How must faster can standard-siren measurements of H_0 be made if we leverage merger afterglows?

Raphaël Duque (IAP)

with S. Mastrogiovanni, E. Chassande-Mottin, F. Daigne and R. Mochkovitch

A tension in the Hubble constant…

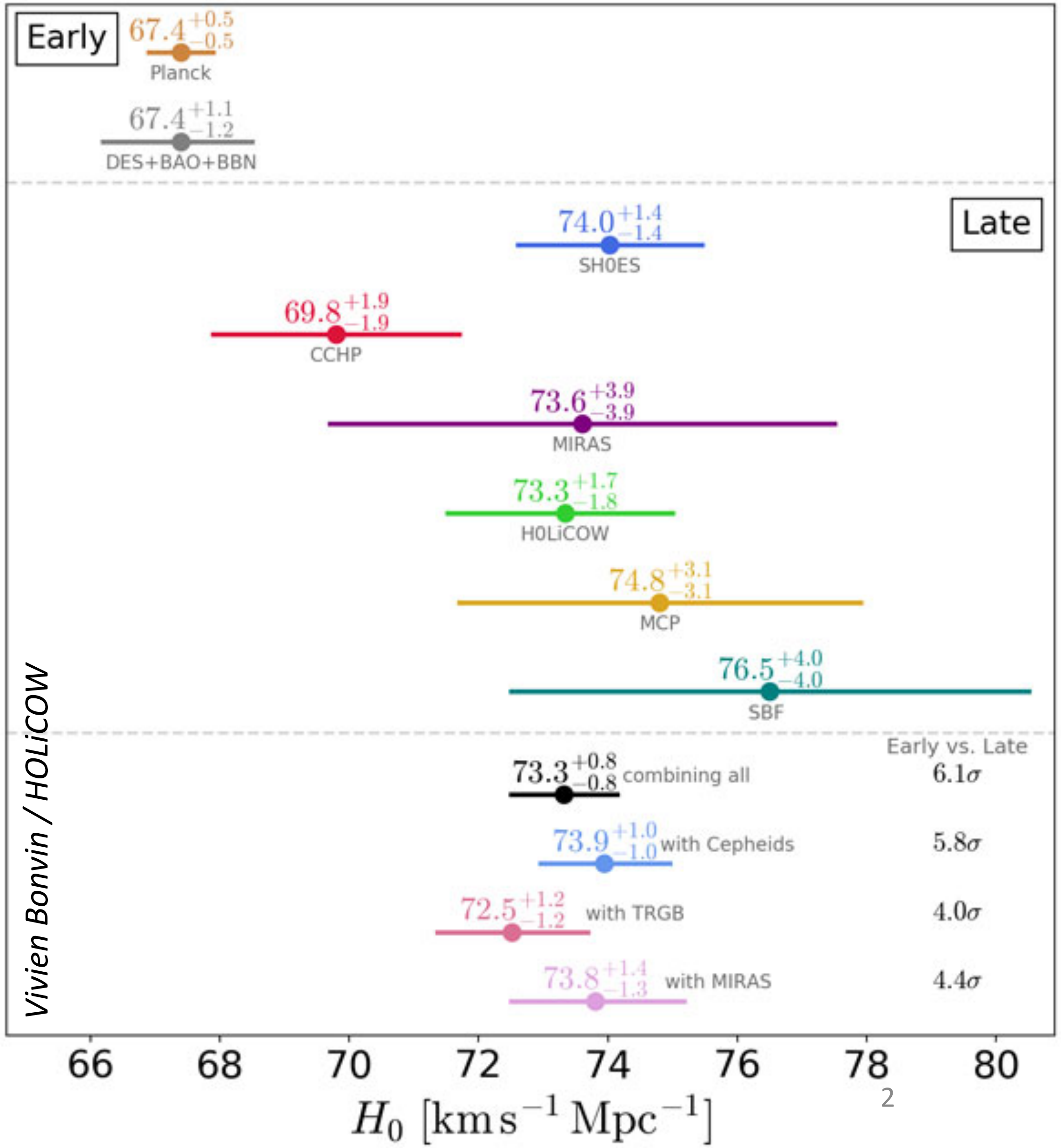
Local velocity field in isotropic universe (linear in *r*)*:*

$$\vec{v}(\vec{r}) = \underbrace{\vec{\Omega} \times \vec{r}}_{\text{Antisym.}} + \underbrace{\Sigma \cdot \vec{r}}_{\text{Sym.}}$$

