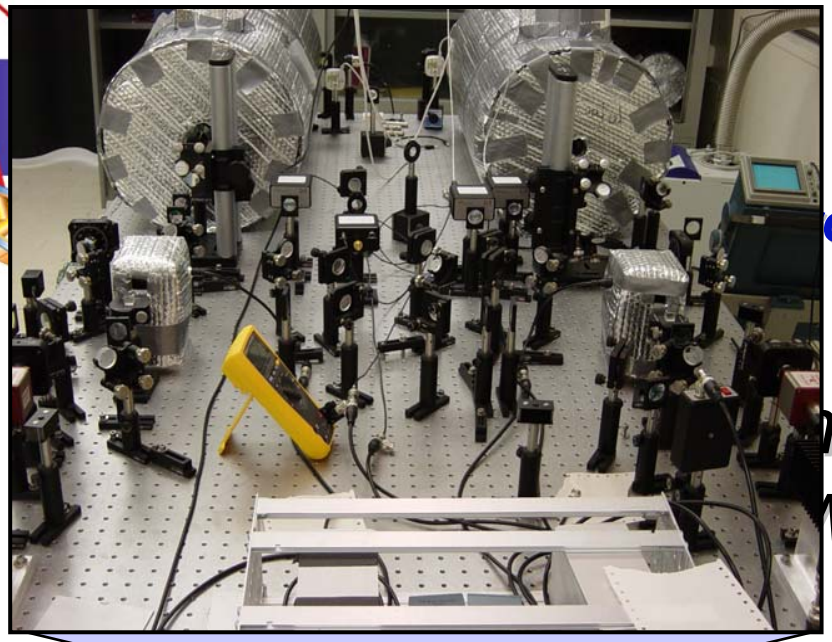
The "Lab"



om the Big Bang to Black Holes

# mation using Numerical Waveforms

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7th International LISA Symposium

