Prospects of detecting early VHE emission from compact binary mergers: ET, CTA synergy

- **Biswajit Banerjee**

Based on:
- ***Banerjee***, Oganesyan, Branchesi et al 2022; arXiv: 2212.14007
- Mei, ***Banerjee***, Oganesyan+ 2022, Nature

Collaborators:
Ulyana Dupletsa, Felix Aharonian, Francesco Brighenti, Boris Goncharov, Jan Harms, Michela Mapelli, Samuele Ronchini, Filippo Santoliquido, O. S. salafia, G. Ghirlanda+

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GRAN SASSO SCIENCE INSTITUTE
CENTER FOR ADVANCED STUDIES INFN

AVENGe, Roma, May 2023

Gravitational waves:

A new window into the Universe

Credit: LIGO–Virgo

KAGRA, Japan

LIGO, Livingston, LA

LIGO, Hanford, WA

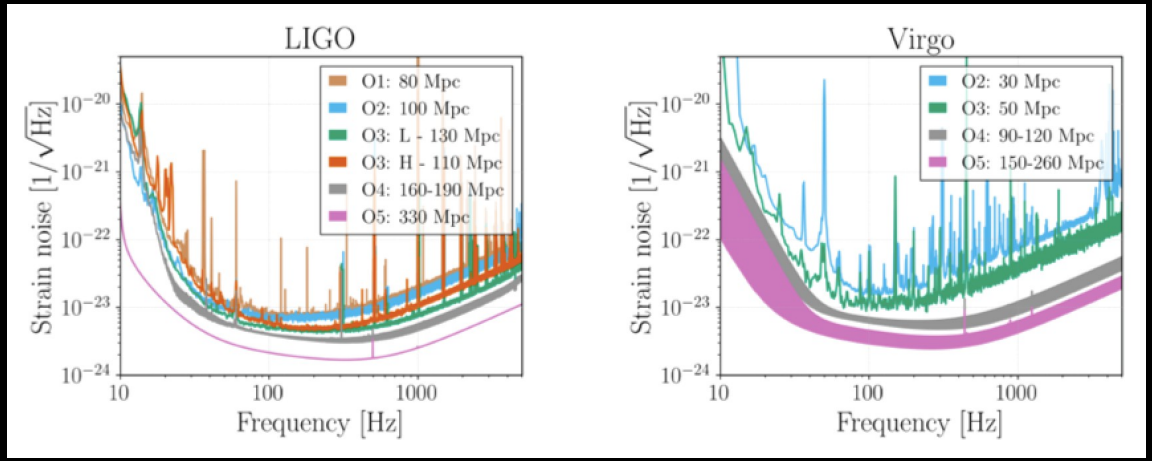
Virgo, Cascina, Italy

LIGO, Livingston, LA

LIGO, Hanford, WA

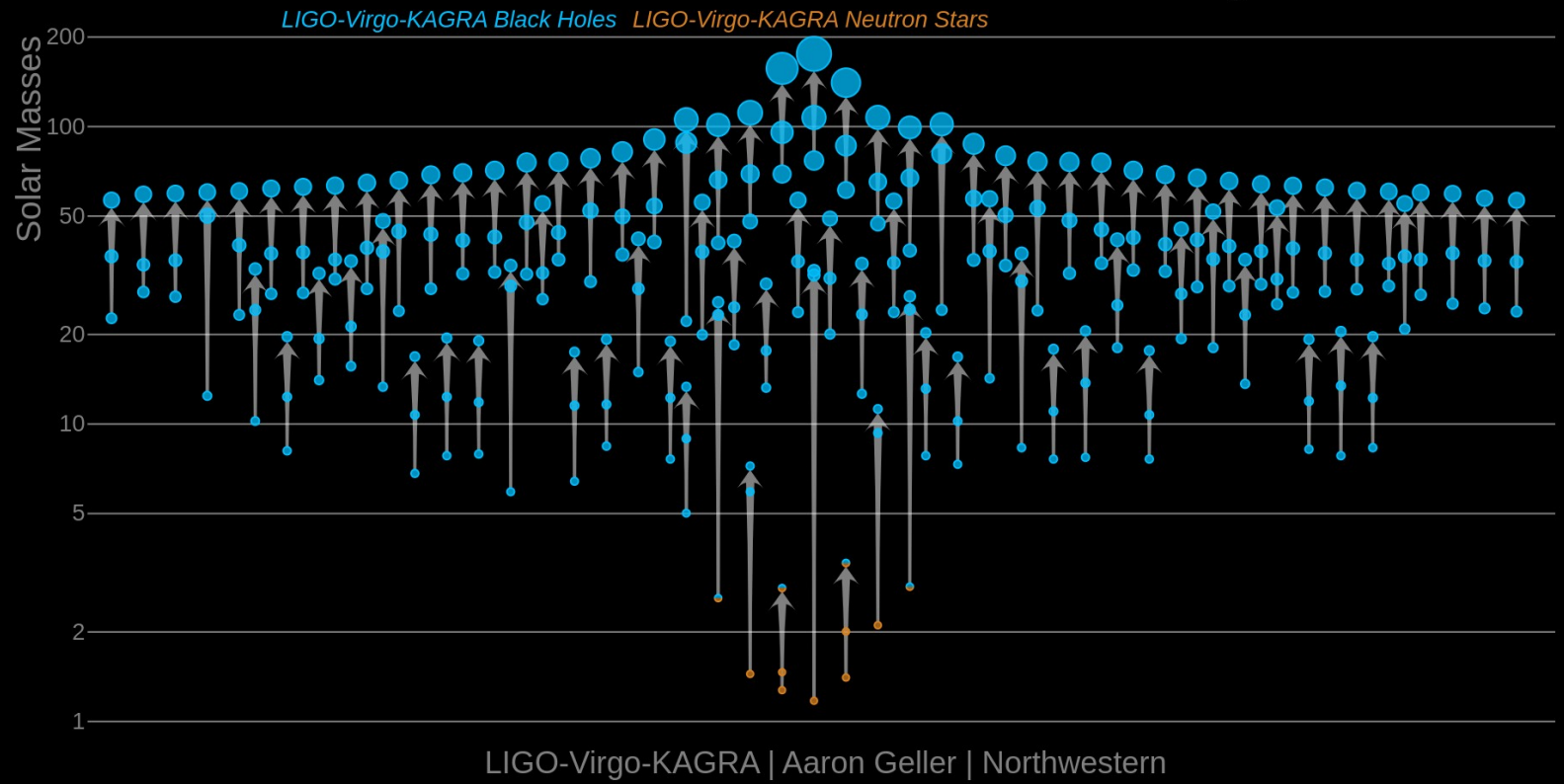
Virgo, Cascina, Italy

O1	O2	O3
Sep ‘15 - Jan ‘16	Nov ‘16 - Aug ‘17	Apr ‘19 - Mar ‘20



Abbott et al. 2020, LRR

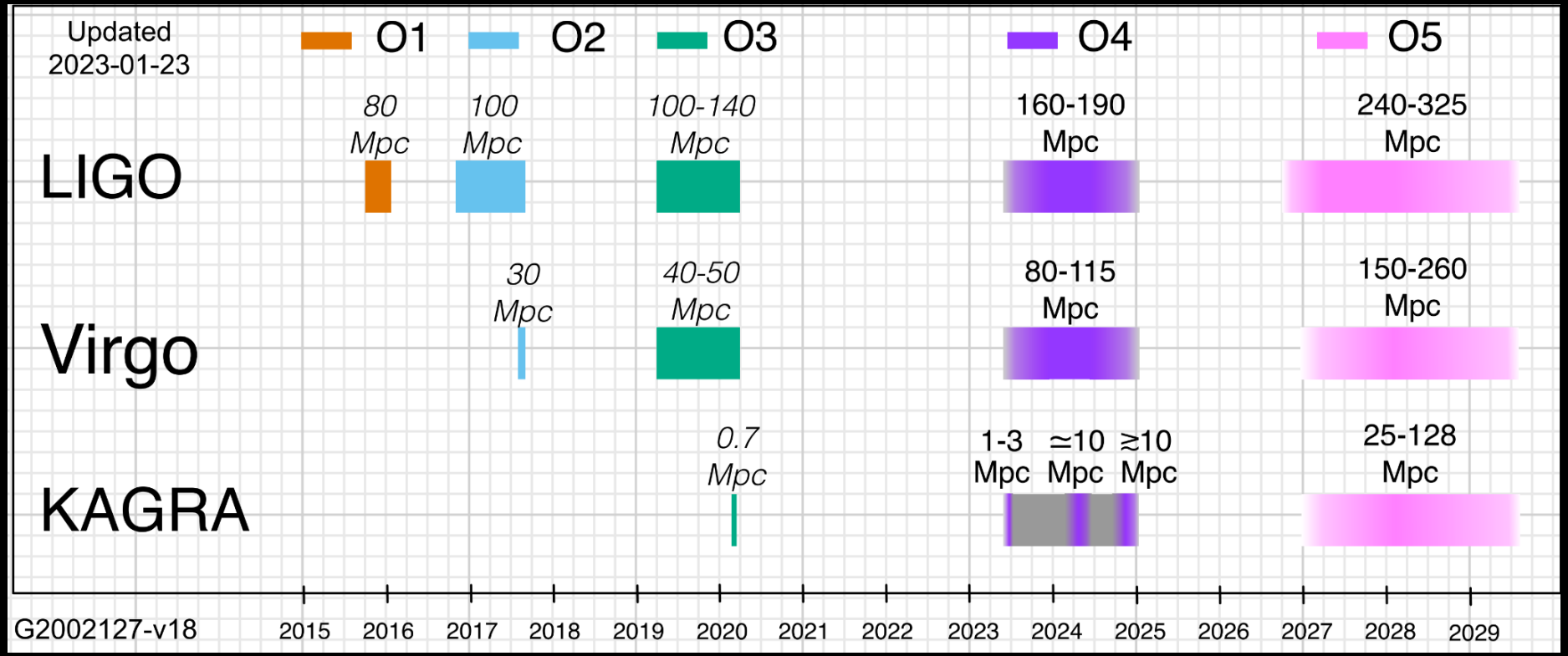
O1+O2+O3
Masses in the Stellar Graveyard



