Gravitational-Wave Populations and Cosmology

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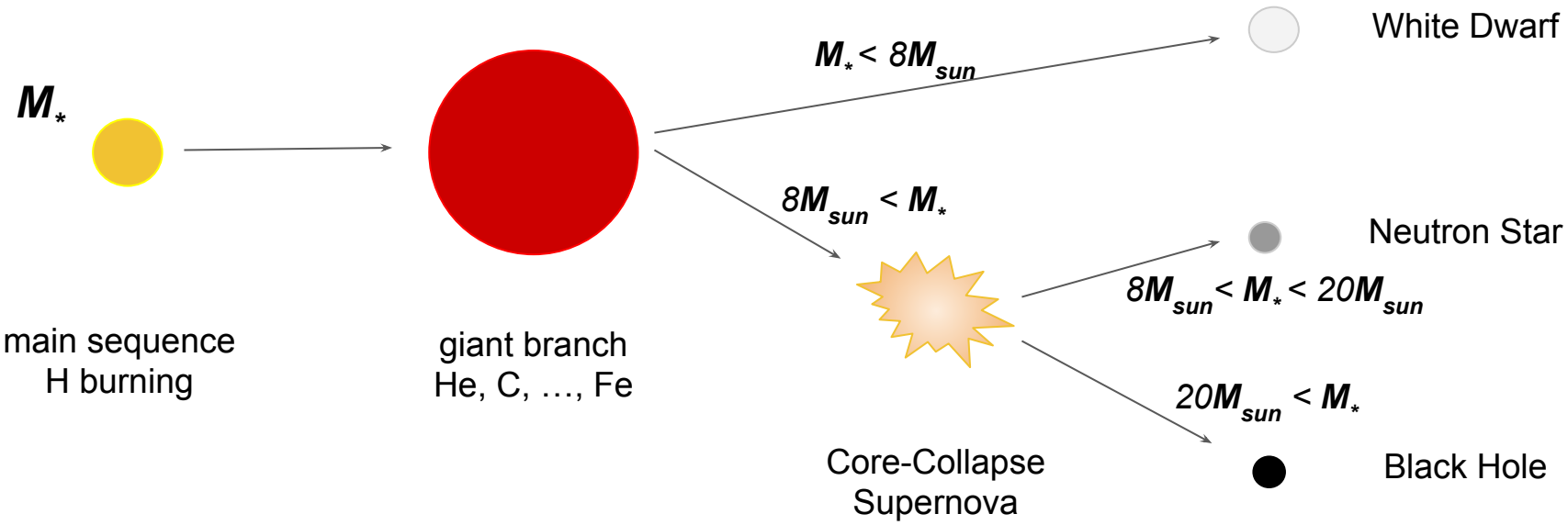
26 October 2019
Compton Lectures
University of Chicago

https://github.com/reedessick/compton-lectures-2019

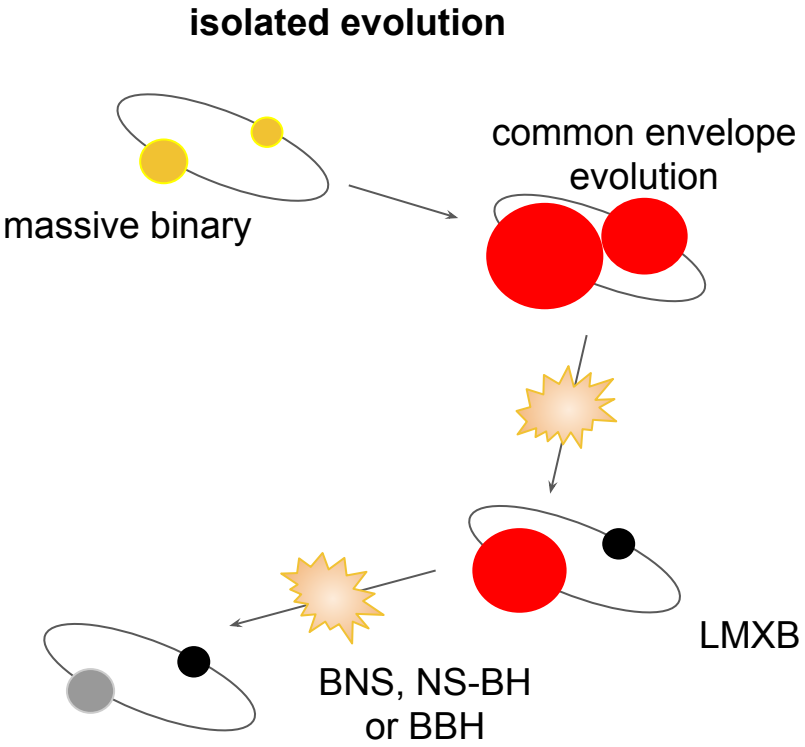
Review

Neutron Stars and **Black Holes** are the end states of massive stars



Review

Binaries containing **Compact Objects** form through



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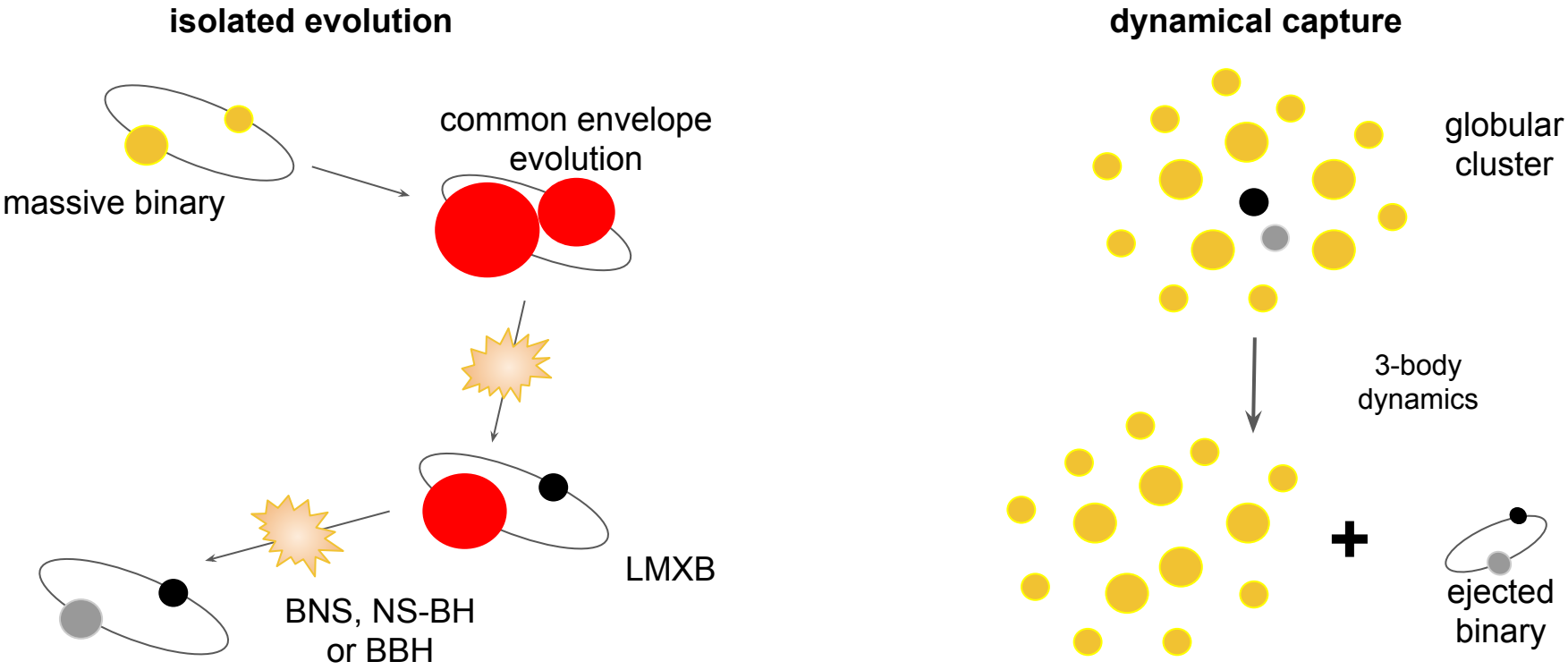

