

Gravitational wave detectors network data analysis

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LIGO-G070198-00-Z



Outline

- Introduction
- Coherent burst gravitational wave searches
 - all-sky searches
 - triggered searches
- Coherent analysis for Inspiral signals

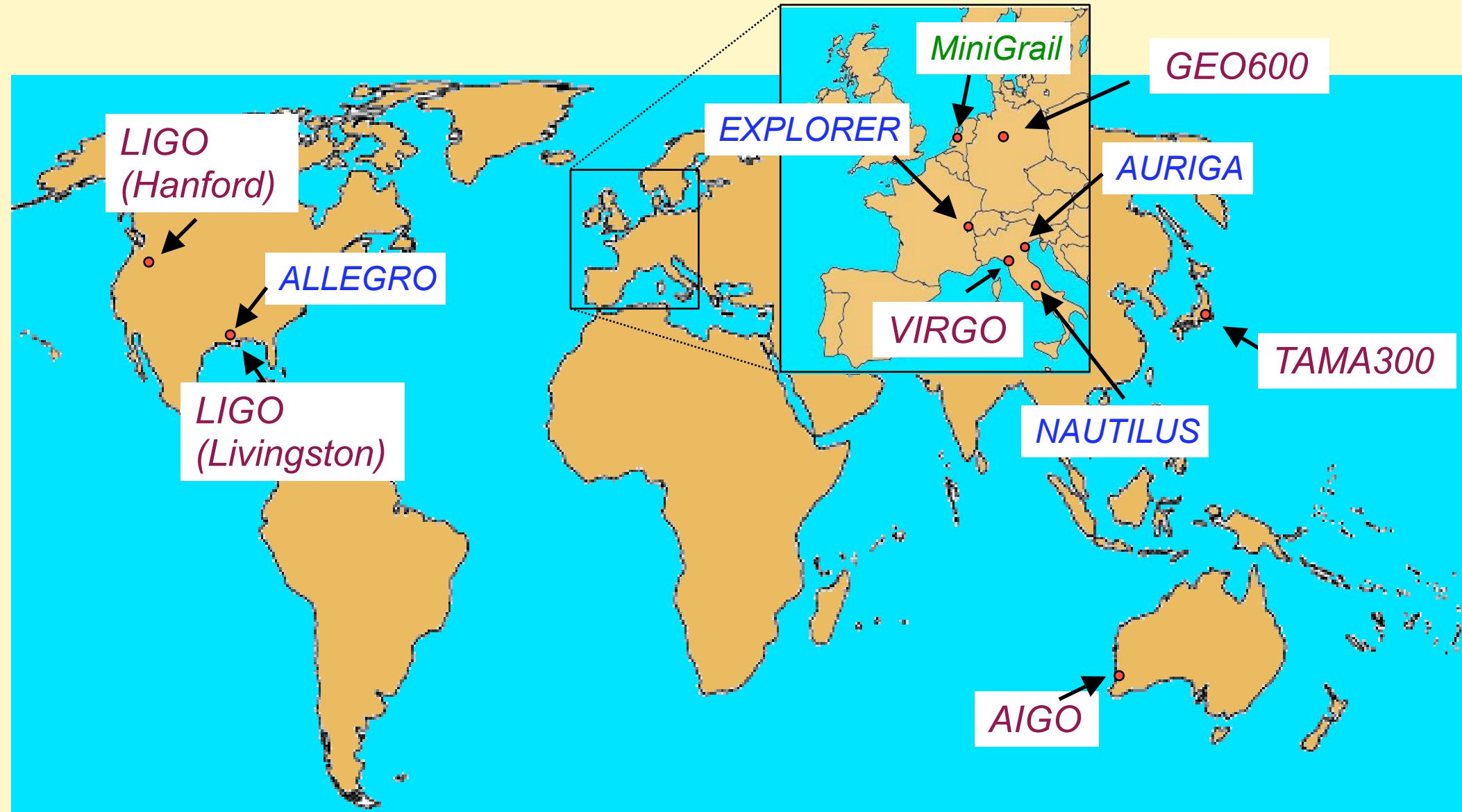


ILIAS N5 WG2

- joint analysis of data from network of detectors
 - co-chairs: G. Guidi & I.S. Heng
- brings together many gravitational wave data analysts from across Europe
 - also have joint meetings with theoretical astronomers
- discuss common issues in development of techniques
- address issues in joint analysis of European network of detectors
 - analysis of data jointly acquired by Virgo interferometer and European resonant-bar detectors
 - IGEC2: global network of resonant-bar detectors
 - implement search for stochastic gravitational radiation background with GEO-Virgo network
- gaining stronger focus on searches associated with triggers in the EM spectrum, addressing data analysis issues for future generations of gravitational wave detectors
 - eg. spin in binary black hole systems, parameter estimation of detected signals

