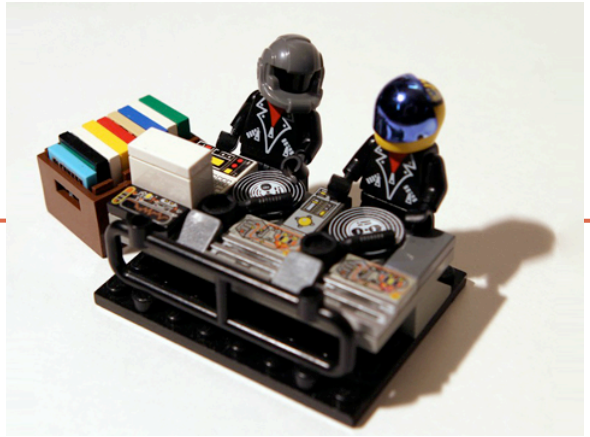
ALL-SKY SEARCHES FOR COMPACT BINARY MERGERS [CBC]

GWPAW 2017 – ANNECY

Thomas Dent

LIGO DOCUMENT G1700704-v3

SEARCHING FOR BINARY MERGERS IN GW DATA



HARDER, BETTER FASTER, STRONGER

T. Dent [AEI, Hannover] & the LSC-Virgo All-sky Compact Binary Search Team

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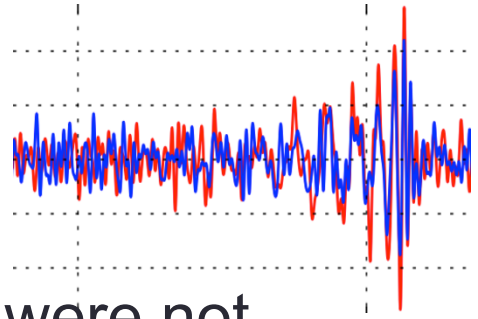
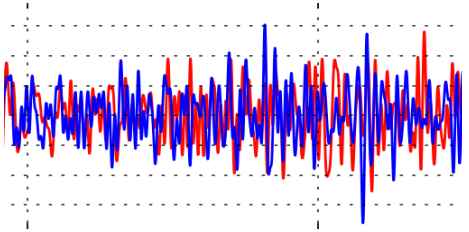
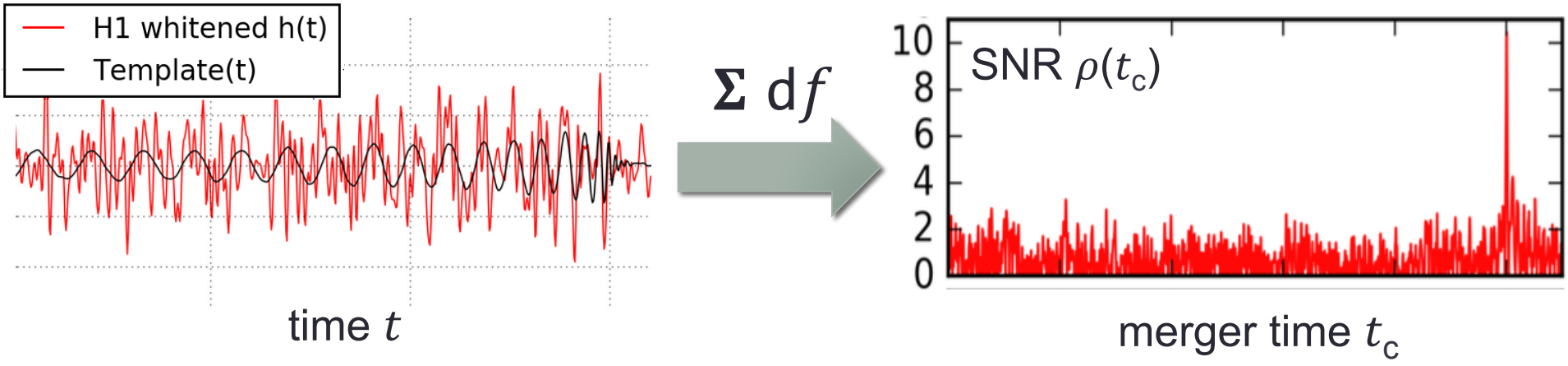
Modelled binary merger searches

