Scientific Benefit of a Larger Gravitational Wave Detector Network

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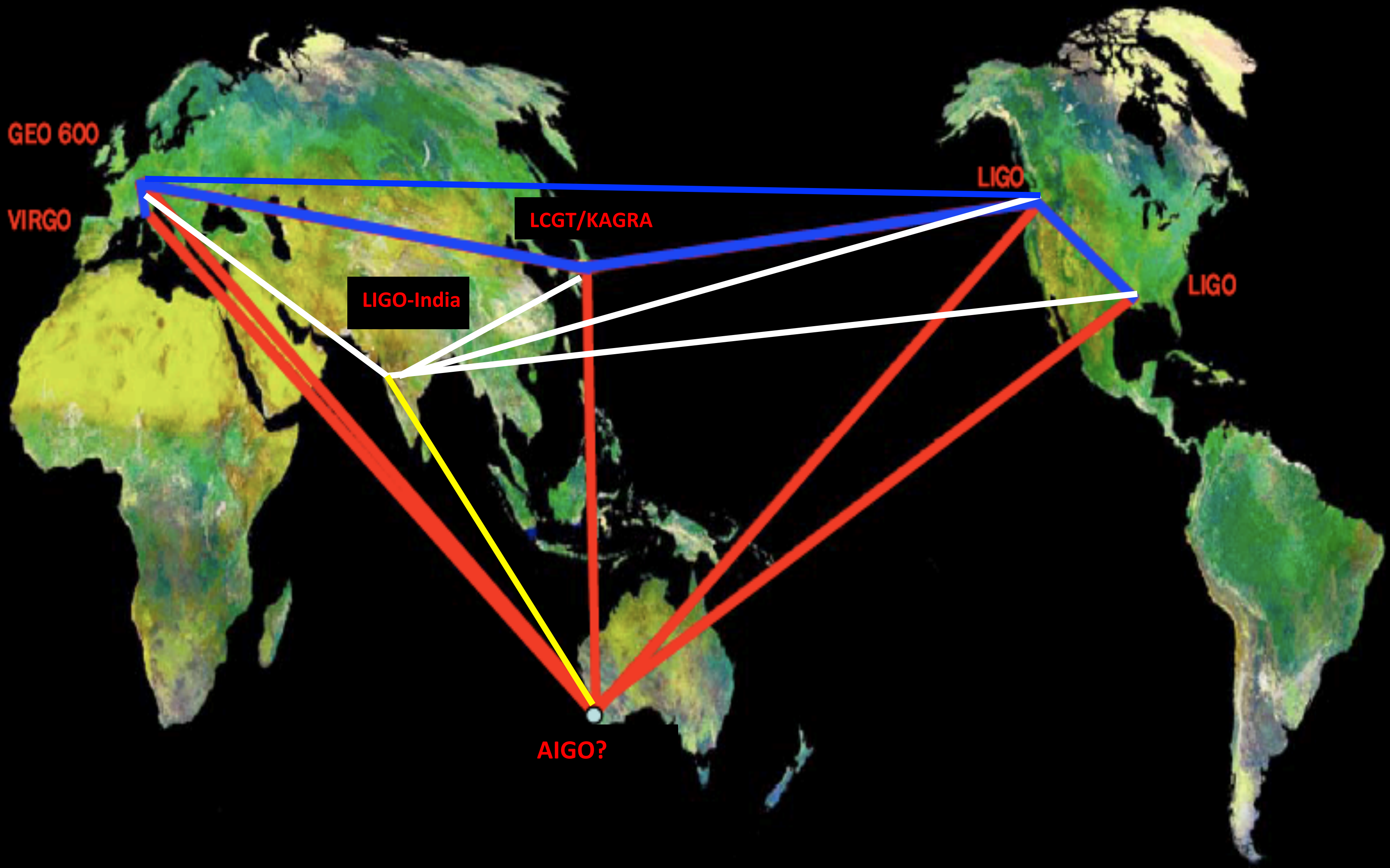
(Perth city viewed from Swan river)

Outline

- Background introduction
  - importance of “early”detection and localization of CBC source
- Angular resolution of a GW detector network
  - importance of a larger network
  - implication on “early” localization of CBC source
  - our effort on real-time, low latency CBC search
- Australian effort
  - status and plan of AIGO
- Conclusion

The Global GW Detector Network



Long baselines allow source localization using triangulation method

Astrophysical Motivation
(for the “early” detection and localization of the CBC source)

“Early ” = detection in real time, without delay, possibly before the merger of the binary

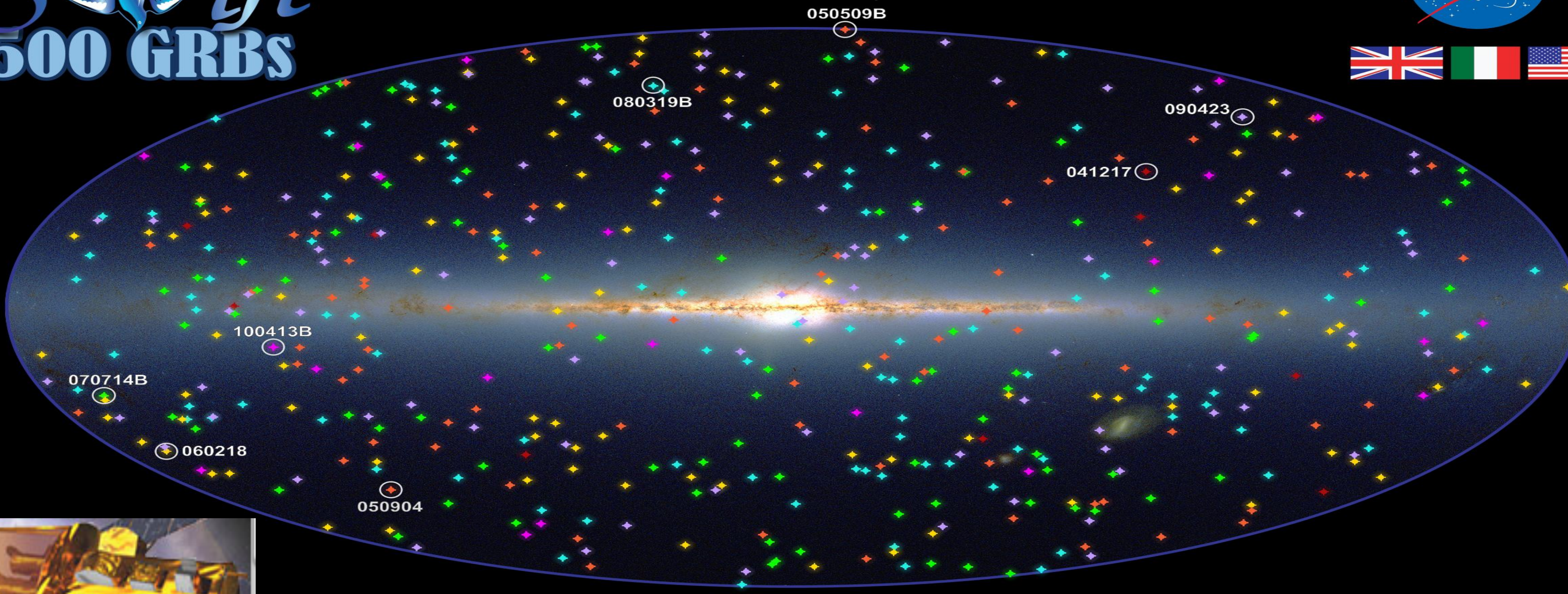
1. * The best bet to firmly link CBC source and the short GRB (sGRB) connection

