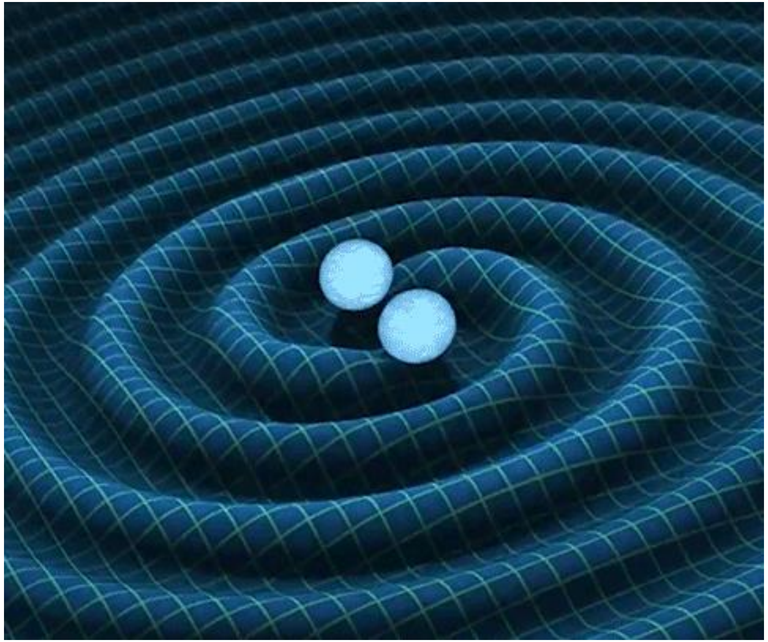


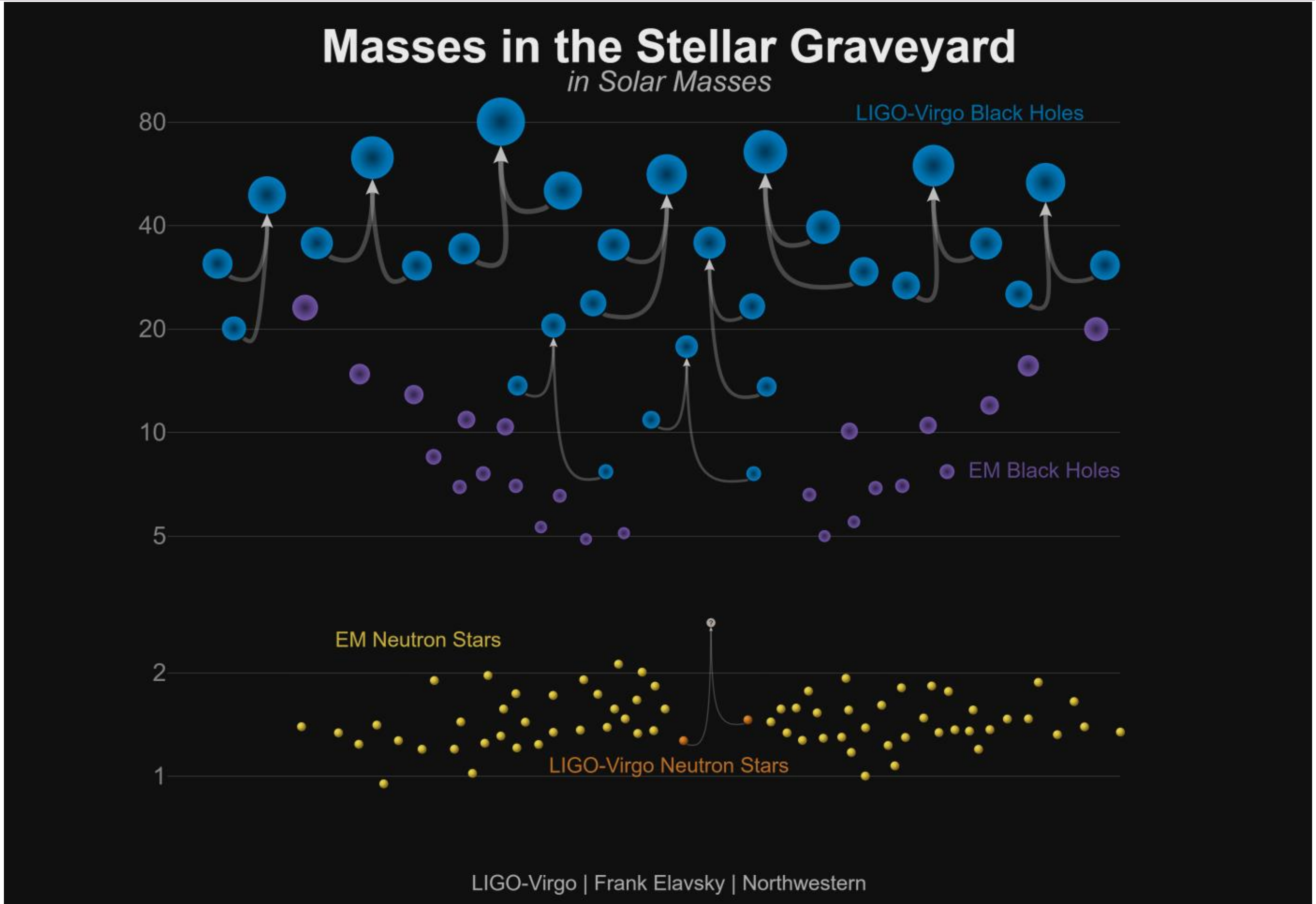
Gravitational Waves as Cosmological Probes

Constantina Nicolaou
12th December 2019

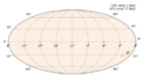
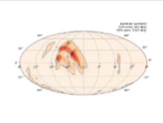
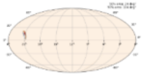
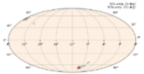
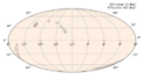
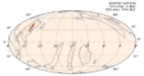
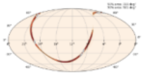
Supervisors:
Prof Ofer Lahav
Prof Simon Arridge