By **isotropy**,

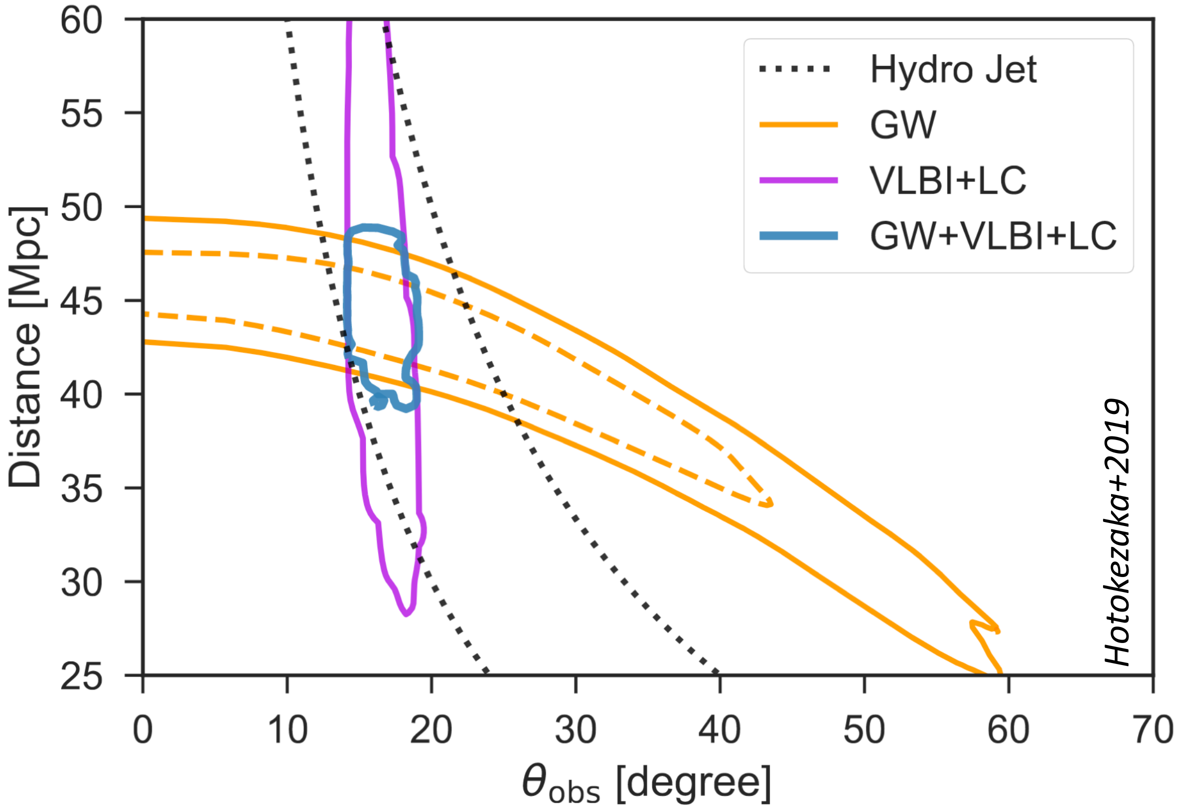
$$\vec{\Omega} = \vec{0} \quad \text{and} \quad \Sigma = \underbrace{H.\mathrm{Id}}_{\text{Pure expansion!}}$$

➔ Local expansion rate is (one of) the most **fundamental parameters of isotropic universe**



