Gravitational wave cosmology and calibration

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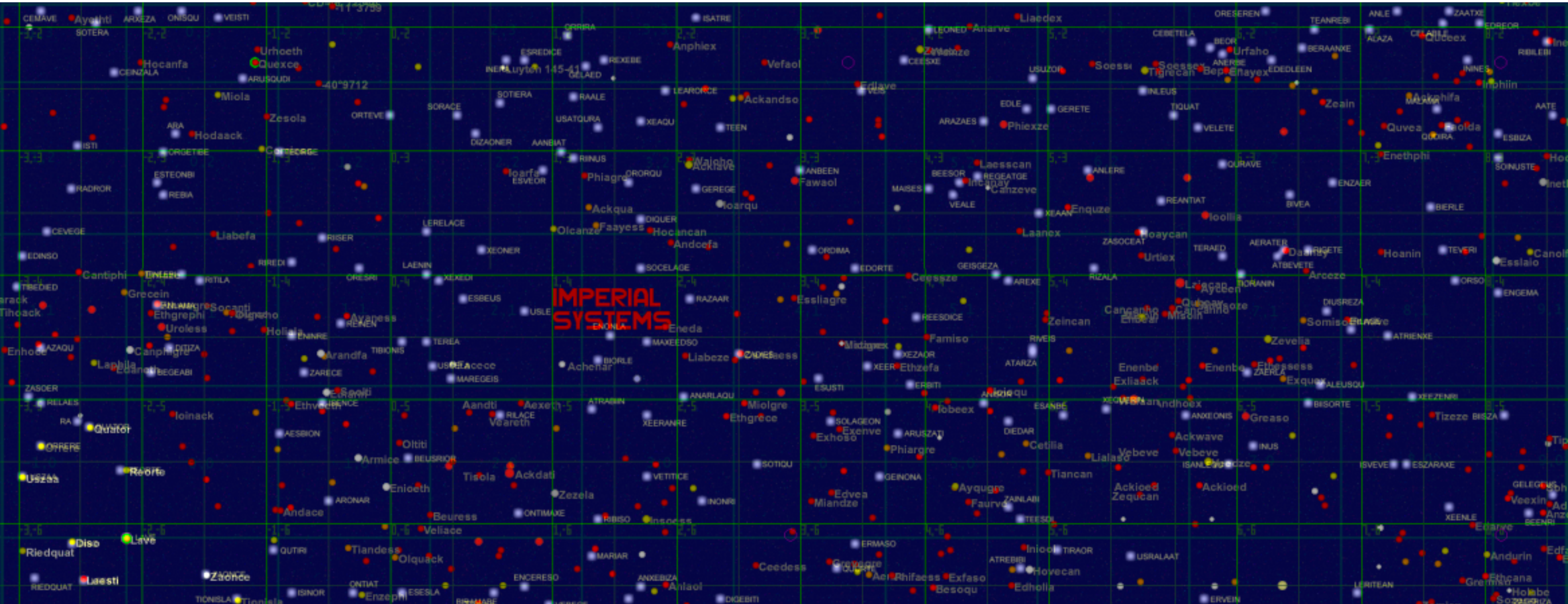
Physics and Astrophysics at the eXtreme Workshop



Outline

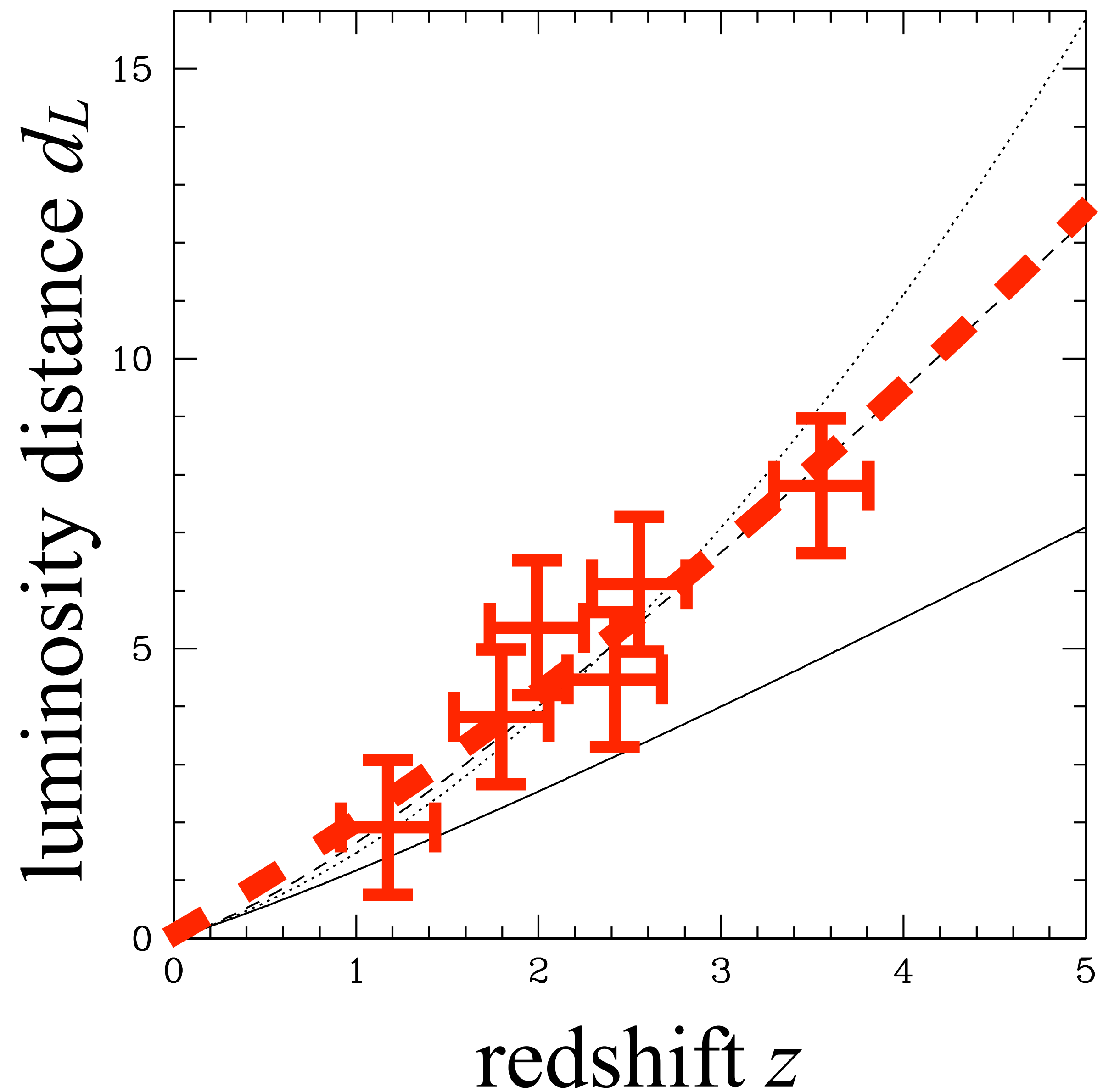
- A summary of “standard” cosmological approaches
- A common problem - calibration
- Astrophysical calibration
- Summary

