Research Curriculum

of Sergio Frasca

I graduated cum laude in Physics at the Sapienza Rome University in 1973, presenting a thesis “On a class of predictive systems: theory and applications”.

Then I won a CNR fellowship at the Institute of Information Sciences of the University of Pisa, where I started to do research in Information Theory, developing the ideas of the thesis.

After the military service (carried on as CBRN officer), I won an “assegno di studio” (ministry fellowship) at the Sapienza University and in 1976 I started to work with the group of gravitational waves, led by prof. E.Amaldi and G.Pizzella. This group was projecting to build a cryogenic resonant gravitational antenna, Explorer, that should have been much more sensitive than the Wiener antenna. This antenna was a high Q aluminum cylinder equipped with a vibration transducer, in order to observe the first longitudinal mode, that is the best one for coupling to the expected gravitational pulses. My main task in the group was the study of the data analysis.

The basic problem of the detection of gravitational waves is the presence of the noise, of different origin, and so various methods should be studied. I introduced, for the first time in that field, the ideas of the digital signal processing, that began to be used in engineering. Therefore, I created an ARMA model of the gravitational antenna noise and built the Wiener filter to estimate optimally the Brownian innovation process and detect the signal.

The first experimental runs of the antennas showed the presence of many different disturbances, of anthropic and geophysical origin. I developed a method to identify the presence of particular periodicities in the data (e.g. tidal periodicities). In order to investigate more this subject, I was sent to work with professor Paul Melchior and collaborators at the Observatoire Royal de Belgique. Then we decided to build a room-temperature (and therefore low sensitivity, but low cost and high availability) gravitational antenna in our institute, equipped with some geophysical sensors: there where some accelerometers, a gravimeter LaCoste-Romberg, an electric antenna, a magnetic antenna and a power line monitor. The antenna was called Geograv. This was the first gravitational to be equipped with geophysical sensors and run for more than 4 years almost continuously. Using a PDP 11/34, I built a simple acquisition system. The operation of the antenna was my responsibility and many interesting ideas were obtained by the rich data analysis that we could obtain. I used also the data of this antenna to search for periodic sources.

With the experience of the Geograv antenna, I realized the acquisition system DAGA (and then DAGA2), based on a MicroVAX, that was used by all the antennas of the group (Explorer, Nautilus, Agata and Geograv). The system had many acquisition channels, at different sampling times, some raw and some with particular filters. There was also an online analysis to find the most relevant events for all channels and an event and statistics data base was created.

I collaborated with A.Mammano and F.Ciatti of the Asiago observatory to analyze the data of the star system SS433 in search of tiny periodicities.

A complication in the filtering of the data is that the noise changes, more or less slowly, its characteristics. In order to solve this problem, I built an adaptive matched filter procedure that continuously "learned" the noise characteristics. In addition, the threshold to determine the presence of an event was computed by a particular adaptive procedure that computed the "noisiness" of the data at a certain time.

In order to enhance the sensitivity of the resonant antennas, I proposed the use of an array of small molybdenum "stumpy" cylinders, each equipped with 3 resonant transducers that could observe not only the longitudinal mode, but also the two (degenerate) discoidal modes. With a particular array analysis of all the detectors of all the cylinders of the array, one can obtain a much larger sensitivity, the information on the direction of the wave and a strong noise rejection.

In 1996 I joined the Virgo French-Italian collaboration, that was projecting to build a big interferometric gravitational antenna in Cascina, near Pisa.

In this collaboration my main task has been the search for periodic sources (CW – continuous waves), i.e. rotating asymmetrical neutron stars. This type of signal is very weak ($h \approx 10^{-26}$) and needs the analysis of very long stretch of data (at least some months), very carefully corrected for the Doppler shift due to the Earth motion.

This search has different characteristics depending on knowledge we have on the source. If we do not have any information on the source, we have a "blind" search. This can be accomplished by a big computing power: the computing power limits the sensitivity and the parameter space (frequency, spin-down, sky position). The interesting point for this type of search is that if one finds a signal, after others can verify it also, and one does not need more than one antenna.

Between 1997 and 2008, I was the coordinator of the collaboration for this type of search.

For this type of search, I proposed the use of a hierarchical procedure, which alternated coherent and incoherent steps, reducing strongly the needed computing power. For the incoherent step, I proposed the use of the Hough transform that transformed peaks in the time-frequency plane to values on the celestial sphere. The main reason of the use of this method was the robustness against the (many) disturbances in the data. This work was developed together with a group of the Max Plank Institute in Potsdam (led by B. Schutz).

After the first results of this method, because of the many artifacts produced by the noise, I projected a different use of the Hough transform, now transforming the peaks of the time/(observed)frequency plane to the (source)frequency/spin-down plane. This appears better and also faster and more precise.

With this procedure, a big number of "candidate sources" are created (now of the order of hundreds of millions, each one with a particular value of the frequency, the spin-down and the sky position). Then the analysis of another period (or of another antenna) should give another set of candidates and finally a coincidence procedure drastically reduces the number of the candidates to be analyzed in the following hierarchical step.

I studied the various procedures to actualize this project and wrote a large part of the software.

For the search for gravitational waves from known pulsar, as Vela or Crab, I proposed a method of analysis based on the use of a 5-vector, a vector with five complex components that depend on the polarization parameters, the sky position of the source and the position and orientation of the antenna on the Earth. The detection and the estimation of the amplitude-polarization parameters is obtained optimally from this. The procedure is much faster than the other in use.

For the work in data analysis on gravitational waves, I created a Matlab toolbox, Snag (Signal and Noise for Gravitational Antennas) that now contains about 2000 functions.

I coordinated the following University projects:

- University project "**Sistema di Memoria per un Data Base Cosmo-Geofisico"** (1992), to realize a file server for the Physics department research groups on gravitational waves, geophysics and cosmic rays. The project was financed up to 1996.
- University project **"Analisi Dati per le Antenne Gravitazionali",** financed in 1997 and 1998.
- Faculty project **"Prototipo di un'Antenna Multimodale per la Realizzazione di un Array Gravitazionale",** partially financed for year 1995.
- Local unit MURST project "**Analisi di Dati di Rivelatori Gravitazionali: Sviluppo di Metodologie e Ricerca di Segnali**", co-financed for 1998-1999.

I published more than 230 scientific papers and 2 university books.

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