RECOVERING HARDWARE INJECTIONS IN LIGO S5 DATA

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Outline

- LOSC Open Science Data Release
- Hardware Injections of compact binary coalescence signals
  - What are these?
  - What do we expect to find in the data?
- How to generate a
- Template matching and signal recovery
- Recovery of Hanford 2 hardware injections
  - Was the match successful?
  - Do we see what we expect?
- Summary of Final Results for All Detectors

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  - H1 and H2 at LHO, L1 at LLO

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- In preparation for the release:
  - Software, cookbooks, wikis, tutorials, and teaching materials
  - Bring 8 year old book-keeping up to date
  - Recover and document hardware injection signals

Hardware Injections

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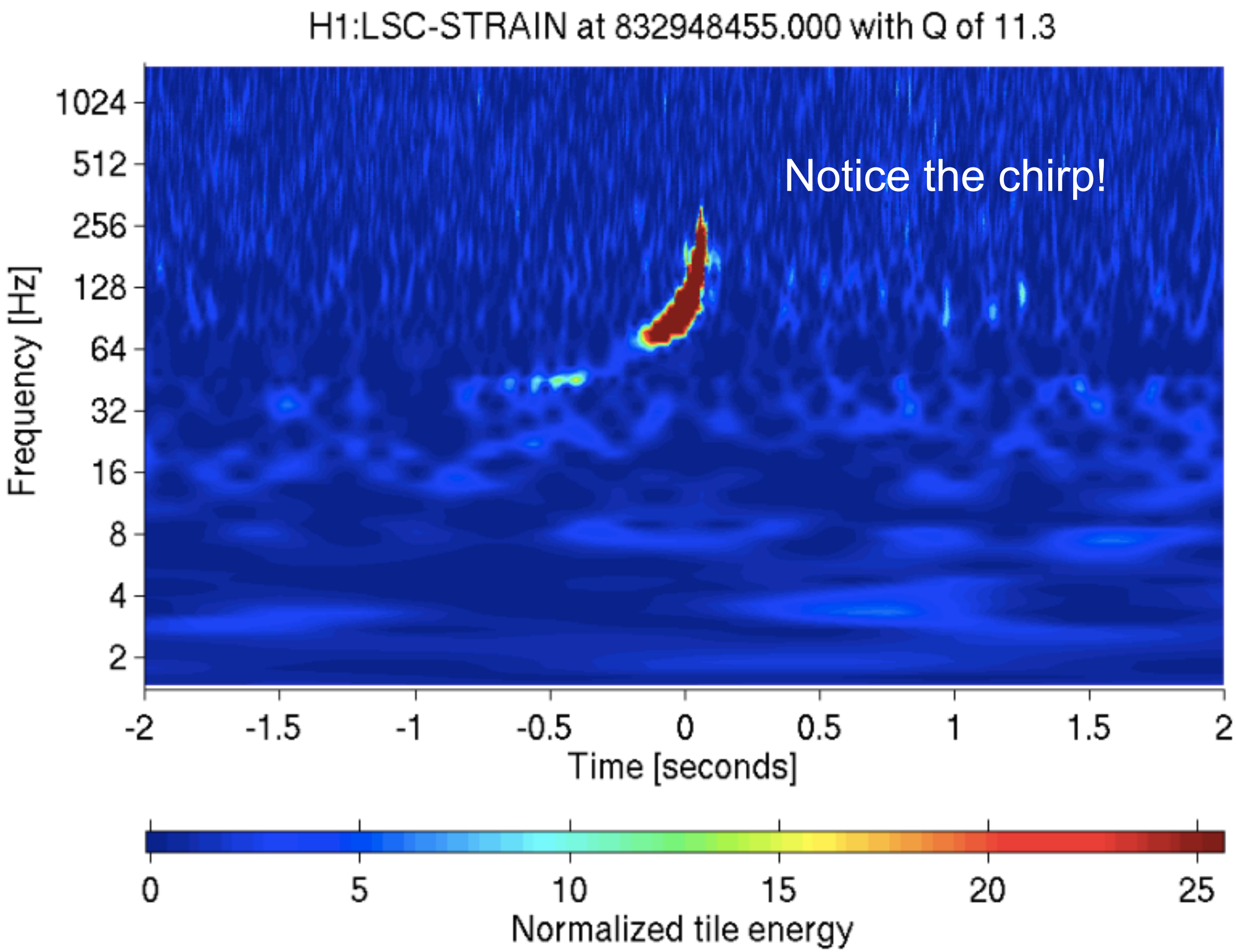
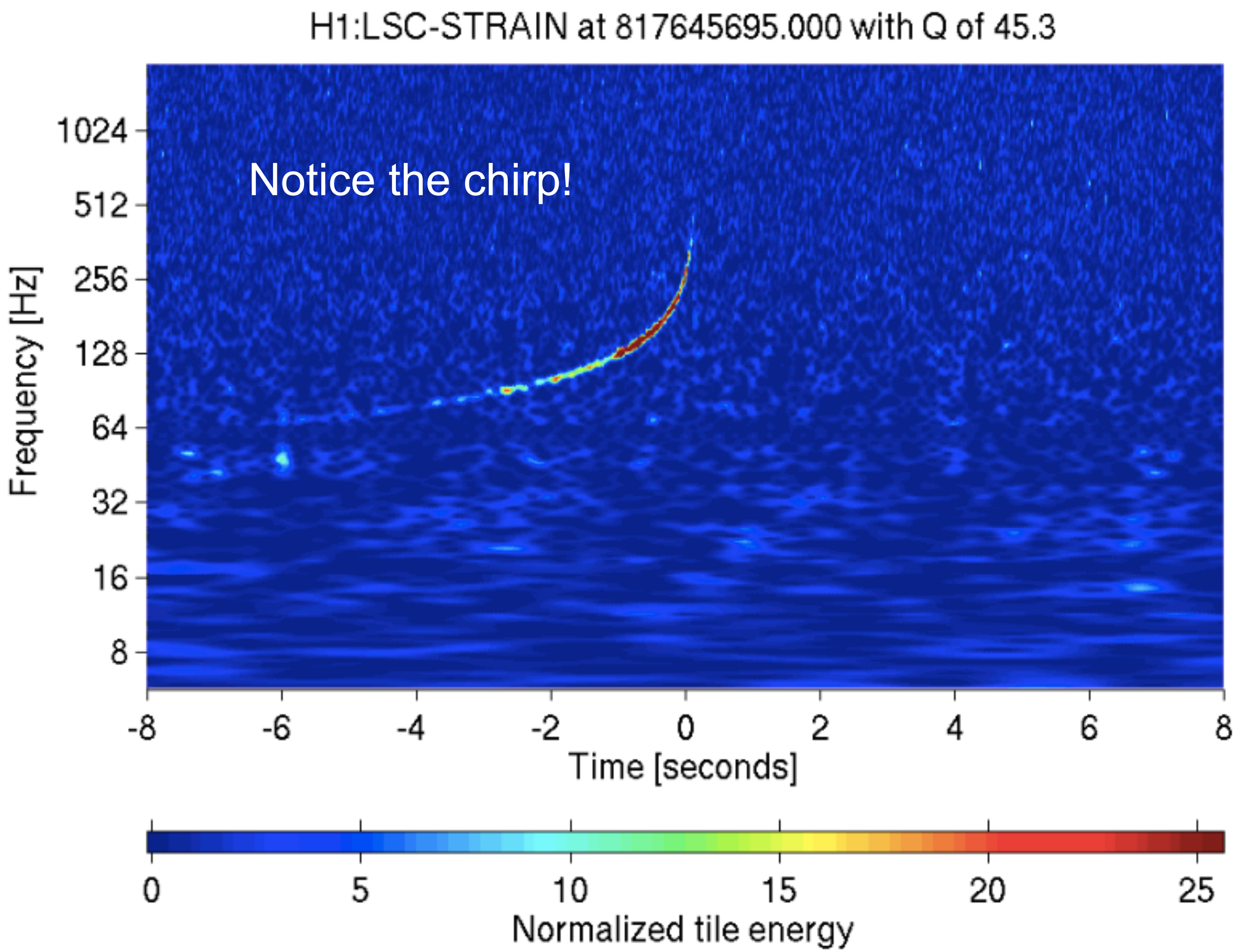
Unsuccessful

