DE LA RECHERCHE À L'INDUSTRIE

cea

TeV gamma-ray observations of GW170817 with H.E.S.S.

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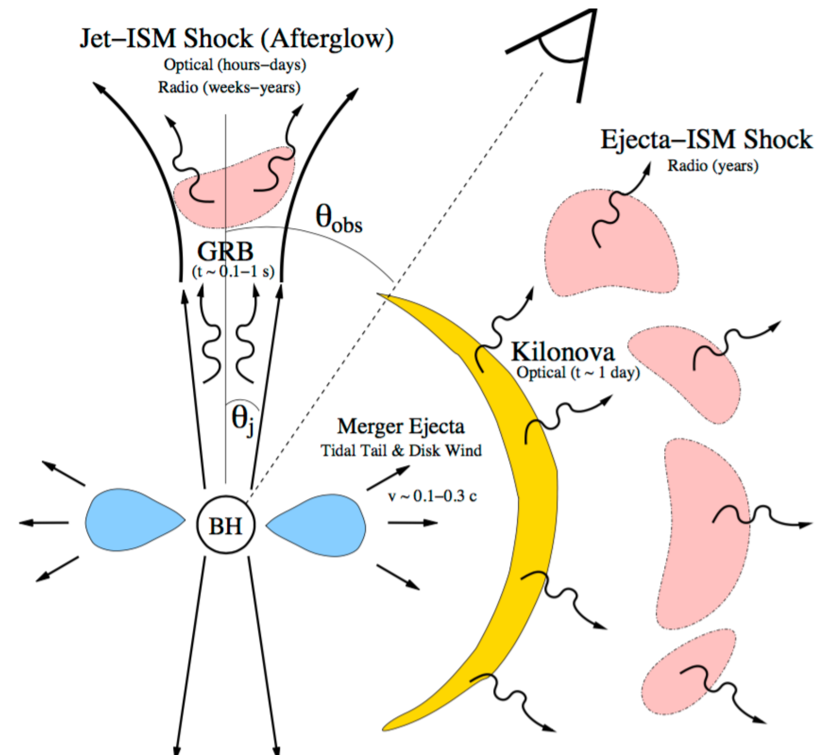
TeV Particle Astrophysics - August 2018 - Berlin

H.E.S.S.

Very High Energy emission in Neutron Star Mergers

- The energy release of sGRBs motivates their origin to be a cataclismic process of compact binaries either **neutron star-neutron star** or **neutron star-black hole** coalescences.

- Examples of Fermi-LAT observations of GRBs showing the presence of high energy emission (GeVs) in prompt phase:
  - GRB 090510: in prompt phase E_{photon}~30 GeV
  - GRB 081024B: in prompt phase E_{photon}~ 3 GeV
  - GRB 130427A : ~minutes: E_{photon}~ 95 GeV, after ~9hours: E_{photon} ~ 32GeV
  - To know about H.E.S.S. GRB observations, go to the poster by Edna Ruiz-Velasco



Berger&Metzger (2012)

- The observation of GeV-TeV emission plays an important role in:
  - Nature of the compact remnant after the coalescence
  - Distinguishing between different ejecta structure and observing the cut-off of GRB spectra

The variety of merger remnants will lead to the detection of different kind of transients

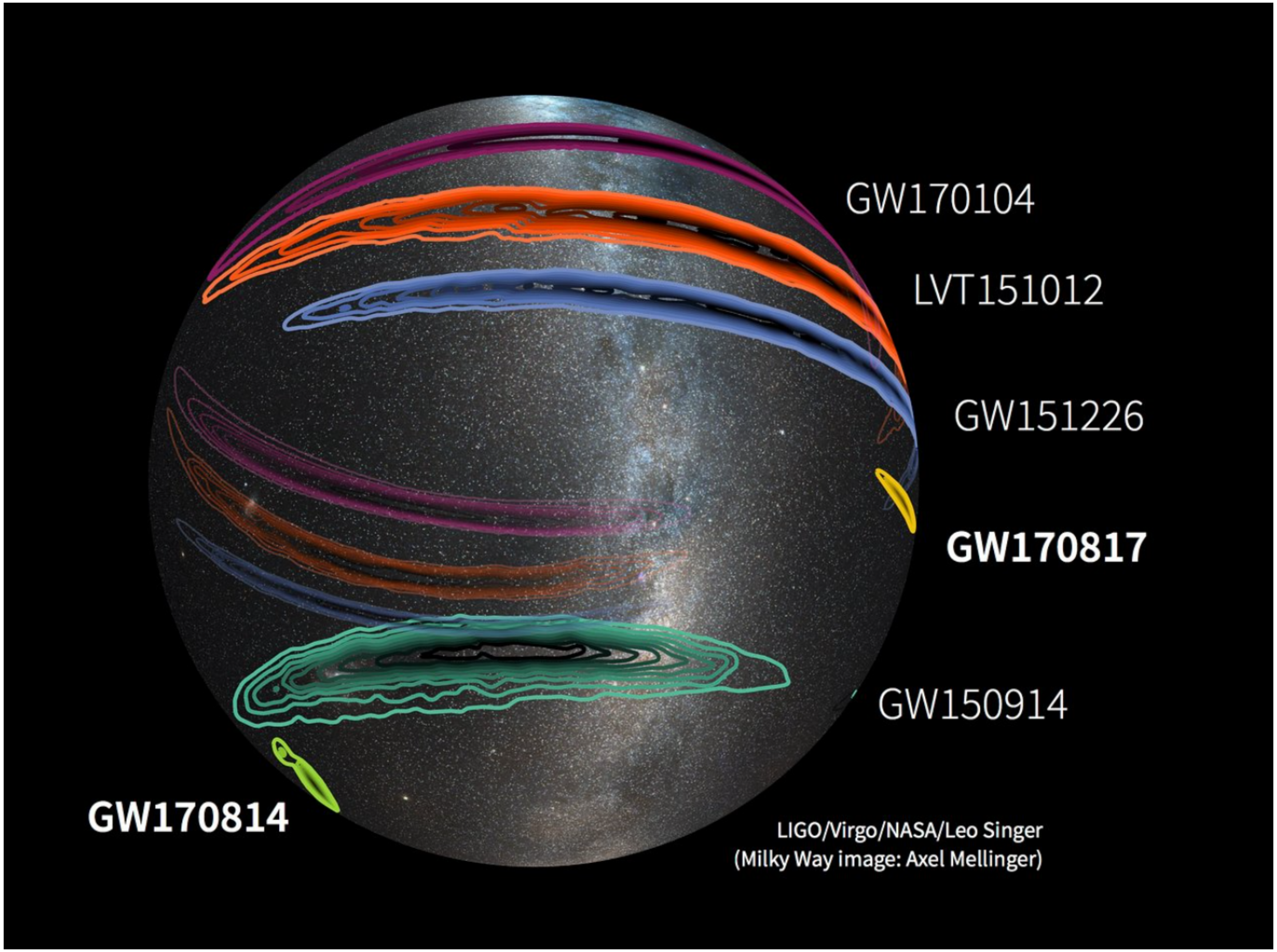
H.E.S.S. experiment

- Located in Namibia at ~1800 meters a.s.l.
- Cherenkov light from air showers initiated by VHE Gamma-Rays (10s of GeVs-10s of TeVs)
- Well suited to follow transients:
  - Rapid follow-up response (~30 seconds)
  - High sensitivity
  - Large FoV for IACT (5°/3.5°)
  - Target-of- Opportunity programs:
    - EM:Gamma-Ray Burst (GRB), Fast Radio Burst (FRB), Multi-wavelength AGN studies
    - High-energy neutrinos
    - **Gravitational waves**

HESS phase I	HESS phase II
4 x 12m telescopes	4 x 12m + 1 x 28 m telescopes
FoV: 5°	FoV: 5° / 3.5°
Energy threshold ~100 GeV	Energy threshold ~30 GeV
Angular resolution < 0.1°	Angular resolution < 0.1- 0.4°

But..

Gravitational Wave localisations covers regions on the sky from ~10s-1000s deg2



Gravitational Wave follow-up program

GW Event — A GW event is triggered. After reconstruction, the event is released as a Open Public Alert (OPAs) — ~minutes

↓

VoAlerter — The GW alert received and parsed at the HESS site in Namibia. — ~seconds

↓

GW Scheduler — Observational constraints are considered
The strategy is chosen depending on the science case.
Time for observation is allocated — ~10 x seconds

↓

Observation — Observation starts. The schedule is subject to further change if considered appropriate. — ~10 x seconds

Total Time ~1 minute

Gravitational Wave follow-up program

GW Event

A GW event is triggered. After reconstruction, the event is released as a Open Public Alert (OPAs)

↓

VoAlerter

The GW alert received and parsed at the HESS site in Namibia.

↓

GW Scheduler

Observational constraints are considered
The strategy is chosen depending on the science case.
Time for observation is allocated

↓

Observation

Observation starts. The schedule is subject to further change if considered appropriate.

> The whole chain is fully automated and on-line. However, if the alert arrives during daytime, the process is done by a human, as was the case for GW170817

Gravitational Wave follow-up program

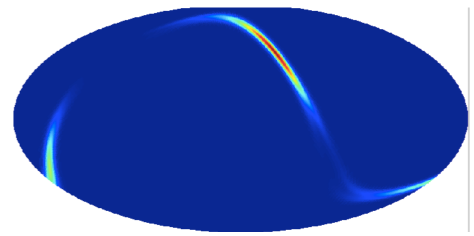
GW Event

VoAlerter

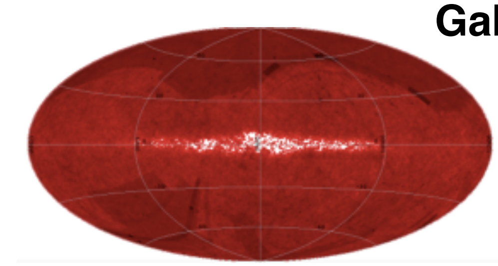
GW Scheduler

Observation

GW sky map



Galaxy catalogue

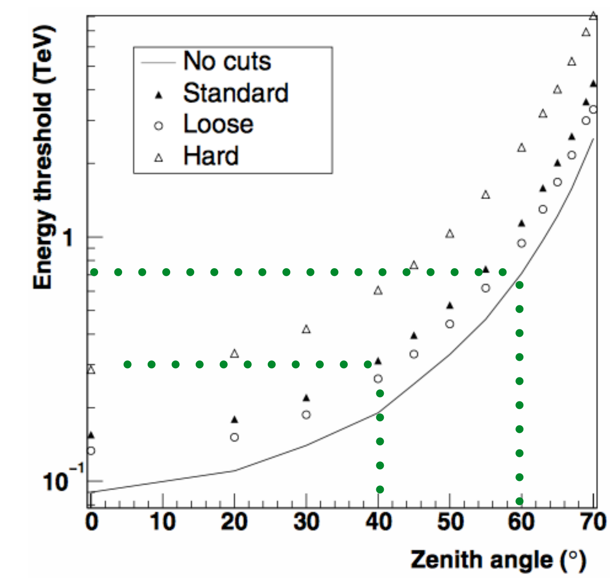


GLADE

- Constructed and matched from galaxy and quasar catalogs
- More than 3 million entries
- Complete in terms of blue luminosity to about 70 Mpc (~50% at 300Mpc)

