LIGO Observational Results I

Patrick Brady
University of Wisconsin-Milwaukee

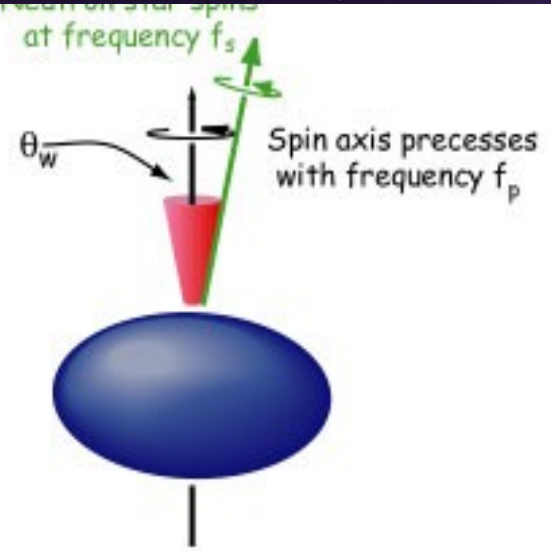
on behalf of
LIGO Scientific Collaboration

LIGO Science Goals

- Direct verification of two dramatic predictions of Einstein's general relativity
  - gravitational waves and black holes
- Physics & Astronomy
  - Detailed tests of properties of gravitational waves including speed, polarization, graviton mass, ...
  - Probe strong field gravity around black holes and in the early universe
  - Probe the neutron star equation of state
  - Performing routine astronomical observations to understand compact binary populations, supernovae rates, test gamma-ray burst models, ...
- LIGO provides a new window on the Universe

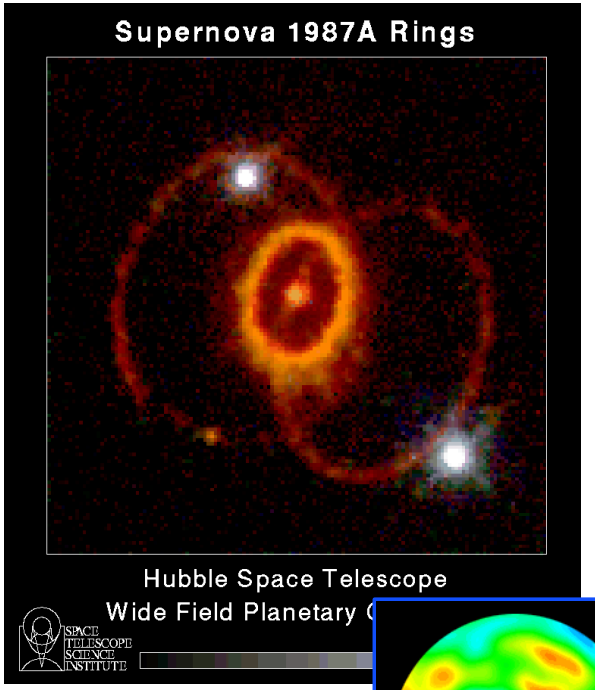
Astrophysical Sources of Gravitational Waves

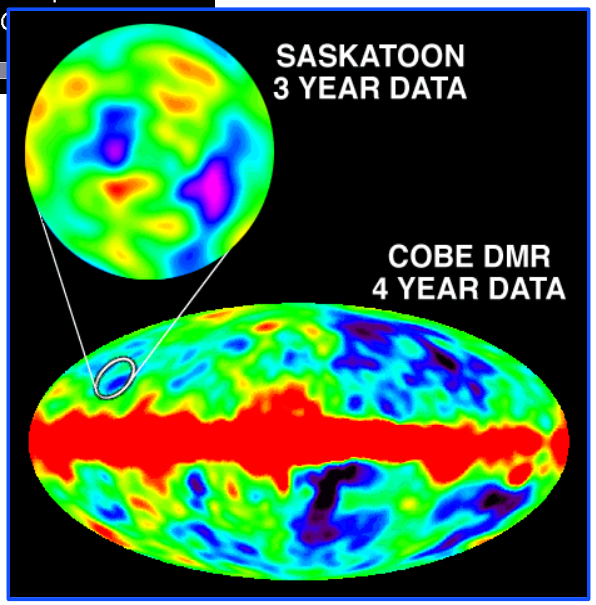
- Compact binaries
  - Black holes & neutron stars
  - Inspiral and merger
  - Probe internal structure, populations, and spacetime geometry
- Spinning neutron stars
  - Isolated neutron stars with mountains or wobbles
  - Low-mass x-ray binaries
  - Probe internal structure and populations



Astrophysical Sources of Gravitational Waves

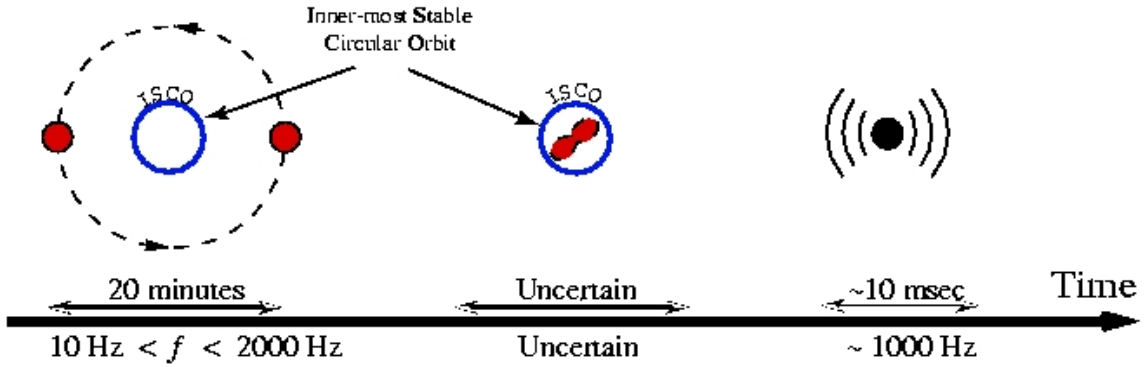
- Bursts
  - Neutron star birth, tumbling and/or convection
  - Cosmic strings, black hole mergers, ...
  - Correlations with electro-magnetic observations
  - Surprises!
- Stochastic background
  - Big bang & early universe
  - Background of gravitational wave bursts

