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Tribute to François Mignard's research

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It is a great pleasure for me to report about your colleague and my friend François Mignard. I know him since now 43 years and shared with him some scientific adventures. If, because of my age, I had to leave the Gaia project, I have followed the tremendous work done since by François Mignard and noticed that, despite his masterly played role as the conductor of the Gaia orchestra, he kept an important scientific activity. Actually, Gaia is far from being all his scientific achievements. And this is what I shall try to convince you.

In 1974, François Mignard graduated in Physics from the Ecole Normale Supérieure, a renown University level establishment in Paris which, in U.K. and USA would be called *College*. Then, he came to Nice with an assistantship at the University and decided to start his scientific career at the newly created CERGA in Grasse (Centre d'études et recherches géodynamiques et astronomiques). Progressing in his university third cycle curriculum, he had to make an original scientific research. I proposed him to work on the motion of a high eccentricity satellite and apply his results to the motion of Nereid. I thought that it would be a good preparation for a doctoral thesis, but the resulting paper astonishingly solved most of the difficulties. The tables derived from his theory were used by the international Ephemerides. This is how I discovered that François was an exceptionally gifted researcher.

He later proposed himself the subject of his doctoral thesis *Tidal phenomena in the evolution of planet-satellite system*, a very difficult and a new subject at that time,. The result was a remarkable piece of work whose application to the evolution of the lunar orbit was described in three articles in *The Moon and Planets* from 1979 to 1981. Using the same algorithms, he also studied the problem of the evolution of the motion of the satellites of Mars. He published a paper on the subject in the Monthly Notices. There he showed that the Laplace plane, used as an intermediary reference, allowed to understand the long-term evolution of the orbit of Phobos. He used a similar approach in the case of Pluto and Charon. In addition, in the frame of his duties in the observing service, he observed with an astrolabe, favouring the observation of planets (Mars and Jupiter).

In 1981, a new period of his activity started with a one year post-doc in Cornell University with J.A. Burns and one year professorship in Marseille. Then, he returned to CERGA. He was interested in many aspects of dynamical planetology, general relativity, data analysis, reference systems and frames. During the ten year period (1982-1992), he published on a large variety of subjects. Let us present some of them.

- He was particularly interested in radiation pressure and dust particle dynamics in the interplanetary medium as well as in the higher atmosphere with emphasis on LAGEOS which was then a major tool of geodesy.
- He studied the dynamics of grains in rings under radiation pressure force. Realizing that the direction of this force varies with time, he gave an integrable solution.
- He worked on the rotation of Hyperion, showing that its oblong shape, together with the high eccentricity of its orbit and the one to one resonance between the orbital and rotational periods, lead to a chaotic rotation.

• Studying the dynamics of the bodies in the Oort cloud, he found that if a star approaches the Solar system by less than one parsec, chances are that the perihelions of some of the bodies become sufficiently low, so that they may be captured by the major planets.

• He also got interested in the dynamics of binary asteroids, although there were no such example at that time.

• One of his constant interests was General Relativity to which the advent of space astrometry opened the way to new practical applications.

Most of these subjects were later, and some even until now, the object of original studies and publications or reports in conferences. This large variety of subjects, encompassing most of Astrometry and Dynamical Astronomy, to which one may add his great interest and knowledge in history of astronomy, made François Mignard a rare example of an astronomer with a wide knowledge and personal achievements. It is with such a background that he entered into space astrometry.

I dragged him into it in 1985, when I realized that some members of the FAST Consortium preparing the Hipparcos data reduction were not in a situation to perform some of the tasks in time. These were photometry and double star reduction. François was the only man in my environment I could trust to redress the situation, and he did it perfectly. He took up the tasks, directed people engaged, but actually did most of the work himself.

In photometry, he showed how to compare the variable amplitude of signals and to establish their eventual periodicities so as to recognize eclipsing variables, Cepheids, RR Lyr, etc.. While the HIPPARCOS mission was originally foreseen to be strictly astrometric, the work of François Mignard showed that each observation gave a mean uncertainty of 0.01 magnitude and the final calibrated combination presented an accuracy of 0.001mag. So, the resulting photometric catalogue and the light-curves of variable stars appeared to be a major improvement to earlier expectations.

In his approach to double stars, he faced a great variety of situations, making the work particularly difficult. He discovered a specific property of photon counts that opened the way to the resolution of binary systems. This led him, using all the observations accumulated during the mission, to obtain the relative astrometry (separation and direction) together with the magnitude difference. This work presented many difficulties, and F. Mignard wrote a very large and complex software that took into account all the possible situations. In this way, he treated 25,000 objects, discovering 10,000 new double stars out of which 70% astrometric data were obtained, and for 85% of them, the difference of magnitudes. Of course, the final catalogue takes into account the results obtained by both reduction consortia, but it is not exaggerating to state that François Mignard was the main contributor. Actually, he continued to work on the data, and extended the results, using ground-based astrometry, so as to determine the parallax of systems and obtain masses and absolute brightnesses of the components of some thirty double star systems.

