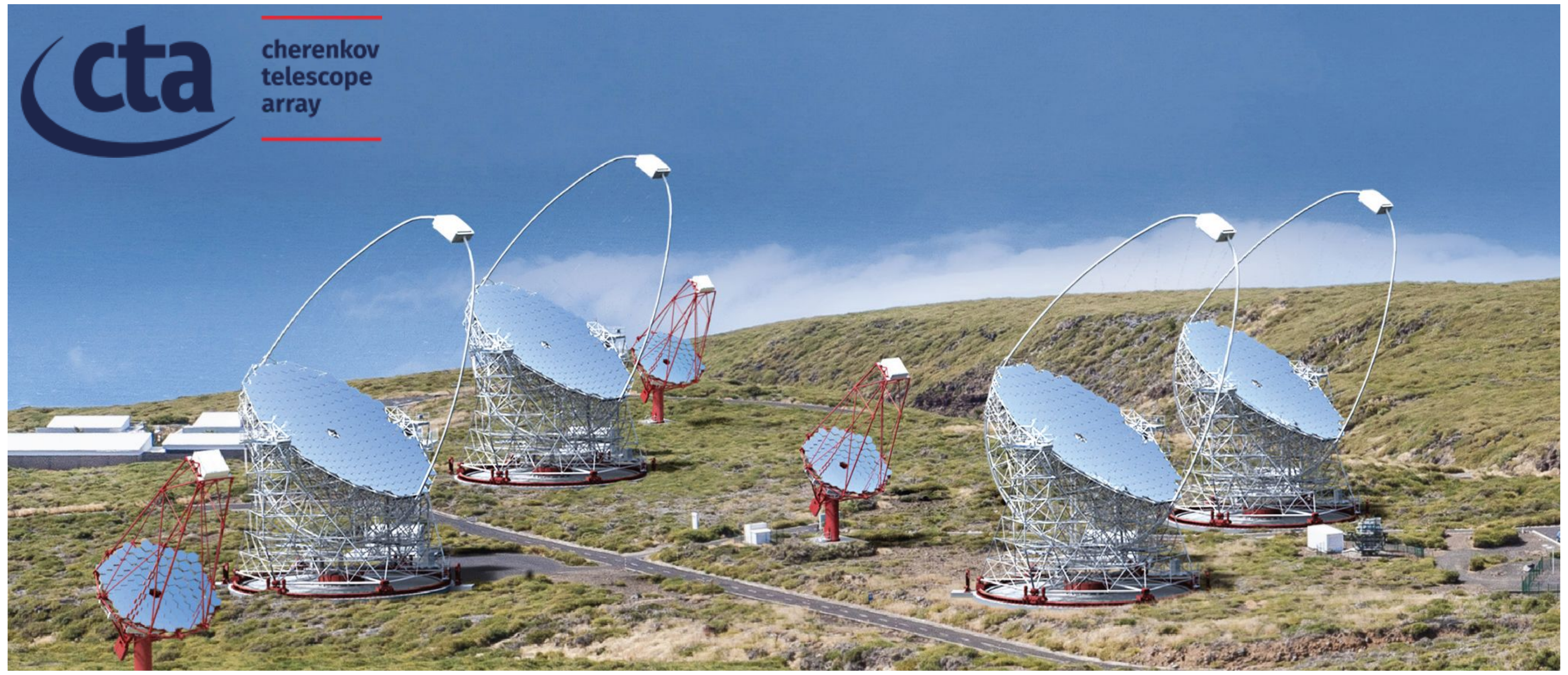

The Cherenkov Telescope Array transient and multi-messenger program

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Abstract

The Cherenkov Telescope Array (CTA) is a next generation ground-based very-high-energy gamma-ray observatory that will allow for observations in the >10 GeV range with unprecedented photon statistics and sensitivity. This will enable the investigation of the yet-marginally explored physics of short-time-scale transient events. CTA will thus become an invaluable instrument for the study of the physics of the most extreme and violent objects and their interactions with the surrounding environment. The CTA Transient program includes follow-up observations of a wide range of multi-wavelength and multi-messenger alerts, ranging from compact galactic binary systems to extragalactic events such as gamma-ray bursts (GRBs), core-collapse supernovae and bright AGN flares. In recent years, the first firm detection of GRBs by current Cherenkov telescope collaborations, the proven connection between gravitational waves and short GRBs, as well as the possible neutrino-blazar association with TXS 0506+056 have shown the importance of coordinated follow-up observations triggered by these different cosmic signals in the framework of the birth of multi-messenger astrophysics. In the next years, CTA will play a major role in these types of observations by taking advantage of its fast slewing (especially for the CTA Large Size Telescopes), large effective area and good sensitivity, opening new opportunities for time-domain astrophysics in an energy range not affected by selective absorption processes typical of other wavelengths. In this contribution we highlight the common approach adopted by the CTA Transients physics working group to perform the study of transient sources in the very-high-energy regime.

