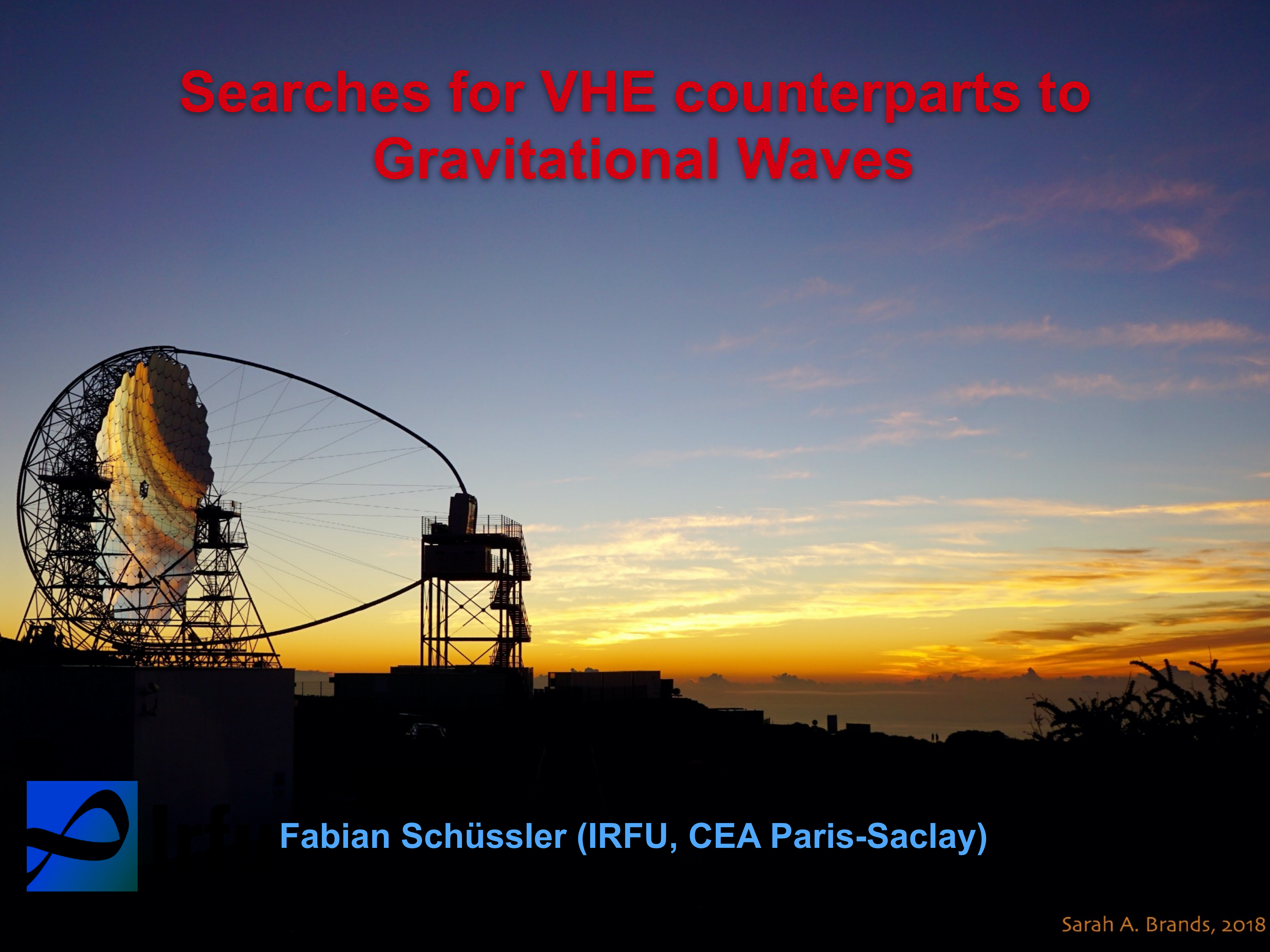
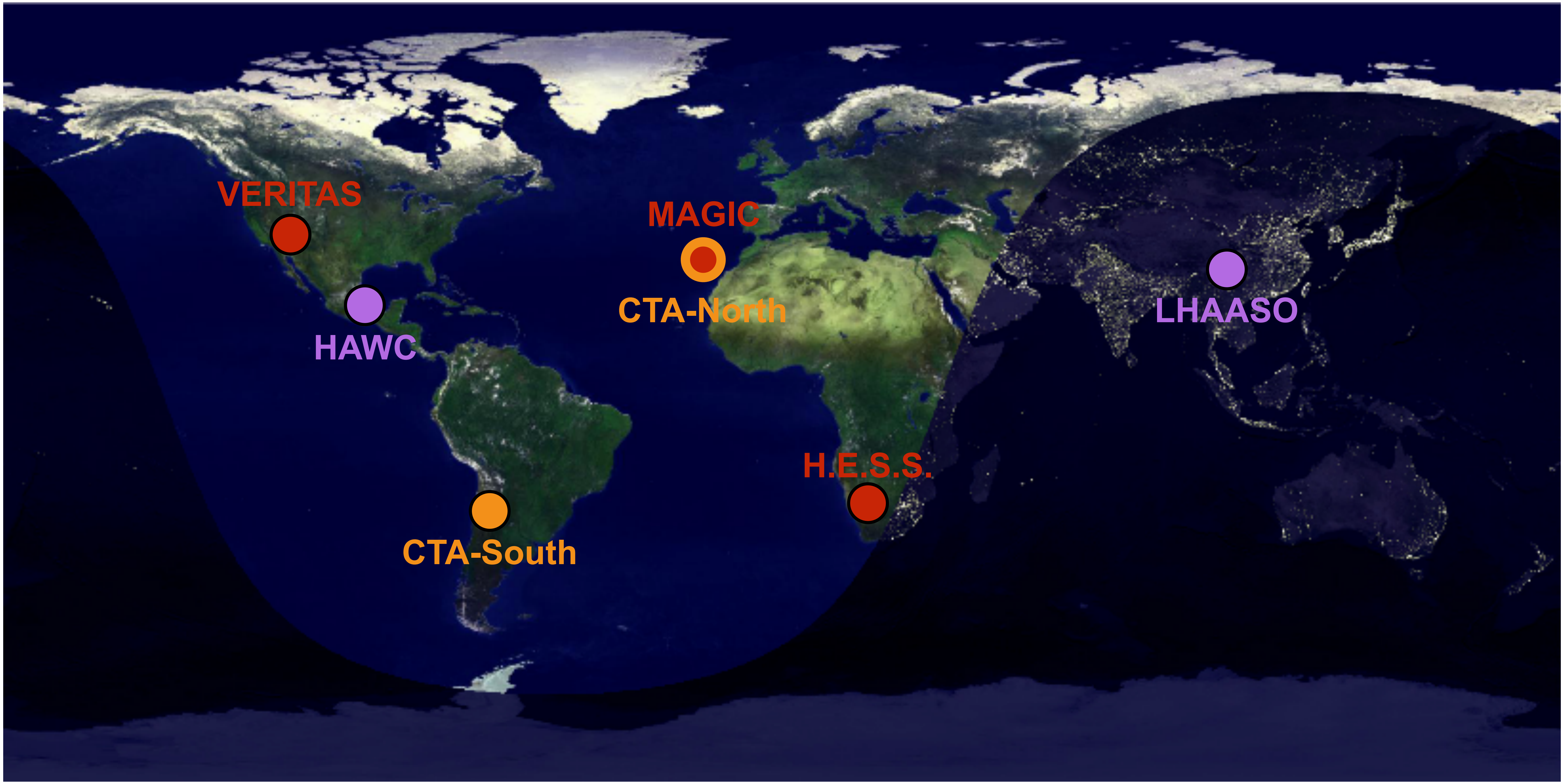
Searches for VHE counterparts to Gravitational Waves



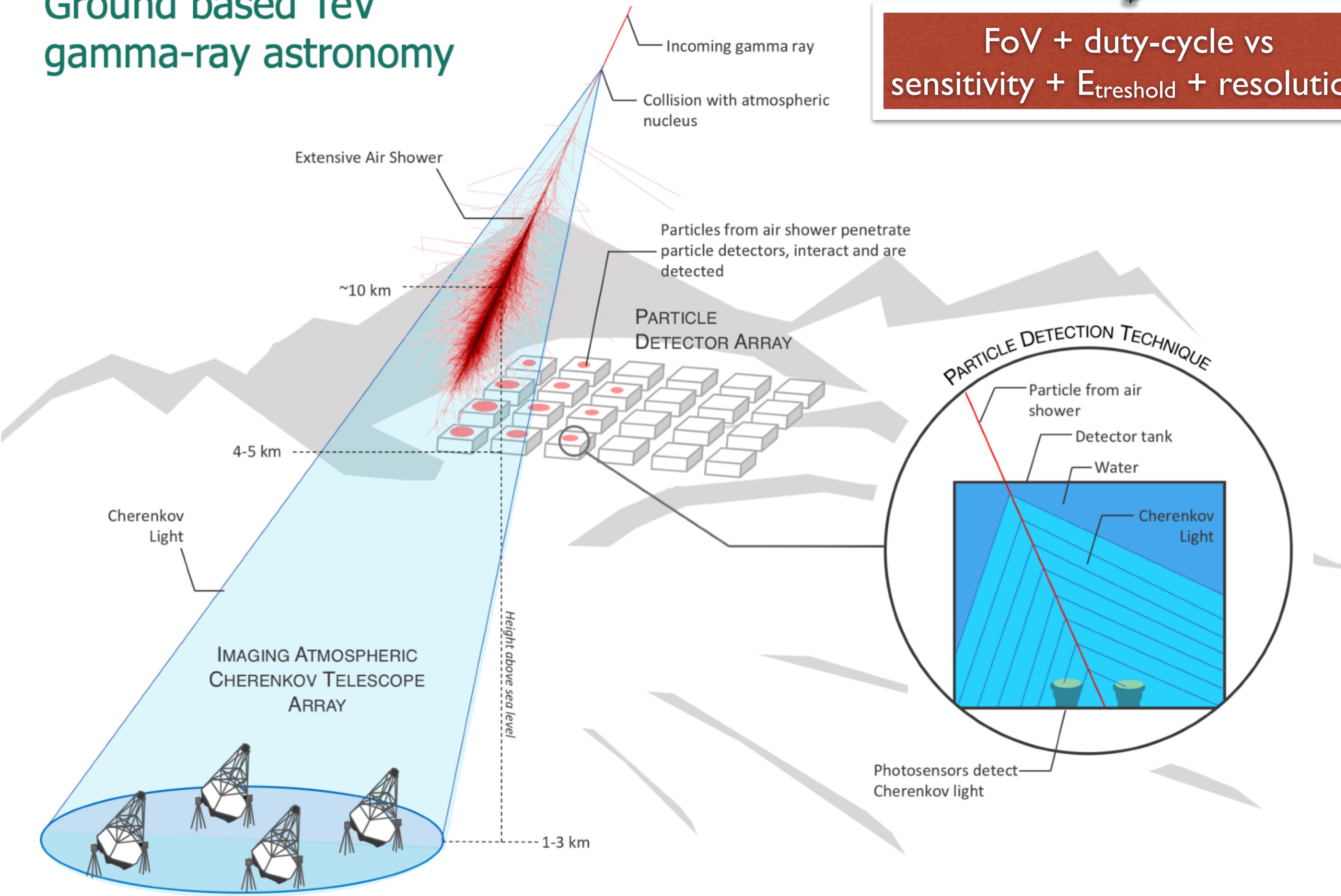
Fabian Schüssler (IRFU, CEA Paris-Saclay)

Major current VHE gamma-ray observatories



Ground based TeV gamma-ray astronomy

FoV + duty-cycle vs sensitivity + $E_{treshold}$ + resolution

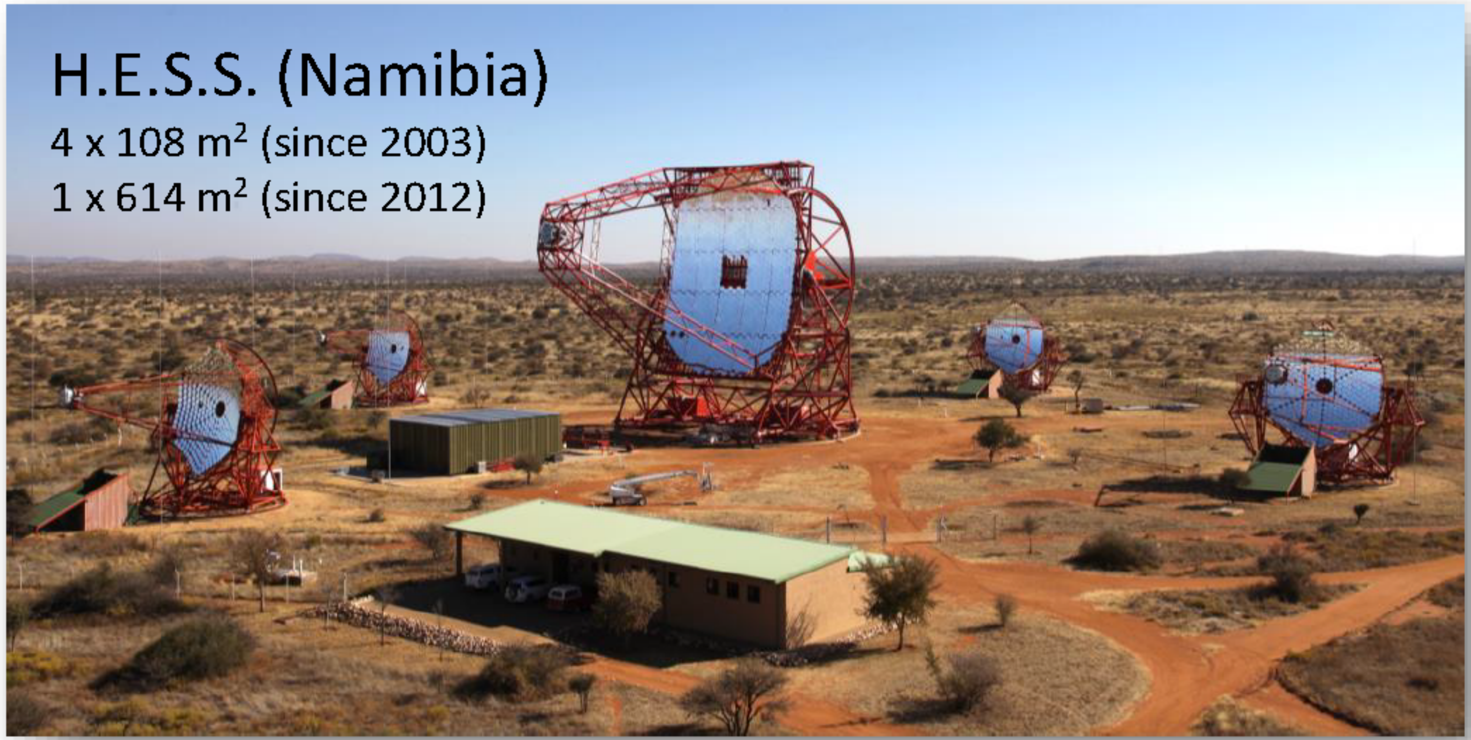


Shower image, 100 GeV γ-ray adapted from: F. Schmidt, J. Knapp, "CORSIKA Shower Images", 2005, https://www-zeuthen.desy.de/~jknapp/fs/showerimages.html

