All-sky LIGO Search for Periodic Gravitational Waves in the Fourth Science Run (S4)

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For the LIGO Scientific Collaboration

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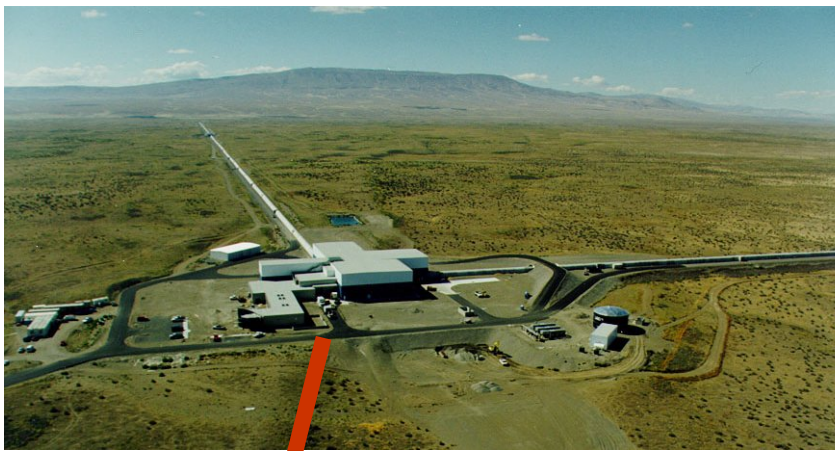
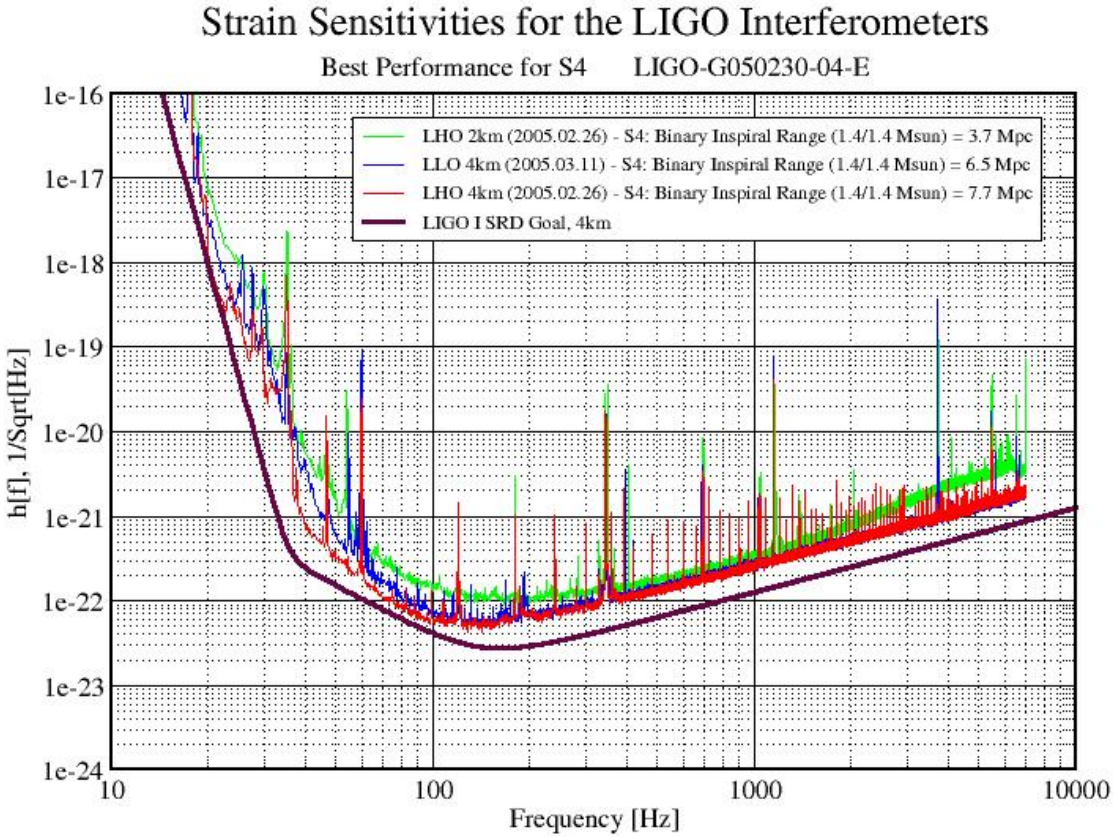
LIGO Interferometers & S4 Run Sensitivities