2. To observe the “unobserved” prompt emission and early afterglows of sGRBs ?

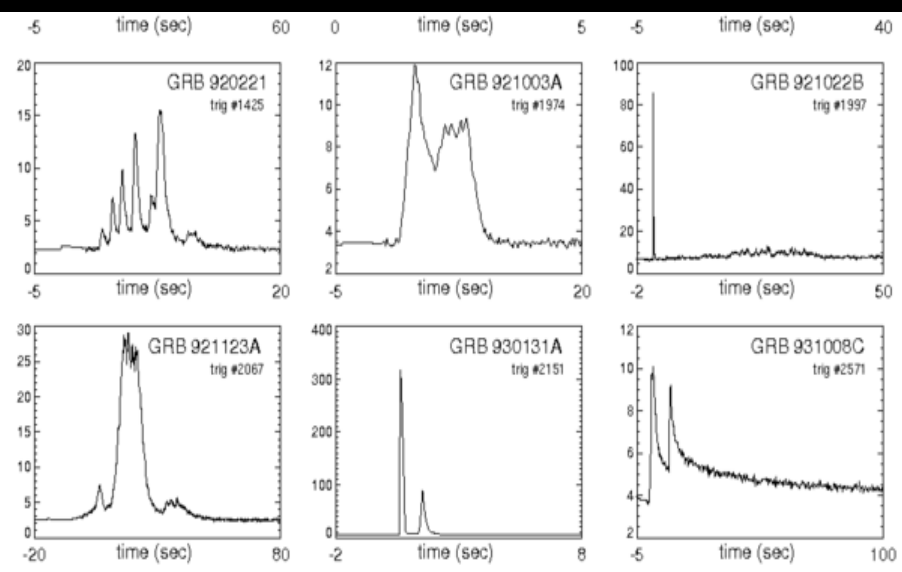
3. Every second counts

4. Larger detector network with AIGO is needed

Gamma-Ray Bursts



- sGRB = duration < 2 s
- 40 years of mystery unsolved
- Popular story:
  - Long GRB : core collapse Sne
  - Short GRB : NS-NS/BH merger



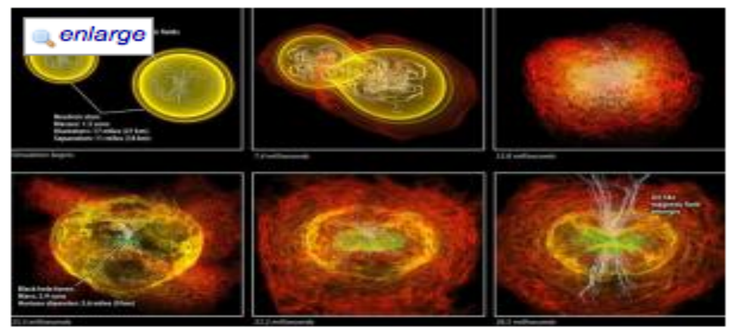
The most favorable story: NS-NS/BH as the progenitor of short GRB

Simulation confirms NS-NS merger as cause for short GRBs.

Science News *... from universities, journals, and other research organizations*

Cause of Short Gamma-Ray Bursts Determined

ScienceDaily (Apr. 7, 2011) — A new supercomputer simulation shows the collision of two neutron stars can naturally produce the magnetic structures thought to power the high-speed particle jets associated with short gamma-ray bursts (GRBs). The study provides the most detailed glimpse of the forces driving some of the universe's most energetic explosions.



These images show the merger of two neutron stars recently simulated using a new supercomputer model. Redder colors indicate lower densities. Green and white ribbons and lines represent magnetic fields. The orbiting neutron stars rapidly lose energy by emitting gravitational waves and

The state-of-the-art simulation ran for nearly seven weeks on the Damiana computer cluster at the Albert Einstein Institute (AEI) in Potsdam, Germany. It traces events that unfold over 35 milliseconds -- about three times faster than the blink of an eye.

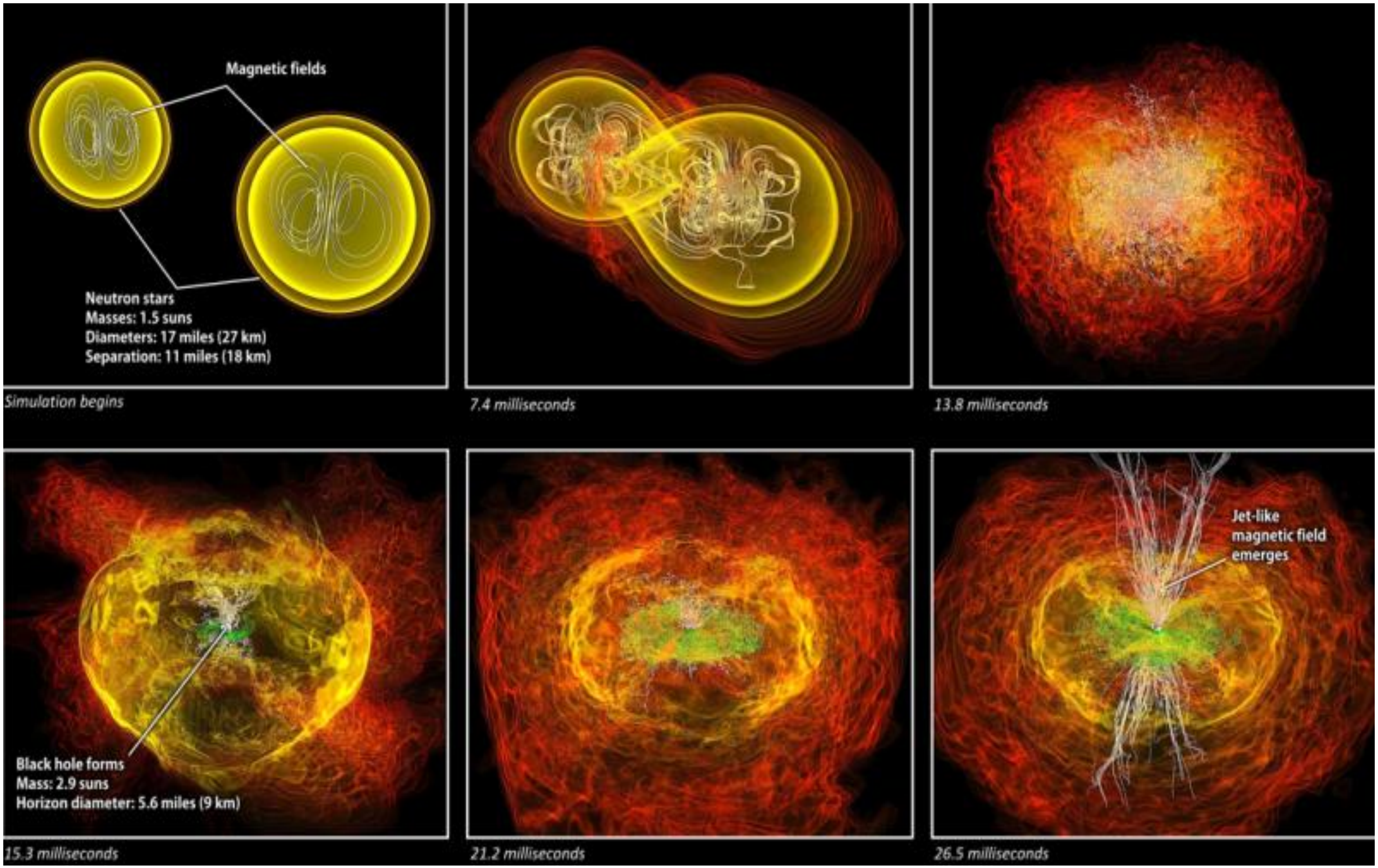
See Also:

Space & Time

- Black Holes
- Stars
- Astronomy
- Astrophysics

(Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla)

NS-NS merger and GRB emissions connected within milliseconds!



