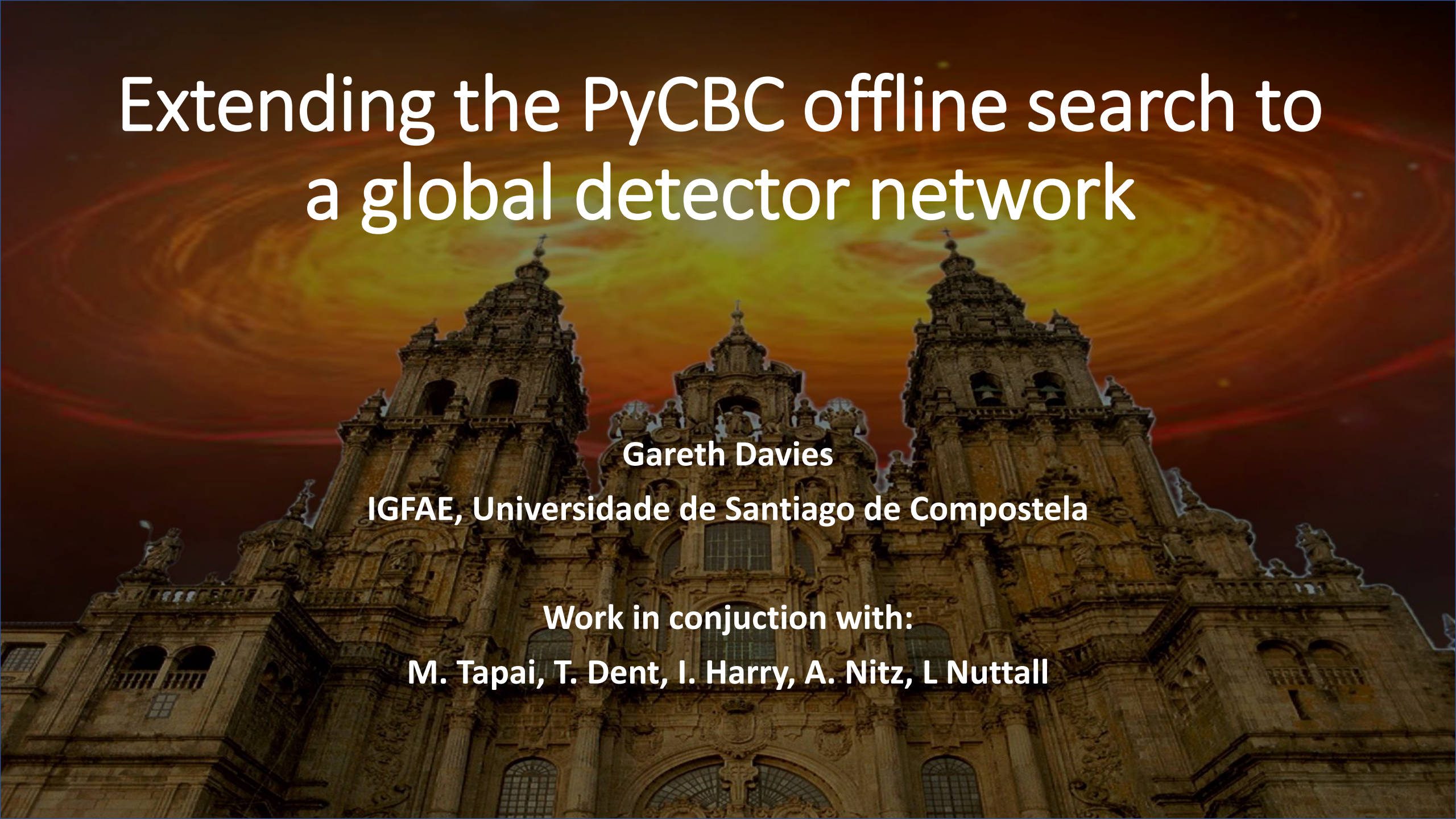
Extending the PyCBC offline search to a global detector network



Gareth Davies

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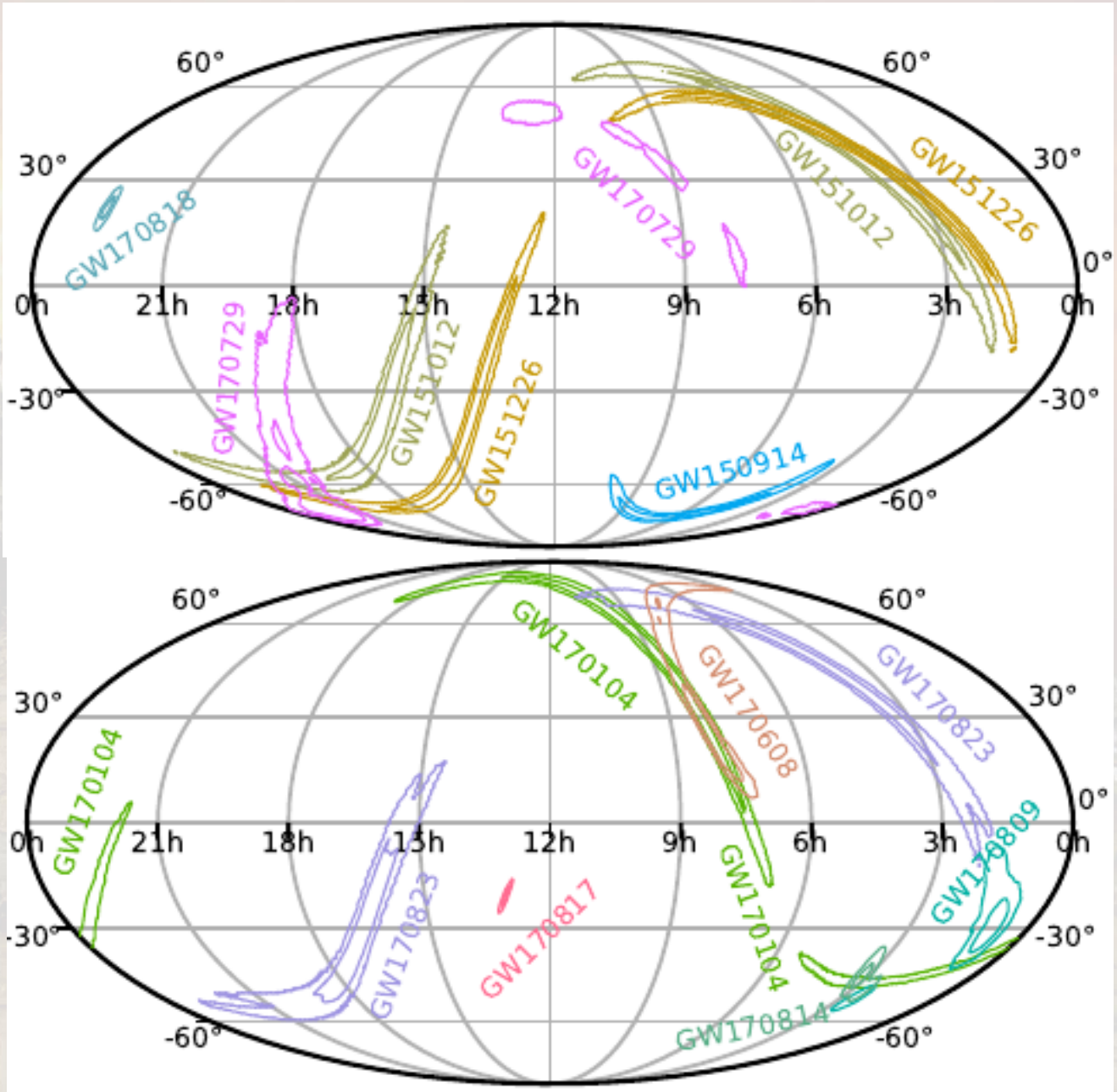
Work in conjuction with:

M. Tapai, T. Dent, I. Harry, A. Nitz, L Nuttall

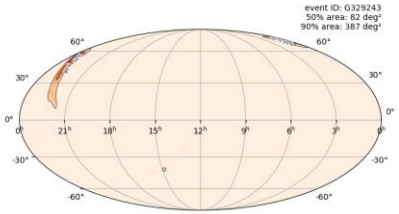
Overview

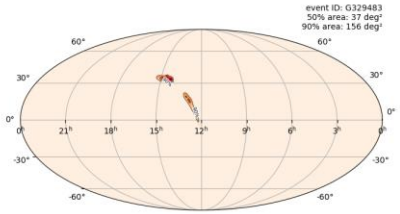
- How does the search work?
- Why extend to more detectors?
- What will be affected by changing to use more detectors?
- What changes have been made?
- What changes still need to be made?

O1-O2 results



O3 so far


S190408an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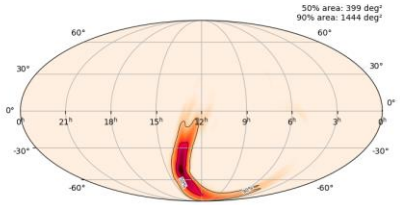
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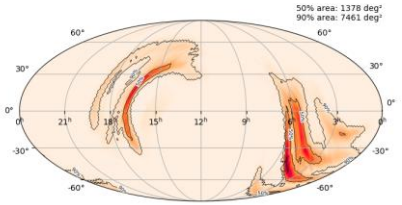
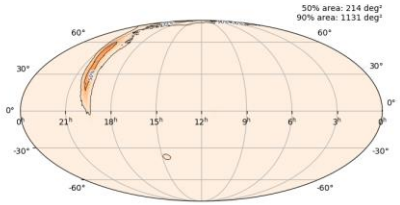
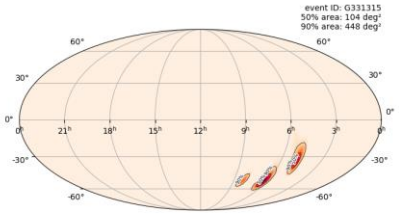

S190425z (BNS!)


S190426c BNS/NSBH?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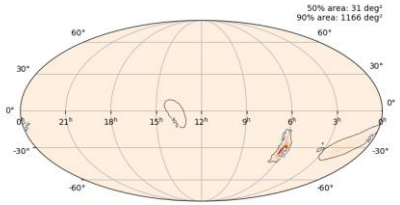
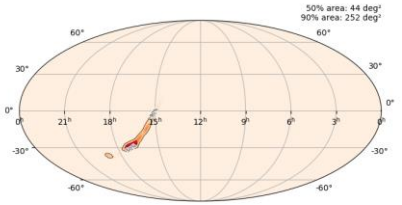

S190510g?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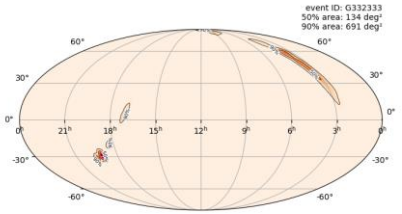
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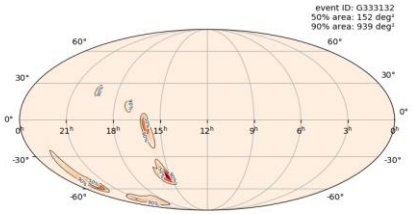
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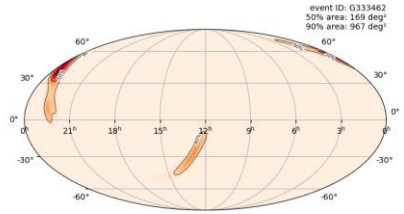
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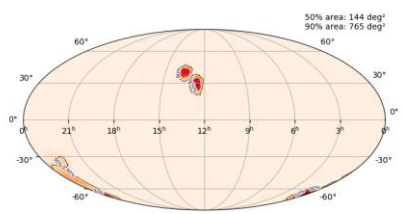
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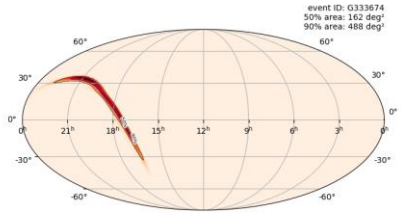
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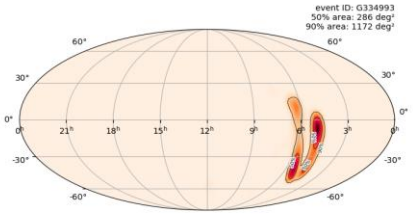

S190602aq
(2 days ago!)

