Probing the magnetic field in the GRB / GW 170817 outflow using H.E.S.S. observations

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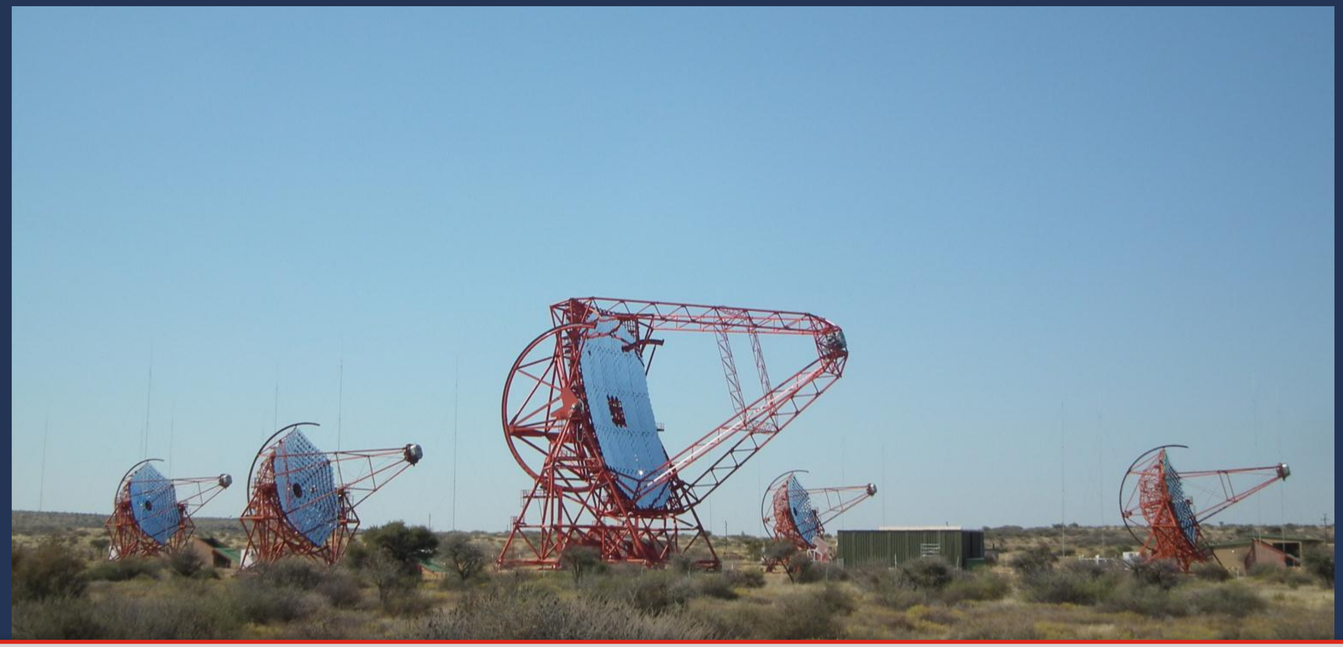


H.E.S.S.

DESY.

The electromagnetic counterpart to GW/GRB 170817 - prompt emission

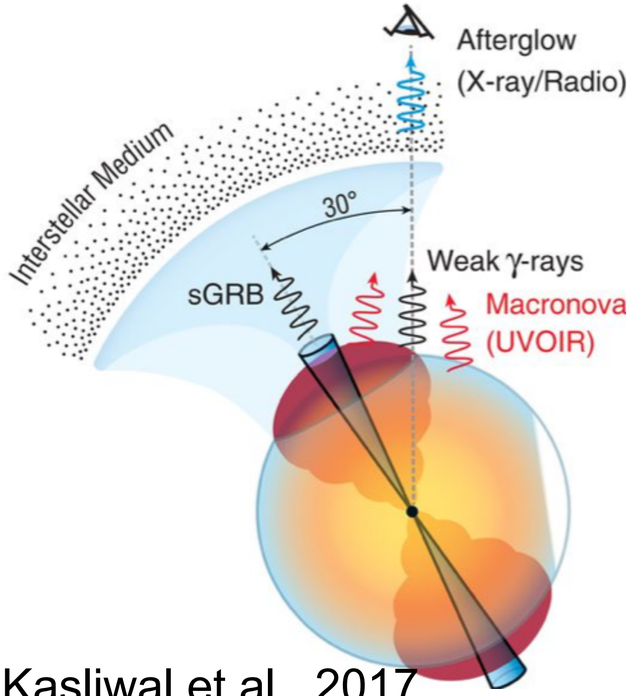
- Origin of prompt emission consistent with
  - NS-NS merger propelled material into intra-merger medium
  - Wide-angle jet inflates ejecta forming a cocoon
  - γ-rays produced in shock-breakout
  - r-process elements forged in ejected material hours after merger

