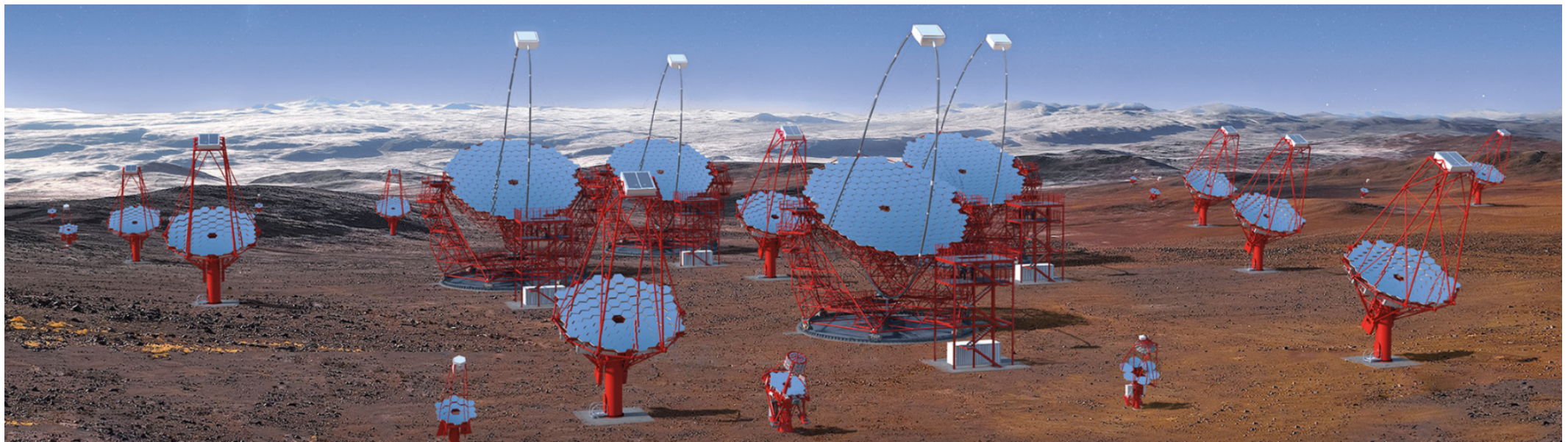




Synergies between CTA and Theseus

Francesco Longo (University and INFN, Trieste)

