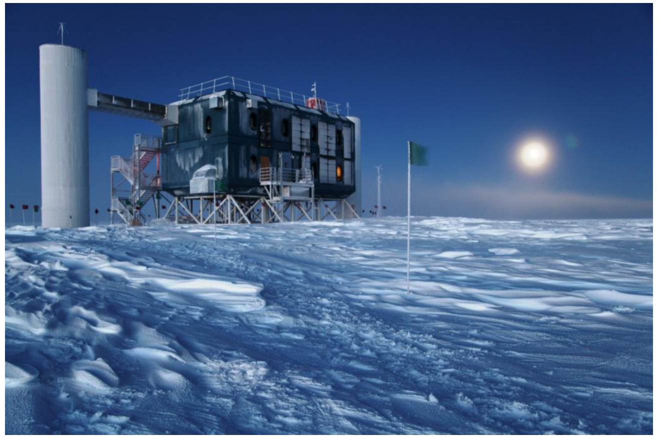
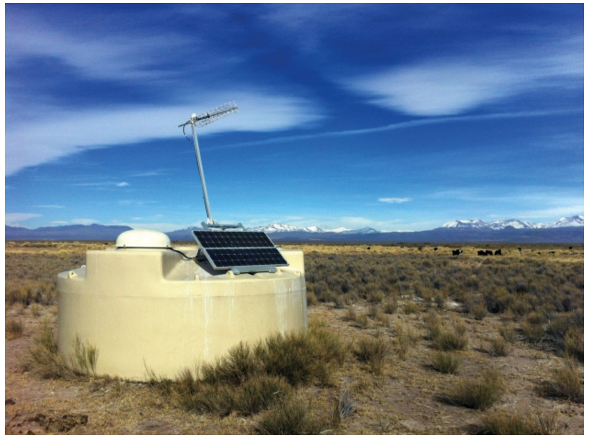
Multimessenger astrophysics

Studying the extreme Universe – recent trends and latest results

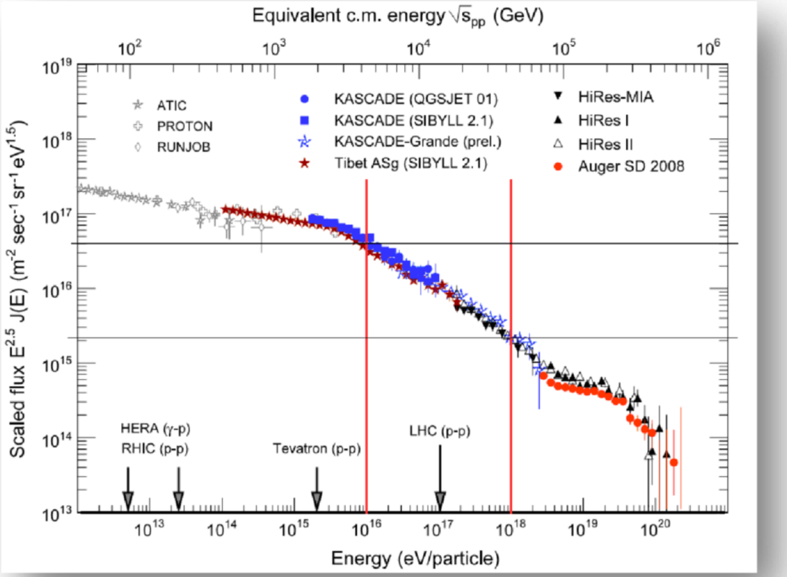


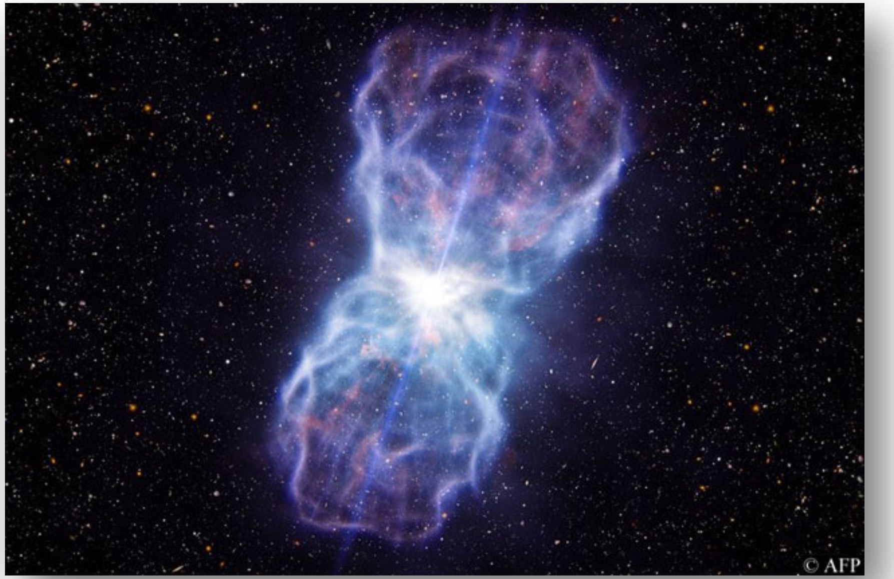

Stefan Ohm (DESY, Zeuthen)

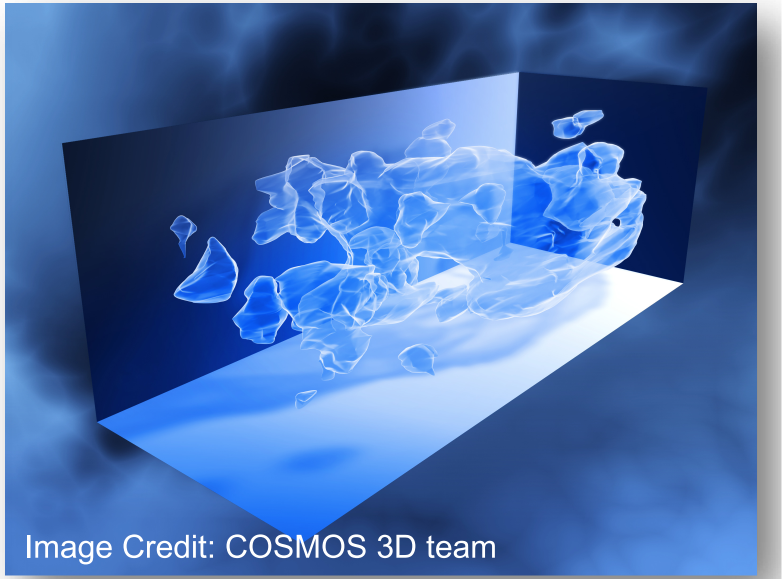
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Astroparticle physics and the non-thermal Universe







Origin of cosmic rays?

Particle acceleration to 10^{20} eV?

Impact of relativistic particles on evolution of the Universe?

Origin of astrophysical neutrinos?

Origin of dark matter?

The Messengers

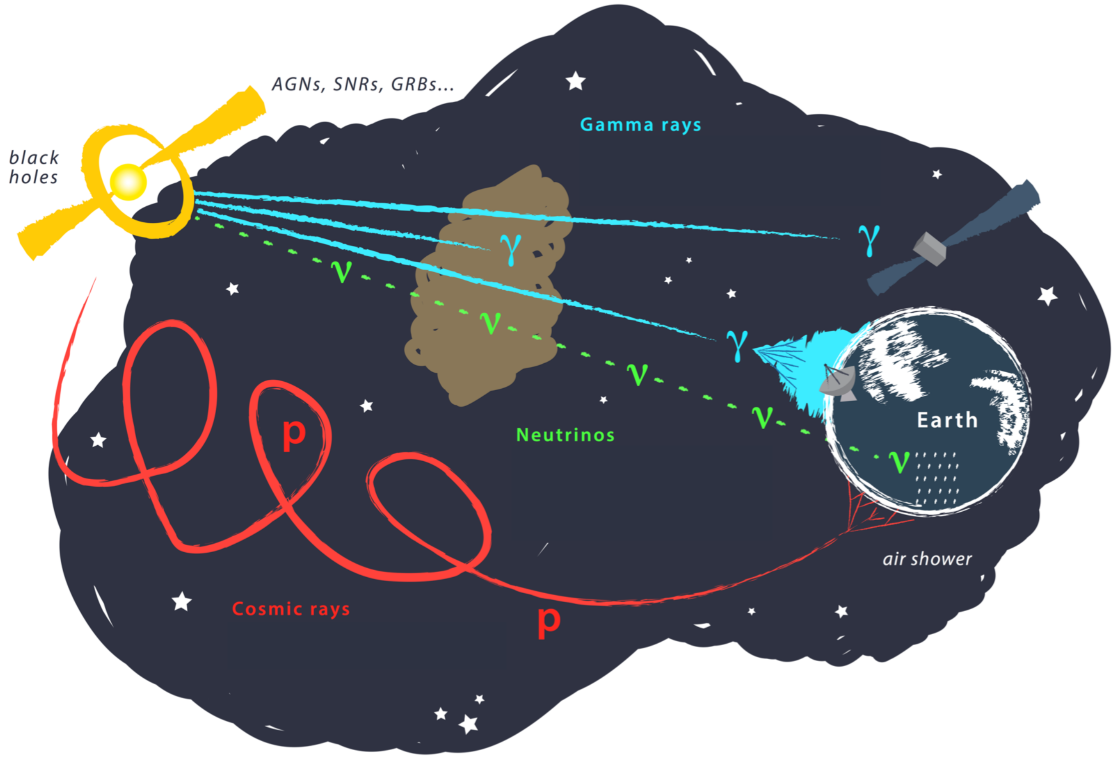
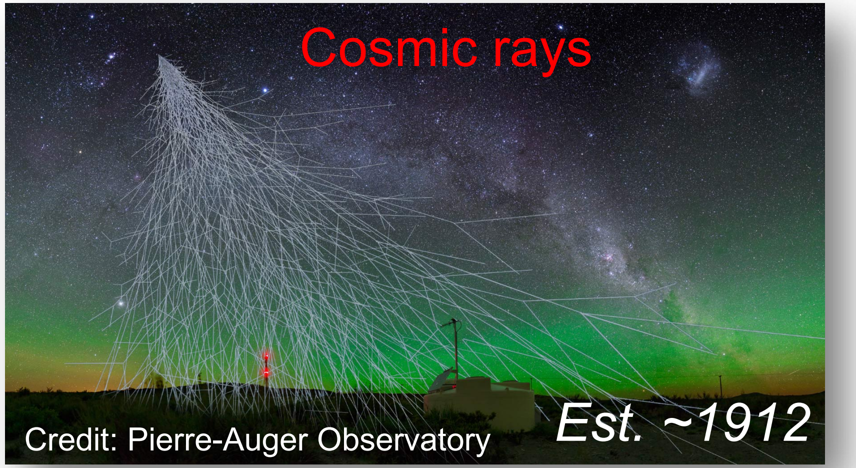


