Low-latency EM-Bright source property inference from Gravitational-wave data

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[2]LIGO Scientific Collaboration

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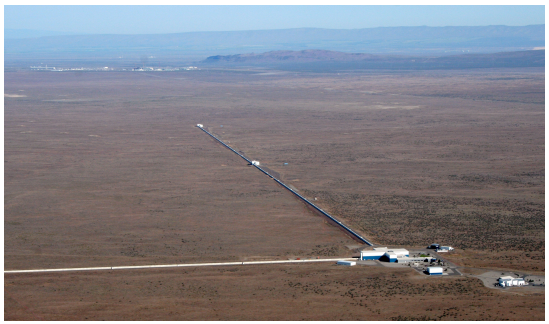
A3D3 Summit
Dallas, TX

LIGO/Virgo has completed 3 observing runs



Detections per run

- O1: GW discovery (GW150914) + 2 more Binary black hole (BBH) mergers
- O2: 10 BBH + 1 Binary Neutron Star (BNS) mergers
- O3: 56 public alerts; cumulative 90 total GWTC-3 [1]
- O4: $\sim$ 1 detection per day

[1] https://www.gw-openscience.org/GWTC-3/

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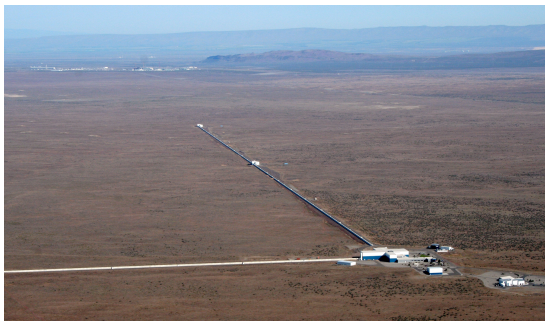

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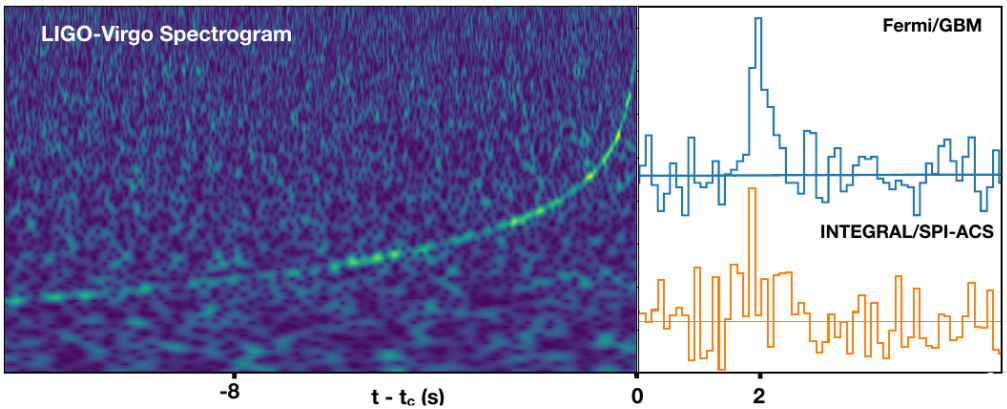
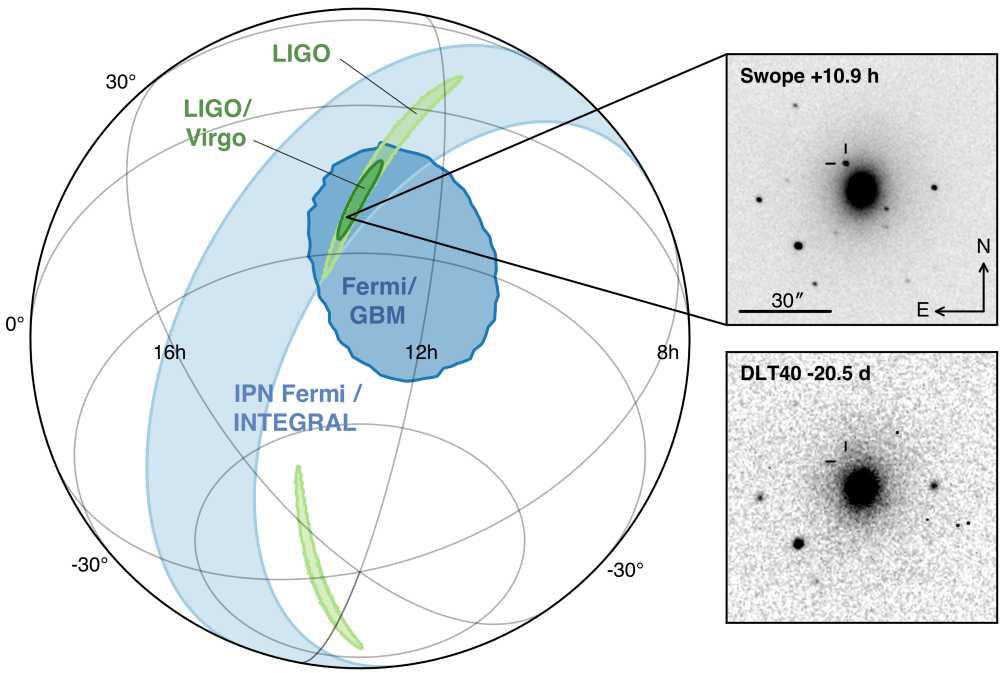
GW discoveries are now routine.

