Determining the Hubble constant from gravitational wave observations – Bernard F. Schutz

Journal Club Presentation Group 11:

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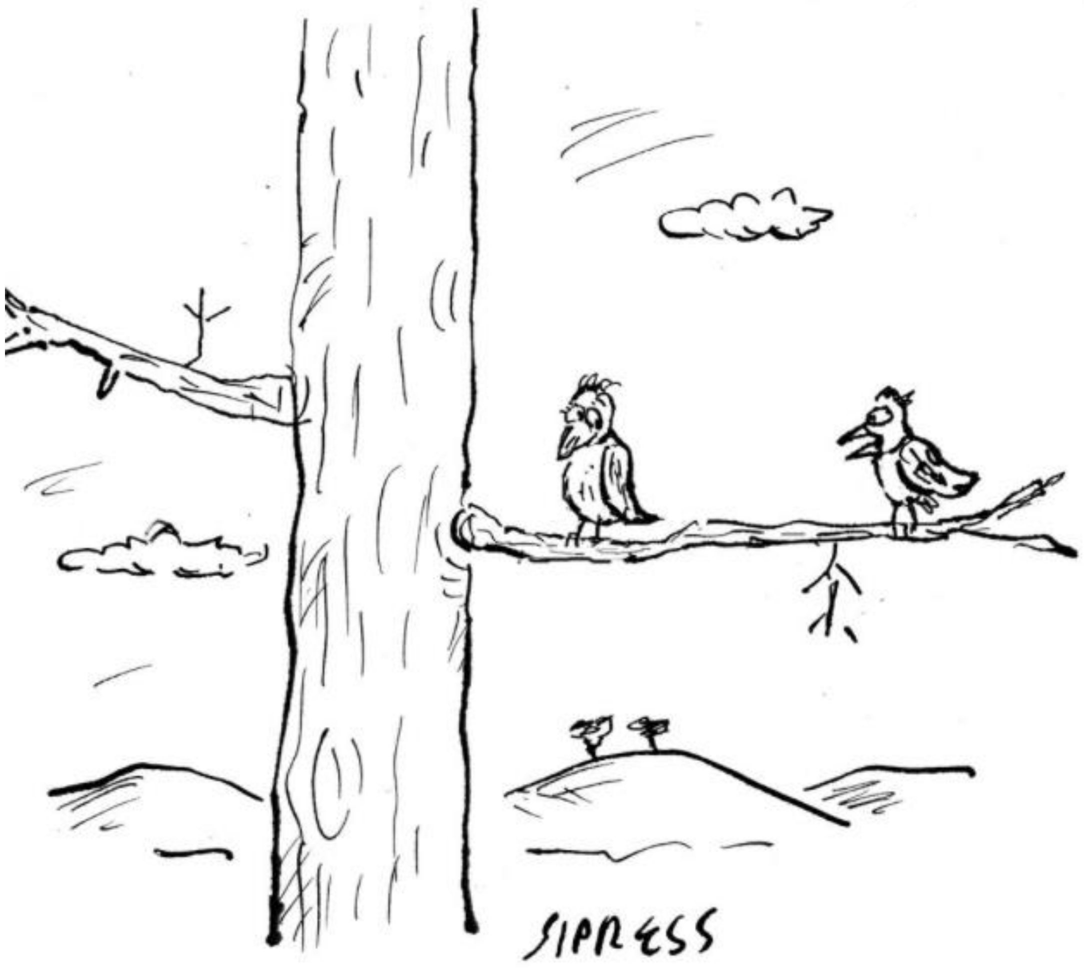
B. F. Schutz. Determining the Hubble constant from gravitational wave observations. *Nature*, 323(6086): 310-311, Sep 1986

Image: https://www.cartoonmovement.com/cartoon/27450

Listen to the chirp: Schutz '86

- Schutz pioneered in using **gravitational waves** to determine the **Hubble constant**
- Main results of Schutz '86:
  - **Independent** distance measurement from gravitational waves.
  - Use of **statistical method** when electromagnetic counterpart is absent



"Was that you I heard just now, or was it two black holes colliding?"

Source:https://www.newyorker.com/cartoons/daily-cartoon/friday-february-12th-gravitational-waves?verso=true

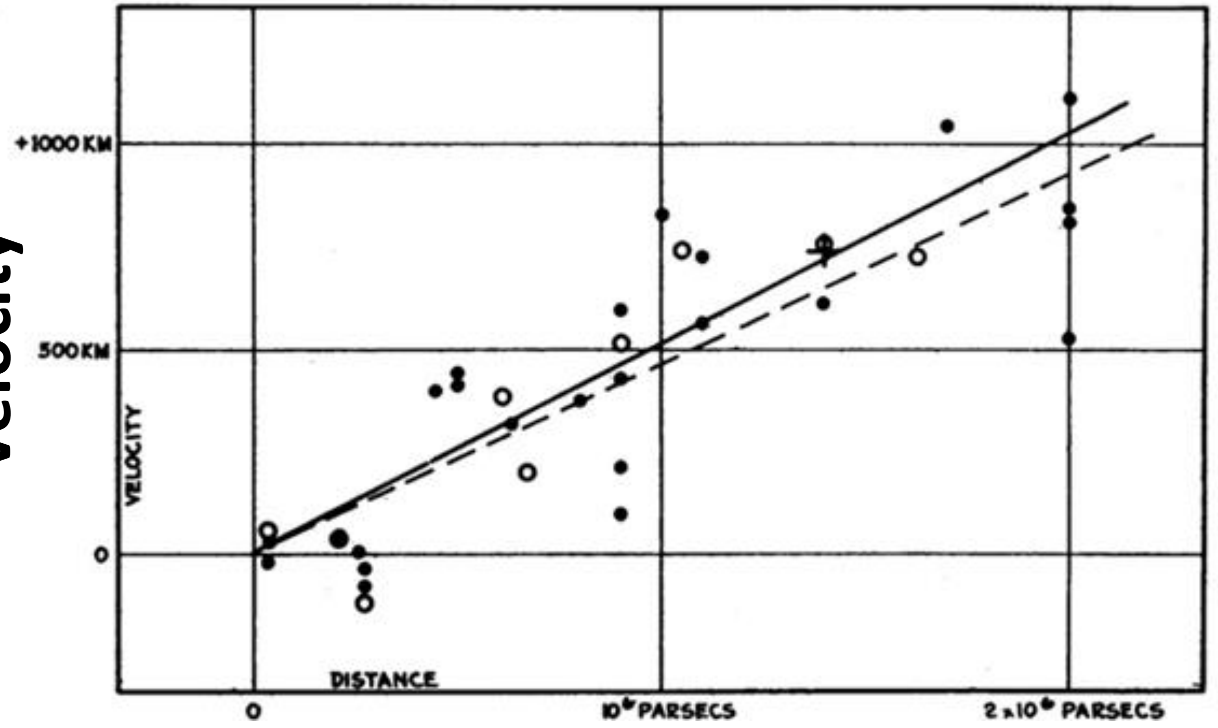
A Brief History of the Hubble Expansion

- Hubble's observation of the galaxies in the nearby universe showed that the **recession velocity, v,** is **linearly** related to the **distance, d,** from them to the Milky Way.

