GW data analysis & IndIGO

Sanjeev Dhurandhar

IUCAA, Pune

8th February Delhi

Plan

- Before IUCAA joining LSC: 1989 – 2000
  Some significant contributions

- IUCAA in the LSC: 2000 – 2010
  Main contributions made to GWDA in LSC

- GWDA plans of IndIGO consortium (LSC):
  2011 +

The one detector search for inspiraling binaries

Sathyaprakash & Dhurandhar 1991, 1994 Phys. Rev D papers

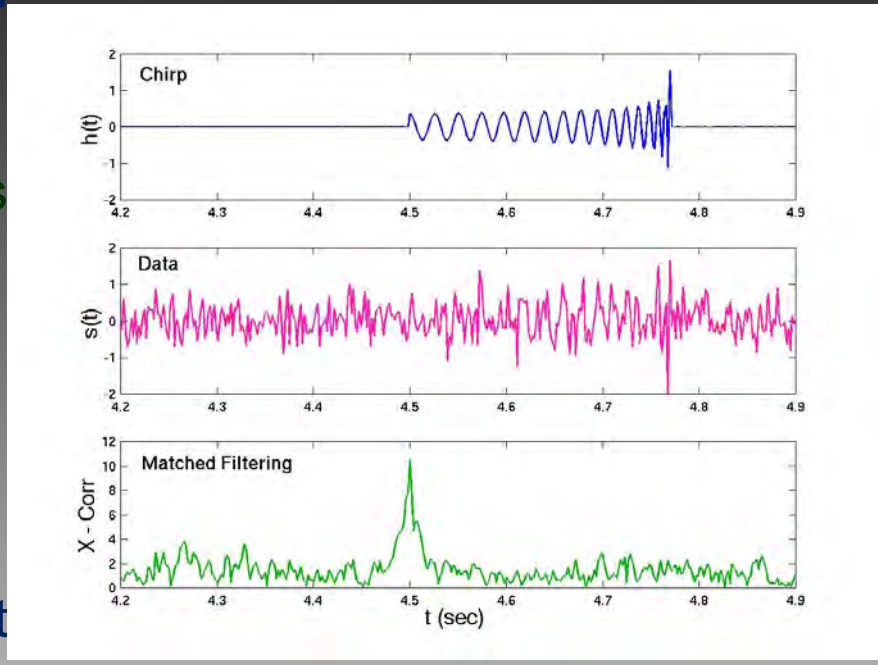
Strategy: Maximum likelihood method

Spinless case:

- Amplitude: Use normalised templates
- time of arrival: FFT
- Initial phase : Quadratures –

  only 2 templates needed for 0 and $\pi/2$
- masses: template bank required
- For each template the maximised statist

with a threshold set by the false alarm rate



Use of the stationary phase approximation: SVD 1987

Inspiraling binaries

- Important result in parameter estimation:

  The covariance matrix does not set a good bound on the parameters at low SNRs even around SNR ~ 10. Error is a factor of 2 or 3 more!

R. Balasubramanian, B. S. Sathyaprakash & SVD, Phys. Rev. D 53, 3033 (1996)

- Using **differential geometry**, the idea of **metric** on the parameter space

- Hierarchical search for inspiraling binaries:
  - hierarchy on the two mass parameters

  S. Mohanty & SVD, Phys. Rev. D 54, 7108 (1996)
  S. Mohanty, Phys. Rev. D 57, 630 (1998)

Inspiral search with a network of detectors

- **Coincidence search**:
  - Event lists, Windows in parameter space

- **Coherent search**

- Phase information used – *matched filtering* thus optimal

- Full data from all detectors necessary to carry out the data analysis

- A single network statistic constructed to be compared with a threshold – network as a single detector – aperture synthesis