10 – 10 Solar Mass Hardware Injection



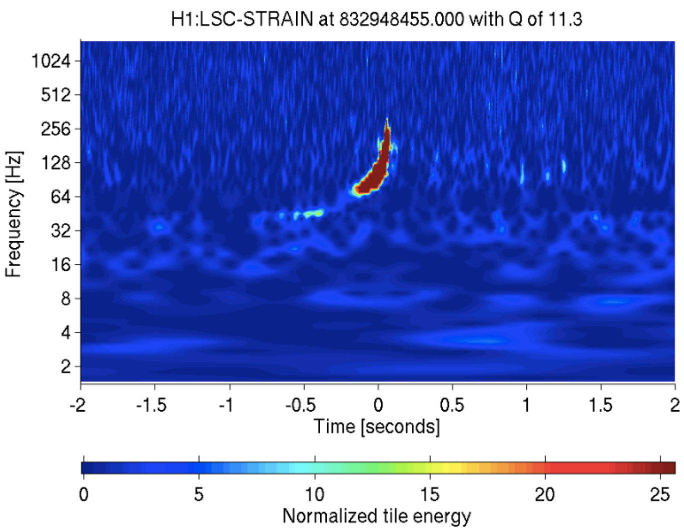
1.4 – 1.4 Solar Mass Hardware Injection



Generate Template

- Create Compact Binary Coalescence templates
  - 1.4 – 1.4 Solar mass binary
  - 3 – 3 Solar mass binary
  - 10 – 10 Solar mass binary
  - 1.4 – 10 Solar mass binary

$$\tilde{h}(f) = \left(\frac{1\,\mathrm{Mpc}}{D_{\mathrm{eff}}}\right) \mathcal{A}_{1\,\mathrm{Mpc}}(M,\mu) f^{-7/6} \mathrm{e}^{-i\Psi(f;M,\mu)}$$



- $\tilde{h}(f)$ – Strain/Hz
- A – Mass dependent amplitude
- f – frequency
- $i\Psi(f;M,\mu)$ – Phase of source

Determining the Amplitude of the Template

$$\mathcal{A}_{1\,\mathrm{Mpc}}(M,\mu) = -\left(\frac{5\pi}{24}\right)^{1/2}\left(\frac{G\mathcal{M}}{c^3}\right)\left(\frac{G\mathcal{M}}{c^2 D_{\mathrm{eff}}}\right)\left(\frac{G\mathcal{M}}{c^3}\pi f\right)^{-7/6}$$

$$= -\left(\frac{5}{24\pi}\right)^{1/2}\left(\frac{GM_\odot/c^2}{1\ \mathrm{Mpc}}\right)\left(\frac{\pi G M_\odot}{c^3}\right)^{-1/6}\left(\frac{\mathcal{M}}{M_\odot}\right)^{-5/6}$$

$\mathcal{M}$ – Chirp mass, units of solar mass

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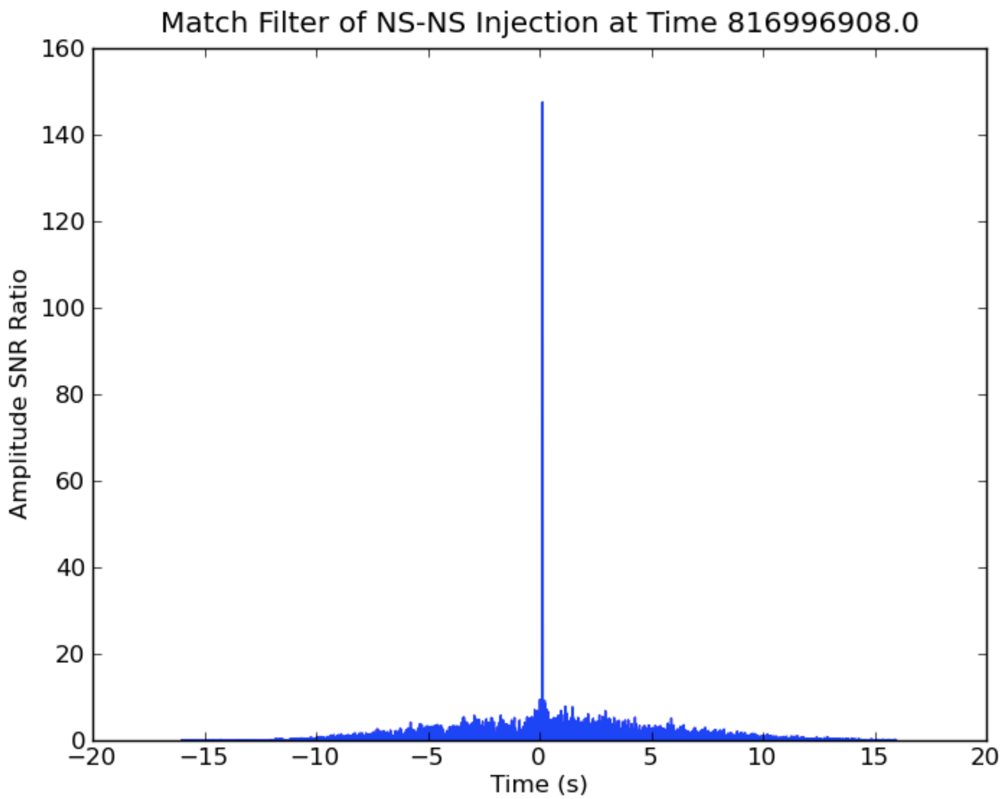
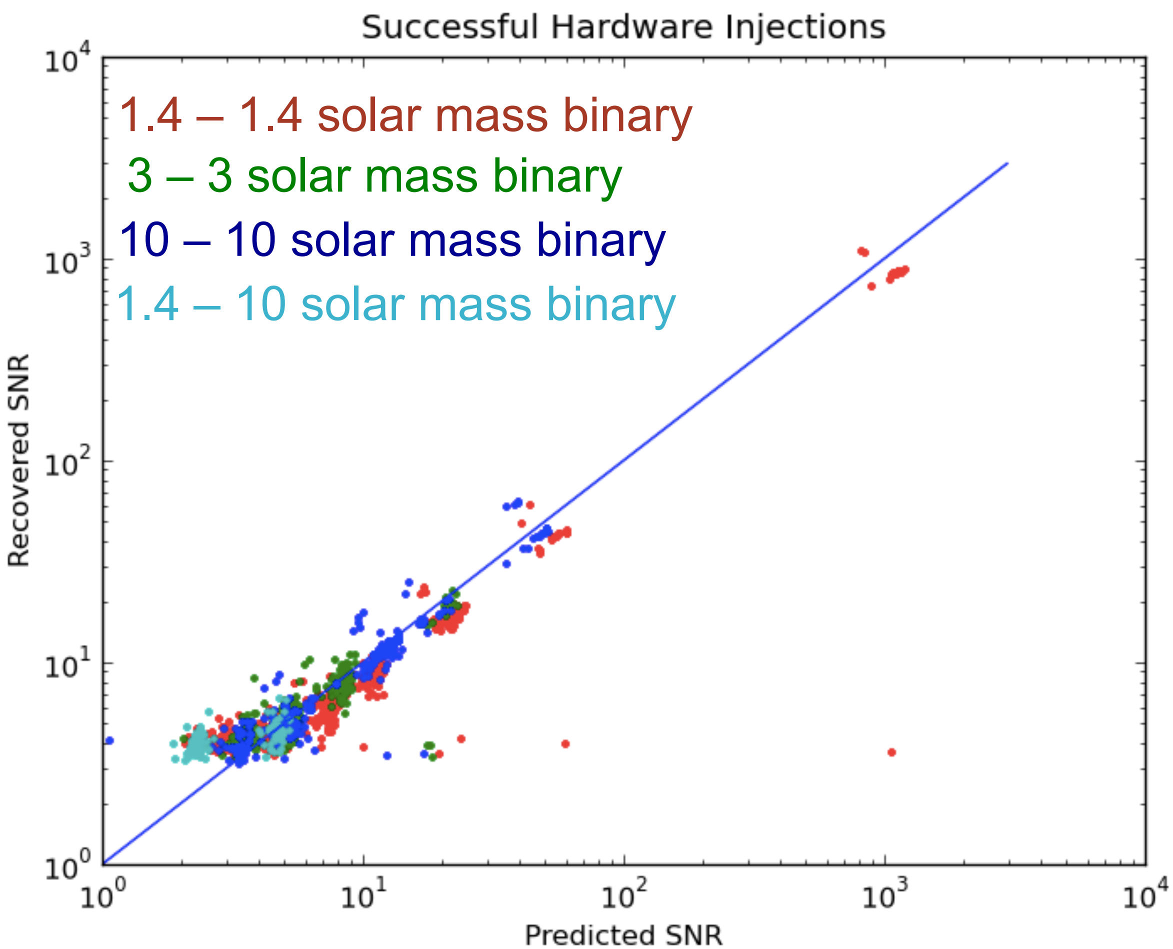
Finding an Injection