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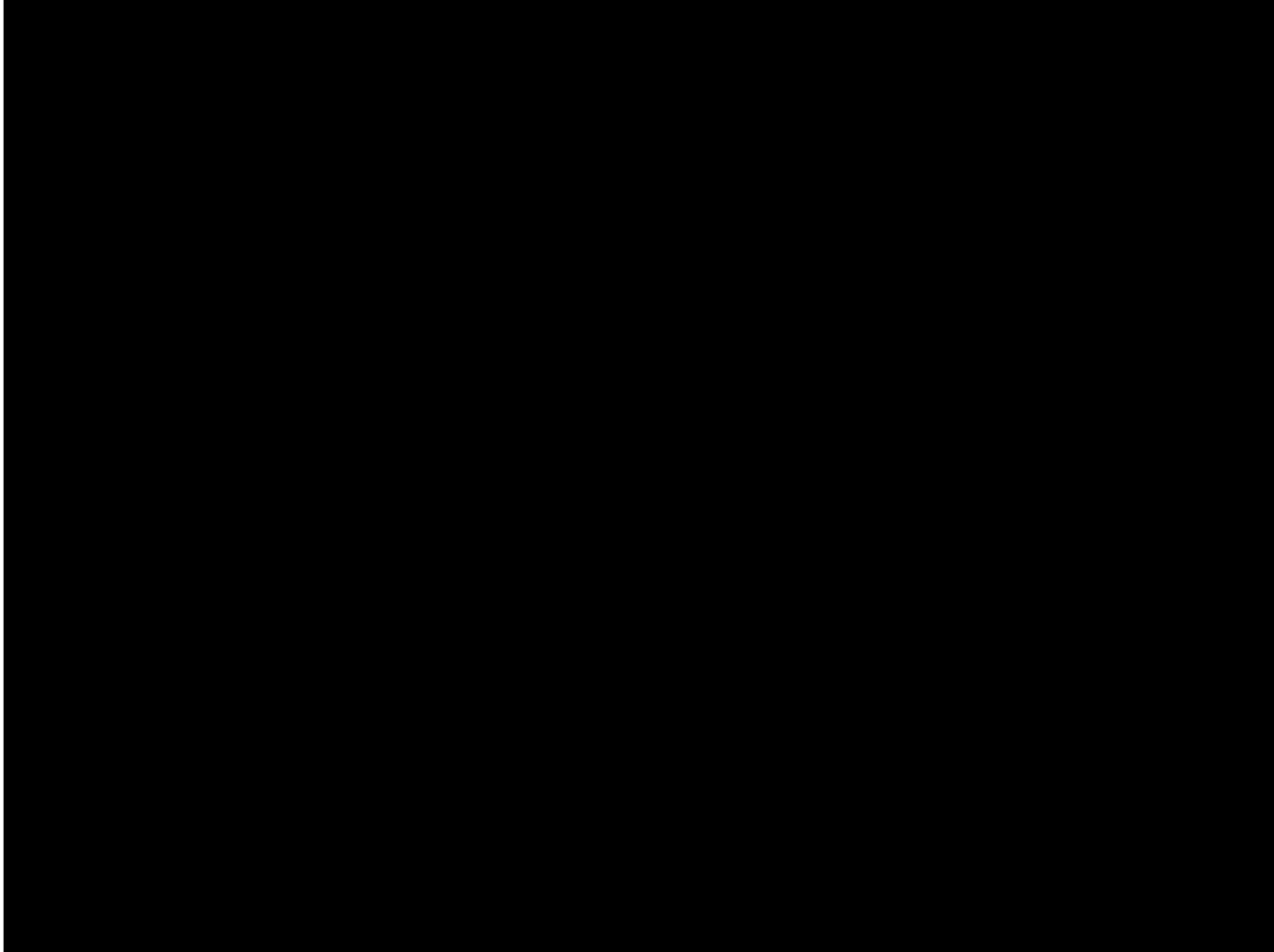

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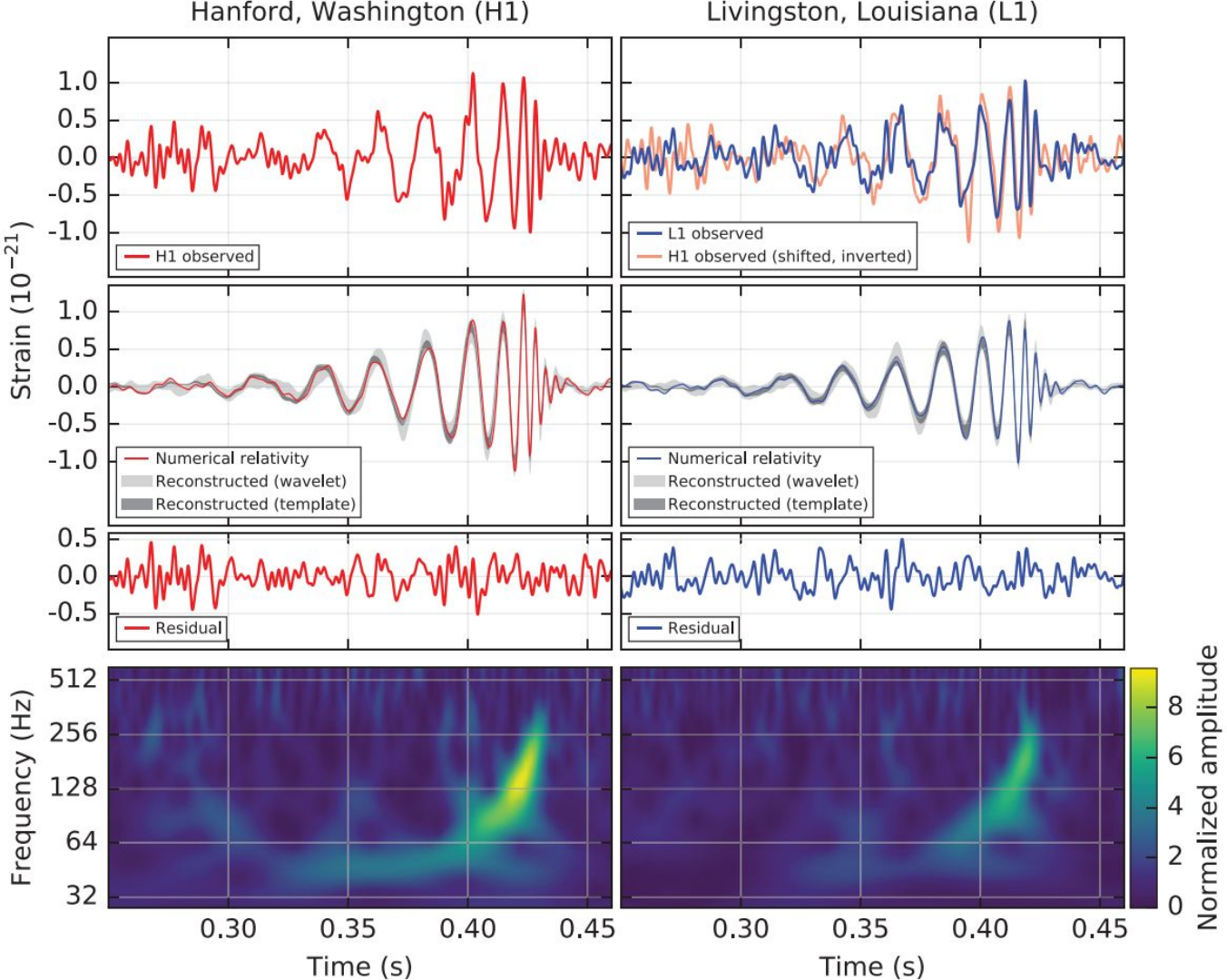