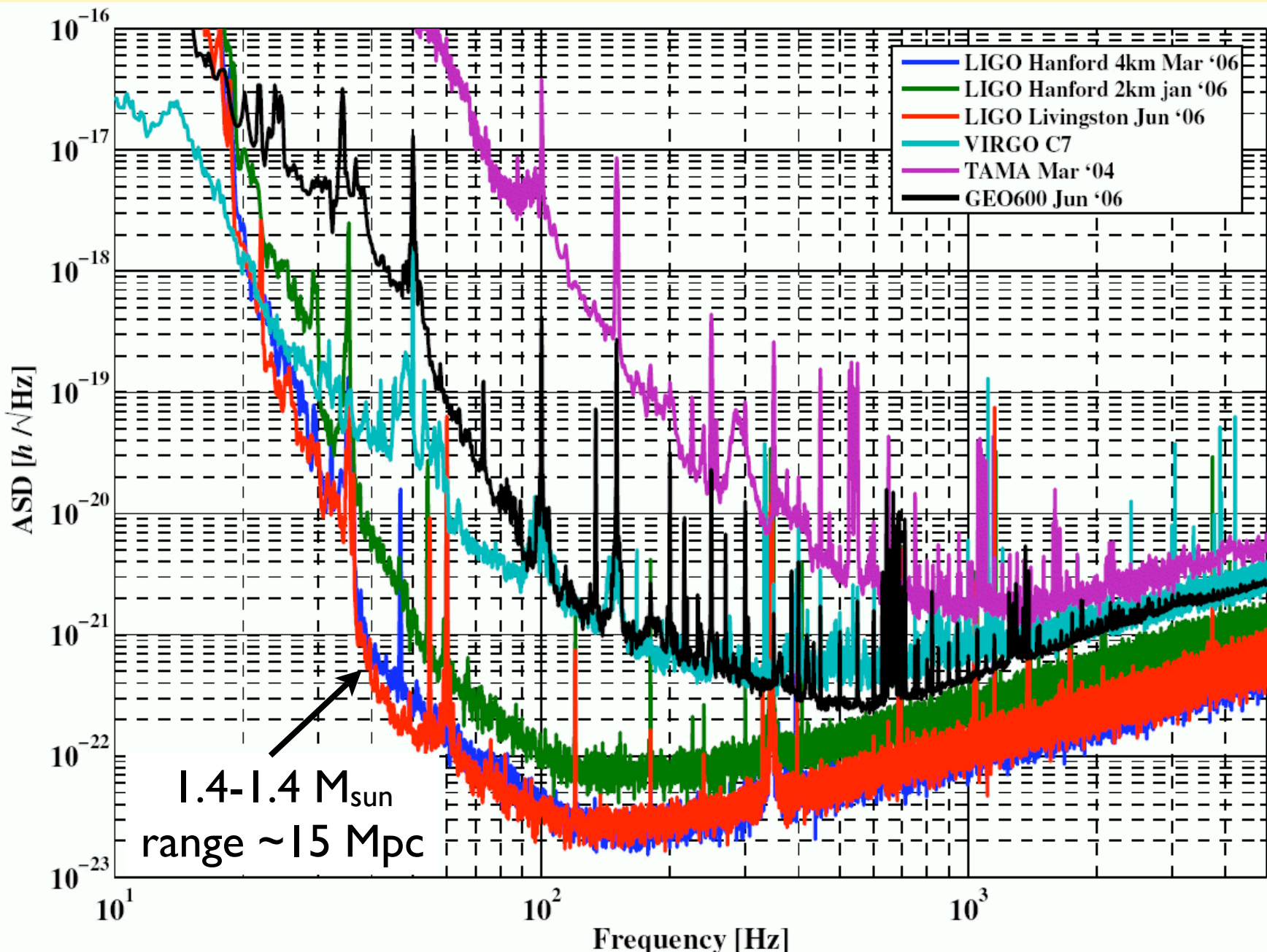


Gravitational wave detectors worldwide



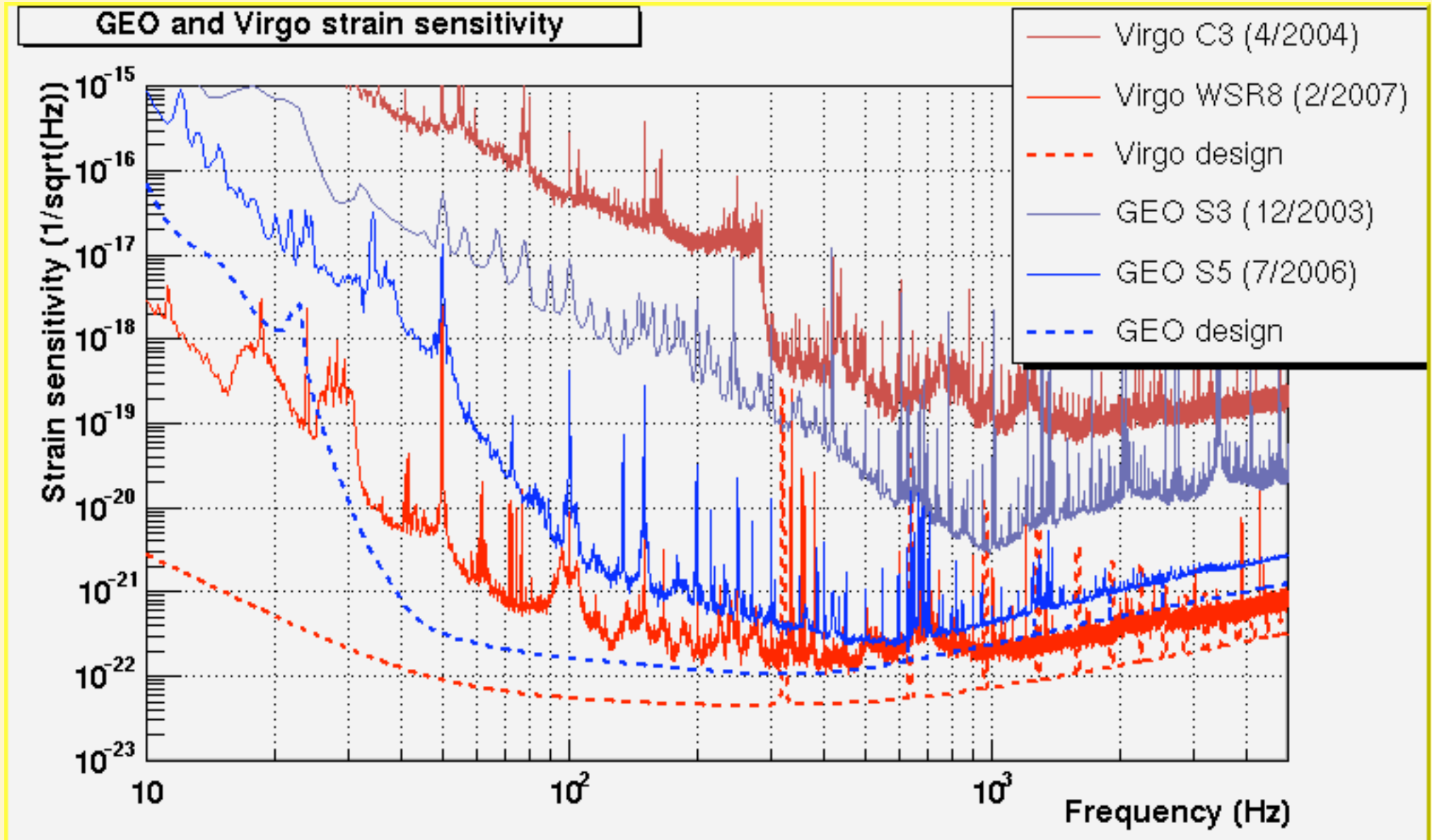


Interferometer sensitivities

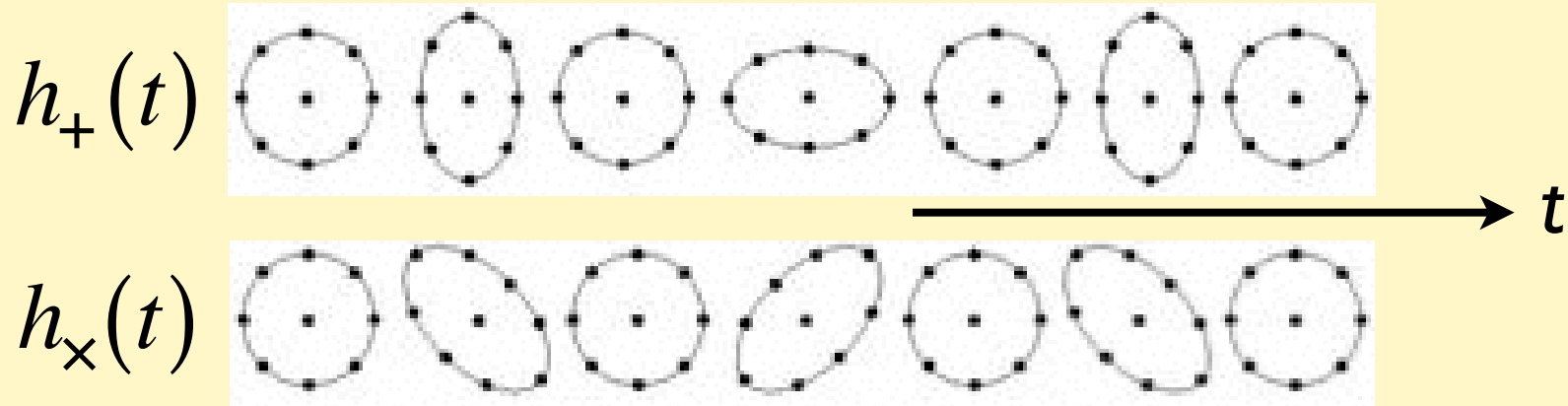




Virgo and GEO600