Basic Cosmology

redshift

$$1 + z = \sqrt{\frac{1 + v/c}{1 - v/c}}$$

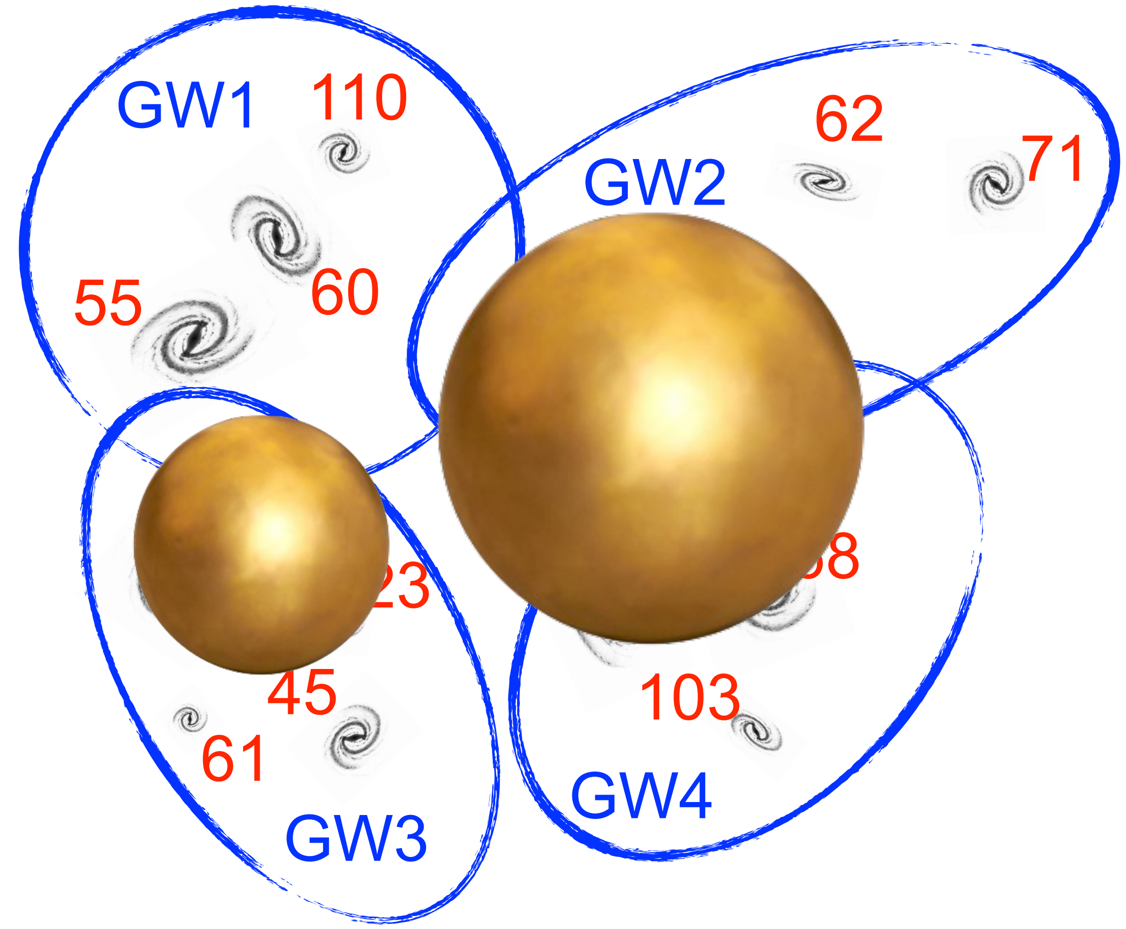
- **The universe is expanding** - Hubble 1929
- The relationship between the luminosity distance and the recession velocity of galaxies is determined by a cosmological model and its parameters.
- Hence, getting measurements of both quantities for multiple galaxies allows us to **compare models and constrain model parameters**, e.g. the Hubble constant H_0.



