COMPARISON OF PARAMETER ESTIMATION BETWEEN ET-B AND ET-C SENSITIVITIES

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Topics

Cosmology

- Infer characteristics of the universe
- Measured parameters

$$\left(\Omega_M, \Omega_\Lambda, \Omega_k, w_0, w_a\right)$$

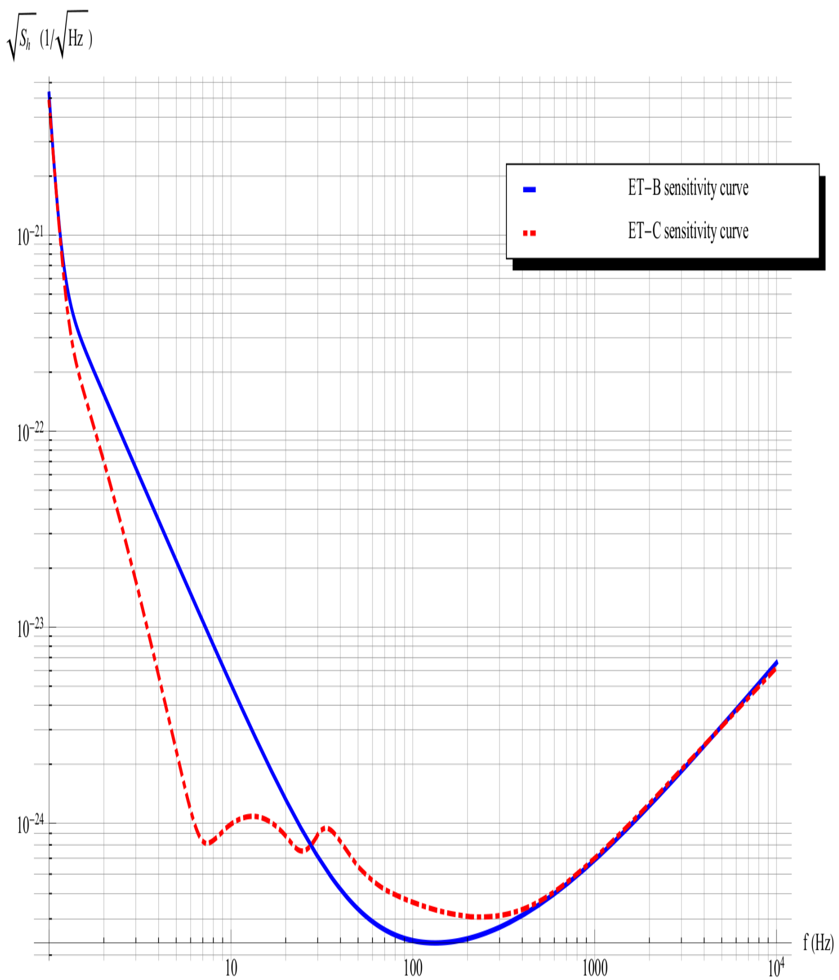
Testing General Relativity

- Test GR through its phase evolution
- Measured parameters

$$\left(\phi_0, \phi_2, \phi_3, \ldots\right)$$

Compare parameter estimation for different Einstein Telescope design studies

Design Sensitivities



- ET-B
  - Single 3rd generation broadband detector
- ET-C: Xylophone
  - 2 band interferometer
  - high-power, high-frequency
  - cryogenic low-power, low-frequency

Cosmography

Infer characteristics of the universe by observing coalescing binary neutron stars

