Early warning detection of gravitational waves from binary neutron star mergers

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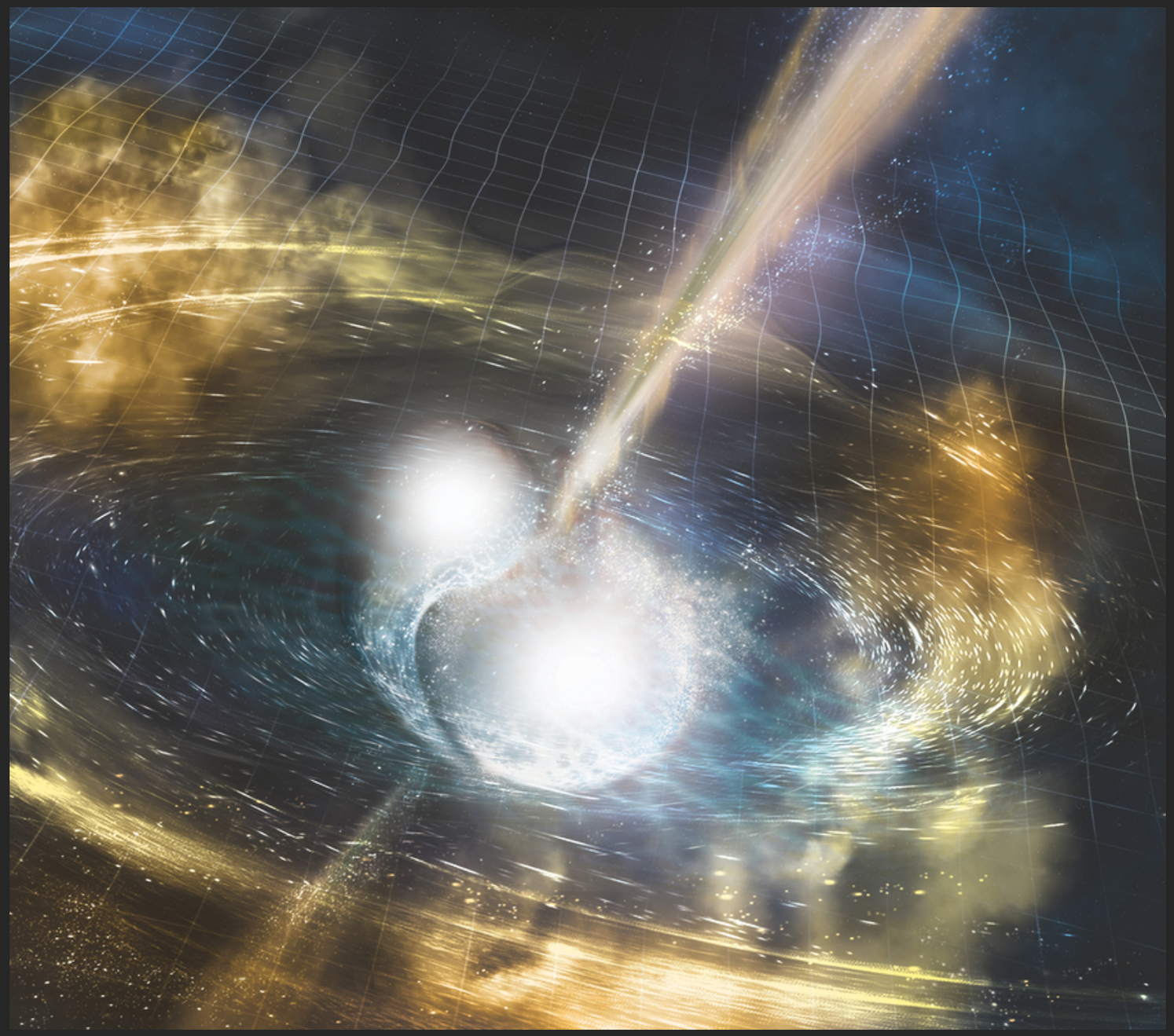
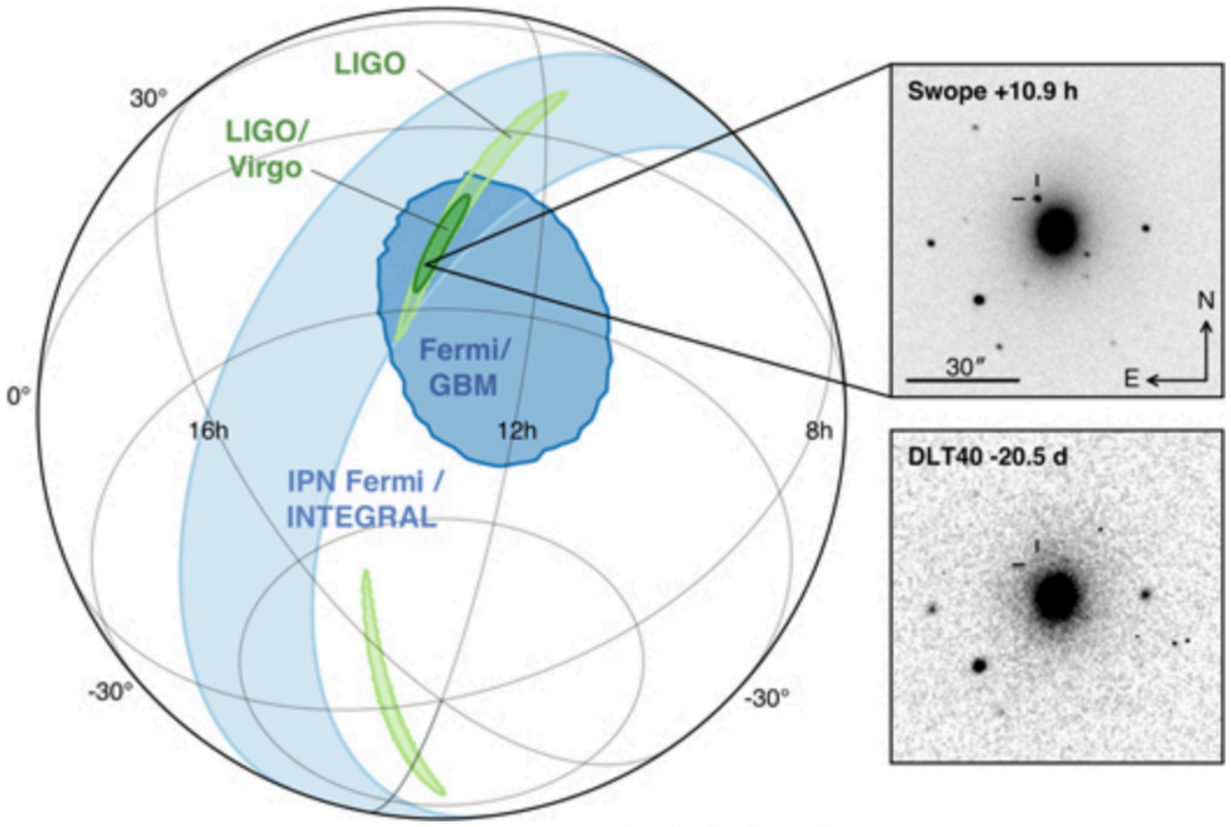


- First multi-messenger event with gravitational waves
- Detected in low-latency by the gstlal inspiral pipeline (Cannon et al. 2012; Messick et al. 2017; Hanna et al. 2019, Sachdev et al.2019; GstLAL 2018; Gstreamer 2018)
- Extensive follow-up in all EM bands