- GW150914 easily visible in detector output



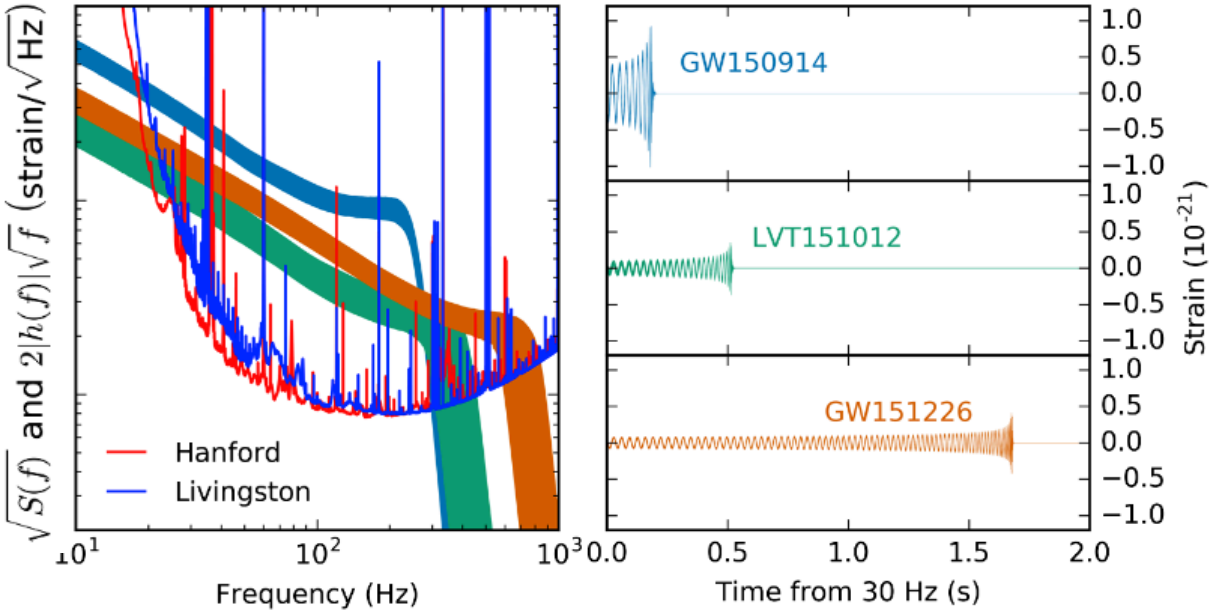
- But 2 out of 3 detections / candidates in O1 were not
- GW151226 detected *only* by matched filtering
  - sum up power coherently over wf cycles





O1 BBH events in 1 slide

- GW150914 :
  - ~10 cycles in band
  - *F*alse*A*larm*R*ate
    - < 6e-7/yr
- LVT151012 :
  - ~25 cycles in band
  - FAR ~ 0.37/yr
- GW151226 :
  - ~75 cycles in band
  - FAR < 6e-7/yr



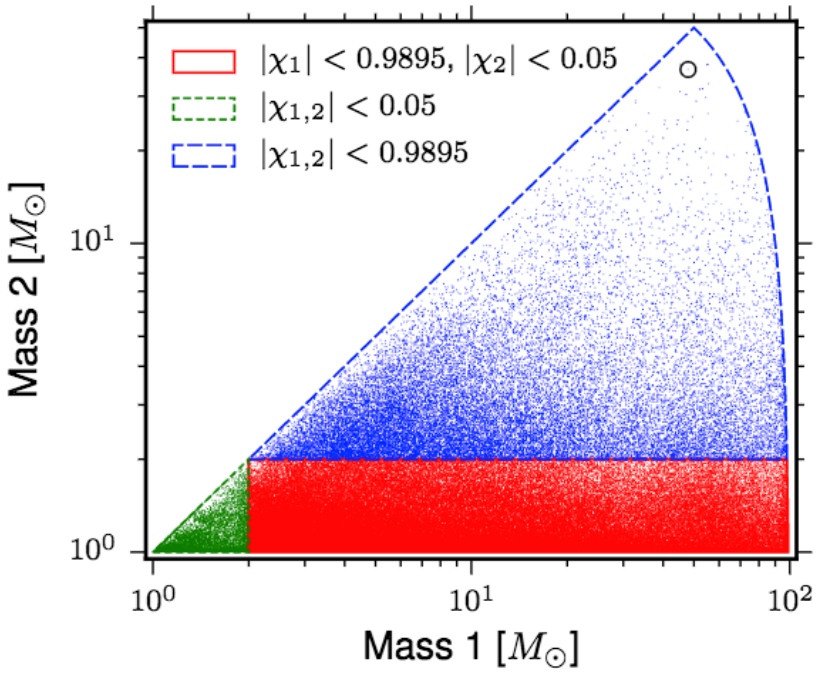
LVC, Phys. Rev. X 6, 041015 (2016)

