Coincident rate EM/LIGO

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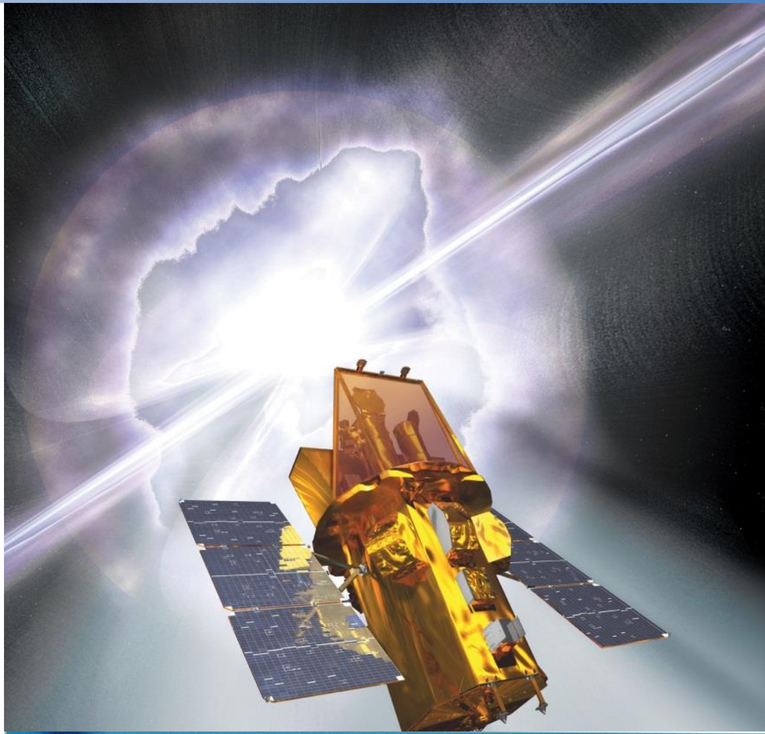
The link with GW

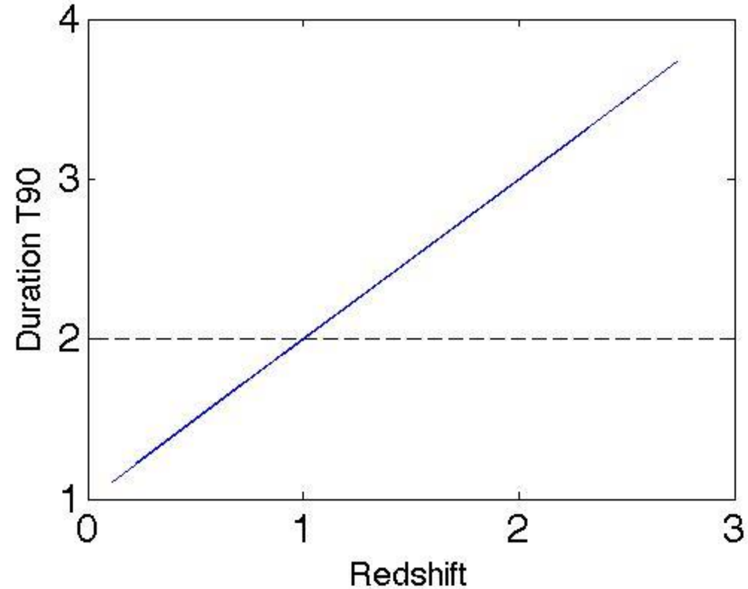
- **Short Gamma-ray bursts (GRBs)**
  - Progenitor : coalescence of binaries neutron stars ?
  - Powerful, but rare in the local universe
  - Defined by duration and hardness
- **Era non-photonic**
  - Gravitational wave detectors in construction
  - Advanced LIGO in 2015 and Advanced VIRGO in 2016
- **Link between gravitational waves and short GRBs**
  - Improving knowledge about short GRB progenitors
  - Rate estimation of simultaneous detection by gravitational wave and gamma ray needed

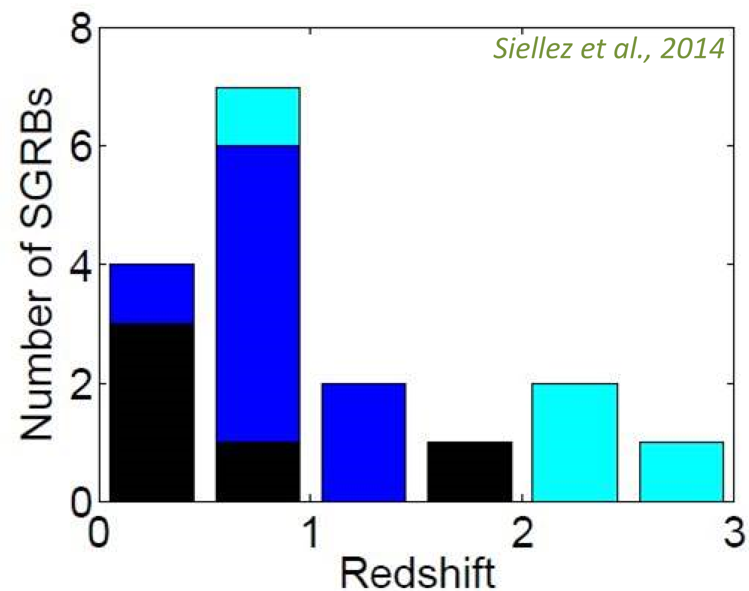


Based on observations

- **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 removed from sample to avoid long GRBs
- **Initial sample size: 32**
  - Reduced to 17 bursts
  - 4 added with this method
  - 4 bursts short like removed