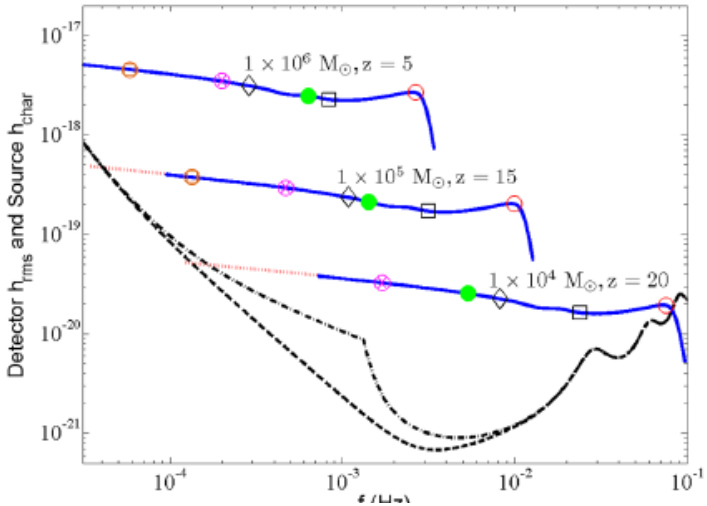
July 19th, 2008

Barcelona, Spain

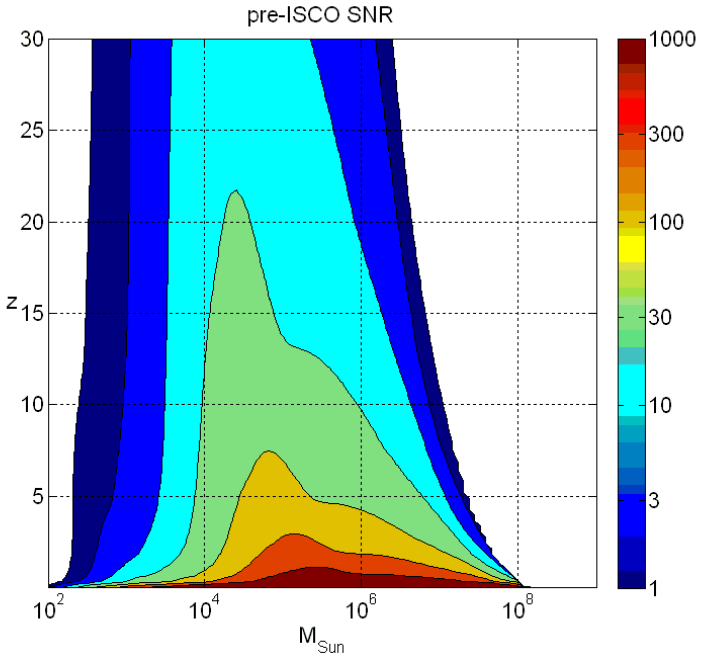
GSFC - JPL

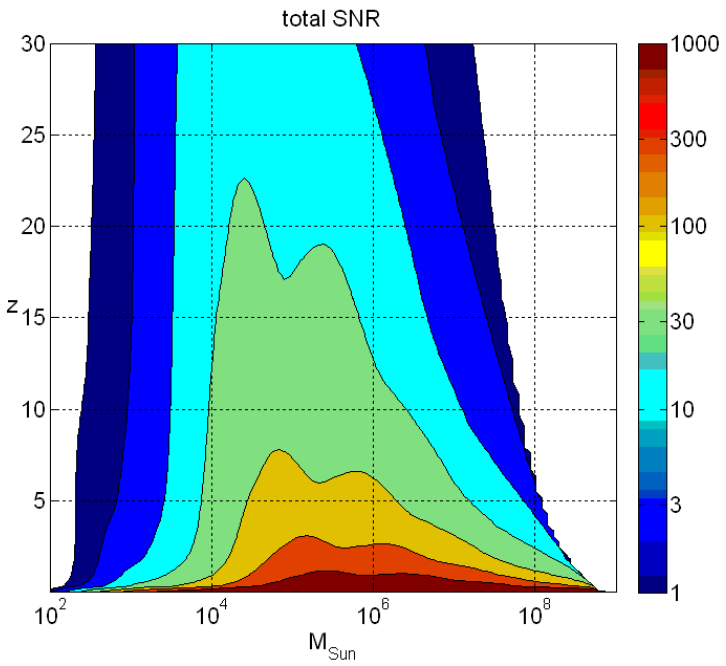
# Significance of Merger Signal

- Merger makes significant contribution to SNR
  - Depends on $M_{tot}$
  - Depends on distance/redshift



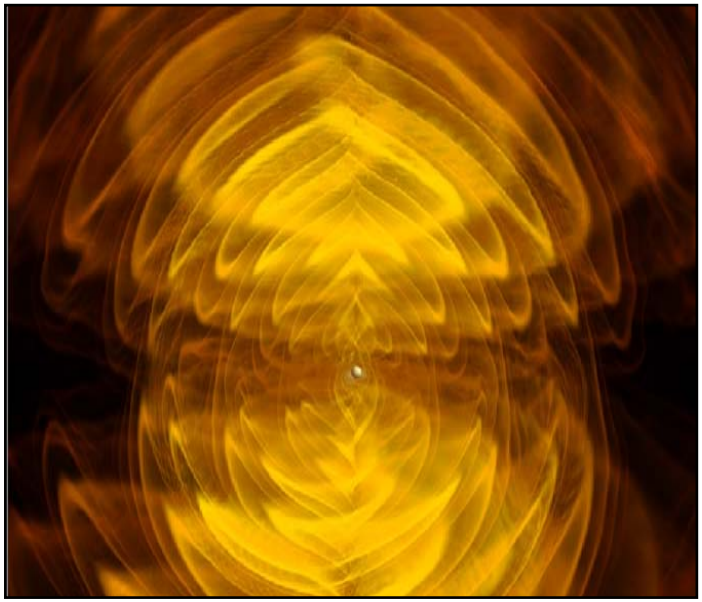

**SNR contours for equal-mass, non-spinning case**



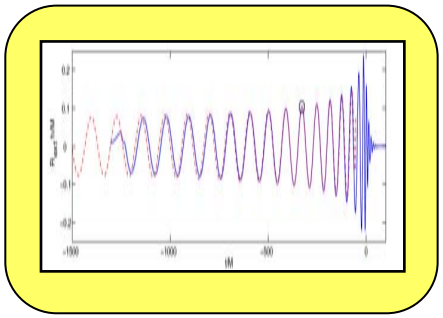
# Effect on Parameter Estimation

- Traditional thought
  - Despite high SNR, merger is short-lived
  - Little orbital modulation
  - Small impact on parameter estimation
- Possible paths for impact
  - Direct
  - Covariance

