DATA ANALYSIS REQUIREMENTS OF NETWORKS OF DETECTORS

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ABSTRACT. It is generally accepted that gravitational wave detectors must work together for successful gravitational wave observations. The most elementary reason is to gain confidence: rare and unmodelled sources of noise in single detectors can be eliminated by demanding that a gravitational wave event must be seen in two or more detectors on different sites. But there are other aspects of joint observation that I discuss here. A complete solution for the gravitational wave requires observations by 4 laser interferometers or 5 bar detectors. There are at least three likely data analysis modes: threshold, summation, and correlation. The summation and correlation modes require the exchange of raw data, the volume of which makes stringent demands of any data storage and transmission methods. The threshold mode will almost certainly be the main mode of operation, and I discuss the question of how to set a threshold for observations against a background of gaussian noise, when one allows for the fact that there are time-delay windows within which coincidences will be accepted, and also that the data will be run through a large number of digital filters. Finally I raise a number of issues that detector groups need to address in planning for laser-interferometric detectors, such as establishing standards for data exchange and storage media, for software, and for the means by which data will be analyzed.

1. BASIC PROBLEMS OF DATA ANALYSIS FOR NETWORKS

Observations by networks of detectors will be necessary to extract the full astrophysical information from any detected gravitational wave. The following simple counting argument shows that a minimum desirable size of network is four if the instruments are broadband and five if they are narrow band. Each detector basically gives only one number, the amplitude of its response at any time. Broadband detectors have in addition sufficient time resolution to determine the delay-time between events in two detectors (typically tens of milliseconds for detectors distributed around the globe). A network of n broadband detectors therefore can produce 2n-1 data (n amplitudes and n-1 independent time delays) for the wave, while a network of n narrowband detectors can produce n data. Now, a wave is characterized by five numbers: two angles giving its direction, two amplitudes for its independent polarizations, and one angle giving the orientation of its polarization ellipse on the plane of the sky. In

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principle, then, we need five narrowband detectors or three broadband detectors for a complete solution. In fact, however, the solution for three broadband detectors is ambiguous (two-valued), so four are necessary.

The management of a network of narrowband detectors is probably not a technically difficult problem. GRAVNET (Blair, *et al*, 1988) has already begun to establish data-exchange agreements and protocols. The volume of data produced will not be particularly large: at a data rate of, say, 10 bytes per second one year's data from a detector would occupy a single 300 Mbyte optical disk. Analysis -- at least for bursts -- will not require sophisticated filtering algorithms and can be accomplished on ordinary computers.

Broadband detectors present a completely different scale of problem. If each detector samples at 10 kHz, uses 2-byte data words, and takes four channels of data (one 'real' output and three housekeeping channels), then it will produce 160 kbytes/sec, and it will fill up that 300 Mbyte optical disc in half an hour. To look for coalescing binaries, the output data needs to be filtered through perhaps 100 filters with different values of the mass parameter; special computing equipment may be needed to keep up with the data rates. Moreover, in order to look for rare or unexpected events it may not be enough simply to analyze each data stream for events and then to exchange lists of them, looking for coincidences: it will be important to cross-correlate the full raw data among all pairs of detectors. It is clear that the problems of data storage and exchange need considerable planning, and one of the reasons for arranging this Workshop was to initiate that process.

Because the broadband detectors present such formidable problems, I will concentrate on them in this paper, although much of what I say will be applicable to narrowband systems as well. In the next section I will identify and discuss three possible modes of data analysis in networks: threshold mode, summation mode, and correlation mode. In the third section I will calculate the thresholds that detectors must set in order to ensure that no more than, say, one spurious noise-generated detection occurs per year. These thresholds depend on the number and relative sensitivities of the detectors in the network, and on such complicating factors as how much of a time delay must be allowed for between detectors, and how many filters will be applied to the data. In turn, they determine how far a network can see and what the rate of events it detects will be. In the final section I will make a few remarks on the data-analysis questions that the current planning exercise (Corbett 1988) might try to answer.

2. METHODS OF COORDINATED DATA ANLAYSIS

In this section I will examine three modes in which data from networks may be analysed for burst events. Each seems to have certain advantages and disadvantages. I will not deal with the thornier problem of finding continuous wave signals in long stretches of data, which is discussed by Livas (1988).