F.Schüssler, R.Zanin, G.Ghirlanda and A.Stamerra

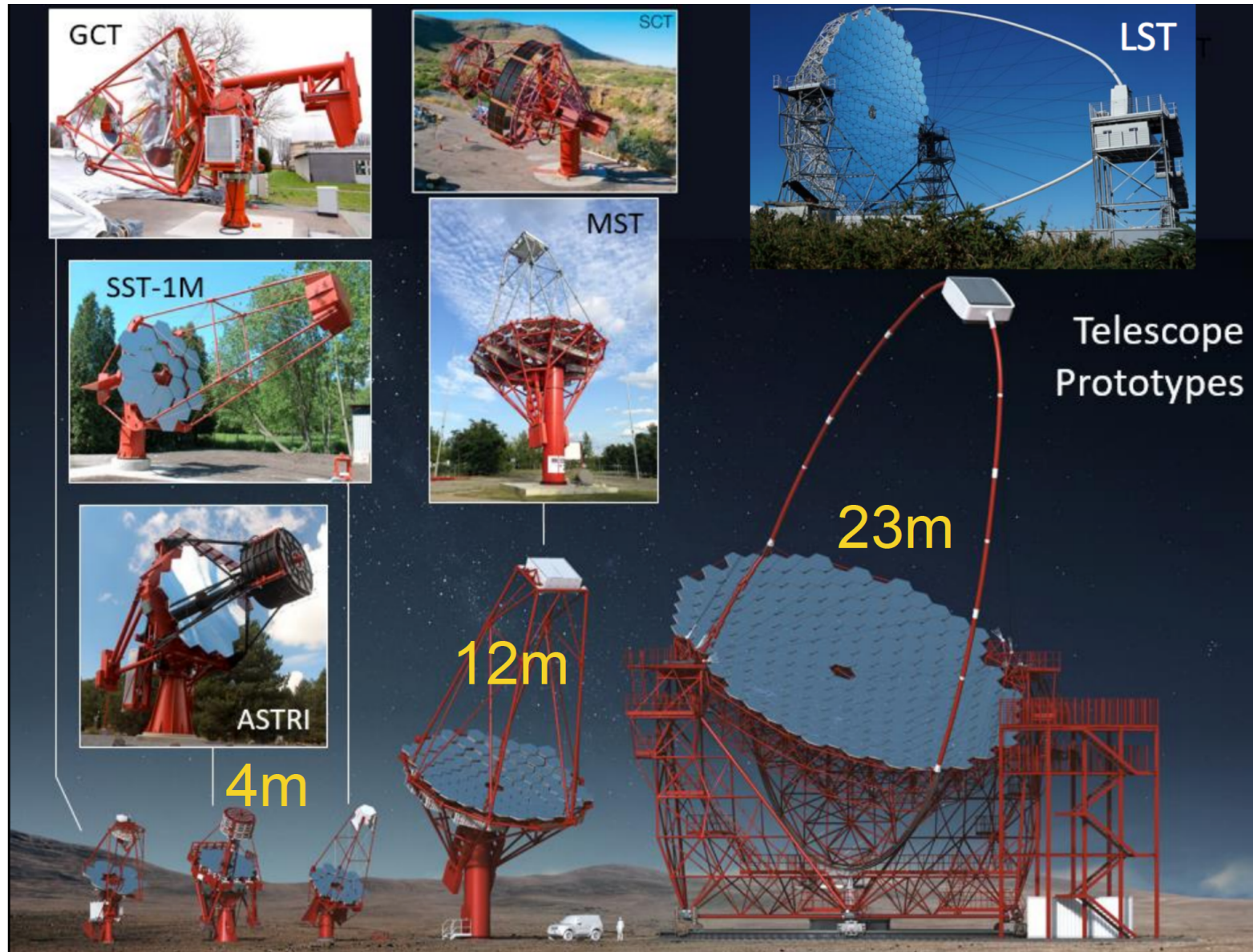


The Cherenkov Telescope Array

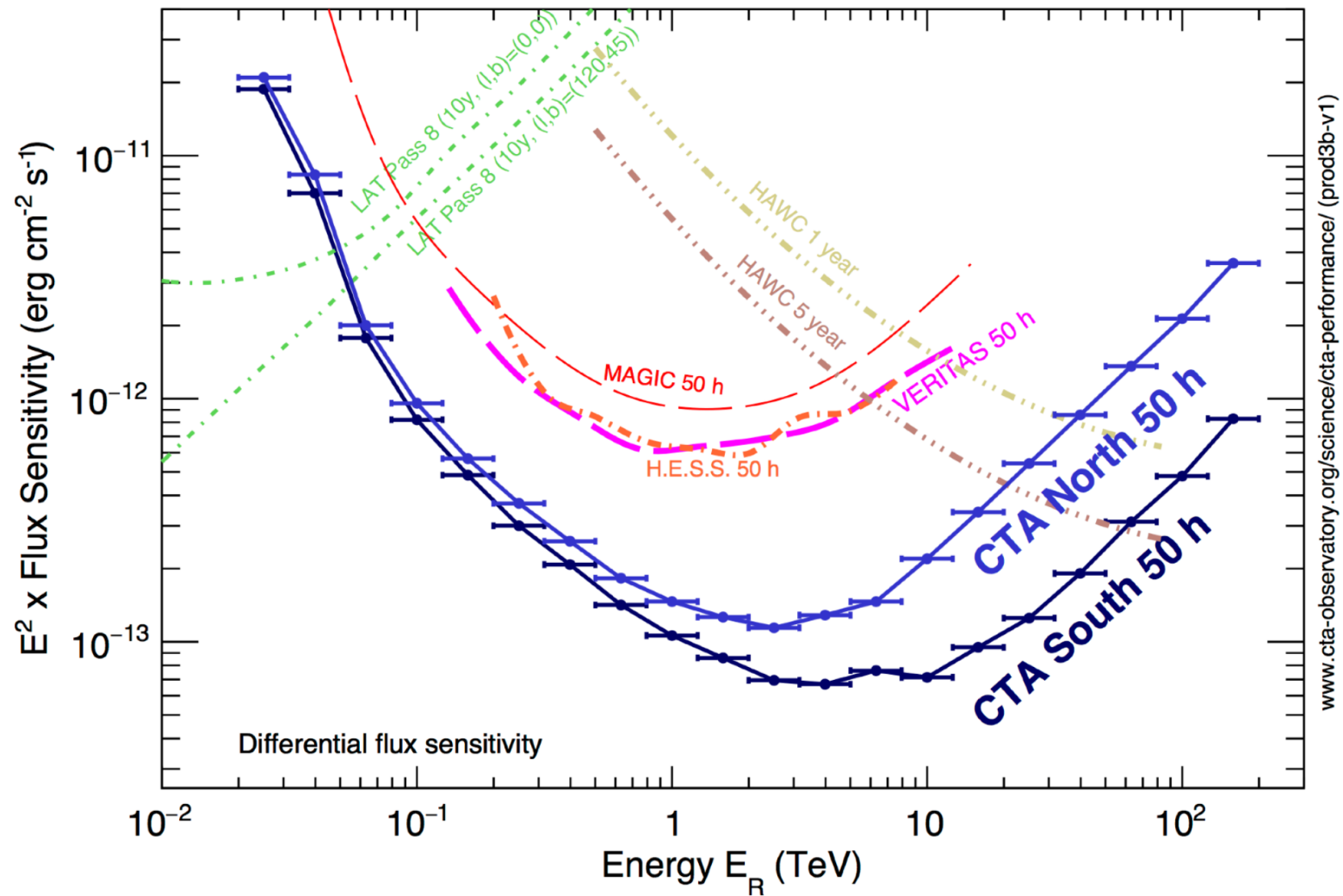
- A global project: one site on each hemisphere + headquarters + science data management center



