H_0 calibration precision through joint ULTRASAT-GW detections

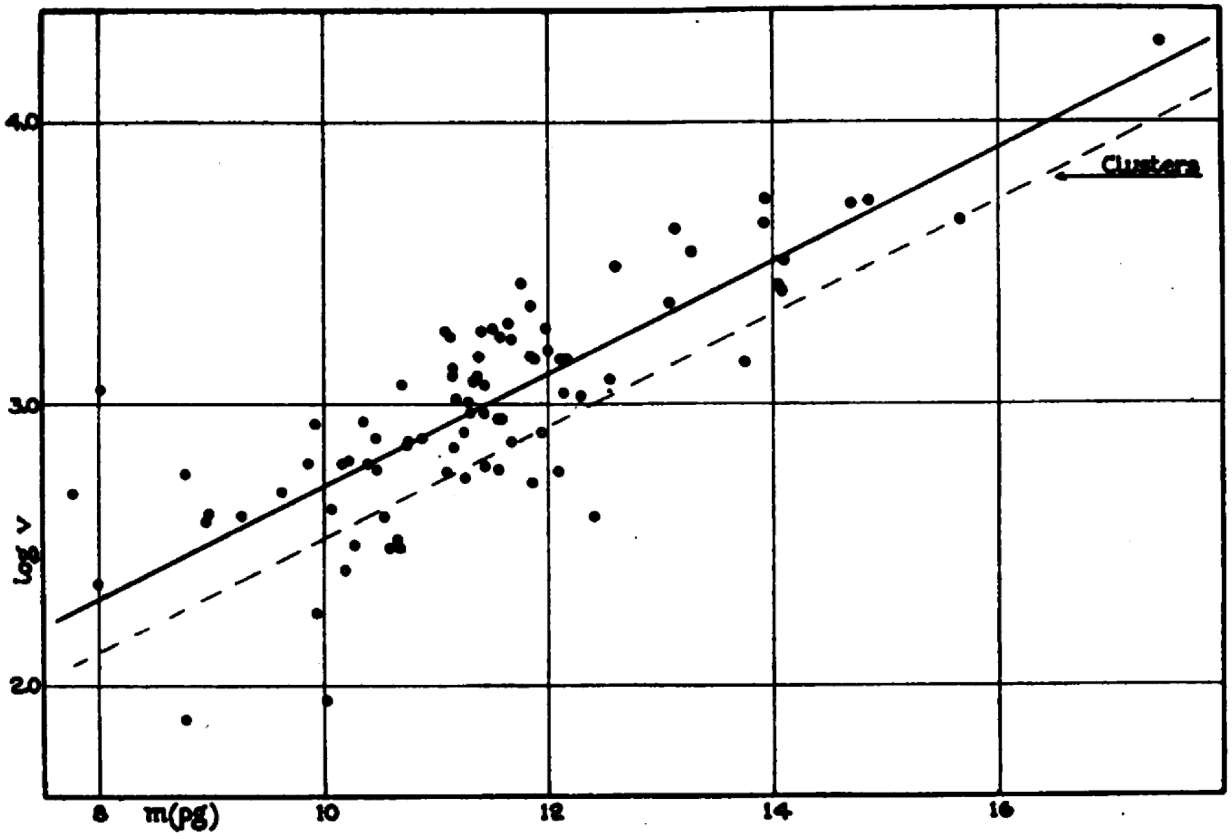
Doron Kushnir (WIS)

Collaborators: Barak Zackay (WIS), Jonas Sinapius (DESY)

