GSSI Science Fair

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Cosmology with GWs

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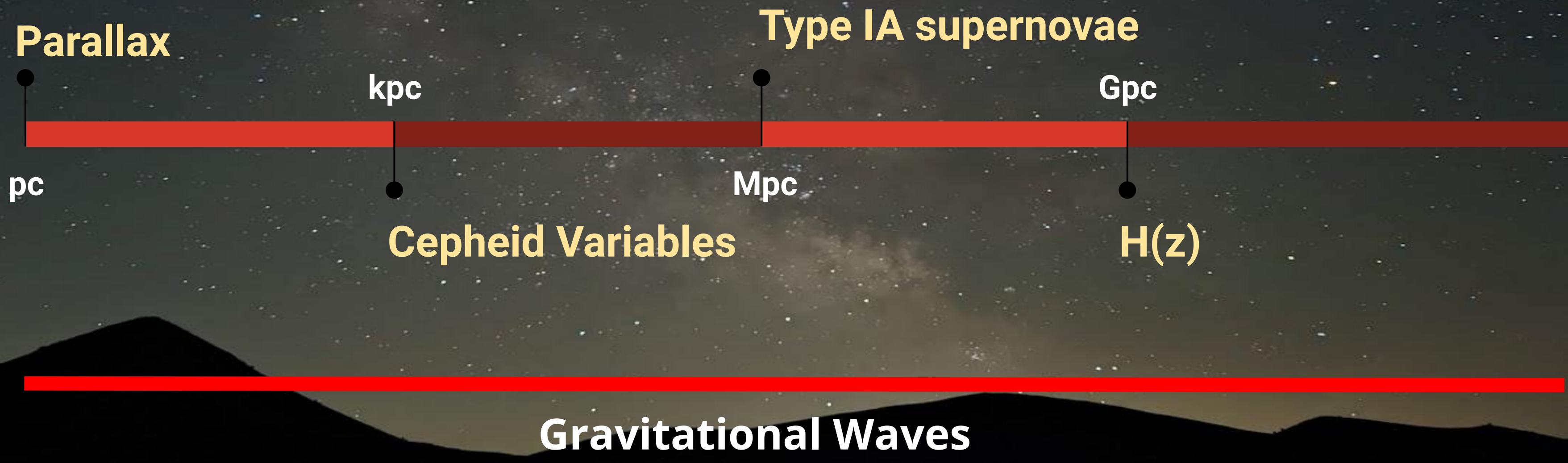
Picture taken at Campo Imperatore, L'Aquila

Why Gravitational Waves?

See Nandini's talk!



Standard Sirens

- Directly measure the luminosity distance to the source: self-calibrated distance indicators (**cosmic rulers**):

$$d_L(z) = \frac{c(1+z)}{H_0}\int_0^z \frac{H_0}{H(z')}dz'$$

- Do not provide a **redshift** measurement:

negligible

$$H(z) = H_0\sqrt{\underbrace{\Omega_\mathrm{m}(1+z)^3}_{\text{Dark matter}} + \underbrace{\Omega_\Lambda}_{\text{Dark energy}} \cancel{+ \underbrace{\Omega_\mathrm{r}(1+z)^4}_{\text{Radiation}} + \underbrace{\Omega_k(1+z)^2}_{\text{Curvature}}}}$$

How do we measure Redshift? So far...

- 3 observing runs (4th upcoming!)
- ~100 events, mostly BBHs, but also BNSs (with counterpart), and NSBHs

