New studies on cosmology with Einstein Telescope

Tjonnie Li
tgfli@ligo.caltech.edu

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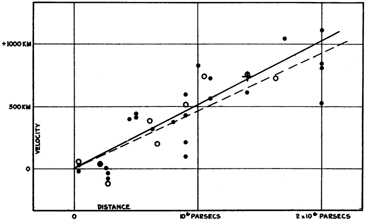
COSMOLOGY

Expanding Universe

The results estabilish a roughly linear relation between the velocities and distances among nebulae …

Hubble (1929)



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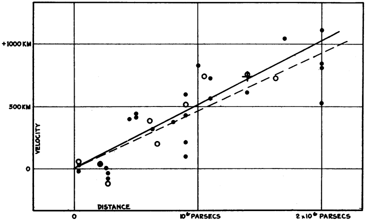
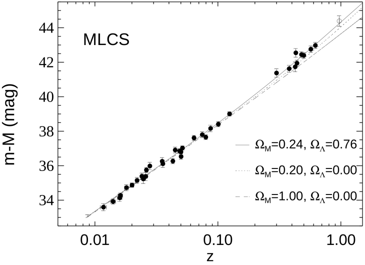


Accelerated Expansion

The results suggest an eternally expanding universe that is accelerated by energy in the vacuum …

Riess et al. (1998)



COSMOLOGICAL PARAMETERS

- Measure the distance and the recession velocity
- Related through cosmological parameters

$$d_L(z; \underbrace{h, \Omega_m, \Omega_k, \Omega_\Lambda, w_0, w_1}_{\text{Cosmological parameters}})$$

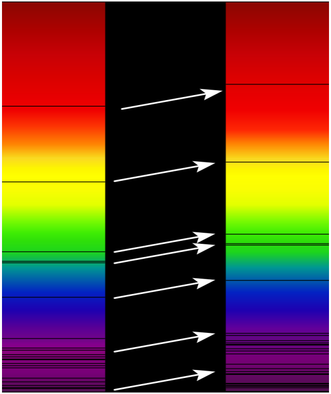
h	Hubble constant
Ω_m	Matter density
Ω_k	Spatial curvature
Ω_Λ	Dark energy
w_0, w_1	Dark energy equation of state

STANDARD CANDLES

Redshift

Measure shift in “known”

- Spectral lines
- Broadband spectrum



STANDARD CANDLES

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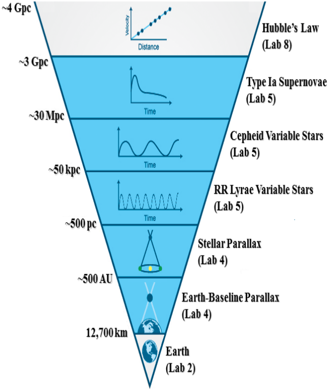
Luminosity distance

Luminosities poorly understood

- Measure flux
- Calibrate luminosity (distance ladder)



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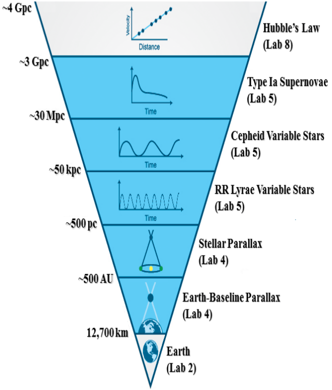
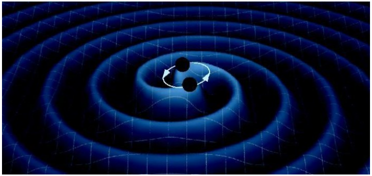
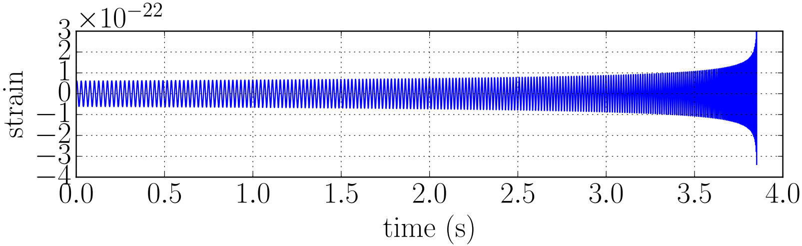


