Status of Initial LIGO

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Outline

- Description of LIGO Detectors
- Status of LIGO's S5 Science Run
  - Sensitivity
  - Duty Cycle
- Data Analysis
  - Results from finished searches
  - Ongoing investigations
- Conclusions

LIGO Observatories

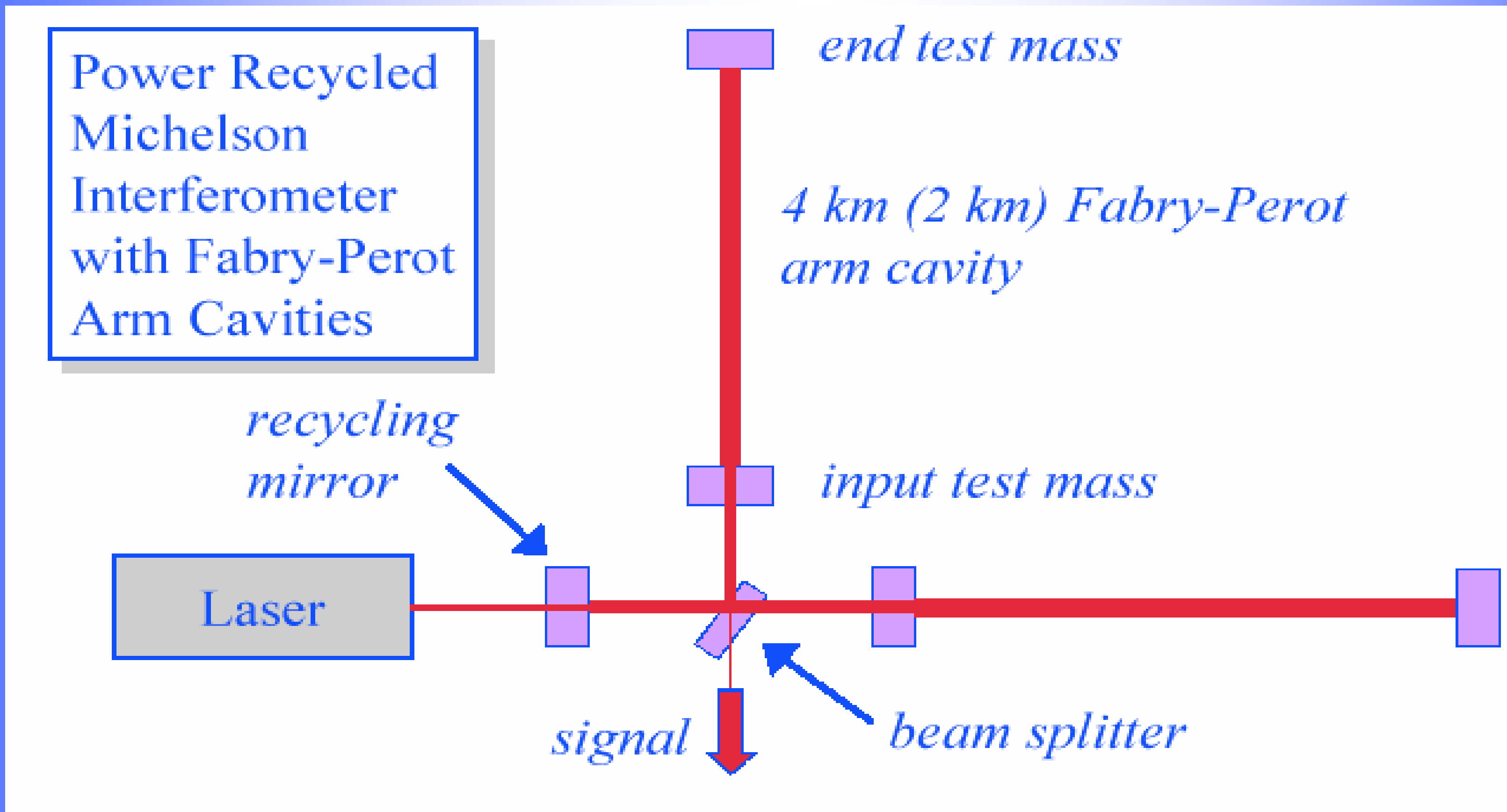
←

LIGO Hanford Observatory
near Richland Washington
4 km interferometer
2 km interferometer