Detectors & polarisations



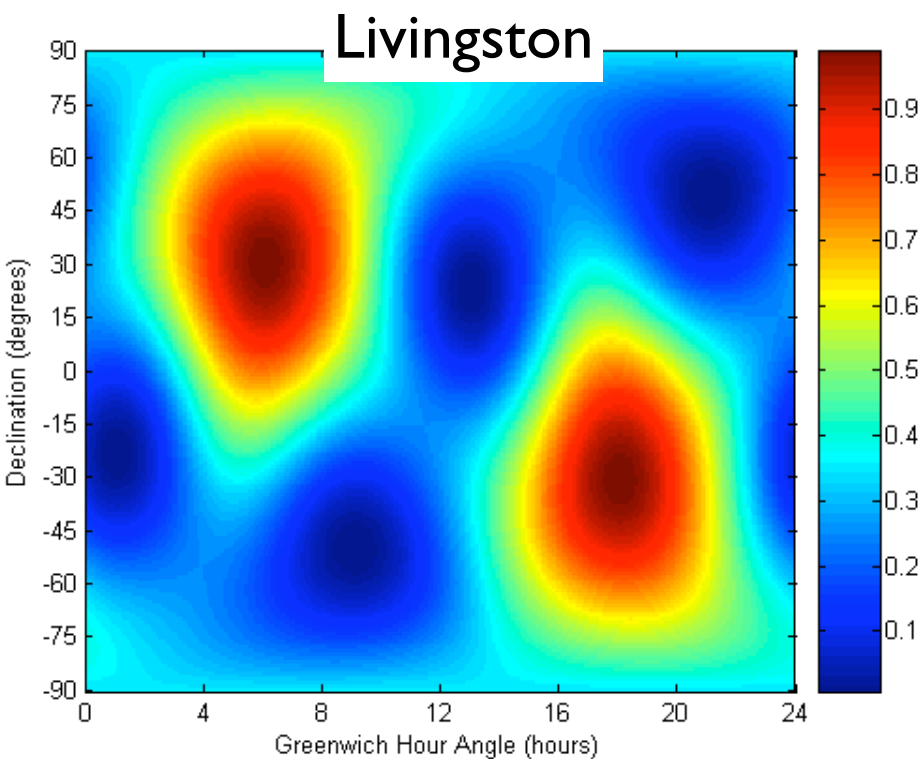
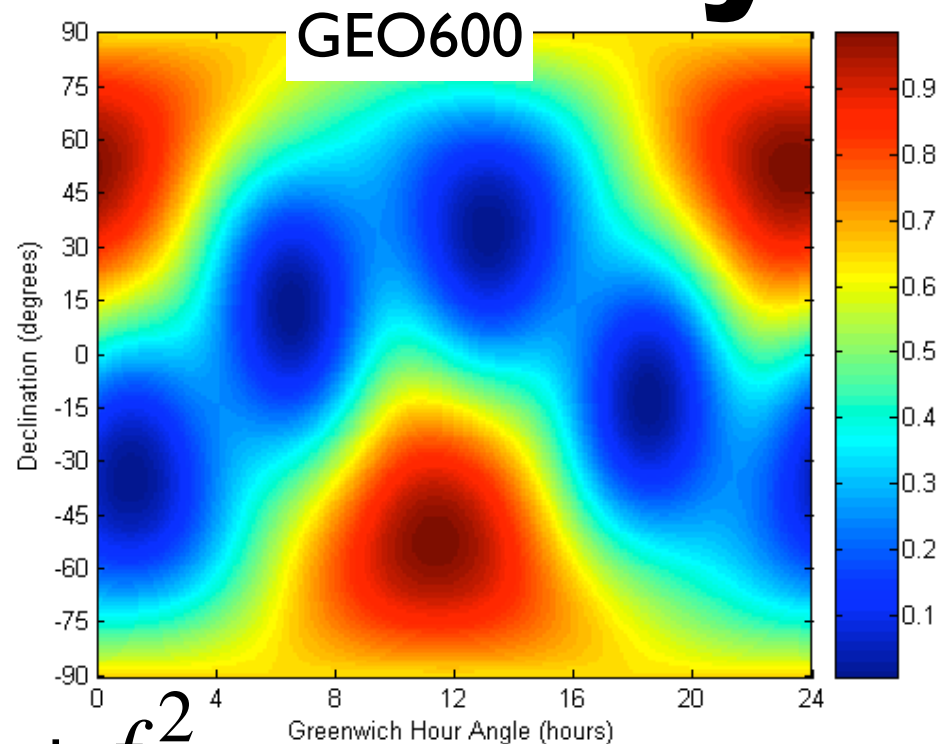
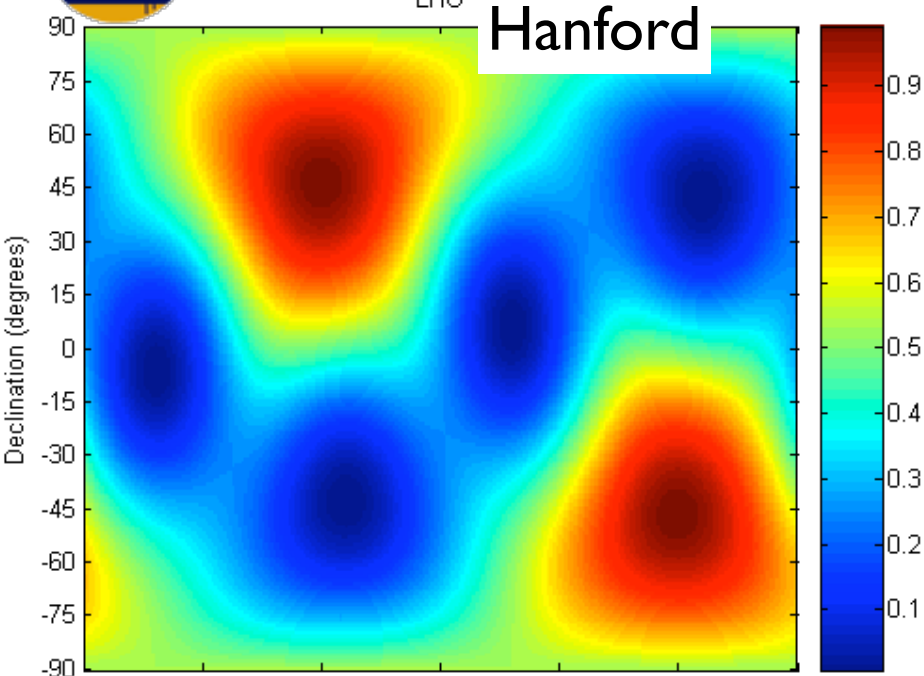
- gravitational wave signal as seen by the detector

