
masses
distance
sky position
GRB satellites network
Duty Time
sky coverage or FoV
Energy band
Sensitivity
|cos i|<|cos B|
Yes
source pointed by satellite
Yes
Lp>Lsen(z)
Yes
GRB detection
estimated sky position and error

Monte Carlo Simulations

Simulated sources with the following input parameters:

- **Polarisation, sky position, inclination**: Uniform distribution
- **Masses of each objects** with a delta function.
  For NS : m = 1.4 $M_\odot$ and for BH: m = 10 $M_\odot$
- **Beaming angle** Θ_B = [5°- 30°]
- Intrinsic **peak luminosity** Lp : broken power law with paremeters derived from population synthesis (Guetta et al. 2005, Hopman et al. 06, Wanderman et al. 14):

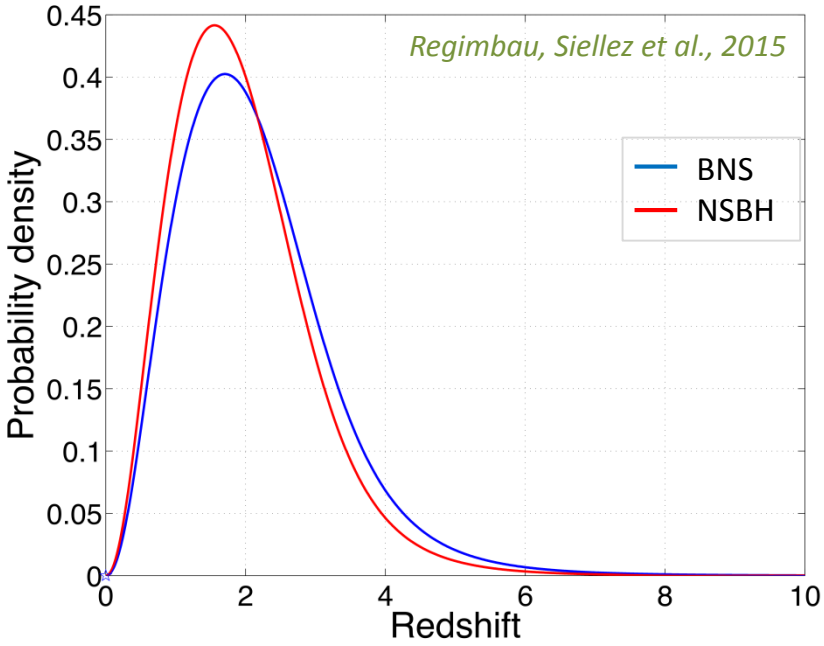
$$\phi(L_p) \propto \begin{cases} (L_p / L_*)^{\alpha} \text{ if } L_* / \Delta_1 < L_p < L_* \\ (L_p / L_*)^{\beta} \text{ if } L_* < L_p < \Delta_2 L_* \end{cases}$$

with $\alpha = -0.6, \beta = -2, L_* = 10^{51}\,\text{erg}, \Delta_1 = 100, \Delta_2 = 10$

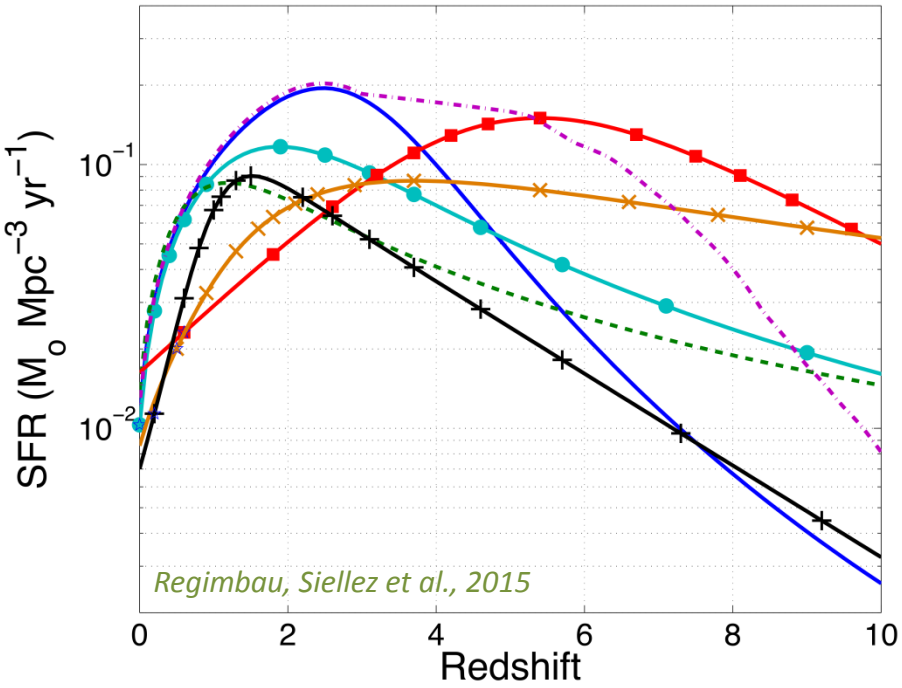
- **Rest Frame duration** : Gaussian distribution for $\log(T_i)$ derived from Zhang et al. 2012 with $\langle \log(Ti) \rangle$ = -0.46 and $\sigma_{\log(T_i)}$ = 0.502

- **Redshift:** Probability distribution of z

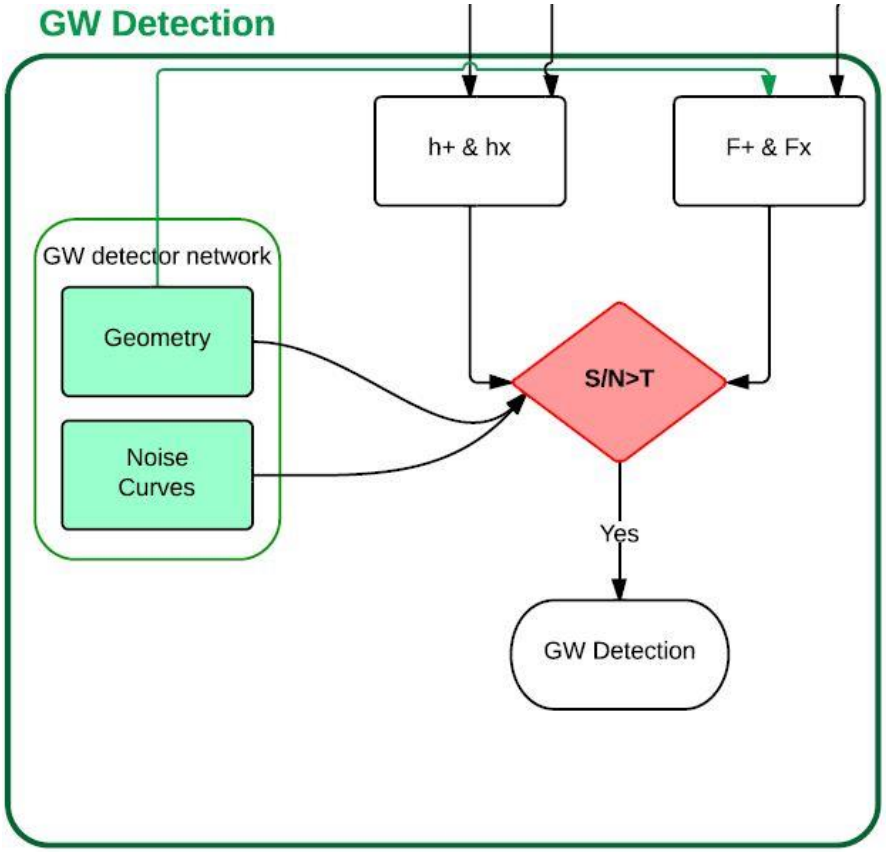
Redshift selection and SFR

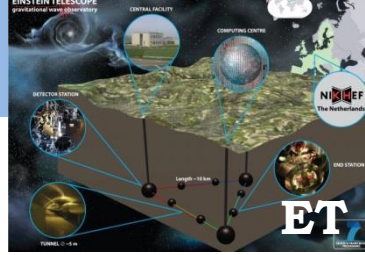


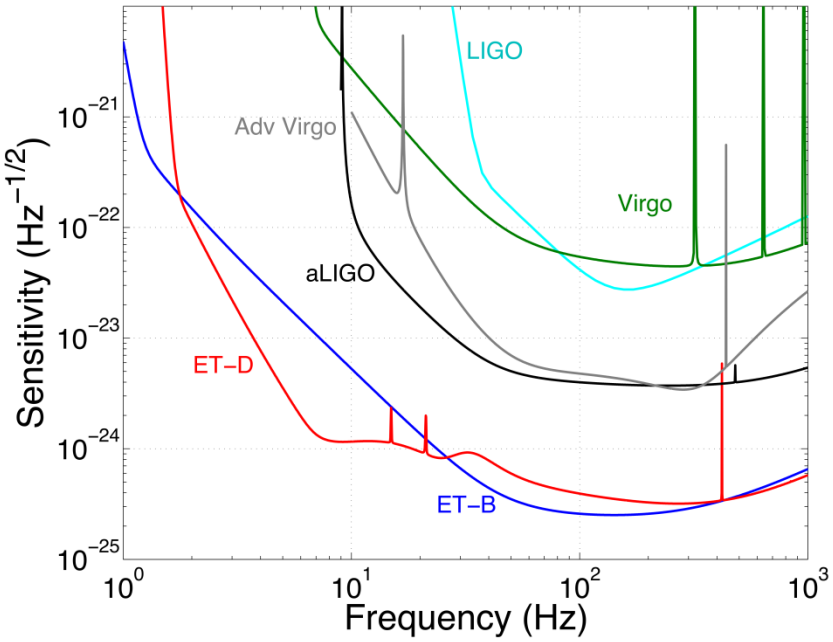
Different SFR:
Hopkins & Beacom 2006 (our reference model), Fardal et al. 2007, Wilkins et al. 2008, Springel & Hernquist 2003, Nagamine et al. 2006, Tornatore et al. 2007, Madau et al. 1998.



Gravitational wave detection







Regimbau et al., 2012, arXiv:1201.3563

SNR individual :

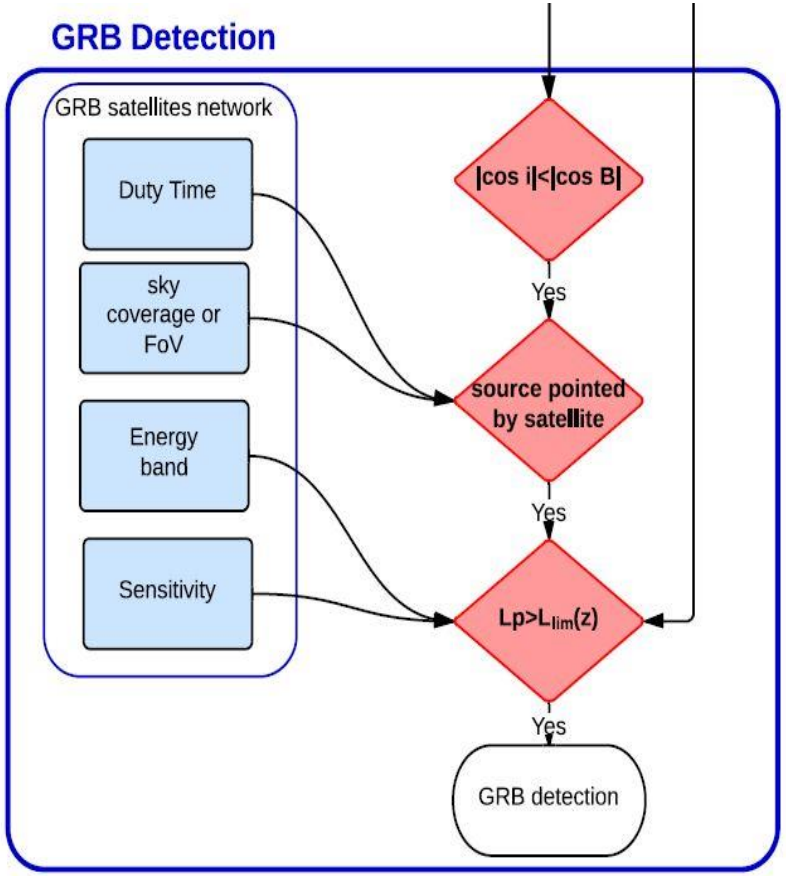
$$\rho_A^2 = \frac{5}{6}\frac{(GM_c(1+z))^{5/3}F_A^2}{c^3\pi^{4/3}d_L^2(z)}\int_{f_{\min}}^{\frac{f_{LSO}}{1+z}} df\,\frac{f^{-7/3}}{S_{n,A}(f)}$$

with $$F_A^2 = \frac{(1+\cos^2 i)^2}{4}F_{+,A}^2(\Omega,\psi,t) + \cos^2 i F_{\times,A}^2(\Omega,\psi,t)$$

