Searching for gravitational waves from compact binary systems in "real" (LIGO) data

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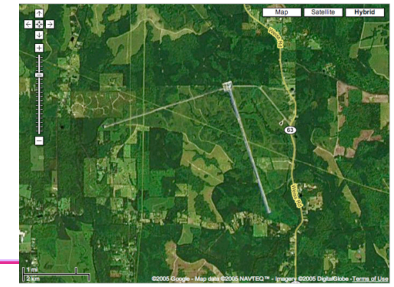
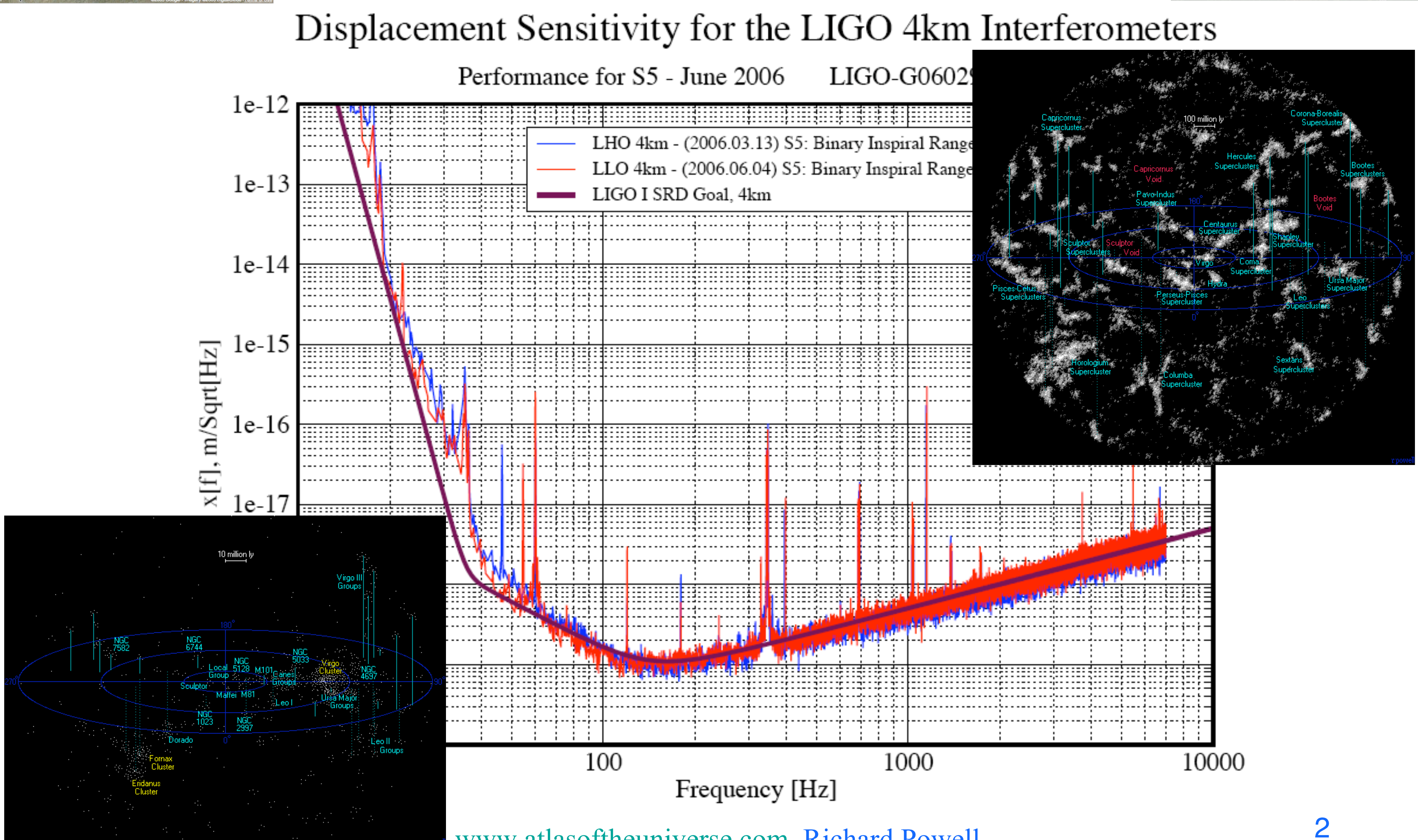
IHP-CEB, Gravitational Wave Data Analysis