Image Credit: NASA/ESA, STScI



Credit: Pierre-Auger Observatory

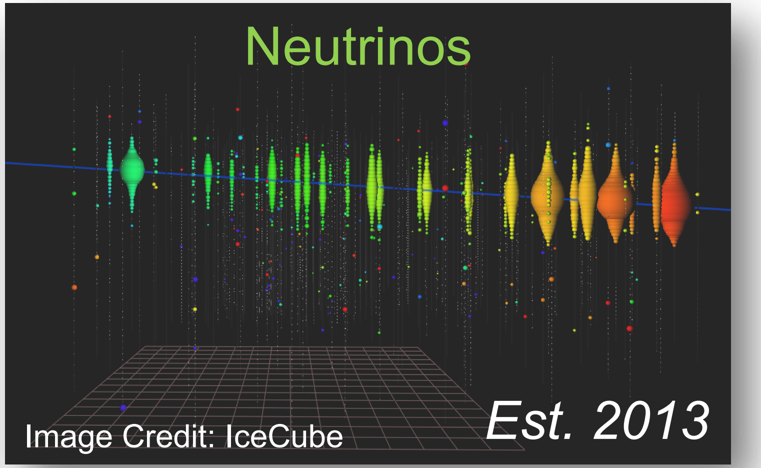
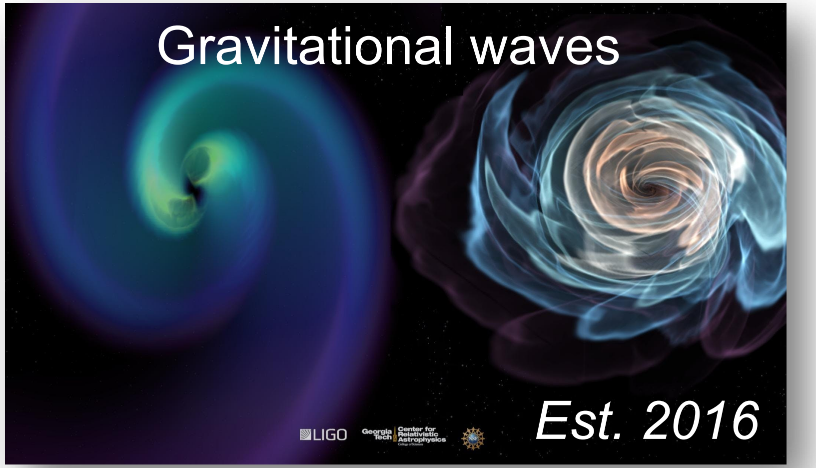
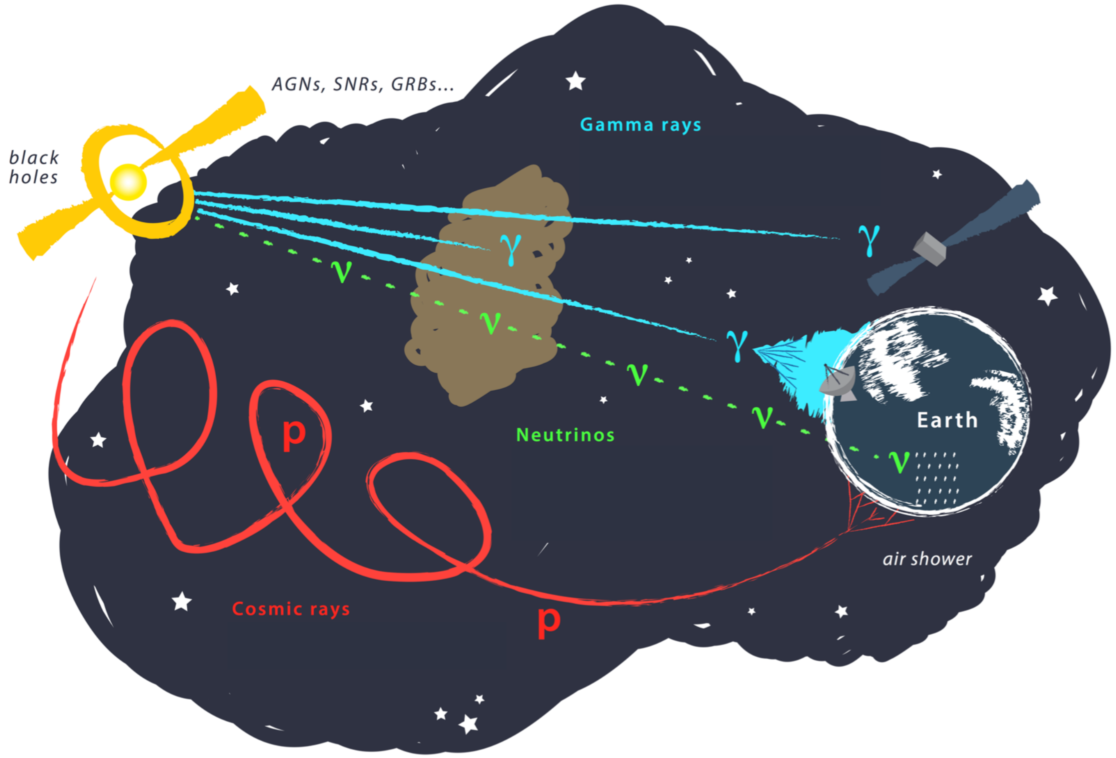