- Cross-correlate template against the data
  - Perform correlation with template starting at different times
- Look for the time shift when the cross-correlation between the template and data is high



H2 Successful Injections



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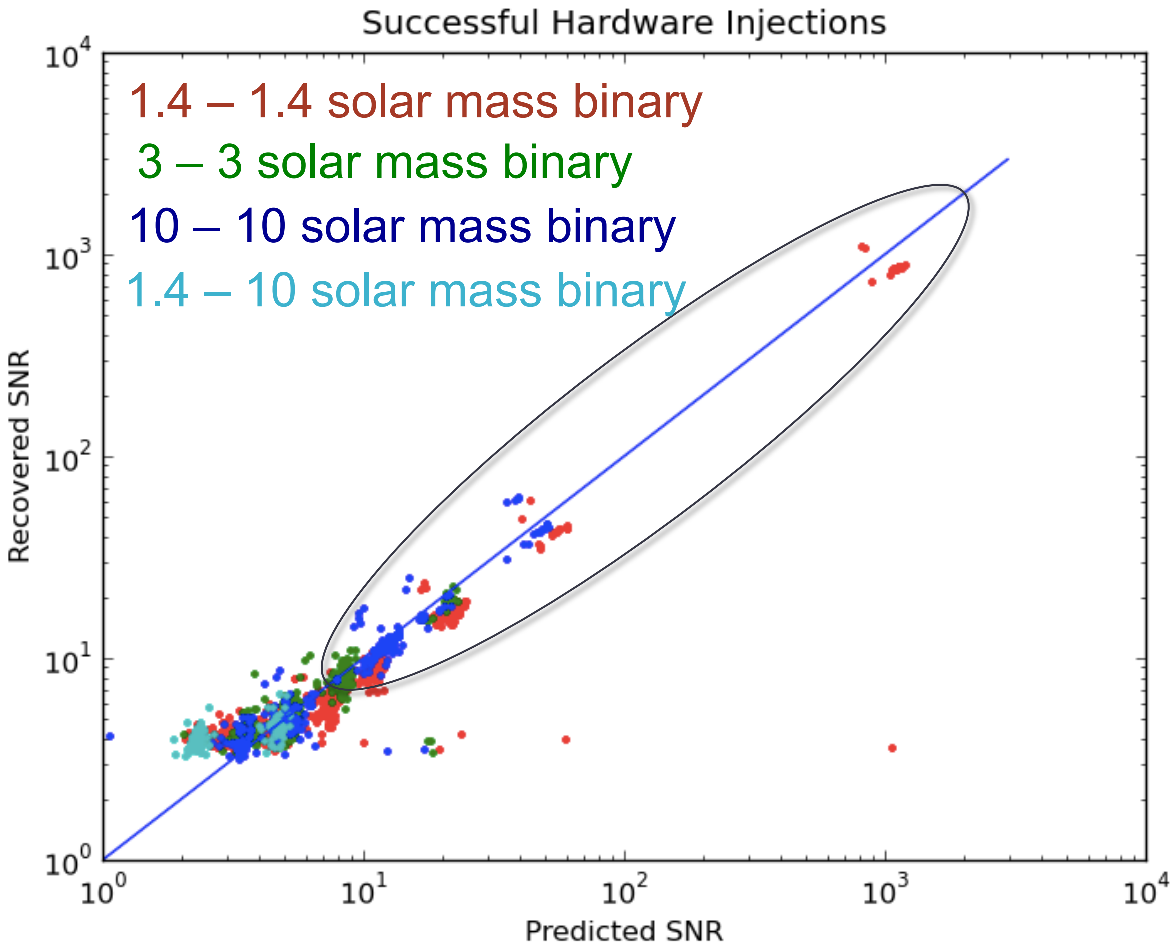

