COSMOLOGICAL IMPLICATIONS OF THE FIRST LIGO AND VIRGO DETECTIONS

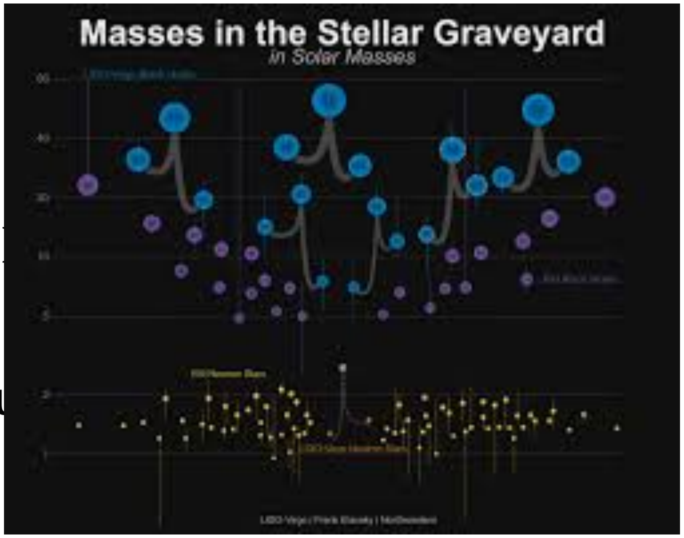
Tania Regimbau

GEMMA, Lecce, 05/06/2018

LIGO Current Detections

- LIGO and Virgo have already observed 5 (+1?) BBHs and 1 BNS.
- The events we detect now are loud individual sources at close distances (z~0.07-0.2 for BBHs and z~0.01 for the BNS).
- Black hole masses (m~7-30) can be larger than previously observed in XR-binaries. Must have been created in low metallicity environement.
- The local rate is in the higher tail of previous estimations.

LIGO Current Detections



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- The estimated local rate is in the higher tail of previous estimations.

Possible Formation Scenarios

- Field: formed from stars born in a binary system that remain bounded after the two supernovas (short or long delays).
- Dynamical: formed by capture in a dense environment through mass segregation that move NSs and BHs to the center
- Primordial BBH: formed by the collapse of dense regions in the very early Universe (hypothetical). Expected to have a large mass distribution.
- We need more data to reconstruct the mass, spin (eccentricity) distribution (see A. Sedda talk)

Abbott et al. Nature, 551, 85 (2017)

Measurement of the Hubble Constant

- GW170817 was observed in both gravitational and electromagnetic waves, making it the first standard siren.

- Direct measurement of the luminosity distance with GWs $d_L = 40^{+8}_{-14}$ Mpc

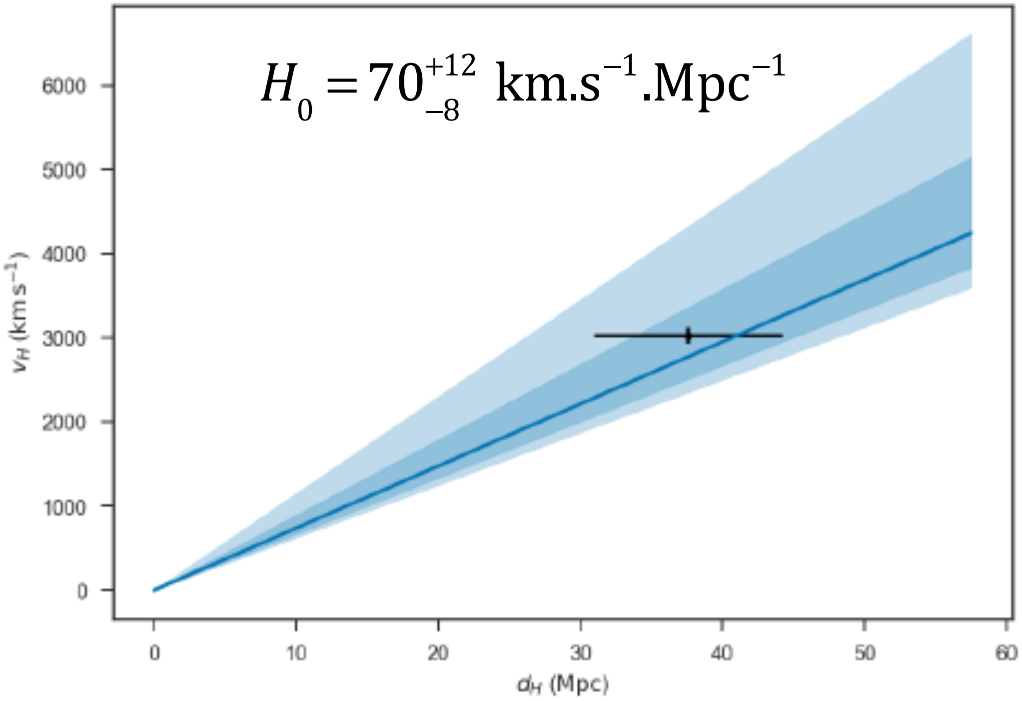
Compared to supernovas, no need for distance ladder.

