What role will binary neutron star merger afterglows play in multimessenger cosmology?

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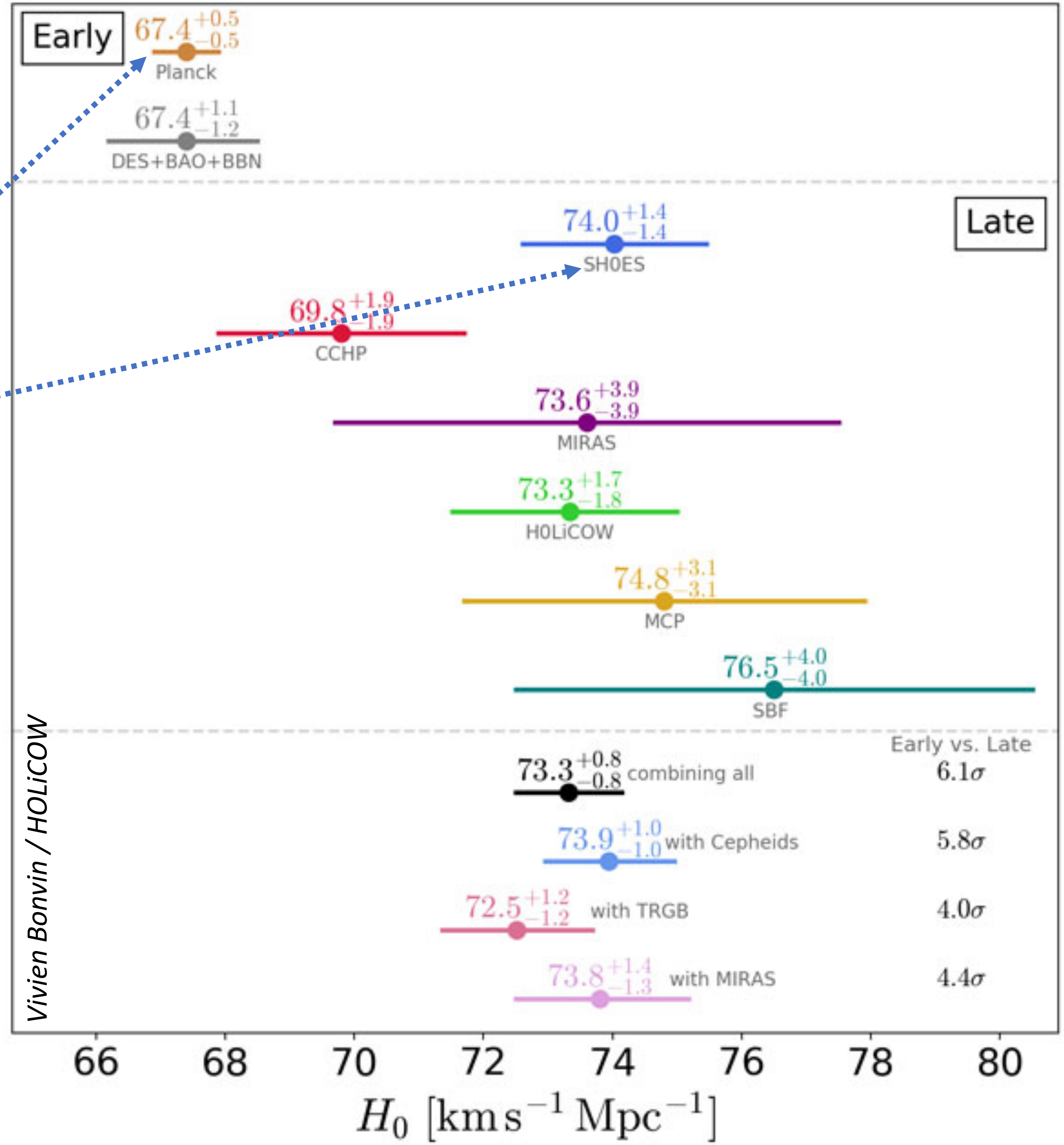
A tension in the Hubble constant…