Coherent SNR:

$$\rho^2 = \sum \rho_A^2$$

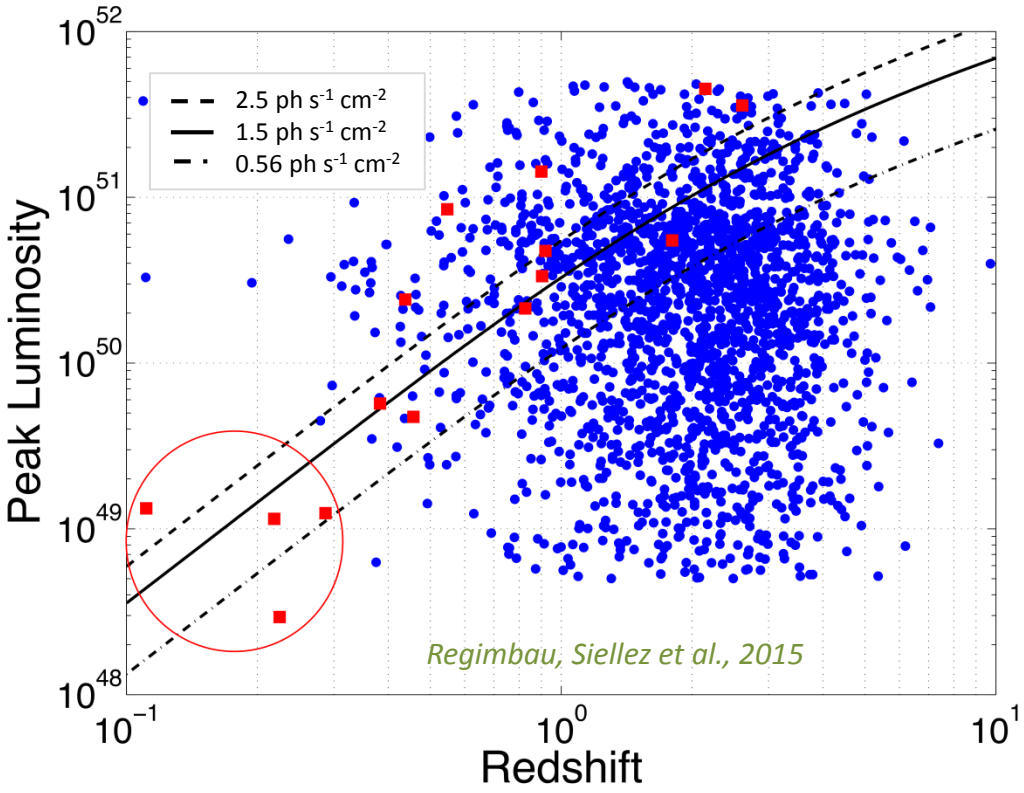
Gamma-Ray Bursts detection



For *Swift*: $L_{\lim}(z) = 4\pi d_L(z) k(z) F_{\lim}$

Simulated sources and sGRBs observed

(Zhang, Z. B. et al. 2012, ArXiV: 1205.2411)



To observe 100% [80%, 50%] of the sources before z~1:

F_{lim} = 0.025 ph s^{-1} cm^{-2} [0.26, 1.3]

Simultaneous simulated rate

ALV-Swift

	5°	10°	15°	20°	30°	GW
BNS						
$\rho_T = 12$	$0.004 - 0.005$	$0.01 - 0.02$	$0.03 - 0.04$	$0.06 - 0.07$	$0.11 - 0.13$	$2.5 - 3.0$
$\rho_T = 8$	$0.01 - 0.02$	$0.05 - 0.07$	$0.10 - 0.13$	$0.17 - 0.23$	$0.35 - 0.46$	
NS-BH						
$\rho_T = 12$	$0.001 - 0.002$	$0.006 - 0.008$	$0.01 - 0.02$	$0.02 - 0.03$	$0.04 - 0.06$	$1.5 - 2.0$
$\rho_T = 8$	$0.004 - 0.007$	$0.02 - 0.03$	$0.04 - 0.05$	$0.06 - 0.10$	$0.12 - 0.19$	

Regimbau, Siellez et al., 2015

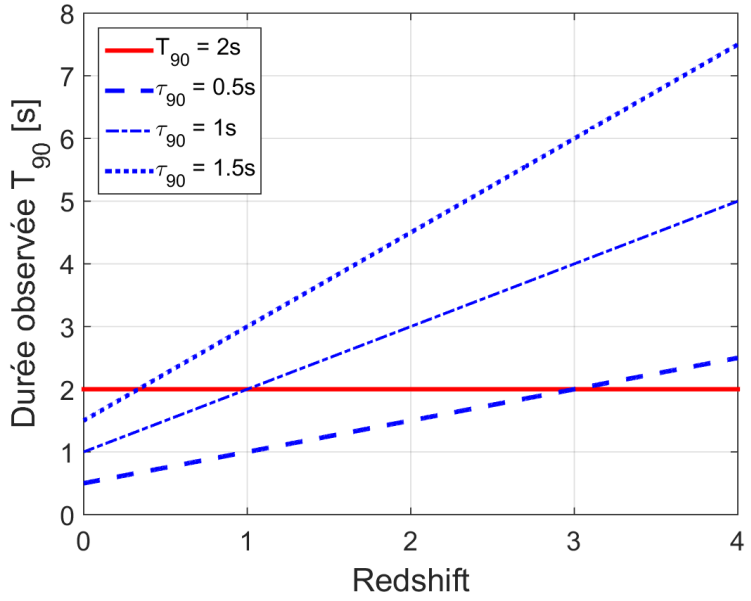
ET – perfect detector

	5°	10°	15°	20°	30°	GW
BNS	$(0.8 - 1.8) \times 10^2$	$(3 - 7) \times 10^2$	$(0.7 - 1.6) \times 10^3$	$(1.3 - 2.8) \times 10^3$	$(2.5 - 5.8) \times 10^3$	$(0.6 - 1.5) \times 10^4$
NS-BH	$7 - 15$	$27 - 61$	$59 - 136$	$104 - 239$	$228 - 517$	$(1.3 - 2.4) \times 10^3$

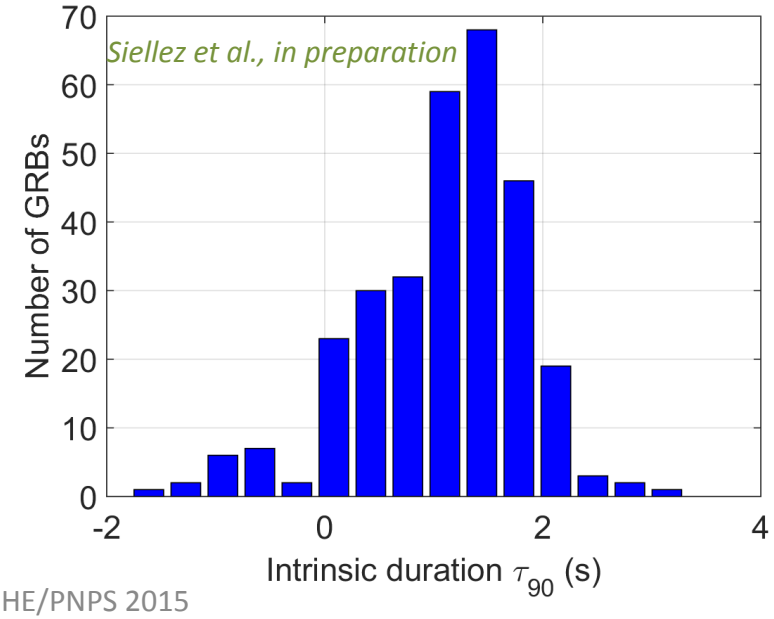
Regimbau, Siellez et al., 2015

New sample of sGRBs

- **Sample based on Swift observations**
  - Redshift measurement



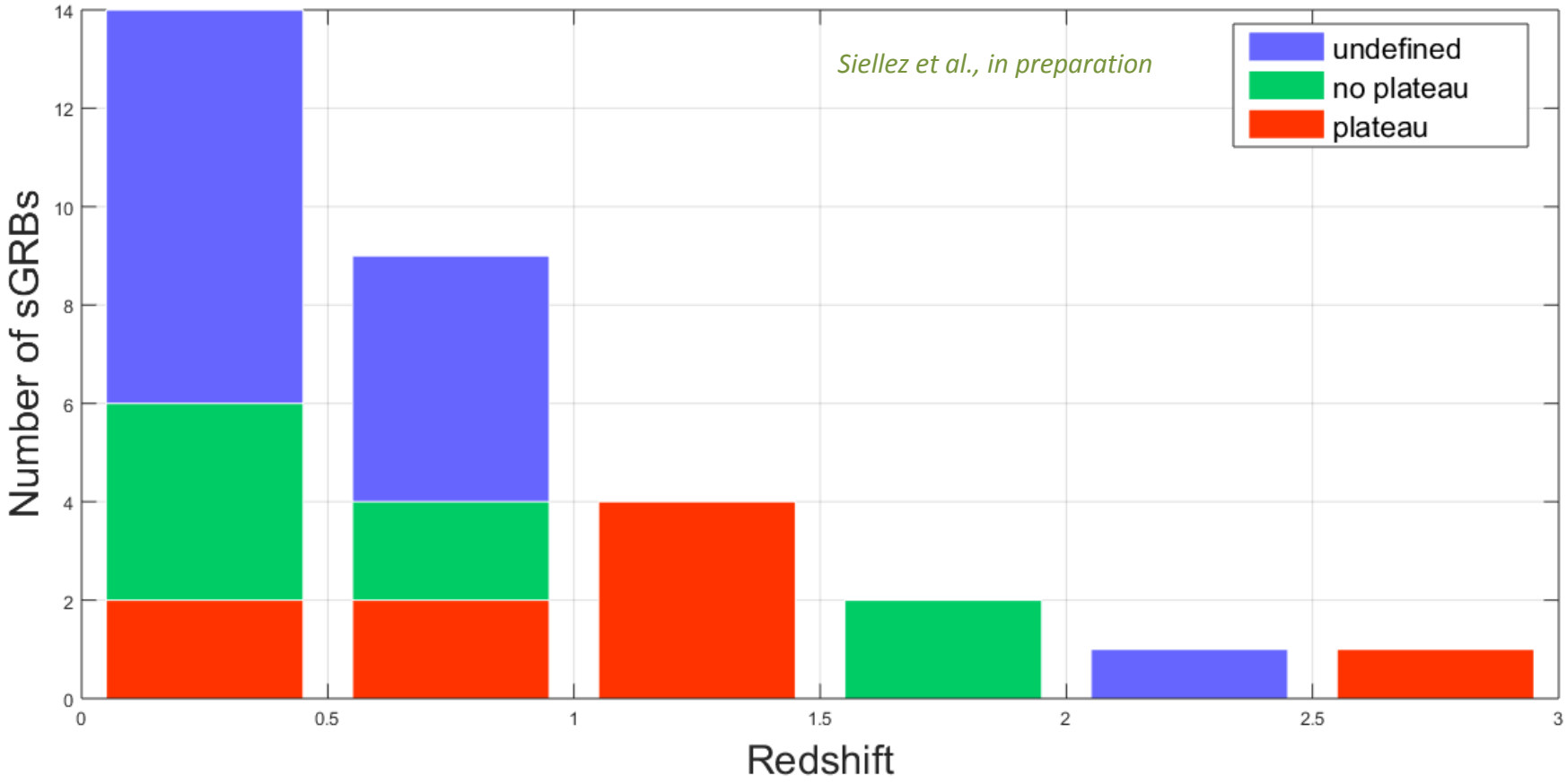
- **Derivation of a sample of "true short" bursts**
  - Use of the rest frame duration
  - Selection by hardness ratio
  - Bursts presenting a soft tail ?