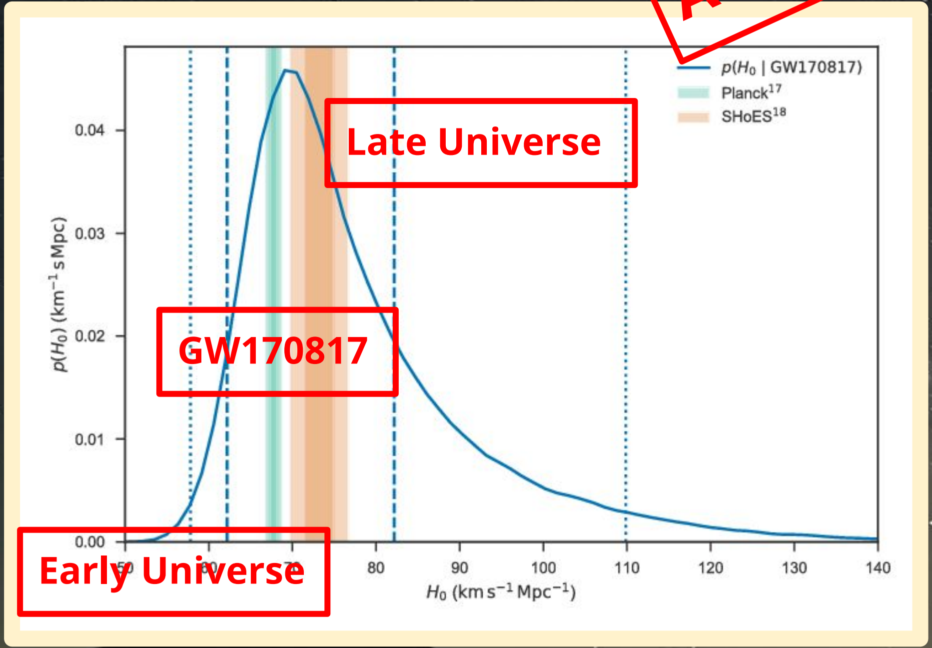
[LIGO-Virgo-KAGRA Collaboration]

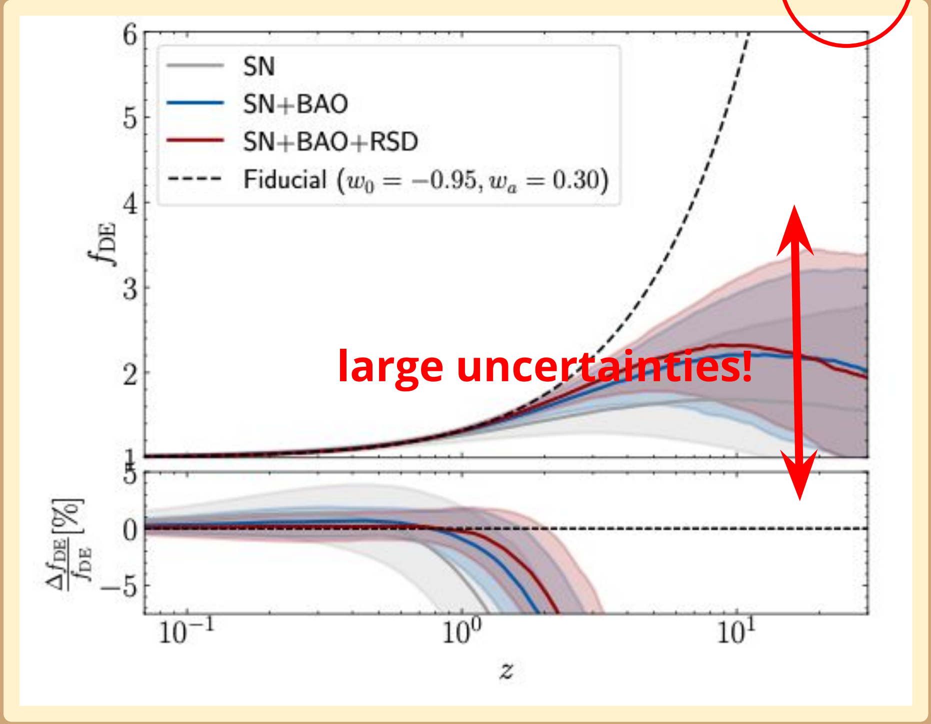
- Methods based on complementary observations:
  - Direct EM counterpart with GW170817 (**bright sirens**)
  - Statistical association with galaxy catalogs (**dark sirens**)
- Methods based on astrophysical models:
  - Source-frame mass modeling
  - Knowledge of NS EOS and tidal deformability measurements

Hubble tension

At high redshift?

$$H(z) = H_0\sqrt{\Omega_m(1+z)^3 + (1-\Omega_m) f_{DE}(z)}$$





[LVK Collaboration, 2017]

[Calderon et al., 2022]

