Search for very-high energy gamma-ray counterparts of gravitational waves with HAWC

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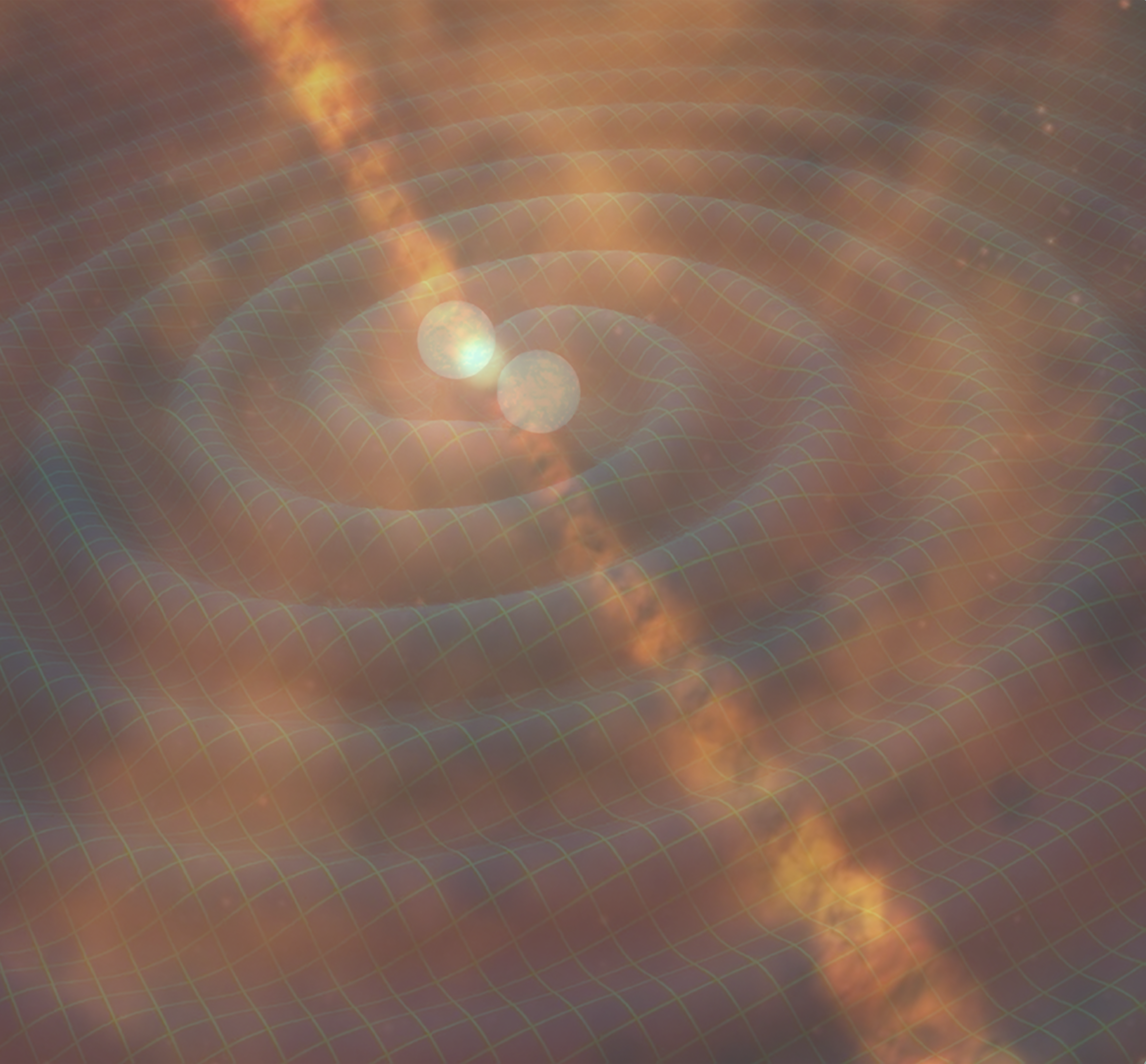
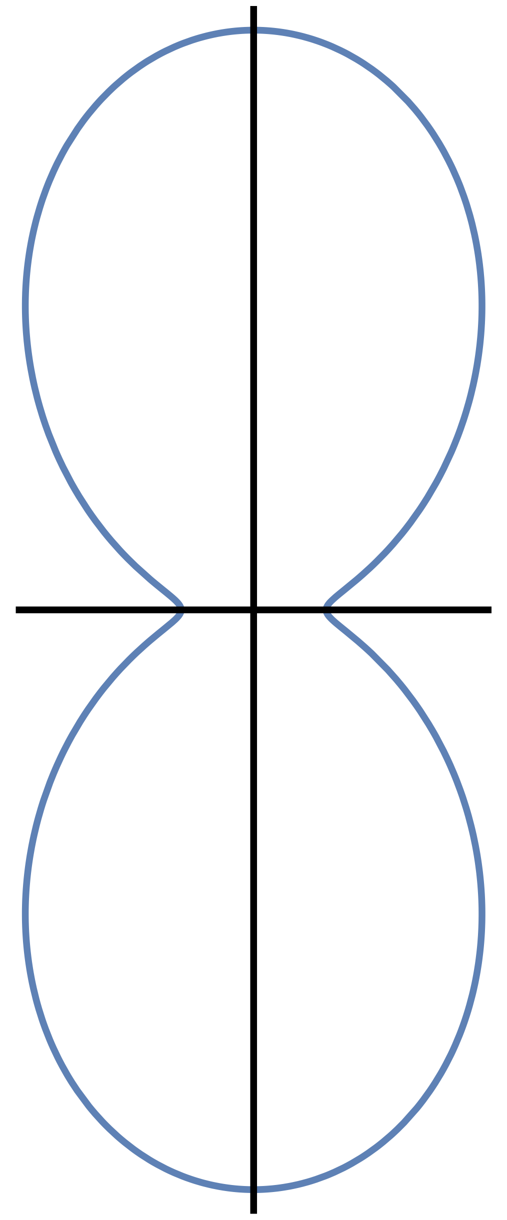
for the HAWC Collaboration
September 19th, 2018

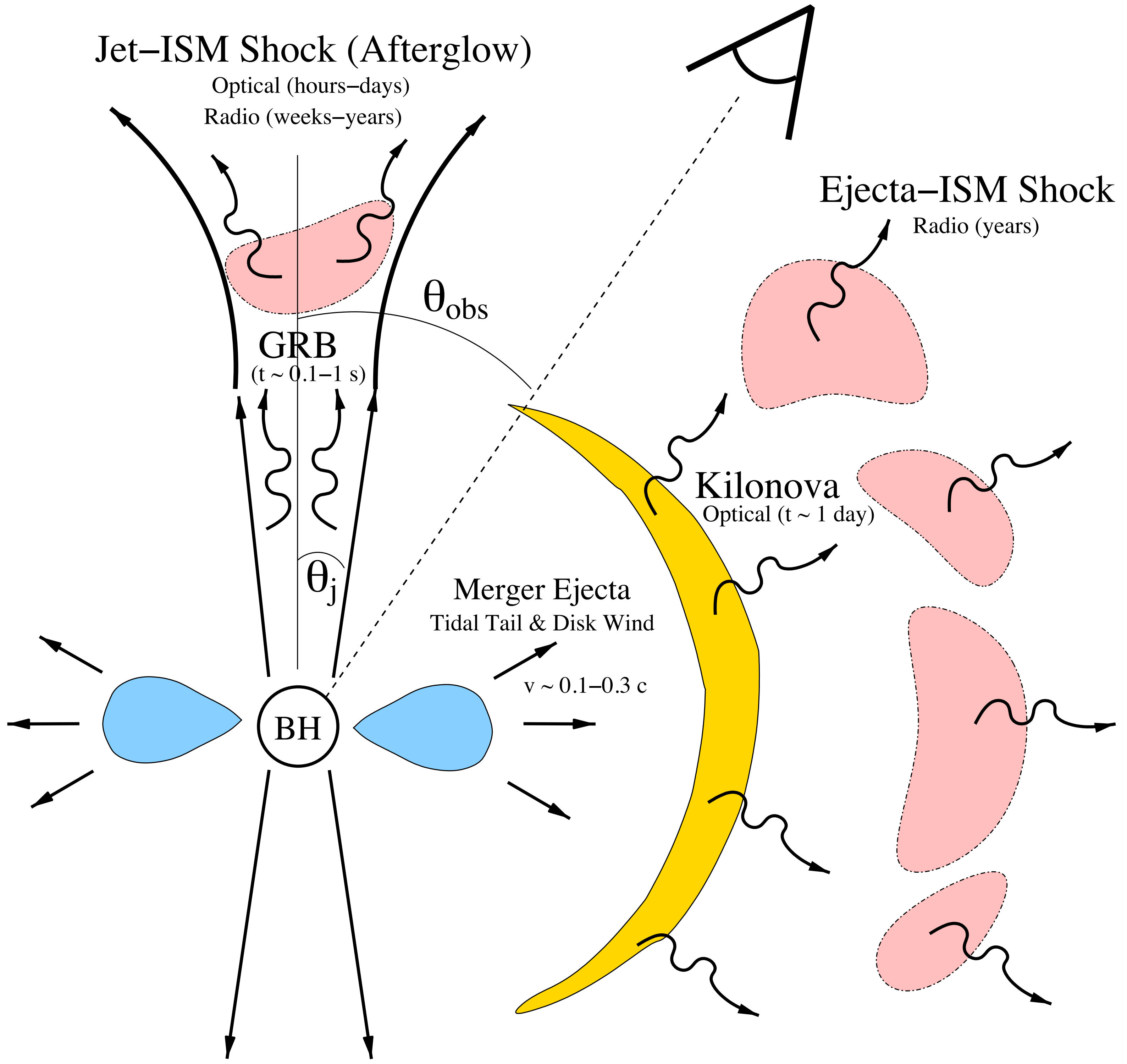


Gravitational waves and Gamma-Ray Bursts

- Binary neutron star mergers have long been candidates for short GRBs progenitors
- LIGO and Virgo are sensitive to the coalescence of compact binaries
- The detection of GW170817 / GRB 170817A / AT 2017gfo represents a milestone in the multi-messenger picture of BNS mergers