(Credit: NASA/AEI/ZIB/M. Koppitz and L. Rezzolla)

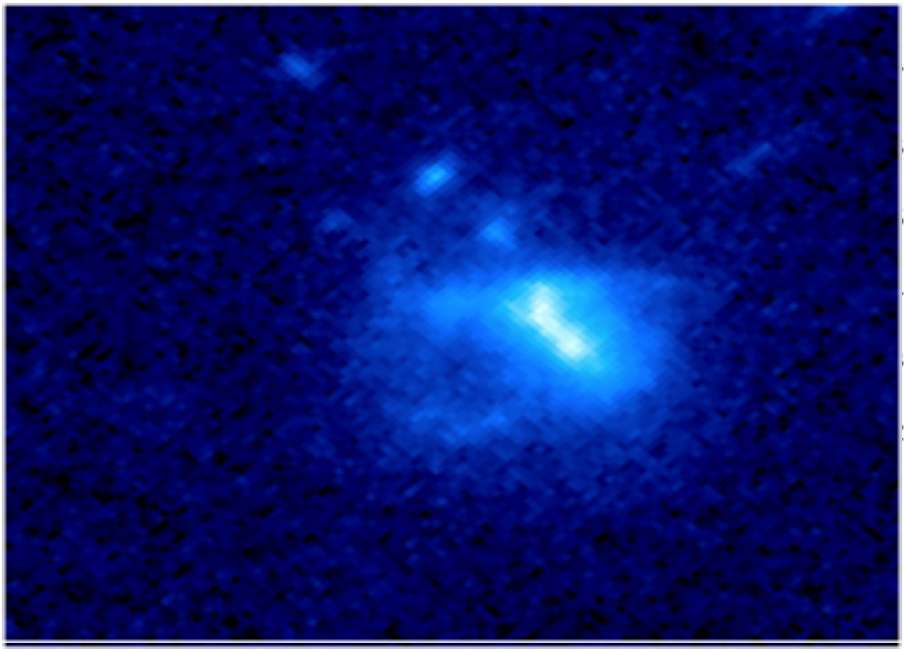
X-ray/Optical Afterglow of sGRB Observed

favors NS-NS/BH connection

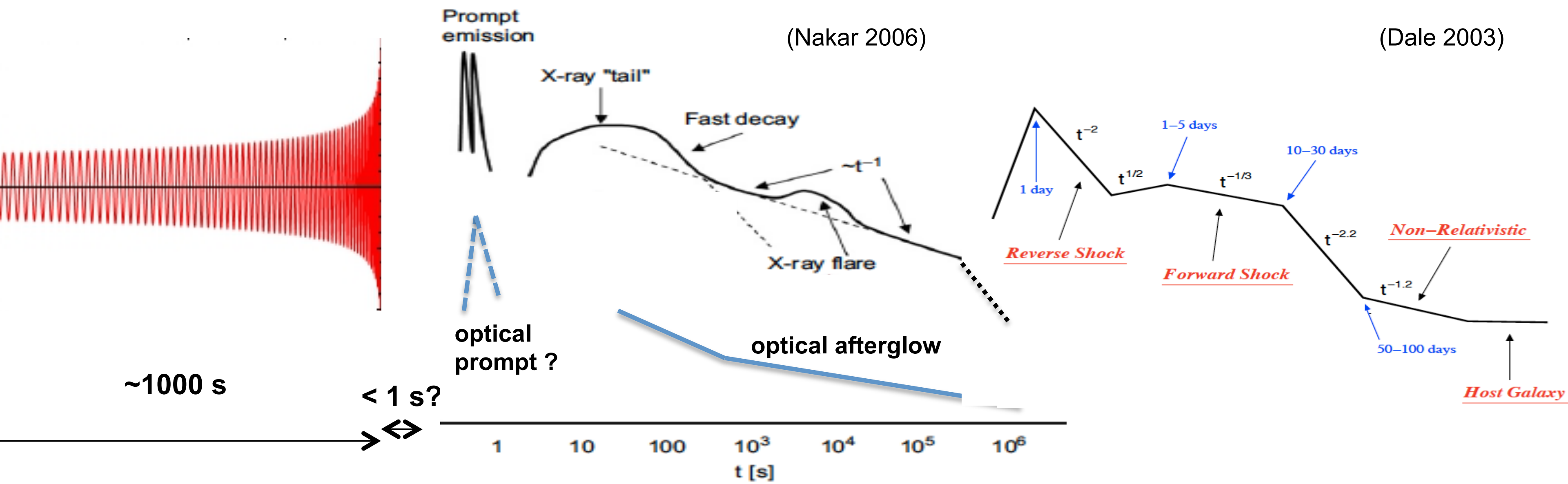
GRB050709

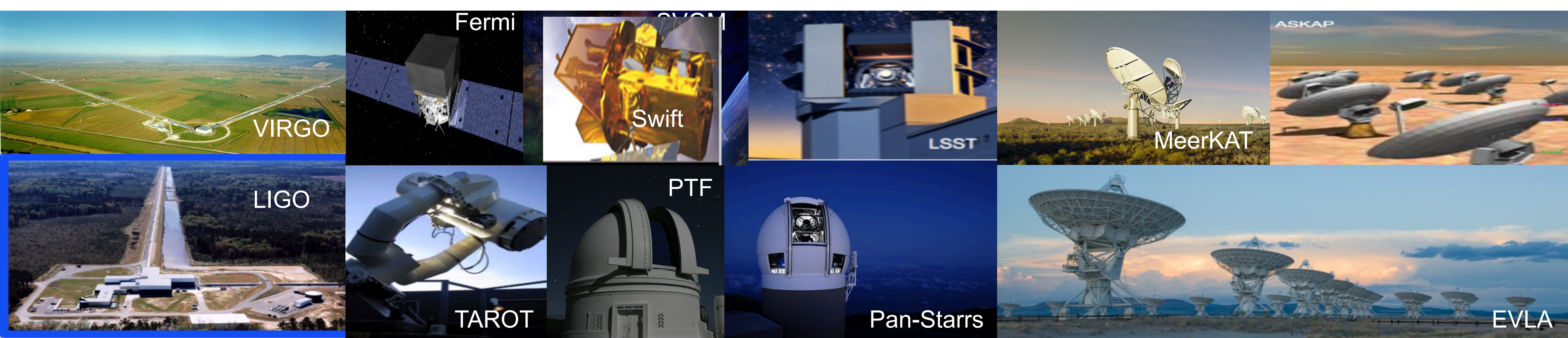
animation.Credit: NASA, University of Copenhagen. Visualization credit: Mike McClare/NASA GSFC.