Introduction

Transients are an integral part of the CTA "Key Science Projects" (KSP). A dedicated Science Working Group is in place to prepare for the first observations (react rapidly to target of opportunities-ToO, define the observational program, prepare the science analysis, etc..) and to set up the needed multi wavelength/multimessenger connections and synergies with external facilities. The main scientific goals of the group, include the release of dedicated *consortium publications* focused on key topics such as GRBs, gravitational waves, neutrino ToOs and galactic transients. The group is also involved in other activities such as evaluating the detection prospects of serendipitous VHE transients identified via the CTA real-time analysis and the VHE transient survey, by exploring the divergent pointing capability and in association with the CTA extragalactic survey KSP.

Gamma-ray Burst

More info: [1]

From "empirical" to "theoretical" approach:

- Simulation of a GRB population by assuming a few intrinsic properties (E_{peak} & z distribution + E_{peak}-E_{iso} correlation)
- Bulk Lorentz factor distribution obtained by measured time of afterglow onset → Bulk Lorentz factor of the coasting phase
- Assumed spectrum allow to compute the flux and fluence in the energy bands corresponding to the instruments used to calibrate the sample
- Calibrated over BAT6 + SBAT4 catalogues

outcome
- GRB detection rate and parameter space study
- Spectra & Light curves
- Assess the effect on different array conf.

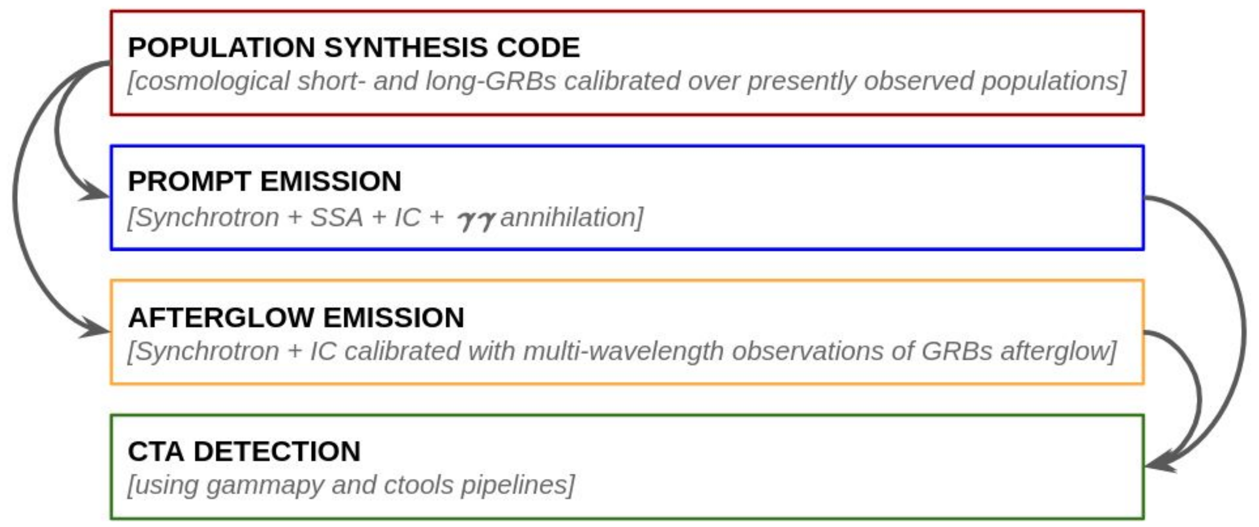


Fig 1: *Scheme of the GRB consortium publication work. Synthetic spectra and light curves are obtained by a population synthesis code and used to feed CTA analysis pipeline*

