Claiming the detection of transient gravitational waves

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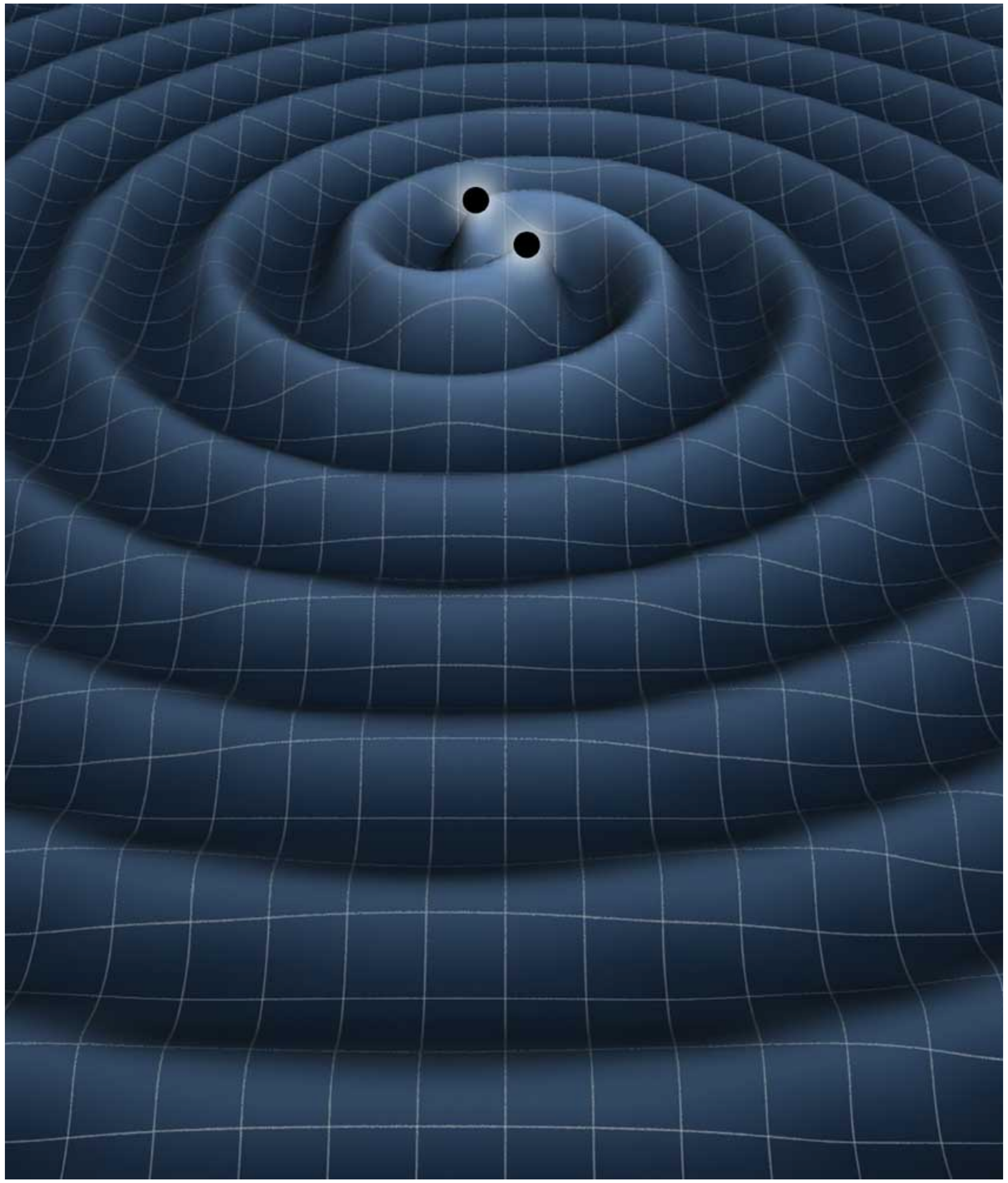
RAS - London, UK - 12th December 2014

Outline

- Detection rates
- The problem of detection
- Background estimation
- Significance
- Ongoing work



Detection rates

LIGO-Virgo Collaboration, arXiv:1304.0670 (2013)

Epoch	Estimated Run Duration	BNS Range (Mpc) LIGO	BNS Range (Mpc) Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	% BNS Localized within 20 deg^2
2015	3 months	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	200	130	0.4 – 400	17	48

detection unlikely but not ruled out in 2015

Table 5. Detection rates for compact binary coalescence sources.