[1] https://www.gw-openscience.org/GWTC-3/

Sole EMGW success: GW170817





GW170817

(Abbott et al., 2017)

GRB 170817A

(Goldstein et al., 2017; Abbott et al., 2017)

SSS17a

EM170817

⋮

AT 2017gfo

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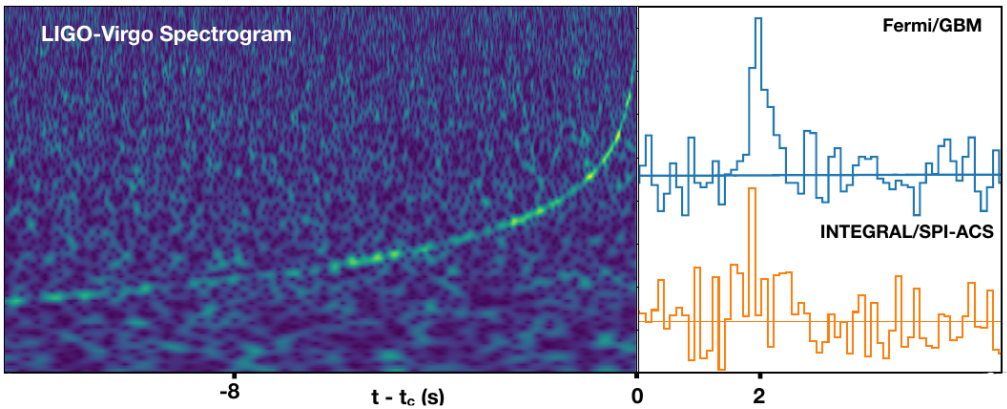
Sole EMGW success: GW170817



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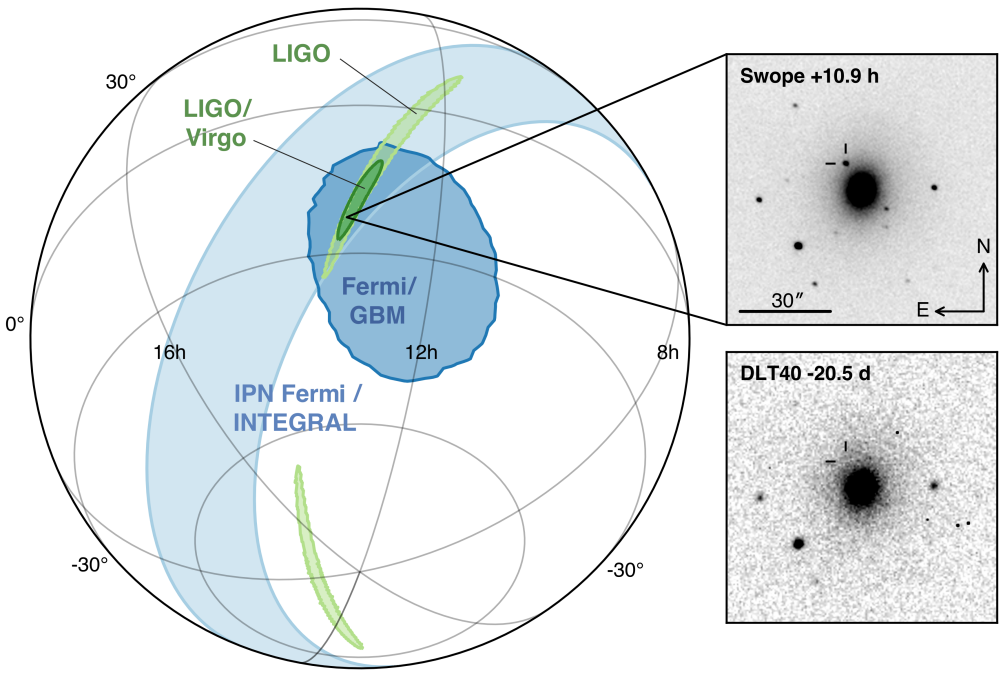