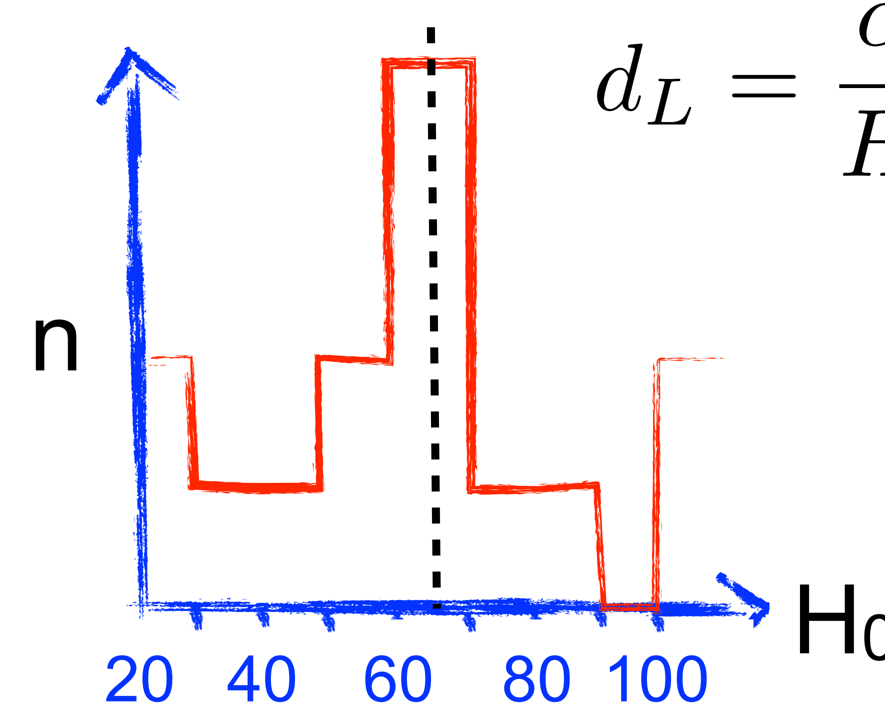
Hogg, arXiv:astro-ph/9905116 (2000)

Different Ideas

- **1986 - Schutz**
- 1993 - Finn & Chernoff
- 2005 - Holz & Hughes
- 2010 - Sathyaprakash, Schutz ,& Van Den Broeck
- 2012 - Messenger & Read
- **2012 - Del Pozzo**
- 2012 - Taylor, Gair, & Mandel
- 2013 - Nissanke, *et al*
- 2014 - Messenger, *et al*



$$d_L = \frac{cz}{H_0}$$



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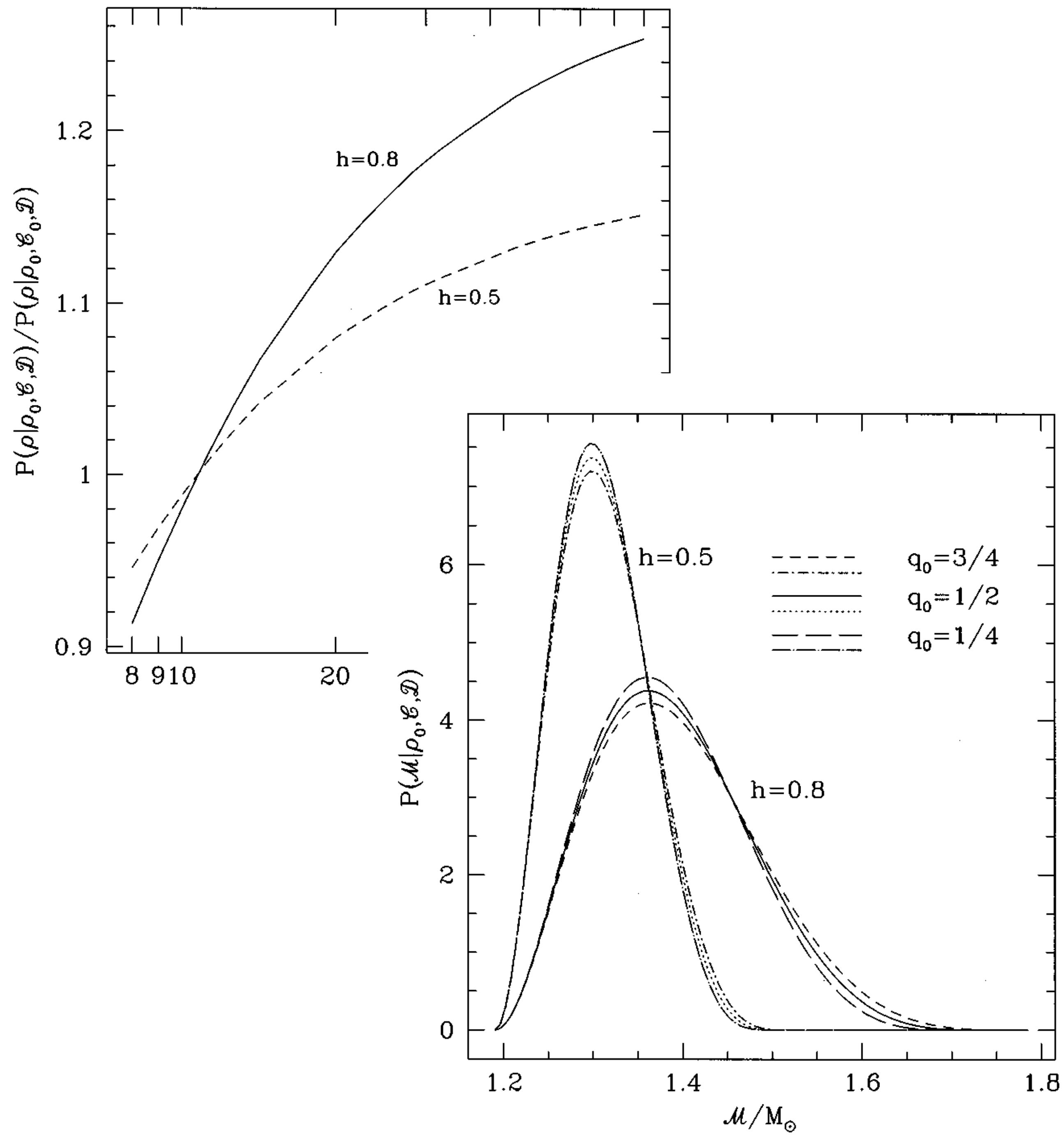