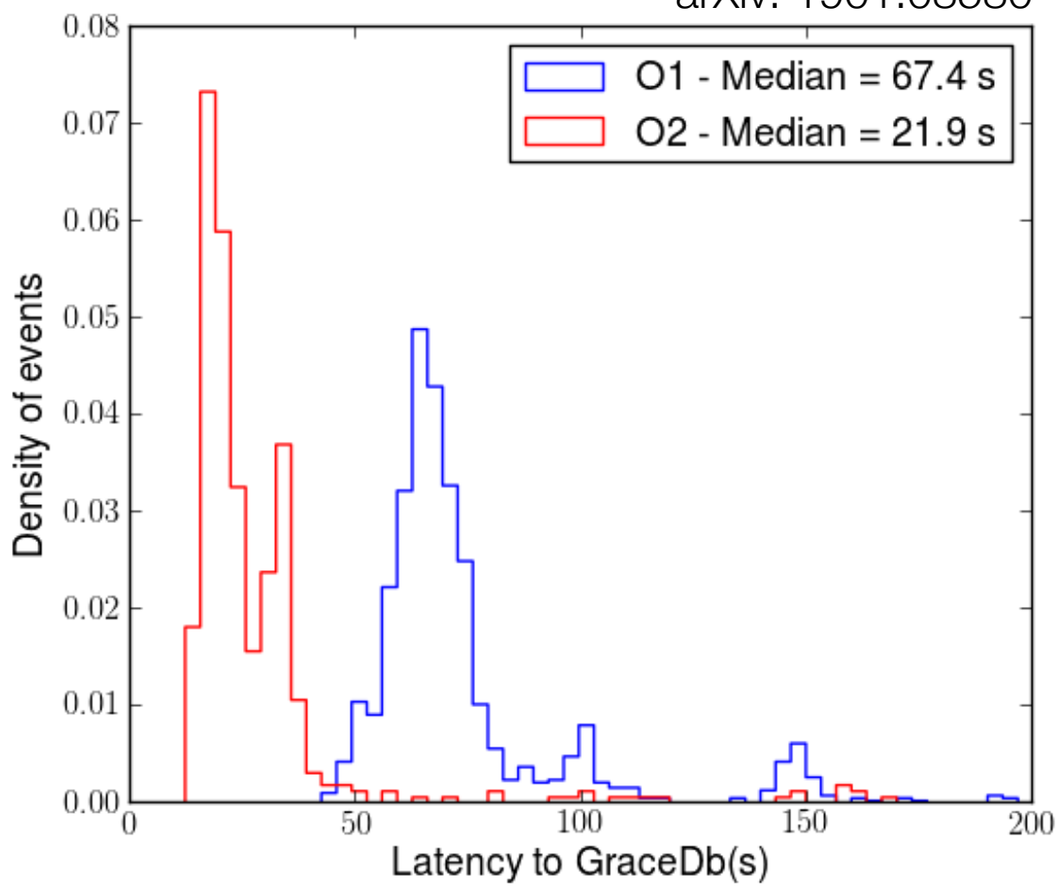
ApJL 848:L12

GstLAL Overview

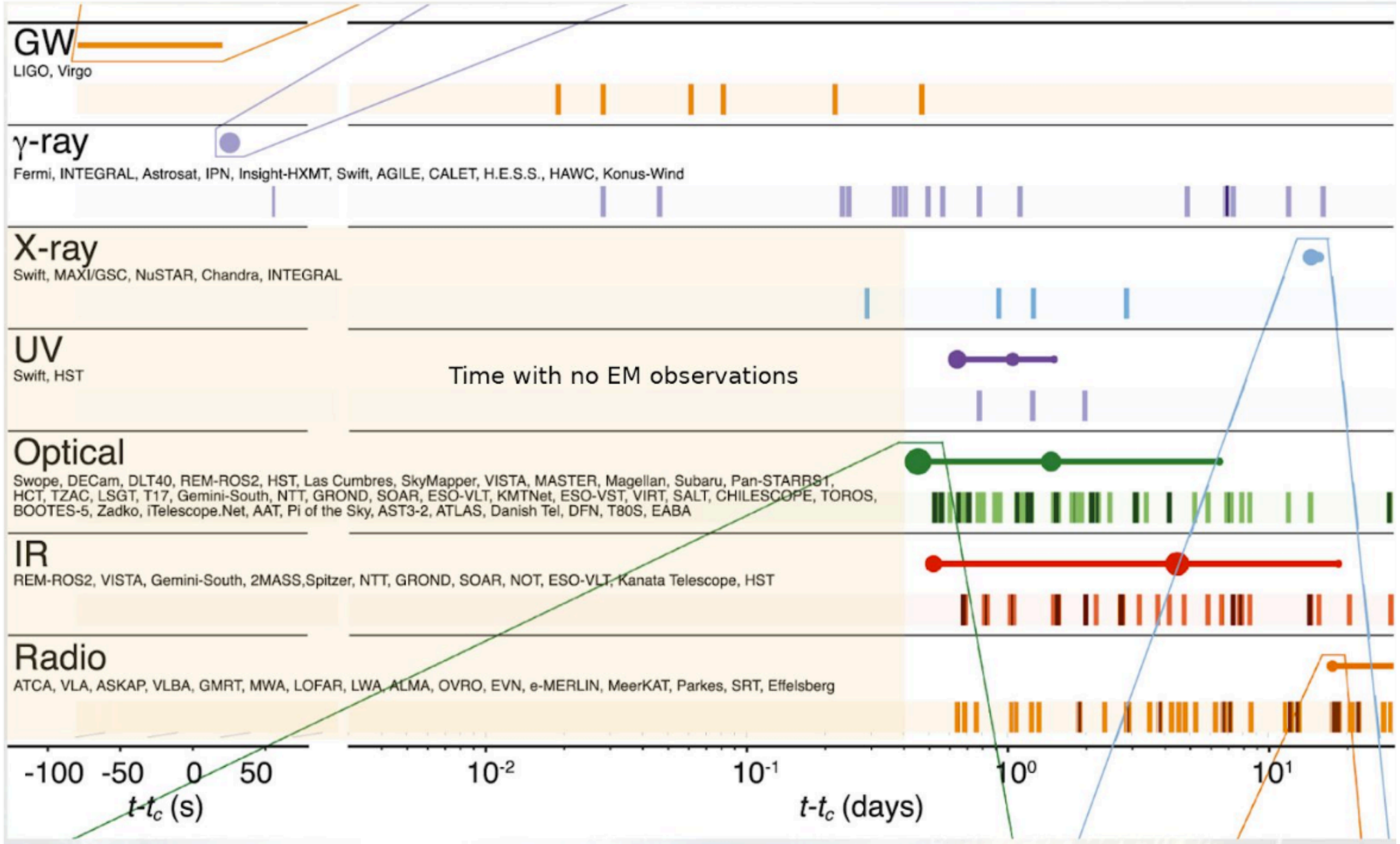
gstreamer

- Matched-filtering search used to look for gravitational wave signals from compact binary coalescences (CBCs) in LIGO data
- Based on **gstreamer**: open-source media library, ideal for real-time signal processing of LIGO data
- Can be run in low latency of **~ 1min (in O1), ~20 s in O2**