$$h_i(t) = f_{i,+} h_+(t) + f_{i,x} h_x(t)$$

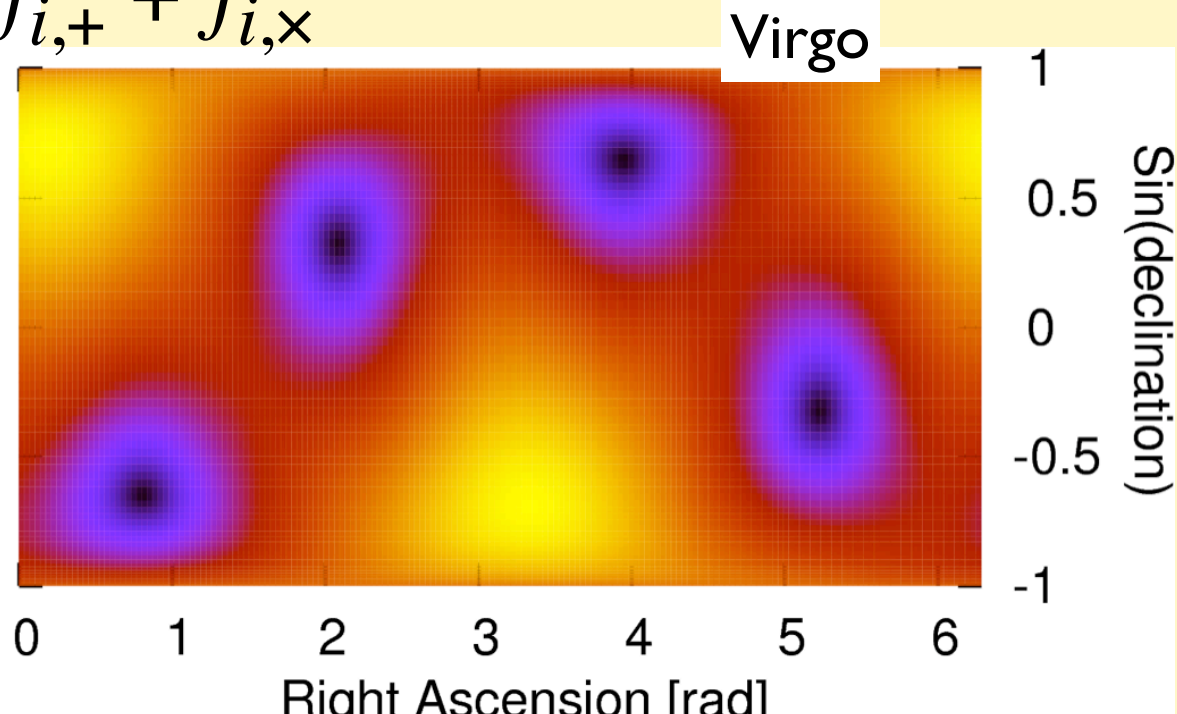
- $f_{i,+}$ and $f_{i,x}$ are a function of the sky location of source
- for detectors that are aligned, $f_{i,+}$ and $f_{i,x}$ are very similar
 - applicable for LIGO network
- for worldwide network, detectors are not aligned to each other