Time allocator:

- Min: 15 minutes, up to 28 min (HESS run duration)
- Optimisation to lower zenith angles due to energy threshold dependency
- Darkness condition: no Moon



Strategy selection

Follow-up strategy selection

	Description	Pros	Type of events
P_{GW}-in-FoV (2D)	Use raw GW sky map and chose highest direction	▪ Fastest ▪ Possibility of low res. GW map ▪ No need to load galaxy catalogues	▪ Bursts-like events ▪ BBH mergers ▪ Poor resolution events
Highest-P_{GWxGAL} (3D)	Select of individual high galaxy according to its P_{GWxGAL} and observe them one-by-one	▪ Fast ▪ Astrophysically motivated ▪ Uses D_{lum} estimates in GW reconstruction ▪ Validated during GW170817 follow-up: NGC 4993	▪ First pointing on NS-NS
P_{GWxGAL} (3D)	Integrate the full FoV P_{GWxGAL} and observe direction with highest value	▪ More performant ▪ Astrophysically motivated ▪ Uses D_{lum} estimates in GW reconstruction ▪ Validated during GW170817 follow-up: NGC 4993	▪ Subsequent pointings on NS-NS

Gravitational Wave follow-up program

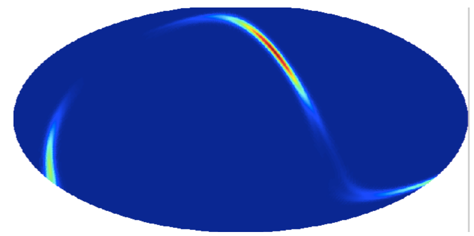
GW Event

VoAlerter

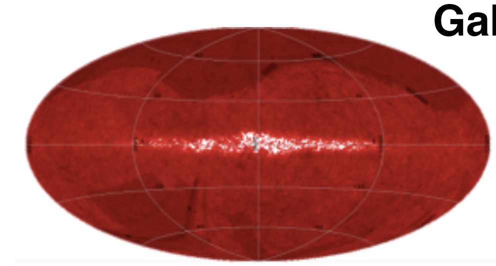
GW Scheduler

Observation

GW sky map



Galaxy catalogue



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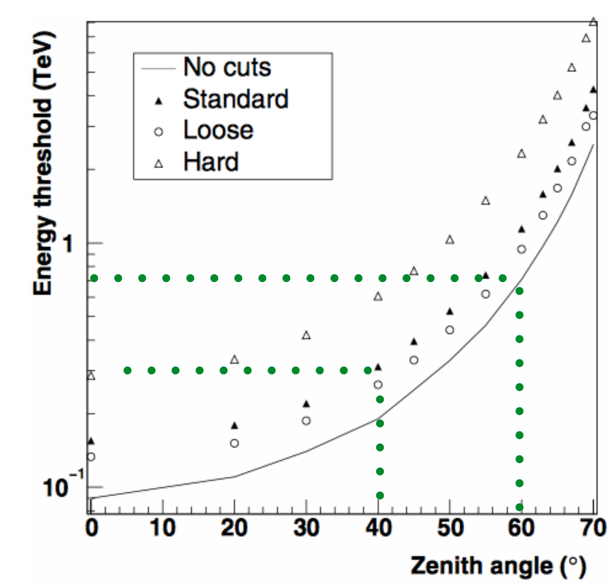


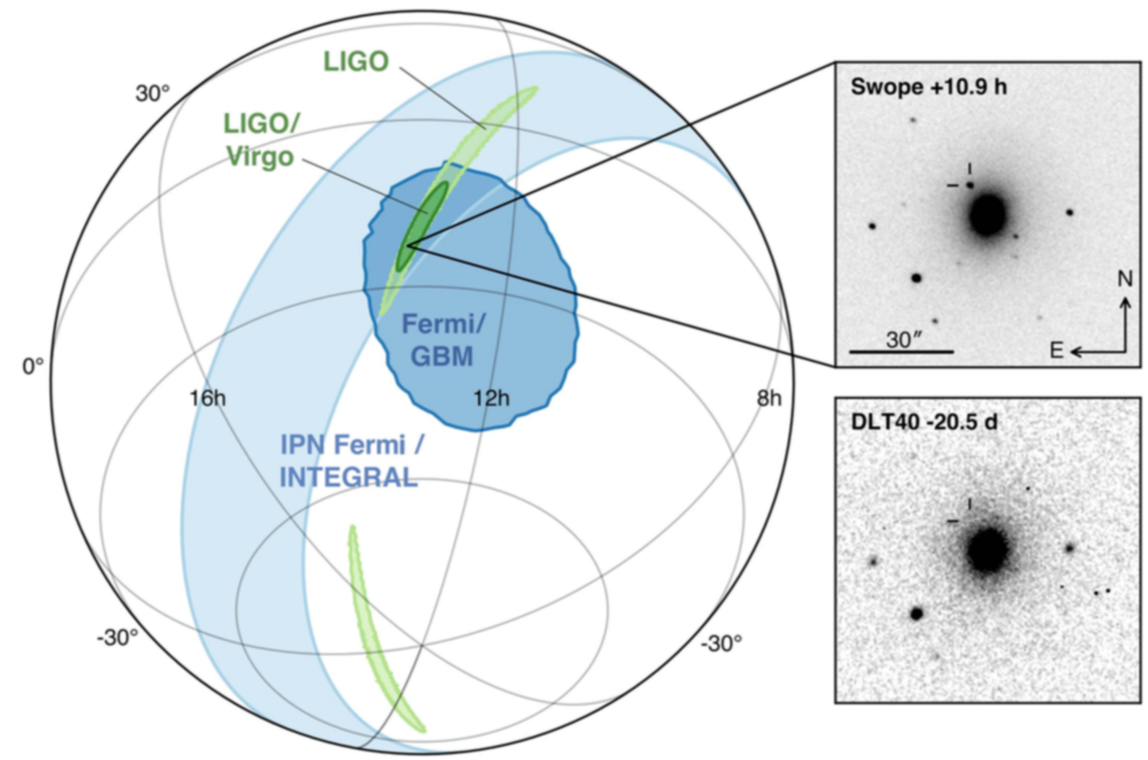
Strategy selection

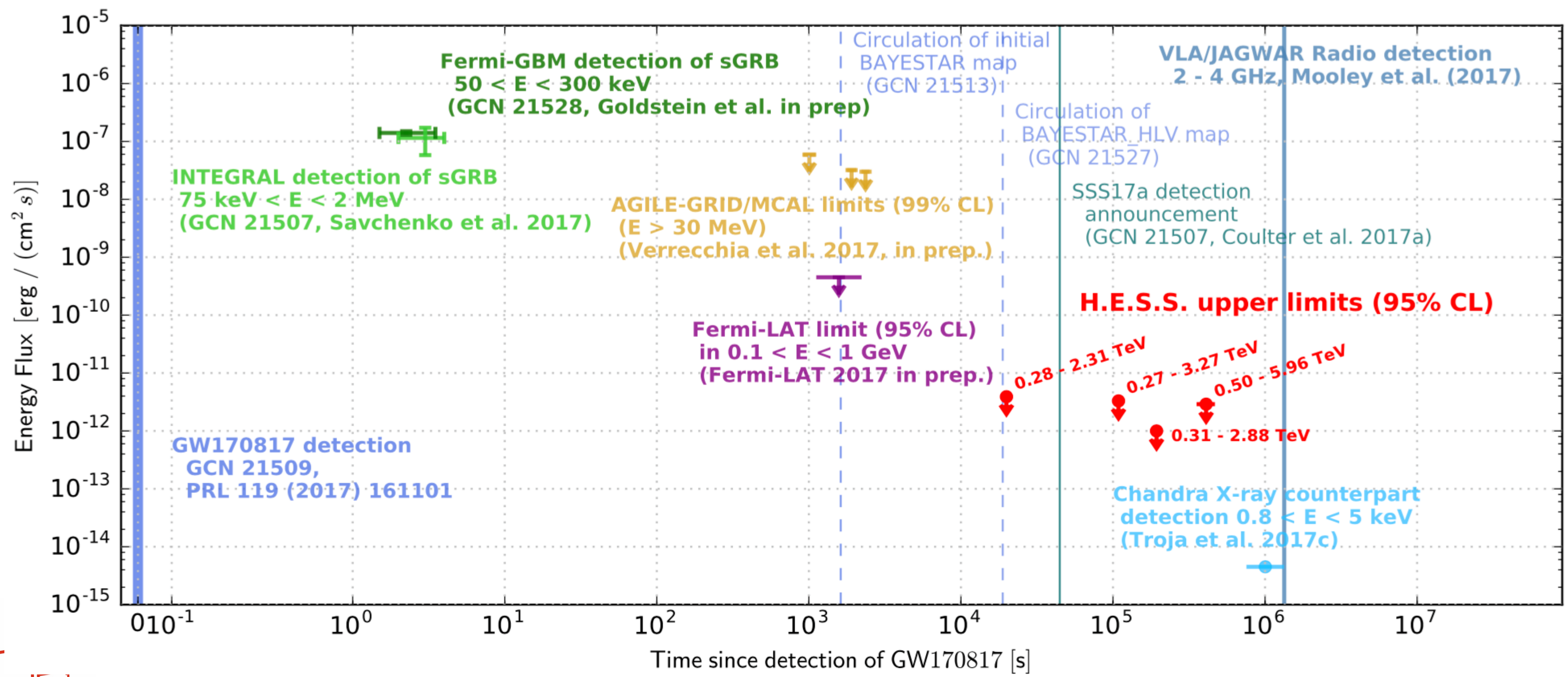
- Reobservation of hot zones: prioritisation + deep exposure
- Rescheduling if increase in significance in Real -Time Analysis

Astrophys. J. Lett. 848, L12 (2017)

