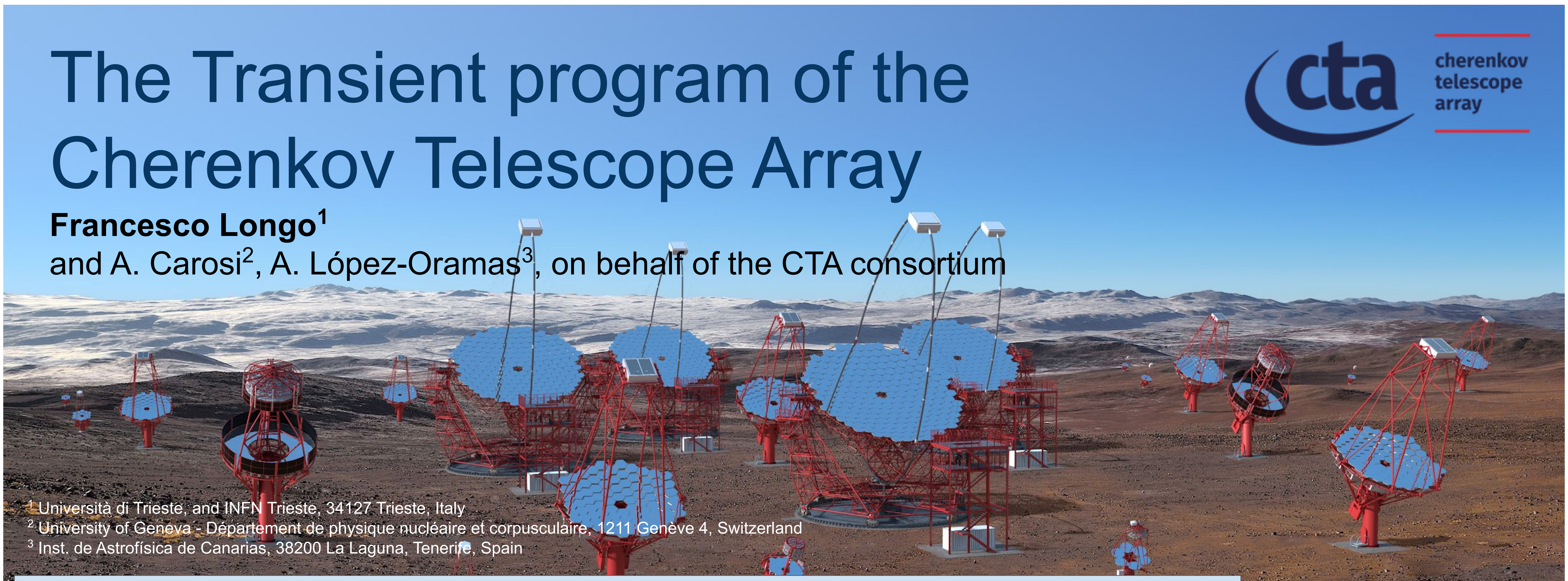
The Transient program of the Cherenkov Telescope Array



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Abstract

The Cherenkov Telescope Array (CTA) will be the next generation very high-energy (VHE) gamma-ray observatory. It will improve the sensitivity of current VHE instruments up to an order of magnitude and will cover the energy range from 20 GeV to at least 300 TeV. With its sensitivity, it will explore high redshift sources and extreme accelerators and will give access to the shortest timescale phenomena. CTA will be then a unique powerful instrument for the exploration of the transient universe. Thanks to its capabilities, CTA will play also a central role in the era of multi-messenger astrophysics. In this presentation, we will outline the CTA Transient program that includes follow-up observations of a broad range of multi-wavelength and multi-messenger alerts, ranging from Galactic transient objects to novel phenomena like Fast Radio Bursts. A very promising case is that of gamma-ray bursts (GRBs) where CTA will for the first time enable high-statistics measurements above ~10 GeV, probing new spectral components and shedding light on the physical processes at work in these systems. Dedicated programs searching VHE gamma-ray counterparts to gravitational waves and high-energy neutrinos complete the CTA transients program.

