Gravitational wave tests of cosmology, gravity and astrophysics

Charles Dalang

Institut Philippe Meyer, LPENS, Paris, France

17th November 2025
FRIF Day

Based on: Isabela S. de Matos, C.D., T. Baker, R. Abramo, J. Ferri, M. Quartin, *in prep*.
C.D., M. Williams, T. Baker, *in prep*.

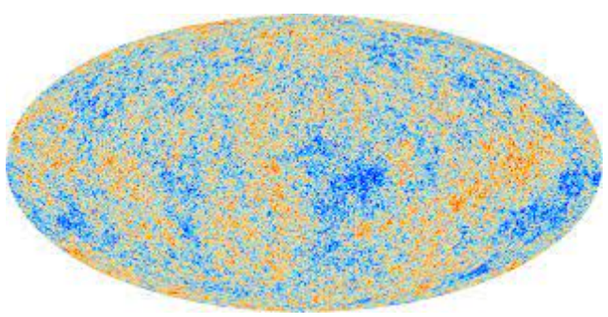
INSTITUT DE PHYSIQUE PHILIPPE MEYER

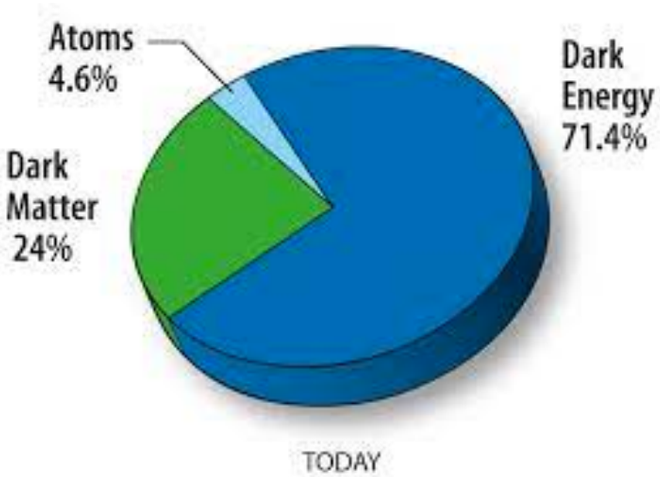
LPENS LABORATOIRE DE PHYSIQUE DE L'ÉCOLE NORMALE SUPÉRIEURE

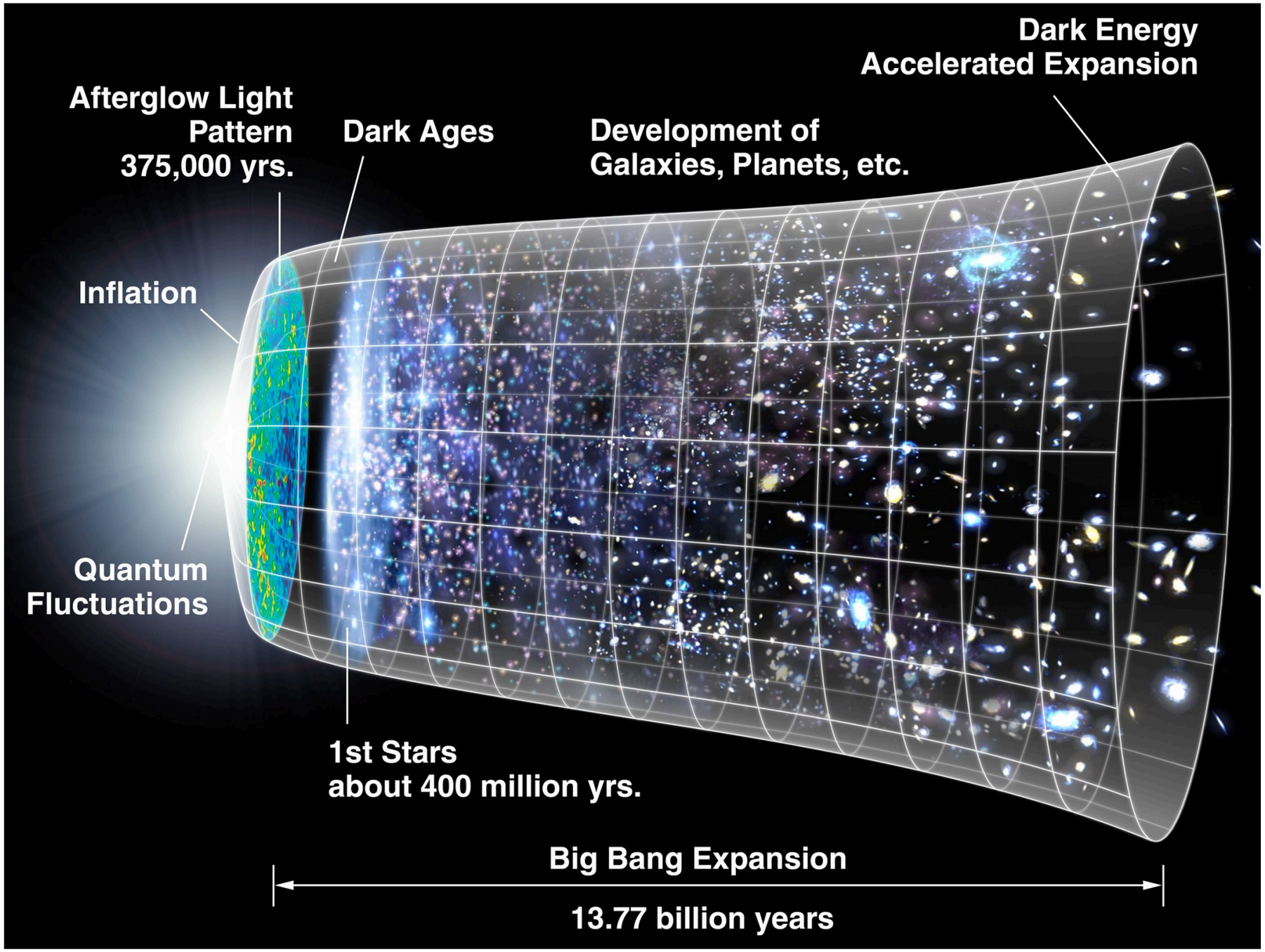
ENS ÉCOLE NORMALE SUPÉRIEURE

Cosmology

S. Perlmutter *et al.* 1998
A. G. Riess *et al.* 1998
WMAP 2013
PLANCK 2018

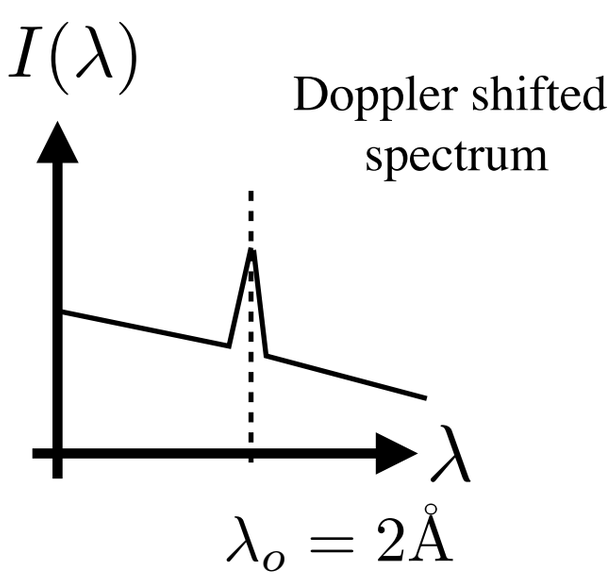


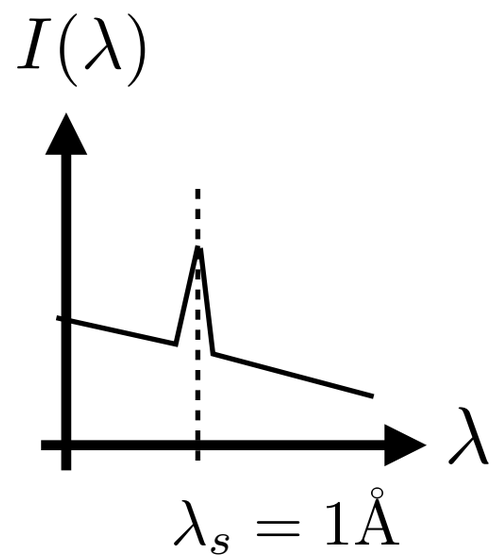




Redshift z

Far away galaxies appear shifted towards the red of the spectrum.





