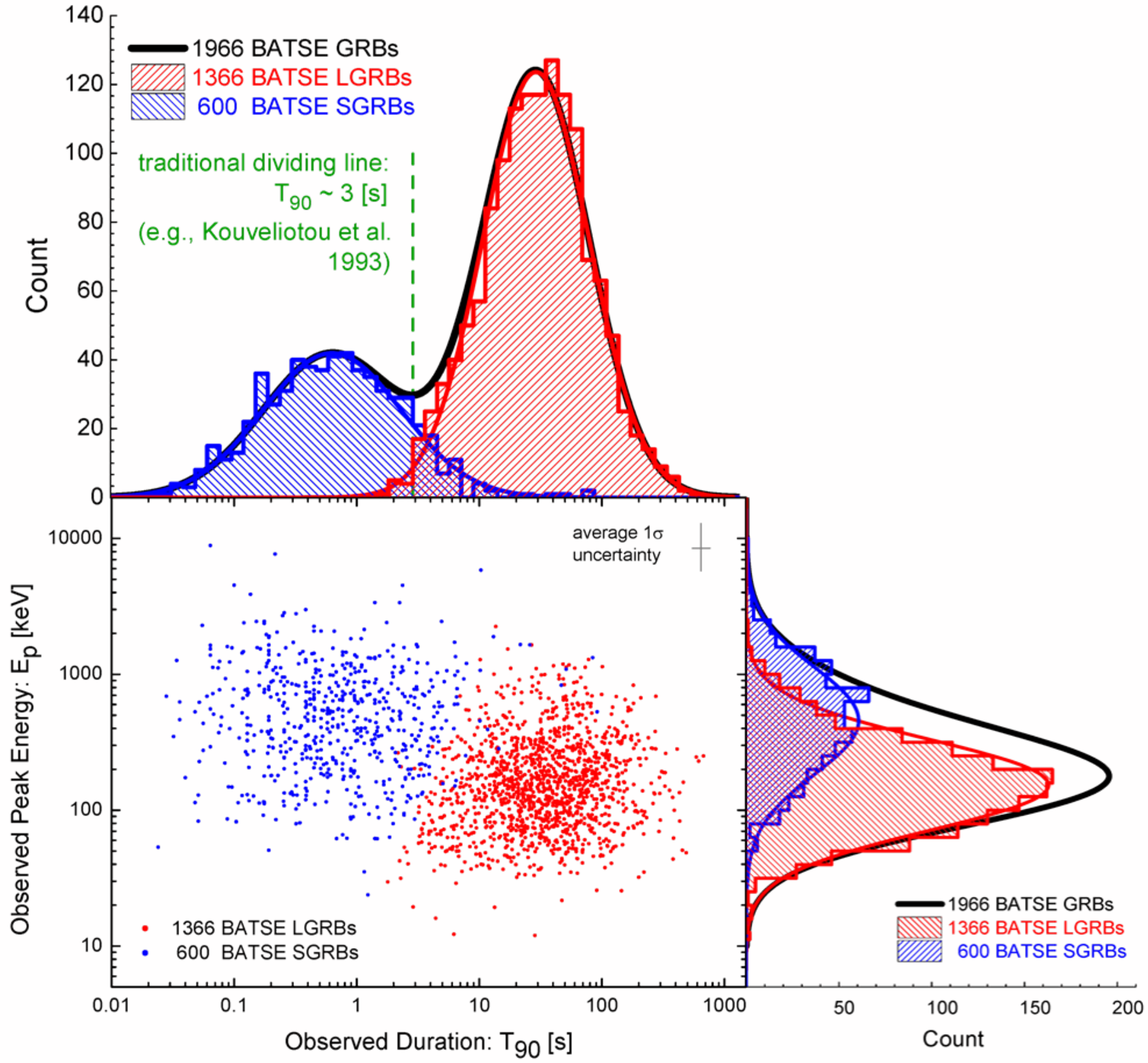
Search for Gravitational Waves Associated with Gamma-Ray Bursts During the First Advanced LIGO Observing Run

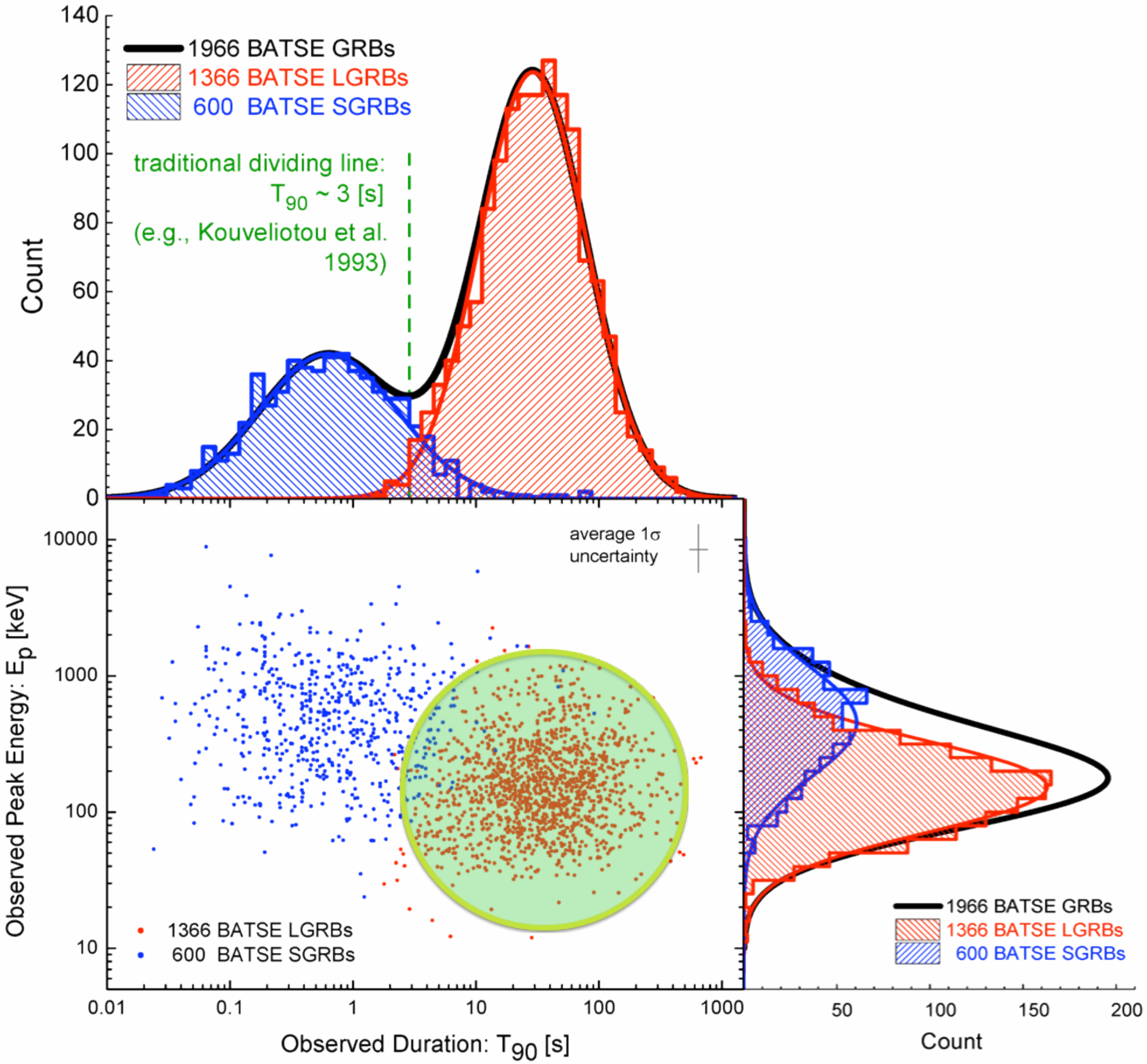
Francesco Pannarale
for the LIGO Scientific Collaboration and Virgo Collaboration
Amaldi 12 Pasadena – July 11, 2017

Gamma-Ray Bursts (GRBs)

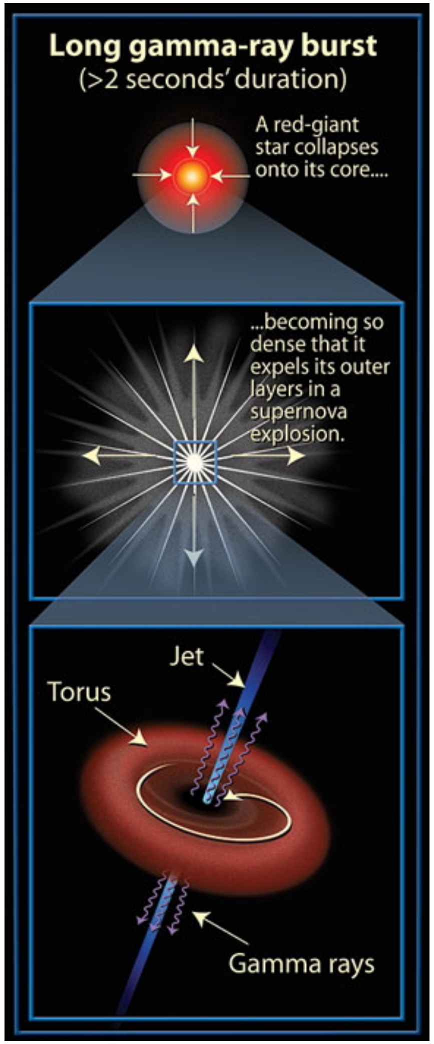


[Shahmoradi & Nemiroff, MNRAS 451, 126 (2015)]

Gamma-Ray Bursts (GRBs)