UCL CDT DIS

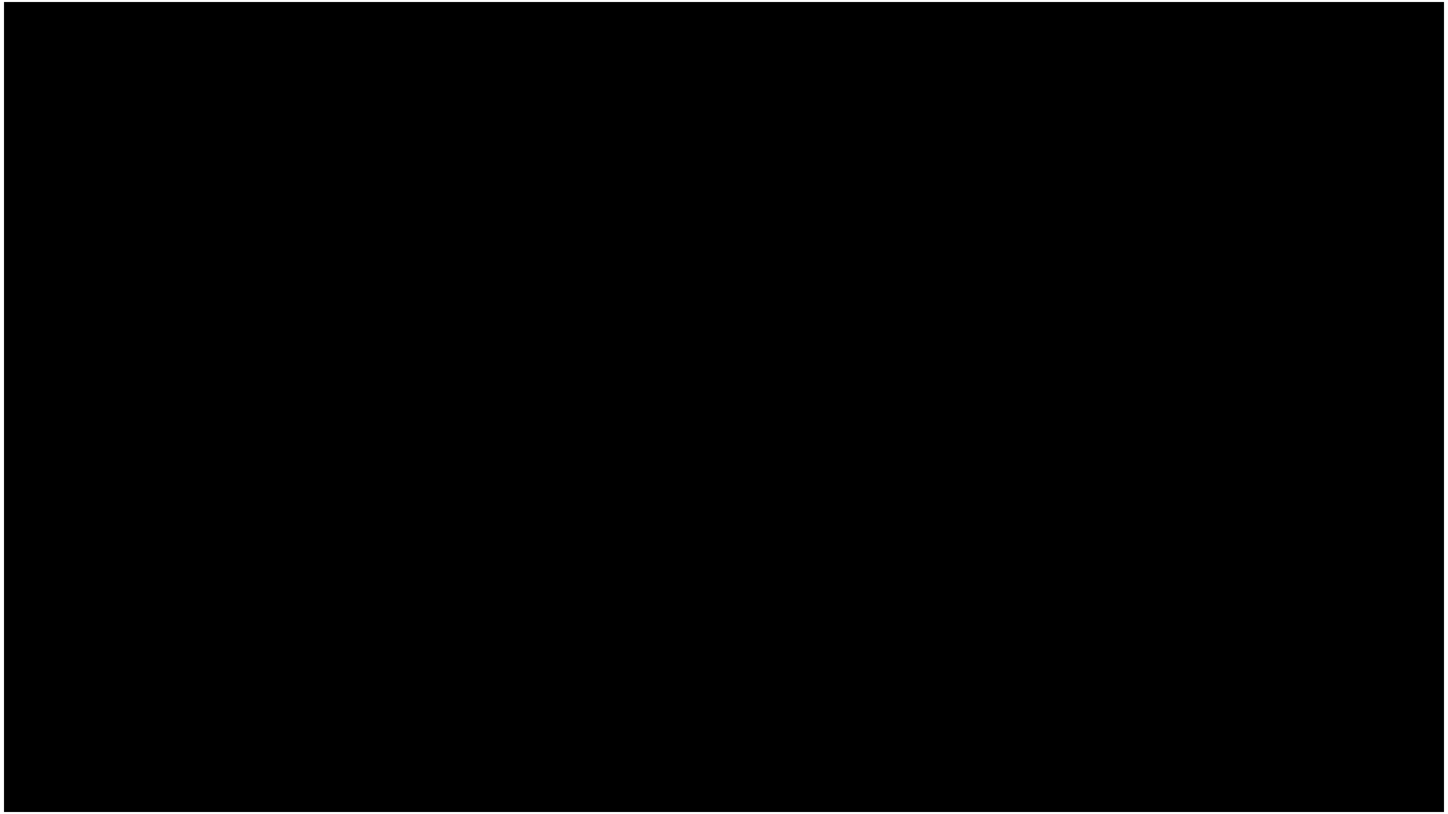
Detections of Gravitational Waves: O1 & O2



O3: Latest – as of 12 Dec 2019 08:23:02 UTC

S190814bv	NSBH (>99%)	Aug. 14, 2019 21:10:39 UTC	GCN Circulars Notices | VOE		1 per 1.559e+25 years	
S190808ae	Terrestrial (57%), BNS (43%)	Aug. 8, 2019 22:21:21 UTC	GCN Circulars Notices | VOE		1.0622 per year	RETRACTED
S190728q	BBH (95%), MassGap (5%)	July 28, 2019 06:45:10 UTC	GCN Circulars Notices | VOE		1 per 1.2541e+15 years	
S190727h	BBH (92%), Terrestrial (5%), MassGap (3%)	July 27, 2019 06:03:33 UTC	GCN Circulars Notices | VOE		1 per 229.92 years	
S190720a	BBH (99%), Terrestrial (1%)	July 20, 2019 00:08:36 UTC	GCN Circulars Notices | VOE		1 per 8.3367 years	
S190718y	Terrestrial (98%), BNS (2%)	July 18, 2019 14:35:12 UTC	GCN Circulars Notices | VOE		1.1514 per year	
S190707q	BBH (>99%)	July 7, 2019 09:33:26 UTC	GCN Circulars Notices | VOE		1 per 6018.9 years	

What are Gravitational Waves?

