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Cosmologia e stelle di neutroni: cosa ci insegna GW170817?

Walter Del Pozzo
Universitá of Pisa

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Neutron Stars

- Latest stages in stellar life

$$m \simeq 1 - 3\,\mathrm{M}_\odot$$

- Very compact

$$R \simeq 10 - 20\,\mathrm{km}$$

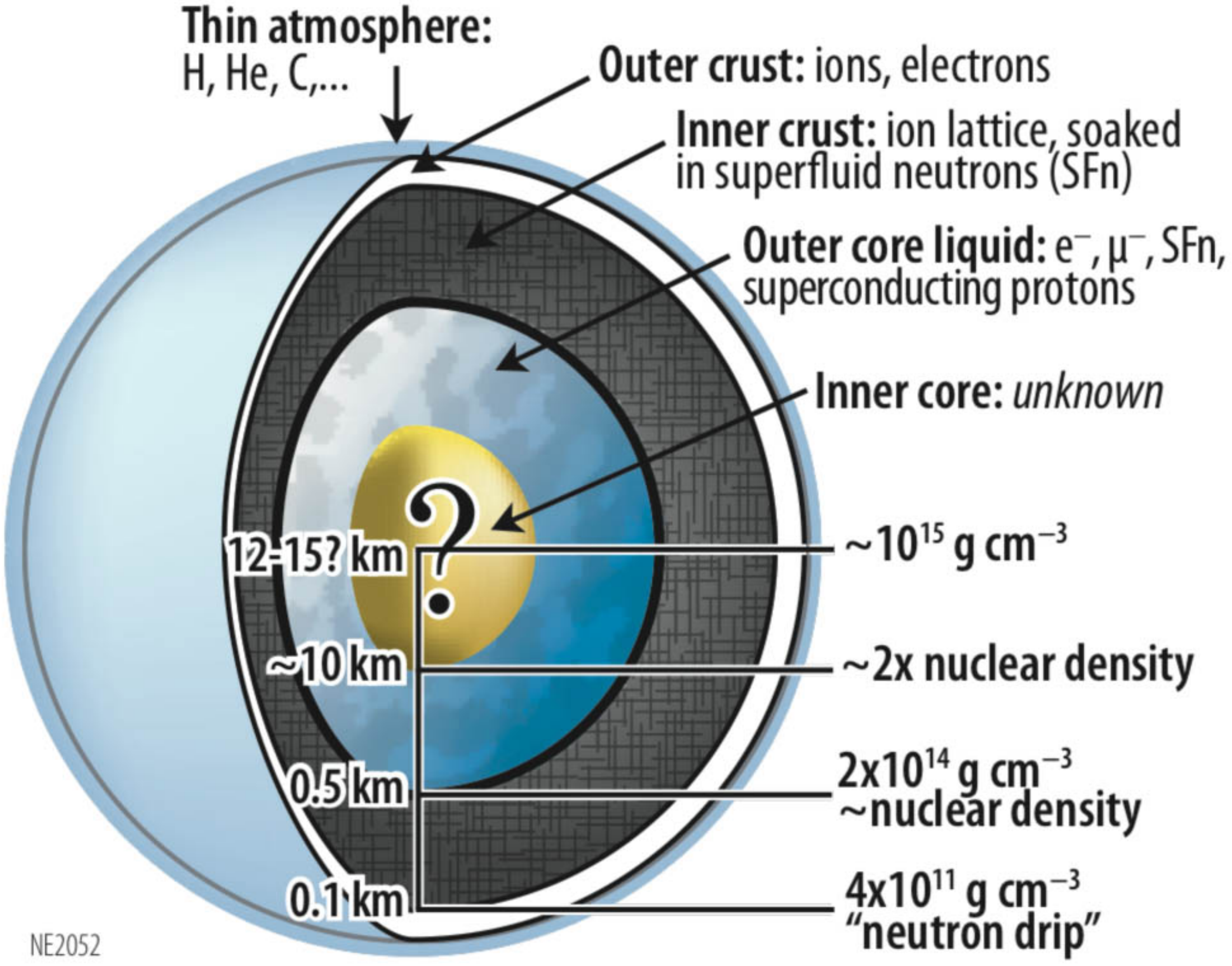
- Very dense

$$\rho_c \simeq 10^{17-18}\,\mathrm{kg\,m^{-3}}$$

- Pulsars