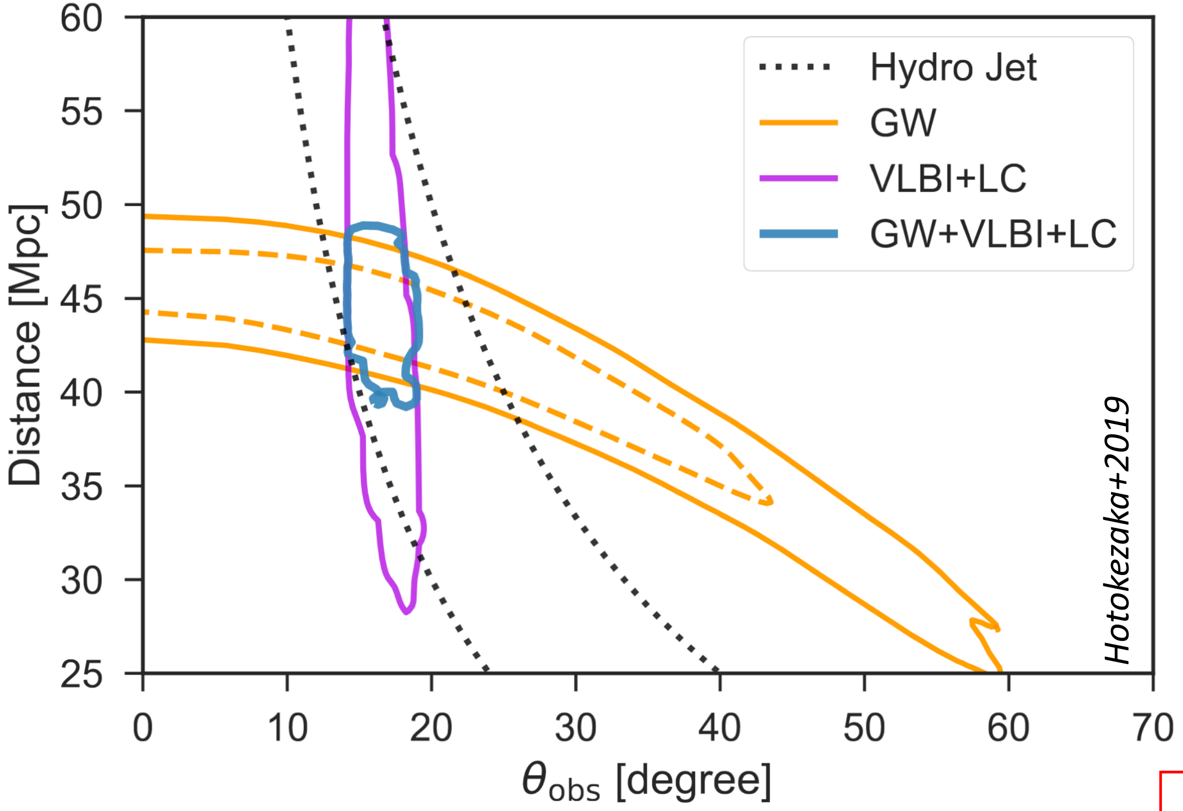
CMB vs. SNIa:
> 5 σ tension



BNS are a new and independent probe of Universe:
Multimessenger cosmology

Standard-siren measurements of H_0

H_0*: need *D* and *z



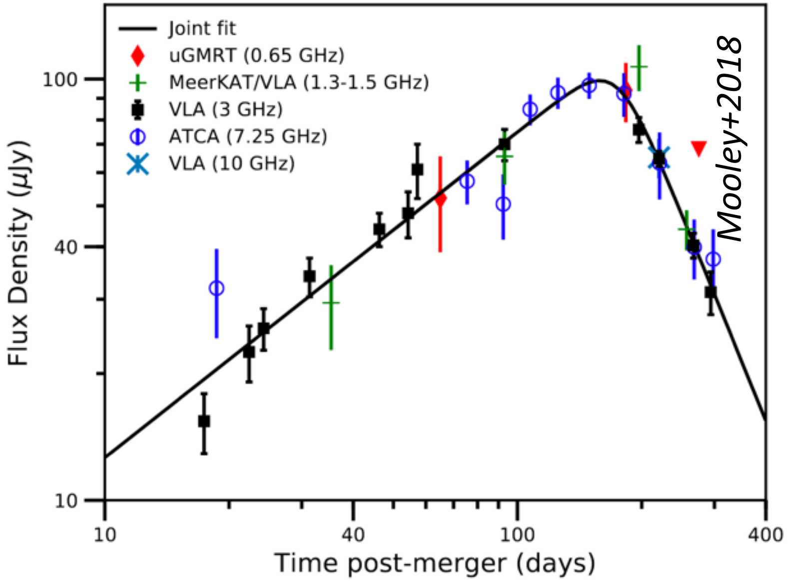
Some degeneracy in *D* and cos *ι* in the GW data