→ Emission traced in optical and soft γ-rays

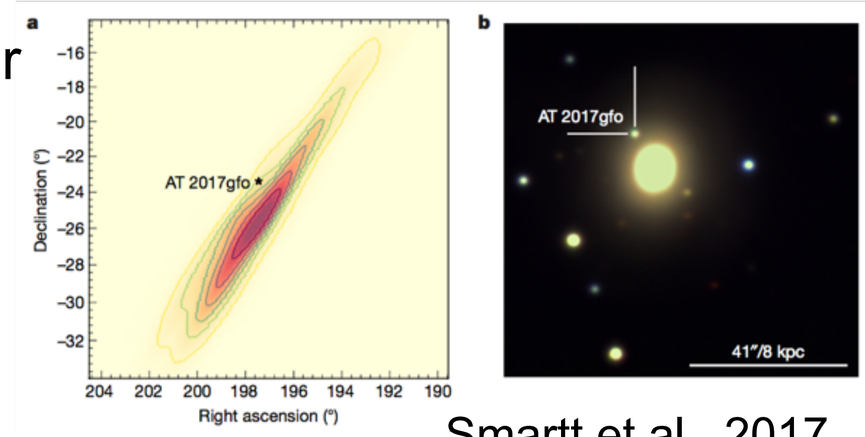
→ No detection of X-rays or radio until multiple days after merger

- Ejecta properties
  - speeds of 0.1 – 0.3 c → strong shocks
  - ejected mass of few % M_{sol} → baryon-rich material

→ Particle acceleration and γ-ray / neutrino production?