90 GW EVENTS!

LVK arXiv:2111.03606

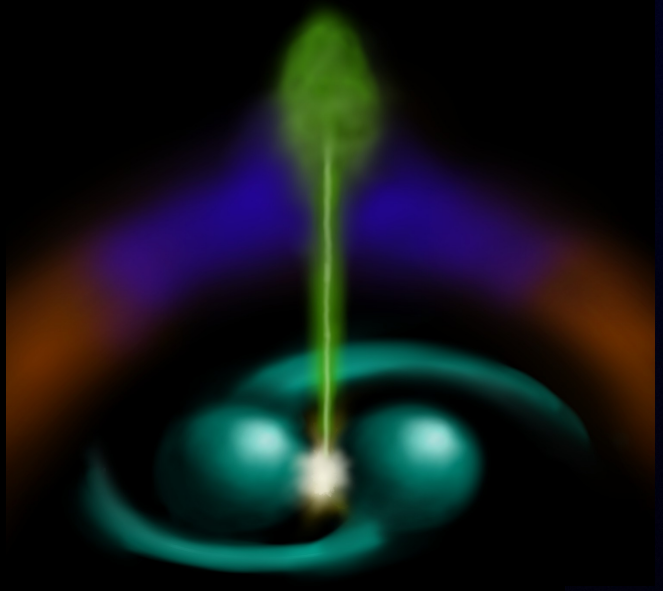
Ongoing observation run of LVK: O4



Abbott et al. 2020, LRR

O4 volume ~ 3*O3 volume
O5 volume ~10*O3 volume

GW 170817



Credit: Ronchini

Fermi

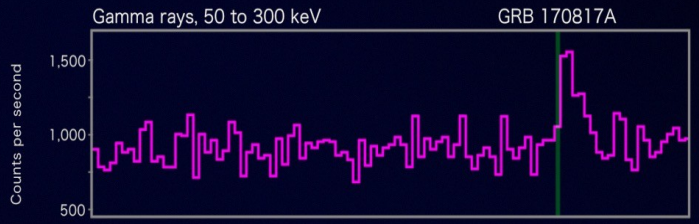
Reported 16 seconds after detection

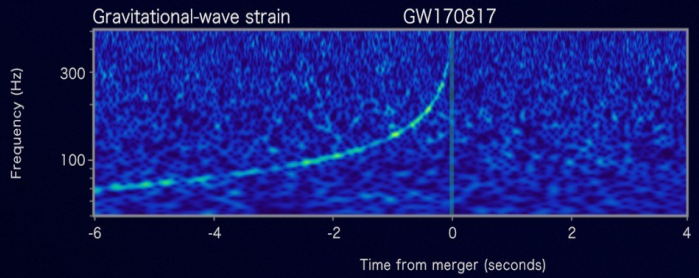
LIGO-Virgo

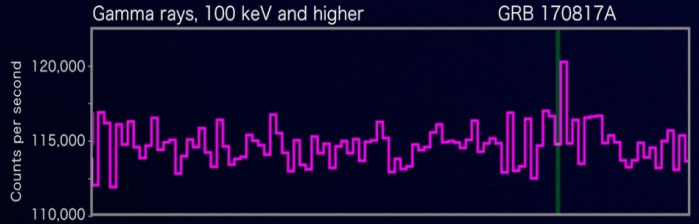
Reported 27 minutes after detection

INTEGRAL

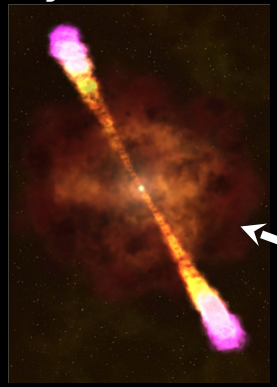
Reported 66 minutes after detection





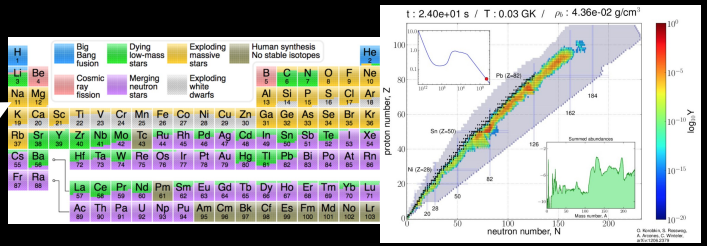


Relativistic astrophysics



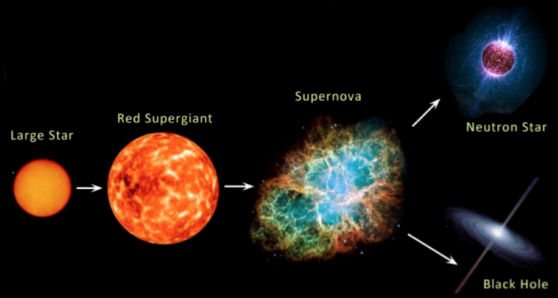
Radioactively powered transients

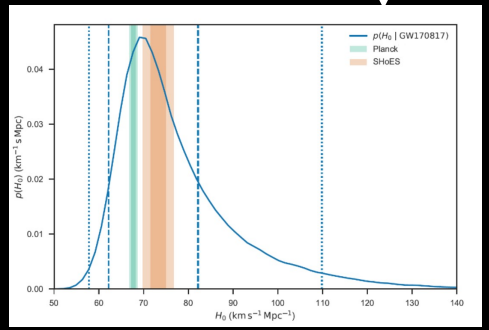
Nucleosynthesis and enrichment of the Universe