Hubble’s constant H_o.

$$v = H_0 d$$

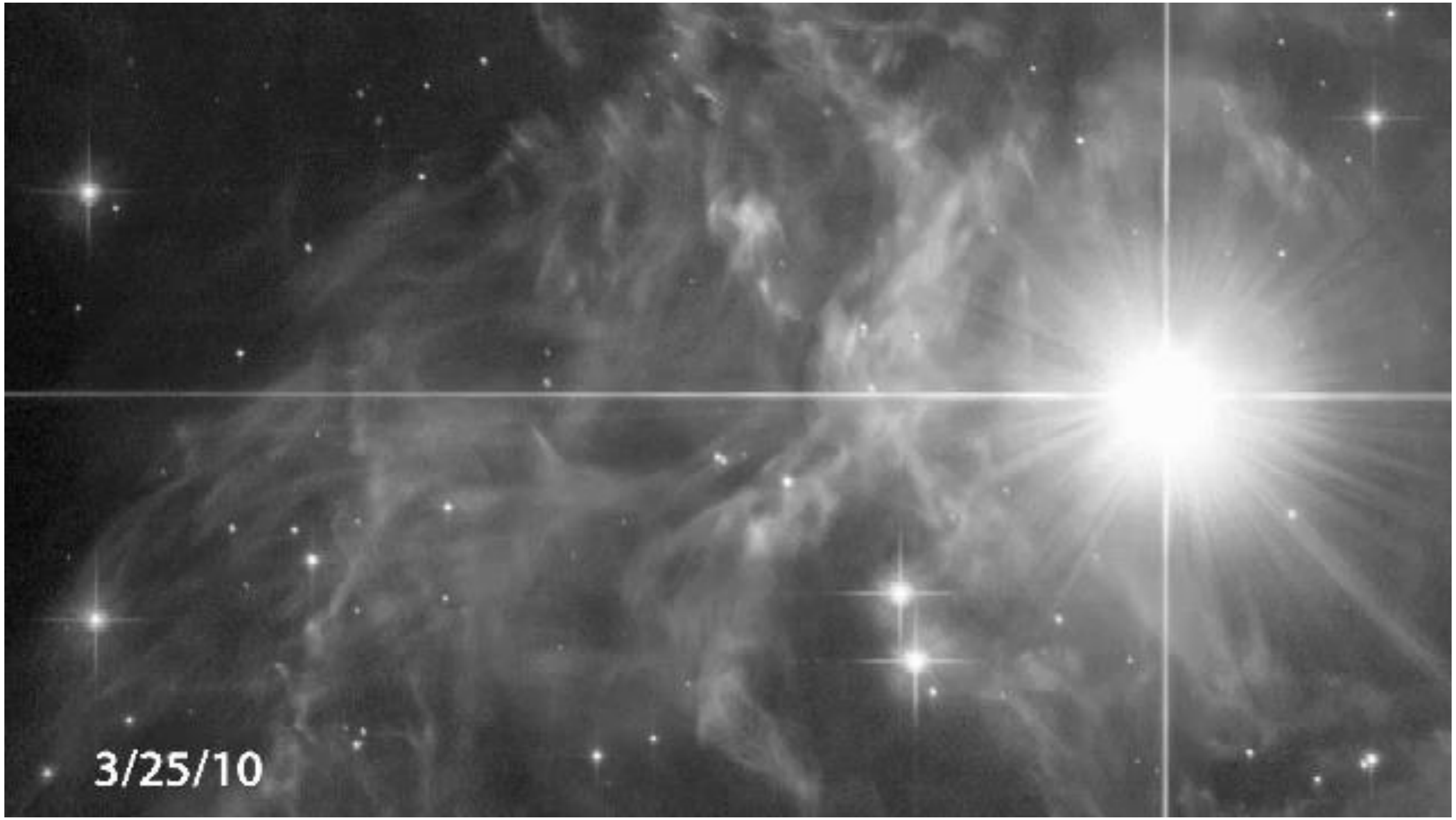
Hubble (1929)



Velocity

Distance

The luminosity-period relation of **Cepheid** helps to detect distance



Brightness varies periodically !

Cepheid

Period

⬇

Luminosity

Brightness

Distance

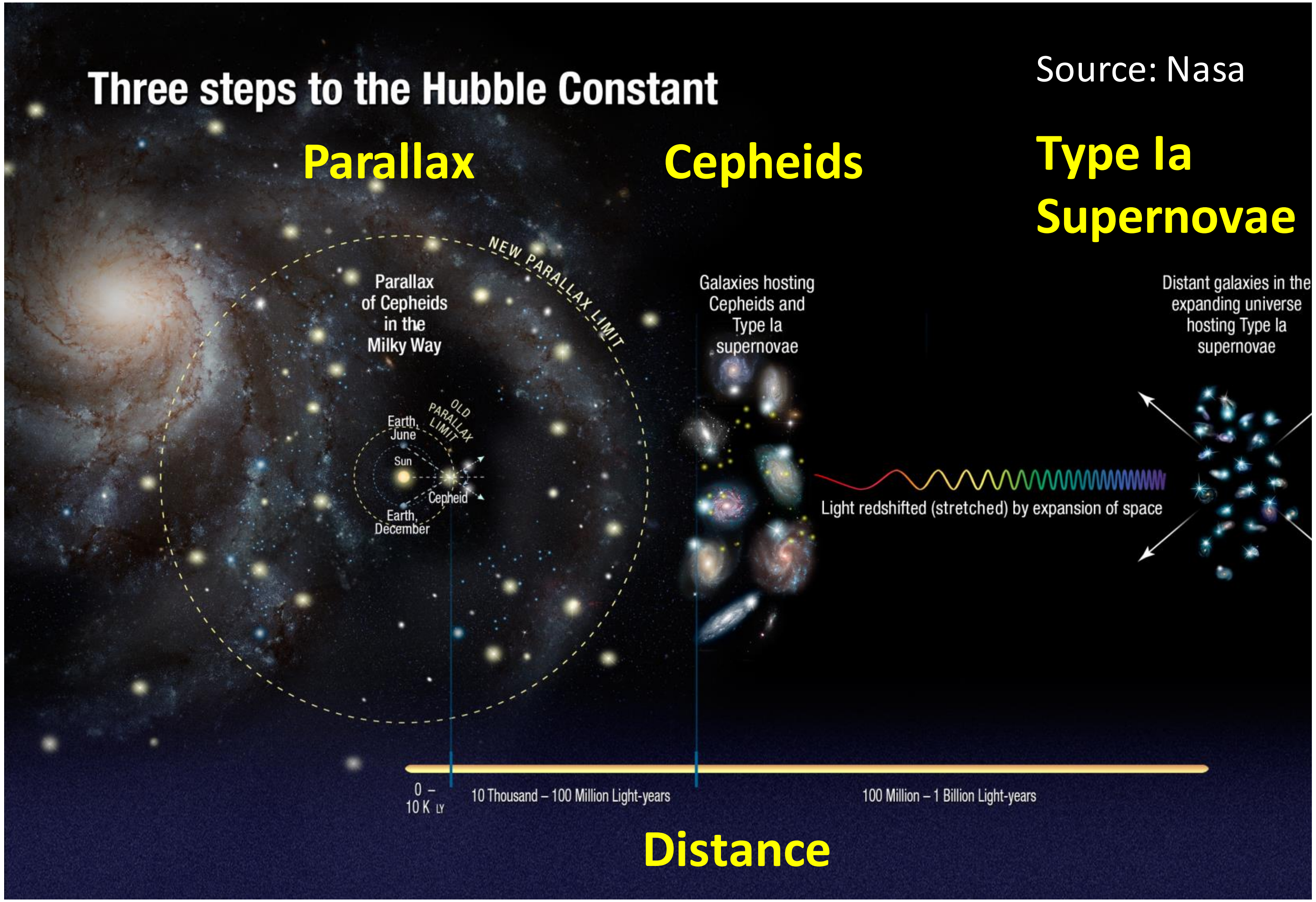
Source: https://hubblesite.org/contents/media/videos/2013/51/748-Video.html?news=true

