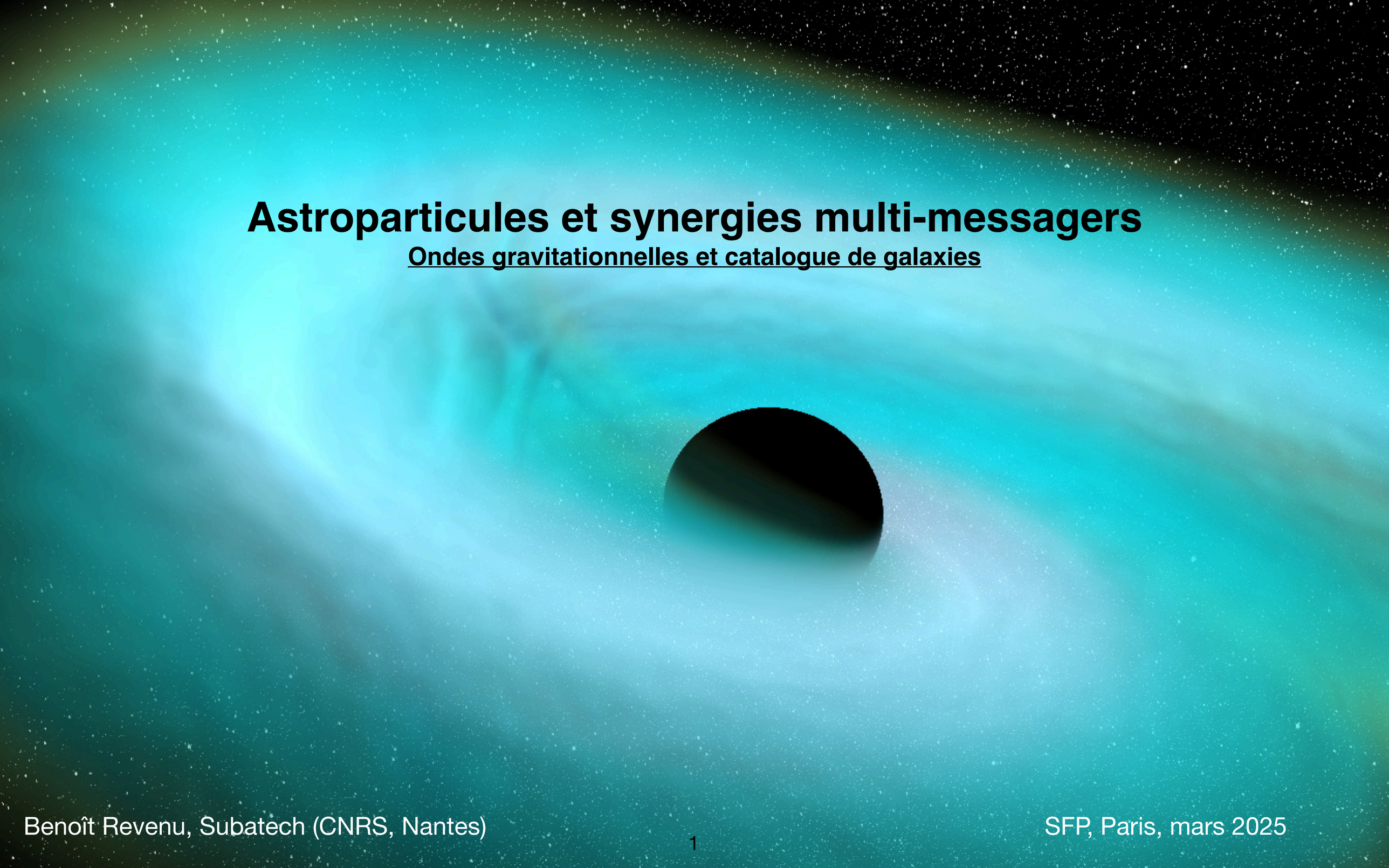
Astroparticules et synergies multi-messagers

Ondes gravitationnelles et catalogue de galaxies



Benoît Revenu, Subatech (CNRS, Nantes)

SFP, Paris, mars 2025

GW, cosmology and galaxies

- **bright sirens**
- **dark sirens: spectral analysis**
- **dark sirens: galaxy catalogue analysis**
- **development of new galaxy catalogues**

GWs and cosmological parameters

In a flat LCDM model, d_L is related to cosmology:

$$d_L = \frac{(1+z)\,c}{H_0}\int_0^z \frac{\mathrm{d}z'}{\sqrt{\Omega_m(1+z')^3+\Omega_\Lambda}} \overset{z\ll 1}{\approx} \frac{c\,z}{H_0}$$

if we know d_L and z then we can measure H_0, Ω_m and Ω_Λ
GW data provides d_L

need information on z

bright siren: the host galaxy is known: the redshift is fixed

spectral analysis: features in the mass spectrum give some constraint on the GW redshift

galaxy catalogue analysis: use the features in the mass spectrum **and** the redshift of the possible host galaxies