11/7/23

H_0 was always about error estimation

$$v = H_0 d$$

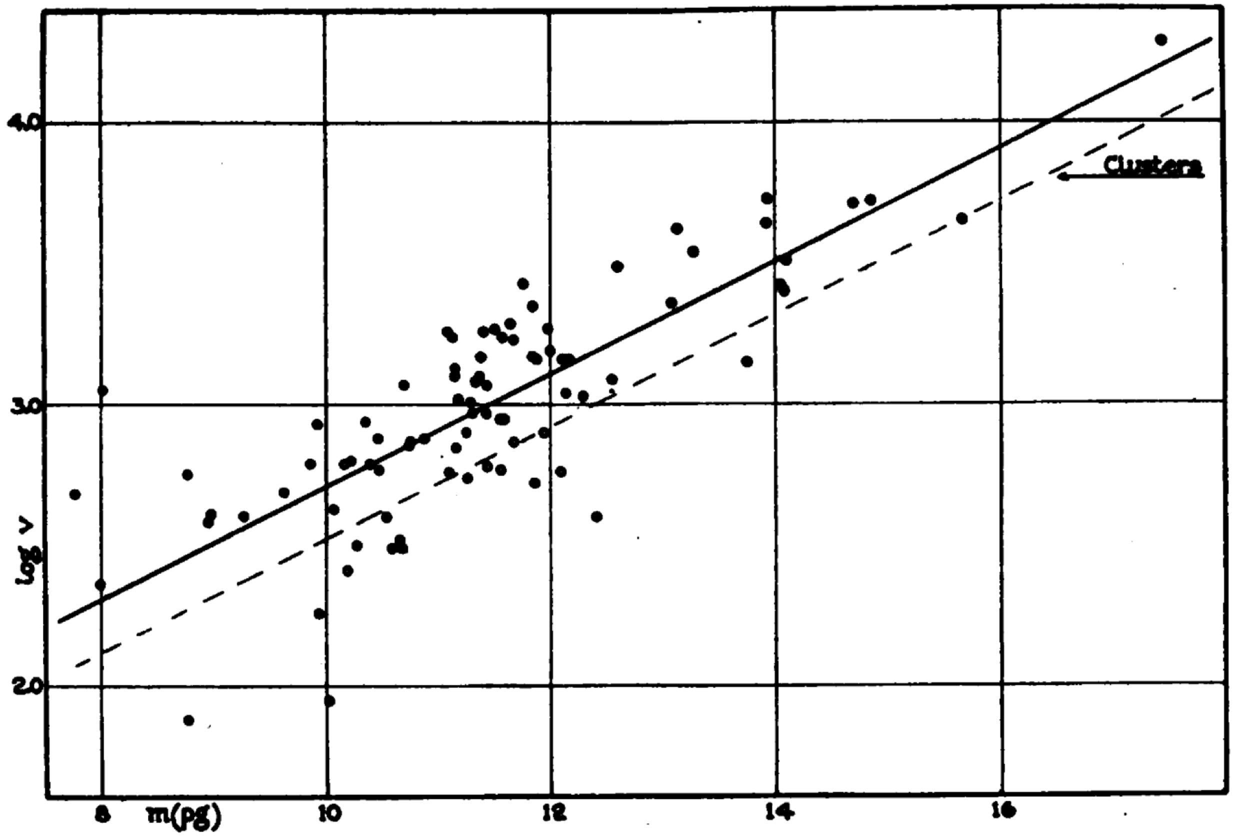


Velocity-Distance Relation for Isolated Nebulae

Hubble & Humason (1934)