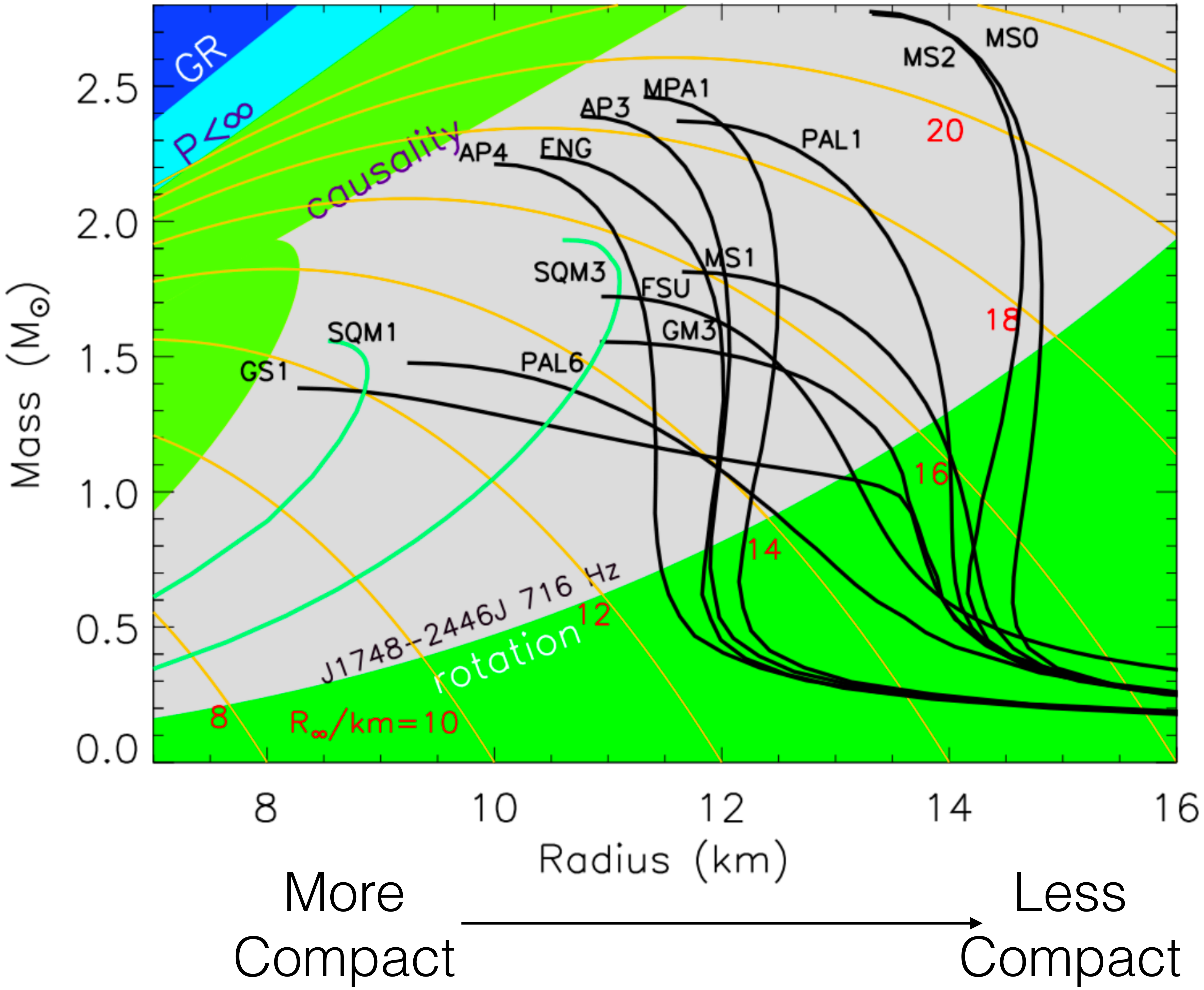
Neutron stars structure

- Internal structure and composition are largely unknown
- Encoded in the neutron star matter equation of state



Neutron Star equation of state and perturbations

- Equation of state of nuclear matter
  - Relation between density and pressure
  - Relation between mass and radius
- Respond to perturbations by deforming and oscillating
- Response is determined by internal properties (density, pressure, …)