How to detect more CBC signals

1) More sensitive detectors ✓
   - ✧ Factor 3+ broad-band reduction in noise from S6 to O1-O2
2) Improve analysis to see more signal
   - ✧ Waveform models that fit real (GR?) signals better
   - ✧ Cover parameter space densely enough with templates
3) Improve analysis to see less noise
   - ✧ Remove data containing loud / merger-like noise artefacts or prevent them occurring ... ⟹ D. Brown's talk
   - ✧ Analysis checks to remove / suppress noise artefacts
   - ✧ Improve separation of signal from noise
     ⟹ method for ranking events

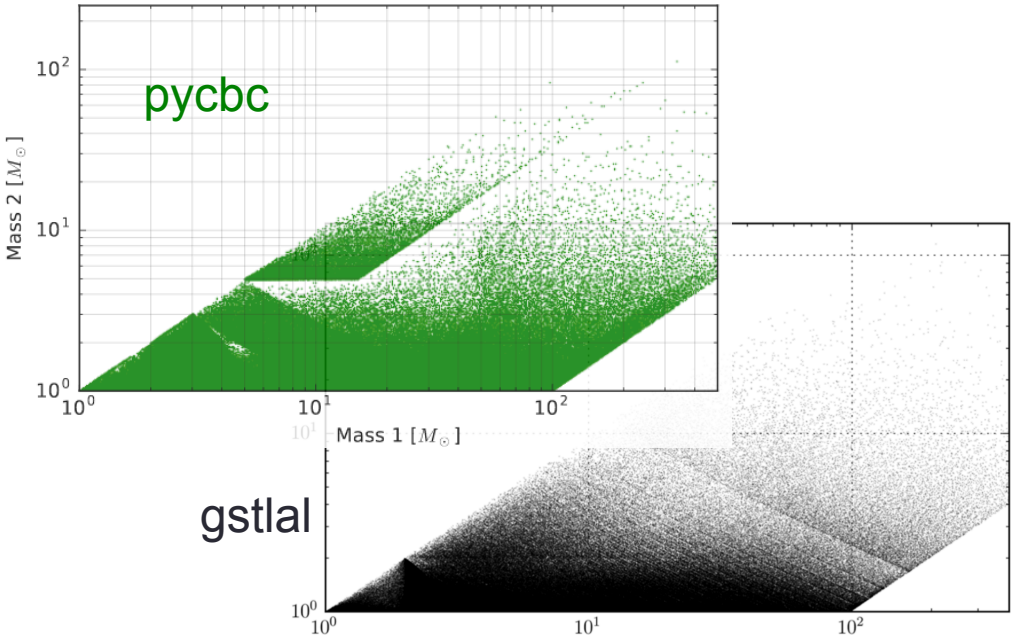
O1 to O2 : template banks

- O1 template waveforms
  SEOBNRv2ROM / 3.5PNTaylorF2
  (M < 4 $M_\odot$ / > 4 $M_\odot$)
- Orbit-aligned component spins



