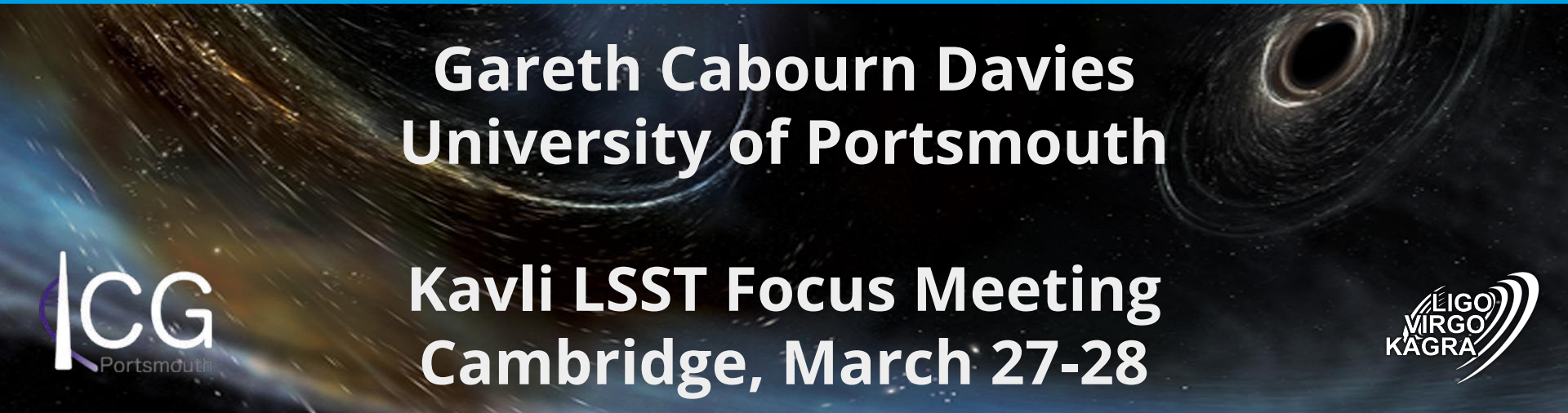
UNIVERSITY OF PORTSMOUTH

PyCBC

Searches for gravitational waves and multi-messenger observations



Gareth Cabourn Davies
University of Portsmouth

Kavli LSST Focus Meeting
Cambridge, March 27-28

ICG Portsmouth

LIGO VIRGO KAGRA

Overview

- Where are we? When are we?
- Sources of Gravitational Waves
- Searches for Gravitational Waves
  - Gravitational-wave searches in low latency
  - Archival Gravitational-wave searches
- Multi-messenger counterparts to gravitational waves
- Signals seen during O3
- Expected signals during O4 and O5
- Beyond O5

An approximate over-view of where we are

Where are we?

LISA (2030s)

