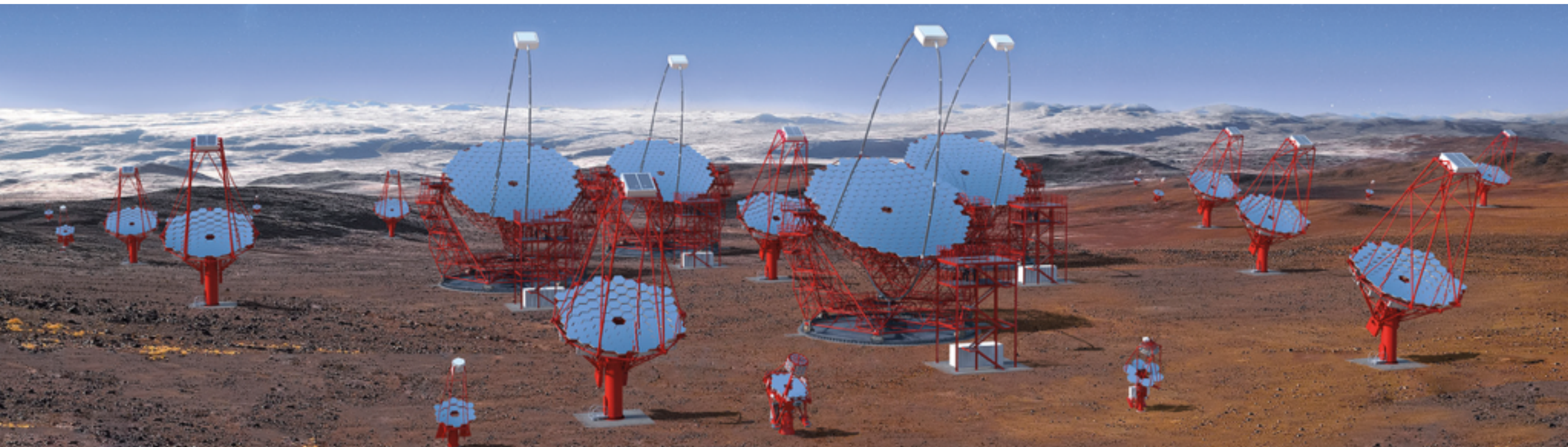
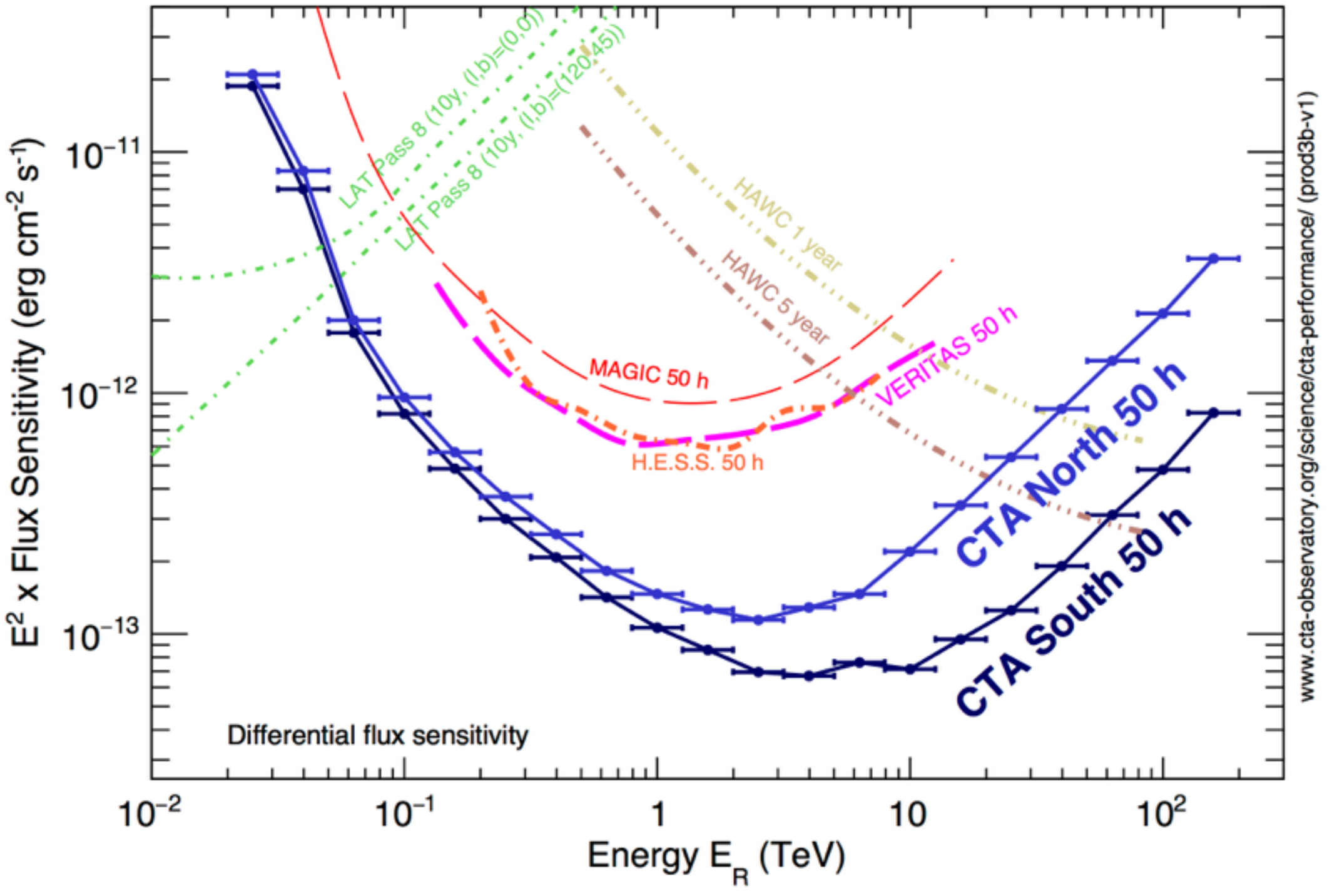
The Transient program of the Cherenkov Telescope Array

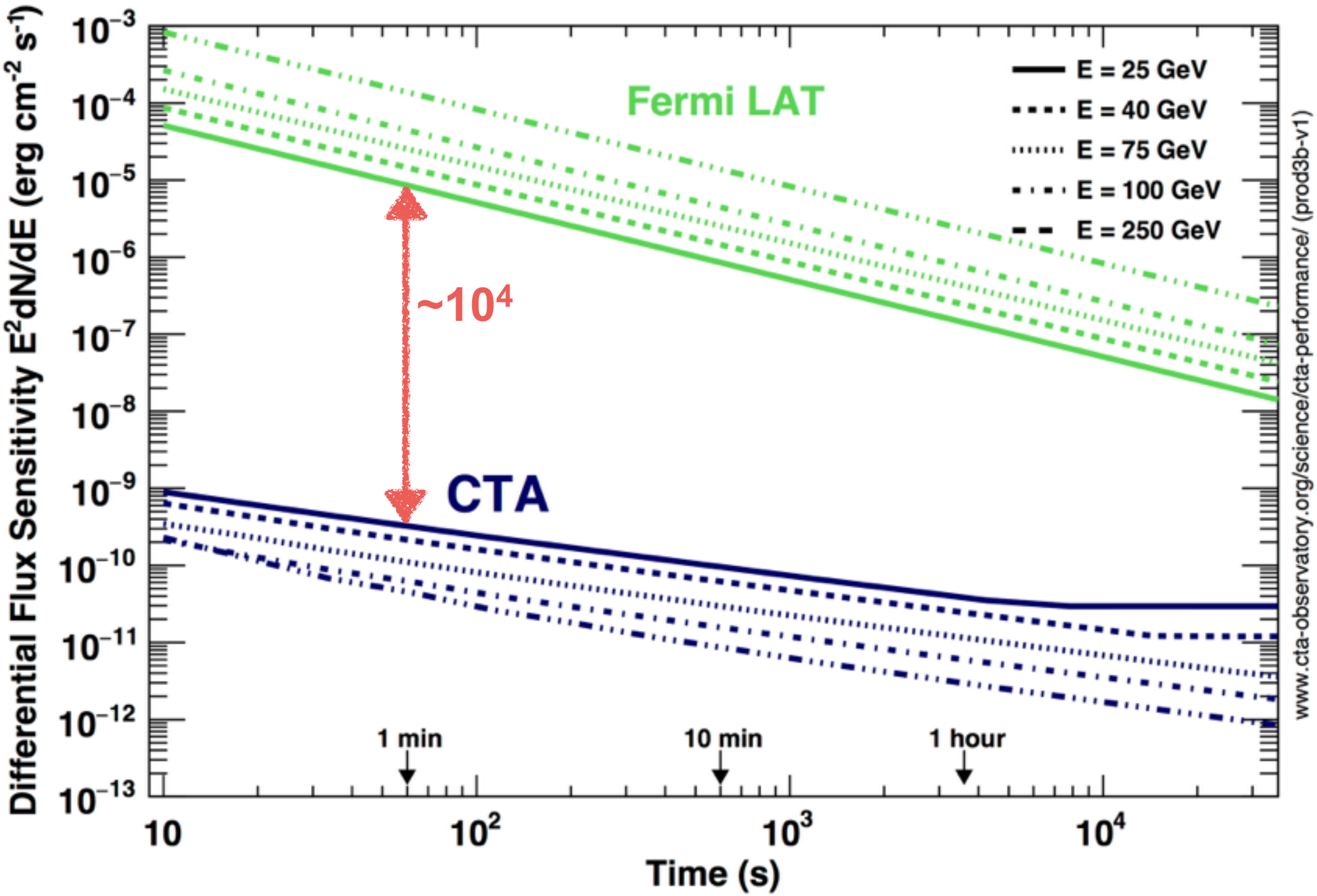
Fabian Schüssler
IRFU / CEA Paris-Saclay

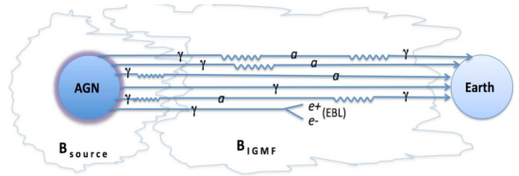


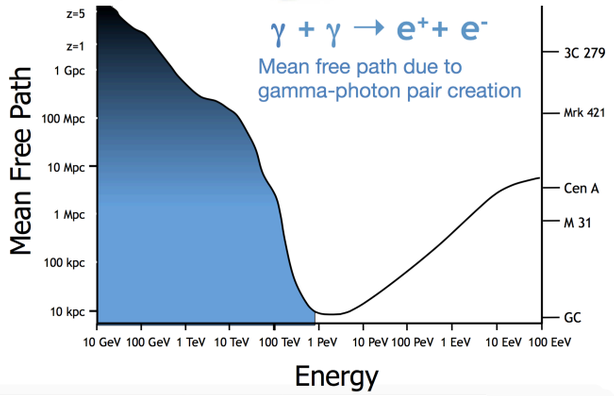
Sensitivity

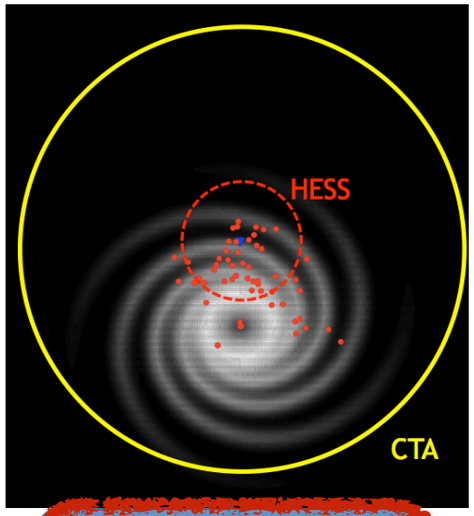


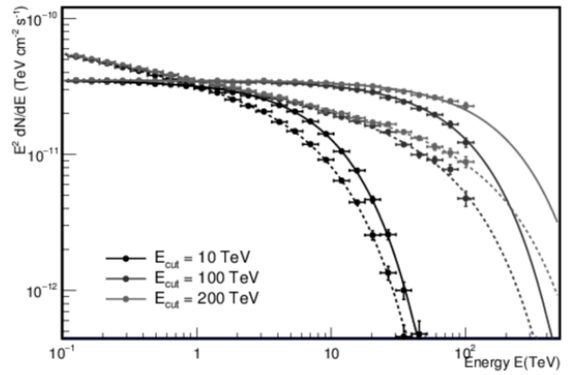
Sensitivity to transient emission

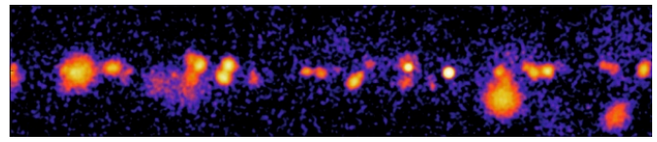








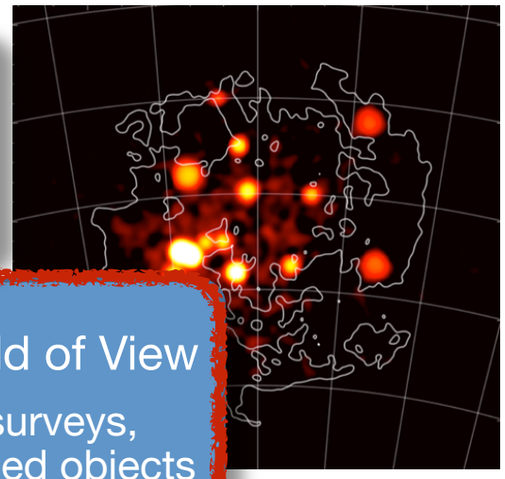


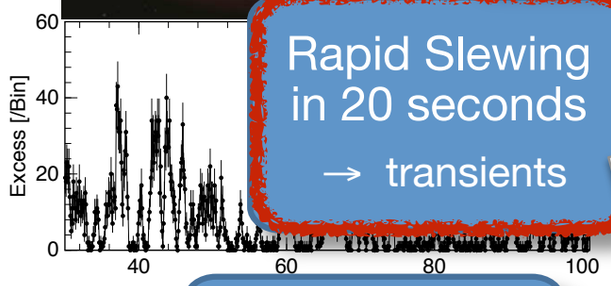


Energies down to 20 GeV
→ Cosmology++

10 x Sensitivity, Large Collection Area
→ all topics

Energies up to 300 TeV
→ Pevatrons



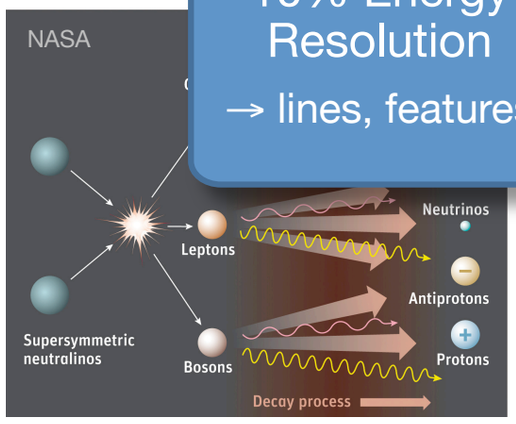


Rapid Slewing in 20 seconds
→ transients

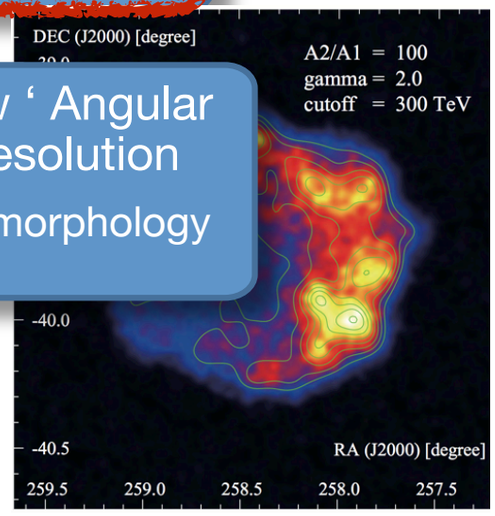
8° Field of View
→ surveys, extended objects

cta
cherenkov telescope array

10% Energy Resolution
→ lines, features



Few ‘ Angular Resolution
→ morphology



The CTA Transient program

- Transients are integral part of the CTA ”Key Science Projects”
  - Observation time allocated to the CTA consortium
- 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.)
  - Real-time analysis of the data => emission of notifications/alerts (internal + external)
- Also: AGN monitoring program + survey of the extragalactic sky + …

