Low-Latency Search for Gravitational Waves from Compact Binary Coalescence

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"the most isolated capital city in the world" --- *Lonely Planet*

Outline

- Who are we?
- Why low-latency search
- Method and result
- Conclusion and future work

Australian National University

The University of Western Australia

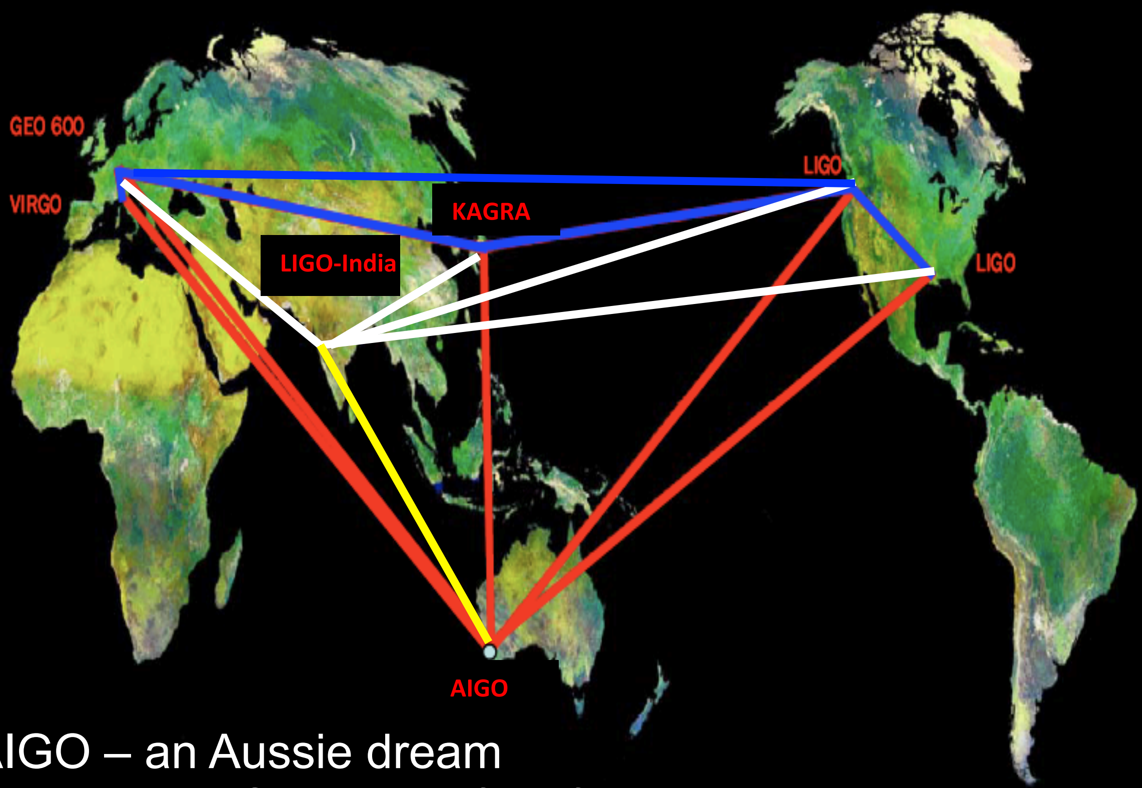
The University of Melbourne

The University of Adelaide

Monash

Australian Centre for Precision Optics

AIGO – a Detector in Southern Hemisphere



AIGO – an Aussie dream

- UWA built NIOBE - one of the first cryogenic bar detectors in the world
- Proposed AIGO site: Gingin, WA, 100 km north of Perth, same site as 80 m prototype
- Significant implication to source sky direciton localization
    - Roughly antipodal to LIGO Livingston
    - Add the longest baseline to the network
    - Break plane degeneracy of detectors in northern hemisphere

Early Detection of Compact Binary Coalescences

- to detect CBC signals in real-time, possibly at or before merger
- desktop search using GPUs ?