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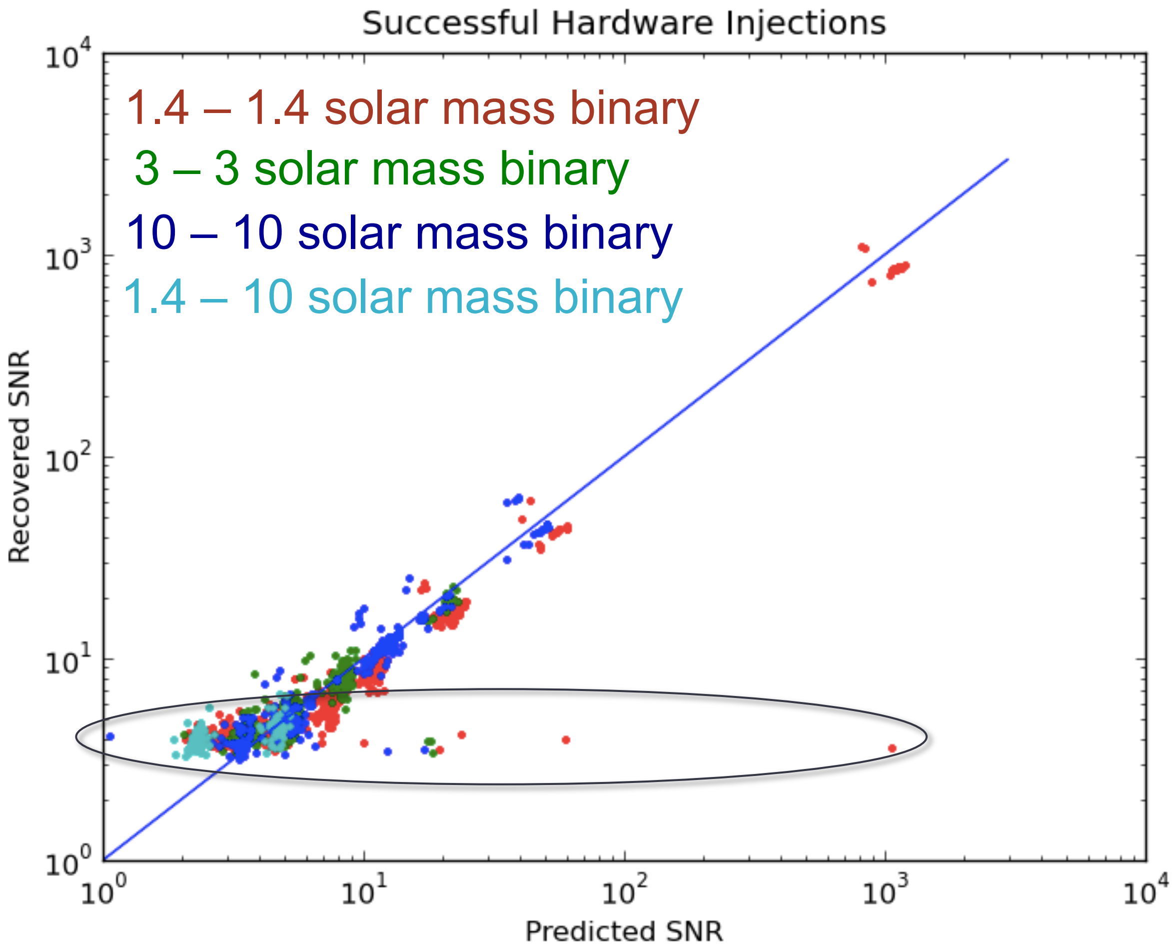
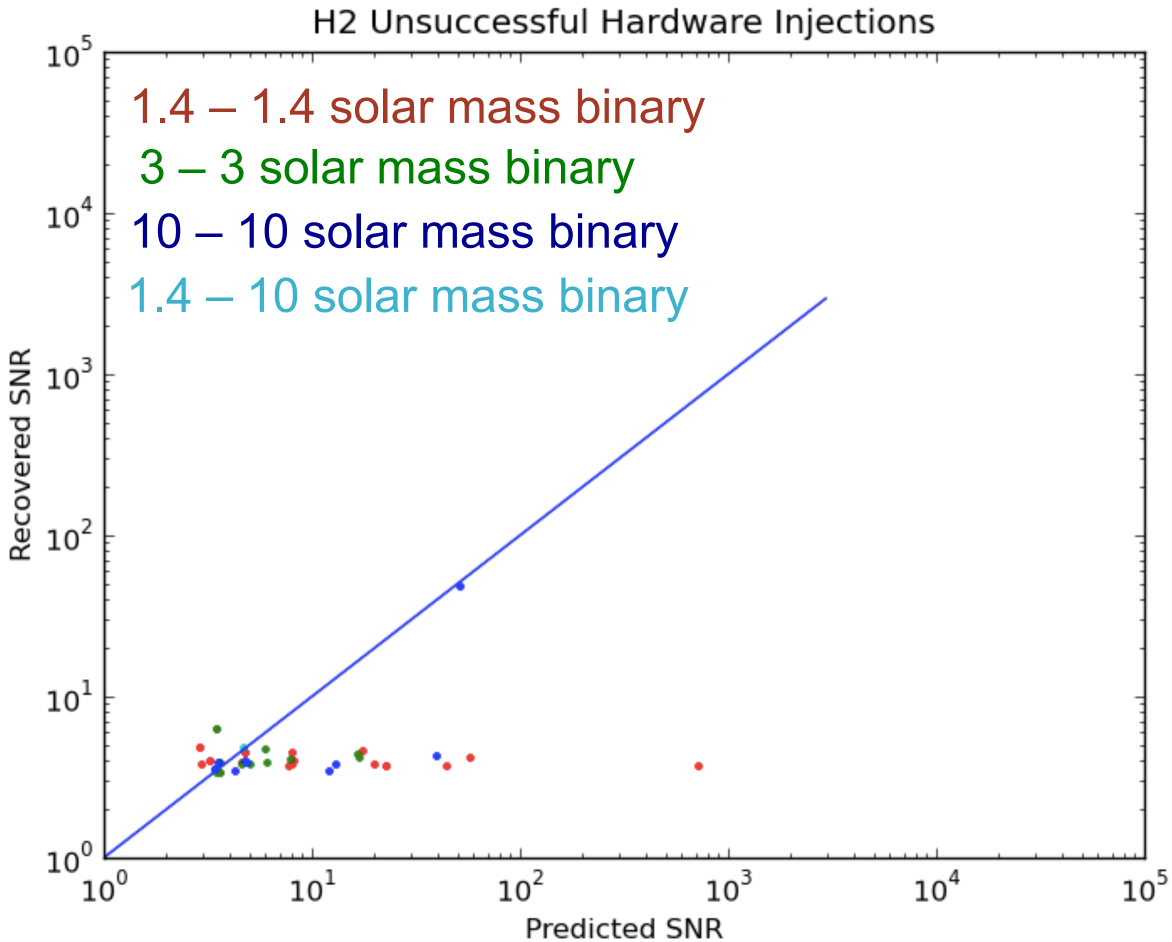