Finn, PRD **53**, 6 (1995)

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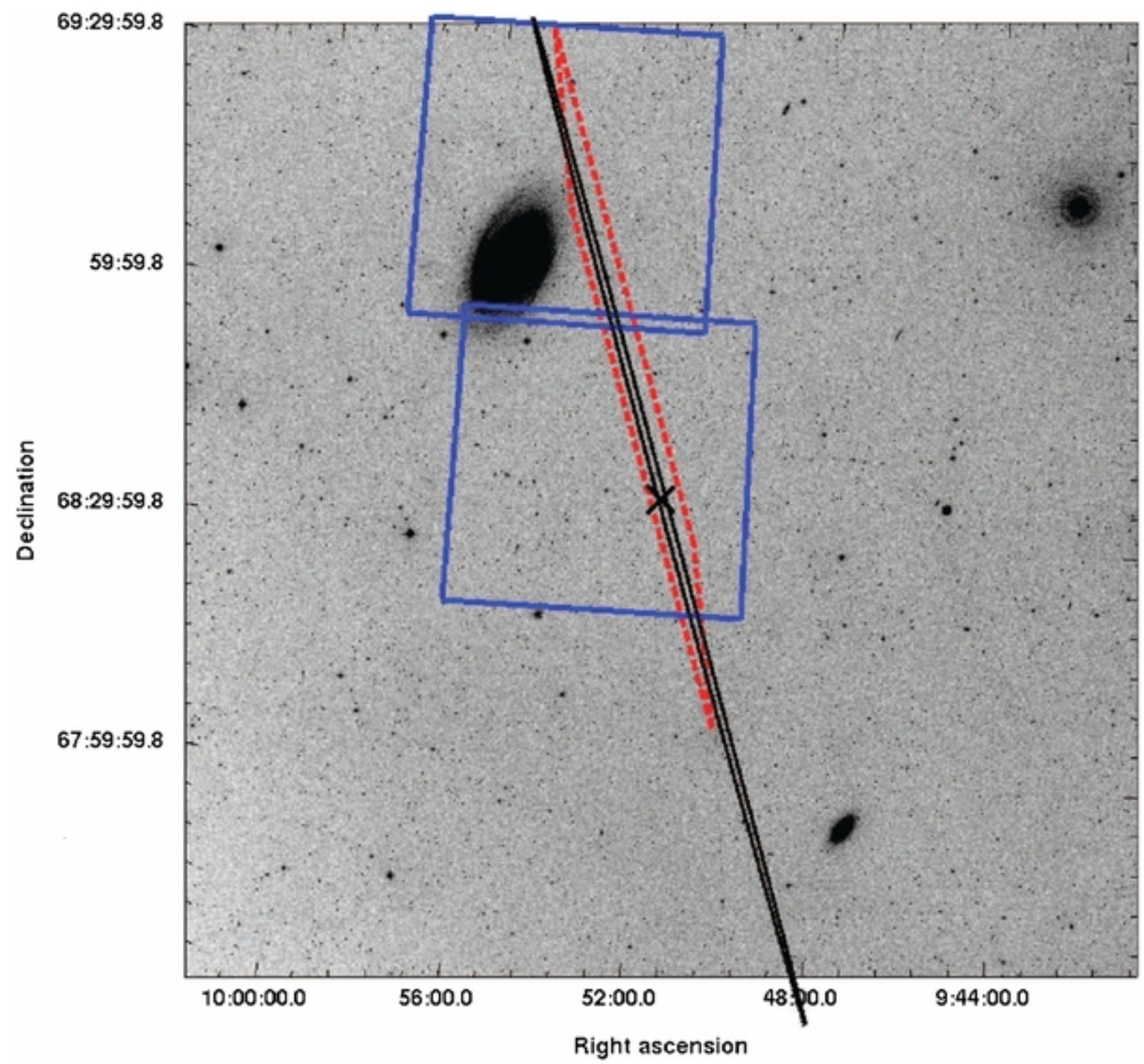

Hurley et al, MNRAS **403**, 342 (2010)
LIGO Scientific Collaboration, ApJ **755**, 1 (2012)