$$1 + z = \frac{\lambda_o}{\lambda_s}$$

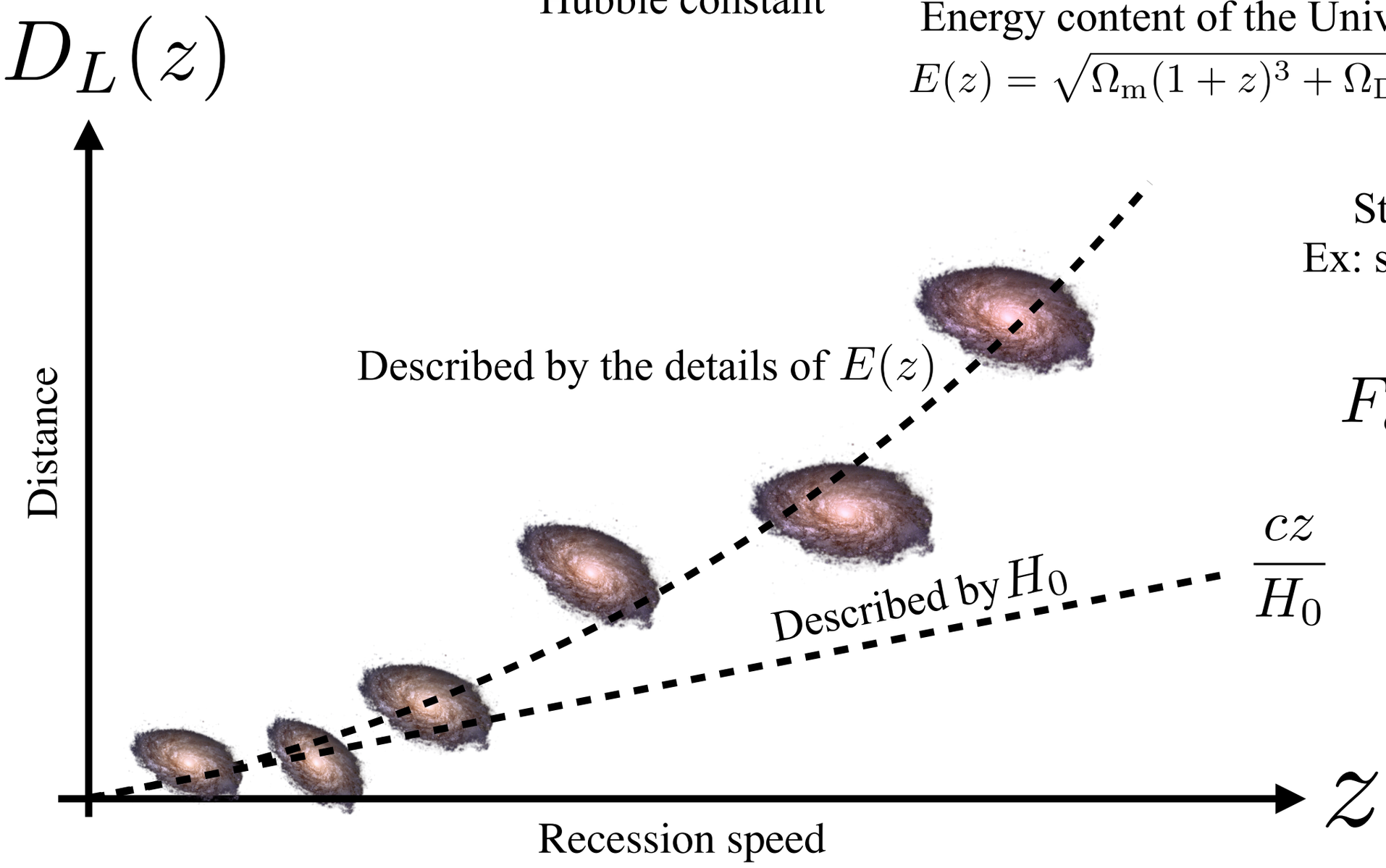
Hubble diagram

$$D_L(z) = \frac{c(1+z)}{H_0} \int_0^z \frac{\mathrm{d}z'}{E(z')} \simeq \frac{cz}{H_0} + \mathcal{O}(z^2)$$