H2 Unsuccessful Injections



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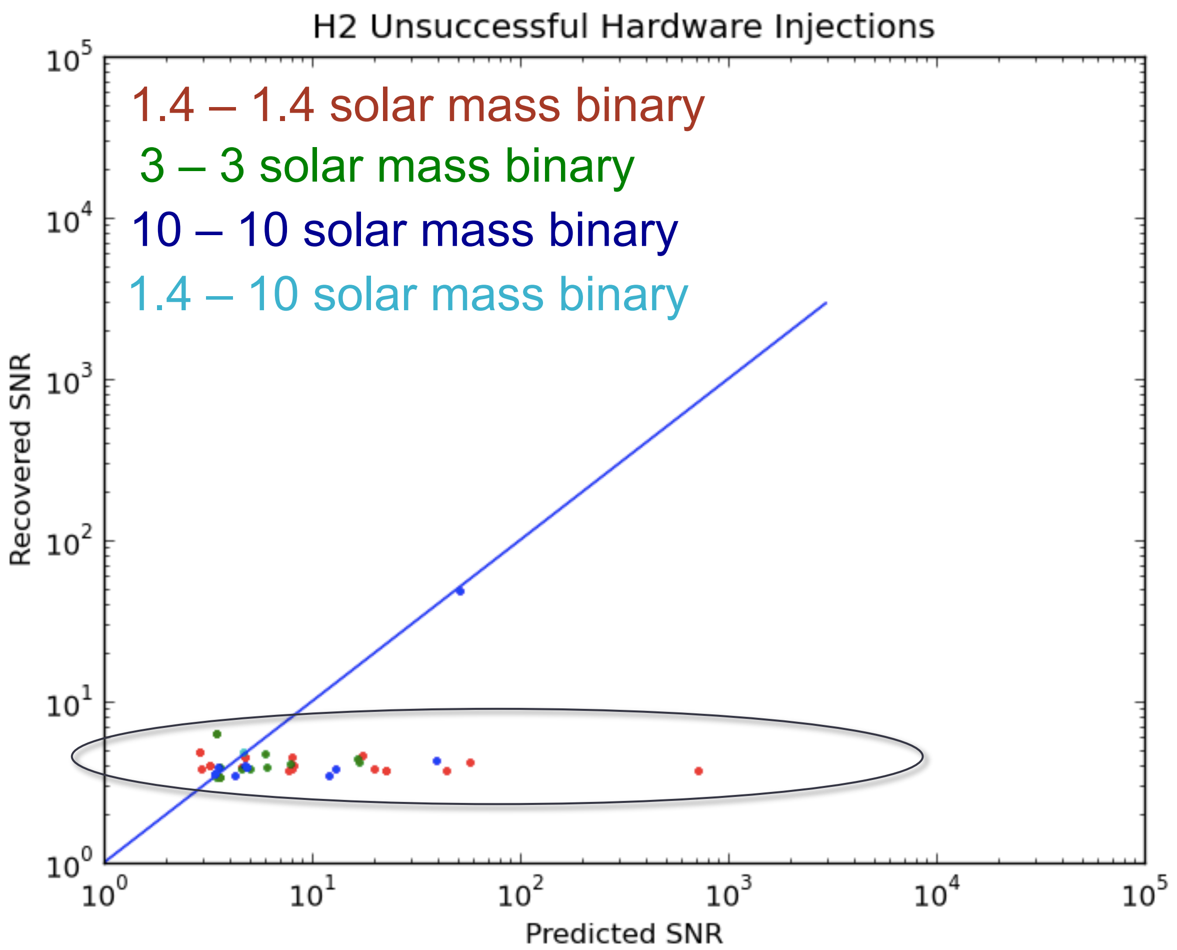

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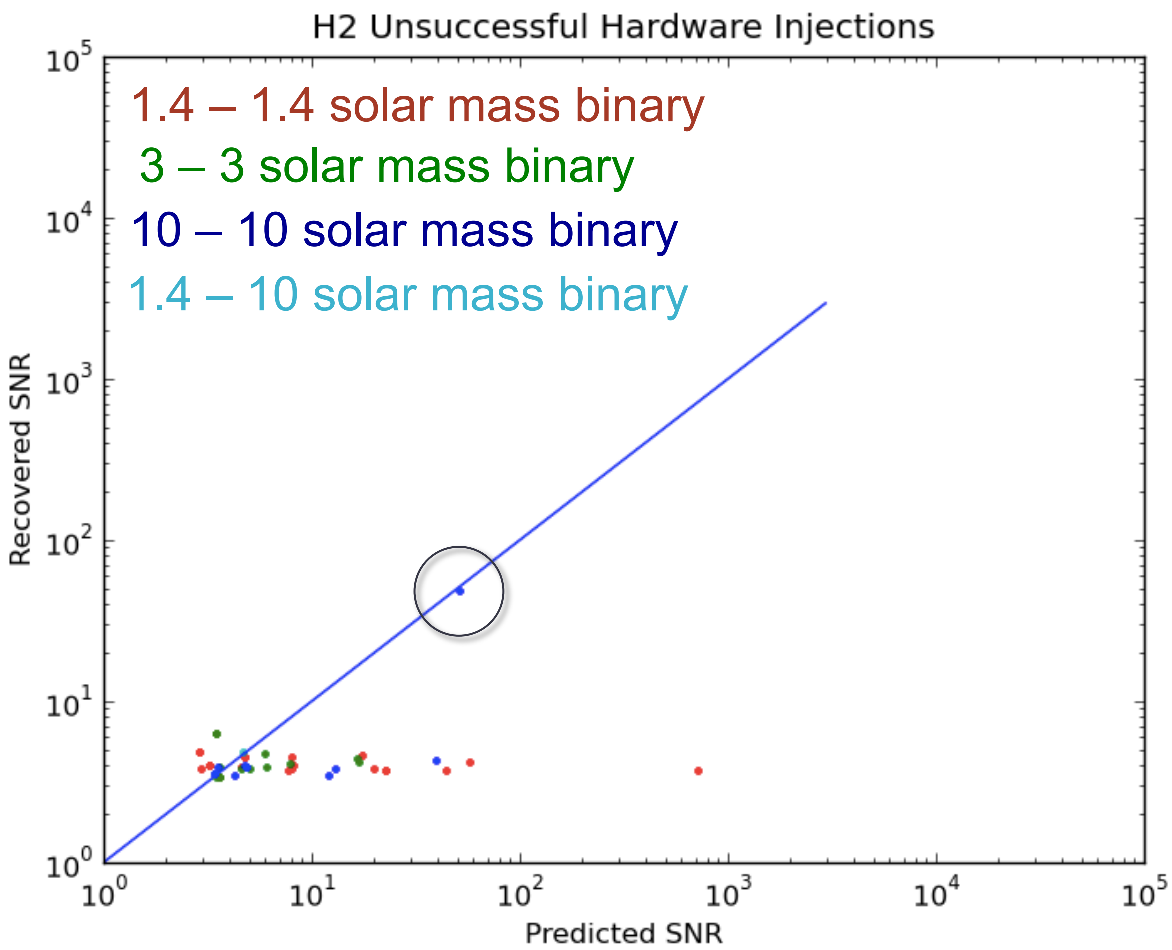