→

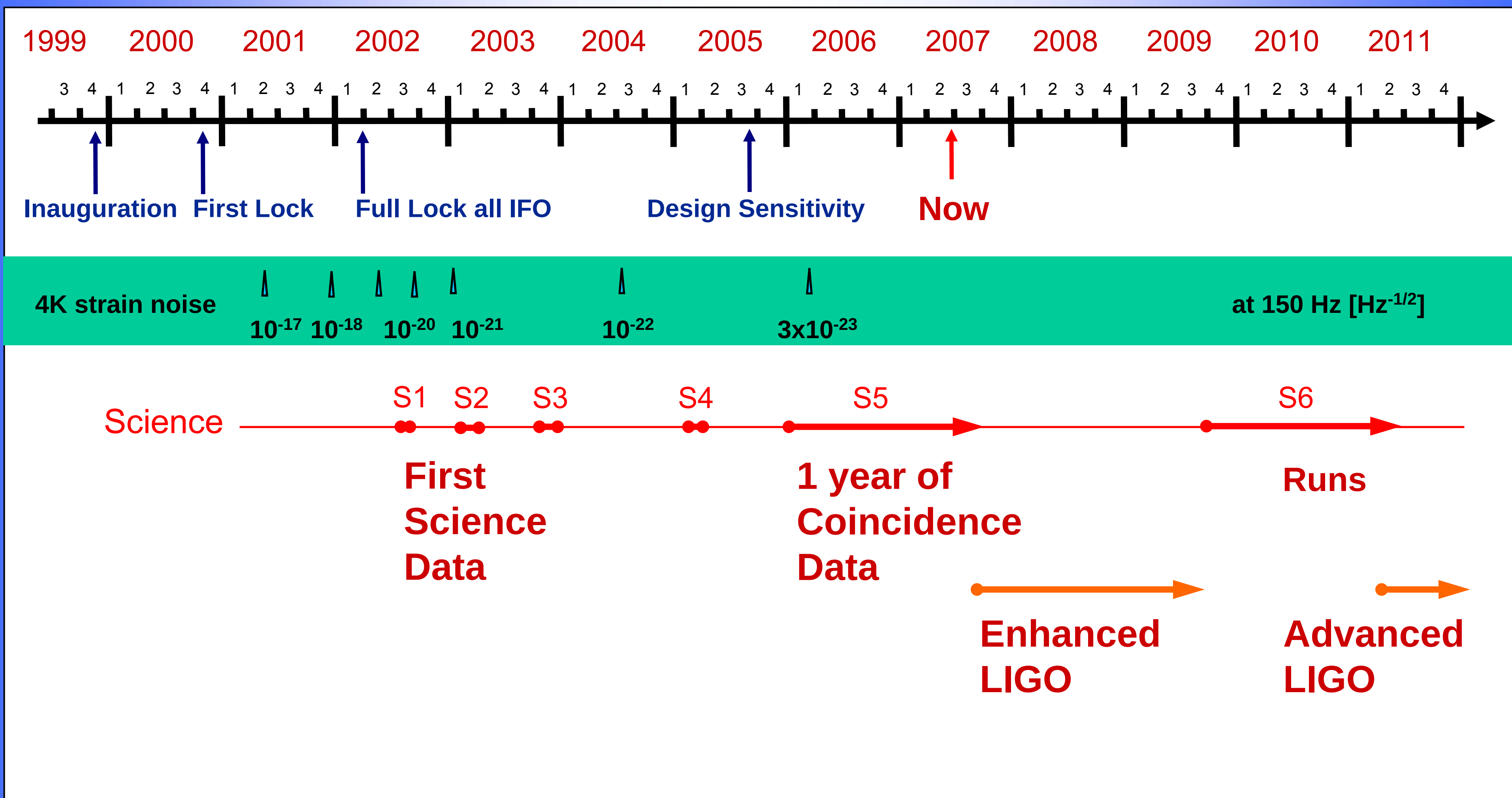
LIGO Livingston Observatory
~40 miles east of Baton Rouge
4 km interferometer