Notations:

CBC = compact binary coalescence, NS-NS/BH binary coalescence

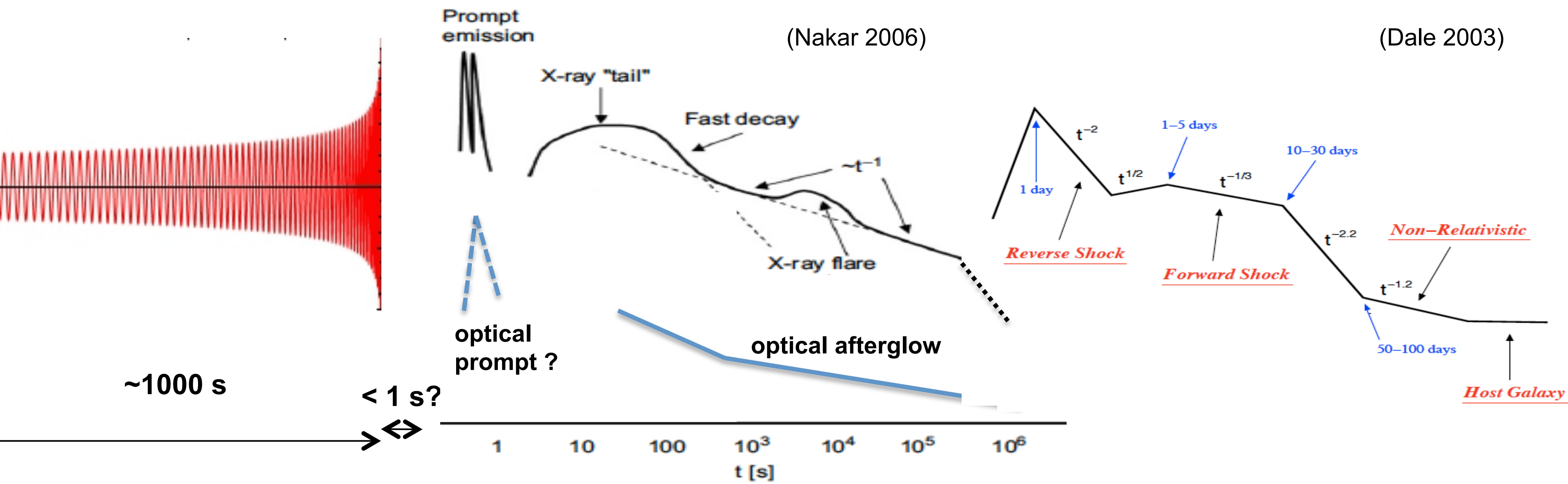
early detection = detection in real time, with no delay, possibly before or around the time of binary merger

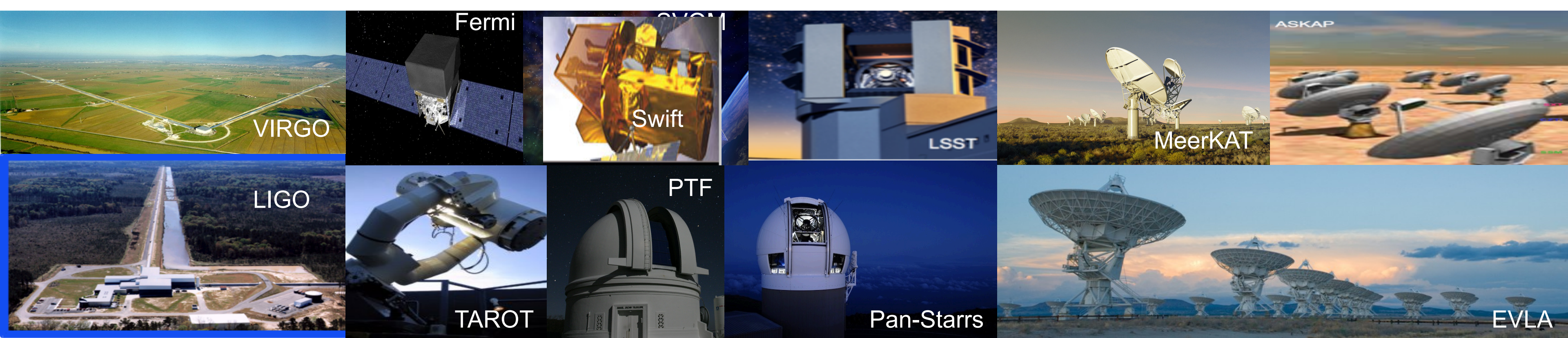
latency = event trigger time – merger time