- Optical identification of the host galaxy NGC4993. Measurement of the Hubble flow from the position and the redshift. Need to correct for the local peculiar velocity (~10%).

- Hubble law: $v_H = H_0 d$ (d<50 Mpc)

Abbott et al. Nature, 551, 85 (2017)

Measurement of the Hubble Constant



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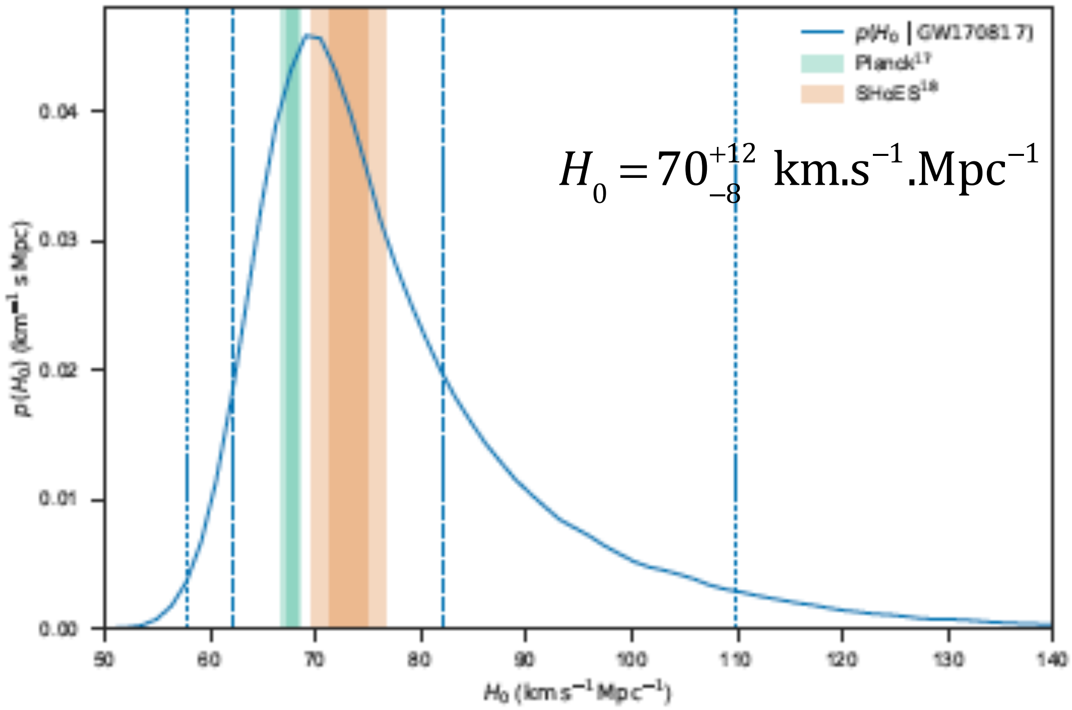


$$H_0 = 70^{+12}_{-8}\ \mathrm{km.s^{-1}.Mpc^{-1}}$$

- Hubble la $_H$ $_0$

The Cosmological Population

- Many more individual sources at larger distance
- Contribute to create a stochastic background, which could be the next milestone for LIGO/Virgo
- Carries lots of information about the star formation history, the metallicity evolution, the average source parameters (and then the main evolution scenarios).
- Using information from the first observations, we were able to revise previous predictions of the GW background from BBHs.

