

## Projects for the detection of a physically-modeled GRB population with Cherenkov Telescope Array

Q. Piel on behalf of A. Carosi and A. Fiasson and the  
H.E.S.S./CTA group at LAPP

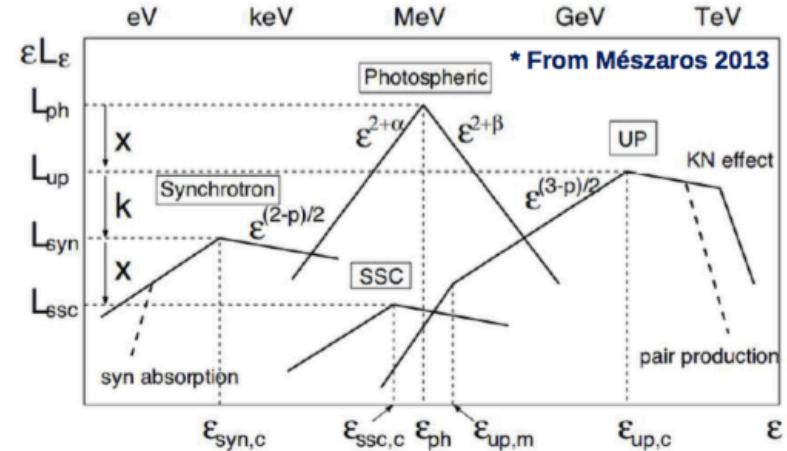
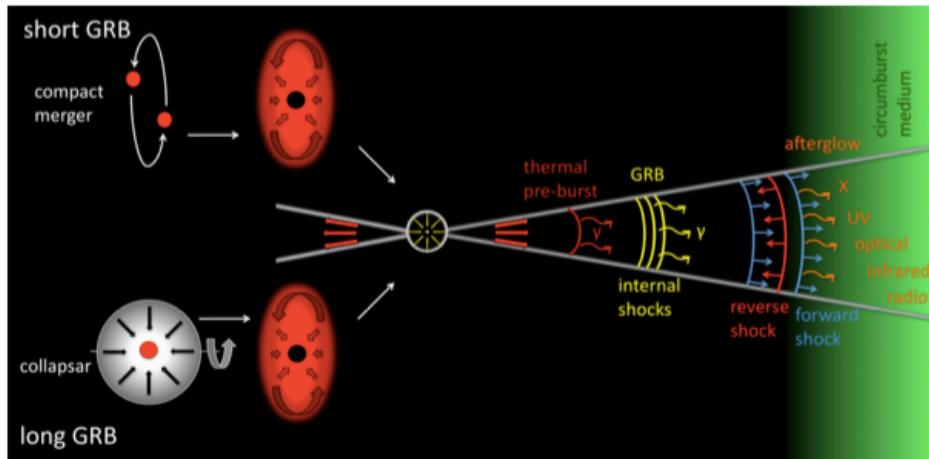


# Content

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- Introduction
  - GRB at High and Very High energies
  - Goals of the study
- Method
  - GRB Modeling
  - CTA array layouts
- Impact of the physical parameters on detection
- Population study and expected detection rate

# Intro: GRB in a nutshell



- Transient events with  $10^{52} - 10^{54}$  erg energy release
- Relativistic jetted outflow formed in stellar collapse or merger
- Emission mechanisms still poorly understood in particular for the prompt emission phase

(Some) Open questions....

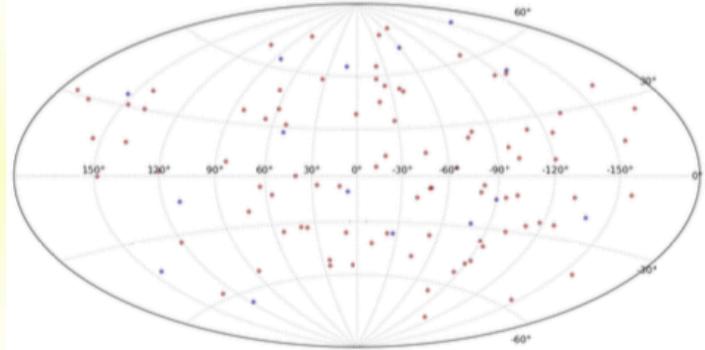
- What are the radiation processes ?
- How are the particles accelerated ?
- What is the central engine ?
- What are GRBs progenitors ?
- Can we use GRB to probe EBL ?
- Are GRB sources of UHECR ?
- Are GRB sources of HE neutrino ?  
(answer already provided by IceCube?)



# Intro: GRB at HE and VHE

GRBs are still un-detected sources at VHE → what do we know so far?