SSS17a

EM170817

⋮

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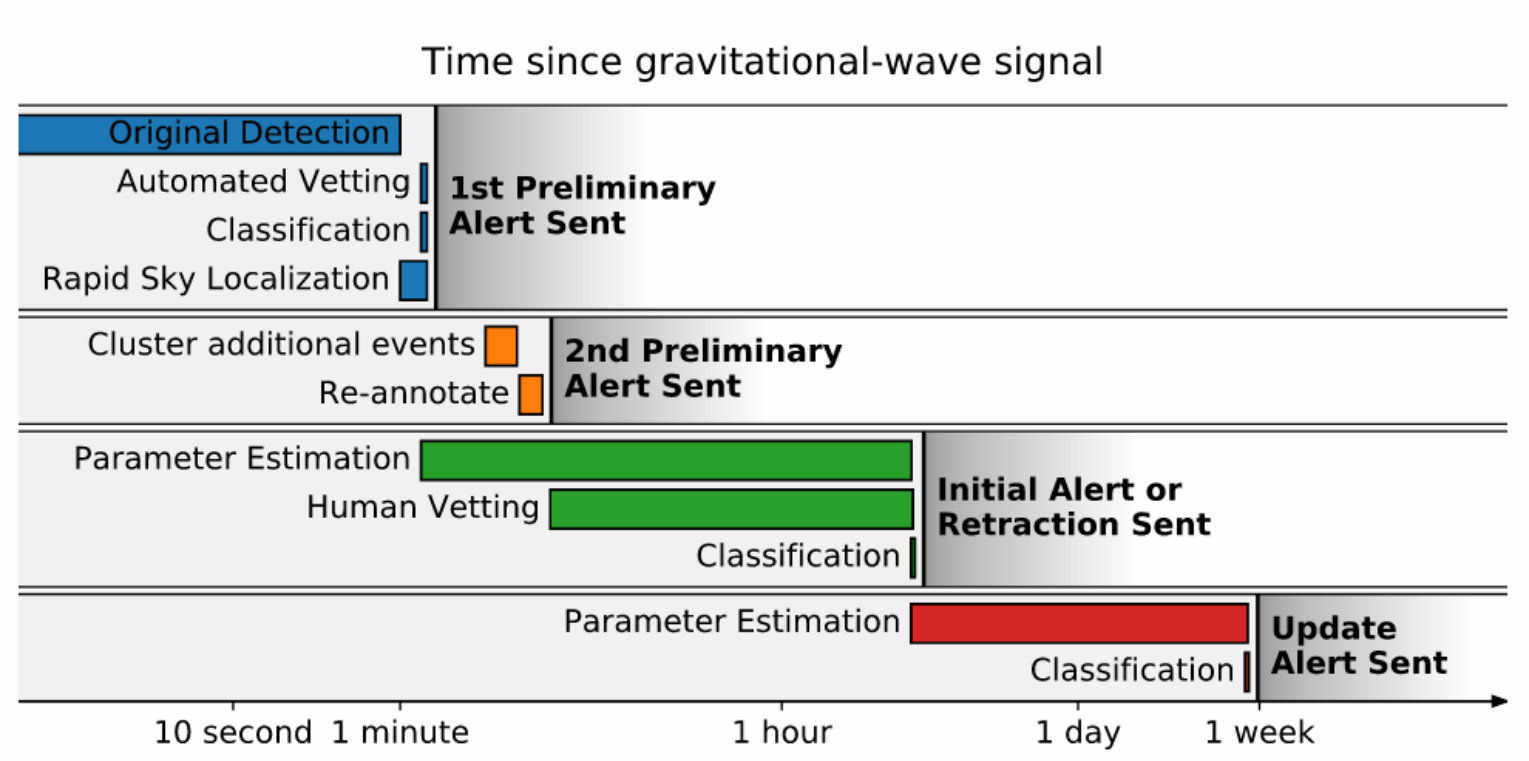
Yet to arrive at routine EMGW era.

Alert timeline

What happens after a GW discovery?