LIGO Interferometer

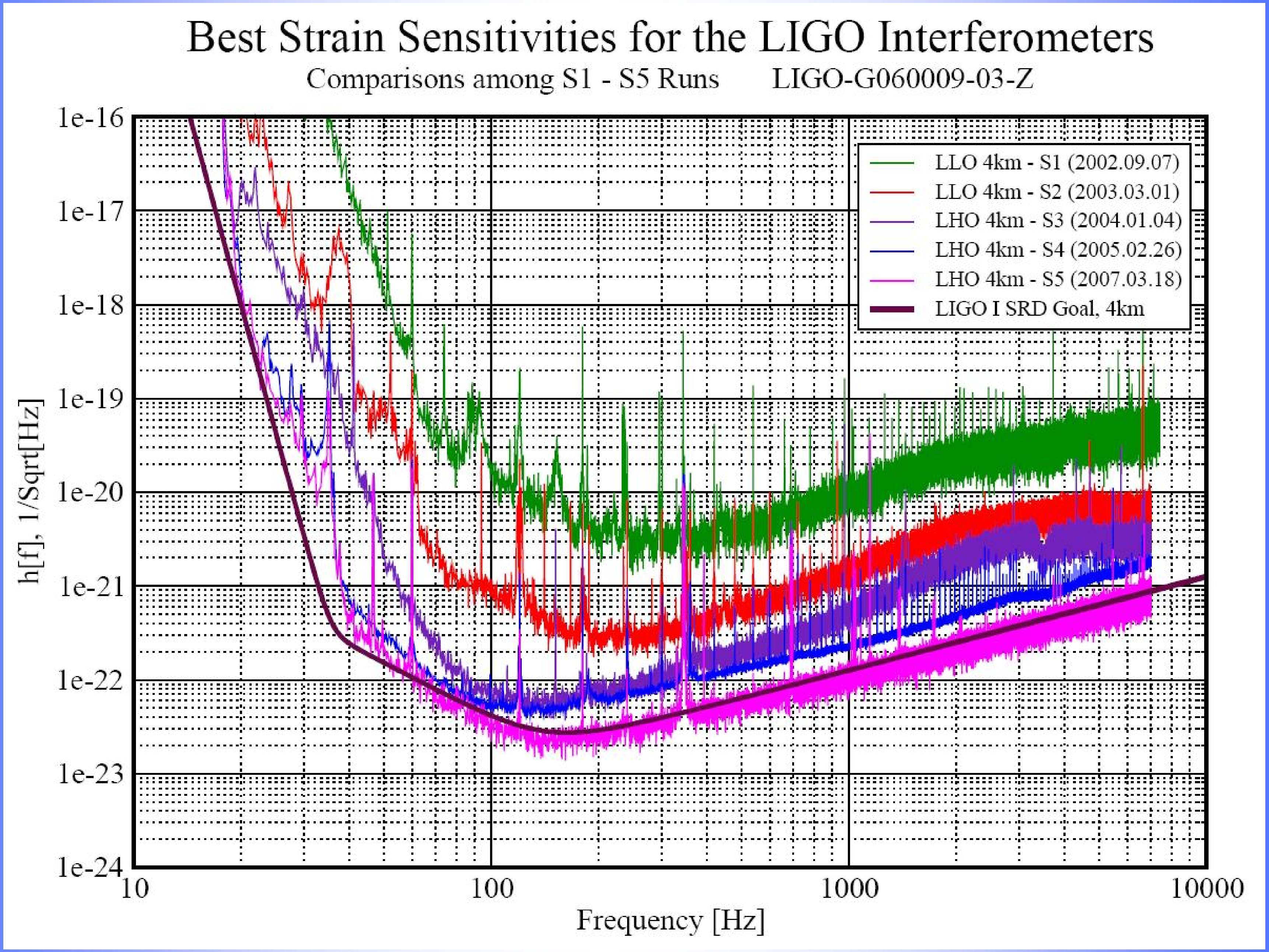


- 4 km-long arms
- Subsystems designed for low noise
- Feedback allows for sensitivity -- $h \sim 10^{-21}$
- Test mass hangs like pendulum
- Approximates freely falling bodies

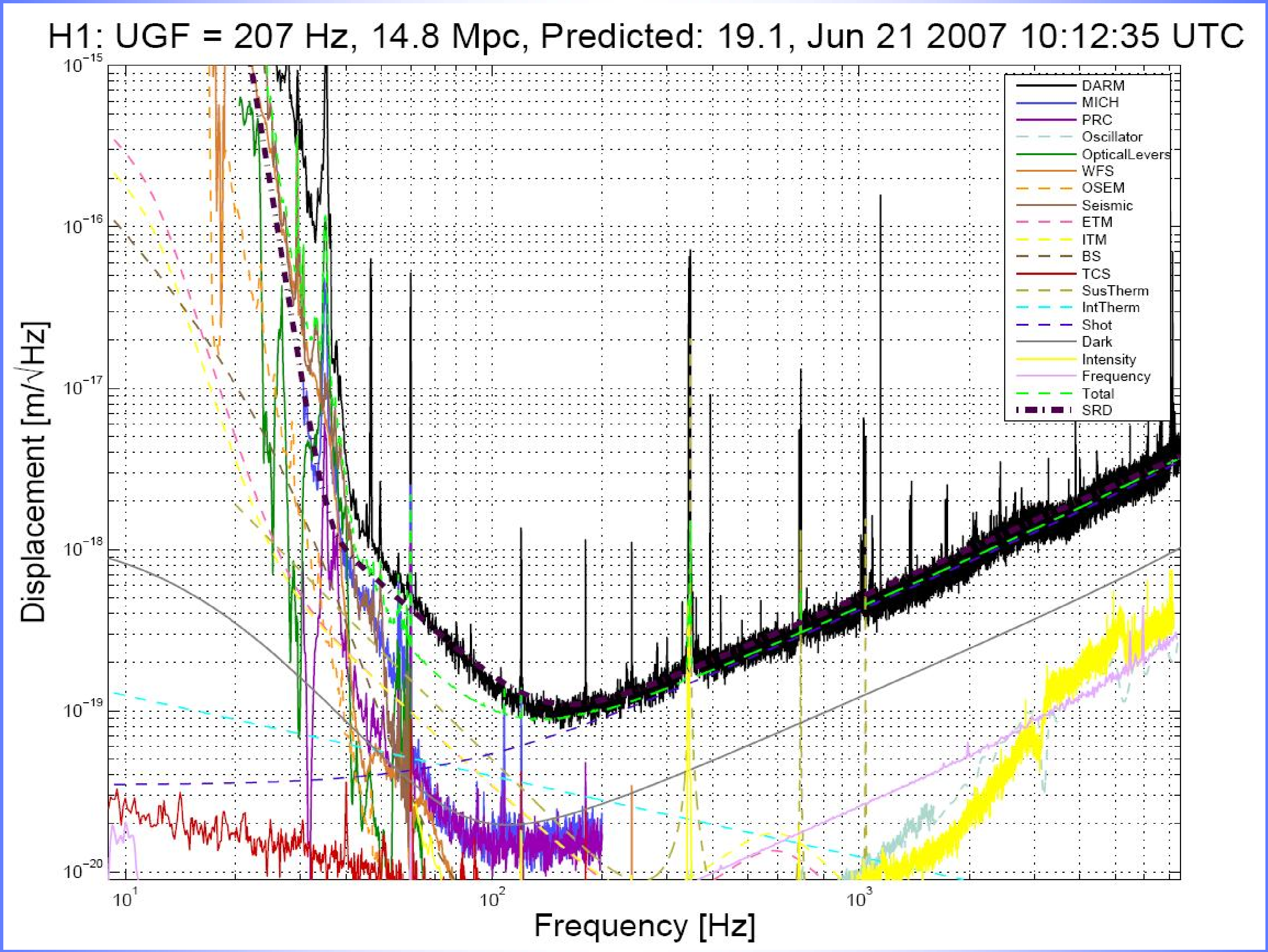
Timeline


1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
Inauguration
First Lock
Full Lock all IFO
Design Sensitivity
Now
4K strain noise
10-17 10-18 10-20 10-21 10-22 3x10-23
at 150 Hz [Hz-1/2]
Science
S1
S2
S3
S4
S5
S6
First Science Data
1 year of Coincidence Data
Runs
Enhanced LIGO
Advanced LIGO