The CTA Transient program

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current status of proposed observation program

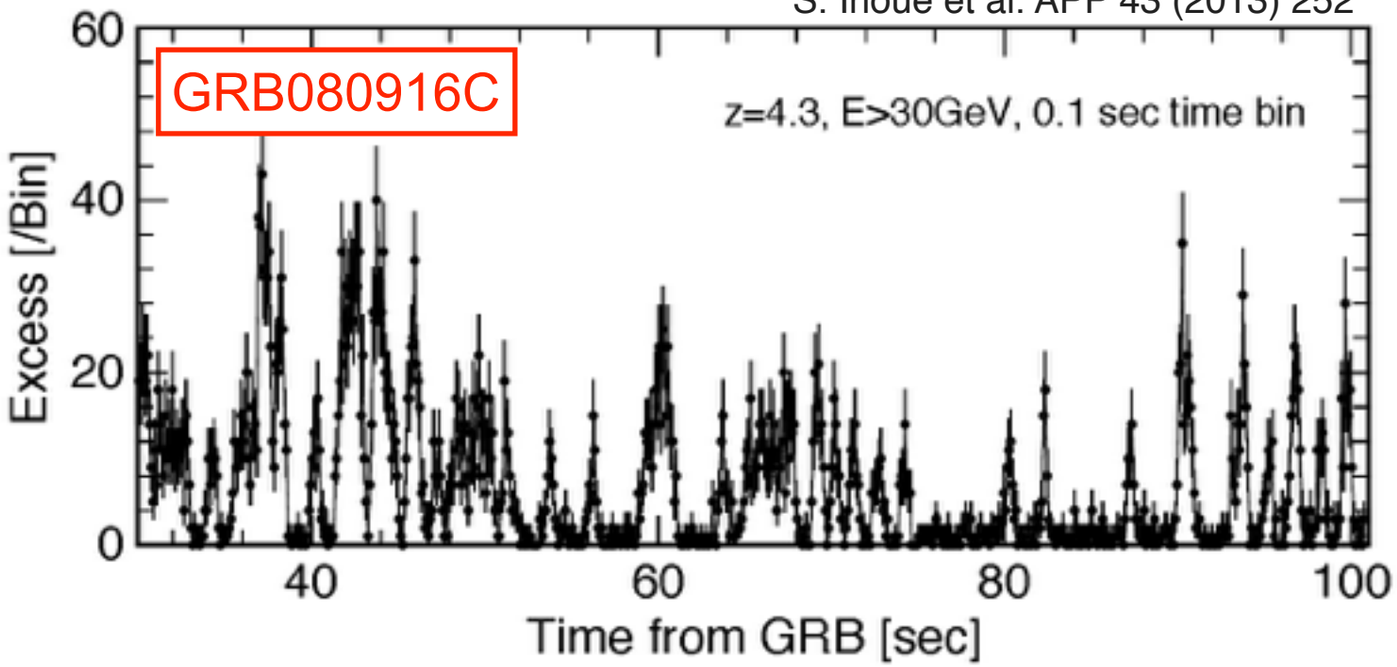
Priority	Target class	Observation times (h yr^{-1} site^{-1}) Early phase	Years 1–2	Years 3–10	Years 1–10
1	GW transients	20	5	5	
2	HE neutrino transients	20	5	5	
3	Serendipitous VHE transients	100	25	25	
4	GRBs	50	50	50	
5	X-ray/optical/radio transients	50	10	10	
6	Galactic transients	150	30	0(?)	
	Total per site (h yr^{-1} site^{-1})	390	125	95	
	Total both sites (h yr^{-1})	780	250	190	
	Total in different CTA phases (h)	1560	500	1520	2020

Gamma-ray burst observations

- Important program with strong links to most other topics (GW!, neutrinos?, etc.)

- rapid reaction time + low E_{thr}
- detailed light curves will provide insight into acceleration processes

S. Inoue et al. APP 43 (2013) 252



- Very recent news:
  - GRB190114C: >300GeV emission 50s after the burst (ATEL #12390)
  - GRB180720B: >100GeV emission 10h after the burst (E. Ruiz Velasco et al., CTA Symposium 2019)
- Ongoing: detailed study of GRB population and prospects for their detection with CTA

Gamma-ray burst observations

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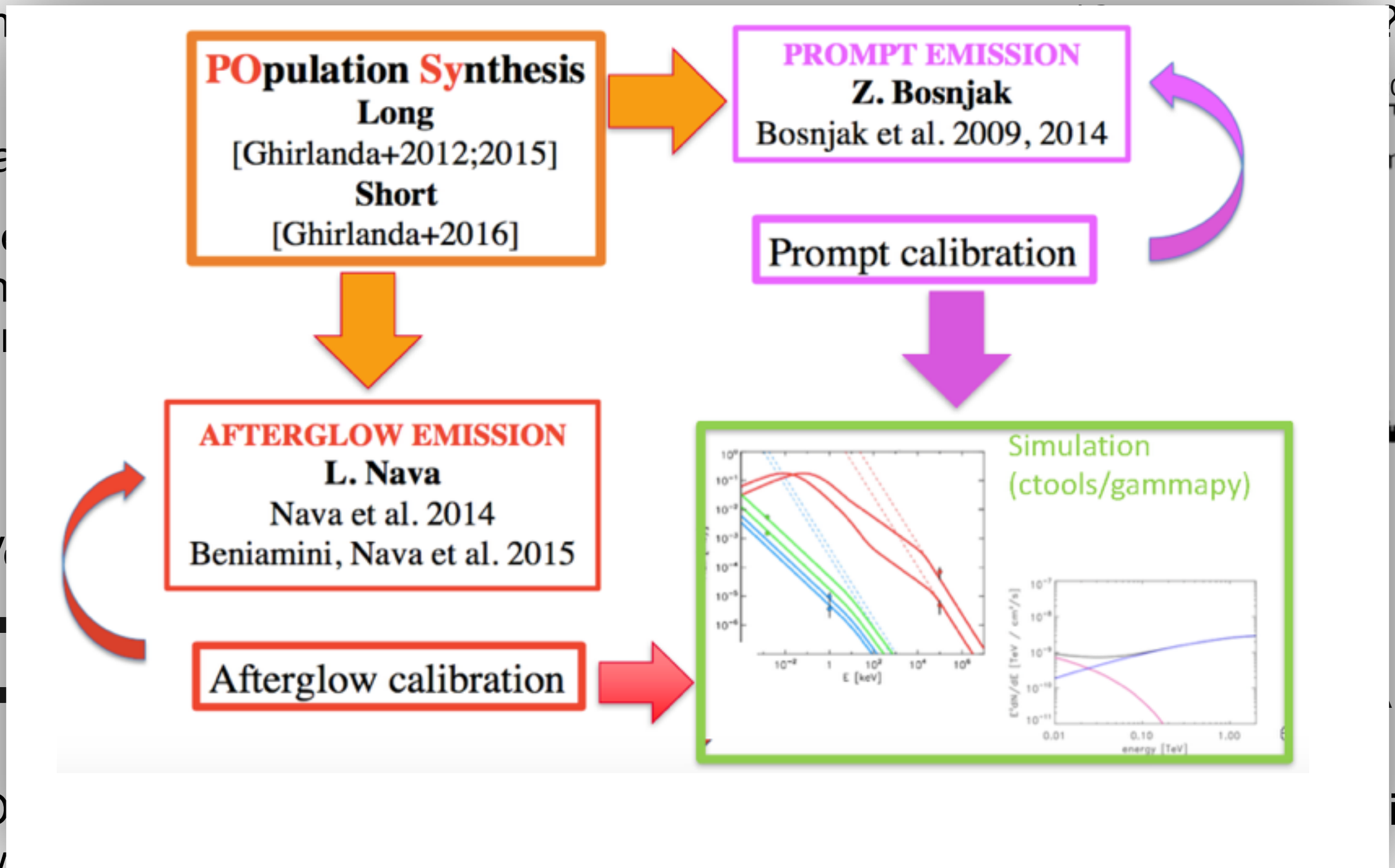

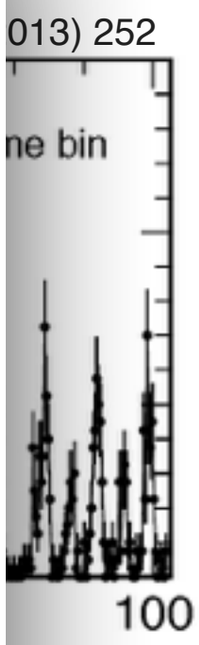

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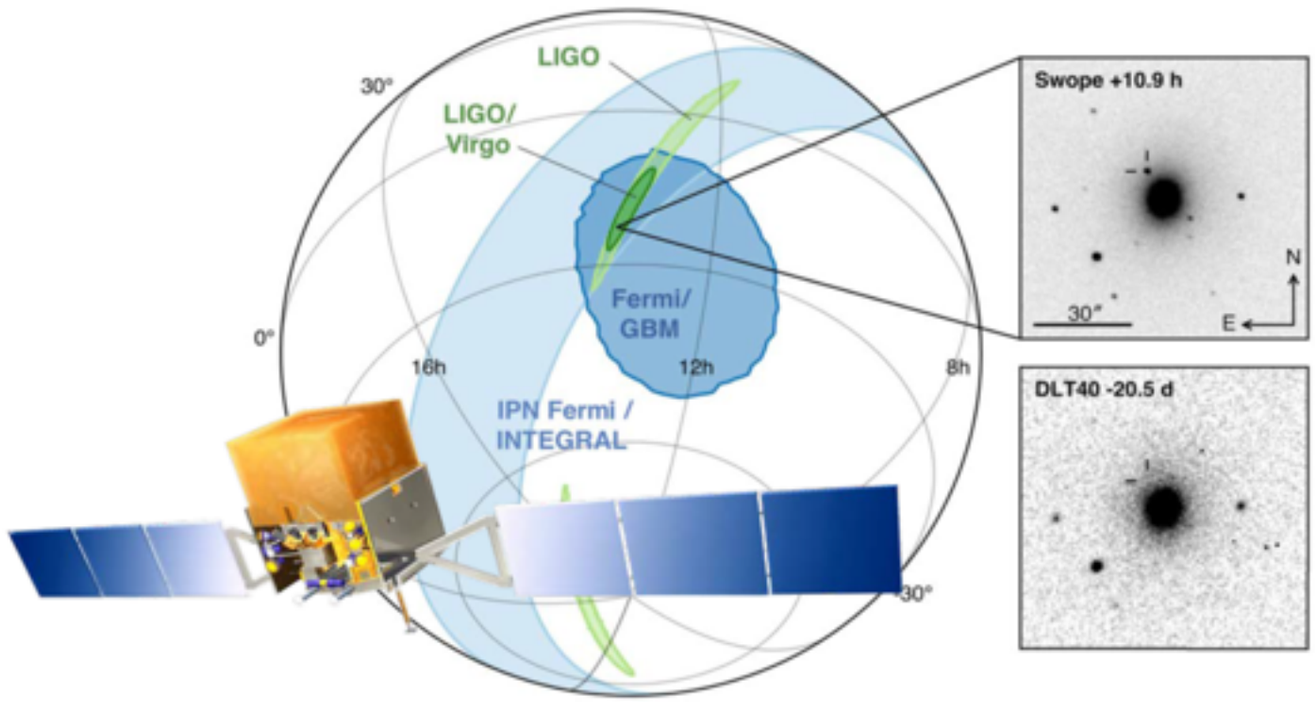
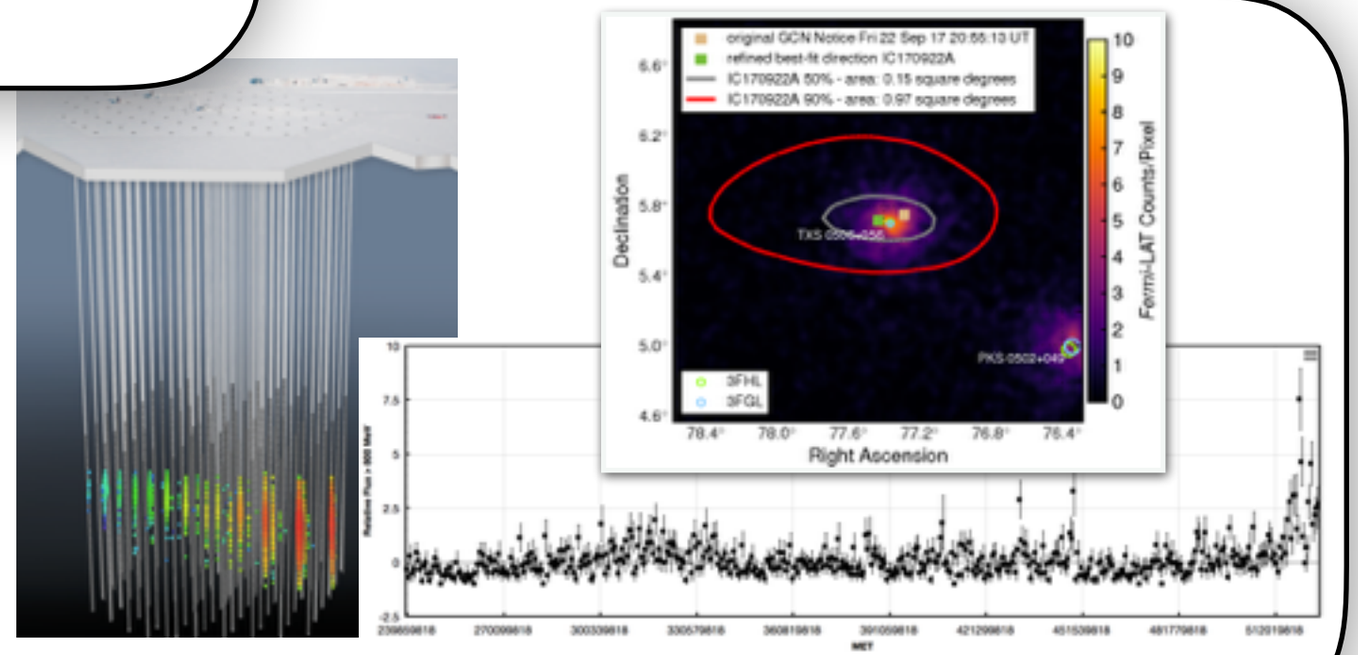
Time-domain multi-messenger astronomy



