Observation of Gravitational Waves from a Binary Black Hole Merger

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Outlines of My Presentation

- *INTRODUCTION*
- *CONTENTS*
- *CONCLUSIONS & OUTLOOK*
- *MY WORK*

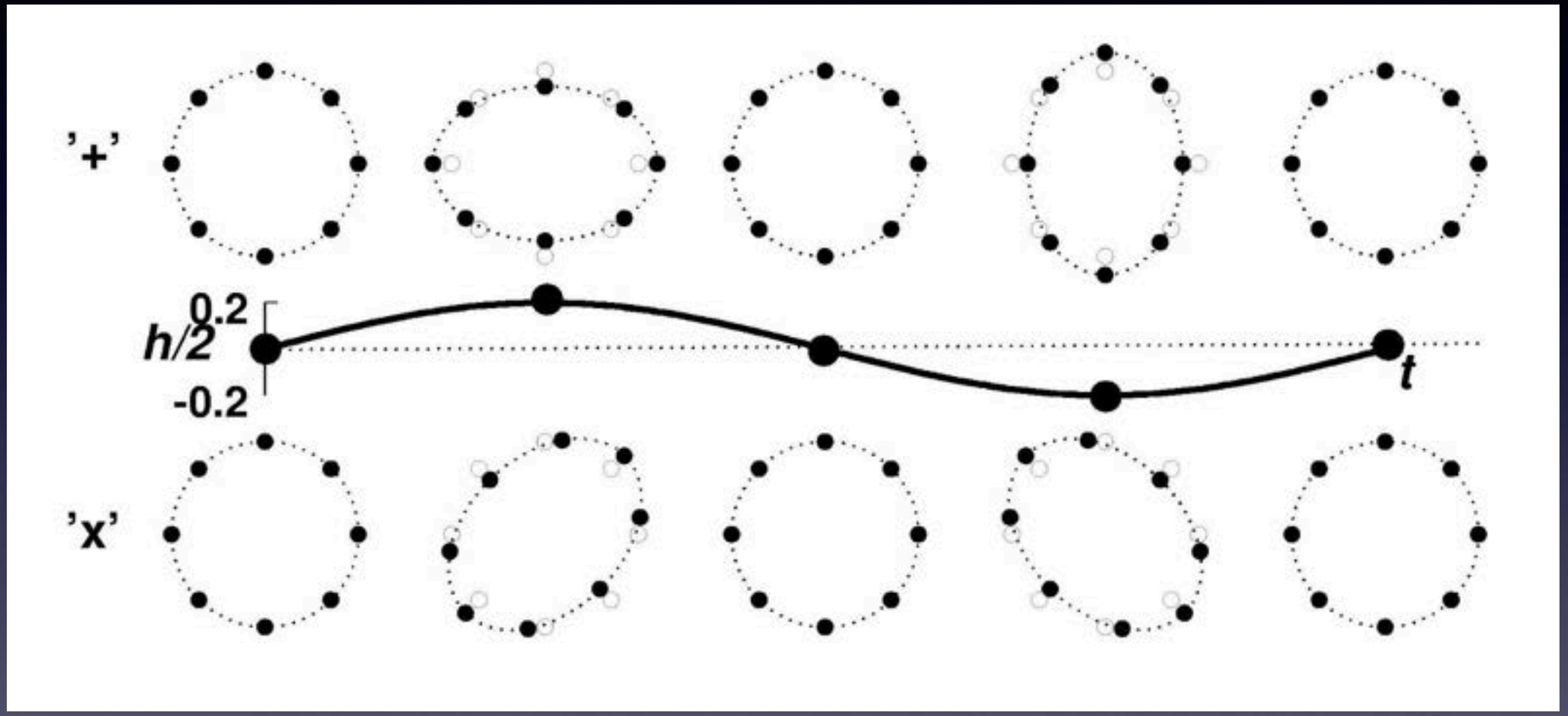
INTRODUCTION

- *Gravitational waves are the most important prediction of Einstein that has been verified by direct detection in the year of 2015. The Hulse-Taylor pulsar system PSR1913+16 gives very strong indirect conformation of the theory.*

- *Gravitational waves carry huge energies, but they interact very weakly with matter. These properties make them ideal probes of some of the most interesting parts of the Universe, now that we have learned how to make sufficiently sensitive detectors.*

- *Unlike in most of electromagnetic astronomy, the gravitational waves detection strategies very different: instead of bolometric(energy) detection in hardware, gravitational wave detection will be by analysis, in software.*

INTRODUCTION - Theory



Gravitational waves have 2 independent polarisations, illustrated here by the motions of free "test" particles.

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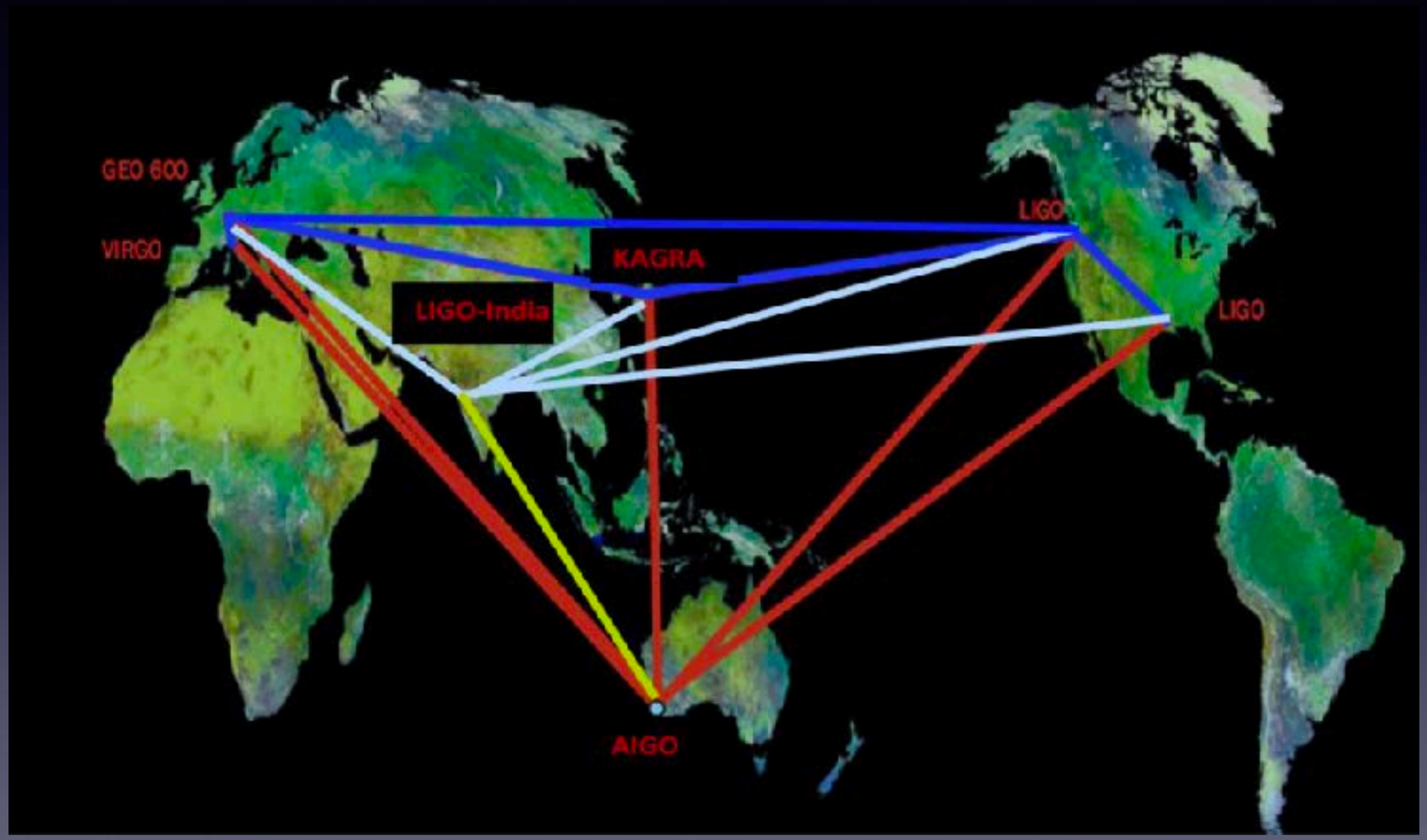
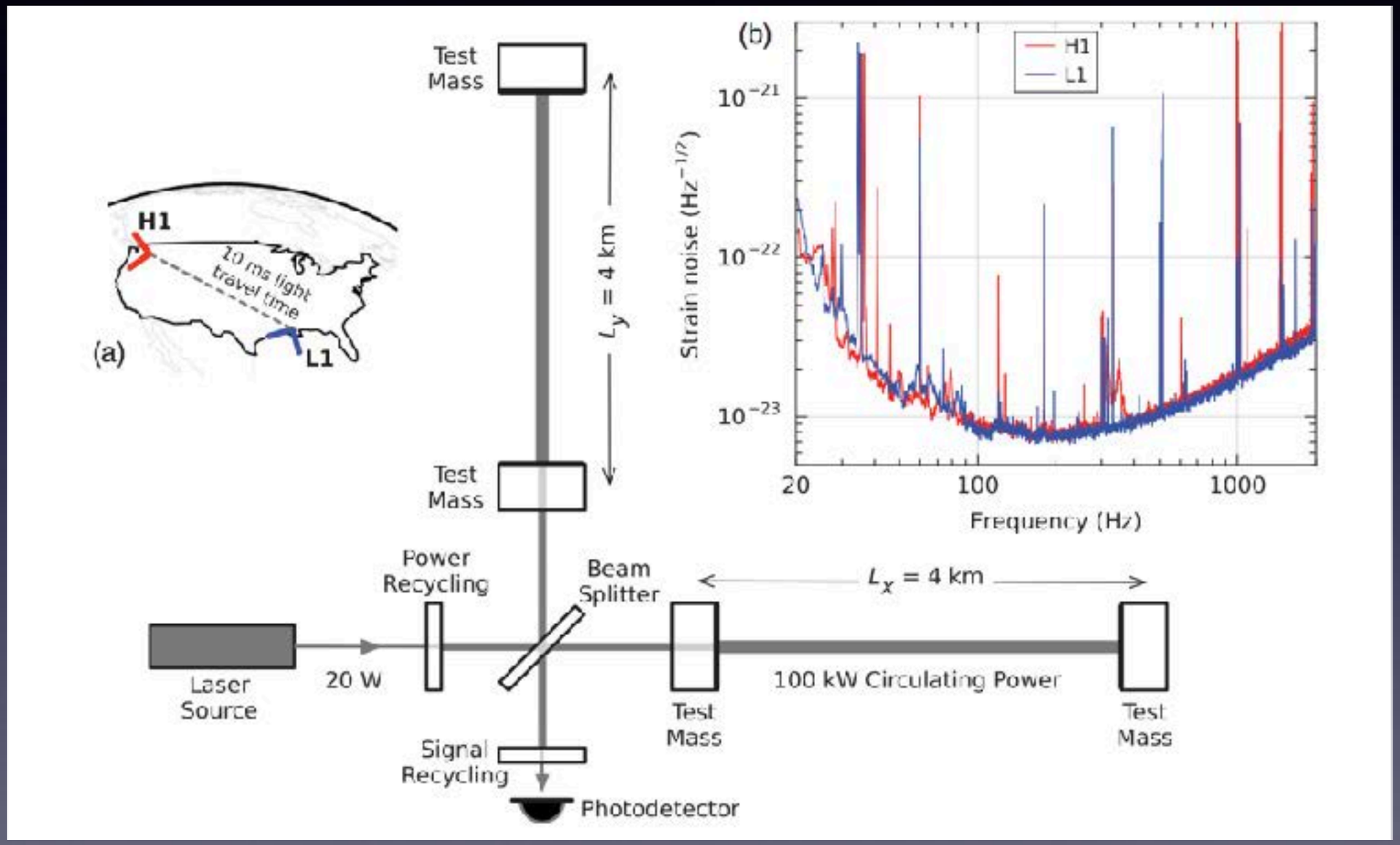
INTRODUCTION - Detector



