Simulating the LIGO Laser Phase Change Resulting from Gravitational Waves

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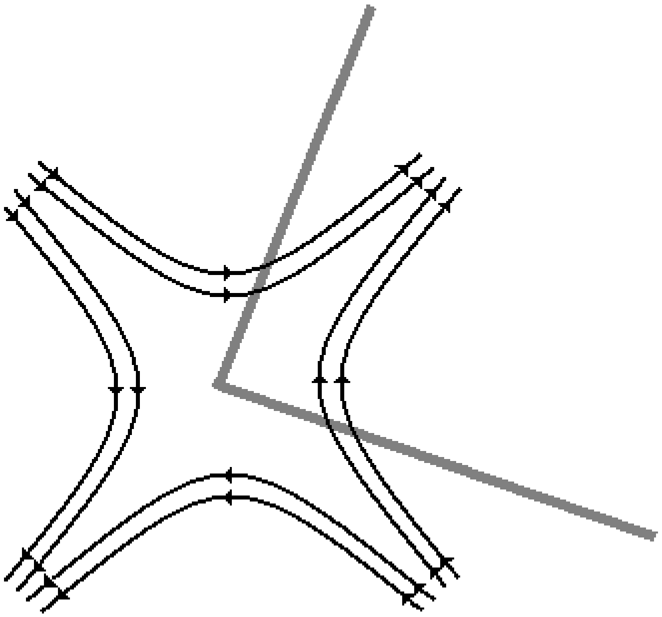
- Simulate GW generation and detection
- Make use of real physics
- Implement in e2e

Physics Background

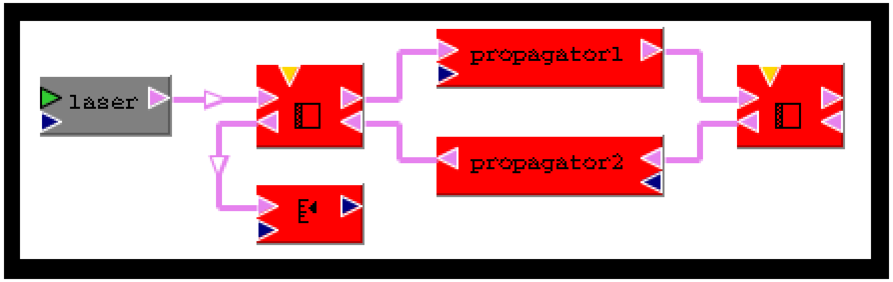
- Essential physics: how GW's affect optical path length of FP cavity
- Extract GW polarization components parallel to arms
- Convert strain into laser phase shift



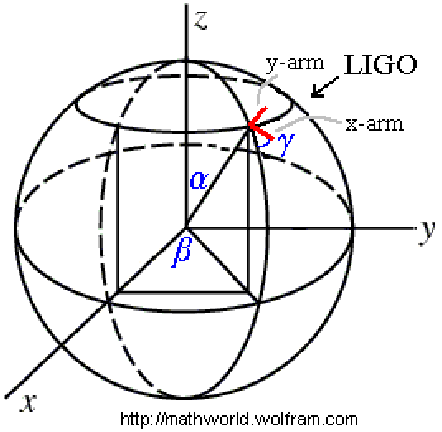
e2e Background

- e2e: time-domain simulation designed for LIGO
- A modeled system is described in terms of interacting modules
- Design new modules: GW sources and detector

- Example: F-P cavity



Let's Approach the Problem



- What factors must we consider?
  - » GW properties, source location
  - » LIGO location and orientation
- How do we take them into account?
  - » Transform GW to LIGO coordinate system
  - » Numerically compute phase shift of laser at each time step
- How can we integrate the results with other modules?
  - » Dynamically pass laser phase information to EM-field propagators