Gravitational waves

In contrast to the GRB case, a purely phenomenological approach is used:

- A short GRB is associated to each simulated binary neutron star (BNS) merger extracted from the public database GWCOSMos providing the GW skymap, distance and orientation
- VHE emission derived from the empirical correlations between X-ray and TeV luminosities (as observed in GRB 190114C)

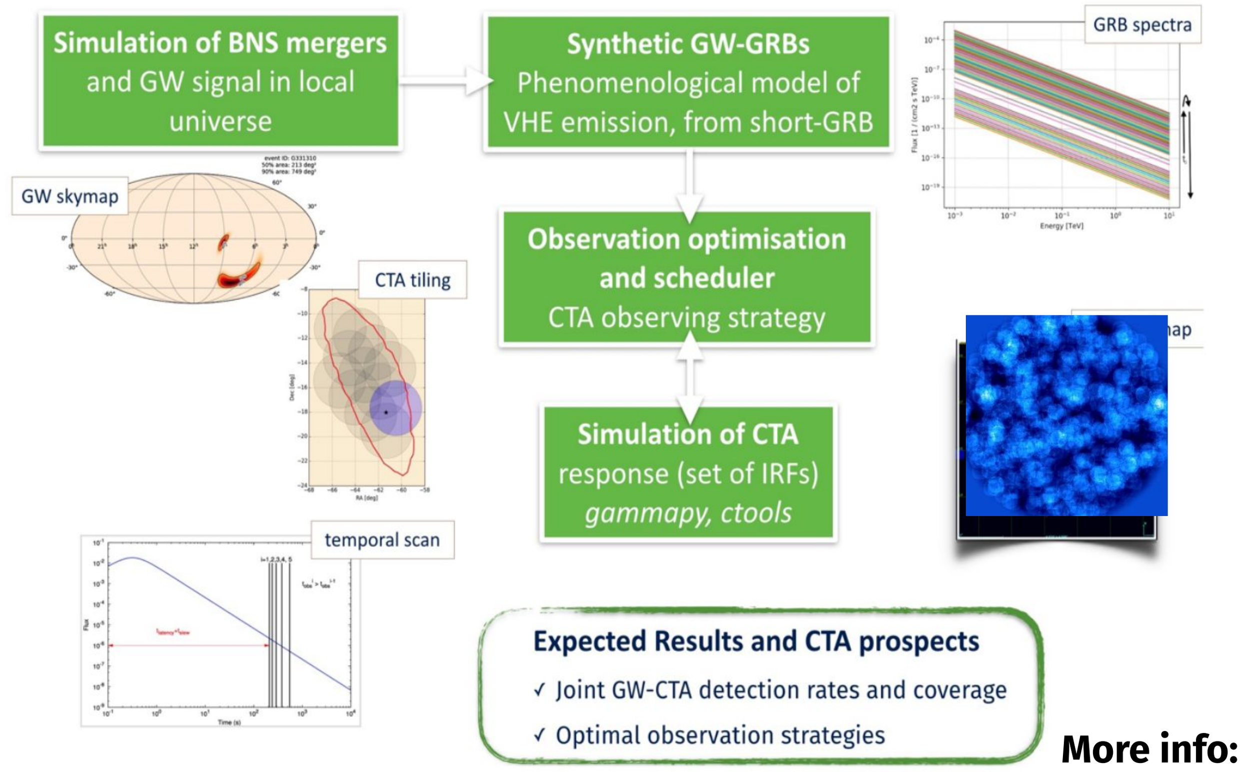


Fig 2: *Workflow of the GW consortium publication. After the simulation of BNS merger, a phenomenological (short) GRB is associated to it. The optimal pointing strategy is then obtained by dedicated algorithm in order to cover efficiently the sky area of the GW source. Each pointing is then analyzed by means of the CTA analysis pipeline.*