Directional sensitivity

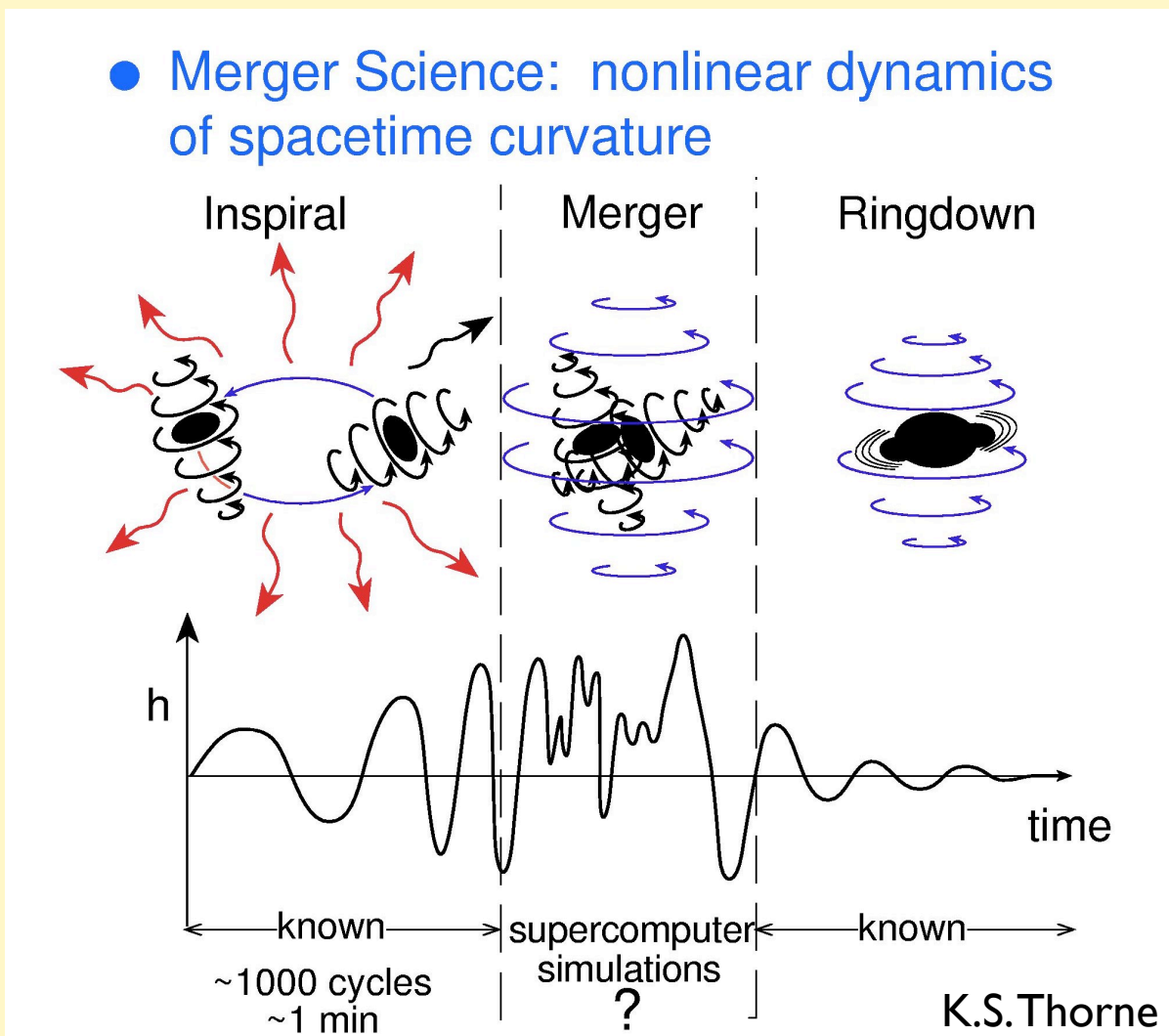


$$f_{i,+}^2 + f_{i,x}^2$$



Inspiral and Bursts

- Bursts
 - unmodelled pulses of GW
- Inspirals
 - coalescing binary compact objects
- Periodic
 - non-axisymmetric rotating neutron stars
- Stochastic
 - background of GW from, for example, superposition of relic GW signals

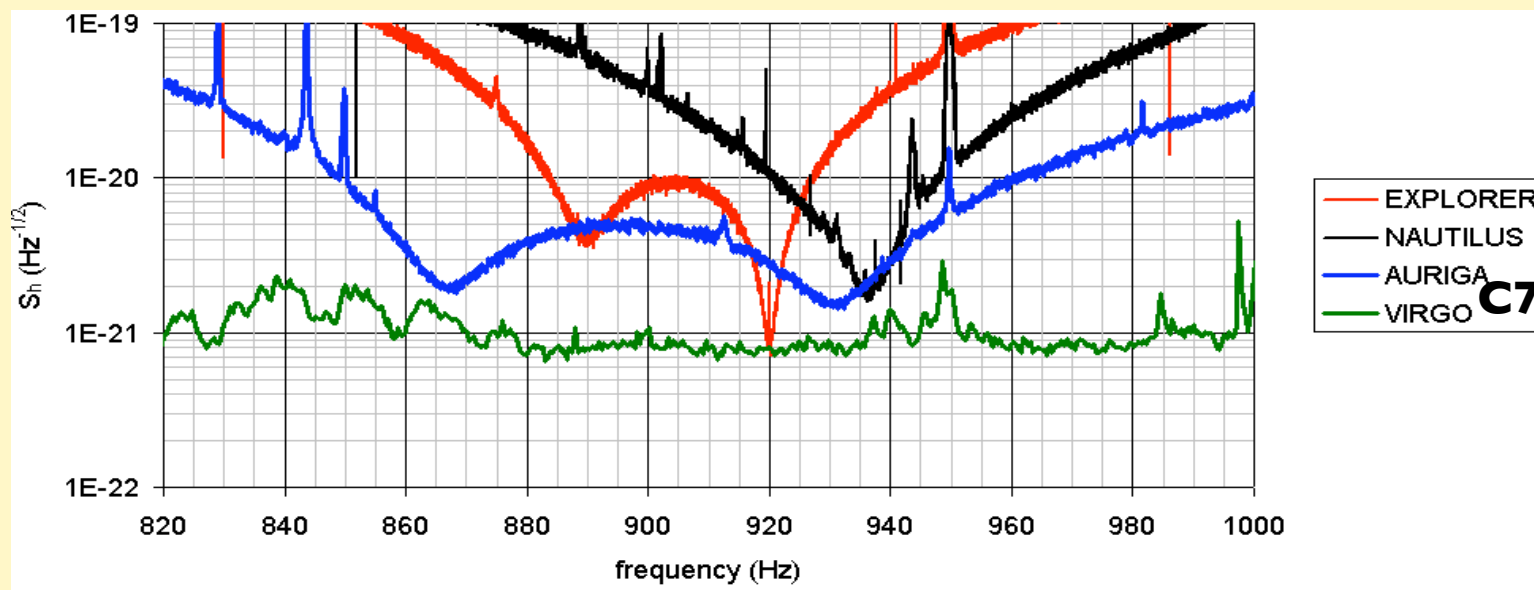




Burst gravitational wave searches

- short (~ 1 ms) pulses of gravitational waves
- sources include supernovae core collapse and merger phase of binary neutron stars
- two broad categories of burst searches:
 - **all-sky**: unknown source parameters, maximise detection efficiency over entire sky
 - **triggered**: search is triggered by observation in EM spectrum (eg. GRB, pulsar glitch)
- most common approach is to search for coincident excess power in network of detectors
 - LIGO detectors are aligned to each other use a cross-correlation follow up

Virgo-bars & IGEC2



- Virgo-bars
 - exchange 24 hours of data
 - L. Baggio (funded by ILIAS Fellowship) part of analysis team
 - null hypothesis confirmed: finalising results and setting upper limit
- IGEC2 (resonant-bar network)
 - exchange 6 months of data: 130 days triple coincidence
 - no Science data available from other detectors during this period
 - null hypothesis confirmed



Coherent burst analysis

- coherent analysis merge data from multiple detectors while taking into account the different noise level and directional sensitivities of each detector
 - improve efficiency of the network
 - reduce false alarms
- one can take two approaches for coherent burst analysis
 - “data combination”
 - “likelihood methods” based on work by Gruesel and Tinto PRD 40, 3884 (1989)
- note that use of coherent methods allow for parameter estimation of detected signal
 - sky location of signal source
 - waveform reconstruction
- other coherent methods:
 - M. Rakhmanov, CQG 23, S673 (2006)
 - L.Wen, gr-qc 0702096



Coherent burst analysis

- “data combination” approach first proposed by J. Sylvestre, PRD 68, 102005 (2003)
- combination outputs of detectors into a single data stream

$$h_{rec} = \sum_i f_{i,+} h_i(t + \delta t_i) / \sigma_i$$

Estimated SNR for source from Galactic Centre for one instance in time

	Coherent	Virgo	Livingston	Hanford	
	4.5	3.5	3.0	1.2	
increasing signal amplitude	5.3	4.2	3.5	1.4	work done by N. Leroy
	7.9	6.3	5.3	2.1	
	13.2	10.5	8.9	3.4	