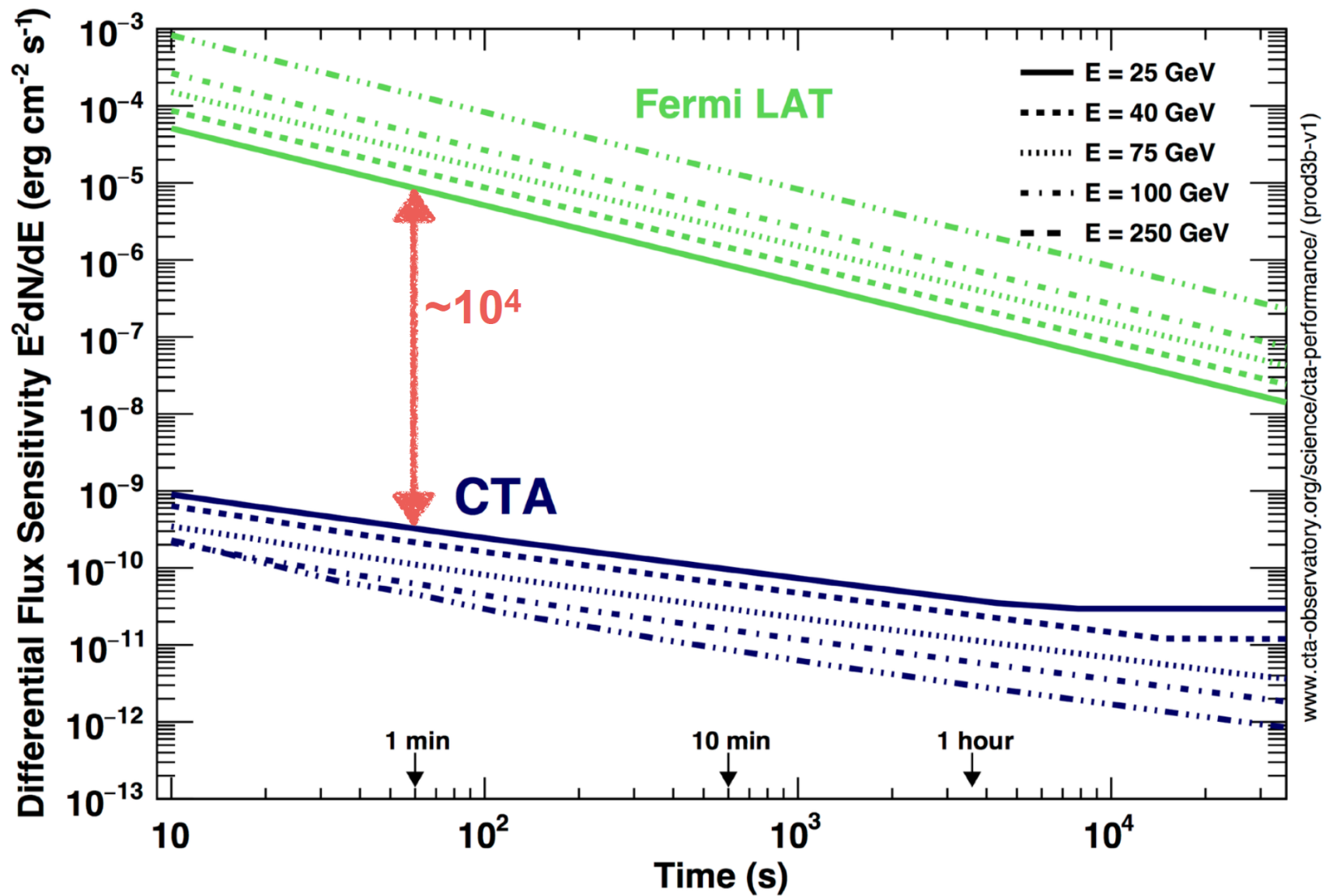
The Cherenkov Telescope Array



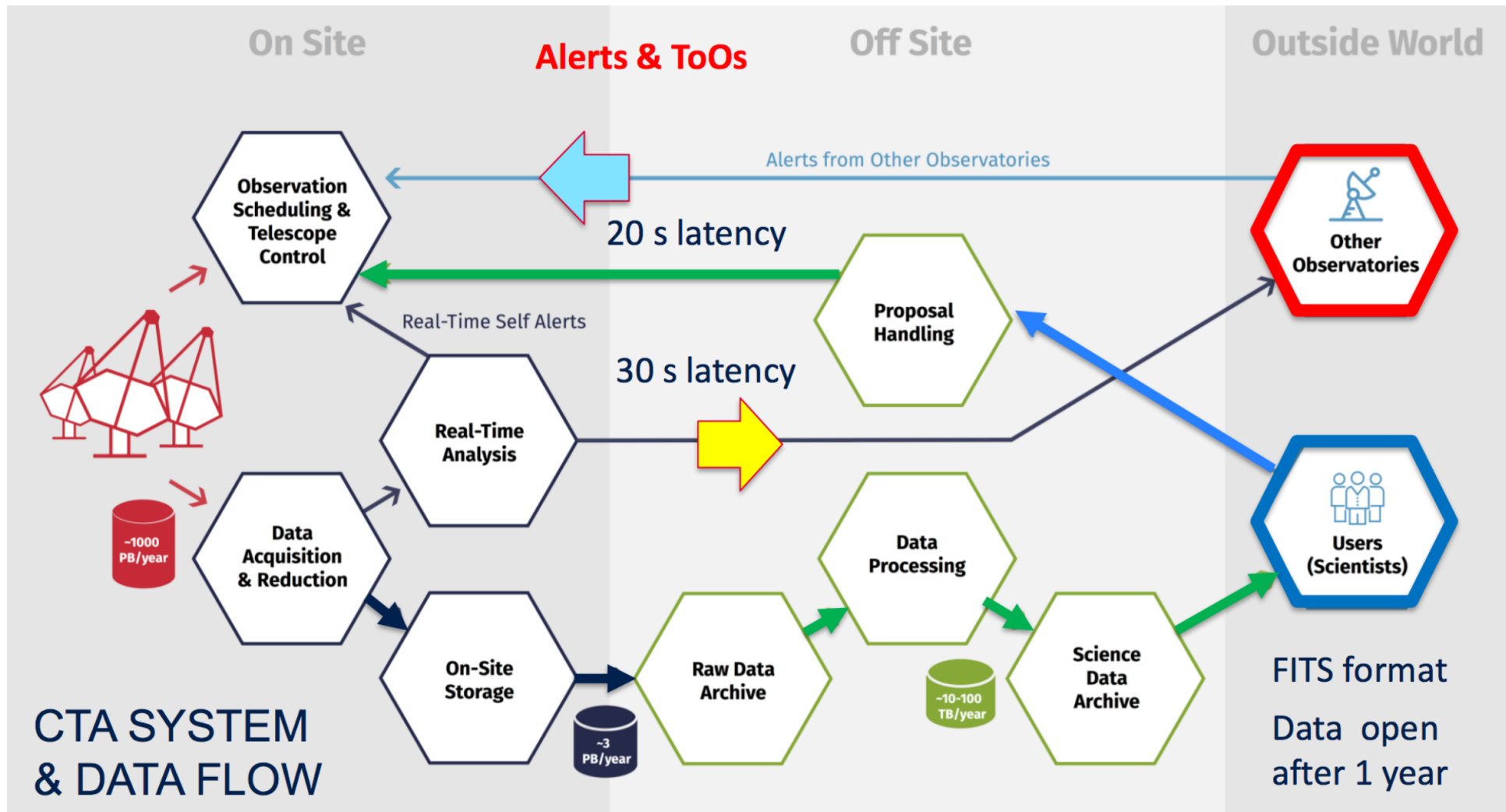
The Cherenkov Telescope Array



The Cherenkov Telescope Array

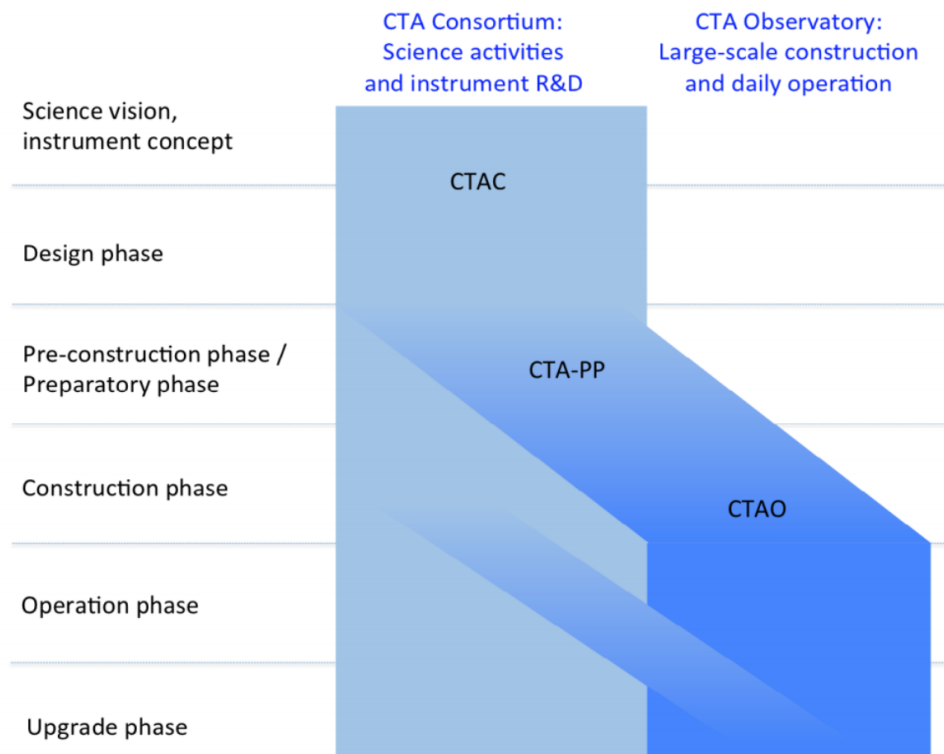


Real time alerts with CTA



The CTA observatory

- built and operated by the "CTA observatory" (CTAO, Bologna)
- in-kind contributions by the "CTA consortium" (CTAC)
- observation time allocated to the CTA consortium for Key Science projects