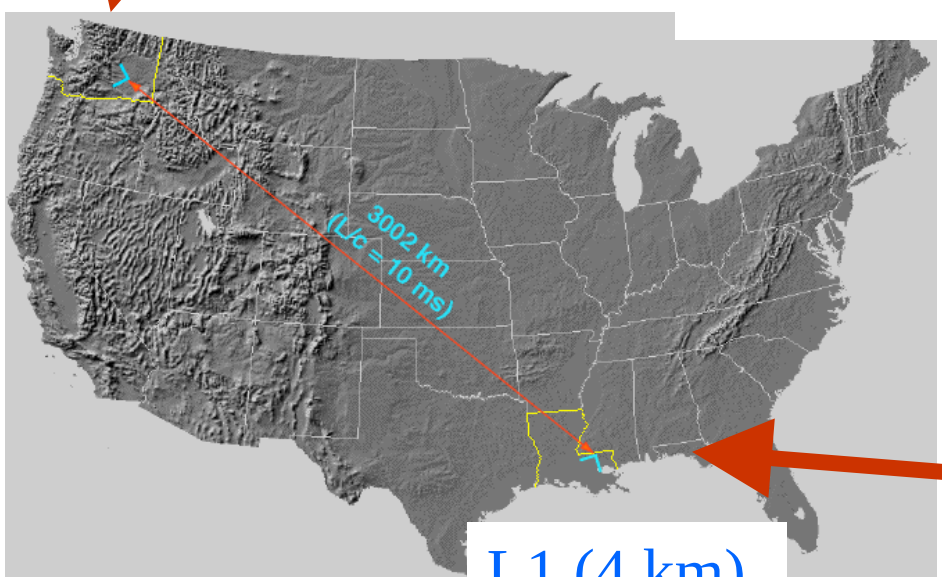
Hanford





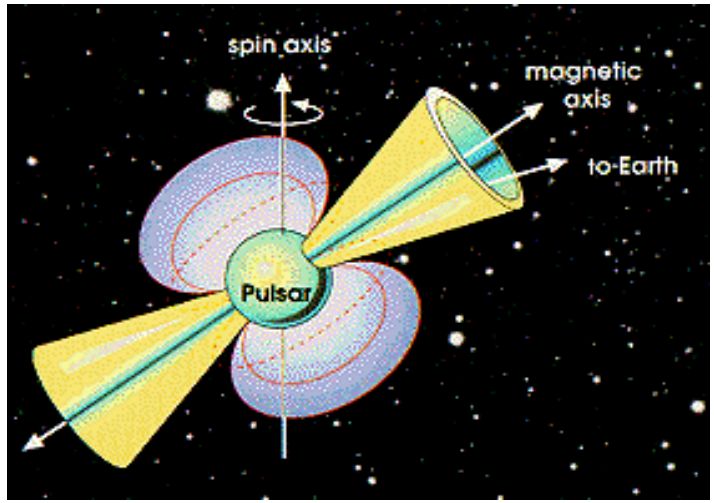
H1
(4 km)

H2
(2 km)



L1 (4 km)

Searching for Spinning Neutron Stars ("Pulsars") with LIGO



Courtesy: NASA

Signals expected to be weak – need long integration times

Coherent all-sky searches over entire data period are computationally intractable because of parameter space explosion:

Doppler modulation corrections require ever-finer sky gridding as the observation time increases

Alternative method: "Semi-coherent" summing of spectra from many shorter time intervals:

- **Advantage: computationally tractable**
- **Disadvantage: unable to exploit full intrinsic sensitivity of detector**