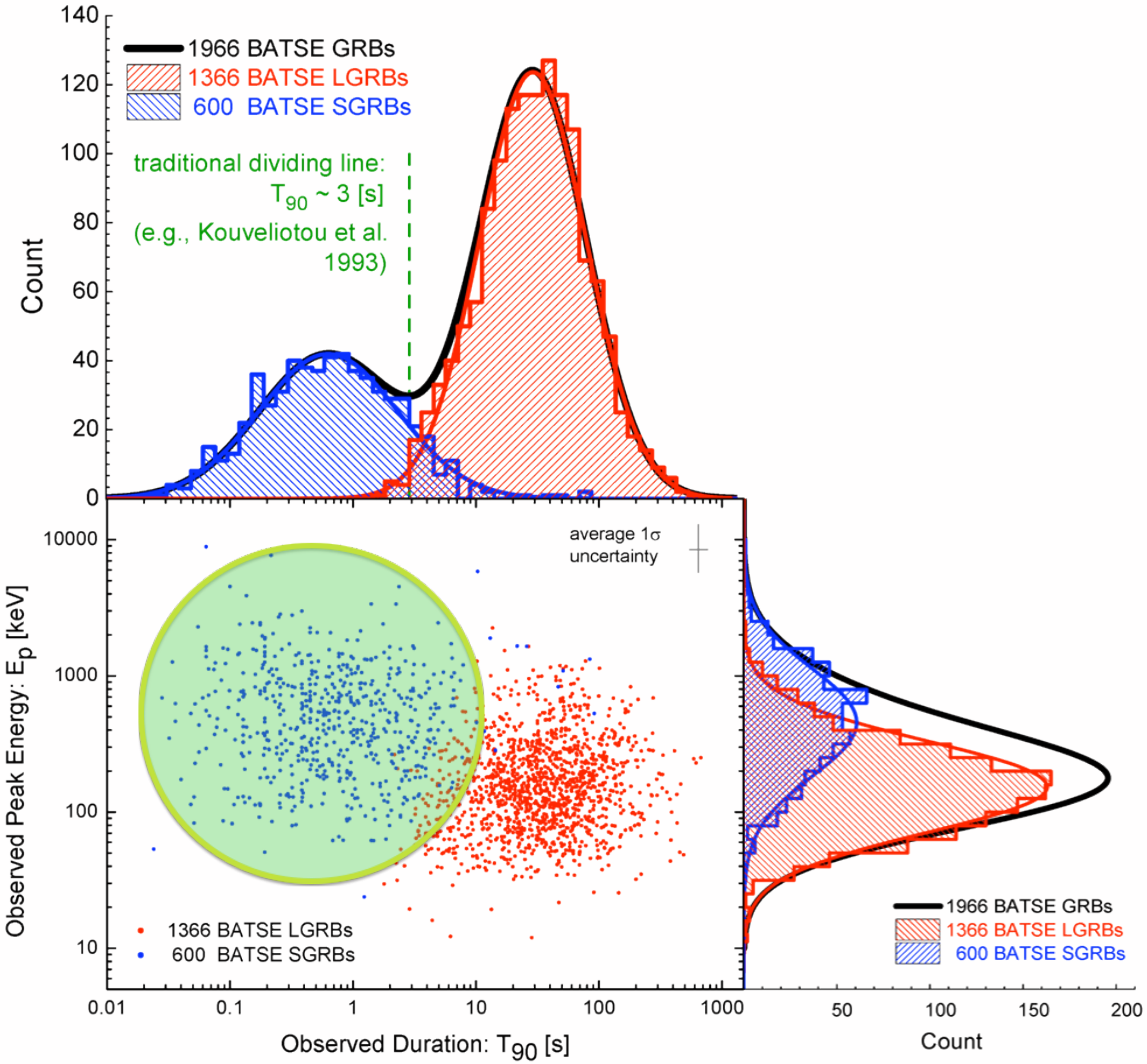


[Shahmoradi & Nemiroff, MNRAS 451, 126 (2015)]

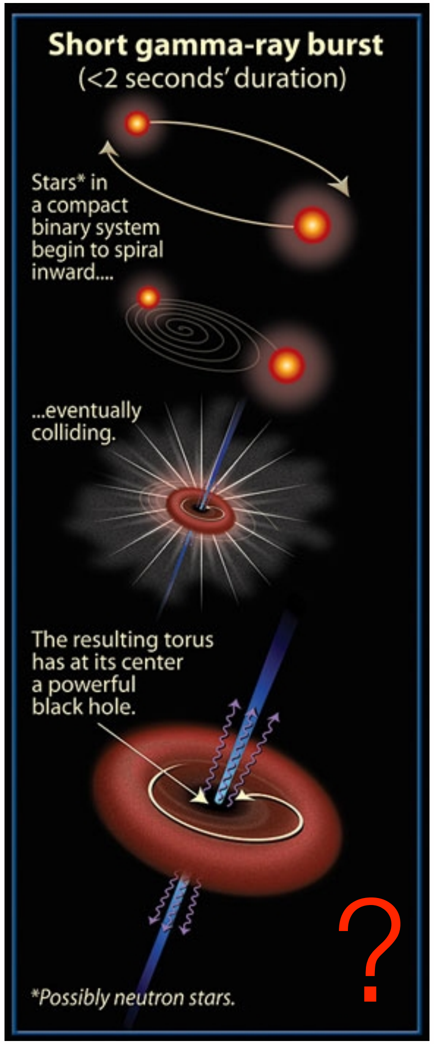


[Encyclopedia of Science]

Gamma-Ray Bursts (GRBs)

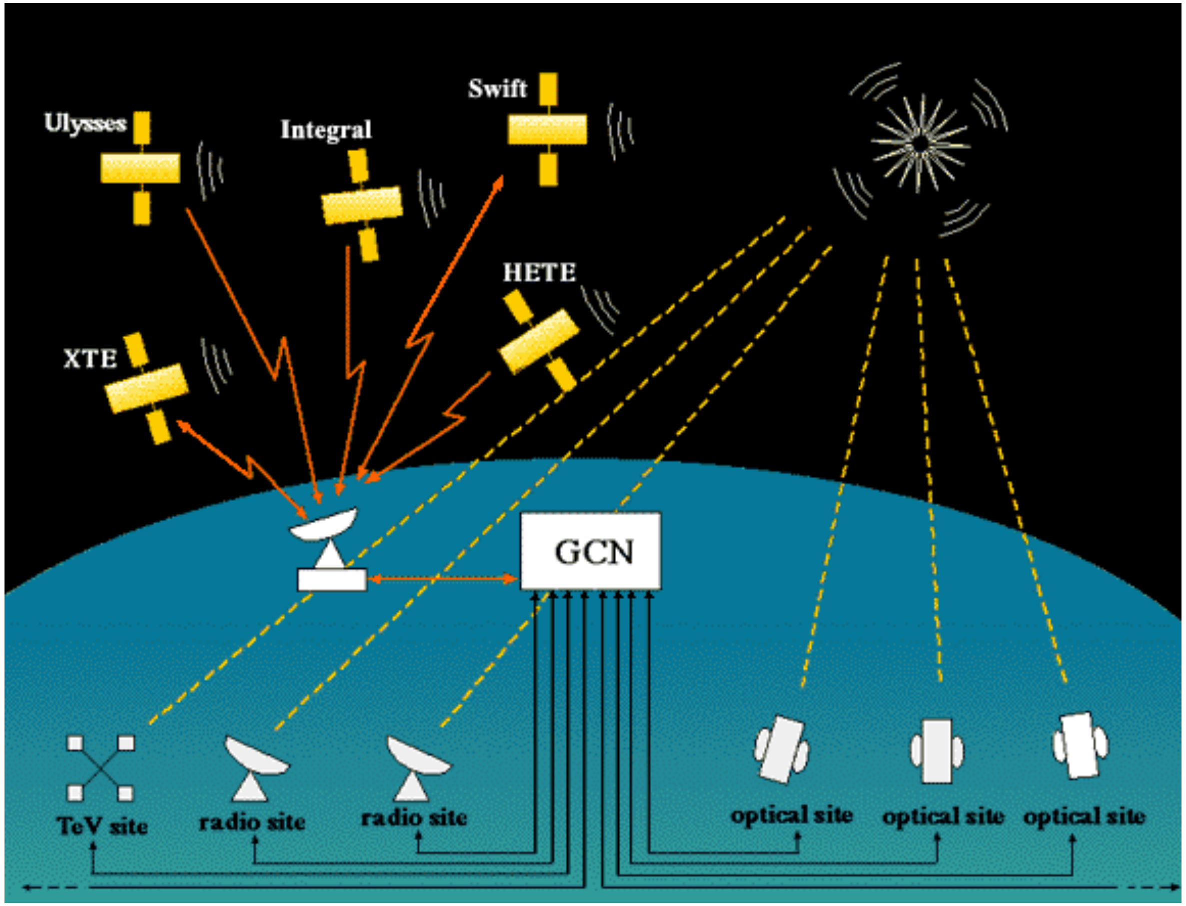


[Shahmoradi & Nemiroff, MNRAS 451, 126 (2015)]



[Encyclopedia of Science]

Triggered Gamma-Ray Burst Searches

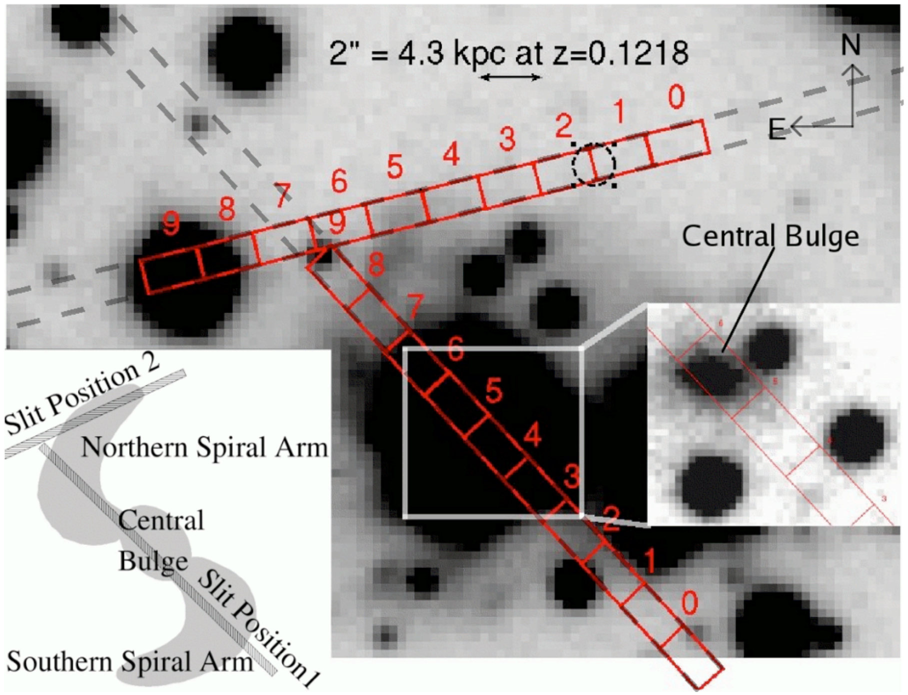


- **Goal**: Determine whether a GW signal is present in the data coming from the same point/patch in the sky and at the same time as an observed GRB

[https://gcn.gsfc.nasa.gov]

GRB 080905A

- Short GRB, z≃0.12, D≃550 Mpc; had advanced LIGO-Virgo been operating:

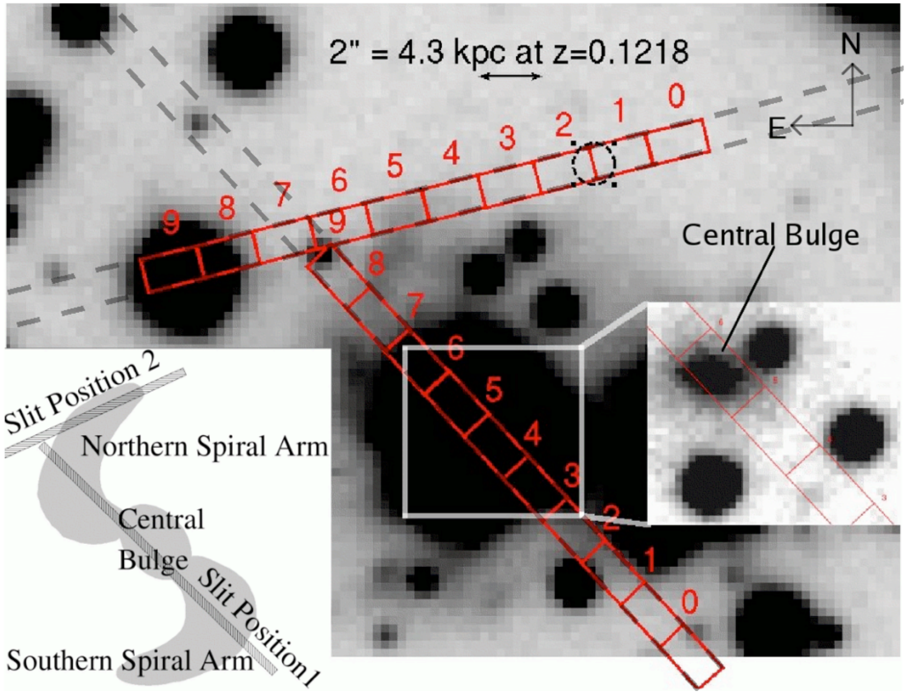


[Rowlinson *et al.*, MNRAS 408, 383 (2010)]

1. NS-NS progenitor:
   - expected SNR ~7.7
   - ~ 1% false alarm probability
   - 60% chance of observing the signal when folding in distance information (vs. 3% for unknown distance)
2. NS-BH progenitor:
   - strong signal
   - either detected or progenitor excluded

GRB 080905A

- Short GRB, z≃0.12, D≃550 Mpc; had advanced LIGO-Virgo been operating:



[Rowlinson *et al.*, MNRAS 408, 383 (2010)]

1. NS-NS progenitor:
   - expected SNR ~7.7
   - ~ 1% false alarm probability
   - 60% chance of observing the signal when folding in distance information (vs. 3% for unknown distance)
2. NS-BH progenitor:
   - strong signal
   - either detected or progenitor excluded

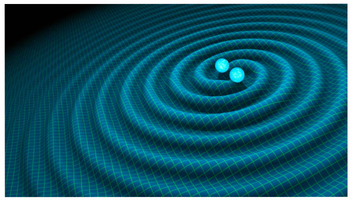
- And more: 131004A (z ≃ 0.088), 090417A (z ≃ 0.088), 070923 (z ≃ 0.076), 061201 (z ≃ 0.11)

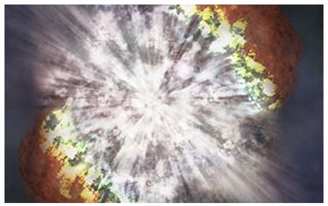
Gravitational-Wave Searches

Transient Signals

Model → Compact Binary Coalescence

No model → Burst

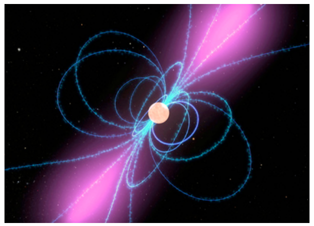


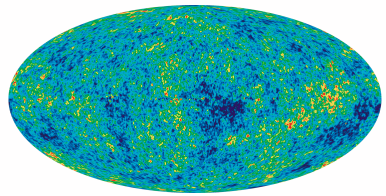


Continuous Signals

Model → Continuous Waves

No model → Stochastic





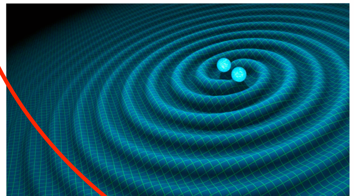
Gravitational-Wave Searches

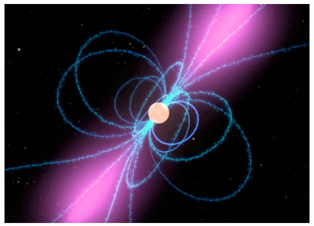
Transient Signals

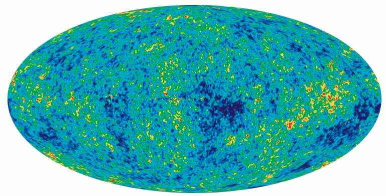
- Model → Compact Binary Coalescence
- No model → Burst

Continuous Signals

- Model → Continuous Waves
- No model → Stochastic







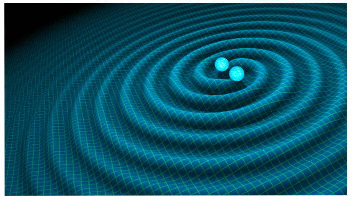
- Advantage: knowing time and/or sky location simplifies analysis, lowers detection thresholds, reduces background ⇒ sensitivity increase
- Challenge: performing a deep search (advantage + coherent search strategy)

