Darkness and Light:

Status of LIGO and Virgo Searches for Black Hole Mergers and Other Signals

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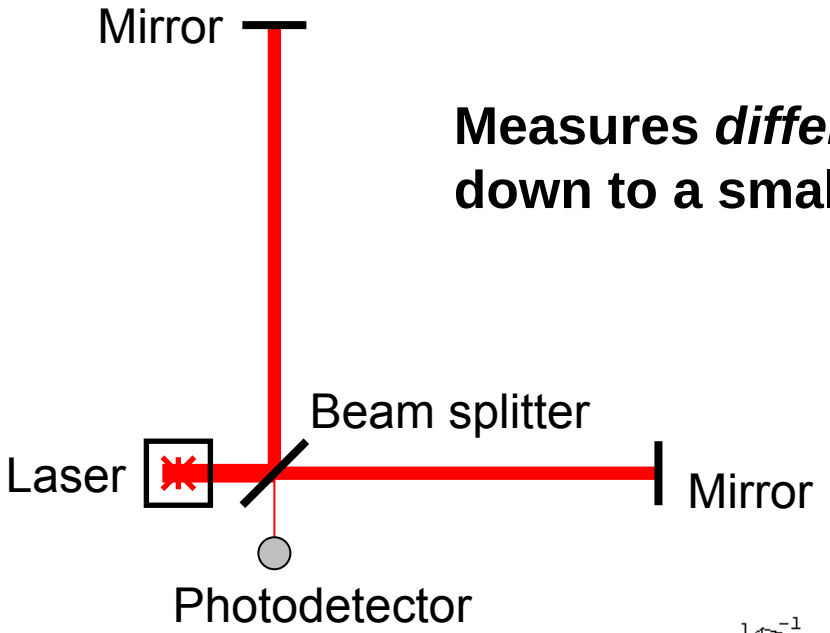
for the LIGO Scientific Collaboration
and the Virgo Collaboration

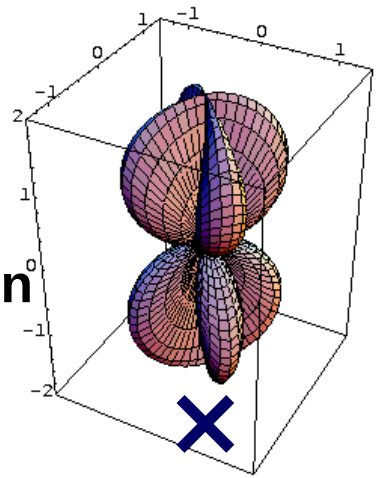
LIGO-G0900748-v1

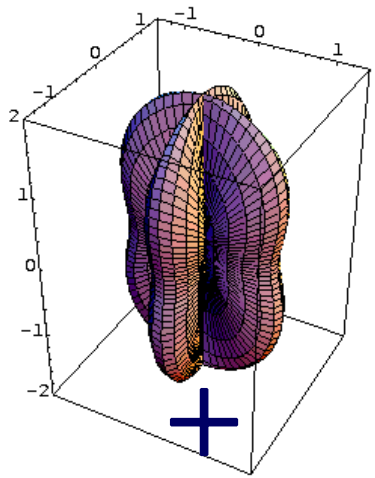
Gravitational Wave Detection with a Laser Interferometer

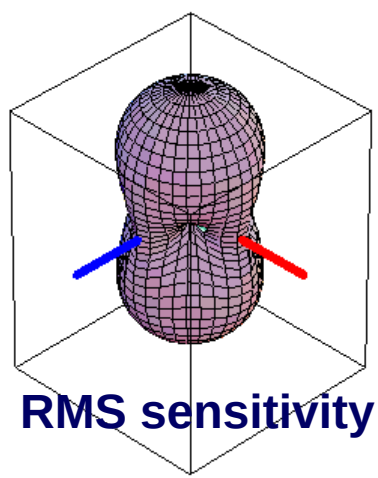


Measures *difference* in effective arm lengths down to a small fraction of a wavelength