arXiv: 1901.08580

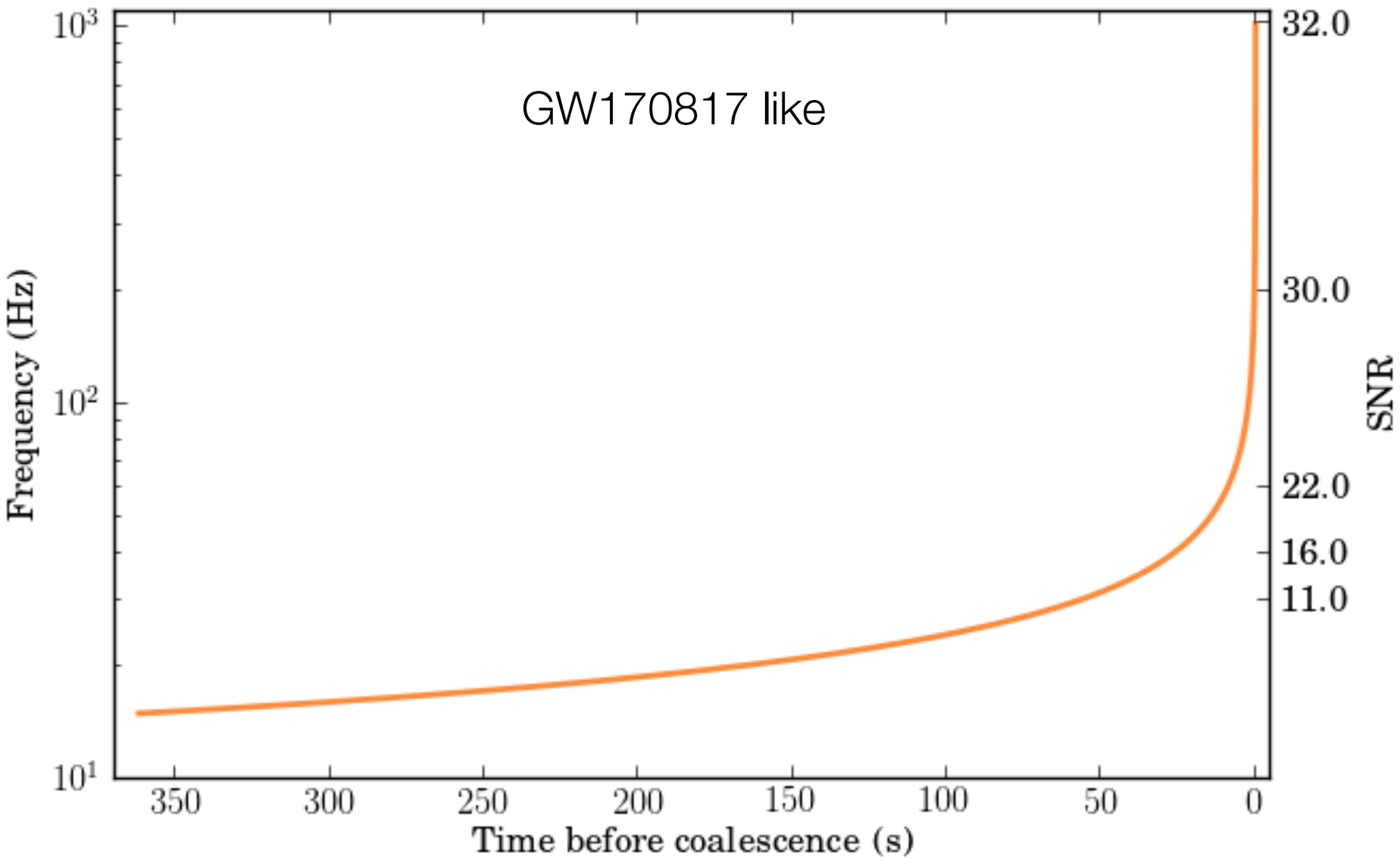


Short GRB, kilonova, late-time radio jet



Modified from ApJL 848:L12

NS-NS time frequency

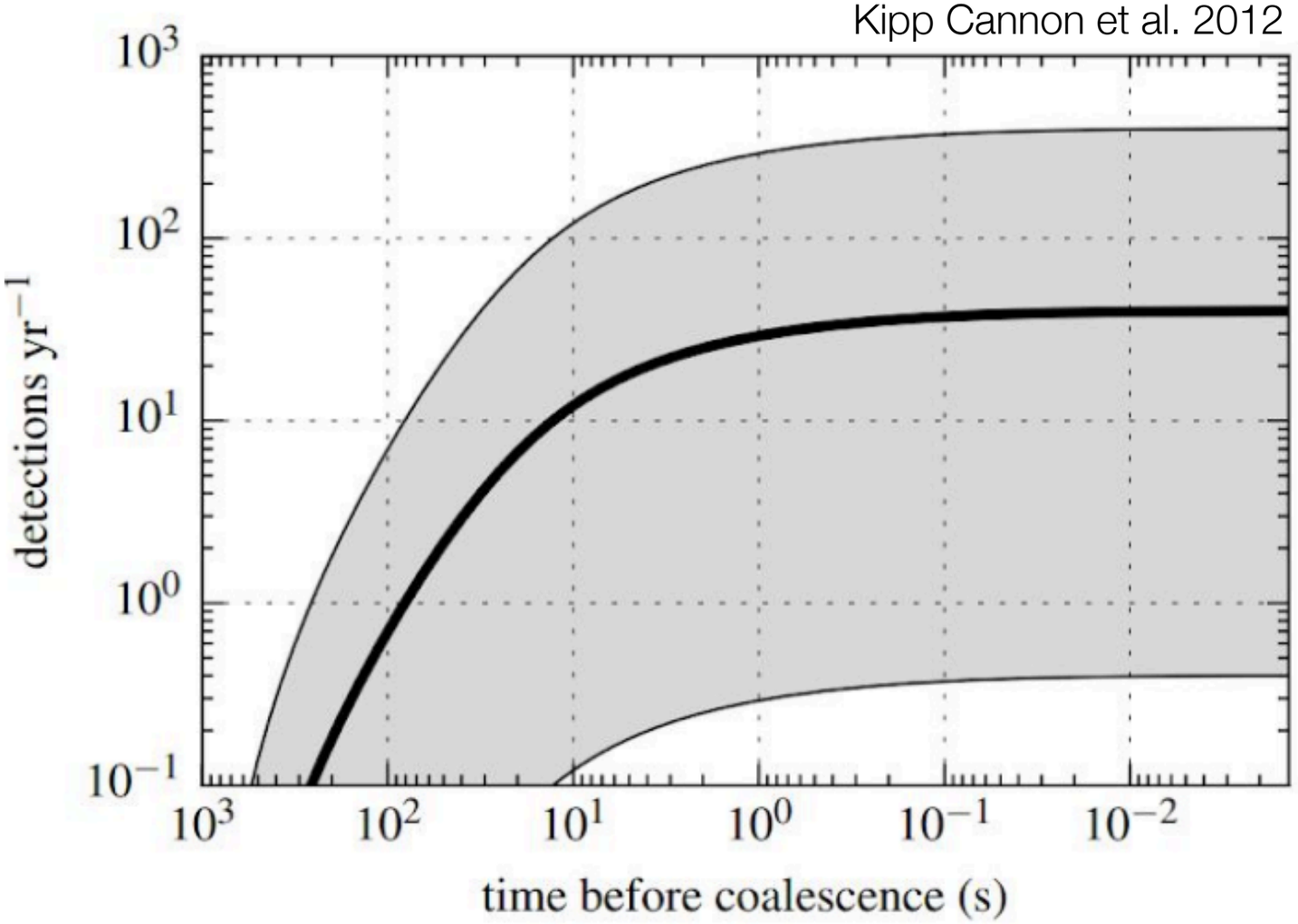


Motivation

- Prompt radio emission
  (short coherent radio pulse near the instant of merger)
  Usov & Katz 2000; Hansen & Lyutikov 2001; Pshirkov & Postnov 2010; Lai 2012; Lyutikov 2013; Totani 2013; Ravi & Lasky 2014; Metzger & Zivancev 2016; Wang et al. 2016; Lyutikov 2018; Wang et al. 2018
- Early UV/optical observations
  (properties of shock-heated ejecta, jet formation,…)
  Metzger et al 2017 (arXiv:1710.05931)
- X-ray signatures
  (prior to merger from NS-NS magnetosphere interaction, crust breaking)
  (immediately after merger, extended emission or X-ray plateaus)
  (in case of a long-lived post-merger NS, there may be X-ray/UV emissions)
  Ciolfi & Siegel 2015; Metzger & Piro 2014; Siegel & Ciolfi 2015
- GRBs
  (for high total mass systems - delay *O*(ms) - *O*(10 ms))