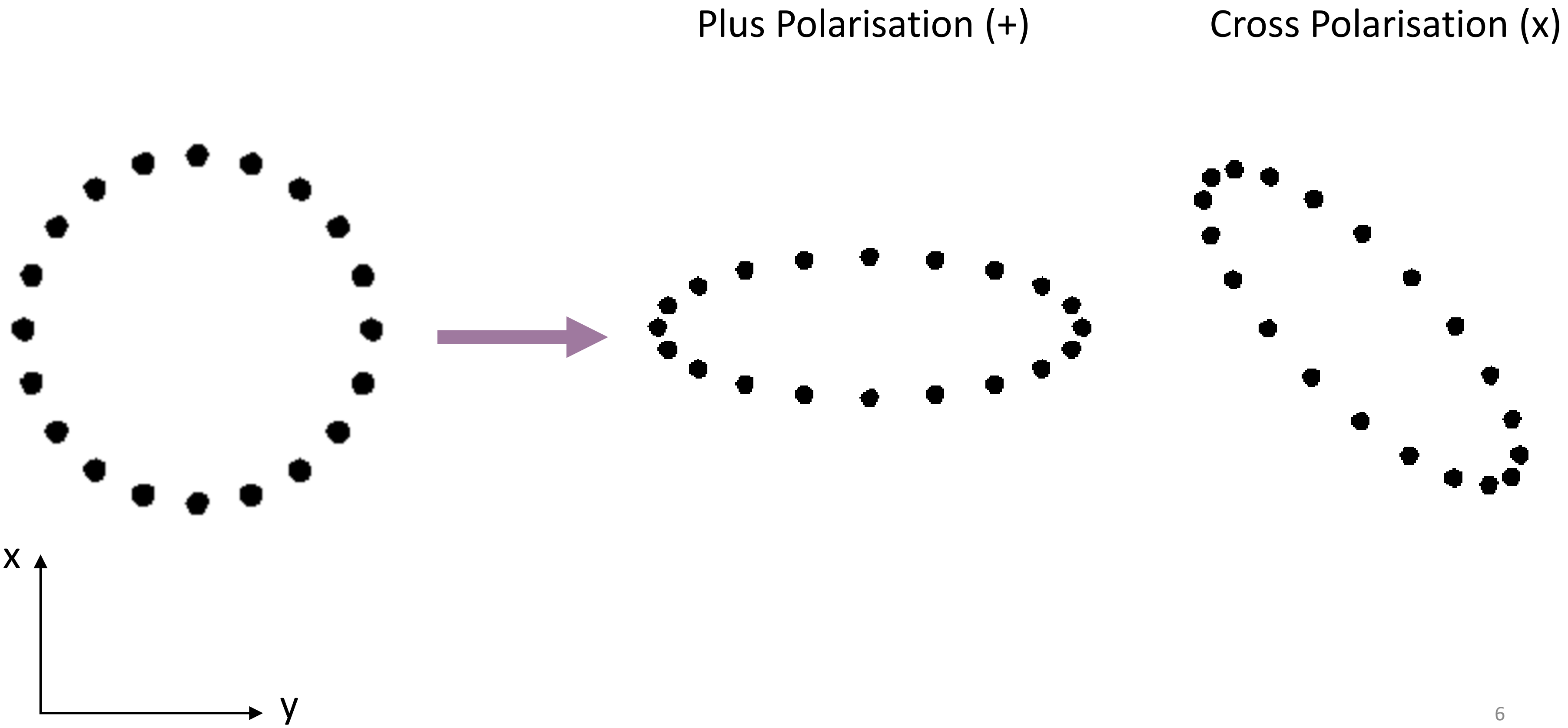


http://phdcomics.com/tv

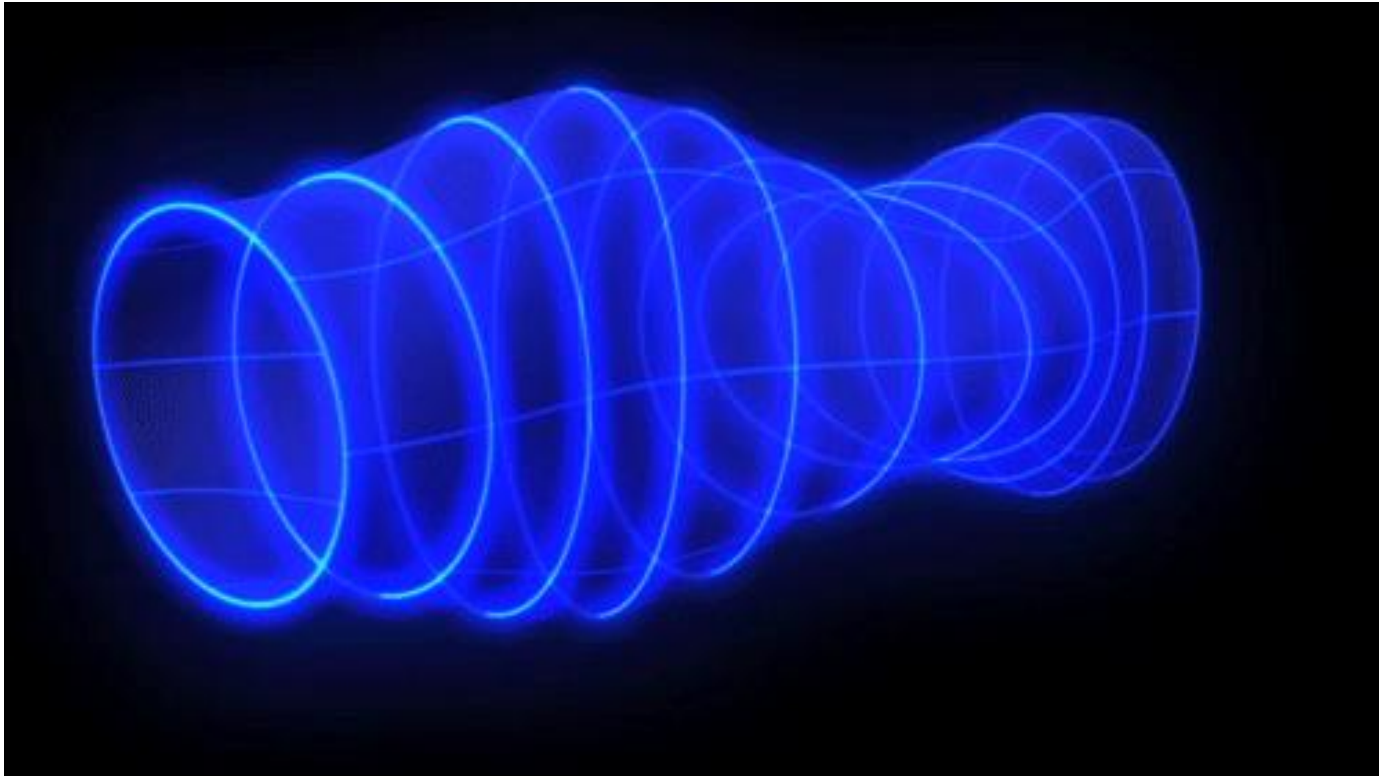
What are Gravitational Waves?

http://phdcomics.com/tv

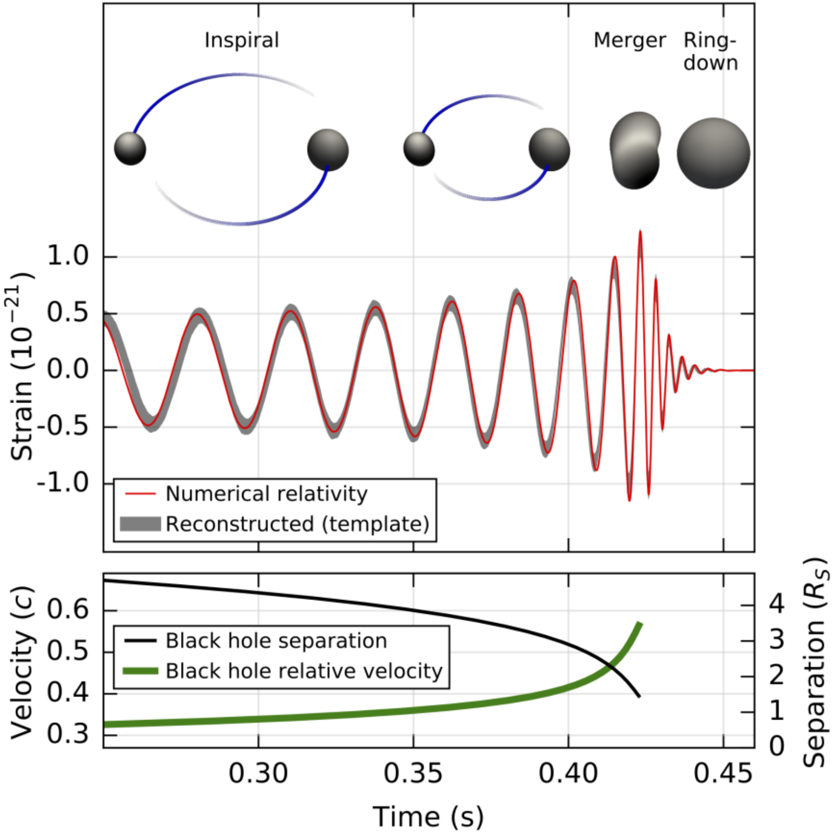
Propagation through space



Propagation through space



GW Standard Sirens

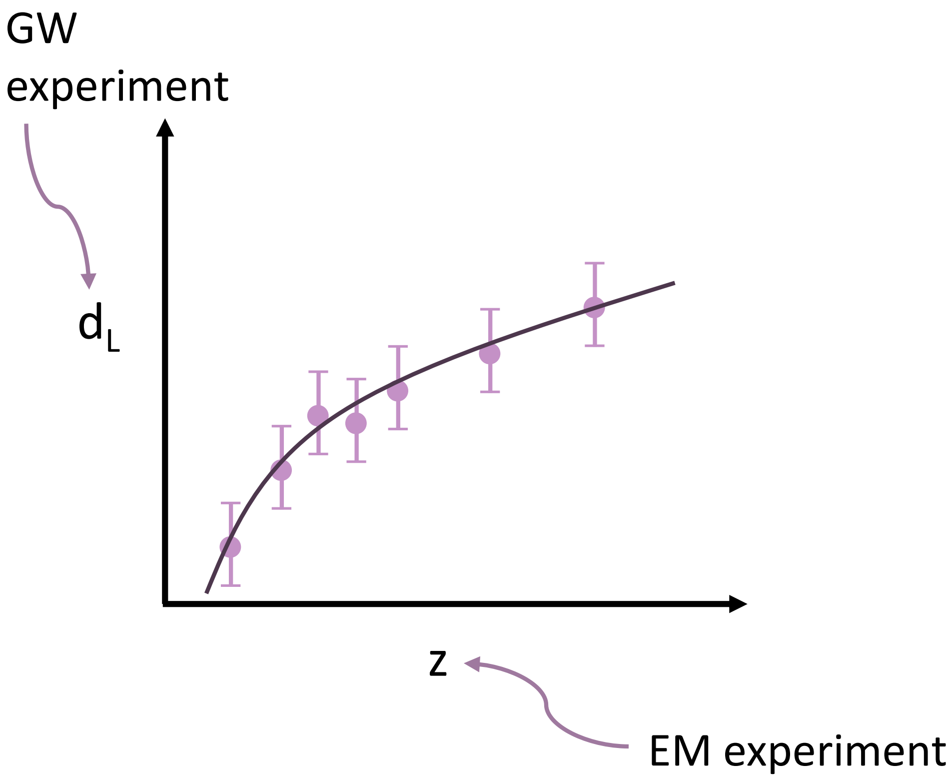


$$h_+(t) = \frac{4}{d_L}\left(\frac{G\mathcal{M}}{c^2}\right)^{5/3}\left(\frac{\pi f(t)}{c}\right)^{2/3}\frac{1+\cos^2\iota}{2}\cos\varphi$$

$$h_\times(t) = \frac{4}{d_L}\left(\frac{G\mathcal{M}}{c^2}\right)^{5/3}\left(\frac{\pi f(t)}{c}\right)^{2/3}\cos\iota\sin\varphi$$