Not to scale

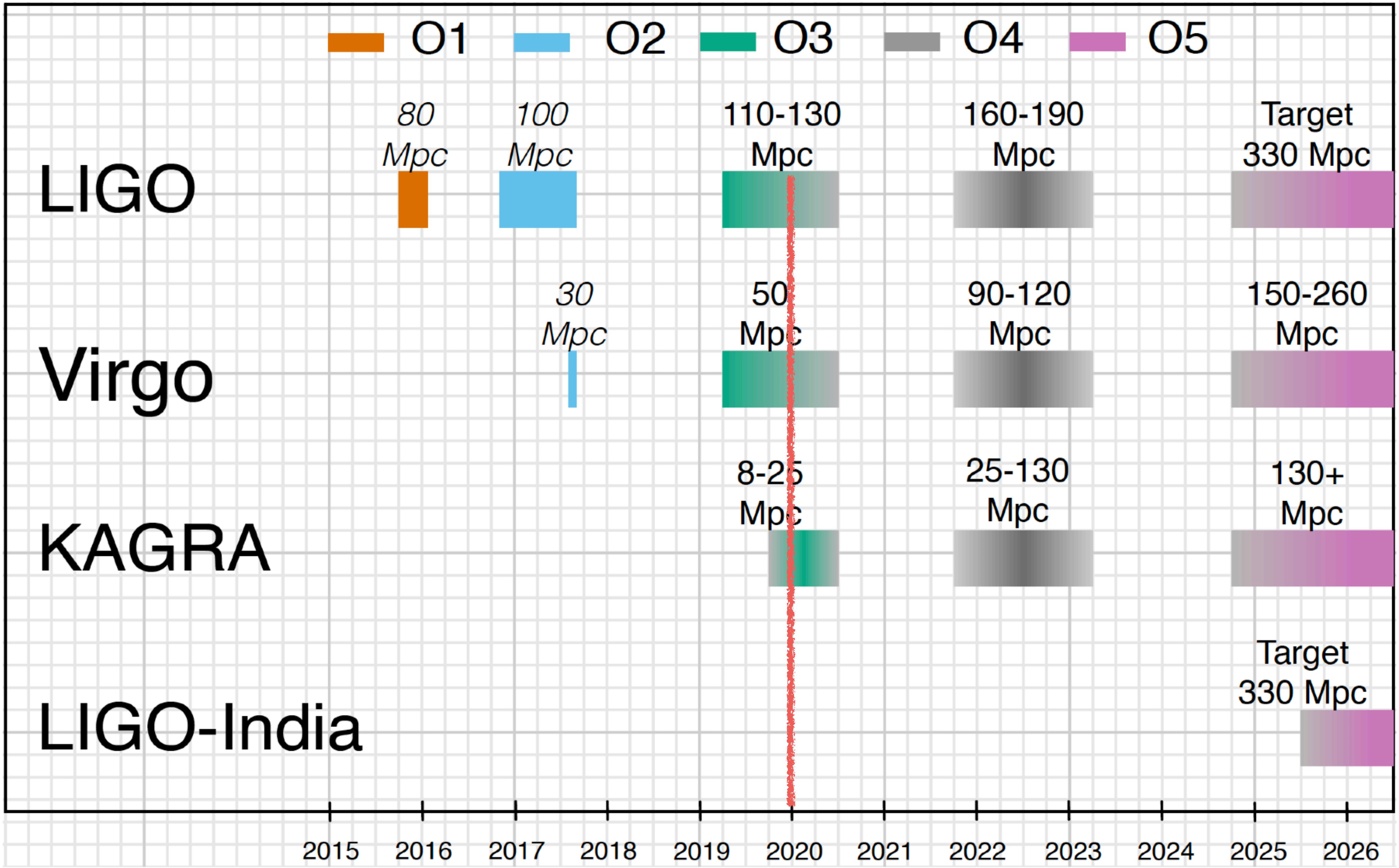
H. Schoorlemmer

From the current IACTs to CTA



Overview: O1 + O2 + O3 + …

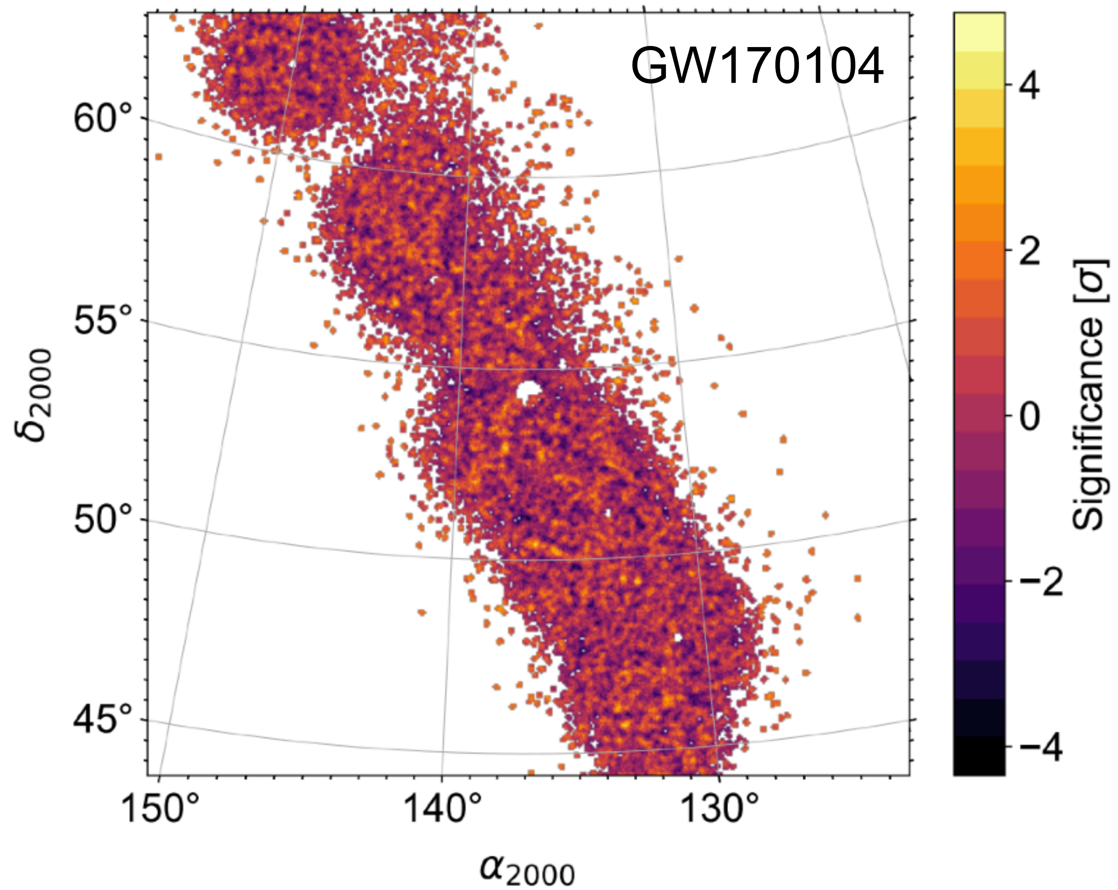
See dedicated talks
e.g. Pia Astone (Monday)



B.P. Abbott et al., arXiv:1304.0670 (v9, 2019-09-27)

VHE searches for GW counterparts during O1 + O2

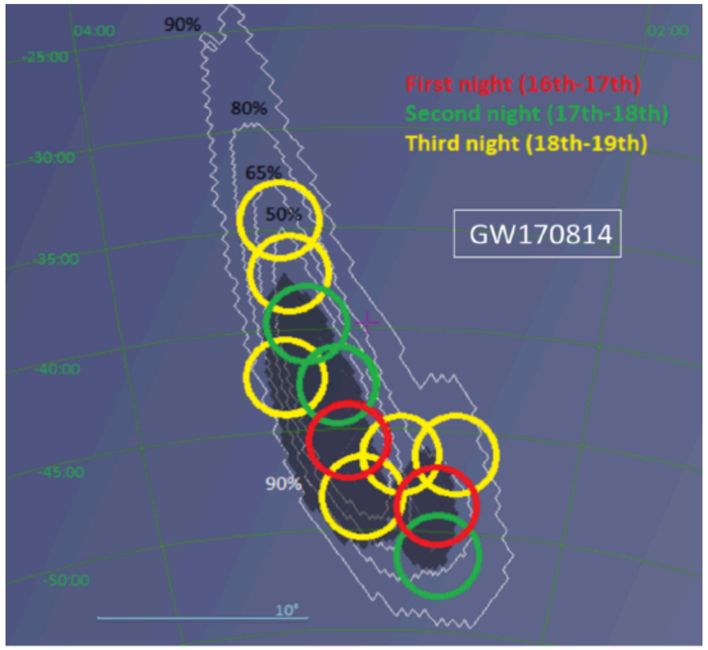
- GW151226 (MAGIC): the second BBH merger
  - Exploratory searches with a few pointings mirroring optical observations
  - De Lotto et al. (MAGIC Collaboration), IAU Symposium 324 (2017)
- GW170104 (VERITAS):
  - 39 pointings (5min each) covering ~27% of the localization region
  - GCN #21153

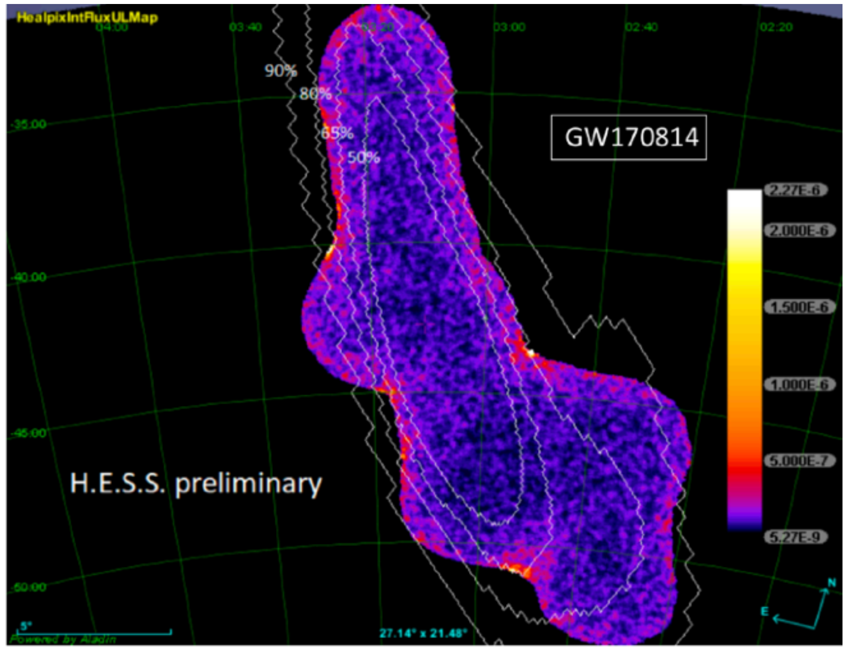


M. Santander et al. (VERITAS), PoS 358, ICRC2019

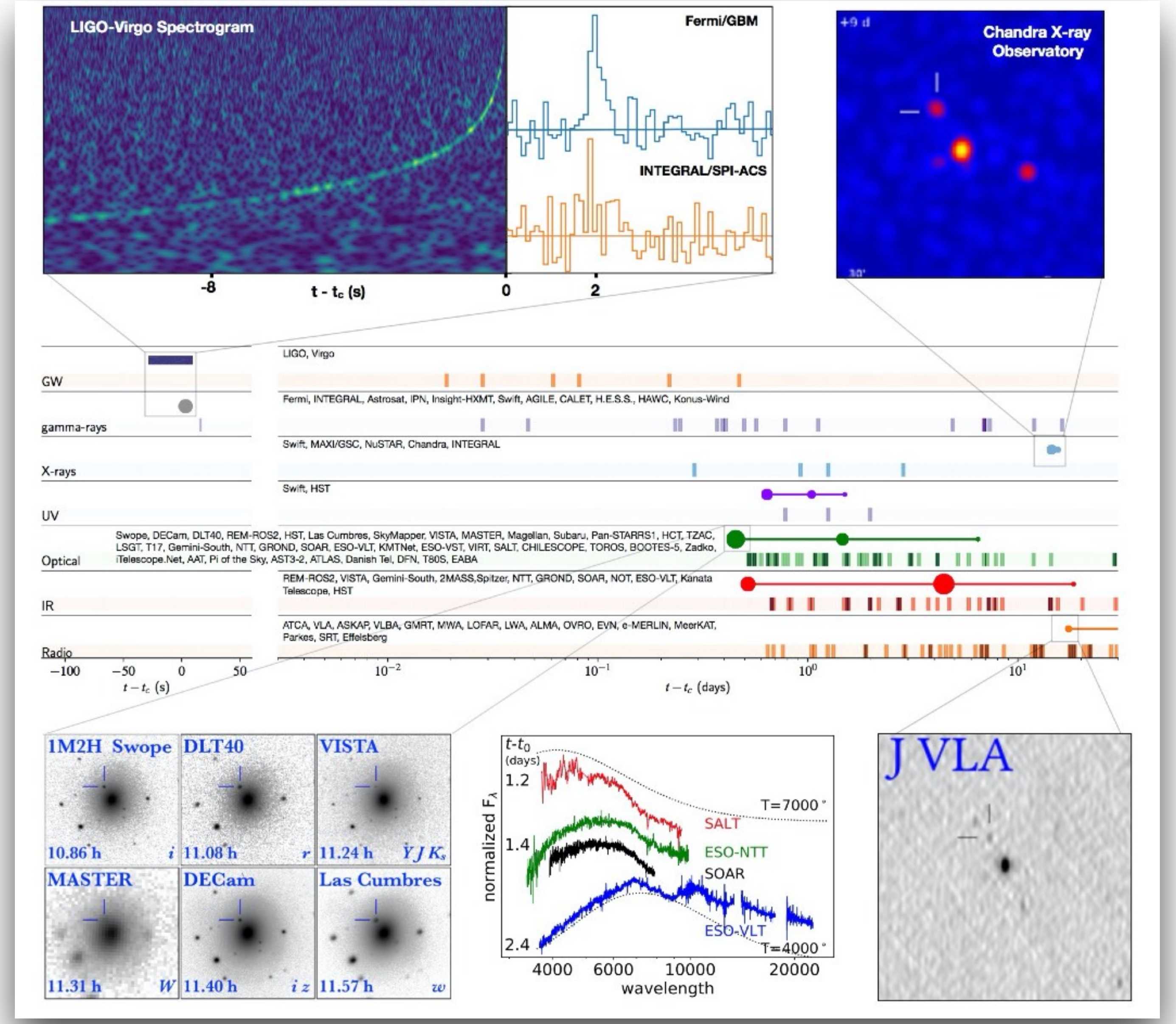
VHE searches for GW counterparts during O1 + O2

