Development and implementation of novel data analysis strategies for tiggered and untriggered gravitational wave searches

Proposal to the NSF

The University of Texas at Brownsville (UTB)

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Co-PI: Soma Mukherjee

Plan of the presentation

- Institution and group, LSC involvement
- Outline of the proposal
  - Support requested
- Proposed Research
  - Scientific motivation
  - Technical approach
  - Group and Collaborations
  - Relevance to LIGO / advLIGO

The University of Texas at Brownsville

- Minority serving institution – 90% hispanic student body
  - 11000 students currently enrolled
- Member institution of LSC since 1999 (J. Romano, M. Diaz)
- Master's program in Physics (2004) ♦ PhD degree program with UT Dallas
- 2003: NASA grant to establish an OMU-URC
  - Romano (Cardiff), Diaz, Anderson (UWM), Lousto, Campanelli
  - 1.2 M$/year × 5 years (+ 5 years)
  - Center for Gravitational Wave Astronomy (CGWA)
  - Objective: R&D, E&O in GW astronomy with a focus on LISA
- Support: ♦ 2 new faculty positions ♦ 3 postodocs ♦ GW Astronomy Summer Schools ♦ Visitors program and conferences ♦ Graduate and undergraduate student support ♦ Conference Travel ♦ Support staff
- Teaching load : 1 undergraduate, 1 graduate course/semester/faculty

The Center for Gravitational Wave Astronomy

Data Analysis	Source Simulation	Astrophysics
•S. D. Mohanty *Asst Prof., joined 2003* •S. Mukherjee *Research Asst. Prof., joined 2003* •M. Diaz *Prof., Director* •R.Grosso *Visiting Prof.* •R. Nayak *–Postdoc, LISA data analysis* •*PhD student*: C. Torres *–Supervisor: W.Anderson* •*MS Students*: R.Stone – Jimenez, Johnston	• M. Campanelli *Asst. Prof., Assoc. Director* •C. Lousto *Assoc. Prof.* •R. Price *Prof., joined 2004* •S. Lau *Research Asst. Prof.* • 2 postdocs • 5 Graduate students	• F. Jenet *Asst. Prof, joined 2004* •Open position

Current LSC involvement

- Mohanty 50% ♦Mukherjee 50% ♦Diaz 50% ♦Stone 15% ♦Torres 15% ♦ Jimenez 15% ♦Grosso (visitor) 10% ♦Lousto 10% ♦Campanelli 10%
- Service activities:
  - Sci-mon Shifts
  - Burst group internal reviewers (Mohanty, Mukherjee)
- Mohanty:
  - Member: Burst and Pulsar UL groups, External Triggers subgroup
  - Co-Author, algorithm for GRB030329 triggered search (CQG, 2004)
  - Author, Running median algorithm and code for Pulsar searches
- Mukherjee:
  - Member: Burst and Pulsar UL groups, External Triggers subgroup
  - Co-author, Kalman filter based violin mode regression (PRD, 2001)
  - LIGO + GEO600 Det Char, IFO Noise Modeling, LIGO-VIRGO data exchange
- Diaz:
  - Member: Stochastic group ♦ LSC telecons ♦ DMT monitor with Grosso
- Lousto, Campanelli: BH-BH merger waveforms (Lazarus project)

Outline of the proposal

- Overall scientific goal: Improve ground based IFO science reach in 3 areas
  1. Modeled sources: Improve hierarchical matched filtering schemes
  2. Un-modeled sources: Use approximate source simulation information
  3. Multi-GRB Search for GRB-GW association: Implementation & science results with LIGO data
  - Software development for 1 & 2 intended but not a part of the proposal
- Duration: 3 years. Total request: $315,552
- Support requested for :
  - 1 new PhD student (3 years): GRB search
  - 1 new Postdoc (2 years): Algorithm development
  - Summer salaries (3 years) for PI and Co-PI
  - Travel to LSC meetings (2 to 3 / year)
- *Travel to GWDAW, AMALDI can be supported by CGWA*

