Post-detection GW Astrophysics: What We Know and Don't Know About the GW Sky

(But Really Want To!)

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DAWN workshop
Atlanta, July 7 2016

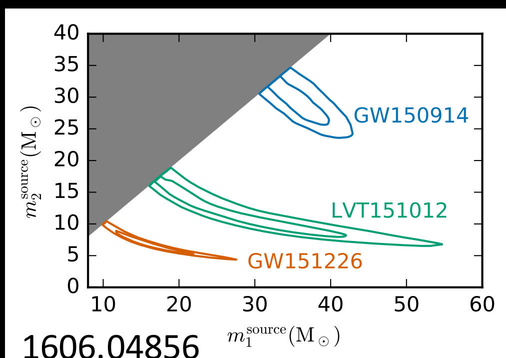
Post detection era

- We need to plan asap for the future of ground-based GW detectors

- What (astro)physical questions have we answered in O1 ?

- What are the open questions?
  - What questions require a significant upgrade?
  - What questions require new facilities?
  - How many detectors should we have online, and under which conditions?

What did we learn in O1 – BH masses



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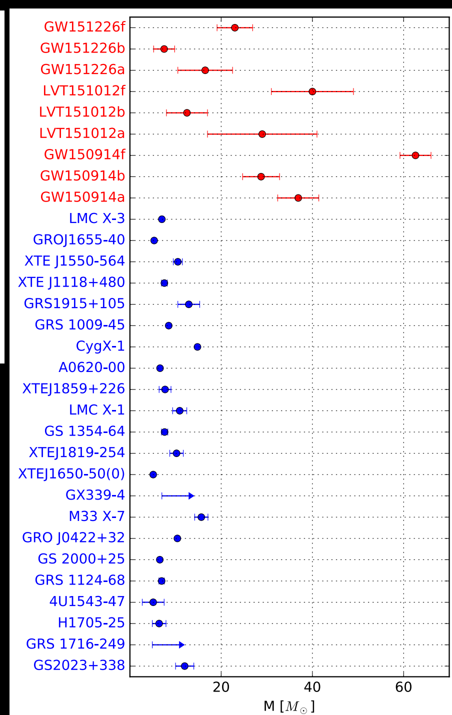
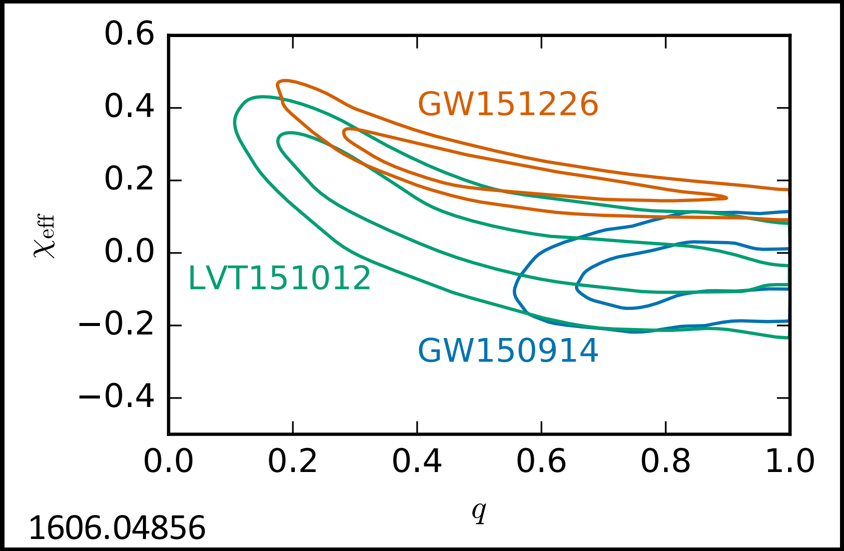


- We measured BH masses *directly*
- BHs can have masses much larger than what found with EM (<~ 15M)
- Implications for metallicity and winds strength in the progenitors