Triggered Search: to establish CBC-sGRB connection

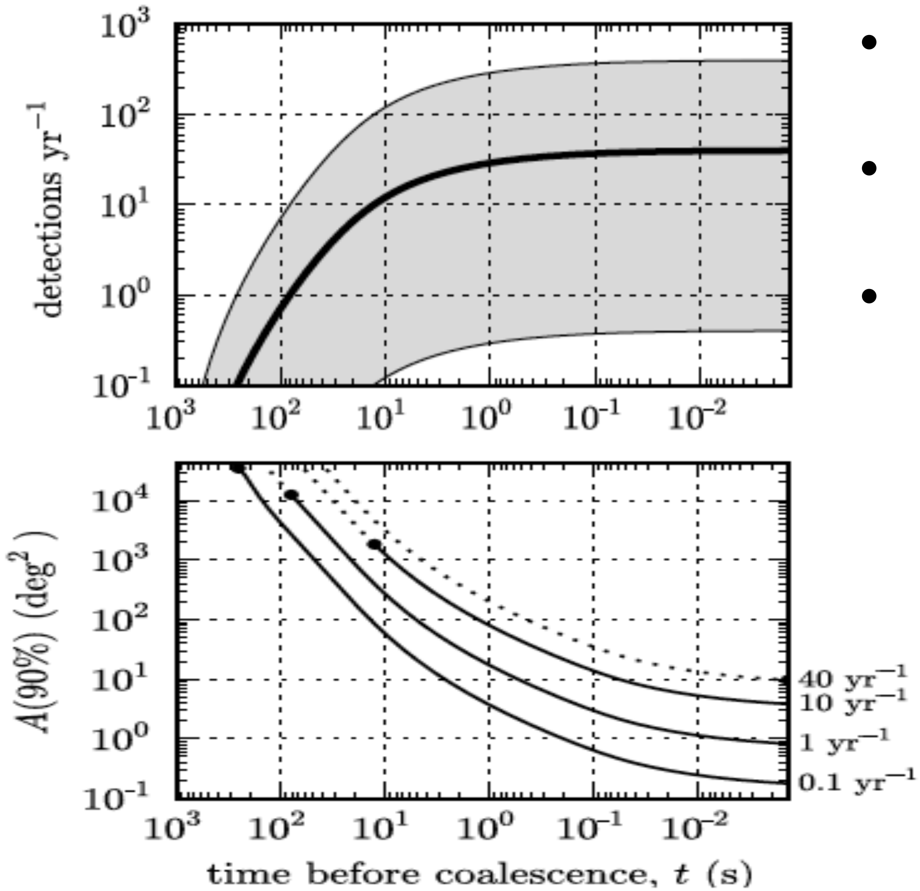
- NS-NS merger and onset of short- GRB possibly within < tens of milliseconds!

Light Curves of NS-NS GWs, short-GRBs' Prompt Emission (X-ray, Optical?), Afterglows in X-ray, Optical, and Radio





Sufficient Event Rate for Early Detection



Cannon, K. et al ApJ 2012

- 1 inspiral event/ yr can be detected 100 s before merger
- 10 events/yr can be detected 10 s before merger
- Challenging to pinpoint source direction
  - 40/yr rate: ~10 sq-deg at merger
  - 10/yr rate: 4 sq-deg at merger
  - 1/yr rate (the best)
    - 100 sq-deg 5 s before merger
    - <~1 sq-degs at merger
    - Larger detector network can help
      - 50 sq-deg LHVK
      - 10 sq-deg LHVIK

(Chu, Q. et al 2012)

On-going Low-latency CBC Search Pipelines

- Frequency domain method
  - Two existing pipelines:
    - MBTA
    - LLOID
  - Technique
    - (Overlapping) FFT method
      - Matched filtering: correlate data with known signal
    - Multi-band multi-rate approach to process less data
    - Template interpolation to reduce number of templates

Time-domain extremely-low latency CBC filtering

- UWA
  - Linqing Wen, David Blair + 1 staff, 3 PhDs, 1 MS
- Collaboration:
  - SPIIR method :
    - Chad Hanna (Perimeter), Kipp Cannon (CITA), Drew Keppel (AEI), Yanbei Chen, Jing Luan, Leo Singer(Caltech)
  - GPU acceleration
    - Zhihui Du, Yuan Liu (Tsinghua U., China)
    - Jian Tao (Louisiana State U.)