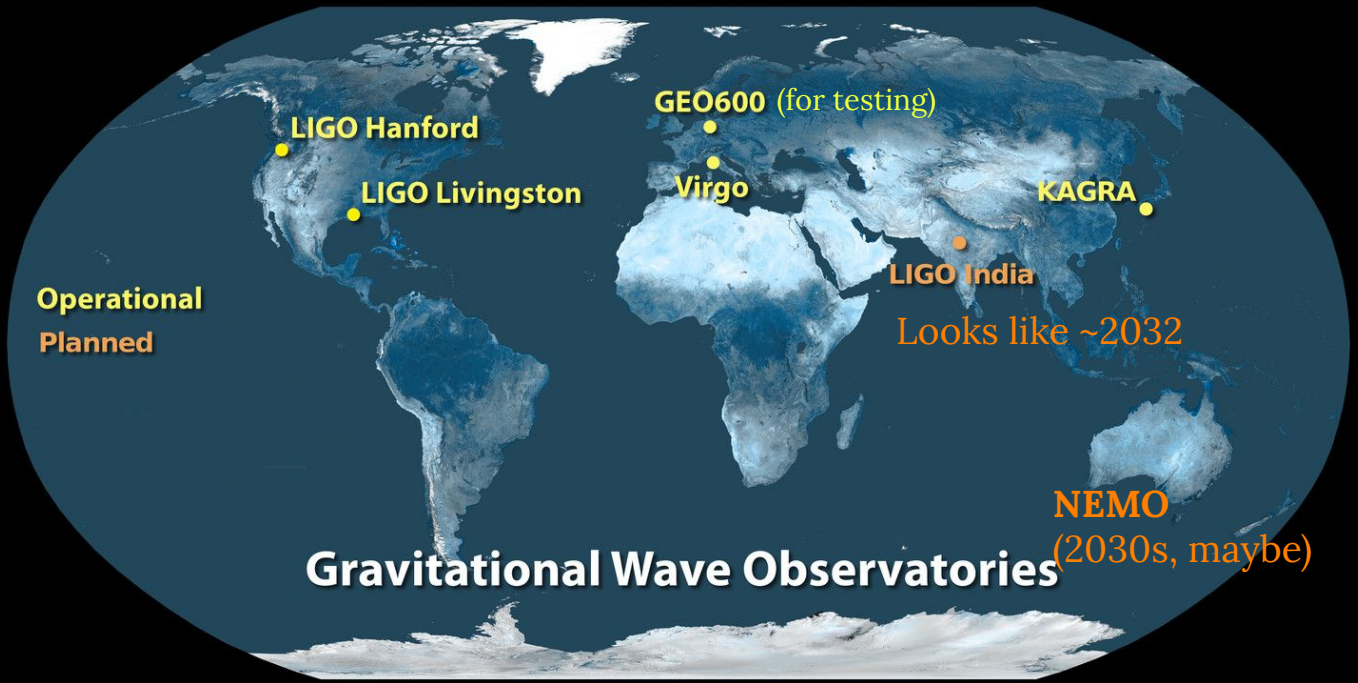


Image credit: Caltech

Overview - timeline

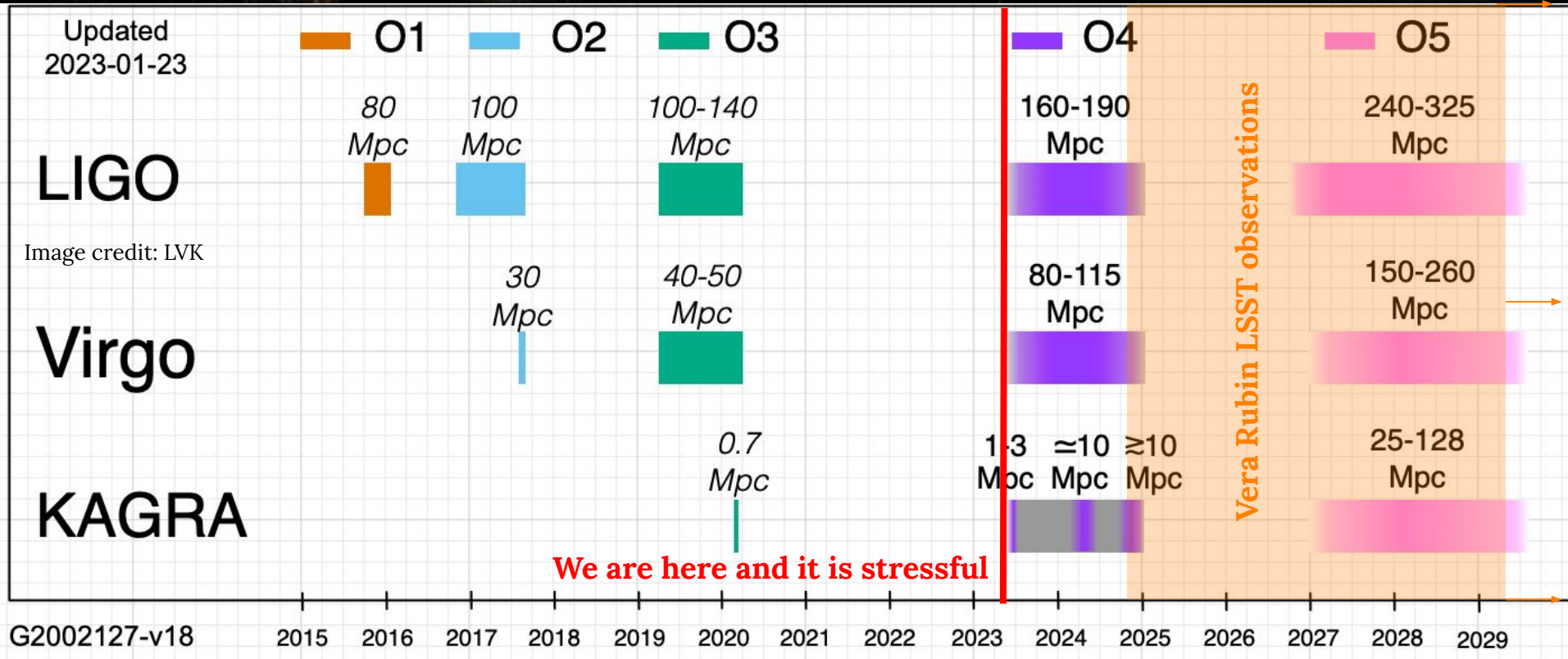


Image credit: LVK


SOURCES OF GRAVITATIONAL WAVES

Compact Binary Coalescence

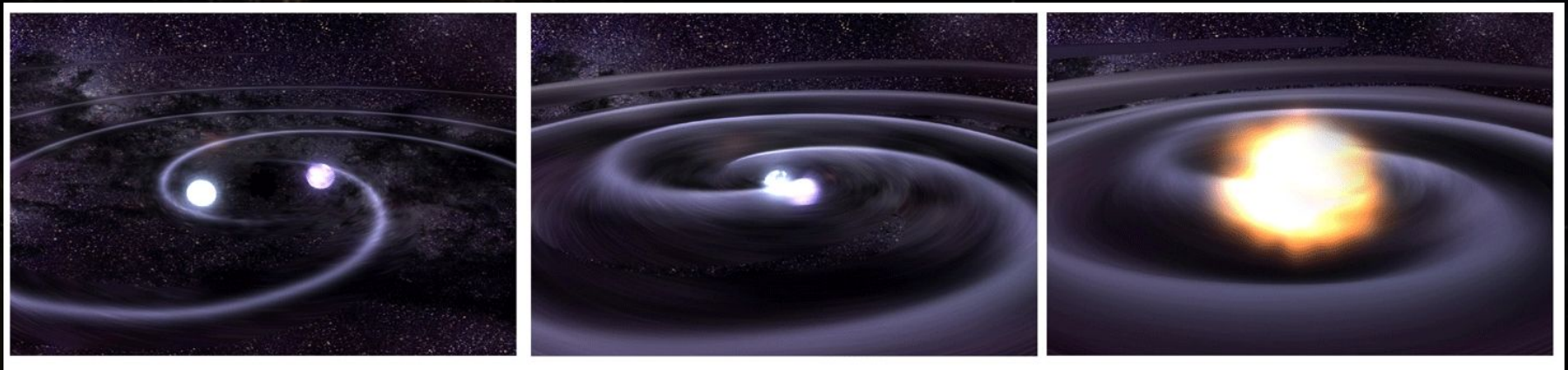
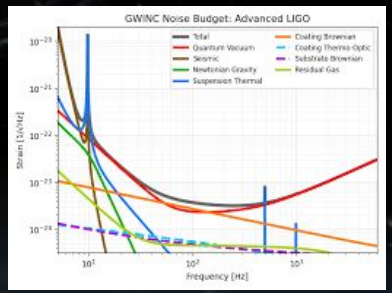


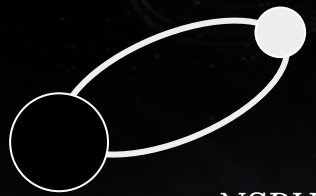
Image: NASA

Two compact objects inspiral, merge (and ringdown, but we can't really see this as it is too high frequency)