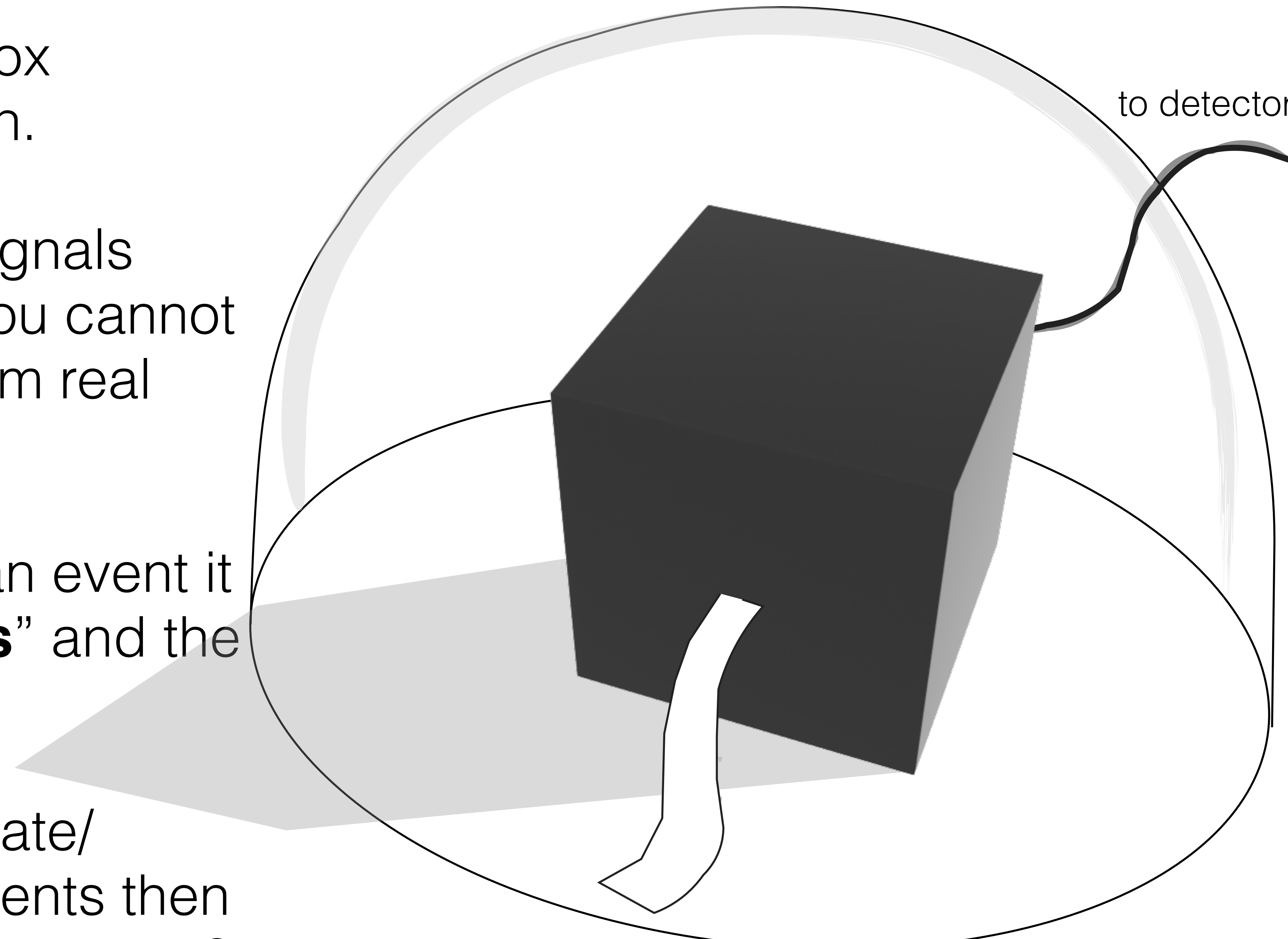
IFO	Source[a]	$\dot{N}_{\mathrm{low}}$ yr^{-1}	$\dot{N}_{\mathrm{re}}$ yr^{-1}	$\dot{N}_{\mathrm{high}}$ yr^{-1}	$\dot{N}_{\mathrm{max}}$ yr^{-1}
	NS–NS	2×10^{-4}	0.02	0.2	0.6
	NS–BH	7×10^{-5}	0.004	0.1	
Initial	BH–BH	2×10^{-4}	0.007	0.5	
	IMRI into IMBH			<0.001[b]	0.01[c]
	IMBH-IMBH			10^{-4}[d]	10^{-3}[e]
	NS–NS	0.4	40	400	1000
	NS–BH	0.2	10	300	
Advanced	BH–BH	0.4	20	1000	
	IMRI into IMBH			10[b]	300[c]
	IMBH-IMBH			0.1[d]	1[e]

older paper with slightly different assumptions

LIGO-Virgo Collaboration, CQG 27, 173001 (2010)

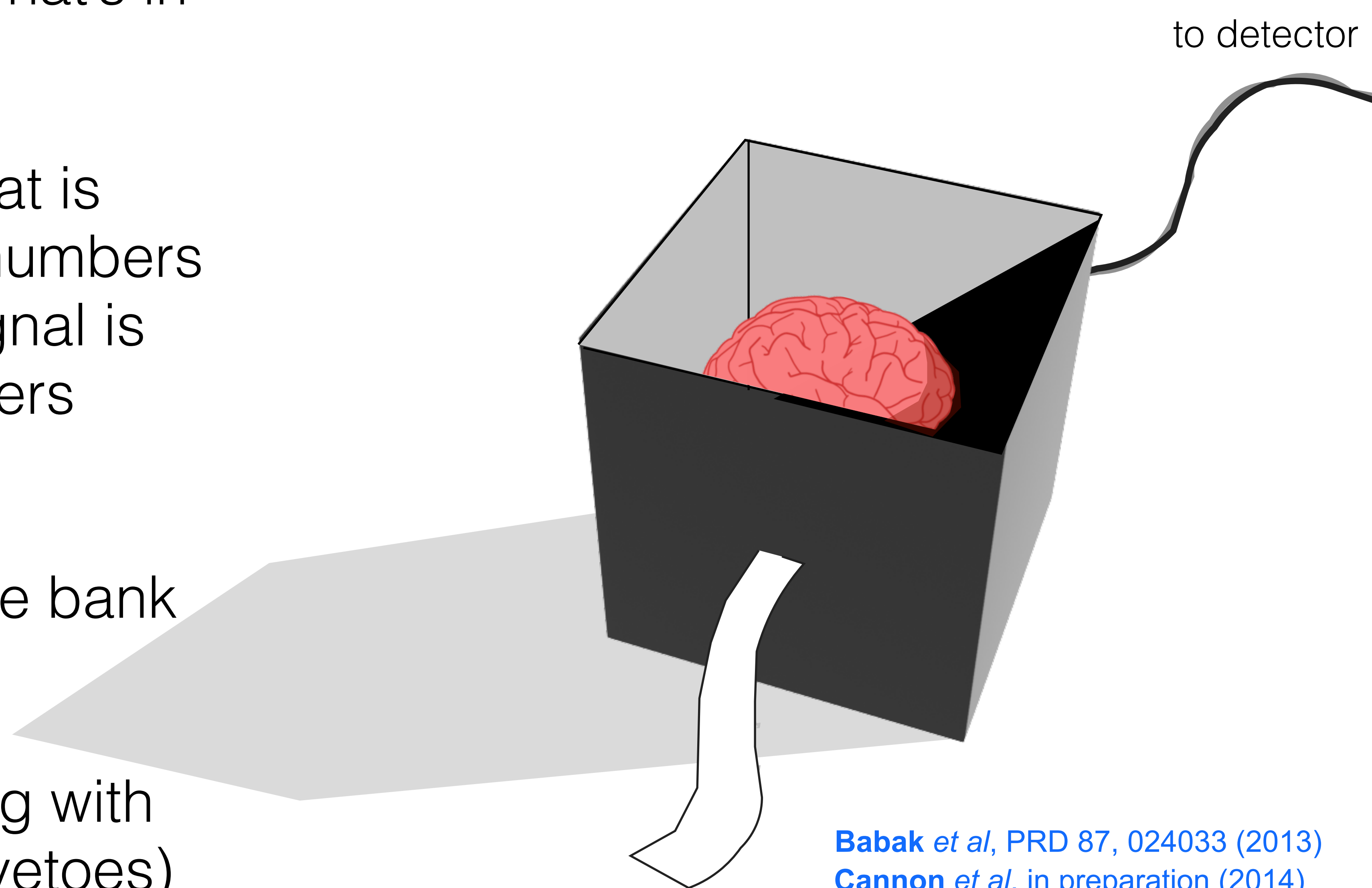
The basic problem

- Imagine you have a box containing your search.
- It is sensitive to real signals **AND noise events**. You cannot shield the detector from real signals.
- Every time it detects an event it outputs the "**loudness**" and the **time**.
- If you don't know the rate/probability of noise events then how do you detect real events?