Cosmology

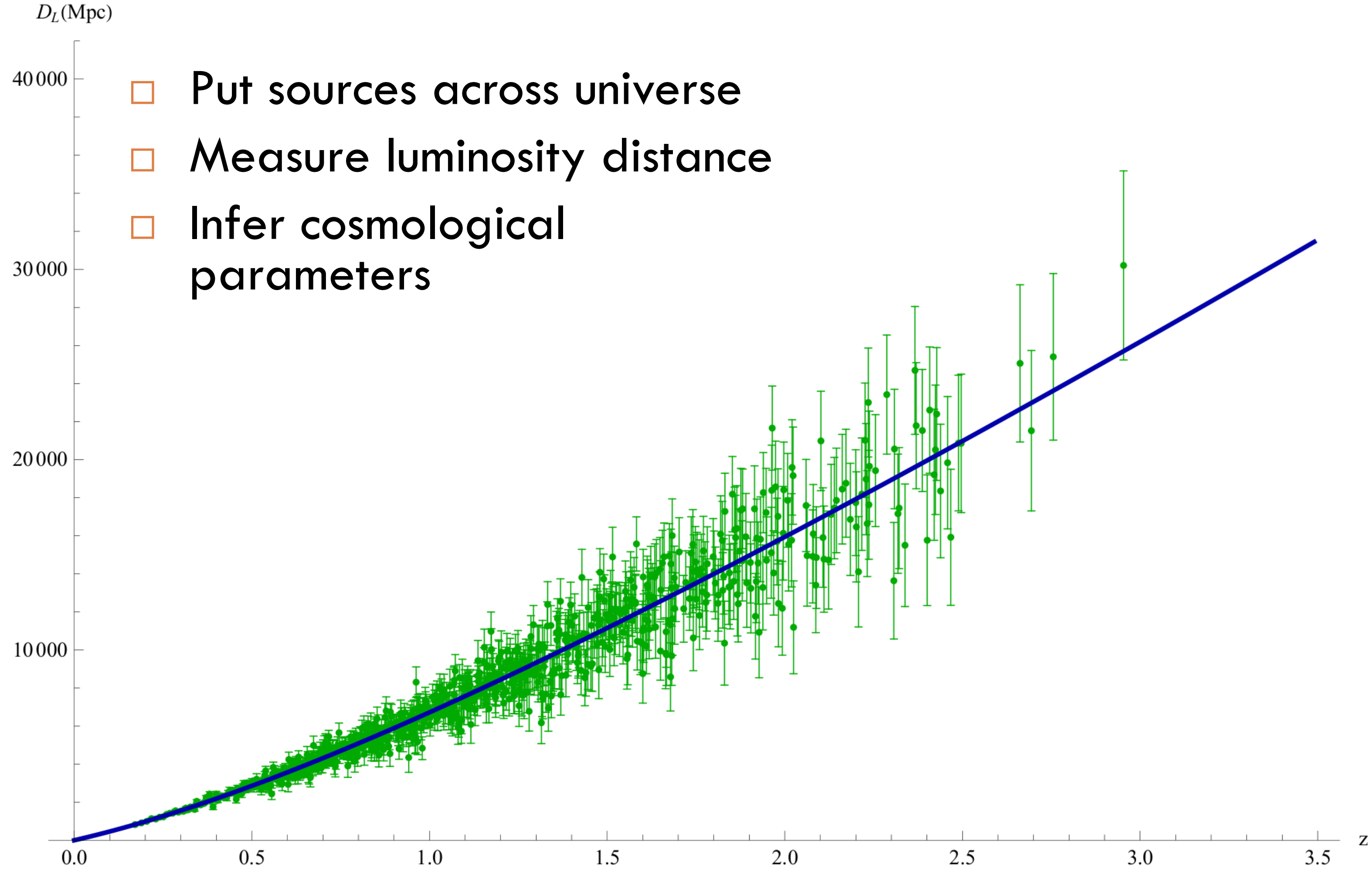
- Infer characteristics of the universe
  - GW signal carries information about content of the universe between source and observer
  - Information encoded in the luminosity distance

$$d_L = d_L(z; \Omega_M, \Omega_\Lambda, \Omega_k, w_0, w_a)$$

- Measure set of parameters
  - Ω_i densities
  - w_i dark energy equation of state

Measure cosmological parameters

- Put sources across universe
- Measure luminosity distance
- Infer cosmological parameters