see also F. Salemi : IMBHB search

- O2 template waveforms
  SEOBNRv4ROM / 3.5PNTaylorF2

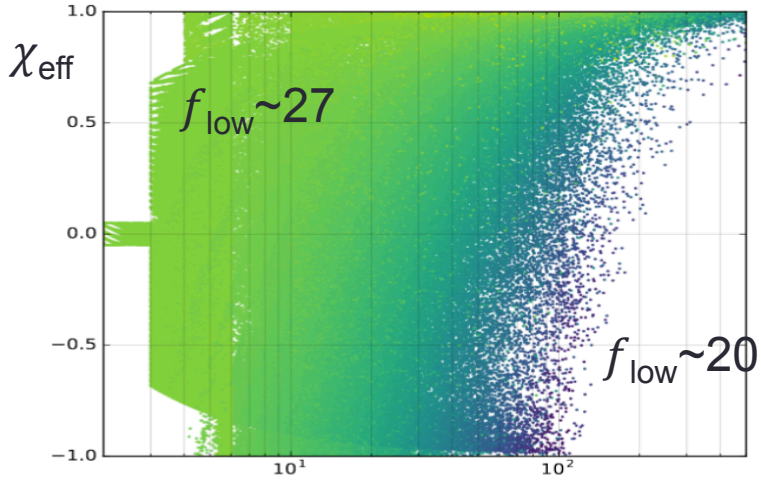


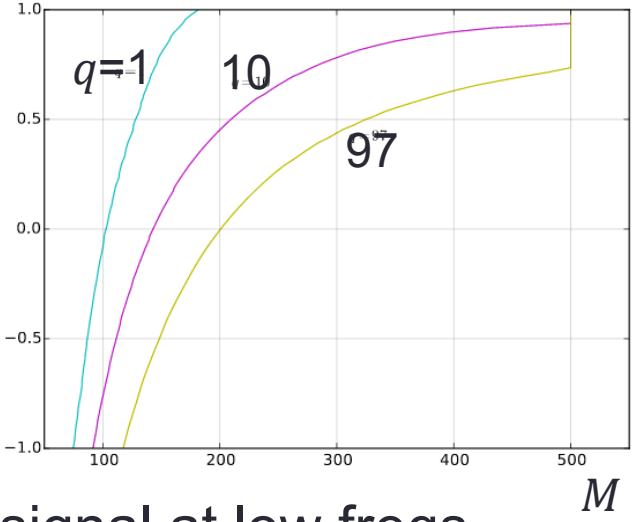
- Bank limits : M < {500, 400} $M_\odot$
  $|\chi|$ < 0.05 (m<2$M_\odot$)
  $|\chi|$ < {0.998, 0.999} (m<2$M_\odot$)

T. Dal Canton & I. Harry, arXiv:1705.01845

High masses and low frequencies

- Very high mass binaries look like short 'bursts' : where do templated search methods become ineffective?
- Upper boundary of O2 bank set by *template duration* (time from lower cutoff to merger)





- Choose $f_{\rm low}$ to strictly limit loss of signal at low freqs (gstlal: set $f_{\rm low}$=15Hz everywhere)

T. Dal Canton & I. Harry, arXiv:1705.01845

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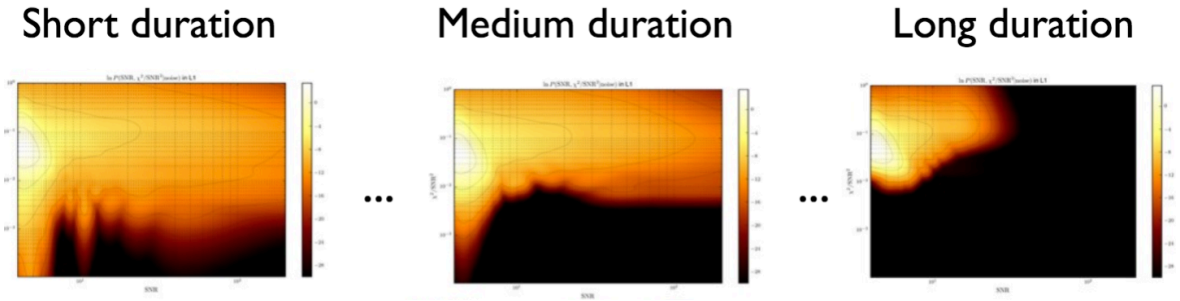
   - ✧ Waveform models that fit real (GR?) signals better