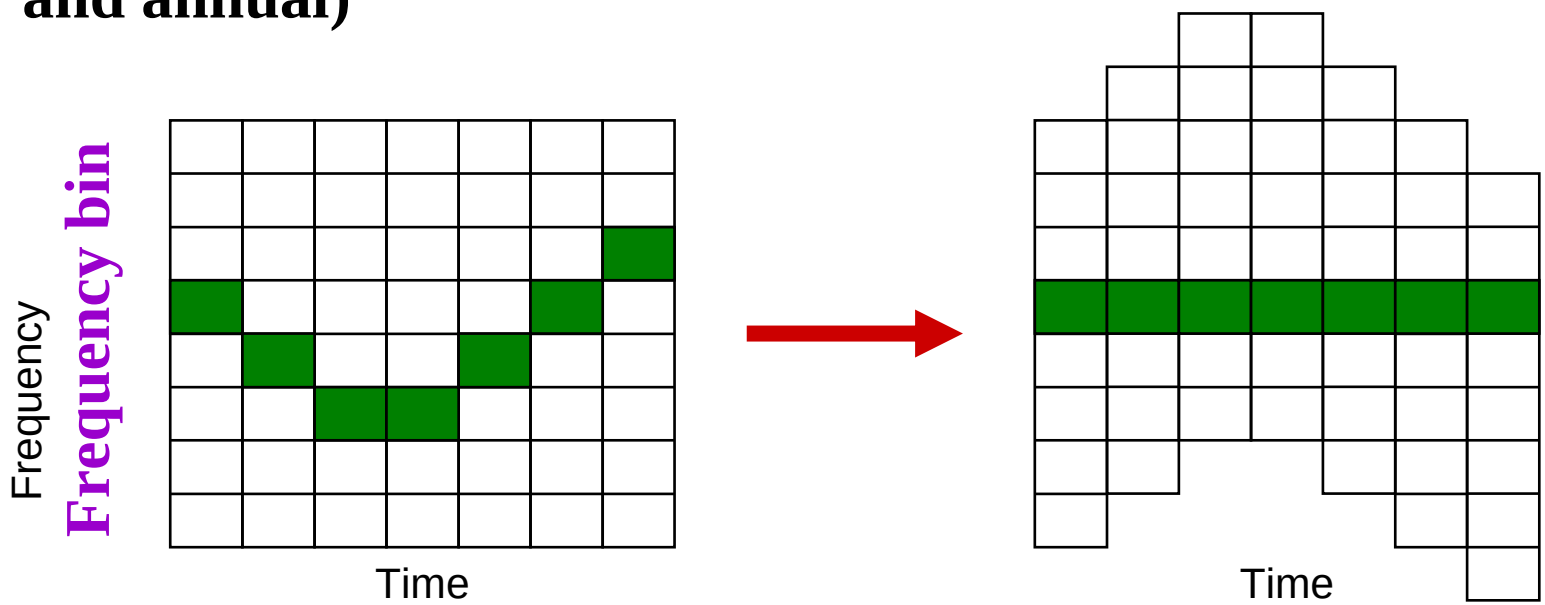
Will summarize and present results from three different methods explored within LIGO to carry out a semi-coherent search:

Stack-Slide

Hough

PowerFlux

All methods correct for Doppler modulations:
(daily and annual)



Number of sky grid points scales like (frequency)^2

Comparing the Methods

What exactly is summed?

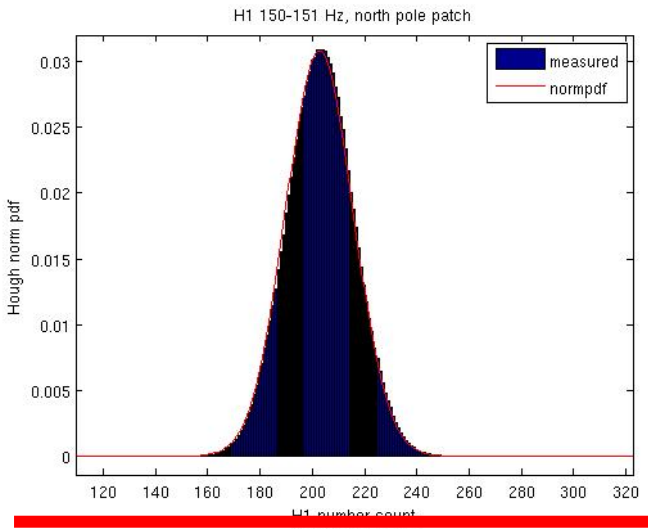
StackSlide – Normalized power (power divided by estimated noise)
→ Averaging gives expectation of 1.0 in absence of signal

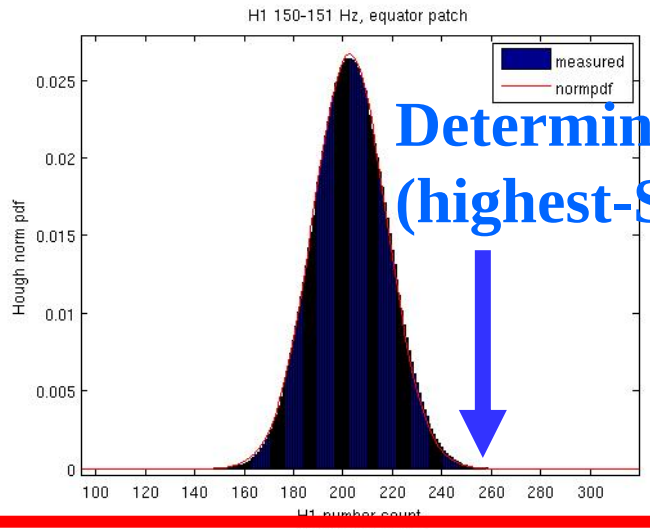
Hough – Weighted binary counts (0/1 = normalized power below/above SNR), with weighting based on antenna pattern and detector noise

PowerFlux – Average strain power with weighting based on antenna pattern and detector noise
→ Signal estimator is direct excess strain power
(circular polarization and 4 linear polarization projections)

Sample 0.25-Hz bands

Hough (2 of 92 sky patches shown)