New sample of sGRBs

Number of sGRBs : 31

- 14 unknown
- 8 no plateau phase
- 9 with plateau phase



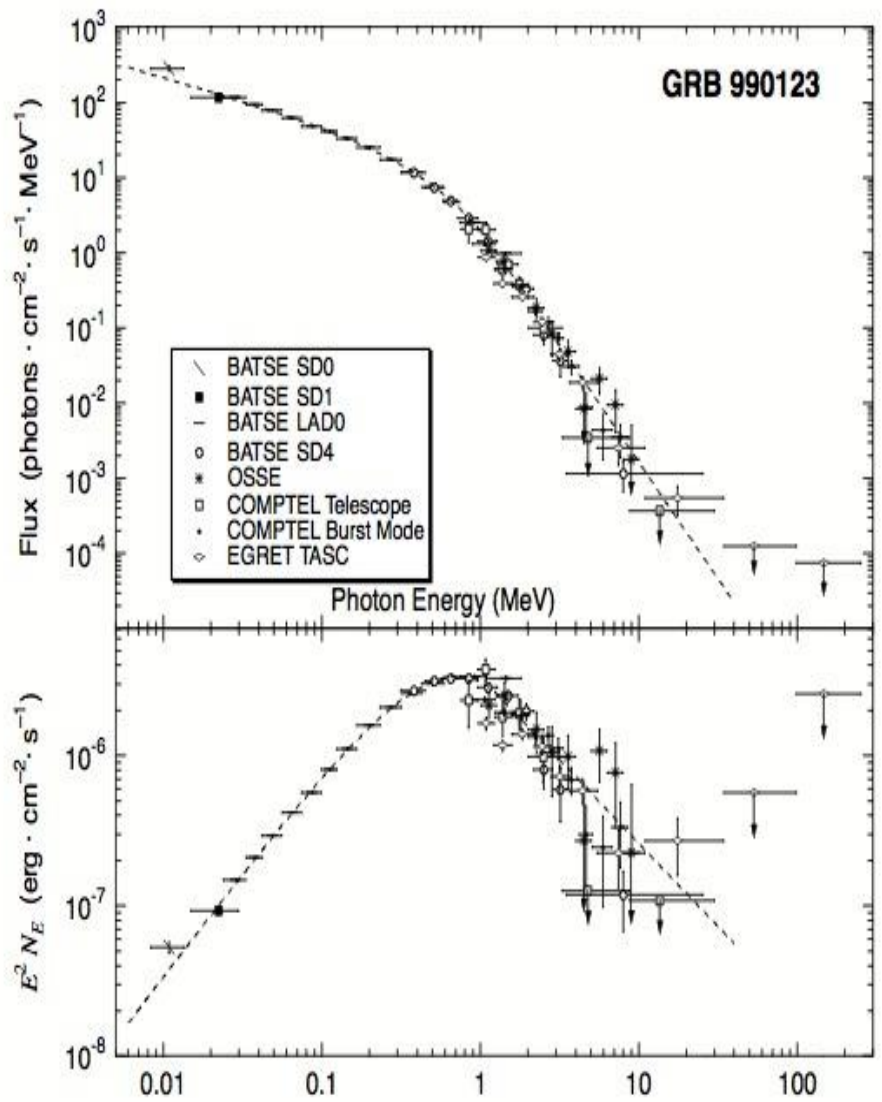
Data analysis

- **Instruments used**

- **KONUS (GCN) :** 8 sGRBs
- **HETE-2 (GCN) :** 1 sGRBs
- **GBM+BAT:** 7 sGRBs
  - 3 sGRBs : Virgili et al. 2012, MNRAS, 424, 2821.
  - 1 sGRBs : Sakamoto et al. 2013, ApJ, 766.
  - [+ 3 sGRBs : my own analysis incoming.]
- **BAT:** 18 sGRBs analysed

- **BAT Analysis**

  XSPEC + ftools



$\alpha = 0,6,\ \beta = 3,11$ et $E_0 = 700$ keV

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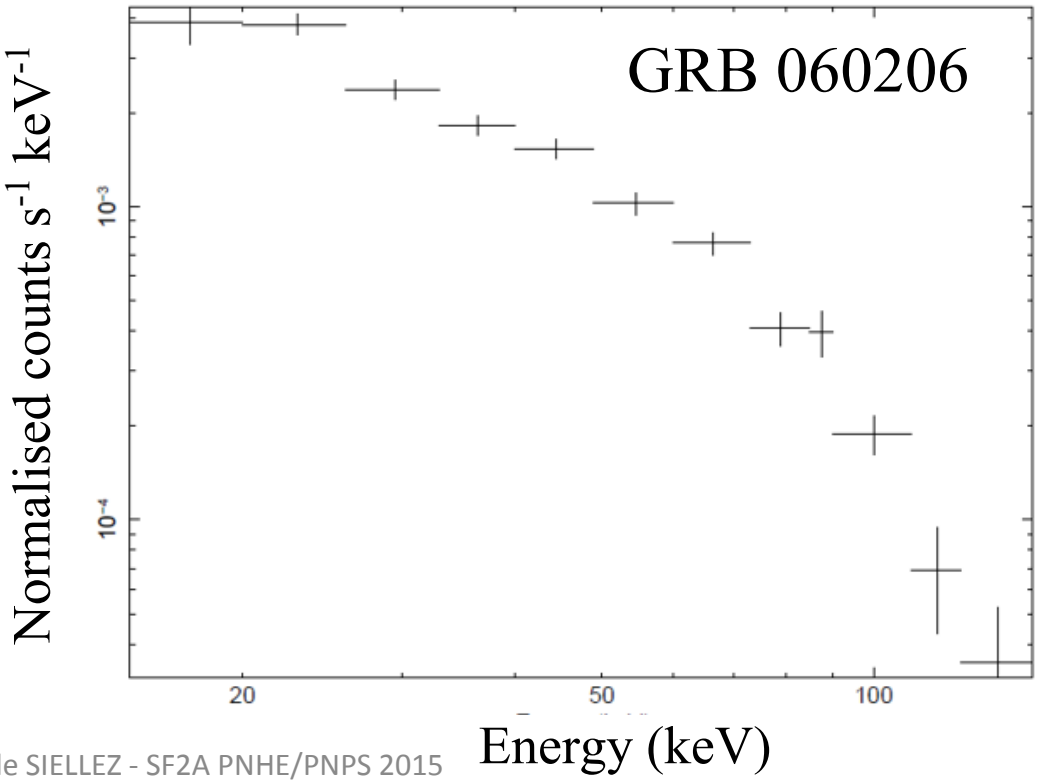

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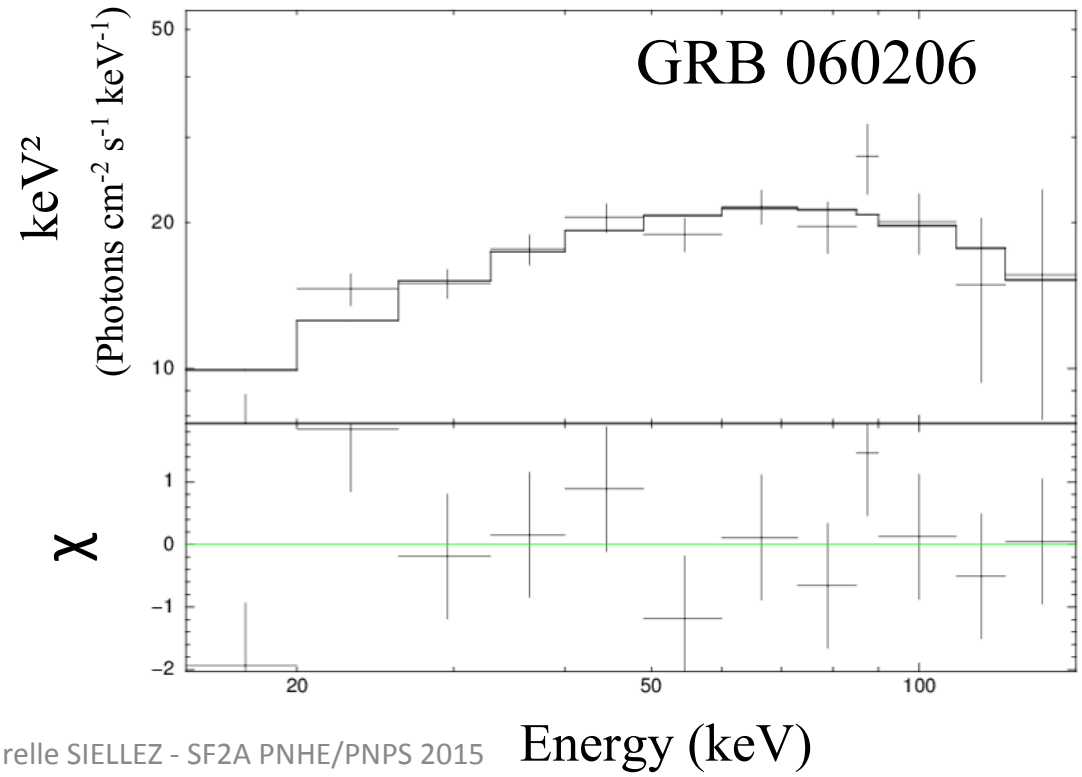
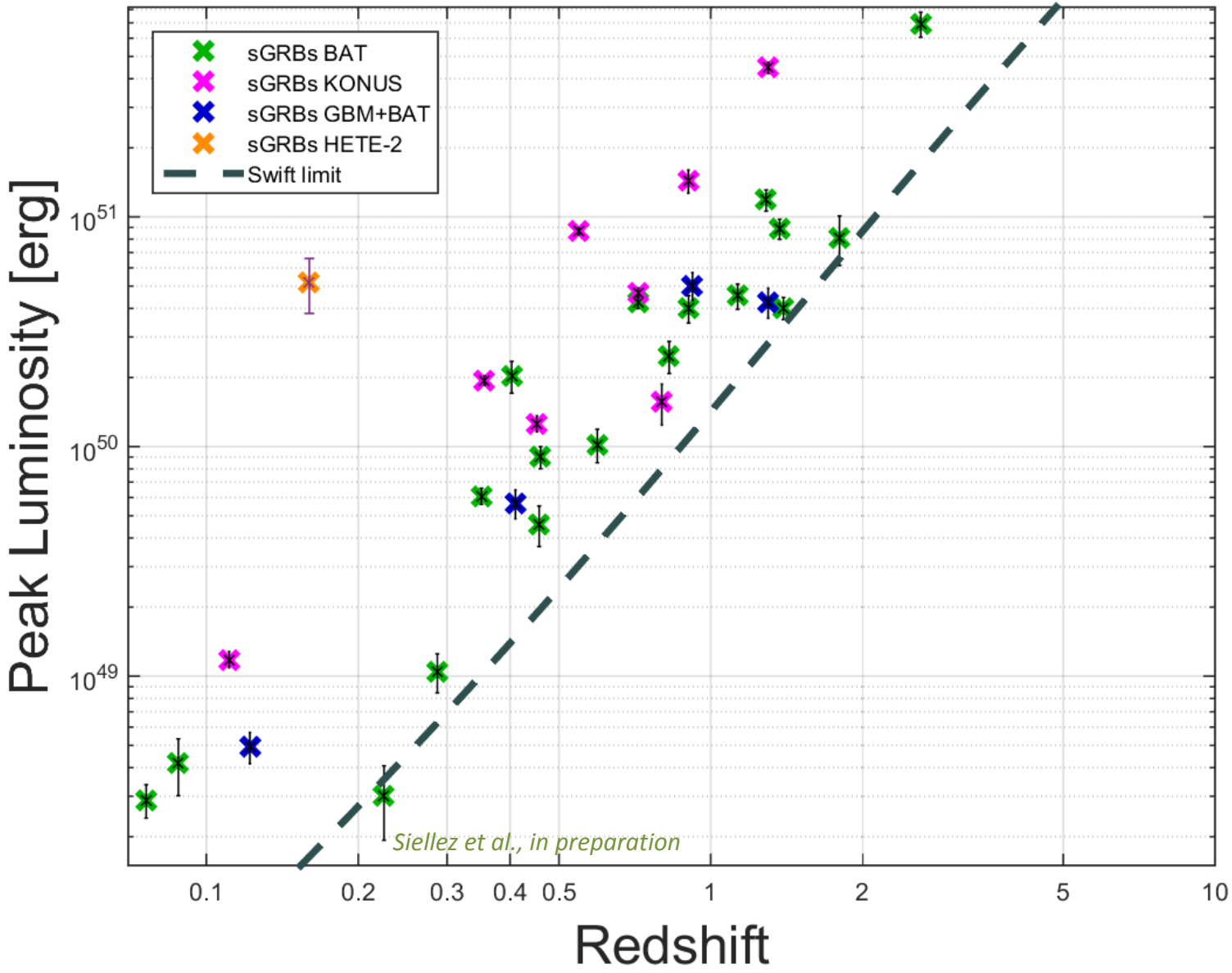
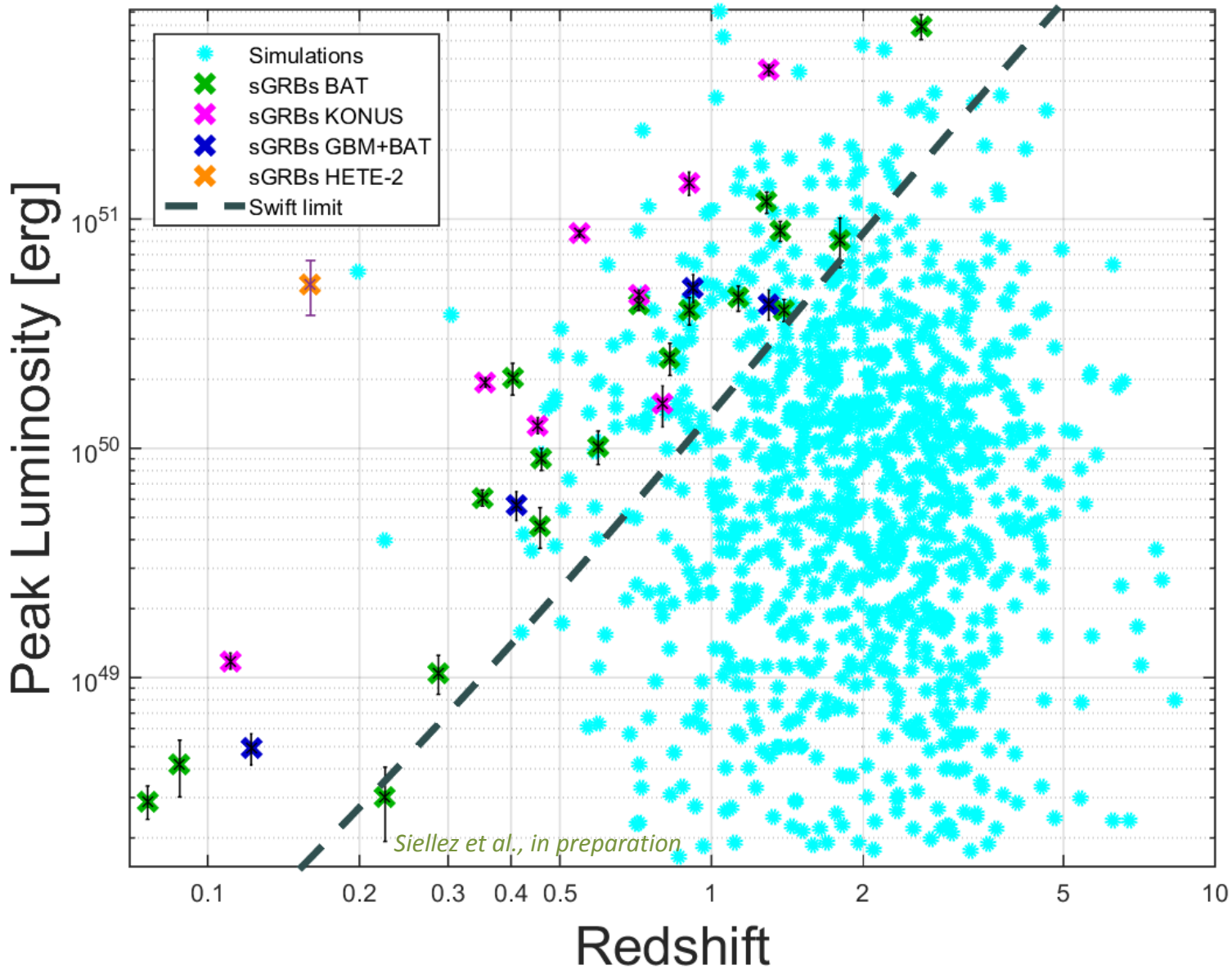
Utilisation XSPEC.