2.1. Threshold mode

In this mode, each detector's output is examined (perhaps after filtering) to determine when it crosses a predetermined threshold. Lists of these 'events' are exchanged among the groups and mutually consistent time-delays are sought in these lists. This is the way that bar detectors currently operate, and it will certainly be the first way that laser interferometers will look for coincidences too.

This has several clear advantages:

(i) It is *fast*. Lists of events for reasonably high thresholds will not be very long, and can be exchanged by electronic mail or telephone line, completely automatically. It allows for quick ($\ll$ 1 day) recognition of significant events, and consequently quick notification of other astronomers who may wish to look at the position of suspected events.

(ii) It is *easy*. The necessary filtering can be done on-line, so that events can be picked up in each detector almost instantly. All the groups can afford to do the coincidence analysis with exchanged lists of events: it requires no great computing or programming overheads.

(iii) It is *versatile*. It is suitable for diverse antennas: bars can operate in coincidence with laser interferometers in this mode with no difficulty.

Against this are some disadvantages of the method:

(i) It can miss relatively significant events which are unanticipated, that is for which no filter has been constructed to pull them out of noise.

(ii) For proper operation, the filters and threshold tests used at different sites must be consistent, and preferably identical. It requires agreements on standardization around the network.

These disadvantages are relatively minor, so this method is likely to become the most important data analysis mode, at least at first. The thresholds must be set by taking into account the number of 'accidental' coincidences that one would expect (false-alarm rate). I shall consider this question in some detail in §3 below, because it determines how far away events can be detected and hence the expected number of events that we can anticipate in our network.

2.2. Summation mode

Given two identical (or at least comparable) antennas, one takes the raw data and simply adds them together before applying any filters or threshold tests. One advantage is that it clearly improves signal-to-noise (S/N) ratios. For example, if two laser interferometers are limited by shot noise, then this is like adding the two beams, doubling the light, and reducing the noise by $\sqrt{2}$. Presumably this gives a potentially better S/N than the threshold mode.

It has at least two disadvantages:

(i) The same event arrives in different detectors at different times, so simply adding data taken at the same instant will not pick it up. One has to allow for these time-delays, as well as for possible differences in waveforms due to the fact that different detectors are

sensitive to different polarization states of the waves because of their different orientations.

(ii) To operate this mode one has to exchange or at least pool the raw data: there are large volumes involved and higher costs in manpower and computing resources dedicated to analysis.

(iii) To operate with different kinds of detectors, say bars and laser interferometers, the data would have to be filtered before addition in order to equalize bandwidths and sampling rates.

This method has not received much attention from the gravitational wave community, and it deserves further study. Despite its disadvantages, the improvement it gives in S/N may make it useful in special circumstances.

2.3. Correlation mode

This method is likely to become a very important adjunct to the threshold mode of analysis. In this, one forms the correlation of two raw data streams,

$$c_{12}(\tau) = \int y_1(t)\, y_2(t+\tau)\, dt. \qquad (2.1)$$

It is useful to think of this as using detector 2 as a *filter* on the output of detector 1. Unlike the ideal filters one would use in the threshold mode, this filter is noisy, and so this introduces extra noise into the system. In compensation, one doesn't have to know ahead of time what to expect: *every* wave event is in the output of detector 2. Thus, its advantages are:

(i) It is *robust*. It can find events that had not been anticipated.

(ii) It is *unbiased*. It does not filter only for our preconceptions, but gives us anything that has occurred.

Its disadvantages are also clear:

(i) Because the filter is noisy, the S/N is worse than in the threshold mode, roughly by $1/\sqrt{2}$ for each pair correlated. Moreover, since the amplitude of the event in the 'filter' is unknown, the amplitude of the response cannot be determined if there are only two detectors. (But it can be if there are three or more.)

(ii) The time delay between different detectors is no problem here, but the possibility that events will not look the same in the two detectors due to their different sensitivities to the two polarizations of the wave is a serious difficulty.

(iii) As in the summation mode, raw data must be exchanged or pooled, with consequent overheads and delays; also the method is hard to apply between detectors of different types.

This is likely to be a network's 'discovery mode': it is the only way to find unanticipated events of moderate to small S/N, provided they have enough structure to be enhanced by filtering. If we theorists are not clever enough, it is even possible that the *first* gravitational waves will be seen this way! More work on this is necessary to understand the expected noise levels and the statistics of detection, especially when there are more than two detectors in the network. (See, *e.g.*, Armstrong 1977.)