Inside the box

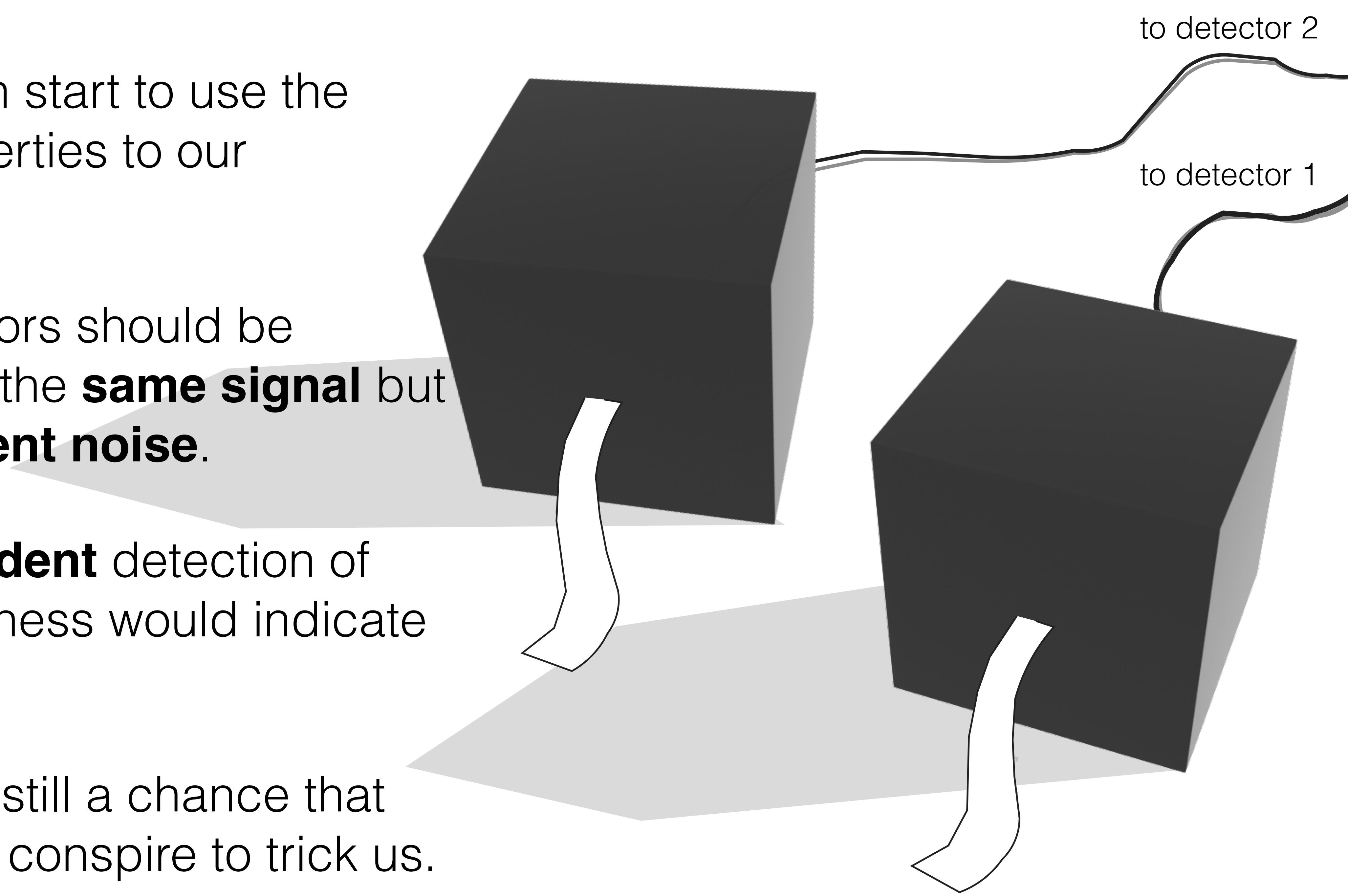
- We do actually know what's in the box.
- We construct a filter that is tuned to output large numbers when our particular signal is present and low numbers otherwise.
- Usually run over a large bank of templates.
- This is matched-filtering with tweaks (signal based vetoes) for deviations from Gaussianity.



Babak *et al*, PRD 87, 024033 (2013)
Cannon *et al*, in preparation (2014)