- Best short GRB sample derived from NS-NS progenitor





Results for the rate of short GRBs

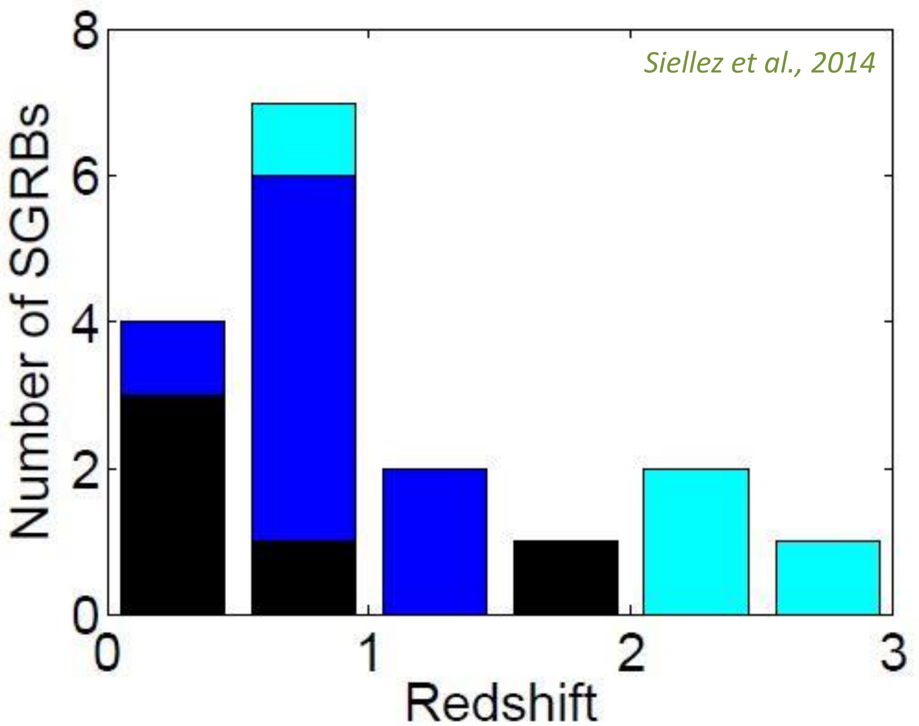


Figure 1. Redshift distribution of the rate of sGRBs by year. We indicate in dark blue the "classical" short bursts, and in cyan the 4 events we added. The black ones are canonical sGRBs with no conclusions on the presence of the plateau phase (see electronic version for colors).

- **Fit of this distribution**
  - Correction for the volume to obtain burst density
  - Model: power law with Poisson Statistic
  - Power law index: -1.6 ± 0.5
- **Estimation of occurence rate in the local Universe :**

  0.3 ± 0.1 sGRB GPc^{-3} y^{-1}
- **Instrumental bias to take into account**
  - Partial field of view (≈10%)
  - Corrected occurence rate of Swift:

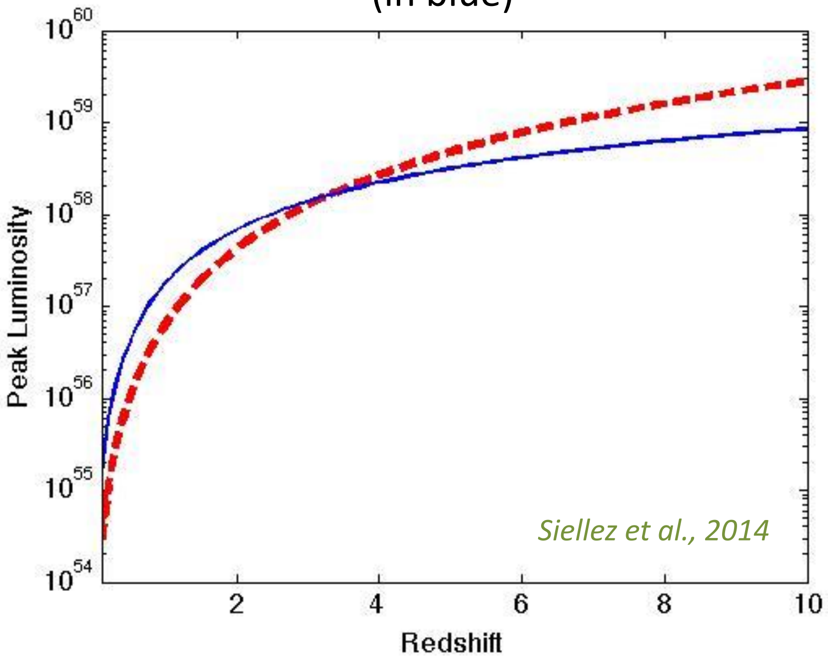
    2.7 ± 0.9 sGRB GPc^{-3} y^{-1}

Bias corrections

- **Instrumental bias**
  - Induce a limit of detection at high z (z>3.3)
  - Each instrument has its own sensitivity and specifications

