

Multimessenger cosmology: Now and in the 2030s

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Dutch multimessenger astronomy in the 2030s
Blooming Bergen, 2019 February 08

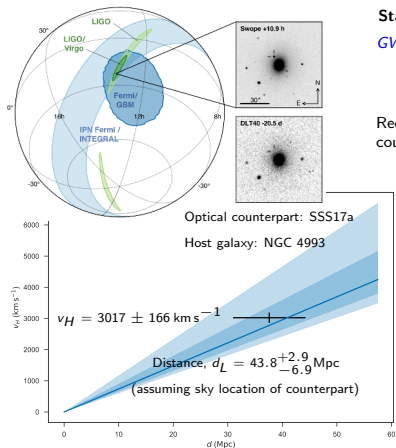


Broad overview to get us on track

- GWs from compact binaries give us direct access to the luminosity distance.

- The capability of compact binaries being standard distance indicators can be exploited to obtain rich and novel science.

H_0 with GW170817



Independent of any distance ladder!

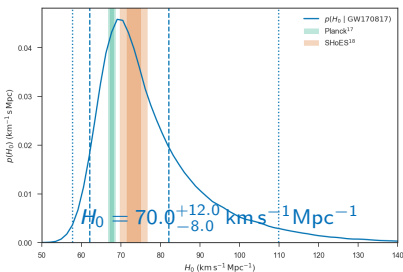
Standard siren

Schutz (1986), Holz & Hughes (2005)

GWs provide a direct measurement of the luminosity distance!

$$v_H = H_0 d_L$$

Recession velocity (or redshift) can come from a transient EM counterpart or an identified host galaxy.



Abbott *et al.* *Astrophys. J.* **848** #2, L12 (2017); LSC-EPO

Abbott *et al.* *Nature* **551** #7678, 85-88 (2017)

Constraints on extra dimensions from GW170817

Abbott et al. arXiv:1811.00364 [gr-qc]

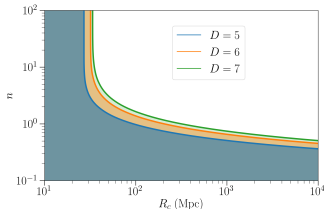
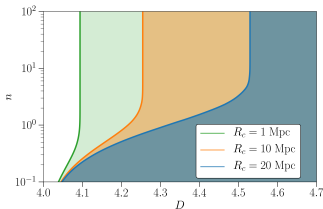
- Modified gravity models with screening mechanism.

Number of dimensions: D

Length scale: R_c

Transition steepness: n

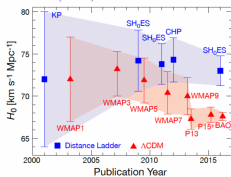
- Expected $1/r$ fall-off of GW amplitude \rightarrow constraints on extra dimensions.



H_0 measurement with GWs: a motivation now

Two contrasting methods applied on nearby and very distant cosmological scales

Freedman (2017)



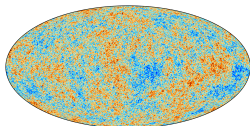
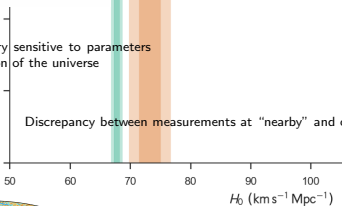
Planck
SHoES

Standard candles

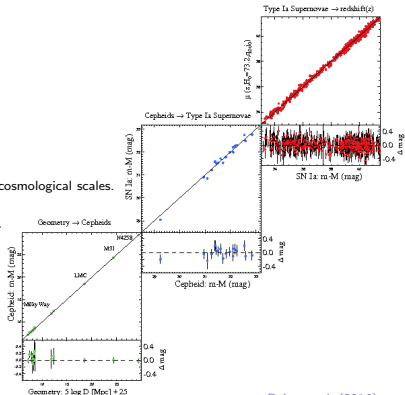
Cosmic distance ladder

CMB anisotropies: very sensitive to parameters that drive the expansion of the universe

Discrepancy between measurements at "nearby" and cosmological scales.



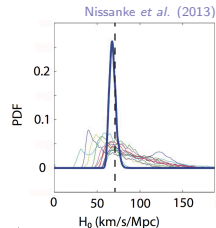
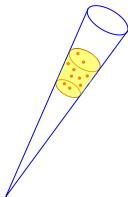
Planck collaboration (2015)



Reiss et al. (2016)

How?

Multiple observations with transient counterparts.



Narrow beam with potential host galaxies around optical counterpart if host galaxy not uniquely identified.