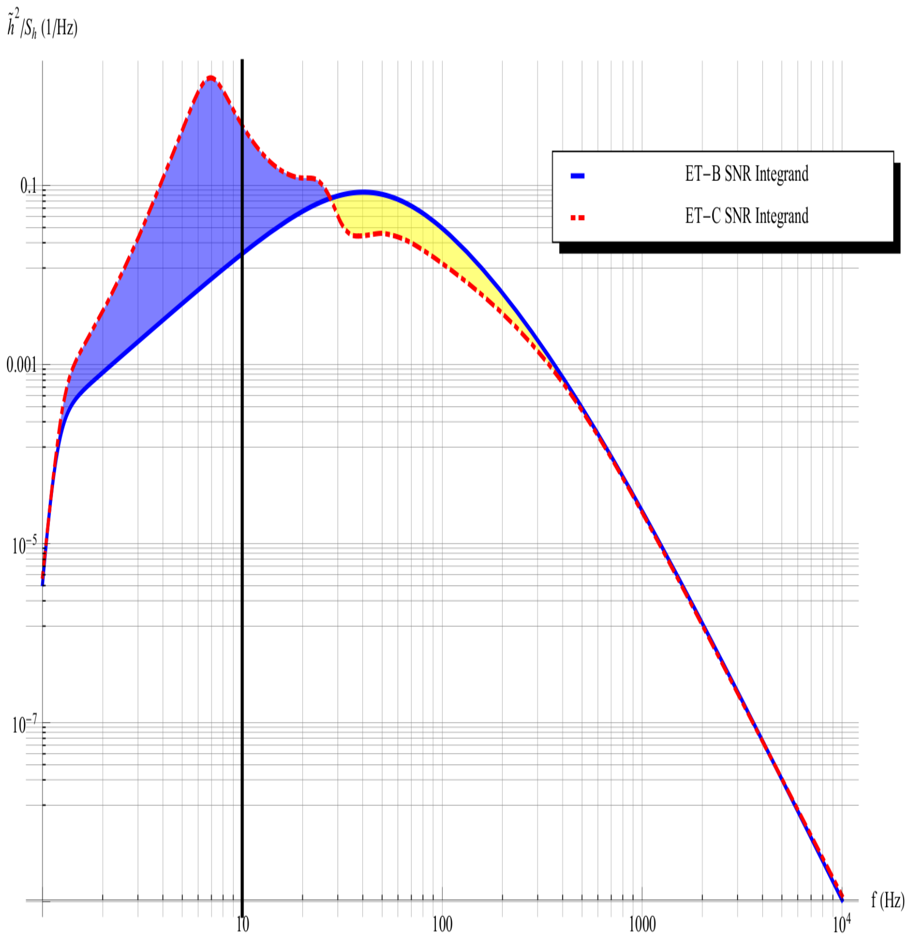


Trade Study

Model	Ω_M	Ω_{DE}	Ω_k	w_0	w_1
Ω_M, Ω_{DE}, Ω_k, w_0, w_1	1.215	1.005	1.049	1.050	1.057
Ω_M, Ω_{DE}, Ω_k	1.298	1.207	1.228	–	–
Ω_M, Ω_{DE}, w_0, w_1	1.104	1.096	–	1.186	1.207
Ω_M, Ω_{DE}, w_0	1.162	1.162	–	1.164	–
Ω_M, Ω_{DE}	1.178	1.178	–	–	–
w_0, w_1	–	–	–	1.158	1.183
w_0	–	–	–	1.151	-
Average relative improvement:	-15.11%				

- Ratio of root mean square errors (ET-C/ET-B)
- Lower cut-off frequency 10Hz

Discussion



- Advantage of ET-C comes in at lower frequencies
  - At 10Hz, higher SNR for ET-B due to better sensitivity for >30Hz
  - Need to go below 10Hz to gain full potential of ET-C

Conclusions

Cosmology

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w_0, w_1	–	–	–	1.158	1.183
w_0	–	–	–	1.151	-
Average relative improvement:	−15.11%				

10Hz

Model	Ω_M	Ω_{DE}	Ω_k	w_0	w_1
Ω_M, Ω_{DE}, Ω_k, w_0, w_1	0.813	0.992	0.967	0.923	0.989
Ω_M, Ω_{DE},Ω_k	0.777	0.826	0.810	–	–
Ω_M, Ω_{DE}, w_0, w_1	0.877	0.884	–	0.828	0.833
Ω_M, Ω_{DE}, w_0	0.815	0.815	–	0.830	–
Ω_M, Ω_{DE}	0.849	0.849	–	–	–
w_0, w_1	–	–	–	0.858	0.842
w_0	–	–	–	0.863	–
Average relative improvement:	13.75%				

5Hz

Model	Ω_M	Ω_{DE}	Ω_k	w_0	w_1
Ω_M, Ω_{DE}, Ω_k, w_0, w_1	0.805	0.993	0.967	0.914	0.969
Ω_M, Ω_{DE},Ω_k	0.765	0.816	0.799	–	–
Ω_M, Ω_{DE}, w_0, w_1	0.872	0.879	–	0.821	0.820
Ω_M, Ω_{DE}, w_0	0.804	0.804	–	0.819	–
Ω_M, Ω_{DE}	0.838	0.838	–	–	–
w_0, w_1	–	–	–	0.850	0.834
w_0	–	–	–	0.854	–
Average relative improvement:	14.66%				

1Hz

- Parameter estimation lower cut-off frequency
  - 10Hz not sufficient to probe full extend of ET-C
  - Only if f_{low} ~ 5Hz, will ET-C be beneficial for parameter estimation

Testing General Relativity

Checking consistency between post-Newtonian phase coefficients

Post Newtonian Formalism

- General form of waveforms in Post-Newtonian (PN) formalism
  - Both amplitude and phase expanded in v/c

$$h(t;\vec{\theta}) = \sum_{n=1}^{N_H}\sum_{k=0}^{K} A_{nk}(t)\cos(n\Phi(t) + \phi_{nk})$$