Improvement in Sensitivity



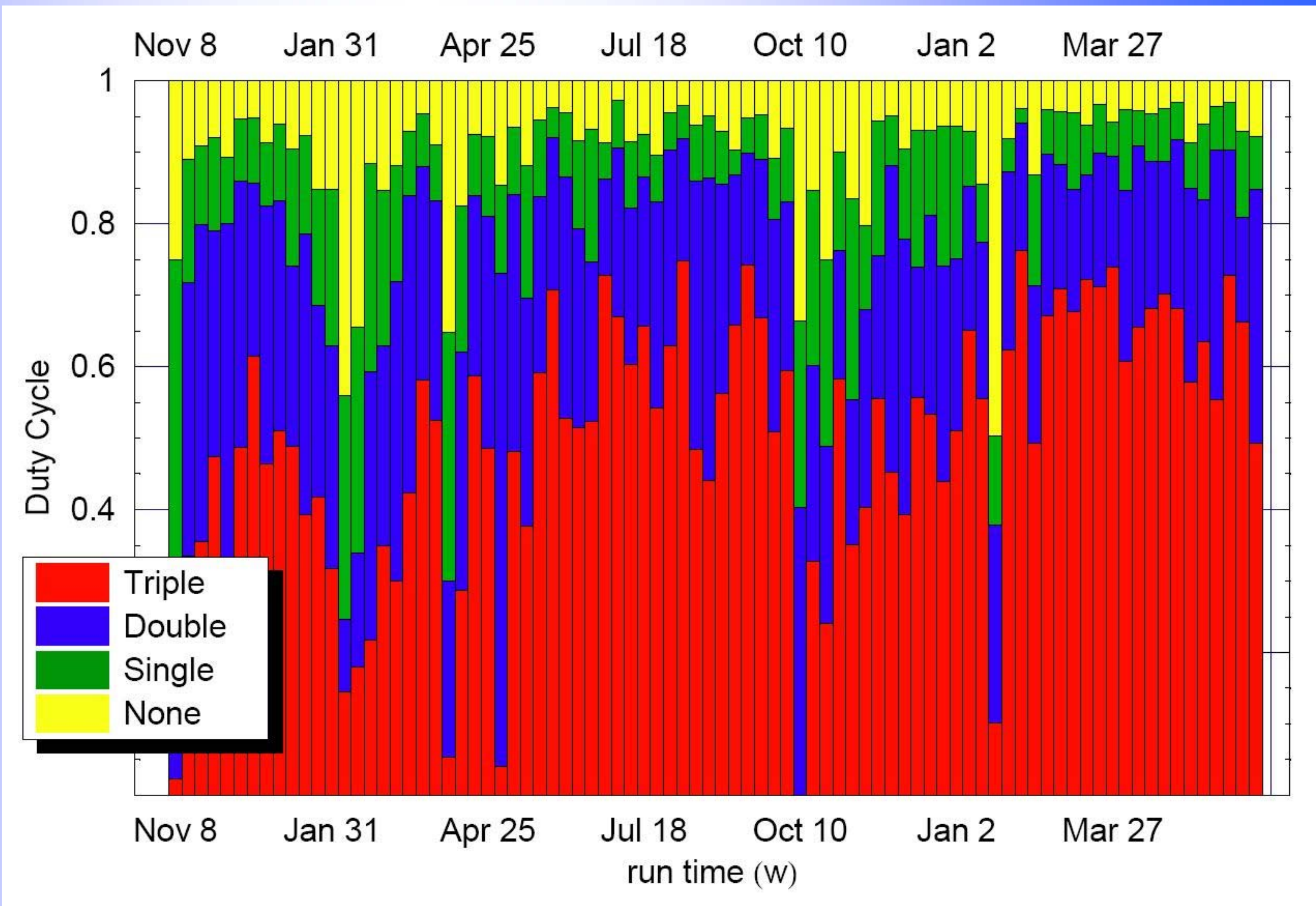
S5 Noise Budget



Fifth LIGO Science Run

- Dates
  - » Start: Nov ‘05
  - » Stop: ~Oct ‘07
- Duty cycle
  - » H1: 76%
  - » L1: 64%
  - » H2: 78%