ApJL, 848:L12, 2017

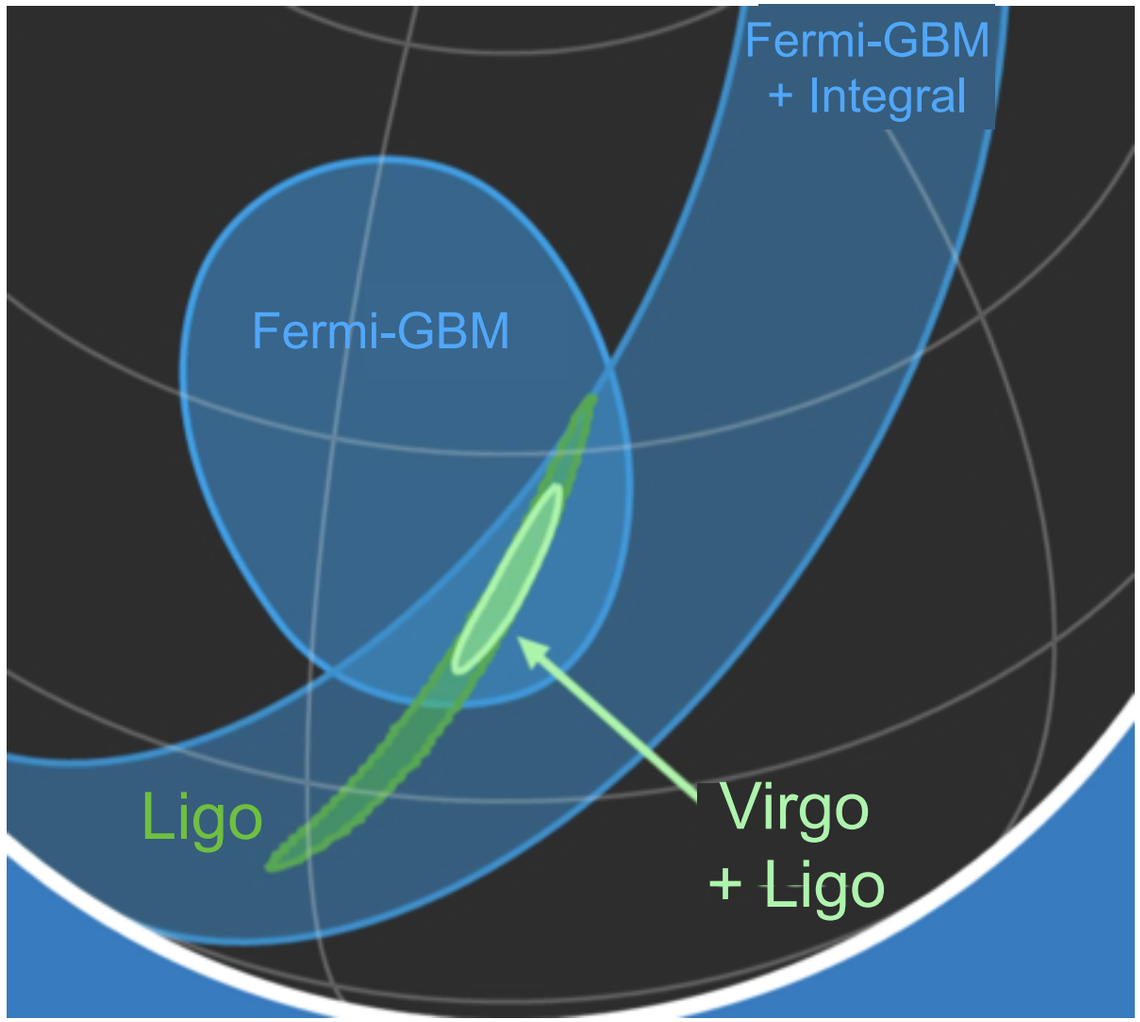
Gravitational waves

High-energy neutrinos



Science 361, eaat1378 (2018)

Scheduling and pointing strategy



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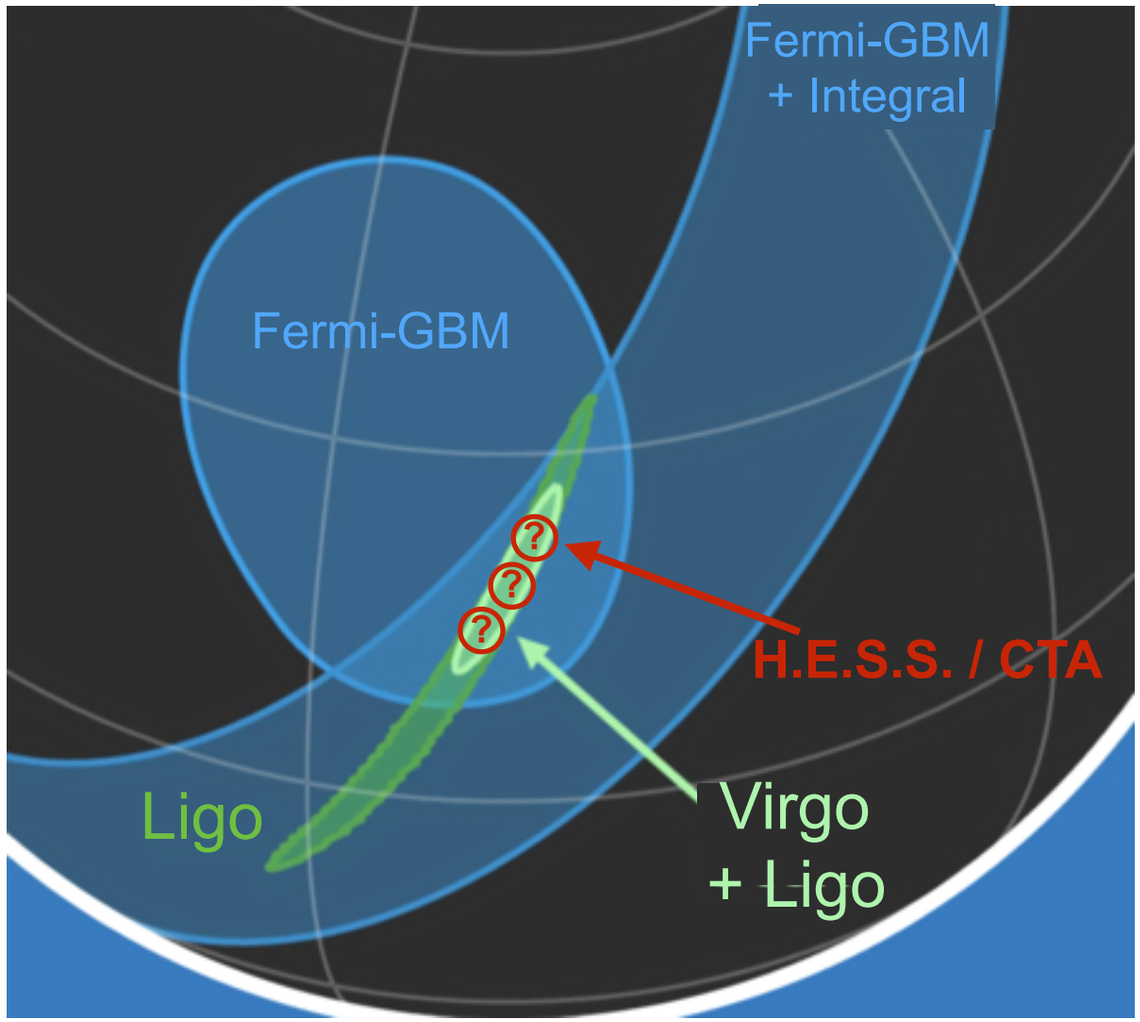

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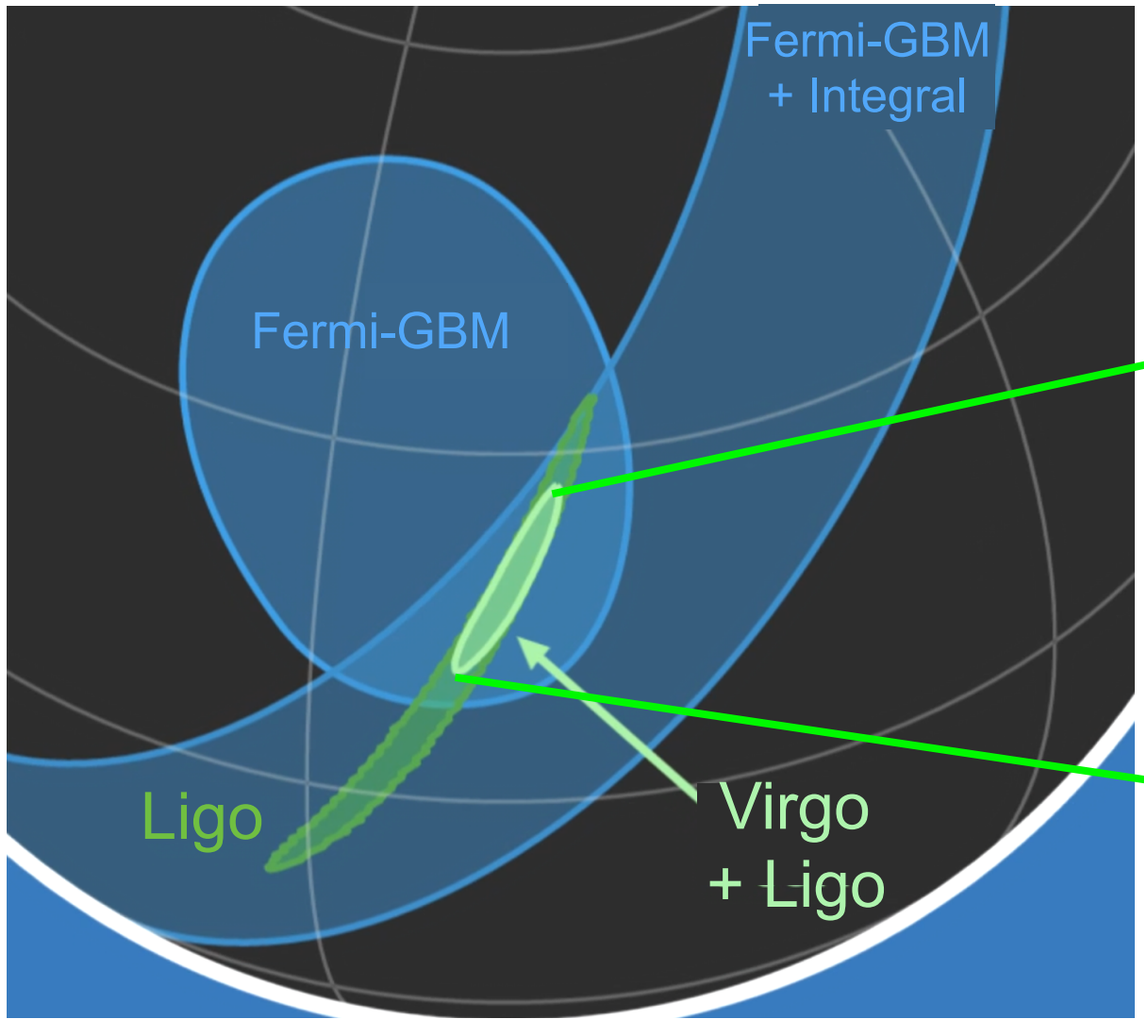
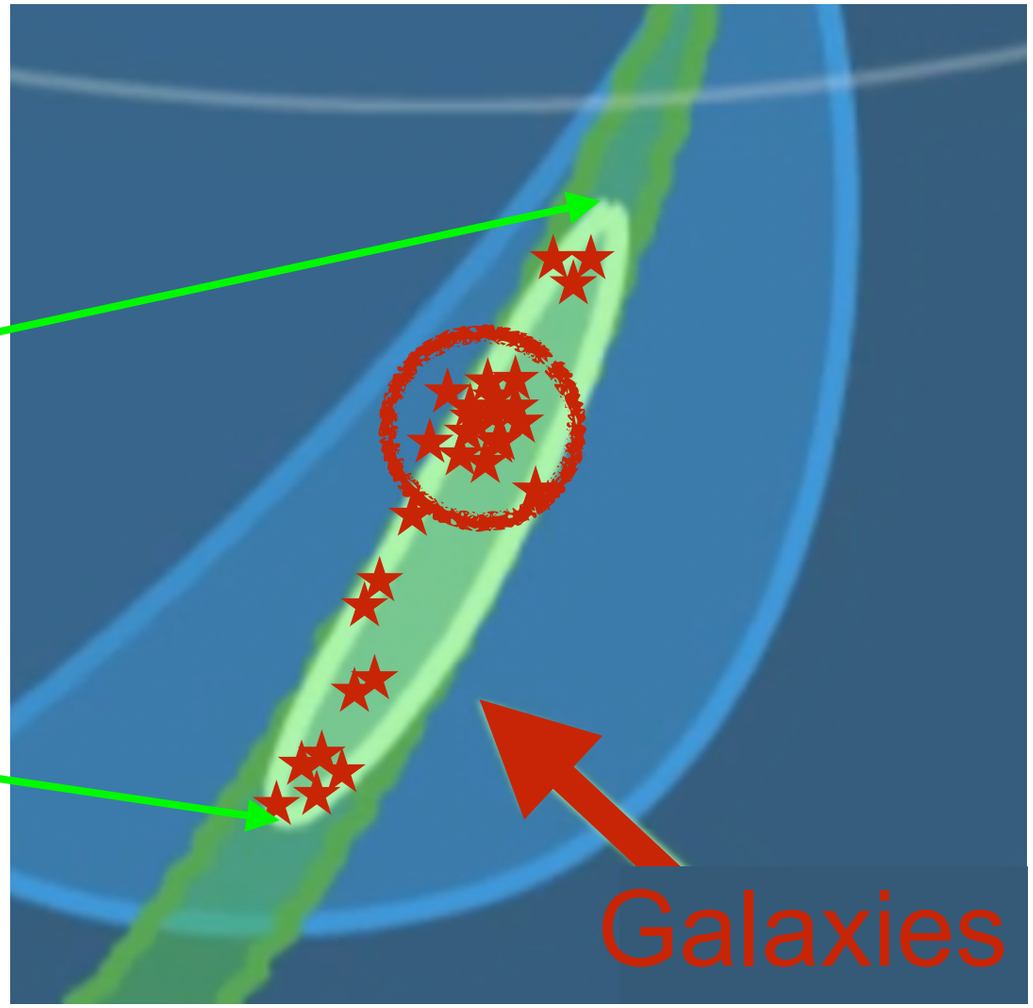
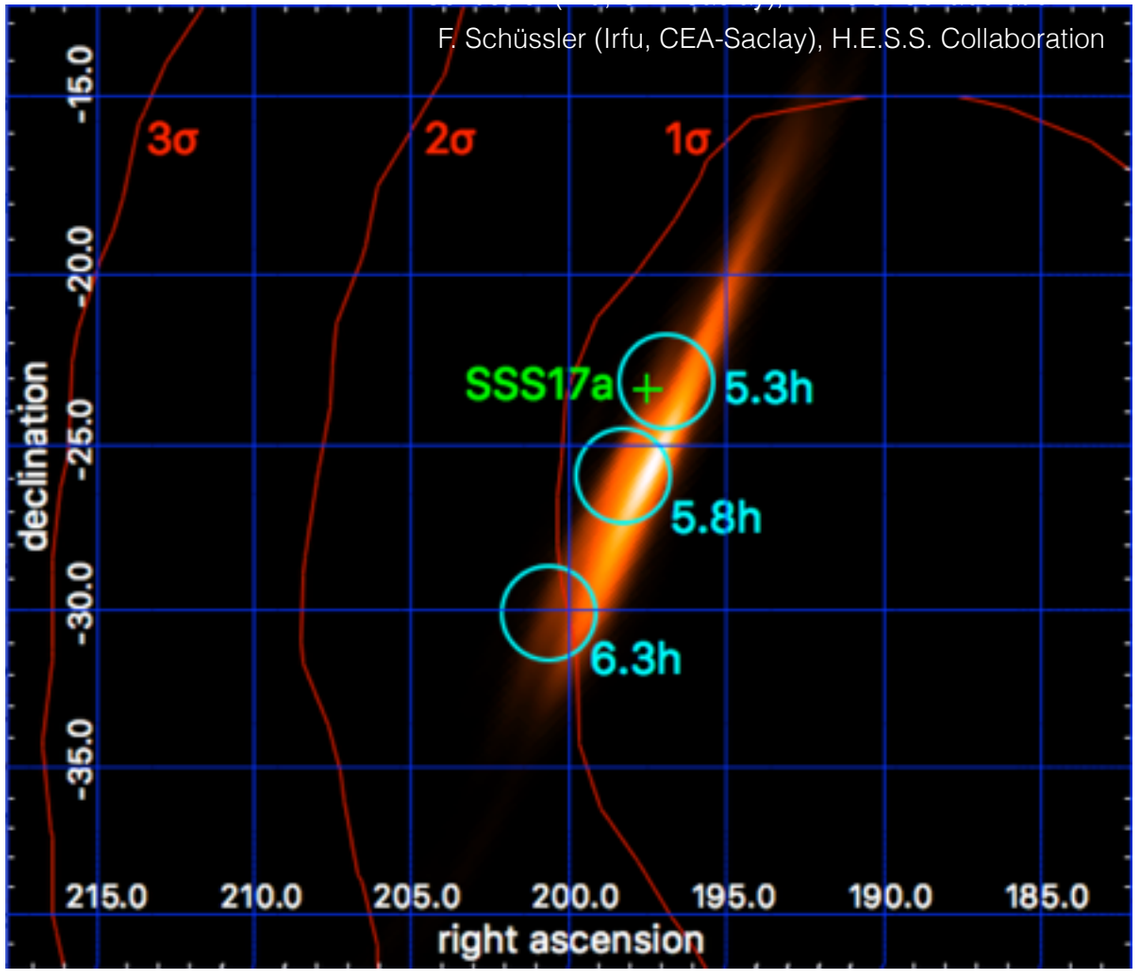




- automatic selection of regions of interest
  - correlation with galaxy catalog(s) in 3 dimensions
  - dedicated algorithms for the different possibilities (e.g. BNS, BBH, bursts, etc.)