Standard-siren measurements of H_0

H_0 : need ***D*** and ***z***



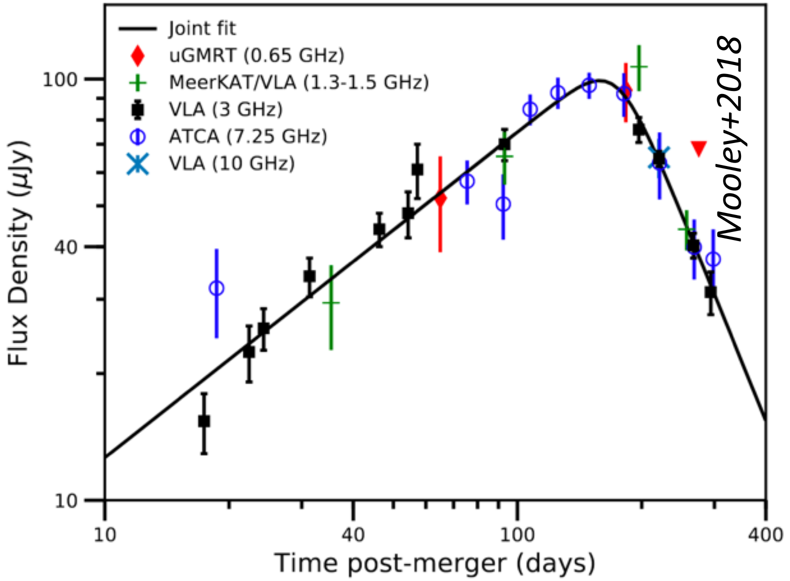
➔ Some degeneracy in *D* and cos *ι* in the GW data

- **"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

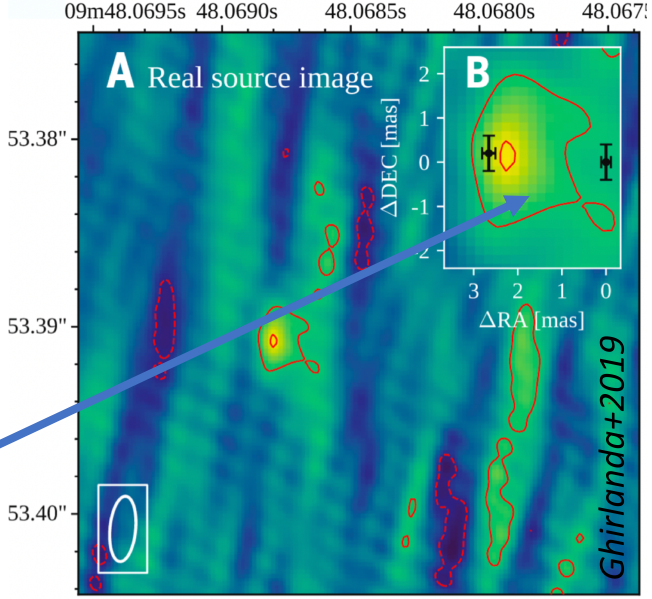
How the merger afterglow can contribute to the measurement

BNS merger afterglow counterpart:

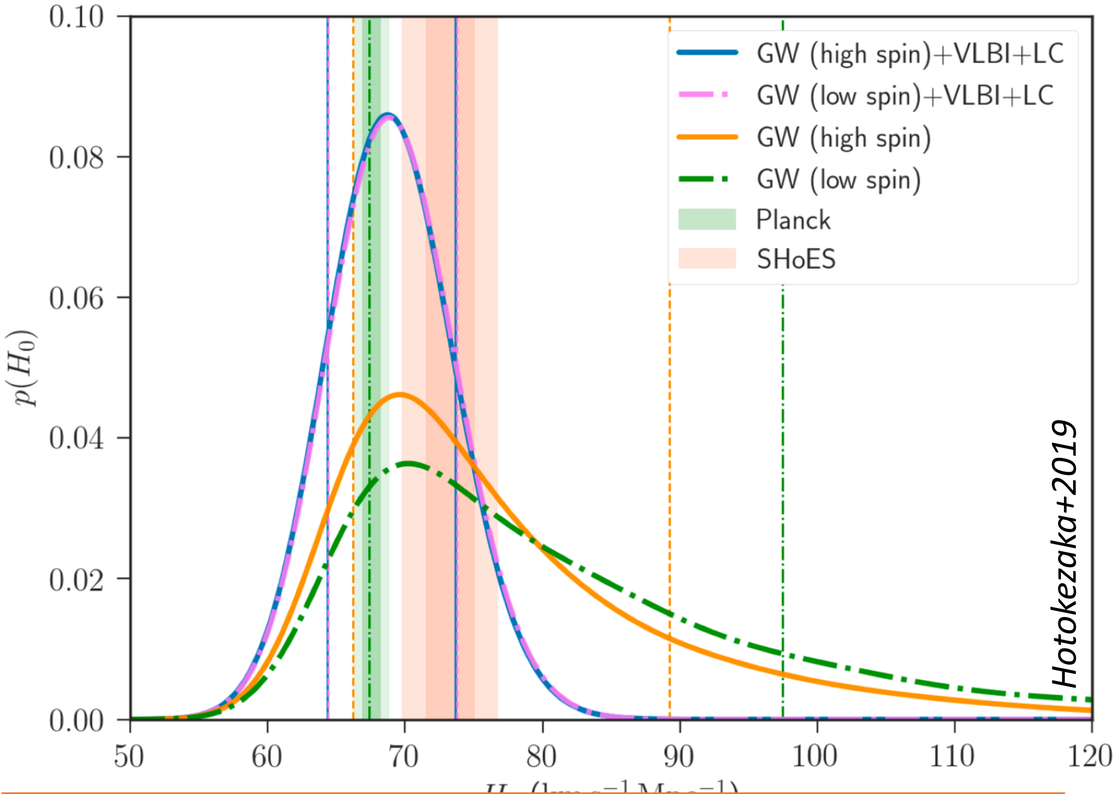
Light-curve:



Imagery (VLBI):



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



➔ Using **afterglow imagery makes 2-fold improvement** in H_0!

Question: In the future, will this afterglow information help? How much faster will the narrowing-down of H_0 be?

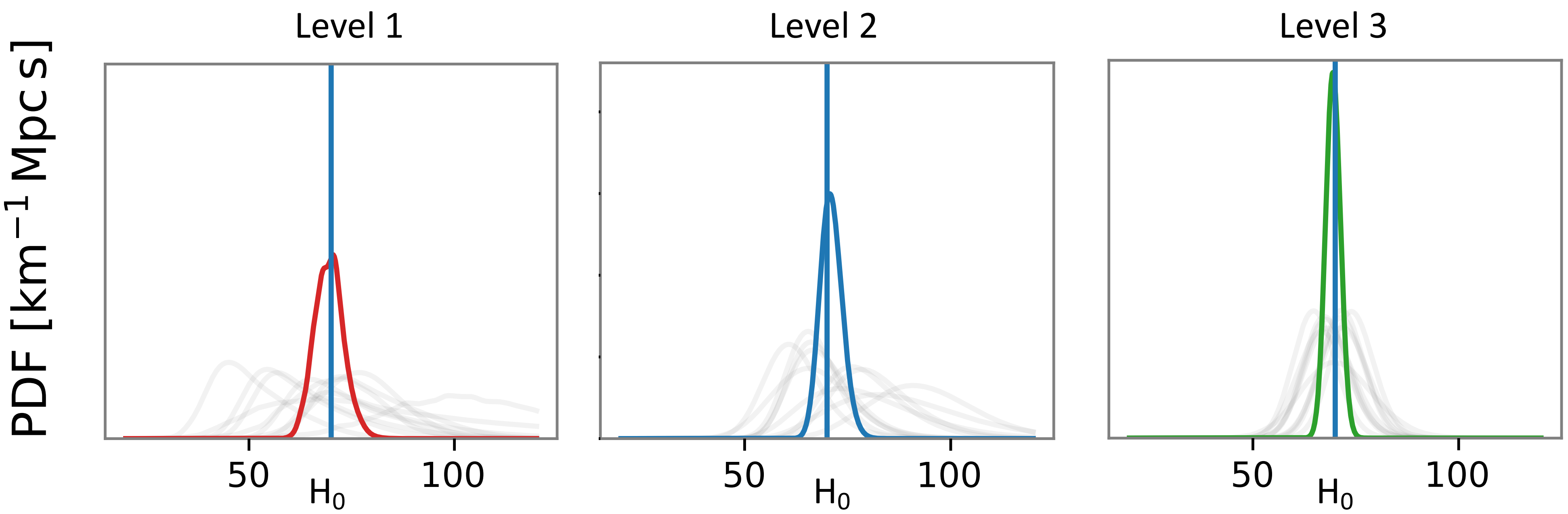
Method

HARDER

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, population source model, angle-measurement model



