Presentation of the Cornell University Relativity Group

to the

LIGO Science Collaboration

Éanna Flanagan

LSC meeting, University of
Gainesville, Florida

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Cornell Relativity Group

Personnel:

1.	Eanna Flanagan	
2.	Wolfgang Tichy	3rd year graduate student
3.	Haw Cheng	undergraduate senior
4.	Katrin Schenk	1st year graduate student
5.	Sharon Morsink	postdoc to start fall 99 (shared with Prof. Teukolsky)

Funding sources:

1. NSF-PHY 9722189, \$60k/yr, 1997-2002
2. Sloan fellowship.

- Group also includes Prof. Saul Teukolsky, postdocs Greg Cook, Mark Scheel, Larry Kidder and graduate student Walter Landry; all focusing on numerical relativity.
- We are hosting 3rd Eastern Gravity Meeting, 26-27 March.

Research plan: summary

- Data analysis: algorithm development and coding. Ongoing, in concert with ASIS/DCSA subgroups of LSC.

  A. Stochastic gravitational waves

  B. Blind signal searches

  C. Multi-detector waveform reconstruction algorithm

  D. Improved inspiral filters

- Long term plans: collaborate with Milwaukee and Caltech groups in next stage of analysis of 40-meter data and/or mock data challenge.

- Complete series of papers with Kip Thorne on light scattering noise in LIGO beam tubes.

- Gravitational wave source/waveform calculations (outside LSC)

Stochastic gravitational waves

[with B. Allen, J. Creighton, and J. Romano].

- Stochastic GWs can be produced either by early Universe processes (cosmic strings, phase transitions, inflation) or by more recent astrophysical processes (supernovae, r-mode instability, spinning NSs).
- Standard detection algorithm (Michelson 1987; Christensen 1990, 1992):

$$s_1(t) = n_1(t) + b(t) \qquad s_2(t) = n_2(t) + b(t)$$

$$\int_0^T s_1(t)\, s_2(t) = \underbrace{\int dt\, n_1 n_2 + \int dt\, (n_1 + n_2) b}_{\sim \sqrt{T}} + \underbrace{\int dt\, b^2}_{T}$$

- Complicating issues:
  a. Time delays between detector sites and detector orientations
  b. More than 2 detectors
  c. $n_1(t)$ and $n_2(t)$ not statistically independent
  d. Is above method optimal?
  e. $n_1(t)$ and $n_2(t)$ not Gaussian and/or not stationary
  f. $s(t)$ not Gaussian: "popcorn"

Stochastic gravitational waves (cont)

Methodology: Use Bayesian analysis. Data is $\mathbf{s}(t) = [s_1(t), \ldots, s_N(t)]$, unknowns are $\Omega_g(f)$ and $\mathbf{S}_n(f)$ ($N \times N$ matrix). Use approximations (correlation time) $\ll$ (observation time) and (signal in each detector) $\ll$ (detector noise). Calculate

$$\mathcal{P}[\Omega_g(f), \mathbf{S}_n(f)|\mathbf{s}(t)].$$

Integrate out $\mathbf{S}_n(f)$ to obtain $\mathcal{P}[\Omega_g(f)]$.

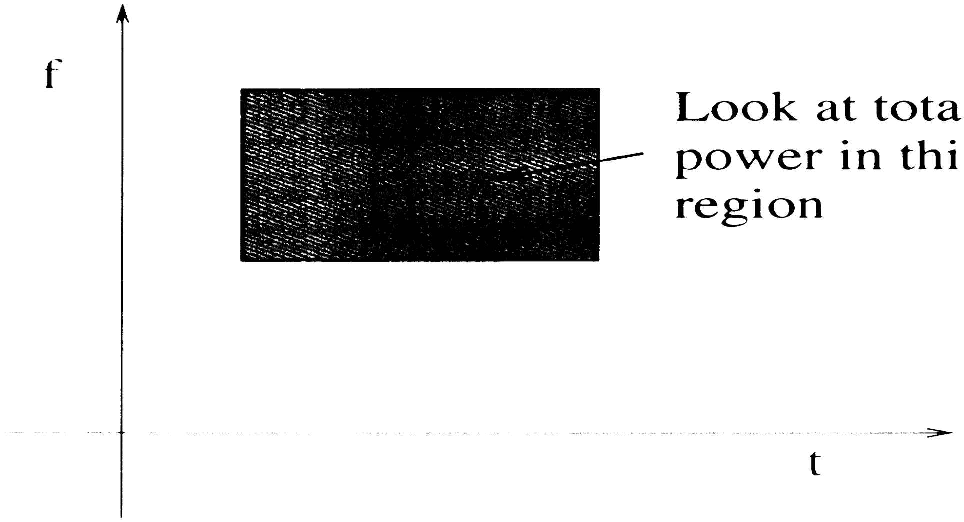
- For stationary, Gaussian noise, above program carried out in EF, Phys. Rev. D 48, 2389 (1993); obtained essentially standard cross-correlation statistic. Addressed issues a,b,c,d.
- For white, *non-Gaussian noise*, above program carried out recently; derived a data analysis method previously guessed by B. Allen wherein one computes the usual cross-correlation statistic after zeroising all data points that are above some threshold.
- In progress: extend analysis to colored, non-Gaussian noise; examine also non-Gaussian stochastic background; implement and test algorithm. Draft of paper exists.