GW power pattern

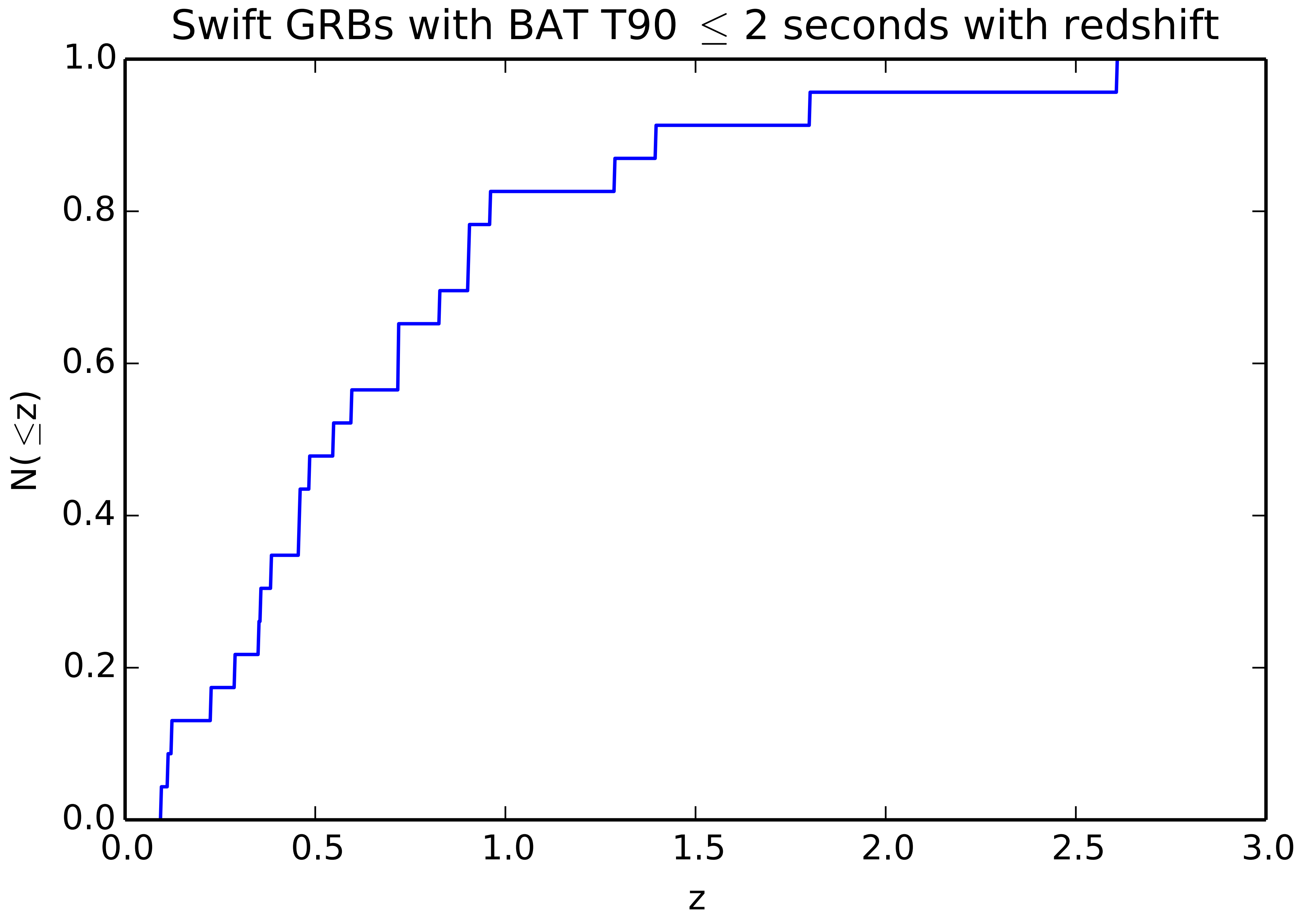




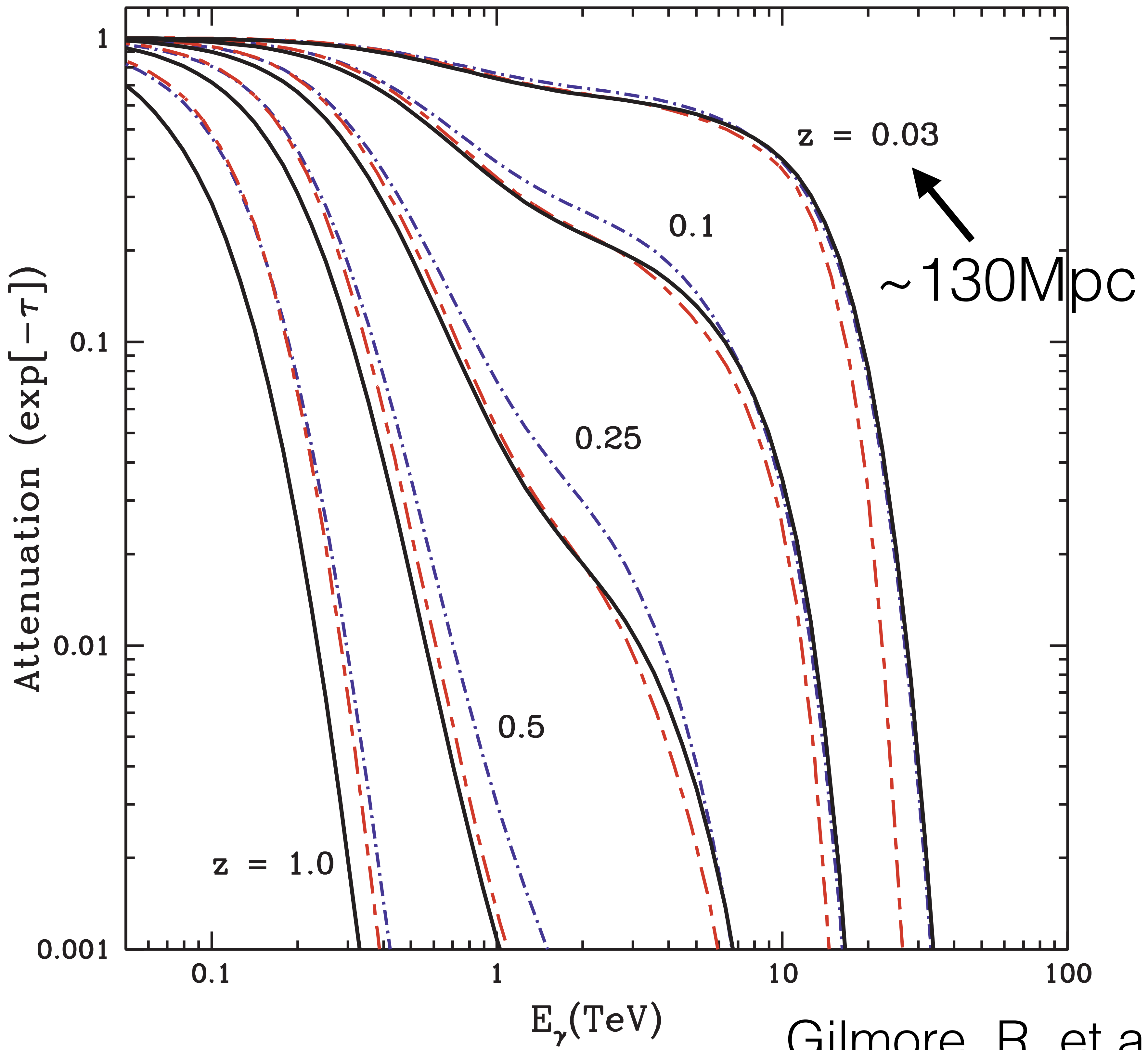
E&M scenario (Metzger & Berger 2012)

GRBs and the very-high energy range

- The detection of very-high energy (100GeV - 100TeV) emission from GRB has remained elusive
- Satellites have a small effective area and IACTs a small FOV
- The bulk of GRBs happen at z>0.5 and the VHE emission is severely attenuated by EBL



https://swift.gsfc.nasa.gov/archive/grb_table/



Gilmore, R. et al 2012

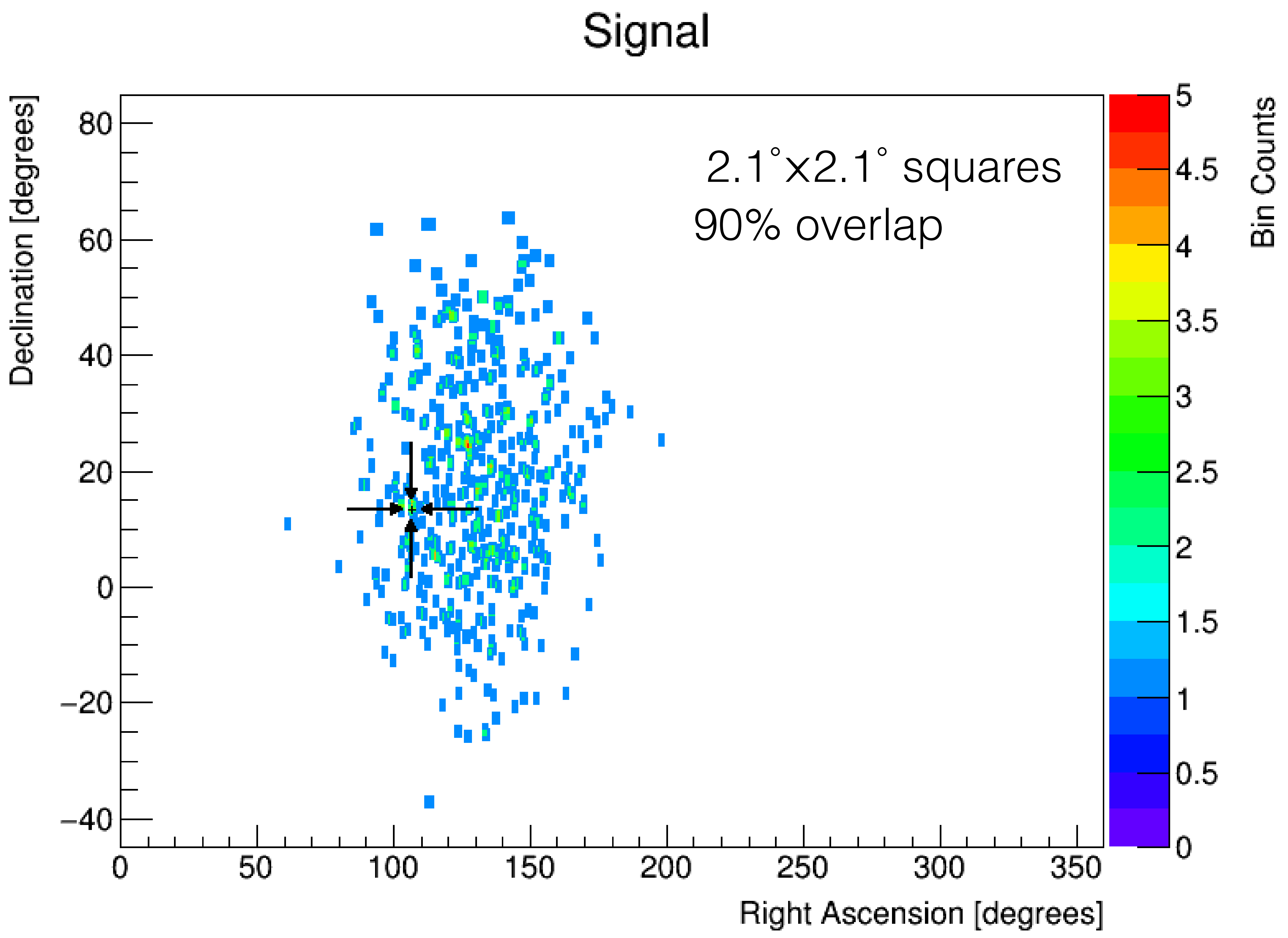
The **H**igh-**A**ltitude **W**ater **C**herenkov Gamma-Ray Observatory

