# Estimating the Hubble Parameter

## PHY 5132

Akshita Mittal
Rithika Ganesan
Shubham Chury

# Motivation and Background

# Why is $H_0$ important?

- Hubble's Law: $v = H_0 d$
- Establishes a relation between:
  - Recessional velocity
  - Luminosity distance
- Confirms expansion of universe
- Best evidence for Big Bang model

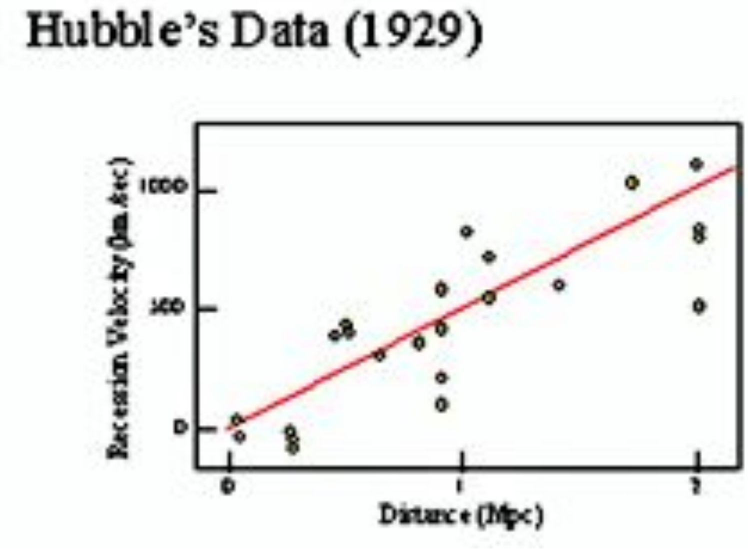


Fig. 1

# Gravitational Waves + Hubble Parameter

- Estimation of $H_0$ from GW signals from BNSs (and BBHs)[1]
- Done by:
  - Redshift of merger (z)
  - Luminosity distance of merger ($D_L$)
- Parameter estimation to determine $D_L$
- Considered BNS event GW170817 for this study

[1] Schutz, B. Determining the Hubble constant from gravitational wave observations. Nature 323, 310–311 (1986). https://doi.org/10.1038/323310a0

# Why BNSs?

- Duration of signal longer than BBHs (40-50s)
- Electromagnetic counterpart present
  - Easier to measure redshift

# Why GW170817?

- Closest BNS event till date
- Highest signal to noise ratio among BNS merger events
- Other parameters have been well constrained by previous studies

# Approach

# Pipeline

- Two inputs needed–
  - Luminosity distance ($D_L$)
  - Recessional velocity (v)
- Luminosity distance obtained from GW Data
  - Other parameters obtained from GWOSC
  - Employing parameter estimation and Bayesian inference
  - Data from H1, L1 obtained from bilby package
- v obtained from redshift of merger

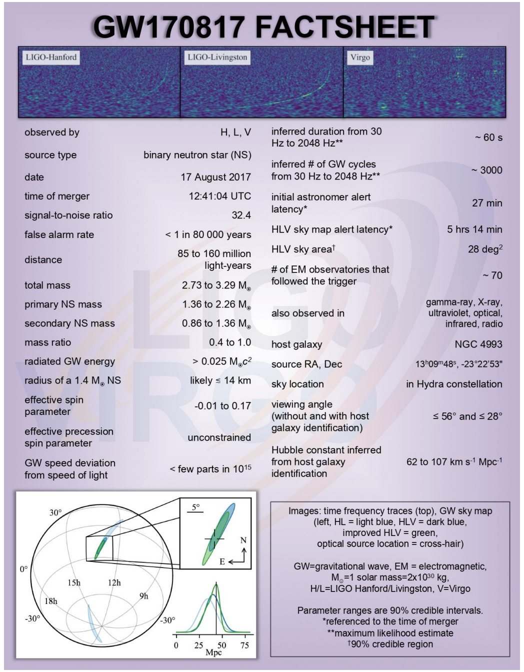


Fig. 1

# Methods

- Injection studies run with priors on:
  - Phase
  - Psi
  - Luminosity distance
- Waveforms used:
  - IMRPhenomPv2
  - IMRPhenomPv2_NRTidal
  - SpinTaylorT4