- **"GW-only"** method: measure *z* from the GW waveform using the NS tidal effects (assumes you know the EoS, Messenger+2012, Del Pozzo+2017)
- **"Dark siren"** method: weigh in the *z* of all the galaxies compatible with the GW skymap (assumes you have complete galaxy catalogs, Fishbach+2019, Gray+2020)
- **"Basic multi-messenger"** method: identify the EM counterpart to the merger, and use the *z* of the host-galaxy (assumes you can find the kilonova counterpart, Nissanke+2013, etc.)
- **"Enhanced multi-messenger"** method: use additional cos *ι* information to make a better H_0 measurement

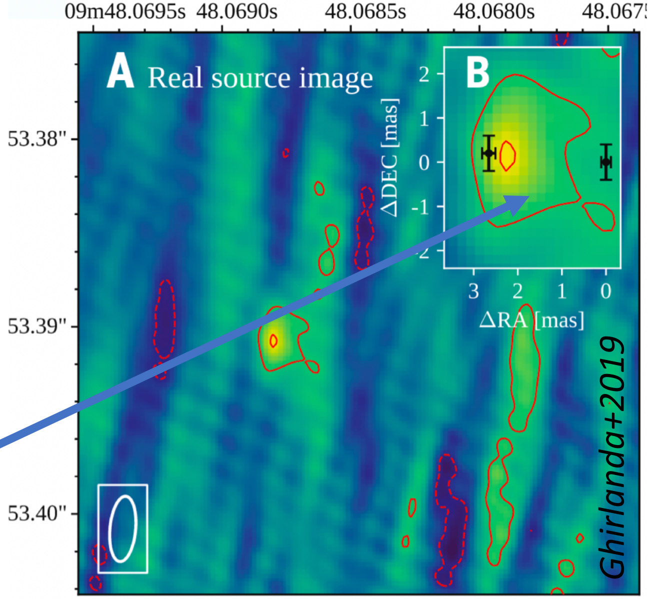
How the merger afterglow can contribute to the measurement

BNS merger afterglow counterpart:

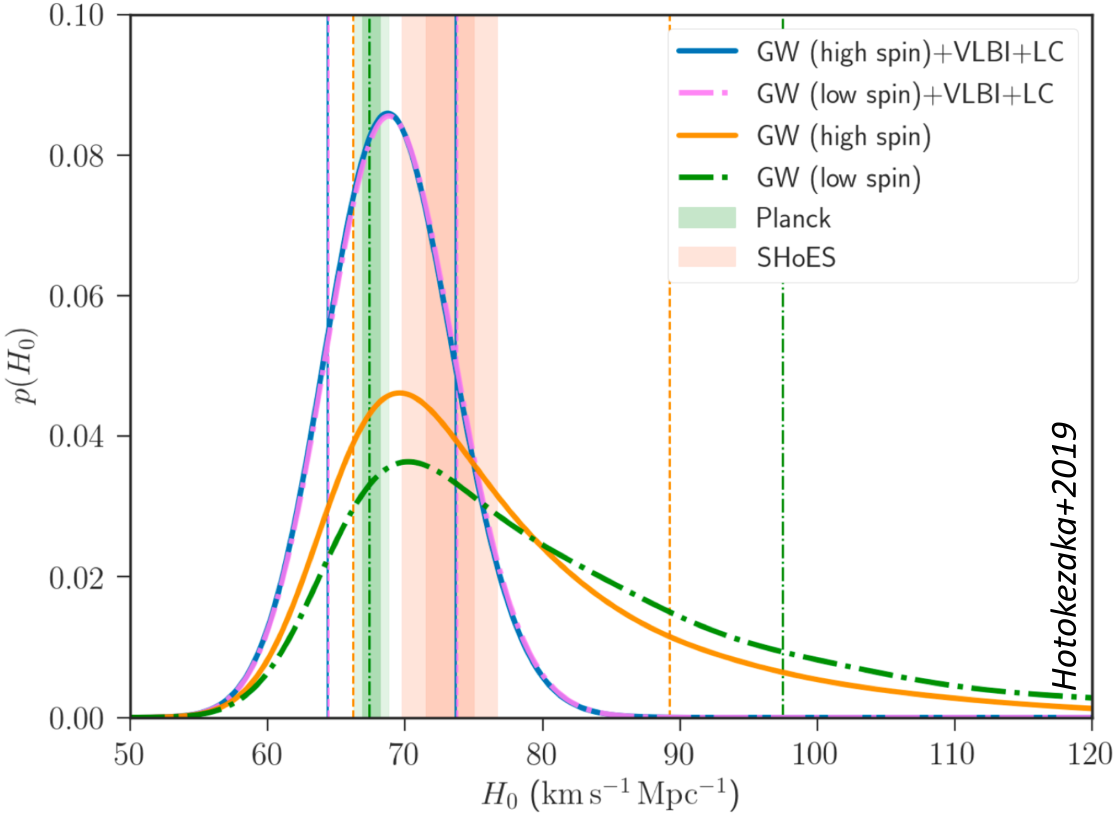
Light-curve:



Imagery (VLBI):



displacement: ~3 mas in 155 days
(Mooley+2017)



➔ Using **afterglow light-curve + imagery makes 3-fold improvement** in H_0!