Assumption: CBCs are hosted in galaxies

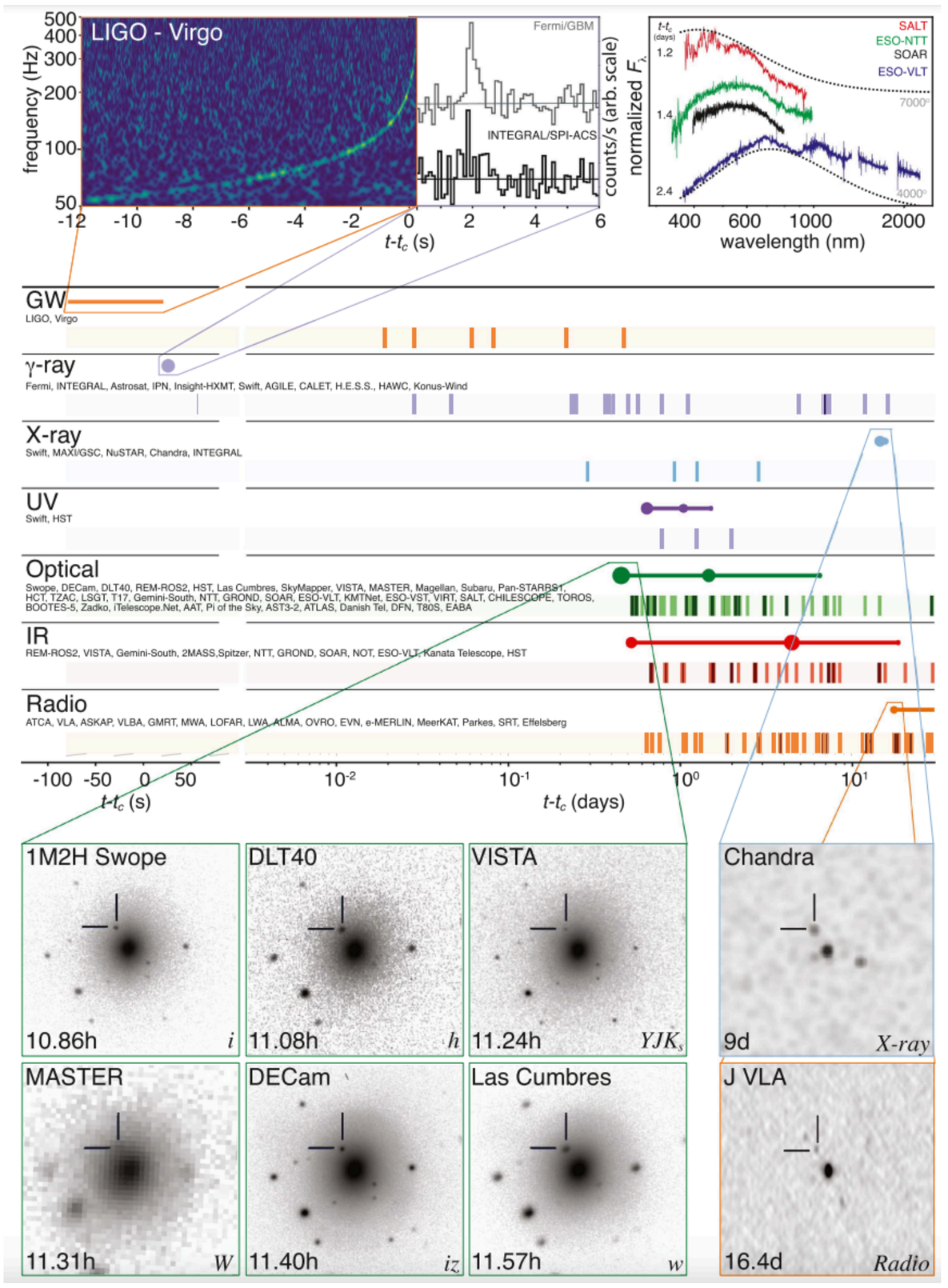
Bright siren: GW170817

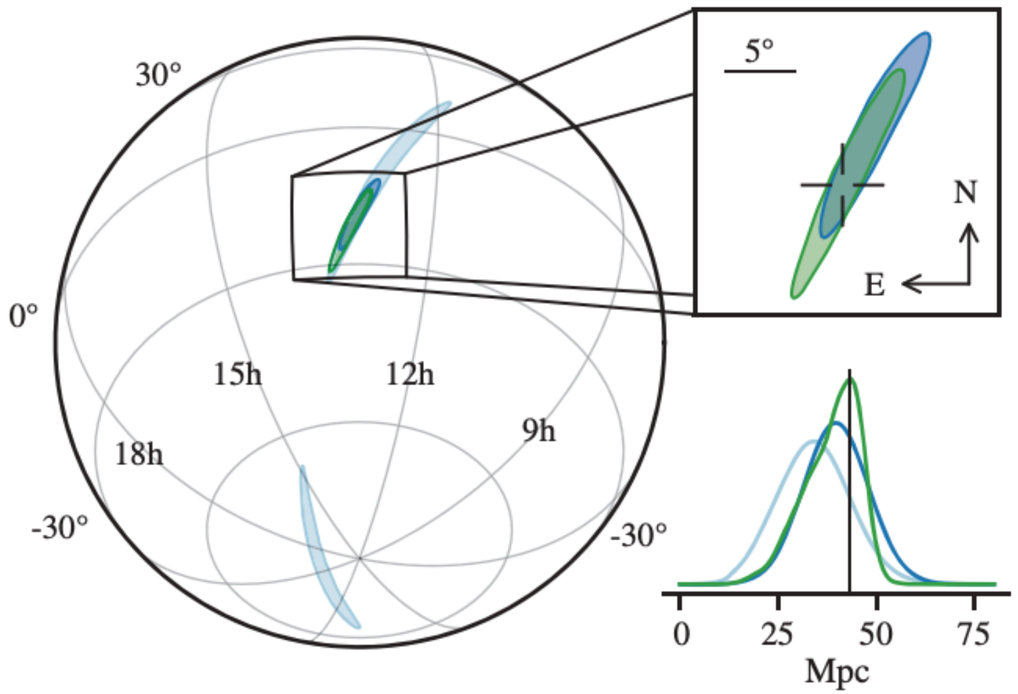
host galaxy: **NGC4993**
44.1 Mpc
redshift is known!
z = 0.0097
ra, dec are known!