Hubble constant

Energy content of the Universe

$$E(z) = \sqrt{\Omega_{\mathrm{m}}(1+z)^3 + \Omega_{\mathrm{DE}}(z)}$$

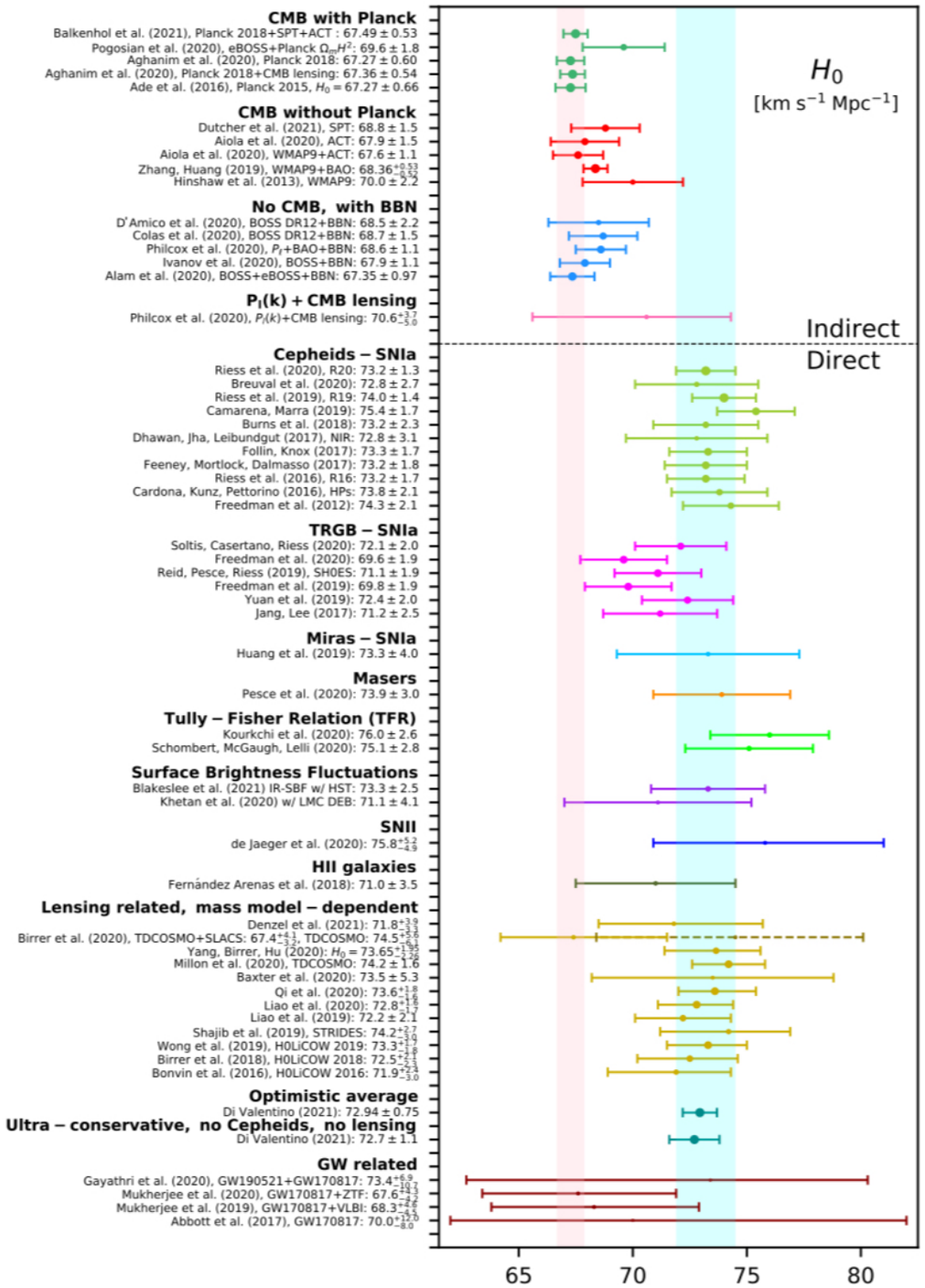


Standard candles,
Ex: supernovae type 1a

$$F_o = \frac{\mathcal{L}_s}{4\pi D_L^2}$$

H_0 tension

E. Di Valentino et. Al., 2021

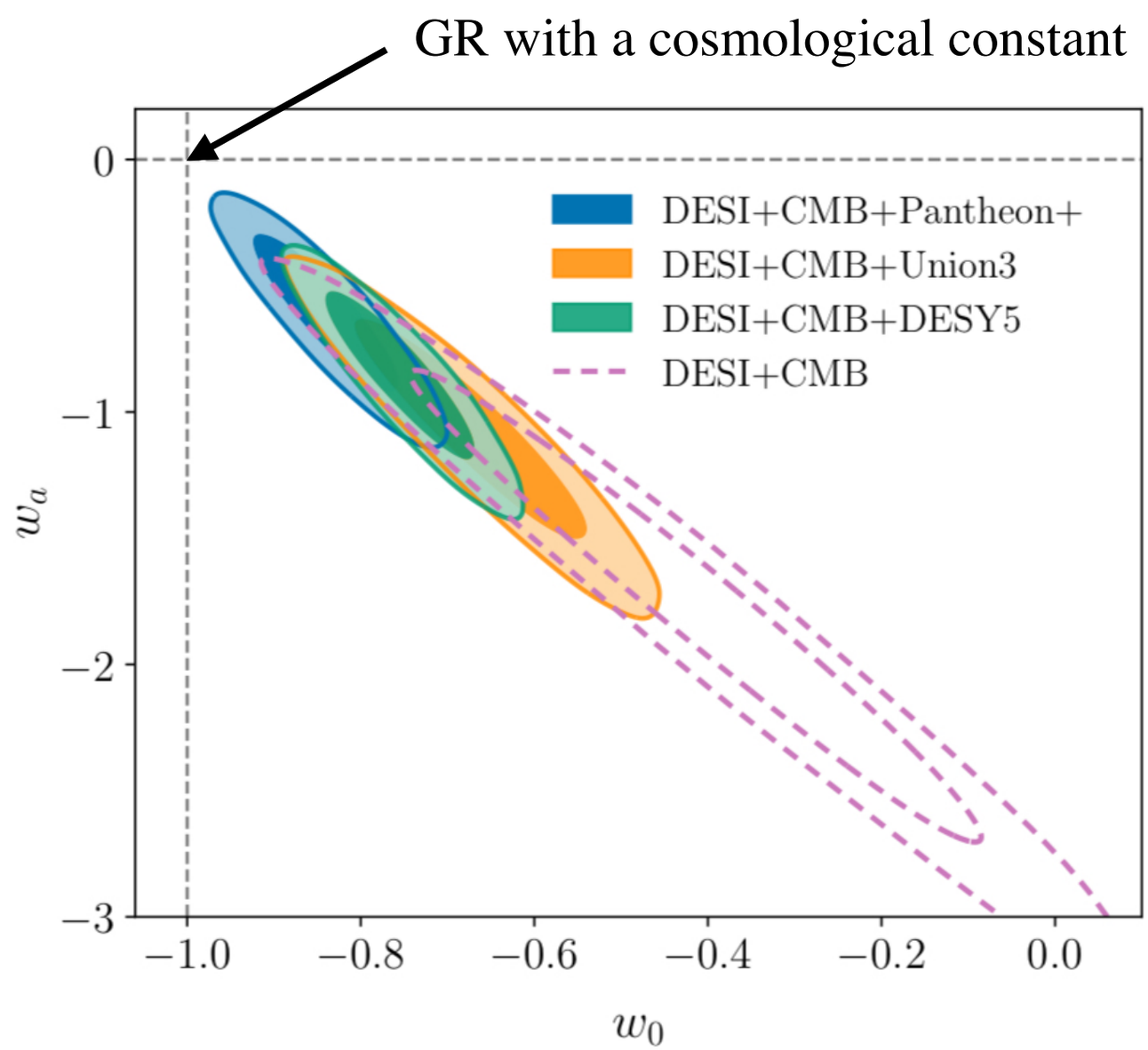


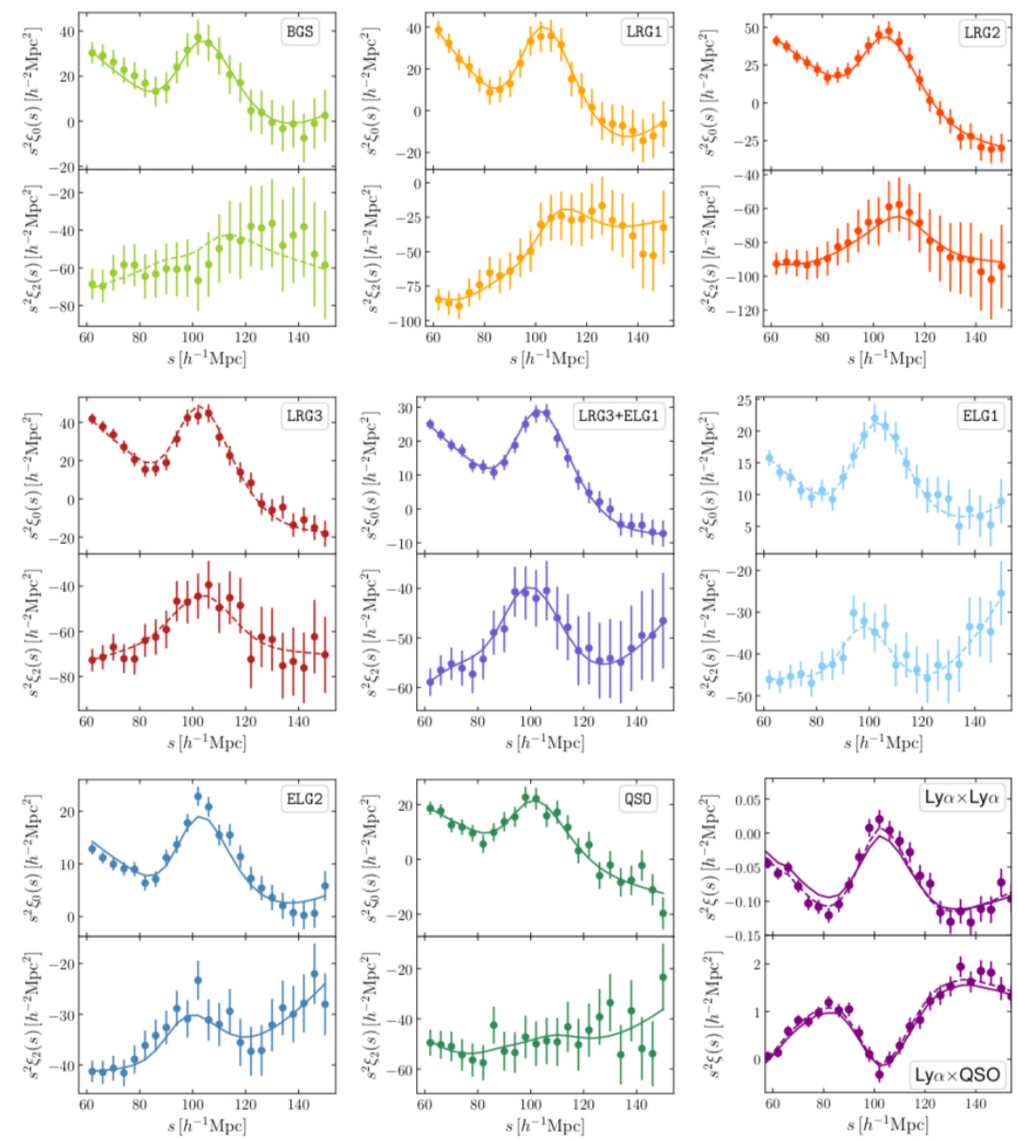
Indirect,
early Universe measurement

Direct,
late Universe measurements

Evolving dark energy…or alternative theory of gravity ?

DESI DR2, 2025



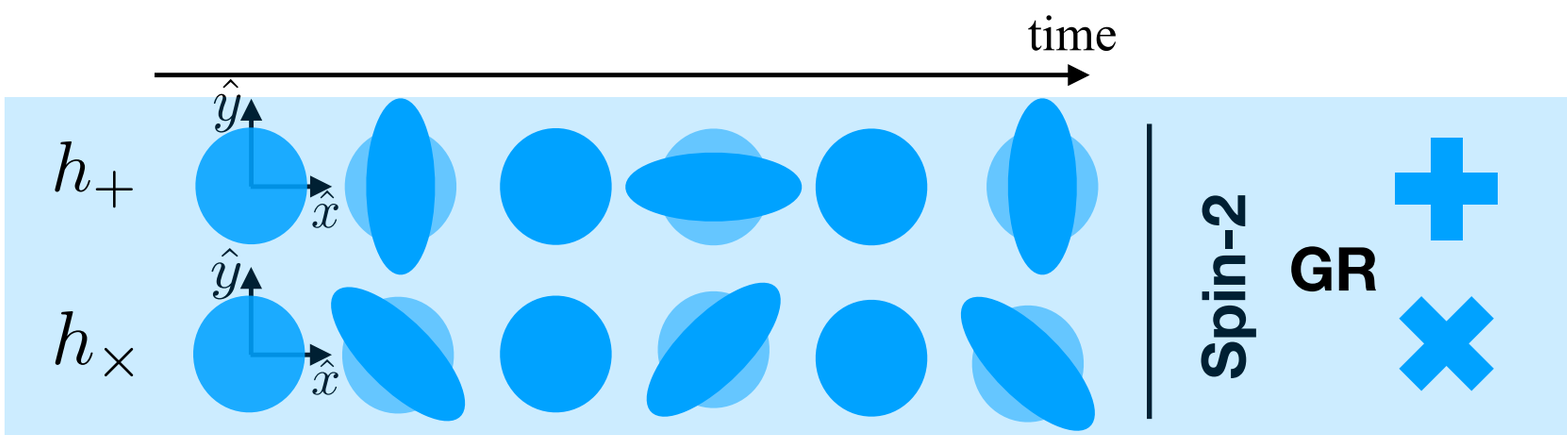


pressure $p = w\rho$ energy density

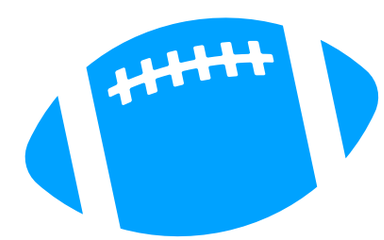
$$w_{\mathrm{DE}}(z) = w_o + w_a \frac{z}{1+z}$$

Gravitational waves in General Relativity

$$\Box h_{\mu\nu} = \frac{16\pi G}{c^4} T_{\mu\nu}$$



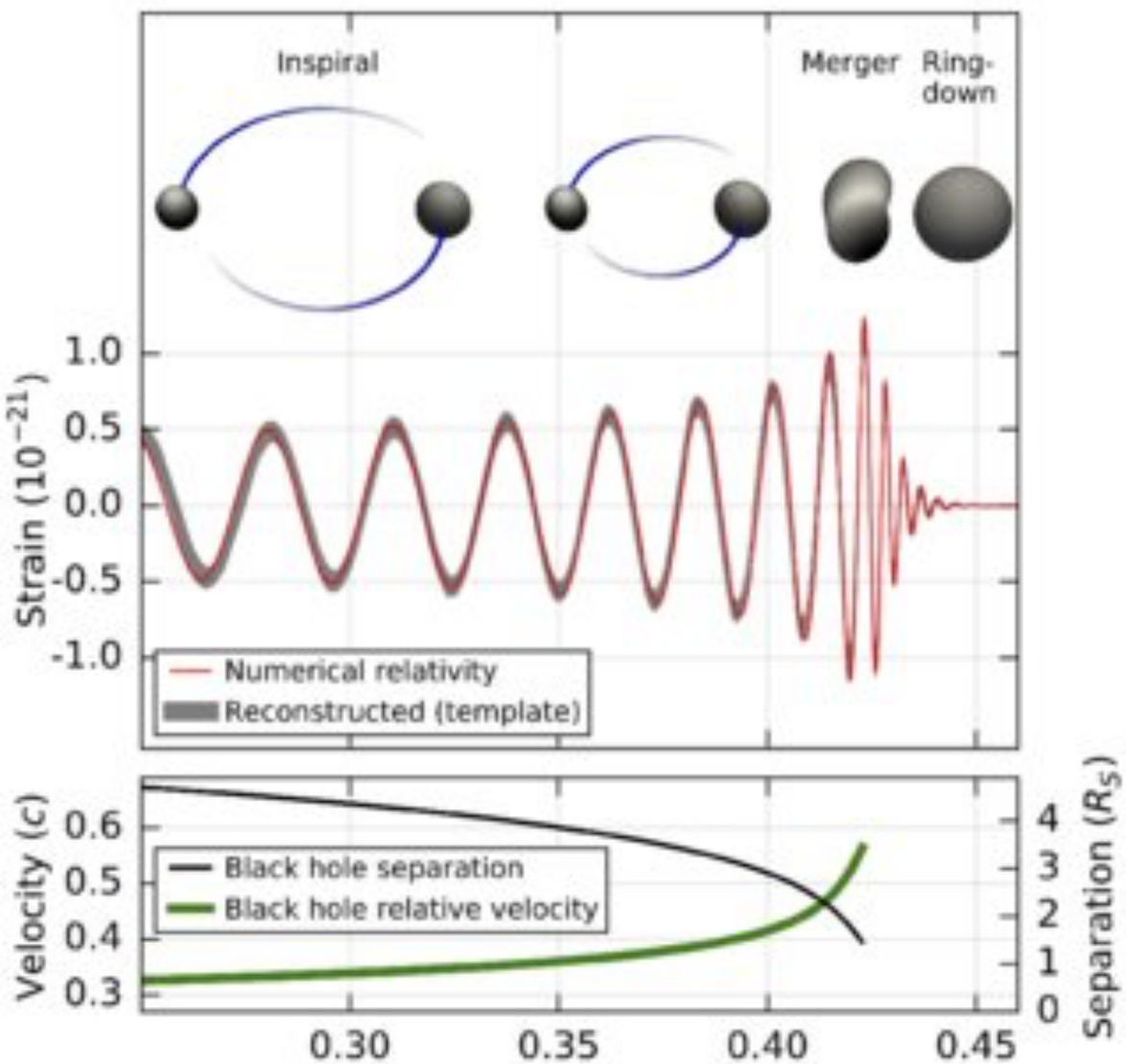
Rotation $2\pi/s$



They propagate at the speed of lights.