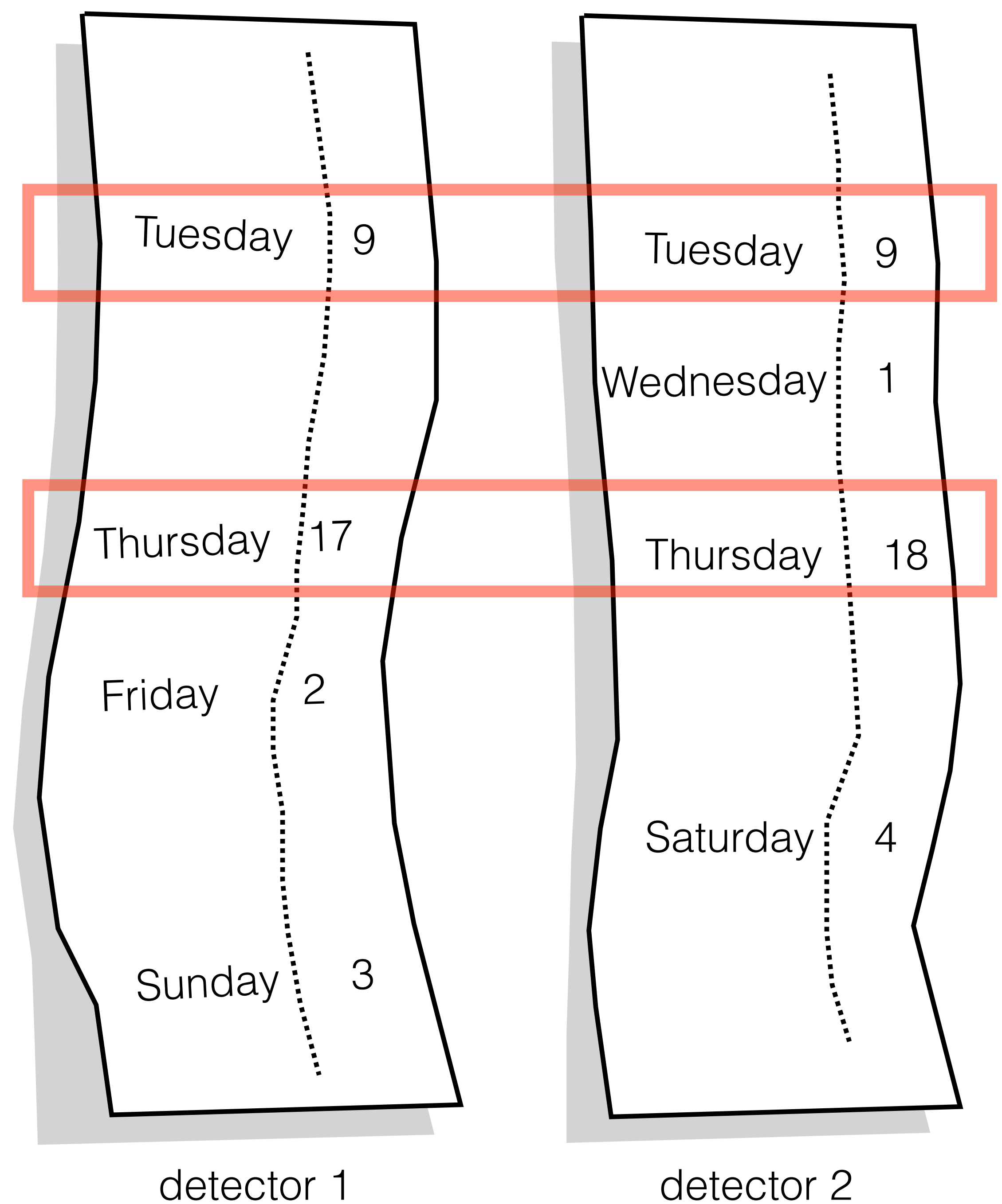
More detectors

- Now we can start to use the signal properties to our advantage.
- Both detectors should be sensitive to the **same signal** but have **different noise**.
- So a **coincident** detection of similar loudness would indicate a signal.
- But there is still a chance that noise could conspire to trick us.



Background estimation

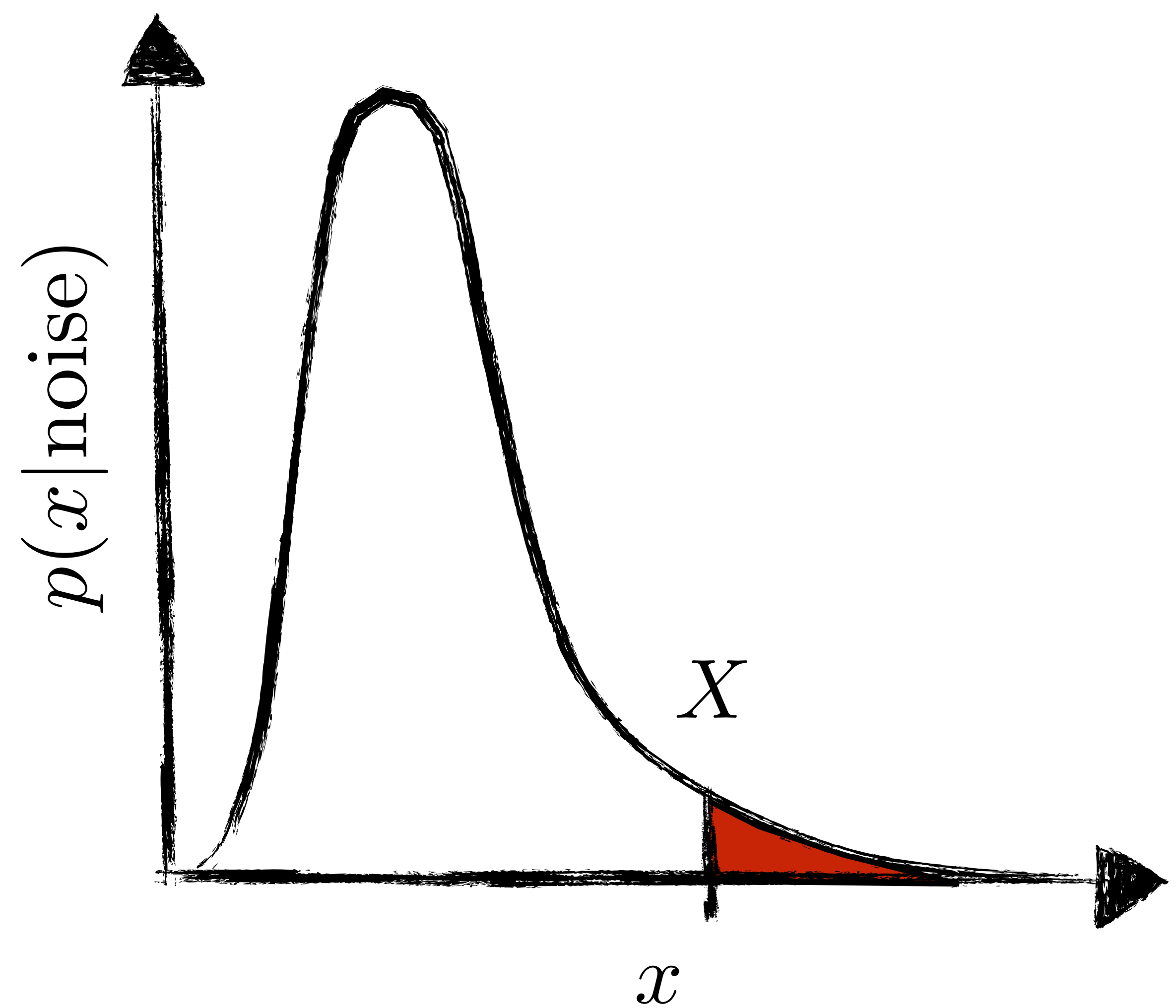
- What if we just **offset** the results of each detector by a **fixed amount of time**?
- Then there would be no chance that any coincident event could be considered a real signal!
- Any resulting coincidence would be representative of the noise, right?
- But what about contamination from signals? (the "**Hamlet**" issue).