BBH

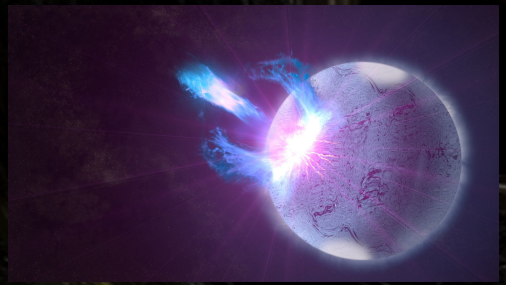
BNS





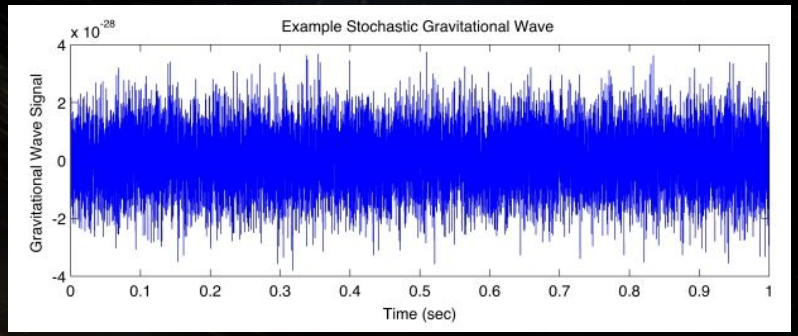
NSBH

Other Sources



Bursts

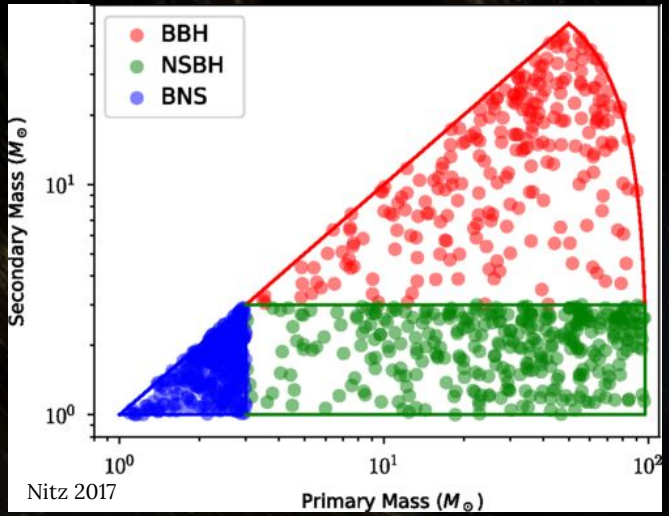
Continuous Waves



Stochastic Background

SEARCHES FOR GRAVITATIONAL-WAVES

Generating Triggers



Nitz 2017

- Decide on a set of templates to compare to the data
- Simplify the signal based on leading-order contributions
  - Aligned spins
  - Face-on binary
  - No eccentricity
- Use matched filter to obtain peaks in SNR (below)

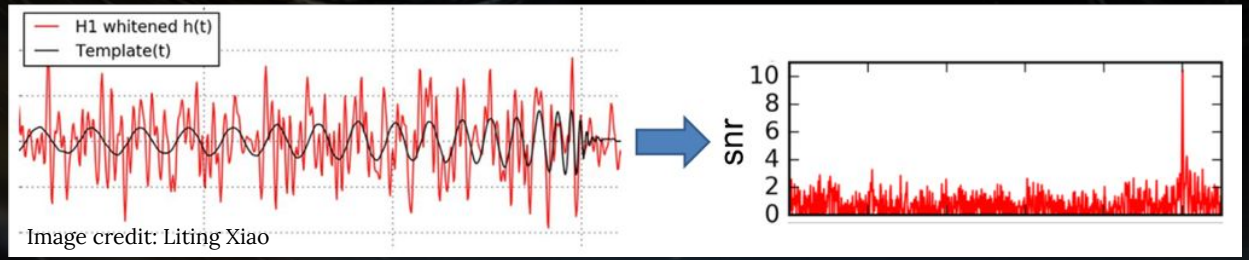


Image credit: Liting Xiao

Low-latency vs Archival Searches

Low-latency

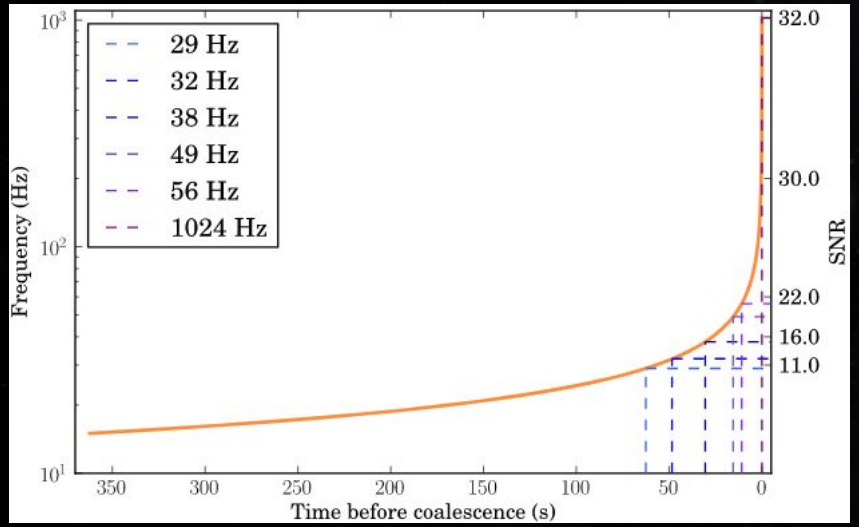
- Uses streamed data
- (Relatively) straightforward statistics about the triggers to assess events
- Fewer templates, more gaps in parameter space, more possible to miss signals

Archival Searches

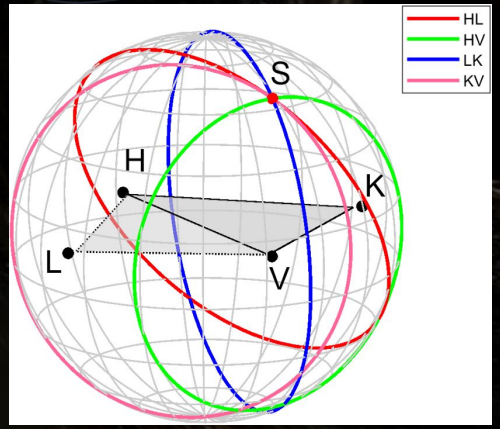
- Uses saved data with updated calibration and detector characterisation information
- More complicated search algorithms and signal consistency tests
- Many many injections to assess sensitivity

NEW!!! EARLY-WARNING ALERTS

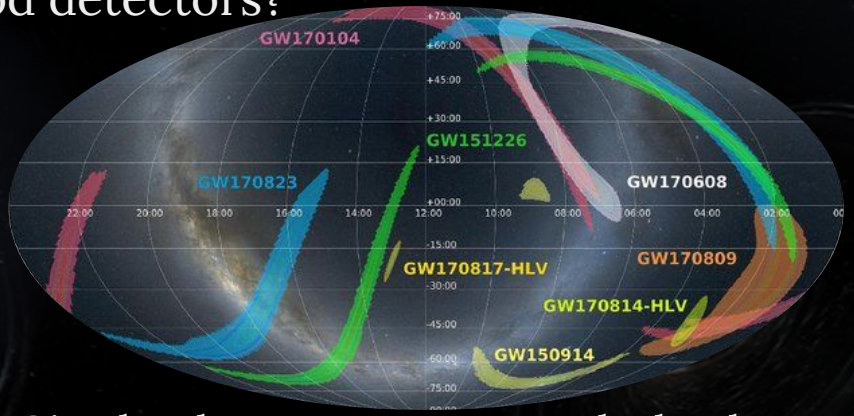
- By using truncated waveforms in the low-latency search, we can get results out ***before*** the merger!
- Possible to get alerts out so that telescopes (e.g. GOTO) can quickly turn and observe the merger
- More likely is that we get the signal early and we can get alerts out so telescopes can start turning towards the approximate area. Full search then gets more accurate skymap and see more of the EM signal



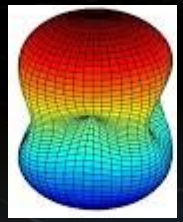
Localisation



I.e. why does it matter that there are three good detectors?