- GW151226 (MAGIC): the second BBH merger
  - Exploratory searches with a few pointings mirroring optical observations
  - De Lotto et al. (MAGIC Collaboration), IAU Symposium 324 (2017)
- GW170104 (VERITAS):
  - 39 pointings (5min each) covering ~27% of the localization region
  - GCN #21153
- GW170814 (H.E.S.S.): the first GW event detected by 3 interferometers
  - First complete coverage of the localization region
  - H. Ashkar et al. (H.E.S.S.), 12th INTEGRAL conference, arXiv:1906.10426





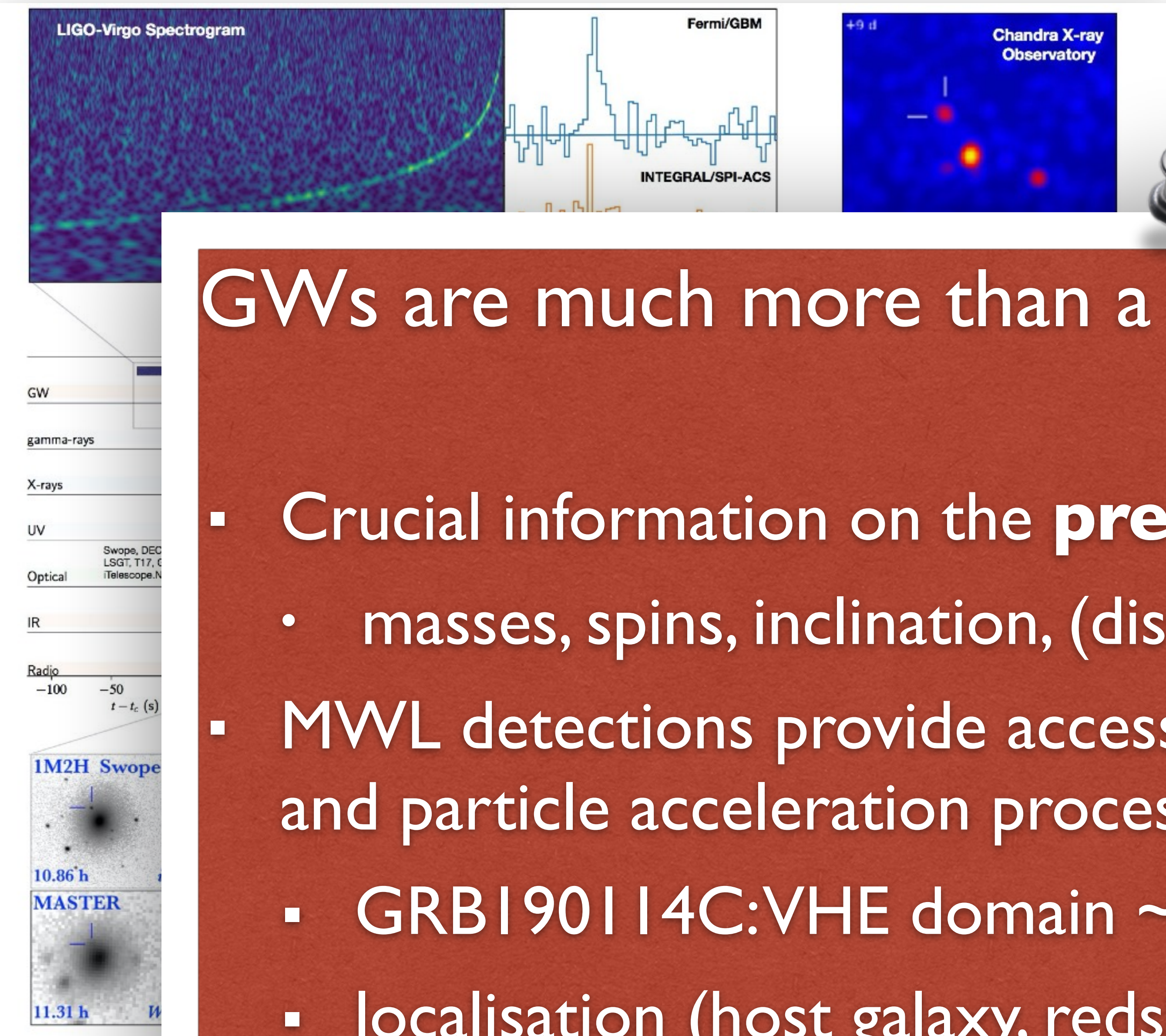
Links to Gamma-Ray Bursts



Abbott, B.P. et al 2017 ApJL 848 L12

- NS-NS mergers are sources of (short) GRBs
- GRB180720B
- GRB190114C
- GRB190829A
- GRBs emit at VHE energies
- VHE emission is strong enough for current IACTs
- **VHE emission is long-lasting (GRB180729B: >10h)**
- Let's detect VHE emission from NS-NS (and NS-BH) mergers…

Links to Gamma-Ray Bursts



- NS-NS mergers are sources of (short) GRBs

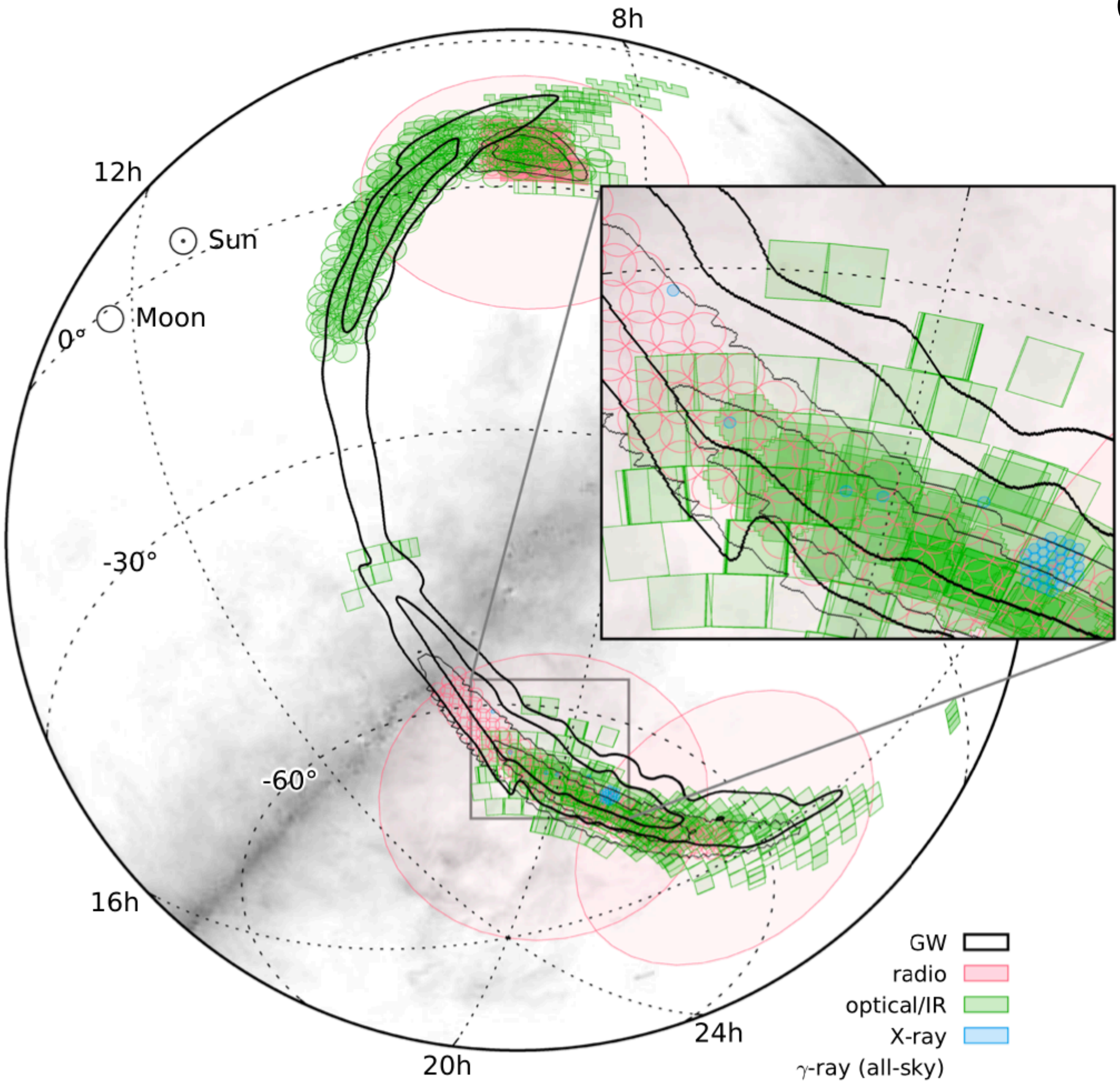
GWs are much more than a new way to detect GRBs

- Crucial information on the **pre-merger** system
  - masses, spins, inclination, (distance), …
- MWL detections provide access to **post-merger** energetics and particle acceleration processes
  - GRB190114C: VHE domain ~50% of L_{tot}
  - localisation (host galaxy, redshift, etc.), local environment, …

for

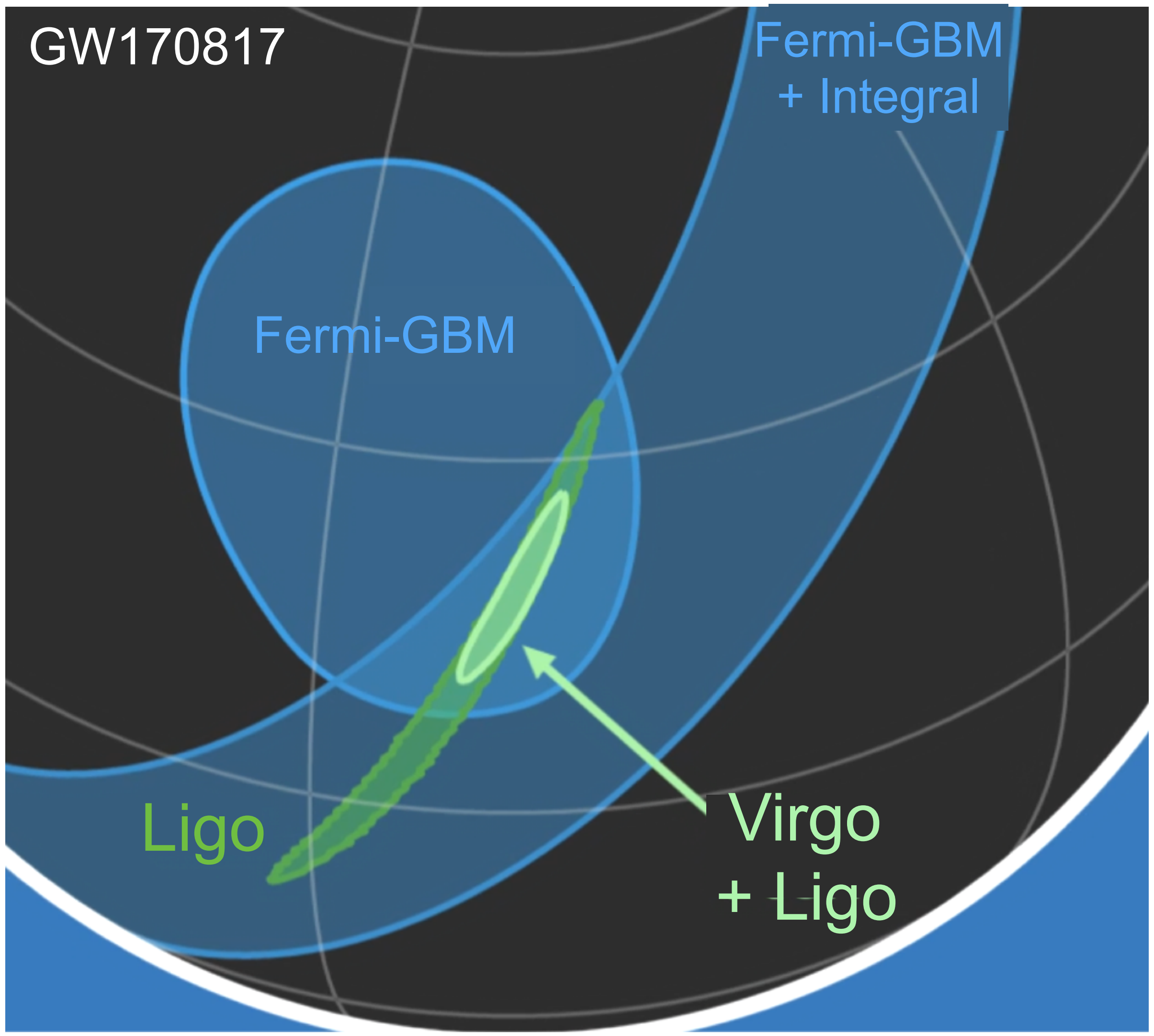
- Let's detect VHE emission from NS-NS (and NS-BH) mergers…

GW150914

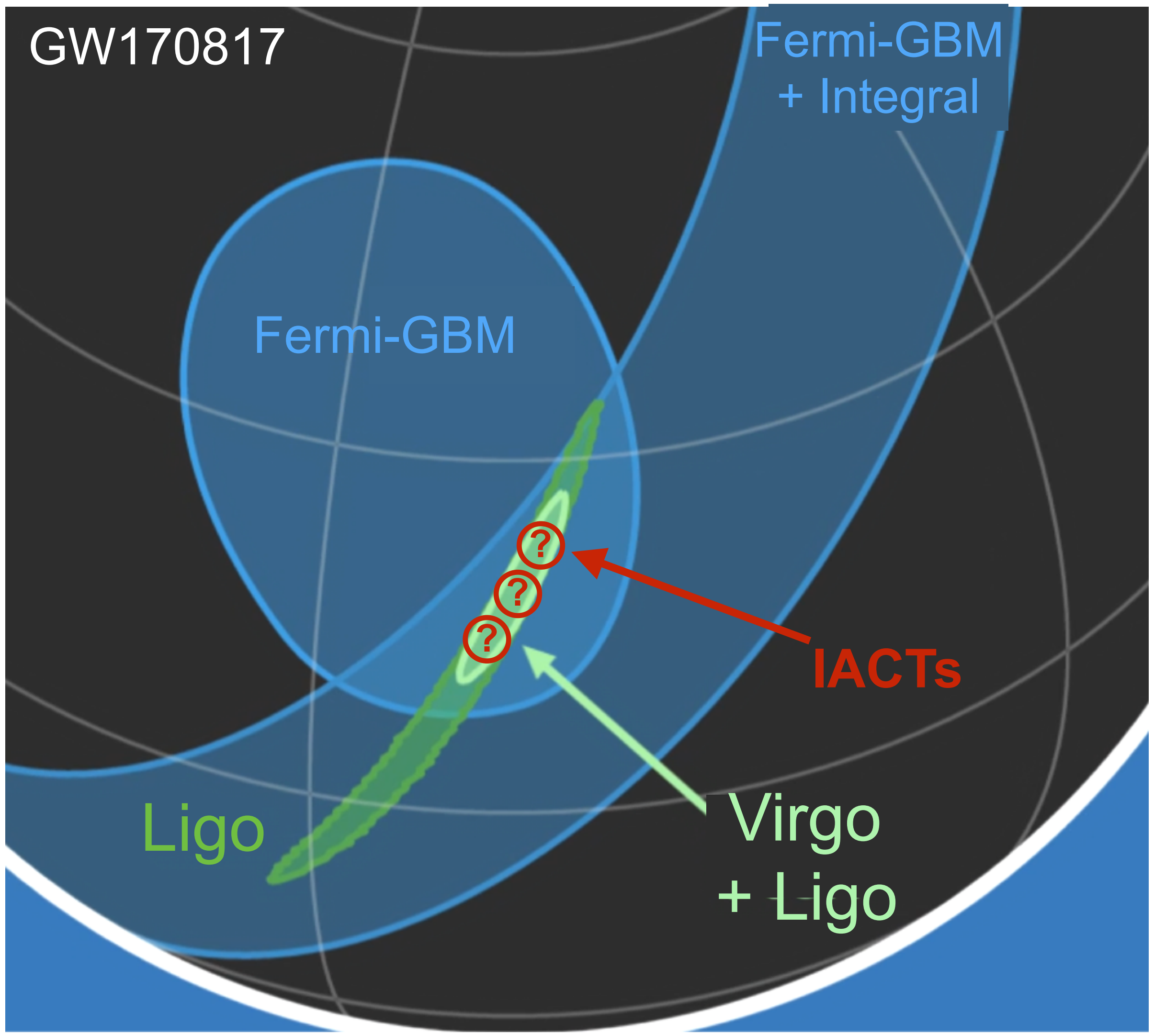


Virgo+Ligo+et al., ApJL 826:L13 (2016)