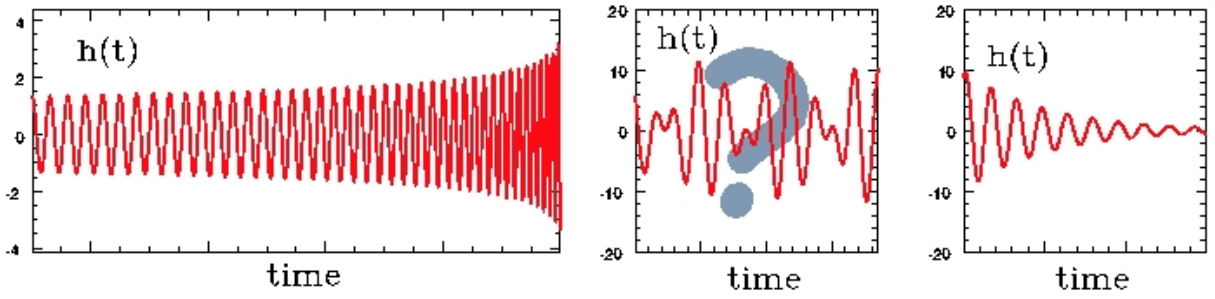




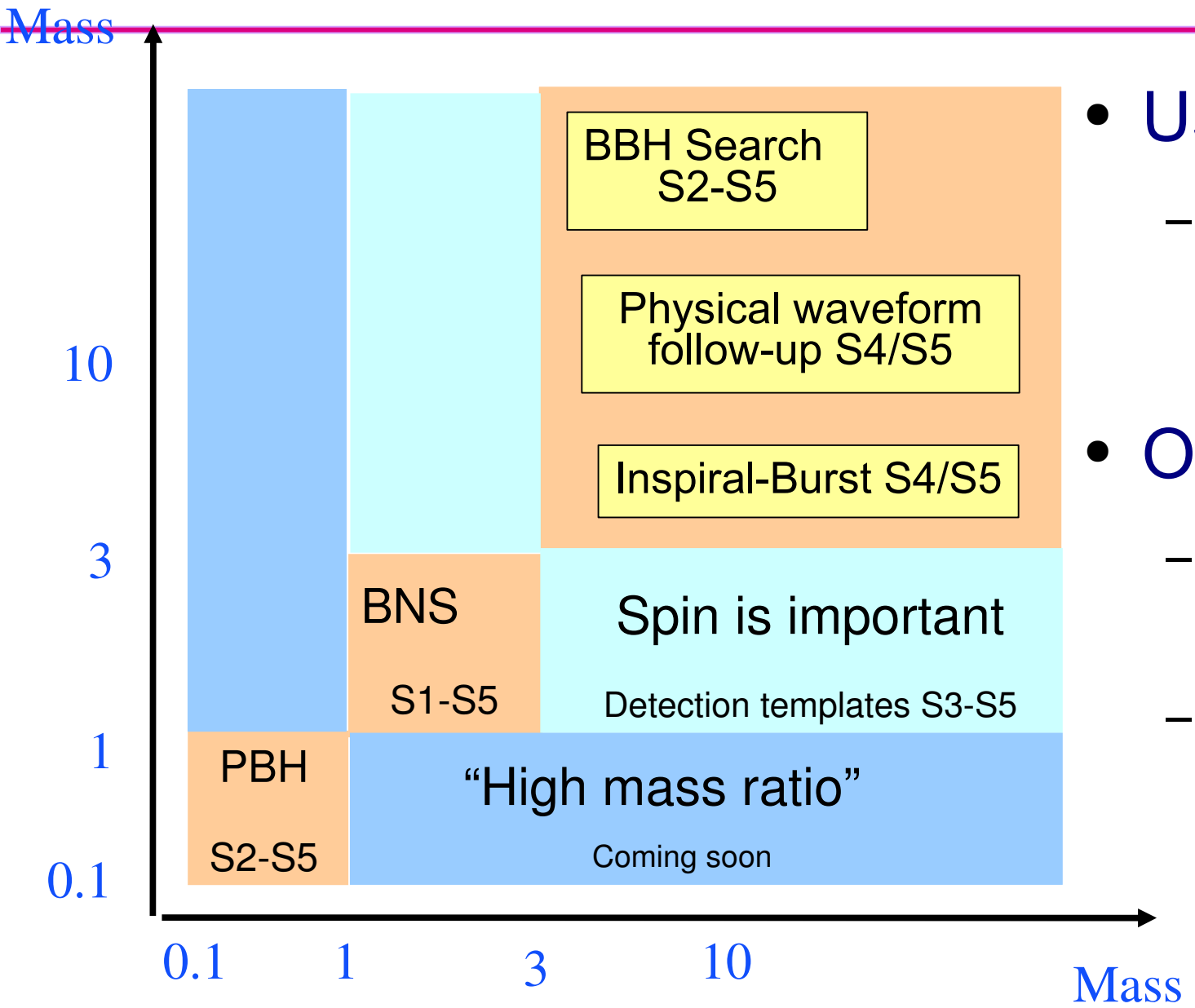
Gravitational waves from compact binaries

- LIGO is sensitive to gravitational waves from binary systems with neutron stars & black holes
  - Waveforms depend on masses and spins.
- Binary neutron stars
  - Estimates give upper bound of 1/3 yr in LIGO S5
- Binary black holes
  - Estimates give upper bound of 1/yr in LIGO S5