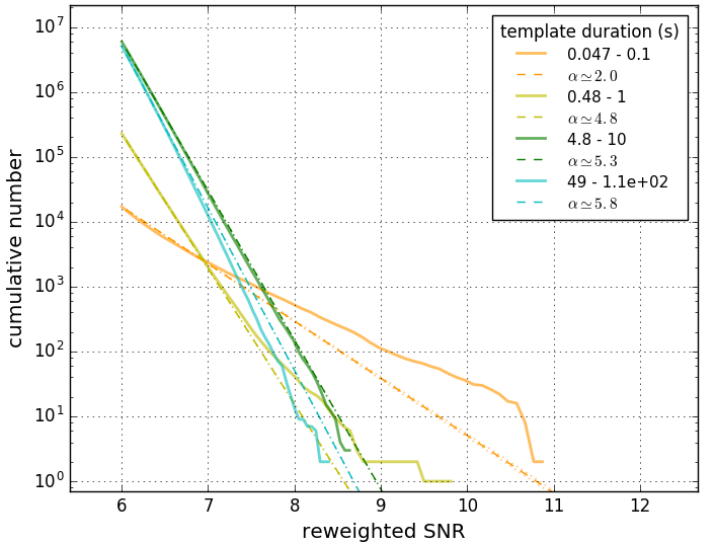
BUT – see Ian Harry's talk!

   - ✧ Cover parameter space densely enough with templates

3) Improve analysis to see less noise
   - ✧ Remove data containing loud or merger-like noise artefacts (or prevent them occurring ...) ⟹ D. Brown's talk
   - ✧ Analysis checks to remove/suppress noise artefacts
   - ✧ Improve separation of signal from noise ⟹ method to rank events