Competition between:

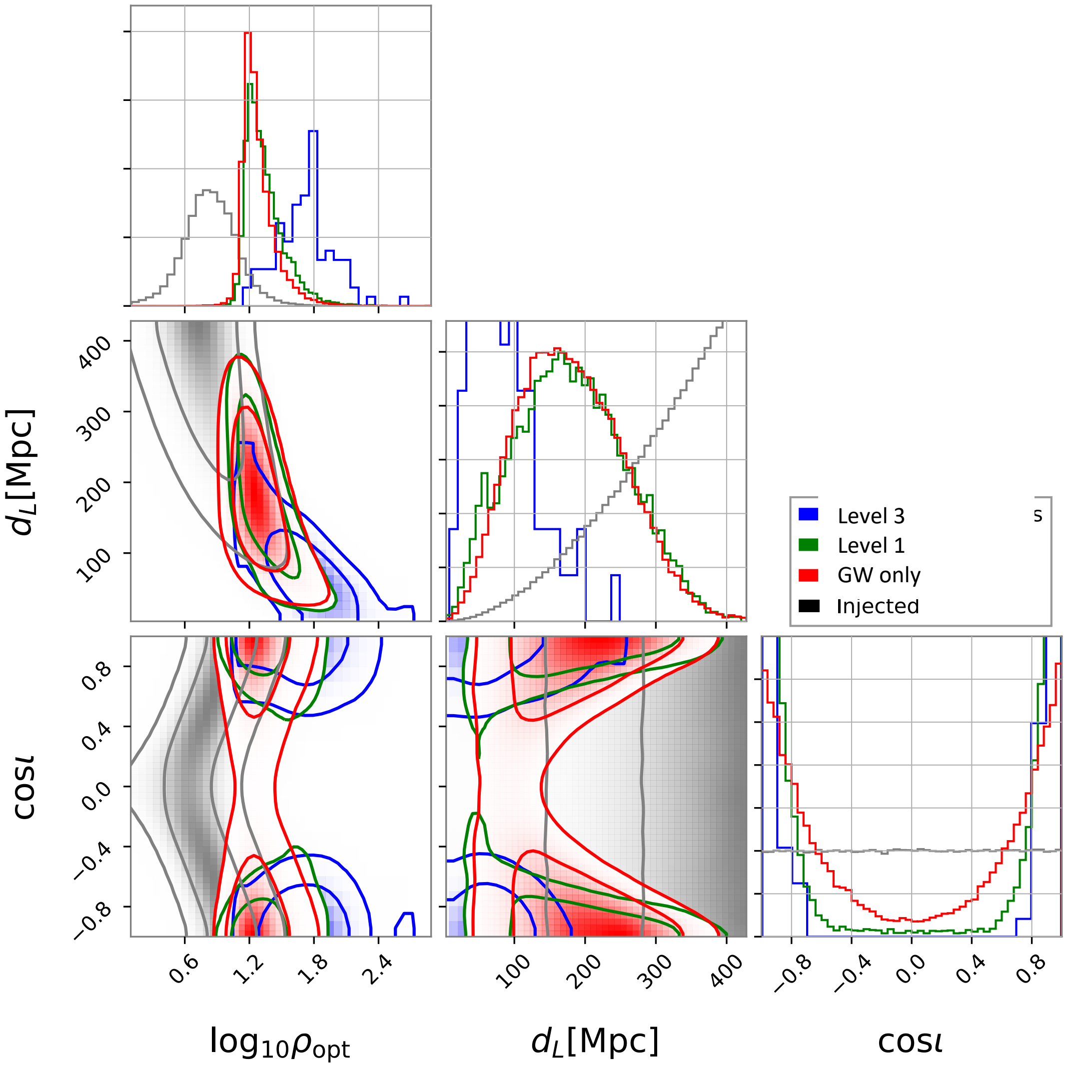
- **Rareness** of counterpart
- **Precision** in measuring angle

Results

Fractions of detected events among all GW events

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

$\underbrace{\text{Level 1}}_{\text{OK}}$ $\underbrace{\text{Level 2}}_{\text{rare}}$ $\underbrace{\text{Level 3}}_{\text{very rare!}}$