- **Redshift bias**
  - 31.6% of sGRB with known z : GOLD sample .
    Rate : 2.7 ± 0.9 sGRB GPc^{-3} y^{-1}
  - SILVER sample : extension for all the sGRB .
    Final occurrence rate corrected :
    9 ± 3 sGRB GPc^{-3} yr^{-1}

Peak luminosity limit in function of the redshift for Swift (in dashed red) compared with the peak luminosity of a representative short GRB (in blue)



Others detectors

- **Rate for several gravitational wave detectors with Swift**

Detectors	Horizon [MPc]	Horizon [z]	Comobile volume [GPc^3]	Occurrence rate EM [events / year]
AdV	150	0.035	0.013	0.013 ± 0.004
aLIGO/AdV combined	355	0.08	0.154	0.11 ± 0.04

- **Coincidence rate estimation for AdV/aLIGO**

Missions	Swift	BATSE	FERMI	SVOM
F.o.V.	1.4 sr	π sr	9.5 sr	2 sr
Energy band	15-150 keV	25 – 1800 keV	8 keV – 40 MeV	4 – 250 keV
Estimated rate (events yr^{-1})	0.11 ± 0.04	0.8 ± 0.3	0.63 ± 0.21	0.14 ± 0.05

Comparison with other rates

Correction for the jet opening half angle Θ_j :

- $\Theta_j = 7°$
- $B(\Theta_j) = [1 - \cos(\Theta_j)]^{-1}$

Work	Method	Estimated GW detection rate ($\mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$)
This work	Observational constraints	92–1154
Coward et al. (2012)	Observational constraints	8–1800
Enrico Petrillo et al. (2013)	Observational constraints	500–1500
Guetta & Piran (2006)	Theoretical modelling	8–30
Abadie et al. (2010a)	Theoretical modelling	2.6–2600