Key features:

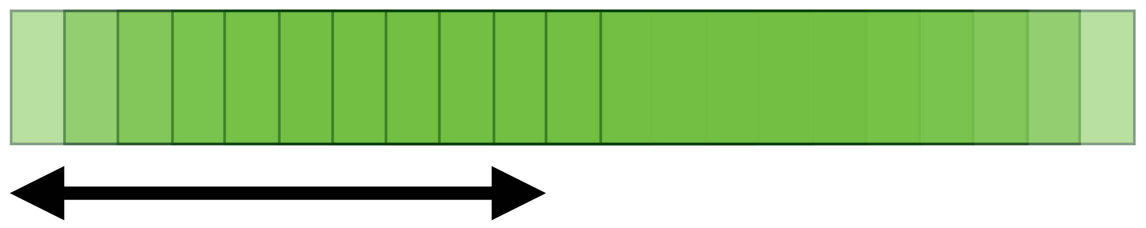
- Energy range: 0.1 - 100TeV
- Large field of view: 2 sr
- High duty cycle: 95%
- Angular resolution: 0.2° - 1°

Real time GRB search

- HAWC counts with a real-time untriggered GRB monitor
- Single square bin analysis designed to be fast



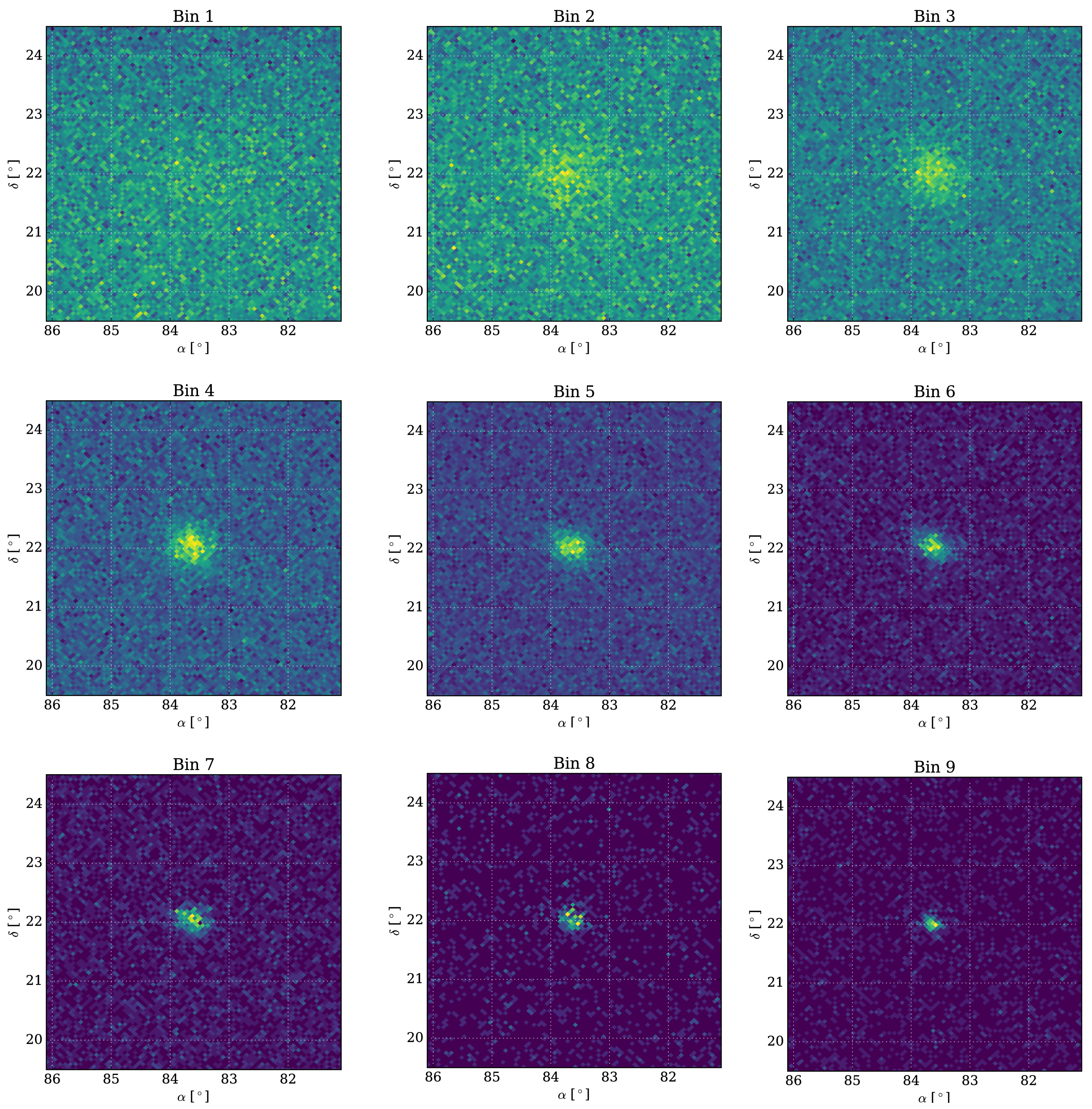
Sliding time windows shifted forward in time in steps of 10%