Hanford, Washington (H1)
Livingston, Louisiana (L1)
H1 observed
L1 observed
H1 observed (shifted, inverted)
Strain (10^{-21})
Numerical relativity
Reconstructed (wavelet)
Reconstructed (template)
Residual
Frequency (Hz)
512
256
128
64
32
0.30
0.35
0.40
0.45
Time (s)
Normalized amplitude
8
6
4
2
0

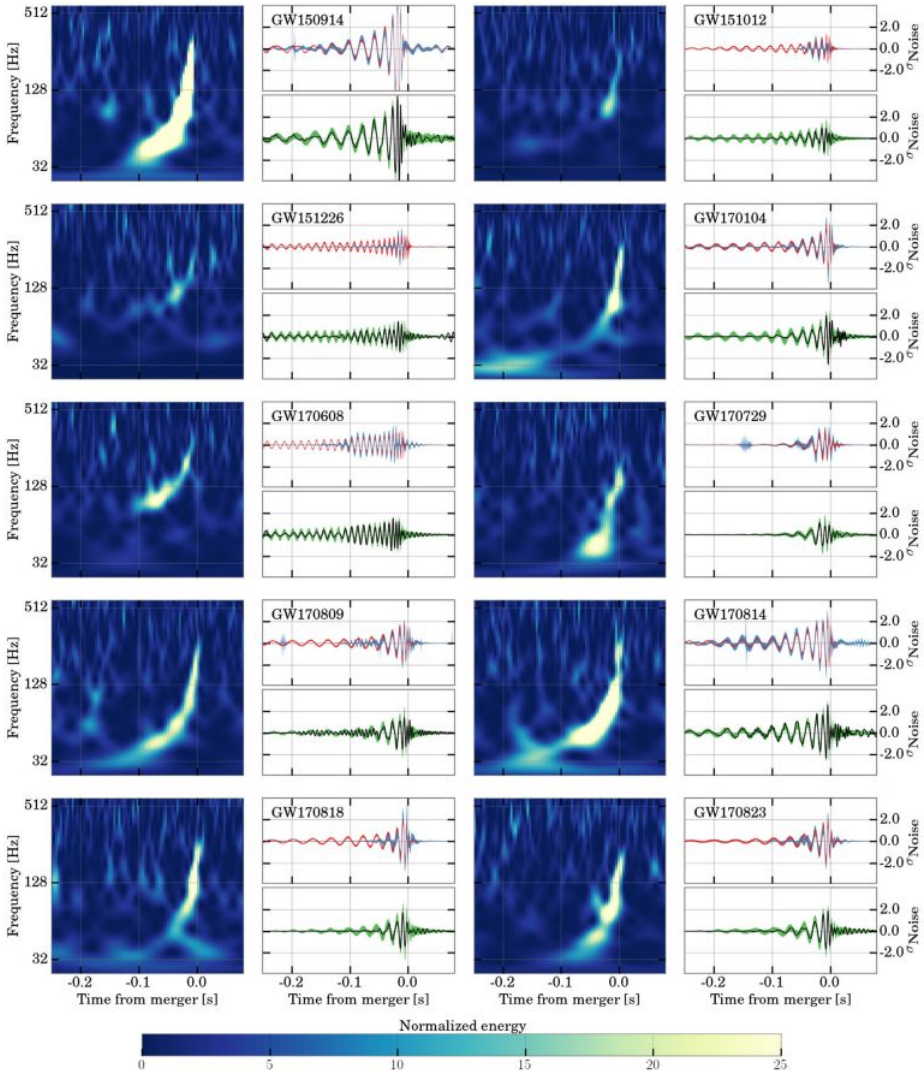
Populations

We have detected 10 binary Black Hole (BBH) and one binary Neutron Star system (BNS) coalescences in the first two observing runs

- O1: Sep 2015 - Jan 2016
- O2: Dec 2016 - Aug 2017

and the third observing run is currently on-going!

- O3: Apr 2019 - Apr 2020

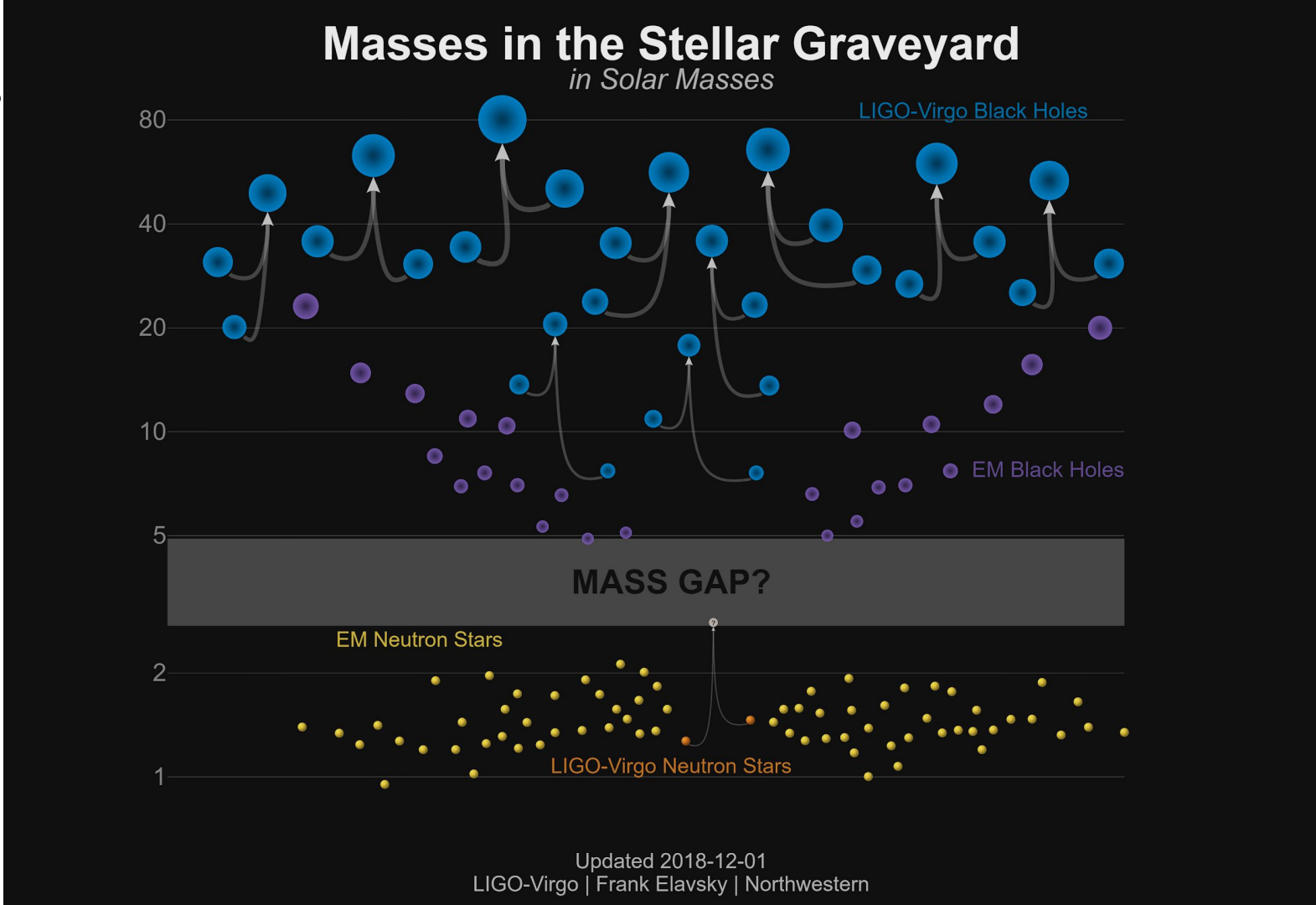


Populations

Populations

What properties can we measure?