GW170817

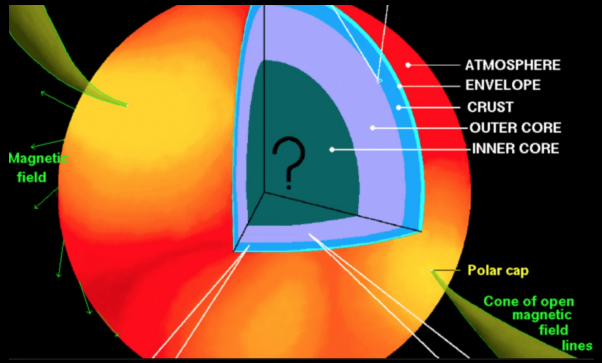
Compact object formation and evolution



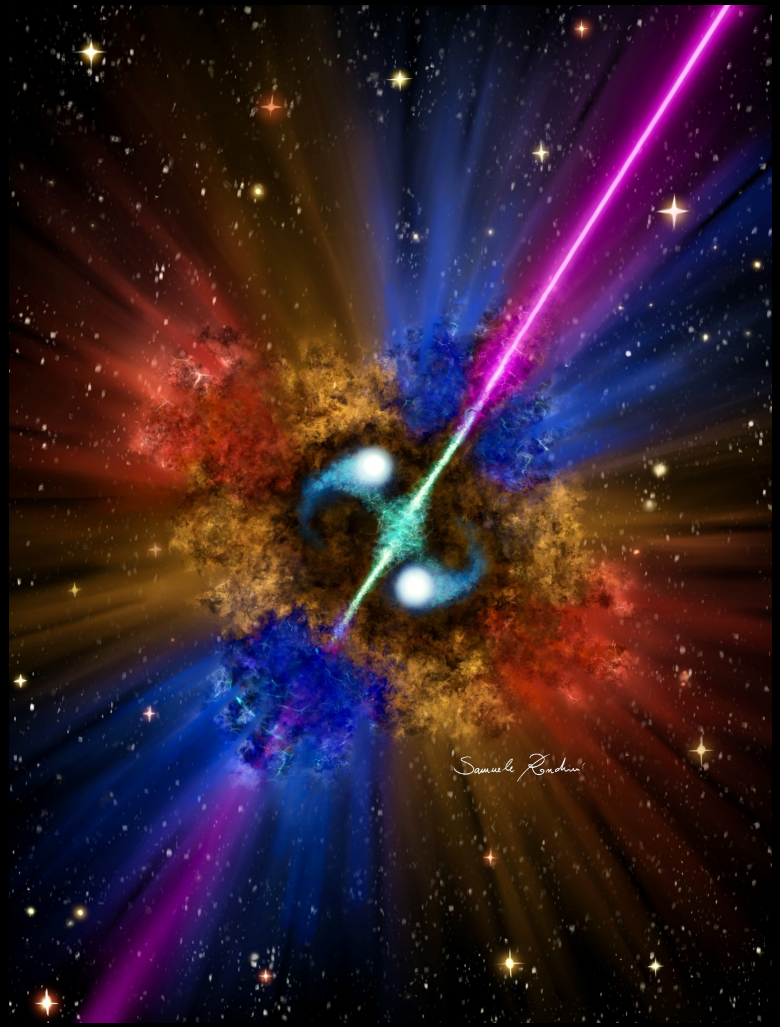


Cosmology

Nuclear matter physics



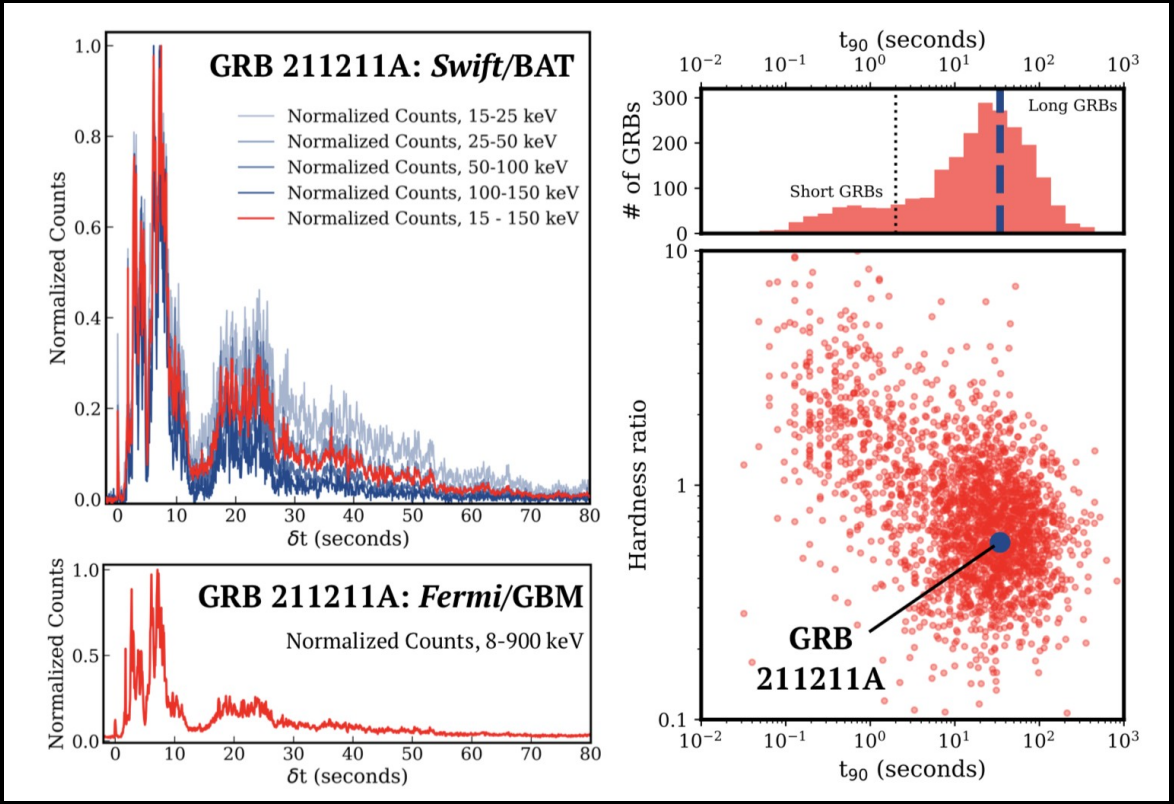
GRB 211211A



GRB 211211A: **long GRB**/ KILONOVA

Minute-duration GRB, prompt and bright spikes last more than 12 s

Nearby GRB at 350 Mpc and 7.9 kpc from the galaxy center

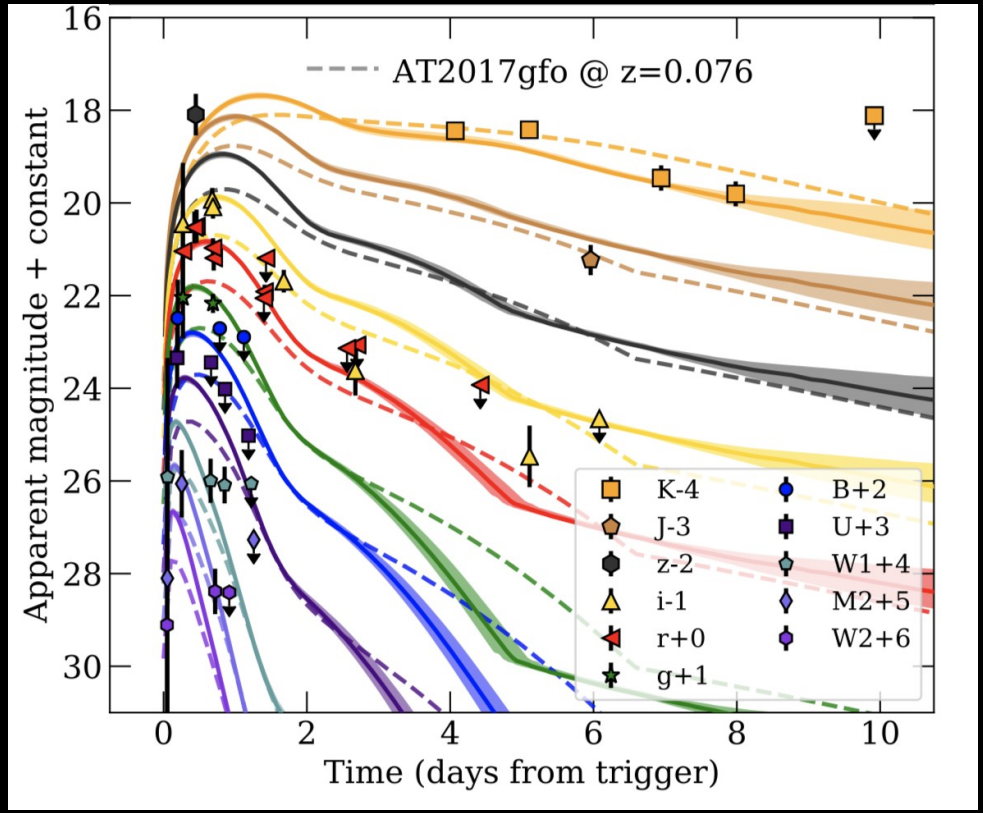


Rastinejad, J. C. et al. 2022 Nature

GRB 211211A: long GRB/ **KILONOVA**

10% of the local long GRB population could arise from mergers

GW170817-like events are within reach



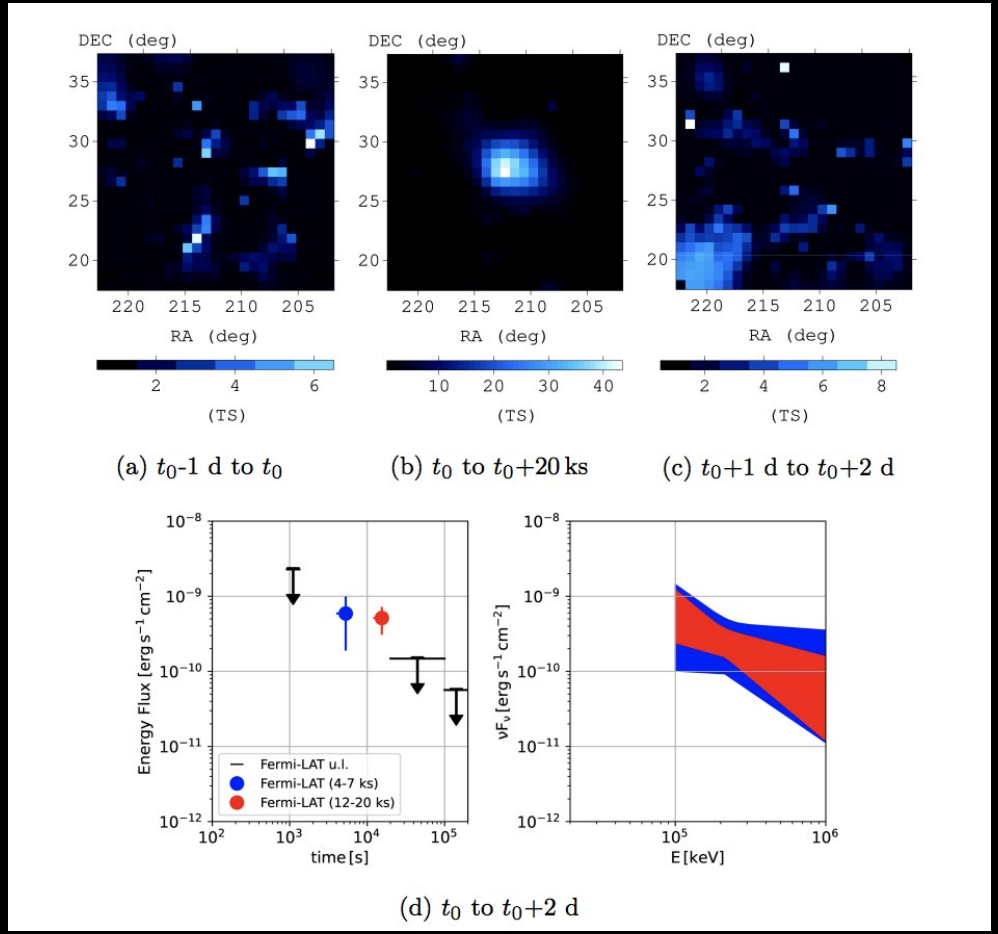
Rastinejad, J. C. et al. 2022 Nature

See alsoTroja et al. 2022 Nature, Xiao, S. et al. 2022 Nature

GRB 211211A: **GeV emission**

Discovery of a significant (>5σ) transient-like emission by Fermi/LAT

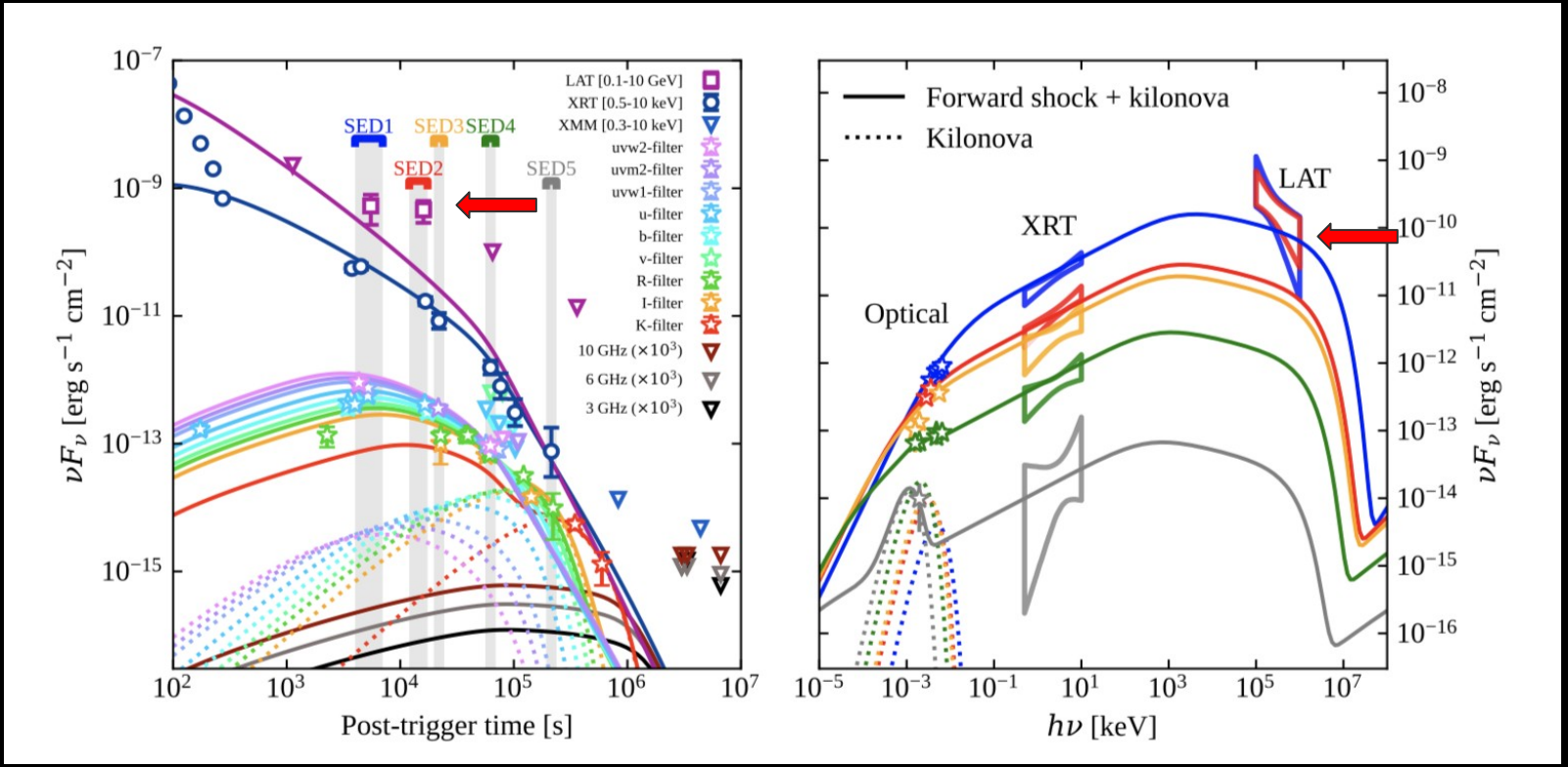
Photon energies 0.1-1 GeV



Mei, **BB** et al. 2022, Nature
Zhang et al 2022, ApjL

GRB 211211A: **GeV emission**

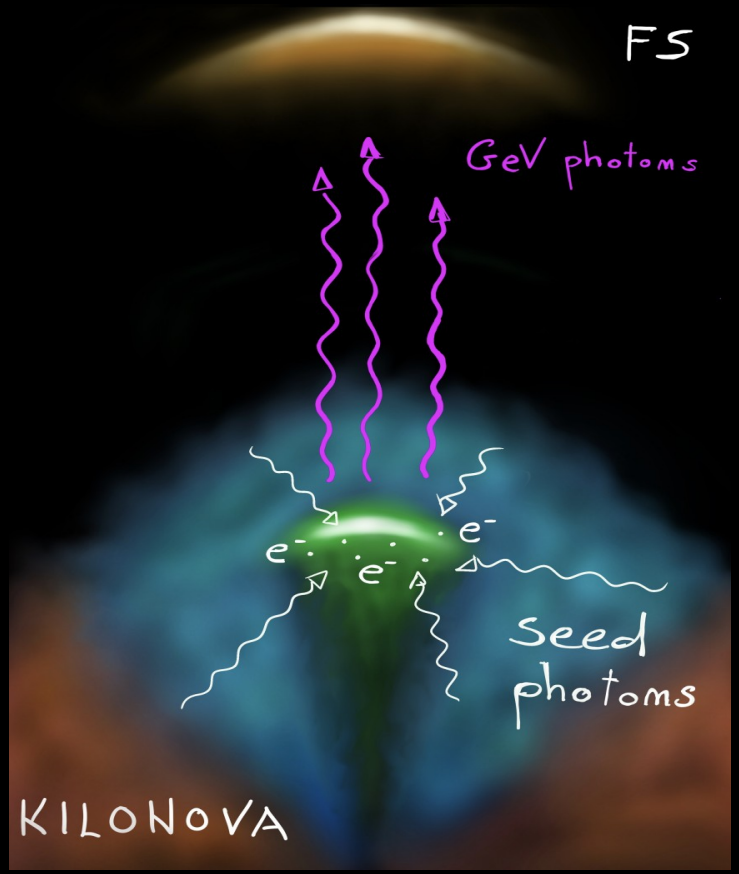
Mei, **BB** et al. 2022, Nature



The GeV emission is in EXCESS with respect to synchrotron emission from standard forward shock of the relativistic jet explaining the afterglow emission in the other bands