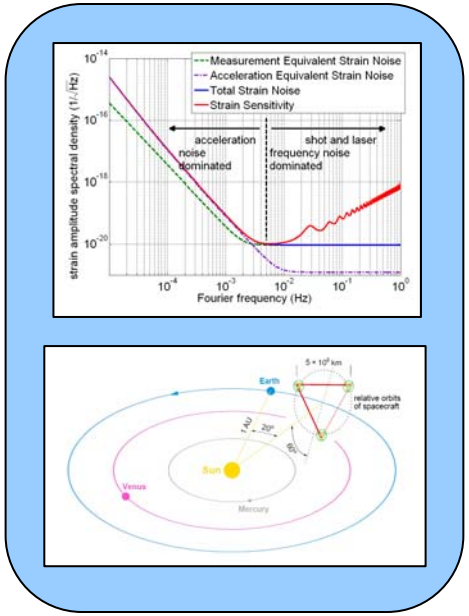


# Goals

- Develop Parameter Estimation Code for Full Waveform
  - Complete inspiral, merger, and ringdown waveform
  - High-frequency instrumental response & noise
  - Fisher matrix approach



**Waveform Model**




**Instrument Model**

$$\Gamma_{ab} = \left( \frac{\partial h}{\partial \theta^a} \middle| \frac{\partial h}{\partial \theta^b} \right)$$

$$(a|b) = 4\,\mathrm{Re} \int_0^\infty df \frac{\tilde{a}^*(f)\tilde{b}(f)}{S_n(f)}$$

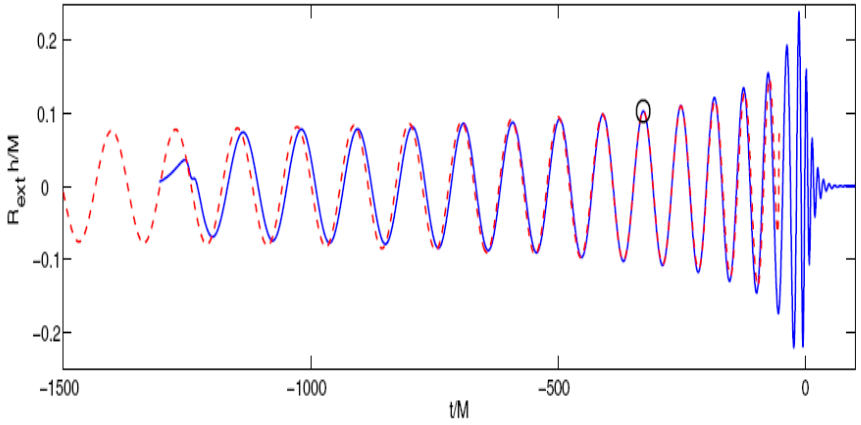
$$\Delta\theta^a \equiv \sqrt{\langle (\delta\theta^a)^2 \rangle} = \sqrt{\Sigma^{aa}}\,.$$

**Fisher Matrix**

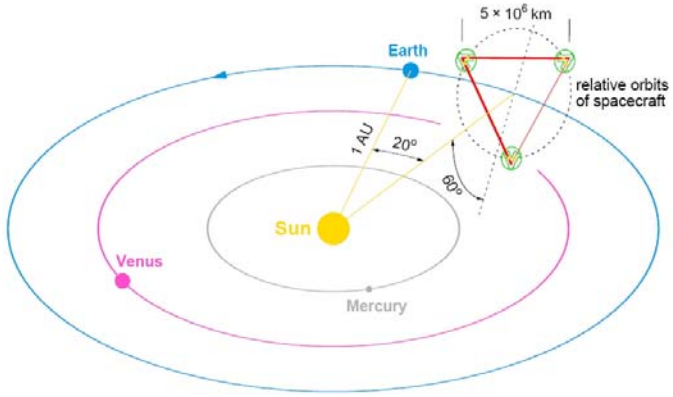
# Modeling

- Waveform Model
  - Combined numerical & PN
  - Equal mass, non-spinning
  - Can be scaled to generate set of templates