$$H_0 = \frac{c\,z}{d_L}$$

detection of the kilonova

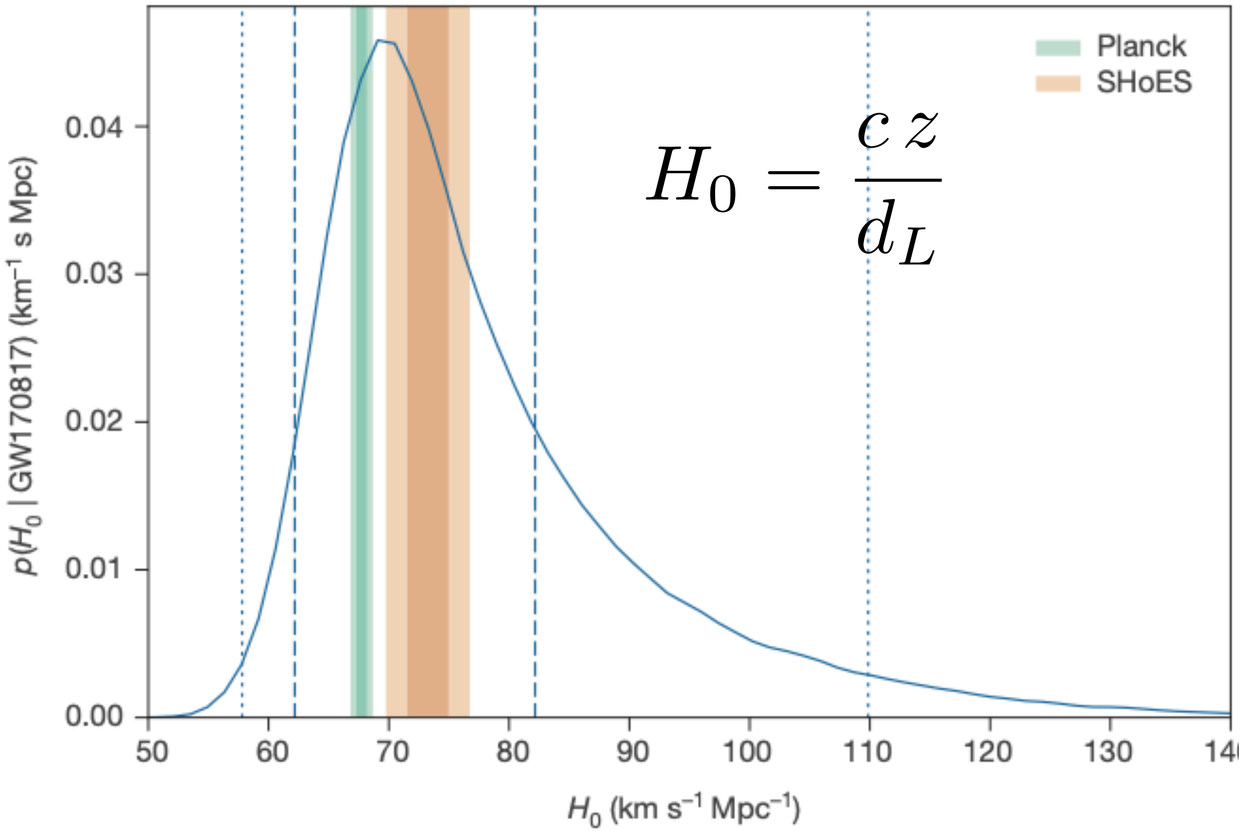
$m_1 \sim 1.5\ M_\odot$
$m_2 \sim 1.3\ M_\odot$
$d_L \sim 40$ Mpc

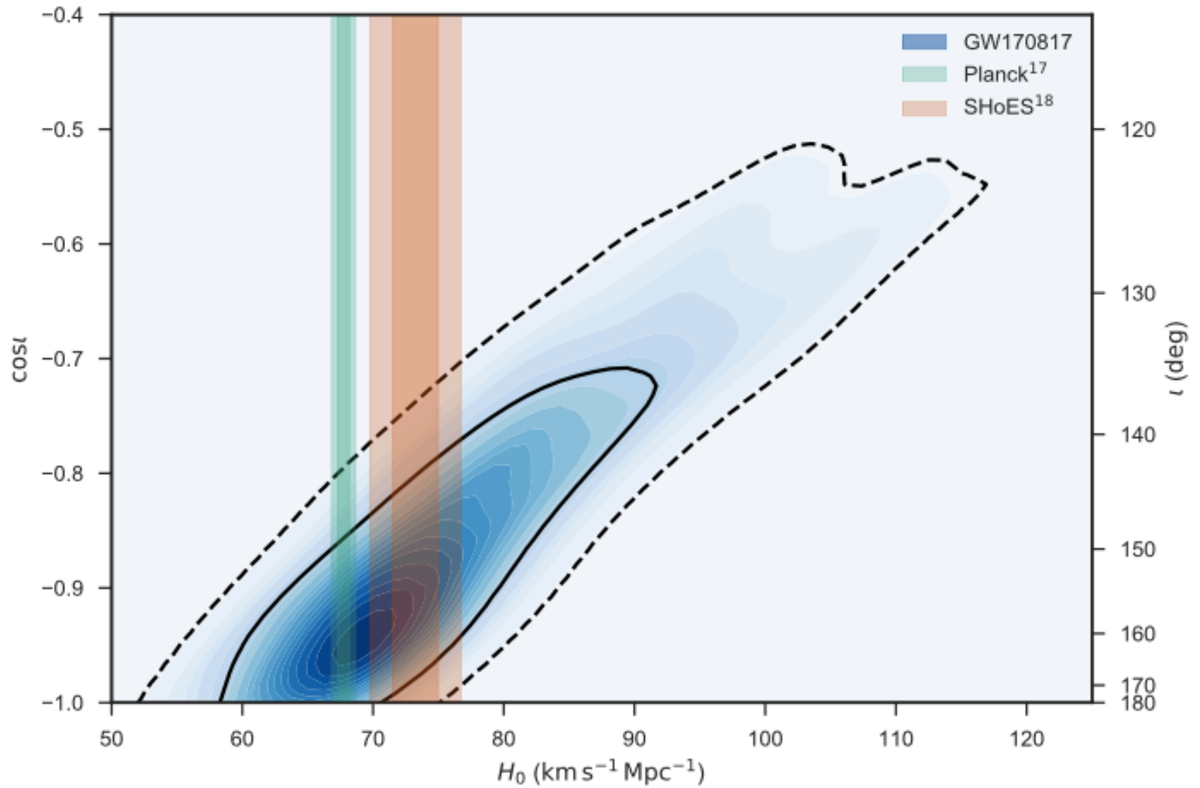




Bright siren: GW170817

Abbott et al. *Nature* 551, 85-88 (2017),
Abbott et al. PRX 9, 011001 2019



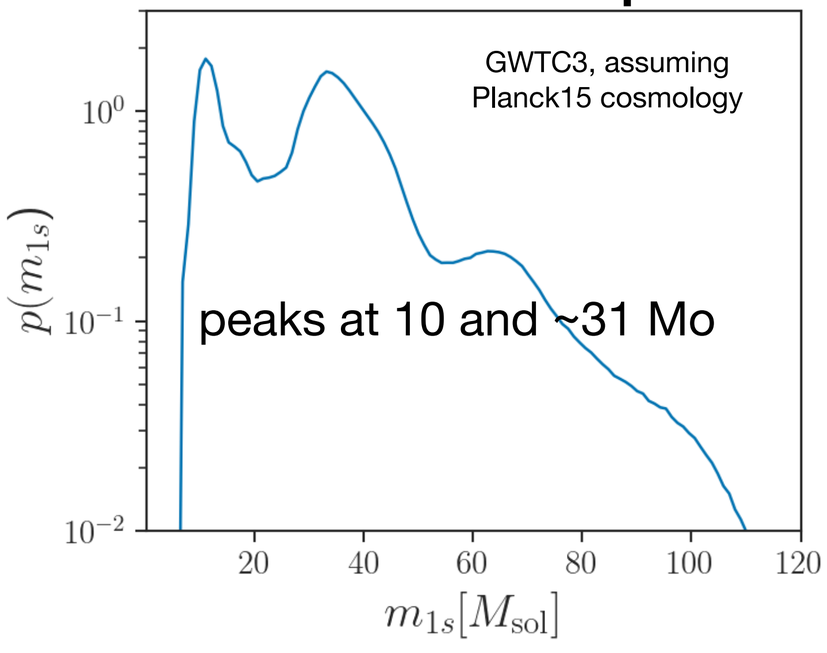


electromagnetic information can provide additional information on the inclination and help to break the degeneracy