O3 so far

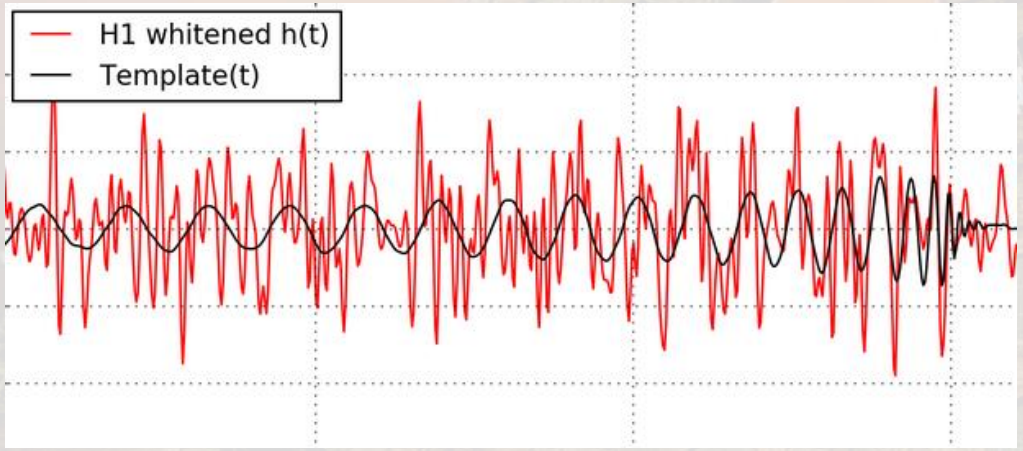
How does the PyCBC offline search work?

Matched Filtering

Video courtesy of Alex Nitz: Video

- Matched filtering gives a time series of SNR based on how much of a match it is to each template. Triggers are points of high SNR

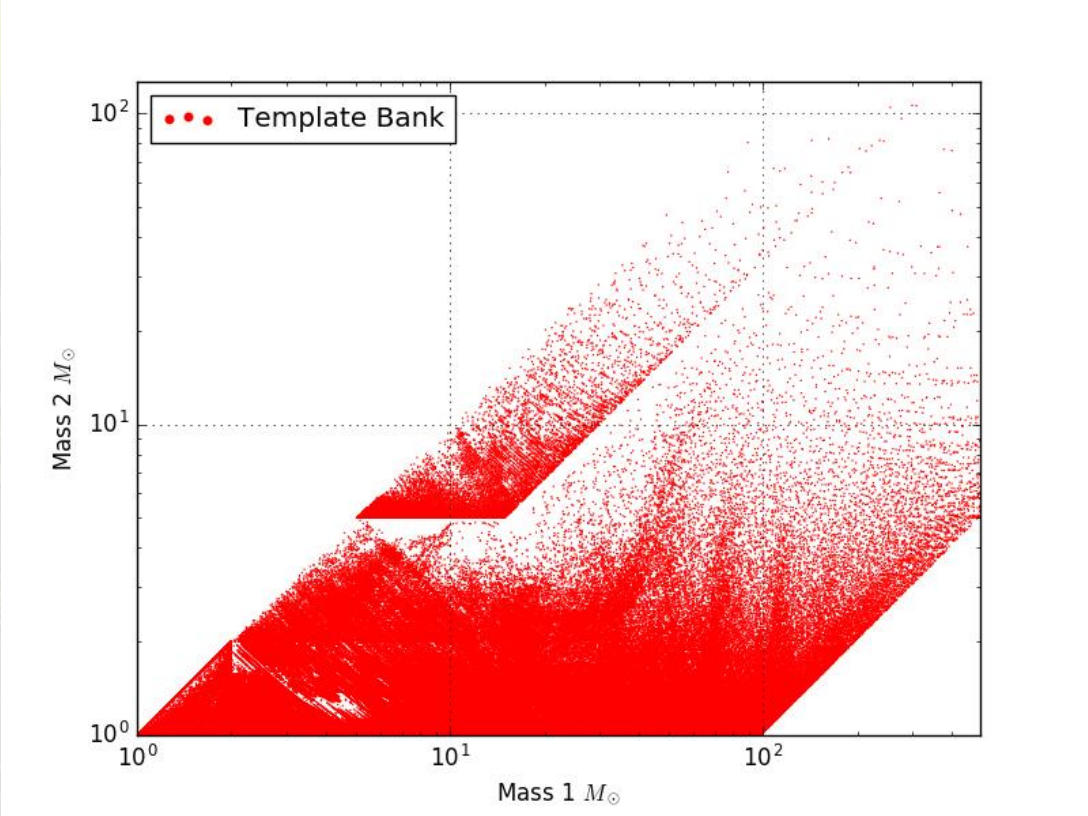
Matched Filtering



- Matched filtering gives a time series of SNR based on how much of a match it is to each template. Triggers are points of high SNR

Template Bank

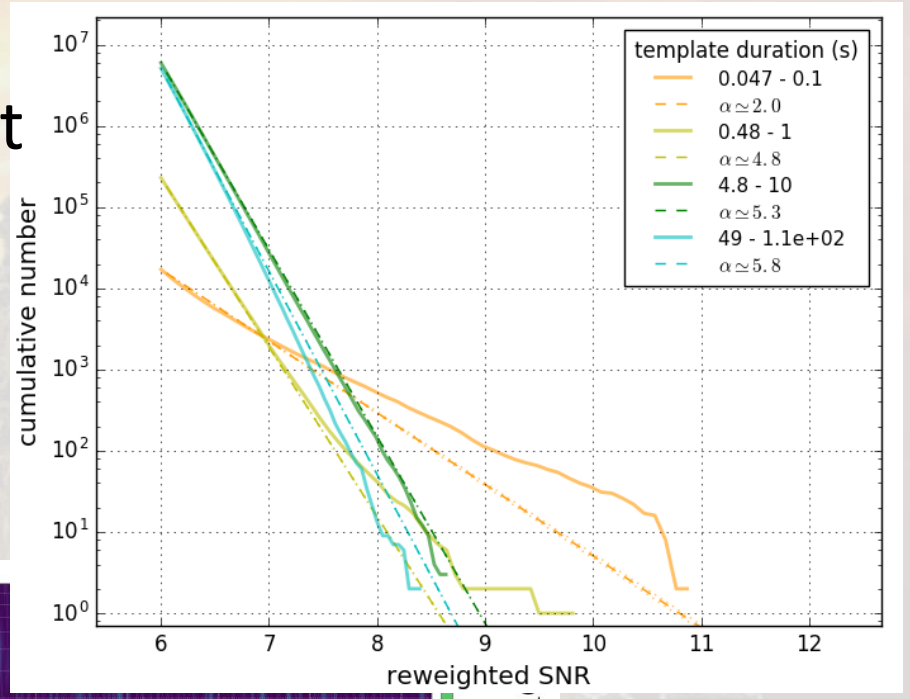
- Filtering is done using match to expected signals
- This is a ‘bank’ of templates which are spaced such that a signal with parameters between these do not lose too much SNR
- In O2 a bank of $\approx 4 \times 10^6$ templates was used

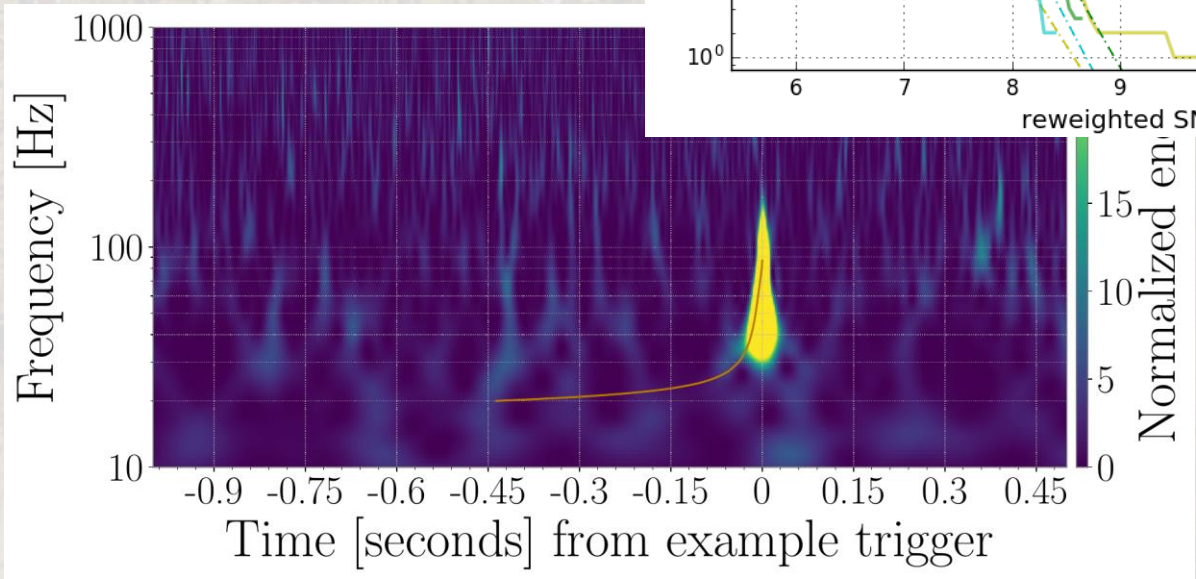


How does the PyCBC offline search work?