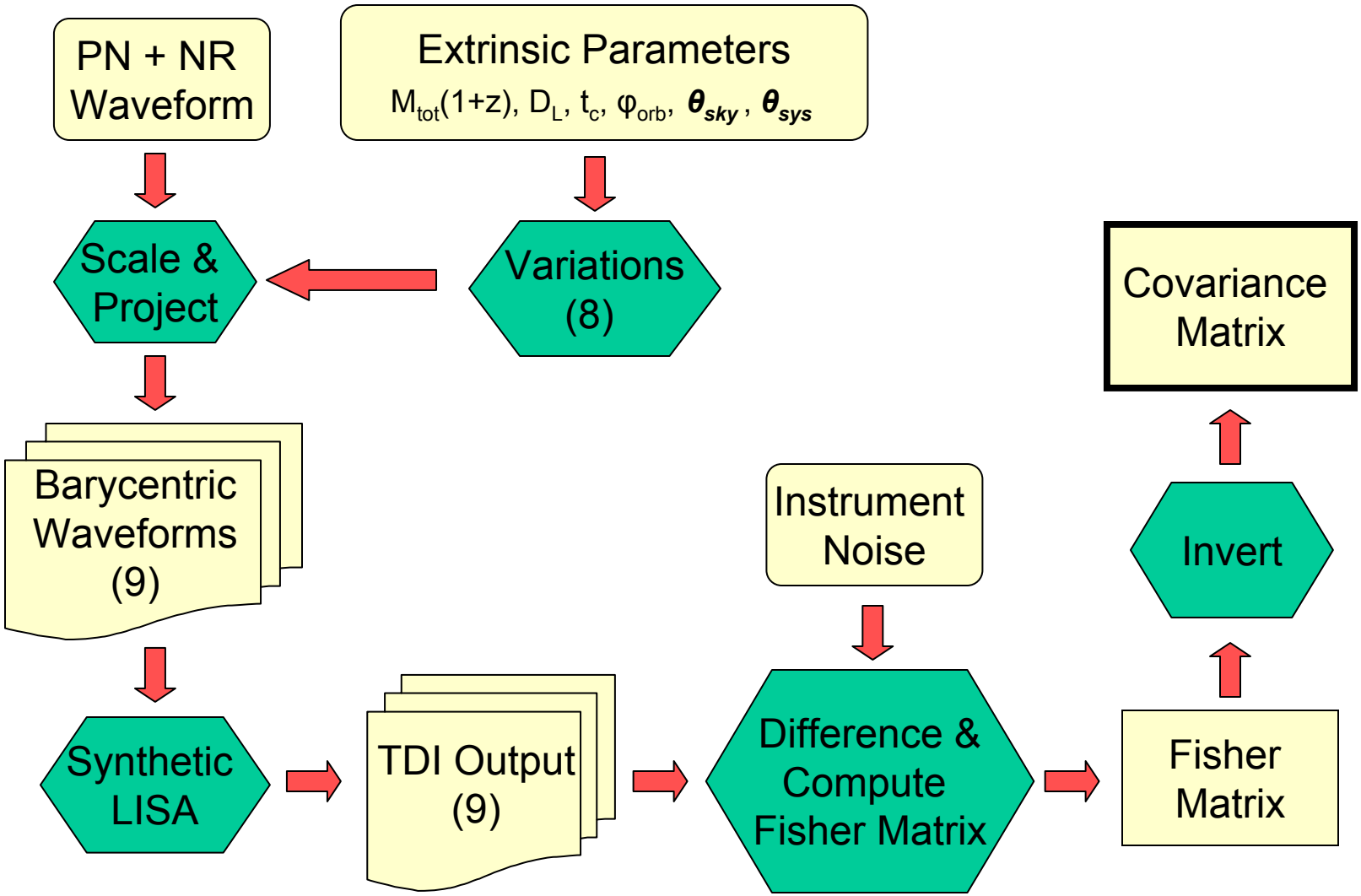
$M_{tot}(1+z)$, $D_L$, $t_c$, $\varphi_{orb}$, $\boldsymbol{\theta_{sky}}$ , $\boldsymbol{\theta_{sys}}$




- Instrument Modeling
  - Synthetic LISA (Vallisneri)
  - Realistic orbital model
  - TDI outputs (pseudo A,E,T)
  - Instrumental noise