Paris, November 17 2006

LIGO-G060683-00-Z

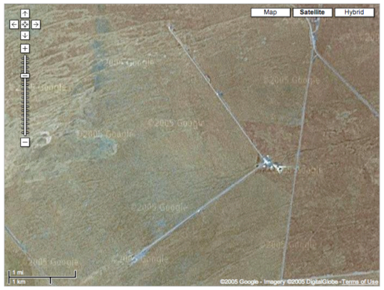
LIGO Current sensitivity

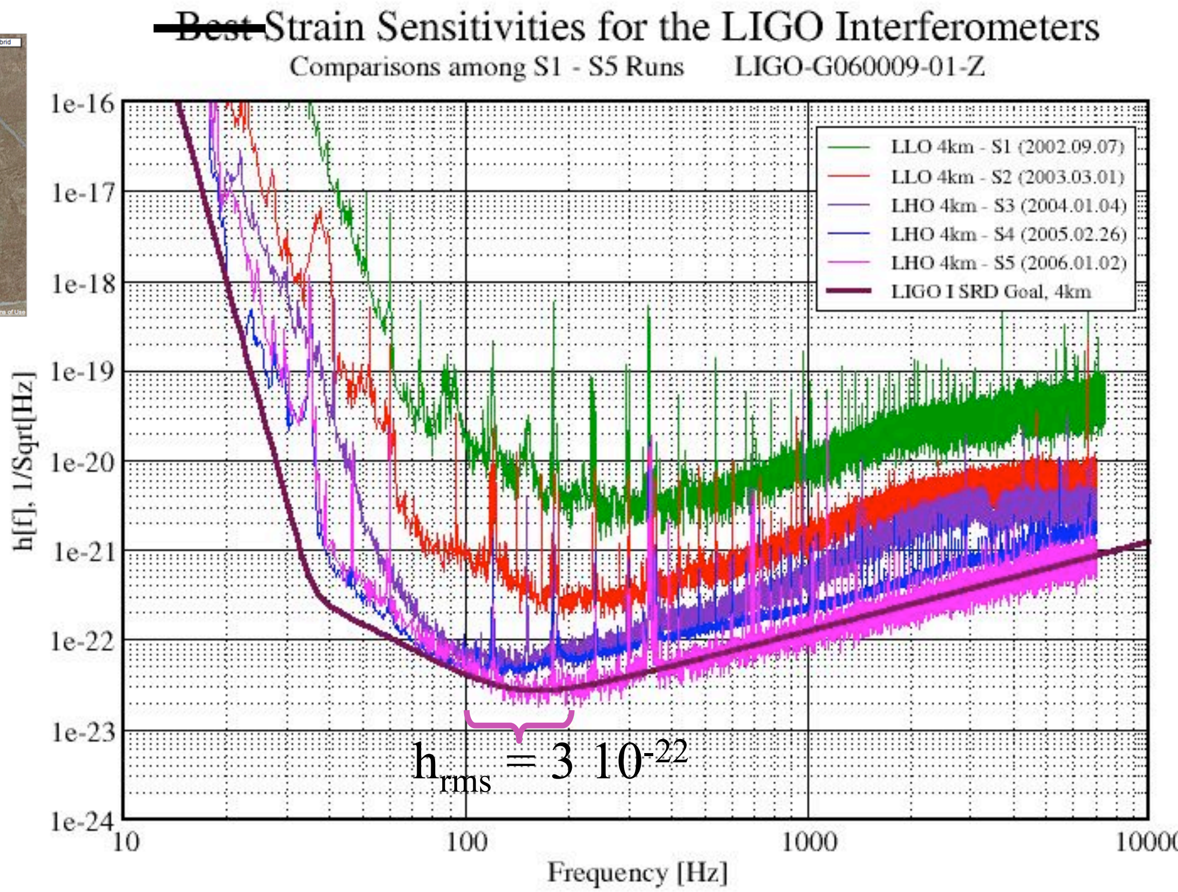


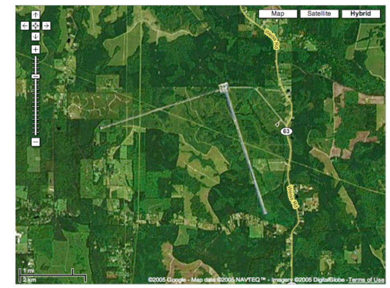


www.atlasoftheuniverse.com, Richard Powell

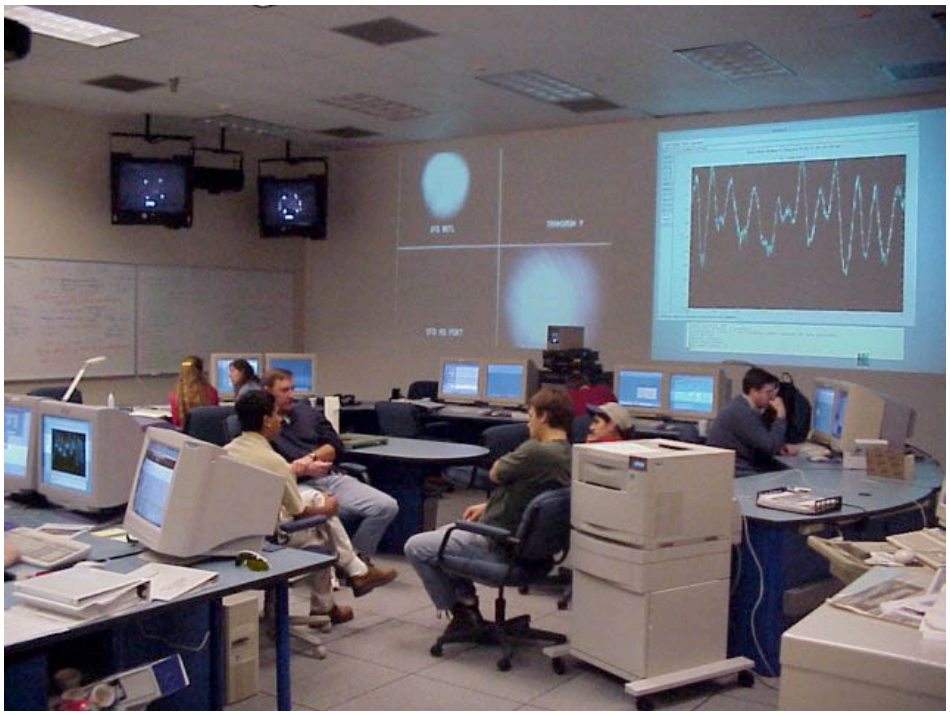
Steady progress: S1-S5

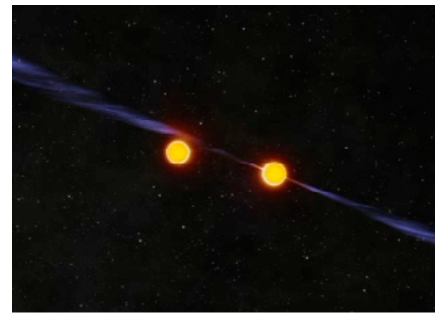




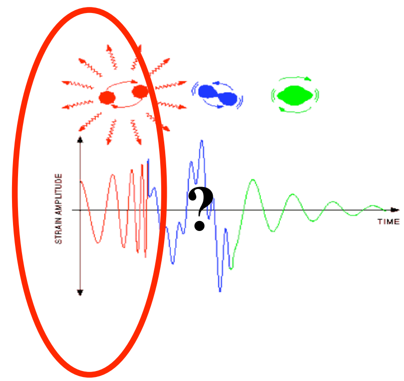


Look for binary systems: easy!?

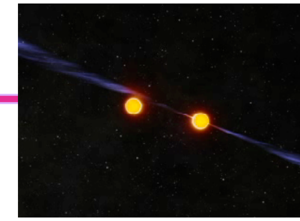




John Rowe, CSIRO



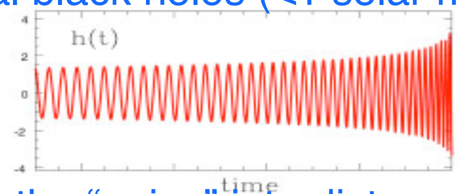
Search for binary systems

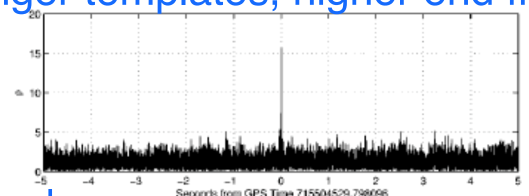


Use calculated templates for inspiral phase (“chirp”) with optimal filtering.

Search for systems with different masses:

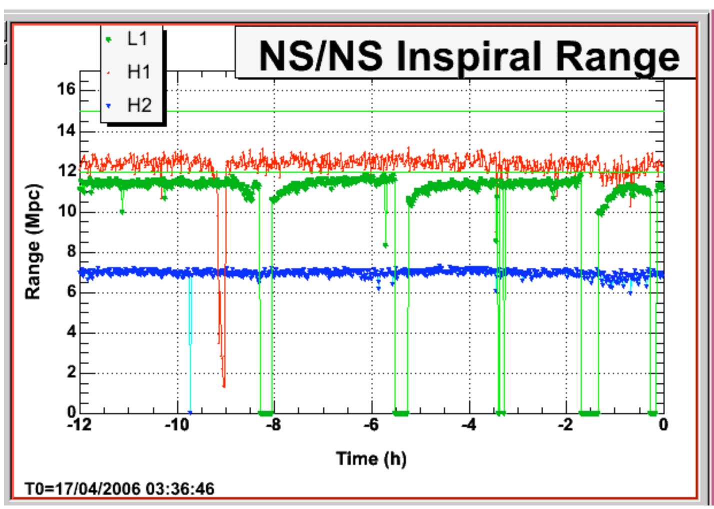
- » Binary neutron stars (~1-3 solar masses): ~15 sec templates, 1400 Hz end freq
- » Binary black holes (< ~30 solar masses): shorter templates, lower end freq
- » Primordial black holes (<1 solar mass): longer templates, higher end freq



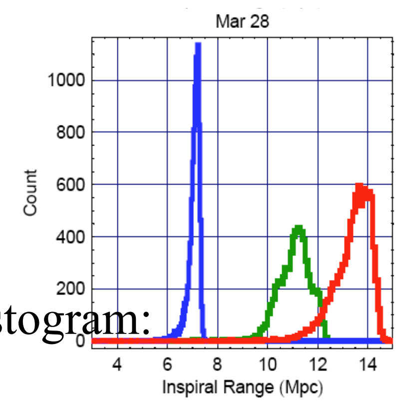


We can translate the “noise” into distances surveyed.

We monitor this in the control room for binary neutron stars:



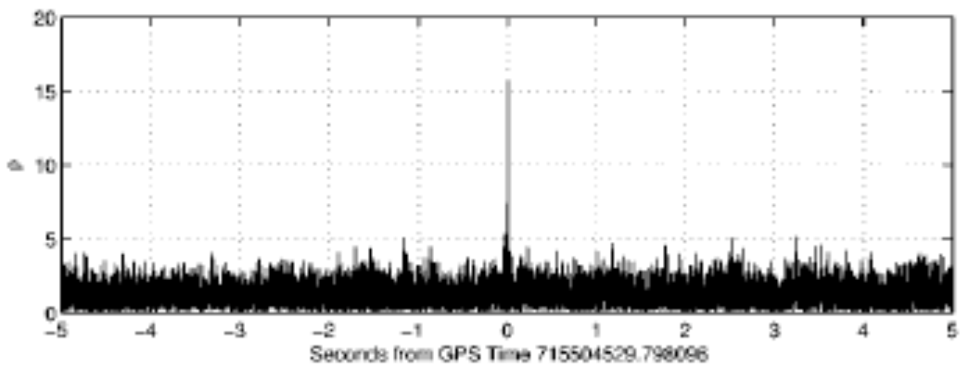
A week’s histogram:



If system is optimally located and oriented, we can see even further: we are surveying <u>hundreds of galaxies</u>!

SNR = false alarm?

- The quantity ρ^2 has a χ^2 distribution with two degrees of freedom : $\mathrm{pdf}(\rho)=\rho\exp(-\rho^2/2)$.
- The median value of this distribution for ρ^2 is two (with a variance of four).
- The cumulative probability that ρ is larger than some value ρ^* is $\exp(-\rho_*^2/2)$.
- The probability that a SNR time series has a value with SNR > 6 is ~1.5e-8.
- Using a 10 ms sampling time, a given template will fire an SNR > 6 once every 8 days.
- Using two detectors, the probability of a given template triggering in both detectors with SNR>6 is $(\exp(-6^2/2))^2$~2.3e-16
- Using two detectors, a given template will trigger in both detectors within 10ms with SNR>6 every 1,400,000 years.
- Using 1,000 templates, there will be a simultaneous firing of any template with SNR>6 once every ~140 years.