  - » 3-coinc.: 51%
  - » HL-coinc.: 59%
- Virgo joined in May 2007



Gravitational Wave Sources

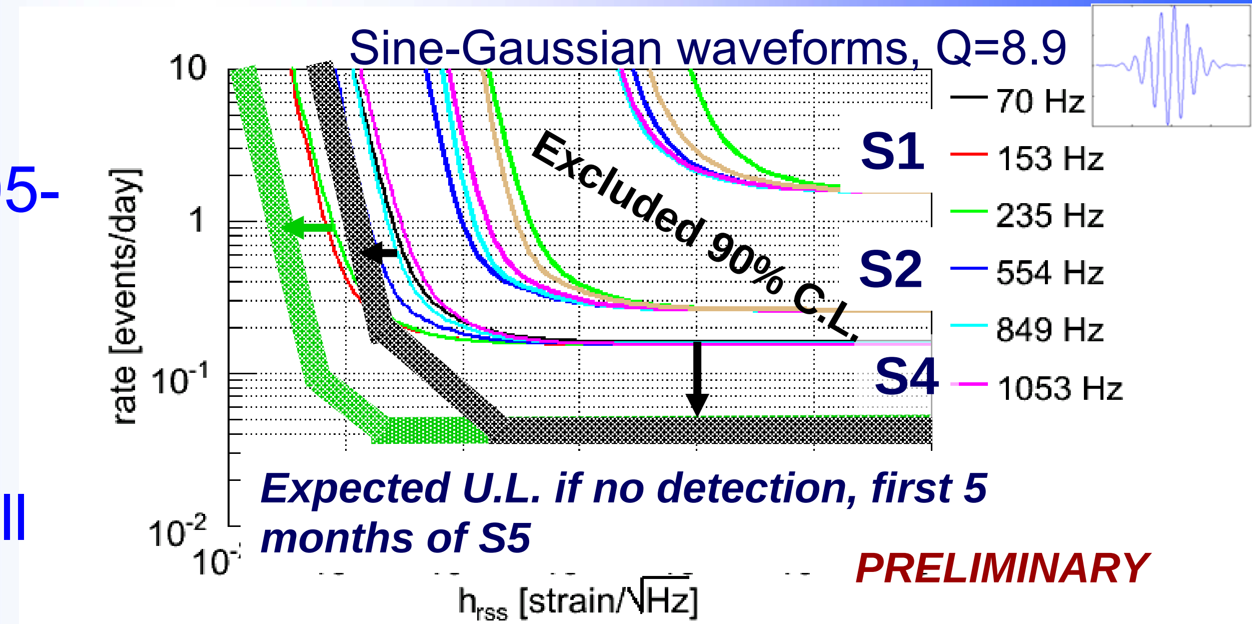
	Modeled	Unmodeled
Transient	Compact Binary Coalescences - Neutron Stars - Black Holes	Bursts - Supernova - GRBs - etc
Continuous	Periodic - Eccentric Pulsars - Accreting Systems - LMXBs	Stochastic Background - Big Bang - Incoherent Sum

Current Published Limits

- Compact Binary Coalescences (S3/S4):
  - Neutron star binary (1-3 $M_\odot$): rate ≤ 1.2/y/L_{10} (90% CL, Milky Way ~ 1.6 L_{10})
  - Black hole binary (3-40/80 $M_\odot$): rate ≤ 0.5/y/L_{10} (90% CL)
  - Primordial black hole binary (0.35-1 $M_\odot$): rate ≤ 4.9/y/L_{10} (90% CL)
  - arXiv:0704.3368v2, submitted to PRD
- Periodic (S3/S4):
  - Limits on 78 pulsars
  - Upper limits on *h* as low as 3.2×10^{-25} (95% CL) and as low as 1×10^{-6} on the eccentricity
  - Physical Review Letters 94 (2005) 181103
- Stochastic background (S4):
  - Energy limit as fraction of closure density: $\Omega_{GW} \le 6.5\times10^{-5}$ (90% CL) for a frequency independent GW spectrum between 51 Hz and 150 Hz
  - The Astrophysical Journal 659 (2007) 918.
- Burst (S4):
  - Sensitivity: $h_{rss} \sim 10^{-21} - 10^{-20}/\sqrt{Hz}$, rate ≤ 0.15/day (90% CL) corresponds to ~ 8×10^{-8} $M_\odot$ at a distance of 10 kpc (150Hz/Q=9 sine gaussian)
  - SGR1806-20 hyperflare on 12/27/04: $h_{rss} \le 4.5\times10^{-22}/\sqrt{Hz}$ and $<4.3\times10^{-8}$ $M_\odot$
  - ArXiv:0704.093, submitted to Classical and Quantum Gravity

Burst Investigations

- All-sky, all-times search for bursts on early S5 (Nov 2005-Apr 2006)
  - Extend S2-S4 methods
  - Analyzed 54 days of triple coincidence data
- LIGO-Virgo joint analysis still being planned
- Fully coherent network searches with S5
- Bursts from Cosmic Strings using S4 and S5 data
- LIGO-GEO all-sky burst search
  - Search performed in 600-2000 Hz bandwidth



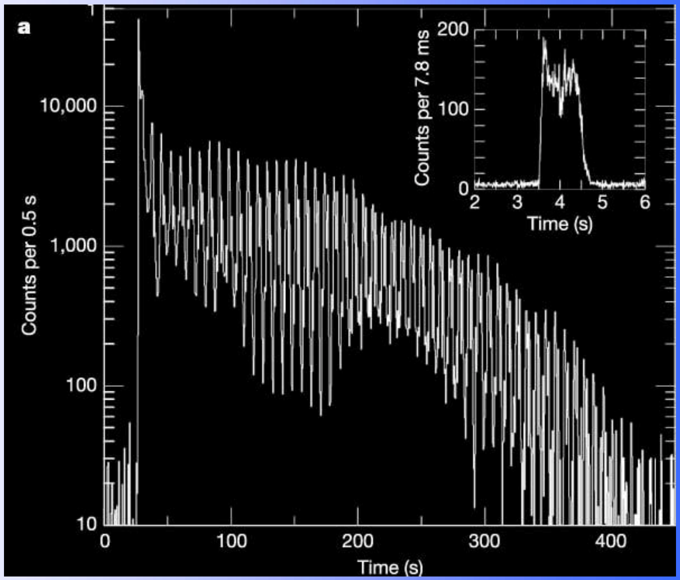
Upper Limits on Rate and Strain for Example Burst

