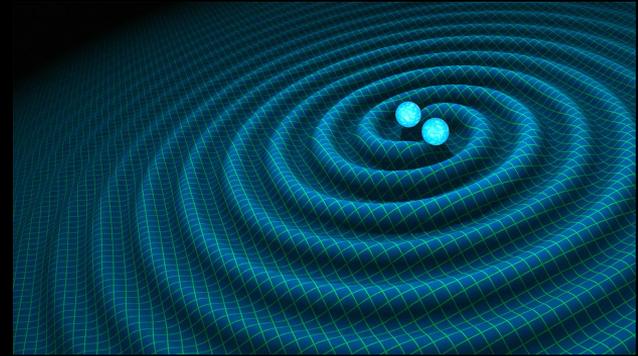


# Cosmology with Standard Sirens



*Eyes and Ears on most  
catastrophic events in the  
Universe...*

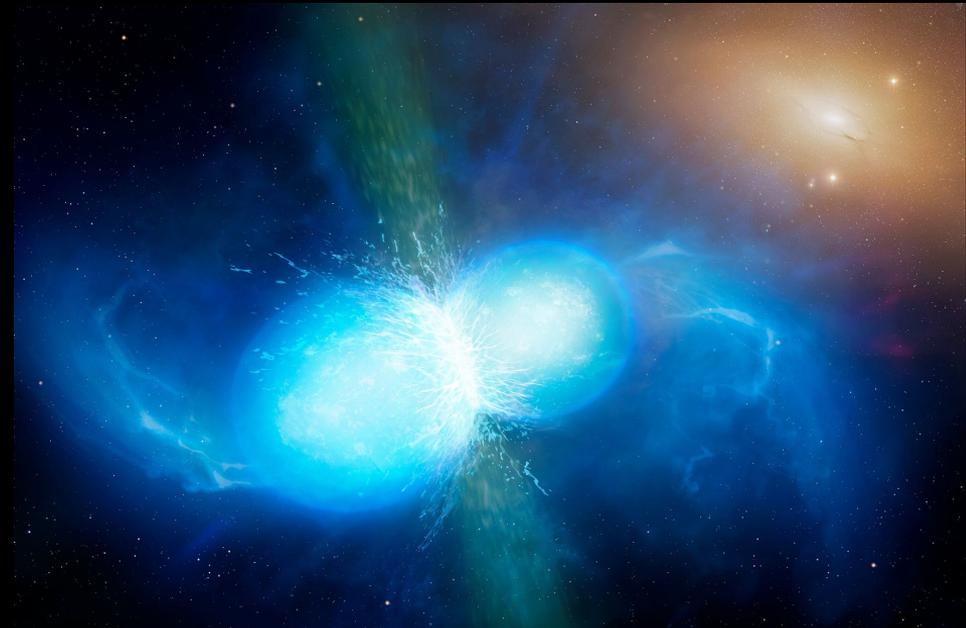
**CHIPP Winter School 2025**

**Simran Kaur**

University of Michigan / University of Zurich

Advisor: Marcelle Soares-Santos (UZH)

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# Hubble Tension and cosmological distances

- Hubble constant,  $H_0$ 
  - Expansion rate of universe
  - Estimate of age of universe

$$d = \frac{v}{H_0} \approx \frac{cz}{H_0}$$

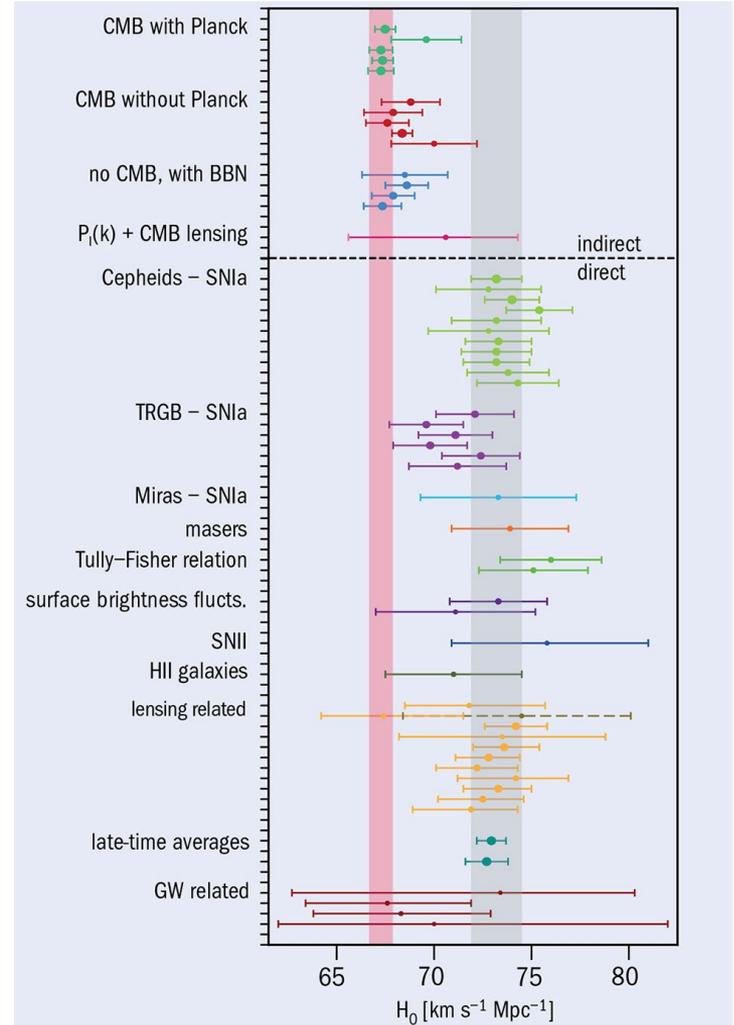
- Probes to measure  $H_0$ 
  - *Cosmic Microwave background*