Wordwide Interferometer Network

From Google

INTRODUCTION - Detector



Simplified diagram of an Advanced LIGO detector (not to scale).

B. P. Abbott et al., Phys. Rev. Lett. 116, 061102 (2016)

INTRODUCTION - Detector

- *Resonant optical cavity - multiply the effect of GW*
- *Power-recycling mirror - increase the laser light*
- *Signal-recycling mirror - optimise the signal extraction*

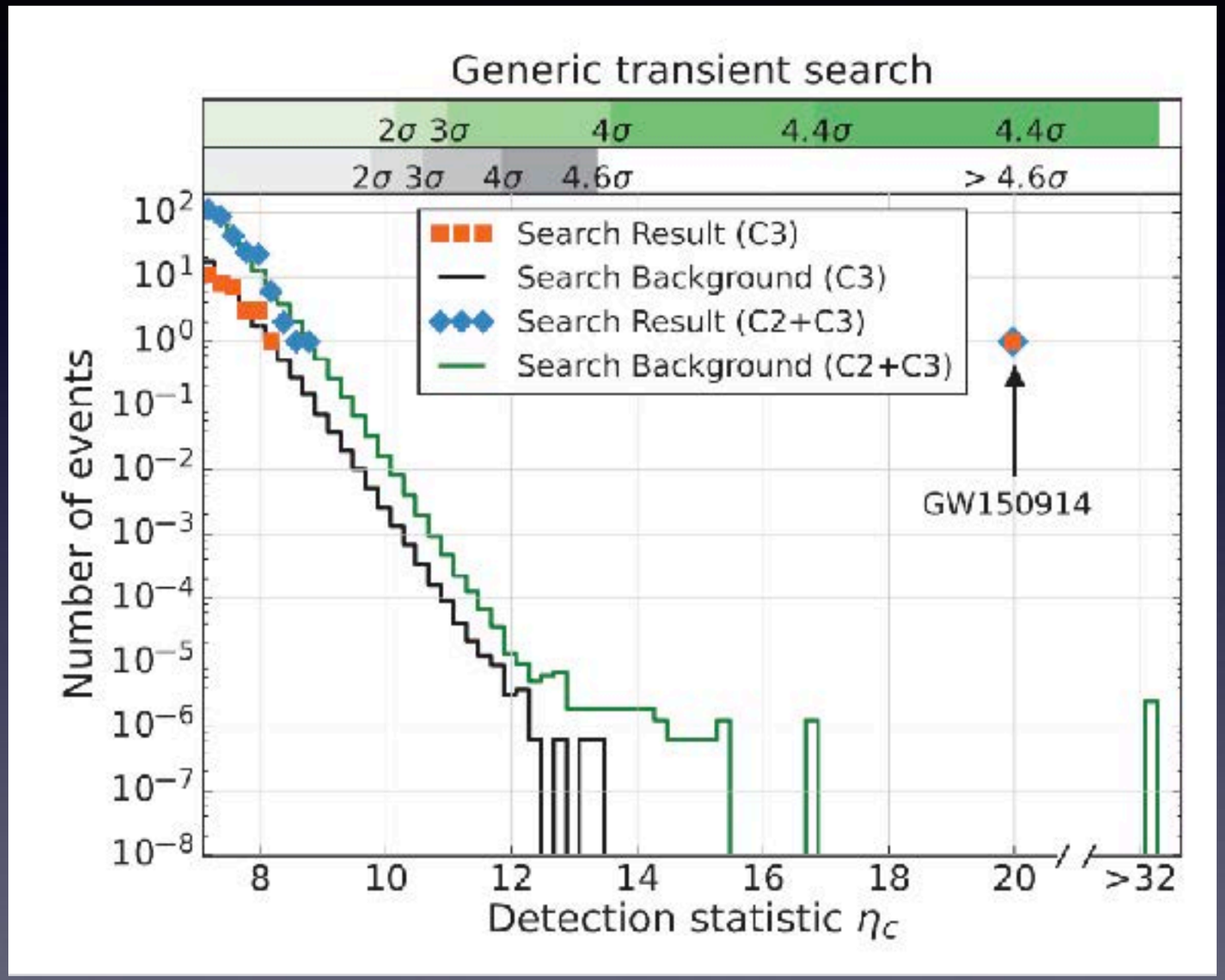
- *Photon shot noise - exceed standard quantum limit*
- *Thermal noise - use low-mechanical-loss materials*
- *Seismic noise - suspend quadruple-pendulum system*

CONTENTS - Search

A. Generic transient Search

- *It targets a broad range of generic transient signals, with minimal assumptions about waveforms.*
- *Each event is ranked according to a detection statistic value to describe the significance.*
- *Time-frequency morphology classification:*
  - *class C1: events with known population*
  - *class C3: events with frequency that increases with time*
  - *class C2: all remaining events*

A. Generic transient Search



Search results from the generic transient search

B. P. Abbott et al., Phys. Rev. Lett. 116, 061102 (2016)

A. Generic transient Search

- *GW150914 is the strongest event of the entire Search and it is found in the Search class C3 of events with increasing time-frequency evolution.*

- *False alarm rate is lower than 1 in 22500 years and the corresponding significance is 4.6 sigma.*

- *A different generic transient Search algorithms and a parameter estimation follow-up detected GW150914 with consistent significance and signal parameters.*