- Phase evolution represented as

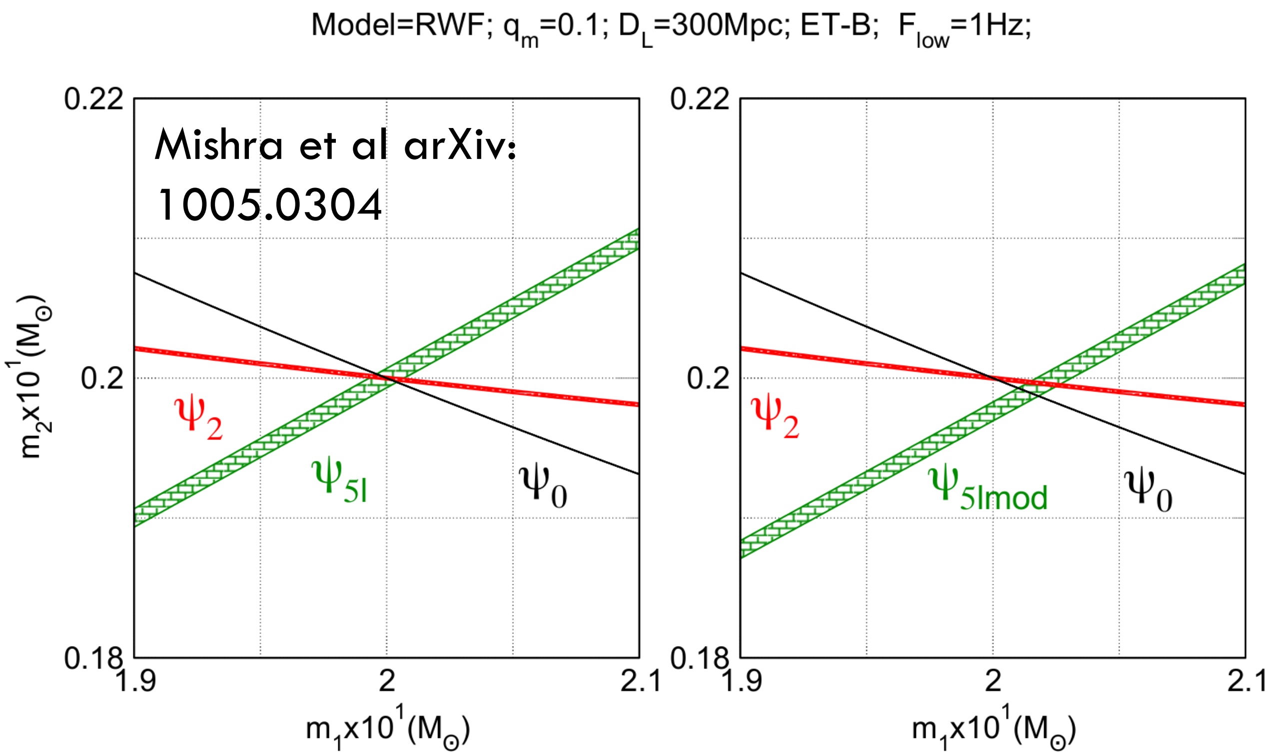
$$\Phi(t) = \phi_c - \sum_{l=0}^{L} \phi_l (t_c - t)^{(5-l)/8} \quad where \quad \phi_l = \phi_l(m1, m2)$$

- Similar in frequency domain (e.g. SPA)

$$h(f;\vec{\theta}) = A(f) e^{i\Psi(f)} \qquad \Psi(f) = 2\pi f t_c - \phi_c + \sum_{l=0}^{L} \psi_l f^{(l-5)/3}$$

Testing General Relativity: Concept

Arun et al. 2006

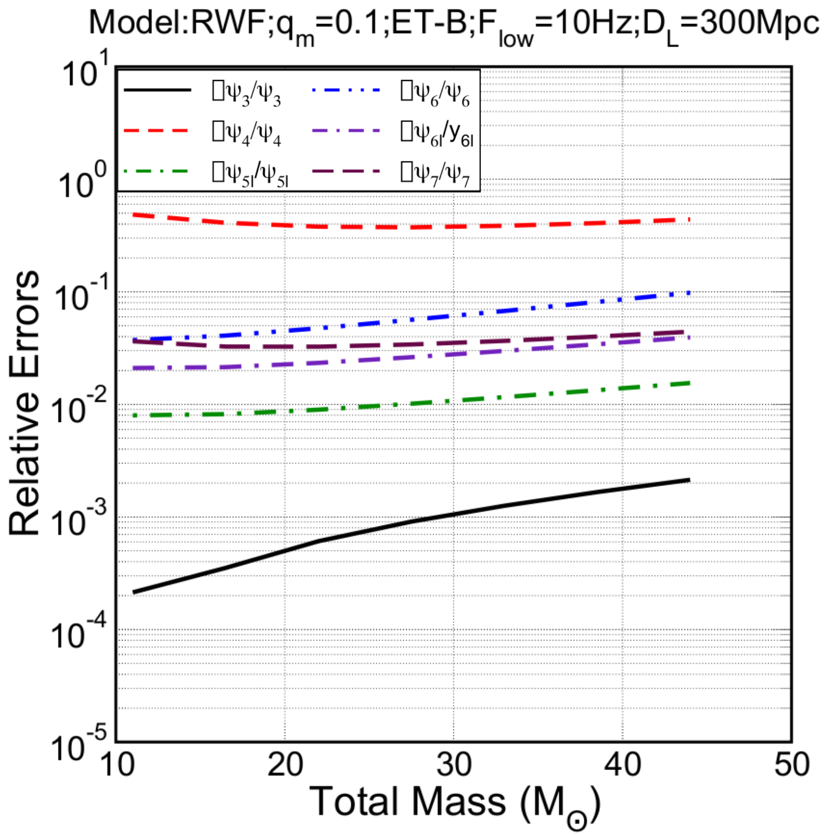


- In GR, only two phase coefficients independent
- Assume spinless systems

- Measure ϕ_0, ϕ_2, ϕ_T independently
- Check for consistency between PN phase coefficients