- Transient Noise events (glitches) have different event distributions in different templates

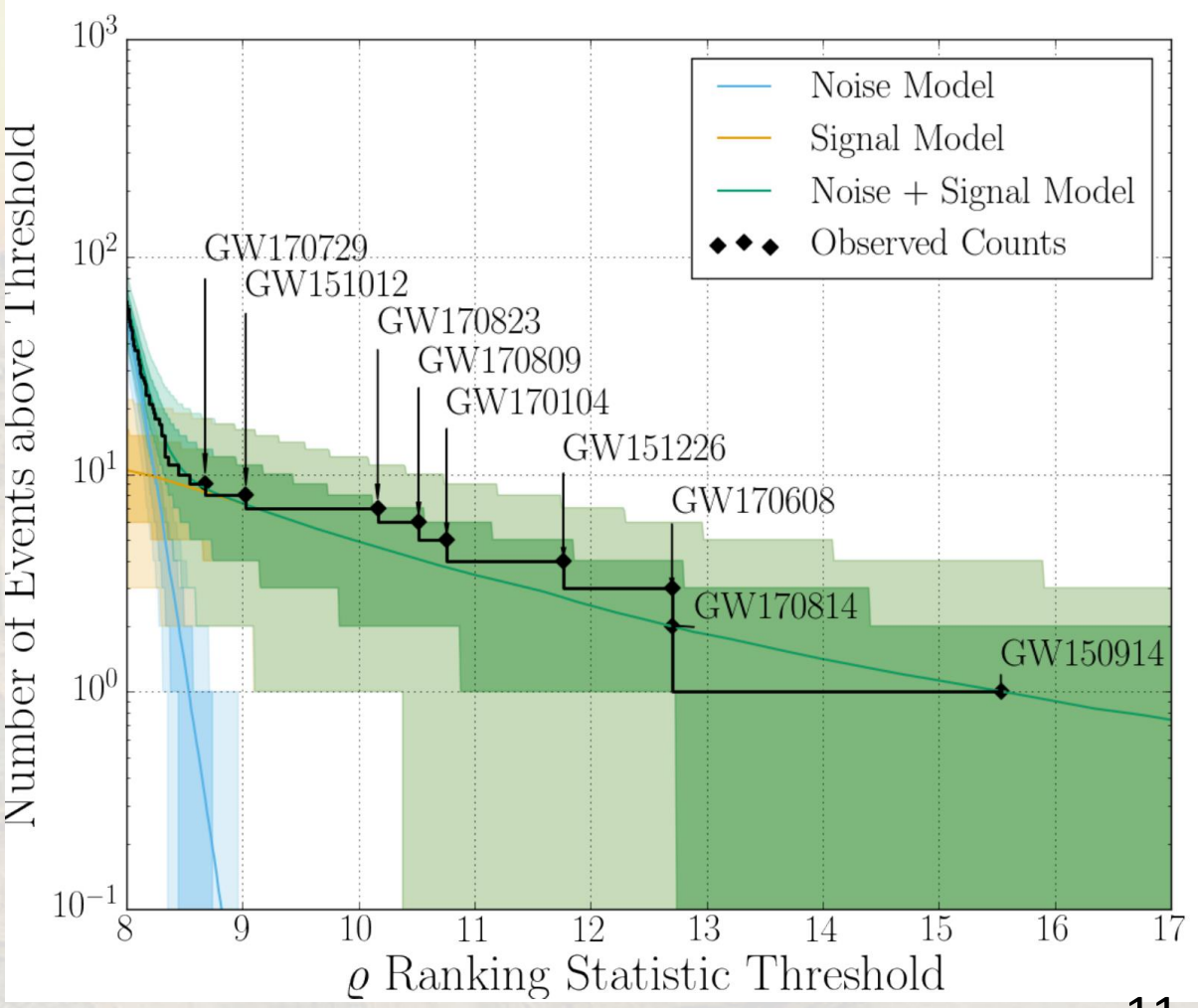
- This distribution is estimated for each template, and the trigger is compared to the background distribution





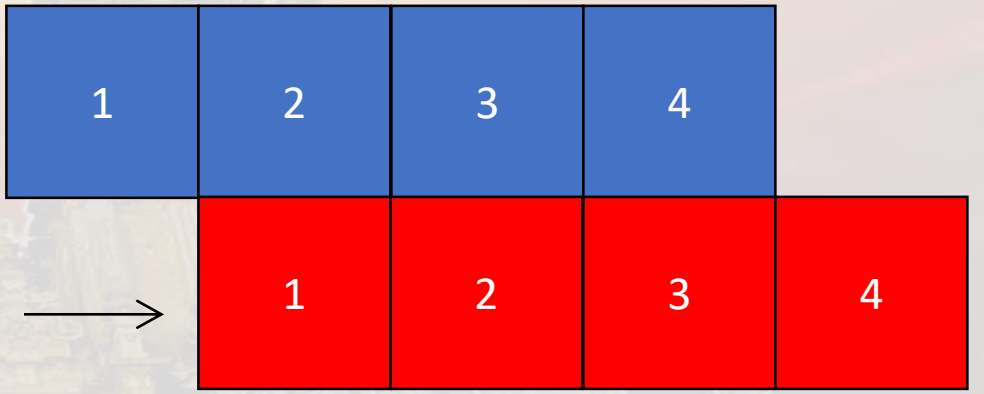
How does the PyCBC offline search work?

- Coincidences are found between (the two) detectors
- The combined detectors statistic $\hat{\rho}_c$ is calculated
- Significance assessed through comparison to expected background rate



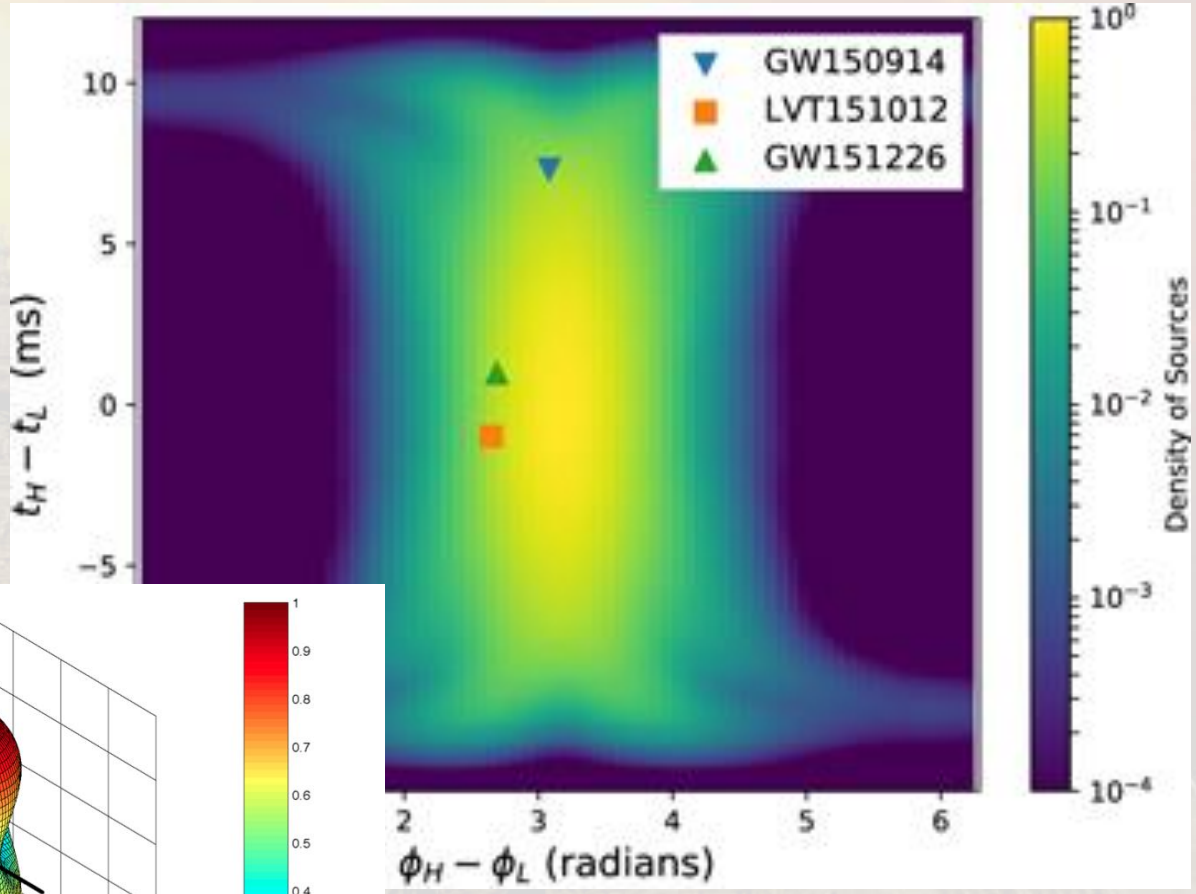
Time slides

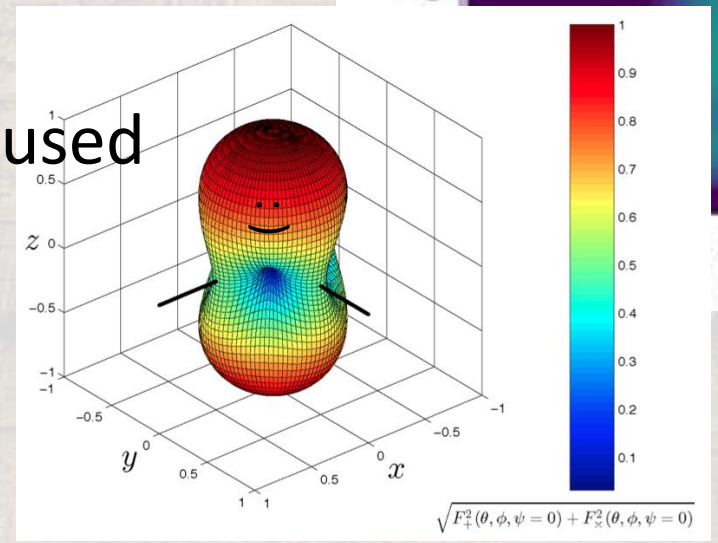
- Background expected rate is estimated through time slides
- When calculating the expected background, we shift the data of one detector relative to the other
- Equivalent analysis time = $\frac{t_H t_L}{\Delta_{slide}}$



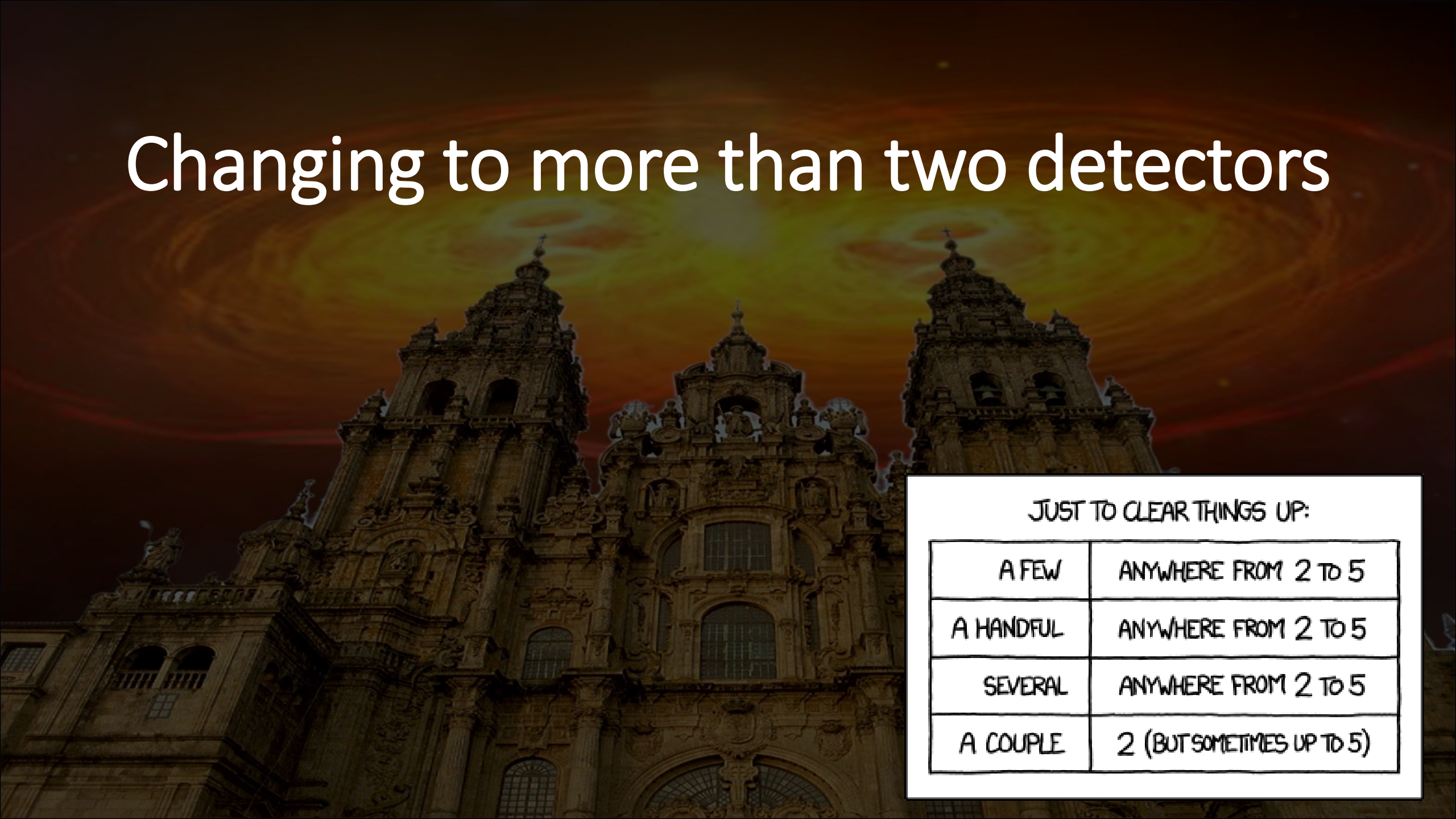
Priors on time and phase differences

- Strong directionality of LIGO detectors
- Some combinations of δt and $\delta\varphi$ are disfavoured
- Astrophysical priors are used to down-weight these combinations