GW170817/GRB170817a trigger

- First detection of gravitational waves coming from a Neutron Star Merger
- First coincidence detection of the GW and EM signatures of NSM
- Galaxy catalogs were used to pinpoint the source
- Follow-up campaign that allowed to study the evolution of the event
- Counterparts in UV,optical & infrared



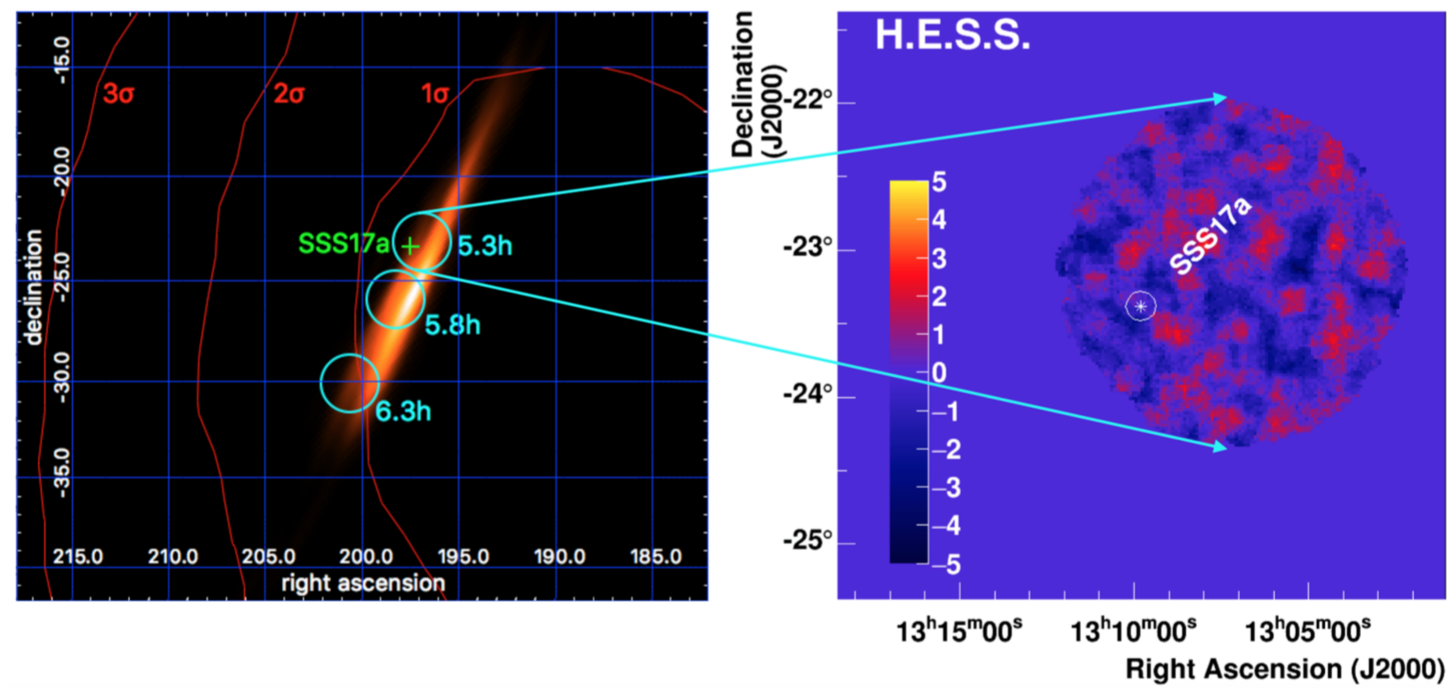


GW170817/GRB170817a observation

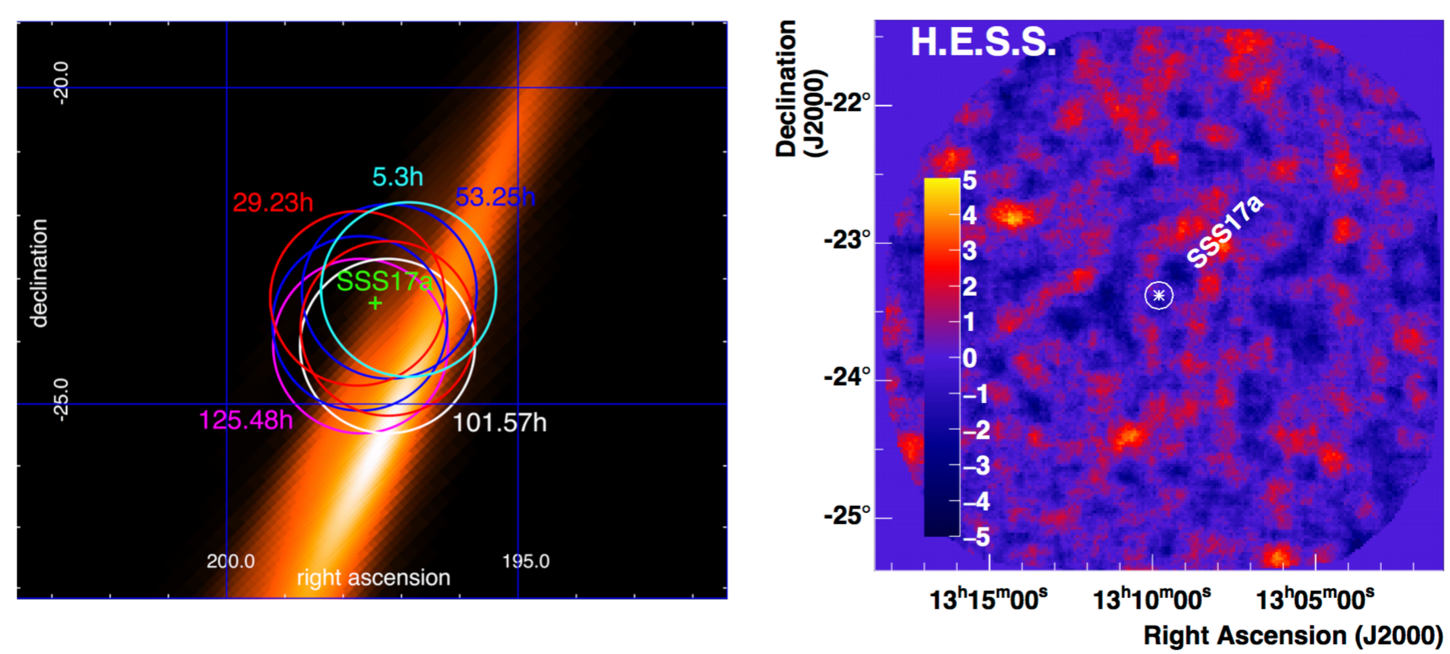
NGC4993, host galaxy, is **NOT** located in the place you would expect by eye (2D strategy)!

- H.E.S.S. was the first ground based instrument on target!
  - 5.3 hours after merger
  - 5 minutes after the update of the GW skymap (LV reconstruction)
- The first observation was on the afterwards identified position of the NS-NS
- In subsequent nights, observations were modified according to the NS-NS location

H. Abdalla et al. (H.E.S.S. collaboration), ApJL 855:L22 (2017), arXiv: 1710.05862



ID	Observation time (UTC)	Pointing coordinates [deg]	<zenith angle> [deg]
1a	2017-08-17 17:59	196.88, -23.17	59
1b	2017-08-17 18:27	198.19, -25.98	58
1c	2017-08-17 18:56	200.57, -30.15	62
2a	2017-08-18 17:55	197.75, -23.31	53
2b	2017-08-18 18:24	197.23, -23.79	60
3a	2017-08-19 17:56	197.21, -23.20	55
3b	2017-08-19 18:24	197.71, -23.71	60
5a	2017-08-21 18:15	197.24, -24.07	60
6a	2017-08-22 18:10	197.70, -24.38	60

