Searches for Gravitational-Wave Compact Binary Merger Signatures in Coincidence with Short GRBs

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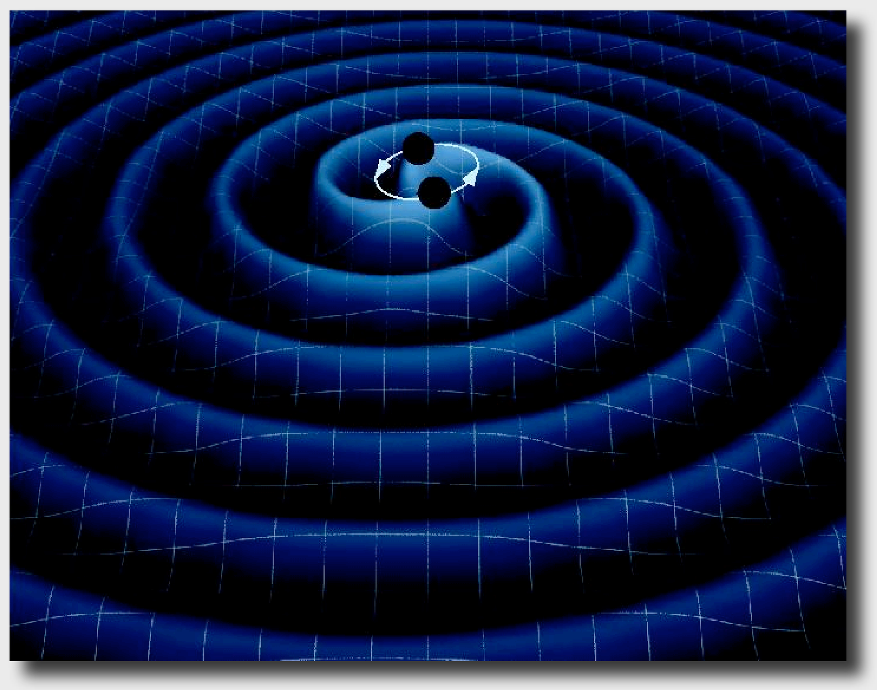
Motivation