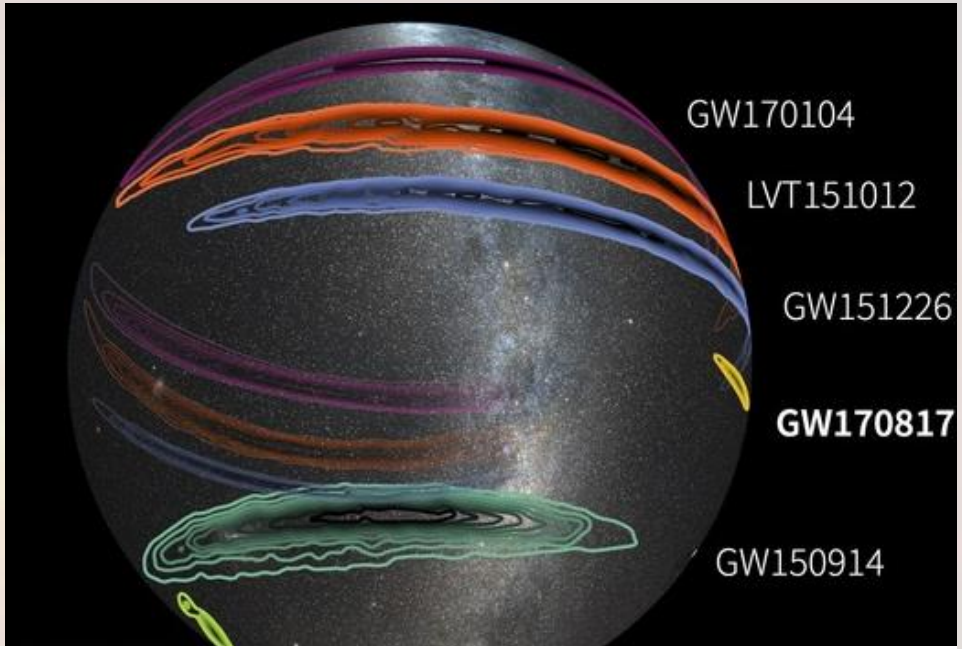


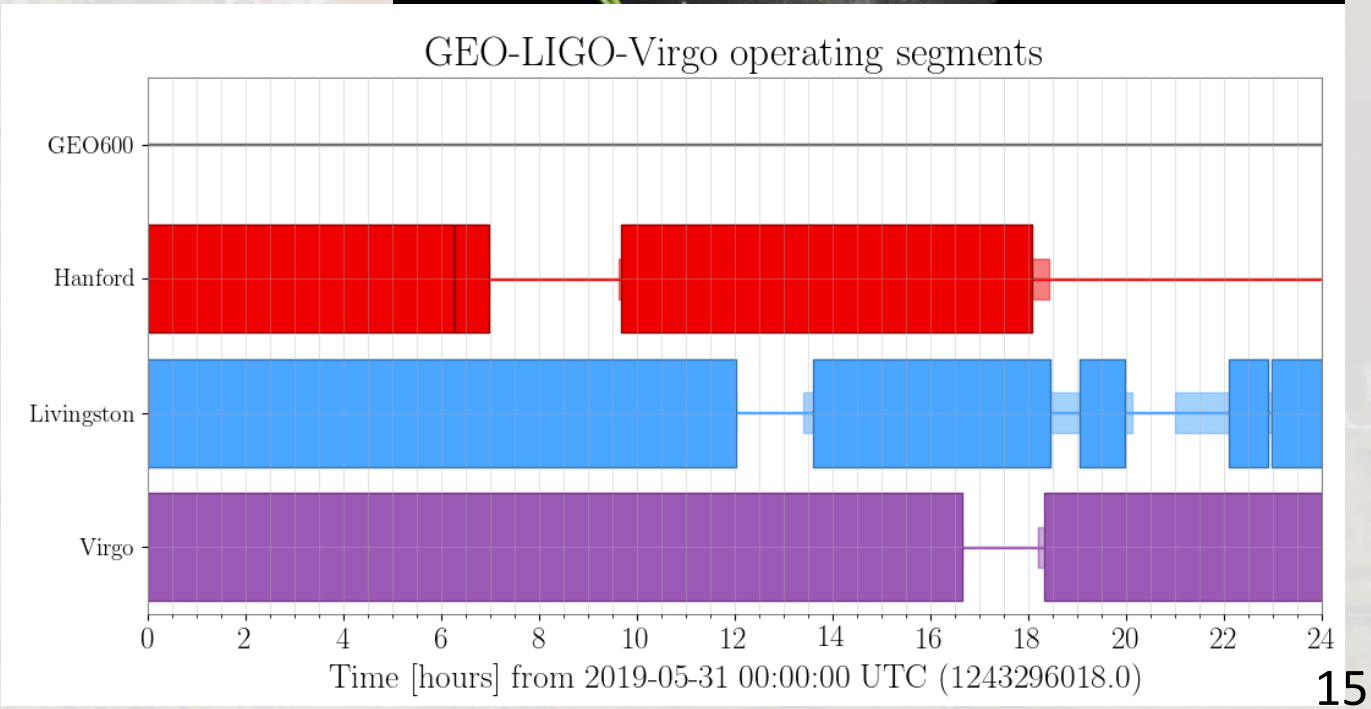
Changing to more than two detectors



Scientific motivations for use of more detectors

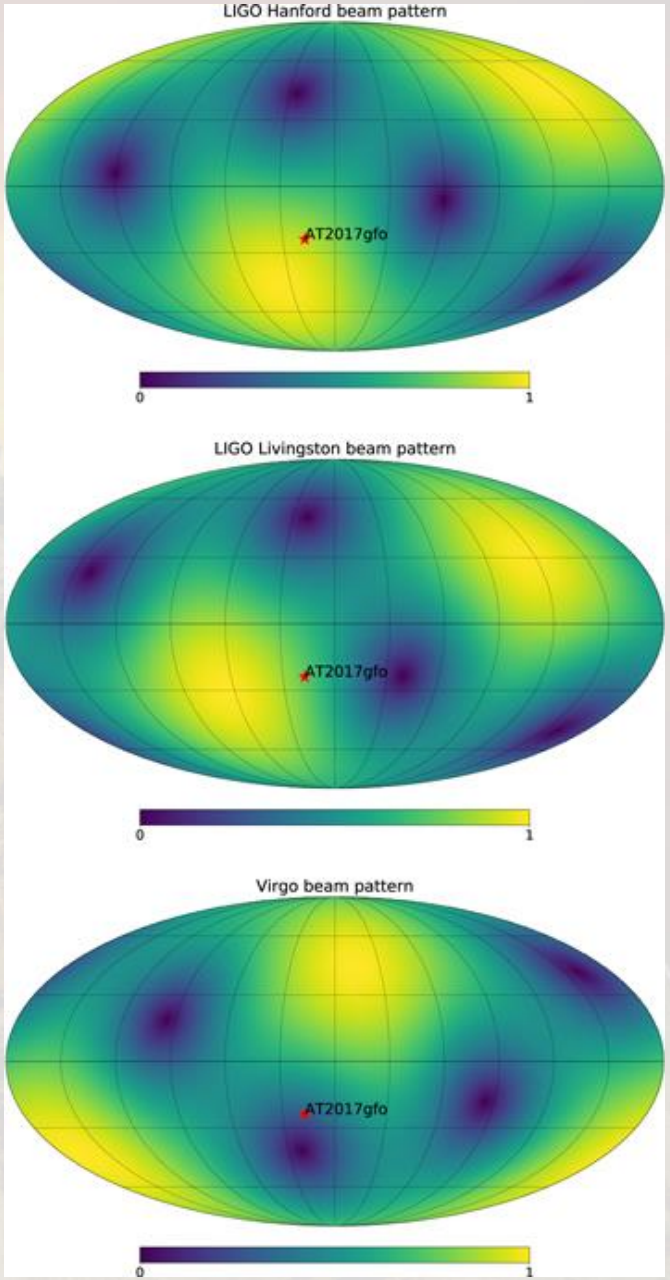
- Sky localisation/distance
- Latency
- Sky coverage
- Statistical confidence
- More detections – more opportunities to be above threshold





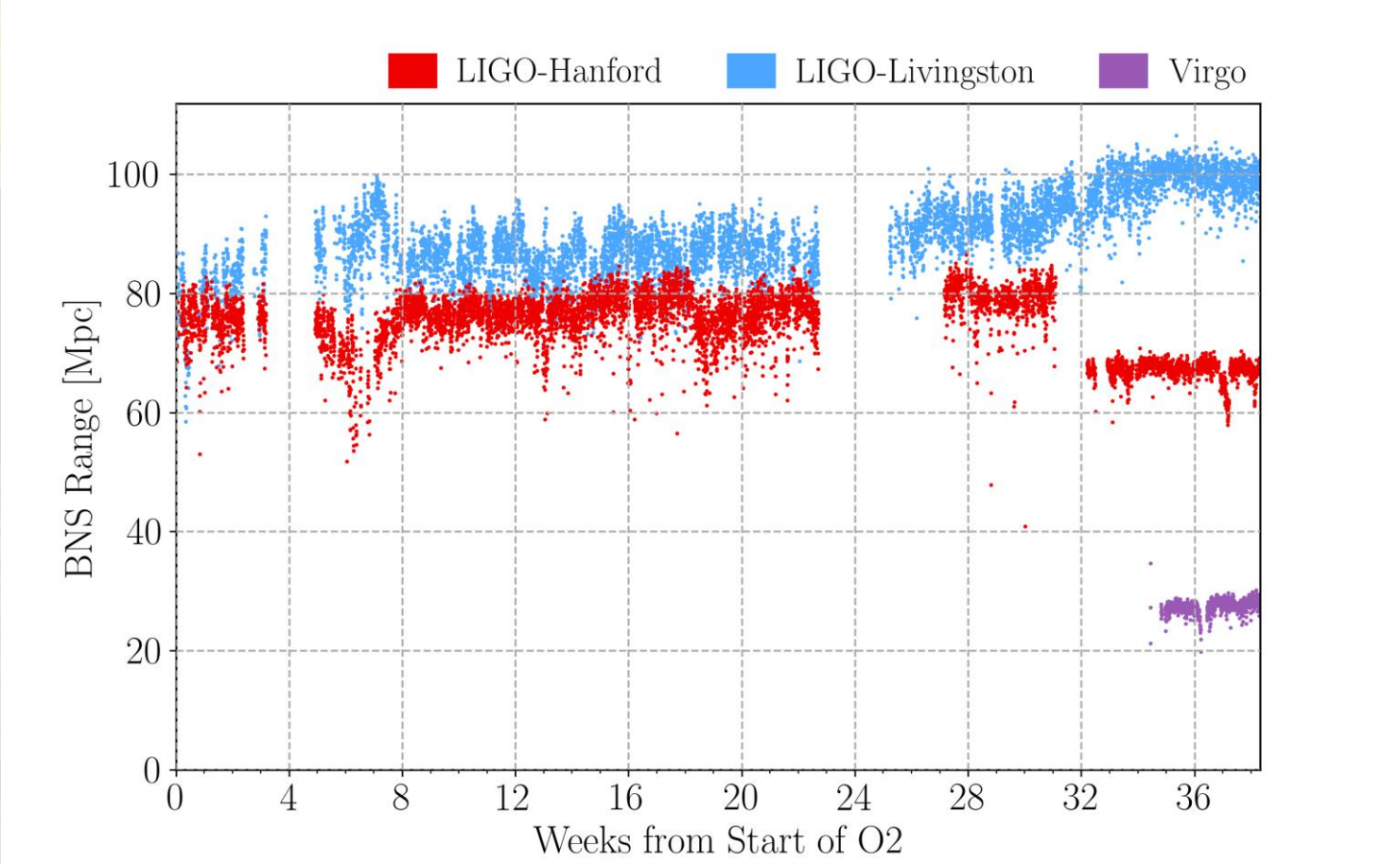
Scientific motivations for use of the third detector