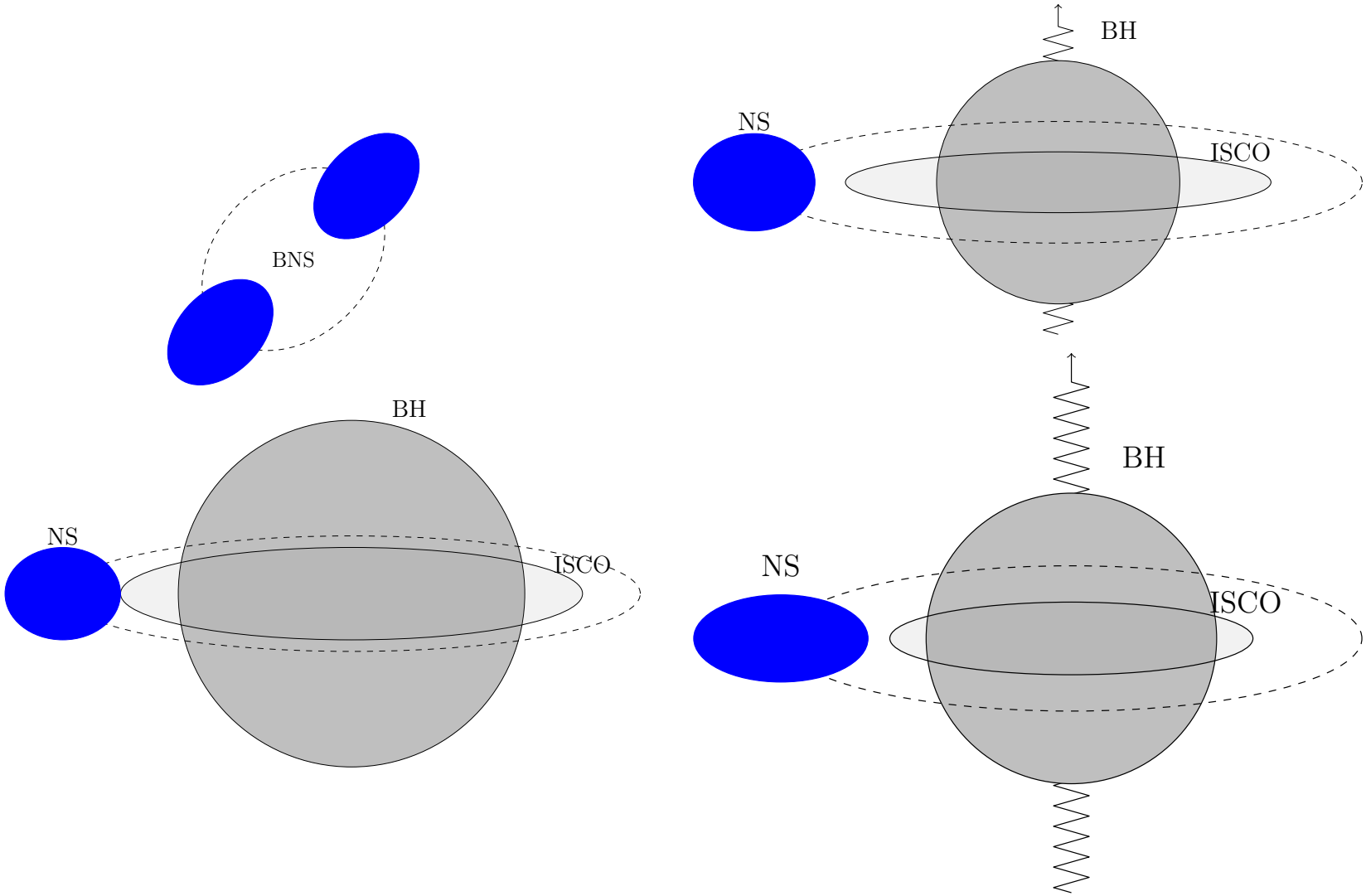


- 80 public alerts sent; 56 non-retracted
- Latency $\sim$ 5 mins in O3; in O4 $\sim$ 30 sec.

https://emfollow.docs.ligo.org/userguide/

Which Mergers To Follow-up?

Those having at least a neutron star



Which Mergers To Follow-up?

Data Products

Source Properties [2]

- `HasNS`:
  Is $m_2 \leq M_{\rm NS}^{\rm max}$?
- `HasRemnant`:
  Is there any remnant matter ?

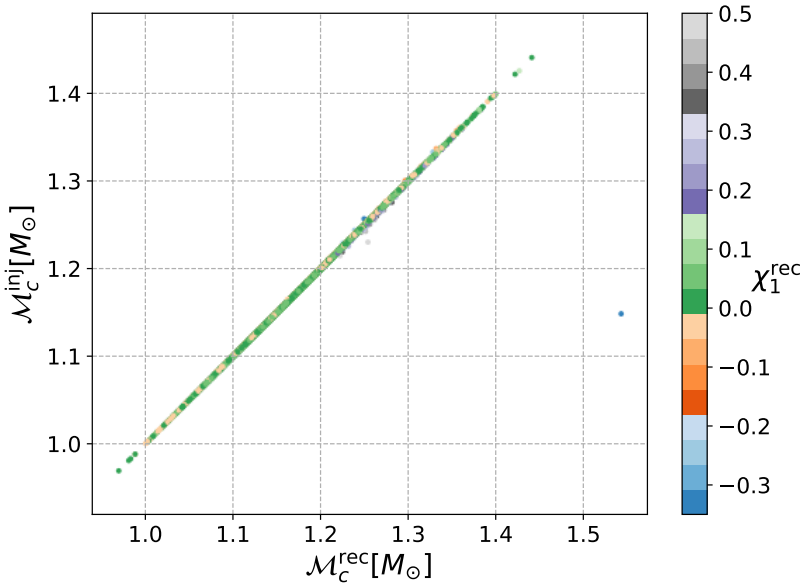
Needed in realtime

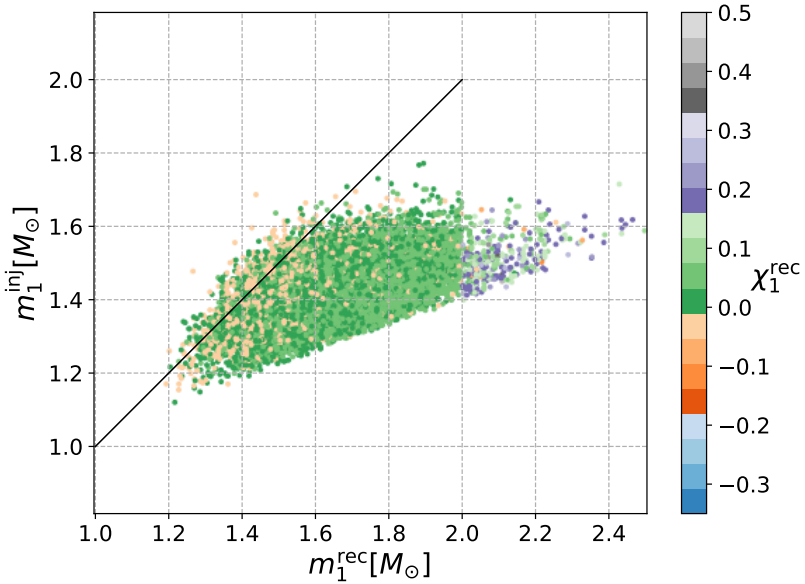
- Kilonova fades $\sim$ 1 day.
- GW bayesian parameter estimation $\sim$ hours – days.