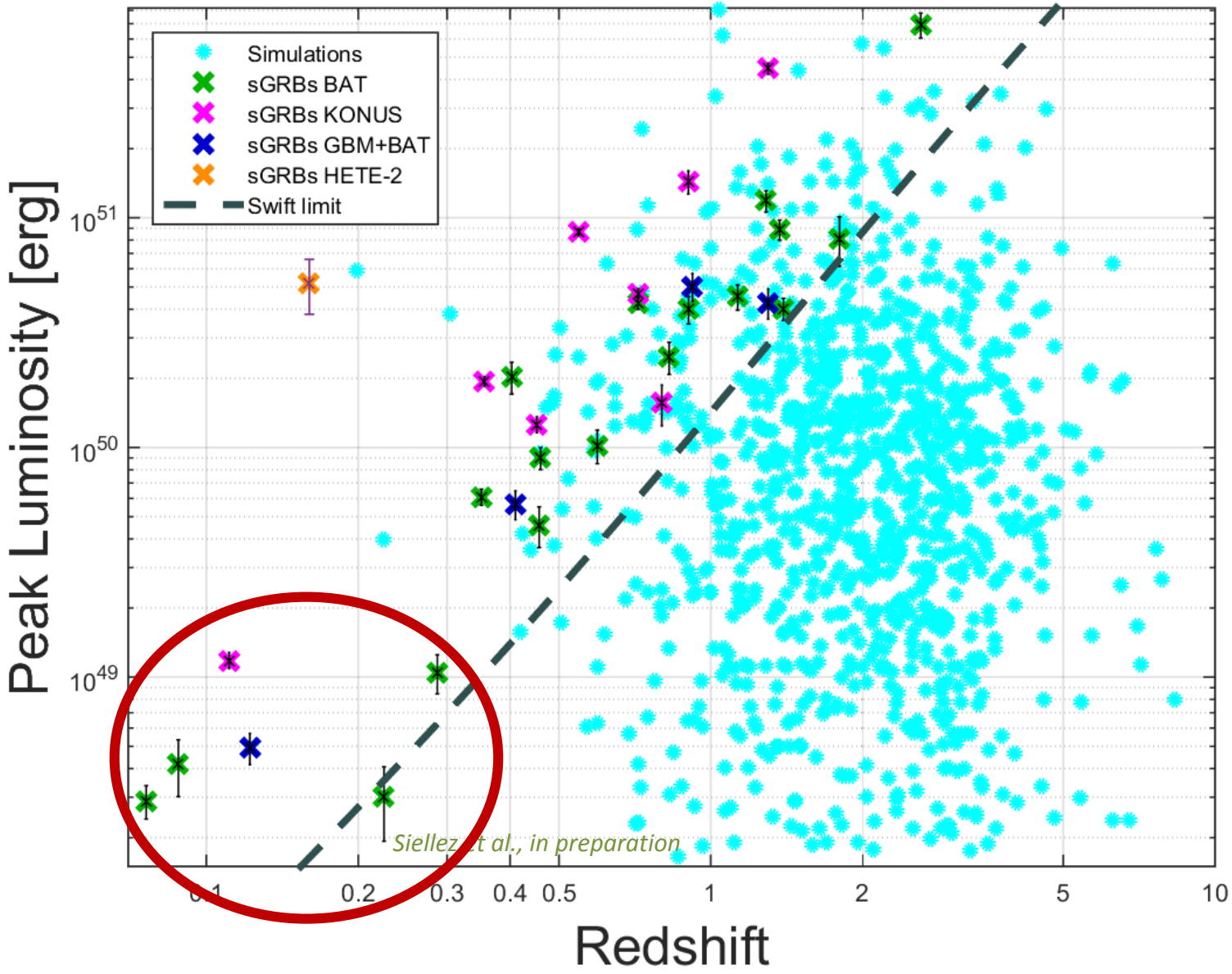
Lpeak (z) : different satellites



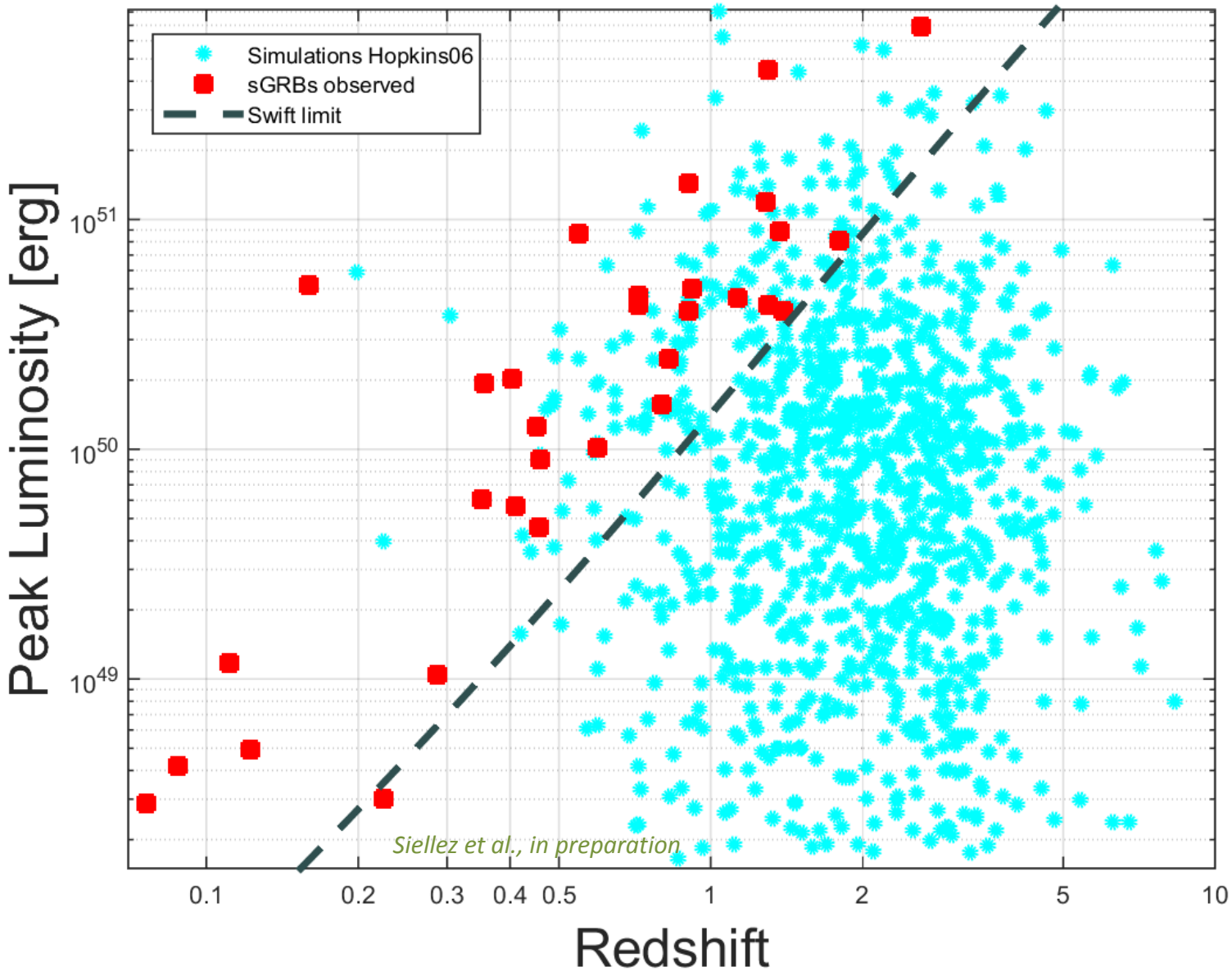
Lpeak (z) : Simulations Hopkins 06



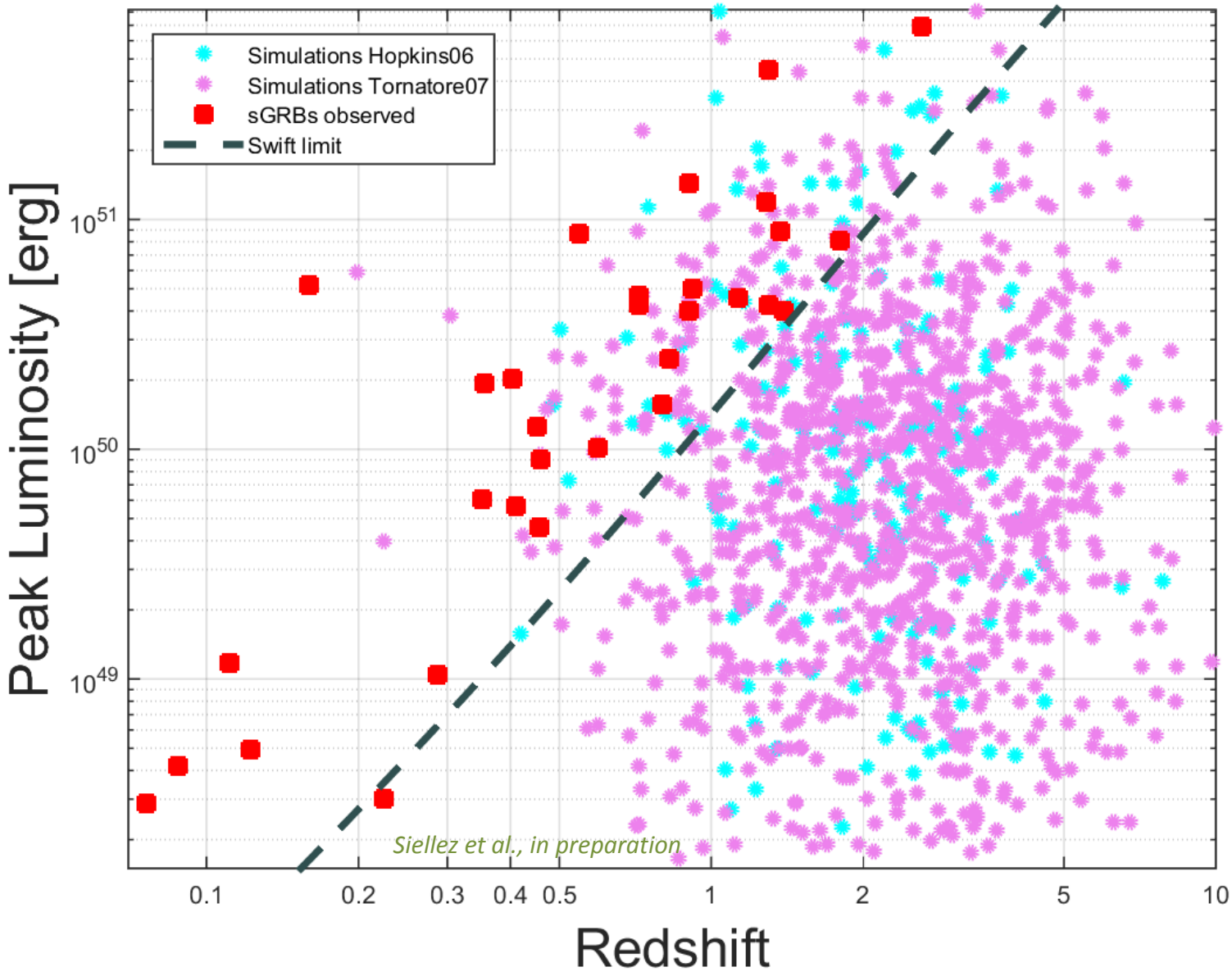
Lpeak (z) : Outlayers



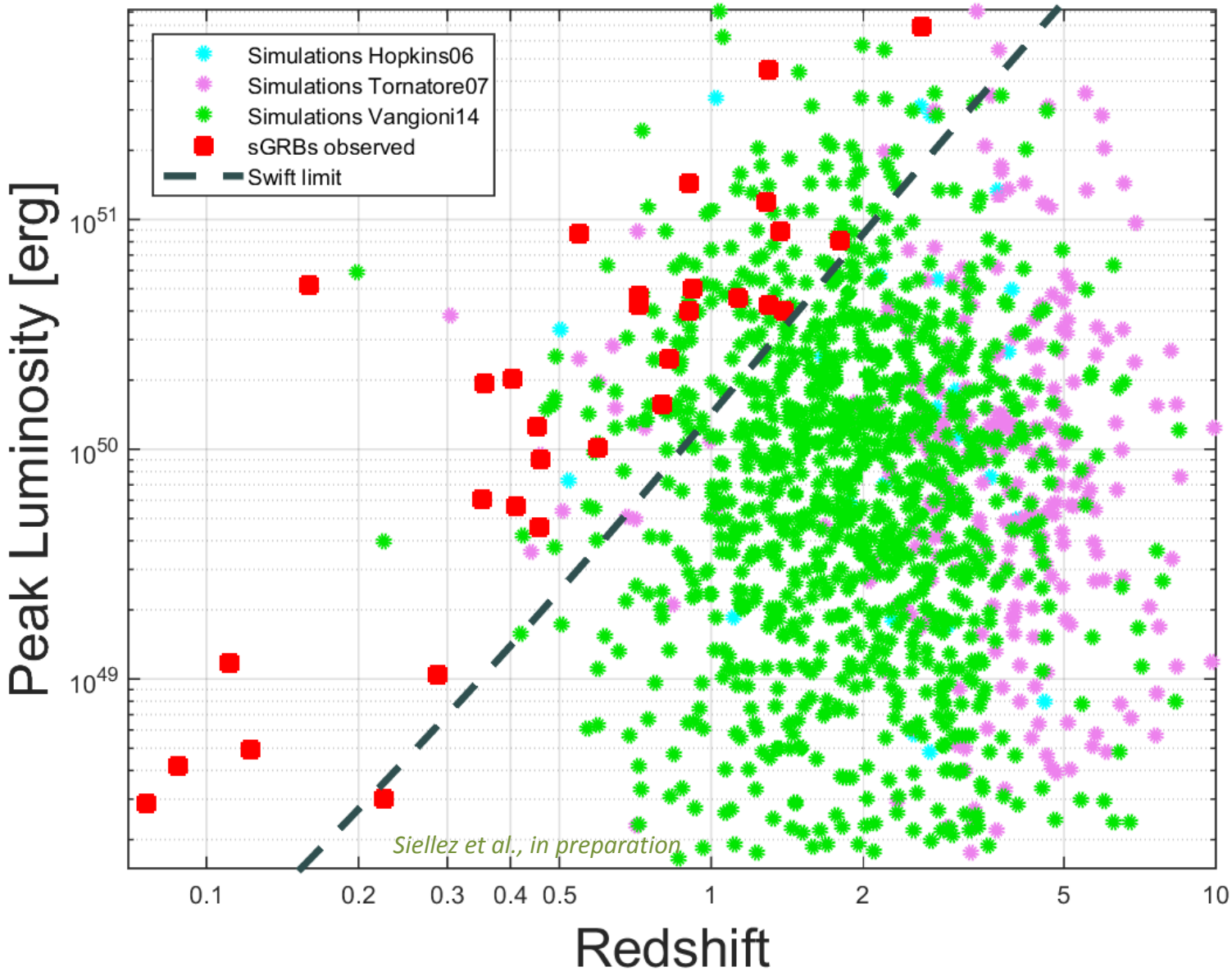
Lpeak (z) : Different SFR models



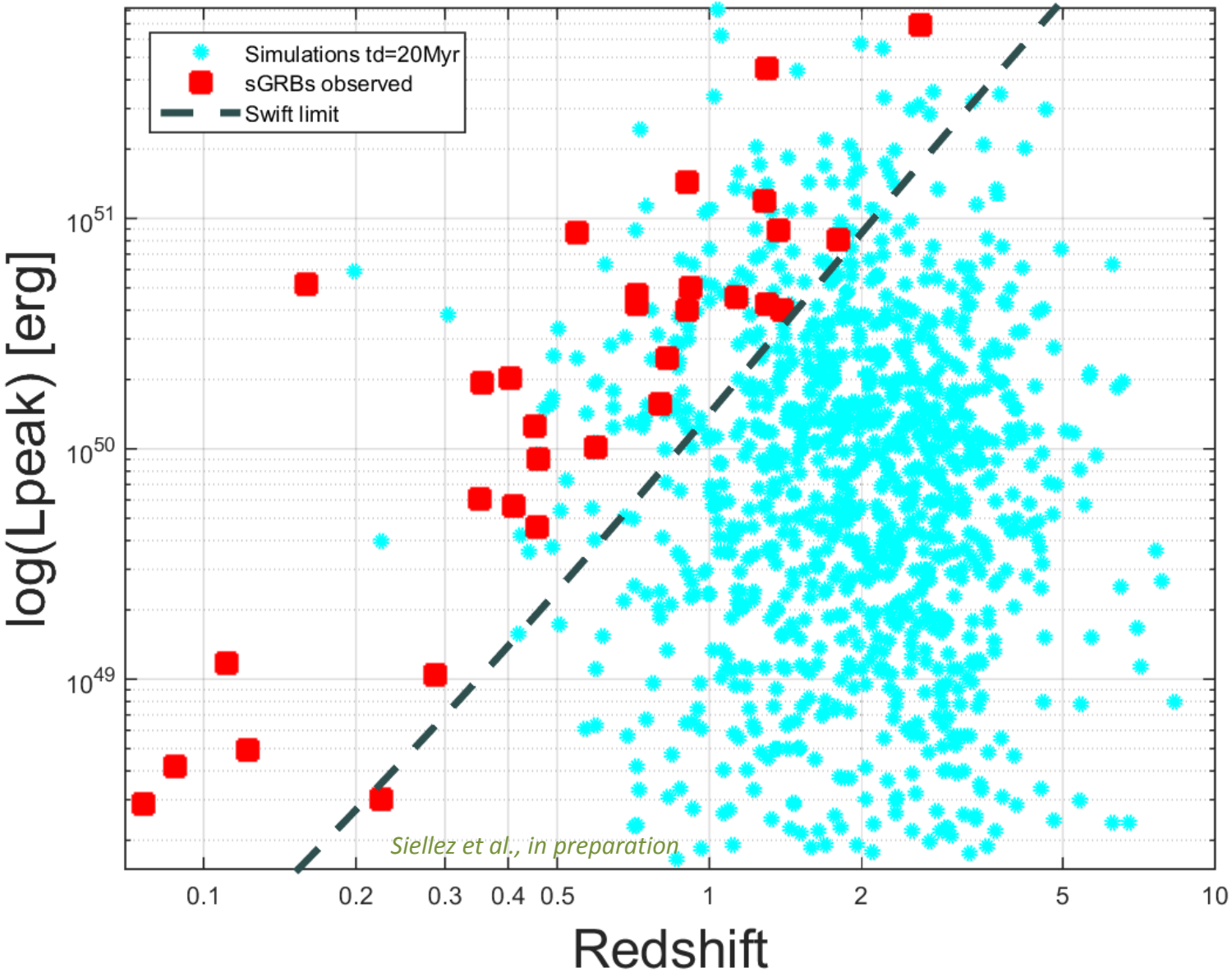
Lpeak (z) : Different SFR models



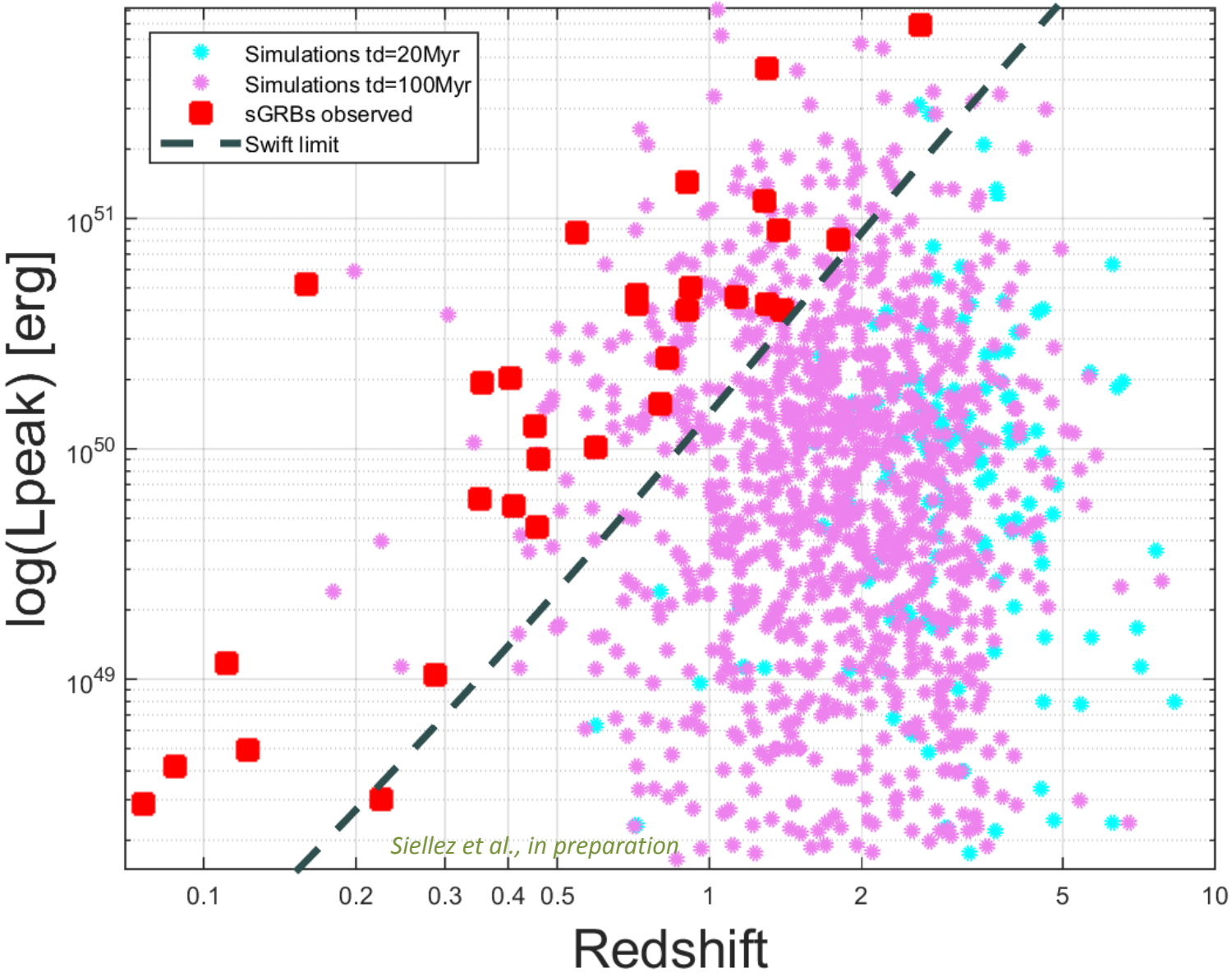
Lpeak (z) : Different SFR models



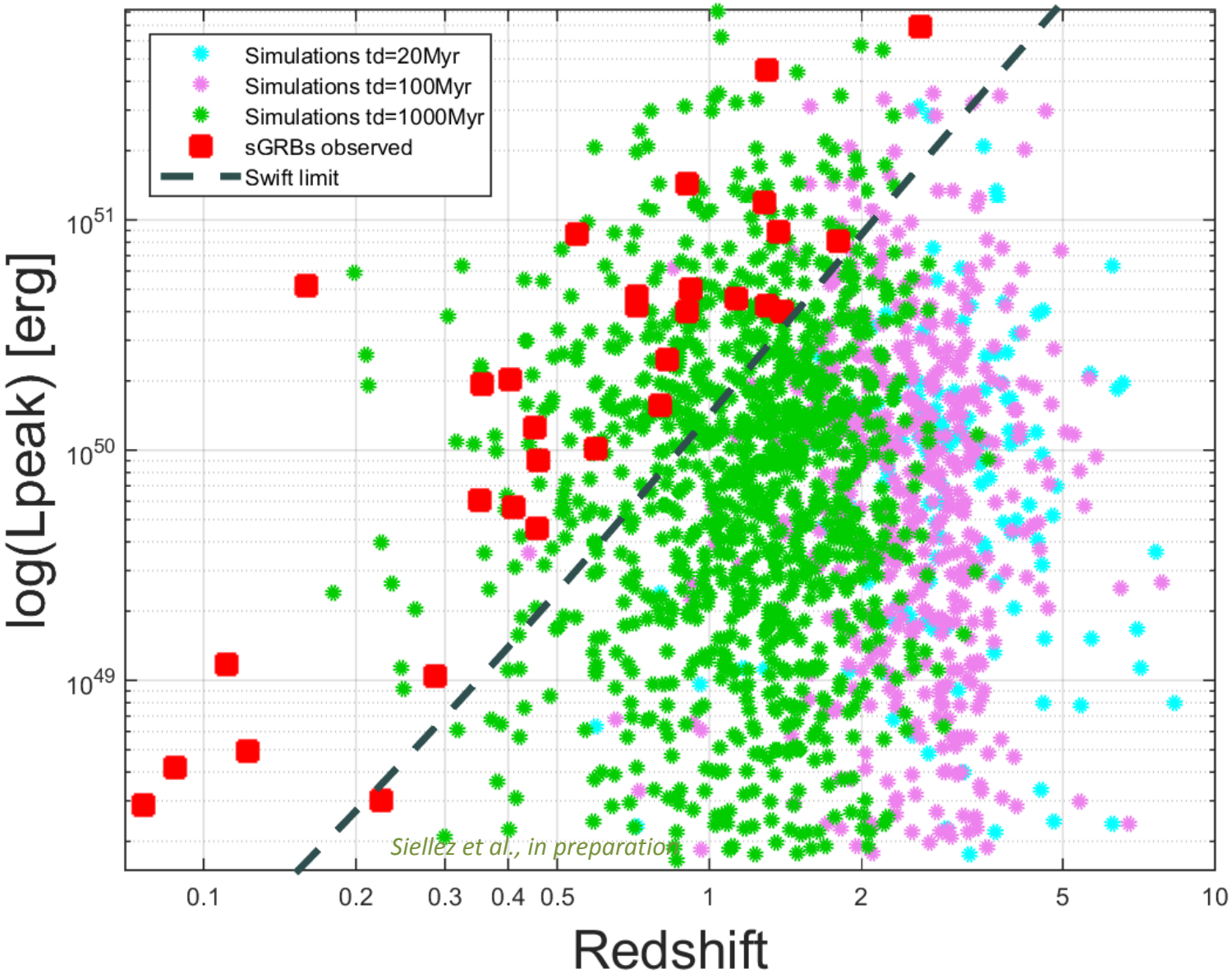
Lpeak (z) : Different delays



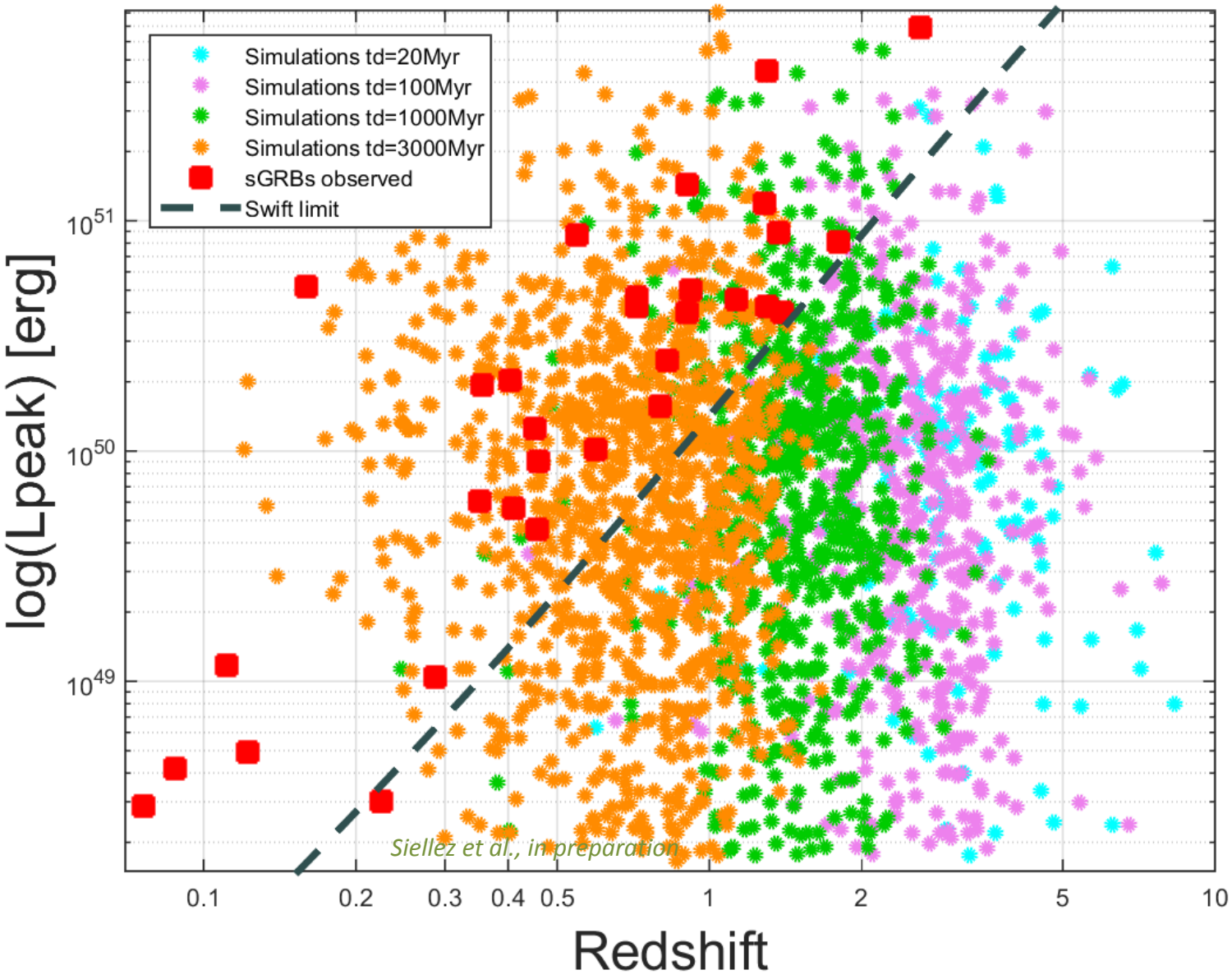
Lpeak (z) : Different delays



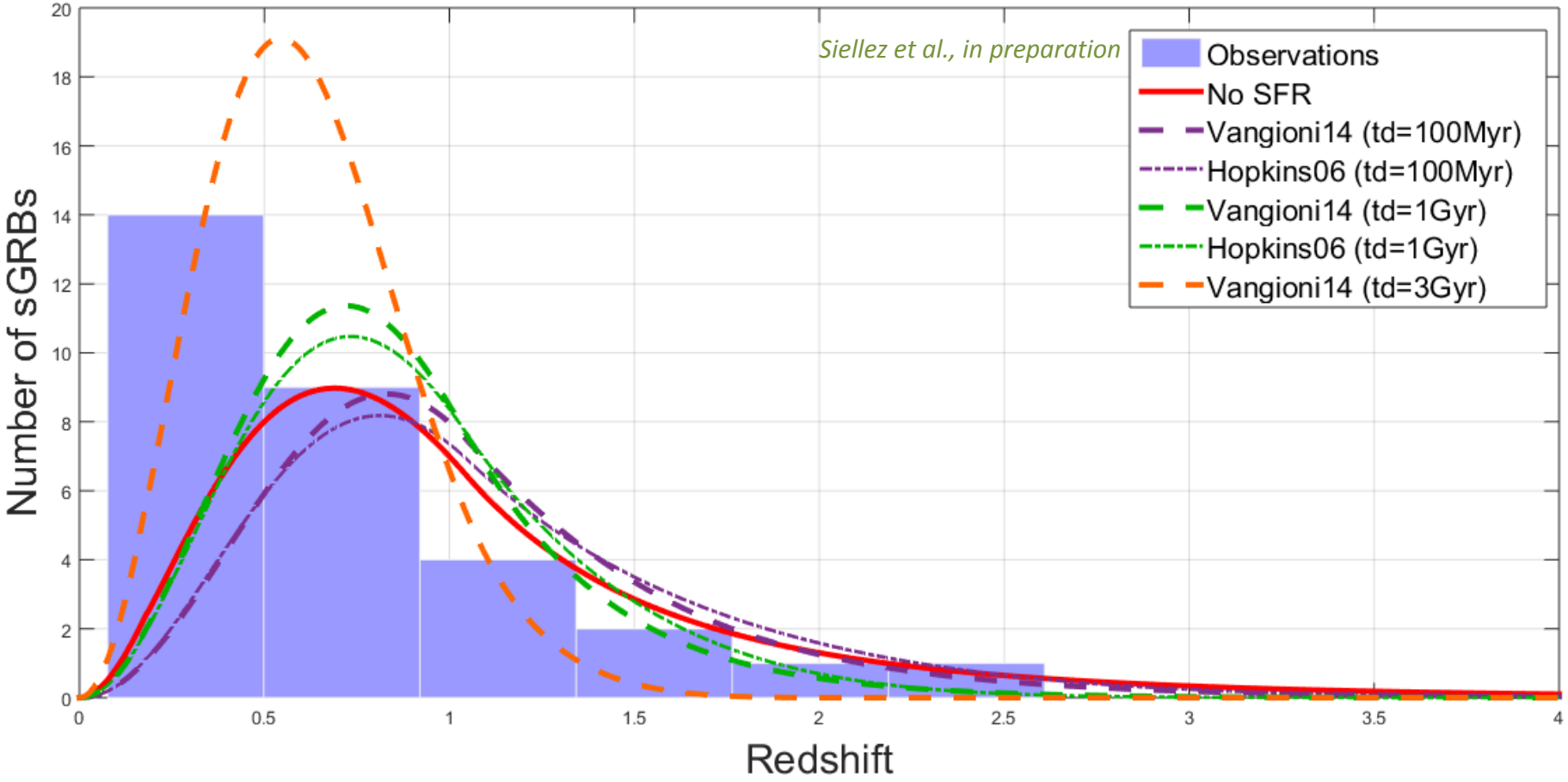
Lpeak (z) : : Different delays



Lpeak (z) : Different delays



Lpeak (z) : Distribution



Summary

- Simulations of the sGRBs observed, using the standard luminosity peak and redshift distribution
  => **impossible to reproduce the low-z low-L_{peak} sGRBs**

- New populations
  => **2 populations of CBC ? Producing sGRBs**

- More statistic ? Guiriec et al. 2015 (ArXiV:1501.07028)