Standard sirens

LIGO
Virgo
KAGRA
B. Schutz, 1986
D. Holz, S. Hughes 2005



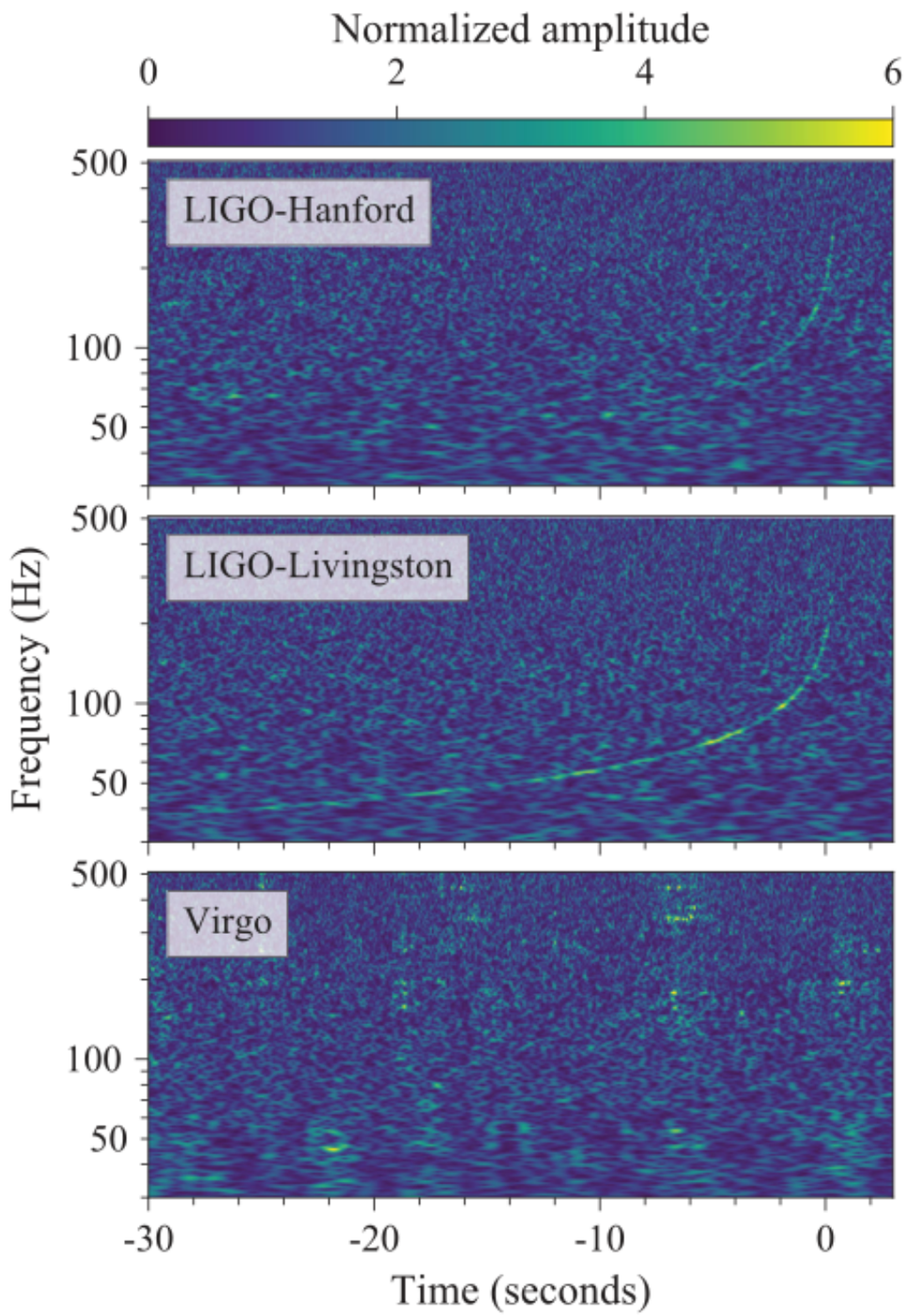
$$\frac{\mathrm{d}f_o}{\mathrm{d}t} = \frac{96}{5}\pi^{8/3}\mathcal{M}_z^{5/3} f_o^{11/3}$$

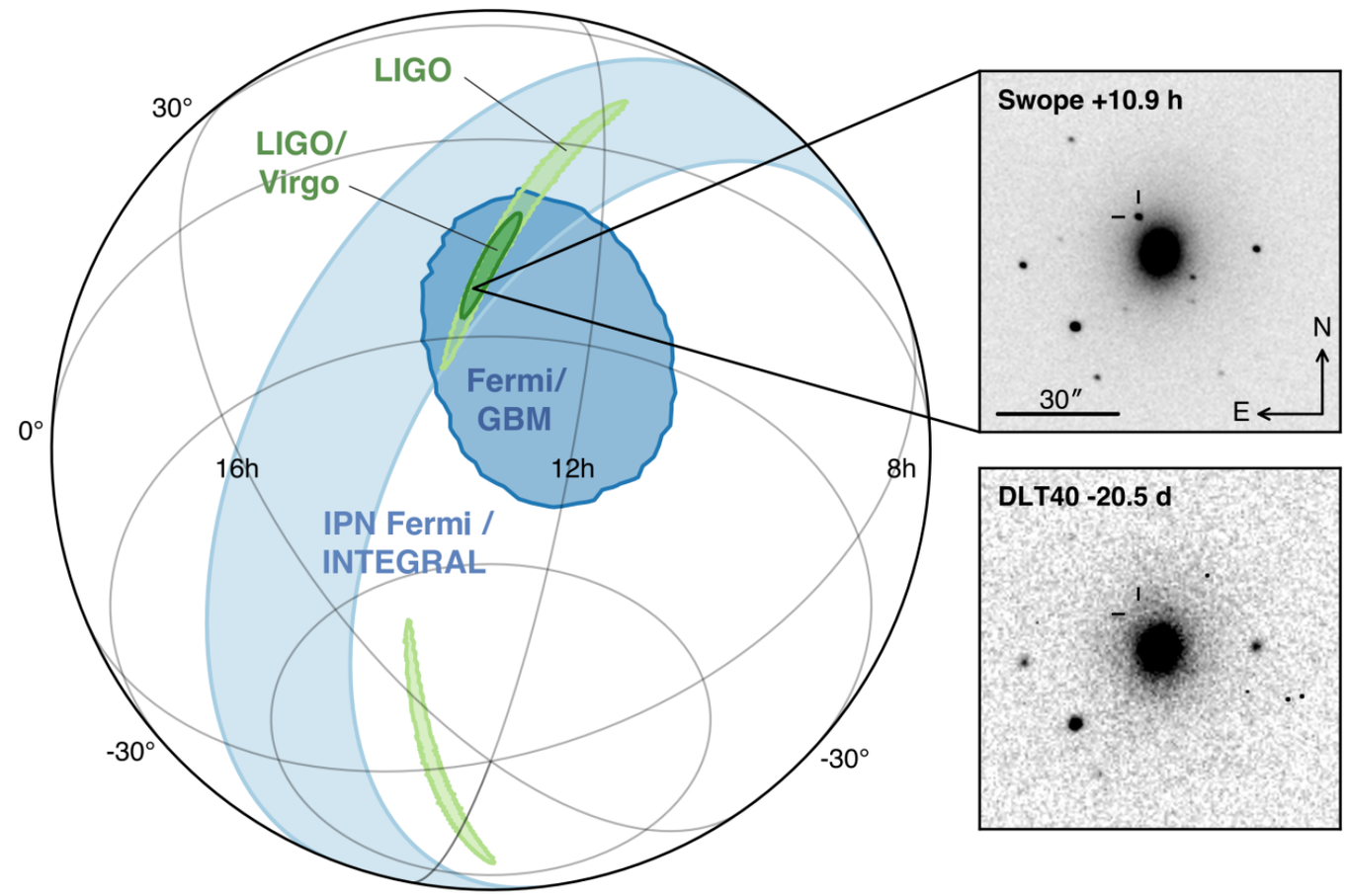
$$\mathcal{M}_z = (1+z)\frac{(m_1 m_2)^{3/5}}{(m_1+m_2)^{1/5}}$$