Directional sensitivity depends on polarization

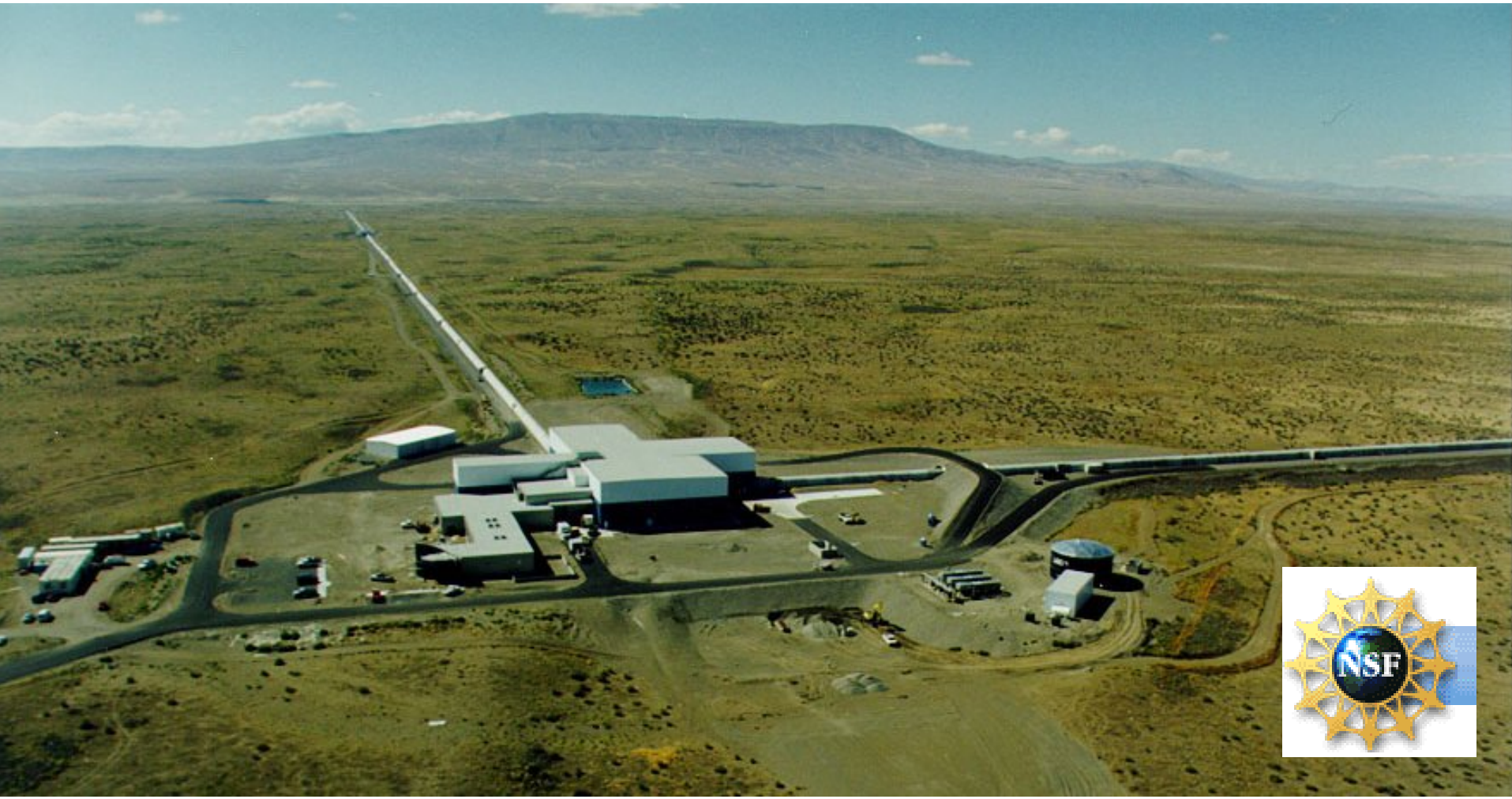




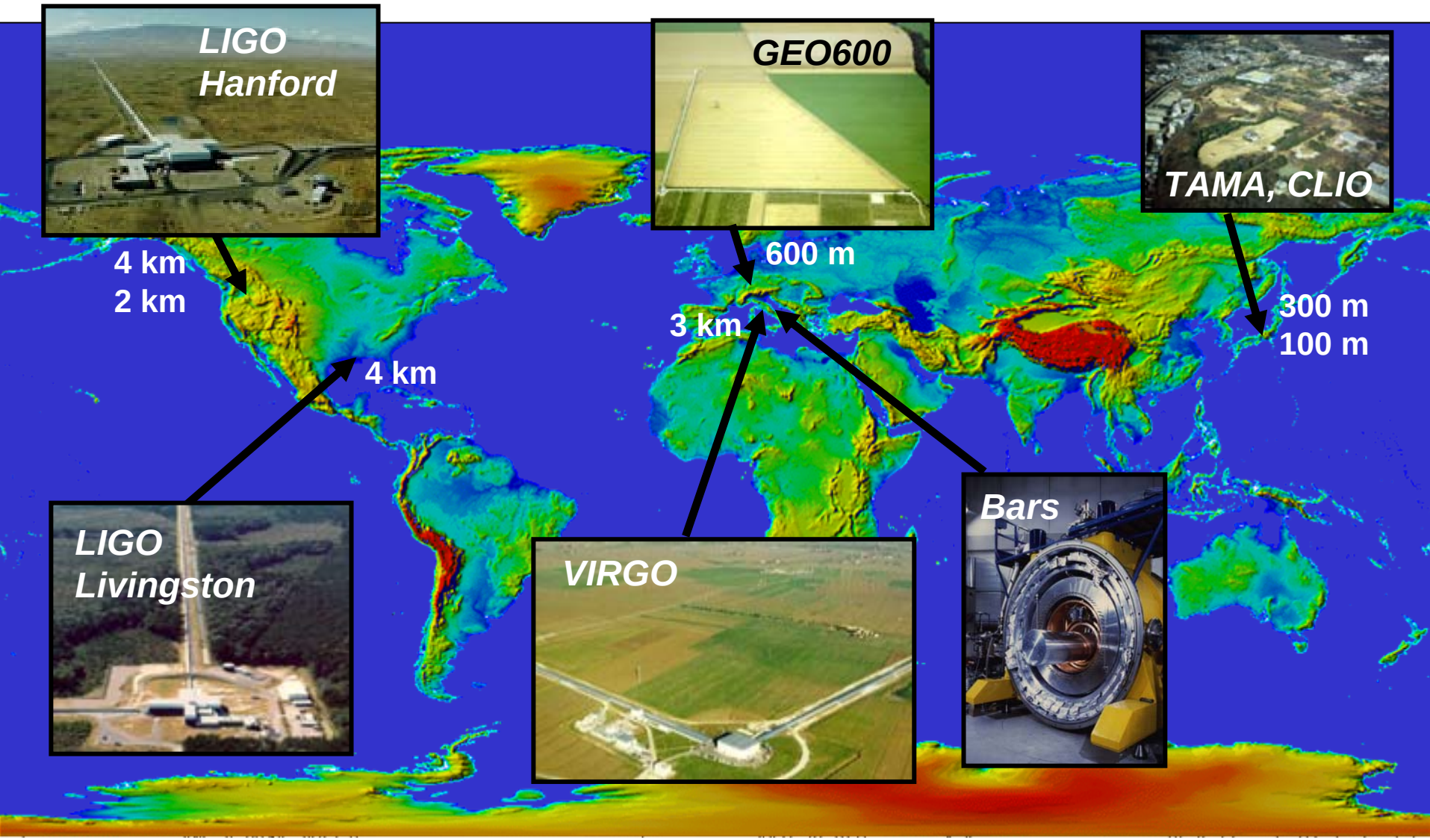


RMS sensitivity

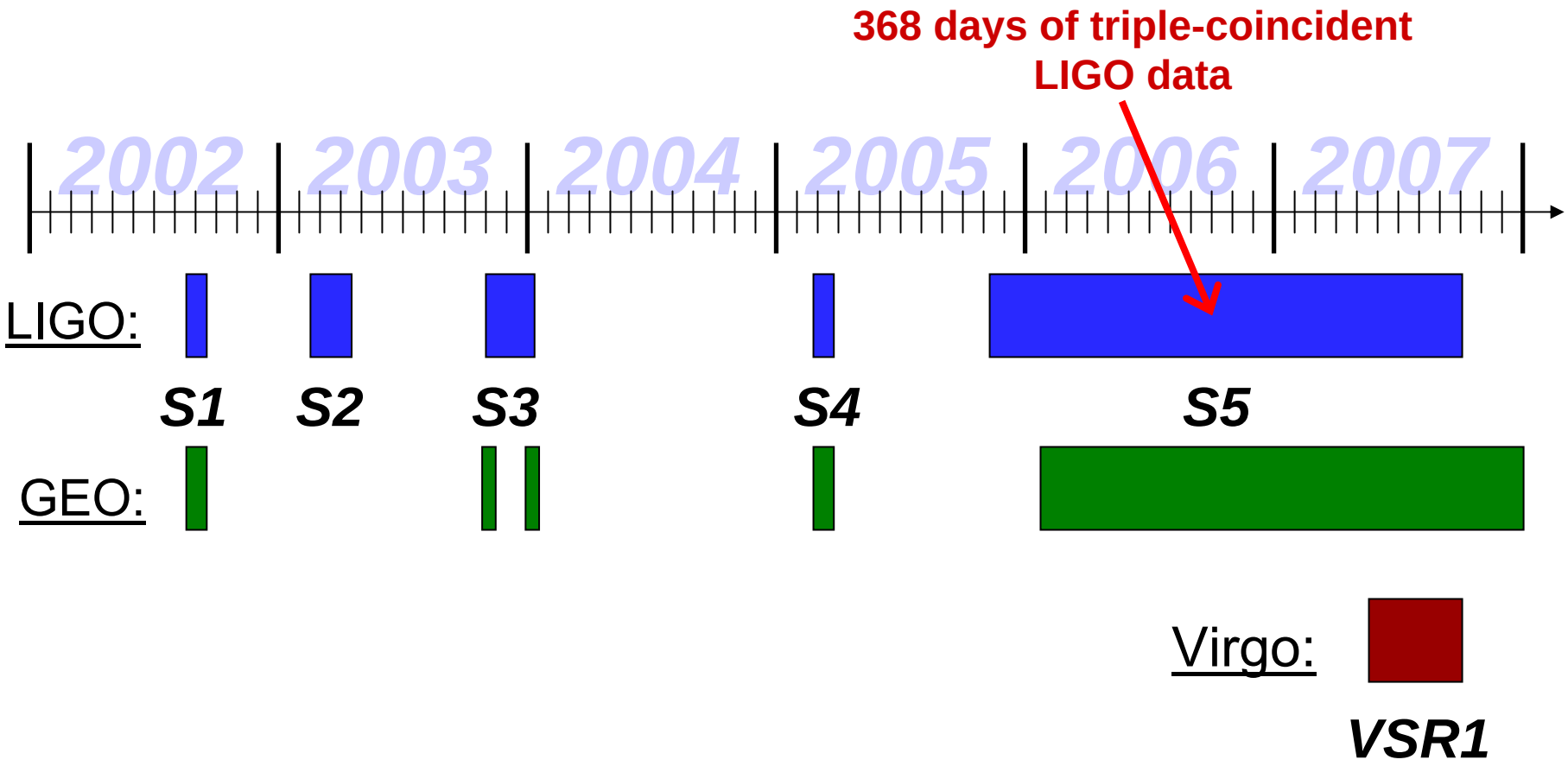
Portrait of a Detector: LIGO Hanford Observatory