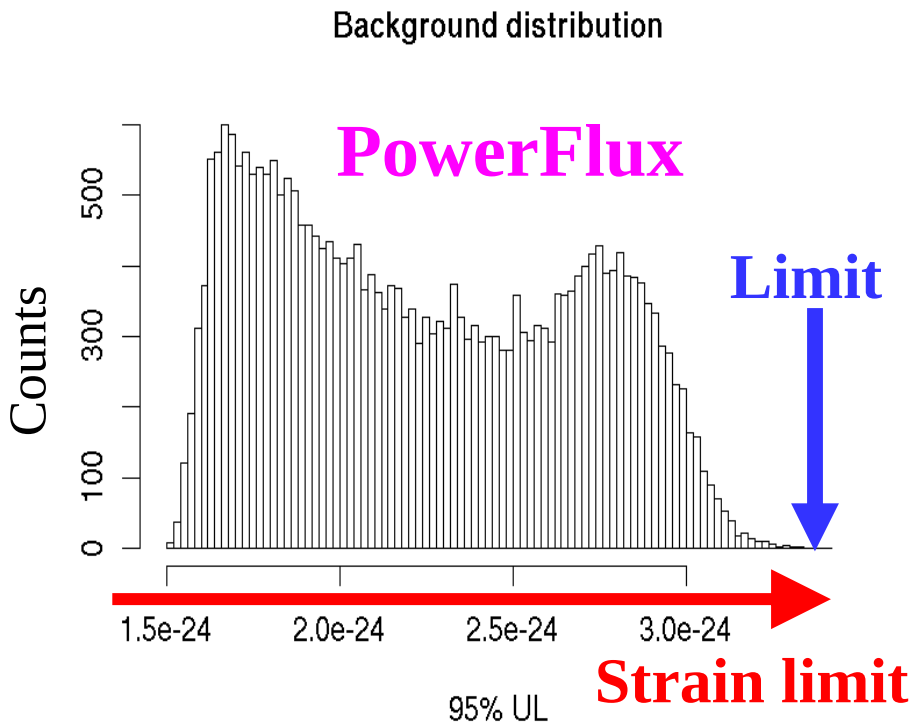




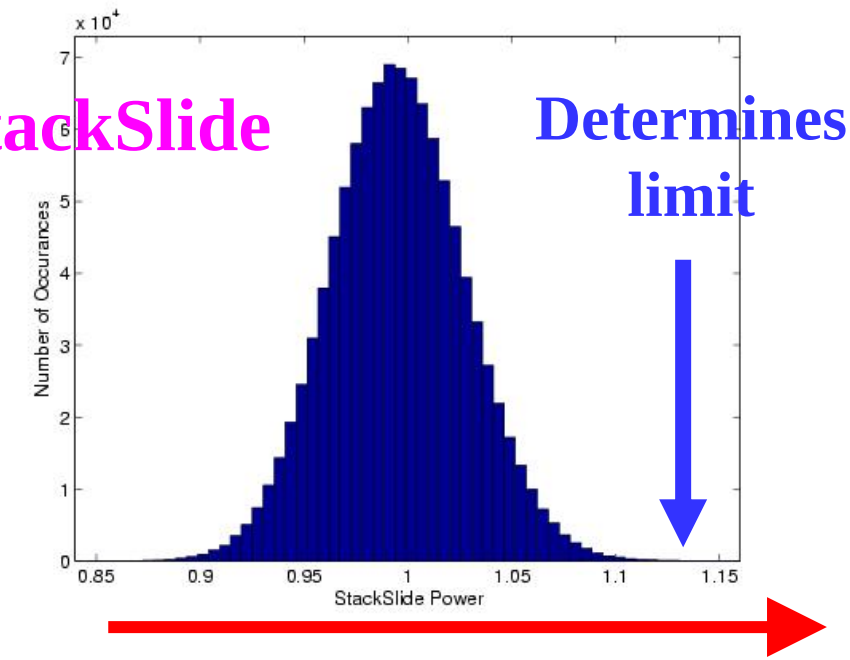
Determines limit (highest-SNR patch)

Hough count

(North Pole) (Equator)



Strain limit



StackSlide power

Comparing the Methods (cont.)

What kind of limits are set?