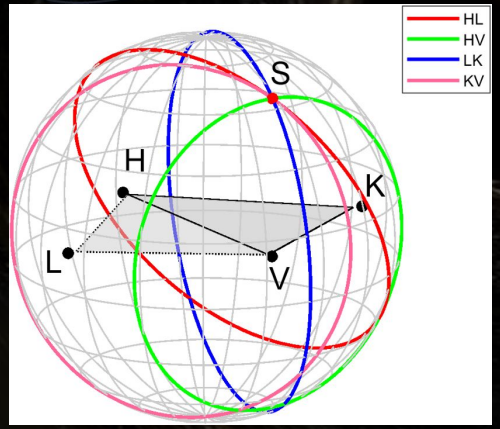


- Single-detector event = whole sky (except blind spots)
- 2-detectors: thousands of deg^2
- 3 detectors: a few hundred deg^2

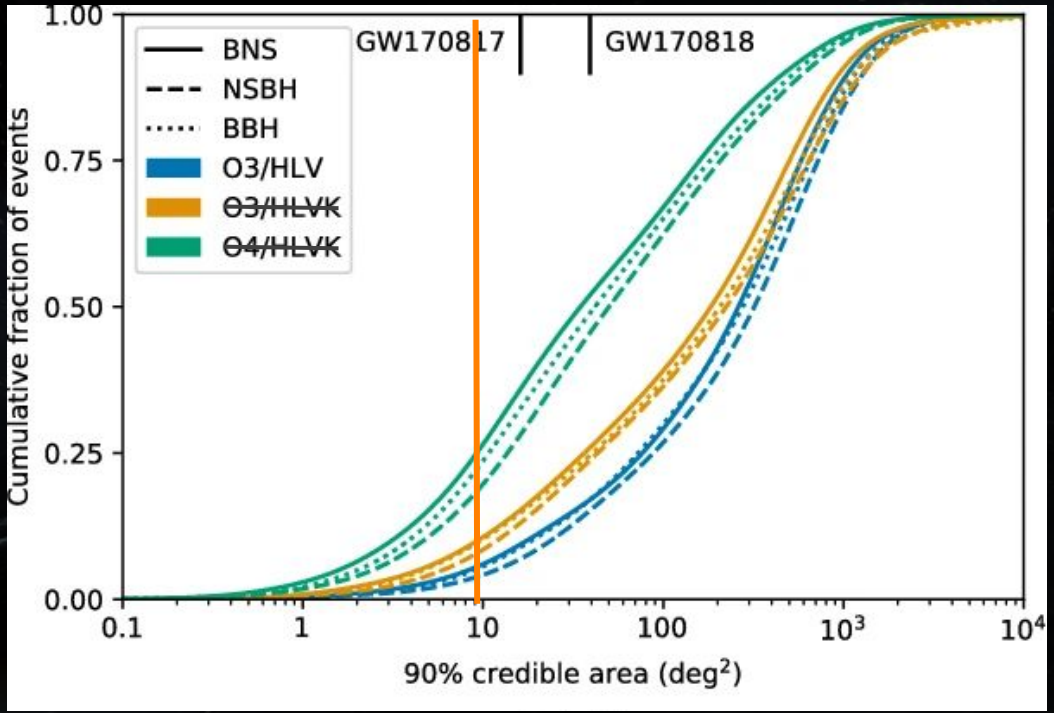


Images: Abbott et al 2020 (prospects), Disney/Pixar

Localisation



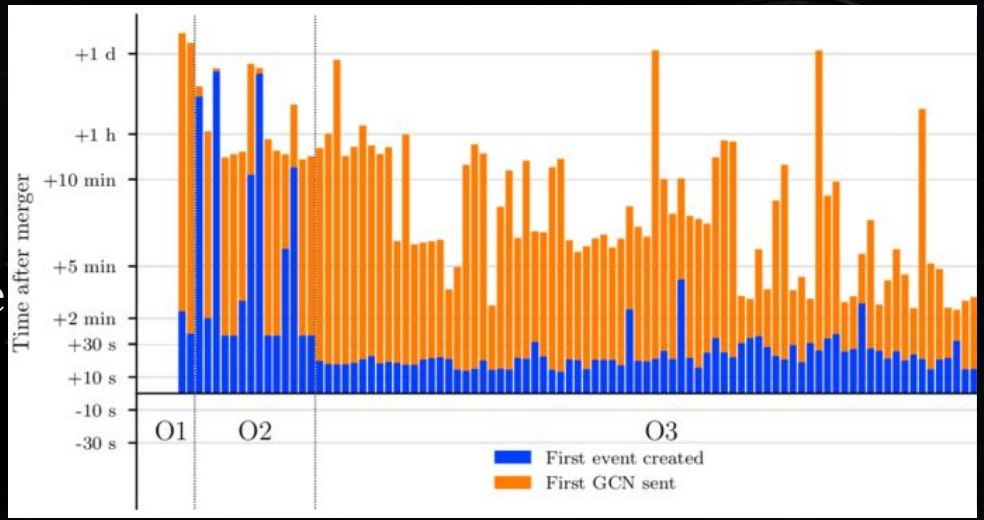
LSST field of view



Images: Abbott et al 2020 (prospects), Disney/Pixar

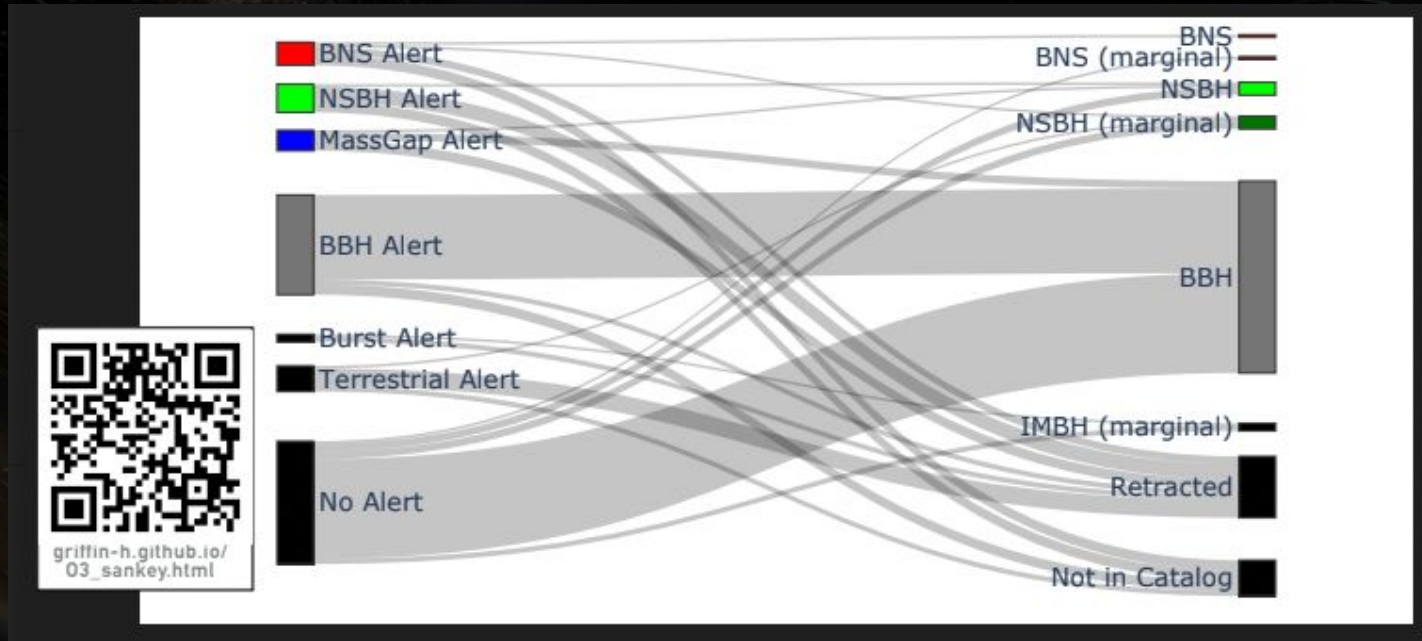
Alerts

- Four modelled, two unmodelled searches in low latency
  - Additional searches to compare to
- Released through NASA GCN system - alerts and human-readable notices
- Generally a few seconds up to a minute to create event, a bit more to send alerts



Do we see online events, offline?

Many alerts are not found in archival searches, many without alerts are found offline (this is more expected)