Redshift measured accurately
Distance susceptible to systematic error

BINARY MERGERS



- Radiate GWs as components orbit each other
- Loss of energy/momentum causes separation to shrink
- Ultimately merge and form single black hole

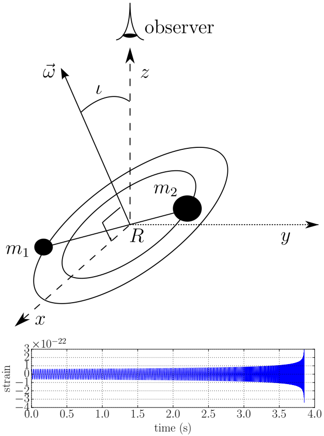


STANDARD SIRENS

Luminosity distance

Well-known $h \sim d_L^{-1}$ relationship

- Measure flux
- Infer luminosity



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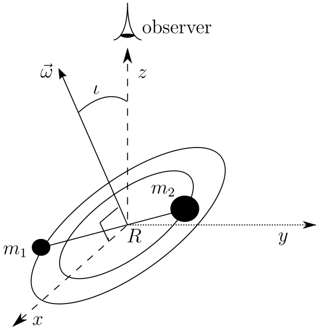
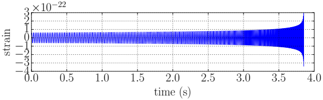
No “known” spectral lines

- Depends on the masses
- Redshifted masses measured





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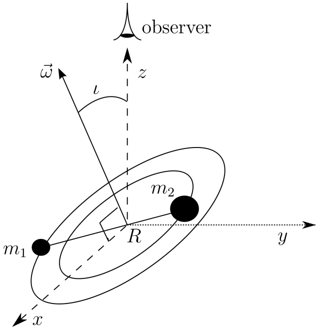
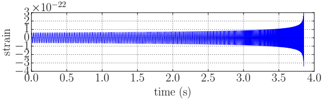
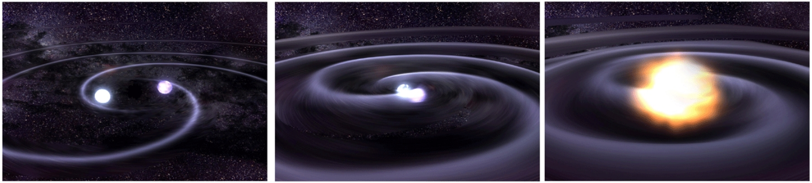




Self-calibrated distance measure
Redshift measurement is a challenge

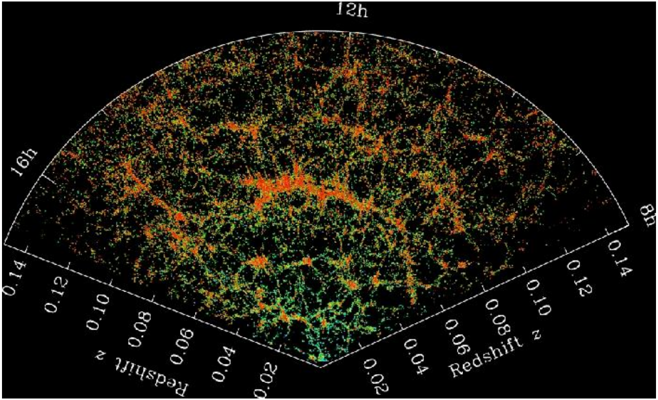
GW REDSHIFT INFERENCE – EXISTING IDEAS

Binary system could be a progenitor for a short hard γ-ray burst. Measure redshift electromagnetically.