- GBM (8 keV -40 MeV) detection:  $\sim 250 \text{ yr}^{-1}$
- ~5% detected by LAT above 100 MeV
- ½ of them with  $> 1 \text{ GeV}$  photons ( $\sim 7 \text{ yr}^{-1}$ )
- max energy detected: 94 GeV (GRB 130427)

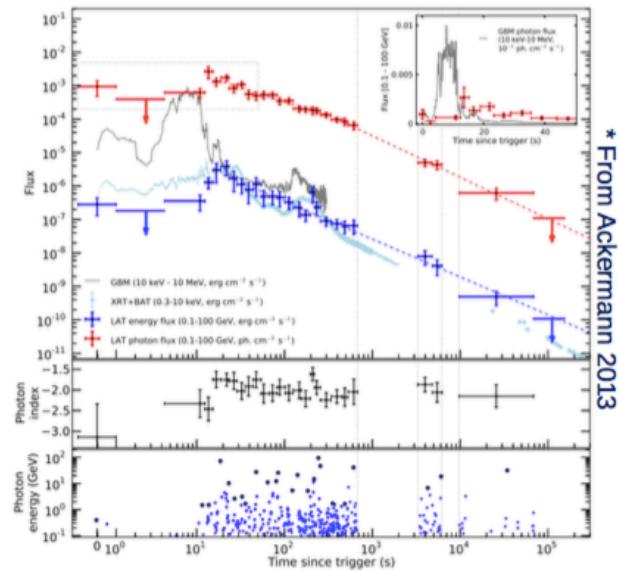


- LAT GRB are the brightest events in both the prompt and afterglow phases
- HE emission is systematically delayed and lasts systematically longer
- Band function usually appropriate for joint GBM+LAT spectrum fit

but...

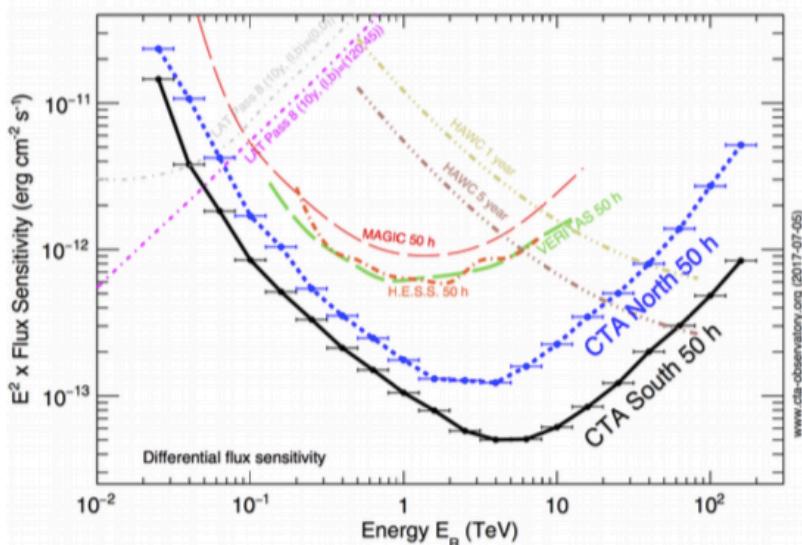
- Few cases with evidence of an extra component

**Do all the GRB have a > GeV component ?**

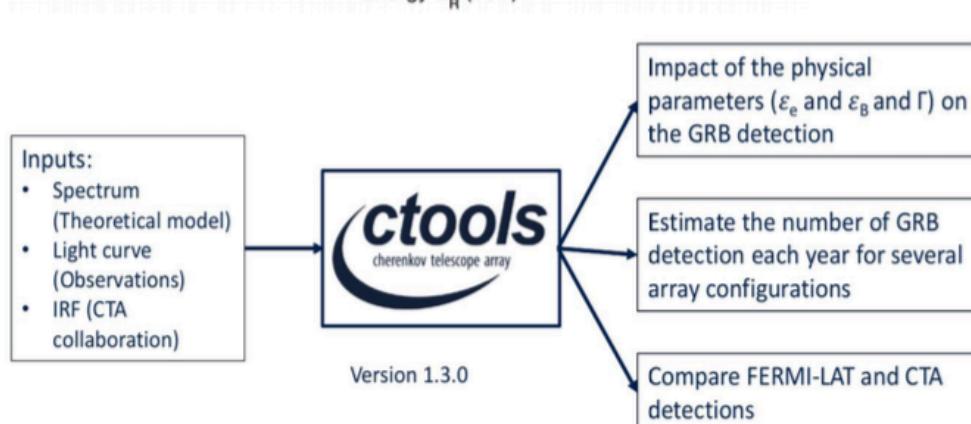
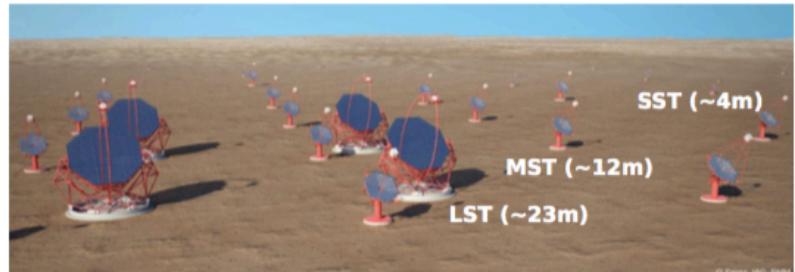