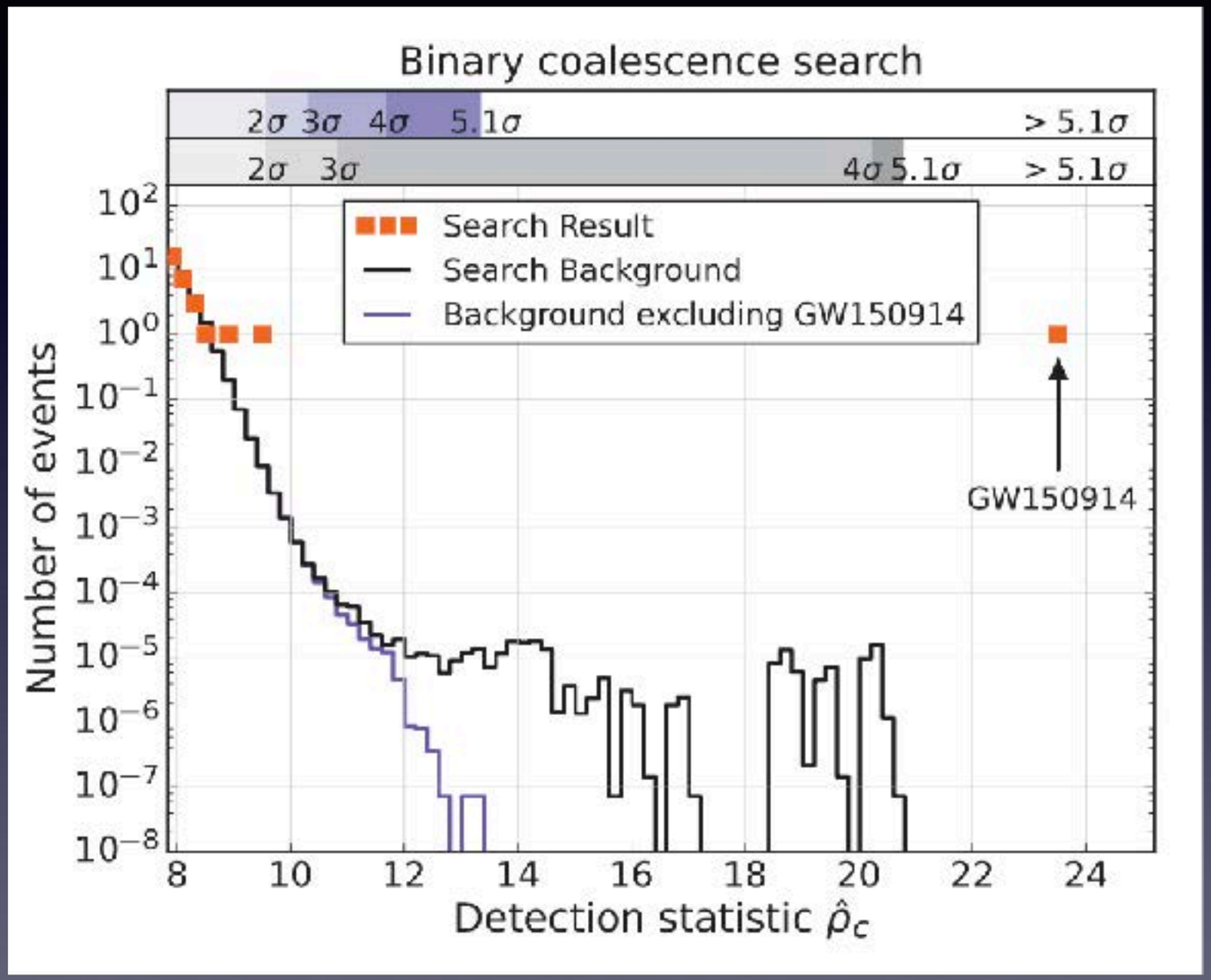
B. Binary Coalescence Search

- *It aims to recover signals from the coalescence of compact object, using optimal matched filtering with waveforms predicted by general relativity.*

- *each event is ranked according to a detection statistic value to describe the significance.*

- *Approximately 250000 template waveforms are used to cover this parameter space.*

B. Binary Coalescence Search



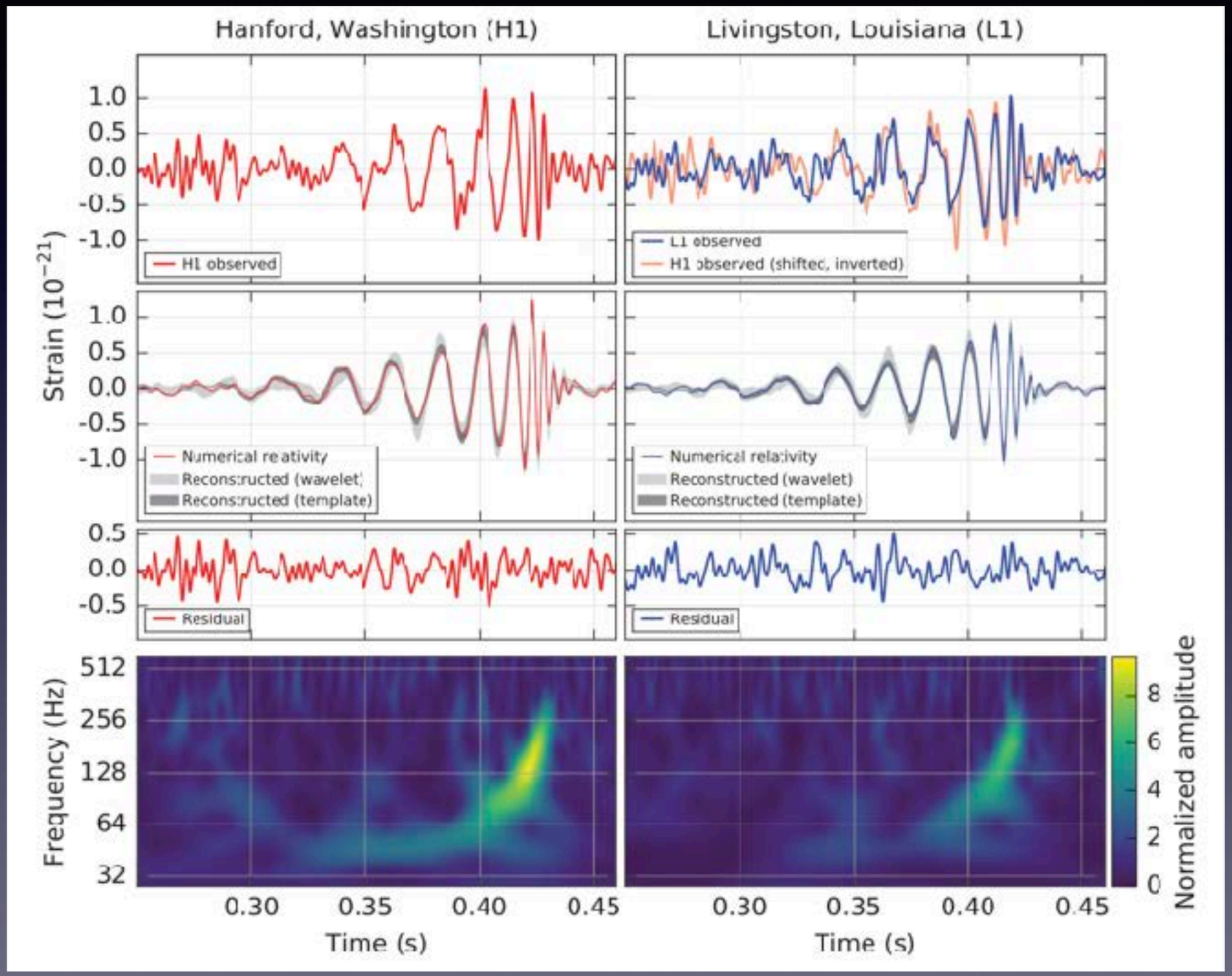
Search results from the binary coalescence search

B. P. Abbott et al., Phys. Rev. Lett. 116, 061102 (2016)

B. Binary Coalescence Search

- *The GW150914 detection value is larger than any background events.*
- *False alarm rate is lower than 1 in 203000 years and the corresponding significance is 5.1 sigma.*
- *An independent matched-filter analysis that uses a different method for estimating the significance of its events, also GW150914 with identical signal parameters and consistent significance.*