H_0 was always about error estimation

$$v = H_0 d$$

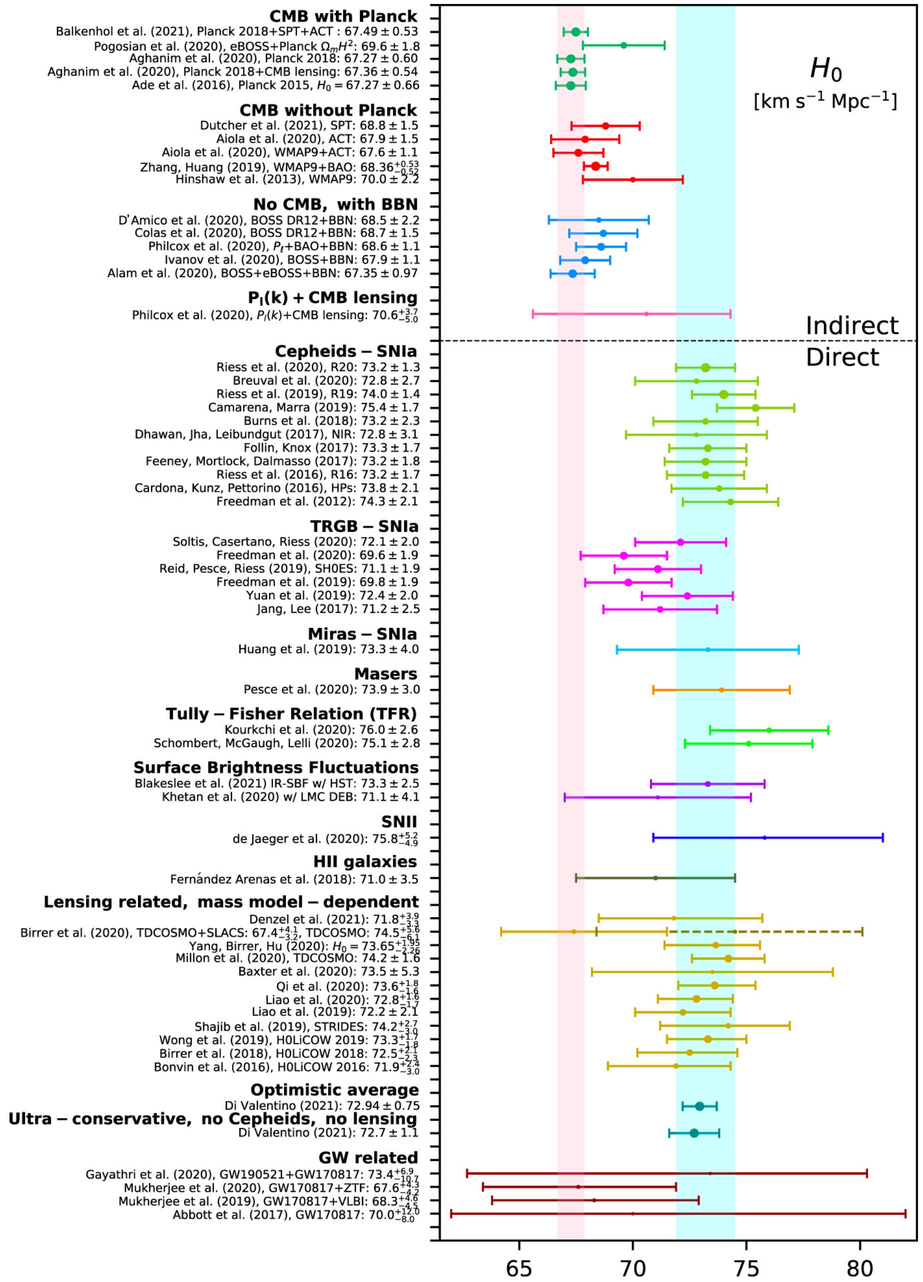


Velocity-Distance Relation for Isolated Nebulae

- H_0 too large by a factor of ≈10.

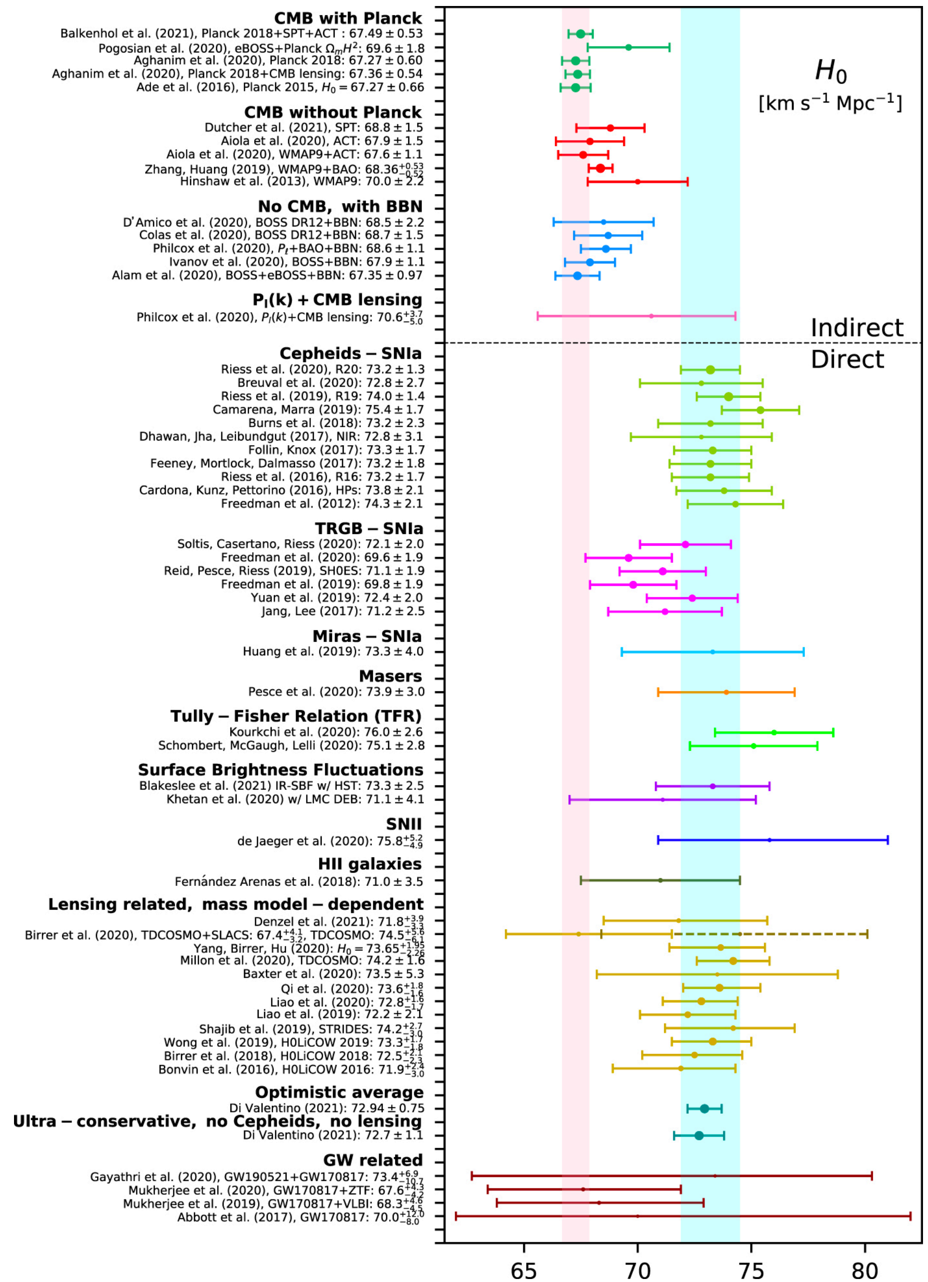
Hubble & Humason (1934)