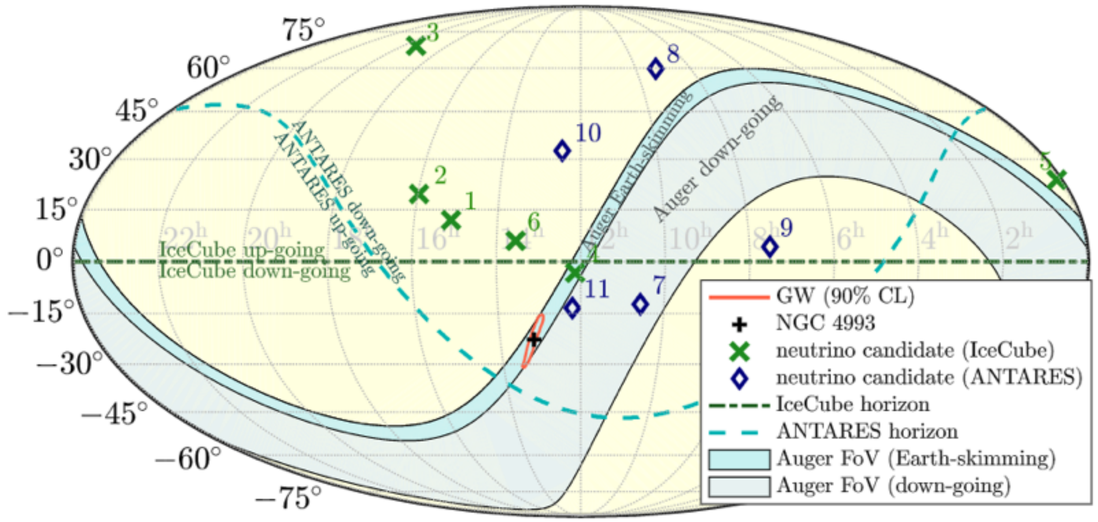
Kasliwal et al., 2017



Smartt et al., 2017

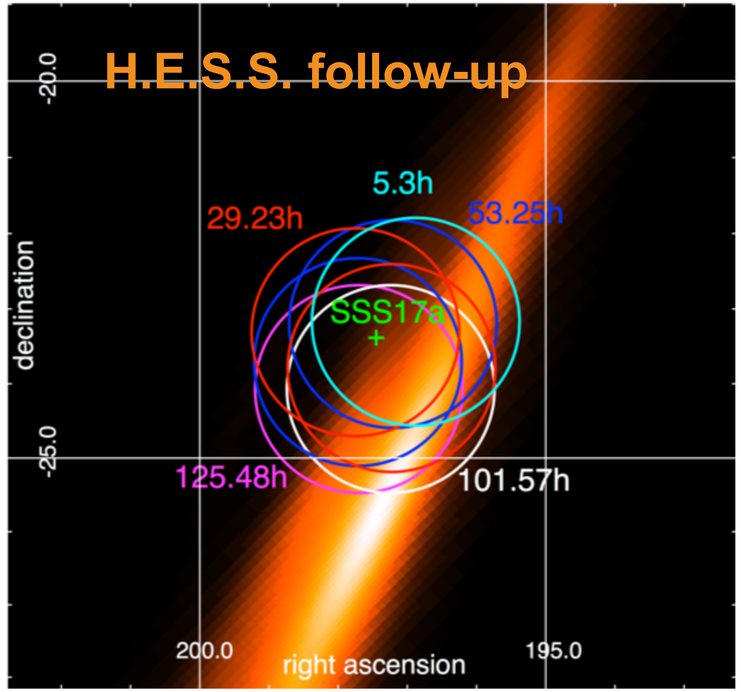
The ‘early’ follow-up of GW/GRB 170817

- Neutrinos + UHE cosmic rays
  - ANTARES, IceCube and Auger search did not reveal counterpart within ±500s of merger
  - Neutrino provides direction and gives insight into source environment



LIGO, Virgo, Auger, ANTARES, IceCube,ApJ 850 (2017)

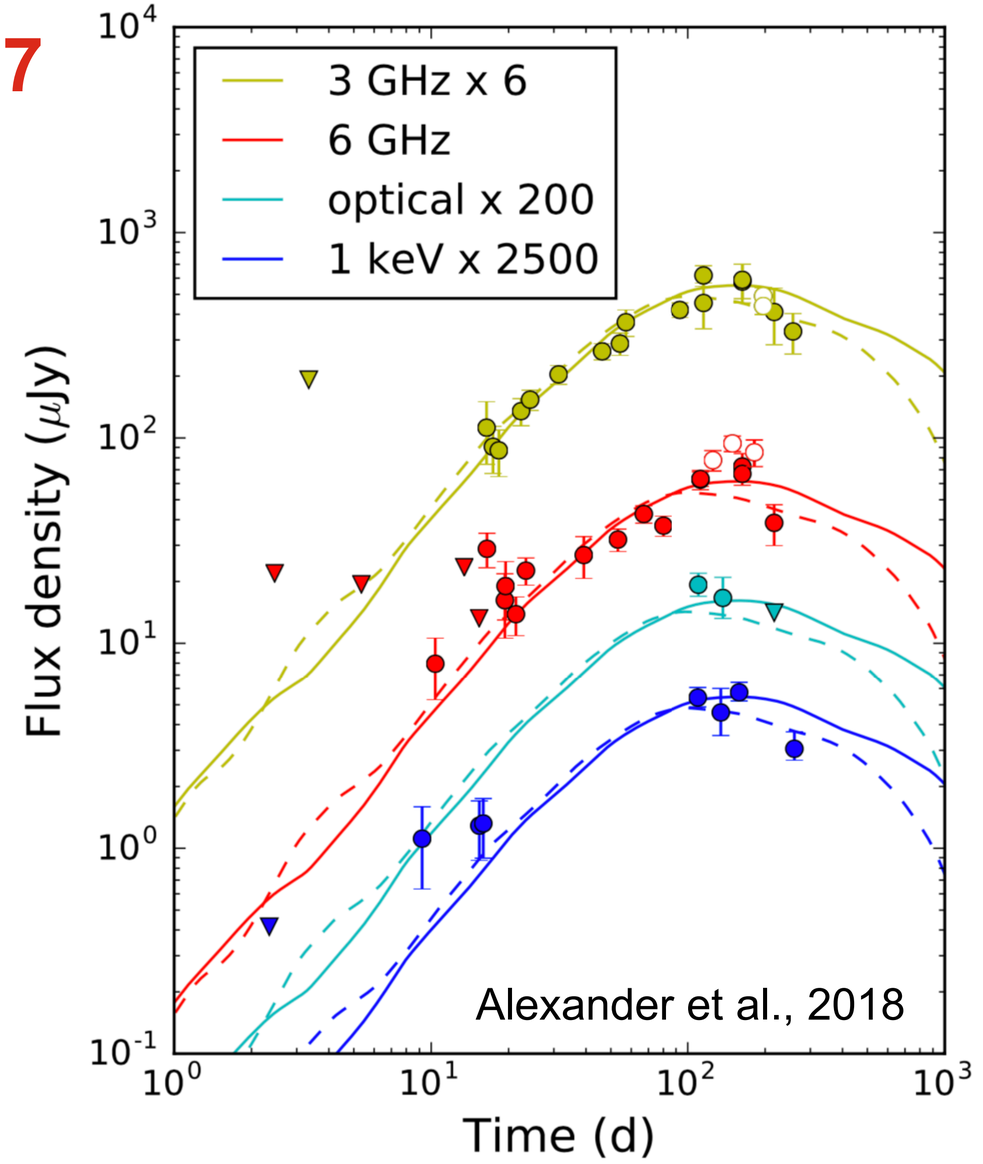
- VHE γ rays
  - H.E.S.S. covers uncertainty region 5 hours after event
  - 1st ground-based pointing telescope to cover NS-NS merger → no detection