$66.93 \pm 0.62$  km/Mpc/s

- *Type Ia Supernovae*

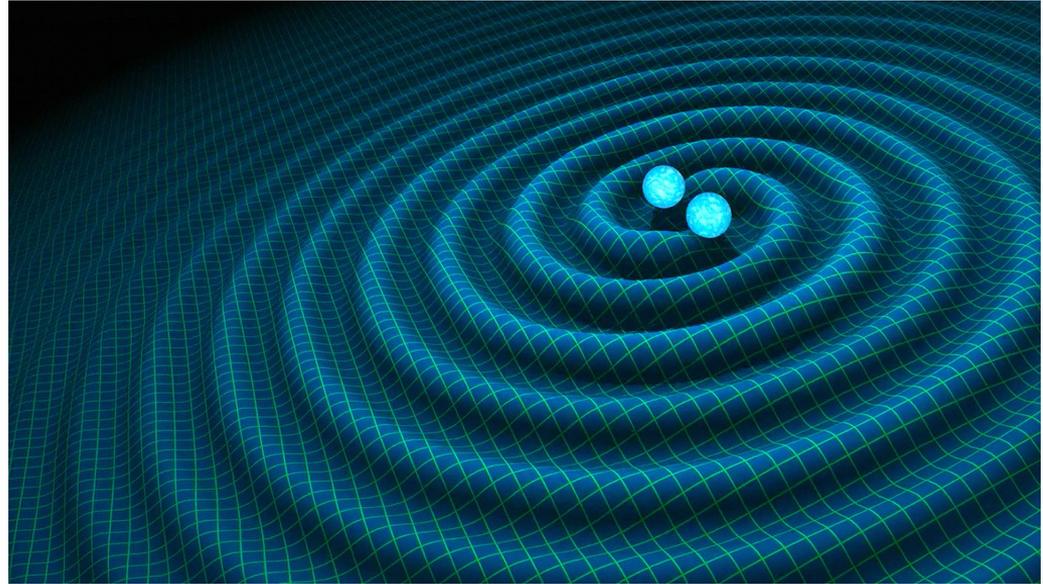
$73.24 \pm 1.74$  km/Mpc/s

- How to resolve this tension?
  - ***Gravitational waves - a new and independent measure of cosmological distances***



# Observing Gravitational Wave Events

- Gravitational waves are '**ripples**' in space-time caused by some of the most violent and energetic processes in the Universe.
  - Collisions of neutron stars and black holes
    - **NS-NS, BH-NS, BH-BH**
- Antennae to 'Hear' GW events
  - *Currently observing detectors:*  
**LIGO** Hanford & Livingston (USA), **Virgo** (Italy)



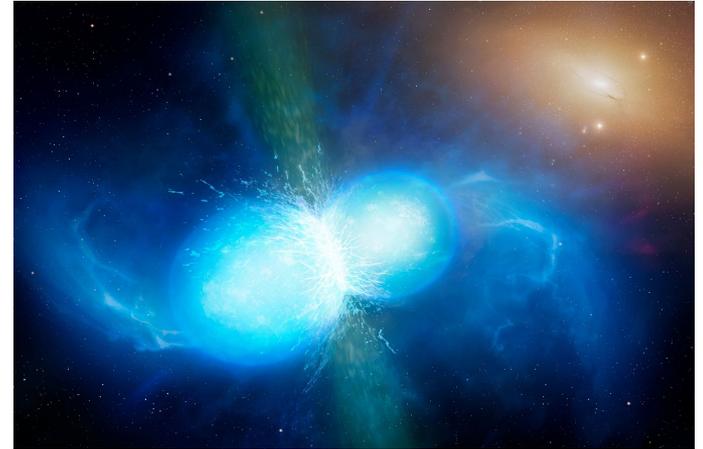
# Observing Gravitational Wave Events

- Also **See** the merger events using Telescopes
  - **Dark Energy Camera (DECam)**, SWIFT, ZTF, upcoming **Legacy Survey of Space and Time (LSST)**, etc.