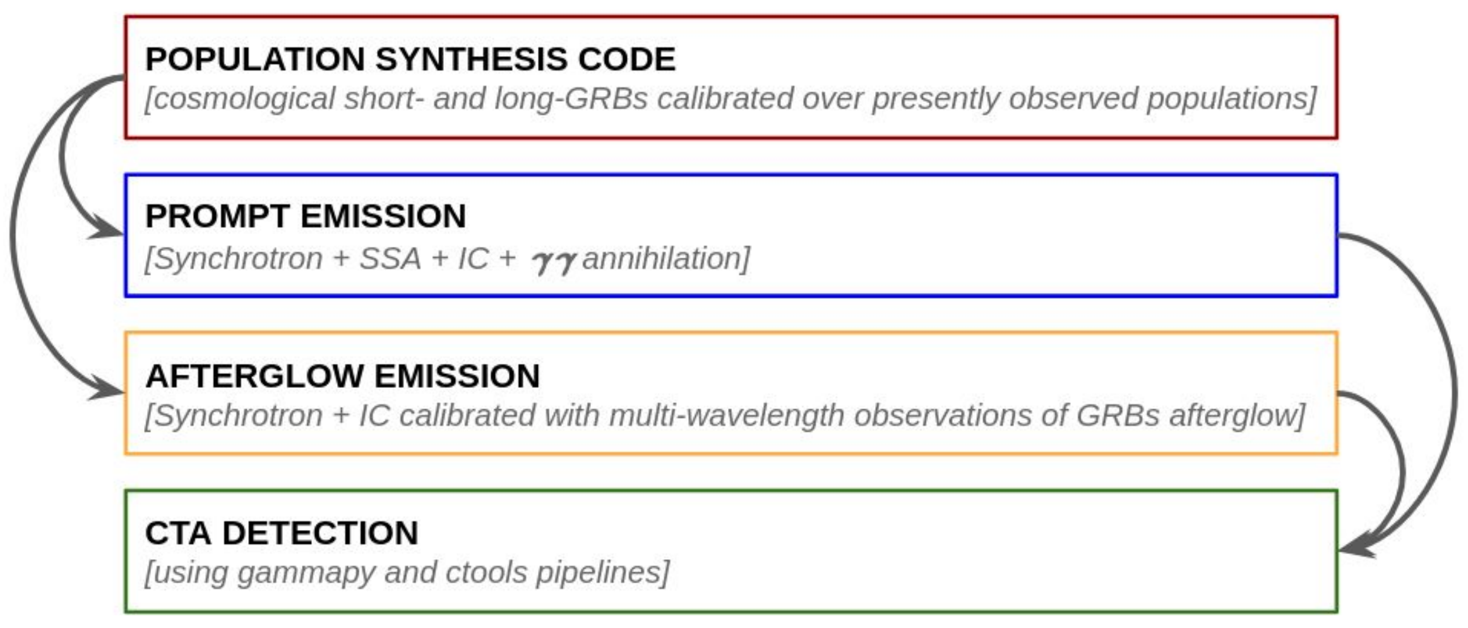
The CTA Transient working group

Transients are integral part of the CTA "Key Science Projects". A dedicated Science Working Group is in place to prepare first observations (react to fast ToO, definition of observation program, preparation of science analysis, etc..) and setup the needed multi wavelength/multimessenger connections and synergies with external facilities. The main scientific outcome of the group is the release starting from 2021 of 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 the detection prospects of serendipitous VHE transients identified via the CTA real-time analysis, in association with the CTA VHE extragalactic survey and by exploring the CTA divergent pointing capability.

