The Role of CACR in the LIGO Gravitational Wave Observatory

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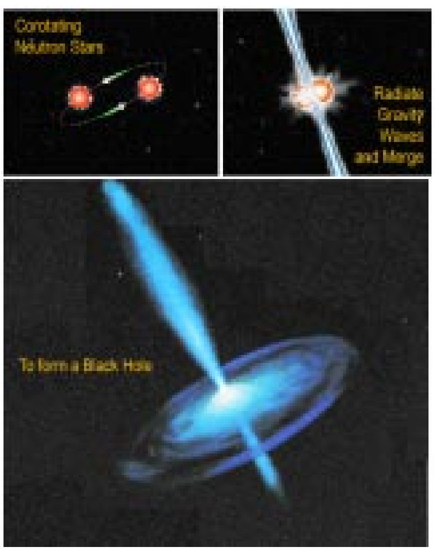
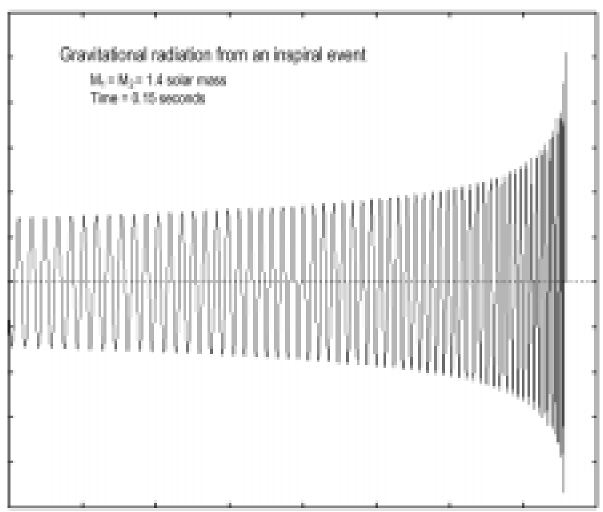
Einstein's general relativity describes curvature of space-time. In the limit of weak, static curvature, it reduces to Newtonian (inverse-square) gravity, and in the limit of weak, dynamic curvature, it predicts gravitational waves. While the former manifests itself every time an apple falls from a tree, the latter phenomenon has never been detected, despite many experiments and many false positives over the last thirty years. The $350 million LIGO project is designed to detect these gravity waves, using two detectors, one in Washington state (artists impression, above) the other in Louisiana. The detectors represent the largest precision optical systems in the world, and each has a pair of 4km vacuum tubes at right-angles, with laser light passing through complex interferometers. The detectors measure distance between the endpoints with incredible precision: if a gravitational wave passes through the system, the tiny changes in geometry can be measured.



Initially, LIGO will search for gravitational waves generated by three classes of astrophysical processes. An inspiral event (left) is generated when a pair of massive, highly condensed objects, such as neutron stars or black holes, spiral in toward each other and collide. As they orbit, kinetic energy is released through gravitational radiation, causing the orbital period to decrease and the radiation to strengthen. LIGO will detect this as a 'chirp' lasting a few seconds, whose signature at the interferometer is shown below.

LIGO will also search for gravitational waves from supernova events and from the rotation of asymmetric compact objects such as neutron stars, but these are more difficult to find than inspirals.