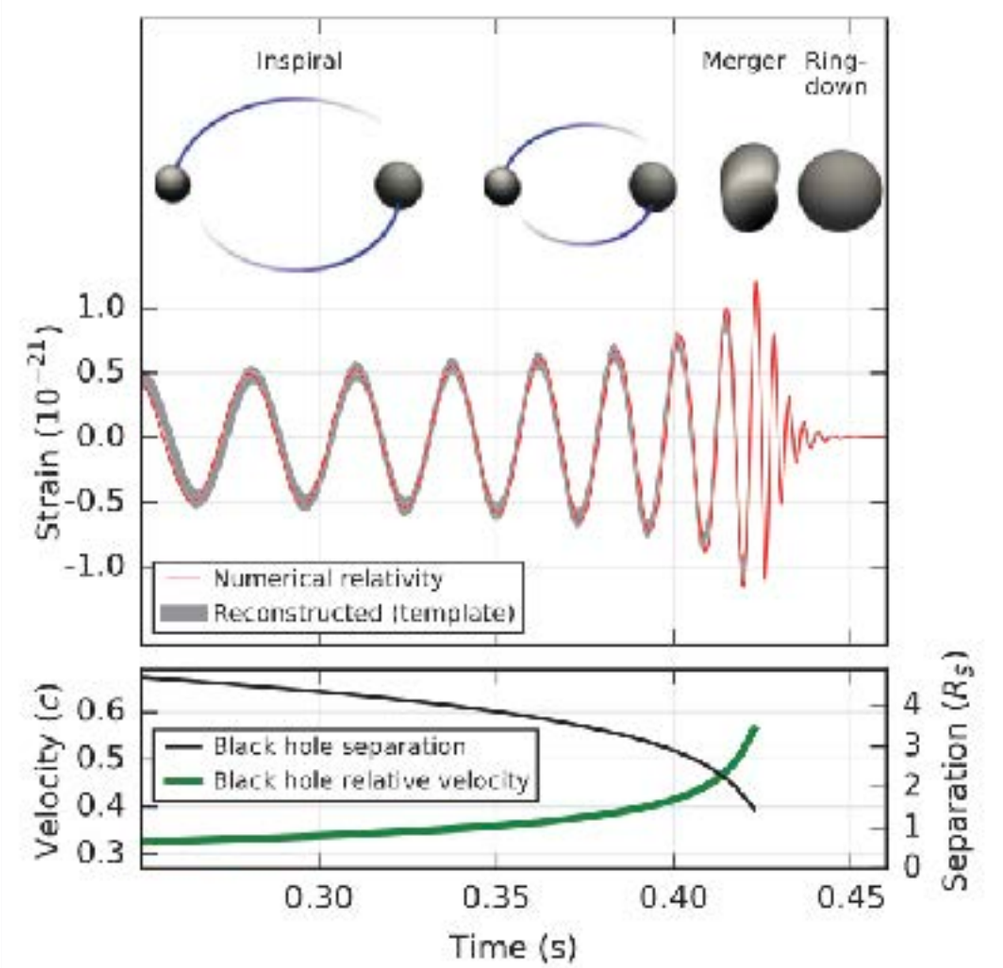
CONTENTS - Observation



The gravitational-wave event GW150914 observed by the LIGO Hanford and Livingston detectors

B. P. Abbott et al., Phys. Rev. Lett. 116, 061102 (2016)

CONTENTS - Observation



Estimated gravitational-wave strain amplitude from GW150914 projected onto the LIGO Hanford

Primary black hole mass	$36^{+5}_{-4} M_\odot$
Secondary black hole mass	$29^{+4}_{-4} M_\odot$
Final black hole mass	$62^{+4}_{-4} M_\odot$
Final black hole spin	$0.67^{+0.05}_{-0.07}$
Luminosity distance	410^{+160}_{-180} Mpc
Source redshift z	$0.09^{+0.03}_{-0.04}$

Source parameters for GW150914

B. P. Abbott et al., Phys. Rev. Lett. 116, 061102 (2016)

CONCLUSIONS & OUTLOOK

CONCLUSIONS

- *The LIGO detectors have observed gravitational waves from the merger of two stellar-mass black holes. The detected waveform matches the predictions of general relativity for the inspiral and merger of a pair of black holes and the ringdown of the resulting single black hole.*

- *a , These observations demonstrate the existence of binary stellar-mass black hole systems.*
- *b, This is the first direct detection of gravitational waves.*
- *c, This is the first observation of a binary black hole merger.*

OUTLOOK

- *a, Efforts are under way to enhance significantly the current gravitational-wave detectors.*
- *b, Additionally, Advanced Virgo, KAGRA, and a possible third LIGO detector in India will extend the network largely.*
- *c , The future global network of detectors will significantly improve the position reconstruction and parameter estimation of sources.*

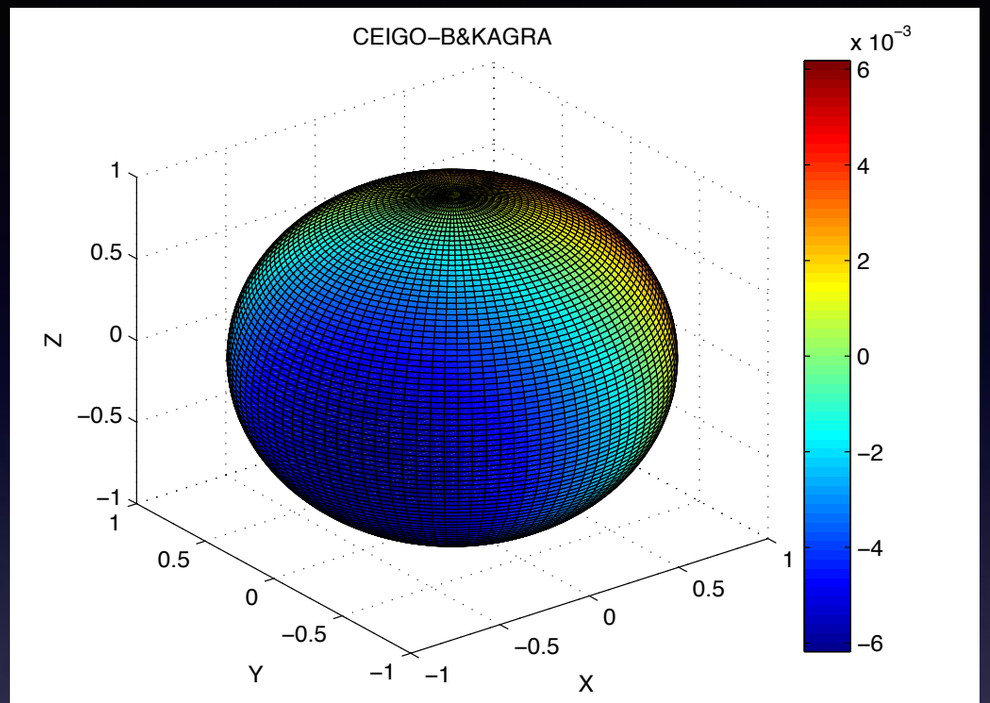
MY WORK

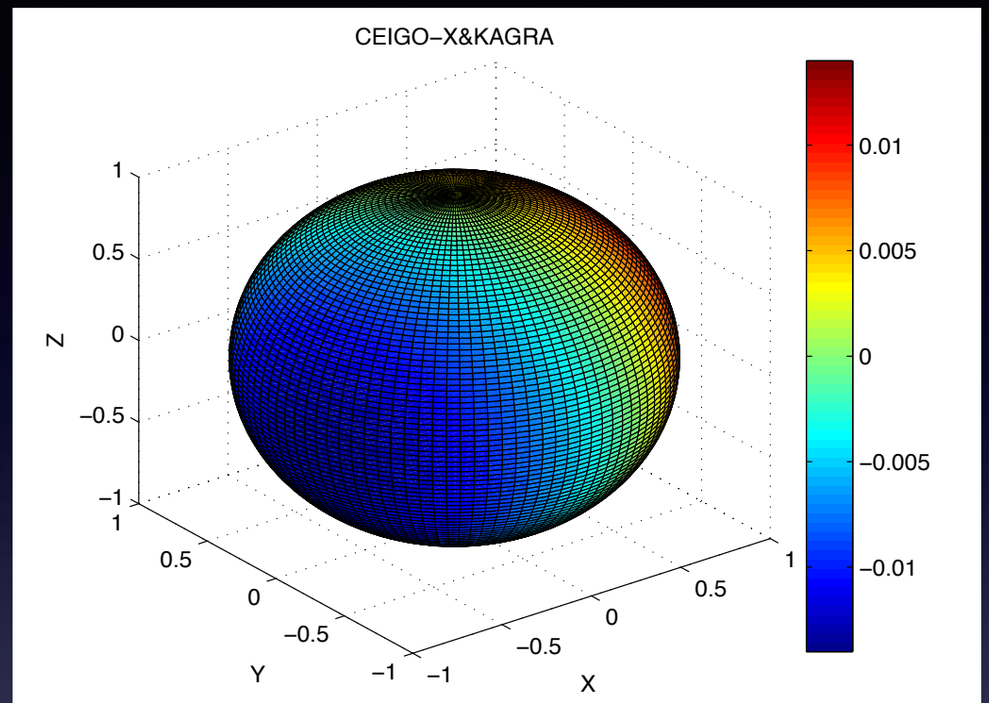
- *The era of regular observation of gravitational wave signals is approaching and therefore it will open the door to multi-messenger astronomy.*

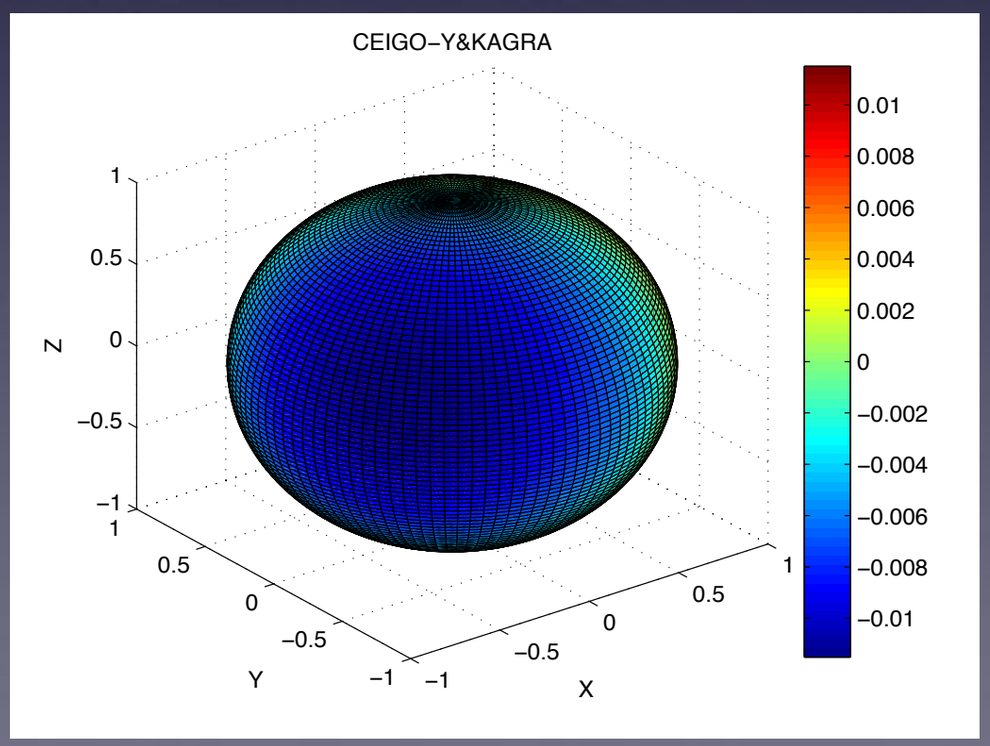
- *One method of performing multi-messenger observations will be to accurately and rapidly localise the source through gravitational wave observations and then use electromagnetic observatories to follow up on the event.*