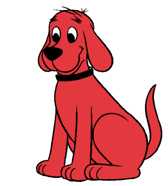


Significance

- Our primary scheme for determining detection is to compare our loudest event(s) with the **estimated** background distribution.
- We then make claims based **entirely** on the consistency of our statistic with the background (estimate).
- If this significance is small enough (5-σ?) then we claim detection.

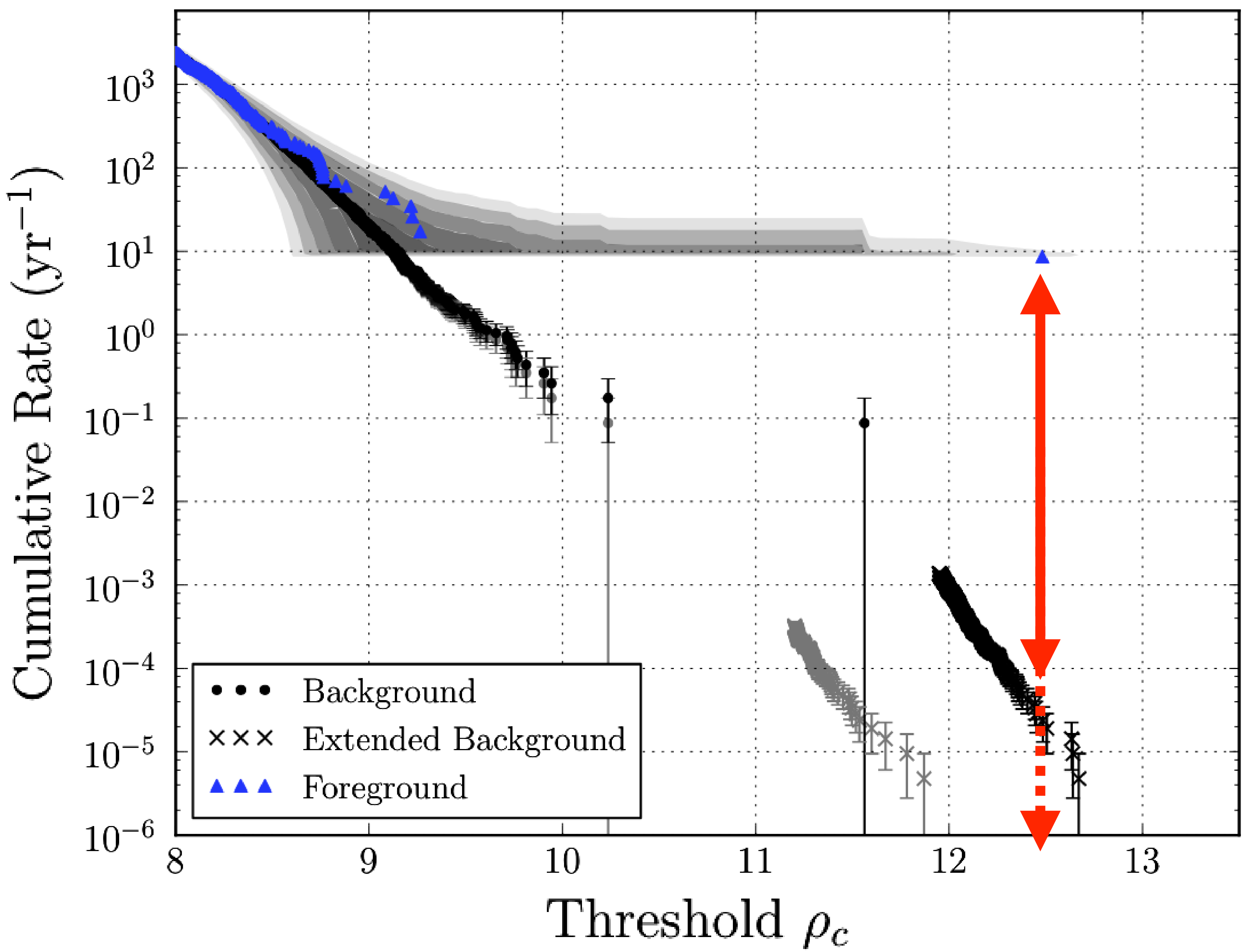
$$S = \int_X^\infty p(x|\text{noise})dx$$





Big dog significance

LIGO-Virgo Collaboration, PRD 87, 022002 (2013)



significance is the ratio of the background (black/grey) with the foreground (blue)

Hamlet : “to remove or not to remove? That is the question

Bayesian? Farr *et al*, arXiv:1302.5341 (2013)

- **Ask a different question**. What's the probability that this event came from an astrophysical distribution vs coming from the background?

$$B = \frac{\int d\vec{\theta}\, p(X|\vec{\theta}, \mathrm{signal}) p(\vec{\theta}|\mathrm{signal})}{p(X|\mathrm{noise})}$$

- Can also factor in what we think about detection prospects ***prior*** to the observation.