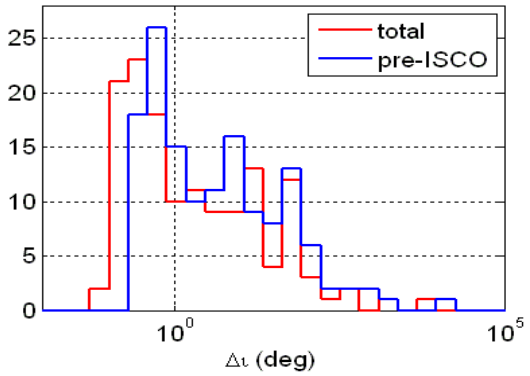


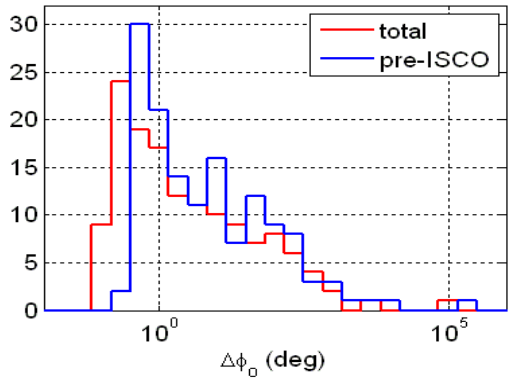
# Parameter Sensitivity Calculation

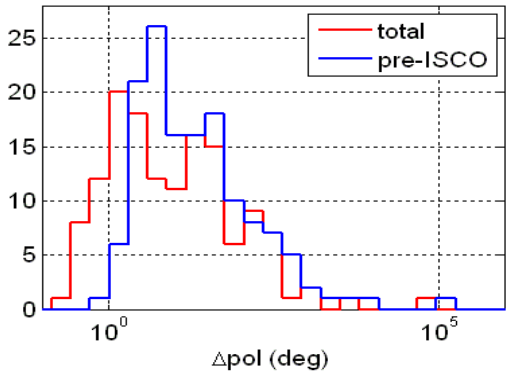


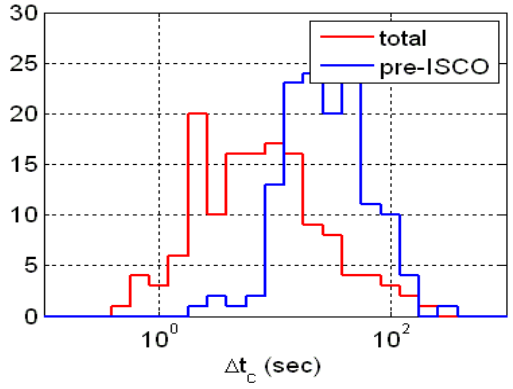
# Results: $M_{tot}(1+z)\sim10^6\ M_\odot$

- Two 2.5 x $10^5$ $M_\odot$ non-spinning BH at z = 1 (~ 6 GPc), 140 cases, pseudo A & E channels only



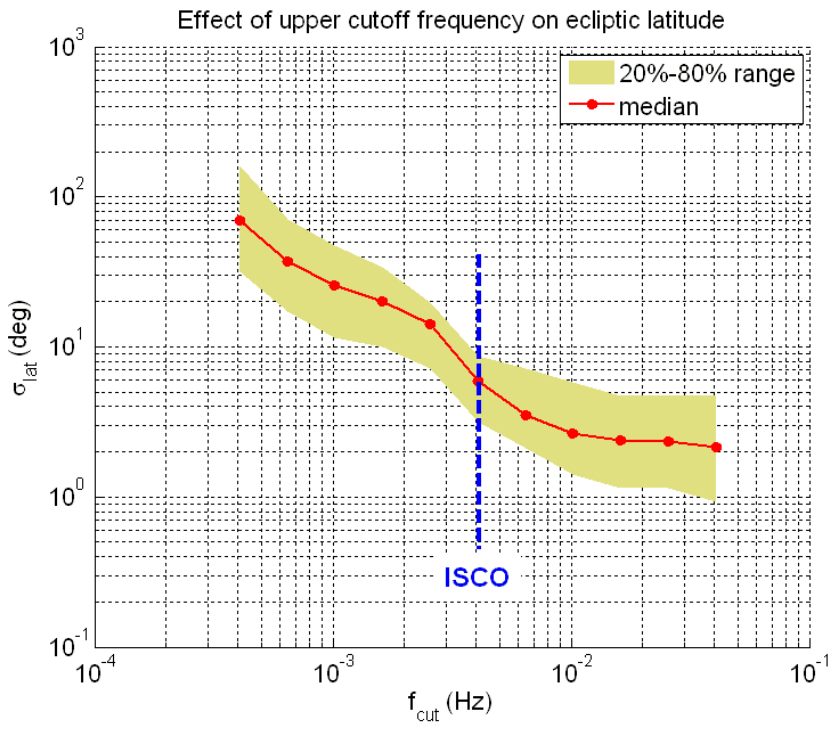
# Results: $M_{tot}(1+z)\sim10^6\ M_\odot$