StackSlide & Hough

Population-based frequentist limits on h_0

Averaged over sky location and pulsar orientation

PowerFlux

Strict frequentist limits on circular and linear polarization amplitudes h_0^{CIRC} and h_0^{LIN}

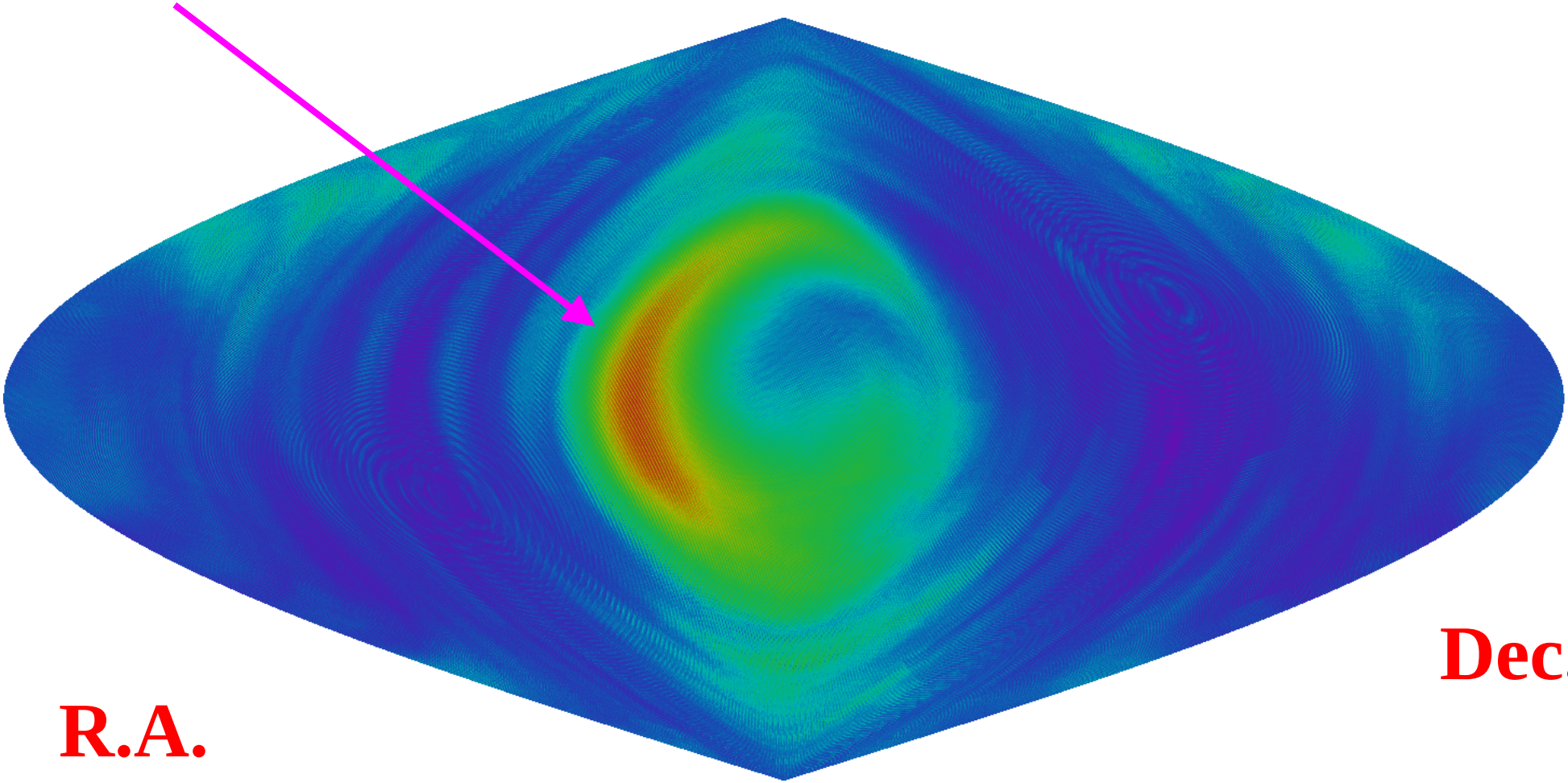
Results interpreted as limits on best-case and worst-case pulsar amplitudes h_0

→ Limits placed separately on tiny sky patches

→ Worst limit over fiducial sky is quoted

Sample PowerFlux circular-polarization strain H1 upper limits in 575.00-575.25 Hz band