LIGO

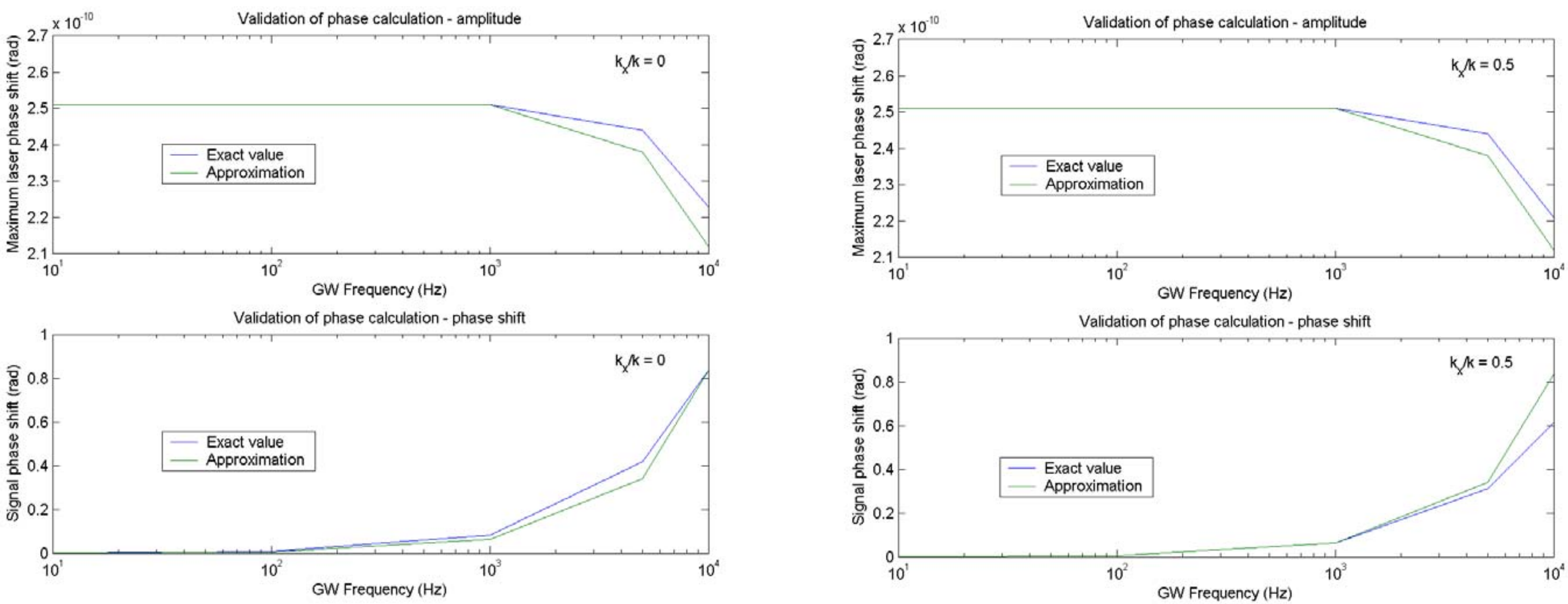
Outline of Solution

- Express GW and LIGO in Earth coordinate system
  - » Rotate GW (from TT) to achieve z-incidence
- Translate strain into laser phase shift
  - » Analytic formula for sinusoidal GW's (P-980007-00, D. Sigg)
  - » Approximation for general GW's
- Write a program to handle computation

Is the Solution Valid?