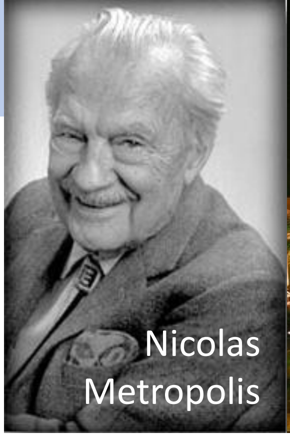
Siellez et al., 2014

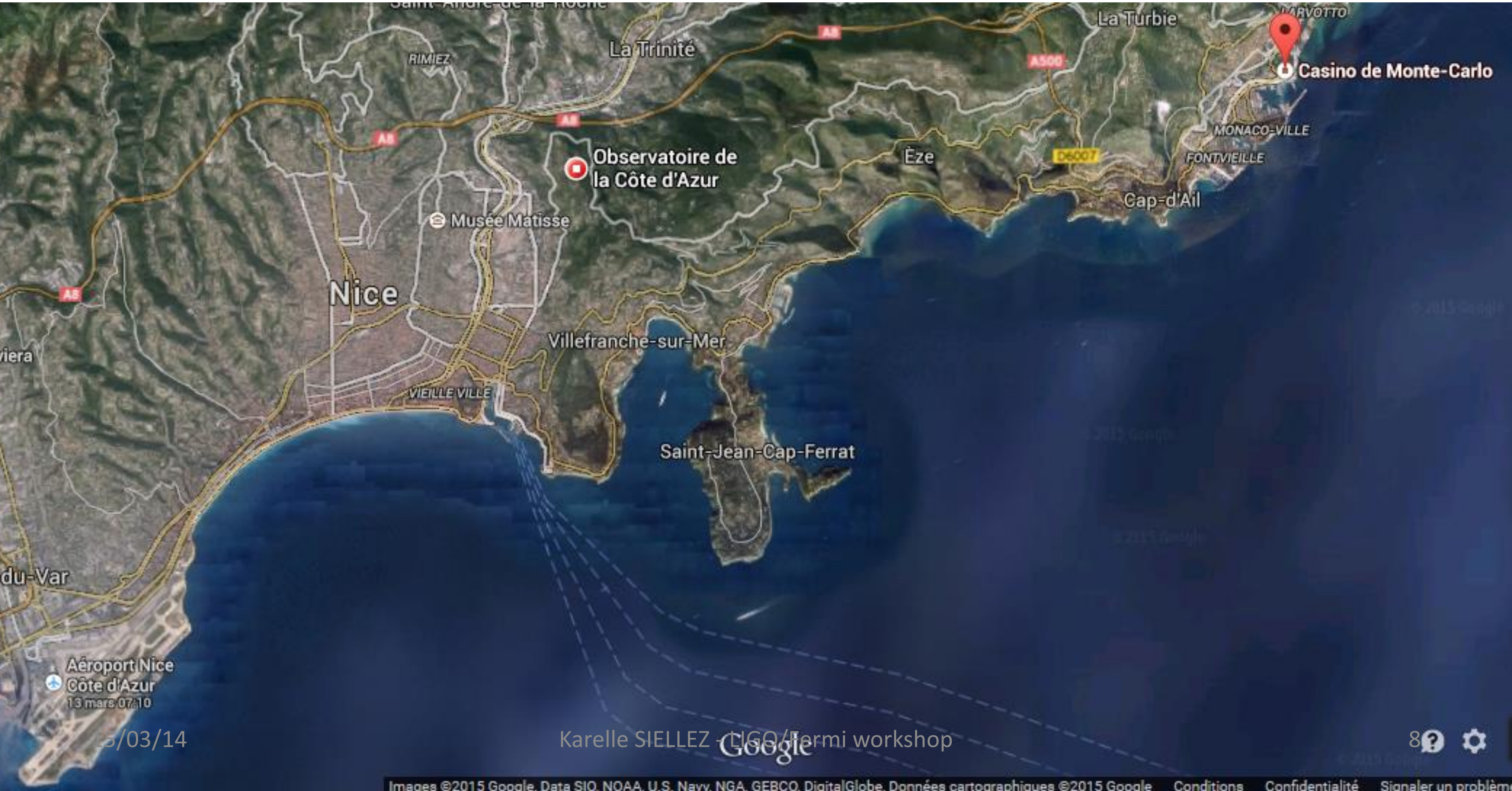
Results consistant with previous works

Monte Carlo

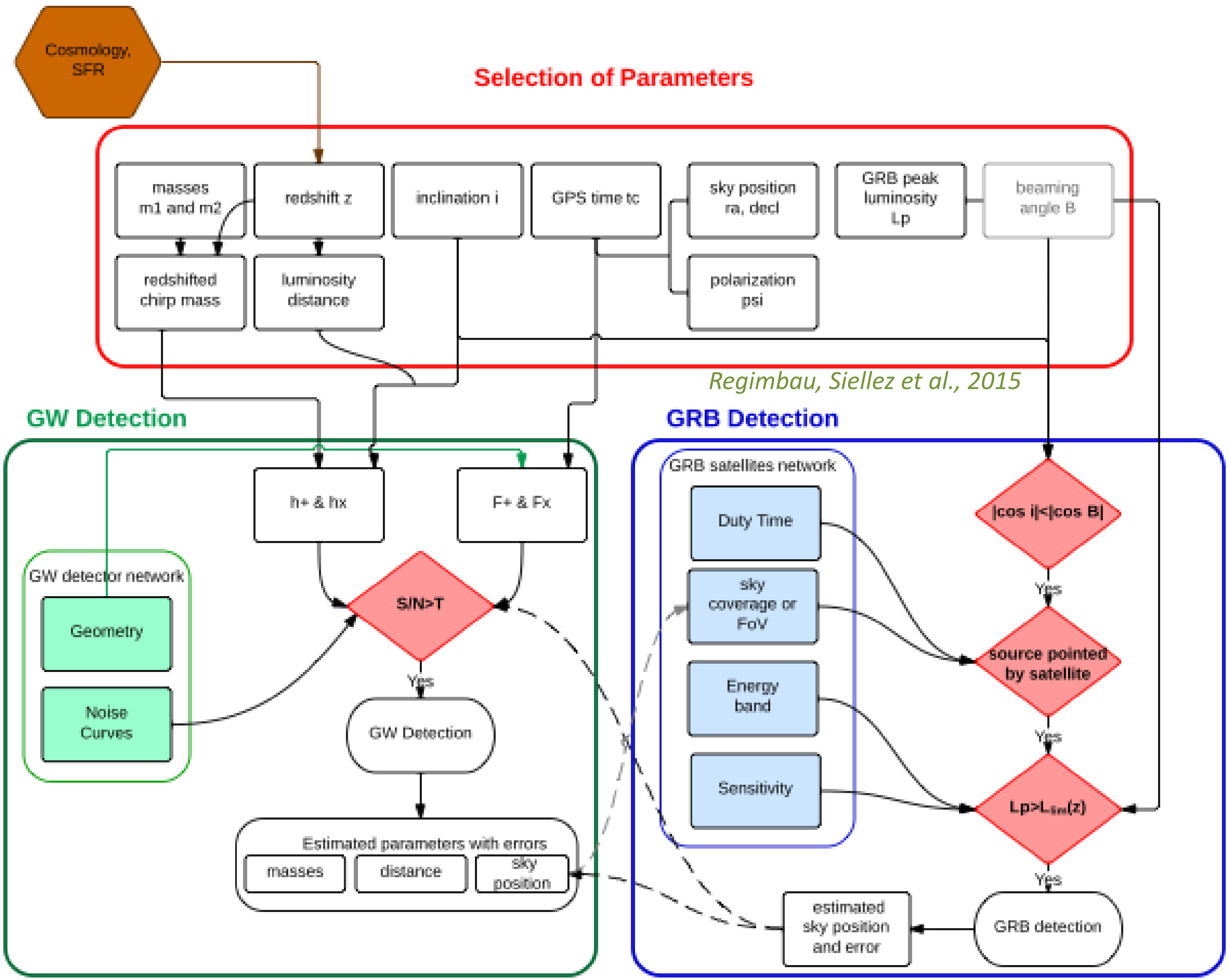
OCA – Monte Carlo casino :