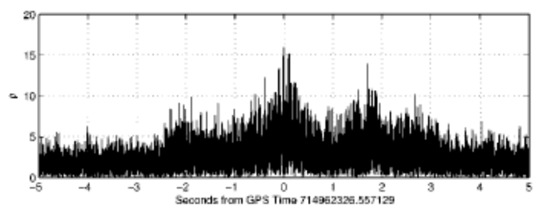


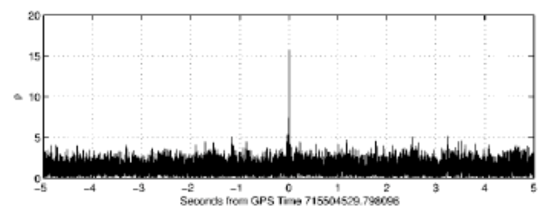
S1 BNS search

Analysis of LIGO data for gravitational waves from binary neutron stars, The LIGO Scientific Collaboration, Phys. Rev. D 69, 122001 (2004)

Use triggers from H 4km and L 4km interferometers:

- » *T = 295.3 hours analyzed (~12 days)*
- » *Max SNR observed:* ***15.9****(!)* in L1 only
- » There were no event candidates in the double or triple coincidence category (with SNR>8); there were ~1,000 triggers in L1 with SNR>8



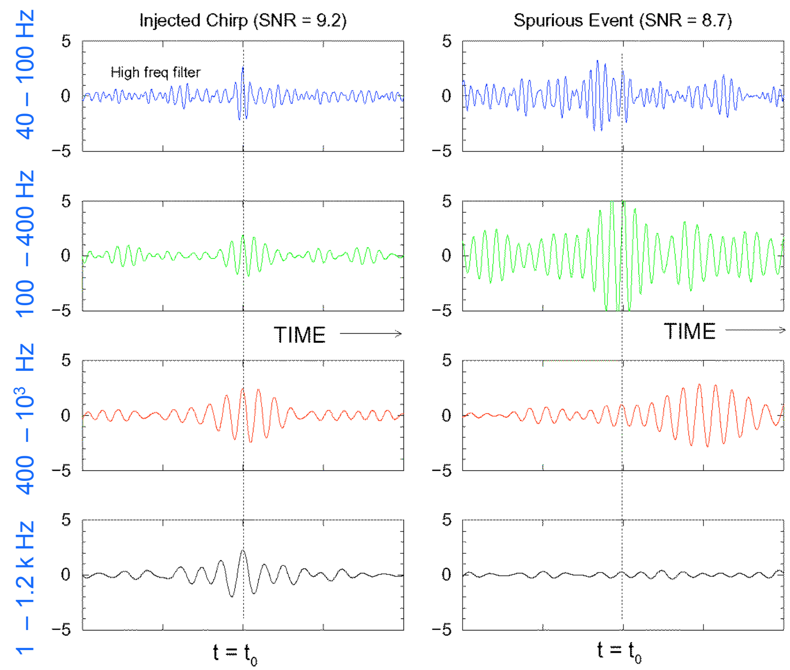


Signal Based Vetoes

- We use signal based vetoes to check that the matched filter output is consistent with a signal
- If we have enough cycles, one of the strongest vetoes is the χ^2 veto

$$\chi^2 = p \sum_{i=1}^{p} \left(\rho_{c,l} - \frac{\rho_c}{p}\right)^2 + \left(\rho_{s,l} - \frac{\rho_s}{p}\right)^2$$

$$\frac{\chi^2}{p + \delta^2 \rho^2} < \text{threshold}$$



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» *Max SNR observed:* ***15.9****(!)* in L1 only

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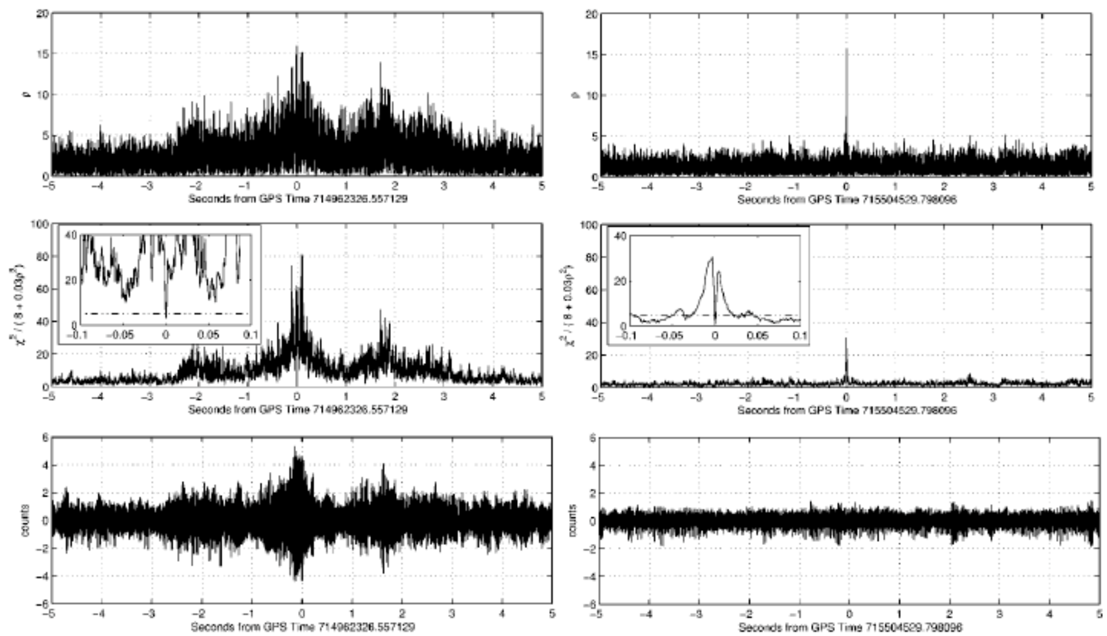

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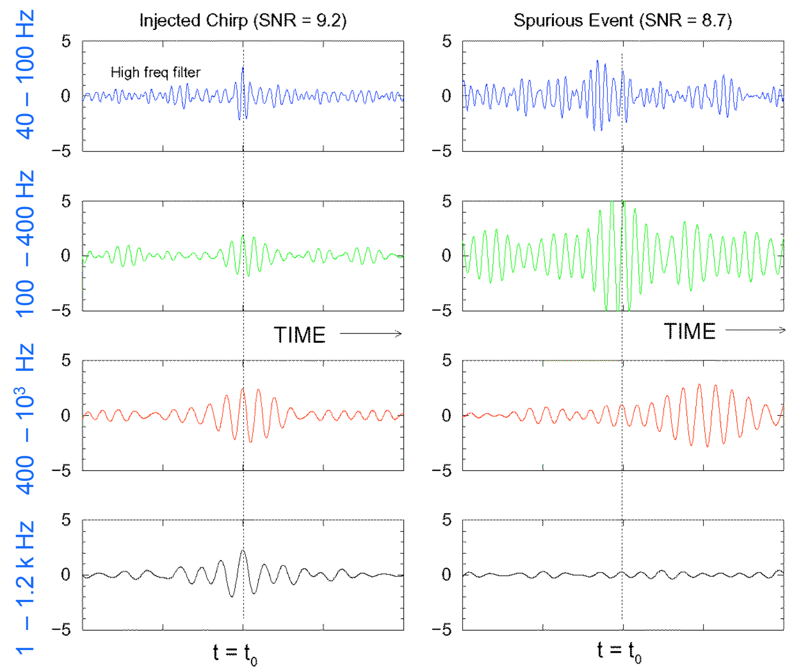
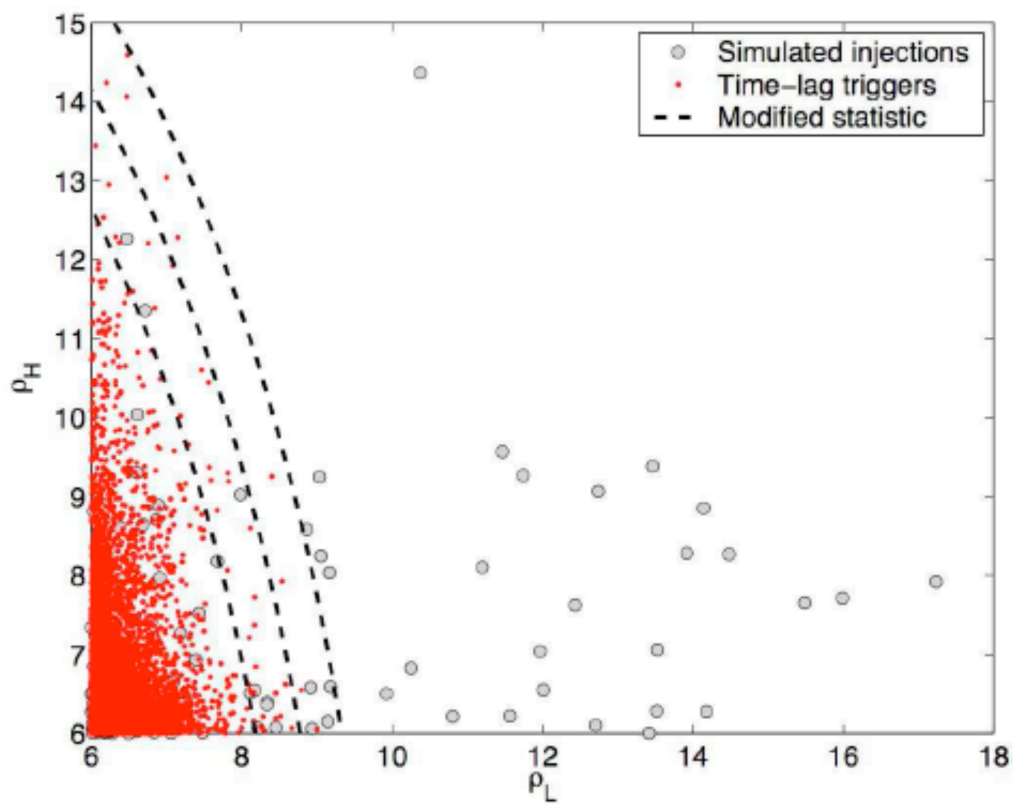


Others in the works… χ^2 time series, template bank ringing,… plus reduction of transients, with better instruments and better vetoes

S2 BNS search

"Measure" the non gaussian background with "time-shifts"
Non gaussian noise in both detectors,
but non-symmetric noise!