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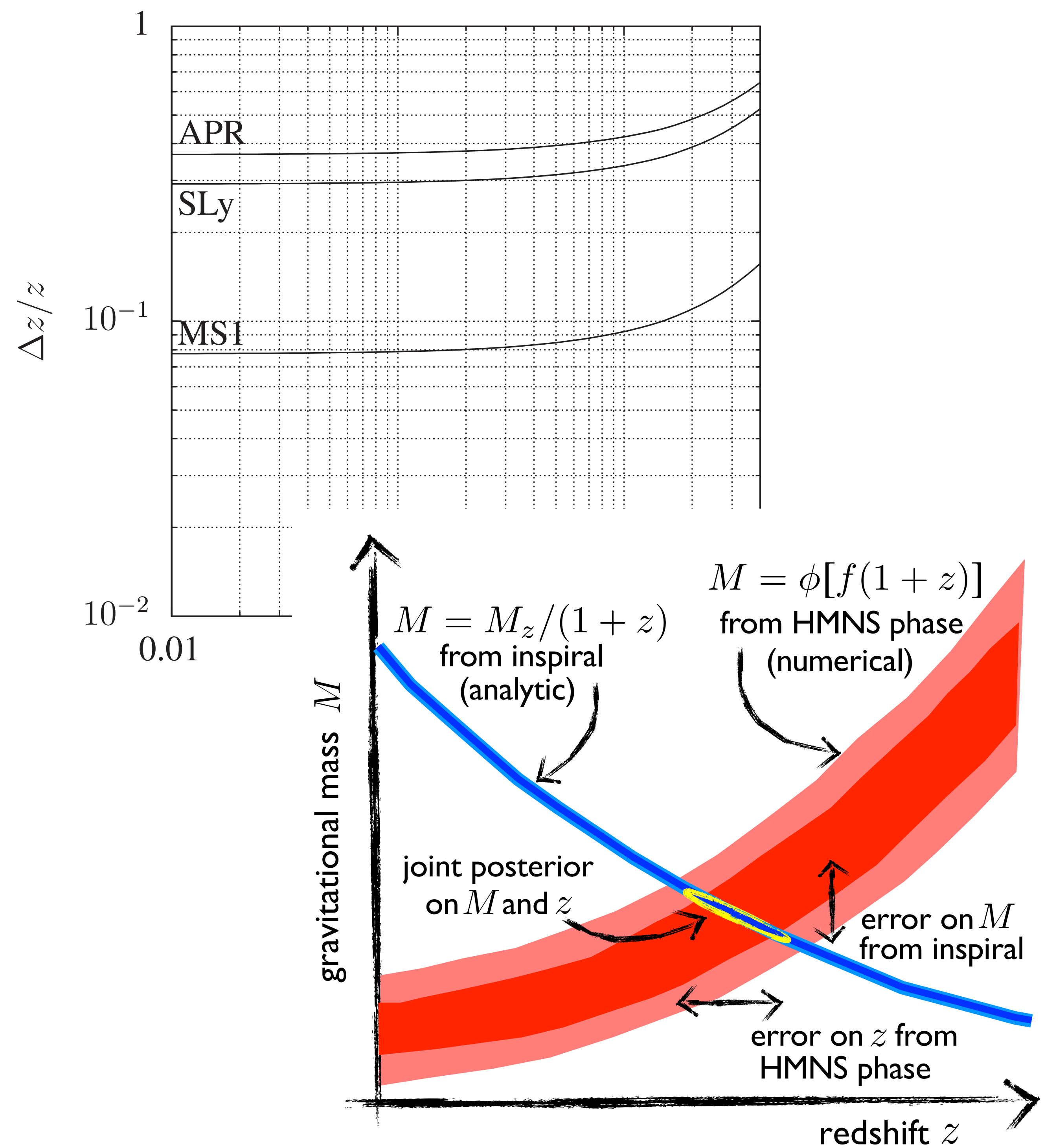
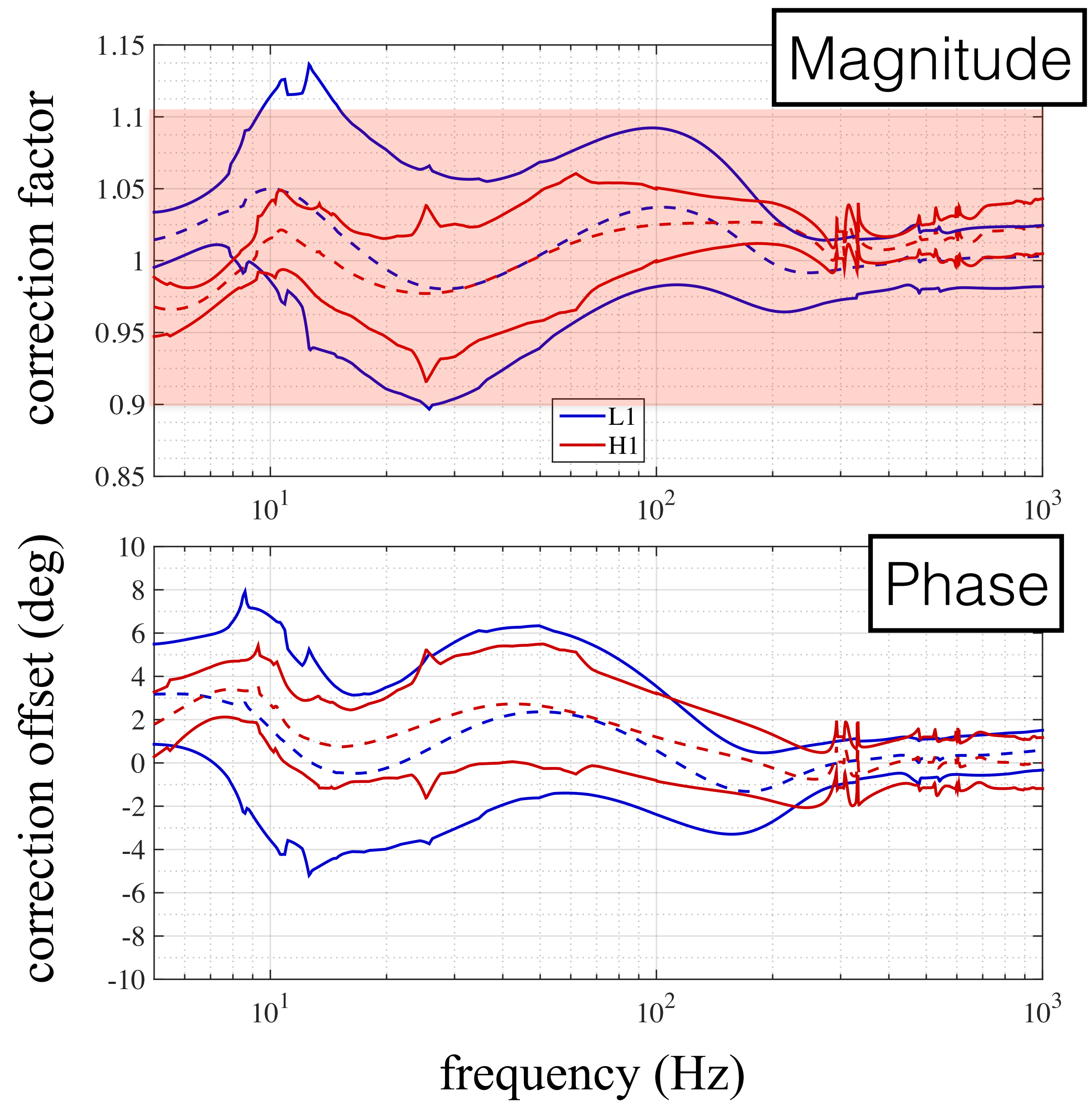