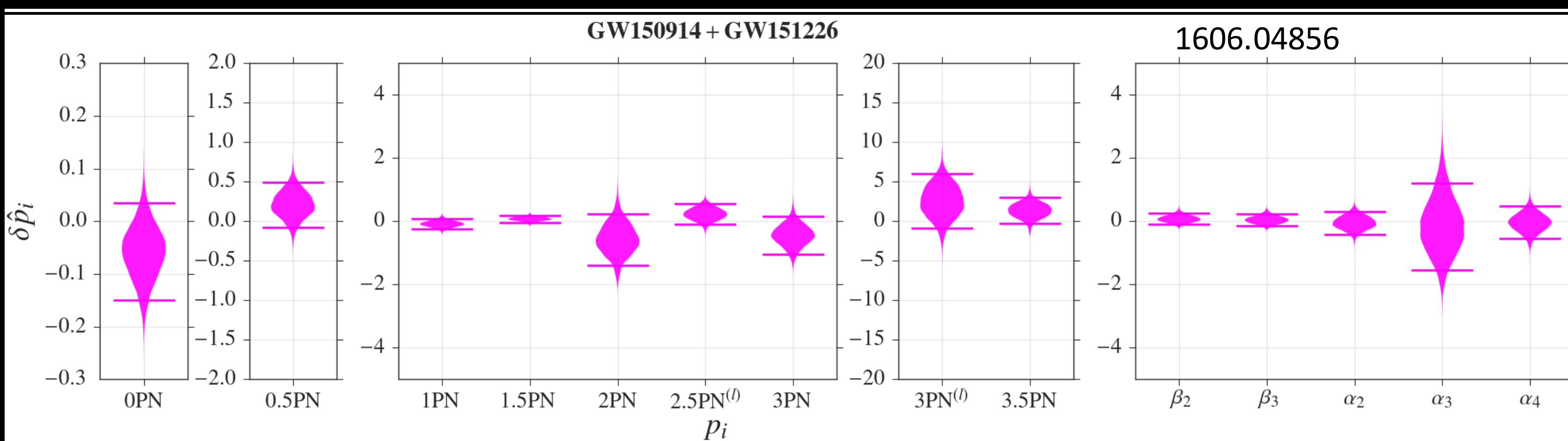
What did we learn in O1 – BH spins



- We measured BH spins *directly*
- Spins for BBH hard to measure due to mass ratio close to 1
- GW151226 had a least a BH with non-zero spin
- No much can be said about spin orientation

What did we learn in O1 - general relativity

- The two events allowed for the firsts tests of GR in a strong field dynamical regime
- Still not a precise test. Will require more events



What did we *not* learn about BHs

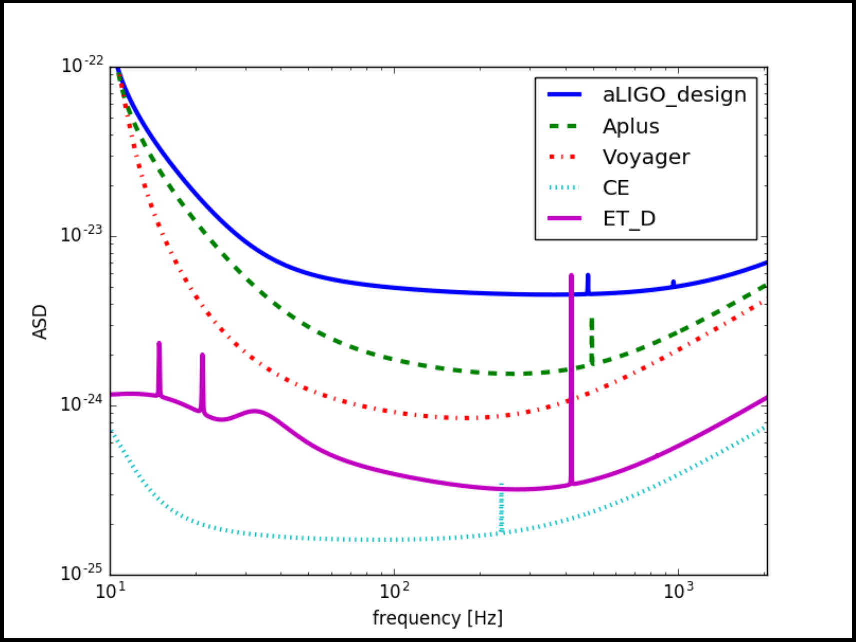
- Mass and spin distribution
- Could not exclude exotic objects (instead of BHs)
- Could not pinpoint to the astrophysical formation channel of the systems
- Did not probe cosmological distances
- Did not see effects of spin precession
- Did not see EM counterpart (if any was present…)
- To address these will take more time, or more detectors, or new detectors