- Sky localisation/distance
- Latency
- Sky coverage
- Statistical confidence
- More detections – more opportunities to be above threshold



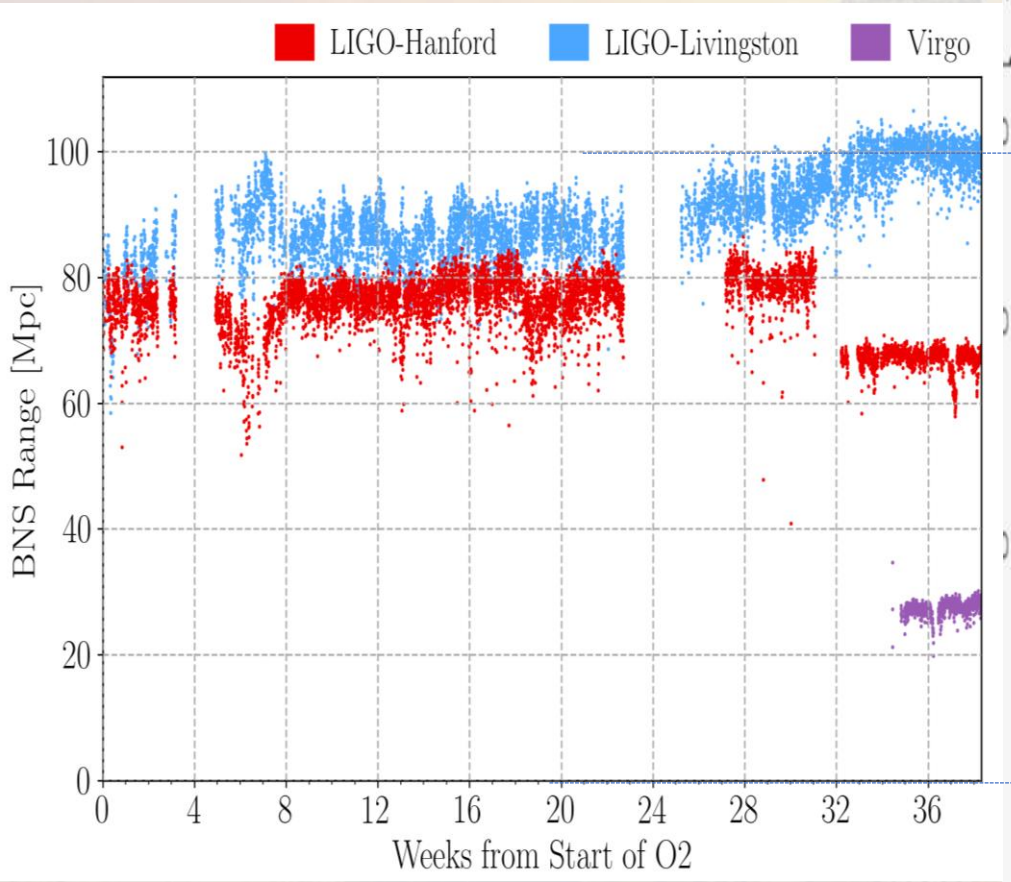
Because it's there

- So far, the PyCBC offline search has used data from the two LIGO detectors
- At the end of O2, Virgo re-joined the game – and is performing well at the start of O3
- KAGRA will be joining soon-ish

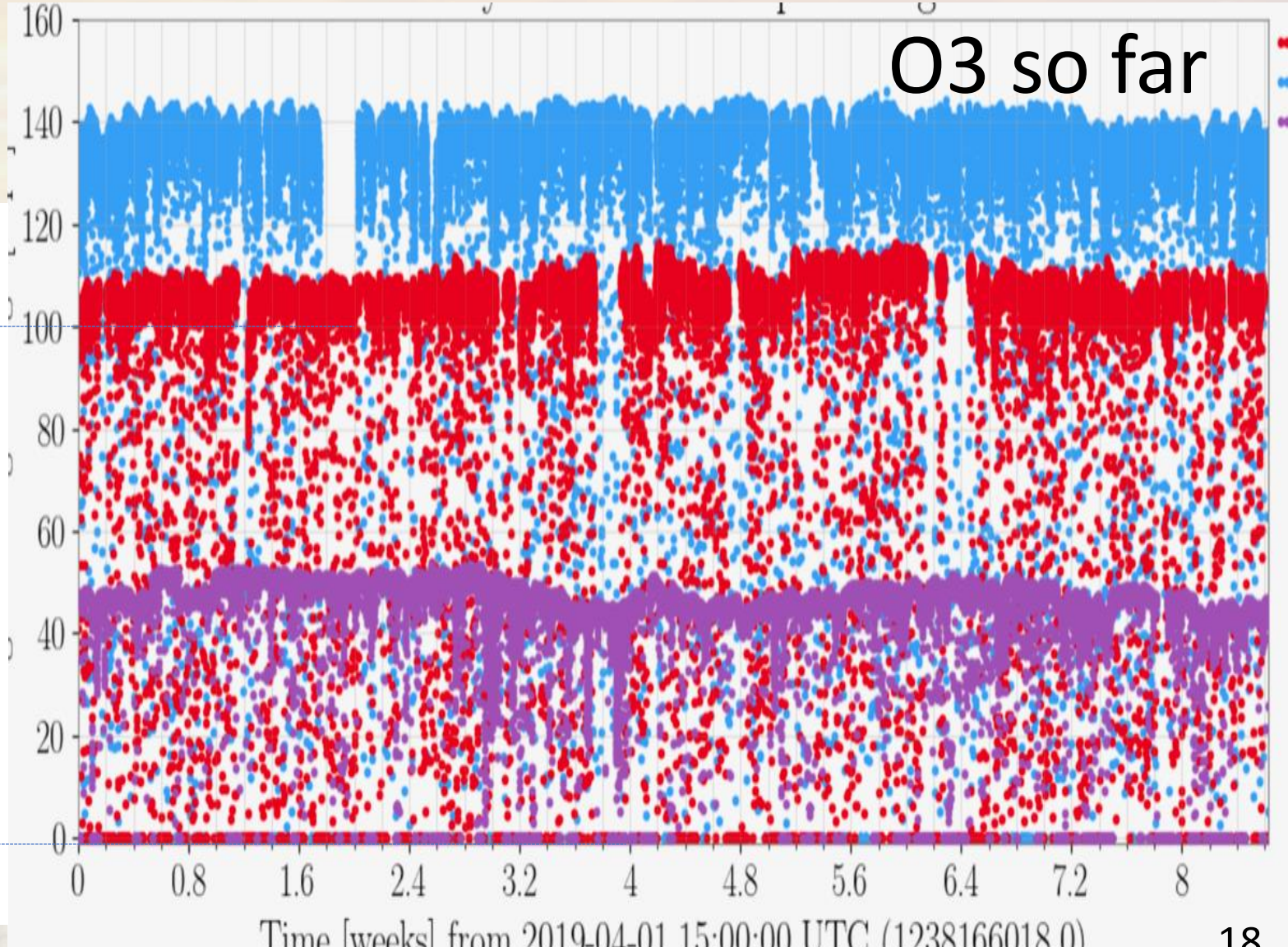


Improvement from O2 to O3

O2 summary



O3 so far



Challenges of using ≥ 3 detectors

Challenges of three-ifo analysis

- How does a three-detector coincidence compare to one in two detectors?
- How to decide which coincidence type to use when clustering?
- How to take number of online detectors into account?

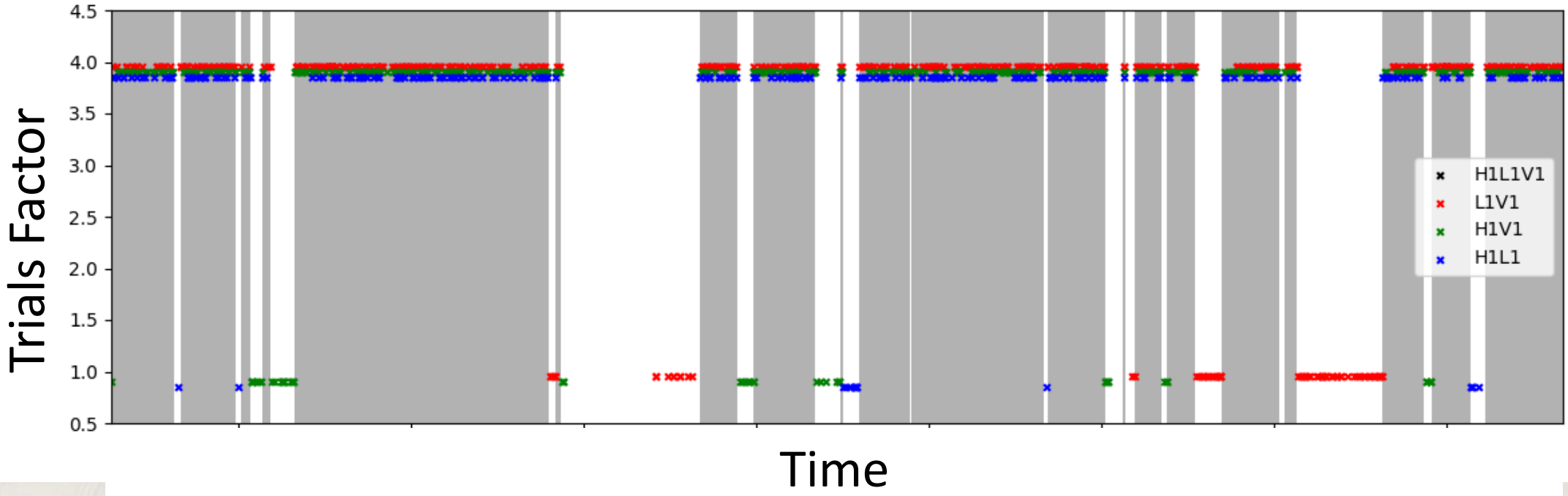
Challenges of three-ifo analysis

- How does a three-detector coincidence compare to one in two detectors?
- How to decide which coincidence type to use when clustering?
- How to take number of online detectors into account?