GRB-GW association

- Gamma Ray Bursts (GRBs)
  - Central engine is most likely a newly formed BH with a transient accretion disc
  - Strong GW sources
    - van Putten model estimates 0.2 solar Mass in GW
    - Kobayashi, Meszaros: Adv LIGO could see one collapsar/year
  - Several observed classes : different progenitors (?)
    - Long duration: Stellar core collapse (GRB030329 confirmed connection)
    - Short duration: NS-NS mergers
    - Intermediate class ? (Mukherjee et al, ApJ, 1998)
  - Ideal triggers for GW searches: directionality, GW-GRB delay < 500 sec
- Limitations
  - Cosmological distances
  - unmodeled sources (duration ~ 100 msec, in LIGO band) $\Rightarrow$ "Bursts"

Multi-GRB search

Extending the science reach

- Finn, Mohanty, Romano, PRD, 1999 (FMR)
  - Directionality & Bursts $\Rightarrow$ Align GW signals & cross-correlate
  - Off-source data : Reference noise sample. Eliminate weak terrestrial signals
  - Multi-GRB Cross-correlation sample:
    - On-source: Gaussian, mean = GRB population average+terrestrial signal
    - Off-source: Gaussian, mean = terrestrial signal
  - Test for difference in distribution : Student t-test
    - More complicated for non-stationary, non-Gaussian data
- Builds up SNR over multiple GRB triggers
  - $N^{-1/4}$ for h_{rms}: due to cross-correlation (can be improved)
- Observations: Astone et al, PRD 2002 & astro-ph/0408544
  - Initial LIGO can improve by a factor of 10 to 100 on bar limits
  - Kobayashi, Meszaros : astrophysically interersting UL on weakest progenitors (BH-WD, BH-He) with adv LIGO, 30 GRBs

Multi-GRB search

Trigger availability

- IPN: HETE, INTEGRAL and others
- GCN: automated trigger distribution.
  - LIGO alarm (Rahkola)
- Swift (launched Nov 2004)
  - 150 detections with redshifts / year × 3 years
  - Redshift information potentially very important for FMR
  - Variety of science results possible
- GLAST (planned)
  - Successor to BATSE
  - Will run in coincidence with adv LIGO (?)

Multi-GRB search

Proposal (PhD student, Co-PI, PI, Postdoc; 3 years)

Science goals

- Implement search on LIGO data. Incorporate VIRGO/GEO/TAMA
- Science results: Upper limits on GRB population averaged h_{rss} ♦ GRB class specific UL ♦ Possible detection

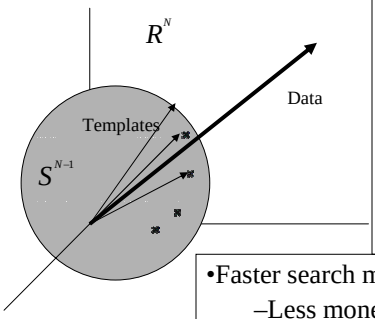
Technical Approach

- Improve Core algorithm and Robustness ♦ Two track implementation
- LSC project: open to participation
  - Within the External Triggers subgroup
  - Basic FMR implementation in progress: Sz Marka, Co-chairs of Burst group informed
- PhD thesis: GRB class-wise science results, Algorithms, Analysis

Outreach

- Web site : Oriented towards violent events and GW ♦ Sky map with detected and used triggers ♦ Will involve undergraduates (CGWA support)

Modeled sources



- Examples: Binary inspirals, Pulsars
- Detection: Matched filtering
- Computationally expensive
  - inspiral (zero spin): > 0.1 Tflops
    - Generally higher costs for Adv LIGO
  - Pulsars (0 spin down, 1 year integration): > 10 Tflops

•Faster search methods ⇒
  –Less money of course …
  –Greater parameter space coverage (e.g., low mass end)
  –Free up computing cycles for other searches
•Constraint: no loss in statistical performance
  –Same detection probability for given min SNR and false alarm probability

Modeled Sources, cont …

- Two stage hierarchical searches for binary inspirals
  - Mohanty & Dhurandhar (PRD 1996, 1998)
  - Stage 1: Coarsely spaced & low threshold
  - Stage 2: Finely spaced around candidate stage 1 crossings
- No loss in statistical performance
- Reduction factor in flops of ≈ 25
  - Depends on noise PSD, parameter space dimensionality
- EHS (Sengupta, Dhurandhar, Lazzarini, PRD 2003): factor of 65 – 70.
- Need to understand:
  - What is the optimal number of stages?
  - What is the maximum reduction possible without loss of performance?
- Pulsar searches: two stage approach is probably not good enough
  - Current Pulsar hierarchical searches use sub-optimal methods