The Background Spectral Properties

- Energy density in GWs characterized by:

$$\Omega_{gw}(f) = \frac{f}{\rho_c}\frac{d\rho_{gw}(f)}{df}$$

- For a population distributed in the parameter space $\theta_k=(m_1,m_2,\chi_{eff})$

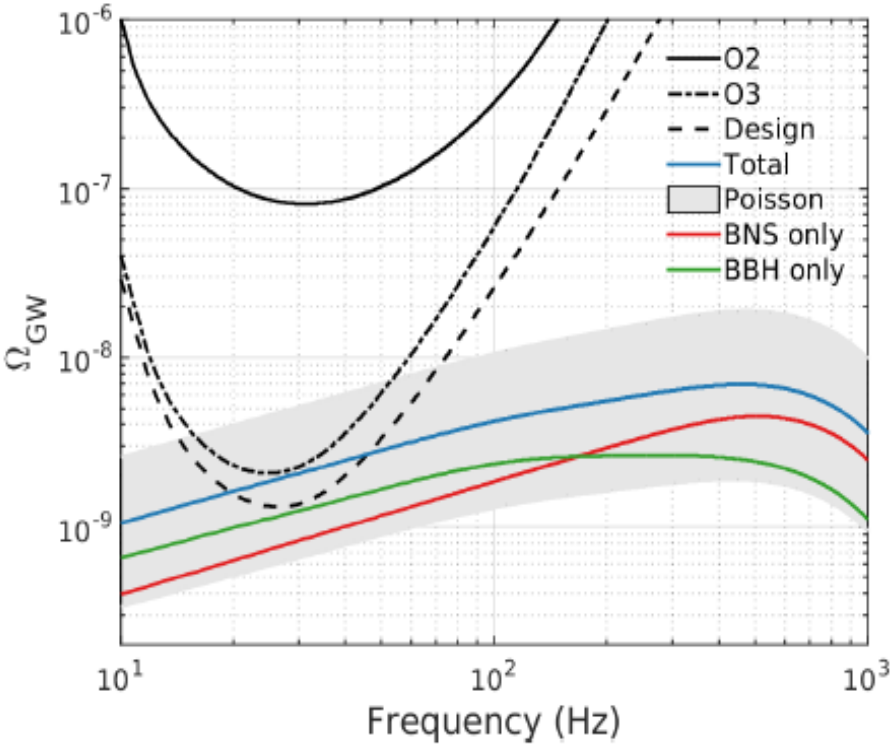
$$\Omega_{gw}(f,\theta_k) = \frac{f}{\rho_c}\int d\theta_k P(\theta_k)\int_0^{10} dz\,\frac{dR_m^k}{dz}(z,\theta_k)\,\frac{\frac{dE_{gw}}{df}(\theta_k, f(1+z))}{4\pi r^2(z)}$$

With rate:

$$\frac{dR_m^k}{dz}(z,\theta_S) = \int_{t_{\min}}^{t_{\max}} R_f(z,\theta_S)P(t_d,\theta_S)\,dt_d$$

Abbott et al. PRL, 120.091101 (2017)