Binary Mass Plane



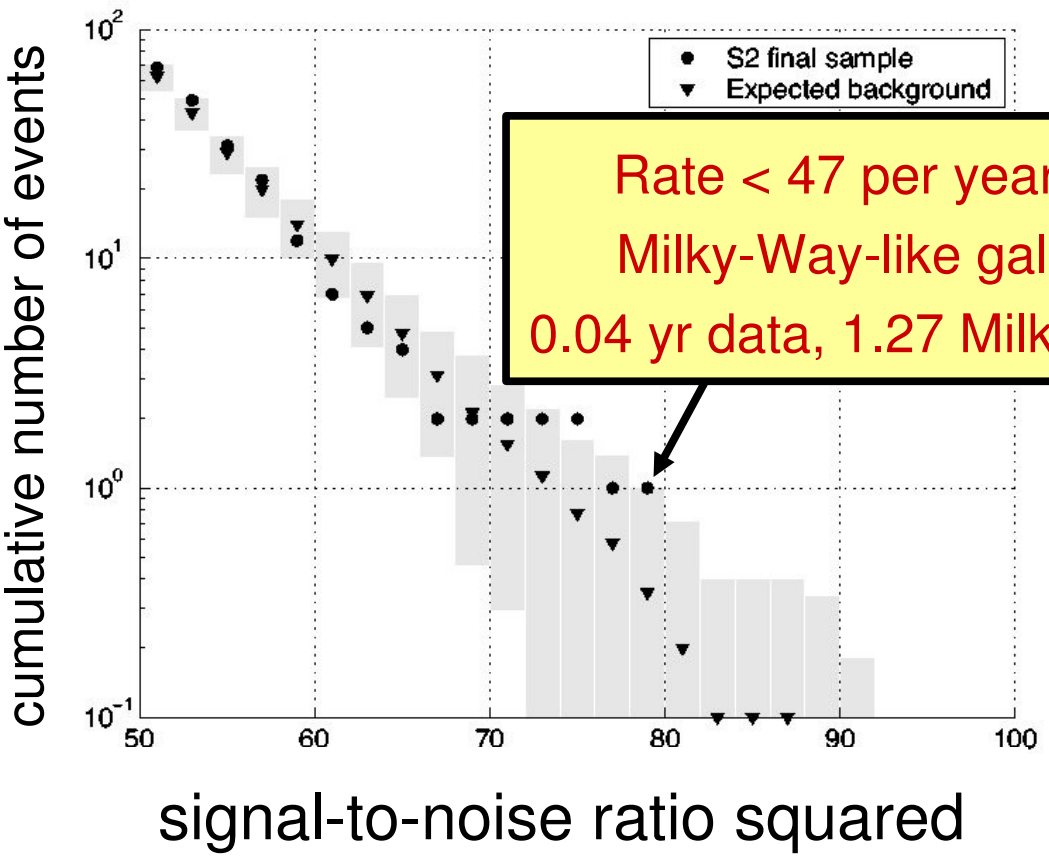
- Use LIGO data
  - Include GEO for detection confidence
- Other activities
  - Collaboration with TAMA & Virgo
  - GRB trigger follow-up

See talk by A. Dietz in session W 11

Binary Neutron Stars

S2 Observational Result

Phys. Rev. D. 72, 082001 (2005)



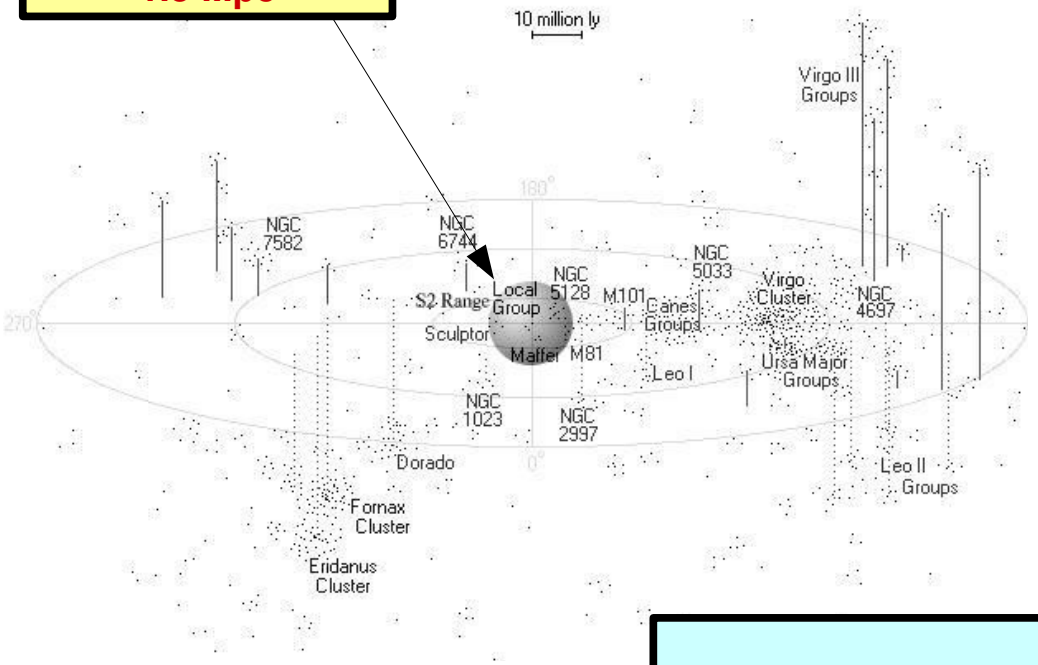
- S3 search complete
  - Under internal review
  - 0.09 yr of data
  - ~3 Milky-Way like galaxies
- S4 search complete
  - Under internal review
  - 0.05 yr of data
  - ~24 Milky-Way like galaxies

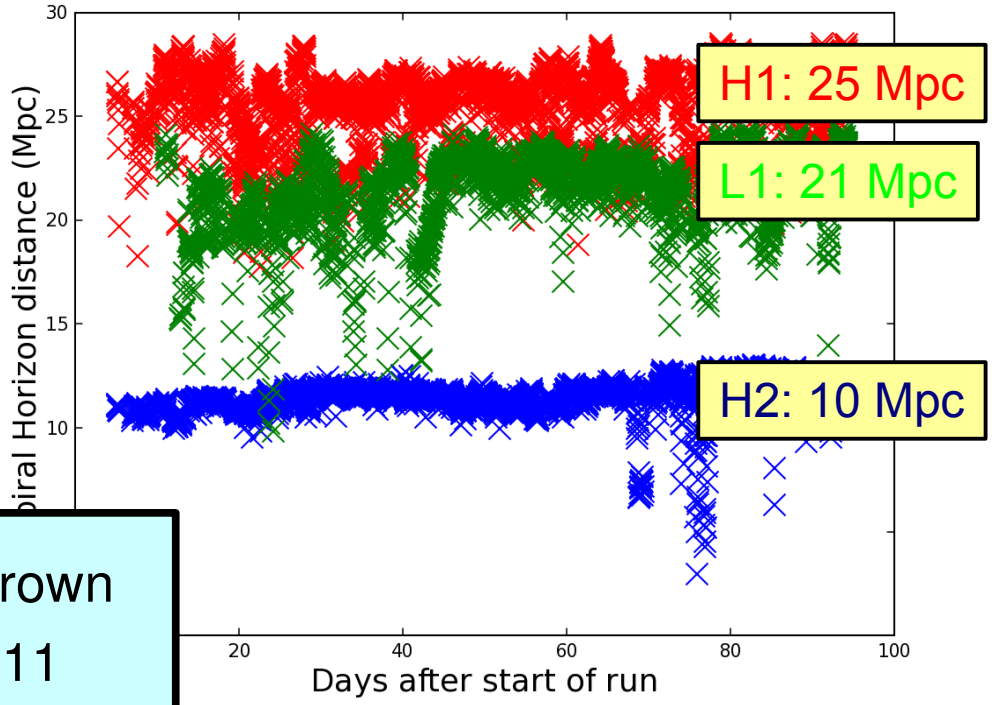
Binary Neutron Stars S5 Search

- First three months of S5 data is analyzed
- Horizon distance
  - Distance to 1.4+1.4 Msun optimally oriented & located binary at SNR=8