Currently there is a tension



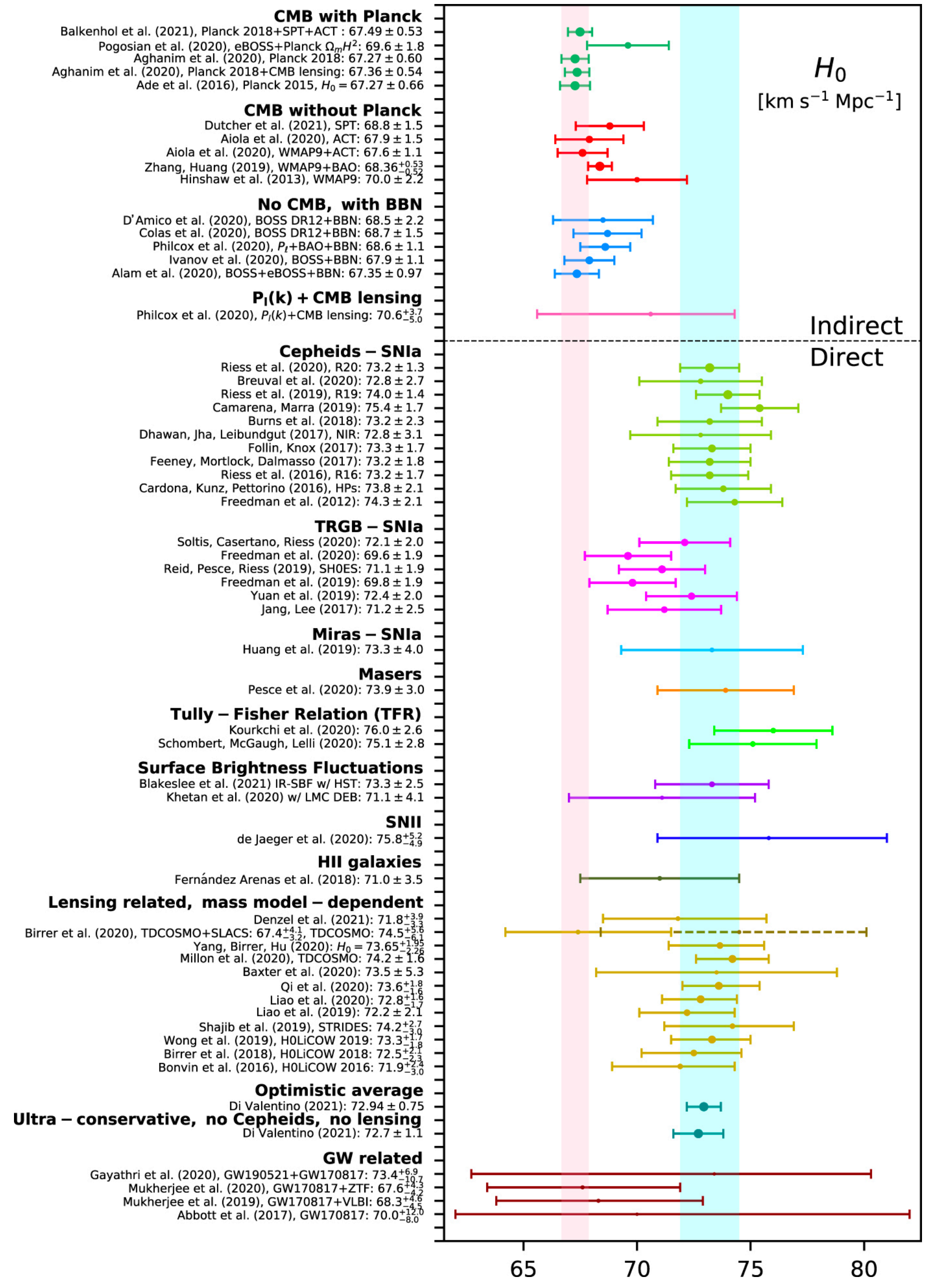
Currently there is a tension

- Strongest tension:
  - *Planck* CMB temperature and polarization anisotropies : **67.4±0.5 km/s/Mpc**
  - SH0ES Cepheid and Type Ia supernovae: **73.04±1.04 km/s/Mpc**