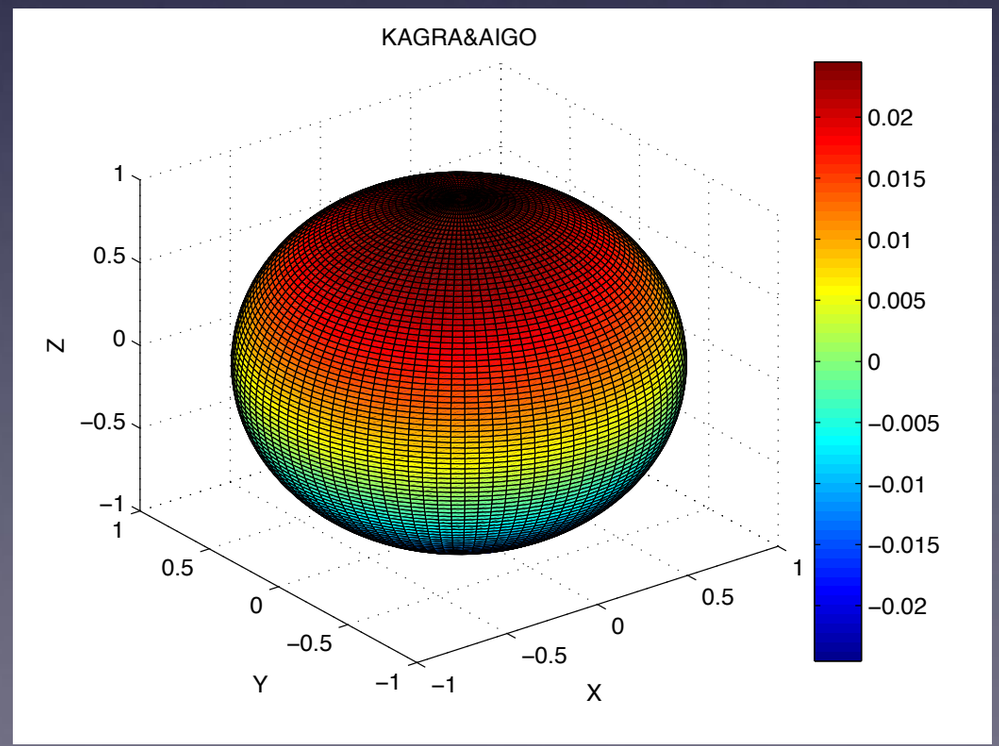
- *Therefore, I use the triangulation method followed by Stephen Fairhurst to localise the GW source.*