- Influence on the coincident detection rate (Siellez et al. 2014, MNRAS,437,649)

Thank you … questions and comments are welcoming

Sample of Zhang et al., 2012, ApJ, 755:55

Table 1
A Sample ($N = 17$) of Short GRBs with Measured Redshifts

GRB[a]	T_{90} (s)	z	P[b] (10^{-6} erg cm^{-2} s^{-1})	Range (keV)	L_p (10^{51} erg s^{-1})	K[c]	$E_{p,i}$[b] (keV)	Refs
050509B	0.04	0.225	0.51 ± 0.3	15–350	0.009 ± 0.004	2.8	$102 \pm$ [10]	(6,6,5,5)
050709	0.07	0.16	5.1 ± 0.5	2–400	0.53 ± 0.05	1.5	100 ± 19	(7,2,2,7)
050813	0.6	1.8	0.41 ± 0.19	15–350	16.07 ± 7.5	1.7	$150 \pm$ [15]	(6,6,5,5)
051221A	1.4	0.547	46 ± 13	20–2000	69.1 ± 6	1.2	621 ± 144	(6,6,5,5)
060502B	0.131	0.287	1.89 ± 1.49	15–350	0.04 ± 0.01	2.7	$193 \pm$ [19]	(6,6,5,5)
061006[d]	1	0.4377	21 ± 2	20–2000	17.8 ± 2.3	1	955 ± 267	(1,2,2,2)
061201	0.76	0.111	2.45 ± 1.95	15–350	1.27 ± 0.25	1.3	969 ± 508	(6,6,5,5)
061217	0.21	0.827	0.44 ± 0.2	15–350	2.49 ± 1.1	1.7	$216 \pm$ [22]	(6,6,5,5)
070429B	0.47	0.904	0.43 ± 0.14	15–350	3.37 ± 1.08	1.9	$813 \pm$ [81]	(6,6,5,5)