M. Seglar-Arroyo + FS (H.E.S.S.), Moriond VHEPU 2017, arXiv: 1705.10138

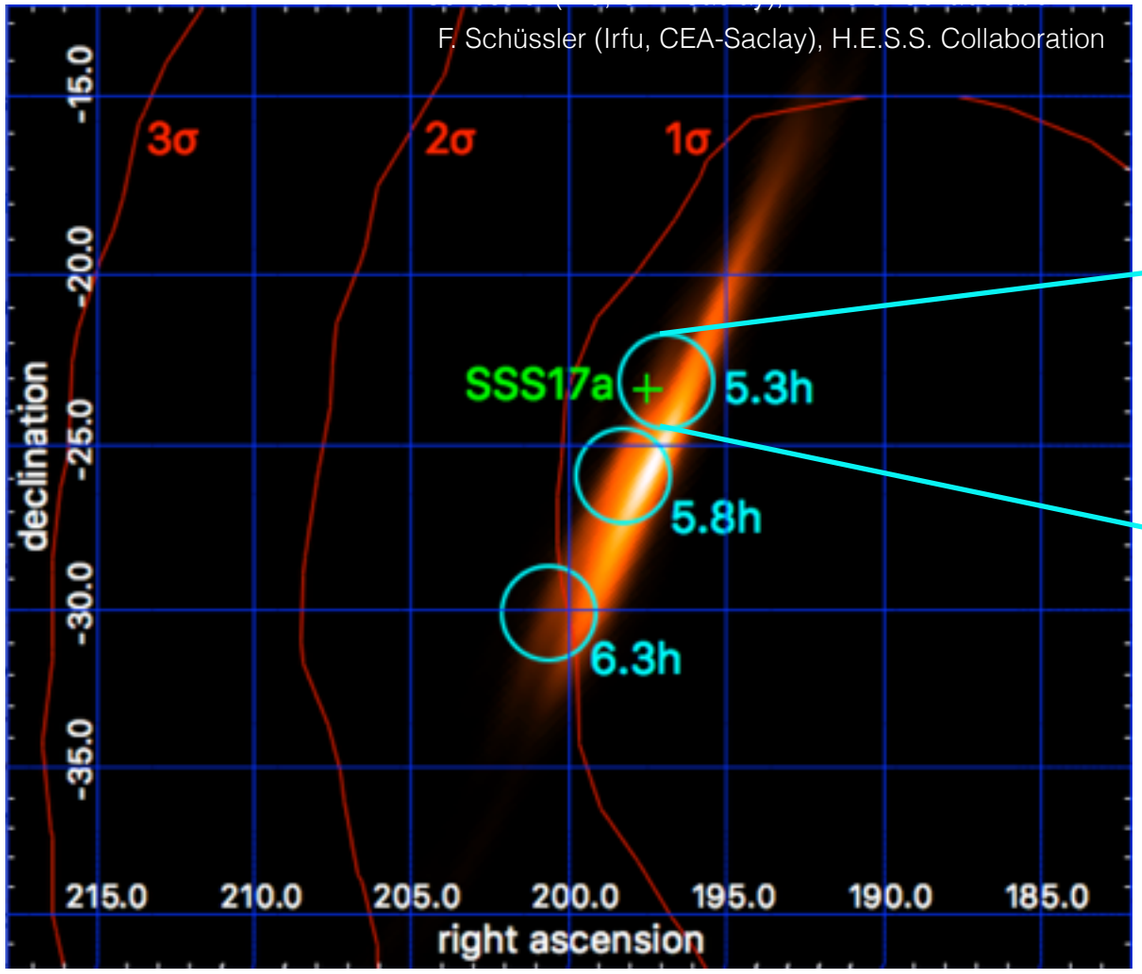
GW170817: TeV gamma-ray follow-up

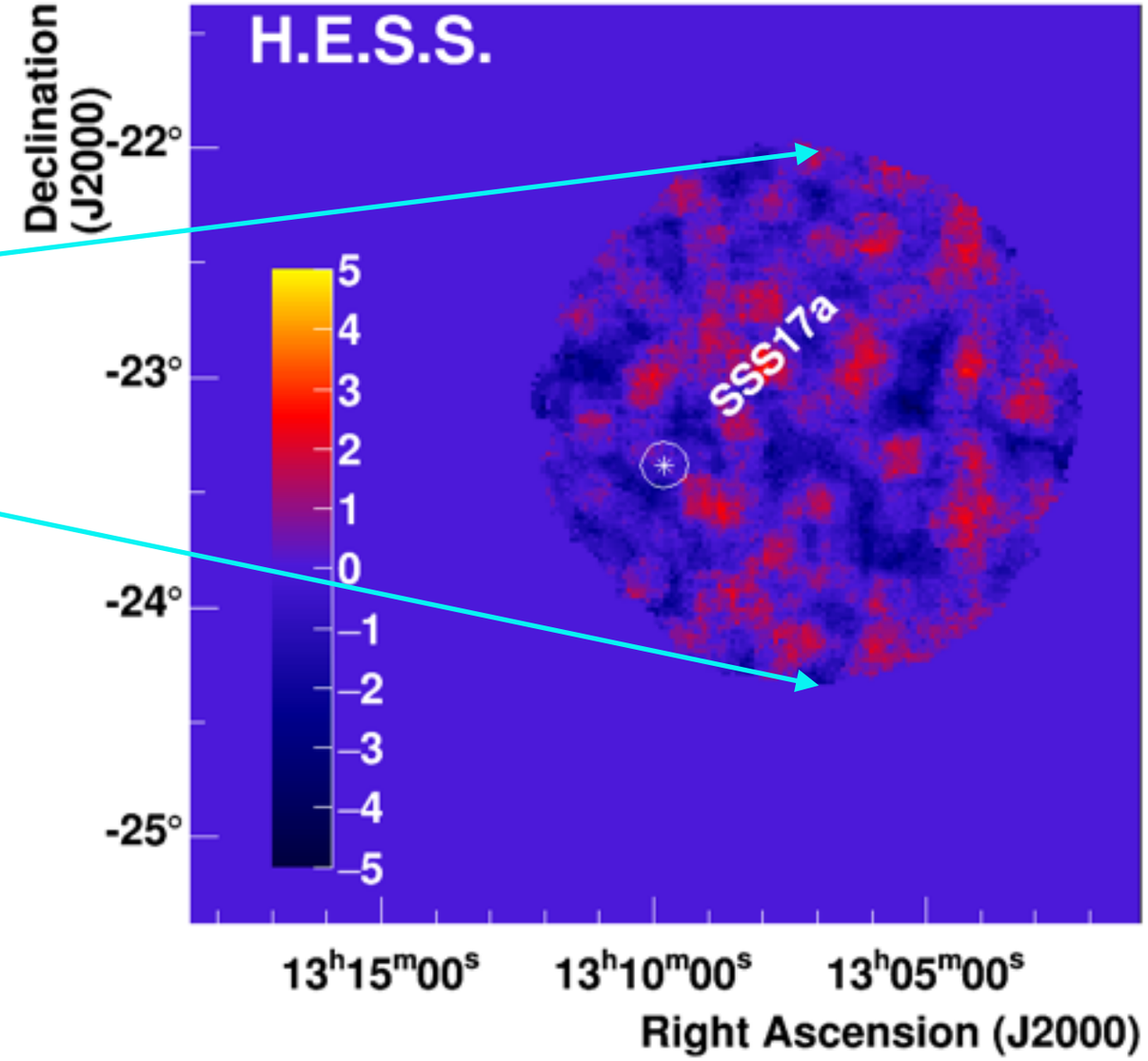


H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017)

- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817 (5 minutes after GCN circular with Ligo+Virgo analysis)
  - first pointing containing SSS17a (AT 2017gfo)

GW170817: TeV gamma-ray follow-up





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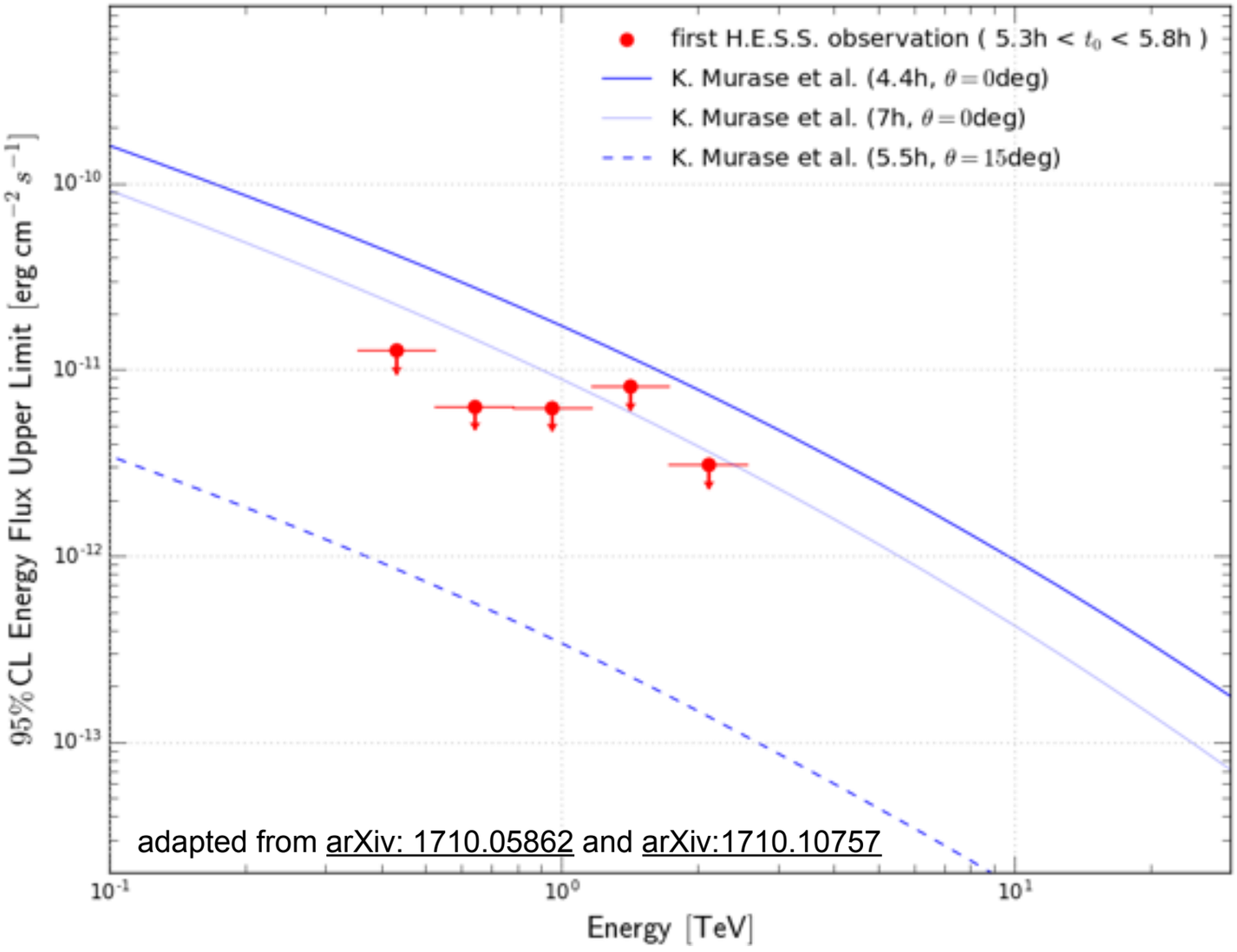
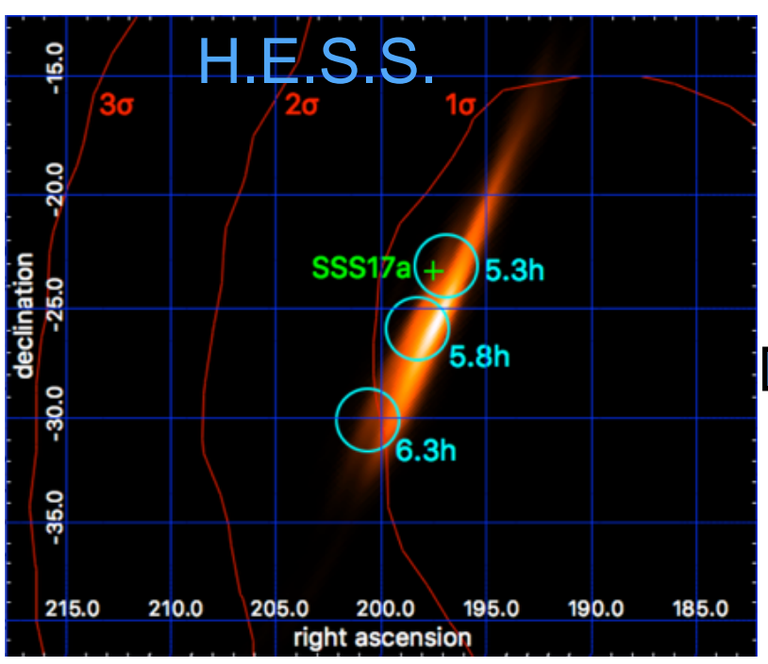
- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817 (5 minutes after GCN circular with Ligo+Virgo analysis)
  - first pointing containing SSS17a (AT 2017gfo)
  - no significant signal: $\Phi\ (0.28 < E\ [\mathrm{TeV}] < 2.31) < 3.9 \times 10^{-12}\ \mathrm{erg\ cm^{-2}\ s^{-1}}$

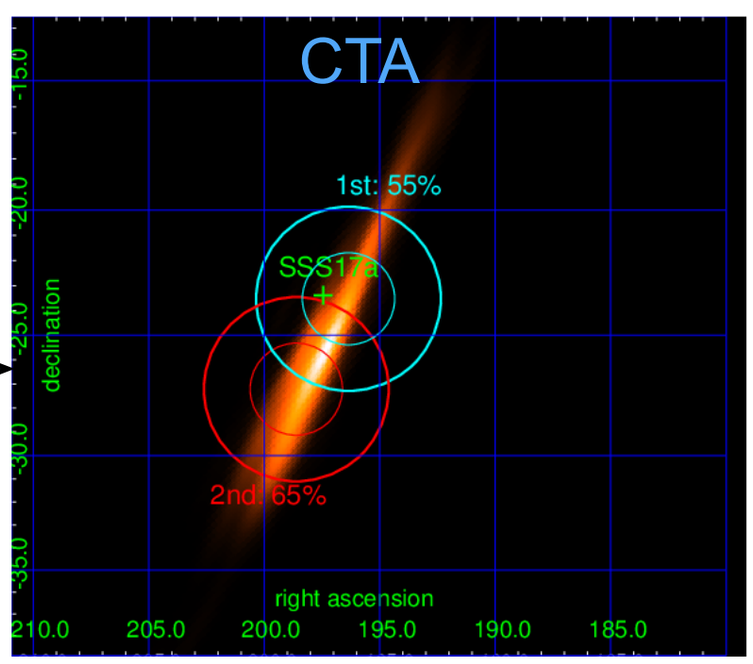
H.E.S.S. observations of GW170817



- e.g. K. Murase et al. (arXiv:1710.10575)
  - high-energy signatures from long-lasting central engines
  - external inverse Compton: X-ray up-scattering by electrons in the jet
  - H.E.S.S. observations constrain on-axis emission
  - CTA will have access to off-axis emission

