The search for gravitational waves at the University of Glasgow

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In recent years the search for elusive gravitational waves (gw) has been hotting up. I will be giving an overview of the background behind and current work in this exciting new field and showing how we could soon be doing real gravitational wave astronomy. Gravitational waves, a direct prediction of general relativity, have been eluding physicists for nearly 40 years. Theory predicts that accelerating masses will emit gws in an almost analogous way to electromagnetic waves being emitted from accelerating charges. These waves stretch and squeeze space in perpendicular directions as they propagate through it at the speed of light. They are often described, in the now rather cliched phrase, as ripples in space-time. To emit gravitational waves at any appreciable level the objects and systems must be some of the most massive and energetic in the universe, such as spinning neutron stars and binary black-hole systems. Even such violent events as these only produce strains in space on the order of the diameter of an atom over the distance between the Earth and Sun. No wonder they are such tricky things to spot.

Back in the 1960's the pioneering experimentalist Joseph Weber of the University of Maryland was the first person who saw the possibility of directly detecting gravitational waves as an achievable goal. To this end he set about designing an instrument that would be able to measure the tiny distortions in space-time that signify a passing gw. This instrument consisted of a large cylindrical bar of aluminium suspended around its centre and ringed with transducers to measure its motions. In theory a gw passing at the resonant frequency of the bar would excite vibrations within which could be picked up by the transducers. For the purposes of claiming a detection it was realised that just one bar would not be enough. No-one would believe a vibration in your bar was not just a random event unless it could be seen in multiple detectors at the same time. Weber himself set up two detectors, widely seperated to avoid any local environmental correlations. In data taken from his detectors in the 60s Weber claimed to see the signature of gws, although this highly controvertial claim could not be verified by other groups who had set up similar detectors to Weber's own. Despite this early controvesy Weber's work sparked off many experimental groups around the world to start designing and building their own gravitational wave detectors and many theorists into thinking about the sort of objects capable of generating waves which would be observable. An example of such an experimental group is that at the University of Glasgow, where people such as Jim Hough and Ron Drever lead many new developments in designing and building better detectors.

In the present day there are many detectors in operation and being commissioned around the world, some based on the same basic design used by Weber, and others based on laser interferometry. These latter type are huge Michelson interferometers on scales of kilometres in which changing arm lengths caused by a passing gw can be measured. Data from the US Laser Intereferometer Gravitational-Wave Observatory (LIGO) project and the UK/German interferometric detector GEO 600 is being analysed at Glasgow as part of the LIGO Scientific Collaboration (LSC). This collaboration is very large consisting of over 300 scientists (experimentalists, theorists, data analysts, computer scientists, etc) from many institutions around the world. Being part of such a large collaboration provides great opportunities to work with a variety of people with varying scientific backgrounds.

The different gw sources being searched for are broadly catagorised into 4 types: continuous wave (periodic) signals from neutron stars, bursts of gws, as might be produced during a supernova, inspiral signal from the merger of compact objects in a binary system, and the stochastic (primordial) gw background from the big bang. The searches for each type of source vary with many different data anylysis techniques being used. Researhers at serveral UK institions including the Universities of Glasgow, Birmingham and Cardiff are involved in all of these searches.

I will now focus on the research being carried out at Glasgow as part of the Institute for Gravitational Research. The data analysis branch of our group is relatively small with currently 1 faculty member and 3 PhD students. Research here is mainly focused towards the continuous wave searches. We are searching for gws from known and unknown pulsars (a pulsar is a spinning neutron star which emits a beam of electromagnetic waves that sweeps across the Earth with every rotation like a lighthouse). It is predicted that if such a neutron star is triaxial in shape, i.e. it has bumps or 'mountains' on either side sort of like a rugby ball, then it will emit gws. For known pulsars (detected mainly by radio astronomers) we know their positions and frequencies and therefore know effectively where and what to look for. By detecting a pulsar gw signal (or even not detecting one) we can say something about the size of these 'mountains' helping constrain models of the internal structure of neutron stars. To put this in a more physical, not to say more impressive context, we are able to directly measure the height of bumps on a neutron stars surface that is many light years away down to less than 1 cm! To test our analysis techniques simulated signals have been injected into the detectors at the amazingly small level of about one thousandth the radius of a proton.

The down side of such a search for *known* pulsars is that expected gravitational wave strengths are smaller than those we expect to be able to detect using the current generation of detectors. Luckily more exciting, and more dectectable, objects might well be out there to find. In terms of neutron stars there are candidates for which all the parameters are not known meaning we have to search over these unknowns. An example of this is our current search for a possible neutron star remnant from the Supernova 1987A in the Large Magellanic Cloud. For this search new statistical techniques based on the Markov-chain Monte Carlo have been developed which allow efficient searches over large numbers of parameters. To perform these searches we have access to several large Beowolf computer clusters around the world providing over 1000 machines.

Glasgow is also contributing to the development of a distributed computing search for continuous gws called Einstein@home for the World Year of Physics in 2005. This project aims search the whole sky and frequency space by letting the public help in the search using their home PCs. A SETI@home style screensaver is being produced which people can download from the internet and search real data. This opens up an extremely large amount of computing power which is needed for the very a large search area.

Other search efforts are being made to help constrain rates of burst gw events, and in combining gw detector data with that from other sources to set limits on a cosmolgical gw background.

The current generation of detectors hold prospects of spotting gws, although to provide certainty of detection next generation detectors with considerably higher sensitivities are being designed. These include Advanced LIGO, comprising upgrades to the current LIGO machines planned for 2007/08, and LISA, a space based gw detector planned for launch sometime between 2010-20. These instruments promise to detect gws and really will open up the gw spectrum as a new window for astronomy.