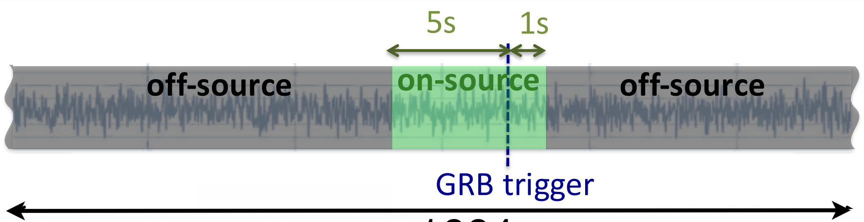
Gravitational-Wave Searches

Transient Signals

Model → Compact Binary Coalescence

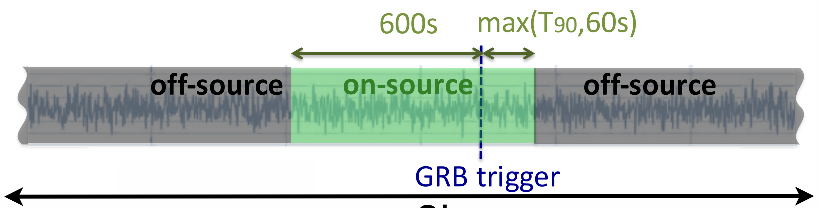
No model → Burst





~1664s

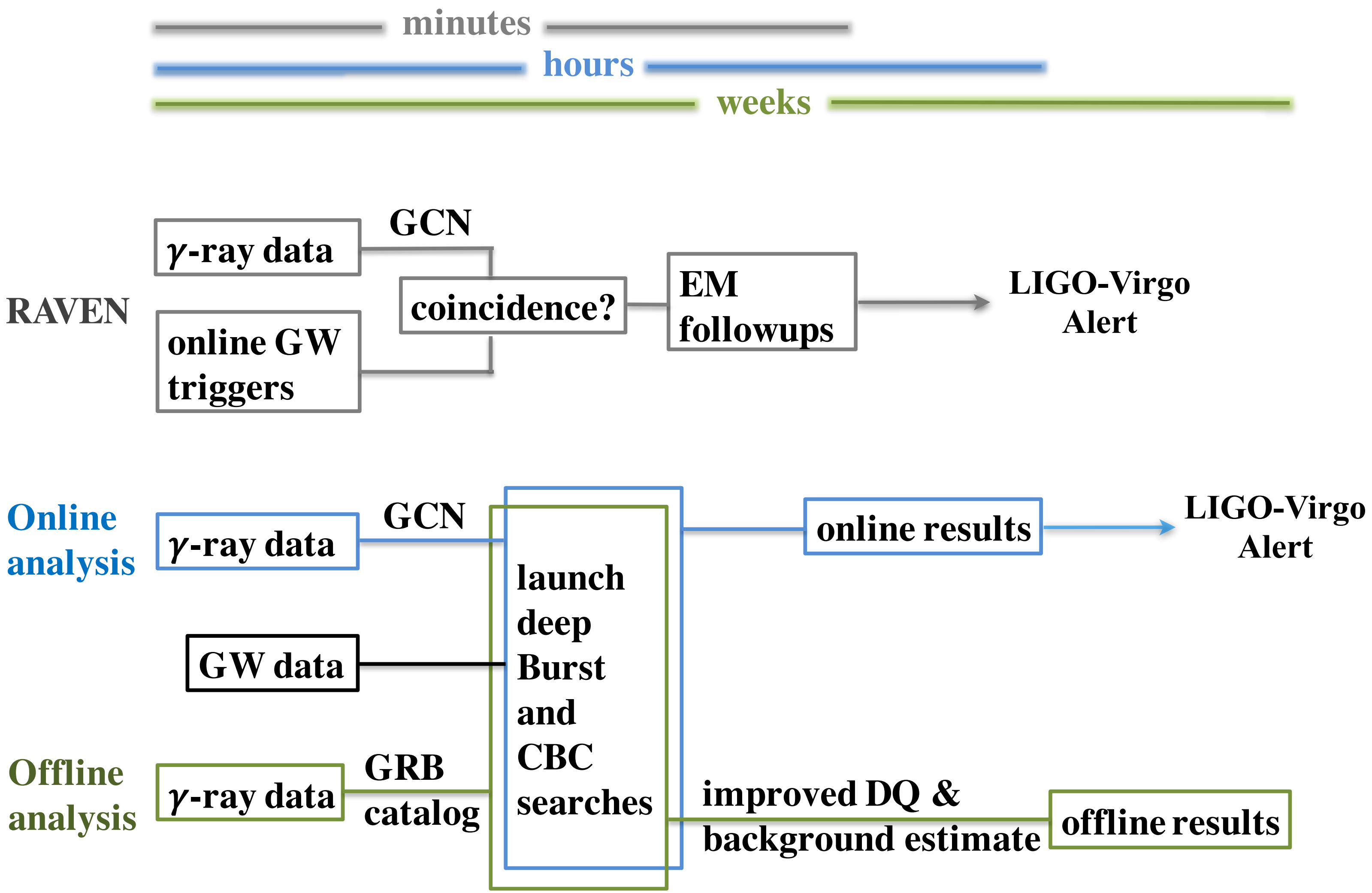
30Hz – 1000Hz



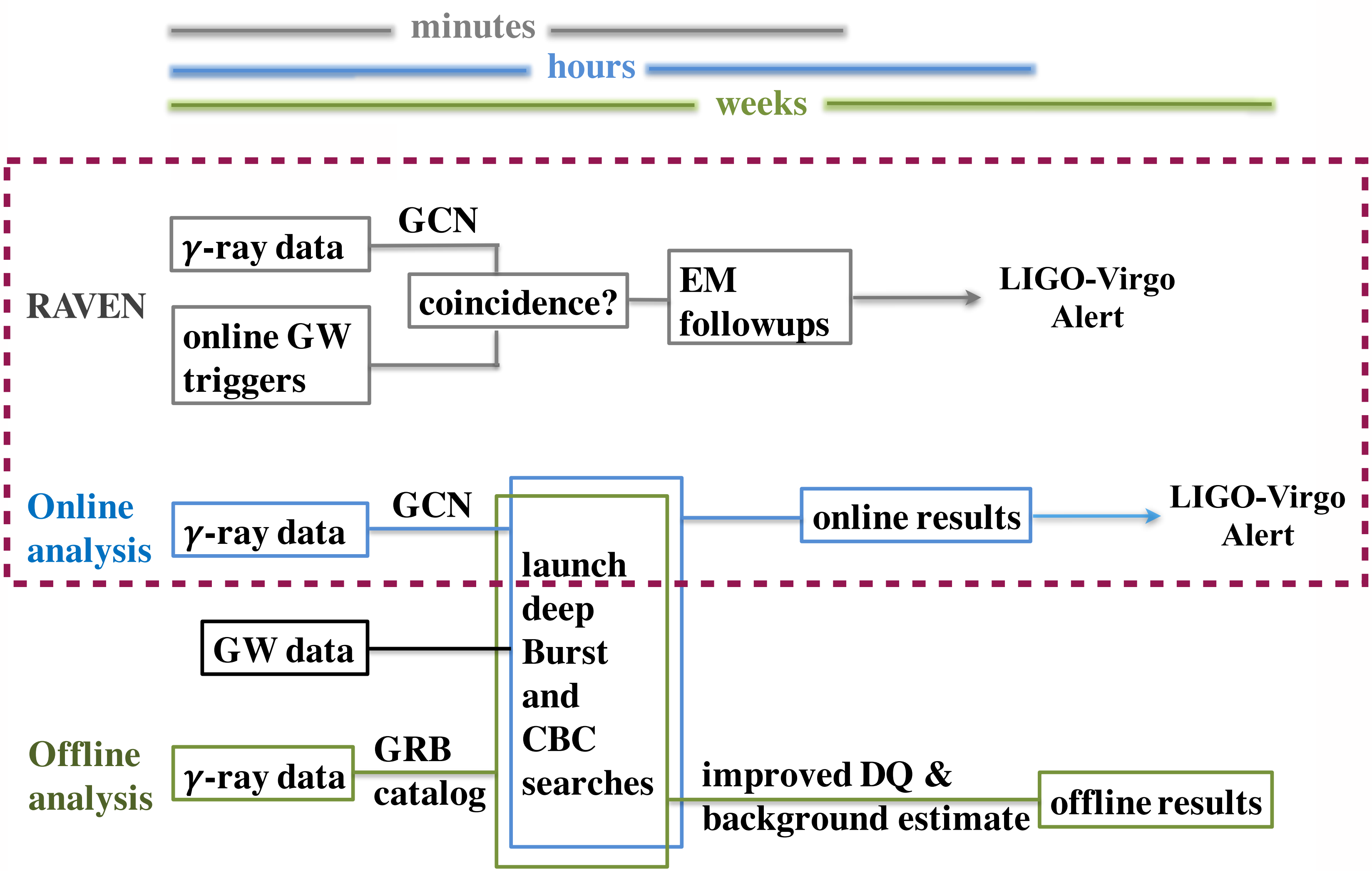
~3h

16Hz – 500Hz

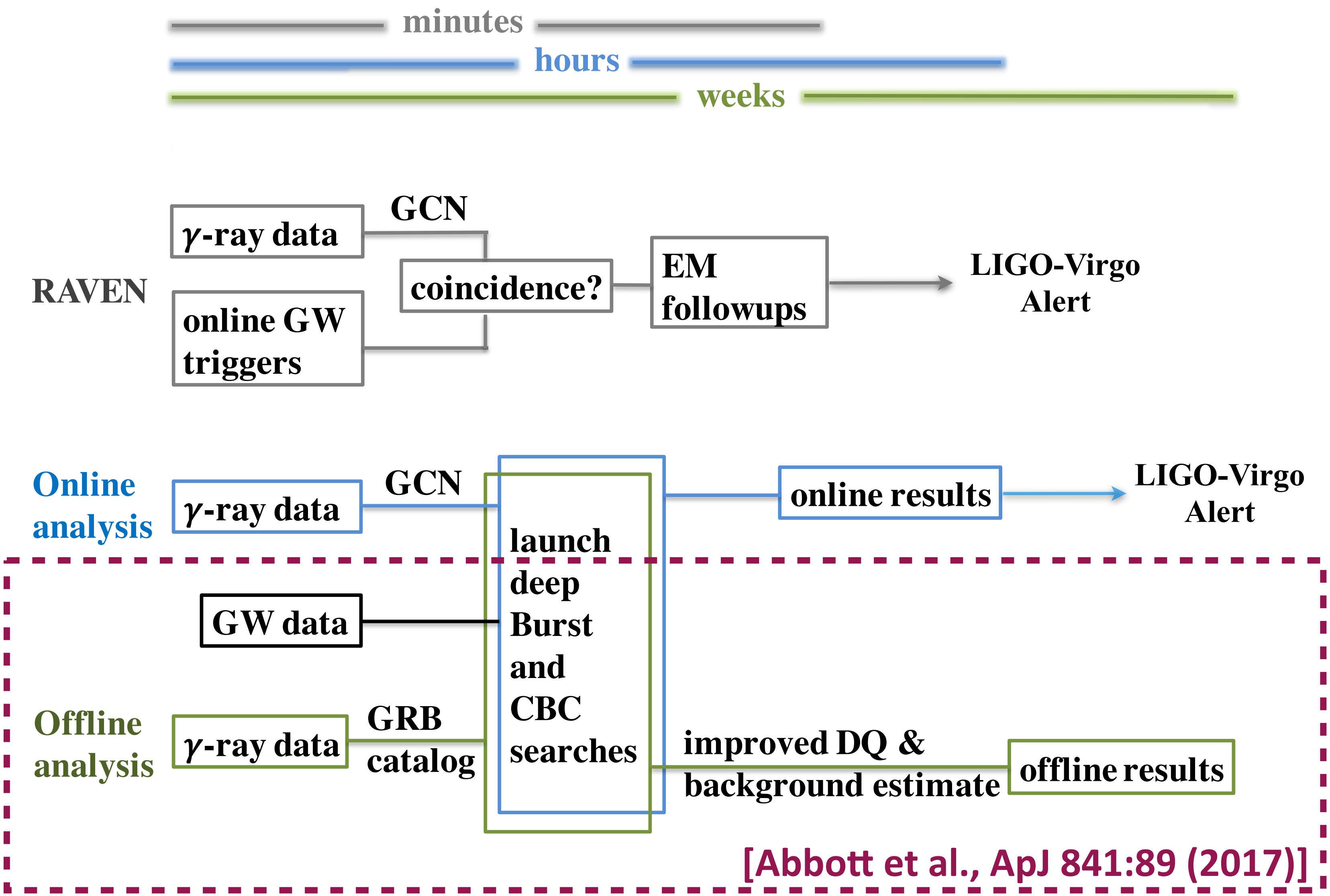
Targeted Gamma-Ray Burst Searches



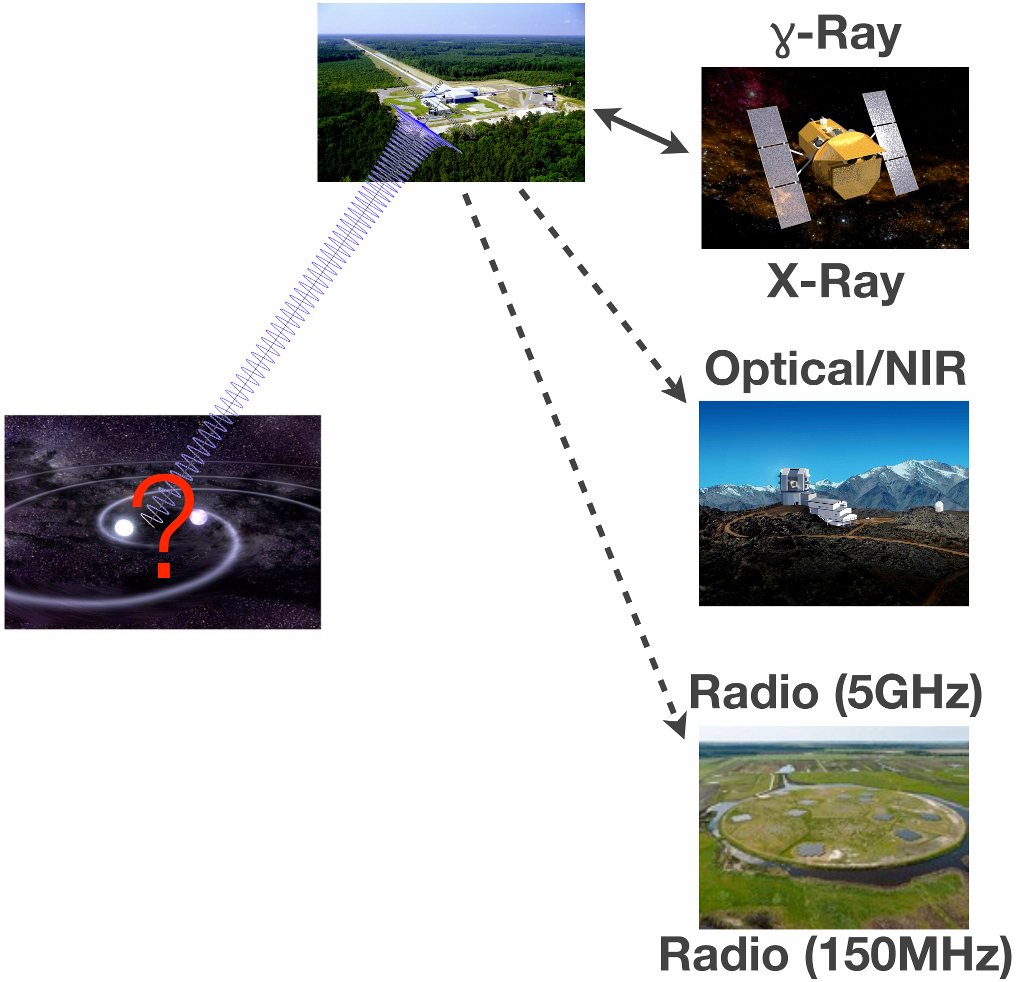