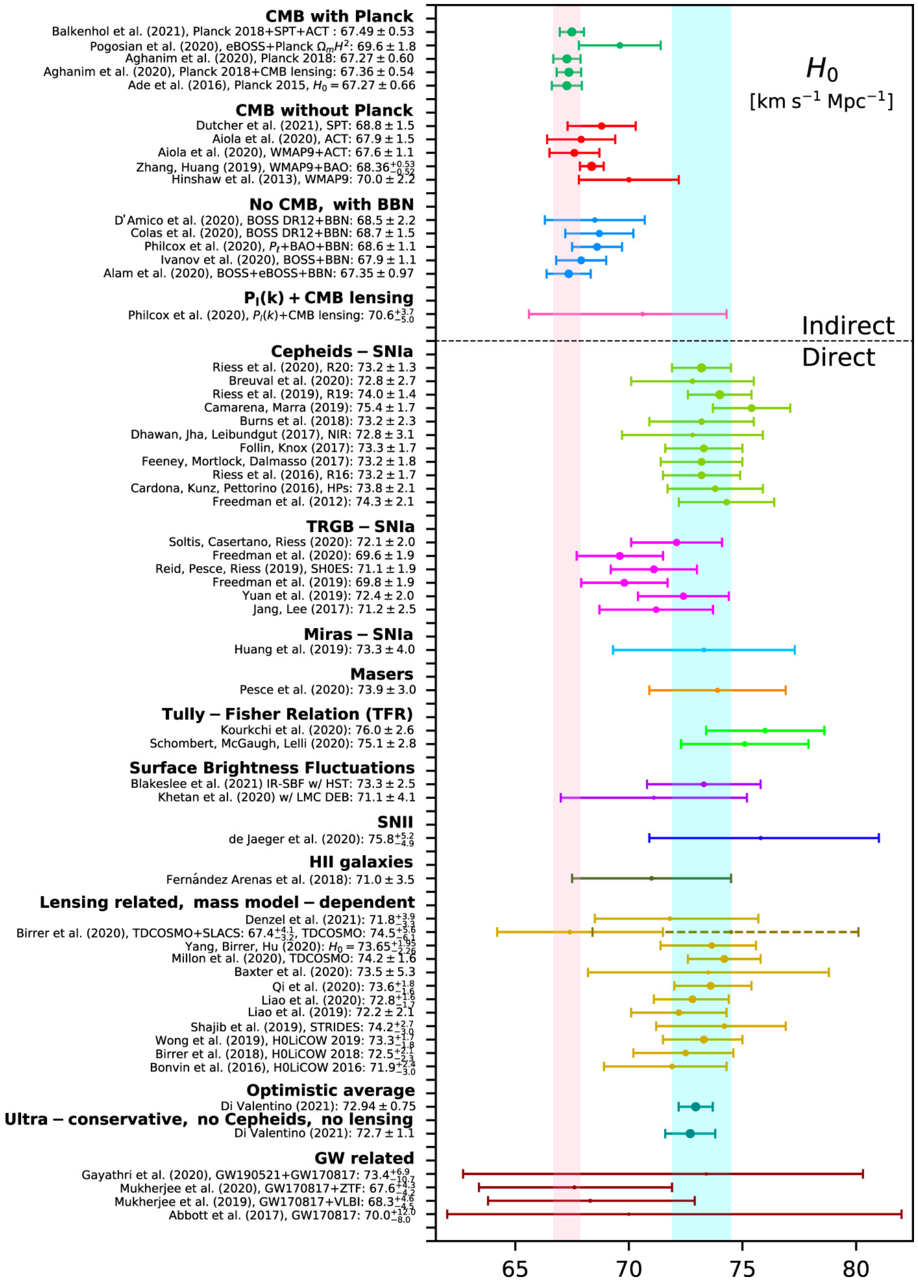
Currently there is a tension

- Strongest tension:
  - *Planck* CMB temperature and polarization anisotropies : **67.4±0.5 km/s/Mpc**
  - SH0ES Cepheid and Type Ia supernovae: **73.04±1.04 km/s/Mpc**
- ≈ 5σ tension