GRB 211211A: **GeV emission**

Mei, **BB** et al. 2022, Nature



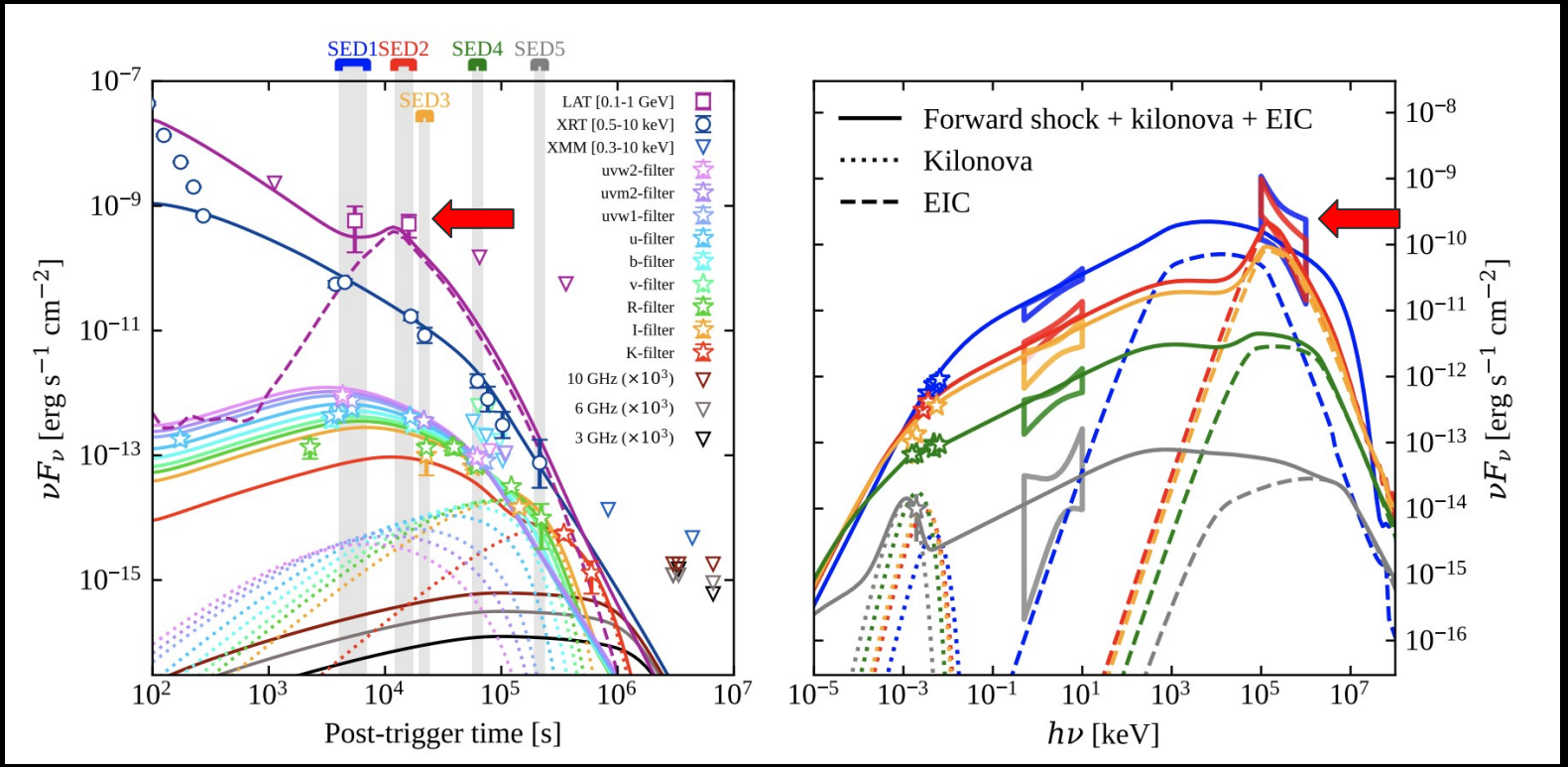
> External Inverse Compton

> kilonova seed photons for the EIC

> electrons nearby the kilonova photosphere at t = 10 ks

> presence of a late-time low-power jet

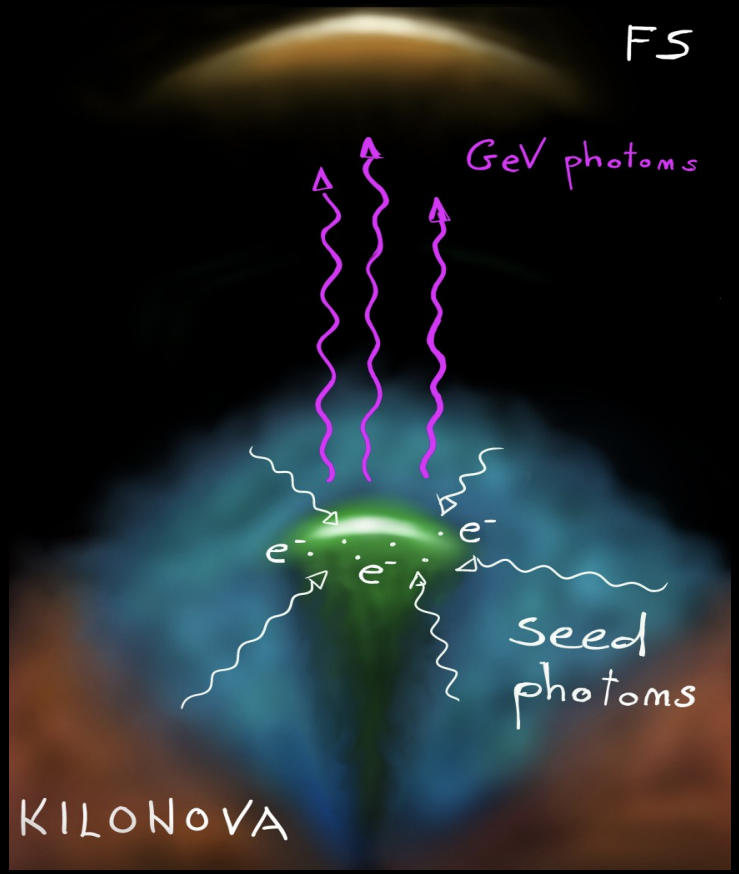
GRB 211211A:
External Inverse Compton from Kilonova photons



Mei, **BB** et al. 2022, Nature

GRB 211211A: **GeV emission**

Mei, **BB** et al. 2022, Nature

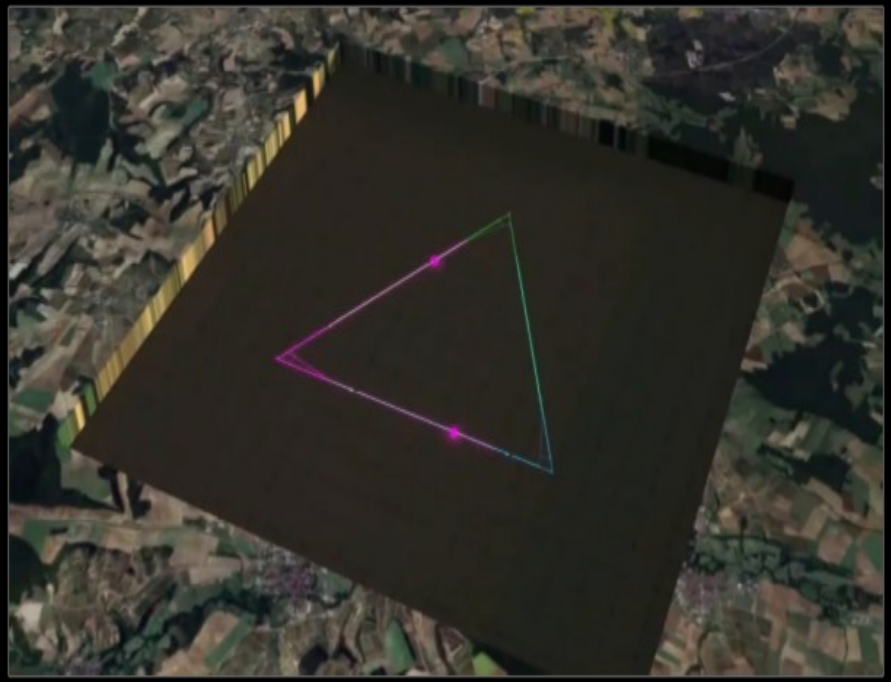


> New counterpart of GW events

> central engine activity can be probed

> GeV and (possibly) sub TeV emission can be expected from CBC at even later times!

ET: the European 3G GW observatory concept

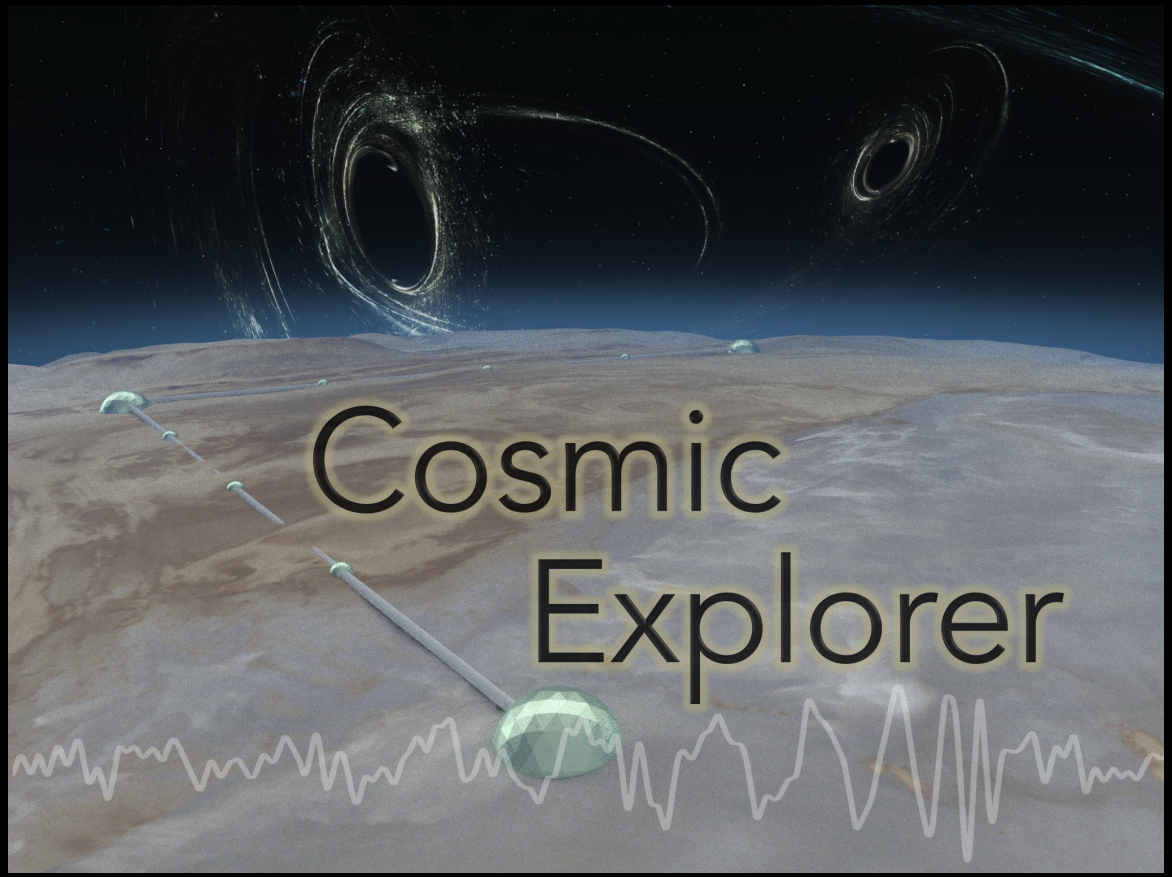


- Delta/ 2L shape
- Length: 10 km (!)
- Underground
- Cryogenic, Increase laser power
- **Branchesi & Maggiore 23** On science cases of ET

Italy to support Sardinian site

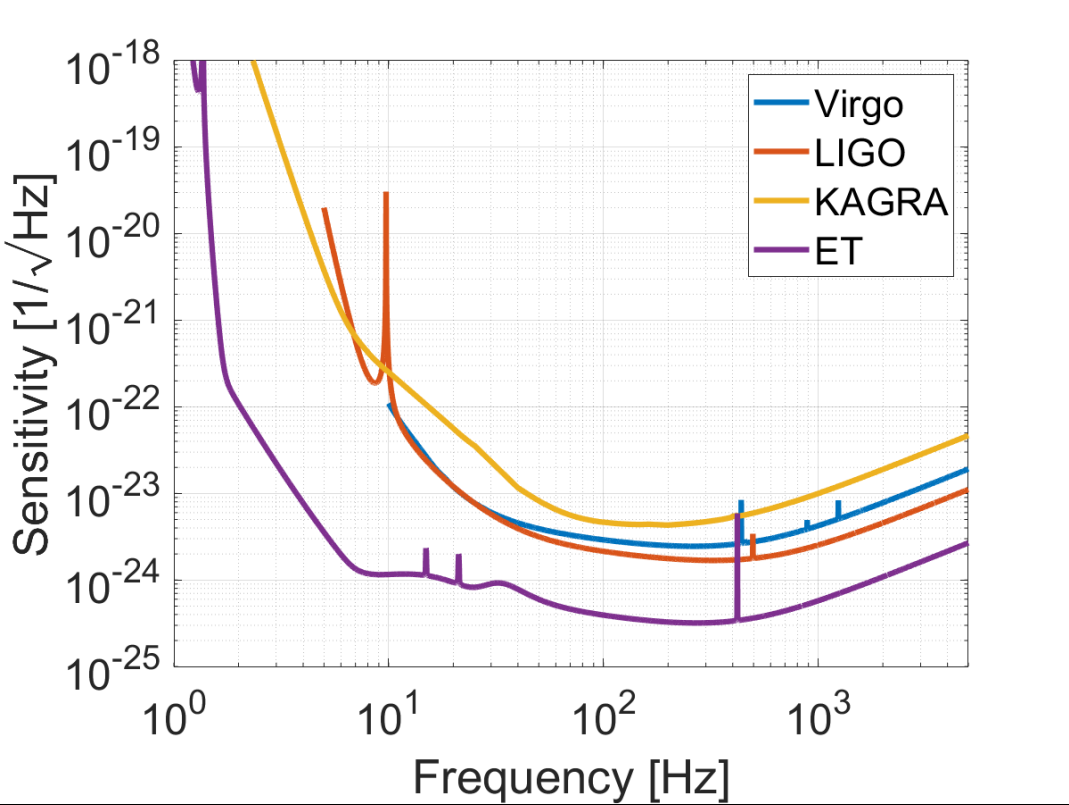
ET ITALY Einstein Telescope

3G effort worldwide: Cosmic Explorer (CE)

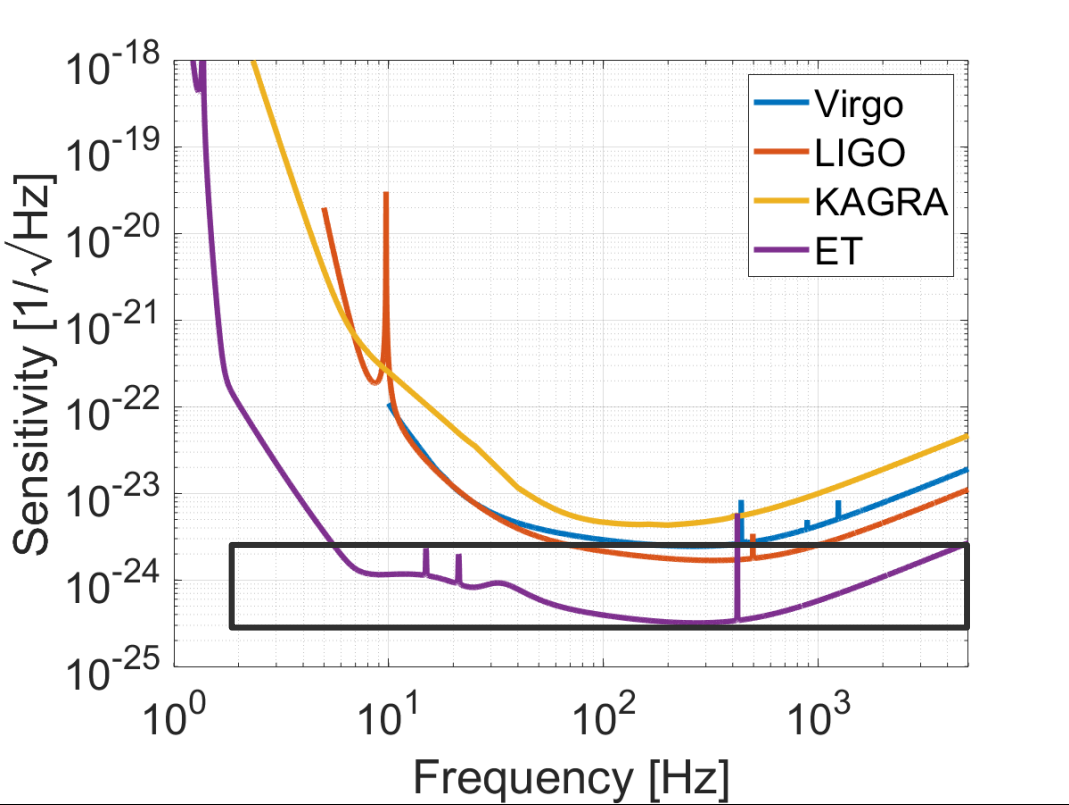


- 2L design; 40 km
- Two sites:
  USA
  Australia

ET sensitivity:
Branchesi, Maggiore et al 2023 (2303.15923)