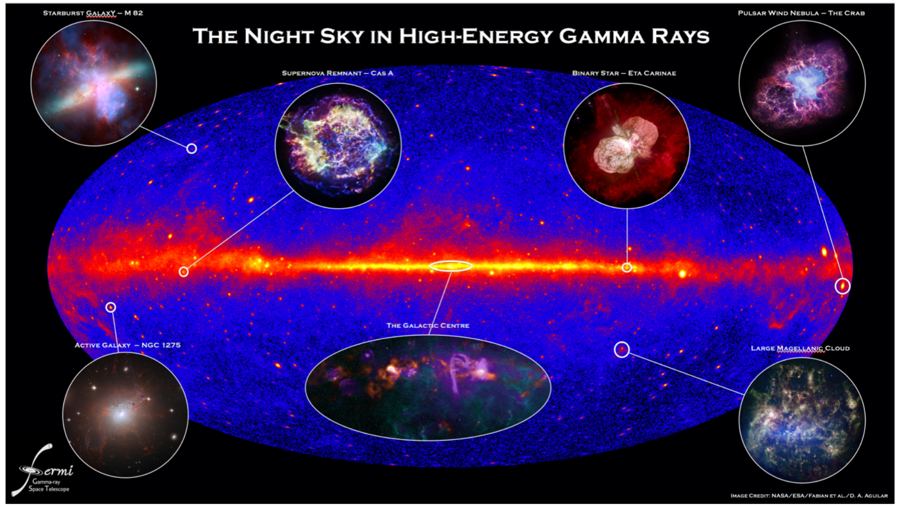
Image Credit: IceCube



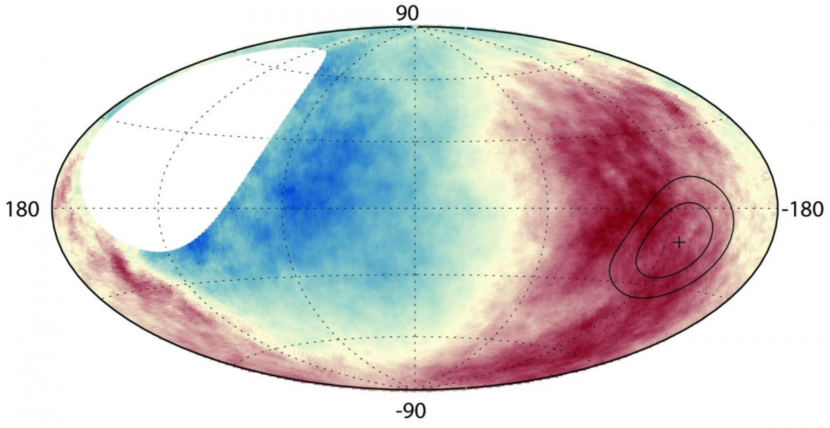
The Multimessenger sky



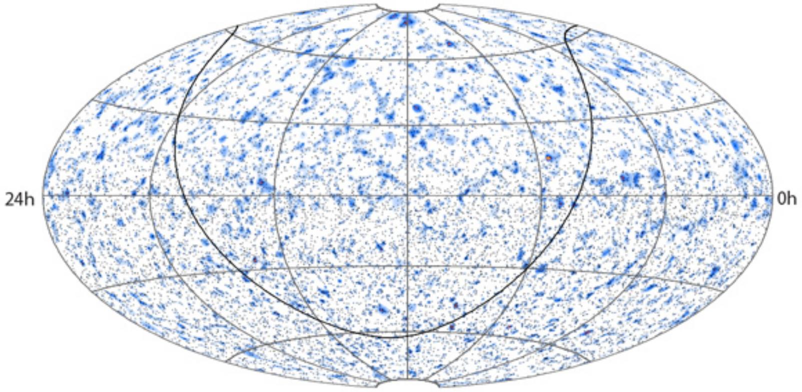
Gamma rays

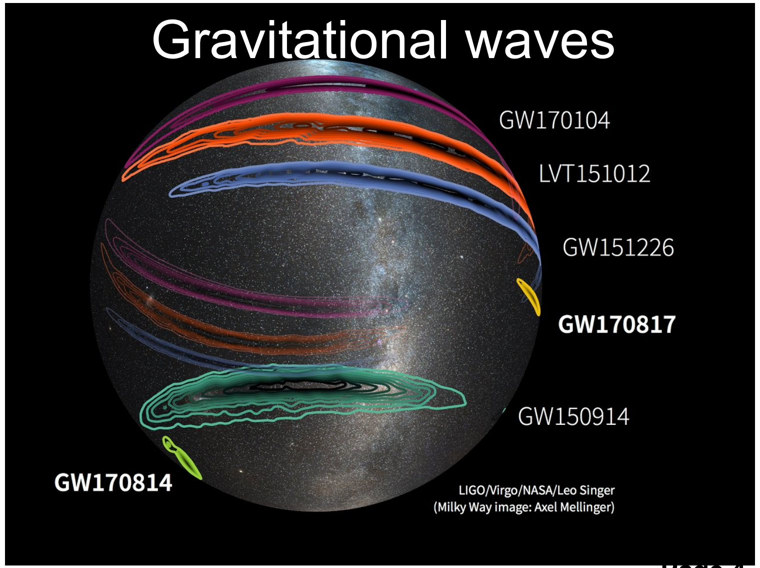


Cosmic rays



Neutrinos





2017 / 2018

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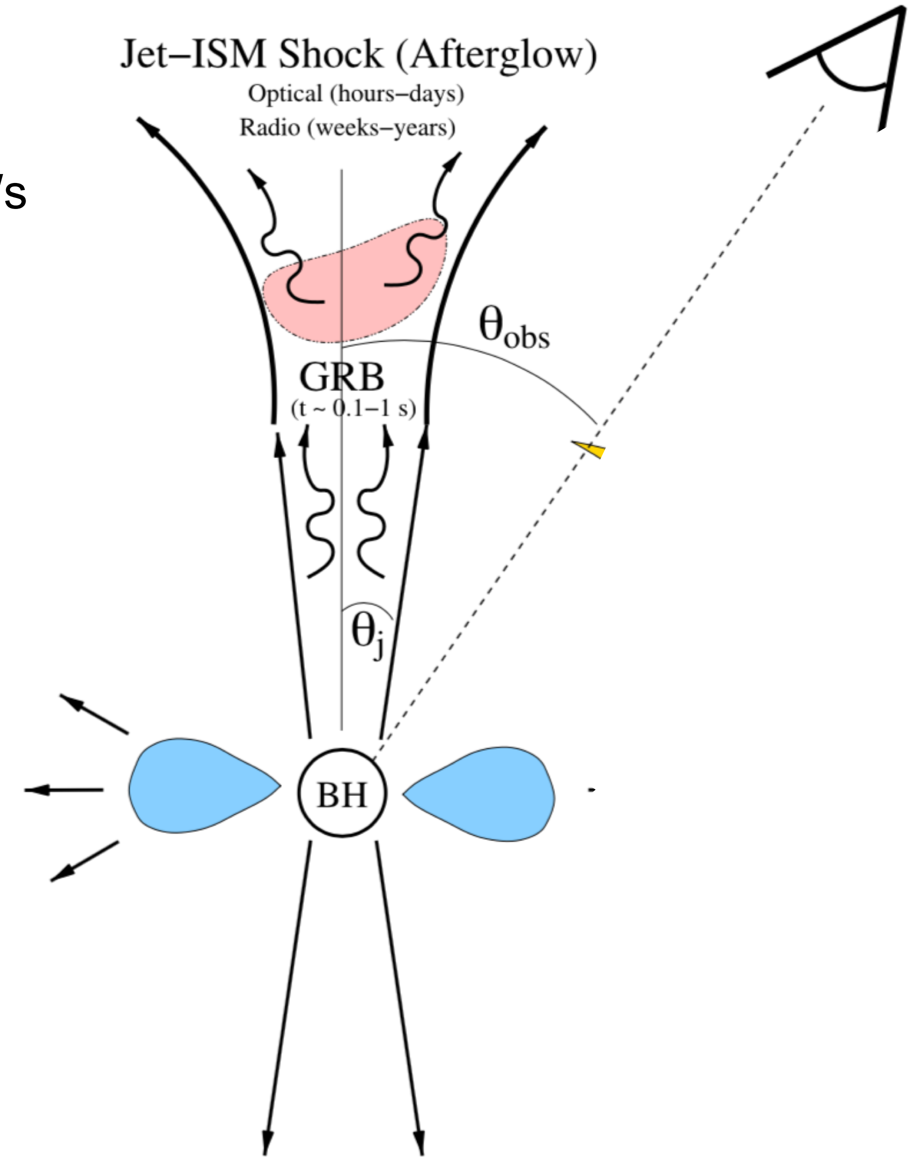
The multimessenger era starts

Binary neutron-star mergers

Expected electromagnetic emission

- Binary NS mergers believed to be sources of GWs & progenitors of short GRBs
- Prompt phase (0.1 – 2 seconds)
  - Internal shocks in jet → particle acceleration
  - Hard X-ray and soft gamma-ray production
- Delayed phase (hours to days to years)
  - Optical and radio emission from jet-ISM interaction



Baiotti & Rezzolla (2017, pre-GW170817)

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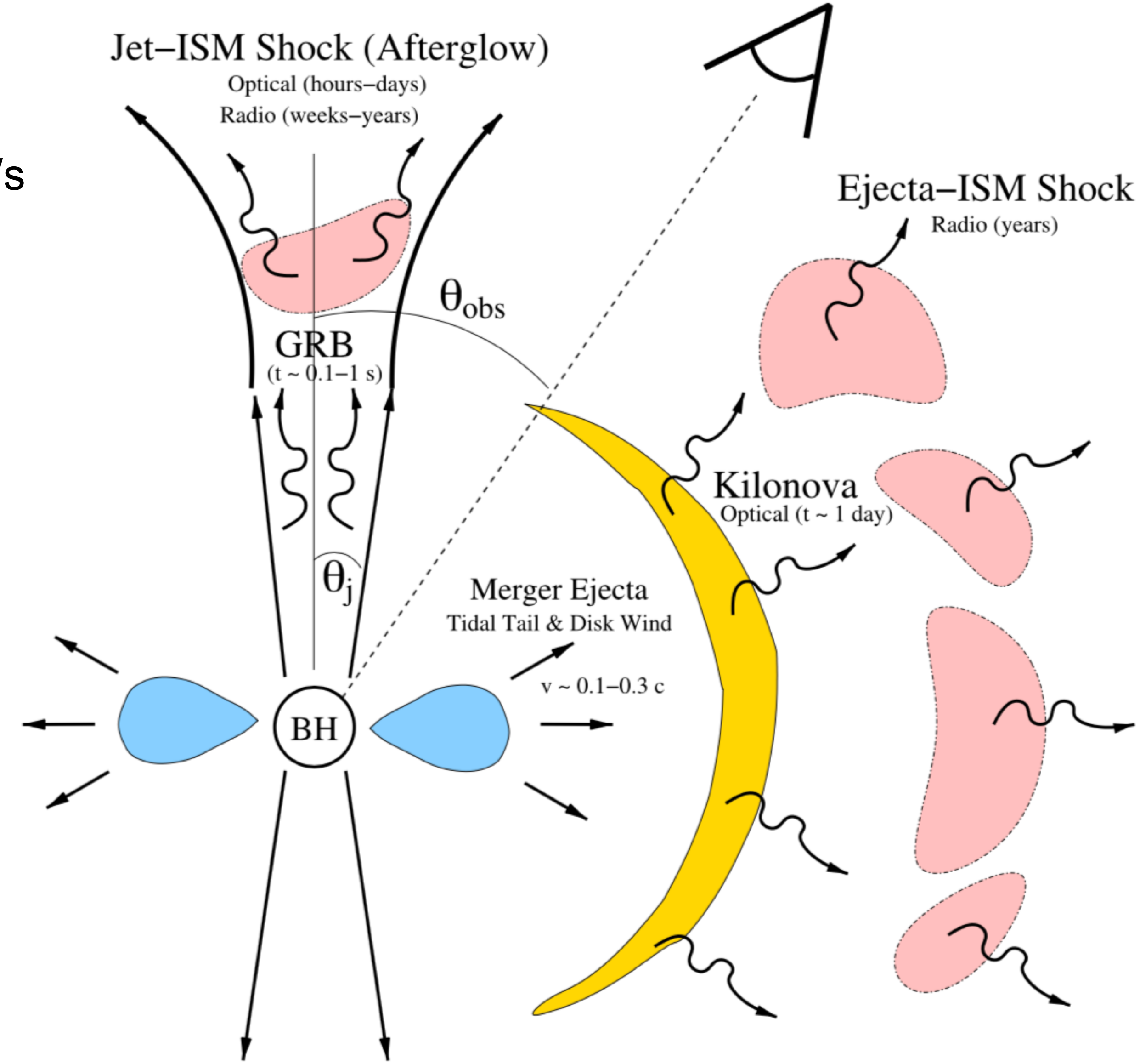
- Delayed phase (hours to days to years)
  - Optical and radio emission from jet-ISM interaction
  - Optical emission from Kilonova
  - Sub or trans-relativistic speeds of ejecta
  - Ejected energy of 10^{48} – 10^{50} erg