Populations



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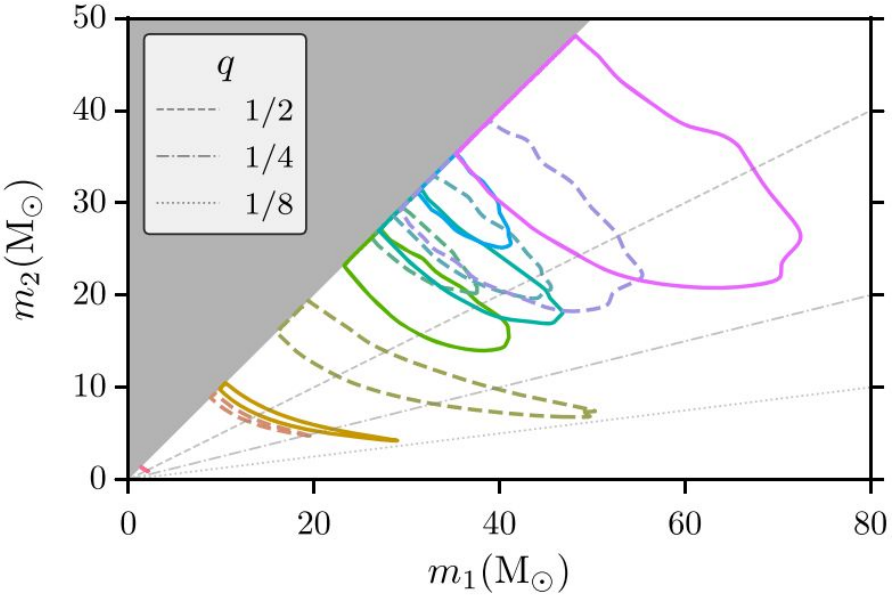
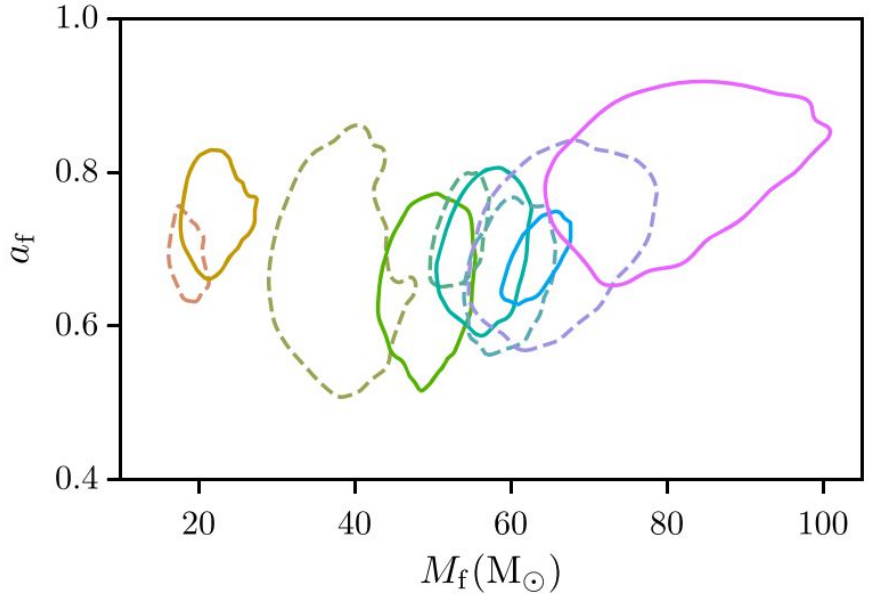
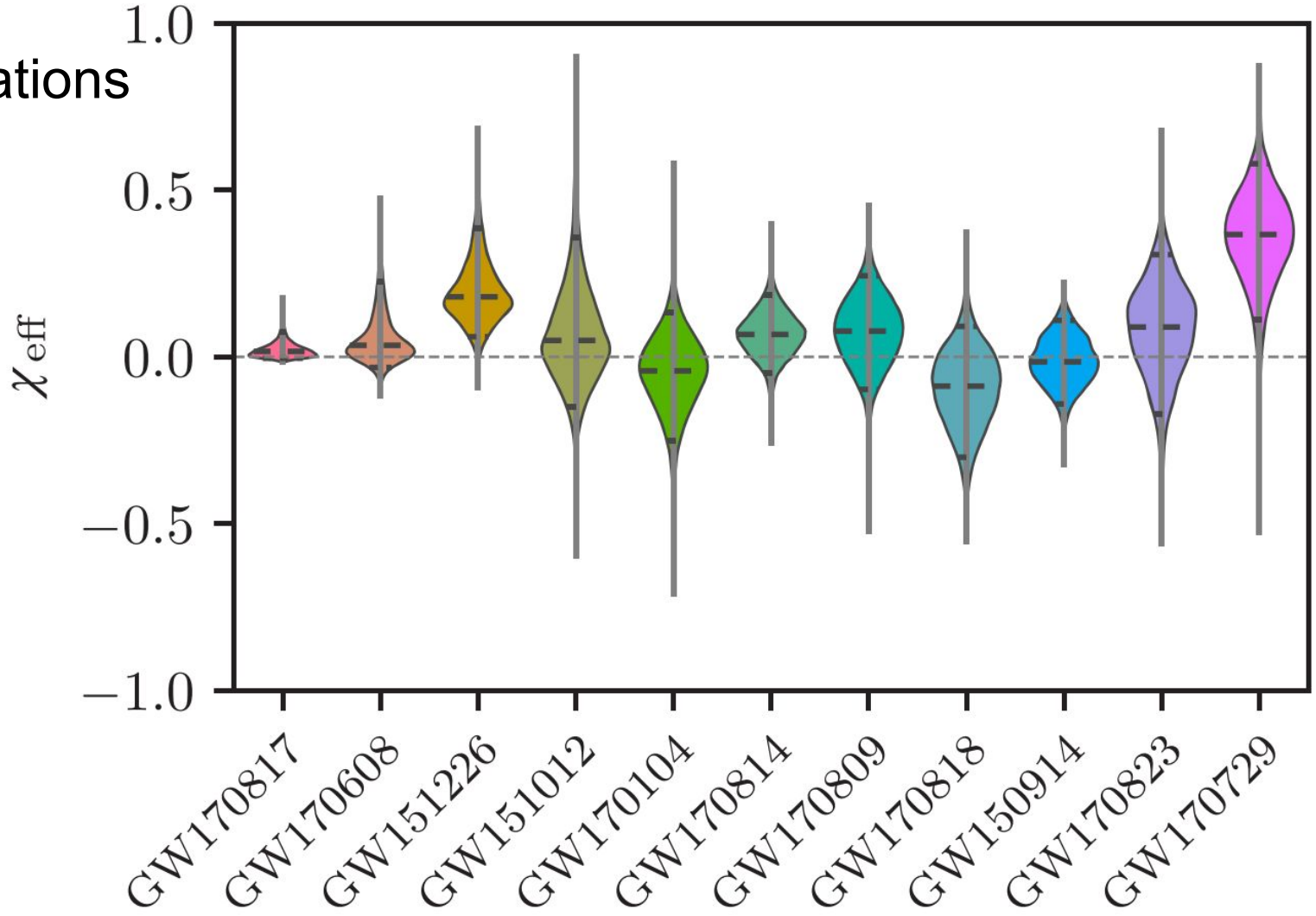