Targeted Gamma-Ray Burst Searches

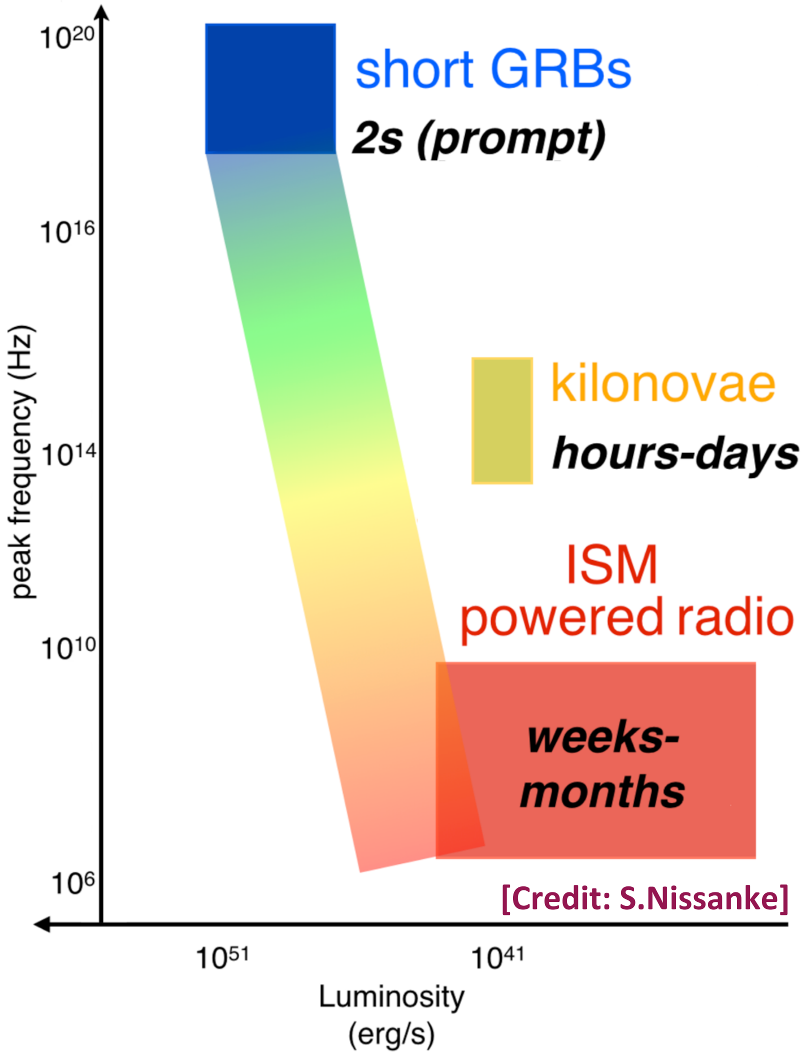


Targeted Gamma-Ray Burst Searches

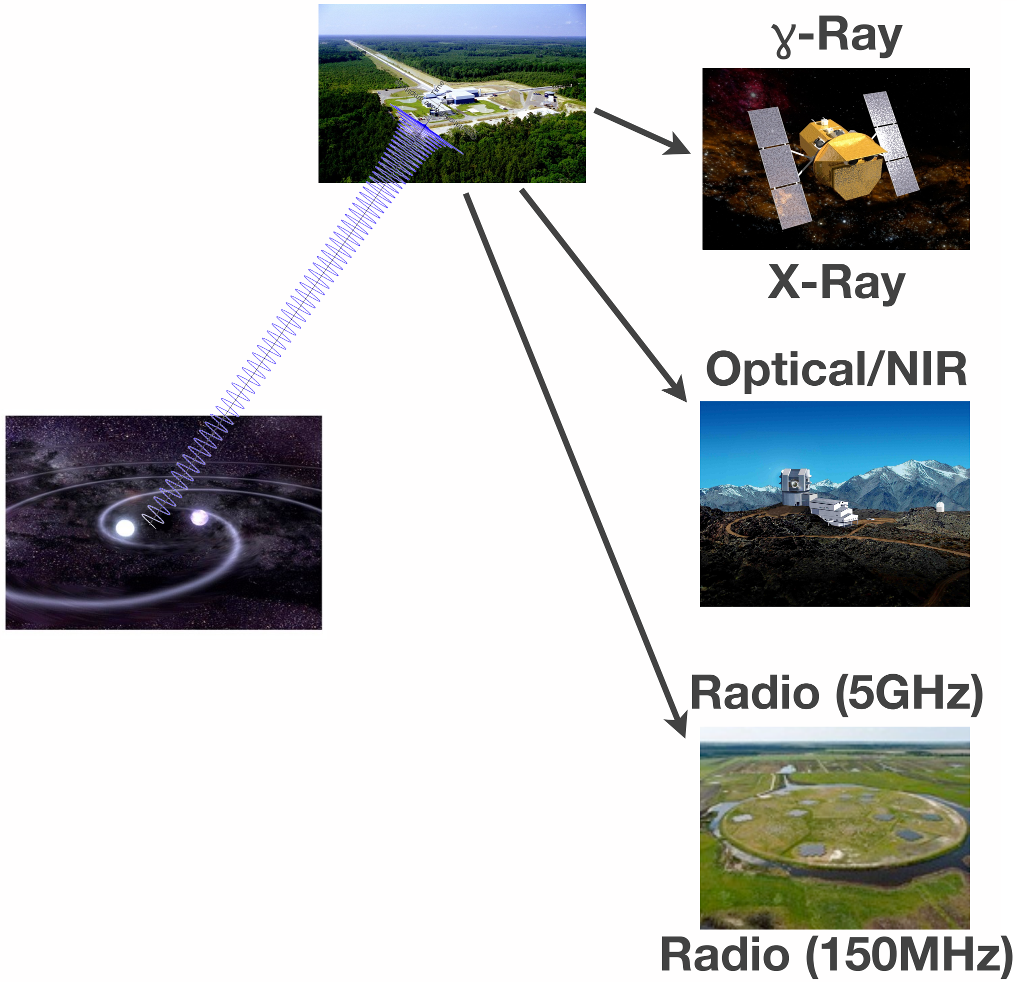


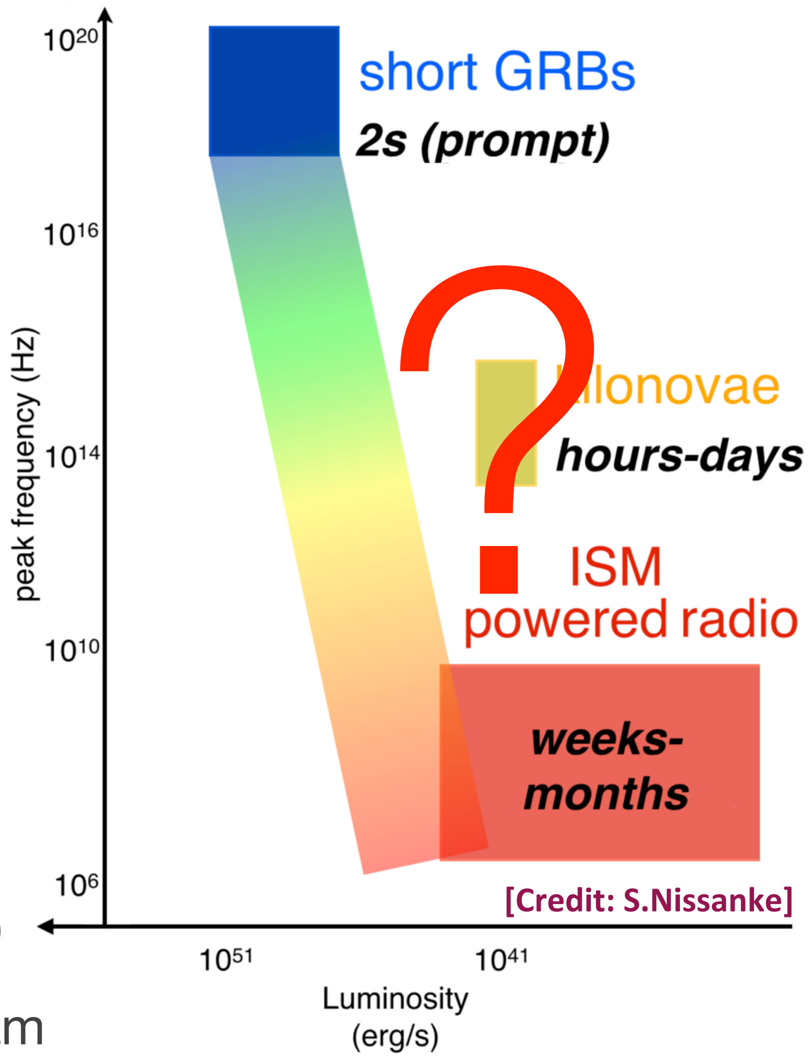
Targeted Gamma-Ray Burst Searches





Targeted Gamma-Ray Burst Searches





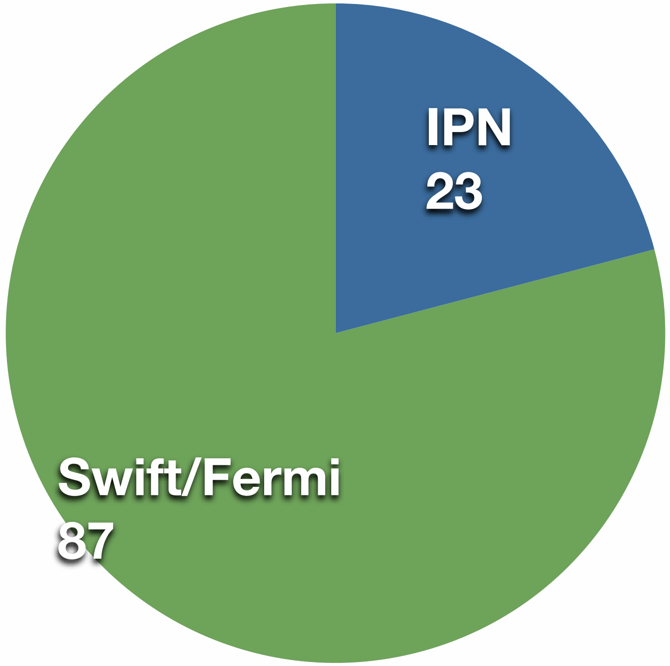
- Complementary to EM follow-up program
- GBM followup of subthreshold GW triggers (see talk by Adam Goldstein)