Question: In upcoming observing runs, will merger afterglows help to measure H_0 faster?

Method

Competition between:

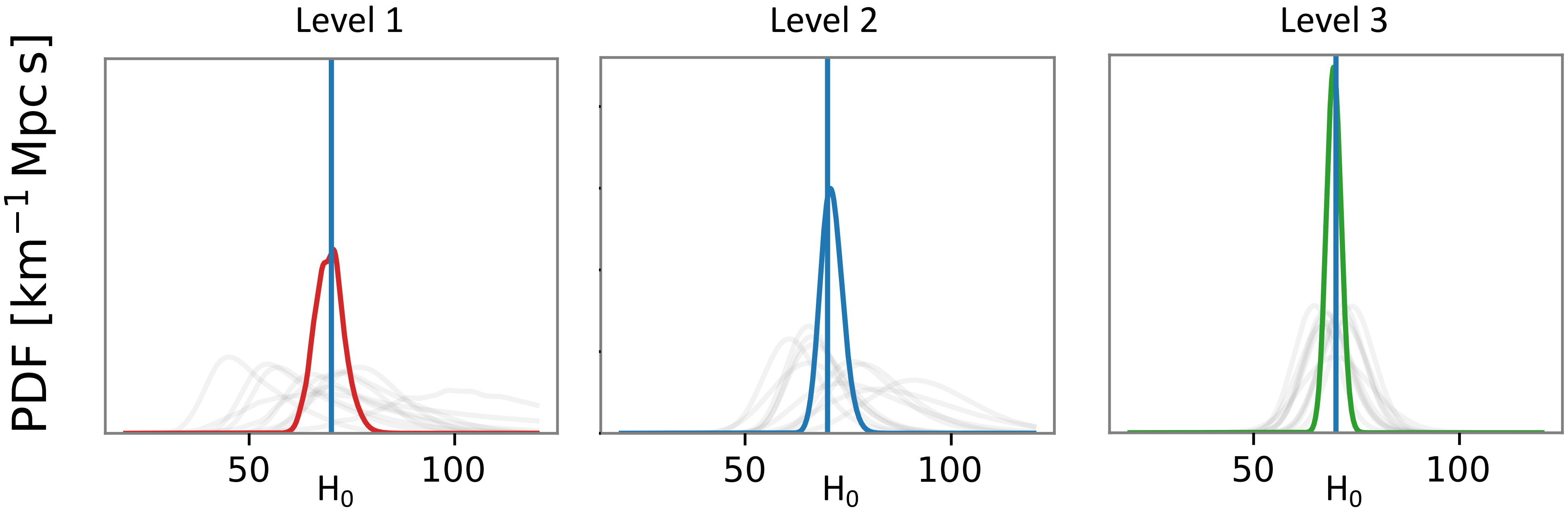
- **Rareness** of counterpart
- **Precision** in measuring angle

RARER

3 levels of inclination angle information:

- Level 1: GW $(\rightarrow D, i)$ + KN $(\rightarrow z)$
- Level 2: GW $(\rightarrow D, i)$ + KN $(\rightarrow z)$ + afterglow light-curve $(\rightarrow i)$
- Level 3: GW $(\rightarrow D, i)$ + KN $(\rightarrow z)$ + afterglow light-curve $(\rightarrow i)$ + afterglow imagery $(\rightarrow i)$

For every signal (GW, KN, afterglow): emission model, detection model, source population model, angle-measurement model