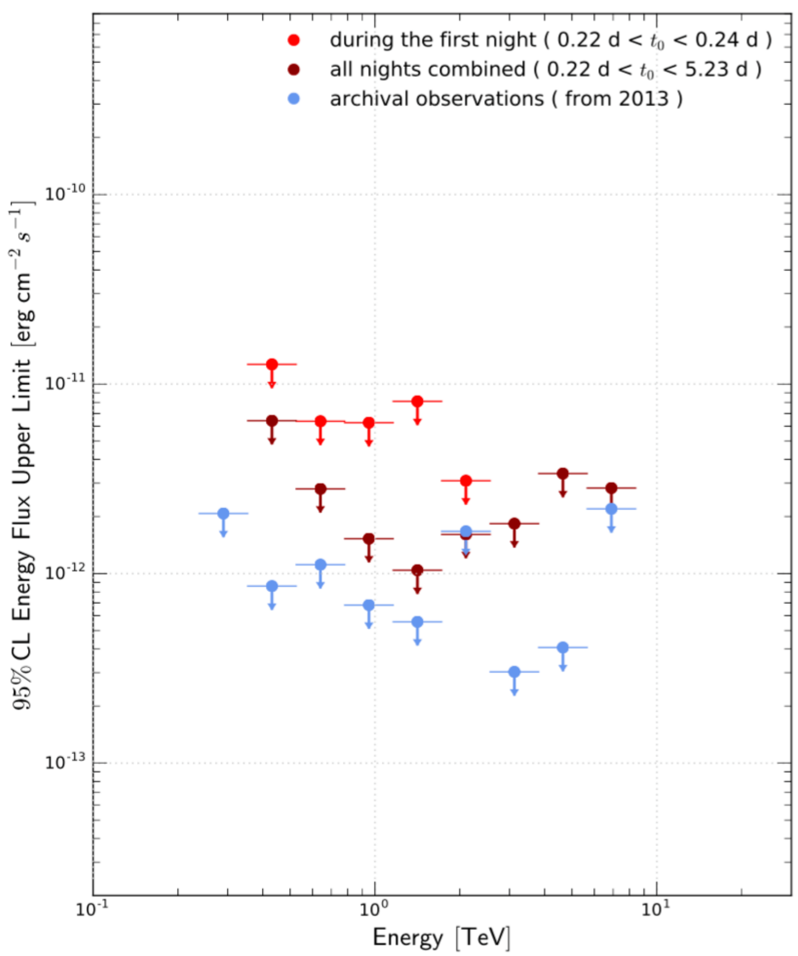


(a) SSS17a: H.E.S.S. pointings (b) SSS17a: H.E.S.S. significance map

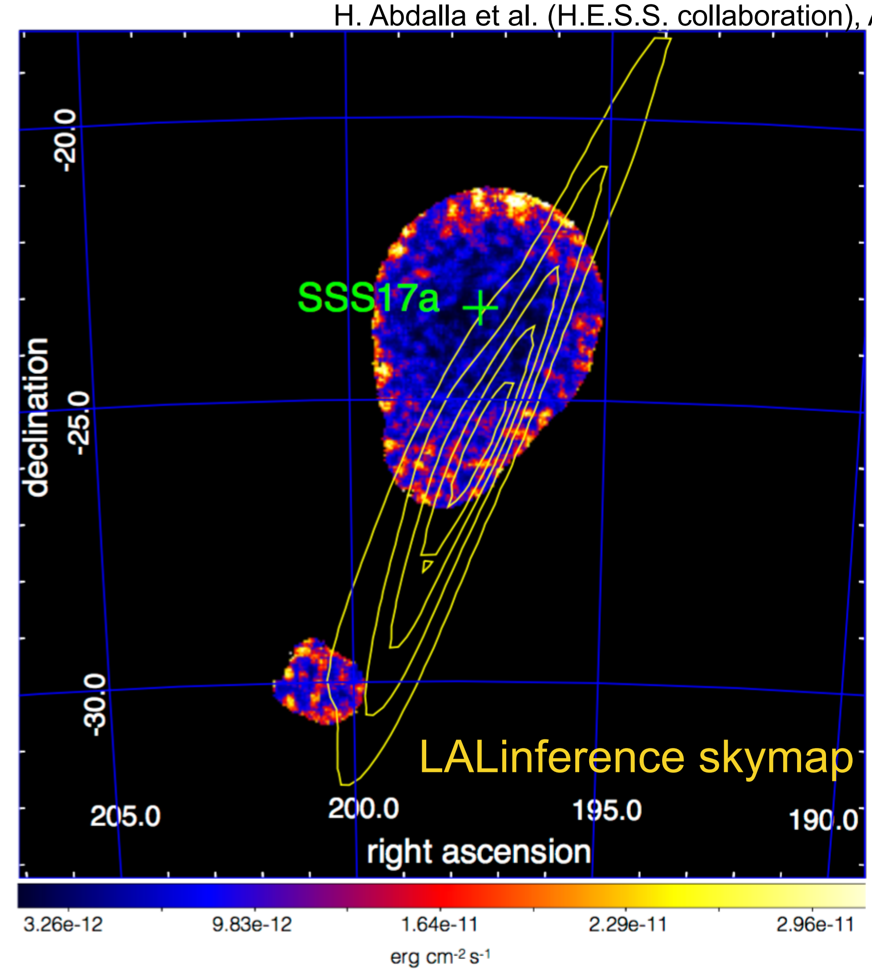
Flux upper limits on GW170817/GRB170817A

- Follow-up campaign of the source
  - Model Analysis (de Naurois et Rolland 2009) results x-checked with ImPACT (Parsons & Hinton 2014)
  - 0.22-5.22 days after merger: 8.5 h of monitoring covering E range from 270 GeV to 8.55 TeV
  - No significant signal: Φ (0.27<E [TeV]<8.55))<1.5 x 10^{-12} erg cm^{-2} s^{-1}
  - PKS1309-216 archival observation (2013): upper limits derived