GRBs in the First Advanced LIGO Observing Run

- Sep 12, 2015 – Jan 19, 2016: 110 GRBs

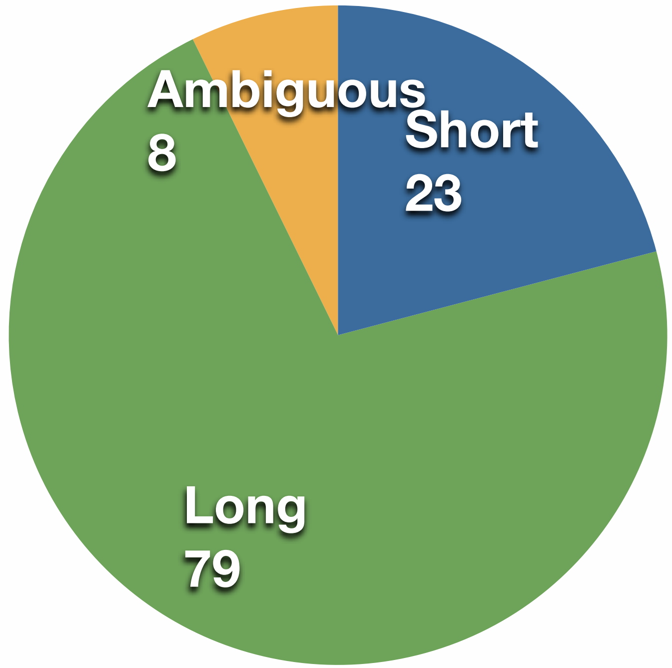
GRBs in the First Advanced LIGO Observing Run

- Sep 12, 2015 – Jan 19, 2016: 110 GRBs



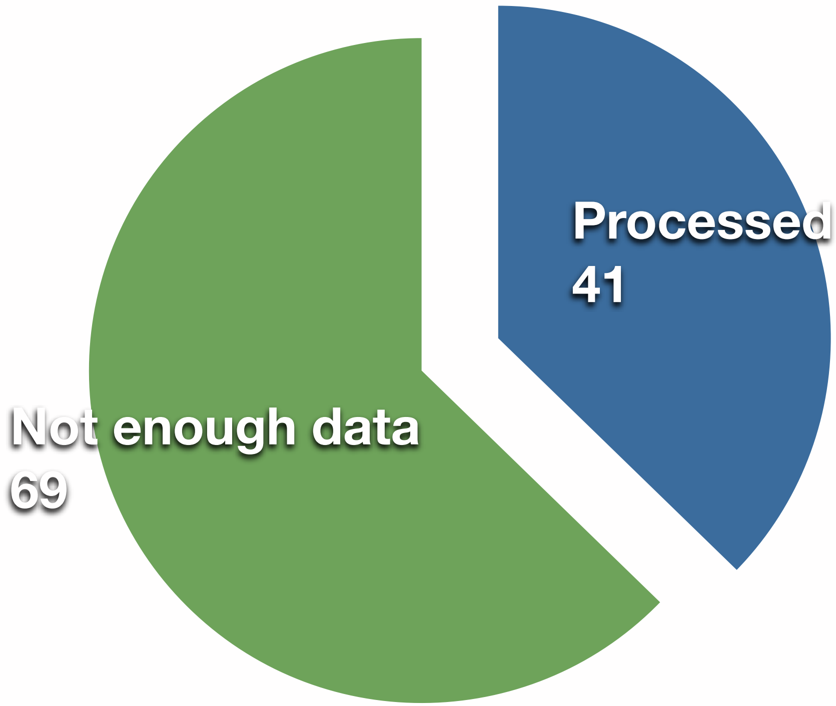
GRBs in the First Advanced LIGO Observing Run

- Sep 12, 2015 – Jan 19, 2016: 110 GRBs



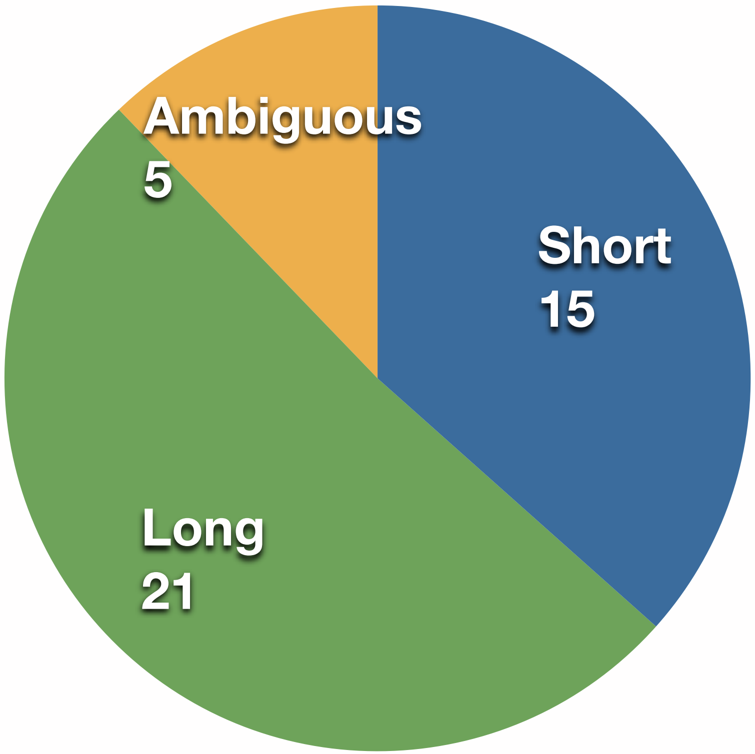
GRBs in the First Advanced LIGO Observing Run

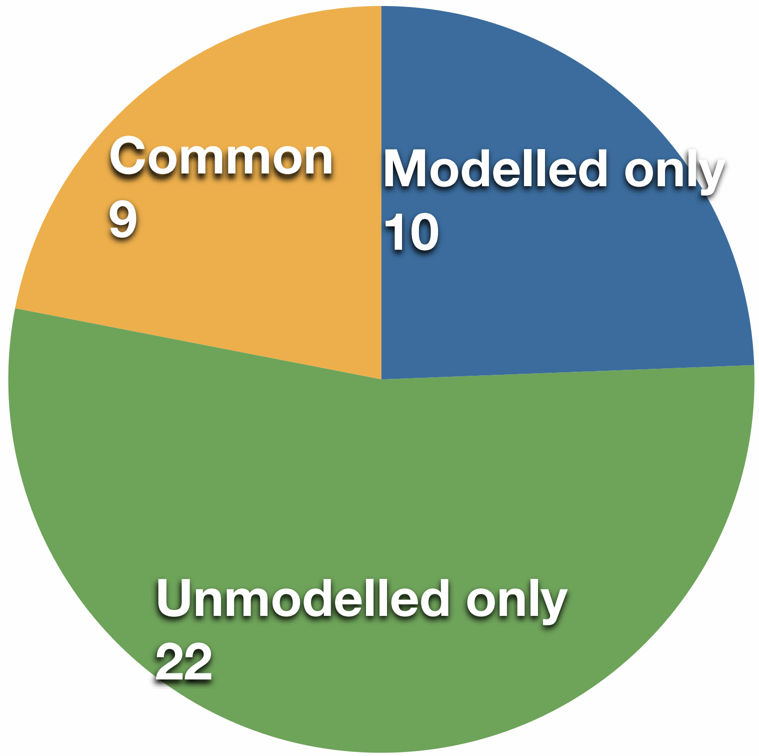
- Sep 12, 2015 – Jan 19, 2016: 110 GRBs



GRBs in the First Advanced LIGO Observing Run

- Sep 12, 2015 – Jan 19, 2016: 110 GRBs

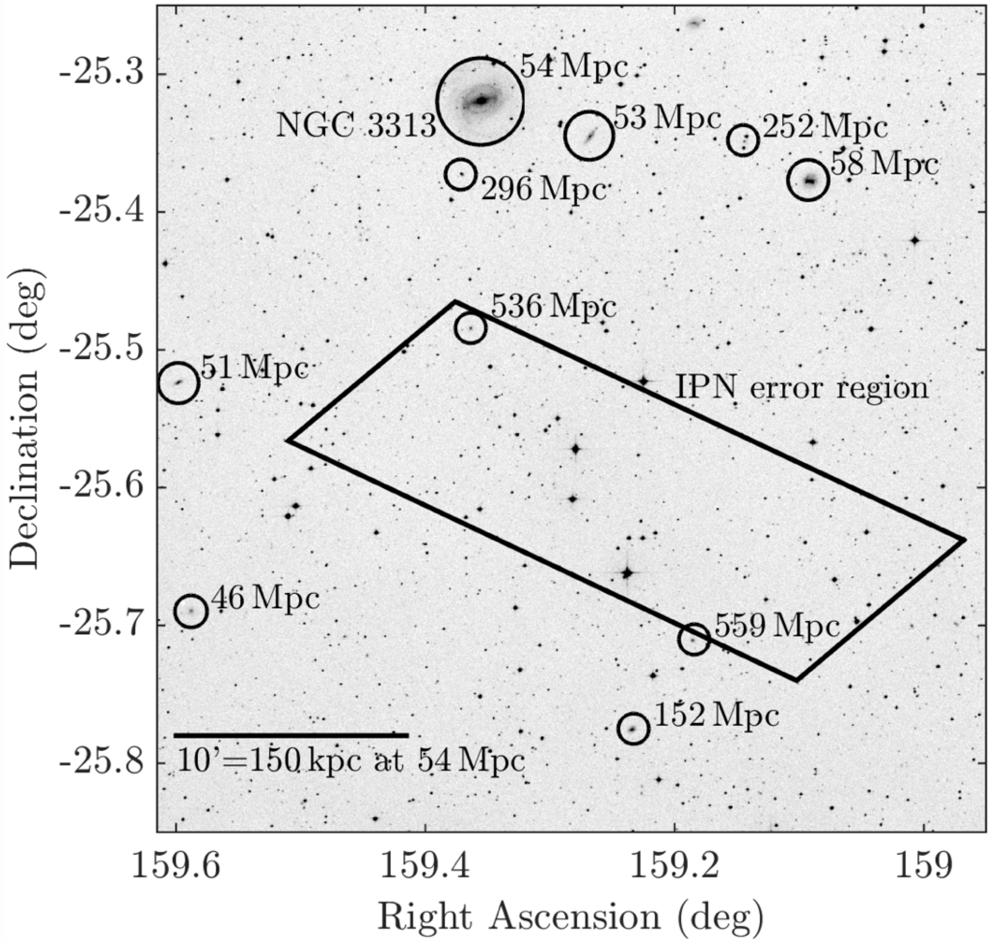




- Modelled: ~61% of short and ambiguous GRBs [61%/52% H1/L1 duty cycle]
- Unmodelled: ~31% of GRBs with sky information [40% coincident duty cycle]