⇒ Electromagnetic (EM) counterpart to BNS events: Gamma Ray Burst, **Kilonova**

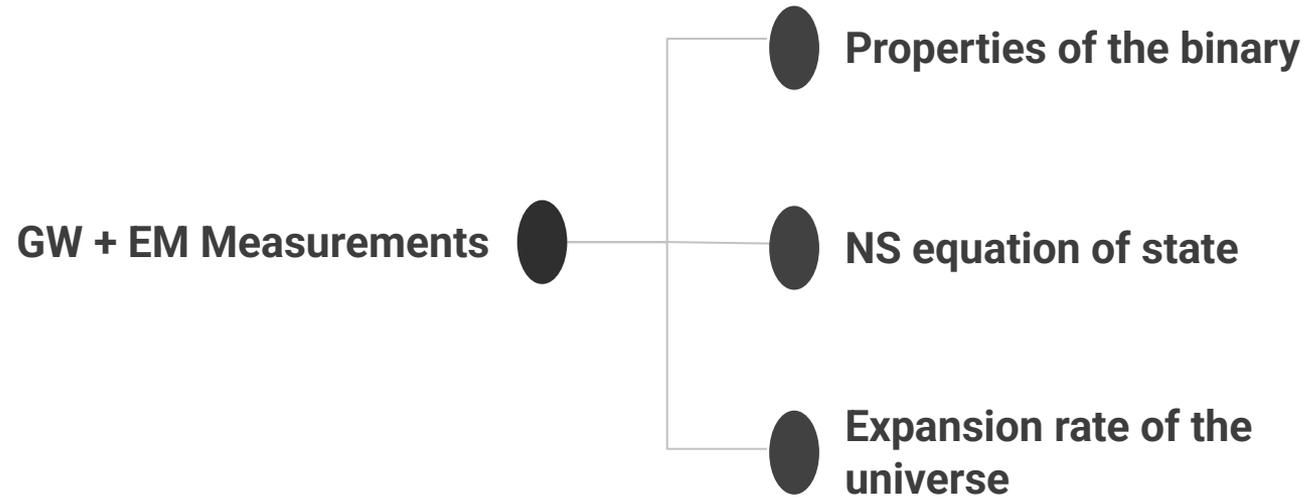


Animation of 2 NSs colliding and producing GW waves and Kilonova



Kilonova Illustration

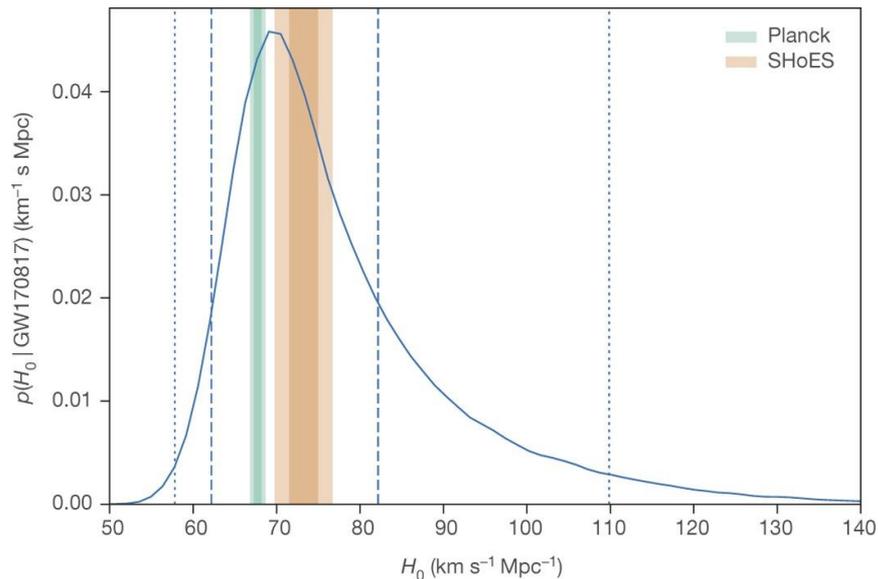
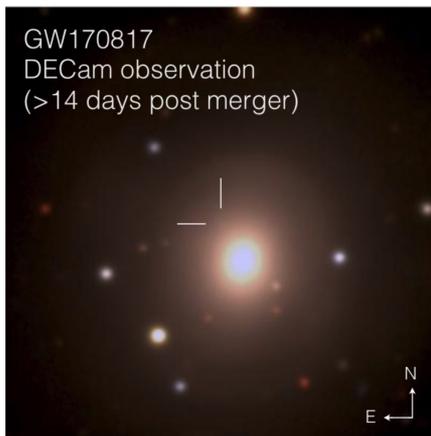
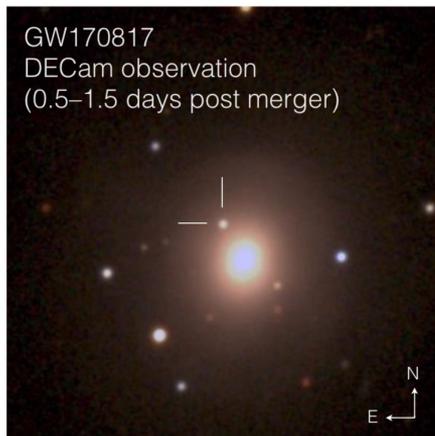
# Science with Gravitational Wave Events