SPIIR: Summed Parallel Infinite Impulse Response (IIR) Filters

$$y_k = a_k \, y_{k-1} + b_k \, x_k$$

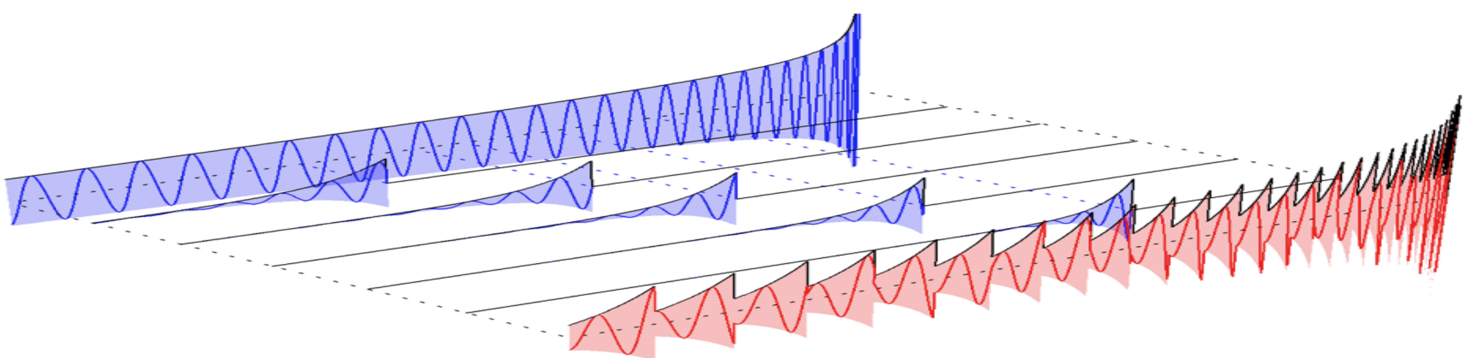
SNR at k-th time step

k-th GW data

SNR at (k-1)-th step

Coefficients calculated for each template at each segment

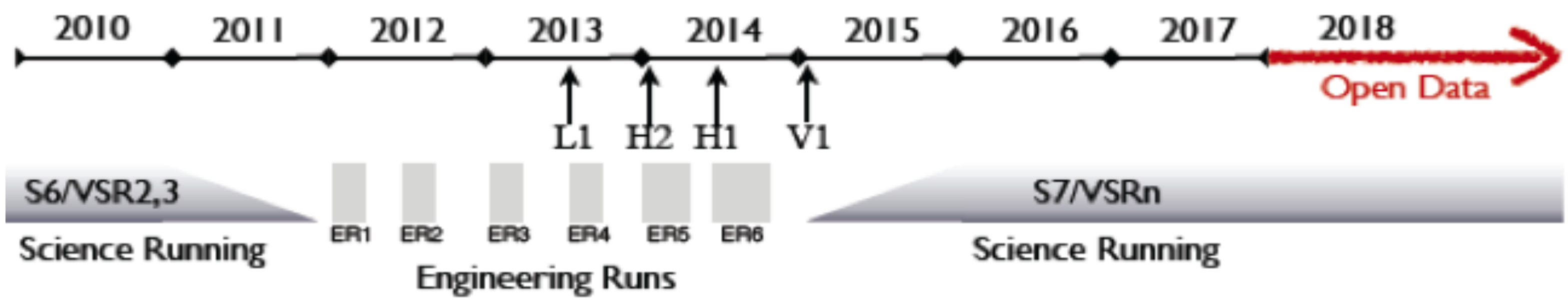
- Equivalent to matched filter data with a constant-f sinusoid of exponentially rising amplitude (+cutoff)