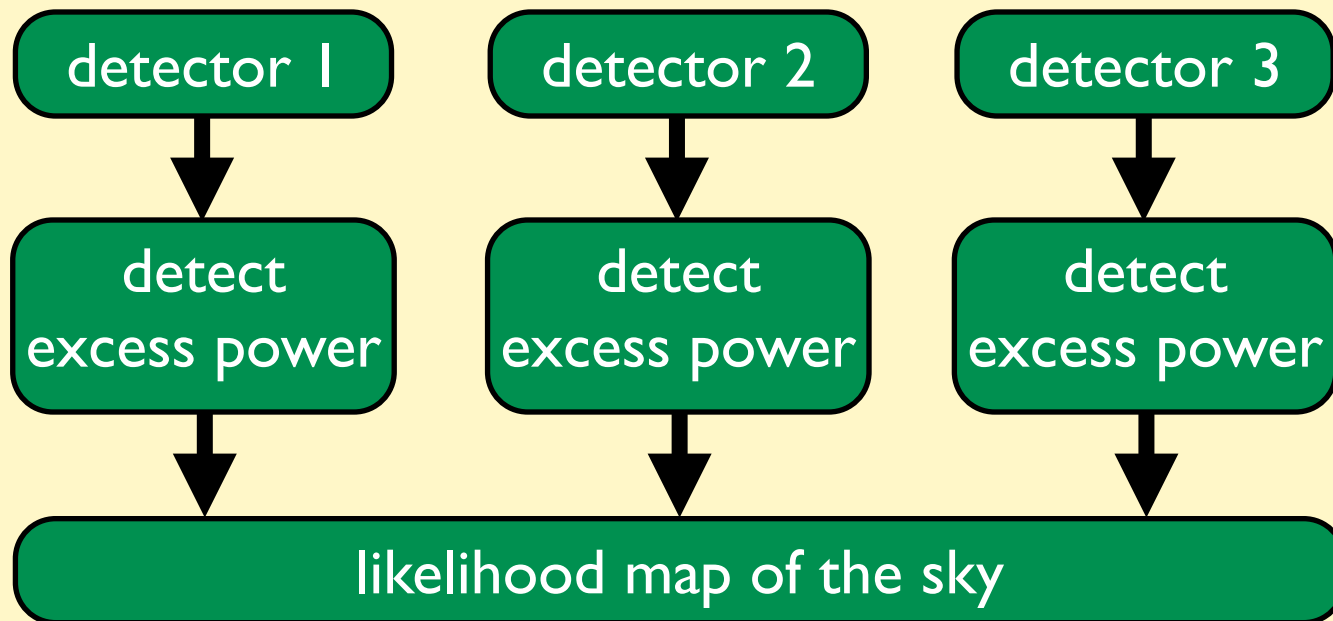


Coherent burst analysis

calculate likelihood of signal originating from all sky locations

$$L = \sum_t \sum_i \frac{1}{2\sigma_i^2} \left[\underbrace{x_i^2(t)}_{\text{detected power}} - \underbrace{(x(t) - \xi(t))^2}_{\text{noise energy}} \right]$$

ξ - reconstructed GW signal



Klimenko et al.
PRD 72 122002
(2005)

Chatterji et al.
PRD 74 082005
(2006)

- one implementation using Wavelet transforms (coherent Waveburst) has been used on data acquired by LIGO and GEO600
- preliminary results show improved sensitivity with respect to non-coherent methods

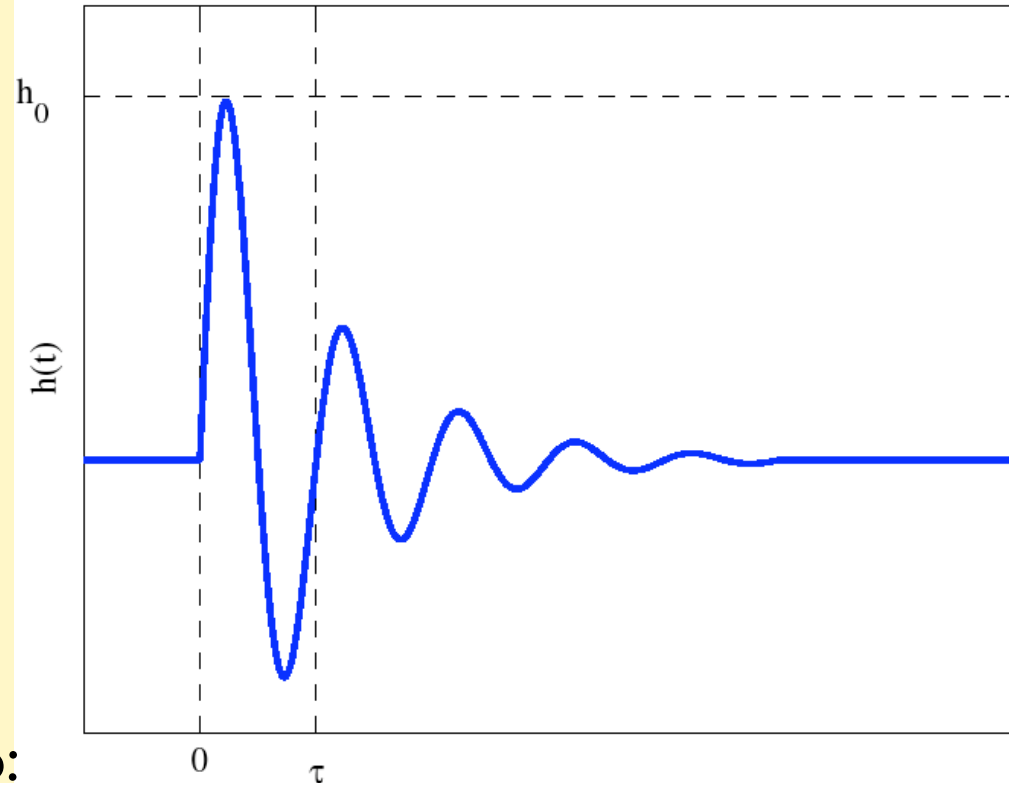


Triggered burst searches

- burst searches triggered by observation in electromagnetic spectrum
- gamma-ray bursts associated with merger of two neutron stars
- glitches in pulsar timing associated with “star quake” leading to normal mode oscillations of neutron star
- fewer free parameters to search over compared to all-sky search
 - know time, sometimes direction and distance
- previous searches have used cross-correlation in data from LIGO detectors
- planning to use coherent analyses to incorporate more detectors
- also developing Bayesian approach for ringdown analysis