→ Optical, IR and UV emission from Kilonova

→ Good conditions for particle acceleration

→ Predicted radio and X-ray emitters

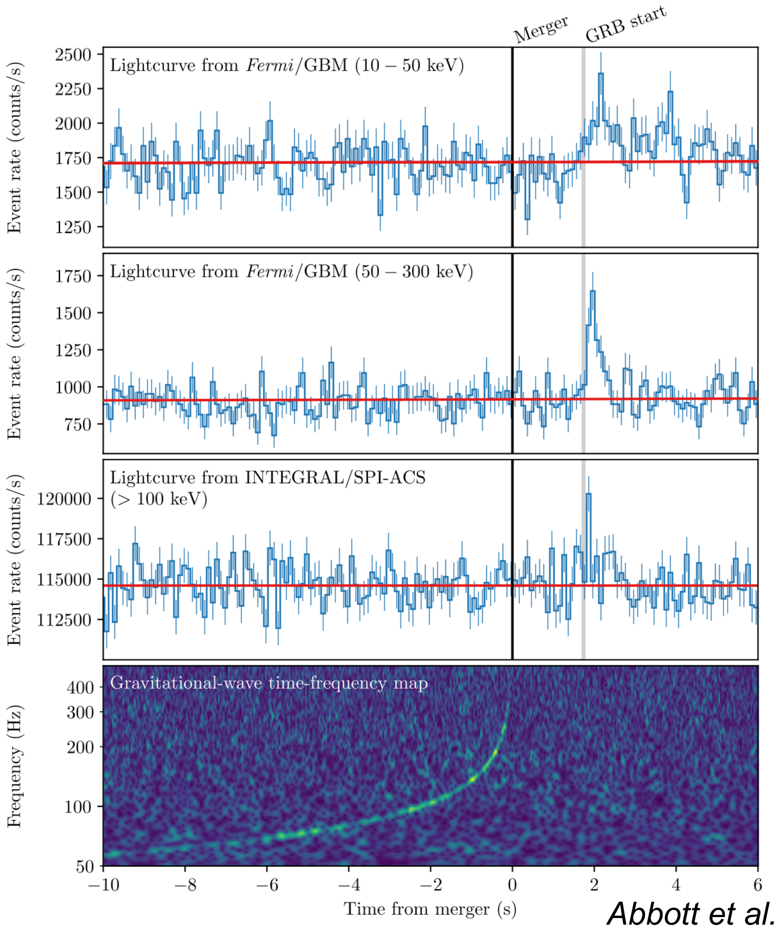


Baiotti & Rezzolla (2017, pre-GW170817)

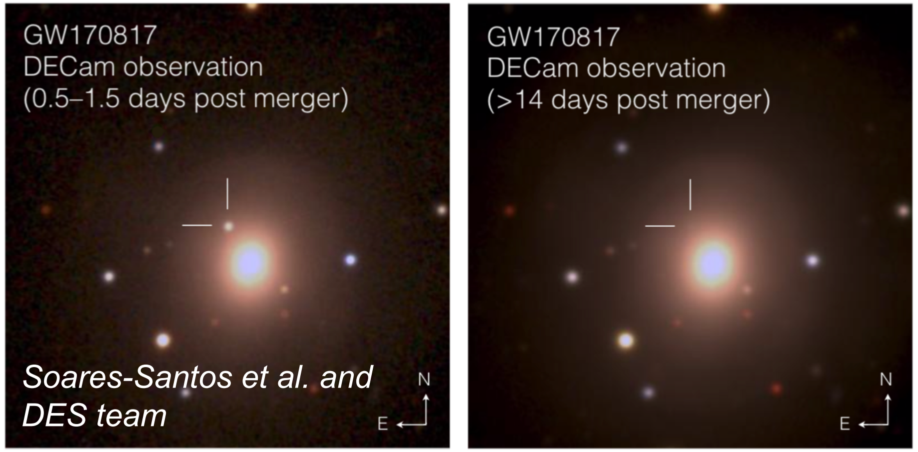
GW/EM170817

- Gravitational Wave detection
  - August 17th 2017: GW detected in both LIGO detectors
  - Automatic classification algorithms suggest NS-NS merger
  - Alert distributed to partners ~5 hours after inital detection

- Multiwavelength / Multimessenger follow-up
  - GRB signal detected in Fermi-GBM and INTEGRAL 2s after
  - Largest astronomical follow-up campaign of all times (⅓ of worldwide community)
  - Counterpart detected in optical, UV, infrared
  - Gamma rays produced in shock-breakout in this scenario
  - r-process elements forged in ejected material hours after merger



Abbott et al. (2017)



Soares-Santos et al. and DES team

The ‘late-time’ follow-up of EM170817

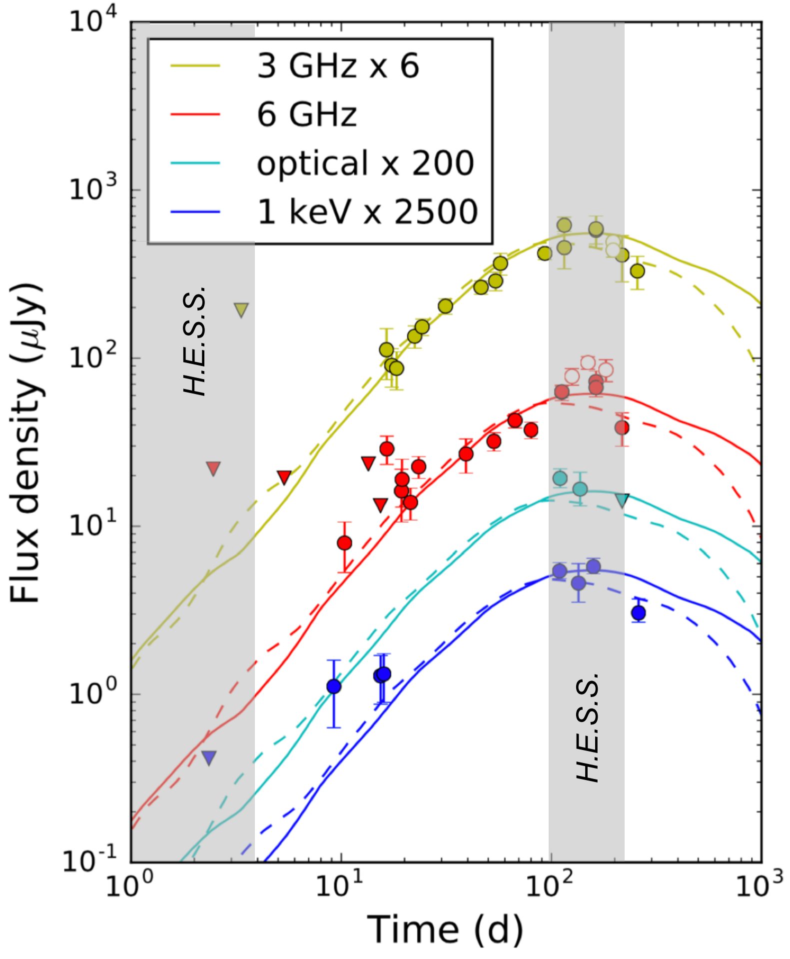
What can we learn from MWL measurements

Radio and X-rays

- 10x flux increase over 150 days
- Turnover after 220 – 260 days
- Electrons are accelerated efficiently
- Acceleration in strong shock

TeV gamma rays, neutrinos & cosmic-rays?