Lattimer, arXiv:1305.3510

Binary Neutron Stars

- Perturbing field is the tidal field of the companion

- Tidal effects enter through the tidal deformability

$$Q_{ij} = -\lambda(\mathrm{EOS}; m)\tau_{ij}$$

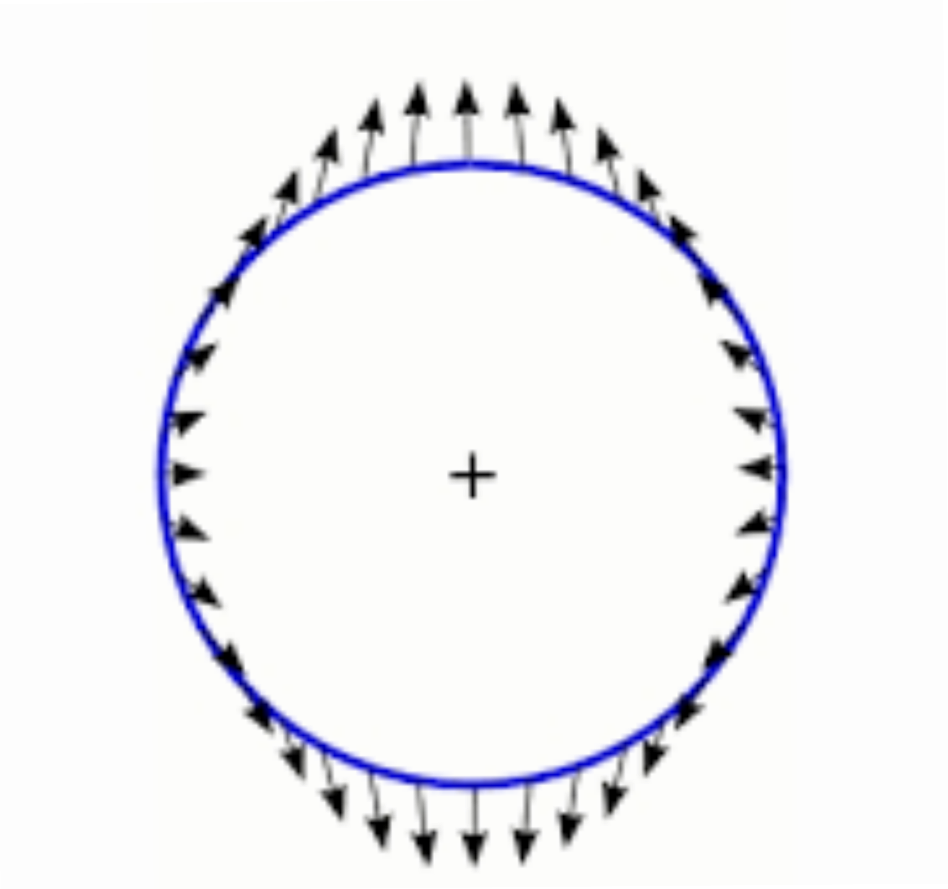
quadrupole moment

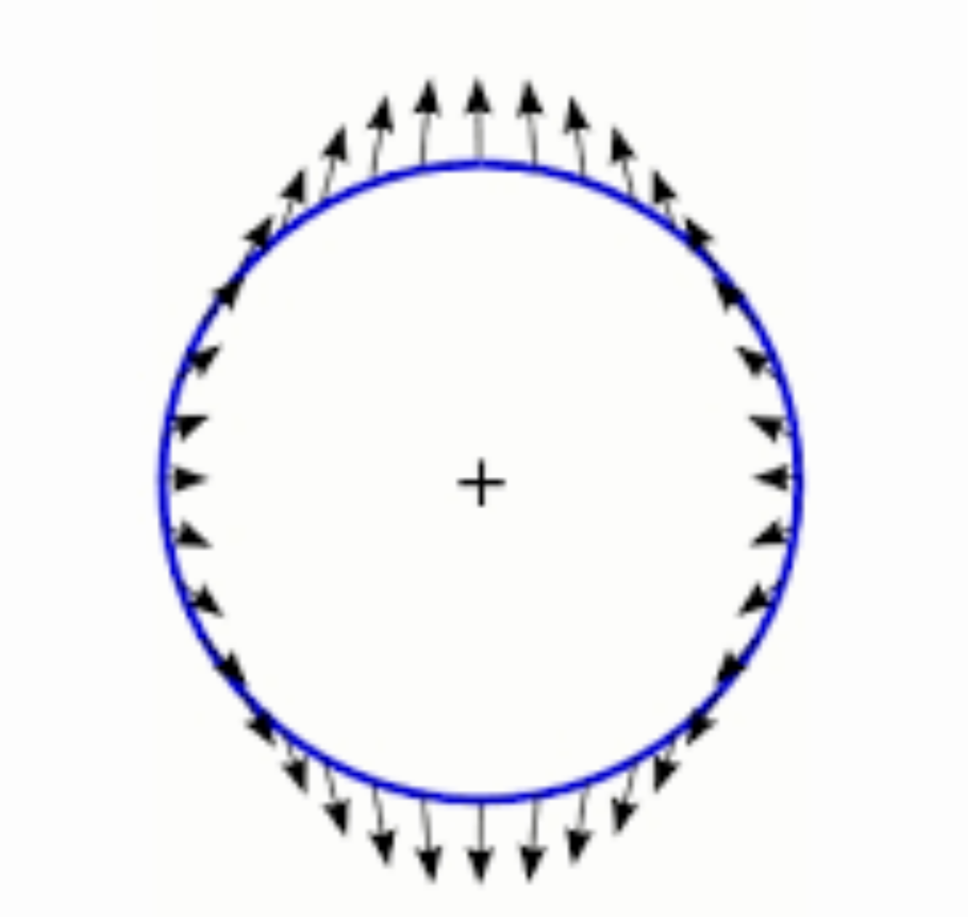
tidal field of companion star

$$\lambda(m) = \frac{2}{3} k_2 R^5(m)$$

second Love number