2015+:
Short GRB Engine Detected in Action ?



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

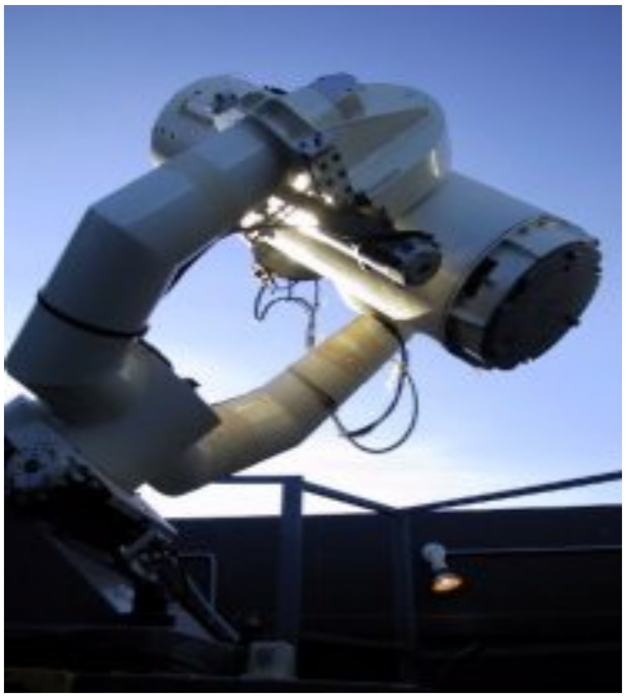




- GW proceeds GRB event for about 1000 s
  - SWIFT has a small chance for sGRB within LV horizon
    - » EM emission beamed ?
  - GW emission is almost isotropic
  - GW can give early detection and localization ?
    - with refining SNR and direction with time

- Catching prompt emission/early afterglows
  - short duration of 2 s for prompt, 10s' s for afterglow
  - Probably immediately after merger
  - can be as bright as that from long-GRBs
  - Not observed yet
    - no SWIFT triggers are fast enough for optical telescopes
    - Can GW trigger help?

Prompt optical follow-ups of sGRBs with robotic telescopes?



- e.g., Tarot robotic telescope
- Response time: < 6s
- Already caught 20+ prompt emissions from long GRBs (linked to SNe)
  - no fast enough SWIFT trigger for sGRB
- 30-40 sq-deg GW localization is possible for prompt follow-ups
  - 3.6 sq-deg fov
  - assuming short exposure

Gendre, B., Boer M. et al

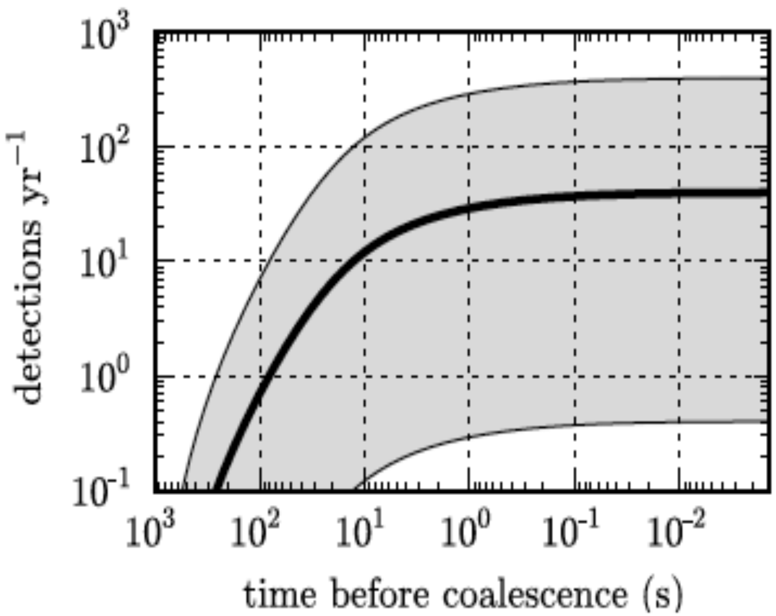
Challenge: GW Localization

- Typical LHV GW sky localization gives tens of sq-degrees error
- Need larger detector network for better angular resolution
  - Wide-field optical camera is desirable
    - But response time might not be fast enough
    - Too busy with other observations
  - Strategy required for pointing instrument

(e.g., Wen, Fan & Chen 2008, Fairhurst 2009, Wen & Chen 2010, Nissanke 2010)

Early Detection and Localization of NS-NS/BH GW Source

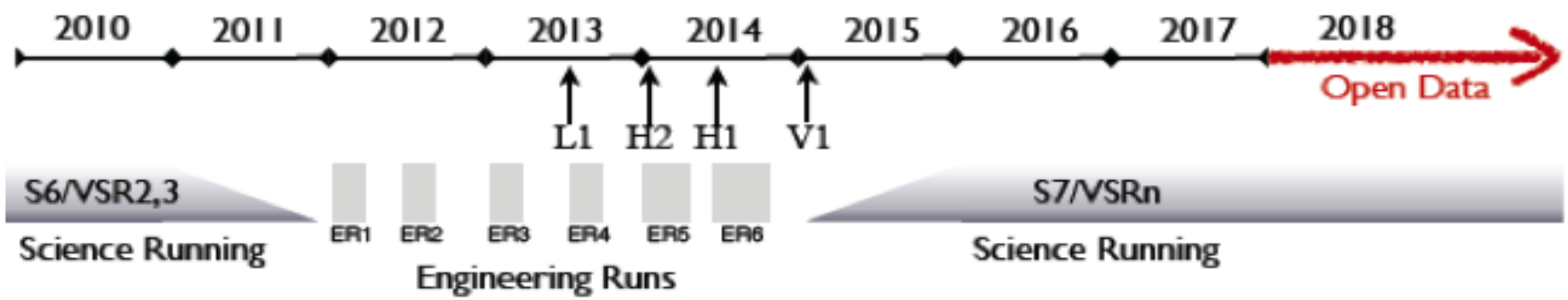
Early Detection of GW Events Possible



Cannon, K. et al ApJ 2012
Luan, J. et al. PRD, 2012
Buskulic, D. et al. CQG, 2010
Hooper, S. et al. PRD, 2012 under review
Liu, Y. et al. CQG, 2012 under review