Measure the Distance: Cosmic Distance Ladder

- One of the best results:

$$H_0 \approx 73 \frac{km}{s * Mpc}$$

Riess A G, Macri L M 2016



Cosmic Microwave Background (CMB) gives a different result

- Plank Satellite (2018) result

$$H_0 \approx 67 \frac{km}{s * Mpc}$$

Hubble tension - The results do not match!

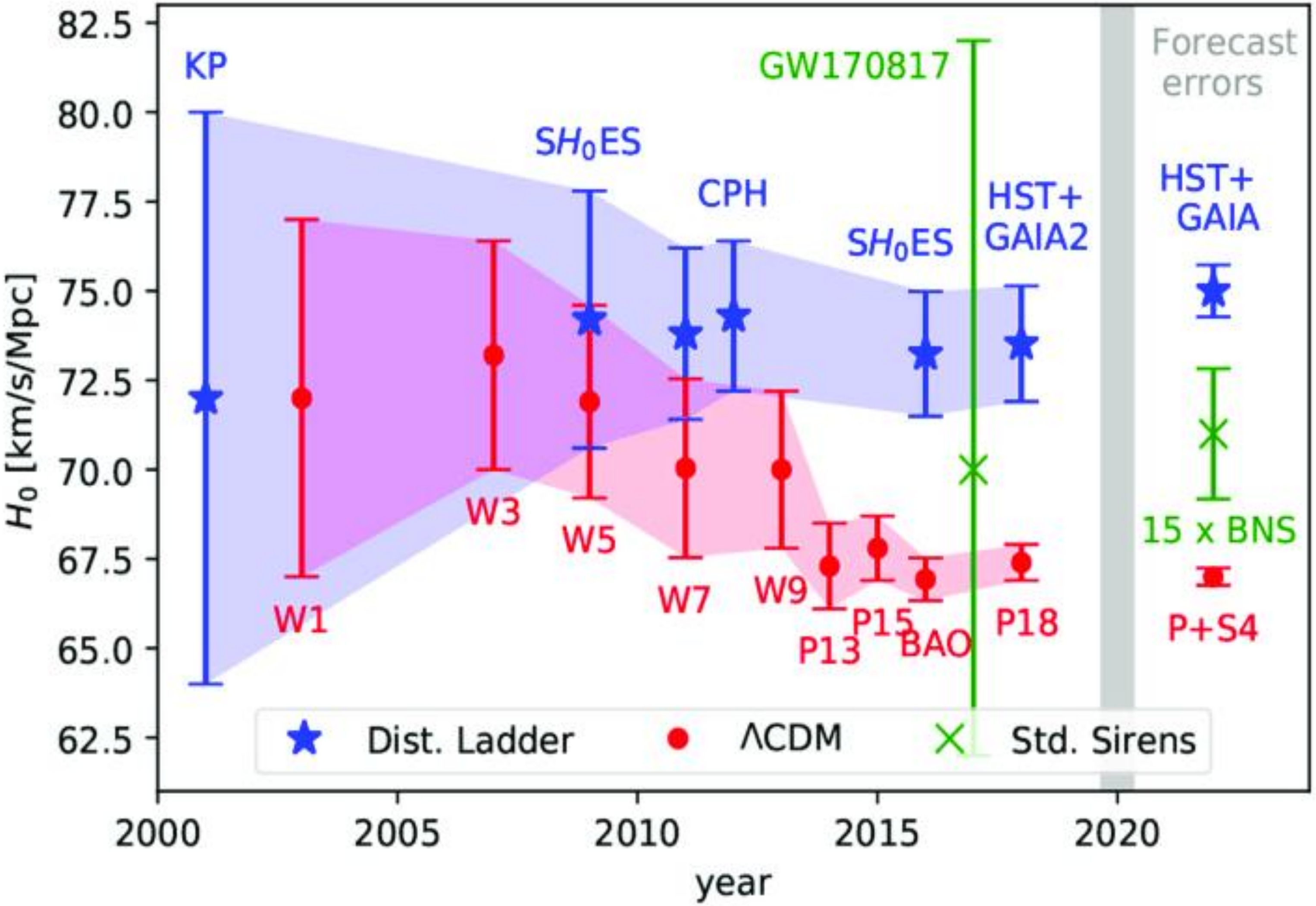


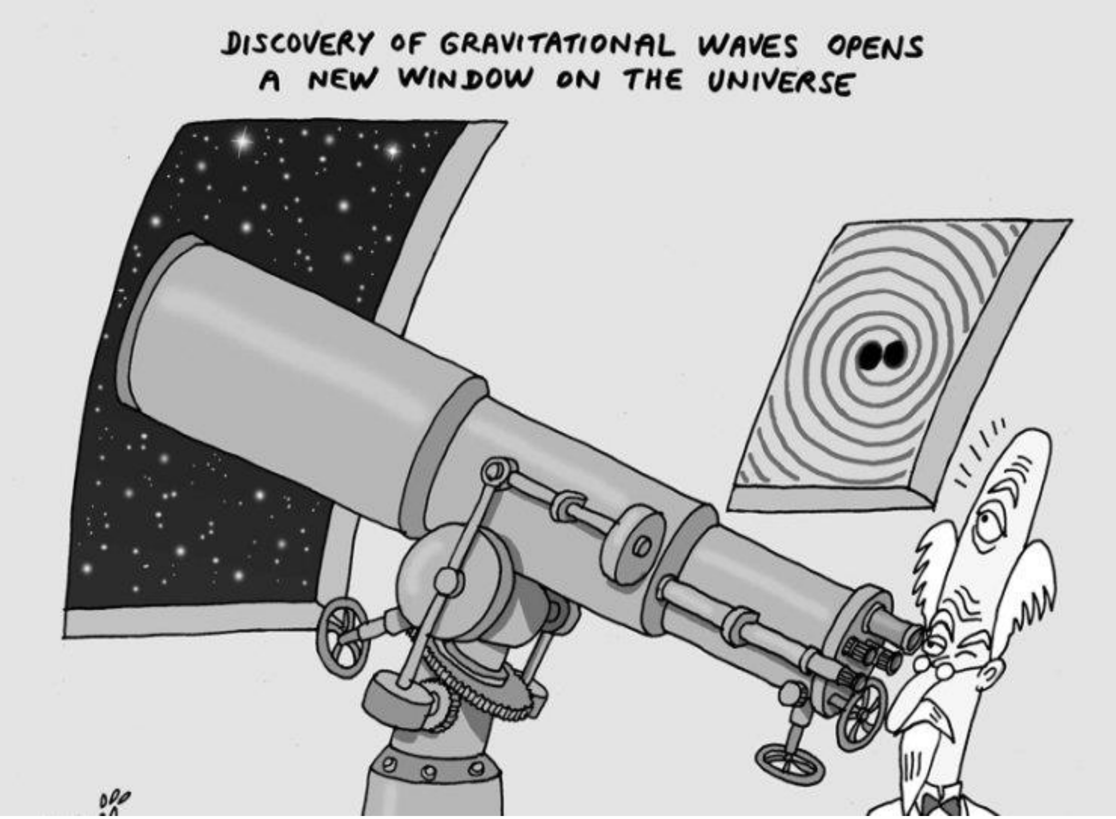
Image: Ezquiaga & Zumalacarregui (2018)