[2] `https://emfollow.docs.ligo.org/userguide/analysis/inference.html#properties`

Inference From Online Searches

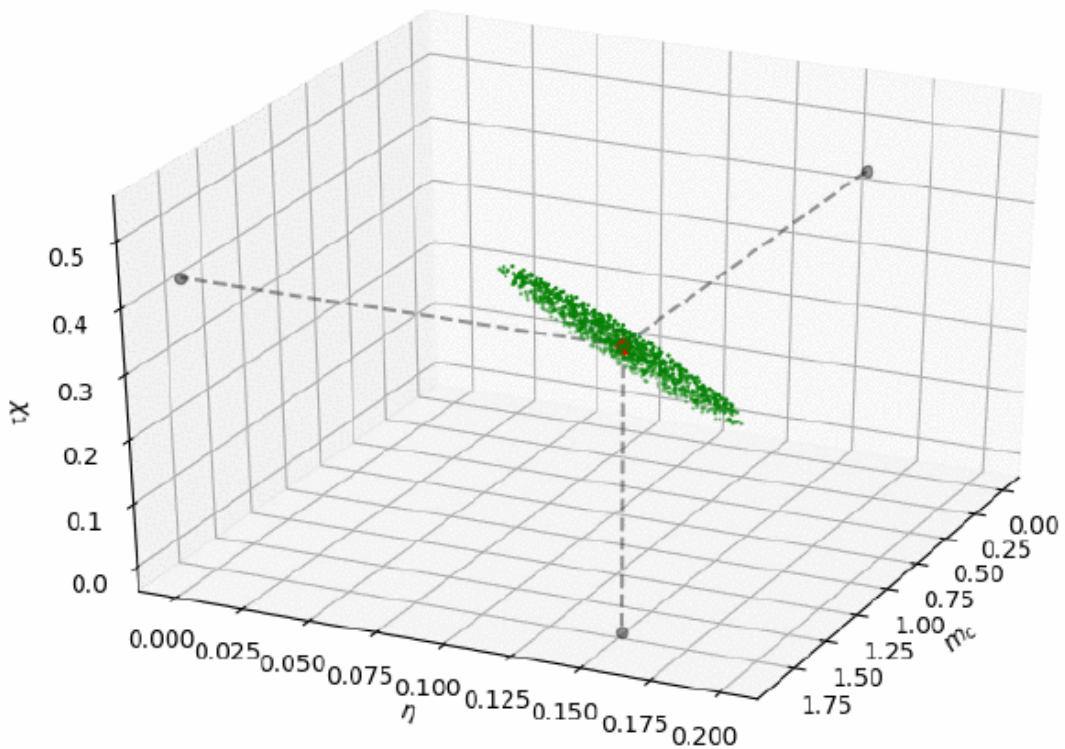
- GW template based analyses.
- Detect GW candidates $\sim$ sub-minute latency.
- Maximize detection efficiency at fixed false alarm.
- *Accurate parameter recovery* is left to bayesian parameter inference





Mitigating Detection Uncertainty

Fisher ambiguity ellipsoid used previously



$$m_c = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}}$$

$$\eta = \frac{m_1 m_2}{(m_1 + m_2)^2}$$

$$\chi_1 = \frac{a_1}{m_1}$$

Statistical uncertainties ✓

Systematic uncertainties ✗

[2] Fig. credits: Shaon Ghosh.