Further ahead…

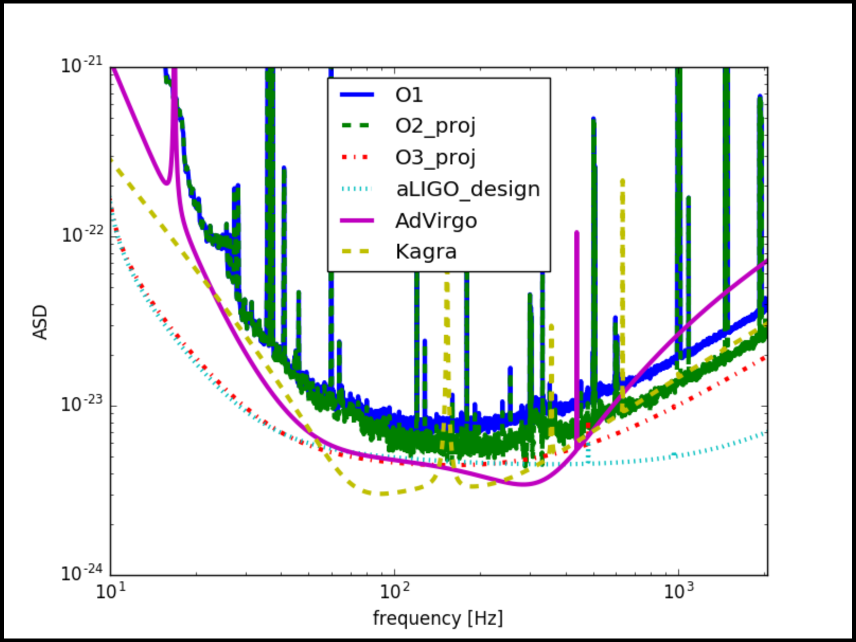
- Cosmic history
  - When did seed black holes form, how heavy were they and how did they grow?
  - What is the geometry, topology and dynamics of large scale structure in the Universe?
  - Did CBC produce most of the metals in the Universe?
- Extreme matter
  - What are the equation of state and internal structure of neutron stars?
  - How fast can black holes spin and how big can they get?
  - How do supernovae explode?
  - How do CBC form, and are they progenitors of short GRBs?
- Extreme gravity
  - Can we test the no hair theorem?
  - Can we probe the space-time around the horizon?
  - Is general relativity correct?

Further ahead…

A+, New facilities



2 G detectors



CBC formation channels

- The two most likely formation patterns for CBCs are:
  - Common envelope. The two objects were in a binary system from the very beginning -> aligned spins
  - Dynamical capture. The two objects were born independently, then met and formed a bound system -> isotropic spins
- If both channels happen, we can estimate the relative ratio
- 10% uncertainty with 200 events

Can be done starting in O2

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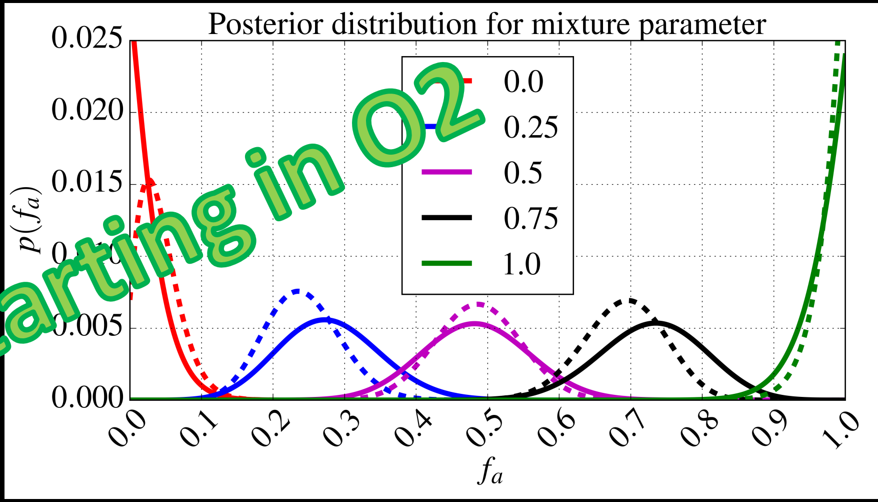