- Accuracy of laser phase shift approximation

$$\Phi(t) = \Phi_0 + A\cos(\Omega t + \phi)$$



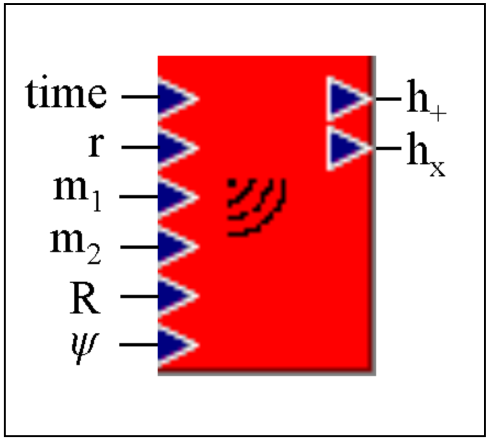
Implement in e2e

- New modules

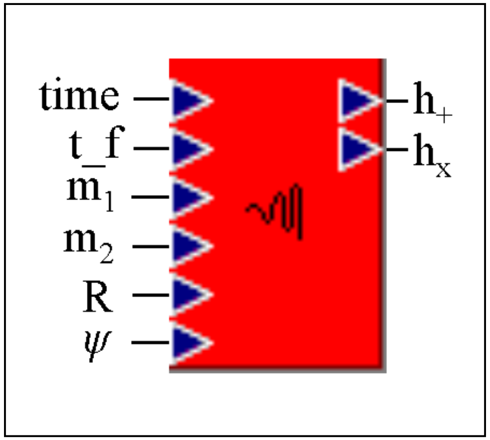
GW signal generation

Detection

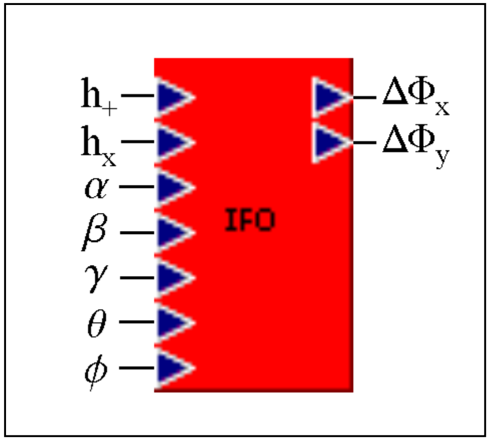
Binary, circular orbit



Inspiralling binary

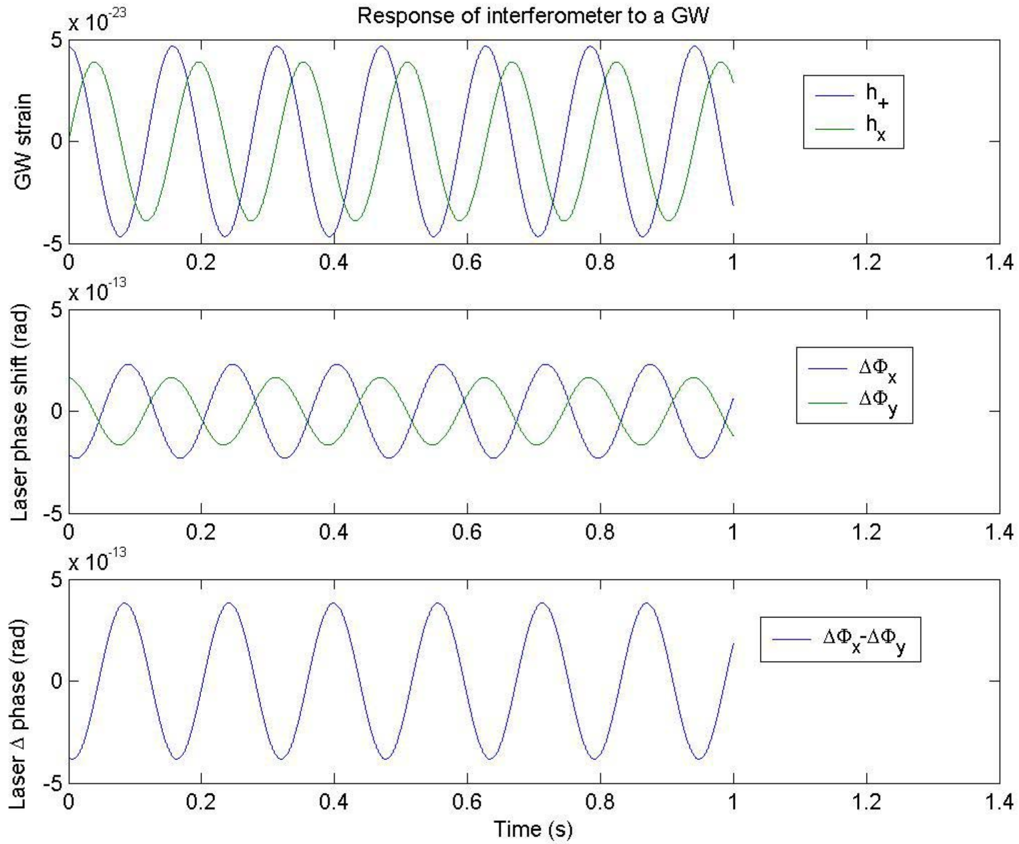


Interferometer



Some Results

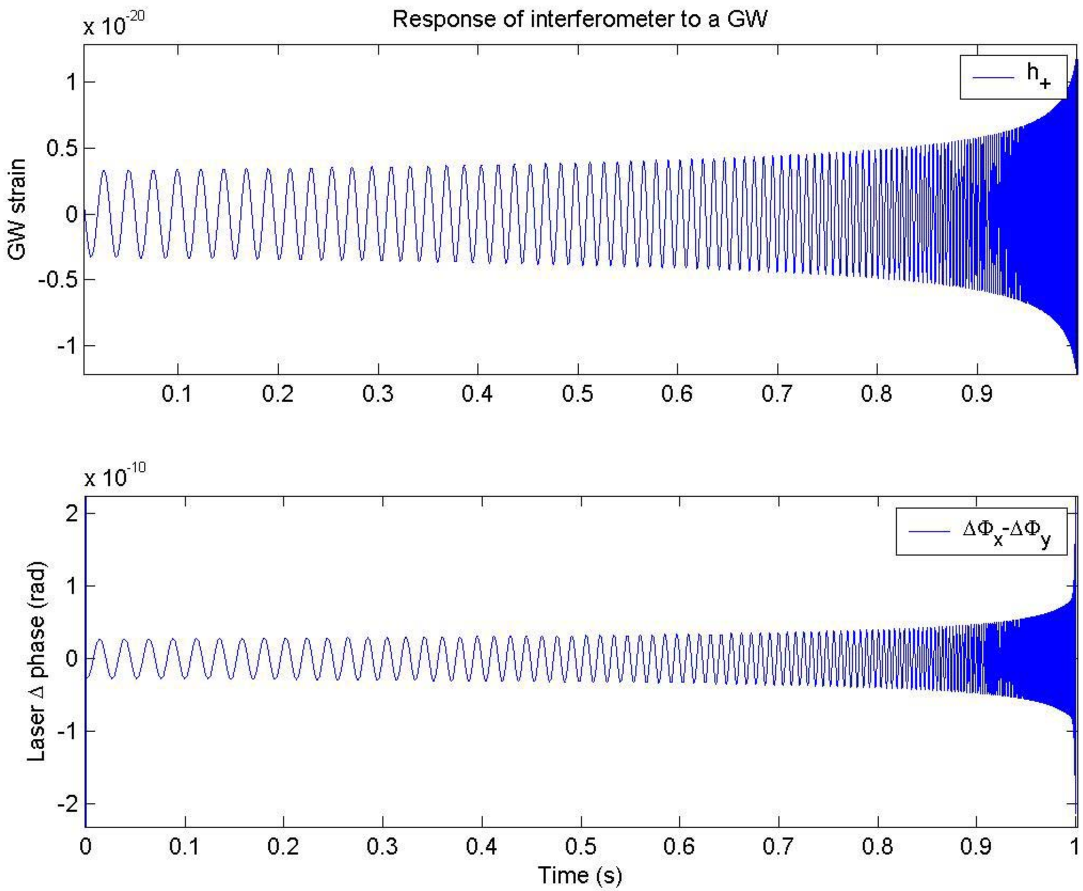
- Binary system
  - » Two 1.5M_{sun} stars
  - » 1000 km apart
  - » 10 Mpc from Earth
  - » 0^o, 0^o incidence
- Detector
  - » LHO



More Results

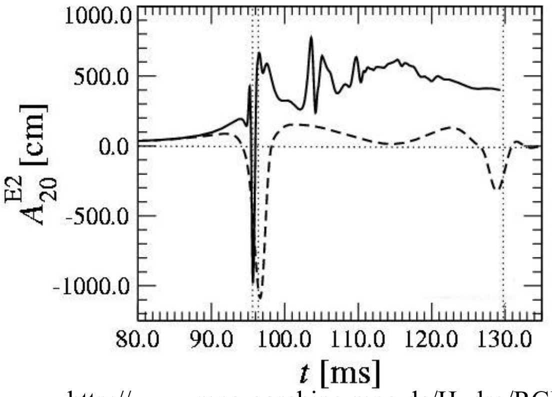
- Inspiral system
  - » $10M_{sun}$ each
  - » 10Mpc from Earth

http://www.phys.latech.edu/official/research/ligo.htm