Modeled Sources

Proposed research (PI + Postdoc, 2 years)

- **Goal:** Obtain the best possible loss-less hierarchical search strategy for a given signal family; Apply to inspiral and pulsar signals
- **Technical Approach:** exploit connection to sampling theory
  - Bandlimited functions and loss-less sampling (Nyquist theorem)
  - Discrete set of templates ≡ Sampling an underlying continuous random field in parameter space
    - Croce et al PRD 2000, Finn & Dhurandhar : sampling theory approach for single stage searches
  - Anti-alias the random field and sample at a lower rate
    - possible by shifting to a modified template family
    - Localized averages of perfect templates
  - Hierarchical search: lower to higher sampling rates
    - Stages: different anti-aliasing kernels, different Nyquist rates
- **Feasibility:** EHS is the first step! (anti-aliasing in time of arrival only)
- **Groups and Collaborations:** Papers to be reviewed by LSC if required

Unmodeled Sources

- Examples: Supernova core collapse, GRB central engines
- Detection: several algorithms in existence
- Approach #1: Assume little prior information about signals
  - Project Data on finite time and/or frequency width “templates”
    - (Example: spectrogram) Detect rare projection patterns
    - TFClusters, Waveburst, Excess Power, ALF, Q-transform
  - Change point detection (KSCD, BlockNormal): assume little prior information about noise
- Approach #2 : Use prior information from source simulations
  - Significantly improves science reach for specific types of sources
  - Sample waveform catalogs available (e.g., Dimmelmeir et al)
  - **Problems**
    - Waveforms not realistic enough to make matched filters
    - Computational limitations⇒ coarse sampling of simulation parameter space

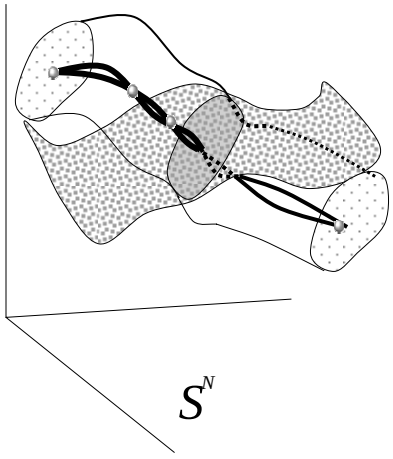
Unmodeled Sources

Incorporating source simulation information

- Anderson et al: Set up a Bayesian prior on space of waveforms
  - Excess Power: simple prior limiting bandwidth and duration
  - No method for translating a catalog to a prior
- Brady, Majumdar: linear subspace incorporating most of the catalog waveforms
  - Binary inspirals (Buonnano et al): submanifold covering all approximations
- Construct a *Covering* manifold: should include true (unknown) signal manifold. Place discrete template grid.
  - Linear subspace: Excess power
- Constraint: Should converge to matched filtering as simulations improve. Should be as small in volume as possible.
  - Smallest linear subspace may be too big

Unmodeled sources

Proposed research (PI+Postdoc, 2 years)



- **Goal:** Incorporate information from approximate source simulations into a detection algorithm
  - Obtain such an algorithm for a specific catalog
- **Technical Approach:**
  - **True manifold**
  - **Approximate manifold**
  - **Samples (Catalog)**
  - **Interpolated manifold**
  - **Thickened manifold**
- **Feasibility:** Several existing approaches are already working along the same common lines
- **Groups & Collaborations**: Papers to be reviewed by LSC if required

Summary

- Proposed work: improve science reach, obtain science results
  - Hierarchical Searches will expand parameter space coverage
  - Incorporating source simulation information will improve sensitivity
  - Multi-GRB search will produce observational constraints. Sensitivity of the search will be improved.
- Outreach: web site for multi-GRB search
- LSC collaboration:
  - Untriggered modeled, unmodeled: Paper reviews by LSC if needed
  - Triggered search: within the External Triggers subgroup♦Burst UL group♦LSC
- Additional required resource: computing
  - UTB Beowulf, LSC tier II facilities
- All proposal components are relevant to LIGO and adv. LIGO
- Integration into LIGO
  - Untriggered: Software implementation intended (CGWA funded Graduate, undergraduate students)
  - Triggered: Basic implementation in progress (Matlab). Preliminary results: 2 to 3 months

PAC meeting, Boston Dec 2004