GRBs in the First Advanced LIGO Observing Run

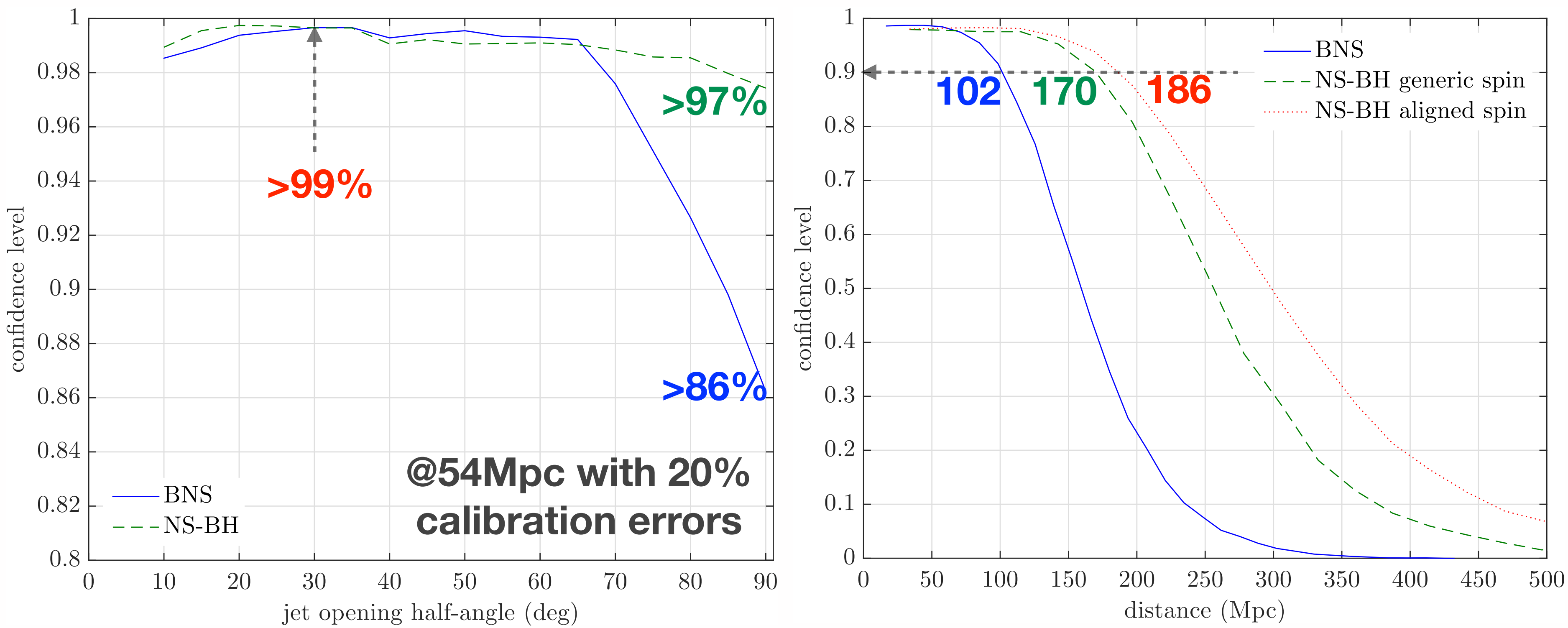
- 42 with GRB 150906B:
  - ❖ Sep 06, 2015 at 08:42:20 UTC
  - ❖ Detected by IPN
  - ❖ Short-duration/hard-spectrum GRB close to the local galaxy NGC3313 (z~0.0124, D=54Mpc)
  - ❖ Only LIGO Hanford on at the time



[Levan *et al.*, GCN 18263 (2015); Dálya et al., (2016)]

Results – GRB 150906B

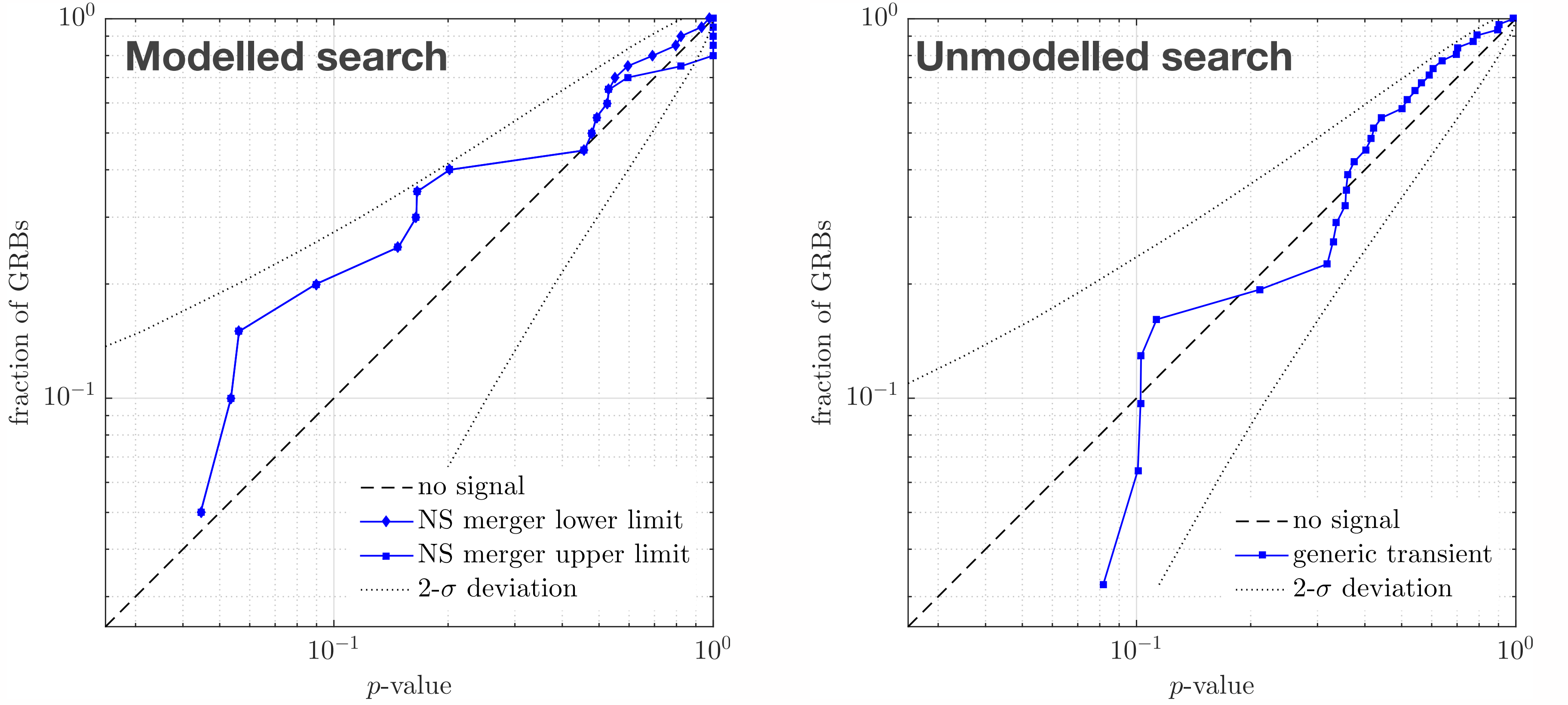
- Assuming a jet half-opening angle ≤ 30° and a [-5s,1s) search window, NS-NS and NS-BH progenitors in NGC 3313 are excluded at >99% confidence
- No evidence for NS-NS/BH GW signals up to 102/170 Mpc



[Abbott et al., ApJ 841:89 (2017)]

Results – No Significant Events

- No coincidences from the all-time/all-sky analysis
- No evidence of GWs associated with any of the 42 GRBs nor of a collective signature of weak GW signals



[Abbott et al., ApJ 841:89 (2017)]

Results – 90% Confidence Level Exclusion Distances

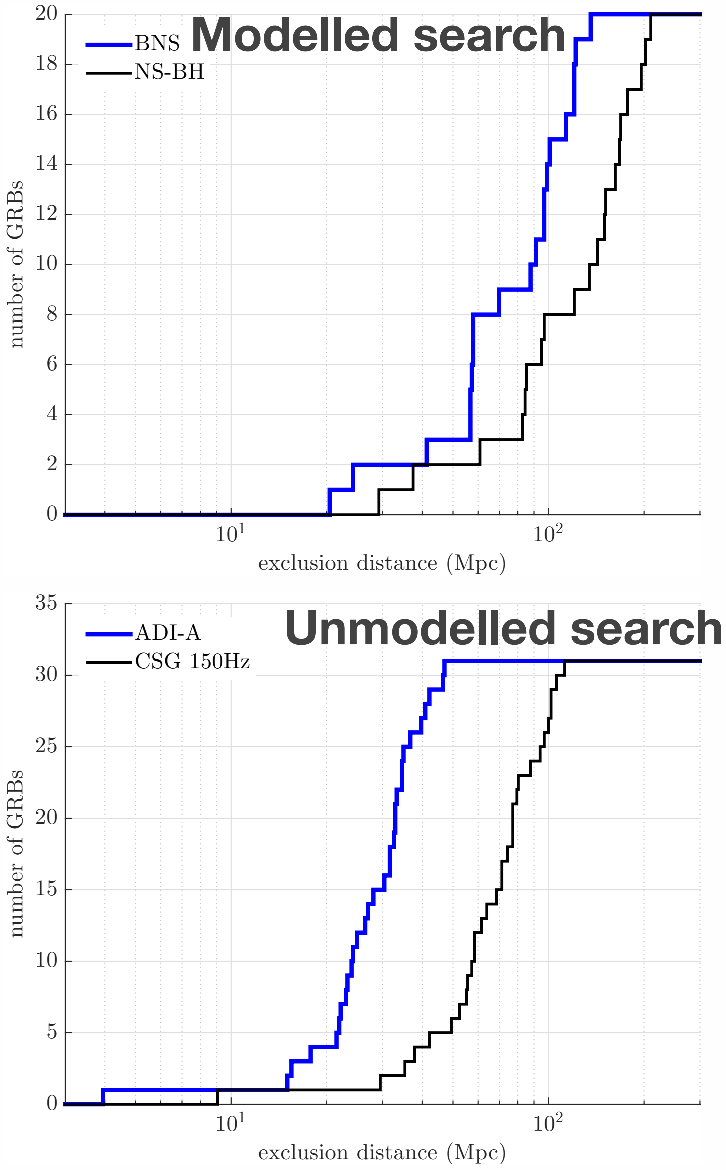


Table 2. Median 90% confidence level exclusion distances $D_{90\%}$

Short GRBs	BNS	NS-BH aligned spins	NS-BH generic spins	
$D_{90\%}$ [Mpc]	90	150	139	
All GRBs	CSG 70 Hz	CSG 100 Hz	CSG 150 Hz	CSG 300 Hz
$D_{90\%}$ [Mpc]	88	89	71	30