Motivation for detecting gravitational waves

- Methods to determine Hubble constant
  - Indirect: Cosmology (CMB)
  - Direct: Electromagnetic signals

    Gravitational waves signals!

- Motivation for the **standard sirens**
  - An **independent** measurement even without an **electromagnetic** counterpart
  - Test of General Relativity



http://www.koreatimes.co.kr/www/opinion/2018/07/195_197912.html

Measuring H_0 requires measuring **distance** and **redshift**

$$v = H_0 d$$

- H_0 relates distance to velocity of galaxies:
  - Induces a relationship between distance and redshift (z)
- H_0 requires a measurement of d and z
  - Z is measured accurately with telescopes

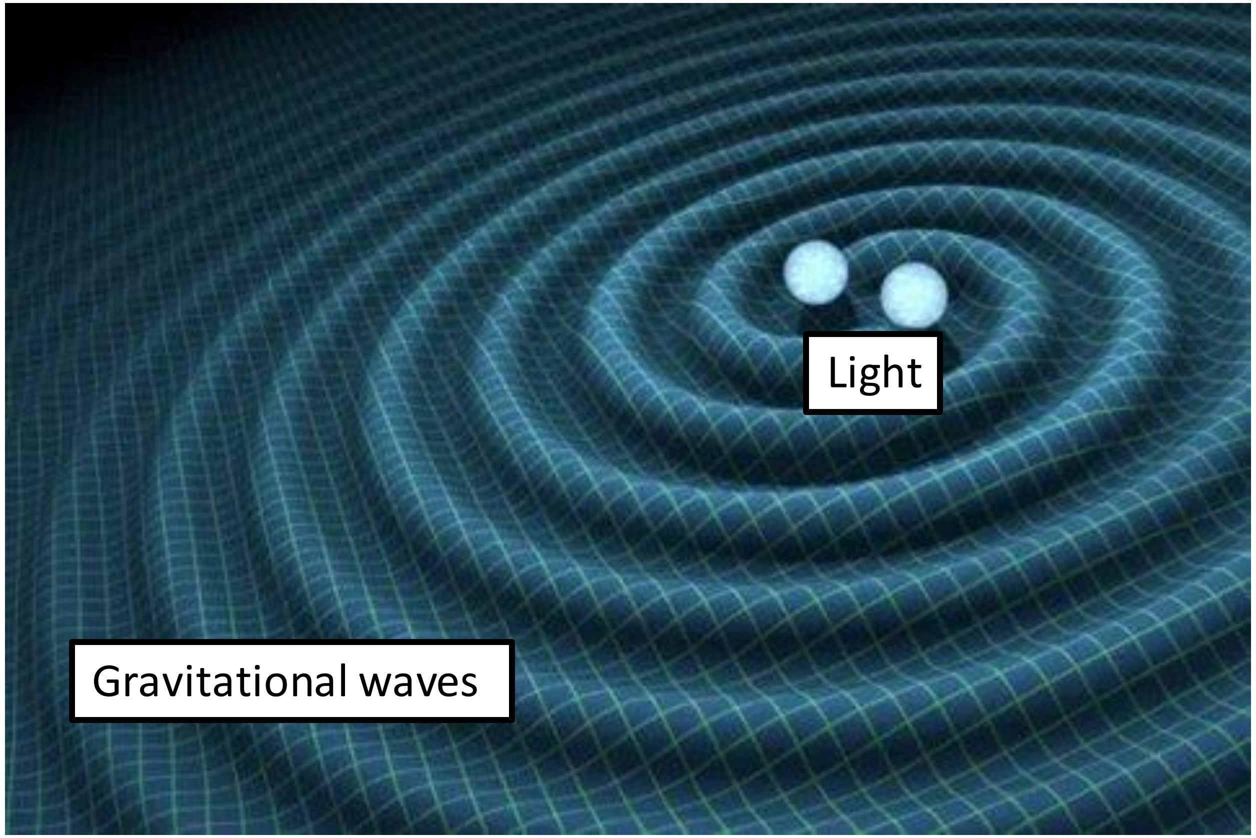
Innovation: Measure distance with gravitational waves

- Must be done in conjunction with optical measurements

Coalescing neutron binaries are a great source

- They emit **both** light and gravitational waves

- Can measure both redshift and distance simultaneously
  - Z using optical telescopes
  - R using grav. waves



– Credit Caltech

Distance: determined from the gravitational waves

- From general relativity quadrupole formula for amplitude, frequency:
  - f = grav wave. frequency
  - h = amplitude
  - tau = timescale of frequency change
  - C is a known numerical constant

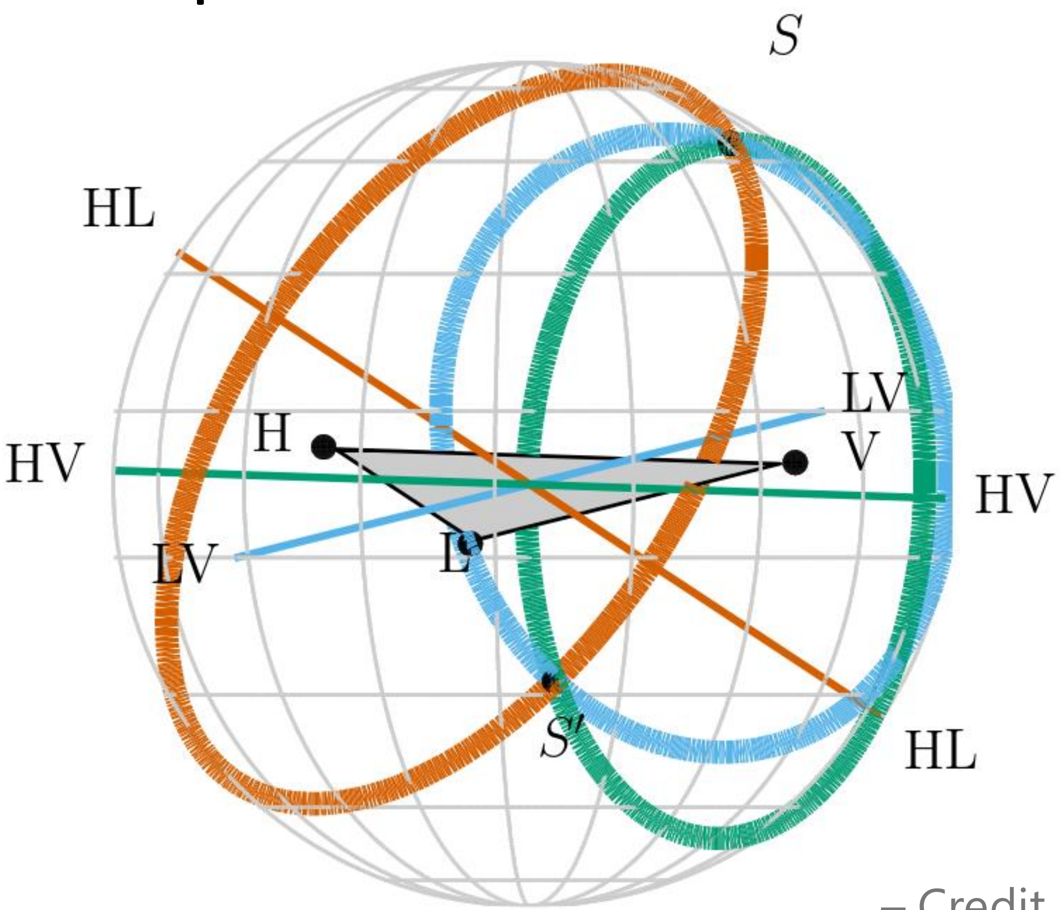
$$r = C f^{-2} \langle h \rangle^{-2} \tau^{-1}$$