Expected early warning rates

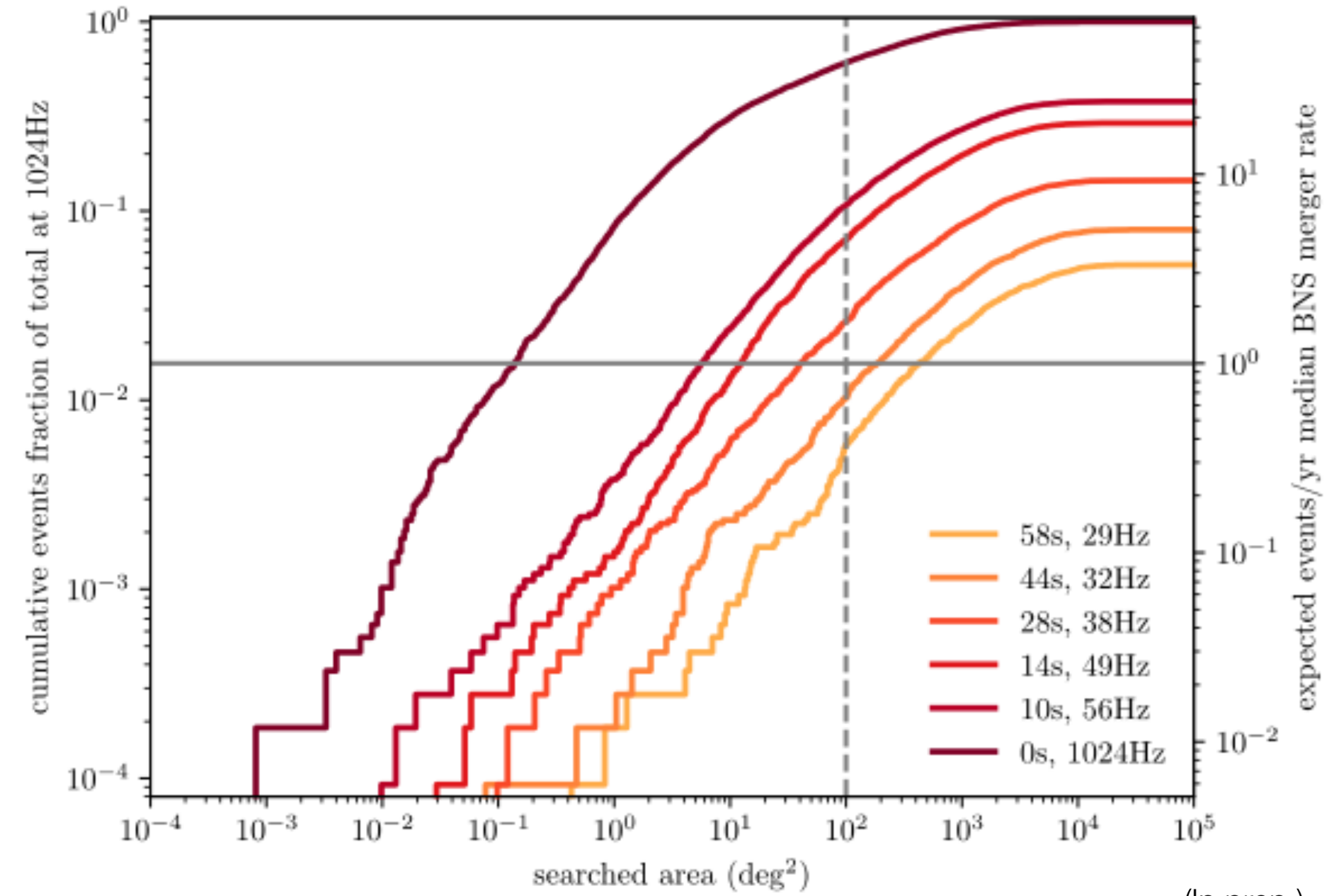
Kipp Cannon et al. 2012



The Analysis

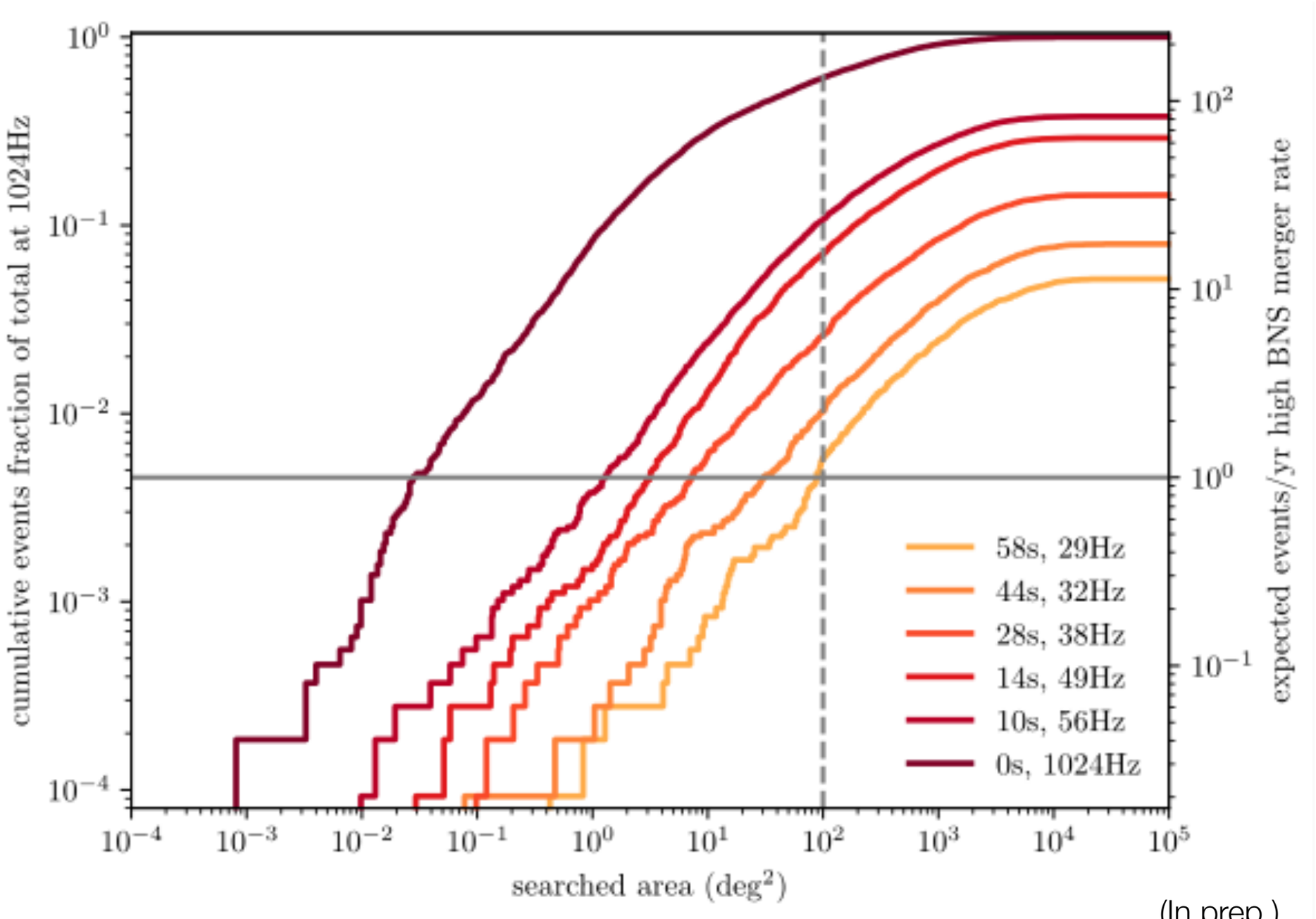
Data	~6 days of Gaussian data recolored to Advanced LIGO final design sensitivity
Network	3 detector network (Hanford, Livingston, and Virgo)
Bank	NS-NS bank (1 to 2 $M_\odot$, chirp mass between 1.04 $M_\odot$ and 1.36 $M_\odot$)
Injections	337,033 injections narrow distribution around 1.4 $M_\odot$ – 1.4 $M_\odot$ up to a redshift of 0.2 uniform in sky and comoving volume probing a spacetime volume of 0.034 Gpc^3 yr
Ending frequencies	29 Hz, 32 Hz, 38 Hz, 49 Hz, 56 Hz, 1024 Hz
Early warning times	58 s, 44 s, 28 s, 14 s, 10 s, 0 s