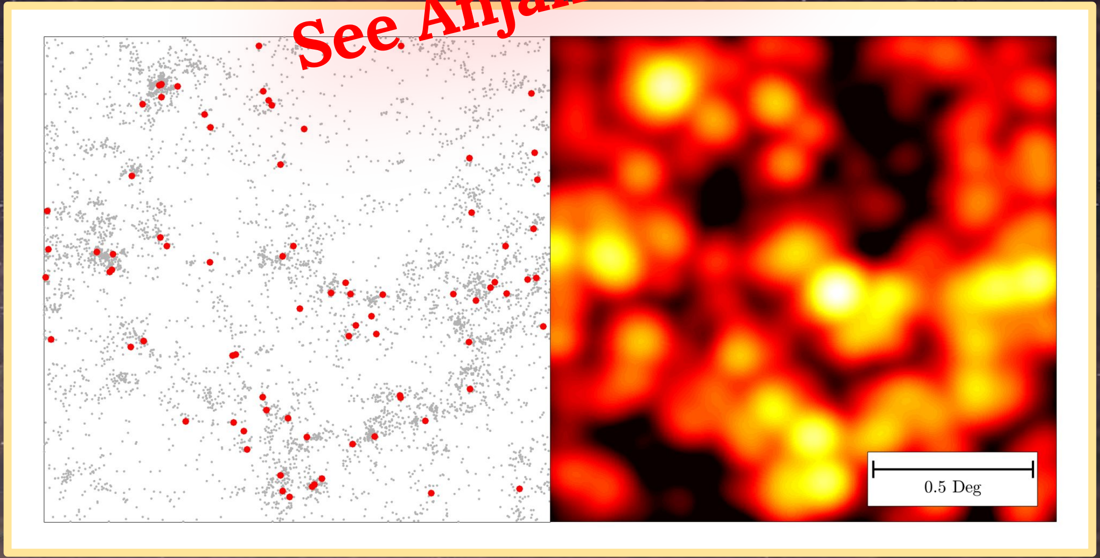
H(z) at low Redshift using the Large Scale Structure

- LSS evolves through competing effects of structure growth and Universe expansion

- **Multi-tracing** approach

Resolved **GW events** + **Intensity mapping** of neutral HI, z<3-4

See Anjali's talk!

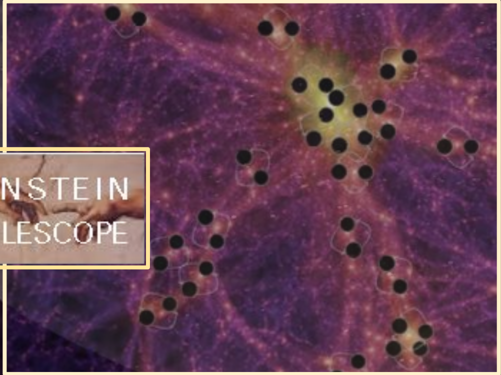


[Kovetz, 2020]

Cross-Correlating GWs and IM

currently working on this!

LSS tracers — Resolved GWs and HI intensity mapping are both **biased tracers** of the underlying density field — Computation of cross-correlations (**angular power spectrum** C_l) — **Fisher matrix analysis** to estimate cosmological parameters and H(z) relation