Absolute distance indicators – self calibrating

Using Standard Sirens as Cosmological Probes



$$d_L(z) = (1+z)\int_0^z \frac{c\,dz'}{H_0\,E(z')}$$

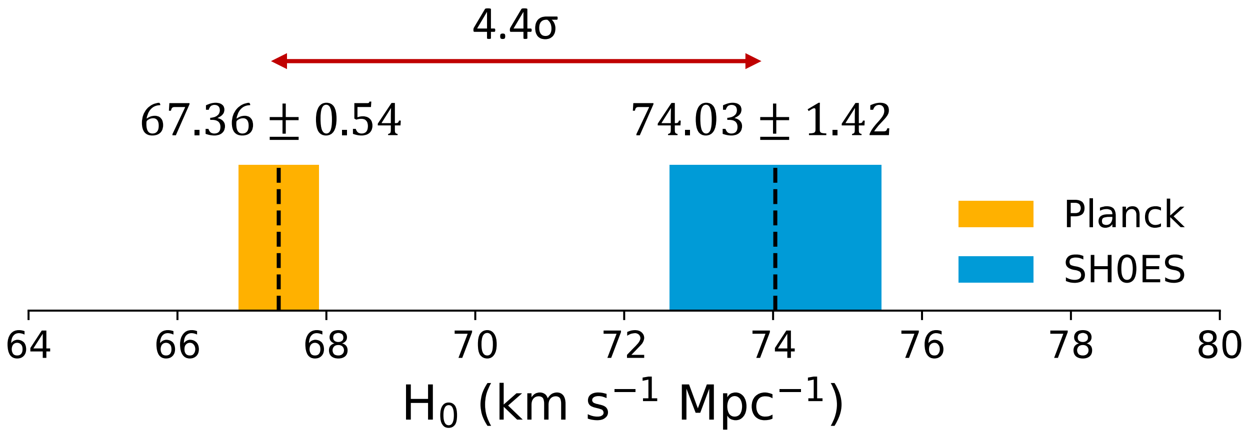
Local Universe:

$$H_0\,d_L \approx cz$$

$z \gtrsim 0.1$:

$$E(z) = \sqrt{\Omega_m\,(1+z)^3 + \Omega_\Lambda}$$

Motivation: The Hubble Constant Tension



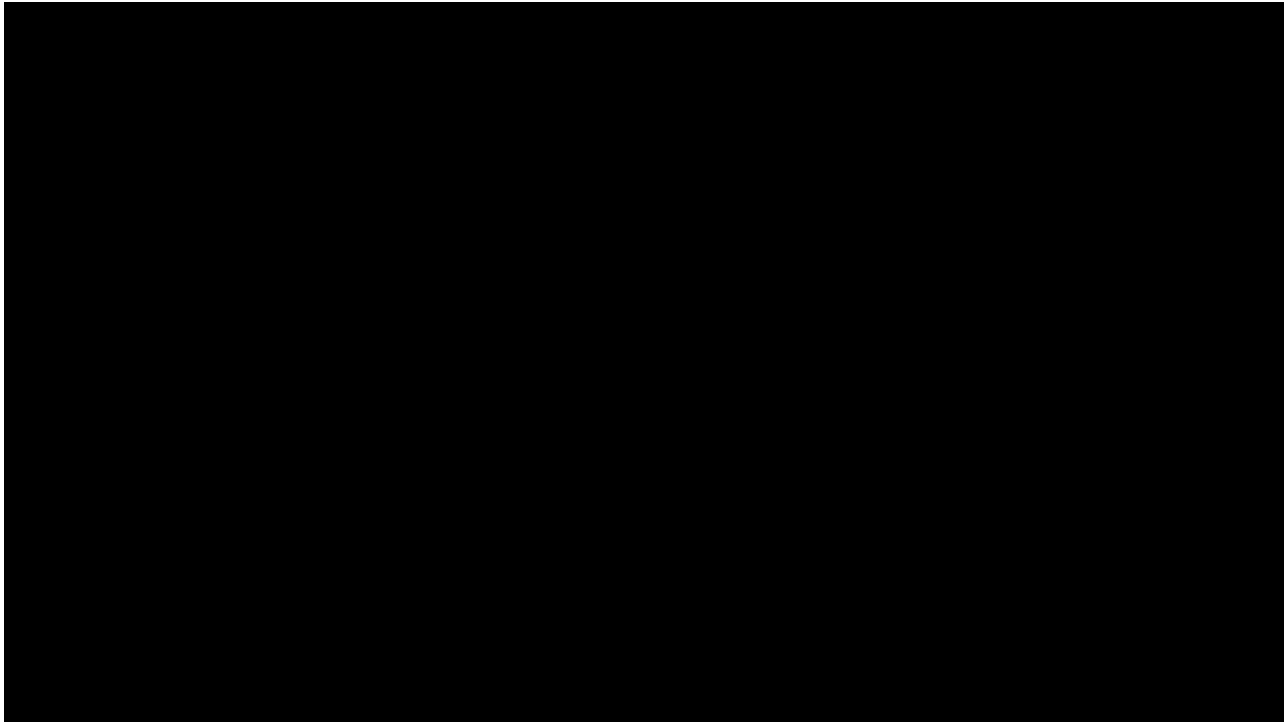
- Systematics or new physics?
- In need of an independent measurement

GWs are ideal to clarify the H_0 tension:

- Independent of distance ladder
- Cosmological model independent

Planck Collaboration et al., 2018, arXiv preprint arXiv:1807.06209
Riess A. G., Casertano S., Yuan W., Macri L. M., Scolnic D., 2019, ApJ, 876, 85

GW170817: The First Multi-Messenger Detection



Inferring H_0 from GW170817

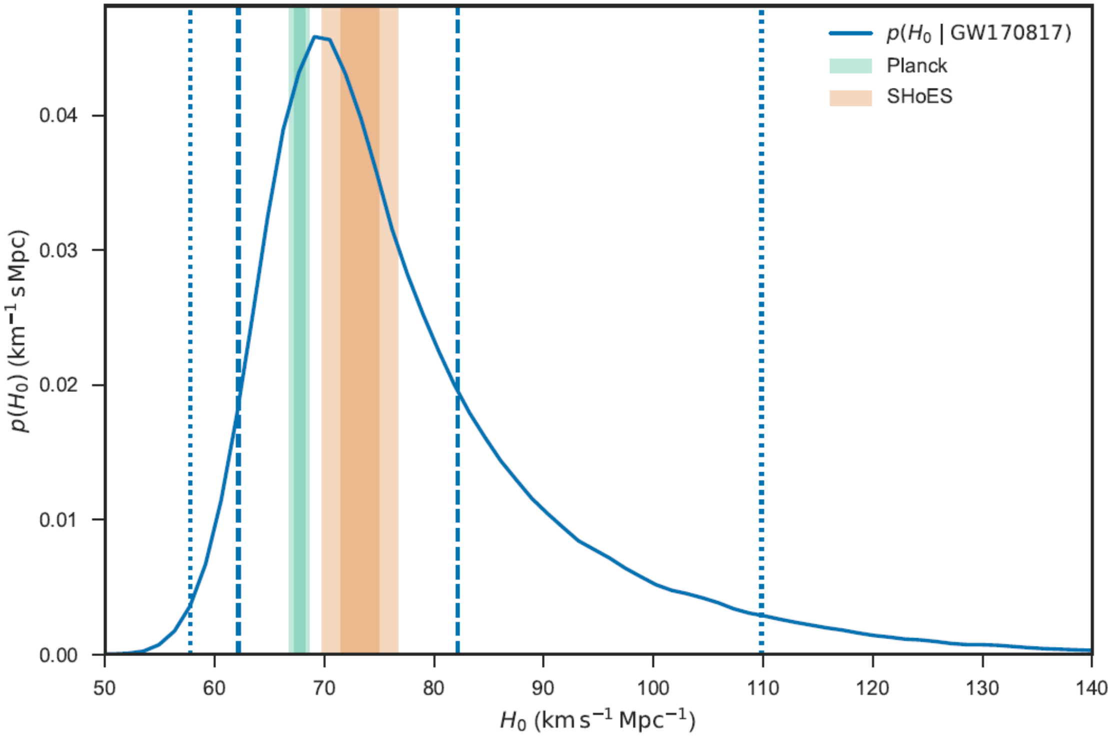
NGC 4993 (~40 Mpc)