GW170817 GW151226 GW170104 GW170809 GW150914 GW170729
GW170608 GW151012 GW170814 GW170818 GW170823

Populations



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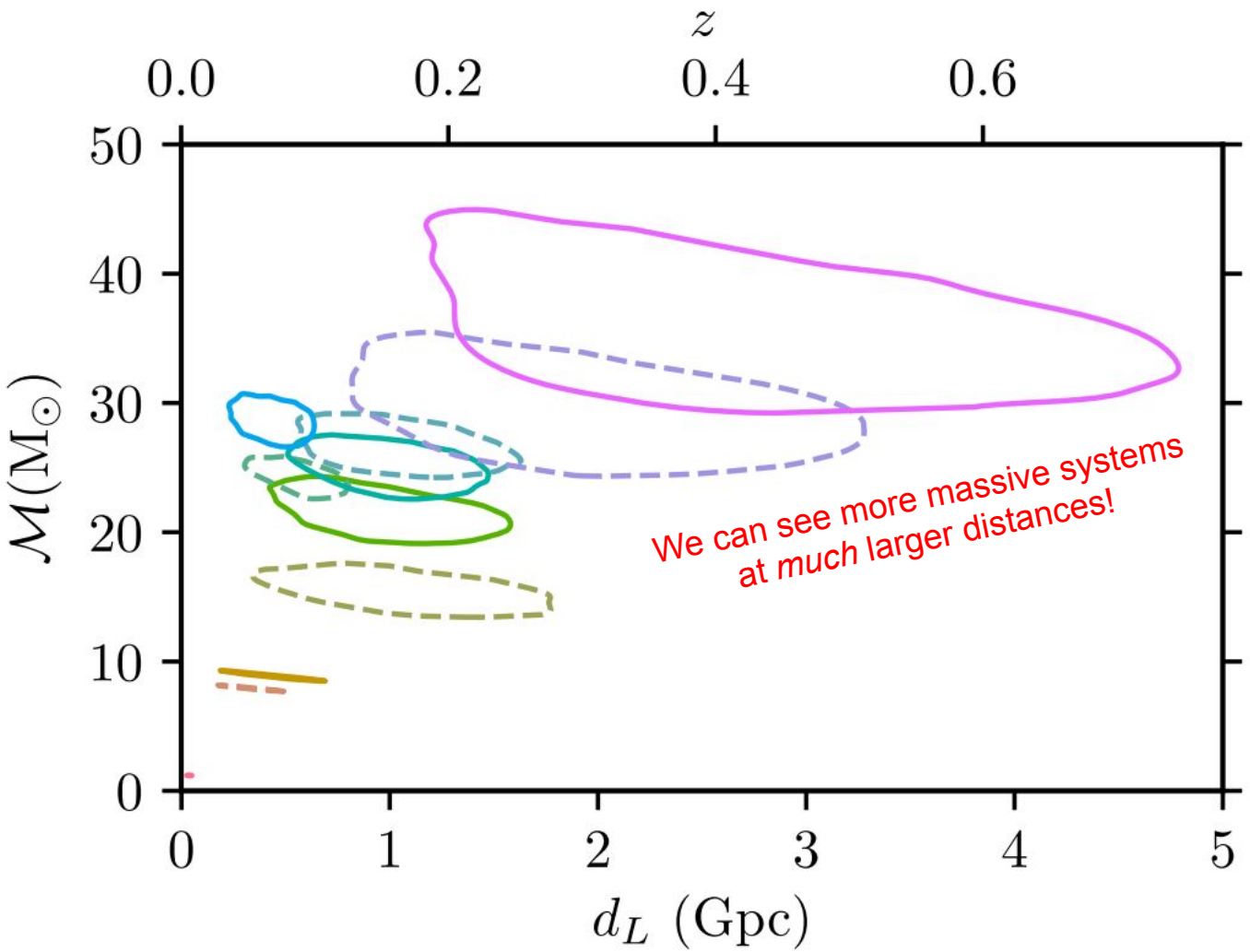
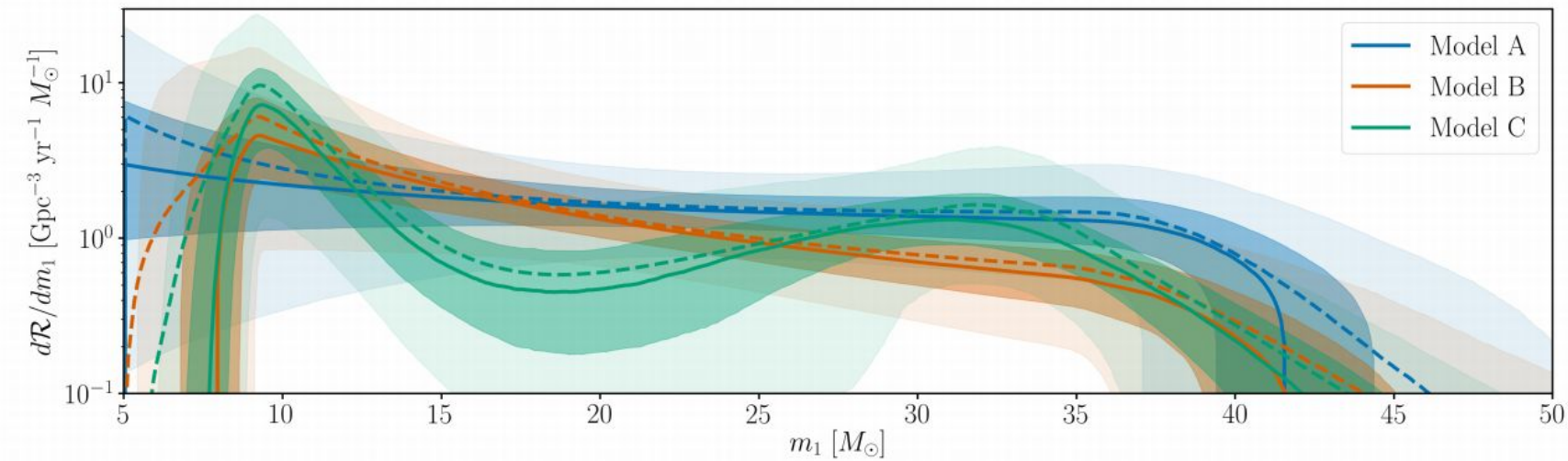


Populations

We can see more massive systems at *much* larger distances!



The absence of detections of very massive systems implies theses systems are very rare!