These equations determine r:
f, h, tau are all measurable

Redshift: determined from optical emission

- Main issue: where in the sky did the grav. wave signal come from?
  - Answer: triangulation

- Upshot: typical error of $\epsilon \sim (6^\circ)^2$



– Credit [1]

With 3-4 GW detectors, source galaxy & redshift can be identified

Statistics can eliminate the need for optical ID

- Source patch has ~36 galaxy clusters, each with different redshift
  - One yields the *true* hubble constant, others random

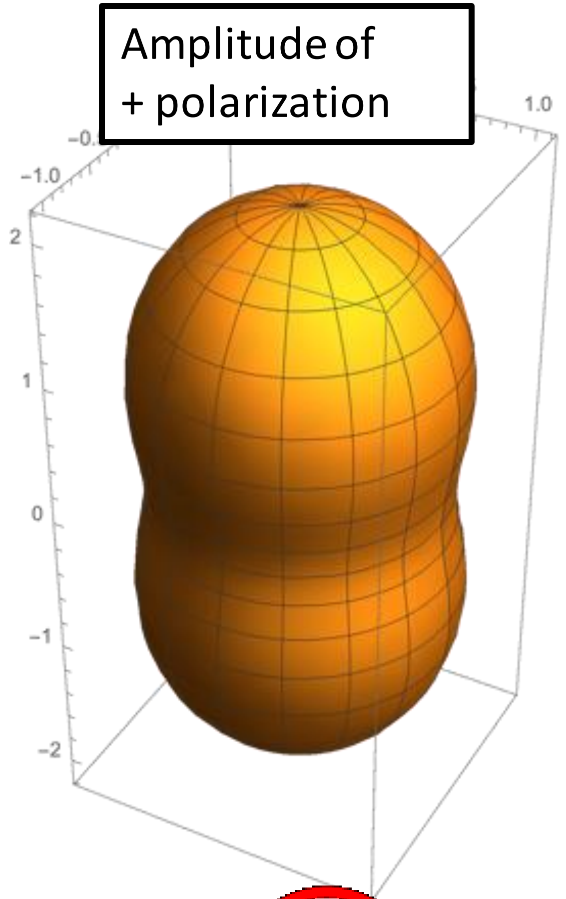
- After many observations/repetitions, true value will stand out from the noise

- Constrained by event rate, galaxy cluster distribution
  - Applicable to black hole mergers as well?

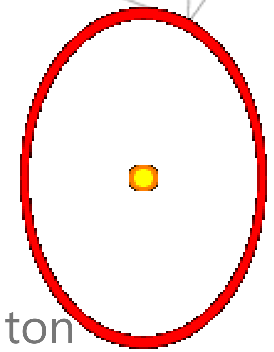
Some subtlety: polarization & source location

- Measured amplitude depends on orientation of the source
  - Fix by measuring polarization