$$h \propto \frac{(G_N \mathcal{M}_z)^{5/3} f_o^{2/3}}{D_L}$$

Bright sirens

LIGO & Virgo collaboration et al., 2017

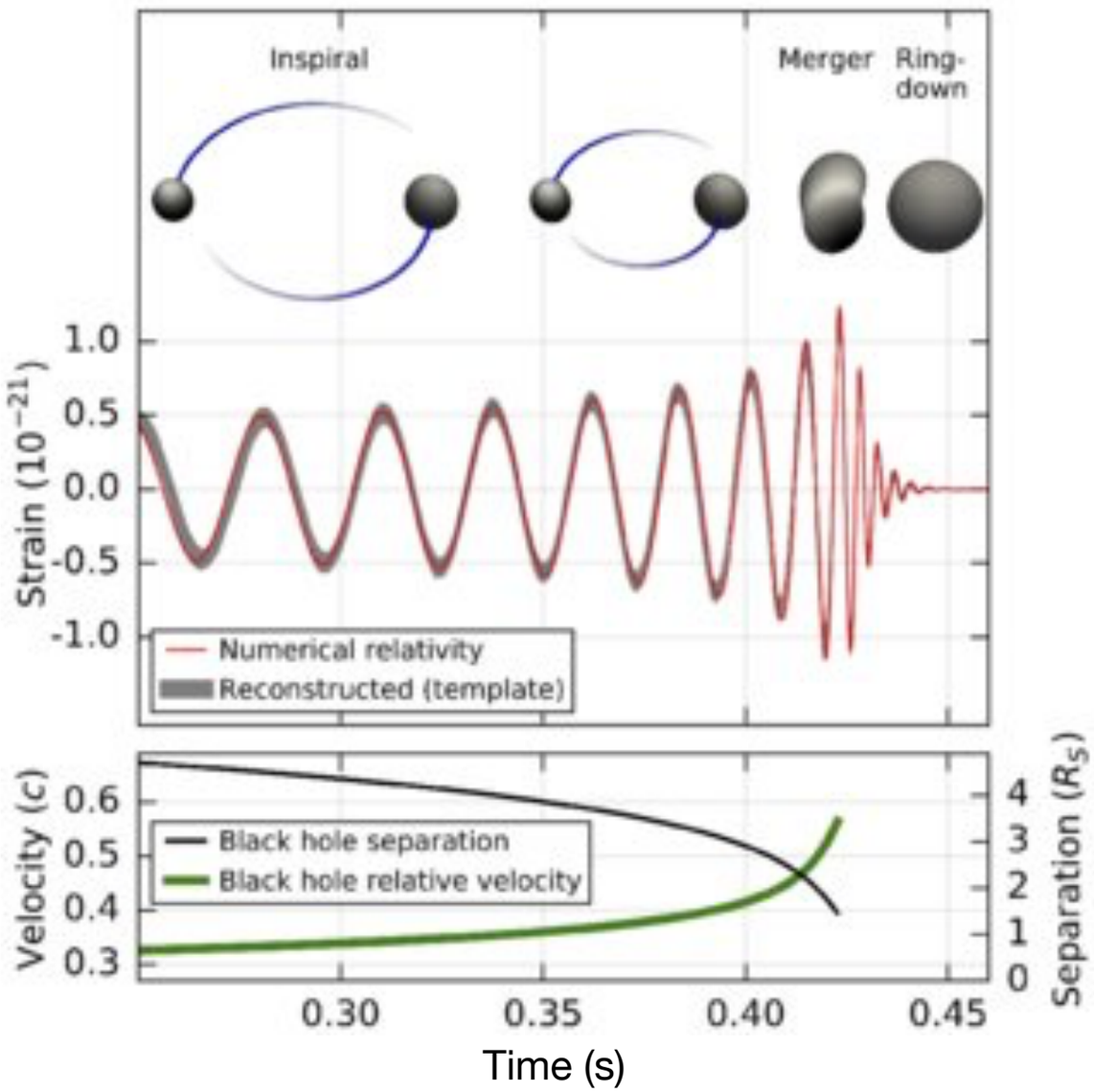




$$H_0 = 70^{+12}_{-8} \mathrm{km\ s^{-1} Mpc^{-1}}$$

Dark sirens

LIGO, 2016
B. Schutz, 1986
MICECAT v2
C.D., T. Baker, *in prep.*

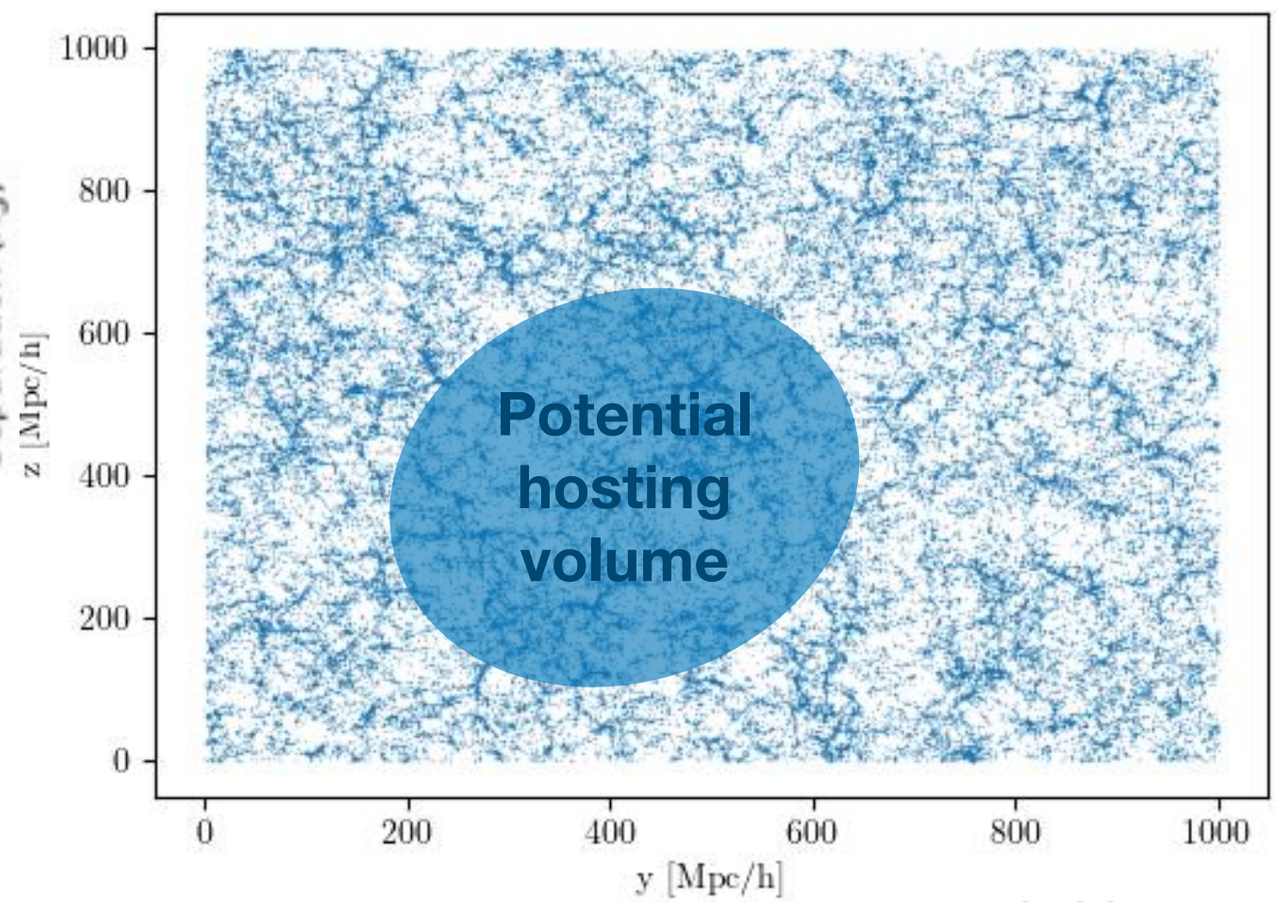


$$\frac{\mathrm{d}f_o}{\mathrm{d}t} = \frac{96}{5}\pi^{8/3}\mathcal{M}_z^{5/3} f_o^{11/3}$$