Num. events & sky location



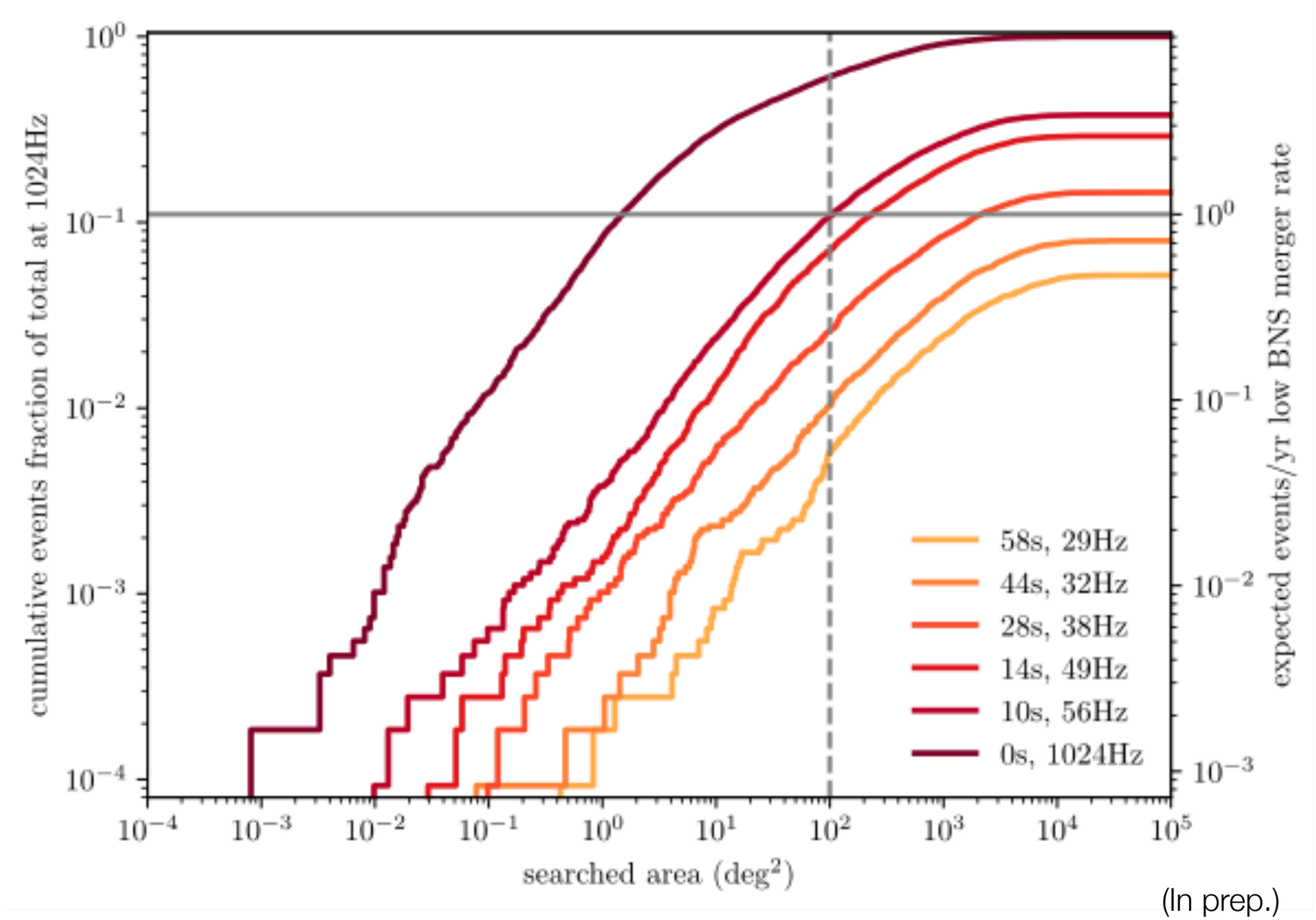
(In prep.)

Num. events & sky location



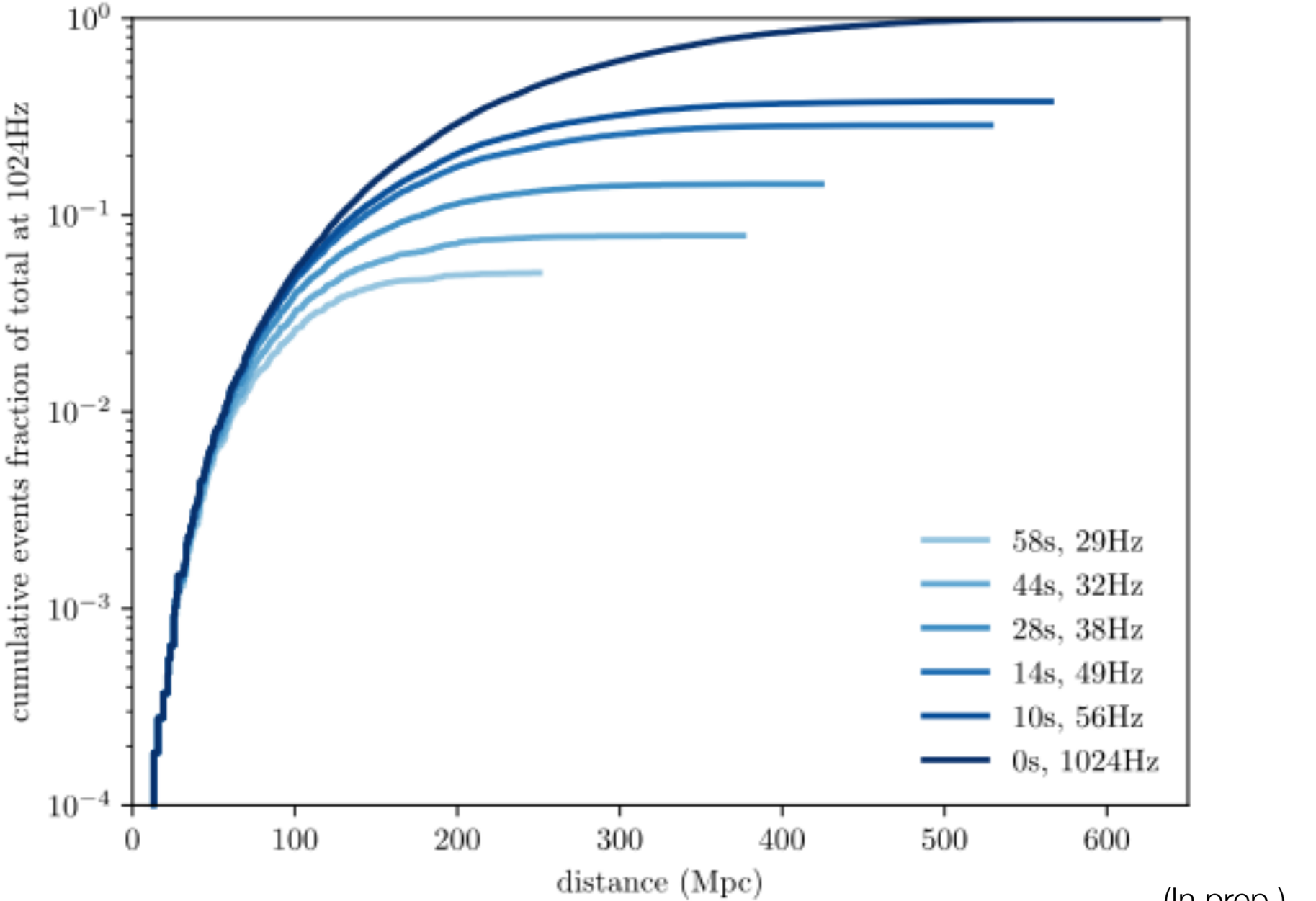
(In prep.)

Num. events & sky location



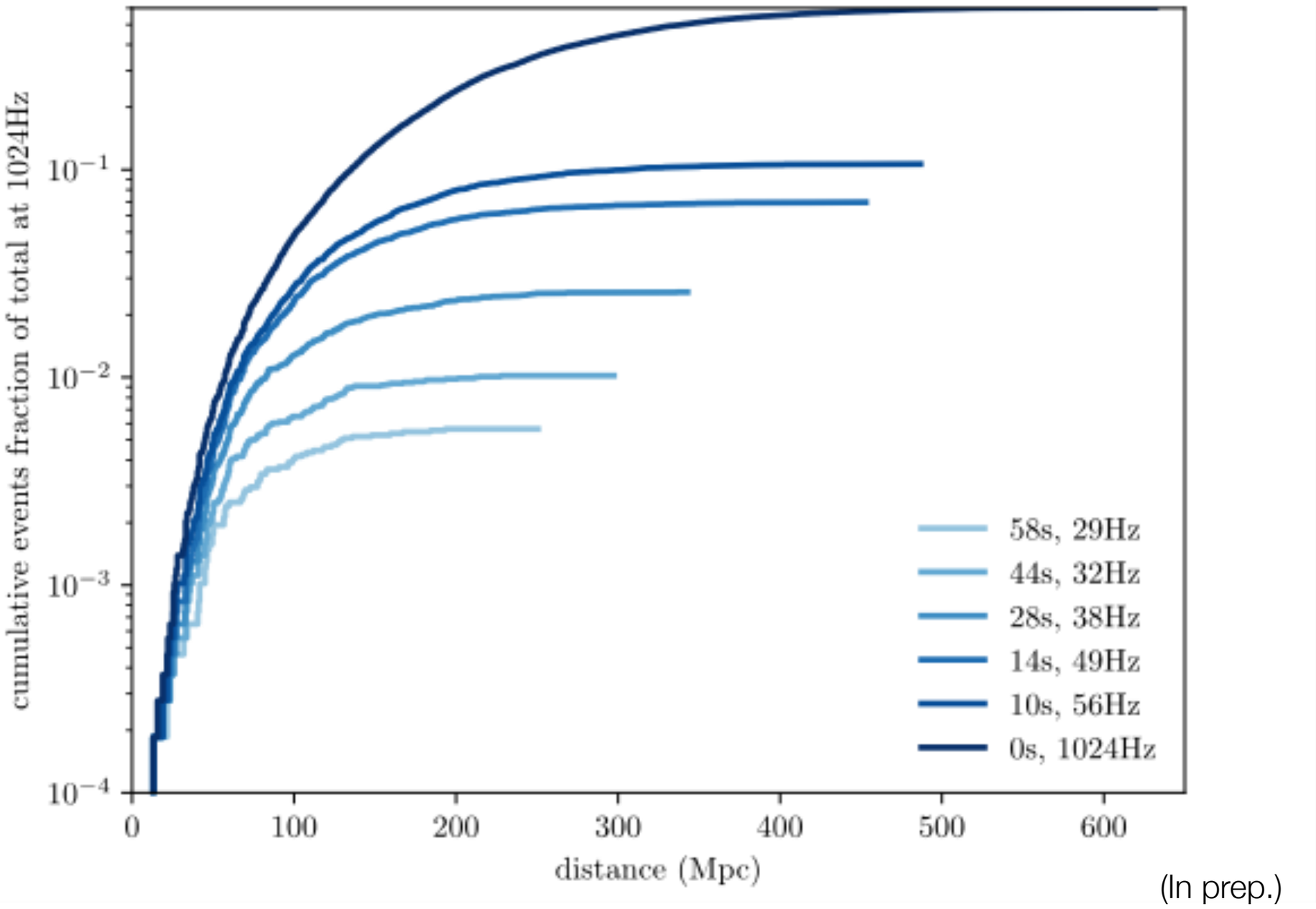
(In prep.)