H.E.S.S. Collaboration (2017)

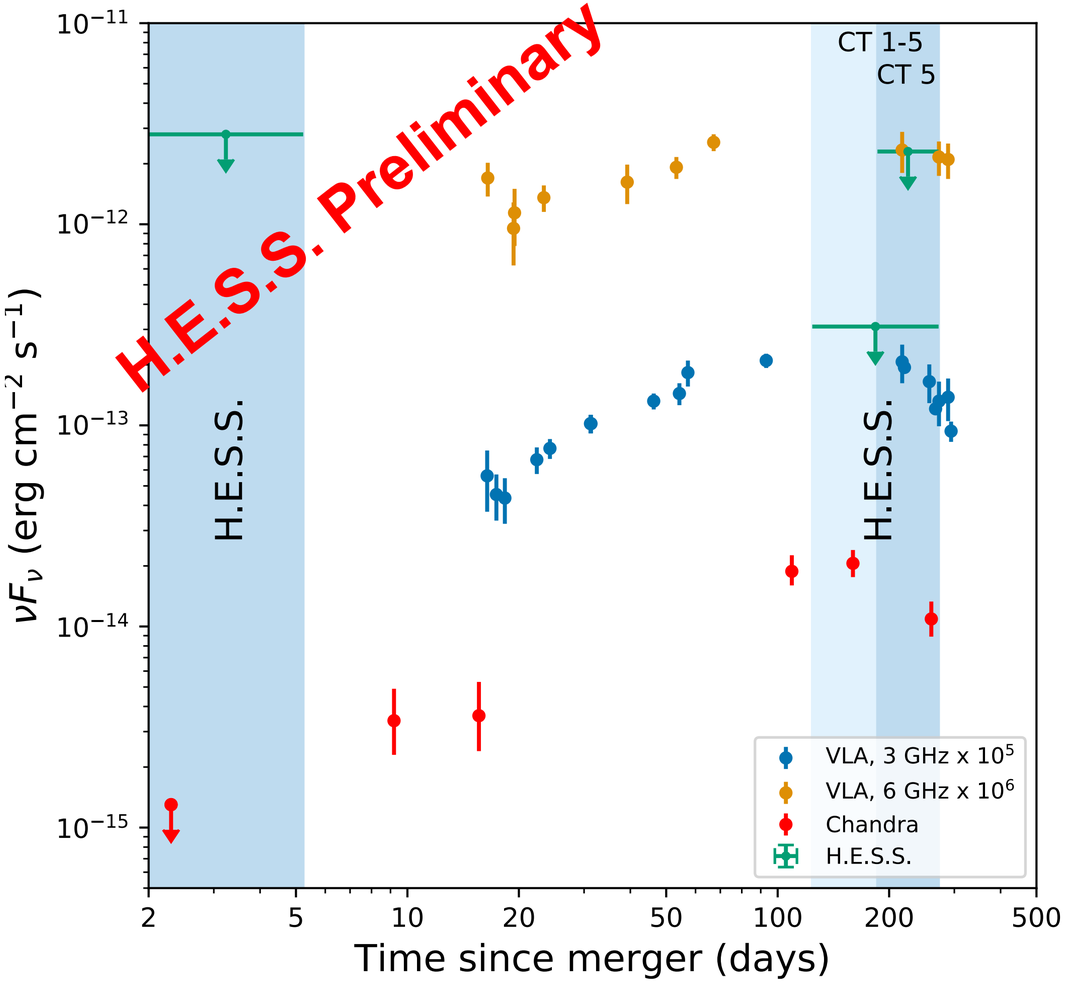
The ‘late-time’ follow-up of GW/GRB 170817