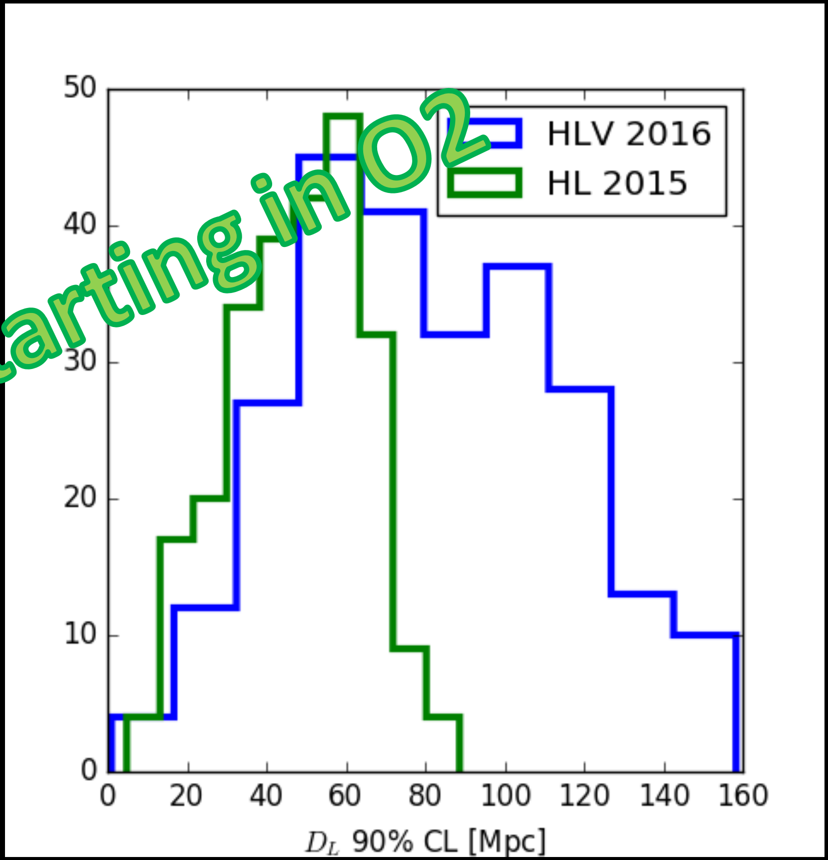
Intrinsic masses

- What we measure with GW are the redshifted masses

$$m_{det} = (1 + z) m_{source}$$

- GWs do not provide z, but luminosity distance
- In absence of EM counterpart, we need to calculate z by assuming a cosmology
- Uncertainties in distance will thus propagate to source masses
- Do we measure distances better with 3 detectors? No!