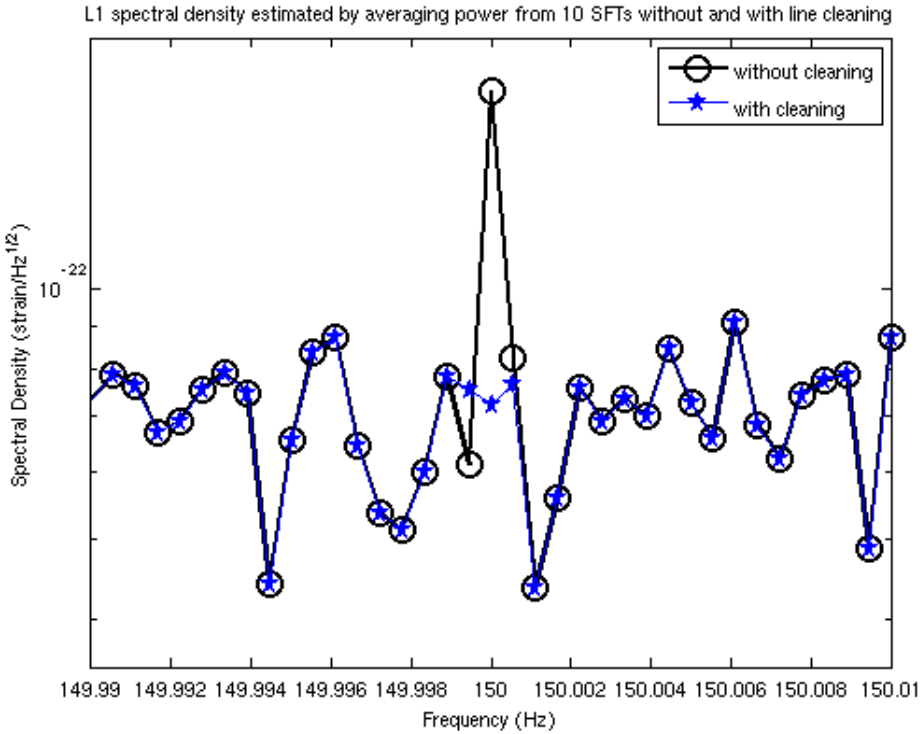
Simulated Pulsar **($A_+ = A_- = 8.4 \times 10^{-24}$ → nearly circ. polarized)**



PRELIMINARY

StackSlide & Hough Line Removal:

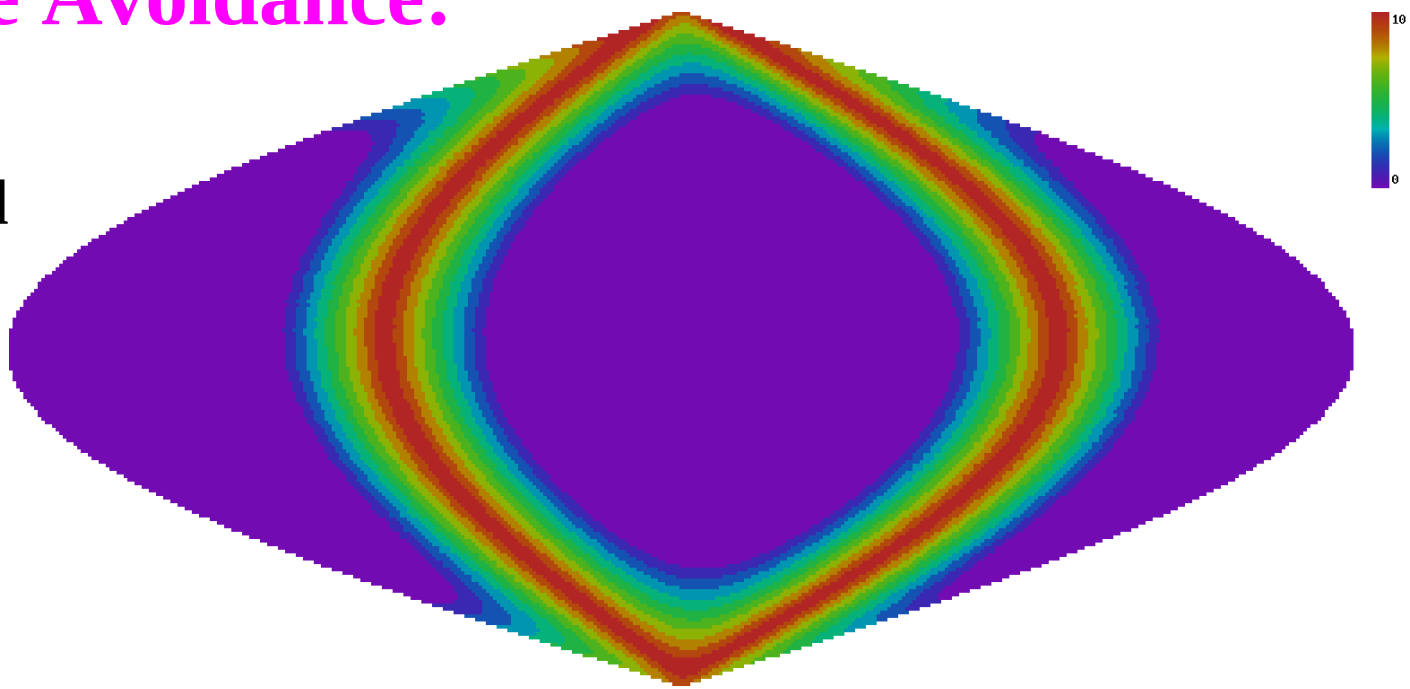
Known lines replaced by random noise
(Effects included in Monte Carlo simulation)



PowerFlux Line Avoidance:

Regions of Doppler stationarity excluded from quoted limits

(frequency & spindown dependent)



Results

What frequency & spindown ranges are covered? **[50-1000 Hz for all]**

StackSlide & PowerFlux:

$$-1.0 \times 10^{-8}\ \text{Hz/s} < df/dt < 0$$

Hough:

$$-2.2 \times 10^{-9}\ \text{Hz/s} < df/dt < 0$$

What interferometer data is analyzed?