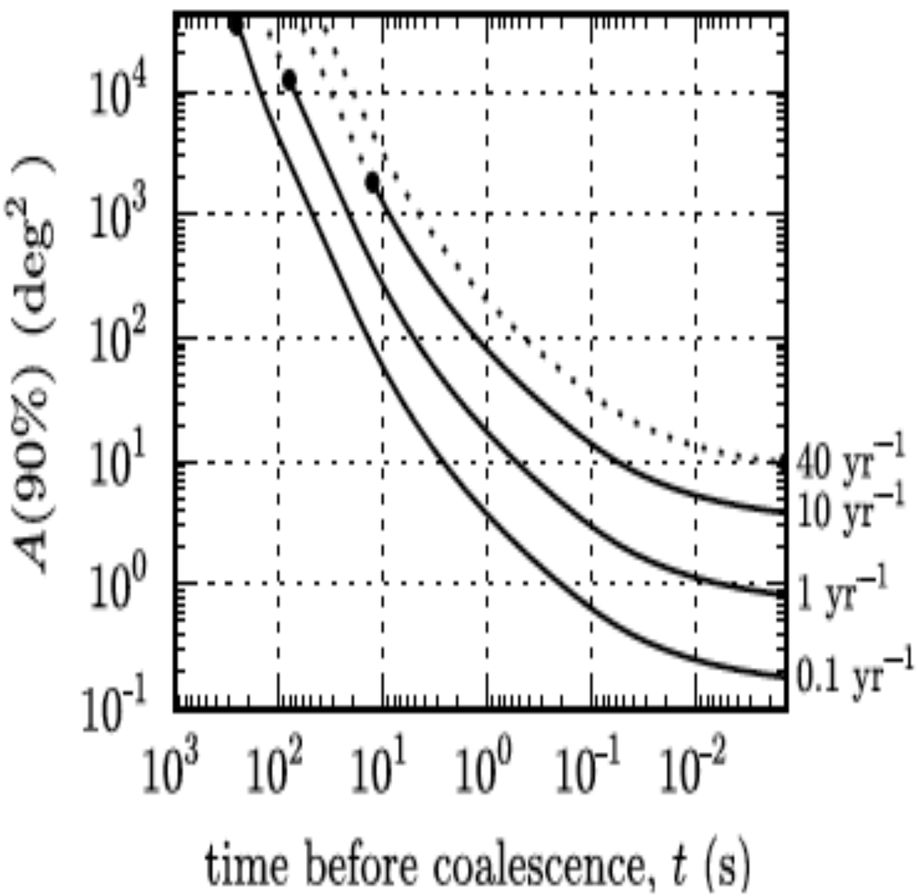
- 1 inspiral event/ yr can be detected 100 s before merger
- 10 events/yr can be detected 10 s before merger
- Fast low latency CBC detection pipelines under development:
  - Frequency domain method
    - Virgo: MBTA
    - LSC: gstlal_inspiral
  - Time domain IIR filter method + GPU acceleration/template interpolation
    - gstlal_iir_inspiral
    - by UWA, and gstlal_inspiral people
    - Theory paper just published
    - Implementation and GPU papers under review
    - Pipeline tested on simulated data

Current LSC Low-Latency Efforts



- ER1 (Jan 18 – Feb 15, 2012):
  - low latency data transfer
    - LIGO ~ 4 s, VIRGO 8-30 s (can be lower if needed)
  - Two frequency-domain low-latency pipelines participated in the analysis
    - gstlal_inspiral: 30-80 s latency
    - MBTA: 250 s latency
    - Latency can be seconds in principle
  - Our gstlal_inspiral_iir is online for ER1+ data
    - Just "detected" a simulated event
    - GPU acceleration needs to be incorporated
    - More optimization elements need to be implemented

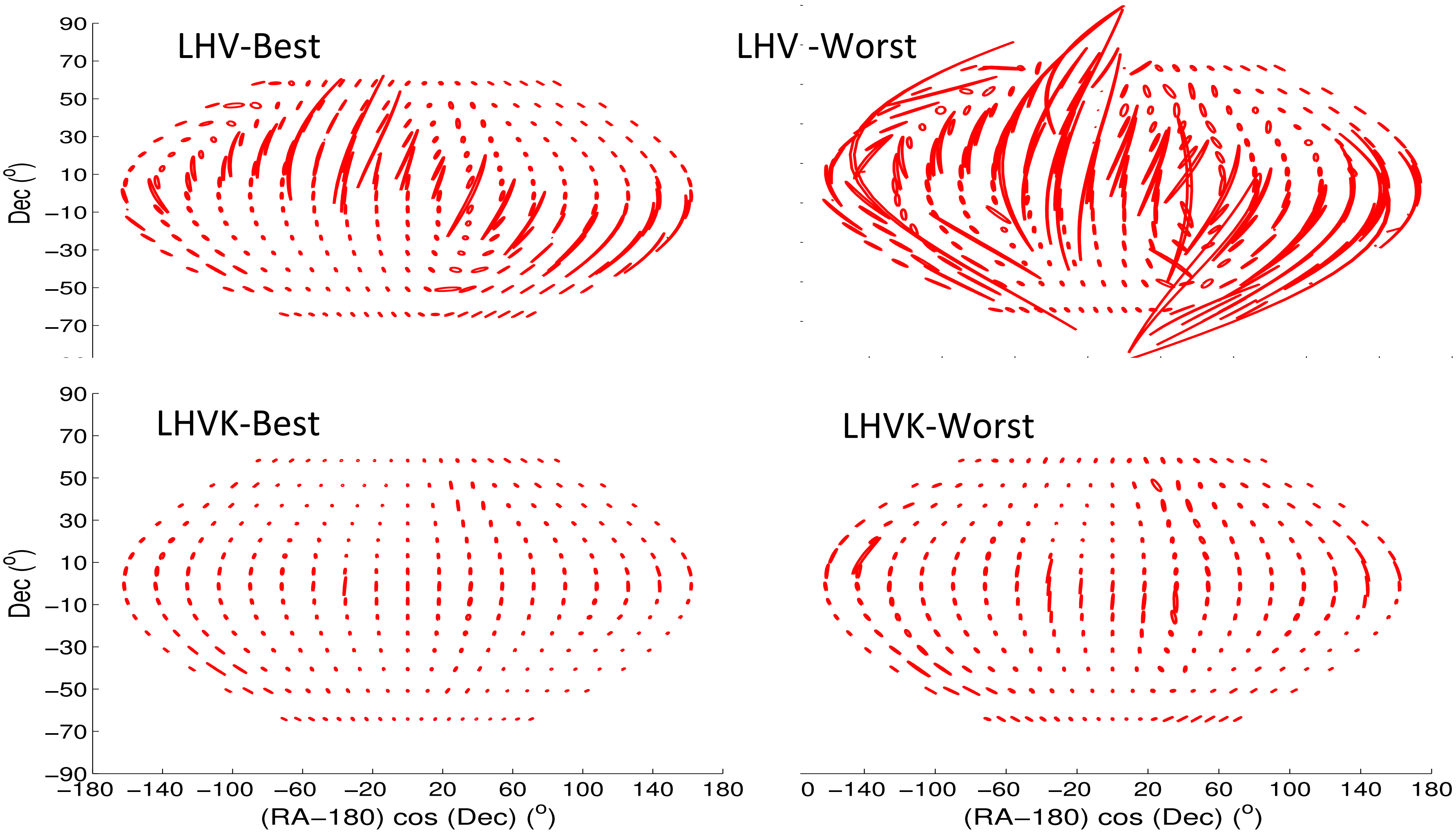
LHV Network Localization



- EM follow-up possible after merger
  - 40/yr rate
    - 10 sq-deg at merger
  - 10/yr rate
    - 4 sq-deg at merger
  - 1/yr rate (the best)
    - 300 sq-deg 10 s before merger
    - <~1 sq-degs at merger
- Extremely difficult to catch sGRB prompt emission or early afterglows