Bayesian ringdown search

- excitation induces “ringing” neutron star or black hole
- search for ringdowns in black holes using LSC detectors performed by L. Goggin (Caltech)
 - matched filtering approach
- Bayesian approach begin developed by J. Clark (Glasgow)
- Detection statistic is the odds ratio:



$$O_{12} = \frac{p(\mathcal{M}_1 | I)}{p(\mathcal{M}_2 | I)} \times \frac{p(\{D\} | M_1, I)}{p(\{D\} | M_2, I)}$$

prior odds \rightarrow $\frac{p(\mathcal{M}_1 | I)}{p(\mathcal{M}_2 | I)}$ \times $\frac{p(\{D\} | M_1, I)}{p(\{D\} | M_2, I)}$ \leftarrow Bayes factor

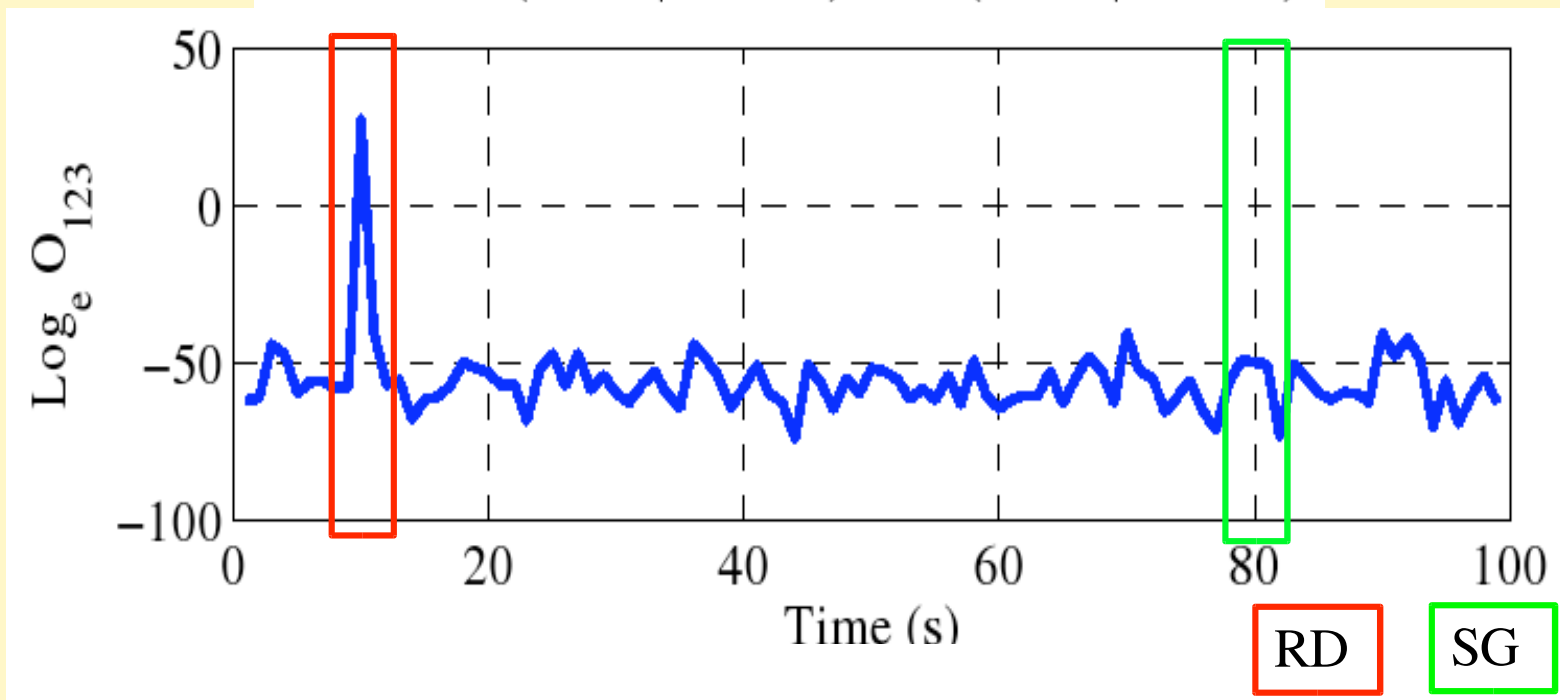
- $p(\{D\} | M_i, I)$ is the evidence for model i given the data, D
 - marginalise over unknown parameters
- model 1: data contains ringdown, model 2: white noise



Bayesian ringdown search

- can be extended to take into account non-gaussian “glitches”

$$O_{123} = \frac{p(\mathcal{M}_1 | \mathcal{D}, I)}{p(\mathcal{M}_2 | \mathcal{D}, I) + p(\mathcal{M}_3 | \mathcal{D}, I)} \leftarrow \text{glitch evidence}$$



- begun collaboration with A. Corsi (INAF-IASF) on ringdowns associated with GRBs
- coherent version of this analysis:

$$p(M_{GW} | \{D\}, I) = p(M_{GW} | I) \prod_i \frac{p(D_i | M_{GW}, I)}{p(D_i | I)}$$