Messenger & Read, PRL **108**, 091101 (2012)
Messenger *et al* PRX **4**, 041004 (2014)

Standard Calibration

- It is **very hard** to calibrate gravitational wave detectors
- The LIGO method is to use a "known" strength laser source to push on the test-mass mirrors.
- **Current calibration levels are at 10% in amplitude** and 10º in phase.
- It is unclear what fraction of uncertainty is systematic - **this is crucial for GW cosmology** - directly impacts distance measurements.



LIGO-Virgo Collaboration, arXiv:1602.03845, (2016)

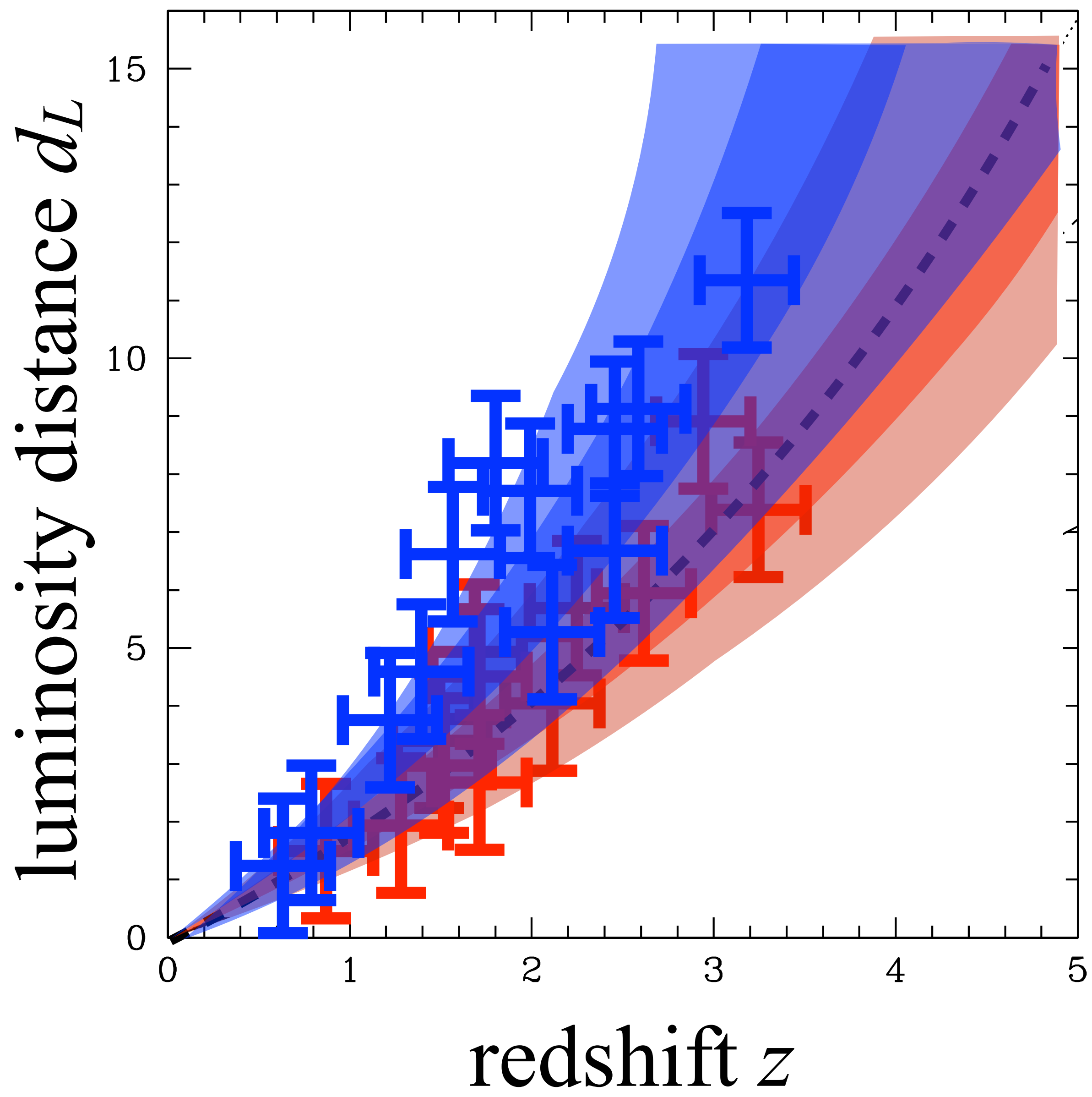
Systematic/Statistical

- The one common issue is that we require measurement of quantities **directly related to the absolute calibration**.