H. Abdalla et al. (H.E.S.S. collaboration), ApJL 855:L22 (2017), arXiv: 1710.05862



(a) SSS17a: H.E.S.S. limits

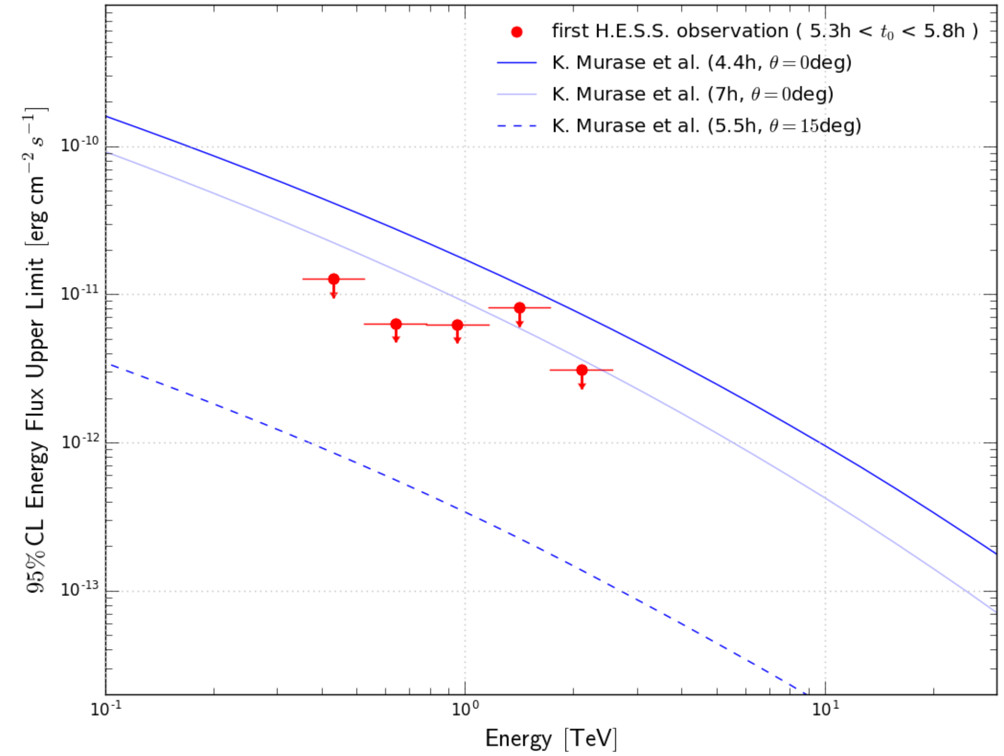


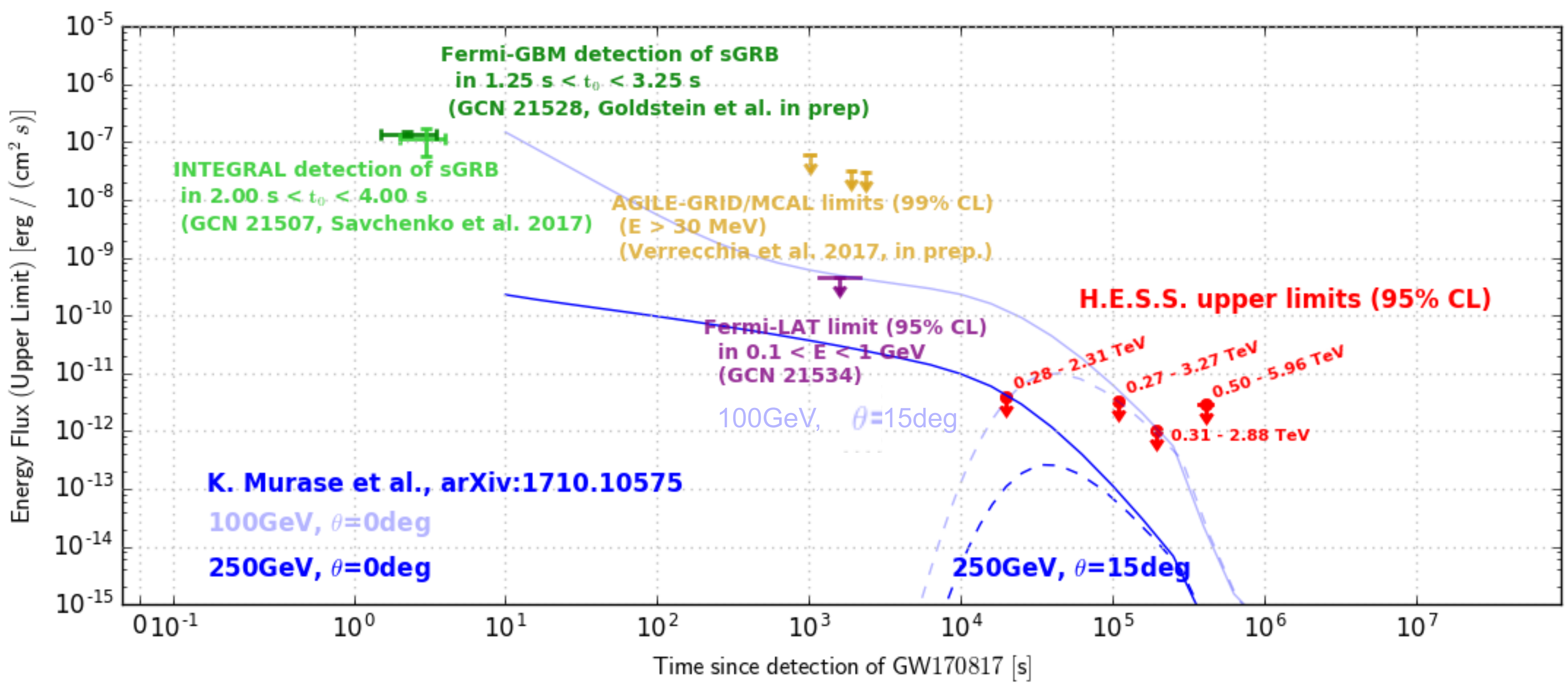
(b) GW170817: H.E.S.S. flux limit map

Integrated upper limits show the deep observations centered in the NSM location

GW170817/GRB170817a observation

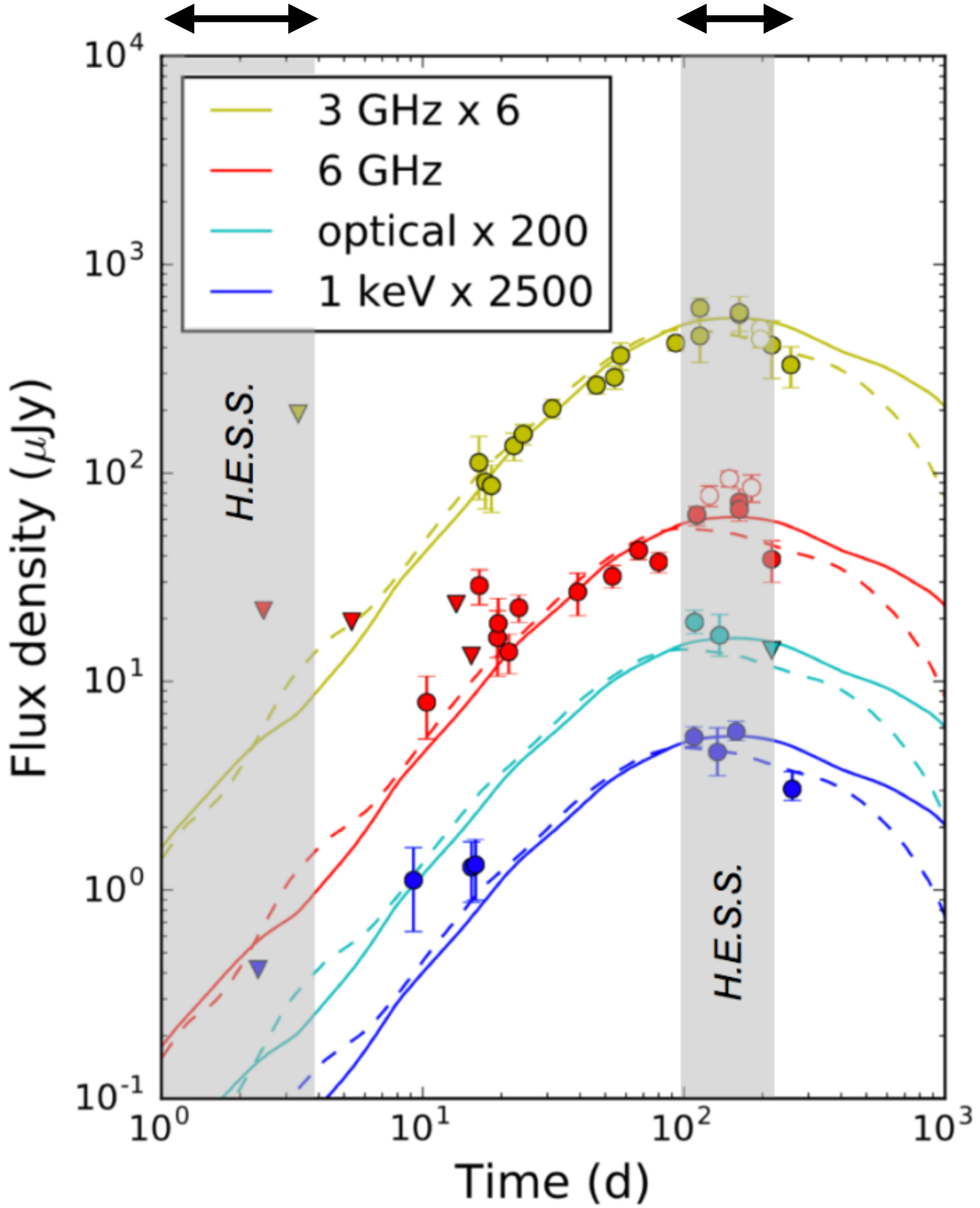
- HESS observations of GW170817 can put constrains on models including long lasting central engines presenting HE signatures
- For further detail, see Murase et al, ApJ, 854(1), 60.





GW170817/GRB170817a: long term observation

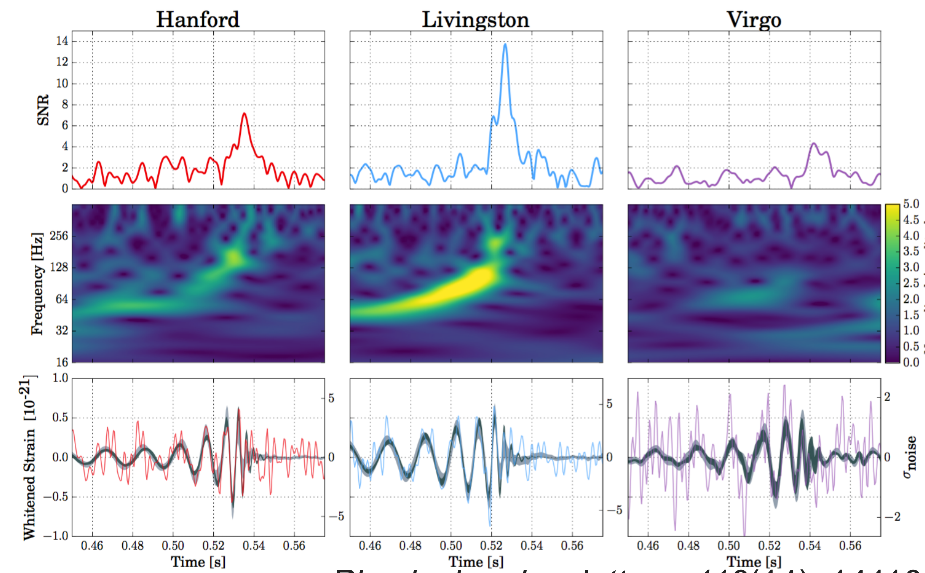
- Late emission
  - Rise of the flux in radio and X-rays 150 days after merger and subsequent decrease
  - H.E.S.S. observations campaign covering the peak of X-ray /radio emission from December till May
  - In the TeV energy range, observations can put constraints on the magnetic field strength of the remnant (Rodrigues, X. et al, arXiv:1806.01624)
  - Analysis in progress



Alexander et al. (2018)

GW170814

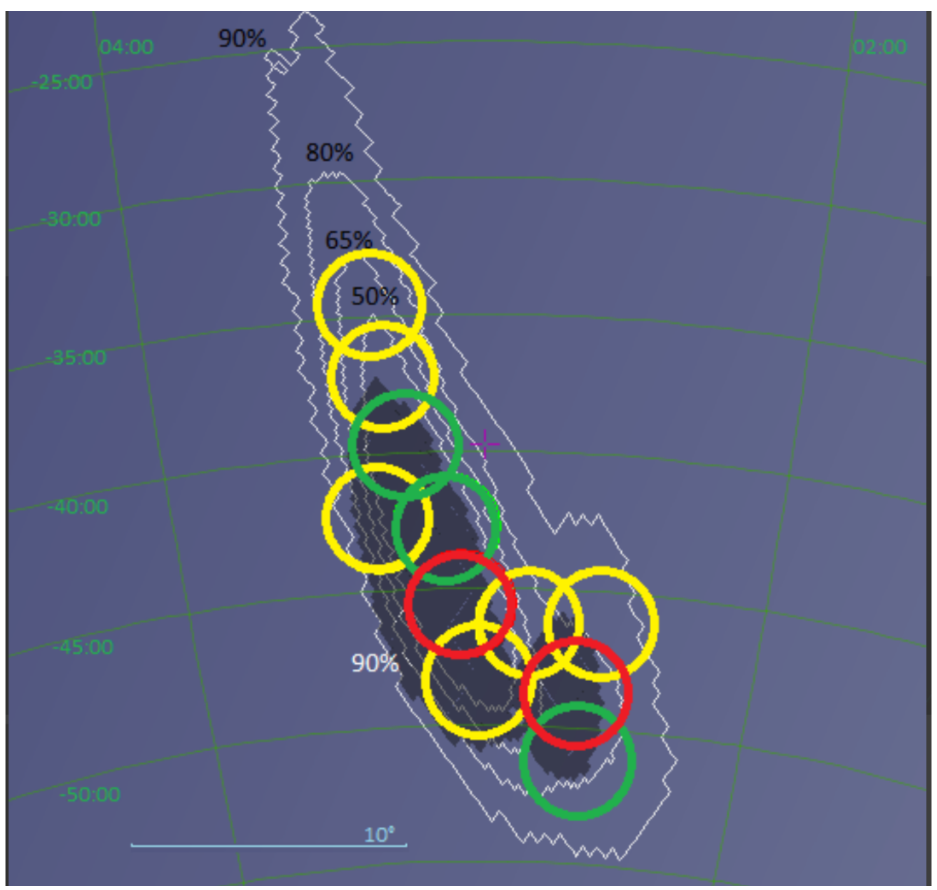
- For O2 technical, trial run on BBH:
  - GW170814 (3 days before real NSM trigger!).

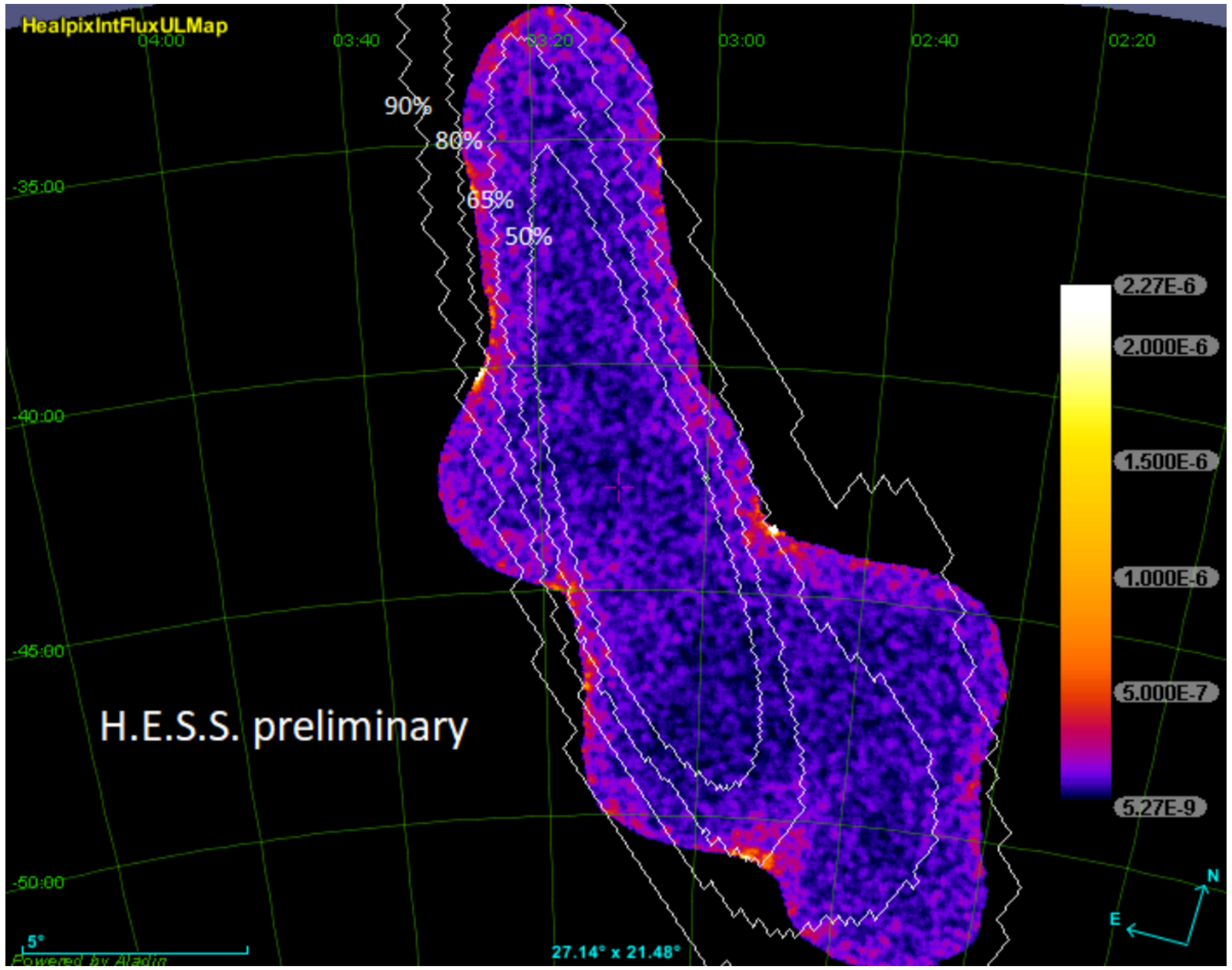


Physical review letters, *119*(14), 141101

- GW170814:
  - 14 August 2017, seen by aLIGO-L, aLIGO-H and Virgo
  - Credible region sky area (without V1): 1160 deg² (with V1): 60 deg²
  - M_1: 28-36 M⊙ M_2 :21-28 M⊙ M_{Total} = 53-59 M⊙