17 km $\cong$ 10 miles





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>L$_{lim}$(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):

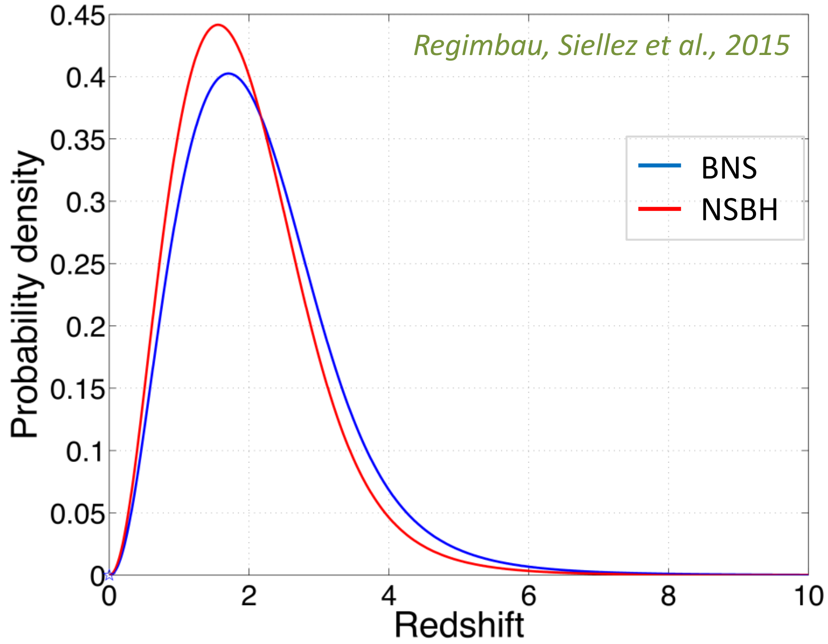
$$\phi(L_p) \propto \begin{cases} (L_p / L_*)^{\alpha} \text{ if } L_* / \Delta_1 < L_p < L_* \\ (L_p / L_*)^{\beta} \text{ if } L_* < L_p < \Delta_2 L_* \end{cases}$$

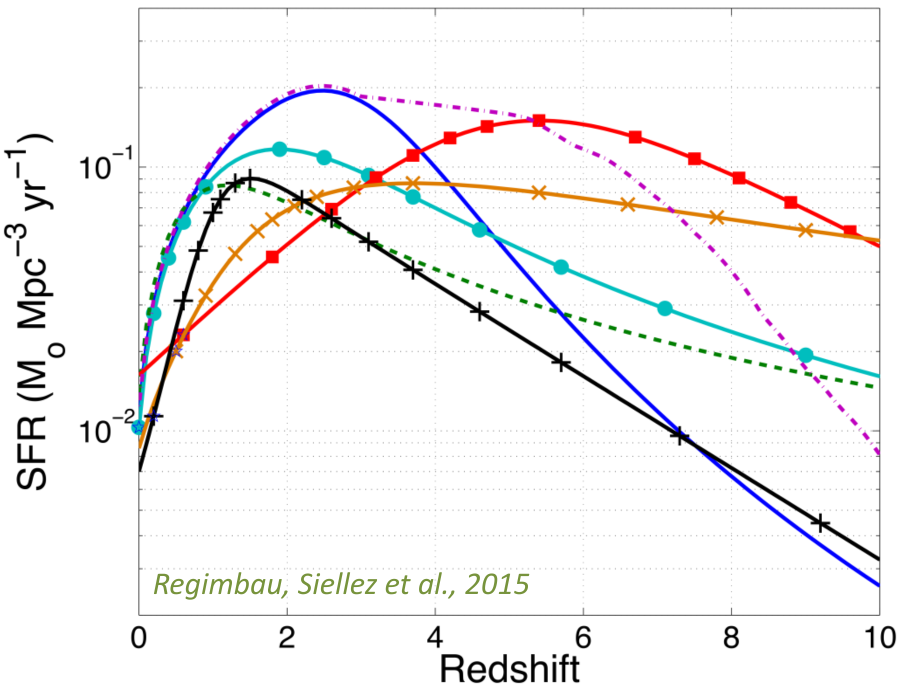
with $\alpha = -0.6, \beta = -2, L_* = 10^{51}\,\text{erg}, \Delta_1 = 100, \Delta_2 = 10$