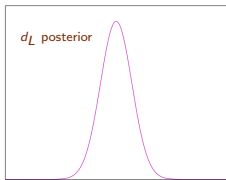
Schutz (1986)

A fully statistical analysis using cross-correlation with a galaxy catalog in absence of a transient optical counterpart.

applicable also for binary black holes

extension to other cosmological parameters?

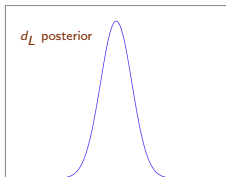
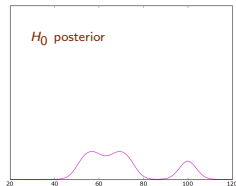
Independent events



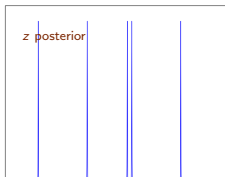
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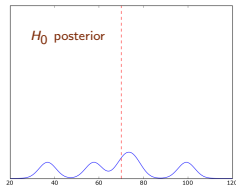
⇒



+



⇒



Different possible galaxies for single event

Multimodal H_0 posterior for each event

Combine information from all observed events ⇒

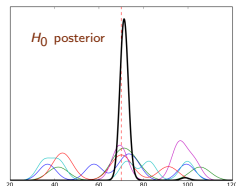


Schutz " H_0 -statistical" method

set of possible host galaxies

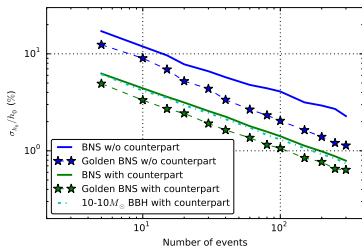
applicable also for **binary black holes**

Schutz (1986); Del Pozzo (2012)

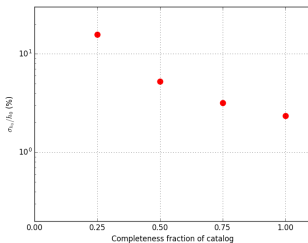


H_0 : results on simulations

Chen *et al.* (2017): counterpart & statistical



Sur (2017, Masters thesis), Gray *et al.* (in prep.)



Statistical: [incomplete galaxy catalogue](#)

Detection efficiency:

$$\mathcal{N}_{\text{eff}}(\Omega) = \int_{\mathcal{E}_{\text{det}}} d\mathcal{E} \int d\theta p(\mathcal{E}|\theta, \Omega, \mathcal{H}, \mathcal{I}) p(\theta|\Omega, \mathcal{H}, \mathcal{I})$$

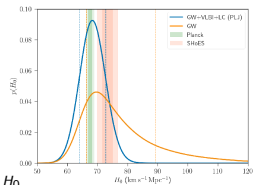
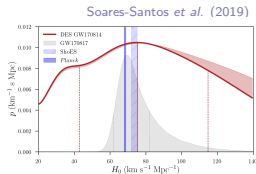
Cosmology Working Group: Ajith, Brady, Chen, Dattier, Del Pozzo, **Fishbach**, Gair, Ghosh, **Gray**, Hendry, Holz, **Magaña-Hernandez**, Messenger, **Qi**, Samajdar, **Sur**, Van Den Broeck, Veitch, . . .

H_0 : towards the eventual near-term goal

Thorough understanding of systematic effects is crucial

- GW calibration uncertainties (GW)
- Selection effects (GW and EM)
- Uncertainties in galaxy catalogues (EM)
- Peculiar velocity flows (EM)

More information from EM follow-up observations!



H_0 and cosmology: for the 2020s?

- Fold in probabilities of galaxies hosting the sources

Luminosity weighting: use luminosity as a proxy for mass and rate distribution

Astrophysically-motivated weighting of host galaxies

- Galaxy clustering

Sources correlated with visible matter distribution: **clustering of galaxies**

Cluster catalogues \Rightarrow probability density of mergers in redshift space

Construct **merger density catalogues**

Beyond H_0 ?

Rewind: Three roads to GW cosmology

- Electromagnetic counterparts:

Transient counterparts

Schutz (1986); Holz & Hughes (2005); Nissanke *et. al* (2013)

Galaxy catalogues

Schutz (1986); MacLeod & Hogan (2008); Del Pozzo (2012)

- Information from physics of NS:

Mass-function.

Taylor *et al.* (2012); Taylor & Gair (2012)

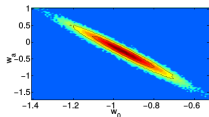
Tidal deformations.

Messenger & Read (2011); Del Pozzo *et al.* (2017)

- Statistical features of GW distributions.