1st night
2nd night
3rd night





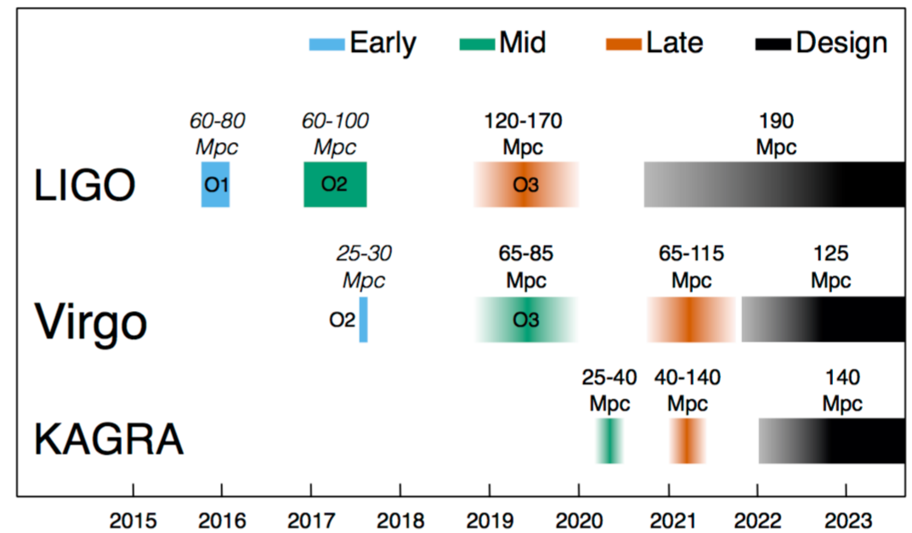
Ashkar, Bonnefoy, Schüssler for HESS collab.

arXiv:1304.0670 v6

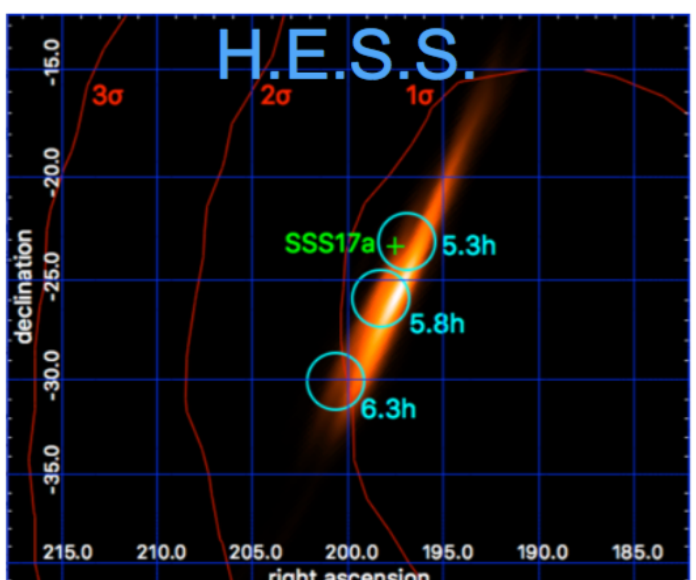
Outlook

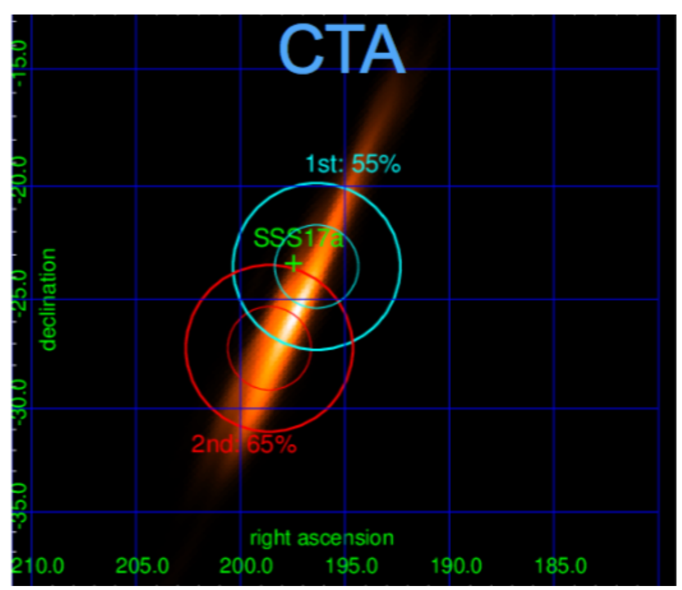
- Automatic and adaptative follow-up strategy in H.E.S.S
- GW170817 has successfully proven our approach to NS-NS and the use of galaxy catalogs.
- Upper Limits on the VHE emission of GW170817 were derived for early phase. Analysis of the late-time observations in progress.

Epoch		2015 – 2016	2016 – 2017	2018 – 2019	2020+	2024+
Expected burst range/Mpc	LIGO	40 – 60	60 – 75	75 – 90	105	105
	Virgo	—	20 – 40	40 – 50	40 – 70	80
	KAGRA	—	—	—	—	100
Expected BNS range/Mpc	LIGO	40 – 80	80 – 120	120 – 170	190	190
	Virgo	—	20 – 65	65 – 85	65 – 115	125
	KAGRA	—	—	—	—	140
Estimated BNS detections		0.05 – 1	0.2 – 4.5	1 – 50	4 – 80	11 – 180



- LST prototype deployed this October!