Cosmology

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What gives rise to cosmological redshifts (and what is a redshift anyway)?

$$z = \frac{\lambda_{\text{observed}} - \lambda_{\text{emitted}}}{\lambda_{\text{emitted}}}$$

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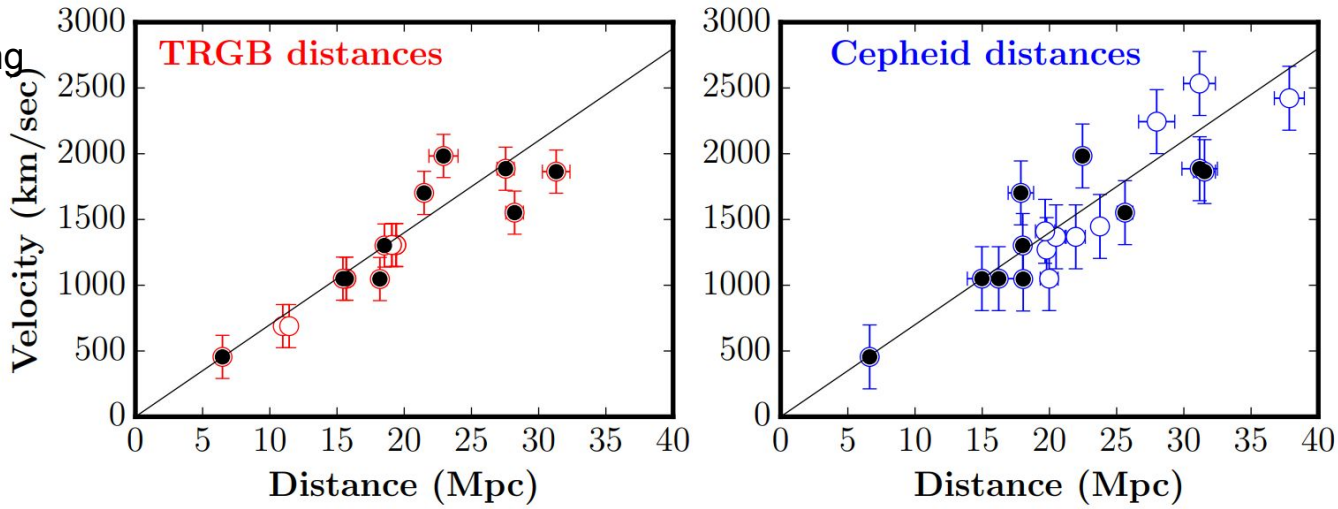
- Hubble's law relates how quickly an object is receding and how far away that object is



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How does this impact gravitational waves?

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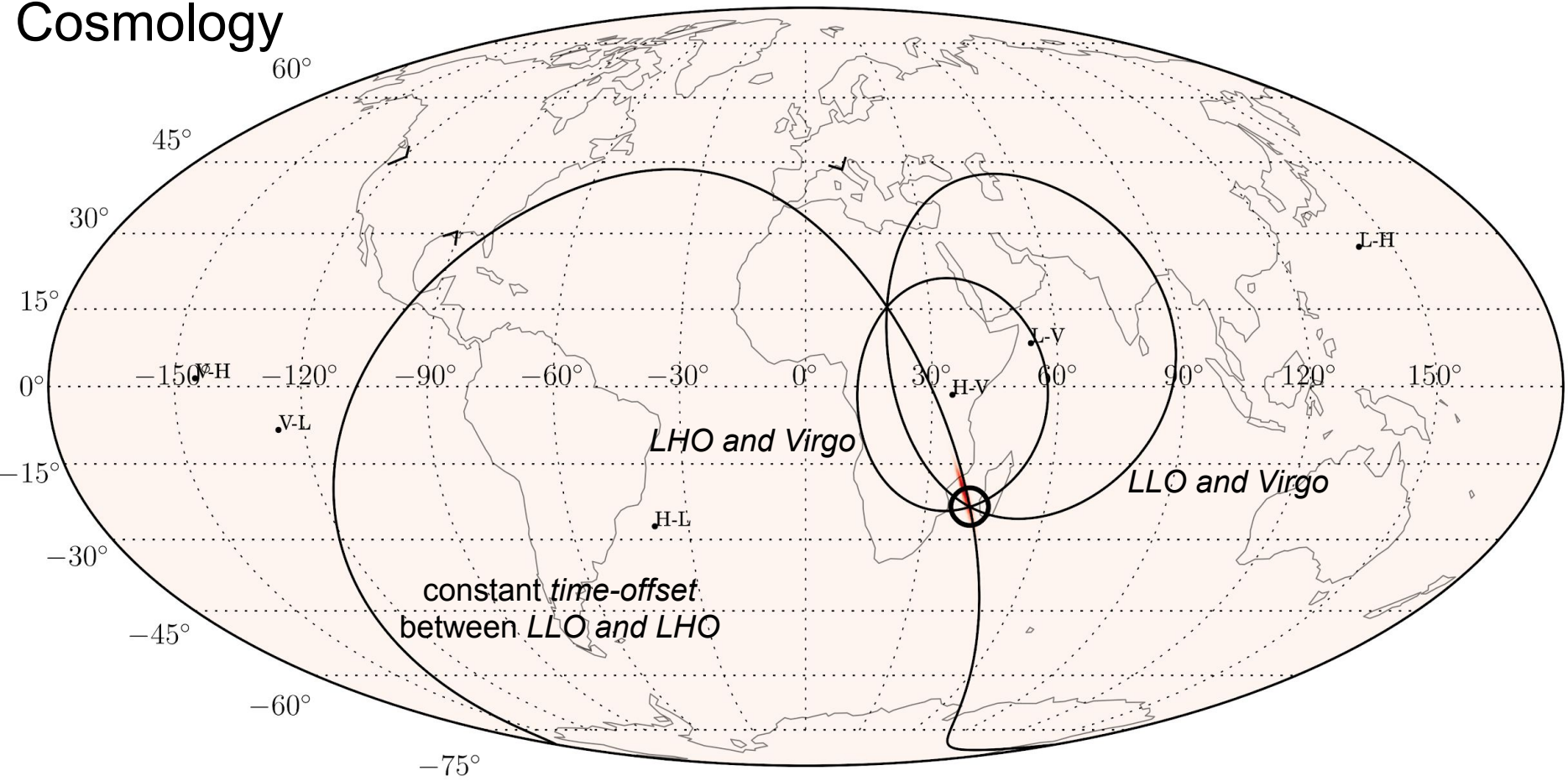
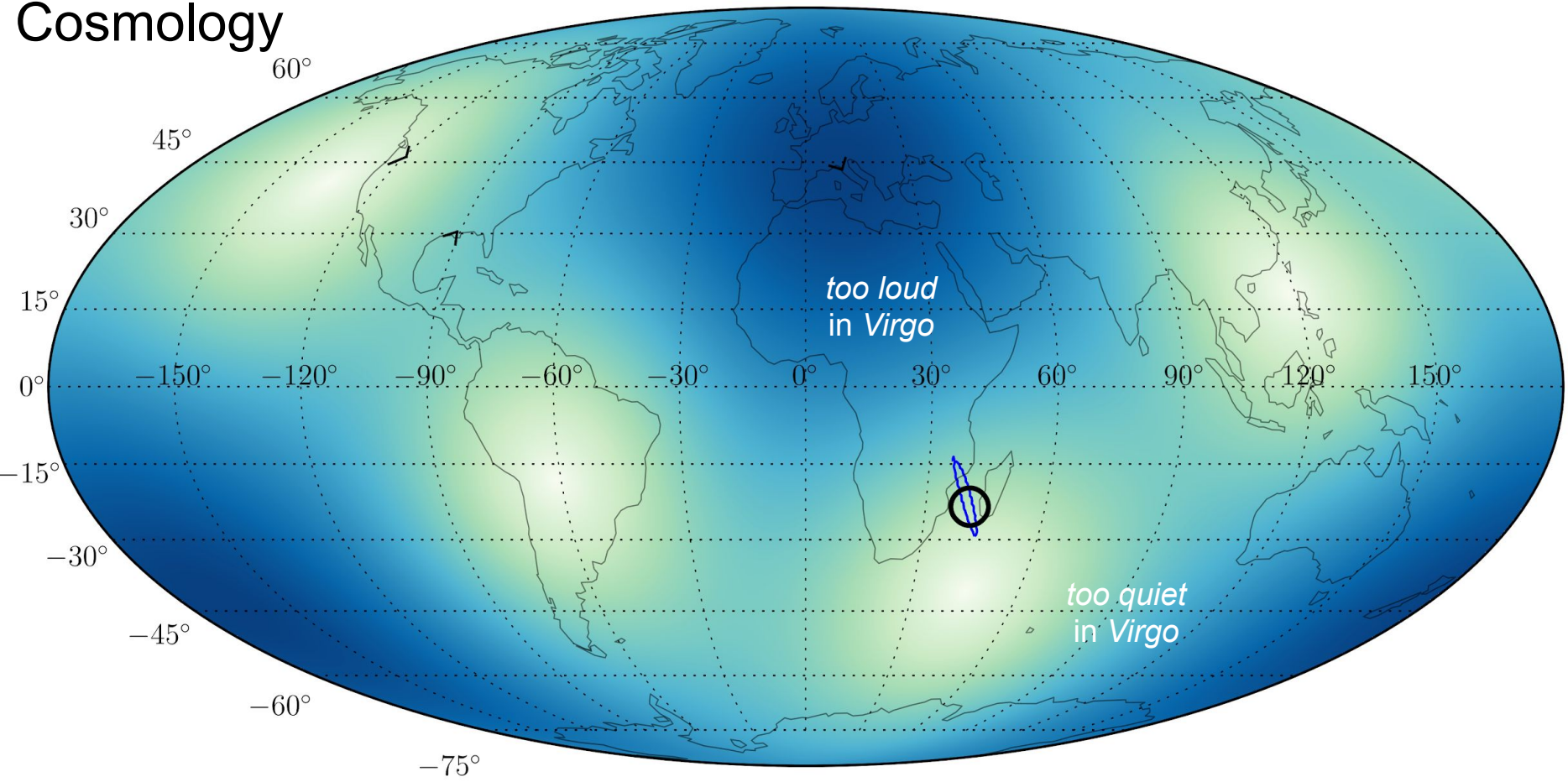
How does this impact gravitational waves?