3. THRESHOLDS IN NETWORKS

In this section I will concentrate on an important aspect of the threshold mode, namely deciding what thresholds produce an acceptable false-alarm rate in a given network for a given type of observation. This is important even in the present stage of planning for the detectors, because the threshold determines how far away detectors will be able to see. Random coincidences among four detectors are obviously less likely than among two or three, so that every time another detector is added to a network, the threshold goes down and the network can see farther and therefore gather a larger number of events.

3.1. Gaussian Noise

Let us assume that in the output, x, of our detector, the only noise source is Gaussian with zero mean and standard deviation σ, so that its probability distribution function is

$$p(\sigma;x) = \frac{1}{(2\pi)^{1/2}\,\sigma}\, e^{-x^2/2\sigma^2} \quad . \tag{3.1}$$

The probability that x will exceed some threshold X in either the positive or the negative direction is given by

$$p(\sigma;|x|>X) = 2\int_X^\infty p(\sigma;x)\,dx$$

$$\simeq \left(\frac{2}{\pi}\right)^{1/2} \frac{\sigma}{X}\, e^{-X^2/2\sigma^2} \left[1 - \left(\frac{\sigma}{X}\right)^2 + \ldots\right]. \tag{3.2}$$

Equation (3.2) is an asymptotic approximation for large X; it is good to 10% for $X > 2.5\,\sigma$, and its first term is good to 10% for $X > 3.2\,\sigma$.

3.2. Simple false alarms

Suppose we define an 'event' in any detector as a time when the response x exceeds the threshold X in either the positive or negative direction. The single-detector probability of a spurious, noise-generated event is therefore $p(\sigma;|x|>X)$. Our aim is to calculate the threshold X required to ensure that the number of spurious gravitational wave 'events' is acceptably small. Clearly, if we determine that an acceptable probability for spurious events ('false alarms') is f, then we must solve the transcendental equation

$$p(\sigma;|x|>X) = f$$

for X. For a detector that samples at 1 kHz, we might want to choose f so that the expected one-detector false alarm rate is once per year, i.e. $f = 3 \times 10^{-11}$. The solution is $X = 6.6\,\sigma$.

If two detectors are operating together, then the simplest coincidence experiment is to look for both detectors to be above threshold at the same time. If the detectors have independent noise (which we shall always

assume) and are identical (we shall drop this assumption later), then the false alarm probability is $[p(\sigma;|x|>X)]^2$. Similarly, for n detectors the n-way false alarm probability is $[p(\sigma;|x|>X)]^n$, and the appropriate threshold is given approximately by the solution to

$$\left(\frac{2}{\pi}\right)^{1/2} \frac{\sigma}{X} e^{-X^2/2\sigma^2} = f^{1/n}. \qquad (3.3)$$

Since the left-hand side is dominated by the exponential term, a rough approximation is that the solution should behave like $X \propto n^{-1/2}$. Thus, if the single-detector threshold is 6.6, then we expect that two detectors can operate at $X \simeq 4.7$, three at $X \simeq 3.8$, four at $X \simeq 3.3$, and five at $X \simeq 3$. The actual solutions to Eq.(3.3) are, for identical detectors with a false alarm probability of 3×10^{-11},

number of detectors n	1	2	3	4	5
threshold X/σ	6.6	4.5	3.6	3.0	2.6

The importance of this decrease of the threshold is that the volume of space that becomes accessible to the network increases dramatically, as $1/X^3$. Roughly, this goes as $n^{3/2}$, so that five detectors can survey a volume of space 11 times as large as one detector can. In fact, the solutions given in the table above give an even more rapid increase in the volume than this: if V_n is the volume accessible to n detectors, then we have

number of detectors n	1	2	3	4	5
V_n / V_1	1.	3.1	6.3	11.	15.

Provided that the first detector can see at least to the Virgo cluster (about 15 Mpc), then the rough homogeneity of the distribution of galaxies further away guarantees that the true gravitational wave event rate will increase by the same factors.

While these numbers are instructive, they leave out some important features of real networks:

(i) real detectors will not all be identical;

(ii) the necessity of allowing for an unknown travel-time delay between correlated events in separated detectors will increase the false alarm rate at a given threshold; and

(iii) the need to filter the data through a hundred or more statistically independent filters to look for coalescences and other events can also increase the false alarm rate.