ET sensitivity:
Branchesi, Maggiore et al 2023 (2303.15923)



ET sensitivity:
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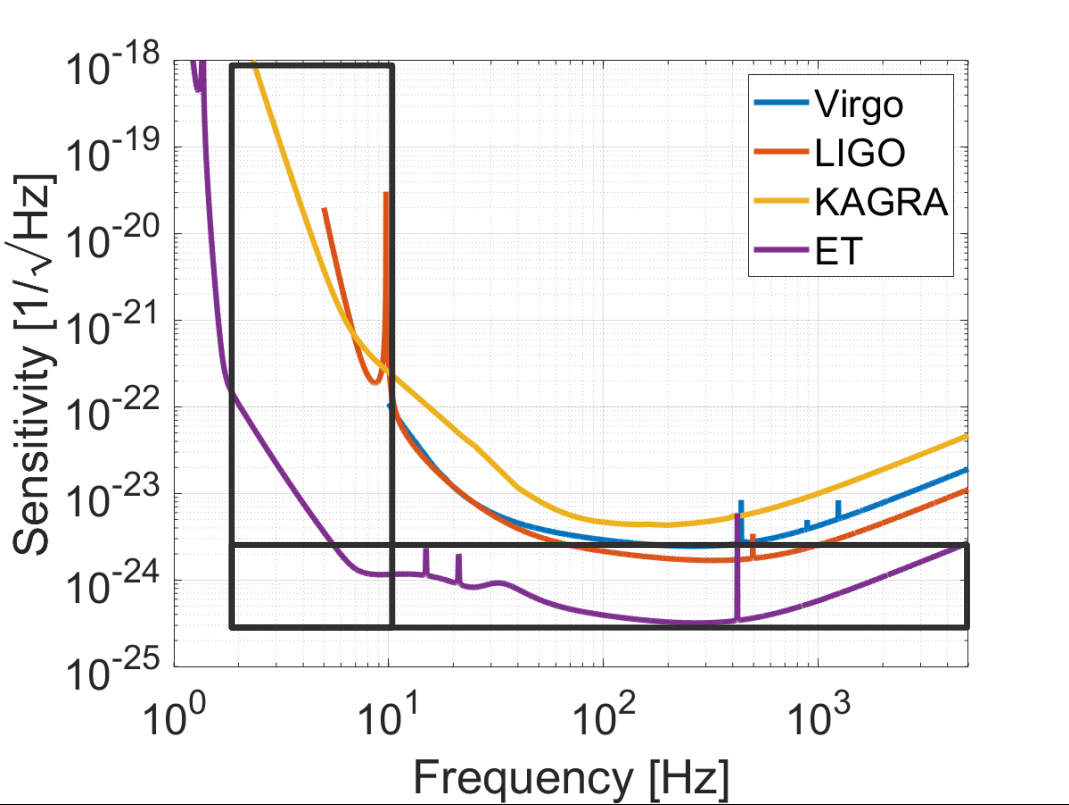
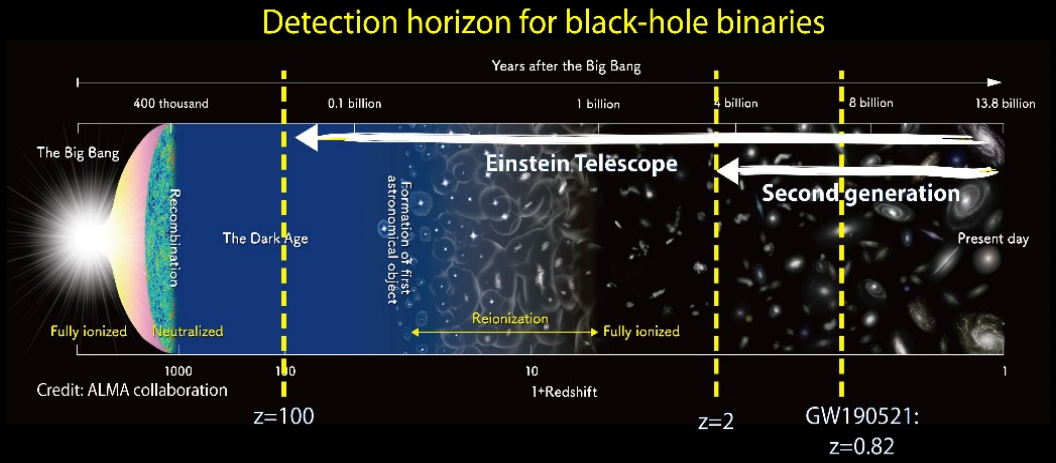
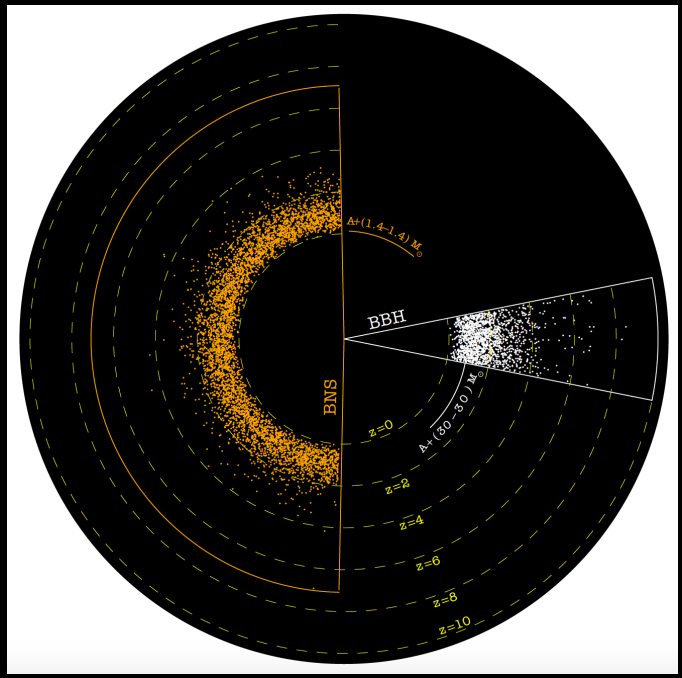


ET sensitivity enables us to explore:

- Large distances back to the EARLY UNIVERSE

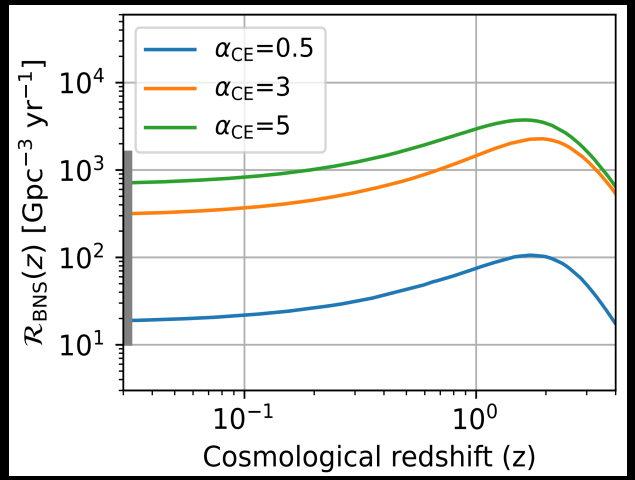




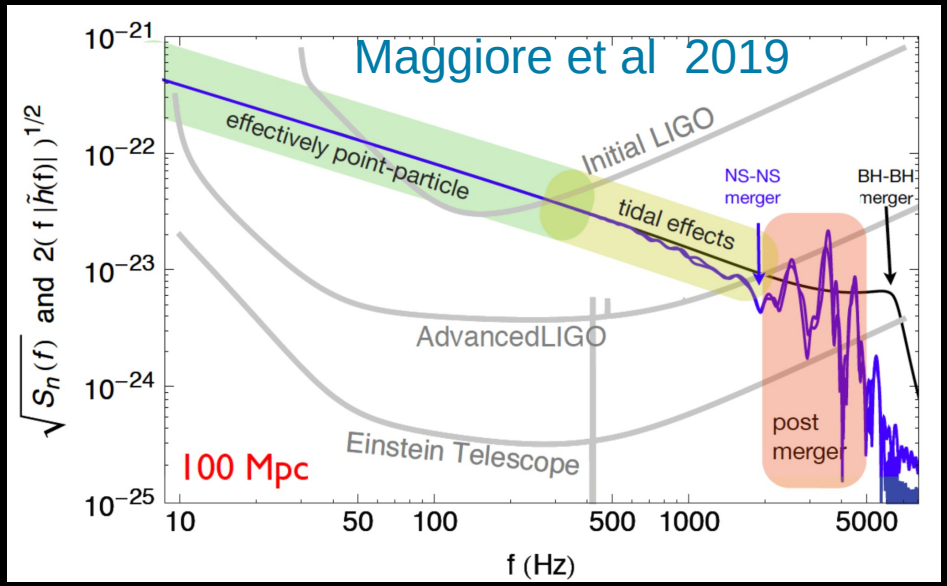
- POPULATION:
  increase number of detections

Analysis tools:

Dupletsa & Harms et al 2023



Santoliquido et al 2021

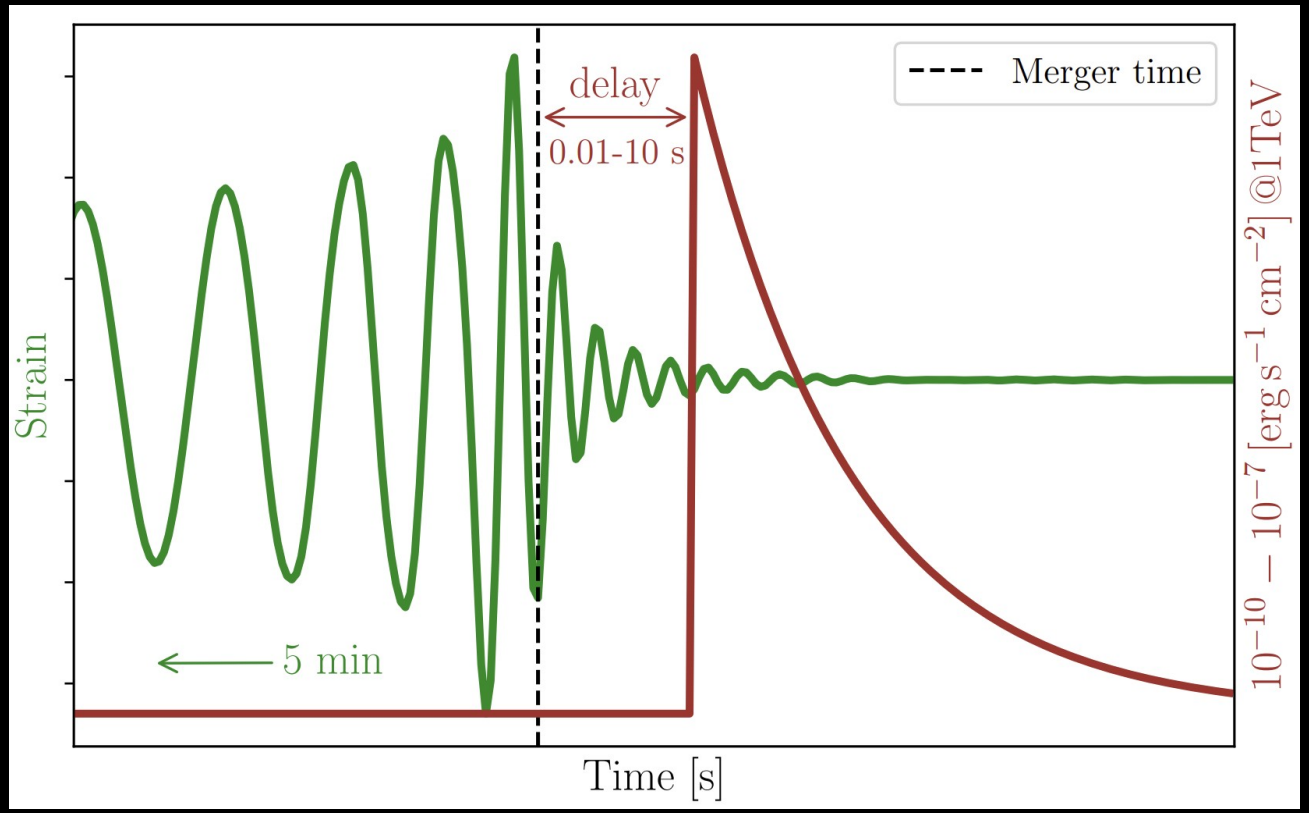


GWFISH

Publicly Available

- Three different populations
- distribution of BNS mass to be a flat between 1.0-2.5 Ms
- ET-D configuration
- Lower freq. down to 2 Hz
- detection in inspiral phase