Frequency Domain Coefficients

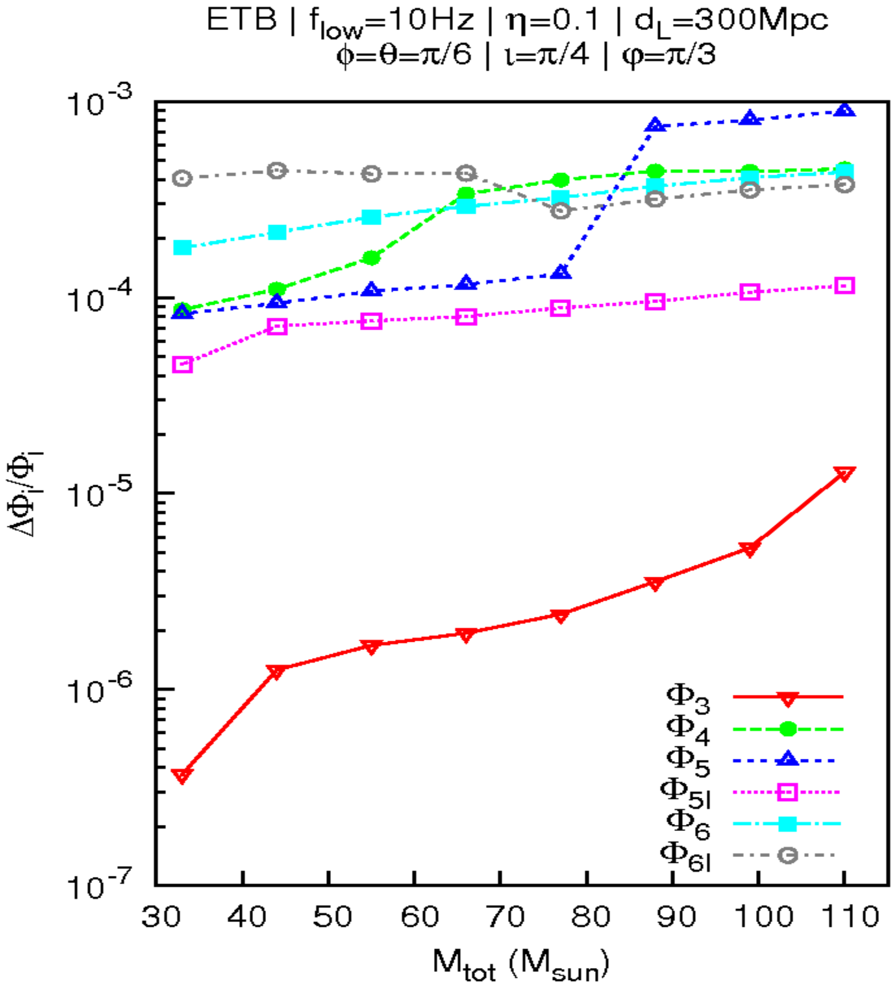
- Proposed test explored in frequency domain
  - Using SPA waveforms
  - ETB shown
- Shows validity of scheme
  - Errors for ψ_3~0.01%
  - Greater errors for ψ_k, k>3 (1%-100%)