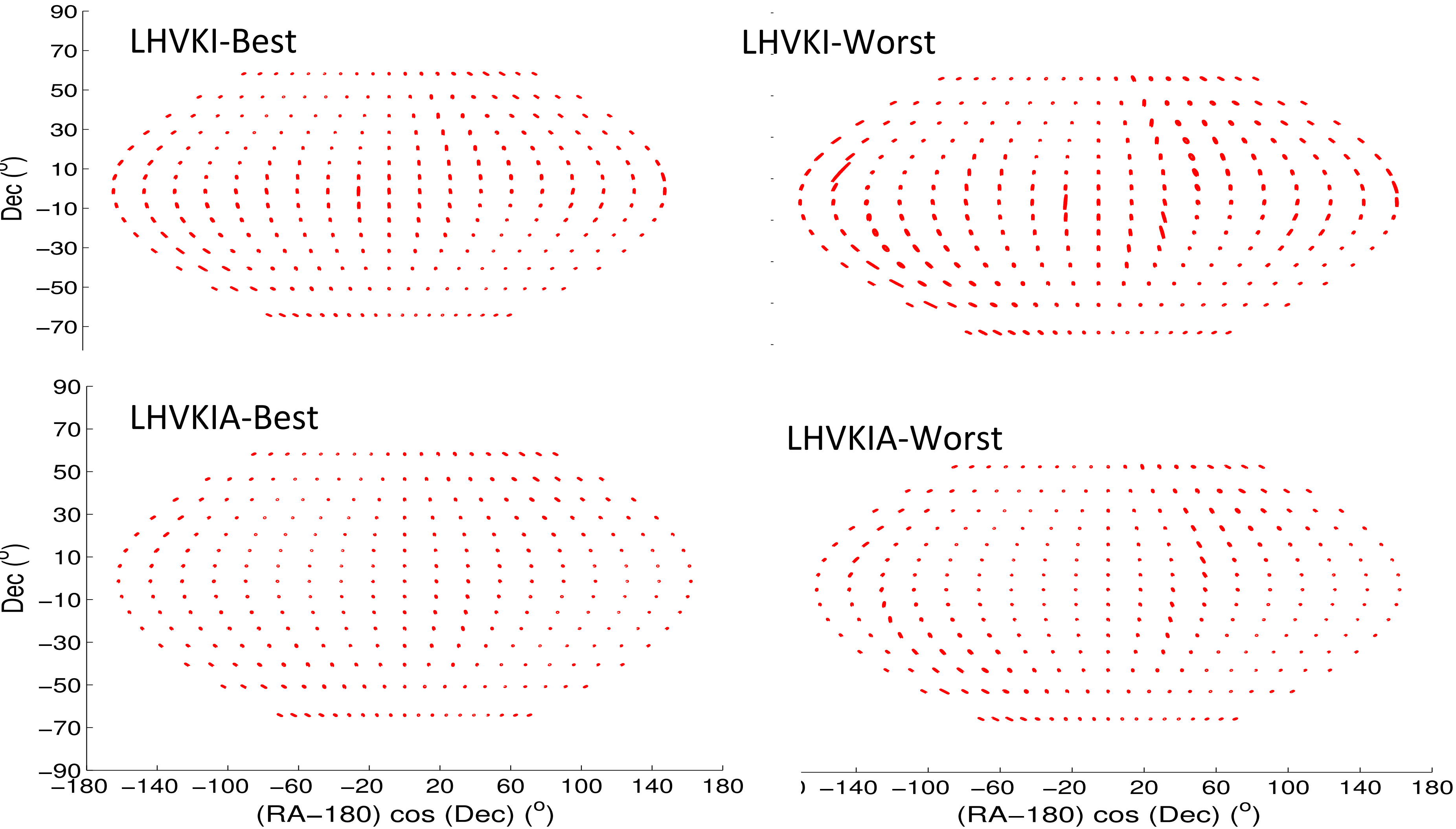
Cannon K. et al. 2012

Angular Resolution LHV vs LHV+KAGRA

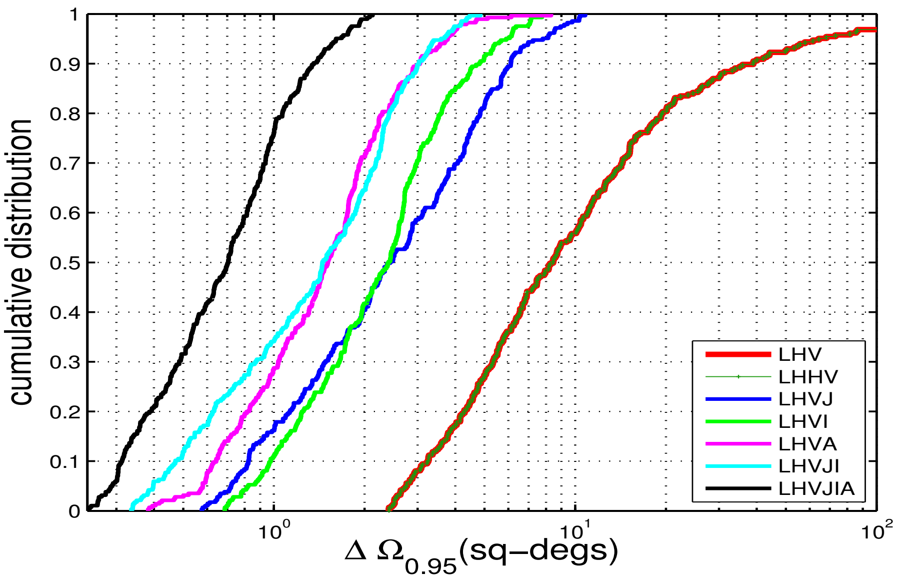


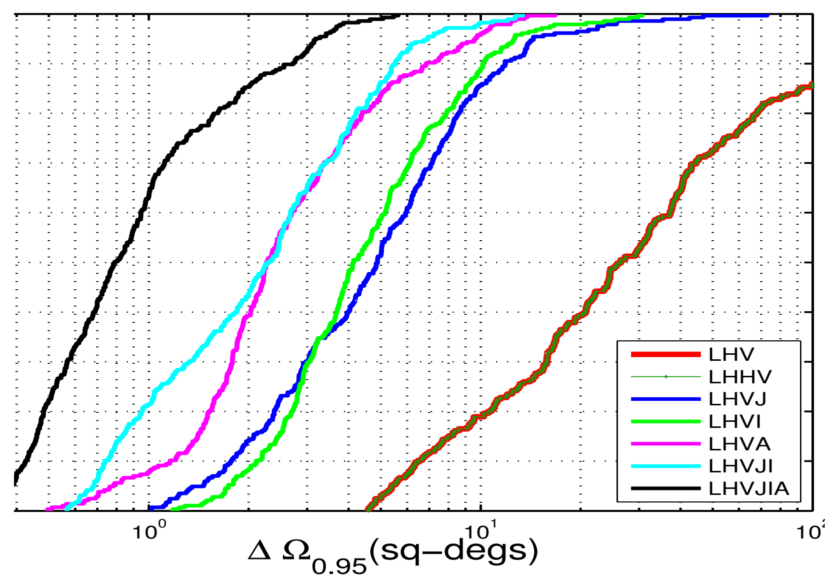
Wen & Chen 2010, Chu, Wen & Blair 2012

LHVKI vs LHVKI+AIGO



Chu, Wen & Blair 2012

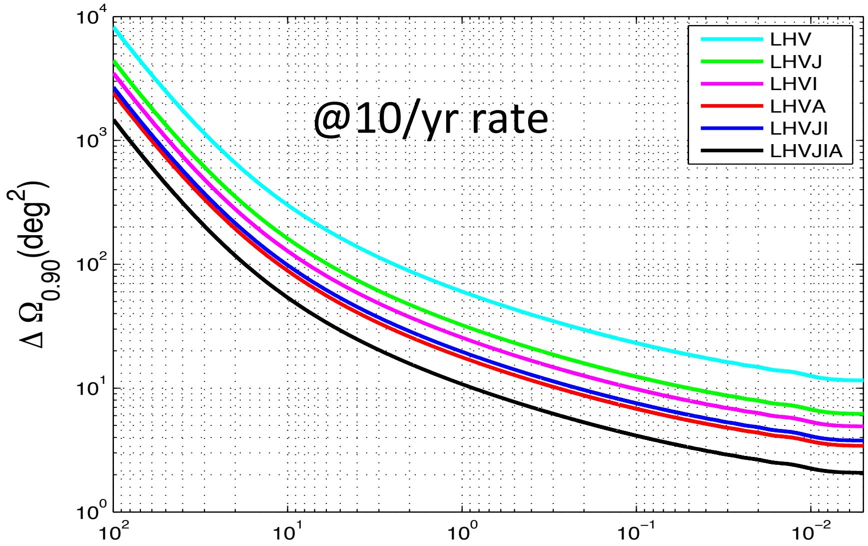


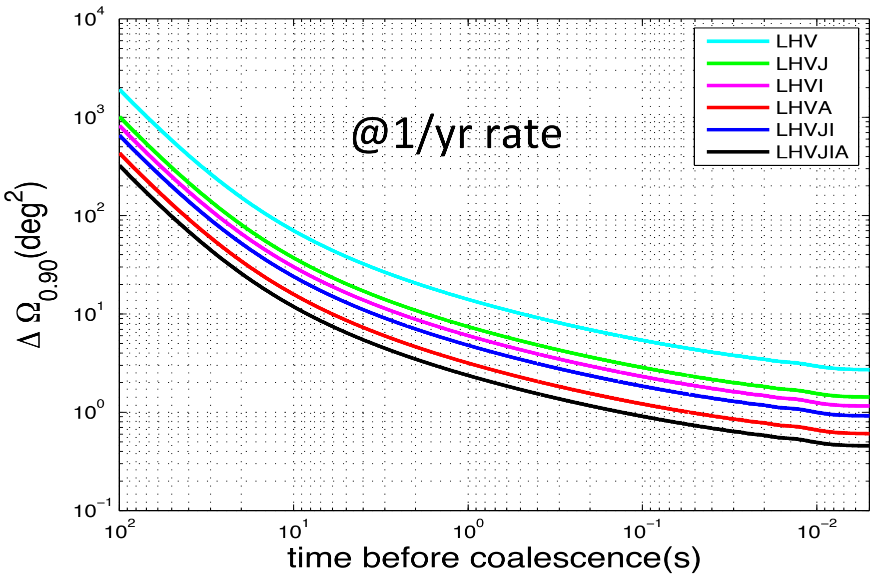


- KAGRA adds x 3-5 improvement to LHV
- AIGO adds x 2 improvement to LHVKI
- LHVKIA adds x 7-10 improvement to LHV

Schutz 2011, Chu, Wen & Blair 2012

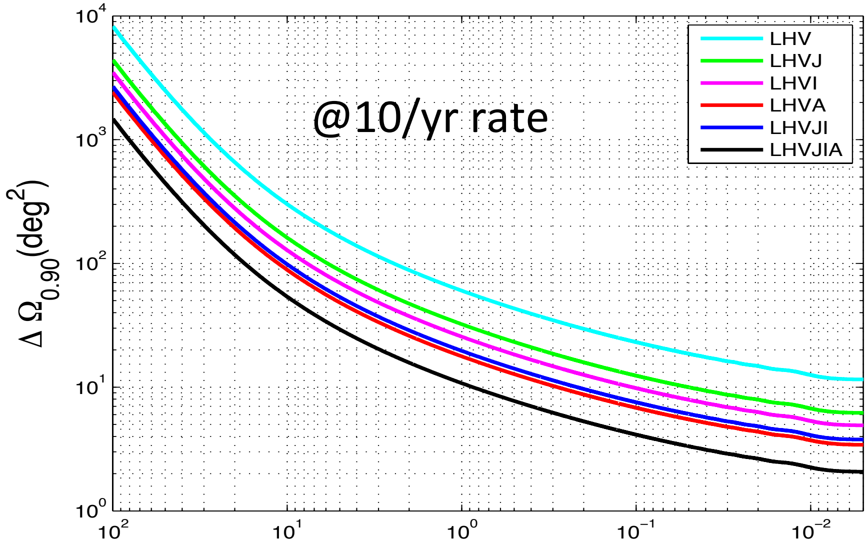
LHV+KAGRA Network (green curve)

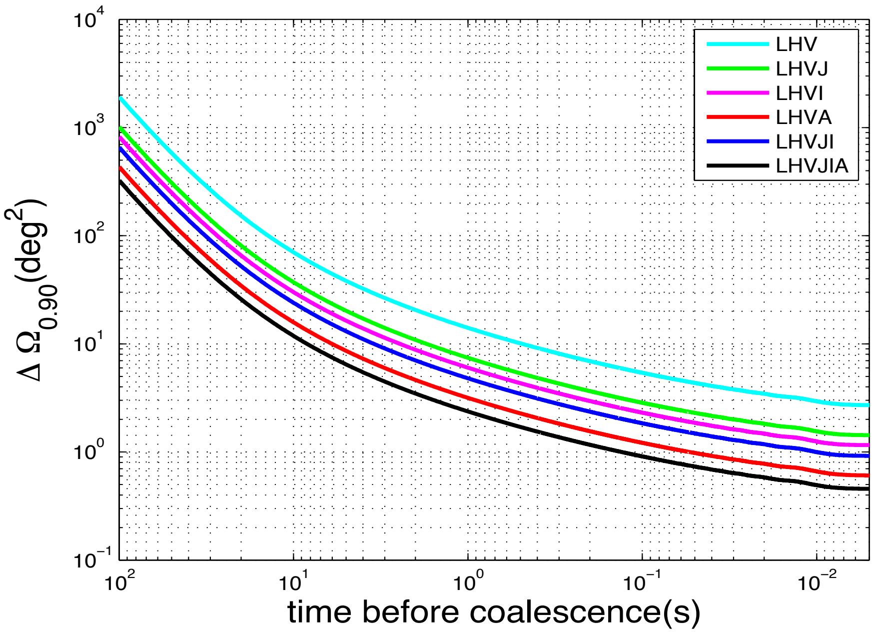




- Better chance for prompt EM follow-up
  - 10/yr rate (upper)
    - 160 sq-deg 10s before merger
    - 6 sq-deg at merger
  - 1/yr rate (lower)
    - 80 sq-deg 20 s before merger
    - 55 sq-deg 10 s before merger
    - 1.4 sq-deg at merger

LHVKI+AIGO Network (black curve)





- Sufficient detection/ localization 10-20 s before merger possible
- Just leaving enough time to catch prompt emission/early afterglows
  - 10/yr rate
    - 50 sq-deg 10s before merger
    - 2 sq-deg at merger
  - 1/yr rate
    - 30 sq-deg 20 s before merger
    - 10 sq-deg 10 s before merger
    - <~0.1 sq-deg at merger
- Will help firmly establish NS-NS/BH sGRB connection

GW Effort from Australia

and our dream

(On behalf of the ACIGA collaboration)