- Good conditions for gamma-ray and neutrino production → no signal seen (yet)
- Long-term follow-up with H.E.S.S.
- Imaging Atmospheric Cherenkov Telescopes can constrain B-field in ejecta

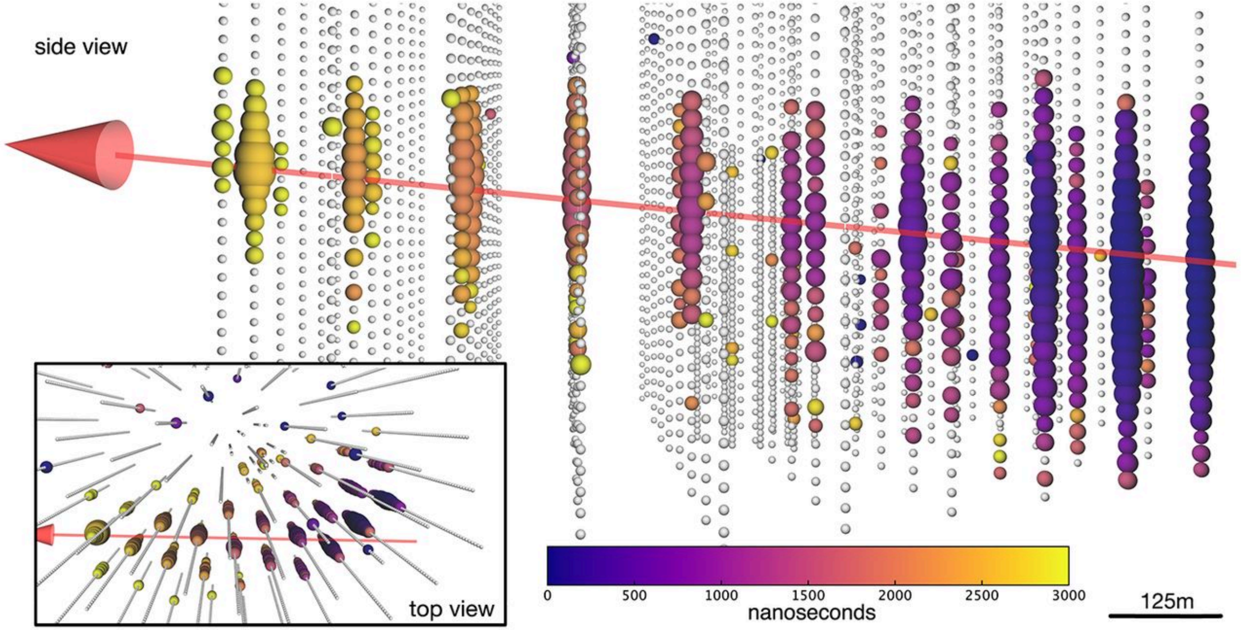


Alexander et al. (2018)

IceCube-170922A

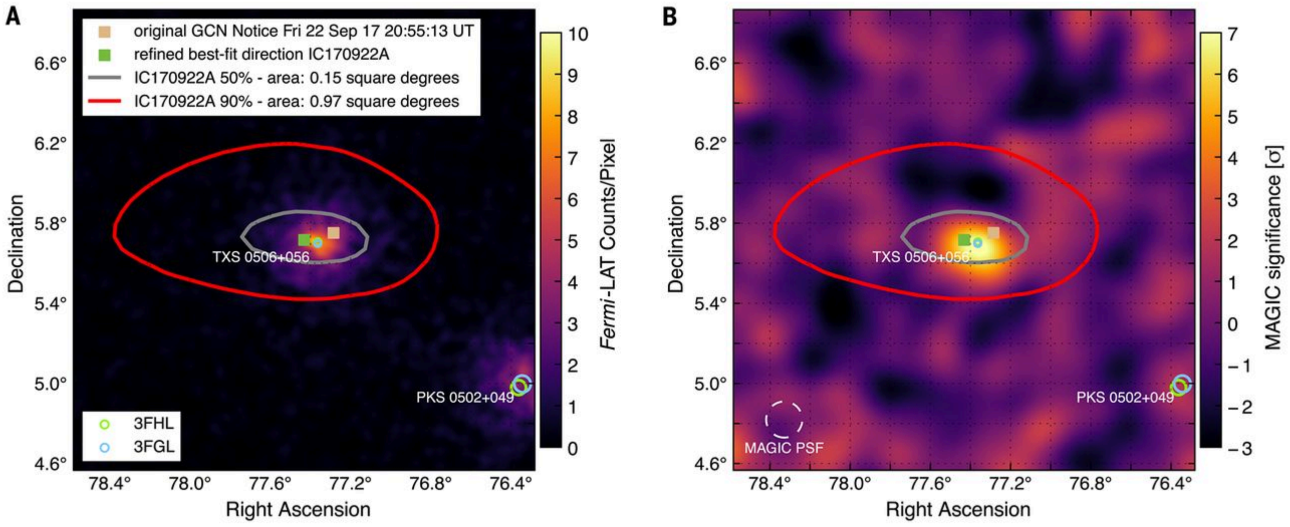
The neutrino detection and EM follow-up

- IceCube detection
  - 290 TeV neutrino detected on September 22nd 2017
  - Alert distributed to all partners within 45 s



IceCube++ (2018)

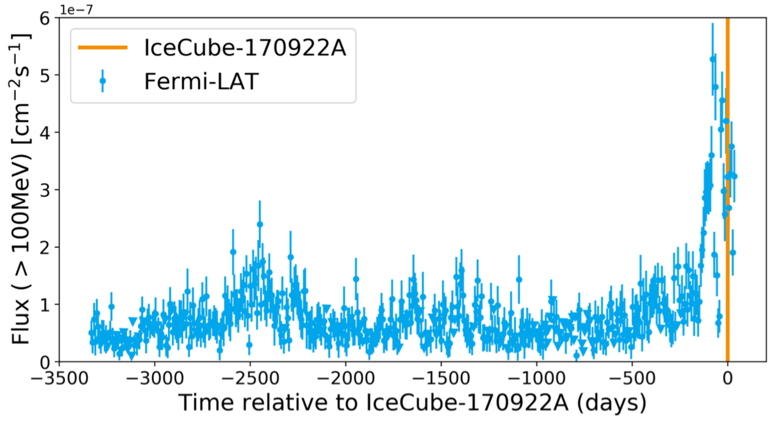
- Multiwavelength / Multimessenger follow-up
  - MWL campaign from radio to gamma-rays initiated
  - TeV observations with H.E.S.S., MAGIC & VERITAS
  - Association with GeV bright blazar TXS 0506+056 in Fermi-LAT archival data a week after
  - MAGIC detection ~1 week after neutrino alert

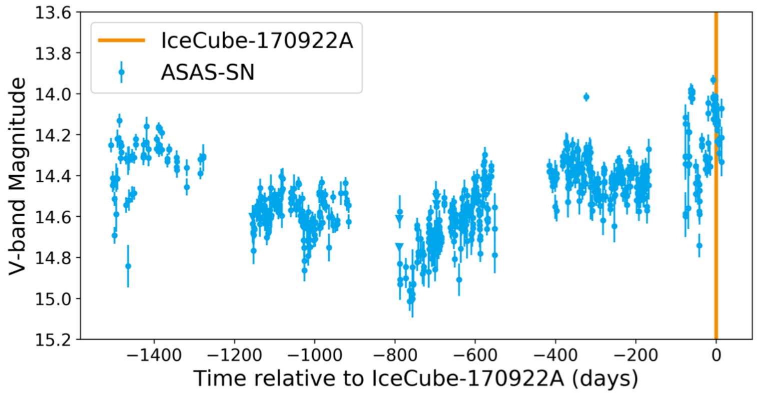


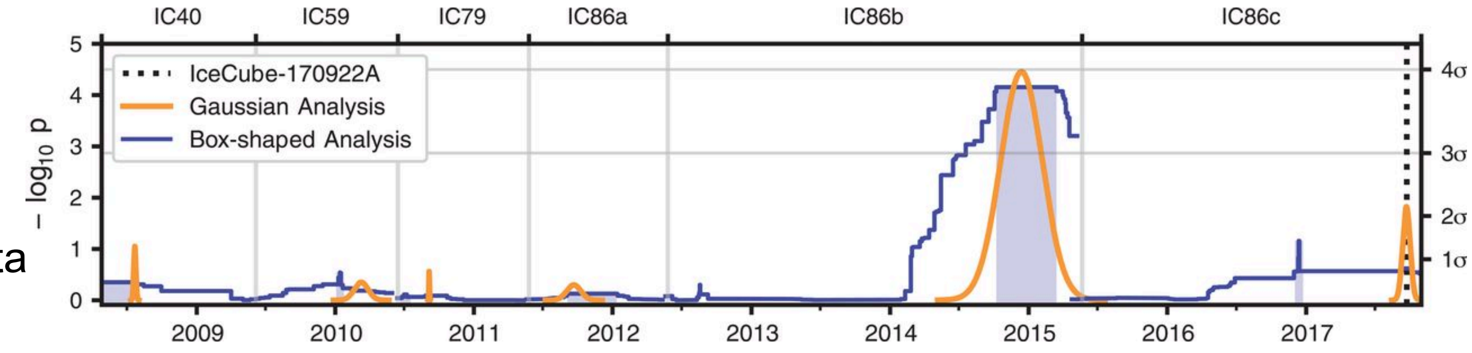
IceCube-170922A

Source properties and association

- TXS 0506+056 characteristics
  - A blazar in an elevated state in almost all wavelengths
  - One of the brightest Fermi-LAT blazars
  - In extended flaring state since ~6 months
  - Redshift of 0.33 (gamma-ray absorption >100 GeV)
- Probability for association
  - Strong indications for association between neutrino and flaring blazar at >3 sigma level
- What else
  - >3 sigma excess seen in IceCube archival data