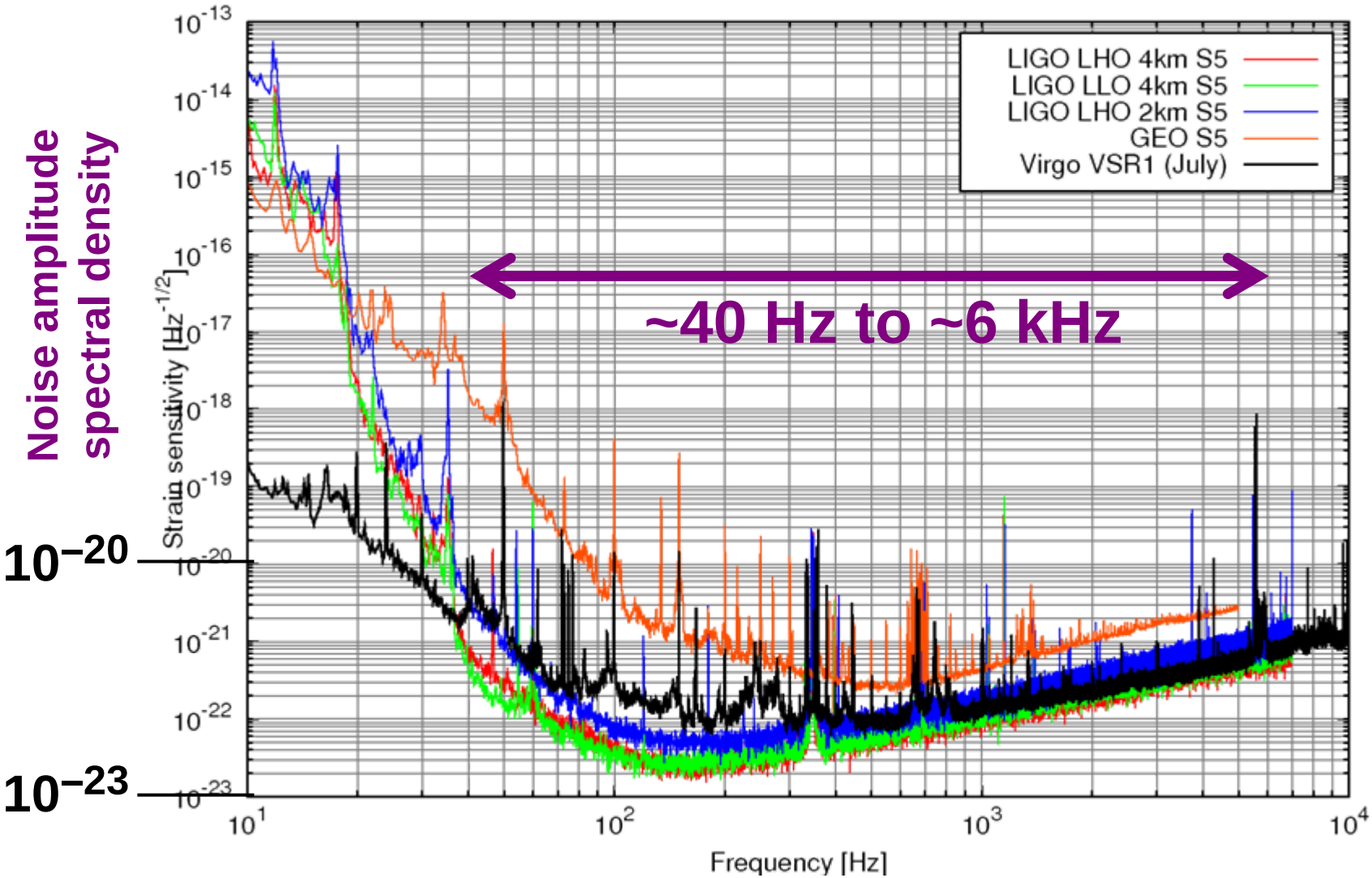
The Worldwide Network of Gravitational Wave Detectors



Completed Science Runs

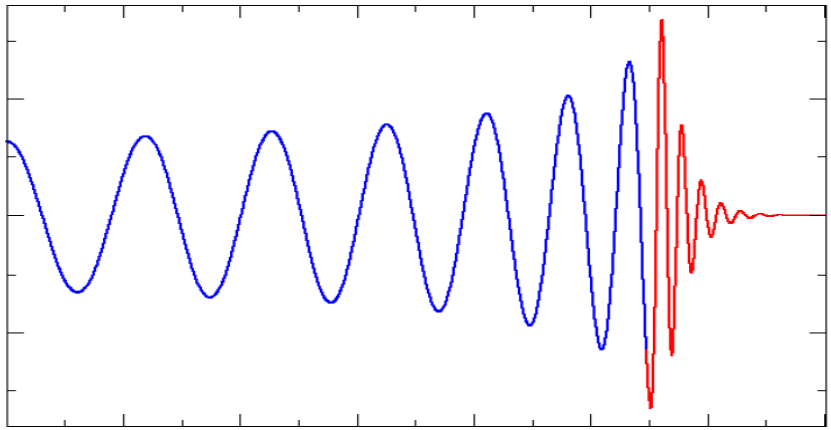


S5 / VSR1 Performance of the Large Interferometers



Binary Inspiral Searches

- Search using **matched filtering**
- Check for coincidence / consistency in two or more detectors
- Apply signal-based vetoes, data quality cuts, auxiliary vetoes