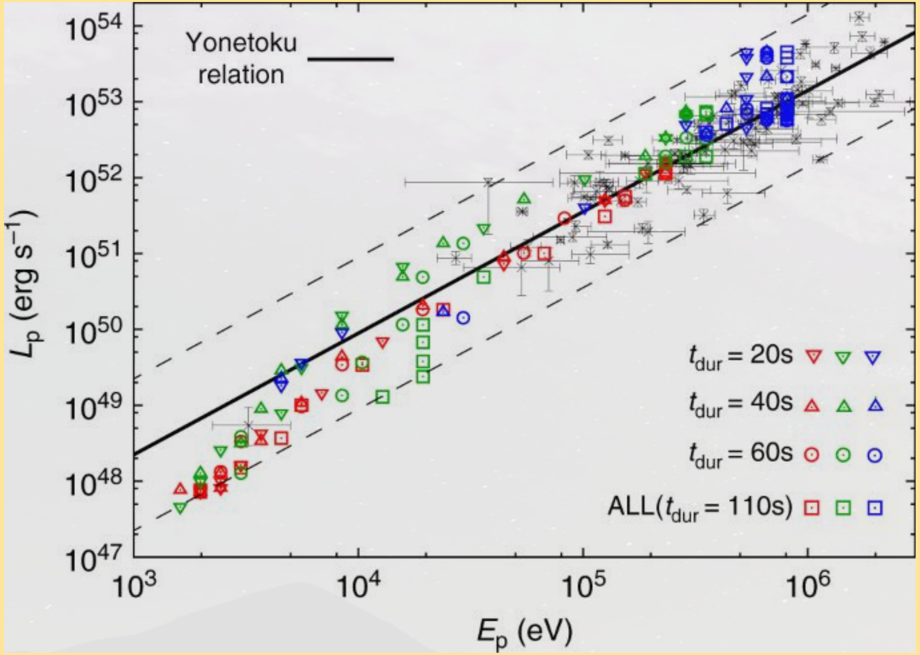


GWFish

Use of **Multi_CLASS** code for to calculate cross-correlations — Multi_CLASS

[Scelfo *et al.*, 2021]

H(z) at high Redshift: exploiting the **Yonetoku relation**



- Relates luminosity of GRB with its peak energy
- Tight relation and holds for both **short and long GRBs**

- **Constrain relation at low z using joint detections of GRBs + BNSs with Einstein Telescope**
- **Assume the relation holds at any z**
- **Exploit the relation at high z using GRBs only (there will be no GWs here!)**

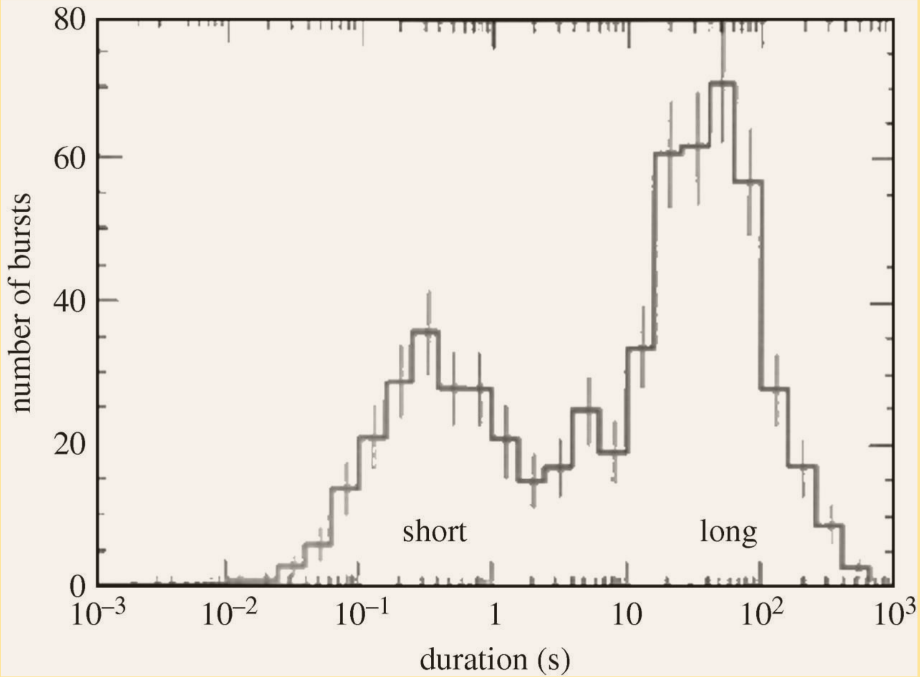
[Ito, H., Matsumoto, J., Nagataki, S. *et al.*, *Nature* (2019)]

See Alessio's talk!

New GRB classification

Collapsars vs non-collapsars

- We need association with BNSs
- New classification is less arbitrary than the ∼2s threshold
- Update current catalogs (∼5 years of more data)



[Bromberg *et al.*, Astrophysical Journal (2013)]

[Kouveliotou et al., Astrophysical Journal (1993)]

GWs: a new Probe for Cosmology!

GWs allow us to do interesting Cosmology at both low and high redshifts

Low redshift

- Use GWs from both BBHs and BNSs
- Take advantage of high precision tomography from LSS
- Cross-correlate GWs x LSS to constrain H(z) at low z

High redshift

- Use GWs from BNSs to calibrate GRB relation at low-z
- Use calibrated relation for GRBs at high-z
- Infer H(z) at high-z


Thank you all and enjoy L’Aquila!