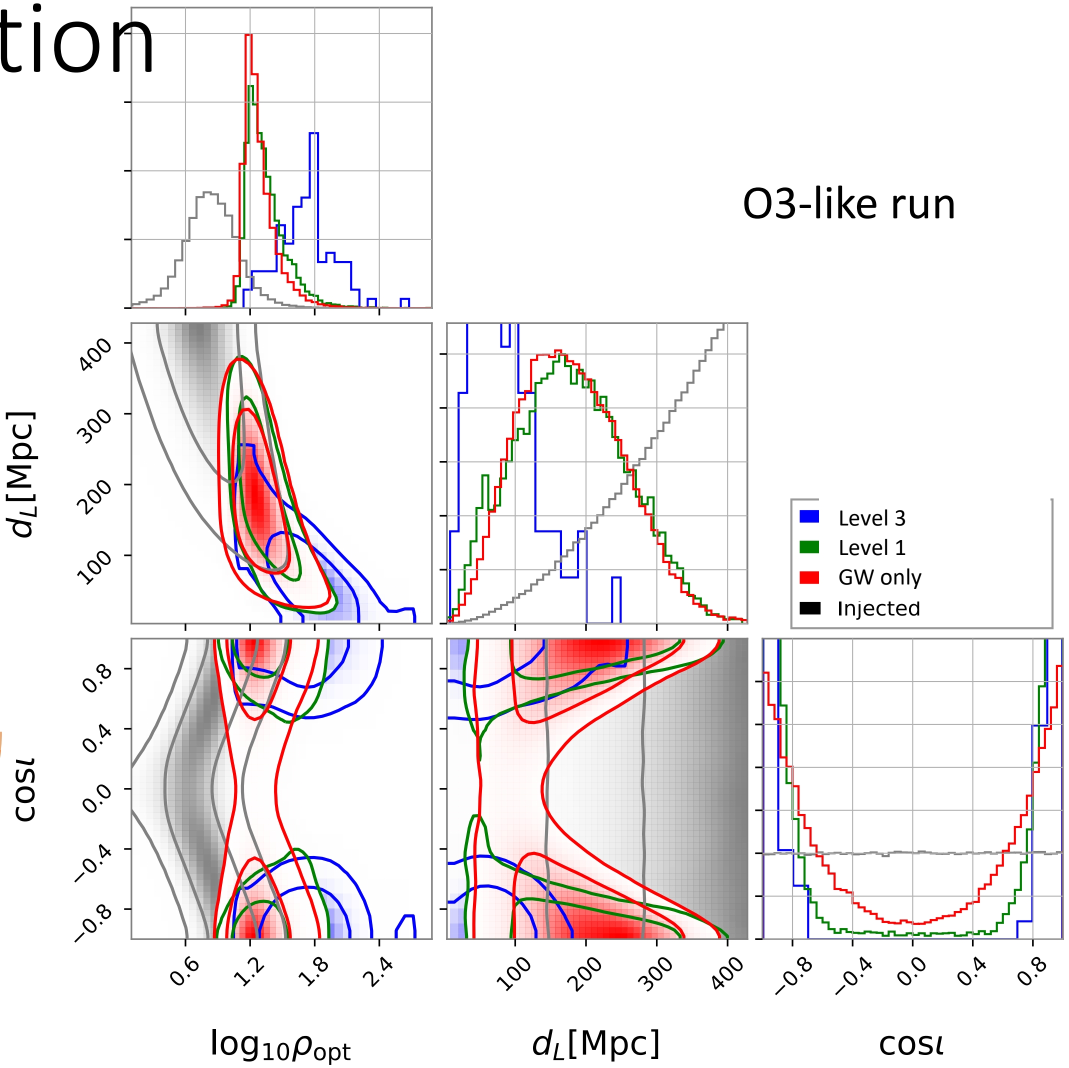
Results I: Expected MM population

Fractions of detected events among all GW events

GW Run	Electromagnetic information level				
	Level 1	Level 2		Level 3	
		WP15	G16	WP15	G16
O2-like	52%	4%	12%	0.67%	7%
O3-like	45%	1.56%	6.13%	0.18%	1.70%
O4-like	26%	0.37%	3.50%	0.01%	0.25%

OK | rare | very rare!