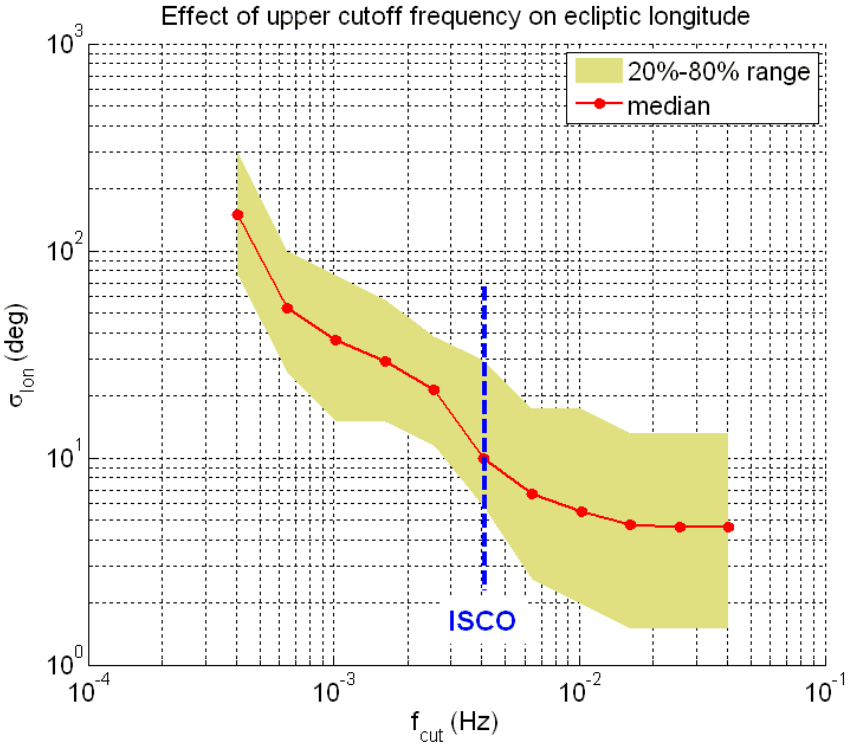
- Two 2.5 x $10^5$ $M_\odot$ non-spinning BH at z = 1 (~ 6 GPc), 140 cases, pseudo A & E channels only

| | Total Mean | pre-ISCO Mean | Total Median | pre-ISCO Median |
|---|---|---|---|---|
| **SNR** | 1.12E+03 | 8.35E+02 | 9.28E+02 | 6.98E+02 |
| **ΔlnM** | 2.35E-06 | 4.00E-06 | 1.66E-06 | 3.26E-06 |
| **ΔD/D** | 3.87E-01 | 6.07E-01 | 4.48E-02 | 1.18E-01 |
| **Δlat (deg)** | 3.84E+00 | 7.19E+00 | 2.15E+00 | 5.28E+00 |
| **Δlon (deg)** | 1.77E+01 | 2.69E+01 | 4.64E+00 | 9.19E+00 |
| **Δiota (deg)** | 8.19E+01 | 1.37E+02 | 1.08E+00 | 3.12E+00 |
| **Δphio (deg)** | 6.07E+02 | 1.27E+03 | 1.59E+00 | 4.26E+00 |
| **Δpol (deg)** | 6.20E+02 | 1.29E+03 | 7.46E+00 | 1.59E+01 |
| **Δtc (sec)** | 1.71E+01 | 3.95E+01 | 6.87E+00 | 2.73E+01 |