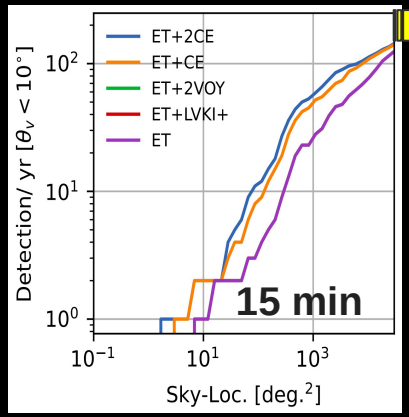
Pre-alert scheme:

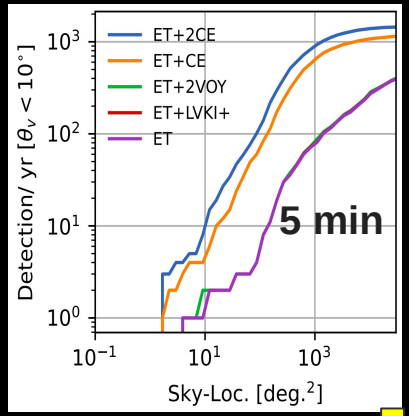


- Detection of BNS during inspiral?
- Sky-localization?
- Pre-alert time?

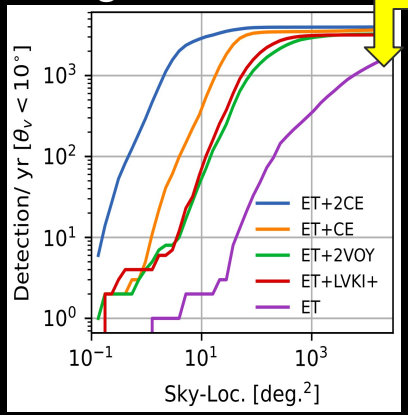
Sky-localization capability:

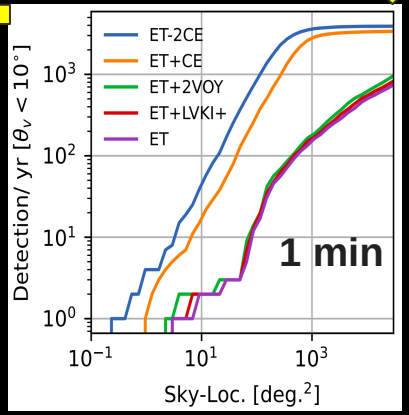
SNR > 8





Merger

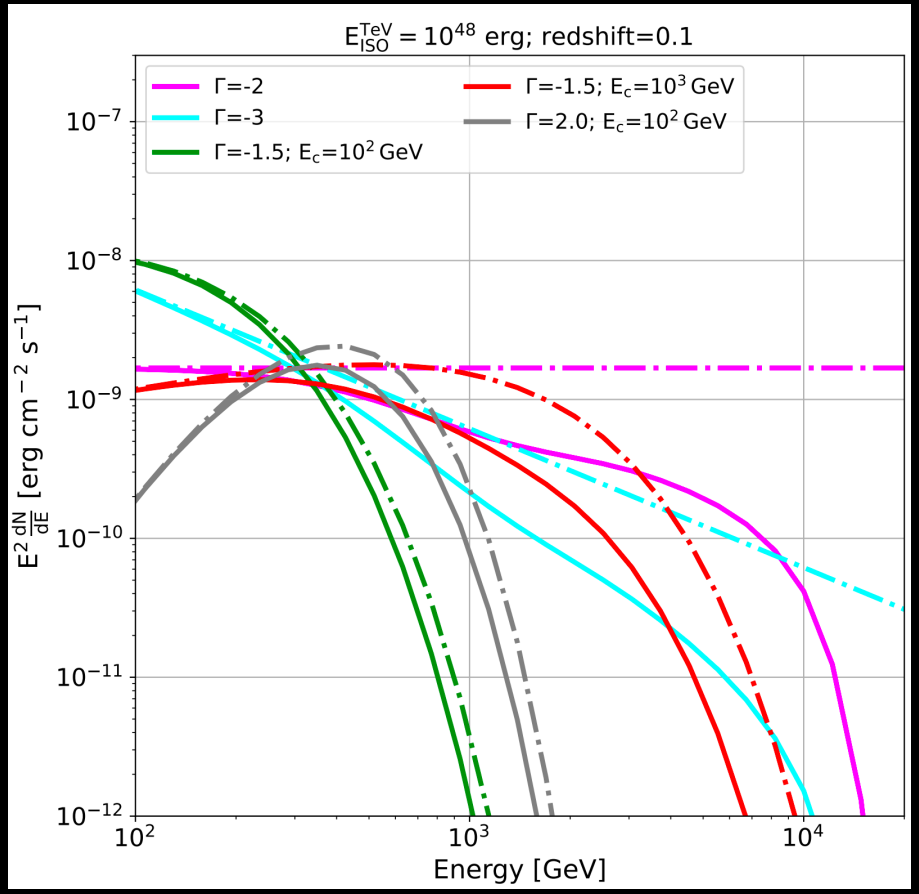


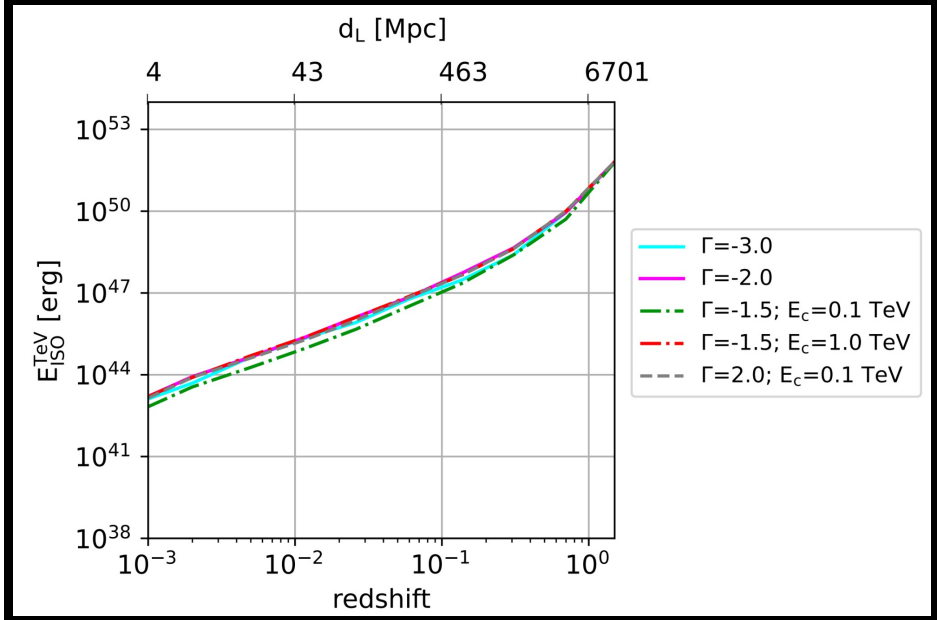


Detector	Ω [deg²]	All orientations			
		15 min	5 min	1 min	0 min
ET + CE	10	21	51	185	6656
	100	442	1325	5075	123303
ET	10	5	5	8	14
	100	90	130	208	436

Detector	Ω [deg²]	Viewing angle (<10⁰)			
		15 min	5 min	1 min	0 min
ET + CE	10	3	5	17	397
	100	21	71	314	3376
ET	10	1	1	2	2
	100	3	6	13	40

Detectability of VHE emission:



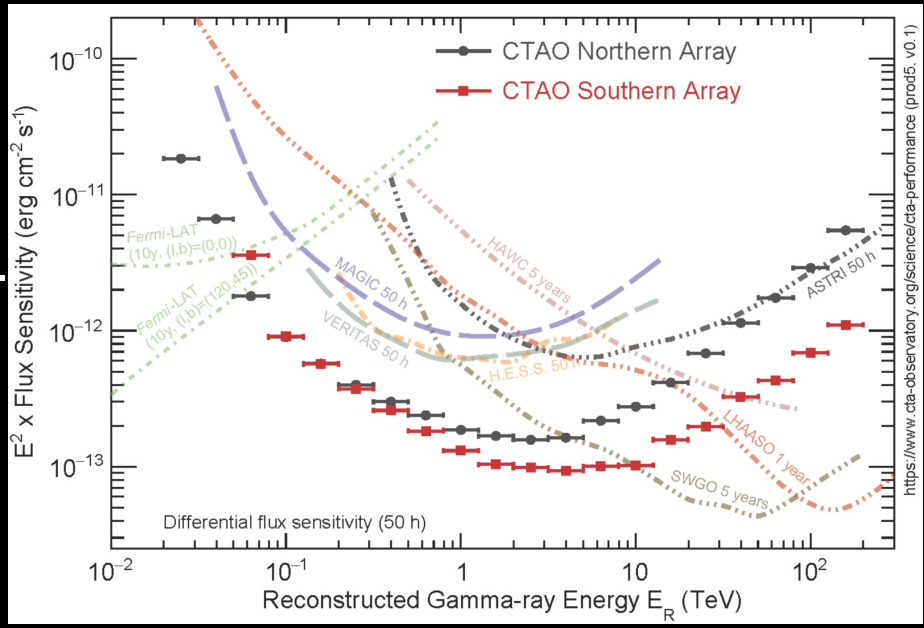


5-sigma in 20s

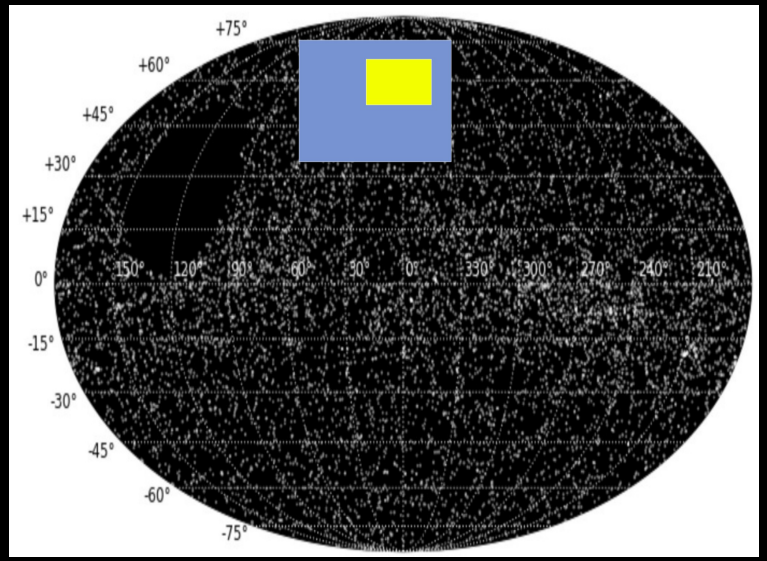
Cherenkov Telescope Array (CTA)

1. Largest ground-based Cherenkov telescope facility, more than 100 IACT with two proposed sites: La Palma, Spain and Chile.
2. 10X sensitivity than MAGIC, HESS.
3. Operational energy range ~0.01-100 TeV
4. Field of view up to ~50 sq. deg.
5. Response time of ~20 seconds.