Current (S5/VSR1) approach:

Search:	Low-mass $M_{\text{Total}} \leq 35\ M_{\odot}$	High-mass $25 - 100\ M_{\odot}$
Templates:	2PN SPA (no spin)	EOBNR (no spin)
Status:	First 18 months of S5 published *[PRD 79, 122001]* *[PRD 80, 047101]* Rest of S5/VSR1 in progress	Full S5/VSR1 in progress

Low-Mass Search Results from first 18 months of S5

[PRD 80, 047101]

No inspiral signals detected

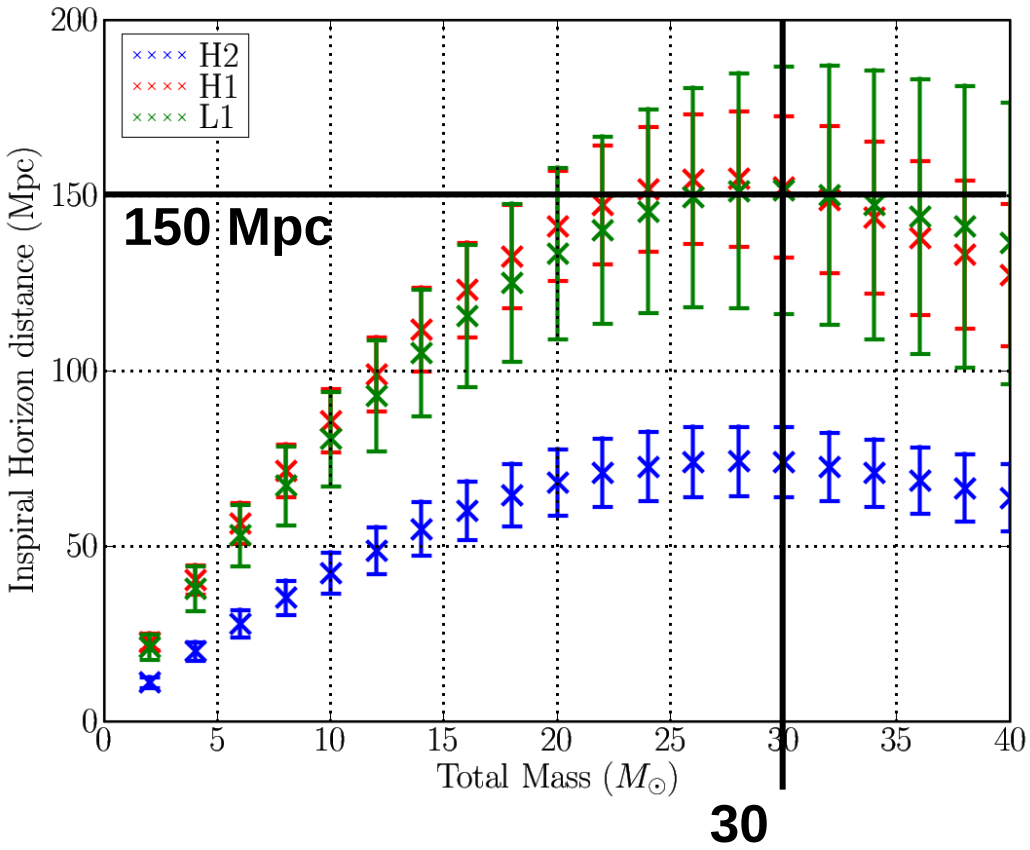
Using population models, calculated 90% confidence limits on coalescence rates:

For neutron star binary:
1.4×10^{-2} per year per L_{10}

For 5+5 $M_\odot$ black hole binary:
9.0×10^{-4}

For BH-NS systems:
4.4×10^{-3}

Slightly tighter limits if BHs are assumed to have no spin



"Horizon" = Distance at which an optimally oriented inspiral would yield SNR=8

Alternative High-Mass Merger Search: Look for the Ringdown

Expect the *l=m=2* mode of a perturbed black hole to produce a damped sinusoid with: *[Echeverria, PRD 40, 3194 (1989)]*

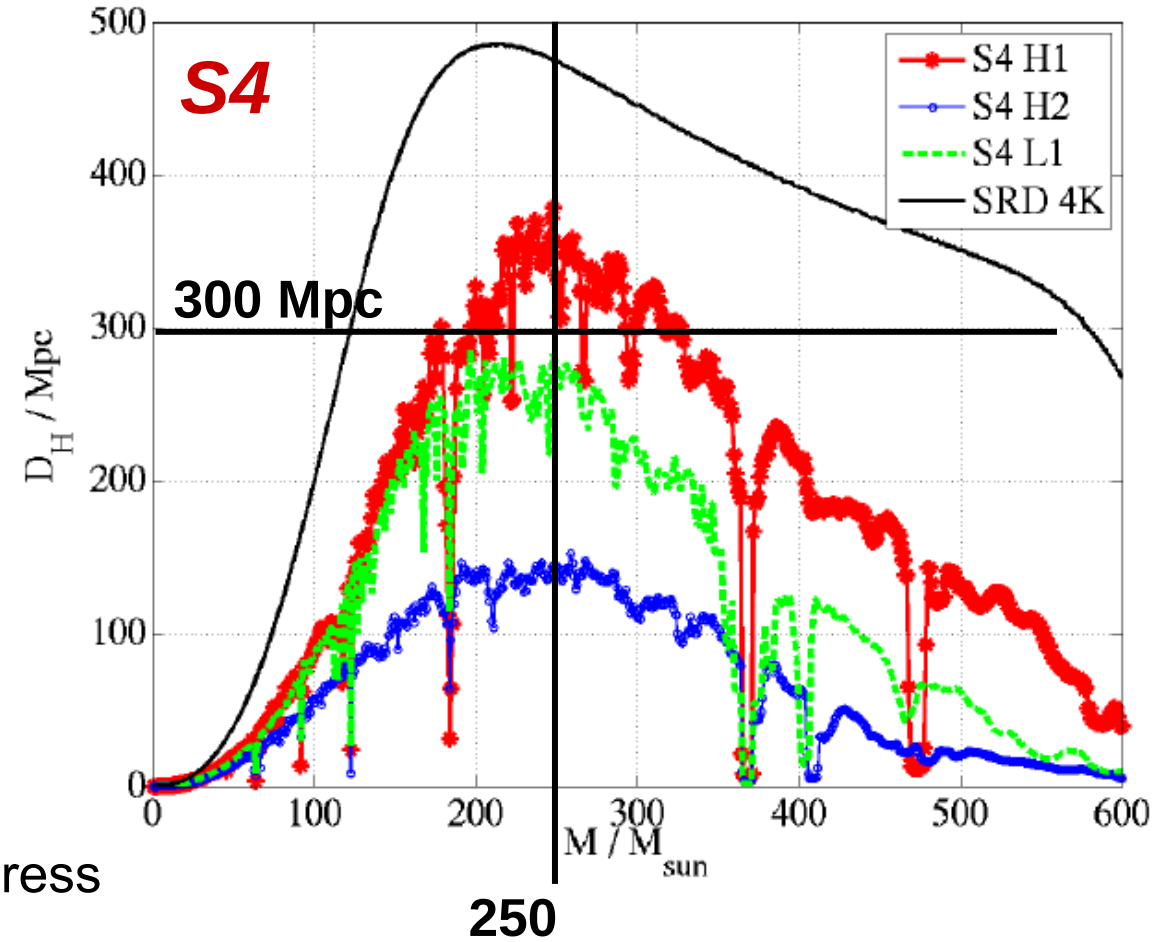
$$f_0 = \frac{1}{2\pi}\frac{c^3}{GM} \times \left[1 - 0.63\,(1-\hat{a})^{3/10}\right]$$