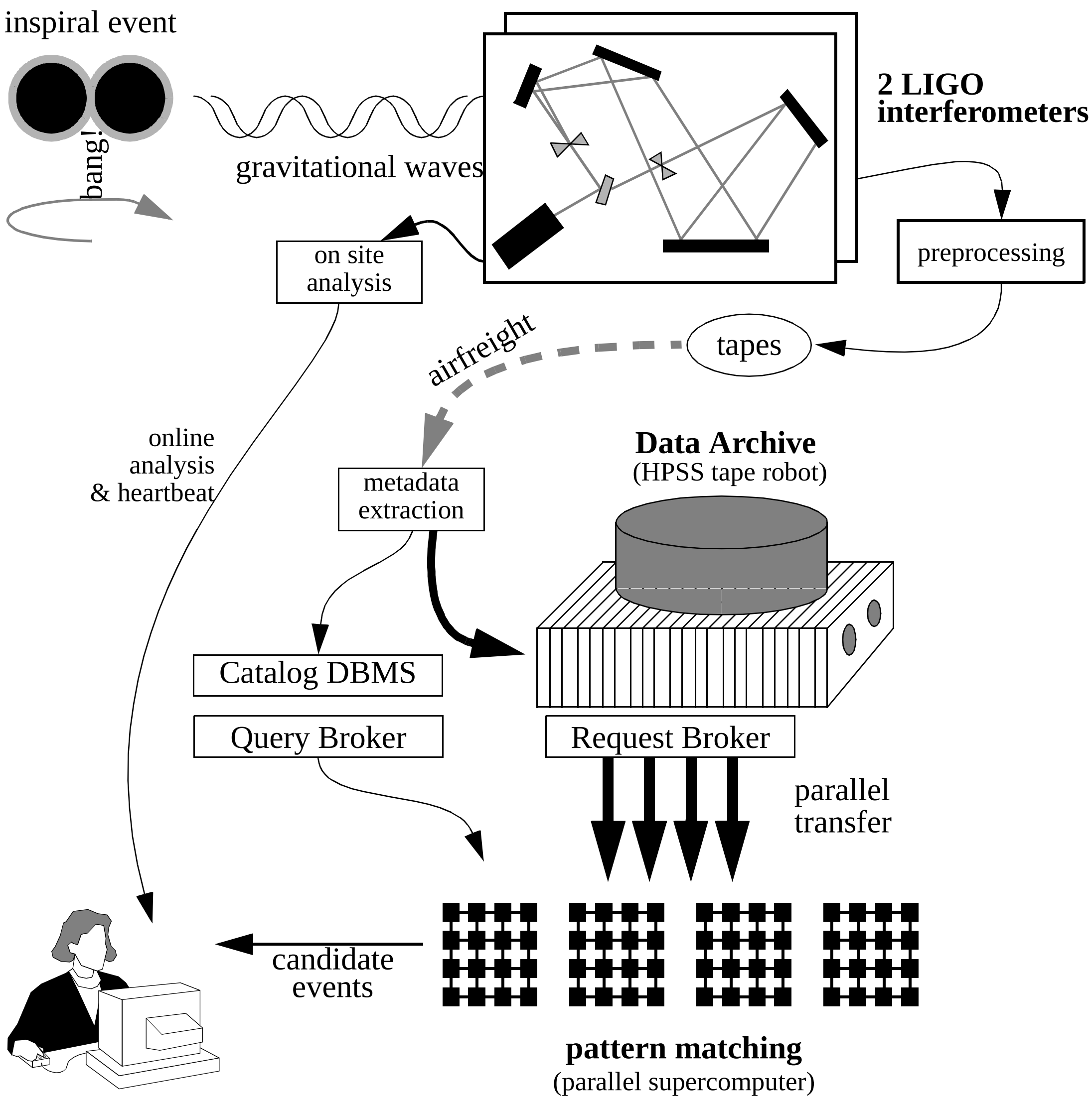


The raw data from the interferometers contains (we hope) extremely faint signals deeply buried in noise, requiring supercomputers to search for a variety of inspiral scenarios in the large volume of data from the interferometers. Once candidate events are found, great care must be taken to eliminate terrestrial effects such as distant earthquakes or spurious electronic signals—in fact, the major reason for having two detectors is to help eliminate local effects.

CACR is collaborating with the LIGO project by providing an ‘active digital library’ to contain a the data and processing facilities. We are currently engaged in the following activities.

- Archiving the data from the interferometers using the HPSS system. We are providing not only data, but searching, filtering, and calibration services, and a variety of retrieval formats.
- Metadata services that can find which data frames cover a certain time interval, history of the state of these complex instruments, and low-resolution ‘thumbnail’ images of the data frames.
- Providing library services that allow a diverse group of investigators access to the archive, including libraries of possibly related events, such as gamma-ray bursts and seismic events, findings of other investigators, and pointers to web pages and the scientific literature.
- Providing computing services which are connected at high bandwidth to the data archive, so that a remote investigator need only download the relatively small result of the data-mining, rather than the enormous raw dataset.
- Visualization software and services that allow investigators to see the signatures of candidate and simulated events, and their correlations with other data sources and computations.
- Porting the analysis algorithms to high-performance parallel machines.

Reference: *LIGO: The Laser Interferometric Gravitational Wave Observatory*, A. Abramovici et. al., Science **256** (1992) 325.



Schematic data flow for LIGO. The interferometers provide a real-time stream to on-line analysis, whose results are broadcasted to interested users. The bulk of the data is written to tape and airfreighted to the CACR, where it is catalogued and archived. Supercomputers use the catalog to convert a high-level query to simple file requests, which are satisfied by a request broker attached to the archive. Parallel data streams flow to the pattern matching code and candidate events are sent back to the user or put into another database.