# Intro: Goal of the study

CTA will be one of the major research infrastructure for VHE astronomy for the next decades

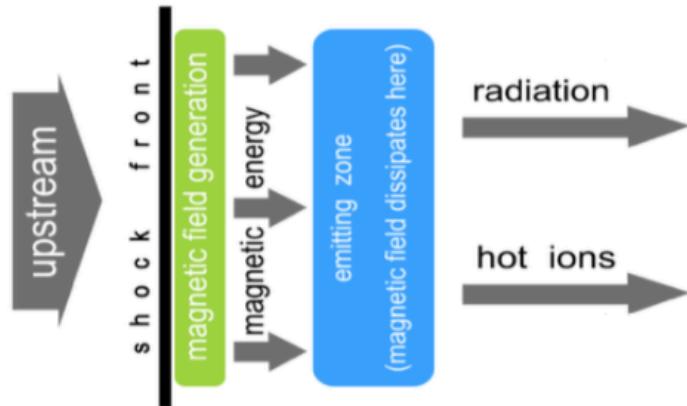


- Low energy threshold (down to 15 GeV)
- Large effective area at multi-GeV range ( $\sim 10^4 \times$  Fermi-LAT)
- Fast slewing capabilities



- ☑ Estimate CTA detection rate from GRB physics and using dedicated analysis tools
- ☑ Impact of physical parameters on GRB detection capability
- ☑ Assess the effect of array configuration on detection prospect

# Modeling of GRB emissions



## relativistic shock wave model

- Particles shock acceleration
  - non-thermal signature
- Magnetic field generation
- Emission mechanism(s)

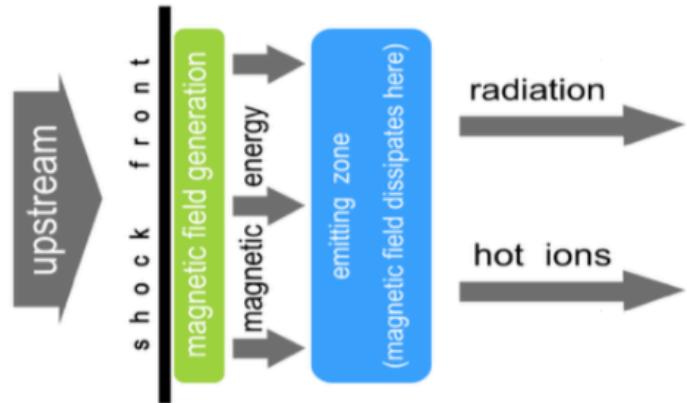
- Synchrotron/SSC (Zhang & Meszaros 2001...)
- Photospheric/UP scattered (Toma+2011...)
- Synch. In external forward shocks (Ghisellini+ 2010...)
- External Compton (Fan 2008...)
- Photo-hadronic interactions (Bottcher & Dermer 1998...)
  - po decay
  - p synchrotron
  - ....

We used a simple leptonic synchrotron+SSC model for both the prompt (Gupta & Zhang 2007) and the afterglow (Zhang & Meszaros 2001)

- internal pair production taken into account (prompt)
- EBL absorption by Dominguez+2011

→ Note: although valid for afterglow, this emission model is likely too simple to describe prompt emission

# Modeling of GRB emissions

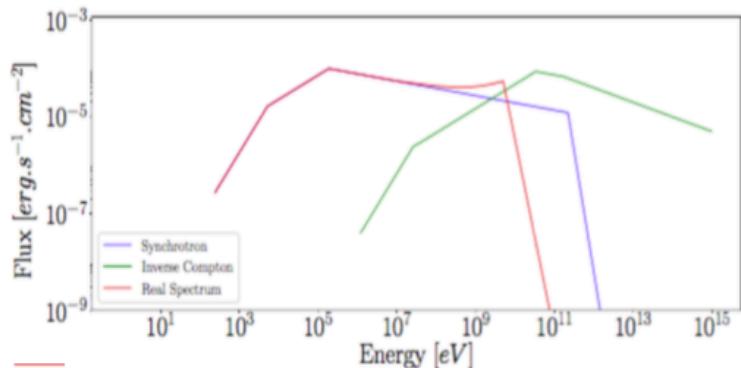


## relativistic shock wave model

- Particles shock acceleration → non-thermal signature
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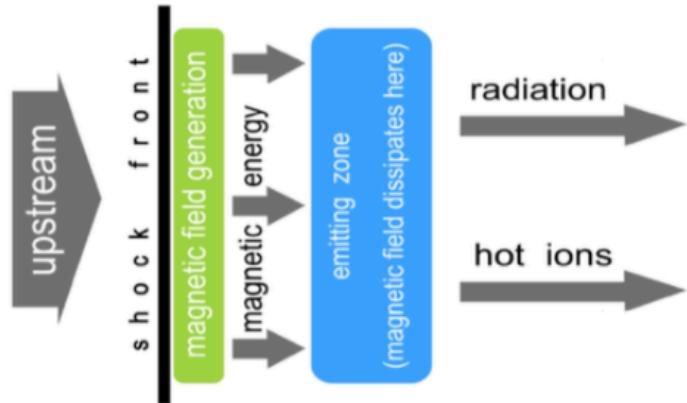
- Photo-hadronic interactions (Bottcher & Dermer 1998...)
  - p<sub>0</sub> decay
  - p synchrotron
  - ....