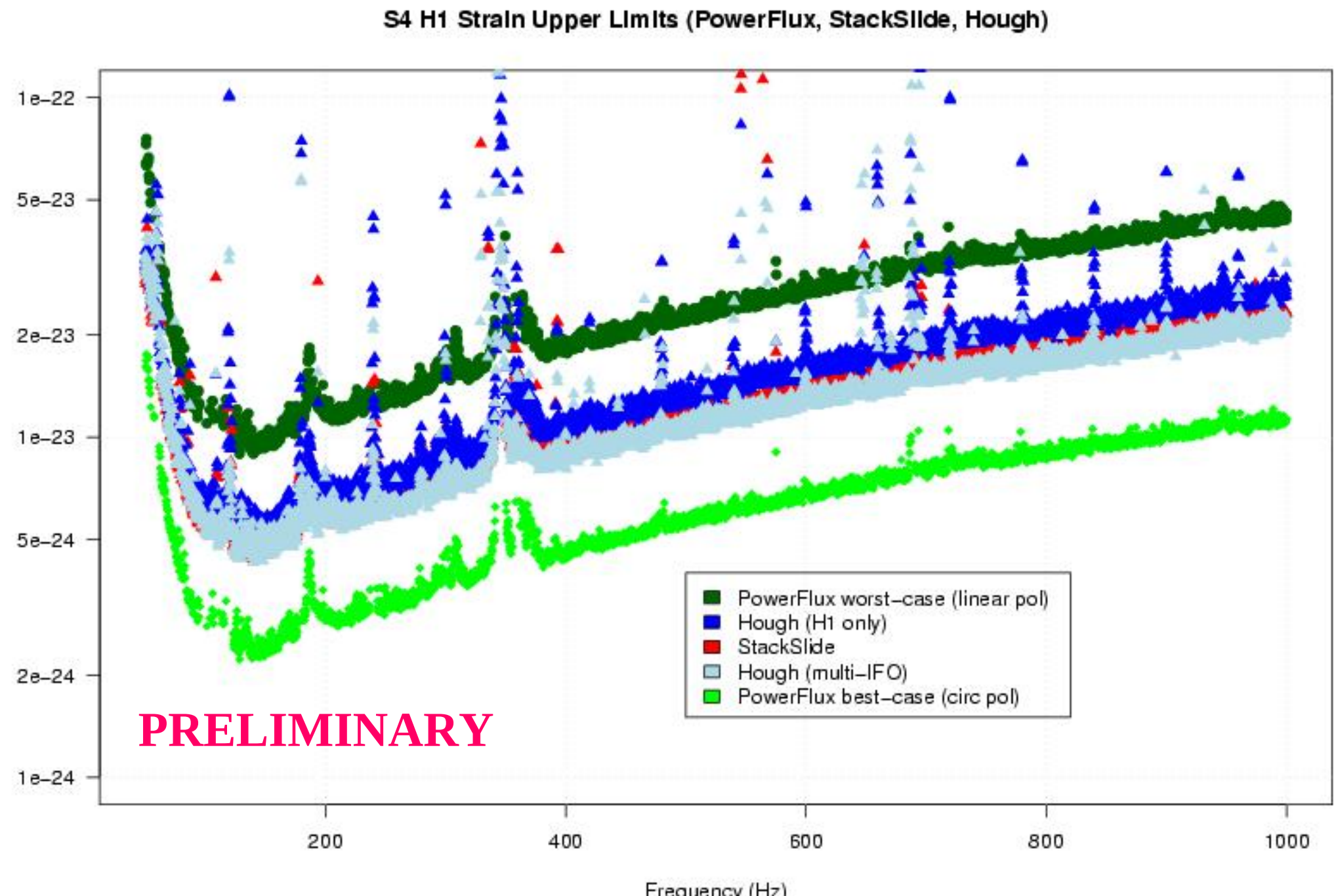
StackSlide & PowerFlux – H1 and L1 individually

(coincidence checks for high-SNR candidates)