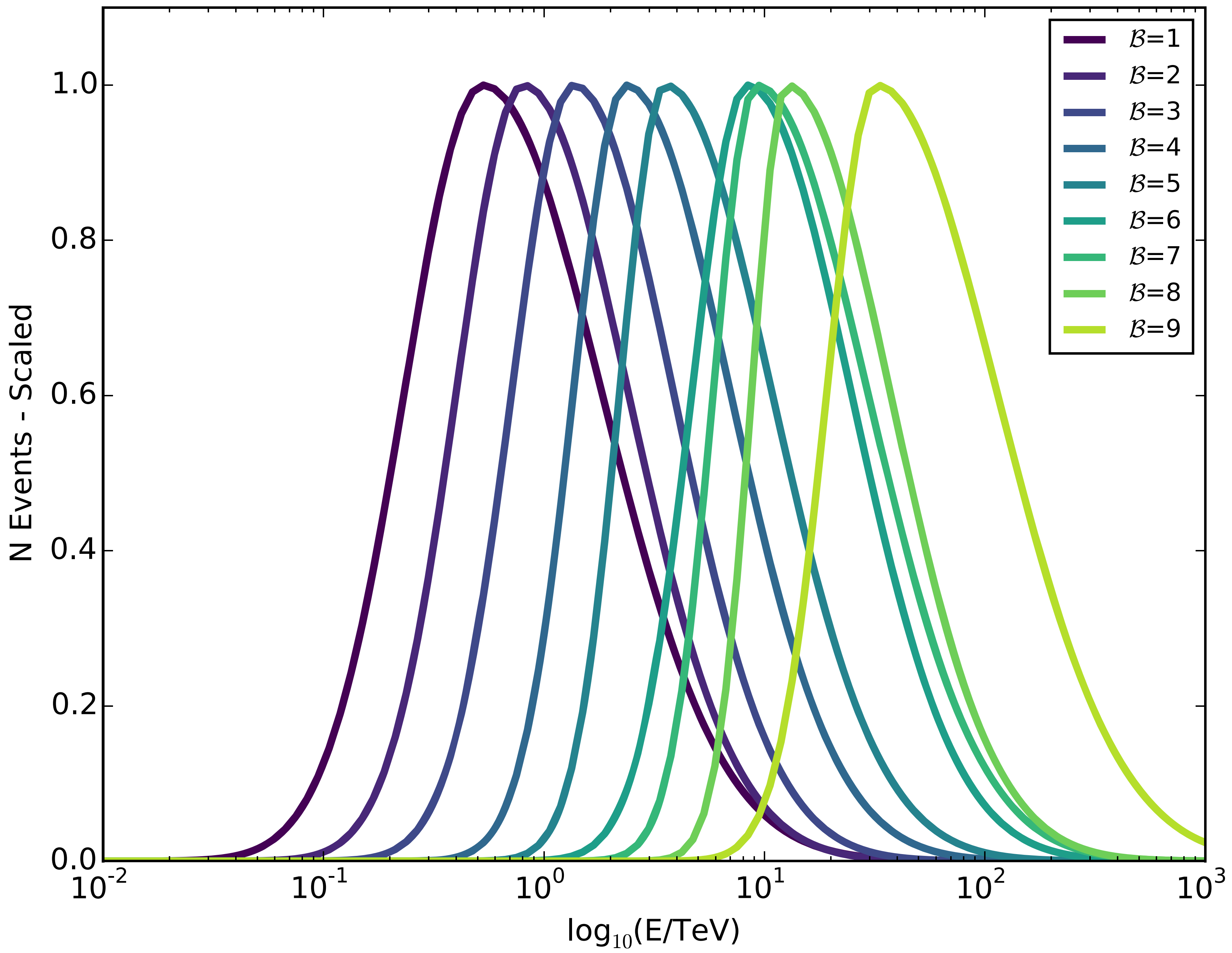


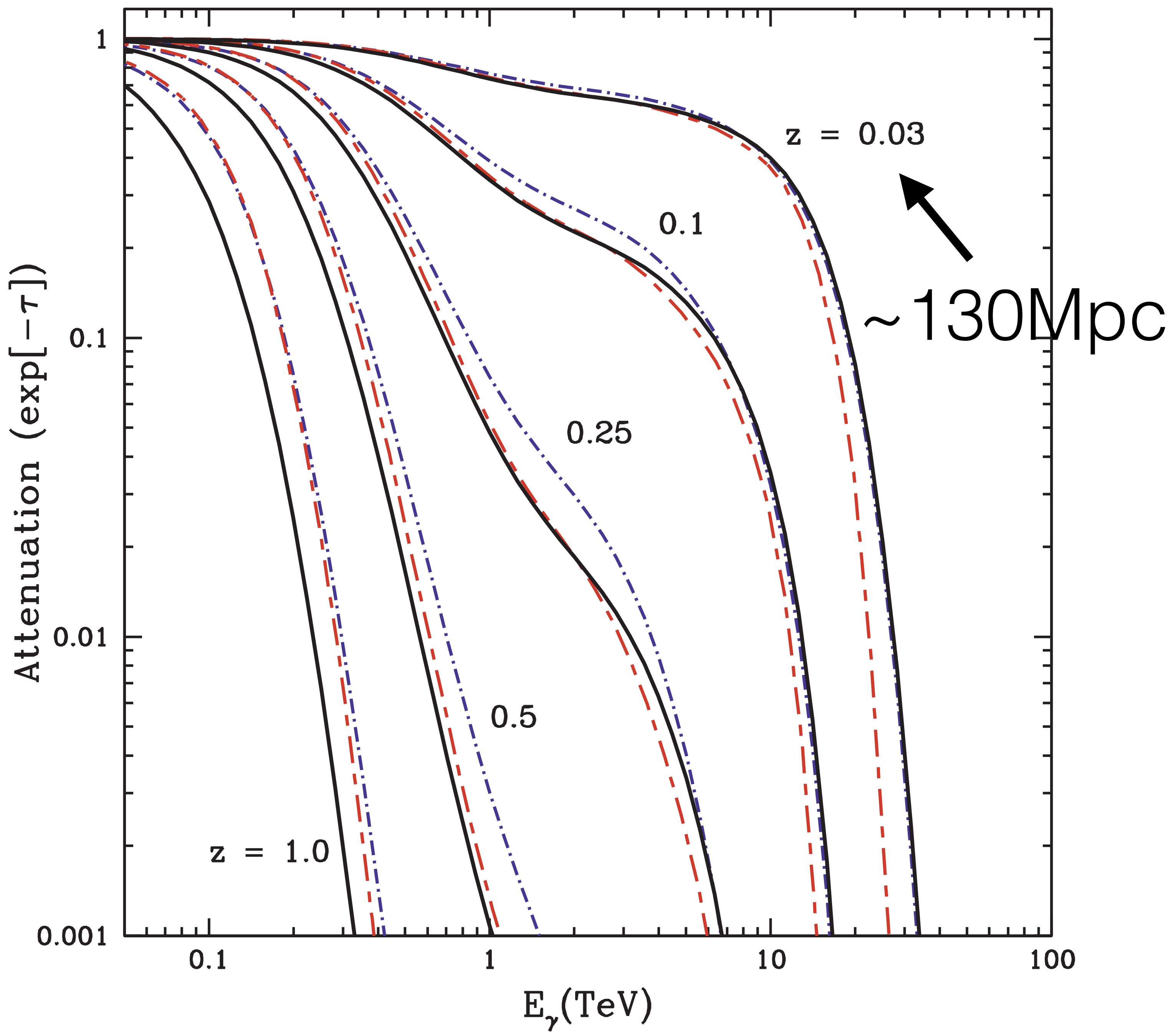
Δt = {0.2s, 1s, 10s, 100s}

Follow-up: event quality bins

- HAWC angular resolution and background rejection improve with the size of the event
- For low redshift sources taking this into account improves the sensitivity
- Requires more computational resources







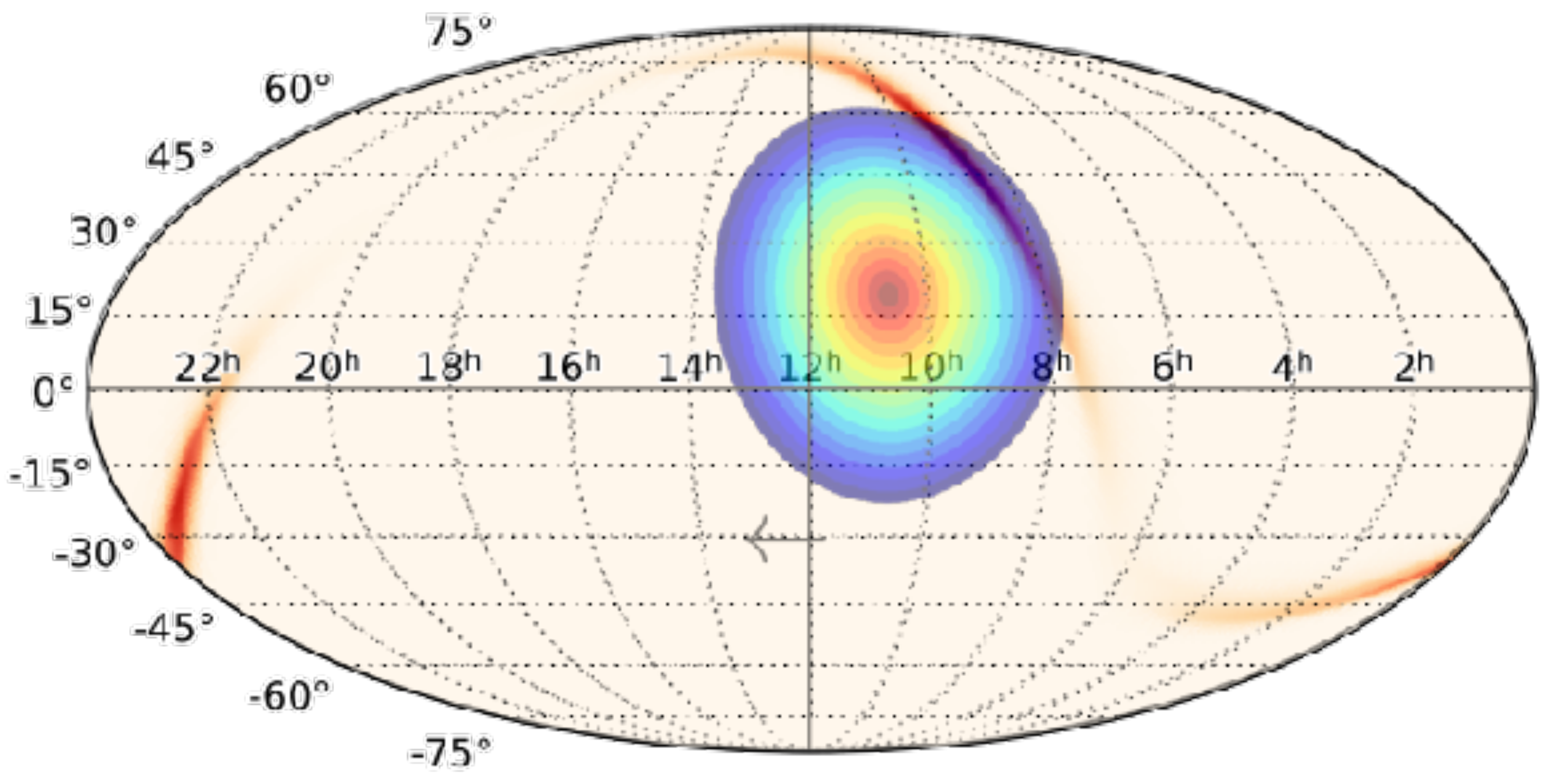
Gilmore, R. et al 2012

Follow-up: likelihood analysis

- We test against a background only hypothesis using a maximum likelihood technique that accounts for event quality and the instrument point spread function

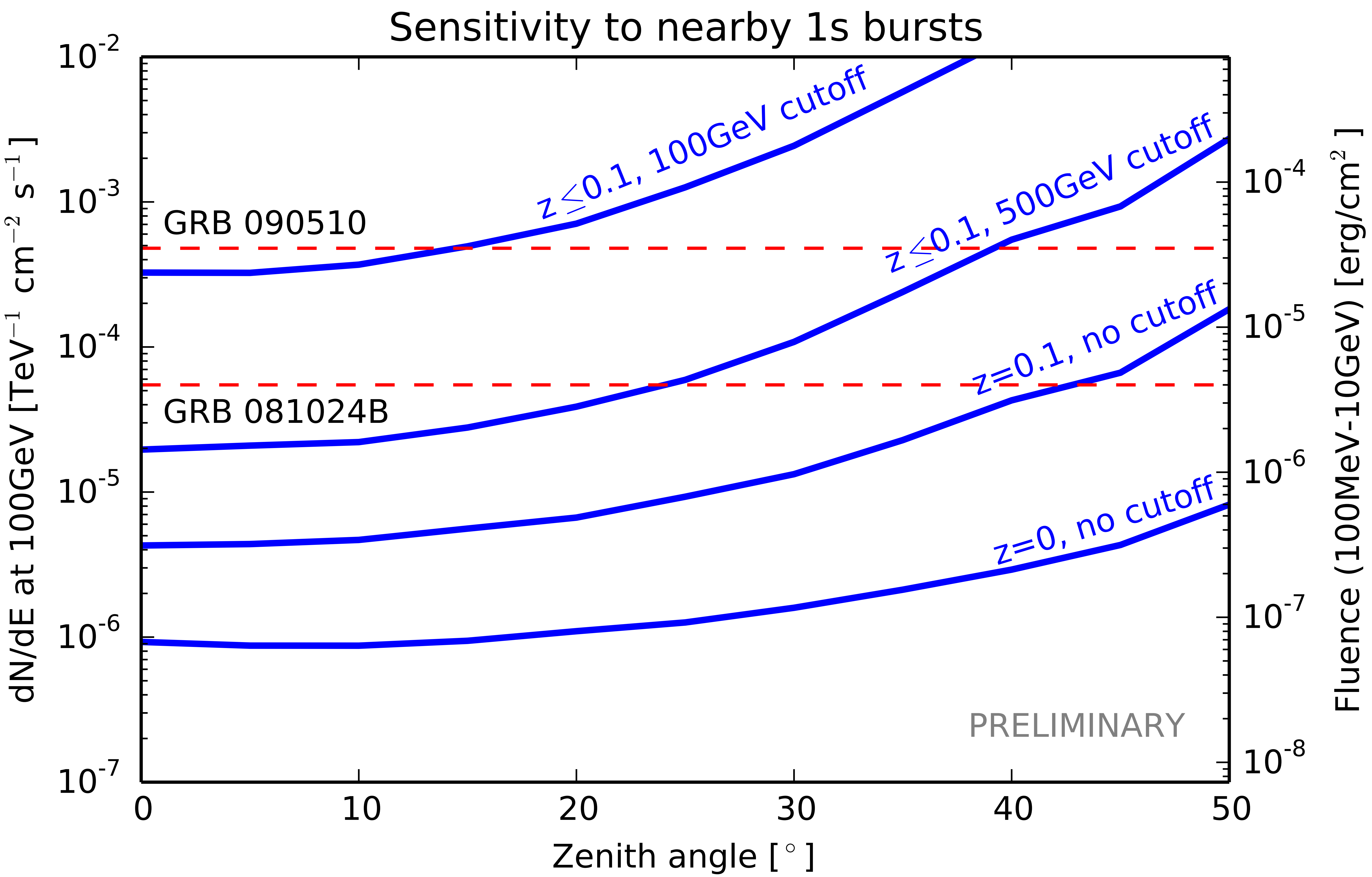
$$TS = 2\log\frac{\mathcal{L}(\mathcal{B}+\mathcal{S})}{\mathcal{L}(\mathcal{B})}$$