S2 Horizon Distance

1.5 Mpc



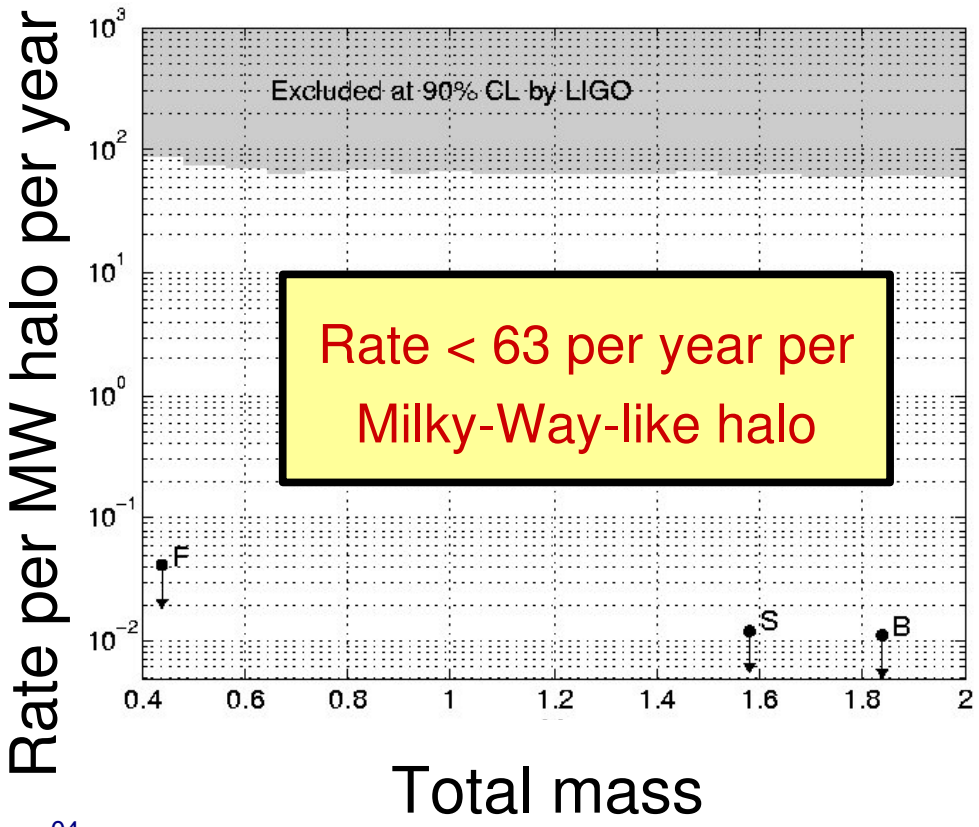


See talk by D. Brown in session W 11

Primordial Black Holes

S2 Observational Result

Phys. Rev. D. 72, 082002 (2005)

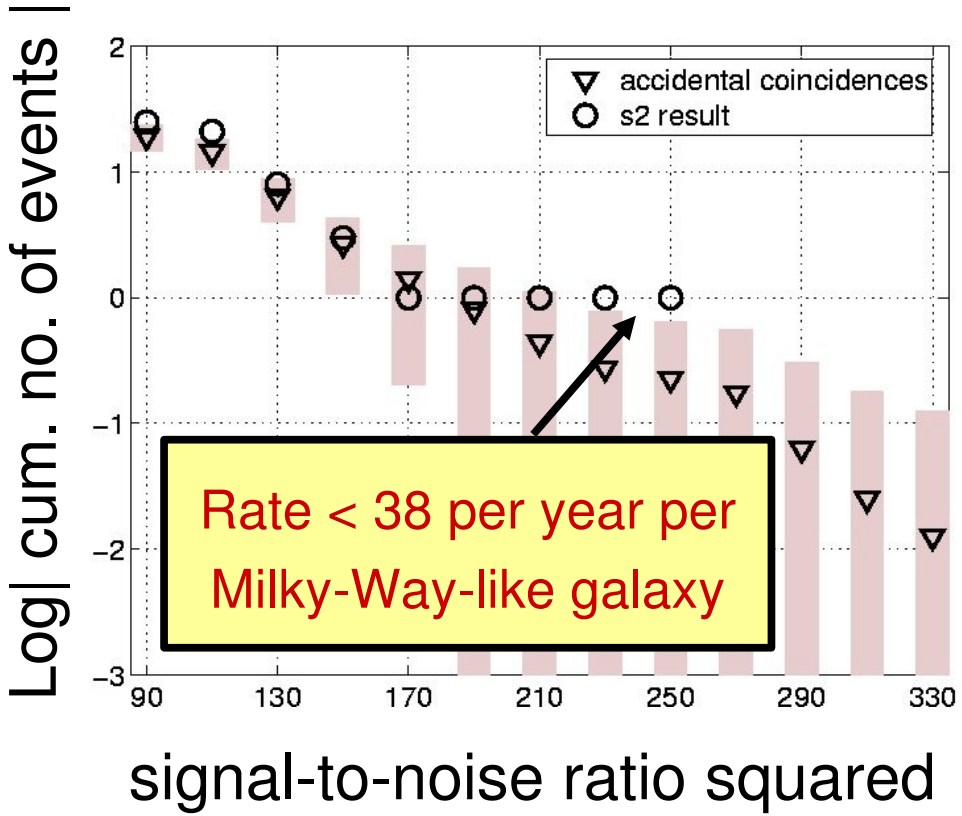


- S3 search complete
  - Under internal review
  - 0.09 yr of data
  - 1 Milky-Way like halo for 0.5+0.5 Msun
- S4 search complete
  - Under internal review
  - 0.05 yr of data
  - 3 Milky-Way like halos for 0.5+0.5 Msun
- S5 getting under way