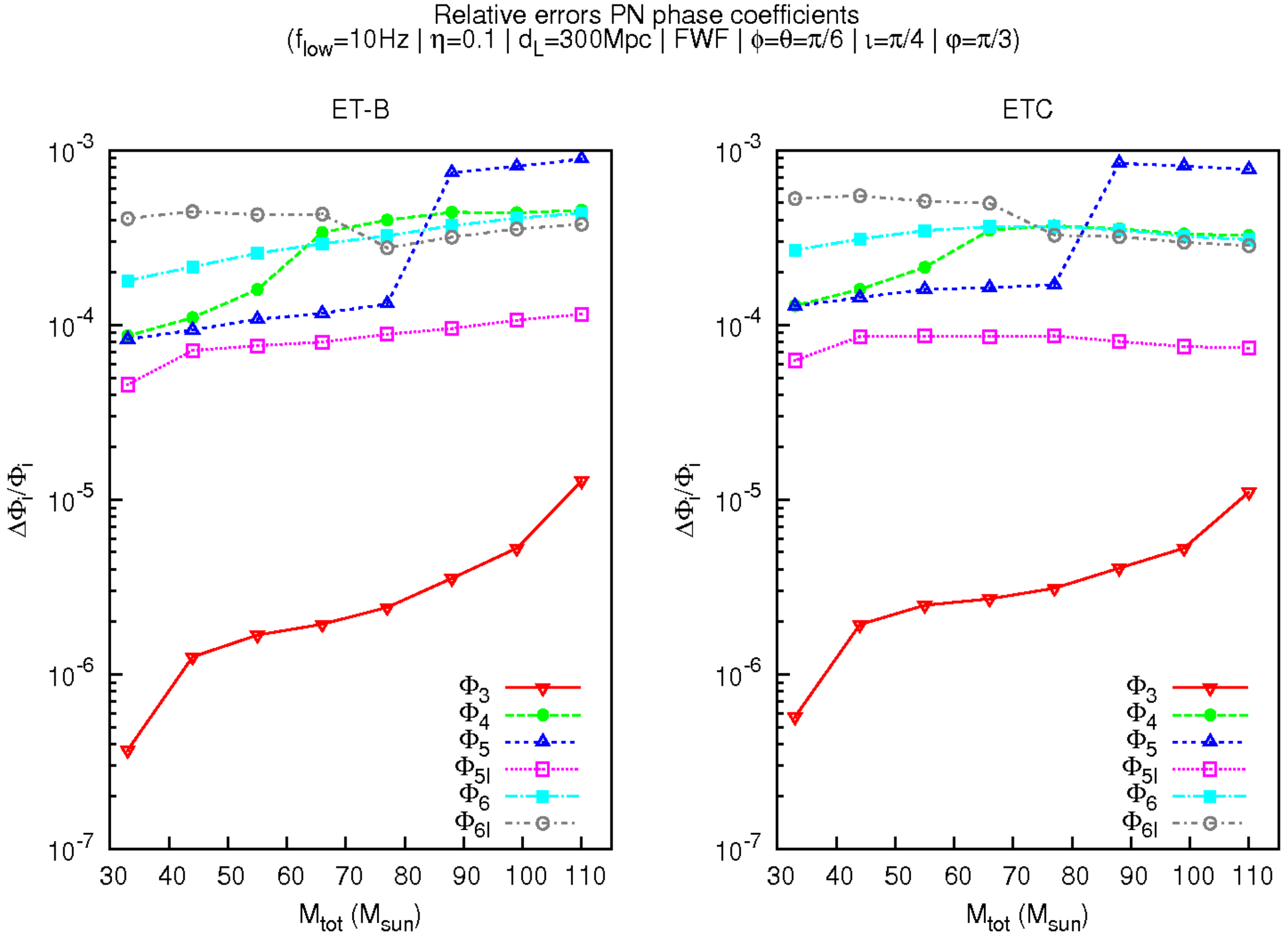
Mishra et al arXiv:1005.0304

Time Domain Coefficients

- Similar can be done for time domain phase coefficients
  - ϕ_i instead of ψ_i
- Time domain parameterisation shows better perfomance
  - ~50x better relative sensitivity
  - Yet to understand in full detail