- CTA as open observatory
- Regular AOs
- Proposals evaluated by TAC
- Observations carried out in queue mode
- Fully calibrated photon lists and analysis tools provided to observers
- Data open after proprietary period of 1 year

From:
Concept for CTA
construction and operation
WH 2011/12

The key science projects

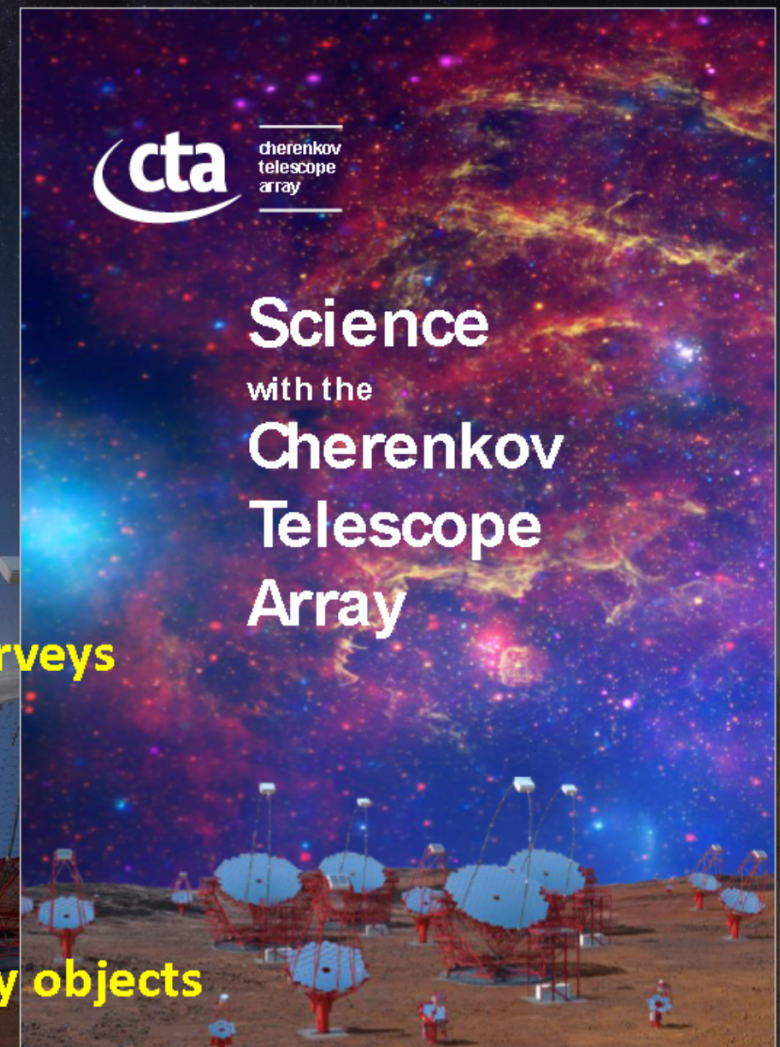
KEY SCIENCE PROJECTS

provide legacy data sets and data products

1. Dark Matter Programme
2. Galactic Centre
3. Galactic Plane Survey
4. Large Magellanic Cloud Survey
5. Extragalactic Survey
6. Transients
7. Cosmic-ray PeVatrons
8. Star-forming Systems
9. Active Galactic Nuclei
10. Cluster of Galaxies
11. Beyond Gamma Rays

Surveys

Key objects

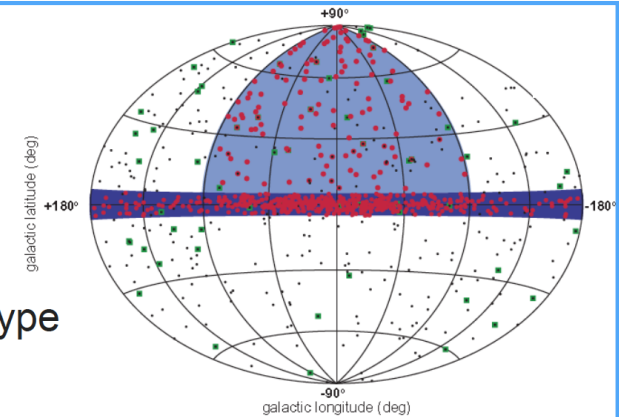


www.worldscientific.com/worldscibooks/10.1142/10986

The Key Science projects

CTA surveys

- CTA will cover large portions of the sky
 - large telescope FoV: 4 - 10deg depending on telescope type
 - may be increased by divergent pointing
- important survey programs (Galactic + Extragalactic)
- input for the THESEUS Guest Observer program
 - joint MWL studies of interesting objects
- CTA will be triggering external observatories like THESEUS during all observations (surveys, pointed observations, etc.)
 - Trigger emission timescale: $O(30s)$, i.e. much shorter than THESEUS reaction times