Binary Black Holes

S2 Observational Result

Phys. Rev. D. 73, 062001 (2006)



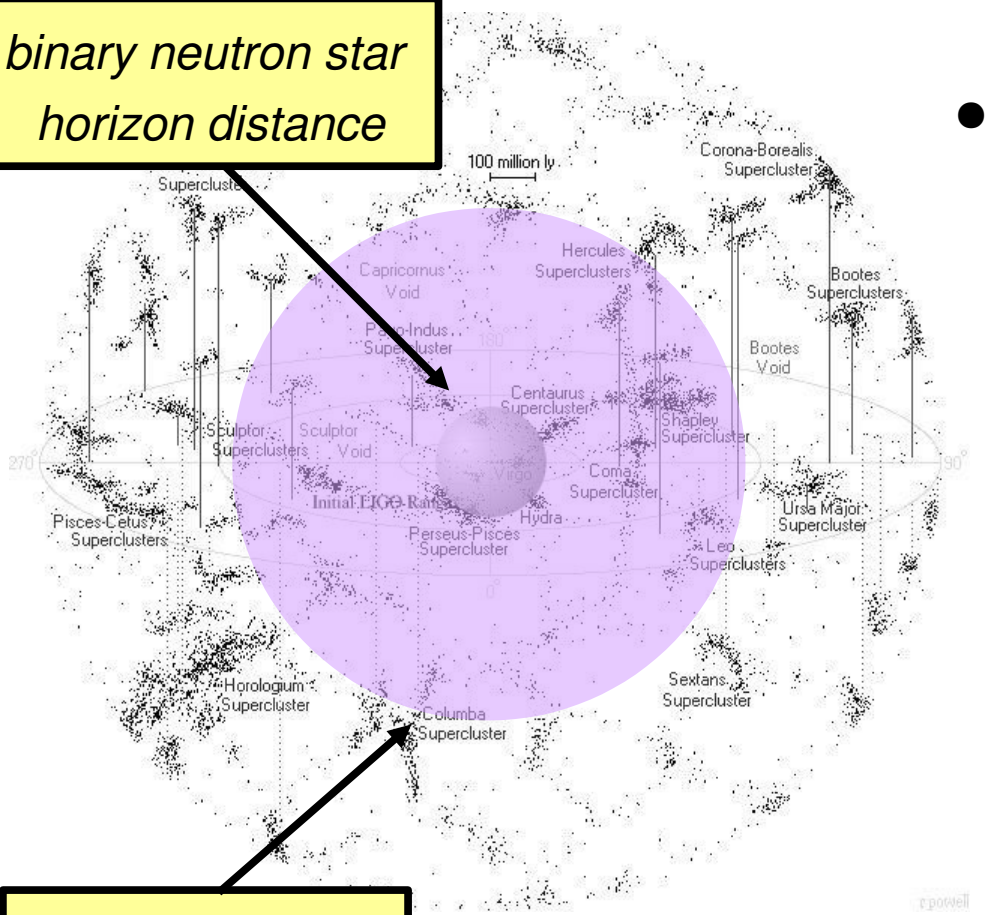
- S3 search complete
  - Under internal review
  - 0.09 yr of data
  - 5 Milky-Way like galaxies for 5+5 Msuns
- S4 search complete
  - Under internal review
  - 0.05 yr of data
  - 150 Milky-Way like galaxies for 5+5 Msuns