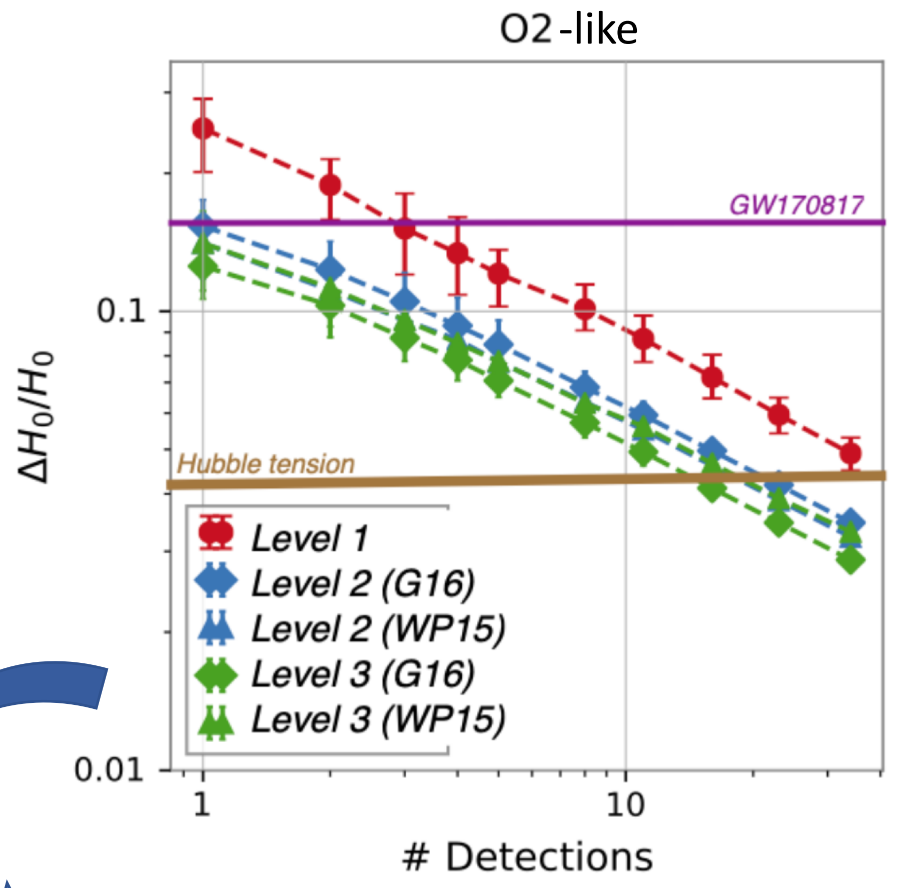
two different GRB prompt luminosity hypotheses ≈ confidence intervals

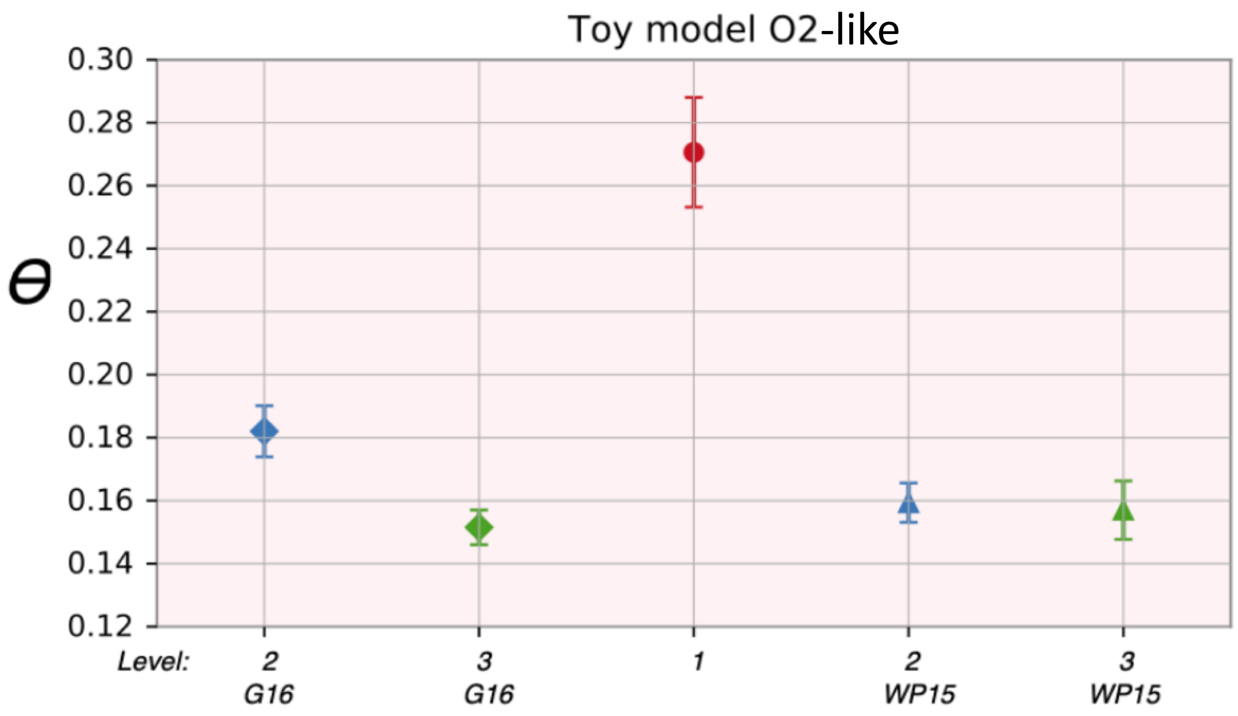


- Level 2 & 3 events are **very** rare! And GW170817 was lucky…
- Beware that **Level 2 & 3 events are closer and have a better GW SNR**