Distance of events



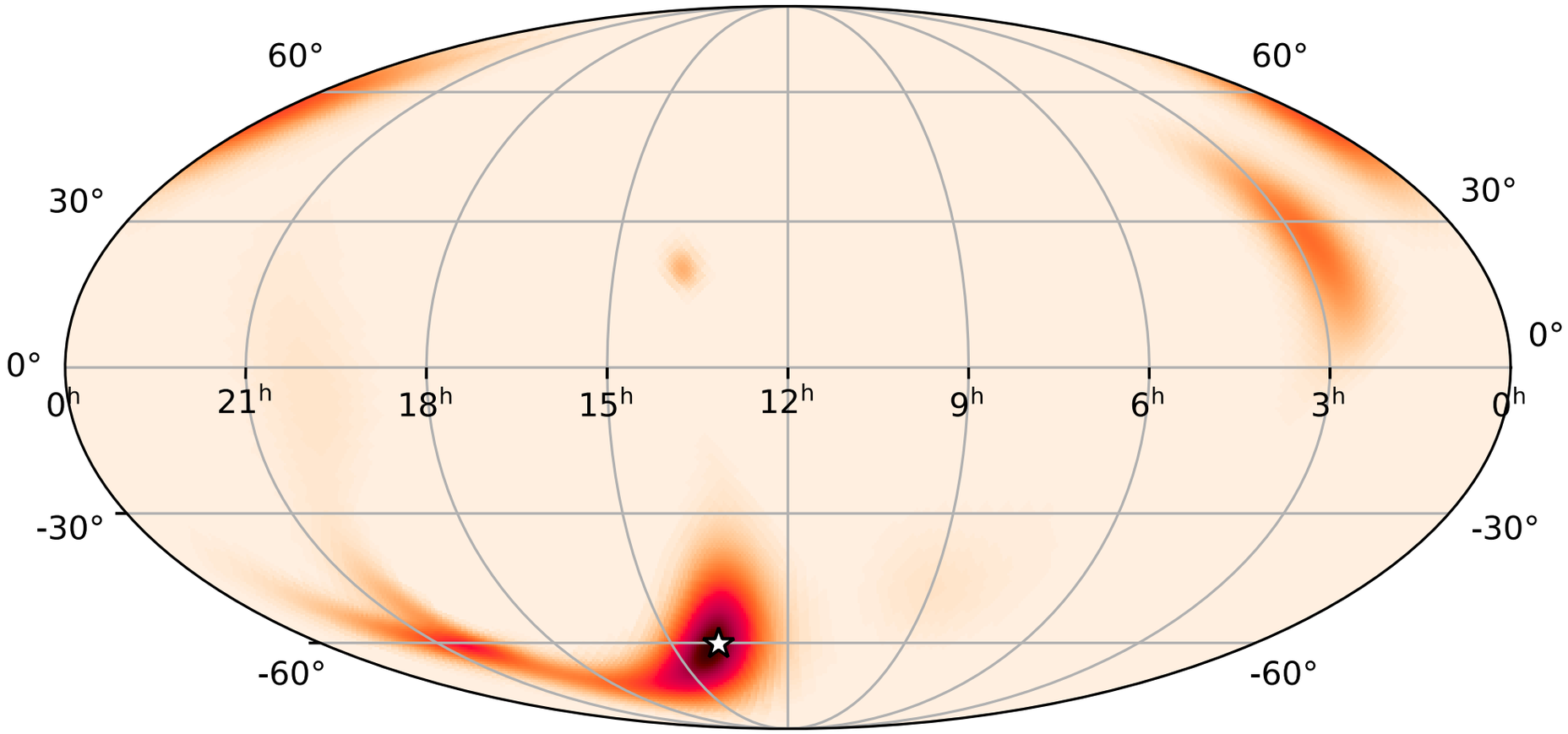
(In prep.)

Distance of events sky loc. < 100 deg^2



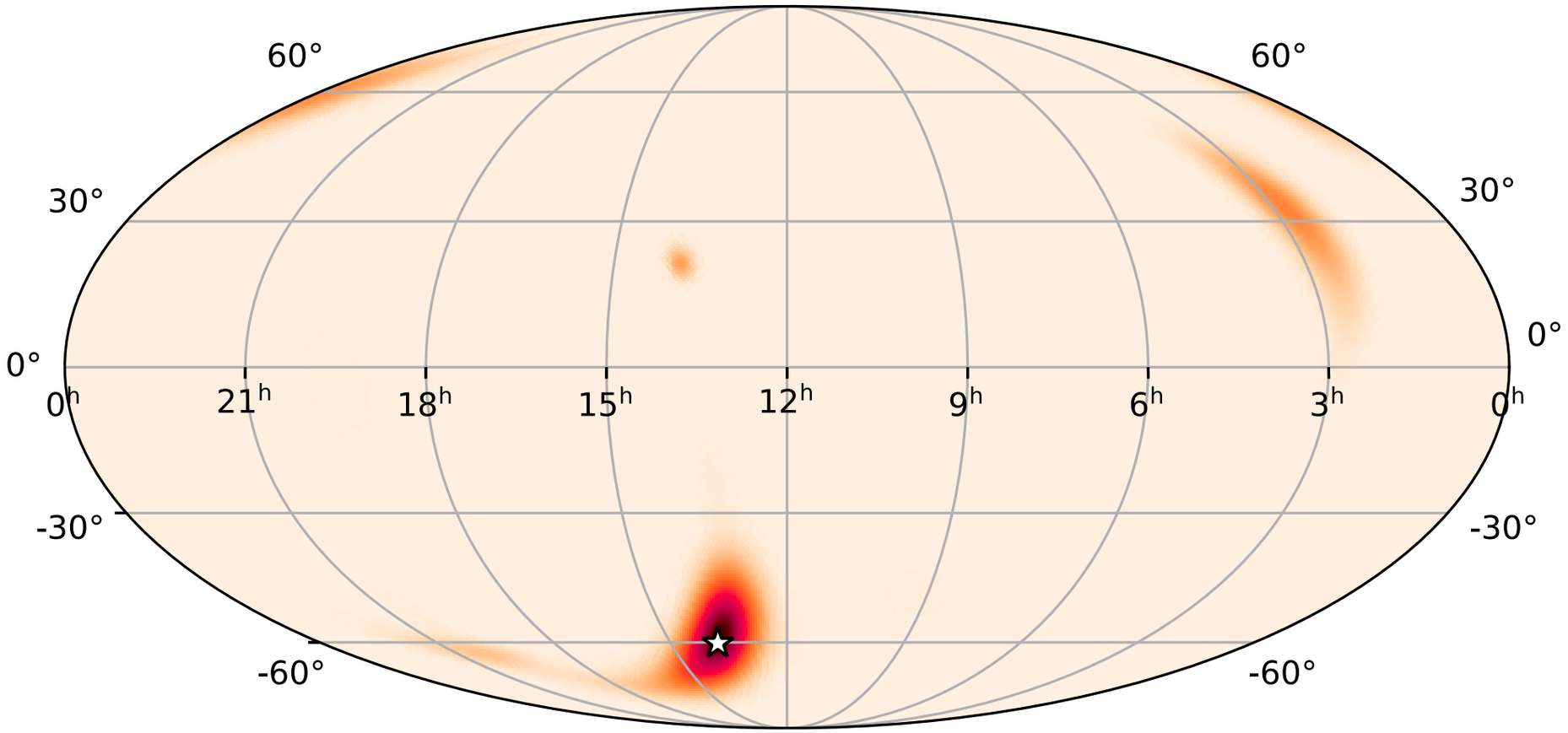
(In prep.)