$$H_0 = \frac{v_r - v_p}{d_L}$$

$v_r - v_p$ → EM

d_L → GW

$$H_0 = 70.0^{+12.0}_{-8.0} \text{ km s}^{-1} \text{ Mpc}^{-1}$$



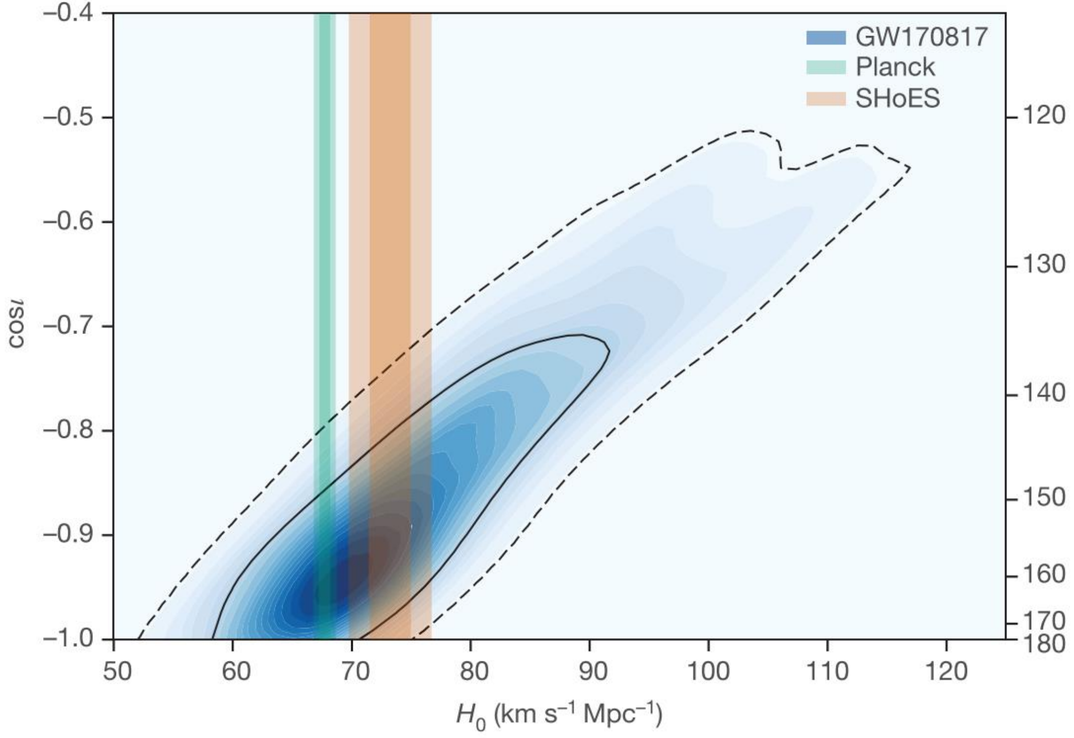
LVC et al. A gravitational-wave standard siren measurement of the Hubble constant. Nature, 2017

Inferring H_0 from GW170817

Limitations:

- Distance – inclination degeneracy

- Peculiar velocity calculation



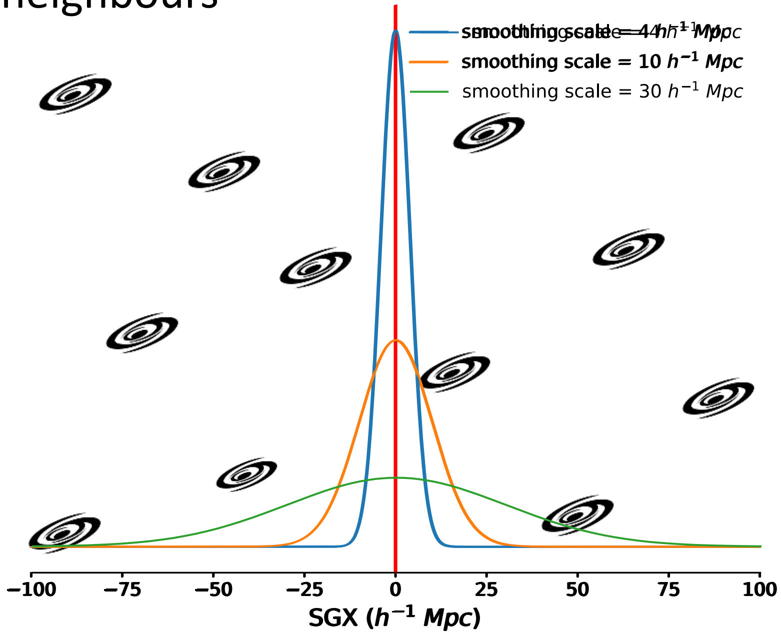
LVC et al. A gravitational-wave standard siren measurement of the Hubble constant. Nature, 2017

Systematics associated with v_p

For the GW170817 event the peculiar velocity of the host galaxy was not measured directly

- Hence its value has to be inferred from neighbours
- Gaussian Smoothing

NGC 4993



* galaxies not drawn to scale!

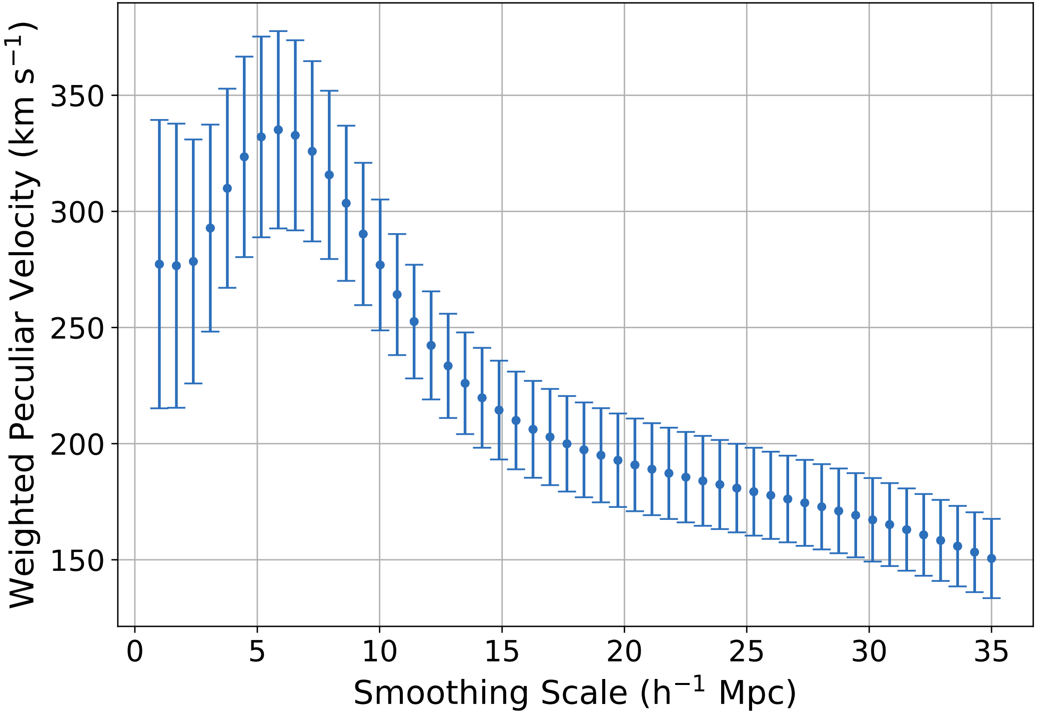
Effect of smoothing scale

LVC:

s = 8 h^{-1} Mpc

$\langle v_p \rangle$ = 310 ± 150 km s^{-1}

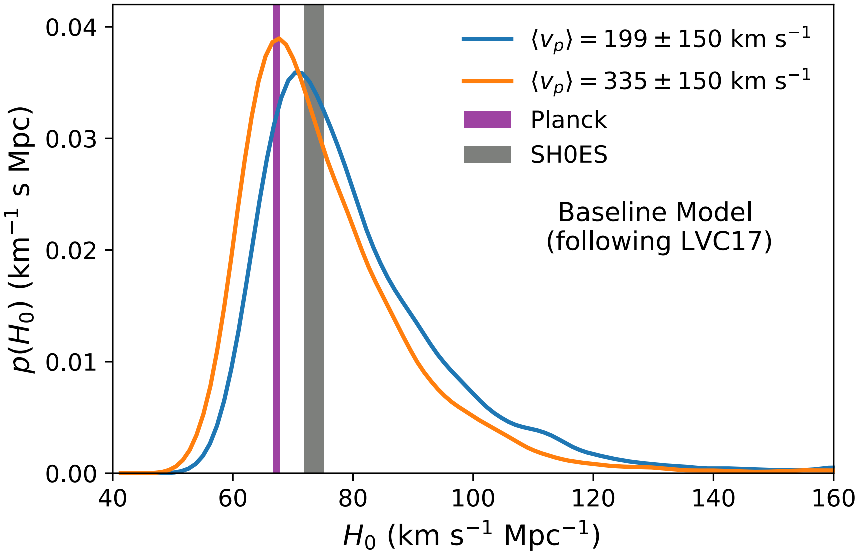
$H_0 = 70.0^{+12.0}_{-8.0}$ km s^{-1} Mpc^{-1}



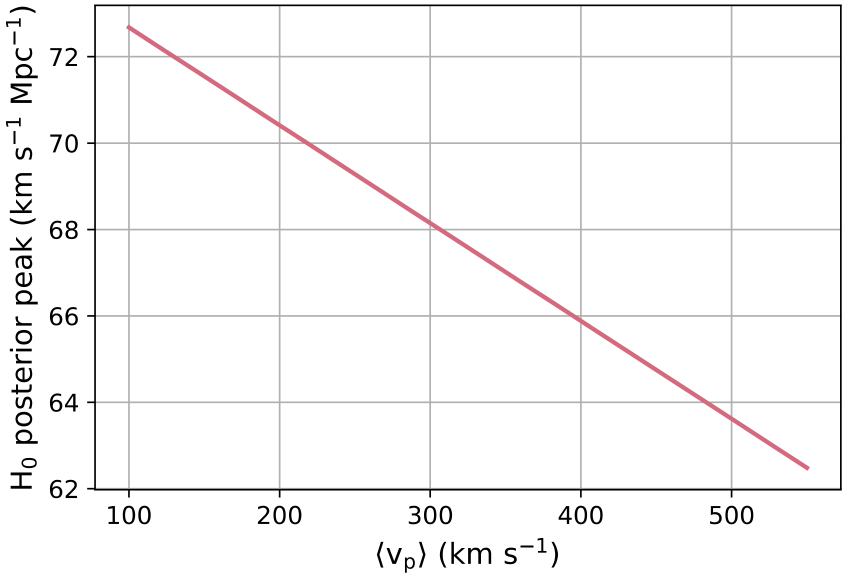
Nicolaou C., Lahav O., Lemos P., Hartley W., Braden J., 2019, arXiv e-prints, arXiv:1909.09609

Effect of smoothing scale on H_0

Two different smoothing scale choices lead to different H_0 values



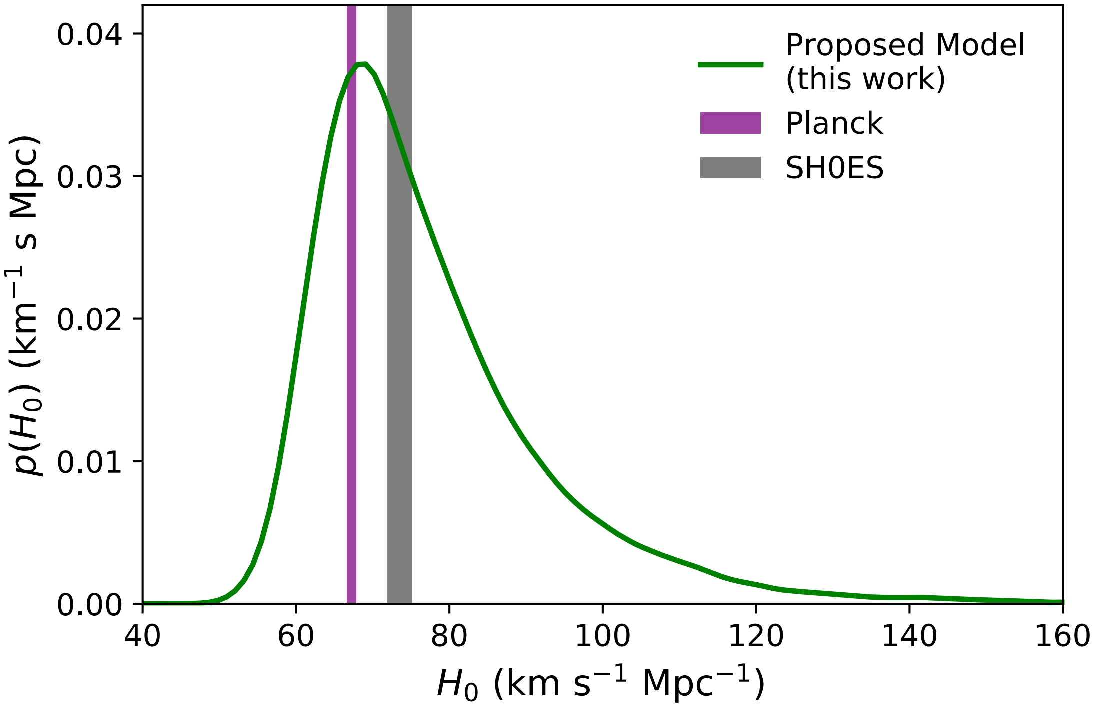
A bias of 200 km s^{-1} on the peculiar velocity imparts a bias on the Hubble constant of 4 km s^{-1} Mpc^{-1}



Nicolaou C., Lahav O., Lemos P., Hartley W., Braden J., 2019, arXiv e-prints, arXiv:1909.09609

Proposed model

Marginalising over choice of smoothing scale



Nicolaou C., Lahav O., Lemos P., Hartley W., Braden J., 2019, arXiv e-prints, arXiv:1909.09609

Conclusions

- GWs great potential to act as cosmological probes
- Demonstrated a bias arising from the peculiar velocity estimate which if unaccounted for results in a bias on H_0
- A bias of 200 km s^{-1} on the peculiar velocity imparts a bias on the Hubble constant of 4 km s^{-1} Mpc^{-1}
- Proposed a way to eliminate the systematic by marginalizing over the choice of smoothing scale

Questions?