Variation of noise over template

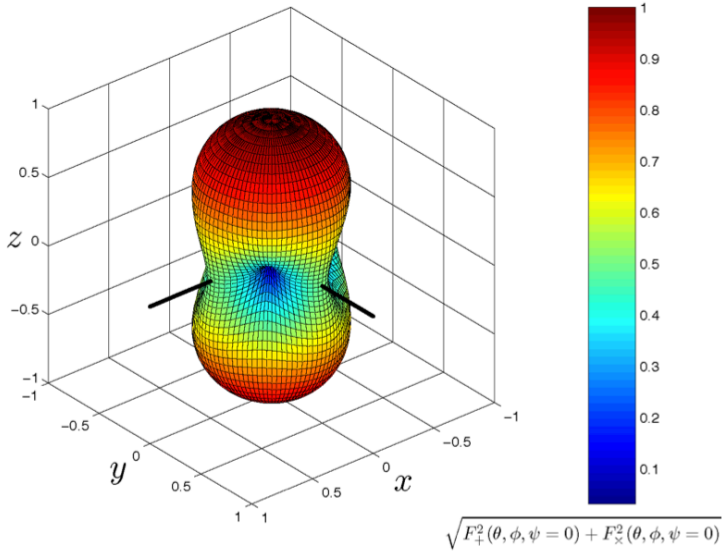


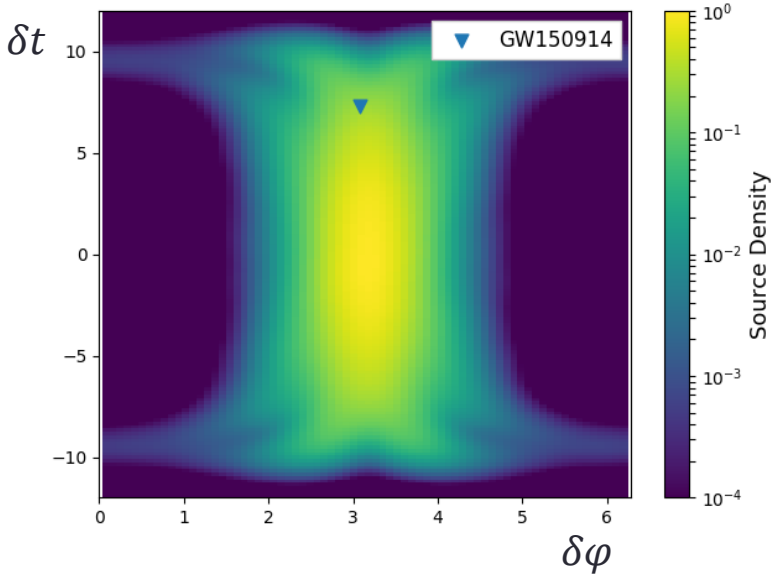


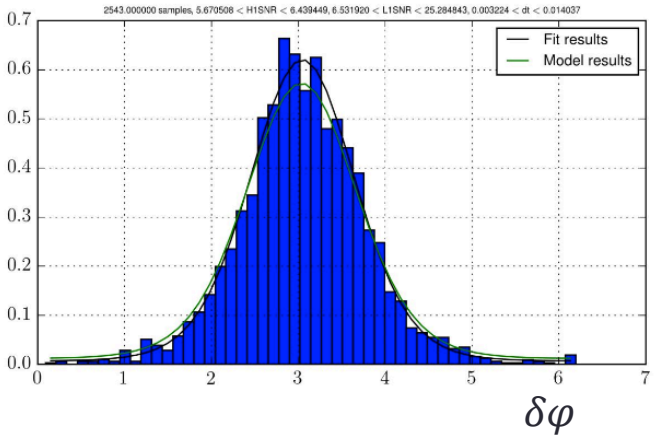
- Transient noise events (glitches) cause different event distributions in different length templates
- Group ‘similar’ templates to measure how noise varies over the bank
- Use info on noise distribution to down/up-rank events in clean/noisy templates
- No more need for “mass bins” in the search !

Geometric prior for signal events

- LIGO detectors have strongly directional sensitivity
- Distribution of detectable signals non-uniform in
  - δt (H-L time difference)
  - $\delta\varphi$ (phase difference)



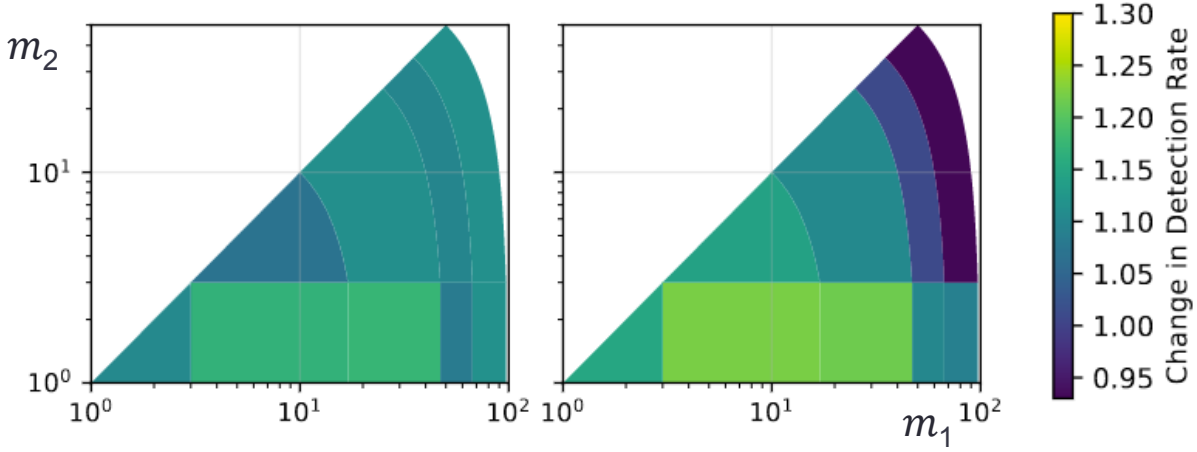




How to detect more CBC signals

- Improve analysis to see less noise
  - Remove data containing loud or merger-like noise artefacts (or prevent them occurring ...) ⟹ D. Brown's talk
  - Analysis checks to remove/suppress noise artefacts
- Improve separation of signal from noise ✓

  ⟹ fold signal / noise event distributions into ranking stat
- O2 ranking : 10-20% sensitivity gains over O1 statistic