- Parameter estimation will/does incorporate calibration uncertainties **BUT…**

- Hierarchical schemes cannot necessarily assume independent distance/SNR uncertainties.

- We can live with a statistical uncertainty but a systematic would kill any Hubble measurement at that level.



Standard Sirens for Calibration

- Compact binaries allow us to accurately measure the redshifted chirp-mass $\mathcal{M}_z = \mathcal{M}(1+z)$ from their frequency evolution.

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

chirp mass

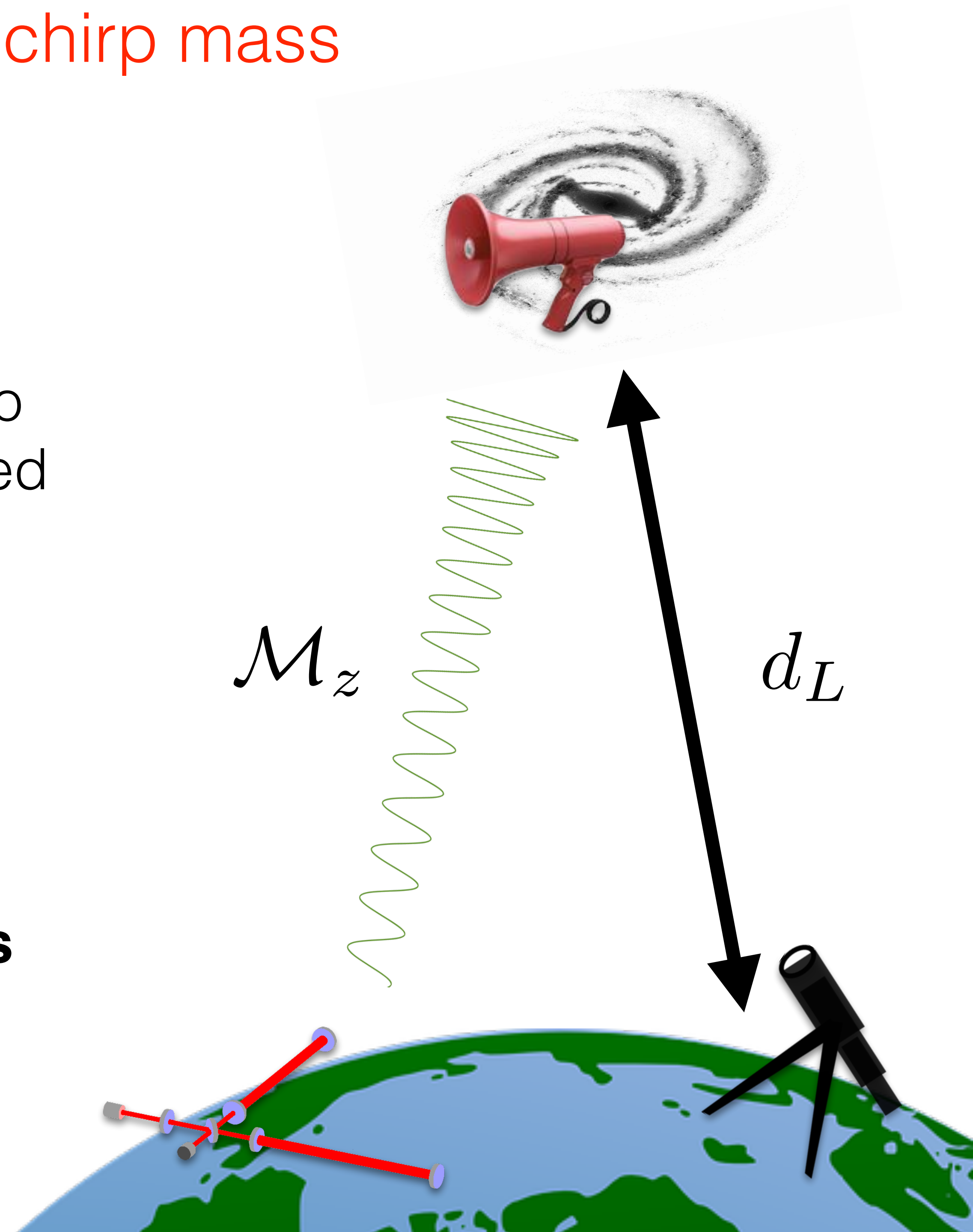
- The amplitude of the signal scales as

$$A \propto \mathcal{M}_z^{5/6} / d_L$$

- So if we **independently** knew the distance to the source then we could predict the received amplitude - and then compare it to the measured value.