# Standard Siren Cosmology

- Standard Sirens: A Merger event that has
  - distance measurement from LVK,  $d_L$
  - cosmological redshift for host galaxy,  $z$
- **First standard siren measurement: GW170817**

$$d = \frac{v}{H_0} \approx \frac{cz}{H_0}$$



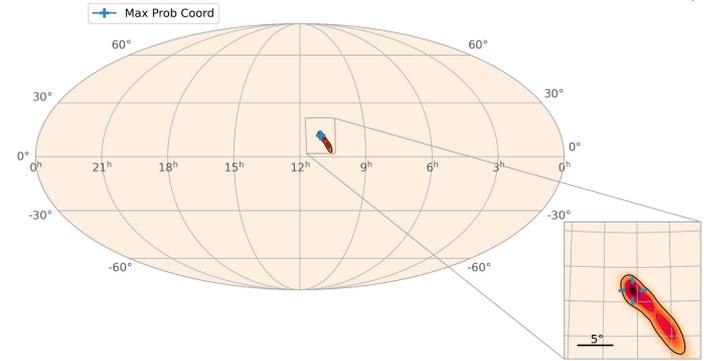
# Standard Siren Cosmology

Event Name: S240413p  
50% Area: 13 deg<sup>2</sup>  
90% Area: 38 deg<sup>2</sup>  
Max Prob Coordinates (degrees): (165.72,11.64)  
Max Prob Distance: 469±112 Mpc

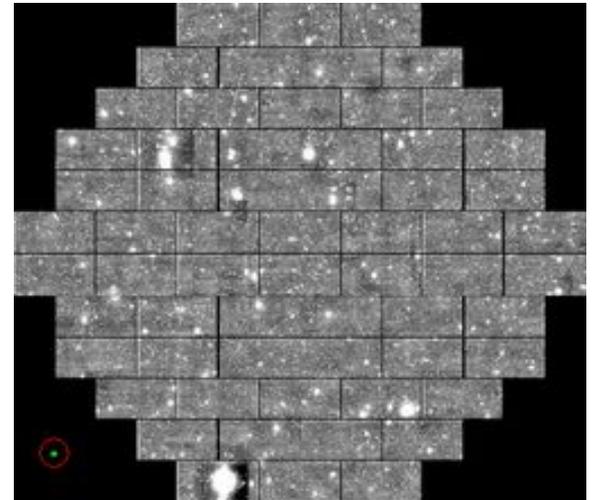
## Standard Siren Technique:

1. LVK releases a public alert : dL, sky localization, FAR, etc.
2. Create a follow up strategy for follow up using DECam, check weather, etc.
3. Trigger DECam and use the strategy to obtain pictures of the relevant patch of sky
4. Process images, apply difference imaging, remove contaminants, apply cuts.
5. **If EM counterpart is identified (Bright Siren):** Identify the host galaxy of the event and use its redshift to make an inference of H0 using Bayesian approach.

**If EM counterpart is not identified (Dark Siren):** Obtain statistical estimate of redshift using distribution of the galaxies in the localization area.



Skymap for S240413p



Example DECam Image

# Current Activities and My Projects

- LIGO/Virgo Observing Run 4 - Currently ongoing
  - majority of alerts are BBH so far
    - Follow up using DECam
    - BBH in AGN disk



## *Another Interesting Project!*

- Legacy Survey of Space and Time (LSST): going on sky in 2025
- Obtain forecast on H0 constraining potential of this probe
  - Why?
    - Make a science case for GW EM follow ups, advocate for telescope time, etc.
  - How?
    - Use GW and LSST simulations for predicted sensitivities for 10 years of LSST (2027-2037)
    - Coincides with LVK O5, O6, ET/CE





Source: ChatGPT

**Thank you for your attention!**  
**Open to Questions**