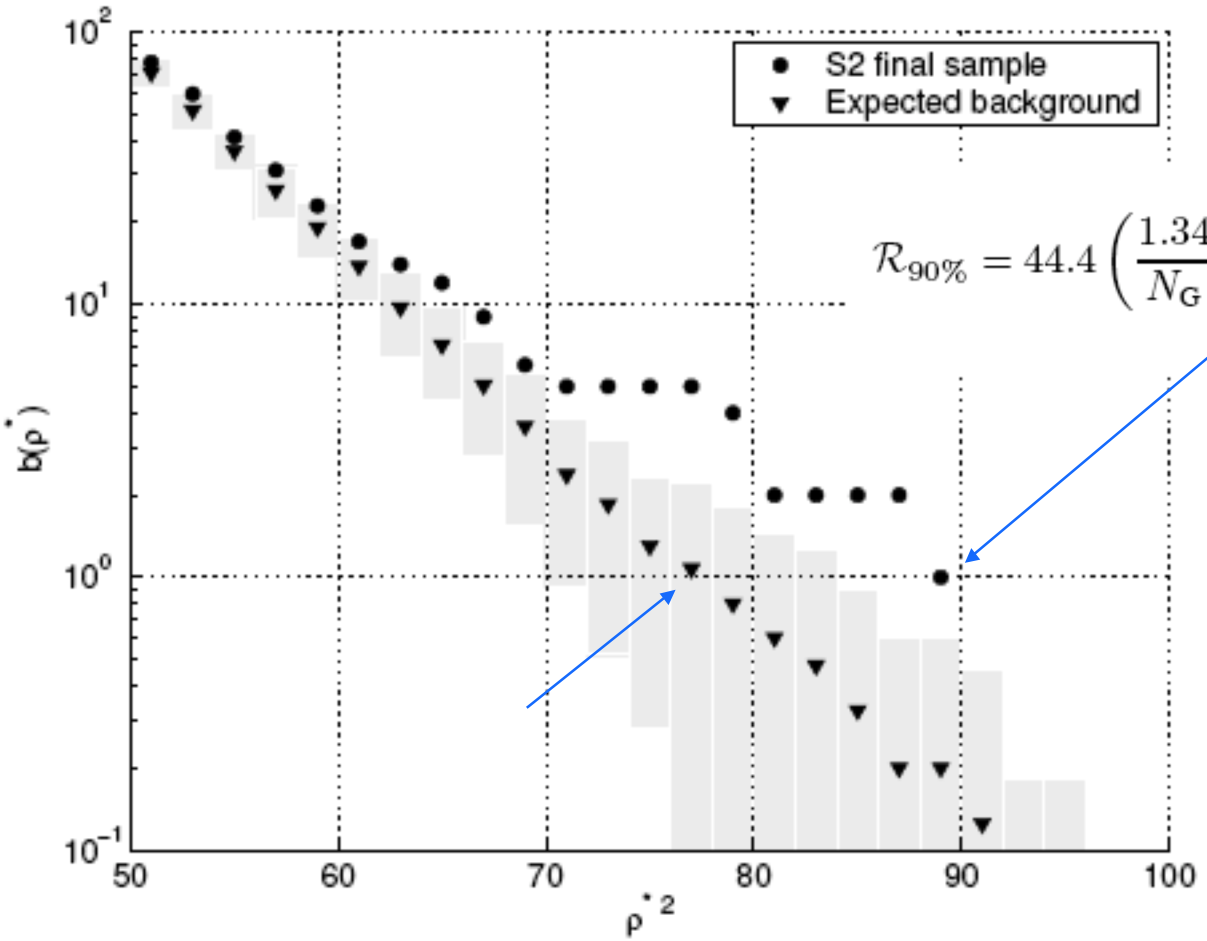


Search for Gravitational Waves from galactic and extra-galactic binary neutron stars , (LIGO Scientific Collaboration), Phys. Rev. D. 72, 082001 (2005)

$$\rho = \sqrt{\rho_L^2 + \rho_H^2/4}$$

~ 350 hours,
100 time shifts

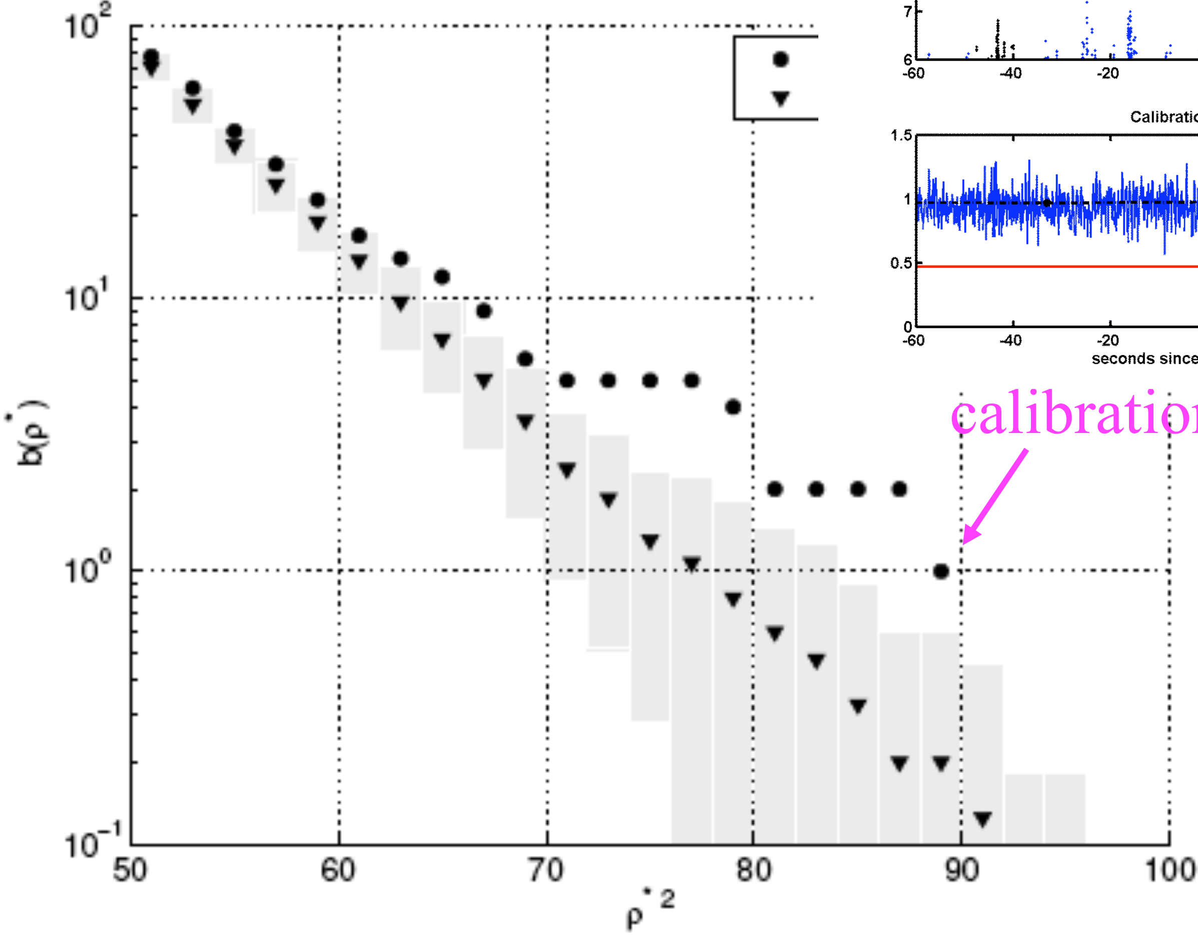
S2 BNS search

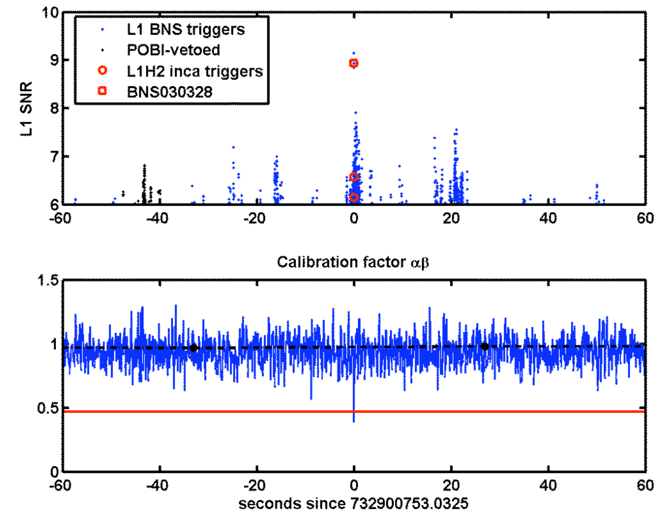


$$\mathcal{R}_{90\%} = 44.4 \left(\frac{1.34}{N_G}\right) \text{y}^{-1}\ \text{MWEG}^{-1} .$$

Prob that ρ>85 in 350 hours is 1!