Beyond O5

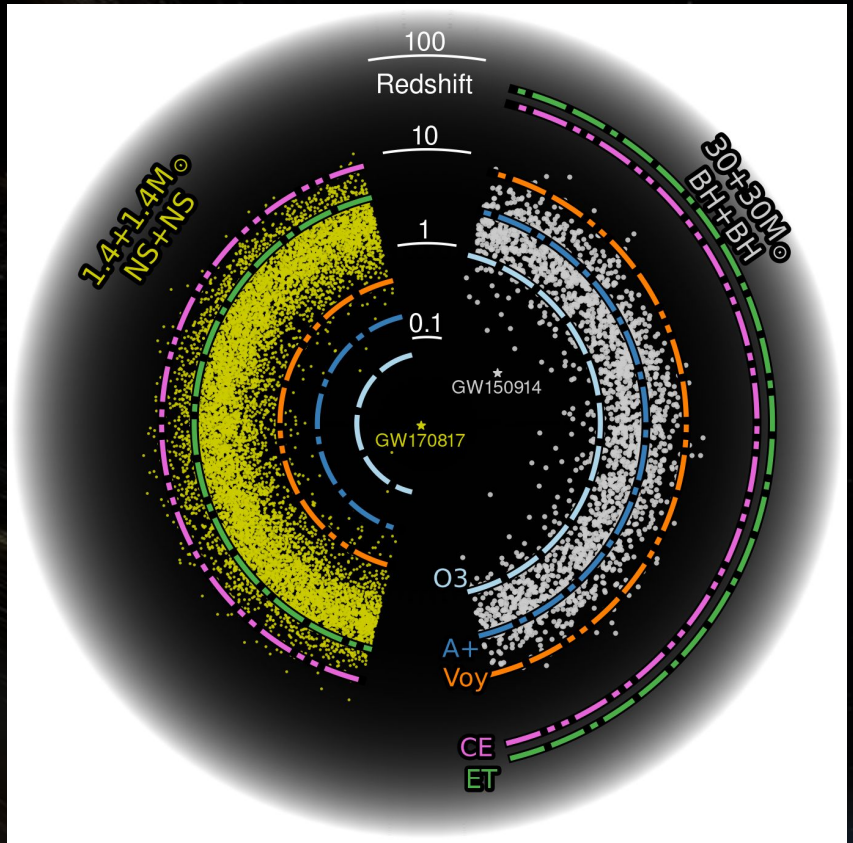


Image credit - can't remember, kicking around in my downloads

Expected events in the future

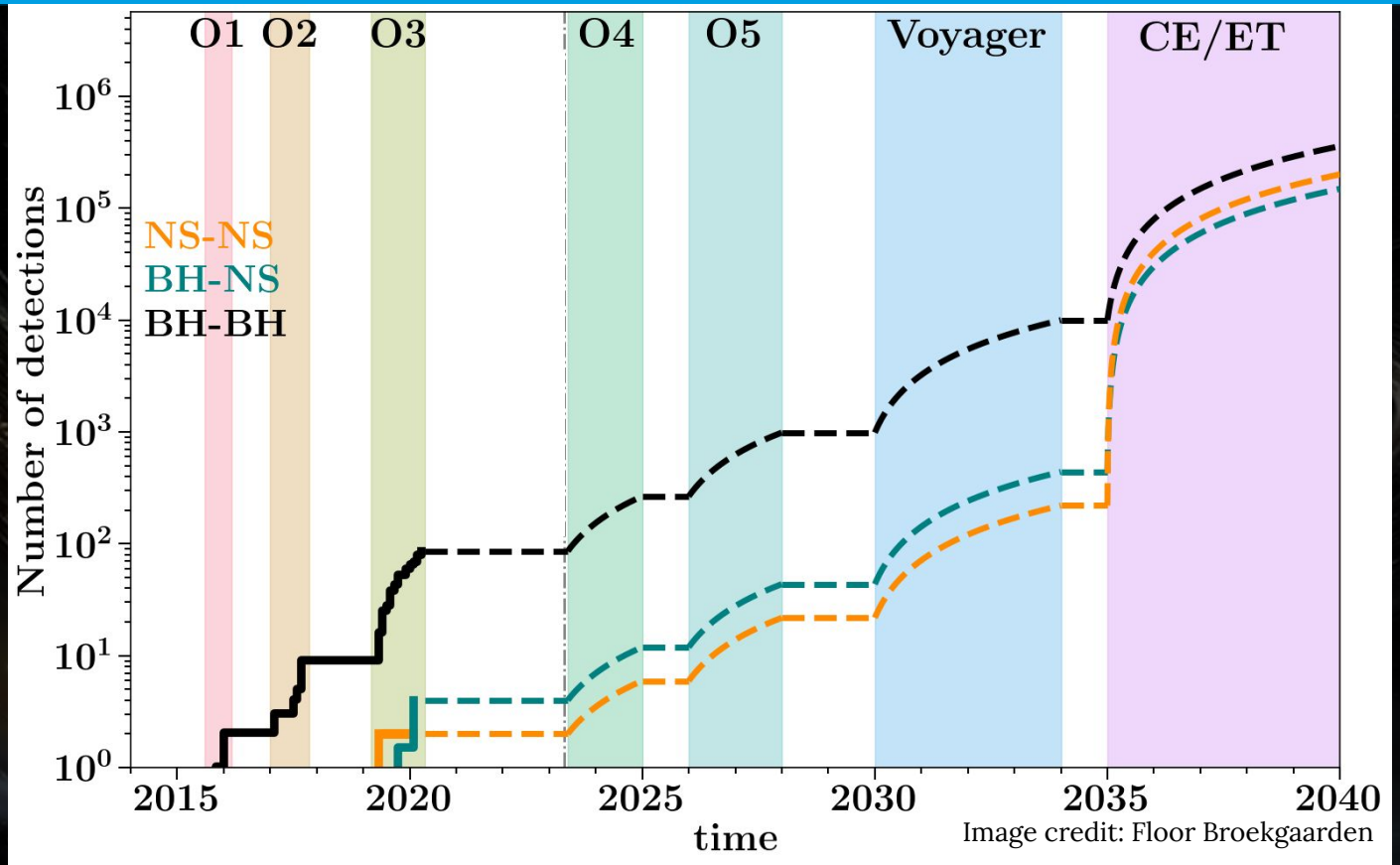


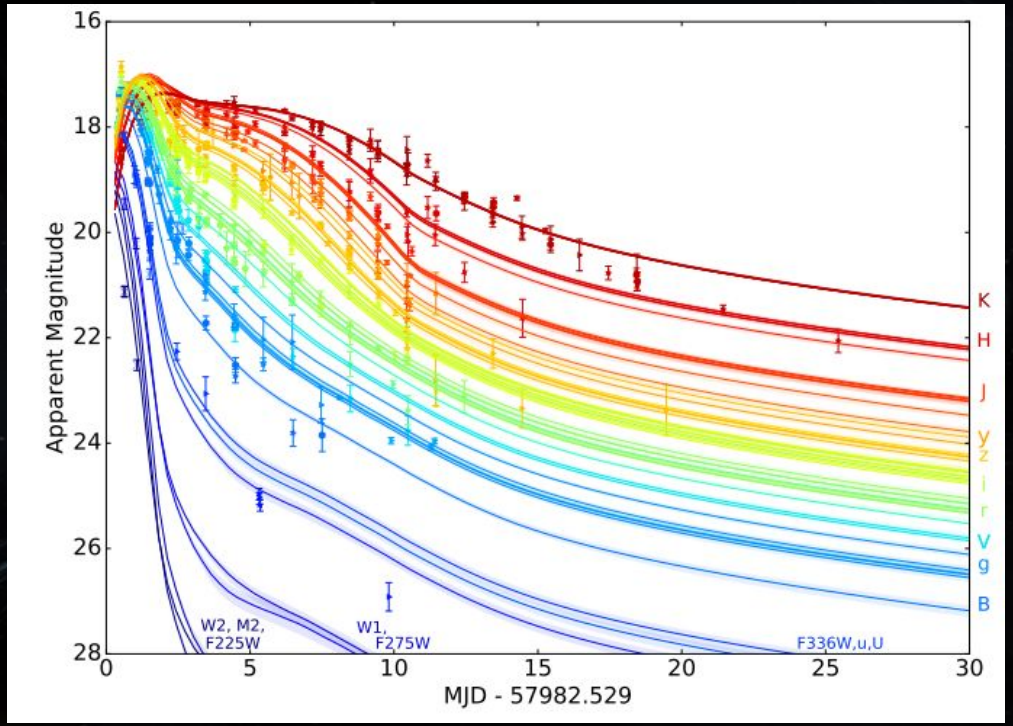
Image credit: Floor Broekgaarden

EM Counterparts to GW signals