- Position fix requires two time lags
  - Three detectors minimum



4+ detectors needed for good accuracy

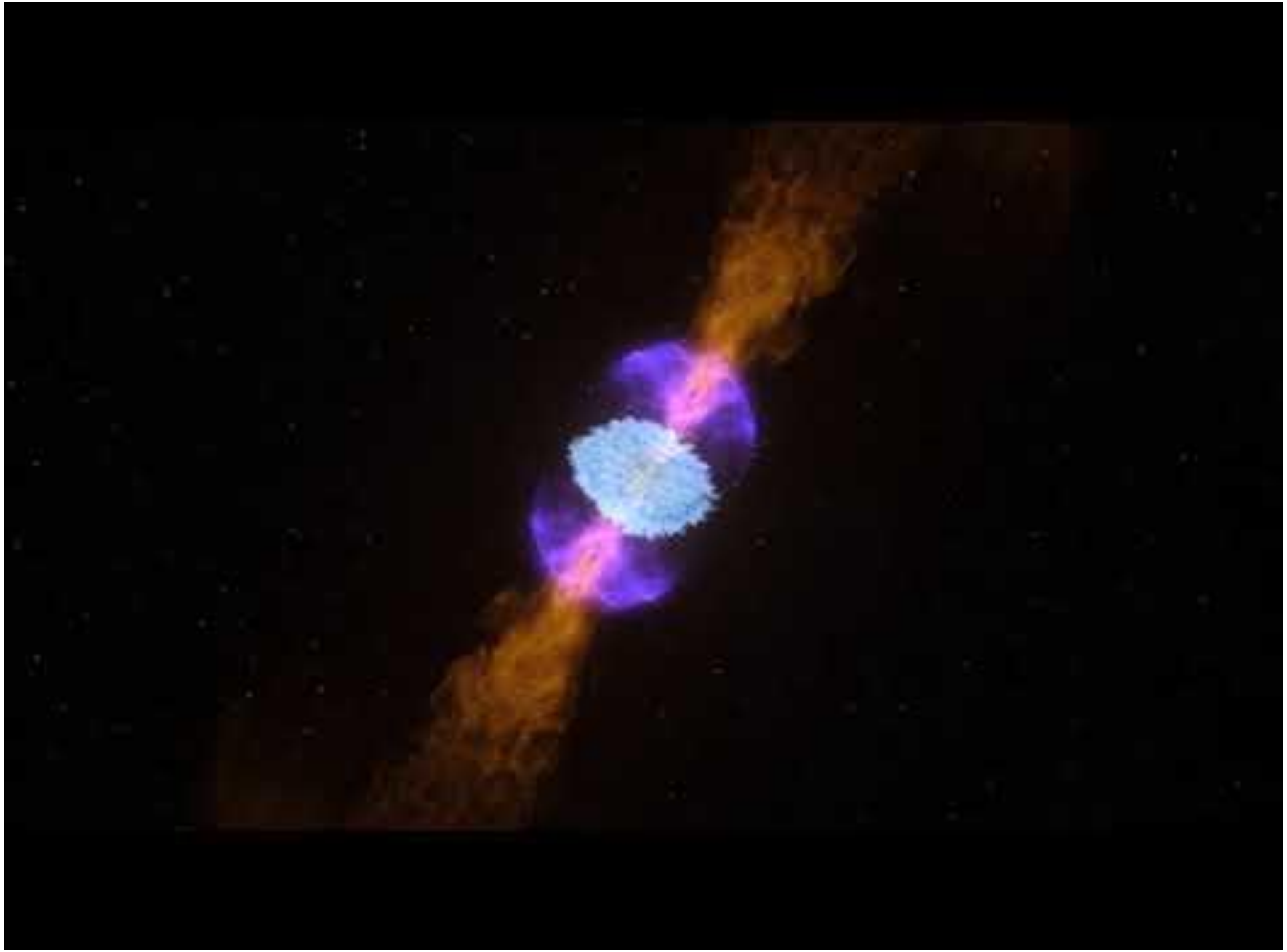


– Credit Teviet Creighton

Critique: Clear, Concise, Short on Details

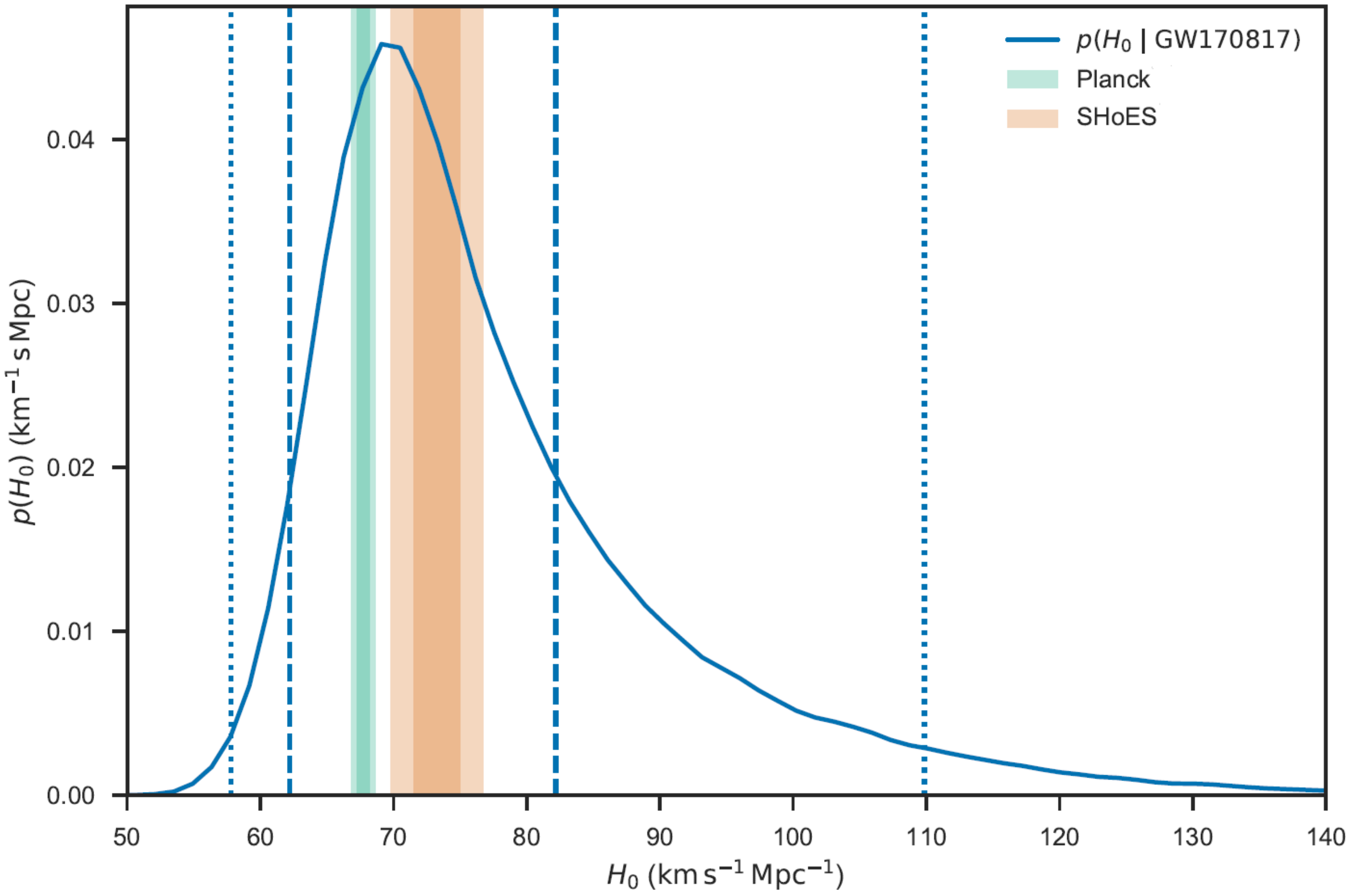
- Short paper appropriate for a simple yet profound idea
- Schutz writes well – easy to follow (read his GR book!)
- Somewhat naive in discussion of statistical method & error
  - Provides illustrative estimates, nothing rigorous
- Provides direction and scope for future work