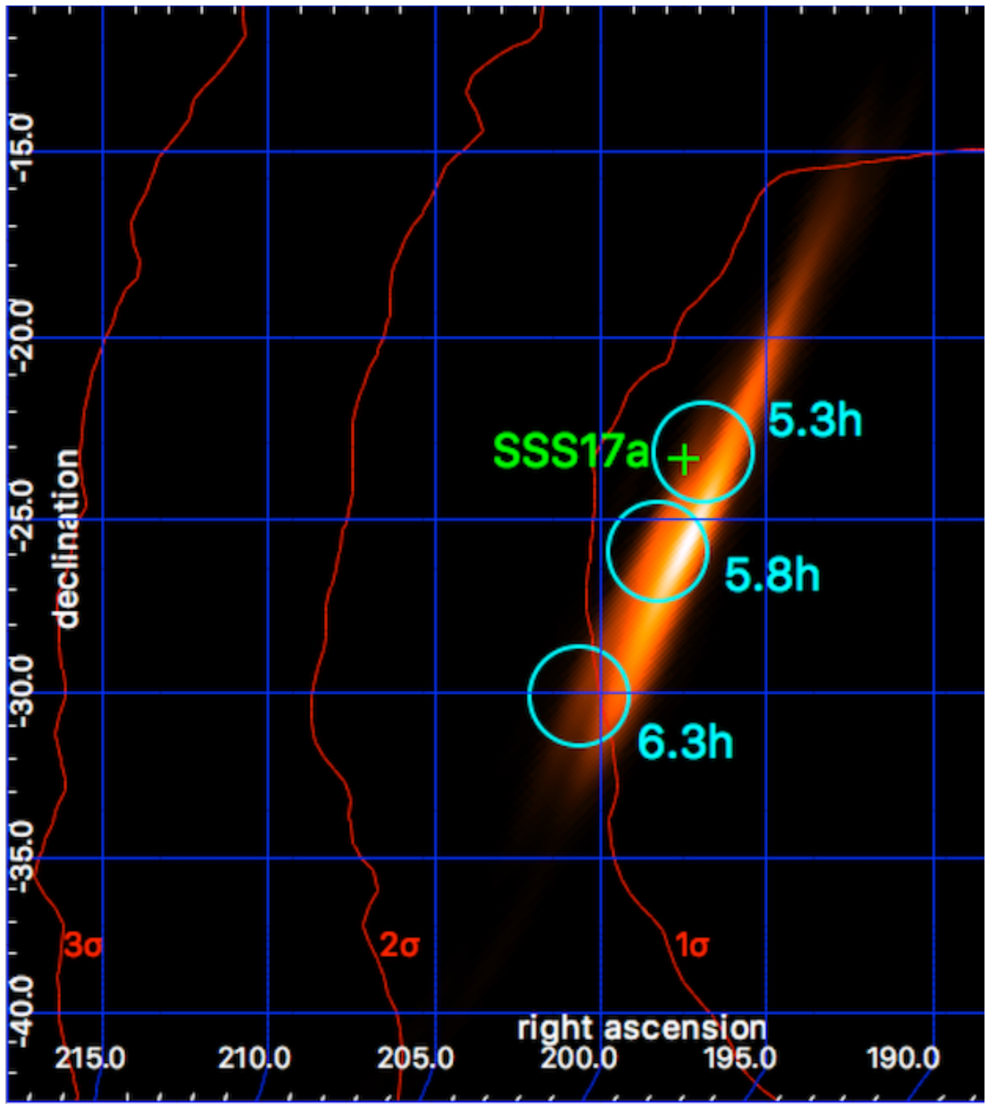




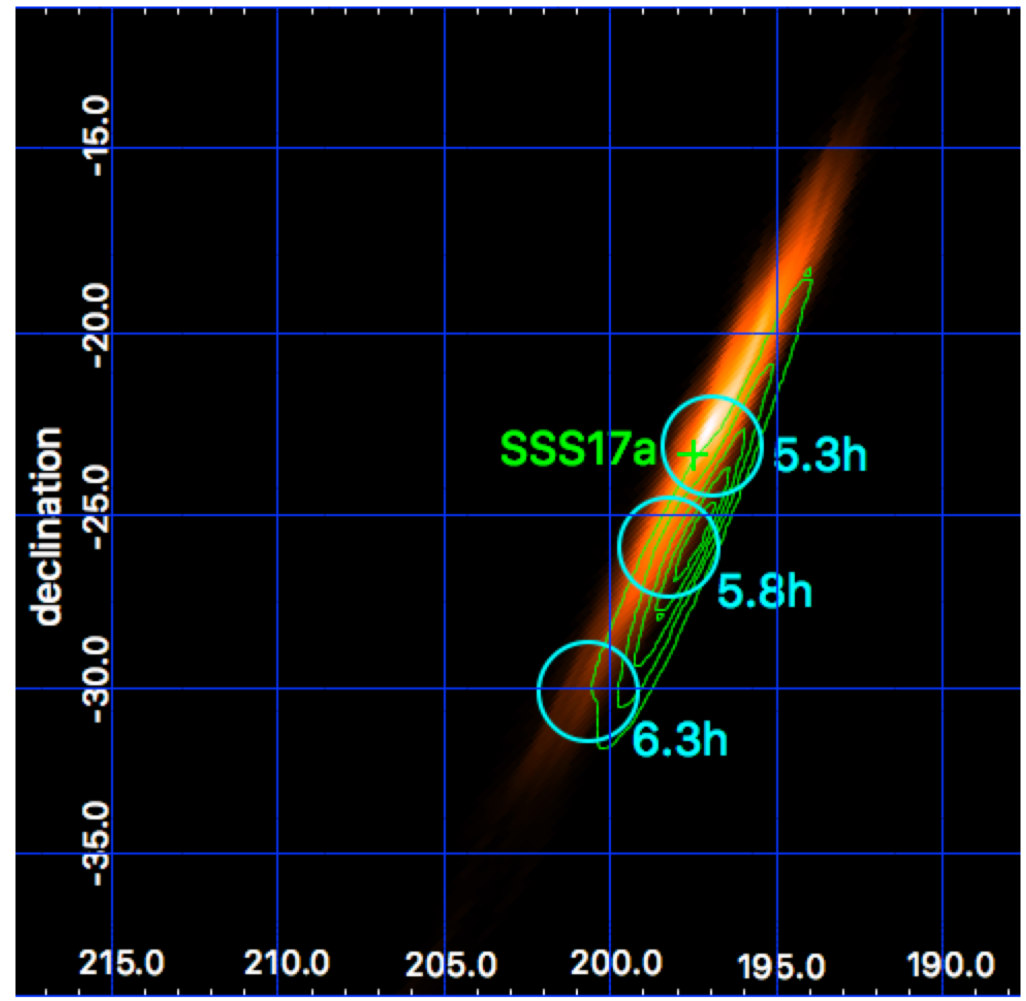
Back-up

Prompt vs. late reconstruction

- The large FoV of HESS can also deal with systematic shifts due to the GW reconstruction



Bayestar
(rapid sky-localization code)



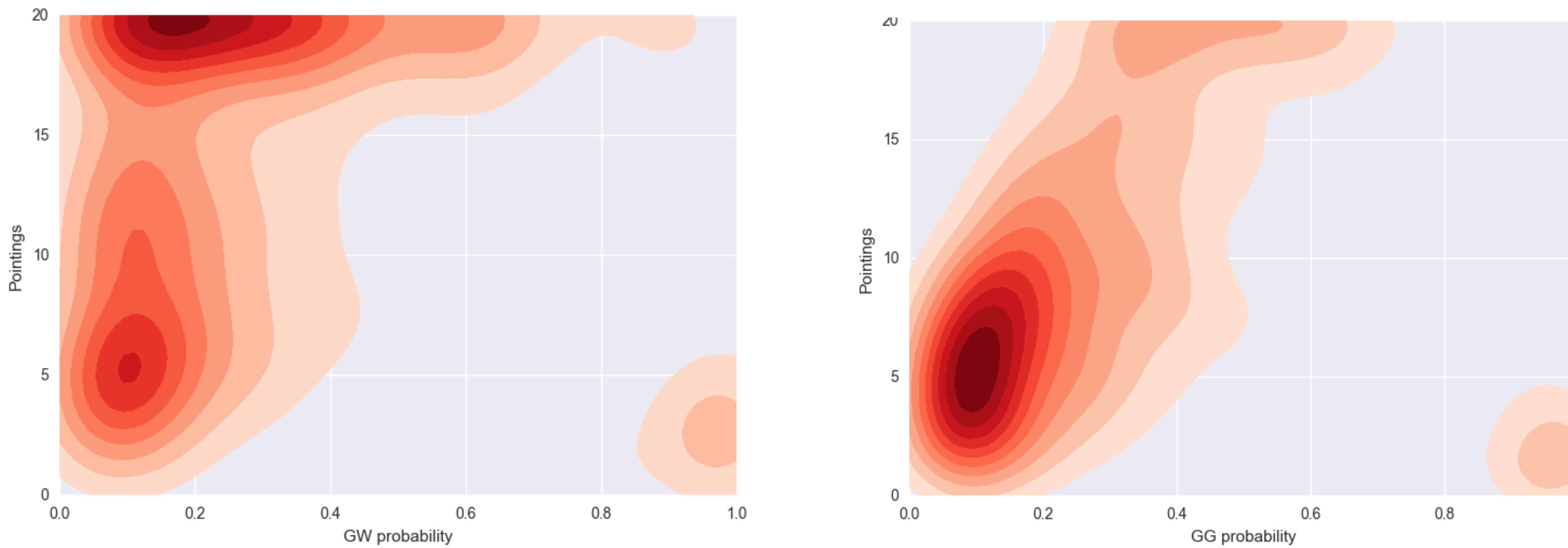
LAL-inference

Highest-P_{GWxGAL} vs. P_{GWxGAL}

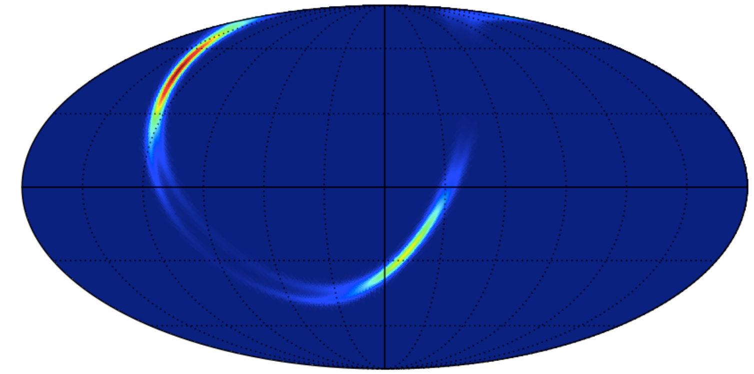
Details in Seglar-Arroyo,M. & Schussler,F.
arXiv:1705.10138

Simulations were done with the following configuration:

- Effective FoV radius: 2.5 deg
- Maximum of 20 observations of 30 minutes, within 3 days
- Random times during the year
- Trigger HESS observation only if a minimum coverage can be achieved.
- 250 available gravitational wave localisation maps derived from simulated NS-NS merger events BayeStar reconstructed (https://losc.ligo.org/s/skymapViewer)
- GLADE galaxy catalogue



P_{GWxGAL} computation

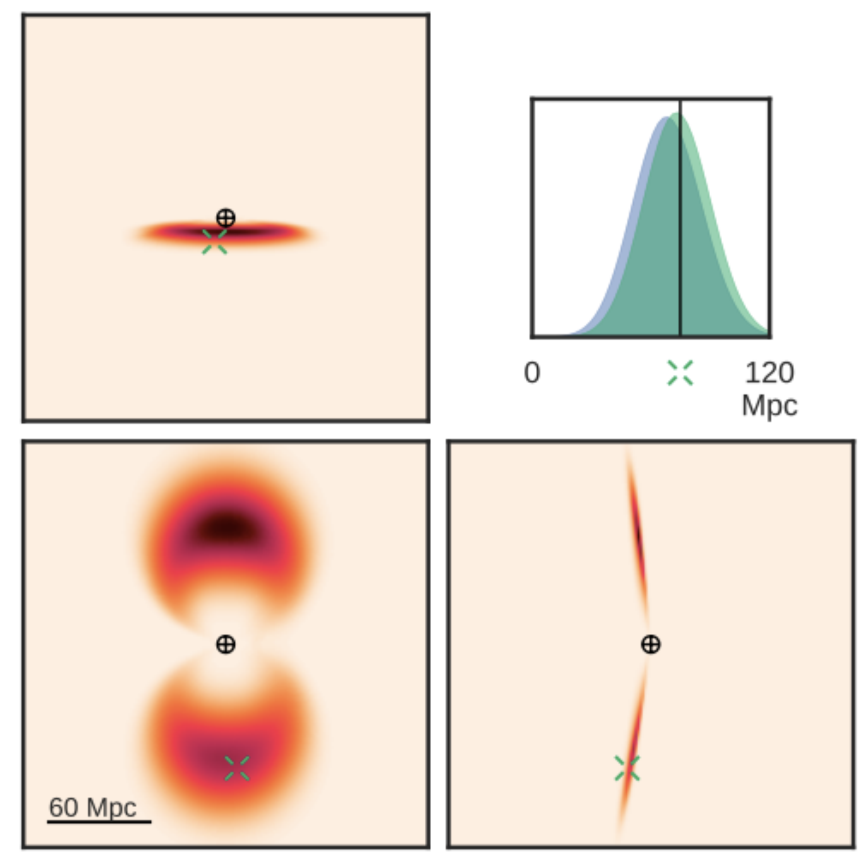


- 2D Probability density from the GW map : $\mathbf{P_{GW}}$
- 3D Probability density from the GW map : $\mathbf{P_{GWxGAL}}$

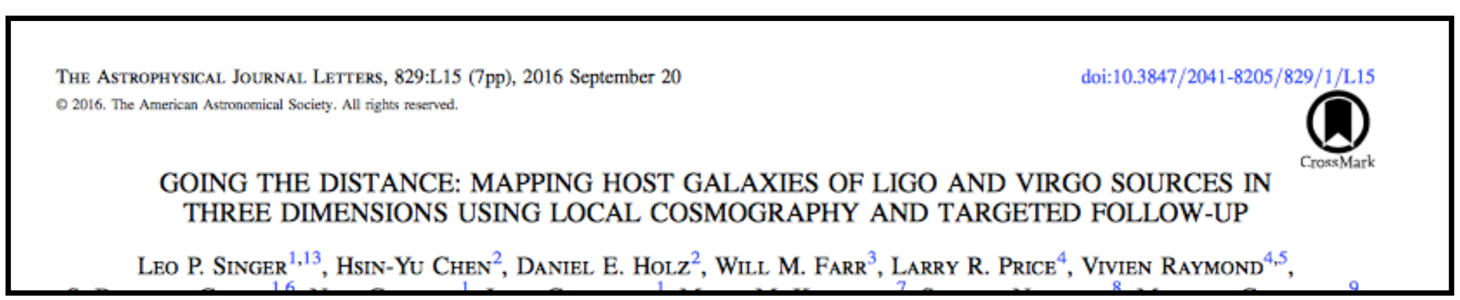
  - The conditional distribution of distance is well fit by an ansatz whose location parameter mu(n), scale s(n), and normalization N(n) vary with the sky location n
  - Gaussian likelihood + uniform prior

$$p(r|\boldsymbol{n}) = \frac{\hat{N}(\boldsymbol{n})}{\sqrt{2\pi}\,\hat{\sigma}(\boldsymbol{n})} \exp\left[-\frac{(r-\hat{\mu}(\boldsymbol{n}))^2}{2\hat{\sigma}(\boldsymbol{n})^2}\right] r^2$$

for $r \geqslant 0$.