Gamma-ray Bursts

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)
- ❏ Coasting phase Bulk Lorentz factor distribution obtained by measured time of afterglow onset
- ❏ Assumed GRB spectrum allows to compute the flux and fluence in the energy bands corresponding to the instruments (for example Swift/BAT) used to calibrate the sample extracted from the synthetic population used to estimate the VHE component
- ❏ Calibrated over BAT6 + SBAT4 catalogues



POPULATION SYNTHESIS CODE
[cosmological short- and long-GRBs calibrated over presently observed populations]

PROMPT EMISSION
[Synchrotron + SSA + IC + $\gamma\gamma$ annihilation]

AFTERGLOW EMISSION
[Synchrotron + IC calibrated with multi-wavelength observations of GRBs afterglow]

CTA DETECTION
[using gammapy and ctools pipelines]

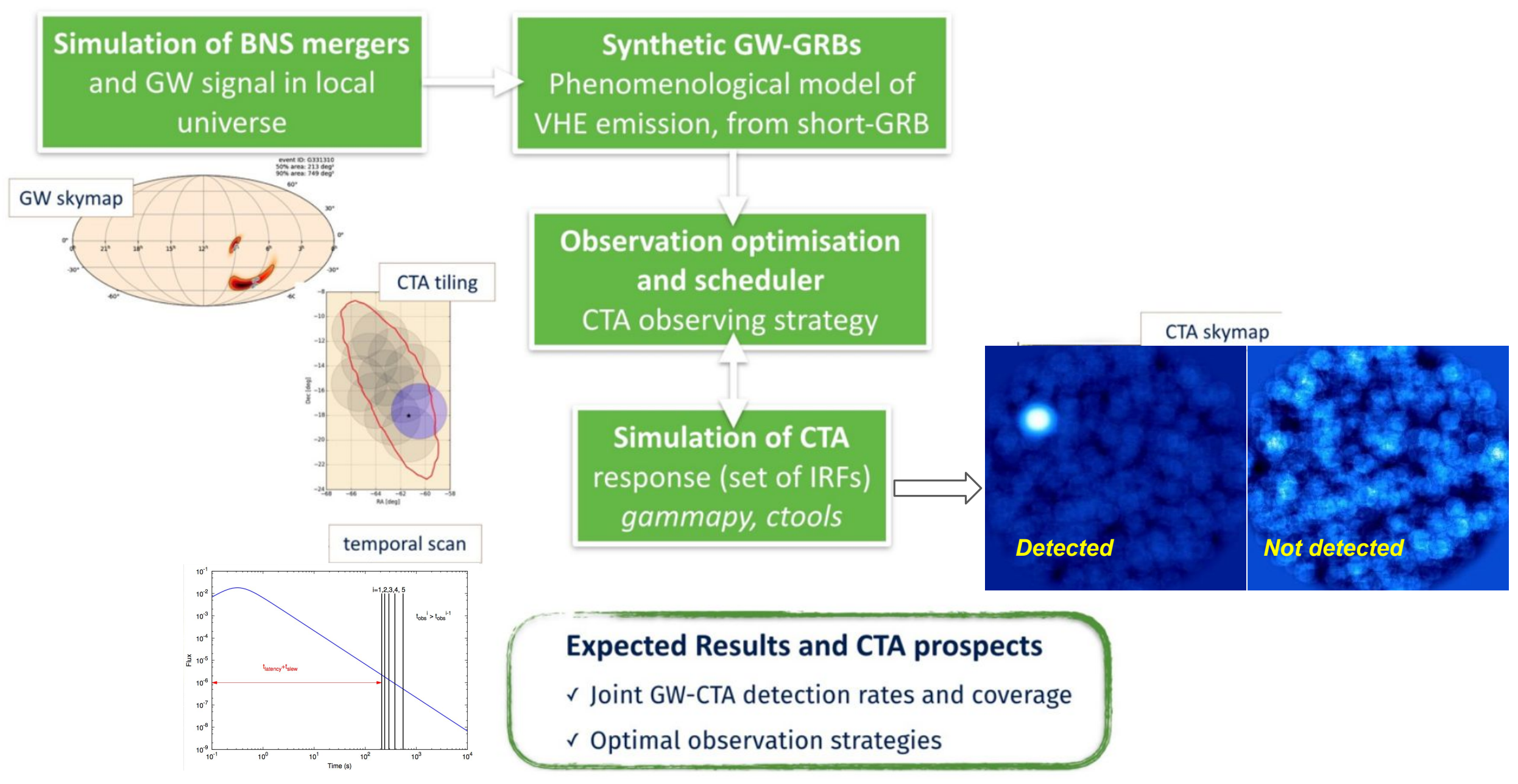
Fig 1: *Scheme of the GRB consortium publication work. Synthetic spectra and light curves are obtained by a population synthesis code and by prompt and afterglow emission codes used to feed CTA analysis pipelines.*