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

- **Redshift:** Probability distribution of z

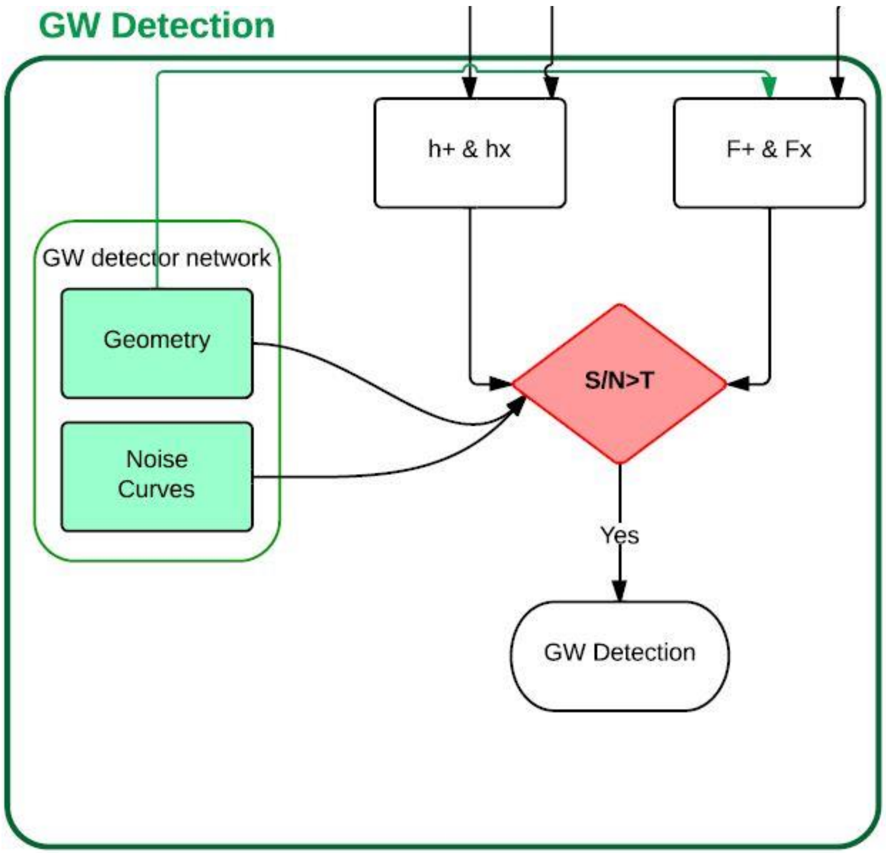
Redshift selection and SFR

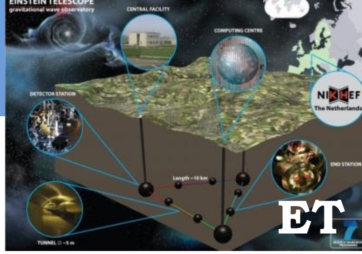


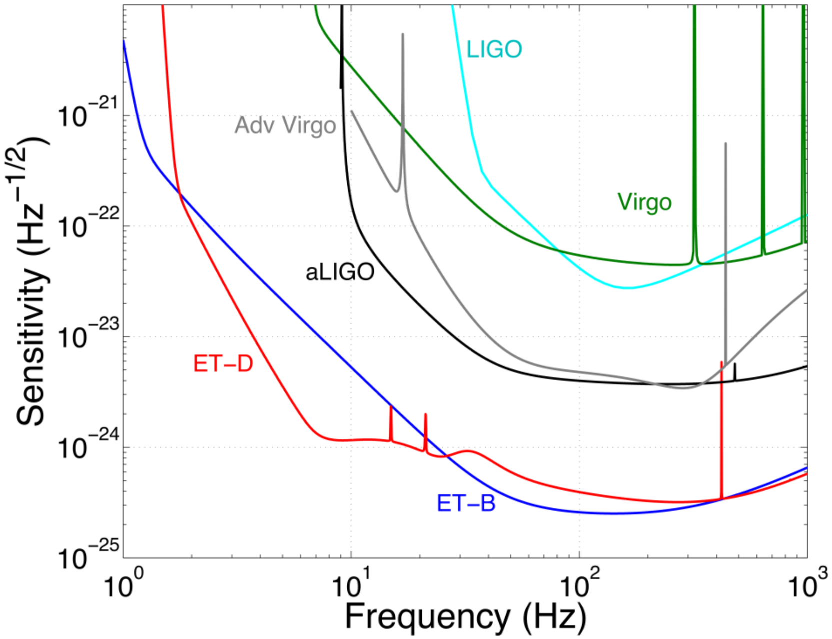


Different SFR:
Hopkins & Beacom 2006 (our reference model), Fardal et al. 2007, Wilkins et al. 2008, Springel & Hernquist 2003, Nagamine et al. 2006, Tornatore et al. 2007, Madau et al. 1998.