Singer, LP., et al., *APJ Letters* 829.1 (2016): L15 arXiv: 1603.07333



The Astrophysical Journal Letters, 829:L15 (7pp), 2016 September 20
doi:10.3847/2041-8205/829/1/L15

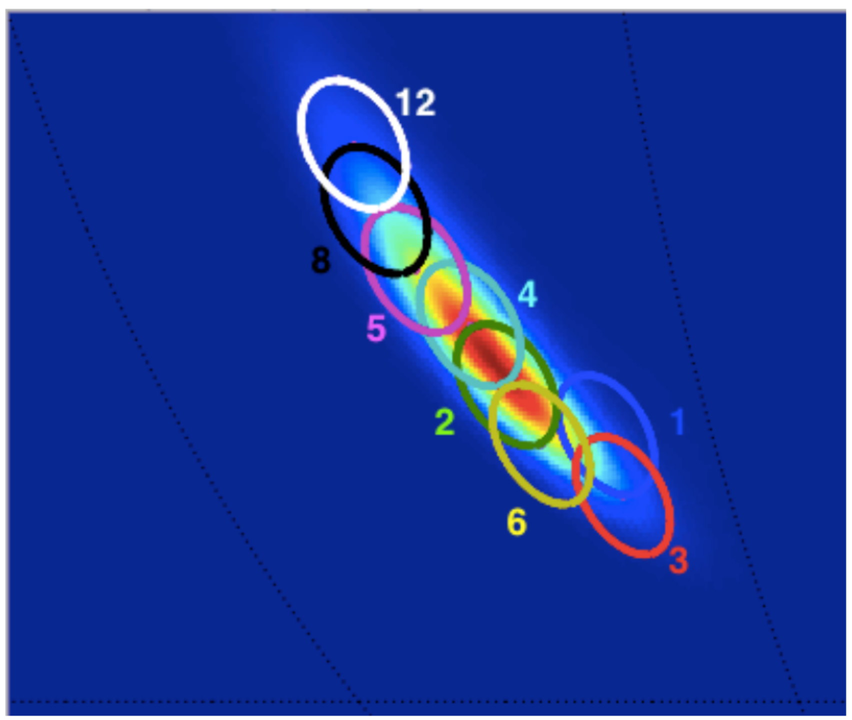
GOING THE DISTANCE: MAPPING HOST GALAXIES OF LIGO AND VIRGO SOURCES IN THREE DIMENSIONS USING LOCAL COSMOGRAPHY AND TARGETED FOLLOW-UP

Leo P. Singer[1,13], Hsin-Yu Chen[2], Daniel E. Holz[2], Will M. Farr[3], Larry R. Price[4], Vivien Raymond[4,5],

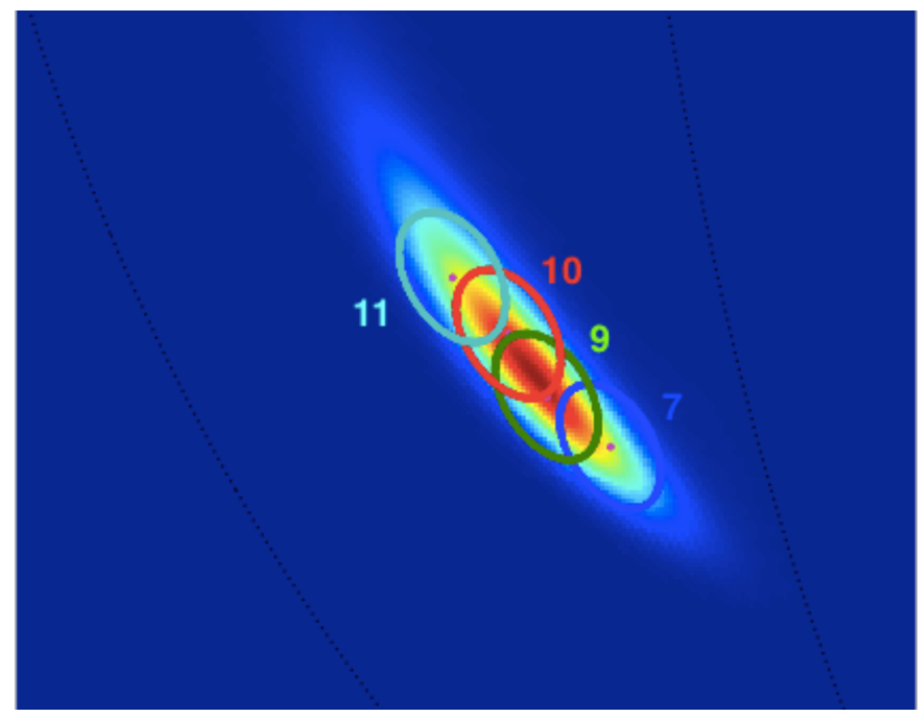
Prioritisation+deep exposure

Reobservation in further time windows with better condition (zenith+increase of dark times) when principal pointing doesn't provide really interesting information

Main pointings



Deep exposure / backup

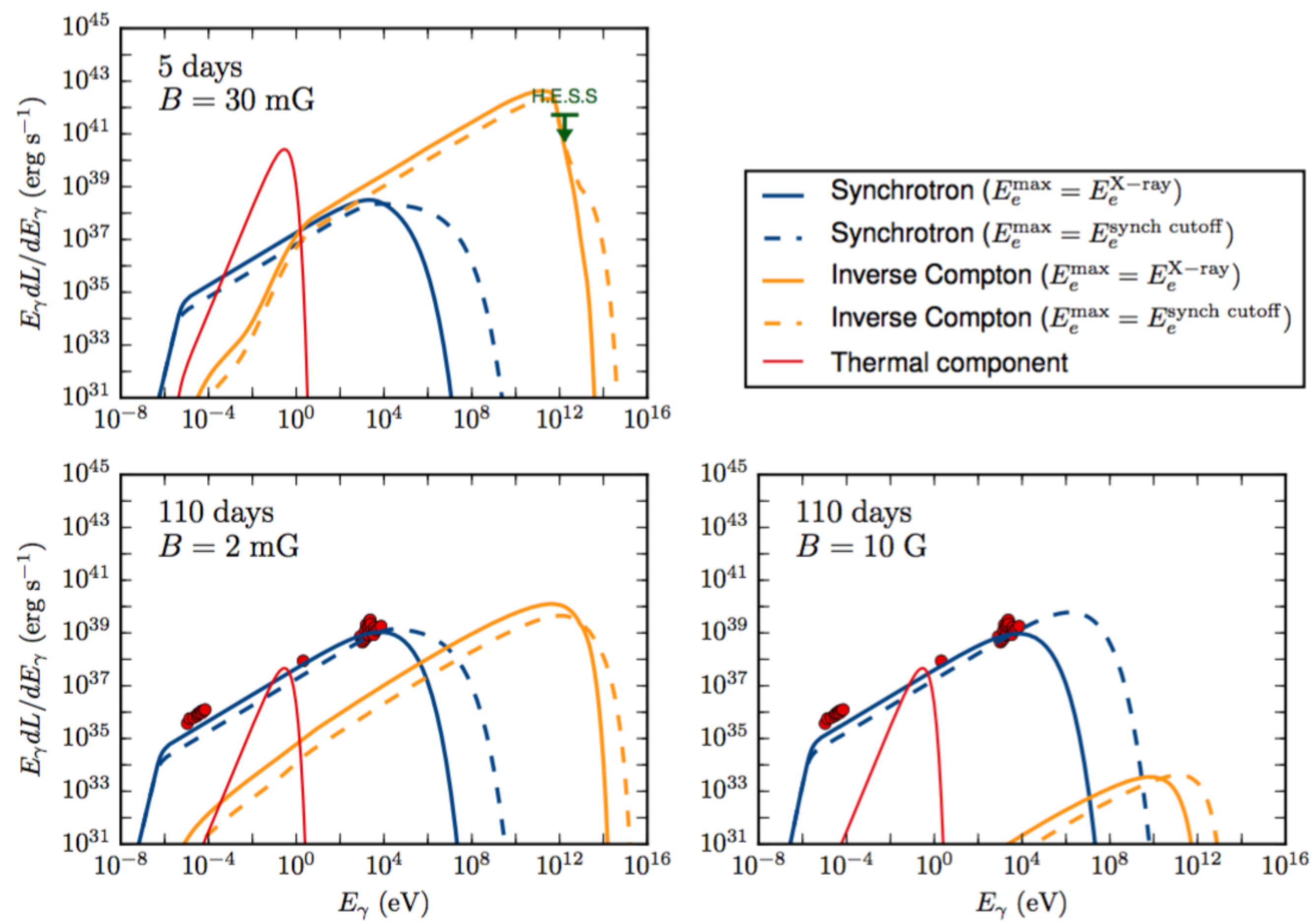


Simulated NS-NS skymap

Looking for ideal compromise between full coverage + prioritisation of zones

TeV late-emission of GW170817

- From the SED, one can extract:
    - Energy in non-thermal electrons
    - Magnetic field (evolution) in the ejecta
    - Dynamics of the ejecta
- Radio & X-rays probe synchrotron emission, Gamma-rays probe IC.
- Together: Constraints on magnetic fields



From Rodrigues, X. et al, arXiv:1806.01624