- **Important - We have to assume a cosmology**.

- **Differences between the amplitude values would imply an incorrectly calibrated dataset**.

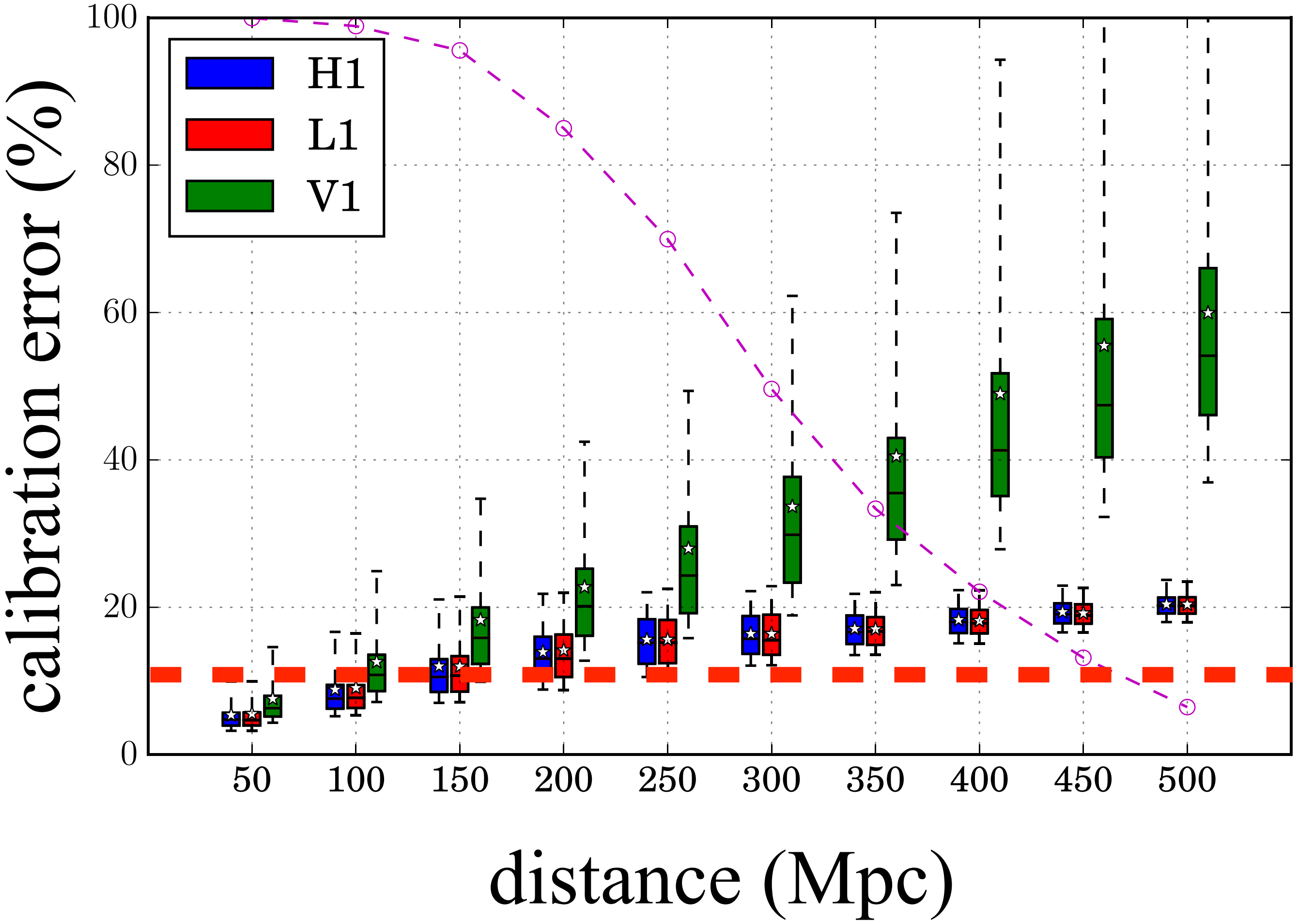


Astrophysical Calibration

- As a feasibility study we looked at the possibility of using **joint GW-Gamma Ray Burst (GRB) detections**.

- In this case we would likely identify the host galaxy from the GRB and **therefore obtain a precise redshift**.

- Using the standard cosmological model we can convert this to a distance - and then to **a predicted amplitude**.



Pitkin, Messenger & Wright, PRD, **93**, 062002 (2016)

Astrophysical Calibration

- Combining multiple EM counterpart results would improve the result **if** the intrinsic calibration was stable over long periods, i.e. **systematic would be good in this case.**

- However, even waiting for one EM counterpart isn't ideal.

- Without a counterpart we can still do **relative network calibration** astrophysically without even assuming a cosmology.

- Will it ever be possible to estimate both the network calibration and cosmological parameters simultaneously? Probably not for H_0 but maybe for other parameters.

Questions

- Can systematic calibration errors be defined alongside statistical errors (plus variation timescales)?
- Can we get systematic calibration uncertainty <1%? (or better)
- Do we need better galaxy catalogues?
- Can we do direct deep EM follow-up on events with <O(10) expected host galaxies.
- How sensitive are statistical approaches to mass priors?
- Combine the results of different correlated approaches or develop a inclusive analysis?
- Can we do a joint EOS-Cosmology-Calibration analysis for BNS?
- Will a few (or single) golden OR joint GW-EM transient events dominate the results.?
- Is a selection bias introduced by only using golden events?
- How long will the "independent measurement" argument work when comparing against ever improving EM measurements?

thank you