- Radio and X-rays
  - 10x flux increase in 150 days
  - Efficient electron acceleration synchrotron emission in merger remnants’ magnetic field
  - Plateauing and turnover after 160 days
  - Similar to situation in young supernova remnant
- TeV γ rays?
  - Good conditions for γ-ray production via sync. self-Compton
  - Magnetic field can be estimated based on dynamical / cooling considerations + radio/X-ray
- Instruments like H.E.S.S. can constrain B-field



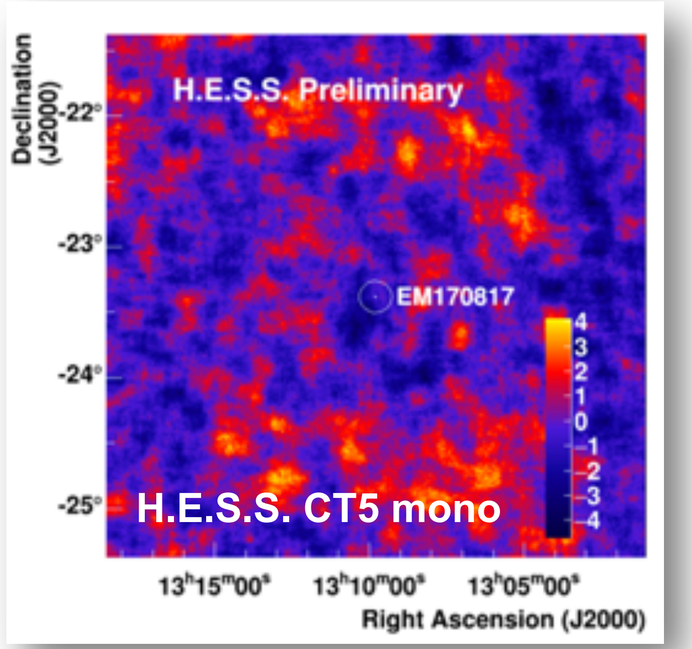
H.E.S.S. telescopes and GW / GRB 170817 observations - The ‘late-time’ follow up

- H.E.S.S.
  - operates in 30 GeV – 100 TeV energy range
  - has a field-of-view of ~10 deg^2
- Data Set
  - pointed observations covering plateau and fading of non-thermal emission (125 – 270 days after merger)
  - 32 hours exposure with CT5 mono
  - 54 hours exposure with CT1-5
- Energy threshold of 130 GeV



H.E.S.S. results on GW / GRB 170817

- H.E.S.S. results
  - No detection in any of the data sets
  - No detection on month timescales
  - Derive differential and integral upper limits of different data sets



- H.E.S.S. upper limits on the VHE γ-ray flux:

H.E.S.S. Preliminary

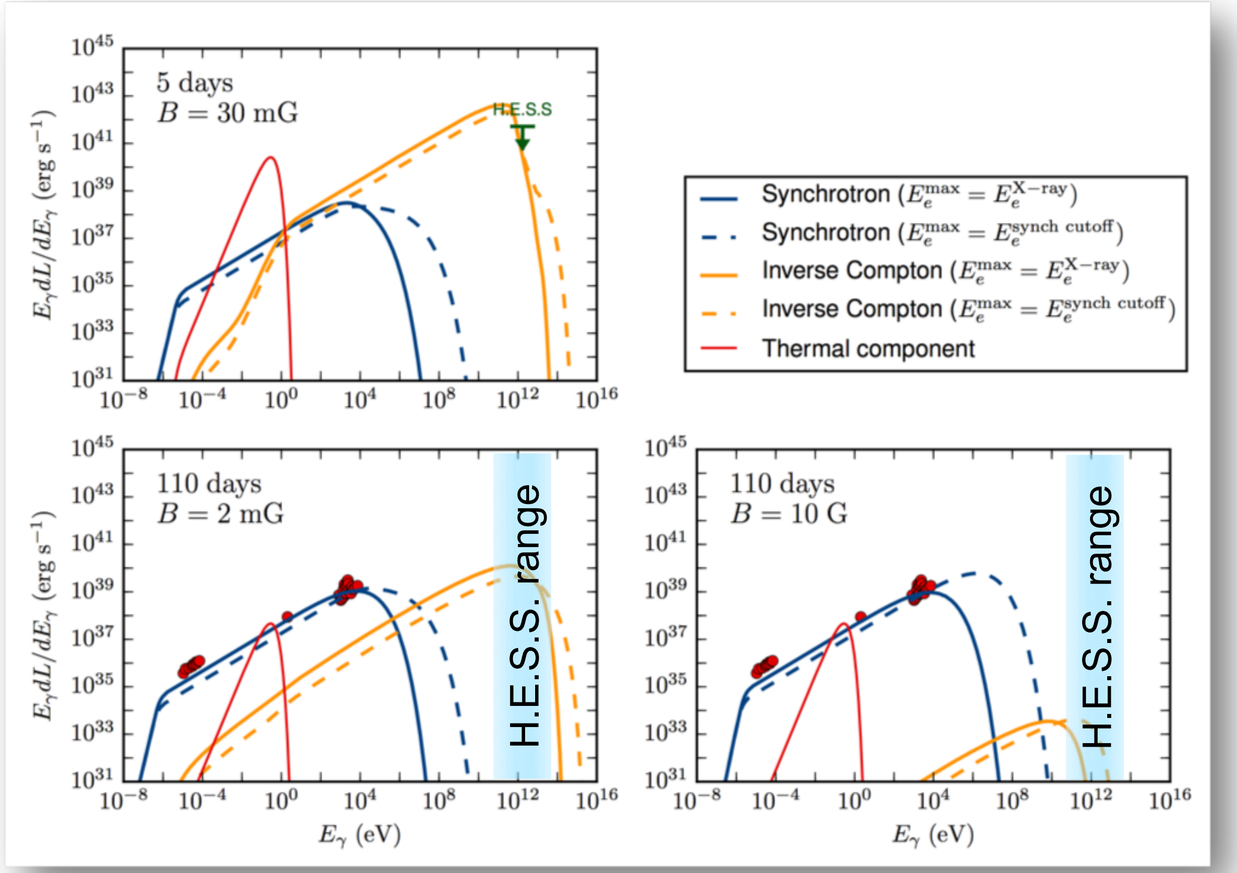
TABLE I: Properties of the H.E.S.S. data sets on GW170817 / GRB 170817A and analysis results.

Data Set	Configuration	$T - T_0$ (days)	Exposure (hours)	$E_{\rm th}$ GeV	$F(> E_{\rm th})$ erg cm^{-2} s^{-1}	$F(1 - 10\,{\rm TeV})$ erg cm^{-2} s^{-1}	Zenith angle °	Reference
I	CT 5	$0.22 - 5.23$	3.2	270	$< 1.5 \times 10^{-12}$		58	Abdalla et al. [4]
II	CT 1–5	$0.22 - 5.23$	3.2	560	$< 4.7 \times 10^{-12}$	$< 2.8 \times 10^{-12}$	58	this work
III	CT 5	$186 - 272$	32.2	130	$< 4.1 \times 10^{-12}$	$< 1.4 \times 10^{-12}$	20	this work
IV	CT 1–5	$124 - 272$	53.9	130	$< 6.2 \times 10^{-13}$	$< 4.1 \times 10^{-13}$	24	this work