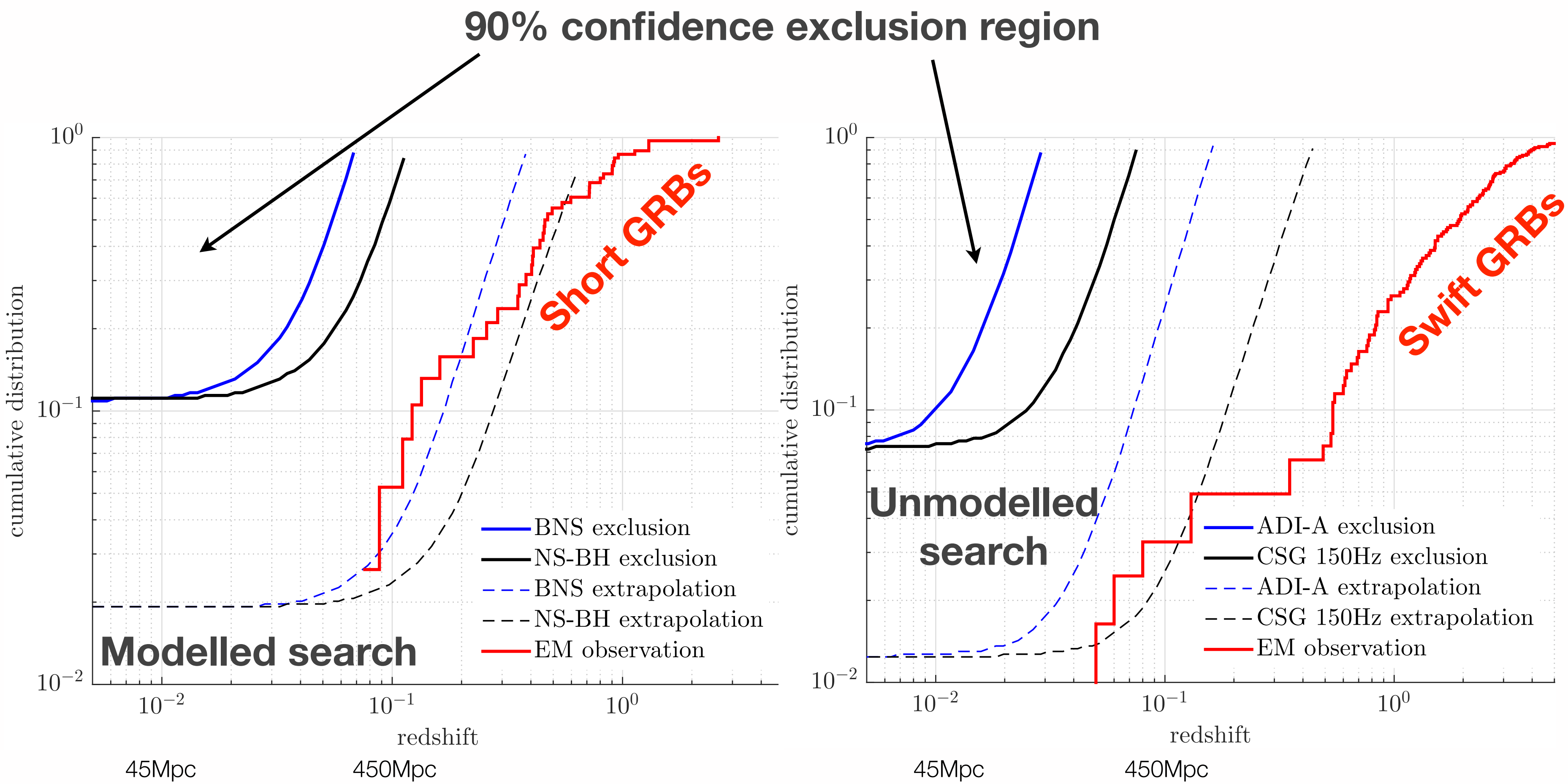
All GRBs	ADI A	ADI B	ADI C	ADI D	ADI E
$D_{90\%}$ [Mpc]	31	97	39	15	36

NOTE—The short GRB analysis assumes an NS binary progenitor. When all GRBs are analyzed, a circular sine-Gaussian (CSG) or an accretion disk instability (ADI) model is used.

Exclusion distances are ~4-5 times higher than in previous search

[Abbott et al., ApJ 841:89 (2017)]

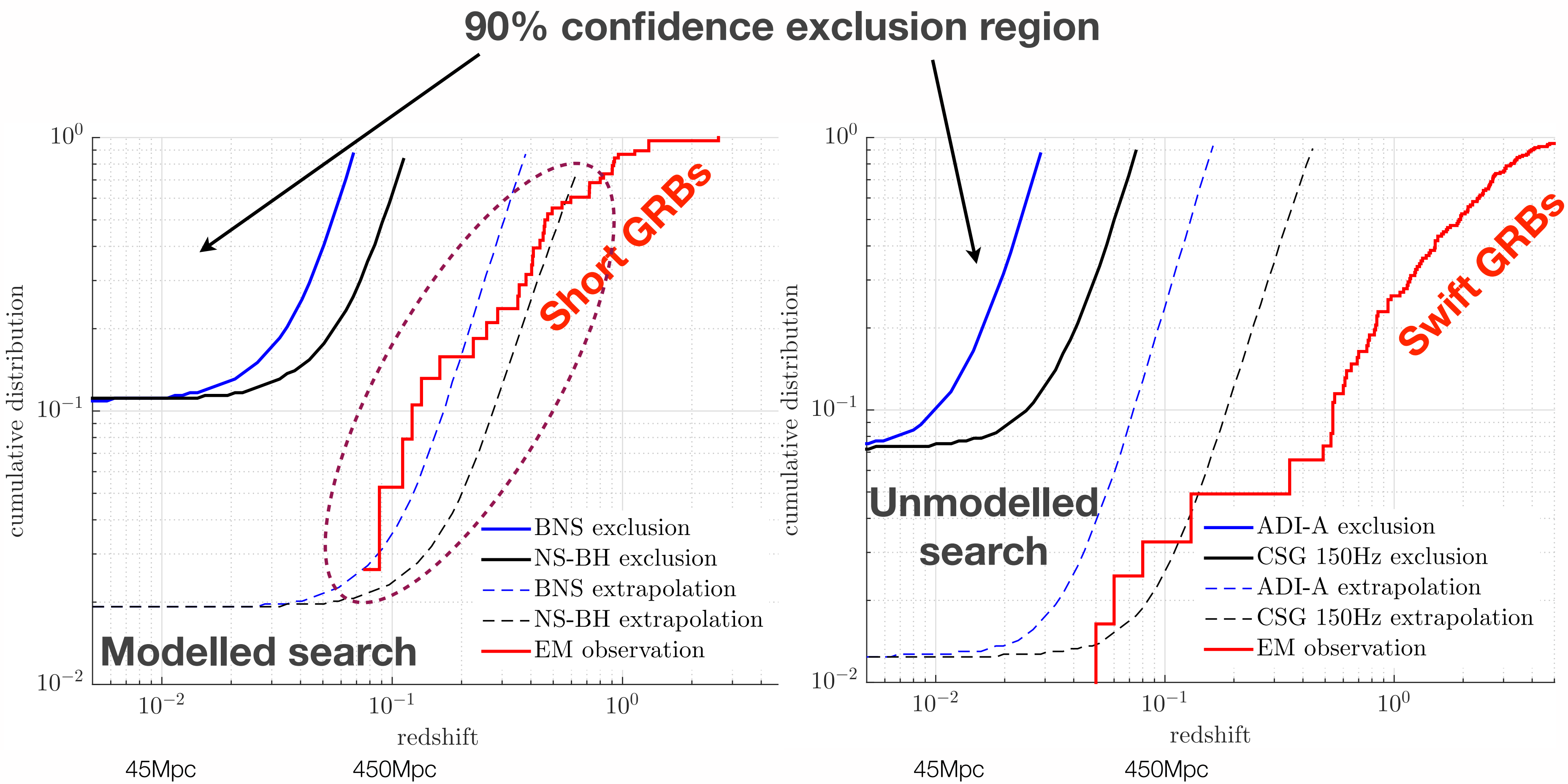
Results – 90% Confidence Level Exclusion Distances



Extrapolation = 2 years at AdvLIGO design sensitivity (factor ~ 3 better than O1)

[Abbott et al., ApJ 841:89 (2017)]

Results – 90% Confidence Level Exclusion Distances



Extrapolation = 2 years at AdvLIGO design sensitivity (factor ~ 3 better than O1)

[Abbott et al., ApJ 841:89 (2017)]

Summary

- Gravitational-wave astronomy has begun
- Joint GRB+GW detections will shed light on the nature of GRB progenitors

- First Advanced LIGO observing run (Sep 12, 2015 – Jan 19, 2016)
  - Analyzed LIGO data to look for GWs coincident with GRBs that occurred in this period (including GRB 150906B)
  - No significant GW event found

- Second Advanced LIGO observing run
  - Running low-latency coincidence search
  - Promptly initiating modelled and unmodelled medium-latency searches
  - Any potential coincidence will be circulated to astronomy partners