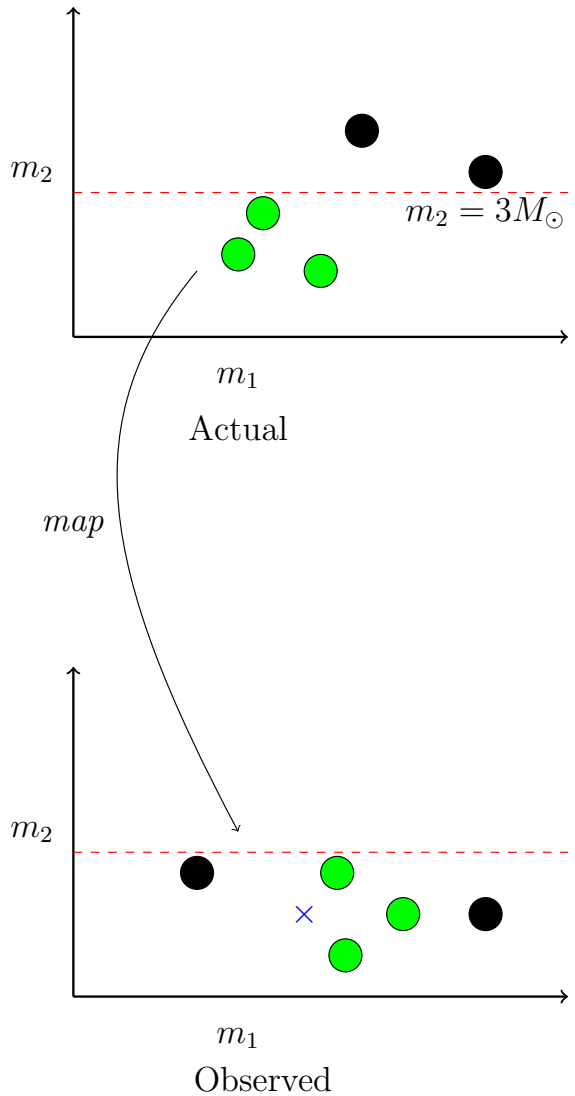
Rethink as Binary classification

Train using fake signals

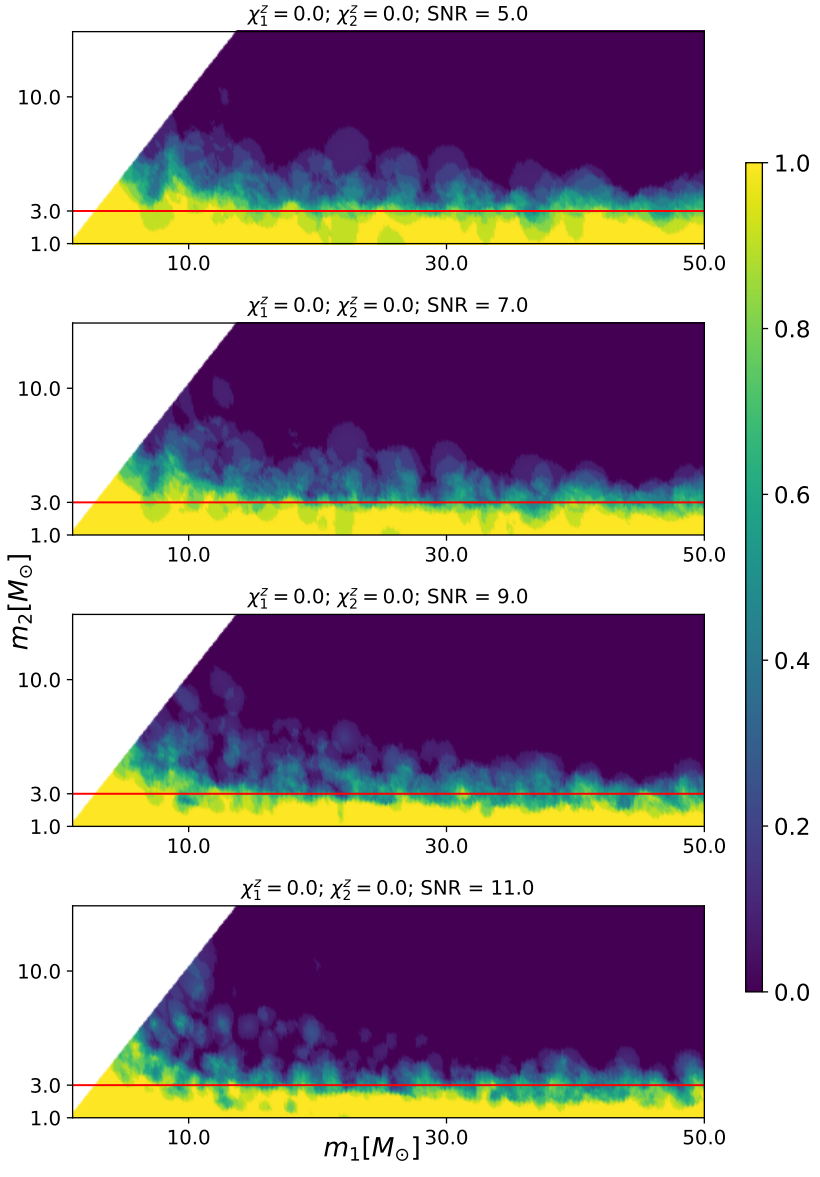
- Binary label from fake signals.
- Training on recovered parameters.

$$\beta = \{\underbrace{m_1, m_2}_{\text{masses}}, \overbrace{\chi_1^z, \chi_2^z}^{\text{spins}}, \underbrace{\rho}_{\text{SNR}}\}.$$