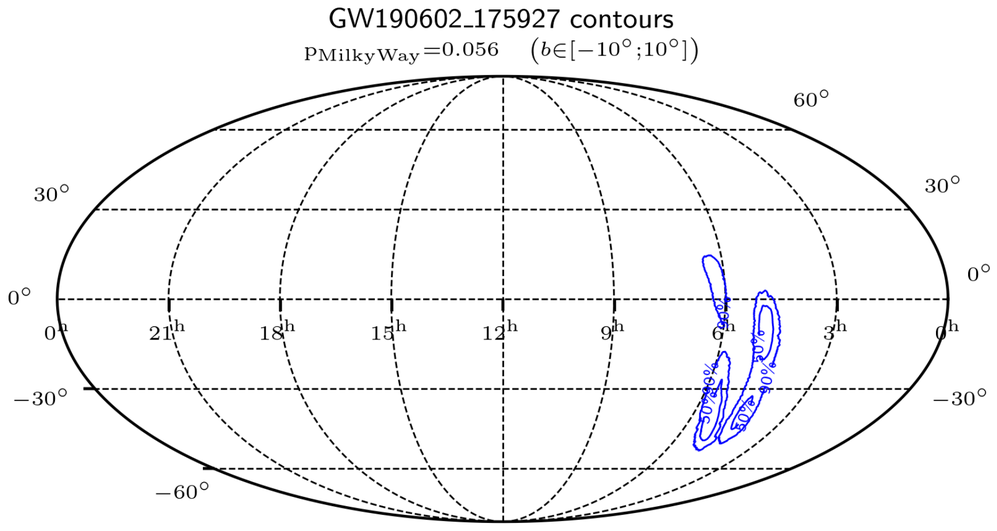
Dark sirens

the GW signal depends on the sky position: 3D localisation of the GW source (ra, dec, d_L)

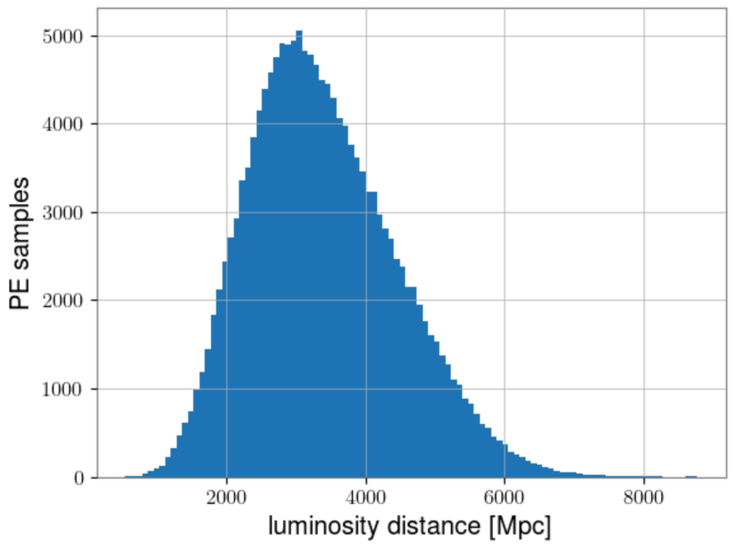
features in the mass spectrum



spectral case: no ra, dec information, potential hosts are distributed **uniformly in comoving volume**