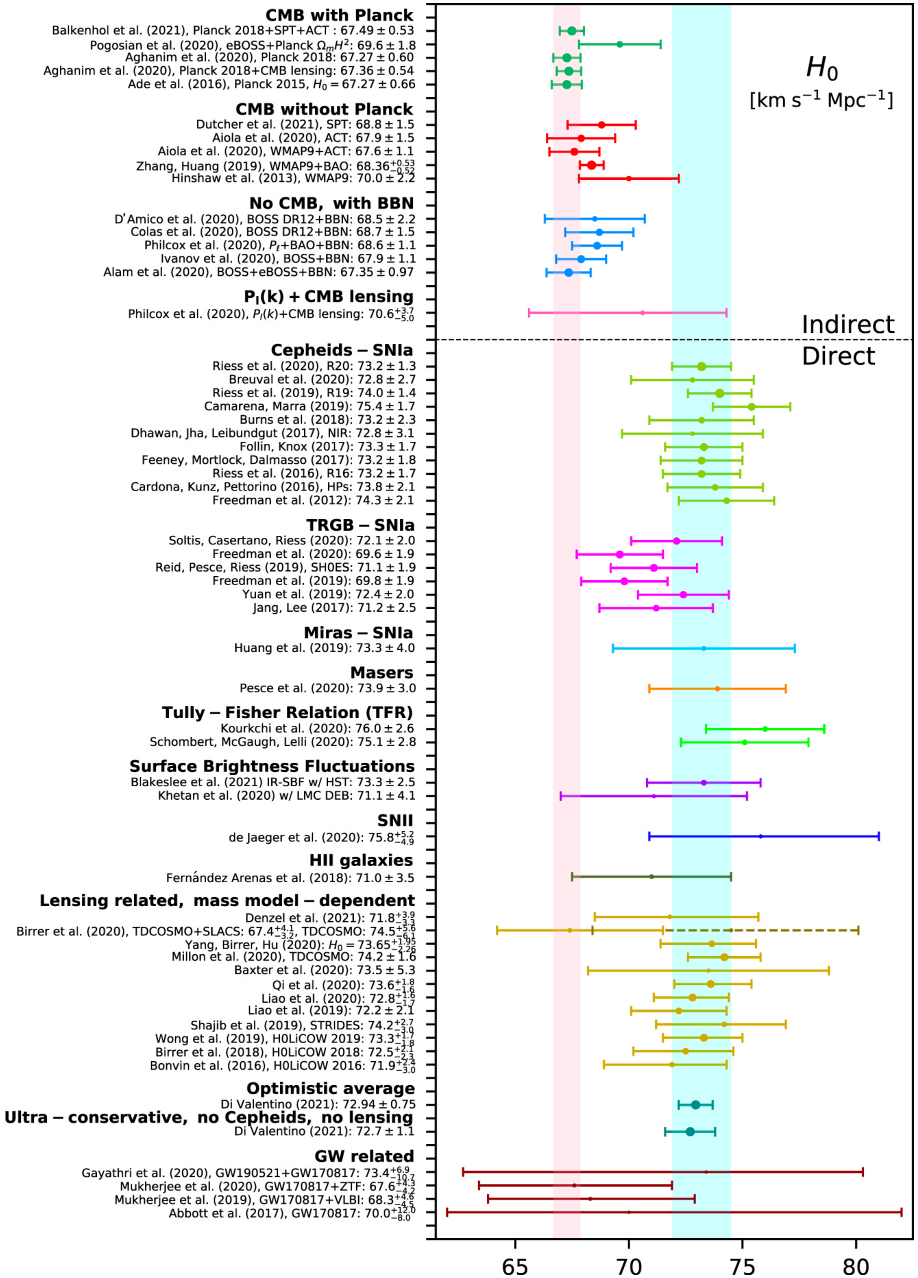
Currently there is a tension

- Strongest tension:
  - *Planck* CMB temperature and polarization anisotropies : **67.4±0.5 km/s/Mpc**
  - SH0ES Cepheid and Type Ia supernovae: **73.04±1.04 km/s/Mpc**
- ≈ 5σ tension
- Either modification to standard ΛCDM cosmology or unidentified systematic errors.