NS radius

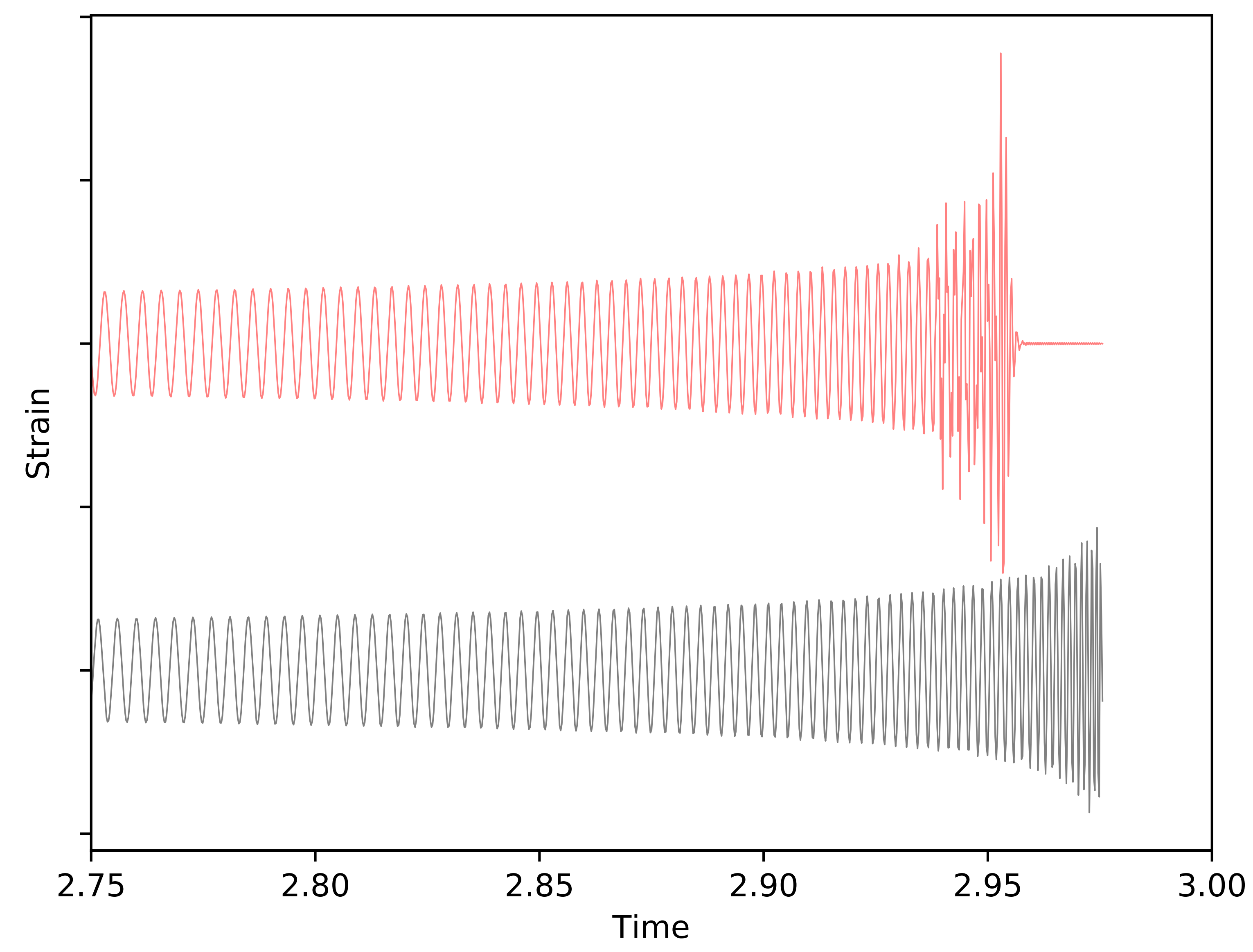


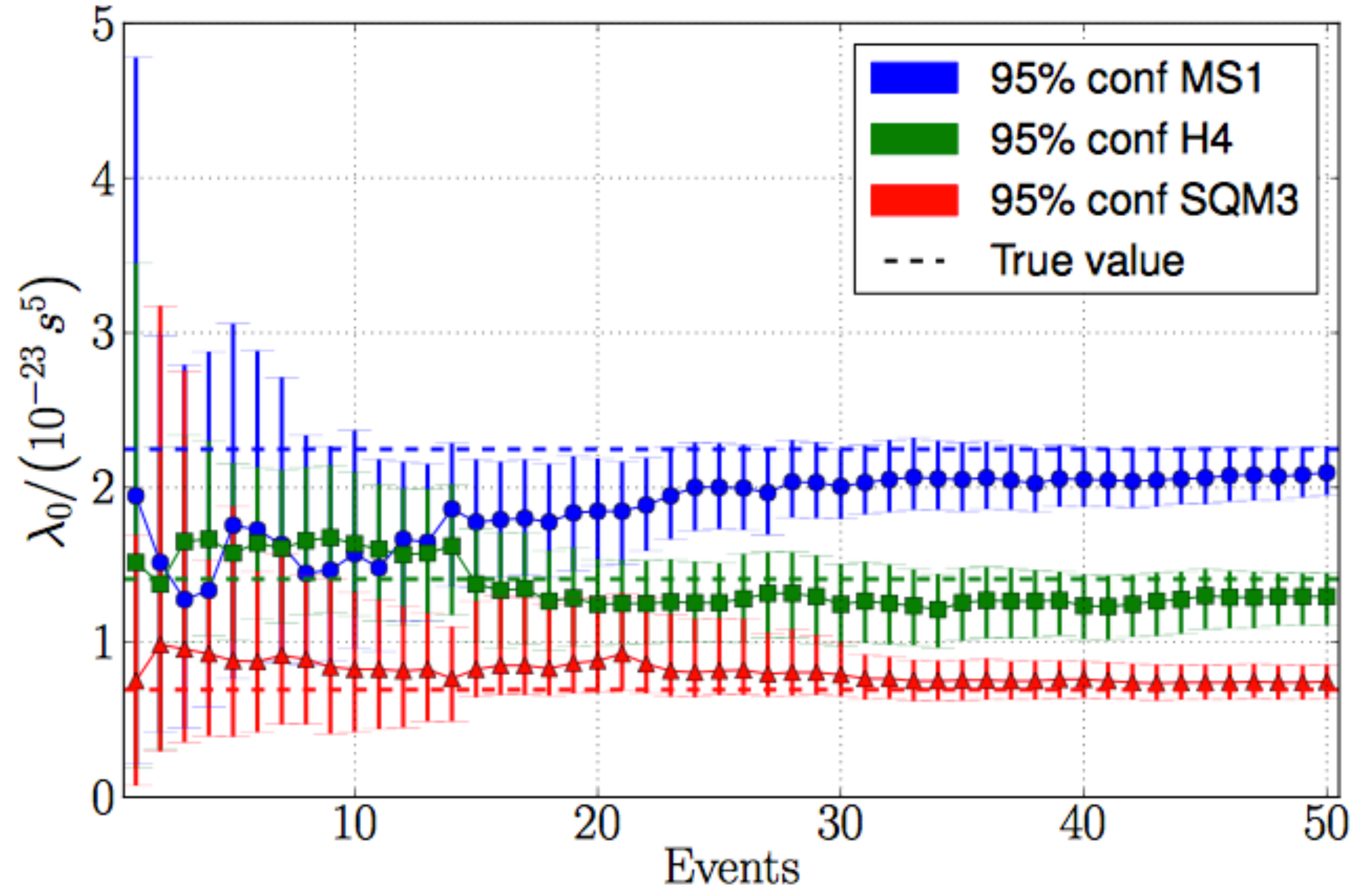


- Time-varying quadrupole => gravitational waves

Imprint of NS deformation in the waveform

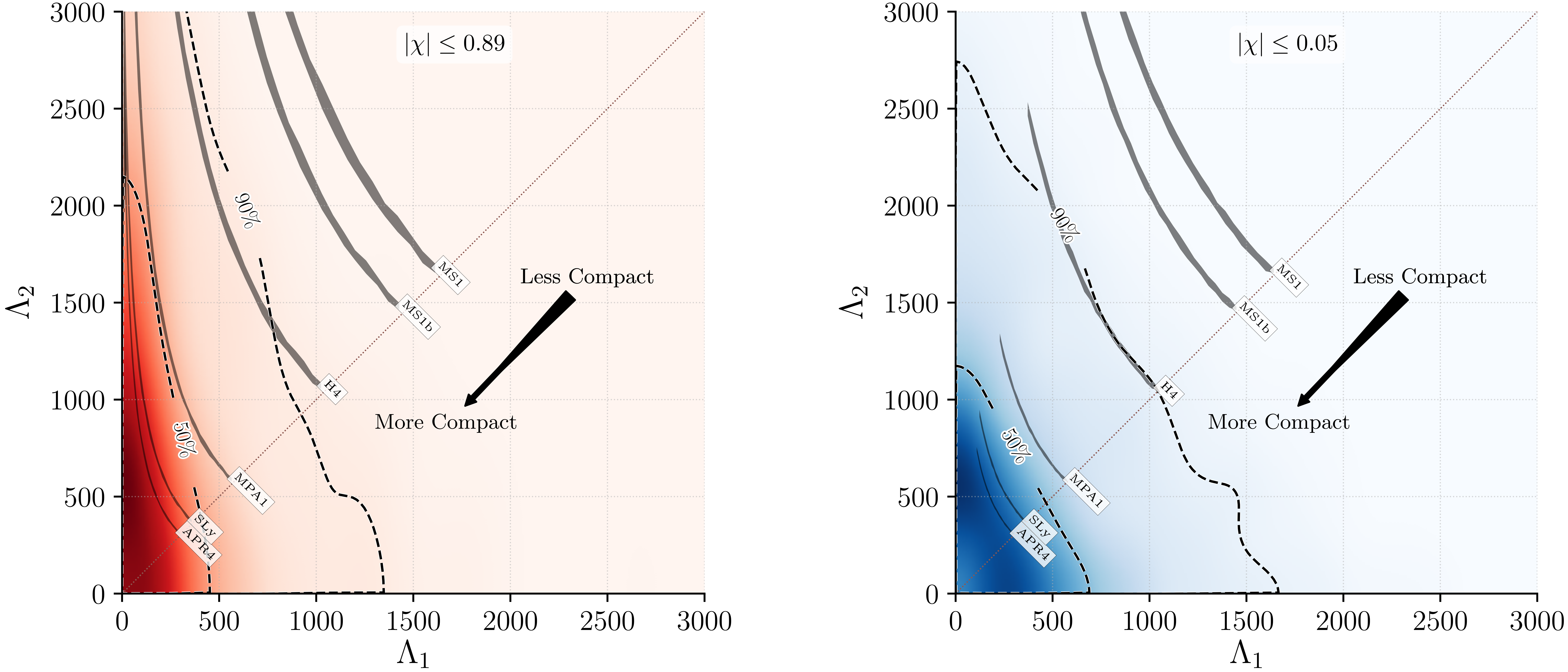
- The imprint on the waveform is theoretically known
  - The deformation extracts energy from the orbit
  - Coalescence (at a given mass) is faster, compared to black holes
    - Shorter waveform
    - Faster phase accumulation
- Expected to be measurable (with multiple observations)





Del Pozzo, arXiv:1307.8338

Measurement of NS deformability



- Stiffest equation of states excluded
- Neutron star radii < 14 km

LVC, arXiv:1710.05832

Hubble diagram

- Distance vs redshift
- The inverse of the slope is the Hubble constant
  - Rate of expansion of the Universe