- Compact binary coalescences are ***standard sirens***
  we can tell how far away they are by how loud they appear!

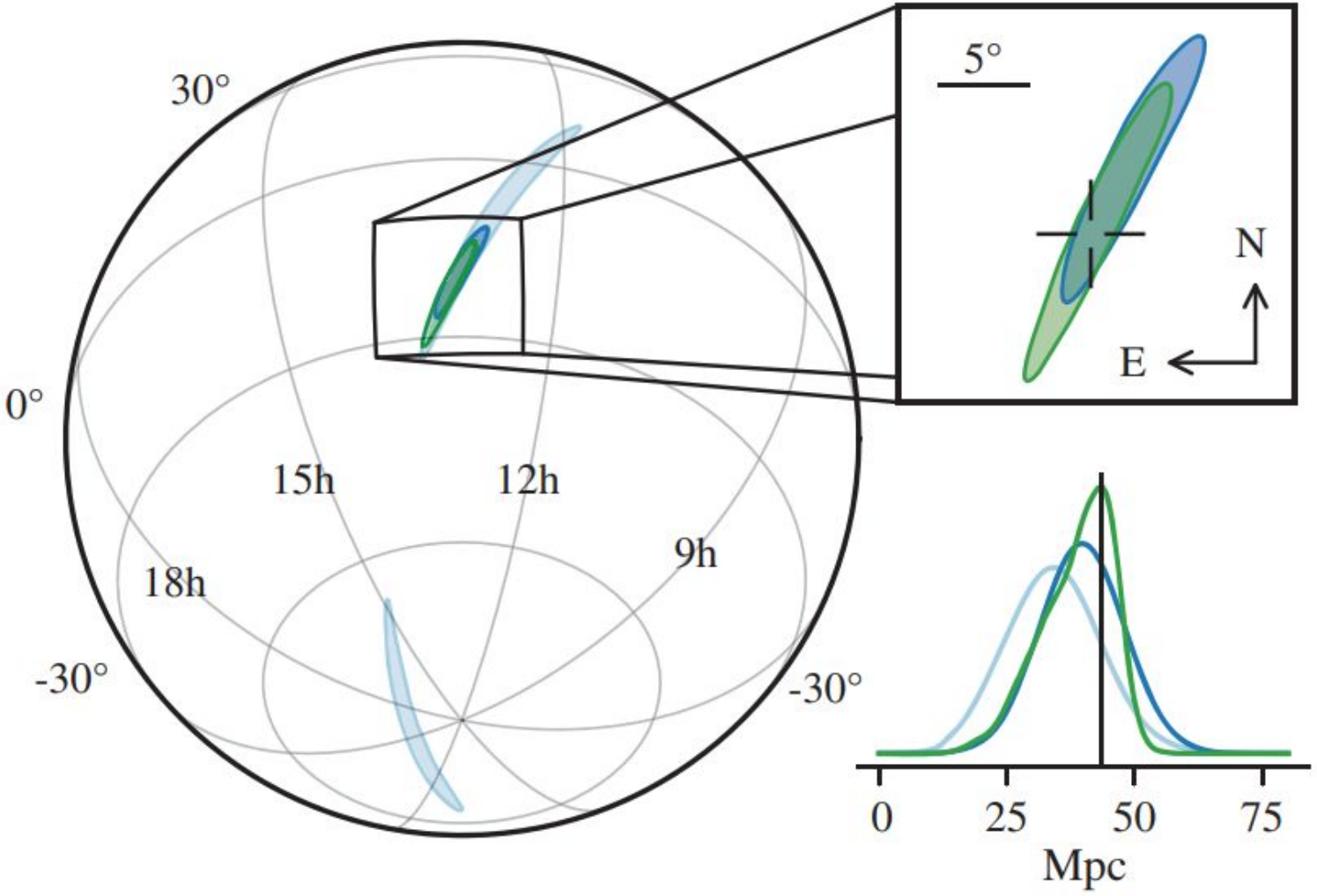
Cosmology


60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
−75°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°
V-H
V-L
H-V
L-V
L-H
H-L
LHO and Virgo
LLO and Virgo
constant *time-offset*
between *LLO and LHO*