GW170817 @ Cherenkov Telescope Array



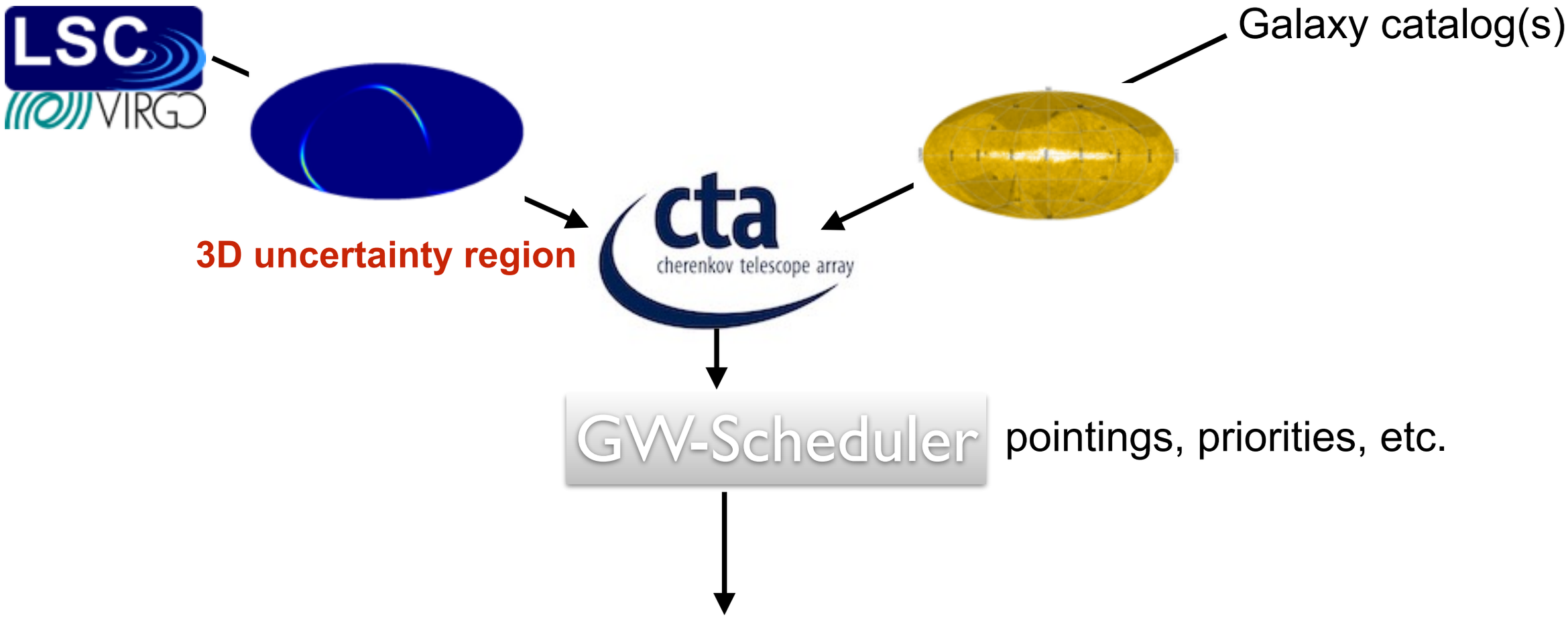


- detailed studies ongoing
- extending work from
  - all current IACTs
  - I.Bartos et al., MNRAS 477 (2018) 639-647
  - B. Patricelli et al., JCAP 05 (2018) 056

H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017)

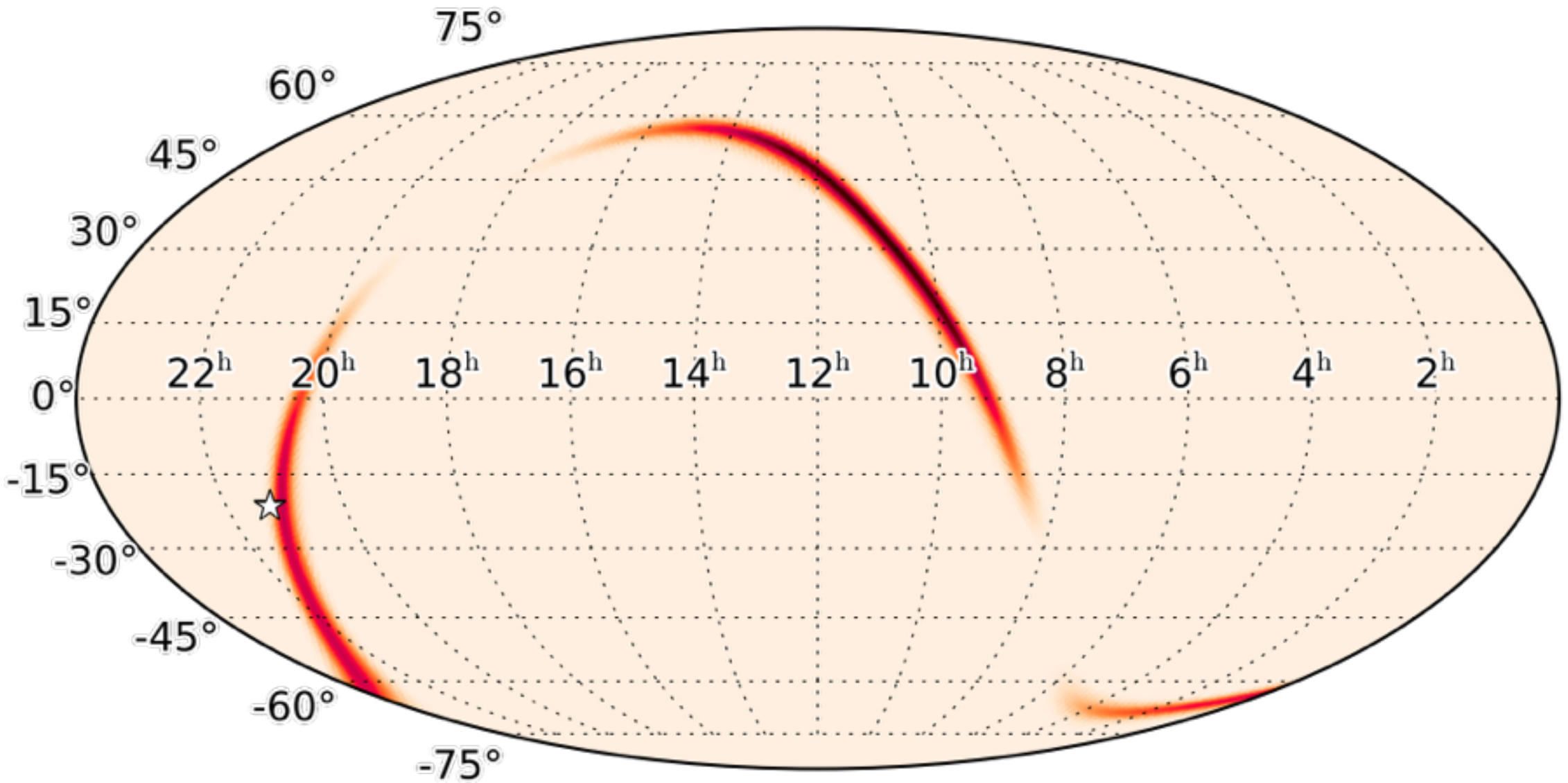
FS (CTA consortium), preliminary

Gravitational Waves: Observation Strategy



- Real-Time-Analysis searching for new/transient sources
- alert emission (internal/external)
- alert reception (EM counterpart)

Searches for GW counterparts with CTA



B. Patricelli et al., GW COSMoS

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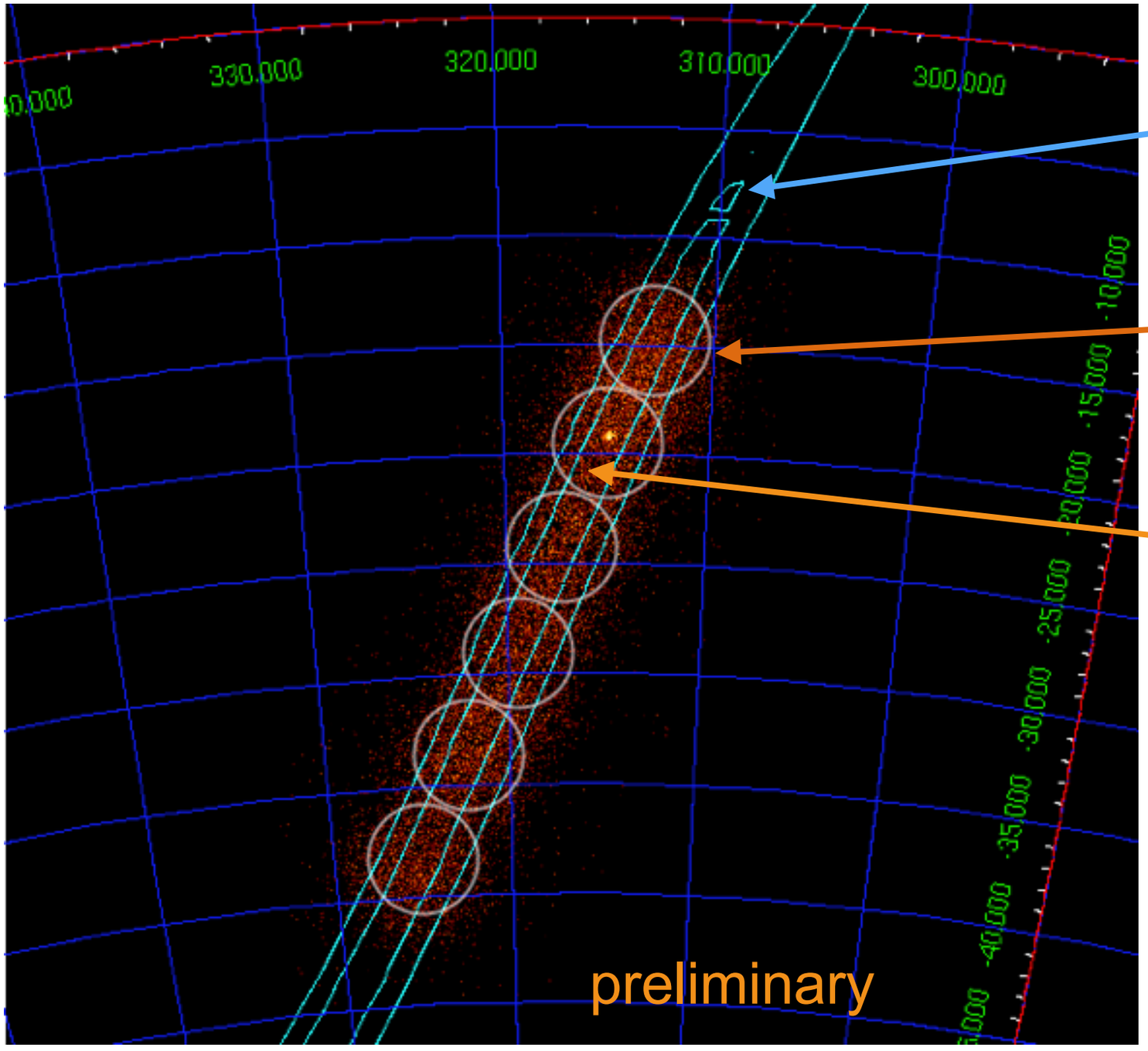


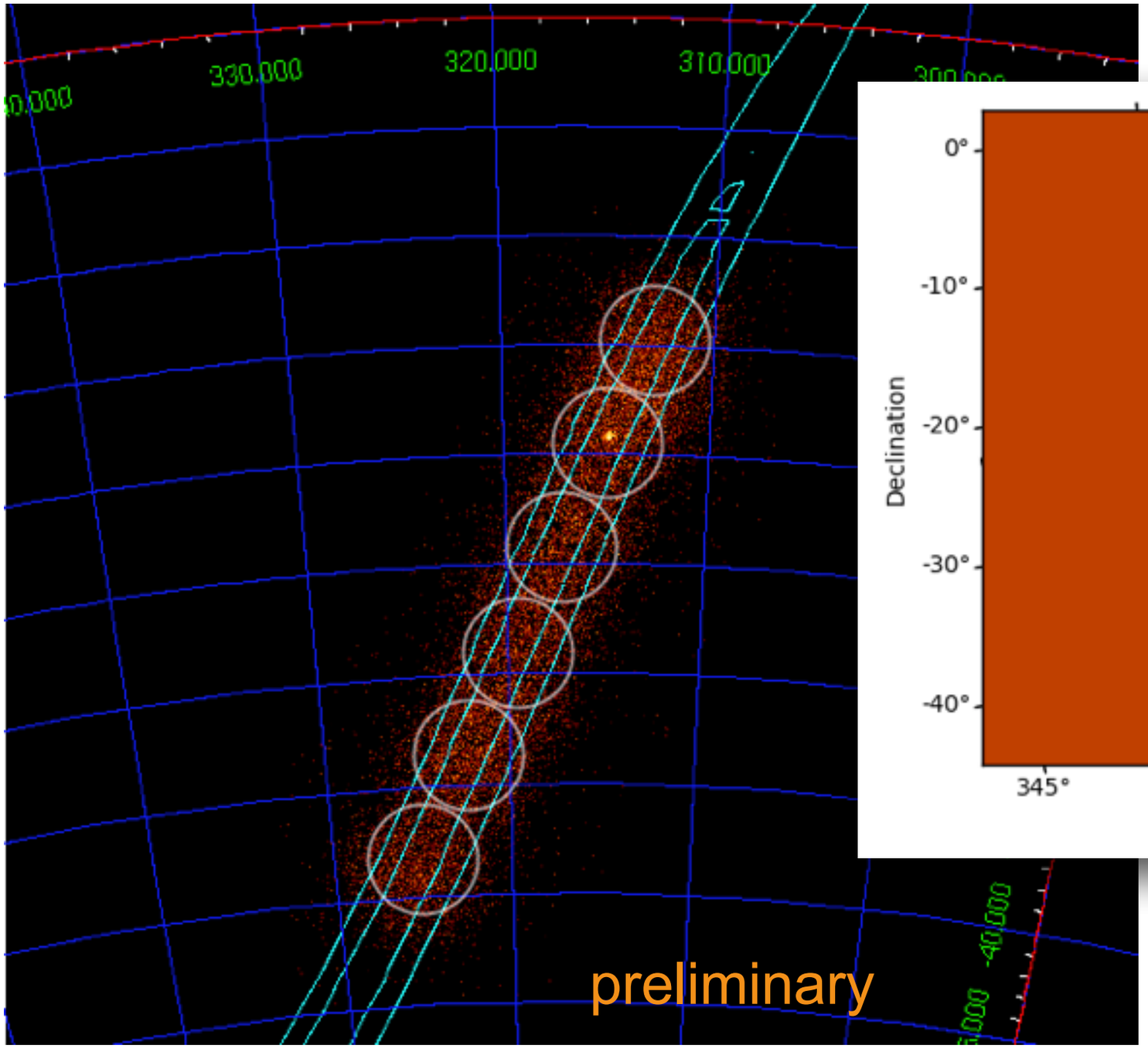
GW uncertainty map

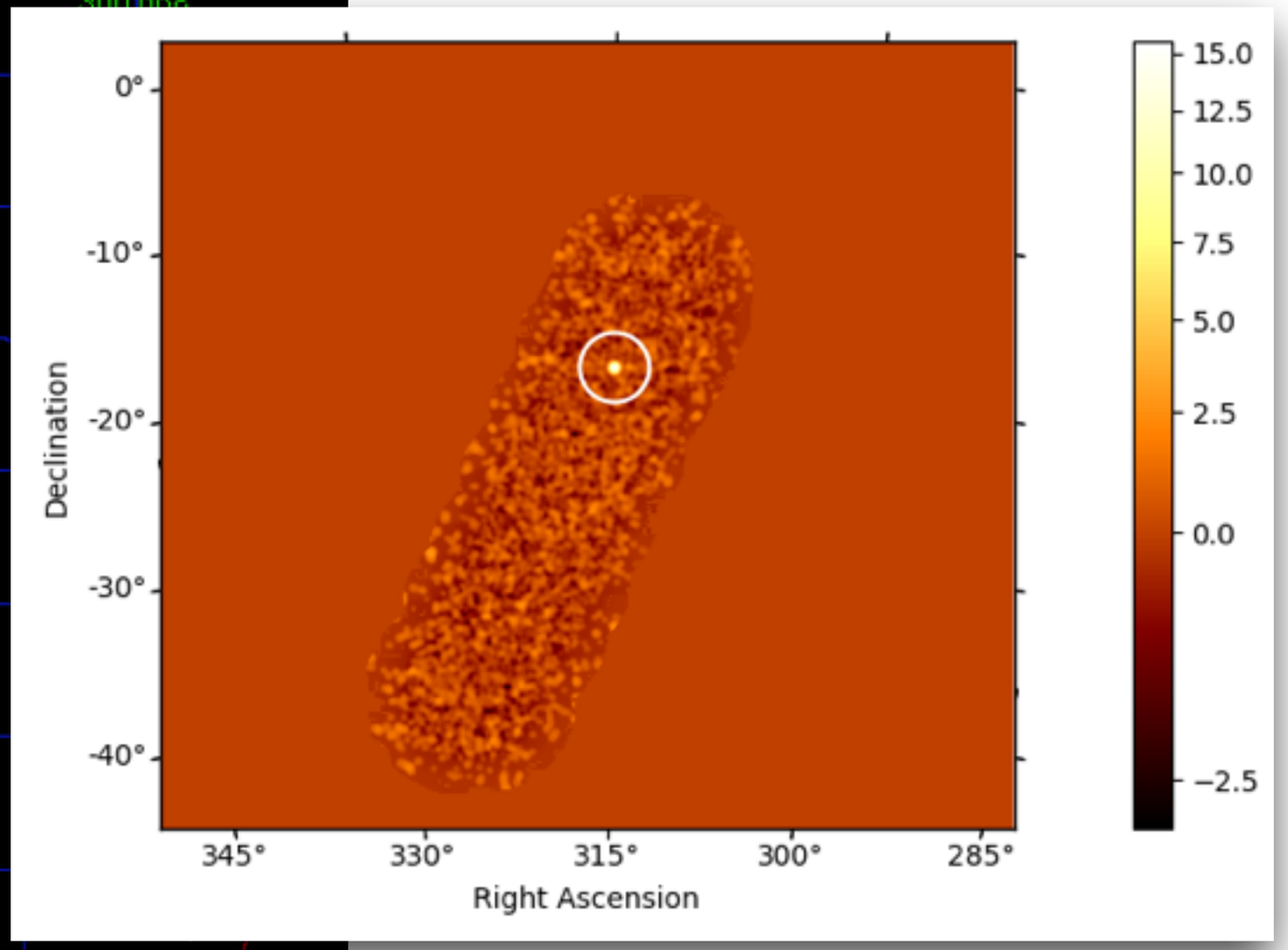
CTA pointings

Gamma-ray counts

GRB190510 model + GW scheduling + GammaPy + …
Monica Seglar-Arroyo + FS (CTA Consortium)