# Evolution of Parameters

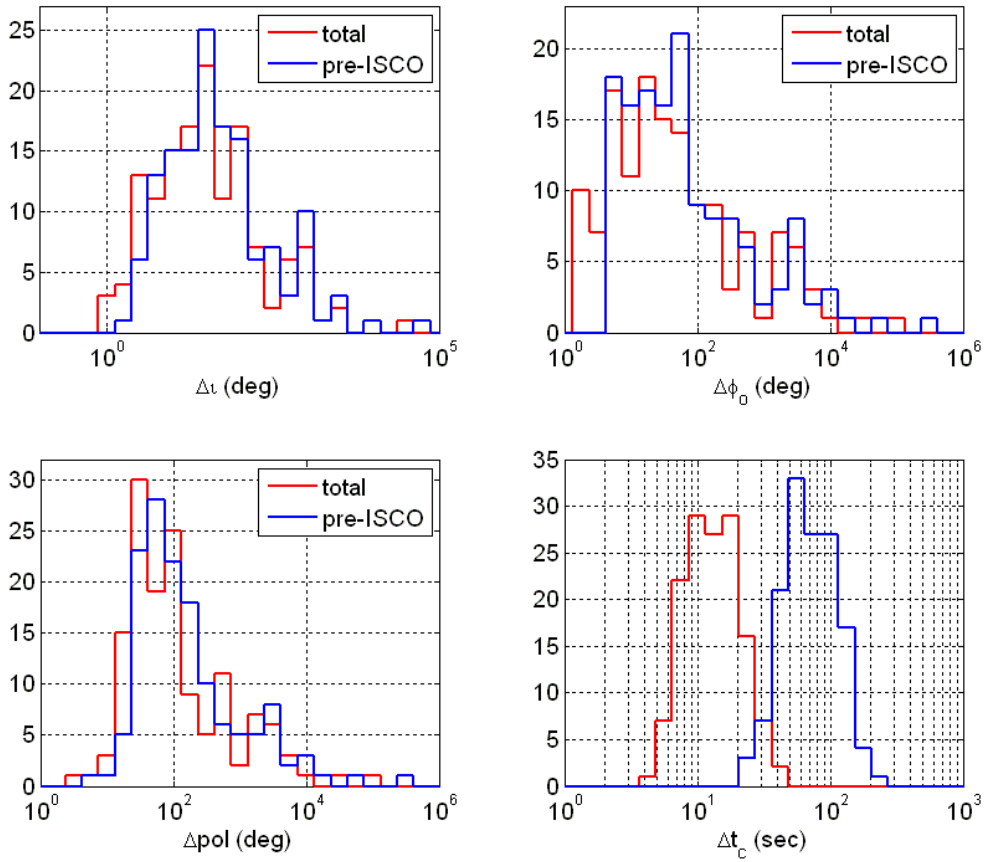
- Two 2.5 x $10^5$ $M_\odot$ non-spinning BH at z = 1 (~ 6 GPc), 140 cases, pseudo A & E channels only



# Results: $M_{tot}(1+z)\sim10^7\ M_\odot$

- Two 2.5 x $10^6$ $M_\odot$ non-spinning BH at z = 1 (~ 6 GPc), 140 cases, pseudo A & E channels only