Estimate from Detected Sources

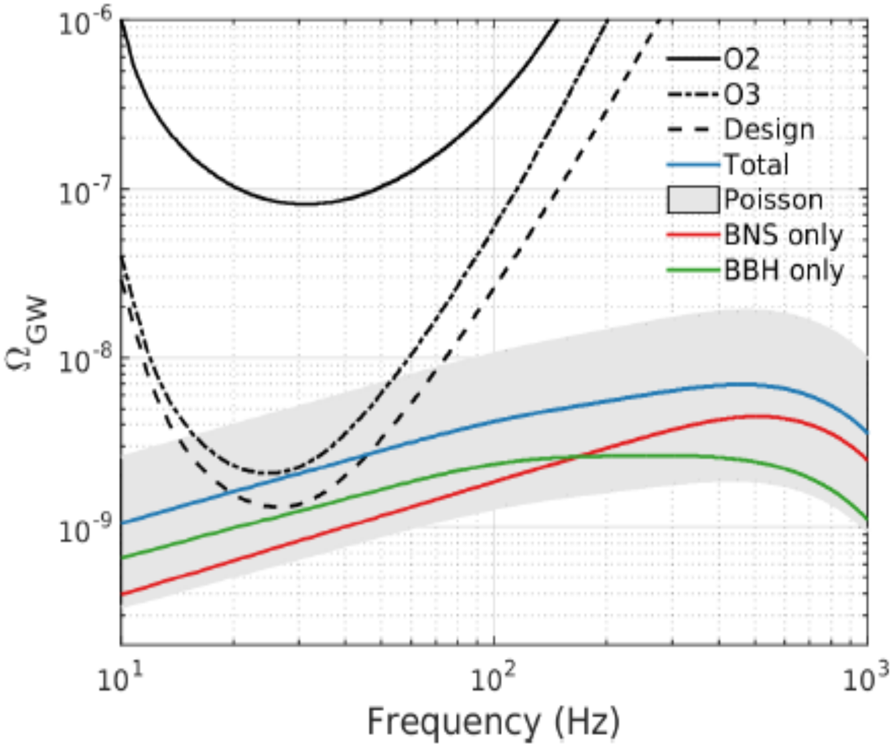


$$\Omega_{gw}^{bbh}(25\mathrm{Hz}) = 1.1^{+1.2}_{-0.7} 10^{-9}$$

$$\Omega_{gw}^{bns}(25\mathrm{Hz}) = 0.7^{+1.5}_{-0.6} 10^{-9}$$

Abbott et al. PRL, 120.091101 (2017)

Estimate from Detected Sources



$$\Omega_{gw}^{bbh}(25\text{Hz}) = 1.1^{+1.2}_{-0.7} 10^{-9}$$

From GW150914 only:

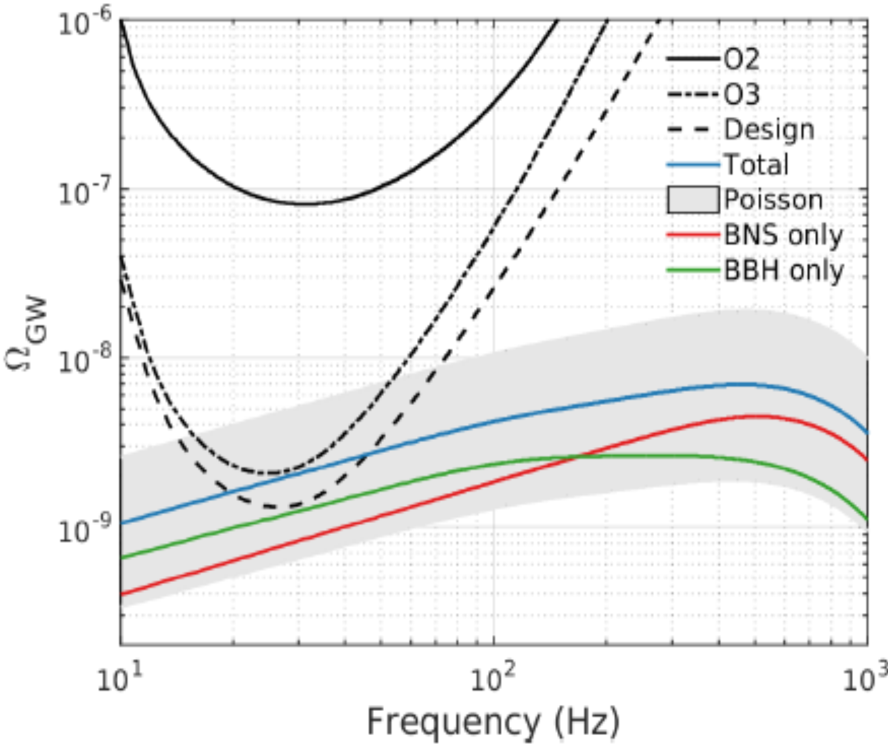
$$\Omega_{gw}^{BBH}(25\text{Hz}) = 1.1^{+2.7}_{-0.9} \times 10^{-9}$$