Currently there is a tension

- Strongest tension:
  - *Planck* CMB temperature and polarization anisotropies : **67.4±0.5 km/s/Mpc**
  - SH0ES Cepheid and Type Ia supernovae: **73.04±1.04 km/s/Mpc**
- ≈ 5σ tension
- Either modification to standard ΛCDM cosmology or unidentified systematic errors.
- GW+kilonova allows local measurement from first principles.



first-principles measurement from GW+kilonova

Number of required events for a given accuracy

Model assumptions

first-principles measurement from GW+kilonova

Number of required events for a given accuracy

←

d_L from GW
z from host
(Chen et al. 2018)

→

Model assumptions

first-principles measurement from GW+kilonova

Number of required events for a given accuracy

d_L from GW
z from host
(Chen et al. 2018)

with afterglow modelling
(Hotokezaka et al. 2019, Govreen-Segal & Nakar 2023)

Model assumptions

first-principles measurement from GW+kilonova

Number of required events for a given accuracy ←

- d_L from GW
  z from host
  (Chen et al. 2018)

- with afterglow modelling
  (Hotokezaka et al. 2019, Govreen-Segal & Nakar 2023)

- with optical kilonova modelling
  (Doctor 2020, Coughlin et al. 2020, Sneppen et al. 2023)

→ Model assumptions

first-principles measurement from GW+kilonova

Number of required events for a given accuracy ←

d_L from GW
z from host
(Chen et al. 2018)

with afterglow modelling
(Hotokezaka et al. 2019, Govreen-Segal & Nakar 2023)

with optical kilonova modelling
(Doctor 2020, Coughlin et al. 2020, Sneppen et al. 2023)

Model assumptions →

$$\boldsymbol{\sigma} \approx \frac{\mathbf{15\%}}{\sqrt{\boldsymbol{N}}}$$

first-principles measurement from GW+kilonova

Number of required events for a given accuracy

d_L from GW
z from host
(Chen et al. 2018)

with afterglow modelling
(Hotokezaka et al. 2019, Govreen-Segal & Nakar 2023)

with optical kilonova modelling
(Doctor 2020, Coughlin et al. 2020, Sneppen et al. 2023)

Model assumptions

$$\boldsymbol{\sigma} \approx \frac{\mathbf{15\%}}{\sqrt{\boldsymbol{N}}}$$

$\Longrightarrow$ ~50 events are required for 2% accuracy

ULTRASAT strategy depends on BNS rate and O5 volume

- BNS rate is 10-1700 $yr^{-1}Gpc^{-3}$

https://emfollow.docs.ligo.org/userguide/capabilities.html

ULTRASAT strategy depends on BNS rate and O5 volume

- BNS rate is 10-1700 $yr^{-1}Gpc^{-3}$
- O4 volume is 0.17 $Gpc^3 \Longrightarrow 34 r_{200}$ annual events with ~0.40 Gpc median distance (already ruled out by 2σ with no detection after 0.12 year).

https://emfollow.docs.ligo.org/userguide/capabilities.html

ULTRASAT strategy depends on BNS rate and O5 volume

- BNS rate is 10-1700 $yr^{-1}Gpc^{-3}$

- O4 volume is 0.17 $Gpc^3 \Longrightarrow 34r_{200}$ annual events with ~0.40 Gpc median distance (already ruled out by 2σ with no detection after 0.12 year).

- O5 volume is 0.83 $Gpc^3 \Longrightarrow 166r_{200}$ annual events with ~0.74 Gpc median distance.

https://emfollow.docs.ligo.org/userguide/capabilities.html

ULTRASAT strategy depends on BNS rate and O5 volume

- BNS rate is 10-1700 $yr^{-1}Gpc^{-3}$
- O4 volume is 0.17 $Gpc^3 \Longrightarrow 34r_{200}$ annual events with ~0.40 Gpc median distance (already ruled out by 2σ with no detection after 0.12 year).
- O5 volume is 0.83 $Gpc^3 \Longrightarrow 166r_{200}$ annual events with ~0.74 Gpc median distance.
- For r_{200}~1, ULTRASAT TOO is sufficient

https://emfollow.docs.ligo.org/userguide/capabilities.html

ULTRASAT strategy depends on BNS rate and O5 volume

- BNS rate is 10-1700 $yr^{-1}Gpc^{-3}$
- O4 volume is 0.17 $Gpc^3 \Longrightarrow 34 r_{200}$ annual events with ~0.40 Gpc median distance (already ruled out by 2σ with no detection after 0.12 year).
- O5 volume is 0.83 $Gpc^3 \Longrightarrow 166 r_{200}$ annual events with ~0.74 Gpc median distance.
- For r_{200}~1, ULTRASAT TOO is sufficient
- TOO is in problem for $r_{200}<0.3$ and/or O5 volume is <0.3 Gpc^3 (median distance ~0.6 Gpc)

https://emfollow.docs.ligo.org/userguide/capabilities.html

ULTRASAT kilonova detection rate

- For BB with L=10^{42} erg/s and T>10kK, kilonova are detected to d~0.6-0.7 Gpc (900 s integration time, 22.5 mag)