$$D \simeq \frac{v}{H_0} = \frac{cz}{H_0} \quad z << 1$$

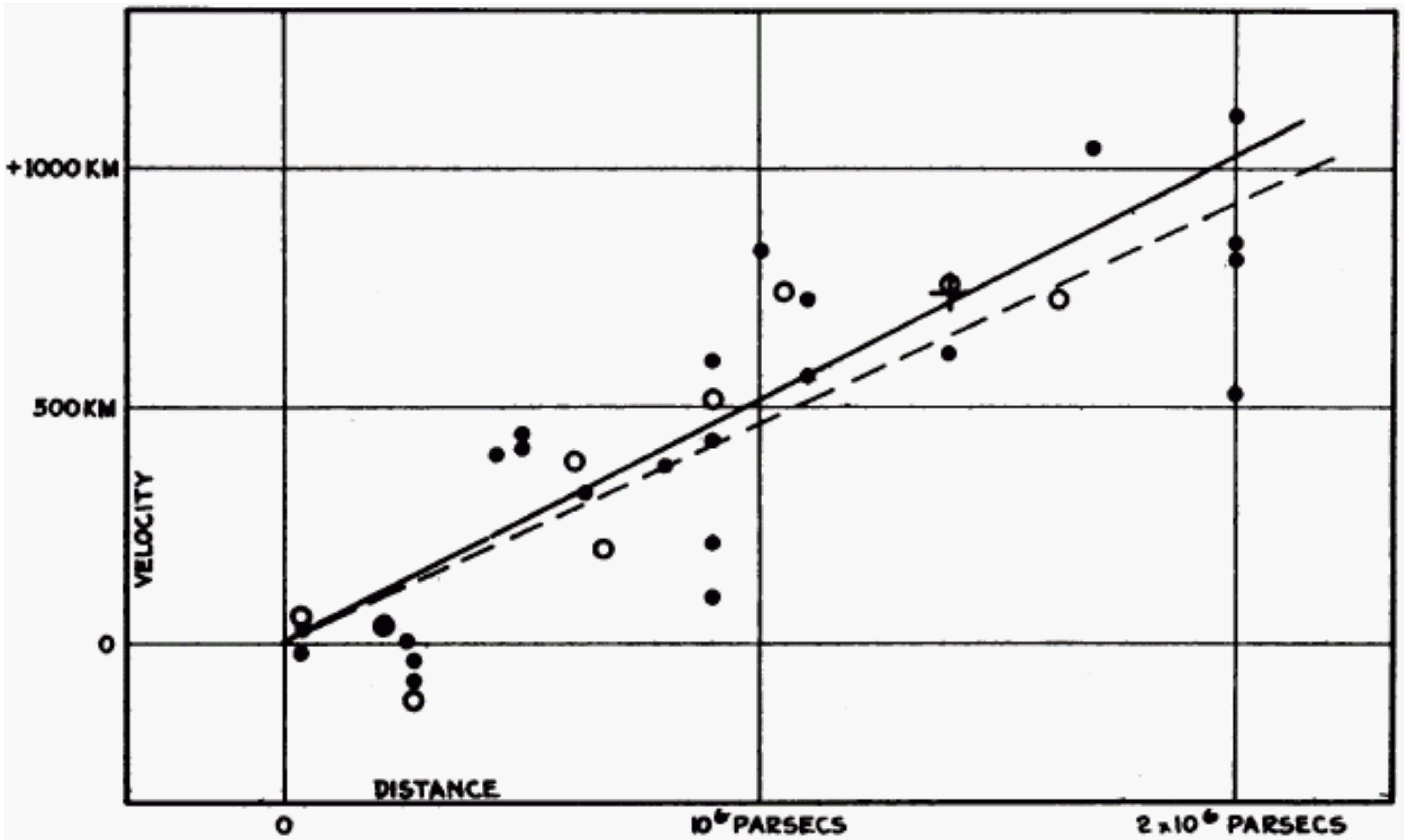
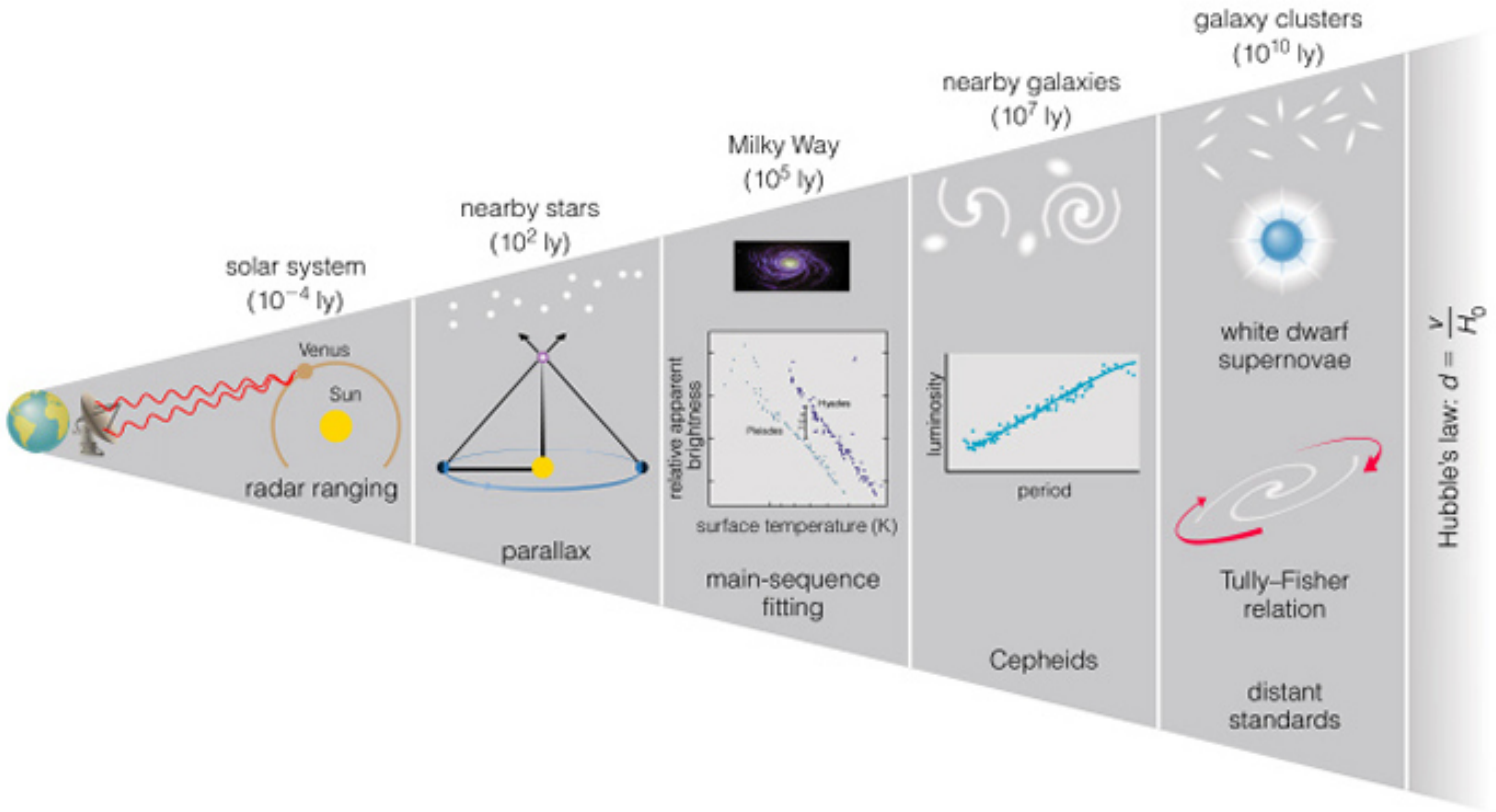


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

Hubble, 1929

Classical determination of Hubble constant

- Spectroscopic redshift (easy)
- Distance requires:
  - identification of “standard candles”
  - cross-calibration of various candles
  - “Iterate and hope it converges” — Shore, S.N.
- The “cosmic distance scale ladder”