MY WORK - Time Delay Maps

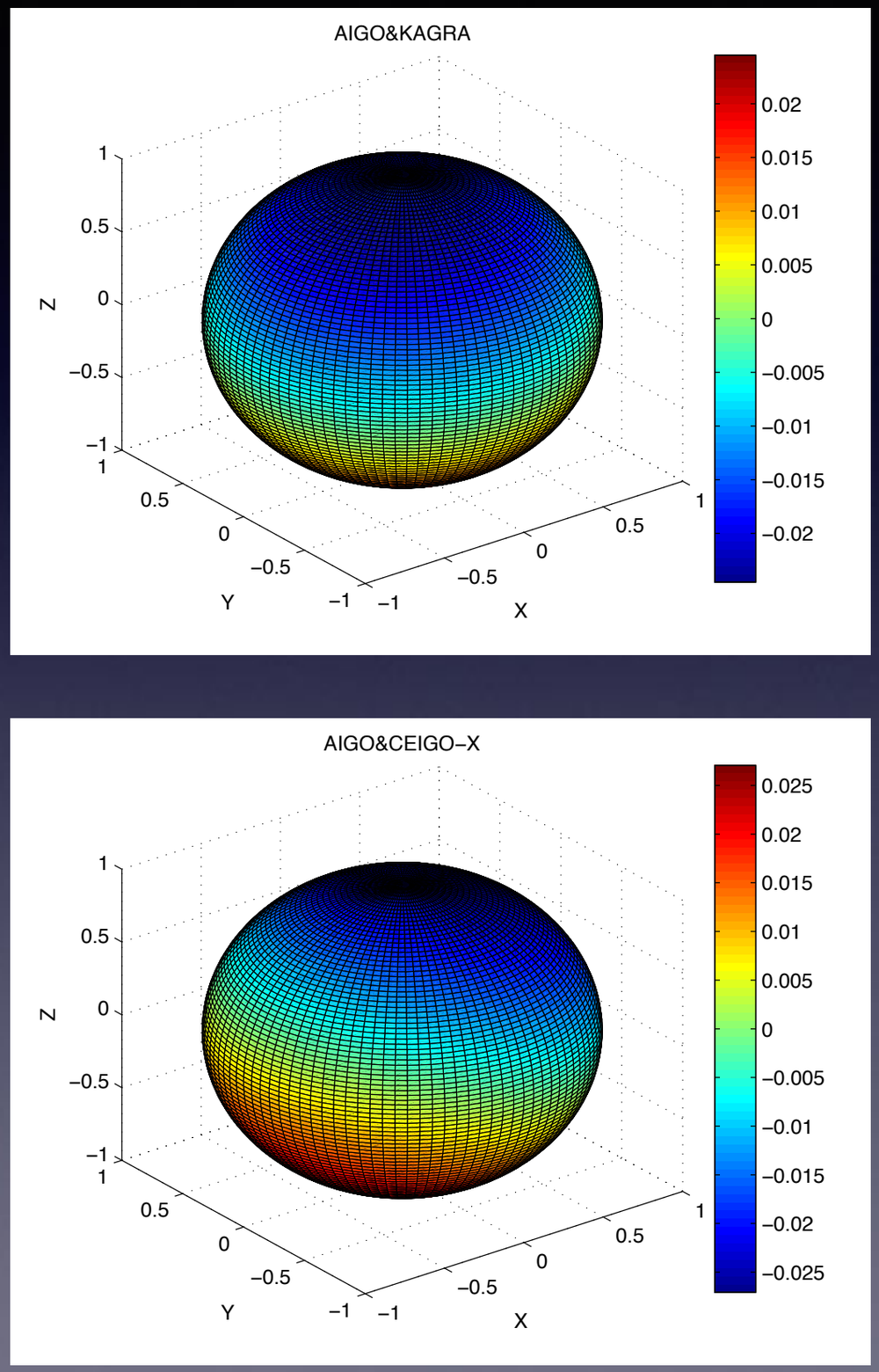


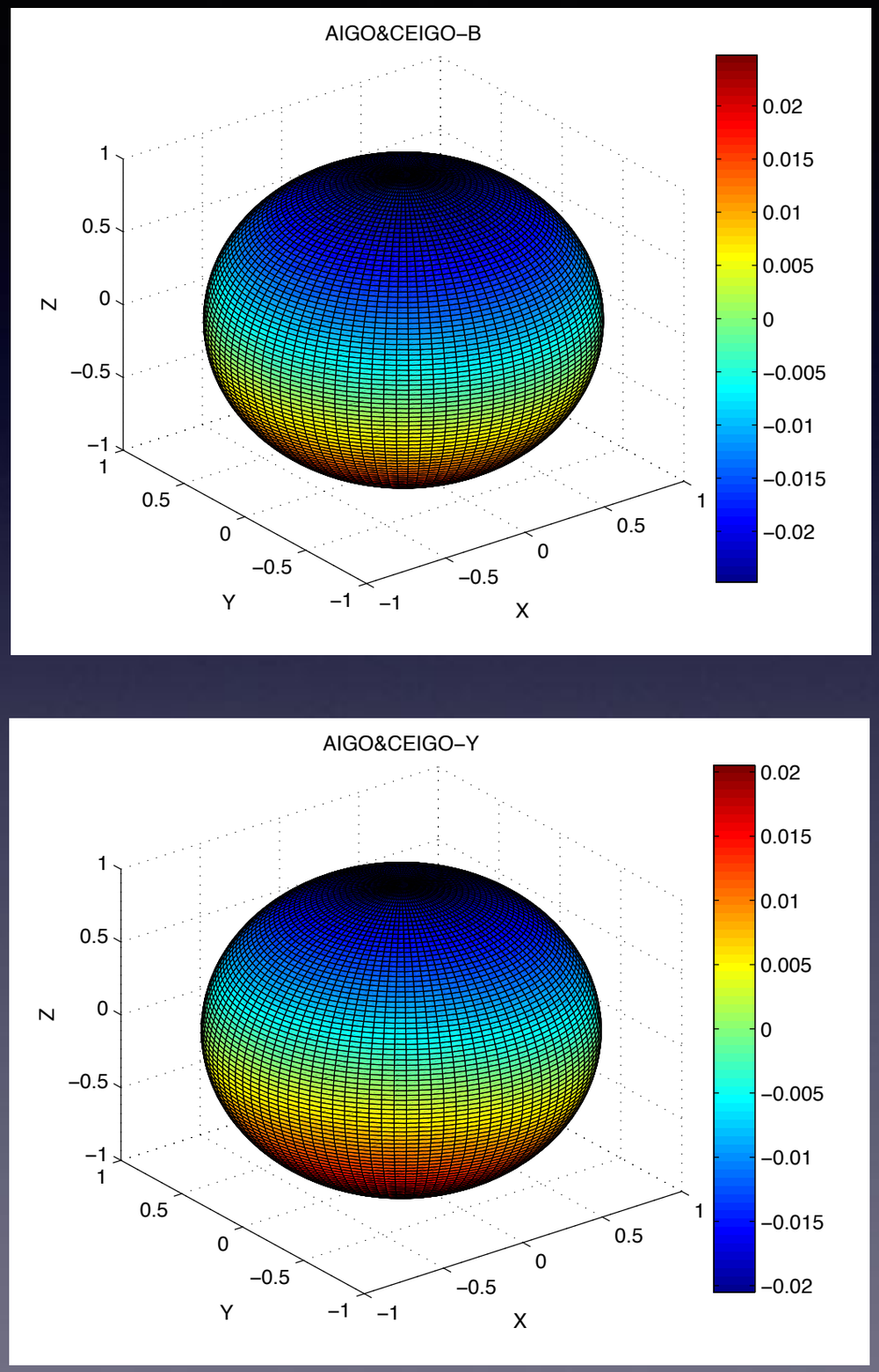




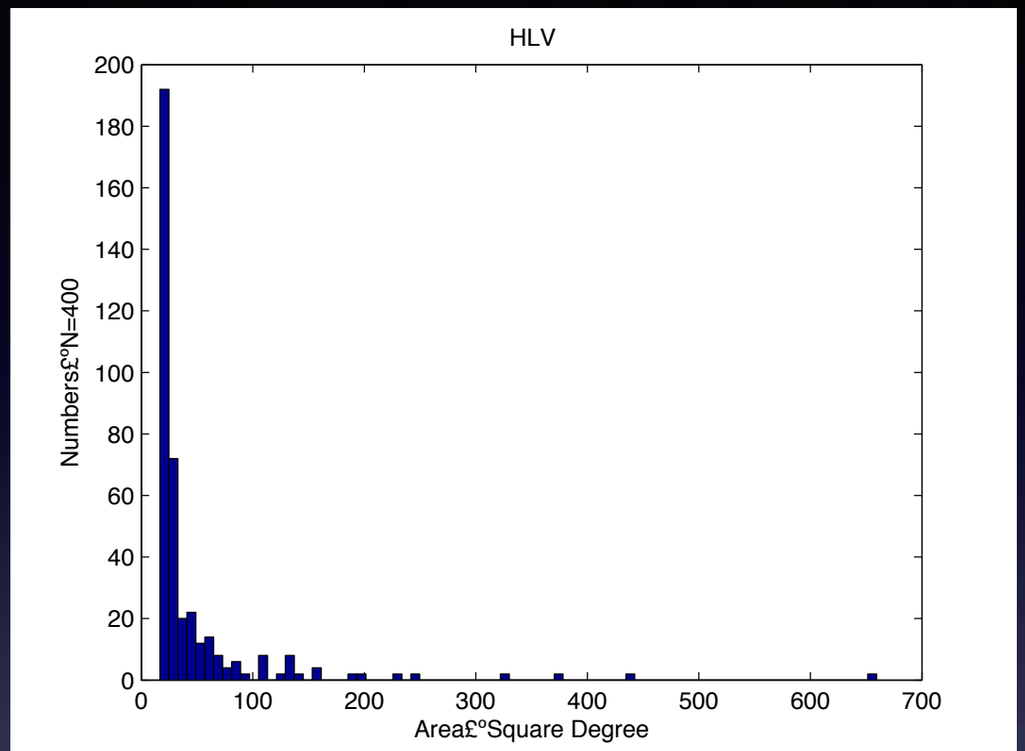


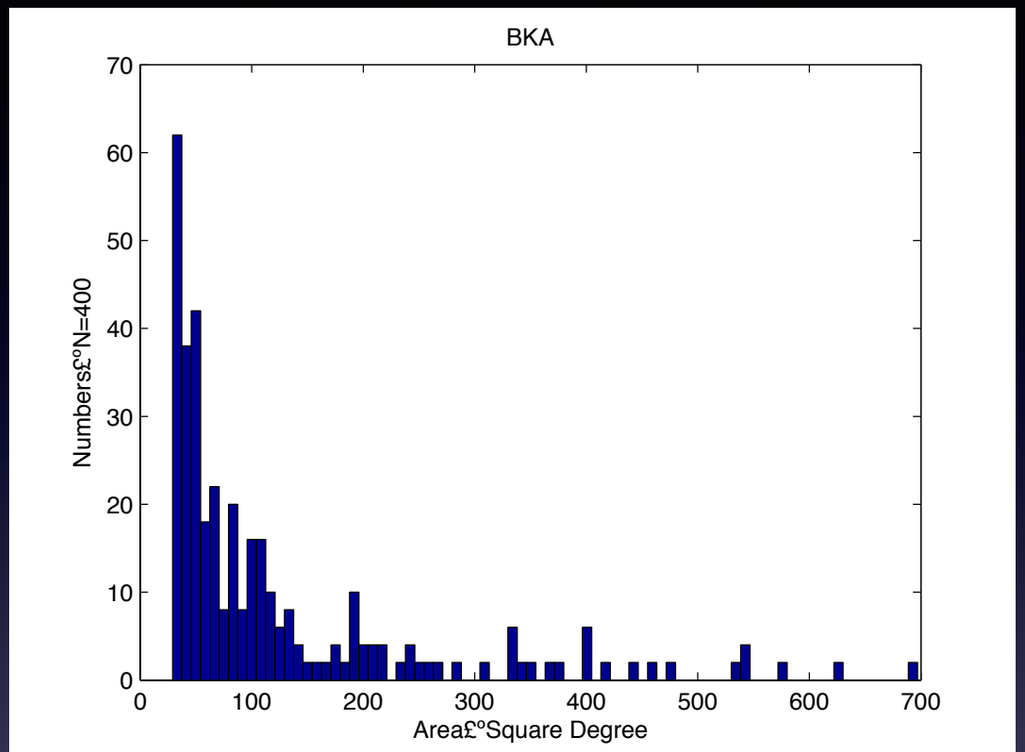
MY WORK - Time Delay Maps

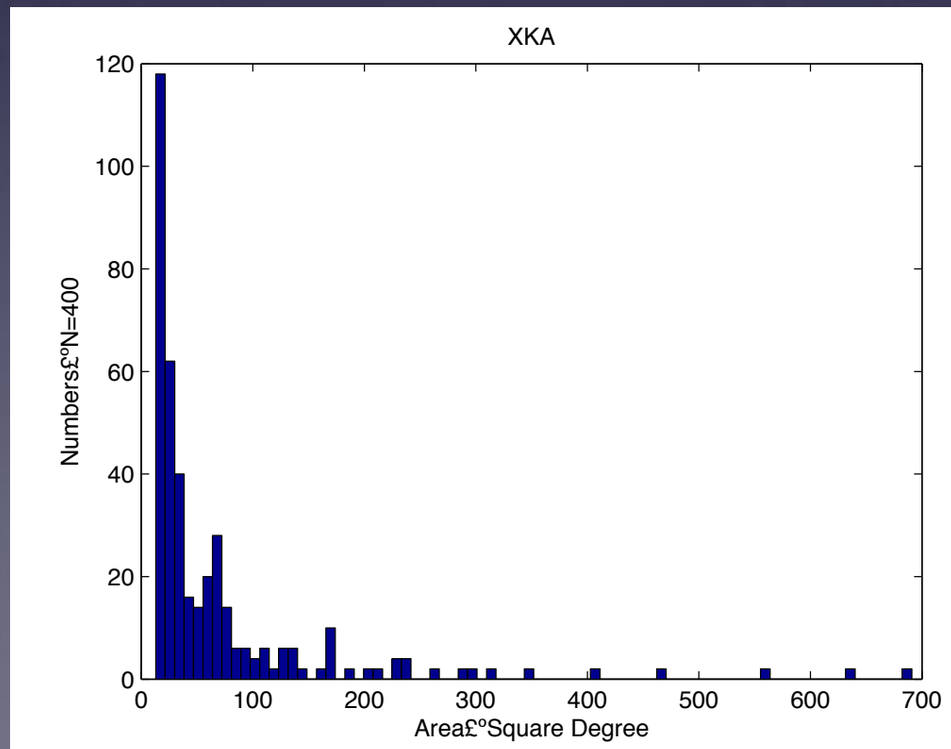


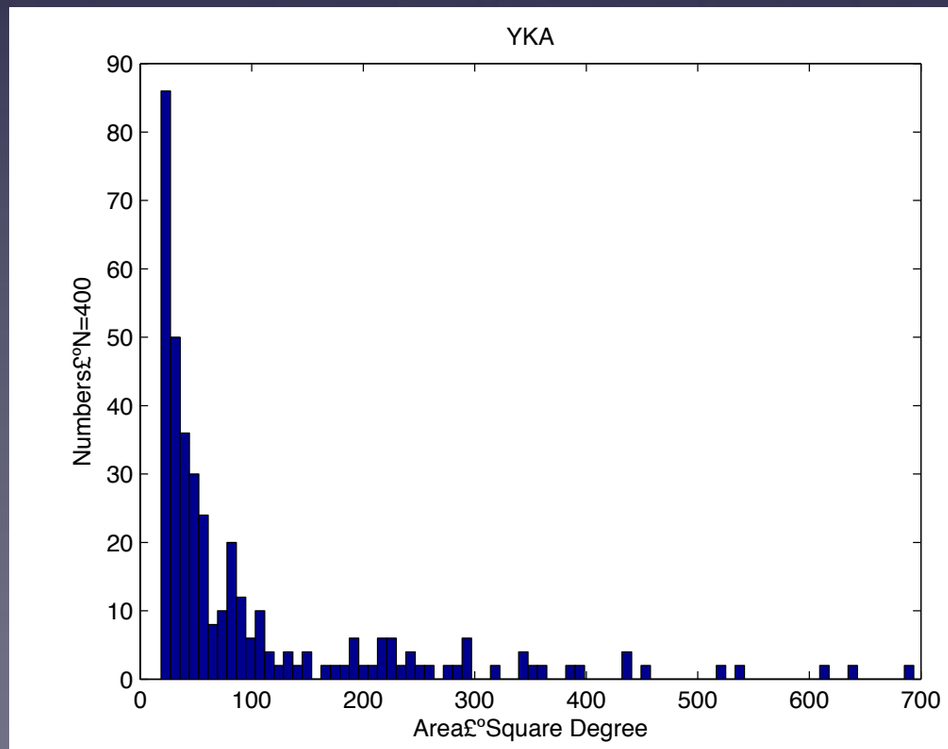


MY WORK - Area Distributions Simulation

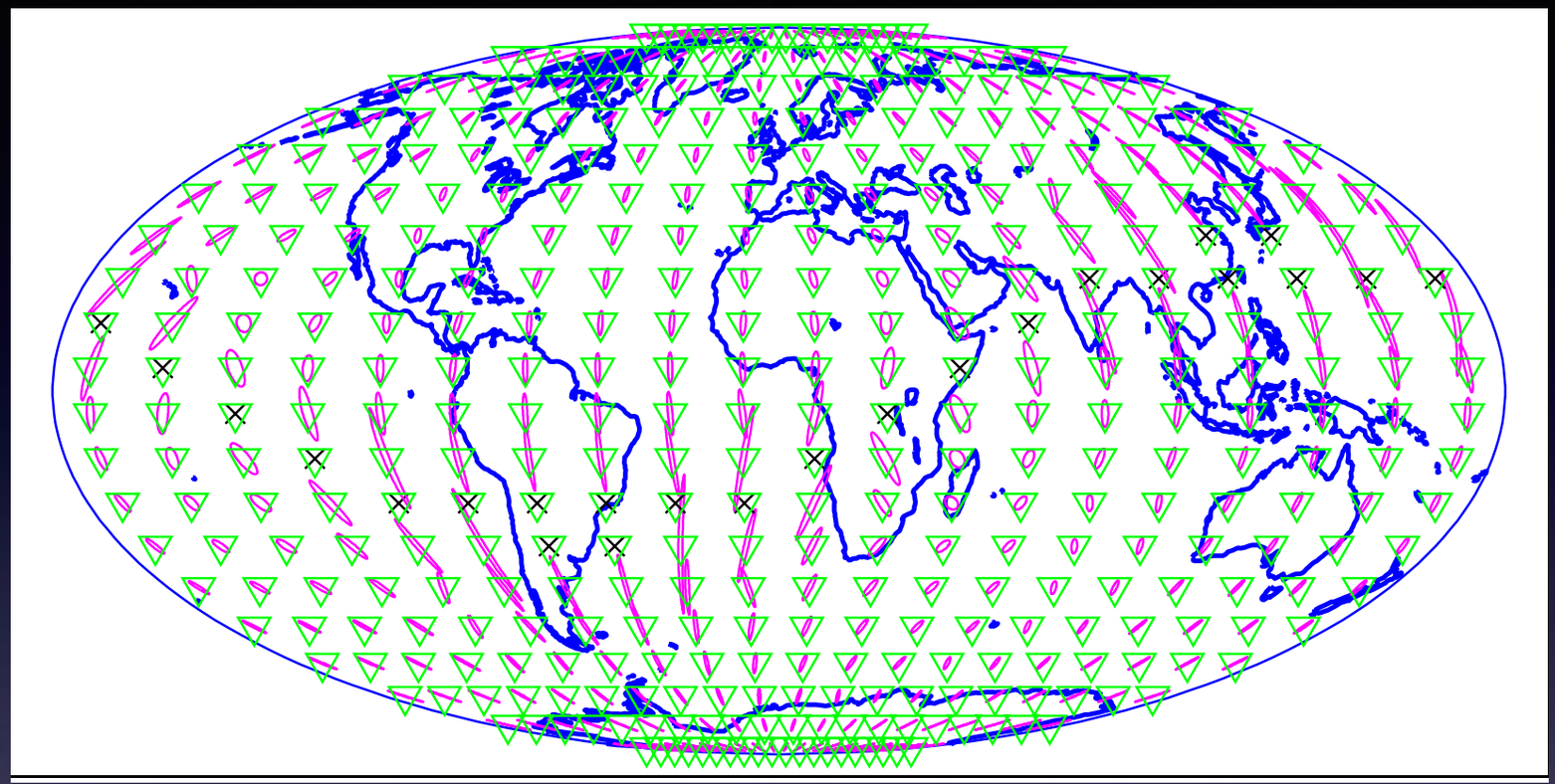




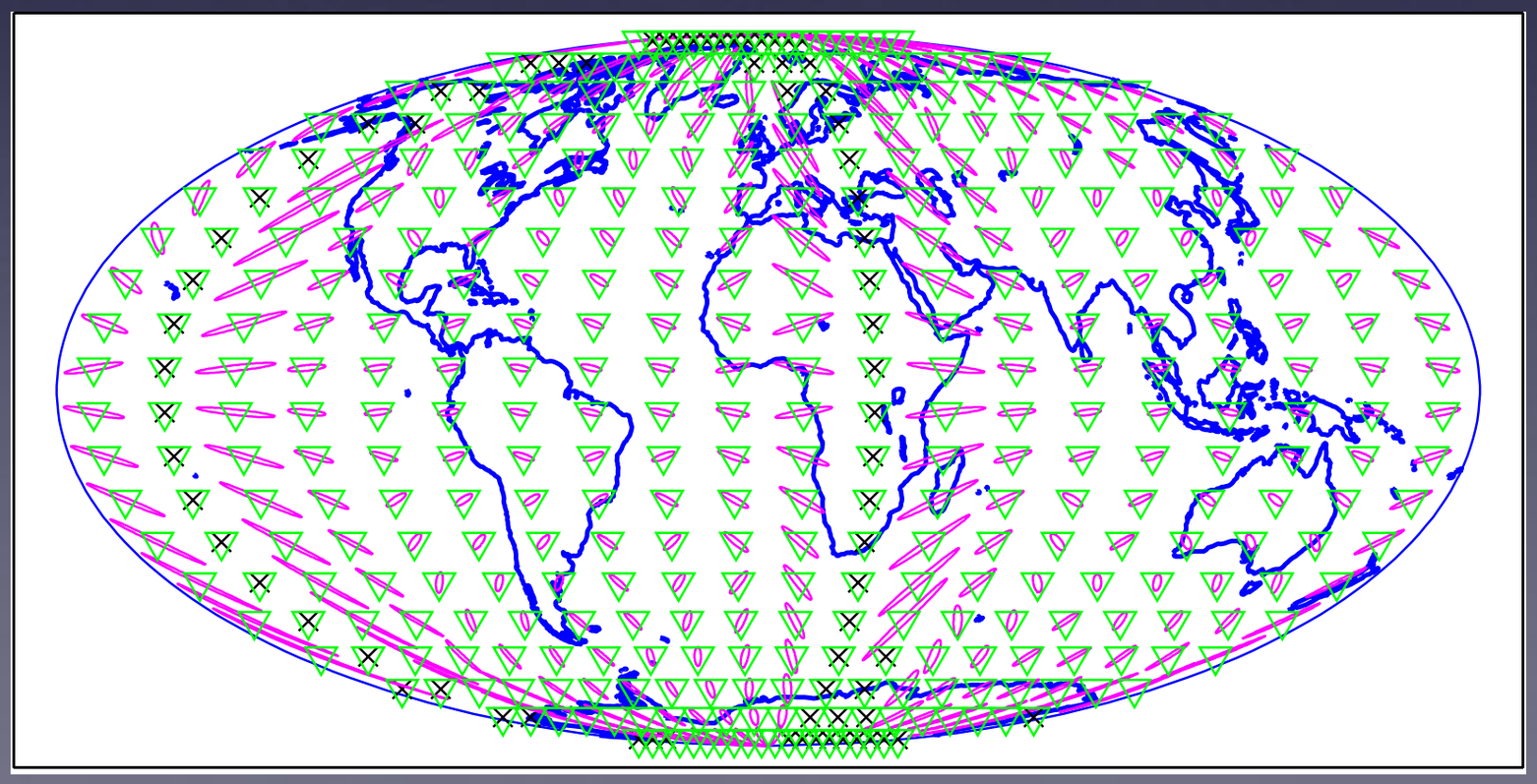