Oguri (2016); Zhang (2018)

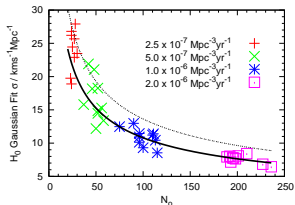
Using information from physics / astrophysics of NS



Mass-function:

Masses / mass distribution of NS

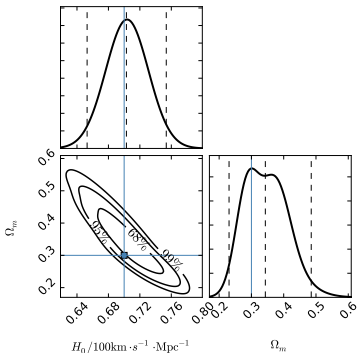
Taylor et al. (2012)



Tidal deformations:

Internal physics of NS

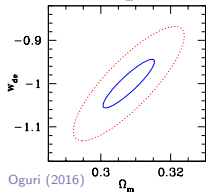
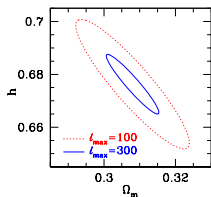
Del Pozzo et al. (2017)



Correlations of GW/EM distributions

Angular / 3D correlation functions

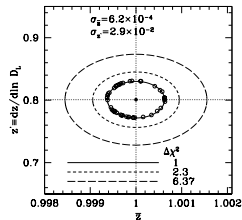
ET



Oguri (2016)

GW distributions with cluster catalogues / LSS

BBO + Euclid / SKA

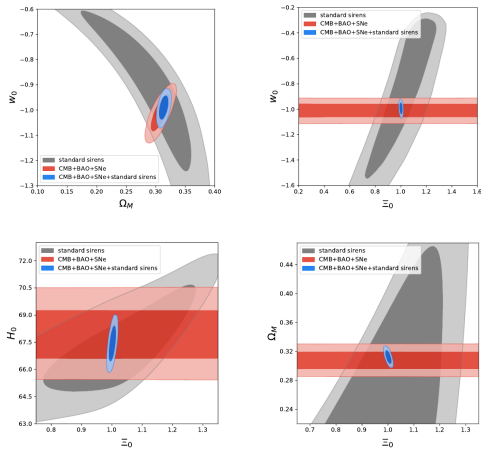


Zhang (2018)

Ground-based 3G expectations

Belgacem *et al.* (2018)

Gravity modifications together with cosmology



LISA projections

Tamanini et al. (2016)

Model	N2A5M5L6						N2A2M5L4					
	$P(\%)$	$\Delta\Omega_M$	$\Delta\Omega_\Lambda$	Δh	Δw_0	Δw_a	$P(\%)$	$\Delta\Omega_M$	$\Delta\Omega_\Lambda$	Δh	Δw_0	Δw_a
5 param.	100	4.31	7.16	1.58	13.2	92.3	67.8	320	799	47.7	344	5530
	100	18.0	24.9	9.95	88.6	392	2.54	$\gg 10^4$	$\gg 10^4$	$\gg 10^4$	$\gg 10^4$	$\gg 10^4$
	100	2.80	5.15	0.681	4.66	55.7	68.6	138	306	13.3	127	2400
Λ CDM + curv.	100	0.0819	0.281	0.0521			91.5	0.471	2.66	0.429		
	100	0.220	0.541	0.136			12.7	$\gg 10^4$	$\gg 10^4$	$\gg 10^4$		
	100	0.0473	0.207	0.0316			90.7	0.174	1.26	0.145		
Λ CDM	100	0.0473	0.0473	0.0210			97.5	0.275	0.275	0.0910		
	100	0.0917	0.0917	0.0480			32.2	0.543	0.543	0.220		
	100	0.0371	0.0371	0.0146			99.2	0.126	0.126	0.0400		
DDE	100				0.253	1.32	97.5				1.03	6.36
	100				0.584	2.78	37.3				4.96	26.1
	100				0.176	1.00	95.8				0.427	2.87
Accel. & curv. test	100	0.0190	0.0735				99.2	0.211	0.396			
	100	0.0280	0.105				37.3	0.977	1.30			
	100	0.0213	0.0631				94.1	0.116	0.202			
Error on Ω_M	100	0.0173					100	0.0670				
	100	0.0238					53.4	0.0755				
	100	0.0172					100	0.0437				
Error on h	100			0.00712			100			0.0146		
	100			0.00996			53.4			0.0175		
	100			0.00531			100			0.00853		
Error on w_0	100				0.0590		100				0.121	
	100				0.0786		53.4				0.146	
	100				0.0467		100				0.0734	

Personal perspective of the 2030s

- 2030s is a while away even on cosmological time scales!

- GW sources as rungs of the distant ladder: nearby and distant.

Standard candles, sirens, rulers, ...

- More interaction between bi/multimessenger communities!