The H.E.S.S. results in the multiwavelength context

- SED contains information on
  - Energy in non-thermal electrons
  - Magnetic field (evolution) in the ejecta
  - Dynamics of the ejecta
- Radio & X-rays probe synchrotron emission
  - provides $N_e * U_B$
  - provide lower limit on $E_{max,e}$
  - alone cannot disentangle the two components
- γ-rays probe inverse Compton emission
  - provides $N_e * U_{rad}$ (U_{rad} ~fixed via sync self-Compton)

→ Radio, X-ray + γ-ray can break ambiguity



Rodrigues et al., 2018

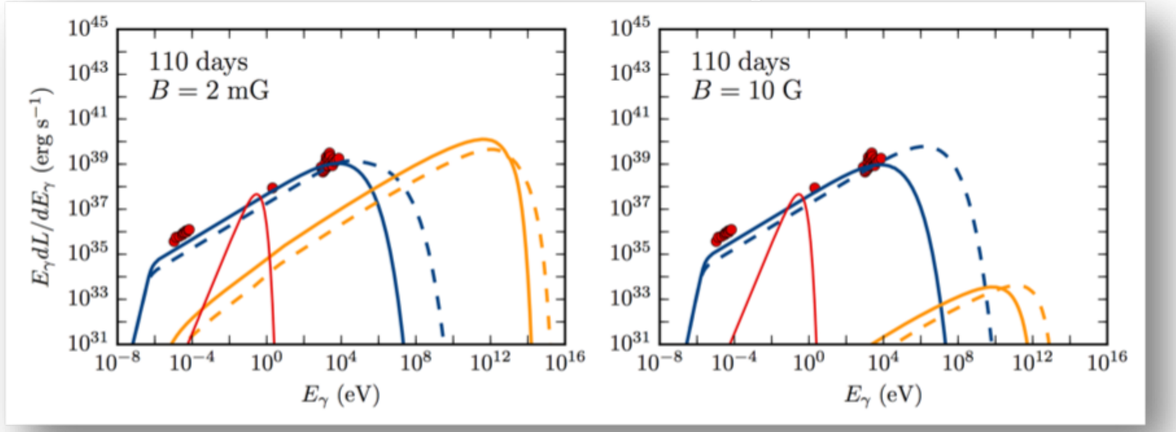
Implications for the ejecta in EM170817

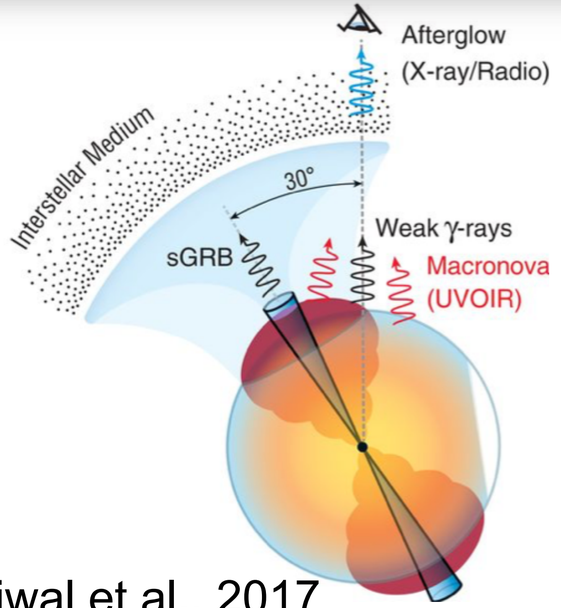
- Radio and X-rays alone imply
  - Lower limit on B from X-ray energies reached
  - Upper limit on B from absence of break in X-rays

$$0.02\,\mathrm{mG} < B < 2\,\mathrm{mG}$$

- Explore two particle-acceleration scenarios
  1. Gamma-ray production in isotropically expanding, non-relativistic outflow (β=0.2)
  2. Relativistic jet, seen off-axis (β=0.94, Γ=3)
- Calculate expected gamma-ray emission and derive magnetic-field limits