070714B[d]	2	0.92	1.2 ± 0.9	15–350	14 ± 1	1	2150 ± 1113	(3,2,2,2)
070724A	0.4	0.457	0.14 ± 0.06	15–350	0.23 ± 0.11	2.2	119 ± 12	(6,6,5,5)
070809	1.3	0.2187	0.17 ± 0.08	15–350	0.05 ± 0.02	1.9	$91 \pm$ [9]	(6,6,5,5)
071020[e]	4	2.145	6 ± 0.6	20–2000	220 ± 10	1	1013 ± 205	(4,2,2,2)
071227[d]	1.8	0.383	3.5 ± 1.1	20–1300	3.11 ± 1.28	1.8	$1383 \pm$ [138]	(6,6,5,5)
080913A[e]	8	6.7	0.13 ± 0.08	15–350	114 ± 15	1	1009 ± 200	(4,2,2,2)
090426	1.2	2.609	0.34 ± 0.23	15–350	18.22 ± 5.7	2.1	177 ± 82	(6,6,5,5)
090510[d]	0.3	0.903	$40 \pm$ [4]	8–40000	516 ± 112	0.6	8373 ± 761	(6,6,8,8)

Notes. References are given in order of duration, redshift, peak flux, and rest-frame peak energy, respectively. (1) Hurley et al. 2006, GCN 5702; (2) Ghirlanda et al. 2009; (3) Kodaka et al. 2007, GCN 6637; (4) Greiner et al. 2009; (5) Butler et al. 2007 (http://butler.lab.asu.edu/swift/); (6) http://heasarc.nasa.gov/docs/swift/swiftsc.html; (7) Villasenor et al. 2005; (8) Ackermann et al. 2010.