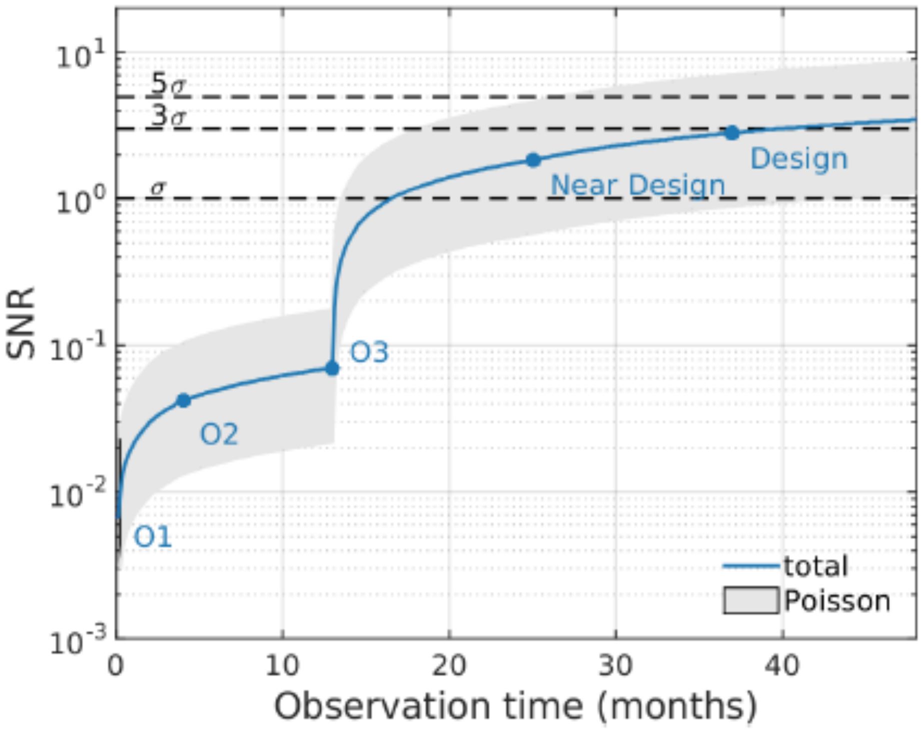
32% of improbement of the error.

Abbott et al. PRL, 120.091101 (2017)

Estimate from Detected Sources

The background could be detected before the detectors reach design sensitivity!



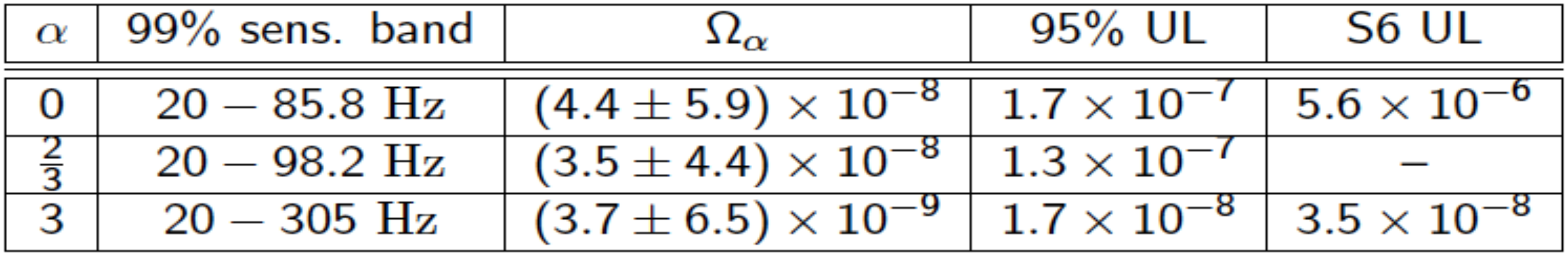


Abbott et al. PRL, 118.121101

Constraints on the GW energy density

- No evidence for a stochastic background (cosmological or astrophysical)

- But set upper limit on the total energy density



α	99% sens. band	Ω_α	95% UL	S6 UL
0	20 – 85.8 Hz	$(4.4 \pm 5.9) \times 10^{-8}$	1.7×10^{-7}	5.6×10^{-6}
$\frac{2}{3}$	20 – 98.2 Hz	$(3.5 \pm 4.4) \times 10^{-8}$	1.3×10^{-7}	–
3	20 – 305 Hz	$(3.7 \pm 6.5) \times 10^{-9}$	1.7×10^{-8}	3.5×10^{-8}