The Key science projects

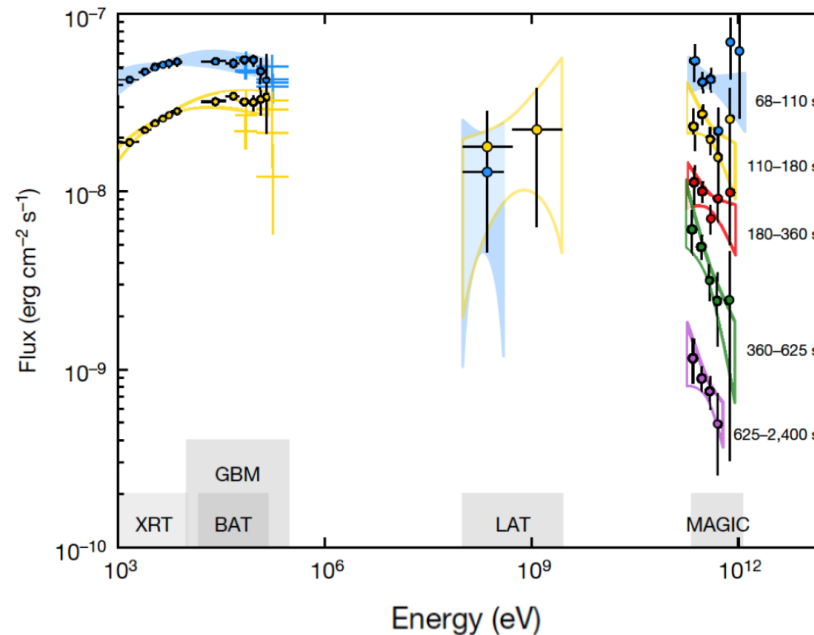
The CTA Transient program

- Transients are integral part of the CTA "Key Science Projects"
- dedicated Science Working Group "Transients and MWL"
 - Preparation of the first observations (reaction to external ToOs, definition of observation program, preparation of science analysis, etc.)
 - Setup of multi-wavelength/messenger connections
 - Main topics: gamma-ray bursts, gravitational waves, high-energy neutrinos, FRBs, Galactic transients (e.g. microquasars, novae, magnetars, etc.)
- Also: AGN monitoring program + survey of the extragalactic sky + ...
- Note: at the THESEUS timescale most (all?) of the CTA observations will be driven by Guest Observer programs



GRB in the TeV energy range

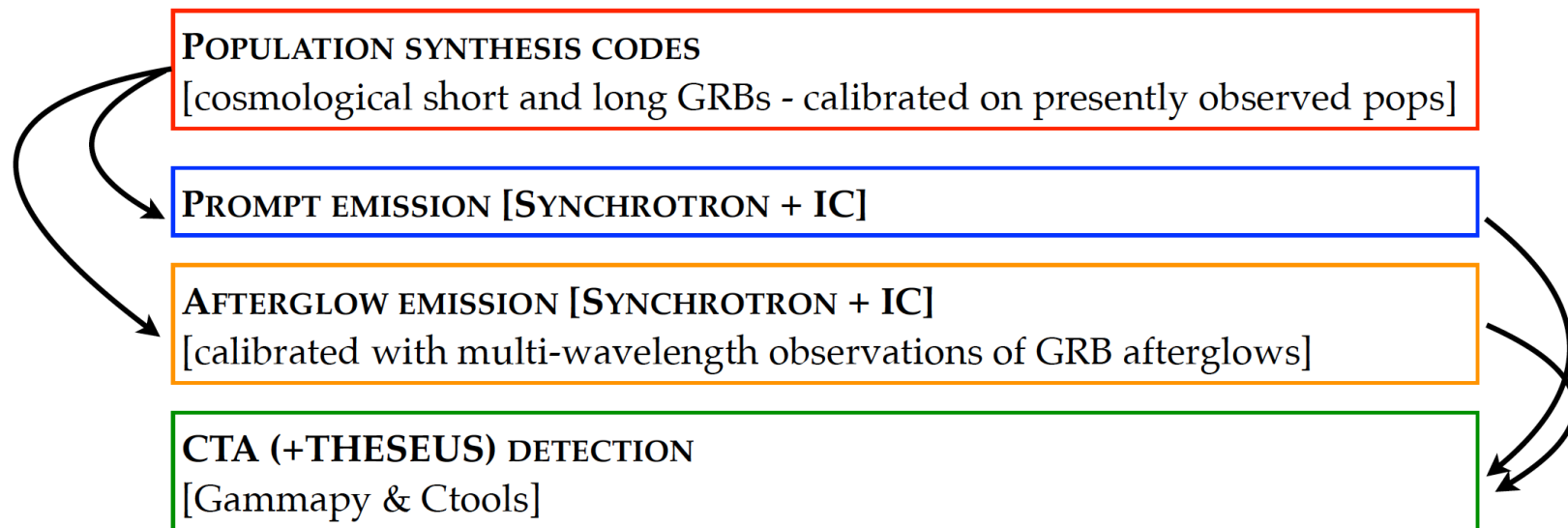
- Important program with strong links to most other topics (GW!, neutrinos?, etc.)
- Recent breakthroughs:
 - GRB180720B: $>100\text{GeV}$ emission 10h after the burst (H.E.S.S., *Nature* **575**, 464–467 (2019))
 - GRB190114C: $>300\text{GeV}$ emission 50s after the burst (MAGIC, *Nature* **575**, 459 (2019))
 - GRB190829A: VHE detection after 4h (ATEL #13052)