See poster by T. Cokelaer

Binary Black Holes S5 Search

- 3 months of S5 analyzed
- Horizon distance versus mass for BBH

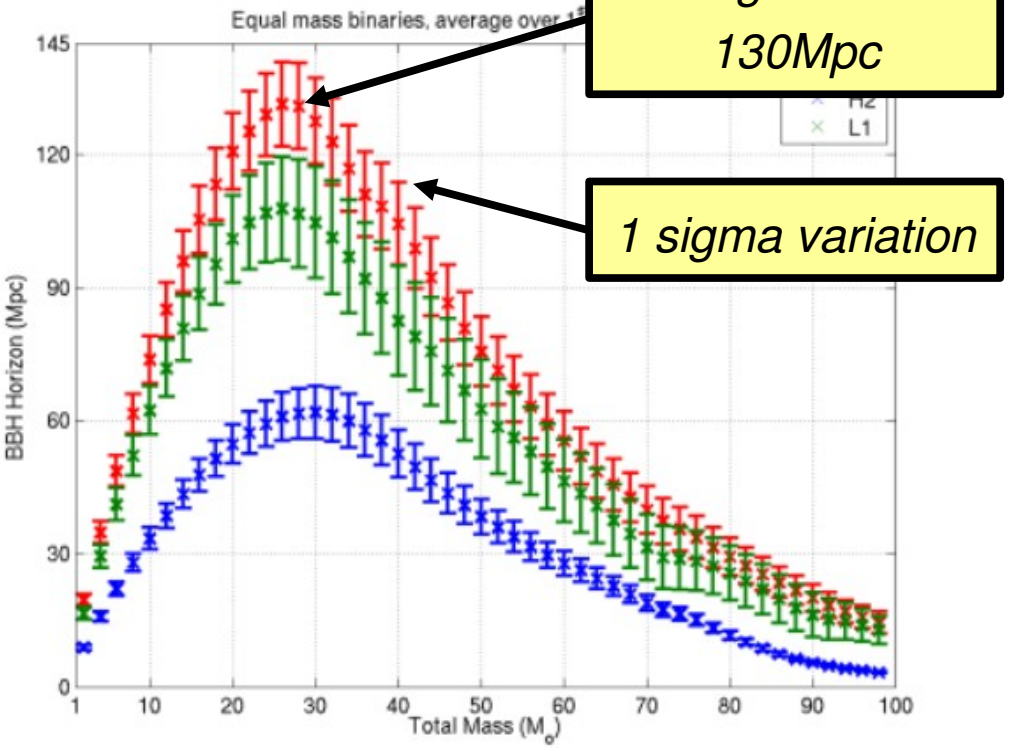
binary neutron star horizon distance



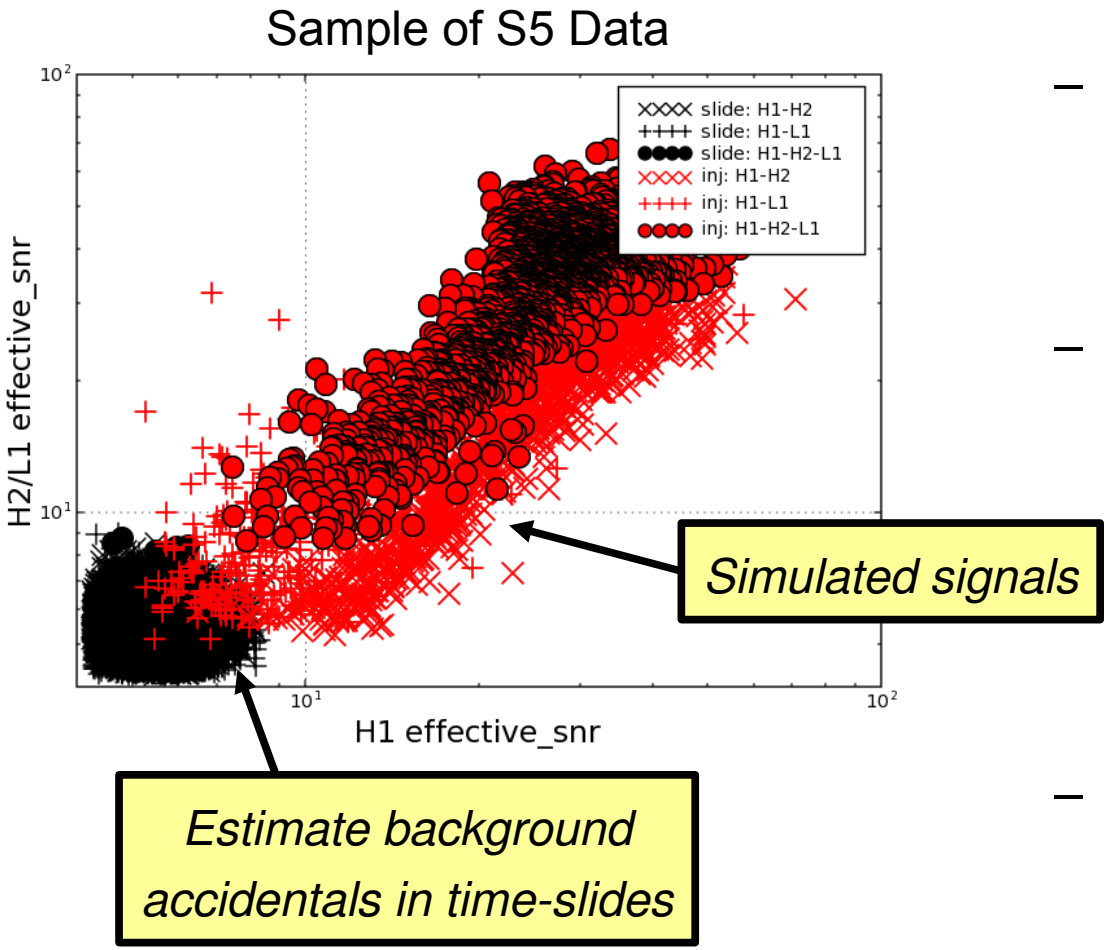
binary black hole horizon distance

Average over run 130Mpc

1 sigma variation

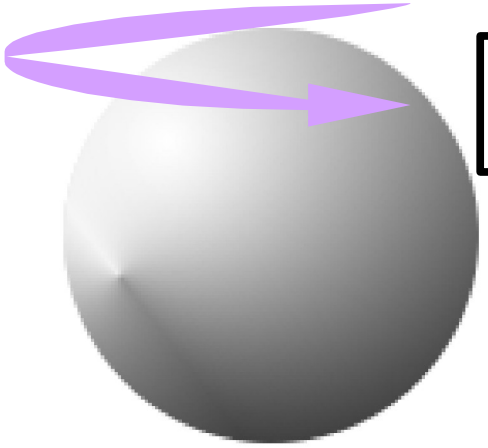


Are we capable of detection?



- Yes! we're getting ready
  - Lower masses, accurate waveforms, gives better discrimination than
  - BBH, waveforms are not accurately known means less discrimination power
  - Instrumental vetoes available; signal based vetoes available
  - Follow-ups on loudest triggers at end of each search as "fire drill"