## PROMPT

- Isotropic equivalent energy ( $E_{iso}$ )
- Prompt emission duration ( $T_{90}$ )
- Energy equipartition parameter ( $\epsilon_e, \epsilon_B, \epsilon_p$ )
- Bulk Lorentz factor ( $\Gamma$ )
- Particle distribution index ( $p$ )

# Modeling of GRB emissions

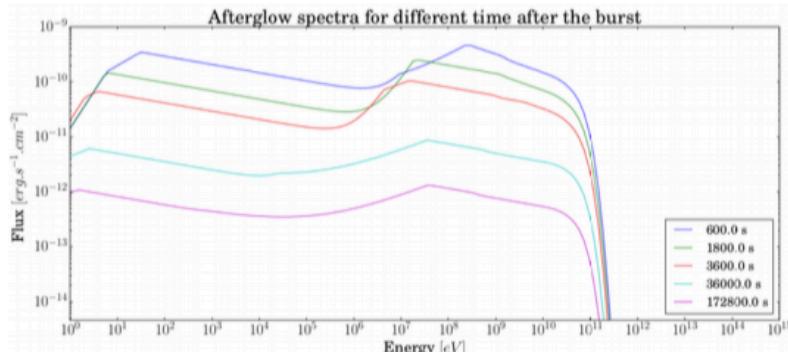


## relativistic shock wave model

- Particles shock acceleration
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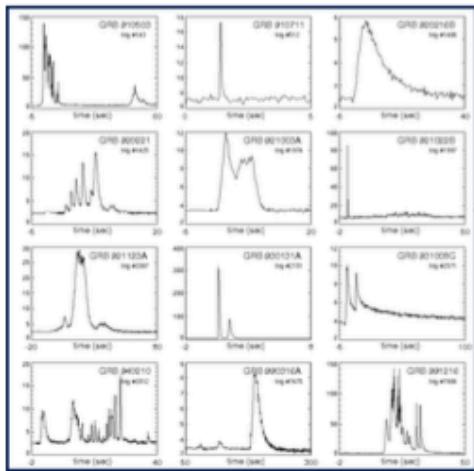
- Photo-hadronic interactions (Bottcher & Dermer 1998...)
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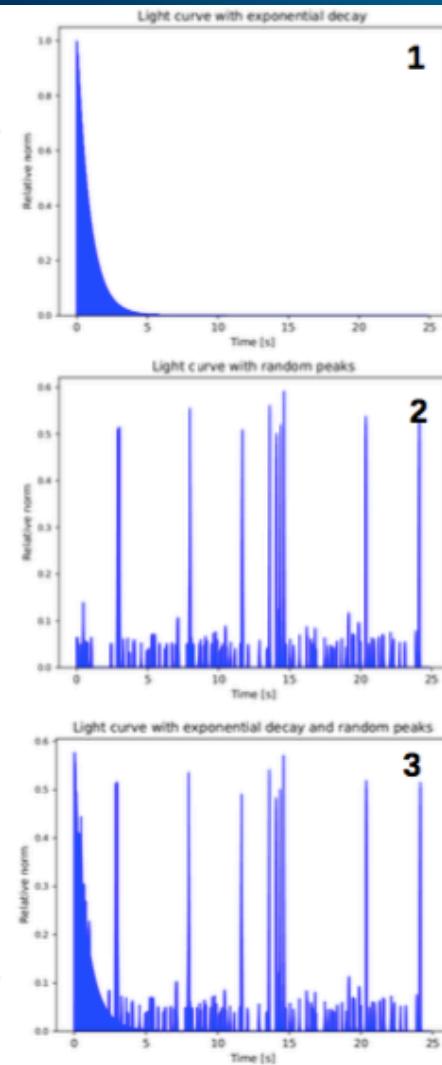
## AFTERGLOW

- Isotropic equivalent energy ( $E_{\text{iso}}$ )
- Observation time ( $T_{\text{obs}}$  :  $\Gamma \rightarrow \Gamma(t)$ )
- Energy equipartition parameter ( $\epsilon_e, \epsilon_B, \epsilon_p$ )
- Ambient density (n)
- Particle distribution index (p)

Large variety of GRB prompt light curves  
(BATSE sample)