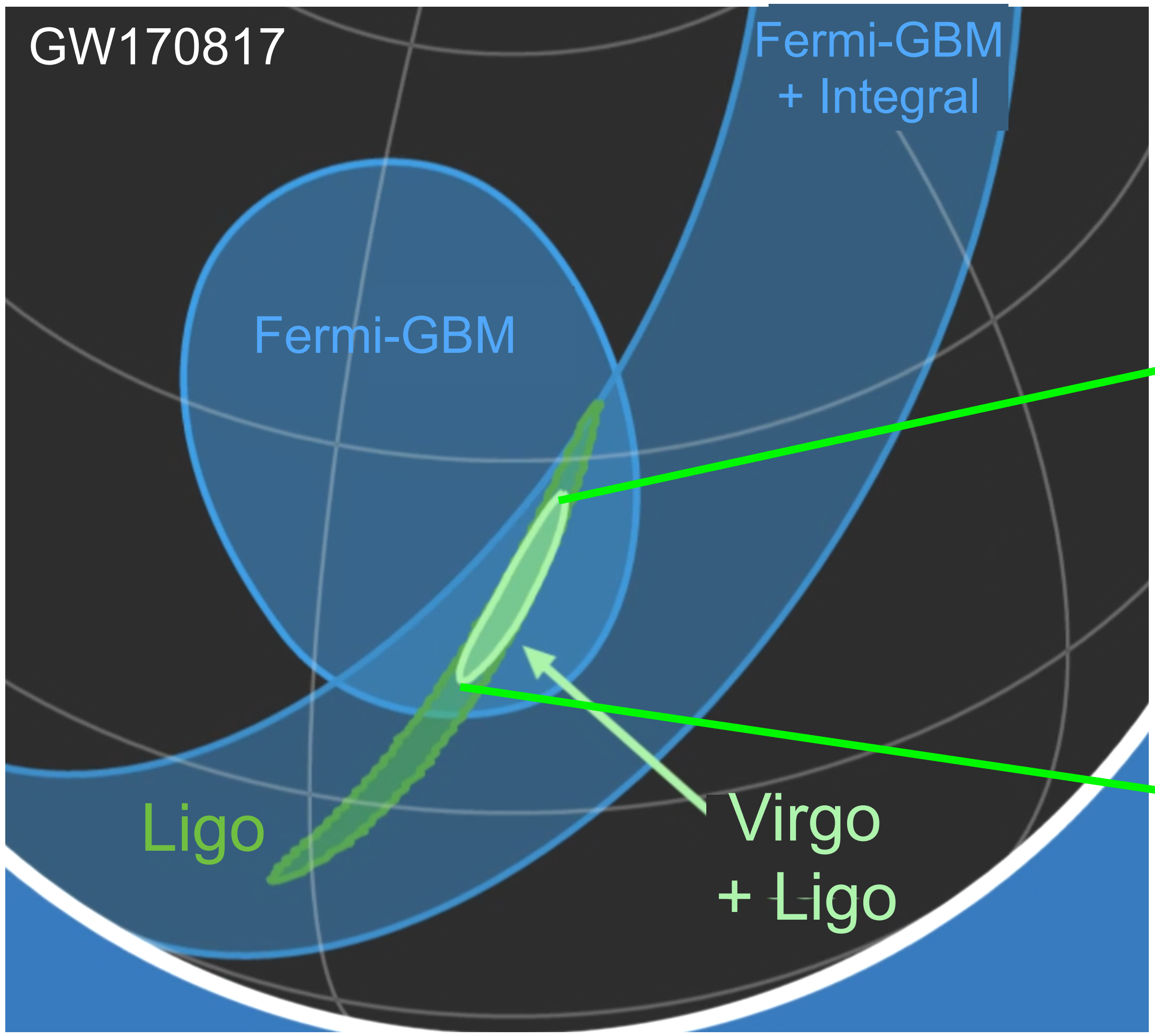
Scheduling and pointing strategy

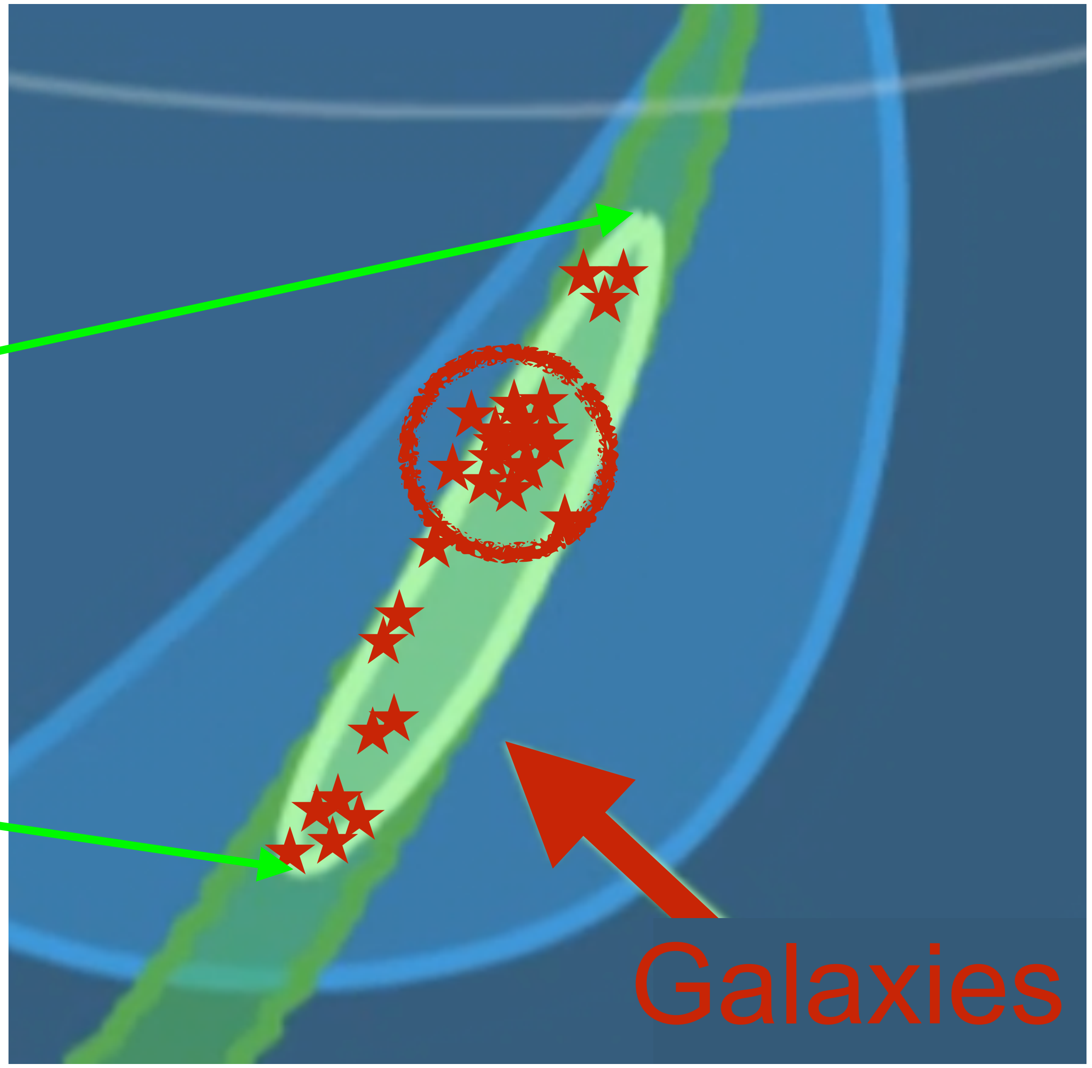


Scheduling and pointing strategy



Scheduling and pointing strategy

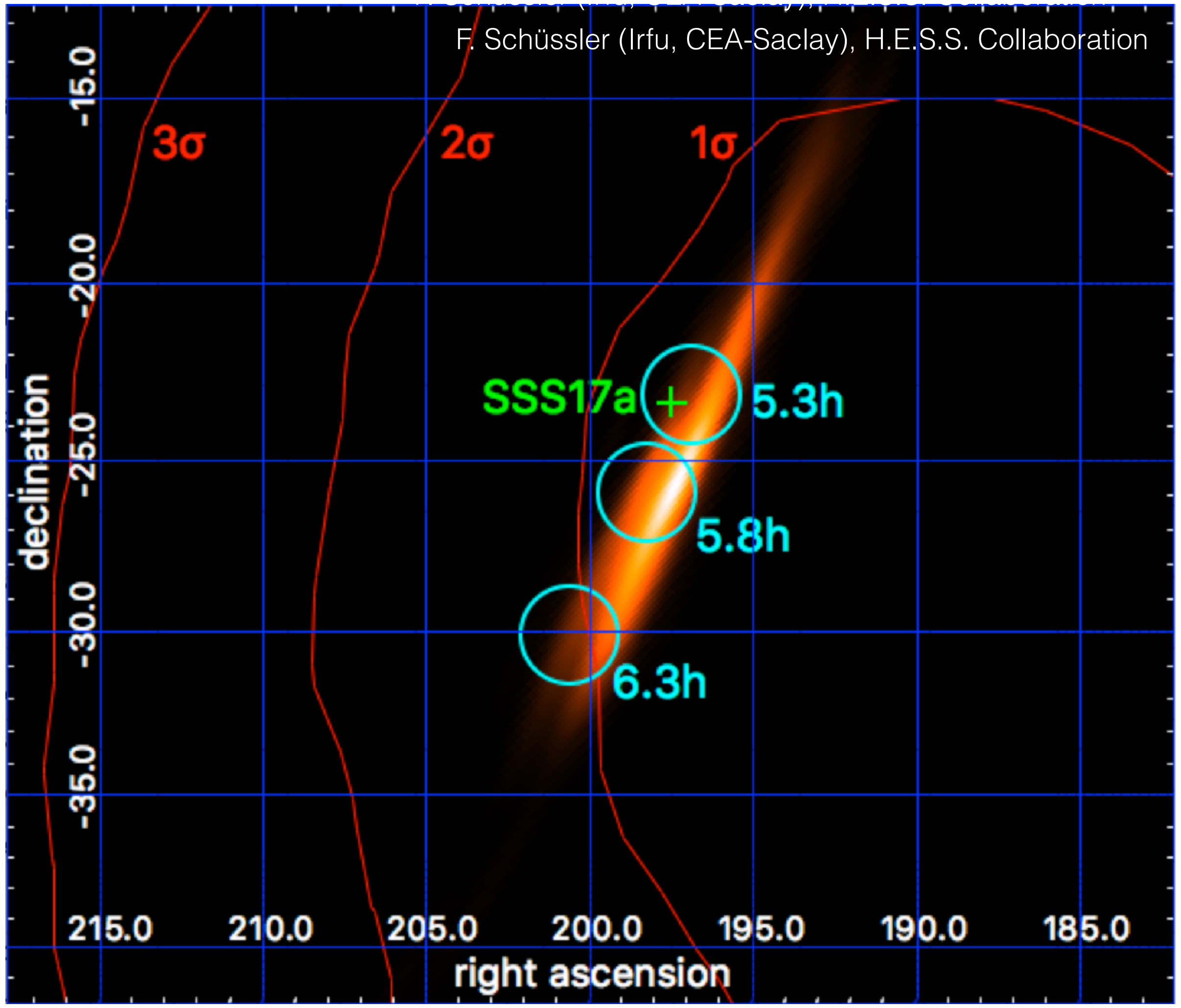




- automatic selection of regions of interest
  - correlation with galaxy catalog(s) in 3 dimensions
  - dedicated algorithms for the different possibilities (e.g. BNS, BBH, bursts, etc.)