We shall now include each of these effects in turn into our threshold calculations.

3.3. Non-identical detectors

What matters for the false-alarm probability is the signal-to-noise (S/N) ratio x/σ in each detector. Suppose we number our detectors (1, ..., n) and normalize the sensitivity of detectors to detector number 1. Suppose that,

for reasons of different intrinsic noise or different size, a given gravitational wave will produce a different S/N in detector j than in detector 1. Let r_j be the ratio of S/N's:

$$r_j = \frac{(S/N)_j}{(S/N)_1}.$$

Then if X is the threshold in detector 1, one will have to set a threshold r_jX in detector j if one wants to detect the same gravitational wave. [This ignores the fact that different detectors are oriented differently and would not respond to a given gravitational wave identically even if they had the same sensitivity. For waves arriving from random directions, this effect presumably averages out, but to take it into account fully would require a Monte-Carlo calculation of the type perfomed by Tinto (1988).] The equation governing the false alarm rate [replacing Eq.(3.3)] is then

$$\left(\frac{2}{\pi}\right)^{n/2} \left(\frac{\sigma}{X}\right)^n e^{-SX^2/2\sigma^2} \prod_{j=1}^{n} \left\{ \frac{1}{r_j} \left[1 - \left(\frac{\sigma}{r_jX}\right)^2\right] \right\} = f, \qquad (3.4)$$

where S is defined by

$$S = \sum_{j=1}^{n} r_j^2.$$

We will not recalculate the thresholds for assumed networks of non-identical detectors until after we have included the effects of time delays and filtering.

3.4. Time-delay windows

Since we must allow for the light-travel time between detectors (some tens of milliseconds in experiments with millisecond or better time resolution), noise-generated events that occur within a certain window of time in separated detectors will contribute to the false alarm rate.

For only *two* detectors operating a coincidence experiment, suppose the time-delay window is W sampling times long, *i.e.* given an event in one detector, any event that occurs within ±W/2 sampling times in the second detector will be accepted. Then since W will be very much smaller than the observation time (which will be days or even years), the false alarm probability just increases by a factor of W to $W[p(\sigma;|x|>X)]^2$. One sets this equal to f and solves for X as above.

If there are three or more detectors the situation is more complex. It is helpful to think in terms of an (n-1)-dimensional 'time-delay' lattice T_{n-1} for n detectors. If we take detector number 1 as the reference, then any event is located in T_{n-1} by the delays to the other detectors (t_2-t_1, t_3-t_1, ...). The space is a lattice because of the finite sampling time: the time delays are integer multiples of this time. In this space there is a region around the origin within which real events must lie, and the 'volume' R_{n-1} (number of lattice cells) of this region is the n-detector analogue of W. We must multiply the left-hand-side of Eq.(3.4) by R_{n-1} and then solve

for X.

Unfortunately, this volume is not straightforward to calculate. For *three* detectors it depends on the relative positions of the detectors. If W is the largest window between any pair, then we overestimate R_2 as W^2. This errs in the conservative direction, producing slightly larger thresholds than optimum. For *four* detectors, further complications set in because the inverse problem is overdetermined. Therefore, any noise-generated event would have to lie in a region of T_3 which was consistent with the amplitudes of the events in the four detectors. Given the amplitudes, we require in principle only one time delay to determine the solution, and we can reject noise-generated events whose second and third time delays do not fit the solution. In practice, there will inevitably be some uncertainty in the measurements of the event amplitudes which will allow some room in T_3 for the noise-generated events. If again we take the largest window to be W, then we shall crudely approximate the error-width of R_3 in the second and third dimensions as εW, where $0 < \varepsilon < 1$. Then we have $R_3 = \varepsilon^2 W^3$. Finally, for *five* detectors the various amplitudes completely determine the solution, so the only room in T_4 is error-generated: $R_4 = \varepsilon^4 W^4$.

The conclusions of this section are summarized in the following array:

number of detectors n	2	3	4	5
window volume R_{n-1}	W	W^2	$\varepsilon^2 W^3$	$\varepsilon^4 W^4$

where W is the maximum window in units of the sampling time and ε is defined above.