A.H. Nitz, T. Dent et al., arXiv:1705.01513

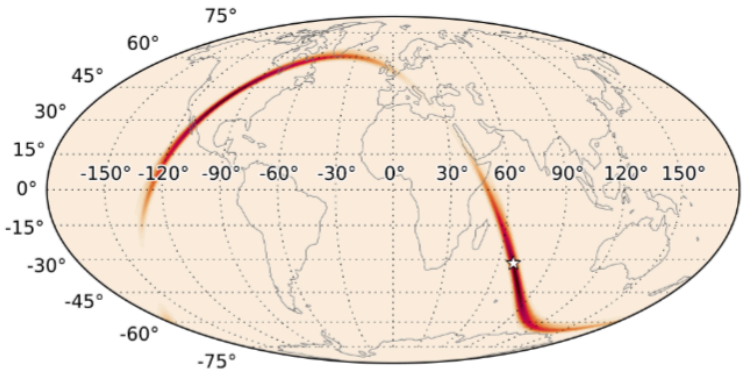
Online search : detection in <1min

- "Offline" pipelines : reproducible, optimized results within 1-2 weeks (publication within ~months ...)
- Online pipelines : matched filter & consistency checks within few×10s of receiving GW data, enable fast EM followup ⟹ *M. Branchesi's talk*
  - **M**ulti**B**and**T**emplate**A**nalysis – split filters into 2 frequency bands to reduce compute cost
    In O2 : include BBH templates, improved cuts to reduce artefacts, ..
  - **GstLAL** – Streaming pipeline, split time-domain filters into 'time slices', reduced SVD basis. Searched BNS/NSBH/BBH in O1.
    In O2 : extend analysis to allow single-detector events
  - **PyCBC Live** – matched filter via overlapping, optimized FFTs
    New in O2, output comparable to other pipelines
  - SPIIR – **I**nfinite**I**mpulse**R**esponse filter representation, coherent combination between detectors – currently under validation

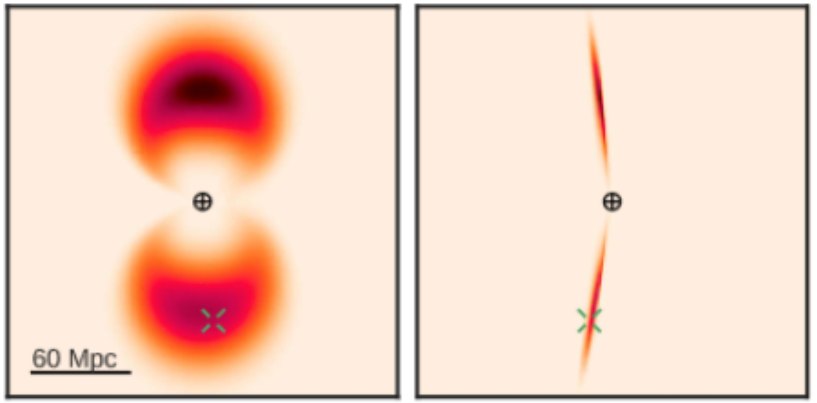
T. Adams et al. CQG 33, 175012 (2015) [MBTA]
C. Messick et al. Phys. Rev. D 95, 042001 (2017) [gstlal]

Source localization – now in 3D

- Online pipelines estimate arrival time, phase, signal amplitude at each detector
- With this info + template masses : constrain direction of GW arrival *and distance to source*
- BAYESTAR : estimate 3d location in <1 minute



Sky direction



Projections of 3d location

L. Singer et al. Astrophys. J 795, 105 (2014)
L. Singer et al. Ap. J L, 829, L15 (2016)

. . . WATCH THIS SPACE !