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

$$h \propto \frac{(G_N \mathcal{M}_z)^{5/3} f_o^{2/3}}{D_L}$$

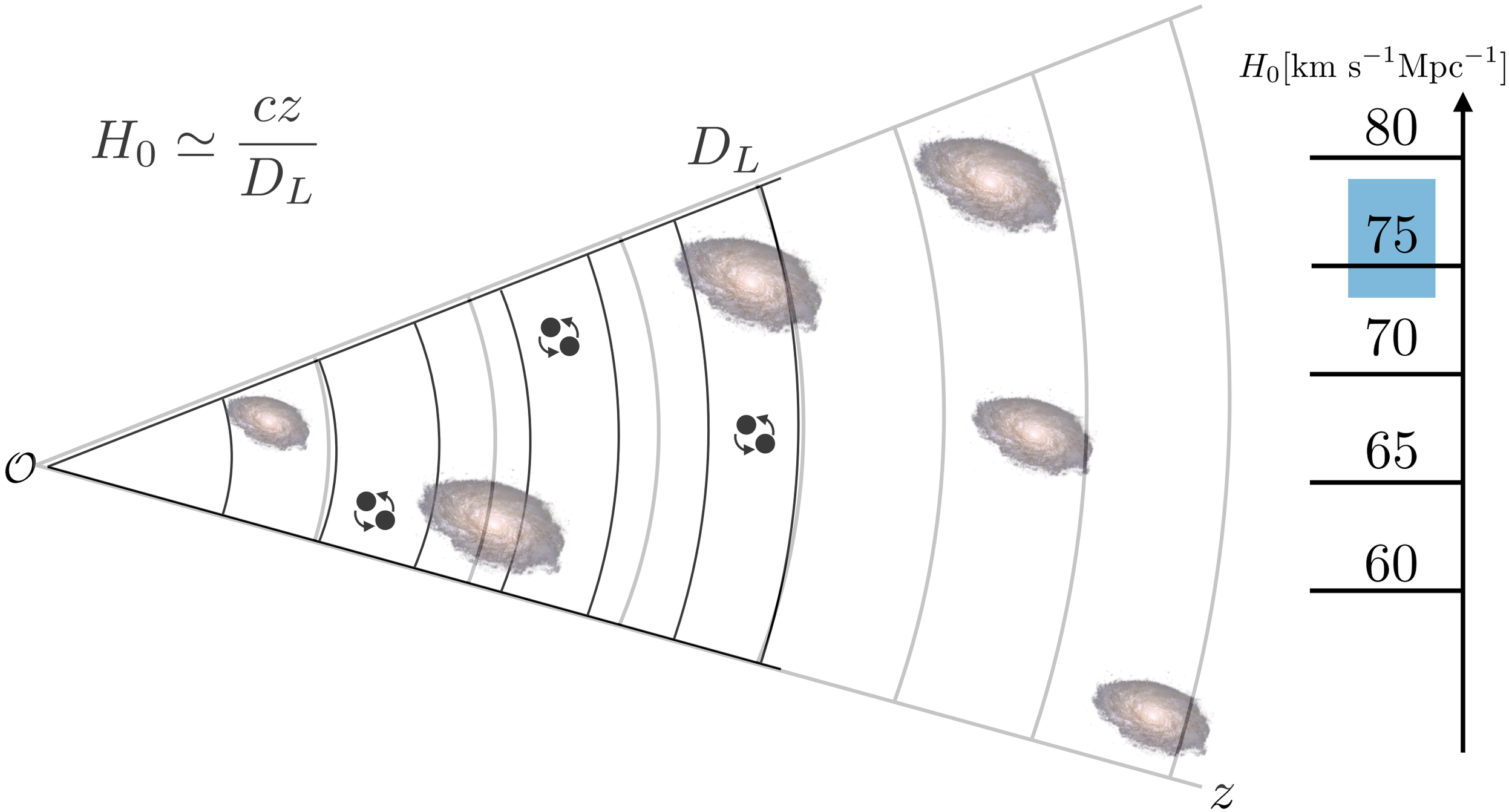
Galaxy catalogue for redshift z



Cross-correlation

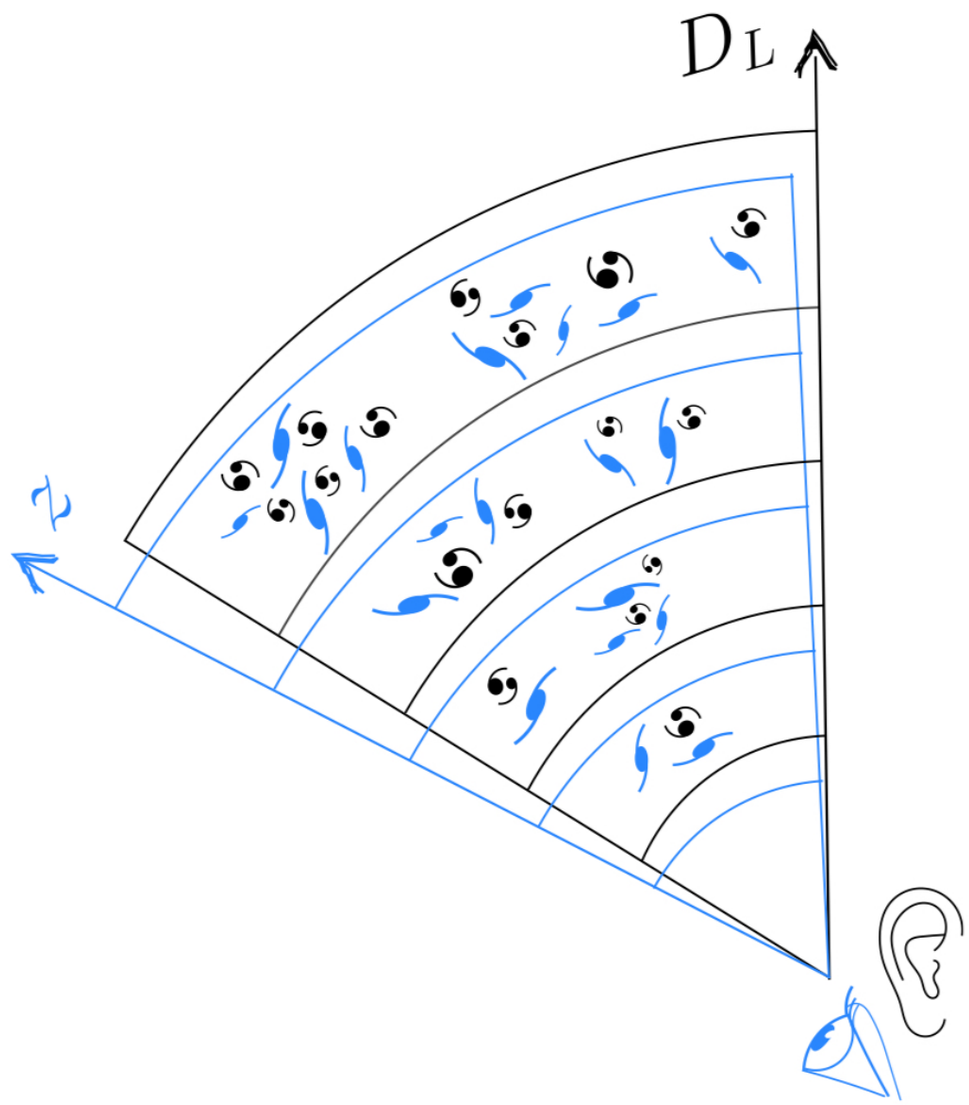
I. S. Matos, C.D. et al, 2025
Animation credit: Charles Dalang