3.5. The effect of filtering

Filtering the raw data numerically has two effects on the setting of thresholds. On the one hand, it is clear that if two filters are statistically independent (no correlation in their outputs when applied to white noise), then they offer twice as much opportunity for false alarms as one. On the other hand, filters reduce the effective noise bandwidth, which has much the same effect as increasing the sampling time and therefore decreasing the false-alarm probability. These two effects tend to compensate each other. In my study of the coalescing binary filters (Schutz 1987), I found that a typical filter had zero correlation with itself when shifted by about 2 msec, so this might indicate an effective sampling time of 2 msec for this problem. The same calculation showed that a typical filter had very small correlation with another whose mass parameter differed by perhaps 2%, which suggests that something like 200 or so filters will be needed to span a reasonable range of mass parameters. But these conclusions are preliminary and require further study. For the present, we will simply take the number N_F of filters and multiply it by R_{n-1} on the left-hand-side of Eq.(3.4). We will take the sampling rate effect into account in setting the false-alarm probability f.

be straightforward to do so. Such a detector has the great advantage that its baseline from the others is very large, permitting good directional sensitivity. This large baseline increases W as well, of course, but this will not prevent the sensitivity of a network from improving when such a detector is added.

3.7. Large-statistics surveys: the false-alarm rate as a fraction of the event rate

In what I have described so far, I have kept the false-alarm rate to a fixed number of events per year (one, if the sampling time is 1 msec). But if the event rate for coalescing binaries turns out to be as large as Tinto (1988) estimates (see the discussion in Schutz 1988), then much of the data will be used to make good-statistics surveys of such things as the homogeneity of the universe and the mass function of neutron stars. In such surveys it would be more appropriate to choose the threshold to guarantee that the false-alarm rate is a specified fraction (say 1%) of the true event rate. This would lower the threshold and allow more of the Universe to be surveyed.

The true event rate will be proportional to the accessible volume, which in turn is proportional to X^{-3}. We want f to be proportional to this. It follows that we need to replace the right-hand-side of Eq.(3.4) by α/X^3, where α is a constant that depends on the true event rate and the fraction of this that can be allowed to be false alarms. If for example we take Tinto's figure of 2000 true events for $X = 4.7\sigma$, and if we accept a 1% false-alarm rate for data sampled at 1 msec intervals, then it is straightfoward to show that

$$\alpha = 0.01 \times 2000 \times 4.7^3 / 3 \times 10^{10} = 6.9 \times 10^{-8}.$$

The four-detector network as proposed by the end of 1986 would then be able to operate with a US threshold of 4.4σ; the German threshold would be 3.5σ and Glasgow 2.1σ. This raises its event rate by perhaps 20% over the rate it would have if it allowed only one false alarm per year. Again, this increase is only illustrative, especially since it depends on the assumed coalescence rate, which is very uncertain.

4. CONCLUSIONS

In this paper I have discussed a few topics that are germane to networks of gravitational wave detectors: the number of detectors needed to reconstruct the wave, the amount of data they will produce, three different modes of data analysis, and the thresholds that are necessary to keep the false-alarm rate at a reasonable level in a network.

I would like to conclude by making some observations about the sort of planning that needs to be done for data analysis in networks of laser interferometers before they become operational. If the data are to be analyzed thoroughly, each detector will have to be equipped with a system to filter the stream of data as it comes out, at a rate that can keep up with the data. Since the most demanding filter for bursts is likely to be

3.6. Realistic thresholds for networks

We are now in a position to redo the calculations of §3.2, taking into account windows and filters in networks of non-identical detectors. In this section I will assume that the sampling time is 1 msec and an acceptable false-alarm rate is once per year, so that f is the same as before, 3×10^{-11}. I will then take W to be 50 (msec), appropriate to a baseline of 7500 km, and I will assume 200 filters. For ε I will take 0.1, but this may be too small, particularly for low thresholds, where the signal-to-noise ratio is small and the errors in the inverse problem are large. The following numbers are therefore illustrative of what the importance of these effects may be: they are not definitive.

First let us assume a network of *identical detectors*, so that we can compare with §3.2. For the thresholds we find

number of detectors n	1	2	3	4	5
threshold X/σ	7.4	5.4	4.6	3.9	3.4

and for the ratios by which the observable volume increases

number of detectors n	1	2	3	4	5
V_n / V_1	1.	2.5	4.1	6.9	11.