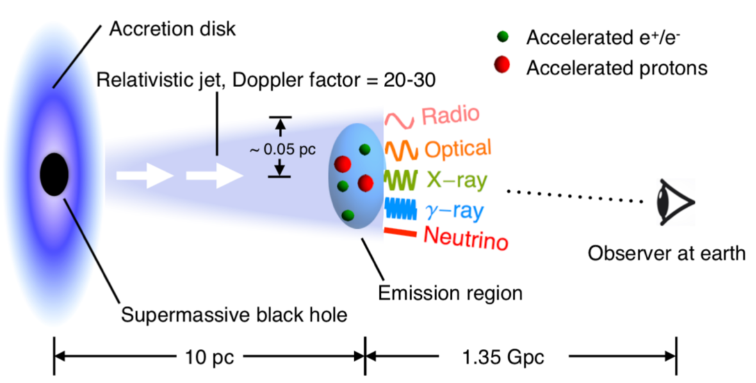






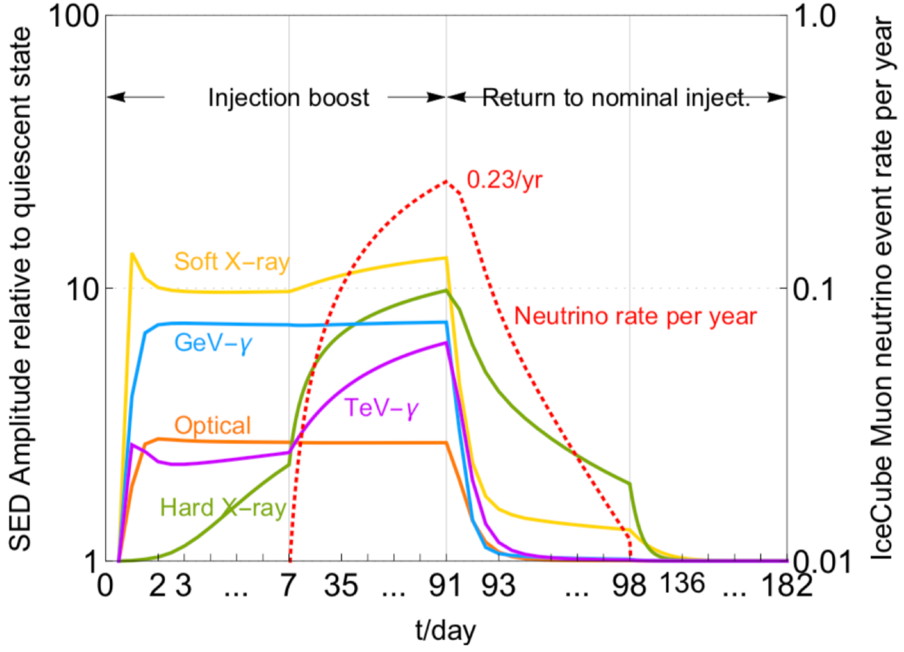
IceCube-170922A

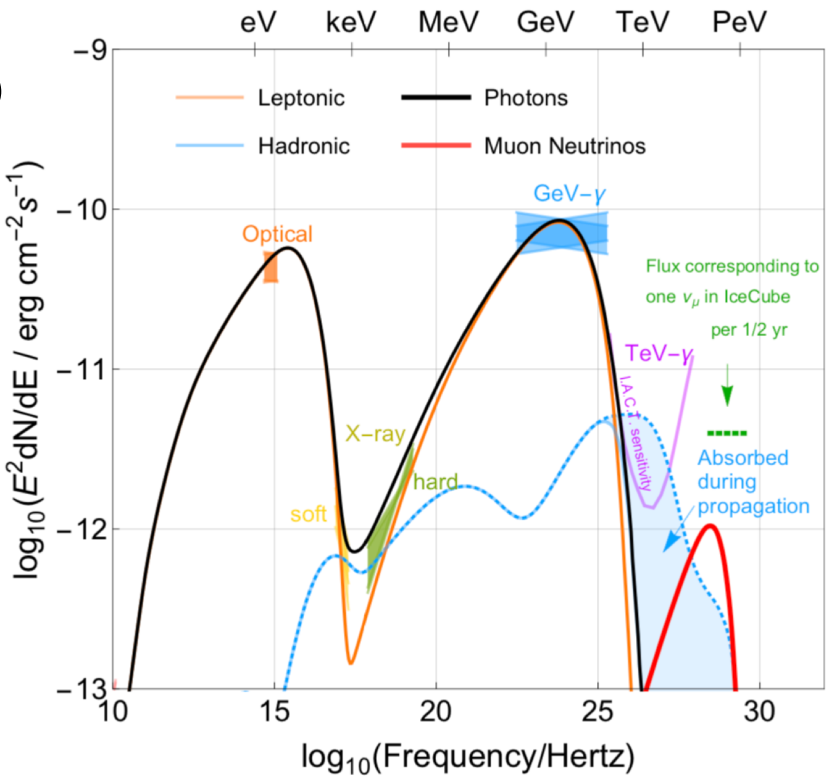
Interpretation



- Pure hadronic models don‘t work
- Hybrid models can explain EM emission and neutrino
- ~0.25 neutrinos per year predicted by model

Gao et al. (2018)





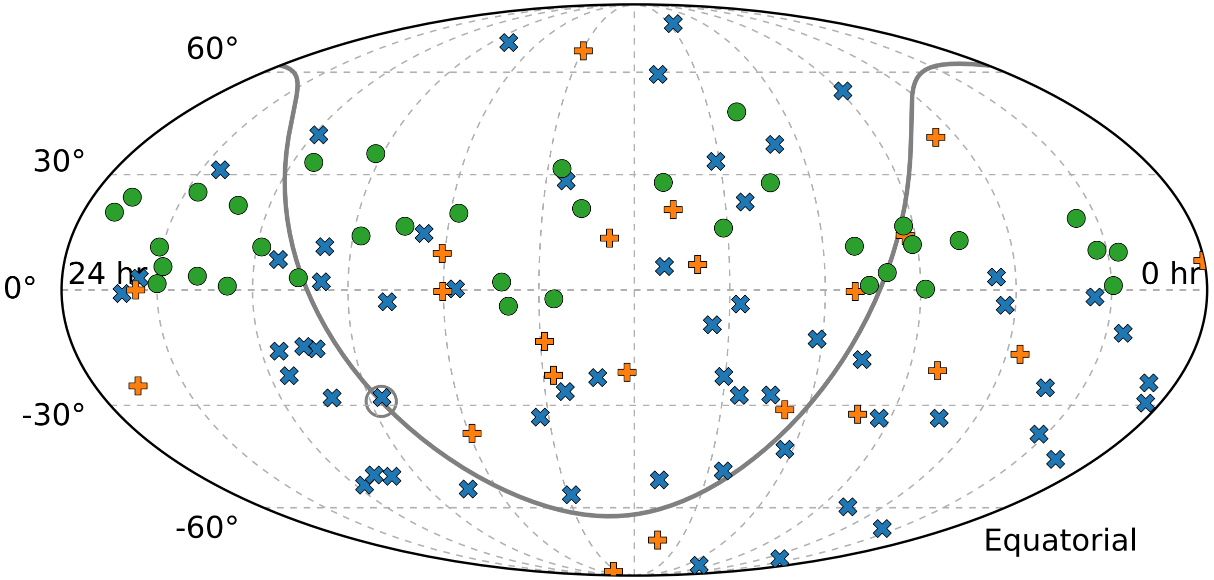
Summary and Outlook

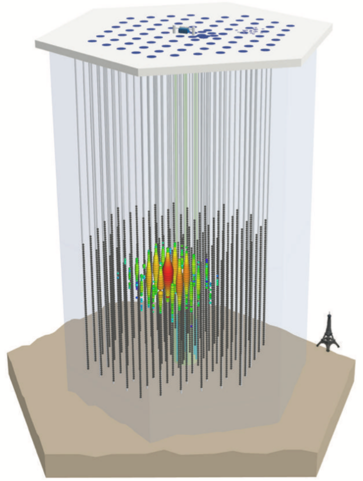
- Different messengers probe different physics on different scales
- Multimessenger astrophysics allows us to
  - Probe the most extreme phenomena in the Universe
  - Combine the pro‘s and mediate the con‘s of different messengers
- Multimessenger astrophysics and time-domain science requires different thinking
- Instruments:
  - LIGO/VIRGO will be turned on for O3 in early 2019 → boost in sensitivity and hence rate of mergers
  - IceCube working on extension of detector (IceCube-Gen2, including PINGU)
  - In gamma-rays, CTA will revolutionize our view of the TeV gamma-ray sky