Filter bank over only intrinsic parameters: masses

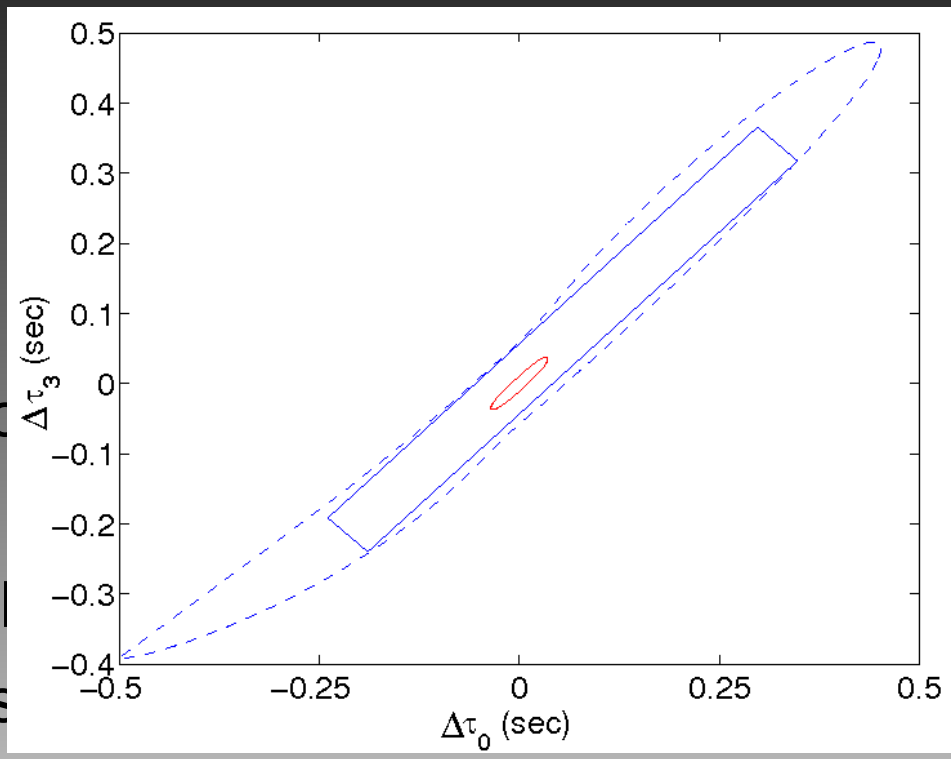
A. Pai, SVD & S. Bose, Phys. Rev. D 64, 042004, (2001) + more

IUCAA joins the LSC in 2000

- **Hierarchical search for inspiraling binaries**
  - Online speed ~ 300 Gflops for f ≥ 10 Hz, masses ≥ 0.2 MΘ
  - 2 step search: 2 template banks

Step I : Coarse bank – fewer templates, low thresho high false alarm rate

Step II: Fine bank - Follow up t false alarms by a fine s



Extended hierarchical search: over time-of-arrival and masses

Results: Factor ~ 60 in Gaussian noise - Actual LIGO I data ~ 10

A. Sengupta, SVD & A. Lazzarini, Phys. Rev. D 67, 082004 (2003)

Stochastic GW background: Directed search

S.Mitra, SVD, T. Souradeep, A. Lazzarini, V. Mandic, S. Bose, S. Ballmer, Phys. Rev. D 77, 042002 (2008).

Produced by unresolved, incoherent, gravitational wave sources Blackhole mergers, r-modes, LMXBs, …

Statistic: Cross-correlation between two detectors using

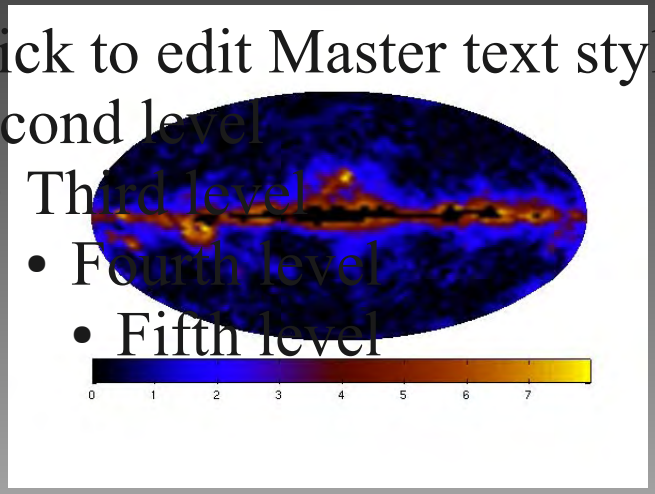
directed filter Q

$$S\left(\hat{\Omega}\right) = \int dt \iint dt'\,dt''\; s_{\text{2}}(t')\, s_{\text{Гъ}}(t'')\; Q(\hat{\Omega}; t, t'-t'')$$

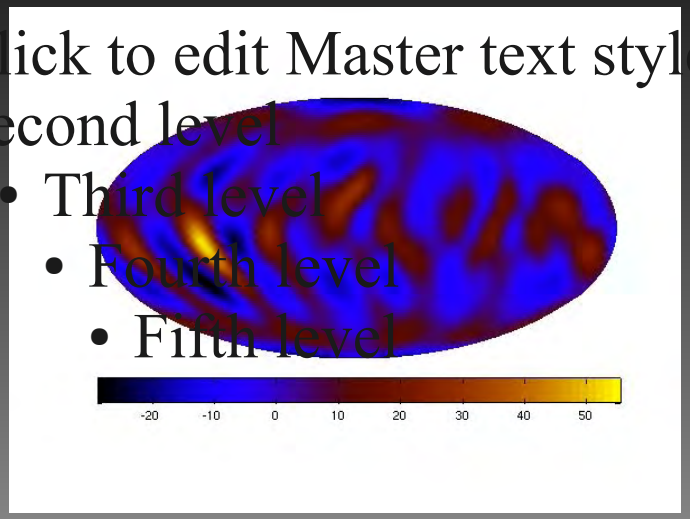
The statistic produces dirty map which is cleaned by deconvulution