S2 BNS search

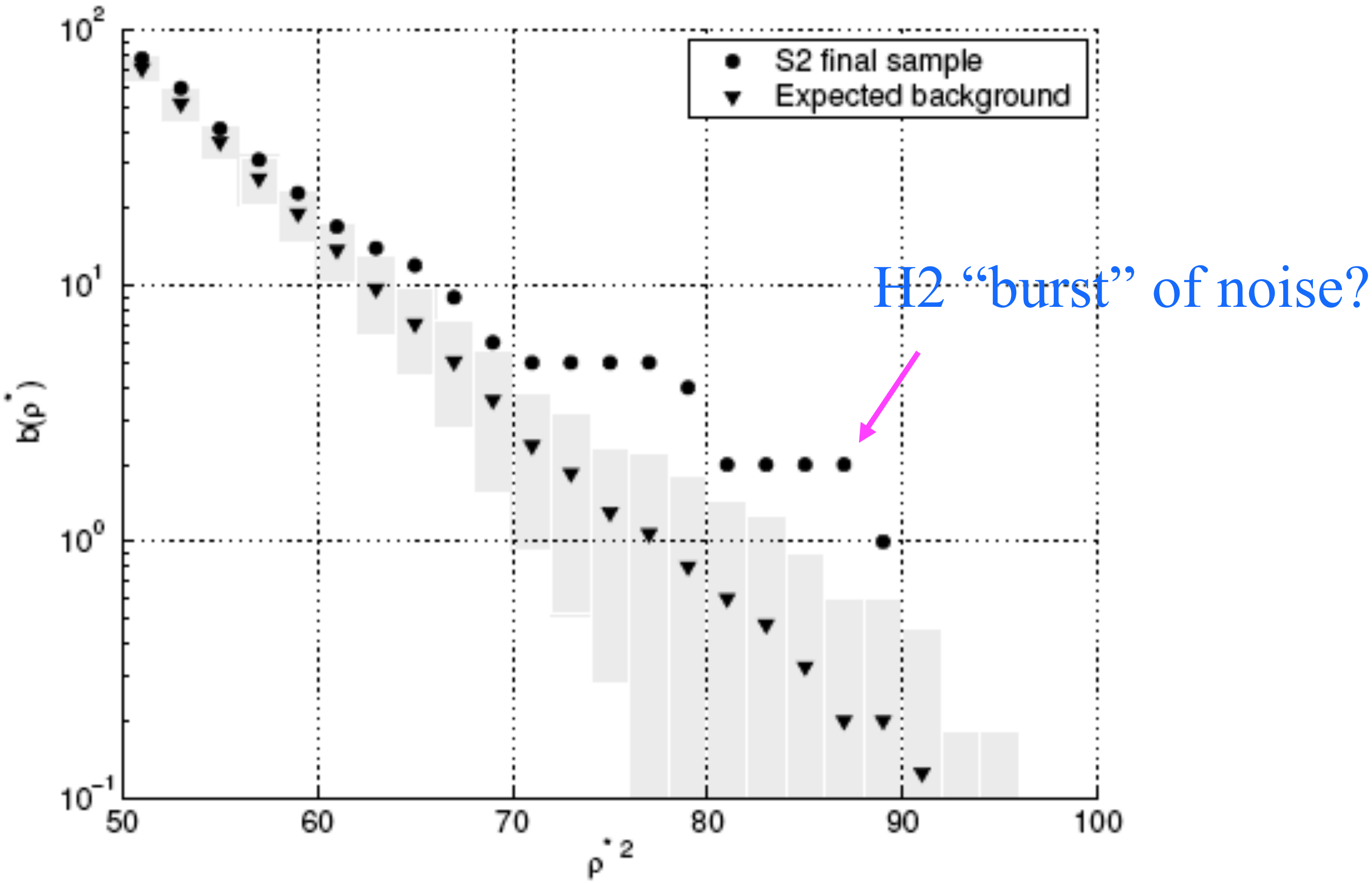




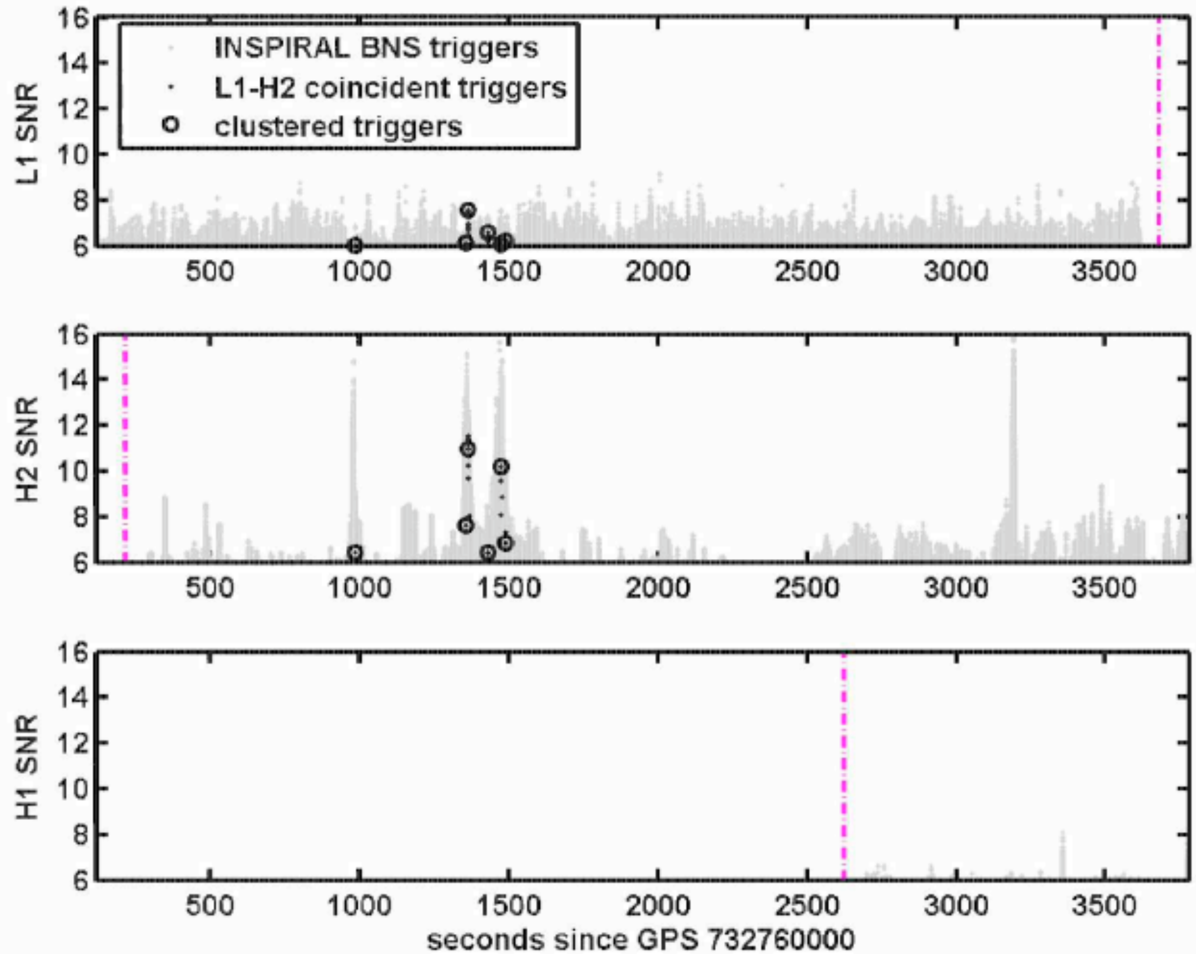
calibration "glitch"