$$Q = 2\,(1-\hat{a})^{-9/20}$$

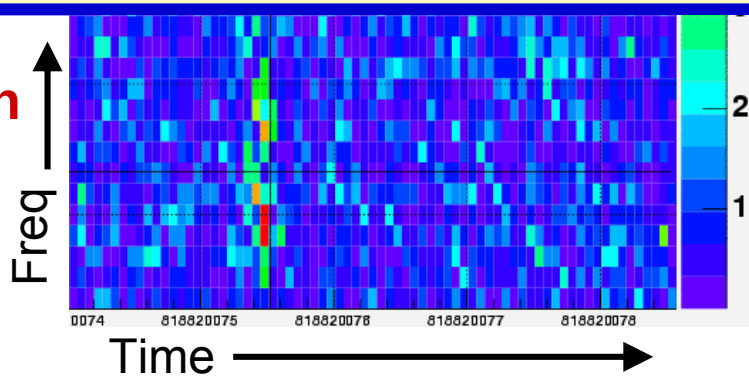
Use matched filtering to search over (f_0, Q) parameter space

S4 result: no detection
[PRD in press, arXiv:0905.1654]

S5/VSR1 analysis in progress



Robust Searches for Arbitrary "Burst" Signals



Use excess power and/or cross-correlation

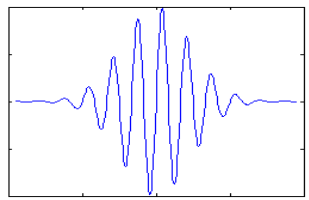
- Multiple methods have been used
- Require coincidence, consistency tests

Or generalize to a fully coherent method

- Combine data streams using self-consistent time delays and antenna factors
- Form coherent sum and null stream(s)

Evaluate sensitivity of search by adding simulated signals to data

- Either ad-hoc or from a model of an astrophysical signal

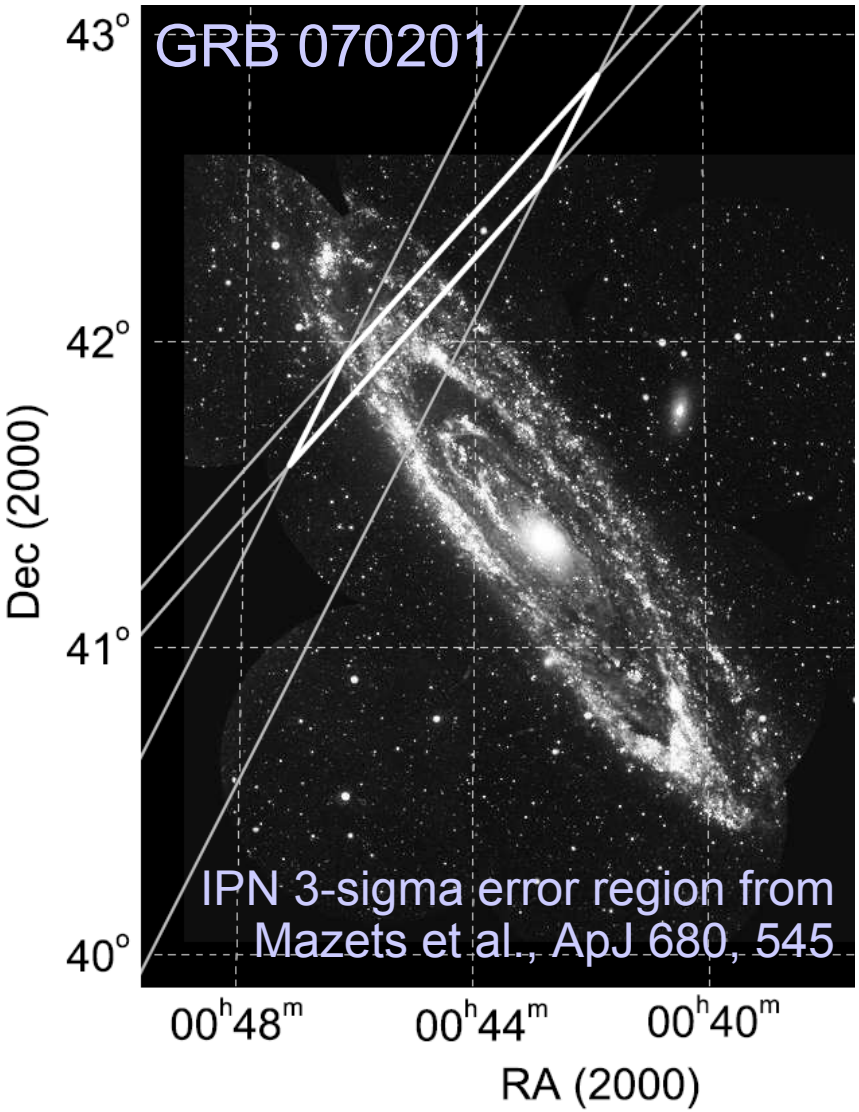


?

All-sky burst search result from first year of S5 run

- *[Submitted to PRD, arXiv:0905.0020]*
- Multiple search methods, emphasis on data quality and vetoes
- Example range estimate: Black hole binary merger with $M_{\mathrm{Total}} = 100\ M_{\odot}$ could have been detectable as far away as ~180 Mpc

Searches *With* an EM Counterpart



Gamma Ray Bursts

GRB 070201 : not a merger in M31
[ApJ 681, 1419]

Lots of GRBs examined in S2/S3/S4 *[PRD 77, 062004]* , S5/VSR1 *[arXiv:0908.3824]*

Soft Gamma Repeater Flares

GW burst at time of flare?
[PRL 101, 211102 ; ApJL 701, L68]

GW QPO in tail of giant flare?
[PRD 76, 062003]

Supernovae

Analysis in progress

Planned: Radio bursts

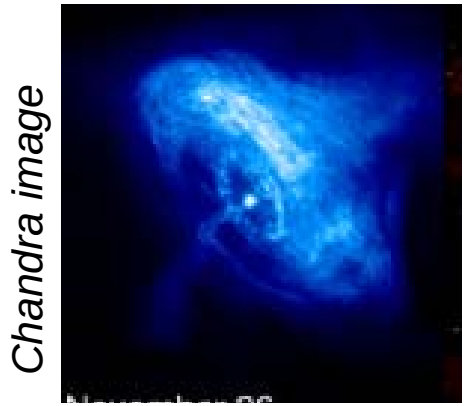
Other Notable Results from S5/VSR1 (so far)