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

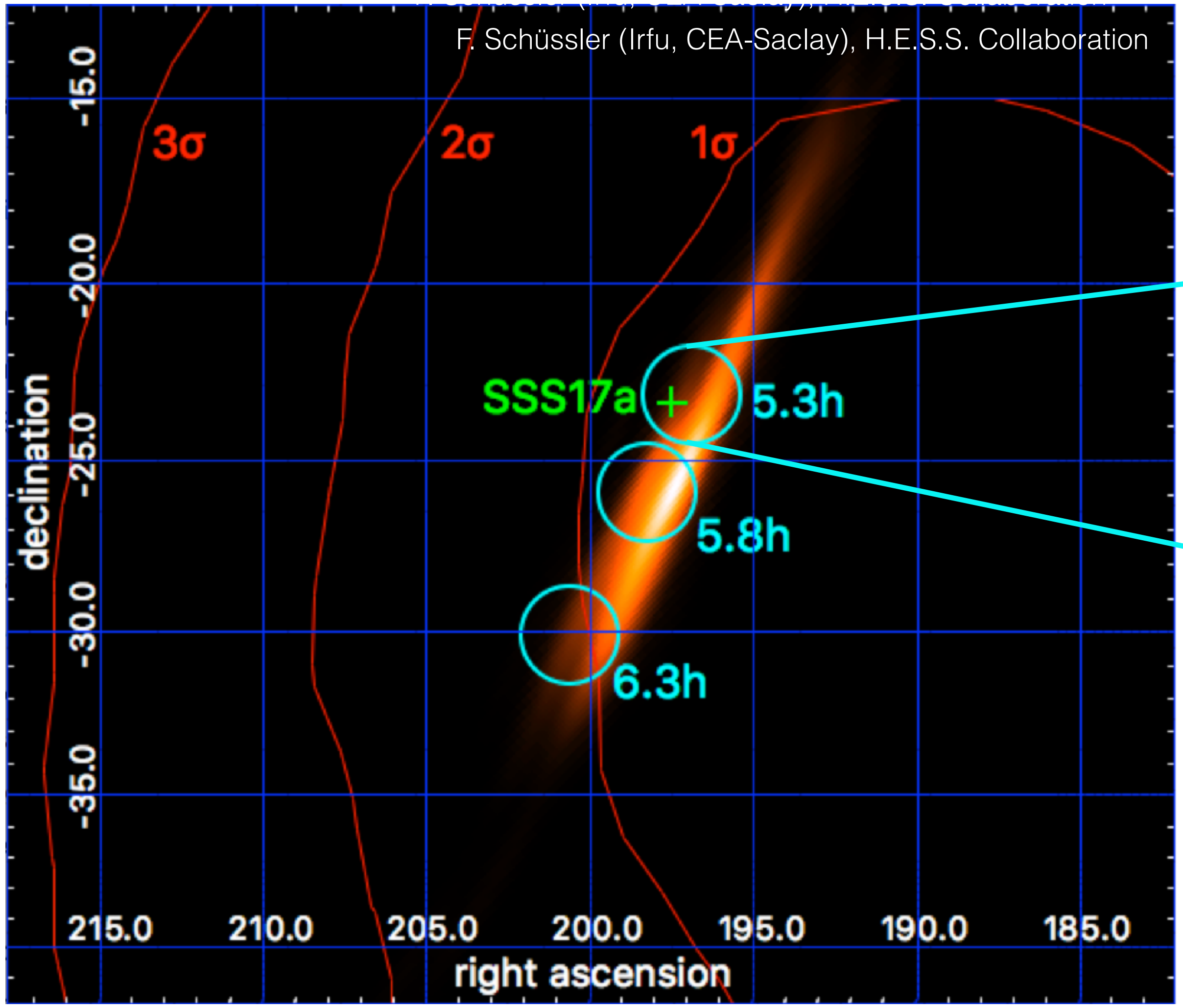
GW170817: TeV gamma-ray follow-up

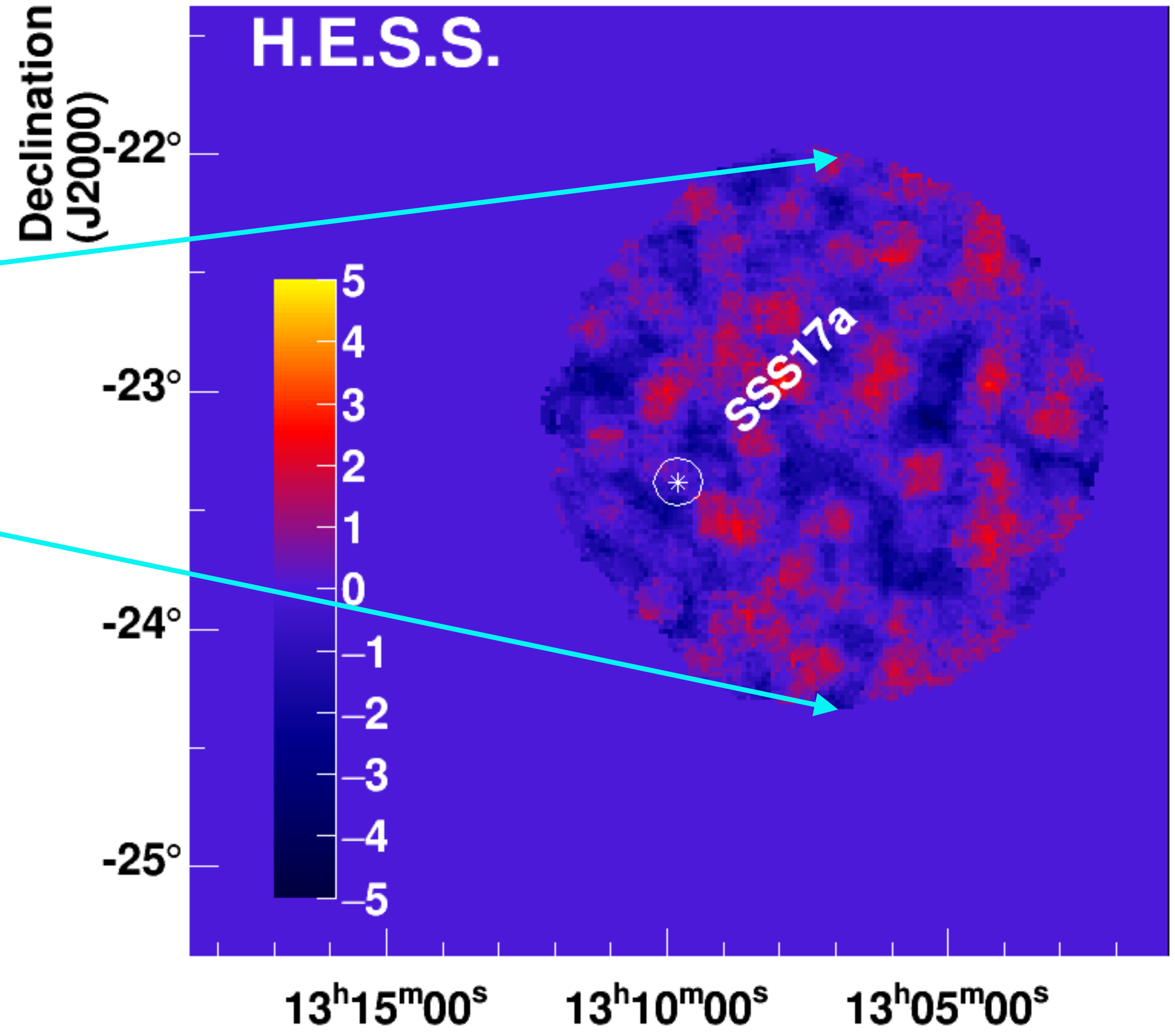


H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017)

- 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)

H.E.S.S. observations of GW170817: prompt observations

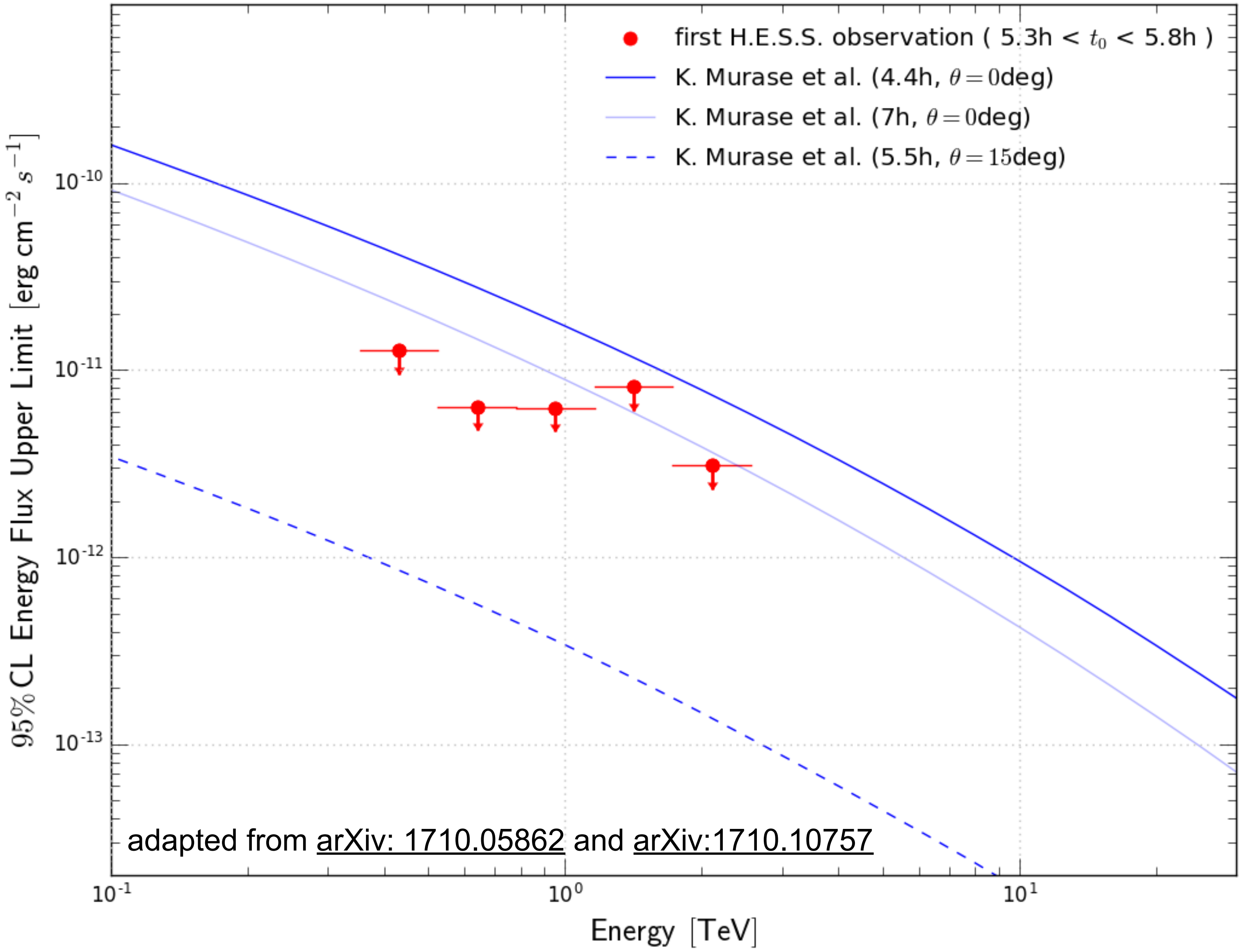




- First observations of a ground-based pointing instrument
  - 5.3 hours after GW170817
  - 5 minutes after the GCN circular announcing the Ligo+Virgo analysis
  - no significant signal: Φ (0.28 < E [TeV] < 2.31) < 3.9 x 10^{-12} erg cm^{-2} s^{-1}
  - monitoring campaign over 5 nights

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

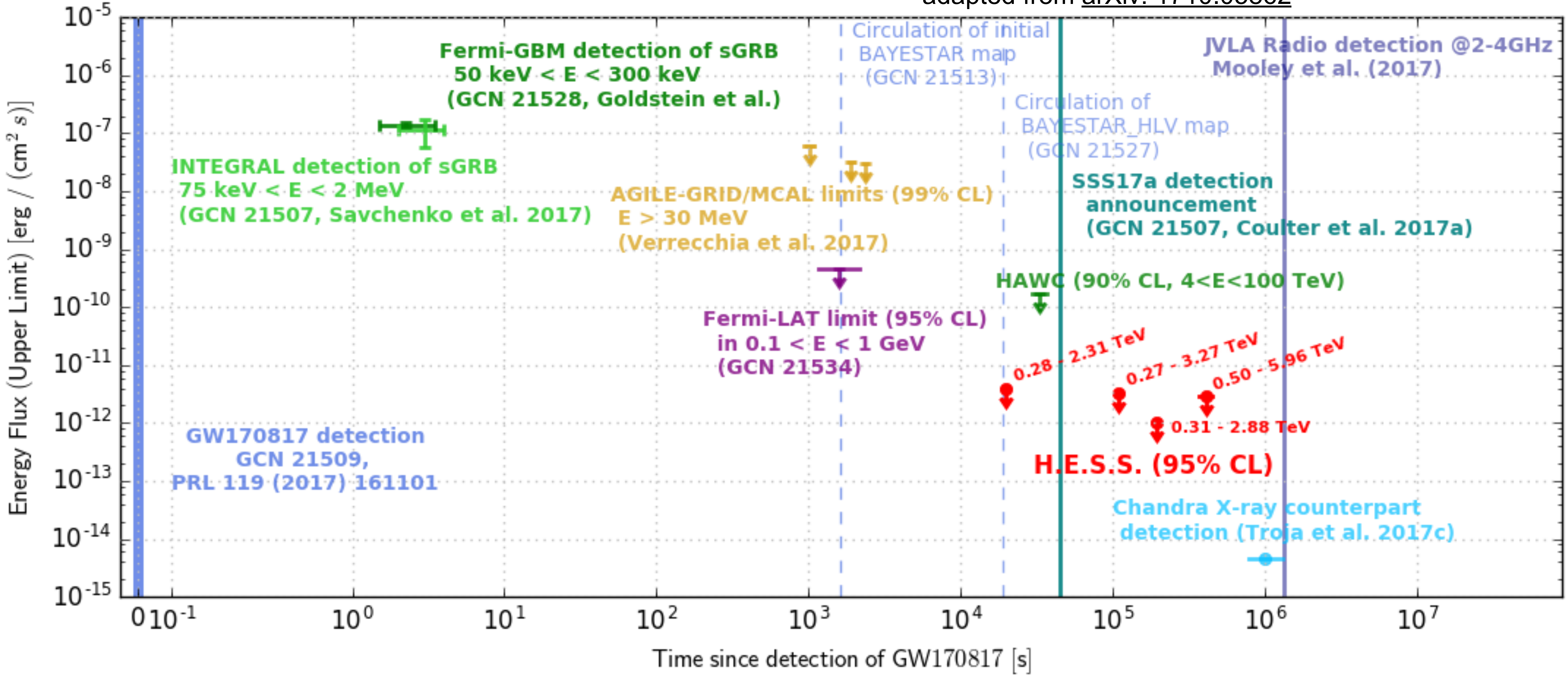
H.E.S.S. observations of GW170817: prompt observations



- e.g. K. Murase et al. (arXiv:1710.10575)
  - high-energy signatures from long-lasting central engines
  - 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