Continuous waves

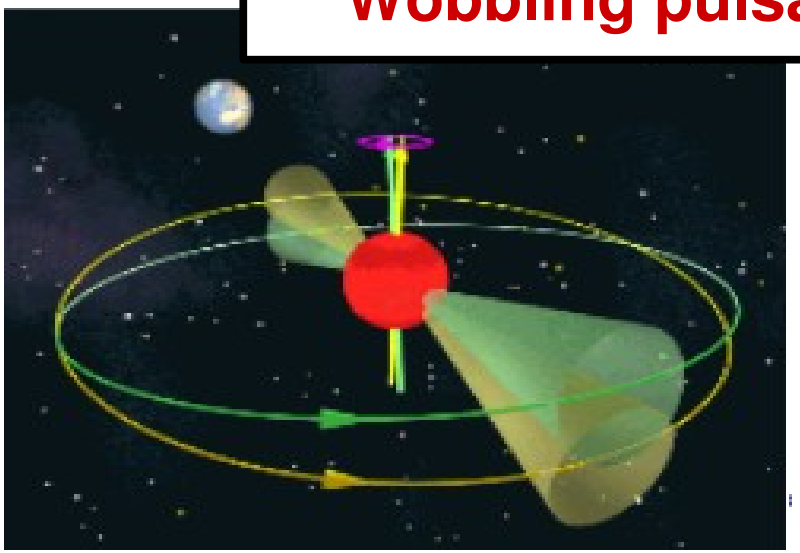


Bumpy Neutron Star

Low-mass x-ray binary

Credit: Dana Berry/NASA

Wobbling pulsars



Credit: M. Kramer

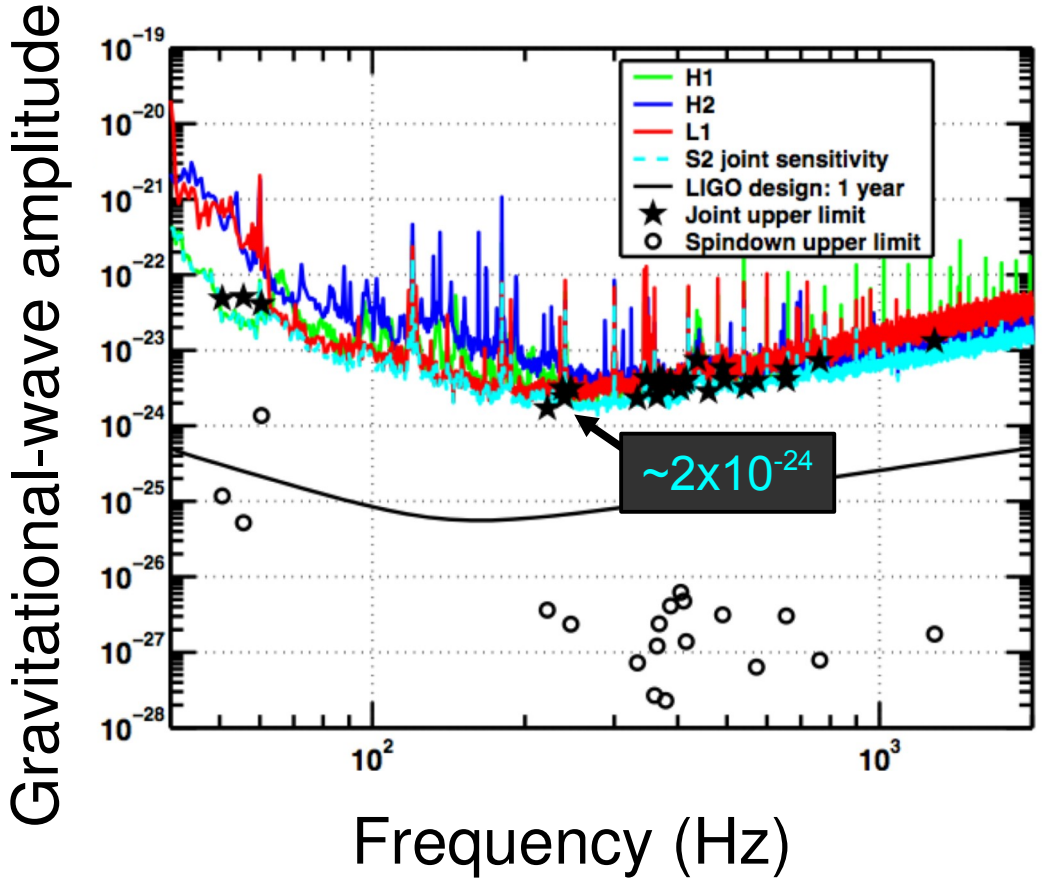
Continuous-wave searches

- Known pulsar searches
  - Catalog of known pulsars
  - Narrow-band folding data using pulsar ephemeris
- All sky incoherent searches
  - Sum many short spectra
- Wide area search
  - Doppler correction followed by Fourier transform
  - Computationally very costly
  - Hierarchical search under development

Search for waves from known pulsars

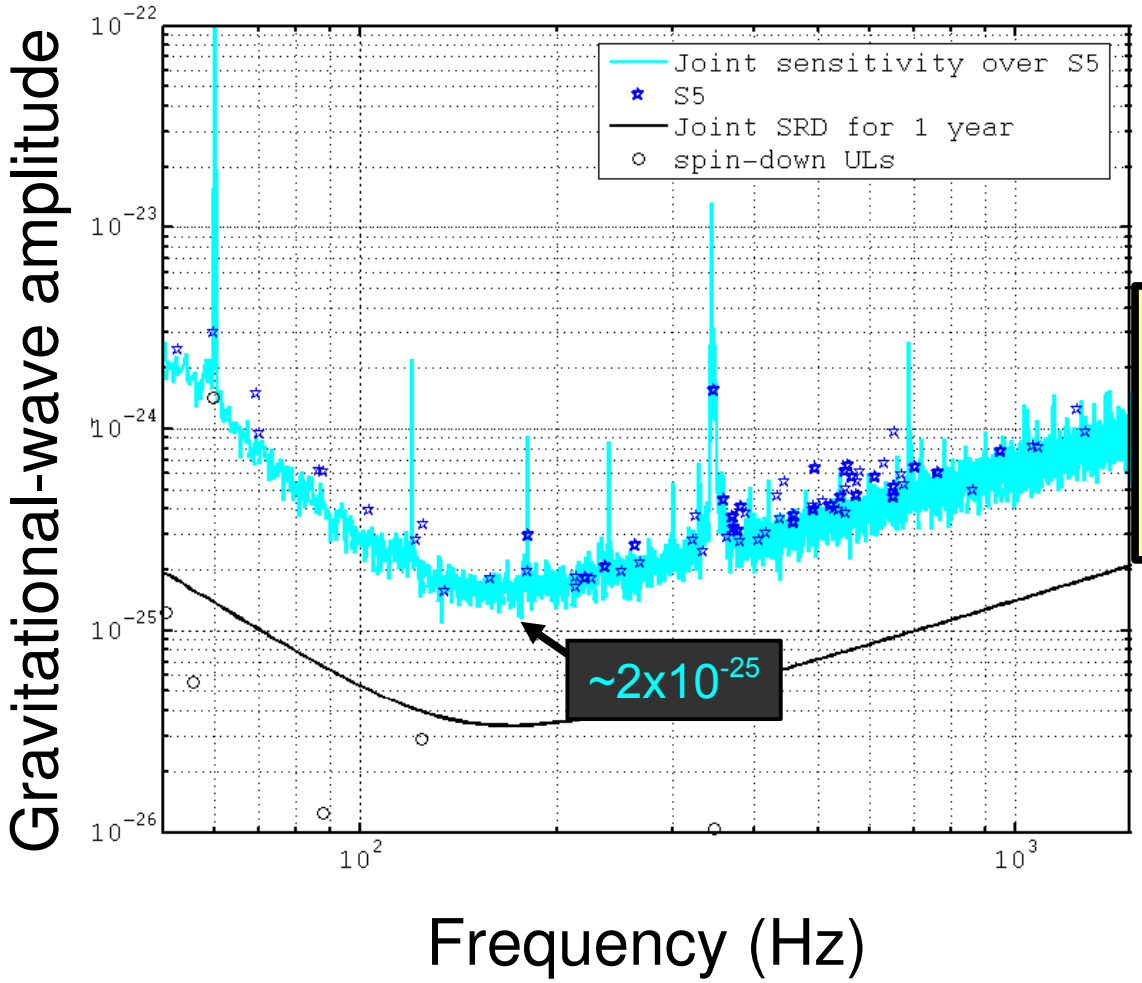
S2 Results reported in

*Physical Review Letters **94** 181103 (2005)*



- Pulsars for which the ephemeris is known from EM observations
- In S2
  - 28 known isolated pulsars targeted
- Spindown limit
  - assumes all angular momentum radiated to GW