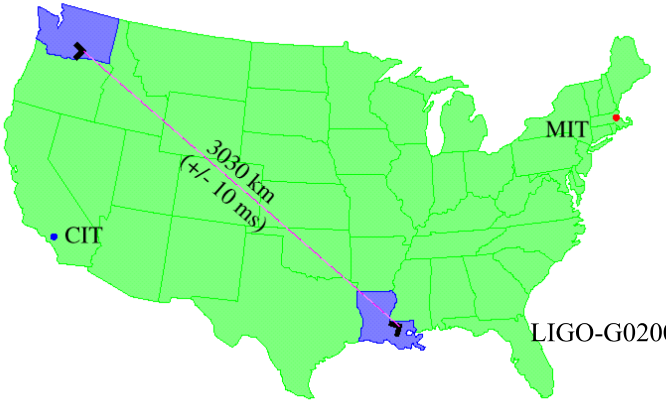
Future Improvements

- More signal types:
  - » Supernova
  - » Black hole formation



http://www.mpa-garching.mpg.de/Hydro/RGRAV/

- Signal delay between two detectors



Applications

- Study properties of LIGO with incident GW's
  - » Learn how imperfections distort signal
  - » What types of noise are most detrimental?
- Data analysis
  - » View photodetector output for signal, embedded in realistic noise
  - » Test existing data analysis techniques

Conclusion

- Now e2e has GW detection functionality
- Can generate variety of signals and study LIGO's response
- Will be able to compare responses of multiple LIGO sites

Acknowledgements

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