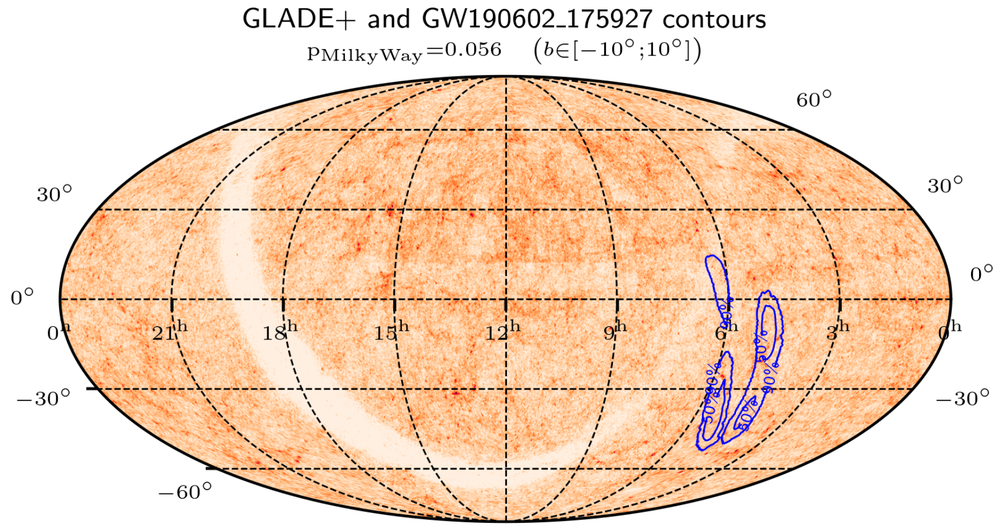


measured luminosity distance



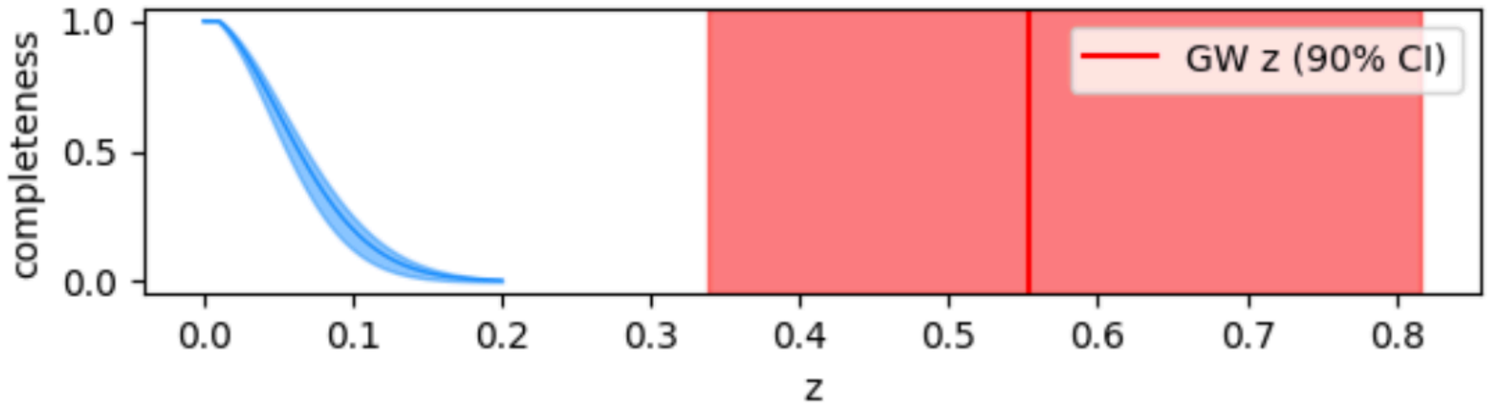
Schutz, B. Nature 323 (1986) 310

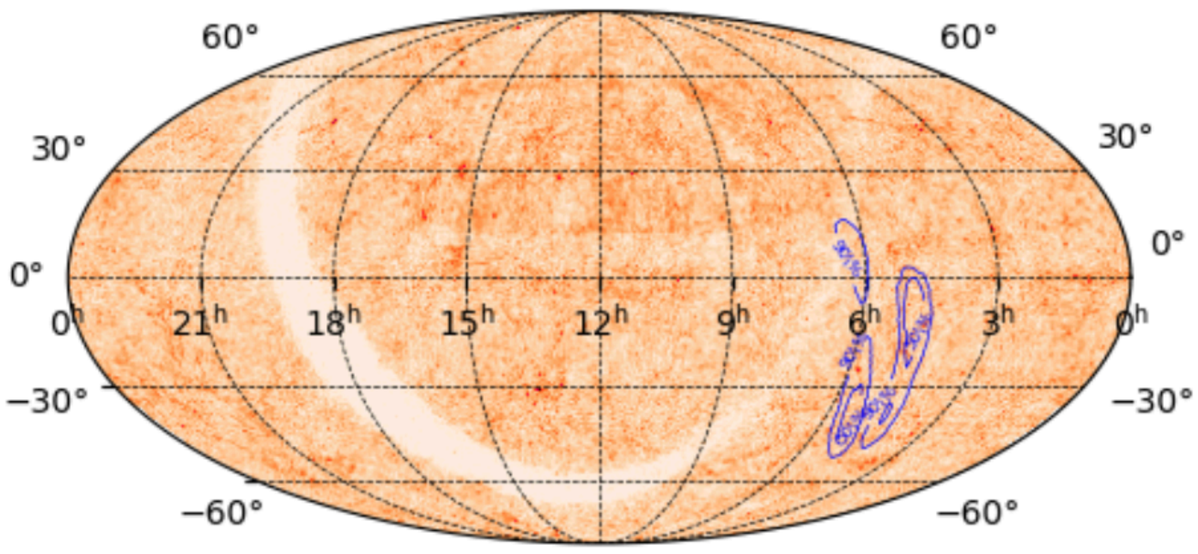
galaxy catalogue case: potential hosts can be part of a **galaxy catalogue** with measured ra, dec, z

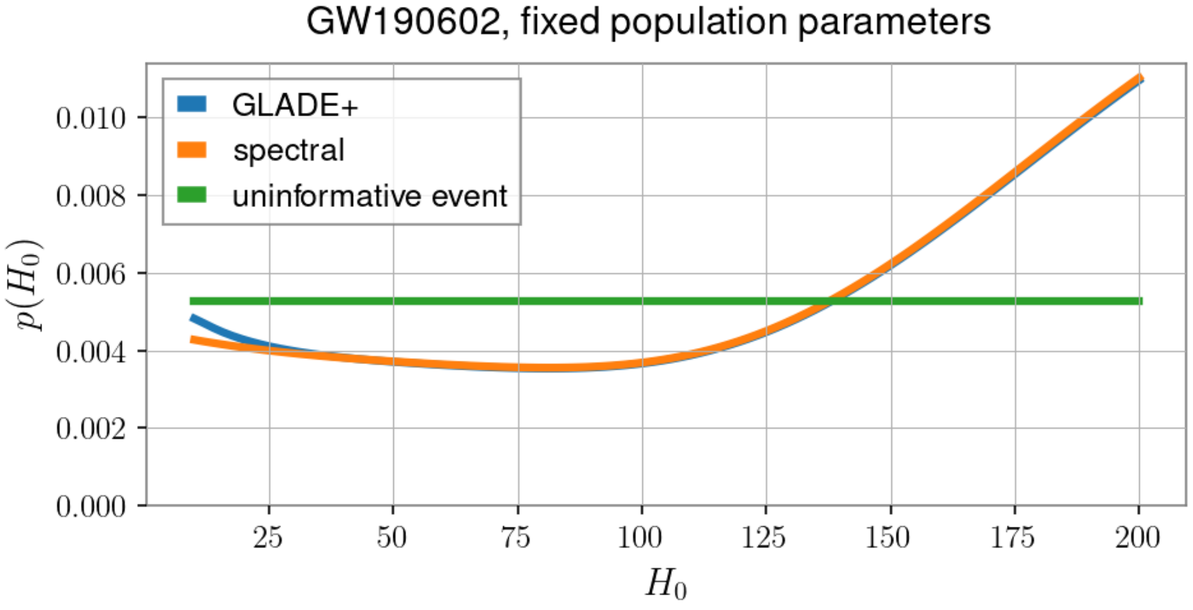


GLADE+: Dalya et al, MNRAS 514, 1403–1411 (2022)