We see that windows and filters can reduce the volume of space that a network of four or five detectors can see by about 30%.

Next we turn to networks of *non-identical detectors*. First consider a network consisting of the four detectors that had been proposed as of the end of 1986, which is the network on which Tinto (1988) has based his calculations of detector efficiency. If we assume that the laser, isolation, and mirror technologies will be comparable in each detector, then their relative sensitivities in recycling mode will scale as the square root of their effective arm lengths. Taking the US 4-km detectors as the standard, then the 3-km German detector with an included angle of 60° has relative sensitivity r = 0.81, and the 1-km Glasgow proposal has r = 0.5. The threshold in the US detectors works out to be 4.7σ, while the German detector would operate at 3.8σ and Glasgow at 2.3σ. Tinto (1988) has used these figures to show that such a network could observe 50% of all coalescing binary events out to 1.7 Gpc, with an estimated event rate of almost two per hour!

We shall also consider other possible networks. The recent Pisa-Orsay collaborative proposal has opened the possiblity of a five-detector network, perhaps with larger European detectors. Let us consider two 4-km US detectors observing with either two or three 3-km European detectors (r = 0.87). When operating with two European detectors, the US threshold is 4.1σ and the European threshold is 3.6σ. This network would be able to see a 50% larger volume of space than the one considered in the previous paragraph, with a corresponding increase in the event rate. Even better, of course, would be the network with five detectors. In it, the US detectors would be set at 3.6σ and the European ones at 3.2σ; this addition of a fifth European detector increases the accessible volume by a further 50%.

There is also now a possiblity that a detector will be built by a group in Tokyo. While I have not included this in my calculations, it would

for coalescing binaries, for which a typical filter would be about two seconds in duration and sampled at 1 kHz, and since one would want to be able to apply perhaps 200 filters to each sample of data, the on-line analysis system will need to be able to perform a 2048-point Fourier transform in 10 msec maximum. This does not seem to be a difficult goal: it is already achievable with special-purpose hardware (array processors, small arrays of digital signal processing chips, or small arrays of transputers), and in five years it may be attainable in inexpensive general-purpose computers. Another problem that will have to be solved, but which does not seem intractable, is to arrange for the data-analysis computers to exchange lists of events automatically, then to process the lists for coincidences (allowing for time delays), and finally to solve the inverse problem and produce lists of gravitational waves with their positions, polarizations, and amplitudes.

A more difficult job may be storing the data. If networks operate in the correlation or summation modes of analysis, then they will have to store and exchange raw data. Even if they operate only in the threshold mode, there is a strong argument for archiving the raw data so that it can be searched later if other observations in astronomy make it seem likely that a gravitational wave event may have occurred at a certain time. At the present time there are optical disc and videotape storage systems available that not only have large capacity but are also relatively easy to store and to transport. Unfortunately there are no international standards for either of these media, and if this situation persists then the network will presumably have to settle on one standard for everyone.

The analysis of data in the threshold mode need not be very demanding, but the joint analysis of raw data, looking for correlations among different antennas, presents problems mainly of getting the data to a single site where the calculation can be performed. The actual calculations are not significantly different from the filtering that will be done on-line, but groups will have to decide whether they want universal data exchange (each group in an n-detector network making n-1 copies of its data and shipping it off to each other group), or alternatively a small number of data-pooling centres where archiving, correlation, and distribution of data will be organized. It may be that in five years there will be relatively inexpensive high-bandwidth fibre-optic or satellite data transmission services that will make the distribution of data easy. But 'universal' data analysis also makes manpower and storage demands, and groups will have to decide whether they wish to meet these or to displace them to data-pooling centres.

In any case, wherever the analysis is done, the network will need to fix certain standards for data formats and for interfaces with data-analysis software. The software has to be designed, at least to the stage of being able to handle the initial data rates and to be able to effect data exchanges. In order to make software transportable and useful everywhere, guidelines need to be agreed as to language, special extensions, I/O formats, and so on. And, very importantly, they will have to agree protocols on the use of data: vetoes on the publication of one's own data, access of third parties to the data, and so on. (GRAVNET already has a set of agreed protocols.) None of these difficulties is unique to gravitational wave research, but they will have to be addressed before the networks can

be fully operational. The working party set up by this meeting (Corbett 1988) will begin the process for networks involving laser interferometers.

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