GW REDSHIFT INFERENCE – EXISTING IDEAS

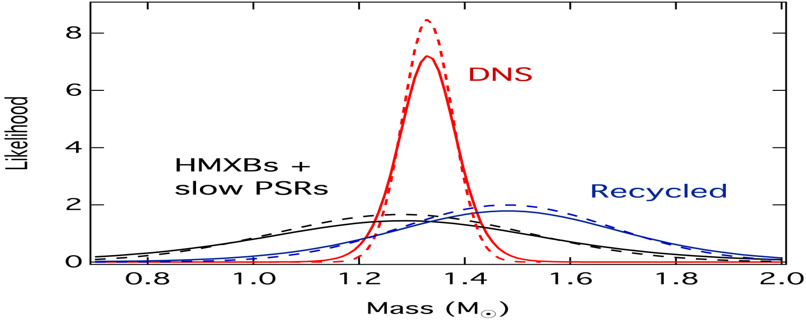
Use a catalogue of known galaxies



GW REDSHIFT INFERENCE – EXISTING IDEAS

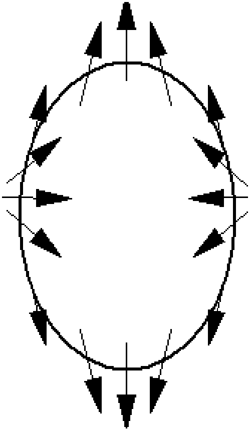
Assume the neutron star mass distribution is known.

$$\underbrace{m'}_{\text{measured}} = \underbrace{m}_{\text{Assume known}} (1 + \underbrace{z}_{\text{inferred}})$$



Özel et al. (2012)

GW REDSHIFT INFERENCE – TIDAL EFFECTS



Messenger and Read (2012)

- Tidal effects on neutron stars affect phase evolution
- Tidal effects depend on rest mass
- Infer redshift if the neutron star equation state is known

$$\underbrace{m'}_{\text{measured}} = \underbrace{m}_{\text{NS EOS}}(1+\underbrace{z}_{\text{inferred}})$$

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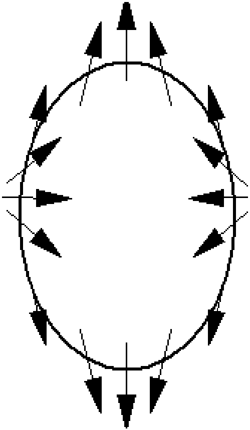

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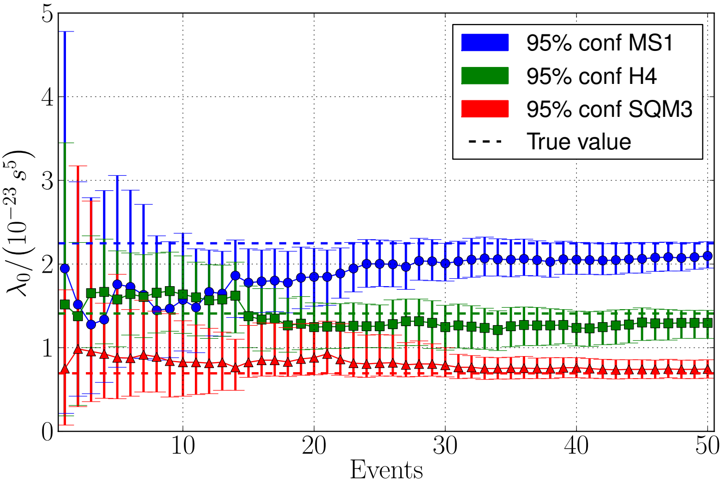
Can we infer the neutron star equation of state?

NEUTRON STAR EQUATION OF STATE



Del Pozzo, TGFL *et al.* (2013)

DATA-ANALYSIS CHALLENGE

Assuming we know the NS EOS, how well can we infer the cosmological parameters?