# Assumptions

- Estimates on tidal deformability parameters $\Lambda_1$, $\Lambda_2$ not well constrained
- Some models do not support these parameters
- Effect of these parameters on the wave data is low
- Also employed calculated psi, phase

# Results

# With calculated psi and phase

# With IMRPhenomPv2 (no prior on psi, phase)

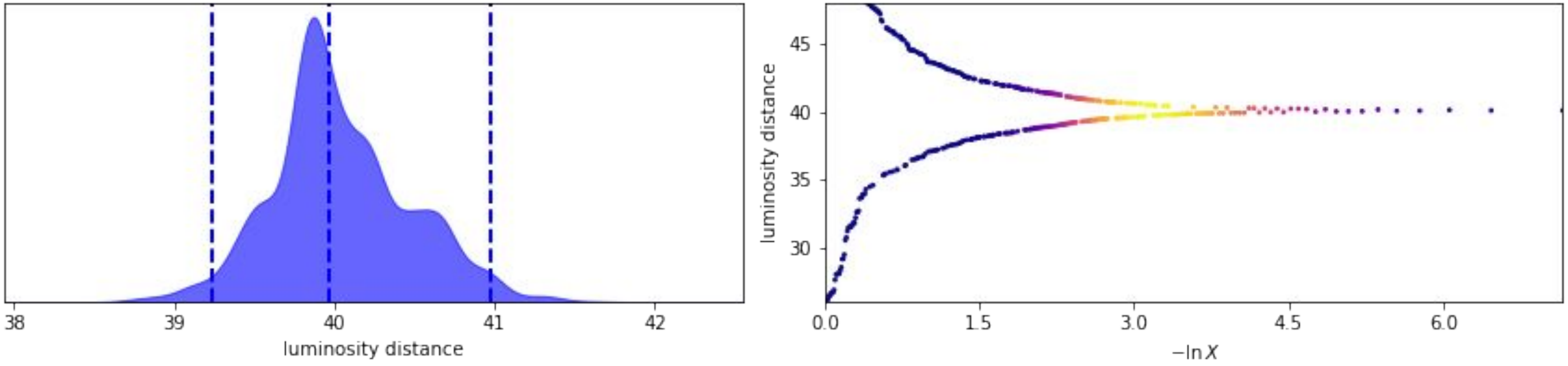


Fig. 2

- Estimate: 39.95892
- 90% Confidence Interval: (39.37567, 40.77348 )
- log Evidence: -372660.1356293629