Searches for GW counterparts with CTA





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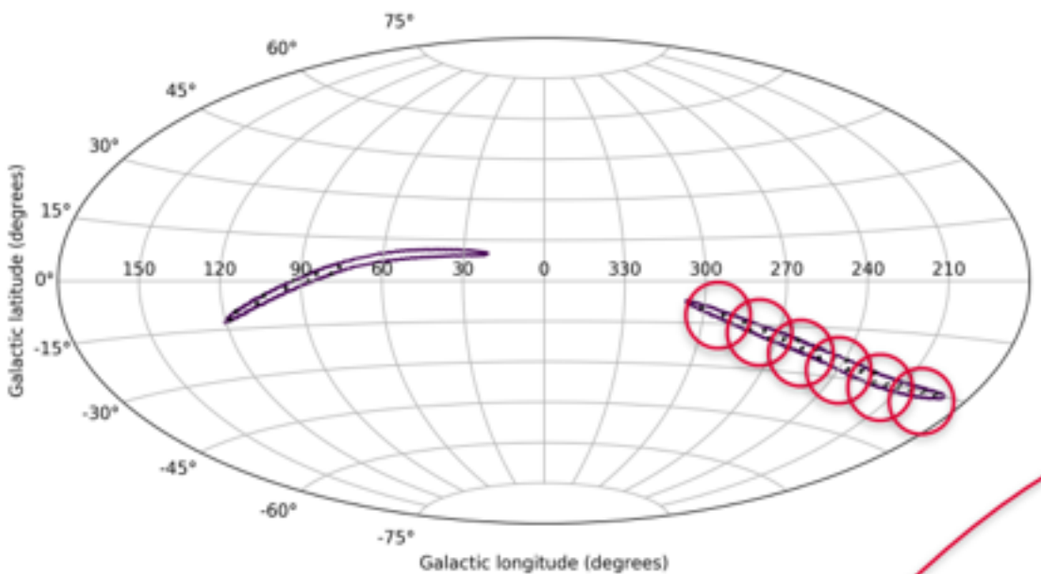
The CTA Real-Time Analysis



next pointing of the grid or end of ToO observation

no

External science alert: GW

New Observation

RTA

detection after X secs?

e.g. a grid of pointing

yes

New optimised observation to the detection site identified by RTA

RTA

still detectable?

no

came back to the original schedule

yes

continue current observation

A. Bulgarelli et al.

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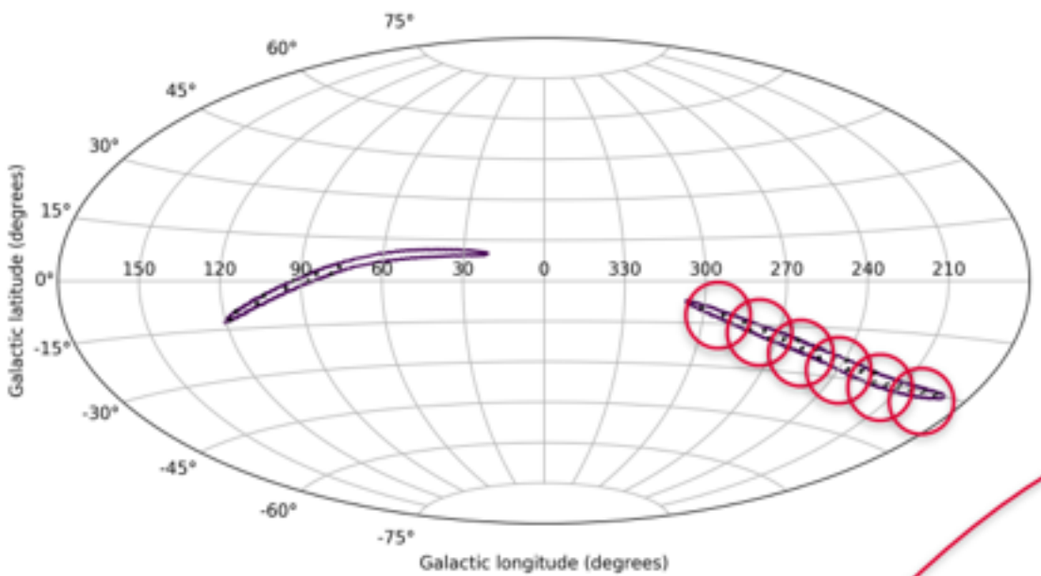

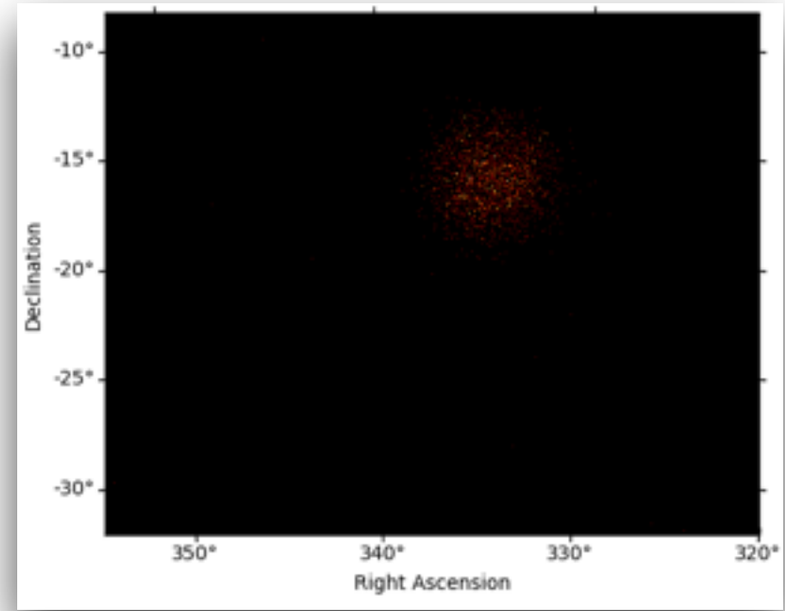

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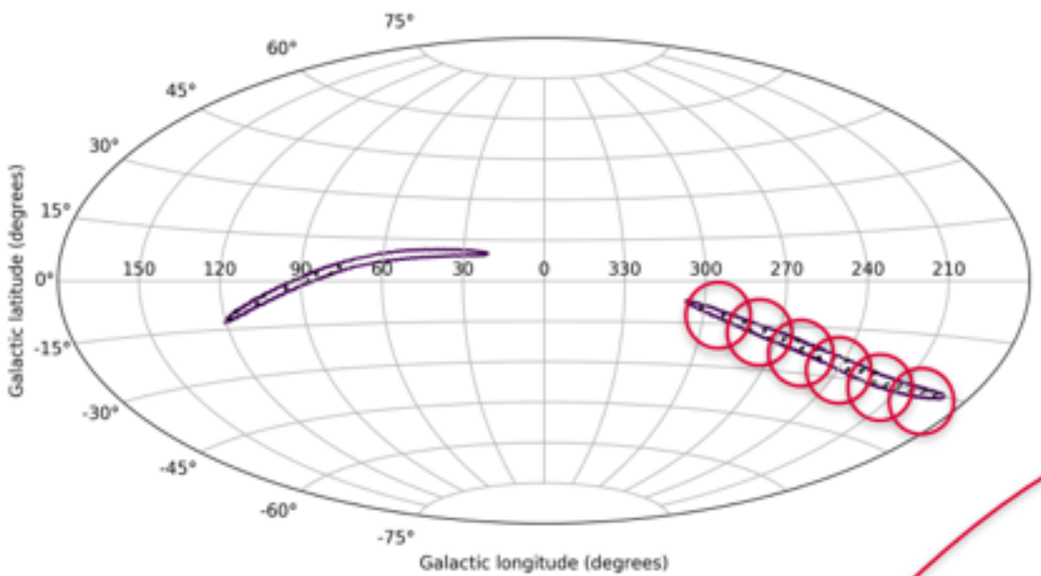

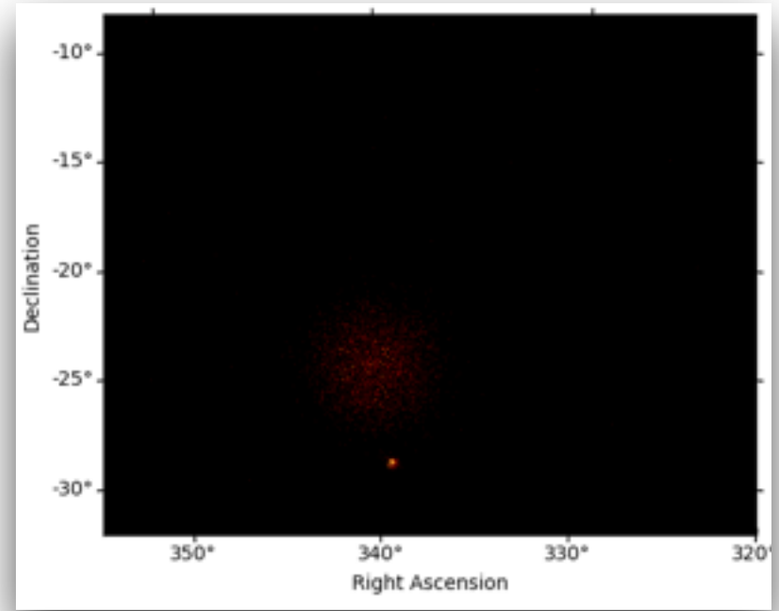

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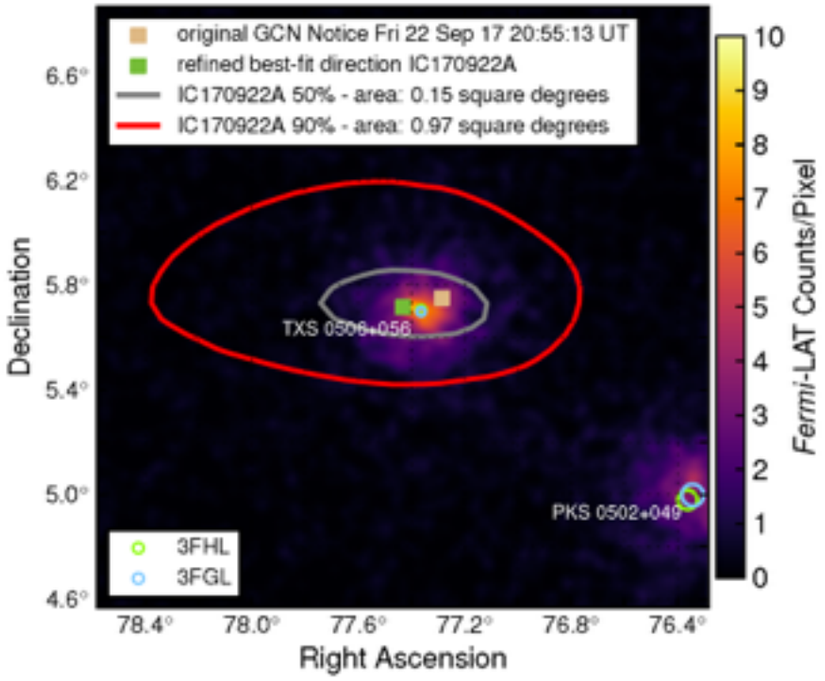
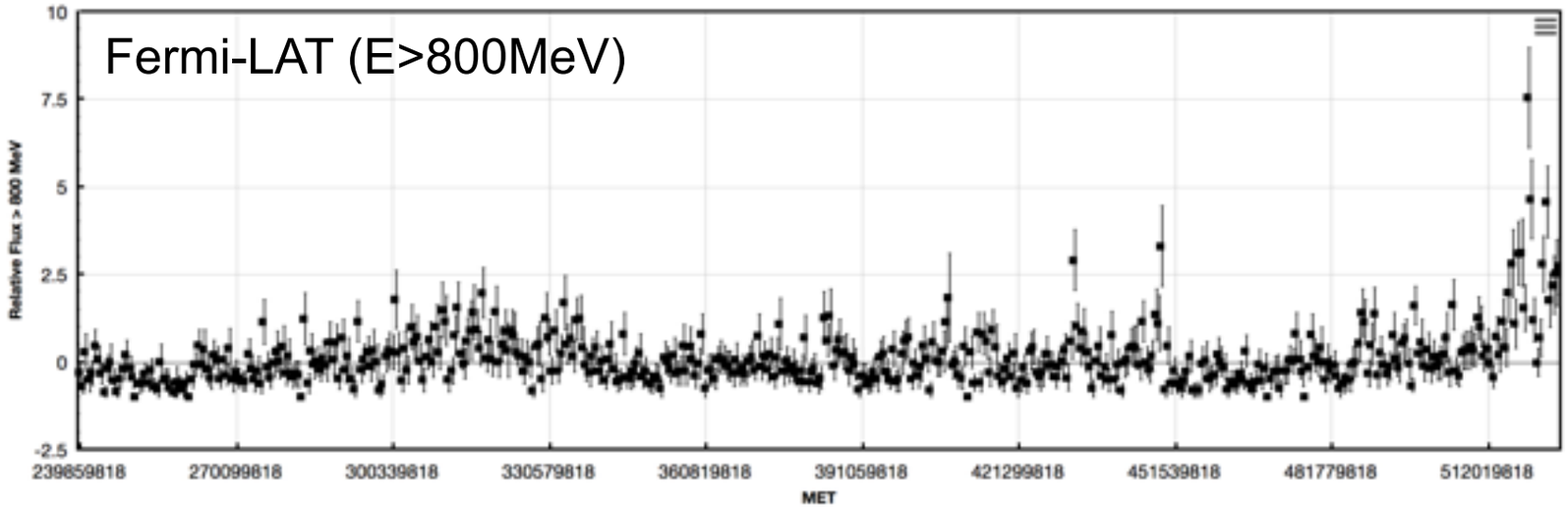
A. Bulgarelli et al.