- New ranking statistic to compare with expected coincident rate of it's own type
- By having a ranking statistic which is comparable over different coincident type
- Use trials factors according to the number of available detector combinations

Trials Factor

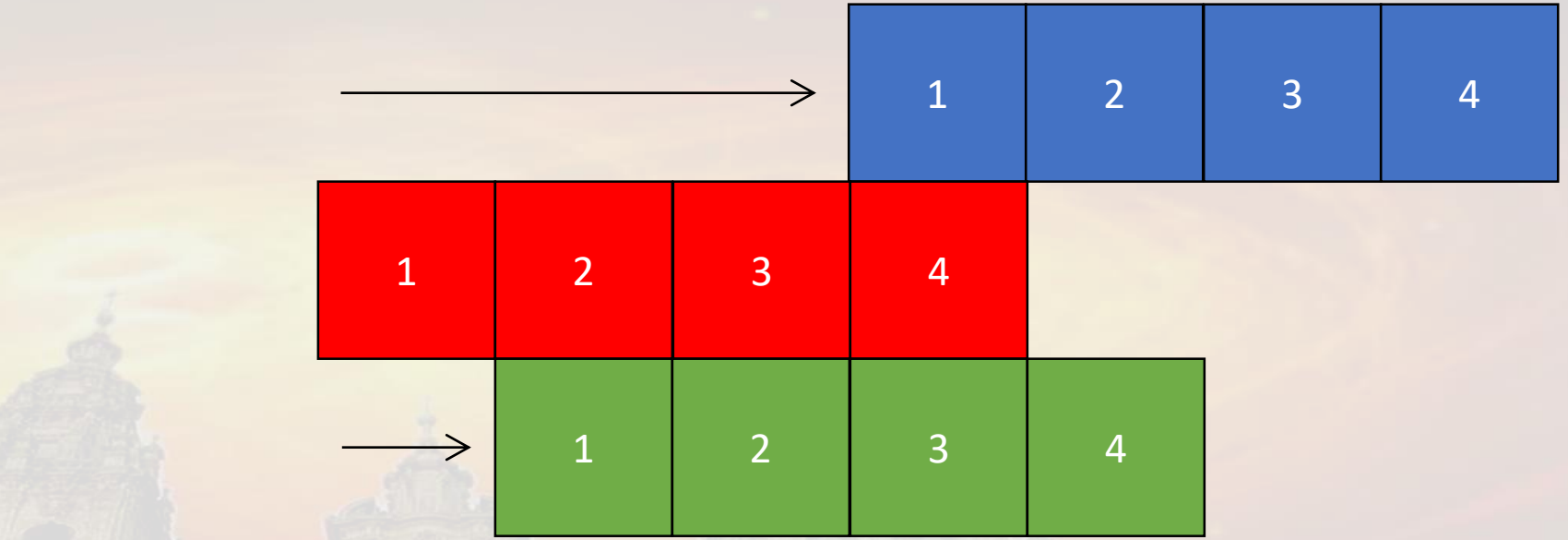
- If the coincidence occurs in triple detector time, then there are four different types of coincidence that can form
- Else there is only one type which can be formed
- Apply a trials factor of the number of possible coincidences



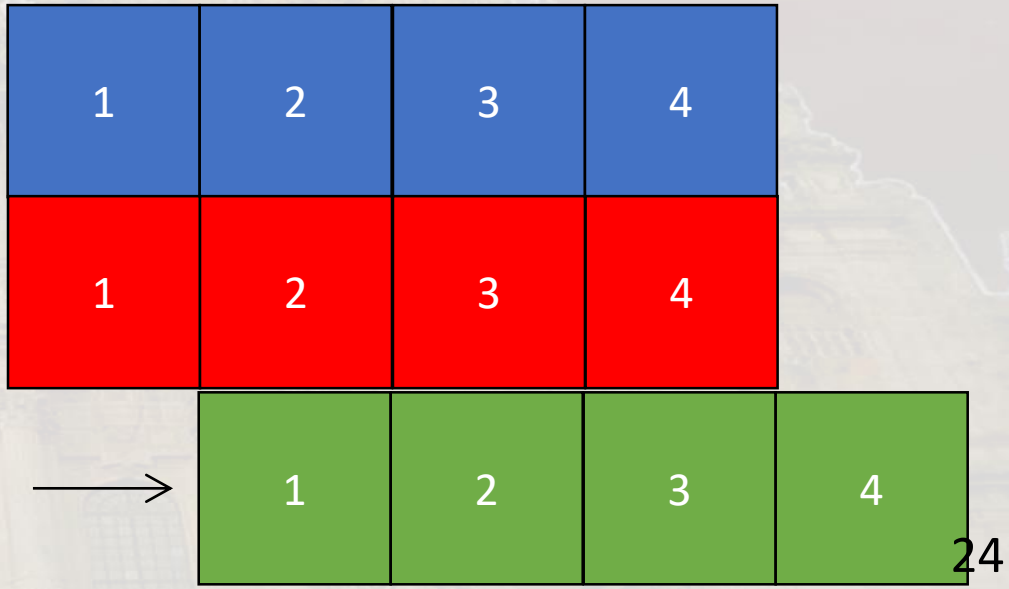
What difference does a third detector make to PyCBC data analysis?

- Time slides
- More data
- Fewer noise coincidences
- Signal consistency

Time slides



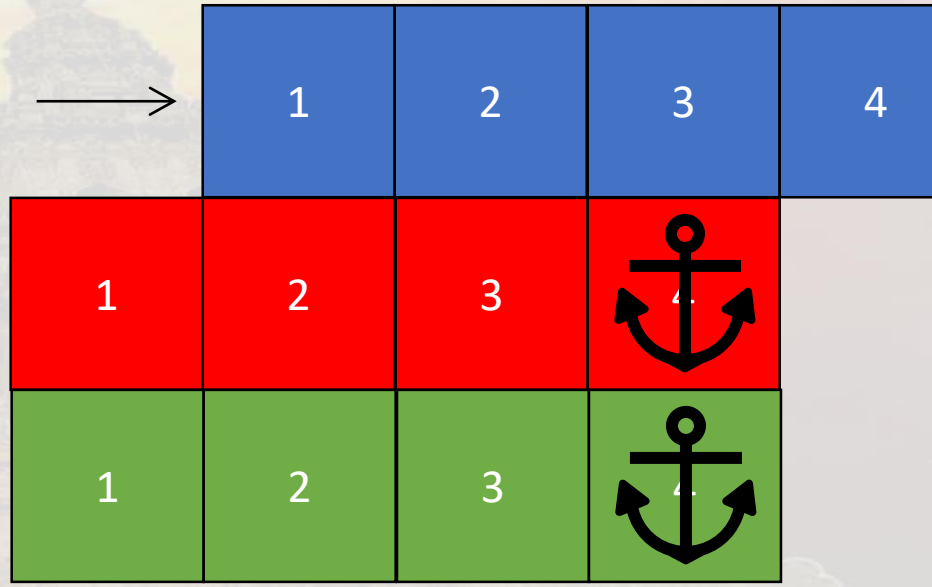
- With 3 detectors – equivalent analysis time = $\frac{t_H t_L t_V}{\Delta^2_{slide}}$ → complicated and a ***lot*** of data



Time slides

- We allow for this by requiring coincidence in all but one detector before sliding just one relative to the others

- With 3 detectors – equivalent analysis time = $\frac{t_H t_L}{\Delta_{slide}}$ → easier



Noise coincidence rate reduced

- For 2 detectors:
  - $r_{12}(\vec{\theta}) = 2\Delta_{12} r_1(\vec{\theta}) r_2(\vec{\theta})$

Small numbers

- For 3 detectors:

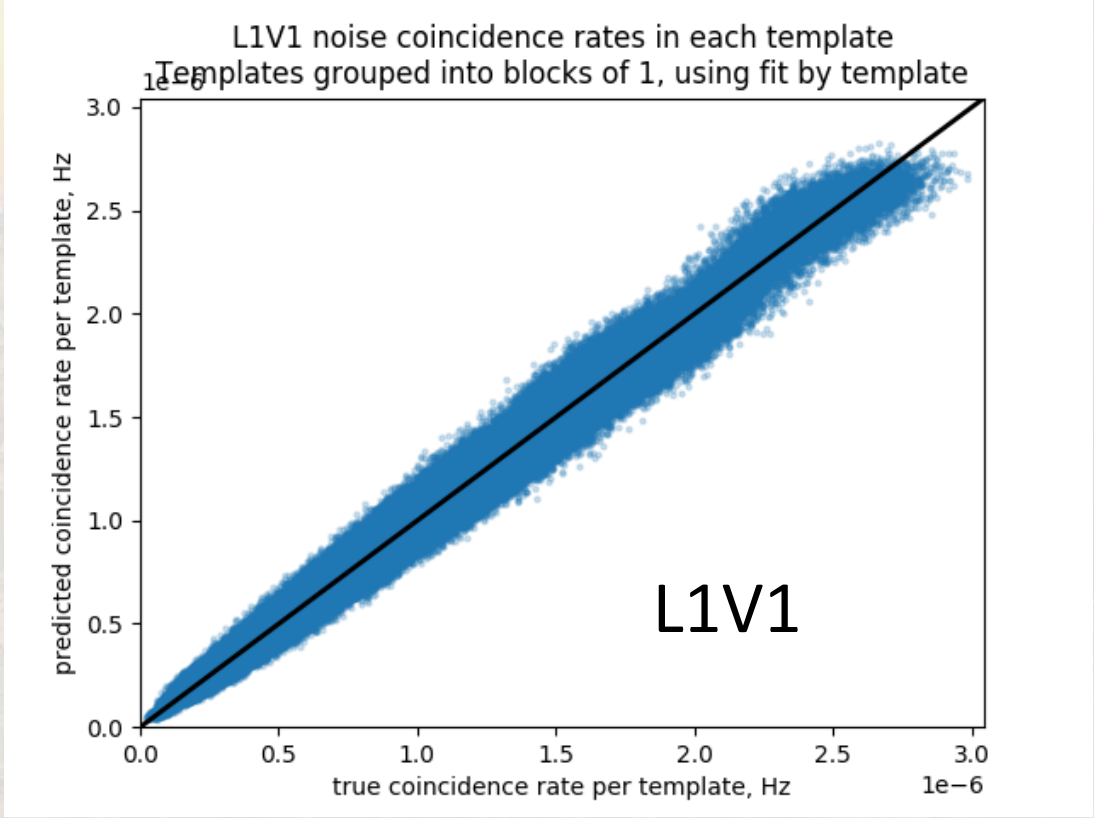
Small numbers

  - $r_{123}(\vec{\theta}) = A_{123} \prod_{i=1,2,3} r_i(\vec{\theta})$
  - $A_{123} = 2\Delta_{12}\Delta_{13} + 2\Delta_{12}\Delta_{23} + 2\Delta_{13}\Delta_{23} - \Delta_{12}^2 - \Delta_{13}^2 - \Delta_{23}^2$

Calculation of expected noise rate

- Given single-detector rates (in each template) we can calculate the number of expected events

- To show the effectiveness of this, we compare to the actual rate of coincidences for each detector combination