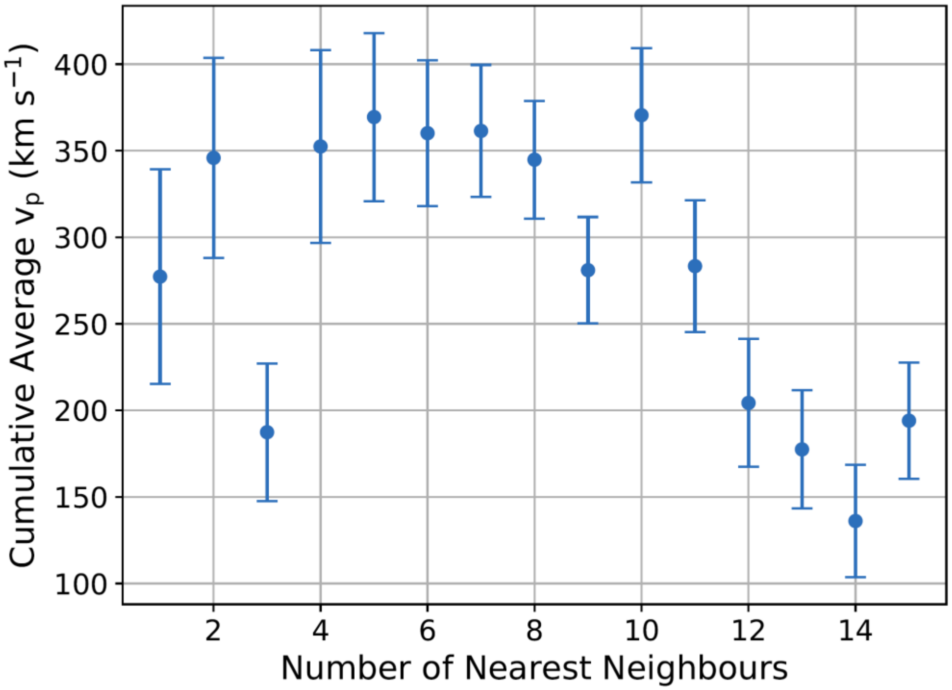
Thank you for your attention!