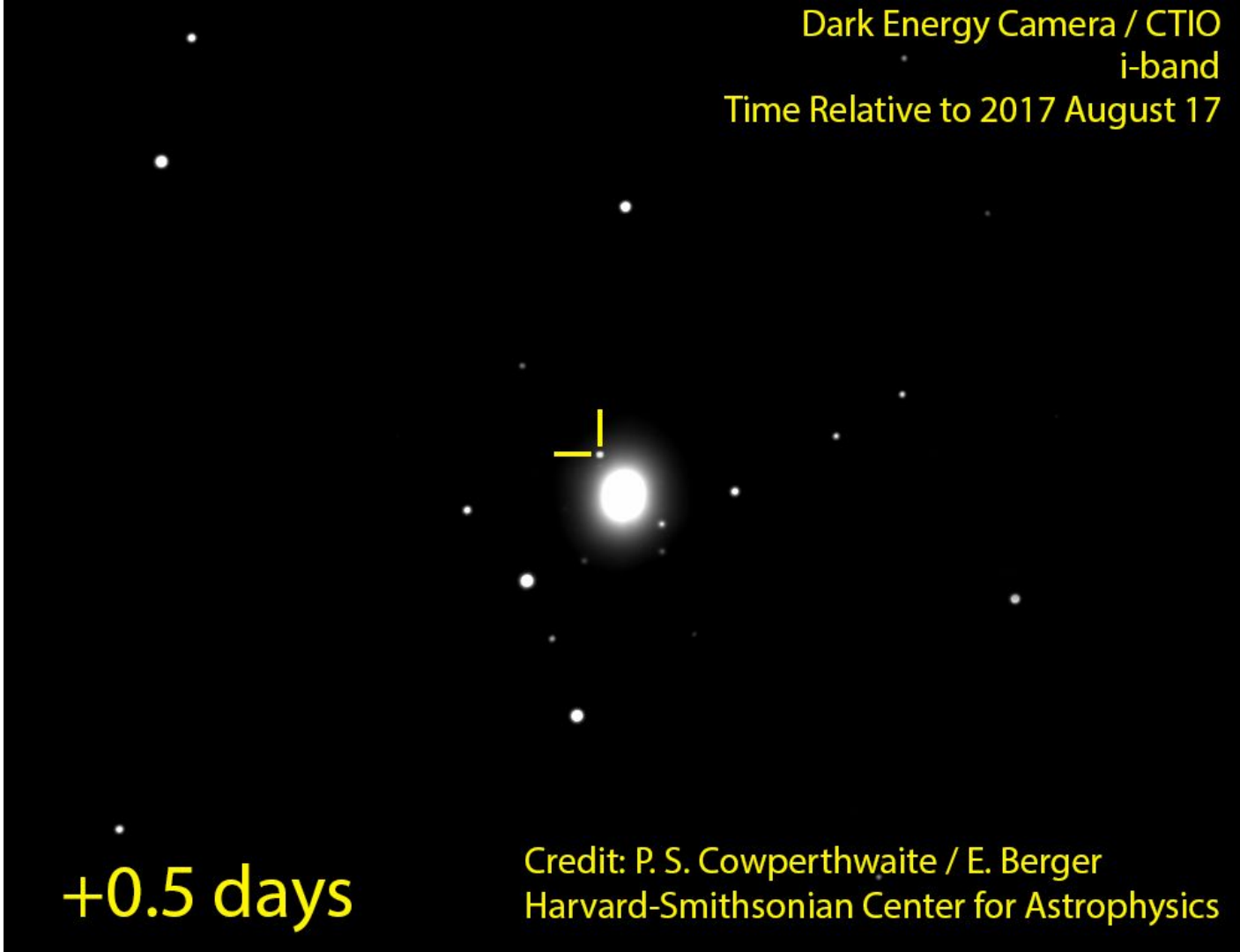
Cosmology


60°
45°
30°
15°
0°
−15°
−30°
−45°
−60°
−75°
−150°
−120°
−90°
−60°
−30°
0°
30°
60°
90°
120°
150°
too loud
in Virgo
too quiet
in Virgo

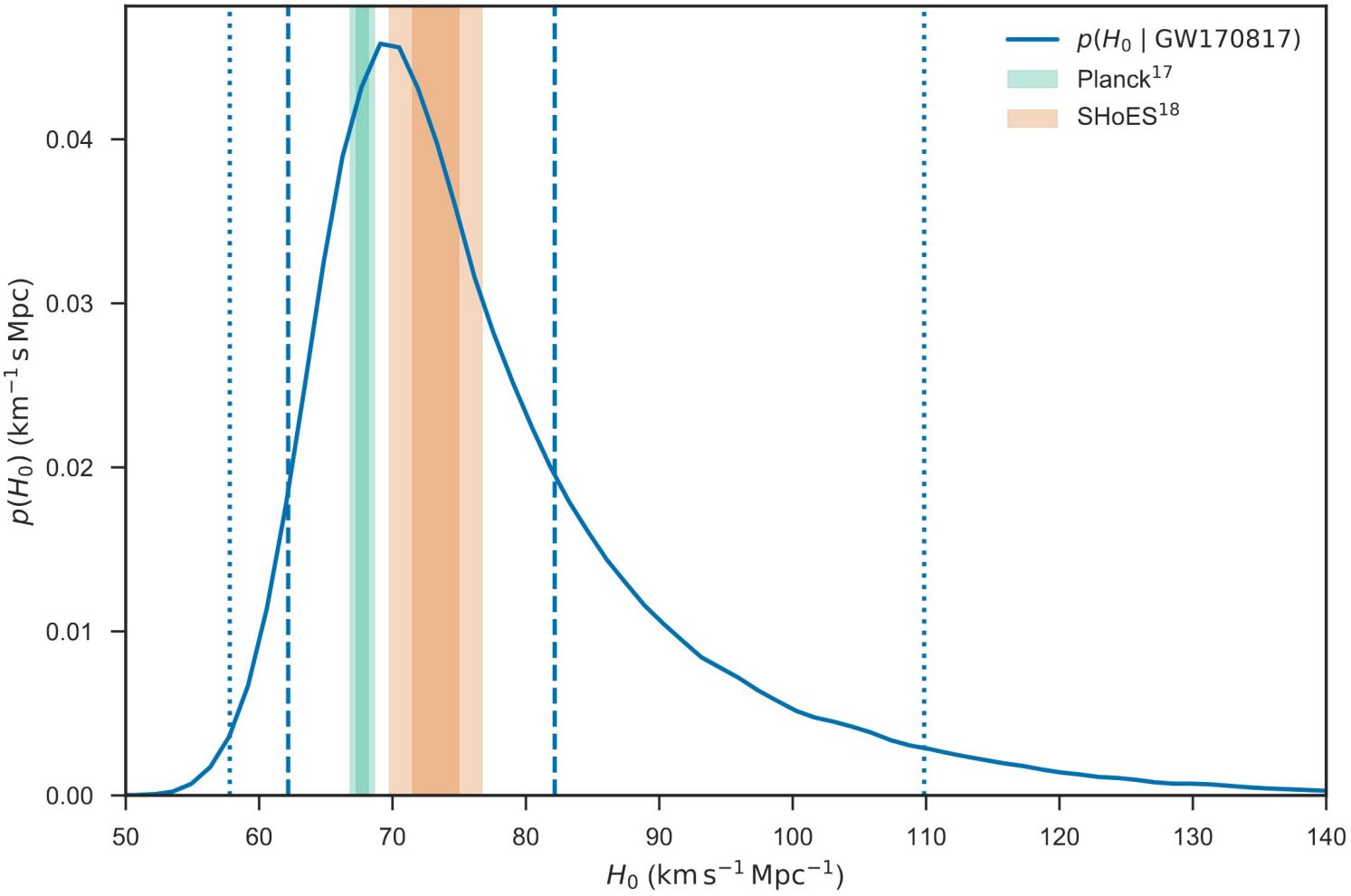
Cosmology



Cosmology


Dark Energy Camera / CTIO
i-band
Time Relative to 2017 August 17
+0.5 days
Credit: P. S. Cowperthwaite / E. Berger
Harvard-Smithsonian Center for Astrophysics

Cosmology


$p(H_0 \mid \mathrm{GW170817})$
Planck[17]
SHoES[18]
$p(H_0)$ (km^{-1} s Mpc)
0.00
0.01
0.02
0.03
0.04
50
60
70
80
90
100
110
120
130
140
H_0 (km s^{-1} Mpc^{-1})

Next time

Multi-messenger Counterparts

- What types of multi-messenger signals would we expect?
- What types of multi-messenger signals have we seen?
- What can we learn from multiple messengers instead of just one?

Suggested Reading

- *GWTC-1: A Gravitational-Wave Transient Catalog of Compact Binary Mergers Observed by LIGO and Virgo during the First and Second Observing Runs*. Phys. Rev. X 9, 031040 (2019).
- https://www.ligo.org/science/Publication-O2Catalog/flyer.pdf
- *Binary Black Hole Population Properties Inferred from the First and Second Observing Runs of Advanced LIGO and Advanced Virgo*. ApJ Lett. 882, 2 (2019).
- https://www.ligo.org/science/Publication-O2BBHPop/flyer.pdf
- https://www.ligo.org/science/Publication-GW170817Hubble/flyer.pdf