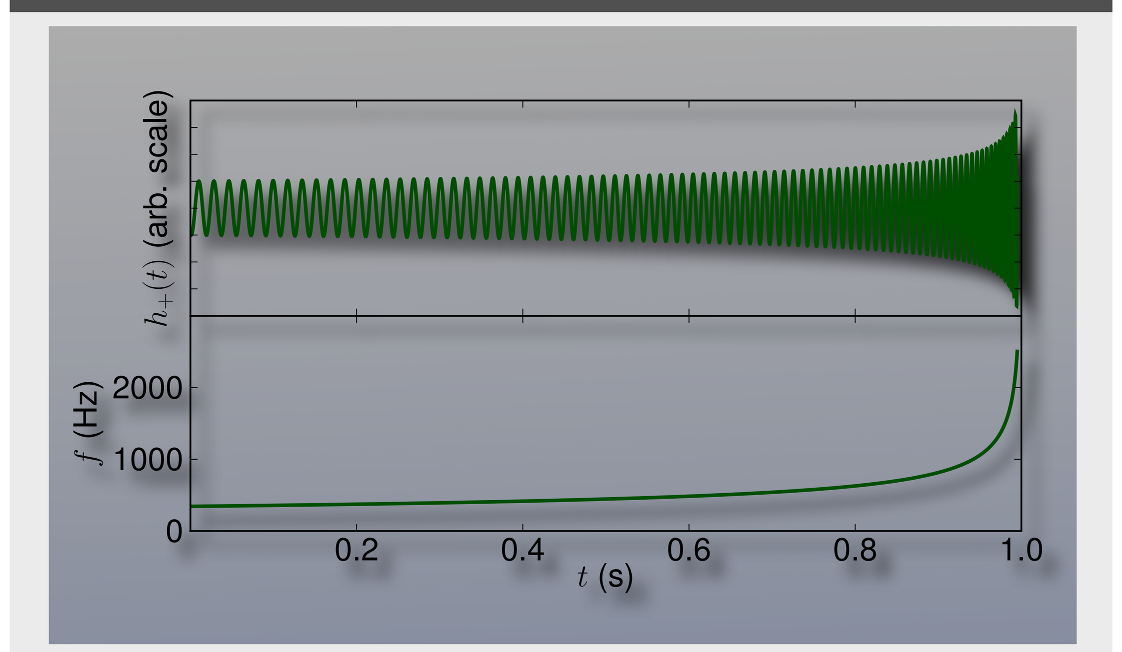
Gravitational Waves from Short GRBs

Short Gamma-Ray Bursts (GRBs) are widely believed to be produced in the merger of a double neutron star binary or a neutron star-black hole binary. Such systems produce strong gravitational waves that could be detectable by the Laser Interferometer Gravitational-Wave Observatory (LIGO) and its European counterparts, Virgo and GEO 600. Because the time and the location of a GRB is known, gravitational-wave data can be searched in coincidence with a GRB with greater sensitivity than previous, untriggered searches.



GWs provide a window into regions of the Universe that are difficult or impossible to observe through electromagnetic astronomy.

GW Merger Signatures



Chirps

As the compact objects tighten their orbits, they emit more gravitational radiation, hastening their inspiral and increasing the frequency of orbit. The signals that LIGO can detect are in the human audible range. Converted to sound, the rise in amplitude coupled with the rise in frequency sound like a what many would call a chirp. Ask me if you'd like to hear one.

Chirps are well-enough characterized to allow us to search by *matched filtering*, a very sensitive technique which filters the signal against a bank of putative waveforms.

Reference

• *Implications for the Origin of GRB 070201 from LIGO Observations*, LIGO Scientific Collaboration and K. Hurley, The Astrophysical Journal, 681:1419–1430, 2008 July 10. arXiv: 0711.1163v2 [astro-ph]

GRB 070201

A Possible Nearby Short GRB!

GRB 070201 was a short GRB that occurred while the two LIGO Hanford instruments were taking data. Its sky localization uncertainty overlapped the spiral arms of M31, the Andromeda galaxy, pictured below.

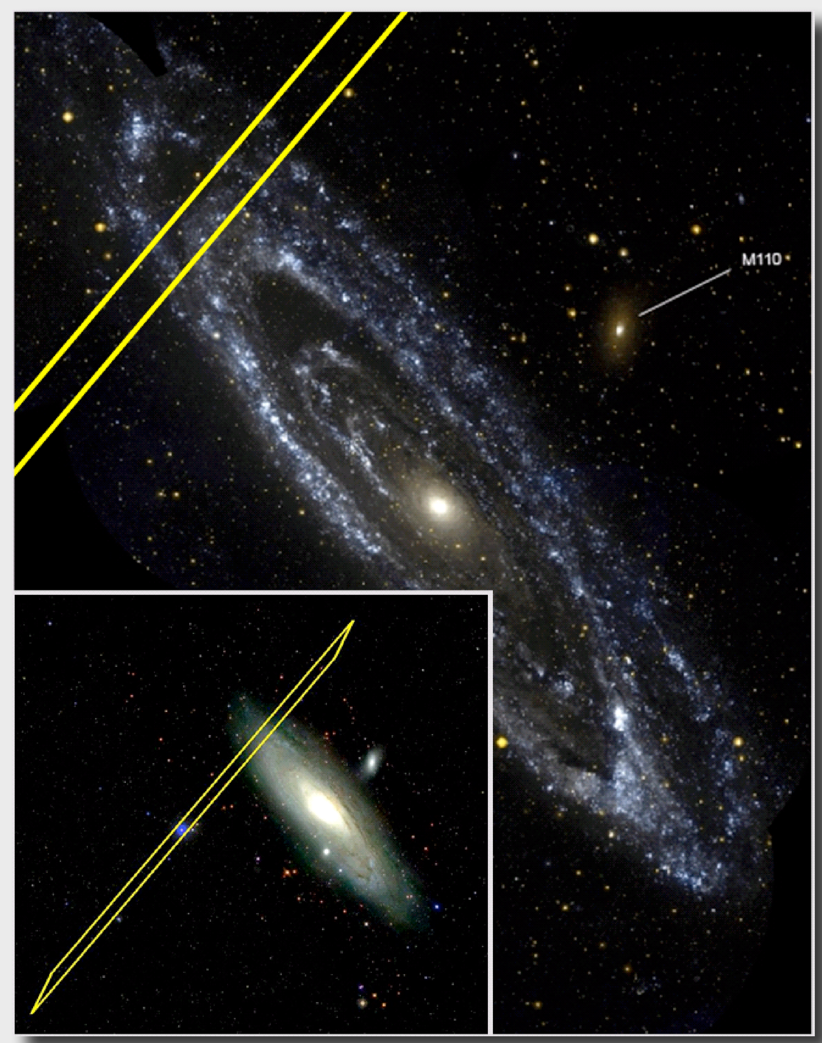


Figure: A GALEX UV image of M31 with the IPN-3 error box of GRB 070201's sky localization. Inset: The corresponding SDSS image with full error box.