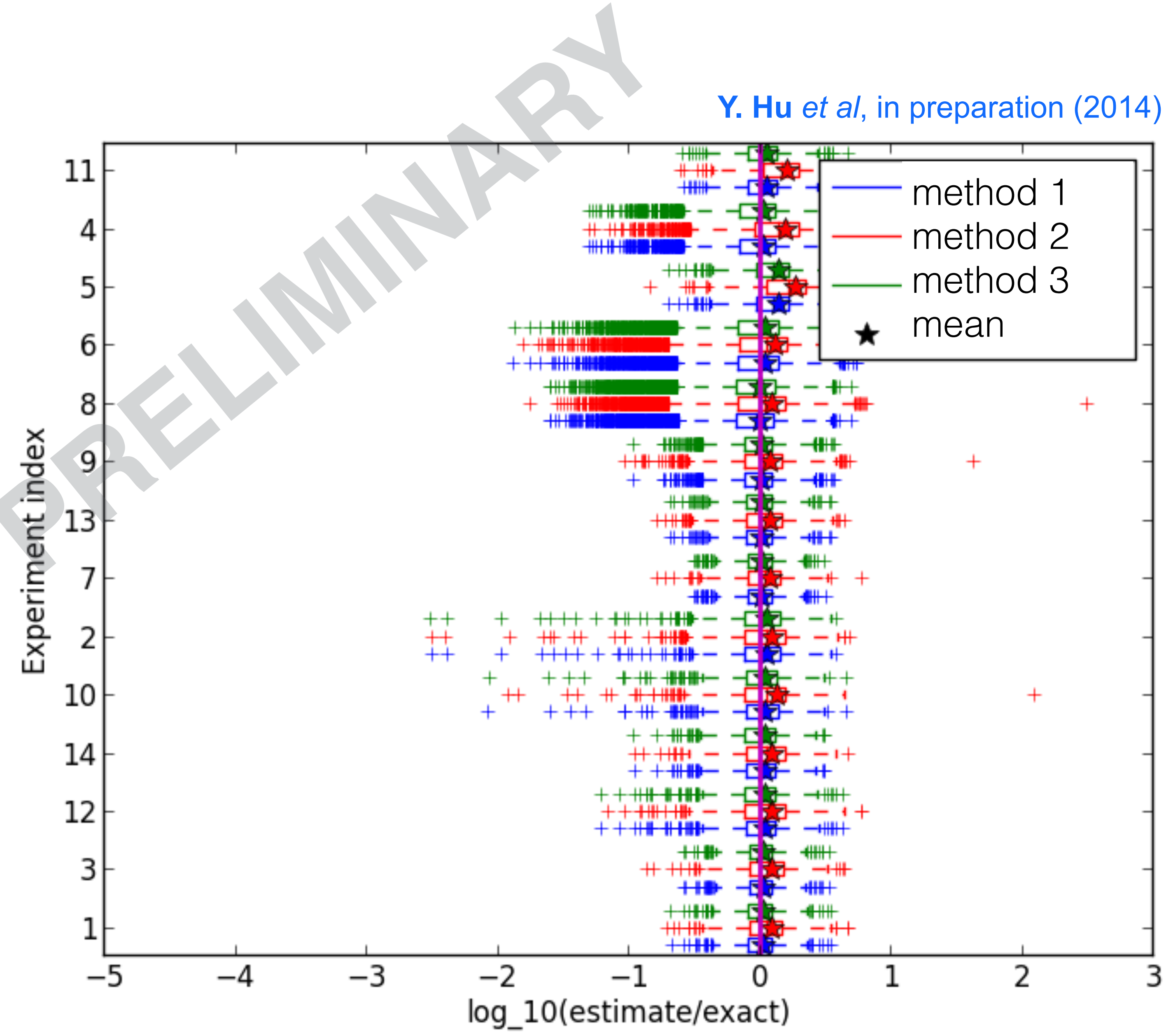
$$O = \frac{p(\mathrm{signal})}{p(\mathrm{noise})} \cdot \frac{\int d\vec{\theta}\, p(X|\vec{\theta}, \mathrm{signal}) p(\vec{\theta}|\mathrm{signal})}{p(X|\mathrm{noise})}$$

- Would you equally value an SNR=8 event differently in the initial and advanced detector era?

Ongoing Work

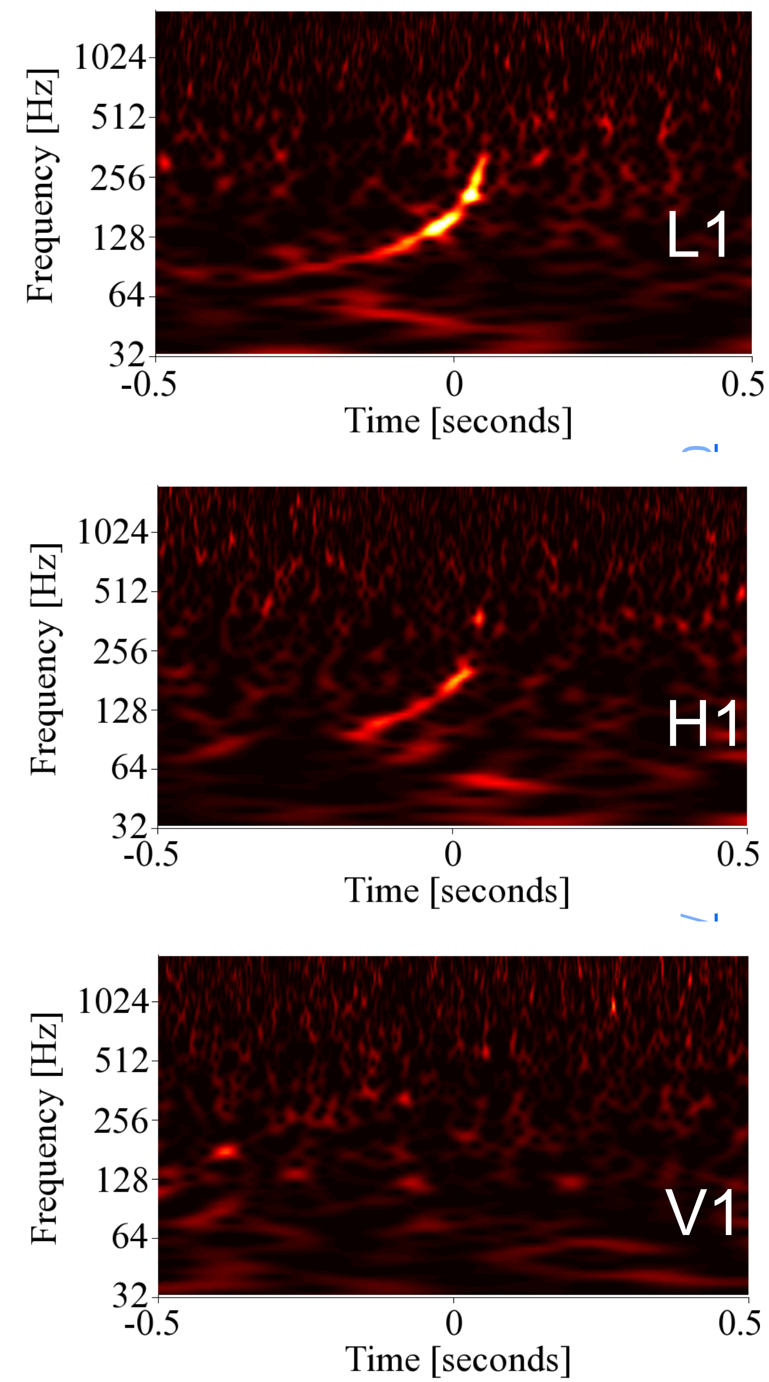
- We are conducting 2 large mock-data challenges to test significance and astrophysical rates estimation.
- **Significance** - resolving the removal vs non-removal issue.
- **Rates** - Testing biases, uncertainties and multiple detections.