- For α=0, 33x better than initial LIGO/Virgo

Abbott et al. arXiv:1712.0116

Constraints on cosmic strings models

- Topological defects which can be formed in GUT-scale phase transitions in the early Universe. They can produce large amount of GWs through the production of loops (cusps and kinks)

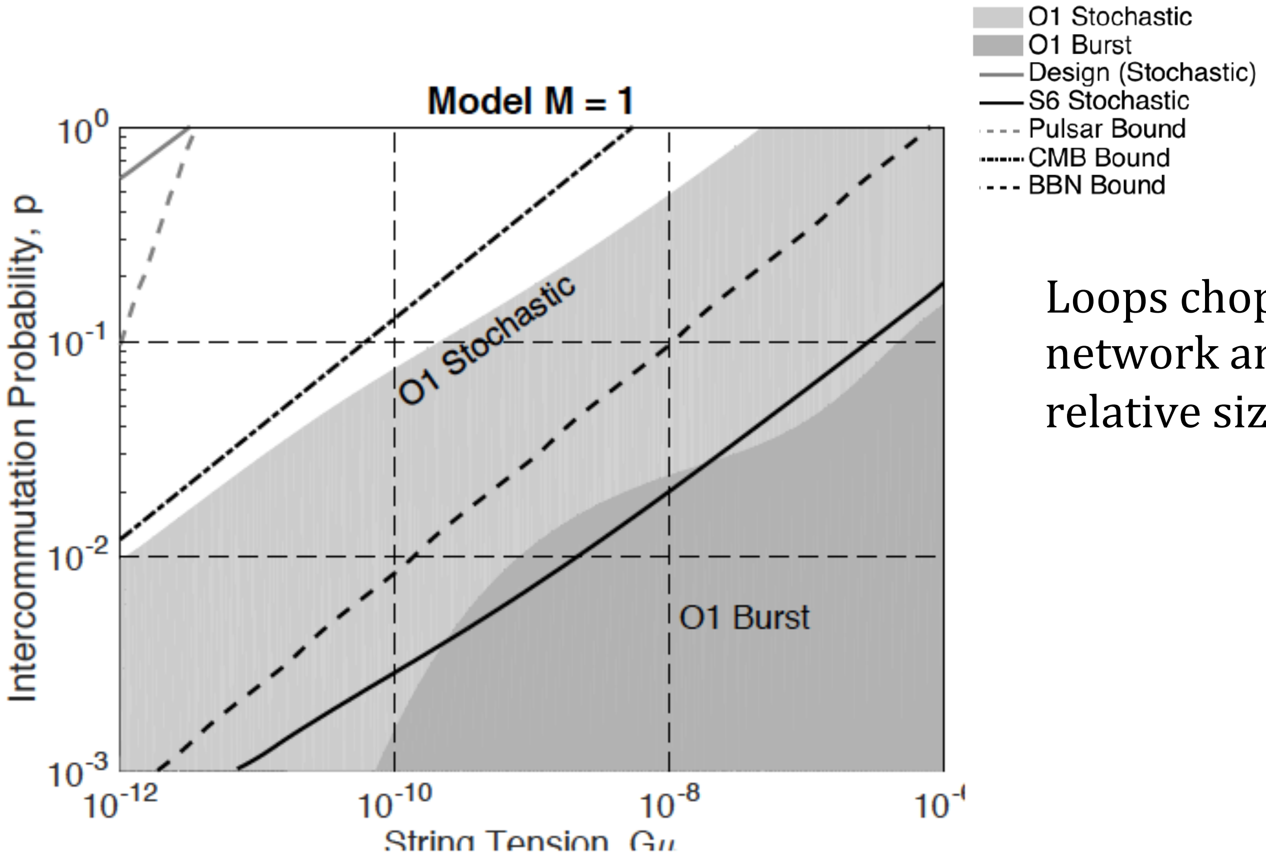
- Strings are charactarized by 2 parameters: tension $G\mu$ and intercommutation probability p