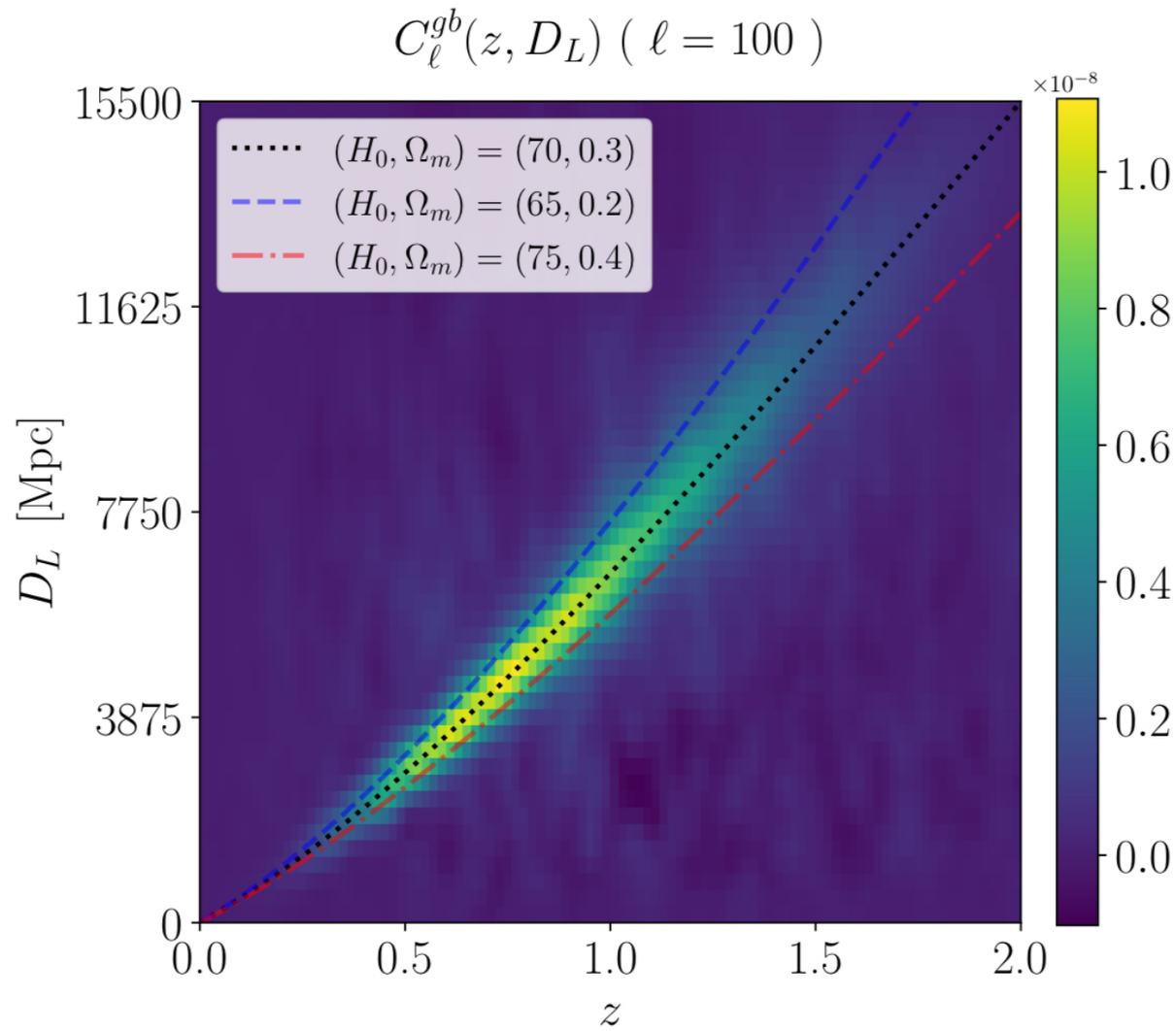
$$H_0 \simeq \frac{cz}{D_L}$$



Peak Sirens,
3G simulations Einstein Telescope

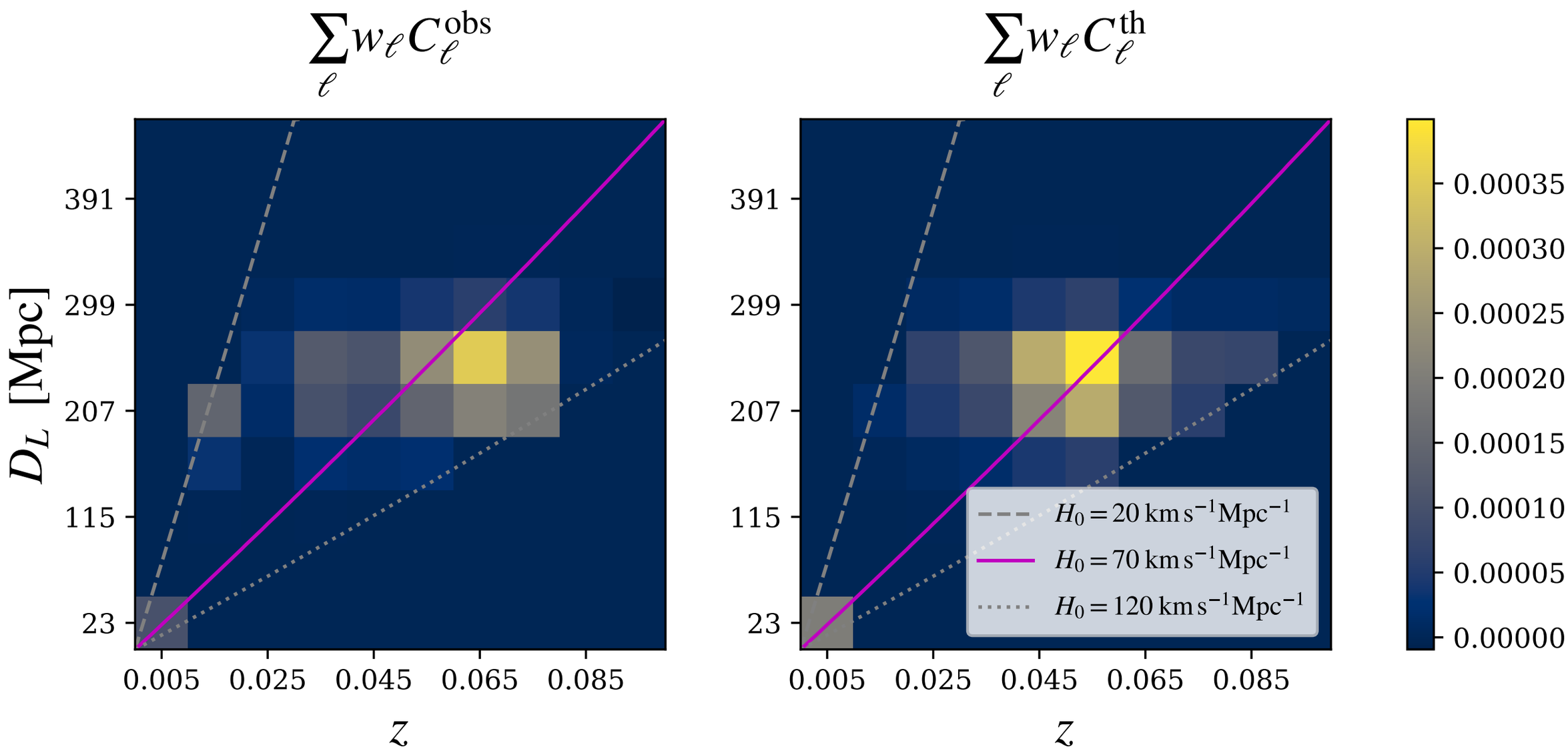
J. Ferri et al. 2025





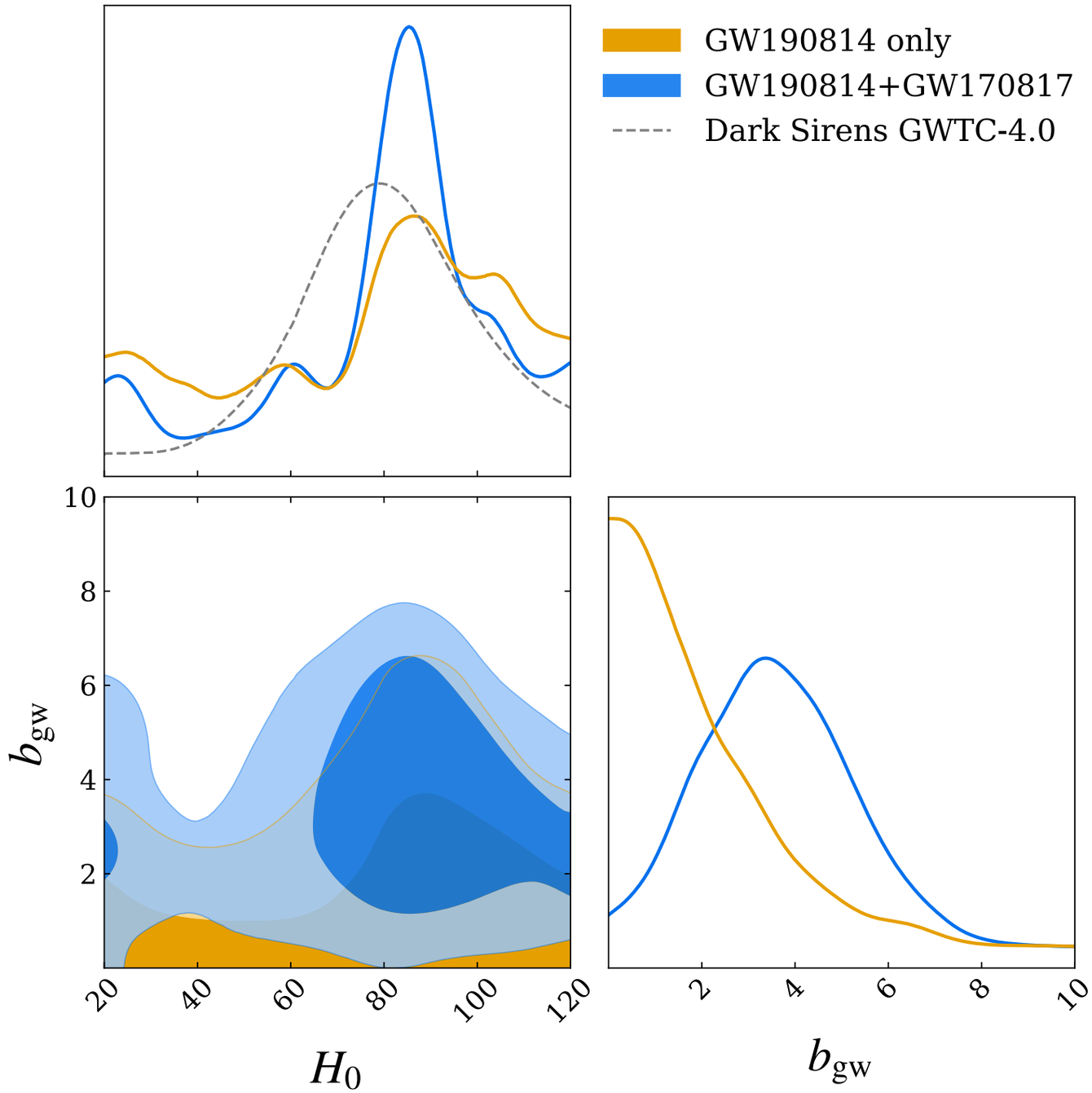
Two well localised events

I. S. Matos, C.D. et al, 2025

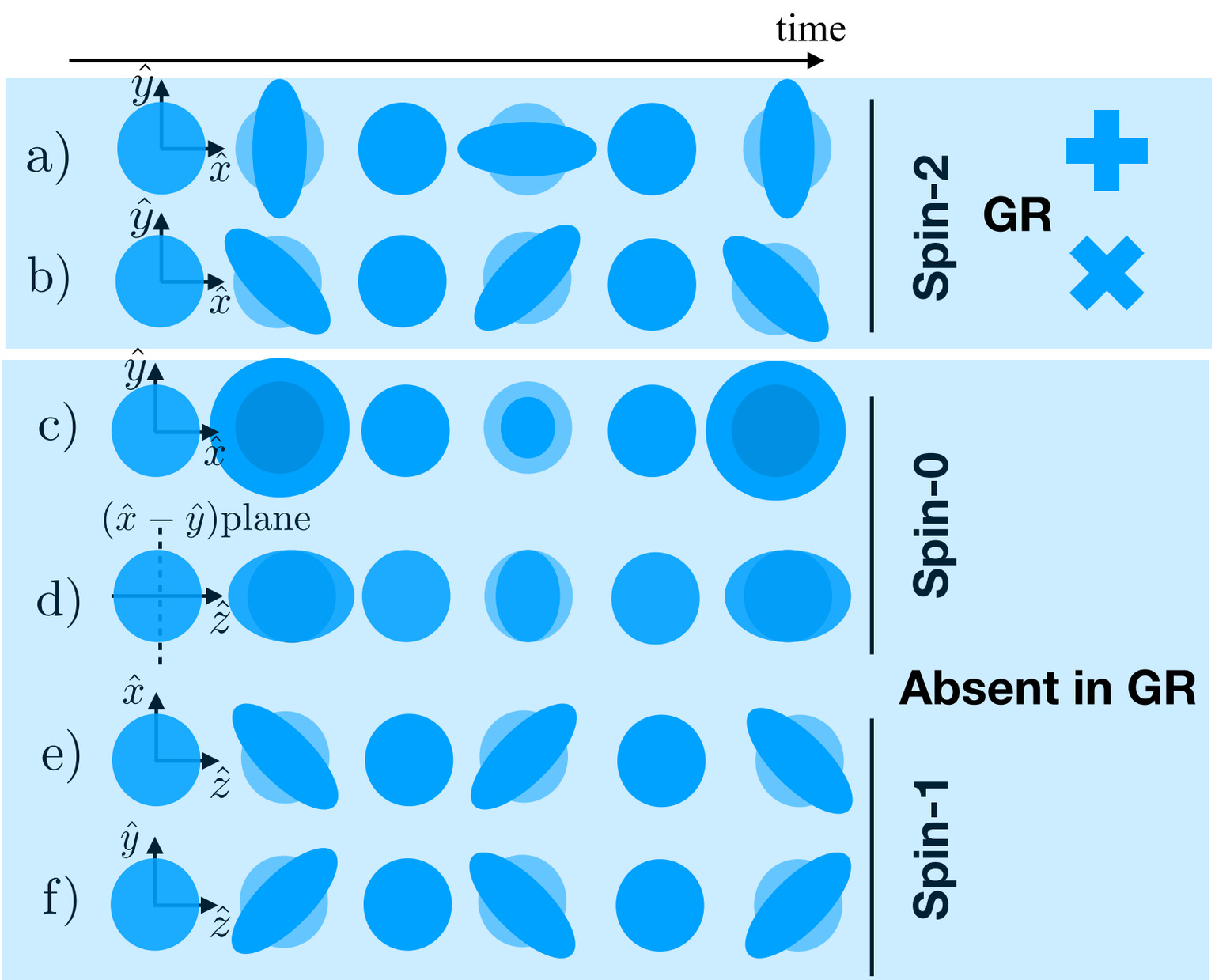


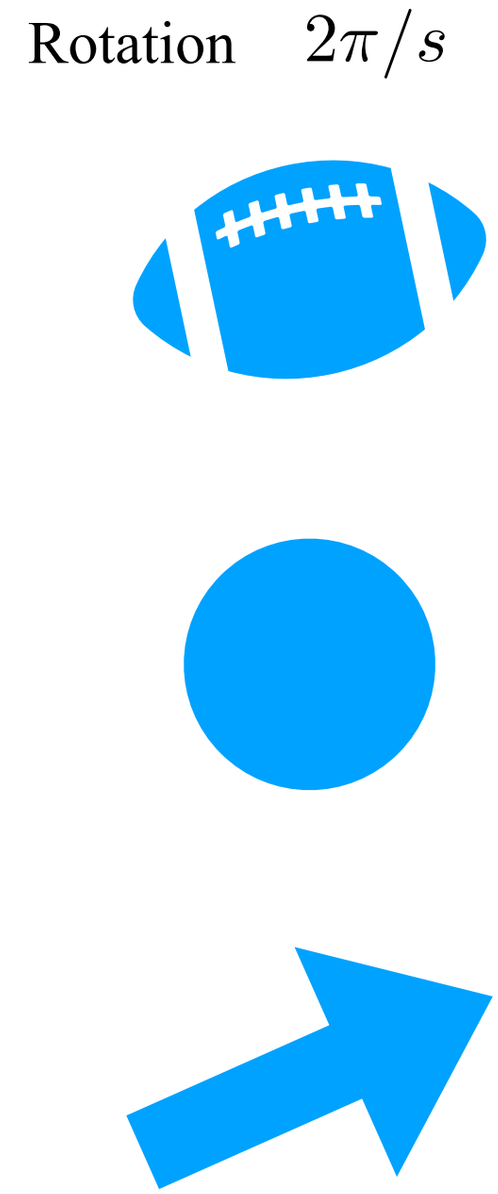
Results

I. S. Matos, C.D. et al, 2025



GW extra polarization modes are a *smoking gun* signature of beyond GR physics.



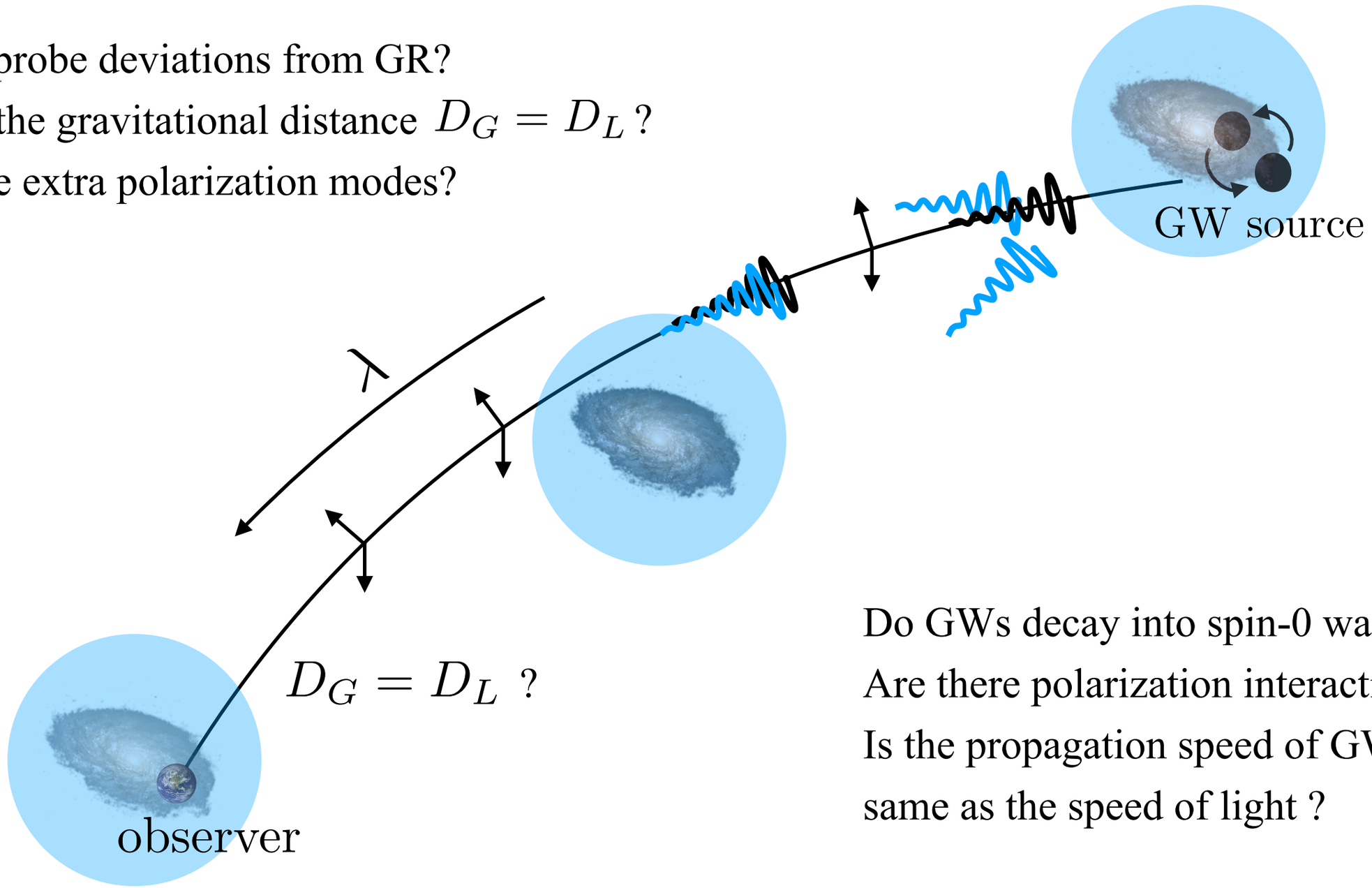


GW propagation

Can we probe deviations from GR?

What is the gravitational distance $D_G = D_L$?

Are there extra polarization modes?



Do GWs decay into spin-0 waves?