Standard Siren GW170817: New era of Cosmology



Standard Siren GW170817: New era of Cosmology

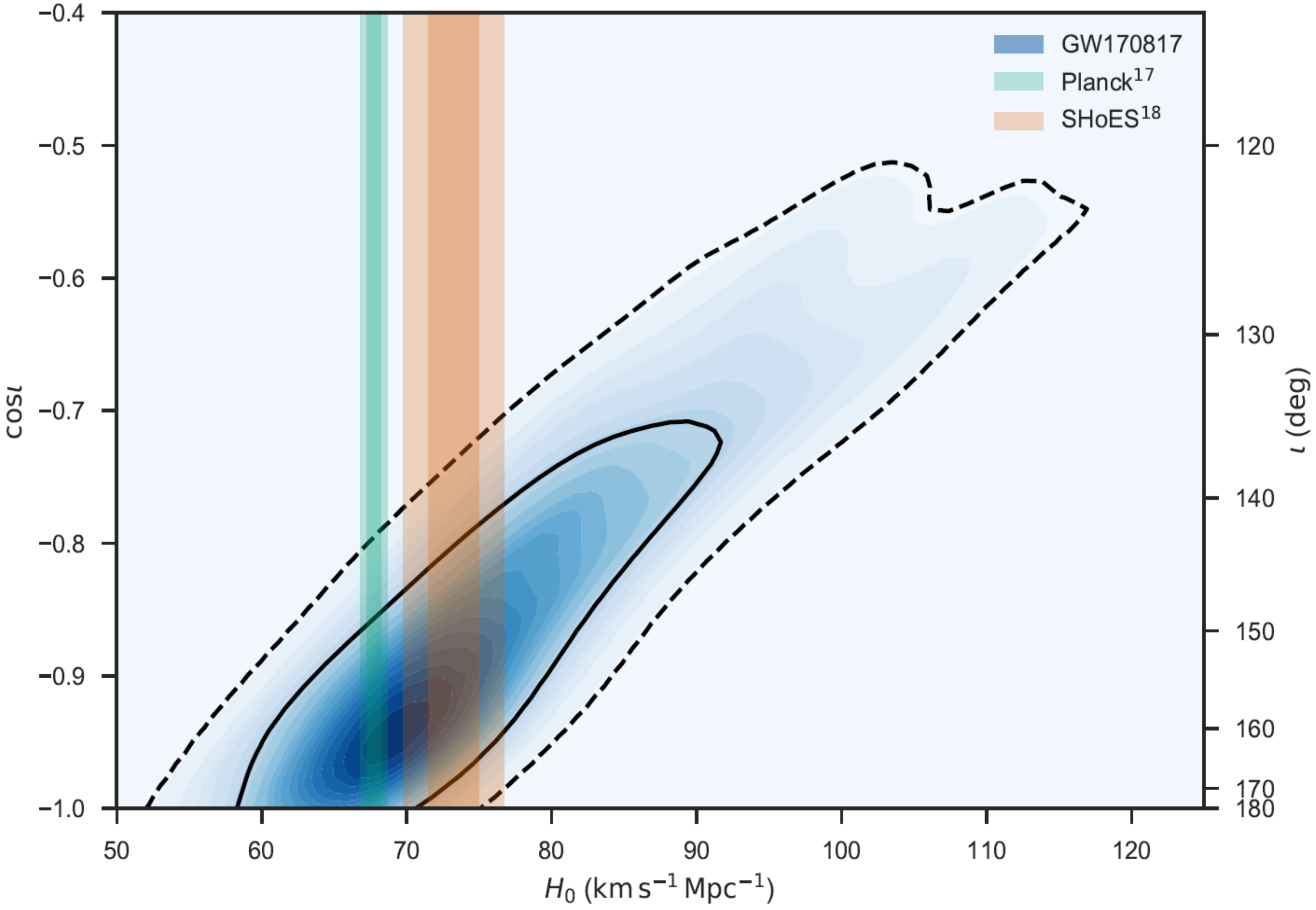
H0 peaks at 70 km/s/Mpc!



https://www.ligo.org/science/Publication-GW170817Hubble/

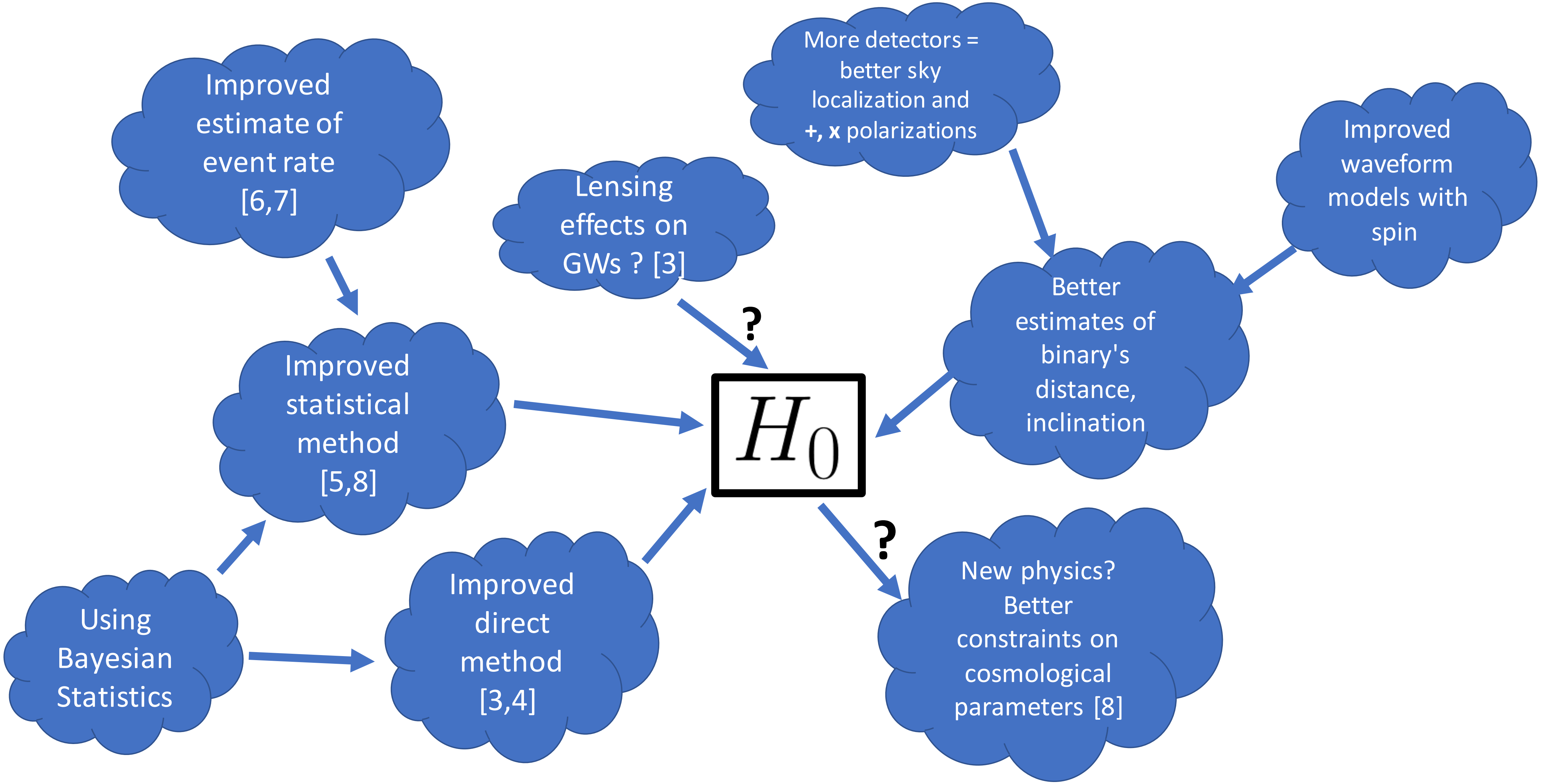
Standard Siren GW170817: New era of Cosmology