MAGIC collab. et al.,
Nature **575**, 459 (2019)

GRB with CTA

- Detailed study to assess the potential of the CTA GRB program
- Core input: GRB population by G. Ghirlanda et al.
 - Clear synergies with THESEUS study
 - Possible extension of the CTA internal study: derive the GRB parameter space accessible by joint CTA and THESEUS
- Timescale: mid/end 2020, hopefully ready for the Yellow Book

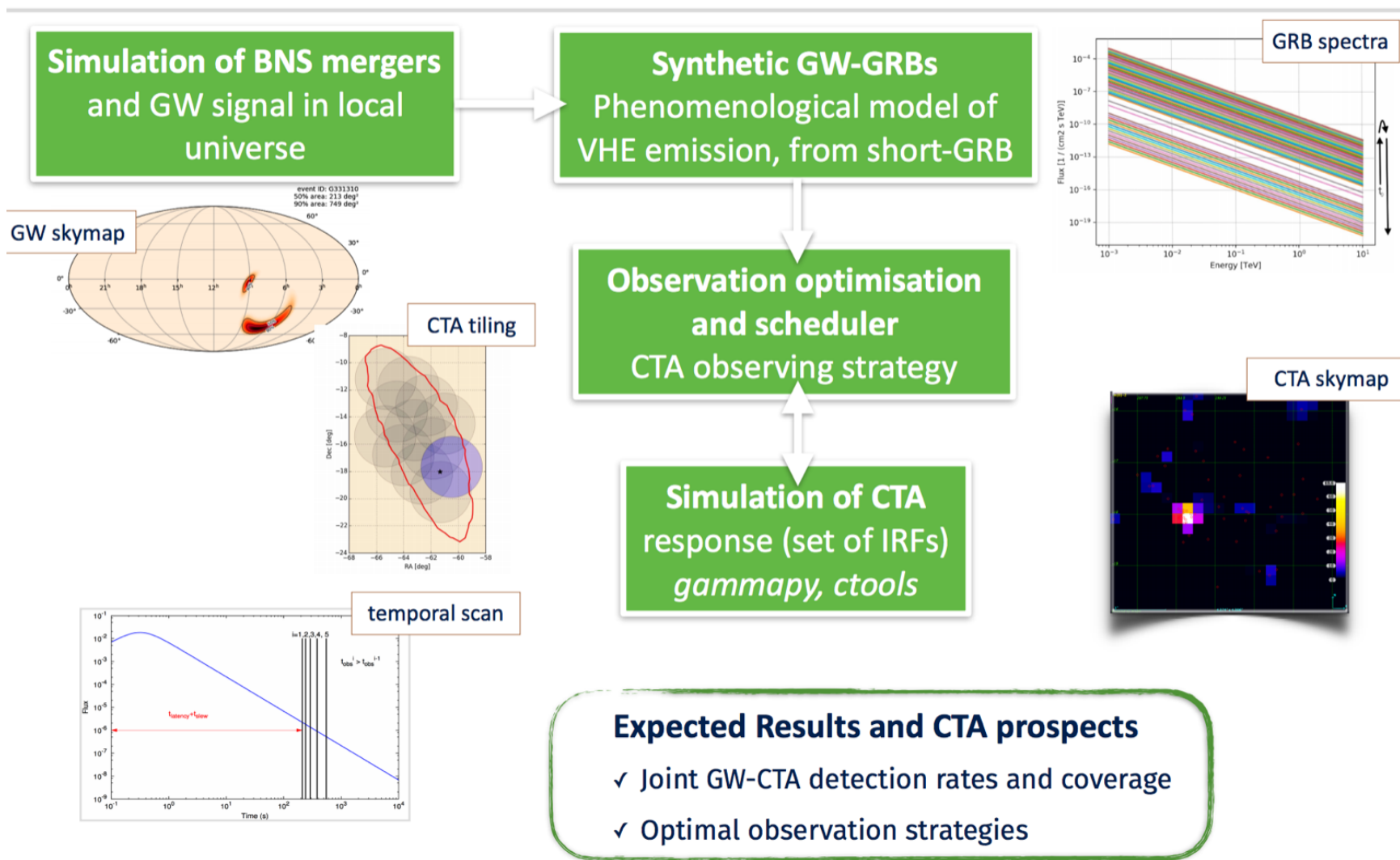


M.G. Bernardini et al. (CTA), PoS(ICRC2019)598

GRBs with CTA & Theseus

- Theseus will serve as a GRB trigger provider to the world (and for CTA...)
 - A fraction (to be estimated) of the events triggered by Theseus followed and detected by CTA
 - The same approach used by Theseus (based on a population study) is used by CTA. Therefore the predictions on the synergies will be straightforward.
- An interesting case considering the larger detection rates of Theseus at any redshift compared to Swift
- Moreover, the softest energy range probed by the soft X-ray instrument (SXI) will uncover, at low redshift (where the EBL is not going to kill the flux) the soft and sub luminous population of GRBs.
 - It will be relevant to explore the sources and their emission with CTA.
 - The present detections, except 190829A, are all relatively normal-to-energetic GRBs.
 - Focus on the low redshift events.
 - CTA key points in providing a view of GRB in the TeV energy range.

GW with CTA



M. Seglar-Arroyo et al. (CTA) PoS(ICRC2019)790

GW and CTA

- Theseus is a key instrument to associated the GW alerts to an e.m. counterpart, and to select useful GW alerts, among the several expected during CTA and GW-interferometers operations.
 - From 2030 it will be the only X-ray instrument available (plus Athena and, possibly, SVOM).
 - CTA data will be important to interpret the whole emission and the energetics.
- The GW-shortGRB connection
 - The connection between Theseus (real-time alerts, localisation, energy estimation) and CTA is clear for GRB.
 - The Connection between short-GRB and BNS mergers, and the corresponding GW emission is established
 - The advantage of Theseus is the extension of the parameter space to lower flux and softer short GRBs
 - study more soft/dim off-axis sGRB, which should be the majority of the corresponding events associated to GW

GW and CTA

- GW alerts and e.m. counterparts
 - Theseus will flight when CTA will be in full operation since few years.
 - In that period GW interferometers will be in a well advanced O5 phase (2025-2026), and this will presumably bring to a good localisation, at least for nearby mergers and bright collapsing objects. During O5 the interferometers can provide good localisation for nearby ($\sim < 200 \text{ Mpc}$) BNS, but it will be similar to the present ($> 100\text{-}1000 \text{ deg}^2$) for more distant ones;