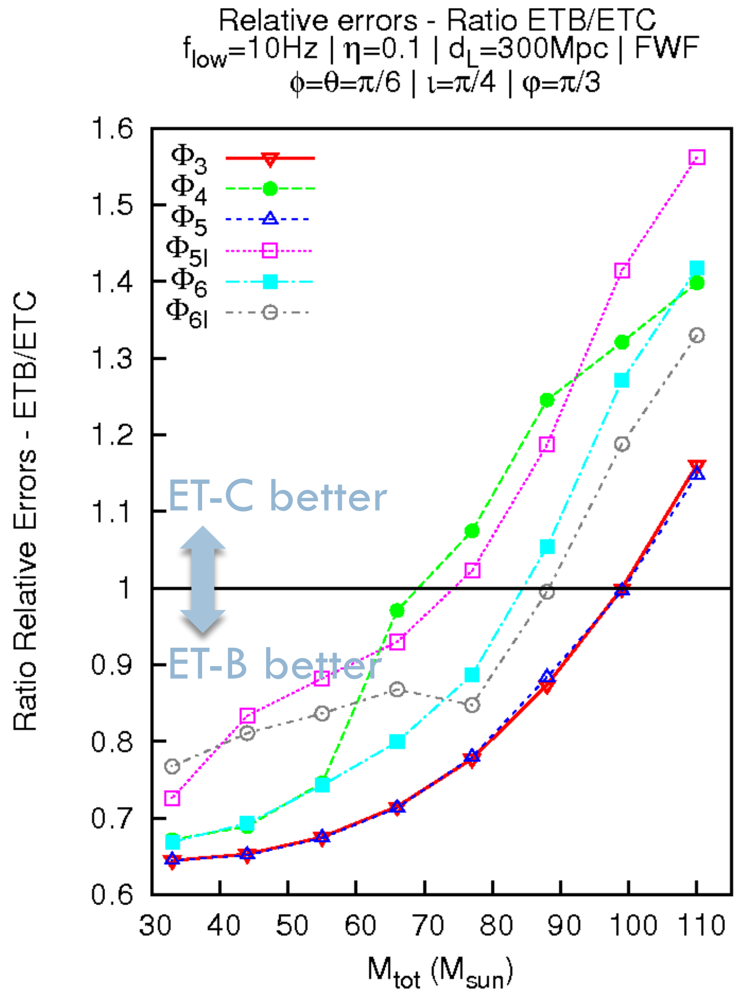


Trade Study



Relative errors PN phase coefficients
(f_low=10Hz | η=0.1 | d_L=300Mpc | FWF | ϕ=θ=π/6 | ι=π/4 | φ=π/3)
ET-B
ETC
ΔΦi/Φi
Mtot (Msun)
10^-3
10^-4
10^-5
10^-6
10^-7
30 40 50 60 70 80 90 100 110
Φ3
Φ4
Φ5
Φ5l
Φ6
Φ6l