Blind Signal Searches

[with P. Brady, W. Anderson and J. Creighton].

- Excess power statistic derived in EF and S. A. Hughes, Phys. Rev. D 57, 4535 (1998), using

$$\frac{p_{\rm signal}}{1-p_{\rm signal}} = \frac{p_0}{1-p_0}\times\int d^n h\, p^{(0)}(\mathbf{h})\exp\left[\langle \mathbf{s},\mathbf{h}\rangle - \langle \mathbf{h},\mathbf{h}\rangle/2\right].$$

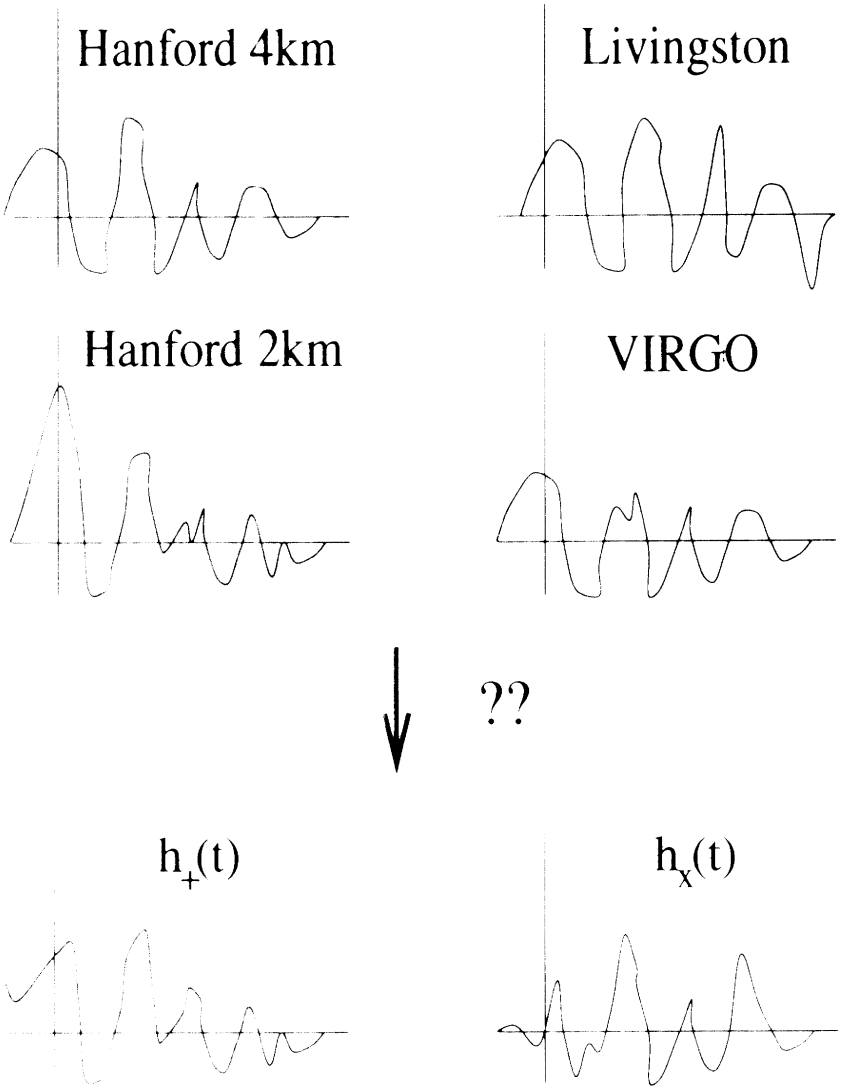


Look at total power in this region

- Statistical properties verified by Monte Carlo simulations. Also explored by P. Hello *et. al.*, 1998.