Counterparts - Kilonovae

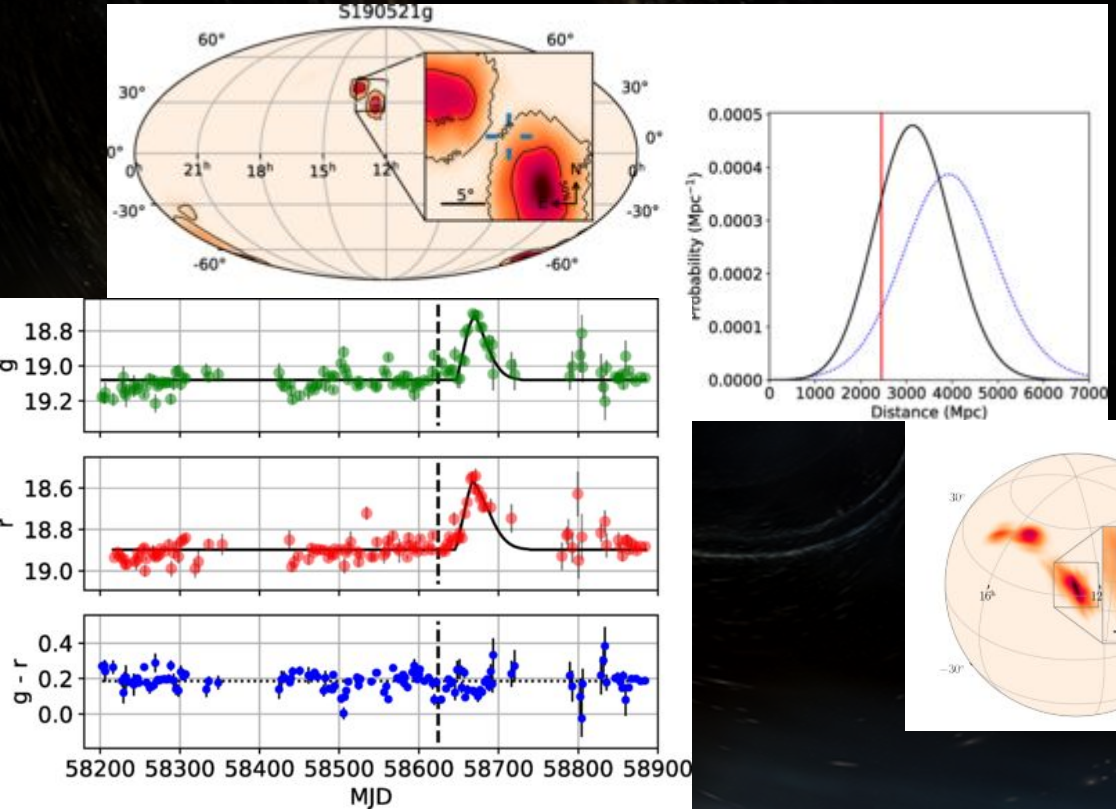
Visible in many many wavelengths

Duration depends on the band, but a few days at least

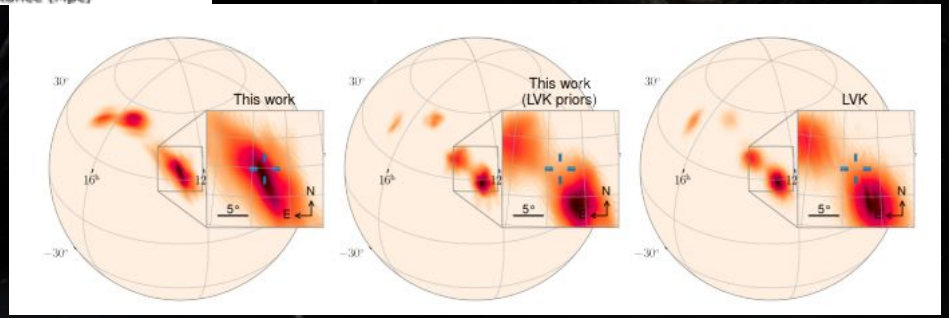


Villar et al 2017, AT2017gfo / GW170817 light curves

Counterparts - AGN?