[a] GRBs 051221A, 061201, and 071227 are discovered by the Konus wind; GRBs 090510 and 050709 are detected by *Fermi*/GBM and *HETE-2*, respectively; the other 12 bursts are observed by *Swift*/BAT.

[b] Values without measured errors have been given a 10% fluctuation, as shown by square brackets.

[c] The value of $K = 1$ has been assigned to the four GRBs selected from Ghirlanda et al. (2009).

[d] "Short" GRBs with extended emission. GRB 090510 is taken from Abdo et al. (2009), others are drawn from Norris et al. (2010).

[e] "Long" GRBs with short-hard properties (see the text in Section 2).

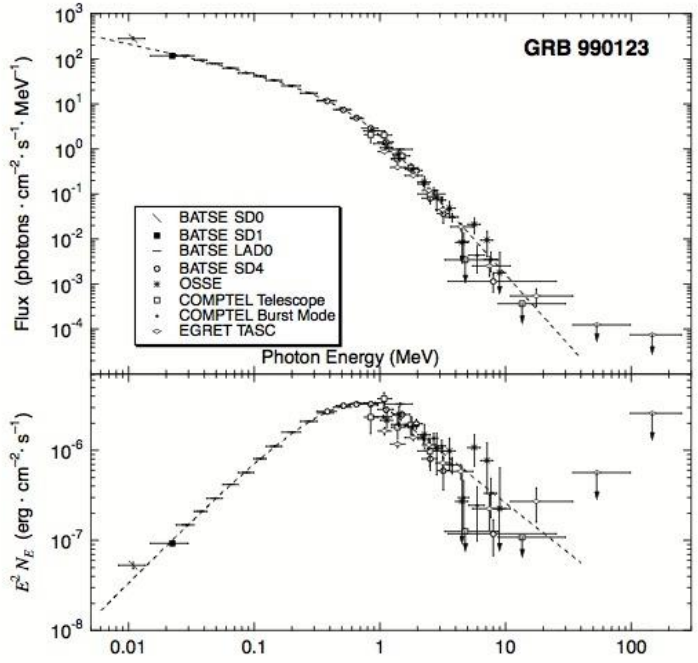
Sample of Zhang et al., 2012, ApJ, 755:55

GRB	Durée [s] Observée	Durée [s] Intrinsèque	Indice photonique [15-150 keV]	Redshift	Détermination	Références	Instruments BAT	Instruments GBM	Instruments KONUS
150423A	0.22	0.09	0.84, PL (0.24)	1.394	A	S	X		
150120A	1.20	0.82	1.81, PL (0.18)	0.460	E	S	X	X	
141212A	0.30	0.19	1.61, PL (0.23)	0.596	Host	S	X		
140903A	0.30	0.22	1.99, PL (0.12)	0.351	A	S	X		
131004A	1.54	0.90	1.81, PL (0.11)	0.71	E	S	X	X	
130603B	0.18	0.13	0.82, PL (0.07)	0.356	A + E	S	X		X
120804A	0.80	0.35	1.34, PL (0.08)	1.3	Host	1	X		X
111117A	0.47	0.20	0.65, PL (0.22)	$1.31^{+0.46}_{-0.23}$	Host	2,3	X	X	
101219A	0.60	0.35	0.63, PL (0.09)	0.718	Host	S	X		X
100724A	1.40	0.61	1.92, PL (0.21)	1.288	A	S	X		
100625A	0.33	0.23	0.90, PL (0.10)	0.452 ± 0.002	Host	4	X	X	X
100206A	0.12	0.08	0.63, PL (0.17)	0.41	Host	S	X	X	
100117A	0.30	0.16	0.88, PL (0.22)	0.915	Host	5	X	X	
090927	2.20	0.93	1.80, PL (0.20)	1.37	A	S	X	X	
090515	0.036	0.026	0.05, CPL (1.36)	0.403	Host	6	X		
090510	0.30	0.16	0.98, PL (0.20)	0.903	E	S	X	X	X
090426	1.20	0.33	1.93, PL (0.22)	2.609	A	S	X		
090417A	0.072	0.066	0.65, CPL (2.11)	0.088	Host	7	X		
080905A	1.00	0.89	0.85, PL (0.24)	0.1218	Host	8	X	X	
070923	0.05	0.046	1.02, PL (0.29)	0.076	Host	9	X		
070729	0.90	0.50	0.27 (n/a)	0.8 ± 0.1	Host	10	X		X
070724A	0.40	0.27	1.81, PL (0.33)	0.457	Host	S	X		
070429B	0.47	0.25	1.72, PL (0.23)	0.904	Host	S	X		
061217	0.21	0.11	0.86, PL (0.30)	0.827	E	S	X		X
061201	0.76	0.68	0.81, PL (0.15)	0.111	Host	S	X		
060801	0.49	0.23	0.47, PL (0.24)	1.1304	Host	11	X		
060502B	0.13	0.10	0.98, PL (0.19)	0.287	A	S	X		
051221A	1.40	0.90	1.39, PL (0.06)	0.547	E	S	X		X
050813	0.45	0.16	1.28, PL (0.37)	1.8	Host	S	X		
050709	0.07	0.06		0.16	Host	12		HETE2	
050509B	0.073	0.060	1.57, PL (0.38)	0.225	A	S	X		

Table of the sample of sGRBs with their observed duration T_{90} and intrinsic duration τ_{90}, their spectral parametra calculated thanks to their distance (redshift z). Références pour z : S sont les données issues de la table Swift : http://swift.gsfc.nasa.gov/archive/grb_table.html/ ; [1] : Berger et al. (2013), [2] : Sakamoto et al. (2013), [3] : Margutti et al. (2012), [4] : Fong et al. (2013), [5] : Fong et al. (2011), [6] : Berger (2010), [7] : O'Brien & Tanvir (2009), [8] : Rowlinson et al. (2010), [9] : Fox & Ofek (2007), [10] : Leibler & Berger (2010), [11] : Berger (2009), [12] : Fox et al. (2005)..