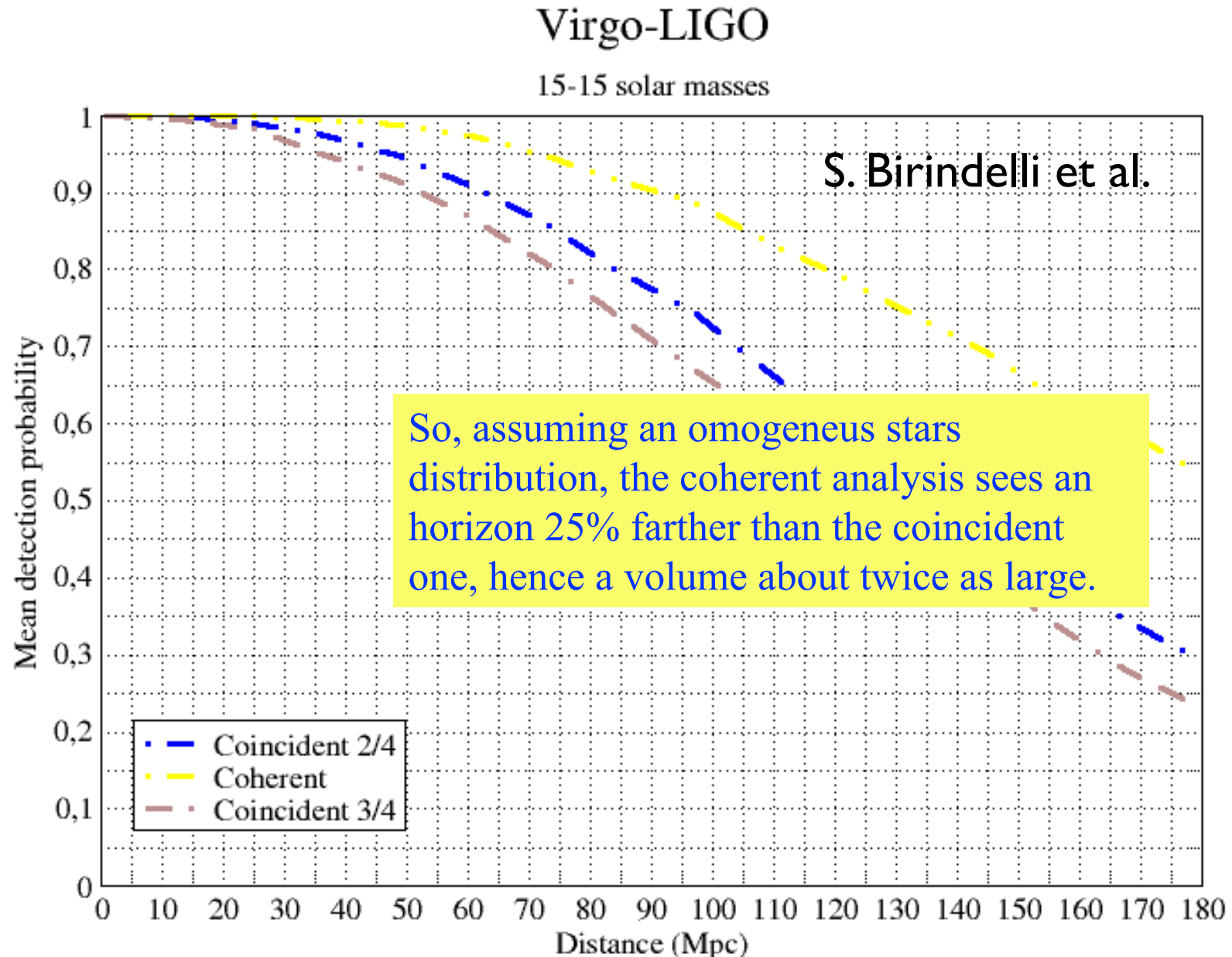
Coherent inspiral analysis

- Inspiral gravitational wave signals arise from inspiral compact objects in binary system
- for coherent inspiral analysis, the log likelihood ratio is derived by A. Pai, S. Dhurandar and S. Bose PRD 64 042004 (2001)

$$LLR = \sum_i \left(\langle s_i, x_i \rangle_i - \frac{1}{2} \langle s_i, s_i \rangle_i \right)$$

- investigation into use of coherent inspiral analysis performed by two groups
 - S. Bose et al.
 - S. Birindelli, L. Bosi, F. Marion and A. Vicere

Inspiral range

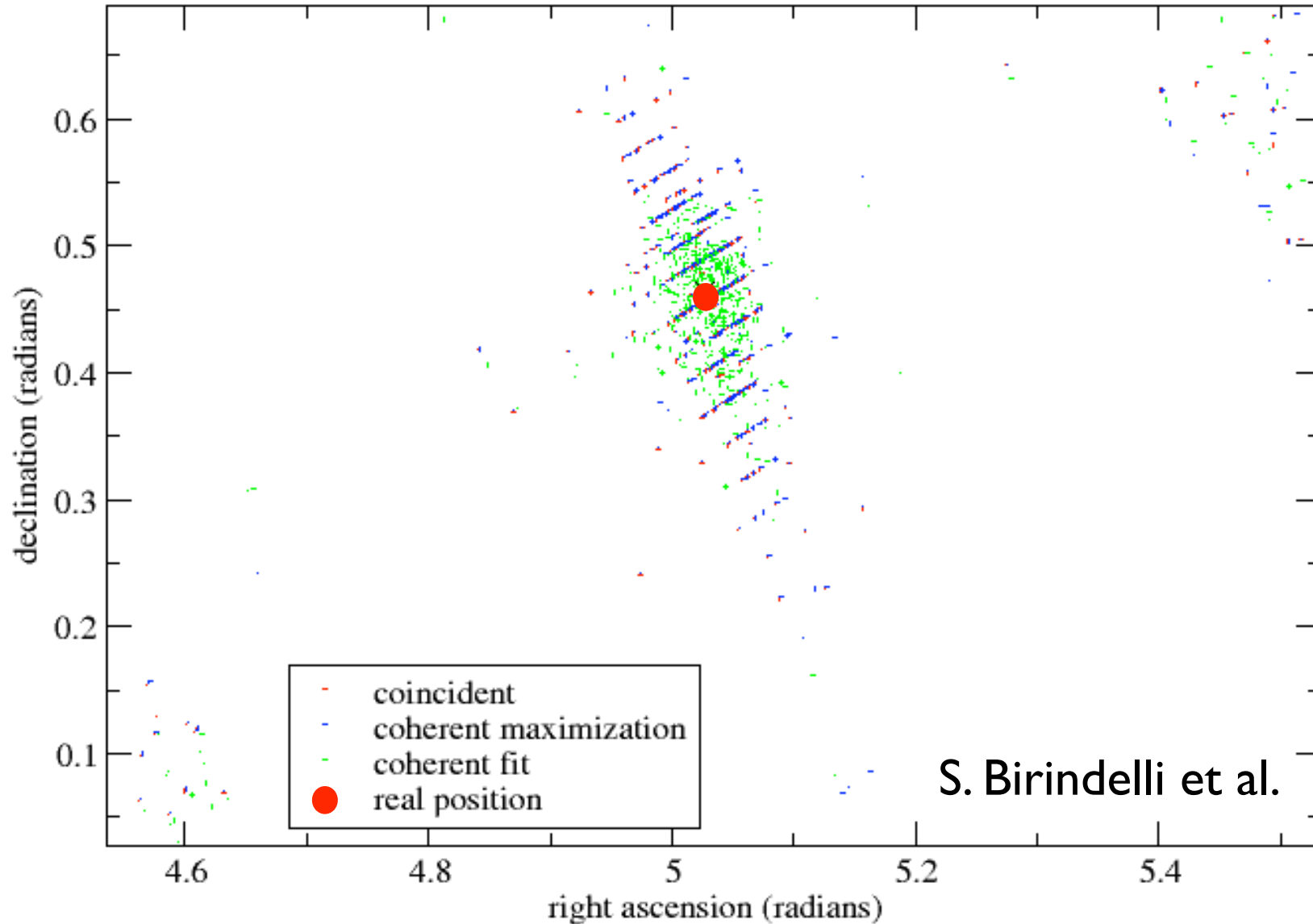




Sky location estimation

Reconstructed position RA 5.026 Dec 0.464

scale distance $8.3333e-2$ SNR (6,6, 6)



S. Birindelli et al.