Solution for a `galactic distribution'

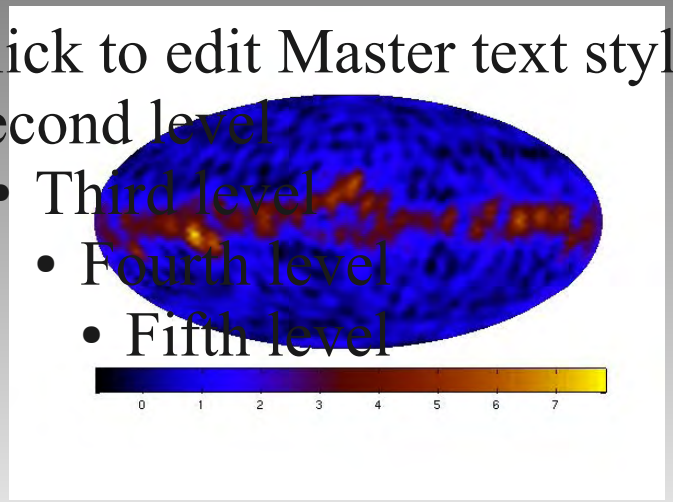
Source:



Dirty :



Cleaned:



Cross-correlation searches

- Cross-correlation search for periodic sources

  SVD, B. Krishnan, H. Mukhopadhyay, J. Whelan, Phys. Rev. D 77, 082001 (2008)

Analogous to the idea of the directed stochastic search **BUT** different in two ways from stochastic

- Non-stationarity of the signal
- Long-term phase coherence

Future GWDA Plans of IndIGO (LSC)

Project leads: Sanjit Mitra, T. Souradeep, …

- Implementation of the cross-correlation search for periodic sources

- This could be in collaboration with A. Melatos, Melbourne, Australia

- **Burst Sources** – sitting duck!

  - Formulation
  - Implementation

Vetoes for non-Gaussian noise for coherent detection of inspirals

Project leads: Anand Sengupta, Archana Pai, M K Harris.

- Non-Gaussian noise plagues the detector data

- Vetoes have been developed in LSC for removal of non-Gaussian noise in the single detector case

- For coincidence search the veto is obvious but for coherent not so.

- **Developing a veto for coherent is crucial –** chi squared

- Scope for improving the current chi squared test – Japanese collaboration

Details in talk by Archana Pai.

Tests of General Relativity using GW observations

Project leads: K G Arun, Rajesh Nayak and Chandra Kant Mishra,

Bala Iyer

- GWs are unique probes of strong field gravity. Their direct detection would enable very precise tests of GR in the dynamical and strong field regime.
- Preparing data analysis algorithms for AdvLIGO in order to test GR and its alternatives is one of the important and immediate goals of LSC.
- Plan to take part in the activity to develop parameter estimation tools based on Bayesian methods.
- Possible collaboration with B S Sathyaprakash (Cardiff University) & P Ajith (Caltech).
- K G Arun's talk for details.

Data Centre for LIGO-Australia

- Plan for a multi-institutional proposal to set up a **data centre** in India

- **Objectives**:
  - High performance computing – 1000 cores
  - Data archival for LIGO-Australia

- A **Resource** that IndIGO brings to LIGO-Australia and LSC

- **Computational requirement and budgeting** to be decided in consultation with experts in LSC -

- Details in the talk by Anand Sengupta

Manpower generated in the past 20 years in GWDA

1. B. S. Sathyaprakash: Leader of the Cardiff, UK, data analysis group, member of the Gravitational Wave International Community
2. S. Bose (Faculty WSU, USA)
3. S. Mohanty: (Faculty U. Texas. B., USA)
4. B. Bhawal (formerly LIGO)
5. P. Dasgupta (Professor, Delhi university)
6. S. Mitra (postdoc at Caltech, US)
7. A. Sengupta (Delhi university, postdoc at Caltech, US)
8. A. Pai (IISER, Trivendrum, postdoc Max Planck I, Germany)
9. R. Nayak(IISER, Kolkata, UTB, US)
10. S. Koshti (formerly IUCAA)
11. V. Chickarmane (Caltech)
12. R. Balasubramanian
13. K. Jotania
14. H. Mukhopadhyay
15. S. Sahay (Gorakhpur university)

Current people and institutions for GWDA

A. Sengupta (Delhi university)
A. Pai (IISER, Trivendrum) + student
K. G. Arun (CMI, Chennai)
K. R. Nayak (IISER, Kolkata)
C. K. Mishra (RRI)
S. Mitra (??)
B. Parmeswaran (??)
T. Souradeep (IUCAA)
B. R. Iyer (RRI)
S. Dhurandhar (IUCAA)