# With IMRPhenomPv2_NRTidal (no prior on psi, phase)

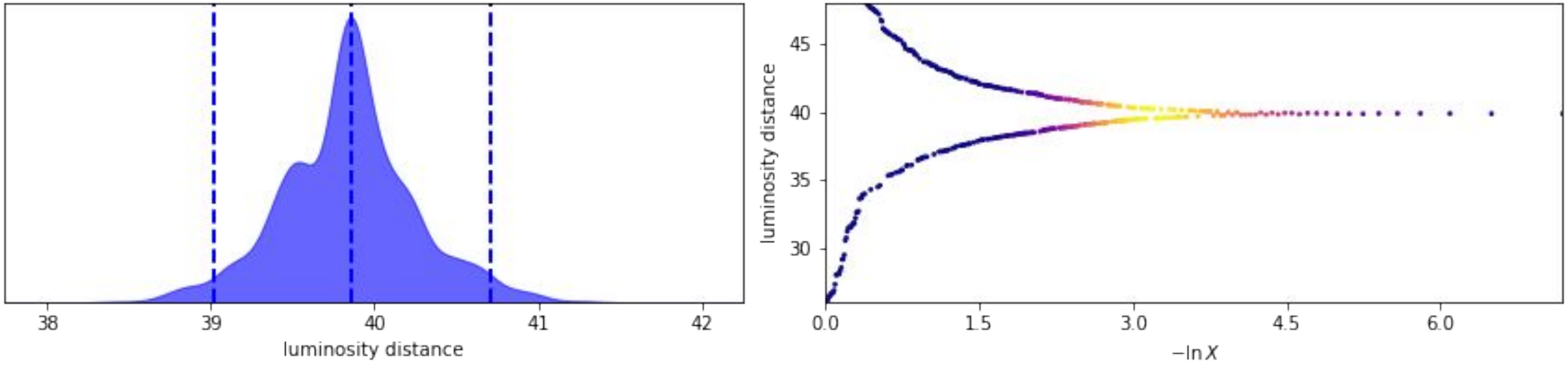


Fig. 3

- Estimate: 39.85408
- 90% Confidence Interval: (39.12711 , 40.58449)
- log Evidence: -372658.938054884

# With SpinTaylorT4  (no prior on psi, phase)

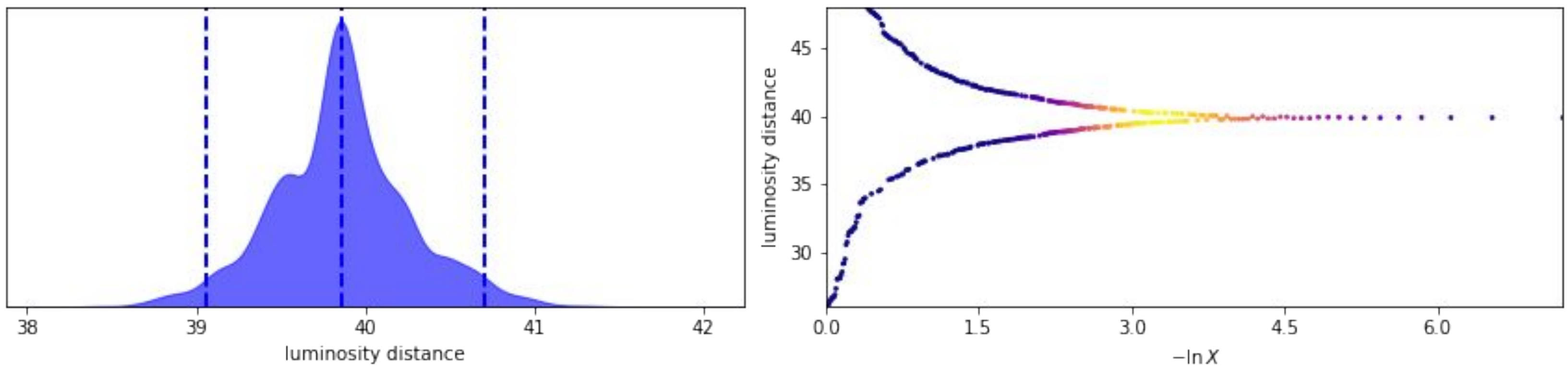


Fig. 4

- Estimate: 39.85905
- 90% Confidence Interval: (39.19163 , 40.59)
- log Evidence: -372659.5405876796