$\rho_c = 9.4$

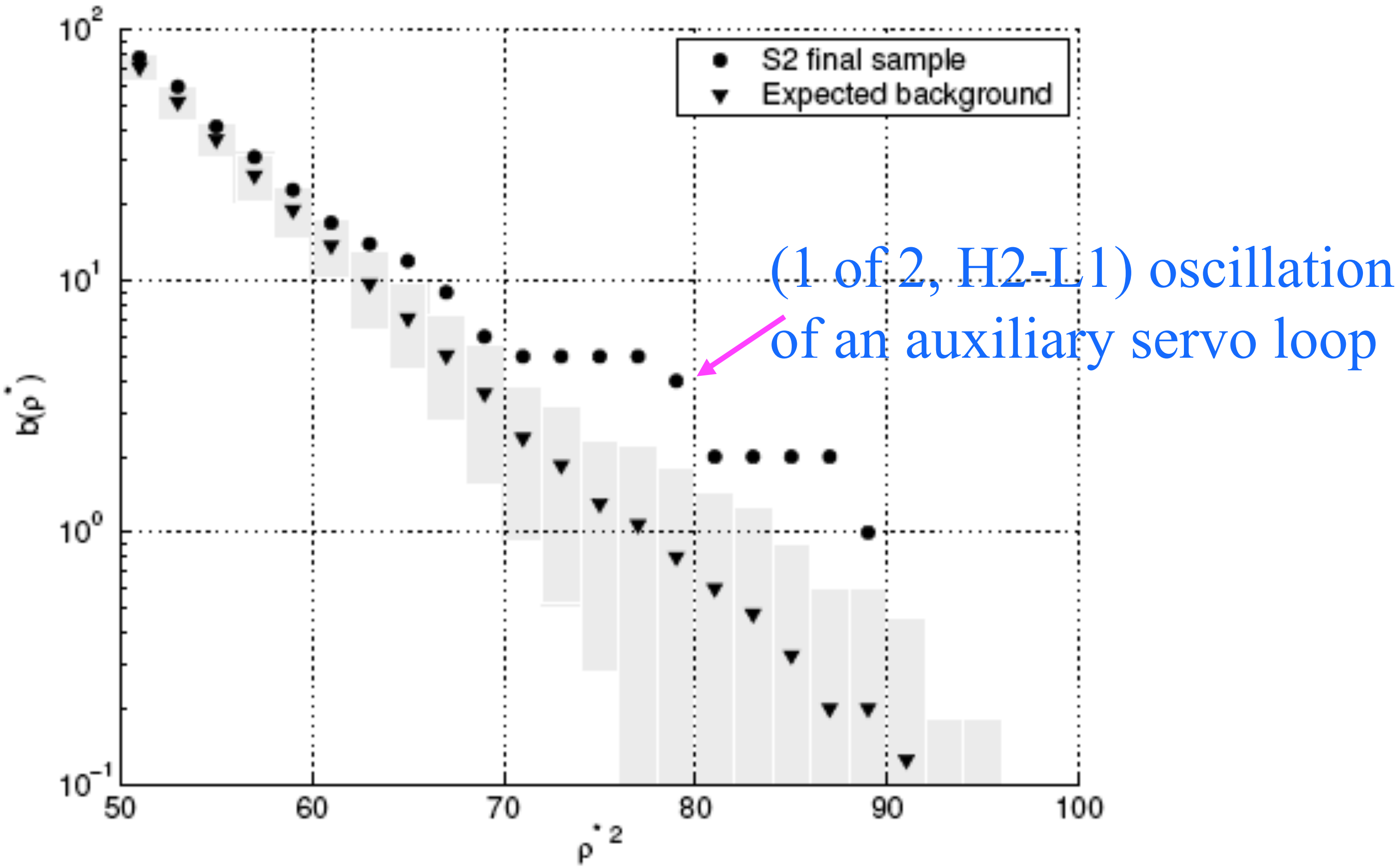
S2 BNS search



S2 H2-L1 “candidate”

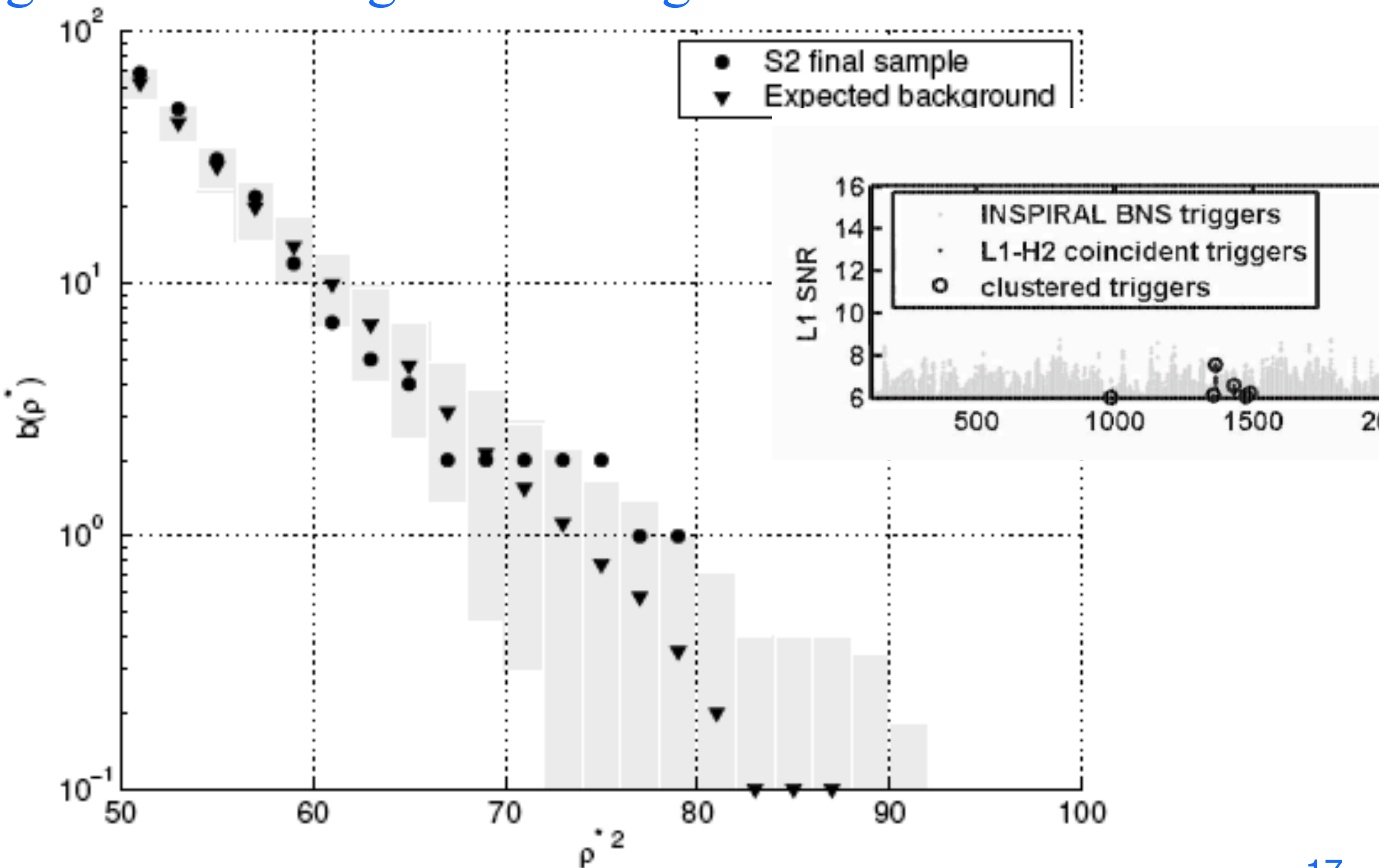


S2 BNS search

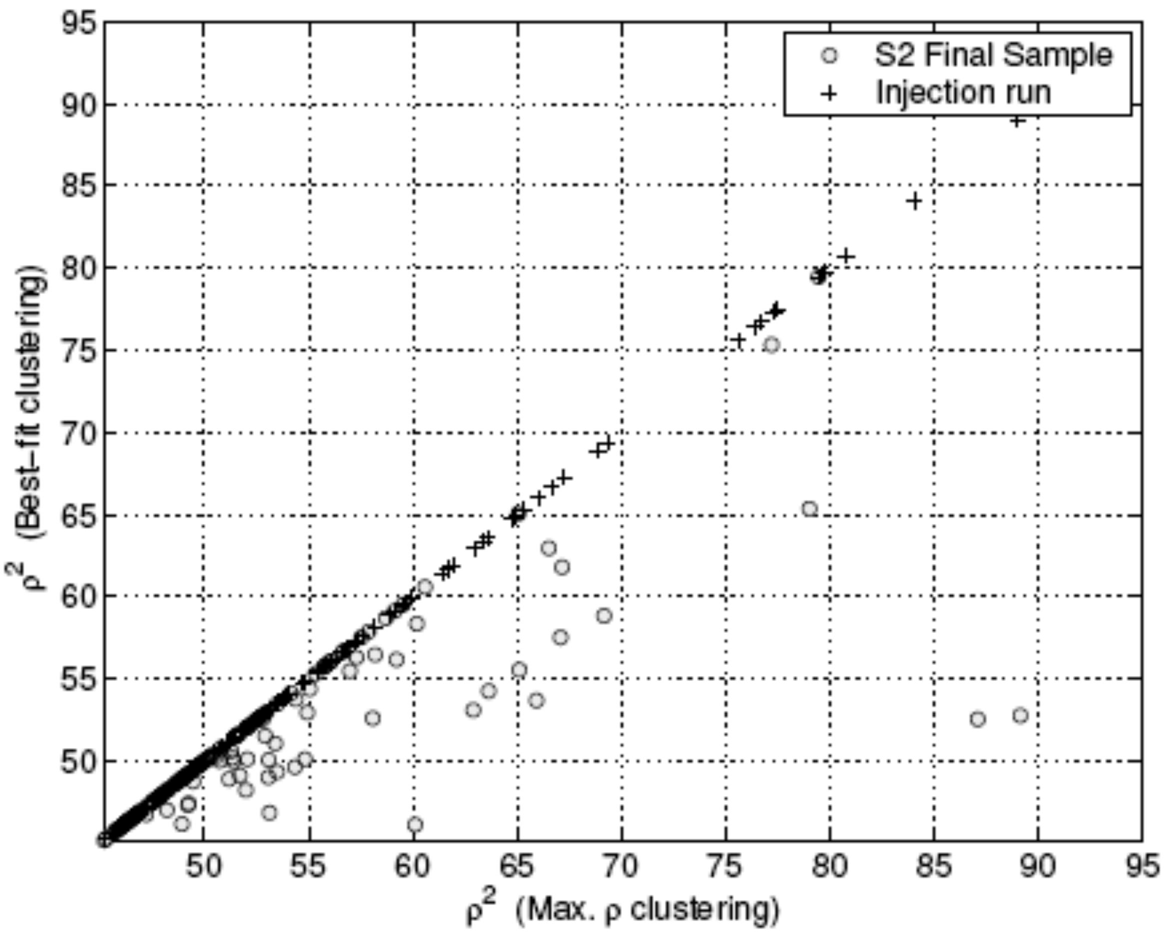


How to choose templates

"Cluster" choosing min chi^2 (not max SNR): foreground vs background changes!