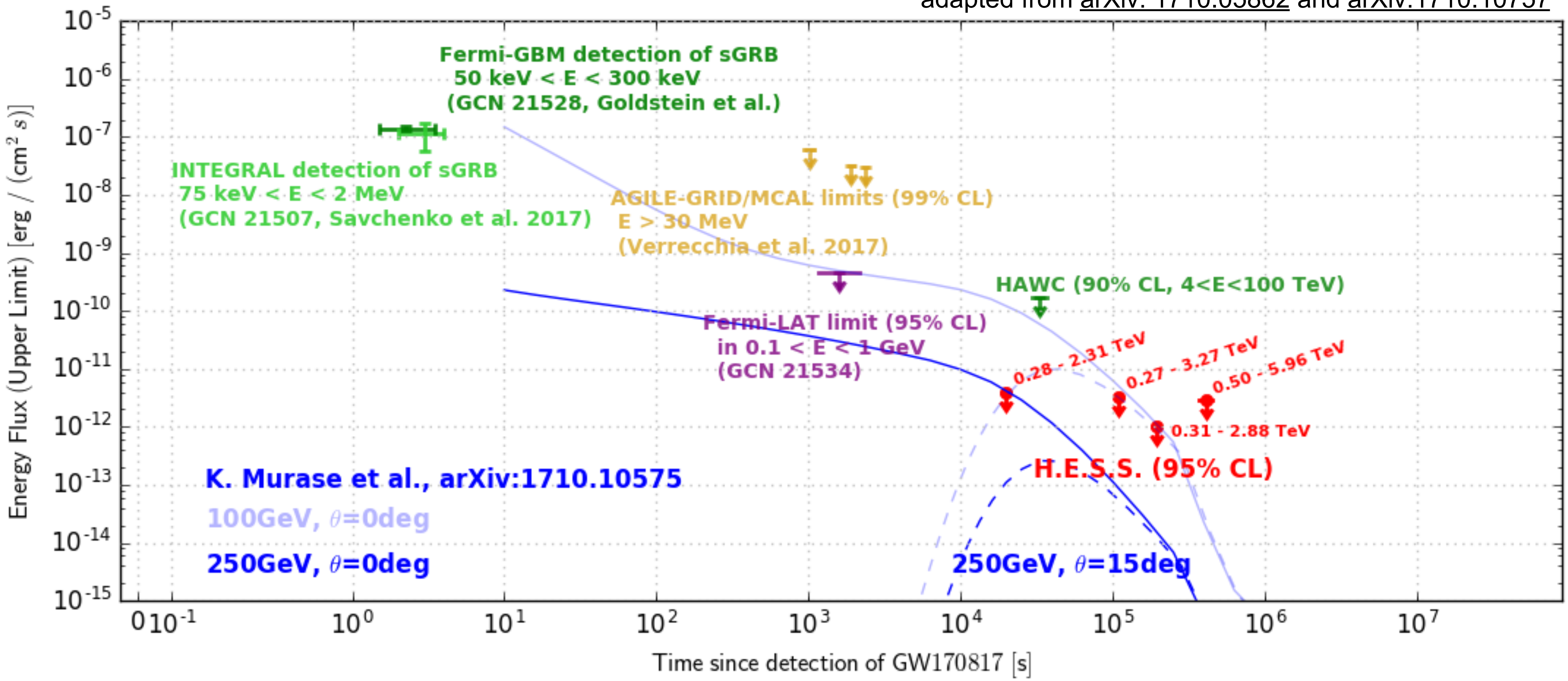
VHE observations of GW170817: prompt observations

adapted from arXiv: 1710.05862

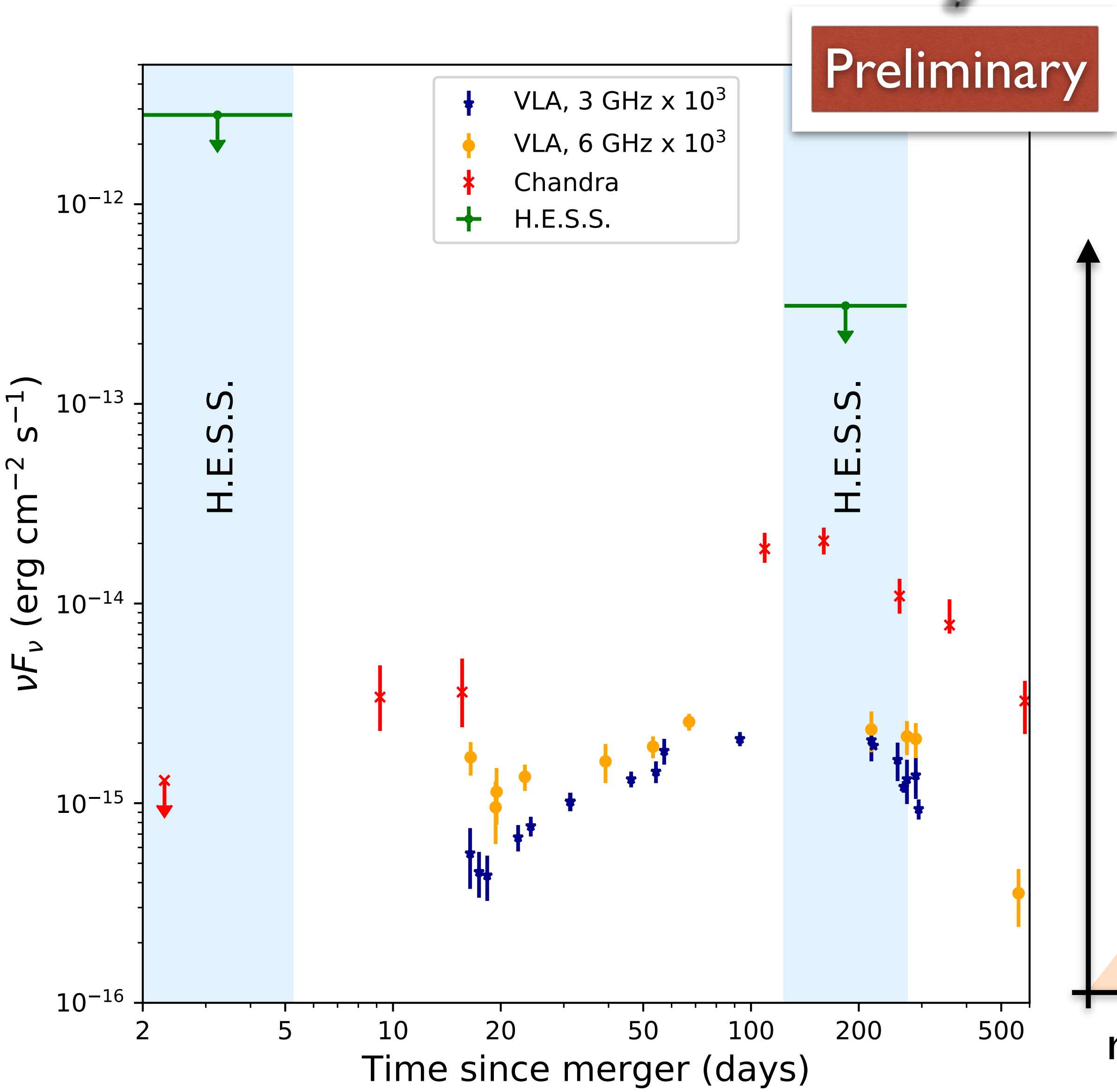


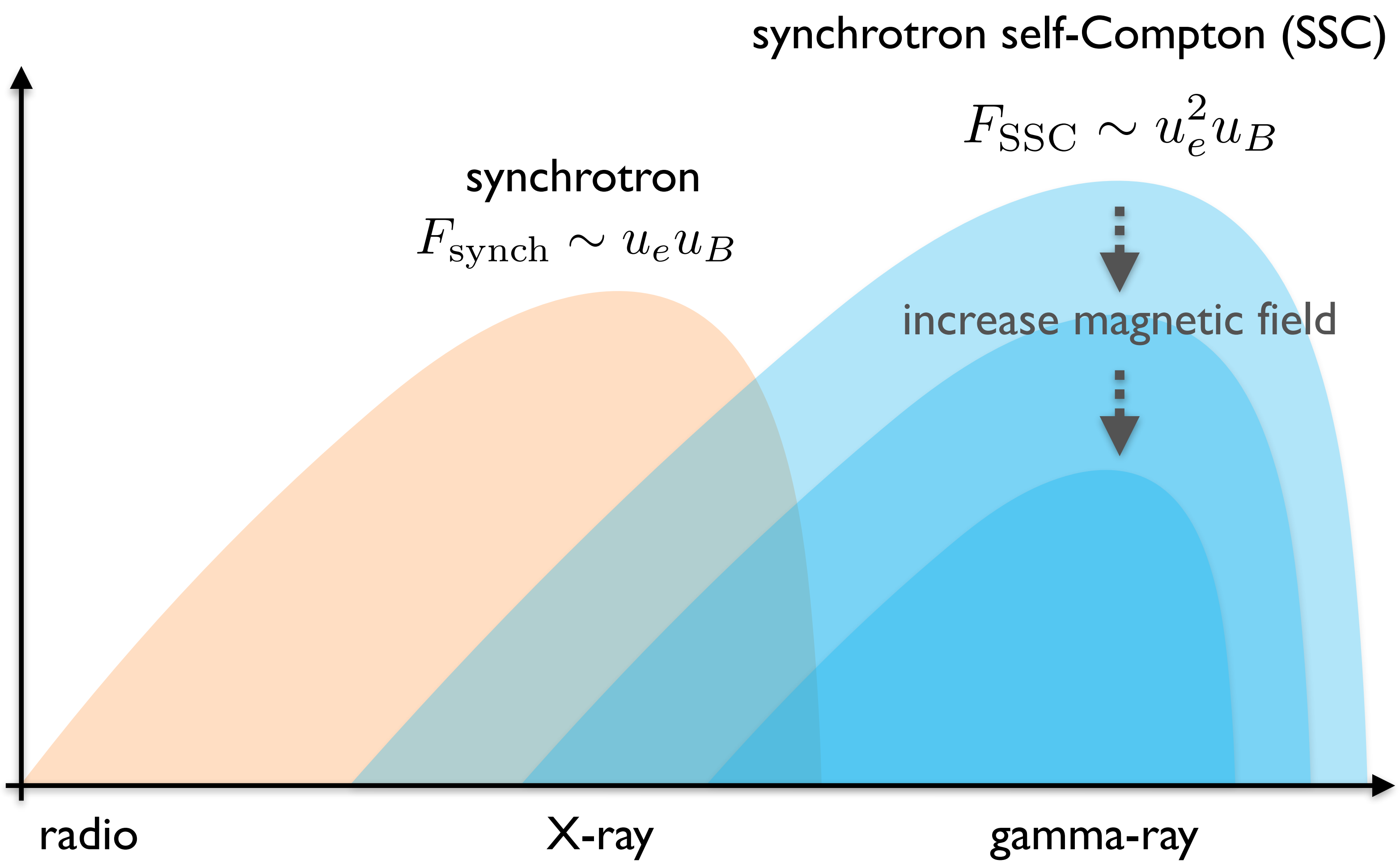
VHE observations of GW170817: prompt observations

adapted from arXiv: 1710.05862 and arXiv:1710.10757



Longterm H.E.S.S. observations of GW170817

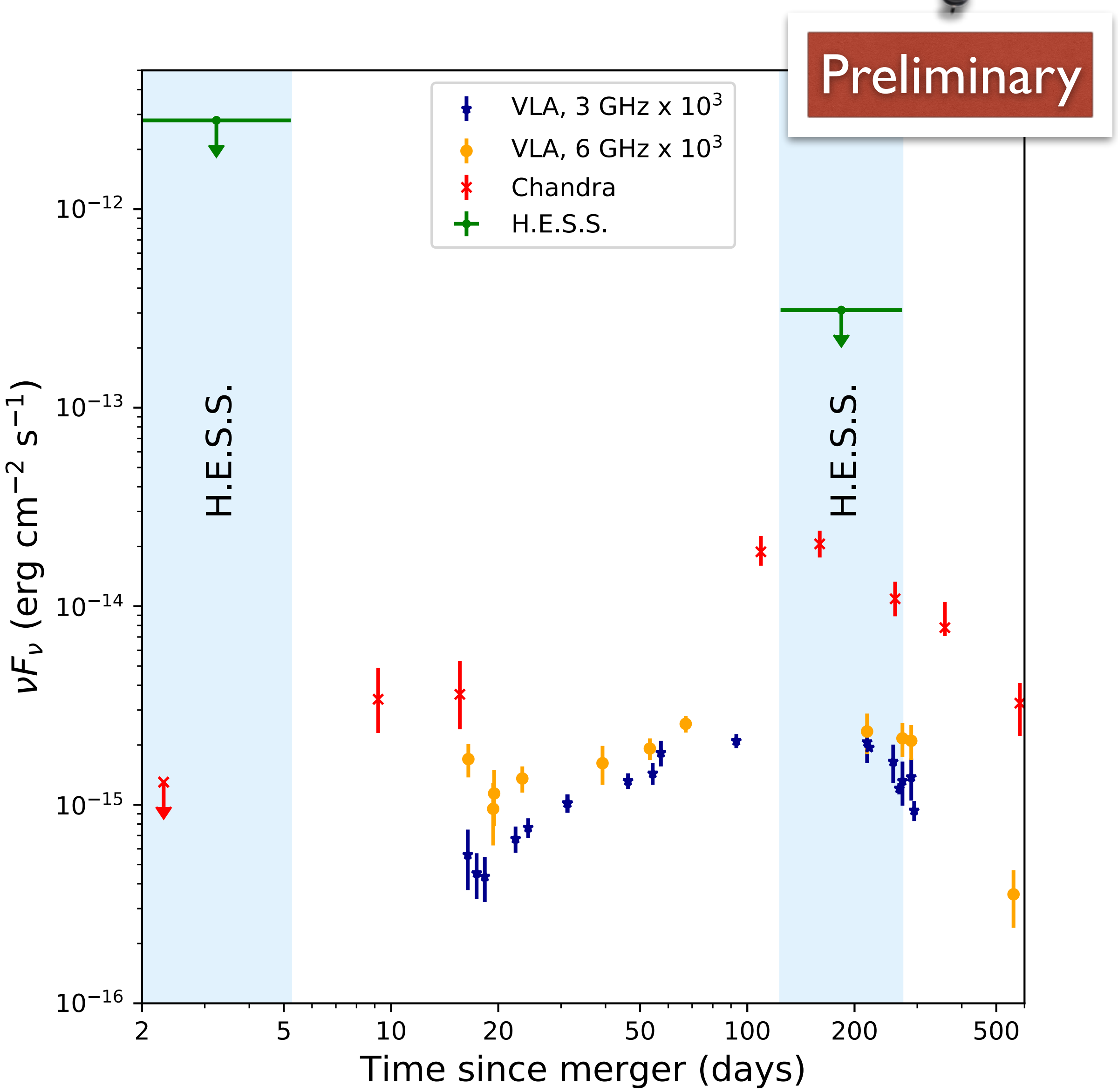


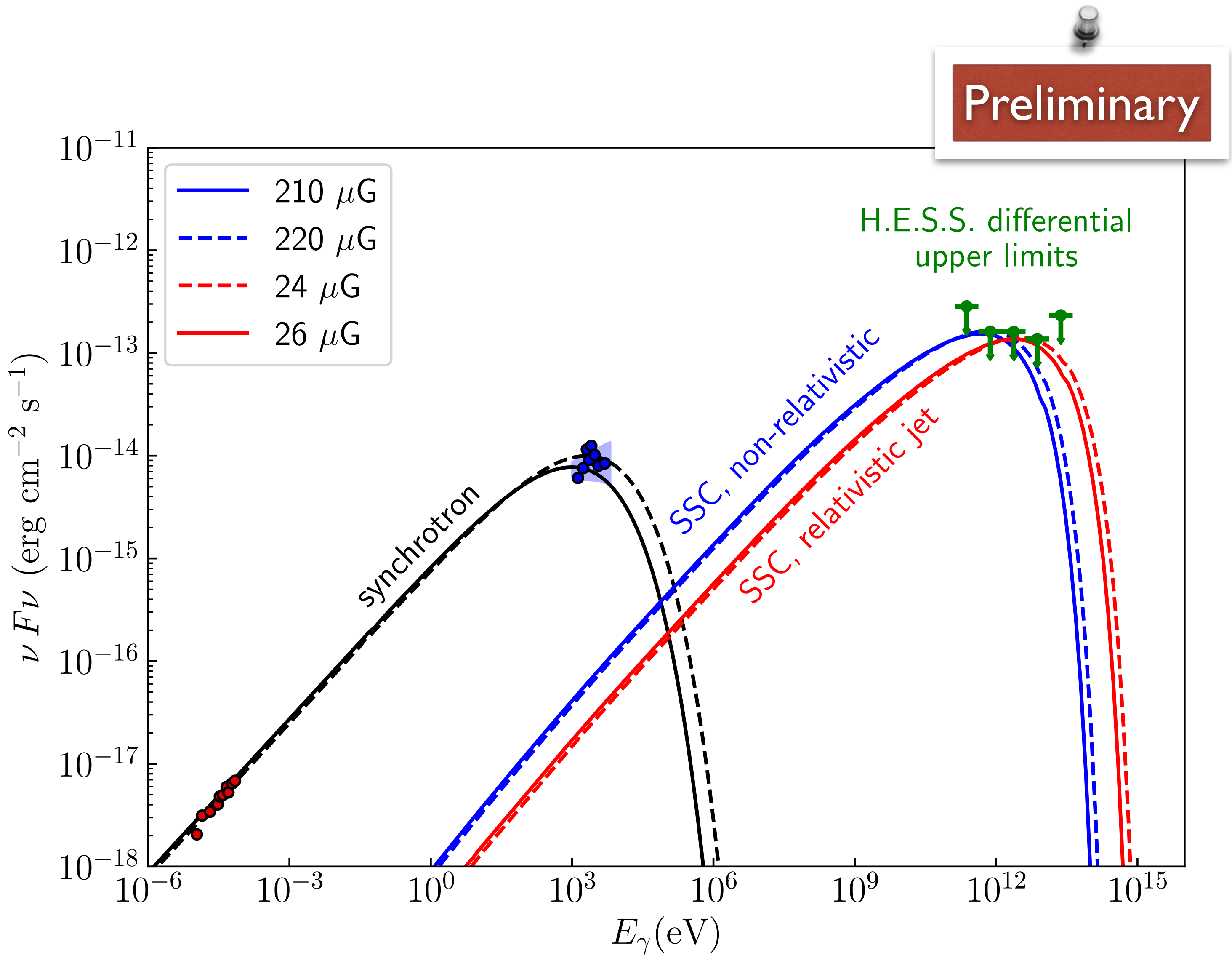


- Extensive H.E.S.S. follow-up during the peak of the X-ray+ radio emission
  - exploiting the link between synchrotron + SSC peaks to put limits on the B-field