- The source location hypothesis is changed to cover the overlap of the LIGO localization contour and the HAWC FoV
- We also look for long timescale emission in the subsequent transits



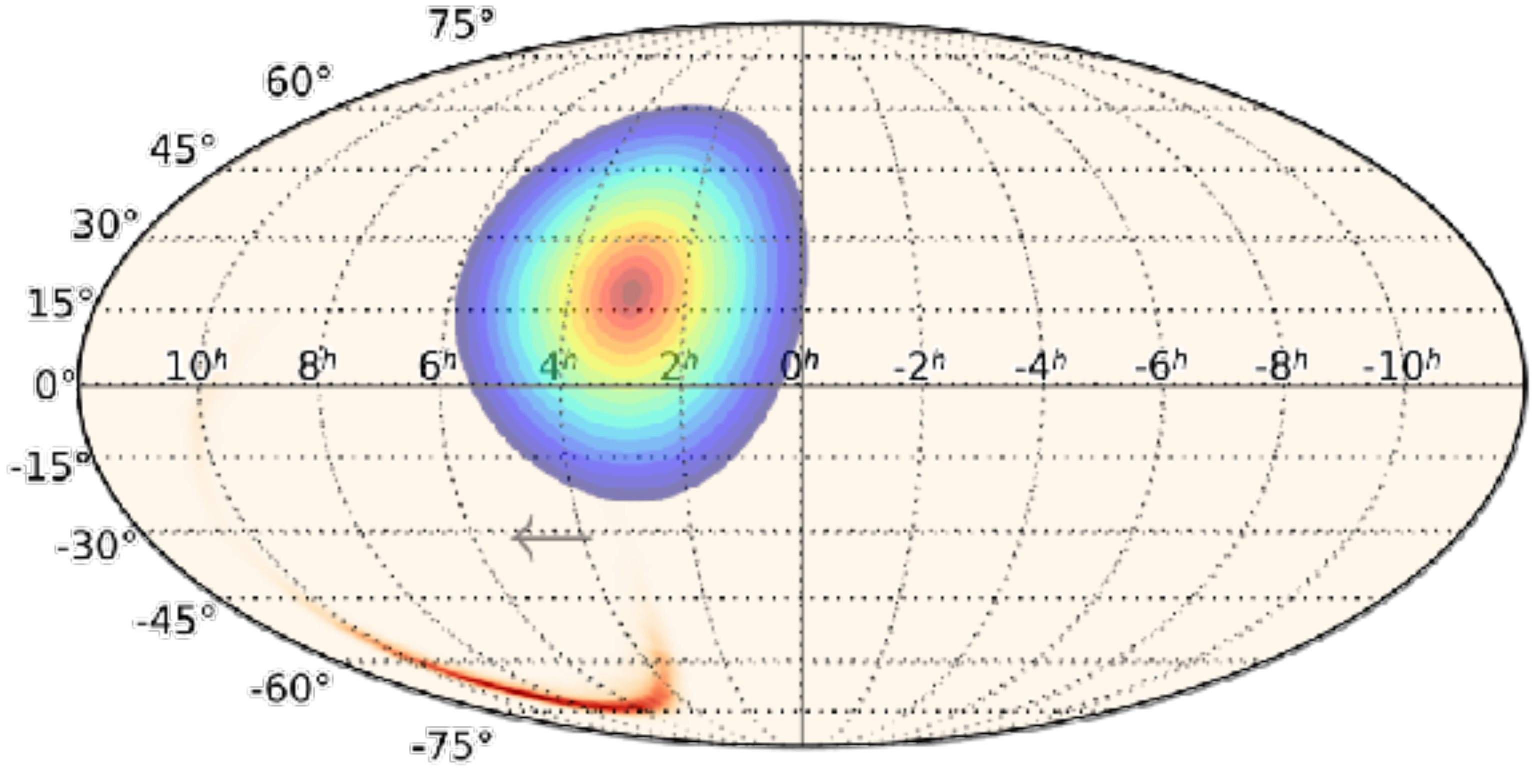
Sensitivity

- HAWC is sensitive to most GRBs in the LIGO-Virgo BNS horizon assuming the spectrum follows a simple power law with an index of -2