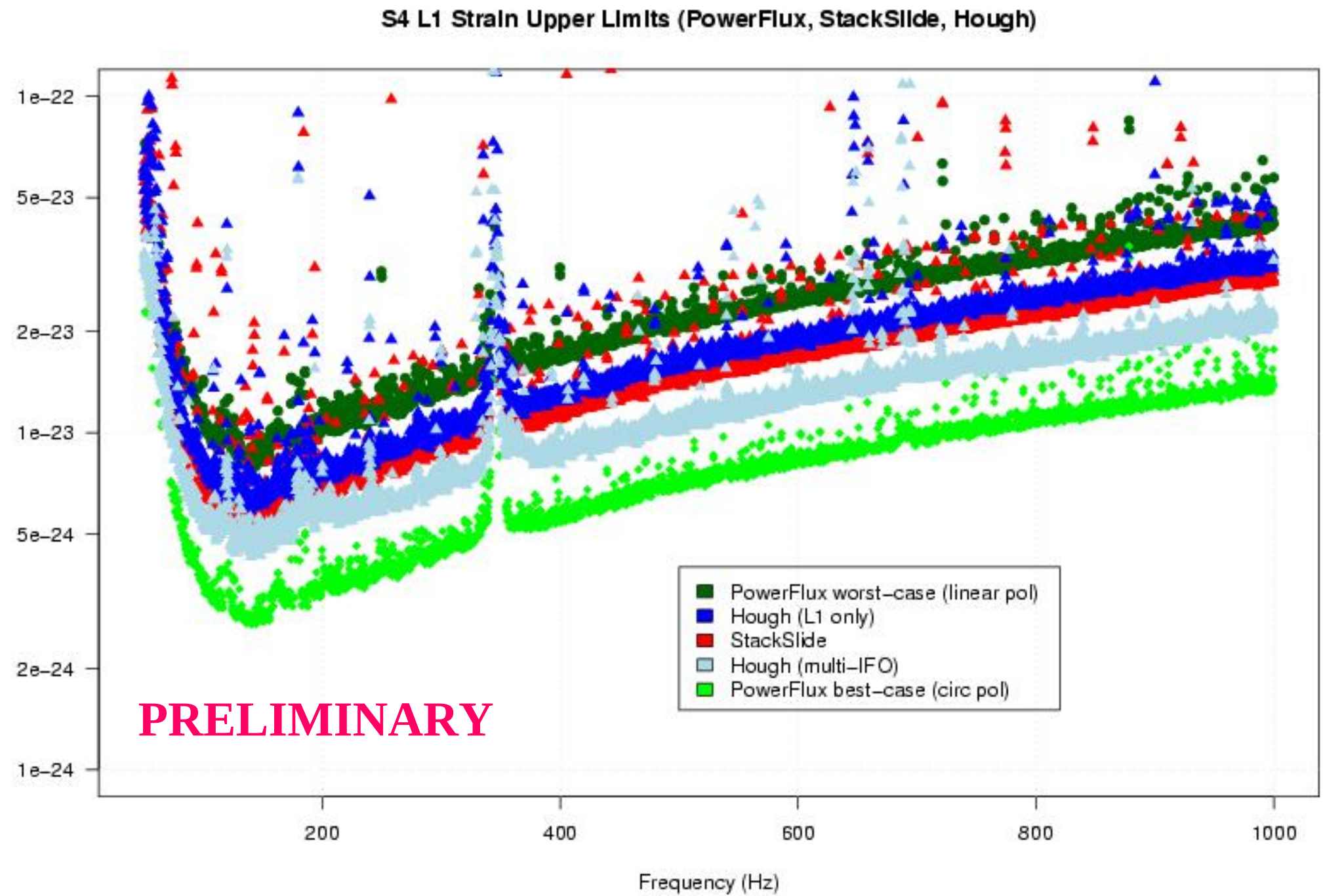
Hough – H1, H2, and L1 combined powers

(coincidence check for high-SNR candidates;
also: sample single-IFO limits produced for comparison)

H1 (Hanford 4-km) and Multi-IFO Results



L1 (Livingston 4-km) and Multi-IFO Results



Results & Prospects

Carried out follow-up coincidence (frequency, spindown, sky location) studies on outliers from individual interferometers

- **No plausible candidates found**

Now carrying out analysis of data from ongoing S5 data run with PowerFlux as "first look" algorithm (see talk by V. Dergachev)

StackSlide & Hough incorporated into distributed-computing project called Einstein@Home, using longer coherence times and a hierarchical search algorithm (see talk by B. Owen)

You can help! → Go to http://einstein.phys.uwm.edu/

Upper limits improving and now probing interesting astrophysical territory ($h < 10^{-24}$) → Stay tuned…

END OF SLIDES

Comparing the Methods

How are instrumental lines handled?

StackSlide & Hough

Direct removal of known lines from spectrum (replaced with random noise)

Allows entire sky to be searched (population-based limits)

PowerFlux

Spectral lines flagged on the fly and bins marked for avoidance

Source occupancy tracked – no limits placed if source would be lost

Leads to exclusion of Doppler-stationary skybands (dependent on frequency and spindown)