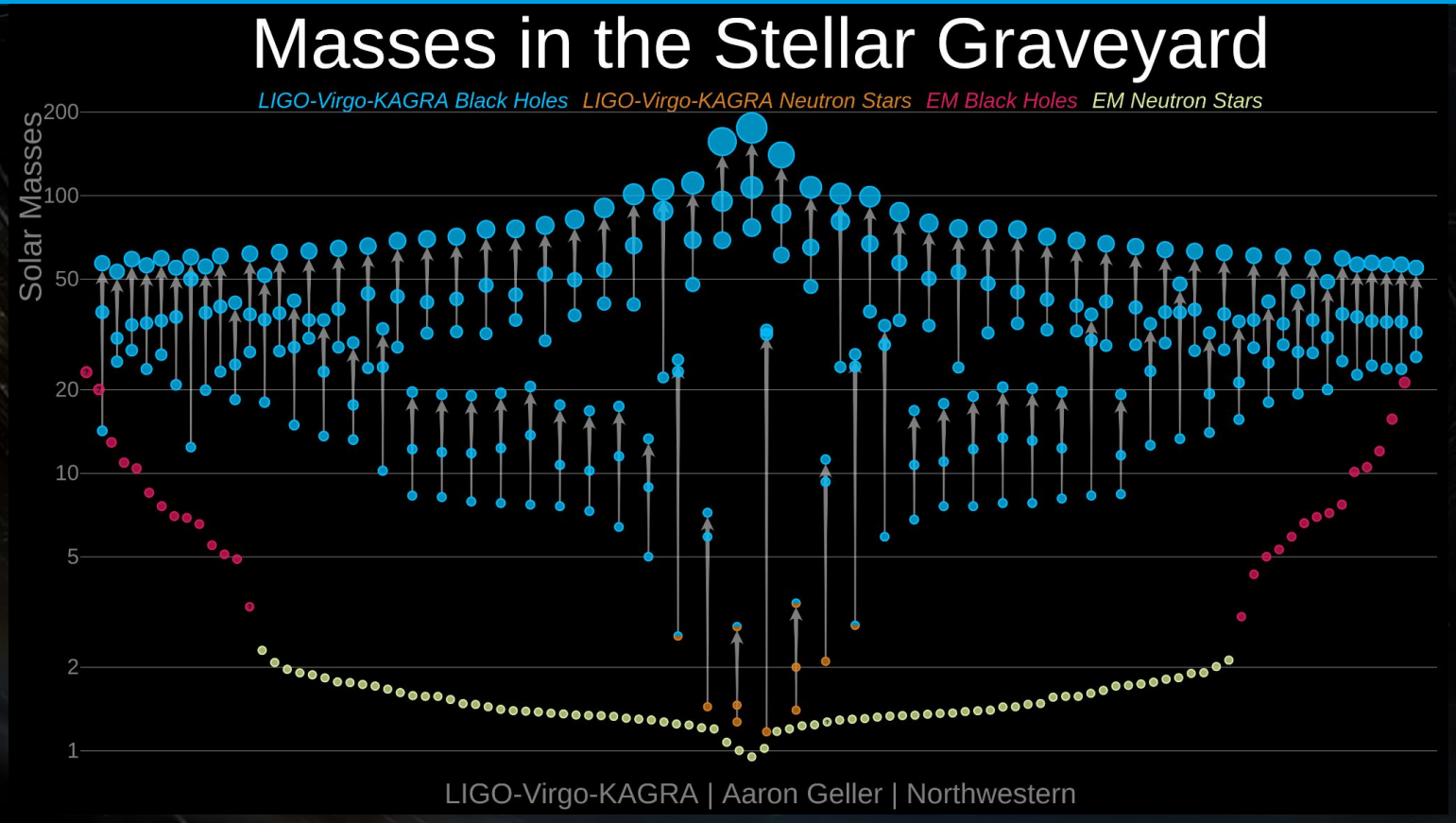


- Graham et al. 2020
- Plausible AGN ZTF19abanrhr
- “electromagnetic flare is consistent with expectations for a kicked binary black hole merger in the accretion disk of an active galactic nucleus and is unlikely due to intrinsic variability of this source”