Luan, J. et al 2012 PRD, Hooper, S. et al 2012 PRD, Hooper, S. 2013 PhD thesis

LIGO-VIRGO aLIGO Engineering Runs

with simulated online detector data + blind signal injection



- ER2 (July-Aug 2012)
  - low latency data transfer
    - ~ 4 s
  - all three low latency pipelines participated
  - all with latency ~ 30-40 s
  - SPIIR
    - latency (30 s) limited by the rest of pipeline
    - Successfully not retrieve signals that were not there ☺

GPU-Accelerated Data Processing in Search for GWs

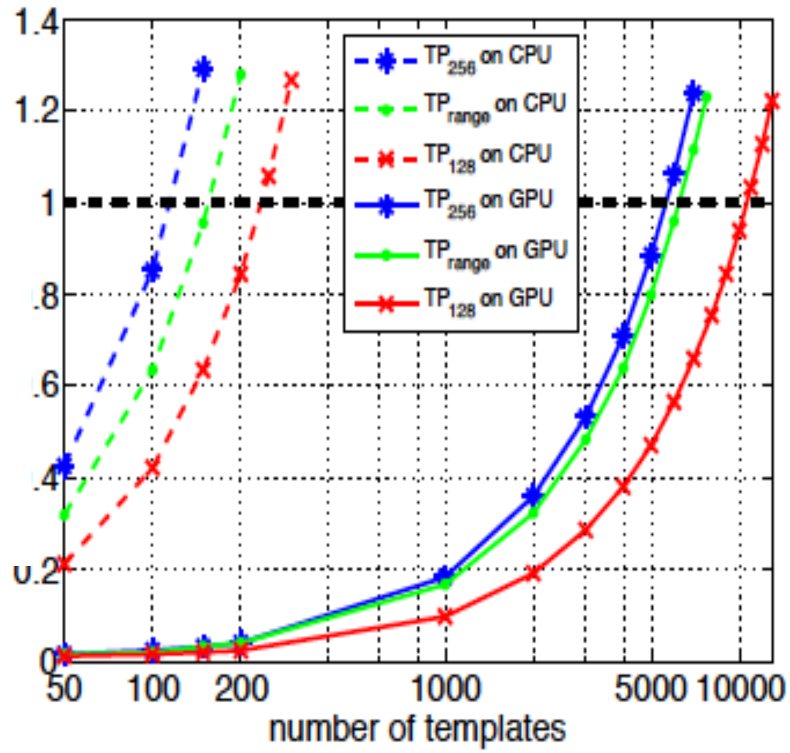
– Tflop supercomputing at desktop !

AUD $400/each

- First application to GW pipeline: x 16 (Chung et al. 2010)
- A community has formed
  - Tools, interface, libraries, template generation
  - Caltech, AEI et al installed the GPU cluster for LIGO data analysis
  - 96 –node GPU cluster @ UWA

C-GPU hybrid pipeline developed and tested on "online" data

Method	Overall Speedup
Straightforward	5.7
Parallel Sum Reduction	14
Reducing Block Level Synchronization	21
Avoid Bank Conflicts	24
Texture Memory	38
Tuning Resource Usage	47



- Used all possible GPU technique one can think of
- x 50 speed-up achieved for search engine compared to single-core CPU
  - Liu, Y. MS thesis 2013
  - Liu, Y. et al 2012 CQG
- Other bottleneck in the pipeline to be solved

Conclusion

- There are motivations to conduct real-time low latency search
  - Triggered search to allow EM follow-up
    - Some NS-NS GW events can be detected 10s' to 100s of seconds before merger events
    - Leave room for EM telescopes to be prepared for prompt follow-ups
  - Early localization problematic but can be helped with larger network
- We have developed an online time-domain search pipeline with 1s latency for the search engine
  - Tested on S5 data with detection efficiency similar to optimal search
  - Successfully run on aLIGO's Engineering Runs
    - latency of 30-40s limited by other part of the pipeline
- Hybrid GPU-accelerated pipeline working
- New template interpolation method (Luan J. et al 2012)
- Possible to detect sGRB engine in action for advanced detectors