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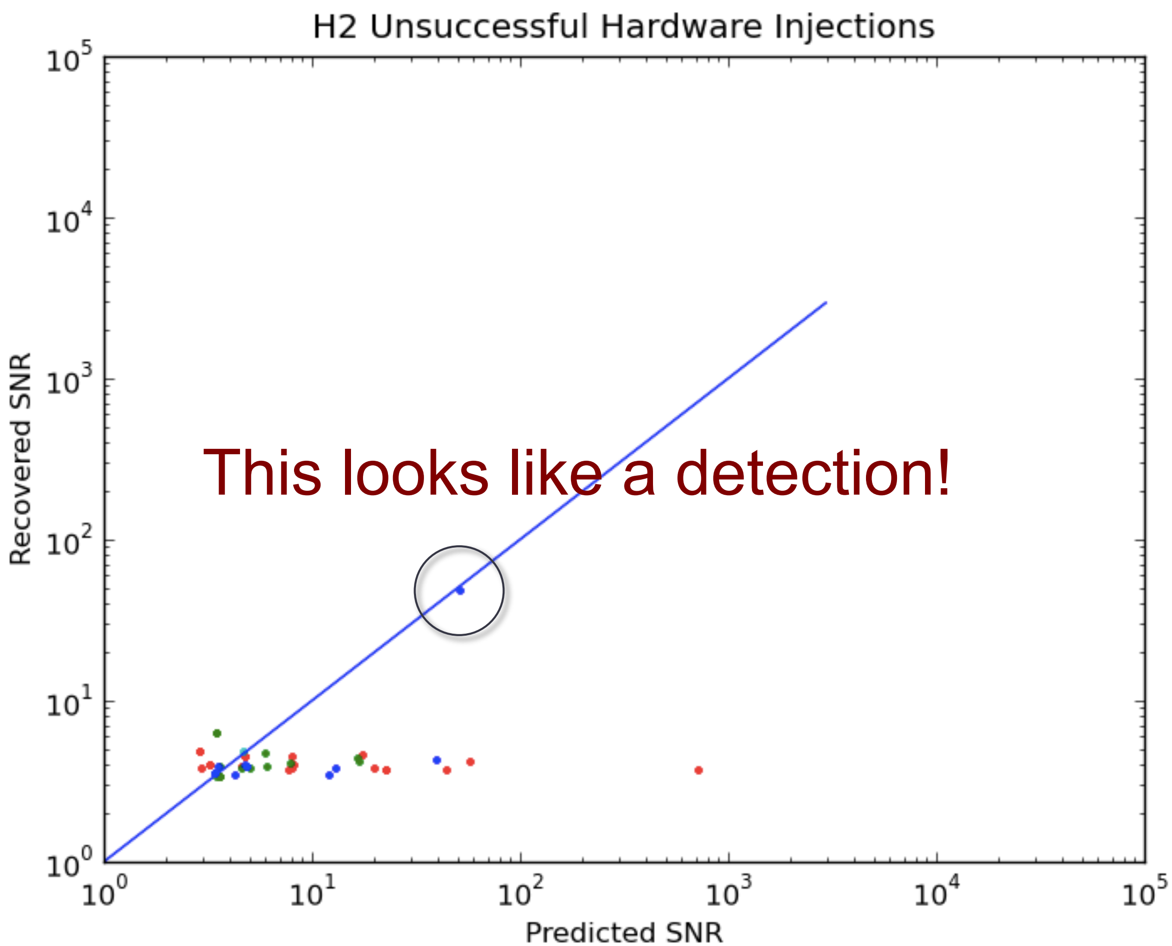
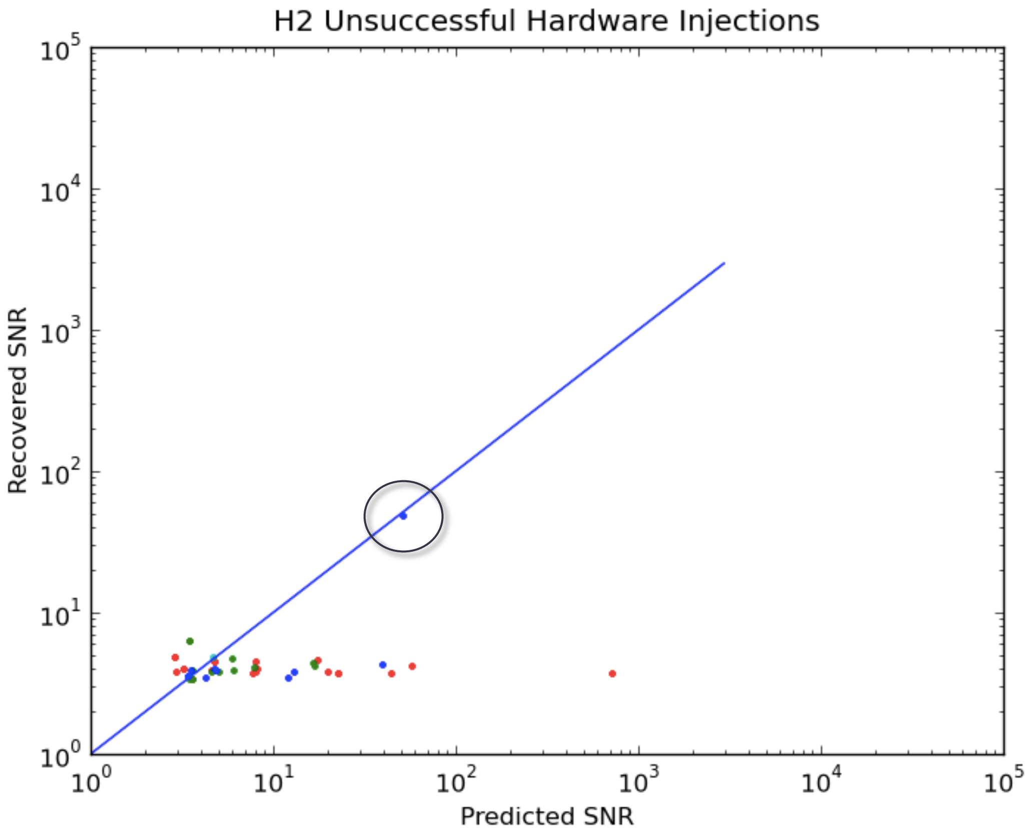


Where Did This Match Come From?

- 10 – 10 solar mass binary located 10 Mpc from Earth
- Marked Injection Compromised