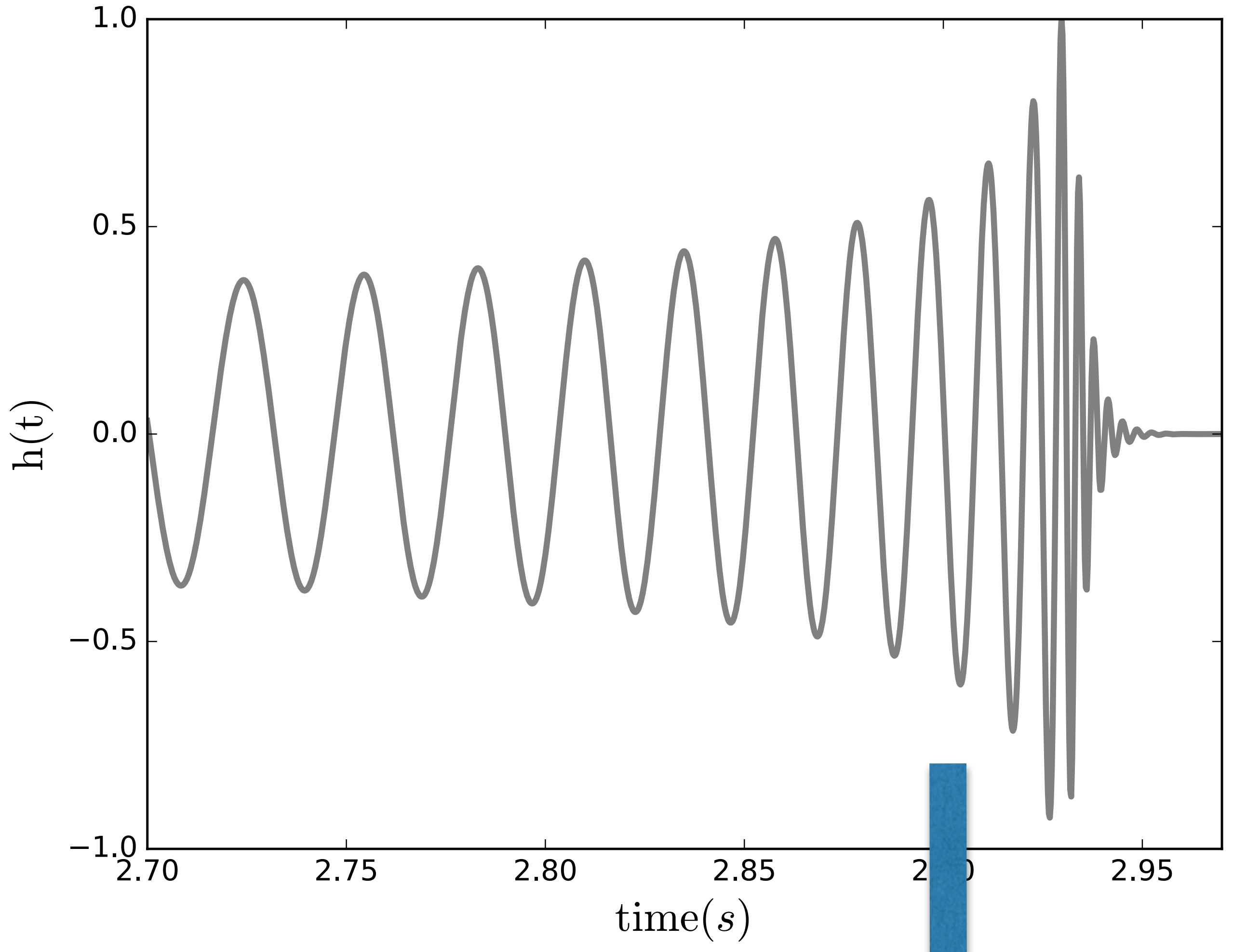


Cosmography with GW

- GW are self-calibrating sources

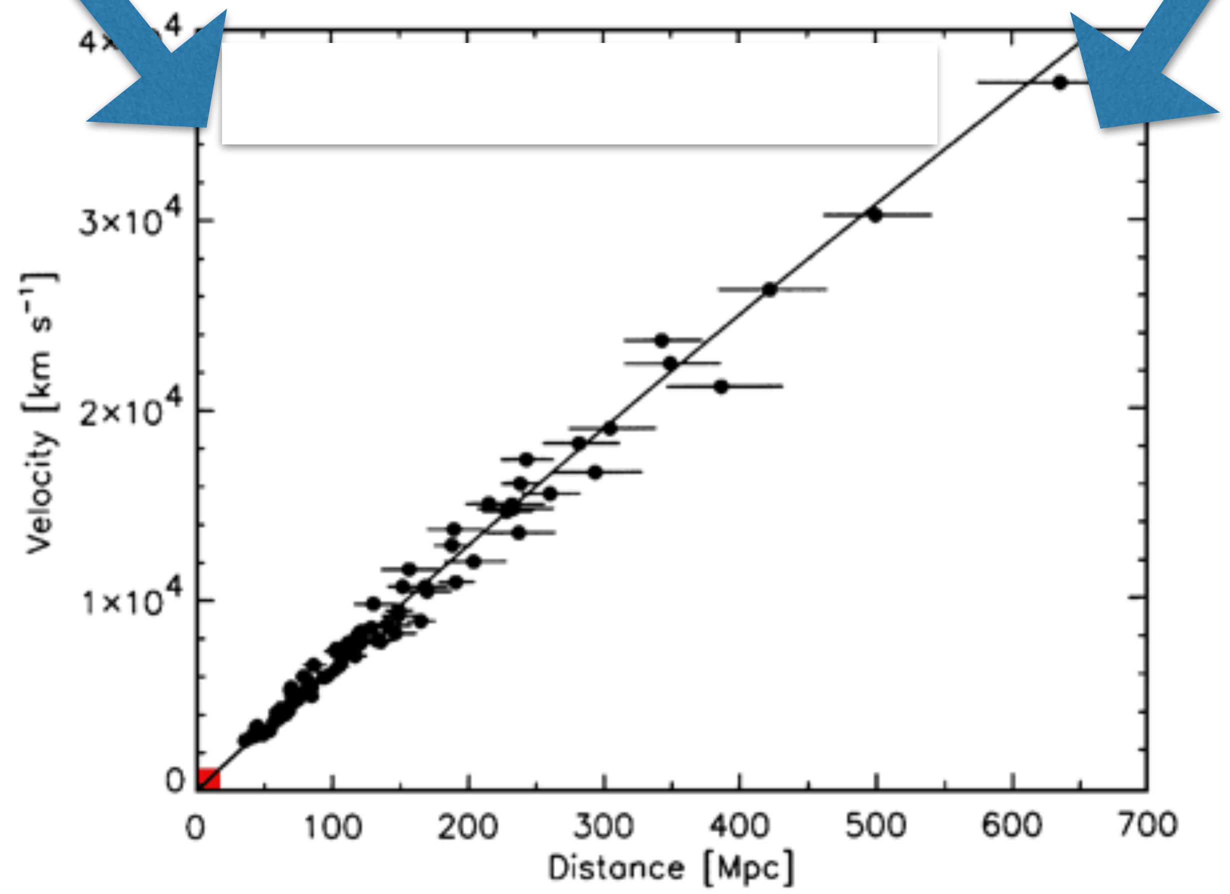
$$h \sim D_L^{-1}$$

  - Direct measurement of luminosity distance
  - “Standard sirens”
- In general, no redshift from GWs