Identifying the sources of high-energy neutrinos

- Building on successful programs of all current IACTs
  - follow-up of individual high-energy neutrinos (e.g. IC-170922A)
  - neutrino ”flares” (all-sky searches, pre-defined candidate sources, etc.)
  - correlations with other observations (e.g. AMON: Fermi, HAWC, etc.)
- Links to CTA AGN program (e.g. duty-cycle of TeV flares) and wide FoV instruments (e.g. HAWC, LHAASO, SWGO)

Science 361, eaat1378 (2018)





Identifying the sources of high-energy neutrinos

- Building on successful programs of all current IACTs
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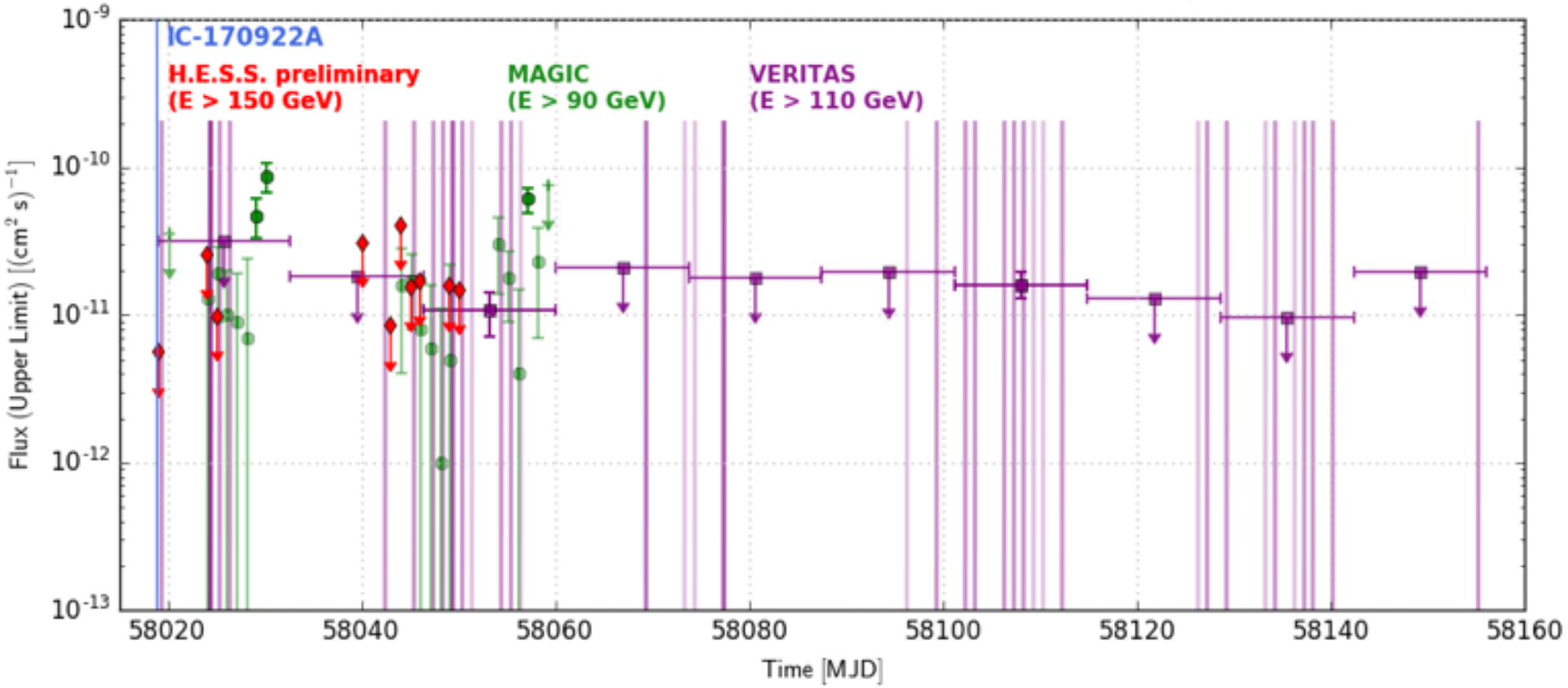
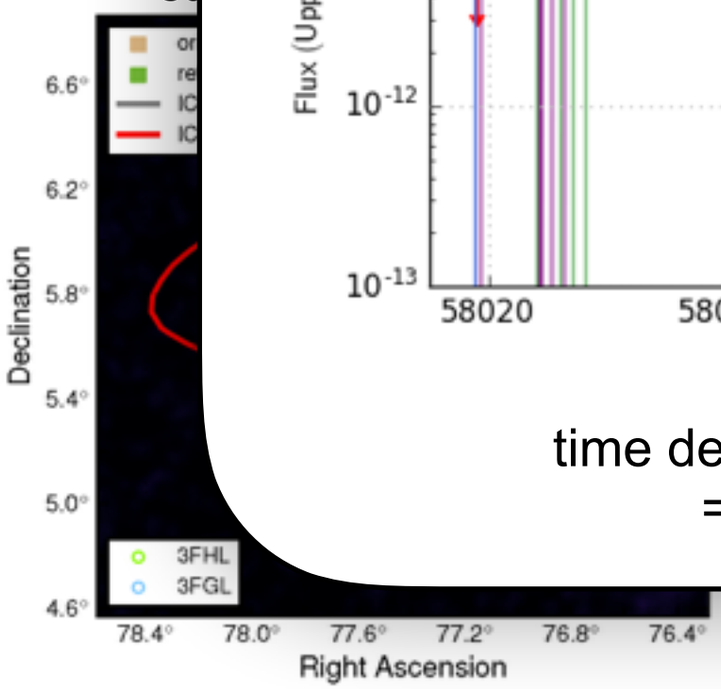
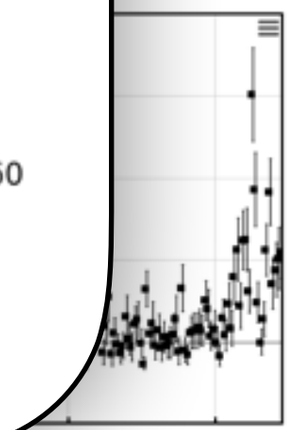
F. Schüssler (H.E.S.S.) + K. Satalecka + many others @ TeVPA 2018



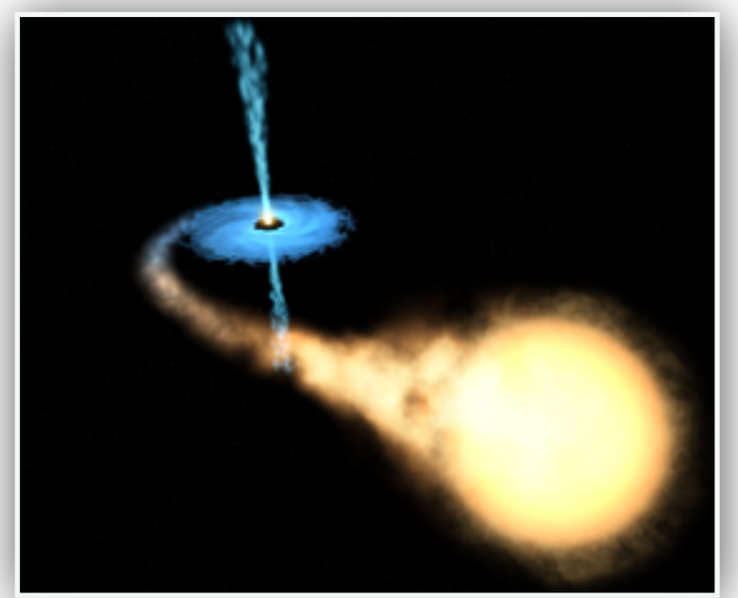
time delays between neutrinos and TeV emission uncertain
=> extensive follow-up campaigns necessary?





Galactic transients

- large number of interesting sources
- e.g. gamma-ray binaries + many prospective possibilities, i.e. no GeV/TeV detections so far
  - microquasars, PWNe flares, etc.

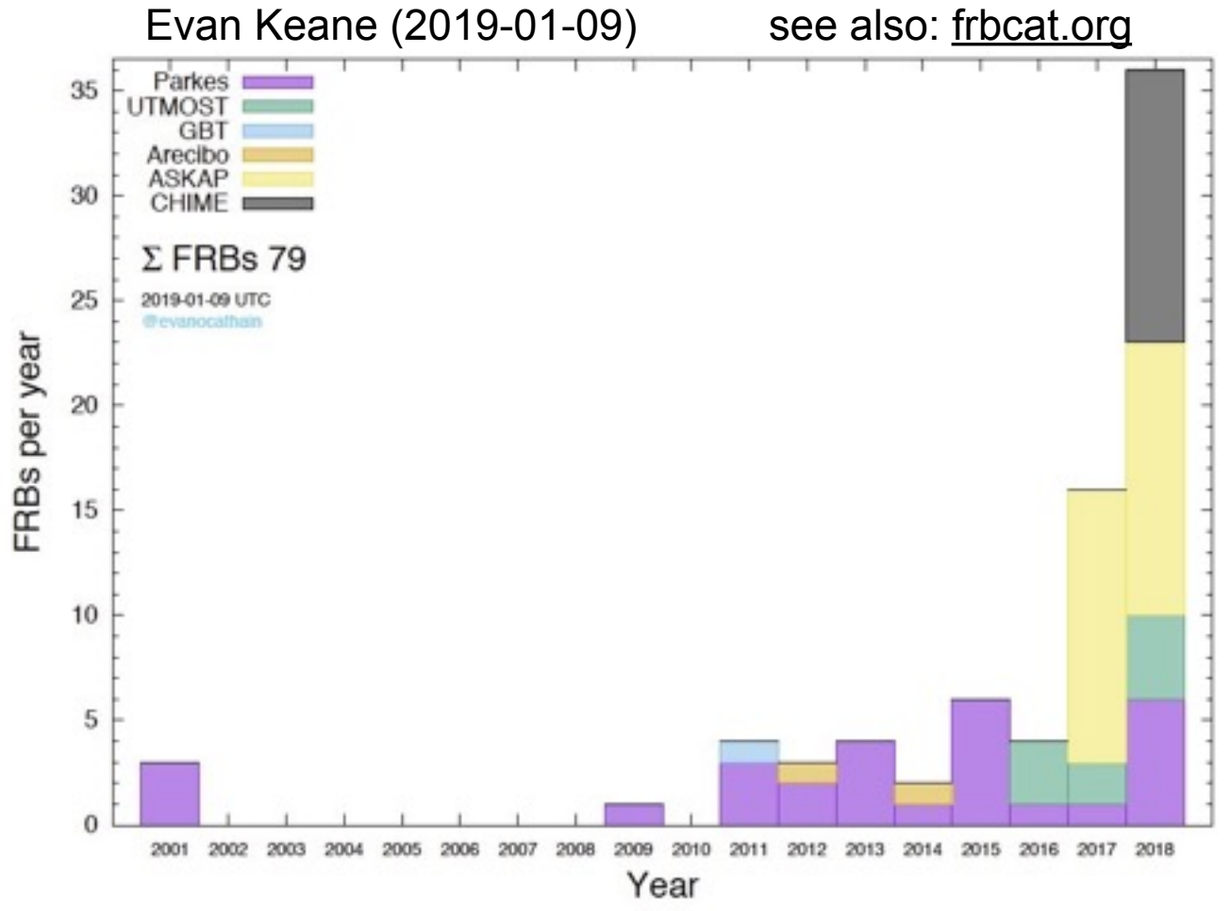


A large zoo of MWL transients

- taking advantage of the time-domain revolution
- optical transient factories (e.g. ZTF, LSST)

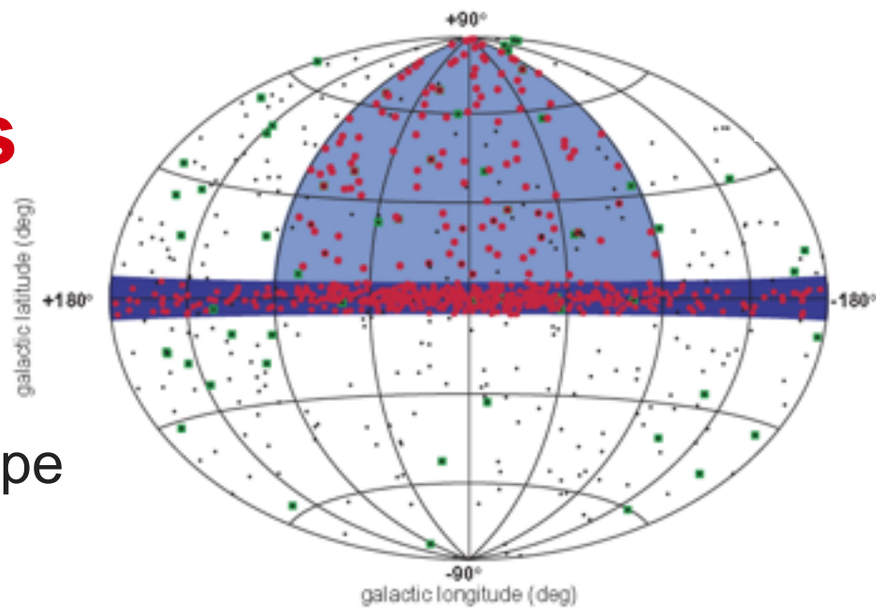
Fast Radio Bursts

- mysterious, millisecond long, strong bursts in the radio domain
- rapid increase in detections over the last years
- only two (irregularly) repeating bursts: different classes?

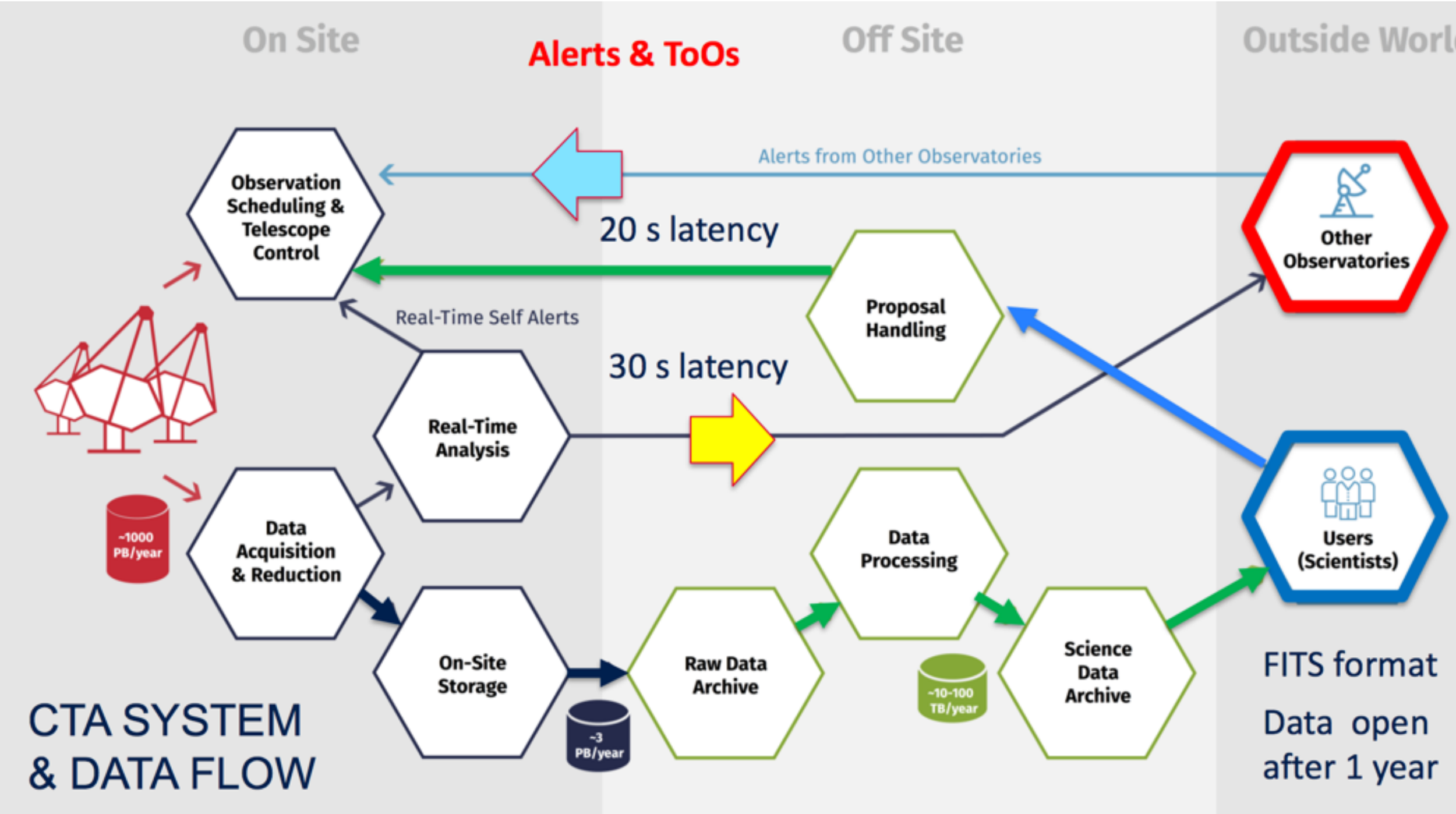


- first TeV follow-up programs (e.g. H.E.S.S: A&A 597, A115, 2017)
- repeating bursts: coordinated campaigns possible (e.g. MAGIC: MNRAS 481 (2018) 2479)
- FRBs as example of futur detections of new transient phenomena