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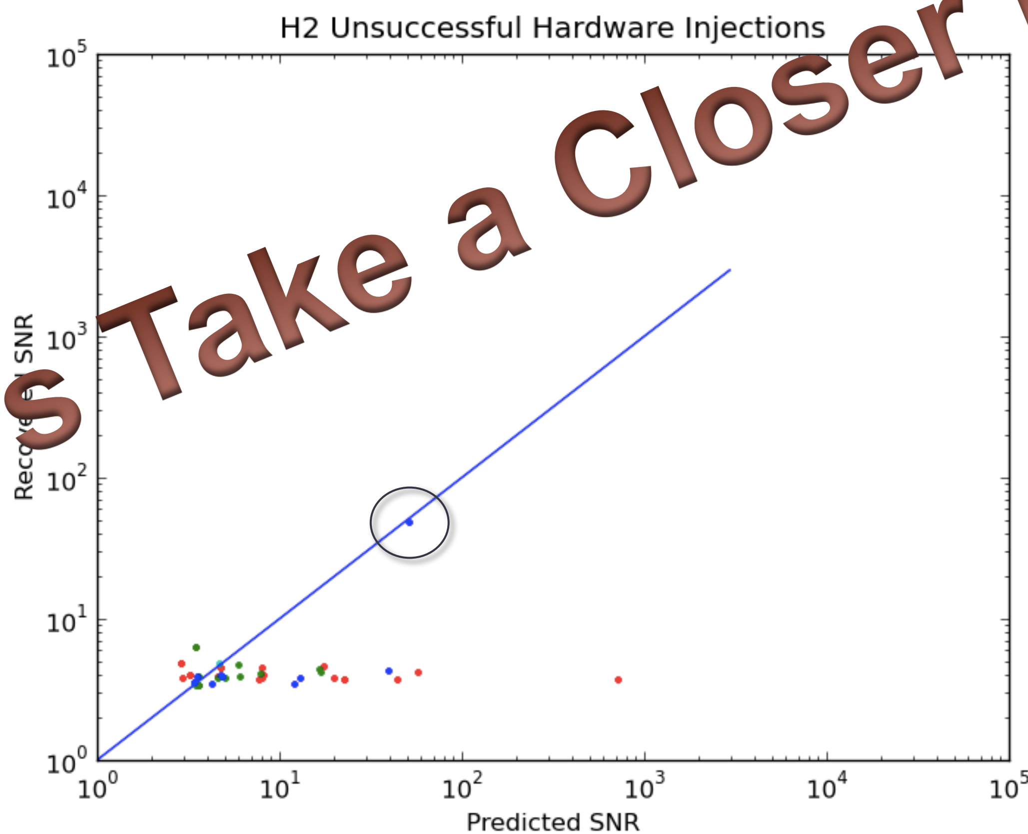
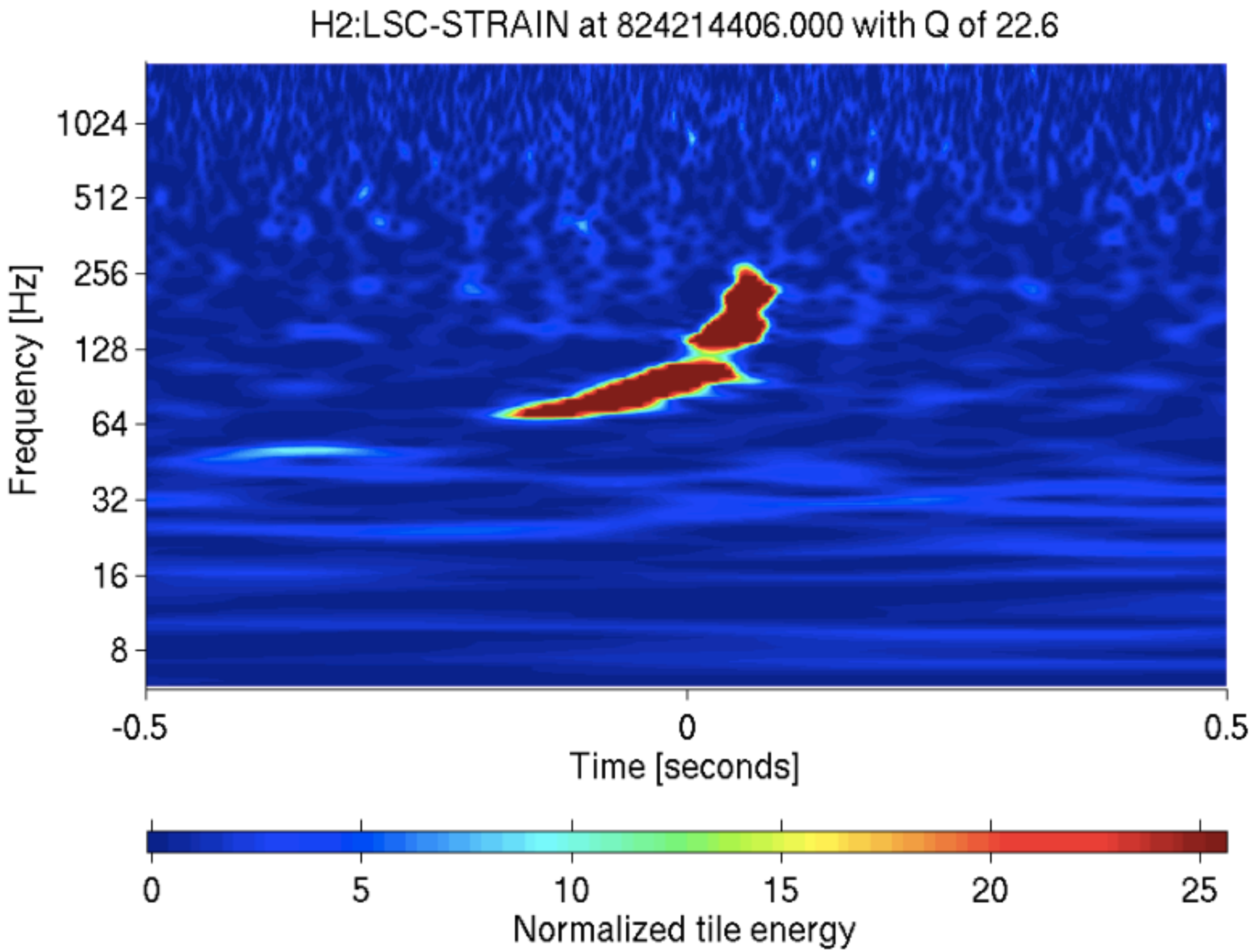
Let's Take a Closer Look!



Spectrogram of The Injection



Summary Table of Final Results

Detector	H1	H2	L1
Total # Injections	1200	1282	1271
Successful Injections	870	929	770
Successful Injections, Predicted SNR > 8	614	333	545
For Injections with Predicted SNR > 8, Injections with Recovered SNR > 6	608	322	538
Successful Injections, Data Unavailable	21	19	14
Unsuccessful Injections	46	45	51
Unsuccessful Injections with Recovered SNR > 6	1	3	2
Unsuccessful Injections, Data Unavailable	263	289	436