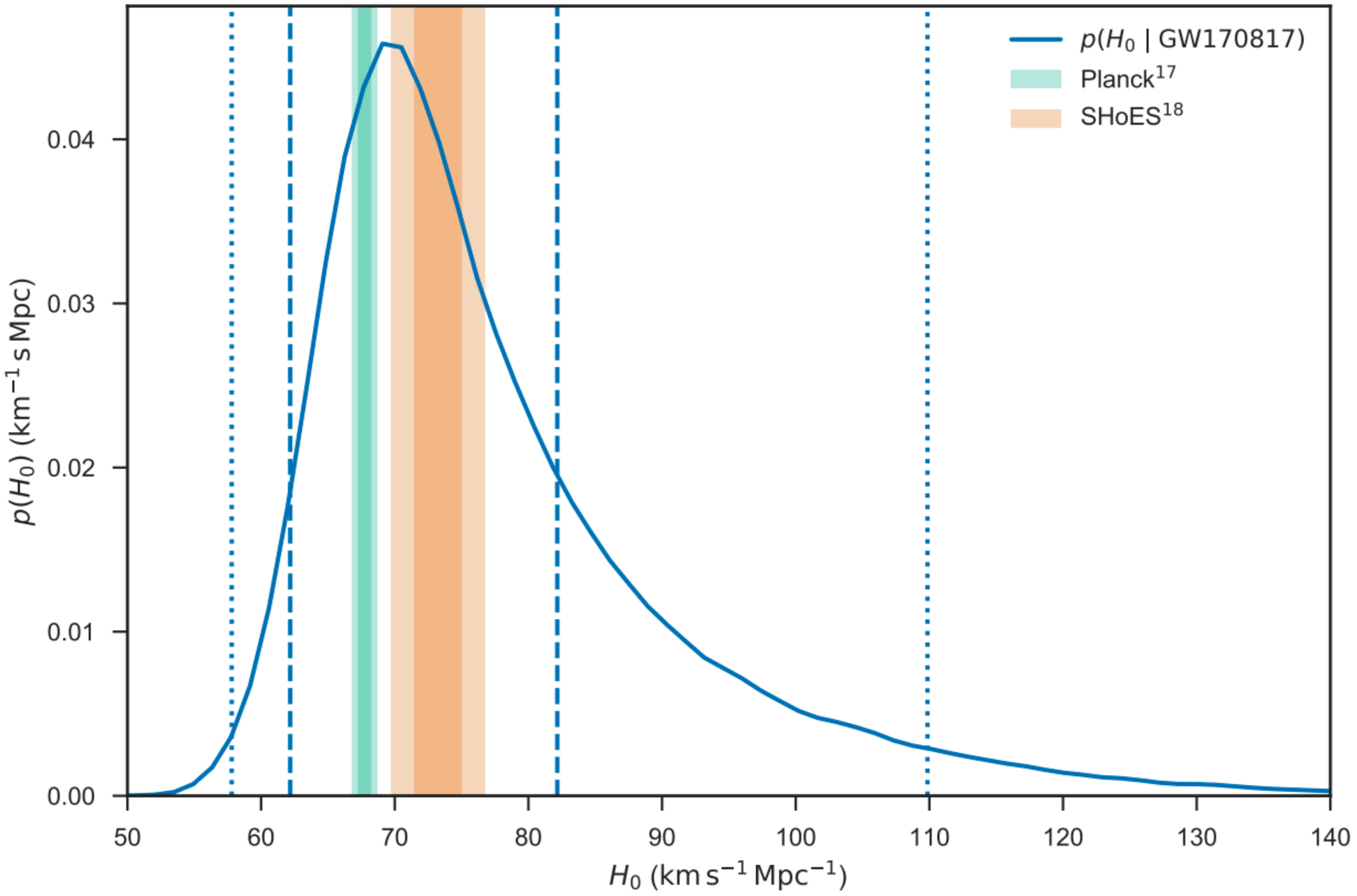


D_L

z



The GW-only Hubble constant



LVC, arXiv:1710.05835

Summary

- GW170817 is another spectacular discovery in the new era of astronomy
- Just a preview of the astrophysics to come from the world-wide network of gravitational wave observatories