Search for continuous GW from the Crab Pulsar

With some assumptions, can limit GW energy emission to no more than ~4% of total spindown energy

[ApJL 683, L45]

New paper with updated result using more data is in preparation



Upper limit on the stochastic GW background

[Nature 460, 990]

Relative to the critical energy density of the universe:

$\Omega_0 < 6.9 \times 10^{-6}$

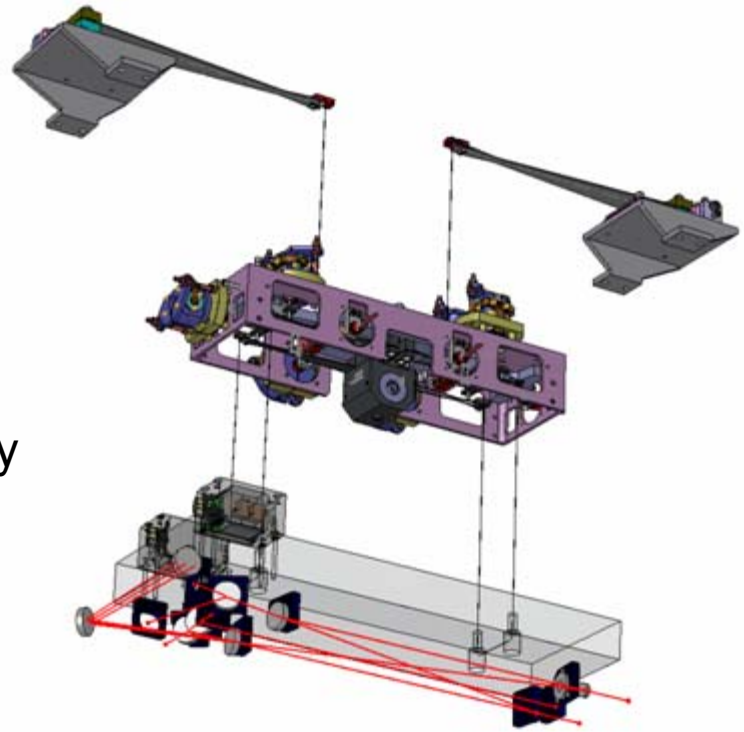
Beats the limit from big bang nucleosynthesis

Also constrains cosmic (super)string models

Happening Now: The S6 / VSR2 Run

LIGO 4-km interferometers have been "enhanced"

- **Increased laser power**
- **DC readout scheme**
  - Photodetector in vacuum, suspended
  - Output mode cleaner



Goals:

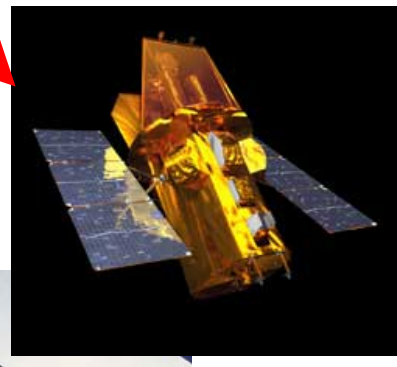
- Collect more data, with improved sensitivity
- Test some Advanced LIGO systems under real running conditions

Virgo has been upgraded too;
GEO working on parts of "GEO HF"

S6 / VSR2 run began July 7

Plan is to run through late 2010 or early 2011

Searches *For* an EM Counterpart



New effort for the S6 / VSR2 run

- **Analyze GW data promptly**
  - Identify reasonably significant event candidates
  - Reconstruct probability map for sky position
- **Call immediately for follow-up observations**
  - *Swift*, if it's a highly significant candidate
  - Wide-field optical telescopes (and possibly others)
    ⇒ the **LOOC-UP** project
  - LOFAR and/or other radio telescopes

Benefits being sought

- Catch an EM transient which otherwise would have been missed
- Gain crucial evidence that the GW event is real
- Determine accurate sky position, other event properties

Prospects for EM Counterparts

Observational examples

- Optical afterglows of (some) GRBs – minutes to hours
- Supernova light curves – days

Some specific models

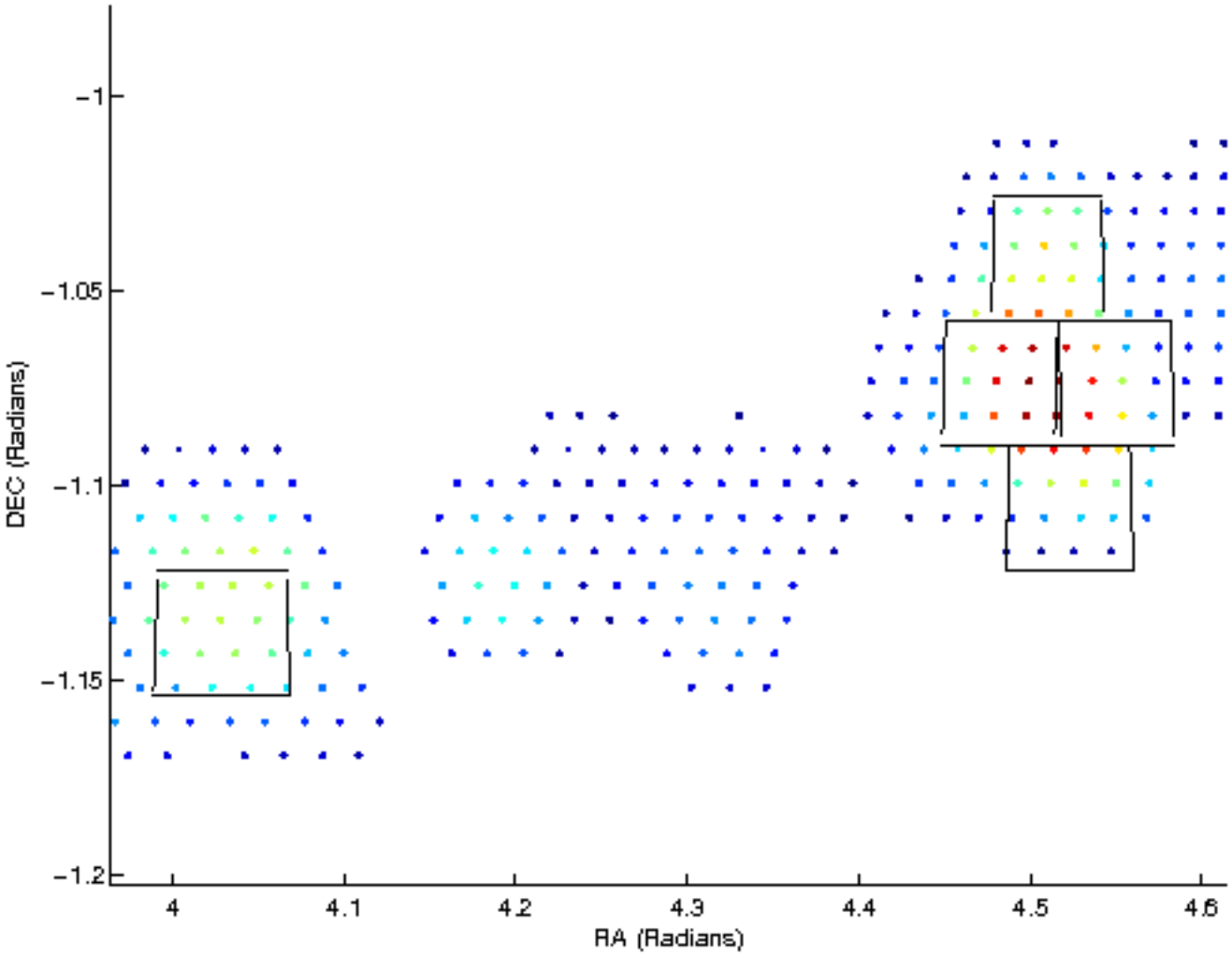
- “Nuclear fireball” model (Li & Paczynski)
- GW acting on plasma (Moortgat & Kuijpers)
- Relativistic magnetized winds acting on ambient medium (Usov & Katz)