Gravitational wave detection







Regimbau et al., 2012, arXiv:1201.3563

SNR individual :

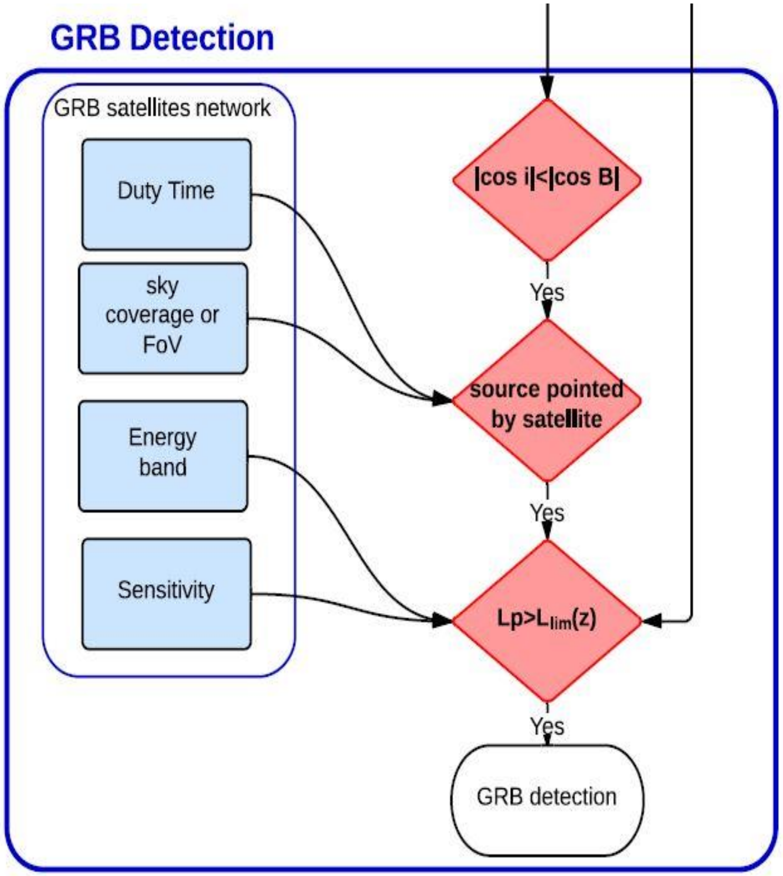
$$\rho_A^2 = \frac{5}{6}\frac{(GM_c(1+z))^{5/3}F_A^2}{c^3\pi^{4/3}d_L^2(z)}\int_{f_{\min}}^{\frac{f_{LSO}}{1+z}} df\,\frac{f^{-7/3}}{S_{n,A}(f)}$$

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:

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

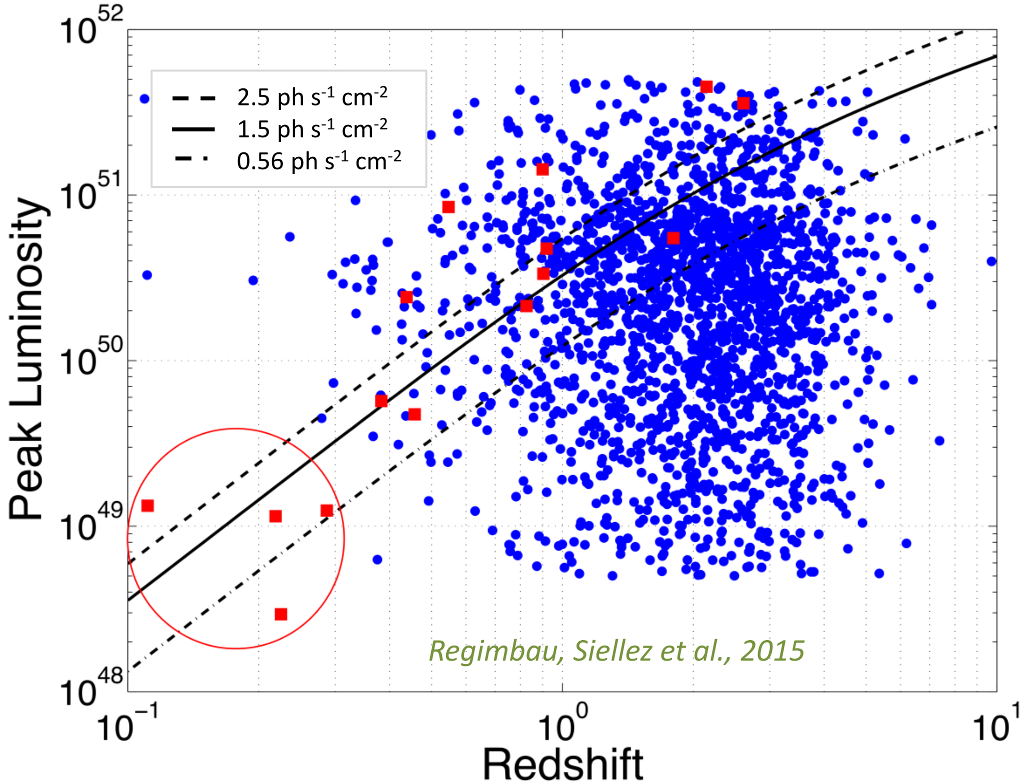
Gamma-Ray Bursts detection



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	$7 - 15$	$27 - 61$	$59 - 136$	$104 - 239$	$228 - 517$	$(1.3 - 2.4) \times 10^3$