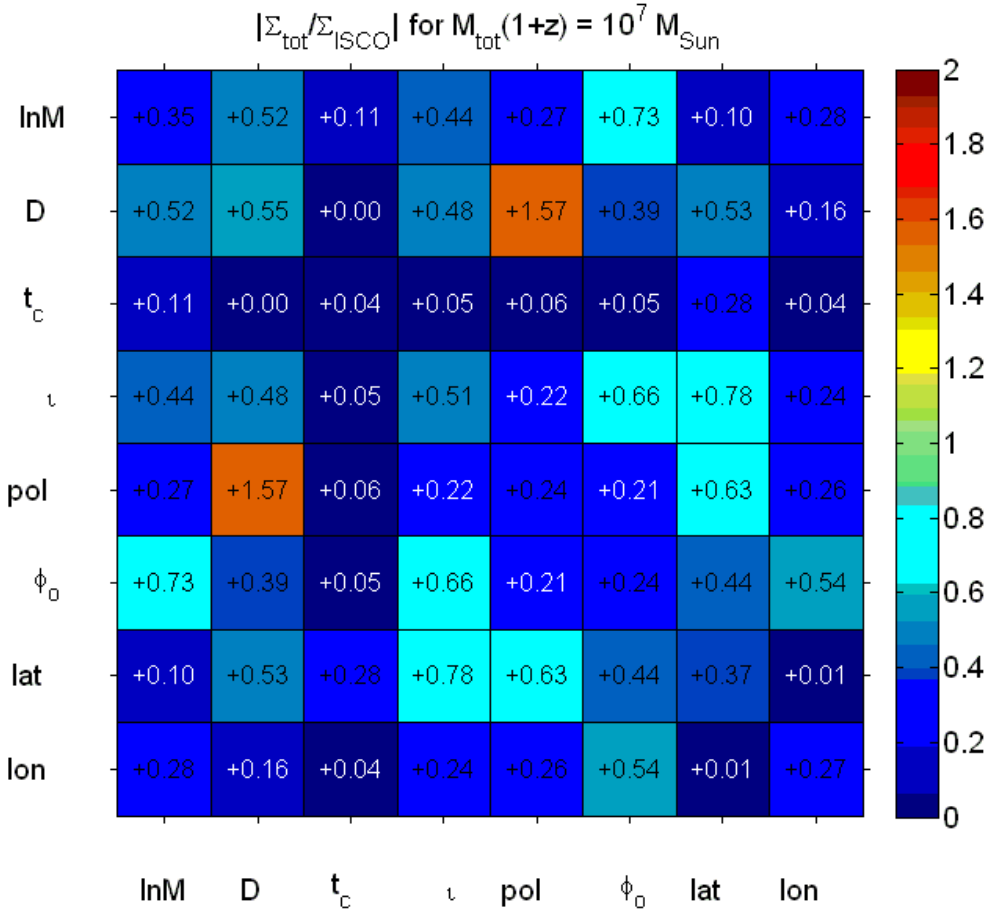
# Results: $M_{tot}(1+z)\sim10^7\ M_\odot$

- Two 2.5 x $10^6$ $M_\odot$ non-spinning BH at z = 1 (~ 6 GPc), 140 cases, pseudo A & E channels only

| | Total Mean | pre-ISCO Mean | Total Median | pre-ISCO Median |
|---|---|---|---|---|
| **SNR** | 9.85E+01 | 2.68E+01 | 8.52E+01 | 2.29E+01 |
| **ΔlnM** | 1.55E-06 | 2.66E-06 | 1.01E-06 | 1.89E-06 |
| **ΔD/D** | 2.17E+00 | 2.83E+00 | 8.04E-01 | 1.07E+00 |
| **Δlat (deg)** | 2.24E+01 | 3.35E+01 | 1.98E+01 | 2.76E+01 |
| **Δlon (deg)** | 5.84E+01 | 1.03E+02 | 2.20E+01 | 3.51E+01 |
| **Δiota (deg)** | 9.65E+00 | 2.52E+01 | 5.88E-01 | 1.40E+00 |
| **Δphio (deg)** | 1.58E+03 | 2.80E+03 | 3.33E+01 | 4.39E+01 |
| **Δpol (deg)** | 1.62E+03 | 2.87E+03 | 7.99E+01 | 1.11E+02 |
| **Δtc (sec)** | 1.47E+01 | 7.72E+01 | 1.31E+01 | 6.85E+01 |

# Results: $M_{tot}(1+z)\sim10^7\ M_\odot$

- Changes in Covariance as merger is added
  - Most covariances decrease, merger is breaking degeneracies
  - Some covariances increase
  - Strong impact on coalescence time



# Summary

- Developed parameter estimation model integrating complete waveforms and improved instrumental models
- Initial results for equal-mass non-spinning systems indicate moderate improvement in most parameters, significant improvement in some
- Near-term improvement
  - Improved statistics
  - T-channel
  - Larger parameter space coverage
- Combination with other results
  - Higher harmonics
  - Spin precession
  - Instrumental effects




# *Backup Slides*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# Results: $M_{tot}(1+z) \sim 10^6 M_\odot$

- Changes in Covariance as merger is added
  - Most covariances decrease, merger is breaking degeneracies
  - Some covariances increase