General motivation:
If we can detect GW, then it must be very energetic and/or nearby.
At least *some* of that energy probably goes into EM emission!

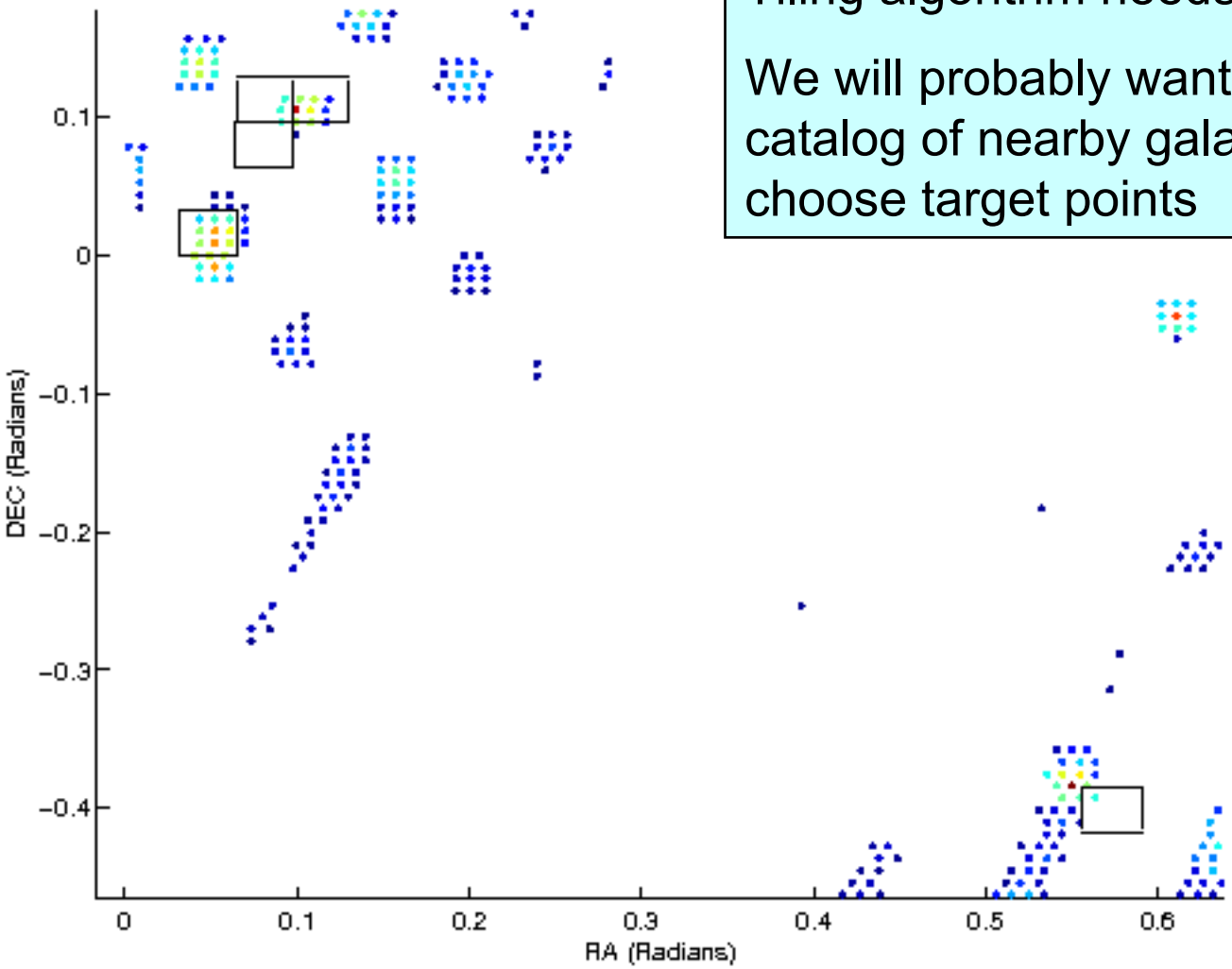
Project status

- Triple-coinc S6/VSR2 data is being analyzed within 10–20 minutes
- Event selection and communication software is being developed / refined

LOOC-UP Sky Tiling Example



LOOC-UP Sky Tiling Example

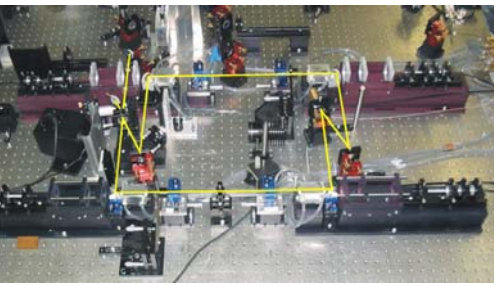


Tiling algorithm needs improvement

We will probably want to use a catalog of nearby galaxies to help choose target points

Advanced LIGO

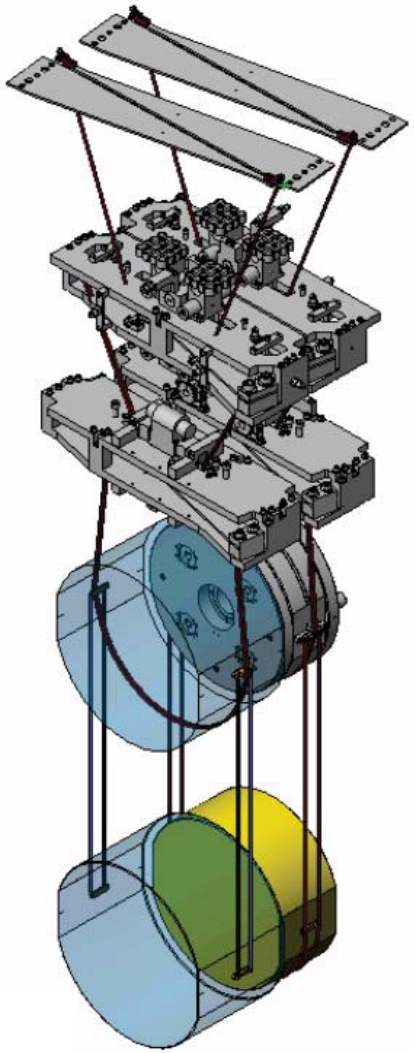
Completely new* interferometers at same observatory sites



New optical layout with *signal recycling*

* Some parts already installed !