➔ their angle information is **not the only source of improvement on H_0**

Results II: Bulk comparison of EM information levels



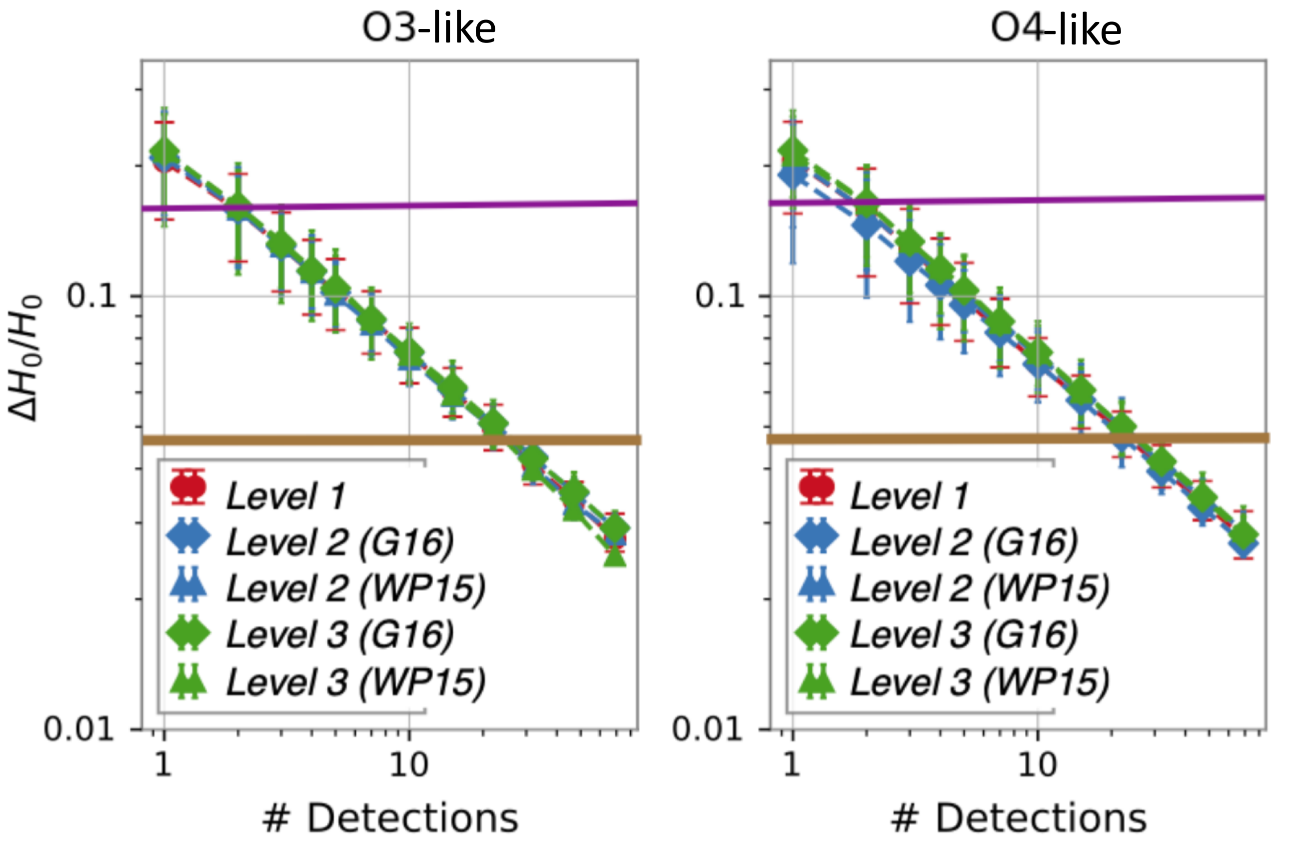


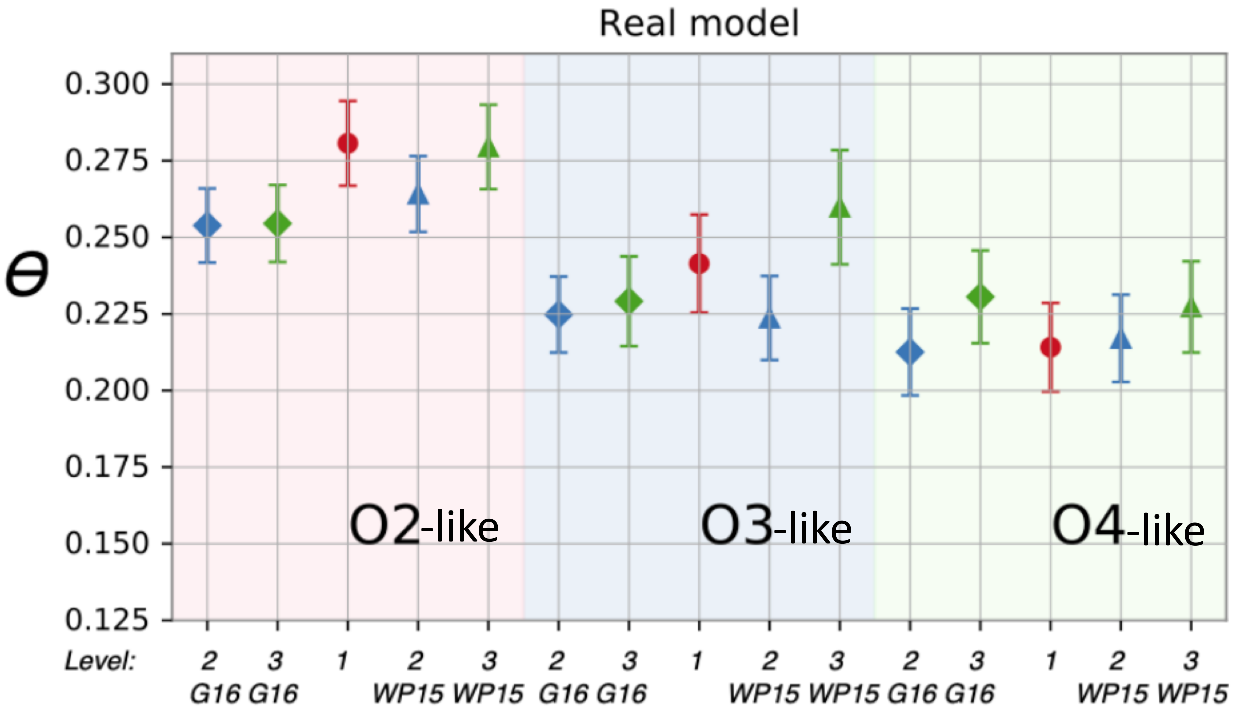
$$\Delta H_0/H_0 \sim \Theta/\sqrt{N}$$

➔ Θ: effective **single-event** H_0 estimation **standard deviation**

➔ If all events had Level 3 EM information, **Hubble tension resolved ~3 times faster**

Results III: Assuming realistic rates of EM counterparts





→ Statistically, **afterglow counterparts are too rare** (or their precision on *i* is too low) **to measure H_0 faster** than the basic multi-messenger method.

Caveats and limitations

The **hypotheses of our study are optimistic**:

- **Electromagnetic detection criterion based only on flux level**. Actual follow-up is much harder than that: GW skymap coverage, source identification, contrast with host galaxy, etc. (cf. O3)
- We considered **afterglow angle information always has GW170817-quality**. But GW170817 had an exceptionally well sampled afterglow light-curve. Quality should decrease with, e.g., source distance
- **Overestimate magnitude of VLBI signal**: the Level 3 fractions should actually be lower
- We consider **no bias in electromagnetic measurement of inclination angle**
- **Our BNS mass function underestimates the GW horizon**: expect even more events without electromagnetic counterparts

Conclusions

1. **Prospects for afterglow-enhanced standard-siren measurements of H_0 are bad**
2. This conclusion is deduced from an **optimistic study**
3. Results should not be misunderstood: **if an image of the merger remnant is acquired, use it!** But, statistically, such data will not help in the long run
4. Our conclusion stems from the fact that, as of O3, **multimessenger detections are completely dominated (i.e., limited by) the electromagnetic domain**. This will be worse for O4 and beyond.
5. To be competitive, **afterglow models should provide degree-level information** on the inclination angle with a typical light-curve (we aren't there yet…)
6. Better **prospects for kilonovae signals**: a ten-degree systematic precision would suffice for them to accelerate H_0 measurement, in reach of **better modelling and kilonovae calibration**, once a larger sample is collected
7. Electromagnetic sector should not drive multimessenger cosmology: fear of **pollution by uncontrolled selection effects or biases** (e.g. Chen 2020) **dismissed**
8. **Number of events to solve Hubble tension: still 20-50** (~ten years of O3-like run)