Are there polarization interactions?

Is the propagation speed of GWs the same as the speed of light ?

Conclusion

I. S. Matos, C.D. et al, *in prep*.
C. D., M. Williams, T. Baker, *in prep*.

- We applied for the first time the Peak sirens method to real data.
- We measured H_0 with this innovative method.
- We measure for the first time the GW bias.
- Tight constraints can be applied to the GW velocity using dispersion induced friction.

"The Universe is under no obligation to make sense to you."
Neil deGrasse Tyson

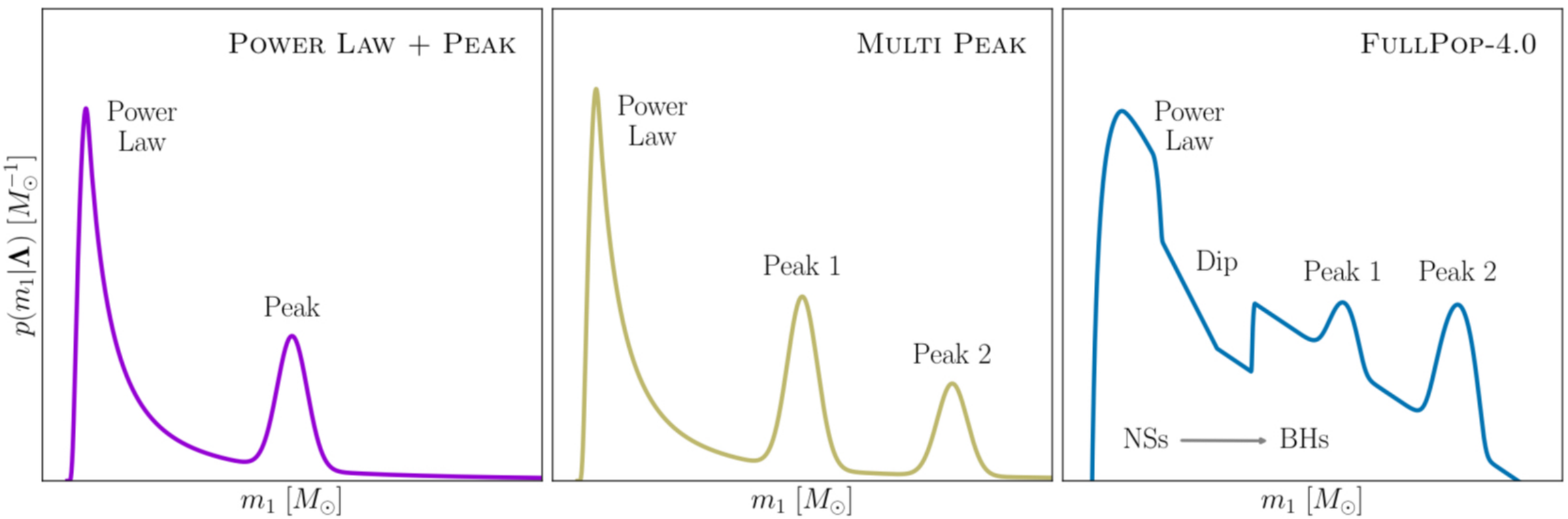
Thank you

Questions?

Population mass hyperparameters

J. M. Ezquiaga, D. Holz, 2020, 2022
R. Gray et al. 2023

One measures $m_z = (1+z)m_s$



Up to 25 parameters !