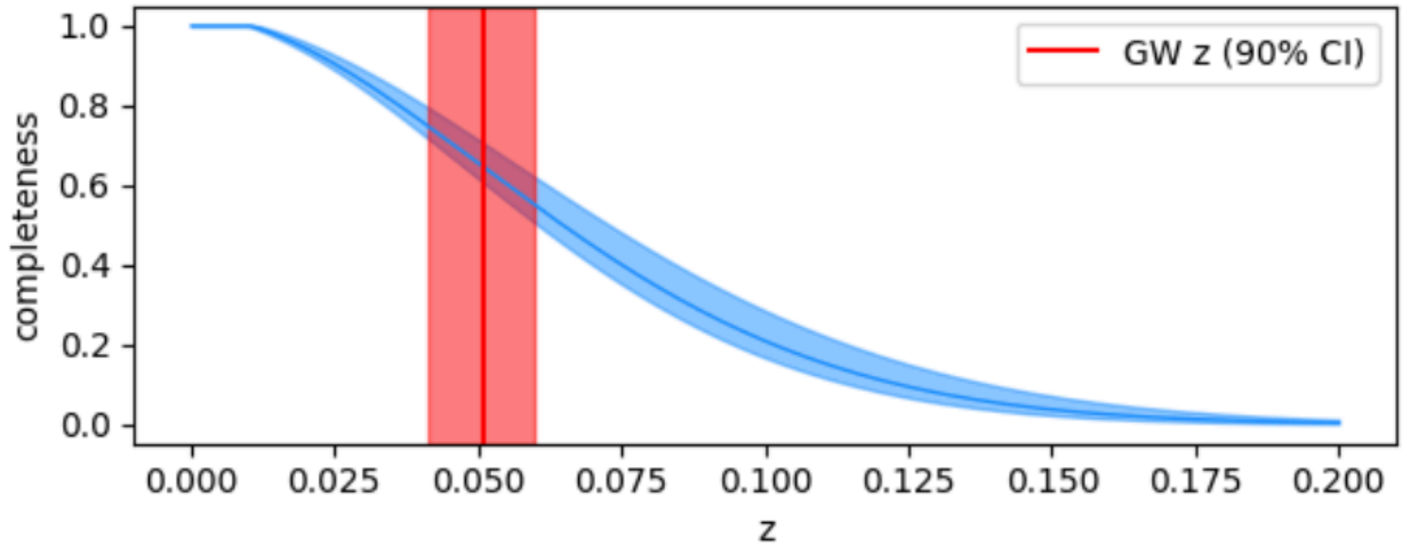
- Typical BBH
- seen by the 3 interferometers
- sky area ~ **10-100 square degrees**
- d_L = **3 Gpc** (z = 0.5)
- the galaxy catalogue is not informative