Serendipitous detections + CTA alerts



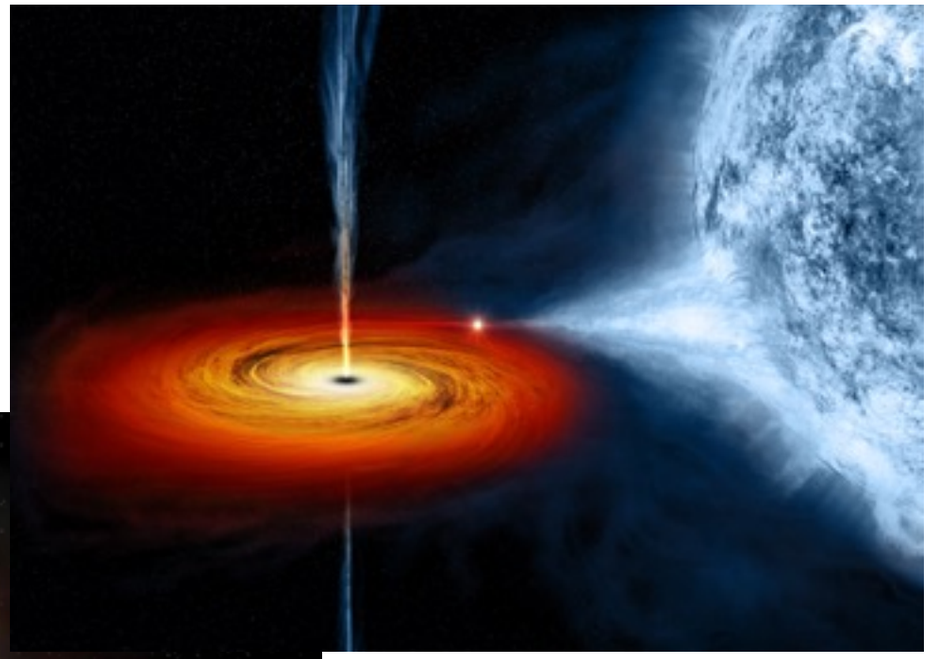
- CTA will cover large portions of the sky
  - large telescope FoV: 4 - 10deg depending on telescope type
  - may be increased by divergent pointing
- important survey programs (Galactic + Extragalactic)
- Real-Time Analysis scrutinizing the data
  - alert emission within 1 minute
  - low rate of serendipitous detections but potentially extremely interesting events
  - counterpart identifications of external alerts (e.g. GRBs, GWs, neutrinos, etc.)

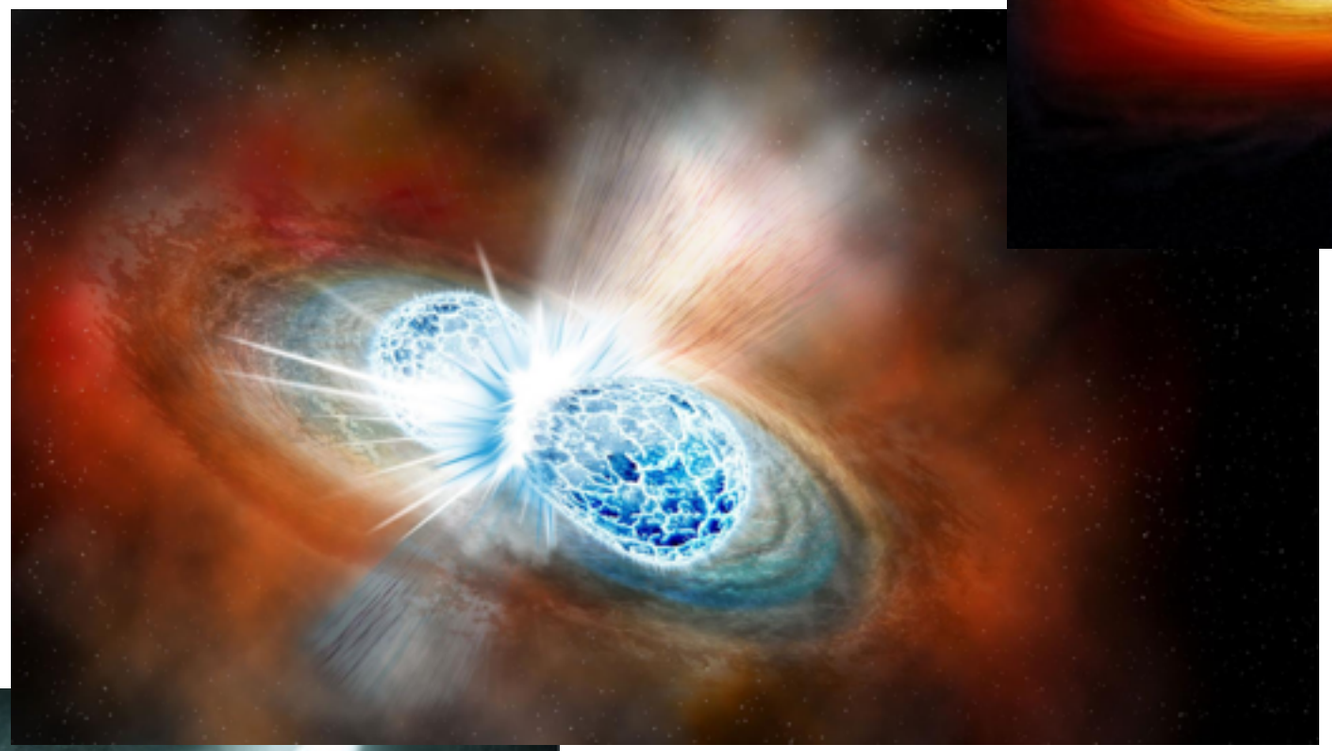

On Site
Alerts & ToOs
Off Site
Outside World
Observation Scheduling & Telescope Control
Alerts from Other Observatories
20 s latency
Other Observatories
Proposal Handling
Real-Time Self Alerts
30 s latency
Real-Time Analysis
~1000 PB/year
Data Acquisition & Reduction
Data Processing
Users (Scientists)
On-Site Storage
Raw Data Archive
~10-100 TB/year
Science Data Archive
~3 PB/year
FITS format
Data open after 1 year
CTA SYSTEM & DATA FLOW

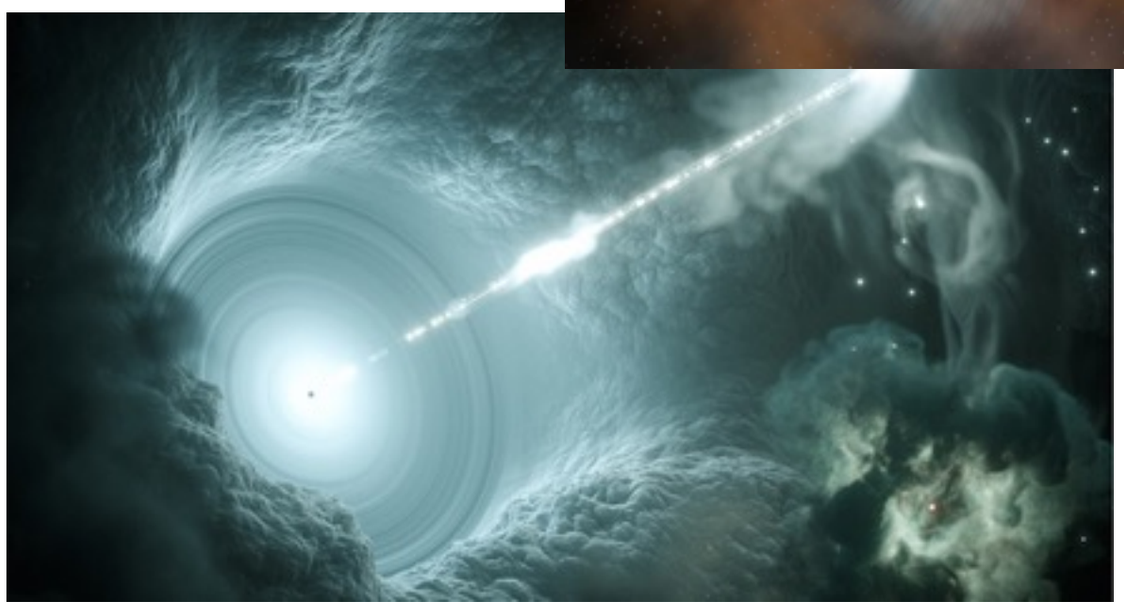
Links to multi-messenger and multi-wavelength community

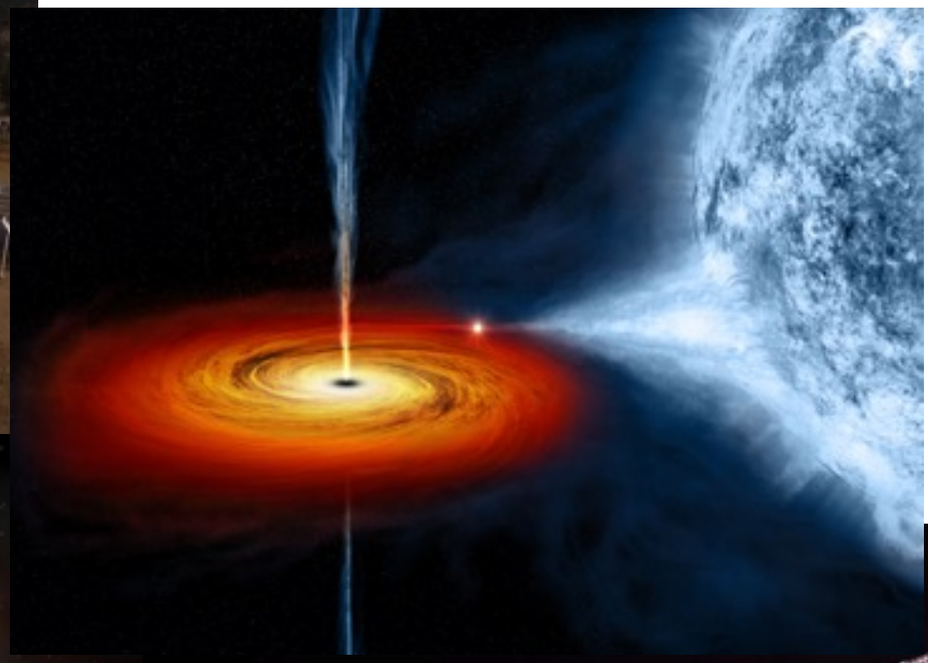
- MWL/MM input necessary for many CTA science cases
- Transients
  - alerts to CTA on a large range of objects/sources
  - public alerts from CTA on transient emission from known and unknown sources
    - Real-time analysis => alert emission with O(30sec)

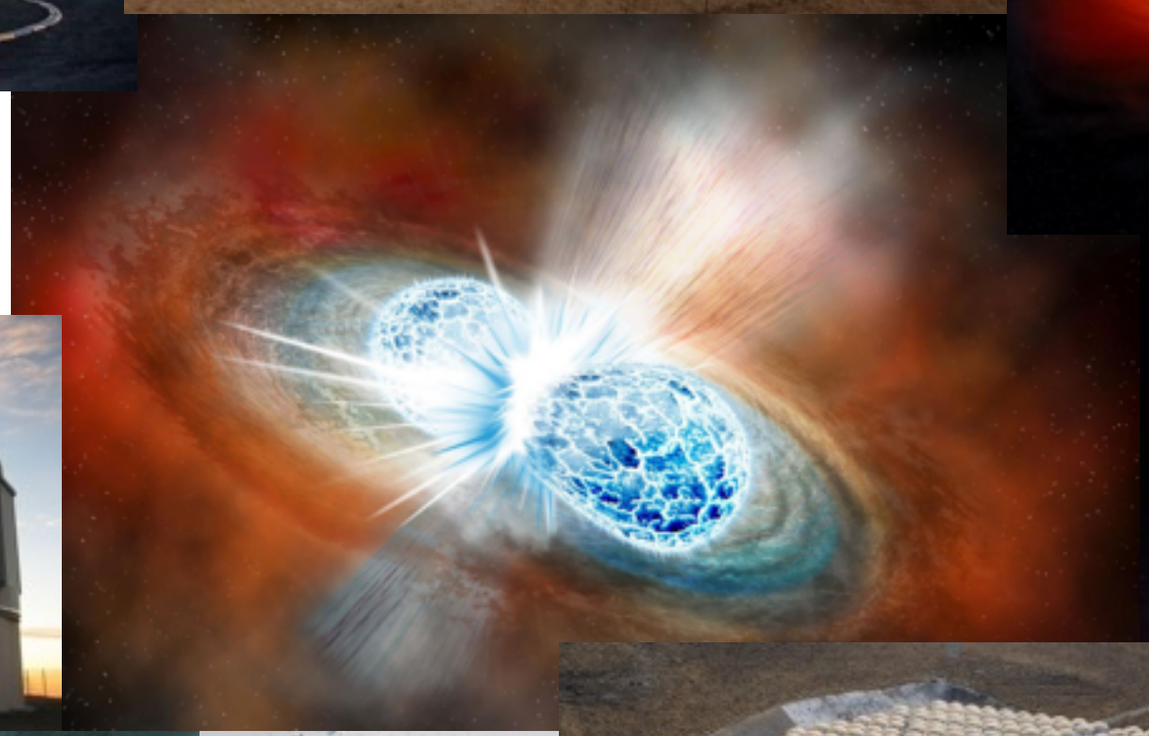
- CTA will be an observatory
  - I outlined the program in preparation by the CTA consortium under its proprietary time
  - CTA will have a significant fraction of observation time open to all of you!
  - Start thinking about what you want to do with CTA!
    - How to trigger CTA?
    - How to respond to CTA alerts?
    - …

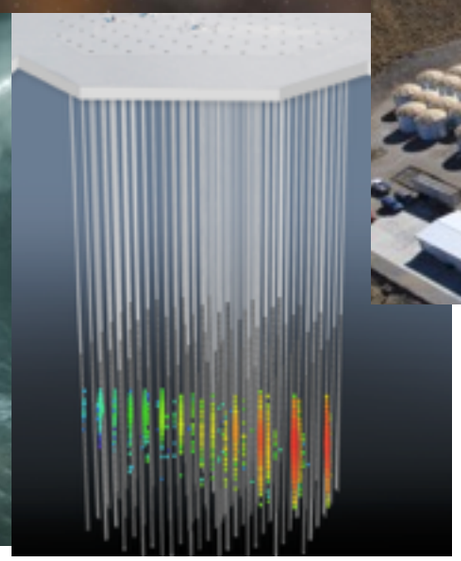


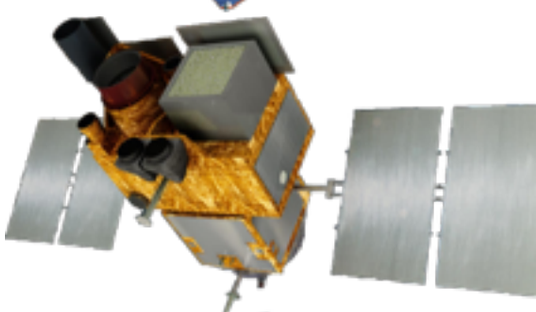












Thanks!