Australian National University

The University of Western Australia

The University of Melbourne

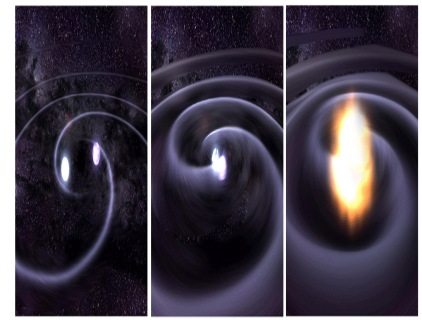
The University of Adelaide

Monash

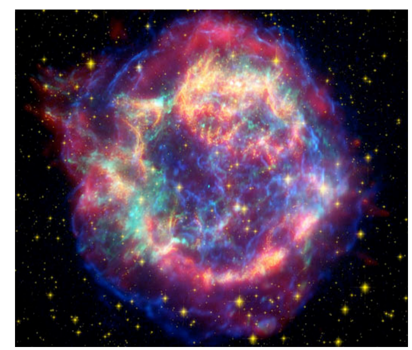
Australian Centre for Precision Optics

GW Signal Processing in Australia

- Prompt detection and localization of coalescing compact binaries (UWA)
  - Using parallel IIR filters for detection
  - Localization using coherent method



- EM follow up (ANU, UWA)



- Detect continuous GWs from neutron stars from Supernova remnant (Melbourne, ANU, Monash)

- GPU acceleration (UWA, ANU)

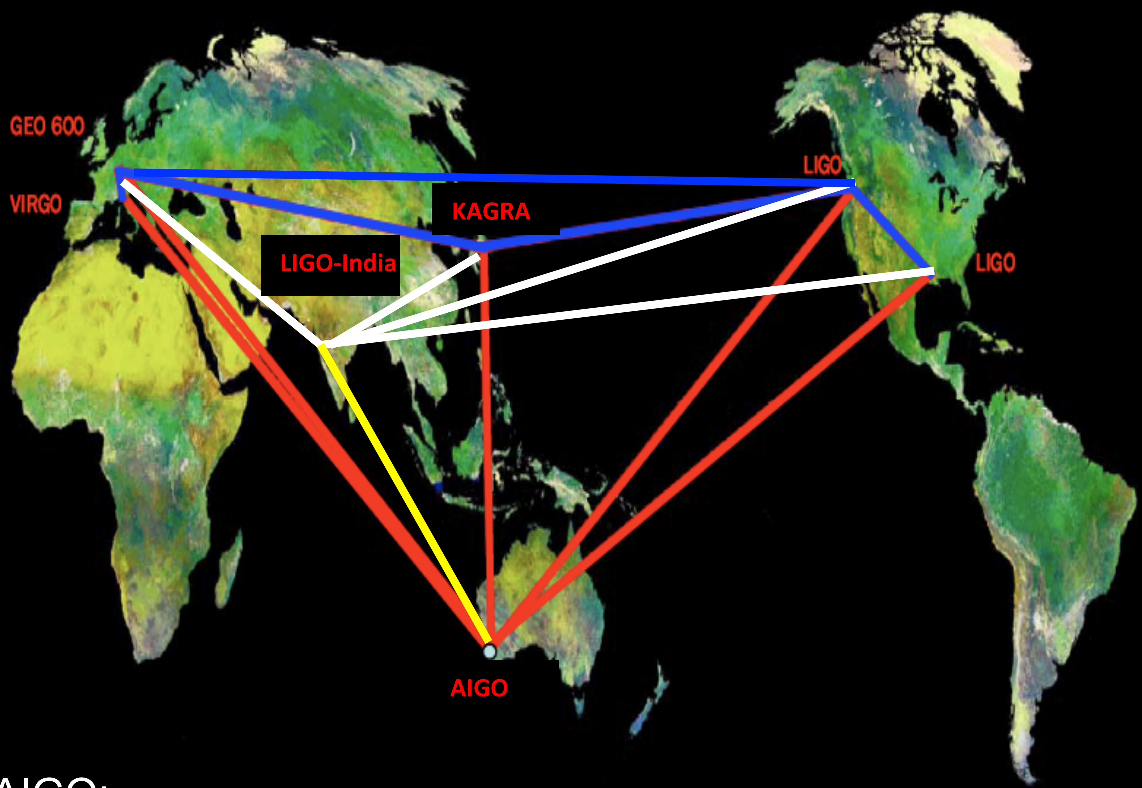
GW Experiments in Australia

- UWA (David Blair)
  - Parametric instability and its control, opto-acoustic parametric amplifier
  - Double optical springs, optical rods
  - Distributed and seismic feed-forward control
  - Extremely low frequency vibrational isolation using Euler springs

- ANU (David McClelland)
  - Advanced interferometer configurations and control systems
  - Measurement of thermal and quantum noise, quantum noise cancellation and QND techniques,
  - Digital interferometry
  - Gravity Recovery and Climate Experiment (GRACE) Follow-On Mission,
  - Frequency stabilization for LISA.

- Adelaide (Jesper Munch)
  - High Power Lasers for Gravitational Wave Interferometry
  - Wavefront monitoring and thermal compensation

The Global GW Network with AIGO ?



AIGO:

- Site at Gingin, WA, 100 km north of Perth, same site as current UWA 80 m prototype
- Roughly antipodal to LIGO Livingston
- Add the longest baseline to the network
- Break plane degeneracy of detectors in northern hemisphere

Gingin 80 m experiment

AIGO Status

- LIGO-Australia bid helped building up momentum
- New landmark funding scheme recommended by Academy of Sciences Physics Decadal Plan 2012

> "Establishing a Landmark Funding Scheme to support major research initiatives (of order $100M) that fall outside the scope of current funding schemes, for example the Laser Interferometer Gravitational-wave Observatory"

AIGO Status

- First commitment from WA state government
  - $10 M conditional offer
  - $35 M being approached
- Advisor to our new Federal Minister in Science visited the AIGO site
- Senior management group forming

AIGO Plan

- Broader international partnership
  - International AIGO meeting at MG13 this July arranged
  - September 2012 meeting in Australia planned
    - seek international participation in the detector definition, key technologies to be used
  - On-going discussions with French and Italian Embassies and EGO leadership
    - collaboration meetings funded

- Planning international group for
  - Conceptual design
  - Budgeting exercise

AIGO

- More international partnership and support needed!
    - Contact David Blair and Ruby Chan for AIGO partnership

Email: David Blair: david.blair@uwa.edu.au,
Ruby Chan: ruby.chan@uwa.edu.au

http://www.anu.edu.au/Physics/ACIGA/

Conclusion

- Observing prompt/early EM emission of sGRB associated with GW events will bridge the missing gap, and firmly establish NS-NS/BH and sGRB connection
- Some NS-NS GW events can be detected 10s' to 100s of seconds before merger events
- However, for LHV network, early localization before merger basically impossible
  - Little chance to catch prompt/early emission of sGRB

Conclusion

- A larger global network with KAGRA, LIGO-India provides x3-5 improvement in angular resolution
  - better angular resolution for EM follow ups after merger
- Adding AIGO introduce another x2 improvement
  - will make EM follow-up at/before merger just possible
  - More likely to catch prompt/early emission of sGRBs
  - Help firmly establish CBC-sGRB connection
- AIGO picking up some momentum from LIGO-Australia
- International partners for AIGO needed