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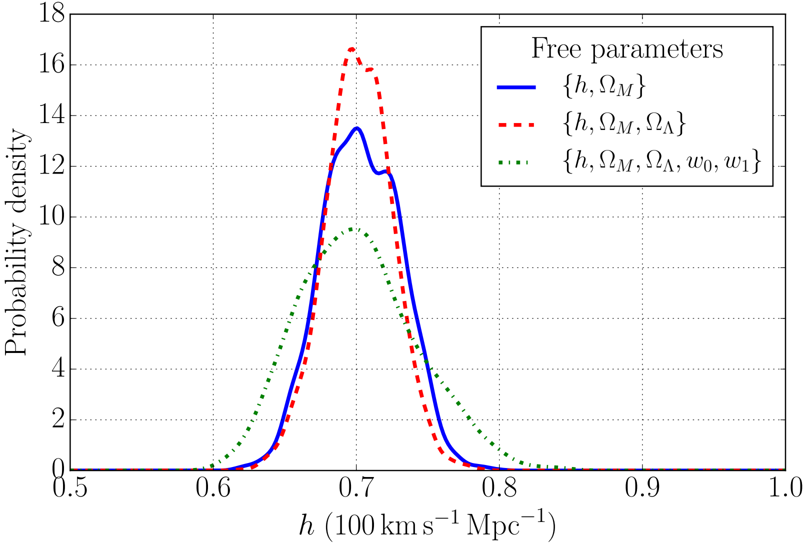
Assuming we know the NS EOS, how well can we infer the cosmological parameters?

Del Pozzo, TGFL et al. (in prep.)

- Simulate a 1000 ET binary neutron stars events
- Astrophysical distribution (most at low SNR)
- Analyse them using a full Bayesian inference infrastructure

Get posterior probability distribution functions for the cosmological parameters $\{h, \Omega_M, \Omega_\Lambda, w_0, w_1\}$

HUBBLE CONSTANT

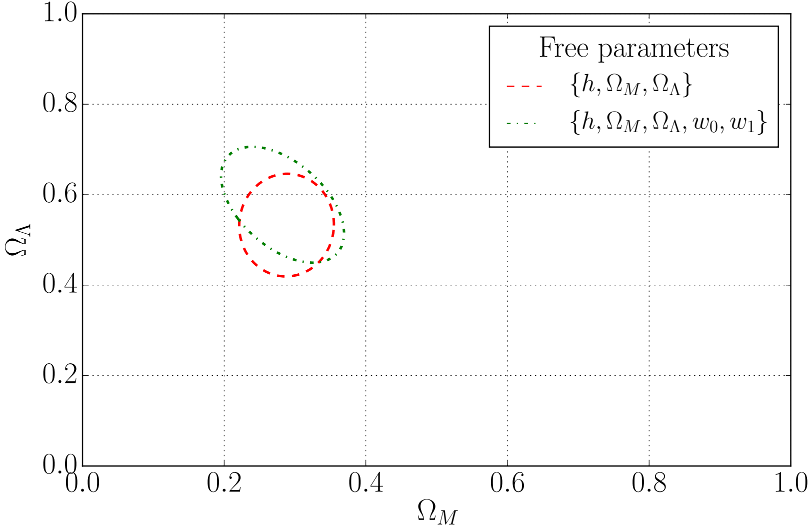


HUBBLE CONSTANT

	Δh		
N_{sources} \ $\vec{\Omega}_{\text{free}}$	10^3	10^5	10^7
h, Ω_M	5×10^{-2}	5×10^{-3}	5×10^{-4}
$h, \Omega_M, \Omega_\Lambda$	5×10^{-2}	5×10^{-3}	5×10^{-4}
$h, \Omega_M, \Omega_\Lambda, w_0, w_1$	8×10^{-2}	8×10^{-3}	8×10^{-4}

Current constrains Planck Collaboration et al. (2014)
$\Delta h = 7 \times 10^{-3}$

ENERGY DENSITIES



ENERGY DENSITIES

	$\Delta\Omega_M$		
N_{sources} $\vec{\Omega}_{\text{free}}$	10^3	10^5	10^7
h, Ω_M	1×10^{-1}	1×10^{-2}	1×10^{-3}
$h, \Omega_M, \Omega_\Lambda$	1×10^{-1}	1×10^{-2}	1×10^{-3}
$h, \Omega_M, \Omega_\Lambda, w_0, w_1$	2×10^{-1}	2×10^{-2}	2×10^{-3}