ULTRASAT kilonova detection rate

- For BB with $L=10^{42}$ erg/s and $T>10$kK, kilonova are detected to $d\sim0.6$-0.7 Gpc (900 s integration time, 22.5 mag)
- High cadence field detects $\sim1.5r_{200}$ events annually.

ULTRASAT kilonova detection rate

- For BB with L=10^{42} erg/s and T>10kK, kilonova are detected to d~0.6-0.7 Gpc (900 s integration time, 22.5 mag)
- High cadence field detects ~1.5r_{200} events annually.
- Low cadence survey detects ~5r_{200} events annually (for UV kilonova time scale of 8 hours, single visit for detection, see Param's talk).

ULTRASAT kilonova detection rate

- For BB with L=10^{42} erg/s and T>10kK, kilonova are detected to d~0.6-0.7 Gpc (900 s integration time, 22.5 mag)
- High cadence field detects ~$1.5r_{200}$ events annually.
- Low cadence survey detects ~$5r_{200}$ events annually (for UV kilonova time scale of 8 hours, single visit for detection, see Param's talk).
- With 24h low cadence survey $\Longrightarrow$ ~$40r_{200}$ events annually.

ULTRASAT kilonova detection rate

- For BB with $L=10^{42}$ erg/s and $T>10$kK, kilonova are detected to $d\sim0.6$-0.7 Gpc (900 s integration time, 22.5 mag)
- High cadence field detects $\sim1.5r_{200}$ events annually.
- Low cadence survey detects $\sim5r_{200}$ events annually (for UV kilonova time scale of 8 hours, single visit for detection, see Param's talk).
- With 24h low cadence survey $\Longrightarrow$ $\sim40r_{200}$ events annually.
- Assume all ULTRASAT events missed by LIGO + later found in post-processing (4 hours trailing-LIGO survey, reasonable to expect ~20% increase in LIGO horizon) $\Longrightarrow$ Significant contribution for O5 volume<0.3 Gpc^3

Summary and future work

- For r_{200}>0.3 and O5 volume >0.3 Gpc^3 ULTRASAT just follows BNS TOO for 2% H_0 measurement.

Summary and future work

- For r_{200}>0.3 and O5 volume >0.3 Gpc^3 ULTRASAT just follows BNS TOO for 2% H_0 measurement.
- For r_{200}~1 and O5 volume <0.3 Gpc^3 ULTRASAT (with major investment) can have a significant, ~40 extra events, contribution.

Summary and future work

- For r_{200}>0.3 and O5 volume >0.3 Gpc^3 ULTRASAT just follows BNS TOO for 2% H_0 measurement.
- For r_{200}~1 and O5 volume <0.3 Gpc^3 ULTRASAT (with major investment) can have a significant, ~40 extra events, contribution.
- Otherwise, ULTRASAT cannot contribute significantly.

Summary and future work

- For r_{200}>0.3 and O5 volume >0.3 Gpc^3 ULTRASAT just follows BNS TOO for 2% H_0 measurement.
- For r_{200}~1 and O5 volume <0.3 Gpc^3 ULTRASAT (with major investment) can have a significant, ~40 extra events, contribution.
- Otherwise, ULTRASAT cannot contribute significantly.
- How would we know kilonova properties (*L*,*T*, UV duration, possibly depend on BNS parameters) prior to O5?

Summary and future work

- For $r_{200}>0.3$ and O5 volume >0.3 Gpc^3 ULTRASAT just follows BNS TOO for 2% H_0 measurement.
- For $r_{200}\sim1$ and O5 volume <0.3 Gpc^3 ULTRASAT (with major investment) can have a significant, ~40 extra events, contribution.
- Otherwise, ULTRASAT cannot contribute significantly.
- How would we know kilonova properties (L,T, UV duration, possibly depend on BNS parameters) prior to O5?
- Can we use single image to increase kilonova detection rate by $(900/300)^{1/4}\sim1.3$?