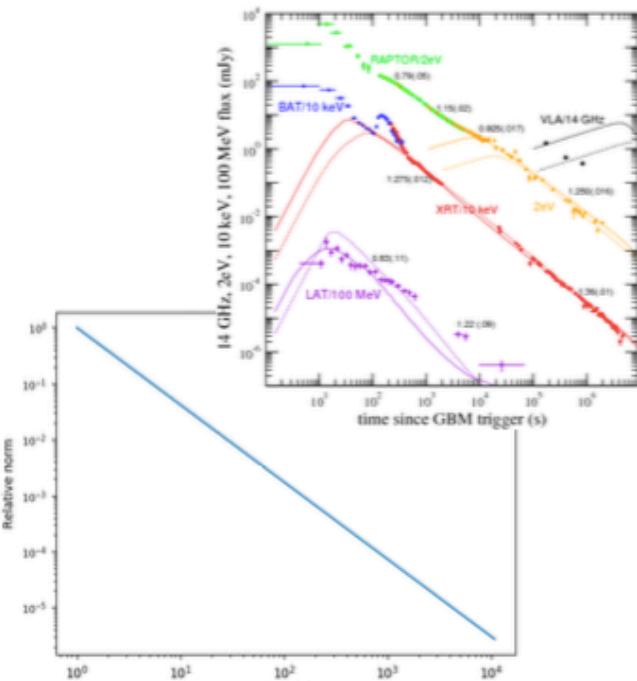


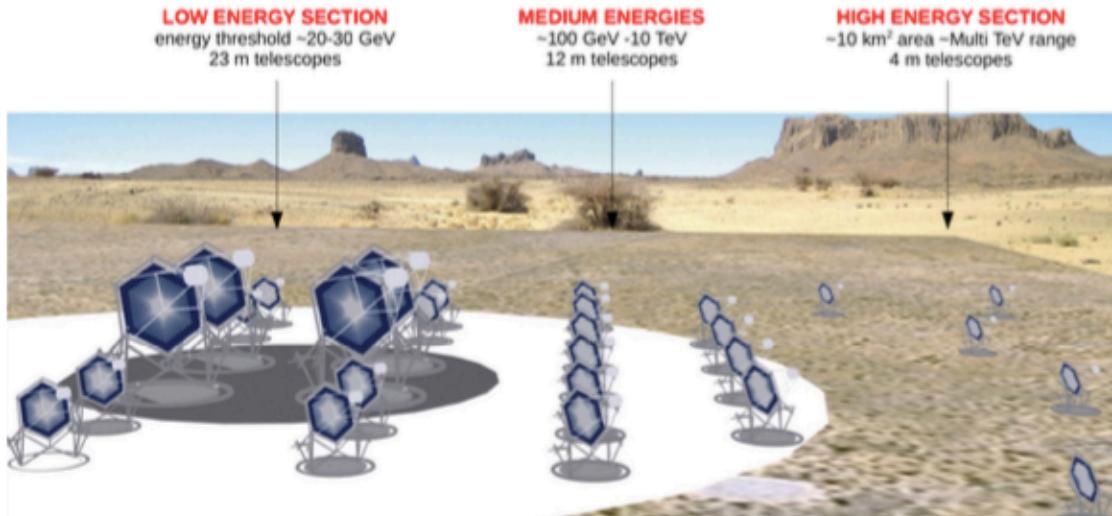
- 1 exp. decay
- 2 random peaks
- 3 exp decay+random peaks



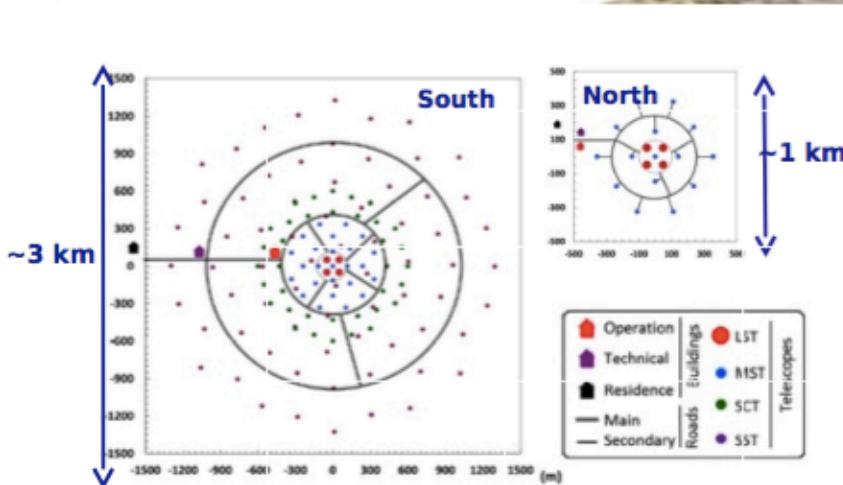
3 representative light curves  
for prompt emission