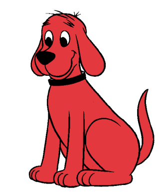
Y. Hu *et al*, in preparation (2014)



Summary

https://dcc.ligo.org/LIGO-P1000146



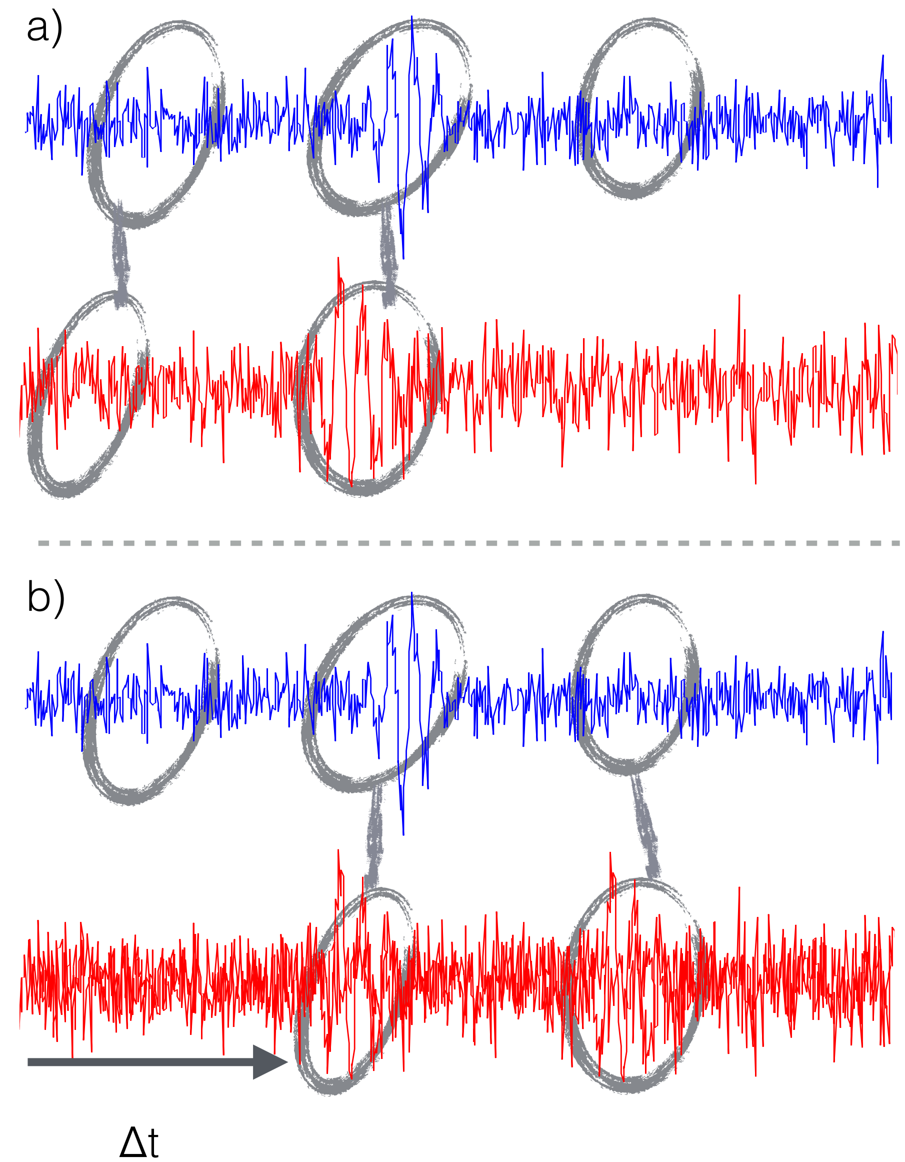


- The advanced GW detector era is fast approaching and detections are anticipated.
- All detection criteria crucially hinge upon background estimation.
- Bayesian approaches could allow us to fold in event rate priors.
- We are in the process of testing our significance and rate estimation through extensive MDCs