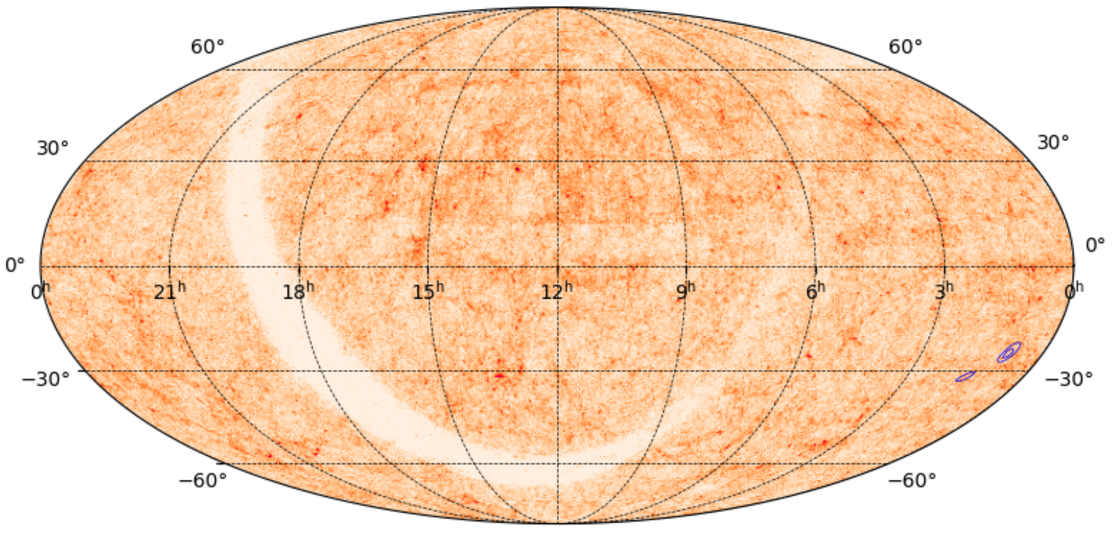


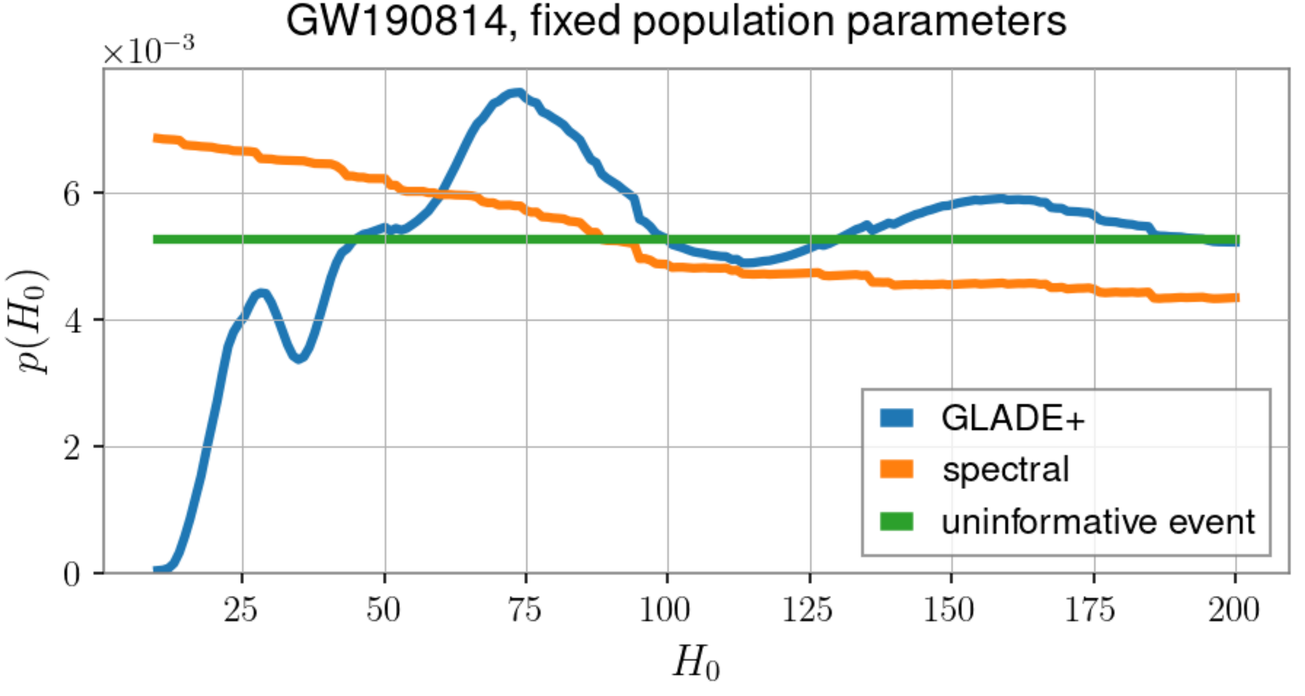




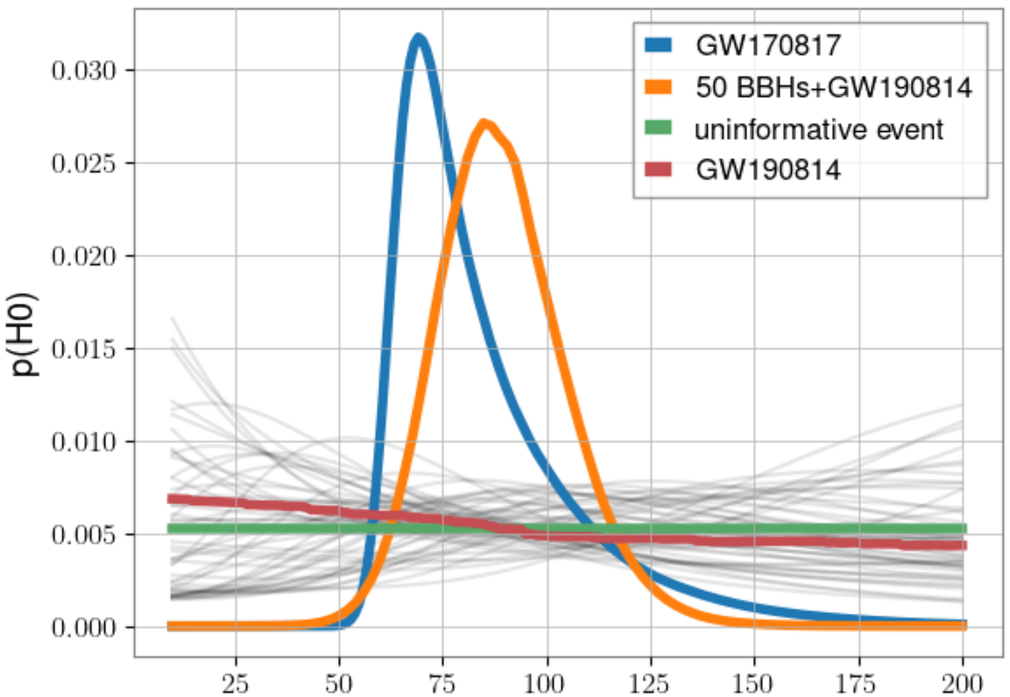
- NSBH
- seen by the 3 interferometers
- sky area ~ **5 square degrees**
- d_L = **240 Mpc** (z = 0.05)
- the galaxy catalogue is very informative





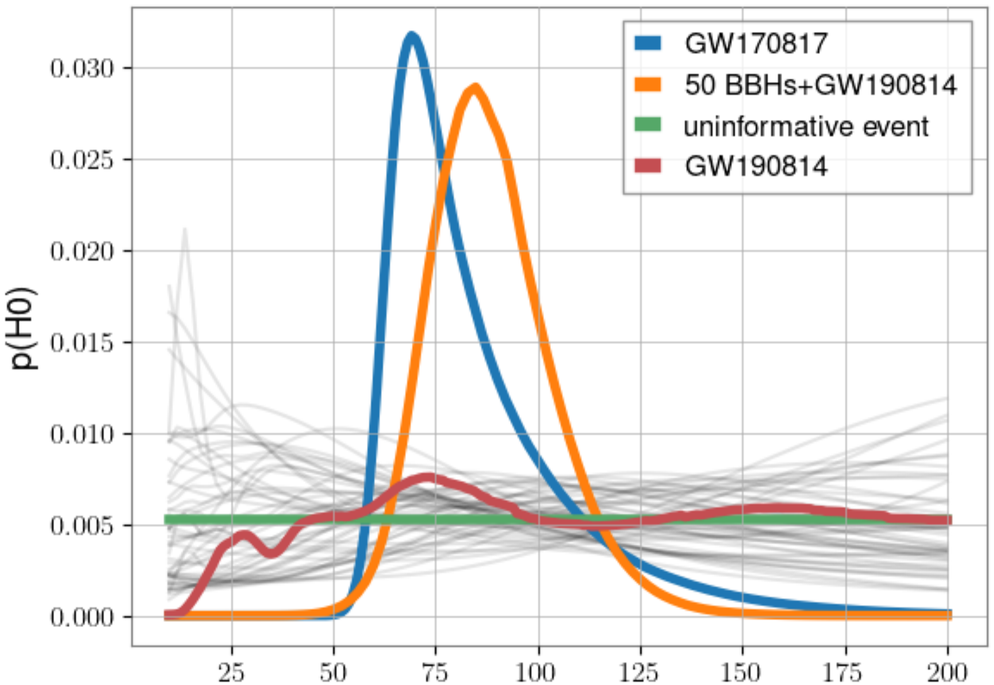


Spectral analysis (fixed population parameters)