# With prior on psi and phase

# With IMRPhenomPv2 (with prior on psi, phase)

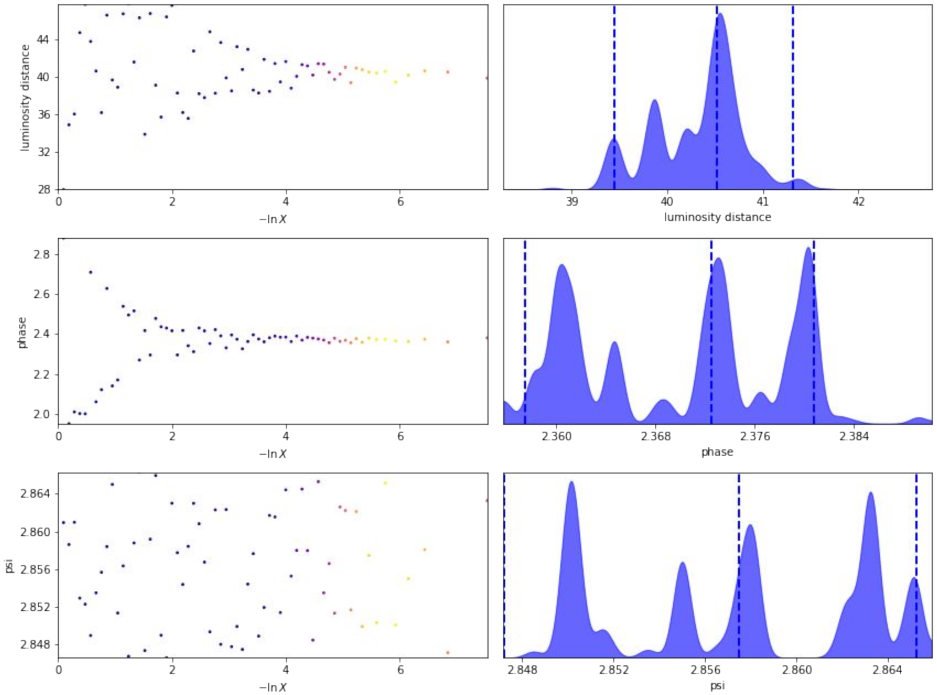


Fig. 5

- Estimate: 40.46503
- 90% Confidence Interval: (39.44871, 40.91322 )
- log Evidence: -372663.40605726547

# With IMRPhenomPv2_NRTidal (with prior on psi, phase)

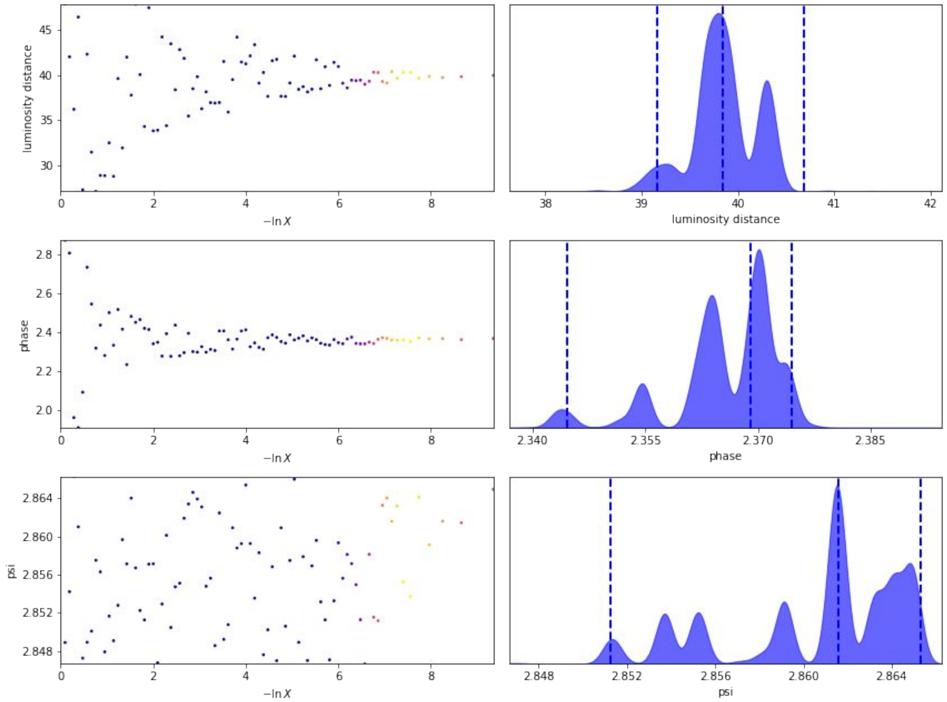


Fig. 6

- Estimate: 39.81041
- 90% Confidence Interval: (39.13407, 40.30831)
- log Evidence: -372663.5570583796