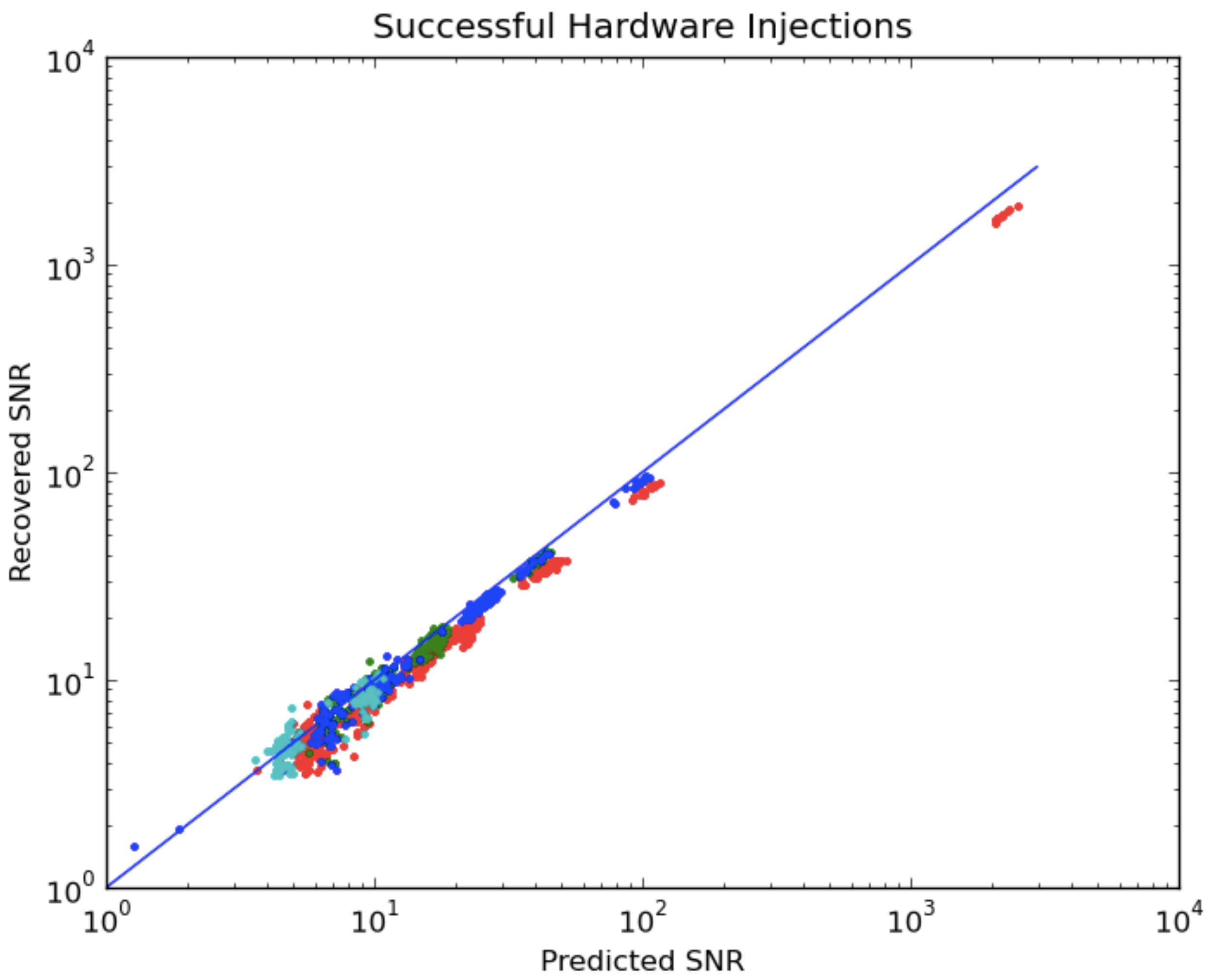
Conclusions

- LOSC will release S5 data to the public
- We search the data for hardware injections
- Our search is successfully identifies whether an injection is successful or unsuccessful
- We find some injections where we do not expect to, referencing past documentation
  - i.e. the detection we discussed
- We will continue to explain these unexpected points and summarize them in the final paper

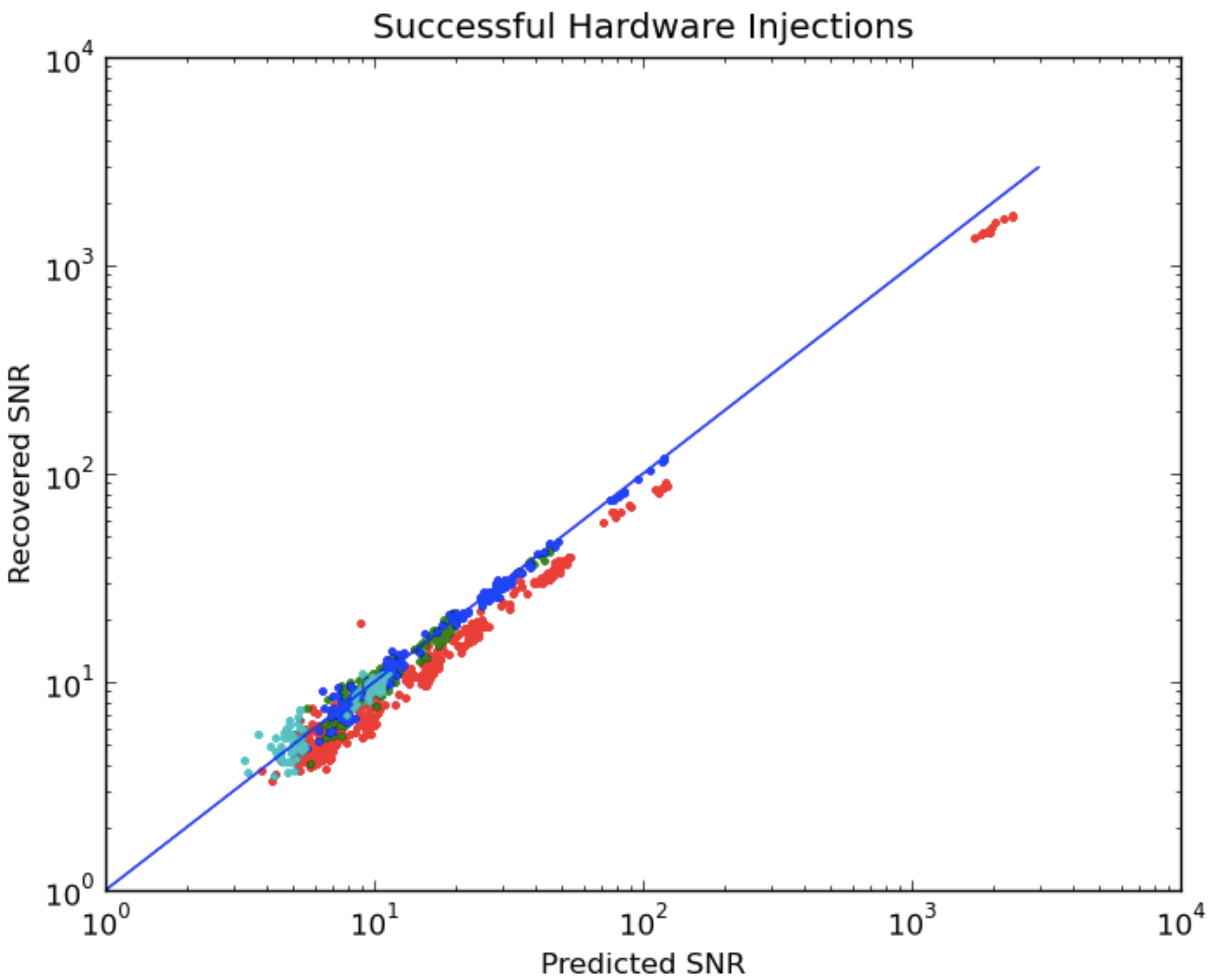
Acknowledgements

- Mentors: Jonah Kanner, Roy Williams, and Michele Vallisneri
- Collaborators: Alan Weinstein and LOSC
- LIGO and National Science Foundation
- Caltech

H1 Successful Injections



L1 Successful Injections



Template Matching: Signal-to-Noise

$$\rho_m(t) = \frac{|z_m(t)|}{\sigma_m}$$

- $\rho_m(t)$ – Amplitude signal to noise ratio of matched filter output
- z(t) – Matched filter output
- σ_m – A measure of the sensitivity of the instrument

$$\rho_{Predicted} = \frac{\sigma_m}{D_{eff}}$$

- $\rho_{Predicted}$ – Predicted signal-to-noise ratio
- D_{eff} – Effective distance from source to Earth

Template Matching: Matched Filter Math

$$z(t) = 4\int_0^\infty \frac{\tilde{s}(f)\tilde{h}^*_{\text{template}}(f)}{S_n(f)} \mathrm{e}^{2\pi i f t} df.$$

- z(t) – Matched filter output
- $\tilde{s}(f)$ - Data in frequency domain
- $\tilde{h}^*_{\text{template}}(f)$ - Complex conjugate of template
- $S_n(f)$ - Power Spectral Density of noise