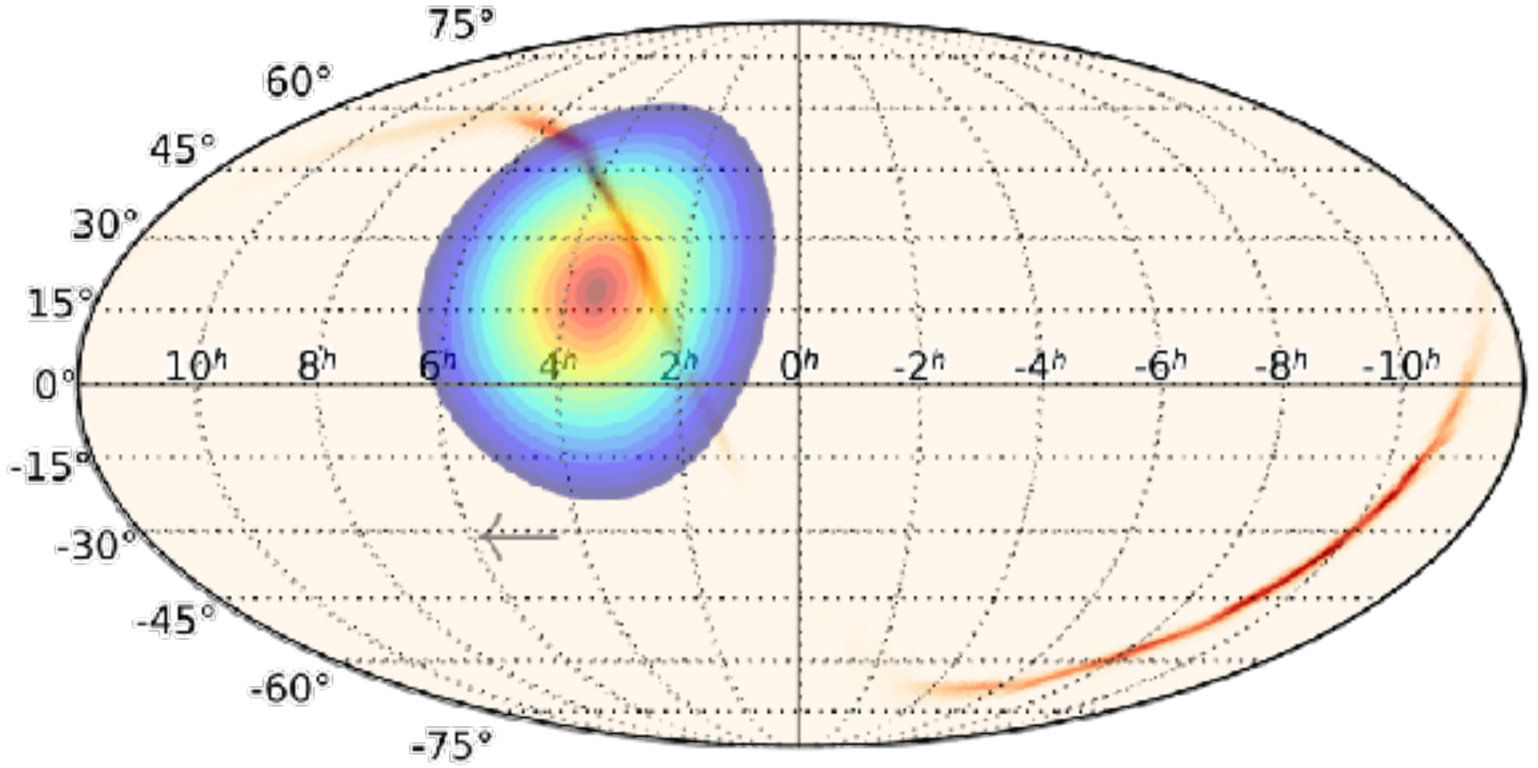


GW detections in HAWC FOV

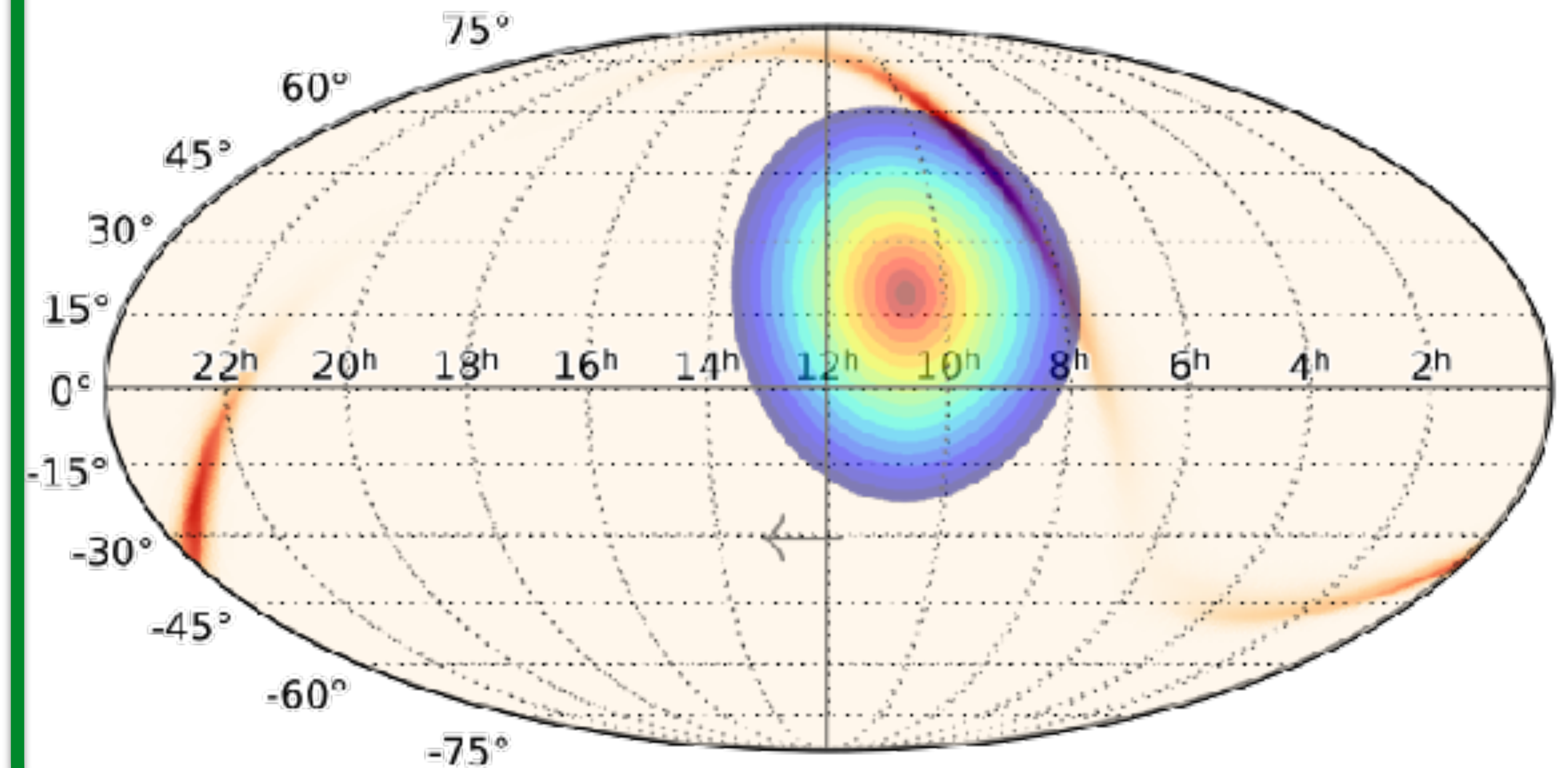
GW150914



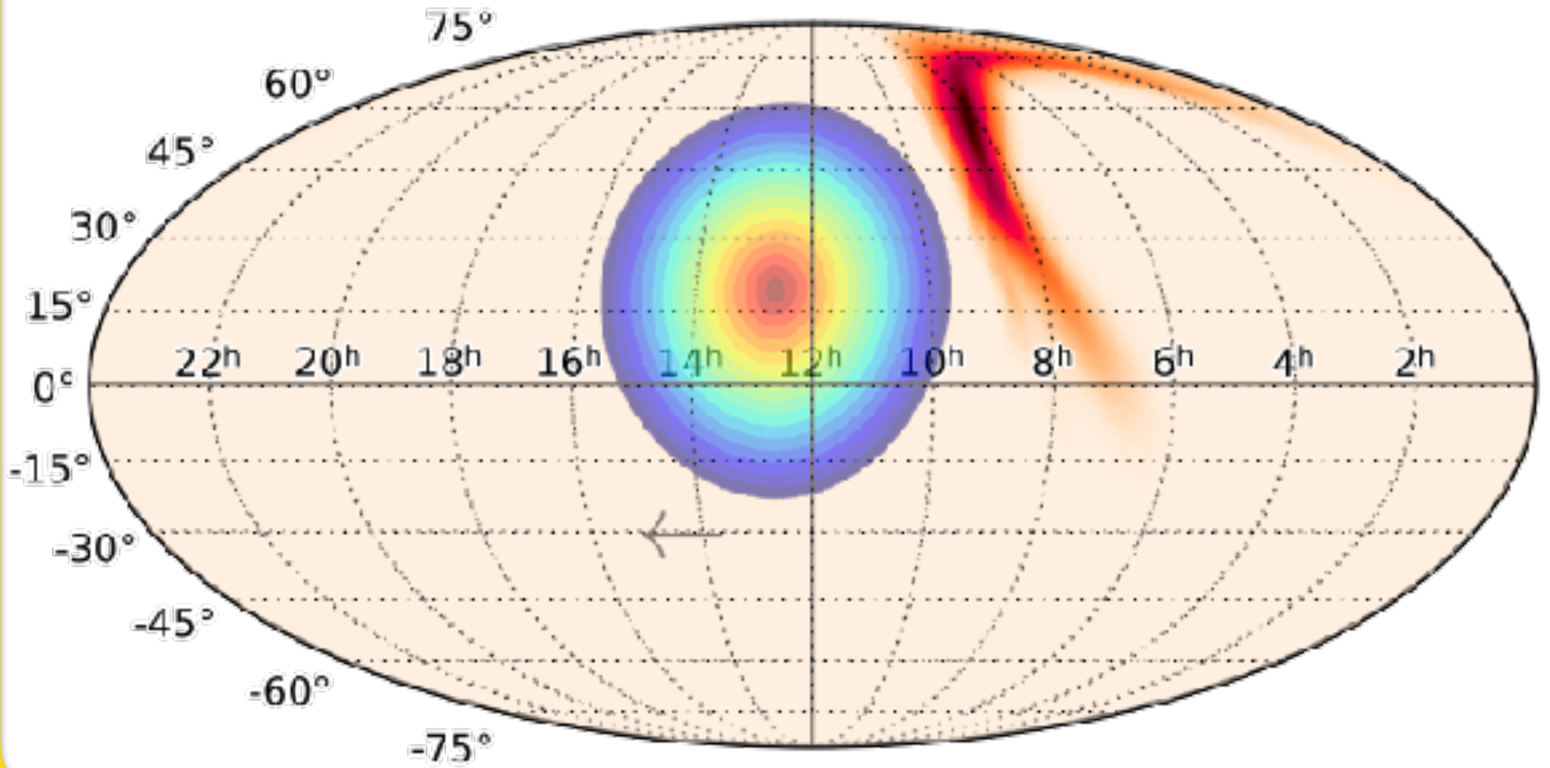
GW151226



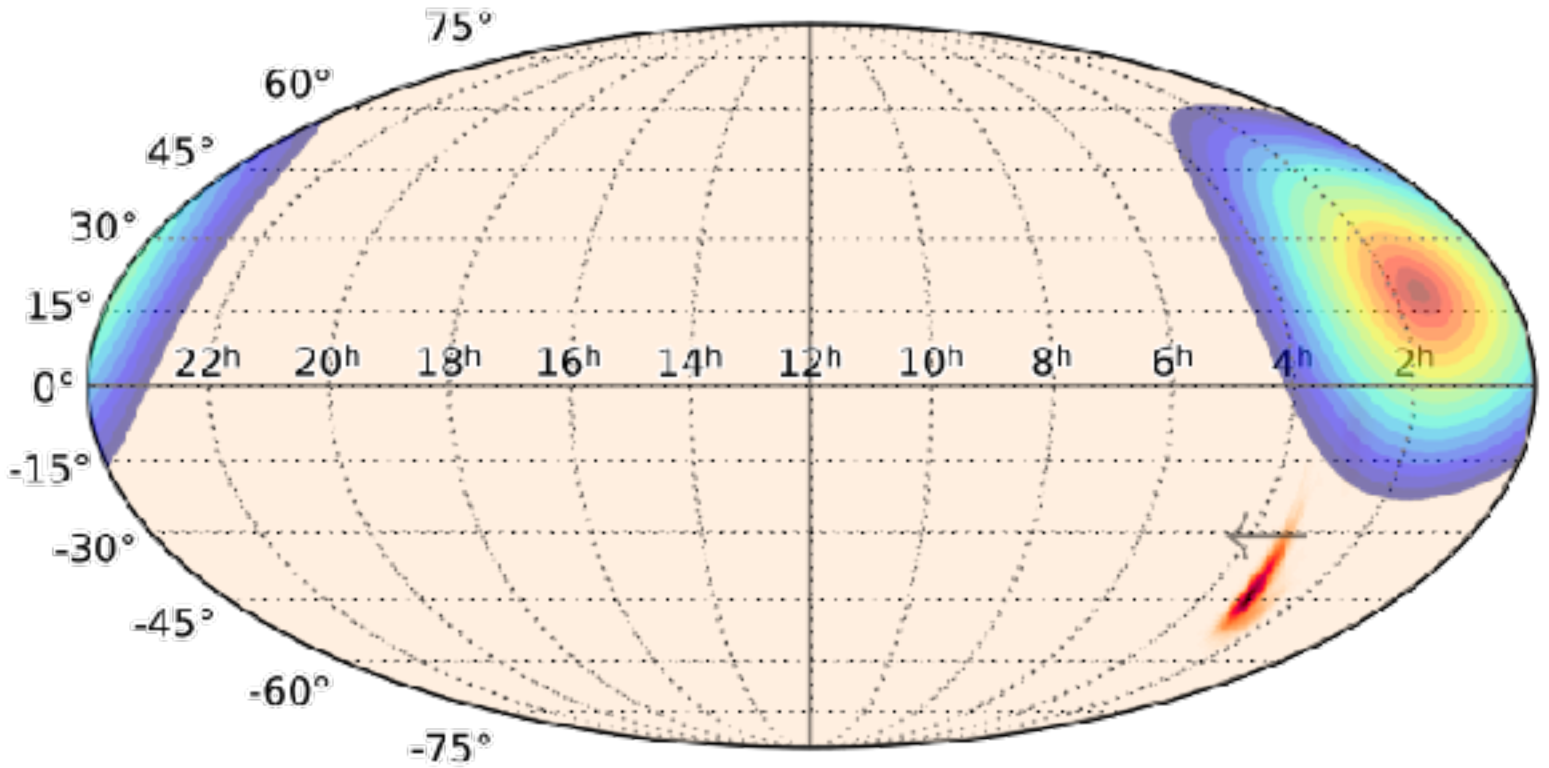
GW170104



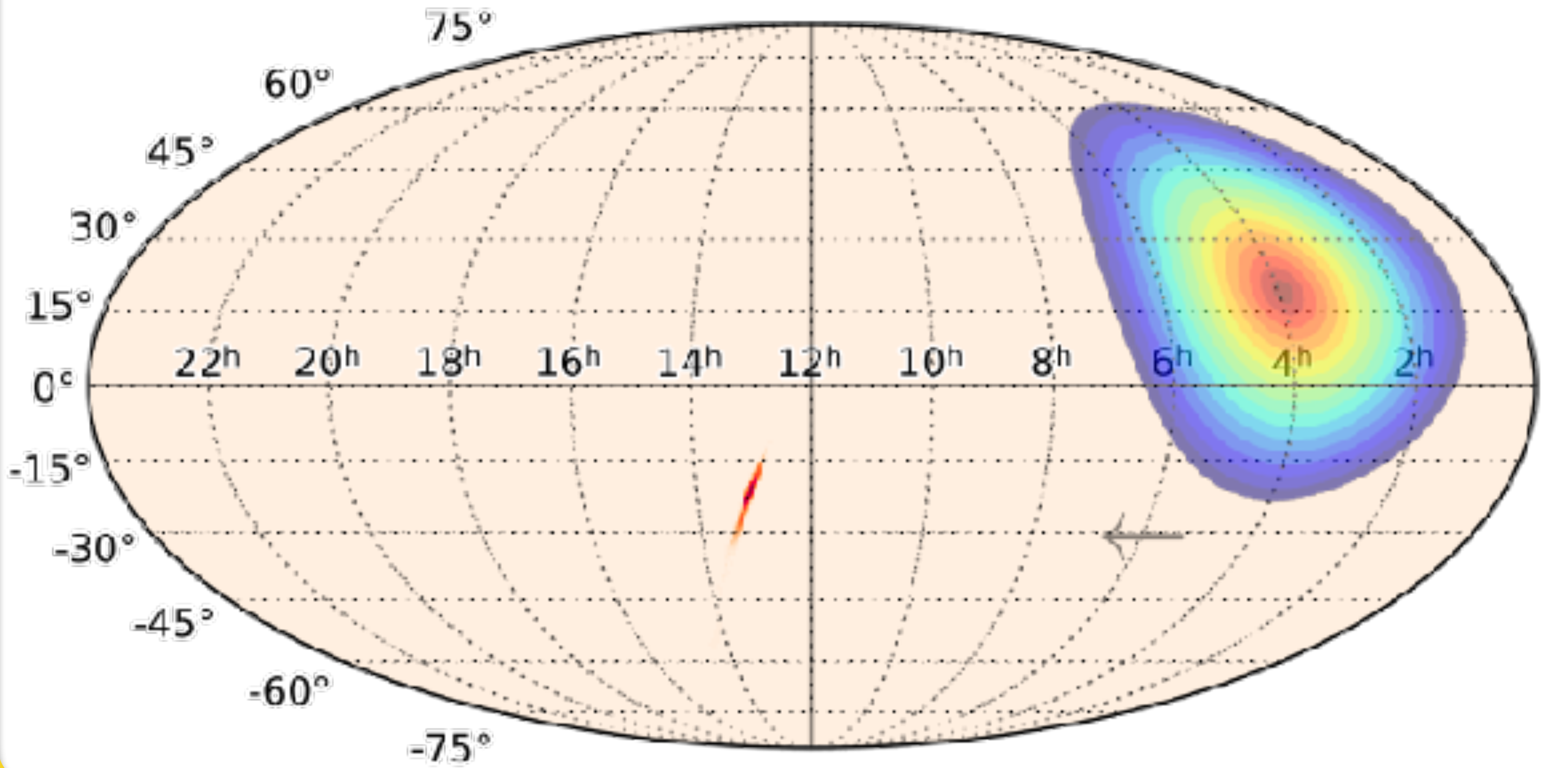
GW170608



GW170814



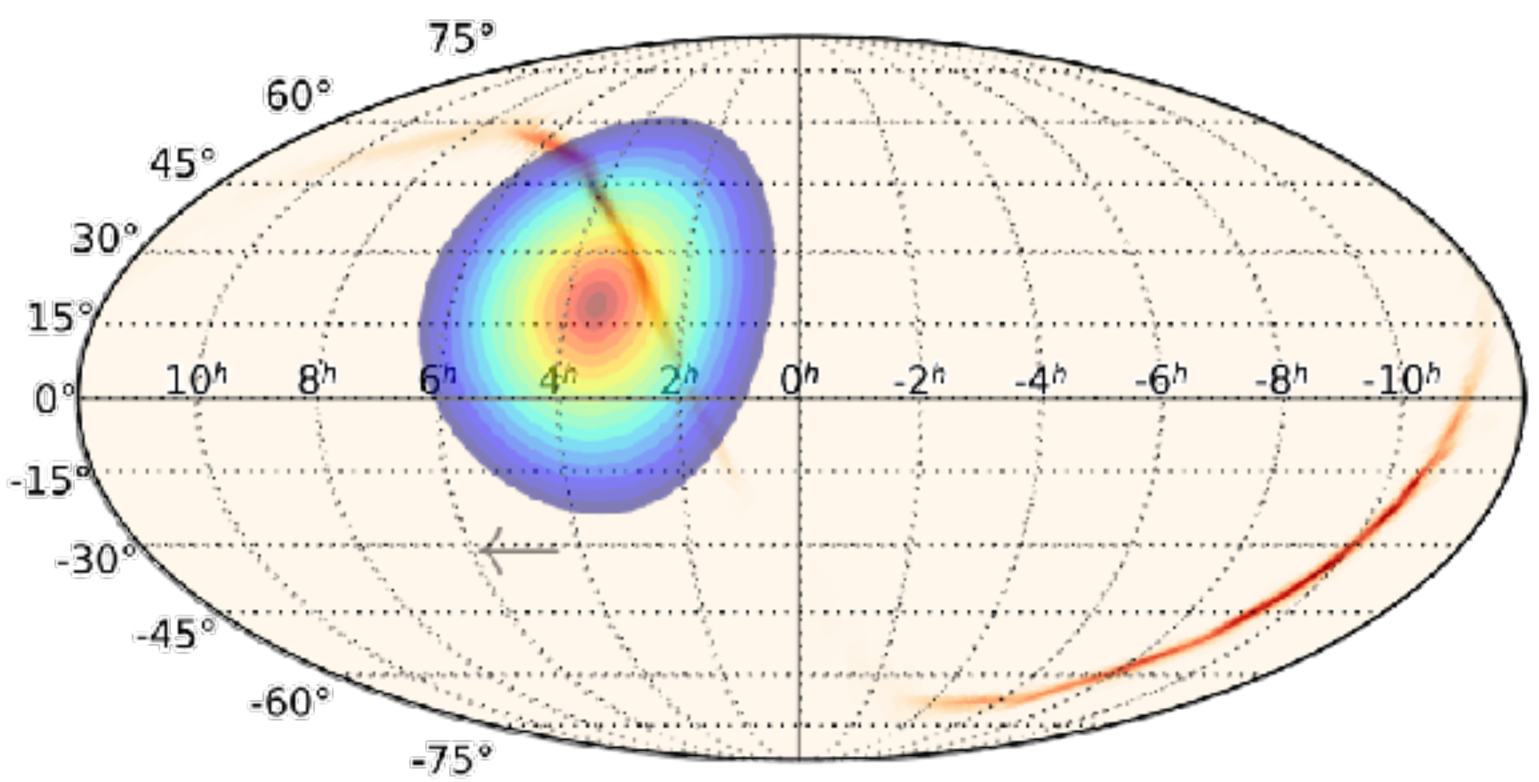
GW170817



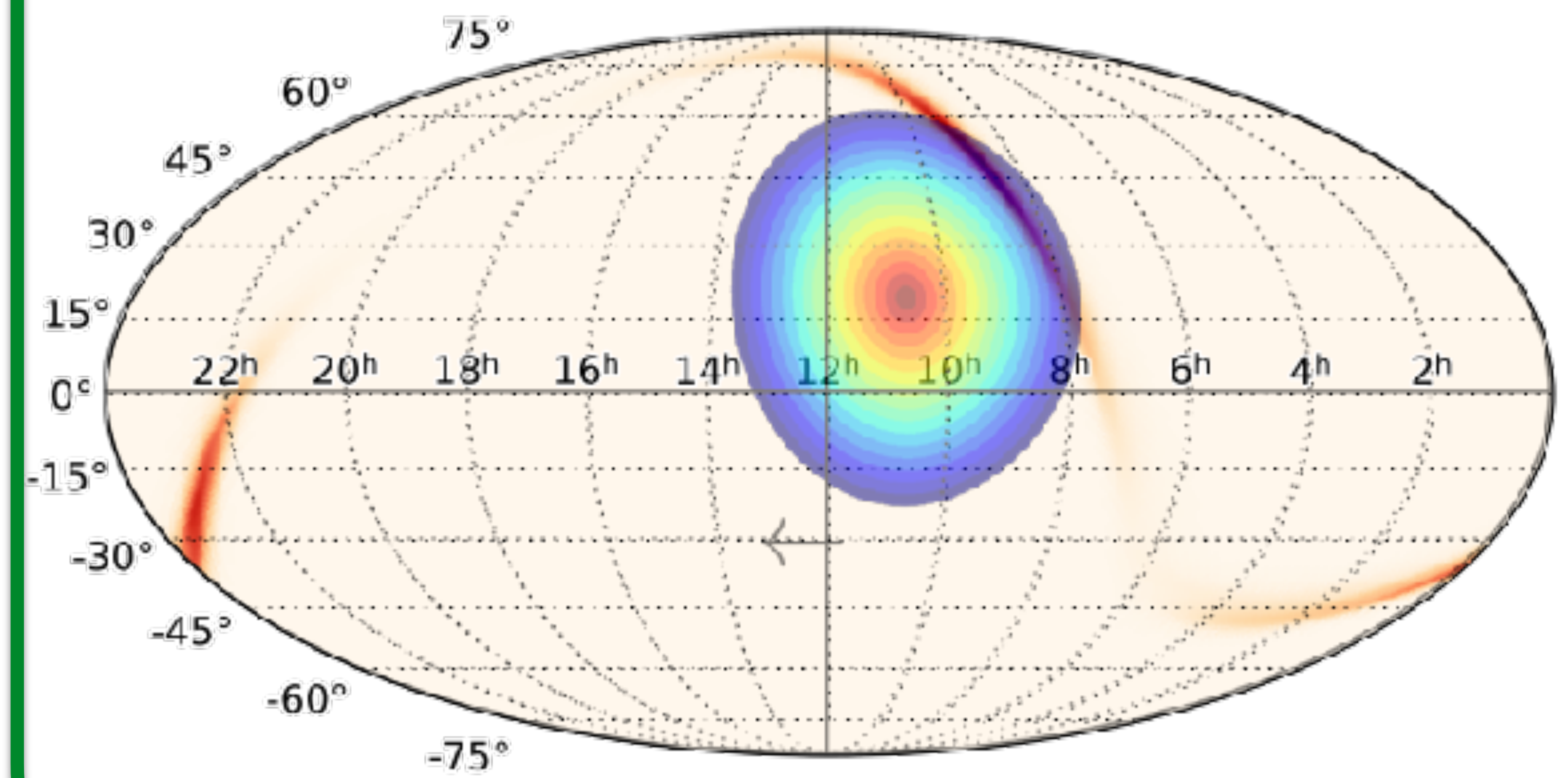
Follow-up of BH-BH mergers

- No electromagnetic emission is expected from the merger of two black holes.
- We found not significant excess