Calderon-Bustillo et al, 2021
Revisits sky-maps and shows better agreement

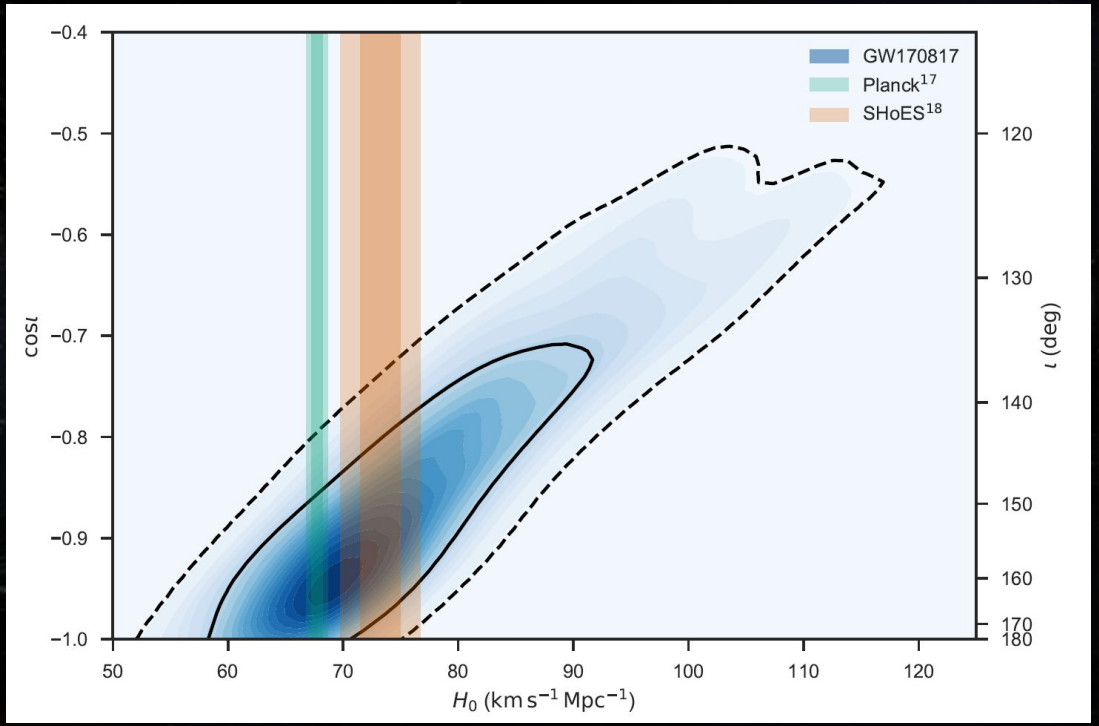
What have we seen up to now?




COSMOLOGY WITH CBCs

Can GWs solve the Hubble tension?

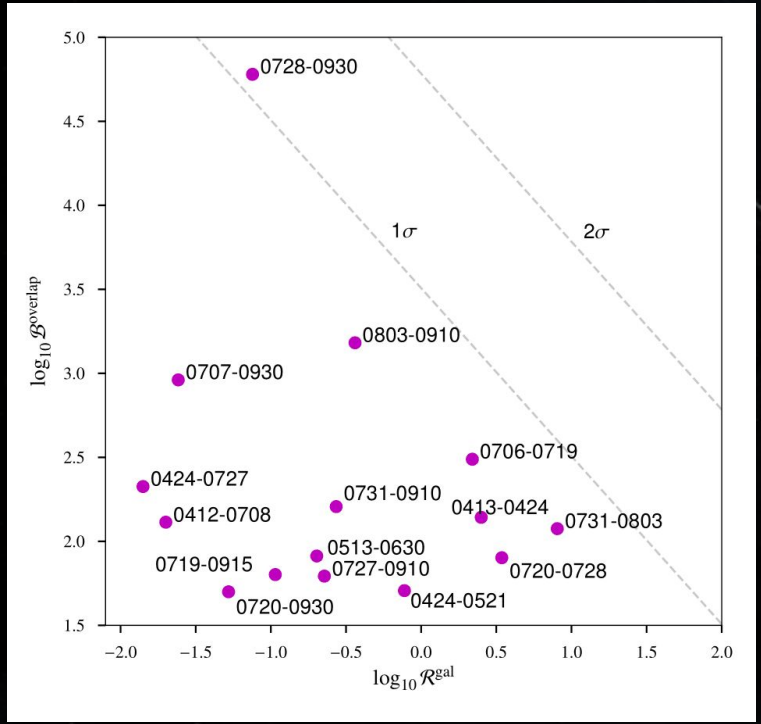
- Yes - eventually
  - With just one joint EM-GW kilonova signal (GW170817/AT2017gfo), we can constrain Hubble to be in the range ~50-120. Need more to solve any tensions
- Dark Sirens - GW signals correlated to galaxy catalogues can provide an additional statistical test for this
  - Catalogue completeness is an issue with this though



Lensed GWs

1. Strong lensing: Compare detected events to see if they have the same sky location and intrinsic parameters within errors
2. Microlensing will produce small beat patterns within the signals - use Bayesian Inference to see whether these are preferred over other mechanisms

Not seen anything so far



A REQUEST

- Outside the LVK, everyone misses out Virgo from papers/talks etc.
  - If you, or any paper you are involved with, want to discuss GW observations. PLEASE include Virgo!
  - Virgo is NEEDED for localisation
  - They are underfunded enough already, and lack of visibility only exacerbates things

Summary

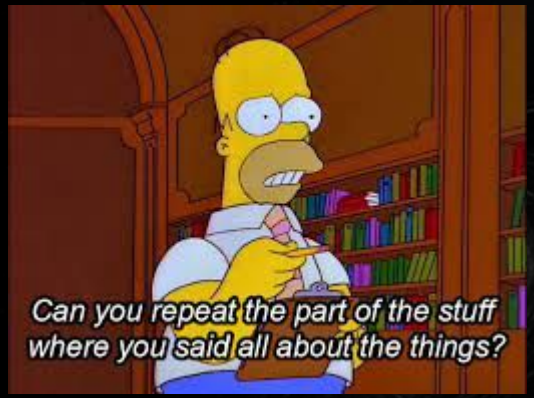
Gravitational wave signals - there should be lots

We search using matched-filtering to find peaks in SNR, and then compare these peaks across detectors

Alerts sent in low latency - maybe some early-warning alerts soon!

EM counterparts can be seen from binary neutron stars (and NSBHs)

Counterparts can help us to produce H_0 measurements



QUESTIONS?