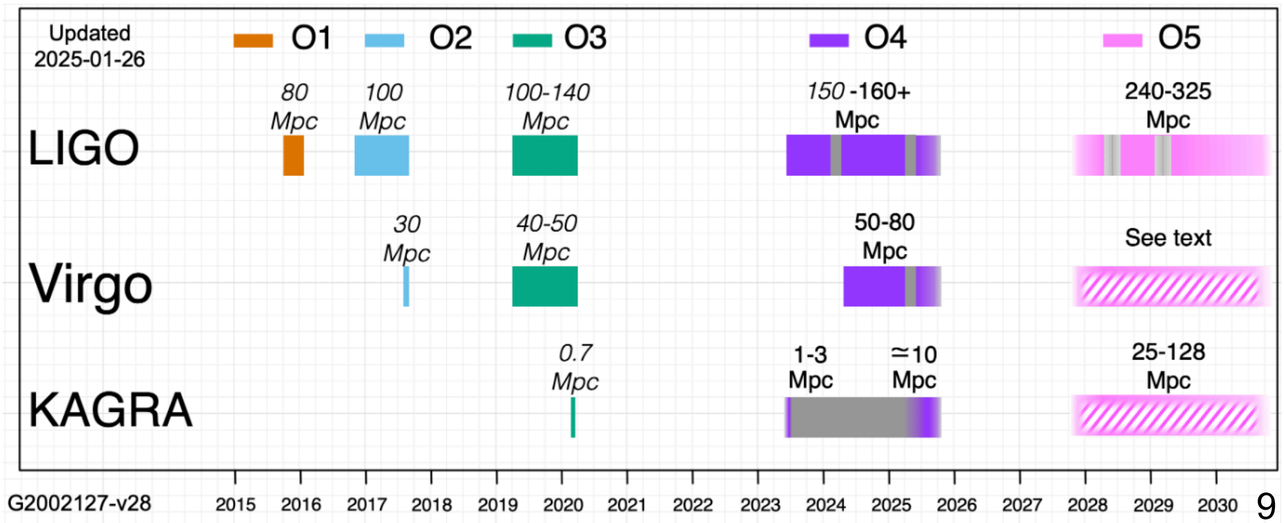


GW190814+galaxy catalogue decreases the H_0 interval by 10%

Galaxy catalogue analysis (fixed population parameters)



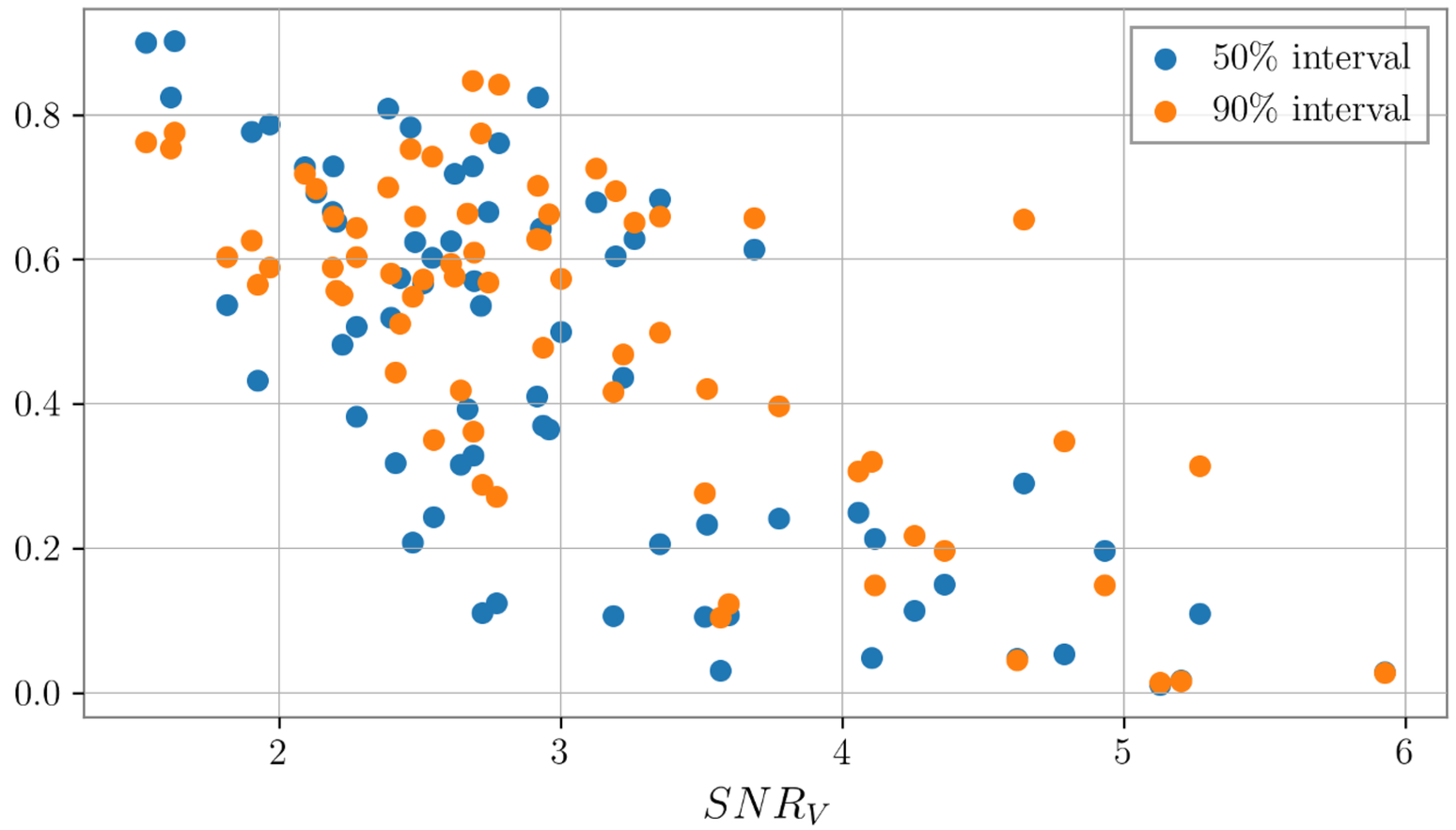
Most of the events are poorly localised (10^2-10^4 square degrees) and distant (1-10 Gpc) with a large uncertainty on d_L



need good localisation (i.e. GWs detected by the 3 interferometers), and d_L range well covered by the galaxy catalogue

(Amazigh Ouzriat private communication)

$$\frac{\mathrm{GWskyarea} - \mathrm{HLV}}{\mathrm{GWskyarea} - \mathrm{HL}}$$



median = 50% improvement on sky localisation when Virgo is present (O4b, vs O4a)
we expect a much better measurement of H_0 with O4b data, with Virgo
+ need at the same time a better galaxy catalogue

Development of new galaxy catalogues

- use a **deeper galaxy catalogue**
  - currently GLADE+ (Dalya et al, MNRAS 514, 1403–1411 (2022)), 22 million of galaxies, compilation of GWGC, HyperLEDA, 2MPZ, 2MASS XSC, SDSS-DR12Q, WISExSuperCosmos
  - upcoming: UpGLADE (with Pan-STARRS DR2, PS-STRM, CatWISE, DESI Legacy Survey, Duncan22), 2 billion of galaxies, much more complete, currently under test (Dalya, 2022)
  - determine the most promising band; K to B band? testing K-corrections
  - use photometric and spectrometric redshifts

- use cluster catalogues at higher redshifts (eROSITA-X survey, Planck SZ catalogue)

- discussion with Euclid consortium, LSST

- study of systematics (choice of the band, evolution of the Schechter funtion, redshift uncertainties...)