Current constrains Planck Collaboration et al. (2014)

$$\Delta\Omega_M = 1.0 \times 10^{-2} \text{ (flat)}$$

$$\Delta\Omega_M = 4.0 \times 10^{-2} \text{ (generic)}$$

ENERGY DENSITIES

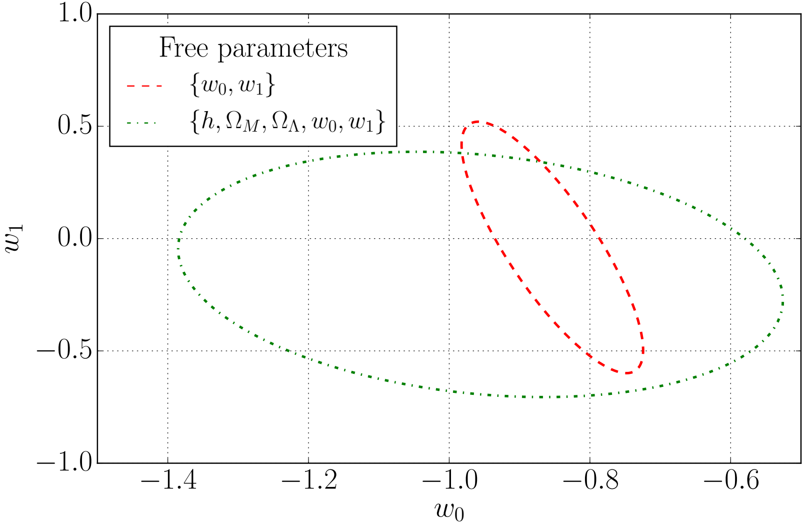
	$\Delta\Omega_\Lambda$		
N_{sources} $\vec{\Omega}_{\text{free}}$	10^3	10^5	10^7
h, Ω_M	1×10^{-1}	1×10^{-2}	1×10^{-3}
$h, \Omega_M, \Omega_\Lambda$	2×10^{-1}	2×10^{-2}	2×10^{-3}
$h, \Omega_M, \Omega_\Lambda, w_0, w_1$	2×10^{-1}	2×10^{-2}	2×10^{-3}

Current constrains Planck Collaboration et al. (2014)

$$\Delta\Omega_\Lambda = 1.0 \times 10^{-2} \text{ (flat)}$$

$$\Delta\Omega_\Lambda = 6.0 \times 10^{-2} \text{ (generic)}$$

DARK ENERGY EQUATION OF STATE



DARK ENERGY EQUATION OF STATE

	Δw_0		
N_{sources} / $\vec{\Omega}_{\text{free}}$	10^3	10^5	10^7
w_0, w_1	3×10^{-1}	3×10^{-2}	3×10^{-3}
$h, \Omega_M, \Omega_\Lambda, w_0, w_1$	9×10^{-1}	9×10^{-2}	9×10^{-3}

Current constrains Planck Collaboration et al. (2014)

$\Delta w_0 = 4 \times 10^{-1}$

DARK ENERGY EQUATION OF STATE

	Δw_1		
N_{sources} / $\vec{\Omega}_{\text{free}}$	10^3	10^5	10^7
w_0, w_1	1×10^0	1×10^{-1}	1×10^{-2}
$h, \Omega_M, \Omega_\Lambda, w_0, w_1$	1×10^0	1×10^{-1}	1×10^{-2}

Currently unconstrained

CONCLUDING REMARKS

- GWs from binaries allow for self-calibrated distance measurement
- Need redshift information to infer cosmology
  - Multimessenger measurement
  - Galaxy catalogue
  - Known neutron star mass distribution
- Investigated new idea: use knowledge of the NS EOS
- Contraints are competitive compared to current and future EM measurement

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Einstein Telescope will give independent and precision information about the current cosmological paradigm

Thank you

ABSTRACT

Compact binaries can be used as standard sirens, the gravitational-wave equivalent of standard candles, to probe the large-scale structure of the Universe. Einstein Telescope, with its prospect of vast numbers of detections, promises to be a great tool to perform precision cosmology. However, redshift information necessary to perform cosmological inference may not be so readily accessible. Several ideas have been put forward to alleviate this problem, such as the use of a galaxy catalogue, a known neutron star mass distribution, or the observation of electromagnetic counterparts. Recently, it was shown that redshift information can also be obtained from the merger of binary neutron stars if the neutron star equation of state is constrained. I will present results from the first realistic investigations into this idea using current data-analysis infrastructures. Moreover, I will show that the Einstein Telescope can put constraints on cosmological parameters that are comparable to future electromagnetic facilities.

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