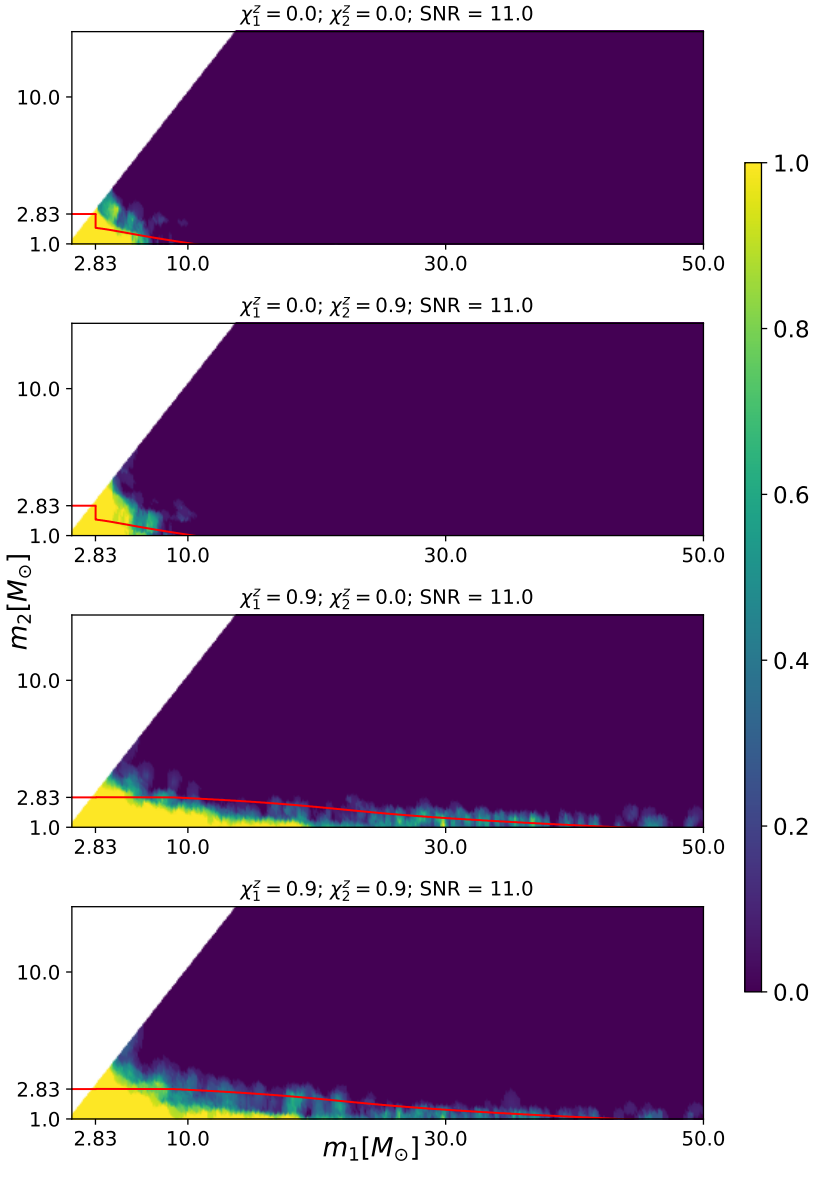
- New trigger $\times$? Predict $p(\bullet / \bullet)$.
- Use Nearest Neighbor algorithm.