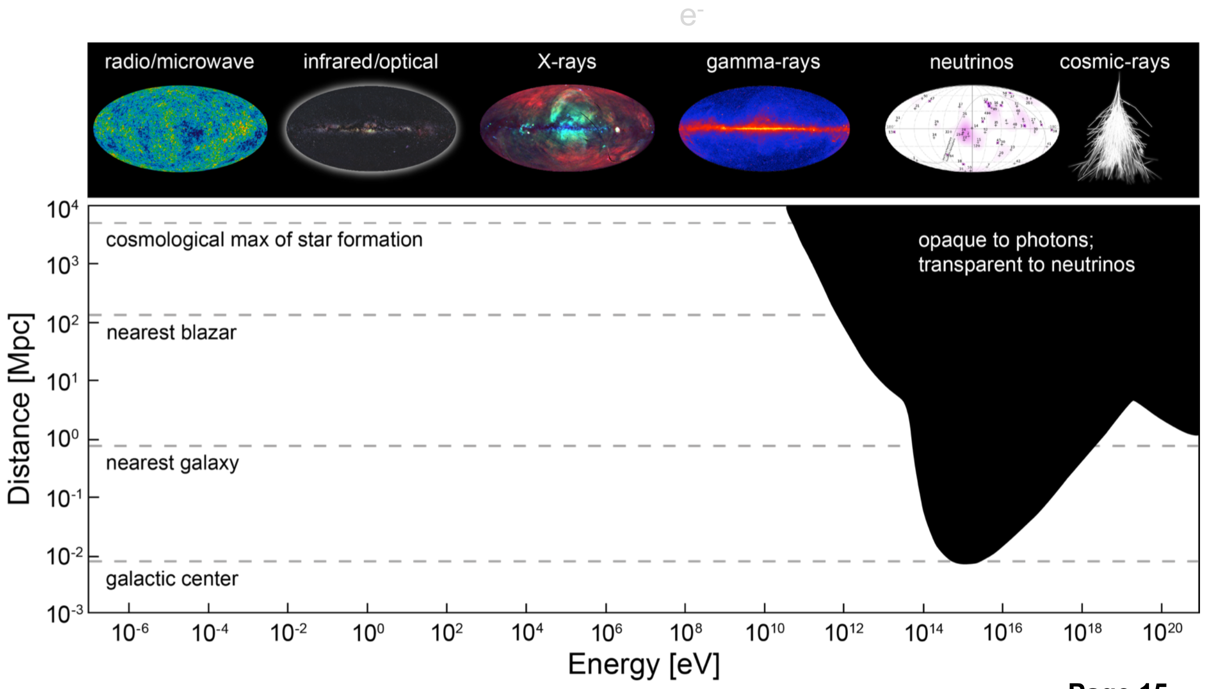
Spares

IceCube

- IceCube
  - continuous data taking since 2010
  - Gives access to astrophysical neutrinos (est. 2013)
  - most sensitive to northern-hemisphere sources
  - 10 TeV – 10 PeV energies
- Origin of astrophysical neutrinos
  - consistent with isotropy → extragalactic sources
  - limits on populations of sources
  - first hints for identified counterpart







The binary neutron-star merger GW/EM170817

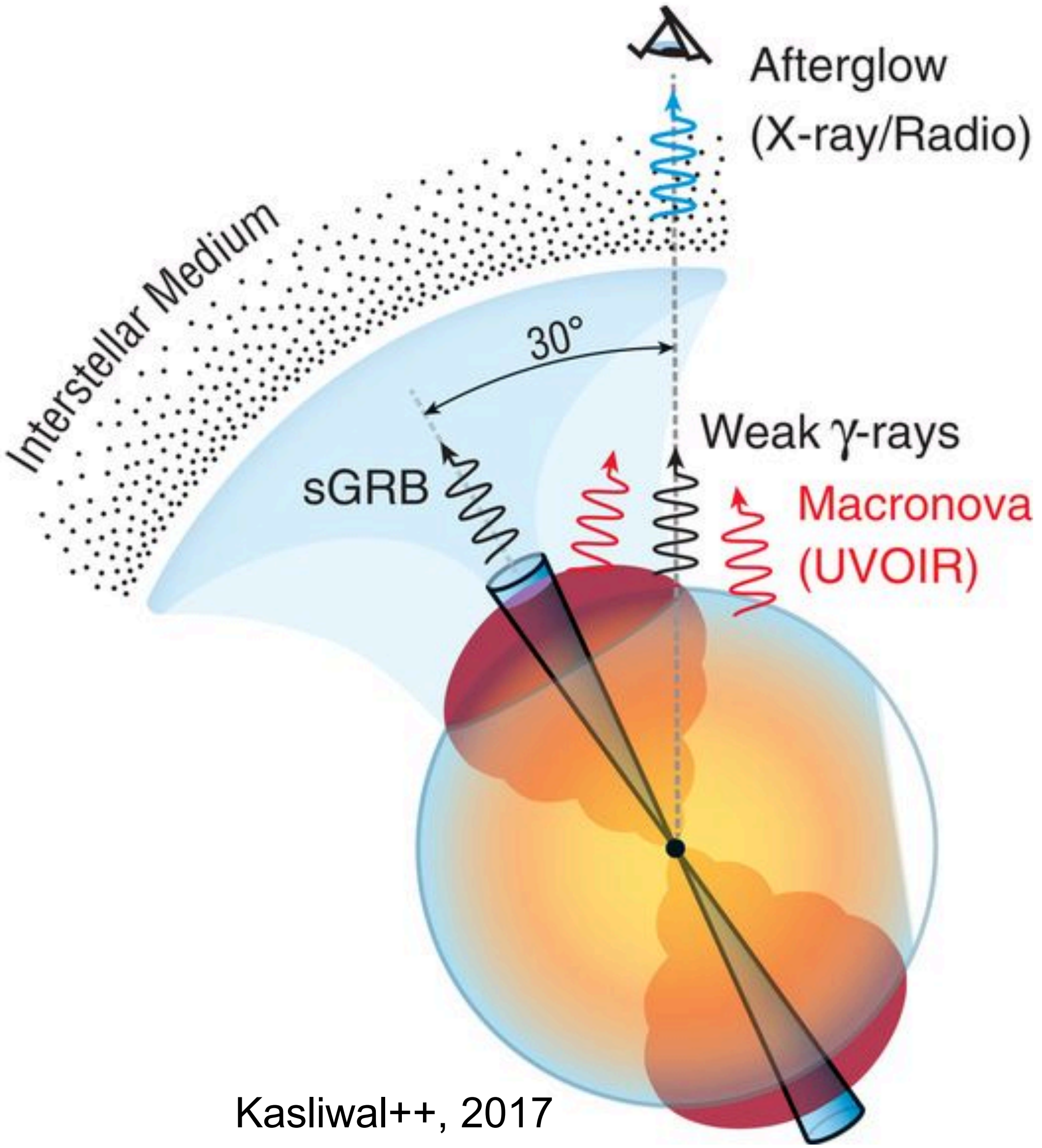
Prompt and delayed emission

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

→ Emission traced in optical and soft γ rays

- Non-thermal emission and long-term behaviour
  - speeds of 0.1 – 0.3 c → strong shocks
  - ejected mass of few 10^{-2} $M_\odot$ → baryon-rich material