MY WORK - Localisation Maps

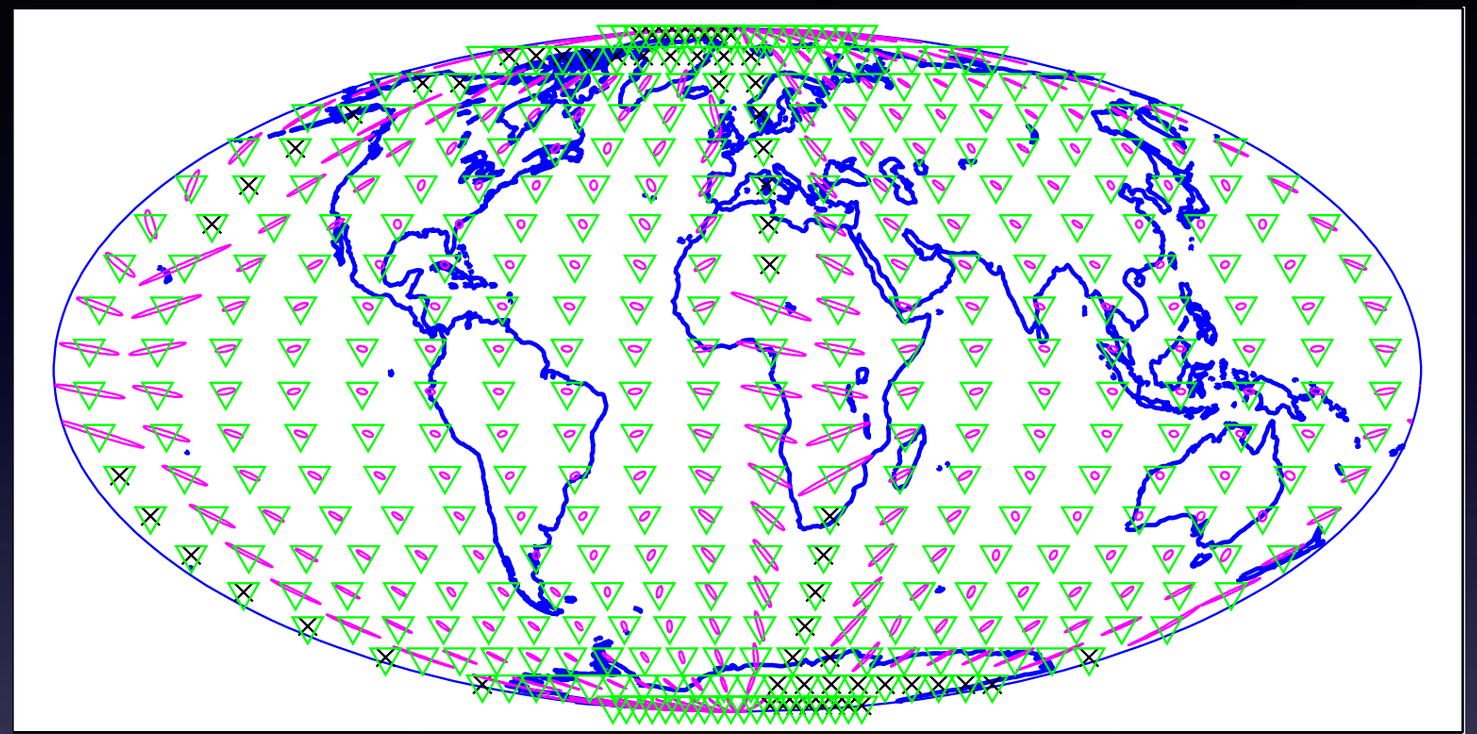


HLV networks

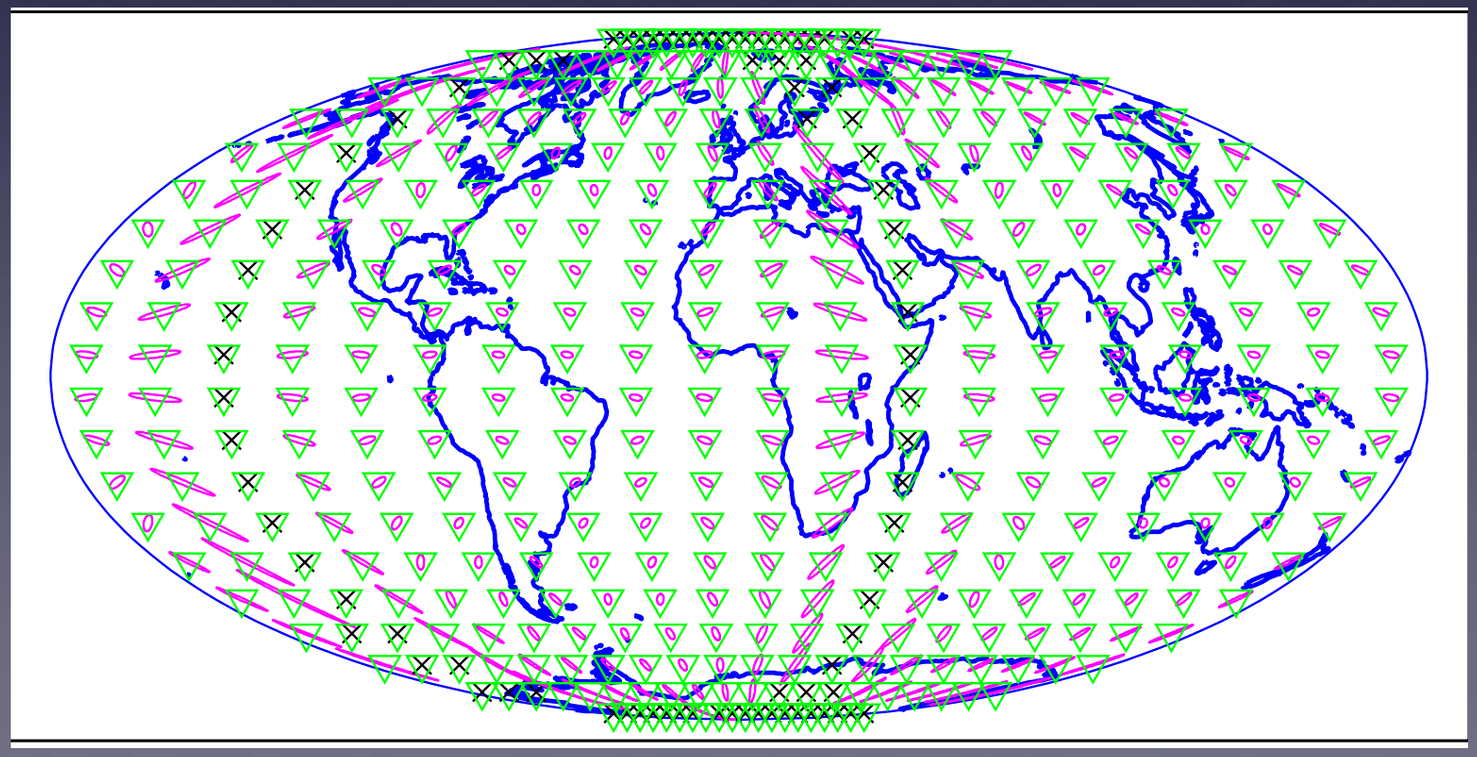


BKA networks

MY WORK - Localisation Maps



XKA networks



YKA networks

MY WORK - Discussion

- *Given the time accuracy, with the extending of baseline between the various detectors, the time delay and localisation ability will be increased as much as possible.*

- *The minimum localisation area of XKA is smaller than HLV network. The localisation ability of network XKA is better than both BKA and YKA.*

- *In the future, more detectors will be constructed and therefore localisation ability will improve significantly.*

Thank you for your patience and dedication!

— For Prof. Alessandro De Angelis

Thank you for your attendance and comments!

— For My Classmates

Grazie Mille A Tutti!