More info: [2]

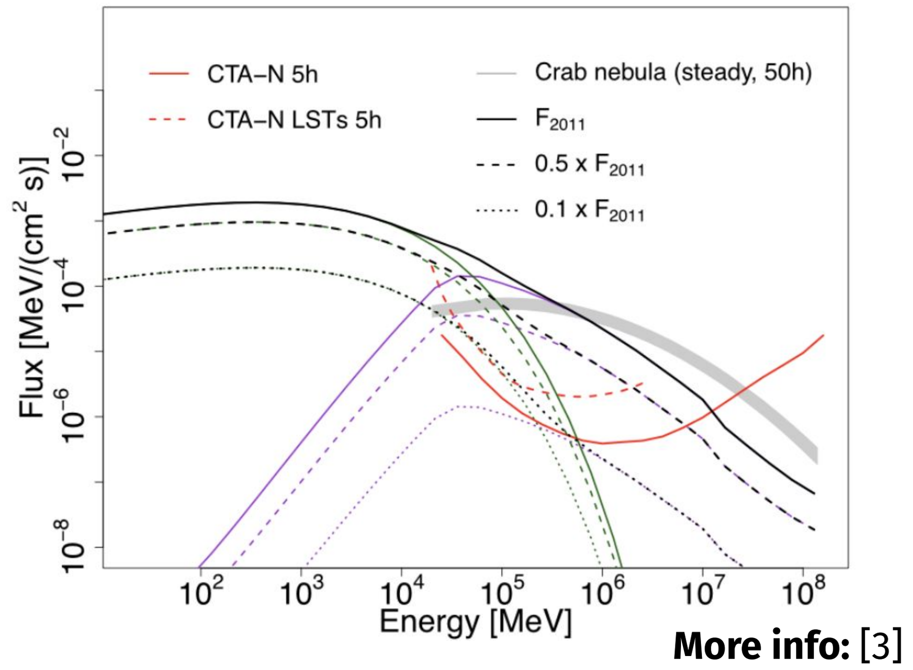
Galactic Transients

Work involving simulation and detection prospect for a wide range of galactic transients:

- Novae
- PWNe flares
- Microquasars
- Magnetars (possibly associated to FRBs)
- super giant fast X-ray transient (SFXTs)
- tMSPs

Detection prospect on possible flares or even steady emission from some specific sources: the microquasars Cygnus X-1 and Cygnus X-3 and the low-mass binary V404 Cygni; the microquasar SS433 as well as flares from the Crab Nebula PWN and emission from the tMSPs PSR J1023+0038 and PSR J1227-4853

Fig 3: *simulation of different flaring models for the Crab Nebula PWN (black lines), result of the synchrotron (green) and IC (purple) contributions. The red lines correspond to the sensitivities of CTA-North (4 LSTs + 15 MSTs - omega configuration) and to the 4 LSTs of CTA-North (for 5h). The steady Crab spectrum is plotted for comparison (gray shaded area).*