Observation and constraints

If GRB 070201 were a) a compact binary inspiral and b) in M31, then LIGO would almost certainly have detected it (>99% CL). However, we did not see any GW counterpart within [-120, 60] s. This implies that the event was not an inspiral, that it originated beyond M31, or both. With the assumption that the progenitor was a compact binary inspiral, we can convert the non-detection into a constraint on the distance to the system, pictured below. This analysis added strength to a subsequent claim of GRB 070201 as being an SGR flare. An unmodeled search for GW bursts constrained the energy of an SGR flare in M31.

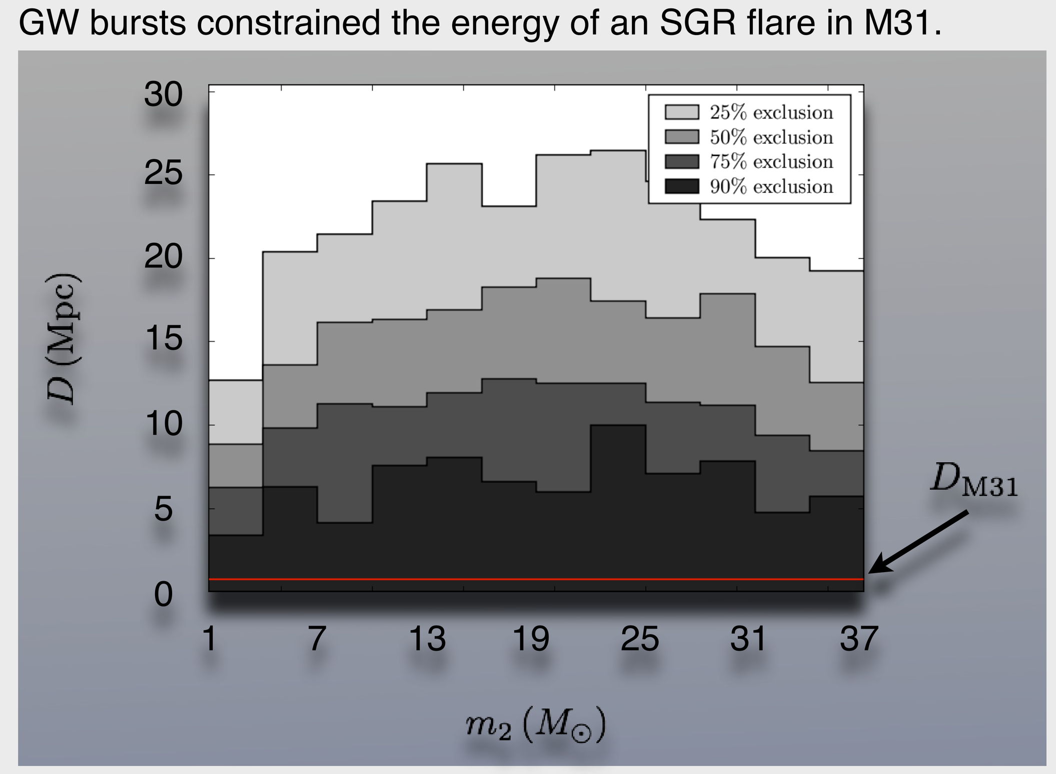


Figure: GRB 070201 exclusion distances as a function of the neutron star's companion's mass. We marginalized over the binary system's other intrinsic parameters and waveform modeling uncertainties. The jaggedness is due to Monte Carlo counting error. These distances can be considered lower limits to where a compact binary inspiral could have occurred.