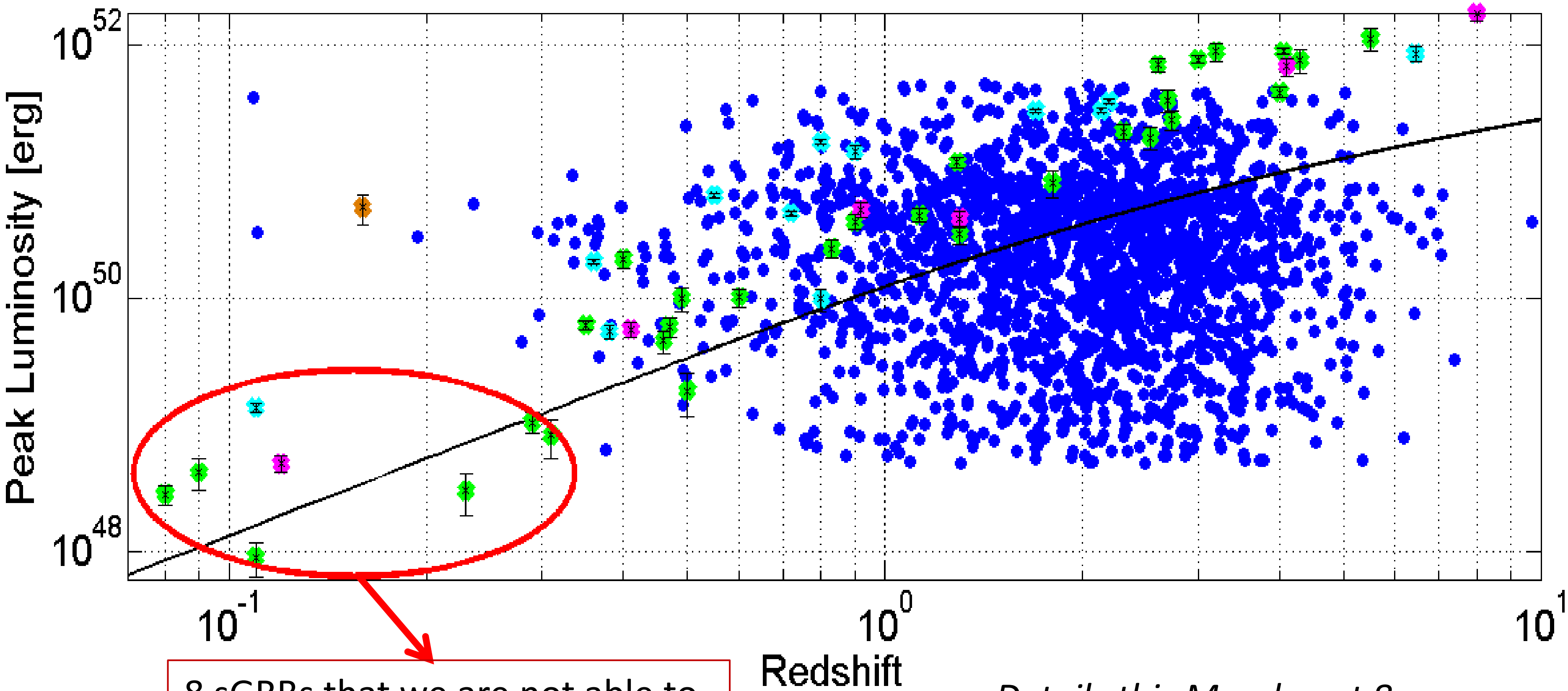
Regimbau, Siellez et al., 2015

Summary

- Coincident rate for ALV/Swift < 1 even per year, in agreement with previous works
- Coincident rate for ET/Ideal GRB detector between 1700 and 4300 per year for $\Theta_B = 15°$
- The coincident sensitivity is limited by GW detector horizon for the ALV, while for ET it is the EM detector sensitivity
  80% of detection efficiency => $F_{lim} = 0.26$ ph s^{-1} cm^{-2}
- New GRB detector needed with a sensitivity increase by a factor or 5 for sGRBs detection to work with ET
  → www.gofundme.com/GoodGRBDetector/

New study

10000 simulated sources (blue circles), Swift sensitivity (dark continuous line), sGRBs observed with spectral parameters extracted from **BAT (green crosses)**, **BAT+GBM (pink crosses)**, **KONUS (cyan crosses)**, **HETE-2 (orange crosses).**



8 sGRBs that we are not able to reproduce with our simulations.

Details this Monday at 8am during the LVC meeting in GRB f2f (ROOM 2 of Hilton Hotel)

Thank you … questions and comments are welcoming