Example sky map 29 Hz



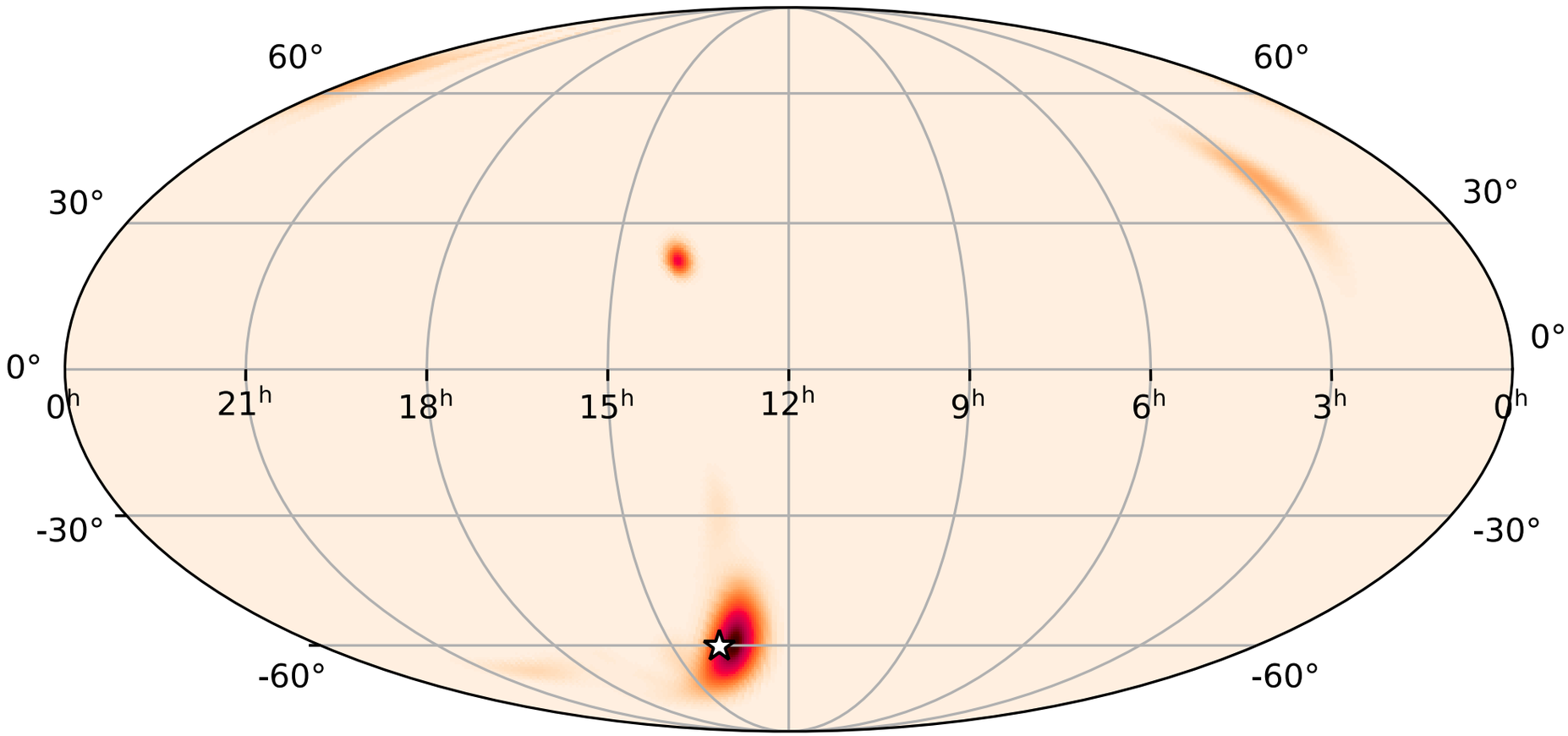
Sky maps created using BAYESTAR

Example sky map 32 Hz



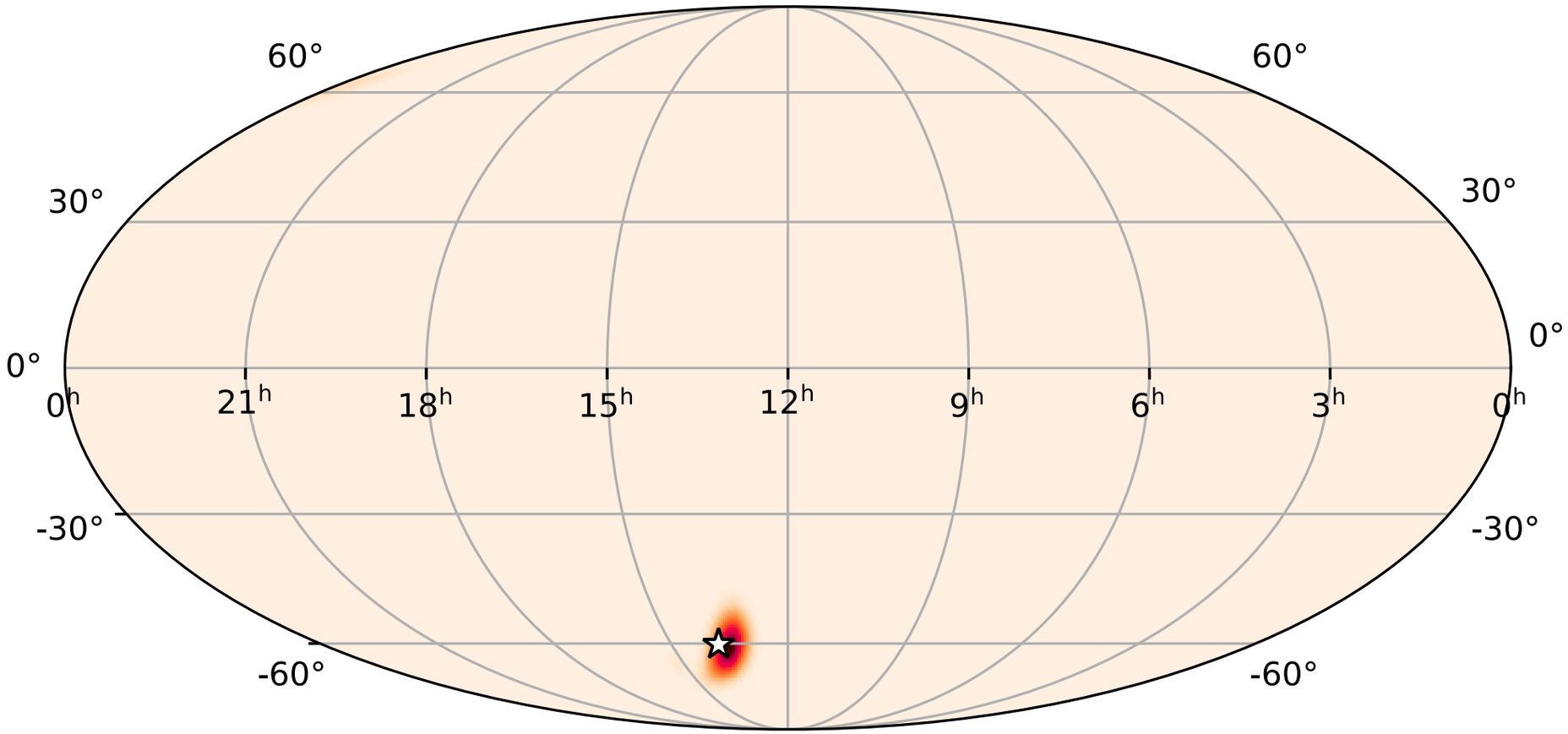
Sky maps created using BAYESTAR

Example sky map 38 Hz



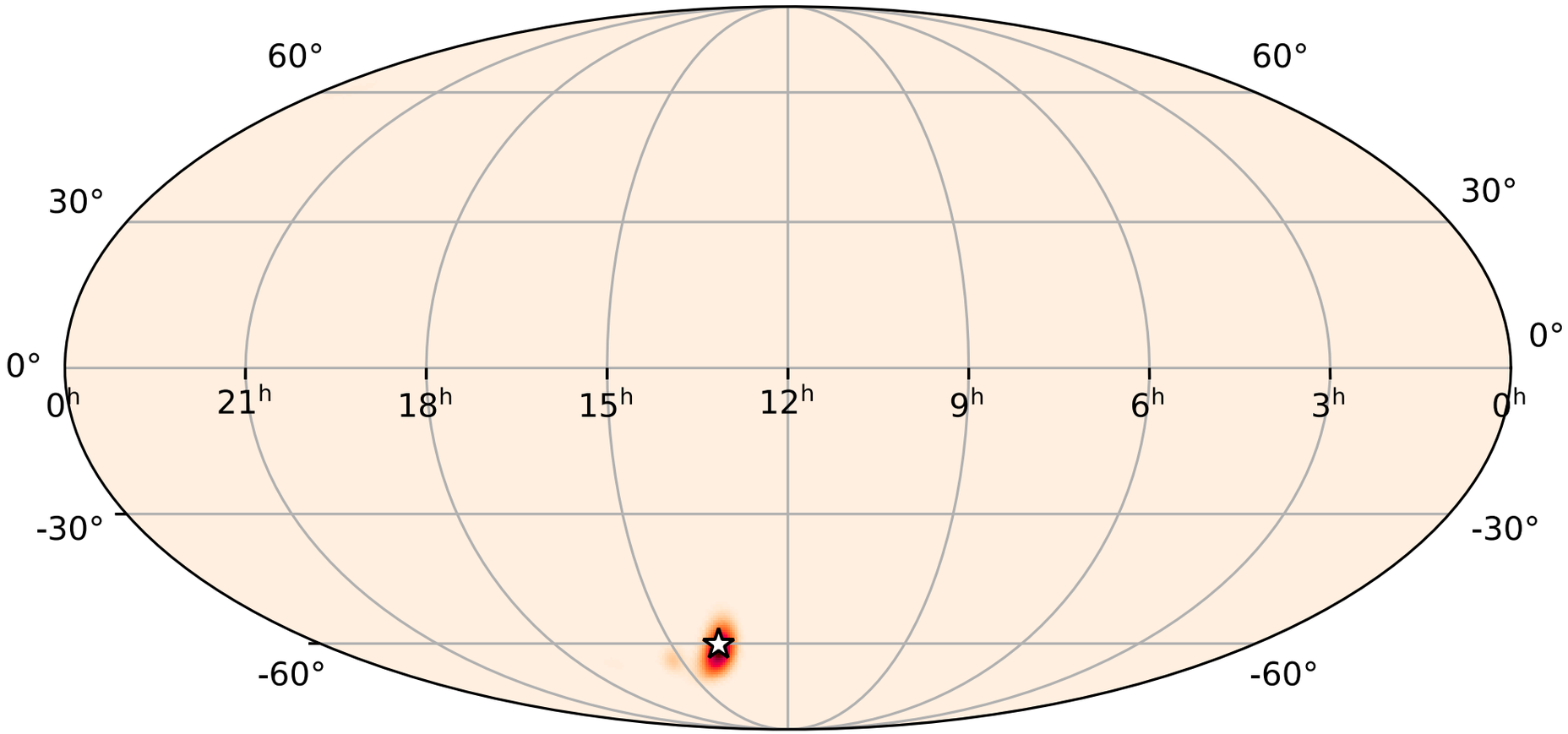
Sky maps created using BAYESTAR

Example sky map 49 Hz



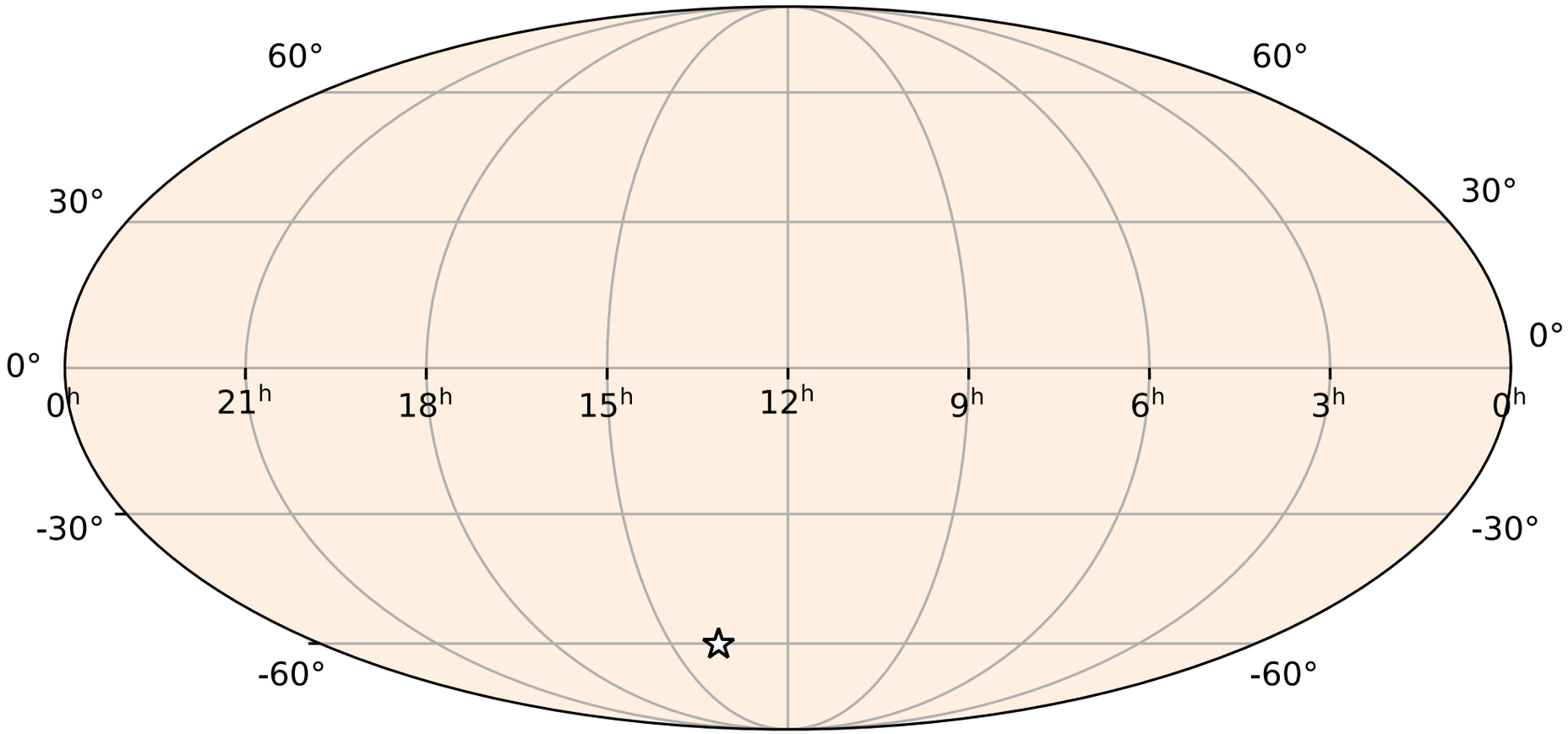
Sky maps created using BAYESTAR

Example sky map 56 Hz



Sky maps created using BAYESTAR

Example sky map 1024 Hz



Sky maps created using BAYESTAR

Future considerations for EW

- Latency (pipeline, data transfer, calibration)
- Tuning the χ^2 test
- Testing and deploying

Acknowledgements

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Thank you ☺️