Present and Future Searches

S5 and VSR1

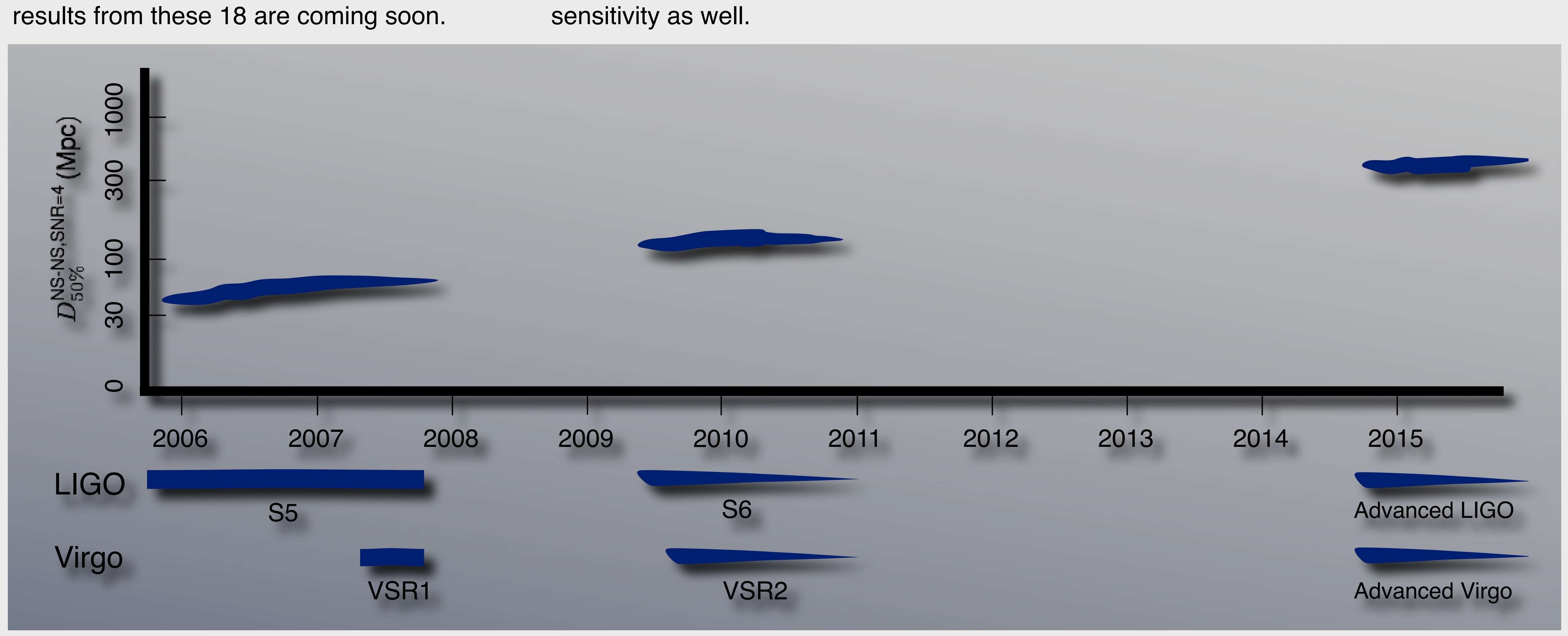
GRB 070201 occurred early in LIGO Science Run 5 (S5), in which the Initial LIGO instruments operated near their design sensitivities. In the last six months of S5, the Virgo instrument began Virgo Science Run 1 (VSR1). Of the 33 short GRBs that occurred during S5+VSR1, 18 occurred while two or more GW detectors were collecting science data; results from these 18 are coming soon.

S6 and VSR2

LIGO Science Run 6 (S6) will involve Enhanced LIGO, an intermediate step between Initial LIGO and Advanced LIGO. Enhanced LIGO will be twice as sensitive as Initial LIGO was in S5, representing sensitivity to eight times the volume. Virgo Science Run 2 (VSR2) will commence shortly after with Virgo+, and will represent a factor of two in Virgo's sensitivity as well.

Looking forward

Advanced LIGO and Advanced Virgo will be the culmination of decades of work, and the GW community's introduction to the regime of routine detection. The data analysis goal is to promptly release astronomical alerts to guide the gathering of electromagnetic radiation associated with interesting GW events.