Known pulsars S5 preliminary

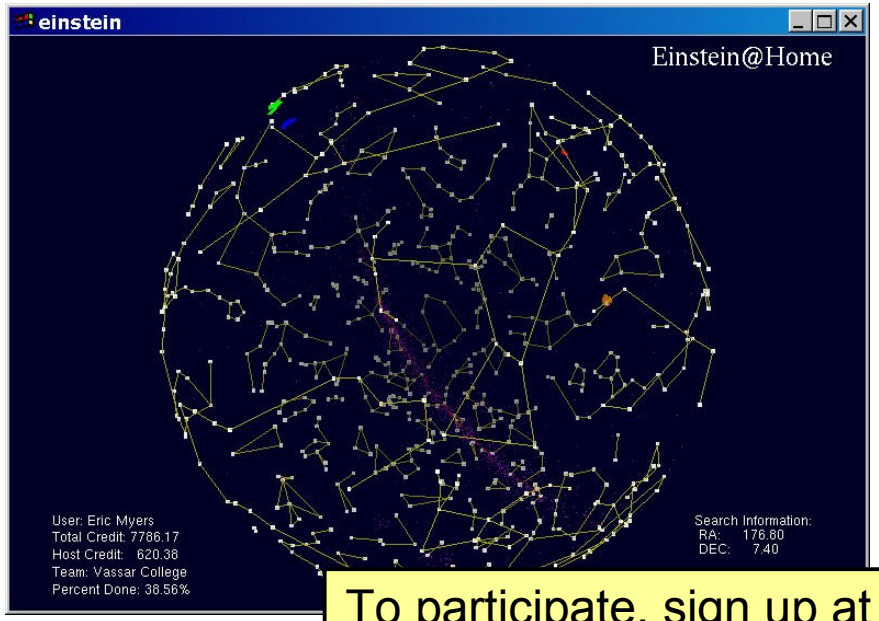


- 32 known isolated, 44 in binaries, 30 in globular clusters

Lowest ellipticity upper limit:
PSR J2124-3358
(f_{gw} = 405.6Hz, r = 0.25kpc)
ellipticity = 4.0×10^{-7}

See talk by M. Pitkin in session C 7

Einstein@Home



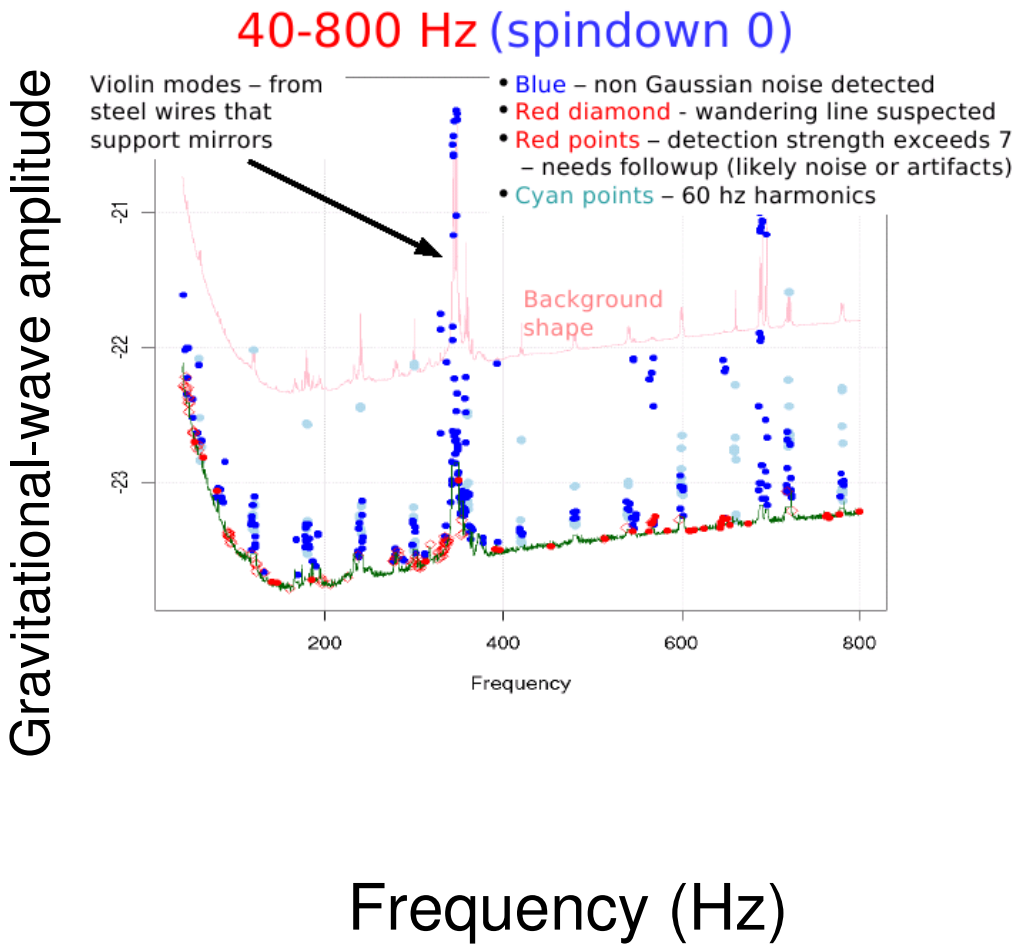
To participate, sign up at
http://www.physics2005.org

- S3 results:
  - No evidence of pulsars
- S4 search
  - Underway

- Matched-filtering for continuous GWs
- All-sky, all-frequency search
  - computationally limited
- Aiming at detection, not upper limits
- Public outreach distributed computing

See talk by R. Prix
in session C 7

Incoherent searches S5 preliminary



- Place sky dependent upper limits by averaging power
- Account for Doppler modulation in average
- Also account for amplitude modulation

See talks by V. Dergachev and G. Mendell in session W 11

Conclusions

- Analysis of LIGO data is in full swing
- Binary inspiral searches
  - Have caught up with data backlog
  - S5 sensitivity makes this a very exciting time for gravitational-wave astronomy
- Continuous-wave searches
  - Known pulsar searches are beginning to place interesting upper limits in S5
  - All sky searches are under way and exploring large area of parameter space

Binary Black Holes S5 Search