LST+MST+SST



Observation strategy:



- Follow prealert
- FoV of CTA
  (~10/ 30 sq. deg)

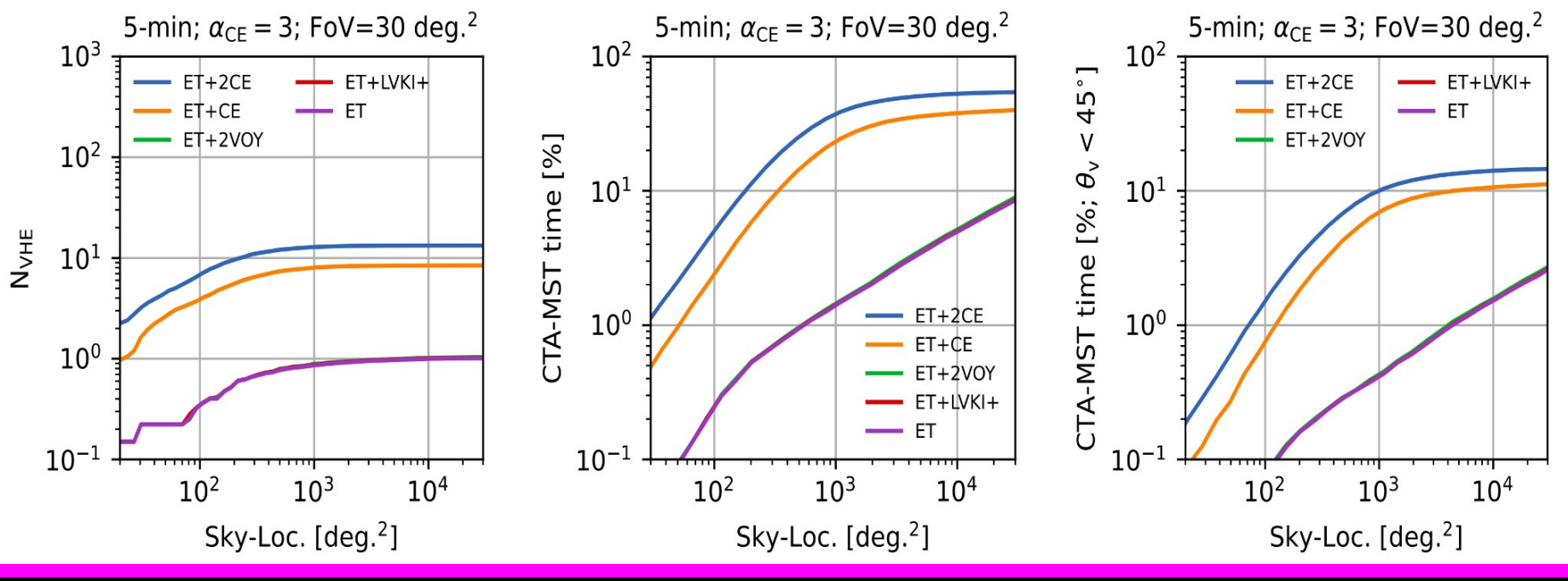
1. Following-up well localized sources (< FoV).
2. Single shot observation
3. Mosaic strategy (see Ronchini, Branchesi, Oganesyan, ***BB*** et al 22)
4. Divergent pointing

Observation strategy: MST

Time before merger	MST-a	MST-b	MST-c	MST-d
15 minutes	Event detected		Event detected with sky-loc $< 10^3$ deg^2	
14.5 minutes	Alert received		Alert received	
5 minutes		Event detected		Event detected with sky-loc $< 10^3$ deg^2
4.5 minutes		Alert received		Alert received
100 seconds		Start slewing		
60 seconds			Parameters updated	
30 seconds			Updates received	
10 seconds	Sky-loc reached	Sky-loc reached	Sky-loc reached	
			Repositioning on the updated sky-loc	
			Updated sky-loc reached	
Merger time		20 s of exposure		

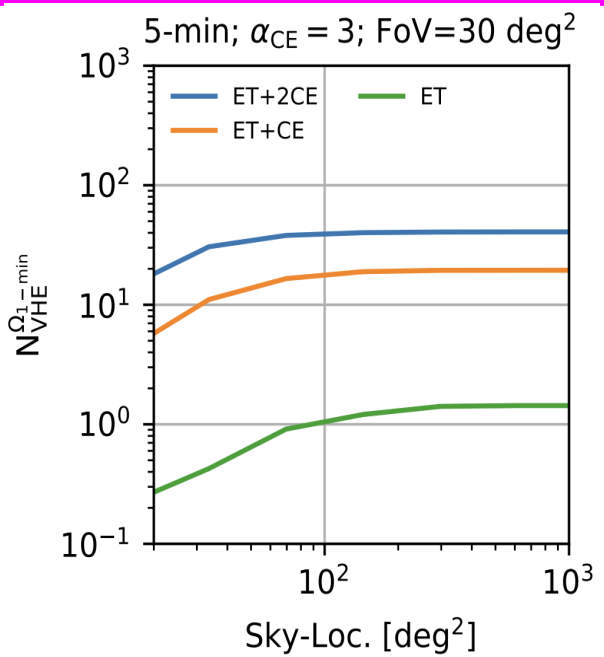
t_{alert}= 30s; t_{slew}= **90s**; t_{rep}= 10s; t_{exp}= 20 s

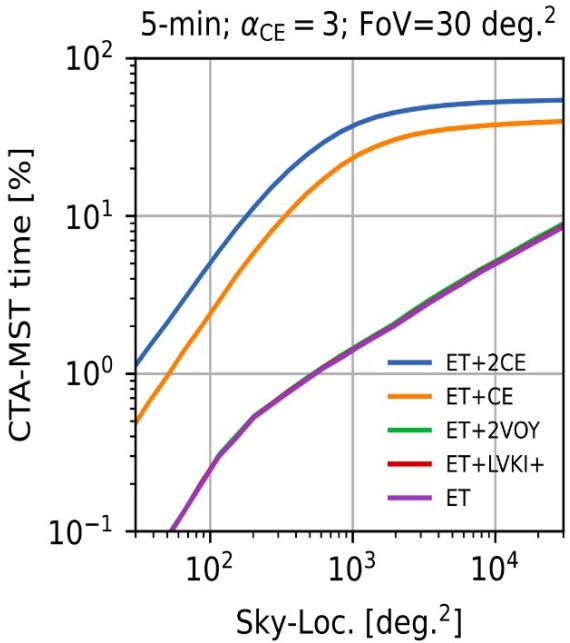
Observation strategy: MST

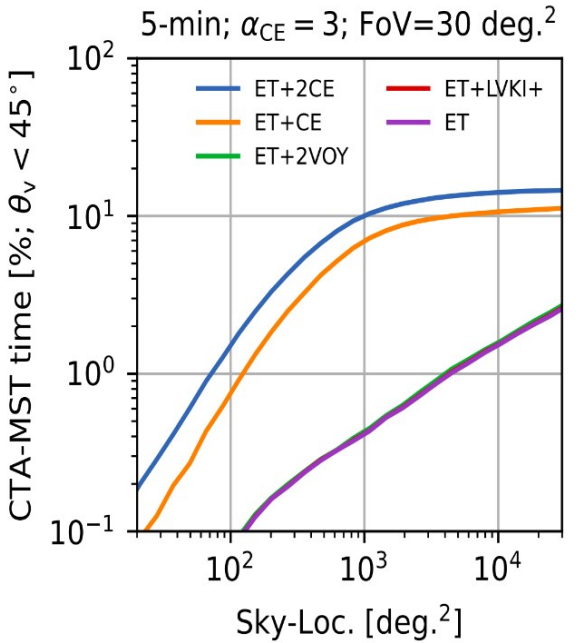


t_{alert}= 30s; t_{slew}= **90s**; t_{rep}= 10s; t_{exp}= 20 s

Observation strategy: MST







t_{alert}= 30s; t_{slew}= **90s**; t_{rep}= 10s; t_{exp}= 20 s

Conclusions:

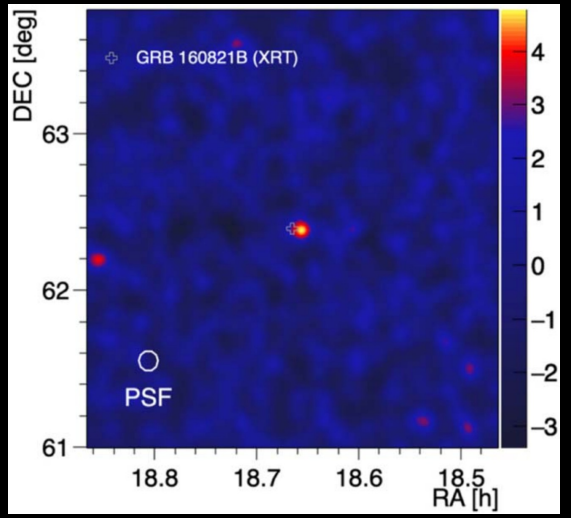
1. The combined effort of ET and CE is capable of increasing EM follow-ups.
2. The prealerts (even before 15 minutes) are useful for ground based and satellites to observe early counterpart from BNS.
3. Expected operational time of CTA after 2030, similar to ET and CE with unprecedented sensitivity and larger FoV compared to the current generation IACT.
4. ET+CE: following all the sources with sky-loc < 100 sq. degrees 5 minutes before the merger with one single observation (FoV=30 sq. deg.) using ~5% of the CTA time about 20 VHE counterpart can potentially be detected.
5. GRB 211211A is an example that long GRBs can originate from CBC
6. The discovery of the GeV component opened up a new search box for the counterpart of GW events also in VHE

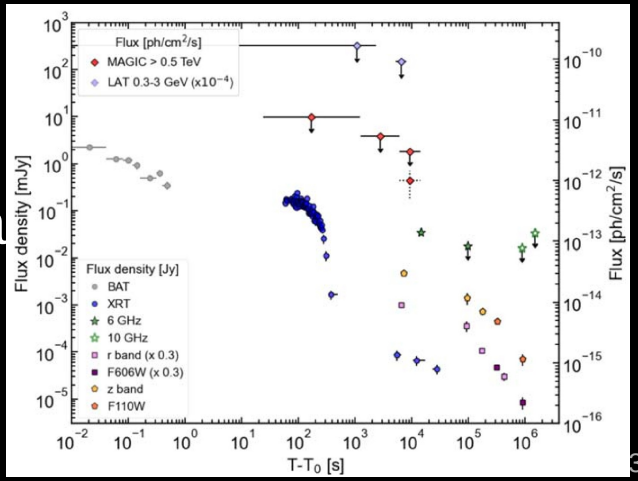
More slides

Hunting sGRB in VHE

The curious case of **GRB 160821B**

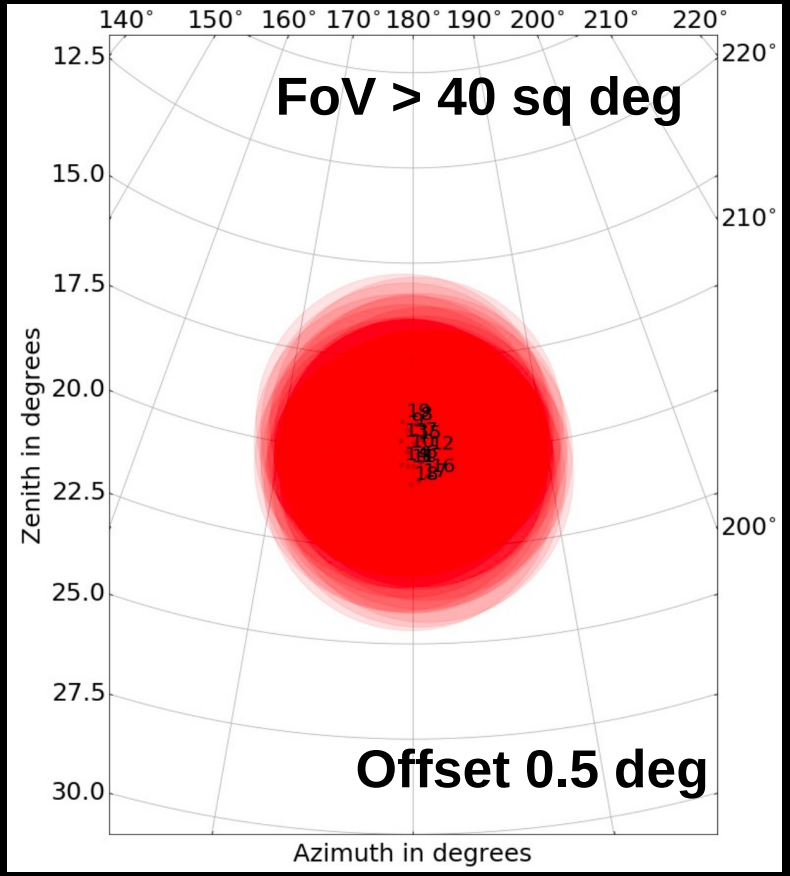
1. Observation started at ~T0+20s, **shortest response time** for any IACT so far.
2. Excess of TeV photons detected ~4ϭ in the energy range > 0.5 TeV co-located a XRT detection of GRB 160821B
3. Results in an upper limit for VHE flux