Power law for afterglow  
 $(\sim t^{1.4})$



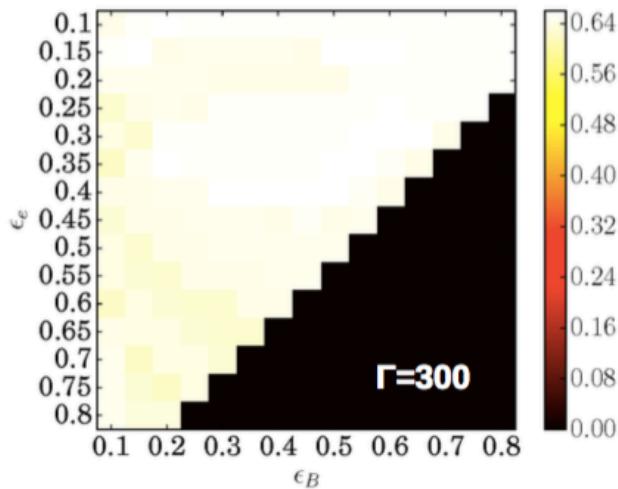


- IRFs (prod3b) for 3 possible array configurations
- ctools v 1.3.0 (<http://cta.irap.omp.eu/ctools/>)



<https://www.cta-observatory.org/>

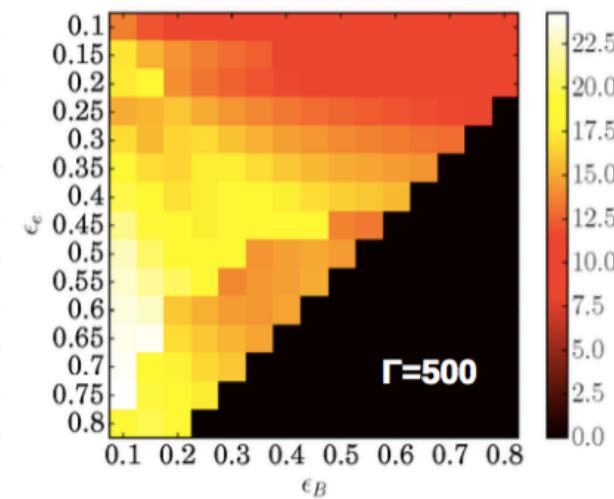
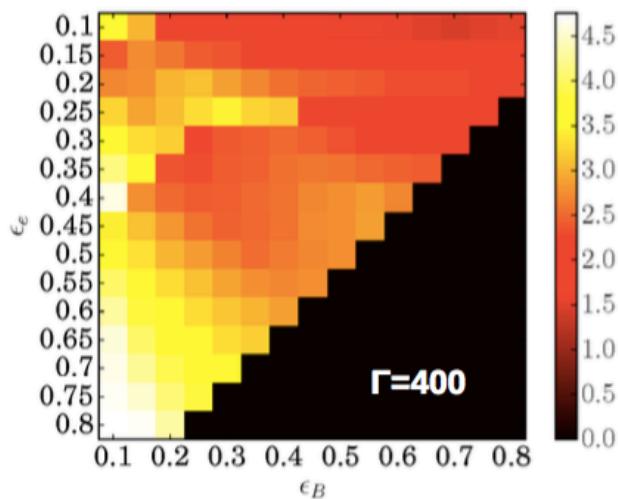
# Physical parameters study (prompt)



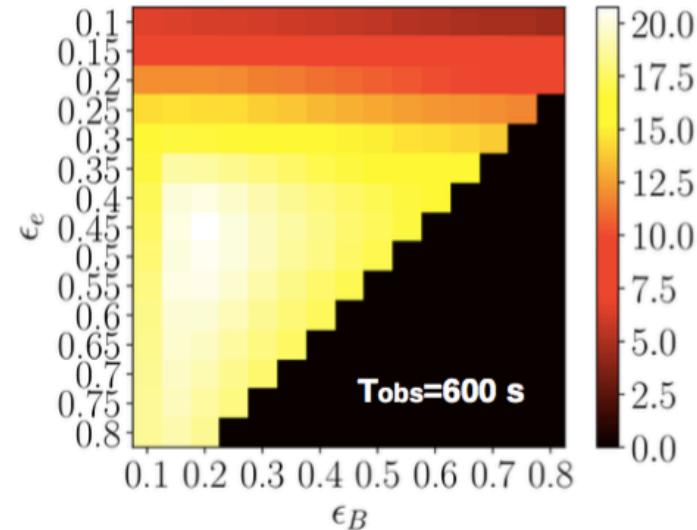
Example for the LST array

- $E_{\text{iso}} = 4 \times 10^{53} \text{ erg}$
- $T_{90} = 40 \text{ s}$
- $p = 2.3$
- $z = 0.5$

- Prompt emission unlikely detectable for burst with  $\Gamma < \sim 500$  due to internal absorption
- In agreement with Fermi-LAT observations