Clustering choices

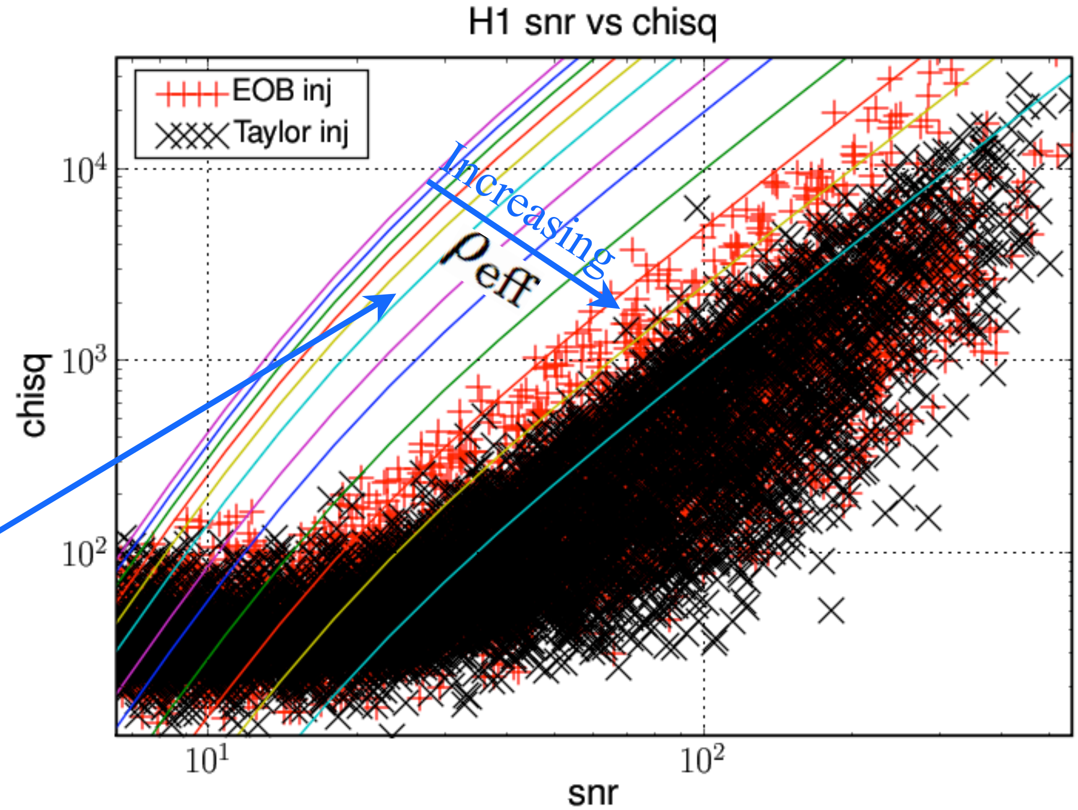


True signals don't care, but false alarms do!

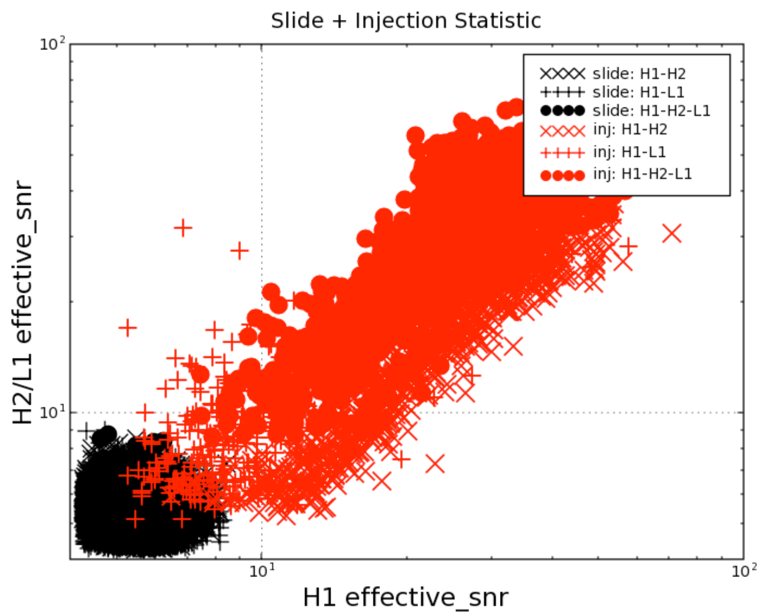
S3/S4/S5: Effective SNR

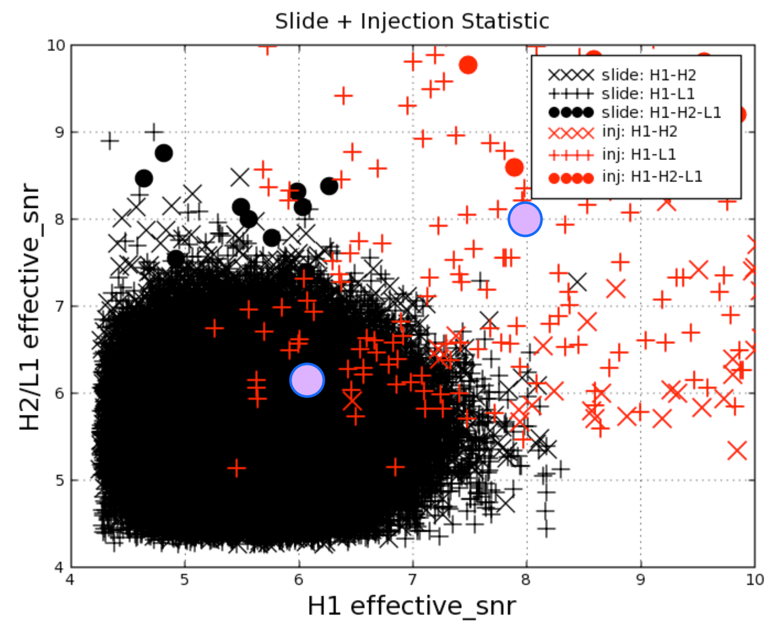
$$\rho^2_{\mathrm{effective}} = \rho^2 \Bigg/ \sqrt{\left(\frac{\chi^2}{2p-2}\right)\left(1+\frac{\rho^2}{250}\right)}$$

Lines of constant effective snr, ρ_{eff}



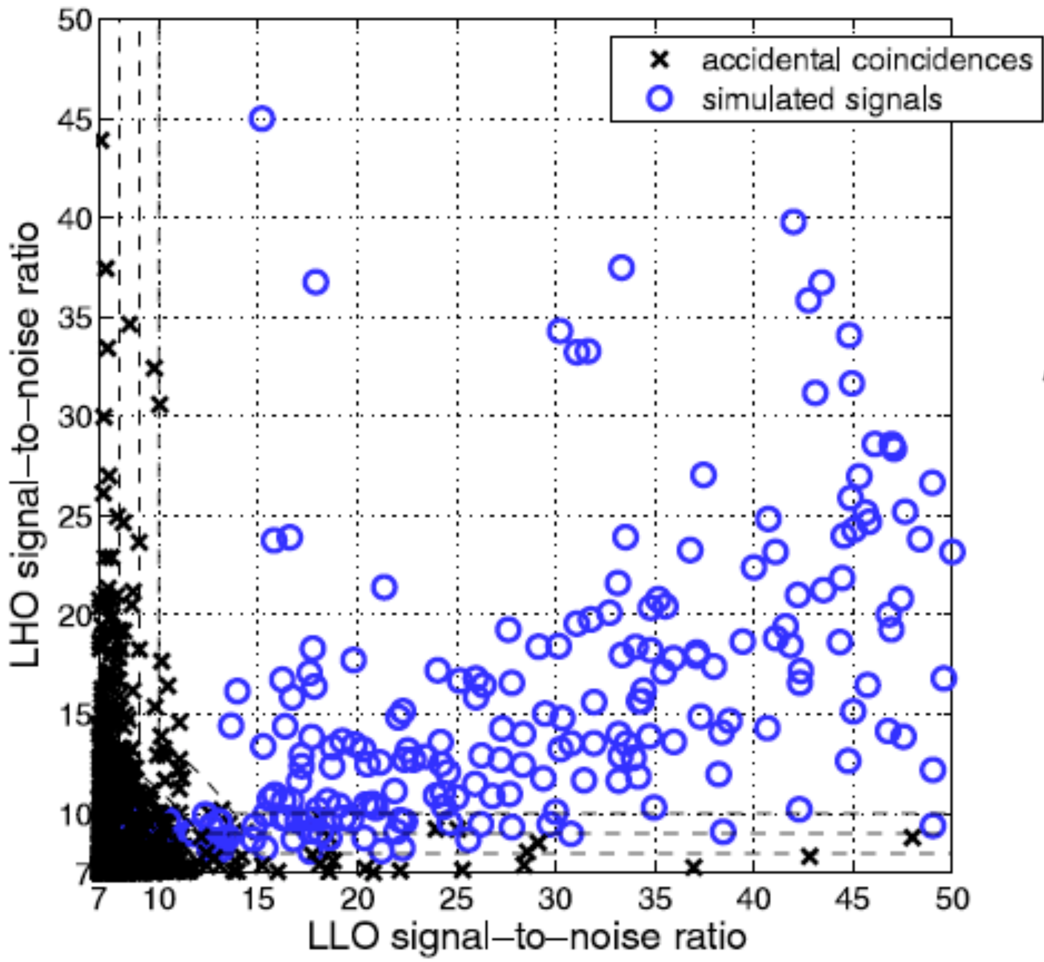
Effective SNR





$$\rho^2_{\text{effective}} = \rho^2 \Bigg/ \sqrt{\left(\frac{\chi^2}{2p-2}\right)\left(1+\frac{\rho^2}{250}\right)}$$