 - In this case the wide field and good localisation of Theseus will be pivotal to let all telescopes, not just CTA, find out the e.m. counterpart.

GW and CTA

- Selection of promising GW e.m. alerts for CTA
 - Theseus can be used to select those that:
 - 1. have an identified X-ray counterpart;
 - 2. have a good localisation;
 - 3. are bright enough in X-rays to foresee a possible TeV emission (which, to the present knowledge, follows the X-ray emitted power).
- To be or not to be a GRB
 - X-ray emission may not be detected in many GW alerts;
 - Most of them will be off-axis and thus the X-ray emission will be observed in later time (hours/days).
 - In these cases, Theseus is important to understand if X-ray emission is detectable during the early phases.
 - How much the off-axis can affect our CTA detection, since it depends on still uncertain details (jet structure, angle...).
 - In this respect, delayed observations with CTA can pose interesting constraints on the interpretation of the delayed emission and on the jet structure, and angle.

GW and CTA

■ Interpretation

- Return of joint CTA-Theseus observations in terms of interpretation and modelling.
- The detection of GeV-TeV emission has strong implications on the energetics of the whole phenomenon, and its interpretation is based on the two key energy ranges, X-rays (soft to hard) and TeV, as was seen with GRB190114C.
- This is also where CTA can definitely add information to Theseus data.

■ Joint Rates

- Assuming a standard jet shape Theseus can detect 5-15 joint GW/GRB per year (see e.g. Stratta+2018) with conservative assumptions. This is the number of joint events that we may expect to follow with CTA.
- GW events that could be detected in the O5 scientific run can reach up to redshift~2 (which may be explored by CTA).

Conclusions

- MWL/MM input necessary for most CTA science cases
 - X-ray domain crucial for interpretations/modelling
- Key Science Projects: significant dataset of the VHE sky (e.g. surveys)
 - Useful as input to the THESEUS GO program
 - Transients
 - Alerts to CTA on a large range of objects/sources (GRBs!) => CTA reaction $O(30s)$!
 - Public alerts from CTA on transient emission from known and unknown sources
 - Real-time analysis => alert emission with $O(30s)$
- CTA will be an observatory
 - A lot of opportunities for joint programs + ToOs
 - At the THESEUS timescale most of the CTA observations will be driven by Guest Observer programs