More info: [1] [2]

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 luminosity (as in GRB 190114C)



Simulation of BNS mergers and GW signal in local universe

Synthetic GW-GRBs Phenomenological model of VHE emission, from short-GRB

Observation optimisation and scheduler CTA observing strategy

Simulation of CTA response (set of IRFs) *gammapy, ctools*

Expected Results and CTA prospects
✓ Joint GW-CTA detection rates and coverage
✓ Optimal observation strategies

Fig 2: *Workflow of the GW consortium publication. After the simulation of BNS merger, a phenomenological (short) GRB is associated to it. The optimized 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] [3]

Galactic Transients

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

- ❏ Core Collapse Supernovae
- ❏ Novae
- ❏ Pulsar wind nebulae (PWN) flares
- ❏ Microquasars
- ❏ Magnetars (possibly associated to FRBs)
- ❏ Super giant fast X-ray transients
- ❏ Transitional millisecond Pulsars (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 (detected both by Fermi-LAT and at higher energies by HAWC); flares from the Crab Nebula PWN and emission from the tMSPs PSR J1023 and PSR J1227

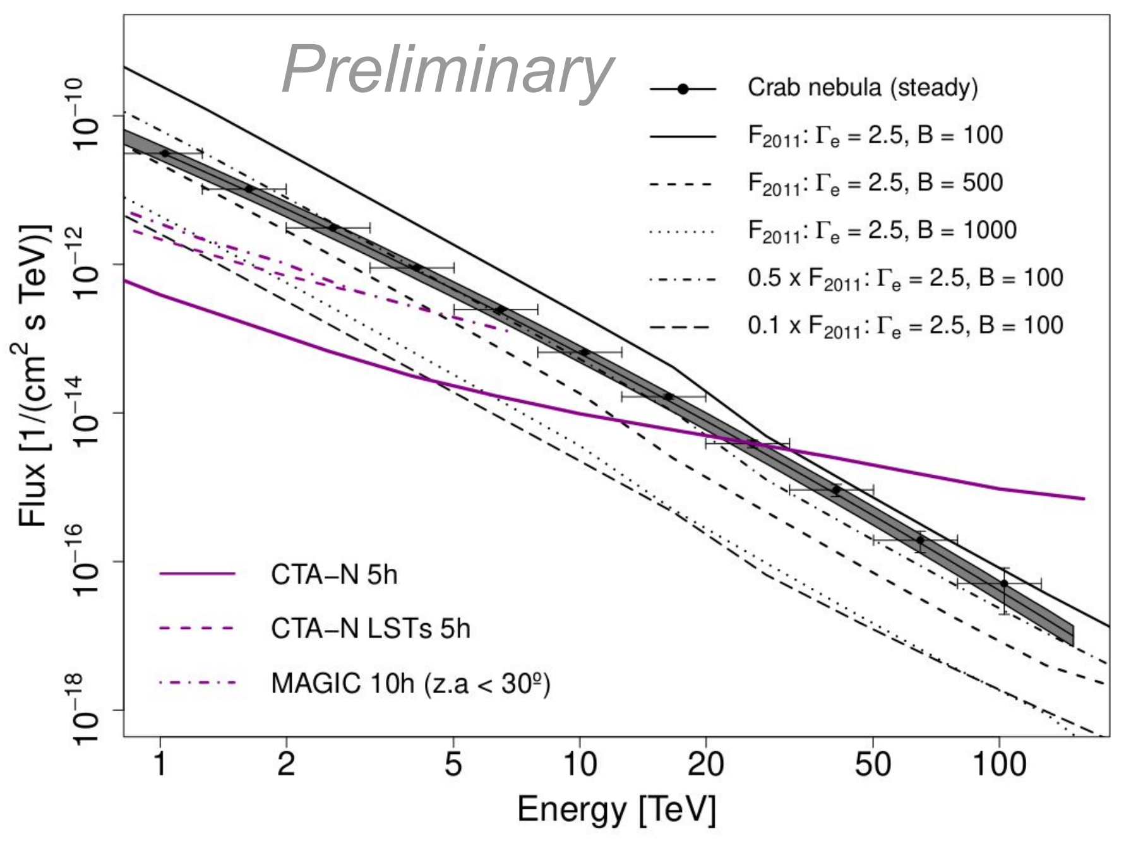


Fig 4: *The expected flux measured during a Crab flare in the TeV energy range, using different spectral indexes Γe and magnetic field values B (in μG) under different configurations of the CTA-North array (full array 5h, 4 LSTs 5 h and MAGIC sensitivity 10h, for comparison) for a variety of flares [7].*

More info: [8]

Neutrinos

The aim of this study is to develop a strategy for CTA follow-up of neutrino alerts for maximizing chances of the VHE counterpart detection. Neutrino point sources 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 inputs for simulating gamma-ray emission and CTA follow-up .

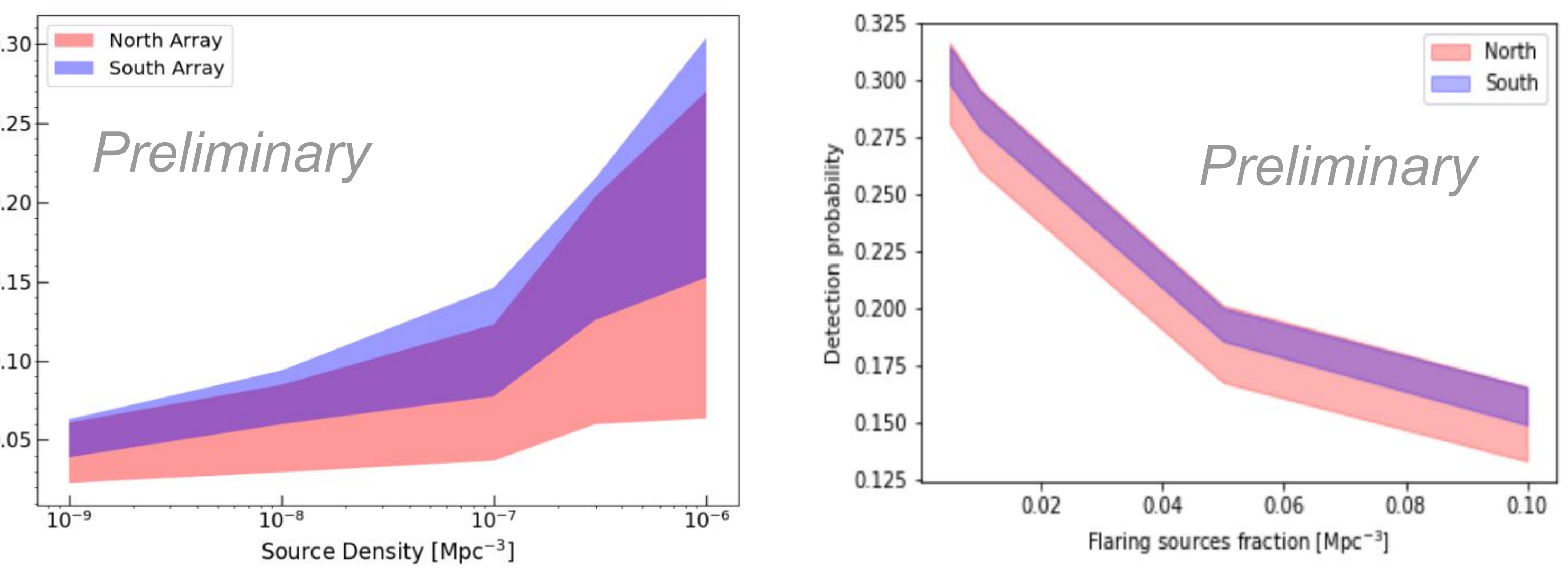


Fig 3: *Probability to detect a neutrino source with CTA in the case of steady sources as a function of the local source density (left panel) and in the case of "TXS 0506+056 - like" blazars, based on the emission model proposed by [6] as a function of the flaring sources fraction (right panel) [5].*

More info: [4] [5]

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