# With SpinTaylorT4  (with prior on psi, phase)

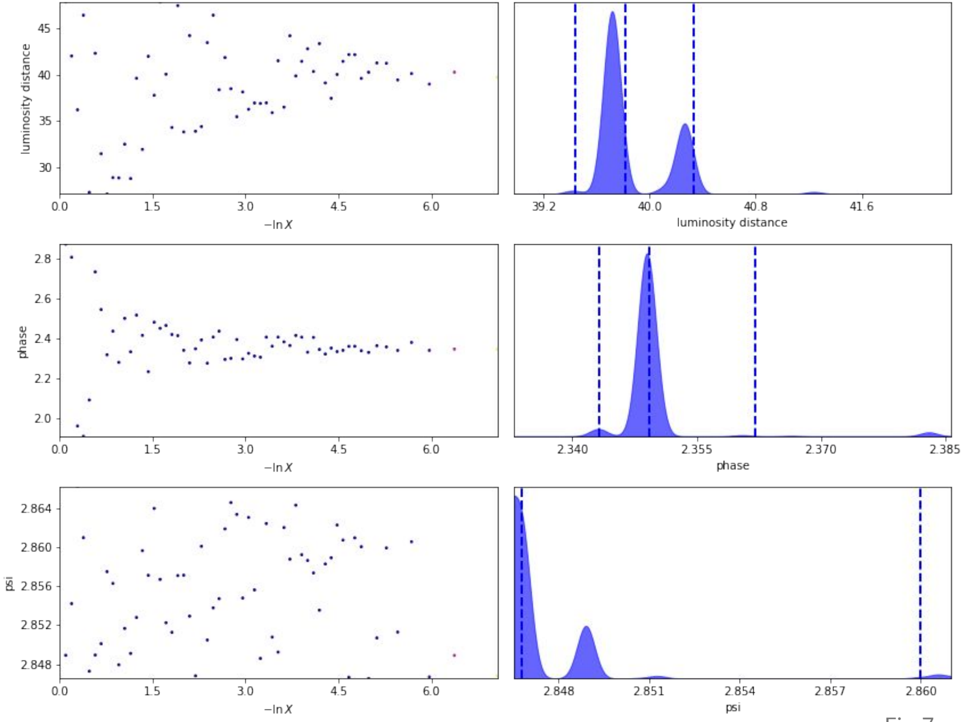


Fig. 7

- Did not converge
- Computationally expensive

# Which model performs best?

- Calculating Log Bayes Factor
  - Log Bayes Factor can be used to compare two models
  - Equals Difference of log Evidence
  - Positive/Negative logBF = Better First/Second model
- We note that IMRPhenomPv2_NRTidal was the best fitting model
- IMRPhenomPv2 was the least fitting model

# Limitations and Future Directions

- Priors on three parameters insufficient
    - Number of calculations scales exponentially with number of priors
- Higher order modes neglected
    - Detectors not sensitive enough in 2017 to detect them

# Limitations and Future Directions

- Only one merger studied so far
    - No well constrained parameters for other BNS mergers
    - Rate of BNS detections is improving

Fig. 8

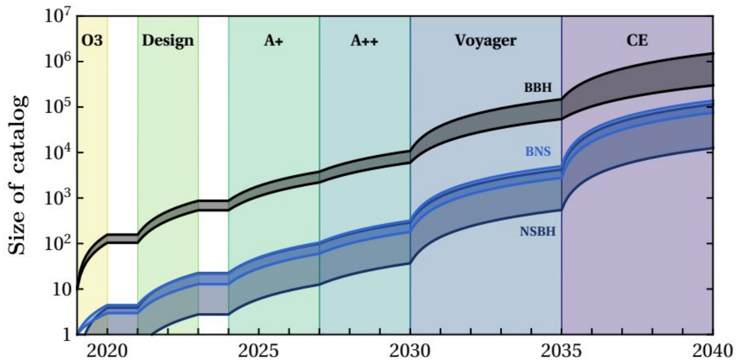


FIG. 4. Growth of catalog size as detectors improve for models in agreement with current observations. The timeline for different detectors and their upgrades is estimated following Refs. [53–55]. We assume an optimistic duty cycle of 100%, which is compatible with expectations for future observations with multiple detectors.

(Baibhav et al., 2019)

# Limitations and Future Directions

- To be extended to BBHs
  - Can use $D_L$ to measure redshift
  - Standard siren to measure cosmological distances