- We consider 3 different models of the number density $n(l,t)$ based on Numbo-Goto numerical simulations ($p=1$), and extend to $p<1$ assuming

$$n(l,t,p<1)=n(l,t,p=1)/p$$

Abbott et al. arXiv:1712.01168

Original Large Loop Distribution

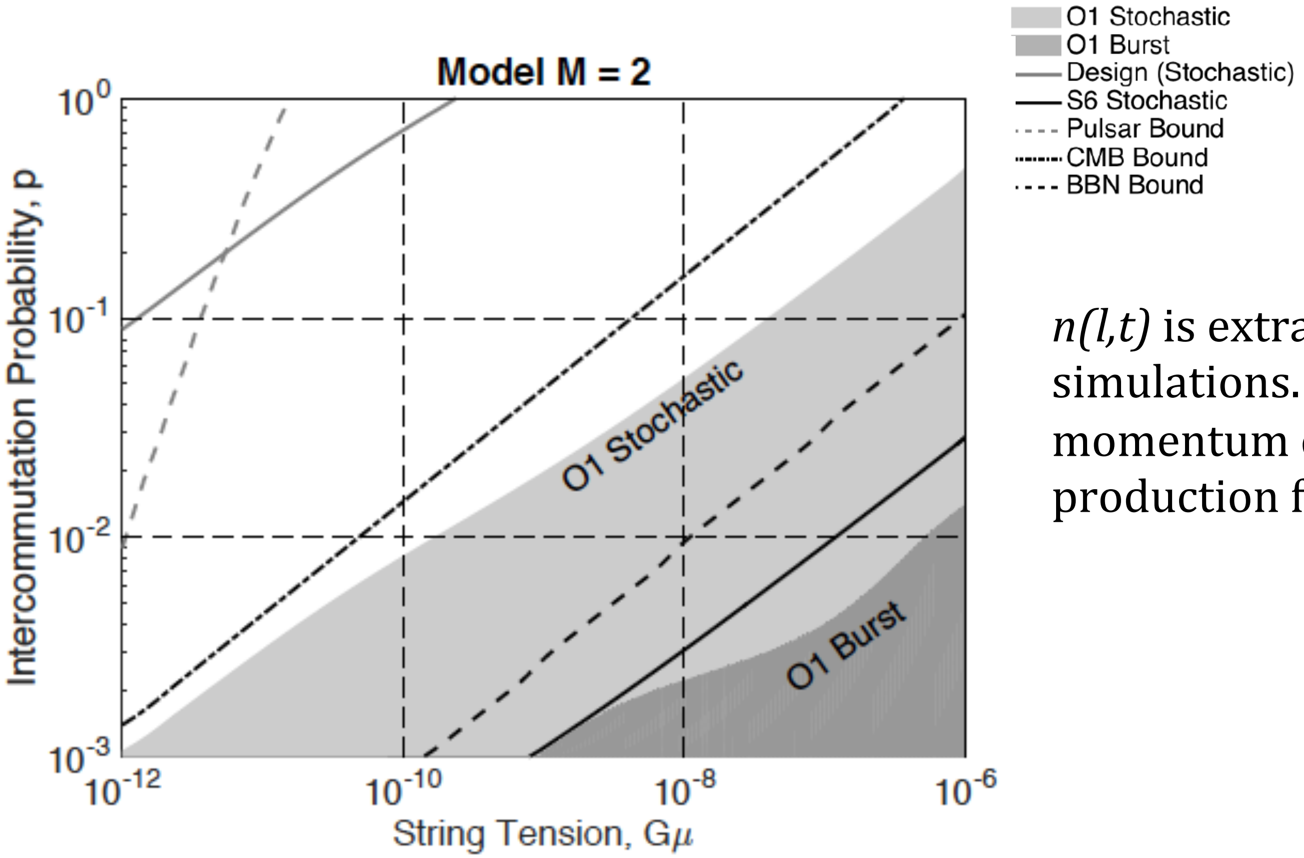


Loops chopped off the infinite string network are formed with the same relative size:

$$l(z) = \alpha t(z)$$

Abbott et al. arXiv:1712.0116

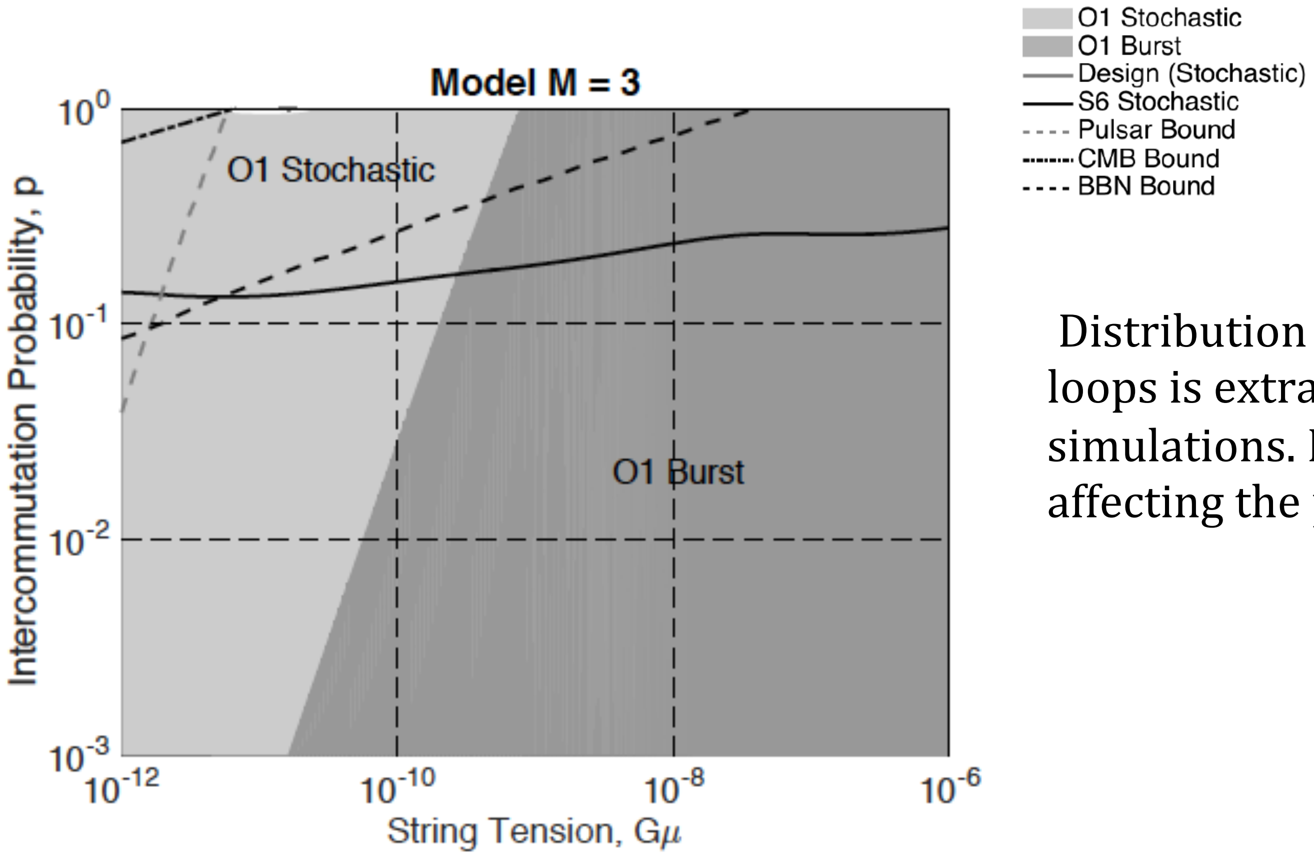
Large loop distribution of Blanco Pillado et al.



n(l,t) is extrapolated from numerical simulations. Assume that the momentum dependance of the loop production function is weak.

Abbott et al. arXiv:1712.01168

Large Loops Distribution of Ringeval et al.



Distribution of non self interacting loops is extrapolated from numerical simulations. Include GW back reaction affecting the production of small loops.

Summary

- The first detections have already provided strong constraints on the Hubble constant, the astrophysical stochastic background and cosmic strings models.

- But it is only the beginning! The improvement of the sensitivity and the detection of many more events at larger distance will enable to measure better the Hubble constant, detect the background from CBCs, and maybe the one from cosmic strings.