S. Ohm, A. Taylor, H. Ashkar, FS, X. Rodriguez et al. (ICRC2019), paper submitted

Longterm H.E.S.S. observations of GW170817



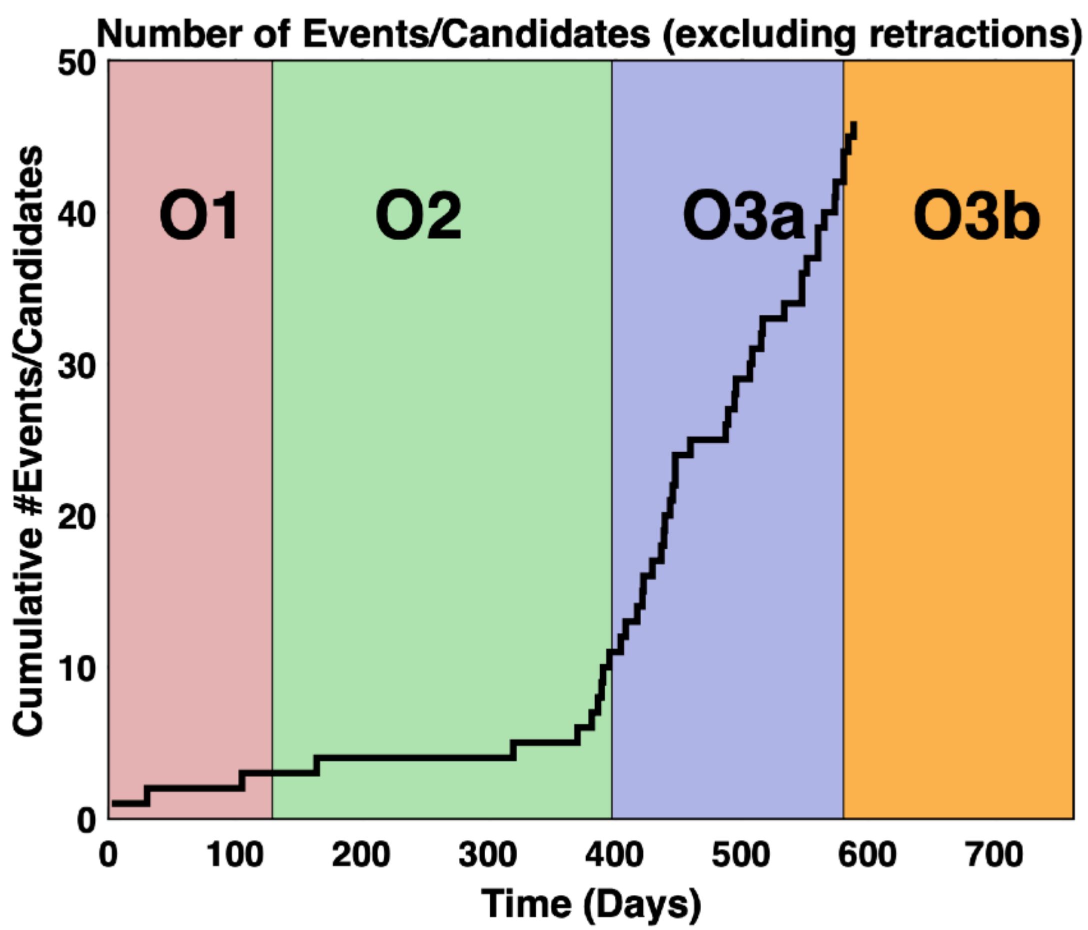


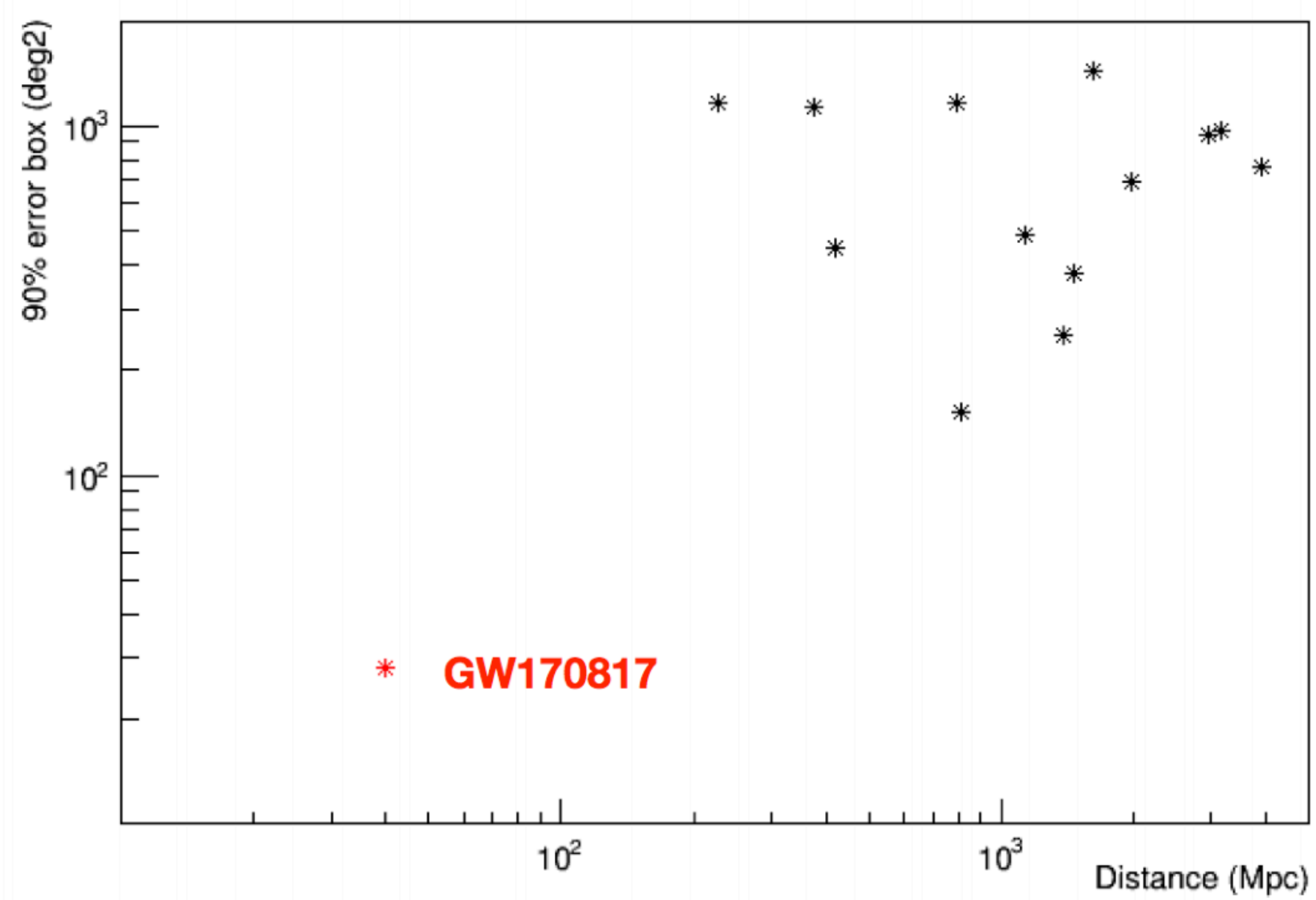
- Extensive H.E.S.S. follow-up during the peak of the X-ray+ radio emission
  - exploiting the link between synchrotron + SSC peaks to put limits on the B-field
  - isotropic, non-relativistic outflow: B ≳ 210μG
  - relativistic jet: B ≳ 24μG

S. Ohm, A. Taylor, H. Ashkar, FS, X. Rodriguez et al. (ICRC2019), paper submitted

First lessons learned from O3

- Number of GW detections matching/exceeding expectations (~1/week)
- New source classes (?): BH-NS mergers + mass gap events 3 < $M_\odot$ <5
- Increased horizon enables detections further away
  - Low S/N events have larger localization uncertainties
  - No EM counterpart found so far





IACT searches during O3a

- VERITAS

GW ID	Delay [hrs]	Compact binary coalescence type	Prob. covered	VERITAS obs. [hrs]
S190412m	24.1	BBH:$>$ 99%	$\sim$ 50%	3.1
S190425z	1.3	BNS:$>$ 99%	$\sim$ 2%	0.9
S190426c	17.6	NSBH:60%, MG: 25%, BNS:15%	$\sim$ 20%	2.5
S190707q	20.3	BBH:$>$ 99%	$\sim$ 30%	3.0

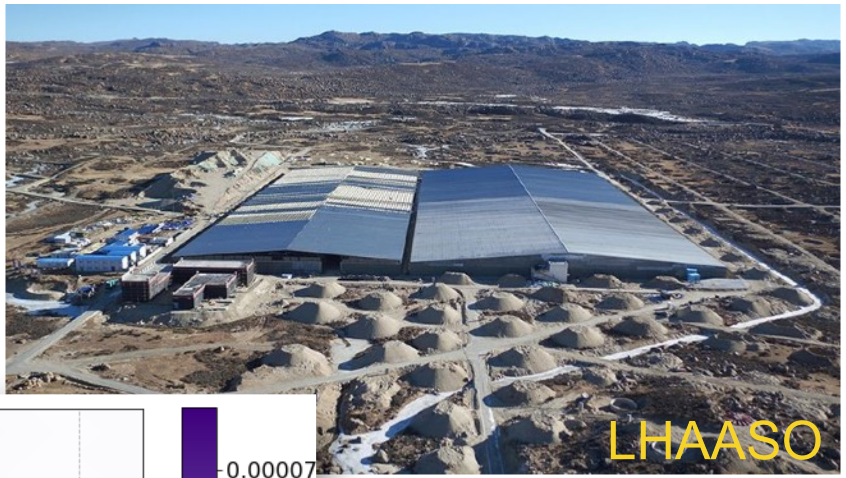
M. Santander et al. (VERITAS), PoS 358, ICRC2019

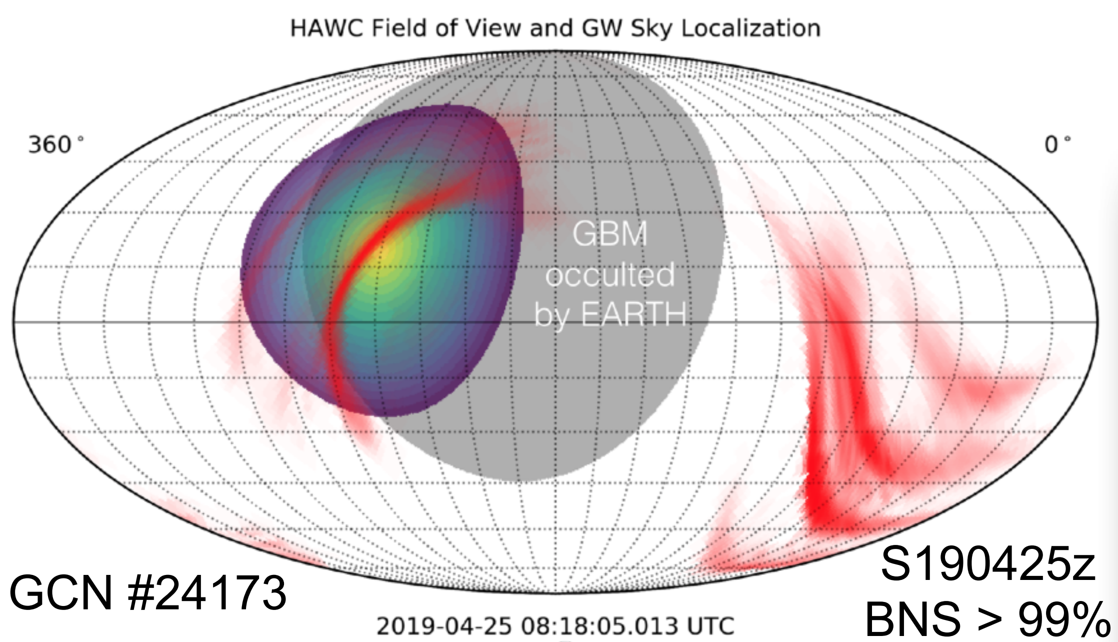
- MAGIC
  - Commissioning automatized reaction to GW events
  - D. Miceli et al. (MAGIC), ICRC2019, arXiv: 1909.03971

- H.E.S.S.
  - S190512at: well localized BBH
  - S190728q: well localized BBH (H.E.S.S.: ~80% coverage, GCN #25237)
  - M. Seglar-Arroyo et al. (H.E.S.S.), ICRC2019, arXiv: 1908.06705