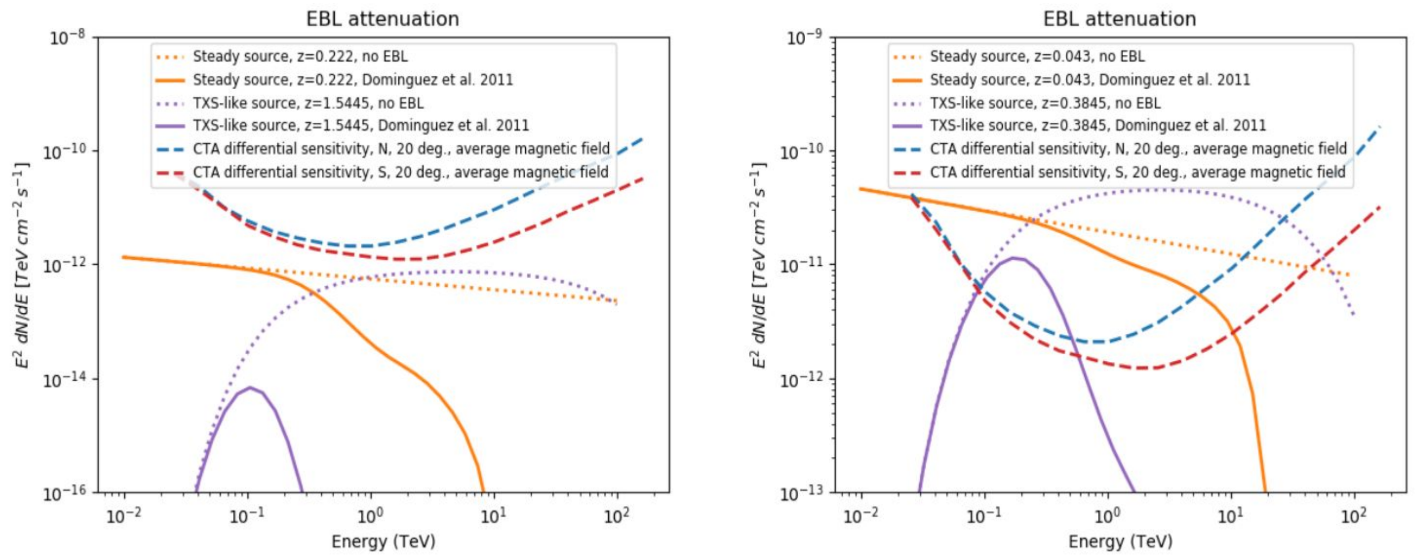


More info: [3]

Neutrino

The aim of this work is to develop a strategy for CTA follow-up of neutrino alerts to maximize the chance of detecting a VHE counterpart. Neutrino point source simulations are based on FIRESONG [4], which take into account the cosmological evolution of different source classes and the recent results from IceCube (i.e., the measured diffuse flux of astrophysical neutrinos). These are then the input for simulating gamma-ray emission and CTA follow-up .

Fig 4: *The energy spectra of potential neutrino sources (without and with the EBL attenuation) overlaid on the CTA differential sensitivity for the undetected (left) and detected (right) sources. CTA sensitivities correspond to the omega configuration for both the Southern (4 LSTs + 25 MSTs + 70 SSTs) and the Northern hemisphere (4 LSTs + 15 MSTs).*



More info: [5]

Core-Collapse Supernovae

A core-collapse supernova (CCSNe) represents the catastrophic explosion of a massive star at the end of its life. The energy is mainly released in the form of kinetic energy of a non-relativistic expanding outflow. In the resulting fast-moving shock wave, particles are accelerated via the first-order Fermi mechanism. The accelerated particles, interacting with the surrounding interstellar matter, might lead to the production of a gamma-ray signal up to the VHE band that can be potentially detected by CTA. A wide range of different types of CCSNe exists (IIP, IIL, IIb, IIn, etc.) which could each have a different signature in the VHE regime. A dedicated work for the prospect for the CTA detection of such a signal has recently started within the Transients working group.

[1] M.G Bernardini et al. (2019) *POSyTIVE, a GRB population study for the Cherenkov Telescope Array* PoS(ICRC2019)598
[2] M. Seglar-Arroyo et al. (2019) *The gravitational-wave follow-up program of the Cherenkov Telescope Array* PoS(ICRC2019)790
[3] A. López-Oramas et al. (2021) *Galactic transient sources with Cherenkov Telescope Array*, this conference, id. 224
[4] I.Taboada et al. (2019) *Constrains on the extragalactic origin of IceCube's neutrinos using HAWC* PoS(ICRC2017)663
[5] K. Satalecka et al. (2019) *Neutrino Target of Opportunity program for the Cherenkov Telescope Array* PoS(ICRC2019)784
[6] F. Halzen et al. (2019) *On the Neutrino Flares from the Direction of TXS 0506+056*, ApJ, 874, L9

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