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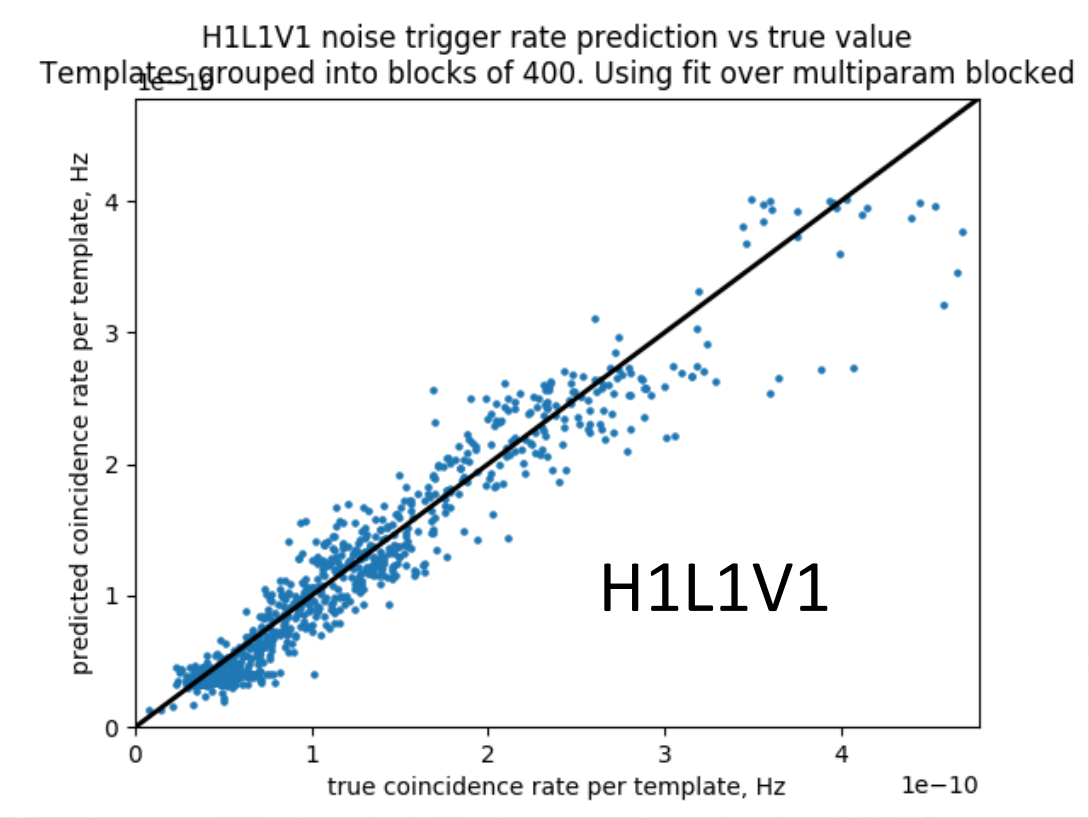
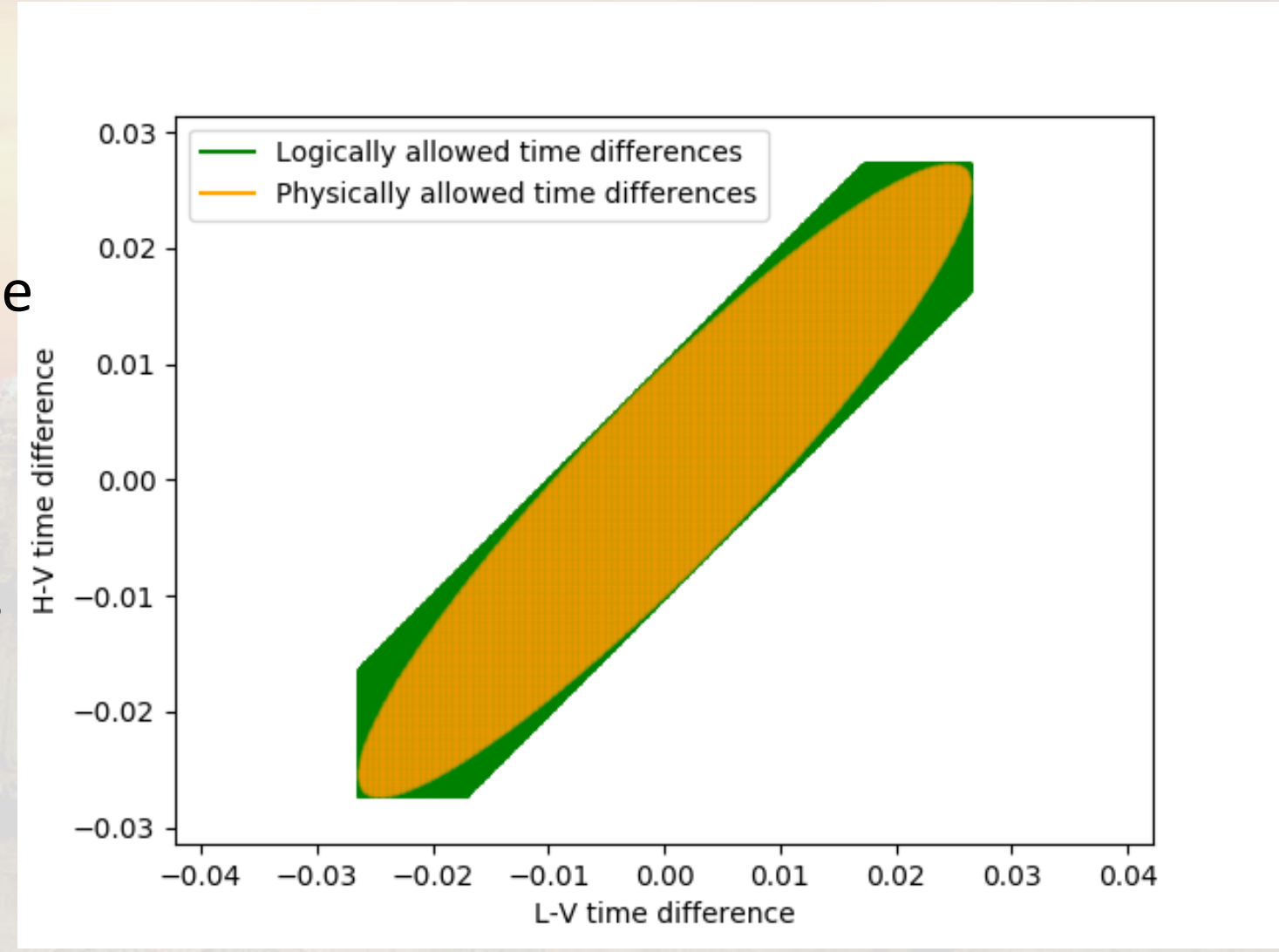


Allowed time differences

- Allowed time differences between two detectors are simple – if its bigger than the time of flight then it is removed

- Maximal time difference for more than one detector combination is not allowed for signals



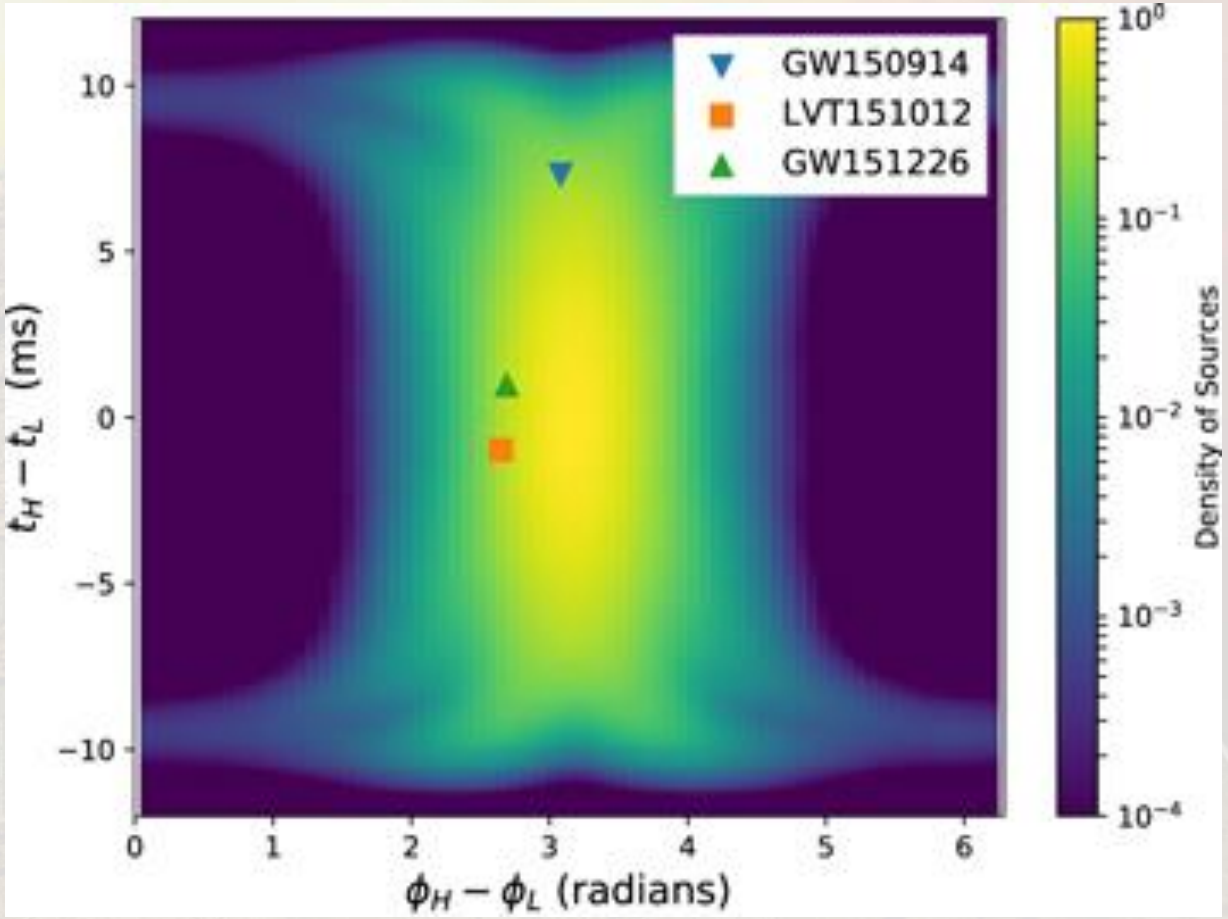
Physically allowed coincidences

- For 2 detectors:
  - $r_{12}(\vec{\theta}) = 2\Delta_{12} r_1(\vec{\theta}) r_2(\vec{\theta})$
- For 3 detectors:
  - $r_{123}(\vec{\theta}) = A_{123} \prod_{i=1,2,3} r_i(\vec{\theta})$
  - $A_{123} = \pi \Delta_{12} \Delta_{13} \sin\phi_{23}$
  - Where ϕ_{23} is the angle between the line-of-sight from detector 1 to detectors 2 and 3 respectively

Future Work

Signal Consistency

- With three detectors, we can add in extra time-phase difference comparisons and improve the constraints
- This work is ongoing