Expected Astrophysical Reach

- Supernova
  - 11 $M_\odot$ – 0.4 kpc
  - 25 $M_\odot$ – 16 kpc
- Black Hole Merger (3% mass into gravitational waves)
  - 10 $M_\odot$ pair – 3 Mpc
  - 50 $M_\odot$ pair – 100 Mpc

Astrophysically Triggered Searches

- Search for short-duration gravitational-wave bursts (GWBs) coincident with GRBs using S2, S3 and S4 data from LIGO
  - No detections
  - Planned for S5 with more sophisticated coherent network methods
- SGR1806-20 hyperflare QPO search
  - No detection
  - Limits: comparable to the emitted energy in the electromagnetic spectrum

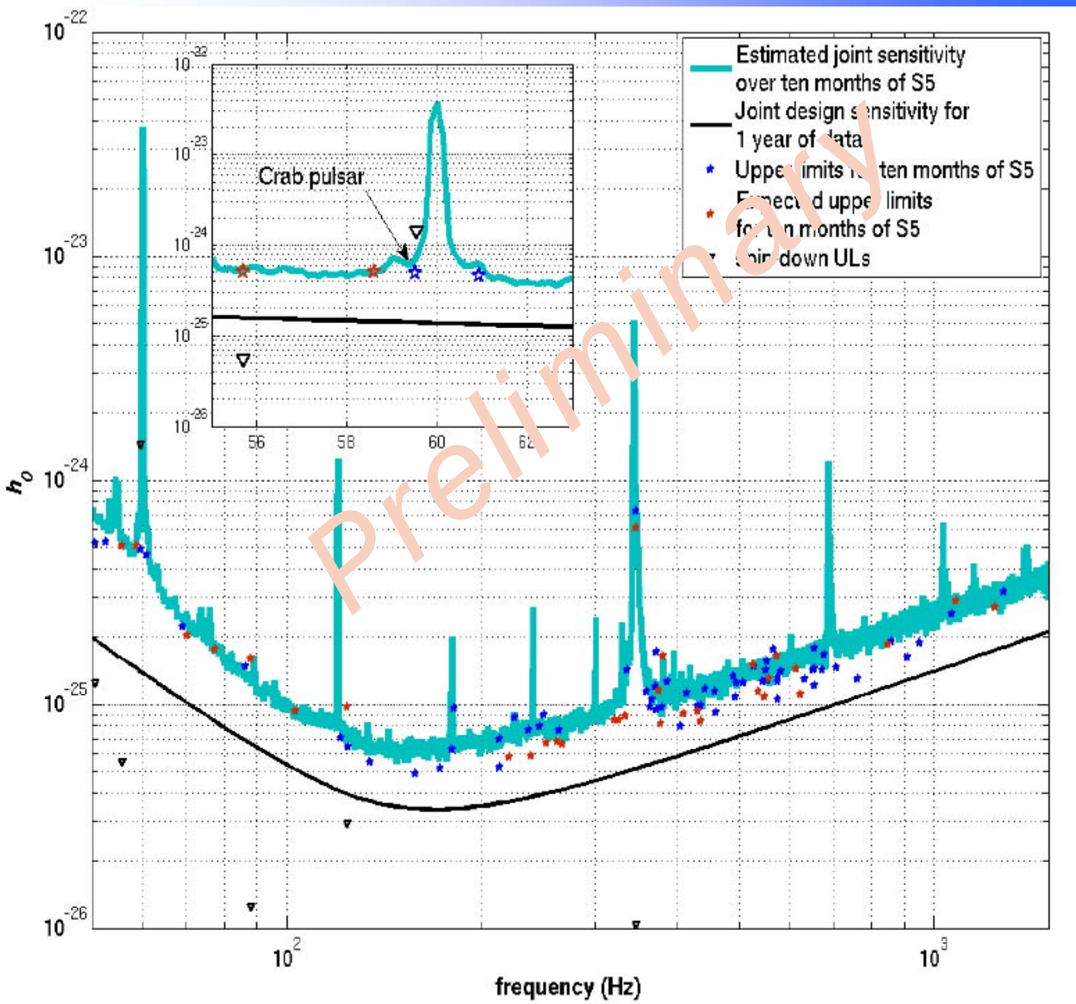


RHESSI X-Ray Light Curve of SGR1806-20 Hyperflare

- Search for gravitational-waves coincident with GRB070201
  - No plausible gravitational waves from compact binary inspiral or short transients were identified that could be related to GRB070201 and inconsistent with the noise
  - It is unlikely that a compact binary progenitor in M31 was responsible for GRB070201

S5 Periodic Investigations

- Known pulsars (radio & x-ray) (e.g., Crab pulsar)
  - Position & frequency evolution known (including derivatives, timing noise, glitches, orbit).
- Unknown neutron stars
  - Nothing known, search over sky position, frequency & its derivatives.
- Accreting neutron stars & LMXBs (e.g., Sco-X1)
  - Position known; some need search over freq. & orbit.
- Targeted sky position: galactic center, globular clusters, isolated non-pulsing neutron stars (e.g., Cas A)
  - Search over frequency & derivatives.