S2 BBH search

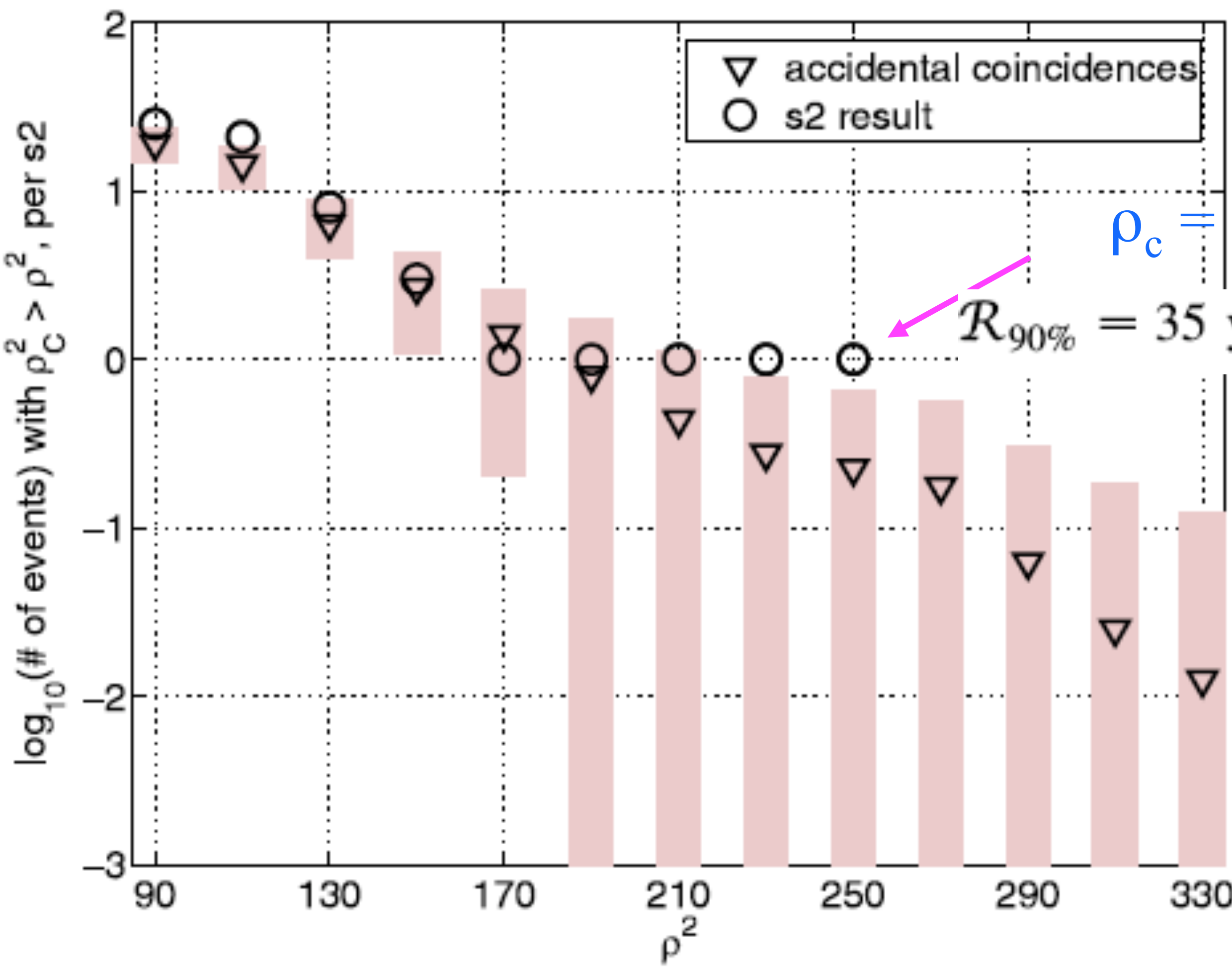


No χ^2, no eff snr

$$\rho_C = \min\{\sqrt{\rho_L^2 + \rho_H^2}, 2\rho_H - 3, 2\rho_L - 3\}.$$

Search for gravitational waves from binary black hole inspirals in LIGO data, (LIGO Scientific Collaboration), Phys. Rev. D 73, 062001 (2006)

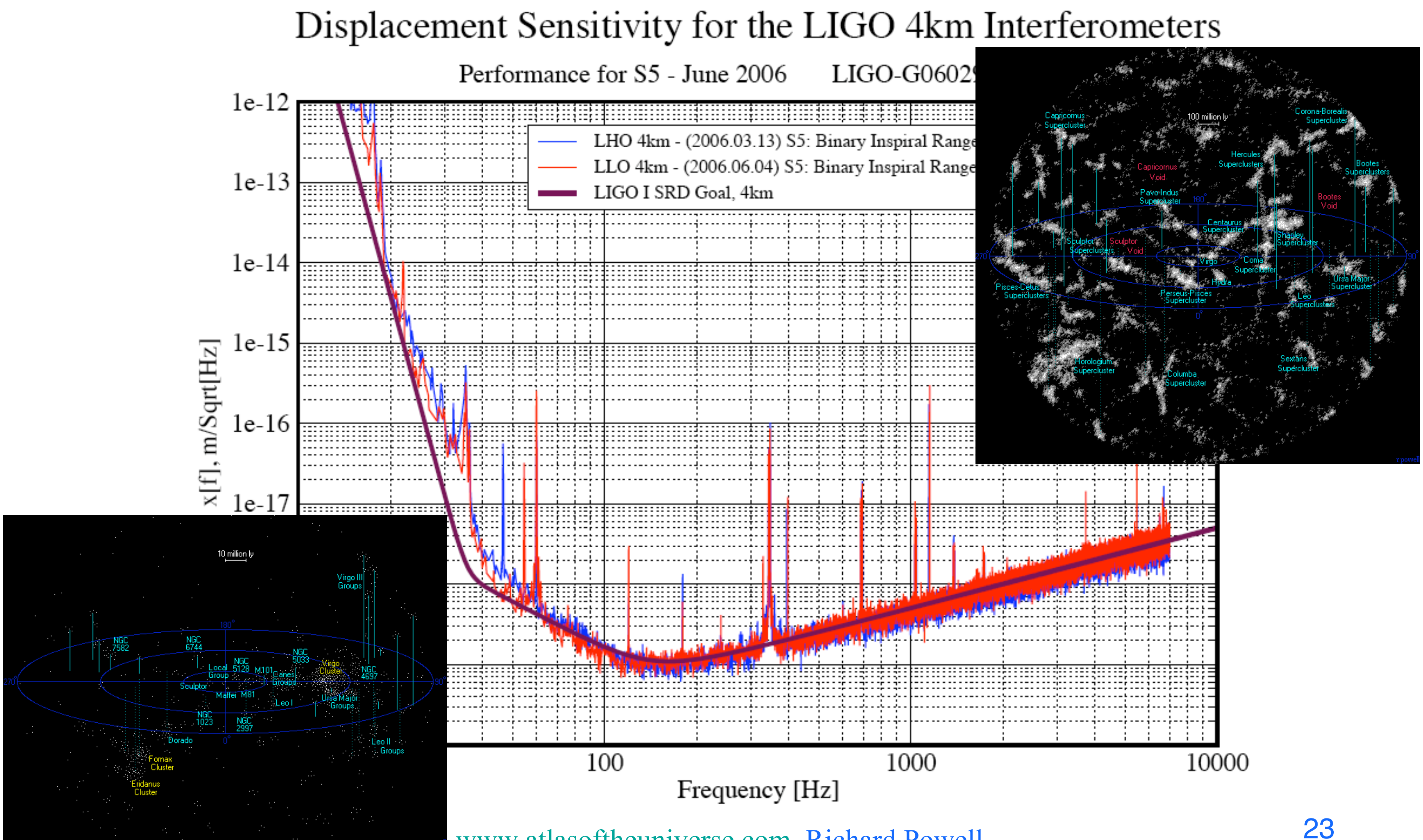
S2 BBH search



$\rho_c = 15.8$

$\mathcal{R}_{90\%} = 35\ \mathrm{yr}^{-1}\ \mathrm{MWEG}^{-1}$

Current sensitivity



www.atlasoftheuniverse.com, Richard Powell