GW Detection

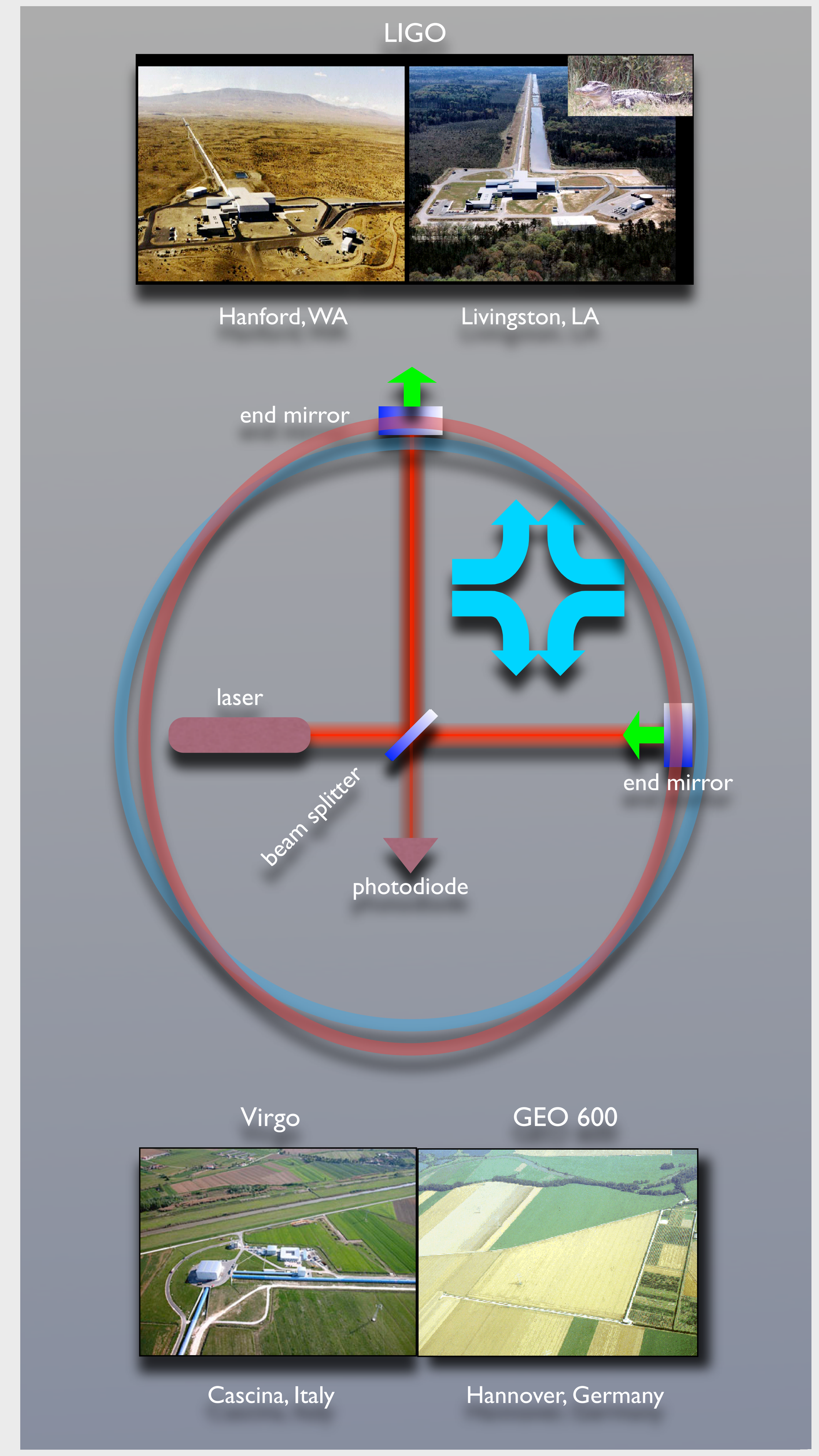


Figure: The GW observatories and (vastly simplified) schematic of the apparatus. A normally incident +-polarized GW stretches and squeezes the space between the beam splitter and the mirrors, which changes how much light arrives at the detection photodiode. In its most sensitive frequency band, LIGO can detect a change in the difference of the length of its arms to a few parts in 10^{-21}. Enhanced LIGO (now under construction) will do substantially better and Advanced LIGO (now funded) shall also give us access to lower frequencies, which are of significant astrophysical interest.

Related GW Searches

LIGO and Virgo data are being searched for events with and without external triggers, for known waveforms and for unmodeled bursts. Triggered searches include those for long and short GRBs, SGR flares, neutrino events, and optical and radio transients. Untriggered searches hope eventually to provide triggers as inputs for electromagnetic observations.

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Feel free to direct questions to `nvf@gravity.phys.uwm.edu`.

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