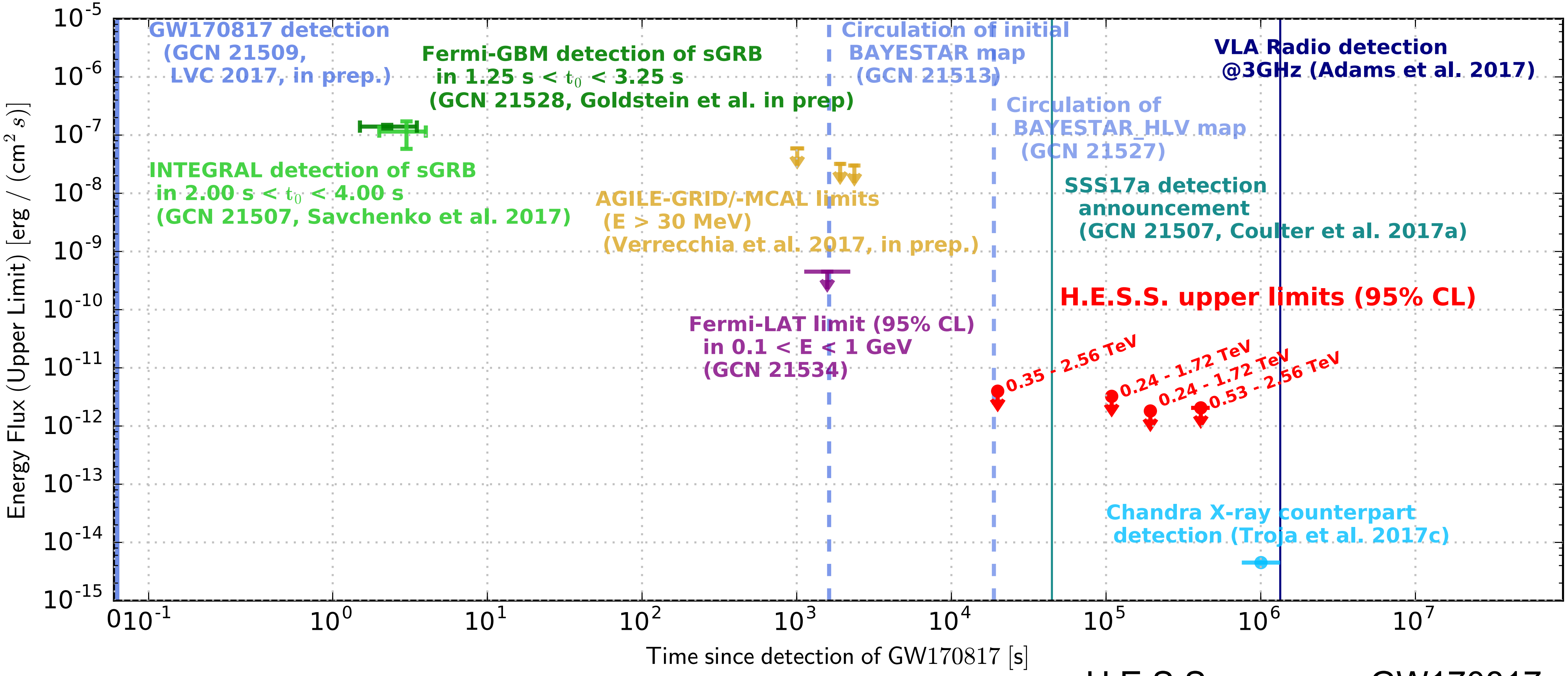
→ Good conditions for particle acceleration and γ-ray and neutrino emission



Kasliwal++, 2017

The EM follow-up of GW/EM170817

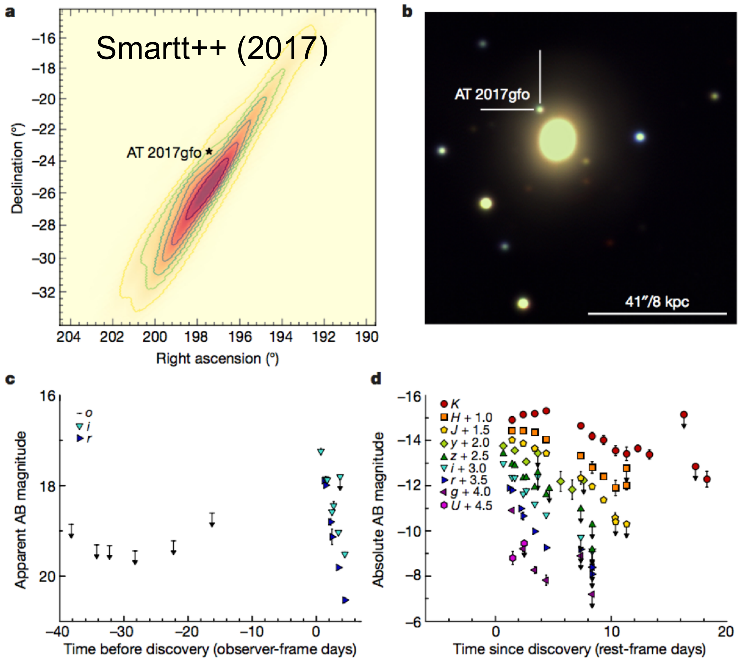
History



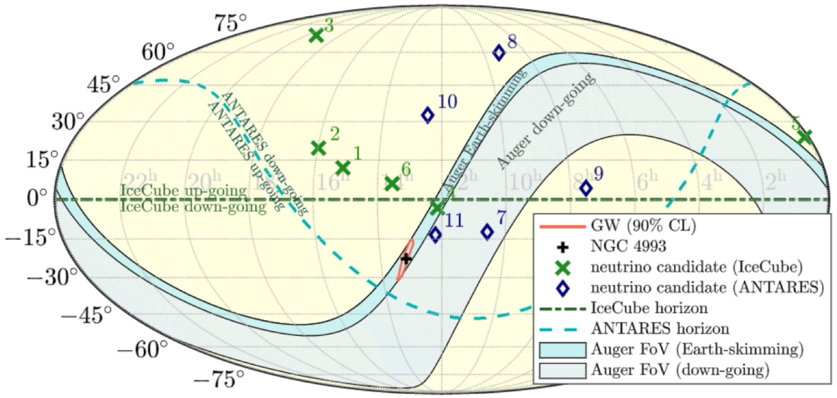
H.E.S.S. paper on GW170817

The ‘early’ follow-up of GW/EM170817

- Optical
  - ZTF was not yet online
  - MK, AF & JN involved in ePESSTO follow-up
  - Emission established to be of kilonovae origin

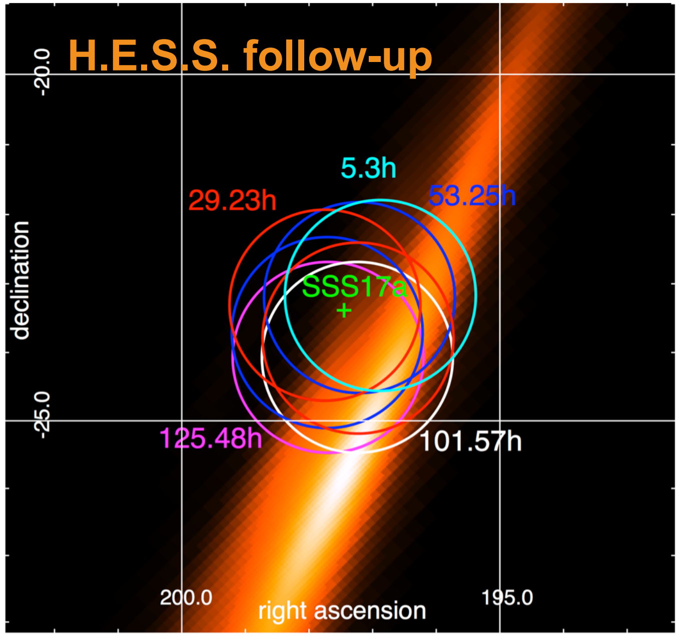


- Neutrinos + UHECRs
  - ANTARES, IceCube and Auger search did not reveal counterpart within ±500s of merger
  - Neutrino provides direction and gives insight into source environment



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. paper on GW170817

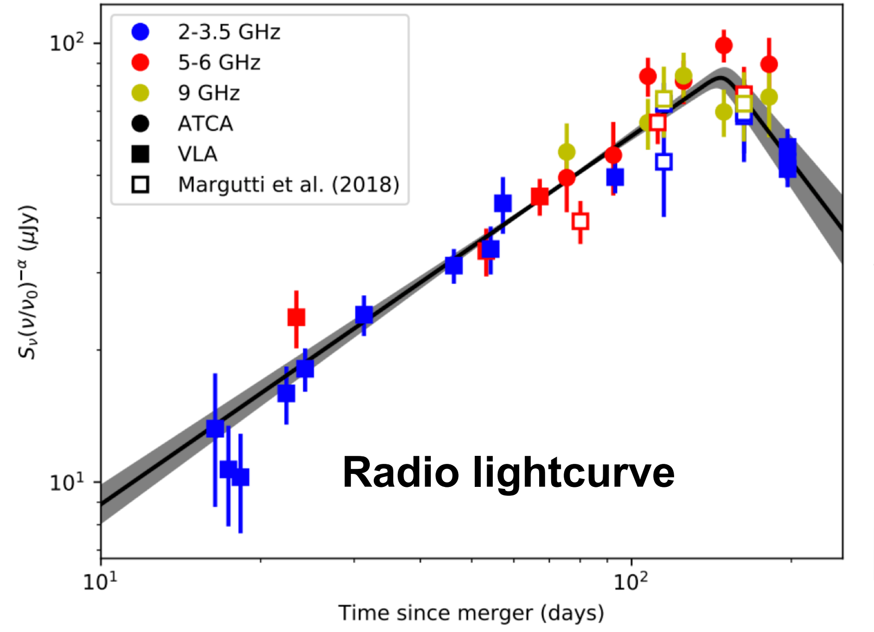
The ‘late-time’ follow-up of GW/EM170817

What can we learn from MWL measurements

- Radio and X-rays
  - spectral index of non-thermal electrons consistent with Γ_e ~ -2.0

  → acceleration in strong shock
  - steady increase in flux from 10 – 150 days after merger
  - peak in radio at 150 ± 2 days
  - indications for turnover in X-rays as well
- Possible Interpretation
  - ejecta decelerating ~now

- GeV γ-rays
  - no detection of emission after original discovery of prompt GRB emission



- VHE γ-ray
  - Expected peak in γ-ray SED between 100 – 500 GeV
  - Sensitivity of H.E.S.S.: ~2 * 10^{-13} erg cm^{-2} s^{-1}
  - Data currently being taken and/or under calibration and analysis