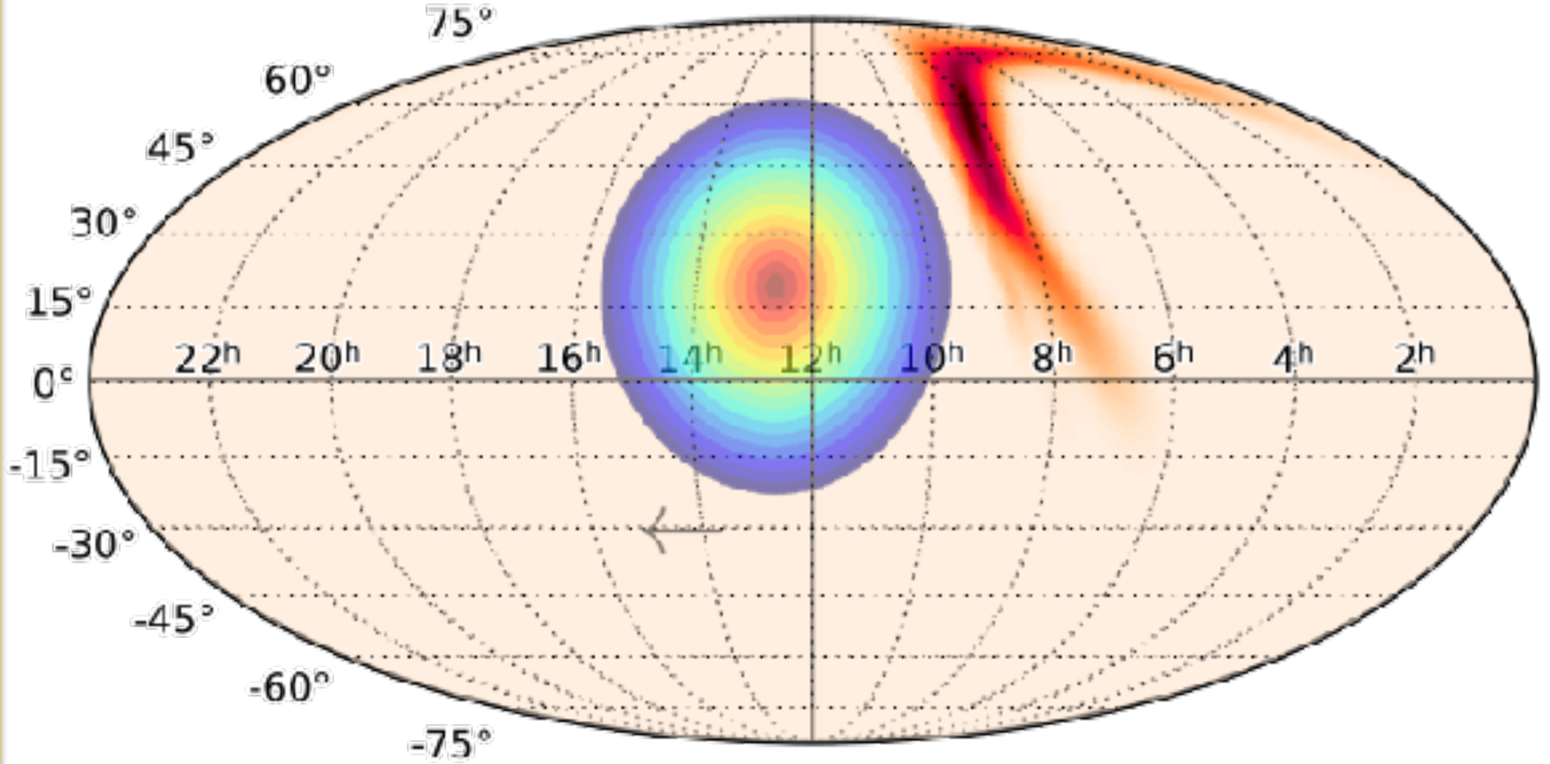
GW151226



GW170104

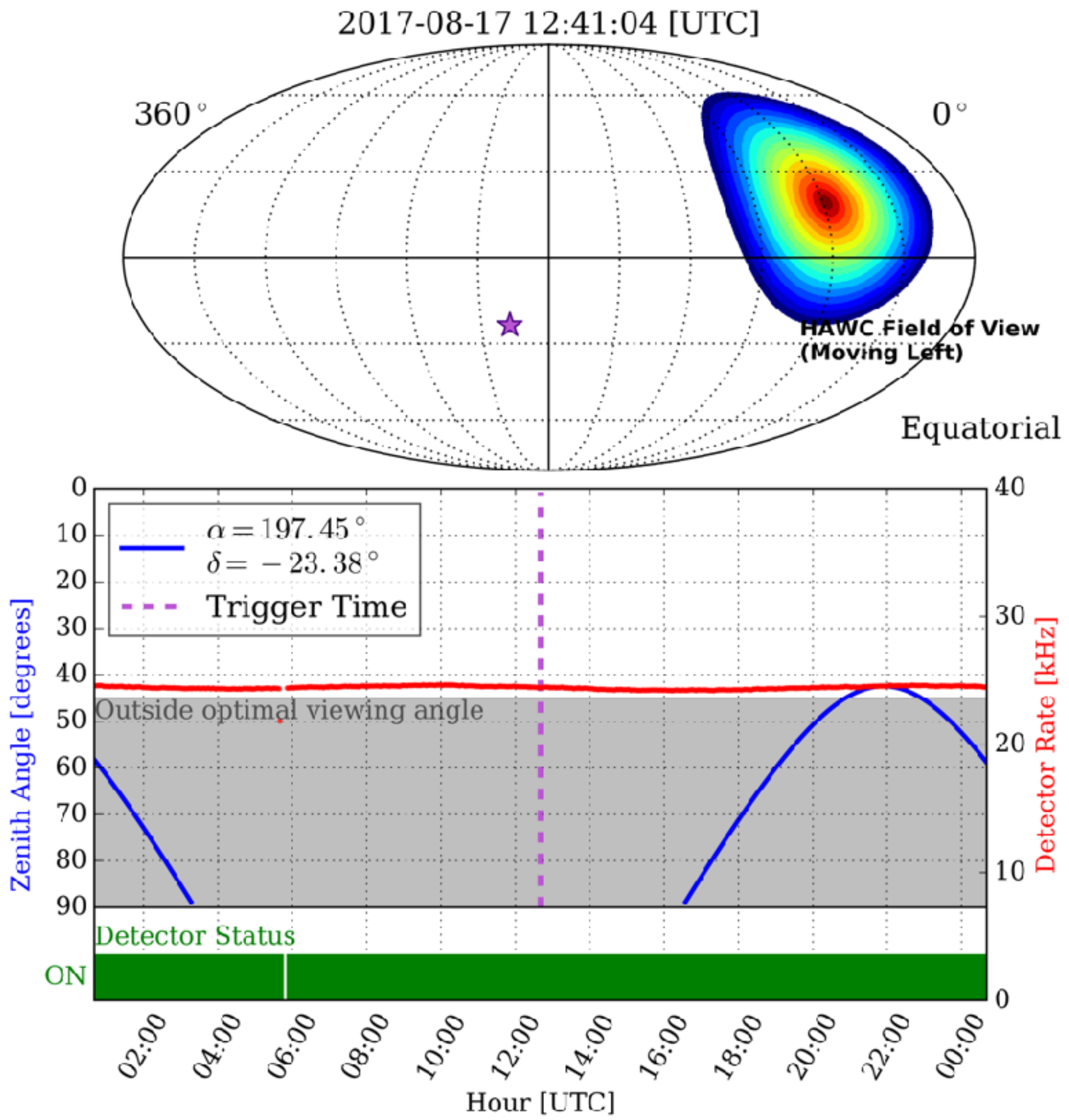


GW170608



GW170817 | GRB 170817A | AT 2017gfo

- GW170917 was consistent with a binary neutron star coalescence
- The electromagnetic counterpart was detected from radio to radio to gamma rays (keV-MeV range)
- The AT 2017gfo location entered the HAWC field of view ~9 hrs after
- The location transits at the edge of our FOV: high energy threshold and poor sensitivity
- We set a 90% CI upper limit between 4-100TeV of 1.7×10^{-10} erg cm^{-2} s^{-1}



Conclusions

- HAWC is sensitive to the potential VHE emission from GRBs occurring in the LIGO-Virgo horizon
- As a large FOV instrument it can reduce the position uncertainty and help pointing instruments
- Simultaneous observations, with or without detection, would play an important role into the multi-wavelength and multi-messenger picture of BNS mergers and GRBs
- HAWC followed up LIGO-Virgo triggers during observation runs O1 and O2, and will continue to do so during O3