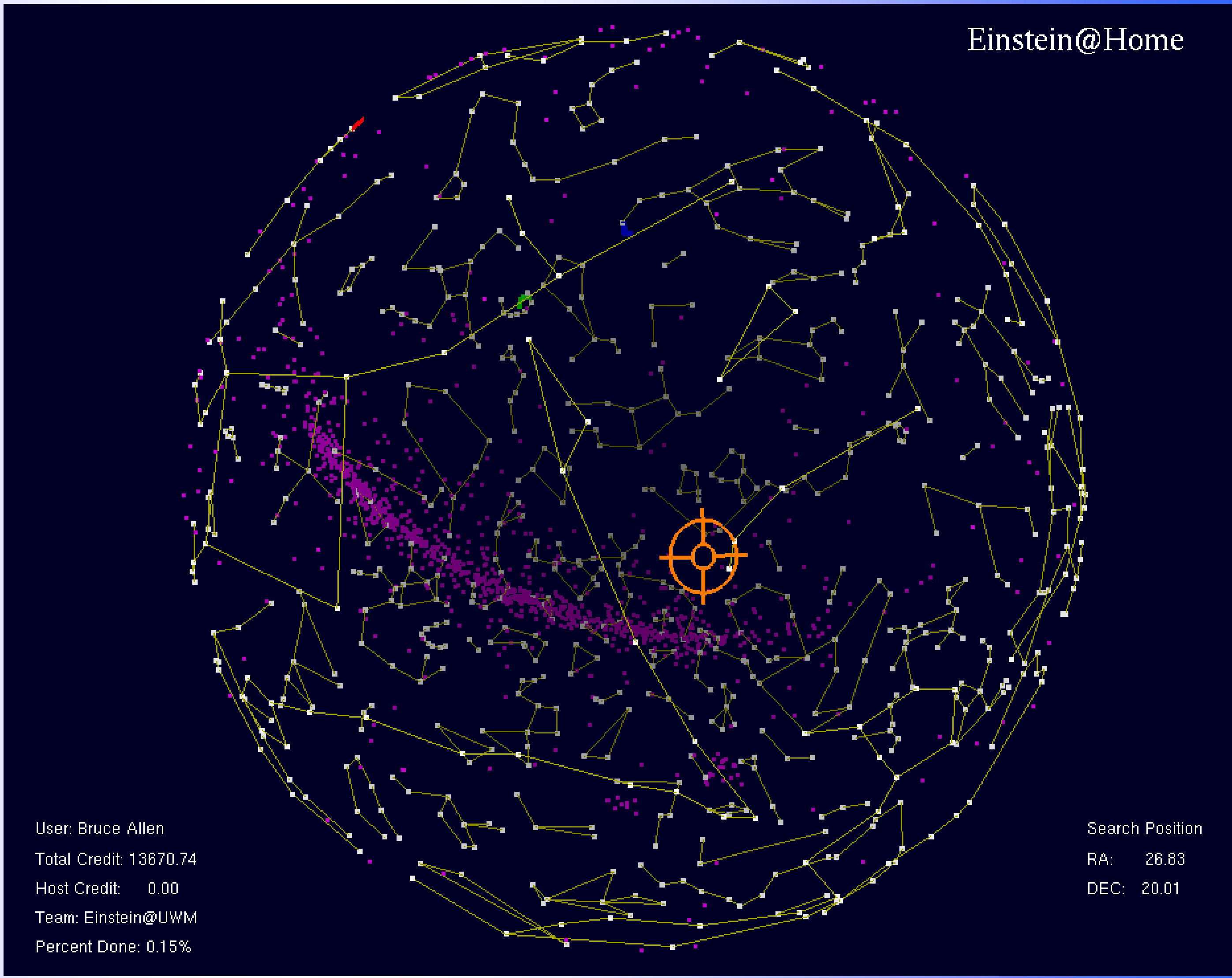


Upper Limits on Gravitational Waves from Targeted Pulsars

Einstein@home

- Like SETI@home, but for LIGO/GEO matched-filtered search for GWs from rotating compact stars.
- Support for Windows, Mac OSX, and Linux clients
- LIGO clusters have thousands of CPUs.
- Einstein@home has many times more computing power at low cost.