Data from 1404.5623

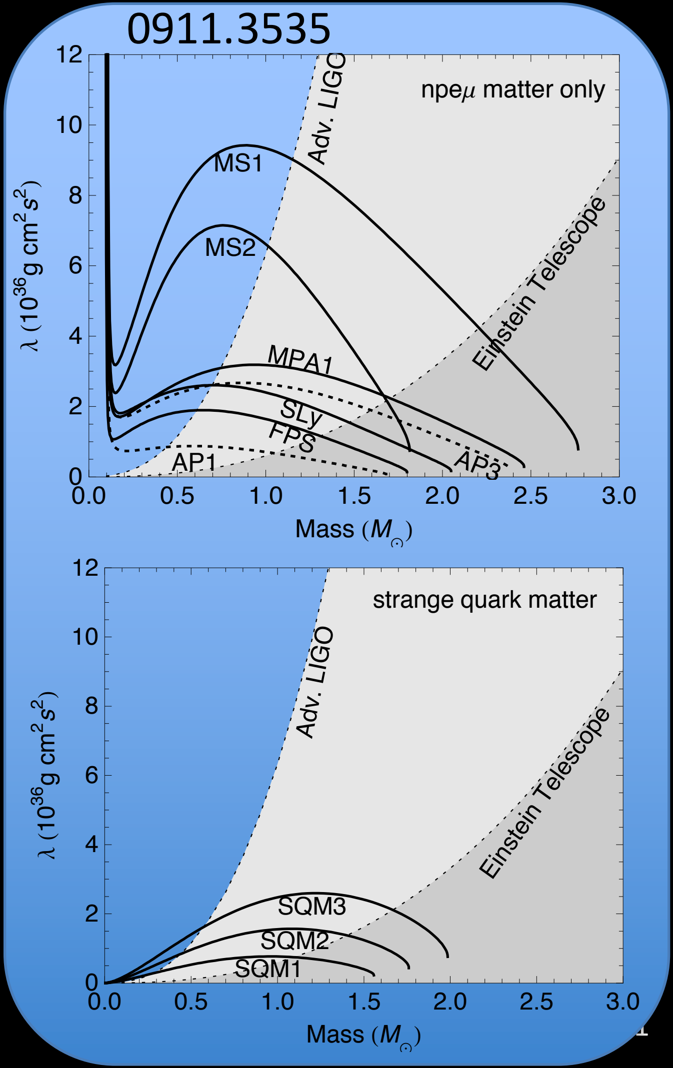


Can be done starting in O2

Neutron stars – equation of state

- CBC detections can be used to measure the equation of state of neutron stars
- EOS ranking could be done with second generation detectors if rate is high
  - Could exclude some extreme EOS
- EOS measurement will likely will happen when new facilities are online
  - Large collection of quiet events
  - Occasional loud events

O3 or later



Continuous wave sources

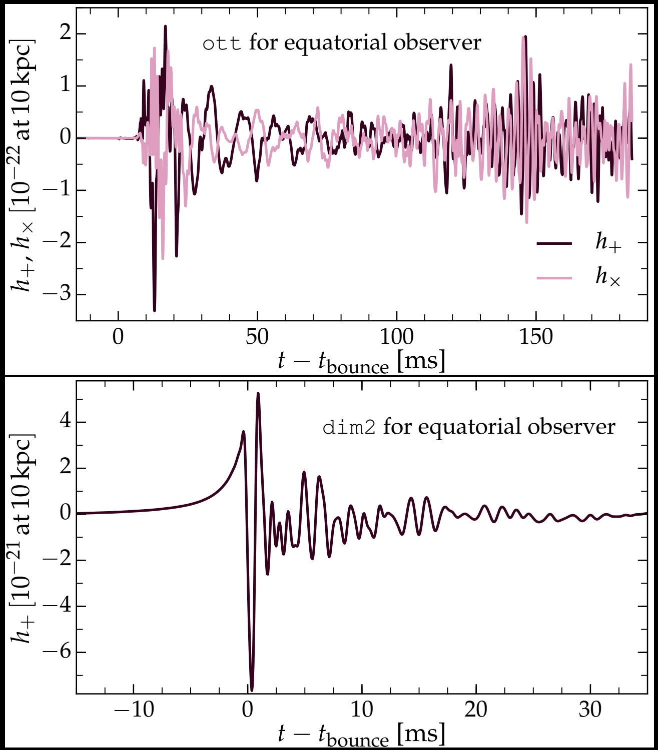
- Spinning neutron stars can have ellipticity and emit GWs
  - Their amplitude strongly depends on EOS
- A detection would provide the quadrupole moment
  - Ellipticity (requires EOS)
  - Differential rotation in the core
- Spin-down limit already beaten for a few pulsars
  - Will improve in the next science runs
  - Could exclude some EOS
- Detection could happen any time from O2 on, depending on EOS (note: O1 analysis not yet concluded!)