15 % error
on distance measurement
(with 3 detectors)



https://www.ligo.org/science/Publication-GW170817Hubble/

Afterthoughts since Schutz '86

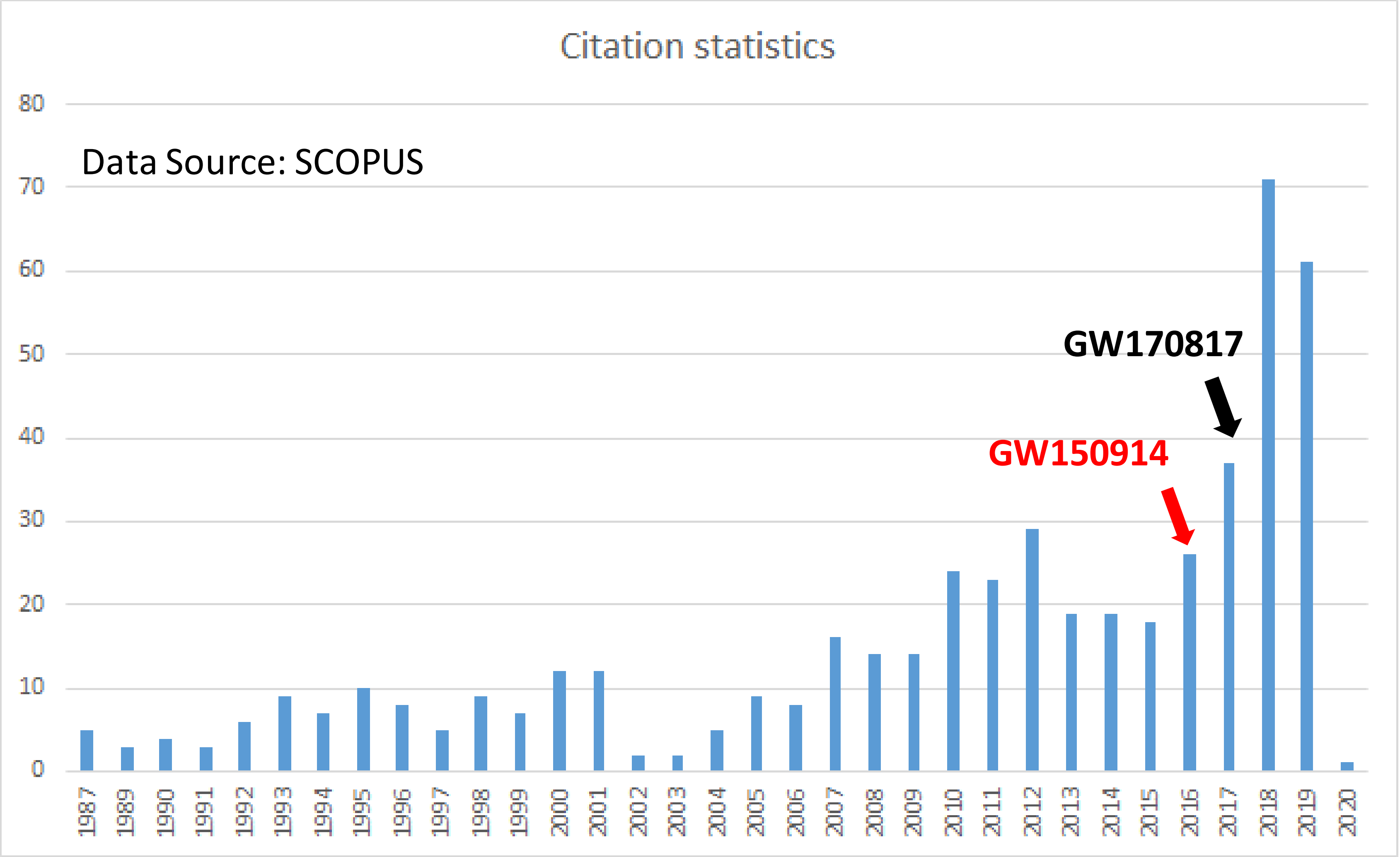


Citation Analysis

- Cited by: 498 records
    - 13 self-citations
- Most-cited paper:

  GW170817

  by LIGO and Virgo



Citation Analysis

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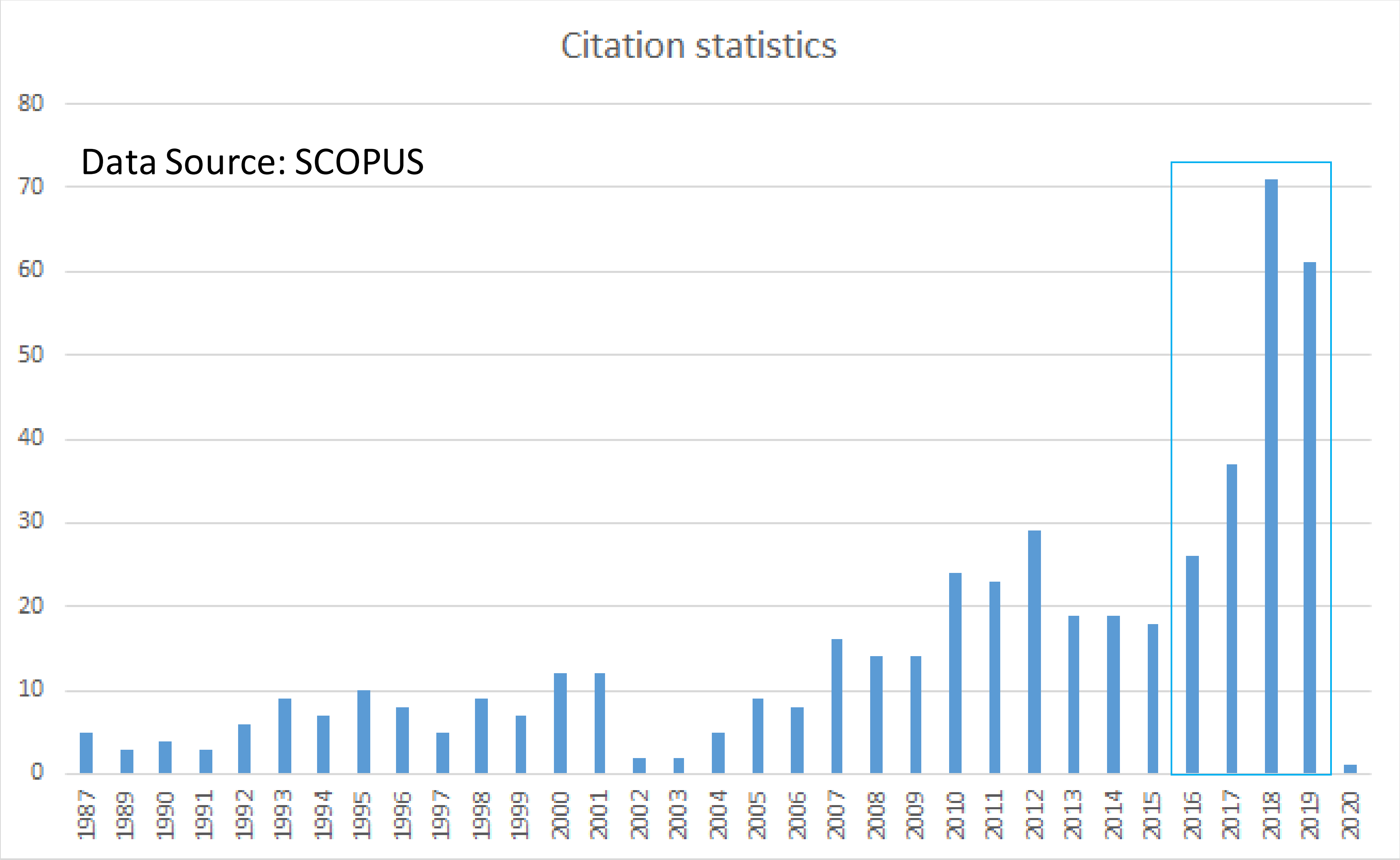
- **Most-cited paper are all done by LIGO and Virgo**
- **from 2016 to 2019**




Thank You!

References

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