Selection of short GRB

Spectral properties : Band model



$\alpha = 0,6,\ \beta = 3,11$ et $E_0 = 700$ keV

Low Energy : harder

$N(E) \propto E^{-\alpha}$

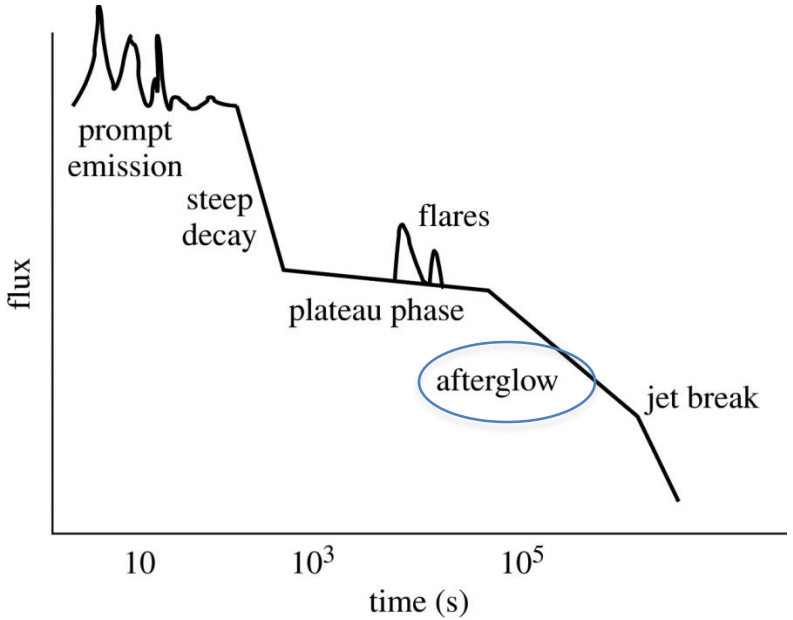
$0,6 \lesssim \alpha \lesssim 1,5$

Hight Energy : softer

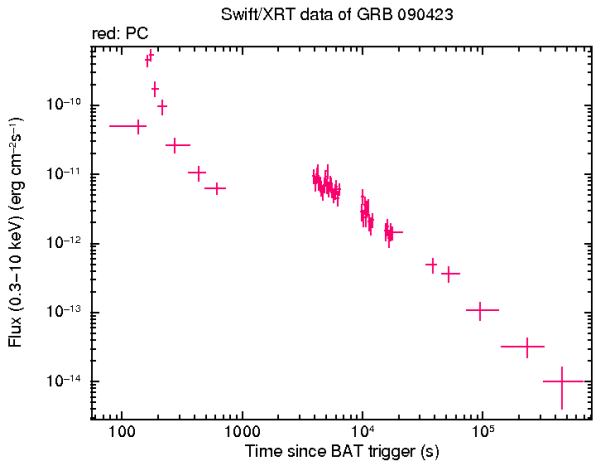
$N(E) \propto E^{-\beta}$

$2 \lesssim \beta \lesssim 4$

Curve of light

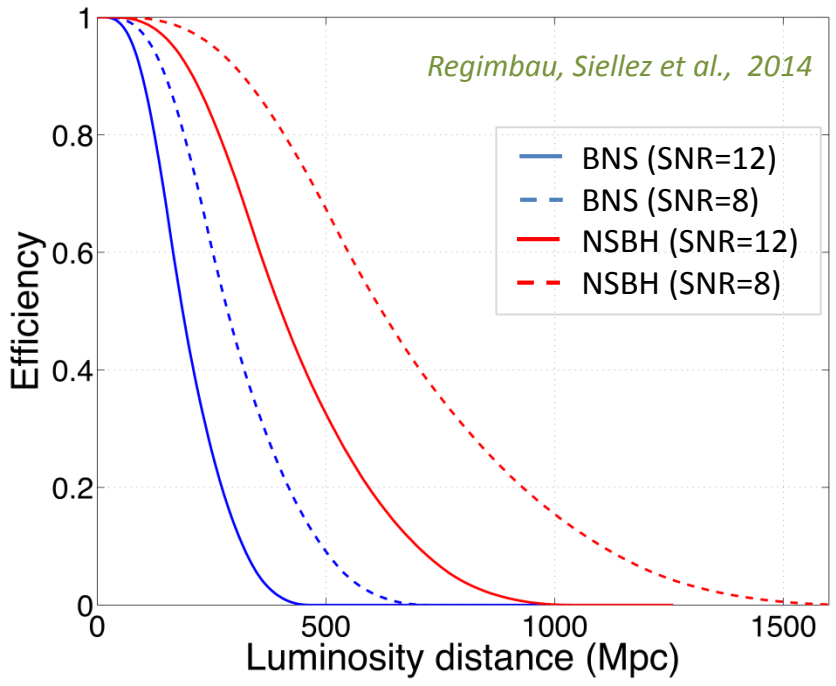


Example

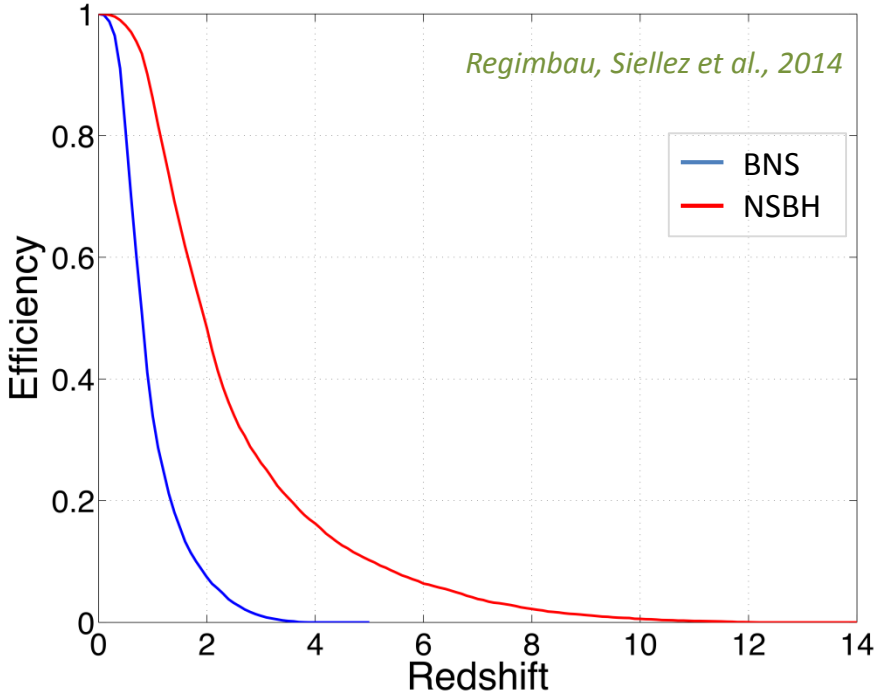


Gravitational wave efficiency

ALV



ET

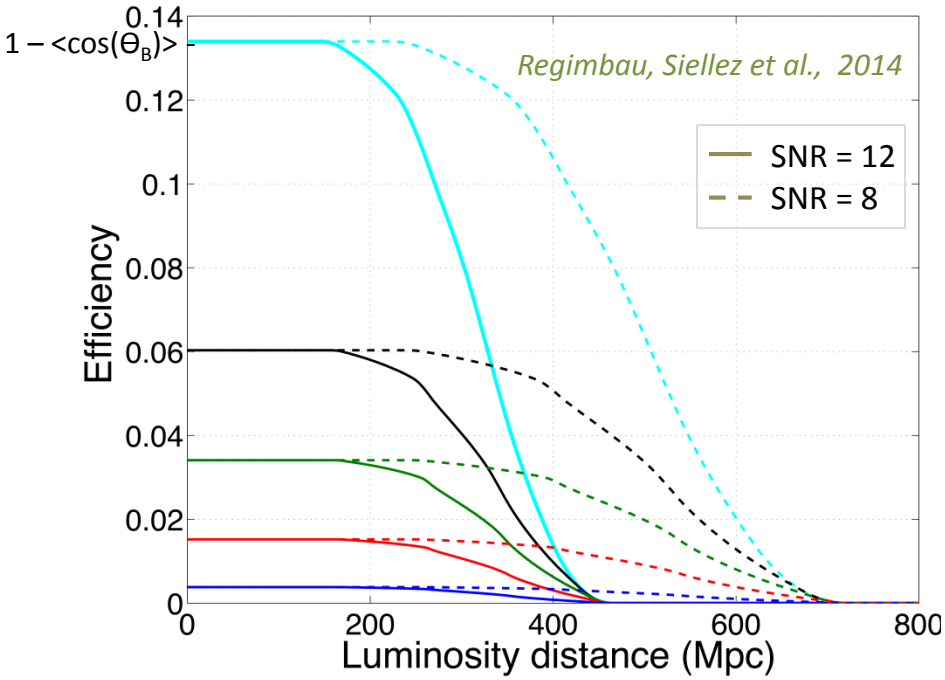


Efficiency for BNS – Perfect detector

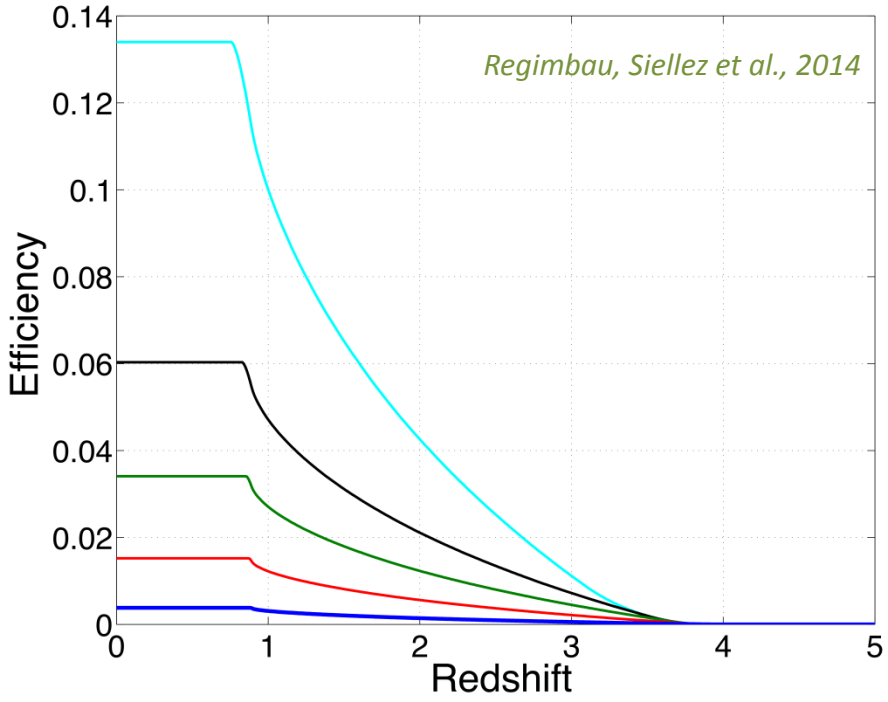
Perfect detector:
DC = 100% ; **FOV** = 4π sr ;
Sensitivity: Infinite

- $\dot{\rho}_c^o \sim 0.06\ Mpc^{-3} Myr^{-1}$
- $\Theta_B = 30°$, $\Theta_B = 20°$, $\Theta_B = 15°$, $\Theta_B = 10°$, $\Theta_B = 5°$.

ALV



ET



Efficiency for BNS – Realistic detector

Realistic detector:

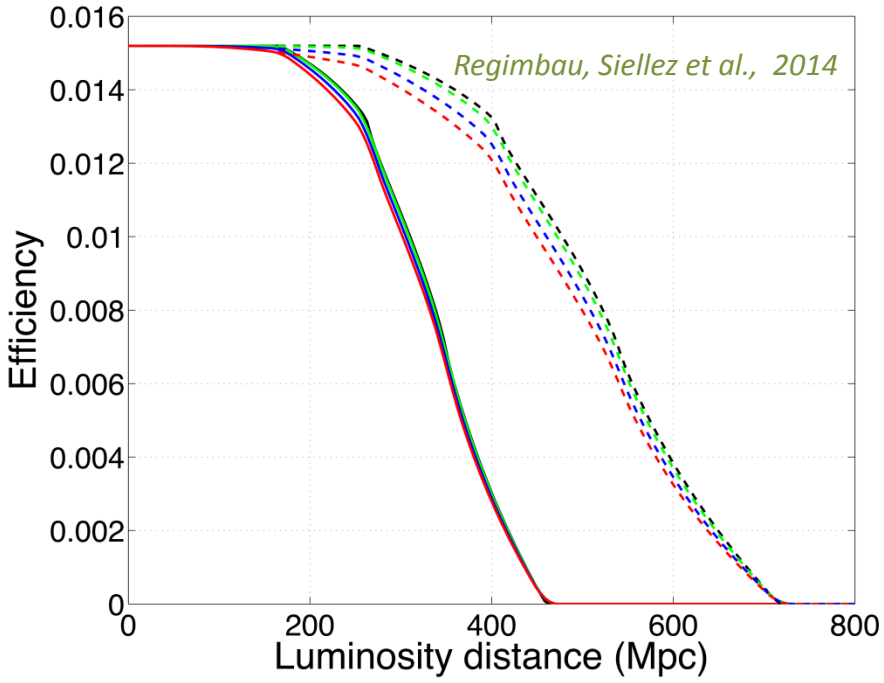
DC = 80% ; **FOV** = 1.4 sr ;

Sensitivity: Infinite, F_{lim} = 0.56 ph s^{-1} cm^{-2},

F_{lim} = 1.5 ph s^{-1} cm^{-2}, F_{lim} = 2.5 ph s^{-1} cm^{-2} .

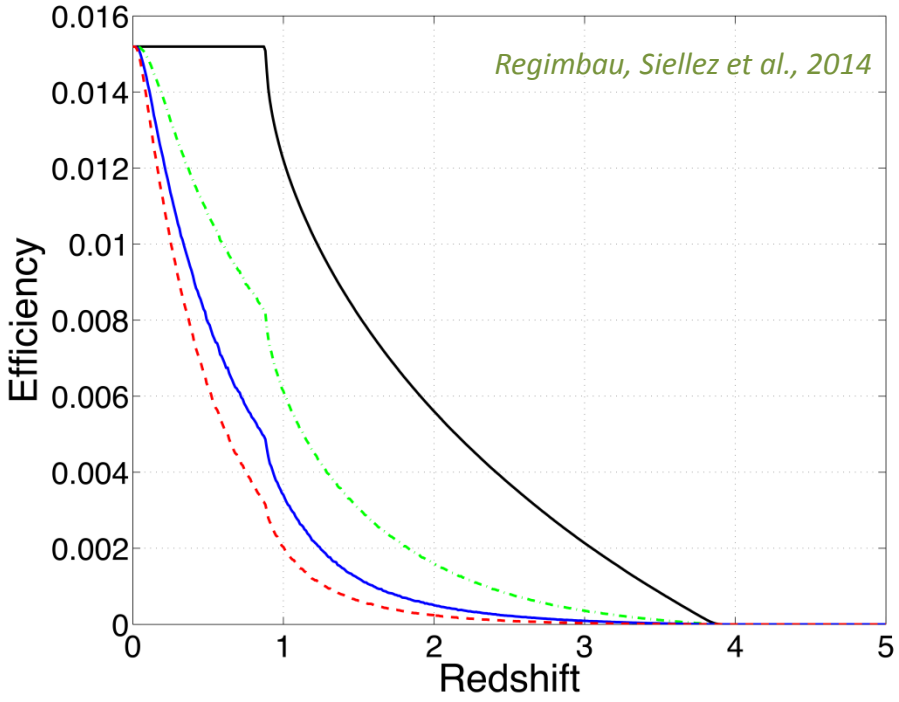
- $\dot{\rho}_c^o \sim 0.06\ Mpc^{-3} Myr^{-1}$
- $\Theta_B = 10°$

ALV



Limited by the GW detectors

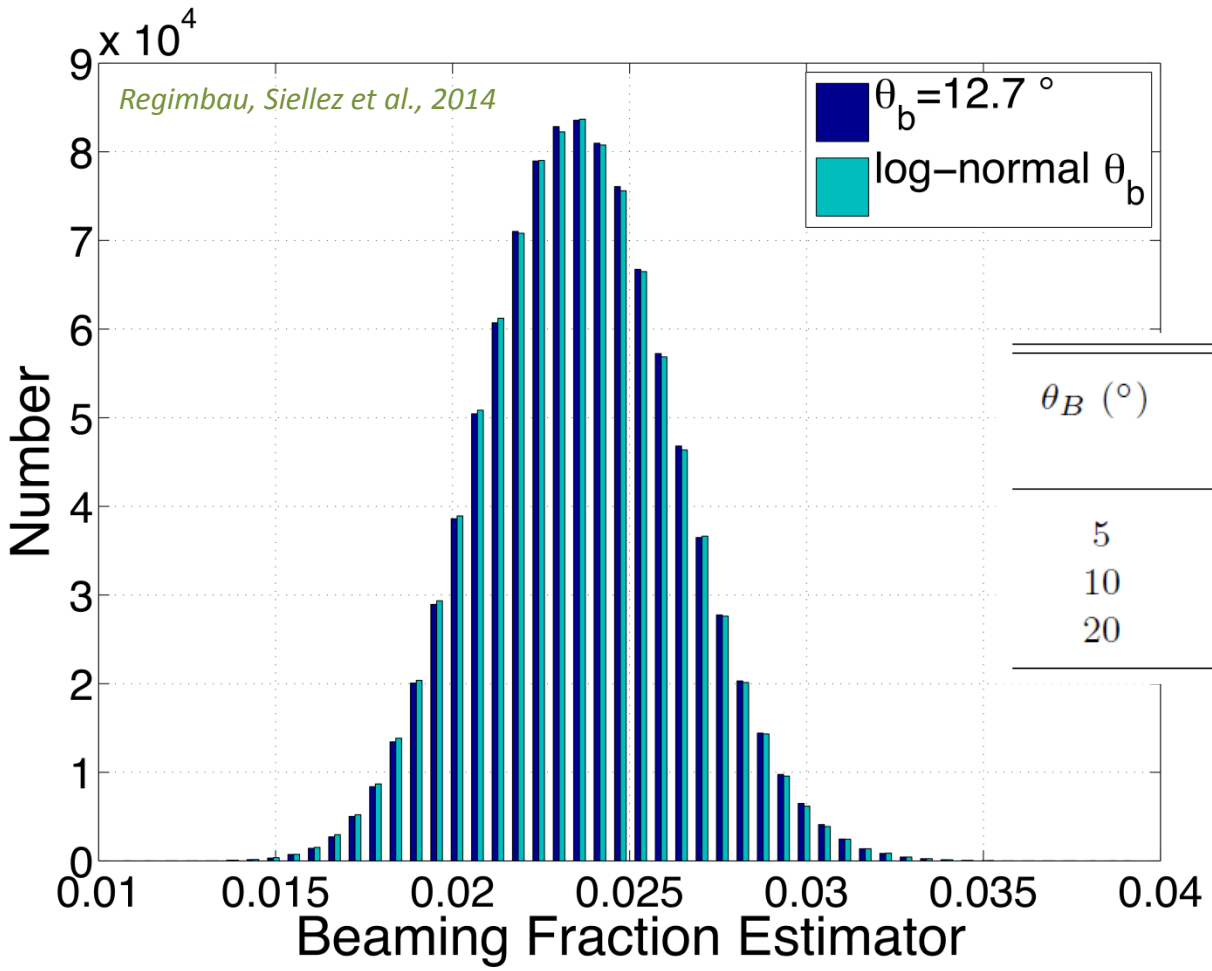
ET



Limited by the flux threshold of the GRB detector

Constraints on the beaming angle

Non biased estimator factor : $\hat{\Theta}_B = (\varepsilon_{FOV} \times \varepsilon_{DC}) \frac{N^0_{\rm cd}}{N^0_{\rm GW}}$



θ_B (°)	$< \hat{\Theta}_B >$	$\sigma_{\hat{\Theta}_B}$	error (%)
5	0.0039	0.0011	29.3
10	0.015	0.0022	14.5
20	0.060	0.00042	7.23