O2 or later

Core-collapse supernovae

- Huge potential impact on nuclear physics and astrophysics
  - Explosion mechanism
- GW rate and waveform very uncertain
- In many models, only galactic SNe would be detectable by 2G
  - Rate of ~1/century
- Third generation detectors could bring this up to ~few/year
- Until new facilities are online, it really boils down to luck…

O2 or later



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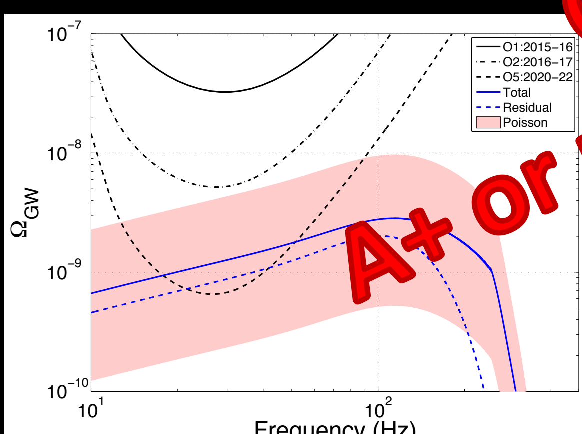
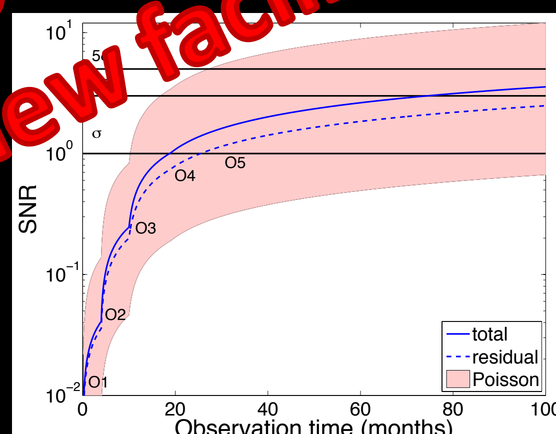
Stochastic background

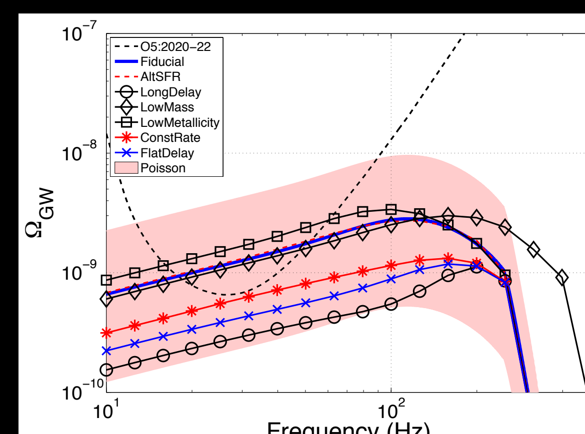
- The stochastic background made of all unresolvable BBH could be detectable already with 2G detectors
- Study of the stochastic signal can potentially help assessing metallicity, delay time and start formation rate of underlying population
  - Requires new facilities
- Background from inflation is a more ambitious goal

O4 for detection

A+ or new facilities for science







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Summary

Note: some of the searches in O1 data are not finished yet!

	BNS	NSBH	BBH
Detection	>= O2	>= O2	😀
Rates	>= O3	>= O3	>= O2
Mass distribution	>= O3	>= O3	Decent in O2
Spin distribution	>= O3	>= O3	>= O2
Formation channels	>= O3	>= O3	>= O2
EOS	> O3, A+, NF	> O3, A+, NF	??
EM connection	> O3	> O3	O2 w/ Virgo?
Detection at z>1	NF	NF	O3
Tests of GR	>=O2	>=O2	😅

NF= new facilities (CE, ET)

	CC SNe	Other bursts
Detection	O2 - NF	O2- NF
Mechanism	From 1st detection	??
Mass → GW efficiency	From 1st detection	??

	BBH bgd	Primordial bgd
Detection	O4, A+, NF	>>> NF
Population studies	A+, NF	Not Relevant

	Targeted CW	Blind CW
Detection	O2 – NF	O2 – NF
Ellipticity/EOS	From 1st detection	From 1st detection
Population studies	Not relevant	A+, NF

- Acknowledge very useful discussions with B. Sathyaprakash, S. Fairhurst, R. Adhikari, M. Evans, D. Sigg, M. Zucker, C. Palomba, M. Zanolin, Y. Chen