Rodrigues et al., 2018



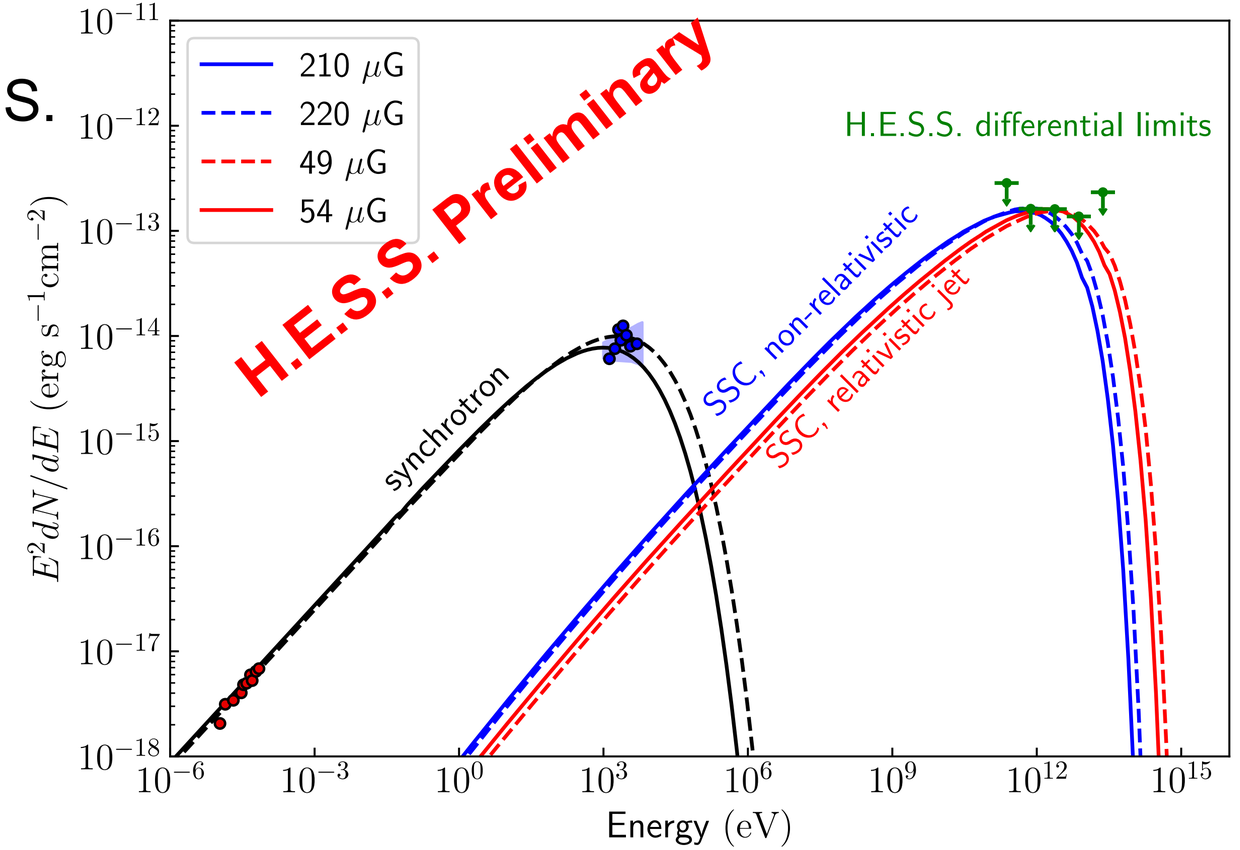


Kasliwal et al., 2017

Implications for the ejecta in EM170817

- Model SSC emission in the two scenarios at 110 days after the merger
- Peak of IC component expected in core H.E.S.S. energy range

1. Isotropic, non-relativistic outflow
   - Assuming a filling factor of 1
   - **Constrains B-field to ≳200 μG**
2. Relativistic jet
   - Assume filling factor according to implied jet characteristics from radio data → f = 2.5e-3
   - **Constrains B-field to ≳50 μG**



Summary

- γ-ray measurements of prompt and late-time BNS merger remnants provide important insight into physical conditions in outflows/jets
- H.E.S.S. observed GW/GRB 170817 shortly after BNS trigger and during peak and fading of the non-thermal X-ray and radio emission
- H.E.S.S. doesn't detect inverse Compton component of the SSC emission in deep observations
- Non-detection used to constrain magnetic field in the ejecta in two scenarios
  1. **Spherical, isotropic outflow: ≳200 μG**
  2. **Off-axis jet: ≳50 μG**
- Future prospects
  - Eagerly awaiting new bright BNS merger triggers by LIGO/Virgo
  - Non-thermal light-curve will depend on geometry and orientation of jet → need to adjust follow-up strategy
- **Paper in preparation**