Predictions



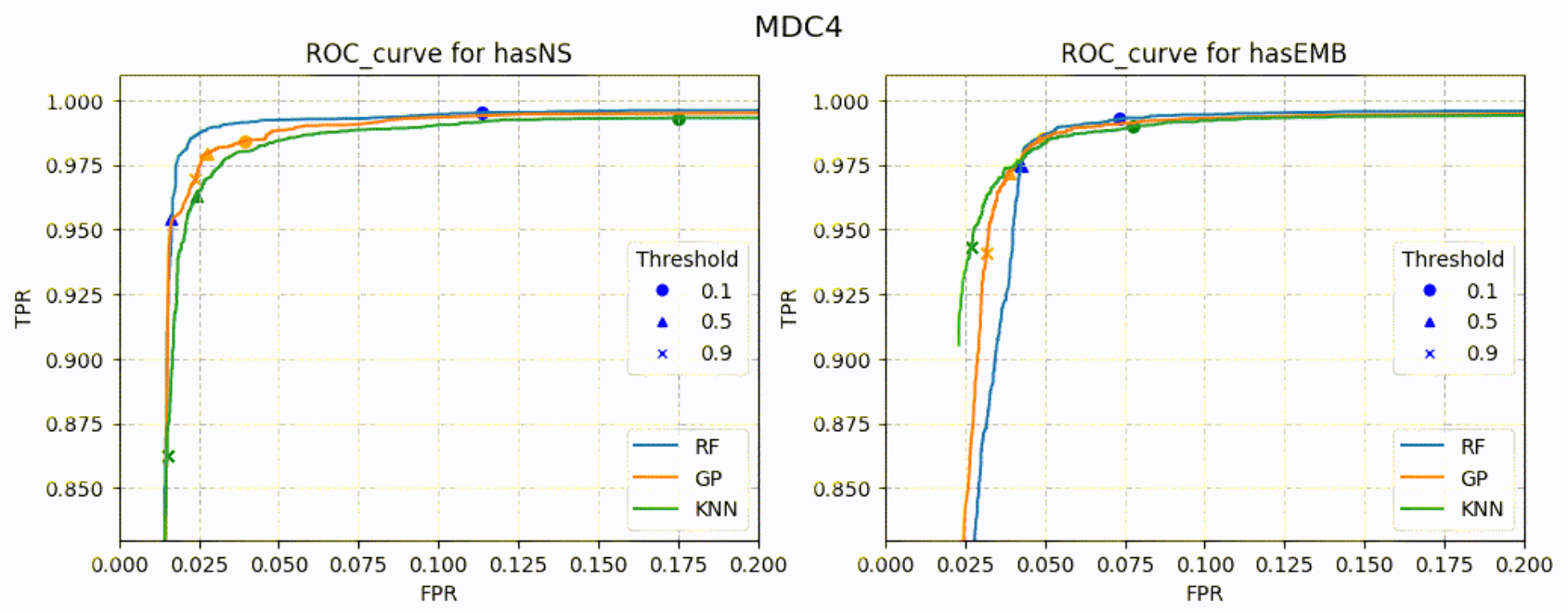
$p(\texttt{HasNS})$



$p(\texttt{HasRemnant})$

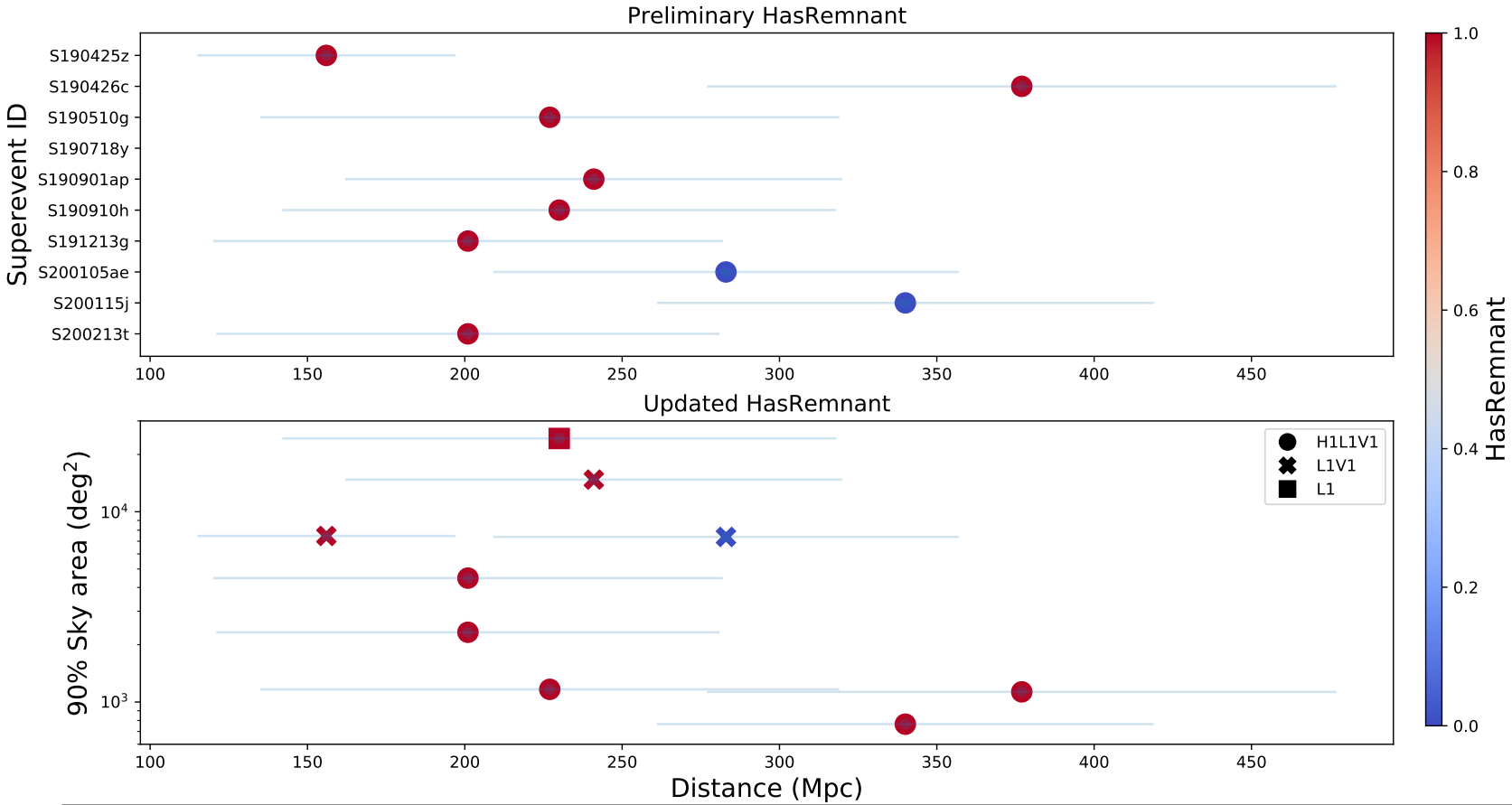
Predictions

Performance on recent MDC



Conclusion

- Decision trees, random forest, nearest-neighbor classification work well for this problem.
- In this case captures systematics across GW modeled search pipelines.
- We marginalize over the NS equation of state uncertaintly
- Easy to train several classifiers per equation of state, reweight results based on previous work on model selection.



Superevent	HasNS	HasRemnant	HasNS*	HasRemnant*
S190425z	1.00	1.00	1.00	1.00
S200105ae	1.00	0.12	0.98	0.00
S200115j	1.00	0.09	1.00	1.00

Starred values from bayesian parameter est. reported in Update Notices.

Extra Slides

Superevent	HasNS	HasRemnant	HasNS*	HasRemnant*
S200213t	1.00	1.00	1.00	1.00
S200115j	1.00	0.09	1.00	1.00
S200105ae	1.00	0.12	0.98	0.00
S191213g	1.00	1.00	1.00	1.00
S190910h	1.00	1.00	1.00	1.00
S190901ap	1.00	1.00	1.00	1.00
S190718y	1.00	1.00	–	–
S190510g	1.00	1.00	1.00	1.00
S190426c	1.00	1.00	1.00	1.00
S190425z [3]	1.00	1.00	1.00	1.00

Starred values reported in Update Notices

[3] Confirmed BNS event (Abbott et al., 2020)

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