Advanced LIGO Mirrors



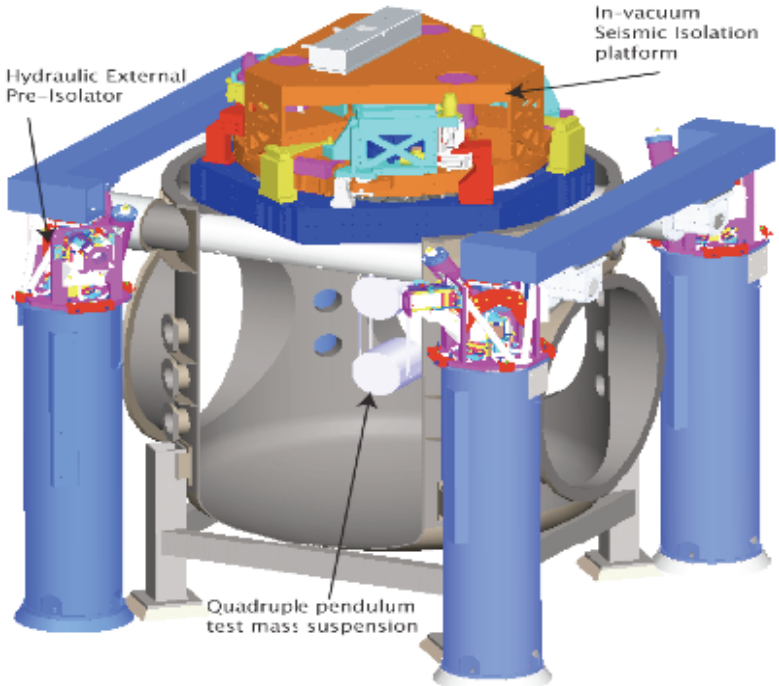
Fused silica, 40 kg

Hung by fused silica ribbons

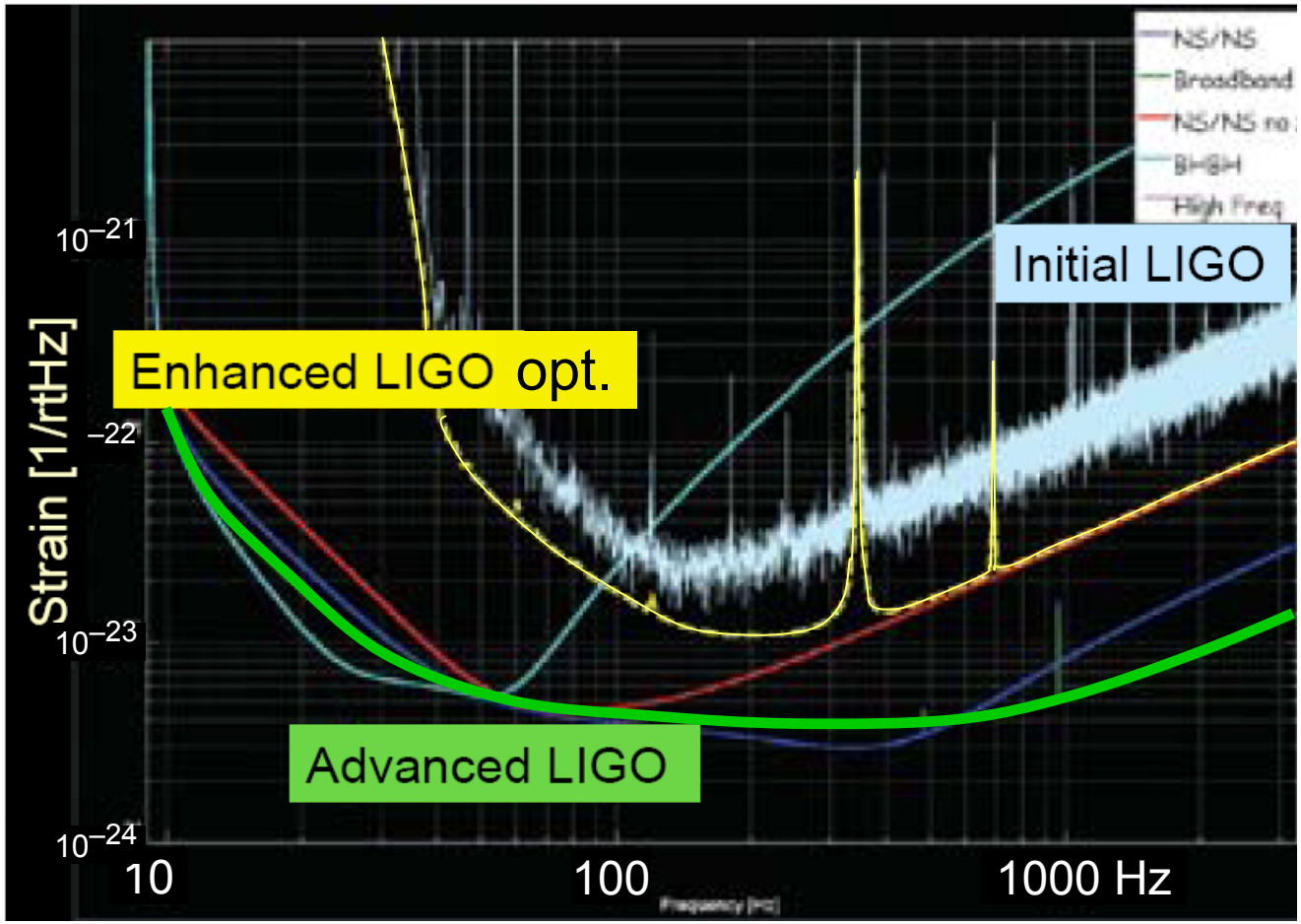
Quadruple pendulum suspension

With reaction masses for quiet actuation

New active seismic isolation systems



Projected Sensitivity



Factor of ~10 in amplitude sensitivity

Factor of ~1000 in volume

Advanced LIGO is approved and funded; construction has begun

Expect to be operational starting in 2014 or 2015

Areas of Current Interest / Questions for Discussion

- What set of searches should we do to have good efficiency for all plausible binary mergers?
- How can we use information from numerical relativity to improve our searches?
- What kinds of optical counterparts should we expect?
- How should we tune the Advanced LIGO sensitivity?
- What astrophysics can we learn from the first few detections?
- How should we be allowing for alternative theories of gravity?