Progressively he got interested in all the reduction procedure and became a major member of the Consortium FAST. For instance, the FAST software on astrometry had some difficulties with stars that happened to be far from their actual position in the Input Catalogue. François wrote a different and independent software that proved to be very useful in those difficult cases and, in addition, it contributed globally to the improvement of the solution. Among his involvement in other tasks contributing to the final catalogue, one may mention the astrometry of minor planets and the efforts to render the catalogue absolute.

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In 1991, he became member of the Hipparcos Science Team and, later, he progressively replaced me as the coordinator of the FAST consortium. He became responsible of a working group of the Hipparcos Science Team in charge of constructing the final catalogue of double stars. In addition to the specific articles on photometry and double stars, the presence of his name in several publications describing the intermediate and final reduction procedures, as well as in the presentation of the final catalogue, prove his wide views of the mission. In addition, he was responsible of seven chapters of the volume describing the methods used in both consortia to construct the catalogue.

Once the Hipparcos catalogue was published, he naturally started to work on the astronomical implications of such rich and precise data. In particular, he made a very deep and detailed analysis of the local galactic kinematics using proper motions from the Hipparcos catalogues.

Let me say that Hipparcos was not the only activity of François Mignard during this time: he continued to work in the fields of atmospheric drag and radiation pressure and published several papers on these subjects. In addition, his long lasting interest in General Relativity led him to be associated to a proposal of an ensemble of four helio-synchronous satellites to test the principle of equivalence. This first proposal was not accepted by ESA. It was however presented again in an improved configuration and, under the new name MICROSCOPE, successfully launched last year and works now very satisfactorily.

Finally, let me mention that, when I retired from my administrative duties, he became director of CERGA in 1993 until 2004. However, at that time for François, Hipparcos was already the past. As early as 1993, together with a few colleagues, the concept of what could be Gaia was presented. Since then, he was advocating it and participating in various groups working on the feasibility and the expected science of this mission. In 1997, a first draft of a scientific proposal was presented by this group to ESA. Interested, ESA created a Scientific Advisory group that included François Mignard, while first technical studies, based on this report, were initiated by ESA.

At that time, NASA was also considering to enter space astrometry and François was called in 1996 to become a member of the Science Working Group on SIM, a space interferometer with a limited number of stars, but very precise even at high magnitudes. I mention this fact to emphasize that, already at that time, he gained a world-wide recognition as a scientist.

During the hectic period in the beginning of this century, during which, the actual future of Gaia was questioned, he strongly defended the scientific quality of the mission, as President of the ESA Gaia Data Analysis Coordination Committee. His major role in the preparation of the treatment of the data was recognized so that when, in 2006, the DPAC (Data Processing and Analysis Consortium) was created, he was naturally chosen as the chairman of its executive Committee for two three years mandates.

During this period ranging from 1997 to 2006, his scientific activities did not weaken but were essentially directed towards General Relativity and reference frames to which Gaia was expected to bring completely new results. Among these, he studied the relativistic effects of Jupiter, in the frame of classical as well as quantum gravity. More generally, he analysed the various aspects of fundamental physics in the framework of Gaia mission. He also examined the best way to attach the Gaia catalogue to an absolute reference frame, the objective being to achieve better than 0.01 microarcsecond per year. He was also interested in the science that could be obtained from the observations of asteroids by Gaia: for instance the determination of their masses or the eventual detection of the Yarkovsky effect in the motion of close to Earth asteroids.

His activity as chairman of DPAC was fantastic. He was present in all the general meetings of the consortium and many of the thematic ones. Actually, he was President

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of two of them (Solar system and Relativity and reference frames). In this way, he co-ordinated, and was the driving force of the whole group. This was not a simple task because on one side he had to be the voice of the scientific community within ESA and, on the other side, to ensure within DPAC that every one has a part of responsibilities in the most favourable conditions for the success of the mission. Later, he was still very much involved in the preparation and in the follow up of the launch. Most of you were witnesses of his formidable energy in this context. This hectic activity of François is, I am sure, partly responsible of the major health problems he suffered.

During this meeting, the first remarkable results of Gaia much better than I could expect at first will be presented. It appears to be only a glimpse in comparison with what François will present you at the end of the colloquium and for which he has had a major share. You will judge by yourselves.

So, I shall stop here and hope that I convinced you that François Mignard is one of the most gifted and hard working astronomer of our time.

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