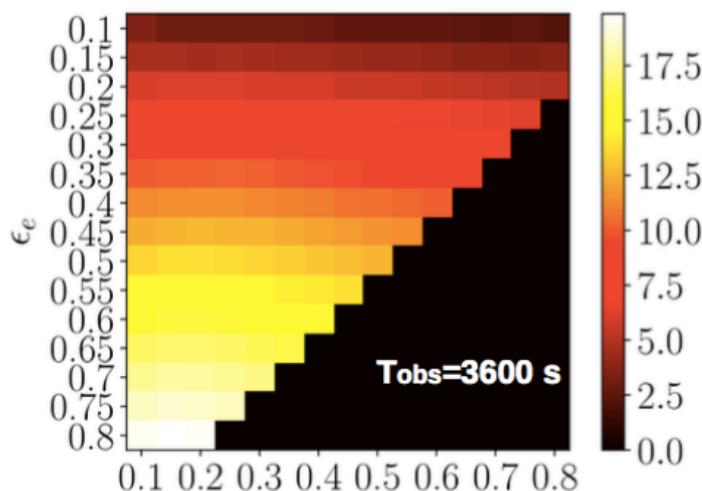


# Physical parameters study (afterglow)



Example for the LST array

- $E_{iso} = 4 \times 10^{53}$  erg
- Ambient density =  $1 \text{ cm}^{-3}$
- $p = 2.3$
- $z = 0.5$



- Detection possible for large range of parameters space up to  $\sim 1\text{h}$  after GRB onset

- early afterglow ( $T < 1000$  s) favored

# CTA detection rate

How to do it?

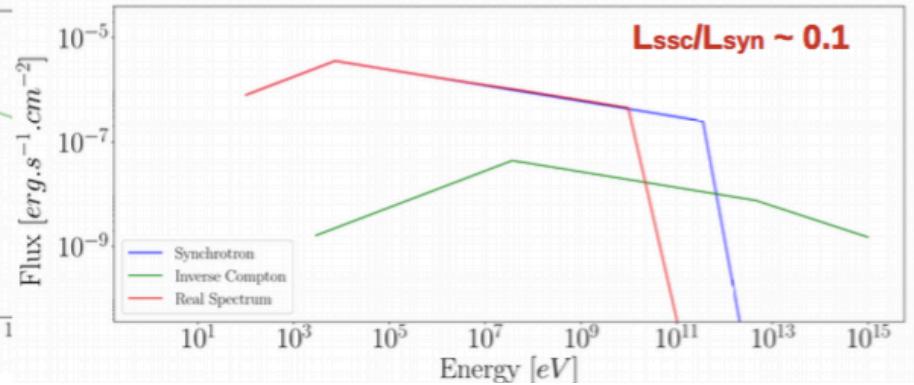
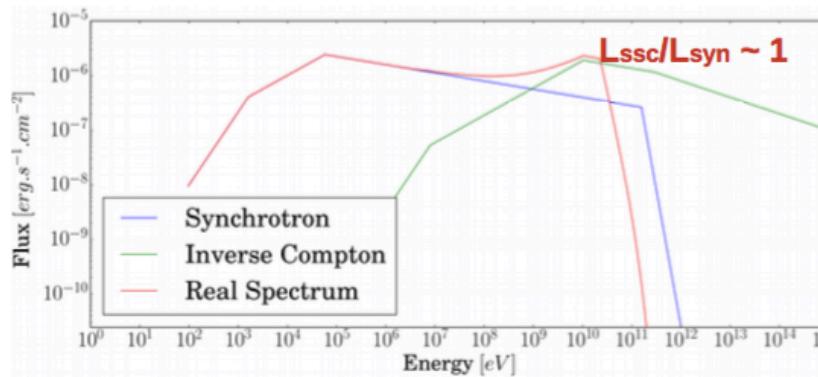
- GRB population simulated with different physical parameters ( $\varepsilon_e$  ,  $\varepsilon_B$  ,  $\Gamma$  ,  $E_{iso}$  ,  $T_{90}$ ) using  $T_{90}$  (Bhat+2006) , redshift (Coward+2013) and isotropic energies (Bhat+2017) distributions
- Evaluation of the number of follow-up per year by CTA
- Count the number of detection above  $5\sigma$

## Large SSC component (Case 1)

- Prompt  $\varepsilon_e = 0.01$ ,  $\varepsilon_B = 0.8$
- Afterglow  $\varepsilon_e = 0.01$ ,  $\varepsilon_B = 0.8$

## Low « real » SSC component (Case 2)

- Prompt  $\varepsilon_e = 0.4$ ,  $\varepsilon_B = 0.4$
- Afterglow  $\varepsilon_e = 0.1$ ,  $\varepsilon_B = 0.01$



# CTA detection rate

Number of observable GRB per year:

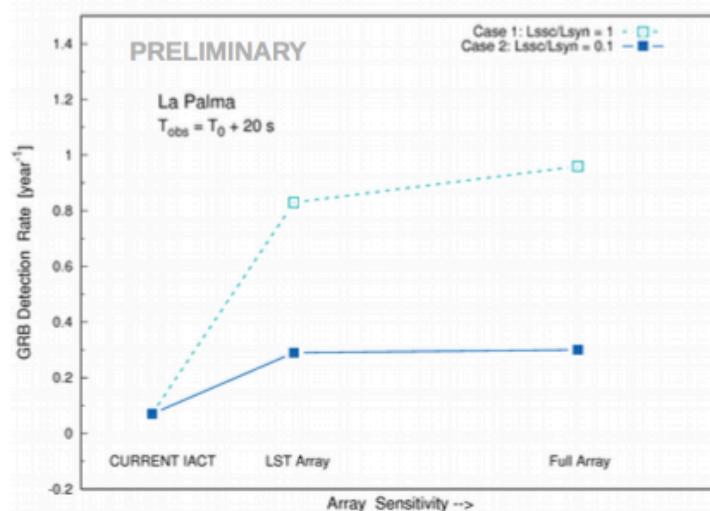
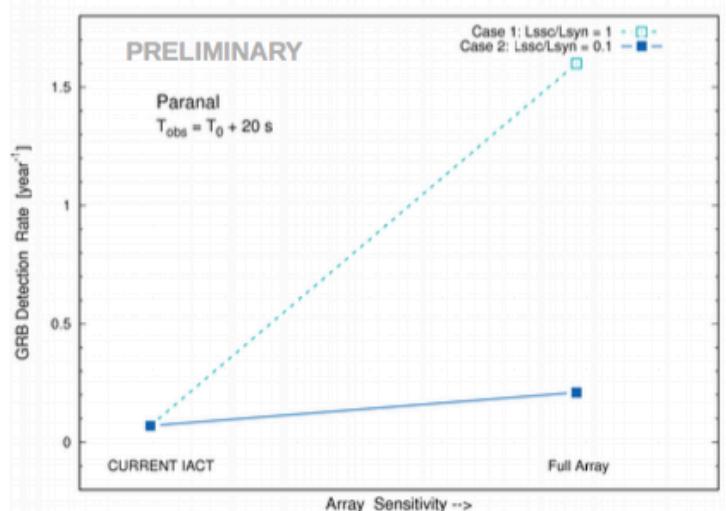
- Duty cycle of CTA ( $\sim 1000\text{h/year}$ )
- Sky coverage of CTA (zenith  $>20^\circ$ )
- 3 zenith bins and corresponding IRFs



**13 GRBs follow-up/year**

( $\sim 1 \text{ GRB/month} \rightarrow \sim 2.5 \text{ reduction for } z < 2$ )  
**1000 x 13 simulations to avoid statistical bias**

Array configuration	Phase	$\epsilon_e, \epsilon_B$	$t_{start} [\text{s}]$	Mean number of detection
South	Prompt	0.4, 0.4	0, 20	$2.2 \pm 0.7, 1.6 \pm 0.7$
North	Prompt	0.4, 0.4	0, 20	$1.8 \pm 0.7, 0.9 \pm 0.5$
LST North	Prompt	0.4, 0.4	0, 20	$1.8 \pm 0.6, 0.8 \pm 0.5$
South	Prompt	0.01, 0.79	0, 20	$0.5 \pm 0.4, 0.2 \pm 0.3$
North	Prompt	0.01, 0.79	0, 20	$0.1 \pm 0.5, 0.3 \pm 0.3$
LST North	Prompt	0.01, 0.79	0, 20	$0.7 \pm 0.5, 0.3 \pm 0.3$
South	Afterglow	0.1, 0.01	$t_{90}, 600, 3600, 7200$	$3.7 \pm 0.7, 2.9 \pm 0.8, 2.9 \pm 0.8, 2.8 \pm 0.8$
North	Afterglow	0.1, 0.01	$t_{90}, 600, 3600, 7200$	$3.5 \pm 0.7, 2.7 \pm 0.8, 2.3 \pm 0.8, 2.5 \pm 0.8$
LST North	Afterglow	0.1, 0.01	$t_{90}, 600, 3600, 7200$	$3.5 \pm 0.7, 2.6 \pm 0.8, 1.3 \pm 0.9, 2.0 \pm 0.8$
South	Afterglow	0.01, 0.79	$t_{90}, 600, 3600, 7200$	$0.2 \pm 0.3, 0.04 \pm 0.1, 0, 0$
North	Afterglow	0.01, 0.79	$t_{90}, 600, 3600, 7200$	$0.3 \pm 0.2, 0.04 \pm 0.1, 0, 0$
LST North	Afterglow	0.01, 0.79	$t_{90}, 600, 3600, 7200$	$0.04 \pm 0.1, 0, 0, 0$



# Conclusions

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- GRBs are still undetected sources in the VHE regime. CTA energy range, large effective area and fast repointing capabilities will allow significant progresses in understanding of this objects
- We investigated the detection prospects on GRB for CTA starting from simple physics model and making use of specific data analysis tools with the latest version of instrument response functions and array configurations
- According to a simple leptonic synchrotron+ssc model, detection capabilities are governed by the ratio of the IC and synchrotron luminosities. However, early afterglow is favored for VHE detection with respect to prompt phase
- According to our estimate, the number of possible detection per year could range between  $\sim 0.3$  GRB/year and  $\sim 3$  GRB/year depending on the GRB spectral characteristics and array layouts and in agreement with previous estimates made with different approach.
- The role of LSTs is crucial.
- Further developments are ongoing to include more emission processes and enlarge parameters space investigation. A more detailed population study is ongoing within the CTA GRB group and it will be the target of a forthcoming dedicated consortium publication