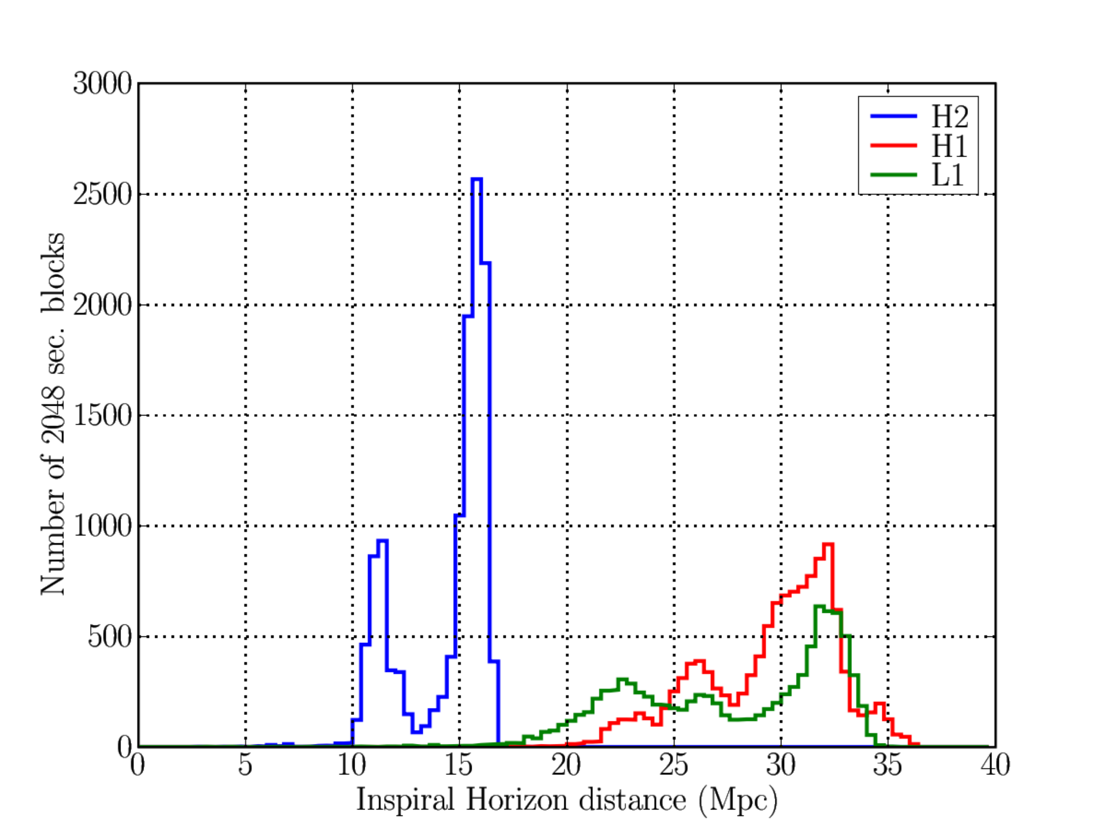
http://einstein.phys.uwm.edu/



Einstein@home Screensaver

Compact Body Coalescence Search

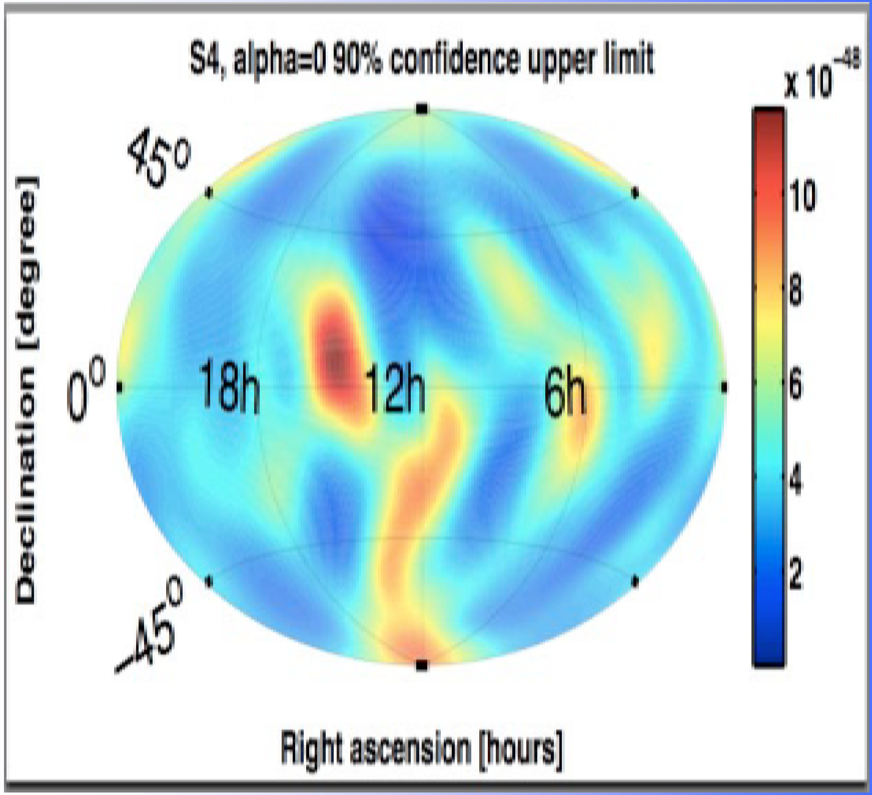
- Compact Body Inspirals
  - Neutron Stars
  - Black Holes
- LIGO – Virgo Inspiral Analysis
  - Being planned, using data since Spring 2007
- Black Hole Ringdowns
  - 6 $M_\odot$ < M < 500 $M_\odot$
  - 0 < L < 0.996
  - S4 analysis complete
  - S5 in progress
- Spinning Compact Body Inspirals
  - Spin-Orbit Coupling
  - S5 in progress



Binary Neutron Star Inspiral Horizon Distance during S5

Stochastic Background Search

- Radiometer
  - Point sources with broadband, flat spectrum
  - S4 complete, no detection
  - S5 in progress
- LIGO - Virgo search
  - In progress for S5 since Spring 2007
- LIGO – Allegro Bar Detector
  - S4 data Ω_{GW} < 1.02 @ 915 Hz
  - Phys Rev D 76 (2007) 022001
- LIGO Hanford 4 km and 2 km
  - Proposal for analysis of S5 data
  - Need tricks to remove common noise



Results of S4 radiometer search

Conclusions

- **LIGO has reached (and slightly exceeded) its design specification for sensitivity**
- **S5 science run in progress and nearing completion**
- **No detections of gravitational waves so far**
  - Most sensitive S5 data has not been analyzed completely yet
- **Setting astrophysically interesting upper limits on many sources of gravitational waves**
- **See Pradeep Sarin's talk for LIGO's future plans**