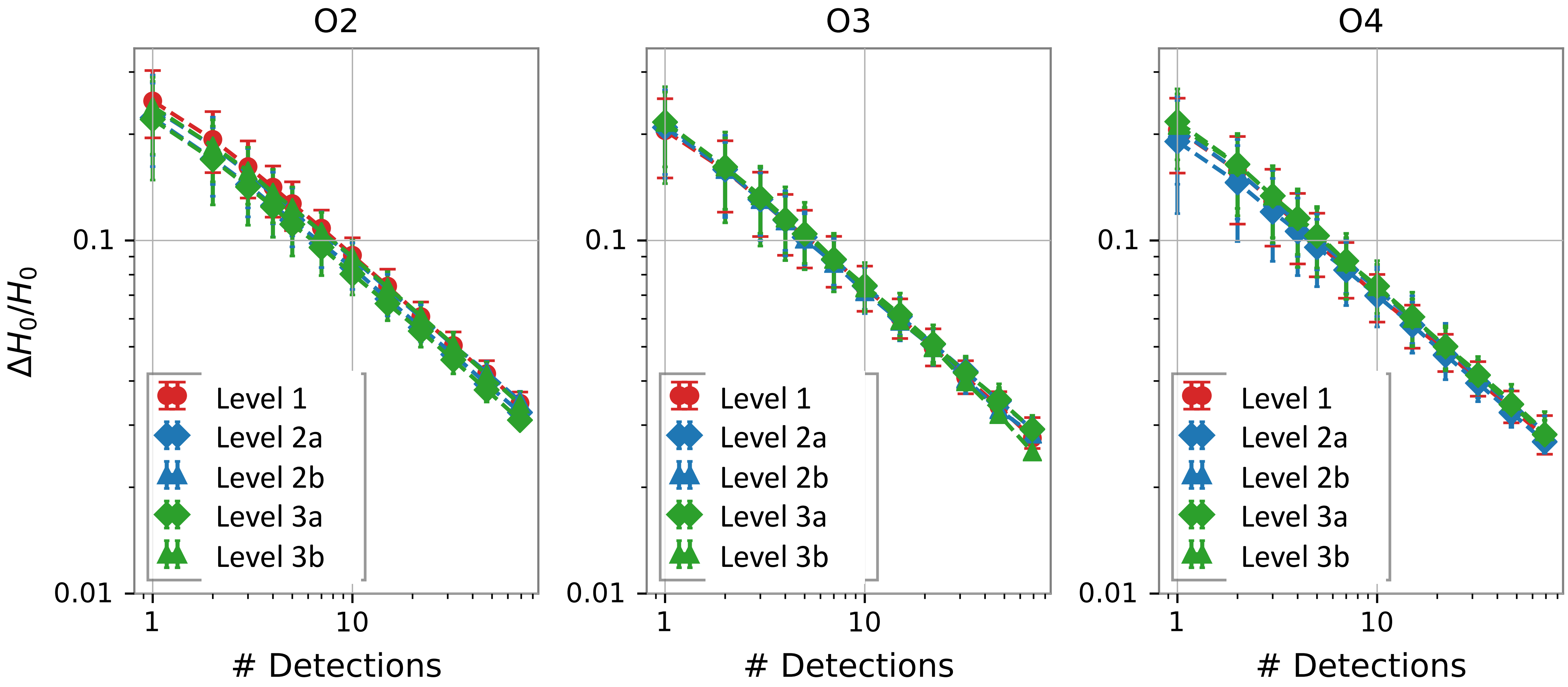


Level 2 & 3 events are **extremely** rare! And GW170817 was lucky…

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



Statistically, afterglow counterpart **is too rare**, (or its precision on *i* is too low) to **accelerate the narrowing-down of H_0** with respect to 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 light-curve. **Quality should decrease with, e.g., distance**.

Conclusions

1. **Prospects for afterglow-enhanced standard-siren measurements of H_0 not great**
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 images will not help in the long run
4. To be competitive, **afterglow models should provide degree-level information** on the inclination angle
5. Follow-up with kilonova difficult (cf. O3), **can we bypass the KN and detect the afterglow directly,** with wide FoV X-ray or radio instruments? (ATHENA, THESEUS, SKA)