Acknowledgments: Pablo Lemos, Will Hartely, Jonathan Braden

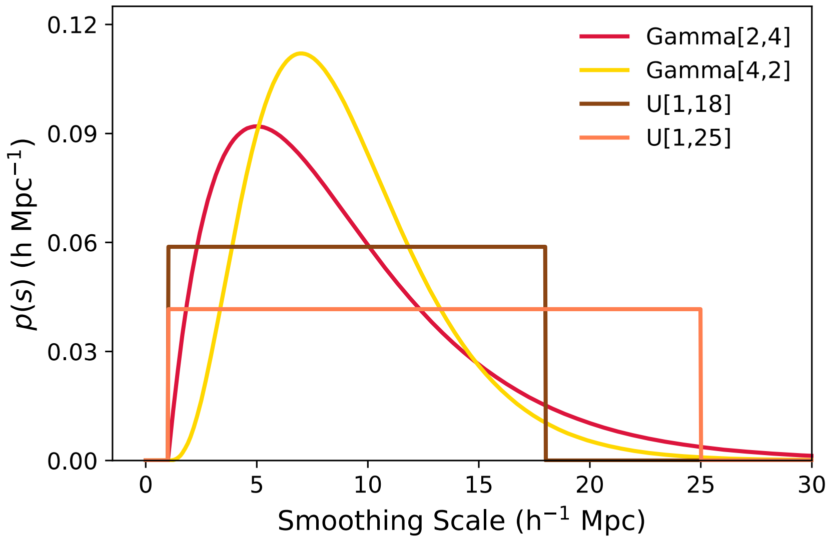
constantina.nicolaou.17@ucl.ac.uk

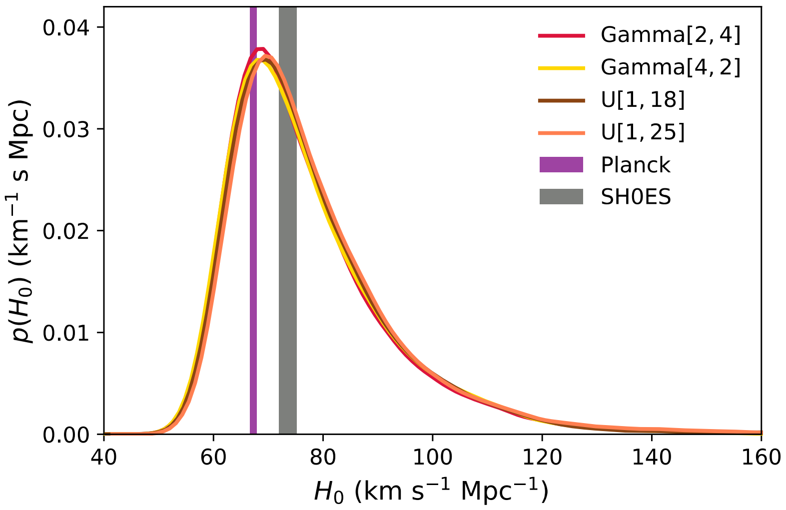
Additional Slides

Nearest Neighbour Statistic

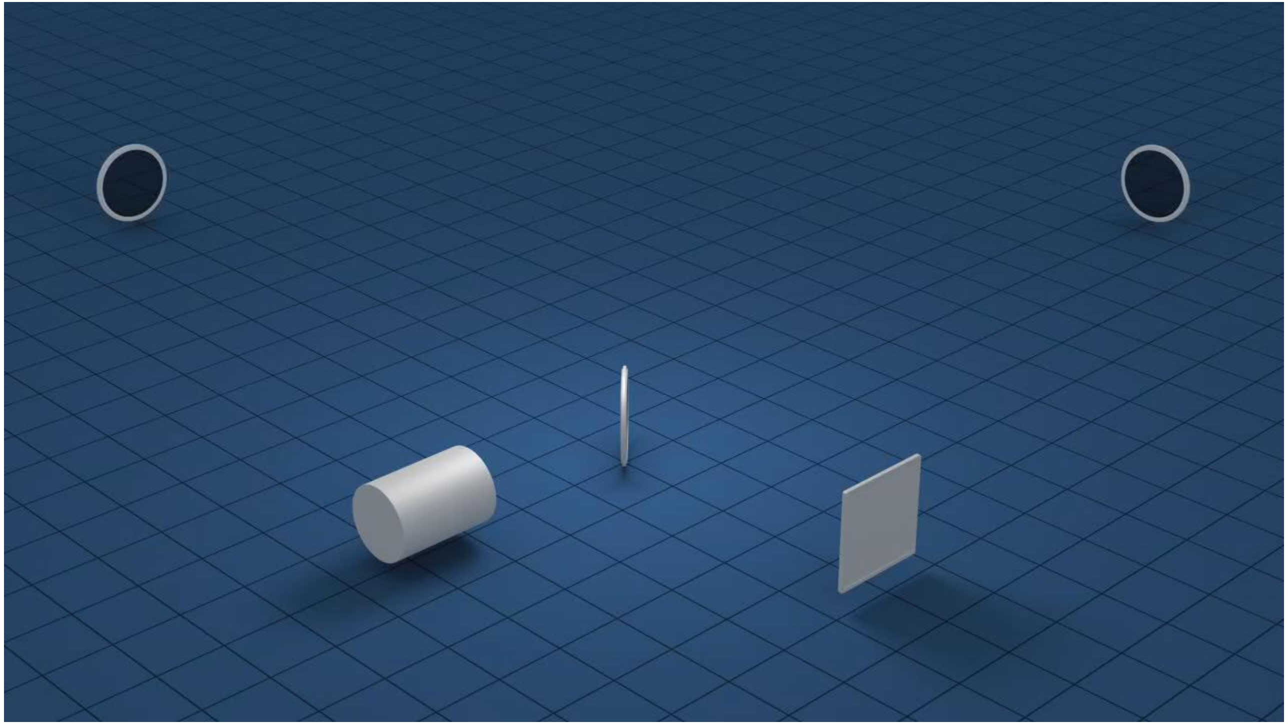


Prior Independence

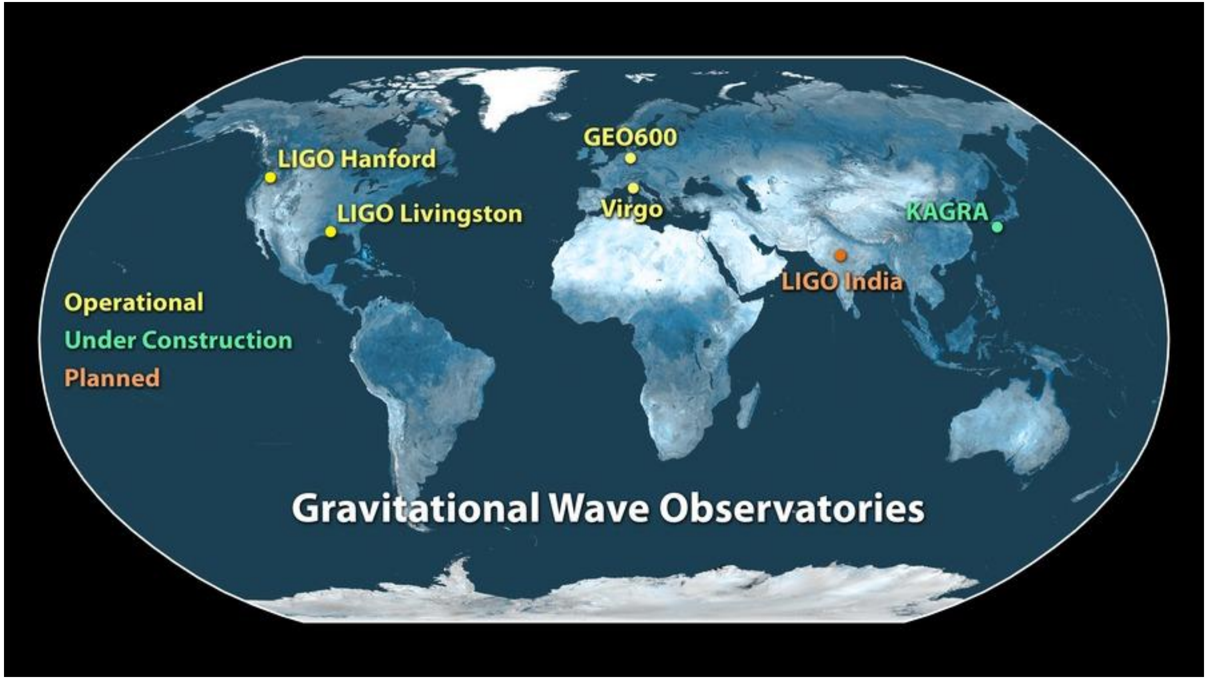


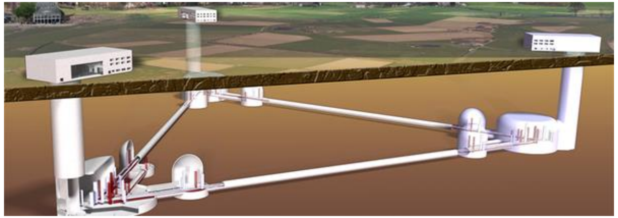


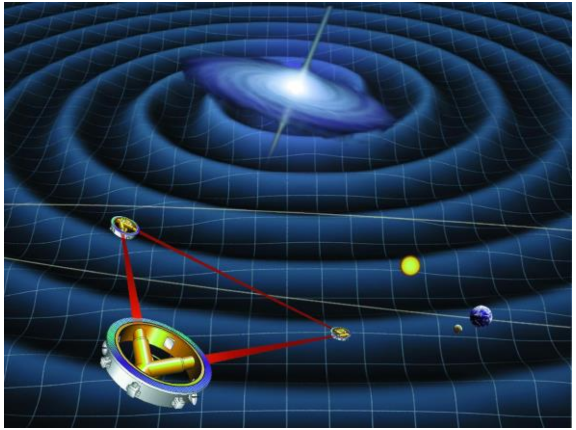
How can we detect them?



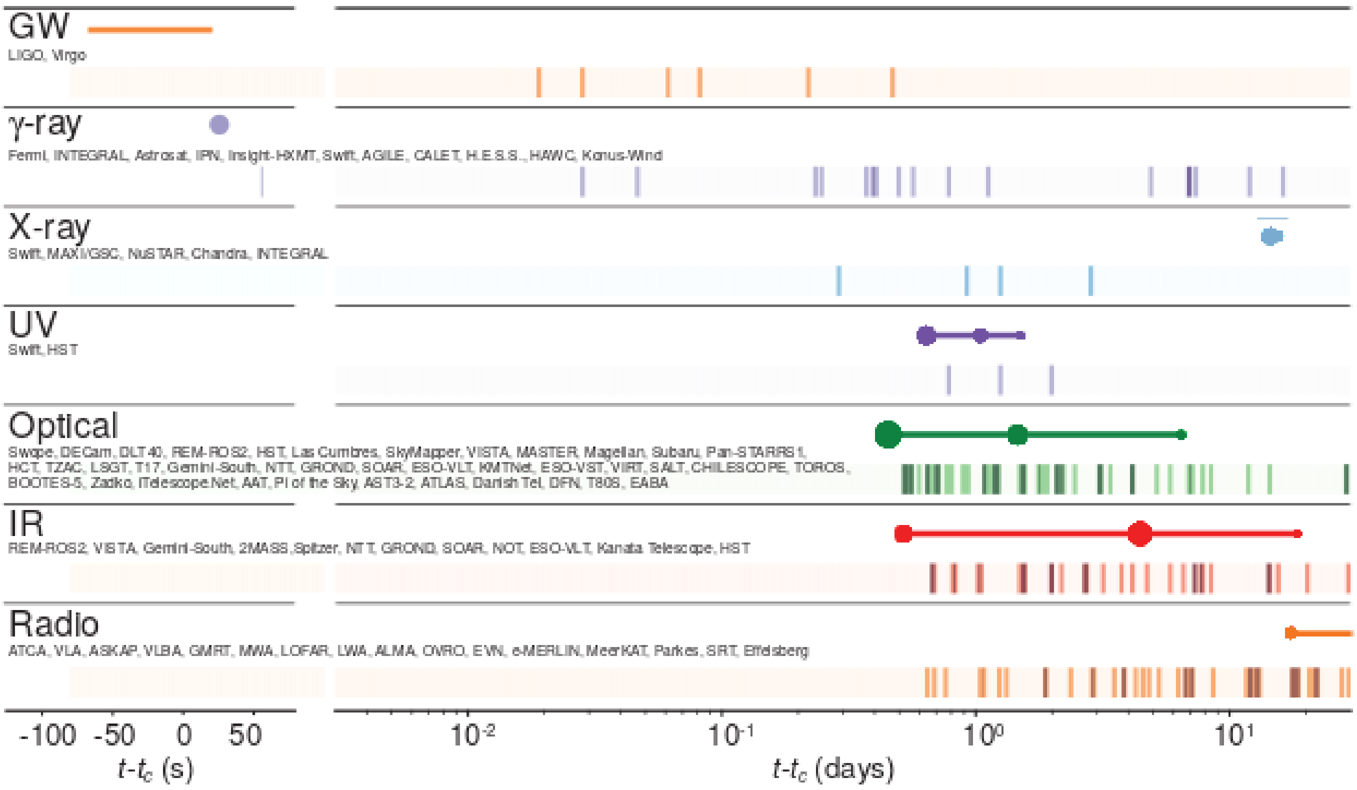
Future observatories







GW170817: The First Multi-Messenger Detection



GW170817: The First Multi-Messenger Detection