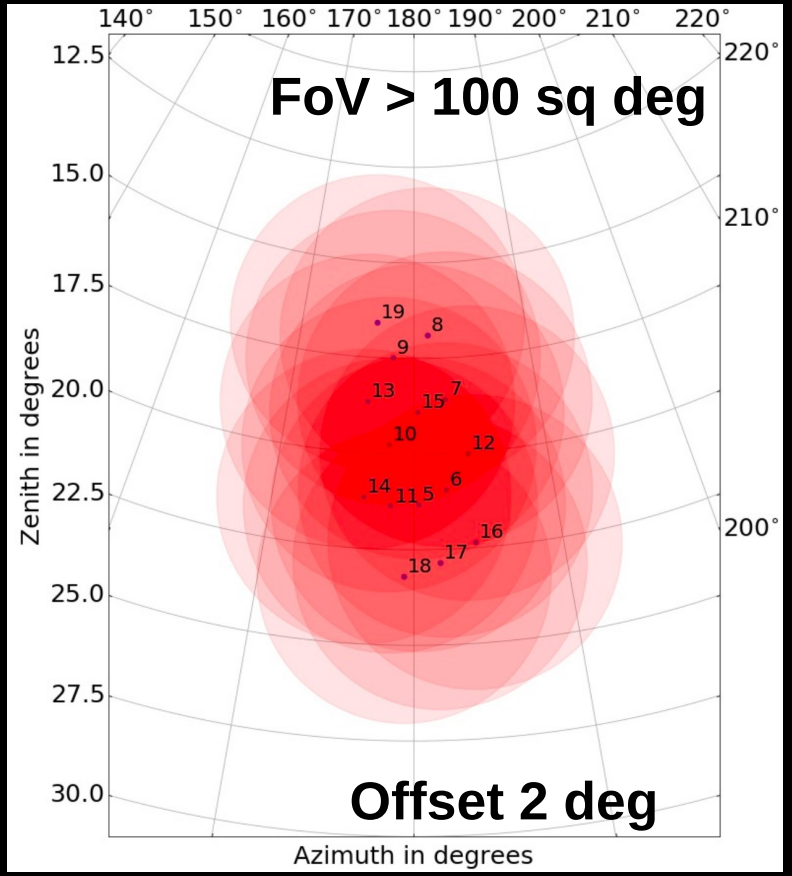




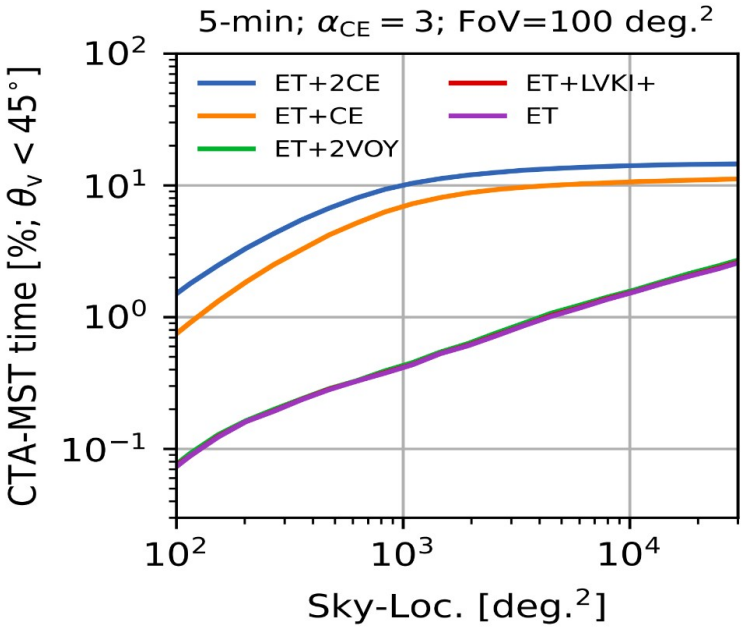
Divergent pointing:

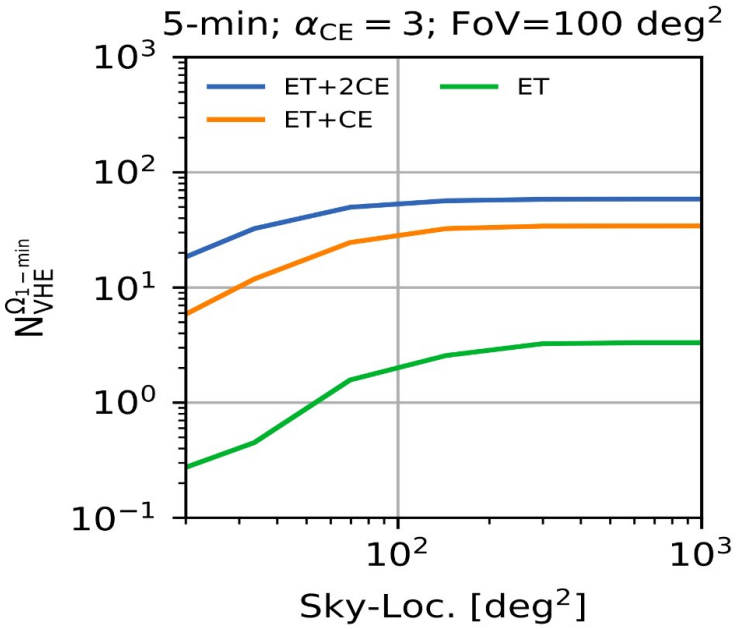
Donini et al 2019





Observation strategy: Divergent Pointing





t_{alert}= 30s; t_{slew}= **90s**; t_{rep}= 10s; t_{exp}= 20 s

$$\mathrm{CTAtime}(\%) = \frac{\mathrm{N}(<\Omega) \times \mathrm{t_{obs}} \times \mathrm{CTA_{vis}}}{\mathrm{CTA_{TOT}}}$$

$$\mathrm{N_{VHE}} = \sum_{i=1}^{\mathrm{N}_{\theta<10^\circ}(<\Omega)} \frac{\mathrm{FoV}}{\Omega_i} \times \mathrm{D.C.} \times \mathrm{CTA_{vis}}$$

Observation strategy: LST

Time before merger	LST-a	LST-b	LST-c	LST-d	LST-e
15 minutes	Event detected			Event detected with sky-loc < 10^3 deg^2	
14.5 minutes	Alert received			Alert received	
5 minutes		Event detected			Event detected with sky-loc < 10^3 deg^2
4.5 minutes		Alert received			Alert received
60 seconds			Event detected	Parameters updated	
30 seconds	Start slewing		Alert received +Start slewing	Start slewing	
10 seconds	Sky-loc reached			Sky-loc reached	
				Repositioning on the updated sky-loc	
				Updated sky-loc reached	
Merger time	20 s of exposure				

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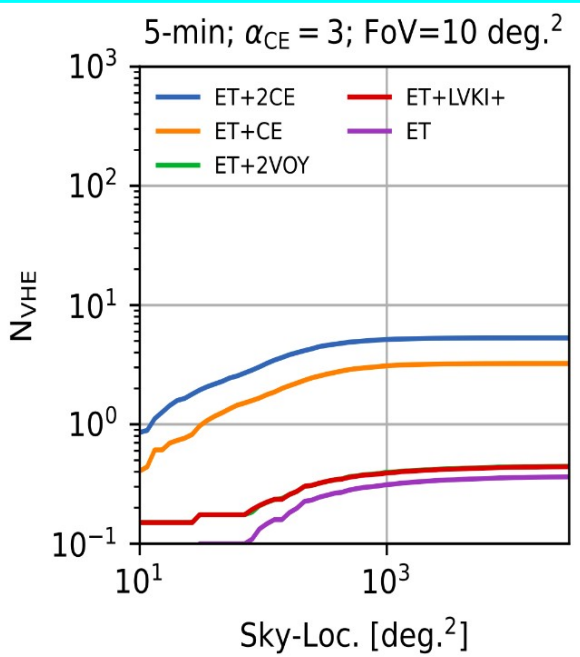

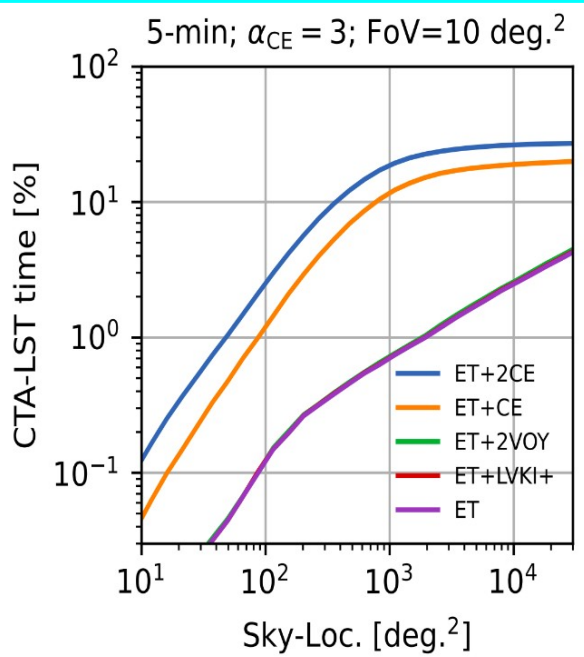

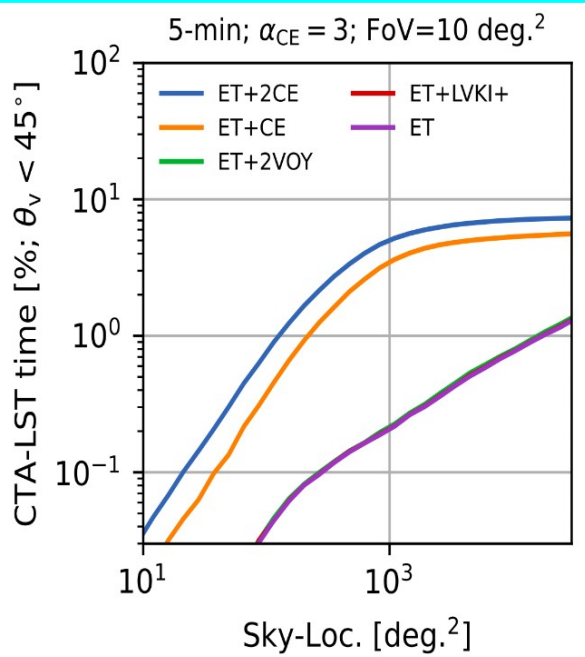

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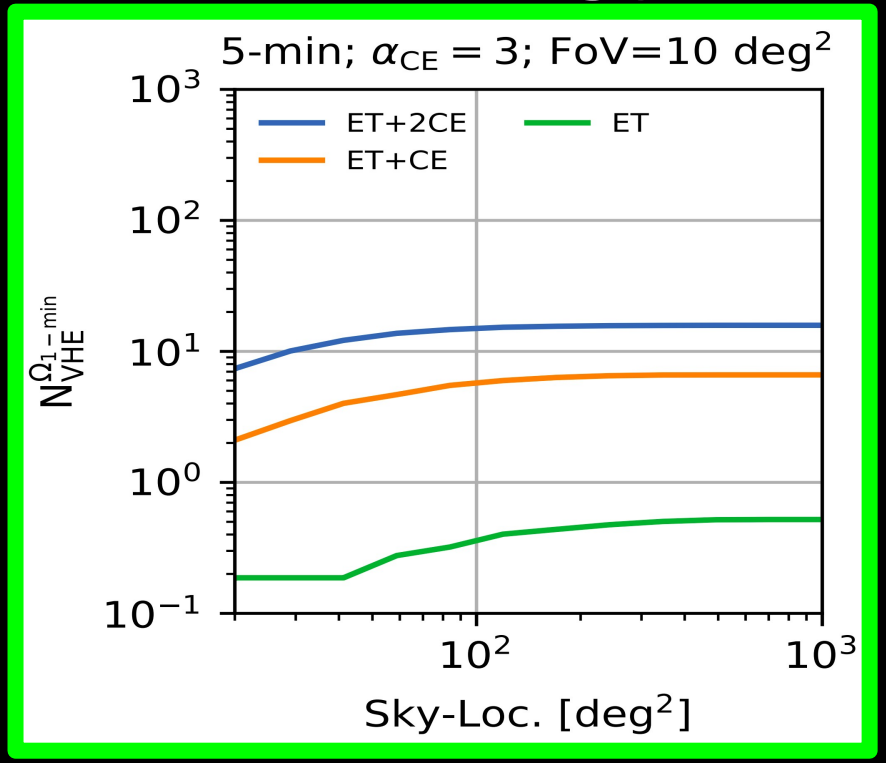

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