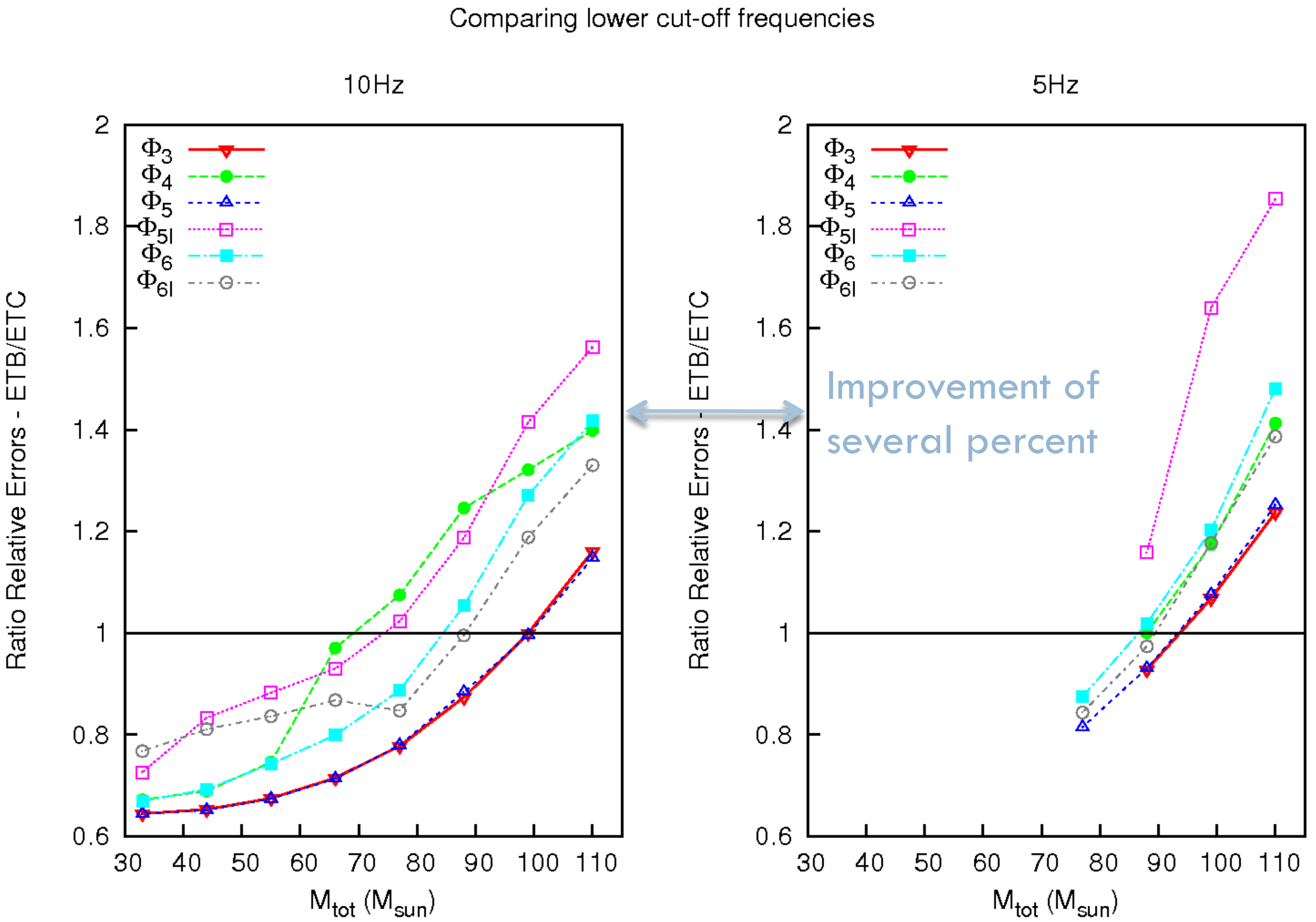
Discussion



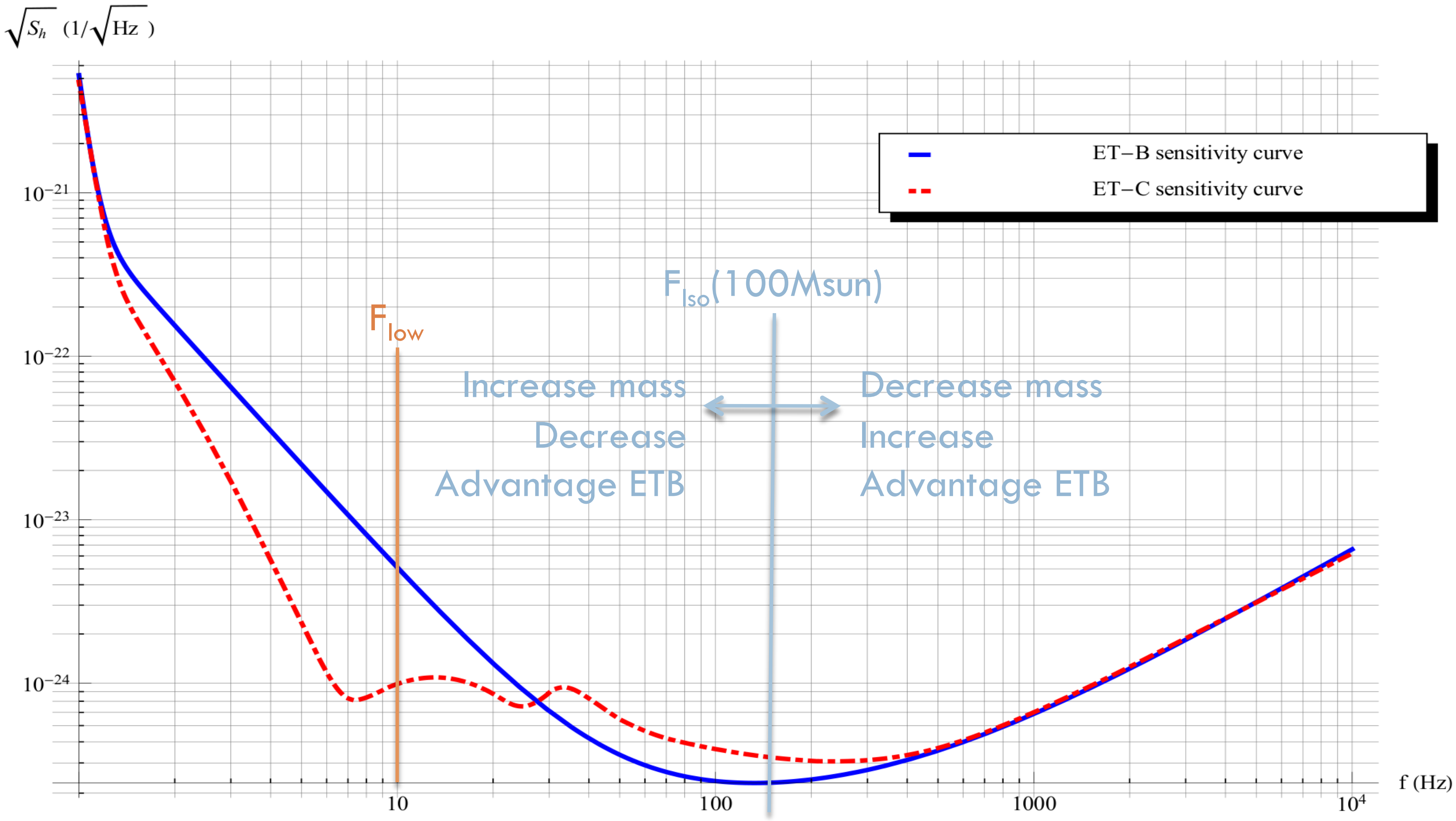
- ET-C performs better than ET-B in the high mass region
  - FIso decreases with mass
- Difference as large as 40%
- Transition around 70-90 Msun

Best performance depends on the sources of interest

Discussion 2



Discussion 3



Concluding Remarks

- Cosmology doesn't benefit from ET-C if lower cut-off is set to 10Hz
- Testing General Relativity only benefits at high total mass systems
- All can be attributed to sensitivity loss between 30Hz-500Hz

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Full benefits of ET-C are only used if the lower cut-off frequency can be pushed down to below 10Hz

Backup Slides

If the talk did not provide sufficient detail