Extra slides

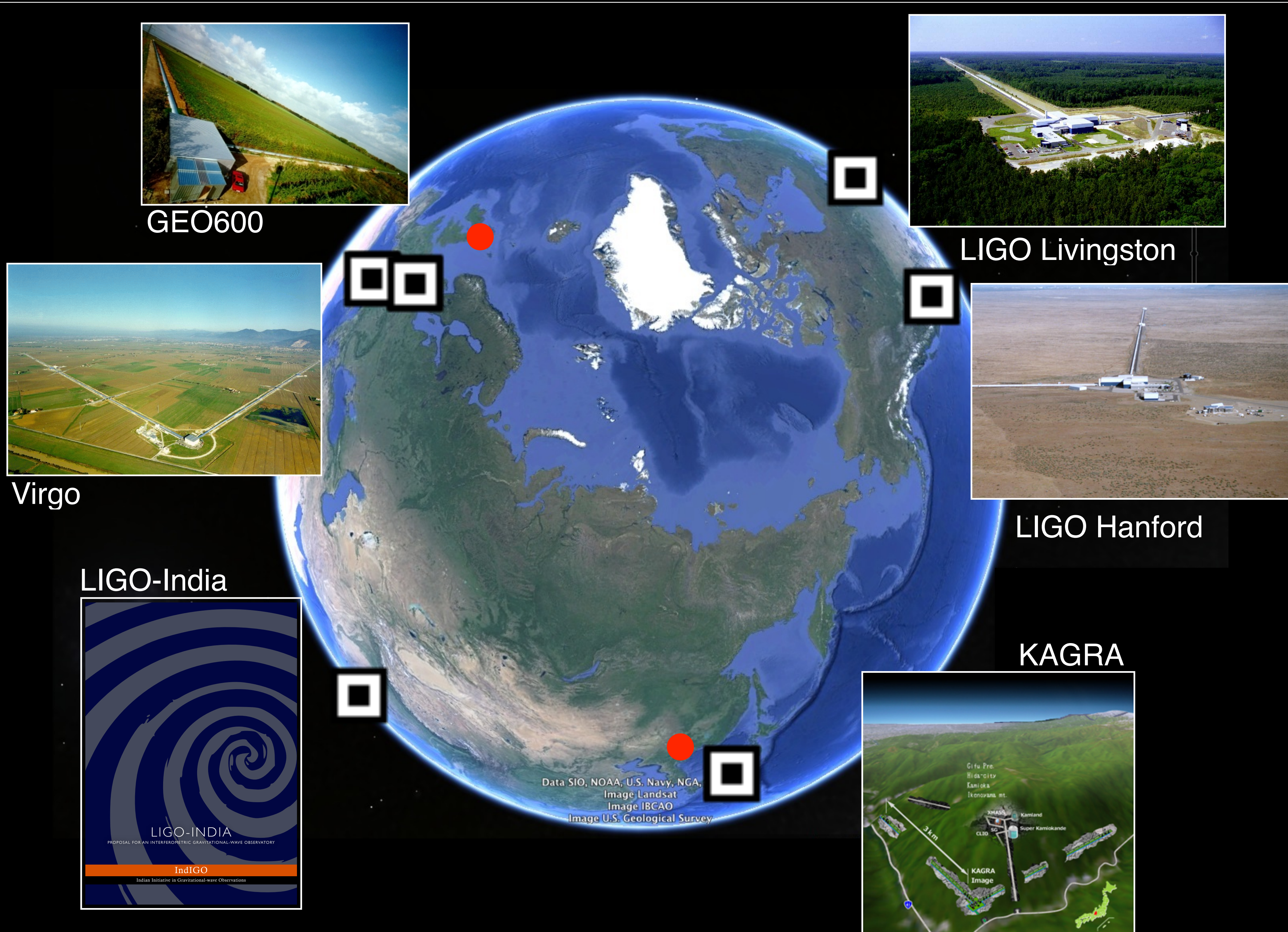
Detection significance

- How do you determine the statistical significance of a GW event?
- We need to know/estimate the background noise distribution.
- But we can't turn off the foreground GW signals.
- Use a technique known as time-slides to estimate the background.



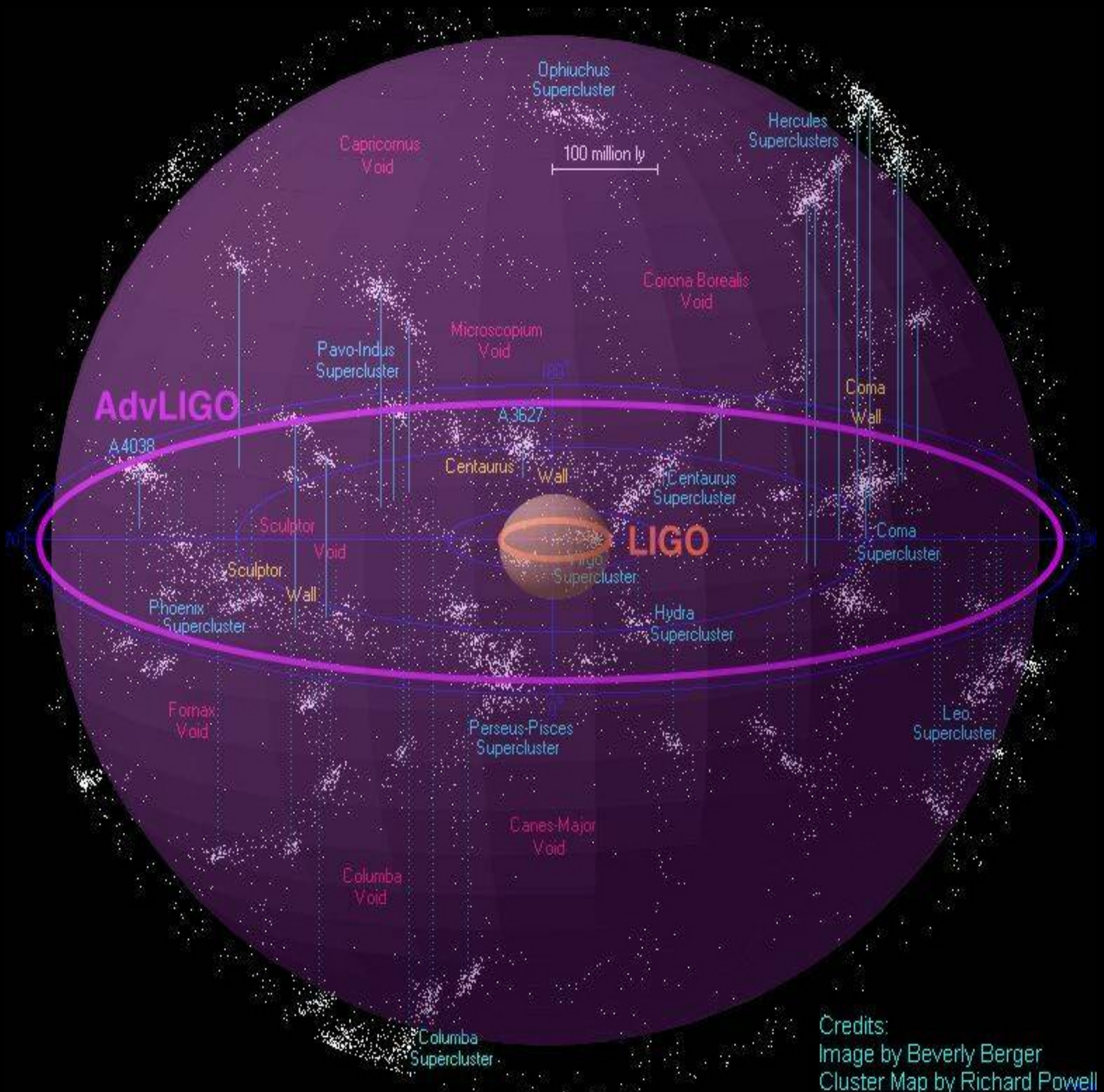
Time-slides. a) Simulated data from 2 detectors, b) detector 2 data is artificially slid in time with respect to detector 1.

A global network



LIGO-G1400947

Advanced detectors



- Advanced detectors have an ~10 X improvement in sensitivity.
- This gives an ~1000 X improvement in volume and therefore event rate!
- The design sensitivity volume includes ~10 galaxy superclusters.