- Preliminary version of multidetector statistic and statistic in presence of non-Gaussian noise has been derived. Draft of paper exists.

Waveform reconstruction



- Such algorithm useful for (i) obtaining GW waveforms after detecting signal, and (ii) Constructing a multi-detector veto (subtract from all detectors best fit signal).

Waveform reconstruction (cont)

- Optimal algorithm for stationary, Gaussian noise derived in EF and S.A. Hughes, Phys. Rev. D 57, 4566 (1998):

$$\mathcal{P}[\mathbf{m}, h_+(t), h_\times(t) | \vec{s}(t)] = \mathcal{K}\, p^{(0)}(\mathbf{m})\, p^{(0)}[h_A(t)]\, e^{-\Lambda'/2},$$

$$\begin{aligned}\Lambda' &= 4\mathrm{Re} \int_0^\infty df \Big\{ \sum_{A,B=+,\times} \Theta^{AB}(f, \mathbf{m}) \left[\tilde{h}_A(f)^* - \tilde{\hat{h}}_A(f)^*\right] \\ &\quad \times \left[\tilde{h}_B(f) - \tilde{\hat{h}}_B(f)\right] + \mathcal{S}(f, \mathbf{m}) \Big\}.\end{aligned}$$

$$\tilde{\hat{h}}_A(f, \mathbf{m}) \equiv \Theta_{AB}(f, \mathbf{m}) \sum_{\alpha=1}^{n_s} F_\alpha^B(\mathbf{m}) \tilde{s}_\alpha(f)\, e^{2\pi i f \tau_\alpha(\mathbf{m})}.$$

$$\Theta^{AB}(f, \mathbf{m}) \equiv \sum_{\alpha=1}^{n_s} \frac{F_\alpha^A(\mathbf{m}) F_\alpha^B(\mathbf{m})}{S_\alpha^{(\mathrm{eff})}(f)},$$

$$\frac{1}{S_\alpha^{(\mathrm{eff})}(f)} \equiv \sum_{a,b \in D_\alpha} \left[\mathbf{S}_\alpha(f)^{-1}\right]^{ab}.$$

- Goal: implement and test this algorithm

Exploration of improved inspiral filters for detecting massive binaries

- For detecting NS/BH and BH/BH binaries, standard post-Newtonian filters can sometimes be inadequate.
- "Empirical" methods for increasing accuracy:
  1. Padé approximants (Damour and Sathyaprakash, 1997).
  2. Effective 1-body treatment (Buonanno and Damour, 1998)
  3. Use post-Newtonian approximation only to obtain equations of motion: from then on solve for templates numerically.
- Goal: scope out performance of 1,2, and 3, by comparing to test mass case (a la Poisson and Droz 1998). [Wolfgang Tichy]

Light scattering noise calculations

Planned papers:

- *Noise due to light scattering in the beam tubes of gravitational wave detectors I: Foundational Analyses*. EF and K.S. Thorne.
- *Noise due to light scattering in the beam tubes of gravitational wave detectors II: Fockker-Planck analysis of forward light propagation*, S.A. Hughes, K.S. Thorne, and A.G. Wiseman
- *Noise due to light scattering in the beam tubes of gravitational wave detectors III: Application to LIGO*. EF and K.S. Thorne.

Goal: complete a draft of paper I by Aug 15. 1999.

GW source calculations

- Neutron star binaries: "To crush or not to crush?"
    a. Demonstration that no crushing occurs in general relativity; EF, Phys. Rev. D 58, 124030 (1998) [also K. Thorne, Phys. Rev. D 58, 124031 (1998)].
    b. Demonstration of error in numerical simulations of Wilson, Matthews and Marronetti, EF, Phys. Rev. Lett 82, 1354 (1999).
- Calculation of local piece of radiation reaction force for compact object inspiralling into large black hole (eg $\sim 300M_\odot$) (with W. Anderson, in progress).

Note 1, LIGO, 03/22/99 02:15:58 PM

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