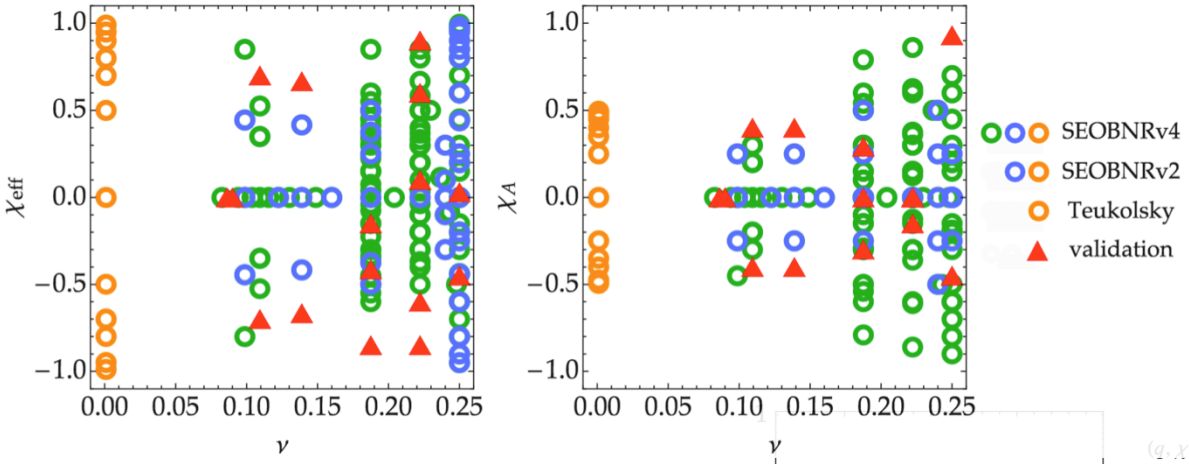
- L-V binary searches are **more than ready** to make more GW detection(s)

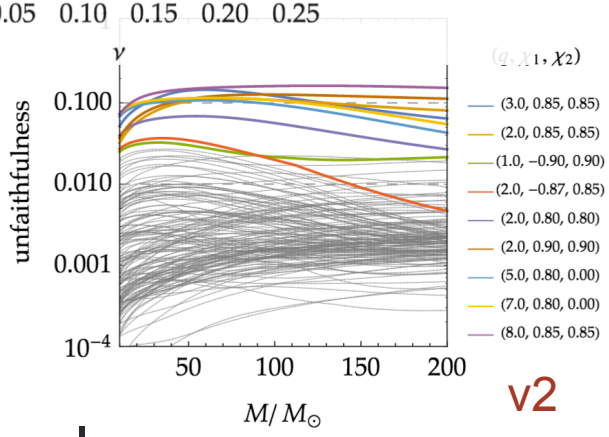
Template bank sizes

- O1 bank [all offline analysis] : ~250,000 templates
- O2 pycbc ‘hyperbank’ : ~400,000 templates
  [denser coverage for BBH with q<3, 20-27Hz varying cutoff, lose at most <0.5% of SNR]
- O2 gstlal ‘hyperbank’ : ~660,000 templates [15Hz cutoff]

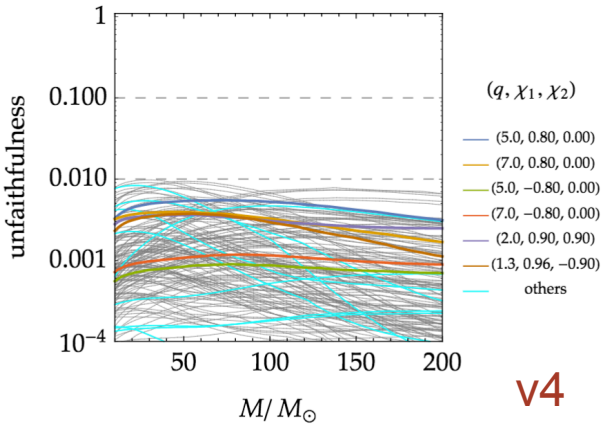
SEOBNRv4

- More accurate model using wider set of aligned-spin NR waveforms for calibration





v2



v4

- Model is 2,2-mode only

Bohé et al., Phys. Rev. D 95, 044028 (2017)

Measuring event significance

- Significance (false alarm probability / rate) measured by comparing candidate ranking statistic value to expected distribution and number / rate of noise events
- O1 : false alarm *probability*, p(at least 1 louder noise event over total experiment time) [~50 days]
  - ‘p-value’ , can be converted to ‘sigma’
  - noise distribution estimated on long data periods (16d+)
- O2 : false alarm *rate*, expected number of louder noise events per experiment time
  - more appropriate for ongoing / continuous experiment
  - can compare to rate of signal events for given detector range
  - noise distribution estimated on 5-6 day data chunks/

Estimate of online latency

- Median latency of active pipelines in O2:
  ~53s (MBTA), ~22s (GstLAL), ~28s (PyCBC Live)