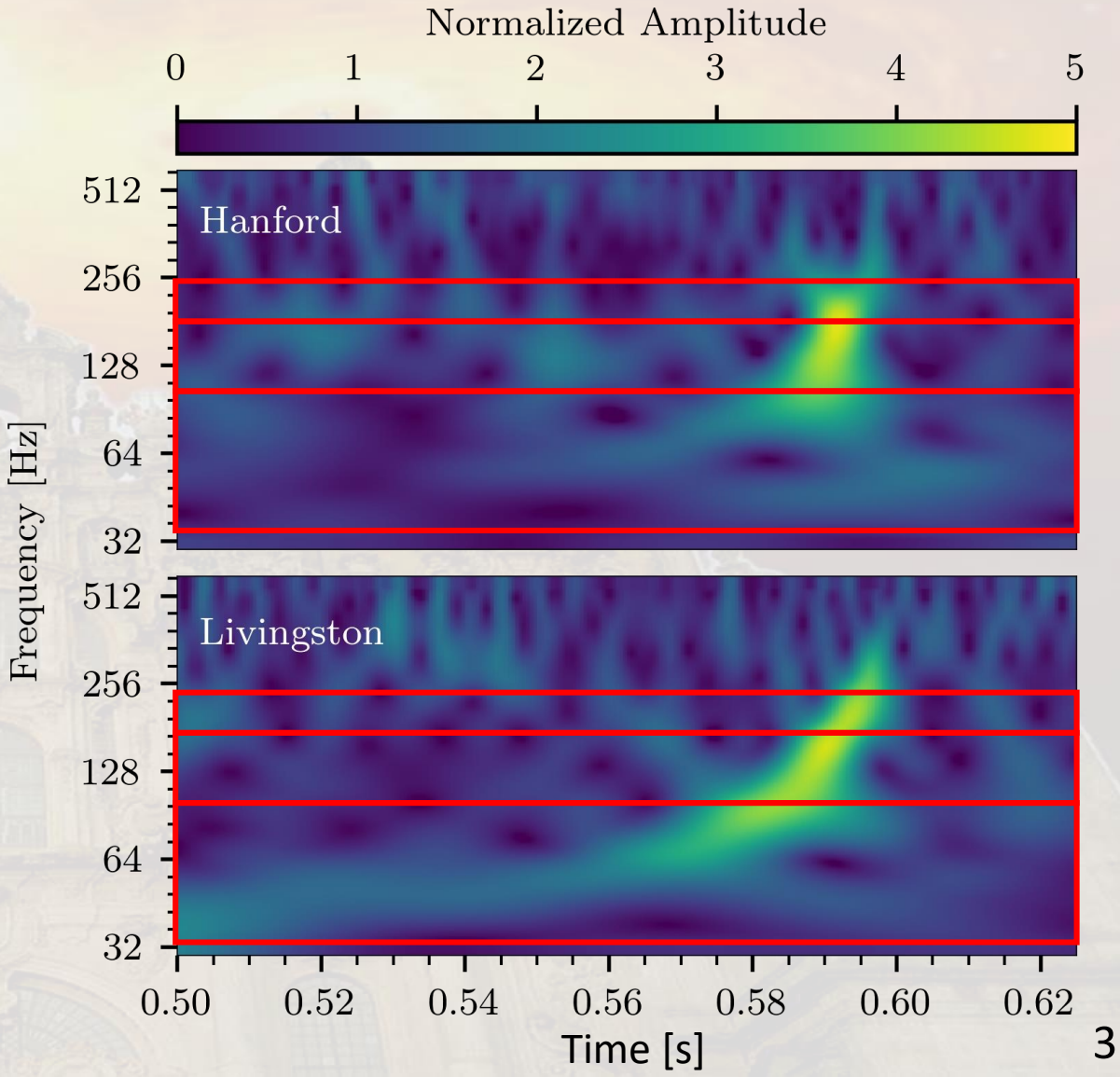
Nitz et al. arXiv:1705.01513v2

Questions?

Extra Slides

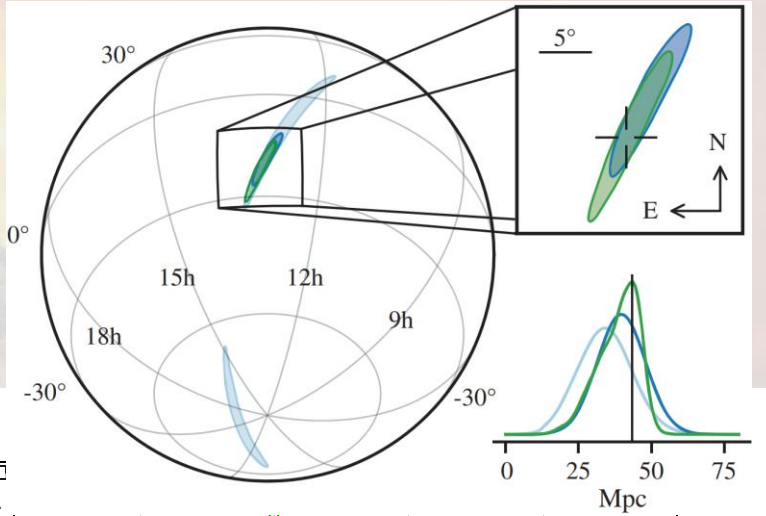
Signal consistency - χ^2 test

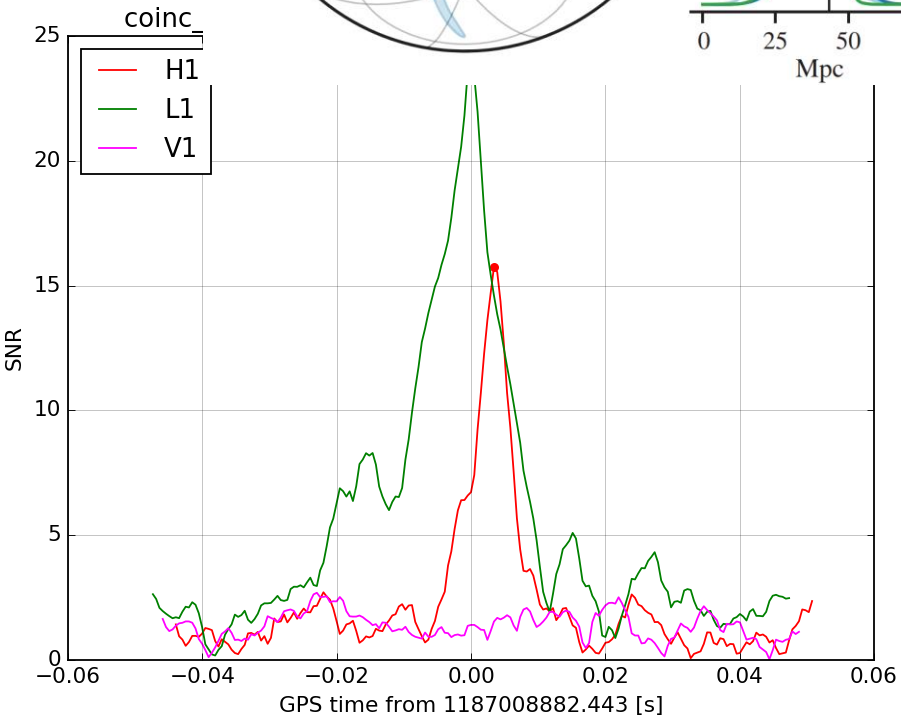
- A χ^2 test is used to reweight for signal consistency
- Chop up matched filter into a number of frequency bins
- This checks that the power in each bin is as expected for a signal



How does PyCBC low latency analysis work?

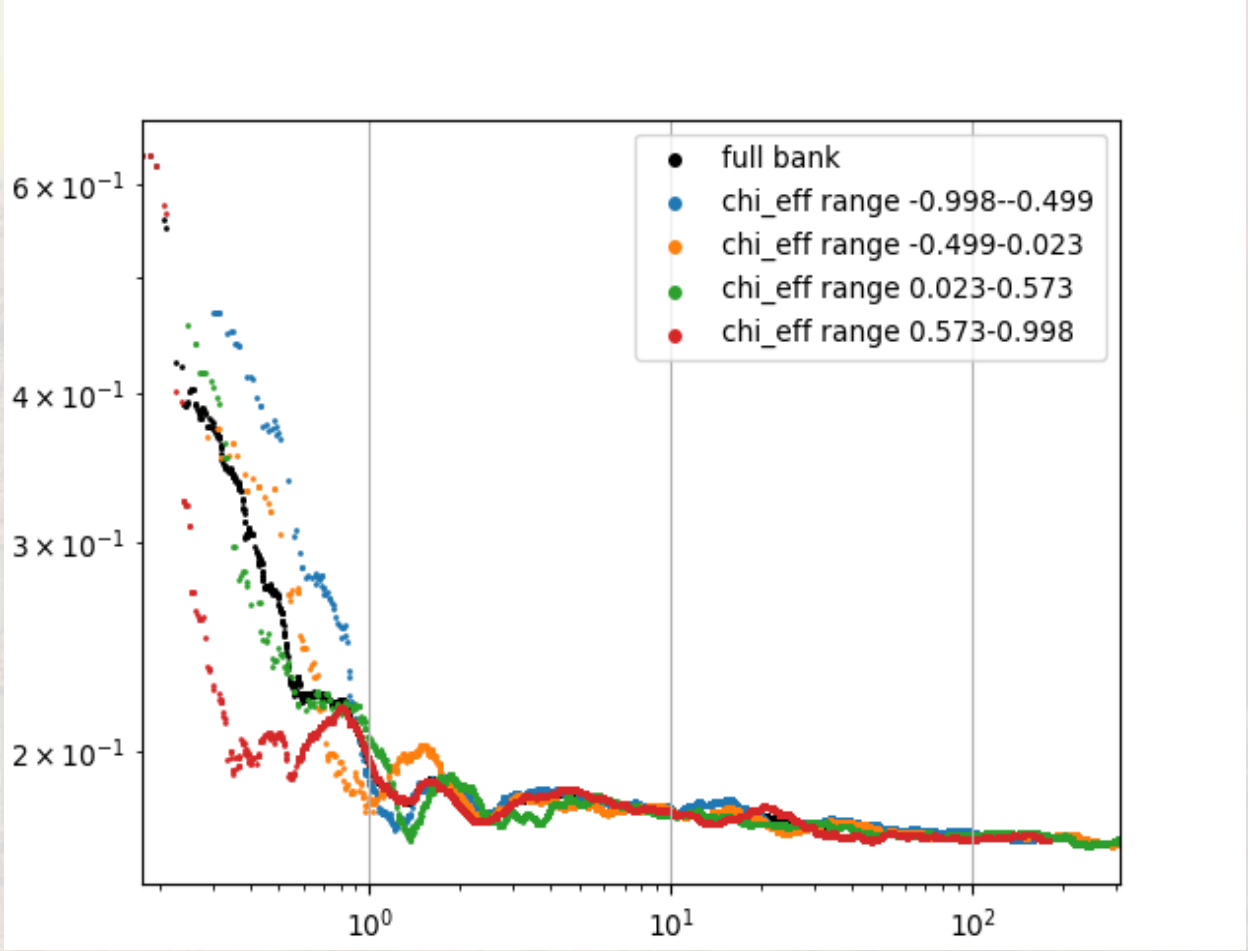
- Use 2 IFOs for detection of candidates
- Use third IFO to follow up and refine sky localisation
- Requires coincidence in the two you're using for the search





Trigger event distribution smoothing

- The fit parameters have been ‘smoothed’ over nearby templates in order to improve statistics
- This has been done by smoothing over template duration
- Changes made mean this is now done for multiple dimensional smoothing



Change to background fitting

- Using the exponential fits to the snr, we can construct a statistic which is $\frac{1}{expected\ rate}$
- However this exponential may not fit all values of SNR, and so work is ongoing to change to a ‘split exponential’ model