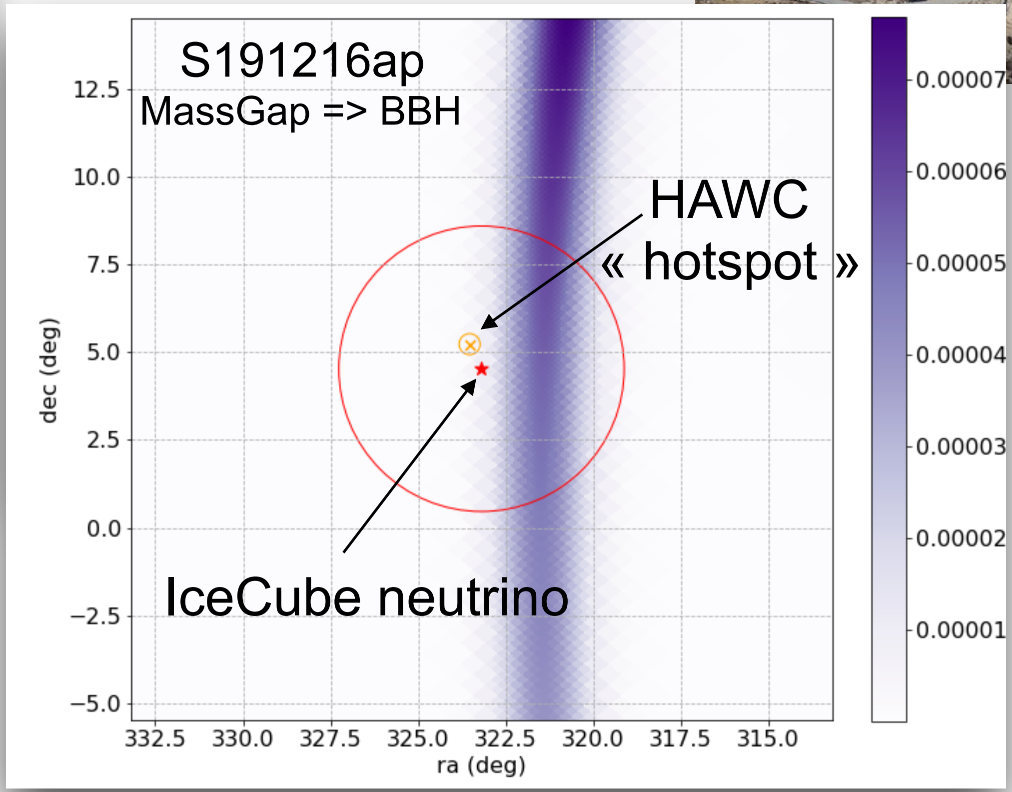
Searches with air shower arrays

- HAWC + LHAASO (+ SWGO, ALTO, ALPACA, etc.)
- Large FoV + high duty-cycle
  - Smaller instantaneous sensitivity + higher Ethreshold
- HAWC: automatized searches for excess at several timescales (0.3s - 100s)



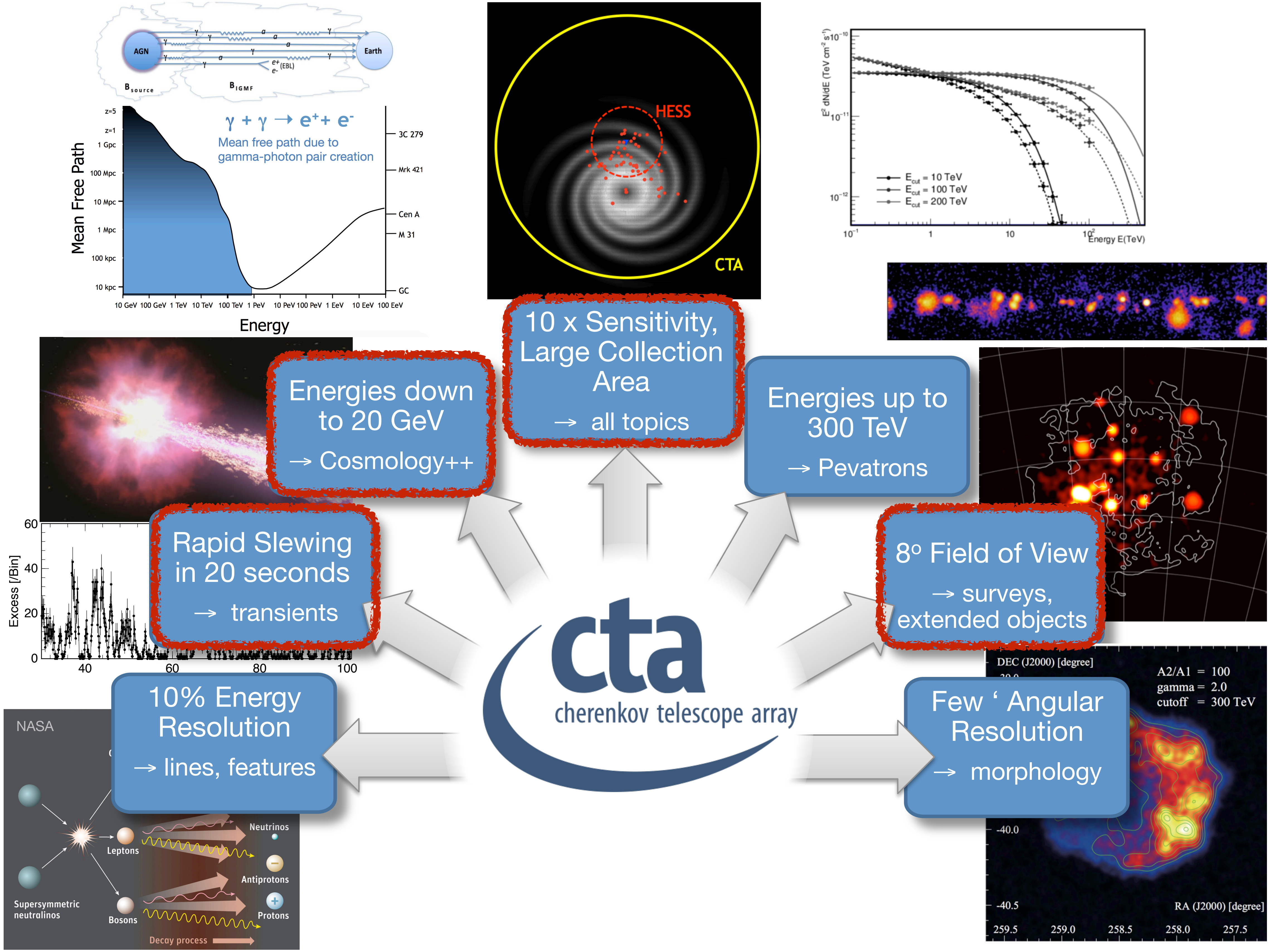


GW event confirmed 2020-01-06
Paper + press release:
https://www.ligo.org/detections/GW190425.php



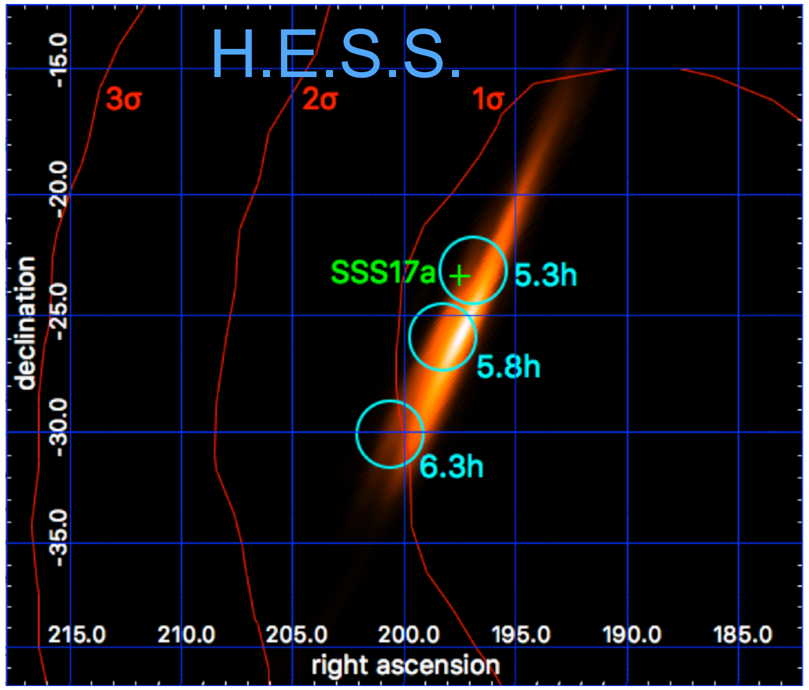
GCN #26455
GCN #26463
GCN #26472
…

I. Martinez + H. Schoorlemmer et al. (HAWC)

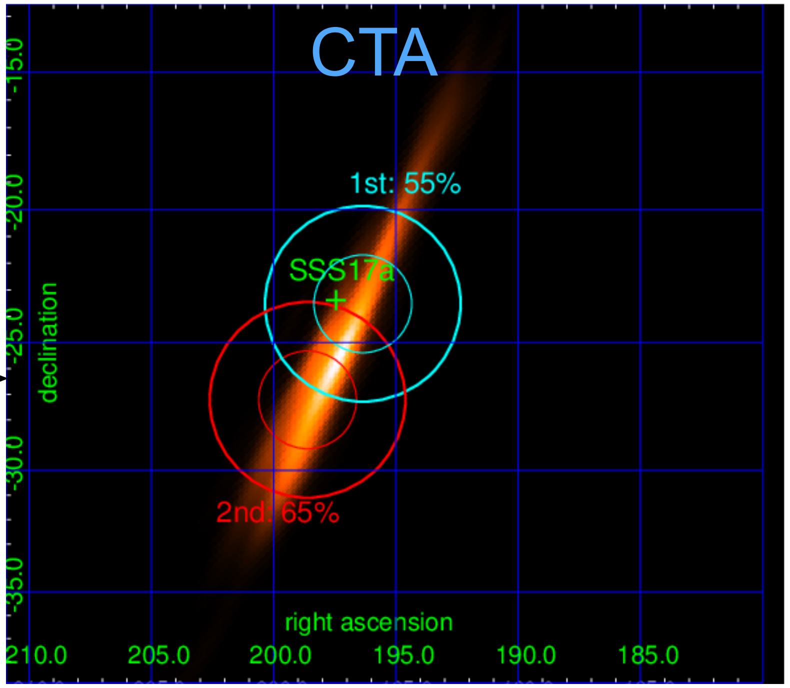


10 x Sensitivity, Large Collection Area
→ all topics
Energies down to 20 GeV
→ Cosmology++
Energies up to 300 TeV
→ Pevatrons
Rapid Slewing in 20 seconds
→ transients
8° Field of View
→ surveys, extended objects
10% Energy Resolution
→ lines, features
Few ' Angular Resolution
→ morphology
cta
cherenkov telescope array
HESS
CTA
γ + γ → e⁺+ e⁻
Mean free path due to gamma-photon pair creation
Mean Free Path
Energy
AGN
Earth
3C 279
Mrk 421
Cen A
M 31
GC
E_cut = 10 TeV
E_cut = 100 TeV
E_cut = 200 TeV
Energy E(TeV)
Excess [/Bin]
NASA
Neutrinos
Leptons
Antiprotons
Protons
Bosons
Supersymmetric neutralinos
Decay process
DEC (J2000) [degree]
RA (J2000) [degree]
A2/A1 = 100
gamma = 2.0
cutoff = 300 TeV

GW170817 @ Cherenkov Telescope Array



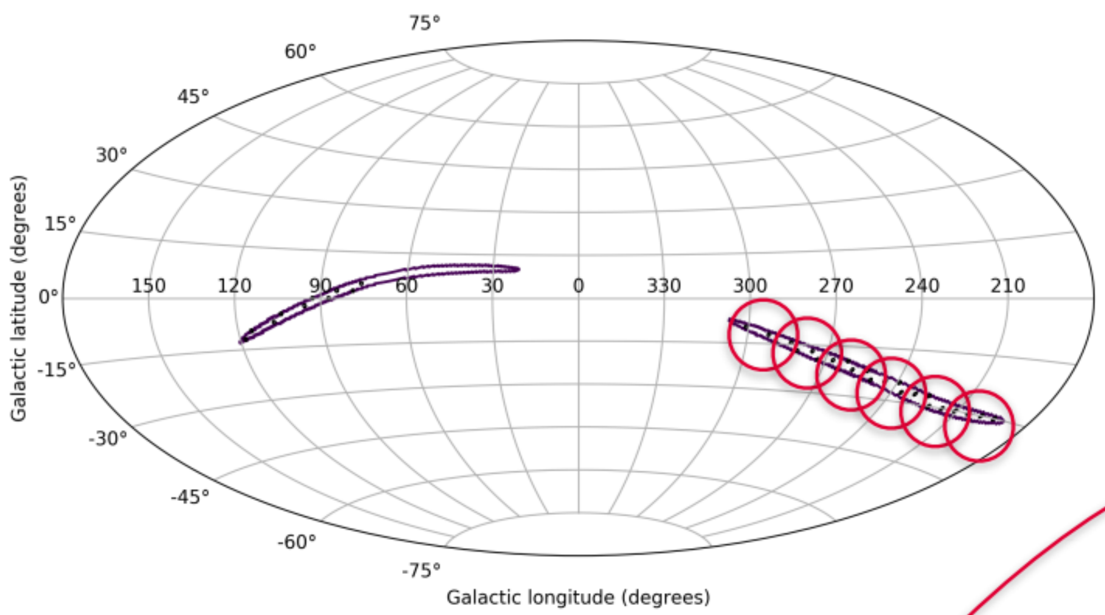
H. Abdalla et al. (H.E.S.S.), ApJL 855:L22 (2017)

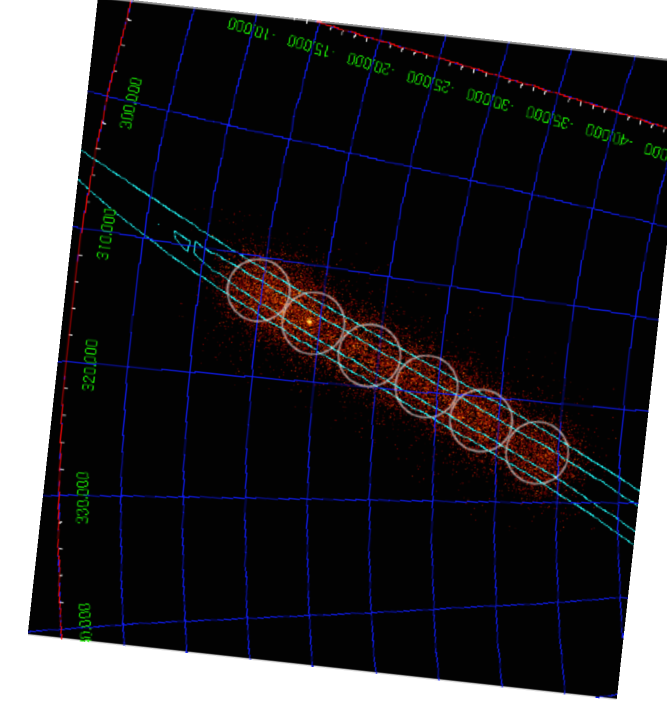


FS (CTA consortium), preliminary

- 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

GW follow-up with CTA: real-time analyses





External science alert: GW

New Observation

e.g. a grid of pointing

RTA

detection after X secs?

no

next pointing of the grid or end of ToO observation

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

M. Seglar-Arroyo et al. (CTA), ICRC2019, arXiv: 1908.08393

Searches for VHE emission associated to GWs

- detection of VHE emission from GRBs boosting GW follow-up searches
  - long-lasting VHE emission possible (also for short GRBs ?)
  - waiting for the next well-localized BNS merger ;-)
- deep MWL observations can provide interesting results on the remnant
  - e.g. constrains on the B-field
- GW follow-up programs are an integral part of all current IACTs
  - significant discovery space
  - lessons learned providing input for the Cherenkov Telescope Array
- Large uncertainty regions and archival searches are prime targets for air shower arrays
  - LHAASO may become a major player